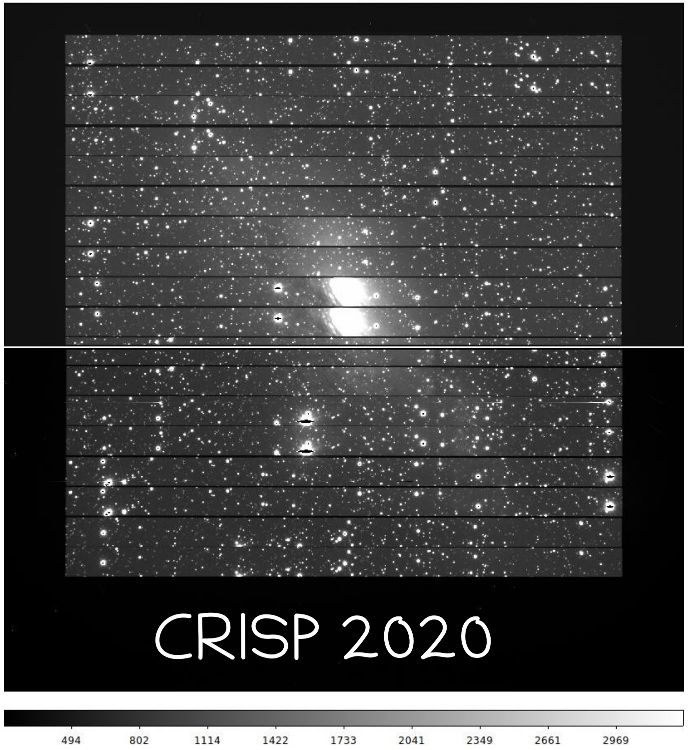
Polarization studies towards Circinus



Santiago González-Gaitán, Ana Mourão, Marko Stalevski, Daniel Asmus

centra

TÉCNICO LISBOA

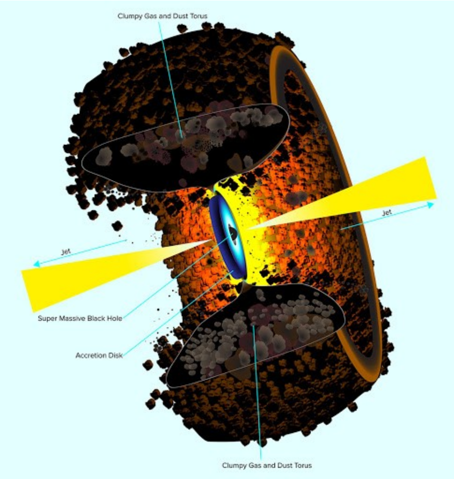
Outline

I. AGN and Circinus
II. Polarization basics
III. Reduction & analysis steps
IV. Preliminary results

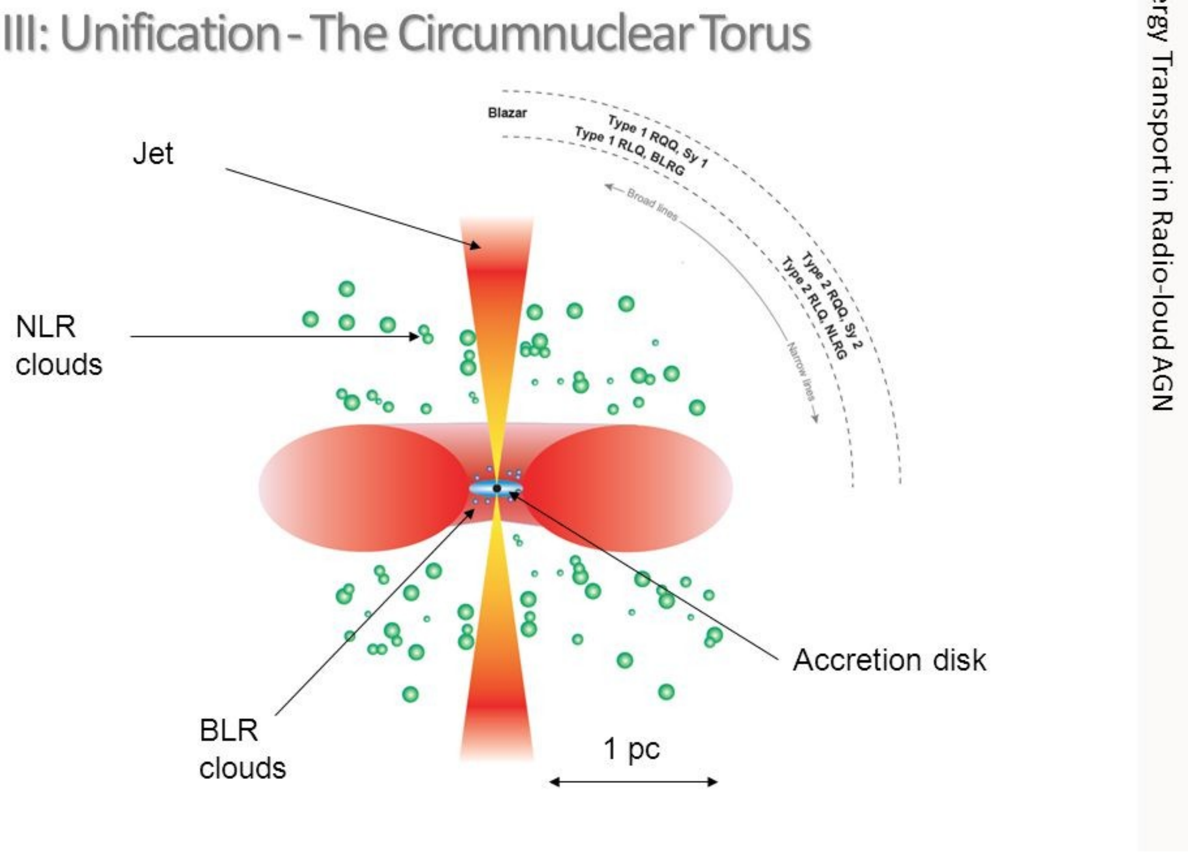
1. AGN and Circinus

Traditional model

- Supermassive black hole and acrretion disk
- Circumnuclear torus of clumpy gas and dust

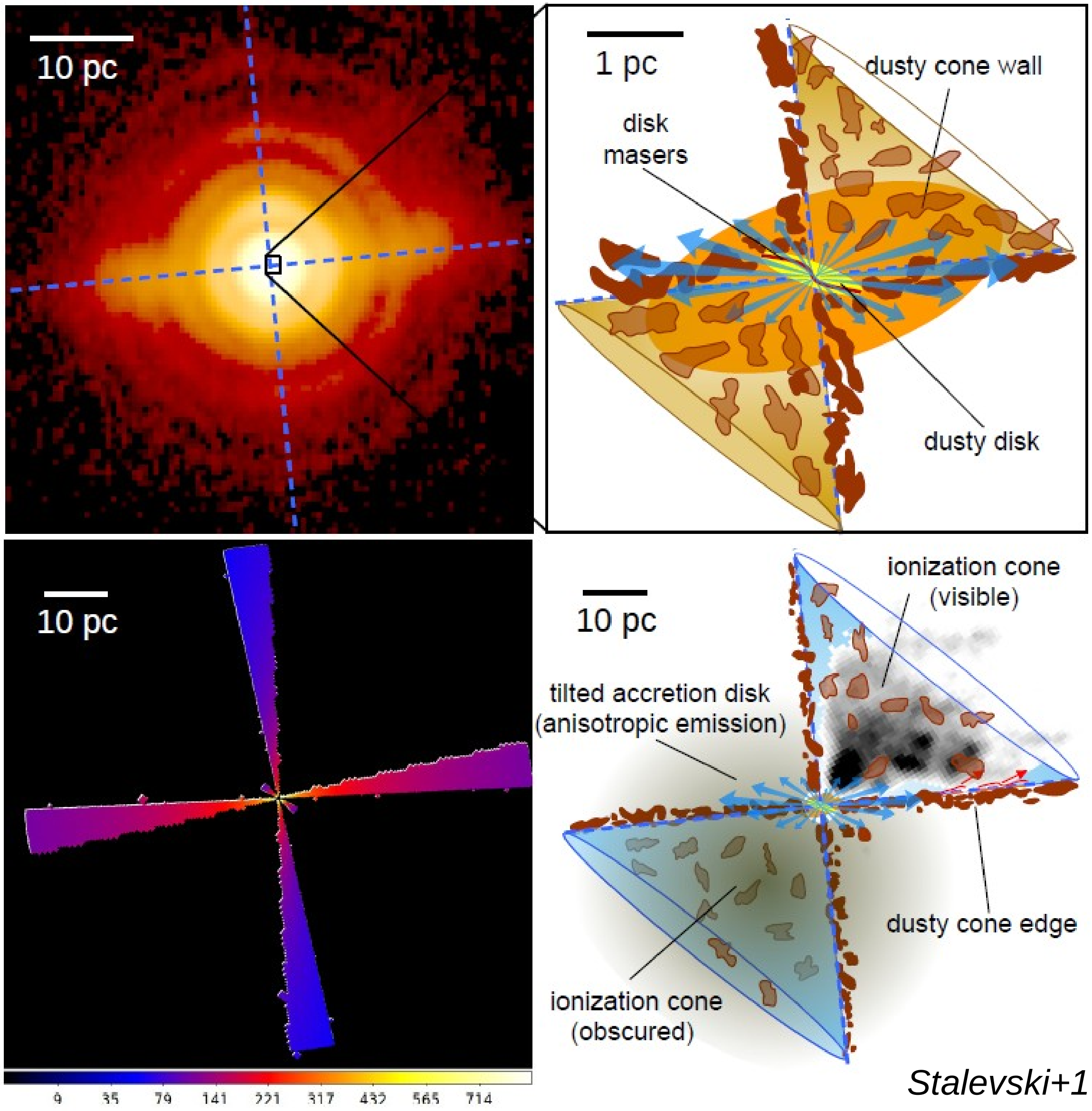


NRAO/AUI/NSF



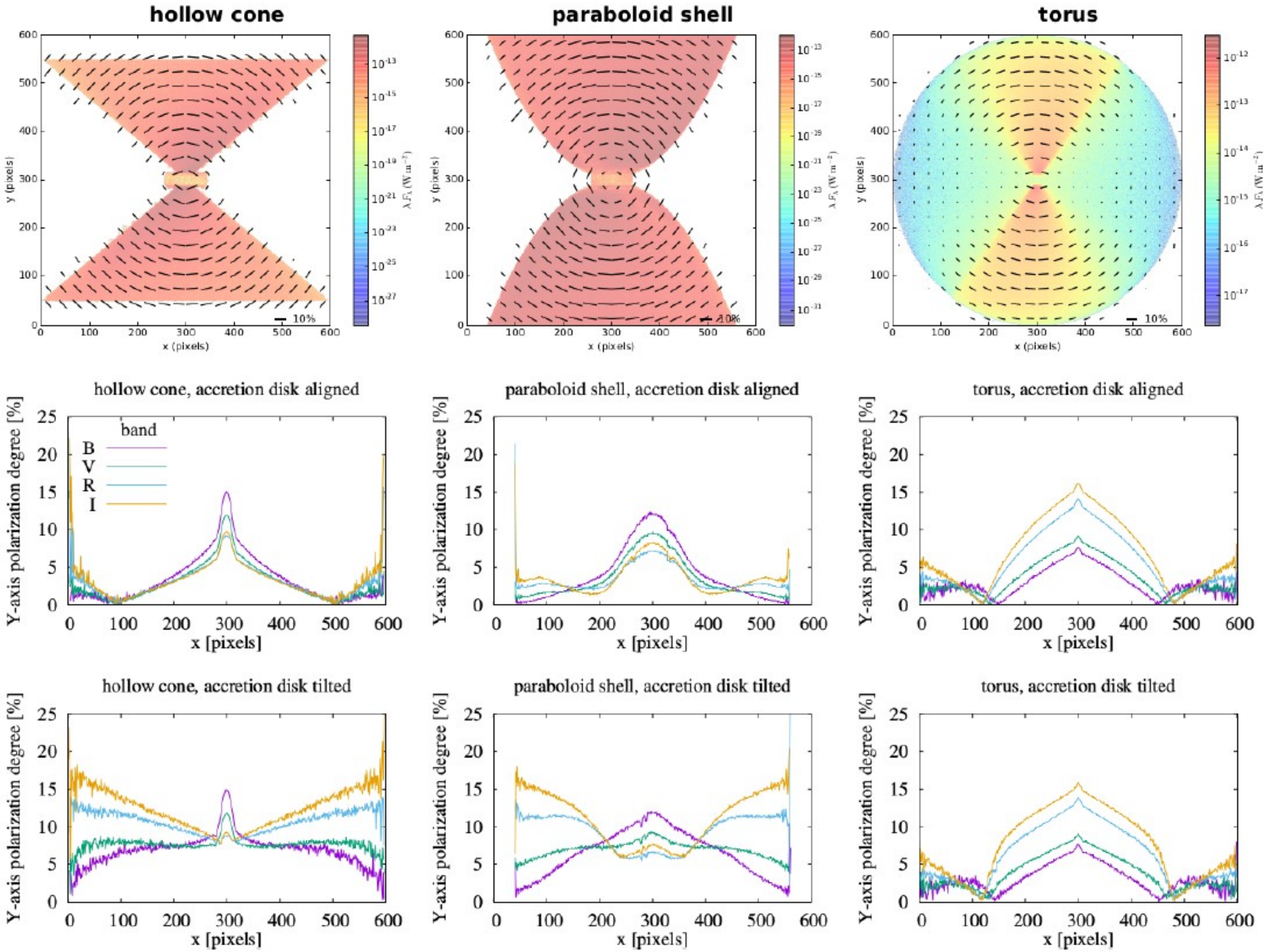
Daniel Evans+

Circinus model



Stalevski+17

Model polarization prediction



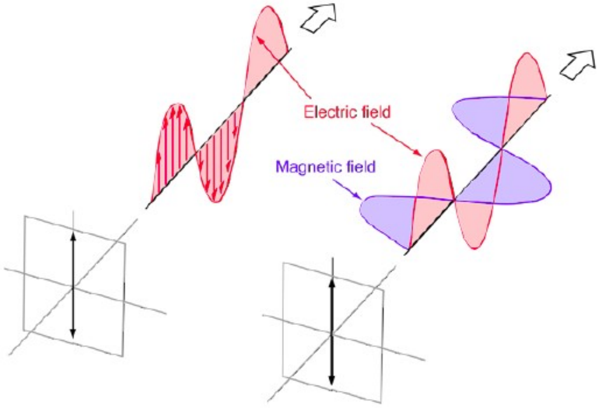
Stalevski+: obs proposal

II. Polarization basics

Polarization

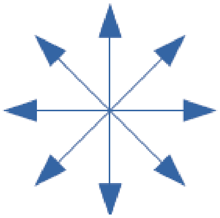
$$\vec{E}(\vec{r},t) = \vec{E}\cos\left(\vec{k}.\vec{r} - \omega t\right)$$

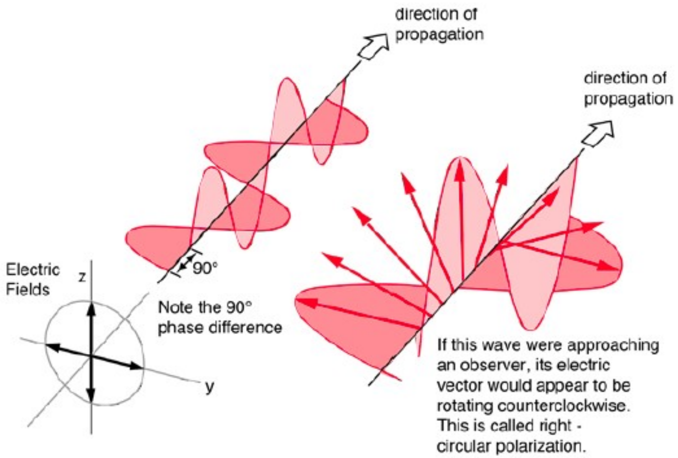
$$\vec{B}(\vec{r},t) = \vec{B}\cos\left(\vec{k}.\vec{r} - \omega t\right)$$



Linear polarization

No polarization



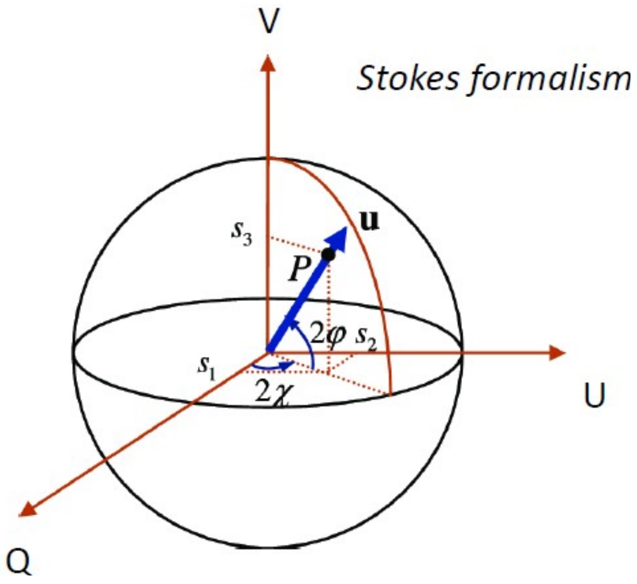


Circular polarization

http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/polclas.html

Polarization: analyzer methods

1) Dichroic polaroid
2) Savart plate
3) Wollaston prism
4) Double wollaston prims



Polarization is a vector value!

$$P(\lambda) = \sqrt{Q(\lambda)^2 + U(\lambda)^2} \qquad \varphi(\lambda) = \frac{1}{2}\mathrm{arctg}[U(\lambda)/Q(\lambda)]$$

From: E.S. Shablovinskaya

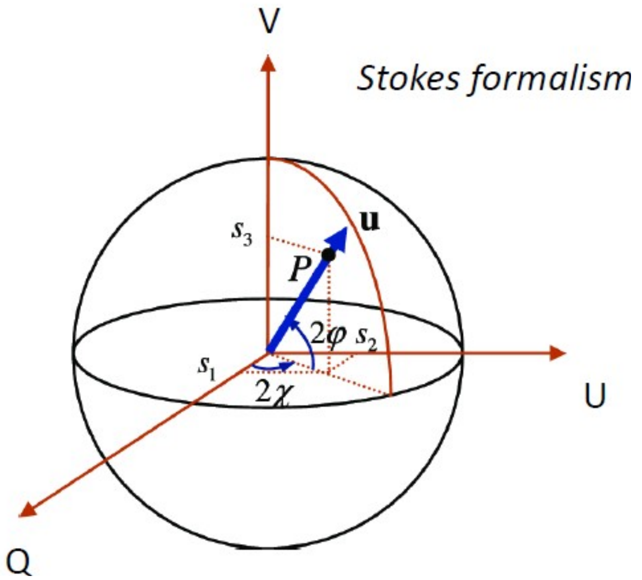
Polarization: analyzer methods

1) Dichroic polaroid

2) Savart plate

3) Wollaston prism

4) Double wollaston prims



Polarization is a vector value!

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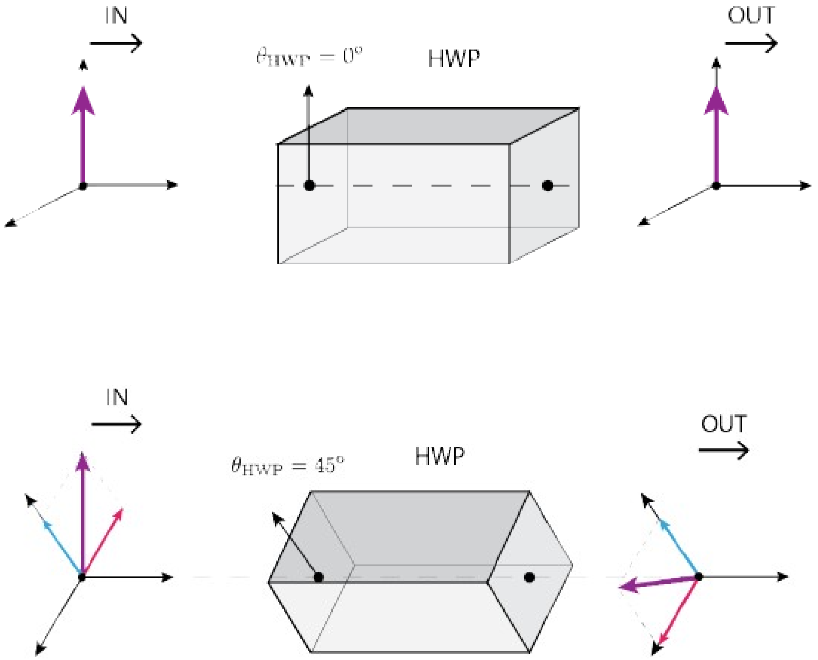
From: E.S. Shablovinskaya

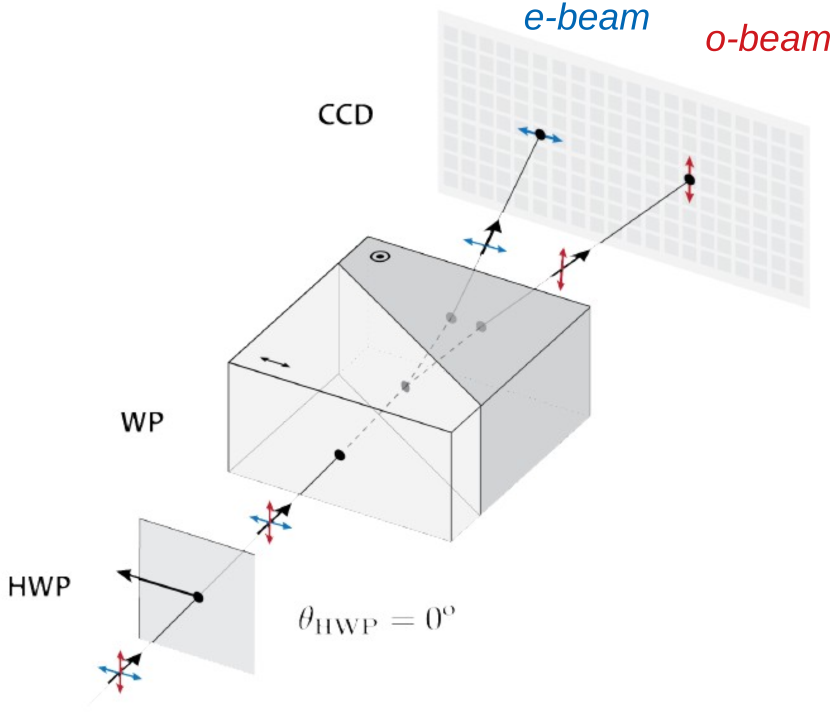
Polarization element: Half-wave plate



A half-wave plate rotation of θ leads to a polarization vector change of 2θ

Plots by J. Lopes

Polarization analyzer: Wollaston prism



$$F_i \equiv \frac{f_{O,i} - f_{E,i}}{f_{O,i} + f_{E,i}}$$

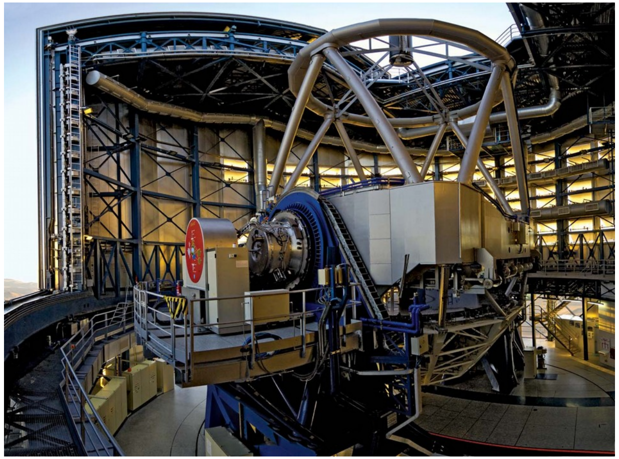
$$Q = \frac{2}{N}\sum_{i=0}^{N-1} F_i \cos\left(\frac{\pi}{2}i\right) \quad \text{and} \quad U = \frac{2}{N}\sum_{i=0}^{N-1} F_i \sin\left(\frac{\pi}{2}i\right)$$

$$P = \frac{\sqrt{Q^2 + U^2}}{I} \qquad \chi = \frac{1}{2}\arctan\frac{U}{Q}$$

- Good for extended sources (need mask)
- Needs half-wave plate
- No simultaneous Q/U

FORS2-VLT: IPOL mode

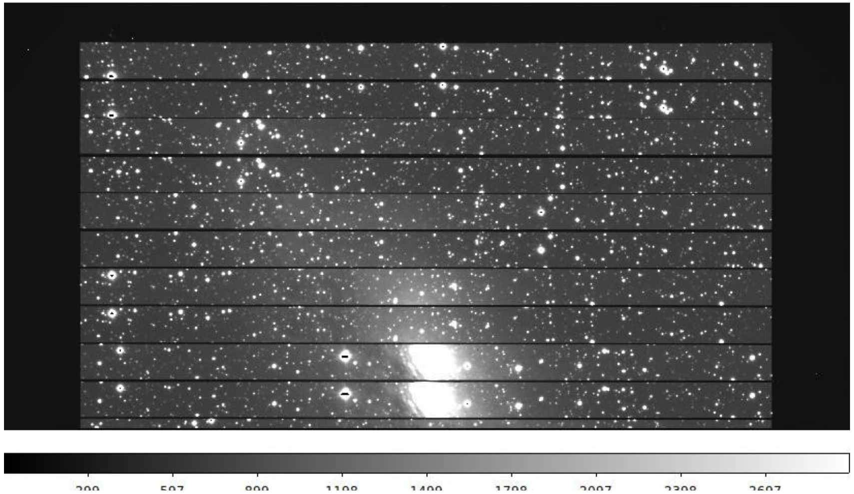
- ESO-VLT: 8.2m
- FORS2: FOcal Reducer and low dispersion Spectrograph
- IPOL: imaging polarimetry
- FoV: 6.8'x6.8'
- 0.25"/pixel

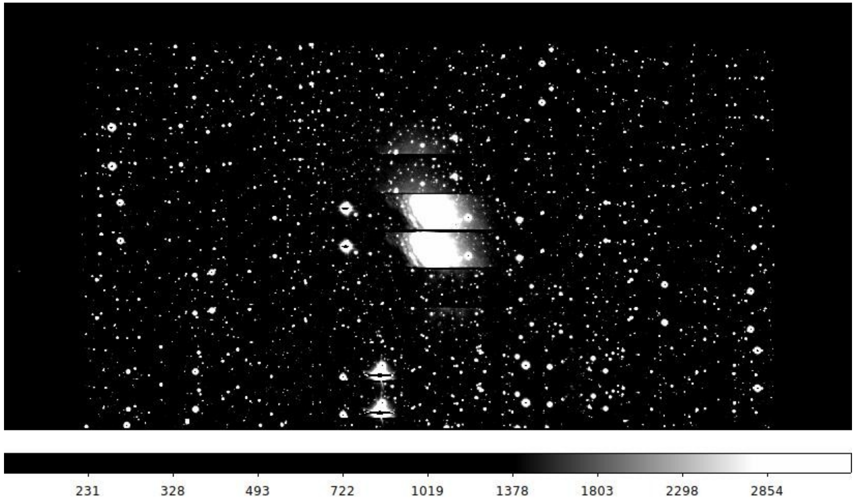


Observation strategy

Program 0103.B-0517 (PI: Stalevski, Asmus)

- At least 4 half-wave plate angles: 0, 22.5, 45, 67.5 deg
- Use of a mask for extended sources
- Four filters: BVRI
- Multiple offsets: B(1x40), V(16x2), R(27x2), I(26x4)

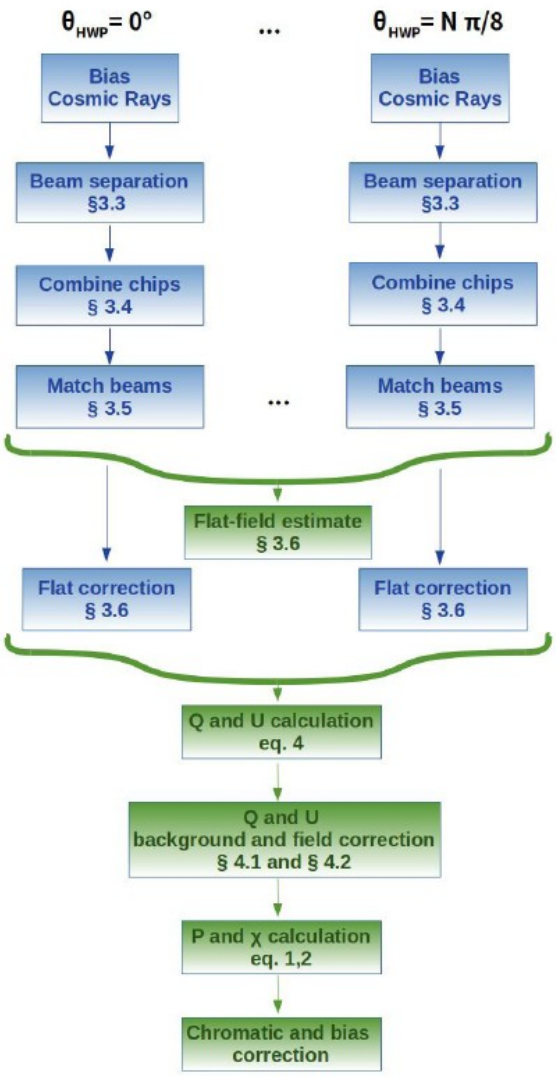




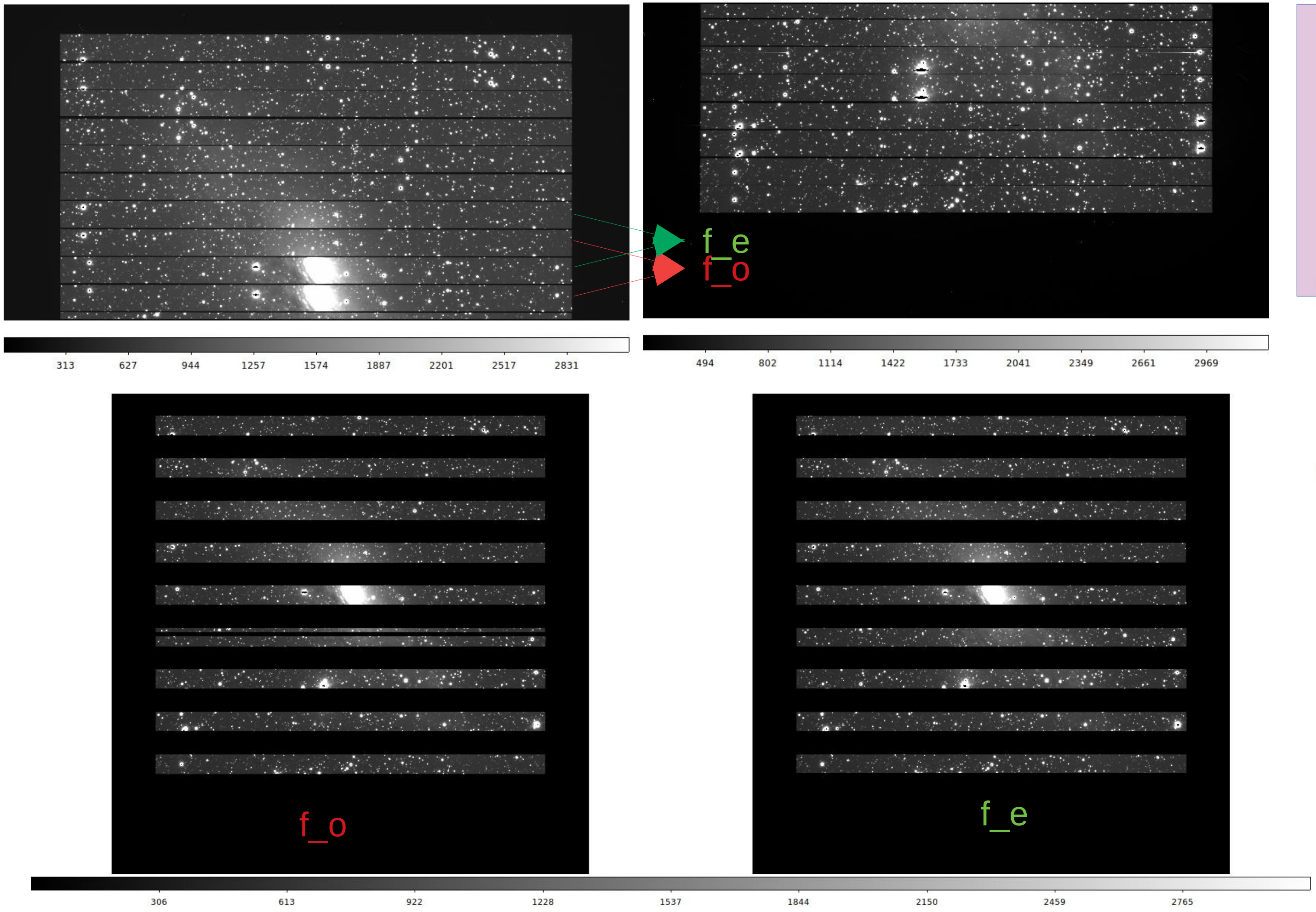
III. Reduction & analysis

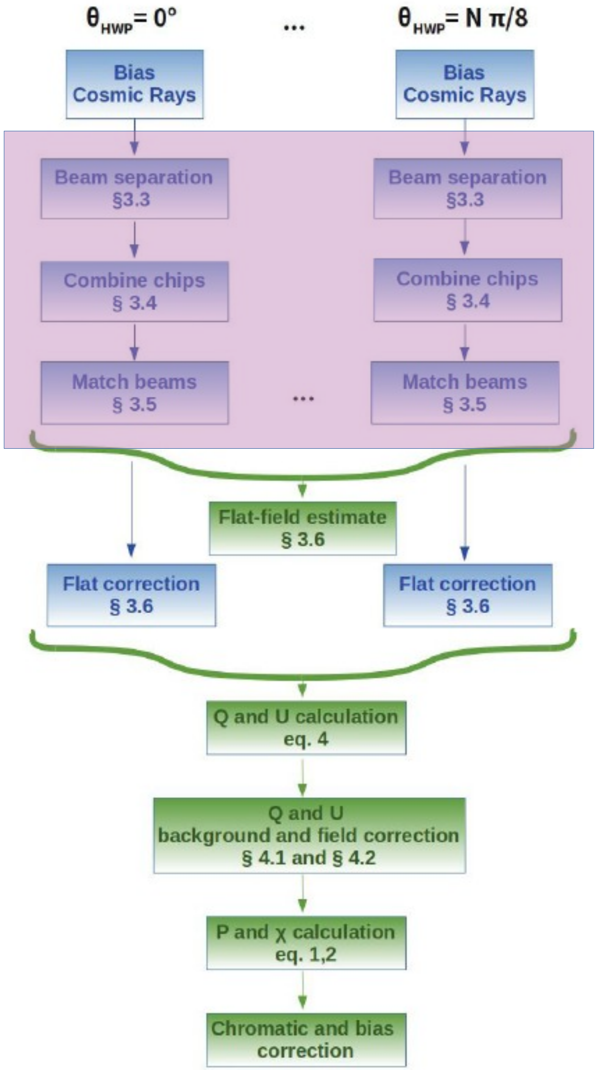
Reduction pipeline

(see González-Gaitán et al. 2020)

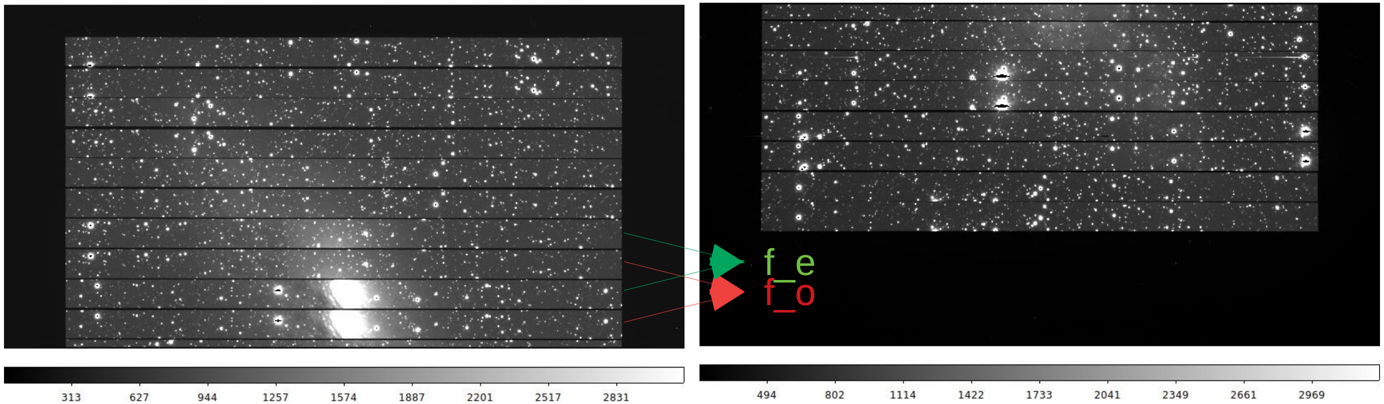


Reduction pipeline

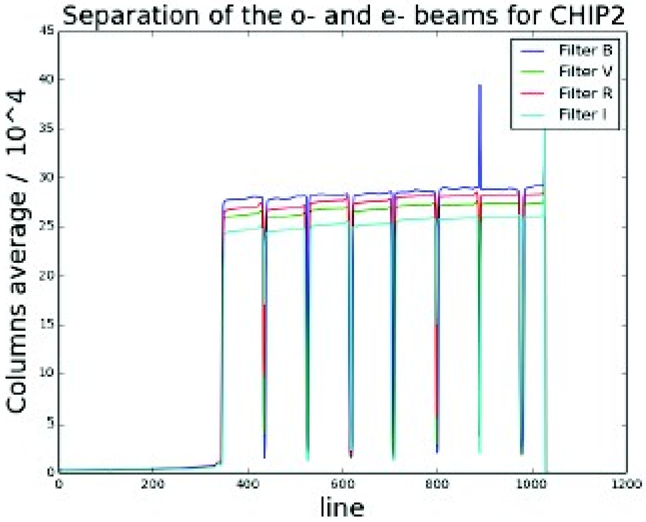




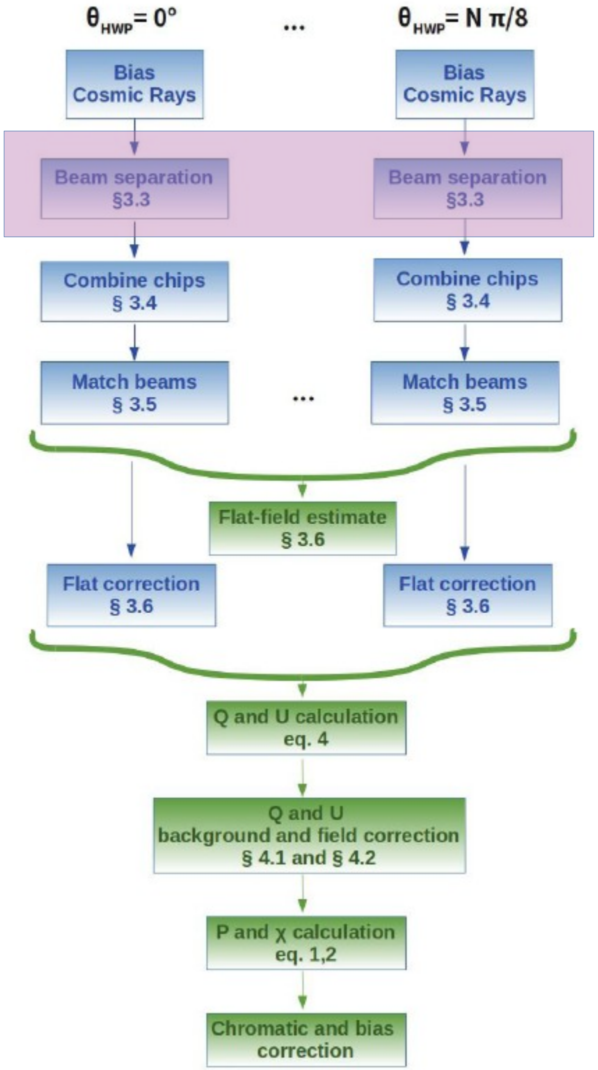
Reduction pipeline



Beam separation

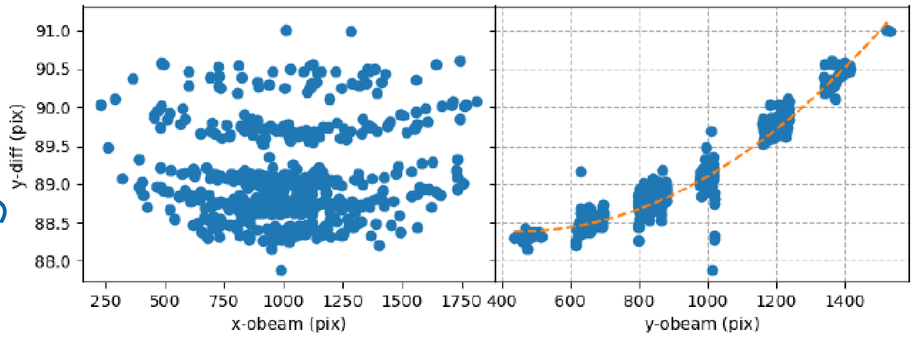


Strip size and position change from the optical axis and according to wavelength

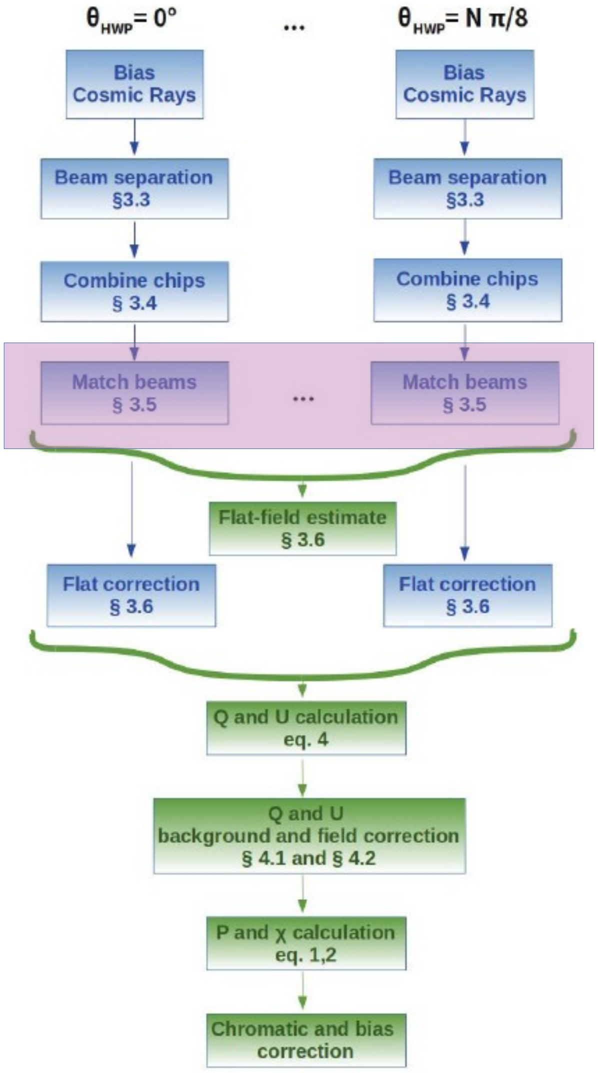


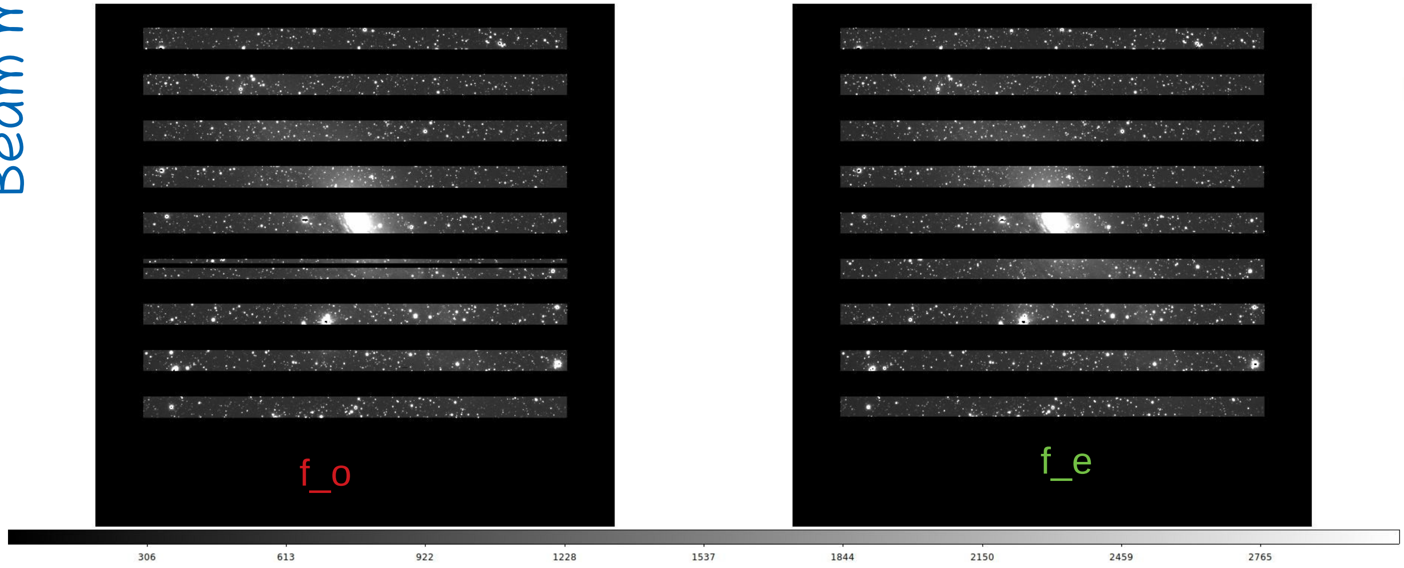
Reduction pipeline

Beam matching



o/e-beam positions change with position in the CCD and with wavelength





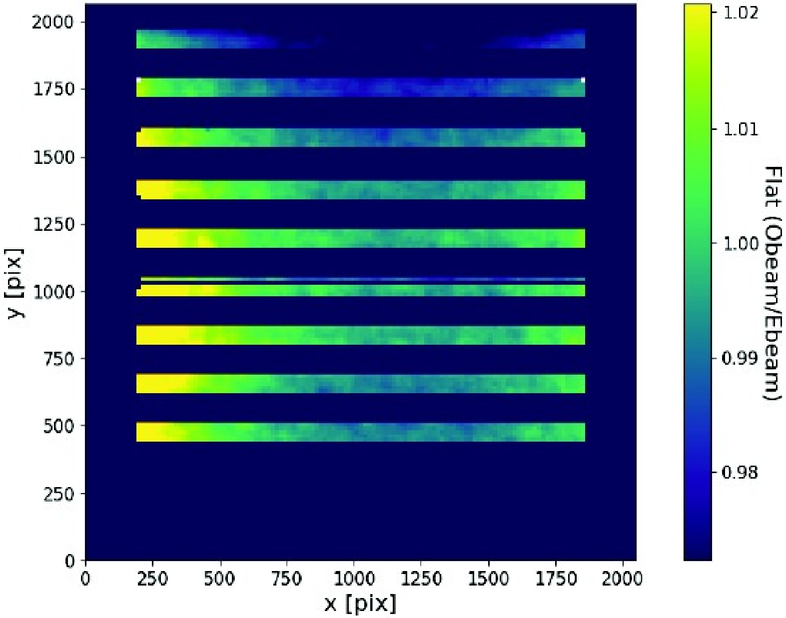
Reduction pipeline

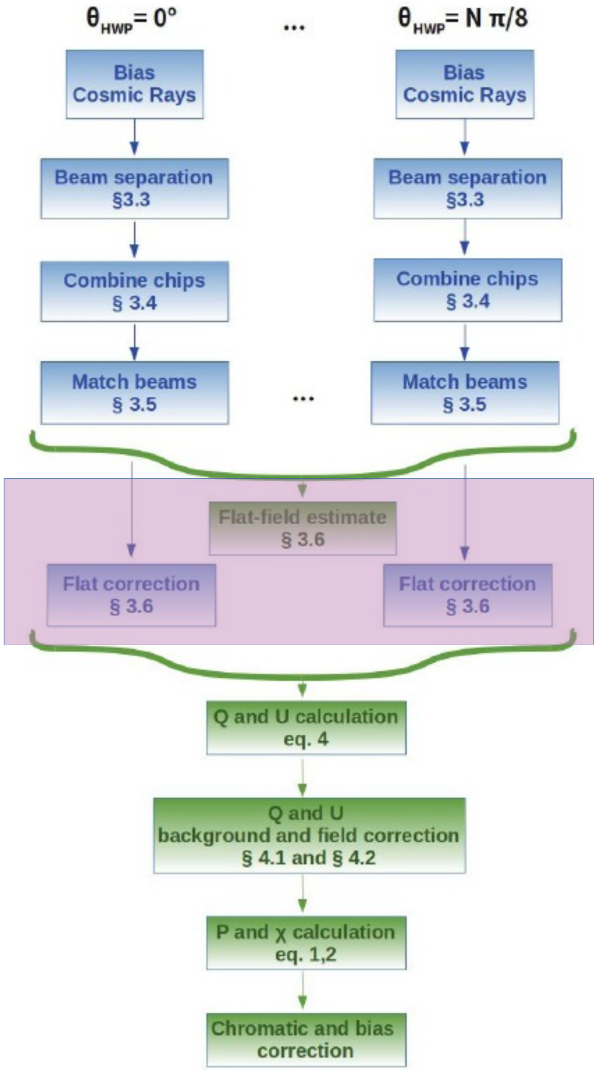
- Difficult: polarization of lamps/twilight
- In principle small effect with more N_{HWP}: $f_O^{\,i} = -f_E^{\,i+2}$
- Sum of all angles and see differences in o/e-beam (constant intensity)

$$F_i \equiv \frac{f_{O,i} - f_{E,i}}{f_{O,i} + f_{E,i}}$$

Flat fielding

$$\sum_{i=0}^{N-1} f_{O,i} = \frac{N}{2} I$$

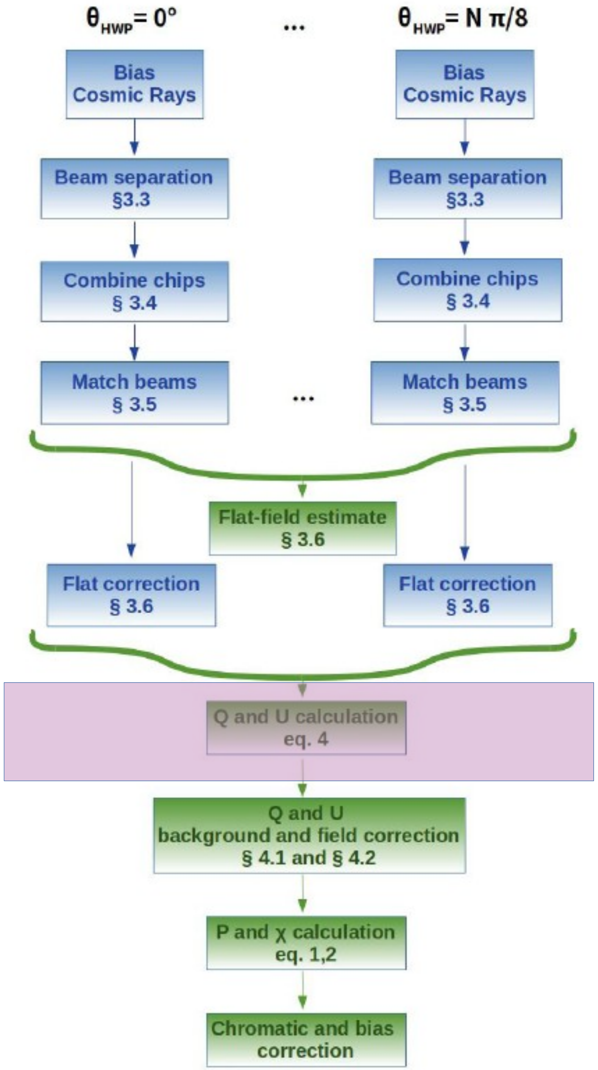




Reduction pipeline

$$F_i \equiv \frac{f_{O,i} - f_{E,i}}{f_{O,i} + f_{E,i}}$$

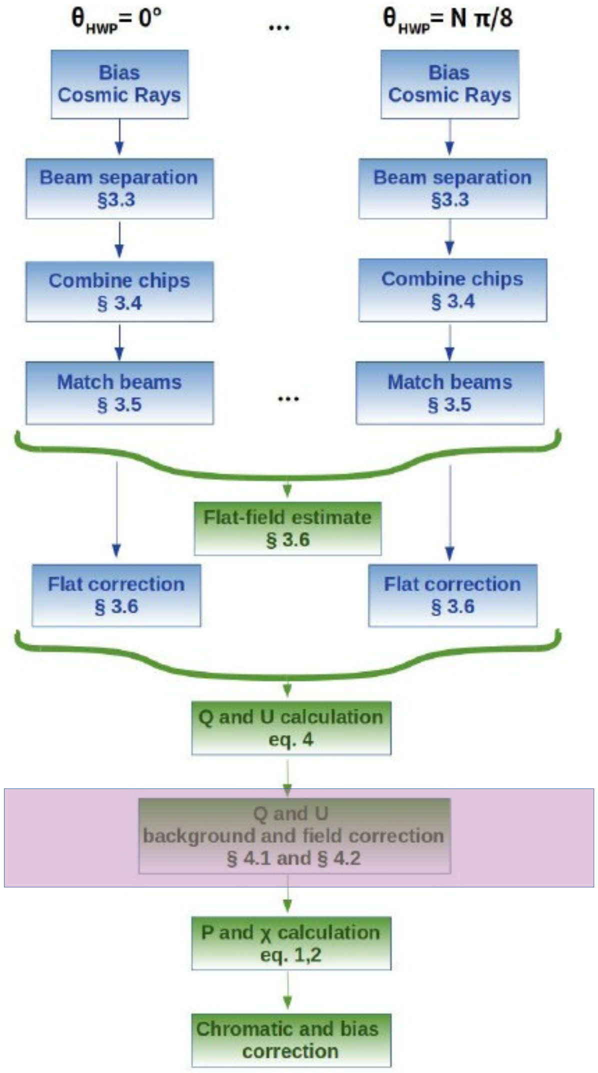
$$Q = \frac{2}{N} \sum_{i=0}^{N-1} F_i \cos\left(\frac{\pi}{2} i\right) \quad \text{and} \quad U = \frac{2}{N} \sum_{i=0}^{N-1} F_i \sin\left(\frac{\pi}{2} i\right)$$



Polarization corrections

- Instrumental field correction
- Background sky correction
- Interstellar polarization (MW)
- Interstellar polarization (Host)

$$Q_{corr} = Q - Q_f - Q_B - Q_{ISP}$$
$$U_{corr} = U - U_f - U_B - U_{ISP}$$



Polarization corrections

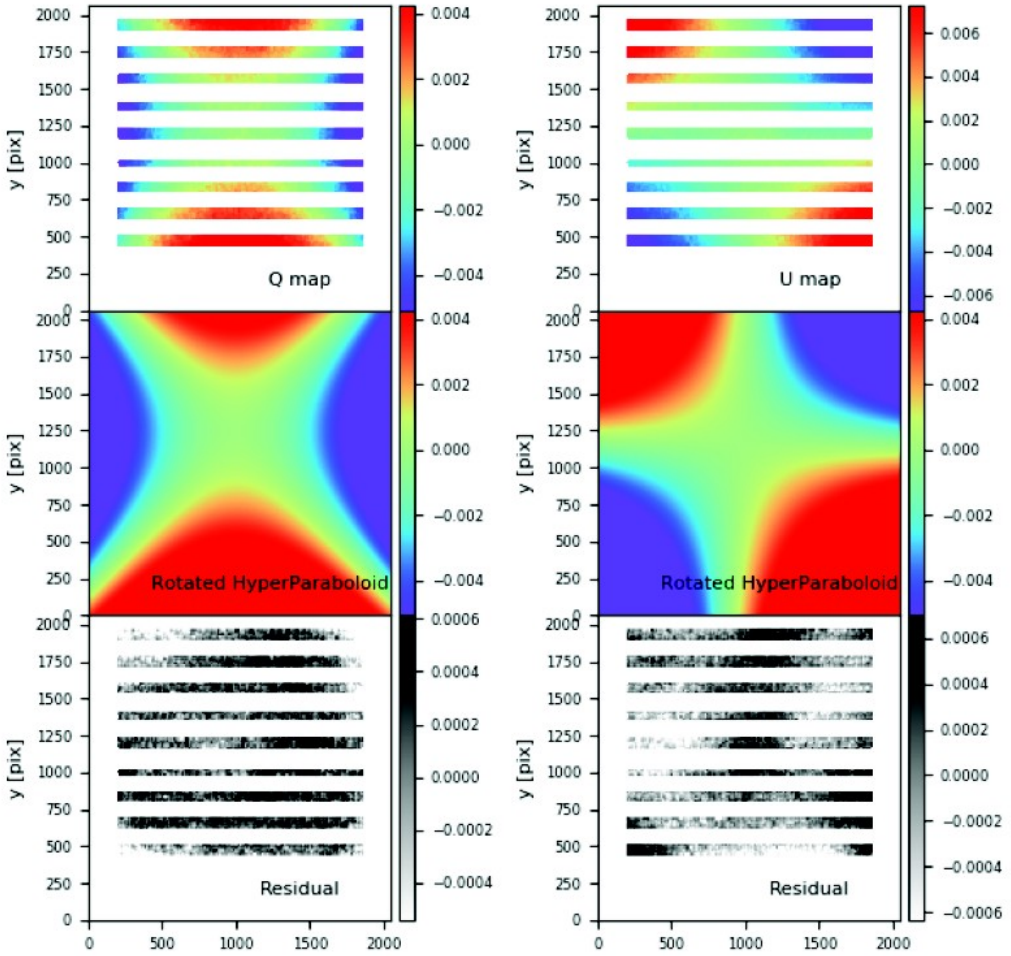
Instrumental field correction

Polarization corrections

Instrumental field correction

Calibration Program

- Use of blank fields with high background moon polarization with 8 HWP angles and 4 filters
- Use of bin boxes (30pix) to increase S/N

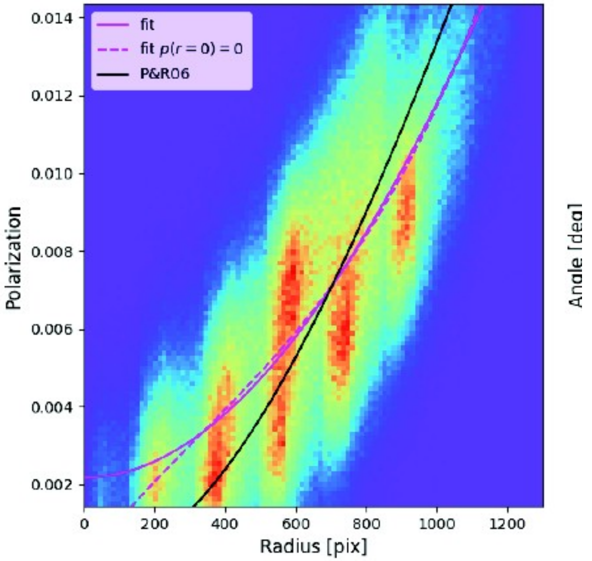


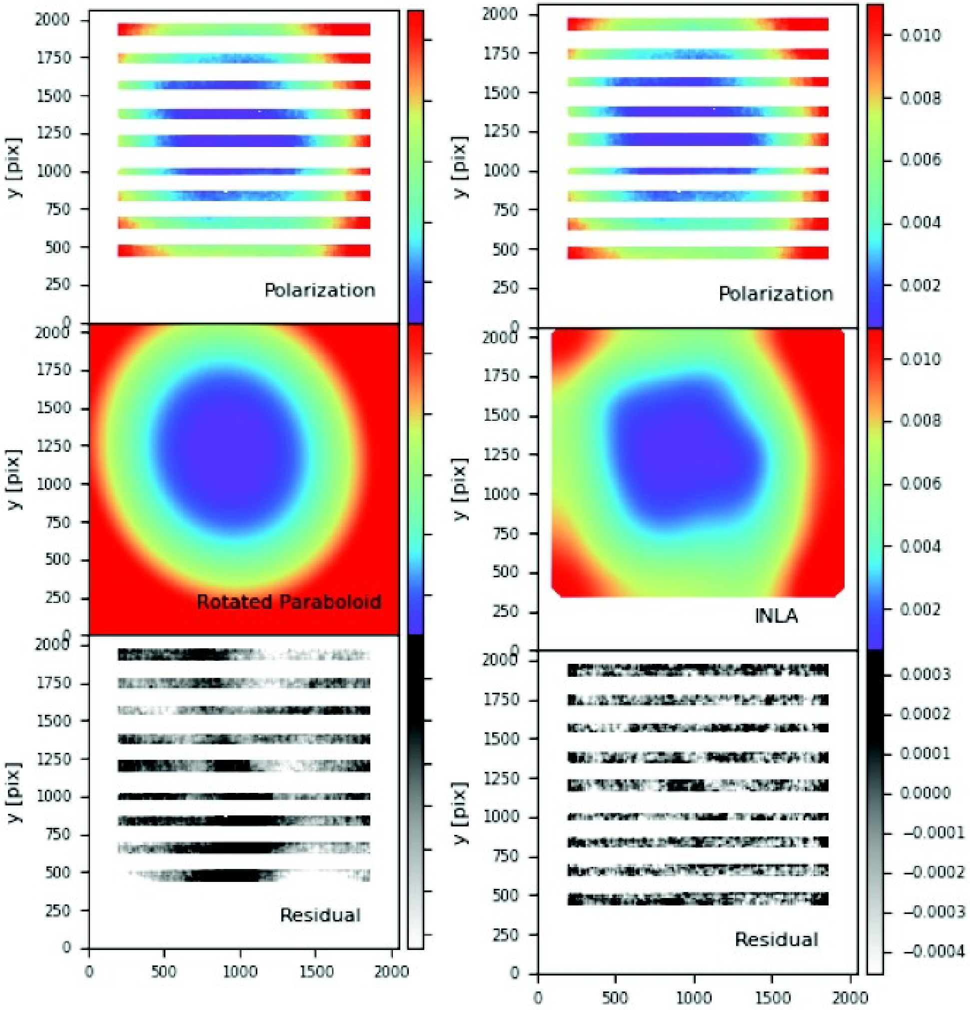
González-Gaitán et al. 2020

Polarization correction

Instrumental field correction

- Radial polarization pattern increasing to 1.2%
- Is it universal? → *new observing proposal*



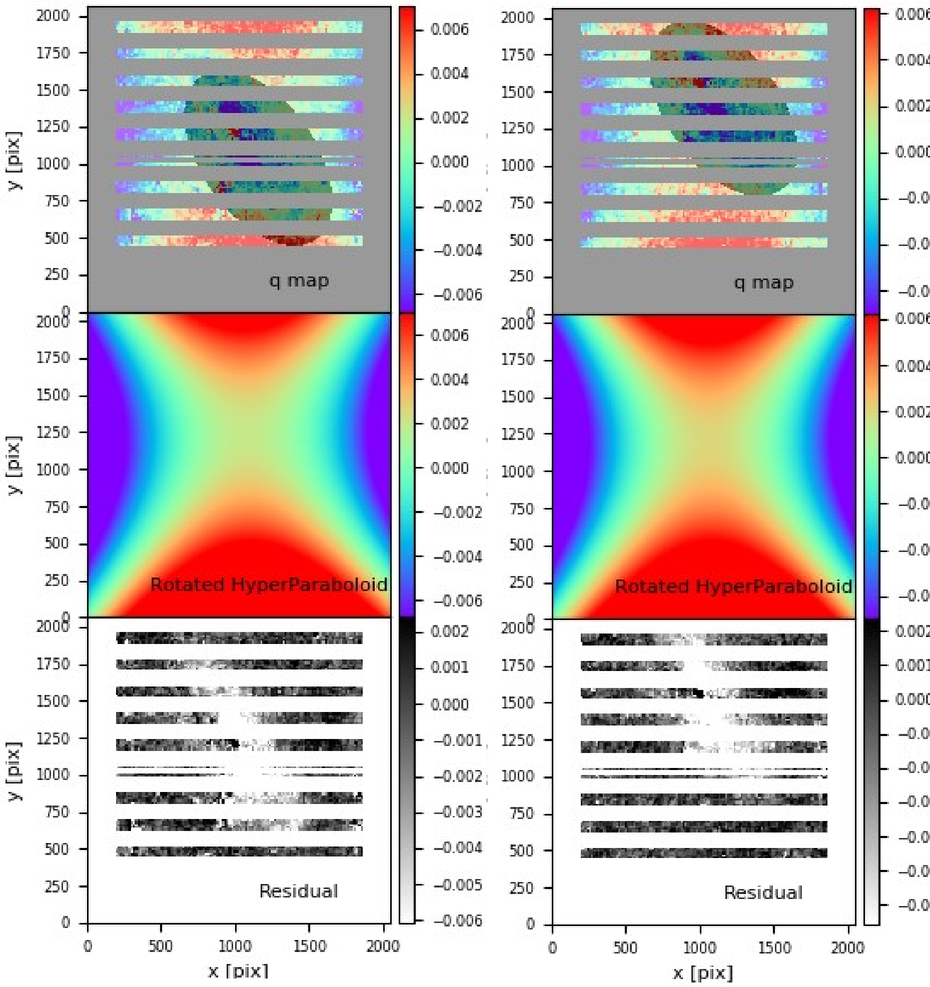


González-Gaitán et al. 2020

Polarization corrections

Instrumental field correction: **in-situ**

- Mask the galaxy: fit isophotes
- Bin boxes fit: seems consistent!



Filter R, offset 0 and 2

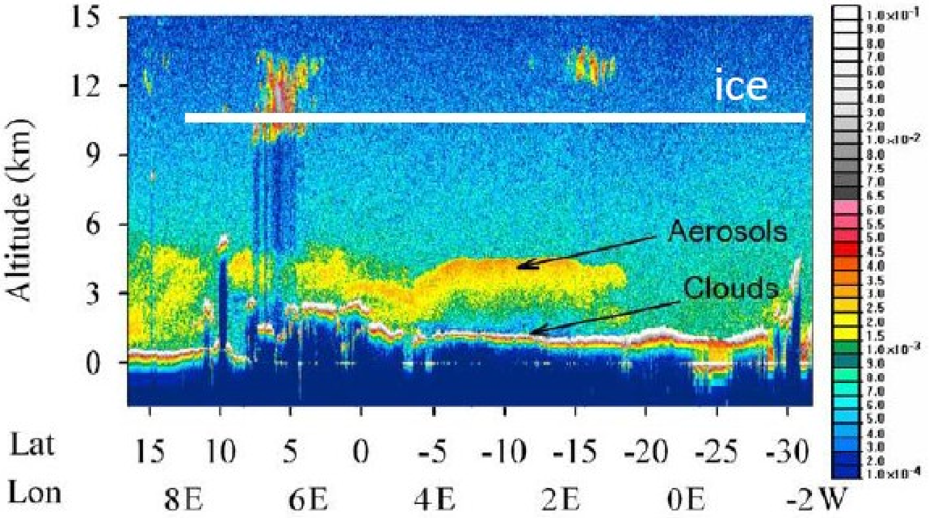
Polarization corrections

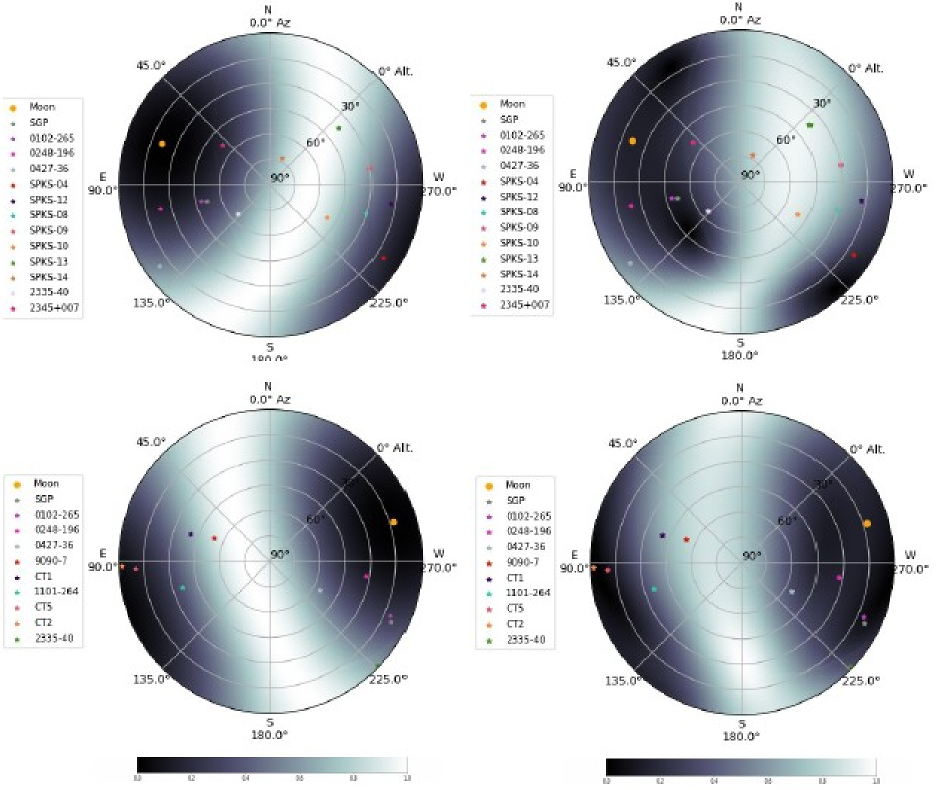
Background sky corrections

Polarization correction

Background sky corrections

- Moonlit sky polarization
- Zodiacal light
- Depolarization in atmosphere





Single Rayleigh scattering vs multiple scattering for two nights
→ *new observing proposal*

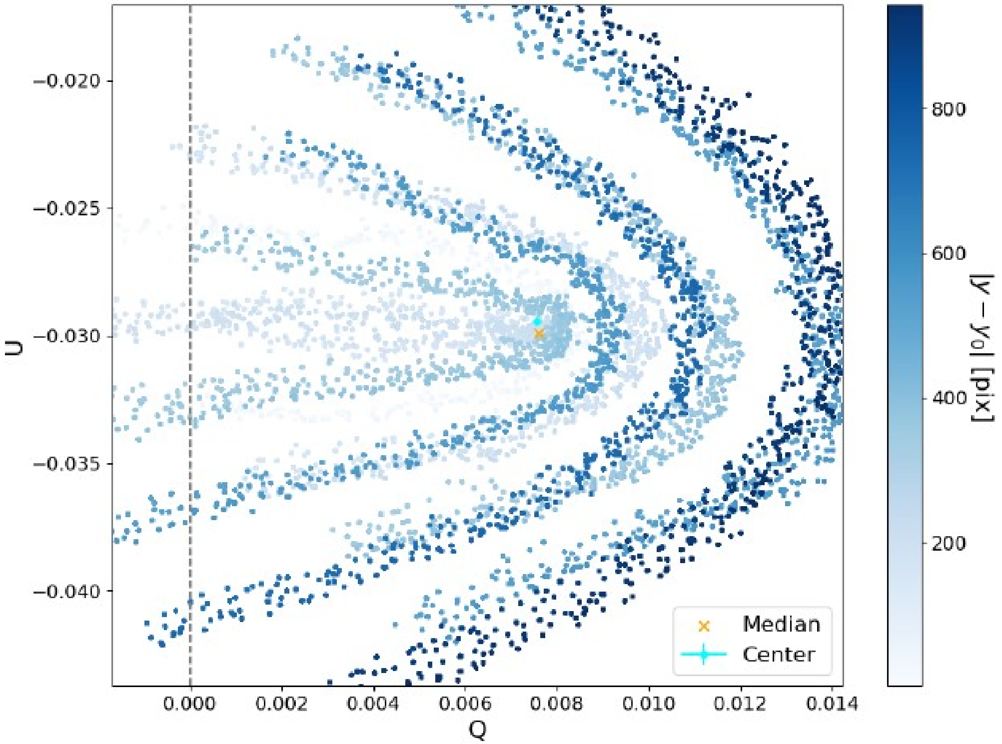
See talk by Beatriz!

Polarization corrections

Background sky corrections: **empirically**

Assume constant across the sky: obtain median value of all pixels/bins:

$Q_B = Q_{med}$, $U_B = U_{med}$



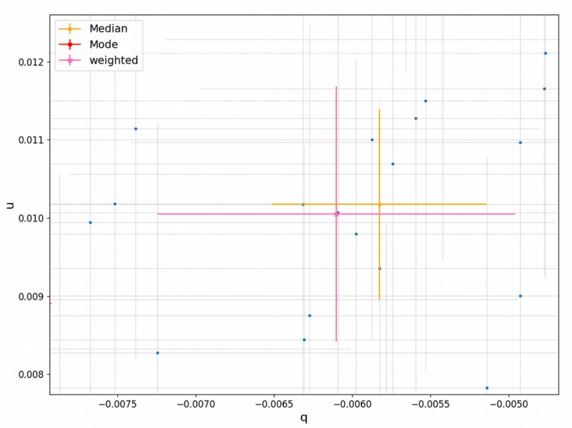
Polarization corrections

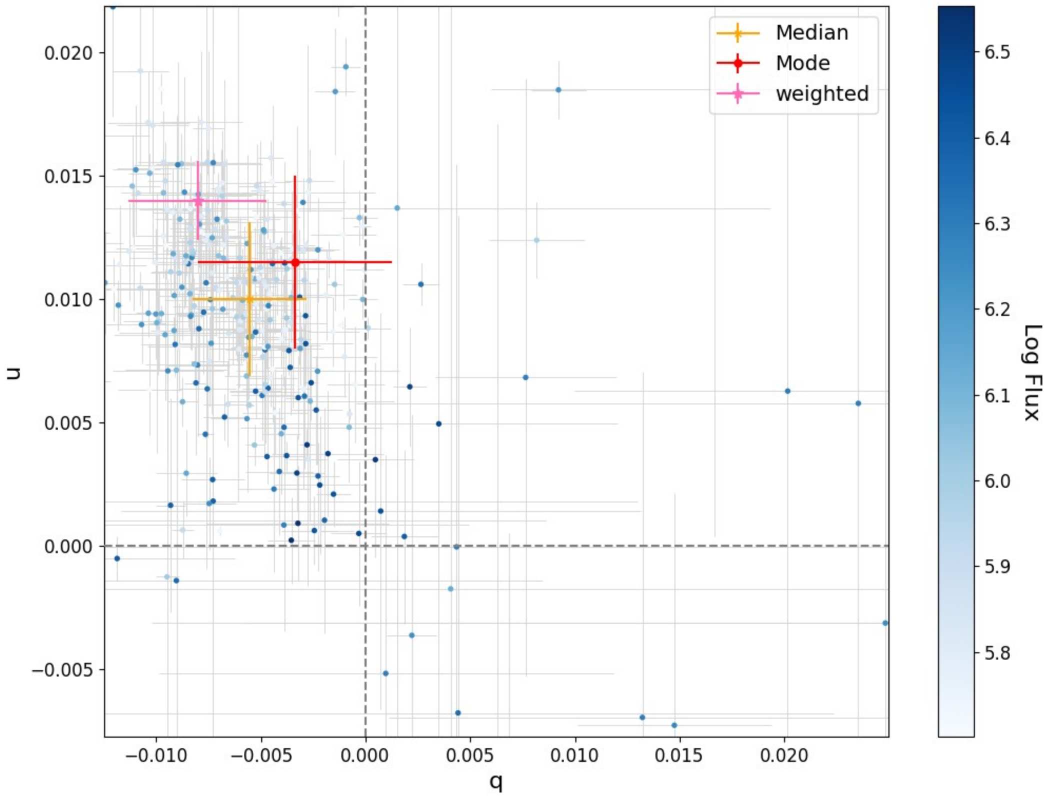
Interstellar polarization (MW)

Polarization corrections

Interstellar polarization (MW)

- Use nearby reference star to obtain Q/U with photometry
- Use stars in the field to obtain Q/U for each with photometry
  - AP/PSF to each angle
  - Q/U field-corrected
  - Cut in magnitude



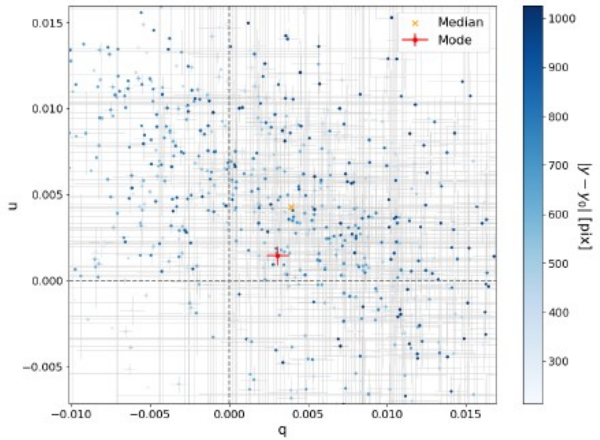


PSF R-band photometry
(all corrected Q/U offsets combined)

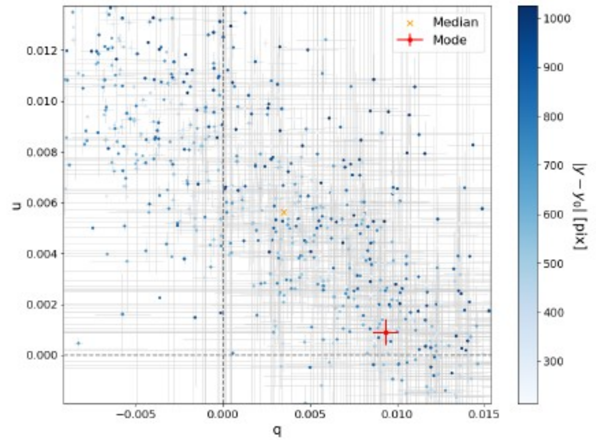
Polarization corrections

Interstellar polarization (MW)

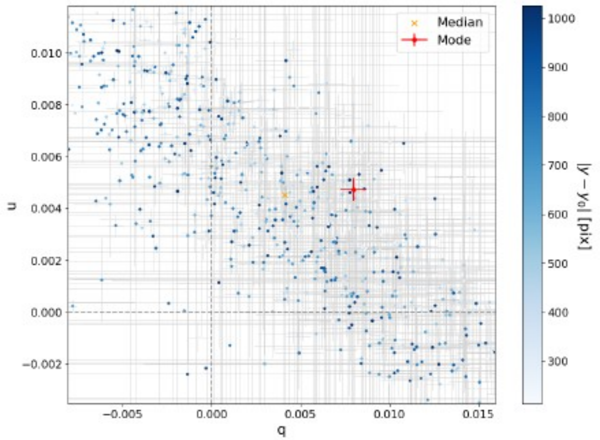
R-band offset 0



raw



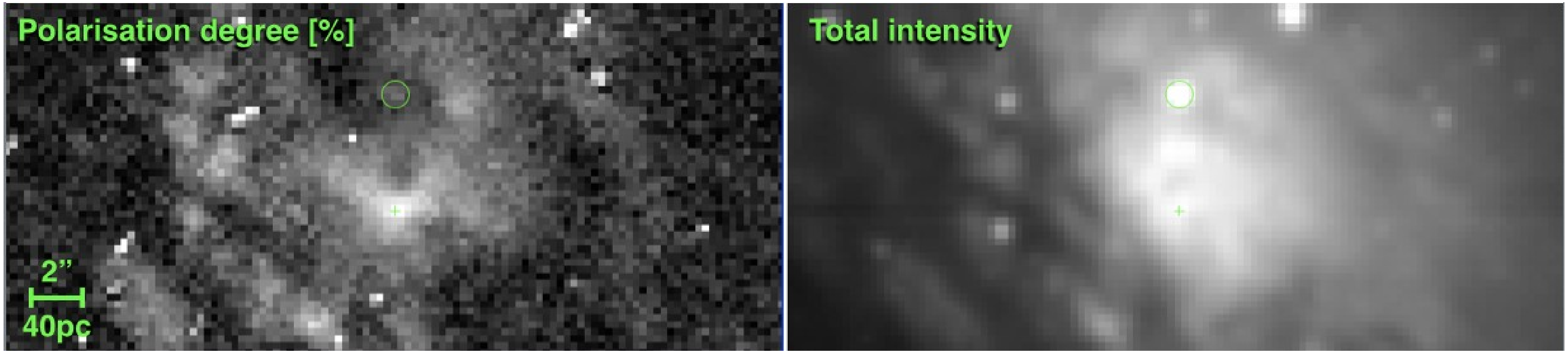
Field-corr in-situ



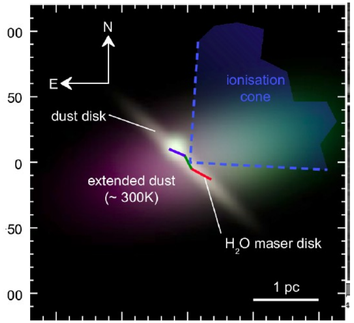
Field-corr paper

IV. Preliminary results

Preliminary results: R-band



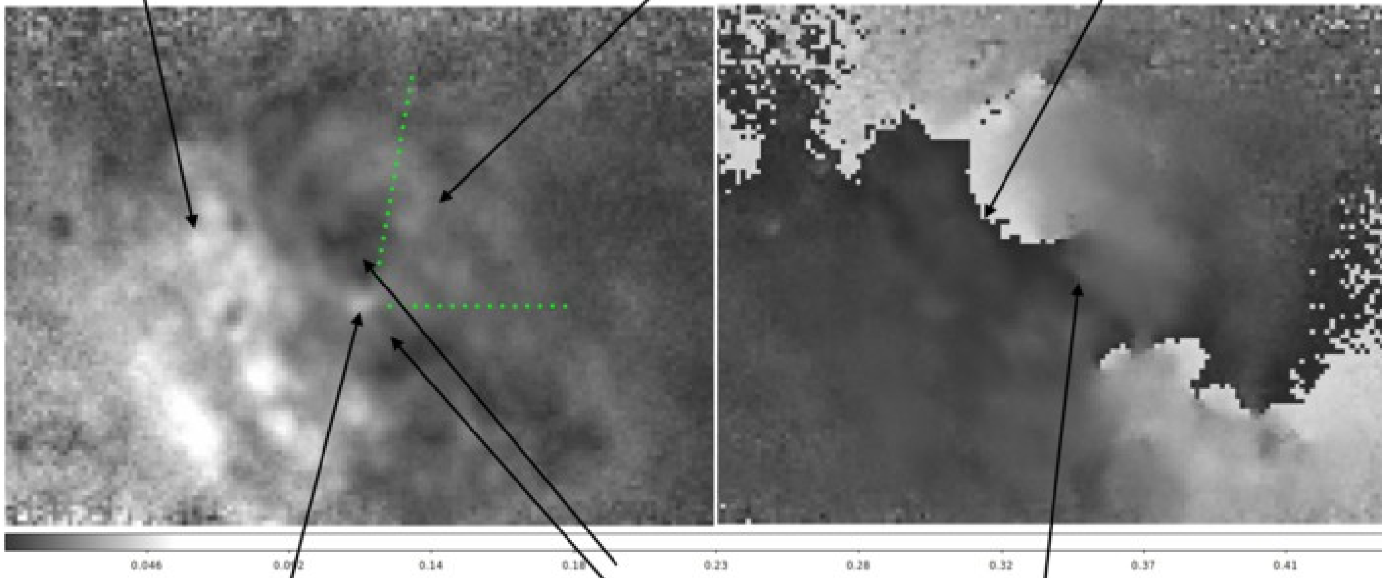
Preliminary results: R-band



On this side, host spiral in front of cone, but pol here from AGN light scattering on surface of spiral?

unobscured ionisation cone polarisation dominated by AGN?

why these sharp edges?



AGN

"the bone" thick material, inflow from host?

AGN (note the switch of angle in the core!)

by Daniel Asmus

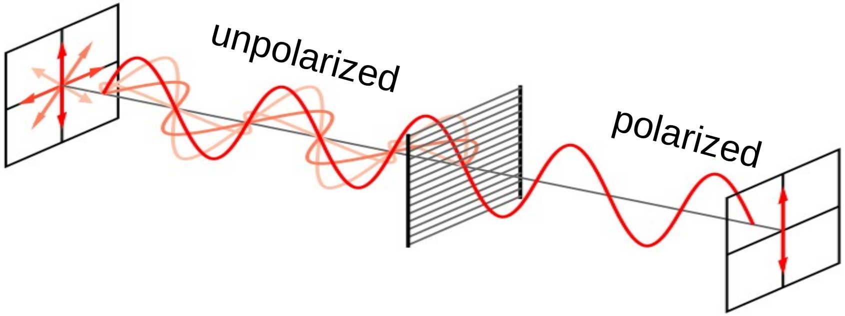
Next steps

- Finish reducing Circinus in all bands (Santiago)
- Interstellar polarization host?
- Interpret our results, model them (Marko, Daniel)
- Apply the machinery to our galaxy sample, starting with a good example
- Obtain galaxy maps of polarization and its wavelength dependence

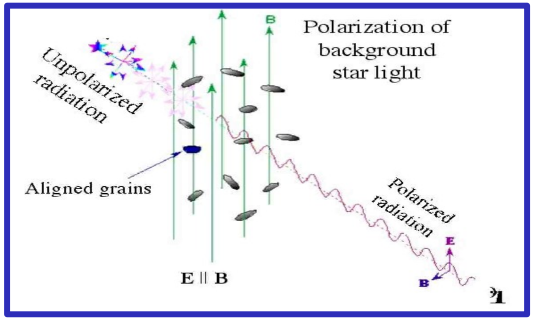
Thanks!

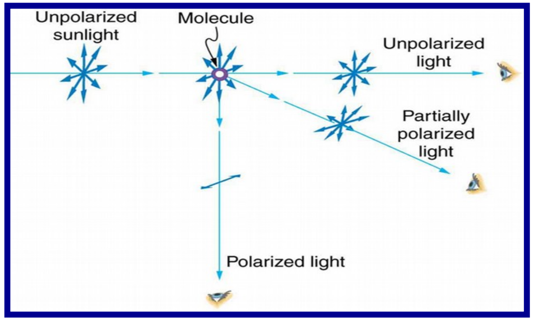
III. Optical linear polarimetry of galaxies

Polarization: light with preferential direction of electric field



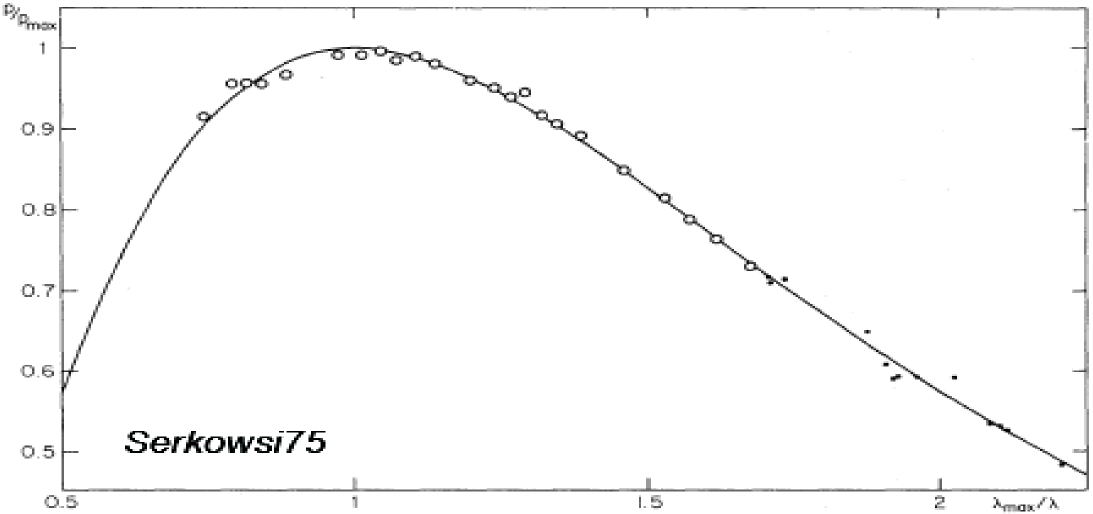
Two effects: dust alignment and dust scattering





III. Optical linear polarimetry of galaxies

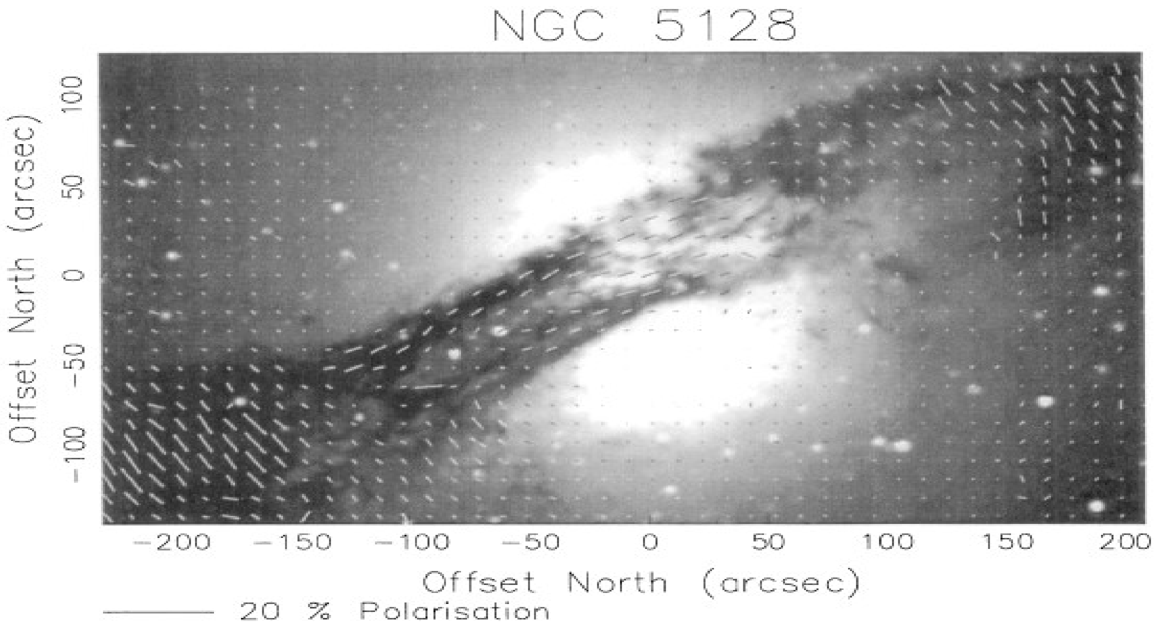
Serkowski law:



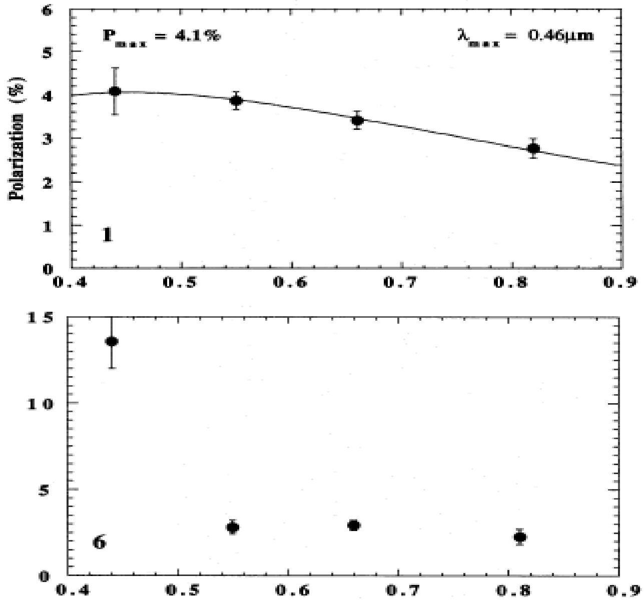
$$p(\lambda) \; = \; p_{max} \exp\left[-K \ln^2\left(\frac{\lambda_{max}}{\lambda}\right)\right]$$

$$R_V \; \simeq \; 3.67(\lambda_{max}/5500\mathring{A}) - 0.29$$

III. Optical linear polarimetry of galaxies



Scarrott+96



Varying Rv's and other things

III. Optical linear polarimetry of galaxies

Preliminary