Polarimetry of Supernova Host galaxies

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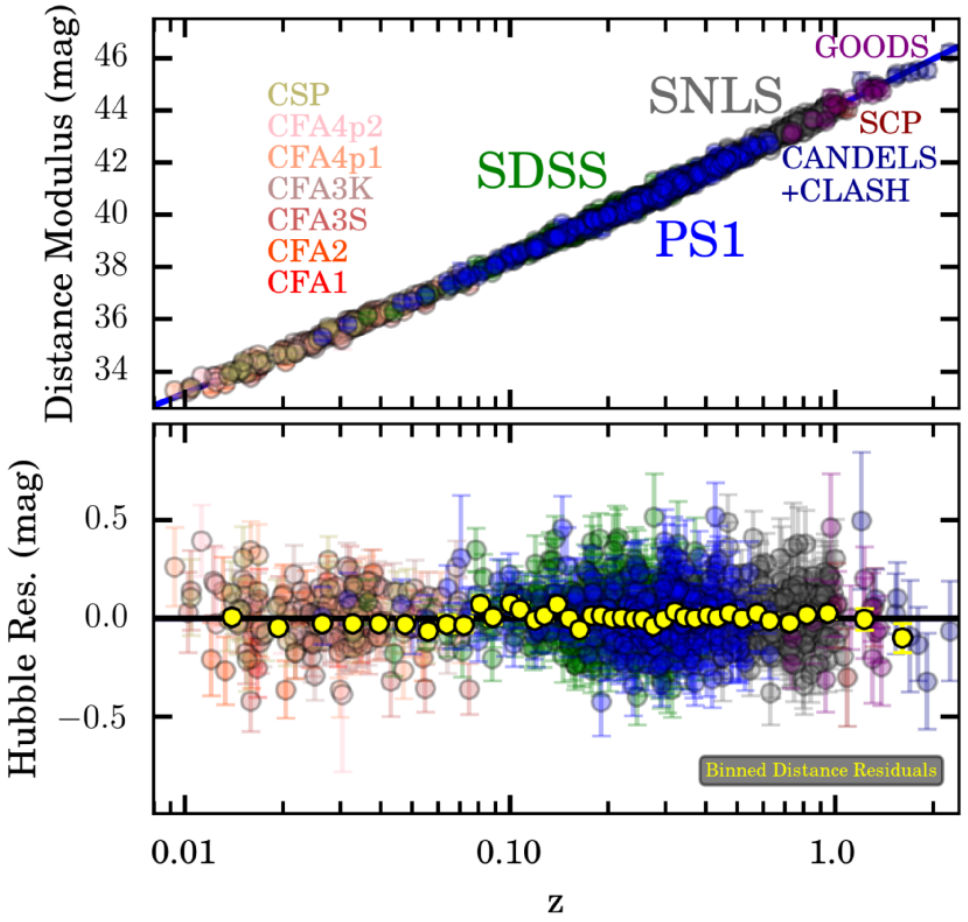
J. Anderson, K. Silva (ESO, Santiago)
A. Cikota (LBNL, USA)
K. Wiersema (Univ. Warwick)
A. B. Higgins (Univ. Leicester)

TÉCNICO LISBOA

centra

COSMOLOGY WITH TYPE Ia SUPERNOVAE



$$m^* - M = 5\log_{10}(d_L/10\,pc)$$

$$\mu = m_B - (M_B - \Delta)$$

$$\mu = m_B - (M_{\rm B} - \alpha(s-1) + \beta C)$$

Pantheon Sample: 1048 SNe 0.03<z<2.3
Scolnic et al, 2018

COSMOLOGY WITH TYPE Ia SUPERNOVAE

SYSTEMATICS IN SN COSMOLOGY

- Progenitor properties: mass, metallicity
- Explosion model: double/single degenerate
  asymmetries in the explosion
- Dust

SYSTEMATICS IN SN COSMOLOGY

INTEGRAL FIELD SPECTROSCOPY

- Local versus global host properties
- Progenitor properties from metallicity of gas and stellar populations
- ...

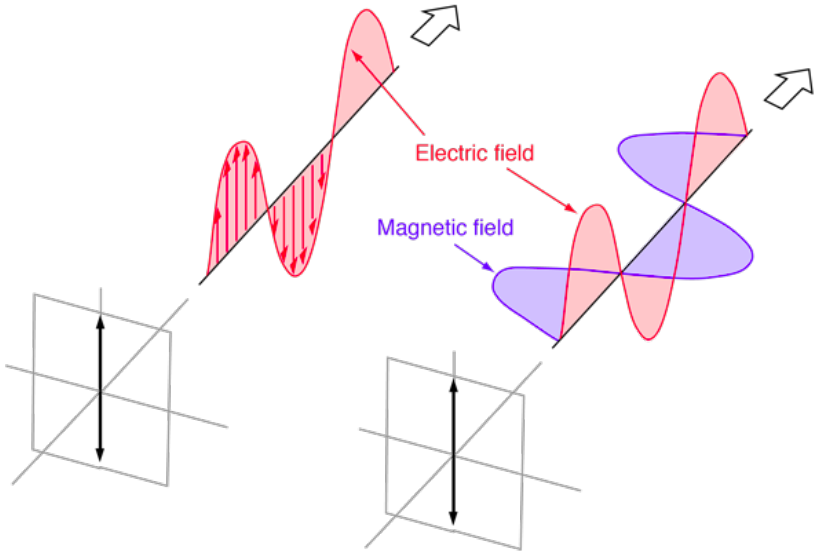
POLARIMETRY

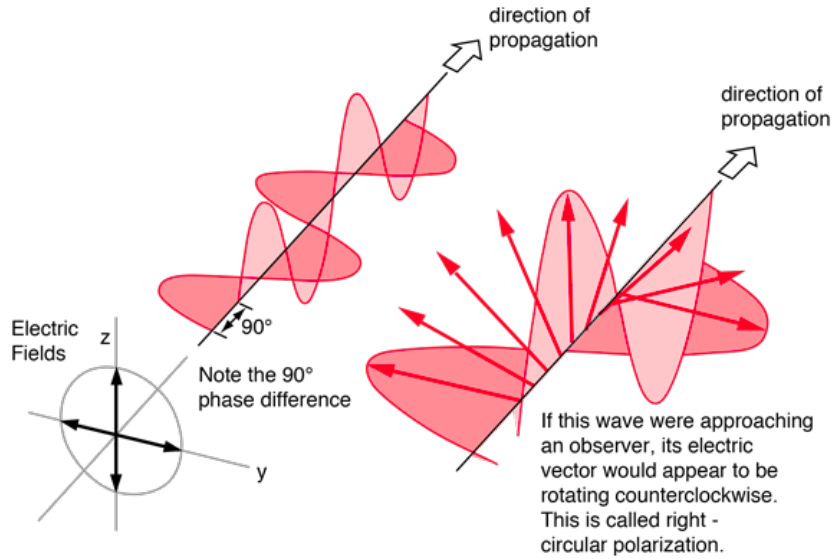
- Dust
- Explosion models

POLARIZATION

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

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

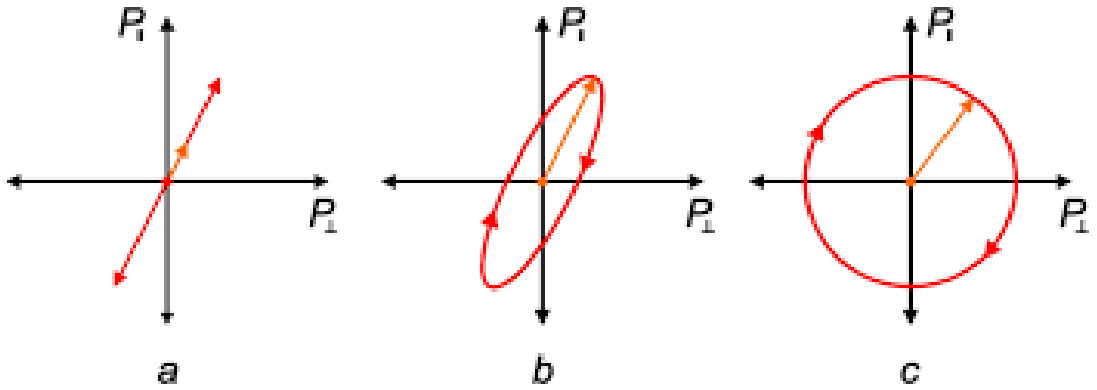




Light composed of 2 plane waves of equal amplitude, or different amplitudes
90º phase difference

http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/polclas.html#c3

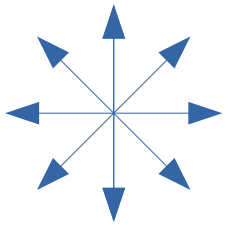
POLARIZATION



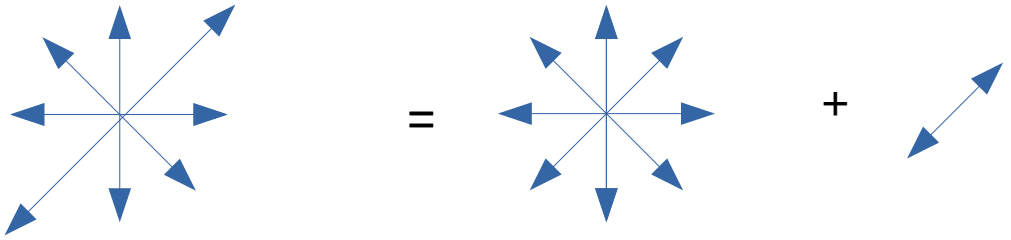
https://www.researchgate.net/figure/a-Linear-polarization-b-elliptical-polarization-c-right-circular-polarization_fig3_324588058

POLARIZATION

Unpolarized light:



Polarized light:



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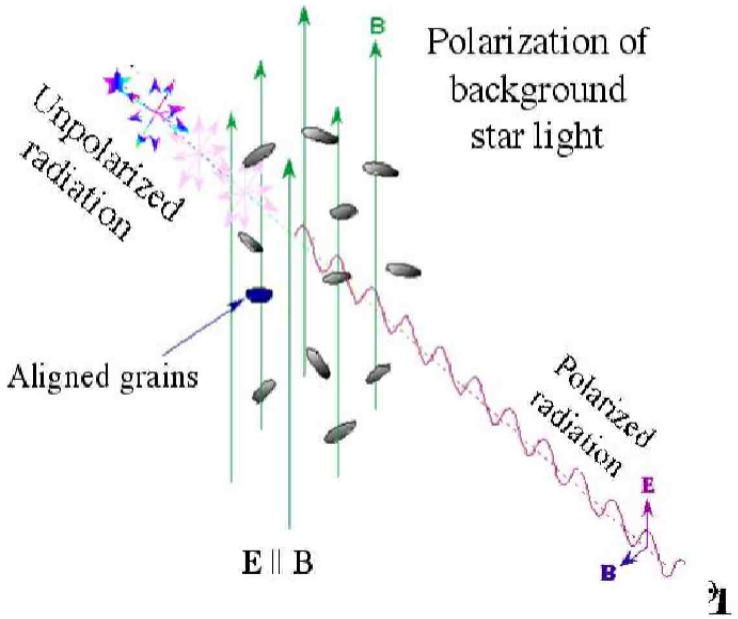
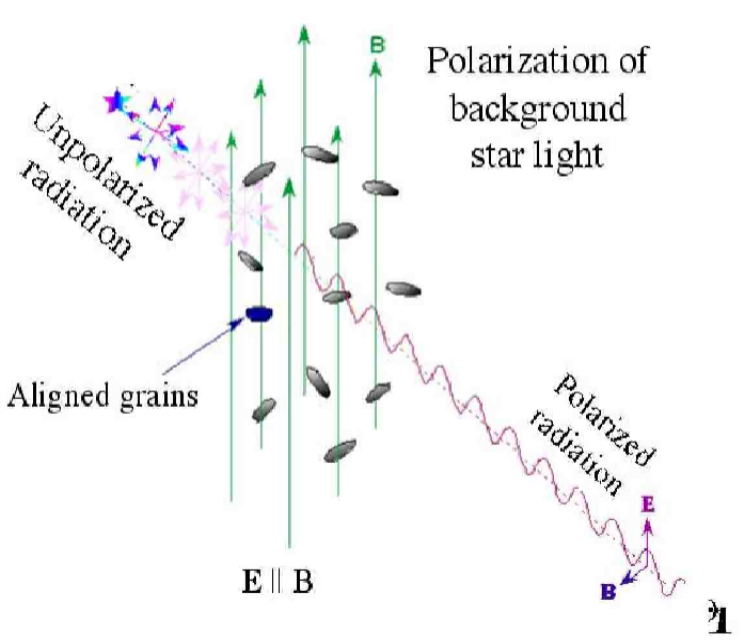
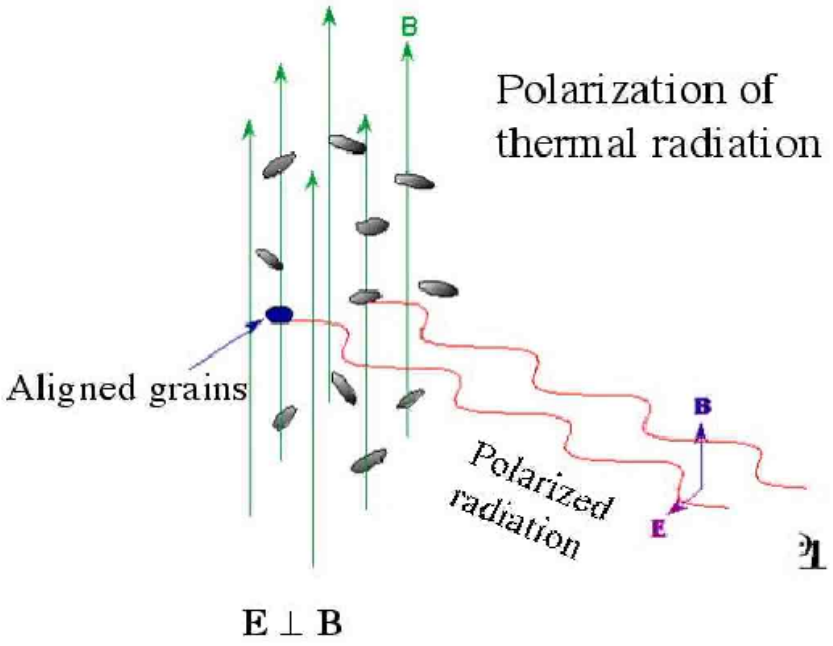
DUST PROPERTIES AND INTERSTELLAR POLARIZATION



Lazarian '08

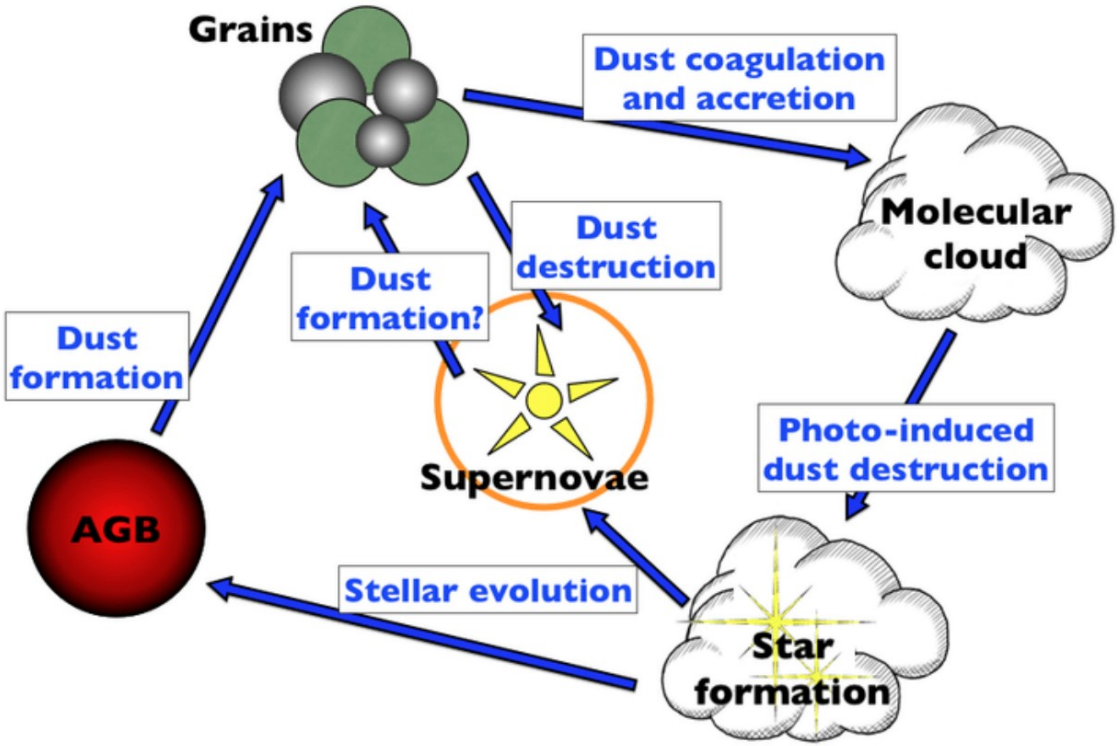
DUST PROPERTIES AND INTERSTELLAR POLARIZATION





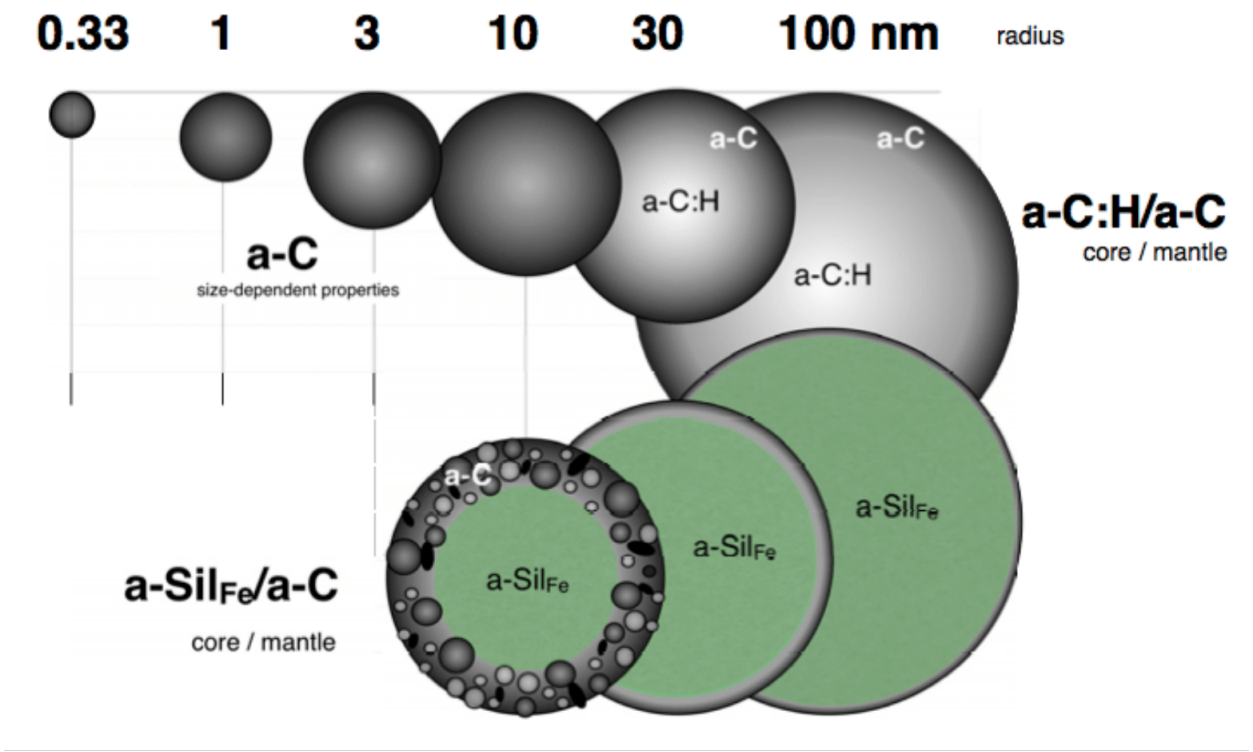
Lazarian '08

DUST PROPERTIES: COMPOSITION AND SIZE



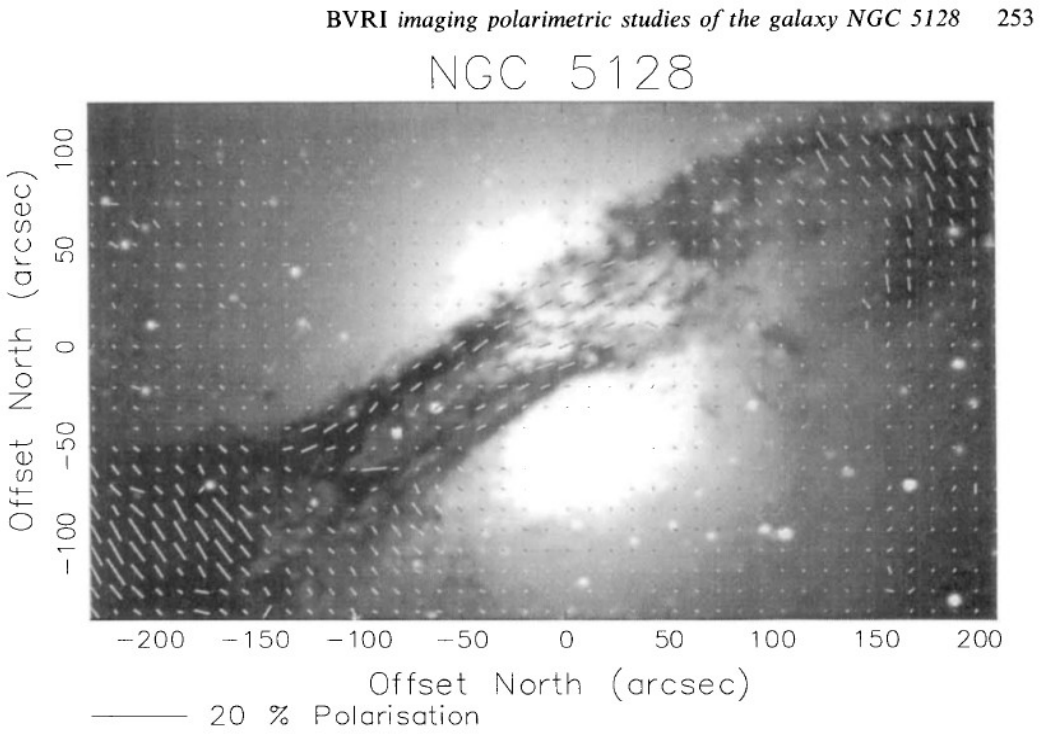
M. Bocchio 2014

DUST PROPERTIES: COMPOSITION AND SIZE



Jones+ 2014

DUST PROPERTIES AND INTERSTELLAR POLARIZATION



Host of the SN1976G

Scarrott+ 1996

DUST PROPERTIES AND INTERSTELLAR POLARIZATION

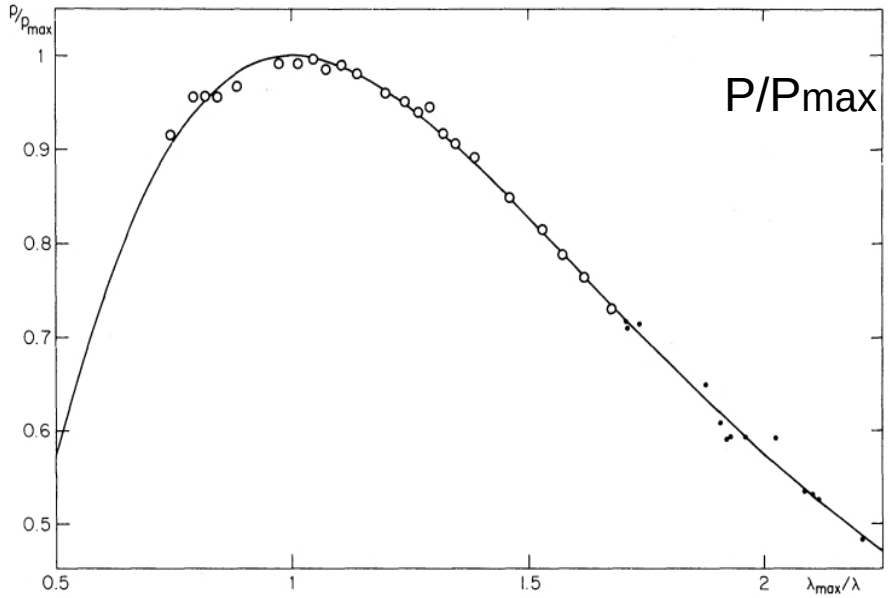


FIG. 3.—The normalized wavelength dependence of interstellar linear polarization derived from the observations with the Siding Spring multichannel polarimeter-photometer. The solid line is calculated from eq. (4) for $K = 1.15$. Every open circle is based on 20 stars, while each dot represents the observations of an individual star with a particular filter.

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

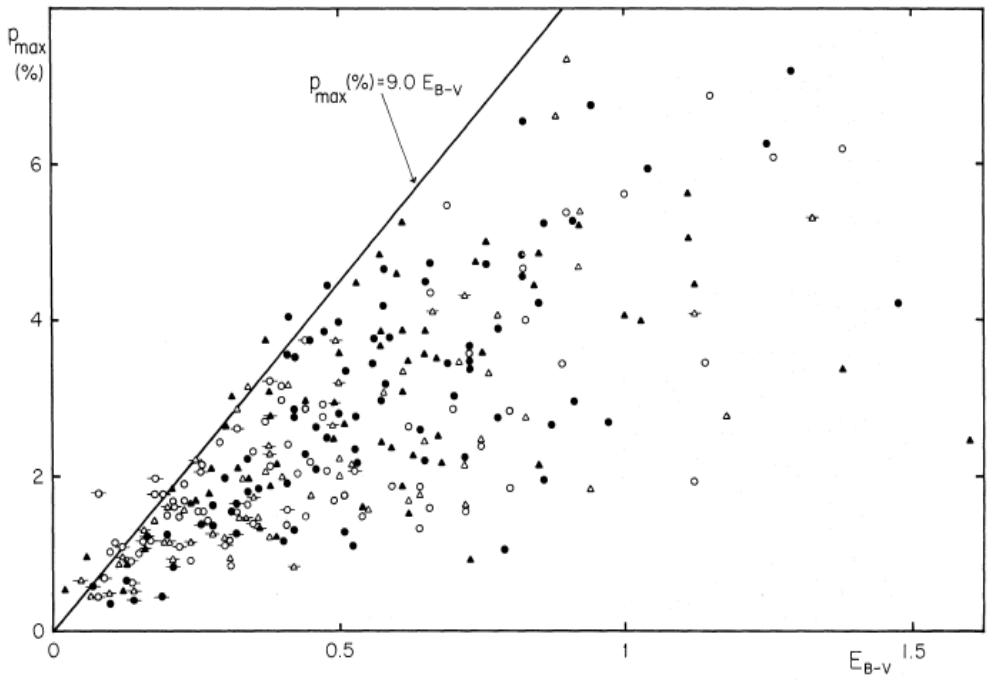
$$K = 1.86\,\lambda_{\max} - 0.1$$

$$R_V = \frac{A_V}{A_B - A_V}$$

$$\lambda_{\max}(\mu m) = (0.17 \pm 0.05) R_V$$

Serkovski+ '75,
Clayton and Mathis '98
Draine '03
Wilking+ '82
Tielens, Interstellar Medium, ' 05

DUST PROPERTIES AND INTERSTELLAR POLARIZATION



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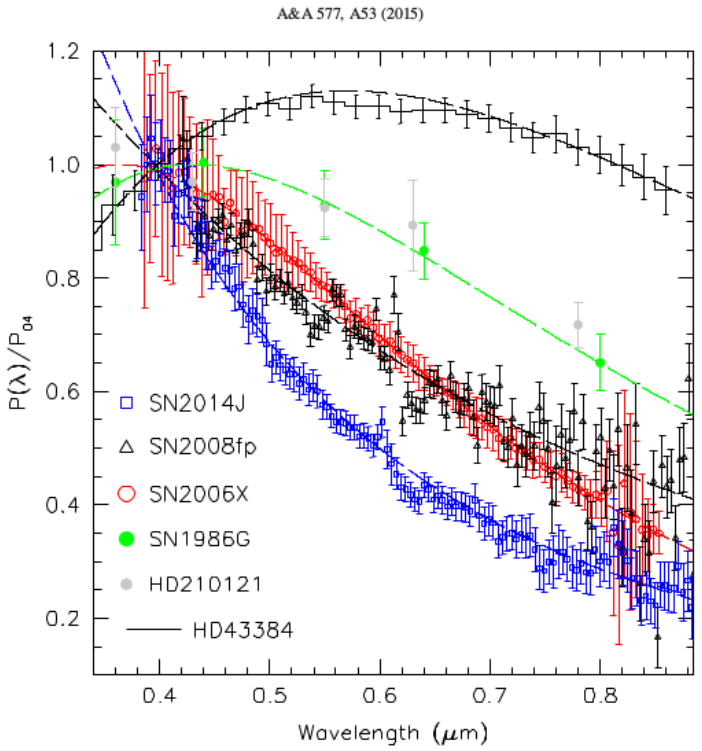
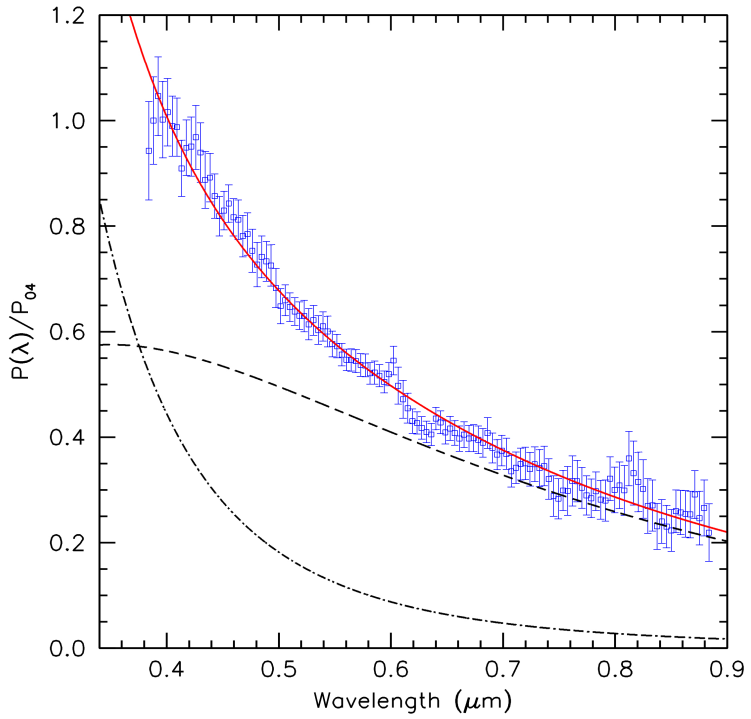
DUST PROPERTIES FROM LINEAR SN POLARIMETRY



Patat+ '15

DUST PROPERTIES FROM LINEAR SN POLARIMETRY



Patat+ '15

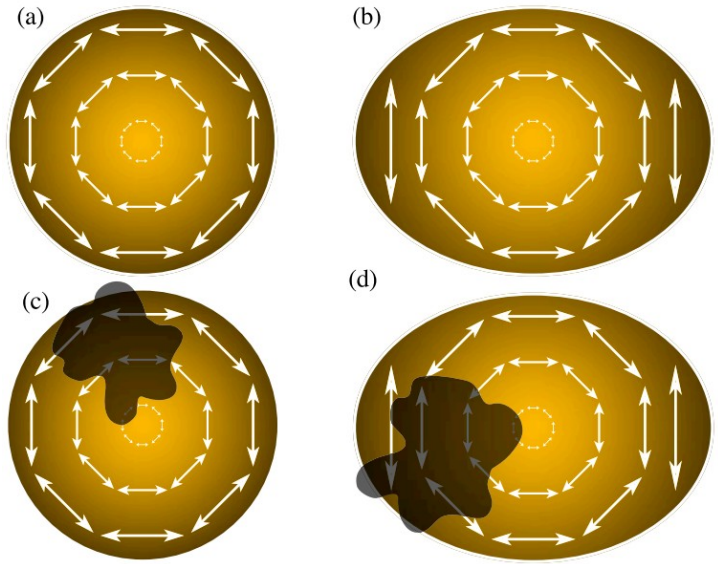
SN2014J
Serkowski and Rayleigh scattering

Nagao+ '18, '19: polarimetry of SNe to infer the presence of CSM

Zelaya+ '13; 18: Sodium lines and spectropolarimetry of SNIa

POLARIMETRY IN SUPERNOVA OBSERVATIONS

Illustration of mechanisms leading to polarization of SN light



Aspherical photosphere:
Net continuum polarization

Aspherical photosphere +
inhomogeneous distribution of materia
Net continuum+line polarization

Cikota + 2019

Usually: continuum polarization ~0.4% → 10 % asphericity Bulla+, 2016
~0,8% continuum polarization observed at the SN1999by , Howell+ 2001

POLARIZATION OF LIGHT FROM SN and SUPERNOVA HOST GALAXIES

IN PROGRESS
First statistical study of
multi-band optical polarimetry
of supernova host galaxies

with FORS2 @ VLT-ESO
PI: Santiago

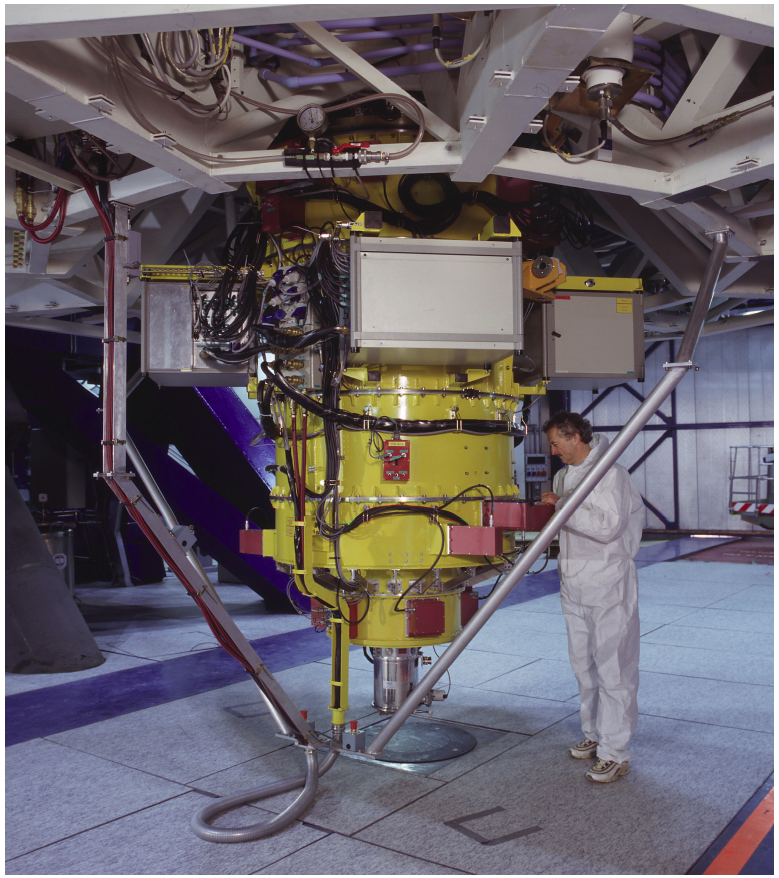
STARTING SOON
Polarimetric follow up of SNe

With CAFOS @ Calar Alto
(PI: Antonia)

GOAL
Map the wavelength dependence
of the polarization

Infer dust properties

POLARIMETRY of SN HOST GALAXIES

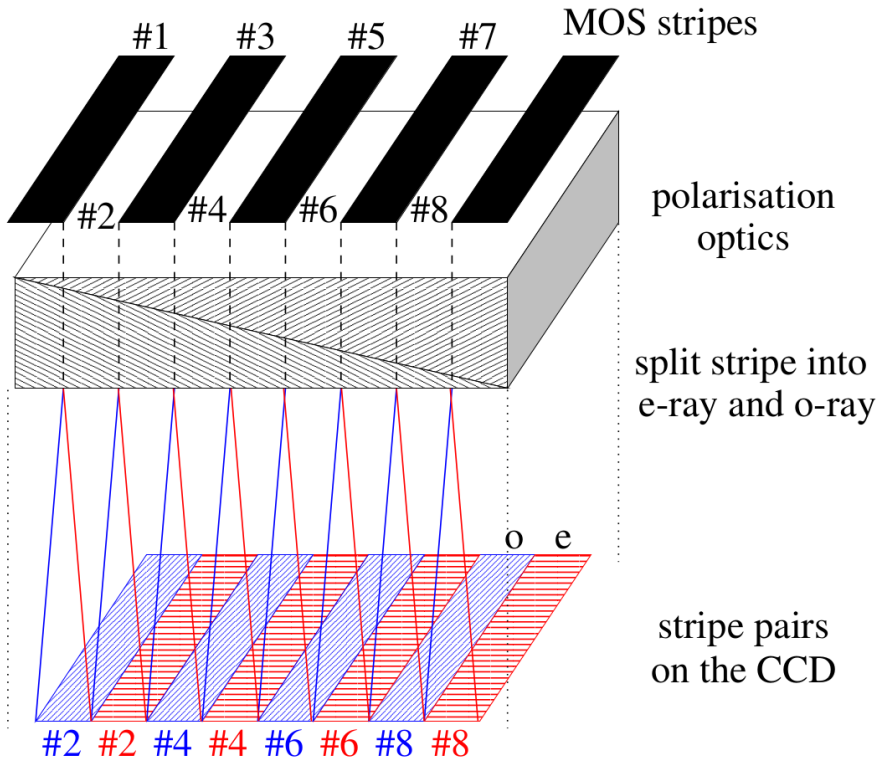


ESO-VLT
FORS2 – Focal Reducer and low dispersion Spectrograph

Polarimetric modes
Imaging Polarimetry mode (IPOL)
Spectro Polarimetry mode
FoV: 6.8’x6.8’
0.25”/pixel

FORS2: POLARIZATION OPTICS

WOLLASTON PRISM

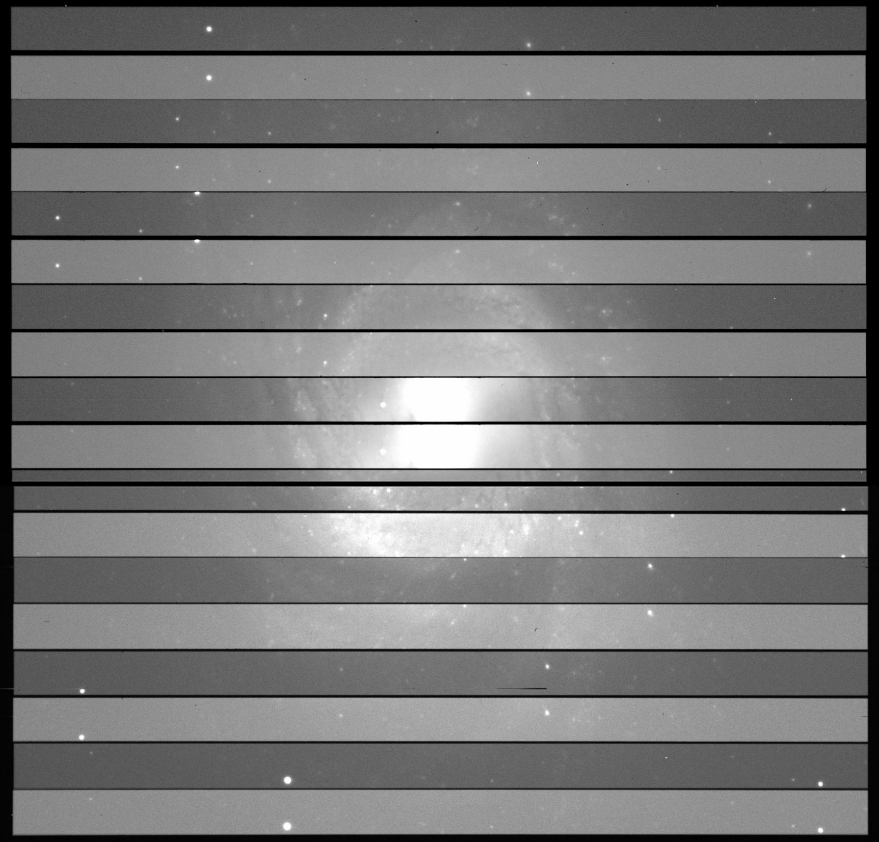


Schematic representation of a dual-beam polarimeter

initial light ray with two polarization states (shown in blue and red)

ESO FORS2 Manual

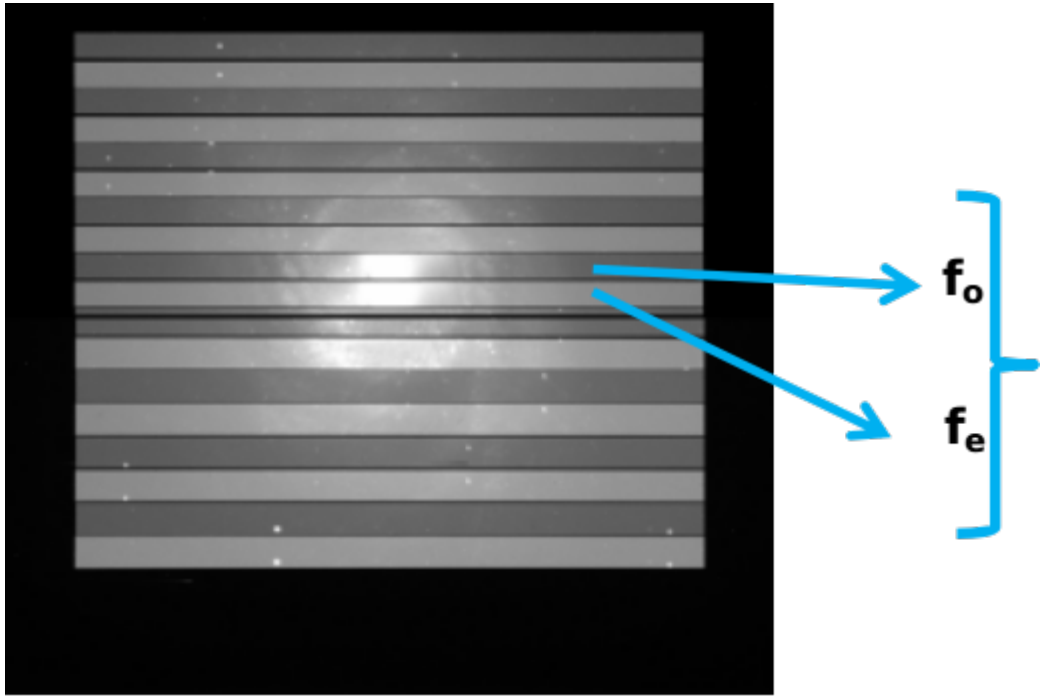
POLARIMETRY of SN HOST GALAXIES

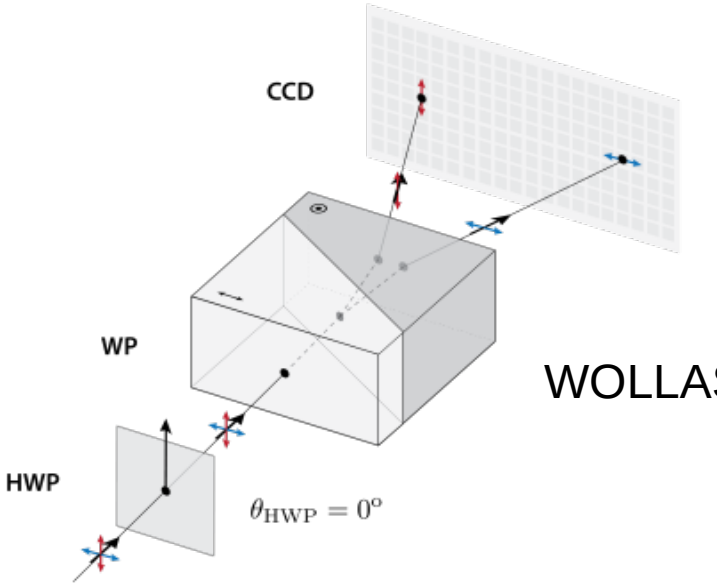


NGC 3351

dam Block, Mt. Lemmon SkyCenter, University of Arizona

FORS2: POLARIZATION OPTICS



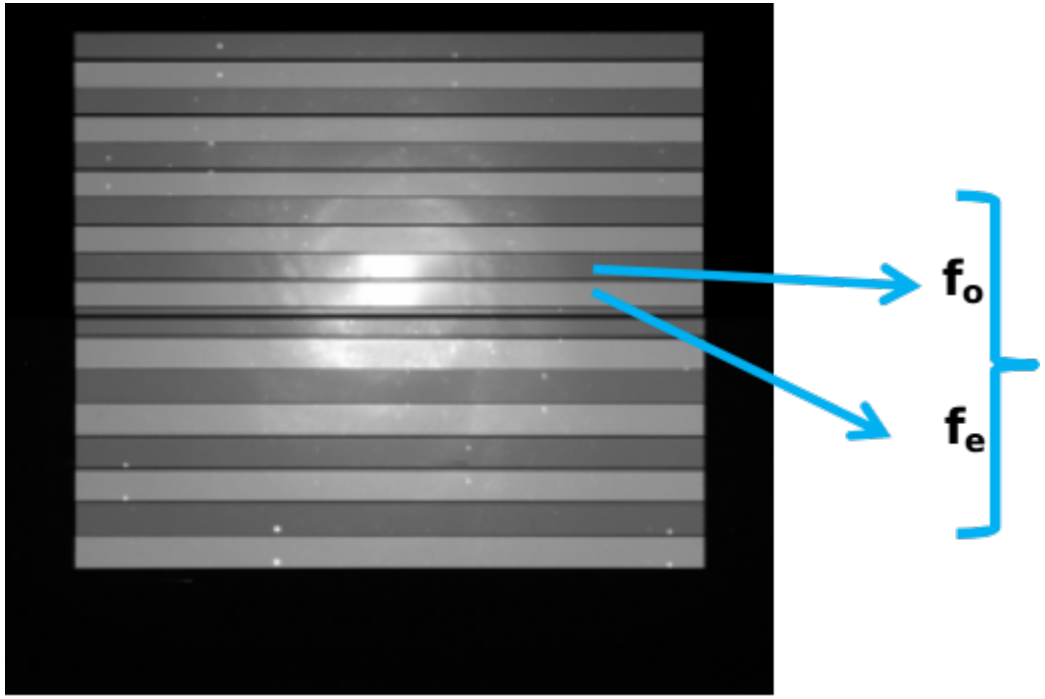


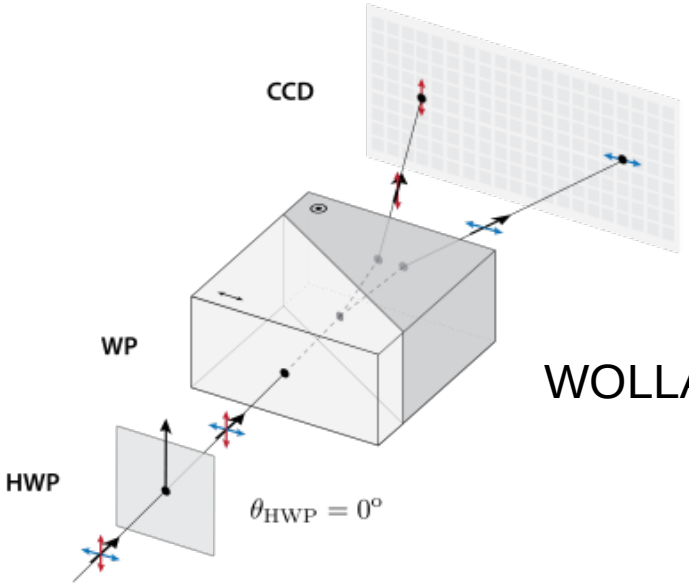
WOLLASTON PRISM

Stokes parameters $\begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix}$

Gonzalez-Gaitan, Mourão, Patat et al, A&A, 2020
Patat & Romaniello, 2006

FORS2: POLARIZATION OPTICS





WOLLASTON PRISM

Stokes parameters $\begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix}$

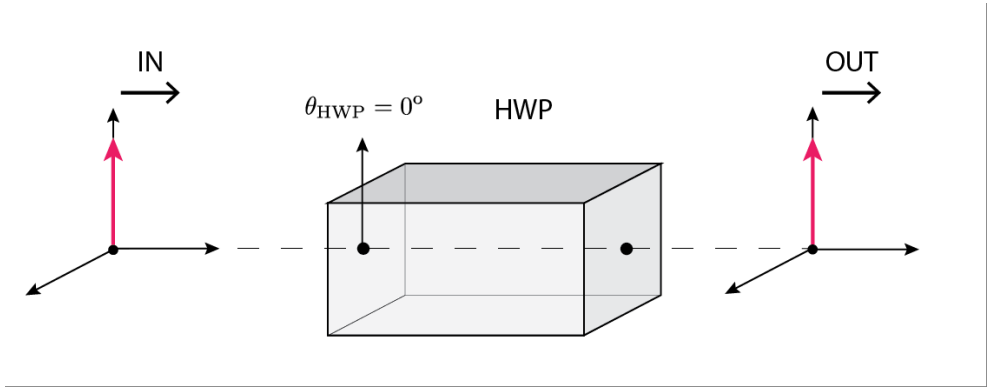
$$P = \frac{\sqrt{Q^2 + U^2}}{I}$$

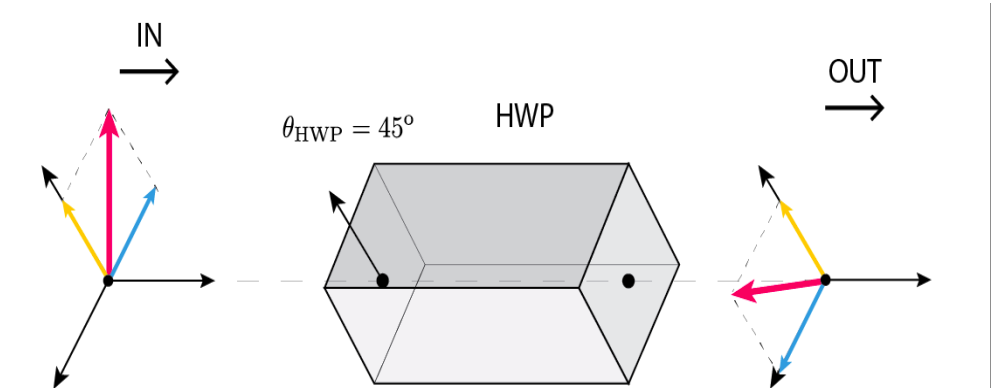
$$\chi = \frac{1}{2} \arctan \frac{U}{Q}$$

Gonzalez-Gaitan, Mourão, Patat et al, A&A, 2020
Patat & Romaniello, 2006

FORS2: POLARIZATION OPTICS

Retarder plate





Gonzalez-Gaitan, Mourão, Patat et al' 20
Plots by J. Lopes

FORS2: POLARIZATION OPTICS

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

$$F_i = \frac{Q}{I}\cos 4\theta_i + \frac{U}{I}\sin 4\theta_i = P\,\cos(4\theta_i - 2\chi)$$

$$P = \frac{\sqrt{Q^2 + U^2}}{I}$$

$$\chi = \frac{1}{2}\arctan\frac{U}{Q}$$

$$\sigma_P = \frac{1}{\sqrt{N/2}(S/N)} \quad \text{and} \quad \sigma_\chi = \frac{\sigma_P}{2P}$$

Patat & Romaniello '06

FORS2: POLARIZATION OPTICS

$$F_i = \frac{Q}{I}\cos 4\theta_i + \frac{U}{I}\sin 4\theta_i = P\,\cos(4\theta_i - 2\chi)$$

$$F_i = Q_o + \sum_{k=1}^{N/2} Q_k \cos\left(k\frac{2\pi\, i}{N}\right) + U_k \sin\left(k\frac{2\pi\, i}{N}\right)$$

$$Q_0 = \frac{1}{N}\sum_{i=0}^{N-1} F_i\ ,$$

$$Q_k = \frac{2}{N}\sum_{i=0}^{N-1} F_i \cos\left(k\frac{2\pi\, i}{N}\right)$$

$$U_k = \frac{2}{N}\sum_{i=0}^{N-1} F_i \sin\left(k\frac{2\pi\, i}{N}\right)$$

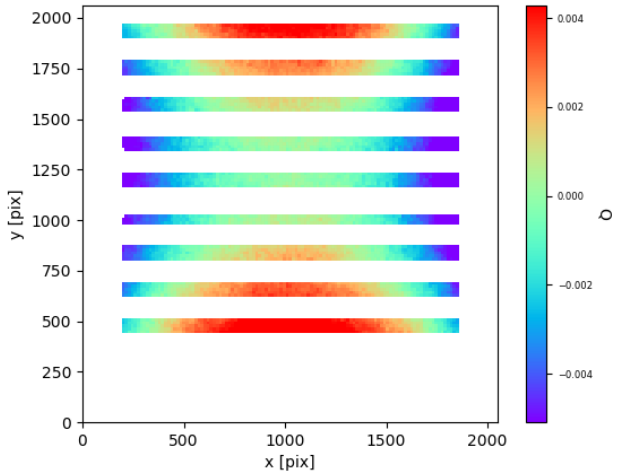
Polarization spectrum

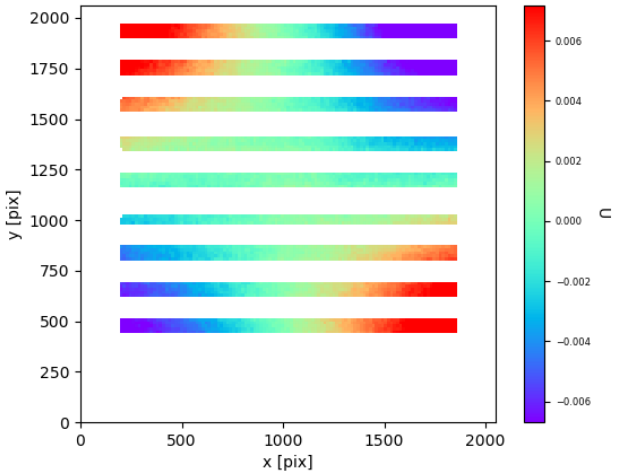
$$P_k = \sqrt{Q_k^2 + U_k^2}$$

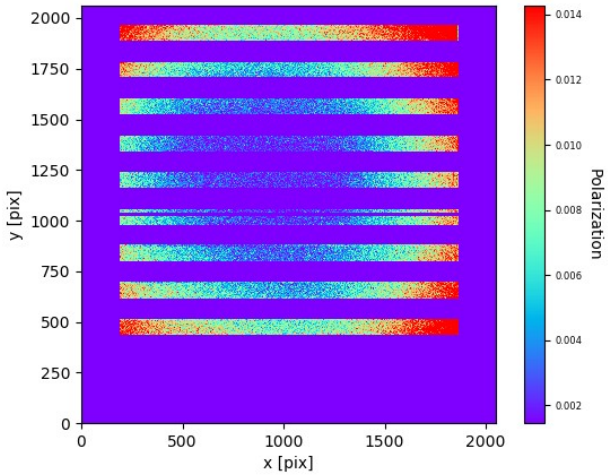
Signal @*N*/4 harmonic

Patat & Romaniello '06

FORS2: IPOL MODE CALIBRATION WITH FULL MOON







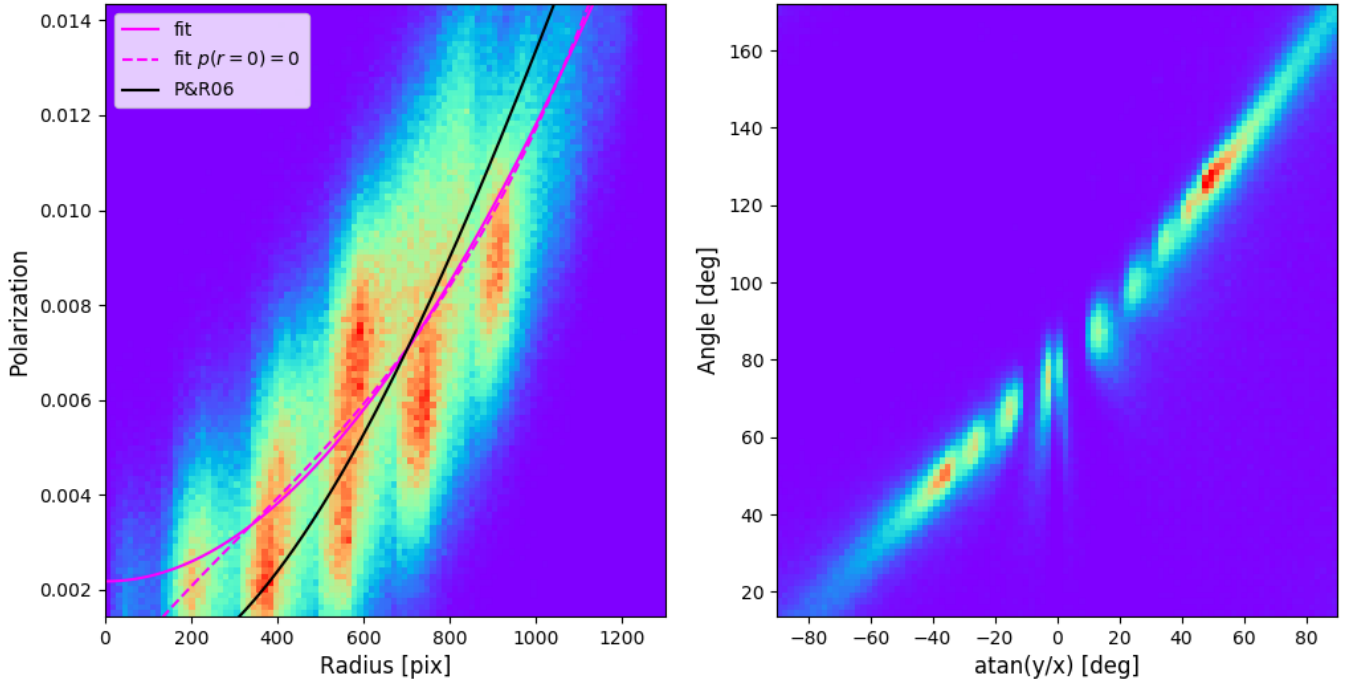
in B

estimation of the instrumental polarization in FORS2, including

- A radial dependence of the instrumental polarization was confirmed
- Extra properties of the detector that must be considered in polarimetry

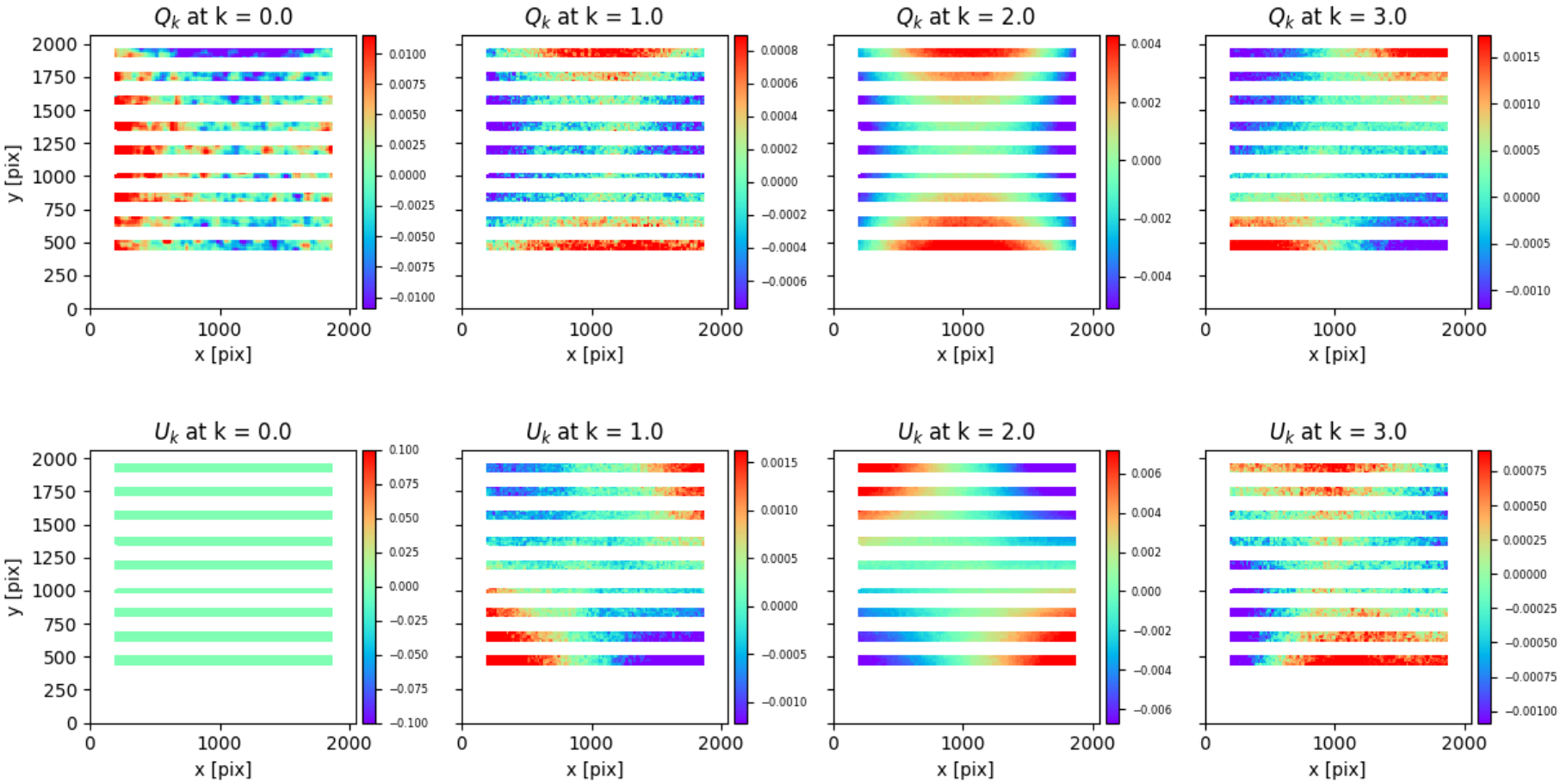
fundamental step towards precision polarimetry with FORS2

FORS2: IPOL MODE CALIBRATION WITH FULL MOON



FORS2: IPOL MODE CALIBRATION

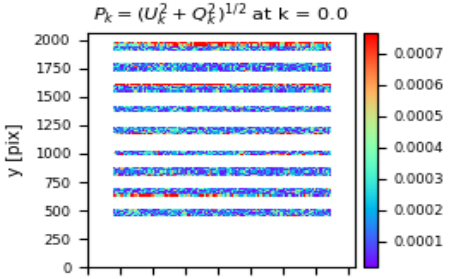
Filter B

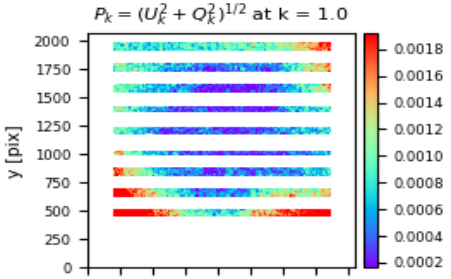


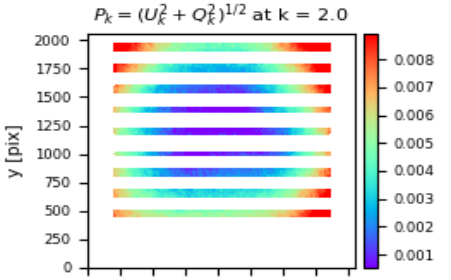
bin: 30x30

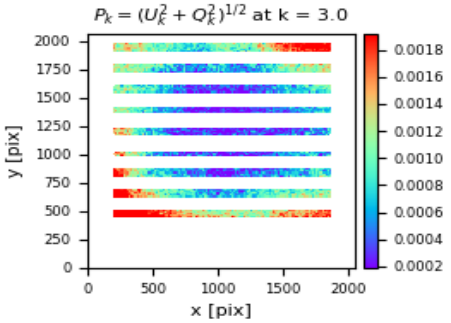
FORS2: IPOL MODE CALIBRATION

Polarization spectrum



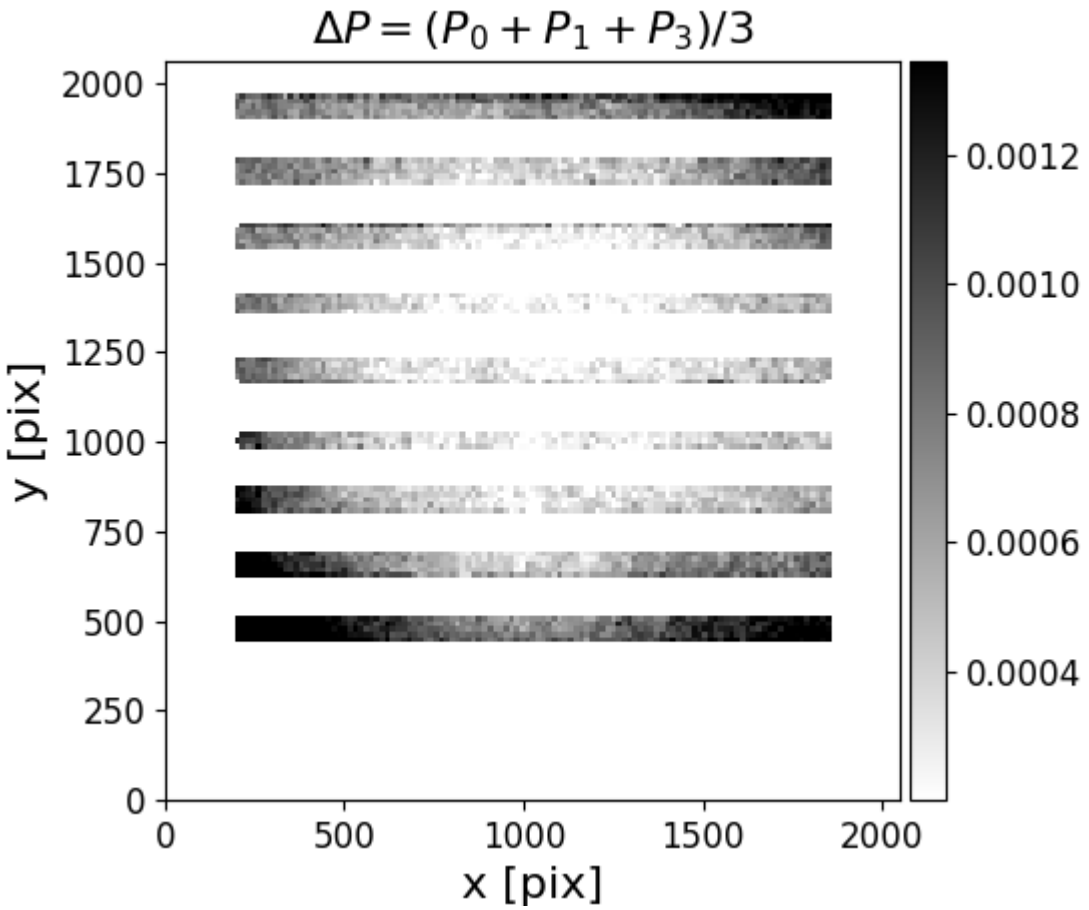






Filter B

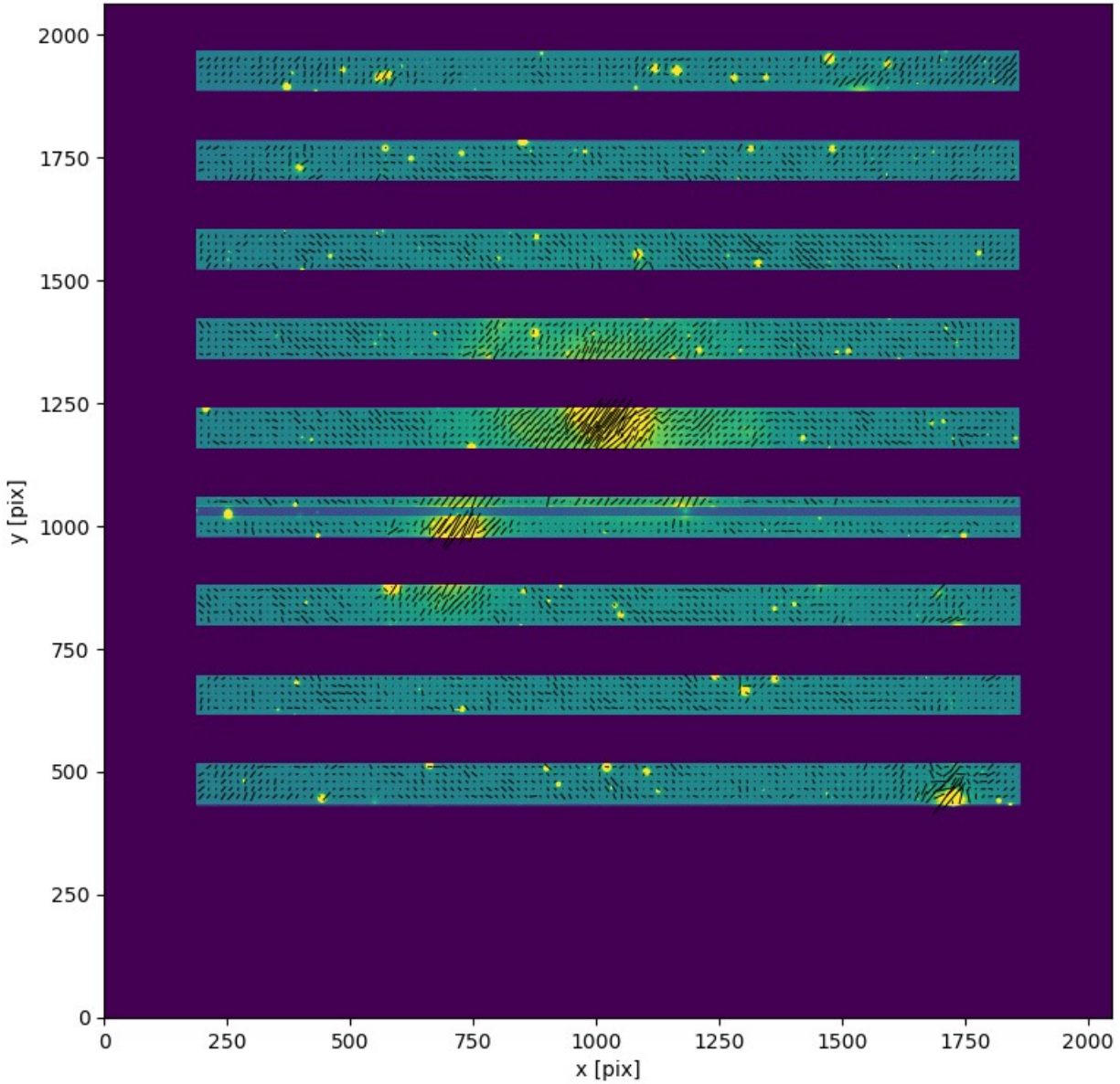
FORS2: IPOL MODE CALIBRATION



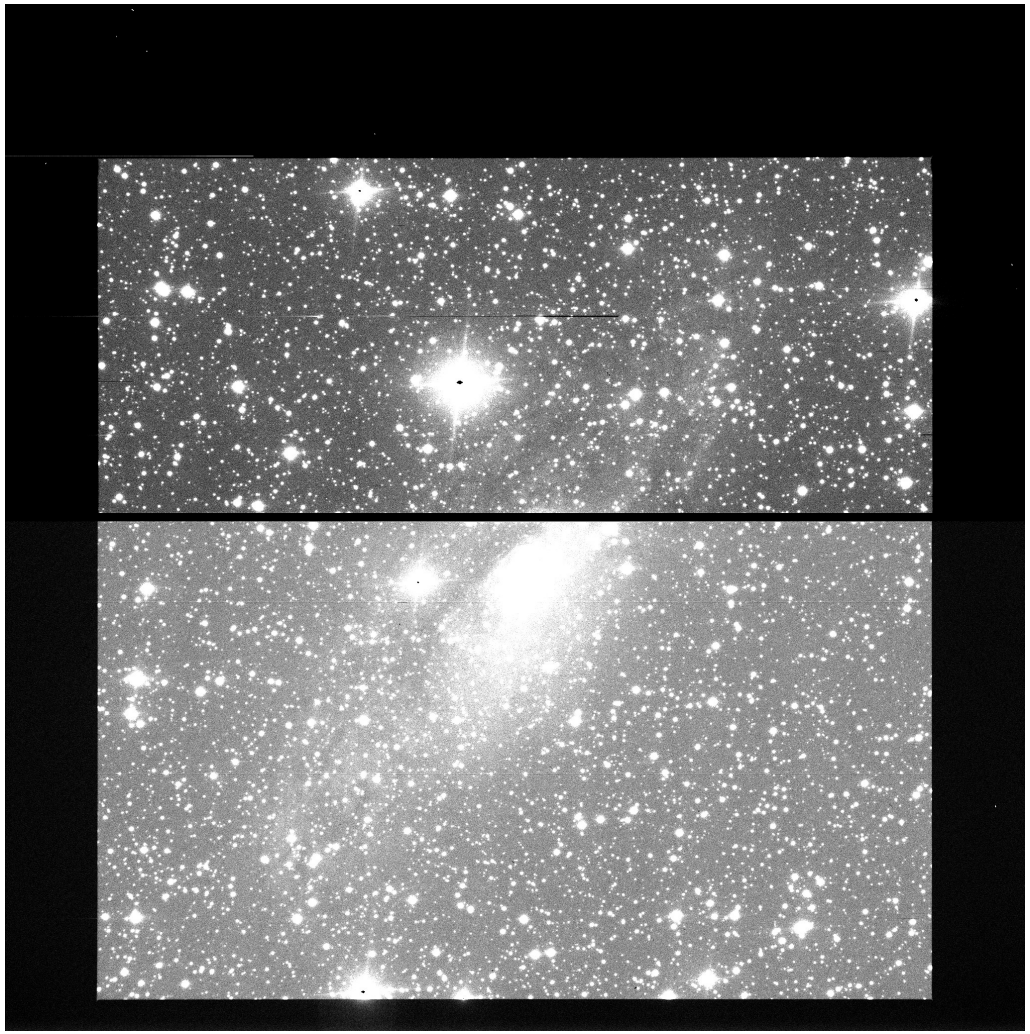
Residual in B

POLARIMETRY OF EXTENDED SOURCES WITH FORS2: SN HOSTS

NGC 6962 from SDSS DR14



POLARIMETRY OF EXTENDED SOURCES WITH FORS2: FIRST STEPS



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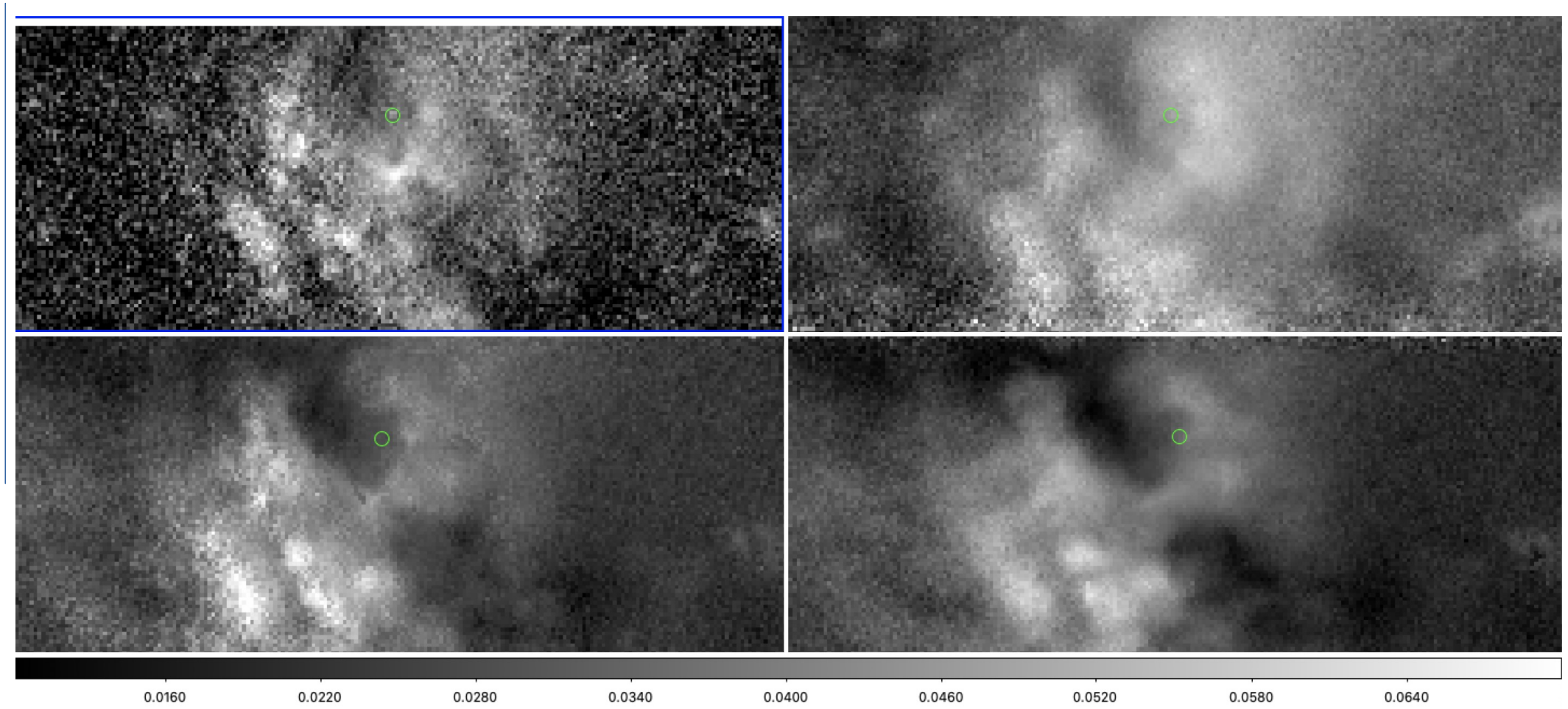


COSMOLOGY WITH SUPERNOVAE: STATUS AND FUTURE

- POLARIMETRY IS A VERY POWERFUL TOOL IN ASTRONOMY

- POLARIMETRY IS A VERY POWERFUL TOOL TO UNDERSTAND

  DUST

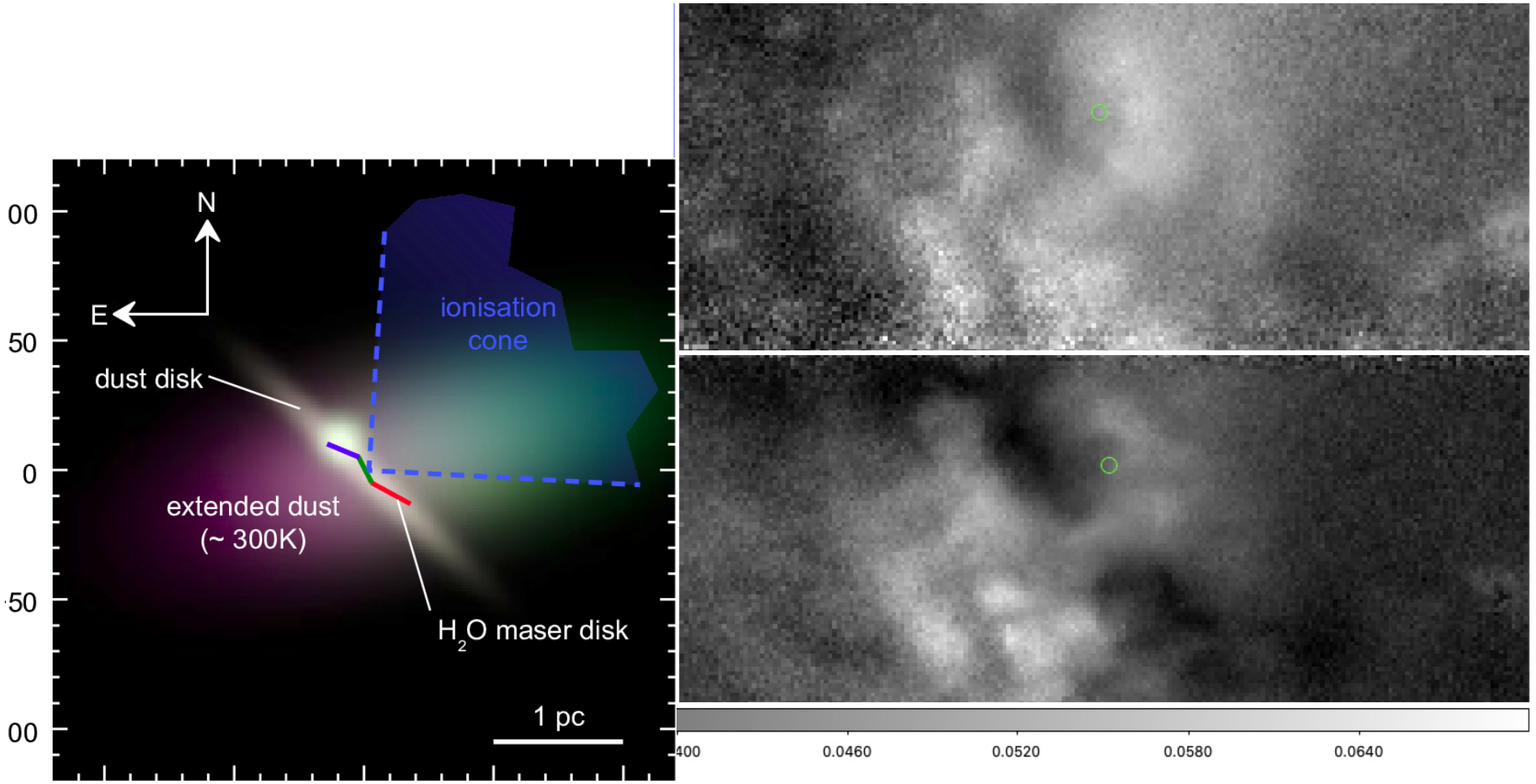
  EXPLOSION MODELS

- OUR WORK: González-Gaitán, Mourão, Patat et al, A&A, 2020

  INDICATES SOME TIPS AND TRICKS FOR THE USE OF FORS2 IN POLARIMETRIC MEASUREMENTS OF EXTENDED SOURCES

- THE METHODOLOGY CAN BE APPLIED TO STUDY OTHER EXTENDED SOURCES

POLARIMETRY OF EXTENDED SOURCES WITH FORS2: FIRST STEPS



Tristram et at, 2014