高温星TOI1355周辺の楕円軌道ホットジュピターの発見

Validation of Eccentric Hot Jupiter Transiting Edge of a Mid-A-type star TOI-1355

Watanabe et al. in prep

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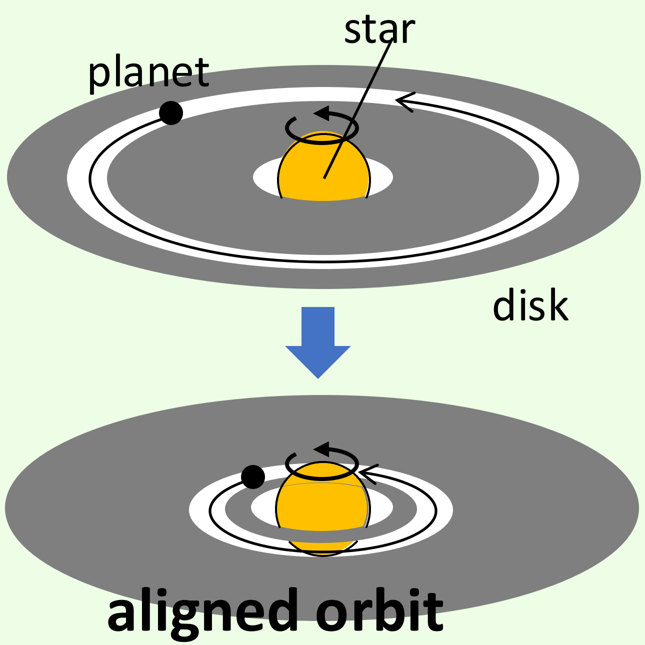
Orbital Evolution Model of Hot Juipter

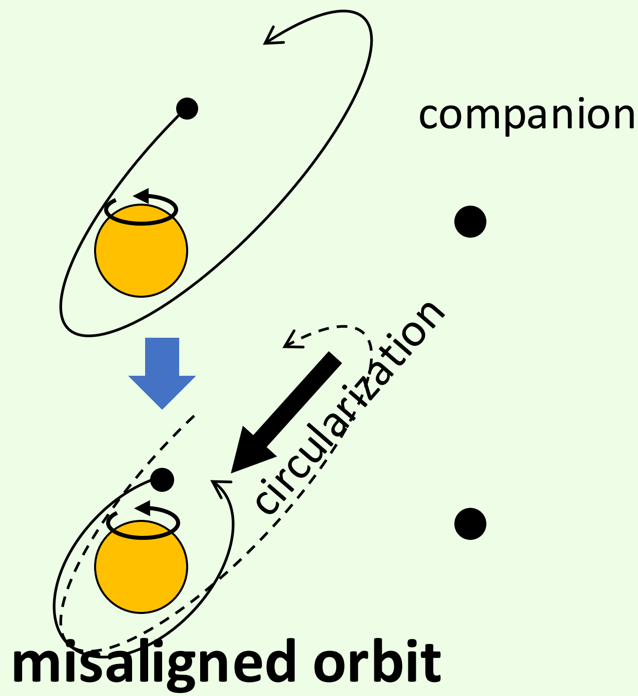
Planet-disk interaction migration

(Lin et al., 1996)



High eccentricity migration

(Planet-planet scattering: Chatterjee et al., 2008)
(Kozai-Lidov migration: Fabrycky & Tremaine, 2007)



Orbital Evolution Model of Hot Juipter

System with a solar-like star (Teff<6250K)

- Thick convective surface
- Realignment by tidal torque

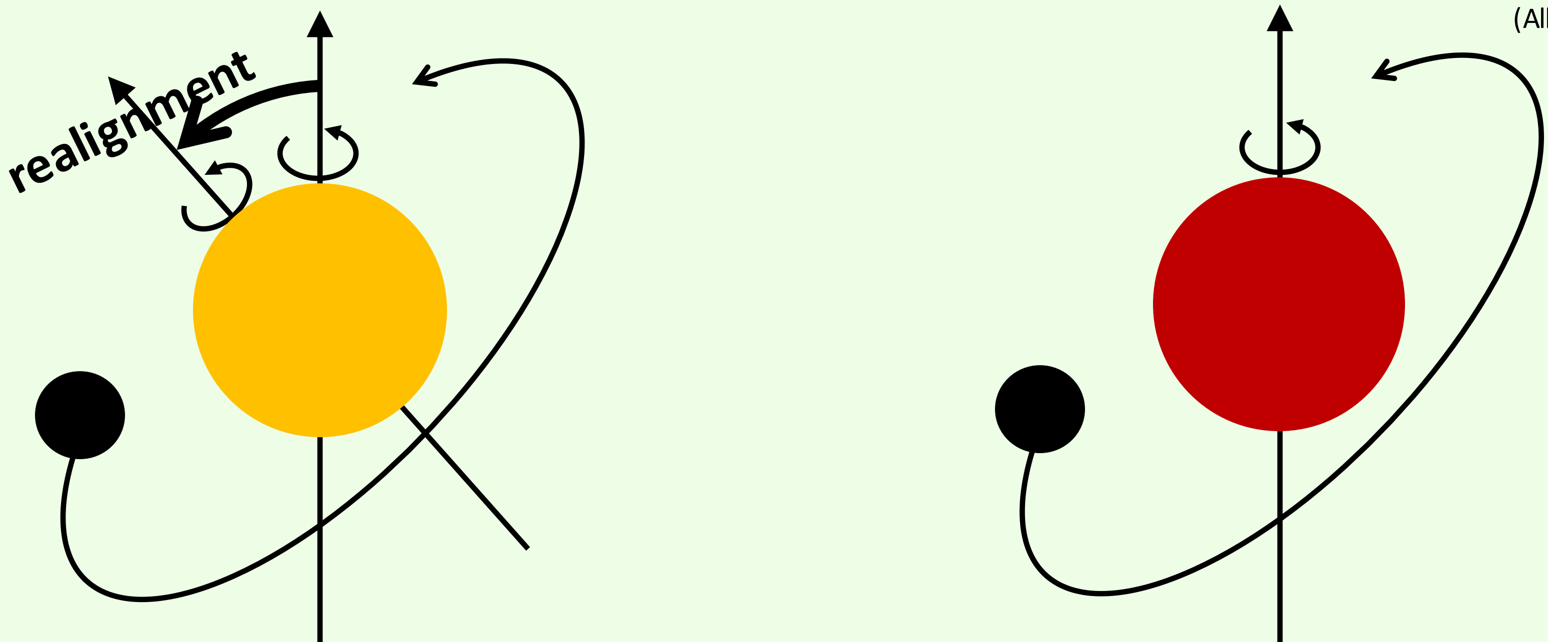
→ Difficult to speculate orbital evolution

System with a hot star (Teff>7000K)

- No convective zones surface
- No effects from tidal torque

→No realignment

(Albrecht et al. 2012)



- **Hot Jupiters around hot stars are favorable to research orbital evolution**
- The number of Hot Jupiters around hot stars is small (~ 20)
- Need to increase the number by confirmation.

TOI1355.01

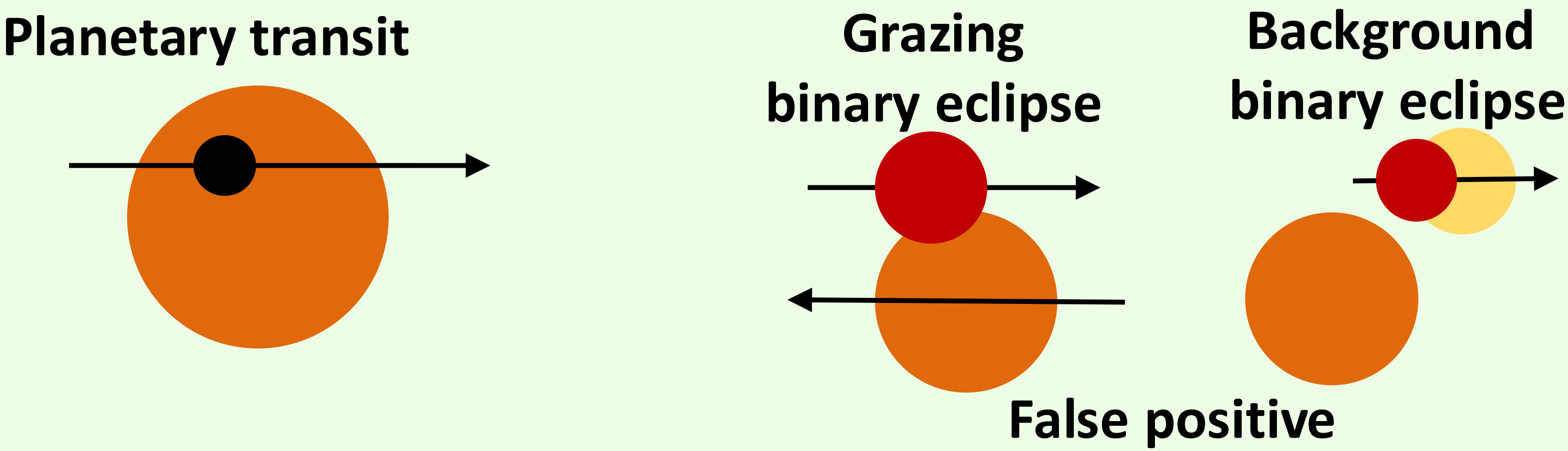
- Hot Jupiter candidate around a rapid-rotating hot A-star.

Stellar parameter		Candidate parameter	
Radius Rs [R_{sun}]	1.853 ± 0.067	Radius Rp [R_{jup}]	1.387 ± 0.051
Mass Ms [M_{sun}]	2.24 ± 0.39	Orbital Period [days]	2.170273 ± 0.000014
Rotational velocity Vsini [km/s]	90.54 ± 1.99	Depth [ppt]	5.613 ± 0.034
Effective temperature [K]	9218 ± 636		
Vmag	8.72 ± 0.03		

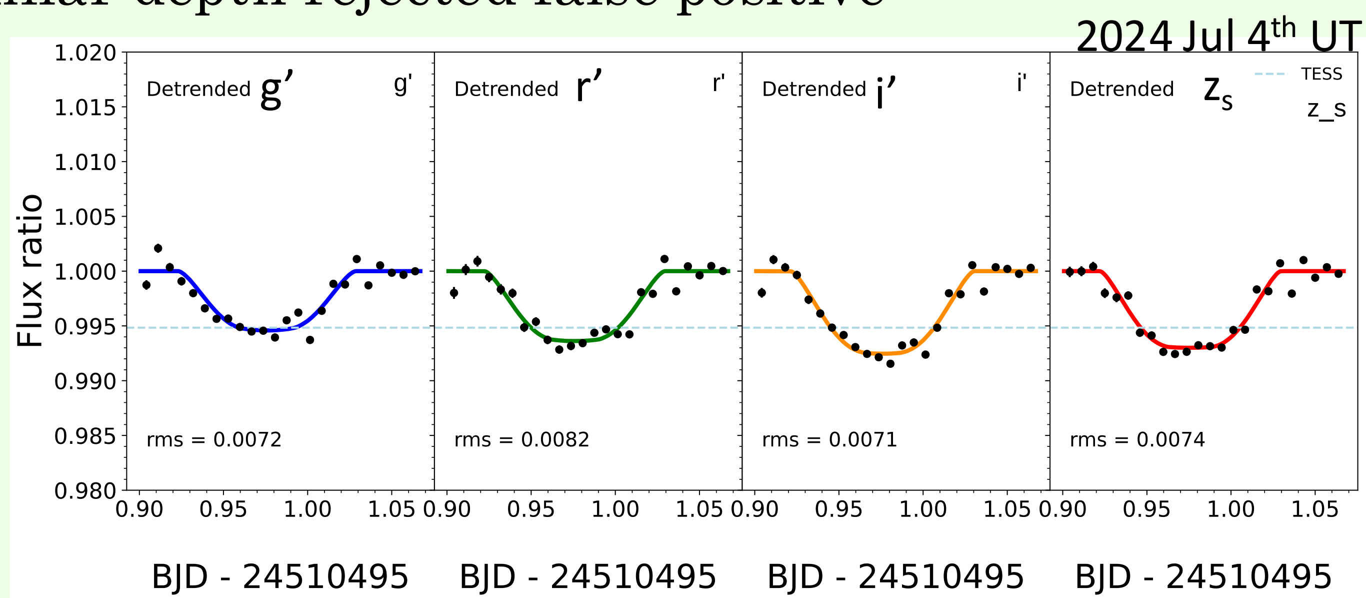
(from ExoFOP)

Validation from MuSCAT3 data

- MuSCAT3 (Simultaneous camera) can distinguish whether the dimming is caused by a planet or a false positive (binary eclipse)

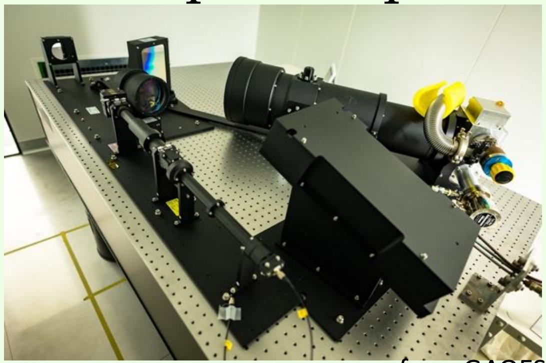


- The similar depth rejected false positive

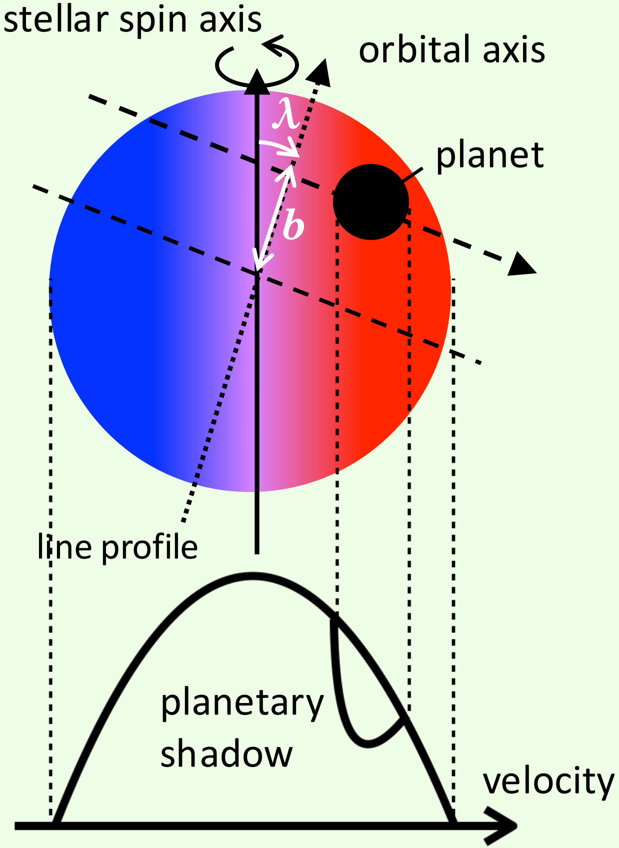


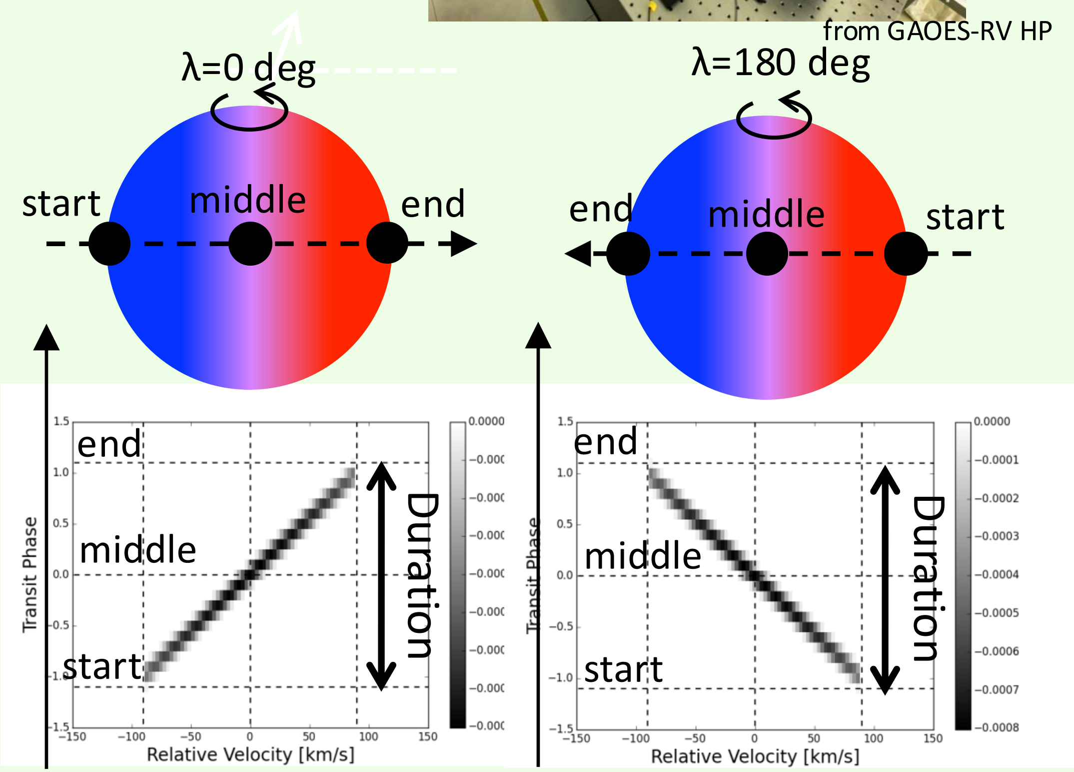
Spectroscopic observation GAOES-RV

- Observed on 27 Jul and 13 Dec in 2023 by GAOES-RV (R~65000)
- 7/27: 1200s*12exp(SNR/pix~90),12/13: 1200s*15exp(SNR/pix ~65)
- Wavelength range: 5170Å~5840Å
- Tried to perform Doppler tomography to measure spin-orbit obliquity (λ)



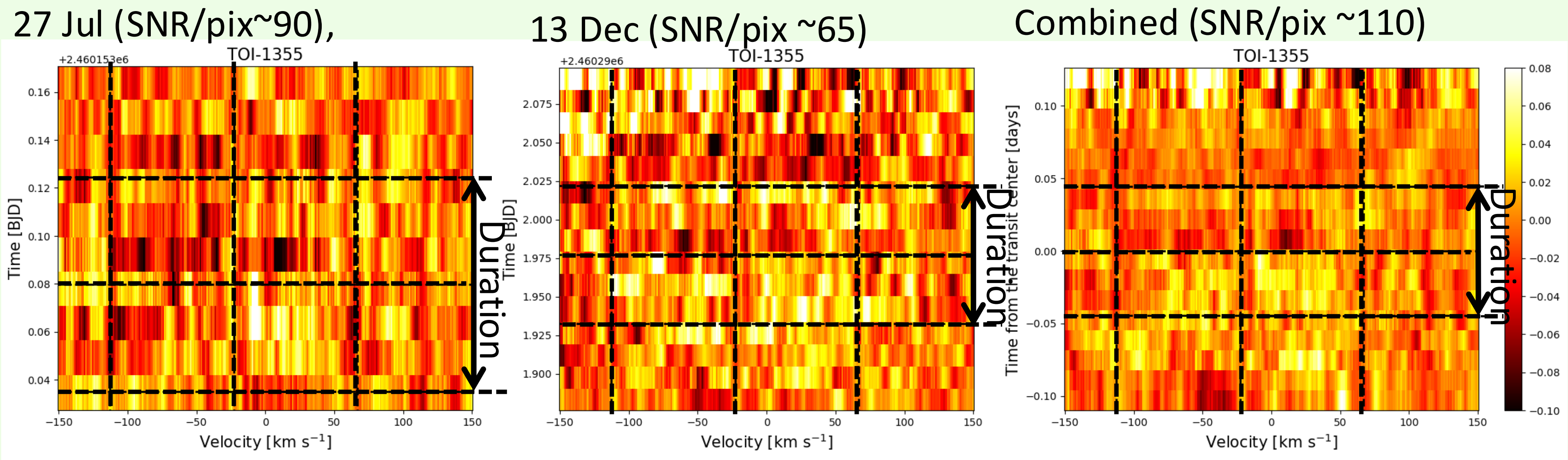
from GAOES-RV HP





Result of Doppler tomography

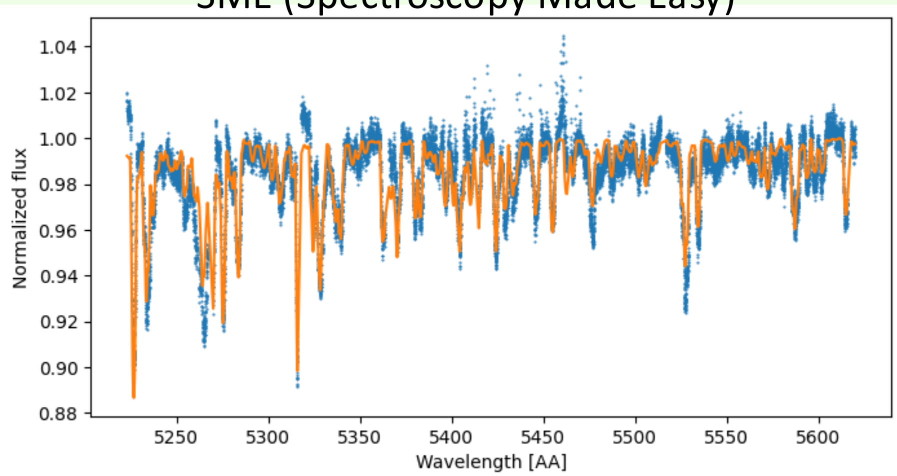
- Failure to detect a planetary shadow



Stellar Parameters from GAOES-RV, etc

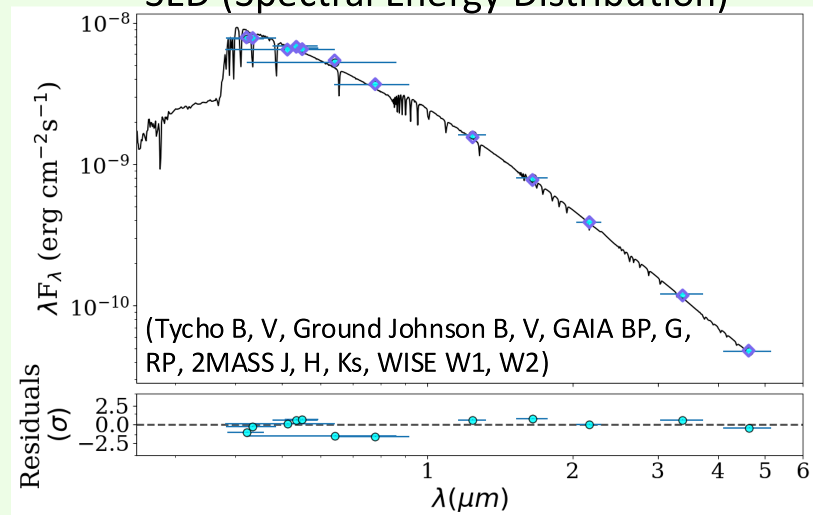
- Derived stellar parameters by SME from GAOES-RV's data and SED from photometric catalog

SME (Spectroscopy Made Easy)



(using PySME (Wehrhahn et al. 2023))

SED (Spectral Energy Distribution)



(using astroARIADNE (Vines et al. 2022))

- The age is younger than the solar system (~ 4.6Gyrs)
- The system is typical age among the hot stars with hot Jupiters (0.1~2 Gyrs). (Albrecht et al. 2022)

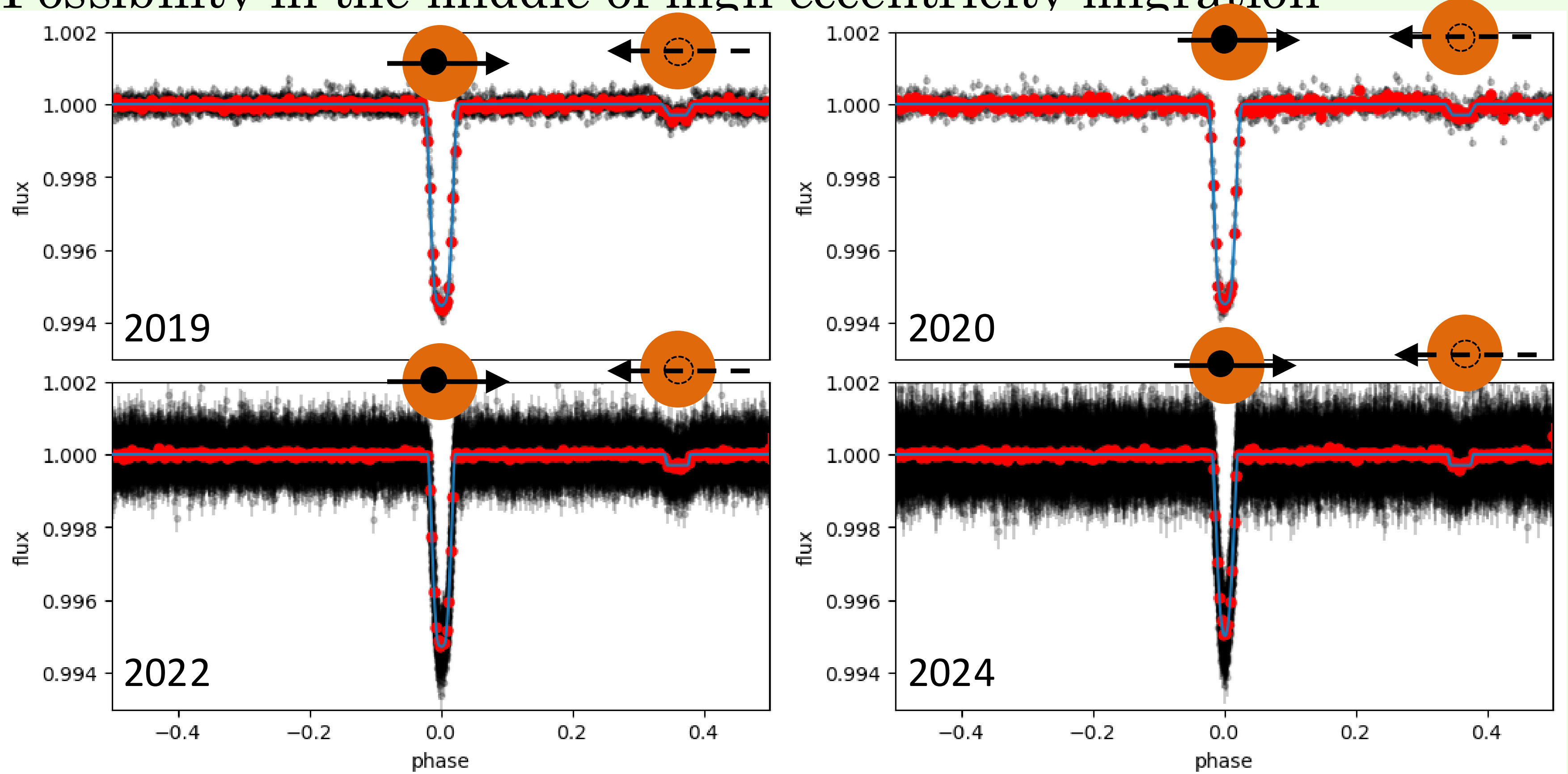
	Effective temperature [K]	Log of surface gravity [cm/s²]	Metallicity [M/H]	Rotational Velocity [km/s]	Age [Gyrs]
This study	8874^{+17}_{-23}	$3.964^{+0.026}_{-0.040}$	-0.023 ± 0.011	78.29 ± 0.22	$0.412^{+0.076}_{-0.083}$
TESS TIC	9218 ± 636	4.271 ± 0.086	-	90.54 ± 1.99	-

Photometric Observation of TESS

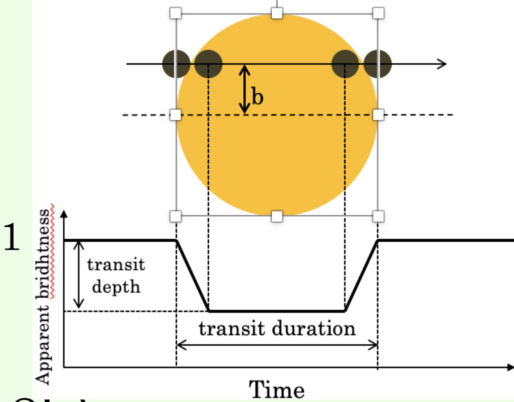
- Used TESS data from 2019, 20, 22, 24 and Analyzed with MCMC
  (Sep-Nov) (Apr) (Oct-Nov) (Mar-May) (PyTransit (Hannu et al. 2015)))
- The secondary epoch is not at phase ~0.5 → not circular orbit
- **The first discovery of an eccentric hot Jupiter around a hot star**

  (e=0.326±0.012、ω=231.1 [+1.8, -2.1] deg)

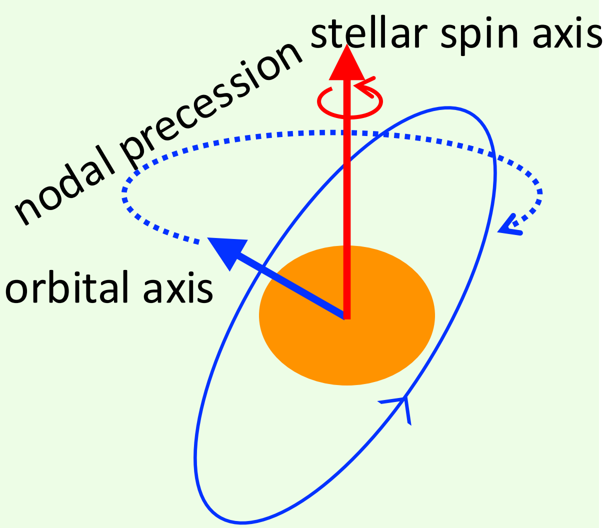
- Possibility in the middle of high eccentricity migration

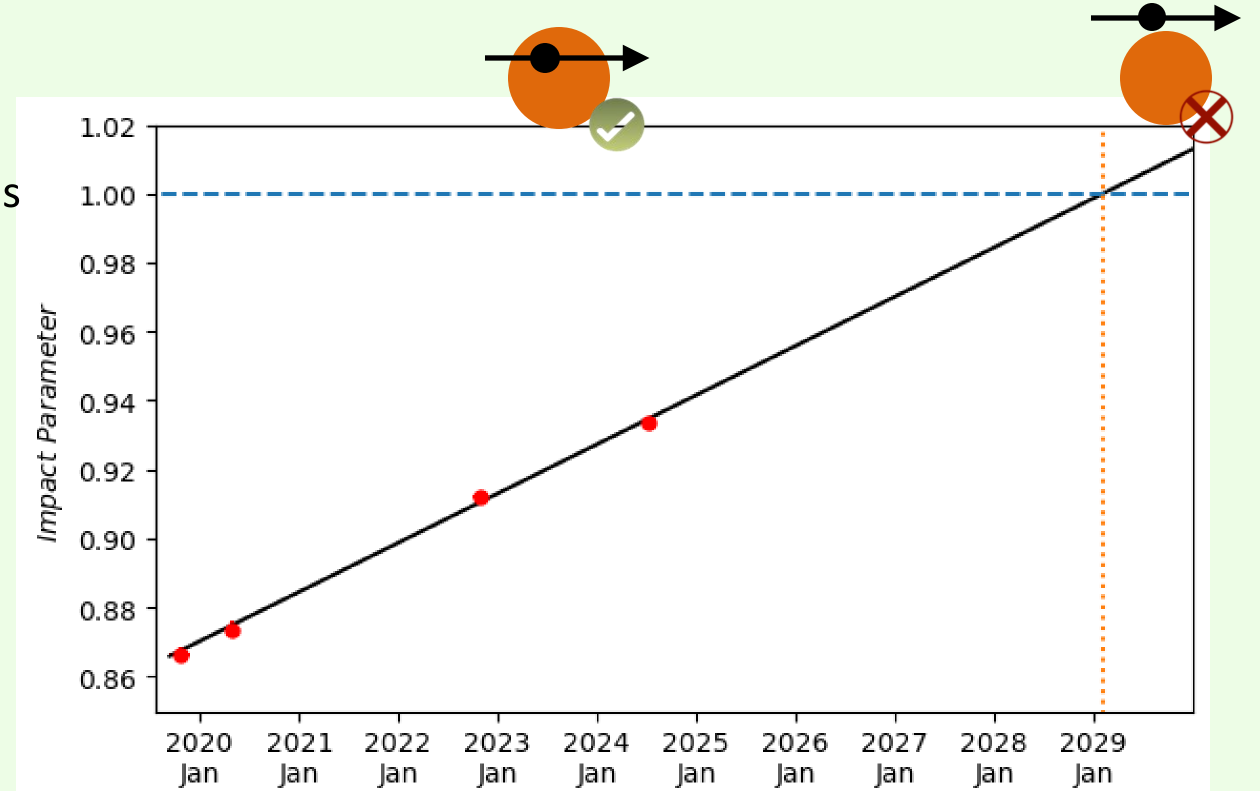


Nodal Precession of TOI1355.01



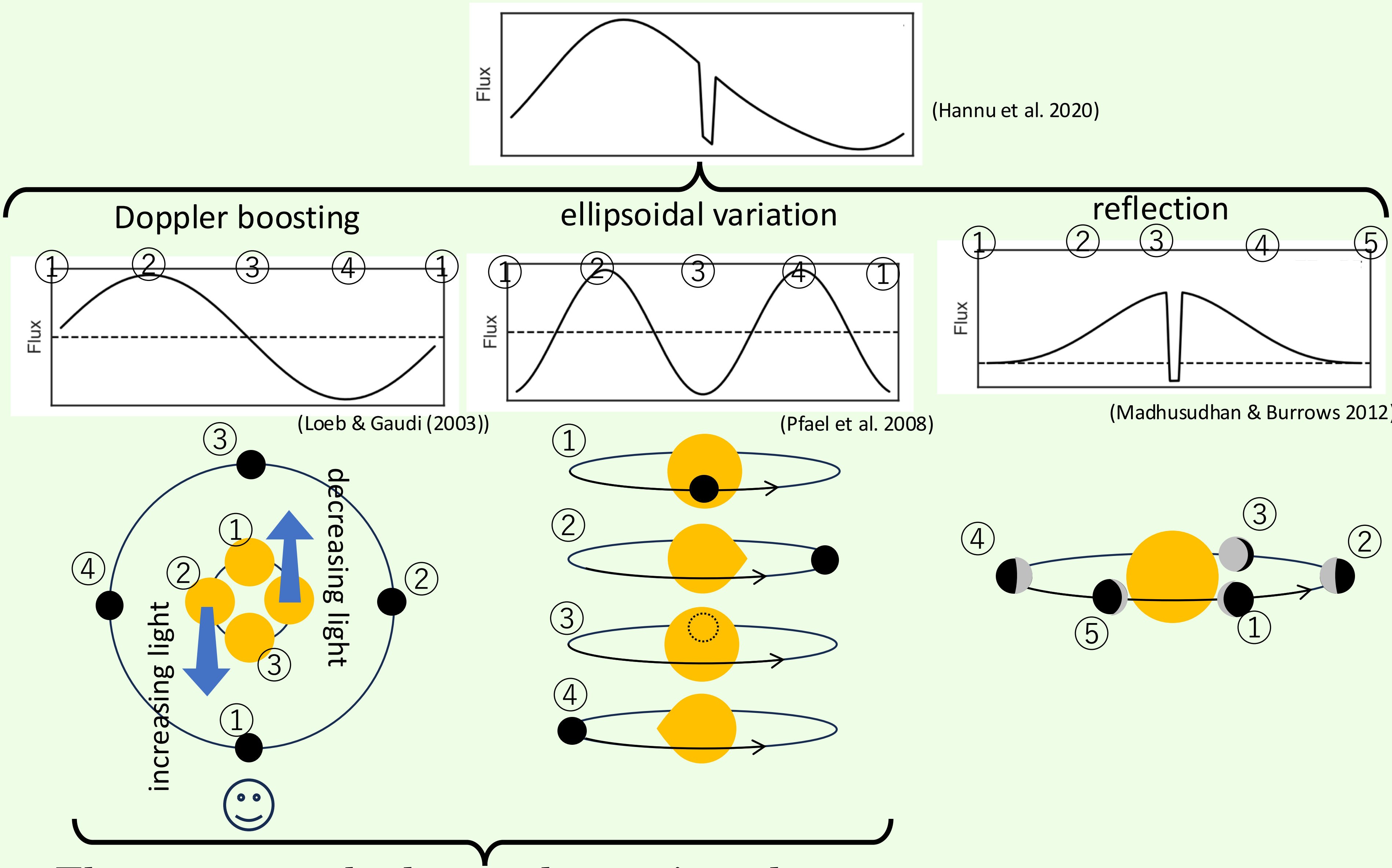
- Detected nodal precession from the change in impact parameter: $db/dt = 0.01426 \pm 0.00050\ yr^{-1}$
- Possibility of near-polar orbit (e.g. Kepler-13Ab, WASP-33b, KELT-9b, TOI-1518b)
  (Masuda 2015) (Watanabe et al. 2022) (Stephan et al. 2022) (Watanabe et al. 2024)
  - Supporting high eccentricity migration
- We cannot observe its transit from the beginning of 2029





Phase Curve Analysis of TESS

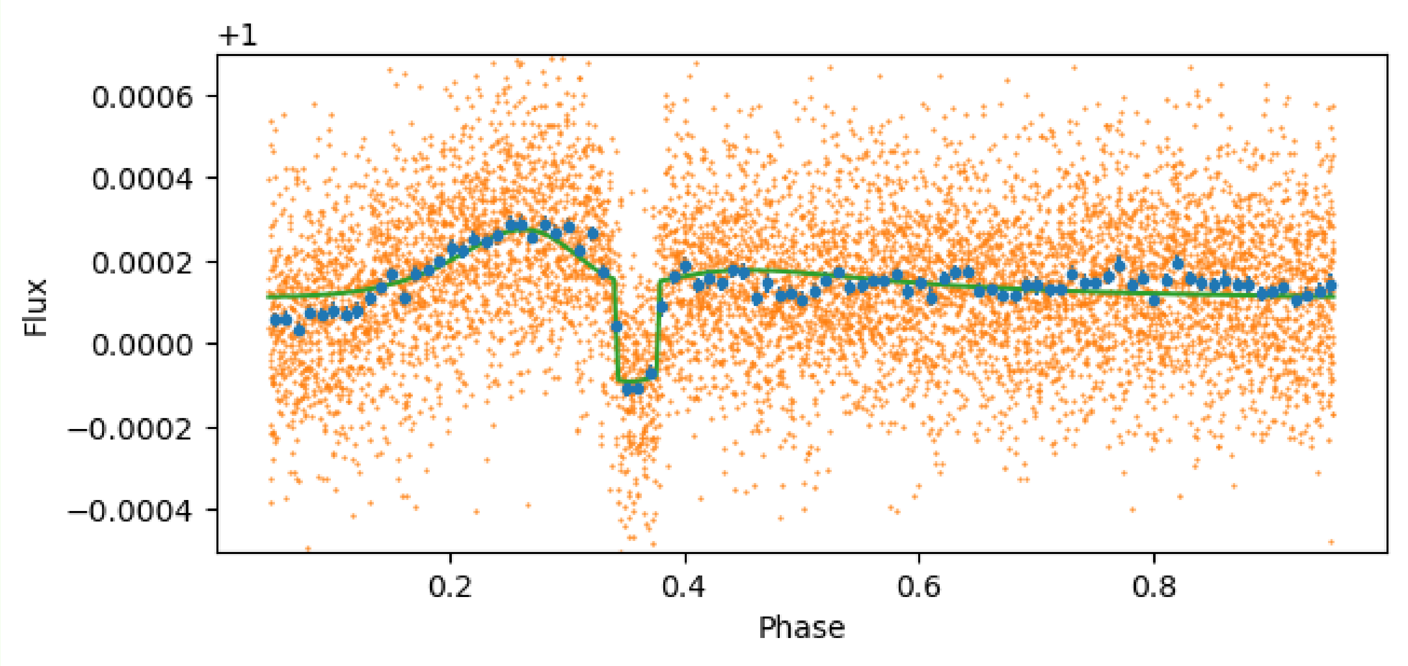
phase curve without primary transit



- These two methods can determine planetary mass

Phase Curve Analysis of TESS

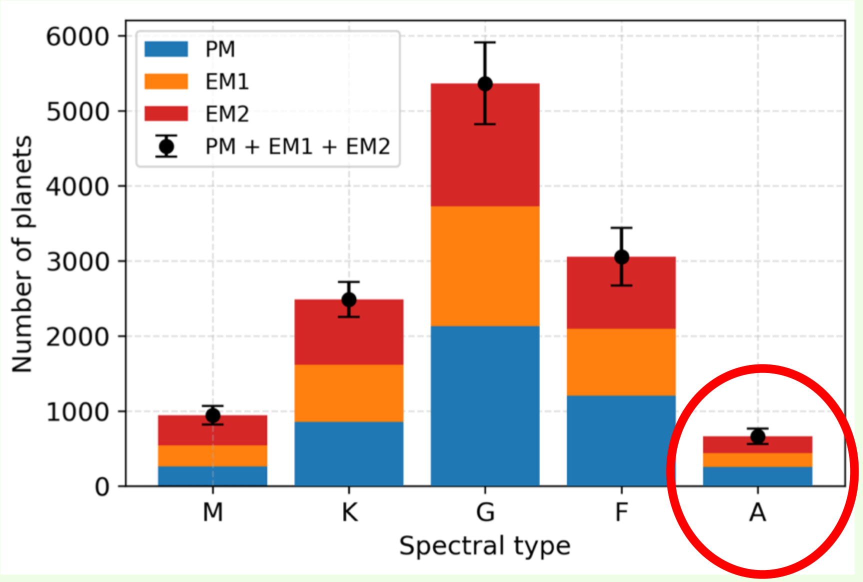
- Measured the mass of TOI1355.01 from the TESS's phase curve of out-of-transit
- Mp=13.4 ± 2.0M_{Jup}
  - **<u>Confirmed a massive eccentric hot Jupiter (or low-mass brown dwarf) around a hot Jupiter</u>**



Future Plans

- Measure the spin-orbit obliquity of TOI1355.01 by Doppler tomography
  - To check whether this planet is misaligned or not

- Confirm other hot Jupiter candidates around hot stars from the TESS survey by spectrograph (including GAOES-RV) and MuSCAT series



(Kunimoto et al. 2022)

Summary

- Hot Jupiters around hot stars are suitable to investigate orbital evolution
- Confirmed a hot Jupiter around a hot star TOI1355
    - The system is younger than the solar system but typical age among hot stars with hot Jupiters
    - This is the **first discovery of eccentric hot Jupiter around hot Jupiter**
    - Detected nodal precession, which supports high eccentricity migration
    - **We cannot observe its transit since the beginning of 2029**
    - The mass is ~13.4MJup, **confirmed a massive hot Jupiter** (or brown dwarf)
- We will measure the spin-orbit obliquity of TOI1355.01 by Doppler tomography
- We will confirm other hot Jupiter candidates around hot stars