MINISTÉRIO DA CIÊNCIA, TECNOLOGIA, INOVAÇÕES E COMUNICAÇÕES
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

SPARC4

Simultaneous Polarimeter and Rapid Camera in 4 bands

Claudia Vilega Rodrigues

claudia.rodrigues@inpe.br

Instituto Nacional de Pesquisas Espaciais

Divisão de Astrofísica

SPANET WORKSHOP ON TIME SERIES IN ASTRONOMY
25 de outubro de 2018

This talk

- Brief description of SPARC4
- SPARC4 status
- SPARC4 science cases

What is SPARC4?

- Simultaneous Polarimeter And Rapid Camera in 4 bands
  - ✓ simultaneous imaging in four bands (griz SDSS)
  - ✓ polarimetry as an option
  - ✓ sub-second time resolution

An instrument to produce time-series data: photometry and/or polarimetry

What is SPARC4?

- Simultaneous Polarimeter And Rapid Camera in 4 bands
  - ✓ simultaneous imaging in four bands (griz SDSS)
  - ✓ polarimetry as an option
  - ✓ sub-second time resolution

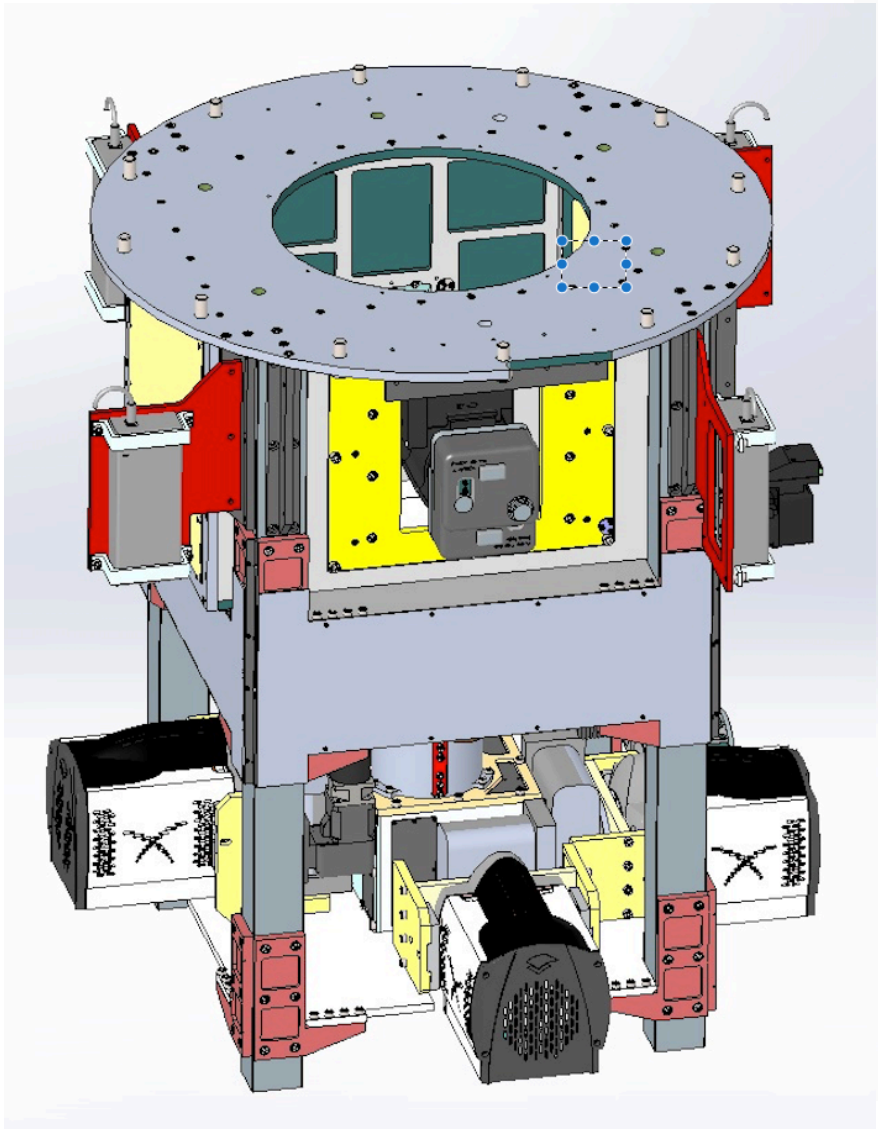
- at 1.6-m telescope of Observatório do Pico dos Dias/LNA

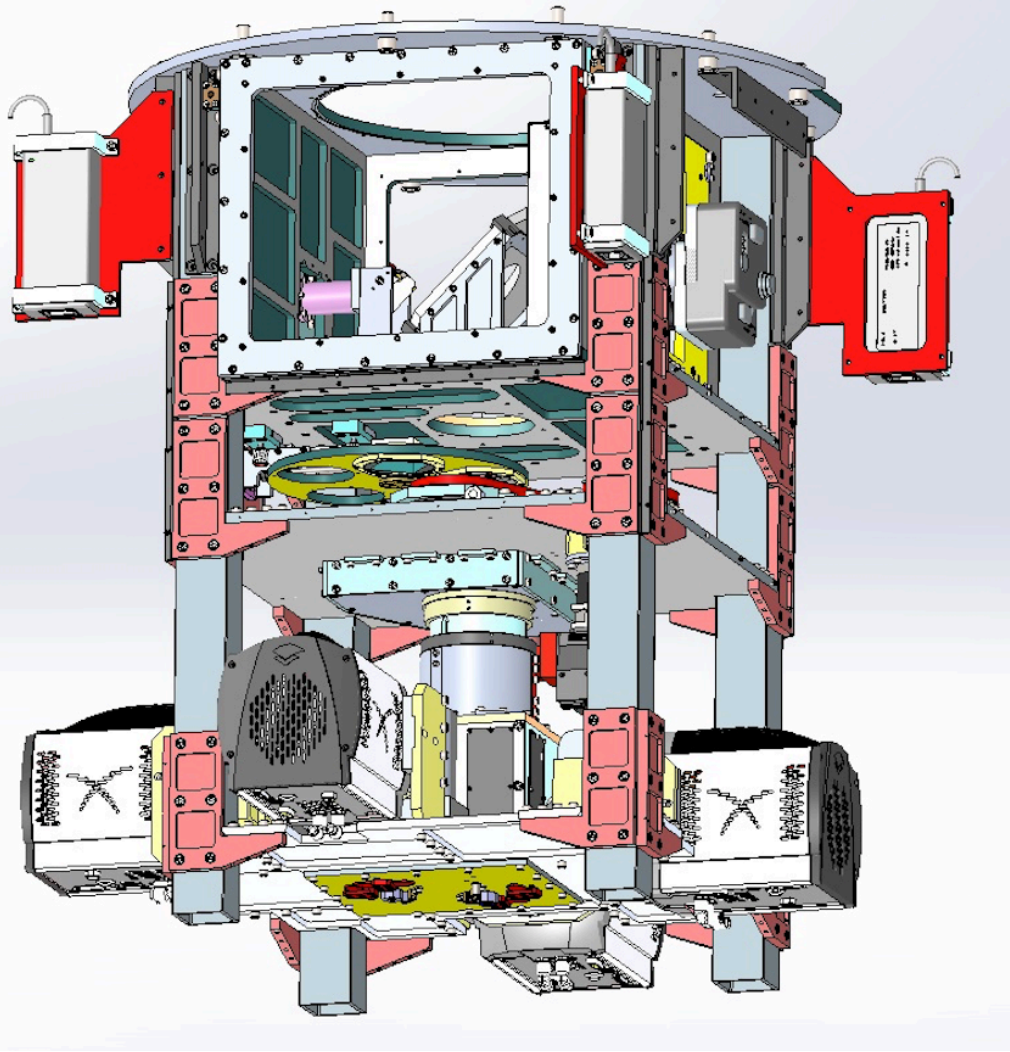
It is planned to be an observatory facility, open to any astronomer.

Why SPARC4?

- SPARC4 is an instrument shaped to differential techniques:
  - ✓ differential photometry;
  - ✓ polarimetry.
- It allows our community to:
  - ✓ get an efficient use of the observatory, considering the atmospheric conditions of the site;
  - ✓ produce competitive science.

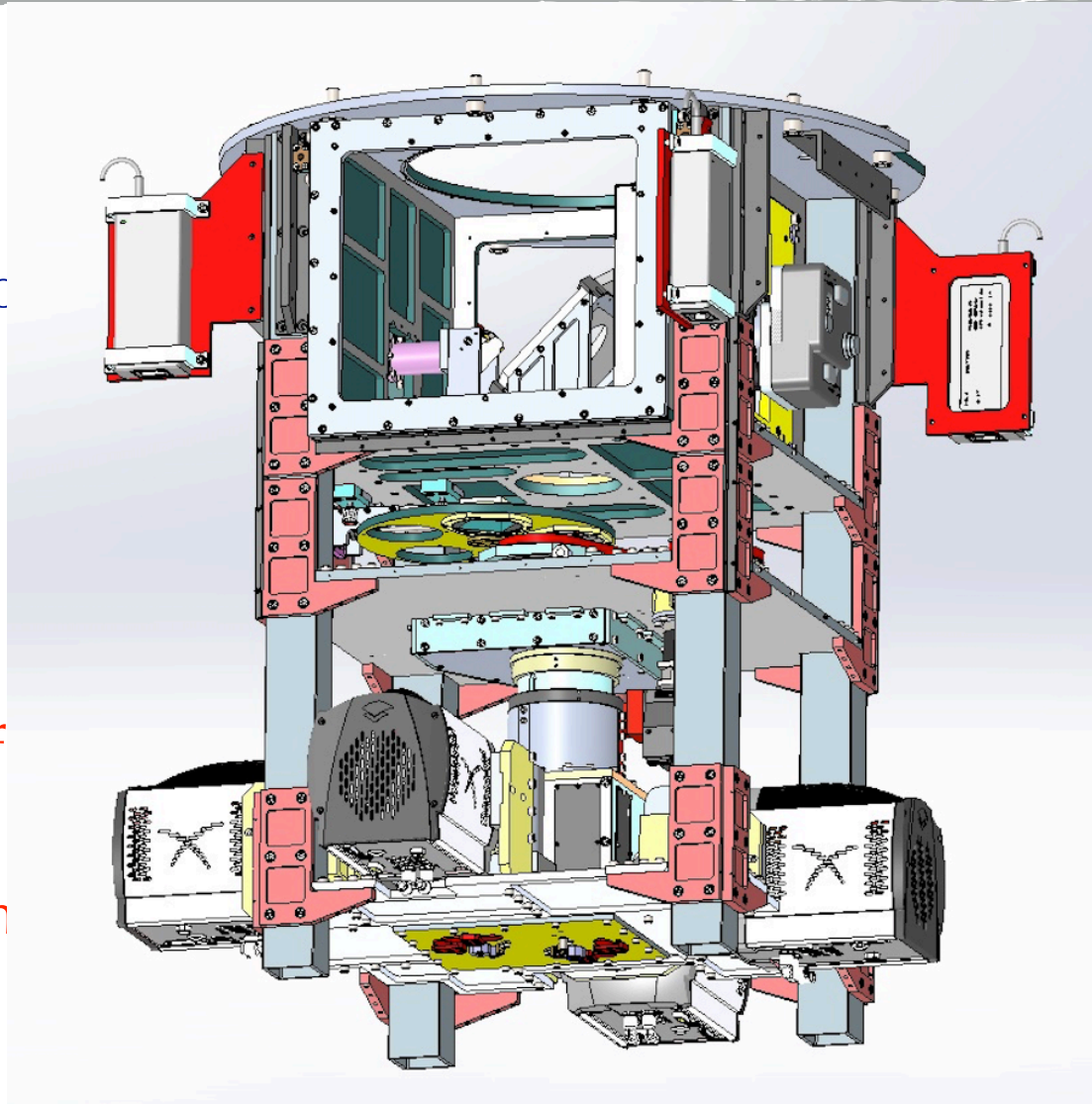
Mechanical structure overview

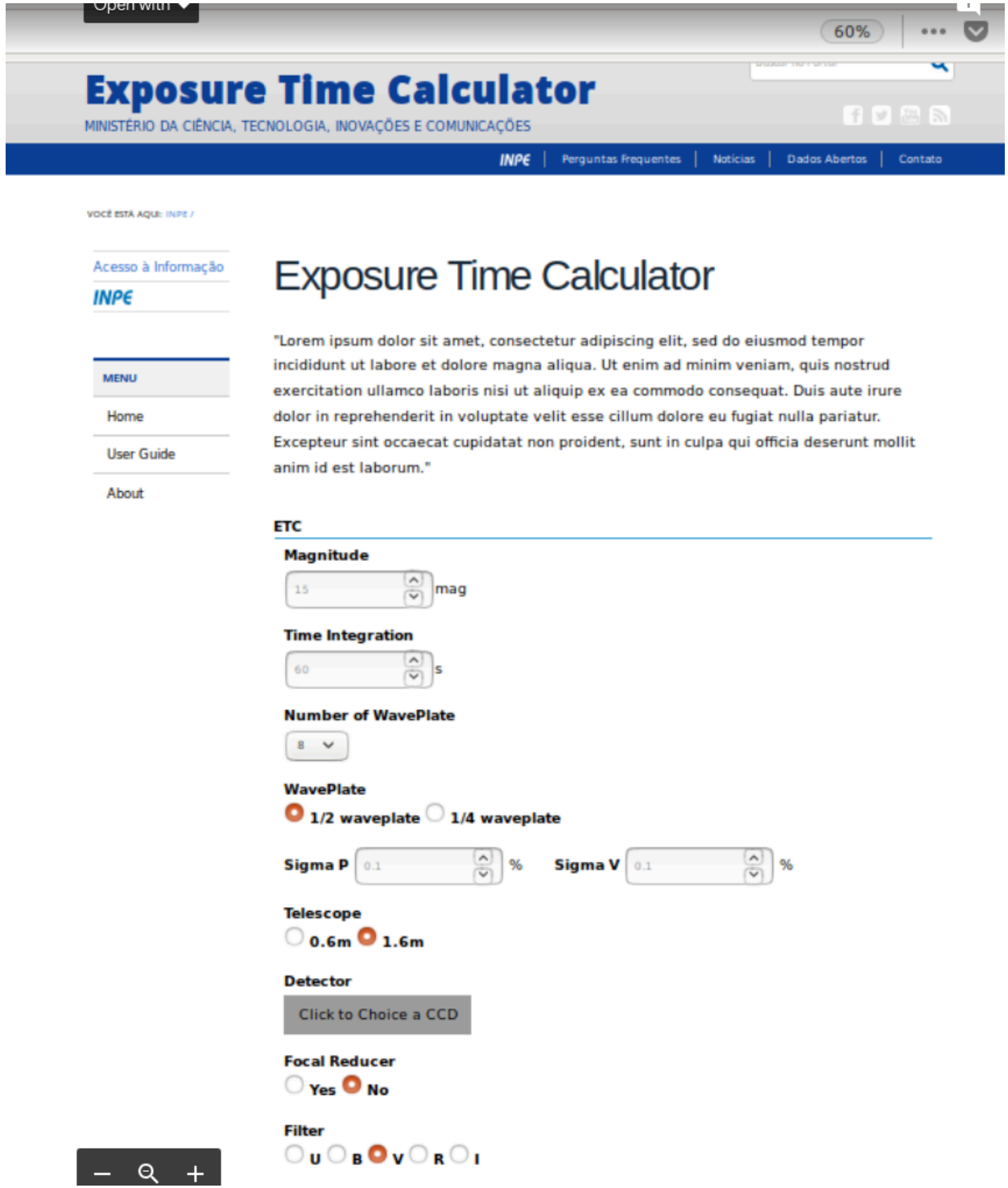




SPARC4 modules

- From the telescope, the i
  - ✓ autoguider and autofc
  - ✓ polarimetric unit
  - ✓ collimator
  - ✓ optical box
    - dichroic splitters
    - supports for specif cases
    - (focal reducer) can
  - ✓ detectors




Open with
60%
Exposure Time Calculator
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA, INOVAÇÕES E COMUNICAÇÕES
INPE | Perguntas Frequentes | Notícias | Dados Abertos | Contato
VOCÊ ESTÁ AQUI: INPE /
Acesso à Informação
INPE
MENU
Home
User Guide
About
Exposure Time Calculator
"Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum."
ETC
Magnitude
15
mag
Time Integration
60
s
Number of WavePlate
8
WavePlate
1/2 waveplate
1/4 waveplate
Sigma P
0.1
%
Sigma V
0.1
%
Telescope
0.6m
1.6m
Detector
Click to Choice a CCD
Focal Reducer
Yes
No
Filter
U
B
V
R
I

Technical team

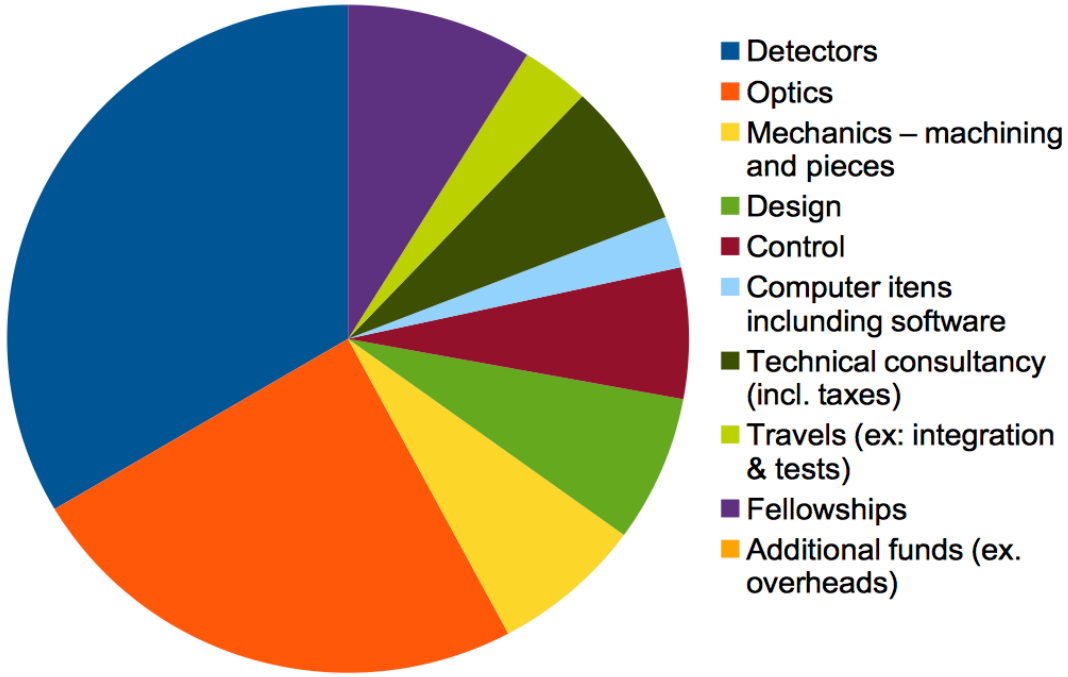
Alessandro da S. Paula (LNA)
Antonio M. Magalhães (USP)
Antonio Pereyra (IGP/Peru)
Braulio de Albuquerque (INPE)
Carlos E. Ferreira Lopes (INPE)
Cláudia V. Rodrigues (INPE)
Clemens Gneiding (LNA)
Damien Jones (Prime Optics)
Denis V. Bernardes (LNA)
Eder Martioli (LNA)
Flavio Ribeiro (LNA)
Francisco Rodrigues (LNA)
Francisco J. Jablonski (INPE)
Jesulino Bispo (LNA)
Keith Taylor (Instruments4)
Lucas Salvador (INPE)
Luciano Fraga (LNA)
Luiz Antonio Reitano (INPE)
Marcio Vital de Arruda (LNA)
Rene Laporte (INPE)

Science team

Alex Carciofi (USP)
André de C. Milone (INPE)
Antonio M. Magalhães (USP)
Antonio Pereyra (IGP/Peru)
Cláudia V. Rodrigues (INPE)
Deonisio Cieslinski (INPE)
Eder Martioli (LNA)
Francisco J. Jablonski (INPE)
Gabriel Franco (UFMG)
Joaquim E. R. Costa (INPE)
Karleyne M. G. da Silva (ESO)
Leonardo A. de Almeida (USP)
Luciano Fraga (LNA)
Marcelo Borges (ON)
Marcelo Assafin (UFRJ)

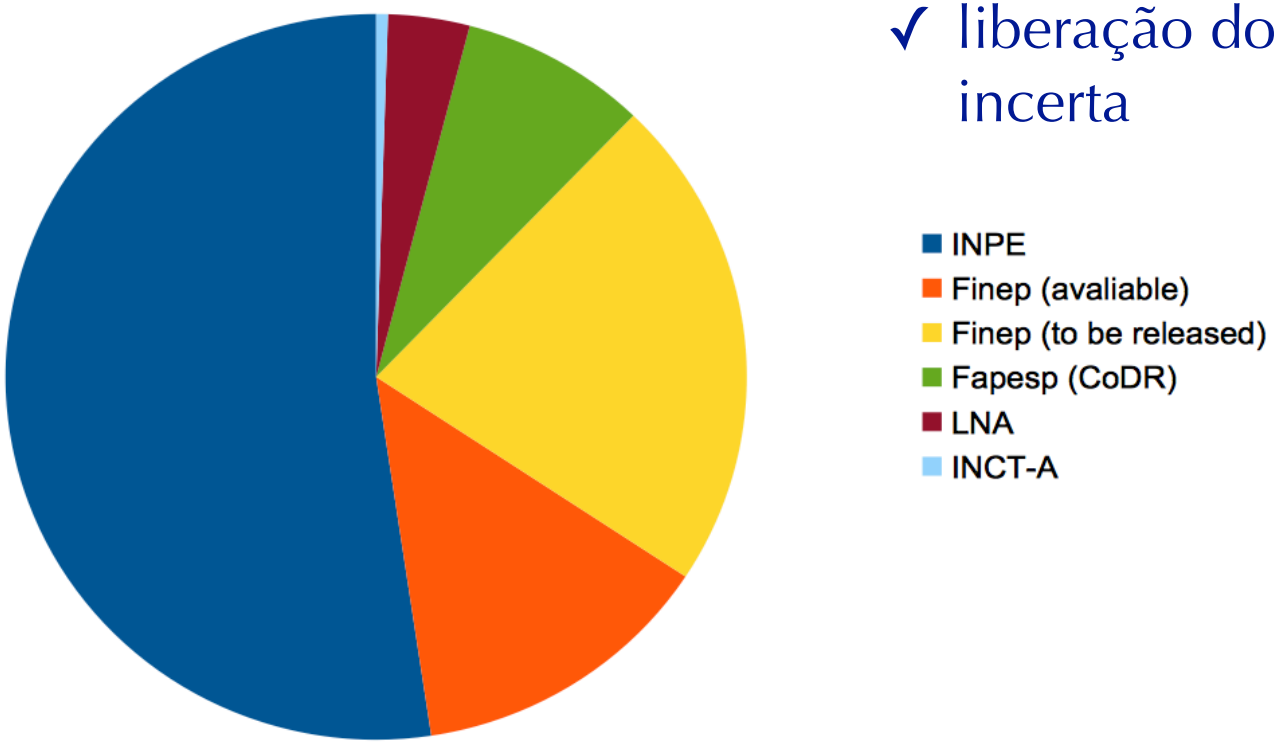
Estimated total cost

US$ 700k



Funding

- Verba aprovada pela Finep é suficiente para completar o projeto, mas…
  - ✓ apenas parte foi liberada
  - ✓ liberação do restante da verba é incerta



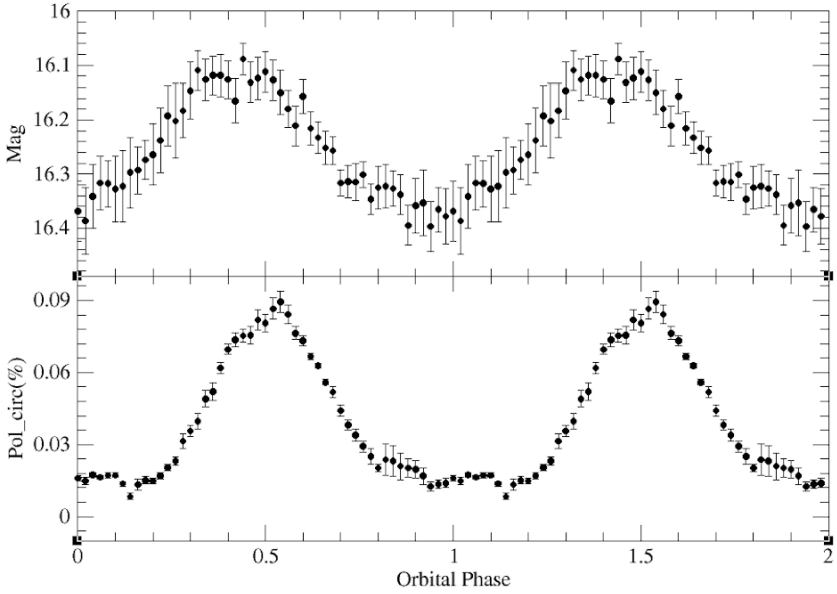
Some examples of present OPD times-series astronomy that can be benefited from SPARC4

Science cases

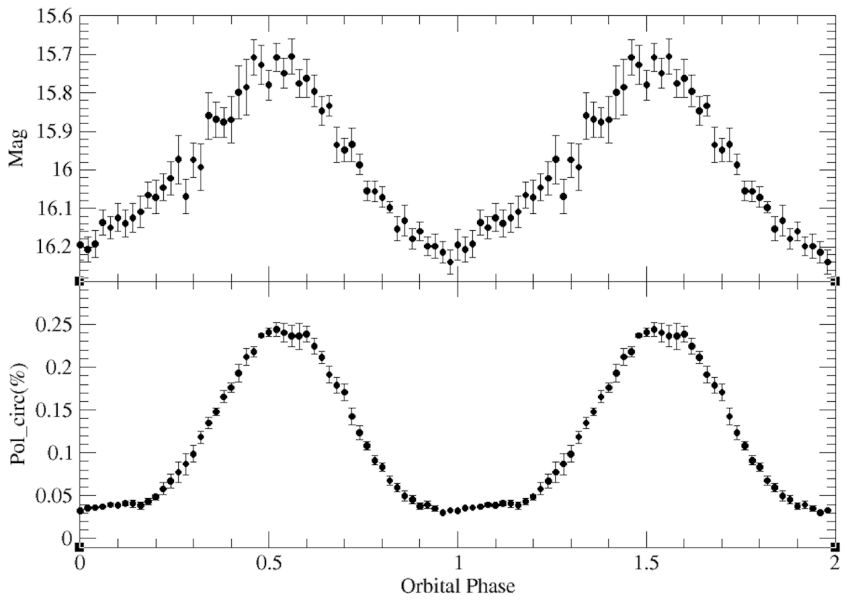
- **Binaries, including interacting binaries**
  - ✓ multi-band light and polarization curves
- **Solar system studies**
  - ✓ multi-band light curves
- **Exoplanets**
  - ✓ multi-band light and polarization curves
- **Pulsating stars**
  - ✓ multi-band light curves
- **Circumstellar envelopes**
  -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

Today - Data from 4 nights

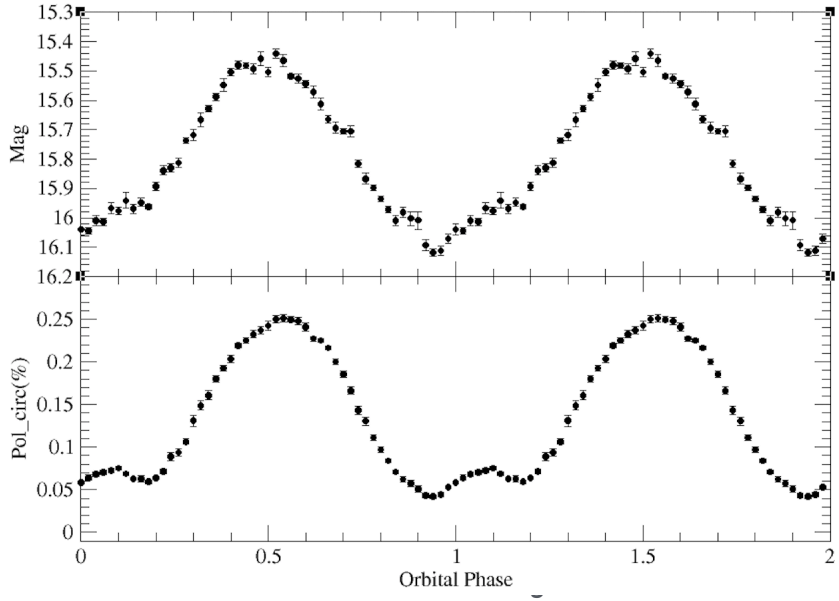
Oliveira+2018, submitted

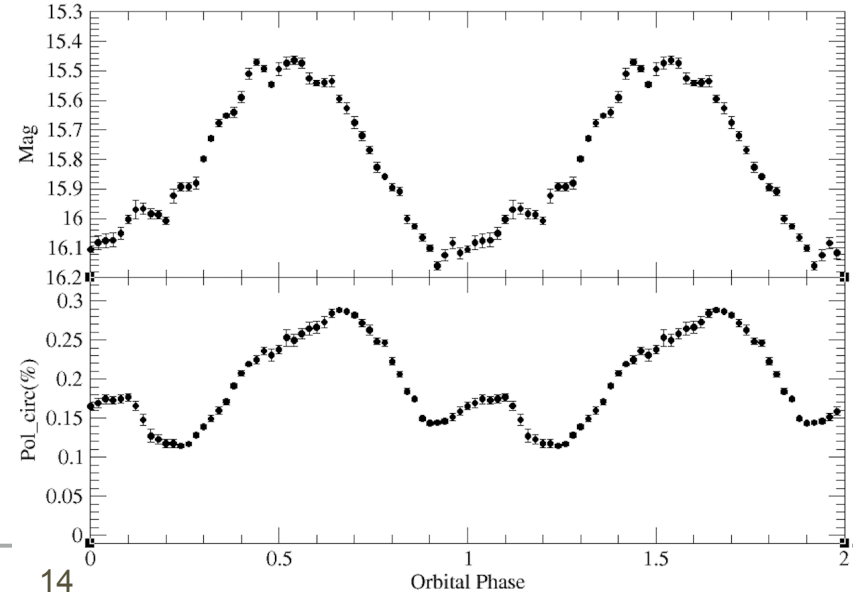


Filter R

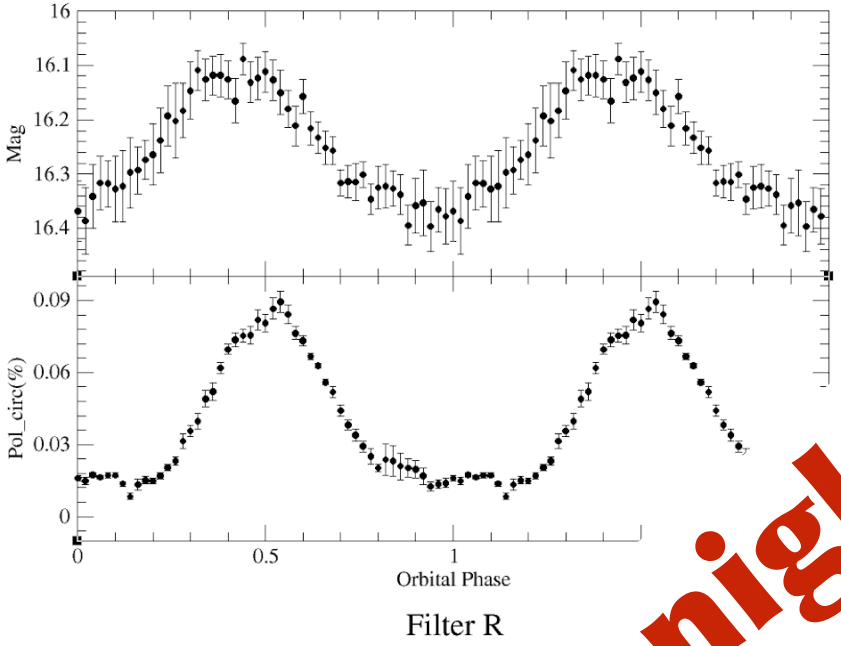


Filter I

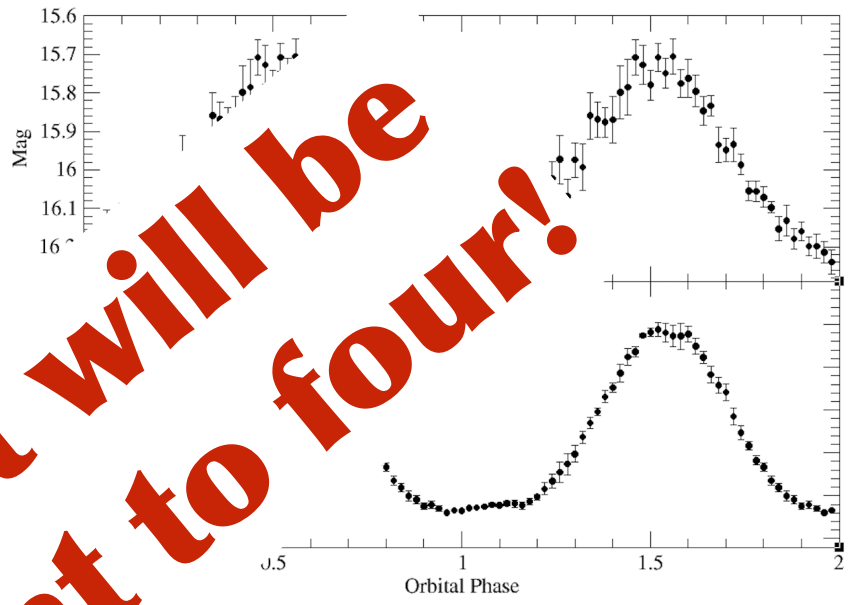




With SPARC4

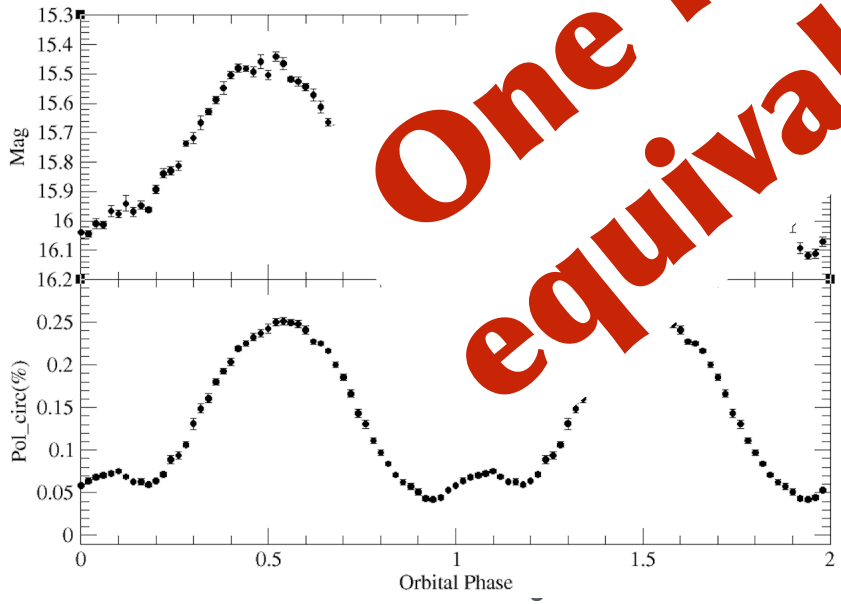


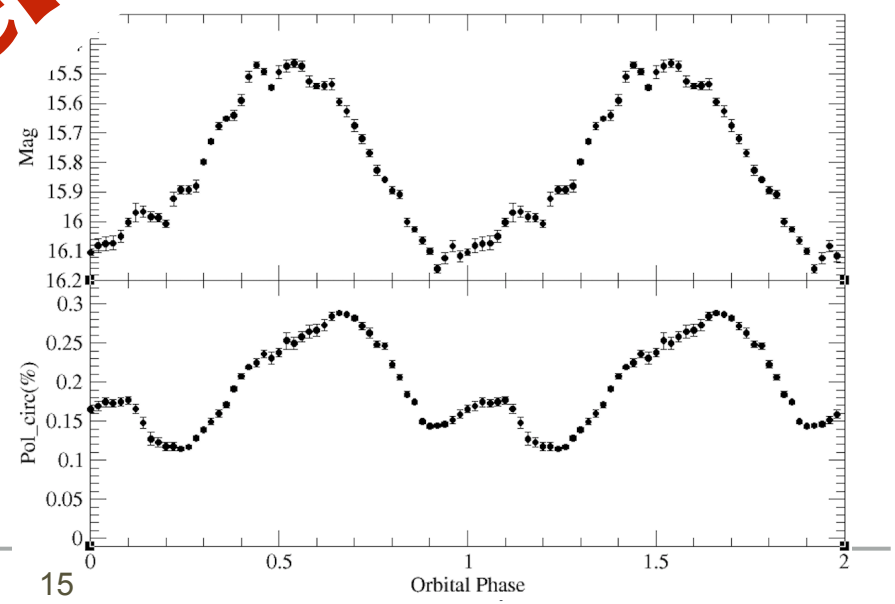
Filter R



Filter I

One night will be equivalent to four!





HS 2231+2441: an HW Vir system composed by a low-mass white dwarf and a brown dwarf ⋆

L. A. Almeida[1]†, A. Damineli[1], C. V. Rodrigues[2], M. G. Pereira[3] and F. Jablonski[2]

2017 MNRAS

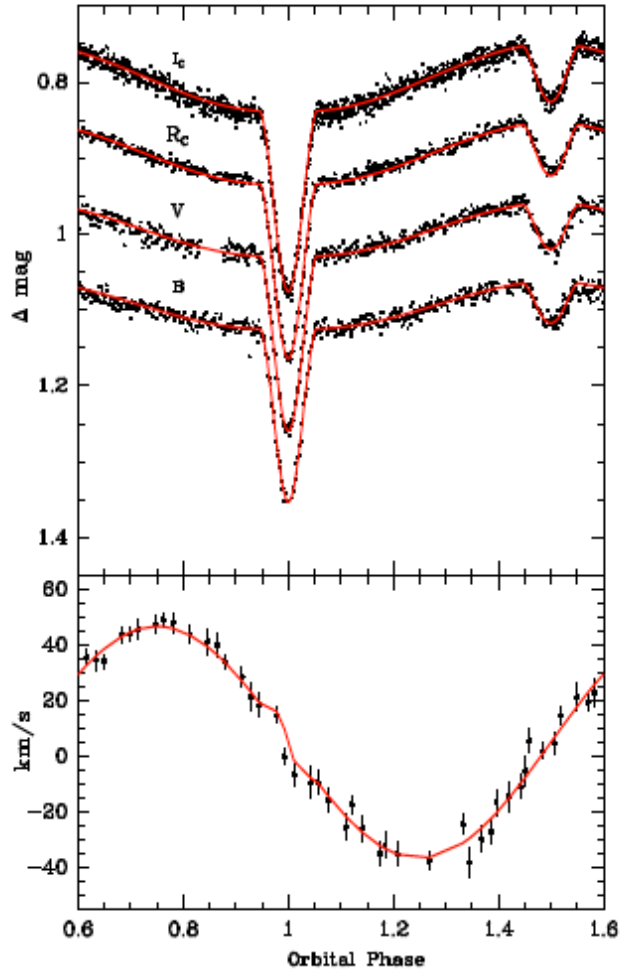


Figure 7. The best simultaneous fit to the light curves in the B, V, R_C, and I_C bands and primary radial velocity curve performed with the Wilson-Devinney code.

Table 4. System parameters of the best model fit to photometric light curves in the B, V, R_C, I_C bands and the primary star radial velocity curve of HS 2231+2441.

Parameter	Value	
Fixed Parameters	Solution 1	Solution 2
$q(M_2/M_1)$	0.190	0.160
T_1(K)	28500	28500
α_1^a(B)	0.290	0.290
α_1^a(V)	0.256	0.256
α_1^a(R_C)	0.222	0.222
α_1^a(I_C)	0.188	0.188
α_2^a(B)	0.727	0.677
α_2^a(V)	0.742	0.651
α_2^a(R_C)	0.705	0.624
α_2^a(I_C)	0.594	0.527
β_1^b	1	1
β_2^b	0.3	0.3
A_1^c	1	1
Adjusted Parameters	**Solution 1**	**Solution 2**
Ω_1^d	4.31±0.05	4.24±0.06
Ω_2^d	2.91±0.03	2.68±0.02
T_2(K)	3010±460	3410±500
i (°)	79.4±0.2	79.6±0.1
a^e ($R_\odot$)	0.59±0.01	0.67±0.02
A_2^c(B)	1.243±0.07	1.39±0.09
A_2^c(V)	1.305±0.06	1.28±0.08
A_2^c(R_C)	1.574±0.05	1.76±0.06
A_2^c(I_C)	1.797±0.05	1.87±0.05
Derived parameters		
M_1 ($M_\odot$)	0.190±0.006	0.288±0.005
M_2 ($M_\odot$)	0.036±0.004	0.046±0.004
R_1 ($R_\odot$)	0.144±0.004	0.165±0.005
R_2 ($R_\odot$)	0.074±0.004	0.086±0.004
log g_1 (cm s^{-2})	5.40±0.03	5.46±0.03
log g_2 (cm s^{-2})	5.25±0.07	5.23±0.006
$v_{rot;1}^f$	65.9±1.9	75.5±2.3
$v_{rot;2}^f$	33.9±1.9	39.4±1.9

[a] Linear limb darkening coefficient from Claret & Bloemen (2011);
[b] Gravity darkening exponent;
[c] Bolometric albedo;
[d] Adimensional potential;
[e] Components separation;
[f] Rotational velocity adopting synchronised rotation ($P_{orb} = P_{rot}$).

Flickering in CVs

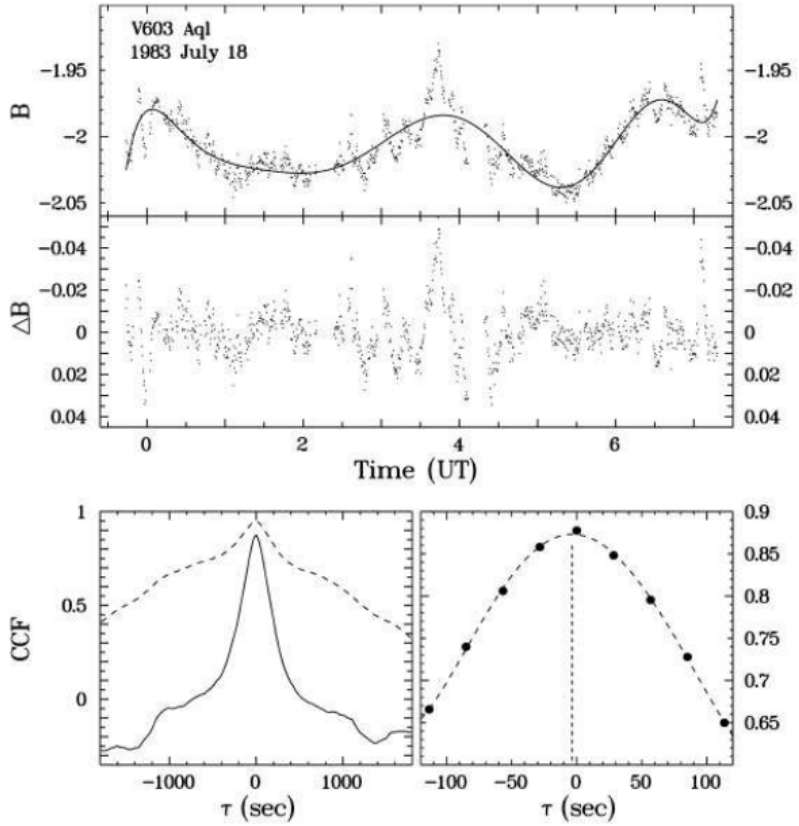


Fig. 1. Example of a light curve and the CCF of the brightness variations in two photometric bands. *Top: B*-band light curve of V603 Aql observed on 1983 July 18. The solid line is a fit of a high-order polynomial to the data. *Centre:* Residuals between the original light curve and the polynomial fit. *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.

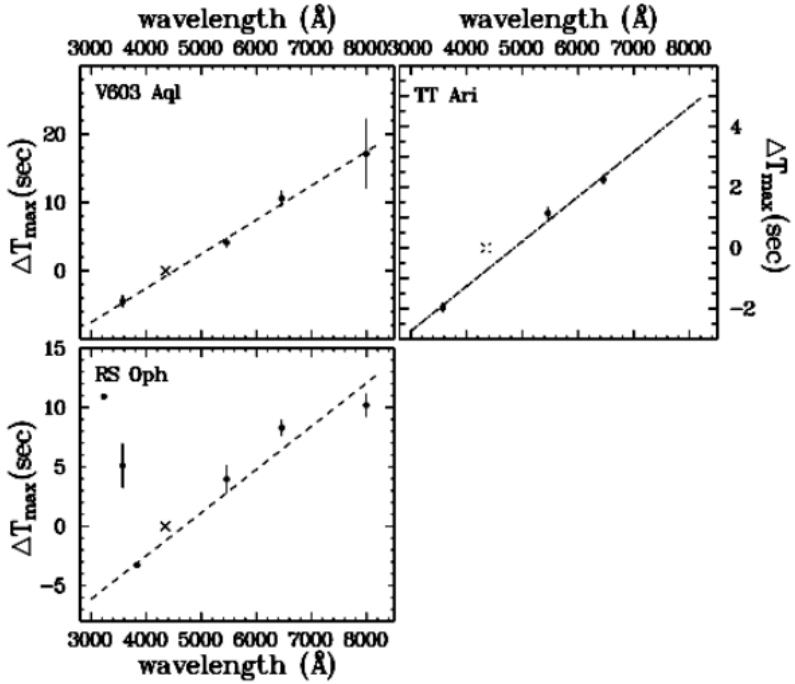
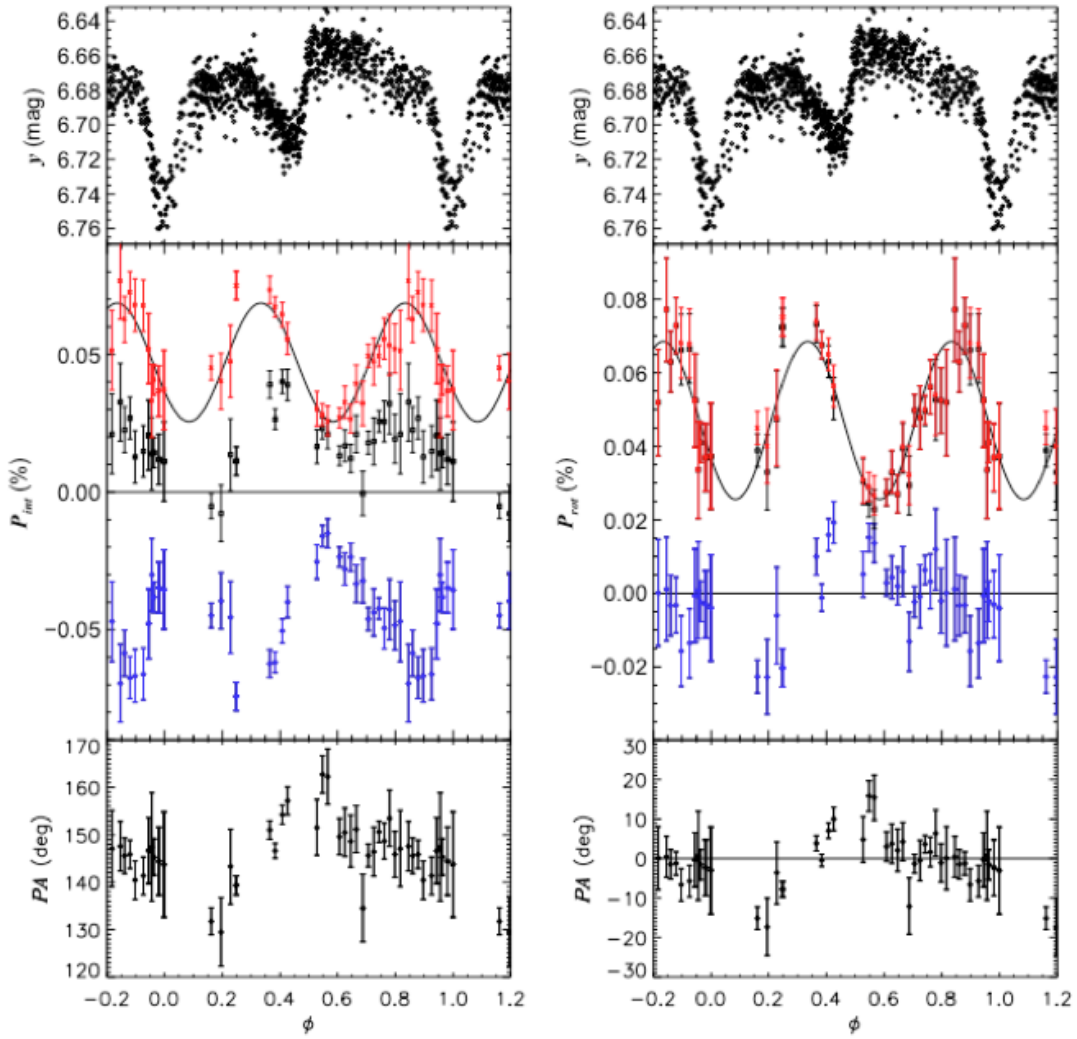


Fig. 4. Average ΔT_{max} derived from high time resolution light curves of V603 Aql, TT Ari and RS Oph as a function of isophotal wavelength of the comparison band. The broken lines are linear least-squares fits to the data points (in the case of RS Oph without considering the points referring to the *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



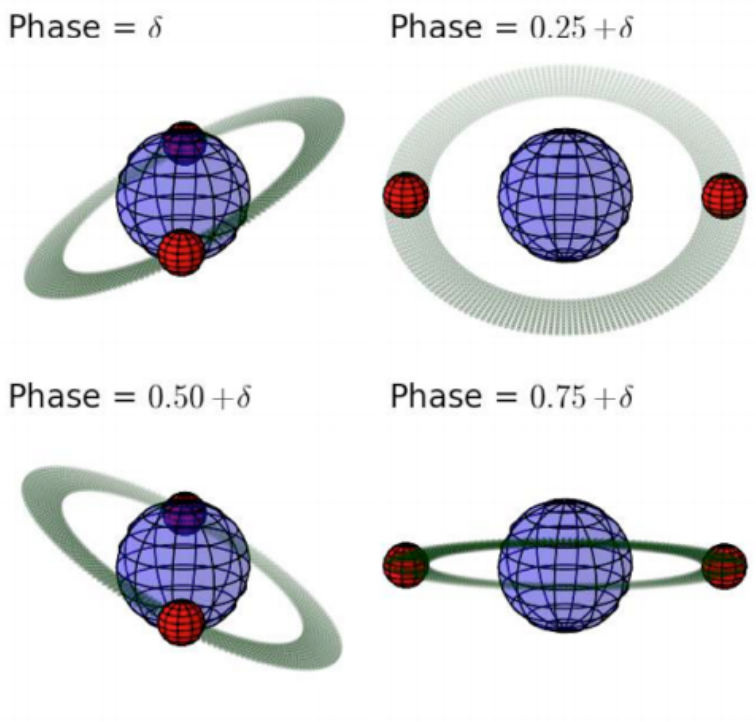


FIG. 3.— Geometric conception of the "dumbbell + disk" model, to scale.

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

Title: Multi-band characterization of the hot Jupiters: WASP-5b, WASP-44b and WASP-46b

Authors: Moyano, M.; Almeida, L. A.; von Essen, C.; Jablonski, F.; Pereira, M. G.

Bibliographic Code: 2017MNRAS.471..650M

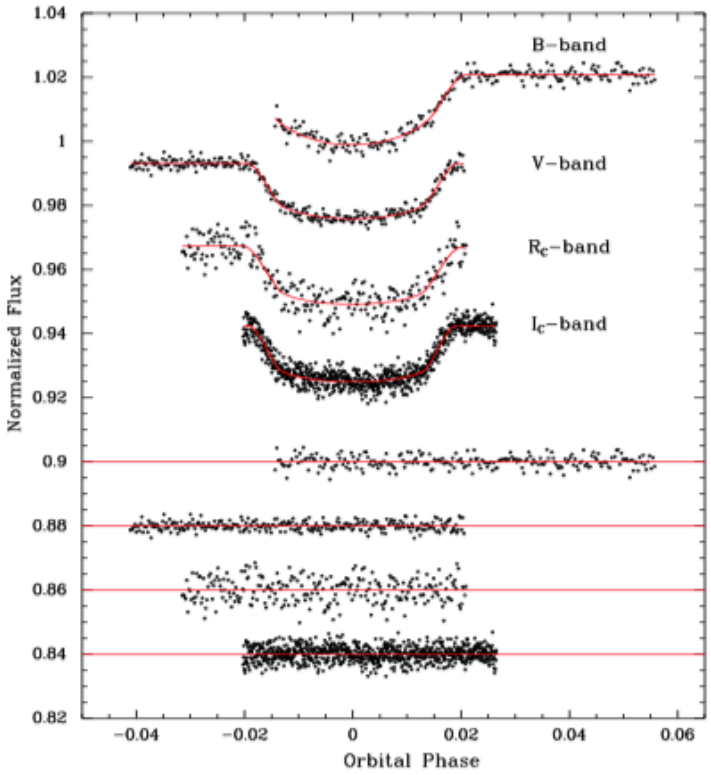


Figure 2. WASP-44b light curves. From top to bottom the B-, V-, R_C-, and I_C-band light curves respectively. The red curves are the best fits superimposed. The residuals of the fitted model are displayed at the bottom. The displayed light curves are decorrelated using the parameters described in Section 3.1.

Table 3. Planetary parameters of WASP-44b.

Symbol	Parameter	V	B	R_C	I_C
a ...	Semi-major axis (AU)	0.0352 ± 0.0014	$0.0328^{+0.0016}_{-0.0015}$	0.0354 ± 0.0016	$0.0349^{+0.0015}_{-0.0016}$
R_P .	Radius (R_J)	$1.12^{+0.10}_{-0.11}$	$1.08^{+0.15}_{-0.13}$	1.18 ± 0.13	$1.121^{+0.080}_{-0.081}$
$R_P/R_\star$	Planet/star radius ratio	$0.1224^{+0.0013}_{-0.0013}$	$0.1346^{+0.0031}_{-0.0031}$	$0.1256^{+0.0033}_{-0.0032}$	$0.1246^{+0.0025}_{-0.0025}$
T_{eq} .	Equilibrium Temperature (K)	1390 ± 120	1200^{+120}_{-100}	1410^{+140}_{-130}	1360 ± 120
$\langle F \rangle$.	Incident flux (10^9 erg s^{-1} cm^{-2})	$0.85^{+0.33}_{-0.25}$	$0.46^{+0.23}_{-0.14}$	$0.89^{+0.40}_{-0.29}$	$0.78^{+0.31}_{-0.23}$
T_C ..	Time of mid-transit(BJD$_{\rm TDB}$-2450000)	$6151.82559^{+0.00046}_{-0.00045}$	$6156.6694^{+0.0014}_{-0.0019}$	$6151.82415^{+0.0010}_{-0.00095}$	6505.70010 ± 0.00025
u_1 ..	linear limb-darkening coeff	$0.493^{+0.094}_{-0.084}$	$0.932^{+0.089}_{-0.12}$	$0.378^{+0.10}_{-0.089}$	$0.331^{+0.071}_{-0.070}$
u_2 ..	quadratic limb-darkening coeff	$0.222^{+0.076}_{-0.088}$	$-0.044^{+0.12}_{-0.095}$	$0.252^{+0.066}_{-0.074}$	$0.252^{+0.061}_{-0.063}$
i	Inclination (degrees)	$86.13^{+0.81}_{-0.58}$	$86.89^{+1.2}_{-0.85}$	$85.85^{+0.74}_{-0.60}$	$86.23^{+0.56}_{-0.48}$
δ	Transit depth	$0.01501^{+0.00065}_{-0.00079}$	$0.0171^{+0.0015}_{-0.0014}$	0.0163 ± 0.0012	$0.01542^{+0.00071}_{-0.00070}$
T_{14} .	Total duration (days)	0.0942 ± 0.0016	$0.0963^{+0.0042}_{-0.0038}$	$0.0937^{+0.0032}_{-0.0030}$	$0.09516^{+0.00099}_{-0.00095}$

The sdA problem – II. Photometric and Spectroscopic Follow-up

Ingrid Pelisoli[1⋆], S. O. Kepler[1], D. Koester[2], B. G. Castanheira[3,4], A. D. Romero[1], L. Fraga[5]

Monthly Notices of the Royal Astronomical Society, Volume 478, Issue 1, July 2018, Pages 867–884, https://doi.org/10.1093/mnras/sty1101

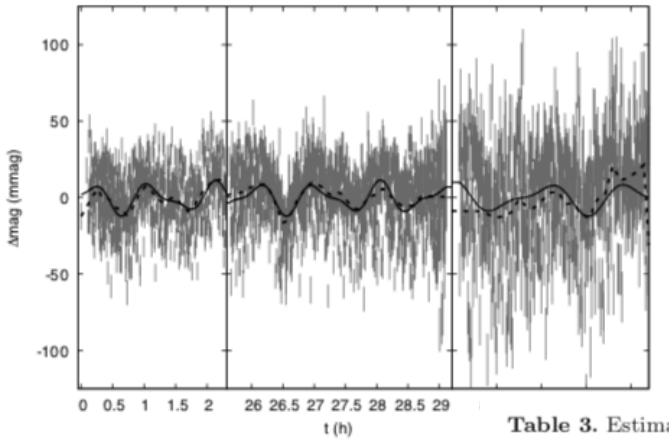


Figure 20. OPD light curve for 222009.74-092 were found above a detection limit of 4 ⟨A⟩ average amplitude of the Fourier transform. curve given these two periods is shown as co dashed line shows the smoothed data.

Table 3. Estimated physical and orbital properties for the new and probable (pre-)ELMs, which are separated by a horizontal line. $T_{\rm eff}$ and log g were estimated assuming $Z = 0.1\ Z_{\odot}$. The secondary mass is the lower limit ($i = 90°$), and the time for merging is the upper limit. The uncertainties in P and K were calculated with a thousand Monte Carlo simulations in PERIOD04.

SDSS J	$T_{\rm eff}$ (K)	log g	M ($M_{\odot}$)	$P_{\rm orb}$ (h)	K (km/s)	M_2 ($M_{\odot}$)	$\tau_{\rm merge}$ (Gyr)
032914.77+003321.8	9077 ± 10	5.179 ± 0.029	0.1536 ± 0.0006	20.0 ± 0.1	83 ± 22	0.17	765
073934.37+172225.5	7548 ± 12	5.056 ± 0.046	0.1450 ± 0.0011	6.64 ± 0.03	82.6 ± 6.8	0.10	68
084034.83+045357.6	7886 ± 32	5.074 ± 0.091	0.1470 ± 0.0022	8.13 ± 0.01	222 ± 13	0.59	28
134336.44+082639.4	8123 ± 10	5.969 ± 0.034	0.1527 ± 0.0011	24.692 ± 0.002	136.2 ± 7.0	0.43	410
142421.30-021425.4	9299 ± 11	5.128 ± 0.031	0.1558 ± 0.0008	6.3 ± 0.4	80 ± 22	0.09	57
205120.67+014554.4	7813 ± 12	5.004 ± 0.055	0.1476 ± 0.0014	22.9 ± 0.2	138 ± 14	0.45	533
092056.09+013114.8	7478 ± 13	4.802 ± 0.044	0.1492 ± 0.0014	15.742 ± 0.003	75.7 ± 8.1	0.09	50
004227.73-010634.9	8051 ± 24	5.510 ± 0.081	0.1449 ± 0.0003	1.52231 ± 0.00002	48.1 ± 1.6	0.14	4.2
011508.65+005346.1	8673 ± 24	5.641 ± 0.080	0.1499 ± 0.0011	1.678517 ± 0.000009	74.5 ± 5.5	0.05	3.1
030608.92-001338.9[a]	7768 ± 10	5.356 ± 0.039	0.1433 ± 0.0004	28.6 ± 1.1	186 ± 61	1.03	546
				13.5 ± 2.3	88 ± 19	0.15	320
045515.00-043231.0	8251 ± 8	4.154 ± 0.031	0.1796 ± 0.0014	4.1 ± 3.8	60 ± 23	0.06	25
090410.00+034332.9	7680 ± 20	4.079 ± 0.046	0.1810 ± 0.0488	14.7 ± 0.3	47.7 ± 2.4	0.08	590
122911.49-003814.4	8305 ± 21	5.652 ± 0.060	0.1477 ± 0.0009	2.96 ± 0.08	47 ± 5.0	0.04	20
162624.91+162201.5	7464 ± 15	3.827 ± 0.032	0.3454 ± 0.0127	8.2 ± 0.1	93 ± 19	0.20	32
233606.13-102551.5	8328 ± 39	5.716 ± 0.147	0.1487 ± 0.0030	2.38904 ± 0.0008	131 ± 11	0.12	3.7

[a] Two distinct periods are possible with the current data. Parameters for both are shown.

Microlenses

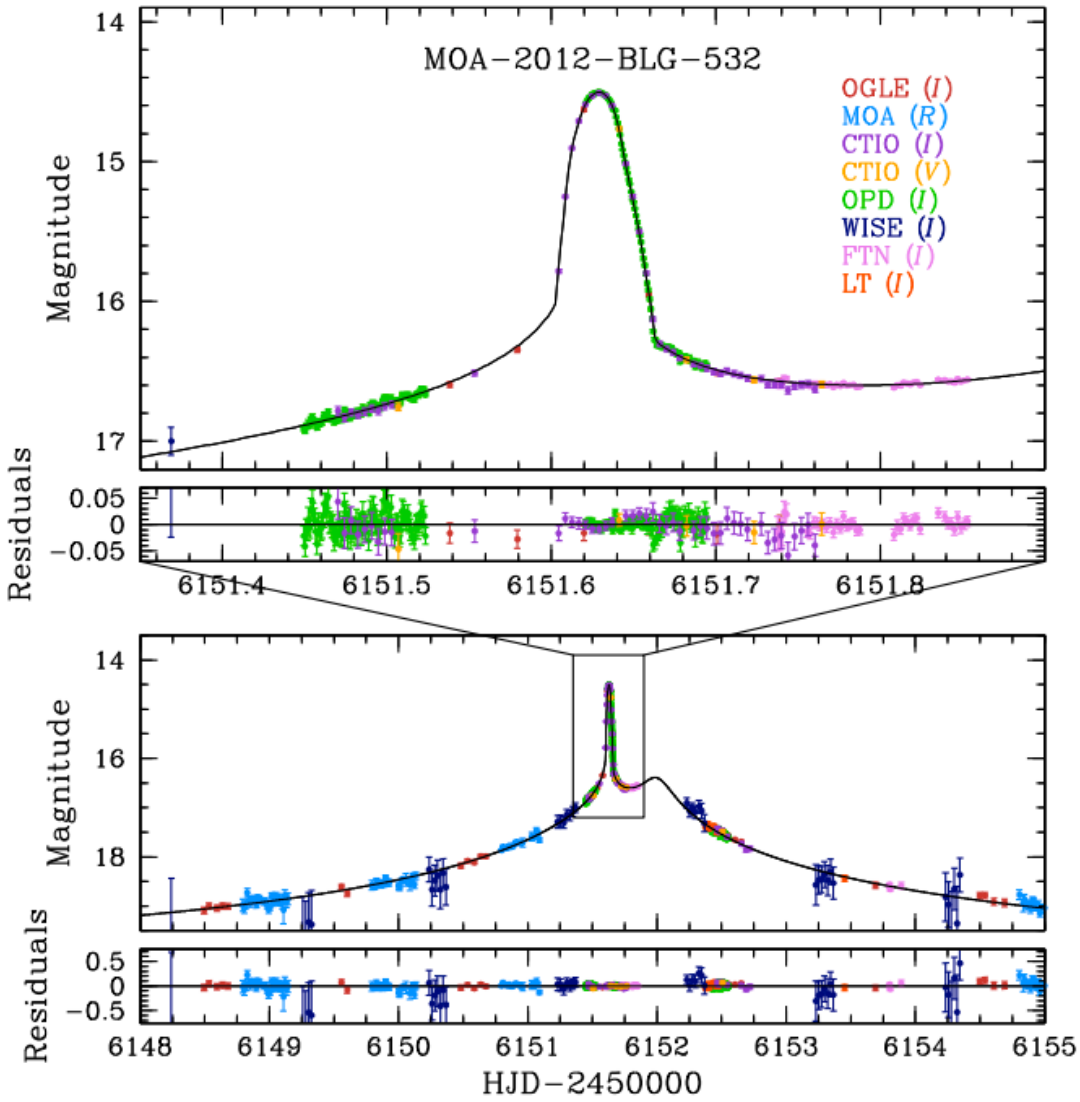
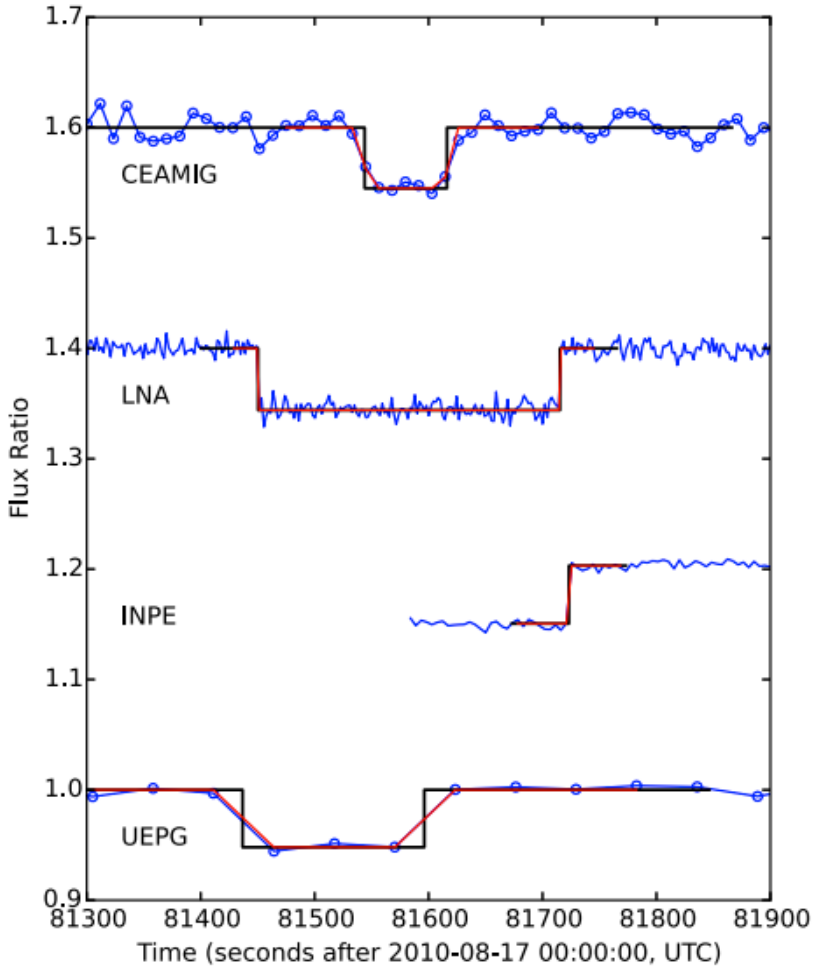


Figure 6. Light curve of MOA-2012-BLG-532. The notations are the same as those in Figure 2.

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+



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

Future

- 2018
  - ✓ start machining
  - ✓ start assembling
  - ✓ start pipeline coding
  - ✓ conclude control project
  - ✓ optical mouting and tests
- 2019
  - ✓ machining
  - ✓ assembling
  - ✓ integration and lab tests
  - ✓ start GUI and acquisition coding
  - ✓ first-light (?)
  - ✓ commissioning and science verification (?)
- 2020
  - ✓ first-light (?)
  - ✓ commissioning and science verification (?)
  - ✓ deliver instrument

Thank you!

Acknowledgements

Finep: Proc. 0/1/16/0076/00)
CNPq: Proc. 306701/2015-4
Fapesp: Proc. 2013/26258-4