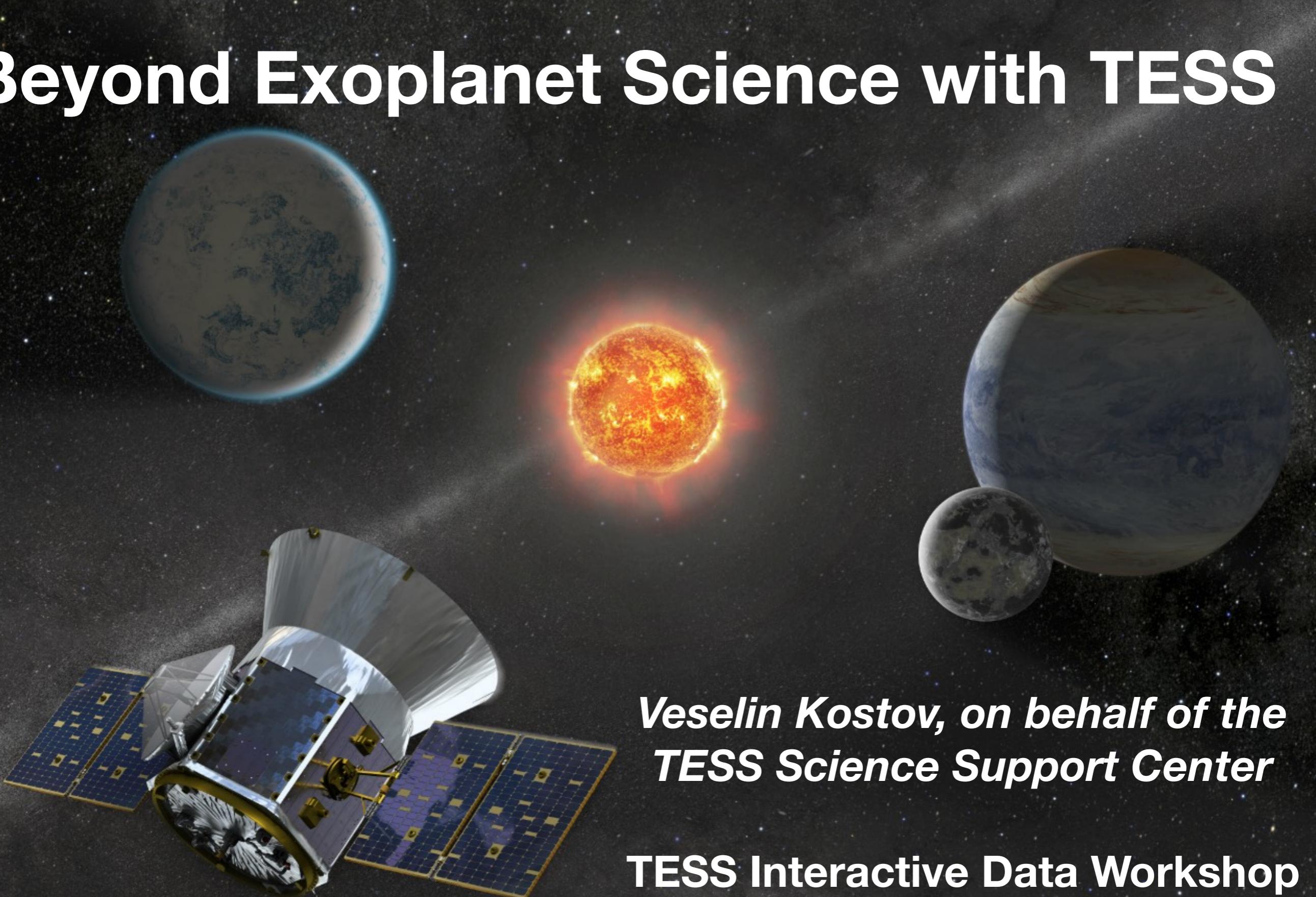


Beyond Exoplanet Science with TESS



*Veselin Kostov, on behalf of the
TESS Science Support Center*

TESS Interactive Data Workshop
AAS 245, Maryland

Beyond Exoplanet Science with TESS

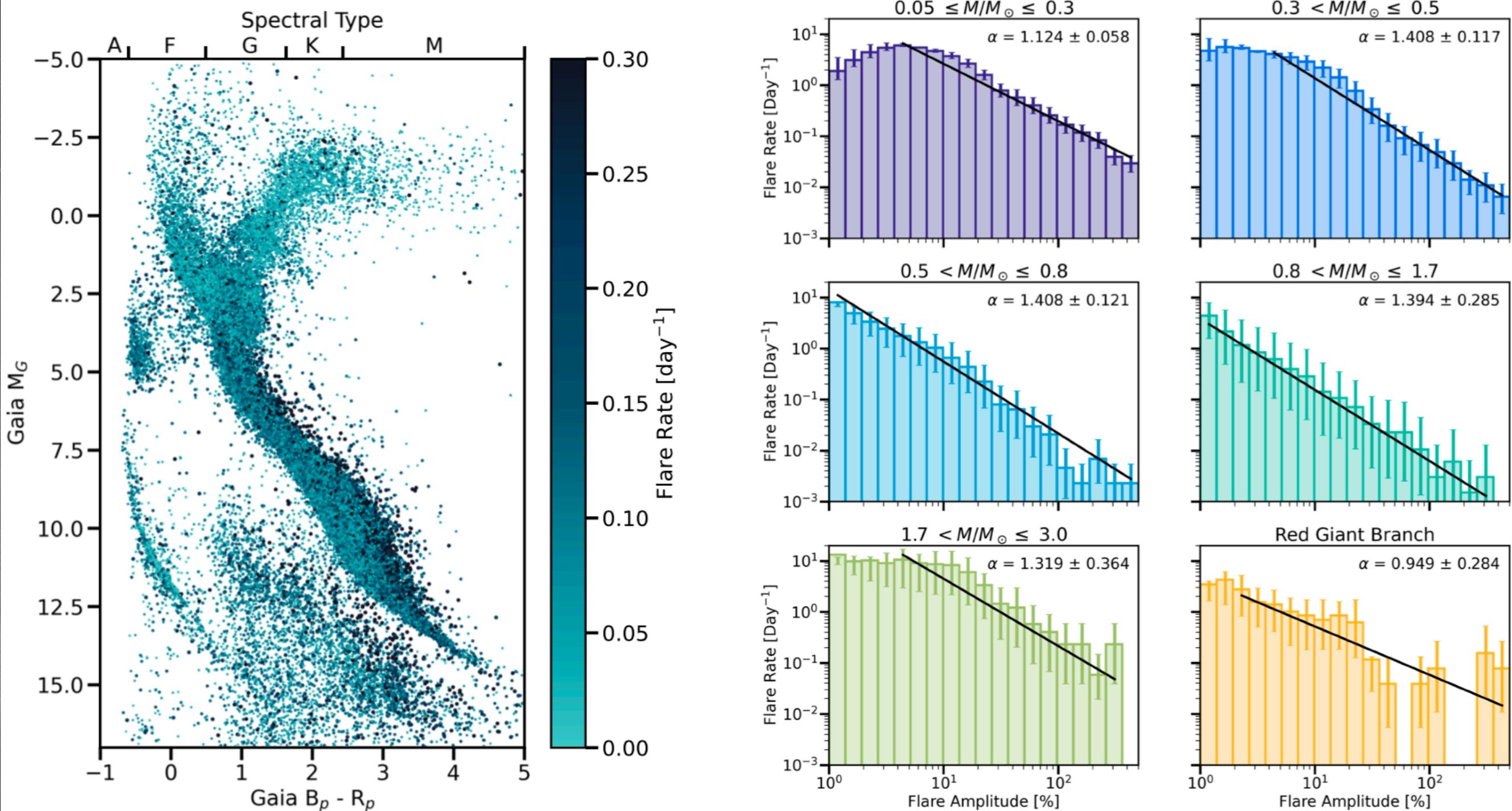
- Stars and Stellar Astrophysics
- Solar System
- Galaxies and Galactic Astrophysics

Stars and Stellar Astrophysics

- *High-cadence observations ideally-suited for detailed asteroseismology studies and analysis of stellar flares*
- *Long-duration observations critical for studying mechanisms responsible for intrinsic stellar variability due to e.g. stellar rotation or episodic/quasiperiodic dimming in young stellar objects*
- *Key contributions in the realms of*
 - *eclipsing binary stars*
 - *multiple stellar systems (eclipsing and non-eclipsing)*
 - *pulsar timing*
 - *cataclysmic variables*
 - *Cepheids*
 - *RR Lyrae*
 - *White dwarfs, Neutron Stars, Black Holes*
 - *Supernovae, GRBs*

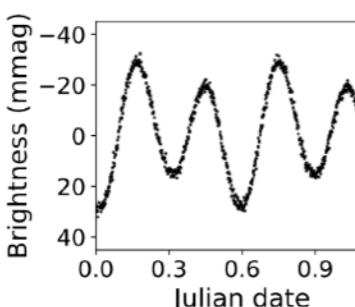
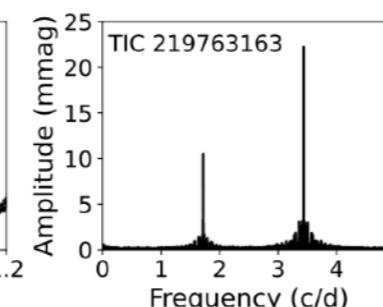
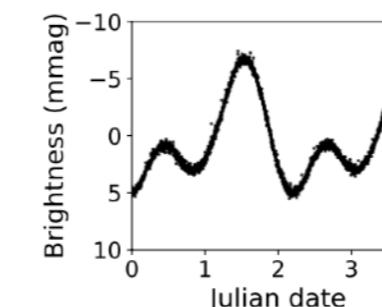
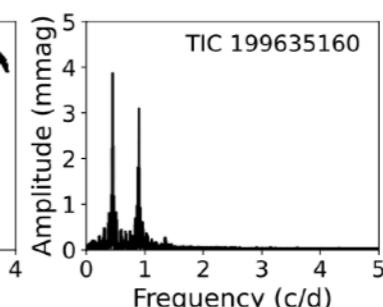
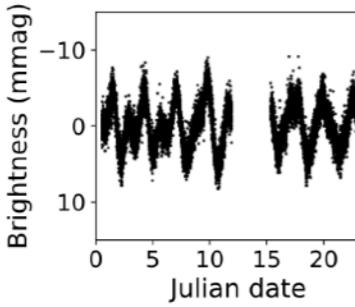
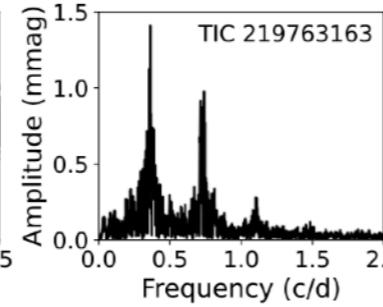
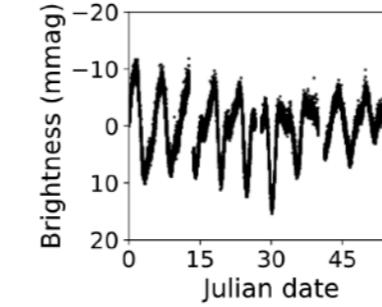
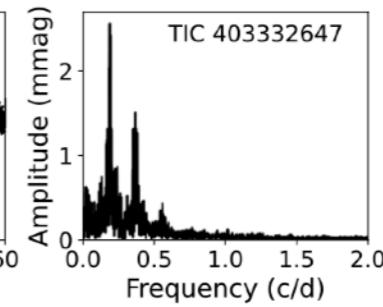
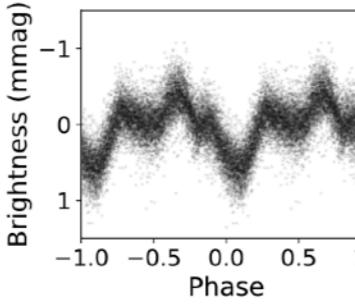
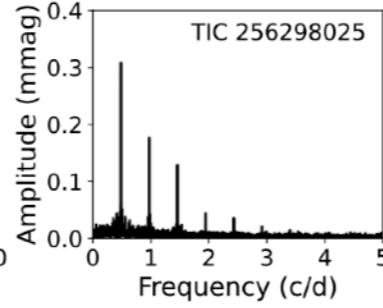
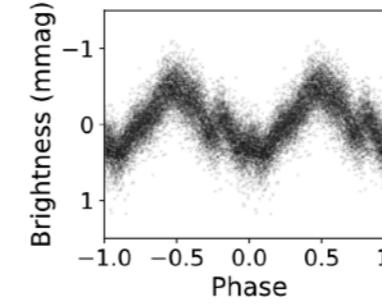
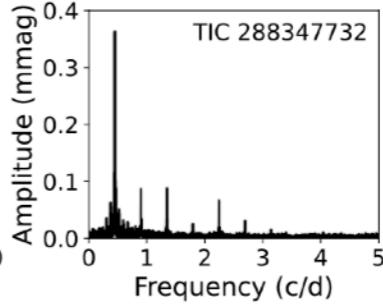
Stars and Stellar Astrophysics

Stellar Flares: 10^6+ flares from 10^5+ stars (e.g. Feinstein et al. 2022; Balint et al. 2024)



Stars and Stellar Astrophysics

Stellar Variability: tens of thousands of variable stars (e.g. Claytor et al. 2022; Skarka et al. 2022; Fetherolf et al. 2023; Colman et al. 2024)

| Type | Light curve | Frequency spectrum | Physical origin |
|------|---|--|---|
| ROTM | strictly repeating pattern, smooth variation without sharp features, maxima and minima generally different, superposition of two waves   | one or two dominant peaks that are harmonics of the basic rotational frequency ($f_2 = 2f_1$), low-amplitude harmonics of f_1 may be present   | rotation of a star with abundance anomaly spots |
| ROTS | semi-regular variations superimposed on a basic periodic pattern   | groups of (unresolved) peaks at positions close to harmonics of the strongest peak   | rotation of a star with migrating (and forming or disappearing) spots, activity similar to our Sun, possible instrumental or data reduction artefacts |
| ROT | repeating stable features   | harmonics of the strongest frequency   | likely some phenomena related to the rotation of the star |

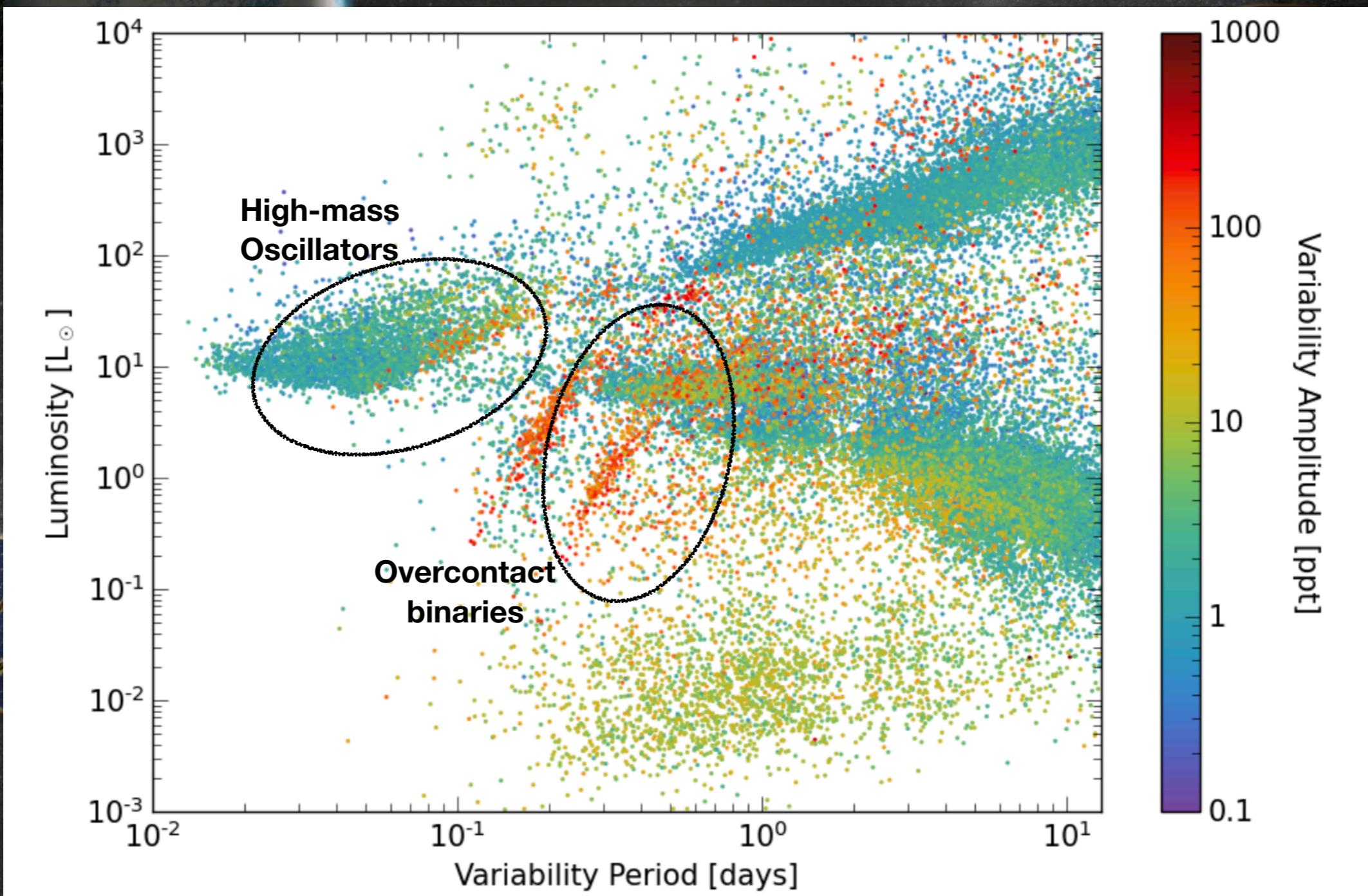
Magnetic Rotators

Solar-type Rotators

Regular FT harmonics

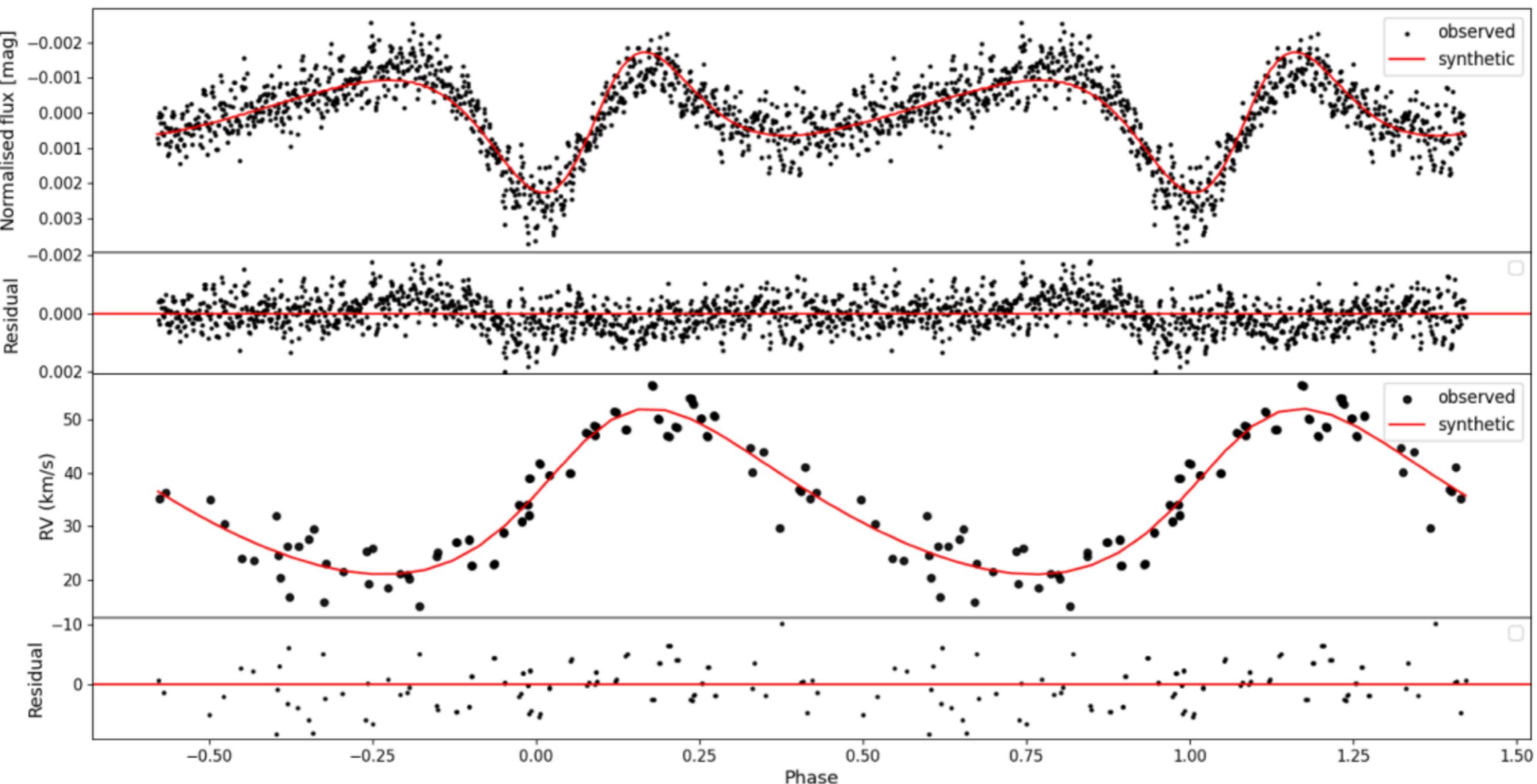
Stars and Stellar Astrophysics

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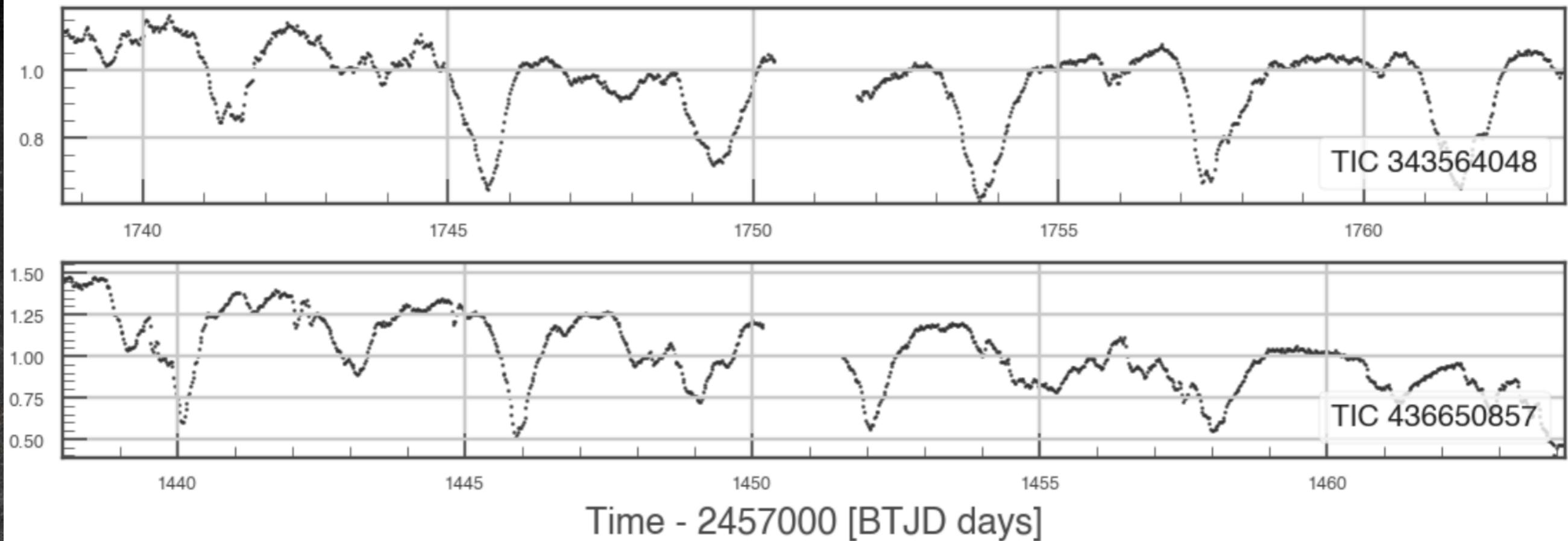
Stars and Stellar Astrophysics

Stellar Variability: blue stragglers in M67 (Vernekar et al. 2023)



Stars and Stellar Astrophysics

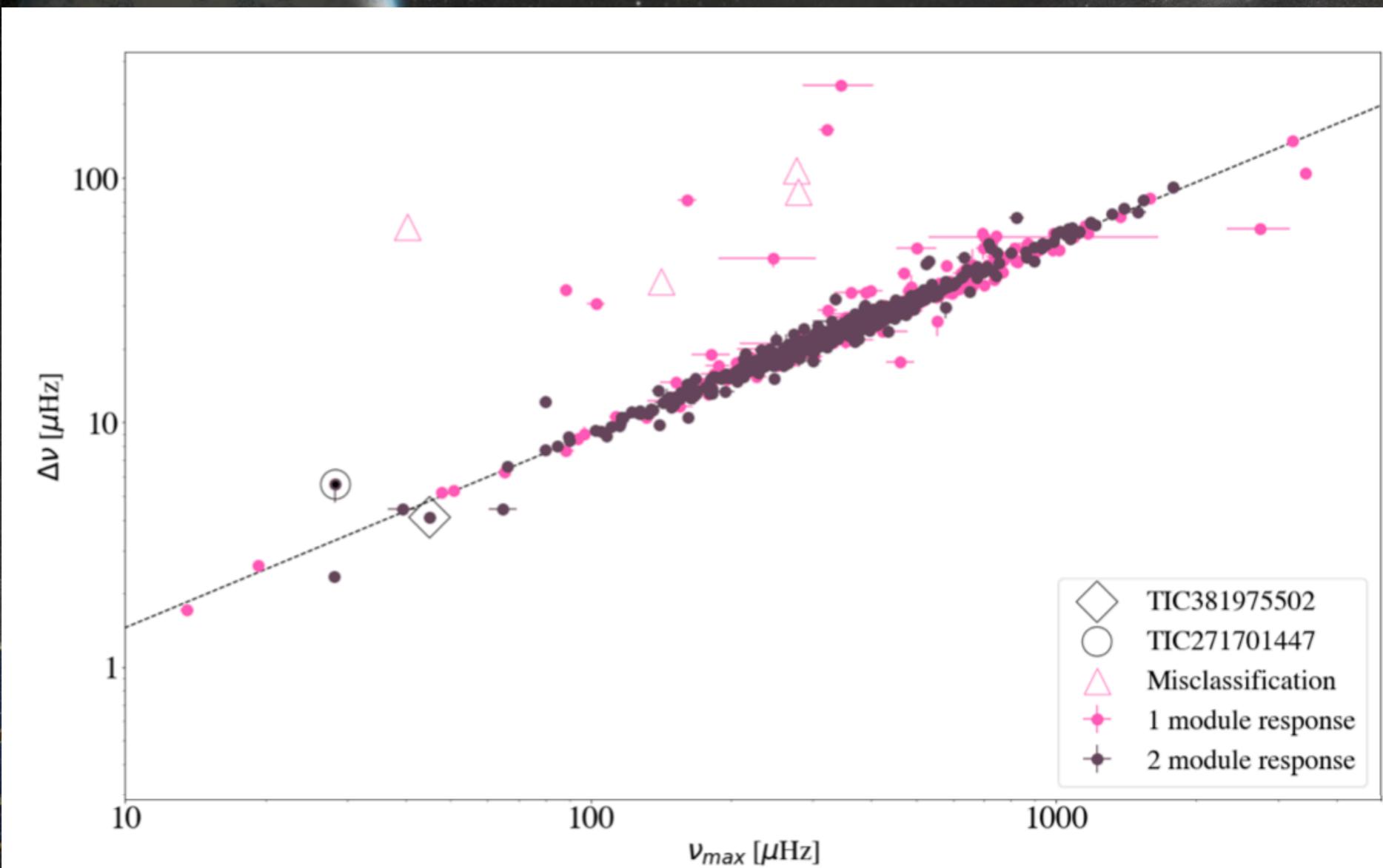
Stellar Variability: Hundreds of new dipper stars (e.g. Capistrant et al. 2022)



Flux asymmetry suggesting dust occultations from a nearly edge-on disk

Stars and Stellar Astrophysics

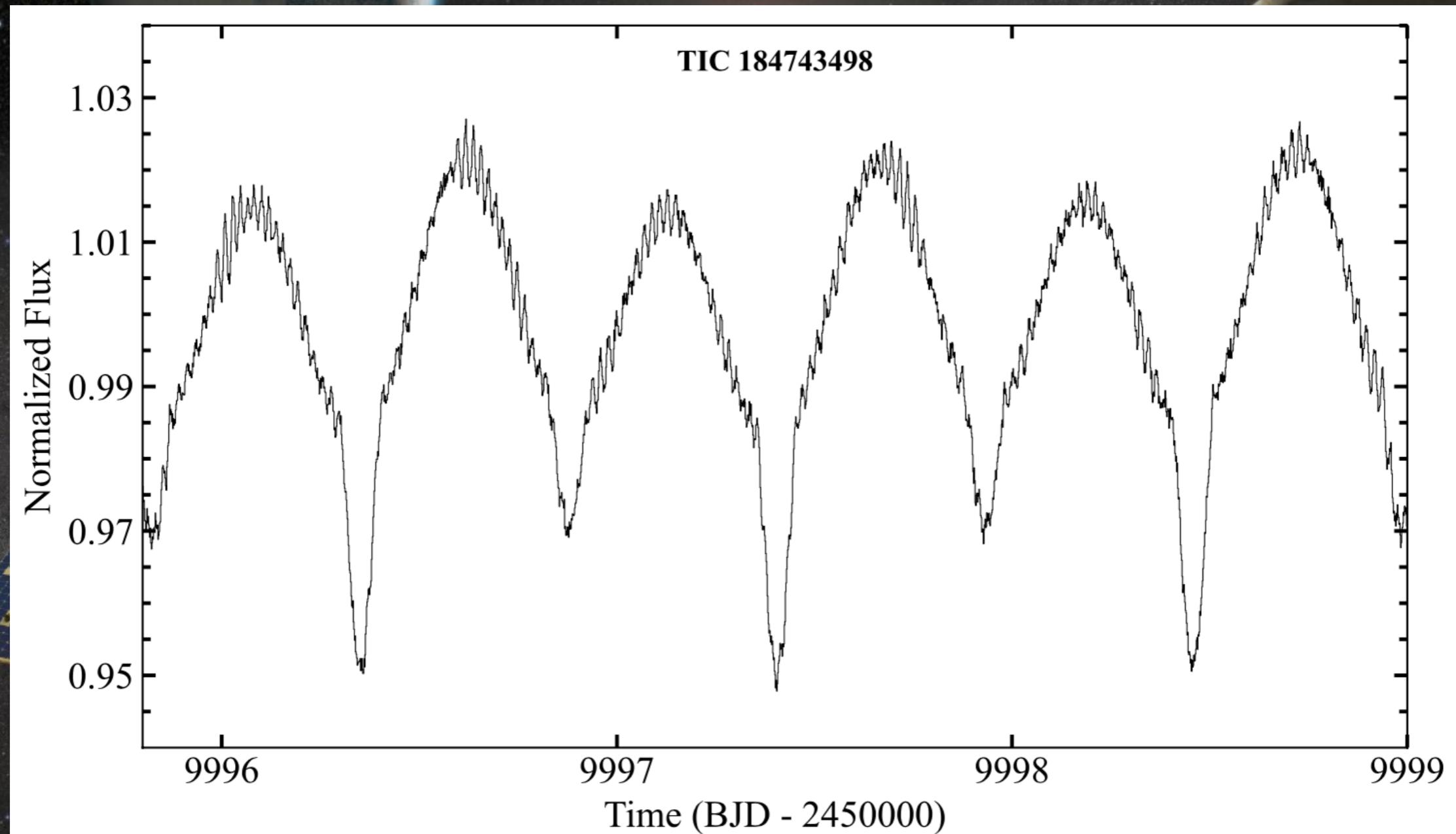
Stellar Variability: Asteroseismology for thousand of Solar-like oscillators
(Hatt et al. 2022; Durfeldt-Pedros et al. 2024)



large frequency separation ($\Delta\nu$) vs frequency at maximum power (ν_{max})

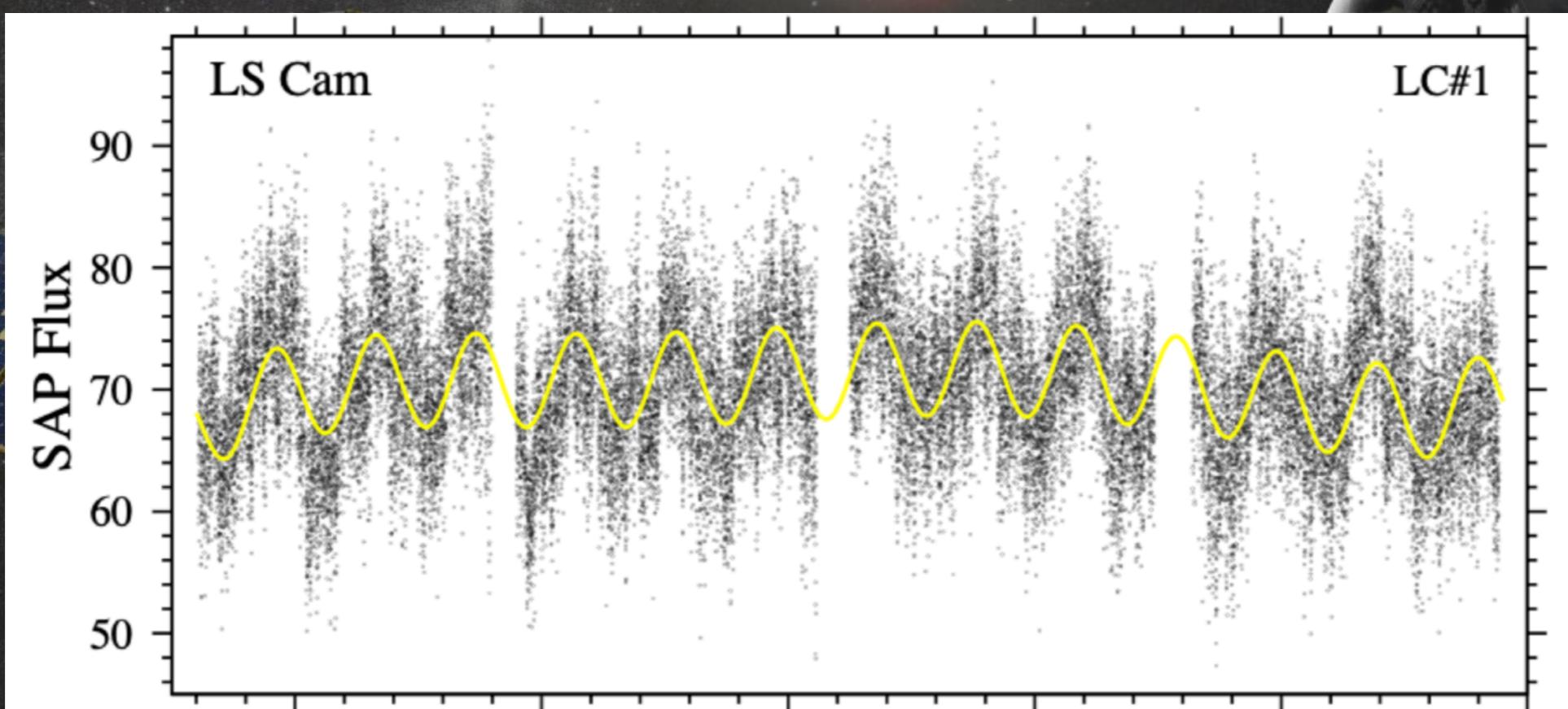
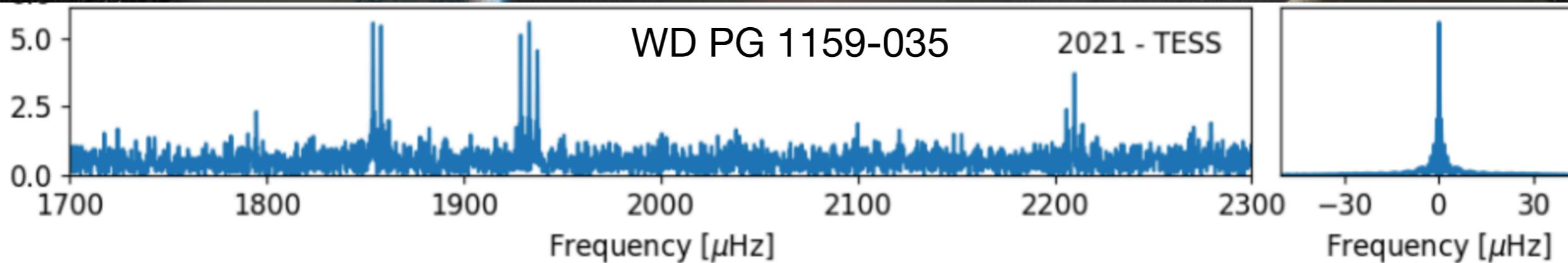
Stars and Stellar Astrophysics

Stellar Variability: TIC 184743498: The First Tri-Axial Stellar Pulsator
(Zhang et al. 2024)



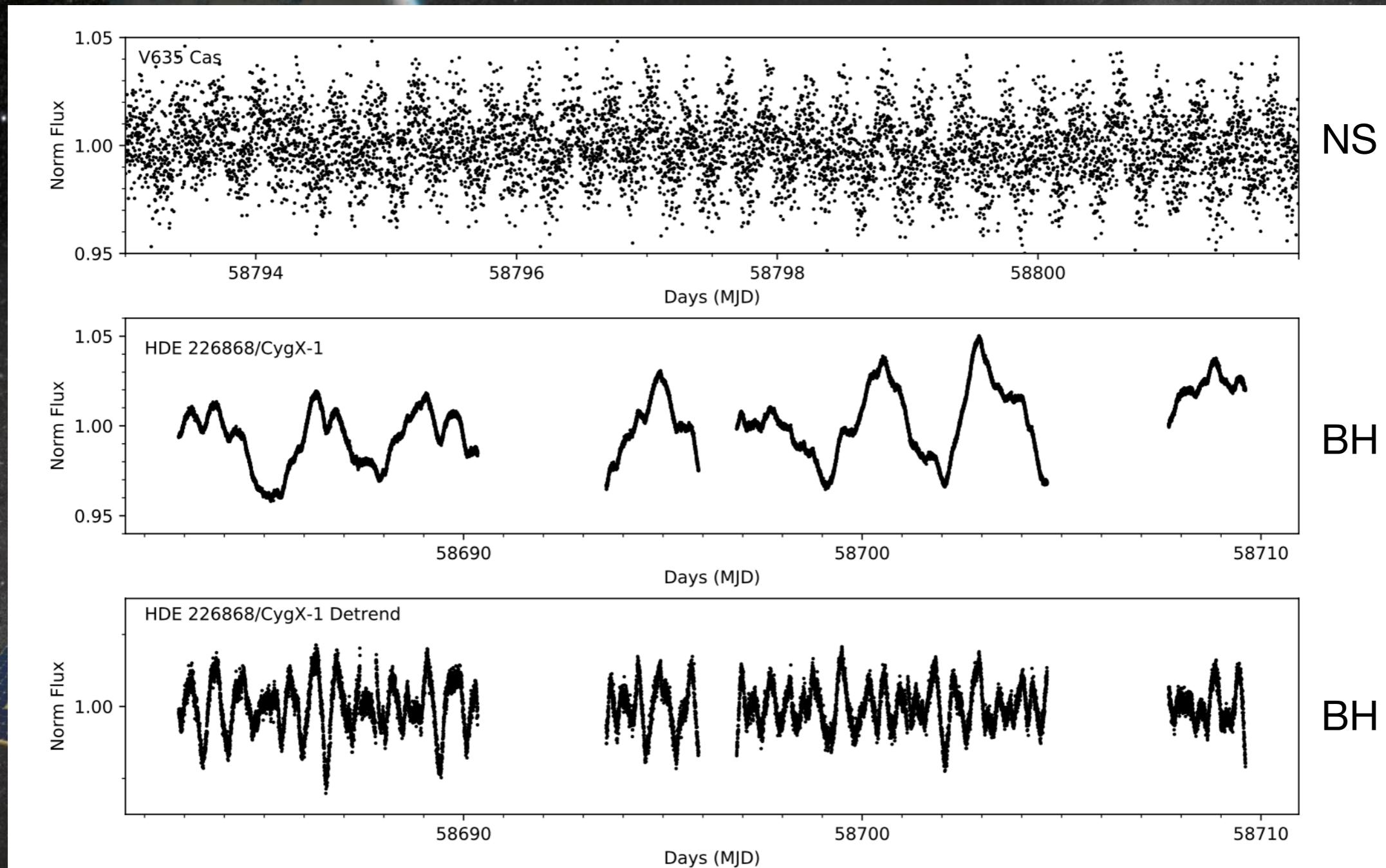
Stars and Stellar Astrophysics

Stellar Variability: Pulsating WD with hundreds of frequencies (top, PG 1159-035, Oliveira da Rosa et al., 2022); Cataclysmic Variables (bottom Bruch 2023)



Stars and Stellar Astrophysics

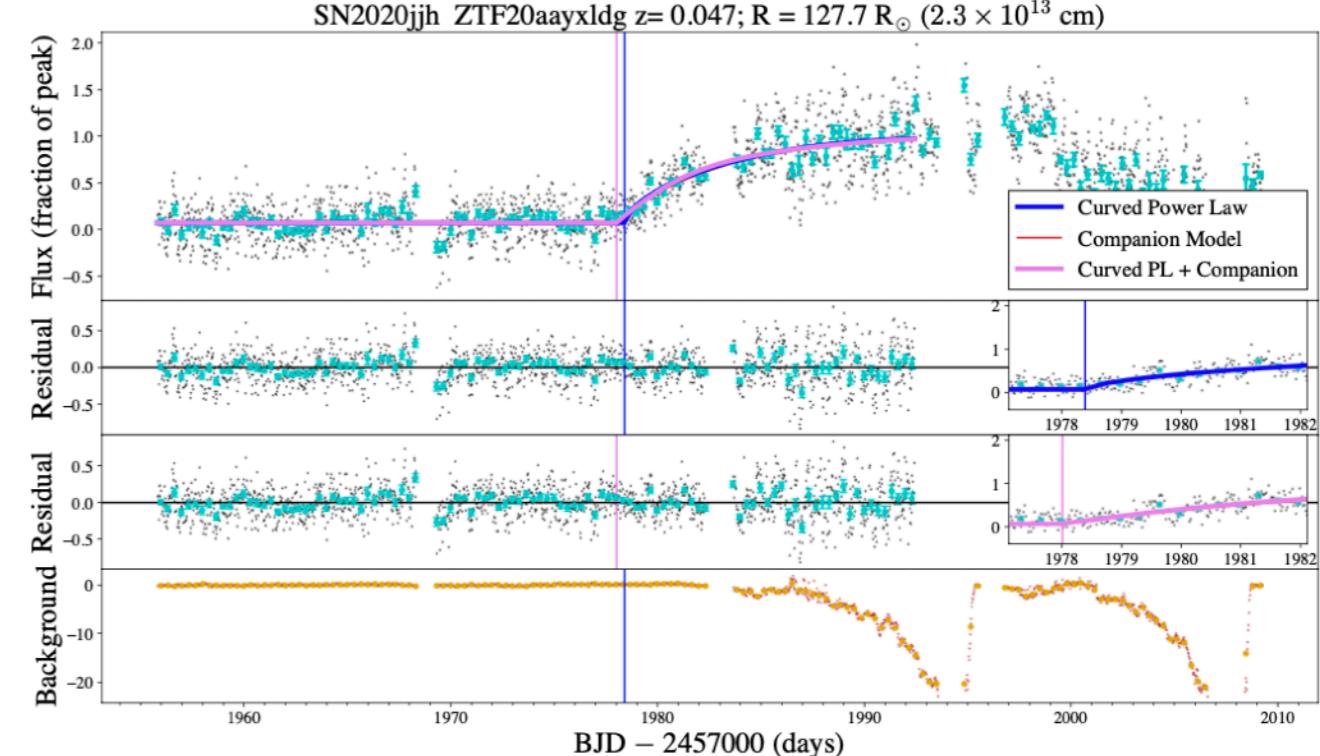
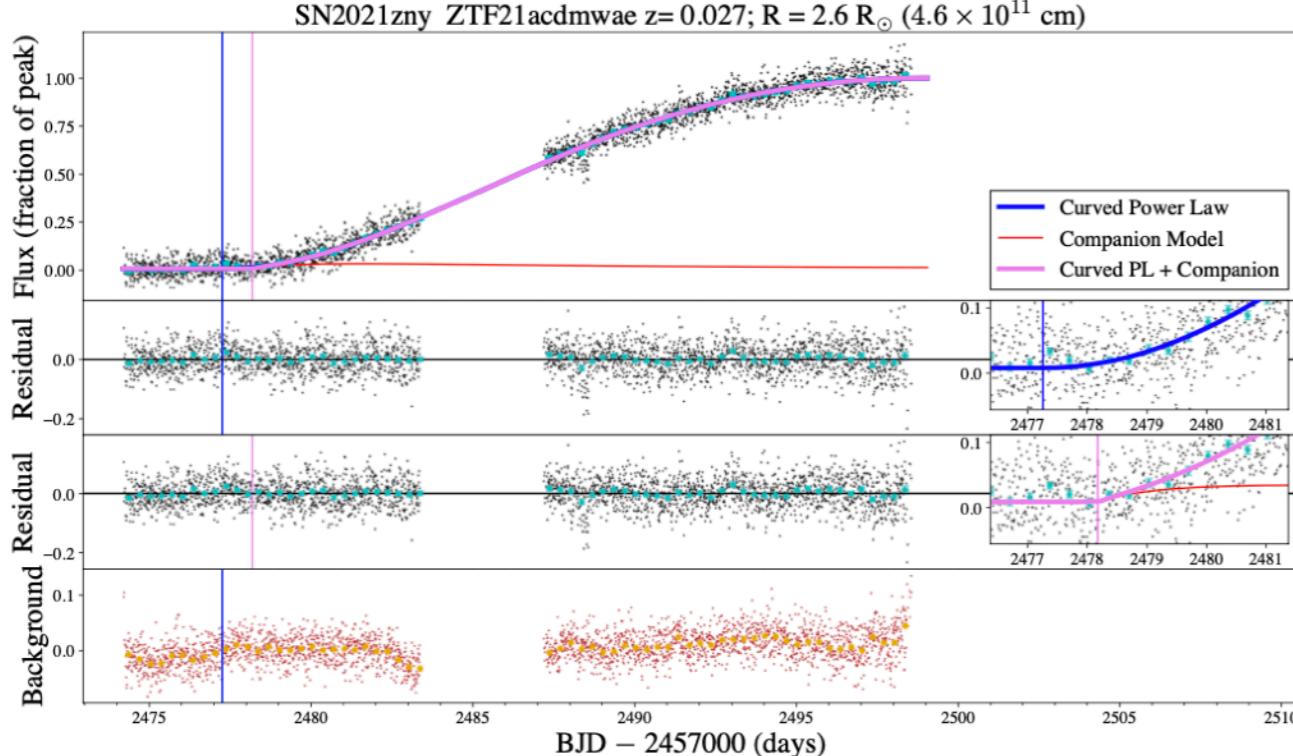
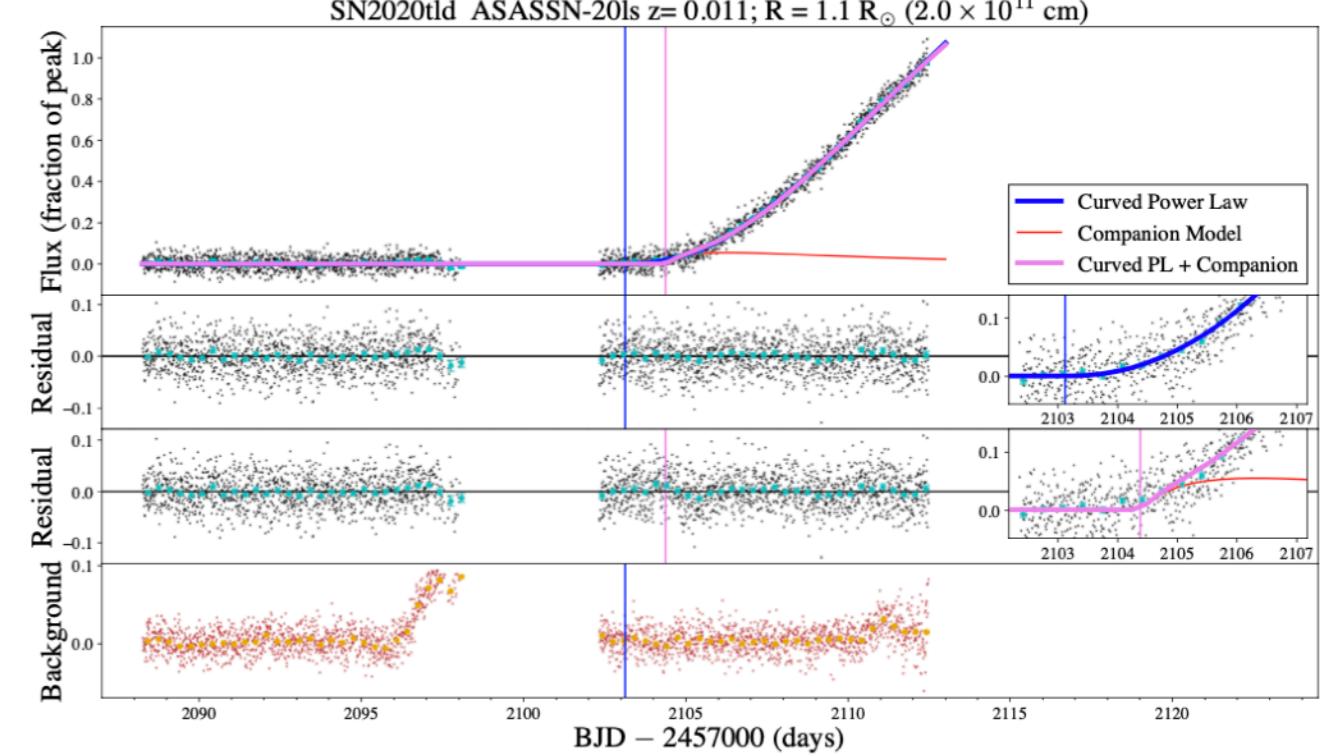
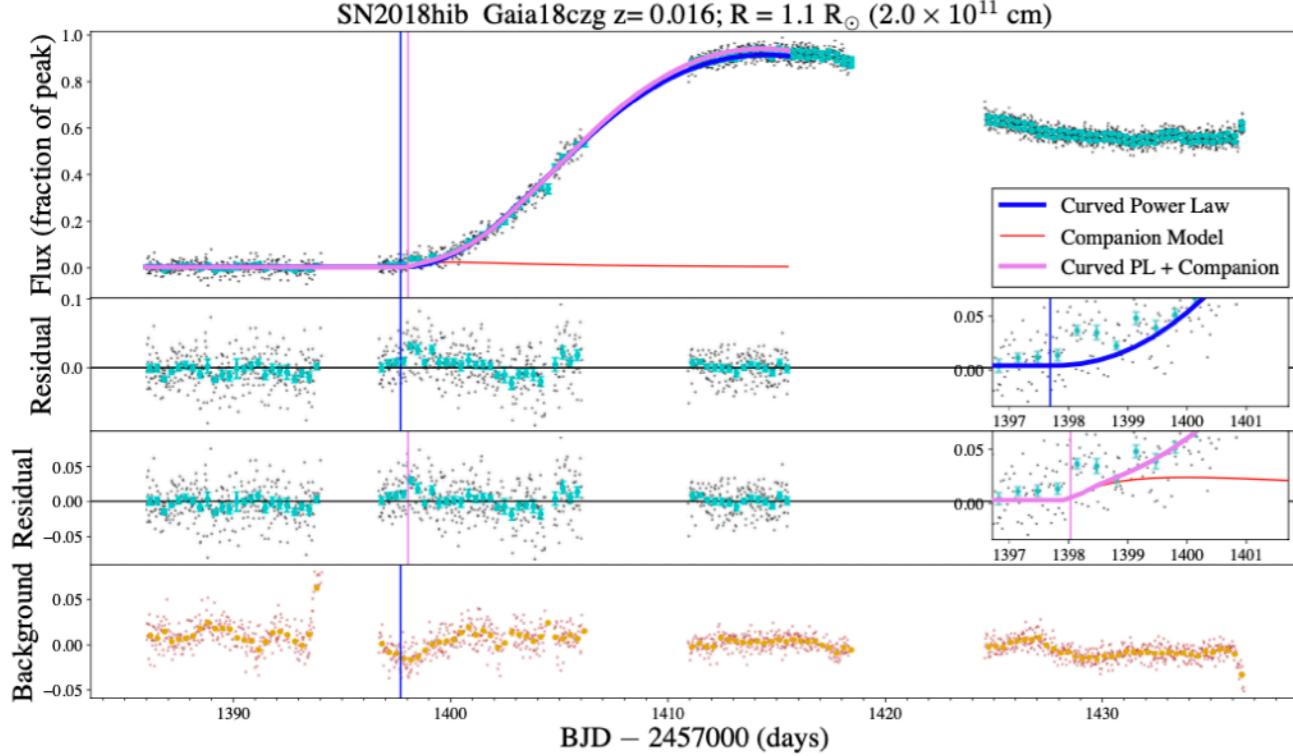
Neutron Stars and Black Holes: Ground-based ~0.5-day variability in High-Mass X-ray Binaries confirmed by TESS (e.g. Ramsay et al. 2022)



Evidence for potential outbursts for some systems (synchronizes with X-ray flares)

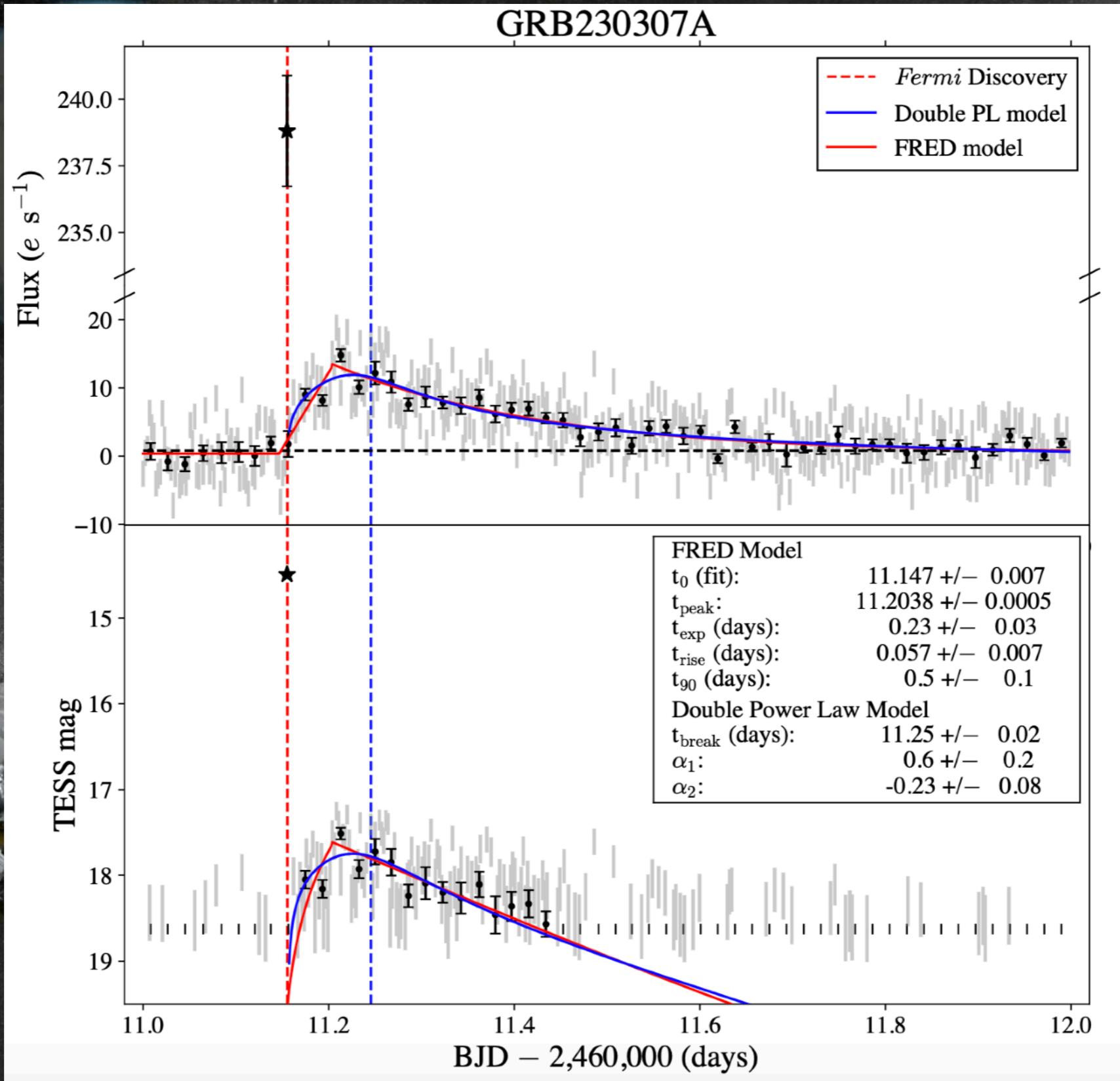
Stars and Stellar Astrophysics

Supernovae: Lightcurves for hundreds of Type Ia SNe (e.g. Fausnaugh et al. 2021, 2023)



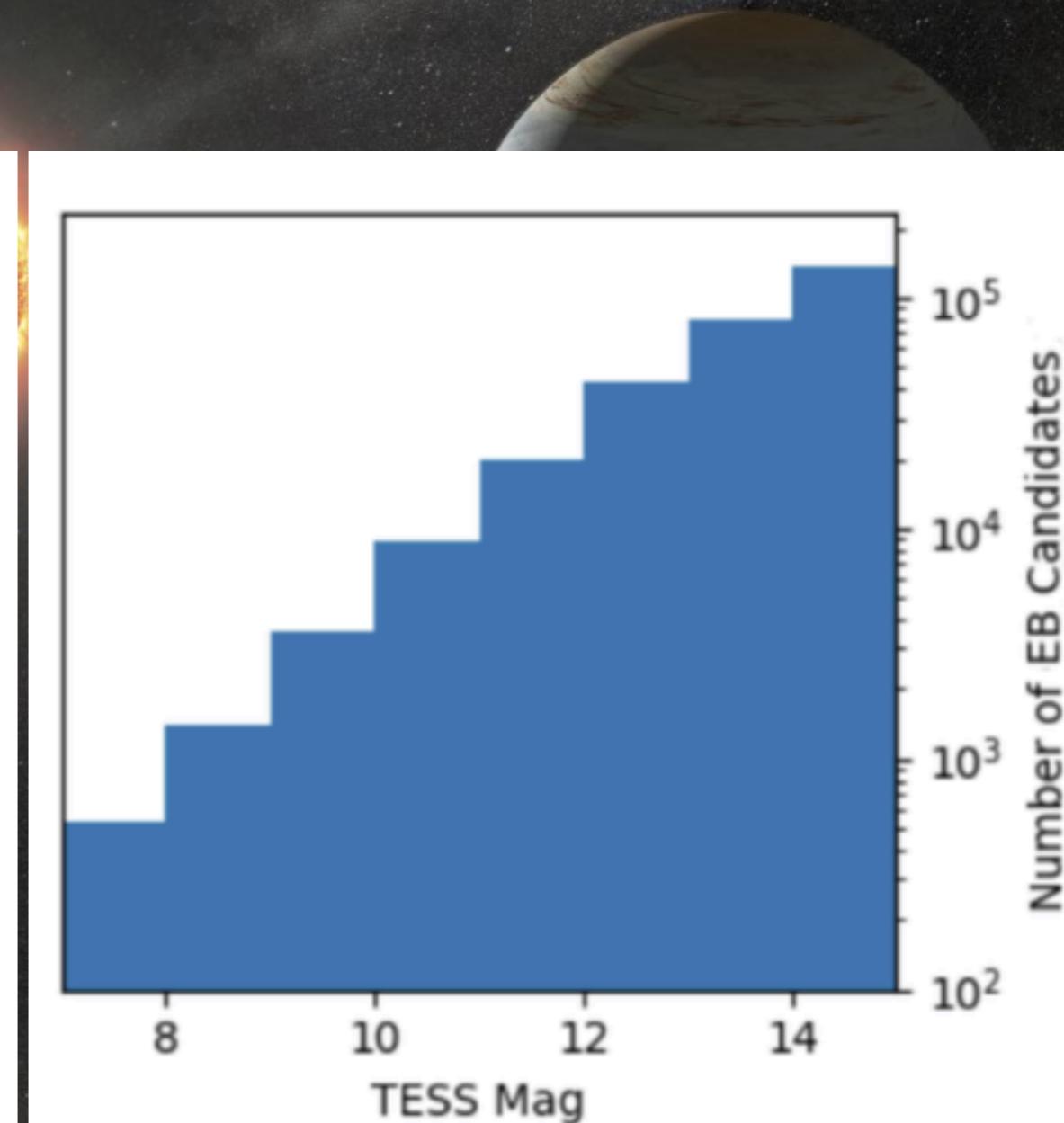
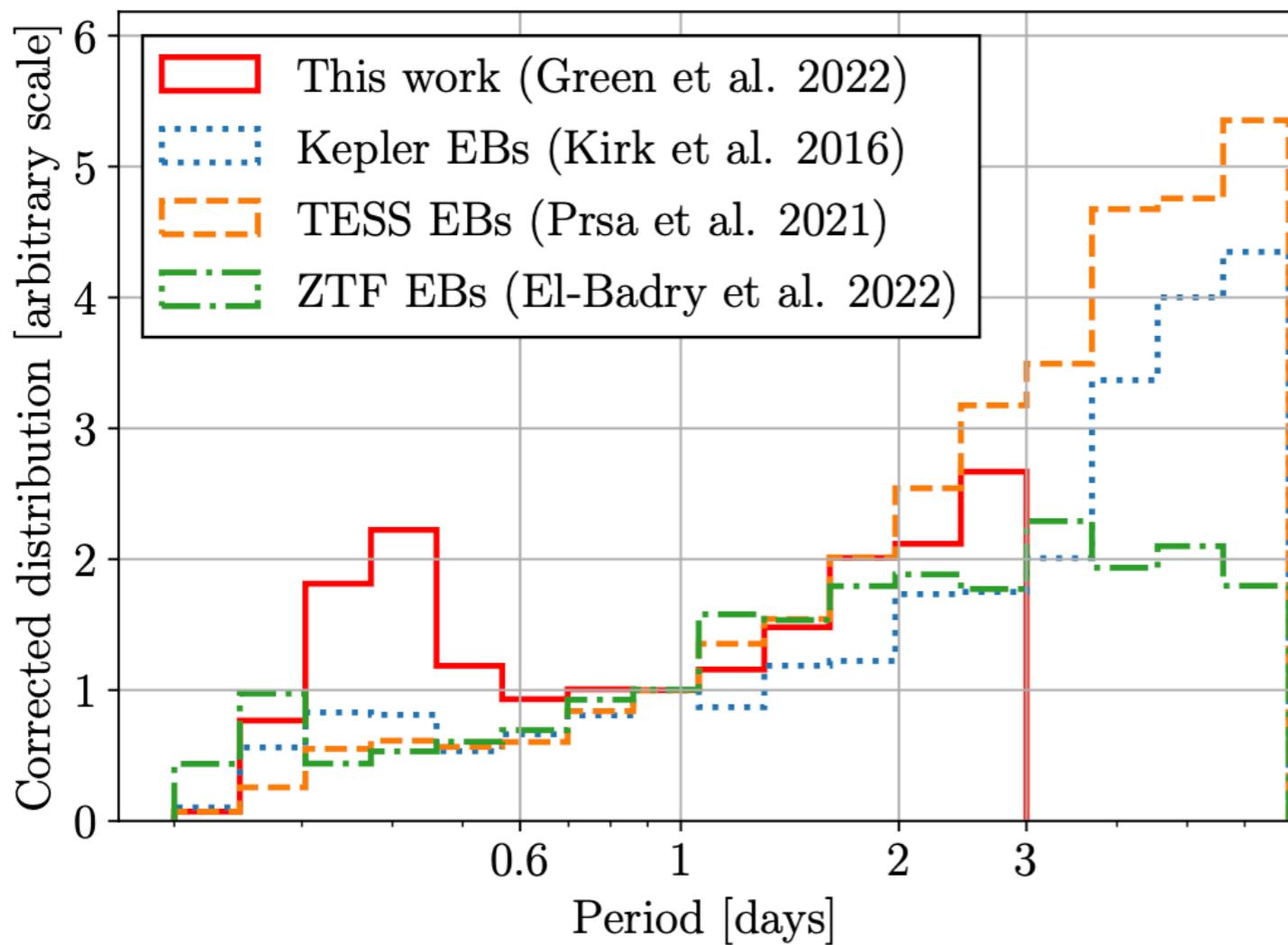
Stars and Stellar Astrophysics

GRBs: Rapid follow-up just days after detection (GRB 230307A, Fausnaugh et al. 2023)



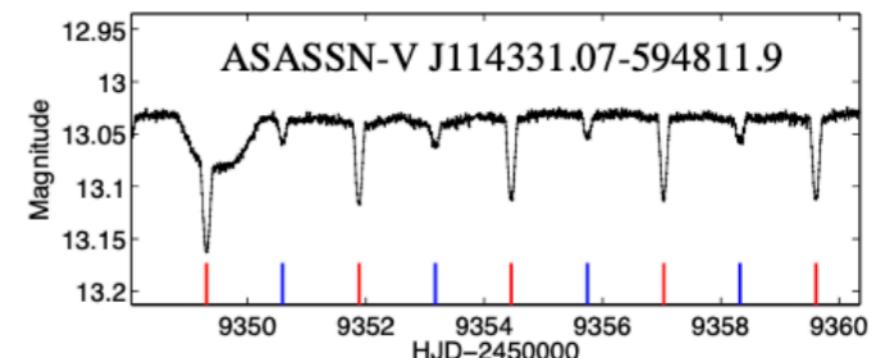
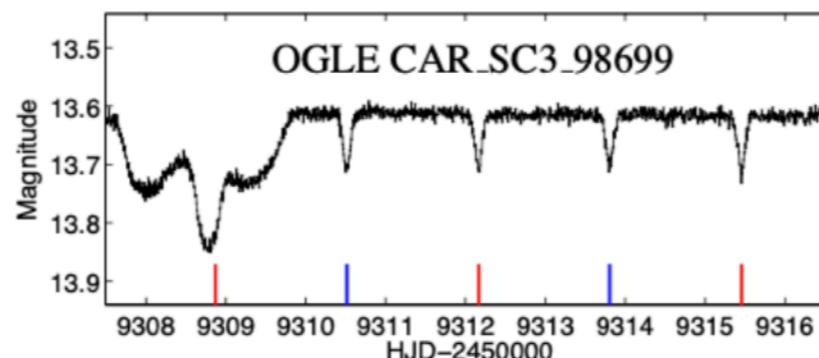
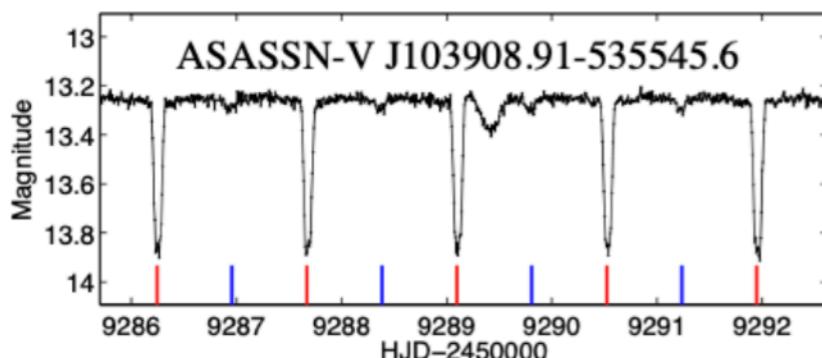
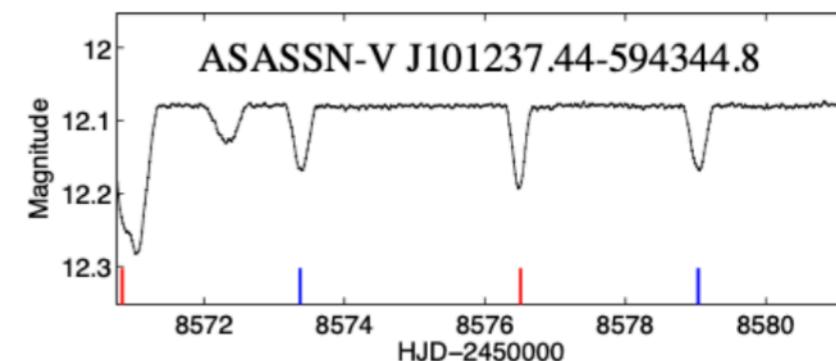
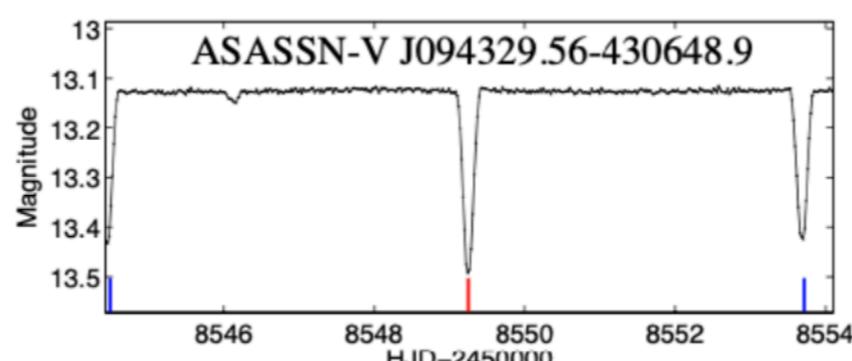
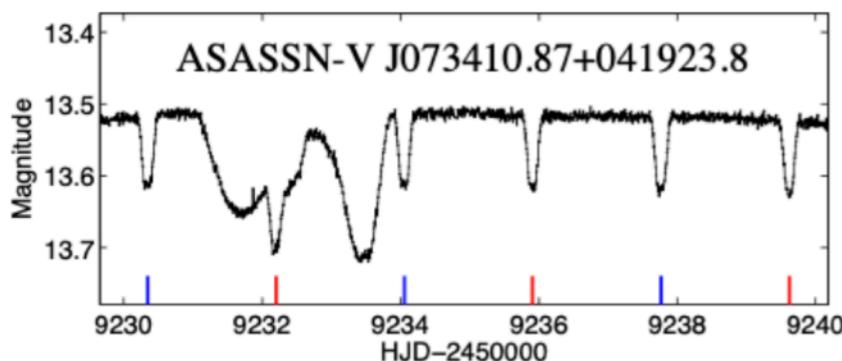
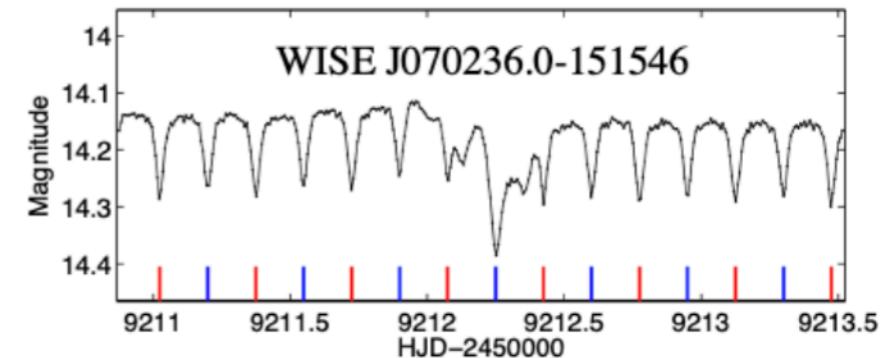
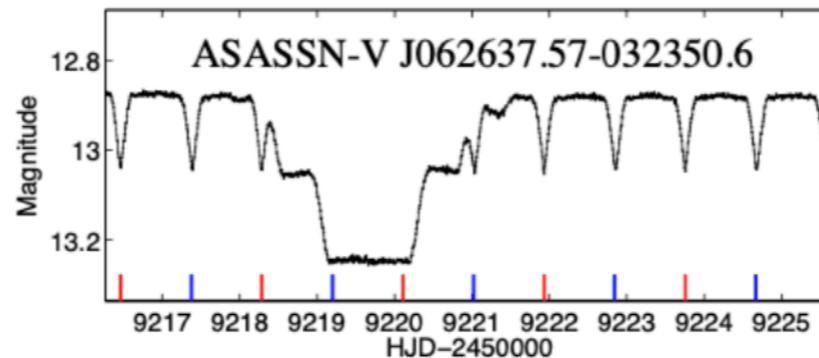
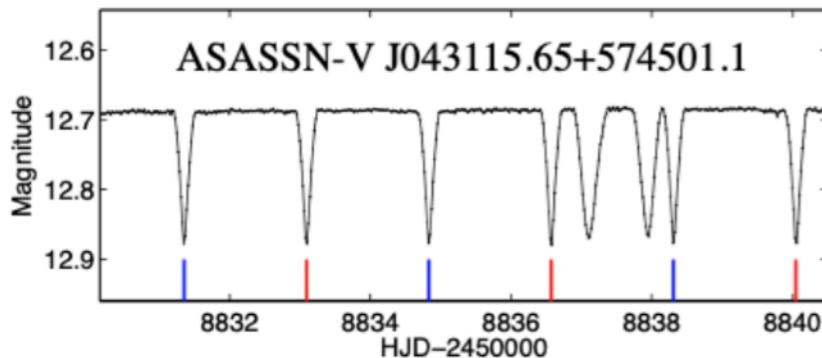
Stars and Stellar Astrophysics

Eclipsing binary stars: Hundreds of thousands of systems (e.g. Prsa et al. 2022; Green et al. 2023; Kruse et al. 2023; IJspeert et al. 2024)



Stars and Stellar Astrophysics

Multiple Stars: Hundreds of multiply-eclipsing stellar triples and quadruples (e.g. Borkovits et al. 2023; Kostov et al. 2023, 2024; Rappaport et al. 2023; Zasche et al. 2023)



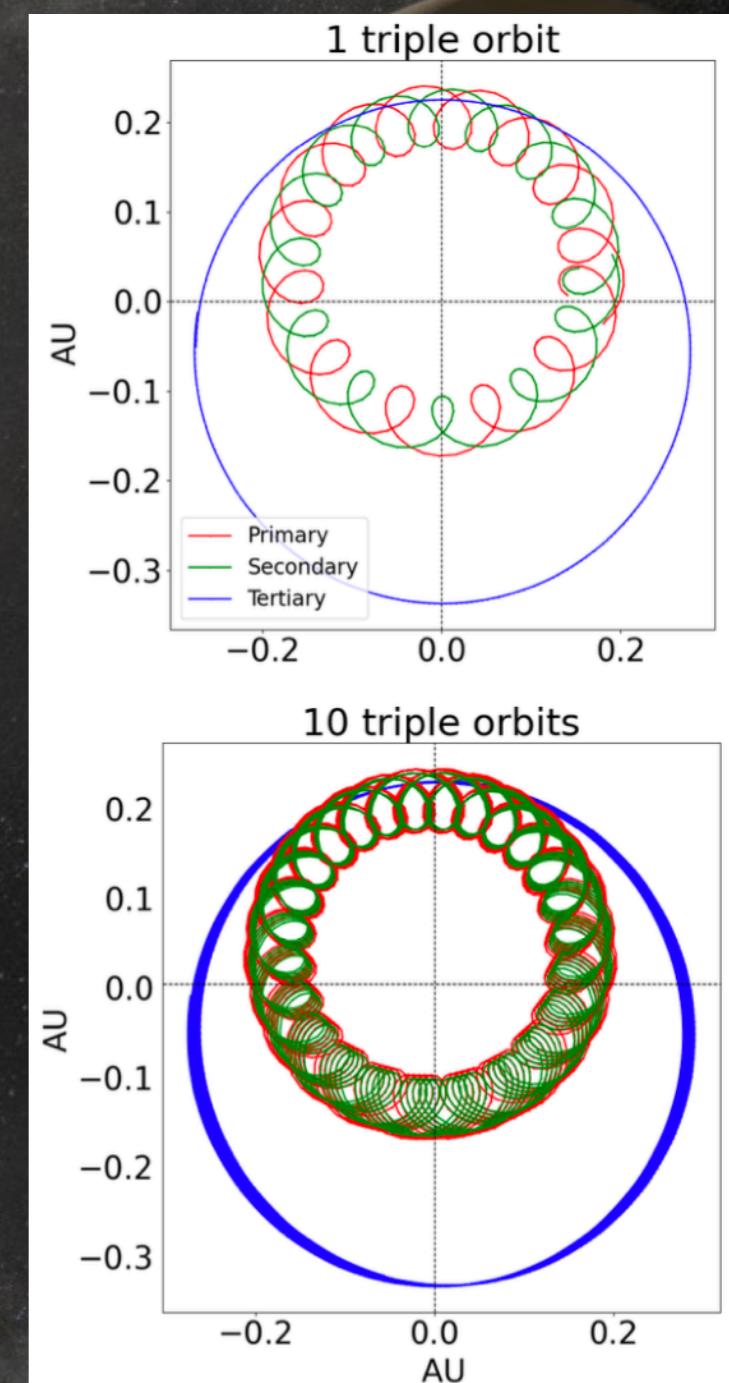
Triply-eclipsing triples

Stars and Stellar Astrophysics

Multiple Stars: TIC 290061484 : A triply-eclipsing triple system with the shortest known outer period of 24.5 days (Kostov et al. 2024); breaks 68-yr old record of lambda Tau (33 days, Ebbighausen & Struve 1956)

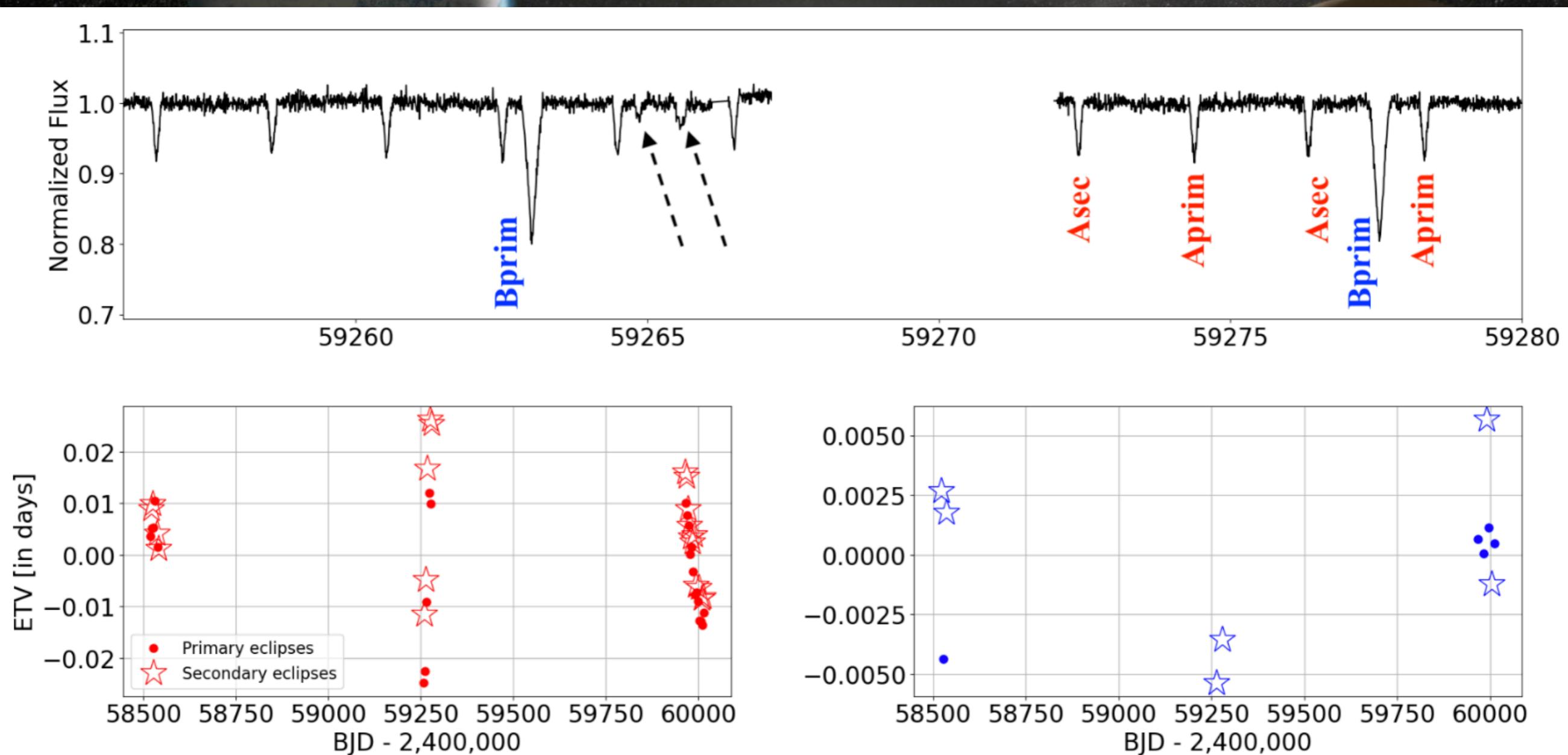


TESS lightcurve of TIC 290061484



Stars and Stellar Astrophysics

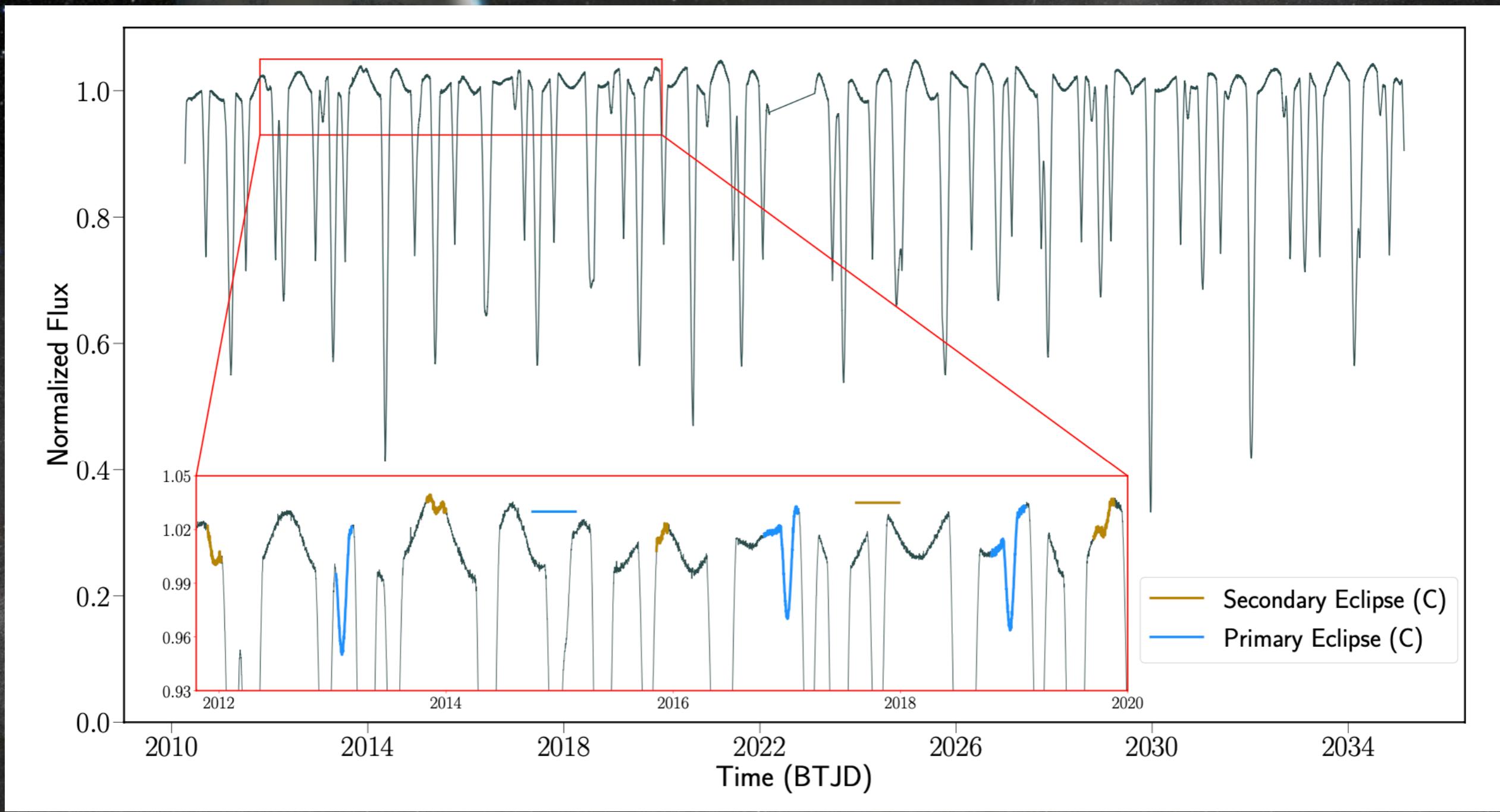
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TESS lightcurve and ETVs of TIC 37376063

Stars and Stellar Astrophysics

Multiple Stars: First two sextuply-eclipsing sextuple system (TIC 168789840, Powell et al. 2022; V994 Her, Zasche et al. 2023)



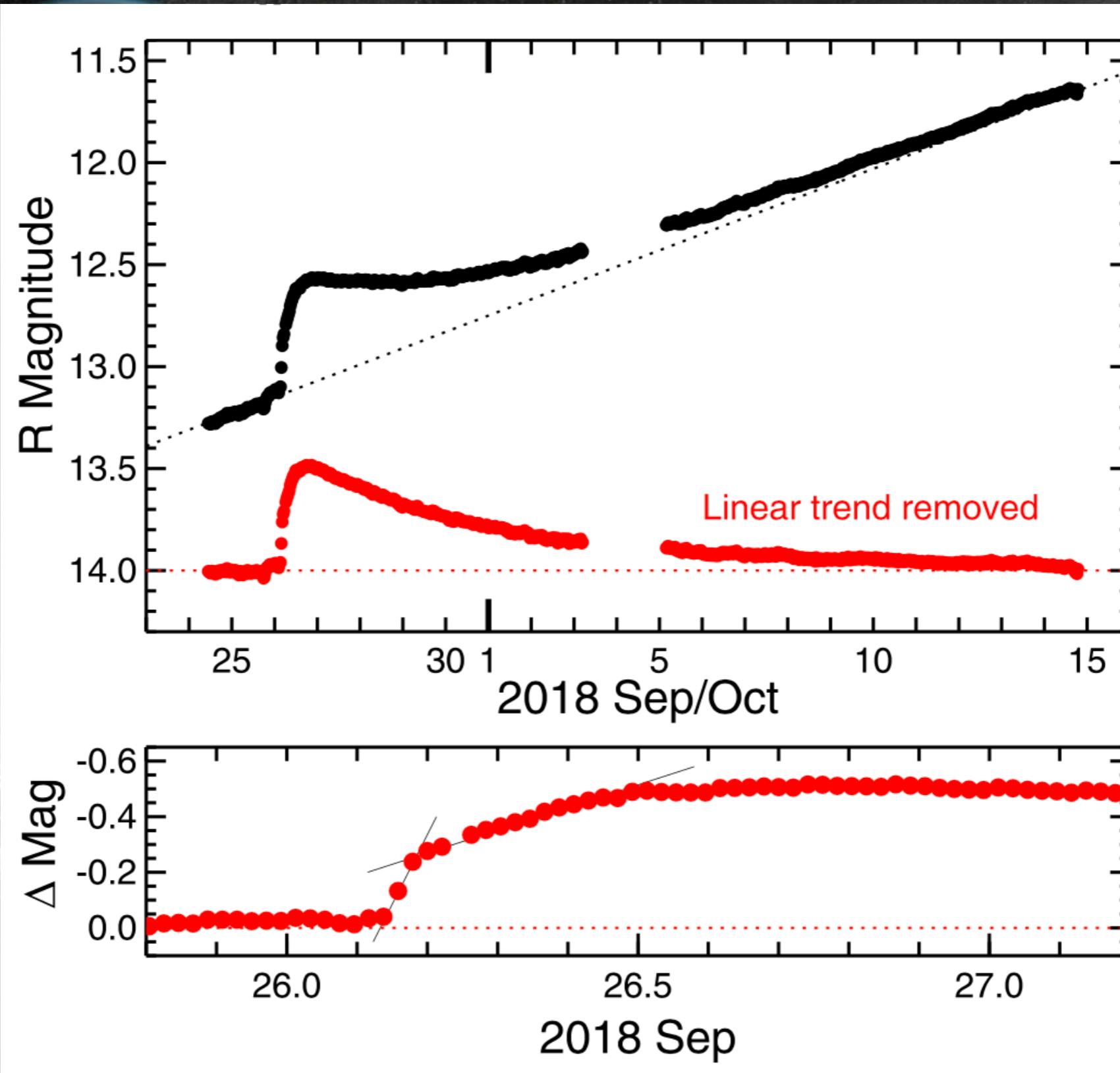
TESS lightcurve of V994 Her

Solar System

- *Better understanding of the origins of the Solar System*
- *Outbursts from comets*
- *Rotation periods and shape constraints for asteroids*
- *Search for Trans-Neptunian Objects*
- *Search for Near-Earth Objects, impact and importance for planetary protection*

Solar System

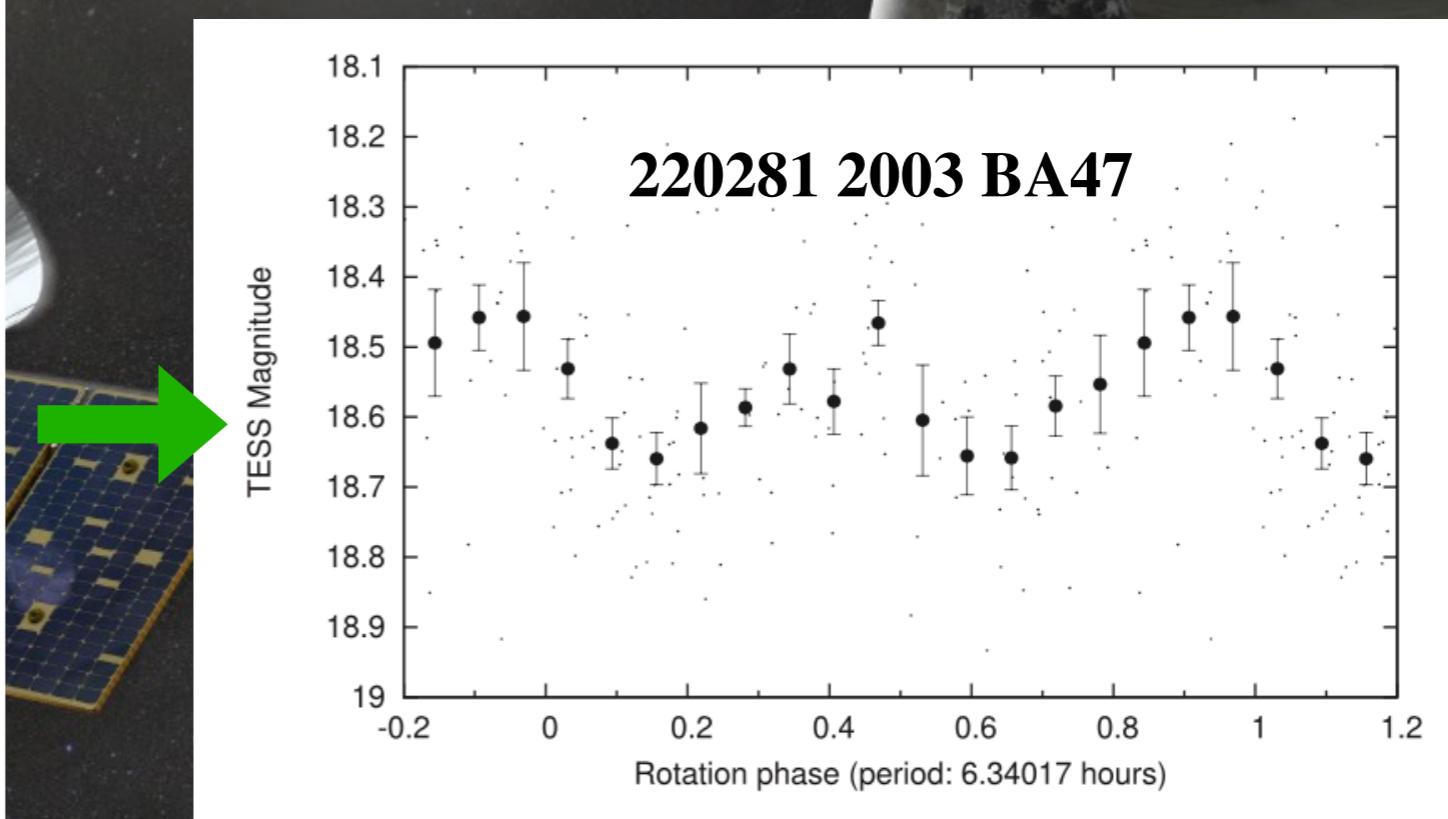
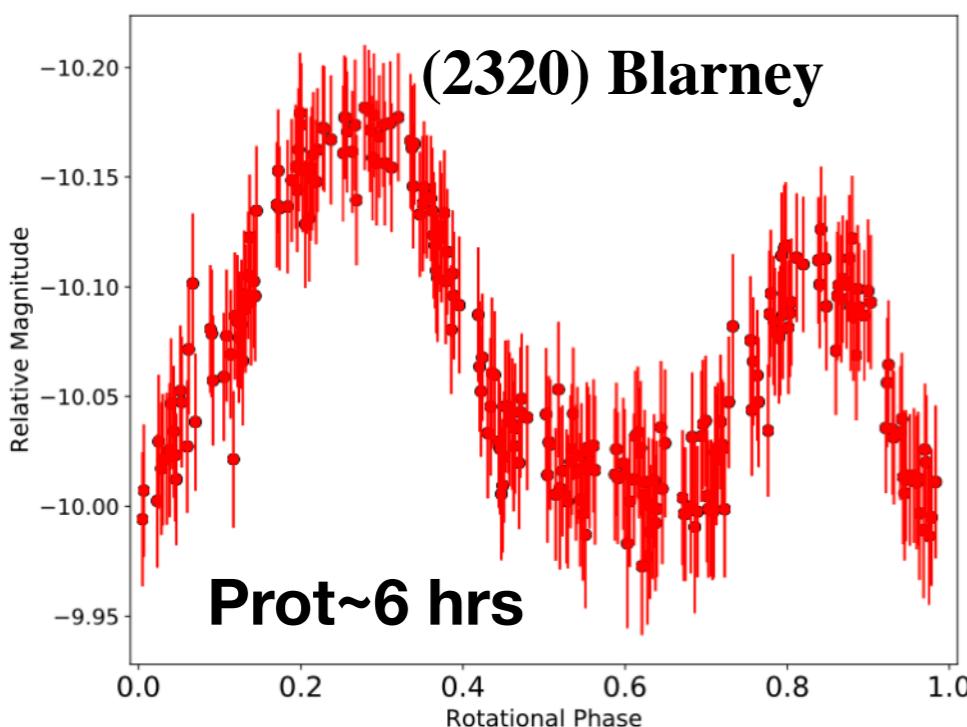
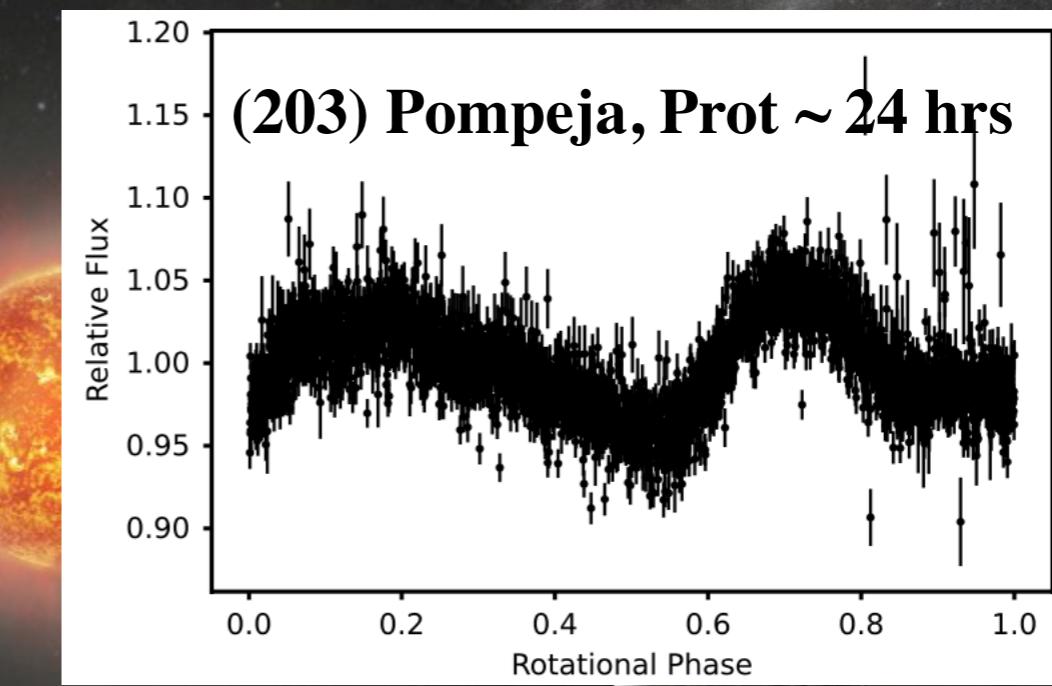
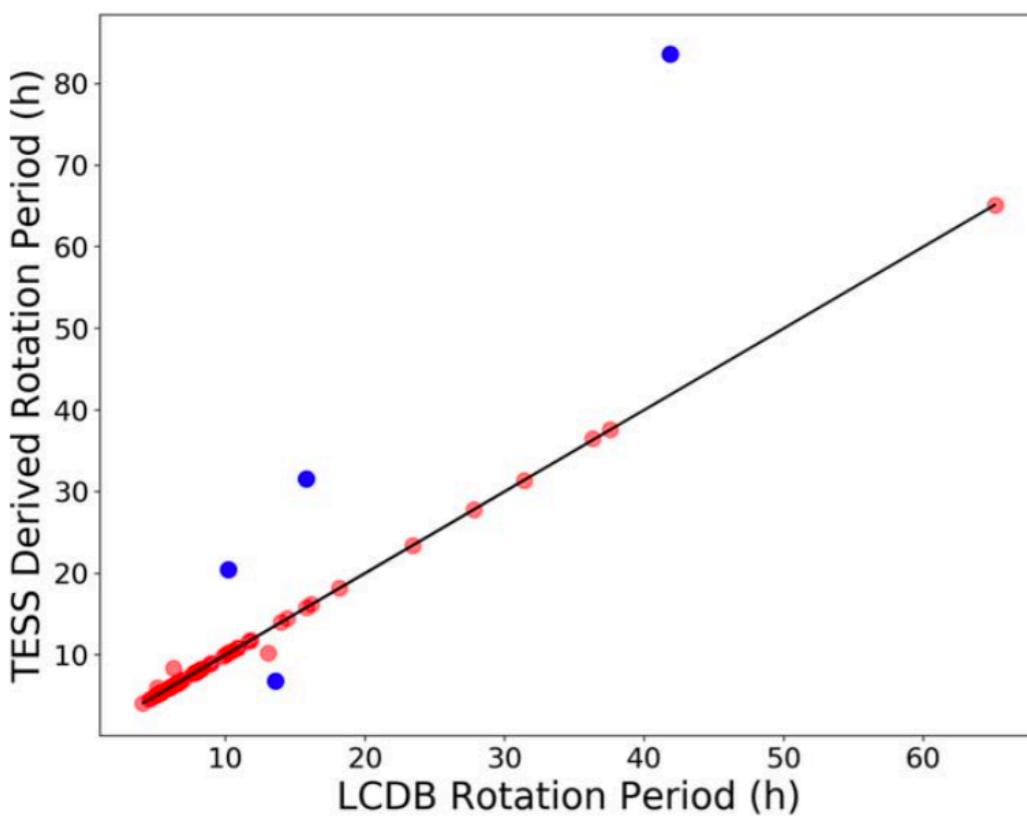
- Comets: outburst from 46P/Wirtanen (Farnham et al. 2022)



FFI detection
of previously
unknown dust
trail

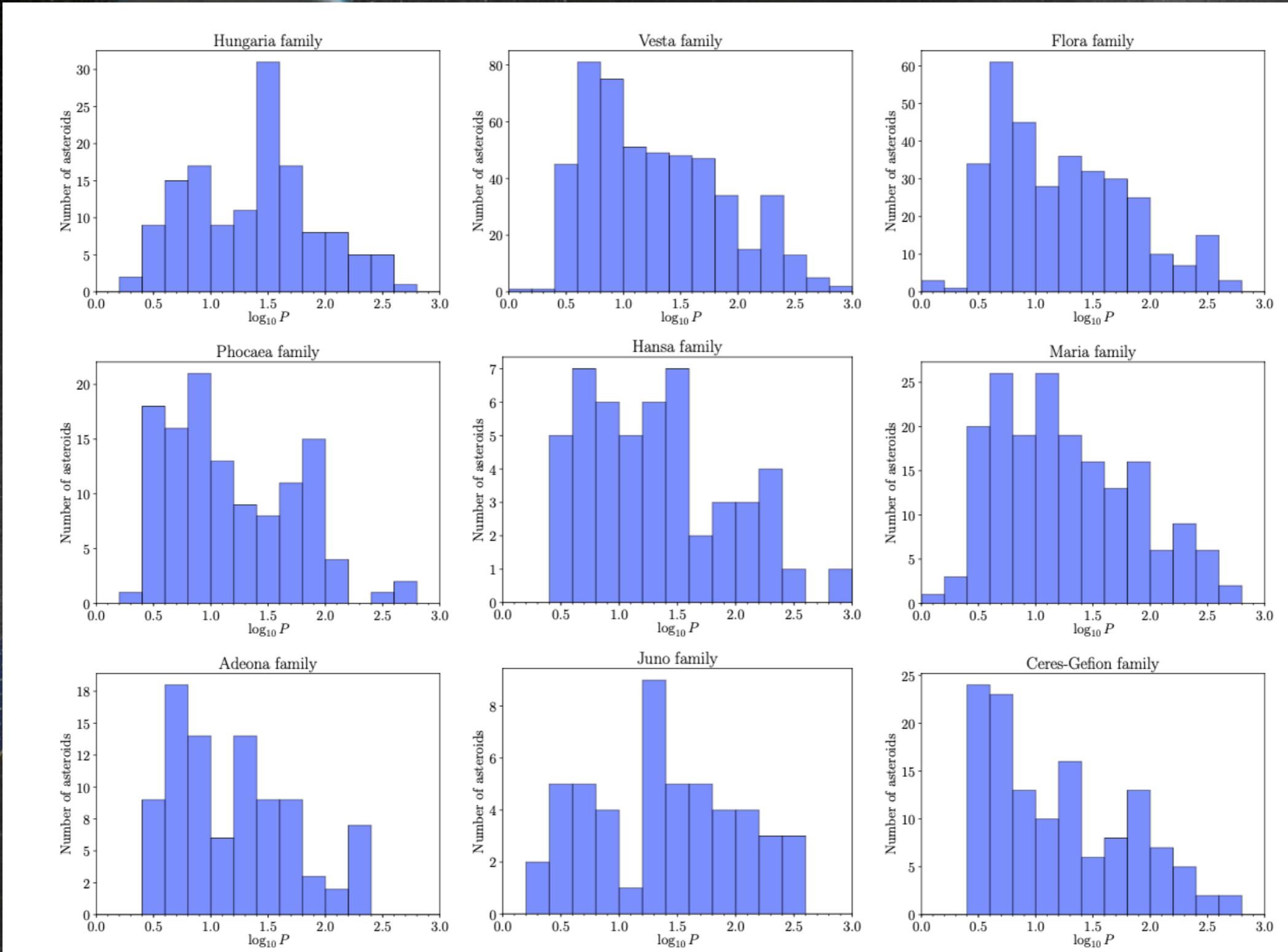
Solar System

- Main belt asteroids: rotation periods and light curve amplitudes for tens of thousands of objects (e.g. McNeill et al. 2019; Pal et al. 2020; Hasegawa et al. 2022; Gowanlock et al. 2024; Humes & Hands 2024)



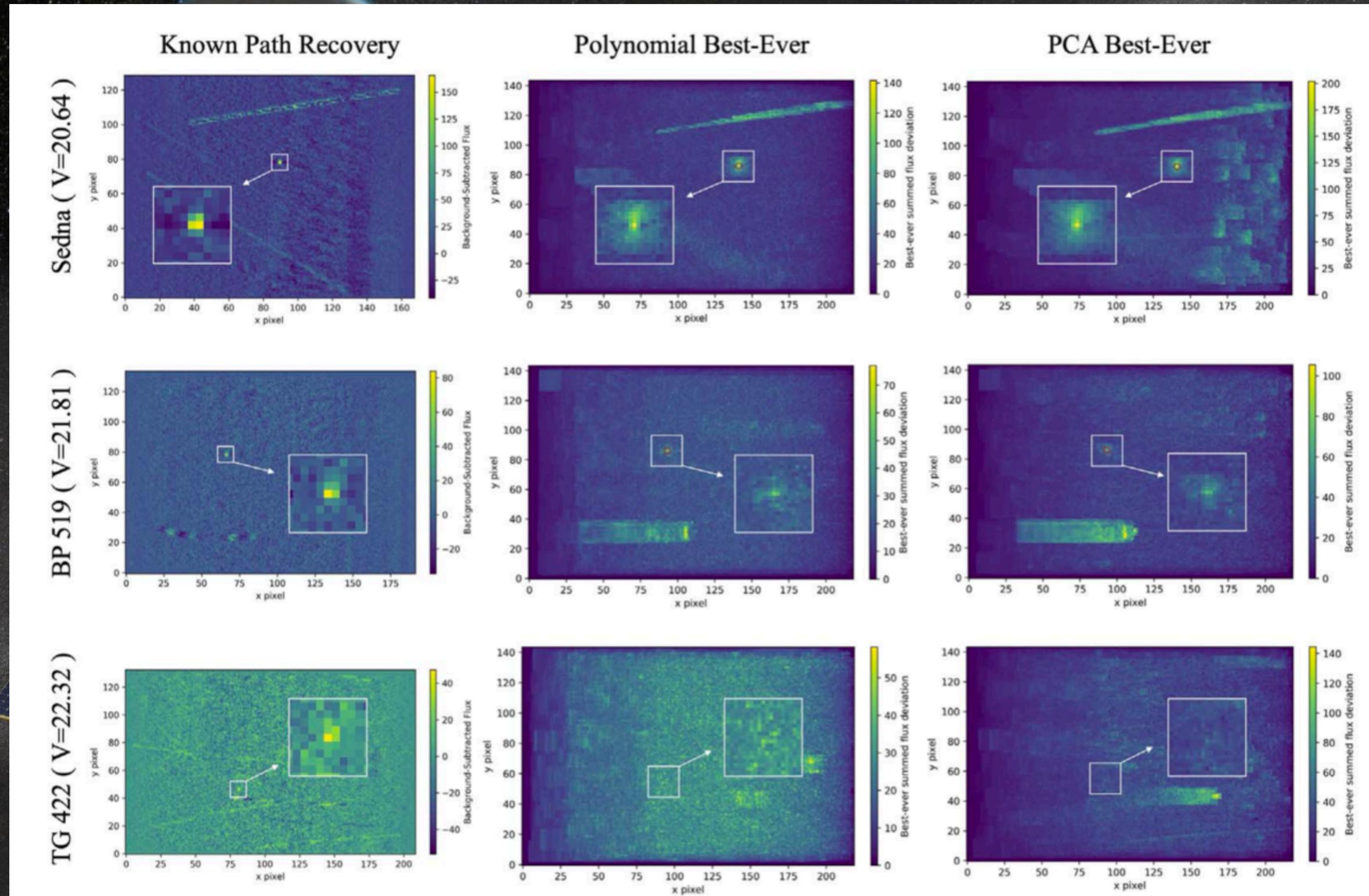
Solar System

- Main belt asteroids: rotation periods and light curve amplitudes for tens of thousands of objects (e.g. Szabo et al. 2022)



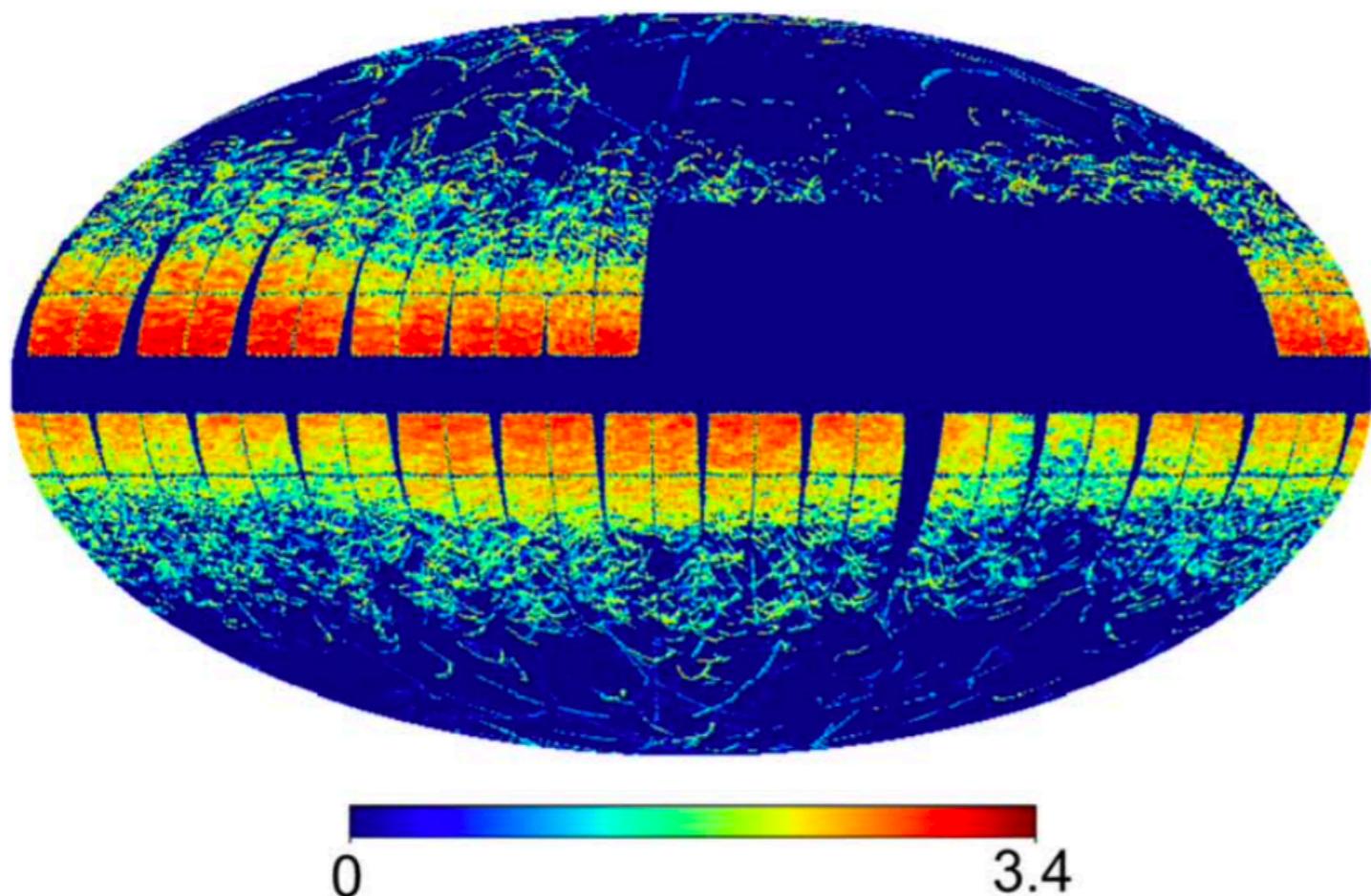
Solar System

- Trans-Neptunian Objects: Recovery of objects up to ~ 150 AU (Sedna, 2015 BP519, 2007 TG422, Rice & Laughlin 2020)

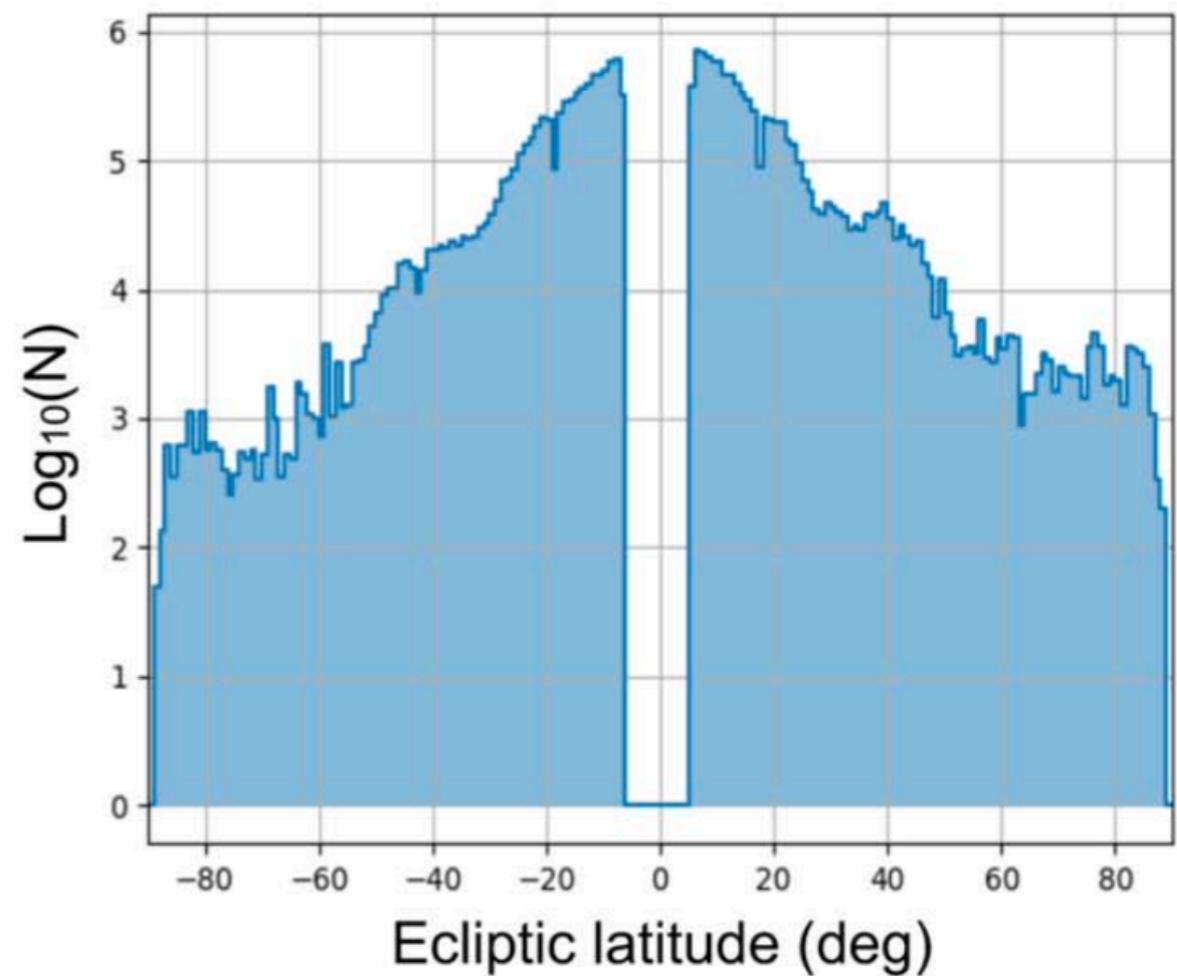


Solar System

- **Small Bodies:** monitoring the motion of millions of small bodies in the Solar System (e.g. Woods et al. 2021)



Moving object tracks (spatial density) for
~42,000 objects



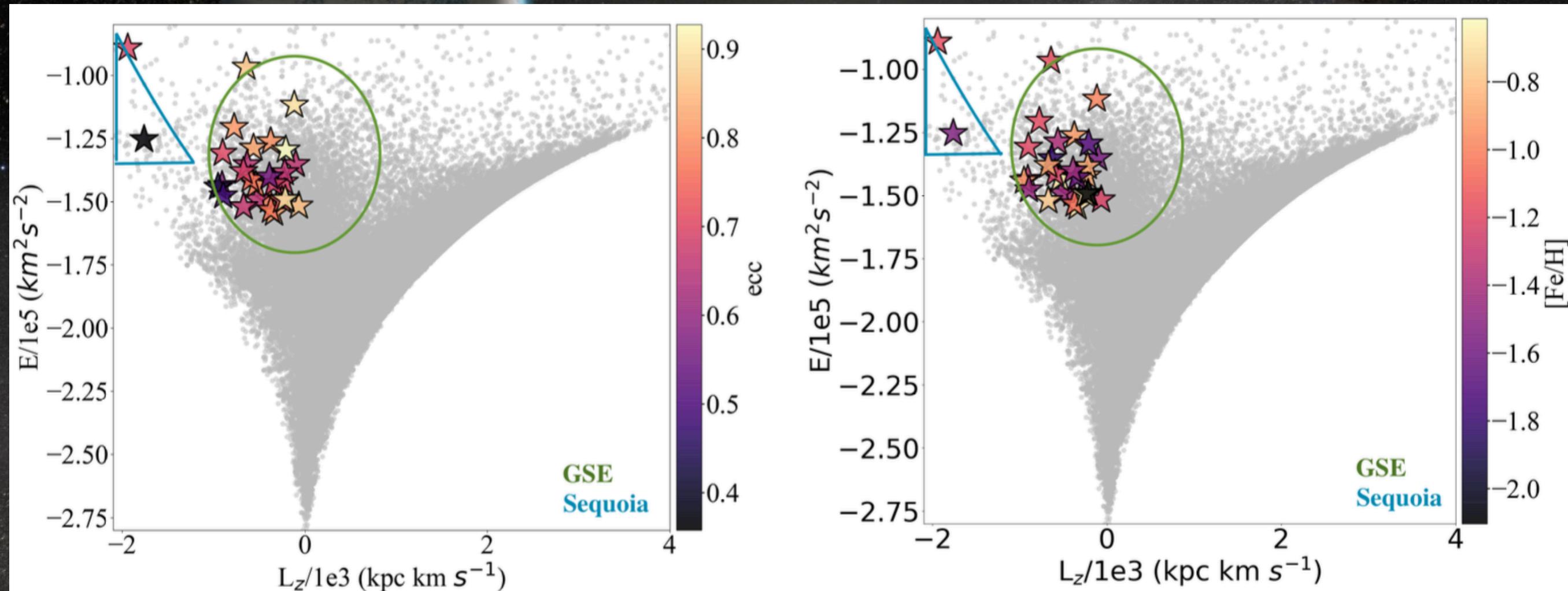
Number of objects as a function of ecliptic
latitude (TESS Year 1 and 2)

Galaxies

- *TESS observations enable systematic studies of hours to weeks-long (and even longer) nuclear variability of galaxies at various distances and luminosities*
- *TESS provides valuable constraints on the characteristic timescales observed in the corresponding lightcurves.*
- *The data helps investigate flaring events such as tidal disruptions, accretion rate changes, ambiguous nuclear transients, etc.*

Galaxies

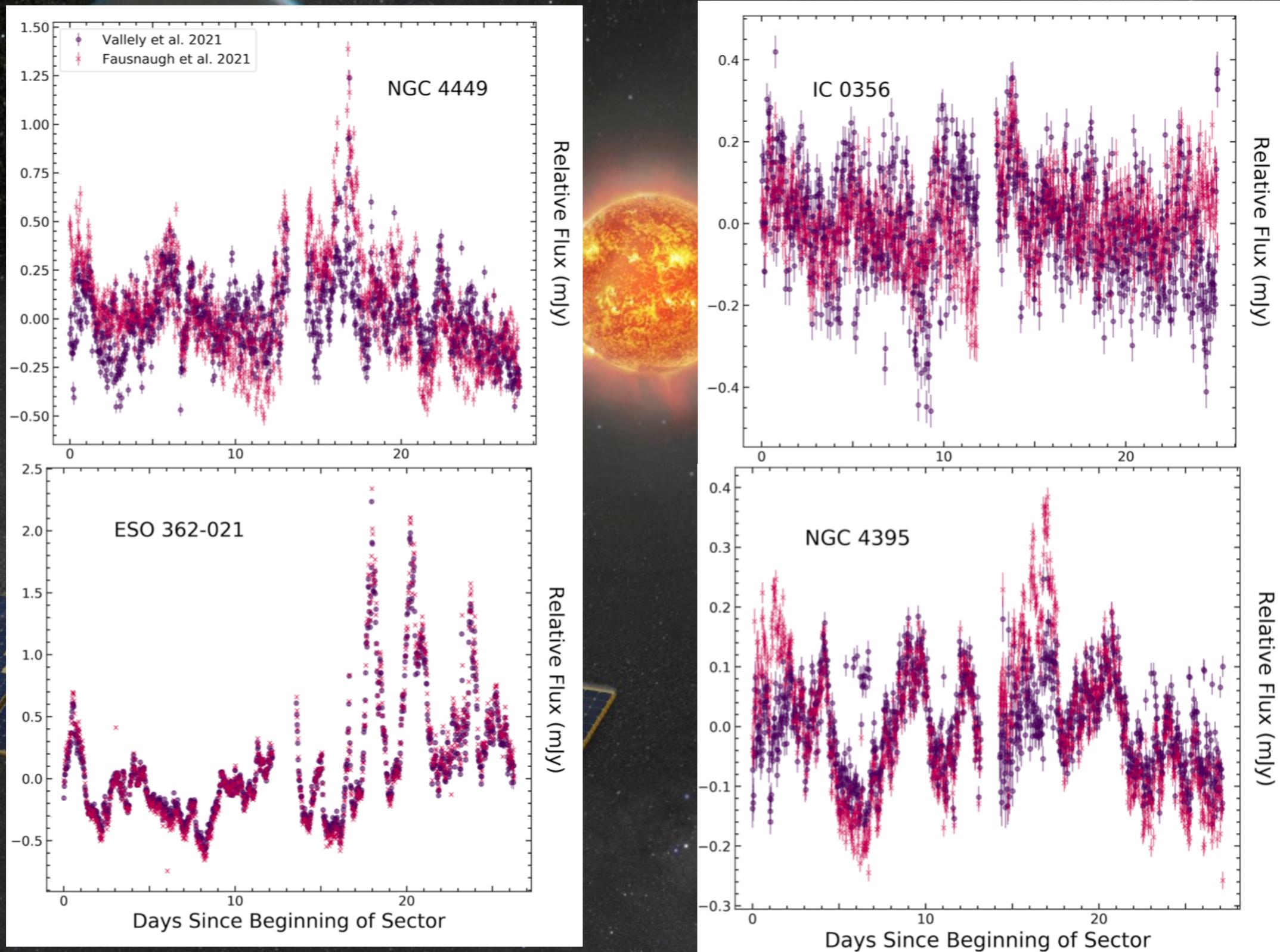
- **Merger history of the Milky Way: observations of dozens of metal-poor accreted star candidates (de Brito Silva et al. 2024)**



Eccentricity and metallicity of TESS-monitored stars in the Gala-Sausage-Enceladus (green ellipse) and Sequoia debris (blue triangle)

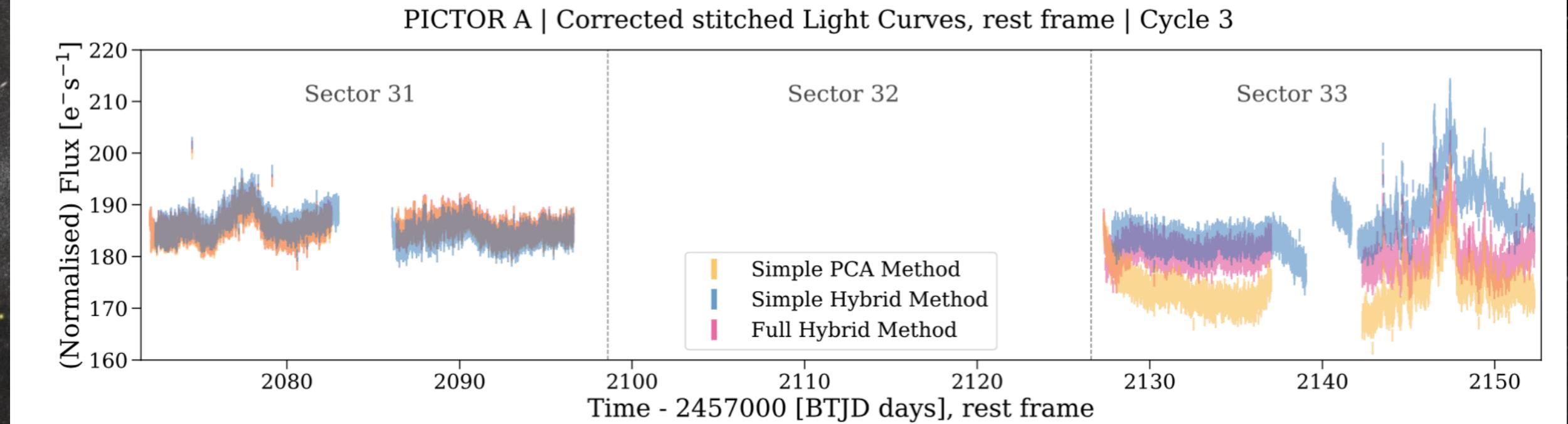
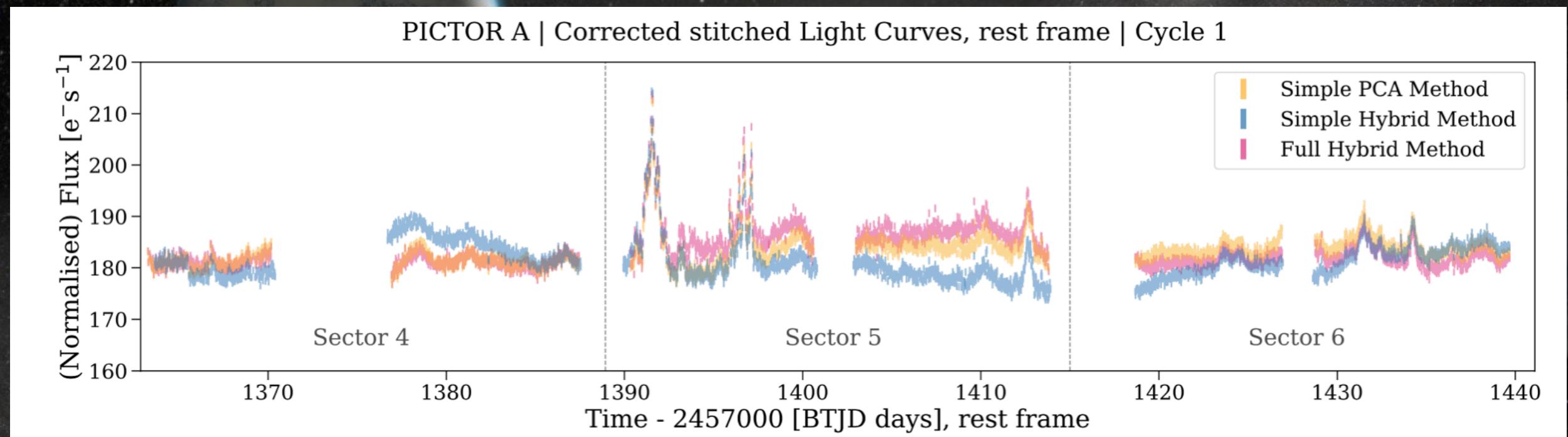
Galaxies

- **AGN Variability:** Identify dozens of AGNs from variability in TESS data (e.g. Burke et al. 2021, Treibel et al. 2022). Timescales ~hours to ~days



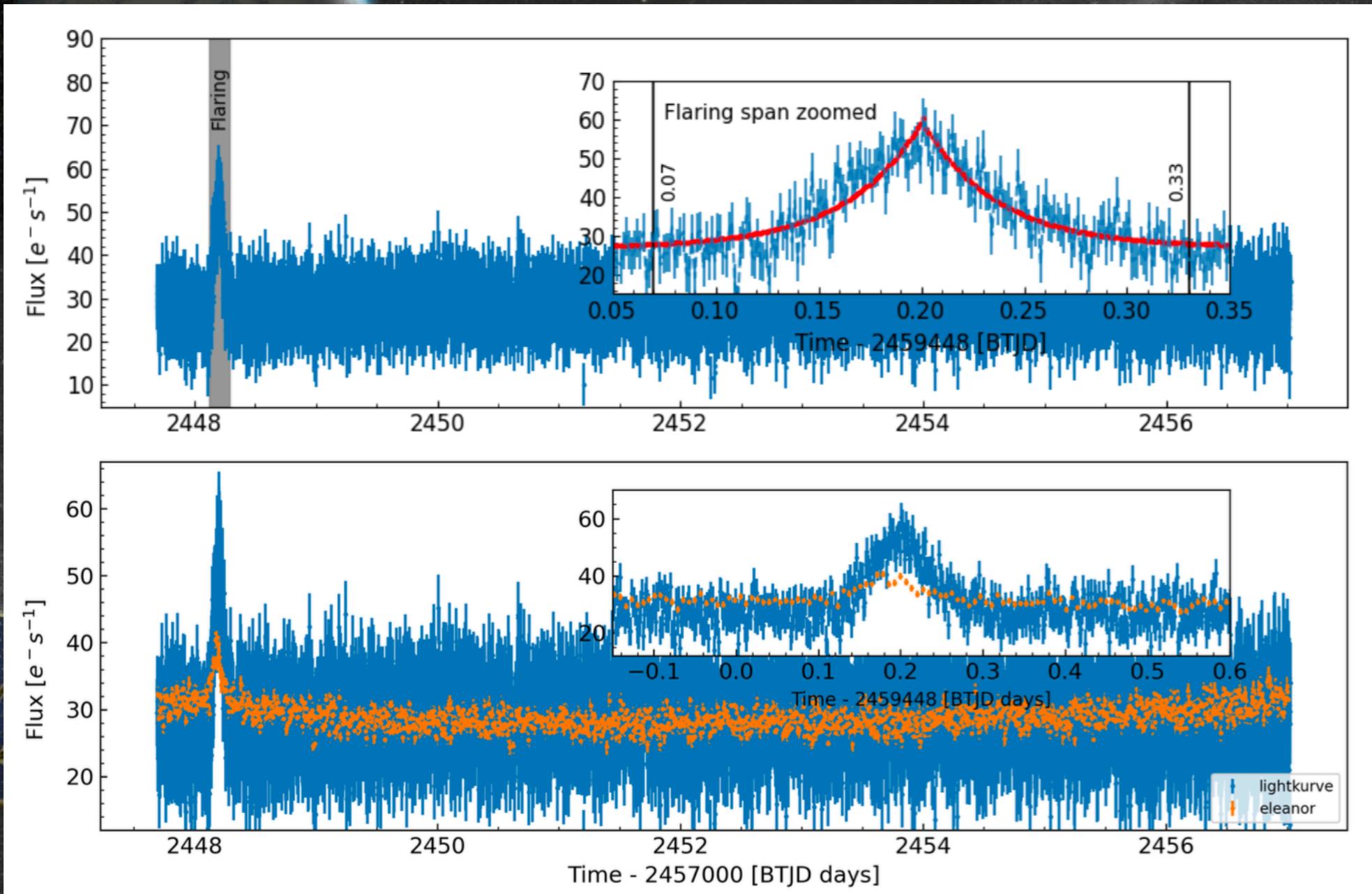
Galaxies

- **AGN Variability:** observations of Pictor A, nearest broad-line radio-loud galaxy (Smith & Sartori 2023); Variability timescales of ~1 day during flares, ~3-6 days otherwise



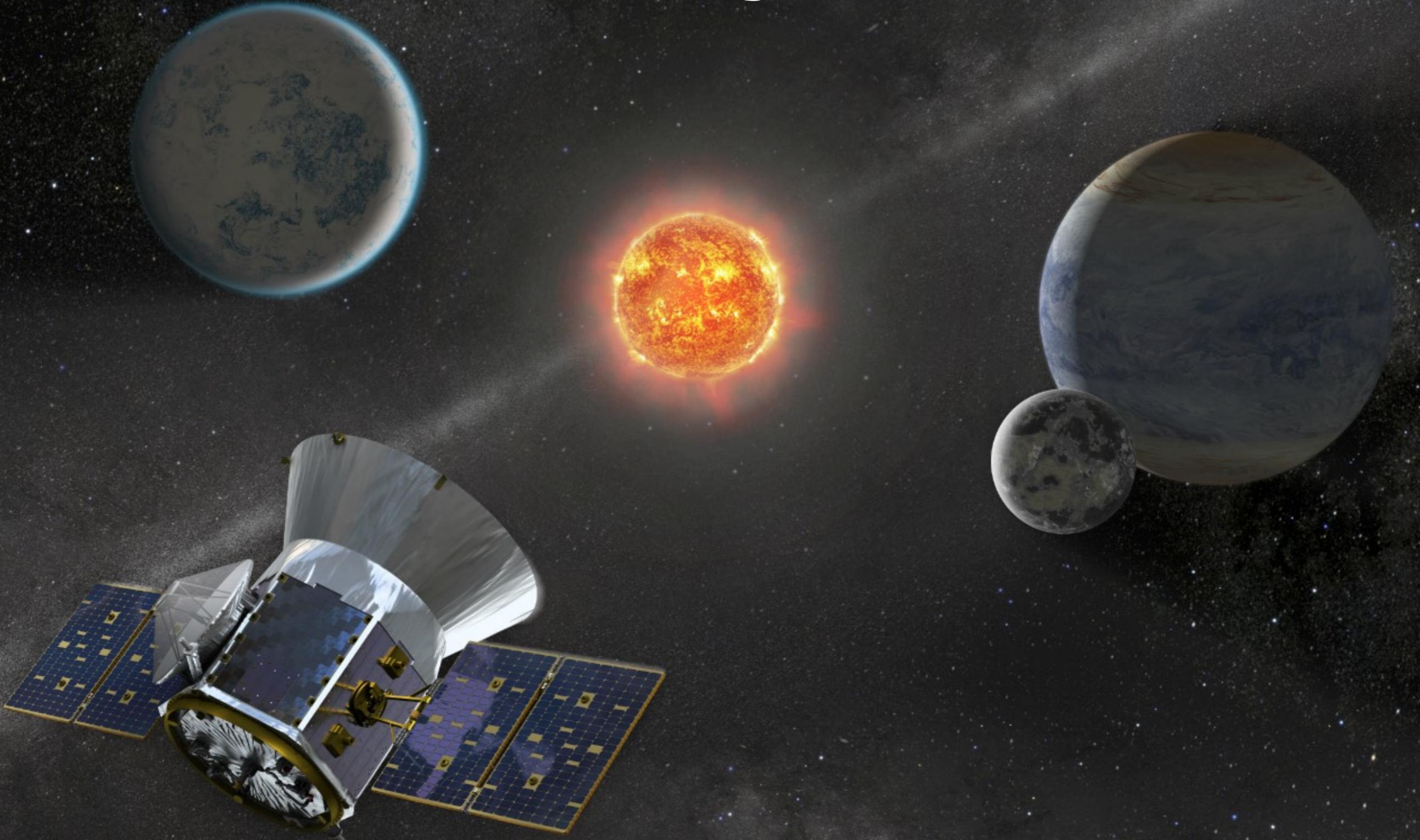
Galaxies

- **AGN variability:** Systematic studies of short-term optical variability for dozens of Blazars (e.g. Pininti et al. 2022; Kishore et al. 2023, 2024):



TESS data of extreme TeV, high-frequency peaked BL Lac-type blazar

Thank you!



Stars and Stellar Astrophysics

Multiple Stars: A Quadruple 2+1+1 System with a 12-day Outer Orbit Eclipse (TIC 114936199, Powell et al. 2022)

