SPARC4

Simultaneous Polarimeter and Rapid Camera in 4 bands

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UK-Brazil partnership on astronomical instrumentation
23/February/2016

What is SPARC4?

- Simultaneous Polarimeter And Rapid Camera in 4 bands
  - ★ imaging in four bands simultaneously
  - ★ polarimetry as an option
  - ★ good time resolution: 1 s or better

- new instrument for the OPD 1.6-m telescope - Laboratório Nacional de Astrofísica (MCTI)

It is planned to be an observatory facility, open to any astronomer.

Why SPARC4?

- SPARC4 is an instrument shaped to differential techniques: differential photometry and polarimetry.

- It allows to get the best use of the observatory, considering the atmospheric conditions of the site.

Science cases

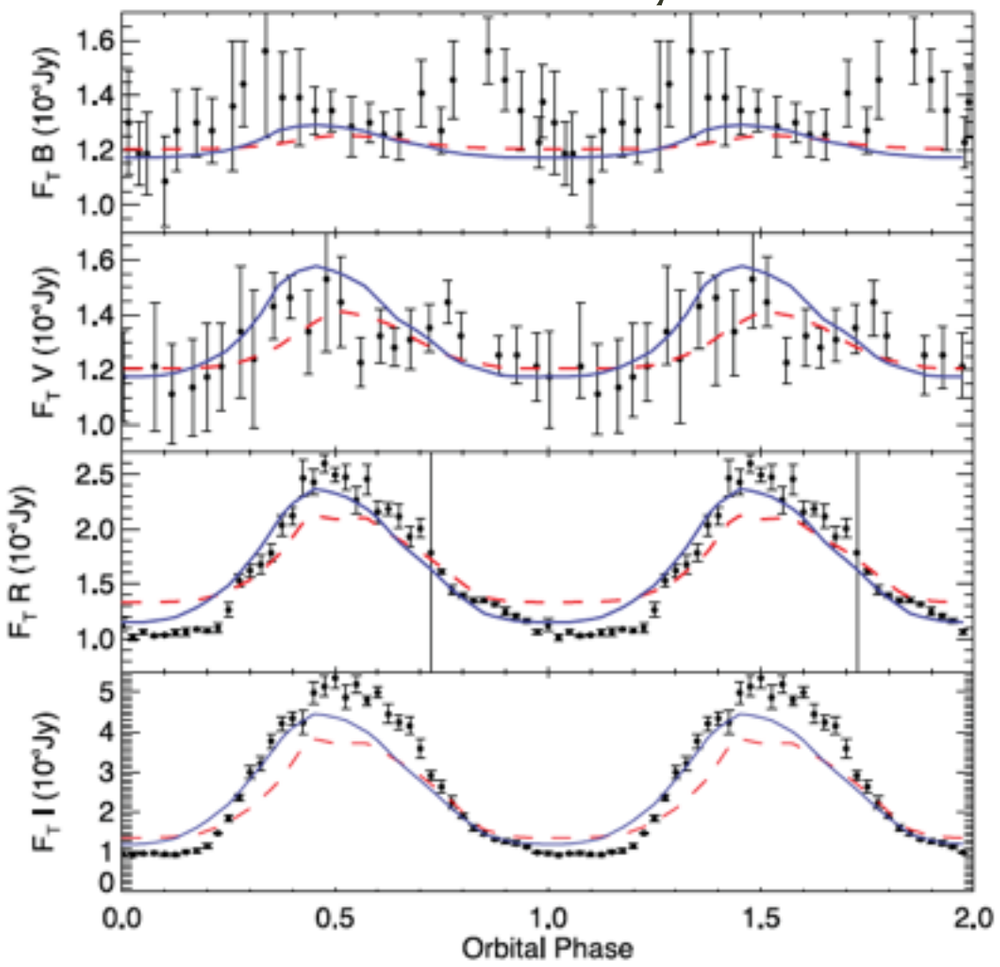
- **Interacting binaries**
  ✓ multi-band light and polarization curves
- **Pulsating stars**
  ✓ multi-band light curves
- **Circumstellar envelopes**
  ✓ multi-band polarimetry
- **Star forming regions**
  ✓ multi-band polarimetry
- **Stellar populations and open cluster**
  ✓ multi-band photometry
- **Solar system studies**
  ✓ multi-band light curves
- **Exoplanets**
  ✓ multi-band light and polarization curves

Some examples of present OPD science that can be benefited from SPARC4

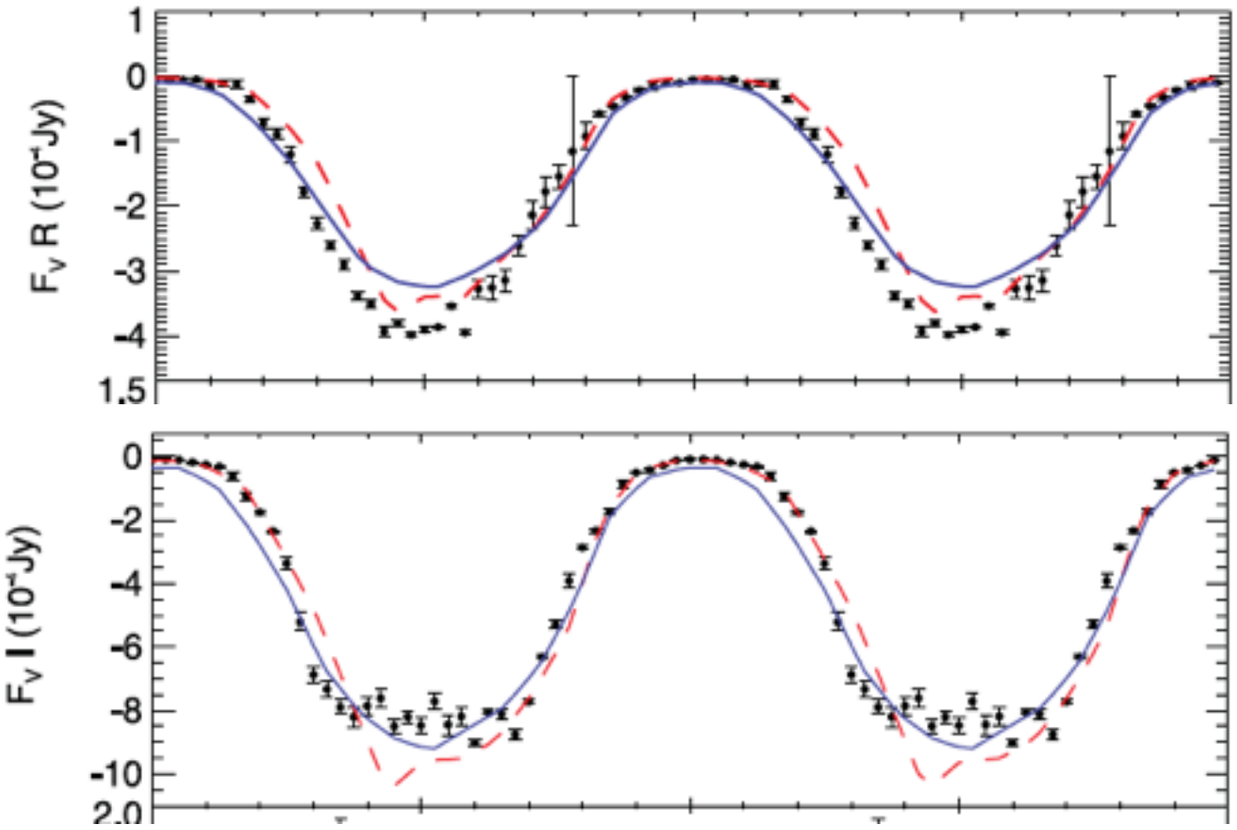
Multicolor time-series: photometry and polarimetry

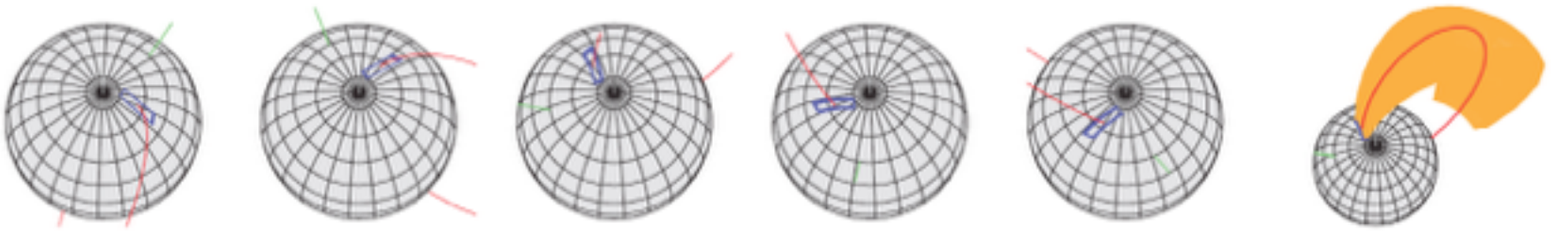
Magnetic accretion in cataclysmic variables

Photometry



Polarimetry





0.2 0.4 0.6 0.8 0.9

Orbital phase

Title: Stokes imaging of AM Her systems using 3D inhomogeneous models - II. Modelling X-ray and optical data of CP Tucanae

Authors: Silva, K. M. G.; Rodrigues, C. V.; Costa, J. E. R.; de Souza, C. A.; Cieslinski, D.; Hickel, G. R.

Bibliographic 2013MNRAS.432.1587S

Flickering in CVs

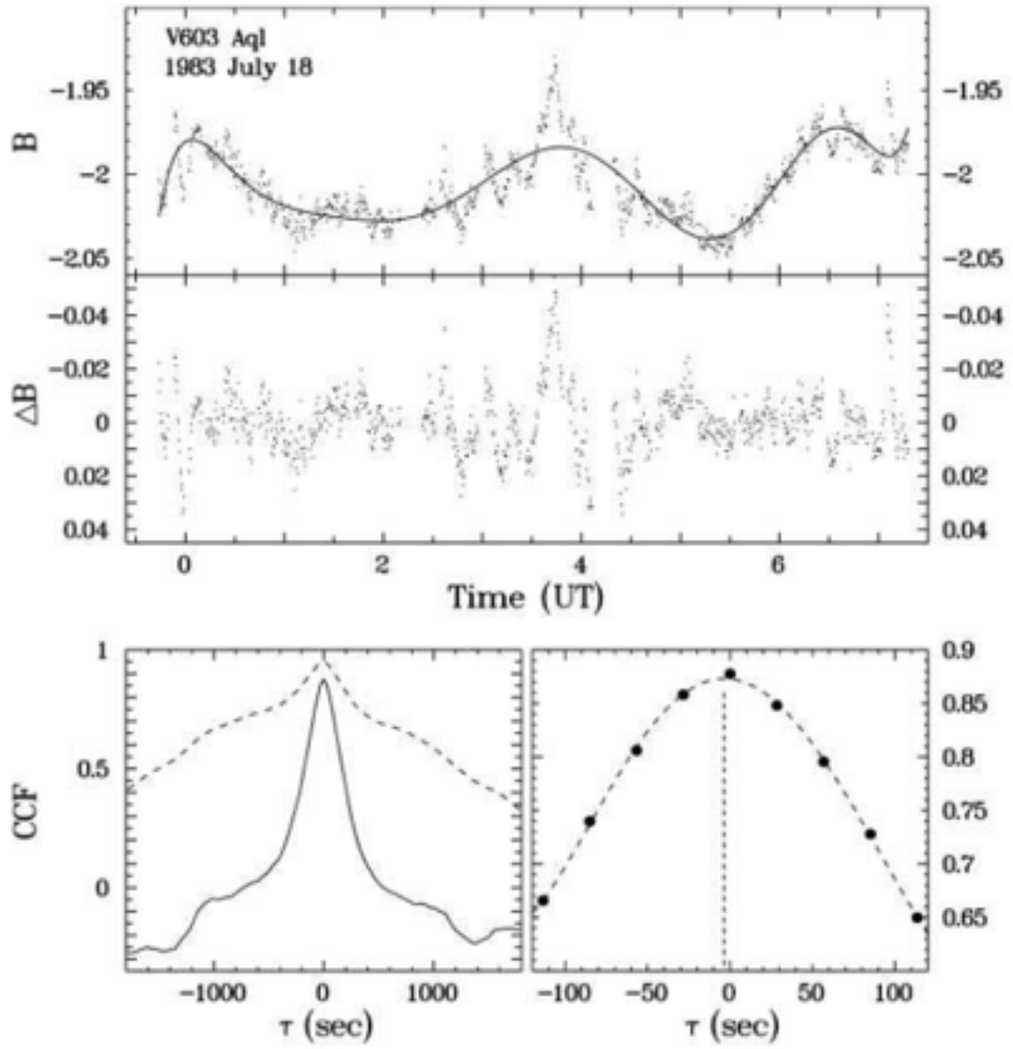


Fig. 1. Example of a light curve and the CCF of the brightness variations in two photometric bands. *Top: B*-band light curve of V603 Aql observed on 1983 July 18. The solid line is a fit of a high-order polynomial to the data. *Centre:* Residuals between the original light curve and the polynomial fit. *Bottom left:* CCF of the light curve shown in the top panel with the simultaneously observed light curve in the *U*-band (broken line) and of the residuals between the original data and the polynomial fit (solid line). *Bottom right:* Enlarged section of the maximum of the CCF shown as a solid line in the lower left panel (dots) together with a fit of a high-order polynomial to the data (broken curve). The broken vertical line indicates the location of the maximum of the fitted polynomial.

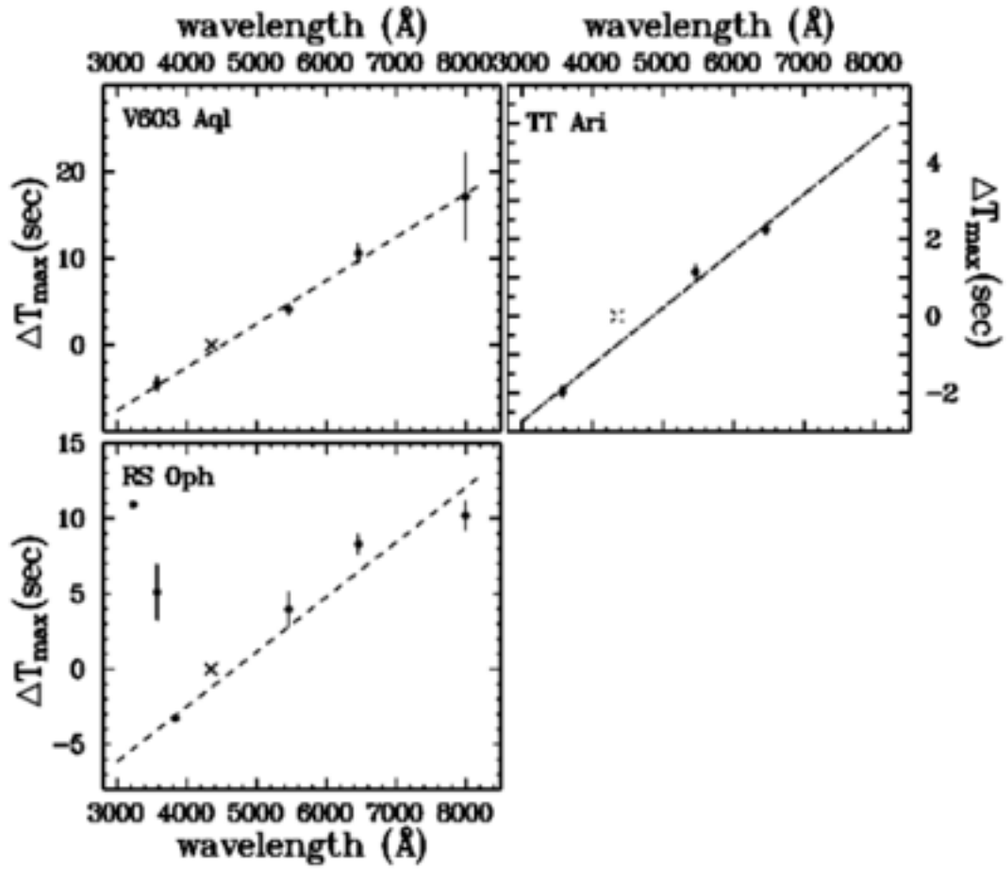


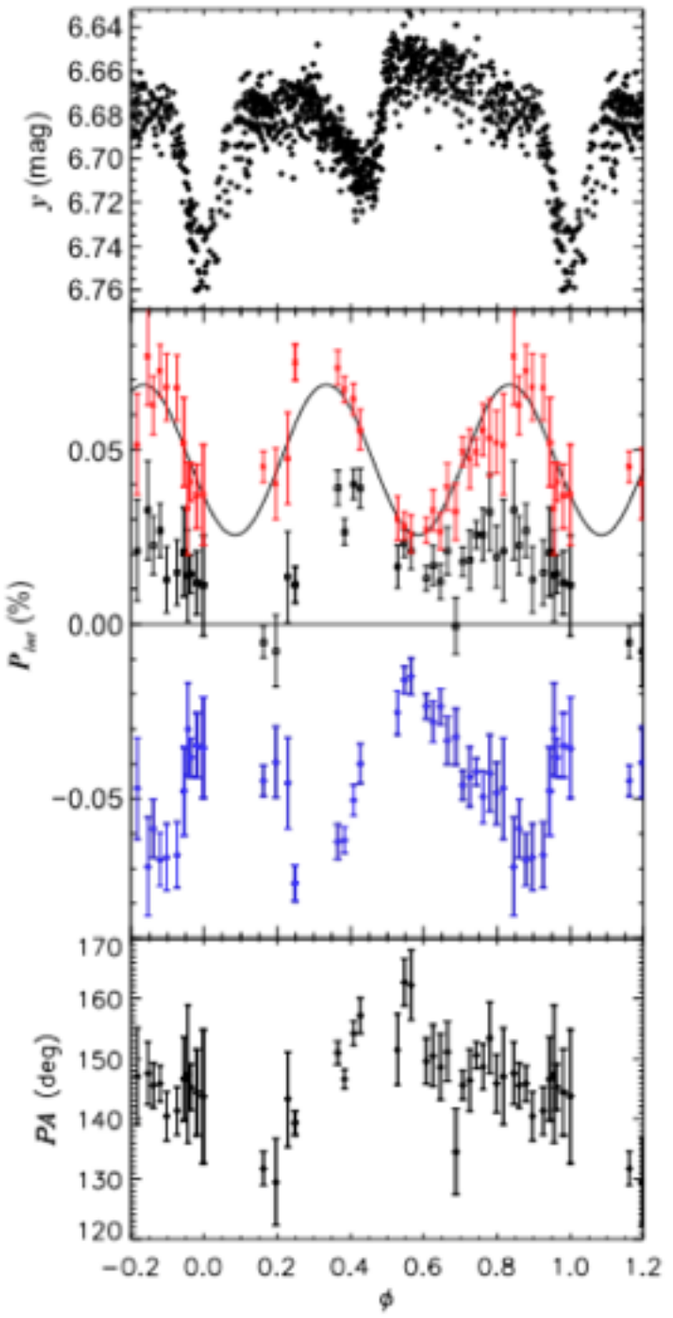
Fig. 4. Average ΔT_{max} derived from high time resolution light curves of V603 Aql, TT Ari and RS Oph as a function of isophotal wavelength of the comparison band. The broken lines are linear least-squares fits to the data points (in the case of RS Oph without considering the points referring to the *W* and *U* bands), weighted by the inverse of their standard deviations. The location of the reference band (*B*) is indicated by a cross. The error bars represent the mean error of the mean.

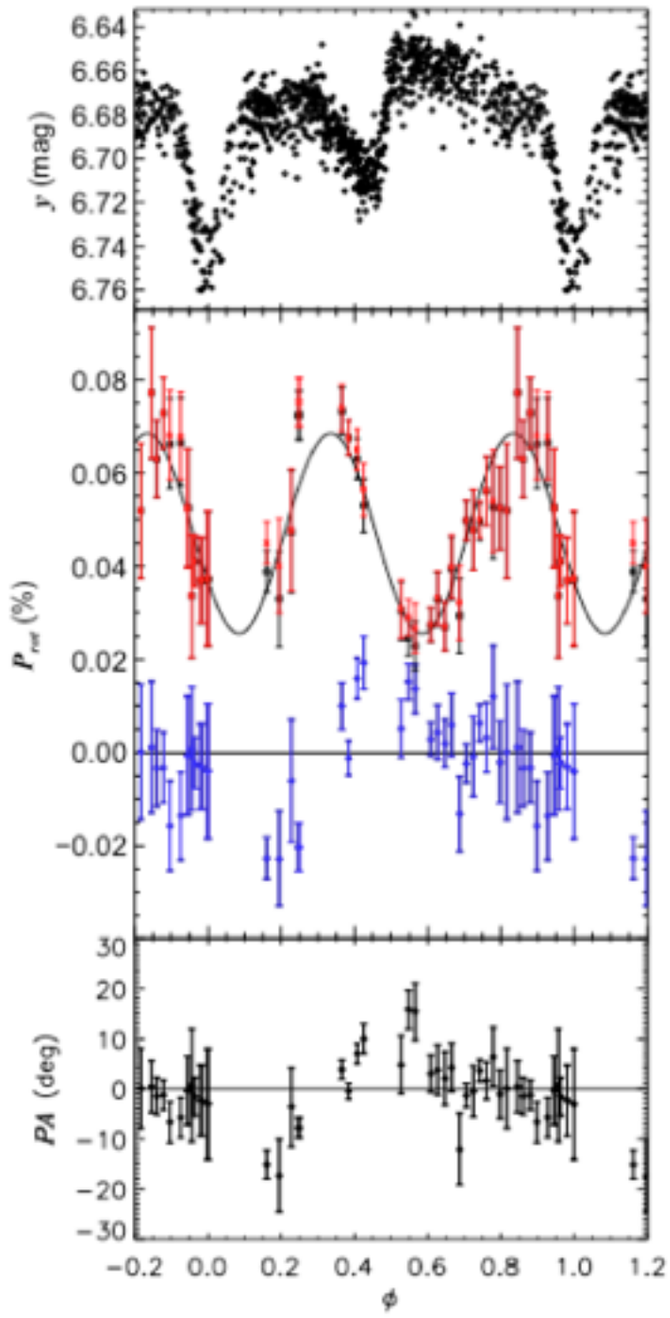
Title: Time lags of the flickering in cataclysmic variables as a function of wavelength

Authors: Bruch, Albert

Bibliographic Code: 2015A&A...579A..50B

Be stars





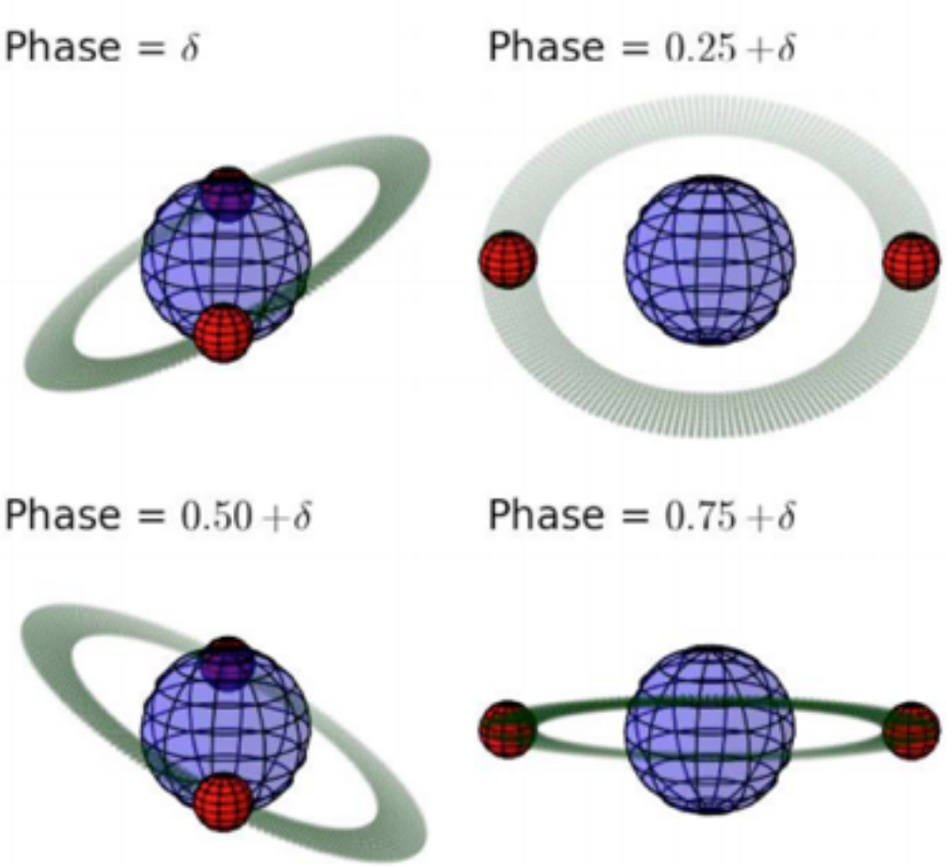


FIG. 3.— Geometric conception of the "dumbbell + disk" model, to scale.

Title: Polarimetric Observations of σ Orionis E

Authors: Carciofi, A. C.; Faes, D. M.; Townsend, R. H. D.; Bjorkman, J. E.

Bibliographic 2013ApJ...766L...9C

Interstellar magnetic field and dust properties

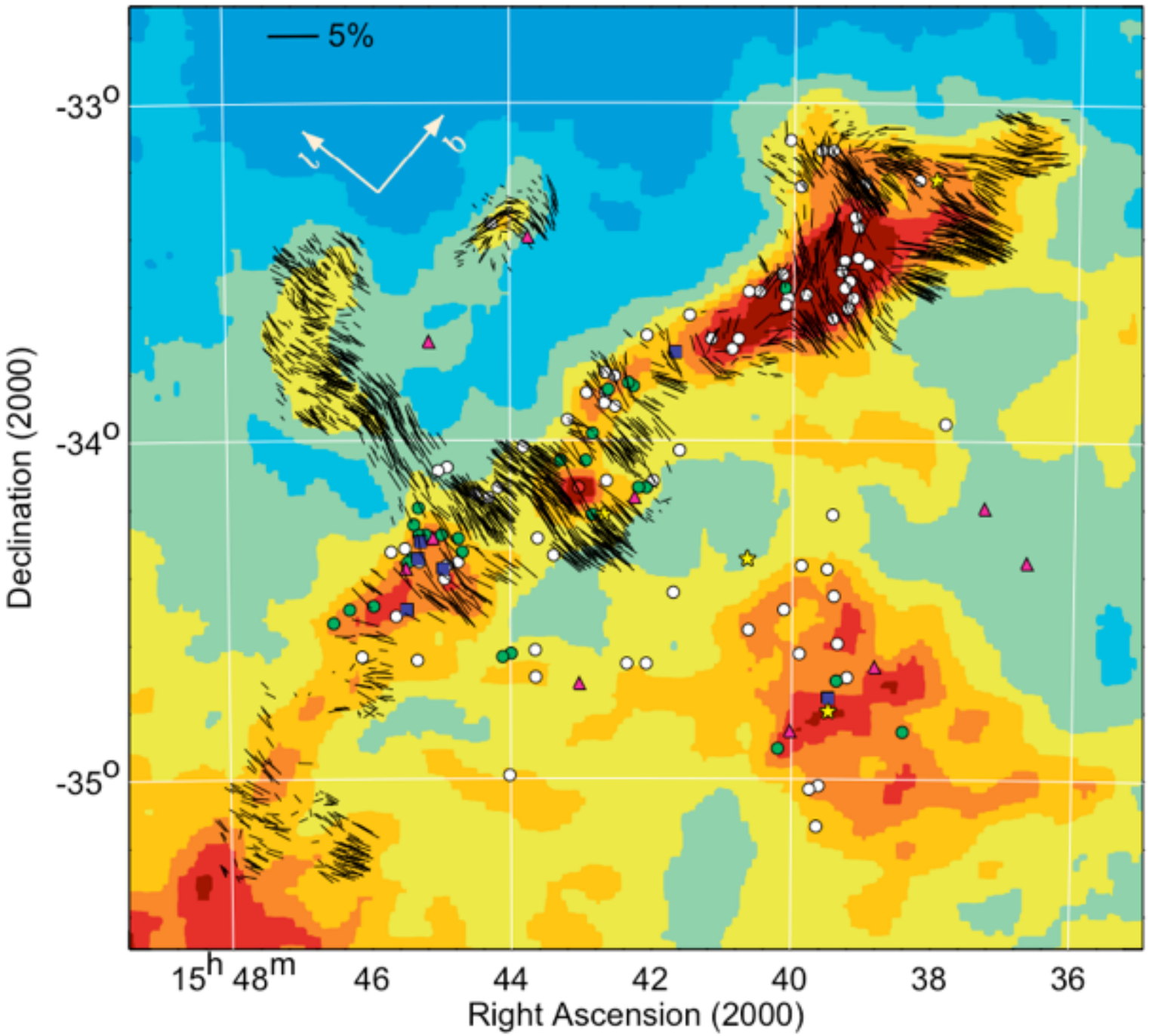


Figure 4. The obtained polarization degree vectors overlaid on the *IRAS* 100 μm emission map of Lupus I and its surrounding region. The length of each vector correlates linearly with the measured degree of polarization according to the scale indicated in the upper left corner, and its orientation gives the direction of the plane-of-sky component of the local magnetic field. The position of different classes of young stellar objects, from Rygl et al. (2013), are indicated according with the following code: unbound cores (white circles), prestellar cores (green circles), class 0 (red circle), class I (triangles), class II (squares), and class III (stars). Directions of increasing Galactic longitude (l) and latitude (b) are shown in the upper left corner.

Title: Tracing the Magnetic Field Morphology of the Lupus I Molecular Cloud

Authors: Franco, G. A. P.; Alves, F. O.

Bibliographic 2015ApJ...807....5F

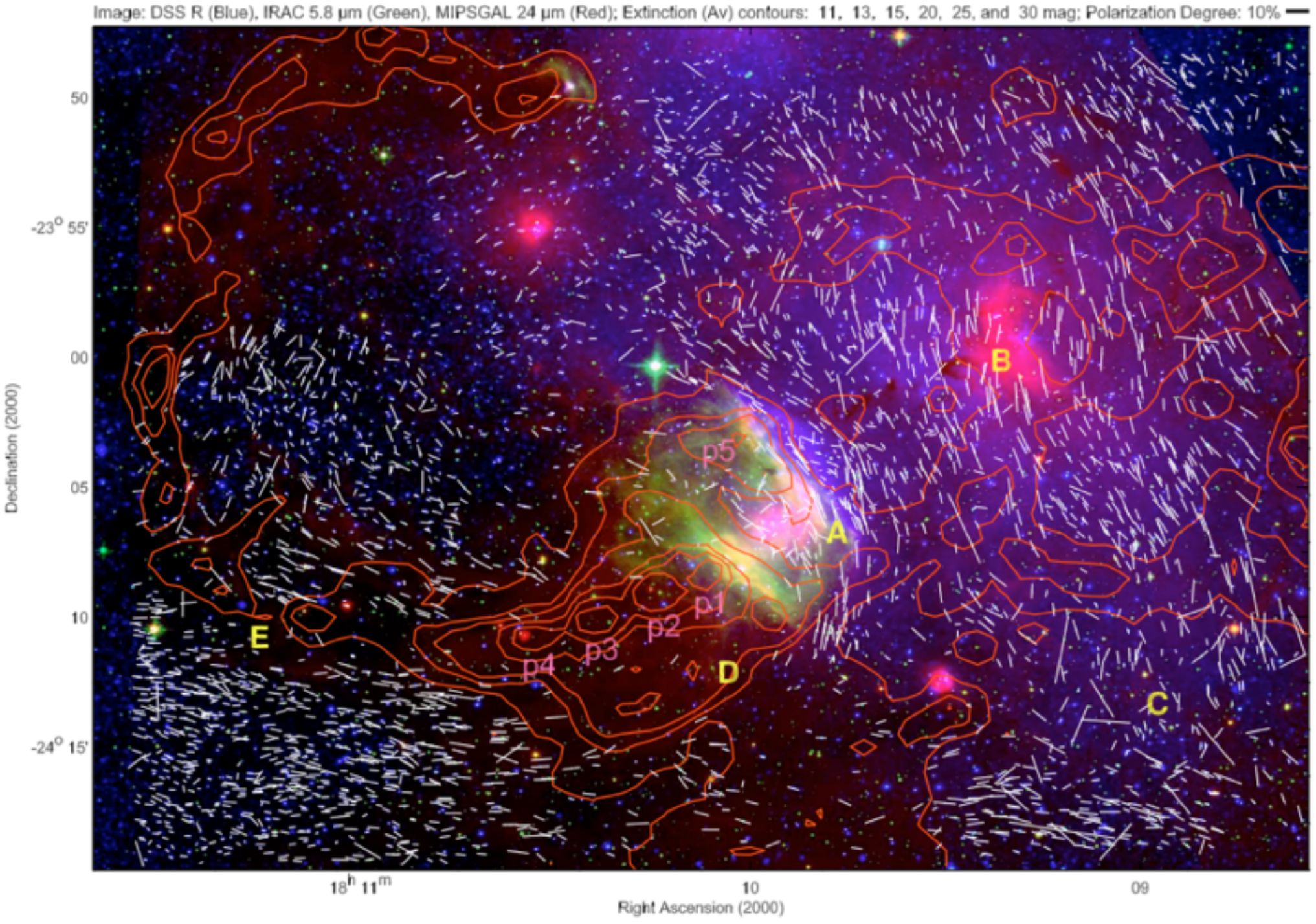


FIG. 4.— R band polarimetric mapping of Sh 2-29. The combined image is composed by the R band (DSS, blue), as well as by the 5.8 and 24 μm bands from *Spitzer* (respectively green and red). The size of each vector is proportional to P (a $P = 10\%$ vector is shown at the upper right). Labels from A to E are used to highlight some of the main features inferred from the polarization vectors' orientation pattern, as discussed in Section 5.1. Indicators p1 to p5 show the location of dense cloud structures around the central cavity, presenting peak extinction values between $A_V = 20$ and $A_V > 35$ (see Section 5.6).

Title: Optical/Near-infrared Polarization Survey of Sh 2-29: Magnetic Fields, Dense Cloud Fragmentations, and Anomalous Dust Grain Sizes

Authors: Santos, Fábio P.; Franco, Gabriel A. P.; Roman-Lopes, Alexandre; Reis, Wilson; Román-Zúñiga, Carlos G.

Bibliographic 2014ApJ...783....1S

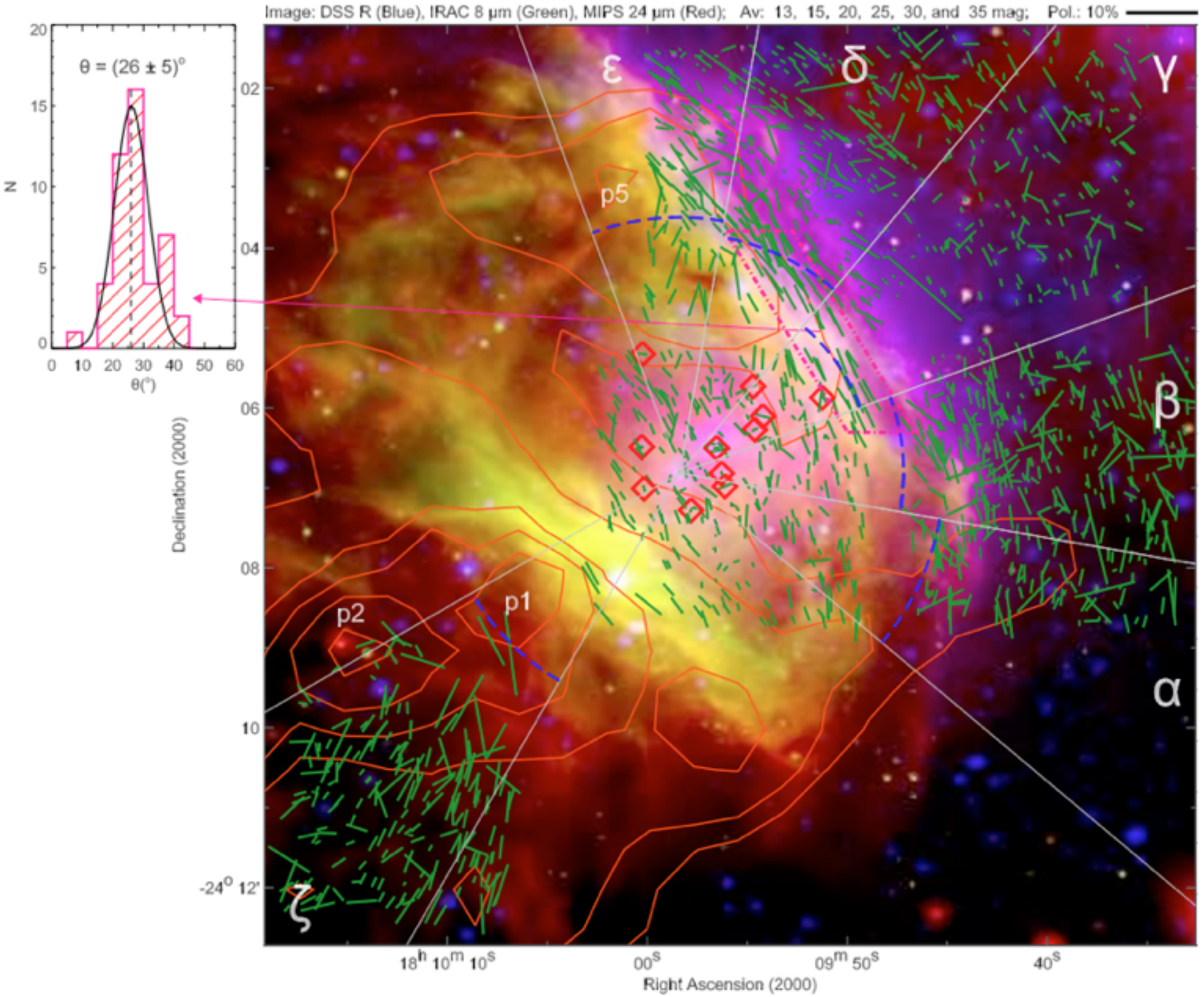


FIG. 5.— Near-IR (H band) polarimetric mapping toward the Sh 2-29 central interstellar cavity. A RGB combined image of this area is used, corresponding to the R-DSS band (blue), as well as the 8 and 24 μm bands from *Spitzer* (respectively green and red). The radial strips labeled from α to ζ are used to study polarization degree as a function of radius (Section 5.5), with the blue dashed lines indicating the positions were a rise in polarization occur. Red diamonds mark the positions of those stars presenting Hα emission (Ogura et al. 2002) that were detected in the polarimetric survey. The dot-dashed pink polygon indicates the area which was used to apply the Chandrasekhar-Fermi method (see Section 5.8). The polarization angle histogram shown at the left is used in this same analysis in order to derive the angle dispersion within this area.

Microlenses

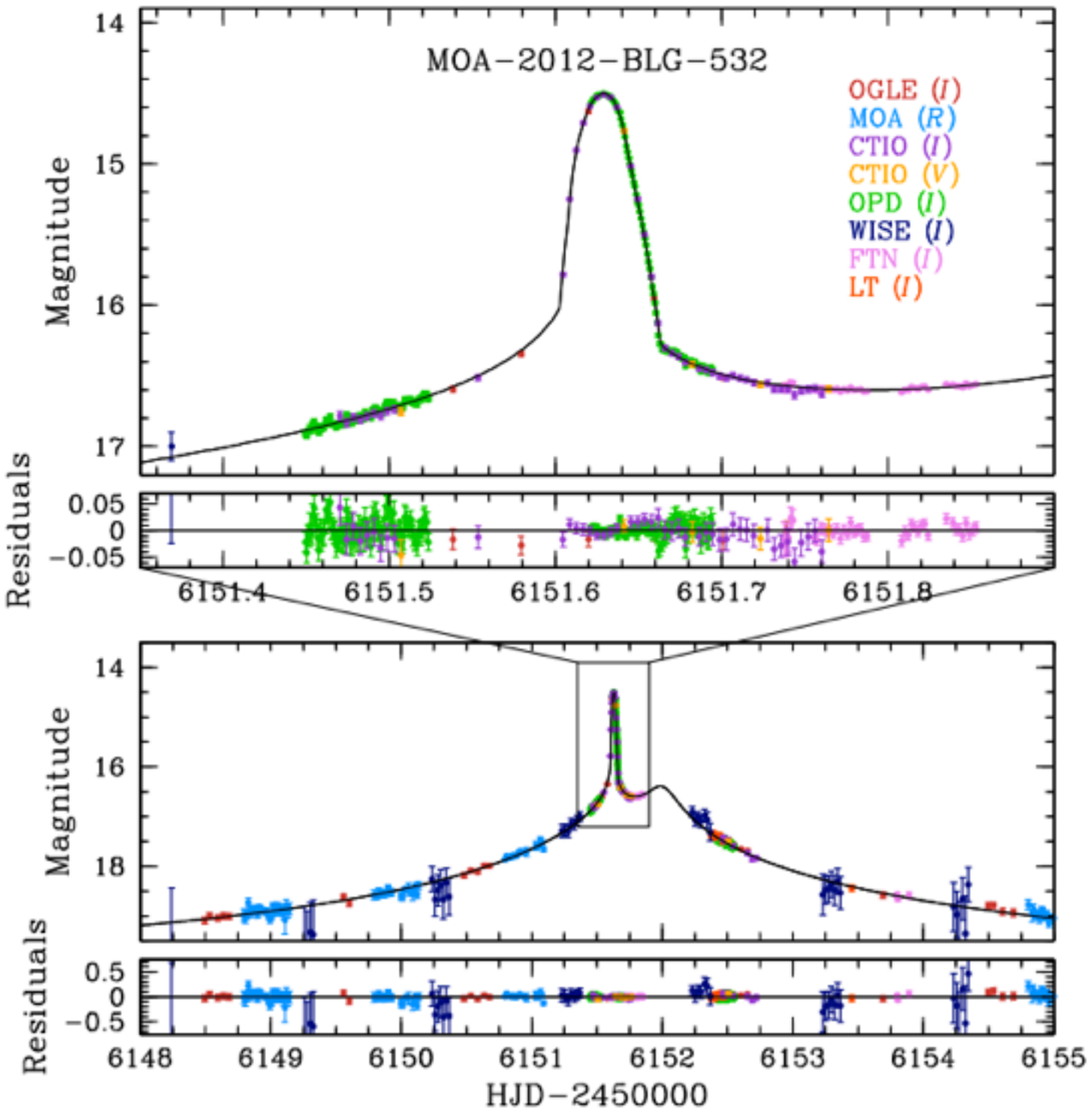
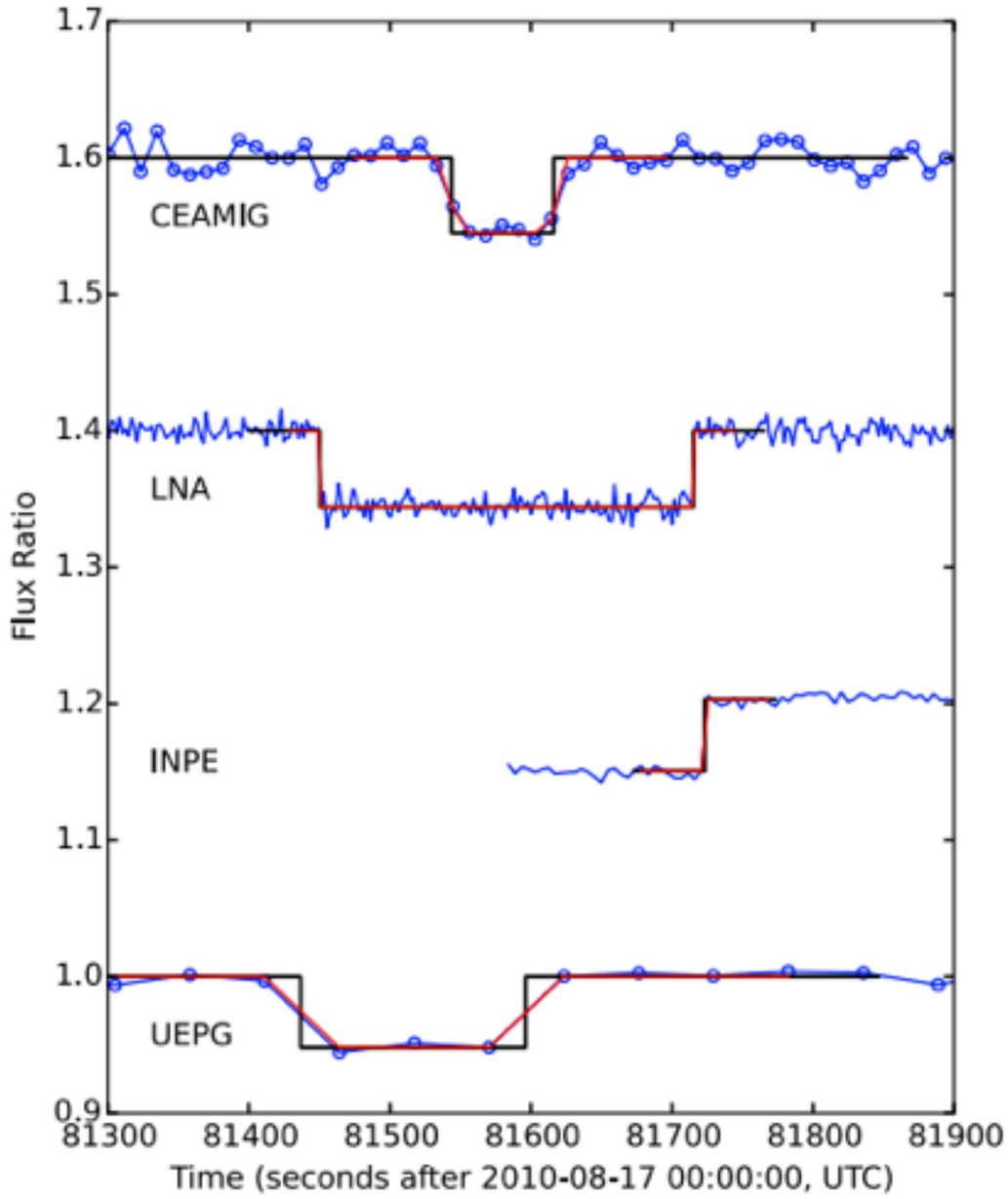


Figure 6. Light curve of MOA-2012-BLG-532. The notations are the same as those in Figure 2.

Title: Candidate Gravitational Microlensing Events for Future Direct Lens Imaging
Publication: The Astrophysical Journal, Volume 794, Issue 1, article id. 71, 11 pp. (2014).

Henderson+

Size of Ceres



Title: Results of two multichord stellar occultations by dwarf planet (1) Ceres

Authors: Gomes-Júnior, A. R.; Giacchini, B. L.; Braga-Ribas, F.; Assafin, M.; Vieira-Martins, R.; Camargo, J. I. B.; Sicardy, B.; Timerson, B.; George, T.; Broughton, J.; Blank, T.; Benedetti-Rossi, G.; Brooks, J.; Dantowitz, R. F.; Dunham, D. W.; Dunham, J. B.; Ellington, C. K.; Emilio, M.; Herpich, F. R.; Jacques, C.; Maley, P. D.; Mehret, L.; Mello, A. J. T.; Milone, A. C.; Pimentel, E.; Schoenell, W.; Weber, N. S.

Bibliographic 2015MNRAS.451.2295G

The instrument

Main properties

Telescope f#	f/10
Telescope aperture	1.6 m
Scientific detectors	Andor Ultra 888
Final f#	f/5
Pixels	1024 x 1024
Pixel size	13 μm (side)
Field of view	5.7 arcmin
Platescale	0.0254 arcsec/μm
	0.35 arcsec/pixel

Electron multiplying detectors

Autoguider detector	Andor Luca(R)
AG Final f#	f/5
AG Pixels	1000 x 1000
AG Pixel size	8 μm (side)
AG Field of view	3.38 arcmin
AG platescale	0.20 arcsec/pixel
Bands	Sloan griz
Weight	172 kg (including 10% contingency)
Center of Mass from	x = 0.0035 m
telescope backplate	y = -0.0003 m
	z = 0.3624 m
Modes of operation	photometry & polarimetry
Time resolution	$<$ 1 s (photometric mode - entire detector - fast readout)
Limiting g magnitudes (SNR = 10)	19, 21, 21.8 for t_{exp} = 1, 10, 300s, respectively

SPARC4 units

- From the telescope, the instruments units are:

✓ autoguider and autofocus module

✓ polarimetric unit

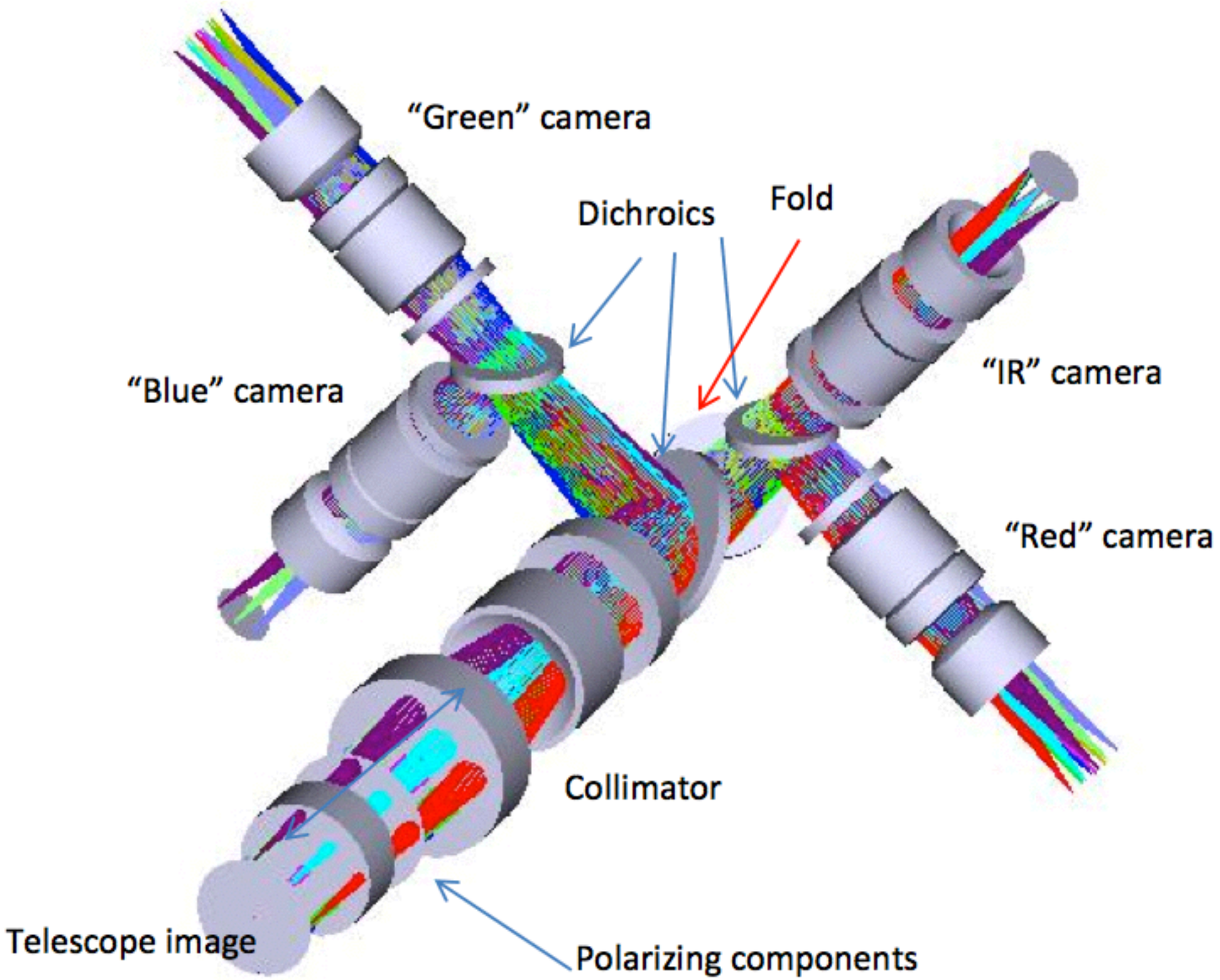
✓ collimator

✓ dichroic splitters

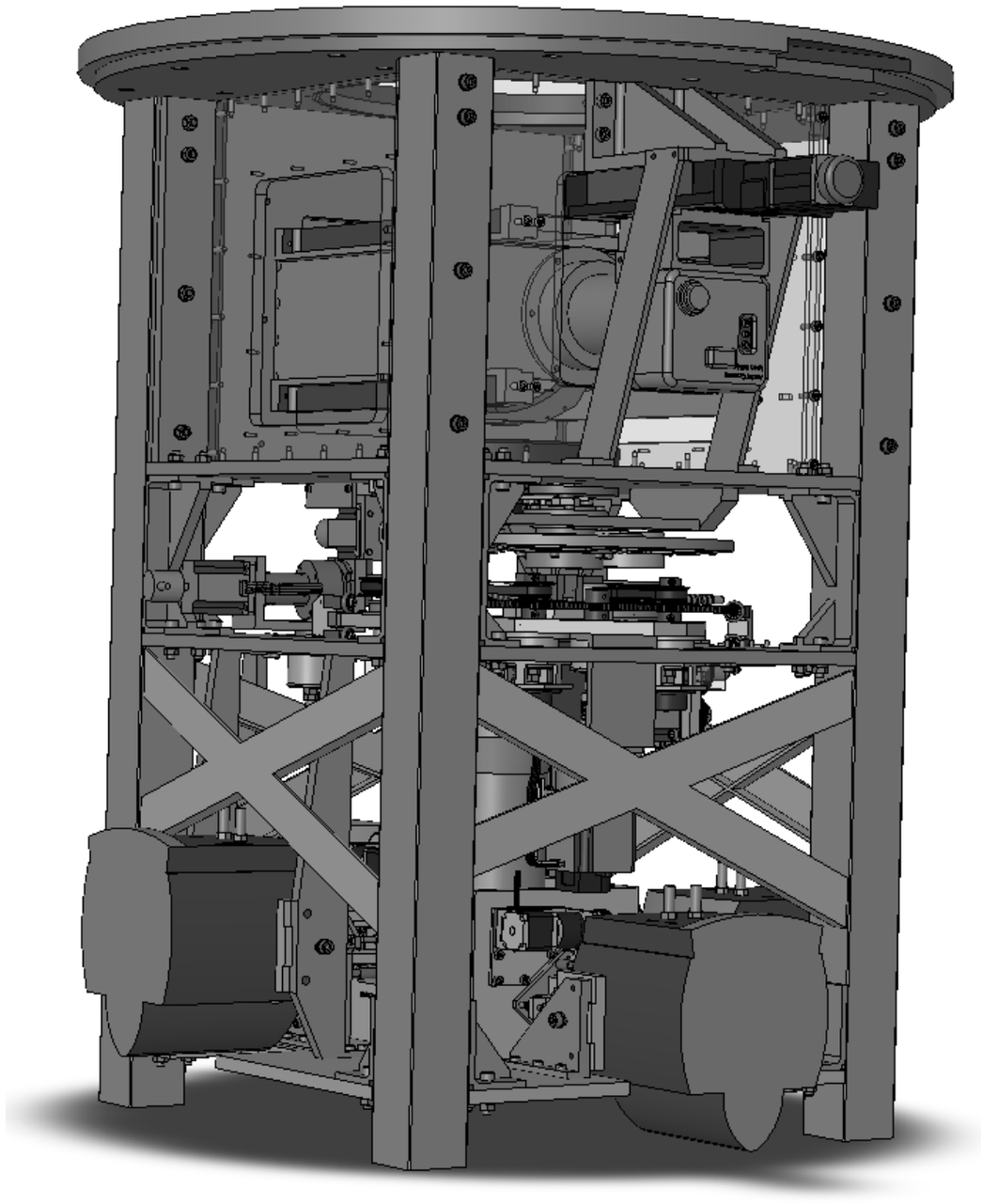
✓ cameras

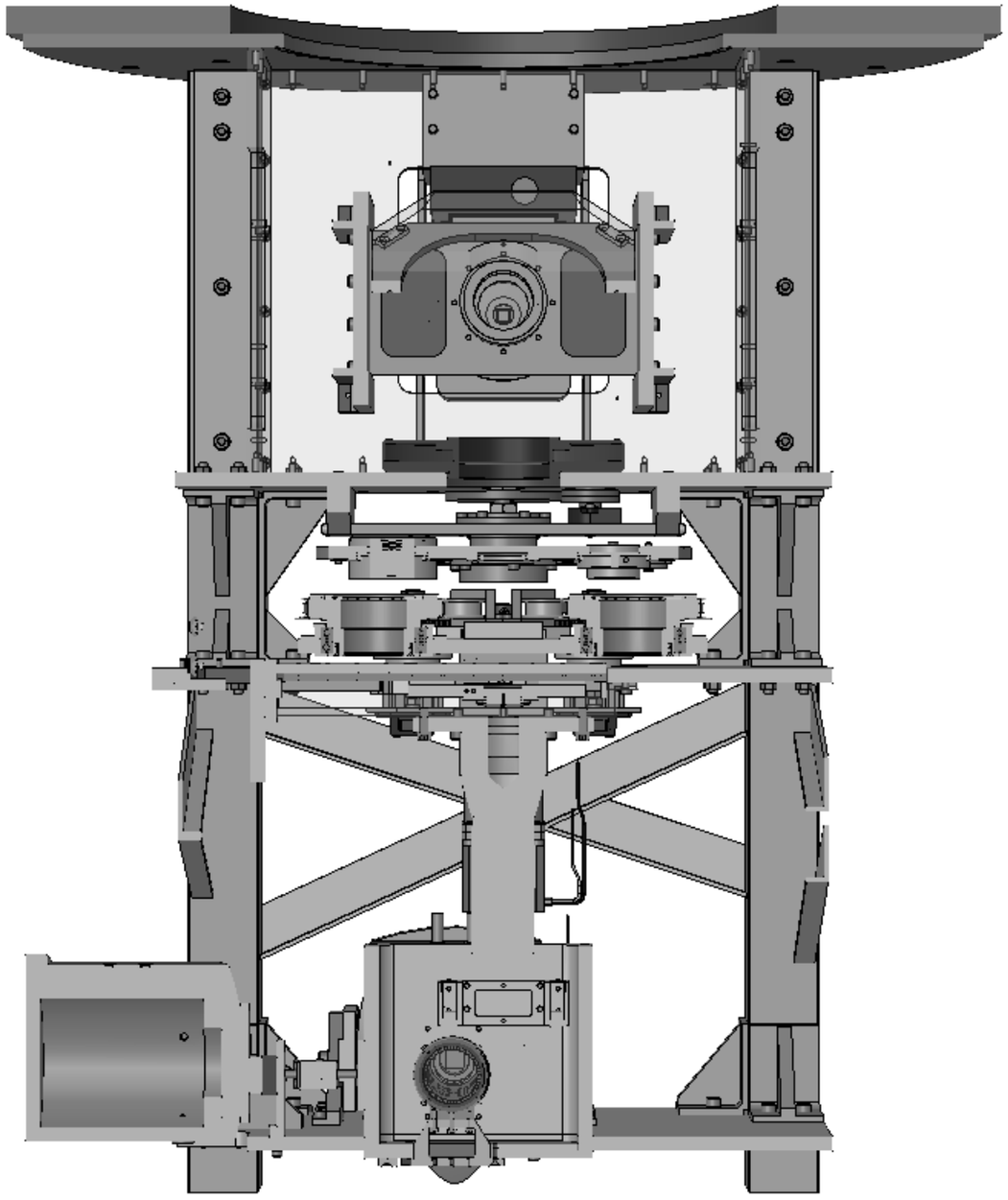
✓ detectors

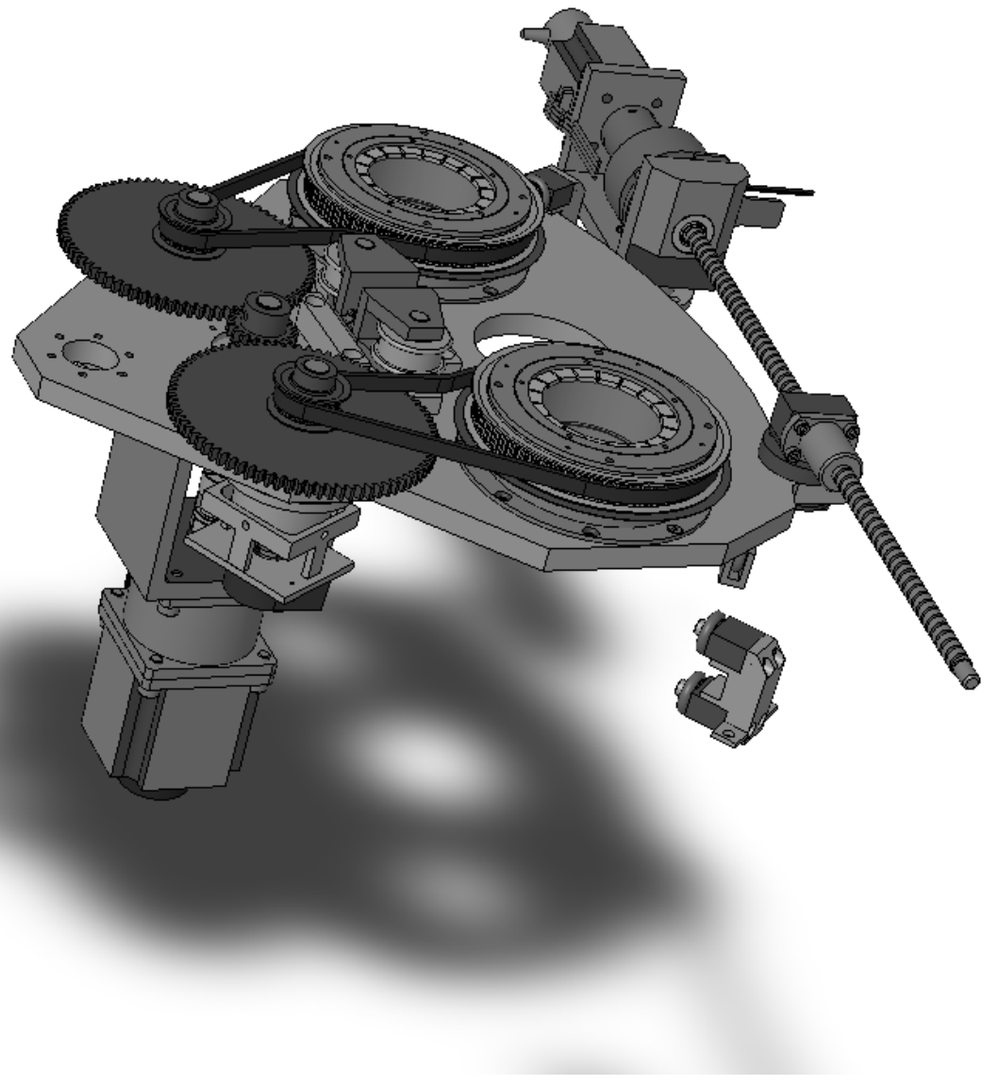
Optics Overview

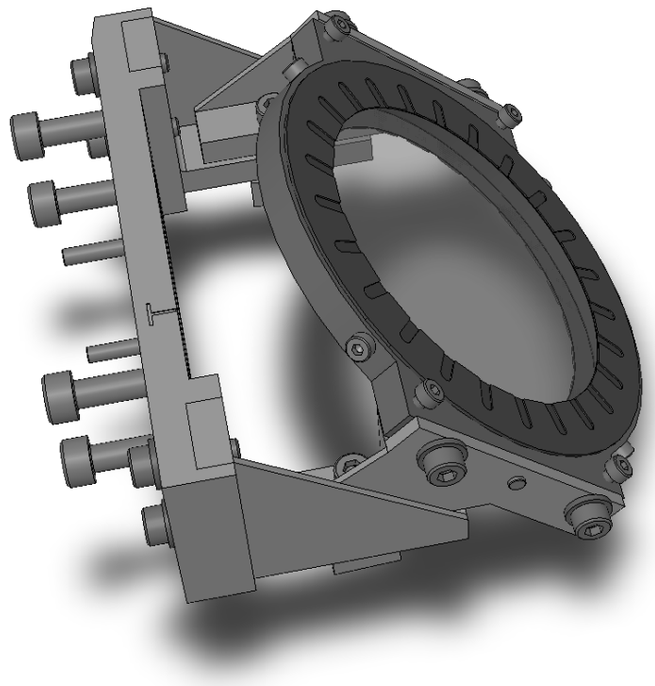


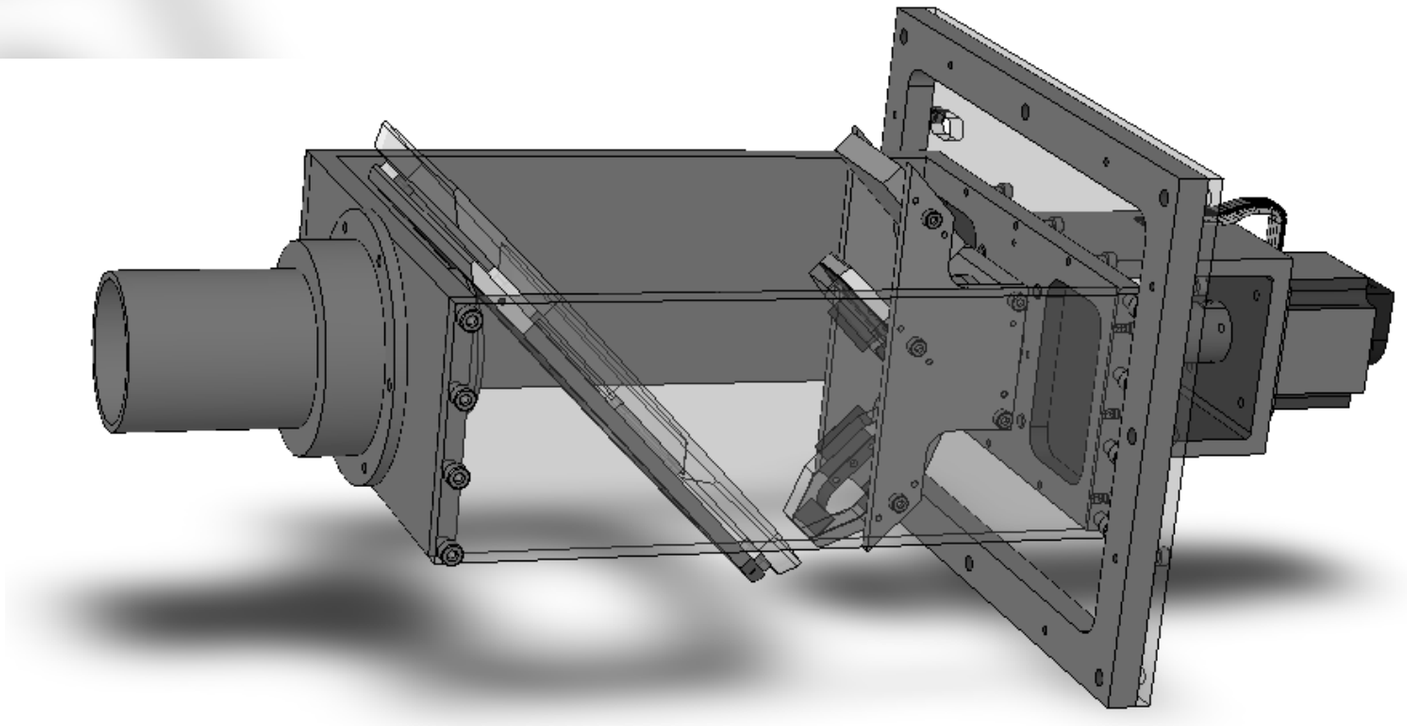
Mechanical structure overview









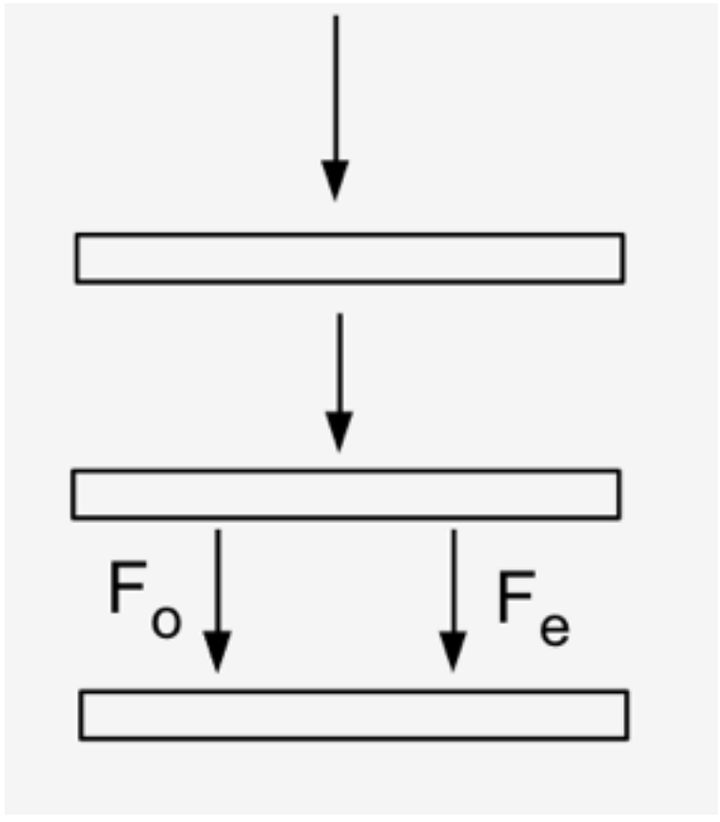


Polarimetry

- The polarimetry is done as explained in Magalhães et al. (1986).

- The retarder can be a half-wave plate or a quarter-wave plate, so linear and circular polarimetry can be performed

- All the polarimetric elements can be off the beam to perform standard imaging

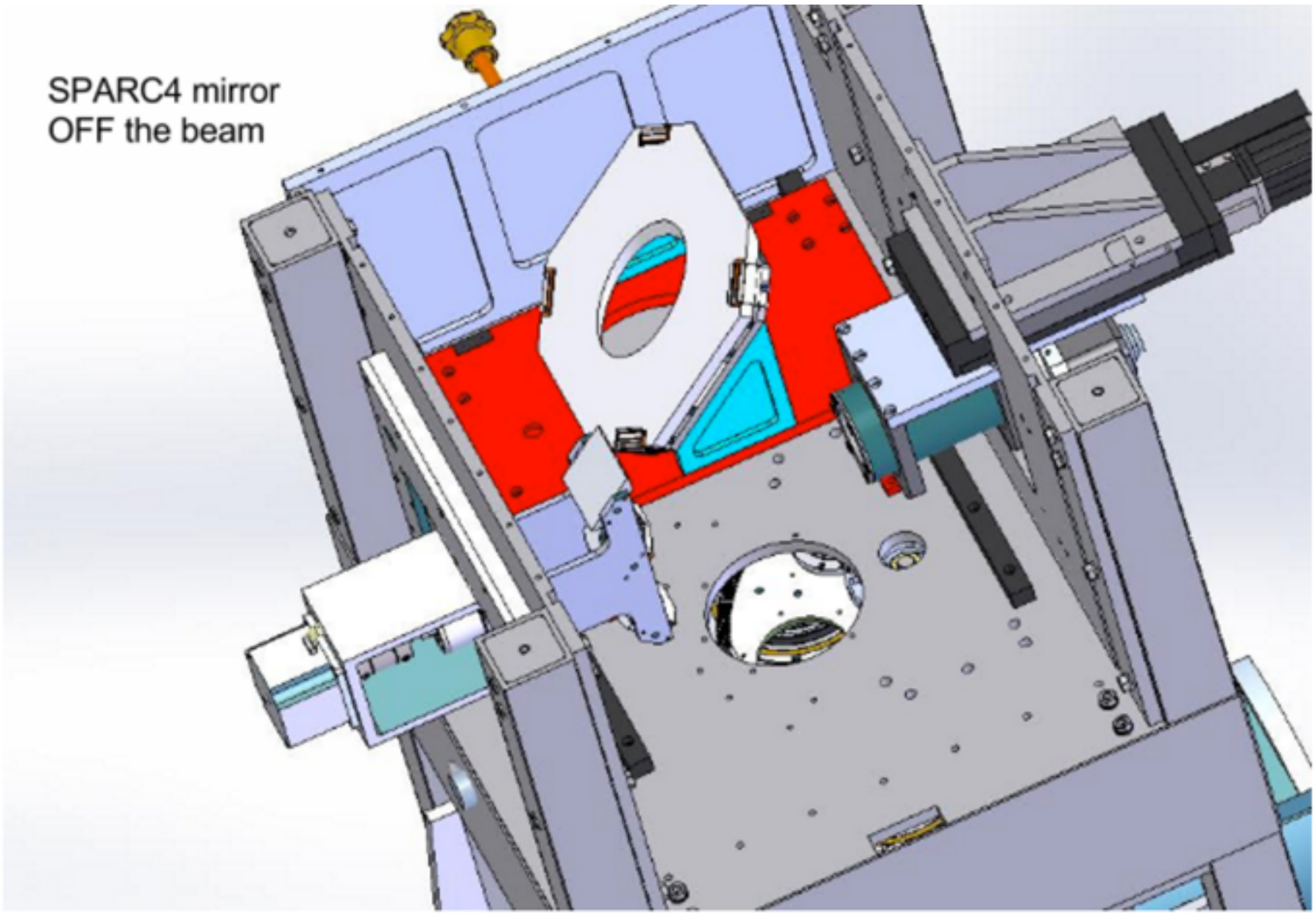


Rotating retarder

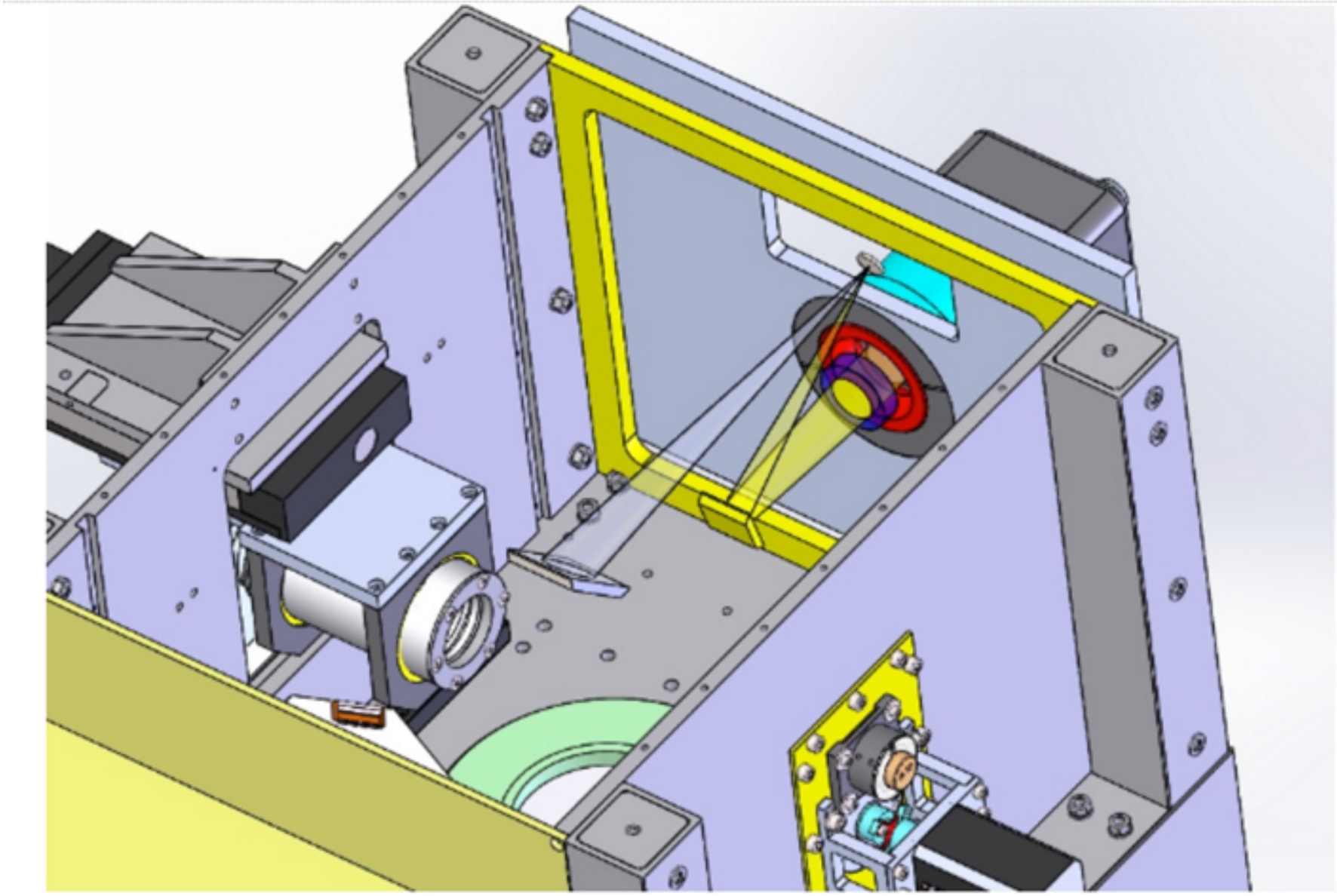
Savart Prism

Ordinary and extraordinary beams at the detector

Echarpe feeder…



- LNA and SPARC4 team are studying to adapt an Echarpe feeder at SPARC4



SPARC4 as a project

- The SPARC4 project aims at:

  ✓ building an instrument

  ✓ developing a control interface with a friendly front-end

  ✓ developing a reduction pipeline

  ✓ delivering documentation to maintenance and users

  ✓ delivering a tested instrument

SPARC4 Team

- Alex Carciofi (USP)
- André de C. Milone (INPE)
- **Antonio M. Magalhães (USP)**
- **Antonio Pereyra (IGP/Peru)**
- **Cláudia V. Rodrigues (INPE)**
- **Damien Jones (Prime Optics)**
- Deonisio Cieslinski (INPE)
- **Eder Martioli (LNA)**
- **Francisco J. Jablonski (INPE)**
- Gabriel Franco (UFMG)
- Joaquim E. R. Costa (INPE)
- Karleyne M. G. da Silva (Gemini)
- **Keith Taylor (Instruments4)**
- Leonardo A. de Almeida (USP)
- **Luciano Fraga (LNA)**
- **Luiz Antonio Reitano (INPE)**
- **Marcelo Assafin (UFRJ)**
- **Rene Laporte (INPE)**
- **Ruben Dominguez (Univ. of Arizona)**

SPARC4
Advisory Board
(FJJ, KT)

Pipeline Data
Reduction
(AP,CVR,EM,LF)

SPARC4
Science Team

Principal Investigator
(CVR)

Technical and
Consultant Team

Project Manager
(KT & CVR)

Acquisition software
(LF)

Optical Design
(DJ)

Mechanical Design
(RL,RD)

Control Engineering
(TBD)

Mechanical Detailing
(LAR)

Schedule, budget and funding

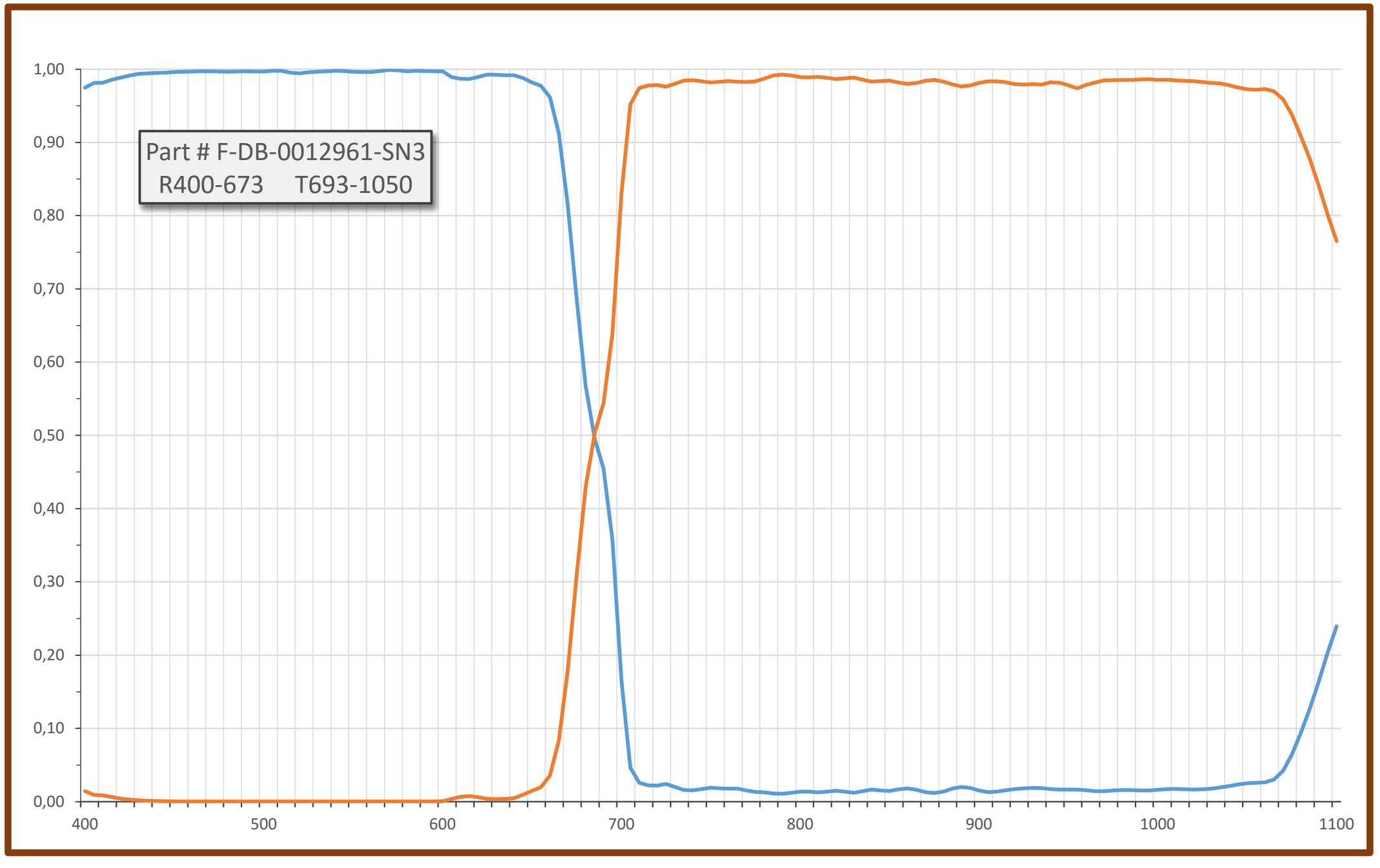
Past milestones

- 2009 Nov: Instrument proposed to LNA
- 2011 May: Granted funding to Conceptual Design Phase by Fapesp
- 2012 Aug: Concept Design Review
  - ✓ Recommendation to go ahead to Preliminary/Critical Design Phase
    - optical design was ready
    - mechanical design was well advanced
- 2013 May: First acquisition: dichroics splitters - LNA + INPE
- 2013 Nov: INPE approved acquisition of scientific cameras
- 2014 Dec: INPE approved acquisition of main optics (collimator, cameras, A&G)
- 2015 Mar: Dichroics arrived at LNA
- 2015 July: Scientific cameras at INPE
- 2015 Nov: Main optics procurement (2016 Feb - waiting authorization for order)
- 2016 Jan: Fapemig approved acquisition of computers and data storage - Luciano Fraga

Dichroics

- Measurements done at LNA

- Thanks to:
  - ✓ Clemens Gneiding - LNA
  - ✓ Rodrigo Prates Campos - LNA
  - ✓ Luidhy Santana da Silva - DAS/INPE
  - ✓ Flavio Ribeiro - LNA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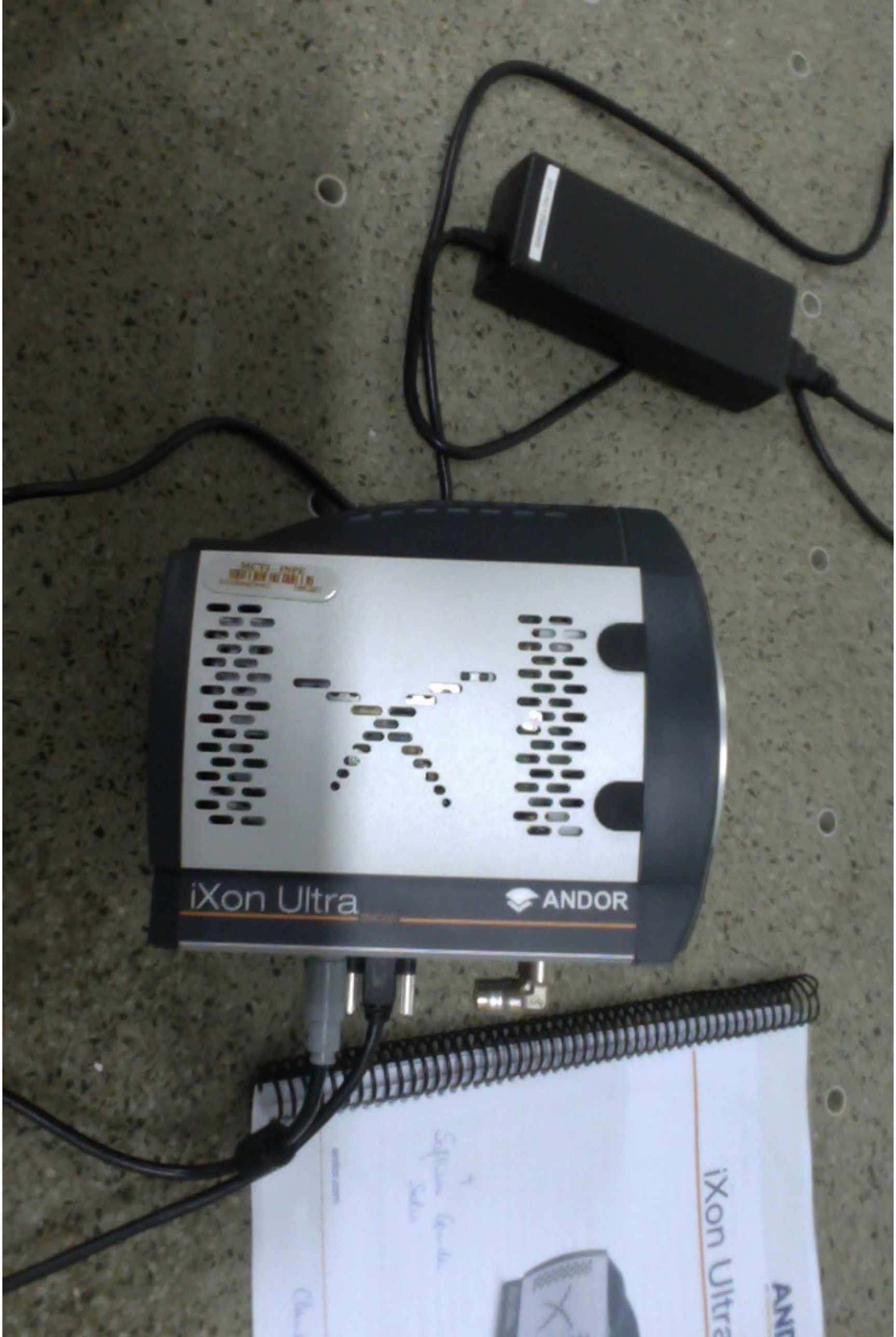
Scientific cameras - Andor Ultra 888


iXon Ultra
ANDOR
iXon Ultra

Andor Ultra 888

- Frame-transfer, electron multiplying cameras
- Each camera has windows and coatings properly chosen to maximize response in the band
- Measurements to confirm specifications are being carried on at INPE.
  - ✓ very preliminary results…
- Preliminary tests of Serial Number X9917
  - ✓ Images: 5 x 100
  - ✓ frame transfer yes
  - ✓ readout rate 1MHz
  - ✓ exposure time: 1,10541 s
  - ✓ pre-amp gain 2
  - ✓ Readout noise: 7.04 ADU (5.6 e-) - Our measurements

SENSOR DETAILS

Manufacturer / Model No.	Pixels	Description
E2V / CCD201-20-1-179	1024x1024, 13µm x 13µm	Back-illum., Fringe Suppression, Dual AR-coated

WINDOW VARIANT

Window Variant	VIS-NIR Enhanced Wedged

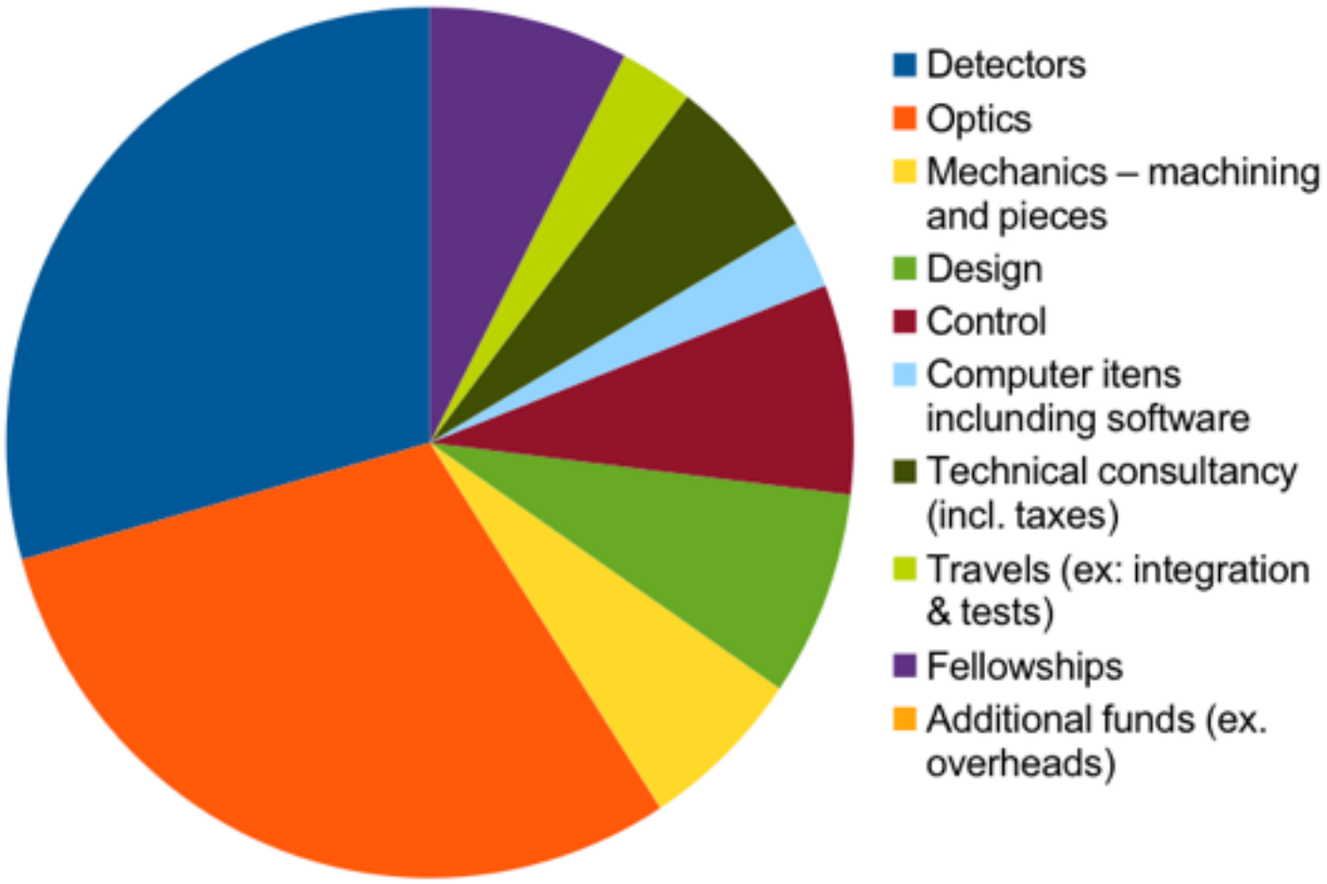
SUMMARY OF SYSTEM TEST DATA

SENSITIVITY & READOUT NOISE

System Readout Rate	Preamp setting	CCD Sensitivity ♦1 (electrons per A/D count)	Single Pixel Noise ♦2 (electrons)
30 MHz, 16-bit Single, EM amplifier	1	17.6	188
	2	5.38	111
20 MHz, 16-bit Single, EM amplifier	1	16.8	148
	2	4.51	67.5
10 MHz, 16-bit Single, EM amplifier	1	16.2	78.6
	2	4.00	39.2
1 MHz, 16-bit Single, EM amplifier	1	16.1	25.1
	2	3.92	12.2
1 MHz, 16-bit Single, Conventional amplifier	1	3.36	6.55
	2	0.800	4.65
0.1MHz, 16-bit Single, Conventional amplifier	1	3.37	8.43
	2	0.800	3.21

Budget/funding

US$	R$	US$	R$	US$	R$
182,034	1,865,961	136,644	1,261,490	45,390	604,471
Total		Secured		To be funded	



70% funded

INPE
LNA
Fapemig
Fapesp

Future

- Mechanical design
  - ✓ Ready to fabrication in April

- Funding
  - ✓ CNPq proposal - limited to R$ 60k (uncertain…)
  - ✓ Fapesp proposal - limited to R$ 200k (uncertain…)
  - ✓ Machining at LNA is a possibility

- Fabrication
  - ✓ We hope to start the machining this year

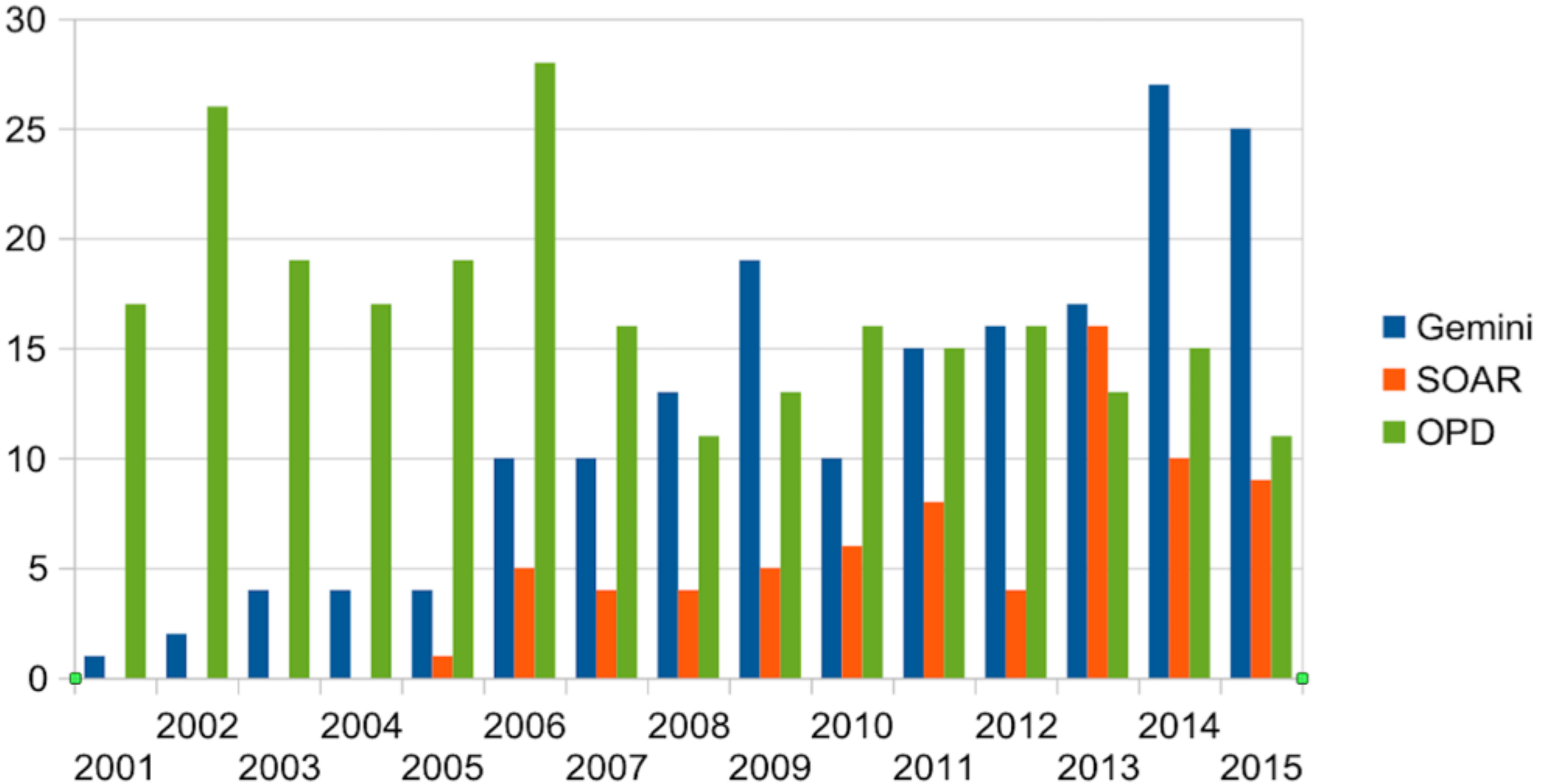
- Project conclusion
  - ✓ It depends on funding: 2 or 3 years to first-light seems realist

Thank you!

Budget – SPARC4 project - 18/Feb/2016

Description	Quant.	Specification/Provider (Funding)	Total value		Total per group Secured		Total per group To be funded	
			US$	R$	US$	R$	US$	R$
Optical design total					12,544			
Optical design	1	Damien Jones	12,544					
Polarimetric optics total					44,400		7,425	
Glan	1	Karl Lambrecht	2,370					
Lyot	1	Karl Lambrecht	1,060					
lambda/2 retarder	1	Karl Lambrecht (INPE – acquisition to be done)	22,200					
lambda/4 retarder	1	Karl Lambrecht (INPE – acquisition to be done)	22,200					
analyser	1	Karl Lambrecht	3,995					
Main Optics						364,762		
	1	Collimator + camera +autoguider optics Rainbow – including barrels (INPE – to be ordered)		364,762				
		Mirrors						
Beam splitters					46,680			
Dichroics	1	Materion Precision Optics & Thin Film Coatings – Barr (	46,680					
Filters							3,700	
SDSS filters	4	Asahi	3,700					
Shutter							2,350	
Shutter	1	Vincent Associates – Uniblitz – Mod: CS90HS	2,350					
Mechanics					33,020		3,980	153,880
Design	1	Ruben Dominguez – University of Arizona	37,000					
Manufacture + material	1	Metalcard		130,000				
Anodization	1	??		5,000				
Technical documentation	1	Fernando Lourenço – TBC		8,000				
Transportation cart	1	Calfer		10,000				
Software	4	Solidworks – renovação anual de licença		880				
Detector systems						701,200	14,935	
Ixon camera – antifringing	1	Andor (INPE)		687,200				
Ixon camera EX	1	Andor (INPE)						
iXon camera BV	2	Andor (INPE)						
Luca camera	1	Andor	14,935					
controller card (5)	4	Andor (INPE)						
Extension cables	4	Andor (INPE)						
Splitter box	4	Andor (INPE)						
re-circulator (4)	4	Andor (INPE)						
SDK	1	Andor (INPE)						
Solis Software	1	Andor (INPE)						
Optical fiber extension USB3.0	2	Ultimate (Fapemig – Luciano)		14,000				

Acquisition desktops						17,600		3,190
Acquisition desktops	2	Dell PowerEdge R430 (Fapemin – Luciano)		17,600				
Display for acquisition	2	LED Samsung 23 VGA/DVI/HDMI(x2), S23B550V		1,190				
Desktop maintenance	2	Desktop maintenance contract		2,000				
Eletronics & software control							13,000	150,000
Service	1	Solunia		150,000				
Linear stage		Newport corporation – importacao pela Fapesp	9,069					
Controller card		Newport corporation – importacao pela Fapesp	3,930					
GUI development								8,164
Software	1	Labview		0				
GUI desktop	1	Desktop de alta performance		6,569				
Desktop maintenance	1	Desktop maintenance contract		1,000				
GUI monitor	1	LED Samsung 23 VGA/DVI/HDMI(x2), S23B550V		595				
Pipeline						16,599		19,727
Desktops to development	2	Desktop de alta performance		13,138				
Desktop maintenance	2	Desktop maintenance contract		2,000				
Monitor	2	LED Samsung 23 VGA/DVI/HDMI(x2), S23B550V		1,190				
Data storage	1	NAS Drobo B800 (Fapemig – Luciano)		16,599				
Disco rigido	5	HD WD 3TB SATA III 64MB 7200RPM – WD30EZRX		3,400				
Technical consultant						161,329		
Service	1	Technical consultancy (INPE) – Final value includes in		161,329				
Travel								72,600
Ruben Dominguez	2	USA-SJC-USA		5,000				
Keith Taylor	4	USA-SJC-USA		10,000				
Team	60	INPE per diem – integration and tests		19,200				
Team	120	Itajuba per diem – integration and tests		38,400				
Fellowships								196,910
Pipeline development	1	24 months – TT6 – 40h – person tbd		147,442				
GUI development	1	24 months – TT4A – 16h – person tbd		40,692				
ETC development	1	24 months – TT2 – 20h – person tbd		8,777				
		Total – SPARC4	**US$**	**R$**	US$	R$	US$	R$
			182,034	**1,865,961**	136,644	1,261,490	45,390	604,471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