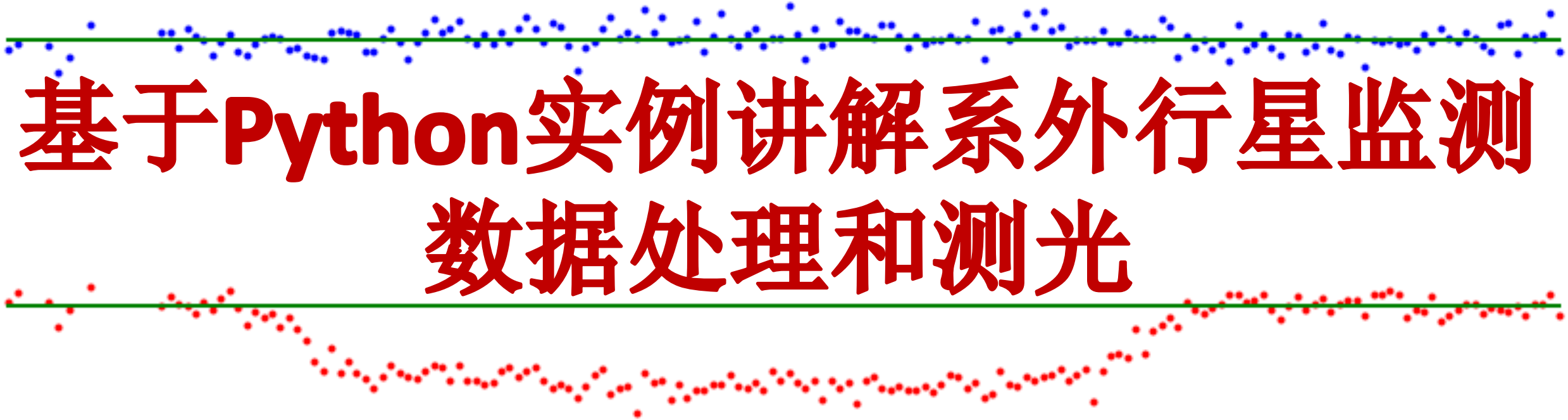
天文数据与Python技术培训



基于Python实例讲解系外行星监测数据处理和测光

邹虎 @ NAOC

2020.12.08

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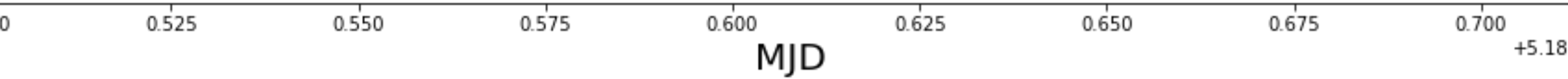


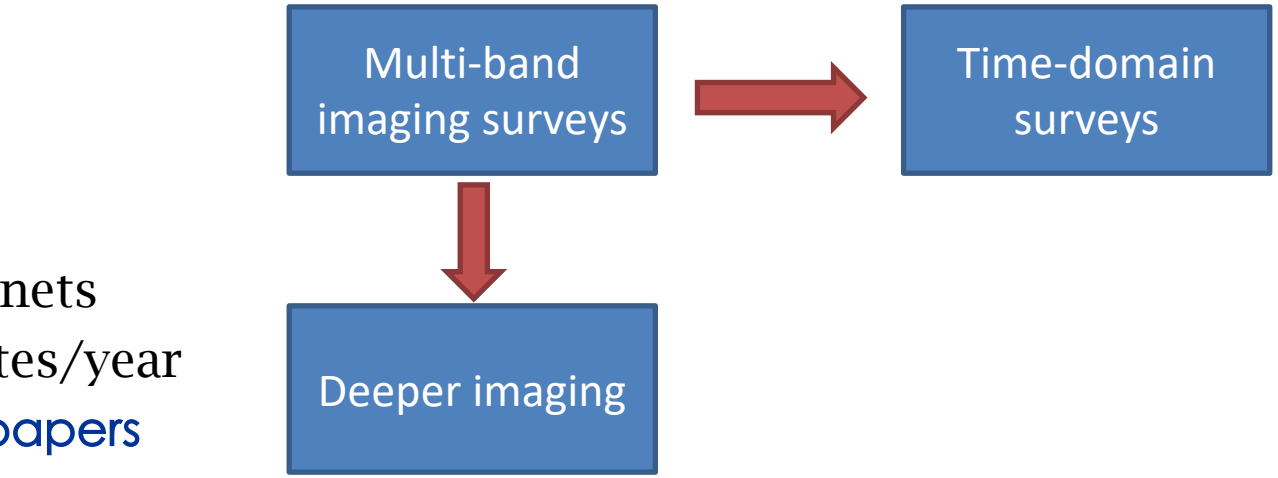
Content

- Exoplanet monitoring by Xinglong 60/90 Schmidt telescope, which is operated by BATC/NAOC group
  - basic data reduction
  - Data analysis: photometry and differential photometry
  - Light curve
- Purely based on Python (software dependencies), reducing data independently
  - Python3
  - astropy
  - numpy
  - matplotlib
  - photutils
  - jupter-notebook

- Acknowledgement: Y. H. Wang (王永浩，previous PhD. Student in our group), for the raw data, and part of the slides in this lecture

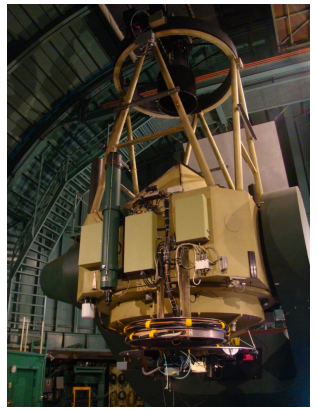
BATC/NAOC leading surveys

- BATC Schmidt telescope
  - BATC multi-color survey: > 400 papers
  - Asteroid survey: about 3000 asteroids
  - BL-LAC object monitoring
  - Exoplanet monitoring: about 70 exoplanets
  - Supernova survey (TNTS): ~50 candidates/year
- Antarctic CSTAR 20 deg^2 monitoring: > 30 papers
- UA Bok telescope
  - South Galactic Cap u-band Survey Survey (SCUSS): for LAMOST and SDSS-IV eBOSS
  - Beijing-Arizona Sky Survey (BASS): Pilot B & targeting for Dark Energy Spectroscopic survey (DESI)



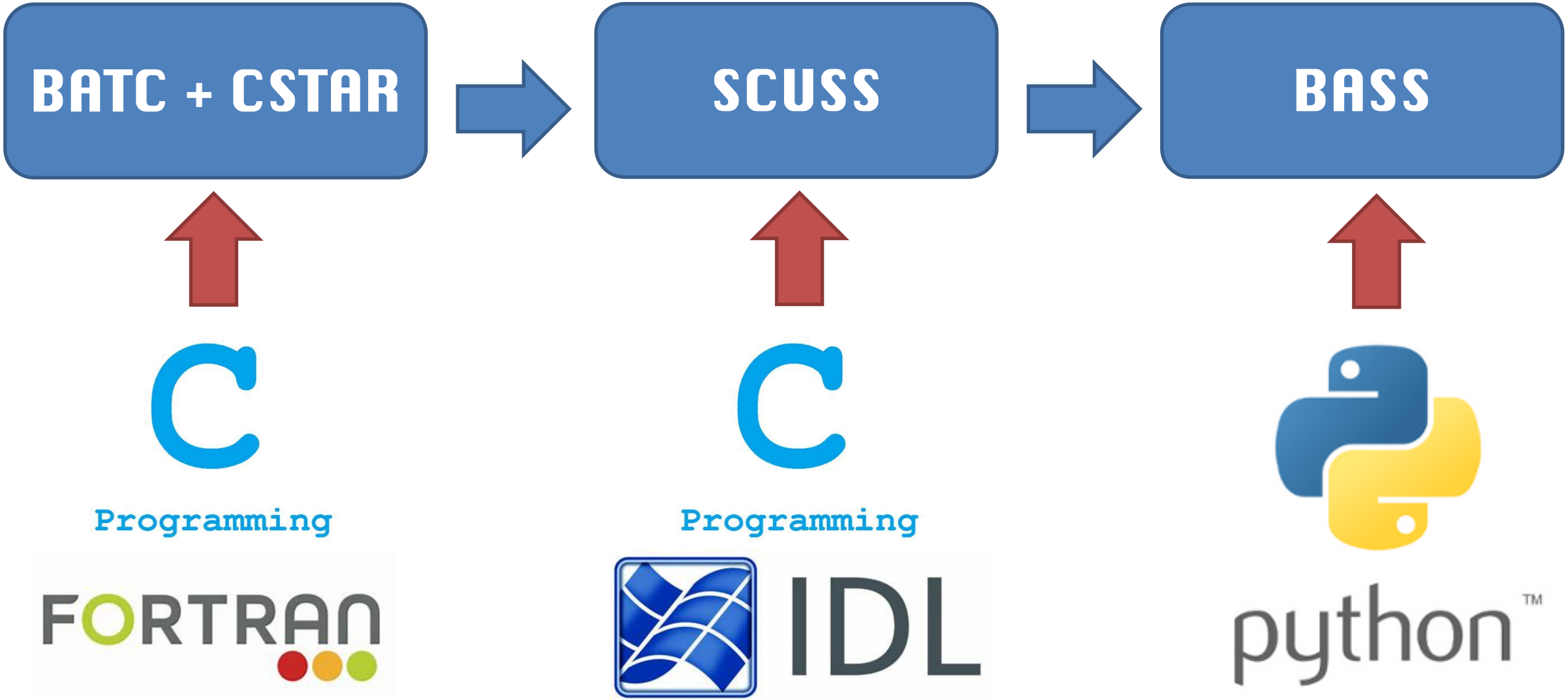
60/90-cm Schmidt telescope

CSTAR 4x 14.5cm telescopes



Bok 2.3 telescope

Programming Languages



Astronomical software for reducing imaging data

- IRAF:
  - imaging and spectral data processing, data analyses (e.g. calibrations, photometry):
  - transition to an end-of-support state, PyRAF (Python wrapper)
- Cfitsio, wcstools:
  - FITS Library and tools for WCS operation
- Scamp, Astronometry.net:
  - Astrometry
- DAOPHOT, SExtractor:
  - source detection, aperture and PSF photometry for point sources
- IDL:
  - IDL Astronomy User's Library
- Python
  - Astropy: common core package for astronomy: FITS, coordinates, WCS, …
  - Astropysics: astrophysics utilities
  - Astrometry.net: astrometry
  - ccdproc: CCD image processing
  - Photutils: sky background, source detection, photometry

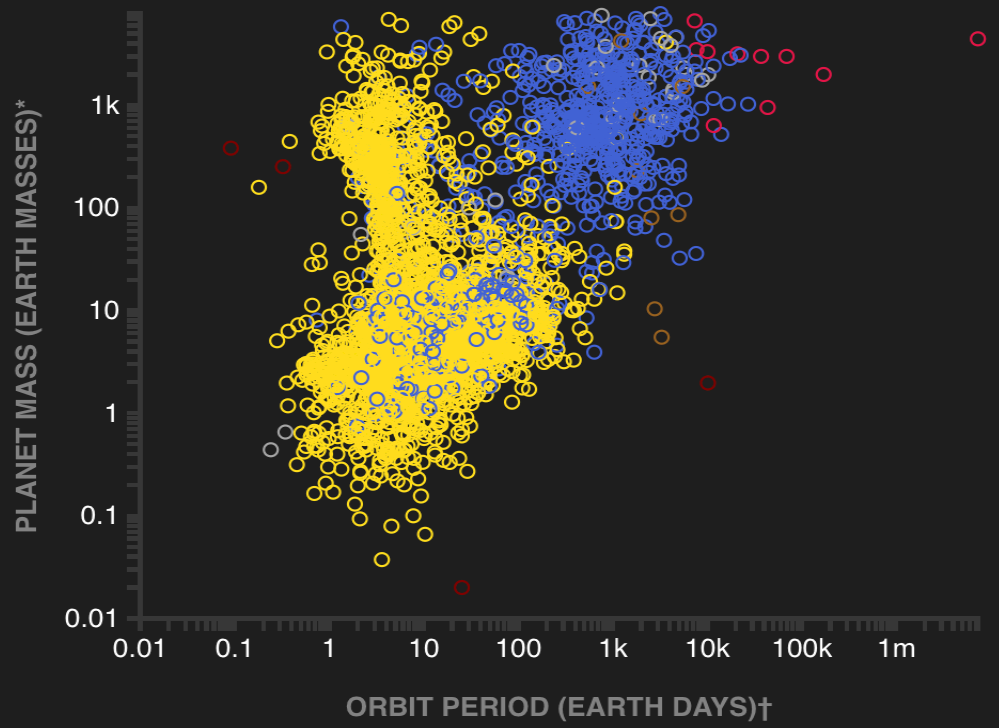
Some background of this lecture

Exoplanet Census

Exoplanet Census

For planets with both measured or estimated orbital period and mass

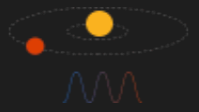
Transit (3246) Radial Velocity (817) Microlensing (9)
Imaging (10) Pulsar Timing (6) Other (41)



YEAR **2020** | DISCOVERIES‡ **4307**

By Method


76.0% Transit


19.1% Radial Velocity


2.5% Microlensing

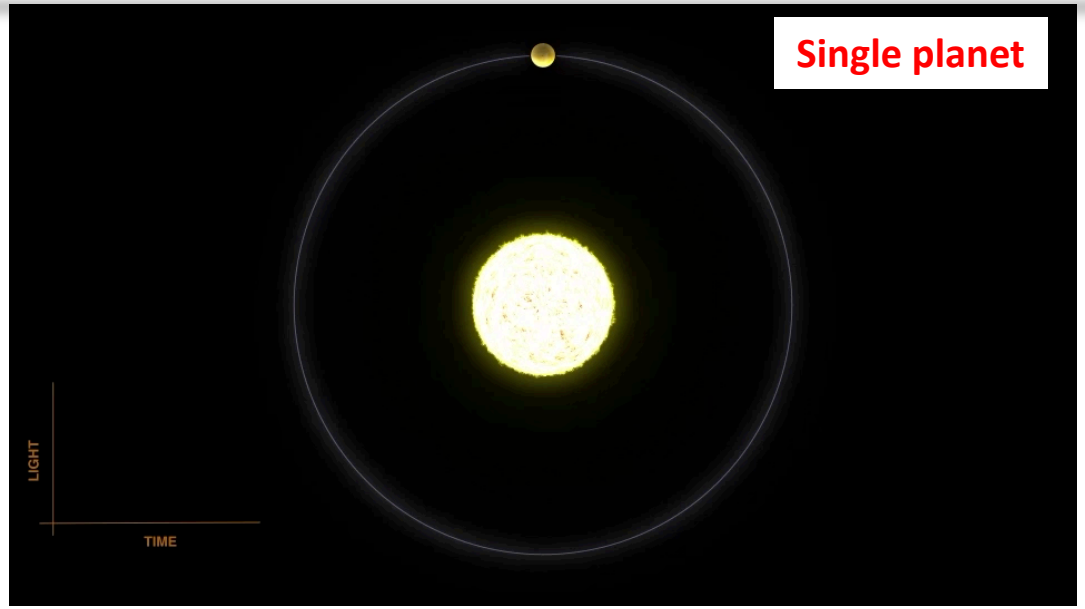

1.2% Imaging

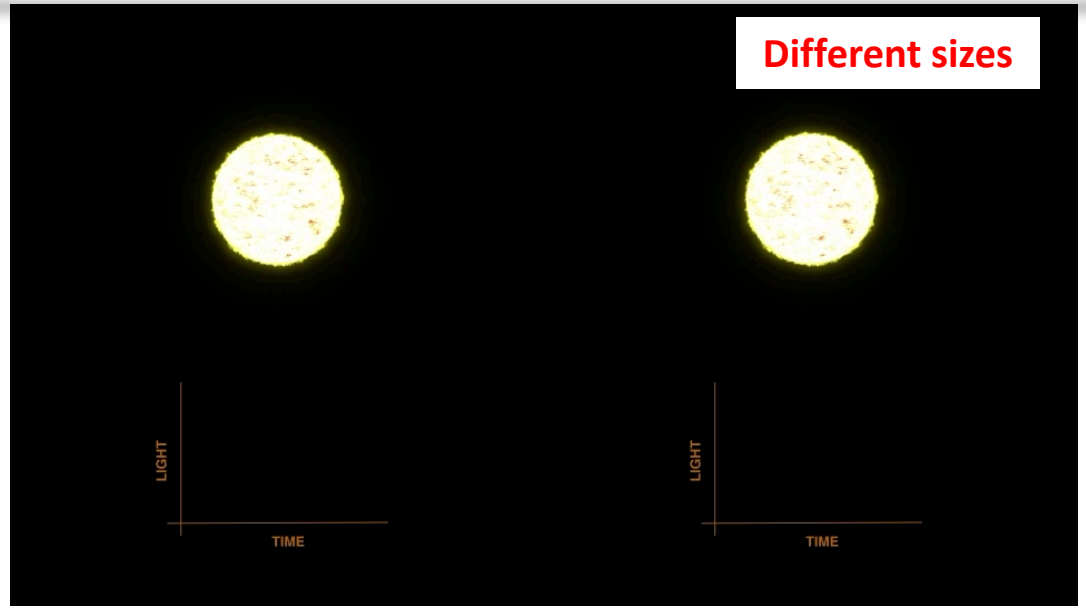
Credit: https://exoplanets.nasa.gov/

0.49% Transit Timing Variations, 0.37% Eclipse Timing Variations, 0.16% Pulsar Timing, 0.14% Orbital Brightness Modulation, 0.05% Pulsation Timing Variations, 0.02% Disk Kinematics, 0.02% Astrometry

› More about planet-hunting methods

Transit: exoplanet detection

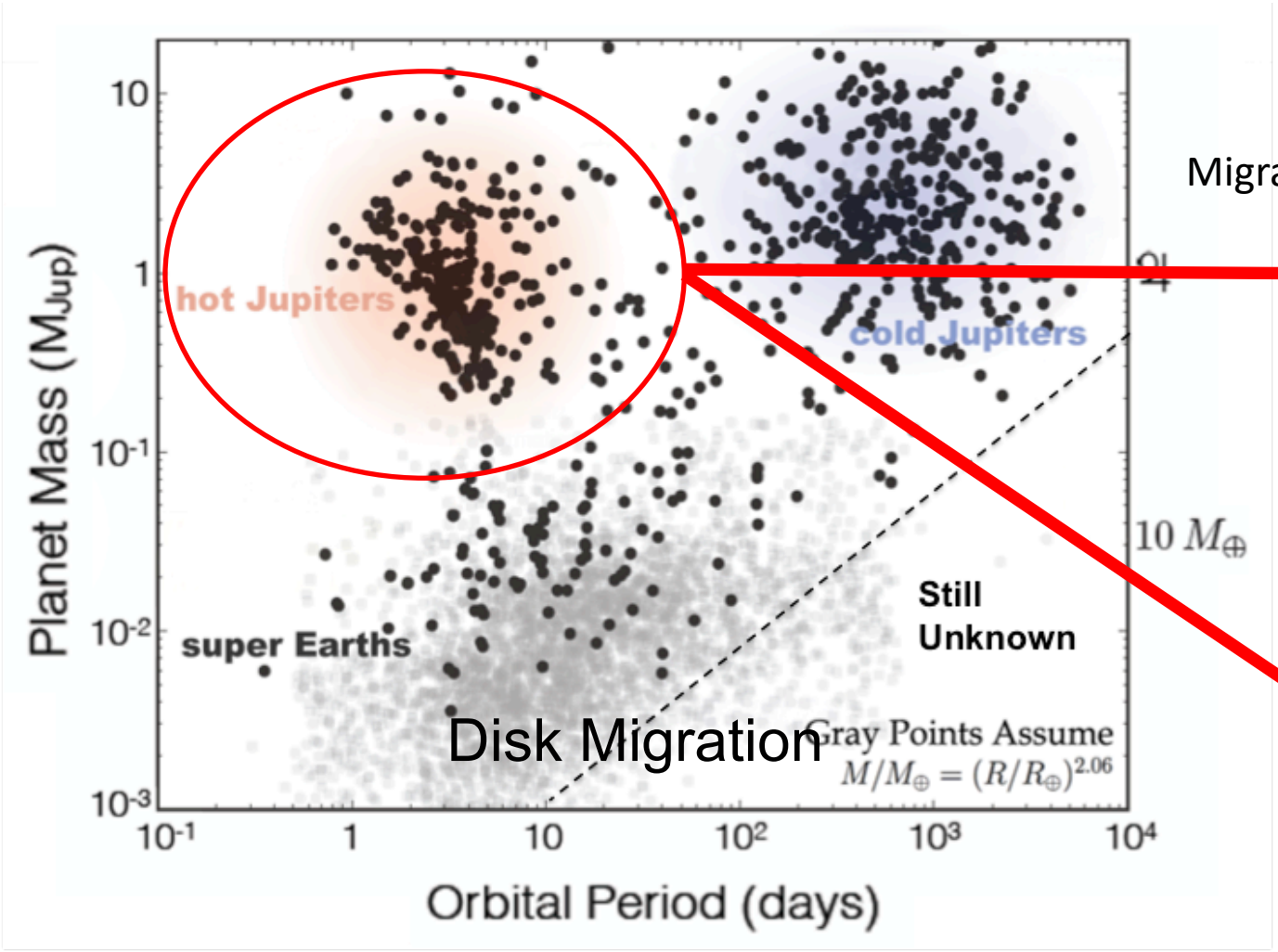




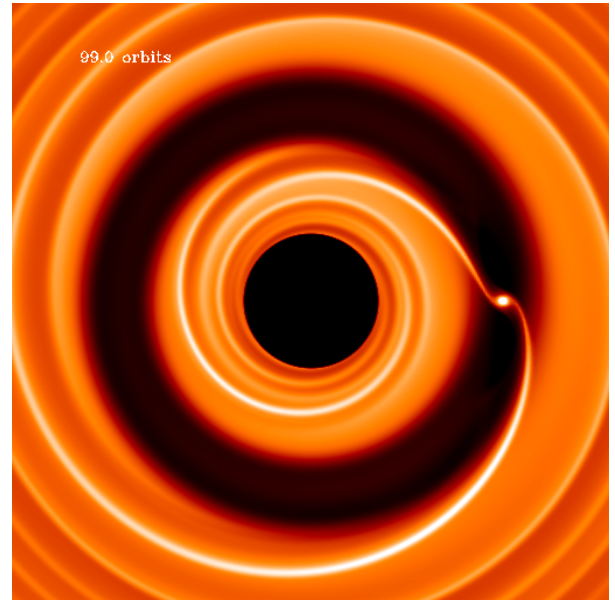
Credit:
https://exoplanets.nasa.gov/

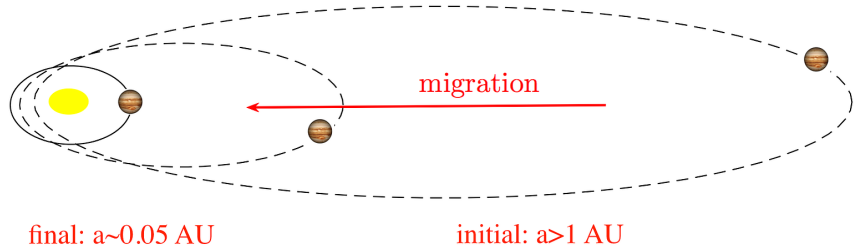
Orbit period
Size
Multiple planetary system
Etc.

Transiting Exoplanet Monitoring Project (TEMP)



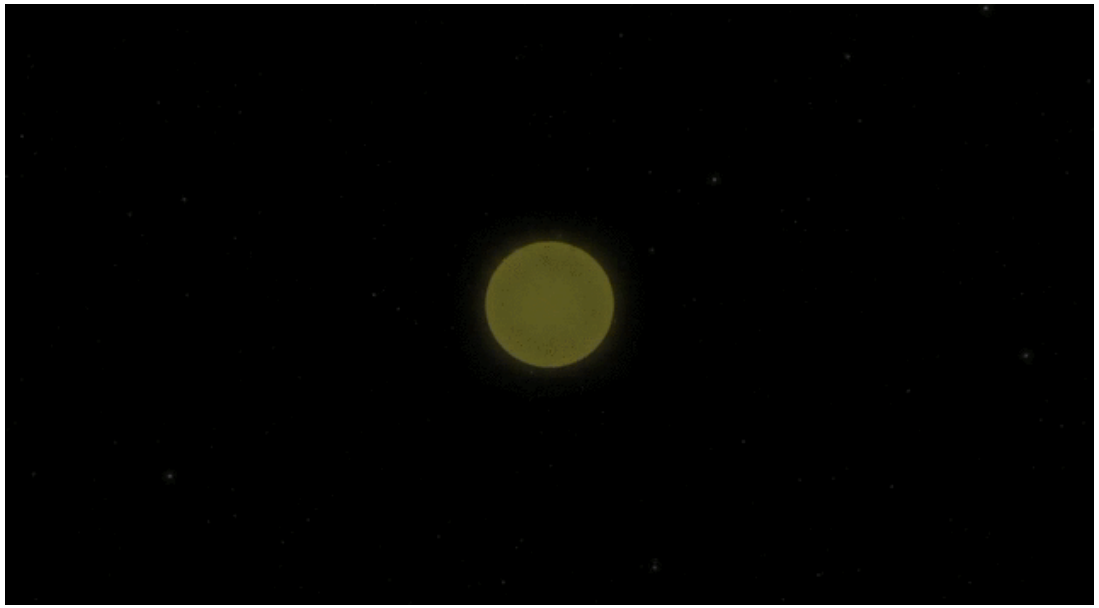
Migration





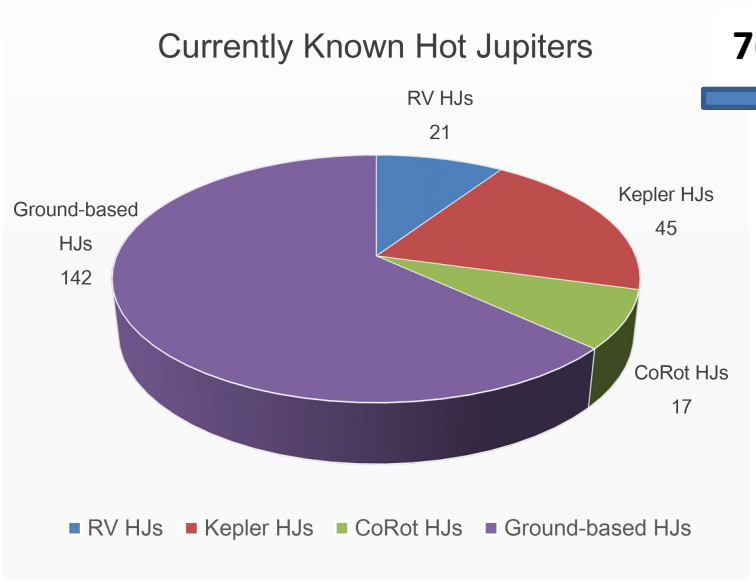
High eccentricity Migration

Hot Jupiter monitoring

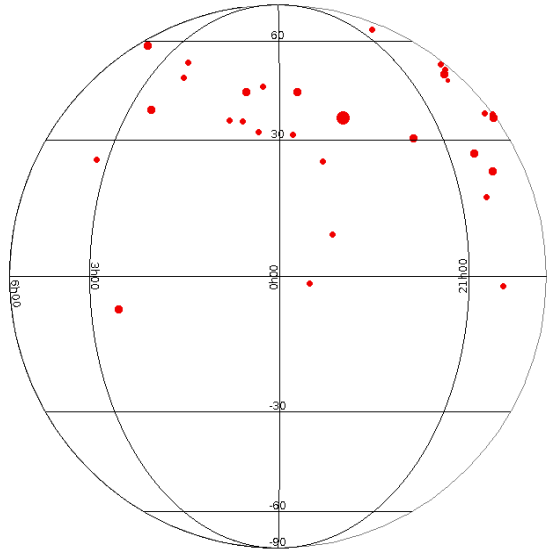


Find close companions for hot Jupiters through TTVs and check the occurrence rate to constrain the mitigation theories

Transit Timing Variation



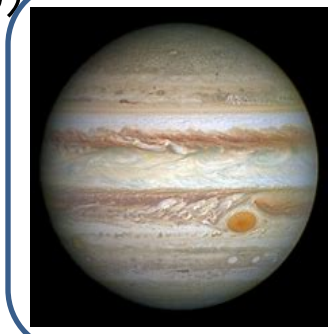
76 HJs



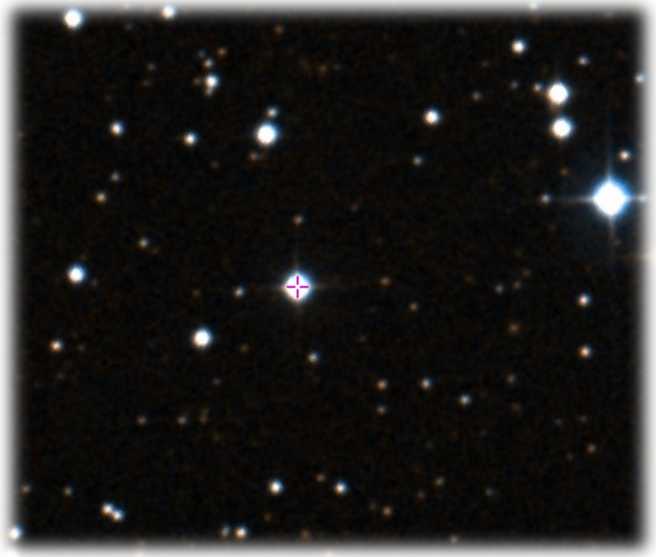
Subject of this lecture

- One of hot Jupiters monitored by the 60/90cm Schmidt telescope
  - HAT-P-32b: a Hot Jupiter (discovered in 2011)
  - RA: 02:04:10.278 DEC +46:41:16.2 (J2000)
  - Mass: 0.68 Jupiters
  - Planet radius: 1.98 x Jupiter
  - Orbital radius: 0.034 AU
  - Orbital period: 2.2 days

  - Host star: F type
  - Distance: 1,044 light years
  - V mag: 11.44 mag
  - Transit depth: 0.0244 mag



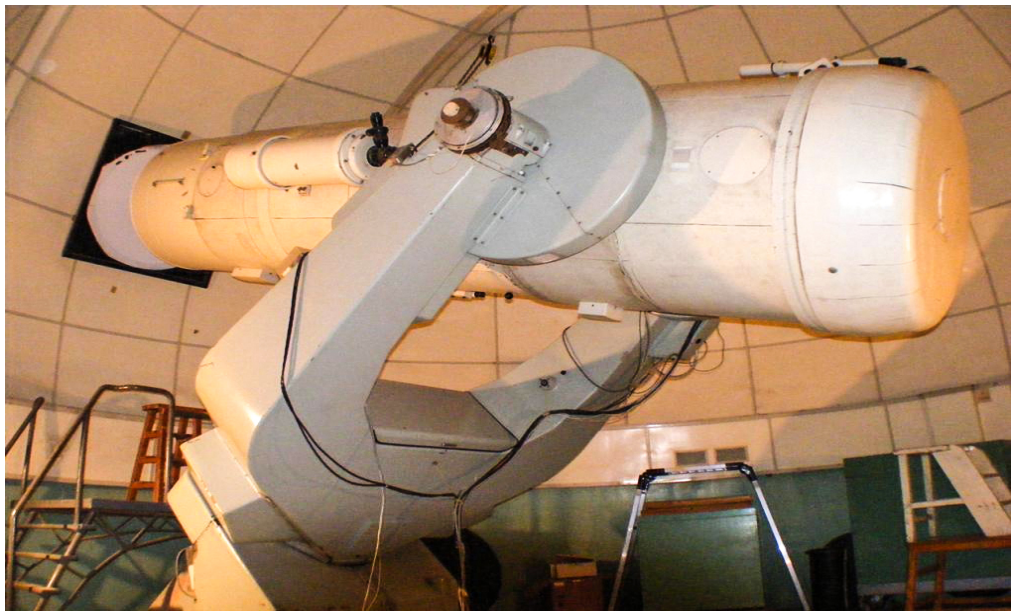
Planet mass: 318 $M_{\oplus}$
Planet radius: 11 $R_{\oplus}$
Orbit period: 11.86 yr
Orbit radius: 5.2 AU



Schmidt telescope

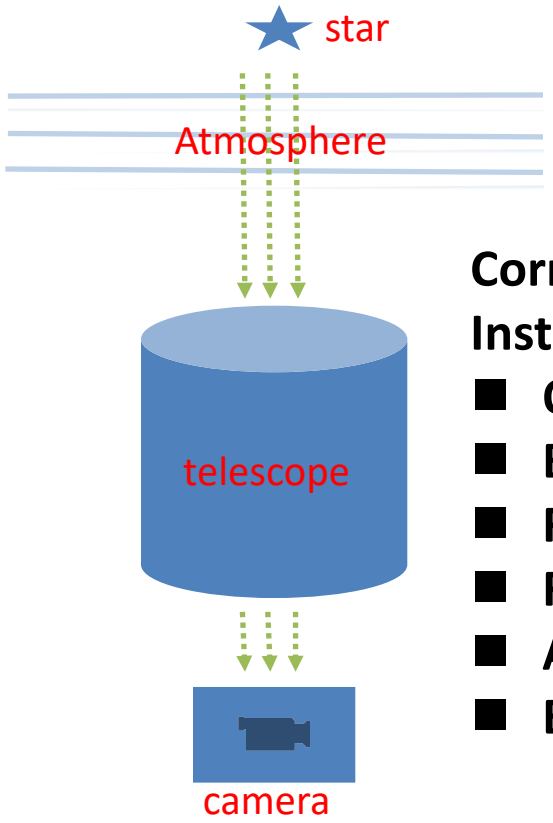
- 60/90 cm telescope
- Focal ratio: F/3
- Camera: e2v 4Kx4K
- FoV: 94’ x94’
- Filters: 15 intermediate bands and broad bands

- Adopted filter: R
- Small Fov: 512x512
- Exposure time: 60s
- BIAS, FLAT and science frames



Basic data reduction flow

Imaging Processing → Astrometry → Flux calibration → Photometry



Correction of Instrument effect

- **Overscan**
- **Bias**
- **Flat**
- **Fringe**
- **Artifacts**
- **Etc.**

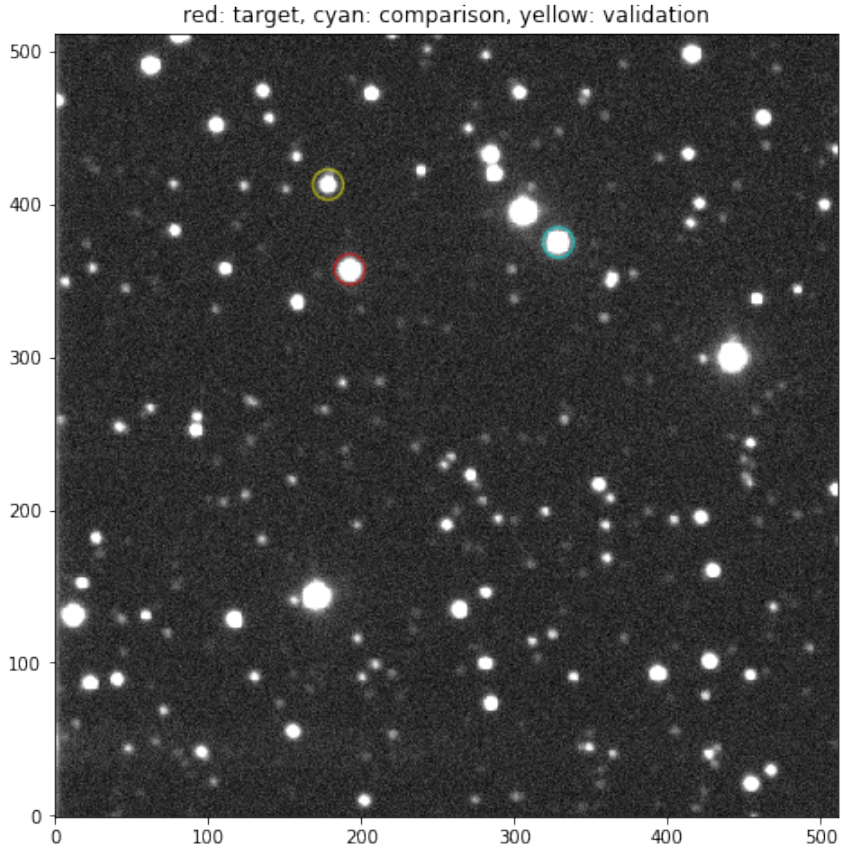
Sky coordinate ← CCD X Y

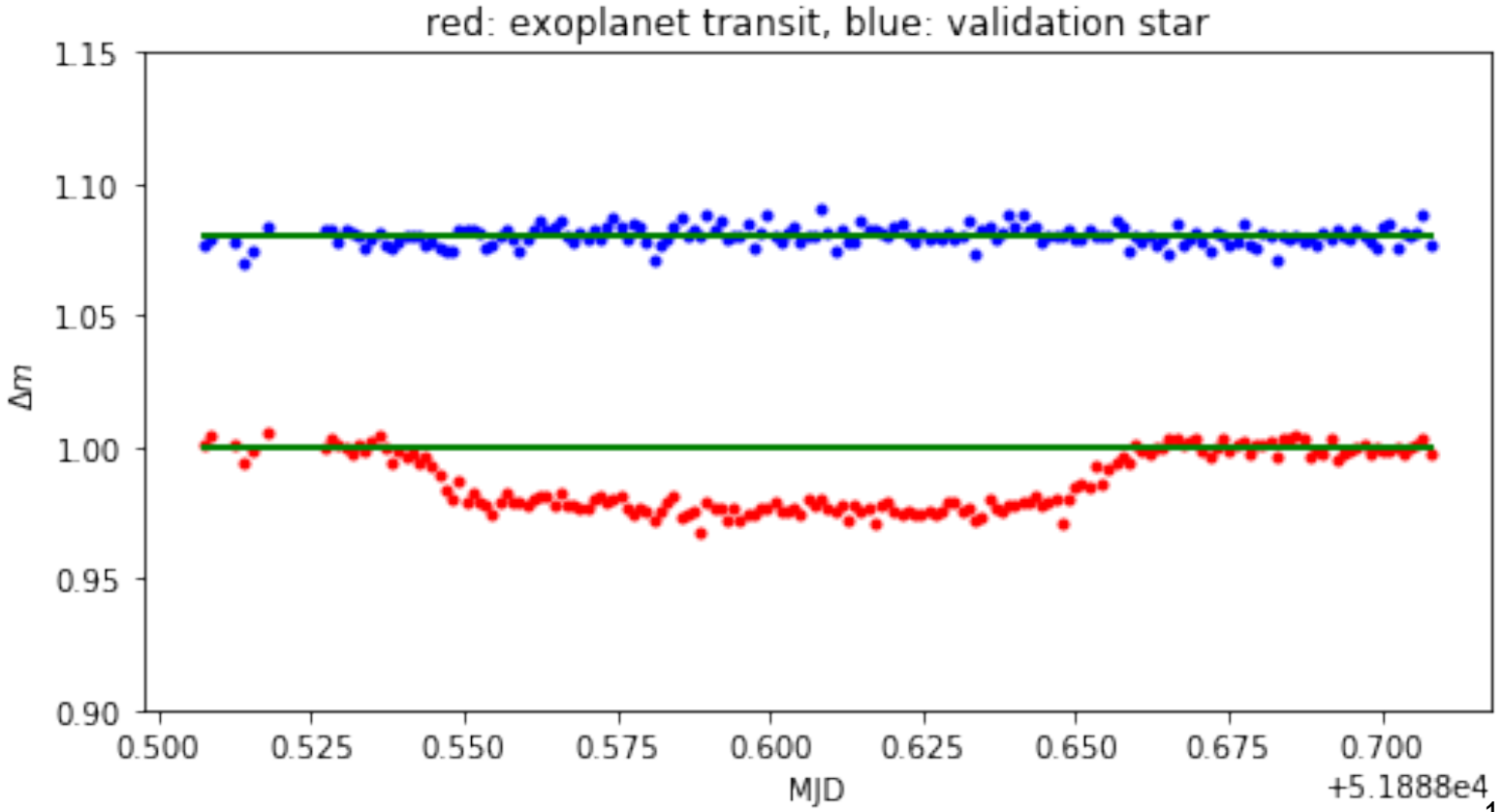
Flux ← CCD count

Brightness shapes ← Light distribution

Differential photometry

- Most useful for light variation of variable objects
- Comparing the photometry of the target and comparison stars: usually use aperture photometry (point sources)





HAT-P-32b data reduction

- Purely Python code (not use third-party software)
  - Training the Python coding
  - Learning some of the Python packages
  - Understanding the basic process of the data reduction
  - Knowing the differential photometry
  - Reducing the data by yourself

QR code for accessing the data and data reduction notebook

Hands-on practice