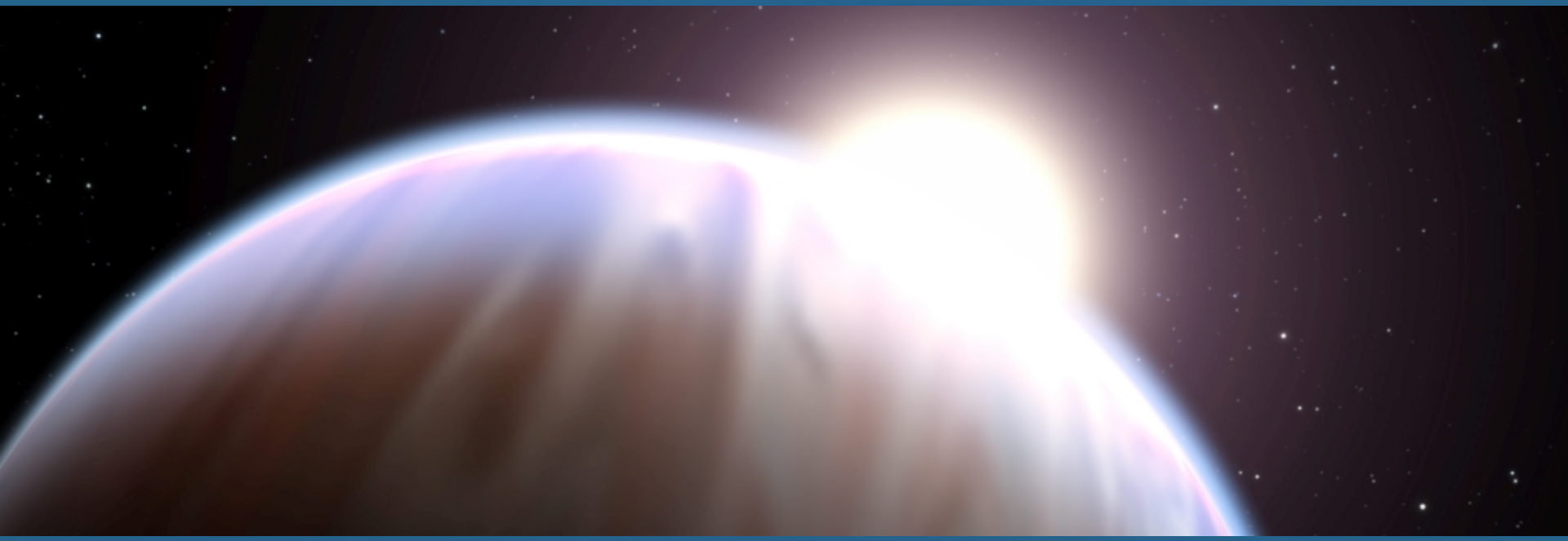
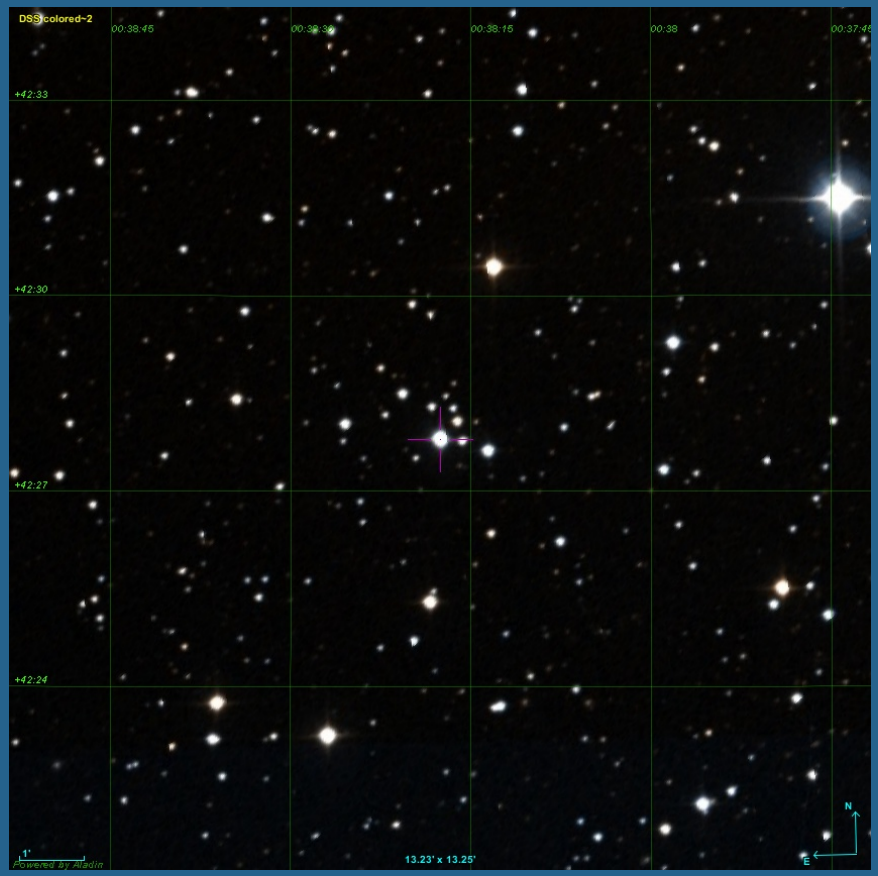
HAT-P-16 OBSERVATIONS
Aperture Photometry & Transit Fitting



Group IV assignment

Nestor Arsenov, Joe Cooper, Joseph Reale, Mindaugas Macijauskas, & Jean Martin

HAT-P-16: Host star

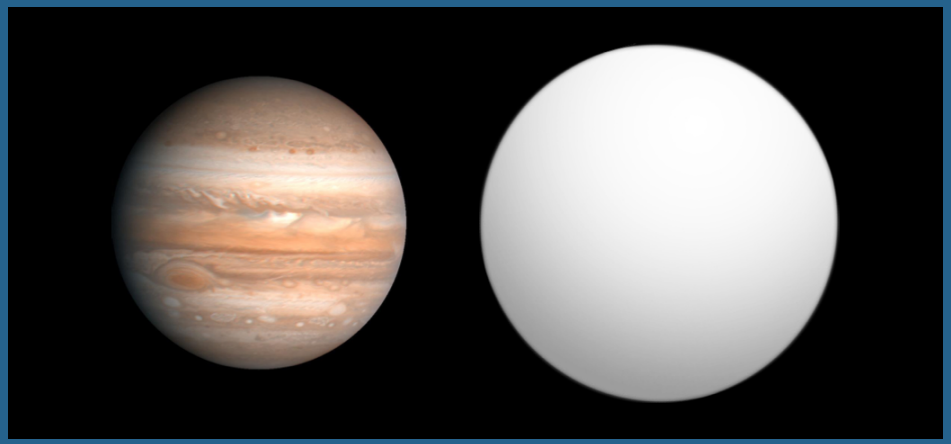


- Name: TYC 2792-1700-1
- RA (2000.0): 00:38:18.0
- DEC (2000.0): +42:27:47
- Magnitude (V): 10.91
- Distance: 232.0 (± 10.0) pc
- Spectral type: F8
- Mass: 1.218 (± 0.039) M_{sun}
- Age: 2.0 (± 0.8) Gyr
- Effective temp: 6158.0 (± 80.0) K
- Radius: 1.237 (± 0.054) R_{sun}
- Metallicity [Fe/H]: 0.17 (± 0.08)

Credit: Aladin sky atlas/DSS2

Sources: Simbad & Exoplanets.eu

HAT-P-16: Transiting planet



Credit: Aldaron

- Discovered: 2010 by HATNet Project
- Mass: 4.193 (± 0.094) M_J
- Semi-Major Axis: 0.0413 (± 0.0004) AU
- Orbital Period: 2.77596 (± 3e-06) JD
- Eccentricity: 0.036 (± 0.004)
- Radius: 1.289 (± 0.066) R_J
- Inclination: 86.6 (± 0.7) deg
- Transit depth: 0.0101 mag

Source: Exoplanets.eu

Observations: 165 cm Telescope at MAO

Credit: Andrius Zigmantas

Basic specifications:

- Ritchey Chretian type
- Primary mirror diameter: 165 cm
- Secondary mirror diameter: 45 cm
- Telescope focal length: 2000 cm
- FOV 8' x 8'
- Mount: Equatorial (Cross-axis)

Source: http://mao.tfai.vu.lt/mao/

Observations: CCD Camera

Credit: Optcorp

Basic specifications:

- Chip: E2V CCD47-10
- Array size: 1024 x 1024
- Pixel size: 13 x 13 microns
- Imaging area: 13.3 x 13.3 mm
- Linear full well: 100K electrons

Source: http://mao.tfai.vu.lt/mao/

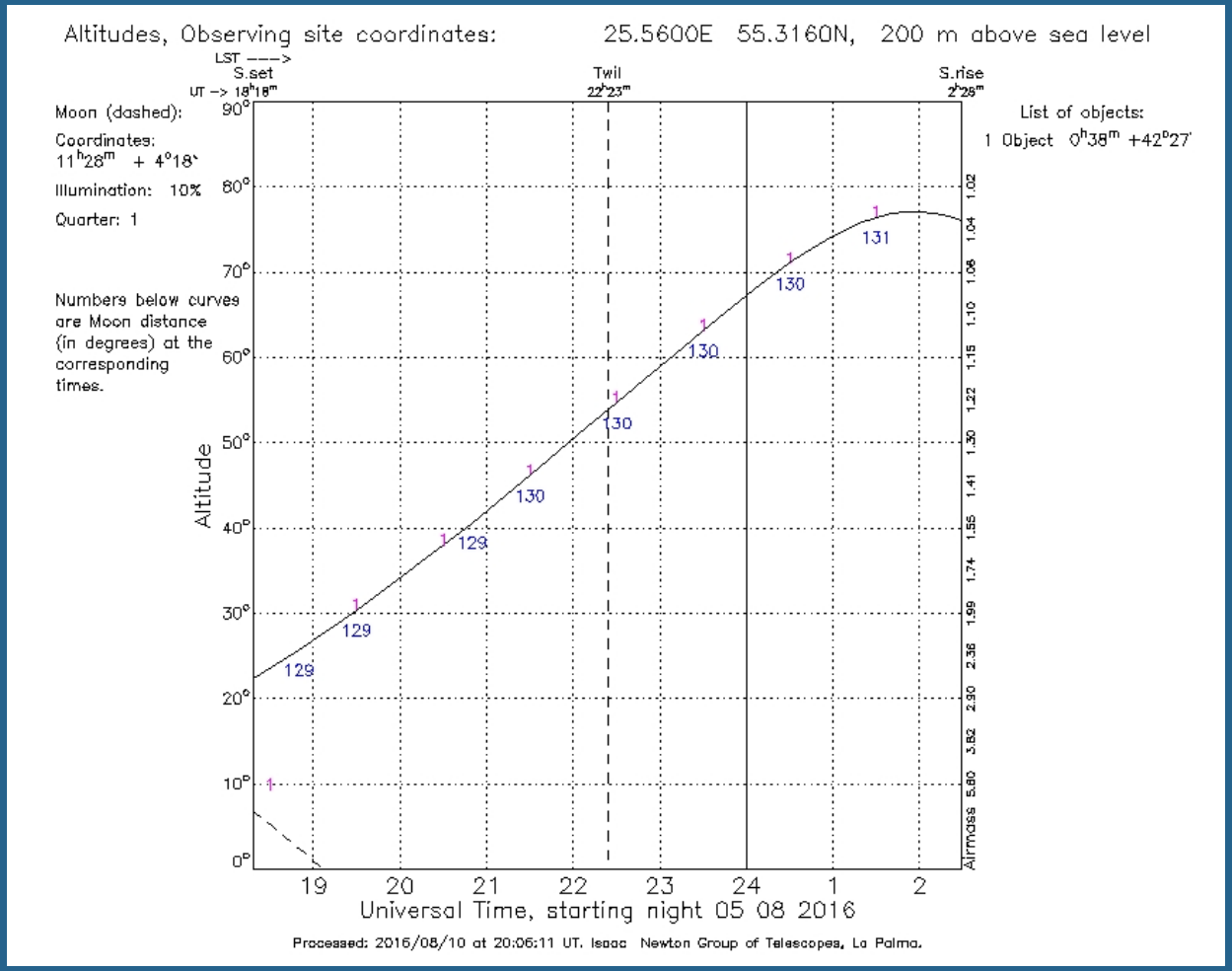
HAT-P-16: Selection

Transits predictions for ELONGITUDE: 25.56320° and LATITUDE: 55.31600°

OBJECT	BEGIN (UT/h,A)	CENTER (DD.MM. UT/h,A)	END (UT/h,A)	D (min)	V (MAG)	DEPTH (MAG)	Elements Coords
WASP-103 b Her	19:00 34°,S	**05.08. 20:18** **28°,SW**	21:36 19°,SW	155.58	12.1	0.0129	56459.59957+0.925542*E RA: 16 37 15.57 DE: + 07 11 00.07
HAT-P-28 b And	21:06 37°,E	**05.08. 22:43** **50°,E**	0:19 62°,SE	193.1	13.03	0.0162	55417.59832+3.257215*E RA: 00 52 00.27 DE: +34 43 42.9
WASP-52 b Peg	21:58 35°,SE	**05.08. 22:52** **40°,SE**	23:47 43°,S	108.58	12	0.0290	55793.68143+1.7497798*E RA: 23 13 58.76 DE: +08 45 40.6
HAT-P-16 b And	21:30 47°,E	**05.08. 23:02** **60°,E**	0:34 72°,SE	184	10.8	0.0101	55027.59293+2.77596*E RA: 00 38 17.59 DE: +42 27 47.2
Kepler-19 b Lyr	22:18 66°,SW	**05.08. 23:59** **53°,W**	1:40 39°,W	201.91	11.898	0.0007	54959.70597+9.2869944*E RA: 19 21 41 DE: +37 51 06
KELT-1 b And	22:53 62°,E	**06.08. 0:10** **71°,SE**	1:27 75°,S	153.245	10.7	0.0066	55909.292797+1.217514*E RA: 00 01 26.92 DE: 39 23 01.7

Transit predictions for 05/08 Aug. Source: ETD - Exoplanet Transit Database

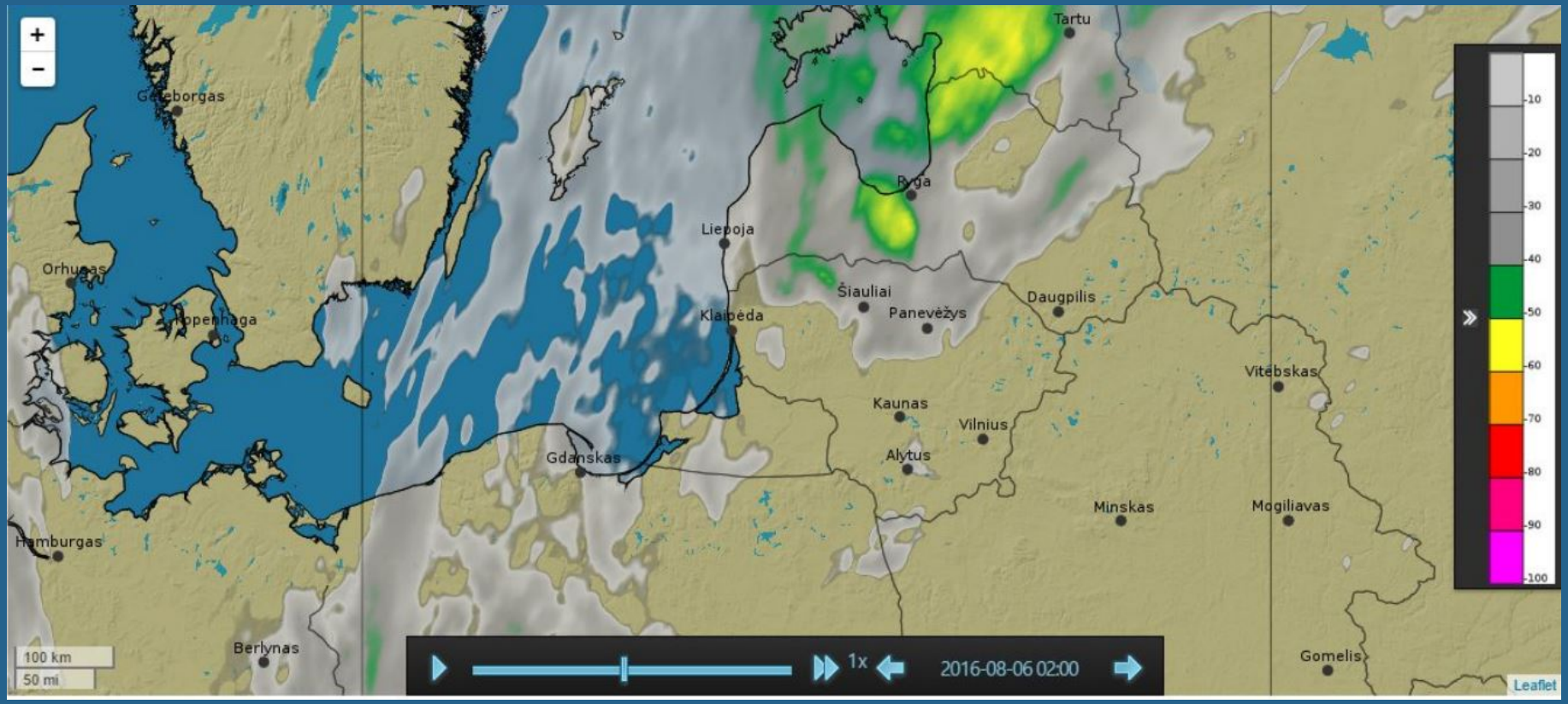
HAT-P-16: Visibility



Obervations from 19:00 – 01:30 UTC

Source: http://catserver.ing.iac.es/staralt/

Weather conditions on 05/06 August

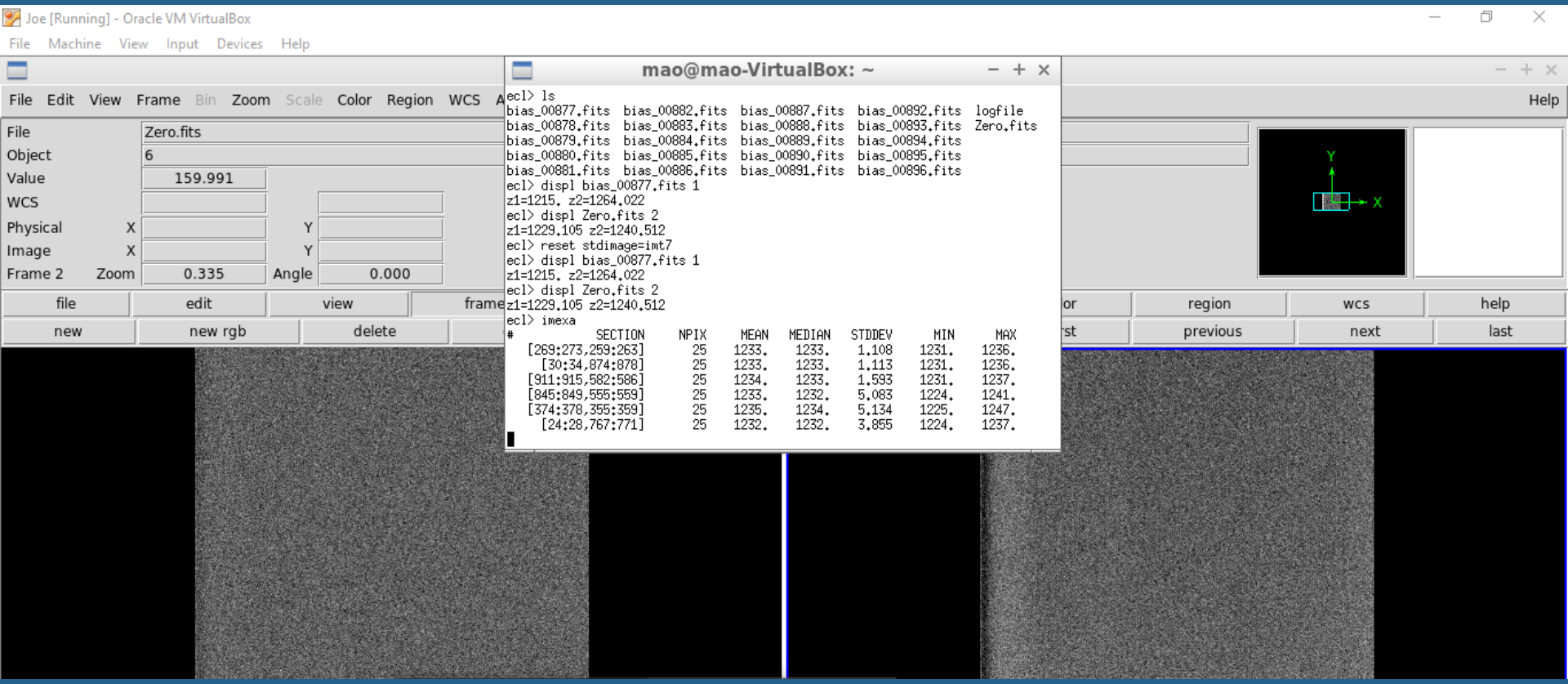


Cloud cover actual for 05/06 Aug

Data processing with IRAF:

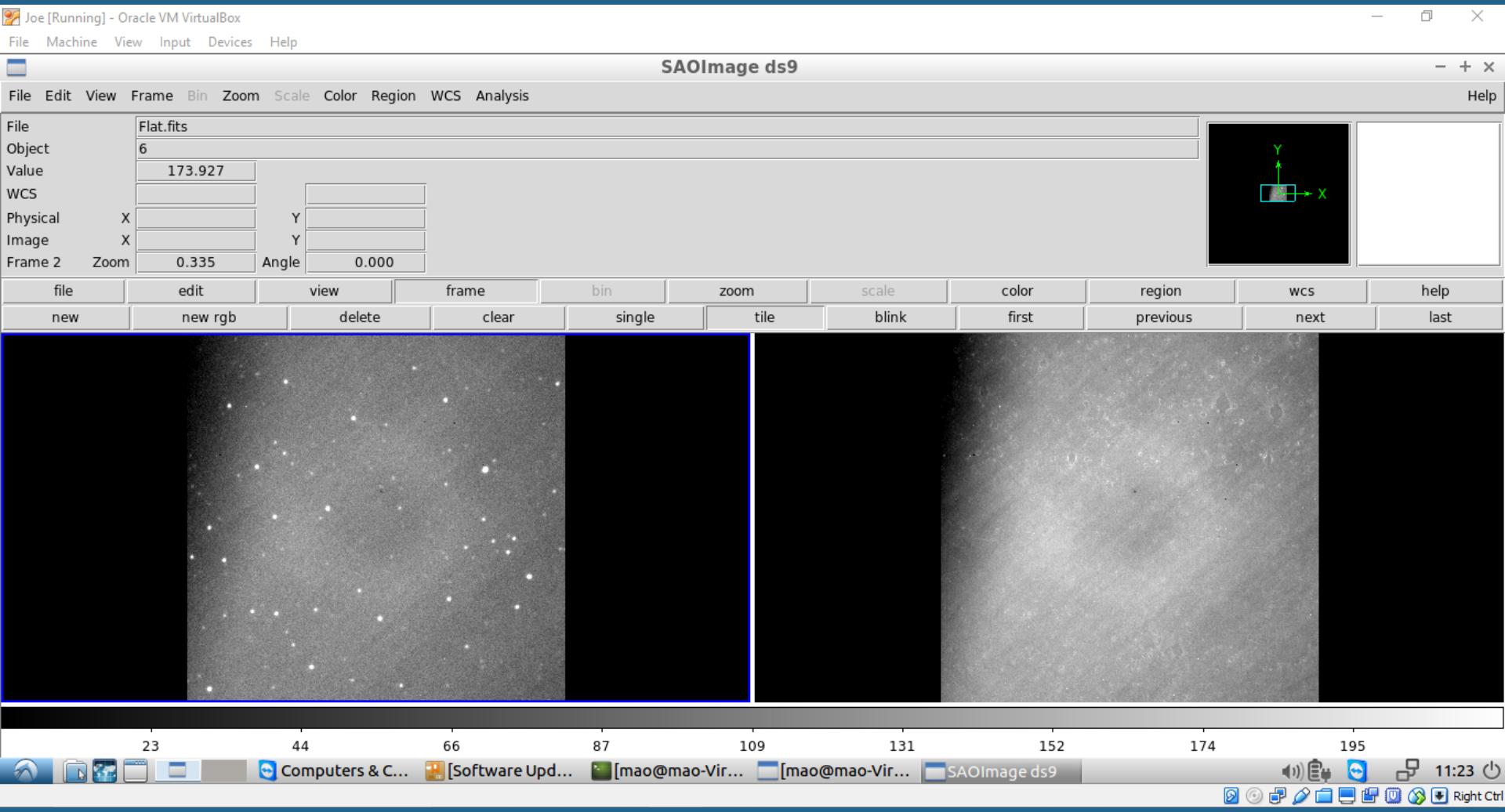
- Calibration of science frames
  - Checking for weird flat features that could ruin photometry
  - Creating master bias
  - Creating master flat
  - Master dark
  - Calibrating science frames
- Finding target star and appropriate reference stars
- Creating coordinate file, and defining aperture(s)
- Performing photometry and extracting relevant info from headers

Data processing with IRAF: Callibration



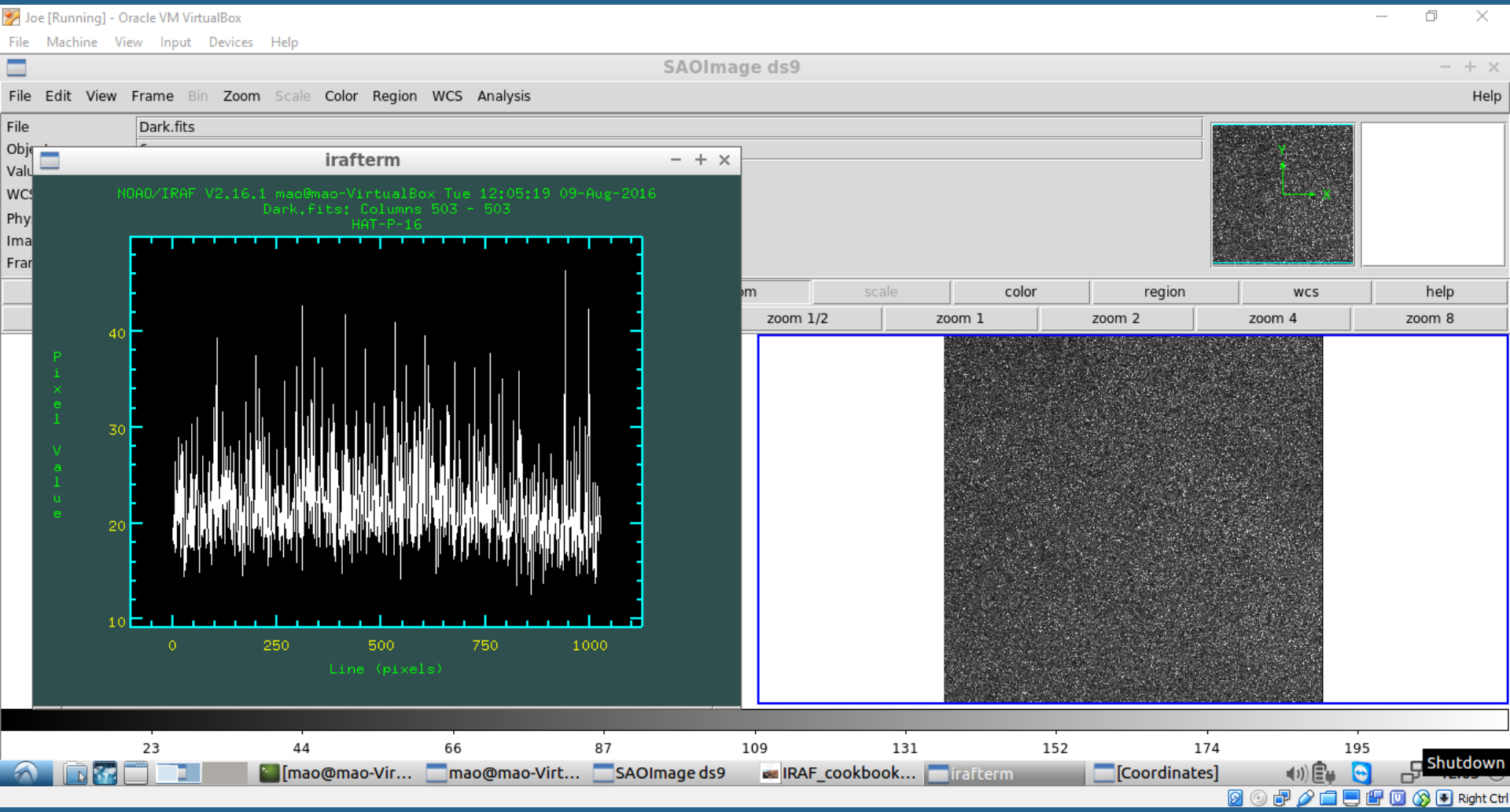
Bias frame and master bias frame → readnoise parameter

Data processing with IRAF: Callibration



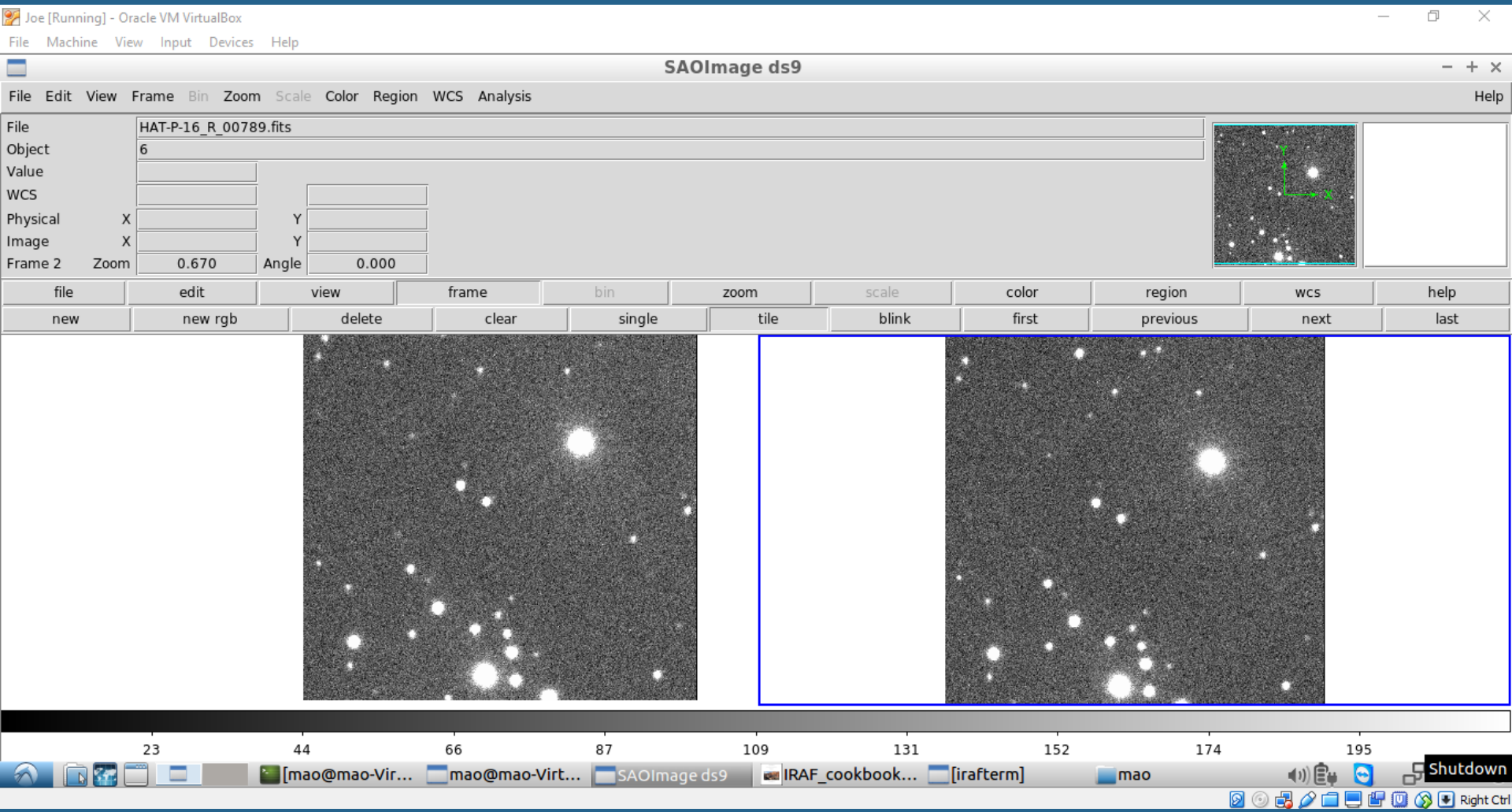
Really really bad master flat….

Data processing with IRAF: Callibration



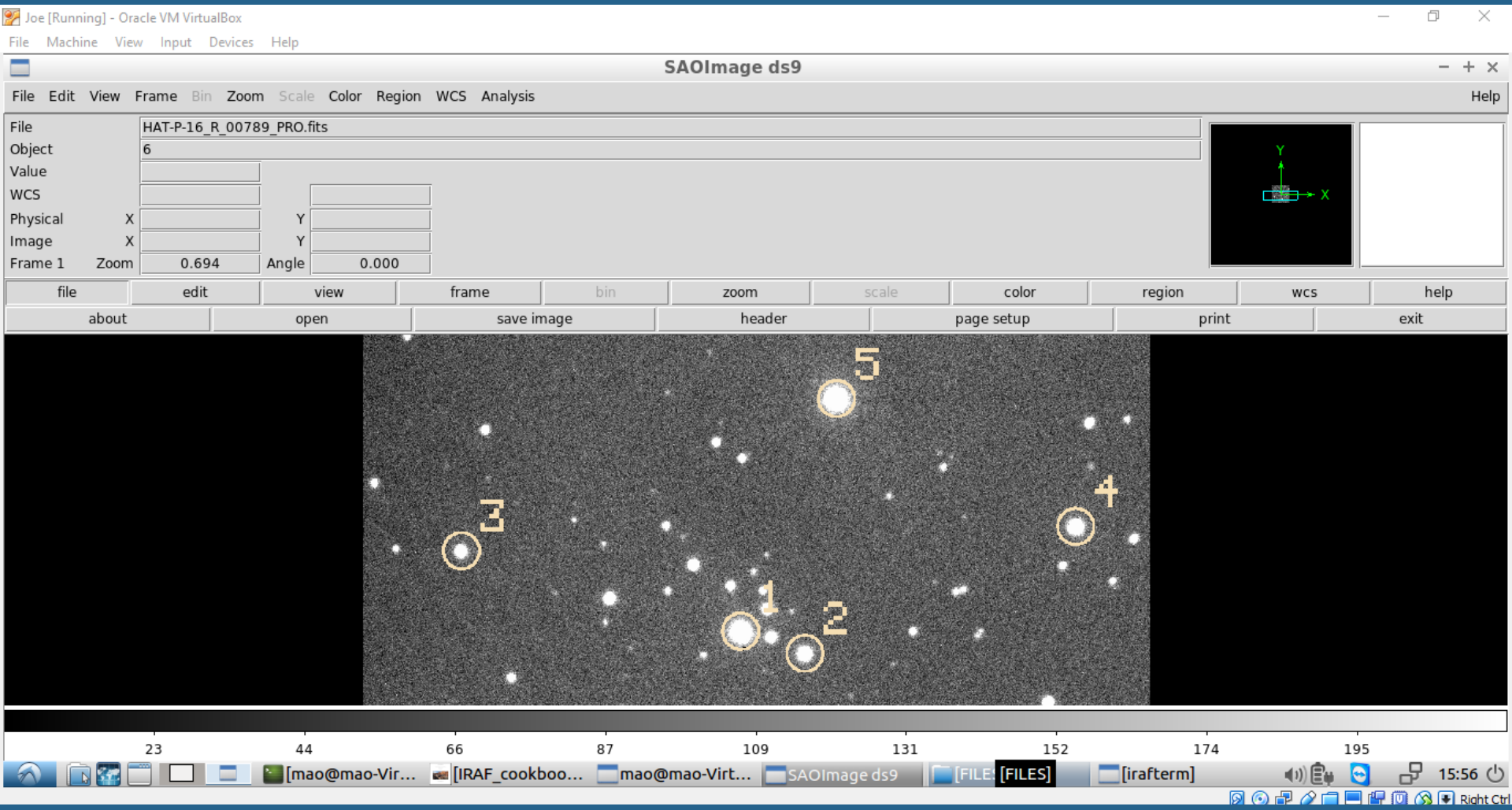
Master dark not used as exposure was only 3 seconds

Data processing with IRAF: Calibration



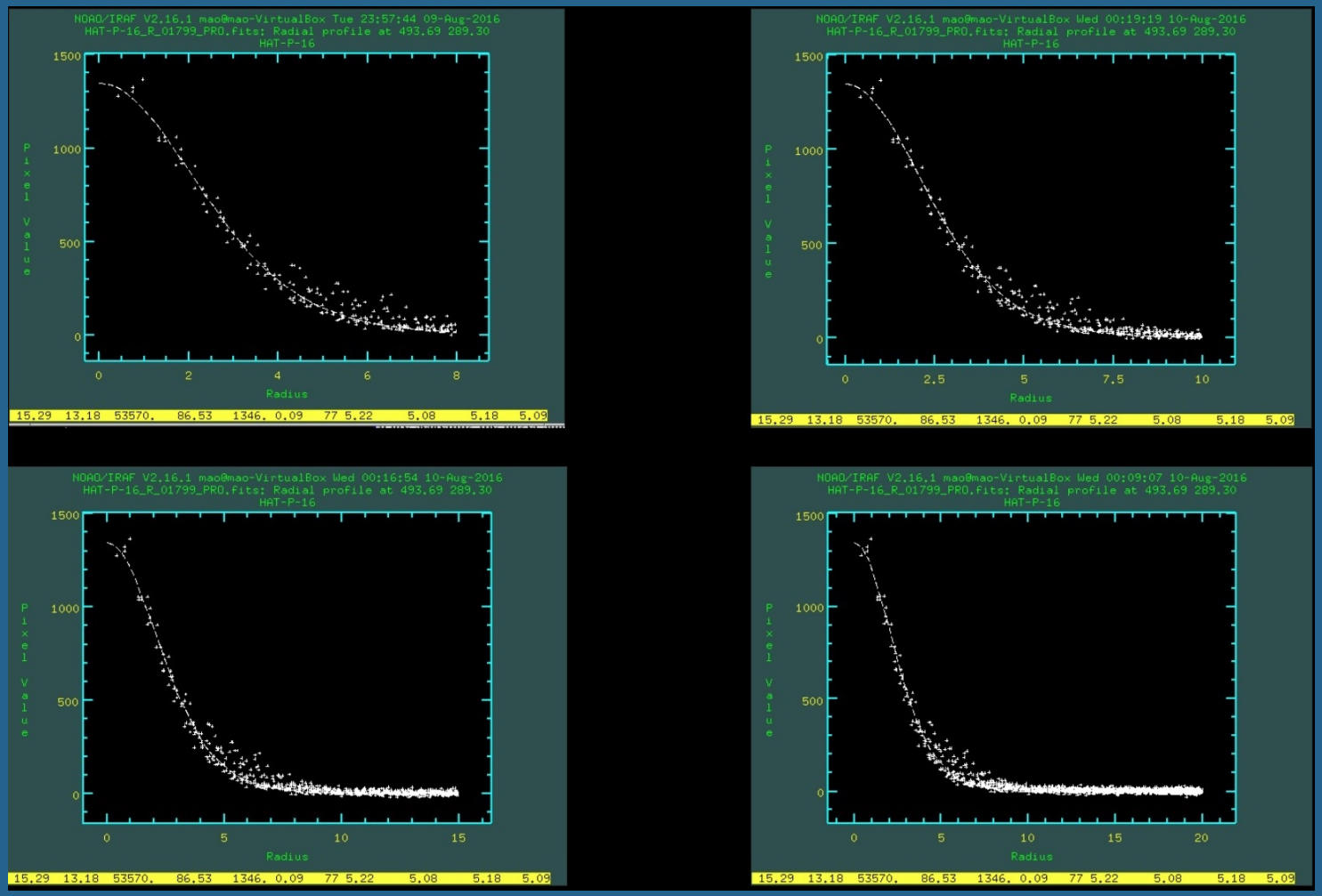
Reduced frame vs origional science frame (Spot the difference!)

Data processing with IRAF: Reference stars



Reference stars selection ($0.5 < \text{Intensity}_{\text{Target star}} < 3$)

Data processing with IRAF: Apertures



Radial profiles of the same star with different aperture radii

Data processing with IRAF

Header file missing two parameters:

airmass

- Arbitrarily set to 1.0

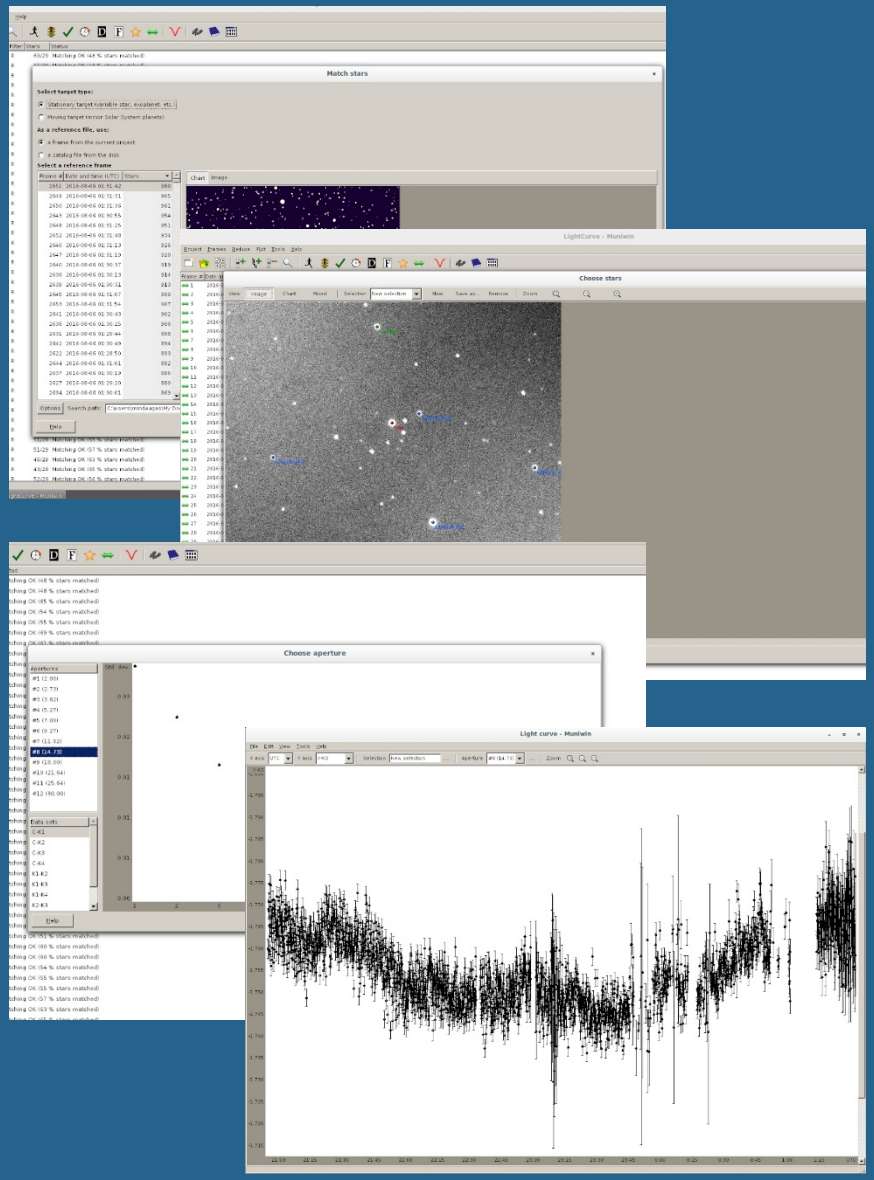
rdnoise

- Obtained from standard deviation of master bias frame.

Files are then ready for aperture photometry.

Script takes flux from each aperture and places in ascii file for later use

Data processing with C-Munipack



Simple steps:

- Generation of:
  - master bias,
  - master dark,
  - master flat frames
- Calibration of science frames
- Identification of stars in science frames
- Selection of reference stars
- Photometry
- Light curve

- For comparison with Python

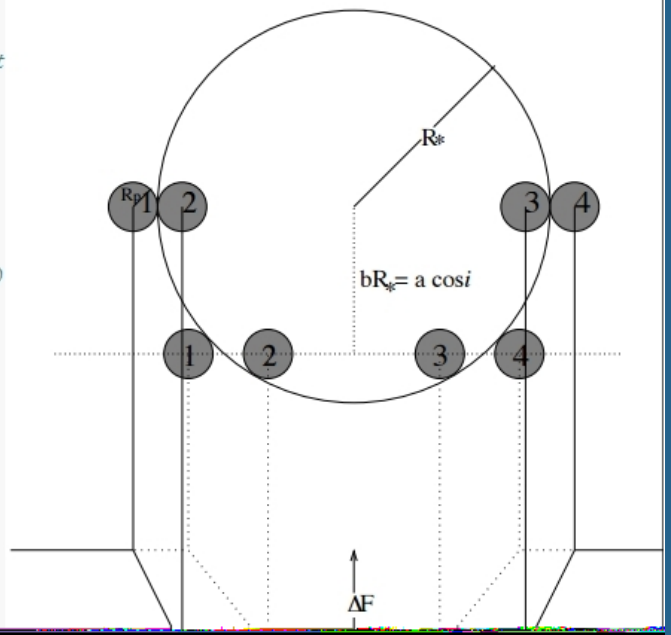
Parameters needed for transit fitting

Editor - Canopy

File Edit View Search Run Tools Window Help

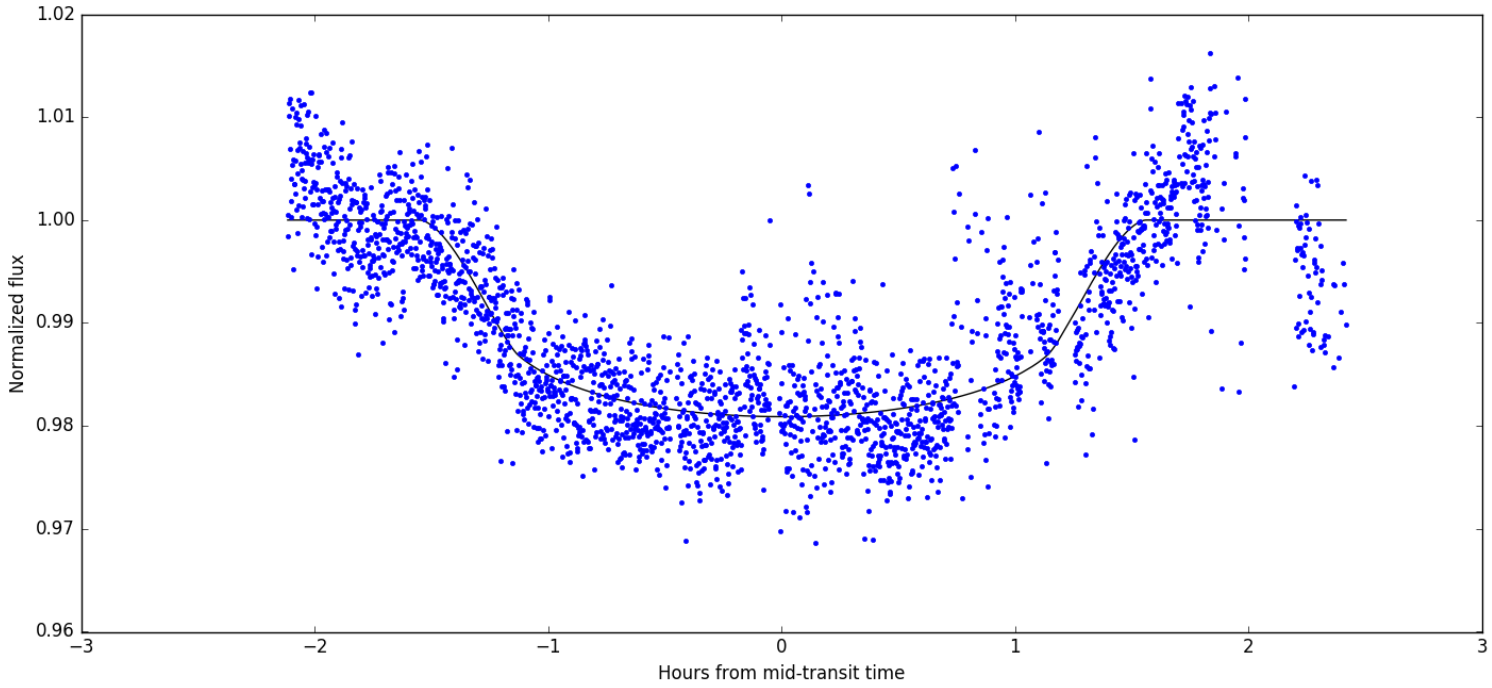
TransitFitting_MCMCEdit.py

```
59 time = time[index]
60 diff_lc = diff_lc[index]
61 err_diff = err_diff[index]
62 ################################################
63 # Create MandelAgolLC object with circular orbit and quadrat
64 ma = ft.MandelAgolLC(orbit="circular", ld="quad")
65
66 # Set parameters for transit:
67 ma["per"] = 2.77596
68 ma["i"] = 86.6
69 ma["a"] = 7.1544
70 ma["T0"] = 0.
71 ma["p"] = 0.092902
72 ma["linLimb"] = 0.5214#a from vizier database, claret (2000)
73 ma["quadLimb"] = 0.2350
74 ma["b"] = 0.
75
76 ma.thaw(["p", "T0"])
77
78 ################################################
79 # Create detrending object:
80 df = DetrendFunction1()
81 # Set parameters for detrending:
82 df["off"] = 1.01
83 df["lin"] = -0.01
84 df["qua"] = 0.01
85 df.thaw(["off", "lin", "qua"])
86
```



Used Simbad & Vizier databases to obtain parameters

Results: least square transit light curve



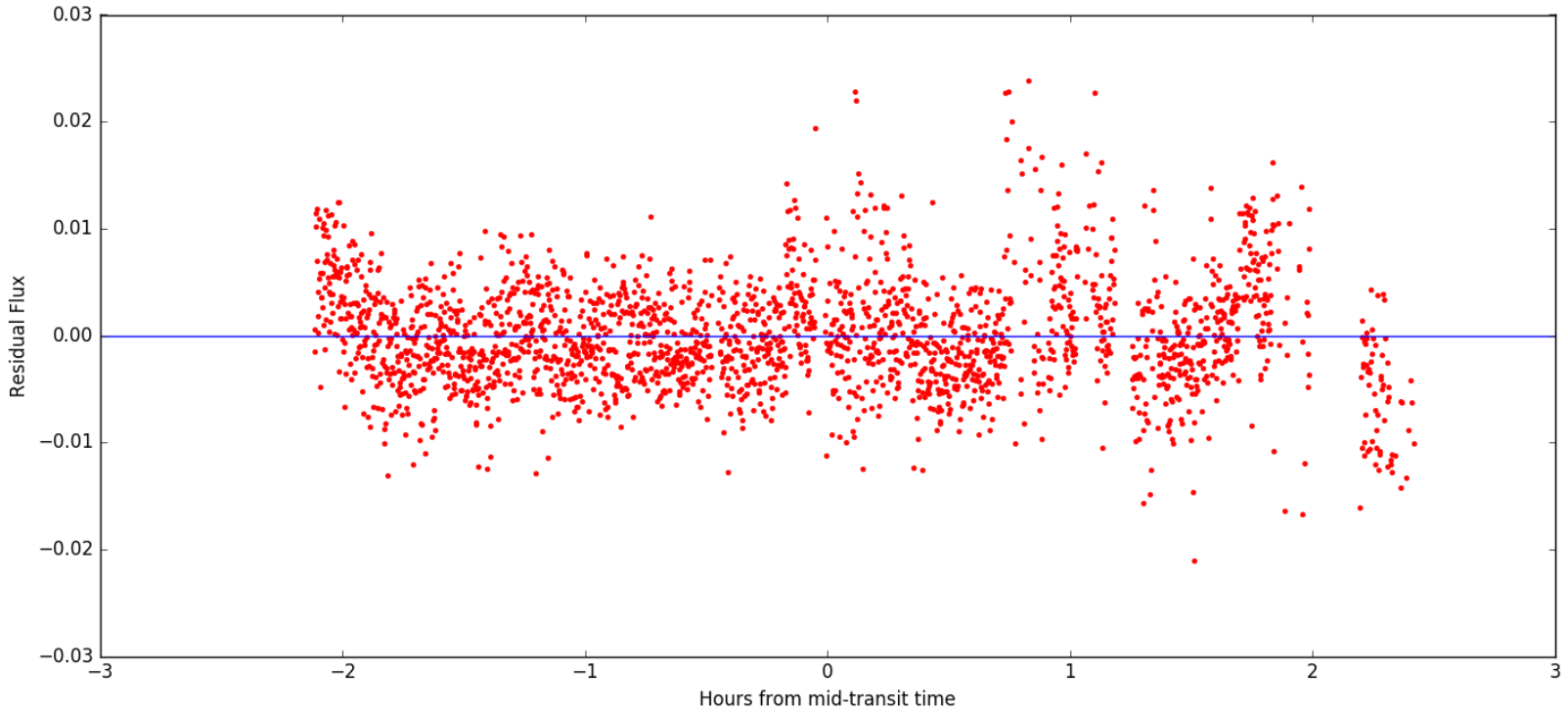
Parameters:

Ratio of Planet/Star Radius (p) = 0.1260947

Epoch of Transit (T0) = 2457606.459722 + 0.000215498 (JD)

Stdev of Residuals (sig) = 0.0050977

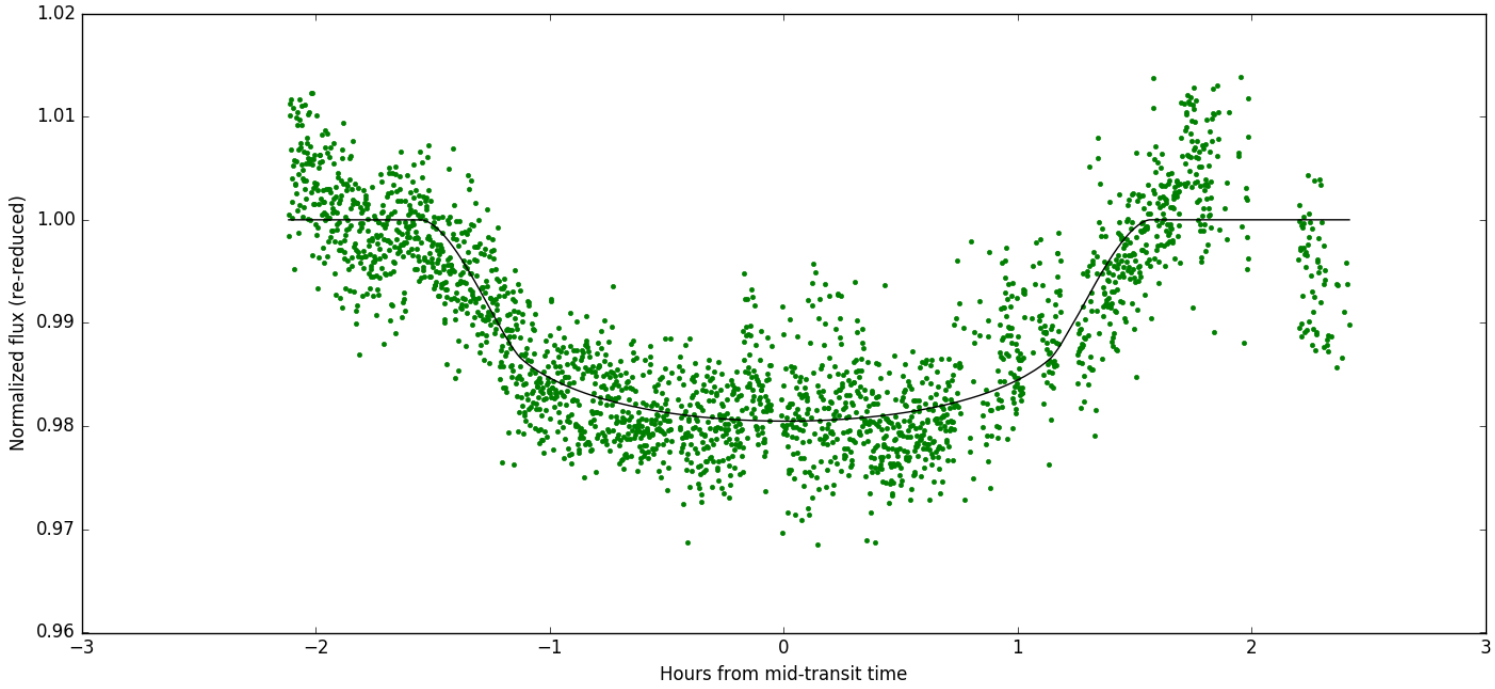
Results: residuals



Cut data points > 3 standard devs from mean

perform fitting algorithm again

Results: re-reduced light curve

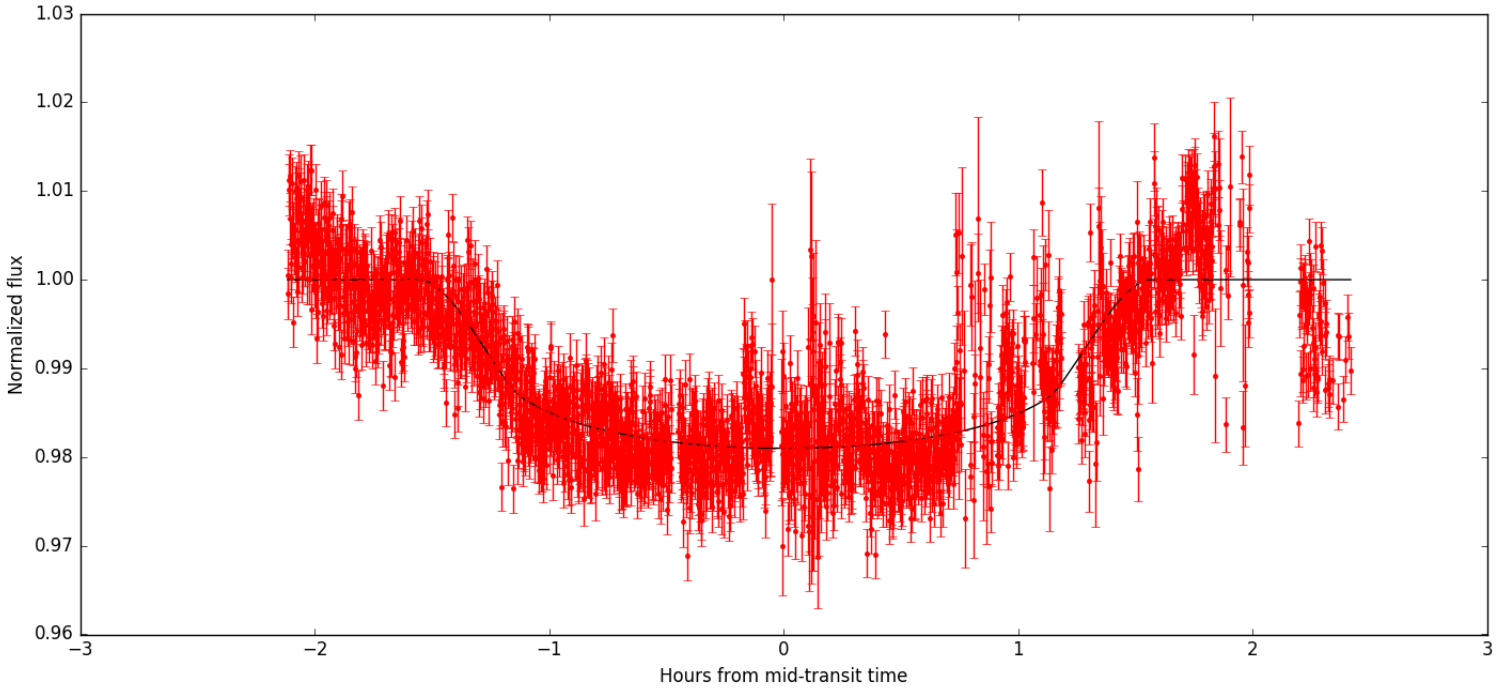


New parameters:

p = 0.12742814

T0 = 2457606.459722 + 0.0003649 (JD)

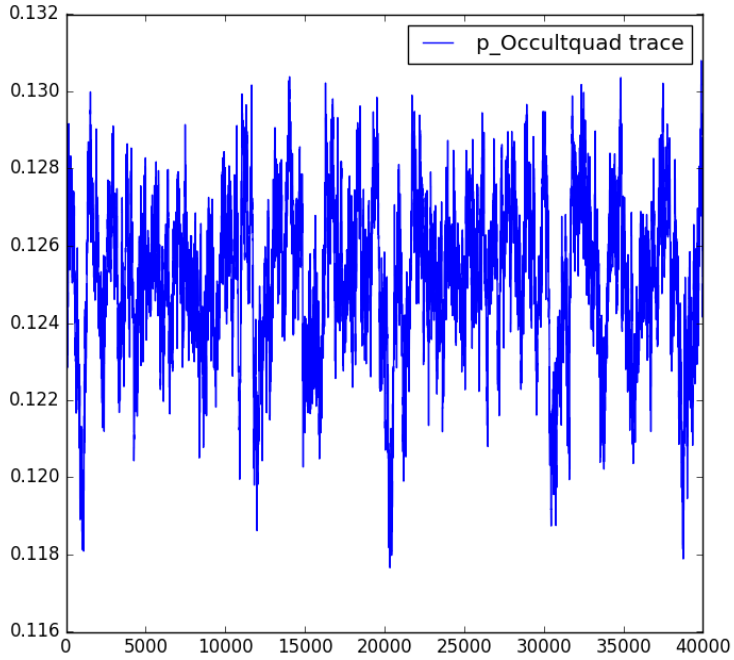
Results: MCMC transit light curve

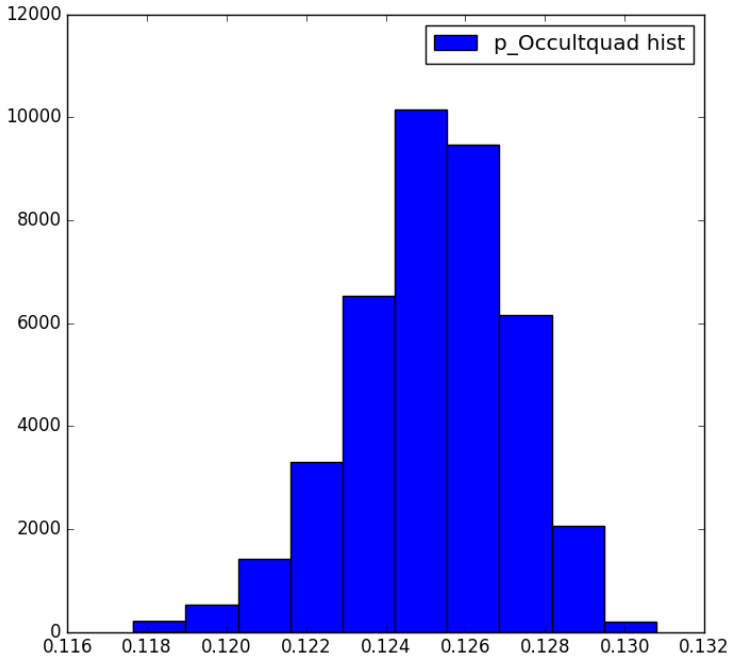


Perform Markov Chain Monte Carlo (MCMC) method to find parameters (T0 , p) for transit fit.

p = 0.126 ± 0.002	Giving:	Accepted values:
T0 = 0.0002 ± 0.0004 (JD)	1.55 ± 0.03 R_J	1.282 ± 0.087 R_J

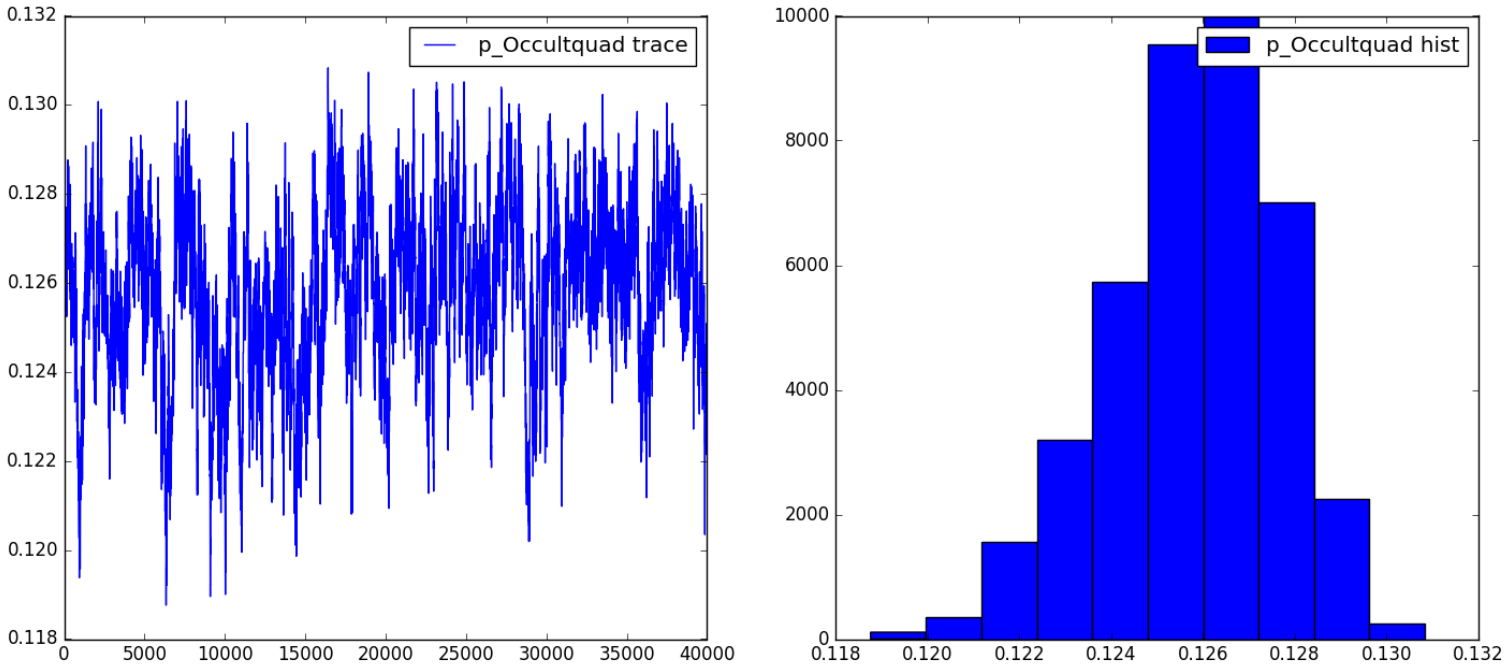
Results: Transit parameter chain





Markov chain for parameter p, with no burn (40,000 iterations)

Results: Transit parameter chain with burn

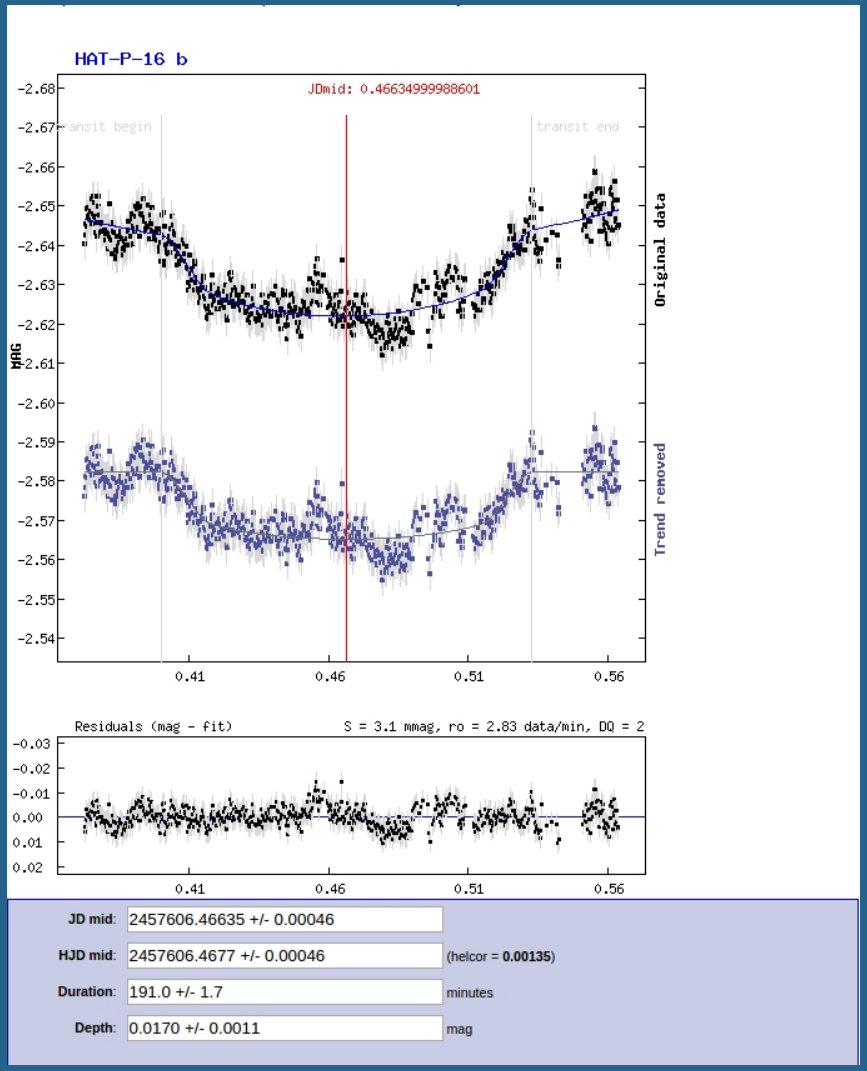


Markov chain for parameter p, with burn (40,000 iterations)

Results: C-Munipack + ETD

Basic results of transit data fitting in ETD (Exoplanet Transit Database)

- Mid-transit time (JD): 2457606.46635 ± 0.00046
- Duration: 191.0 ± 0.00046 min.
- Transit depth: 0.0170 ± 0.0011 mag



Conclusions

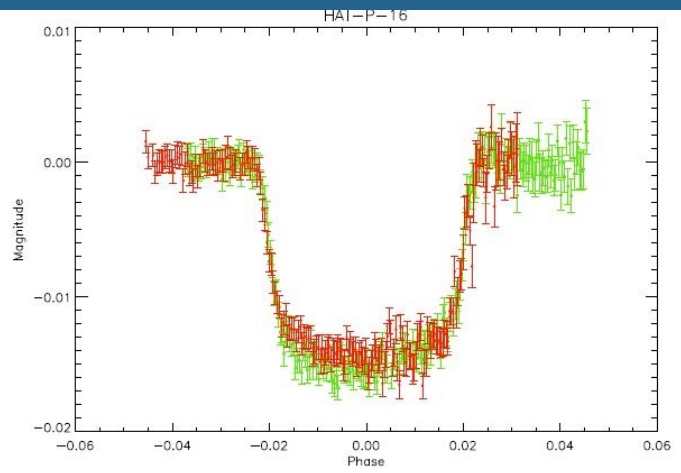
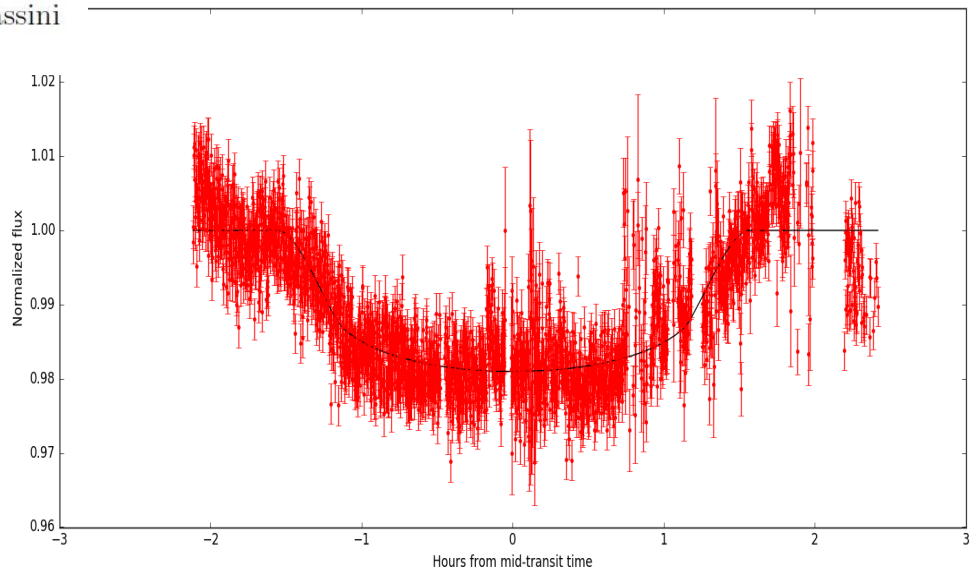


Fig. 1. Observations of the October 2012 transit of HAT-P-16. The green points show the data from the CA 1.23 m telescope, and the red points the data from the Cassini telescope.

Source: Ciceri et al. (2011)



Conclusions

- success in obtaining transit from obtained light curve - goal of summer school achieved!
- IRAF sufficient for
  - gaining transit from data,
  - Introducing students to aperture photometry
- demonstrated simple instrumentation can detect transits of Hot Jupiters (Not so 20 years ago!)
- even smaller exoplanets observable with:
  - better weather
  - improved reduction (flat, dark)
- prospect for more "simple" exoplanet research (e.g. GJ1132) and future summer-schools

Acknowledgements

Many thanks to Carolina & Erika!