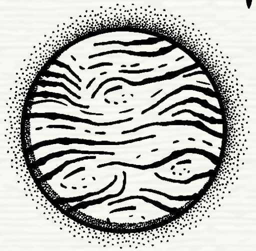
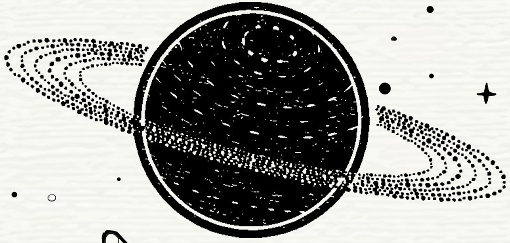
KNOW THE UNIVERSE:

WASP-97 SYSTEM





Elizaveta Julius Anna Ema

Supervisor: Veronika Schaffenroth

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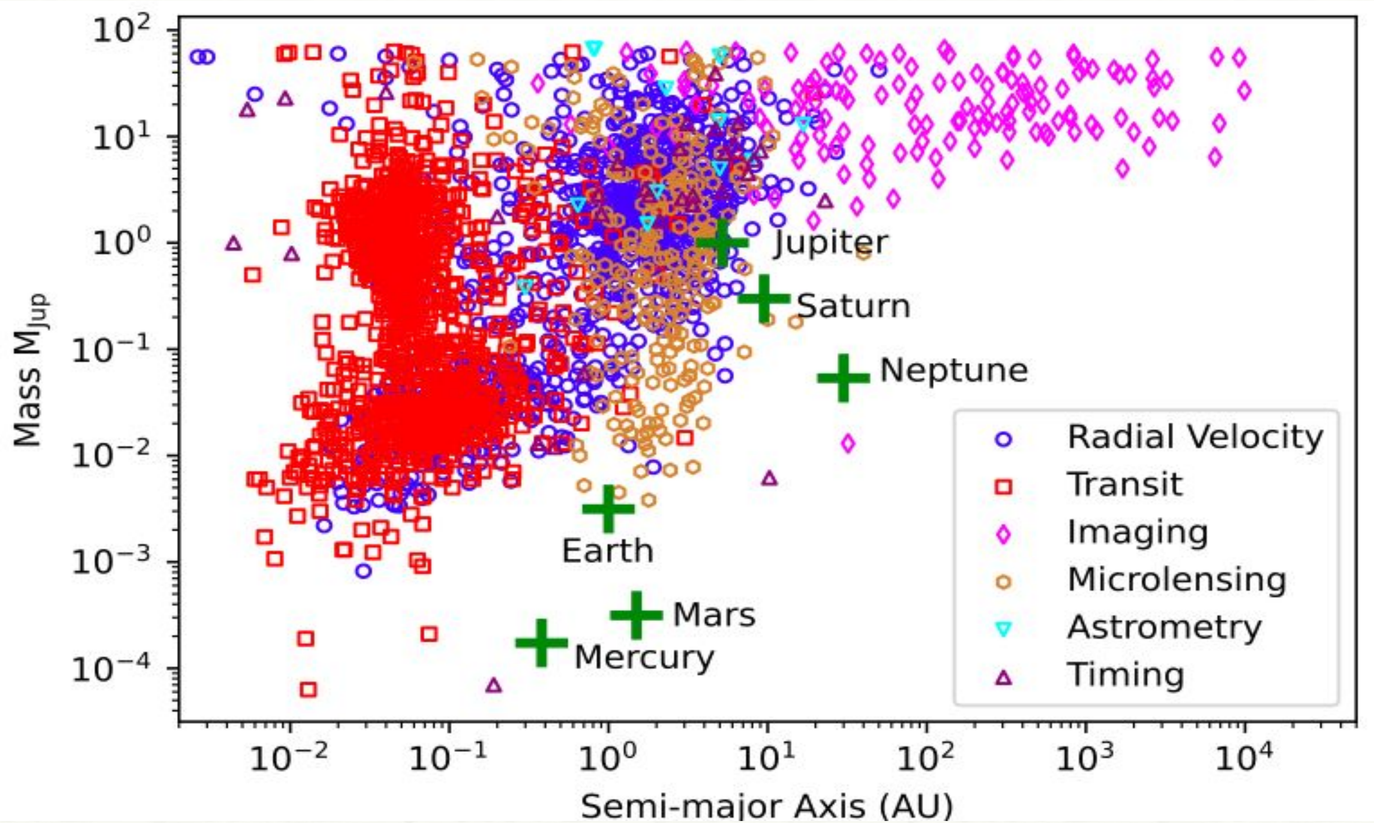
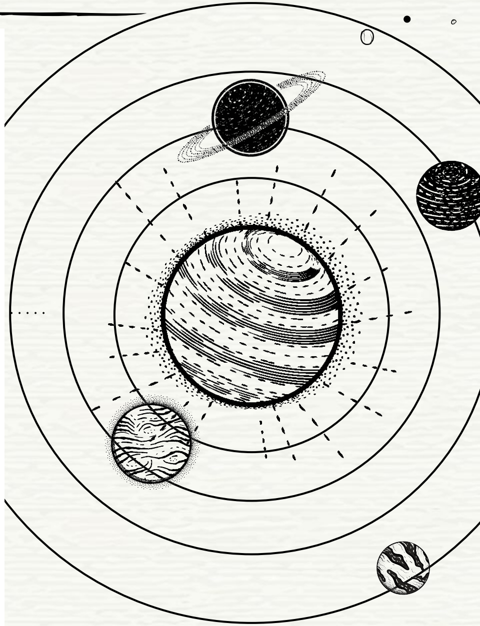
OVERVIEW

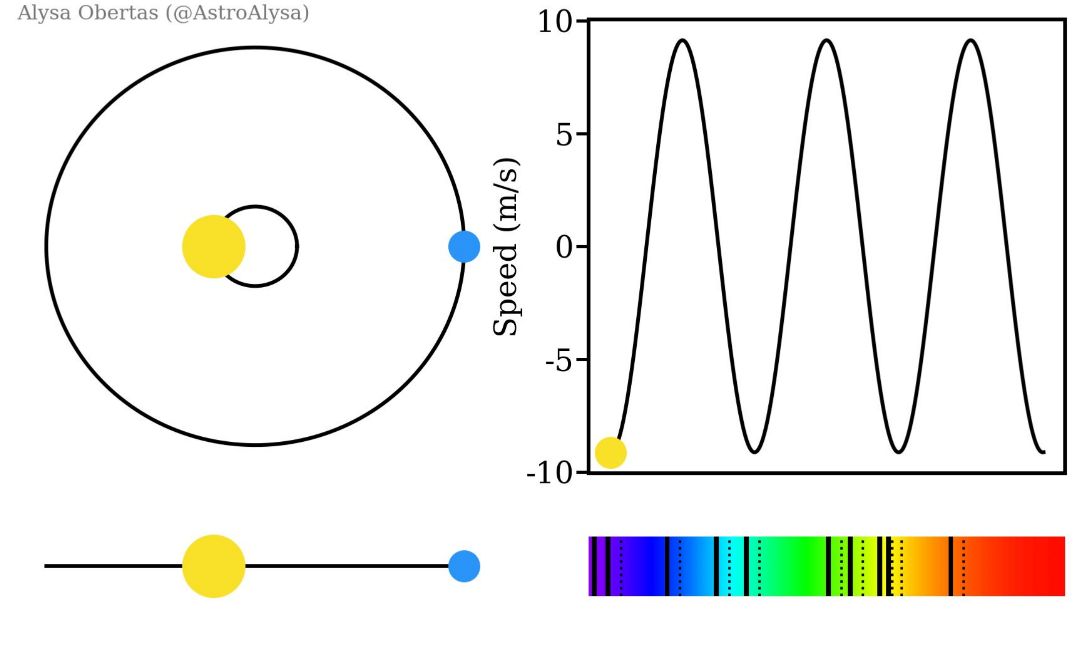
Theory, instruments,
and target selection

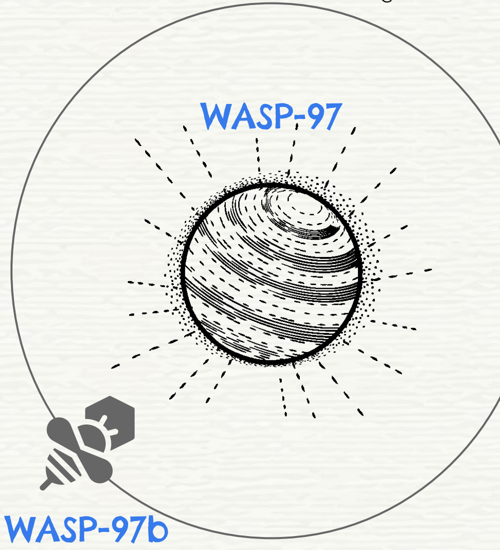
Motivation behind the project





Radial Velocity measurements

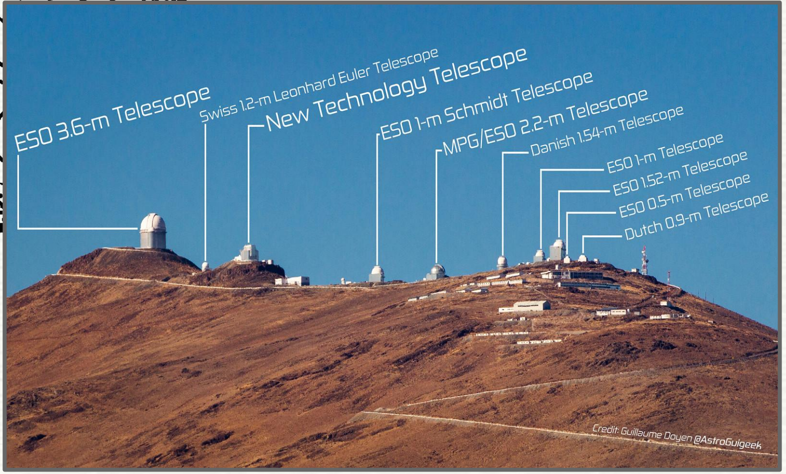


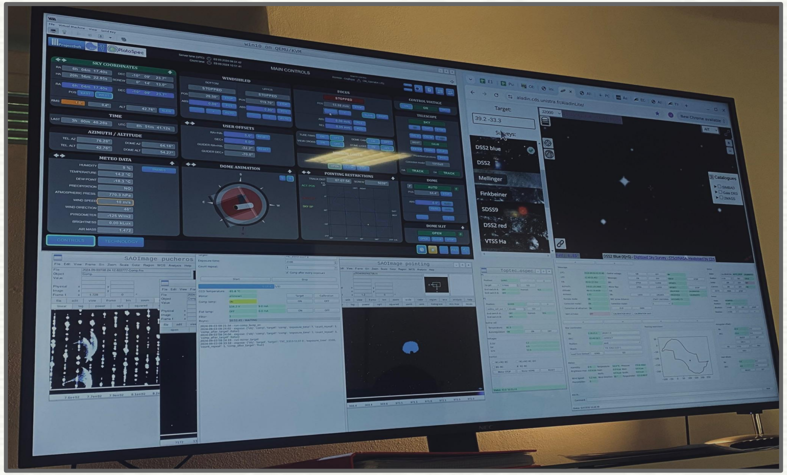


$$f(m) = \frac{M_2^3 \sin^3 i}{(M_1 + M_2)^2} = \frac{PK_1^3}{2\pi G}$$

$$\frac{\Delta\lambda}{\lambda} = \frac{v_{\rm rad}}{c}$$

Observations with 1.52 m telescope

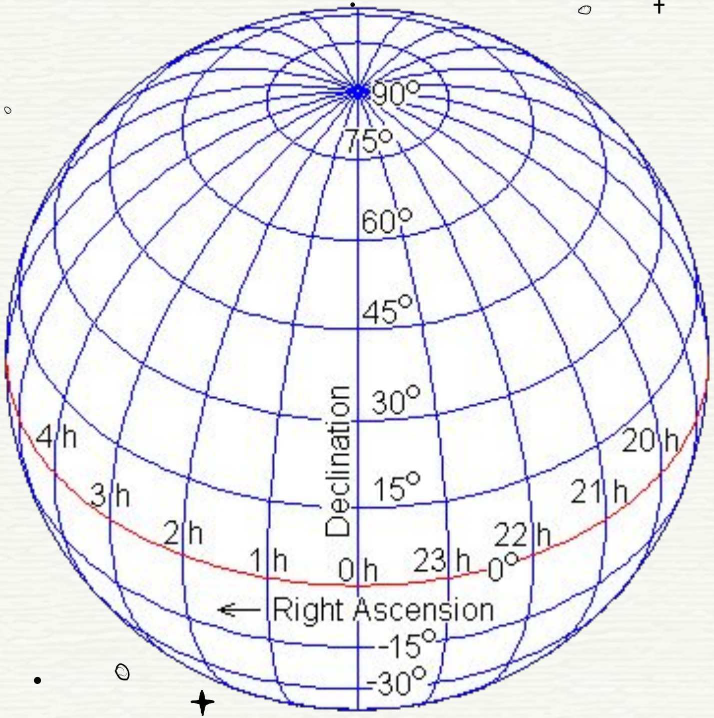




Echelle spectograph	Parametere value
Wavelength coverage	390-730 nm
Spectral resolution	18k
Thermal stability	0.5deg
RV accuracy	20m/s (nightly 5 mag star)
Calibration	ThAr (not simultaneous)

https://www.avcr.cz/en/news-archive/The-Czech-flag-in-the-Atacama-Desert-Czech-astronomers-in-charge-of-telescope-in-Chile/ ; https://stel.asu.cas.cz/plato/spectrograph.html

Observations with 1.52 m telescope



La Silla location:

Coordinates: 29°15′27″S 70°44′15″W / 29.2575°S 70.7375°W

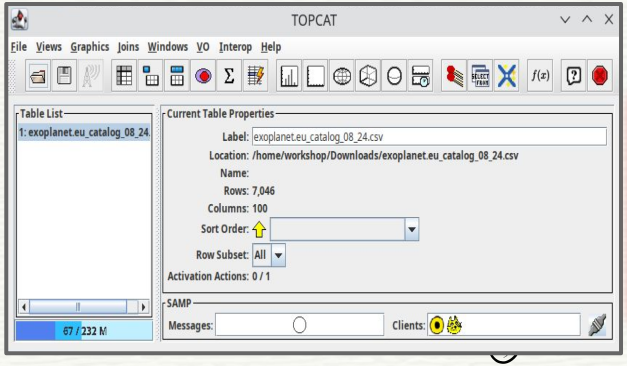
RA criteria: 0h < RA < 4h and RA > 23h

DEC criteria: -65 deg < DEC < -5 deg

https://www.avcr.cz/en/news-archive/The-Czech-flag-in-the-Atacama-Desert-Czech-astronomers-in-charge-of-telescope-in-Chile/ ; https://stel.asu.cas.cz/plato/spectrograph.html

TOPCAT to work with the catalogs;
Database: exoplanet.eu

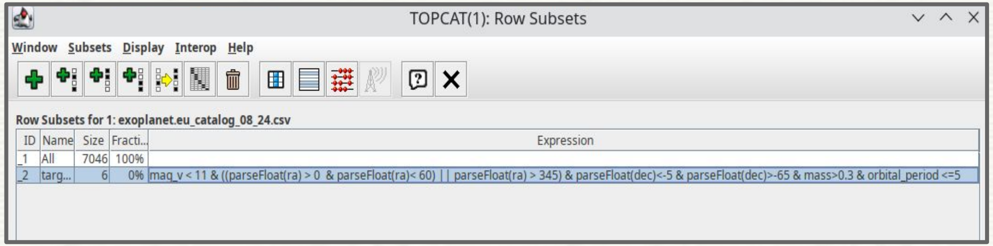
Target selection



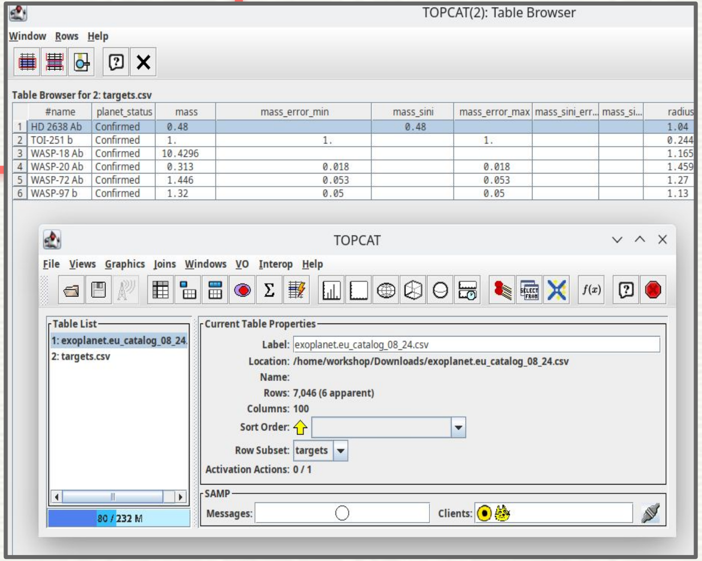
1. Upload the catalog to the TOPCAT

Selection criterias:

V Magnitude < 11
Mass > 0.3 M_jup
Orbital period <=5 days

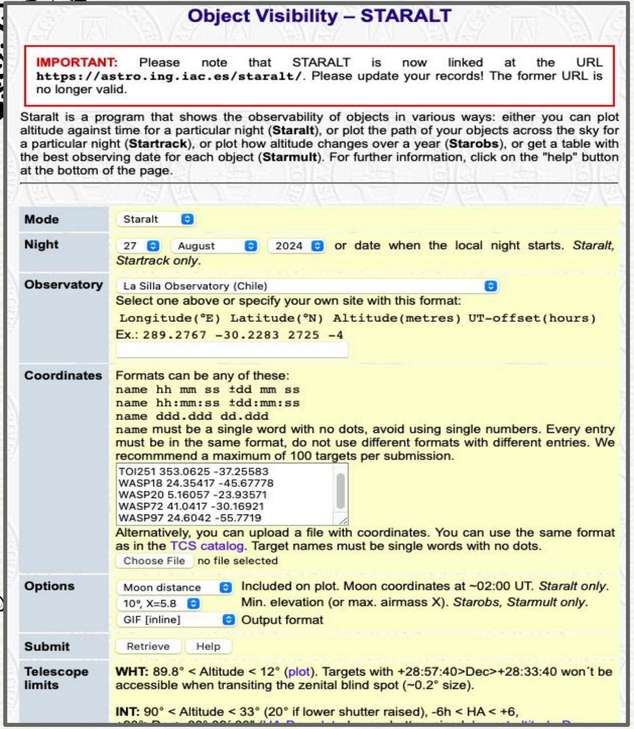


2. Create the subset based on defined criterias. Be careful with the syntax in TOPCAT! Use & for AND expression; | | for OR expression



3. Display and save your results

Target selection



Object Visibility – STARALT

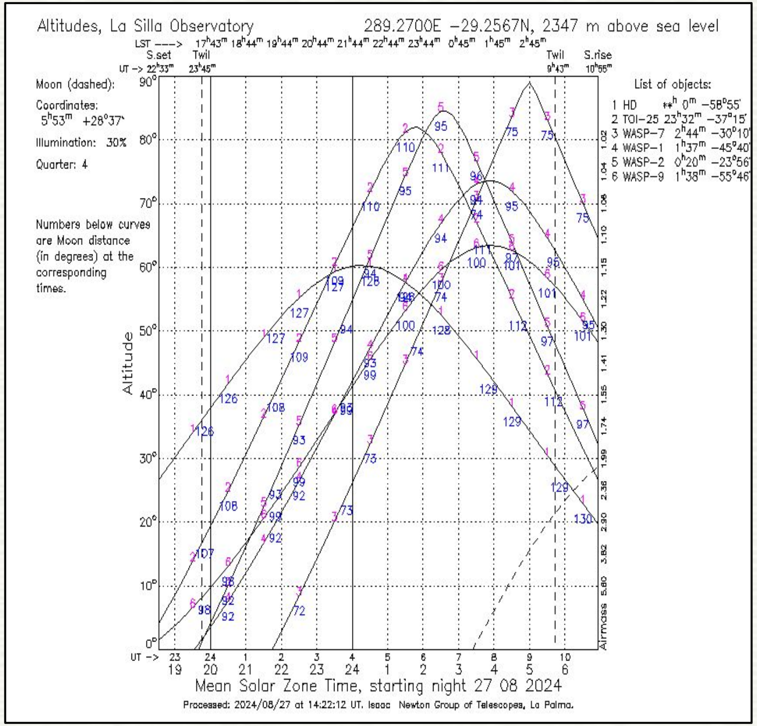
IMPORTANT: Please note that STARALT is now linked at the URL **https://astro.ing.iac.es/staralt/**. Please update your records! The former URL is no longer valid.

Staralt is a program that shows the observability of objects in various ways: either you can plot altitude against time for a particular night (**Staralt**), or plot the path of your objects across the sky for a particular night (**Startrack**), or plot how altitude changes over a year (**Starobs**), or get a table with the best observing date for each object (**Starmult**). For further information, click on the "help" button at the bottom of the page.

Mode	Staralt
Night	27 August 2024 or date when the local night starts. *Staralt, Startrack only.*
Observatory	La Silla Observatory (Chile) Select one above or specify your own site with this format: `Longitude(°E) Latitude(°N) Altitude(metres) UT-offset(hours)` Ex.: `289.2767 -30.2283 2725 -4`

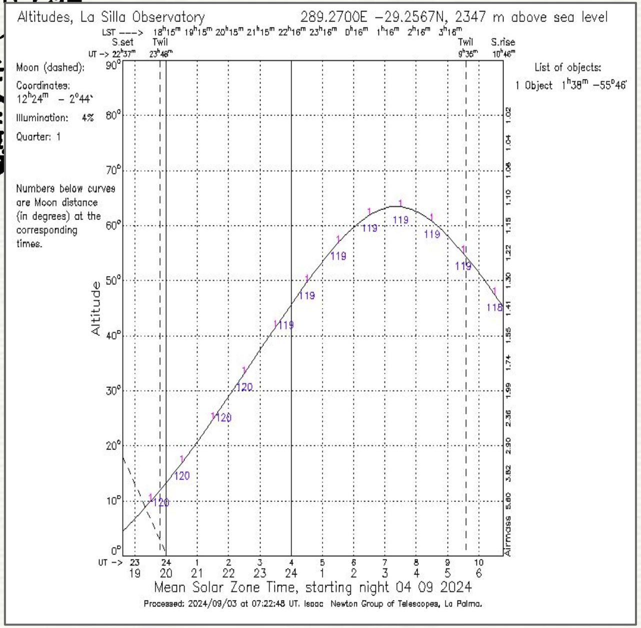
Coordinates	Formats can be any of these:
	`name hh mm ss ±dd mm ss`
	`name hh:mm:ss ±dd:mm:ss`
	`name ddd.ddd dd.ddd`
	`name` must be a single word with no dots, avoid using single numbers. Every entry must be in the same format, do not use different formats with different entries. We recommmend a maximum of 100 targets per submission.
	TOI251 353.0625 -37.25583
	WASP18 24.35417 -45.67778
	WASP20 5.16057 -23.93571
	WASP72 41.0417 -30.16921
	WASP97 24.6042 -55.7719
	Alternatively, you can upload a file with coordinates. You can use the same format as in the TCS catalog. Target names must be single words with no dots.
	Choose File no file selected

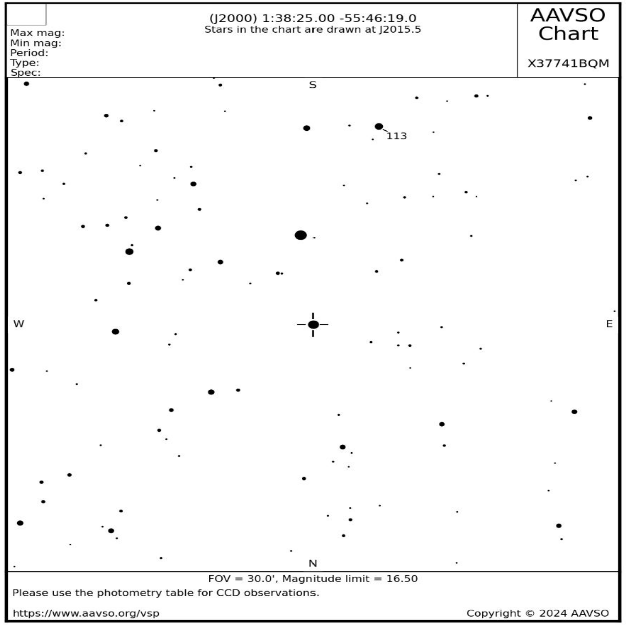
Options	Moon distance — Included on plot. Moon coordinates at ~02:00 UT. *Staralt only.* 10°, X=5.8 — Min. elevation (or max. airmass X). *Starobs, Starmult only.* GIF [inline] — Output format
Submit	Retrieve Help
Telescope limits	**WHT:** 89.8° < Altitude < 12° (plot). Targets with +28:57:40>Dec>+28:33:40 won´t be accessible when transiting the zenital blind spot (~0.2° size). **INT:** 90° < Altitude < 33° (20° if lower shutter raised), -6h < HA < +6,



- Object Visibility - STARALT;

Target selection





Take the charts with you for the observations!

- https://apps.aavso.org/vsp/

Parameters of the system WASP-97

Planet

Basic informations 28 parameters

Name	WASP-97 b	
Planet Status	Confirmed	
Discovered in	2013	
Update	2014-05-28	
Mass	$1.32 \left(\begin{smallmatrix}+0.05 \\ -0.05\end{smallmatrix}\right) M_J$	1 publication
Mass*sin(i)	—	
Semi-Major Axis	0.03303(± 0.00056) AU	1 publication
Orbital Period	2.07276(± 1e-06) day	1 publication
Eccentricity	—	1 publication
ω	—	
T_{peri}	—	
Radius	$1.13 \left(\begin{smallmatrix}+0.06 \\ -0.06\end{smallmatrix}\right) R_J$	1 publication
Inclination	$88.0 \left(\begin{smallmatrix}+1.3 \\ -1.0\end{smallmatrix}\right)$ deg	1 publication
Detection Method	Primary Transit	
Mass Meas. Method	—	
Radius Meas. Method	—	
Primary transit	2456438.18683(± 0.00018) JD	1 publication
Secondary transit	—	
λ	—	

Star

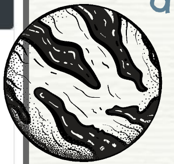
Basic informations 13 parameters

Name	WASP-97	
Distance	—	
Spectral type	G5	
Apparent magnitude V	10.6	
Mass	1.12(± 0.06) M_{Sun}	1 publication
Age	$11.9 \left(\begin{smallmatrix}+16.0 \\ -8.3\end{smallmatrix}\right)$ Gyr	1 publication
Effective temperature	5640.0(± 100.0) K	1 publication
Radius	1.06(± 0.04) R_{Sun}	1 publication
Metallicity [Fe/H]	0.23(± 0.11)	1 publication
Detected Disc	—	
Magnetic Field	—	
RA_{2000}	01:38:25.0	
Dec_{2000}	-55:46:18.8	
Alternate Names	—	

Planetary system 1 planet

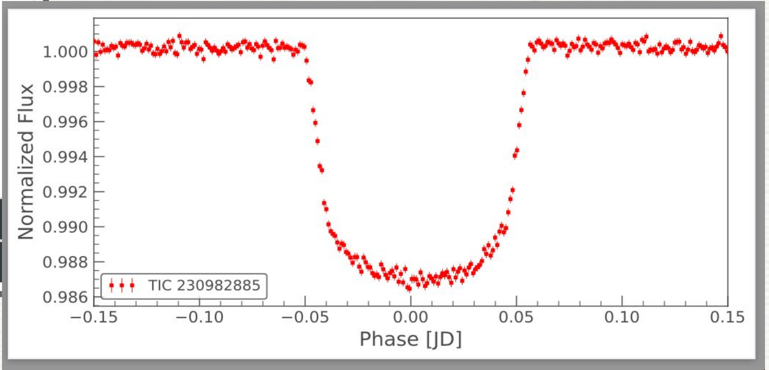
Remarks Some remarks

* https://exoplanet.eu/catalog/wasp_97_b--1425/



WASP-97b is a Hot Jupiter with a period of 2.07 days and mass 1.32 Mjup - good for RV

TESS Light curve of WASP-97 during the WASP-97b transit



Credit: Veronika Schaffenroth

1,32

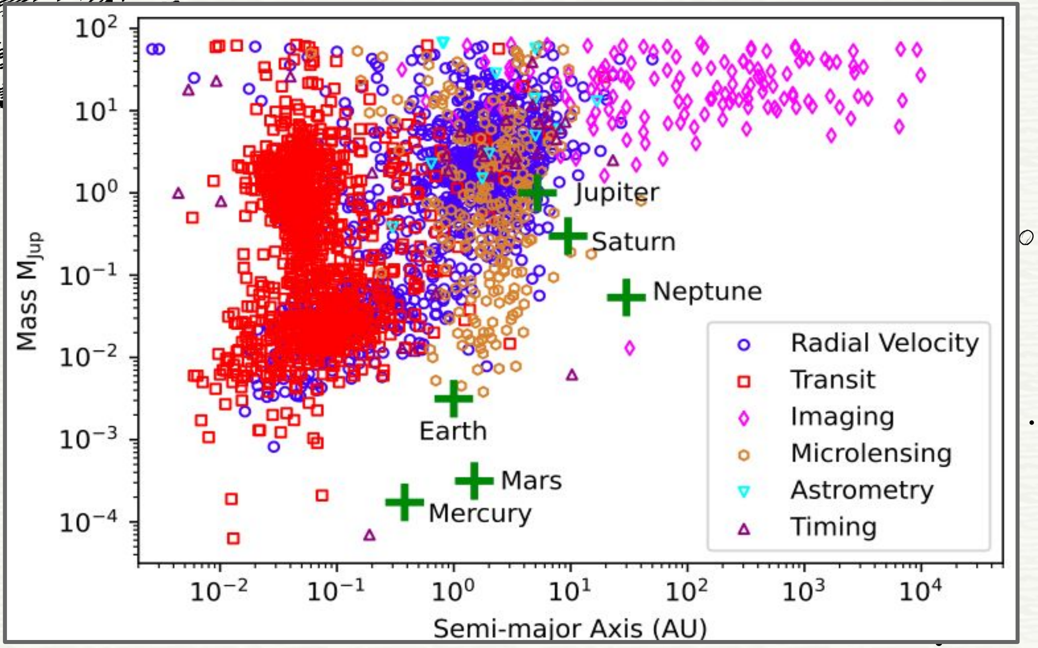
Mass of WASP-97b in Jupiters' mass

2d 1h 40m

WASP-97b orbital period

0,03 AU

It's the distance between host-star and the planet



02

DATA REDUCTION

From raw to reduced data

Script creation in IRAF

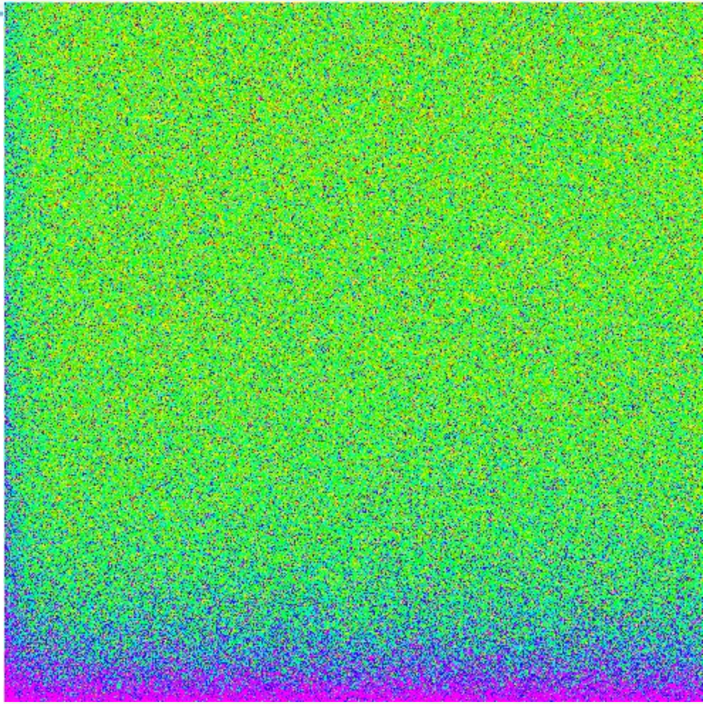
- Use **mkscript** in IRAF Terminal to add a task to preexisting script.cl file

```
echelle> mkscript
Script file name (compare.cl):
Delete file 'compare.cl' ? (yes): no
Task name of command to be added to script (specplot):
```

- Use **cl < script.cl &** to execute the script
- Before running script, make sure all files that will be created don't
- exist already → if they exist delete them
- Normal Data Reduction: **30 min**
- Script Data Reduction: **10 sec**

BIAS COMBINATION

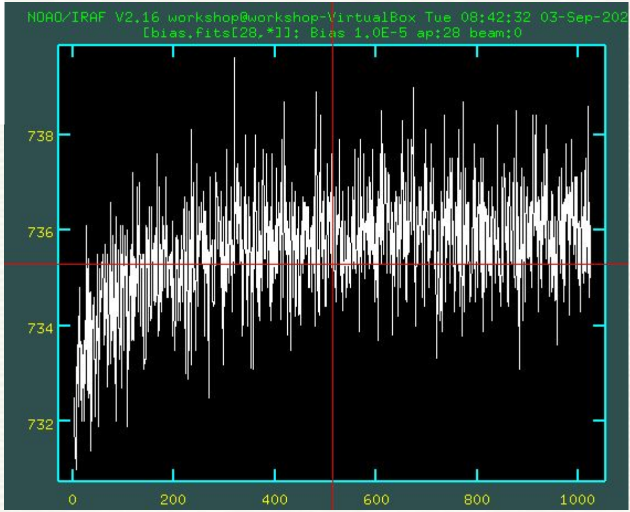
```
!ls *Bias.fits > bias.lis

imcombine ("@bias.lis",
"bias.fits", headers="", bpmasks="", rejmasks="",
nrejmasks="", expmasks="",
sigmas="", imcmb="$I", logfile="STDOUT",
combine="average", reject="sigclip",
project=no, outtype="real", outlimits="", offsets="none",
masktype="none",
maskvalue="0", blank=0., scale="median", zero="none",
weight="median",
statsec="", expname="", lthreshold=INDEF,
hthreshold=INDEF, nlow=1, nhigh=1,
nkeep=1, mclip=yes, lsigma=3., hsigma=3., rdnoise="0.",
gain="1.",
snoise="0.", sigscale=0.1, pclip=-0.5, grow=0.)
```



BIAS COMBINATION

- Extract mean bias value out of combined fits file
- Use **scanf** function in IRAF to assign mean bias value to variable x

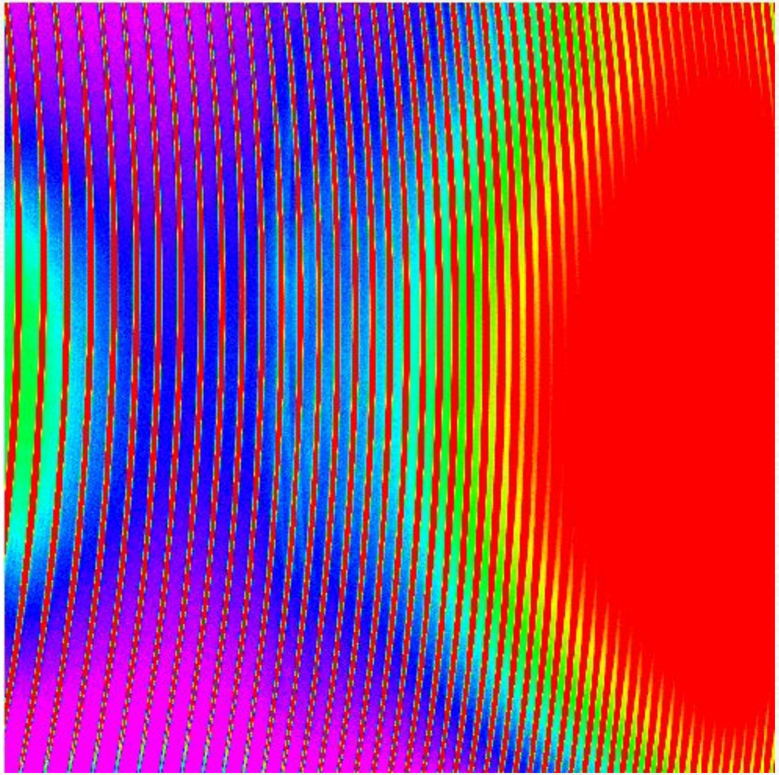
```
imstat ("bias.fits",
fields="mean", lower=INDEF, upper=INDEF, nclip=0, lsigma=3.,
usigma=3.,
binwidth=0.1, format=yes, cache=no) | scanf("%3f",x)
```



FLAT COMBINATION

- **Flat Frames** correct for uneven field illumination and optical imperfections.
- Combine all flat.fits files into one flat file with **imcombine**

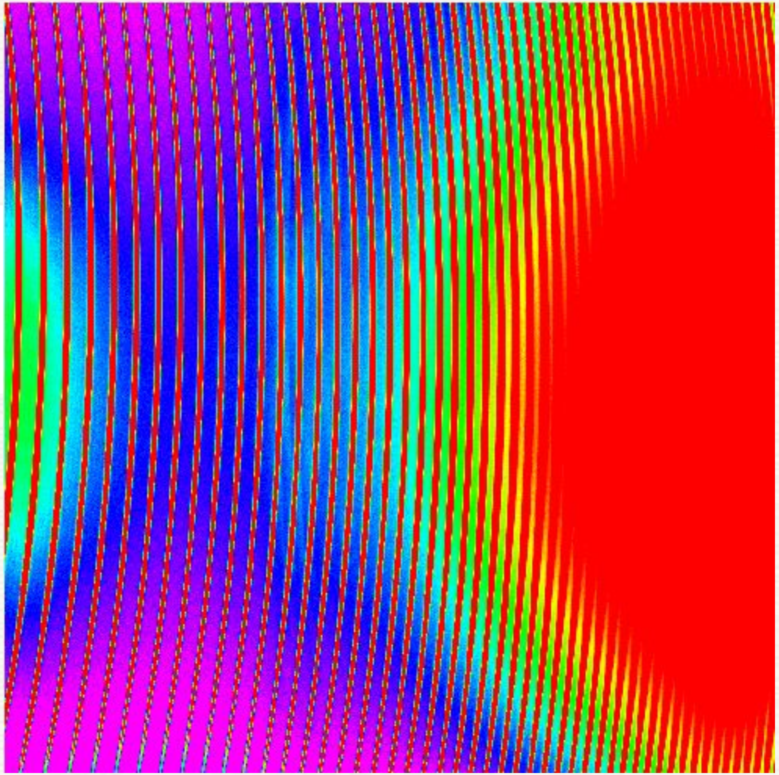
```
!ls *Flat.fits > flat.lis

imcombine ("@flat.lis",
"flat.fits", headers="", bpmasks="", rejmasks="",
nrejmasks="", expmasks="",
sigmas="", imcmb="$I", logfile="STDOUT",
combine="average", reject="none",
project=no, outtype="real", outlimits="", offsets="none",
masktype="none",
maskvalue="0", blank=0., scale="exposure", zero="none",
weight="none",
statsec="", expname="EXPTIME", lthreshold=INDEF,
hthreshold=INDEF, nlow=1,
nhigh=1, nkeep=1, mclip=yes, lsigma=3., hsigma=3.,
rdnoise="READNOIS",
gain="GAIN", snoise="0.", sigscale=0.1, pclip=-0.5,
grow=0.)
```



FLAT CORRECTION

- From combined flat file subtract mean bias Value x with **imarith** → flat.fits - x = flat_b.fits

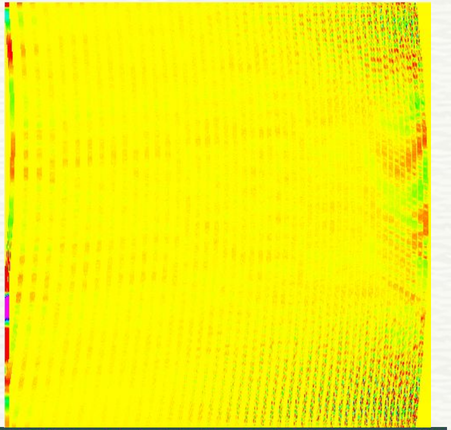
```
imarith ("flat.fits",
"-", x, "flat_b.fits", title="", divzero=0., hparams="",
pixtype="",
calctype="", verbose=no, noact=no)
```

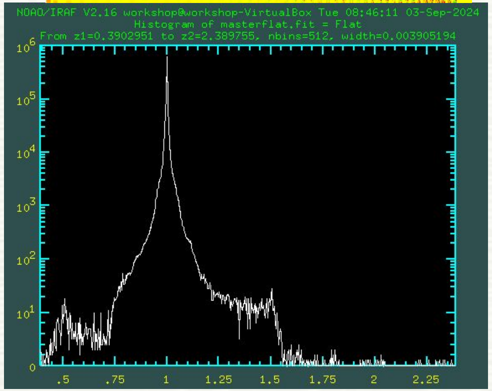


MASTERFLAT FRAME

- Flat file 'normalized' for the count, in order to keep the Count of the object data with **apflatten**

```
apflatten ("flat_b.fits",
"masterflat.fits", apertures="", references="find_orders",
interactive=no,
find=yes, recenter=no, resize=no, edit=no, trace=yes,
fittrace=yes,
flatten=yes, fitspec=no, line=INDEF, nsum=10,
threshold=10., pfit="fit1d",
clean=yes, saturation=INDEF, readnoise="0.", gain="1.",
lsigma=4., usigma=4.,
function="legendre", order=10, sample="*", naverage=1,
niterate=0,
low_reject=3., high_reject=3., grow=0.)
```

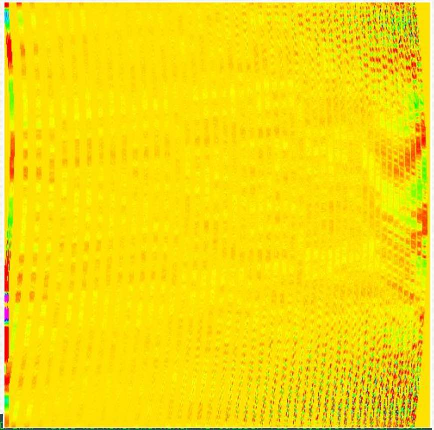


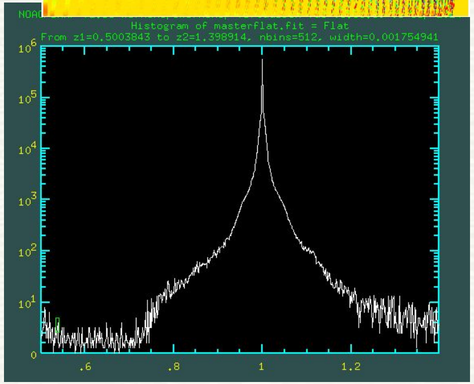


CUT MASTERFLAT

- Check the value distribution in the Masterflat with **imhist**
- Cut out unwanted values with **imreplace**

```
imreplace ("masterflat.fit",
1., imaginary=0., lower=3, upper=INDEF, radius=0.)

imreplace ("masterflat.fit",
1., imaginary=0., lower=INDEF, upper=0.5, radius=0.)
```

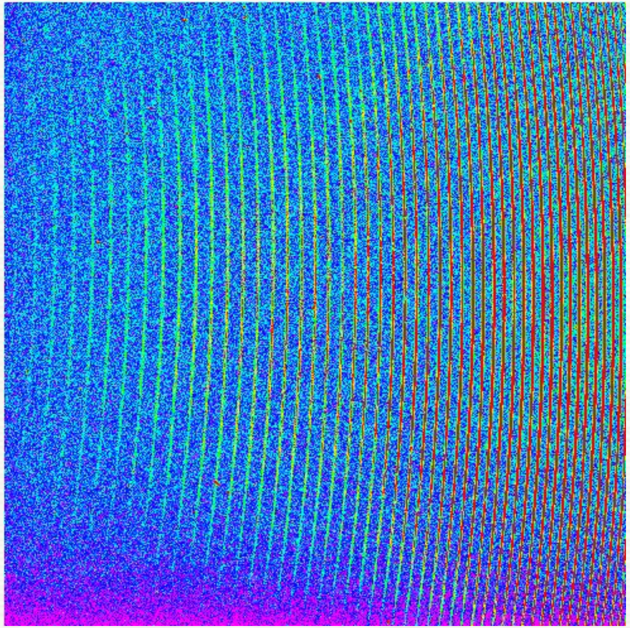




SCIENCE FRAME BIAS CORRECTION

- The bias frame is subtracted from the object or other calibration frames. The task **imarith** is used

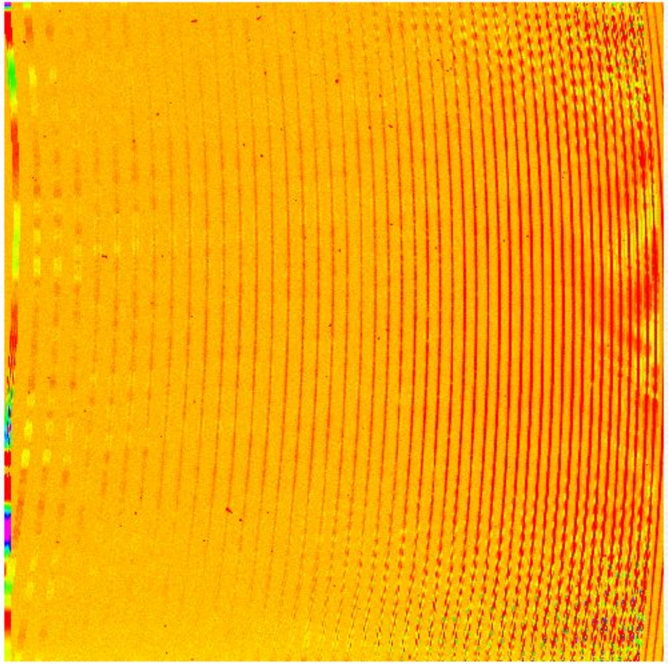
```
!ls *WASP-97*.fits > sci_fra.lis

imarith ("@sci_fra.lis",
"-", x, "@sci_fra.lis//a", title="", divzero=0.,
hparams="", pixtype="",
calctype="", verbose=no, noact=no)
```



SCIENCE FRAME FLAT CORRECTION

- Flat fielding of an object frame is made by dividing the object frame by the normalized flat frame with the task **imarith**:

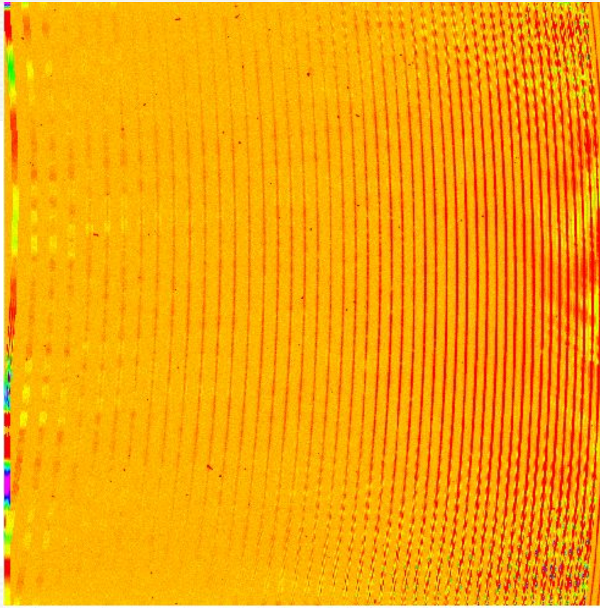
```
!ls *WASP-97a*.fits > sci_fra_a.lis

imarith ("@sci_fra_a.lis",
"/", "masterflat.fit", "@sci_fra.lis//b", title="",
divzero=0., hparams="",
pixtype="", calctype="", verbose=no, noact=no)
```



SUBTRACTING SCATTERED LIGHT

- counts of the region between the two adjacent orders are not zero due to the scattered light
- Subtract with **apscatter**

```
!ls *WASP-97b*.fits > sci_fra_b.lis

apscatter ("@sci_fra_b.lis",
"@sci_fra.lis//c", apertures="", scatter="",
references="find_orders",
interactive=no, find=no, recenter=no, resize=no, edit=no,
trace=no,
fittrace=yes, subtract=yes, smooth=yes, fitscatter=yes,
fitsmooth=yes,
line=INDEF, nsum=10, buffer=1., apscat1="", apscat2="")
```

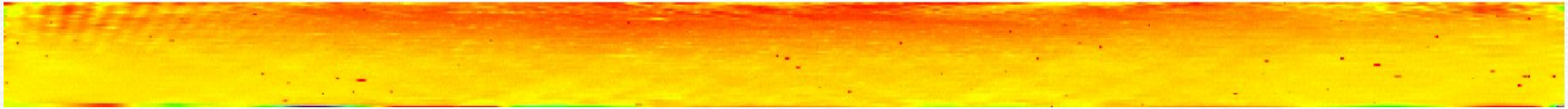


EXTRACTING THE SPECTRA

- We want to extract the flux from individual apertures
- The apertures are already defined

- The output is the spectrum of an object in individual apertures

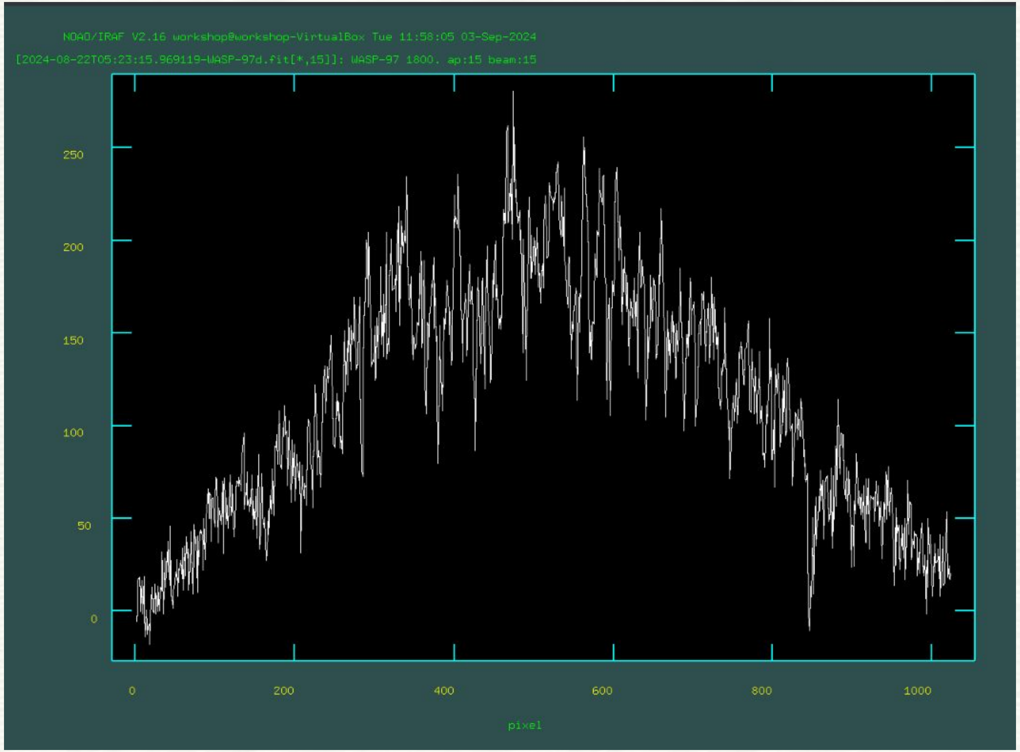
```
!ls *WASP-97c*.fit > sci_fra_c.lis

apall ("@sci_fra_c.lis",
48, output="@sci_fra.lis//d", apertures="", format="echelle",
references="find_orders", profiles="", interactive=no, find=yes,
recenter=yes,
resize=no, edit=yes, trace=no, fittrace=no, extract=yes, extras=no,
review=no,
line=INDEF, nsum=10, lower=-5., upper=5., apidtable="",
b_function="chebyshev", b_order=1, b_sample="-10:-6,6:10",
b_naverage=-3,
b_niterate=0, b_low_reject=3., b_high_rejec=3., b_grow=0., width=5.,
radius=10., threshold=0., minsep=5., maxsep=100000.,
order="increasing",
aprecenter="", npeaks=INDEF, shift=yes, llimit=INDEF, ulimit=INDEF,
ylevel=0.1, peak=yes, bkg=yes, r_grow=0., avglimits=no, t_nsum=5,
t_step=5,
t_nlost=5, t_function="legendre", t_order=5, t_sample="*",
t_naverage=1,
t_niterate=0, t_low_reject=3., t_high_rejec=3., t_grow=0.,
background="none",
skybox=1, weights="none", pfit="fit1d", clean=no, saturation=INDEF,
readnoise="0.", gain="1.", lsigma=4., usigma=4., nsubaps=1)
```



EXTRACTING THE SPECTRA

- **Problems:**
  - Blaze function
  - Pixels on the x axis

- **Solutions:**
  - Blaze function fit by Viper
  - Pixels to wavelength conversion done by using the ThAr spectra



THORIUM-ARGON SPECTRA

- We choose one of the *Comp.fits files
- We need to correct them the same way as the target data - bias substaction, flat division, scattered light, extracting the spectra

```
!ls *Comp*.fits > Comp.lis

imarith ("@Comp.lis",
"-", x, "@Comp.lis//a", title="", divzero=0., hparams="", pixtype="",
calctype="", verbose=no, noact=no)

!ls *Compa*.fits > Comp_a.lis

imarith ("@Comp_a.lis",
"/", "masterflat.fit", "@Comp.lis//b", title="", divzero=0.,
hparams="",
pixtype="", calctype="", verbose=no, noact=no)

!ls *Compb*.fits > Comp_b.lis

apscatter ("@Comp_b.lis",
"@Comp.lis//c", apertures="", scatter="", references="find_orders",
interactive=no, find=no, recenter=no, resize=no, edit=no, trace=no,
fittrace=yes, subtract=yes, smooth=yes, fitscatter=yes, fitsmooth=yes,
line=INDEF, nsum=10, buffer=1., apscat1="", apscat2="")
```

```
!ls *Compc*.fit > Comp_c.lis

apall ("@Comp_c.lis",
48, output="@Comp.lis//d", apertures="", format="echelle",
references="find_orders", profiles="", interactive=no, find=yes,
recenter=yes,
resize=no, edit=yes, trace=no, fittrace=no, extract=yes, extras=no,
review=no,
line=INDEF, nsum=10, lower=-5., upper=5., apidtable="",
b_function="chebyshev", b_order=1, b_sample="-10:-6,6:10",
b_naverage=-3,
b_niterate=0, b_low_reject=3., b_high_rejec=3., b_grow=0., width=5.,
radius=10., threshold=0., minsep=5., maxsep=100000.,
order="increasing",
aprecenter="", npeaks=INDEF, shift=yes, llimit=INDEF, ulimit=INDEF,
ylevel=0.1, peak=yes, bkg=yes, r_grow=0., avglimits=no, t_nsum=5,
t_step=5,
t_nlost=5, t_function="legendre", t_order=5, t_sample="*",
t_naverage=1,
t_niterate=0, t_low_reject=3., t_high_rejec=3., t_grow=0.,
background="none",
skybox=1, weights="none", pfit="fit1d", clean=no, saturation=INDEF,
readnoise="0.", gain="1.", lsigma=4., usigma=4., nsubaps=1)
```

WAVELENGTH CALIBRATION

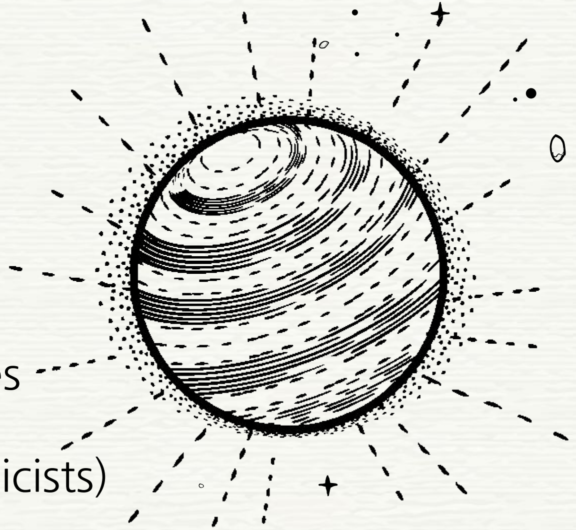
- **Second Step** : use **ecidentify** to identify lines
- **Third Step:** use **refspectra** to assign ThAr spectra to science frame
- **Fourth Step:** use **dispcor** to do wavelength calibration

```
!ls *Compd*.fit > Comp_d.lis

ecreidentify ("@Comp_d.lis",
"ThAr", shift=0., cradius=5., threshold=10., refit=yes,
database="database",
logfiles="STDOUT,logfile")

refspectra ("@sci_fra_d.lis",
"yes", references="@Comp_d.lis", apertures="", refaps="", ignoreaps=yes,
select="average", sort="", group=" ", time=no, timewrap=17., override=yes,
confirm=yes, assign=yes, logfiles="STDOUT,logfile", verbose=yes)

bool log

dispcor ("@sci_fra_d.lis",
"@sci_fra.lis//e", linearize=yes, database="database", table="", w1=INDEF,
w2=INDEF, dw=INDEF, nw=INDEF, log=no, flux=yes, blank=0., samedisp=yes,
global=no, ignoreaps=yes, confirm=no, listonly=no, verbose=yes,
logfile="")
```

03

VIPER

Obtaining the radial velocities
from reduced data
(another snake for astrophysicists)



INPUT

Cell spectra

Observation (with cell)

Stellar template (without cell)

$$I_m = k(T_{\mathrm{cell}}(\lambda) I_{\mathrm{stellar}}(\lambda + \Delta\lambda)) \cdot \mathrm{IP}$$

Normalization
(Blaze function)

wavelength estimation
via wavelength
solution

RV shift

Instrument Profile

OUTPUT

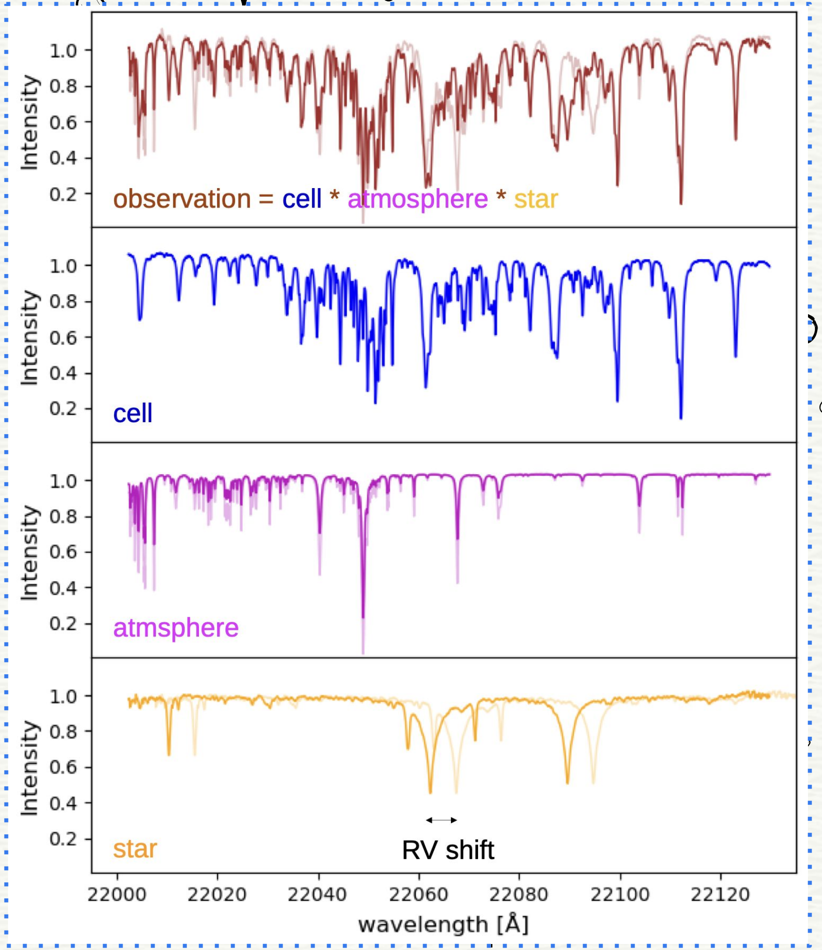
optimization of parameters using **least-square fit**

based on Butler et al., 1996

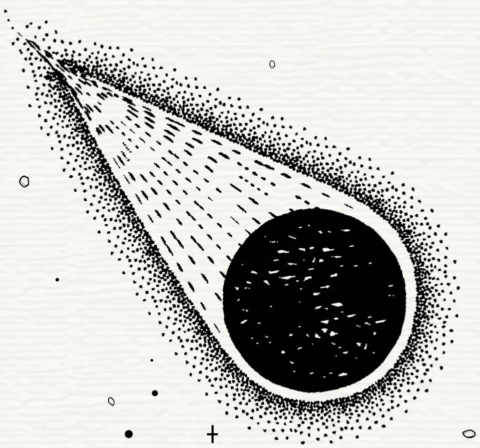
HIGH PRECISION
RADIAL VELOCITIES

$$I_m = k(T_{\mathrm{cell}}(\lambda)T_{\mathrm{atm}}(\lambda + \Delta\lambda_{\mathrm{atm}})I_{\mathrm{stellar}}(\lambda + \Delta\lambda_{\mathrm{star}})) \cdot \mathrm{IP}$$

radial velocity = $\dfrac{\Delta\lambda}{\lambda}c$



Credit to Jana Köhler



Velocity & IP Estimator

Started by **Mathias Zechmeister** & **Sireesha Chamarthi**

Available for CRIRES+, TLS, UVES, KECK, Ondrejov OES, CES, **PUCHEROS**

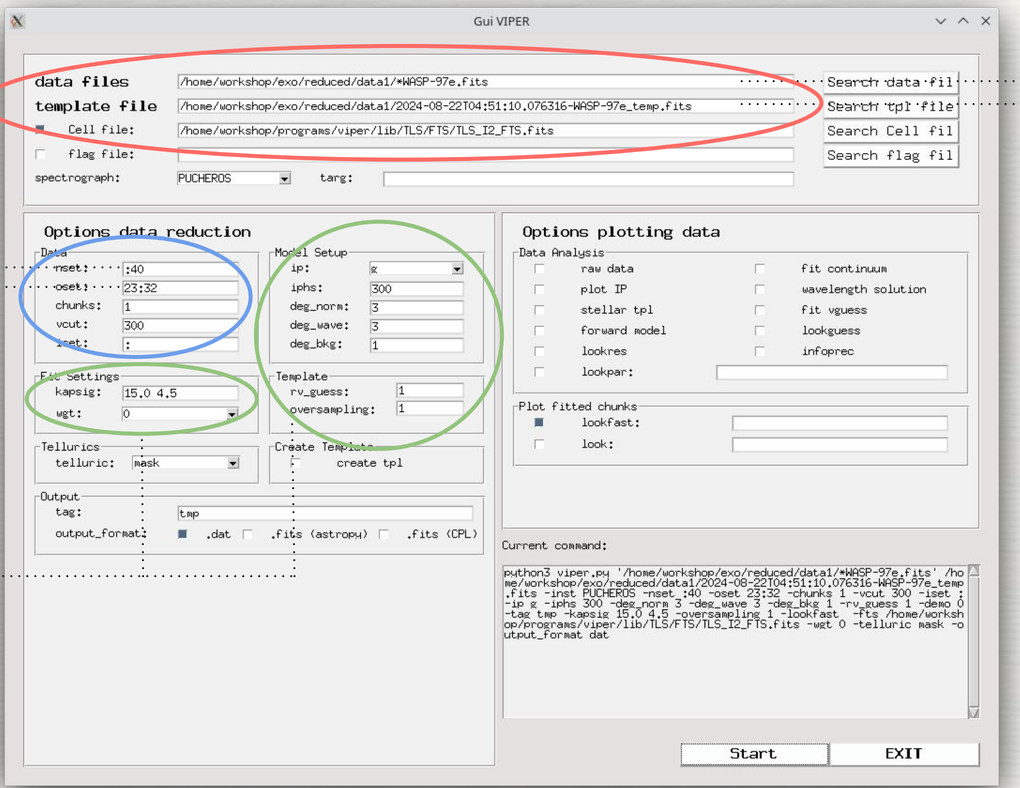
Github: https://github.com/mzechmeister/viper

Citation: https://ui.adsabs.harvard.edu/abs/2021ascl.soft08006Z.

VIPER INTERFACE

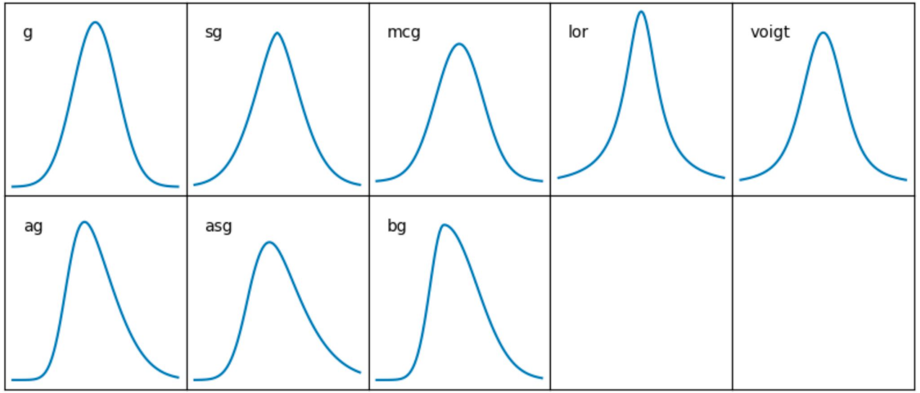
Input data
Observation files
Template file

Observation settings
# of files
aperture range



Parameters
IP model + halfsize,
flux normalization,
wavelength scale,
pixel range,
kappa sigma clipping,
RV start guess + oversampling

IP MODELING



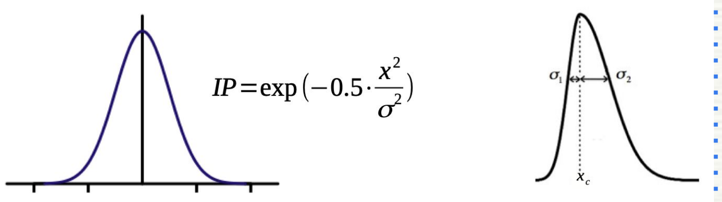
Example plots for the various IP models implemented in viper.
Top: Symmetric IP models. Bottom: Asymmetric IP models.

Gaussian

`-ip g`

BiGaussian

`-ip bg`



PARAMETERS

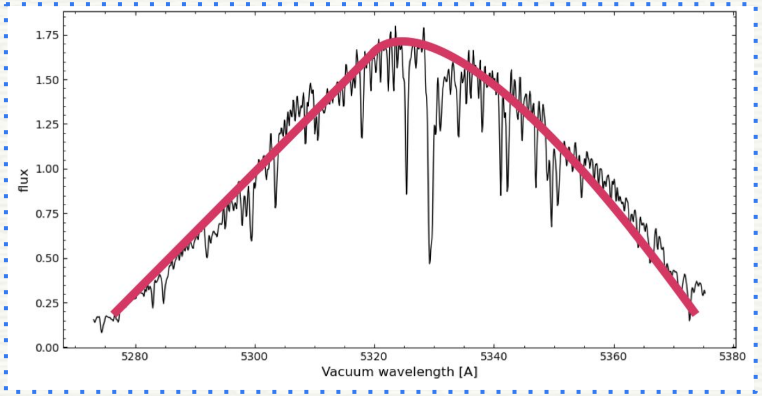
Wavelength solution

$$\lambda = a_0 + a_1 \cdot x + a_2 \cdot x^2 + a_3 \cdot x^3$$

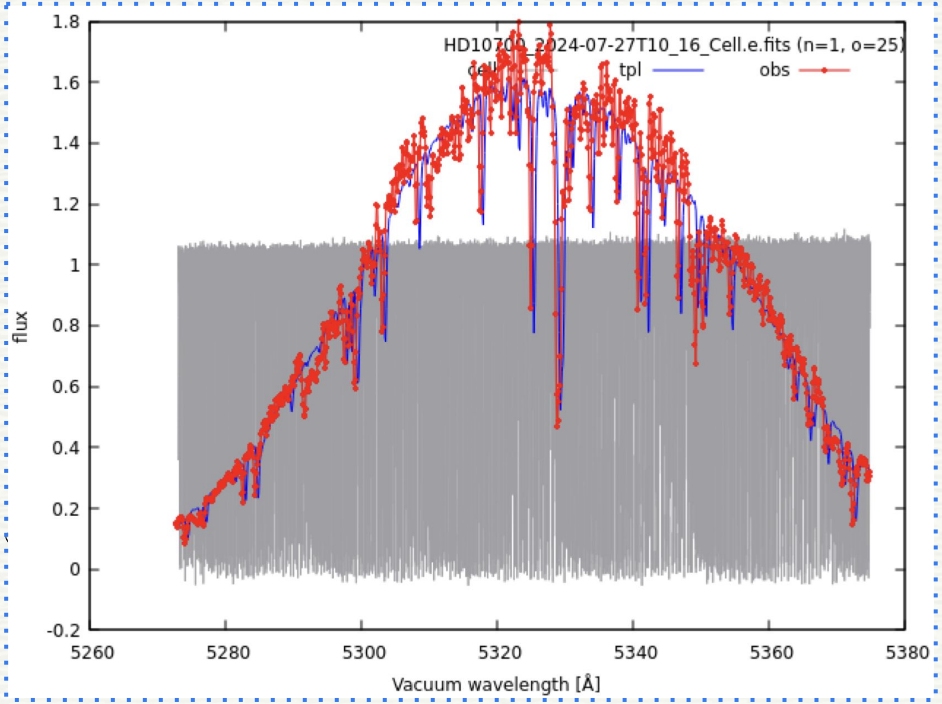
x = detector pixel

Blaze function

$$k = b_0 + b_1 \cdot x + b_2 \cdot x^2 + b_3 \cdot x^3$$



THE RAW DATA



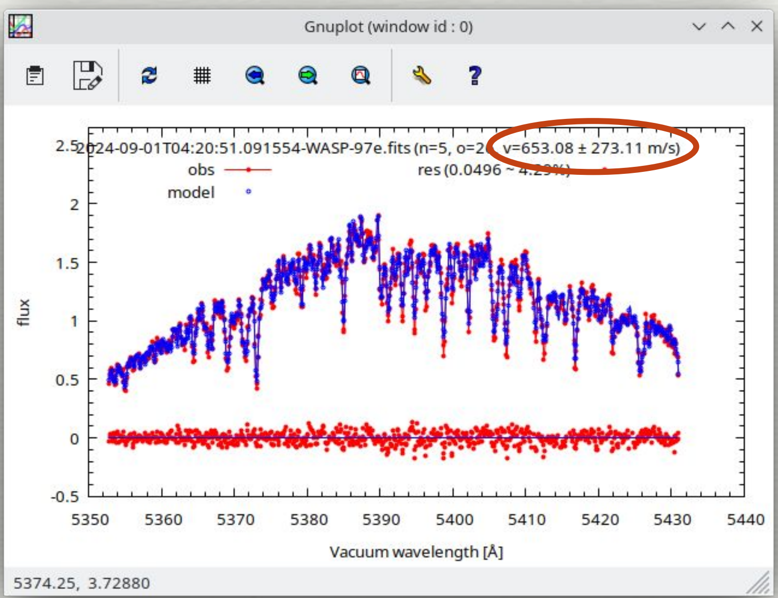
$$I_m = k(T_{\text{cell}}(\lambda) I_{\text{stellar}}(\lambda + \Delta\lambda)) \cdot \text{IP}$$

Observation with cell

Stellar template

FTS of cell

MODELING THE DATA



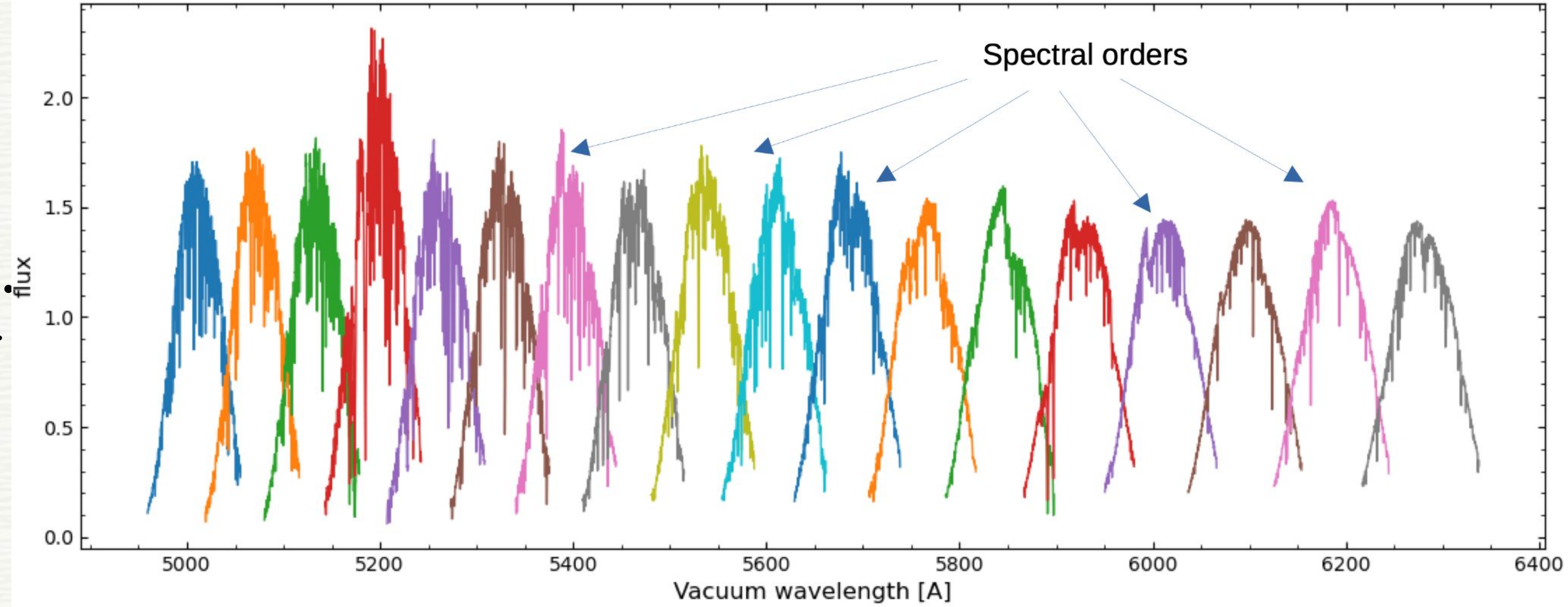
Start guess

$$I_m = k(T_{\text{cell}}(\lambda) I_{\text{stellar}}(\lambda + \Delta\lambda)) \cdot \text{IP}$$

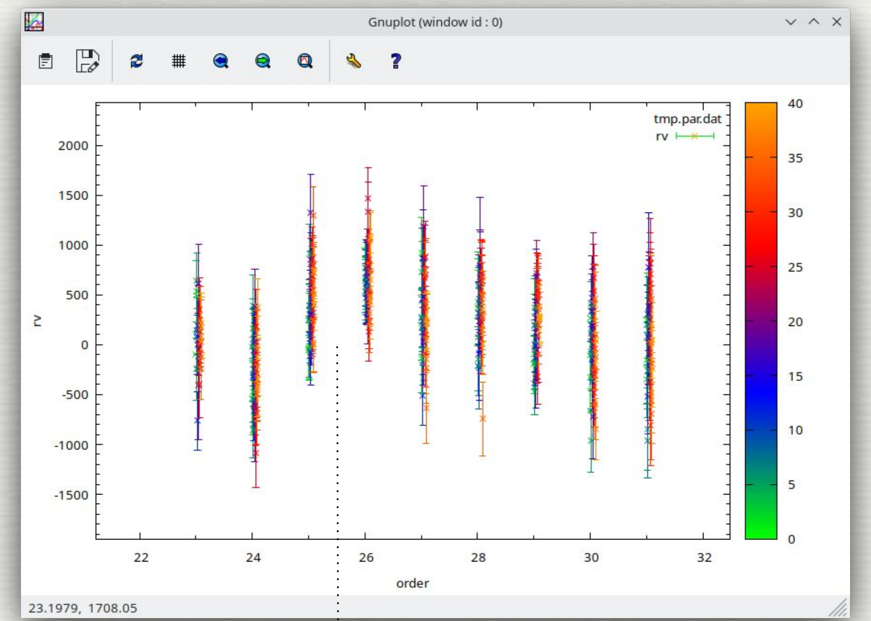
Optimization

RV ESTIMATION

parameters vary for each order
separate estimations & combination by weighted mean



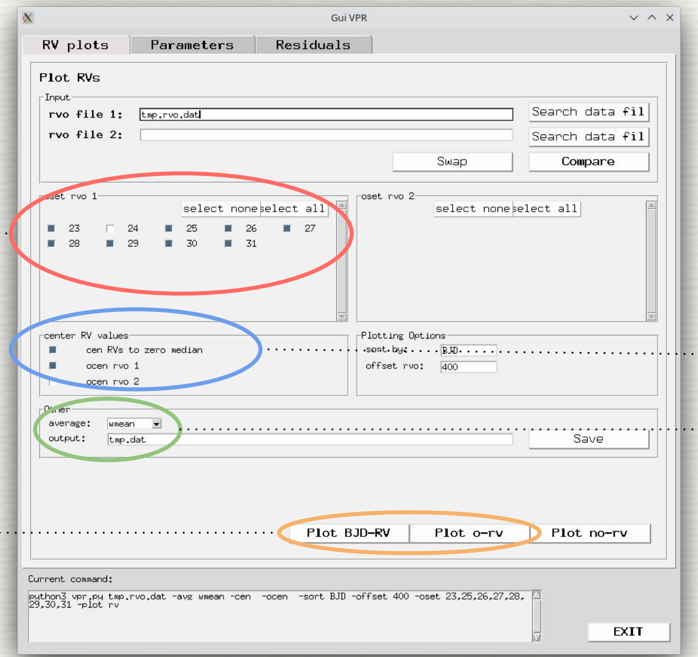
POST-PROCESSING WITH VPR



check the parameters for each order, deselect orders with high error values

POST-PROCESSING WITH VPR

deselect problematic orders



center RV values

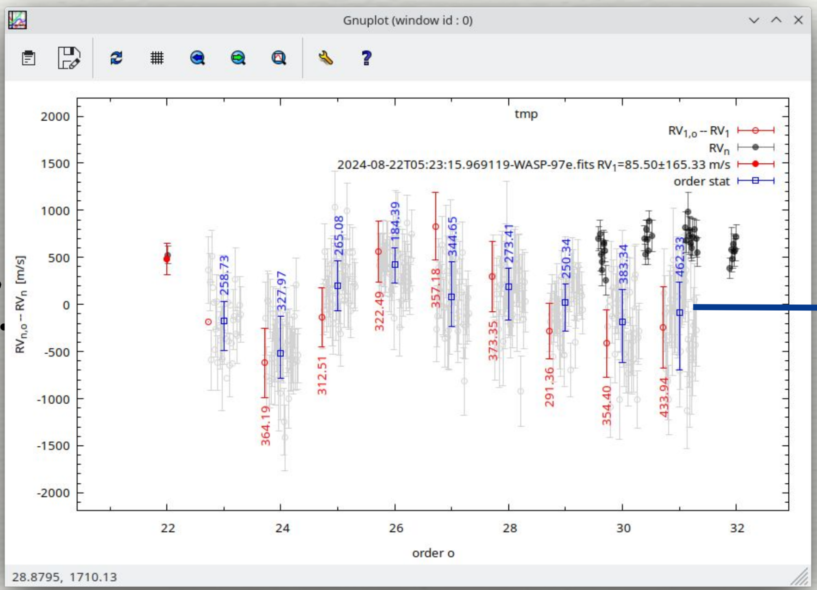
save data as .txt file

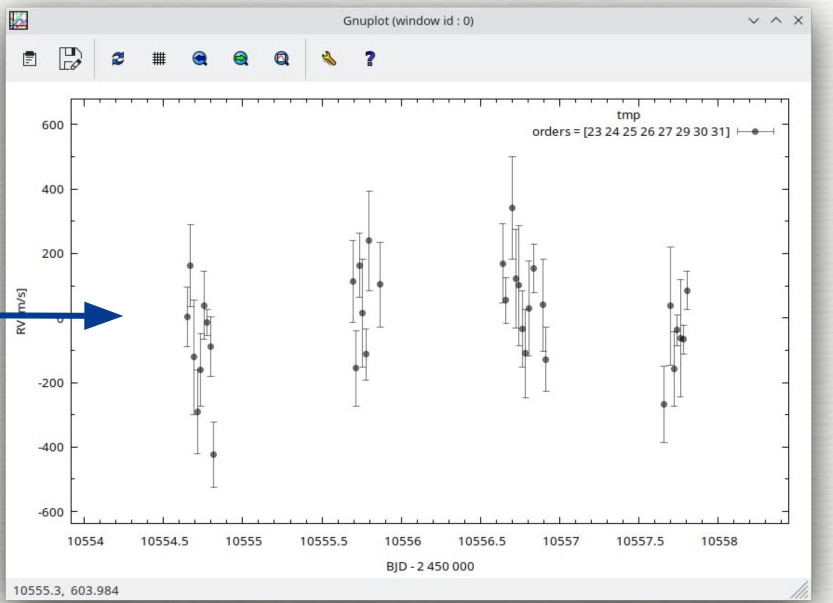
plot RV values over date (BJD) or order (o)

RV COMBINATION

$$RV = \frac{\sum rv_i w_i}{\sum w_i}$$

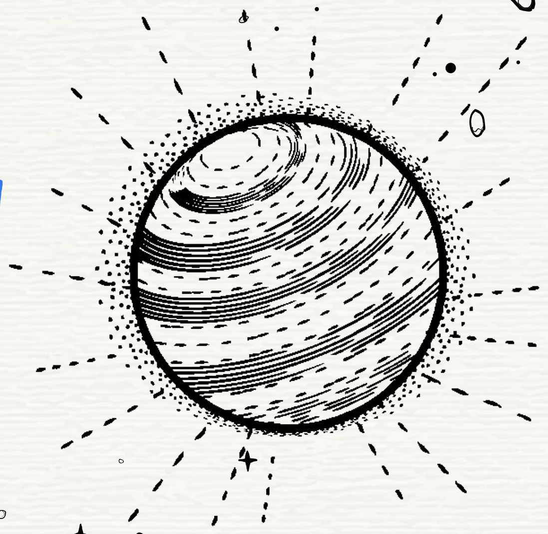
$$w_i = 1/e_i^2$$





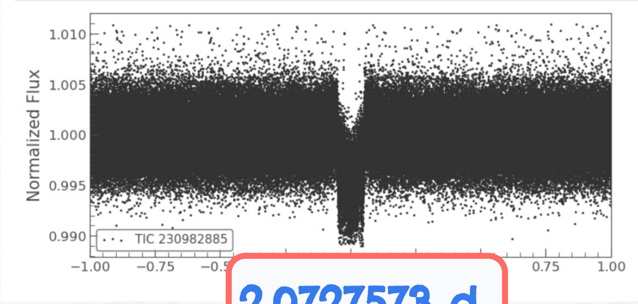
04

PERIOD DETERMINATION & RV FITTING

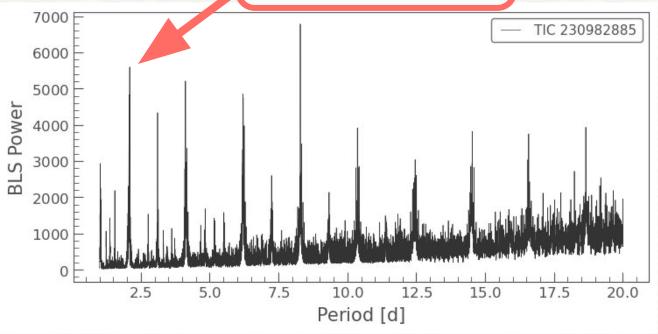


WASP-97 AS SEEN BY TESS

Phase-folded light curve

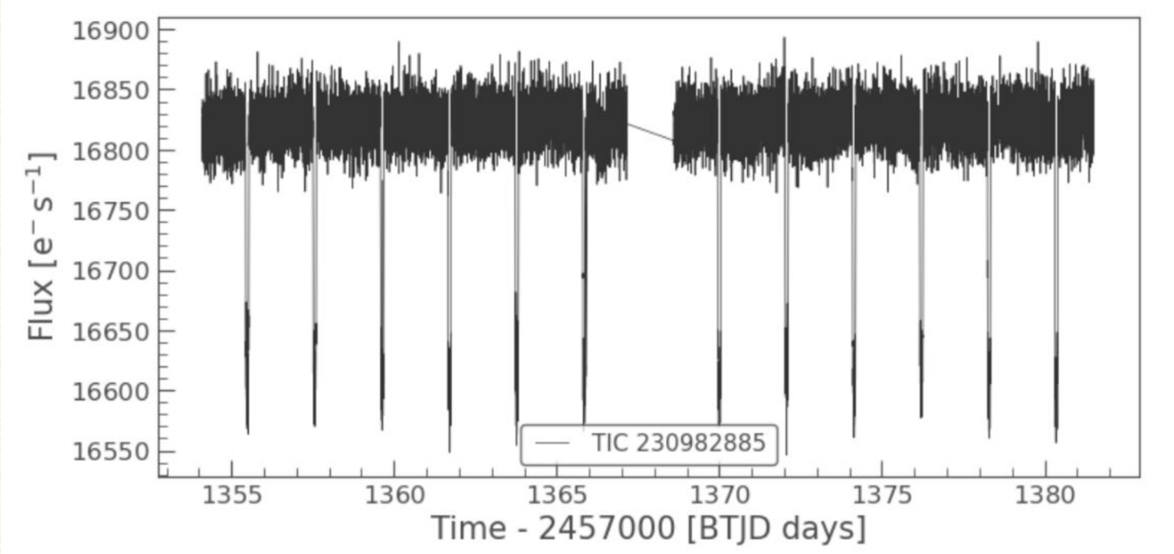


2.0727573 d



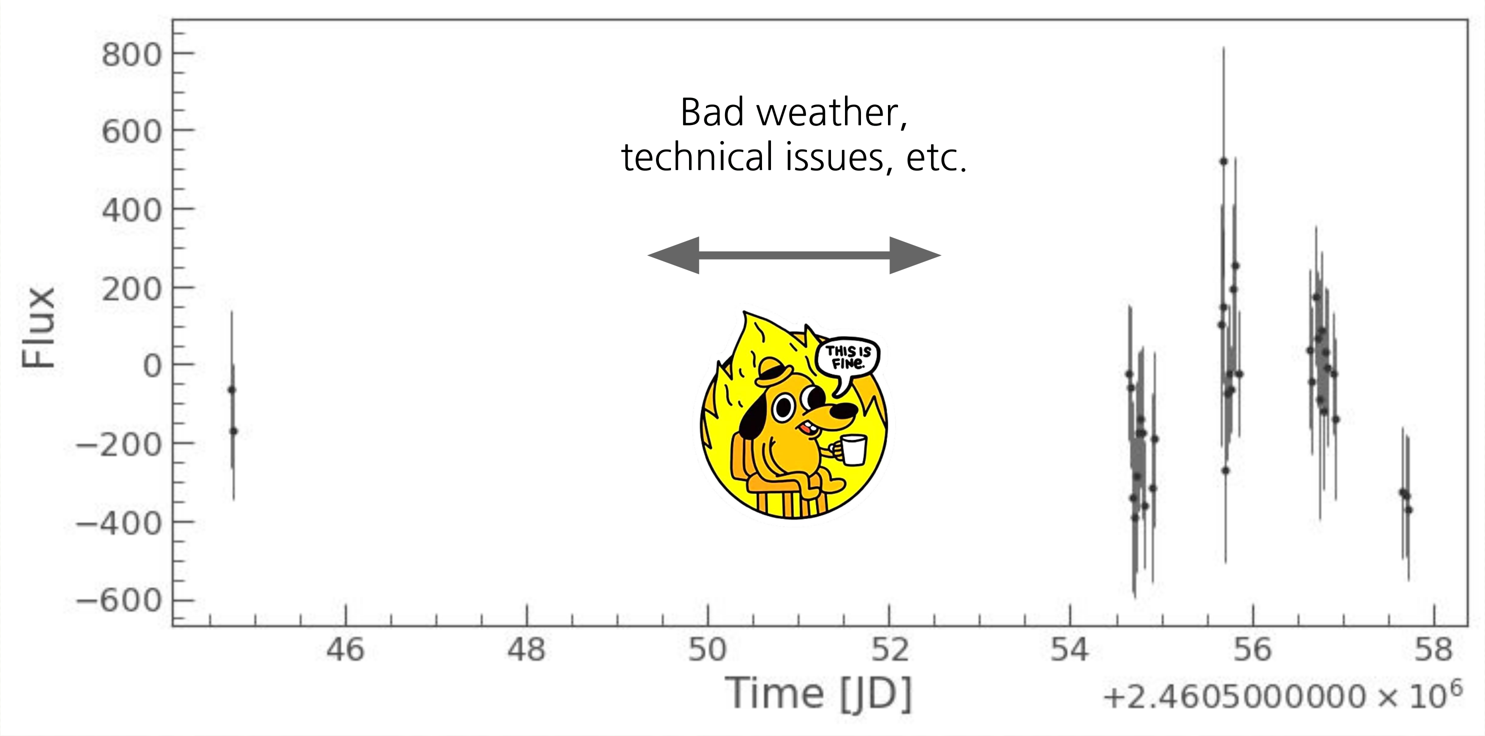
Periodogram

Photometric data, sector 2



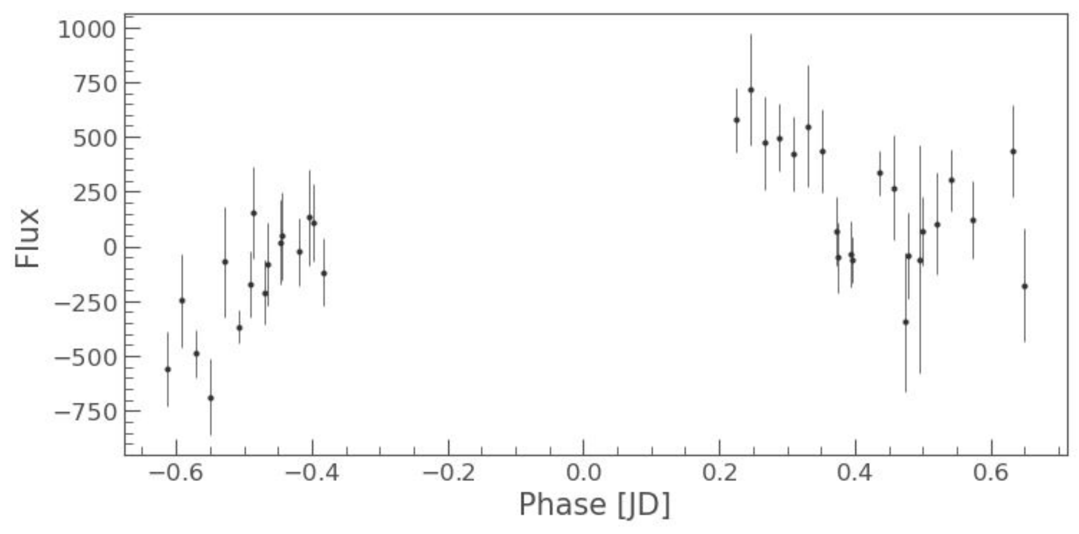

```
import astropy
import lightkurve as lk
```

PERIOD DETERMINATION FROM RVs

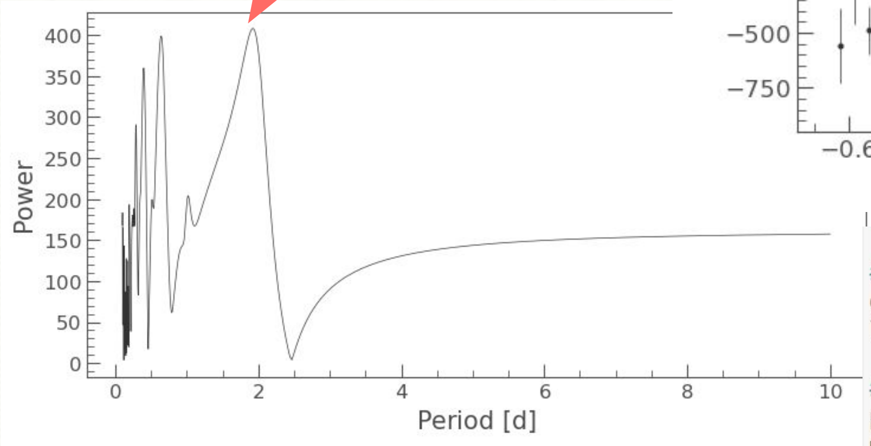


Data we worked with

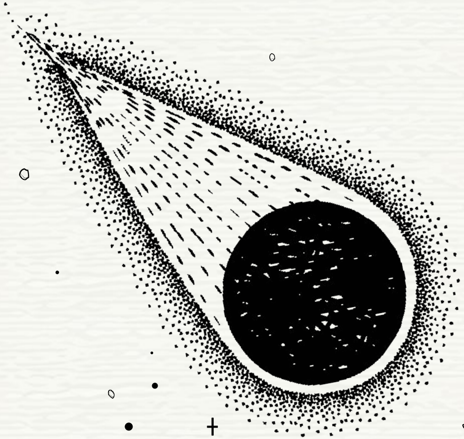
PERIOD DETERMINATION FROM RVs



1.9244184 d




```
#read-in data and convert to lightkurve format
data=np.loadtxt('data1.txt')
lc=lk.LightCurve(time=data[:,0],flux=data[:,1],flux_err=data[:,2])

#Lomb-Scargle periodogram to determine most likely period
pg=lc.to_periodogram(oversample_factor=100,minimum_period=0.1,
maximum_period=10,normalization='amplitude',ls_method='auto')
```



The Radial Velocity Fitting Toolkit

Authors: **BJ Fulton**, **Erik Petigura**, **Sarah Blunt**, and **Evan Sinukoff**

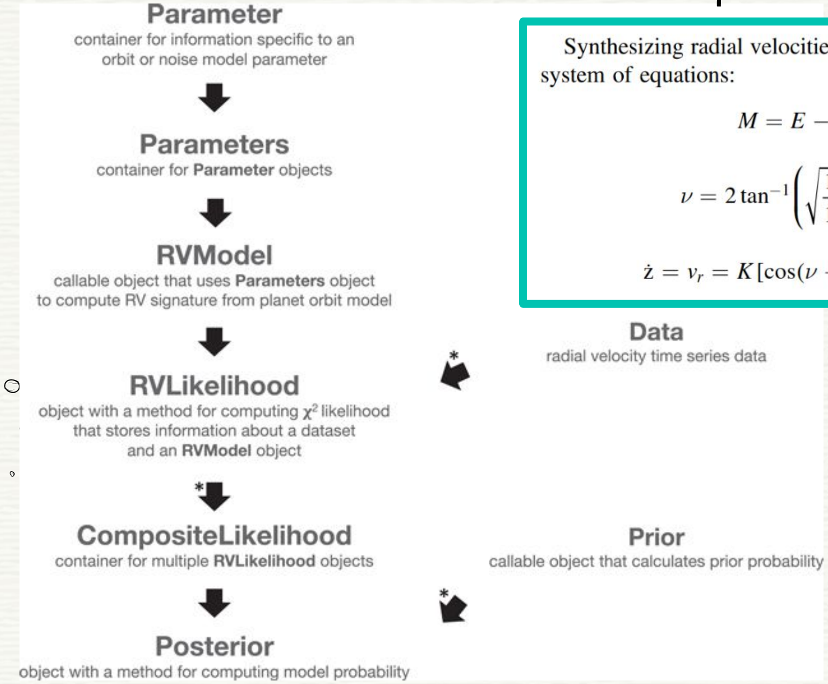
Github:
https://github.com/California-Planet-Search/radvel

Citation:
https://ui.adsabs.harvard.edu/abs/2018PASP..130d4504F/abstract

HOW DOES IT WORK?

Markov Chain Monte Carlo (MCMC)

+



Synthesizing radial velocities involves solving the following system of equations:

$$M = E - e \sin E, \tag{1}$$

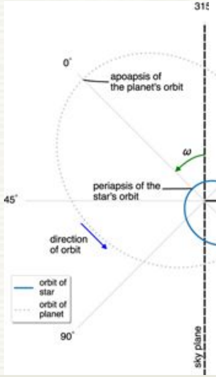
$$\nu = 2 \tan^{-1}\left(\sqrt{\frac{1+e}{1-e}} \tan \frac{E}{2}\right), \tag{2}$$

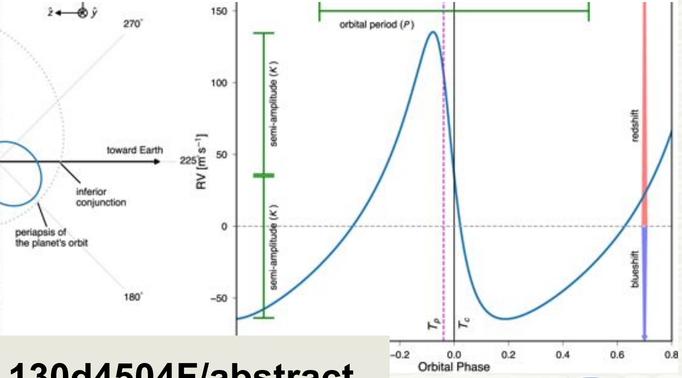
$$\dot{z} = v_r = K[\cos(\nu + \omega) + e \cos(\omega)], \tag{3}$$

Table 1
Keplerian Orbital Elements

Parameter Description	Symbol
Keplerian Orbital Parameters	
Orbital period	P
Time of inferior conjunction (or transit)[a]	T_c
Time of periastron[a,b]	T_p
Eccentricity	e
Argument of periapsis of the star's orbit[b]	ω
Velocity semi-amplitude	K
Mean and Acceleration Terms	
Mean center-of-mass velocity[c]	γ_i
Linear acceleration term	$\dot{\gamma}$
Second-order acceleration term	$\ddot{\gamma}$
Noise Parameters	
Radial velocity "jitter" (white noise)[c]	σ_i

Notes.
[a] Either T_c or T_p can be used to describe the phase of the orbit. Both are not needed simultaneously.
[b] Undefined for circular orbits.
[c] Usually specific to each instrument (i).





See more: https://ui.adsabs.harvard.edu/abs/2018PASP..130d4504F/abstract

FITTING THE RVs

You can include different observations

We need to add planet parameters and system parameters. We assume circular orbits (eccentricity = 0)

```python
# Example Keplerian fit configuration file

# Required packages for setup
import os
import pandas as pd
import numpy as np
import radvel

# Define global planetary system and dataset parameters
starname = 'WASP-97'
nplanets = 1    # number of planets in the system
instnames = ['k']    # list of instrument names. Can be whatever you like (no spaces) but should match 'tel' column in the input file.
ntels = len(instnames)       # number of instruments with unique velocity zero-points
fitting_basis = 'per tc e w k'    # Fitting basis, see radvel.basis.BASIS_NAMES for available basis names
bjd0 = 0   # reference epoch for RV timestamps (i.e. this number has been subtracted off your timestamps)
planet_letters = {1: 'b'}   # map the numbers in the Parameters keys to planet letters (for plotting and tables)


# Define prior centers (initial guesses) in a basis of your choice (need not be in the fitting basis)
anybasis_params = radvel.Parameters(nplanets,basis='per tc e w k',planet_letters=planet_letters)    # initialize Parameters object

anybasis_params['per1'] = radvel.Parameter(value=2.07276, vary = False)      # period of 1st planet
anybasis_params['tc1'] = radvel.Parameter(value=2460556.7604166665,vary = False)      # time of inferior conjunction of 1st planet
anybasis_params['e1'] = radvel.Parameter(value=0, vary = False)          # eccentricity of 1st planet
anybasis_params['w1'] = radvel.Parameter(value=np.pi/2.)          # argument of periastron of the star's orbit for 1st planet
anybasis_params['k1'] = radvel.Parameter(value=100.0)          # velocity semi-amplitude for 1st planet
```

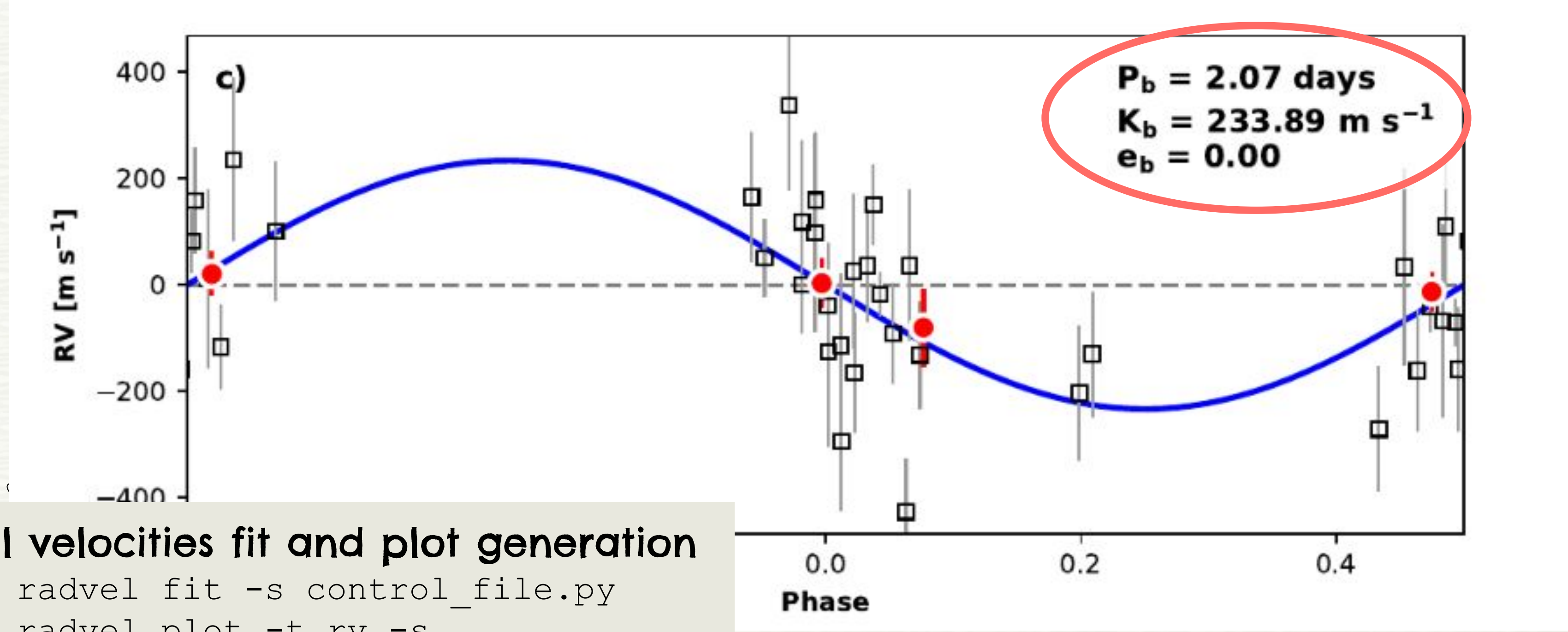
control_file.py

FITTING THE RVs

Article data

2014MNRAS.440.1982H

$$K_1 = 194.5 \pm 2.3ms^{-1}$$

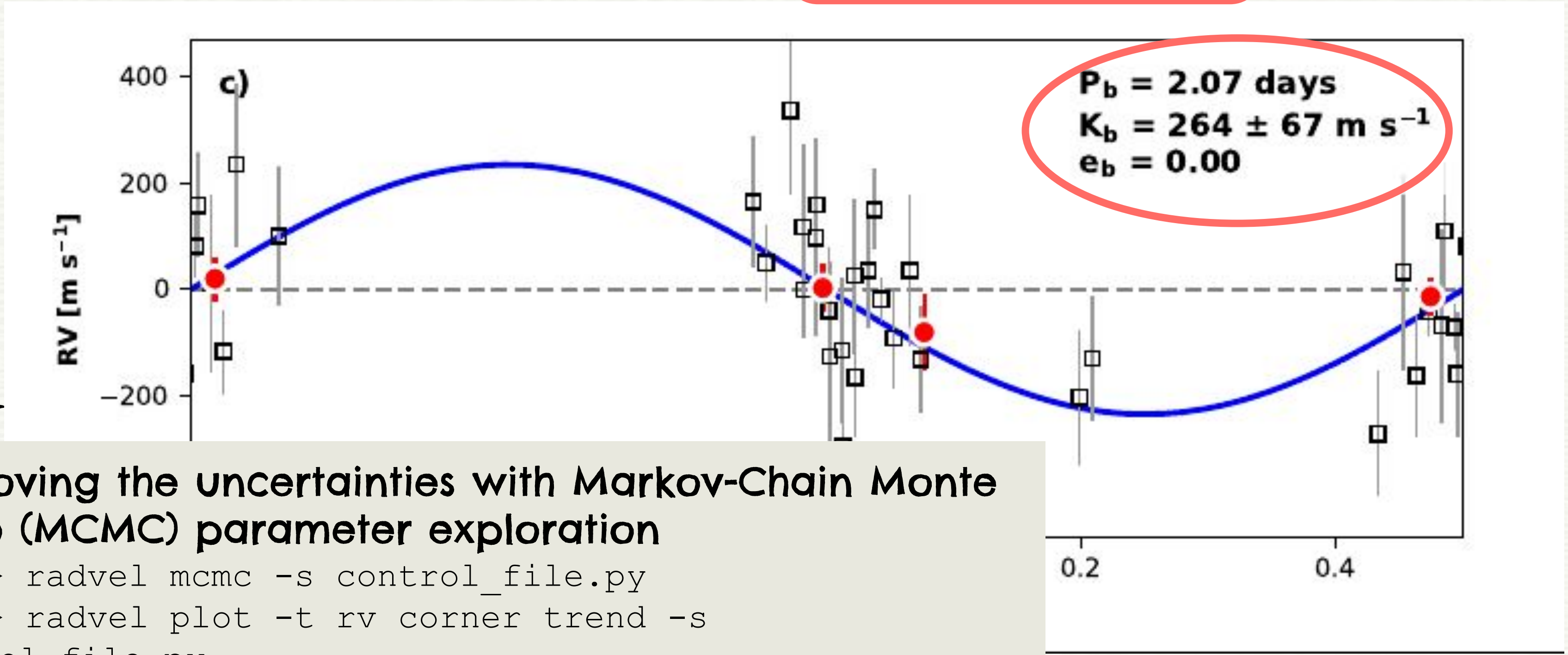


Radial velocities fit and plot generation

```
> radvel fit -s control_file.py
> radvel plot -t rv -s
control_file.py
```

FITTING THE RVs

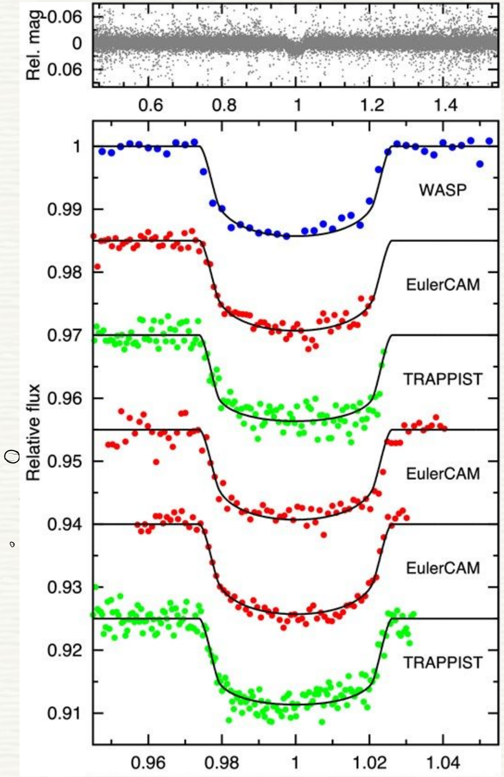
Article data
2014MNRAS.440.1982H
$K_1 = 194.5 \pm 2.3ms^{-1}$

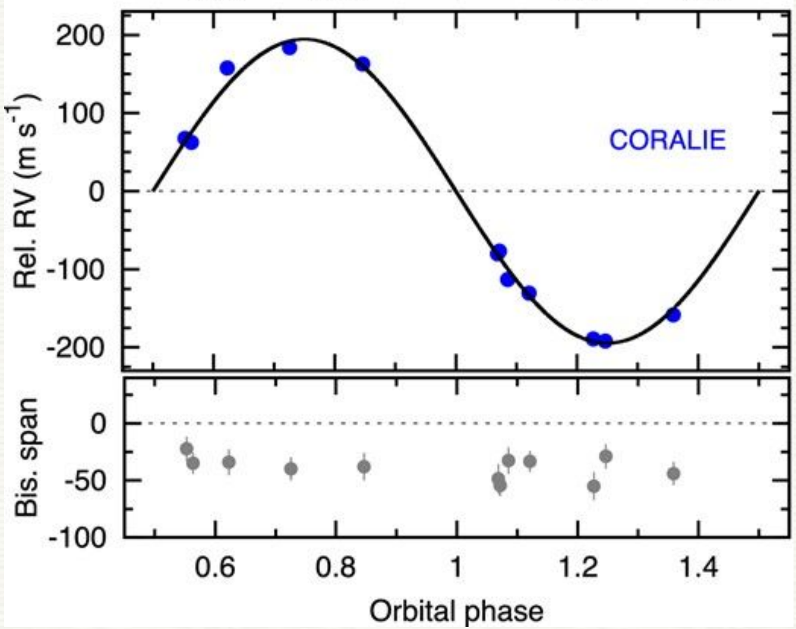


Improving the uncertainties with Markov-Chain Monte Carlo (MCMC) parameter exploration

```
> radvel mcmc -s control_file.py
> radvel plot -t rv corner trend -s control_file.py
> radvel derive -s control_file.py
> radvel ic -t nplanets e trend -s control_file.py
```

WASP-97 IN LITERATURE





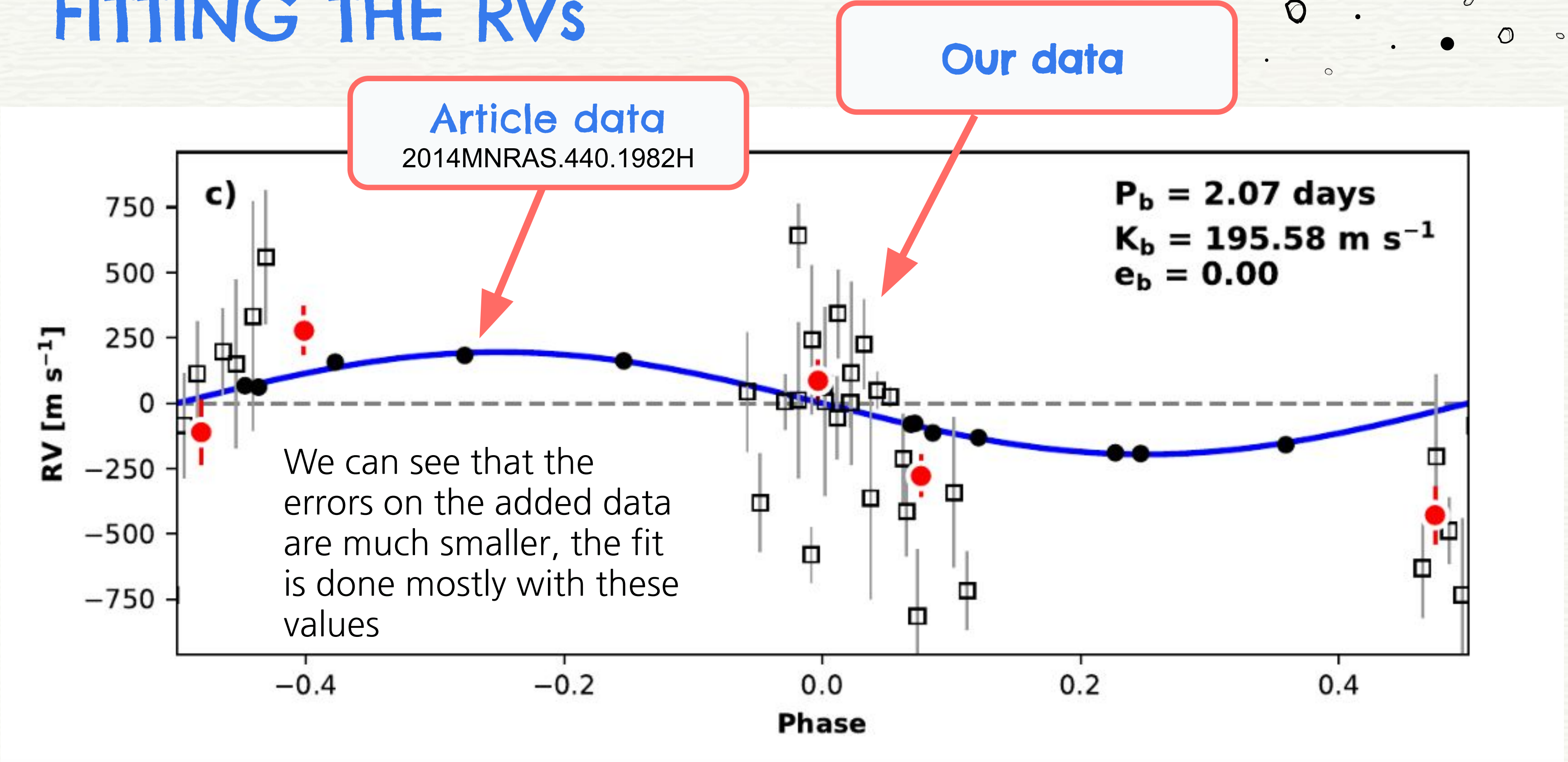
Article data

2014MNRAS.440.1982H

$$K_1 = 194.5 \pm 2.3ms^{-1}$$

We add the RV data to our sample, and try computing the RVs

FITTING THE RVs



We can see that the errors on the added data are much smaller, the fit is done mostly with these values

05

RESULTS & DISCUSSION

MASS OF WASP-97b

2.07276(±1e-6) d

We assume inclination ~ 90°

264(±67) m/s

We want to know this

=1

$$\frac{M_2^3 \sin^3 i}{(M_1 + \cancel{M_2})^2} = \frac{PK_1^3}{2\pi G}$$

1.12(±0.06) M_{sun}

We can neglect this term (M_{star} >> M_{planet})

All values were taken from the exoplanet database: https://exoplanet.eu/catalog/wasp_97_b--1425/

$1.78 \pm 0.45\ M_J$

The value from literature:

$1.32 \pm 0.05\ M_J$

All values were taken from the exoplanet database: https://exoplanet.eu/catalog/wasp_97_b--1425/

Thank you for your attention!