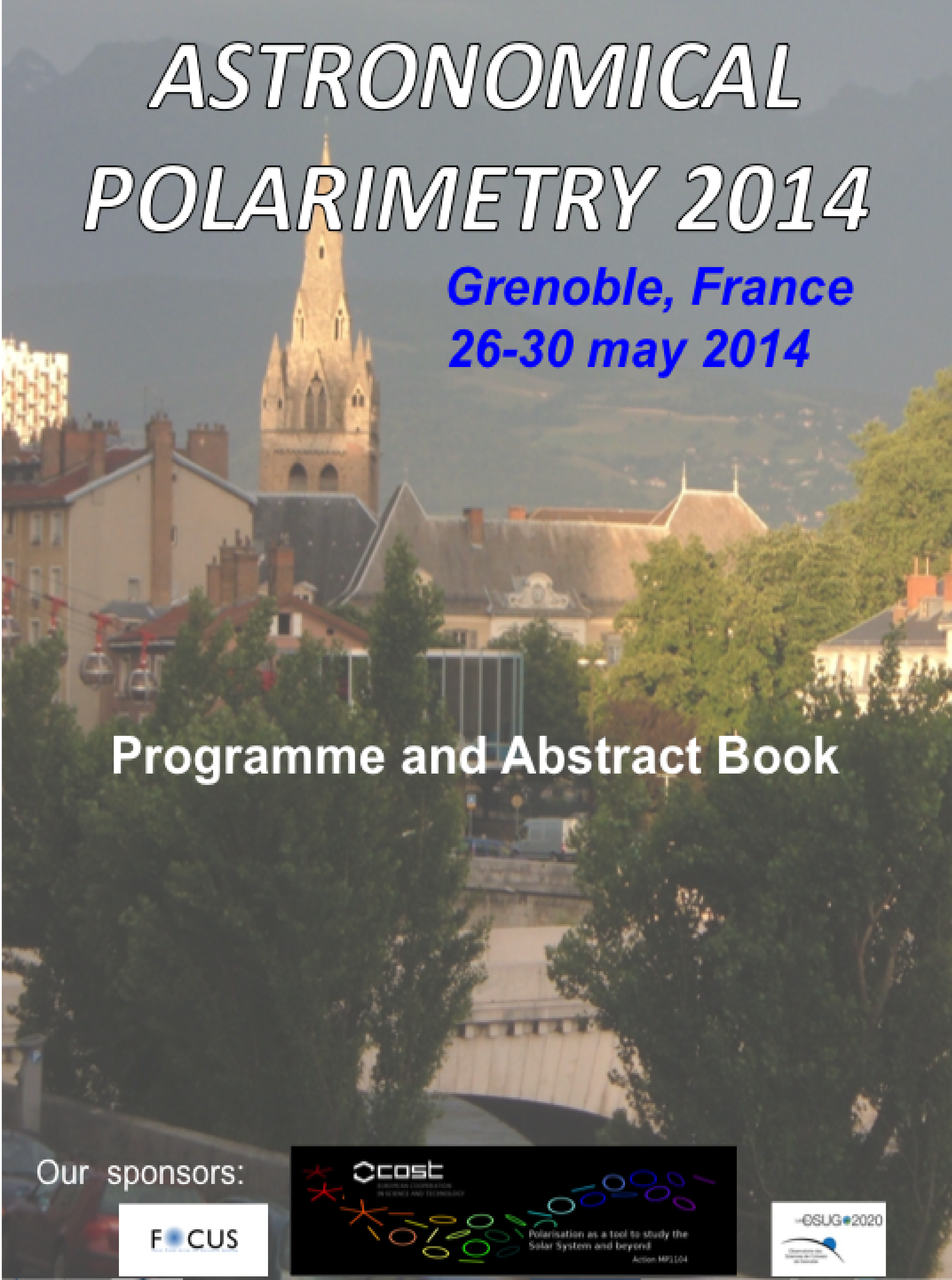
ASTRONOMICAL POLARIMETRY 2014

Grenoble, France
26-30 may 2014



Programme and Abstract Book

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ASTRONOMICAL POLARIMETRY 2014

Abstract Booklet

Contents

Grenoble, France, 26-30 May 2014

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***** CONFERENCE PROGRAMME *****

I Invited talk
S Solicited talk
C Contributed talk

DAY 1 : Monday, May 26th

08:30-09:30 Arrival, Registration
09:30-09:45 Welcome words.

SESSION I: New Instrumentation, Facilites, and Techniques : Optical and Near-Infrared

09:45-10:05 **M. Perrin** – Polarimetry with Gemini Planet Imager (C)
10:05-10:25 **D. Mouillet** – Polarimetry with VLT / SPHERE (C)
10:25-10:45 **T. Fujiyoshi** – N-band polarimeter for SUBARU/COMICS (C)

10:45-11:20 Coffee and Posters

11:20-11:40 **H.-M. Schmid** – Concept and test results for ZIMPOL (C)
11:40-12:00 **M. Rodenhuis** – The EXtreme POlarimeter and its successor (C)
12:00-12:20 **D. Vorobiev –** Polarization-sensitive imaging sensors (C)

12:20-14:00 Lunch

14:00-14:20 **A.M. Magalhaes** – The SouthPol survey (C)
14:20-14:55 **F. Snik** – Polarimetry with Extremely Large Telescopes (I)

SESSION II: New Instrumentation, Facilities, and Techniques: Far-Infrared and Radio

15:00-15:35 **H. Nagai** – ALMA polarimetry, current status and cycle 3 capabilities (I)
15:35-15:55 **C.D. Dowell** – SOFIA HAWC+: FIR dust polarimetry (C)
15:55-16:15 **C. Thum** – IRAM XPOL: capabilities and results (C)

16:15-17:00 Coffee and Posters

17:00-17:20 **I. Mizuno** – Polarimetry at the Nobeyama 45m (C)
17:20-17:40 **A. Ritacco** – NIKA: the New IRAM KID Arrays (C)
17:40-18:00 **H. Wiesemeyer** – Submillimeter polarimetry with APEX (C)

DAY 2 : Tuesday, May 27th

SESSION III : Particle Properties, Laboratory Measurements, and Modelling.

09:00-09:35 **O. Muñoz** – Light scattering measurements of cosmic dust analogs(I)
09:35-09:55 **D. Guirado** – Extrapolation of scattering matrices (C)
09:55-10h15 **E. Hadamcik** – Observations and expérimental simulations in optically thin clouds (C)

10:15-11:00 Coffee and Posters

11:00-11:35 **K. Muinonen** – Multiple scattering of light by the surfaces of planetary objects (I)
11:35-11:55 **I. Milic** – Scattering line polarization in rotating optically thick disks (C)

SESSION IV: ISM, Molecular Clouds, Star Formation

11:55-12:25 **A. Lazarian** – Grain alignment: theory (S)

12:30-14:00 Lunch

14:00-14:30 **B-G Andersson** – Grain alignment: observations (S)
14:30-14:50 **T. Hoang** – ISM magnetic field measured using UV dust polarimetry (C)
14:50-15:10 **T. Robishaw** – The Zeeman effect to study ISM magnetic fields (C)
15:10-15:30 **F. Levrier** – Polarization of Galactic foreground from Planck (C)
15:30-15:50 **J. Vaillancourt** – FIR and mm polarization in galactic clouds (C)
15:50-16:10 **M. Houde** – Characterization of magnetized turbulence (C)

16:10-16:55 Coffee and Posters

16:55-17:25 **C. Hull** – Multiscale view of magnetized star formation(S)
17:25-17:45 **J. Davidson** – L1527, a cautionary tale (C)
17:45-18:15 **J. Kwon** – Circular polarization from star forming regions (S)
18:15-18:35 **F. Alves** – Multi-wavelength polarimetry of a pre-stellar core (C)

18h30 - 21:00 Dinner at MINATEC (long period for poster): Bread, Wine, and Cheese

DAY 3 : Wednesday, May 28th

SESSION V: Circumstellar Matter

09:00–09:30 **S. Quanz** – Polarimetric imaging of disks (S)
09:30–09:50 **H. Canovas** – NaCo imaging polarimetry of HD 142527 (C)
09:50–10:10 **H. Avenhaus** – Multi-epoch polarisation differential imaging of HD 100546 (C)
10:10–10:30 **M. Millar-Blanchaer** – GPI observations of the debris disk of HD 61005 (C)

10:30–11:10 Coffee and Posters

11:10–11:30 **C. Telesco** – Magnetic fields in young disks and their environments with GTC /CanariCam (C)
11:30–11:50 **C. Wright** – CanariCam imaging and spectro-polarimetry of YSO driving bipolar jets (C)
11:50–12:10 **J. Vink** – Spectropolarimetry and the circumstellar environments of young and massive stars (C)
12:10–12:30 **P. Kervella** – Polarized light in the dusty nebula of the cepheid RS Puppis (C)
12:30–12:50 **R. Tylenda** – Linear polarization of the red nova V4332 Sgr (C)

12:50–13:00 Logistics , info

13:00 – Free Afternoon

DAY 4 : Thursday, May 29th

SESSION VI: Solar and Stellar Magnetic Fields

09:00–09:30 **M. Faurobert** – The Solar magnetic field (I)
09:30–09:50 **R. Kano** – Magnetic fields in the Solar chromosphere with Lyman alpha polarimetry (C)
09:50–10:25 **J. Morin** – Magnetic fields of cool stars (I)

10:25-11:15 Coffee and Posters

11:15–11:50 **C. Neiner** – Magnetic fields of hot stars (I)
11:50–12:10 **S. Jeffers** – The BCool survey of solar-type stars (C)
12:10–12:30 **S. Boro Saikia** – Variable magnetic field of the young sun HN Peg (C)

12:30-14:00 Lunch

SESSION VII: Solar System and Exoplanets

14:00–14:30 **S. Wiktorowicz** – Status of exoplanet polarimetry (I)
14:30–14:50 **N.M. Kostogryz** – Polarimetry of the transiting exoplanetary system HD 189733 (C)
14:50–15:10 **A. Bazzon** – The polarization of Earth (C)
15:10–15:30 **T. Enomoto** – Monitoring of Venusian clouds with HOPS(C)
15:30–15:50 **S. Bagnulo** – Spectro-polarimetry to study small Solar System bodies (C)
15:50–16:10 **S. Berdyugina** – Remote detection of biological pigments on Earth-like planets (C)

16:10-16:50 Coffee and Posters

SESSION VIII: Cosmological Microwave Background

16:50–17:20 **C.D. Dowell** – Detection of B-mode polarization at degree angular scales using BICEP 2 (I)
17:20–17:50 **J. Macias Perez** – Polarisation of the CMB: first results from Planck (I)
17:50–18:10 **V. Guillet** – Polarized emission of Galactic dust seen by Planck (C)
18:10–18:30 **J. Peloton** –The Polarbear experiment: first results (C)

18h40-21h00 DINNER at WTC + long poster session : Local specialties Ravioles de Roman and Mini Quenelles de Lyon

DAY 5 : Friday, May 30th

SESSION IX: External Galaxies, Active Galactic Nuclei

09:00–09:35 **C. Tadhunter** – Optical and near-infrared polarimetry of AGNs(I)
09:35–09:55 **E. Ramirez** – NIR polarimetry of narrow-line radio galaxies with HST (C)
09:55–10:15 **C. Ramos Almeida** – VLT/FORS spectropolarimetry of Seyfert galaxies (C)
10:15–10:35 **C. Packham** – Infrared polarimeters and AGNs (C)

10:35–11:20 Coffee and Posters

11:20–11:40 **E. Lopez-Rodriguez** – Polarimetry in AGNs (C)
11:40–12:00 **B. Shahzamanian** – Near infrared polarized light from Sgr A* (C)
12:00–12:20 **M. Yoshida** –Spectropolarimetry of starburst galaxies(C)

12:30–14:00 Lunch

SESSION X: High Energy Astrophysics, Gamma-Ray Bursts, Supernovae

14:00–14:20 **K.M.G. Silva** – Polarimetric observations and modelling of V393 Pav and other AM Her systems (presented by CV Rodrigues) (C)
14:20–14:40 **E. Angelakis** – Optical polarization monitoring of gamma-ray-loud Blazars (C)
14:40–15:00 **P. Moran** – INTEGRAL/IBIS and optical monitoring of the CRAB nebula/pulsar polarization (C)
15:00–15:20 **K. Takaki** – Polarization observations of 5 GRB afterglows (C)

15H20-15H30 LAST WORDS + GOODBYE !

POSTERS :
By default all abstracts not selected for talks are expected to become posters. Posters will be visible all week.

POSTER SIZE : recommended is A0 in Portrait mode.
(or about 90cm wide (horizontal) by 120cm high (vertical))

1 Session I.
New Instrumentation, Facilities & Techniques: OPTICAL / NIR

Polarimetry with the Gemini Planet Imager

Marshall D. Perrin[1], James R. Graham [2], Max Millar-Blanchaer[3], Sloane Wiktorowicz[4], Gaspard Duchene[2], Michael Fitzgerald[5], Paul Kalas[2], Bruce Macintosh[6], and the Gemini Planet Imager team

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[2] UC Berkeley, jrg@berkeley.edu
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[5] UCLA, mpfitz@ucla.edu [6] Stanford University, bmacintosh@stanford.edu

The Gemini Planet Imager is one of a new generation of specialized adaptive optics instruments, fully optimized for the detection of planets and circumstellar dust at high contrast and small angular separations. For studies of circumstellar disks in polarized light, GPI includes an imaging polarimetry mode implemented via a novel "integral field polarimetry" architecture. GPI achieved first light in November 2013 and is currently proceeding through a verification and commissioning phase, including shared-risk community science time. I will describe the technical advances that enable GPI to achieve contrasts up to a factor of ten better than previous generation instruments at small separations, discuss the design decisions made in developing GPI's polarimetry mode, and present some of our initial results from first light and commissioning. Starting in 2014B the GPI Exoplanet Survey campaign will carry out a large survey for circumstellar disks and exoplanets around nearby young stars, while GPI will be available to the community for investigations ranging from solar system targets to post main sequence stars.

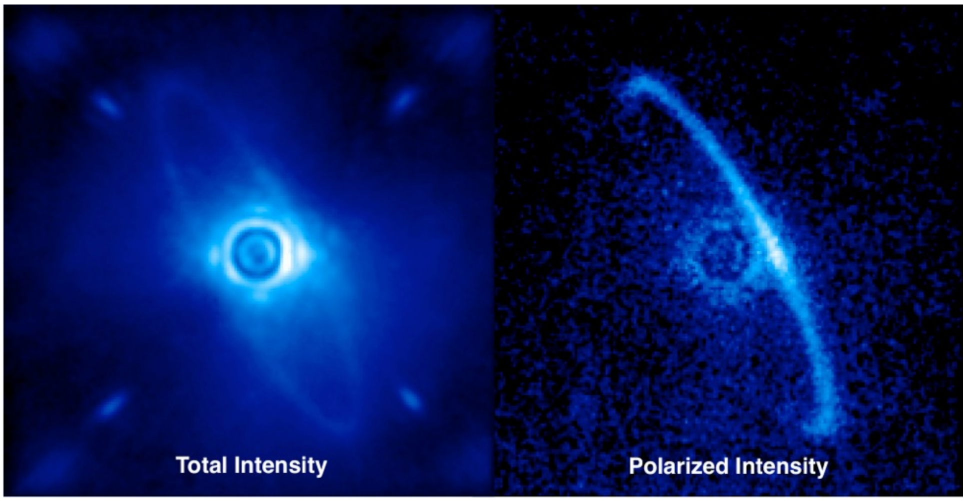

Figure 1: GPI first light polarimetry observations of HR 4796A

Polarimetry with the VLT/SPHERE high contrast imager.

D. Mouillet [1], J.L. Beuzit [1], K. Dohlen [2], Hans-Martin Schmid [3], and SPHERE consortium

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[3] ETH Zurich, Institute of Astronomy, Wolfgang-Pauli-Str 27, 8093 Zurich, Switzerland

SPHERE is a second generation instrument for the VLT, dedicated to high contrast imaging of bright stars in the visible and near IR. It is now in commissioning phase.
I will first remind the strong motivation of accurate polarization measurement, both for its intrinsic astronomical interest to characterize the scattering properties of the circumstellar material, and for its helps to achieve very high contrast capabilities through differential measurements.
Second, on the instrumental side, I will discuss at high level how this polarimetric capability has been implemented in the instrument design. The induced polarization effects from the telescope and the instrument are kept at a relatively low level despite its location at Nasmyth focus, and a complete calibration scheme has been defined. The discussion will distinguish whether the astronomical purpose of a given observation requires absolute polarimetric accuracy or differential measurement of a localized polarimetric signature within a stellar halo. In visible, ZIMPOL is a dedicated polarimetric instrument with a very specific polarimetric measuring principle, while IRDIS is a very sensitive double beam imager and spectrograph with a quite "traditional" polarimetric mode for double beam polarimetry with beam exchange. I will emphasize some specificities raised by the combination of high contrast and high accurary polarimetry which led to some unprecedented specifications and new challenges for some optical components.
Finally, I will illustrate the high contrast performance that can be obtained with the complete system in polarimetry. Such polarimetric imaging can be performed both in visible an near IR, by two different approachs. The combination of near-IR polarimetry and visual polarimetry will provide much enhanced diagnostic power for the investigation of scattering phenomena.

An N-band polarimeter for COMICS

Takuya Fujiyoshi,[1] Mitsuhiko Honda,[2] and Hideaki Fujiwara[3]

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We are in the final stages of the construction of an add-on N-band (8$-$13 μm) polarimeter for the facility mid-infrared imaging-spectrometer COMICS for the Japanese 8.2-m Subaru Telescope in Hawaii, USA. In this presentation, we will outline the design of the polarimetry unit and describe some of its key components. We would also like to draw attention to the fact that, because COMICS is a facility instrument, after necessary engineering and commissioning processes, the polarimeter will be available to the wider astronomical community, including the Japanese community, and the Keck and Gemini communities through the time exchange programme with Subaru Telescope.

Polarimetric concept and test results for the ZIMPOL high-contrast imaging polarimeter of the SPHERE planet finder

Hans-Martin Schmid[1], Ronald Roelfsema[2], Andreas Bazzon[1], Johan Pragt[2], Daniel Gisler[3], Bernardo Salasnich[4], Alexey Pavlov[5], Andrea Baruffolo[4], Anthony Boccaletti[6] Jean-Luc Beuzit[7], Anne Costille[8], Sebastian Deiries[9], Kjetil Dohlen[8], Carsten Dominik[10], Mark Downing[9], Eddy Elswijk[2], Markus Feldt[5], Markus Kasper[9], David Mouillet[7], Pascal Puget[7], Christian Thalmann[1], Francois Wildi[11]

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[10] Astronomical Institute Anton Pannekoek, 1098 SJ Amsterdam, The Netherlands
[11] Observatoire Astronomique de lUniversit de Genve, 1290 Sauverny, Switzerland

ZIMPOL is as subsystem of the upcoming SPHERE VLT planet finder which will provide high contrast and high resolution imaging polarimetry. ZIMPOL works in the wavelength range 500–900 nm and is optimized for the search and characterization of scattered and therefore polarized light from faint sources around bright stars using differential polarimetry for speckle noise suppression.
ZIMPOL is very innovative polarimeter which includes several polarimetric concepts which are implemented for the first time for night-time telescopes:

- fast modulation / demodulation imaging polarimetry with a frequency of about 1 kHz for the efficiency suppression of the speckle noise,
- broad-band compensation of the telescope polarization at the Nasmyth focus fo an alt-azimuth telescope,
- combination of polarimetry with image derotation,
- and a three stage polarimetric calibration strategy.

All these polarimetric functions are realized, together with complex AO and coronagraph control functions, in a user-friendly telescope instrument. We promote this instrument with test results, which demonstrate that a guest observer, who does not need to be an instrument expert, can obtain with this system easy to reduce, well calibrated data.
SPHERE-ZIMPOL should become in the near future "our best" instrument for very high sensitivity linear polarization measurements with unprecedented spatial resolution and contrast for the visual range. This opens up many new research opportunities like the search for scattered light from extra-solar planets, the characterization of circumstellar material such as disks and shells, and the polarimetric mapping of solar system objects and very extended red giant stars.

The Extreme Polarimeter and its successor, the Polarimetric IFU: Design, results & lessons learned

M. Rodenhuis [1], H. Canovas [2], S. V. Jeffers [3,1], M. Min [4,1], J. de Boer [1,5], C. U. Keller [1]

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[2] Departemento de Física y Astronomia, Universidad de Valparaiso, Chile.
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[4] Sterrekundig Instituut Anton Pannekoek, Universitieit van Amsterdam, Amsterdam, The Netherlands.
[5] European Southern Observatory, Santiago, Chile.

At the previous AstroPol conference, the design and first laboratory results of the Extreme Polarimeter (ExPo), an imaging polarimeter developed for high-contrast observations of starlight scattered by circumstellar material, were presented. In the intervening period, the successful observations with this instrument have demonstrated both the contrast enhancing and the diagnostic power of imaging polarimetry. The results include:

- Imaging of sub-arcsecond structures in protoplanetary disks
- Observation of localized dust clouds emitted by the evolved variable star R CrB
- Constraining the three-dimensional morphology of dust clouds around both young and evolved stars
- Characterization of circumstellar dust grain size distribution
- Imaging of intriguing polarized features in the atmospheres of Venus and Saturn.

Here we present a compilation of these results and the lessons learned during the development and operation of ExPo.
One key lesson learned is that wavelength information greatly increases the diagnostic capabilities of imaging polarimetry, in particular for characterizing circumstellar dust. Future ELT exoplanet direct imaging instruments will require wavelength resolution to go beyond mere exoplanet detection. Based on our experiences with ExPo, we have developed the Polarimetric Integral Field Unit (pIFU). This instrument offers the imaging polarimetry capabilities of ExPo with simultaneous imaging in 20 contiguous wavelength bands in the visible part of the spectrum. It relies on several innovative technologies such as a polarization grating and polychromatic polarization modulation. We present the design of this new instrument and the results from recently obtained first-light observations.

Polarization-sensitive imaging sensors for astronomy

Dmitry Vorobiev [1], Zoran Ninkov [1]

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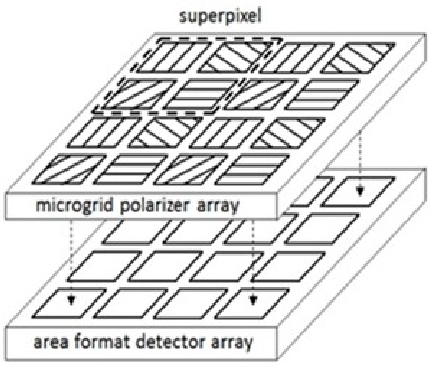
Recent advancements in microfabrication techniques have facilitated the development of micropolarizer arrays. These devices consist of pixel-sized polarizers (or retarders), which can be used with conventional imaging sensors (in the optical and infrared regimes) to creative polarization-sensitive detectors. This technique is analogous to the use of color filter arrays to create color-sensitive detectors. Although RGB imagers are of limited use to astronomers (who are often interested in specific parts of the spectrum), this division-of-focal plane technique efficiently samples the electric field and allows the determination of the Stokes parameters using a single exposure (Figure 2).
Polarimeters based on micropolarizer arrays are attractive due to their compactness, small weight, lack of moving parts, large field of view, broad spectral response and "snapshot" capability. At RIT, we are investigating the potential utility of these novel devices in astronomy using high resolution 3D simulations, as well as our first prototype, the RIT Polarization Imaging Camera (RITPIC). We report our initial findings, describe useful calibration techniques and outline our goals for future work.



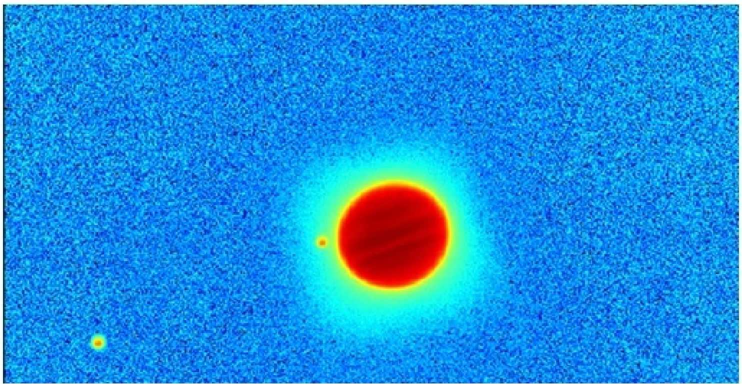


Figure 2: Micropolarizer arrays can be used to add polarization sensitivity to conventional imaging sensors. These hybrid devices are capable of "snapshot" acquisition of Stokes parameters across a broad spectral range. The compactness and mechanical robustness of these devices makes them ideally suited for deployment on space-based and airborne platforms.

SOUTH POL: Revealing the Polarized Southern Sky

A.M. Magalhães [1], E. Ramirez [1], N.L. Ribeiro [1], M. Rubinho [1], D.B. Seriacopi [1], T. Ferrari [1], J. Felix [1], A.J.F.B. Barbosa [1]

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SOUTH POL will be a survey of the Southern sky in optical polarized light. It will use a newly designed polarimeter for an 80cm Robotic Telescope. Telescope and polarimeter will be installed at CTIO, Chile, during 2014. The initial goal is to cover the sky south of declination $-15°$, aiming at a polarimetric accuracy $\leq 0.1\%$ down to V=15, with a camera covering a field of about 2.0 square degrees.
SOUTH POL will impact areas such as Cosmology, Extragalactic Astronomy, Interstellar Medium of the Galaxy and Magellanic Clouds, Star Formation, Stellar Envelopes, Stellar Explosions and Solar System, among others.
The polarimeter, with its optics and control electronics, has just been built. We will describe the Survey, the instrument and the data reduction pipeline.

This project is supported by FAPESP. AMM is also supported by CNPq.

INVITED: Polarimetry with Extremely Large Telescopes

Frans Snik[1]

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The upcoming generation of 30–40-m optical telescopes (the "extremely large telescopes") will truly revolutionize astronomy. Many exciting scientific discoveries will be enabled by the optimal implementation of polarimetric instrumentation at these telescopes. Their aperture sizes furnish the large photon collection rates that highly sensitive polarimetric measurements require, and they can deliver an unprecedented spatial resolving power that will unveil currently undetectable polarization signals.
To maximize the science potential of polarimetric instrumentation, they demand an integrated design at systems level. I will provide an overview of polarimetric modulation concepts that limit the influence of systematic effects (e.g. seeing and differential abberations) to the polarimetric *sensitivity*. In general, the polarimetric *accuracy* will be limited by the instrumental polarization of the telescope mirrors. I introduce modulation, calibration and mitigation strategies to constrain the overall polarimetric error budget within the stringent requirements for several proposed instruments. Moreover, I will present modeling results of the polarization structure in the PSF due to a segmented primary mirror, taking into account the effects of multiple missing segments and limited adaptive optics performance.
We apply these concepts to the EPICS instrument for the 39-m European Extremely Large Telescope, which will be capable to provide the first images of habitable-zone rocky exoplanets owing to its combination of sensitive imaging polarimetry with other high-contrast imaging techniques.

2 Session II. New Instrumentation, Facilities & Techniques: FIR / Radio

INVITED: ALMA Polarimetry: Current Status and Cycle 3 Capability

Hiroshi Nagai [1, *], Kouichiro Nakanishi [2, 1], Ed Fomalont [2, 3], George Moellenbrock [4], and ALMA Polarization Commissioning Team

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The Atacama Large Millimeter/submillimeter Array (ALMA), an international partnership of Europe, North America and East Asia in cooperation with the Republic of Chile, is the largest astronomical project in existence. ALMA will be a single telescope of revolutionary design, composed of 66 high precision antennas located on the Chajnantor plateau, 5000 meters altitude in northern Chile. Thanks to the unprecedented sensitivity and high angular resolution, ALMA is a promising telescope to open a new window for exploring the astrophysics in connection with the magnetic field in millimeter and sub-millimeter regimes.
The polarization commissioning team has been working on the verification of instrumental polarization (D-term), which is a key part of polarization sensitivity, and development of the calibration plan. Recent results suggest that

1. mean on-axis D-term of 12m antenna is few percent in bands 3/6/7,
2. considerable frequency dependence of D-term (peak-to-peak amplitude $\sim \pm 3\%$ at most) is seen in bands 3/6 but is less apparent in band 7,
3. the peak-to-peak amplitude of frequency structure becomes larger with increasing the distance from the on-axis up to half-power beam width, but mean D-term level at each off-axis field is not much different from that at on-axis field.

We confirmed that the on-axis D-term was successfully calibrated at a level of 0.1% with continuum observation mode (low frequency resolution / time-domain mode). Based on these results, ALMA Observatory offers the polarization observation capability at 3 mm (band 3), 1.3 mm (band 6), and 0.85 mm (band 7) for compact and continuum sources in Early Science Cycle 2. We are now testing the polarization characteristics in higher frequency resolution (frequency domain mode) and wider field of view for both 12m and 7m antennas. In this presentation, we will introduce (i) ALMA polarization observation system, (ii) calibration strategy, (iii) summary of Cycle 2 capability, and (iv) prospects for Cycle 3 capability.

SOFIA/HAWC+: Upcoming Capability for Mapping Interstellar Magnetic Fields through Far-Infrared Dust Polarimetry

C. Darren Dowell[1], for the HAWC+ Instrument and Science Teams

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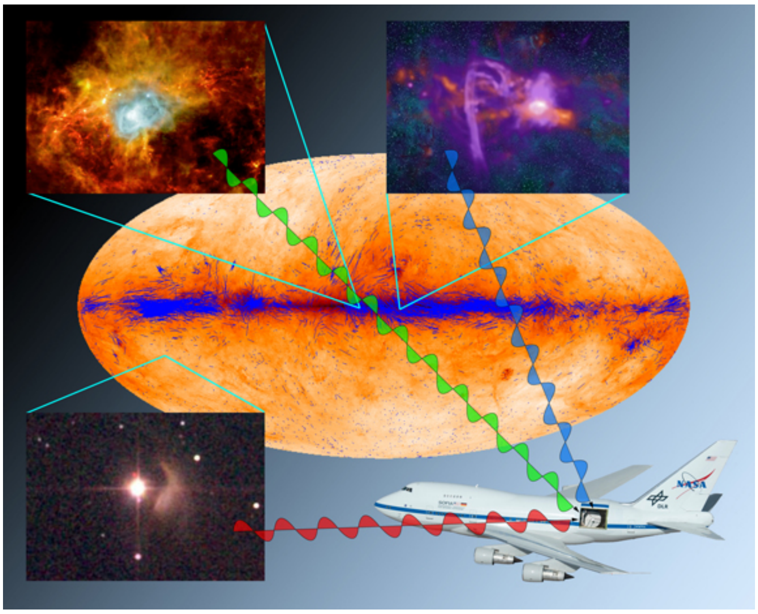
Prior work with airborne, ground-based, balloon-borne, and space missions has established the utility of infrared polarimetry of dust emission in establishing and understanding the magnetic field structure of dense molecular clouds. Furthermore, the discovery of unexpected trends in the wavelength dependence of far-infrared/submillimeter polarization has given clues to, and important constraints on, the alignment of the dust grains producing the polarization. Current facilities for far-IR/submm polarimetry have limitations in sensitivity, angular resolution, wavelength coverage, and/or availability to a wide community. Here, we describe HAWC+, a facility far-IR polarimetric imager for SOFIA. It is currently under construction, with first flights expected in 2015. HAWC+ will have state-of-the-art thousand-element detector arrays from NASA/GSFC, allowing operation with high quantum efficiency at the photon noise limit over a broad wavelength range, initially fielded as five continuum bands at 53, 62, 89, 155, and 216 μm. The angular resolution of SOFIA/HAWC+ is $5''$ at 53 μm, scaling with wavelength, and the flight altitude of SOFIA provides the sensitivity to map to the edges of molecular clouds and over scales of many arcminutes. Initial targets for HAWC+ include 1) the Galactic Center, where the interaction of magnetic fields, dense gas, rotation, and tidal forces will be explored on scales from 1 to 100 pc; 2) circumstellar environments of protostars, where HAWC+ will have sensitivity to both disks and envelopes; 3) diffuse molecular gas in a variety of environments, where we will test theories of grain alignment and apply Chandrasekhar-Fermi techniques to estimate magnetic field strengths. HAWC+ will be offered to the community as a SOFIA facility, likely in Observing Cycle 4.



XPOL - capabilities and results

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As soon as the IRAM 30m telescope was equipped with dual polarization receivers, a procedure designated XPOL was developped for making efficient polarization observations. The procedure measures all Stokes parameters and handles both spectral lines and continuum. We describe XPOL and demonstrate its main strengths and limitations. The intricate correction for polarized sidelobes, necessary in observations of extended sources, is illustrated by our observations of the Crab Nebula where we derived an upper limit of its circular polarization of 0.2% (Wiesemeyer et al. 2010).
We further describe and present first results from a monitoring program of the polarization of the brightest AGN which we started in 2006. Originally intended to monitor the instrumental polarization properties of the then somewhat unstable receiver configuration, we obtain reliable results for the linear and circular polarization of more than 200 AGN. A subset of 40 sources (Fig. 3 shows an example) was observed more than 50 times until end of 2013. The database is being prepared for consultation through the web.

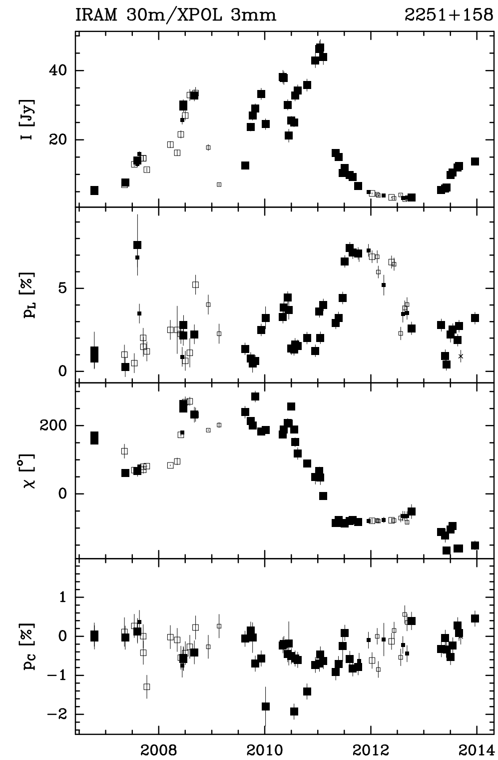

Figure 3: Polarization parameters of the QSO 2251+158 (z = 0.859) observed with XPOL at the IRAM 30m telescope as part of a program to monitor mm–loud QSO (I. Agudo et al., to be published).

New full Stokes polarization observing system in Nobeyama 45m radio telescope

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We have developed a full Stokes observing system at 45 GHz on the Nobeyama 45-m telescope to measure magnetic fields in star-forming cores through the Zeeman shift of the CCS molecular line. The new recever, Z45, performs $T_{\rm RX} \sim 50$ K for dual linear polarizations (X and Y) in 43 – 46 GHz band. The new software-based polarization spectrometer, PolariS, is capable to caluculate power spectra ($\langle XX^* \rangle$ and $\langle YY^* \rangle$) and cross power spectra ($\langle XY^* \rangle$) to output full Stokes spectra of I, Q, U, and V with a high spectral resolution of 61 Hz. We also developed polarization calibration method for that system., in terms of diffecences in complex gain between two polarizations and cross talk also known as the D-term. Phase difference between two polarizations is determined by using artifitial linearly polarization signal thtough a wire grid. Gains and D-terms can be estimated by observations toward unpolarized sources like planets and linearly polarized sources like the limb of the moon. We will present the performance of the polarization observing system, accuracy in the calibration scheme, and the initial results of full-Stokes spectra of SiO masers and CCS molecular emission.

First polarization measurements with the New IRAM KID Arrays (NIKA)

Alessia Ritacco [1], Andrea Catalano [2], Nicolas Ponthieu [3] and the NIKA Core Team

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The New IRAM KID Array (NIKA) is a dual-band camera operating with 315 frequency multiplexed Lumped Element Kinetic Inductance Detectors (LEKID) cooled at 100 mK. It is designed to observe the intensity and polarization of the sky at 1.25 and 2.05 mm from the IRAM 30 m telescope. NIKA is a test-bench for the final NIKA2 camera that will be made of about 1000 detectors at 2.14 mm and 2 x 2000 detectors with polarization capability at 1.25 mm. NIKA2's field of view will be circular with a 6.5 arcmin diameter and will be commissioned at the end of 2015. To modulate the incoming polarization, we continuously rotate a warm half-wave-plate (HWP) in front of an analyzer. In this way, a linearly polarized signal is modulated by the combined action of an "ideal" HWP and subsequent analyzer at four times the mechanical rotation frequency. It can hence be extracted with a lock-in procedure by isolating the amplitude of the mechanical rotation's fourth harmonic. The accuracy of this strategy lies in the calibration of the HWP: the correct amplitude of the Fourier components is required in order to decouple unwanted instrumental contaminations from the desired signal. This specificity was tested during NIKA's last technical run in January 2014. This contribution aims at presenting the performances of this system together with the first results obtained on some extended and point sources.

Submillimeter Polarimetry with the APEX: Filling the Gap between Planck and ALMA

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The Planck all-sky survey of polarized dust emission at 353 GHz, with a spatial resolution of 4$'\!.$8, will become a valuable tool to study large-scale correlations between the topology of Galactic magnetic field components and the dust emission from diffuse gas and molecular cloud complexes. ALMA, on the other hand, will observe the polarization of protostellar condensations, accretion disks and their associated outflows. The intermediate scales define the boundary conditions for gravitational instabilities, and are observed by (sub-)millimeter cameras with an instantaneous field of view of typically 10$'$.

In order to fill this gap, and motivated by the 345 GHz ATLASGAL survey of the Galactic plane, we equipped the Large Bolometer Camera of the APEX telescope with PolKa, a reflection-type polarimeter (see Figure below). This contribution will present the commissioning of the instrument and first polarization maps with 20$''$ resolution, along with algorithms for the data reduction and the correction of the instrumental polarization. An outlook will be given on the next-generation polarimeter for the A-MKID dual-color camera.

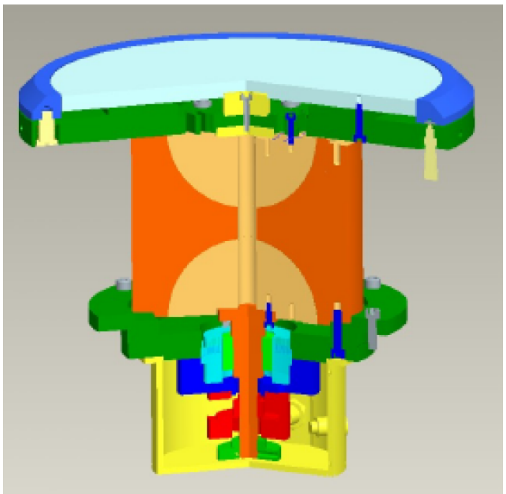

Figure 4: Design drawing of PolKa. The tunable grid-mirror unit (azure and bright blue) is mounted on top of an air bearing (the two hemispheres shown in pale orange).

3 Session III. Particle properties, Lab Measurements, modelling

INVITED: Light scattering measurements of cosmic dust analogs at visible wavelengths. The IAA Cosmic Dust Laboratory.

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Small irregular dust particles are present in a wide variety of astronomical environments. By analyzing the light scattered by those particles we can retrieve valuable information about their physical properties (shape, size, and composition) as well as their location within a certain atmosphere. The main goal of this talk is to show how experimental data of intensity and polarization of the scattered light of different cosmic dust analogs can be used to shed some light on the nature of dust particles. In particular, we will focus on samples relevant for the study of the atmospheres of planets, satellites, and comets in the Solar System. The measurements have been performed at the IAA COsmic DUst LABoratory (IAA-CODULAB) (Muñoz et al. 2011). The experimental data are freely available in digital form in the Amsterdam-Granada Light scattering Database at www.iaa.es/scattering (Muñoz et al., 2012). The database consists of two branches, one with experimental data from the Amsterdam Light scattering setup (Hovenier, 2000) and the other one with experimental data from the IAA-CODULAB.

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Extrapolation of scattering matrices

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Based on the modulation of the polarization state of light scattered by dust aerosols, all elements of the scattering matrices of such dust samples are measured as functions of the scattering angle at the COsmic DUst LABoratory (CODULAB) [1]. Due to physical restrictions, only a limited range of scattering angles can be measured: the laser beam hits the frame of the detector when this is located close to the forward or backward direction. Typically, this limited range is [3,177] deg. for CODULAB. But we need to know the scattering matrix in [0,180] deg. for several purposes, as the calculation of the polarimetric color of a sample or the utilization of a measured scattering matrix as an input for a Monte Carlo simulation of radiative transfer of polarized light. Several extrapolation methods have been proposed [2]. These methods take advantage of some physical conditions that must be fulfilled at 0 and 180 deg. for some of the elements of the scattering matrix, but not for all. Recently, a new paper has been published that reveals that derivatives must be zero at the strict forward and backward directions [3] for all elements of a scattering matrix. A new technique which compiles the method given in [2] and the condition unveiled by [3] has been implemented. Important differences for Monte Carlo simulations of radiative transfer of polarized light will be shown, as well as the application of this method to polarimetric measurements by another setup: FIGIFIGO [4].

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Polarimetric observations and experimental simulations in optically thin clouds: case of cometary and interplanetary dust

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Remote polarimetric observations are used to tentatively infer the physical properties of the dust particles in cometary and interplanetary environments. The scattered light is partially linearly polarized with a polarization degree depending on the physical properties of the dust and on the geometry (phase angle) and wavelength of observations. To interpret the observations numerical and experimental simulations are necessary. Light scattering measurements on levitating particles with the PROGRA2 experiment -in dedicated microgravity flights or in the laboratory for low-density particles- provide relevant simulations of the scattering properties of real particles, which can present large size distributions and a large variety of structures and materials (Hadamcik et al., 2009). Previous systematic experiments, together with numerical models and laboratory analysis of cosmic particles (e.g. Stardust samples) allow to optimize dust particles properties -such as their structures, sizes, size distributions, and silicate to organics ratios.
Intensity and polarization images of cometary comae provide evidence for changes in the polarization properties in the internal regions of the coma (Hadamcik et al., 2003), linked to the variation of particles properties with nucleus distance and/or rotation phase (Hadamcik et al., 2013). Associated experimental simulations help us to interpret how particles evolve within different coma regions and at different solar distances. We expect in situ confirmation of our results during the Rosetta mission to comet 67P/Churyumov-Gerasimenko in 2014-2015 (Hadamcik et al., 2010).
Analyses of observations of the zodiacal light scattered by the interplanetary dust cloud particles have shown local polarisation changes with the solar distance (Levasseur-Regourd et al., 2001). Such changes are interpreted through numerical models to be related to variations in the composition and physical properties of the particles through various processes including thermal degradation (Lasue et al., 2007; Levasseur-Regourd et al., 2007). This interpretation is now validated on real mixtures of particles corresponding to the zodiacal dust composition at different solar distances.

INVITED: Multiple Scattering of light by the surfaces of atmosphereless planetary objects

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Scattering of electromagnetic waves in a macroscopic particulate medium composed of microscopic particles constitutes an open computational problem in planetary astrophysics. This problem manifests itself in the absence of inverse methods to address fundamental astronomical observations of atmosphereless planetary objects. There are two ubiquitous phenomena observed at small solar phase angles (the Sun-Object-Observer angle) from, for example, asteroids, the Moon, Saturn's Rings, and transneptunian objects. First, a nonlinear increase of brightness is observed toward the zero phase angle in the magnitude scale that is commonly called the opposition effect. Second, the scattered light is observed to be partially linearly polarized parallel to the Sun-Object-Observer plane that is commonly called the negative polarization surge.
The aforedescribed polarimetric and photometric observations of atmosphereless planetary objects are interpreted using a radiative-transfer coherent-backscattering model (RT-CB) that makes use of a so-called phenomenological fundamental single scatterer (Muinonen and Videen 2012). For the validity of RT-CB, see Muinonen et al. (2012). The modeling allows us to constrain the single-scattering albedo, phase function, and polarization characteristics as well as the mean free path length between successive scatterings. With the help of laboratory experiments and exact theoretical methods, it further allows us to put constraints on the size, shape, and refractive index of the fundamental scatterers.

Acknowledgments: The research has been partially funded by the ERC Advanced Grant No 320773 entitled Scattering and Absorption of Electromagnetic Waves in Particulate Media (SAEMPL), by the Academy of Finland (contract 257966), NASA Outer Planets Research Program (contract NNX10AP93G), and NASA Lunar Advanced Science and Exploration Research Program (contract NNX11AB25G).

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Scattering Line Polarization in Rotating Optically Thick Disks

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In this contribution we study polarized line formation in optically thick disks which are either self-emitting or illuminated by a host star. Disks are rotating obeying Keplerian law with typical velocities of up to ten Doppler velocities of the line. We study a prototype line in the framework of a two-level atom model and employ fully-consistent NLTE numerical radiative transfer techniques for the transfer of polarized radiation on cylindrical axisymmetric grids where physical parameters depend only on z and r coordinates. We find that presence of rotation of the disk severely influences emergent polarization. Especially interesting are the models where the rotating disks are illuminated from the inside by the host star. In such models we find significant Stokes U (i.e. the rotation of the polarization plane). A specific shape of the dependence of the rotation angle on the wavelength could prove to be useful diagnostics tool for diagnostics of disk geometry and rotation velocity.

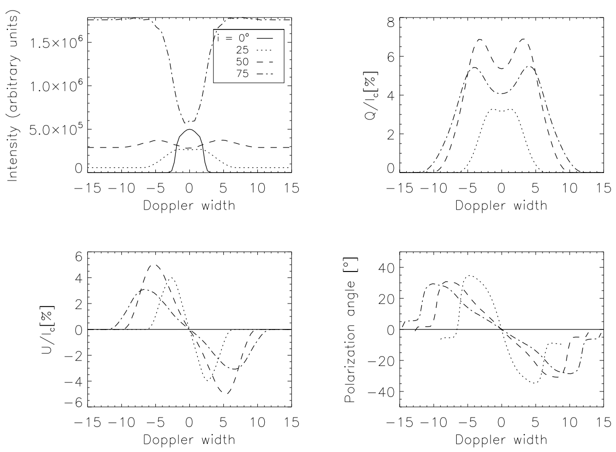

Figure 5: Intensity and polarization line profiles for an internally illuminated rotating disk with radial and vertical optical thickness' equal to 1000 and 10, respectively. Note significant Stokes U, which does not exist in the absence of rotation. Different line styles correspond to different inclinations of the system with respect to the observer.

4 Session IV. Results: ISM , Molecular Clouds, Star Formation

Grain Alignment: Current State of Theory

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Dust is known to be aligned in interstellar medium and the arising polarization is extensively used to trace magnetic fields. What process aligns dust grains was one of the most long-standing problems of astrophysics in spite of the persistent efforts to solve it. For years the Davis-Greenstein paramagnetic alignment was the primary candidate for explaining grain alignment. However, the situation is different now and the most promising mechanism is associated with radiative torques (RATs) acting on irregular grains. I shall present the analytical theory of RAT alignment, discuss the observational tests that support this theory. I shall also discuss in what situations we expect to see the dominance of paramagnetic alignment.

Observational tests of grain alignment mechanisms

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Dust induced interstellar polarization in the optical and infrared is a potentially powerful method for probing the magnetic field strength and structure. Its use for these purposes has however been hampered by the uncertain nature of the physical alignment mechanisms for the dust grains. Over the last decade observations have now shown - at least for the "large" dust grains - that the classical paramagnetic relaxation alignment is likely not viable. In contrast, a number of observational tests, both at optical/NIR and FIR wavelengths, have been carried out which all support the Radiative Alignment Torque (RAT) mechanism. I will review these observations and show that a quantitatively established grain alignment theory will not only allow better probes of the ISM magnetic field, but also provide new probes of the dust characteristics and the ISM environment.

A novel method for measuring interstellar magnetic fields using UV dust polarimetry

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We present a novel method to measure the strength of interstellar magnetic fields based on ultraviolet (UV) polarization of starlight, which is in part produced by weakly aligned, small interstellar grains. We begin with calculating degrees of paramagnetic alignment of small (size $a \sim 0.01\mu$m) and very small ($a \sim 0.001\mu$m) grains in the interstellar magnetic field by the Davis-Greenstein relaxation and resonance relaxation. We compute the degrees of paramagnetic alignment with the ambient magnetic field B using Langevin equations. In this paper, we take into account various processes essential for the dynamics of small grains, including infrared (IR) emission, electric dipole emission, plasma drag and collisions with ionized species. We find that weak alignment of small grains is required to reproduce the observed polarization in the UV, although the polarization arising from these small grains is negligible at the optical and IR wavelengths. Based on fitting theoretical models to observed extinction and polarization curves, we find that the best-fit model requires a higher degree of alignment of small grains for the case with the peak wavelength of polarization $\lambda_{\rm max} < 0.55\mu$m, which exhibits an excess UV polarization relative to the Serkowski law, compared to the typical case $\lambda_{\rm max} = 0.55\mu$m. We interpret the correlation between the systematic increase of the UV polarization relative to maximum polarization (i.e. of $p(6\mu m^{-1})/p_{\rm max}$) with $\lambda_{\rm max}^{-1}$ by appealing to the higher degree of the alignment of small grains. We identify paramagnetic relaxation as the cause of the alignment of small grains and utilize the dependence of the degree of alignment on the strength of magnetic fields B to suggest a new way to measure the strength of magnetic fields using the observable parameters $\lambda_{\rm max}$ and $p(6\mu m^{-1})/p_{\rm max}$. Applying our new technique to the available observational data, we estimate the upper limit of interstellar magnetic field $B \sim 10 - 15\mu$G for the typical sightline ($\lambda_{\rm max} = 0.55\mu$m), which is consistent with the strength obtained from other available techniques.

The Zeeman Effect As a Tool to Study Magnetic Fields in the Interstellar Medium

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The Zeeman effect is the only observational tool that allows us to directly measure the magnetic field strength and direction in the interstellar medium. We provide an overview of ongoing projects in which we are using the Zeeman splitting of the 21-cm line and the 18-cm hydroxyl (OH) transitions in order to probe astrophysical magnetic fields. We will also discuss previous measurements of the Zeeman effect in Galactic 21-cm radio emission, some of the instrumental challenges involved in such measurements, and the ambiguities that circular polarization conventions have introduced in their interpretation. We will present highlights that include the first detection of extragalactic Zeeman splitting in the OH megamaser emission from starburst galaxies and results from a southern hemisphere survey of Zeeman splitting in OH masers in our Milky Way's spiral arms that suggest field reversals relative to the field directions probed by Faraday rotation. Finally, we discuss plans for and preliminary results from a large-scale 21-cm emission Zeeman survey underway on the 64-m Parkes Telescope and the 26-m John A. Galt Telescope at the Dominion Radio Astrophysical Observatory.

Polarized thermal dust emission from *Planck*

F. Levrier [1] on behalf of the *Planck* Collaboration

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The *Planck* satellite has mapped the polarized microwave and submillimetre sky (from 30 GHz to 353 GHz) with unprecedented sensitivity and angular resolution. This wealth of data sheds new light on the polarization of Galactic foregrounds, especially that of thermal emission from aligned aspherical dust grains, which dominates the polarized cosmic microwave background (CMB) at the high end of the *Planck* frequency range. I will present the first results from the current analysis of *Planck* polarization data related to thermal dust emission. The *Planck* polarization data is scheduled to be made publically available in the fall of 2014.

Observations of Far-infrared and Millimeter Polarization in Galactic Clouds

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Polarized radiation at far-infrared (FIR) through millimeter (MM) wavelengths ($\lambda \sim 50$–2000 μm) arises from thermally emitting dust grains whose axes exhibit a net alignment with the local magnetic field. As a result of this mechanism, FIR/MM polarization observations have been used successfully for decades to measure magnetic field strength and structure in the densest molecular clouds in the Galaxy. Most recently the advent of more sensitive single-dish instruments and interferometers have extended such observations to individual proto-stars and clusters, thus allowing more definitive tests of magnetically-regulated and turbulence-regulated star formation. Additionally, more advanced physical models of grain alignment mechanisms have been proposed, models that lend themselves to tests with multi-wavelength FIR/MM observations. In the absence of a well-understood alignment model, the aforementioned magnetic field measurements would all be suspect. The FIR/MM spectra require models with multiple domains of grain temperature, alignment efficiency, and possibly composition. Extension of Galactic cloud observations to MM wavelengths, extension of FIR observations to low-density clouds, and complementary optical polarization observations will provide improved tests of alignment models covering a wide range of astrophysical/environmental conditions (e.g., density, temperature, radiation field, composition).

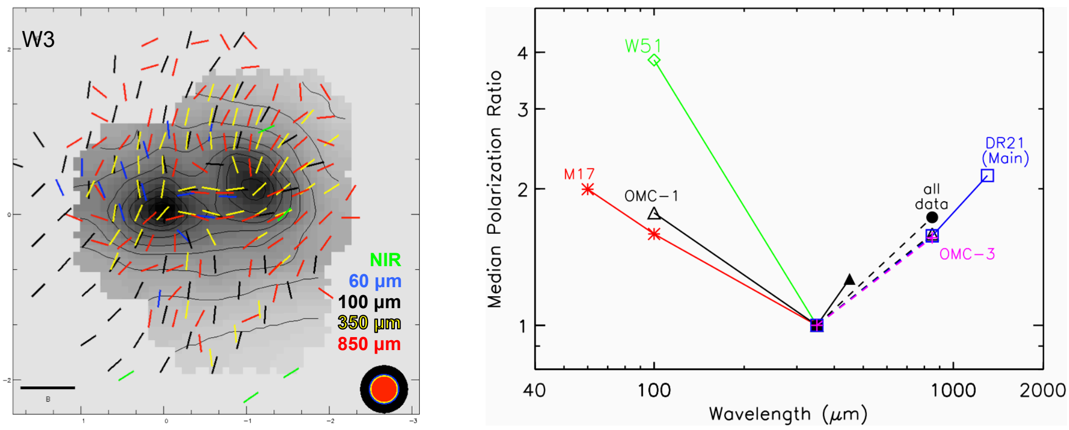

Figure 6: *Left*: Multi-wavelength polarization measurements in the molecular cloud W3. *Right*: Median polarization at multiple wavelengths in five different clouds.

Characterizing Magnetized Turbulence with Polarization Maps

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I will discuss how an analysis in the angular dispersion of polarization vectors can be used to characterize fundamental parameters pertaining to magnetic fields and turbulence in the interstellar medium. I will use different sets of data, ranging from lower resolution single-dish to high-resolution interferometry polarization maps (or a combination of both), to describe how, for example, magnetic field strengths, correlation length scales, and the anisotropy of turbulence leave their imprint on the data and can be accurately measured in molecular clouds (e.g., Orion KL and DR 21(OH)) and galaxies (M51). I will also show how the inertial and dissipation ranges of the turbulent power spectrum can be parameterized when the data were obtained with high-enough resolution.

INVITED: From clouds to cores to envelopes to disks: a multi-scale view of magnetized star formation

Charles L. H. Hull[1], Richard L. Plambeck[2], & the TADPOL collaboration[3]

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Magnetic fields have long been thought to play an important role in the formation of stars. However, that importance has been called into question by previous observations showing that bipolar outflows and magnetic fields (B-fields) are misaligned in young protostars, and that B-field morphology in these objects can change near the ~1000 AU scales of the protostellar envelope. To investigate these inconsistencies, we used the 1.3 mm full-Stokes polarimeter at CARMA to map dust polarization toward 30 star-forming cores as part of the TADPOL survey (see Figure 7 for sample maps). We find that a subset of the sources have consistent B-field orientations between large (~10,000 AU) scales and the small (~1000 AU) scales measured by CARMA, and that those same sources also tend to have high fractional polarization. This suggests that in at least some cases B-fields play a role in regulating the infall of material all the way down to the protostellar envelope scale. We also find that outflows appear to be randomly aligned with B-fields; although, in sources with low polarization fractions, there is a hint that outflows are *preferentially perpendicular* to small-scale B-fields, which suggests that in these sources the fields have been wrapped up by envelope rotation.

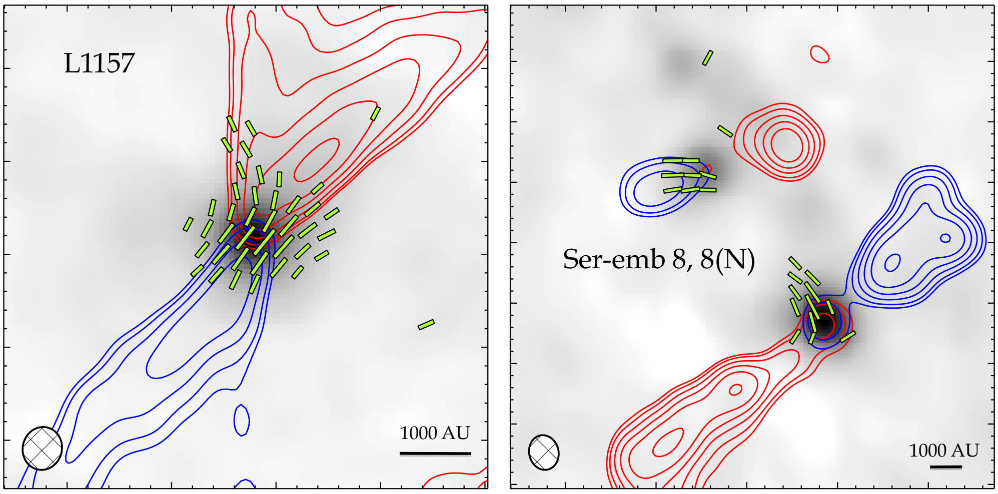

Figure 7: Sample maps of low-mass protostellar cores from the TADPOL survey. The line segments show the inferred magnetic field orientations; they have been rotated by 90° relative to the polarization orientations. The segment lengths are proportional to the square root of polarized intensity, *not* fractional polarization. The grayscale is proportional to the total intensity (Stokes I) dust emission. The blue and red contours are the blue- and redshifted spectral line wings [L1157: CO($J = 2 \rightarrow 1$); Ser-emb 8: SiO($J = 5 \rightarrow 4$)].

The magnetic field structure of L1527: A Cautionary Tale

Davidson, J.A. [1], Li, Z-Y. [2], Chapman, N. [3], Crutcher, R. [4], Hull, C.[5], Kwon, W. [6], Looney, L. [4], Matthews, B. [7], Novak, G. [3], Plambeck, R. [5], Stephens, I., [4, 8] and Tobin, J.[9]

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Many studies average the orientation of magnetic field vectors (as inferred from polarisation) over an observed region of a cloud core to estimate the initial uniform magnetic field orientation for that core. We have used global core collapse models with orthogonal and aligned initial magnetic fields with respect to the rotation axis of the core (inferred by a core's bipolar outflow) to see if these spatial averages of the magnetic field orientations give misleading results in regards to the initial field orientation. We also compared these models to the 131 polarisation vectors measured for a well-studied, nearby, cloud core containing a Class 0 embedded protostar, L1527. The models were integrated along the line-of-sight coincident with the observed vectors, with optical depth and beam effects included. Our results show that for weak magnetic field strengths, global core collapse models retain very little of their initial magnetic field orientation and have very similar evolved morphologies; only for strong fields do the aligned and orthogonal models evolve significantly different morphologies. Our results also show that spatial averages of field orientation angles depend strongly on the regions sampled in the cloud core for the averages and so these averages can be very misleading in regards to the initial field orientation.

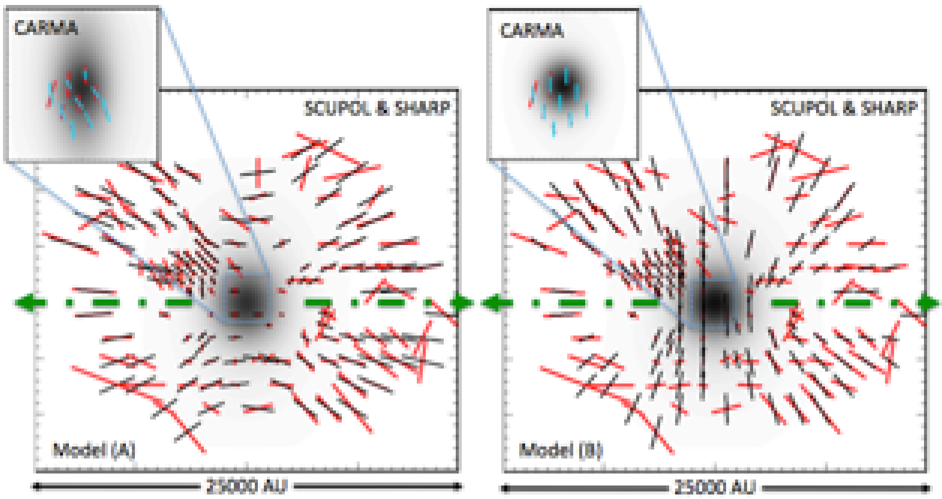

Figure 8: Magnetic field orientations in L1527: red vectors are based on SCUPOL, SHARP and CARMA observations; black and cyan vectors are based on the models. Vector lengths are proportional to polarisation fractions. Model (A) represents an initial weak field aligned with the outflow; Model (B) represents an initial weak field orthogonal to the outflow. Green arrows represent the outflow axis for L1527. The greyscale shows the model integrated intensities.

INVITED: Circular polarization from star forming regions

Jungmi Kwon [1], Motohide Tamura [2], SIRPOL team [3]

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The star and planet formation is one of the foremost issues in Astronomy. However, the history of star and planet formation still remains a mystery, even though for a single star and its parent cloud including a molecular cloud core there are many studies in recent years. Near-infrared polarimetry is powerful technique to study the dust scattering and magnetic fields in star forming regions that is heavily obscured by dense clouds of gas and dust. Linear imaging polarimetry has been extensively explored so far, while circular imaging polarimetrh has much less utilized, especially at infrared wavelengths. In this presentation, we present the first near-infrared circular and linear polarimetry survey of famous star forming regions observed in the near-infrared bands with the unique polarimeter SIRPOL on the InfraRed Survey Facility (IRSF) 1.4m telescope that is placed in South African Astronomical Observatory (SAAO). It is the only instrument that can make polarimetric imaging with a wide fields ($7.7' \times 7.7'$) in three bands (J, H, K_s), simultaneously. The results of circular polarimetry are also compared with that of linear polarimetry. Our data is covering covering from high-mass to low-mass young stellar objects, and it means we can perform statistical discussions for the first time. Our results show not only the magnetic field orientation of around young stellar objects, but also the structure of circumstellar matter such as outflow regions and their parent molecular cloud along the line-of-sight. In addition, we tried to understand the origins of circular polarization, especially for the high circular polarization that was not well explained with the present scattering mechanisms and ever verified by both observations and models. Our survey results may support the circular polarization in star forming regions as an origin of the biological homochirality on Earth, as proposed for the Orion nebular.

Multi-wavelength polarimetry toward a magnetized prestellar core

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Magnetic fields are thought to prevent or delay the formation of new stars within a molecular cloud, but how this process occurs during the earliest stages of star formation is still unclear. Our team presents new polarization data toward one of the starless cores found in the magnetized and sub-Alfvénic Pipe nebula. The new data reveal a strong submillimeter (submm) polarization flux toward Core 109, a textbook case of a prestellar core on the verge of collapse. This object is embedded in a very magnetized gas, as revealed by optical and near-infrared polarization data. In this talk, I will show how the submm polarization compares with the shorter wavelengths. An intriguing magnetic field configuration from the core envelope to the center is observed. The magnetic field in the core has field lines which are very ordered but slightly misaligned with the envelope B-field, in disagreement with theoretical predictions. I will discuss the possible scenarios associated to the dynamical evolution of this object by comparing our polarization maps to molecular data.

5 Session V. Results: Circumstellar matter

INVITED: A VLT/NACO program to study the inner regions of protoplanetary disks

Sascha P. Quanz[1], Henning Avenhaus[2], Antonio Garufi[2], Hans Martin Schmid[2], Esther Buenzli[3], Michael R. Meyer[2], Carsten Dominik[4], and Sebastian Wolf[5]

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In the past few years, we have used the adaptive optics assisted high-resolution near-infrared camera NACO at the Very Large Telescope to study the protoplanetary disks around 8 young intermediate mass Herbig Ae/Be stars. All disks were observed in polarimetric differential imaging mode providing unprecedented sensitivity and resolution at separations down to 0.1″ (∼10 AU from the central stars). Our images reveal a variety of previously unseen sub-structures in most of the disks. This talk will summarize the key results from this program and compare them with complementary datasets to address to what extent ongoing planet formation within the observed disks is the result – or the cause – of the detected structures. Outstanding questions will be discussed and an outlook will be provided what can be expected from the next generation of high-contrast imagers now coming online at the VLT and Gemini Observatory.

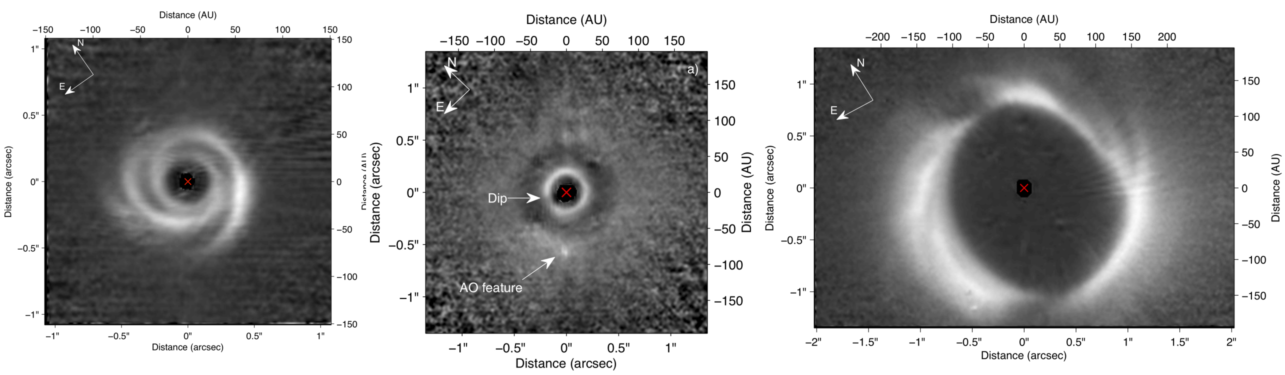

Figure 9: Exemplary results from our NACO/PDI program: The disks around SAO206462, HD169142, and HD142527 (Garufi et al. (2013, A&A 560, 105); Quanz et al. (2013, ApJL 766, 2); Avenhaus et al. (2014, ApJ 781, 87)). Possible signs of (forming) planets (e.g, spiral arms, cavities and gaps) are commonly observed in the inner 10-100 AU.

Imaging polarimetry of the potentially planet-forming circumstellar disk HD 142527. The NaCo view.

Cánovas, H. [1,8], Ménard, F. [2,8], Hales, A.[3,8], A. Jordán[4,8], M. R. Schreiber[1,8], S. Casassus[5,8], T. M. Gledhill[6], C. Pinte[7,8]

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[8] Millenium Nucleus "Protoplanetary Disks in ALMA Early Science"

HD 142527 is a unique system in terms of planet formation. Its high accretion rate combined with its huge inner gap and short age make of it an ideal candidate for harboring forming planets. ALMA cycle-0 observations revealed gap crossing gas streams and showed that the millimeter-sized dust particles are distributed in a horse-shoe shape. Here I present our recent NIR imaging polarimetry results of HD 142527 obtained with NaCo/VLT. By means of polarimetry, we remove most of the stellar light, directly imaging the disk's inner regions. Our observations allow us to constrain the dust properties (size, composition and porosity) on the surface of the the outer disk. We also detect two regions of the disk with low emission ("nulls") both in polarized and unpolarized light. Intriguingly, one of these nulls is azimuthally coincident with the maximum of the horse-shoe shape detected by ALMA. We discuss the possible link between these two (different?) features.

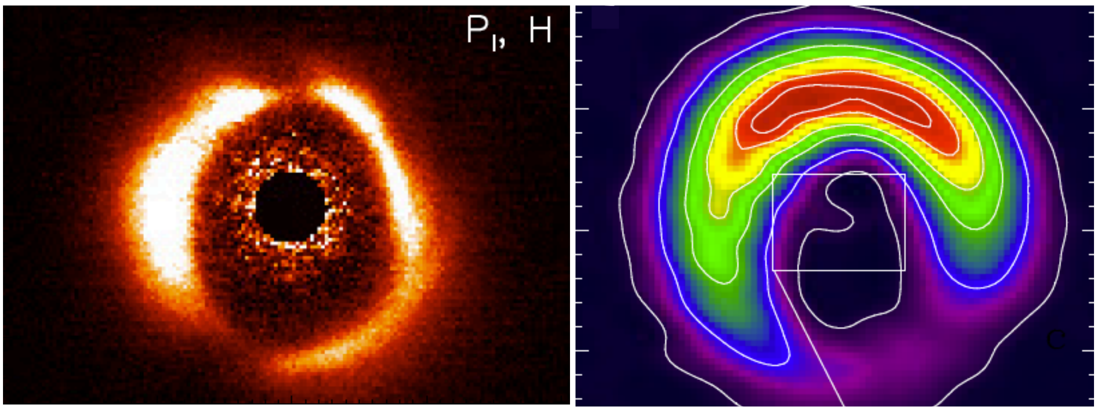

Figure 10: Left: Polarized intensity images of HD 152427 at H-band (adapted from Canovas et al. 2013). Right: Continuum ALMA Band-7 image (345 GHz, 0.87 mm), adapted from Casassus et al. 2013). The maximum emission at the continuum is roughly coincident with the gap observed in polarized intensity in the H-band at top position.

Multi-epoch Polarimetric Differential Imaging of HD100546

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The transition disk of HD100546 has been imaged in both thermal and scattered light. Recently, it got further attention by the detection of two companion candidates: One within the inner gap of the disk, which has a radius of ∼15 AU, and a second one further out in the disk at ∼68 AU. This makes HD100546 an especially interesting object, because we may be observing the formation of planets and their interaction with the surrounding gas-rich disk directly. In 2013, we obtained second-epoch Polarimetric Differential Imaging (PDI) data, which I will present here along with a re-reduction of data taken in 2006 using a new, improved pipeline. We also, for the first time ever, were able to image the scattered light of a circumstellar disk using PDI in the L' band. We achieve an inner working angle of ∼0.1", and clearly reveal the disk and its gap at high signal-to-noise ratio. In my talk, I will summarize our key results for this interesting transitional disk and discuss possible connections between the disk and the two proposed companions.

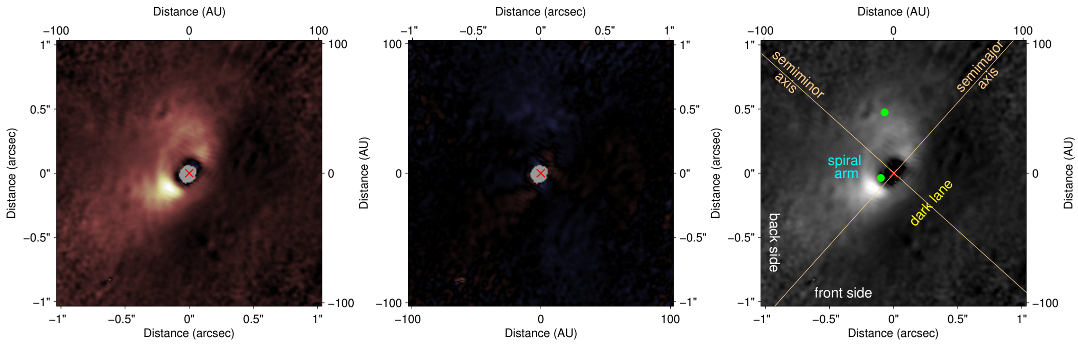

Figure 11: PDI results for HD100546. Left: $P_\perp$ for the K_s filter. Positive values in orange, negative values (not seen) in blue. Middle: $P_\parallel$, which contains essentially noise on the same level, for comparison. We achieve a high S/N ratio. Right: Features marked in the disk. The green points are the approximate positions of the two companion candidates (see Avenhaus et al. submitted for further information).

Polarimetry with the Gemini Planet Imager: Speckle Suppression and the HD61005 Debris Disk

Max Millar-Blanchaer[1], Marshall D. Perrin[2], James R. Graham[3], Sloane Wiktorowicz[4], Bruce Macintosh[5], Michael P. Fitzgerald[6], Fredrik Rantakyro[7], Pascale Hibon[8] and the Gemini Planet Imager Team

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The Gemini Planet Imager (GPI), currently undergoing commissioning at the 8-m Gemini South Telescope, is equipped with a dual-channel polarimetry mode designed for the detection of scattered, polarized light from circumstellar disks around nearby stars. GPI has been on-sky since November 2013 and the polarimetry mode has been operational since December 2013. We provide results from the ongoing characterization of the instrument. Observations of the twilight sky, strongly polarized due to Rayleigh scattering in the upper atmosphere, provide a simple first order test of GPI's ability to measure the position angle of polarized light. We successfully recover the expected position angle of the polarized twilight sky, at 1.1, 1.6, and 2 microns. Coronagraphic observations of unpolarized stars demonstrate GPI's ability to suppress unpolarized light by over a factor 150 at working angles as small as 0.3 arcseconds, from 1.1 to 2 microns. In addition, we present H-band images of the circumstellar environment of HD61005, where we resolve "The Moth" debris disk in both total intensity and polarized intensity at smaller angular separations down to 0.3 arcseconds.

Exploring Magnetic Fields in Young Circumstellar Disks and their Environments with CanariCam Polarimetry at the GTC

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Astronomers are well aware that magnetic fields (B-fields) play a critical role in the formation of stars and planets. Numerous theoretical studies have demonstrated that B-fields alter, and in many regimes, control, the dynamics and lifetimes of cloud collapse and subsequent protostellar evolution. The resultant young circumstellar disks are likely threaded by B-fields that are first pulled inward as part of the collapse, then twisted into the disk plane by Keplerian rotation. Magnetic coupling of gas at different orbital radii, along with the Keplerian shear, must give rise to turbulence and a highly irregular B-field structure in the disk. The turbulence and resultant viscosity are thought to have a dramatic effect on planet-formation timescales. However, few, if any, observations exist that constrain B-field strengths and morphologies in planet-forming disks, which has been a major obstacle to progress in planet-formation studies. With the start of its commissioning and science operations in 2012, the facility multi-mode mid-IR camera CanariCam at the Gran Telescopio CANARIAS (GTC) on La Palma, has emerged as a promising and powerful tool in the exploration of B-fields in these and other environments. In particular, CanariCam's 8-13 micrometer polarimetric mode offers the potential for astronomers to determine B-field structure with approximately 0.3 arcsec resolution and unprecedented sensitivities in young disks and their environments. After a brief overview of CanariCam's polarimetric mode, we will present recent results from our GTC program to explore B-fields in young disks and their environments, results that demonstrate CanariCams capabilities. Among these results are: (1) the mapping of the B-field variations both across, and potentially along the line of sight within, the disk and environment of the YSO K3-50; (2) tentative evidence for detection of the B-field within the environment of the Herbig Ae star AB Aur. The GTC is a joint initiative of Spain, the University of Florida, and Mexico.

CanariCam imaging- and spectro-polarimetry of embedded Young Stellar Objects driving bipolar outflow

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Some of the key questions behind our origins can be probed via thermal (or mid-) infrared polarimetric observations. These include the influence of magnetic fields during the early evolution of young stars, and the compositional and mineralogical evolution of cosmic dust.

Conservation of angular momentum dictates that as a forming star gravitationally contracts it would spin up to a break-up point unless some mechanism exists to prevent it. A cosmic magnetic field is the main suspect, whereby it acts in concert with rotation to tap the gravitational potential well of a star+disk system to eject material along the poles. The ejected material carries away angular momentum, allowing infall and accretion to proceed. An ability to map the magnetic field in the near environs of a young star is an ideal way to study this and related processes.

Cosmic dust grains are the raw material for the formation of rocky planets. But the process(es) by which multi-trillions sub-micron sized pieces of grit are transformed into a planet are poorly understood. Yet these processes must surely have some influence on the dust itself, inducing chemical, physical and/or morphological changes. An ability to constrain and/or determine dust properties in the envelopes and disks around young stars is crucial to better understand these processes.

Polarimetry in the mid-infrared is an especially powerful technique to address the issues outlined above. The polarization is due to emission from, or absorption by, a medium of dust grains whose short axes have been preferentially aligned with the ambient magnetic field. Thus, the polarization position angle observed from such a medium is related to the magnetic field direction projected onto the plane of the sky. Further, the cross sections for absorption of radiation along the major and minor axes of a spheroidal dust grain peak at different wavelengths, and the polarization is formed by a difference between these cross sections. They are sensitively dependent on the grain dielectric function, a unique identifier of the responsible material, as well as grain shape and presence of a mantle.

Since mid-2012 we have been using the world's newest and most advanced mid-IR instrument, CanariCam, on the world's largest single-aperture optical/IR telescope, the 10.4 m Gran Telescopio CANARIAS (GTC), to observe the polarization from a sample of embedded Young Stellar Objects. We will present a selection of results from multi-filter imaging polarimetry across the 10 μm silicate band, which has allowed the separation of magnetic field components within *both* emitting and absorbing regions near the source. We will also present some early spectropolarimetric observations, which have revealed in unprecedented detail the unusual dust mineralogy toward several young stars.

Linear line spectro-polarimetry and the circumstellar medium around young and massive stars

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Linear line spectro-polarimetry is a powerful tool to probe circumstellar structures on spatial scales that cannot yet be achieved through direct imaging or interferometry. I discuss the role that emission-line polarimetry can play in constraining both geometrical and physical properties of a wide range of circumstellar environments, varying from the accretion disks around pre-main sequence (PMS) T Tauri and Herbig Ae/Be stars, to the issue of stellar wind clumping, and the aspherical outflows from the massive star progenitors of supernovae (SNe) and long gamma-ray bursts (GRBs).

Play of polarized light in the dusty nebula of the long period Cepheid RS Puppis

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The long-period Cepheid RS Pup is one of the most luminous Cepheids in the Milky Way (P = 41.4 days). It is surrounded by a large circumstellar dusty nebula reflecting the light from the central star. The origin and physical properties of the nebula are however uncertain: was it created through mass loss from the star, or is it a pre-existing interstellar cloud ? To address this question, we used the VLT/FORS instrument to map the degree of linear polarization p_L in the nebula. Using a simple polarization model, the scattering angle can be recovered from p_L, and therefore give access to the 3D dust distribution. We derive a total dust mass of $M_{\rm dust} = 2.9 \pm 0.9\,M_\odot$ within $1.8'$ of the Cepheid. This very high mass excludes that it was created by the star itself. Due to the changing luminosity of the central source, light echoes propagate into the nebula. This remarkable phenomenon can yield a reliable geometric distance to RS Pup, provided we achieve a sufficient accuracy on the 3D structure of the dust distribution. Such a distance is highly valuable e.g. to calibrate the Leavitt law, as well as the Cepheid's projection factor p used in Baade-Wesselink distance estimates. We obtained 7 epochs of polarimetric imaging with HST/ACS, from which we derive a distance $d \approx 2$ kpc, and a p-factor around 1.3 (work in progress).

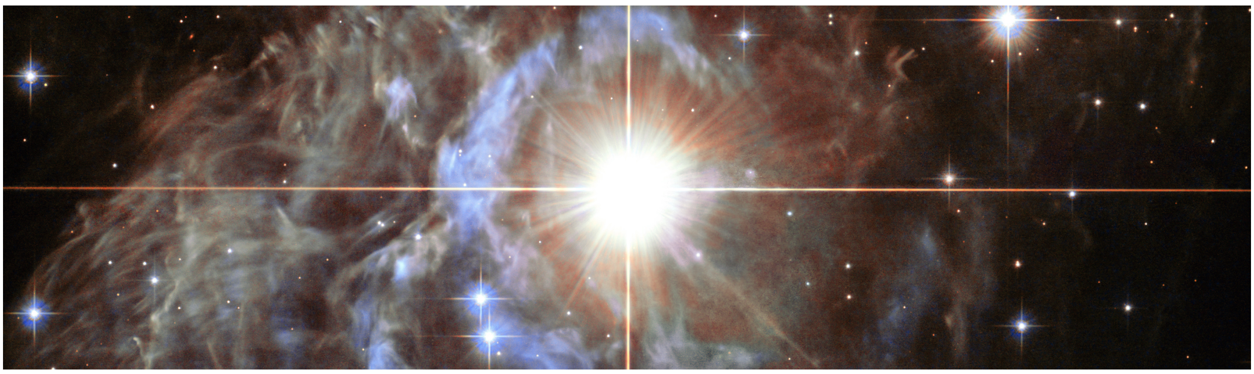

Figure 12: Three-color composite view of the nebula of RS Pup (HST/ACS).

Strong linear polarization of the optical continuum of the red nova V4332 Sagittarii

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V4332 Sgr is a red nova (also named as red transient or V838-Mon-type object), which erupted in 1994. Red novae, contrary to classical novae, evolve during the eruption to progressively lower effective temperature and decline as late M-type (super)giants. We now know that the red novae result from stellar mergers.
V4332 Sgr did not atract any interest from observers until the V838 Mon eruption in 2002, when astrophysicits realised that both objects belong to the same class and are very intriguing. Spectroscopic observations of V4332 Sgr done in 2003 revealed an unusual spectrum as for stellar objects: strong emission lines of neutral atoms and molecules superimposed on a weak, early M-type continuum.
In previous studies we have shown that the main object in V4332 Sgr is not visible for us as it is now embedded in a dusty disc: the observed stellar-like continuum in the optical most probably arises from scattering of the main object spectrum on dust grains, while the emission features are produced by atoms and molecules in the outflowing matter in the process of resonant scattering. Consequently the continuum should be considerably polarized but not the emission features. Our recent spectropolarimetric observations (as presented in the figure) show that this is indeed largely the case although not entirely.

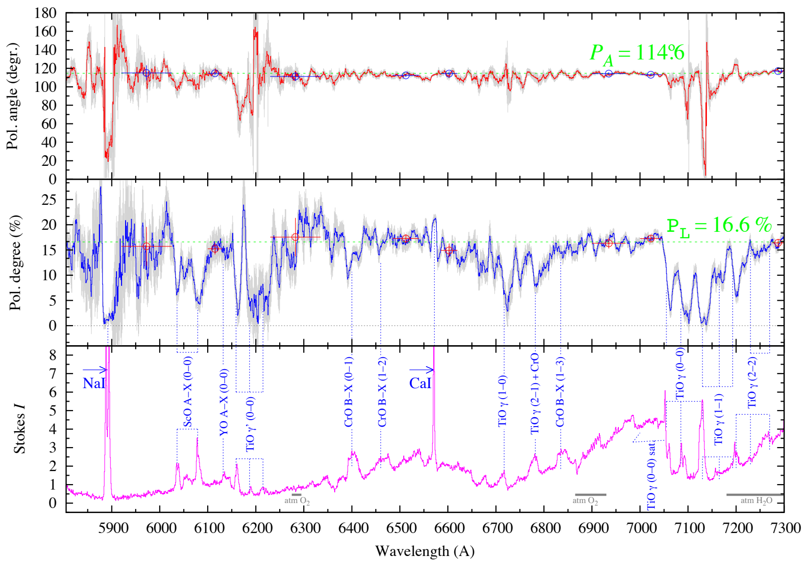

Figure 13: Spectropolarimetry of V4332 Sgr. Bottom: spectrum, middle: polarization degree, top: polarization angle.

6 Session VI. Results: Solar & Stellar Magnetic Fields

Invited: Solar magnetic fields

M. Faurobert [1]

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The Sun is the first astrophysical object where magnetic fields have been detected and measured. As our closest star it offers the possibility of studying a case of stellar magnetism with great details. Its complex magnetic structuring has been explored with increasing spatial and temporal resolution, in particular recently from space born instruments such as SOT on the Hinode satellite, HMI on SDO or IMAX on SUNRISE . I will present some of the new results obtained with these instruments and give some directions for future developments.

Exploration of Magnetic Fields in Solar Chromosphere by High-Precision Lyman-Alpha Polarimetry

Kano, R. [1], CLASP team

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Above the solar surface (photosphere) with temperature of ~6000 K, hotter plasma occupies the outer solar atmosphere: the chromosphere is ~10,000 K and the corona is over 1 million K. The heating mechanism of these high-temperature layers is one of the longstanding mysteries of solar physics. Magnetic fields generated in the solar interior and emerging through the photosphere must play an important role in the heating mechanism. This topic has been investigated by using photospheric magnetic fields derived by the Zeeman effect from spectro-polarimetric observations as well as chromospheric/coronal activities taken by EUV-spectroscopic or X-ray-imaging observations. However, observations by the Japanese solar satellite "Hinode" discovered a variety of dynamic events in the chromosphere such as jets and waves, indicating that these events may be responsible for heating the chromosphere and corona. Such discoveries imply that the next frontier in solar physics lies in simultaneous observations between the dynamics and magnetic structures in the chromosphere and transition region, where the gas-dominant photosphere changes to the magnetic-dominant corona.

In the chromosphere or above it, the polarization by the Zeeman effect is not applicable to derive magnetic fields, because of the weaker magnetic fields than the photosphere's. However, the recent model calculations suggest that the Hanle effect can make small but observable amount of polarization in the hydrogen Lyman-alpha line (121.6 nm) even in the chromosphere and transition region. Now, a sounding-rocket experiment called the Chromospheric Lyman-Alpha Spectro-Polarimeter (CLASP) is under development to measure the linear polarization profiles caused by scattering processes and the Hanle effect in the Lyman-alpha line with high accuracy (0.1%), and then to infer the magnetic fields in the chromosphere. The Lyman-alpha is the brightest line among the chromospheric lines in vacuum ultra-violet wavelengths, and bright anywhere on the solar disk. Therefore, the high-precision polarimetric observation in the Lyman-alpha is a good start-point to explore weak magnetic fields in the outer solar atmosphere.

Review: Exploring the magnetic Hertzsprung-Russell diagram with spectropolarimetry

Julien MORIN [1]

[1] LUPM - Univ. Montpellier 2

During the past few years, magnetic fields have been detected and studied on stars throughout the Hertzsprung-Russell diagram, and spectropolarimetric techniques have played a key role in this exploration. In this review I will briefly summarize the theoretical puzzles we want to address in the field of stellar magnetism, discuss issues specific to stellar spectropolarimetry, and present a selection of recent results obtained with spectropolarimetry alone or coupled to other techniques. Finally, I will present how future instruments operating in the near infrared will contribute to the next advances in the field.

Review: spectropolarimetry of massive stars

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I will review the low- and high-resolution spectropolarimetric techniques used for the study of magnetism in massive stars, the results obtained for those objects in particular by the MiMeS and BinaMIcS collaborations on the occurrence of magnetic fields, their origin, and their impact on the star and its environment, as well as future projects in this domain.

The Bcool magnetic snapshot survey of solar-type stars

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Stellar magnetic field measurements obtained from spectropolarimetry offer key data for activity and dynamo studies, and we present the results of a major high-resolution spectropolarimetric Bcool project magnetic snapshot survey of nearly 200 solar-type stars from observations with the Telescope Bernard Lyot and the Canada-France-Hawaii Telescope. Surface magnetic fields were detected for one third of our sample, including surprising detections on a few subgiant stars. In this talk we will show how the magnetic field strength (longitudinal field) is correlated with basic stellar parameters such as rotation rate, age, chromospheric activity indicators as well as with spectral type. This survey constitutes the most extensive spectropolarimetric survey of cool stars undertaken to date, and suggests that it is feasible to pursue magnetic mapping of a wide range of moderately active solar-type stars to improve understanding of their surface fields and dynamos.

Variable magnetic field of the young sun HN Peg

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We investigate the variability of the large-scale surface magnetic field and chromospheric activity of the young G0 dwarf HN Peg. The large-scale magnetic field geometry is reconstructed using Zeeman Doppler Imaging at six epochs over seven years of observations. The chromospheric variations were also measured using three chromospheric lines: Ca II H&K,Hα and Ca II Infrared Triplet. The magnetic field topology of HN Peg exhibits a variable and complex geometry. While the poloidal component exhibits a stable magnetic geometry at each observational epoch, the toroidal component is strongly variable in strength, where a positive polarity toroidal band at equatorial latitudes undergoes significant variations through out the observational timespan. HN Peg exhibits a weak longitudinal magnetic field over the epochs of this analysis, with no signicant long term trend. The chromospheric activity indicators exhibit long-term variations over our time span of observations, where the variability in Ca II H&K and Hα proxies exhibit a long-term correlation.

7 Session VII. Results: Solar System & Exoplanets

INVITED: Status of Exoplanet Polarimetry

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The last decade has witnessed an explosion in the atmospheric characterization of spatially unresolved exoplanets using transmission and emission spectra, but understanding is hampered by degeneracies resolvable by optical scattered light observations. In particular, transmission spectra of many exoplanets are equally consistent with atmospheres dominated by clouds or by water vapor. While several recent studies provide compelling evidence for the presence of clouds on exoplanets, cloud particle composition is as yet unknown. In the early 1970s, ground-based polarimetry of Venus enabled the discovery of sulfuric acid cloud particles by drawing on the sensitivity of Rayleigh/Mie scattering to the size distribution, shape, and chemical composition of cloud particles, and also to scattering optical depth. Thus, the presence of clouds on exoplanets, and their chemical composition, is an extremely important issue in exoplanet characterization that may require polarimetry to identify. The technical challenges inherent in separating scattered exoplanetary light from direct illumination by the host star are severe: 1) high contrast imaging is required to spatially resolve long-period exoplanets, and 2) highly stable, accurate polarimeters are required to measure the small, periodic change in system polarization due to short-period exoplanets. However, complementary instrumentation now exists to suppress stellar flux and isolate exoplanetary scattered light at both period regimes. As with all high-sensitivity observations, measurement and control of systematic effects is the key to accurate study of exoplanets in polarized, scattered light. I will report on the current status of the detection and study of exoplanets with polarimetry. This work is supported by a NASA Sagan Fellowship, a NASA Origins of Solar Systems grant, and UCO/Lick Observatory.

Polarimetry of transiting exoplanetary system HD 189733

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We present and discuss a polarimetric effect caused by a planet transiting the stellar disk and, therefore, breaking its symmetry and resulting in linear polarization of a partially eclipsed star. Estimates of this effect for transiting planets were made only recently. In particular, we demonstrated that the maximum polarization for one of the brightest transiting planets HD189733b strongly depends on the centre-to-limb variation of linear polarization for the host star. However, observational and theoretical studies of the limb polarization have been largely concentrated on the Sun. As was shown in our previous study, we expect to observe a larger centre-to-limb linear polarization for cooler stars. Here we solve the radiative transfer problem for polarized light and simulate the centre-to-limb polarization for stars of different spectral classes taking into account various opacities.

The polarization of Earth

Earthshine polarimetry in the B, V, R, and I band as function of phase

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Earth-like extrasolar planets may soon become observable with upcoming high-contrast polarimeters. Therefore, the characterization of the polarimetric properties of planet Earth is important for the interpretation of expected observations and the planning of future instruments.
We present benchmark values for the polarization signal of integrated light from planet Earth in broad band filters B, V, R, and I, derived from our polarimetric observations of the earthshine backscattered from the Moon's dark side for Earth-phase angles α between 30° and 110°.
The observations were carried out with a new, specially designed wide field polarimeter at a 21 cm Dall-Kirkham Cassegrain telescope. Depending on wavelength λ and lunar surface albedo a the polarization of the back-scattered earthshine is strongly reduced. To determine the polarization of Earth, we correct our earthshine measurements by a polarization efficiency function $\epsilon(\lambda, a)$ for the lunar surface derived from measurements of Apollo lunar soil samples from the literature.
The fractional polarization for Earth is decreasing with wavelength and at quadrature phase we find values 24.6 % for the B band, 19.1 % for the V band, 13.5 % for the R band, and 8.3 % for the I band. Together with literature values for the spectral reflectivity we obtain a contrast between the polarized flux of Earth and the (total) flux of the Sun with an uncertainty of less than 20 %, and we find that the best phase to detect an Earth twin is around $\alpha = 65°$. Our results are in qualitative agreement with polarimetric models of Earth-like planets and they can now be used to guide more detailed computations.

Monitoring of Venusian clouds and hazes with an imaging–polarimetry system "HOPS"

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Linear polarization of reflected sunlight from the optically-thick Venusian clouds carry a wealth of information about the atmosphere and aerosols. Hansen and Hovenier [1974] analyzed the ground-based (disk-integrated) polarimetric data of 1960's and found the Venusian clouds are composed of sulfuric acid droplets (1 μm in radius). Kawabata et al. [1980] analyzed "spatially-resolved" polarization maps from Pioneer Venus Orbiter (PVO) and discovered for the first time that there were abundant sub-micrometer sized particles "hazes" mostly on polar regions, which obviously were not present in 1960's.
To monitor Venusian upper hazes, we performed observations in 2012 and 2013 by attaching a two-beam imaging polarimeter HOPS (details in another paper) to the 65cm refracting telescope at Hida observatory of Kyoto University. Polarimetric data of Venus were acquired at solar phase angles around 39°, 56°, 58°, 85° and 129° in 4 bands from blue (438nm) to IR (930nm). The reference planes of polarization were calibrated by observations of polarized standard stars (BS6353 and oSco). We averaged observed degree of linear polarization (DOLP) over the polar regions (latitudes higher than 60°). Obtained DOLP at IR and phase angle 85° are, for example, 4.6 % and 1.5 % for northern and southern polar regions. Though PVO while in orbit measured polarization of Venus from a variety of latitudes, the initial-phase data were so compiled that they can conveniently be compared with ground-based observations [Kawabata et al., 1980]. Comparison with our IR data exhibits a major difference in the neutral point (the phase angle of null polarization). It is around 75° in our data in contrast with around 40° in the PVO initial-phase data. As the PVO initial-phase is known for optically thick hazes in polar regions, difference in the neutral point may be a result of different condition of hazes in 2012 - 2013.
We performed radiative-transfer analysis and searched for the best combination of the particle radius of hazes ($r_{\rm eff}$) and optical thickness of haze layer ($\tau_{\rm h}$). The resultant parameters for northern and southern polar region are $r_{\rm eff} = 0.22$ μm, 0.20 μm, $\tau_{\rm h} = 0.09$, 0.05 at IR, respectively. The optical thickness is comparable with those observed during the declining phase during PVO mission period [Sato et al., 1996]. The mechanism of such a variation is not understood, so polarimetry is useful tool to monitor the microphysical parameters of Venusian cloud and hazes.

Spectro-polarimetry as a new diagnostic tool for the physical characterisation of small Solar System bodies

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Most investigations in the field of polarimetry of the small bodies of the Solar System have been traditionally focused on measurements of the variation of linear polarisation in the V band as a function of the phase-angle (the angle between the directions to the Sun and to the observer as seen from the target asteroid). The so-called phase-polarisation curves obtained from observations have been used to derive the geometric albedo of the objects, and, in case of asteroids, Centaurs, and trans-Neptunian objects, some information on the typical sizes of regolith particles covering asteroid surfaces.
Something that has been poorly studied until now is the dependence of polarisation upon wavelength. Earlier studies, essentially based on limited sets of measurements in different colours, suggested that at large phase-angles the linear polarisation of moderate-albedo asteroids decreases wtih wavelength, whereas at smaller phase angles, in the so-called negative polarisation branch, polarisation increases with wavelength. Interestingly, low-albedo objects were found to exhibit an opposite behaviour. If this is true, one single spectro-polarimetric measurement obtained at a suitable phase angle might be sufficient to distinguish between bodies belonging to different albedo classes.
To test this hypothesis, we have performed what is to our best knowledge the first spectro-polarimetric survey of small bodies of our solar system. We have discovered that asteroids exhibit a large variety of spectro-polarimetric behaviours, that may be used to obtain a substantial improvement of their classification and characterisation. In this talk we will present some preliminary results of our survey. We will also compare our new data with our laboratory spectra of organic material and with Earthshine spectro-polarimetric data, and discuss the use of spectro-polarimetric techniques for the search of extra-terrestrial life.

Remote detection of biological pigments on Earth-like planets with spectropolarimetry

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Recently, it was demonstrated that polarized reflected light can be detected from exoplanetary atmospheres (Berdyugina et al. 2008, 2011). Here we focus on identifying biosignatures resulting from biological polarization, e.g., selective light absorption or scattering by biogenic molecules.
The terrestrial biosphere dominates both the planetary surface and the atmosphere, which is used as a major dispersal route by many organisms. In fact, there is a substantial amount of bioaerosols in the atmosphere. Both surface biosphere and bioaerosols are directly in contact with Sun's radiation. Many of these organisms evolved a potential to produce pigments, i.e., molecules that selectively absorb certain wavelengths of light, in order to harvest energy or protect the organisms. We aim at identifying unique spectro-polarimetric signatures of pigmented organisms found either on planetary surfaces or in their atmospheres, which can be employed for remote sensing of life forms on the Earth and extraterrestrial environments.
We have carried out a laboratory spectro-polarimetric study of light reflected by various bacterial types and terrestrial plants, which contained different photosynthetic and non-photosynthetic pigments. Measurements on non-biological samples (e.g., rocks and sands) were also performed in order to avoid false positives. These measured reflection spectra were then used to synthesize polarized spectra of Earth-like planets with various contributions from the land, photosynthetic organisms, ocean, atmosphere, and clouds. We estimate the required photometric and polarimetric sensitivity to detect such planets in habitable zones of nearby stars. We show that spectro-polarimetry provides a great advantage for high-contrast remote detection of biological photosynthetic organisms as compared to spectroscopy.

8 Session VIII. Results: Cosmological Microwave Background

INVITED: Detection of microwave B-mode polarization at degree angular scales using BICEP2

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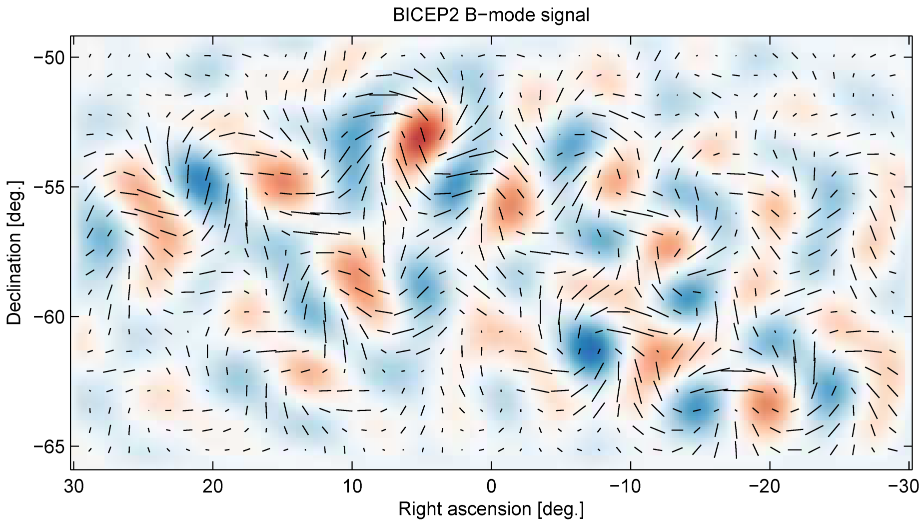
We report results from the BICEP2 experiment, a Cosmic Microwave Background (CMB) polarimeter specifically designed to search for the signal of inflationary gravitational waves in the B-mode power spectrum at degree scales. The receiver was comprised of a 26 cm aperture all-cold refracting telescope equipped with a focal plane of 512 antenna-coupled 150 GHz bolometers. A low-foreground region of sky with an effective area of 380 square degrees was observed from the South Pole to a depth of 87 nK-degrees in Stokes Q and U. We find an excess of B-mode power over the base lensed-LCDM expectation in the range $30 < \ell < 150$, inconsistent with the null hypothesis at a significance of $> 5\sigma$. Through jackknife tests and simulations based on detailed calibration measurements we show that systematic contamination is much smaller than the observed excess. We also estimate potential foreground signals and find that available models predict these to be considerably smaller than the observed signal. These foreground models possess no significant cross-correlation with our maps. Additionally, cross-correlating BICEP2 against 100 GHz maps from the BICEP1 experiment, the excess signal is confirmed with 3σ significance and its spectral index is found to be consistent with that of the CMB, disfavoring synchrotron or dust at 2.3σ and 2.2σ, respectively. The observed B-mode power spectrum is well-fit by a lensed-LCDM + tensor theoretical model with tensor/scalar ratio $r = 0.20 + 0.07 - 0.05$.



CMB polarisation observations with the PLANCK satellite

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CMB temperature and polarisation anisotropies have become a key cosmological probe to both measure cosmological parameters and study the early universe. The Planck satellite has measured with unprecedented accuracy the CMB temperature and polarisation anisotropies over the full sky using 9 frequency bands from 30 to 857 GHz. We will present in this talk the first Planck polarisation results. These will include a review of polarised foreground emission including synchrotron and thermal dust emission. We finally discuss the capabilities of Planck to measure the CMB polarisation and discuss recent results.

Polarized emission of Galactic dust as seen by Planck : new constraints for dust models.

Vincent Guillet[1], on behalf of the Planck collaboration

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The HFI instrument onboard the *Planck* satellite is providing a full-sky coverage of the dust submillimeter polarized emission, with an unprecedented view onto the diffuse ISM. This diffuse dust polarized emission is important both for Galactic physics (dust polarization traces the Galactic magnetic field) and for cosmology (dust is the a dominant foreground to the CMB polarization at high frequencies). In this talk, I will present the derived dust thermal SED, from 353GHz down to 70GHz, in total and polarized intensity. I will also show that the dust polarized emission observed at 353GHz correlates very well with starlight polarization measures, allowing us to define new dust physical quantities, the submm-to-optical polarization ratios, which are found to be rather uniform in the diffuse ISM. These new observational constraints will be compared with existing dust models.

Polarbear experiment: Results from the first observational campaign and systematic instrumental effects characterization

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Recent measurements of the B-mode polarization power spectrum in the cosmic microwave background (CMB) have started opening up a new window onto cosmology. While the bicep-2 experiment has reported a detection of the B-mode polarization at the largest angular scales, a complementary observation conducted by the Polarbear experiment located on the Atacama Desert in Chile has recently provided tight constraints on the small scales.
The characterization and the control of systematic instrumental effects on B-mode polarization data are particularly demanding for such efforts. In this talk, I will describe the Polarbear results focusing on the analysis techniques developed to characterize and control the spurious effects of the Polarbear data set. In particular I will present an end-to-end simulation pipeline used to determine their impact on the final CMB's B-mode angular power spectrum.

Figure 14: Photograph of the Huan Tran Telescope deployed at the James Ax Observatory in the Atacama Desert in Northern Chile.

9 Session IX. Results: External Galaxies, Active Galactic Nuclei

INVITED: Optical and near-IR polarimetry of active galactic nuclei

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I will review the application of optical and near-IR polarimetry techniques to the study of Active Galactic Nuclei (AGN), highlighting the key importance of polarimetry for investigating the geometries of the unresolved nuclear regions of AGN, testing the unified schemes that attempt to understand the relationships between the various types of active galaxies, and investigating the evolution of the AGN host galaxies. Following an historical introduction, I will describe the latest results from the Hubble Space Telscope and various ground-based 4 and 8m class telescopes, before assessing the prospects for future progress in this field.

Near-infrared polarimetry of a complete sample of narrow-line radio galaxies with *Hubble Space Telescope*

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We present the analysis of 2.05 μm *Hubble Space Telescope* (*HST*) polarimetric data for a sample of 13 narrow-line radio galaxies (NLRG) Fanaroff and Riley type II (FRII) powerful radio galaxies at $0.03 < z < 0.11$. We found that the NLRG in our sample are intrinsically highly polarised (6–60 per cent), with the electronic-vector (E-vector) perpendicular to the radio axis in 54 per cent of the sources. We analyse the mechanisms that could be producing the measured degree of nuclear polarisation: i) dichroic extinction, ii) synchrotron radiation, and iii) scattering. We found that the extinction required to produce such high levels of near-infrared polarisation based on the dichroic mechanism, is similar to that estimated in the basis of four different techniques reported in Ramirez et al. (2014), provided that the dichroic mechanism has its maximum efficiency. This consistency suggests that the nuclear polarisation may be due to dichroic extinction, the product of elongated dust grains aligned in a toroidal magnetic field in the torus. However, additional polarimetry observations at other near- or mid-IR wavelengths are needed to distinguish between the dichroic or scattering polarisation mechanism.

VLT/FORS2 spectropolarimetry of Seyfert galaxies

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The origin of the unification scheme for Seyfert galaxies (Antonucci & Miller 1985) was the detection of polarized broad lines in the nucleus of the Seyfert 2 galaxy NGC 1068. Although very successful and widely used, this simplistic geometrical model is unable to explain several observational properties of Seyfert galaxies. For example, only 30-50% of nearby Seyfert 2 galaxies show a type 1 polarized spectrum (Tran 2001). This might imply that either 1) not all Seyferts harbour a hidden BLR (e.g. Tran 2001, 2003; Gu & Huang 2002) or 2) the distribution of dust within the torus and its inclination are not as simple as predicted by the unified model. In Ramos Almeida et al. (2009, 2011) we reproduced high spatial resolution spectral energy distributions (SEDs) of a sample of nearby Seyfert galaxies with clumpy torus models and found that the torus properties of the individual Seyfert 2s are different among them. In some cases we reproduced the infrared SEDs with edge-on, large covering factor tori (as predicted by the unified model), but others required small covering factor tori with intermediate inclinations. These results could explain the lack of polarized broad lines in 50-70% of nearby Seyfert 2 galaxies. I will present preliminary results of spectropolarimetric observations obtained with the instrument FORS2 on the 8 m VLT. These observations constitute a homogeneous dataset of polarized optical spectra for a representative flux-limited sample of Seyfert galaxies for which we have constraints on their torus properties.

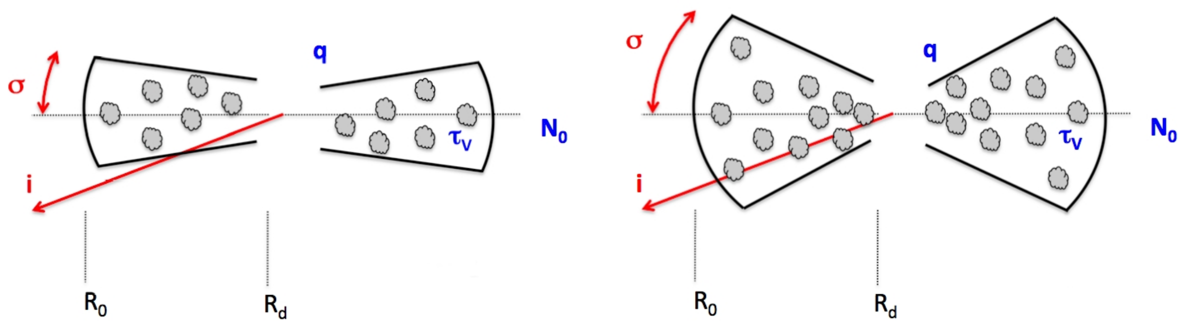

Figure 15: Different clumpy tori for different Seyfert 2 galaxies. Left panel shows an example of low covering factor torus (narrow clouds distribution and low number of clumps) and right panel shows a larger covering factor torus, Figure adapted from Ramos Almeida et al. (2014).

IR Polarimeters & AGN

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Observations of AGN (active galactic nuclei) using polarimetry have been key to understanding their central engines. Early observations used optical polarimeters in natural seeing conditions, but suffered from the dual effects of obscuration in the nuclear regions of the AGN and relatively poor spatial resolution leading to a low degree of measured polarization. Near-infrared (IR) polarimeters afforded a clearer view through the obscuring dust, and the advent of adaptive optics (AO) offers diffraction-limited resolution, and most recently mid-IR (MIR) polarimetry has been offered on the 10m Gran Telescopio Canarias. We briefly discuss these instruments and present some of the early results from observations of AGN in polarimetric mode as well as from surveys of hidden/non-hidden broad-line AGN.

Polarimetry in Active Galactic Nuclei

Lopez-Rodriguez, E.[1], Packham, C.[1], McMaster, L.[1], Jones, T.[2], Young, S.[3], Elitzur, M.[4], Tadhunter C.[5], Mason R.[6], Perlman E.[7], Alonso-Herrero A.[8], Ramos Almeida C.[9], Ichikawa K.[10], Levenson N. A.[11], Rodríguez-Espinosa J. M.[9], Shenoy, D.[2], Álvarez C.[12], Ramírez E. A.[13], Telesco C. M.[14]

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Magnetohydrodynamical theories consider the torus of Active Galactic Nuclei (AGN) to be part of an outflow wind moving away from the central engine. In this framework, the torus is a particular region of the wind, where dusty and optically thick clouds are formed. The outflows are strongly related to the accretion rate and magnetic field strength, which play an important role in the creation, morphology and evolution of the torus. Through high-angular ($\sim$0.1$''$-0.6$''$) infrared (IR, 1-13 μm) polarimetry observations, this work (1) explores the role and strength of magnetic field in the torus; (2) studies the AGN/Host galaxy connection; and (3) investigates the nucleus of radio-loud AGN. Although several models have been made to account for the outflowing dusty winds from the central engine, the magnetic field strength at the position of the torus remains poorly characterized. Through a novel study using near-IR polarimetry, the magnetic field strength within the clumpy torus of AGN are estimated. For the archetypical radio-loud AGN, Cygnus A, mid-IR imaging polarimetry using CanariCam (8-13 μm) on the 10.4-m *Gran Telescopio Canarias* revealed a high polarized, 11$\pm$3% and 12$\pm$3% (at 8.7 μm and 11.6 μm respectively) unresolved nucleus. Polarimetric modeling suggests that the MIR polarization arises from a synchrotron component. This result represents the most compelling MIR polarization detection of synchrotron radiation in Cygnus A.

NIR polarized light from Sagittarius A*

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We present an overview of polarized near-infrared (NIR) observations of Sagittarius A* (SgrA*) which is associated with the super massive black hole at the center of the Milky Way. The observations have been carried out using NACO adaptive optics instrument at the VLT(ESO) (from 2004 to 2012). We will present several polarized flares that have been observed during these observations and will present the statistical properties of NIR K-band polarization of SgrA*. Information about linear polarization at 2.2 micron and its variations can help us to constrain the physical conditions of the accretion process around this SMBH.

Spectropolarimetry of Nearby Starburst Galaxies: Kinematics of the Dust Wind

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We report the results of spectropolarimetry of nearby starburst galaxies, M82 and NGC 2146, and discuss the kinematics of the large scale dust outflow from the nuclear star-forming regions.
It has been evident that significant amount of dust is associated with superwinds in starburst galaxies. However, the fate of this dust has been uncertain yet because of the lack of kinematic information of the dust. Optical spectropolarimetry is one of the promising ways to probe the dust motion. Outflowing dust grains scatter and polarize continuum and emission lines emanated from the nuclear light, so that radial velocities of the polarized emission lines reflect the dust motion with respect to the nucleus. We made optical spectropolarimetric observations of nearby starbust galaxies with Subaru/FOCAS in order to reveal the kinematics of the large scale dust outflow. The target galaxies were M82 and NGC 2146.
In M82, the polarized light is substantially redshifted with respect to the unpolarized light. We found that the dust flow is much slower than the ionized gas flow and even slower than the molecular gas, and that there is a decreasing tendency of the dust outflow velocity from the central region to the outer. These results indicate that the dust outflow in M82 is kinematically decoupled from the other outflowing materials and the most of the dust would fall back to the disk. On the other hand, the polarized light in NGC 2146 showed a clear double-peak profile near the nucleus and an asymmetric profile — a blue peak and red wing structure — at ~ 0.6 kpc from the nucleus. The polarization angles (Pol-A) of the blue component (BC) and red component (RC) are quite different; the Pol-A of the BC $\sim 90°$, whereas that of the RC $\sim 170°$ near the nucleus. The Pol-As of both components are gradually changed as going further from the nucleus. These results are consistent with the idea that the infalling dust (BC) and outflowing dust (RC) scatter spatially different light sources, starburst clusters, in the vicinity of the nucleus.
Our work first unveiled the kinematics of the dust flows and the circumnuclear structures of the nearby starburst galaxies.

10 Session X. Results: High Energy Astrophysics, Gamma-Ray Bursts, Supernovea

Polarimetric observations and modelling of V393 Pav and other AM Her systems

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AM Her systems, also called polars, are magnetic cataclysmic variables: a binary system composed by a highly magnetized white-dwarf, B larger than around 5 10^6 G, and a Roche lobe-filling low-mass dwarf star. In polars, the accretion occurs along a magnetic accretion column and the rotation of both stars are synchronized with the orbital period. In optical and infrared wavelengths, the accretion column emits cyclotron radiation, which is highly anisotropic and polarized. AM Her stars are the strongest sources of circular polarization, up to 50% in V band. The total flux and polarization observed are modulated along the orbital cycle due to the variation of the viewing angle. This characteristic allows to map the accretion column location and to estimate many of its geometric and physical parameters by modeling. To perform such modeling, our group has developed the Cyclops code. This code calculates the cyclotron and bremsstrahlung emission of a 3D magnetic accretion column and considers the white-dwarf occultation and the absorption caused by the column itself. Optical depth effects are taken into account in the radiative transfer. Applications were previously made for V834 Cen and CP Tuc. Multiband observations are important to constrain the physical properties of polars, but few systems have such kind of data. To fill this gap, we are carrying out an observational follow-up of polars. In this study, we present recent results of this effort. We also present the CYCLOPS modelling of VRI photometry and polarimetry of V393 Pav in bright state. V393 Pav is a polar presenting an active secondary star.

The RoboPol optical polarisation monitoring of an unbiased subset of gamma-ray-loud blazars

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The extreme phenomenology exhibited by blazars (FSRQs and BL Lacs) as well as their importance in the study of extragalactic plasma jet physics arise from the close alignment of the their jets to the line of sight. Being the beamed and boosted subset of Active Galactic Nuclei associates them with extremely intense variability which happens fast, very broad-band emission reaching up to GeV and TeV energies, as well as complex relativity-induced effects. Their emission - attributed to incoherent synchrotron processes involving relativistic electrons - appears highly polarised especially in the optical bands. The specific conditions required for the emergence of polarisation, the emission and radiative transfer processes subsequently make the polarisation parameters and their dynamics, unique probes of the microphysics of the emitting plasma as well as the conditions at the emission site. The recent discovery of rotations of the polarisation angle seen associated with high energy flares observed in the GeV energy bands, opened up a new field dealing with the nature of the emission and variability mechanisms, the configuration of the magnetic field and high energy emission site etc.
The degree of difficulty involved, has limited the polarisation studies - and especially monitoring - to hand-picked cases rather than unbiased samples forbidding systematic population studies. In order to lay the ground for systematic and extensive polarimetric studies we have conceived, designed, constructed a novel-design optical polarimeter that has already been commissioned at the Skinakas telescope in Crete. The program aims at monitoring the linear polarisation for a sample of almost 100 gamma-ray loud sources that comprise an unbiased set and 15 gamma-ray quiet ”comparison sample sources” with a duty cycle of close to 3 days for non active sources and for a fraction of a night for cases in active state. The achieved precision in the polarisation degree reaches a fraction of the percentage for sources of 18-th magnitude. Here we present: (a) the scientific motivation, (b) the design of the instrument, (c) the sample selection and (d) the results from the first season of operation. We show that while the fractional polarisation for both gamma-ray–loud and gamma-ray–quiet sources are well-described by exponential distributions, the two classes have different optical polarisation properties. This is the first time this statistical difference is demonstrated in optical wavelengths.

INTEGRAL/IBIS and optical monitoring of the Crab nebula/pulsar polarisation

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Neutron stars power bright synchrotron nebulae consisting of relativistic charged particles, and the emission from such systems is strongly polarised. Polarimetry provides an unique insight into the geometry of pulsar emission regions and therefore observational constraints on the models proposed to describe their emission mechanisms. Previous INTEGRAL/IBIS observations have shown that the gamma-ray radiation of the Crab Nebula is highly polarised and remarkably aligned along the axis of rotation of the pulsar (Forot et al. 2008). Their study was based on the first four years of operation of the satellite. Here we present an analysis based upon data from over ten years of operation. This new analysis allows a better characterisation of the polarisation fraction and position angle, a measure of spectral energy distribution of the polarised component, and in particular, to search for any variability in the polarisation of the system in this energy regime (250-800 keV). These results are then compared to the known optical polarisation of the pulsar and nearby synchrotron knot. In the future we shall compare the gamma-ray polarisation with the phase-resolved optical polarisation using instruments such as GASP (Kyne et al. 2010).

Polarization observations of 5 GRBs afterglow

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Gamma-ray Burst (GRB) is the most energetic explosions, which releases enormous energy such $\sim 10^{52}$ erg within a very short time scale. It is known that the afterglows acompany substantial amount of GRBs, which are seen over wide range of wavelength; from radio to X-ray. Synchrotron radiation is most likely the responsible radiation mechanism, suggesting that GRB can be polarized to some extent. From the polarization of the GRB afterglow, we can estimate the structure of magnetic field and geometric structure around emission region. However, the GRBs and their afterglows are relatively short-lasting events and it is not easy to perform polarimetry. To date we have only a few polerimetric samples obtained for early optical afterglow. HOWPol (Hiroshima One-shot Wide-field Polarimeter) attached to 1.5-m "Kanata" telescope is dedicated for such prompt observation of early optical afterglow of GRB.

Since the beginning of HOWPol observation in 2009, we have sucsessfully obtained polarimetric data of five GRBs; GRB 091208B, GRB 111228A, GRB 121011A, GRB 130427A, and GRB 130505A. (i) The afterglow of GRB 091208B showed $\sim 10\%$ polarization degree (PD) at $\sim$150–700 s after GRB trigger (Uehara et al. 2012). (ii) In case of GRB 111228A, we extensively observed over $\sim$160–19000 s. It showed also large PD ($>\sim 10\%$) and its position angle (PA) rotated approximately by 90° with time. Although such a rotation of PA has been expected across jet break time, we have little evidence of jet break during our observation period. (iii) The afterglow of GRB 121011A showed only small PD ($< 2.5\%$) at $\sim$90-1100 s. (iv,v) The afterglow of GRB 130427A and GRB 130505A were observed at somewhat later phases ($\sim$ 2-4 hr) and they both showed only small PD ($< 2\%$ and $< 3.5\%$, respectively).

These results suggested that (1) the polarization of the earliest afterglows (at < 1000 s) is likely devided into two groups: larger polarization ($>\sim 10\%$) population and smaller ($< 0.5\%$) one, which is consistent with the compilation figure (Fig.3) in Mundell et al. (Nature, 2013 Dec 5), and (2) GRB 111228A showed a quite unique polarization evolution that has not been observed. We discuss the origin of the magnetic field and the site of emission region (e.g., forward/backward shock region) for the afterglows of these GRBs.

Optical and Near-infrared Simultaneous Polarimeter HONIR

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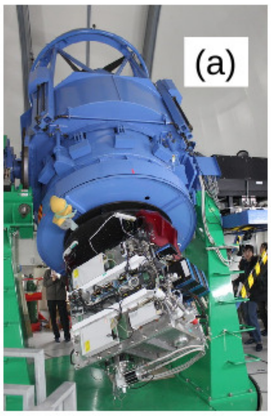
We are developing an optical and near-infrared (NIR) instrument HONIR (Fig. 16(a)) for the 1.5-m Kanata telescope at Higashi-hiroshima Observatory of Hiroshima University. HONIR is capable of imaging or spetcroscopy simultaneously at two bands: optical (0.5-1.0 μm) and NIR (1.1-2.4 μm) wavelengths. In early 2014, we installed polarimetric optics (an YLF Wollaston prism, Pancharatnam type half-wave plate, and appropriate focal masks) into the instrument, which enables us to perform optical and NIR simultaneous imaging-polarimetry and spectro-polarimetry. An evaluation of its polarimetric performance is now in progress. Instrumental polarization is at very low level ($< 0.05\%$ at V–J-band, and $< 0.10 - 0.15\%$ at H–K-band). We have successfully measured the linear polarization spectra of interstellar polarization over the whole wavelengths in good agreement with the previous measurement from the literature (Fig. 16(b)).



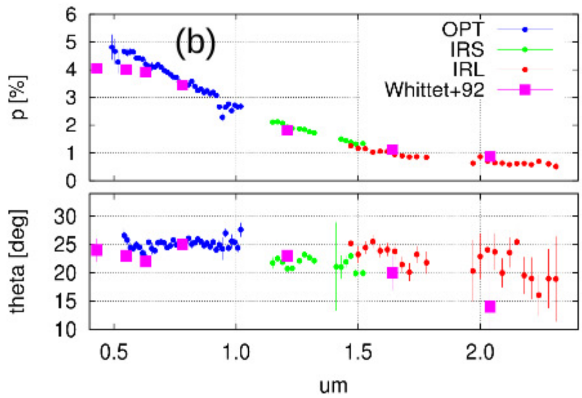


Figure 16: (a) HONIR on the Kanata telescope. (b) Spectro-polarimetry of a star HD29835 (interstellar polarization). The previous measurement (Whittet et al. 1992) is also plotted.

Polarimetric measures of Low-Mass X-ray Binaries

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We present a polarimetric study of two low mass X-ray binaries with the aim of detecting the possible emission of relativistic particles jets. We selected the brightest transient LMXB in quiescence known, Cen X-4, in order to perform the first polarimetric analysis of a quiescent LMXB and the ultracompact persistent system 4U0614+091.
Cen X-4 does not possess a significant polarisation in the optical (BVRI, from ESO/3.6m data) and infrared (J-band, from TNG data). In particular, we are able to obtain very constraining 3 sigma upper limits to the polarisation degree, e.g., in the I-band, we have $P < 0.52\%$. We estimate an upper limit of $\sim 10\%$ to the contribution of the possible emitted jet radiation to the total infrared flux (Baglio et al. 2014, A&A submitted).
The persistent system 4U0614+091 has been found to emit a relativistic particle jet from the analysis of its infrared Spectral Eenergy Distribution (Migliari et al. 2010). We performed a polarimetric analysis of R-band data obtained with both the TNG and the NOT polarimeters, observing a non-modulated polarisation degree of a several %, consistently with the jet emission (Baglio et al. 2014 in preparation).

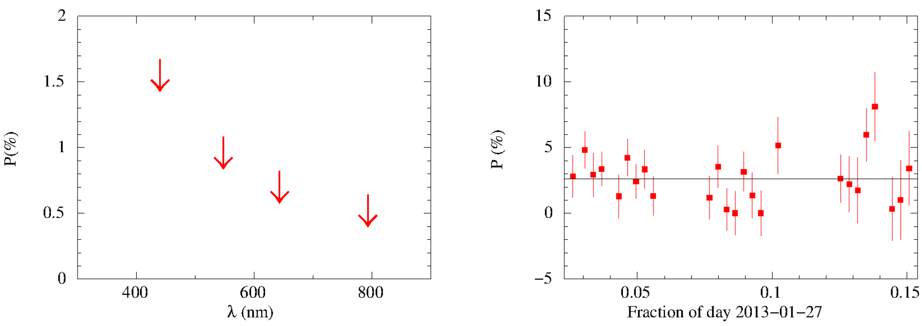

Figure 17: *Left panel*: 3σ upper limits on the polarization degree trend of the LMXB Cen X-4 in quiescence with respect to the wavelength of the four optical $BVRI$ filters (Baglio et al. 2014, A&A submitted). *Right panel*: R-band polarization degree represented as a function of time for the persistent system 4U 0614+091. Superimposed, the fit with a constant function which yielded a $\sim 3\%$ polarization degree measured for the source (Baglio et al. 2014 in preparation).

Status and Commissioning of POL-2: Update

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POL-2 is a polarimeter built for use at the JCMT with the detector SCUBA-2. The instrument was presented at the last two ASTROPOL conferences (Bastien et al. 2005; 2011). Commissioning data were obtained in September 2012 and on request on various dates between October 2012 and December 2013. There was a strong concerted effort by this "commissioning team", in particular during the period May-September 2013. Unfortunately, POL-2 could not be commissioned on time, at the end of September 2013, so that it could have been offered to general observation by the astronomical community during the current management period of the telescope, before the end of September 2014.

In this contribution, we will discuss the various issues involved, presenting the work that was done and what the remaining issues are. However, POL-2 remains a very attractive instrument for future users of the telescope, with some additional work necessary to solve the remaining problems.

Polarimetric detection and characterization of hot Jupiters

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The light scattered in the planetary atmosphere is linearly polarized perpendicular to the scattering plane. In general, when the planet rotates around the parent star, the scattering angle changes and the Stokes parameters Q and U of linear polarization vary. If the orbit is close to circular, two peaks per orbital period are observed. The observed polarization variability exhibits therefore the orbital period of the planet and reveals the inclination, eccentricity, and orientation of the orbit. Due to their proximity to the star, hot giant planets with short orbital periods (Hot Jupiters) may develop extended peculiar atmospheres and halos which effectively scatter the light in the blue spectral region. This can give rise to a degree of polarization detectable with the currently existing modern polarimeters. Parameters of this polarization, e.g., wavelength dependence, are defined by physical conditions in upper layers of the planetary atmoshpere. Thus, polarimetry of hot Jupiters in combination with other methods of observations may be used to draw conclusions on properties of their atmospheres.
Recently, we have demonstrated that polarized reflected light can be detected from exoplanetary atmospheres (Berdyugina et al. 2008, 2011). We have determined for the first time the geometrical albedo in different colors and concluded that the high reflectivity of the hot Jupiter HD189733b in the blue due to Rayleigh scattering determines its blue appearance. This was confirmed with secondary eclipse spectro-photometry in the near UV (Evans et al. 2013).
Here we present new polarimetric observations of several hot Jupiters, both transiting and non-transiting, in three bands: blue (UB), green (V), and red (RI). These data were obtained with our new Double Imaging Polarimeter (DIPol-2) at the 60cm KVA telescope on La Palma, routinely providing polarimetric accuracy of 10^{-5}. We analyse these data using our model calculations and infer planet orbit parameters and atmosphere reflectivity. We compare our results with measurements of the secondary eclipses of hot Jupiters.

Characterisation of the polarimetric mode of the FoReRo2 instrument of the BNAO – Rozhen: problems and solutions.[1]

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The 2-Channel Focal Reducer (FoReRo2) is multipurpose instrument attached at the 2 m Ritchey-Chrétien-Coudé (RCC) telescope of Bulgarian National Astronomical Observatory (BNAO) – Rozhen. In its polarimetric mode it uses a Wollaston prism, placed before a dichroic that splits the signals into two different channels, but unfortunately does not include a modulator. A Wollaston prism splits the collimated light into two mutually-orthogonal polarised beams. Given the lack of a modulator, the instrument suffers from comparatively high instrumental polarization (up to $\sim 2\,\%$), that has been proved difficult to calibrate. Therefore, we decided to implement a beam swapping technique based on simple instrument rotation. We observed a number of unpolarised and high polarized standard stars setting the instrument position angle to 0, 45, 90, ..., 315 deg, then we combined the observations obtained with the instrument position angle 90 deg apart. Thanks to this technique, instrumental effects cancel out, and the instrumental polarisation drops to $\sim 0.05\,\%$. To investigate the spatial instrumental effects, we also observe all standard stars in different position in the instrument field of view. Here we report the results of our investigations, which prove that FoReRo2 is an instrument capable of delivery high precision imaging and spectro-polarimetric measurements. However, rotating the instrument limit the capabilities to observe extended objects, and is also unpractical. As a result of a collaboration between Armagh Observatory and the Rozhen Observatory, a $\lambda/2$ retarder waveplate has been acquired, which will allow us to apply the beam swapping technique without physically rotating the instrument. The commissioning of a modified version of FoReRo2 will happen during summer 2014.

Acknowledgements: Authors gratefully acknowledge observing grant support from the Institute of Astronomy and Rozhen National Astronomical Observatory, Bulgarian Academy of Sciences. Part of this work was supported by the COST Action MP1104 "Polarization as a tool to study the Solar System and beyond". In particular, we gratefully acknowledge funding for a Short Term Scientific Mission (STSM) at the Armagh Observatory.

[1]Based on data collected with 2m RCC telescope at Rozhen National Astronomical Observatory.

Polarimetry with the Southern African Large Telescope

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We discuss the polarimetric modes of the Robert Stobie Spectrograph (RSS) on the Southern African Large Telescope, for which commissioning began in late 2011, but was curtailed due to technical issues with the polarizing beamsplitter. From the beginning, RSS was designed with polarimetry in mind, and the capabilities include linear, circular or all-Stokes modes, for both imaging and spectropolarimetry. We discuss these capabities and some of the unique modes of operation and their science drivers. Initial commissioning results are presented, specifically the instrumental calibrations. Modification to the beamsplitter design was subsequnetly required, due to problems of fluid coupling the eighteen calcite Wollaston prisms comprising the beamsplitter mosaic. This is due for completion in 2014, restoring full polarimetry capability with SALT and allowing completion of the commissioning and the initiation of polarmetric science programs.

A catalogue of High DoLP Astronomical Sources Outside the Solar System

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In the framework of the ESA-Solar Orbiter mission, a catalogue of strongly linearly polarized astronomical objects with a DoLP greater than 0.1, outside the solar system (Hi DoLPASOSS) has been compiled for the detection of linearly polarized targets for the in-flight calibration of the polarimetric visible light channel of the METIS instrument.
Only a weak subset of the identified objets represents a good target for the purpose of this investigation, due to the calibration requirements. Here we shows the full catalogue, compilated starting by several availables catalogues. This catalogue includes objects presenting strong linear polarization at different wavelengths (mainly in visible or infrared)and absolute magnitude less then 20. Stable and instable objects are included in the catalogue.
The main purpose of the catalogue is to give a reference to all the people interested in astronomical poalrization. Some objects (a few percent of the total) should be considered as calibrators. Statistics about these objects and the whole catalogue are presented.

POLARIMETRIC BEHAVIOUR OF BLAZAR OJ 248

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We present an analysis of optical photometric, spectroscopic, and polarimetric data of the blazar OJ 248, obtained by different observatories participating to the GLAST-AGILE Support Program (GASP) of the Whole Earth Blazar Telescope (WEBT; http://www.oato.inaf.it/blazars/webt/). The WEBT was born in 1997 as a network of optical, near-infrared, and radio observers who in concert have the capability to obtain continuous, high-temporal-density monitoring of blazars. This is extremely useful for understanding the broad-band continuum emission of these sources, especially when the study is performed in conjunction with observation at higher frequencies (ultraviolet, X and gamma-rays) by satellites and ground-based TeV telescopes. In the framework of the WEBT one can also get continuous polarimetric monitoring of blazars in the optical (and recently near-infrared) bands. The polarimetric studies give us information on the magnetic field in the jet and on the interplay between the polarised synchrotron radiation from the jet and the thermal emission from the accretion disc. The behaviour of the polarisation degree and angle can be compared to that of the source flux at various wavelengths to shed light on the variability mechanisms (e.g. Shocks propagating downstream the jet) and on the geometrical structure of the jet (e.g. Helical morphology).

We present an analysis of the multiwavelength behaviour of the quasar-like blazar OJ 248 at redshift z=0.939 in the period 2006-2013. We use low-energy data (radio, optical and near-infrared) obtained by 15 observatories, as well as high-energy data from the Swift (UV and X-rays) and Fermi (gamma-ray) satellites, to study flux, spectral, and polarimetric variability and correlations among emission in different bands.

The study focuses mainly on the major flare that occurred at the end of 2012, lasting until the beginning of 2013, which was detected at all frequencies. This event is compared to the previous optical outburst, occurred in 2006-2007, and radio outburst observed in 2010-2011.

A statistical study of the quiet sun polarization

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In the quiet solar photosphere the coupling of the turbulent plasma with the magnetic field gives rise to a complex magnetic structuring which is still partly unknown. In particular, the magnetic energy contained in weak "turbulent" magnetic features is a key issue which has been debated for many years. Here we propose to investigate the magnetic structuring of the quiet photosphere of the Sun on a statistical point of view by using high quality images of the circular and linear polarization of magnetic sensitive lines.
The SOT/SP instrument onboard the Hinode satellite provides us with high resolution images of the circular and linear polarization in the FeI 630 nm solar lines. We consider the polarization patterns as tracers of the magnetic field structures.

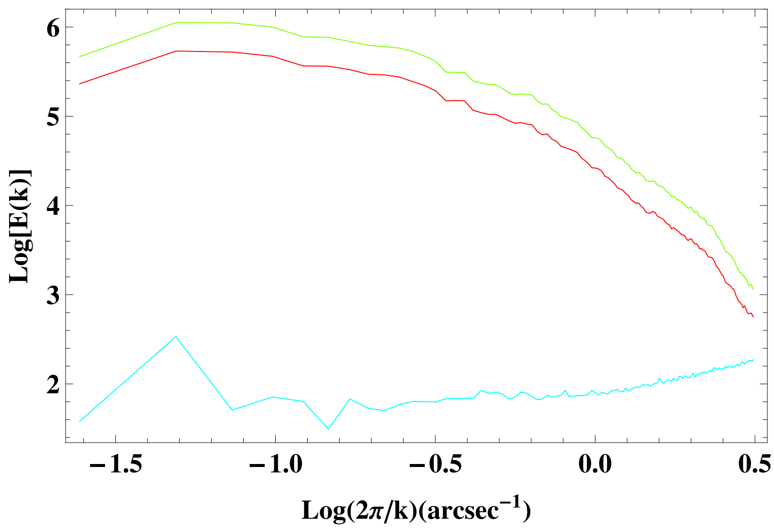

Figure 18: Power spectrum of the FeI 630.15 nm (red curve) and 630.25 nm lines (green curve) circular polarization fluctuations recorded at the center of the solar disk. The light-blue curve gives an estimate of the noise level.

The Fourier spectra, as shown in Fig. 18, allows us to investigate the structures of the images from the supergranulation scale (40 arcsec) down to subgranular scales on the order of 0.3 arcsec. We shall comment on the properties of these spectra and show how they bring new insight on the magnetic structure of the quiet Sun.

CorMag - Coronal Magnetograph

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The Turin Astrophysical Observatory, Italy, has developed a liquid crystal Lyot filter for spectro-polarimetric observations of the coronal green-line emission (FeXIV, 530.3 nm). The science goal of the planned observations is the study of the coronal magnetic fields that drive the dynamics of the solar wind. The Turin coronal magnetograph (CorMag) has been integrated, as focal-plane instrumentation, to the Zeiss-200/300 coronagraph of the Lomnicky Peak Observatory, Slovakia. The Turin coronal magnetograph (CorMag) is a four-stage Lyot filter with an electro-optically tunable bandpass. The full width at half maximum of the filter is 0.15 nm. The center wavelength of the bandpass is tuned by using nematic liquid crystal variable retarders (LCVRs). A separate LCVR, in tandem with the filter, is used for the polarimetric measurements. The INAF-Turin team has successfully operated the CorMag during the 2010 eclipse, acquiring coronal images of the green line emission.
This presentation will illustrate the CorMag and Zeiss-200/300 coronagraph, and will describe the preliminary results from the first-light observations. The presentation will discuss the future observing plans from this new coronagraphic facility. These observations would provide the unique opportunity to start reviving ground-based coronagraphy in Europe by combining first-class, classical telescope technology (the Zeiss coronagraph at Lomnicky Observatory) with modern, cutting-edge electro-optical technology (the LC Lyot filter of the Turin Observatory) originally developed for space applications.

Polarized radiative transfer equation: **curvilinear coordinates and refraction**

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Apart from situations where general relativity is essential (accretion disks around and jets from black holes and neutron stars), radiative transfer equation in general, and polarized radiative transfer equation (PRTE) in particular, most often is considered assuming plane-parallel symmetry and Cartesian coordinate system. Sometimes it is written and solved in spherical coordinate system, and quite seldom - in circular cylindrical coordinate system. But nonrelativistic astronomical objects (Solar prominences, other features and outflows from the Sun and stars, Be stars, planetary and protoplanetary nebulae, circumstellar dust envelopes etc.) have many other types of symmetry as well.

In this contribution, the results of systematic derivation of PRTE in different coordinate systems are reviewed. The medium is assumed to be polydisperse; the statistical ensemble of small particles is dispersed in some continuous host medium e.g. vacuum. It is assumed that birefringence in the effective medium is negligible but refraction due to smooth (spatially differentiable) inhomogeneity of the statistical properties of polydisperse medium maybe exists. Differential operator of PRTE is just that part of PRTE dependent on the spatial coordinate system; the rest terms of PRTE (those describing extinction, scattering and primary sources) are independent of coordinate system. For polarized radiation, seeming rotation of the linear polarization plane often takes place, and Rytov's law is satisfied if the medium is inhomogeneous and refraction exists.

Until this moment, triaxial ellipsoidal system with either x or z axis being the longest, oblate and prolate spheroidal, elliptic conical, elliptic cylindrical, classical toroidal and simple elliptic (oblate and prolate) toroidal coordinate systems have been considered. For most of these coordinate systems, two alternative choices of the polar axis for the description of propagation direction of radiation $\vartheta = 0$ were made; for classical and each of simple toroidal systems only single choice of polar axis was assumed. These results can be regarded not only as basic for the development of new algorithms for numerical solution of PRTE fully reflecting the symmetry of the physical problem, but also as the starting point for analytic research revealing the analytic properties, asymptotics and maybe some exact benchmark solutions of PRTE in different curvilinear coordinate systems.

These results demonstrate the effectiveness of the general method based on use of covariant derivatives and described in papers by Freimanis (2011,2013). One more paper, with lengthy but clear final expressions, is submitted to "Journal of Quantitative Spectroscopy & Radiative Transfer".

Photometric, polarimetric and spectroscopic investigation of the new polar USNO-A2.0 0825-18396733

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We report the photometric, polarimetric and spectroscopic observations of a new variable star USNO-A2.0 0825-18396733. The photometric data allowed us to refine the orbital period of the system, P=0.^{d}084841(2) (2.036h). A strong variability of circular polarization led us to the conclusion that this object is a polar (an AM Her type star). Circular polarization reached maximum value of -30%±3. The obtained spectra of the object reveal red continuum and strong emission lines of hydrogen and helium. Moreover, the spectra show a CIII-NIII emission blend and lines of other elements. Using the emission lines of H_β and HeII 4686Åwe computed the radial velocity curves. After analysis of obtained data we estimate mass of the white dwarf M_1=0.71-0.78M_o. The Doppler mapping has revealed two emission regions near the inner Lagrange point. Circular polarization data was analyzed with spatial distribution of cyclotron emission model.

Spectropolarimetry and modeling of Galactic Wolf-Rayet star WR156

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For the first time spectropolarimetric observations of Wolf-Rayet star WR156 were conducted. Medium resolution spectropolarimetric data in the range of 3500−7200 Åwere obtained at 6-m telescope of Special Astrophysical Observatory. These data show that the light from the star is significantly polarized, with the degree of polarization $P = 1.38 \pm 0.06\%$, and the position angle $\Theta = 77.4^o \pm 1.2^o$. This polarization is, most probably, has an interstellar origin, as its magnitude and orientation are similar to the ones of field stars. Also, we present results of numerical modeling of WR156 atmosphere performed using CMFGEN code. According to it, WR156 is the richest hydrogen WR star of WN8 type in the Galaxy.

Shadows and cavities in protoplanetary disks: HD163296, HD141569A, and HD150193A in polarized light

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The morphological evolution of dusty disks around young stars is pivotal to better understand planet formation. Since both dust grains and global disk geometry evolve on short timescale, high-resolution imaging of a sample of objects may provide important hints towards such an evolution. We enlarge the sample of protoplanetary disks imaged with high-resolution (less than $0.2''$) by observing HD163296, HD141569A, and HD150193A in polarimetric differential imaging. We integrate our data with previous datasets to paint a larger picture on their morphology. In particular, we report a marginal detection of the disk around HD163296 in both H and K_S band. The disk is resolved as a broken ring structure with a significant light drop inward of $0.6''$. No sign of extended emission is resolved around HD141569A and HD150193A. We propose that the absence of scattered light in the inner $0.6''$ around HD163296 and the non-detection of the disk around HD150193A may be due to similar geometric factors. On the other hand, the non-detection of HD141569A is consistent with previous datasets revealing the presence of a huge cavity in the dusty disk.

Modeling the polarization in complex environments with the 3D radiative transfer code STOKES

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We present the 3D radiative transfer code STOKES designed to model time-dependent spectropolarimetry and polarization imaging in complex reprocessing environments across the optical, ultraviolet and X-ray domain. Based on the Monte Carlo method, the code includes various relevant processes (de-)polarizing radiation: electron scattering, dust extinction, photo-absorption and recombination. Emission and scattering geometries can be constructed based on elementary or sophisticated geometrical shapes and the escaping radiating is evaluated at all possible viewing angles. Time-dependent effects can be included to produce series of polarization spectra and/or images. The code was originally written to model the polarization of Active Galactic Nuclei but can be applied to a whole range of astrophysical objects in which reprocessing is an important source of polarization.

Modeling linear and circular polarization due to radiatively aligned grains in special astrophysical environments

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Grain alignment by radiative torques (RATs) has been extensively studied for various environment conditions, including interstellar medium, dense molecular clouds, and accretion disks, thanks to significant progress in observational, theoretical and numerical studies. In this paper, we explore the alignment by RATs and provide quantitative predictions of dust polarization for a set of astrophysical environments that can be tested observationally. We first consider the alignment of grains in the local interstellar medium and compare predictions for linear polarization by aligned grains with recent observational data for nearby stars. We then revisit the problem of grain alignment in accretions disks by taking into account the dependence of RAT alignment efficiency on the anisotropic direction of radiation fields relative to magnetic fields. Moreover, we study the grain alignment in interplanetary medium, including diffuse Zodiacal cloud and cometary comae, and calculate the degree of circular polarization (CP) of scattered light arising from single scattering by aligned grains. We also discuss a new type of grain alignment, namely the alignment with respect to the ambient electric field instead of the alignment with the magnetic field. We show that this type of alignment can allow us to reproduce the systematic features of CP observed across a cometary coma. Our findings suggest that polarized Zodiacal dust emission may be an important polarized foreground component, which should be treated carefully in B-mode polarization cosmic microwave background experiments.

Non-Zeeman Circular Polarization of Molecular Spectral Lines in the ISM

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I will discuss the recent discovery of circular polarization signals in the rotational line profiles of molecules that are negligibly sensitive to the Zeeman effect. Initial findings obtained for CO in the Orion KL star-forming region with the Caltech Submillimeter Observatory were recently followed with similar detections for two transitions of CO in an exhaustive study of the supernova remnant IC 443 (G), led at the MPIfR with the IRAM 30m and APEX telescopes. These new results have clearly established that circular polarization arises, as predicted, from the conversion of linear polarization signals incident on the molecules responsible for the detected radiation. I will further show how the anisotropic resonant scattering model developed to explain these observations also provides a viable mechanism to explain the polarization characteristics of SiO maser lines in the circumstellar envelope of evolved stars. As this scattering model directly involves the ambient magnetic field, these results suggest the possibility of starting a whole new subfield of more incisive studies of magnetic fields in the interstellar medium.

High Resolution Imaging Polarimetry of Hypergiants with MMTPol

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We present imaging polarimetry at J (1.25 μm), K (2.2 μm) and Ls (3.1 μm) of the warm hypergiant IRC +10420 and the red supergiant VY CMa made with MMTPol. These observations reveal polarization features in the light scattered from dust around these stars at $0.18''$ spatial resolution. These observations are combined with broad band imaging at K, L′ (3.8 μm) and M (5 μm) using LMIRCam on the LBT to investigate the geometry and nature of the dust in close to these rare, unusual stars. For IRC +10420, we find the dust is distributed mostly in the plane of the sky showing high polarization with scattering optical depths ranging from optically thin to partially optically thick. This geometry is consistent with IRC +10420 having an equatorial 'skirt' that is part of a bipolar outflow viewed nearly pole-on. For VY CMa, we find a very optically thick clump with a mass greater than 5 Jupiters about $0.9''$ from the star that is relatively highly polarized, indicating a low albedo for the dust. This clump was ejected from the star about 250 years ago in a single, very energetic event. The underlying cause of these mass-loss events are not understood.

SGMAP: An Optical Polarimetric Survey Project in Hiroshima

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We are promoting SGMAP (Search for the Galactic Magnetic-field by All-sky Polarimetry survey) project. The goal of this project is to produce a homogeneous polarimetric catalog of all astronomical objects brighter than 13-14 magnitudes at optical three bands in northern hemisphere ($\delta > -25°$), which will be obtained by non-biased observations with a specially-designed wide-field three-channel imaging polarimeter attached to a modified 2-m MAGNUM telescope (Univ. of Tokyo). The number of the sample objects will reach more than several millions, which is more than hundred times as large as the sample number of the currently-existing compilation of optical polarimetry (e.g., Heiles 2000). It is still in a fund-raising phase. If this project is realized, the produced catalog will contribute to many fields of astronomy, e.g., Galactic magnetic field (with helps of future Gaia/nano-JASMINE astrometry, radio survey with SKA and so on), interstellar media, mass-losing stars, etc, together with ongoing survey projects as SOUTH POL (Magalhaes et al. 2012) and GPIPS (Galactic Plane Infrared Polarization Survey; Clemens et al. 2012), etc. The polarization map will also be useful to correct foreground polarization components in extragalactic targets like CMB or AGNs.

Discriminating stochastic from deterministic EVPA swing mechanisms in AGN jets

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Jets in active galacti nuclei emit synchrotron radiation from radio to optical or x-rays. At optical wavelengths these sources show linear polarization up to 45structure in the corresponding emission region. Blazars, active galactic nuclei with a jet closely aligned with the line of sight, exhibit strong variation of the polarization degree and the electric vector position angle (EVPA). Optical EVPA rotations up to 720 degrees and changing rotation directions have been reported as well as correlations between optical EVPA rotations and flares in optical and gamma-rays. Models explaining EVPA swings range from stochastic processes in a turbulent magnetic field to deterministic processes in a large-scale helical magnetic field. The jet magnetic field structure is one of the major open questions in blazar research.
Applied to a unprecedented data set of optical polarization for the archetypical blazar 3C279 we present a method to discriminate between stochastic and deterministic EVPA swing mechanisms. During low-brightness states 3C279 resembles stochastic polarization variation, but is dominated by a deterministic process during flaring states. Moreover we present a toy model capable of producing large EVPA rotations with changing rotation directions based on an emission feature on a helical trajectory in a helical magnetic field configuration.

Near-Infrared Imaging Polarimetry toward a Bright-Rimmed Cloud

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Bright-rimmed clouds, which are located at the periphery of H_{II} regions, are considered to be potential sites for induced star formation by UV radiation from nearby massive stars. We have carried out near-infrared (JHK_s) imaging polarimetry with the imaging polarimeter SIRPOL toward a blight-rimmed cloud (SFO 74) in order to reveal a magnetic field structure of SFO 74. The SIRPOL, which is polarimetry mode of the SIRIUS camera, is mounted on the IRSF 1.4 m telescope at the South Africa Astronomical Observatory. The SIRIUS camera is equipped with three 1024 × 1024 HgCdTe (HAWAII) arrays, JHK_s filters, and dichroic mirrors, which enable simultaneous JHK_s observations with the field of view at each band $\sim 7'.7 \times 7'.7$. The polarization vector maps obtained by the observation clearly show that the magnetic field in the layer just behind the bright rim is running along the shape of rim, which is quite different from the ambient magnetic field. The direction of the magnetic field just behind the tip rim is perpendicular to that of the incident UV radiation, and the magnetic field configuration appears to be symmetric as a whole with respect to the cloud symmetric axis, which runs along the UV direction. In addition, we also derived the magnetic field strength in the two regions (just inside and far inside the tip rim), applying the Chandrasekhar-Fermi method. The estimated magnetic field strength just inside the tip rim, $\sim$100 μG, is stronger than that far inside, $\sim$40 μG, suggesting that the magnetic field strength just inside the tip rim is more enhanced by the UV radiation. The shock induced by the UV radiation increases the density within the top layer gas around the tip rim, and thus increases the magnetic field strength. The magnetic and turbulent pressures is likely to be comparable just inside the tip rim, implying a significant contribution of the magnetic field to the total internal pressure. The estimated mass-to-flux ratio is close to the critical value just inside the tip rim, indicating an importance of the magnetic field in cloud dynamics.

On the consistency of magnetic field measurements of Ap stars: lessons learned from the FORS1 archive

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For a decade, the FORS1 spectropolarimeter was a workhorse instrument for the measurement of stellar magnetic fields. We have revised all its archive data to evaluate the quality and consistency of field measurements obtained with FORS1, and by extension with its successor FORS2 and other similar instruments.
Almost all of the unambiguous magnetic field detections obtained with FORS1 have been in magnetic Ap or Bp stars. We have compared FORS1 field measurements of such stars externally with what is previously known about specific stars, and internally for consistency with the known behaviour of Ap stars, in order to assess the overall quality of FORS1 magnetic measurements.
In general, FORS1 magnetic measurements are consistent with other field measurements of individual stars, and the internal consistency of measurements is also excellent. However, it is important to recognise that each choice of grism and wavelength window constitutes a separate instrumental system, and measurements with various instrumental systems of a single star at one time can vary from one another by 10 or 20 %. Furthermore, it is found that measurements made using only hydrogen lines yield results that are meaningfully different from measurements with metal lines only for stars with effective temperatures above about 9000 K. Finally, it is necessary to be aware of a problem of occasional outliers in the data.
Magnetic measurements made with FORS1 are generally of excellent quality when appropriate care is taken in data reduction. This instrument has provided an excellent worked example from which important lessons applicable to other Cassegrain spectropolarimeters have been learned.

Evaluation of the Mueller Matrix for Ellipsoidal Grains with Spline Interpolation

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This paper discusses a method for evaluation of the Mueller matrix for the transformation of polarization status, i.e. the Stokes parameters (I, Q, U, V), when light is scattered by a dust grain. This matrix is necessary to calculate polarization in radiative transfer models.

Large linear and circular polarization is observed in/around many young stellar objects (YSOs) in dense clouds. In those dense clouds, multiple light scattering should occur, since the dust density is high. The dust grains in those regions are expected to grow and should be larger than in diffuse space. In addition, it is suggested that those grains are nonspherical and aligned in a particular direction. These lines of evidence require a multiple light scattering model with large aligned grains, e.g. $\gtrsim 1\mu$m, to understand the observed polarization and other properties of YSOs (Vandeportal et al. in preparation).

However, evaluation of the Mueller matrix for large nonspherical grains is not an easy task. Since the scattering properties depend on incidence and scattered directions, the matrix is a function with four angles, i.e. two for incidence and other two for scattering, measured in the grain's reference frame. If the grain size is smaller than wavelength, the Rayleigh approximation is valid and it is relatively simple. However, this is not the case for larger grains. We thus evaluate the matrix in arbitrary directions using a spline interpolation method, on the basis of numerical tables obtained with the Fredholm integral equation method (Matsumura and Seki 1996; Matsumura and Bastien 2009). This paper studies the accuracy and efficiency of this method.

ALMA Polarization: Commissioning and Verification Status

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Atacama Large Millimeter/Submillimeter Array (ALMA) can receive two orthogonal linear polarization simultaneously, and we can obtain the four Stokes parameters and measure polarization of emission from astronomical sources. The polarization commissioning team has been working on the system and science verification of polarization observation. ALMA offers polarization observations from the Early Science Cycle 2, although there are some limitations. Commissioning activities to improve and expand the polarization observation capability is going on.
We report current status of the commissioning activities and also report our future commissioning plan. We have been focusing on verification of continuum polarization observation. Instrumental polarization properties (frequency dependencies, stability, and changes in a field of view), which directly affect polarization sensitivity and development of calibration plan, have been investigated intensively. We find that the instrumental polarization is very small and stable, and ALMA can observe polarized flux of $\sim 0.3\%$ of the total flux for spatially compact objects. Recently, we get started commissioning and verification of spectral line polarization observation to try to offer it in the near future. This is just the beginning of the activity, and we are finding that the instrumental polarization of the spectral line mode is likely to have similar properties to that of the continuum mode.

Imaging polarimetry of the dust-rich comet C/2011 L4 after perihelion

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We present preliminary results based on CCD imaging polarimetry of comet C/2011 L4 (PanSTARRS), observed during two nights, April 30 and May 30, 2013, at phase angles 41 deg and 32 deg, respectively. The observations were obtained with the 2-meter telescope of the National Astronomical Observatory (NAO), equipped with two-channel focal reducer, FoReRo2 (Jockers et al. 2000). Narrow-band filters centered at 443 nm and 684 nm (blue and red channel, respectively) were used for cometary continuum observations. In the RC-focal plane, in front of the focal reducer, a rectangular mask was mounted with a projected FOV on the sky of 430×50 arcsec^2. The entire focal reducer was rotated at the position angle of the comet. A Wollaston prism splits the collimated light into two mutually-orthogonal polarised beams, aligned parallel and perpendicular to the scattering plane. In this configuration the linear polarization is derived by merely using the relation $(F_\perp - F_\|)/(F_\perp + F_\|)$. A second advantage of this configuration is that it allows the construction of polarization maps of the cometary dust distribution in solar and anti-solar directions.
Both sets of observations consist of 5 exposures per filter, with a duration of 300 s each. In order to derive the level of instrumental polarization, the unpolarized nearby standard star HD154345 (Gehrels, 1974) was observed immediately before the comet. We constructed maps of the linear polarization by integration of fluxes in different apertures around the photometric center. The phase-angle dependence of the linear polarization was derived for the circumnuclear region. A comparison between the data obtained in the red and in the blue channel was used to derive the spectral dependence of the linear polarization. Indications are found that the degree of linear polarization is greater close to the nucleus and gradually decreases with increasing cometocentric distance.
The results concerning the spatial distribution, the phase-angle and spectral dependence of the linear polarization of comet C/2011 L4 are discussed by comparing them with the data published by Kiselev et al.(2006).

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Anisotropic orientations of polarisations from quasars ligth: a new statistical method and analysis

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We recently built a new statistical method dedicated to the study of the dispersion of polarisation vector directions coming from sparse cosmic sources. We will basically review the content of the paper (Pelgrims and Cudell, 2014)[2]; namely, we will present the basis of the new method and we will discuss the results of its application to the sample of quasar polarisation measurements in optical wavelength compiled in (Hutsemékers et al., 2005)[3]. Using the new method, we found that the probability that the large-scale alignments of polarisation vectors are due to chance is as low as 0.003%.

[2] Pelgrims, V. and Cudell, J.R., 2014, in press [arxiv:1402.4313]
[3] Hutsemékers, D., Cabanac, R., Lamy, H., Sluse, D., 2005, A&A, 332, 410

Measuring the continuum linear polarization with ESPaDOnS

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Our goal is to test the feasibility to obtain accurate measurements of the continuum linear polarization from high-resolution spectra using the spectropolarimetric mode of ESPaDOnS at the Canada-France-Hawaii telescope. We used the new pipeline OPERA to reduce recent and archived ESPaDOnS data. A couple of standard polarization stars and several science objects were tested (an example is shown in Fig. 19, left). Synthetic broad-band polarization was computed from the ESPaDOnS continuum linear polarization spectra and compared with published values to quantify the accuracy of the instrument. The continuum linear polarization measured by ESPaDOnS is consistent with the broad-band polarimetry measurements available in the literature (Fig. 19, right). The polarization degree accuracy is better than 0.2% considering the full sample. The accuracy in polarization position angle using the most polarized objects is better than 5°. Our results suggest that measurements of the continuum linear polarization using ESPaDOnS are viable.

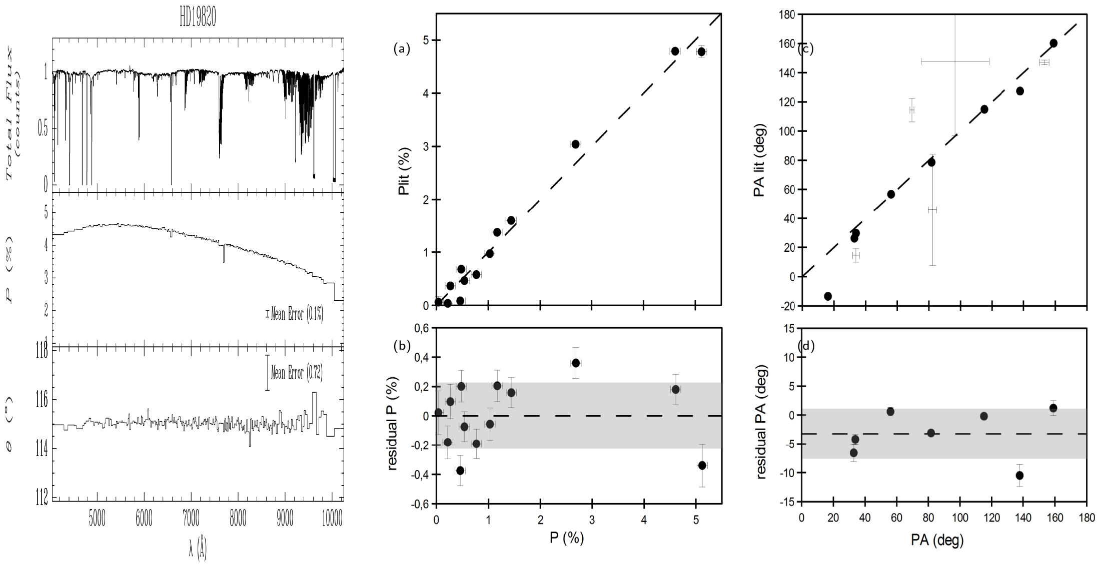

Figure 19: (*Left*) Linear continuum polarization of the polarized standard star HD19820 from ESPaDOnS data. (*Right*) Comparison of synthetic V broad-band polarization from ESPaDOnS and literature values. Polarization level (a) and position angle (c) with residuals (b and d). The gray zone indicates a 1-sigma dispersion around the mean value.

Magnetic field components analysis of the SCUPOL 850 microns polarization data catalog

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We present an extensive analysis of the 850 microns (353 GHz) polarization maps of the SCUBA Polarimeter Legacy (SCUPOL) Catalogue produced by Matthews et al.. A description of the several methods used for the analysis of the polarization maps of a sample of molecular clouds and star-forming regions is given. We discuss another method used for describing the turbulent regimes of the four well sampled regions, S106, OMC-2/3, W49, and DR21 in term of sonic and Alfven Mach numbers. We shown how this method can be used in order to constrain the values of the inclination angle of the mean magnetic field with respect to the line of sight. Our estimates of the sonic and Alfven Mach numbers as well as our calculations of the inclination angle of the mean magnetic field are consistent with results obtained from independent observation data analysis by other authors. Our conclusion is that simple, ideal, isothermal, and non-self-gravitating MHD simulations may be sufficient in order to describe the large-scale observed physical properties of some molecular cloud envelopes.

Low-Frequency Galactic Polarization Foregrounds Probe with QUIJOTE

Frédérick Poidevin[1] on behalf of the QUIJOTE team.

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QUIJOTE is a new CMB polarimetry experiment aimed at characterizing the low-frequency polarized foregrounds and to detect the primordial B-mode signature. The first QUIJOTE telescope and its first instrument the multi-frequency instrument (MFI) are operative since november 2012 from the Teide observatory (Tenerife, Spain). I will present the MFI capabilities at central frequencies of 11, 13, 17 and 19 GHz and the on going observation campaign with this instrument. I will summarize additional developments of the experiment including commissioning of new instruments and a second telescope. I will discuss preliminary results regarding anomalous microwave emission (AME) and diffuse synchrotron emission obtained with the MFI.

Polarimetry at the South African Astronomical Observatory

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I discuss the suite of optical and IR polarimeters of the South African Astronomical Observatory. This includes the High speed Photo-POlarimeter (HIPPO) of the 1.9m telescope, the Infrared simultaneous JHK polarimeter of the 1.4m telescope and the soon to be installed MASTER 2*0.4cm telescopes.

The potential of multi-wavelength continuum polarimetry to constrain the magnetic field morphology in the ISM

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Motivation: Magnetic fields are crucial to many astrophysical phenomena in the interstellar medium (ISM), such as collapsing giant molecular clouds, accretion of matter, and subsequently star and planet formation. In addition, dust grains also play a central role in the ISM from thermodynamics to the polarization effects of light by dust grains aligned with the direction of the magnetic field. As a result, previously unpolarized light will gain polarization perpendicular and parallel, respectively, to the magnetic field lines. Although the polarization of light by interstellar dust was discovered half a century ago, its potential to trace the magnetic field in the ISM is still far from being exhausted. In particular, circular polarization provides important information making multi-wavelength polarization measurements on multiple scales a promising tool to complete our picture of the fundamental physics of the star formation process.

Goal: We evaluate the potential of multi-wavelength continuum polarization measurements on multiple scales to constrain the impact of magnetic fields on star formation. For this purpose we post-process complex magnetic field, temperature, and density distributions as well as velocity fields resulting from MHD simulations of collapsing molecular clouds and cloud cores to create synthetic polarization maps. Dependent on the local conditions in the ISM dust grains are partially misaligned. Therefore, the analysis and interpretation of polarization measurements depends also on a detailed understanding of the dominating grain alignment mechanisms inside the ISM. Revealing the underlying magnetic field morphology with the help of polarization measurements requires dust radiative transfer calculations in arbitrary 3D geometries.

Our approach: To test the role of magnetic fields during star formation we developed an extended, adaptive grid version of the 3D Monte-Carlo radiation transfer code MC3D (Wolf et al., 1999, 2003) suitable for multi-wavelength polarization simulations. The code solves the radiative transfer problem combined with the polarization effects of dichroic extinction, thermal reemission, and scattering acting on stellar light and background radiation using an algorithm similar to the one described in Whitney & Wolff (2002).
The optical properties of the dust grains are calculated on the basis of laboratory data for the complex refraction indices of astrosilicate and graphite, applying the Discrete Dipole Approximation (DDA). The idea behind this method is to approximate the shape of the dust grains with a distinct number of dipoles and material constants as it is implemented in the well tested program DDSCAT 7.2 (Draine & Flatau 2012).
Existing theories of grain alignment agree that rotating non spherical dust grains align with their shorter axis parallel to the magnetic field direction (Voshchinnikov 2012). However, the dominant alignment mechanism is still a matter of debate. To make predictions about the impact of imperfectly aligned dust grains on polarization measurements we go beyond previous approaches in this field. We combine radiative transfer and polarization algorithms with state of the art dust grain alignment theories. Here, we implement the classical imperfect Davis-Greenstein (IDG) alignment due to paramagnetic relaxation (Davis and Greenstein 1951; Voshchinnikov 2010), the radiative torque alignment (RAT) because of radiation-dust interaction (Lazarian 2007) and considered the effects of mechanical alignment (Gold 1951; Lazarian 1996) as a result of gas streams.

Results: We demonstrate the potential of multi-wavelength polarization measurements and predict unique patterns in linear and circular polarization maps for different density distributions and magnetic field morphologies for test setups and sophisticated MHD collapse simulations. Various dust grain parameter and advanced multi-scale MHD scenarios are considered to offer maps for a broad variety of ISM configurations.
Here, we conclude that:

- Measurements of linear polarization at a distinct wavelength alone are insufficient to identify the underlying magnetic field morphology.
- Possible ambiguities in the interpretation of observational data can be resolved by including additional measurements of circular polarization in future observations.
- An additional source of ambiguity is inherent in the dichroic polarization mechanism itself. We identify two wavelength dependent effects of rotation in the orientation angles of the vectors of linear polarization projected on the plane sky.
- Different alignment mechanisms acting on dust grains significantly influence the pattern of linear and circular polarization in an unique way allowing to identify the dominant alignment mechanism.

- The main factors limiting an accurate interpretation of continuum polarization measurements are the current uncertainty of different physical parameter concerning alignment theory and dust composition.

The result of this study provides a more sophisticated insight in the effects of grain alignment on polarization measurements and constraints for the accuracy, spectral coverage and spatial resolution of polarization measurements required to constrain the magnetic field morphology in molecular clouds .

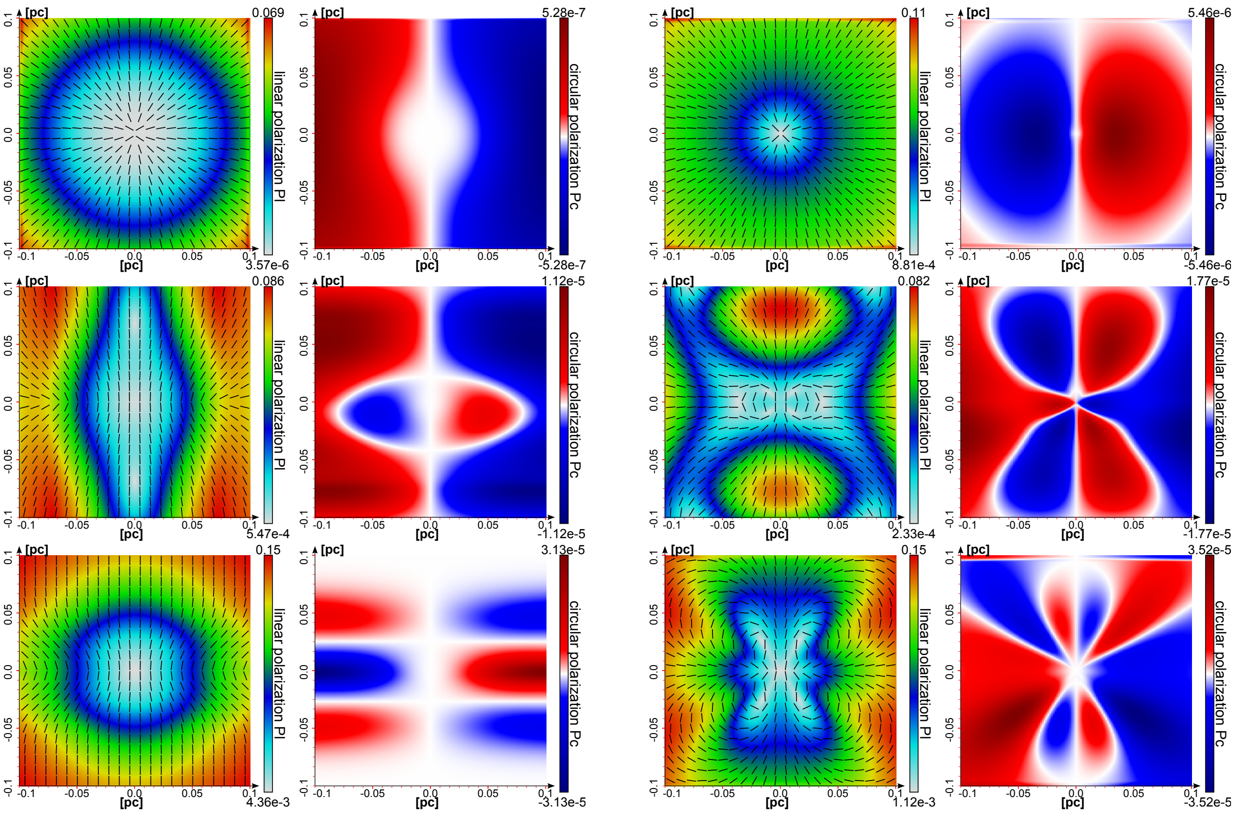

Figure 20: *Illustration of the potential of circular polarization measurements:* The figure shows maps of linear polarization and circular polarization at a wavelength of 811 μm of a Bonnor-Ebert sphere with a characteristic radius $R_c = 1100$ AU and a density $n_0 = 10^{13}$ m^{-3} in the center. The inclination angles are 3° (top), 45° (middle) and 87° (bottom). We modeled a 3D magnetic hourglass morphology (left) and quadrupole morphology (right) with analytical functions. The temperature distribution is adjusted to keep the gas temperature and dust temperature in a range of 10 K – 25 K and 5 K – 15 K, respectively. The dust particles are imperfectly aligned according to the IDG mechanism and the vectors of linear polarization have an offset angle of 90° to match the projected magnetic field. With increasing inclination angle the underlying hourglass morphology (left) and quadrupole morphology (right), respectively, becomes apparent. However, for low inclination angles the vector fields of linear polarization shows a similar radial symmetric pattern in both configurations. The underlying magnetic field morphologies would be indistinguishable by measurements of linear polarization alone. In contrast to the ambiguities in the pattern of linear polarization, the maps of circular polarization remain unique for each field morphology independent of inclination angle. *[from Reissl et al., A&A accepted]*

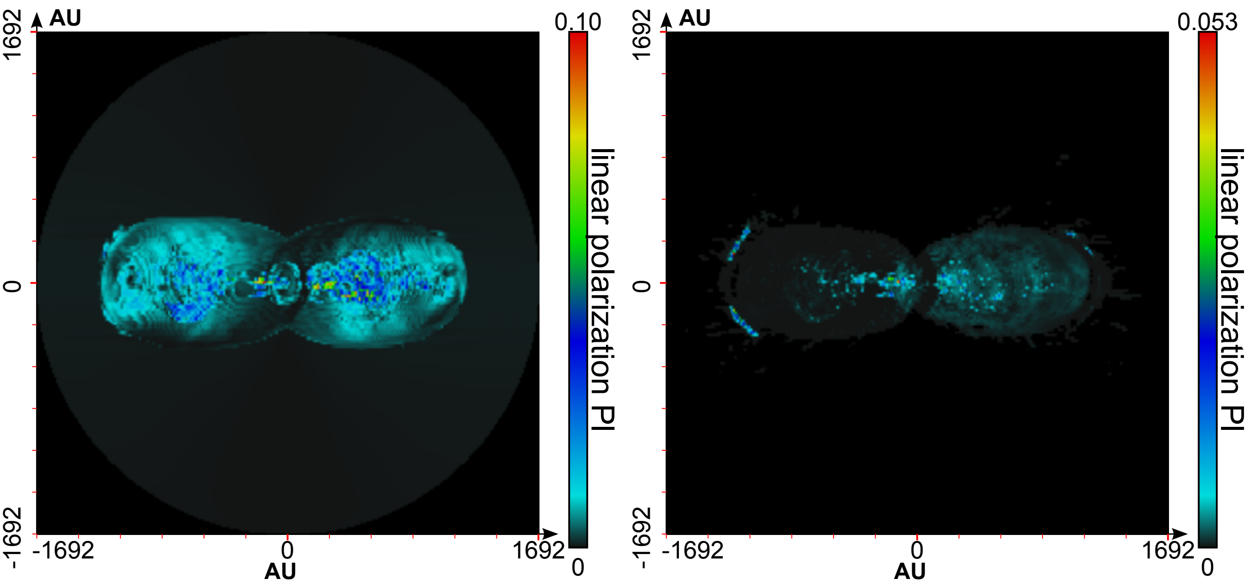

Figure 21: *Illustration of the impact of different alignment mechanisms on polarization measurements:* The figure shows the resulting maps of the degree of linear polarization for a post-processed MHD simulation with an accretion disc in the center and outflows in the surrounding ISM. We took a snapshot of a run with a mass of 100 $M_{\odot}$ after a simulation time of 5000 yr. The radiative transfer and polarization simulation was performed at a wavelength of 23 μm. We compare the impact of the of different aliment mechanisms on the resulting pattern of linear polarization. The map of linear polarization with the IDG alignment mechanism is on the left hand side and the RAT alignment mechanism is on the right hand side. We demonstrate that synthetic polarization maps resulting from radiative transfer simulations with different alignment mechanisms provide the possibility to identify the dominant alignment mechanism in the ISM by its influence on the pattern of linear polarization.

SPARC4
Simultaneous Polarimeter And Rapid Camera in 4 bands

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We present the status of the development of SPARC4 - Simultaneous Polarimeter And Rapid Camera in 4 bands. The camera will obtain simultaneously four images in the SSDS *griz* bands. Each image will have a field-of-view of 5.6 × 5.6 arcmin. The instrument will obtain linear and circular polarimetry and photometry of point sources with subsecond temporal resolution. It will be installed at the 1.6-m telescope of the Observatório do Pico dos Dias, in Brazil. While a versatile instrument, which may be used for several astrophysical purposes, the primary scientific applications will be those related to fast time variability of stellar sources. The instrument interface will be done using a friendly GUI. We plan to deliver a reduction pipeline and a suite of quicklook routines. The project will now proceed to the Critical Review Phase.

Retrieval of Venus cloud layers parameters with polarimetric data from SPICAV/VEx

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The study of Venus's cloud layers is important in order to understand the structure, radiative balance and dynamics of the Venusian atmosphere. Polarization measurements have given important constraints for the determination of the constituents of the clouds. In 1974, Hansen & Hovenier used ground-based observations to establish that the main cloud particles are micrometric droplets of a concentrated sulfuric acid solution. The overlying haze has been identified as $r \sim 0.25$ μm particles by Kawabata et al. (1980) using Pioneer Venus OCPP measurements. Temporal and spatial variability of the haze has also been observed.
Our study uses the polarimetric data from the SPICAV-IR spectrometer onboard ESA's Venus Express spacecraft. The degree of linear polarization of the light scattered at cloud top is measured in the 0.65 –1.7 μm range, with a global coverage of the northern hemisphere of Venus. The polarization observed is consistent with previous ground-based observations and with Pioneer Venus OCPP polarimetric measurements, yielding a negative polarization degree at all phase angles, corresponding to the micrometric, sulfuric acid, cloud particles. The polarization reaches strong positive values at high latitudes, indicating an increased contribution of the submicron haze. A polarization glory is observed on several orbits, and is used to put constraints on the refractive index, size and variance of the cloud particle distribution.
We present here results of the modeling using the Doubling-adding method on the glory to characterize the cloud particles, and at higher latitudes to investigate the variation of the haze layer optical depth. We confirm that the clouds are made of ~ 1 μm sulfuric acid droplets, and we observe an increase of the haze optical thickness with increasing latitude.

Hida Optical Polarimetry System (HOPS)

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We have developed a "two-beam type" imaging polarimeter, HOPS, designed for use with the 65-cm refracting telescope at the Hida Observatory, Kyoto University. The name HOPS is an acronym of "Hida Optical Polarimetry System". The mission of HOPS is to map the linear polarization of reflected sunlight in visible wavelengths from major planets (Venus, Mars, Jupiter, and Saturn). The original model of HOPS was built in 2000, called HOPS2000, and had its first-light took place in 2001 (Satoh *et al.,* in *Proceedings of the 34th ISAS Lunar and Planetary Symposium,* 2001).

The basic design of HOPS is straightforward. The first element is a collimator lens, for which we use a Nikon zoom lens ($f = 80 - 200$ mm). After the entrance beam is collimated, a super-achromatic half-wave retarder plate (Pancharatnam type) on a motor-driven rotating stage alters the polar angle of polarized beam. The beam then enters a calcite Wallaston prism which separates the ordinary ray and extraordinary ray with a separation angle of 5°. These two beams are focused onto a CCD with an imaging lens.

In HOPS2000, the CCD detector chip was Kodak KAF-1600 (1552×1032 pixels with 9-μm pixel pitch). The imaging lens, Nikon $f = 85$ mm, yielded an appropriate pixel separation (~ 800 pixels) of two beams on the CCD. This CCD was no longer operational, when we started the monitoring program of Venus in 2012, so we had to use an alternative CCD and to modify the optics accordingly. The new HOPS uses the SBIG STL-1001E camera, of which CCD is Kodak KAF-1001E (1024×1024 pixels with 24-μm pitch). To somewhat compensate for the effect of larger pixel pitch, we replaced the imaging lens with a Nikon $f = 135$ mm lens. This yields the separation of two pixels about half a pixel number of HOPS2000 (~ 400 pixels), acceptable for observation of planets by considering the typical seeing at the Hida Observatory. On the internal filter wheel of STL-1001E camera, 4 narrow-band filters: 438 nm, 546 nm, 650 nm, and 930 nm, are installed.

At the workshop, we discuss details of the new HOPS and its performance with some example linear polarization measurements for major planets. Preliminary results of Venus monitoring program are reported in another paper (Enomoto *et al.*).

Magnetic Field in The Isolated Massive Dense Clump IRAS 20126+4104 II. A Study Across High Spatial Dynamic Range

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We report on a study of the magnetic field structures of IRAS 20126+4104, a massive dense clump in which the rotation axis and the magnetic field axis are misaligned. In addition to the SHARP/CSO data that we reported in 2012 (Shinnaga et al. 2012), we analyzed polarization data sets that were taken with the SMA along with SCUPOL/JCMT, both at 850μm. Comparing with the recent VLBI measurements of spectropolarimetric observations of this object (Surcis et al. 2014), these four independent data sets allow us to investigate the magnetic field structures across a high spatial dynamic range, between 20 AU scale and 1 pc scale of the massive dense clump – massive ($\sim 10M_\odot$) (proto)star system. The magnetic field vectors measured in these four different spacial scales are consistent. At the scale observed with SMA the magnetic field appears to be rather perpendicular to warm bipolar outflow direction. We carried out detailed theoretical simulations for this object based on the study by Kataoka et al. 2012. By comparing the observational results with the theoretical simulations, we find that the magnetic field plays a critical role during the course of the gravitational collapse of the massive dense clump.

Monte Carlo radiative transfer modeling of polarization by scattering in AGN

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The central engine of active galactic nuclei (AGN) is surrounded by optically and geometrically thick, roughly toroidal structure of dust. This structure, dubbed "the dusty torus", is absorbing the incoming radiation, re-emitting it at infrared, and scattering mostly at optical/UV wavelengths. Scattered light is polarized and the angle of polarization depends on the direction of the last scattering, so it is is expected to be related to the structure of different emitting and scattering regions. As the radiation of AGNs is polarized over a broad wavelength range, the polarization can be exploited to constrain their structure and geometry. Previously we have studied infrared emission of the dusty torus, using SKIRT, an efficient 3D continuum radiative transfer code based on the Monte Carlo algorithm. The code offers full treatment of absorption and multiple anisotropic scattering by dust, the thermal re-emission of dust, and the emission from very small grains and polycyclic aromatic hydrocarbon molecules. In this contribution we will discuss recent efforts to implement treatment of polarization by scattering in SKIRT and present preliminary results of application in the case of AGN dusty torus.

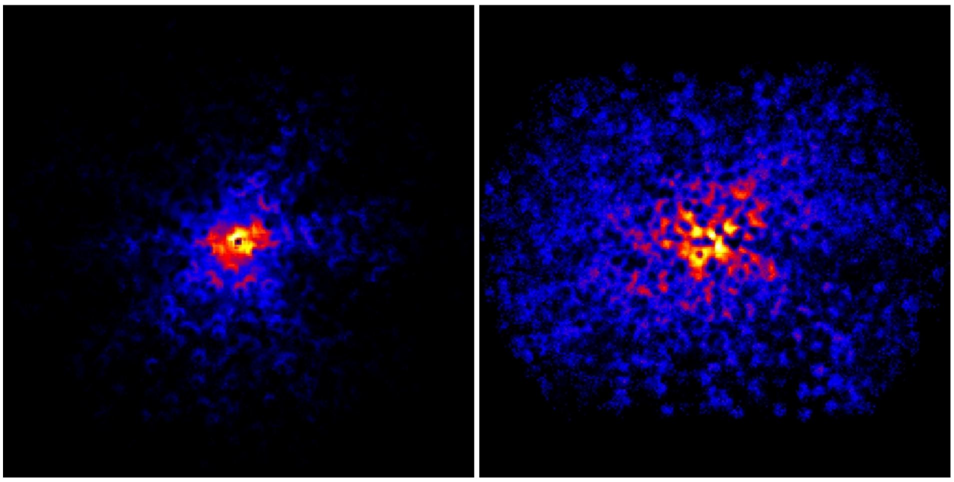

Figure 22: Face-on (left) and edge-on (right) scattered flux images of the dusty torus obtained with SKIRT.

Near-Infrared Imaging Polarimetry of the Serpens South Cloud in Aquila.

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We have conducted JHKs polarimetric observations of the the Serpens South cloud and its northward extension region, which are consist of multi filaments (André et al. 2010). This study is the further work of our previous observation (Sugitani et al. 2011) toward the Serpens South protocluster, which is associated with the hub region of infrared dark cloud filaments and is believed to be in the very early stage of star cluster formation (Gutermuth et al. 2008). The imaging polarimeter SIRPOL (polarimetry mode of the SIRIUS camera) mounted on the IRSF 1.4-m telescope at SAAO was used, and the most part of these regions was covered with 30 FOVs of SIRPOL. Here we present results of our extensive polarization observations, including the previous polarimetric data around the protocluster, by comparing with the column density map made with the Herschel Gould Belt survey data. Our linear polarization measurements of near-infrared point sources indicate an ordered global magnetic field that is nearly perpendicular to the main filaments in the observed area, implying that the magnetic field is likely to be relatively strong. On the other hand, the sub filaments, which are less dense than the main filaments, tend to run along the magnetic field.

Differential Heating of Magnetically Aligned Dust Grains

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We use far-infrared photometric maps from IRAS and *Herschel* to search for the differential heating of asymmetric dust grains aligned with respect to an interstellar magnetic field and heated by a single star. The grains are known to be asymmetric and have a net alignment of their axes from observations of background starlight polarization. Modern grain alignment theory predicts a relation between the alignment efficiency and the angle between the magnetic field and the direction to the aligning radiation source. Along with the observed polarization, such a geometry also has consequences for the distribution of grain heating. For example, asymmetric grains whose largest cross sections are normal to the incident stellar radiation will reach warmer equilibrium temperatures compared to grains whose largest cross-section is parallel to that direction. This should be observed as an azimuthal dependence of the dust color temperature. We present evidence of such a dependence using IRAS data at 60 and 100 μm. We expect this effect to be stronger using longer wavelength (i.e., 160 μm) data better coupled to the "big-grain" dust population, grains that are also more efficiently aligned with the local magnetic field. Here we also present the results of our on-going work to search for this signal using *Herschel* maps towards three candidate stars.

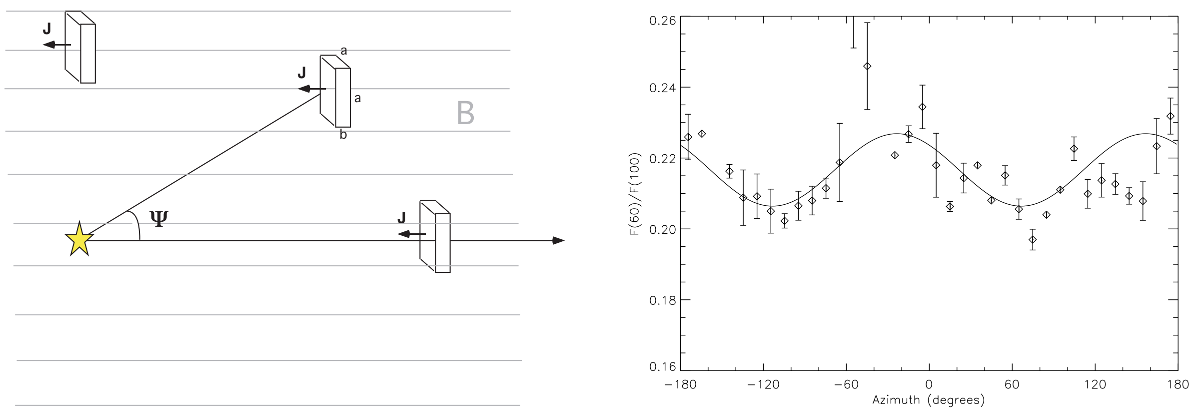

Figure 23: *Left*: Geometry of grain heating showing the relative orientations of stellar photons, magnetic field lines (B), and dust grain axes (rectangular boxes with angular momentum J). *Right*: Intensity ratio (60-to-100 μm) centered on the star HD 23777 as a function of azimuth (Ψ) at a distance of $\sim 0.5°$ from the star.