Imaging polarimetry and spectropolarimetry of comets

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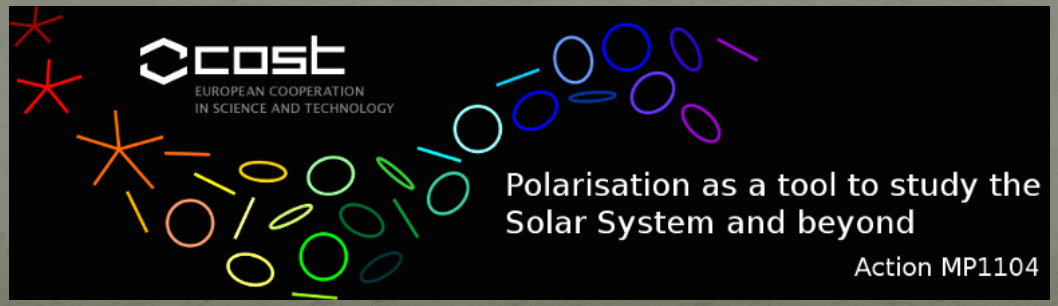

2-m Ritchey-Chrétien-Coudé Telescope

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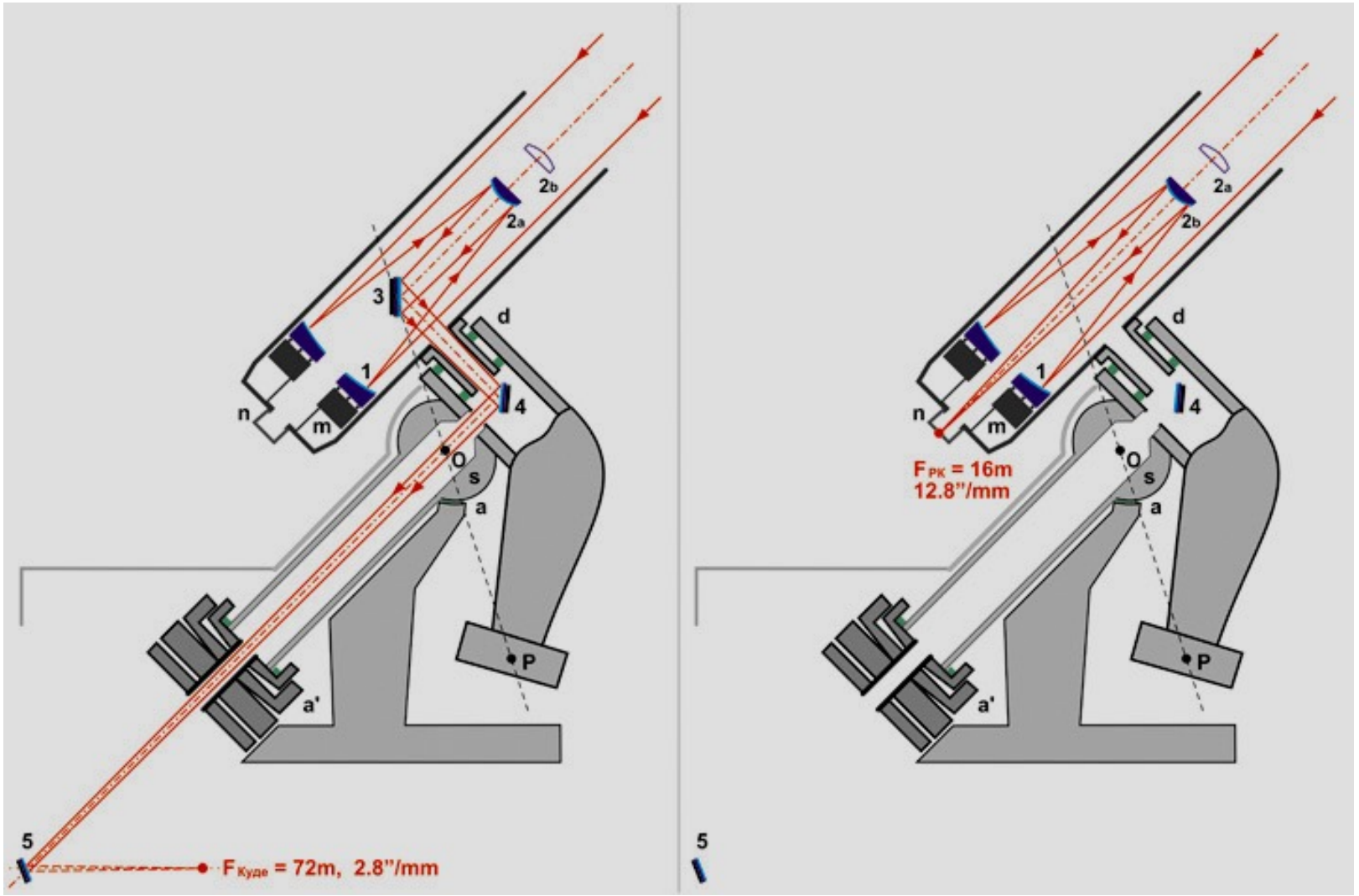
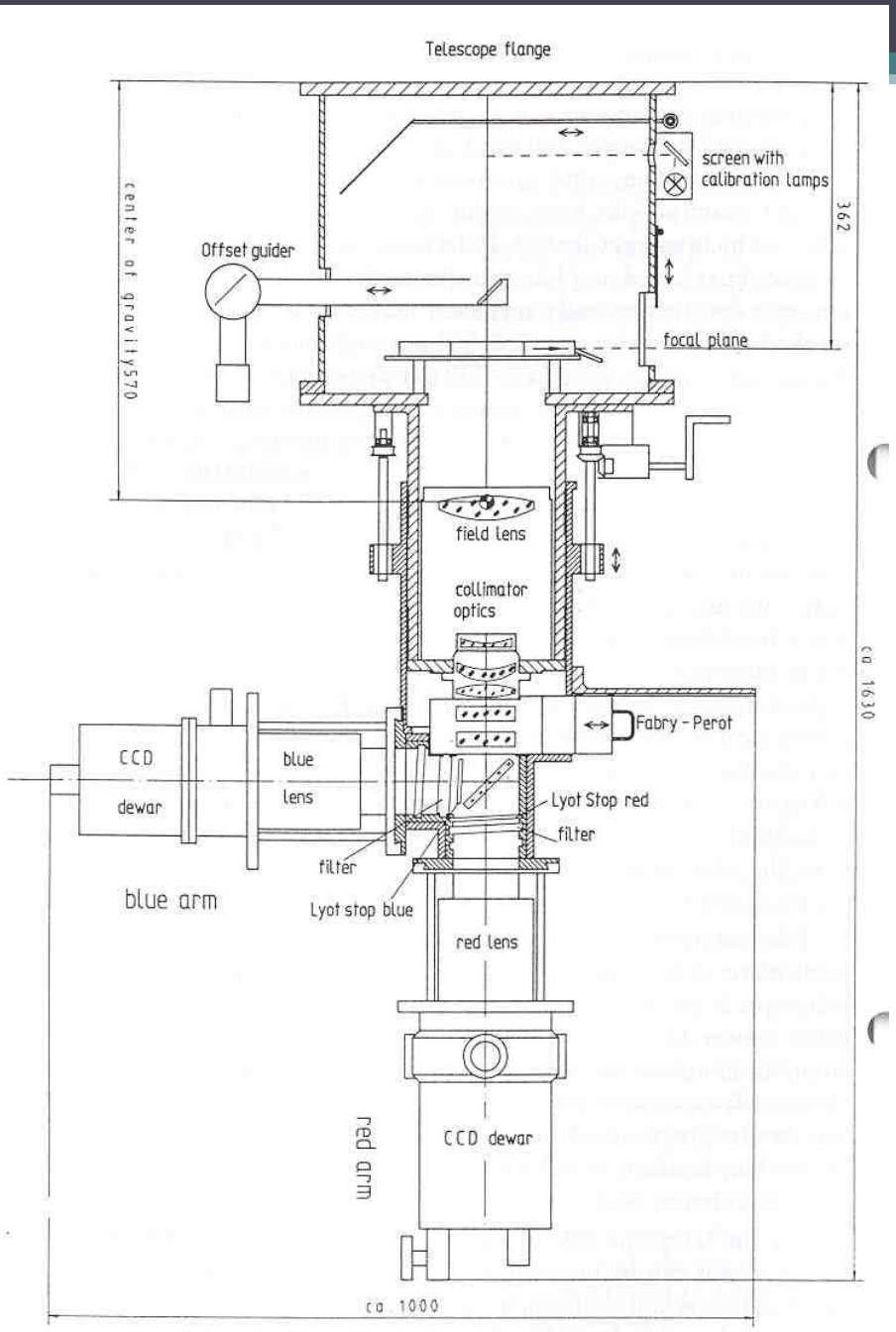
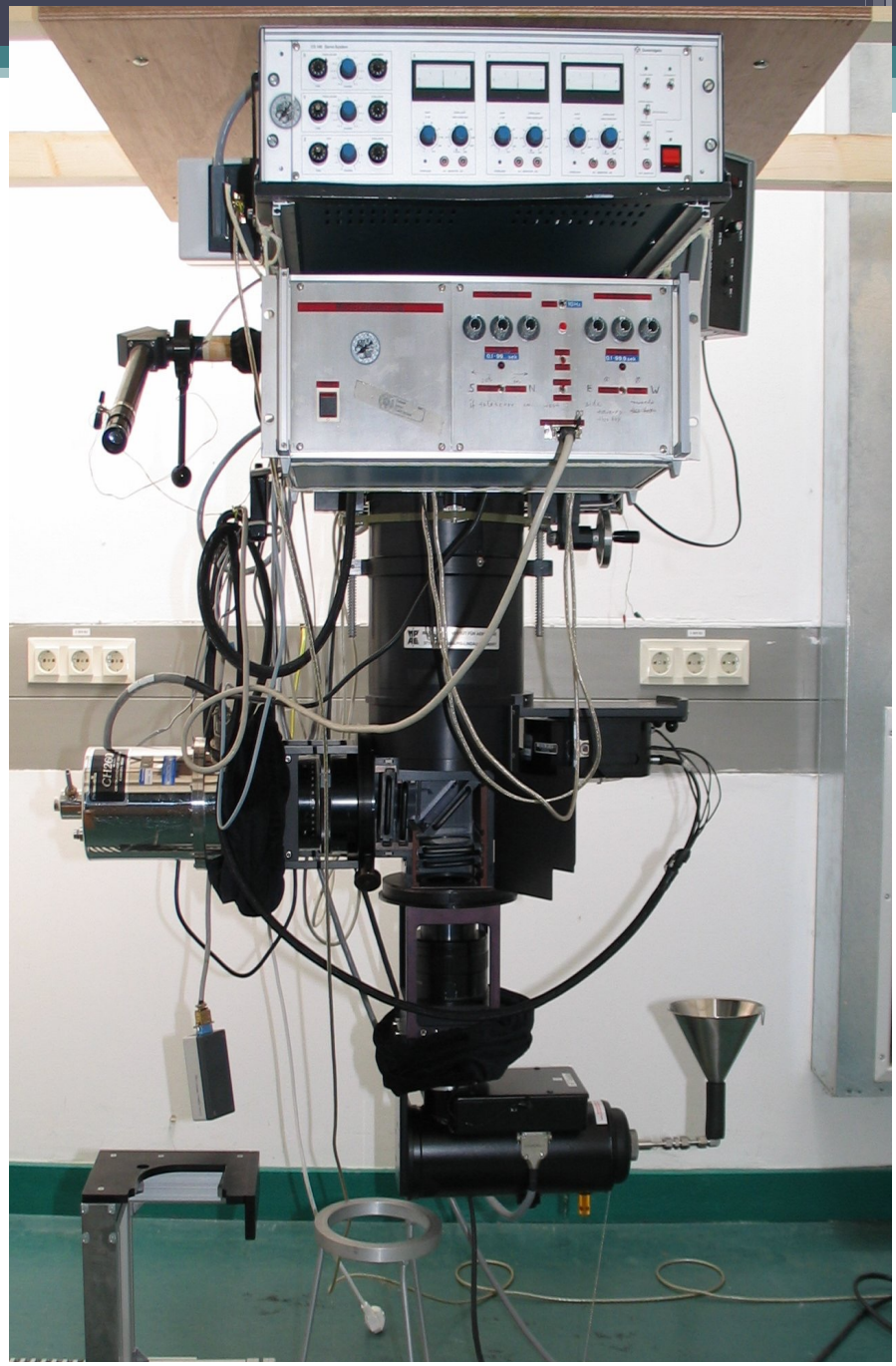


2-Channel Focal Reducer - Rozhen

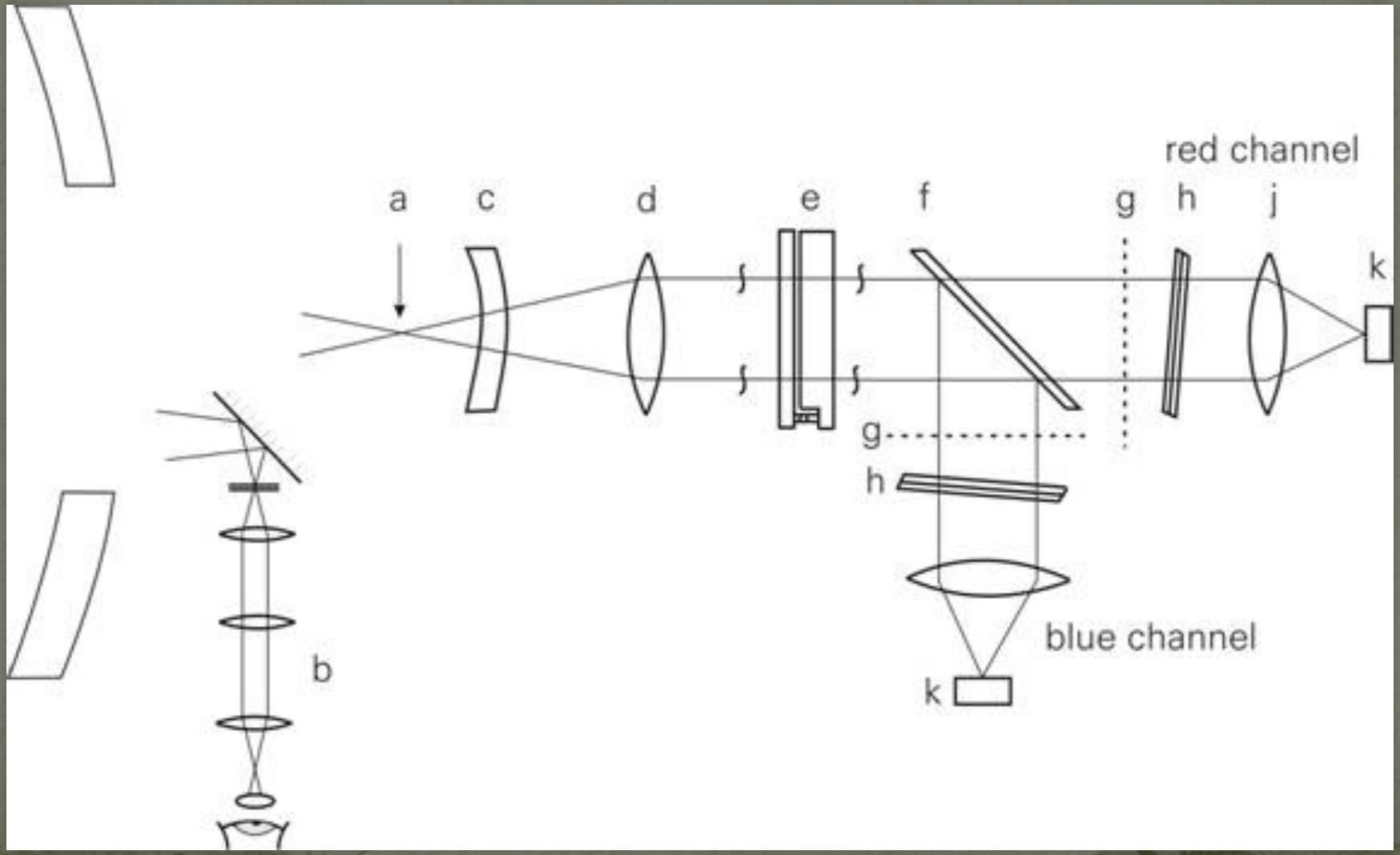
FoReRo2

16 m	Focal length	5.6 m
f/8	f ratio	f/2.8
0.31 arcsec/px	Scale (1 px = 0.024 mm)	0.88 arcsec/px


Telescope flange
screen with
calibration lamps
362
center of gravity570
Offset guider
focal plane
field lens
collimator
optics
ca 1630
Fabry - Perot
CCD
dewar
blue
lens
Lyot Stop red
filter
filter
blue arm
Lyot stop blue
red lens
CCD dewar
red arm
ca 1000



NAO – Rozhen
2m RCC Telescope – FoReRo2

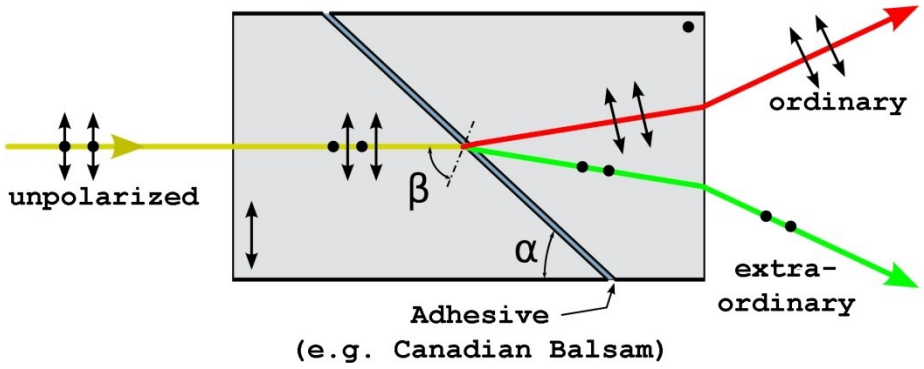


Ideal Polarimeter

Stokes vector $\mathbf{S}(I, Q, U, V)$

$$P = \frac{\sqrt{Q^2 + U^2}}{I} = \sqrt{\bar{Q}^2 + \bar{U}^2}, \text{ where } \bar{Q} = \frac{Q}{I}, \bar{U} = \frac{U}{I}$$

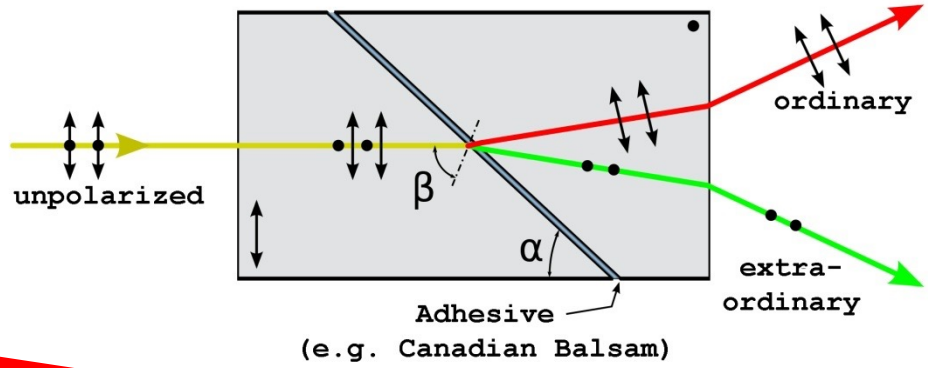
$$\theta = \frac{1}{2} \arctan\left(\frac{U}{Q}\right)$$



$$Q = I_0 - I_{90}$$

$$U = I_{45} - I_{135}$$

Real life polarimeter



$$F_{\parallel} = I + Q$$
$$F_{\perp} = I - Q$$

$$\frac{F_{\parallel} - F_{\perp}}{F_{\parallel} + F_{\perp}} = \frac{(I+Q) - (I-Q)}{(I+Q) + (I-Q)} = \frac{Q}{I}$$

$$\frac{F_{\parallel} - F_{\perp}}{F_{\parallel} + F_{\perp}} = \frac{k_{\parallel}(I+Q) - k_{\perp}(I-Q)}{k_{\parallel}(I+Q) + k_{\perp}(I-Q)}$$

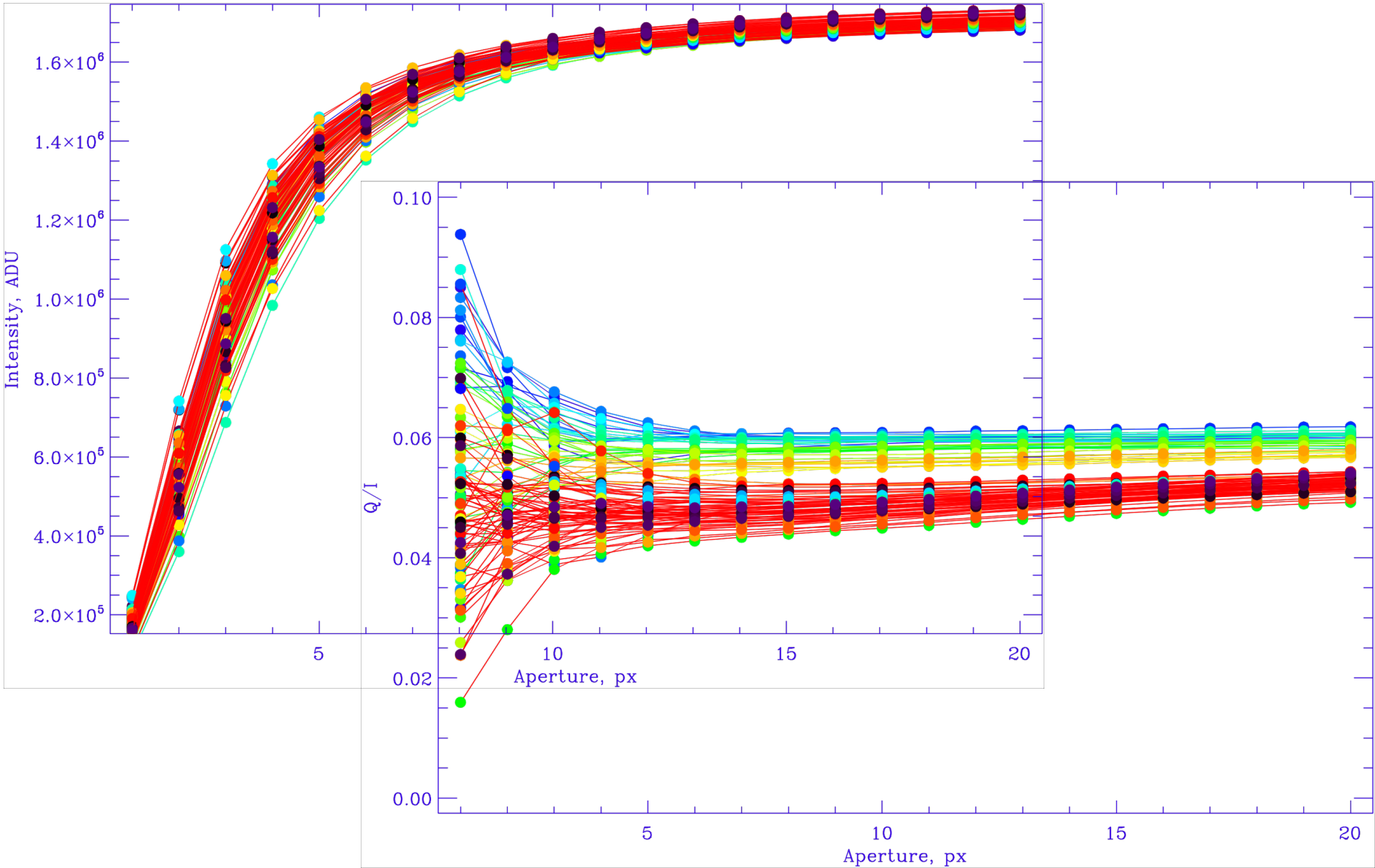
Polarimetry - Beam swaping

$$\frac{1}{2}\left[\frac{k_{\parallel}(I+Q)-k_{\perp}(I-Q)}{k_{\parallel}(I+Q)+k_{\perp}(I-Q)}-\frac{k_{\parallel}(I-Q)-k_{\perp}(I+Q)}{k_{\parallel}(I-Q)+k_{\perp}(I+Q)}\right]$$

$$\frac{1}{2}\left[\frac{(k_{\parallel}-k_{\perp})I+(k_{\parallel}+k_{\perp})Q)}{(k_{\parallel}+k_{\perp})I+(k_{\parallel}-k_{\perp})Q}+\frac{-(k_{\parallel}-k_{\perp})I+(k_{\parallel}+k_{\perp})Q)}{(k_{\parallel}+k_{\perp})I-(k_{\parallel}-k_{\perp})Q}\right]$$

$$\frac{(k_{\parallel}+k_{\perp})^2IQ-\overbrace{(k_{\parallel}-k_{\perp})^2}^{0}IQ}{(k_{\parallel}+k_{\perp})^2I^2-\underbrace{(k_{\parallel}-k_{\perp})^2}_{0}Q^2}=\frac{Q}{I}$$

Aperture photometry



Polarimetry - Beam swapping

Unpolarized standard star **HD 42807**

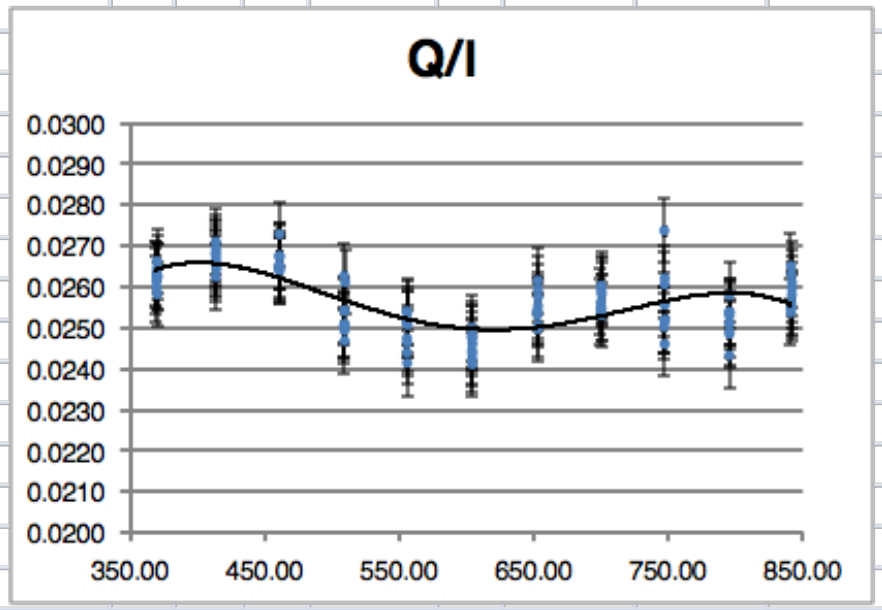
Filter	Q/I	U/I	P, [%]
IF443	0.00057	-0.00079	0.098
IF642	-0.00013	0.00122	0.123

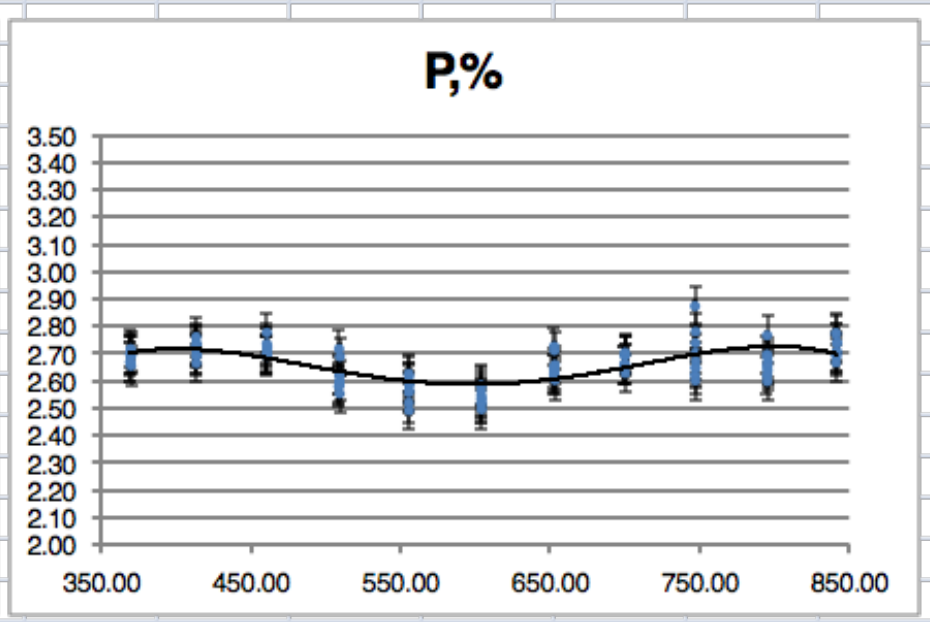
High polarized standard star **HD 14433**

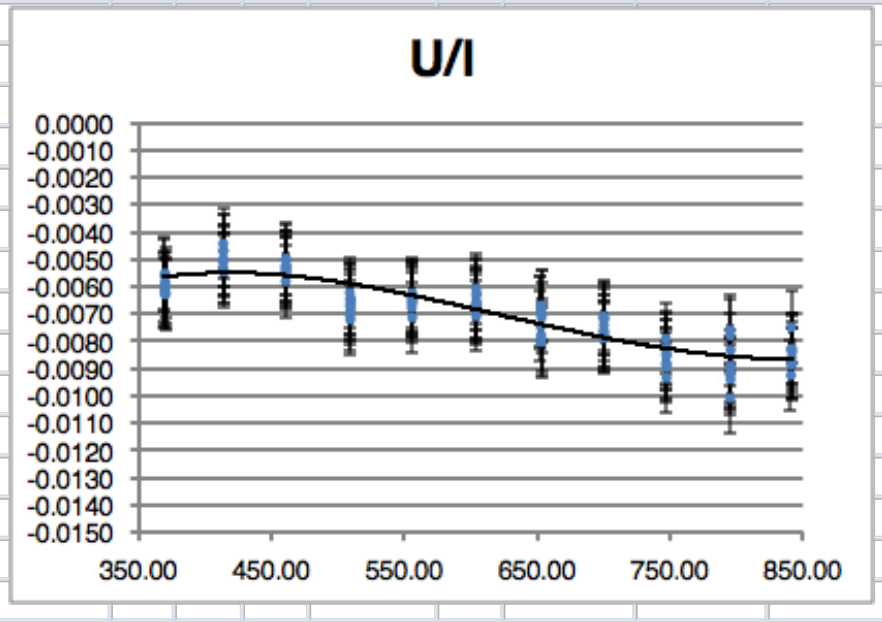
Pmax(%)	λmax	λ	P443[%]	λ	P684[%]	θ	mv
3.9	0.51	0.443	3.81	0.684	3.53	112	6.4

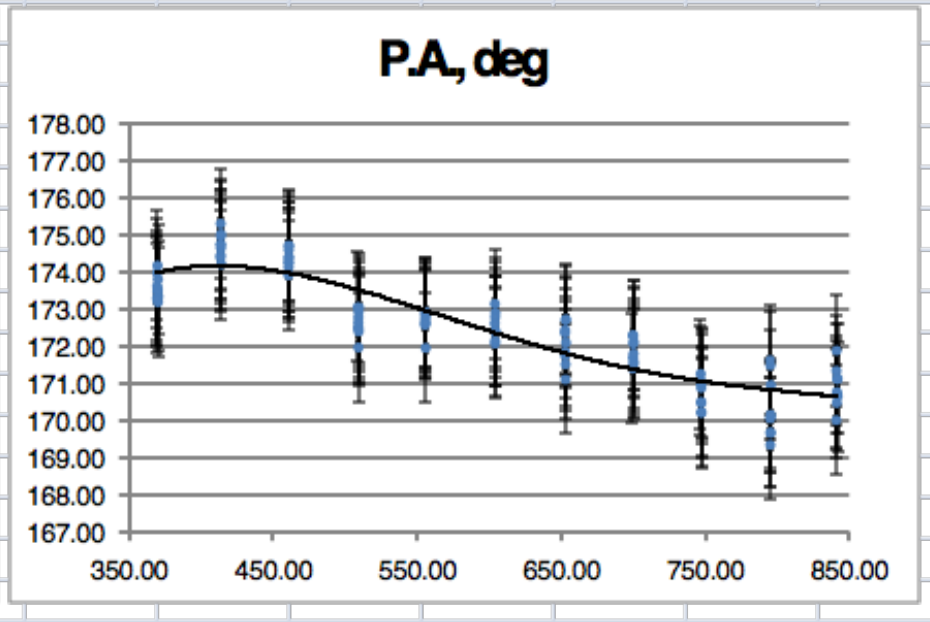
Filter	Q/I	U/I	P, [%]	θ,[deg]
IF443	-0.02465	-0.02698	3.65	111.21
IF642	-0.02435	-0.02616	3.57	111.48

	P,%	σ	P.A., deg	σ
Obs	2.66	0.07	172.43	1.43
Cat	2.96		170.00	



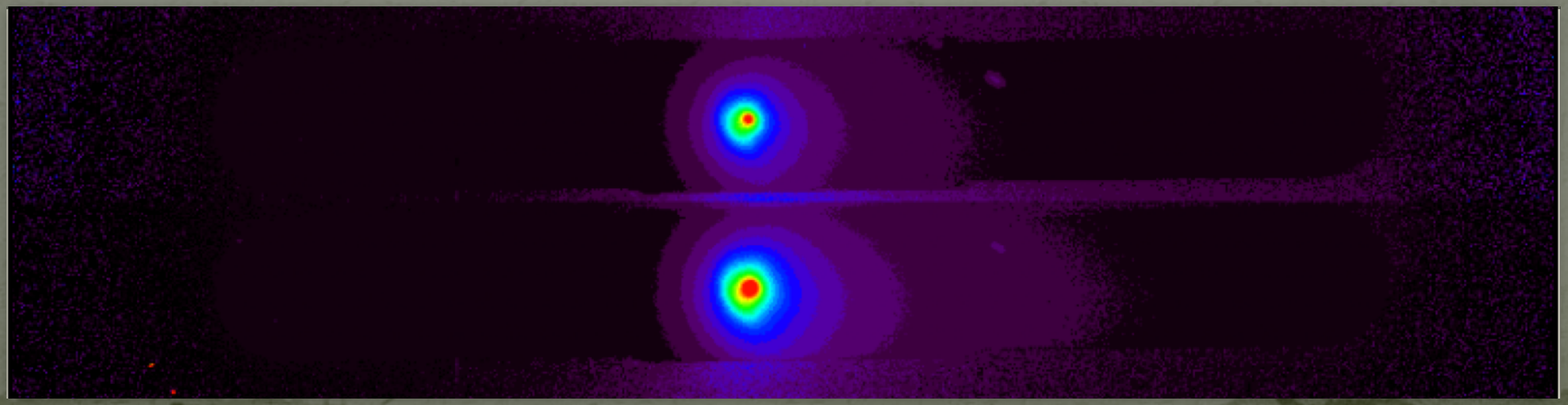


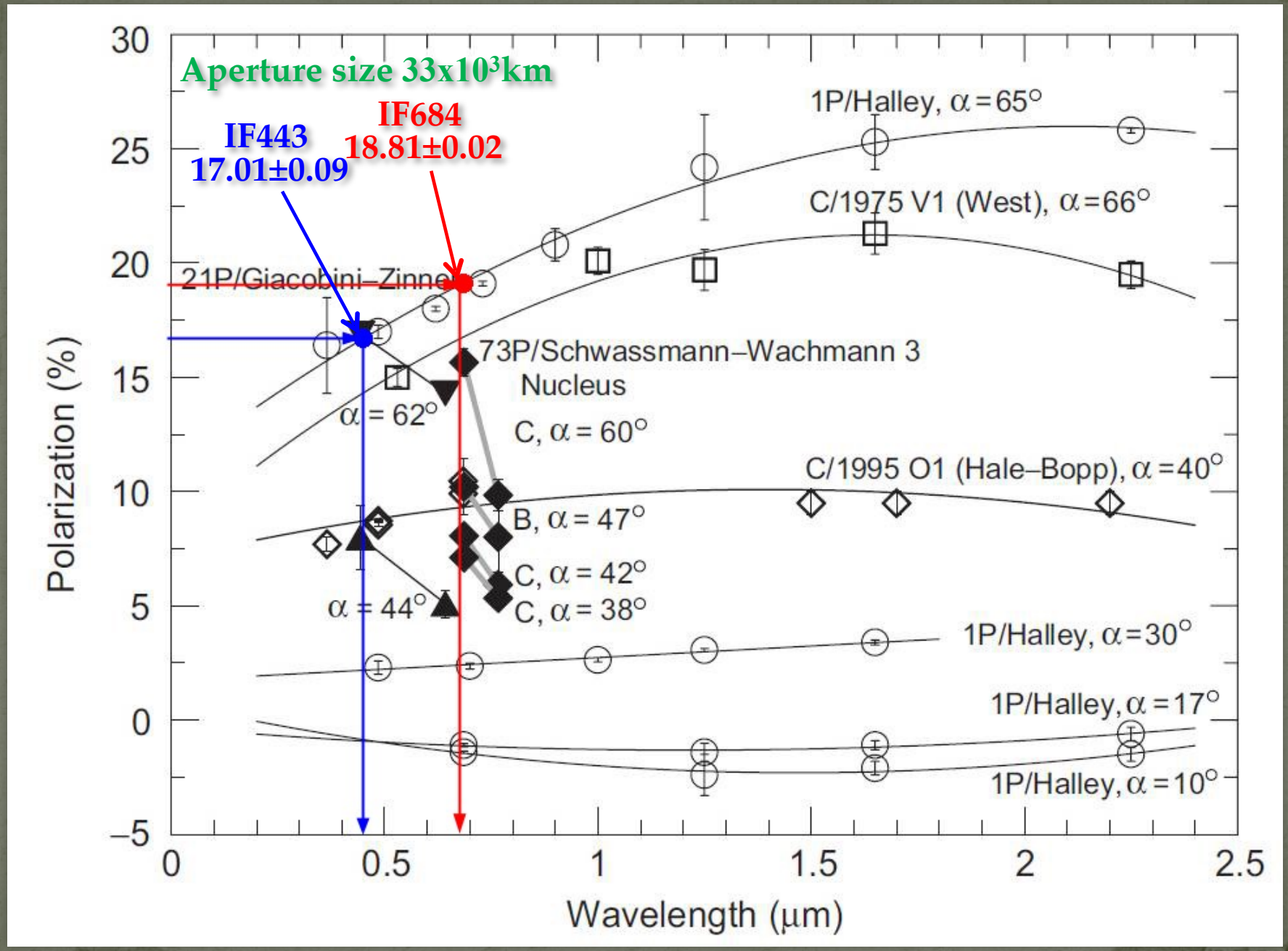




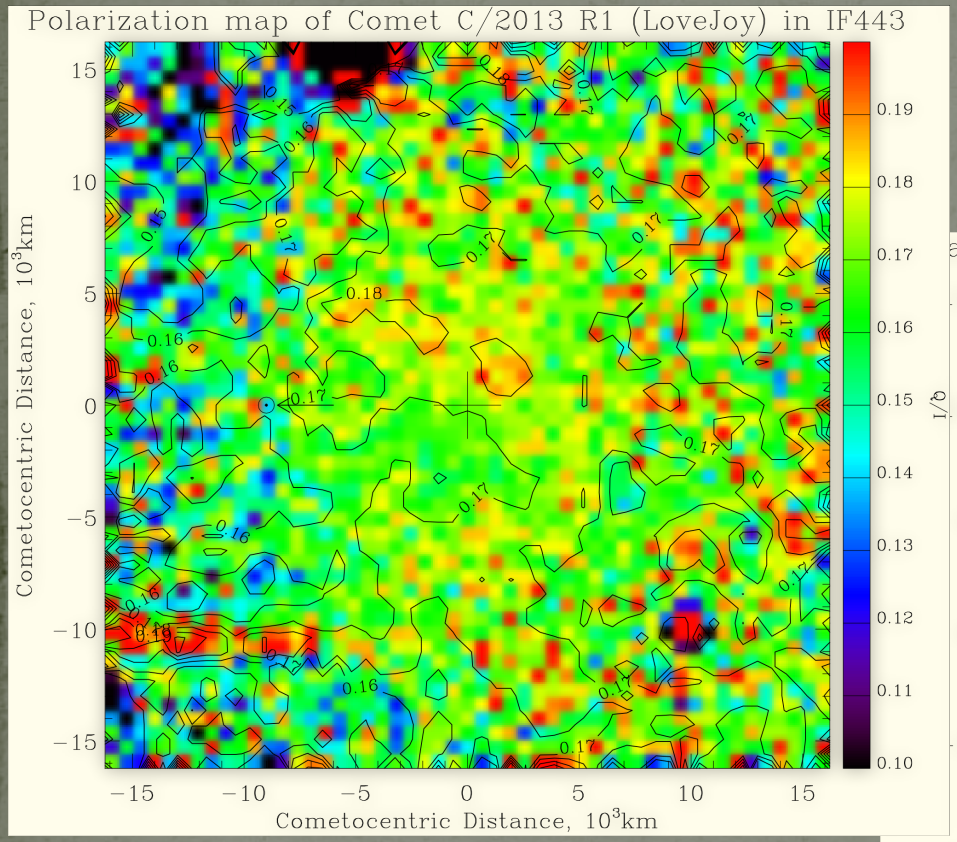
Observations of comet C/2013 R1 (Lovejoy)

- Imaging polarimetry
  - Wollaston prism
  - Dichroic beam splitter
  - Blue continuum (BC) at 443 nm – filter IF443
  - Red continuum (RC) at 684 nm – filter IF684
    - Beam swapping technique
      - P.A. 53deg – 3 x 180 sec
      - P.A. 143 deg – 3 x 180 sec

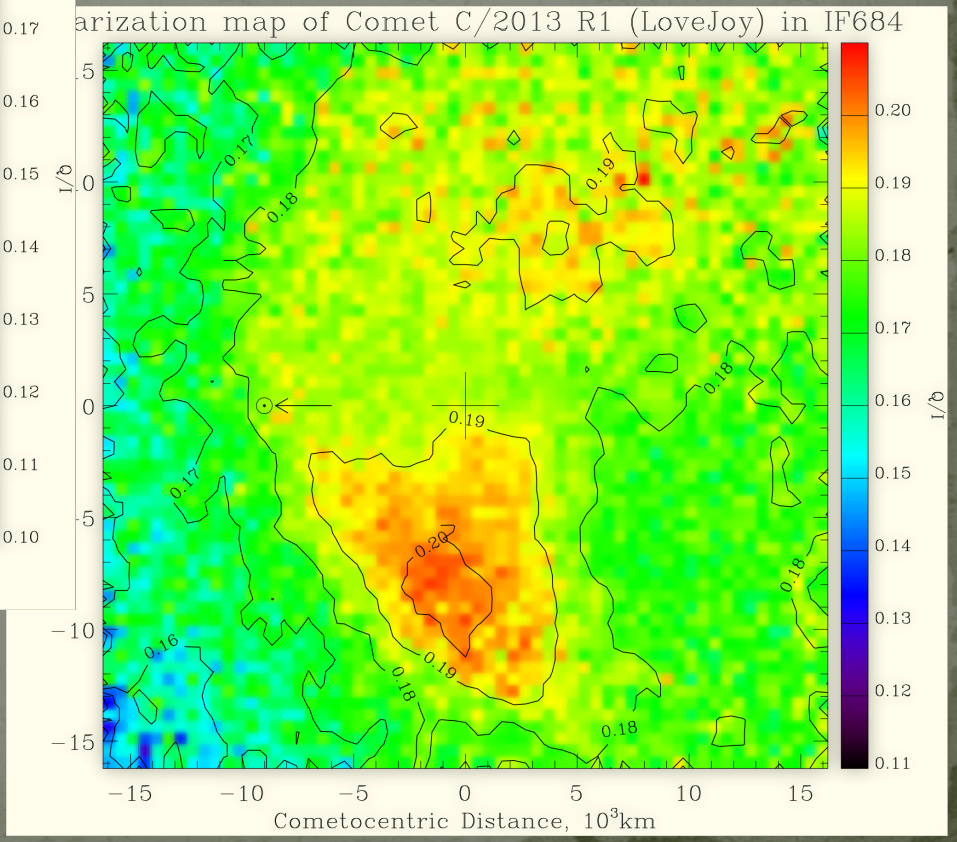



Aperture size 33x10³km
IF443
17.01±0.09
IF684
18.81±0.02
1P/Halley, α=65°
C/1975 V1 (West), α=66°
21P/Giacobini–Zinner
73P/Schwassmann–Wachmann 3
Nucleus
α = 62°
C, α = 60°
C/1995 O1 (Hale–Bopp), α=40°
B, α = 47°
C, α = 42°
α = 44°
C, α = 38°
1P/Halley, α=30°
1P/Halley, α=17°
1P/Halley, α=10°
Polarization (%)
Wavelength (μm)
30
25
20
15
10
5
0
−5
0
0.5
1
1.5
2
2.5

Polarization maps – Dust continuum

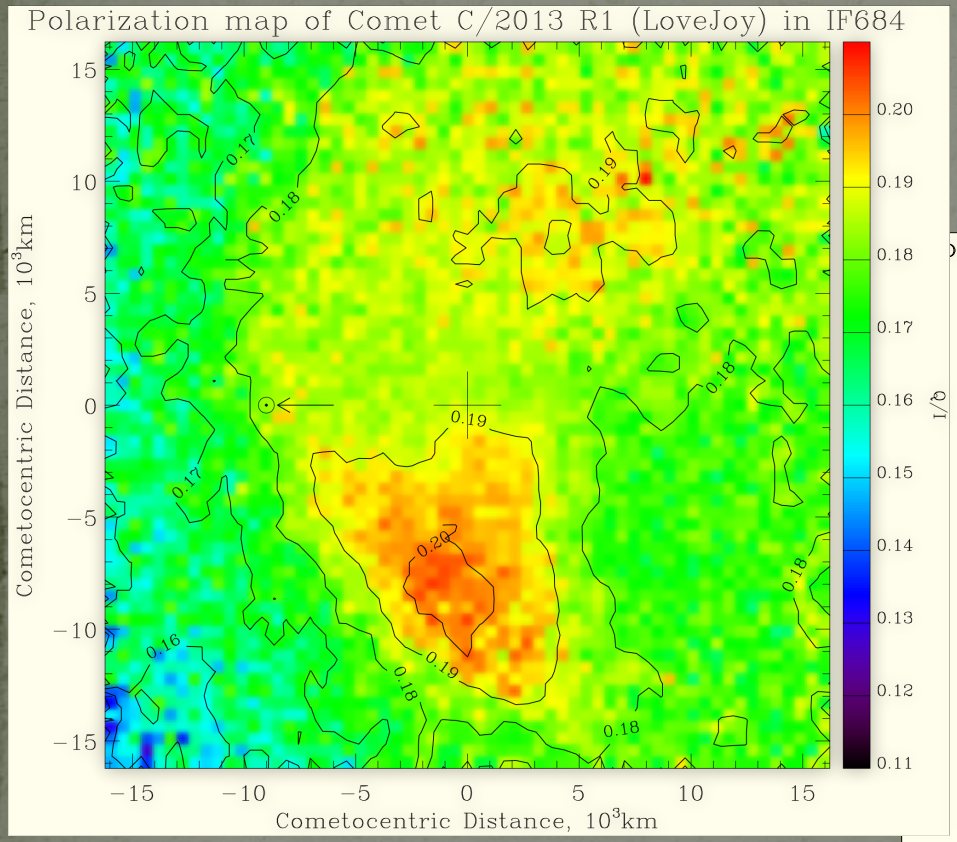


BC: IF 443nm

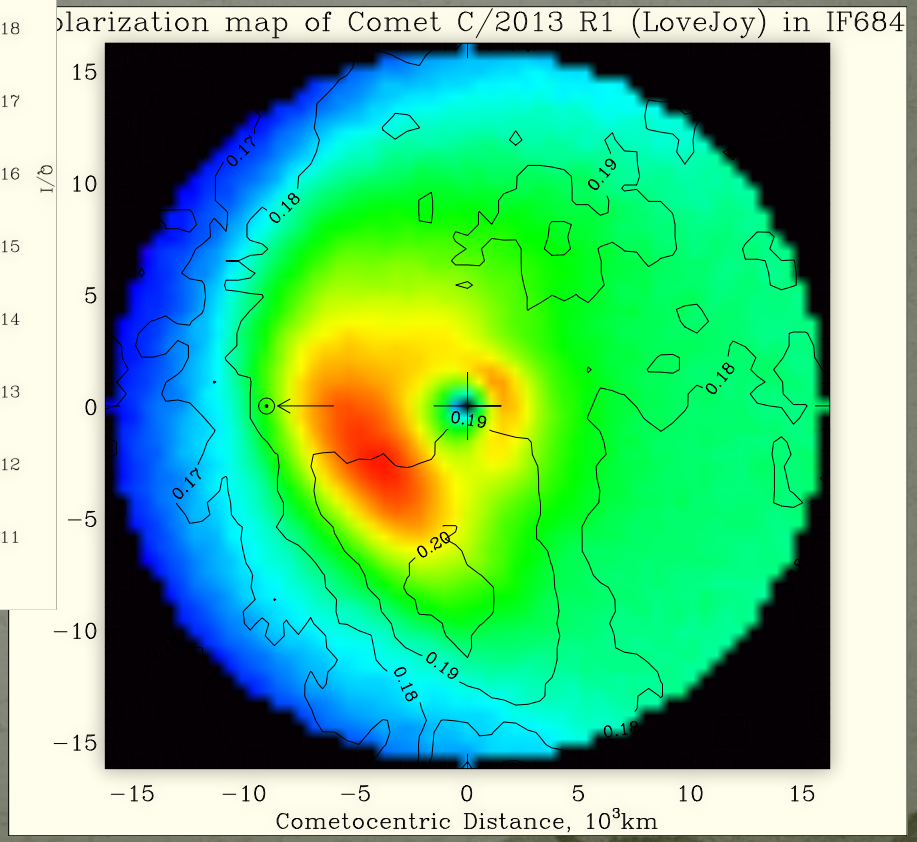


RC: IF 684nm

RC Polarization map Structures

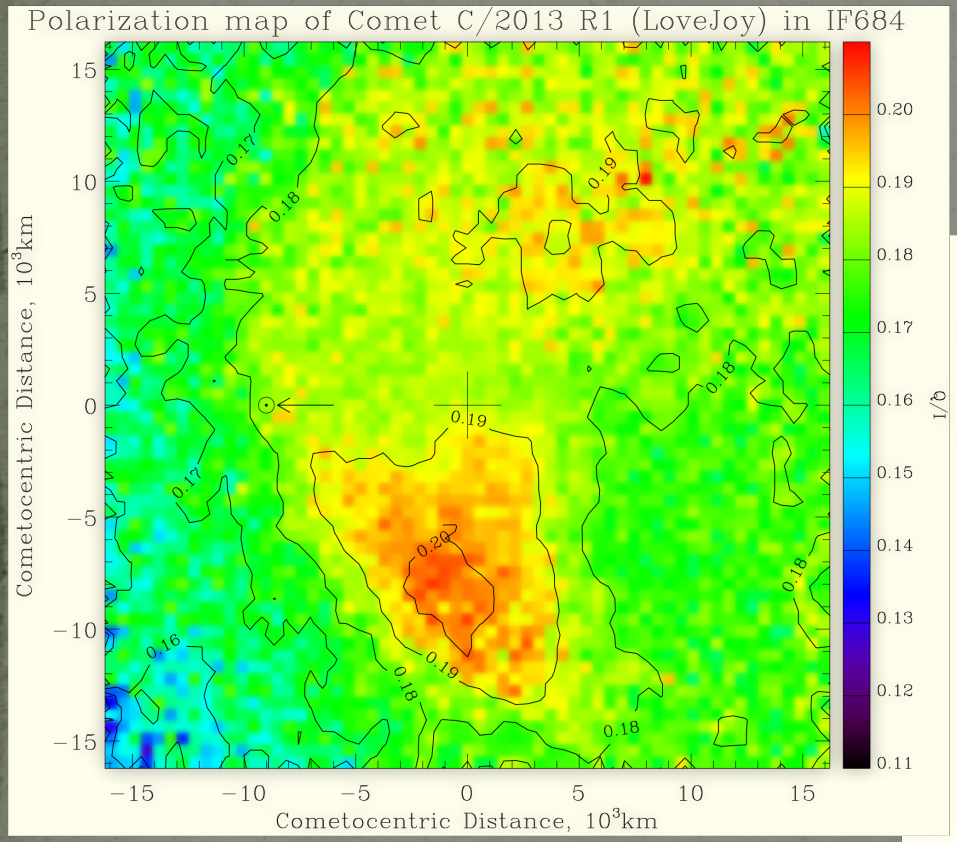


RC: IF 684nm

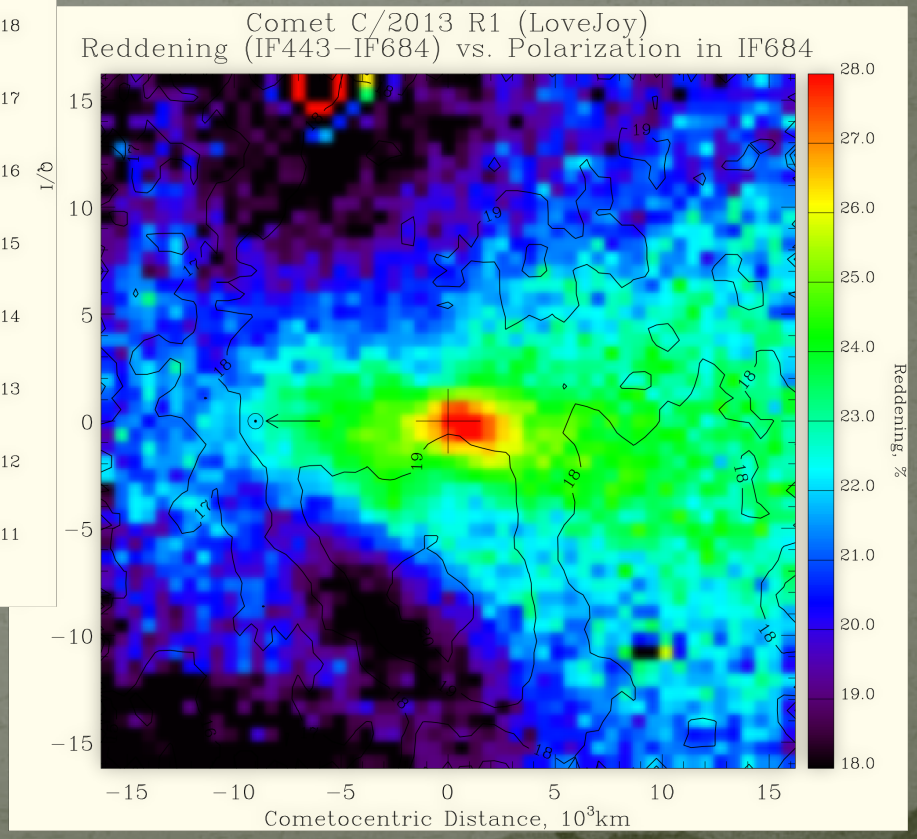


Enhanced dust coma structures

RC Polarization map Structures vs. Dust coma reddening – Color map



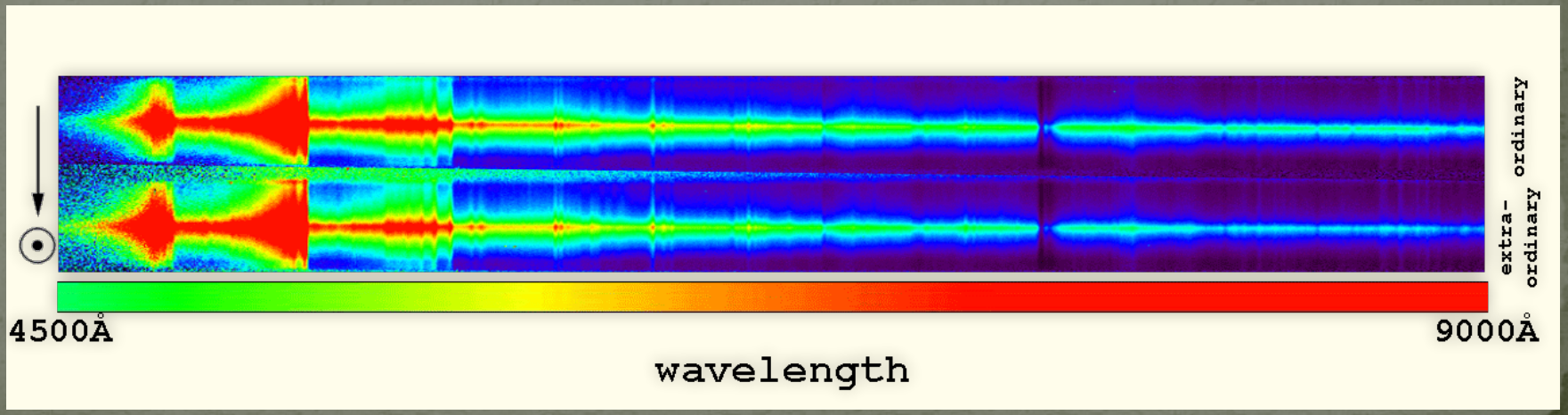
RC: IF 684nm



Dust reddening Color map

Observations

- Spectro polarimetry
  - Long slit & Grism 300 lines/mm
    - Wavelength coverage – 450 – 900 nm
      - Beam swapping technique
      - P.A. 48 deg – 2 x 300 sec
      - P.A. 138 deg – 2 x 300 sec



Observations

- Spectro polarimetry
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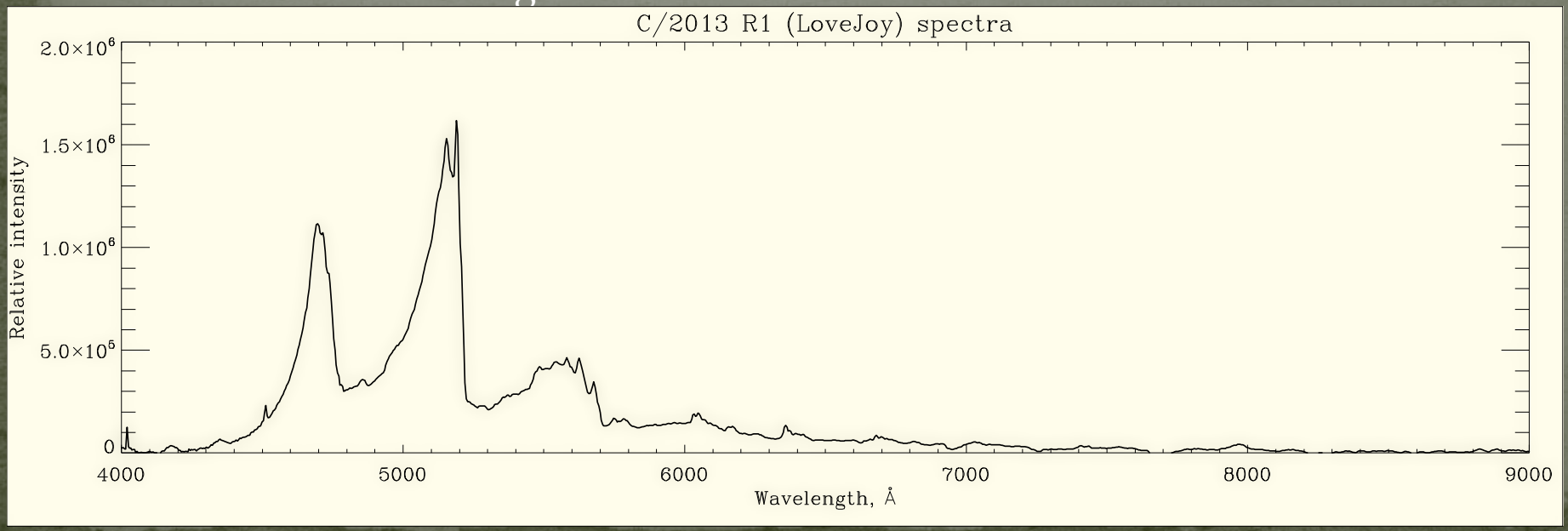
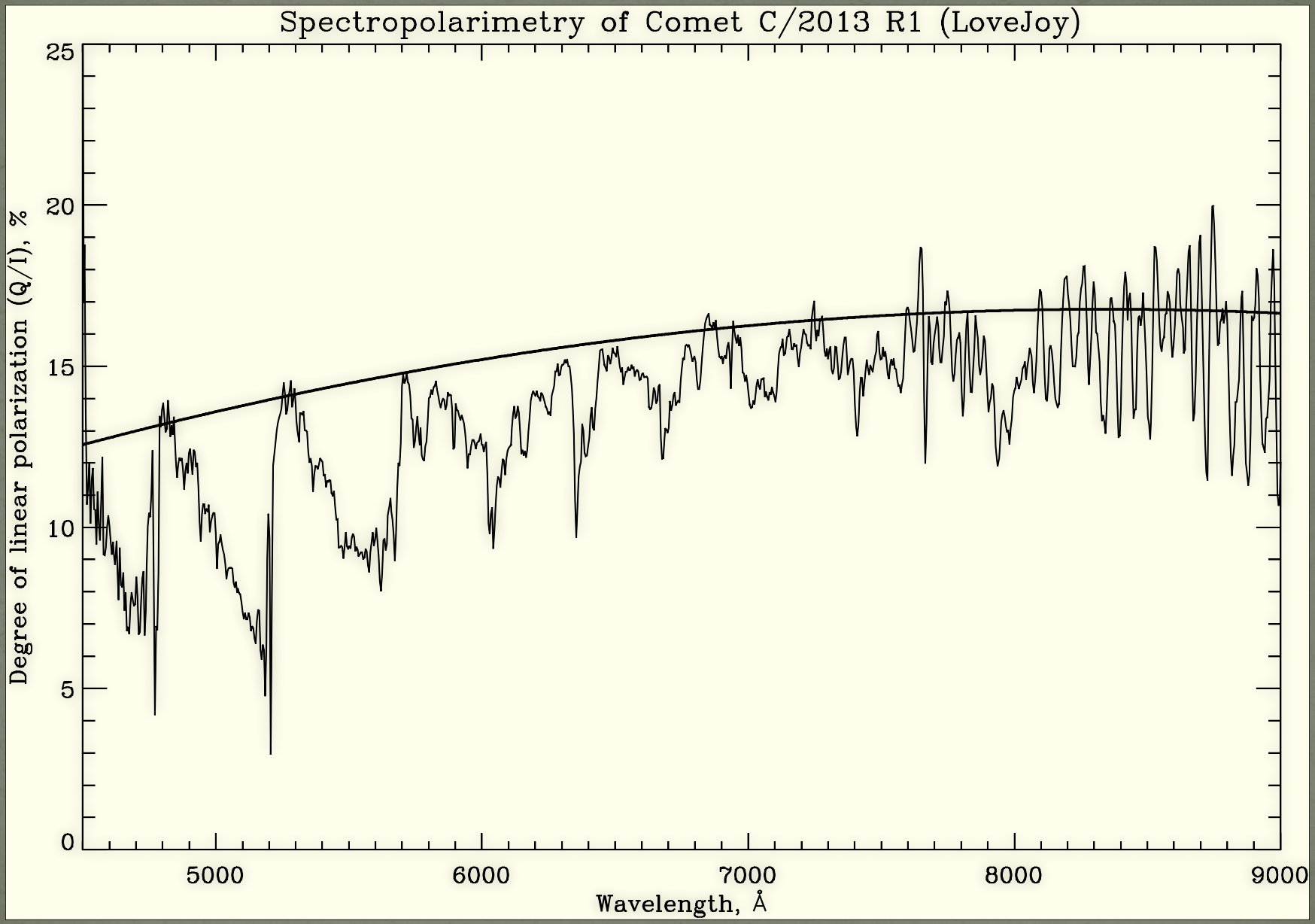
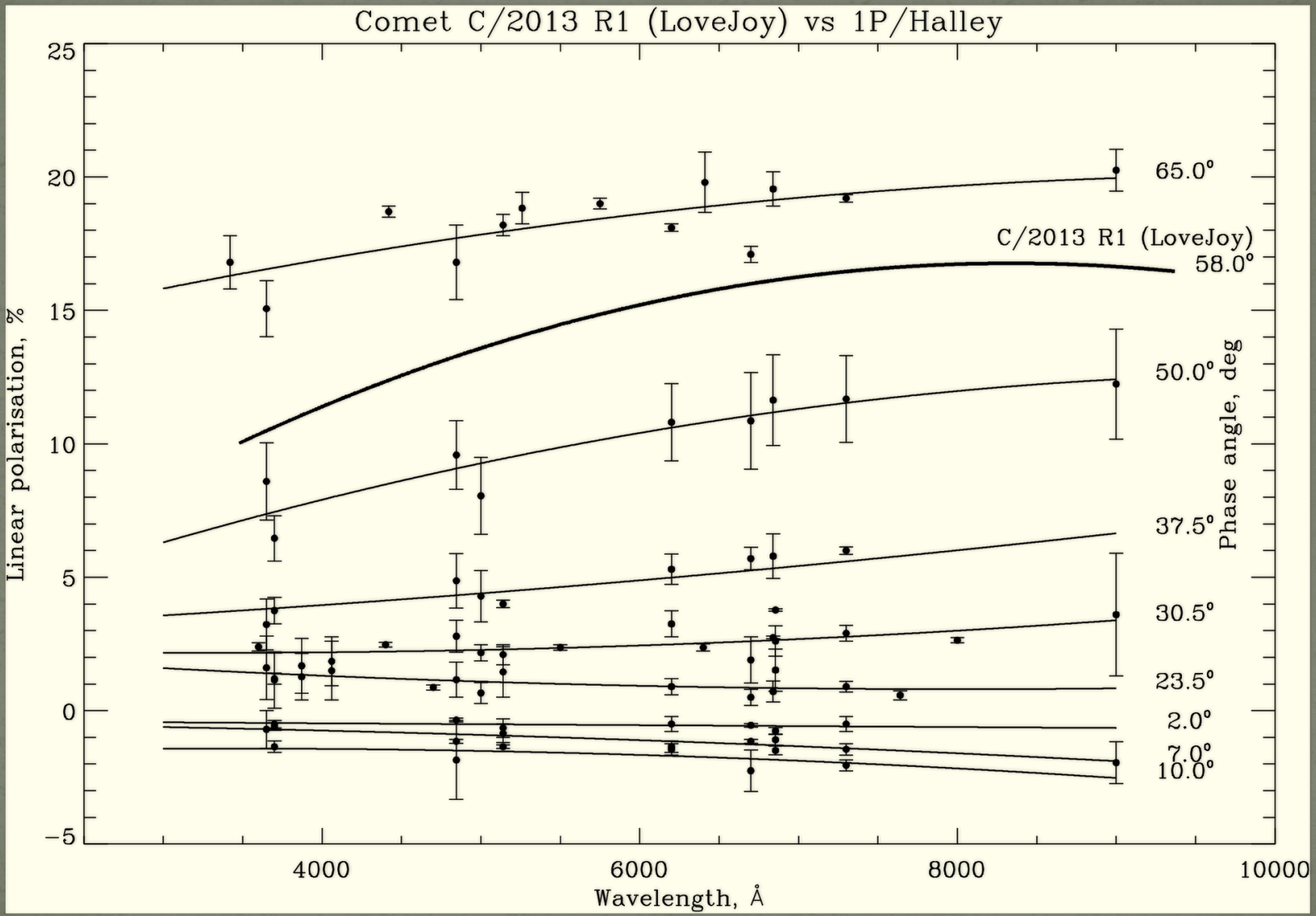



Spectropolarimetry of Comet C/2013 R1 (LoveJoy)
Degree of linear polarization (Q/I), %
0
5
10
15
20
25
5000
6000
7000
8000
9000
Wavelength, Å


Comet C/2013 R1 (LoveJoy) vs 1P/Halley
Linear polarisation, %
Wavelength, Å
Phase angle, deg
C/2013 R1 (LoveJoy)
65.0°
58.0°
50.0°
37.5°
30.5°
23.5°
2.0°
7.0°
10.0°
25
20
15
10
5
0
−5
4000
6000
8000
10000

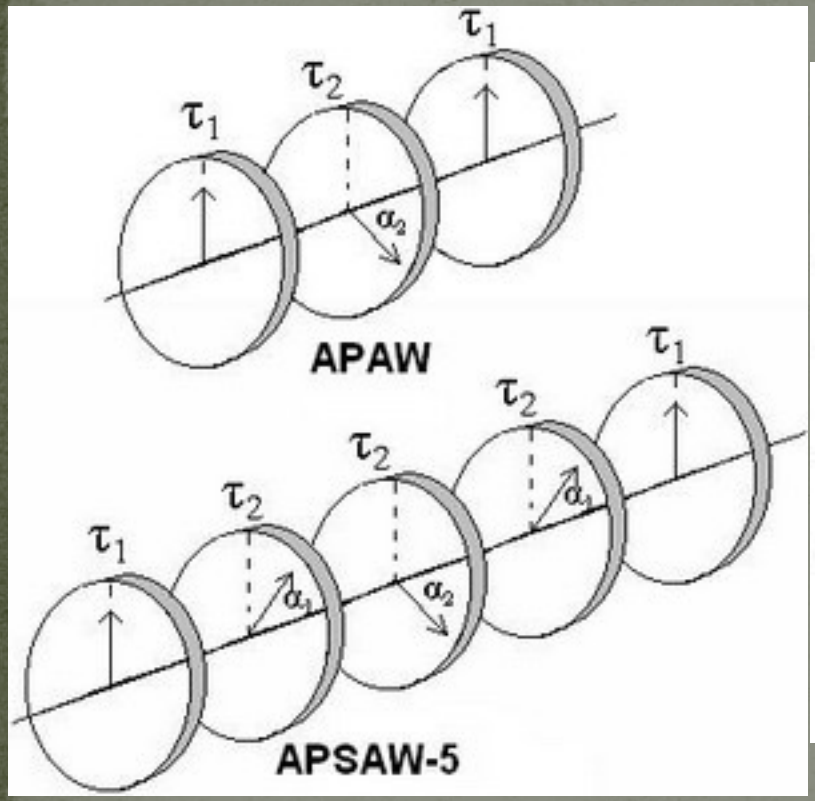
λ/2 retarder half-wave plate

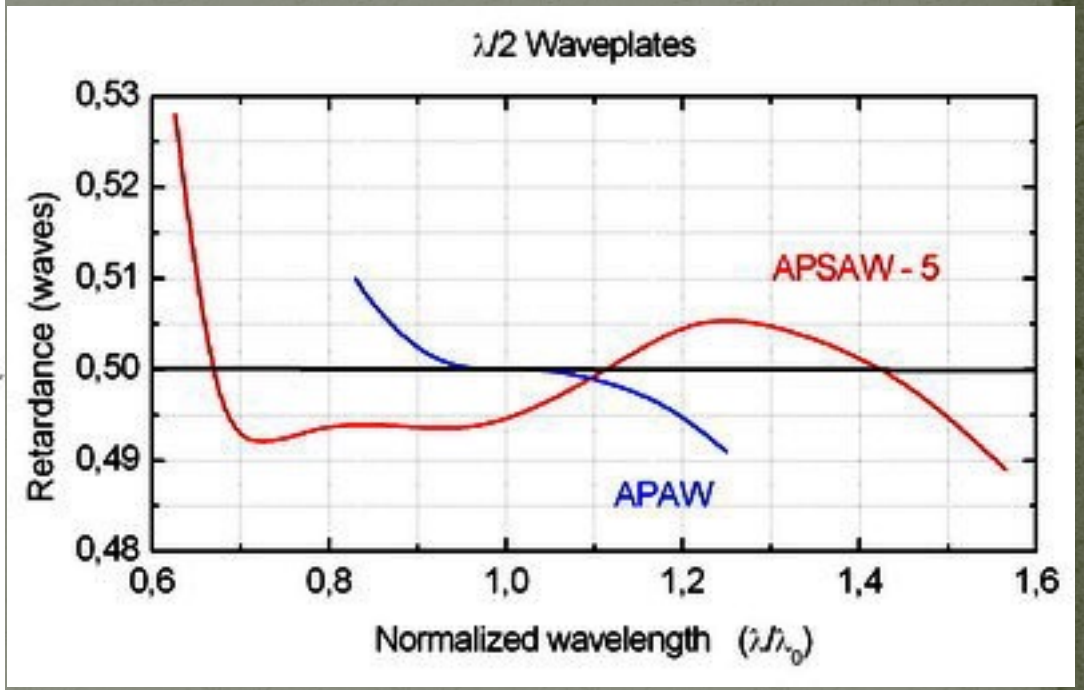
ASTROPRIBOR

SIC ITUR AD ASTRA

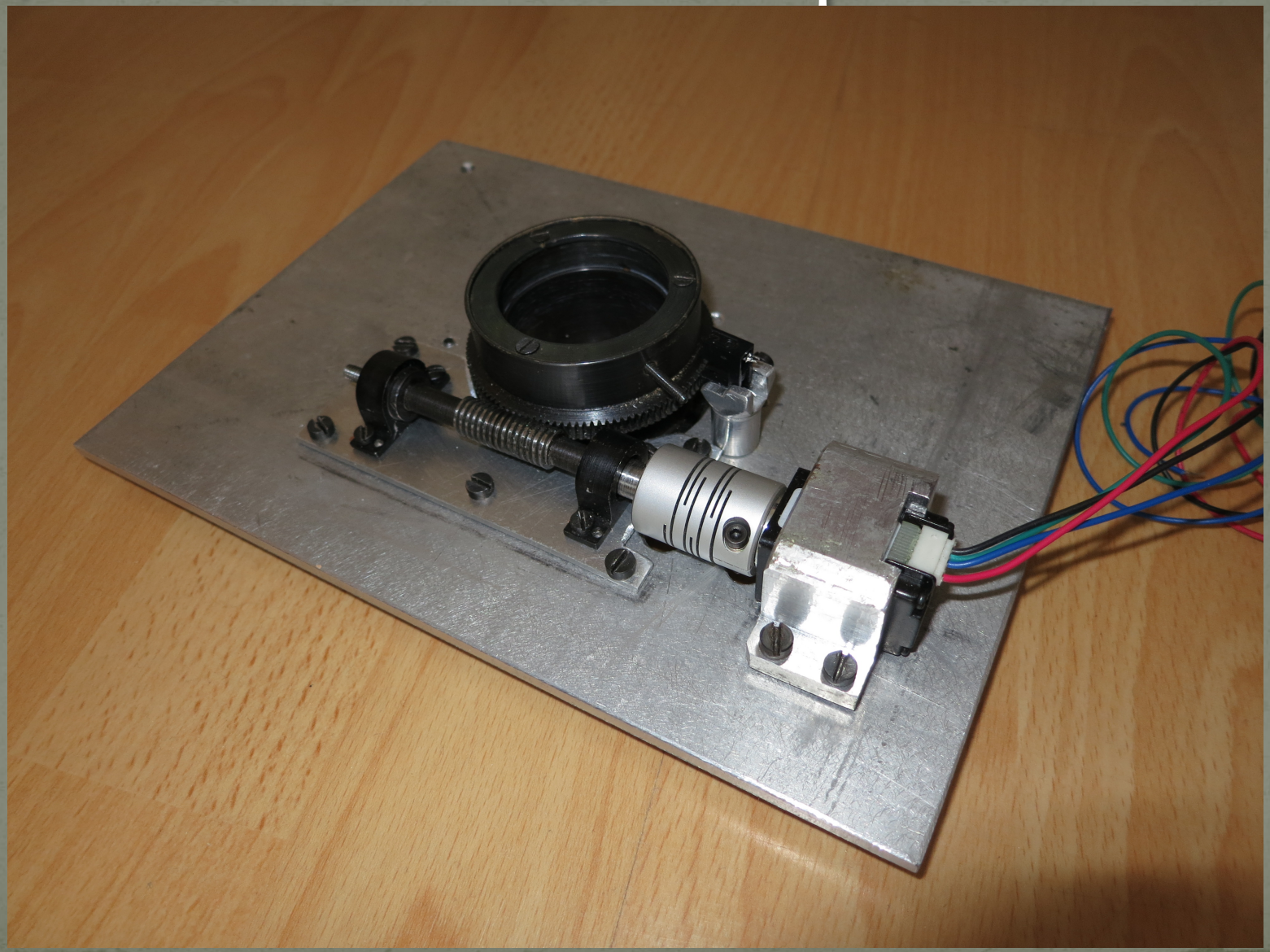
Kind of Waveplate (Retarder) Characteristics	Achromatic True Zero-Order Waveplates (APAW)	Super-Achromatic True Zero-Order Waveplate–5 (APSAW-5)	Super-Achromatic True Zero-Order Waveplates – 7 (APSAW-7)
Angular Acceptance	±7°	±10°	±10°
Thickness	4÷8	5÷12	7÷14
Wavelength Range, nm	380÷570 400÷600 450÷675 500÷750 600÷900 700÷1050 800÷1200	380÷790 400÷830 450÷930 500÷1040 550÷1140 600÷1240	380÷890 400÷940 450÷1050 500÷1170 550÷1280

λ/2 retarder half-wave plate



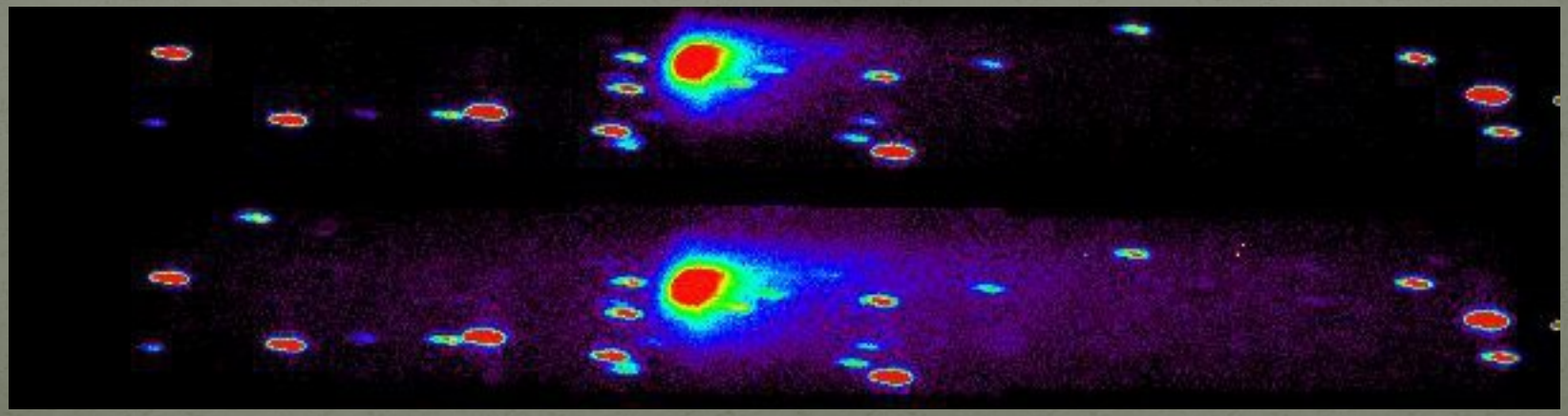


$\lambda/2$ retarder half-wave plate

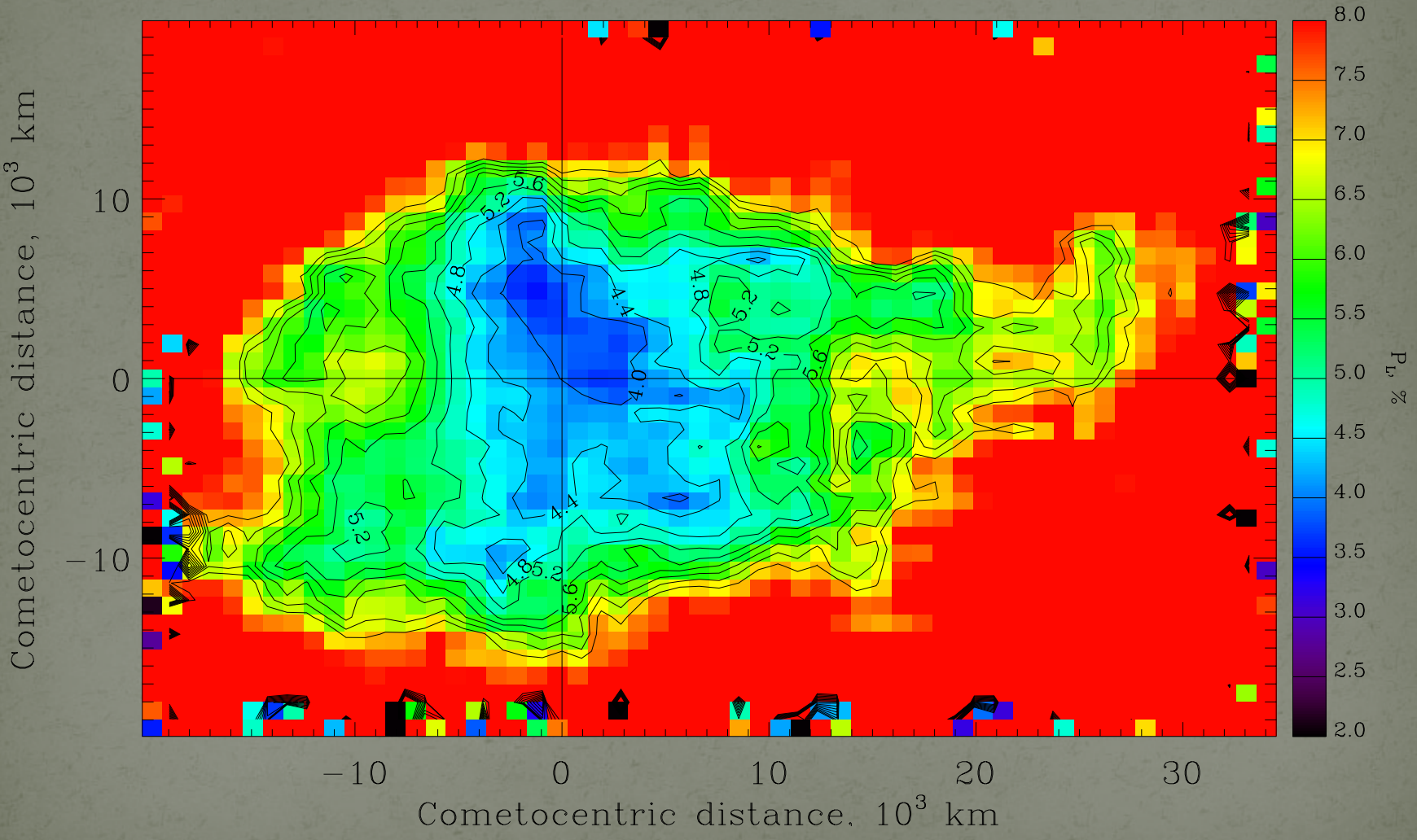


Comet 67P Чурюмова - Герасименко (C-G)

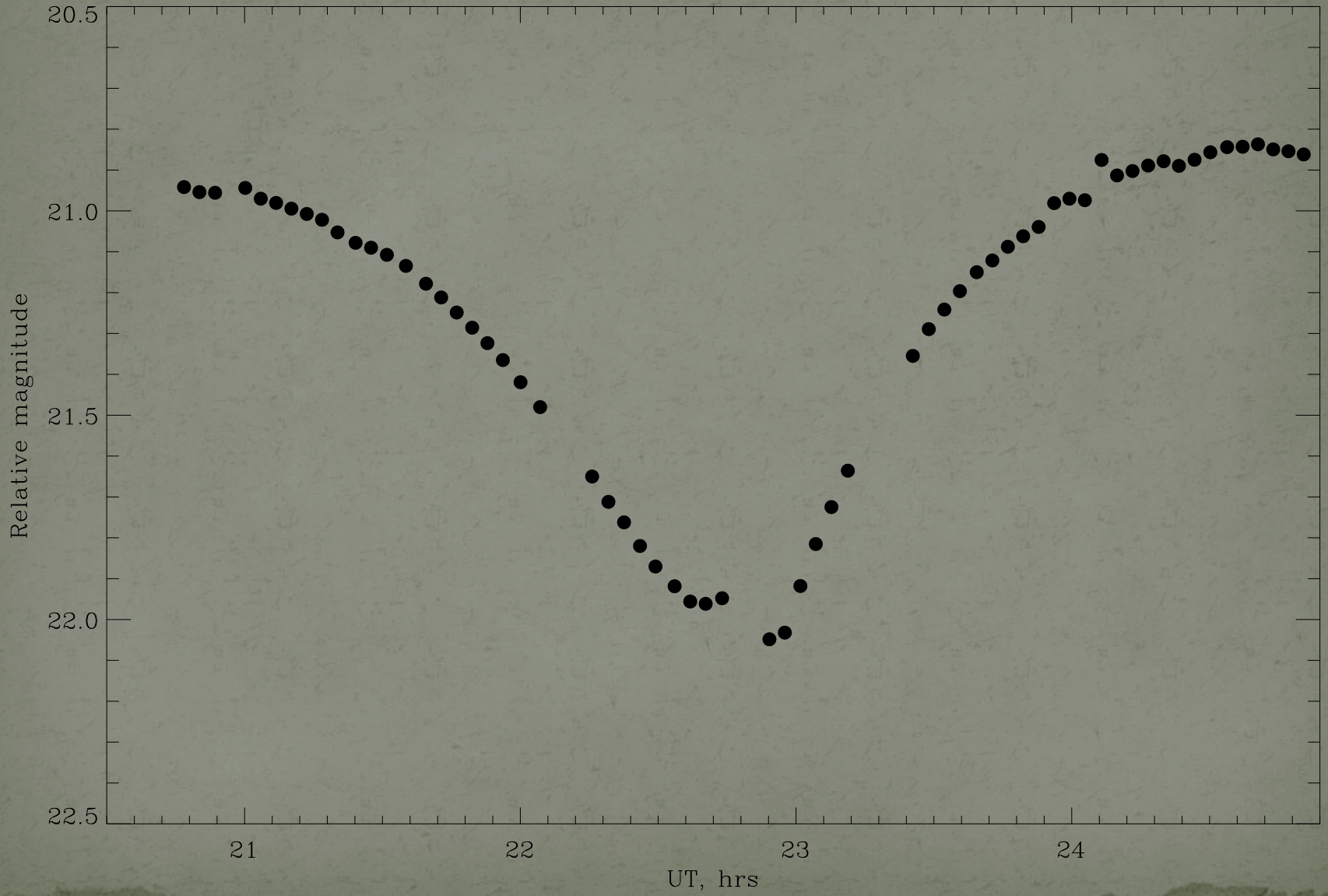
- Imaging polarimetry
  - Wollaston prism
  - Dichroic beam splitter
  - Red filter (Rx) at 694 nm (FWHM=74 nm)
  - 1/2 λ retarder hale-wave plate
    - Beam swapping technique - 8 retarder angles 0, 22.5, … 157.5



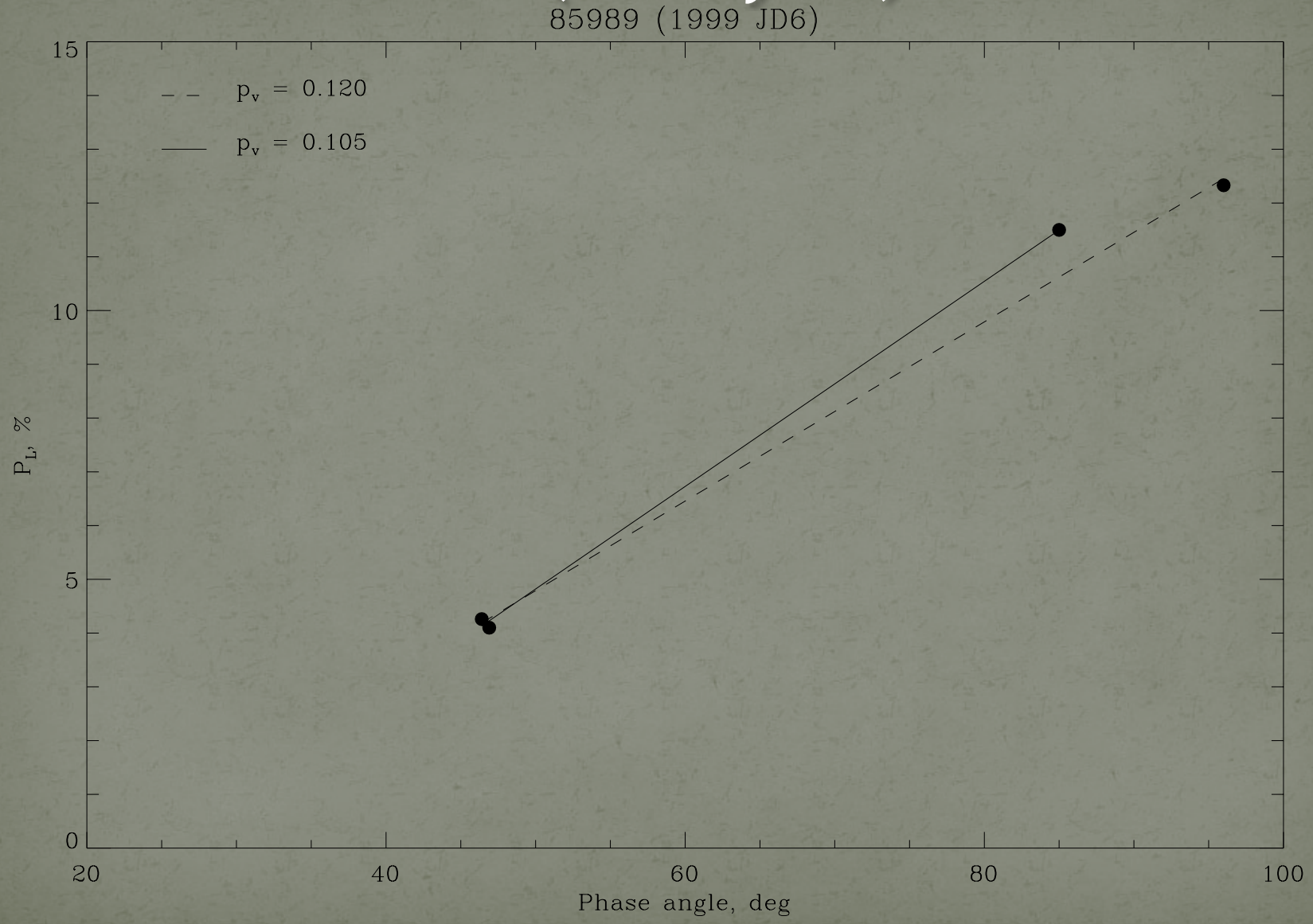
Polarisation map at Rx filter



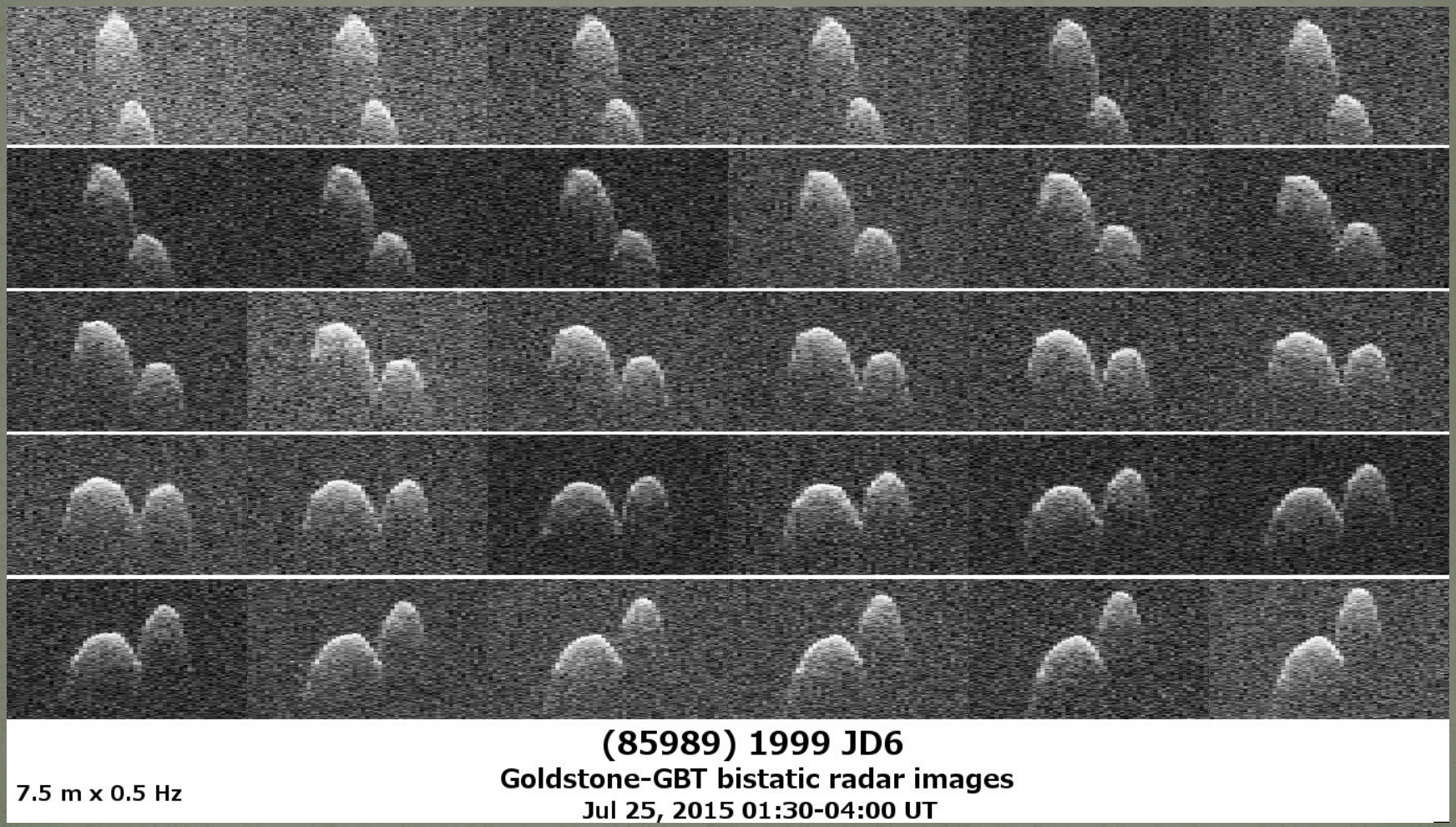
Asteroid 85989 (1999 JD6)



Asteroid 85989 (1999 JD6)



Asteroid 85989 (1999 JD6)



Thank You for Your Attention!

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