TORO: A ROBOTIC TELESCOPE FOR POLARIMETRY

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OUTLINE

- Scientific motivation
- Telescope
- Instrument
- Pipe-line data reduction program
- Conclusions

Scientific motivation:

Polarimetric monitoring of Blazars at San Pedro Martir

- The long-term project "Polarimetric monitoring of Blazars at San Pedro Martir" started in January 2008 using the 0.84-m telescope.
- A dozen scientists from Mexico, the US and Europe are involved of the project.
- Optical observations of Blazars have being routinely made since more than a decade on a large number of observatories .
- Observations are traditionally carried out by means of flux measurements only, which allows to investigate e.g. the energy budget in these sources.
- Largely neglected has been the potential of determining the properties of the sources in polarized light. This is a powerful tool, to e.g. determine strength and orientation of magnetic fields giving rise to the variable synchrotron radiation.
- Only few programs are currently conducted in this direction as e.g. the polarization monitoring on OJ 287, the MAPcat program (PI. I. Agudo) or the one carried out in Alan Marscher/Svetlana Jorstads group.

Scientific motivation:

Polarimetric monitoring of Blazars at San Pedro Martir

•The observations are carried out with the 0.84-m telescope + and the POLIMA polarimeter at San Pedro Martir. Since POLIMA has currently only a rotatable polarization polarizer available to carry out polarization measurements (with the hope to move to a calcite system in the near future) our observations are currently strongly influenced by the presence of moonlight and/or cirrus/clouds. Thus our observations are currently carried out on a monthly basis always during 7 night runs centered on new moon.

• Throughout the year, a set of ~ 35 bright sources are observed. They are divided in groups of "brighter" and "fainter" sources. The "brighter" sources are observed each night when observable, the "fainter" sources are observed only 1-2 times per run

Scientific motivation:

Polarimetric monitoring of Blazars at San Pedro Martir

The main scientific projects are:

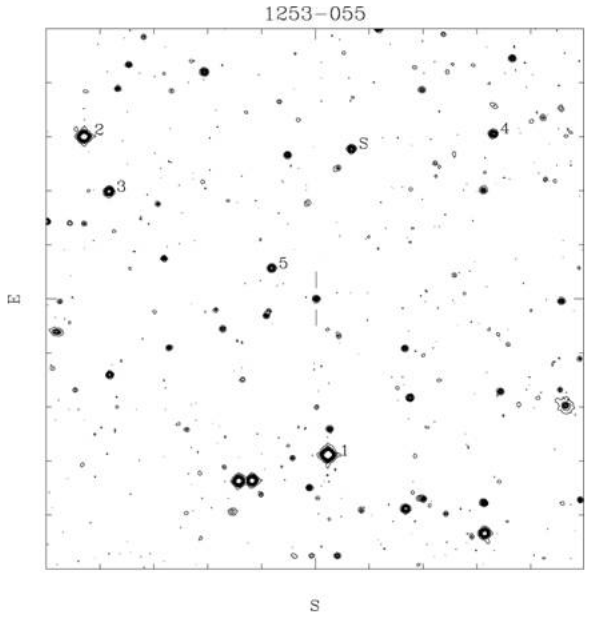
• To determine statistically the duty cycle (variability in total and polarized light, changes/stability of polarization angle etc.) on timescales of days on a long-term basis and compare them with other properties of the sources. This will be done for the "bright" sources.

• To monitor the sources as part of the GASP = The GLAST - AGILE Support Program and to set an alert in case of unexpected high activity of one of the sources.

• To participate in multi-lambda campaigns initiated due to high activity of one of the GASP-sources (or others).

1253-055 (3C 279, 4C -05.55, CTA 56)

Coordinates
R.A. = 12:56:11.1665, Dec. = -05:47:21.523 (2000.0)
z = 0.5362



GASP suggested stars: 1 2 3 5

Comparison stars

Star	U	B	V	R	I
1	13.08 (0.06)	13.02 (0.03)	12.42 (0.03)	**12.05 (0.02)**	11.70 (0.02)
2	14.06 (0.07)	13.73 (0.04)	12.99 (0.04)	**12.56 (0.03)**	12.17 (0.03)
3	15.51 (0.07)	15.49 (0.03)	14.87 (0.03)	**14.53 (0.02)**	14.20 (0.08)
4		16.53 (0.05)	15.66 (0.03)	15.13 (0.02)	
5	17.23 (0.16)	16.79 (0.04)	15.98 (0.04)	**15.47 (0.02)**	15.00 (0.04)
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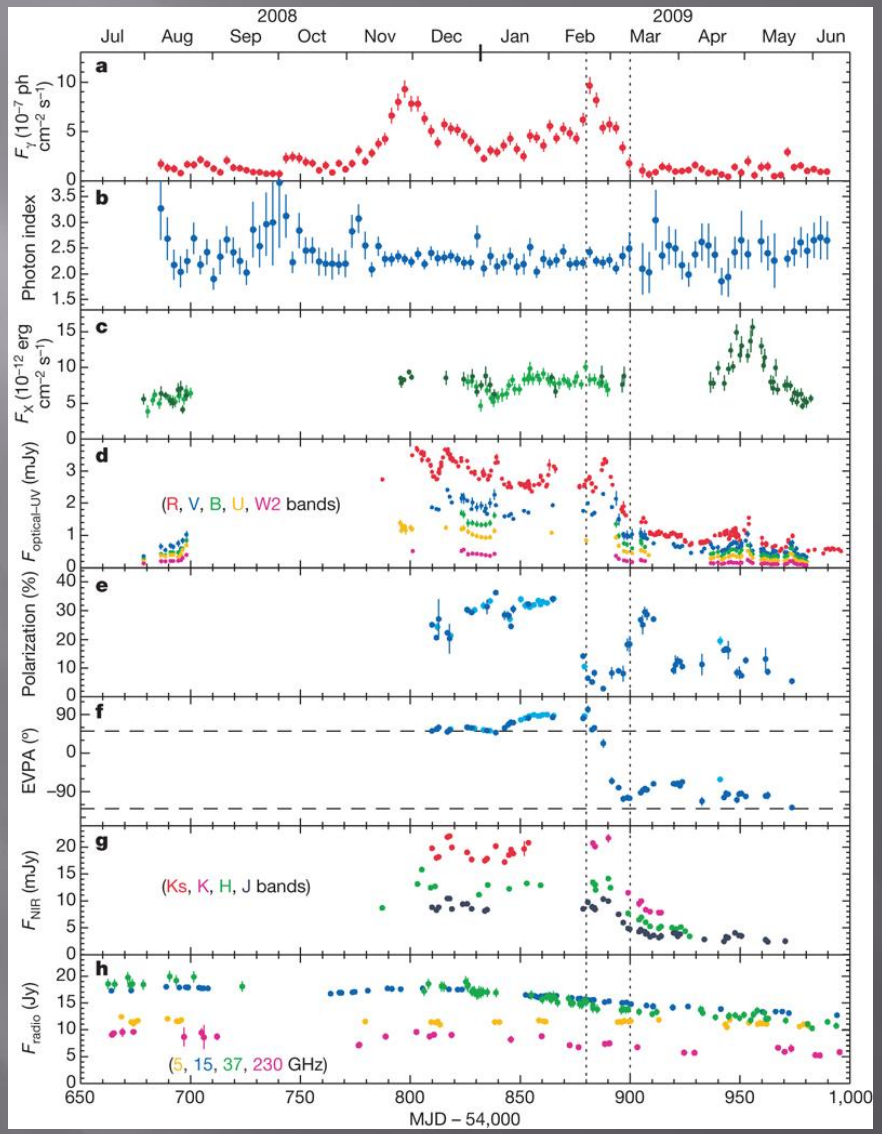
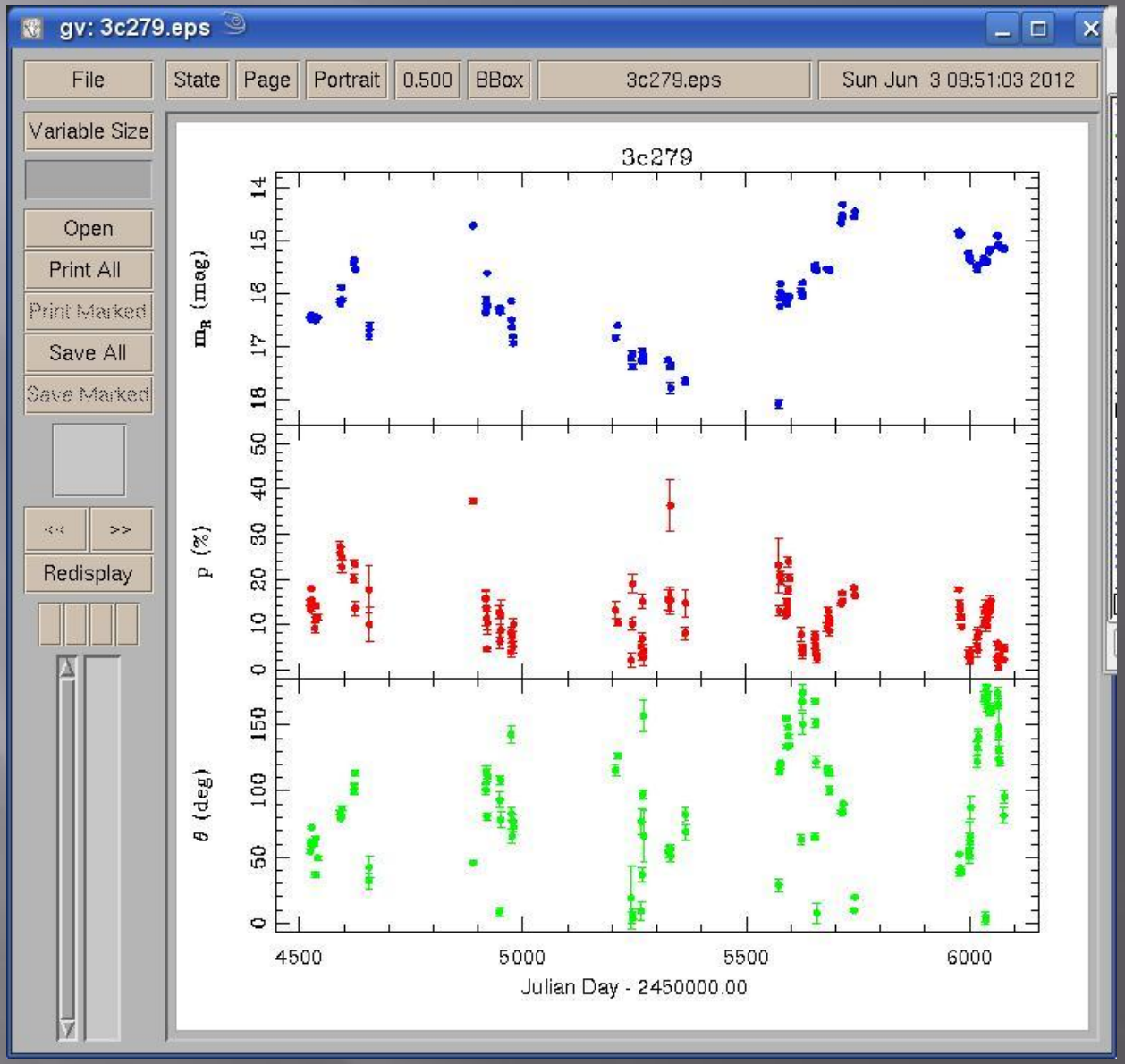
comparison stars from Raiteri C.M. et al., 1998, A&AS 130, 495
U and I data from Smith P.S. & Balonek T.J., 1998, PASP 110, 1164

Abdo, A. et al 2010, Nature, 463,919



Hiriart et al. 2012, in preparation

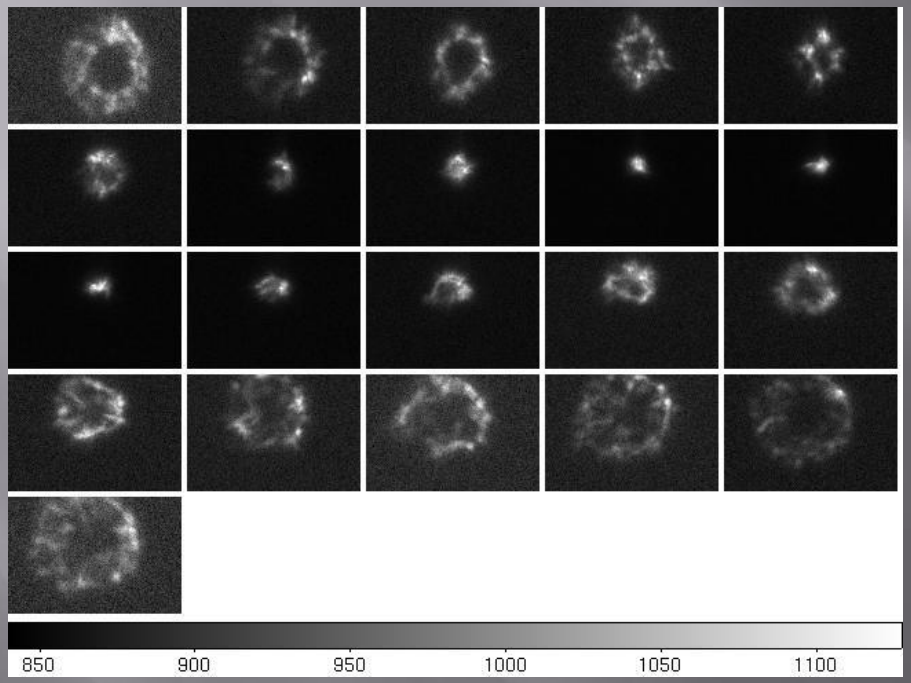


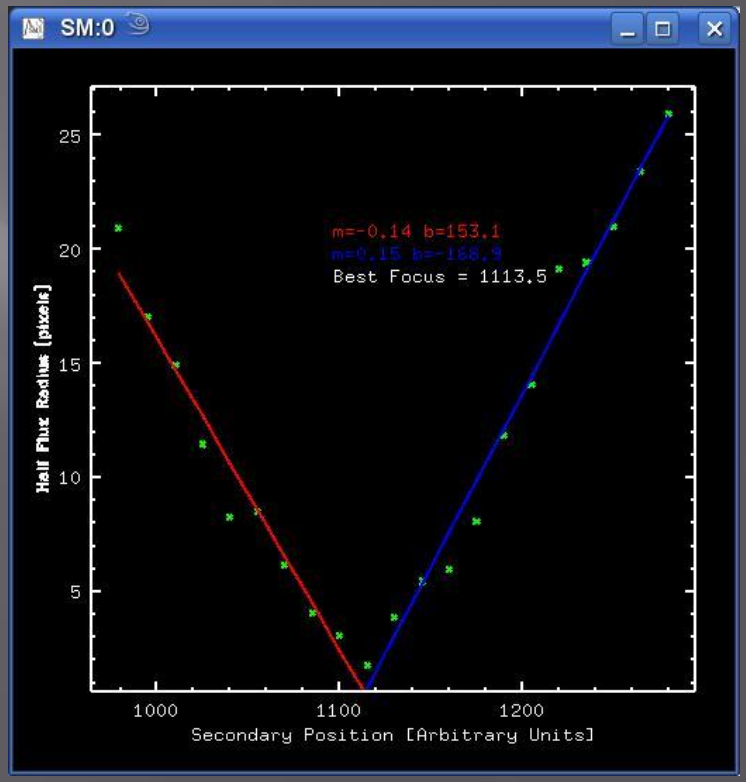
The Telescope

- **0.84 m telescope with euatorial mount**
- **Ritchey-Chretien**
- **f/15 Secondary (~ 16.43 "/mm)**
- **Limits:**
  HA: ±5^{h} 29^{m}
  DEC: +75° to -39°
- **We started operating telescope and instrument in a classic mode: manually opening the dome shutter, the telescope and finder lids, supervising imaging, etc.**
- **The first system automatiza was the focusing because was a very time consuming.**

Fitting a Gaussian profile to the star profile and using FWHM as a figure of merit **does not work !**

"*Fast Auto-Focus Method and Software for CCD-Base telescops*",
Larry Webster y Syeve Brady, en "Minor Planet Amateur/Profesional Workshop" pp.104-113 Tucson, Az.

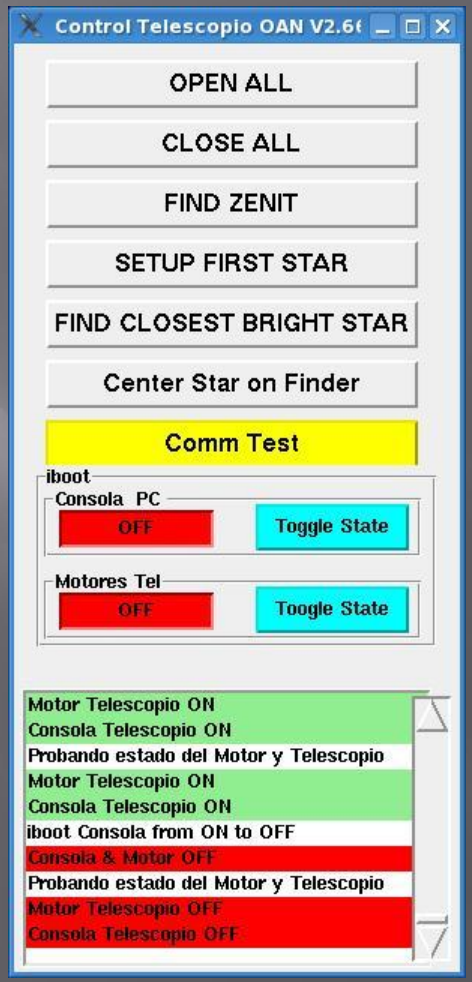




Graphic Interface to test different systems on the telescope

To test the diferent systems of the telescope we create a graphic interface.

The button actions can be alos executed by line commands in a script

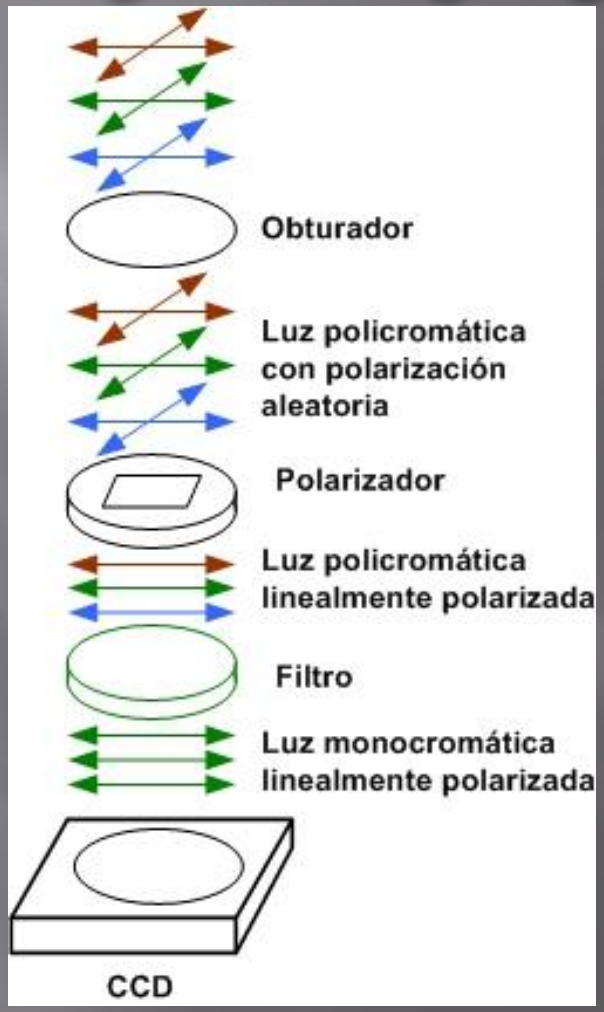


Automatic control of opening dome shutter and opening telescope and finders lids.

Power pad for energizing dome shutter

Telescope lid

POLIMA: A Single Imaging Polarimeter



Observing with POLIMA linear polarimeter:

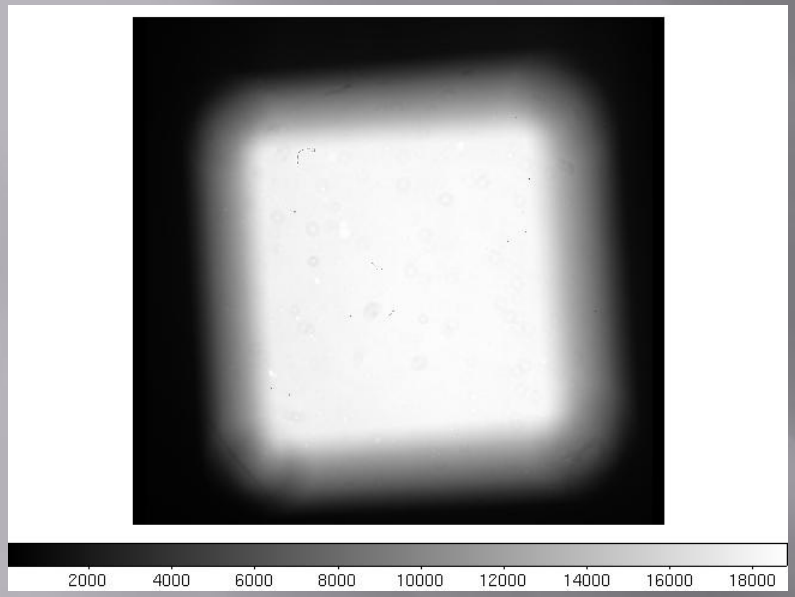
- At dawn and dusk, get flat field images at relative position angles of the polarizer at 0°, 45°, 90°, and 135° for each filter.

- During the observing run, get a set of bias images.

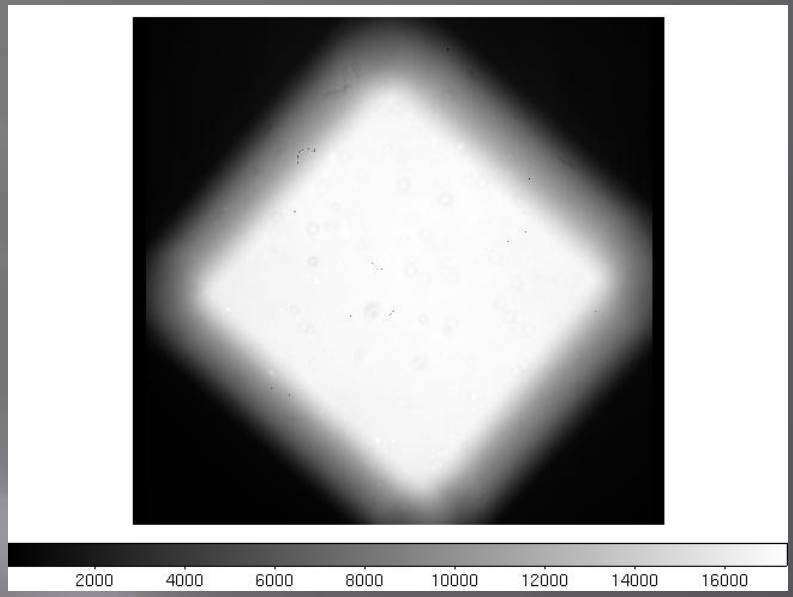
- At each object, get images at each filter at the position angles of 0°, 90°, 45°, and 135° (IN THAT ORDER!) for the study objects.

- Repeat the previous step for the polarized and non-polarized standard stars.

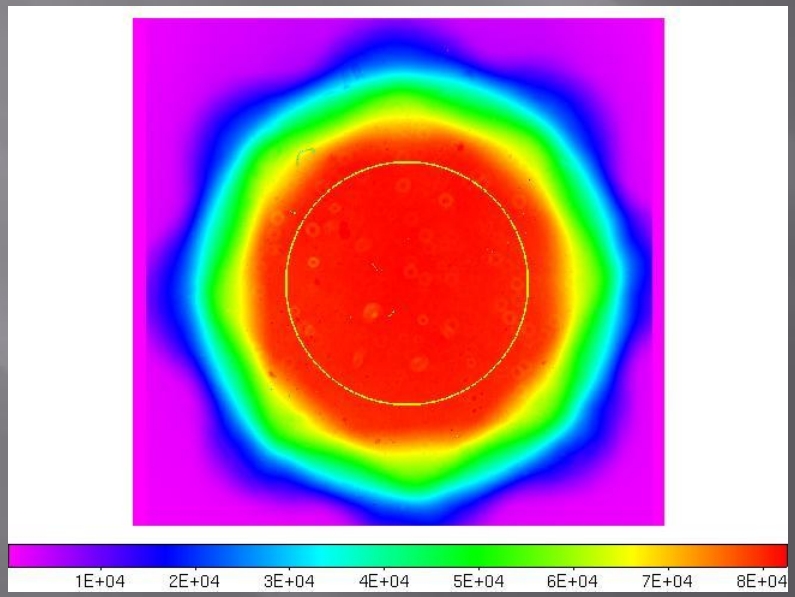
- We automatiza the flat fields and data acquisition images (polarimeter angle, image acquisition, illumination level, etc.)

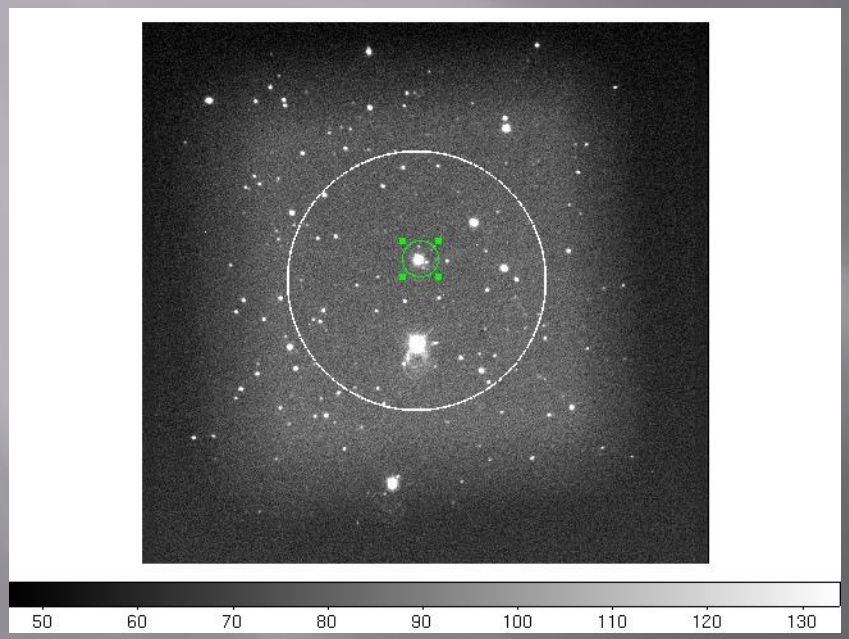


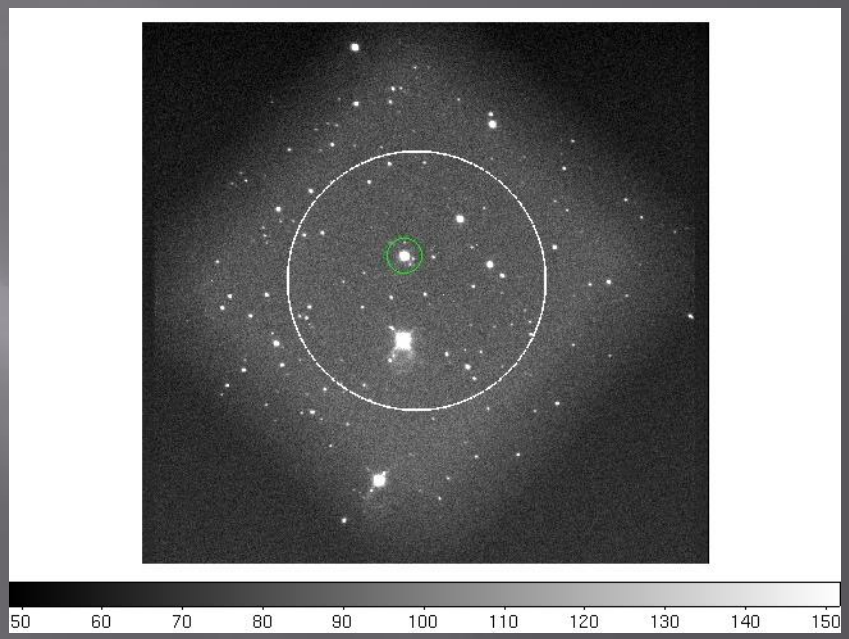
Flat image at 0° and 90°



Flat image at 45° and 135°







White circle is the vignating free area

Normalized Stokes parameters, u=U/I and q= Q/I are defined by

$$u = U/I = [I(0°)-I(90°)] / [I(0°)+I(90°)]$$

and

$$q = Q/I = [I(45°)-I(135°)] / [I(45°)+I(135°)]$$

where I(θ) is the intensity at polarizer position angle θ.

The degree of linear polarization is given by

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

and the position angle by

$$\theta = \frac{1}{2}\tan^{-1}\left(\frac{\mathbf{U}}{\mathbf{Q}}\right)$$

Stoke parameter, the intensity of the source, is not measured directly but it can be obtained from

$$I = I(\theta) + I(\theta+90°)$$

Therefor, from our four images at polarized angles of 0, 45, 90, and 135 We can get two estiamtes for the total intensity $I = I(0°)+I(90°)$ and $I=I(45°)+I(135°)$. If there are no variations of the object or the sky, both values should be pretty similar.

To determine the instrumental polarization and to calibrate the offset angle of the polarizer we use the polarized and non-polarized estandar star from Schmidt, Elston & Lupie (1992)

G 191B2B (NON POLARIZED STANDARD STARS)
05 05 30.61 +52 49 51.9 (2000)
V = 11.79

	P%	+/-	Theta
U	0.065	.038	91.75
B	0.090	.048	156.82
V	0.061	.038	147.65

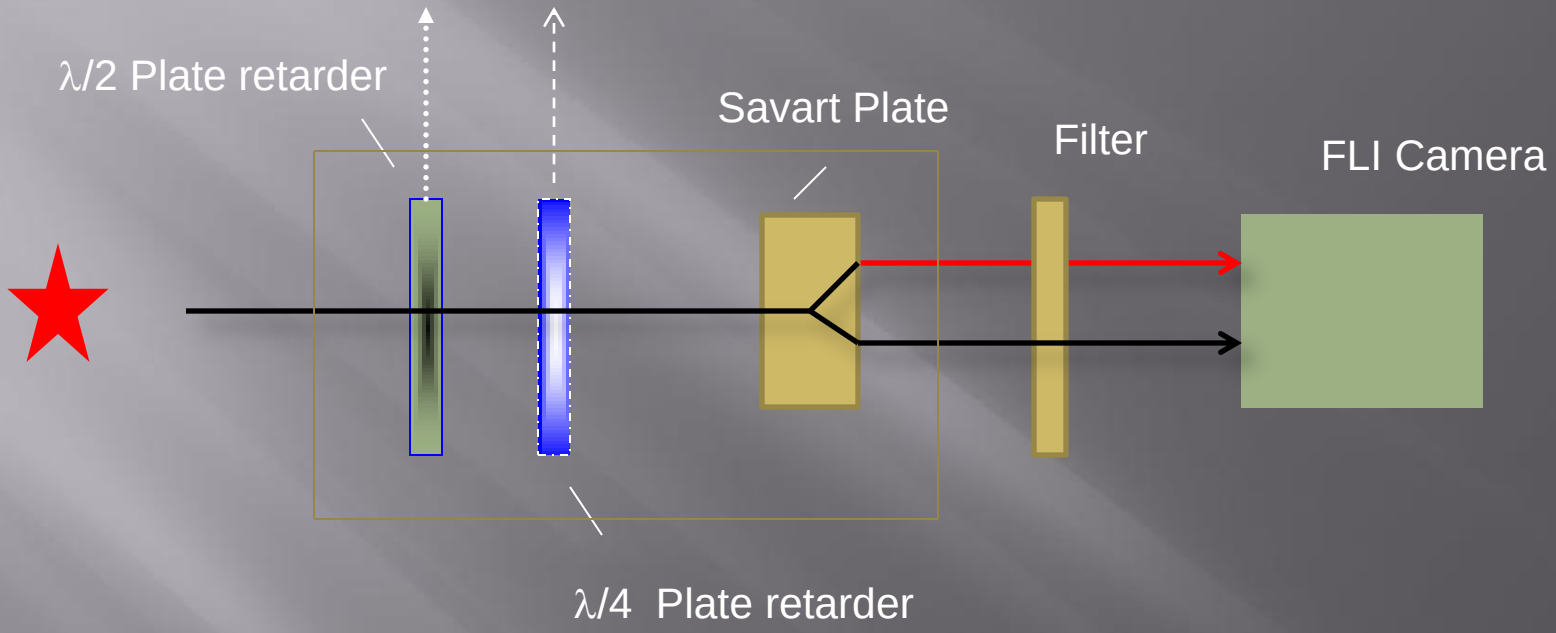
BD +59 389 (POLARIZADA STANDARD STARS)
02 02 42.09 +60 15 26.44 (2000)
V = 9.07

	P%	+/-	Theta	+/-
N	5.525	0.098	98.78	0.51
U	5.772	0.051	98.22	0.26
B	6.345	0.035	98.14	0.16
V	6.701	0.015	98.09	0.07
R	6.430	0.022	98.14	0.10
I	5.797	0.023	98.26	0.11

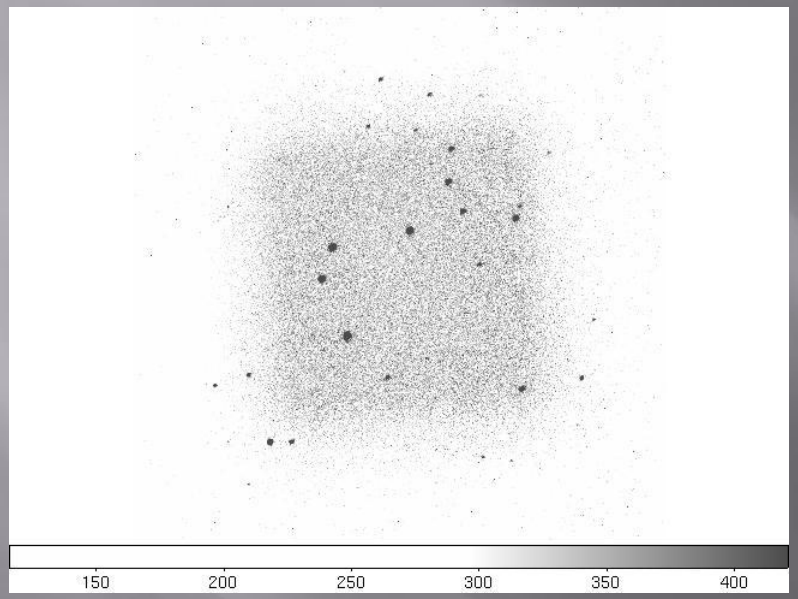
Instrumental errors:

- Atmospheric seeing and guiding errors.
- Instrumental polarization due to optics of the instrument and the telescope.
- Scattered light at the telescope and the instrument.
- Temperature dependene of the optical components.
- Ghoat images.
- Variable sky background.
- Non polarized scatterded ligt from the sky and the optics.

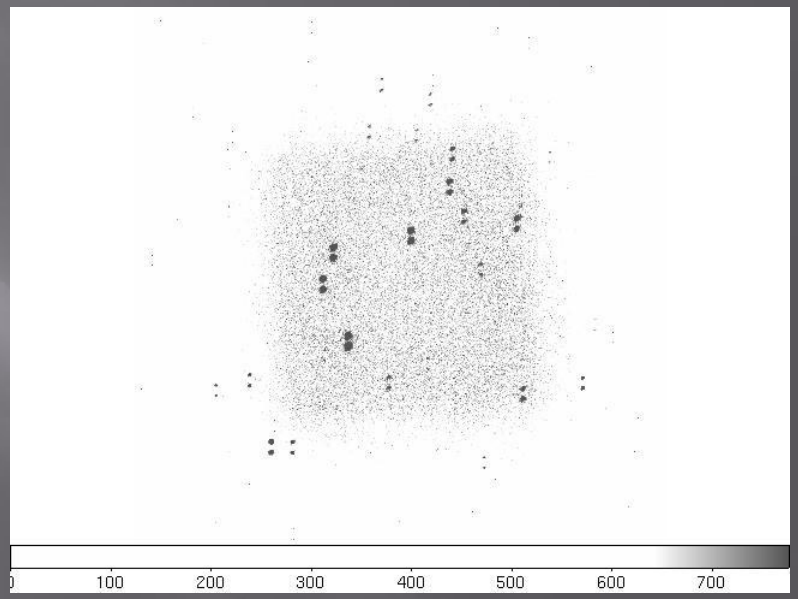
Double beam polarimeter (POLIMA-2):



Direct imaging and polarimetry capabilities

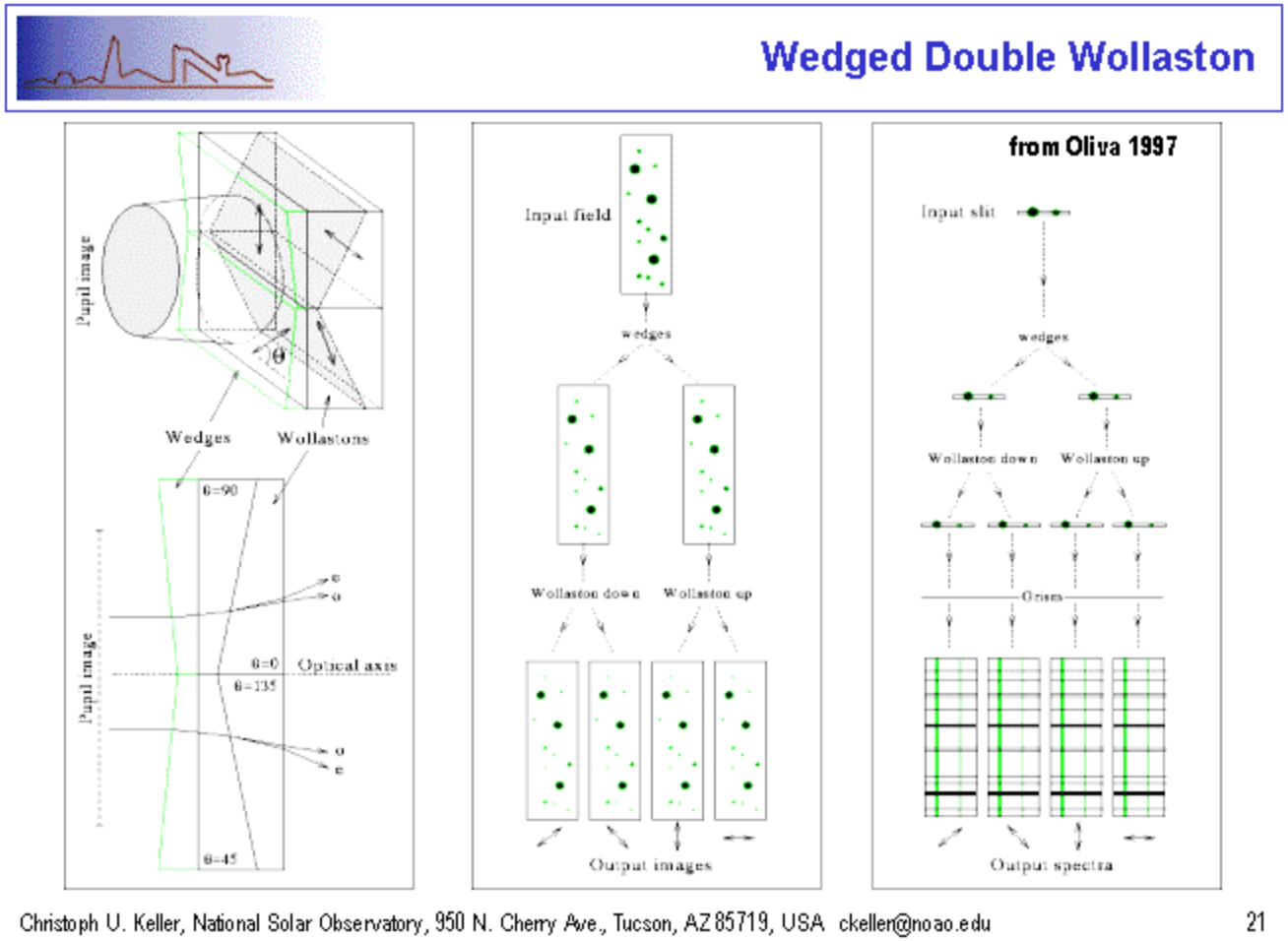


POLIMA (Single Beam polarimeter)



POLIMA-2 (Double beam polarimeter 8 arc-sec)

A four-fold beam polarimeter



Pipe-line data reduction for POLIMA:

• Subtract dark current image from raw data images

• Divide the raw images by the flat field image at the respective angle.

• Calculate the fluxes at the four positions of the polarizer: 0º, 45º, 90º , and 135º (subtract the sky contribution at each angle).

• Get the Stokes parameters.

• Subtract the instrumental polarization.

• Correct the polarization angle.

For POLIMA:
Instrumental polarization (0.6± 0.5)%
Position Angle offset = -(92±2)°

Conclusions:

1. We started the conversion from classic to robotic operation of the 0.84-m telescope of the San Pedro Martir Observatory.

2. A new polarimeter is being built to take advantage of the robotic operation of the telescope.

3. The scientific motivation behind this project is the monitoring of the optical polarization of bright blazars. However, it can be used also for imaging of extended objects or polarimetry of point sources.