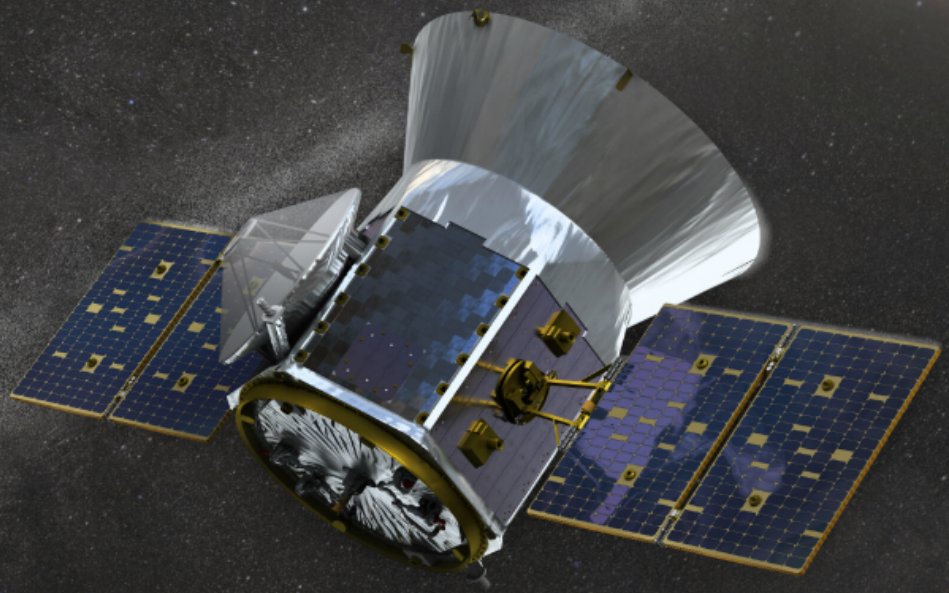
Beyond Exoplanet Science with TESS



Veselin Kostov, on behalf of the TESS Science Support Center

TESS Interactive Data Workshop
AAS 243, New Orleans

Beyond Exoplanet Science with TESS

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

Stars and Stellar Astrophysics

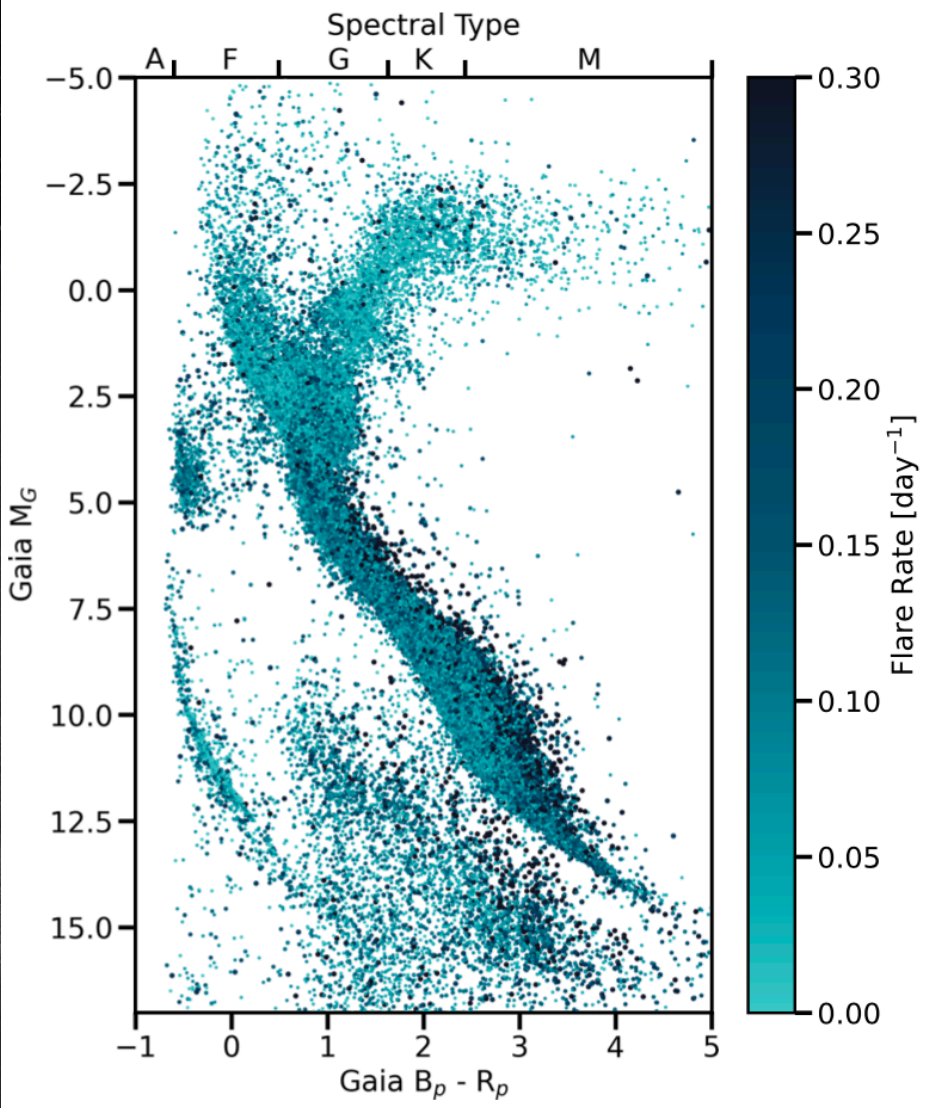
- *High-cadence observations ideally-suited for detailed astreroseismology studies and analysis of stellar flares*

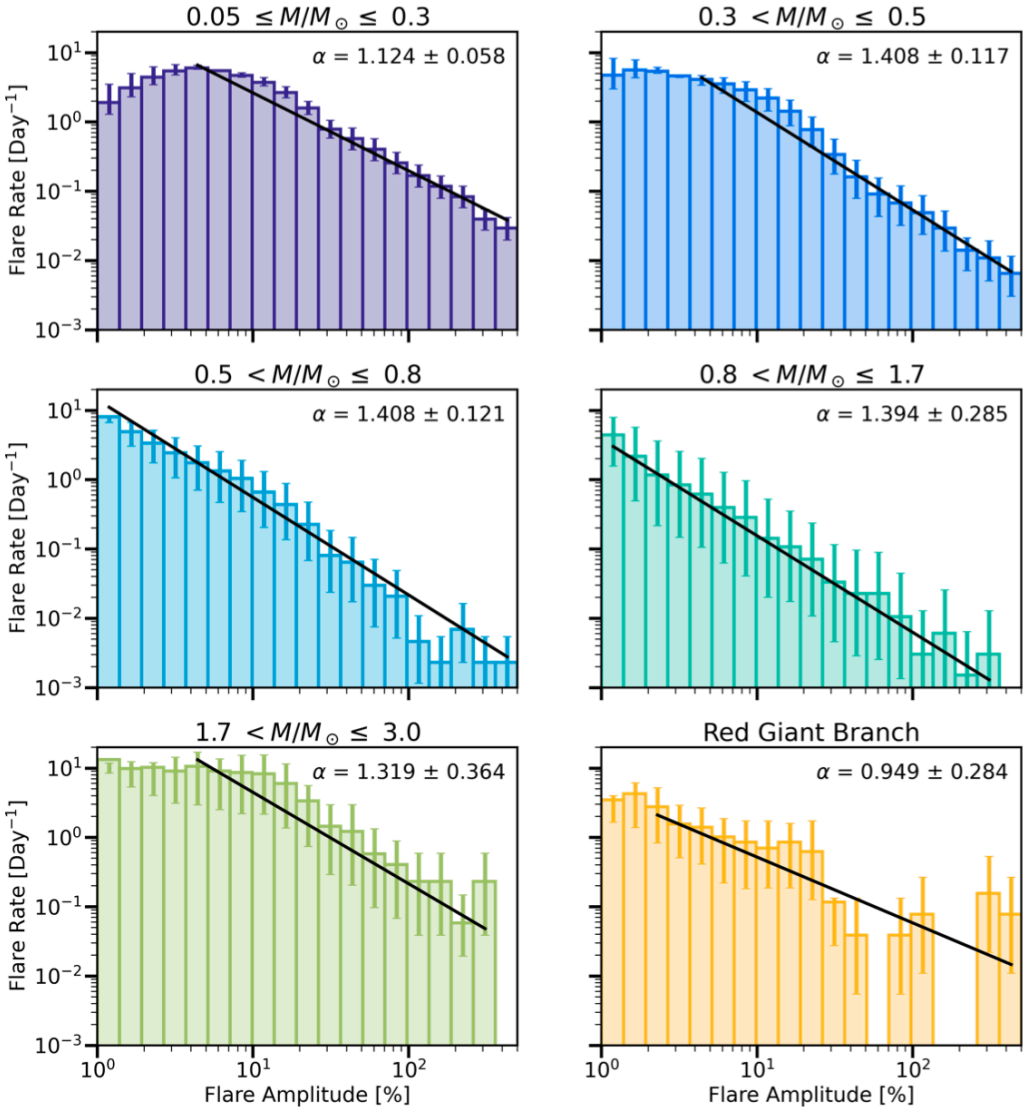
- *Long-duration observations critical for studying mechanisms responsible for intrinsic stellar variability due to e.g. stellar rotation or episodic/ quasiperiodic dimming in young stellar objects*

- *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: A million flares from 100,000 stars (e.g. Feinstein et al. 2022)

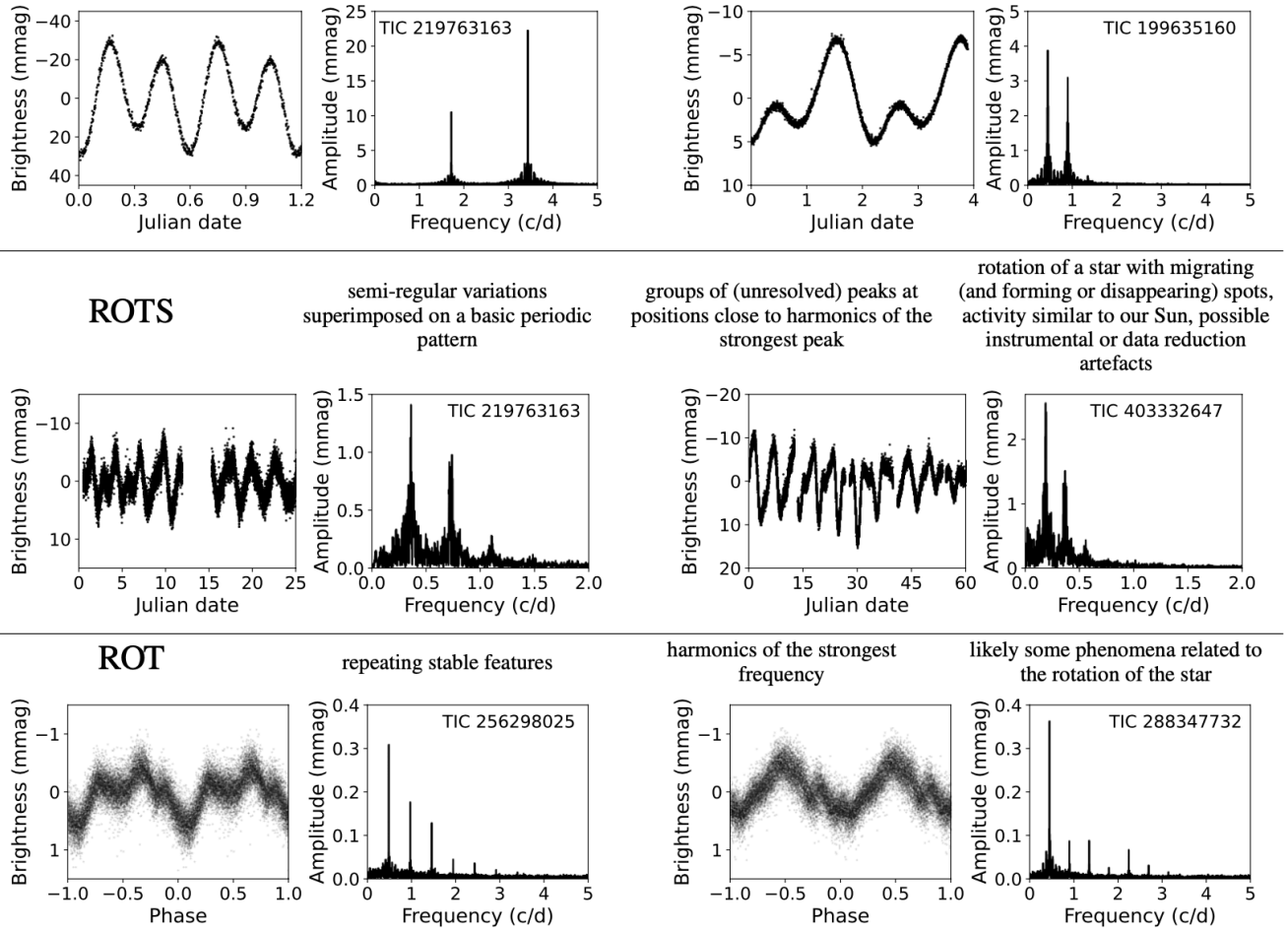




Stars and Stellar Astrophysics

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

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



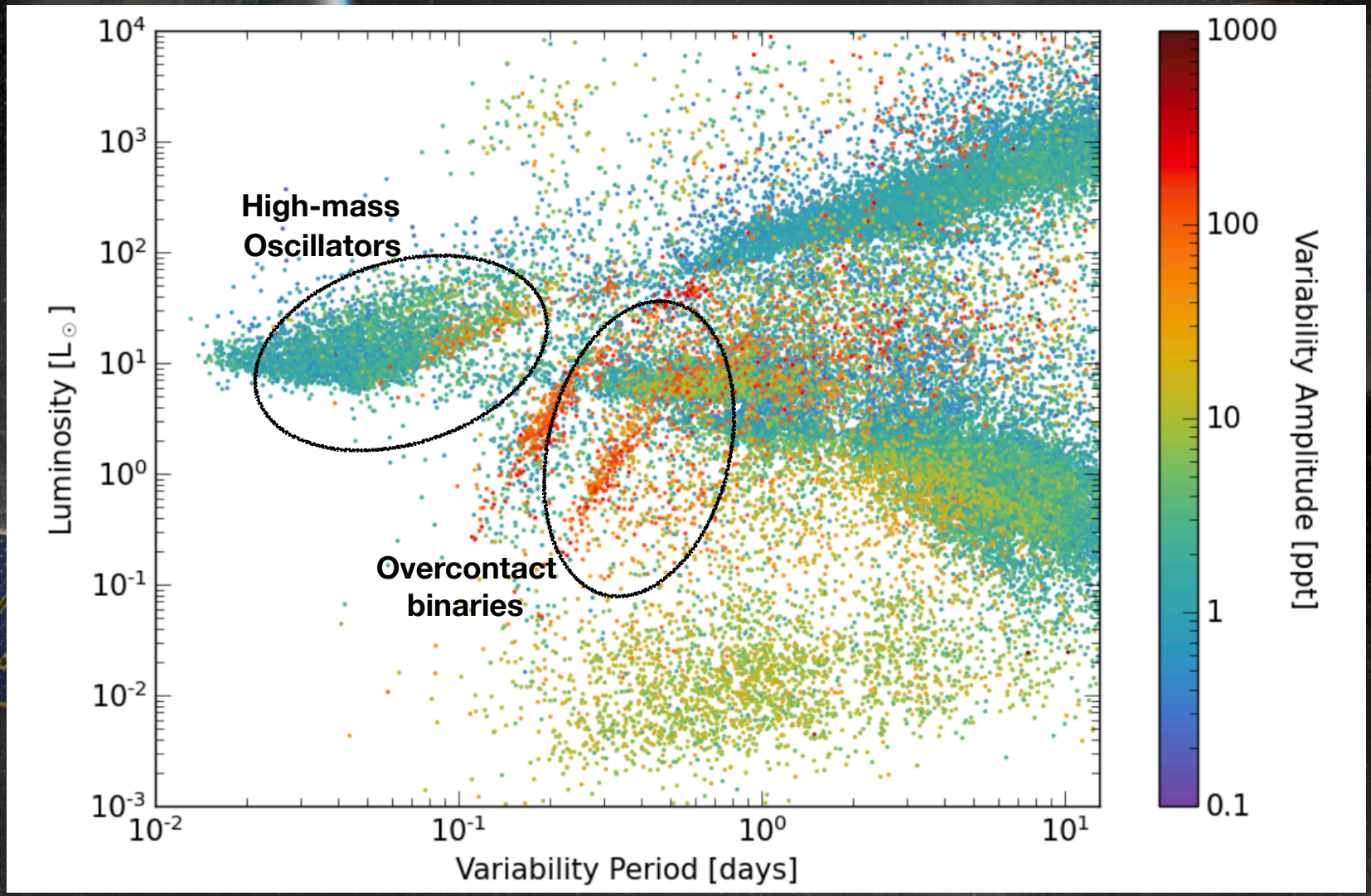
Magnetic Rotators

Solar-type Rotators

Regular FT harmonics

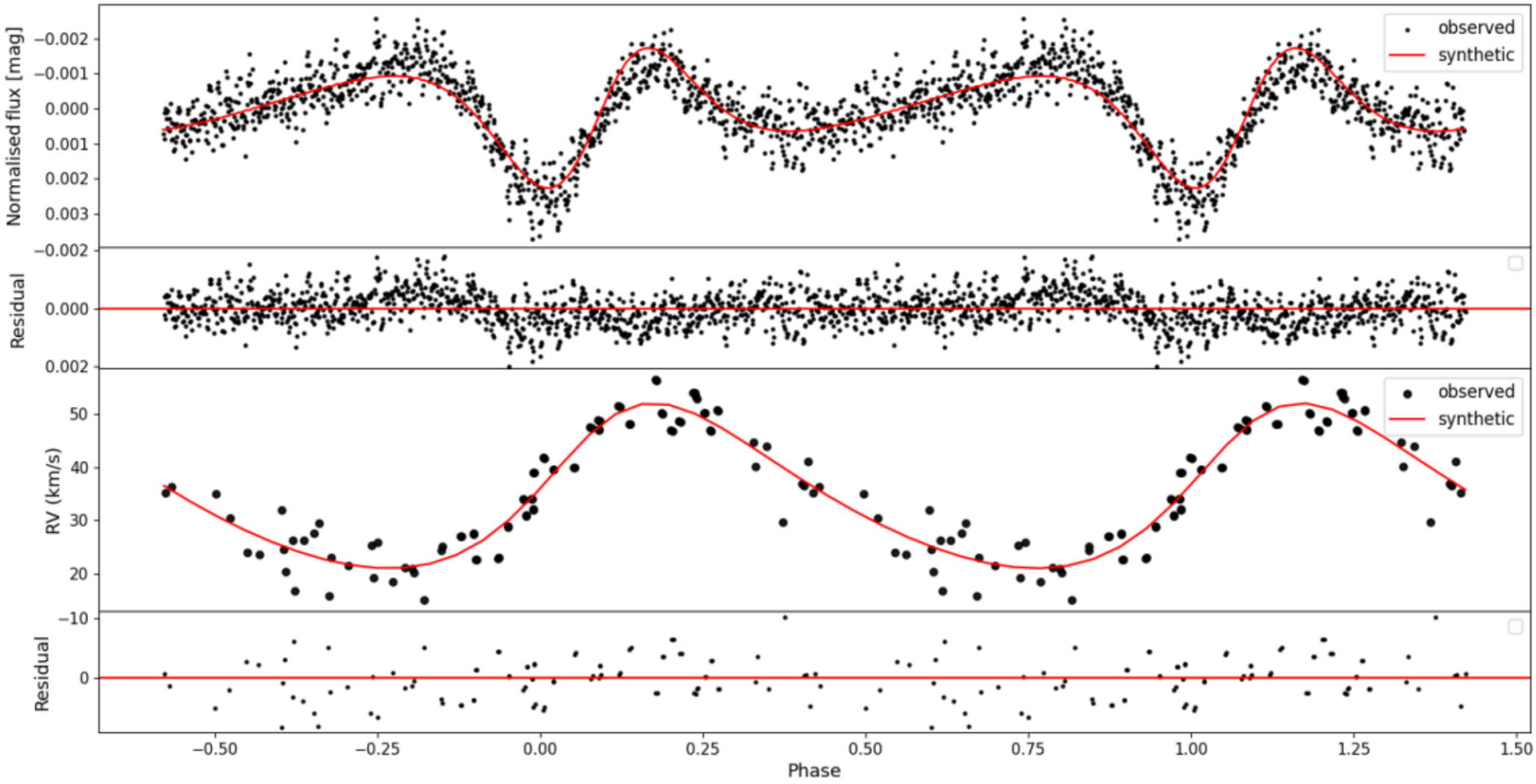
Stars and Stellar Astrophysics

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



Stars and Stellar Astrophysics

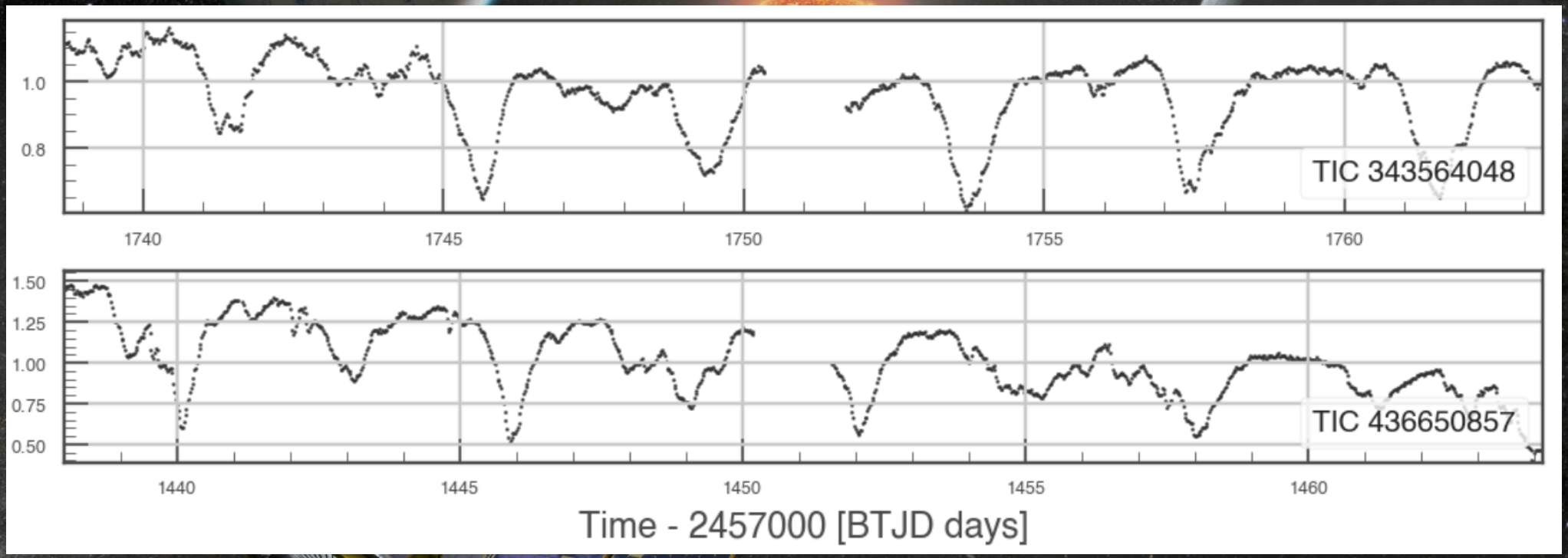
Stellar Variability: blue stragglers in M67 (Vernekar et al. 2023)



WOCS 1007: TESS supports mass-transfer formation

Stars and Stellar Astrophysics

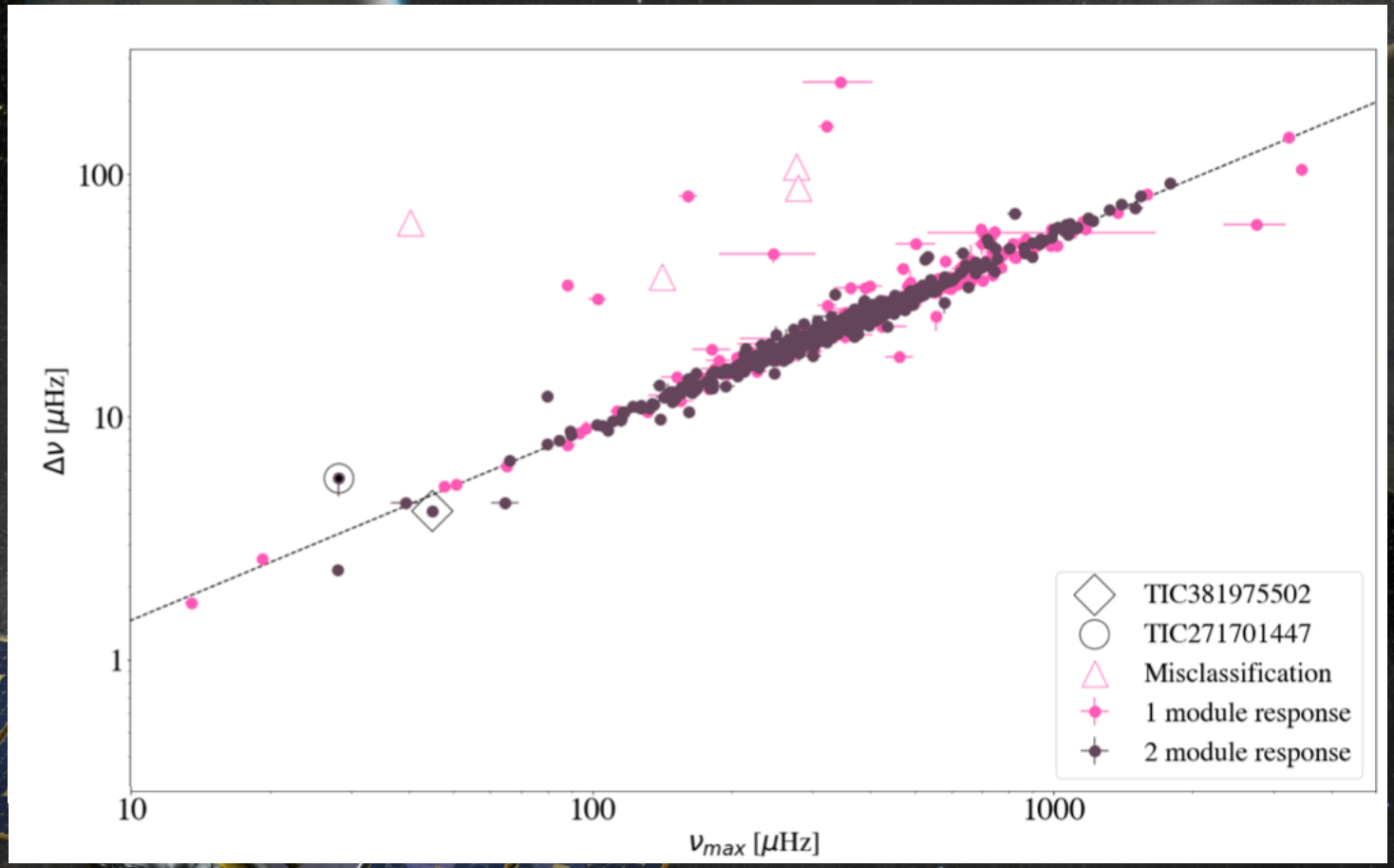
Stellar Variability: Hundreds of new dipper stars (e.g. Capistrant et al. 2022)



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

Stars and Stellar Astrophysics

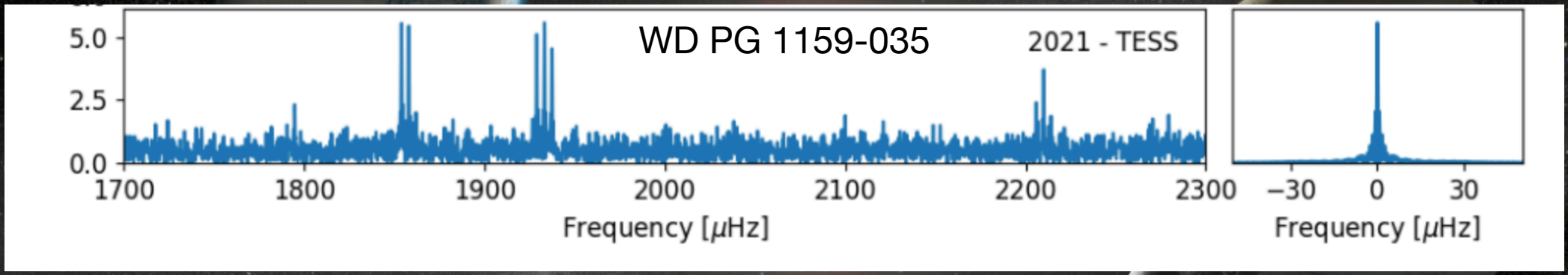
Stellar Variablity: Asteroseismology for thousand of Solar-like oscillators (Hatt et al. 2022)

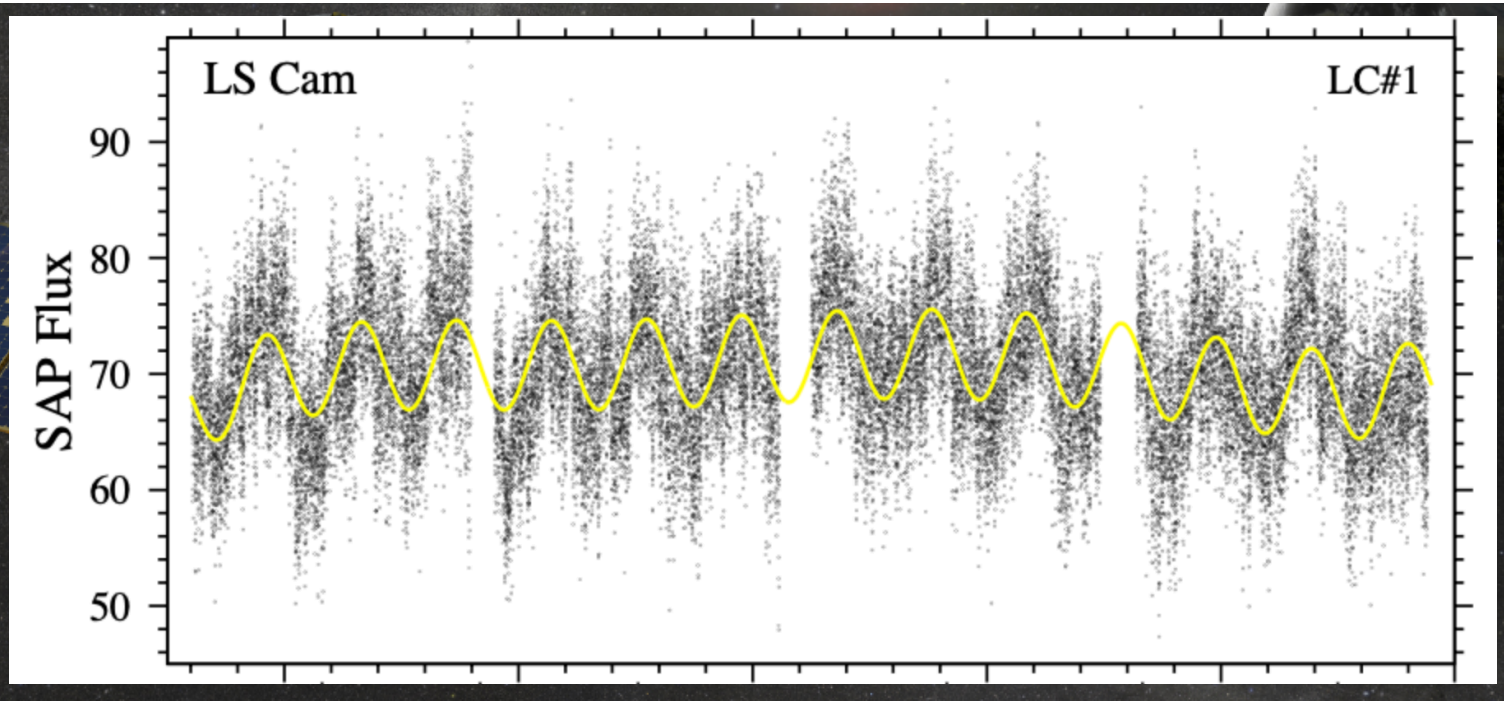


large frequency separation (Δν) vs frequency at maximum power (νmax)

Stars and Stellar Astrophysics

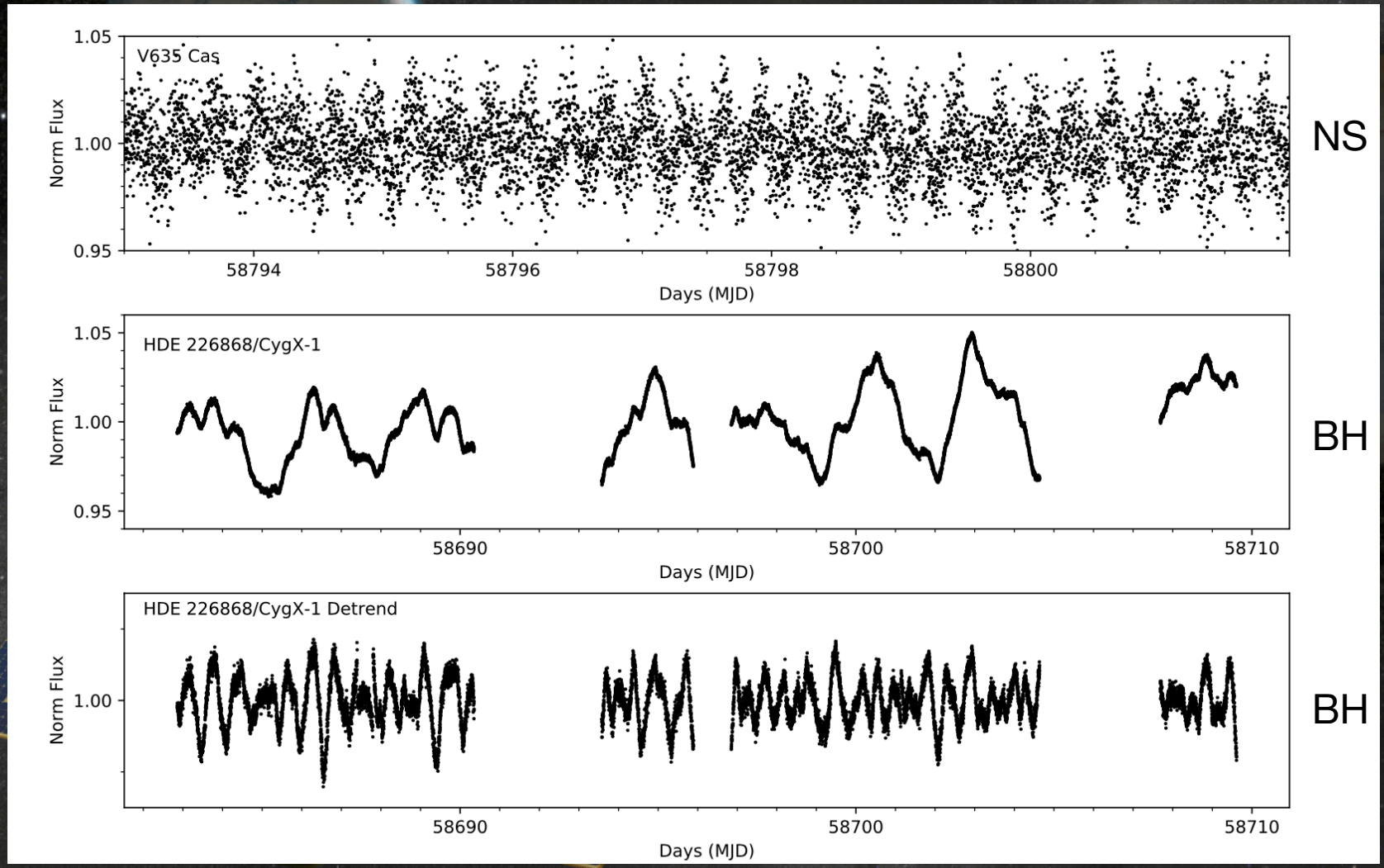
<u>Stellar Variability</u>: Pulsating WD with hundreds of frequencies (top, PG 1159-035, Oliveira da Rosa et al., 2022); Cataclysmic Variables (bottom Bruch 2023)





Stars and Stellar Astrophysics

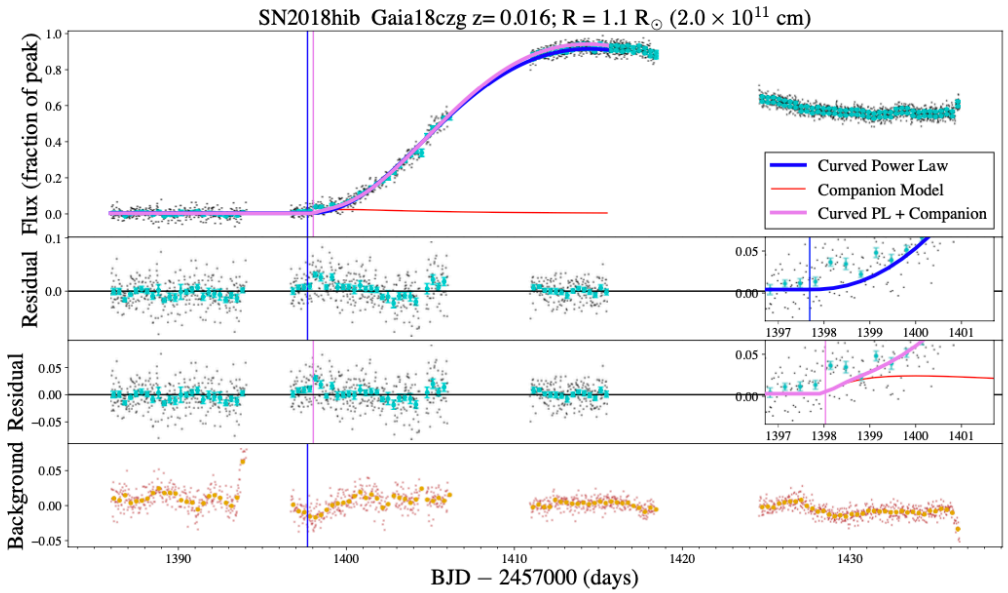
Neutron Stars and Black Holes: Ground-based ~0.5-day variability in High-Mass X-ray Binaries confirmed by TESS (e.g. Ramsay et al. 2022)

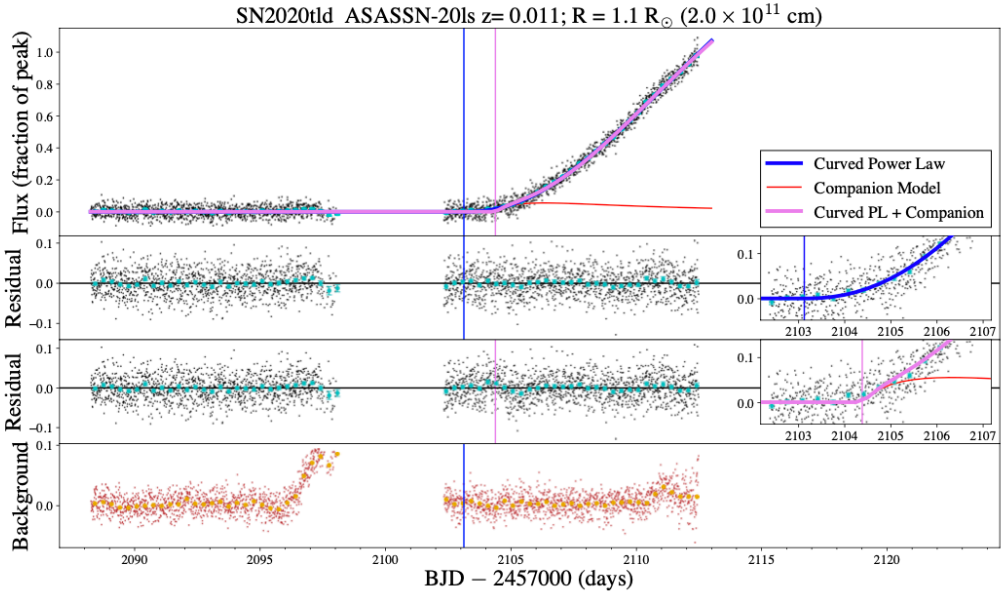


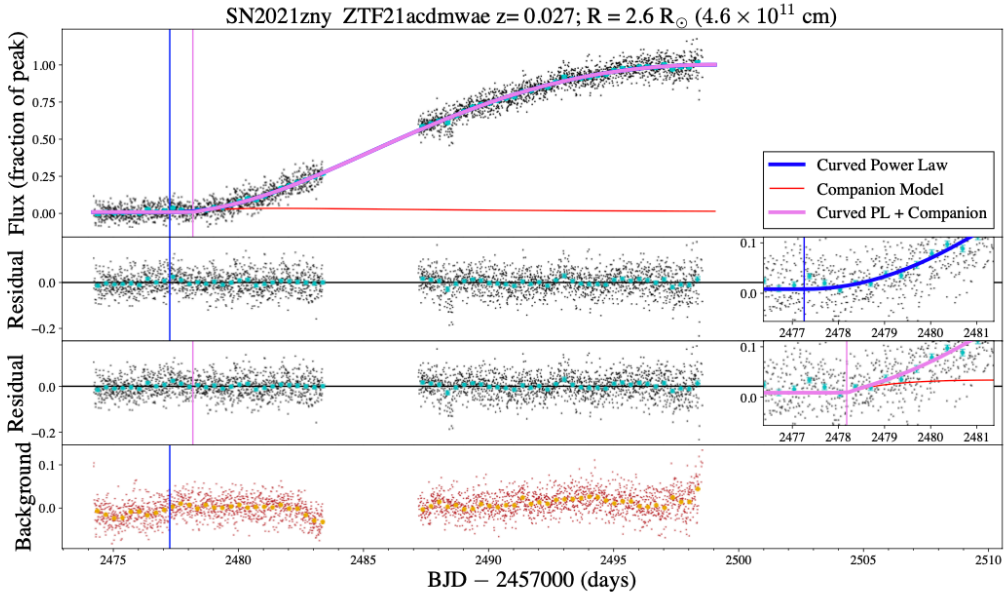
Evidence for potential outbursts for some systems (synchronizes with X-ray flares)

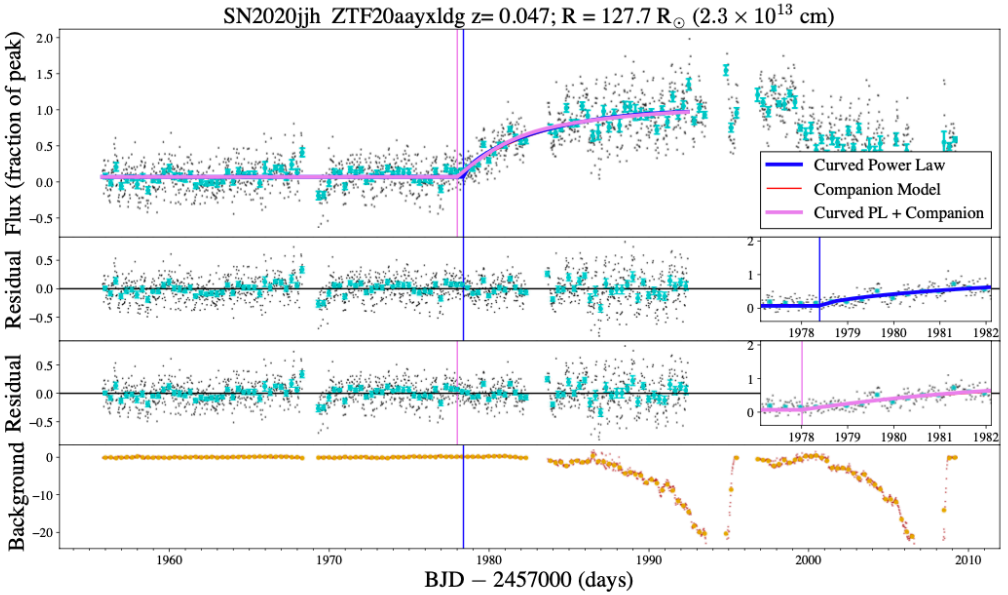
Stars and Stellar Astrophysics

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



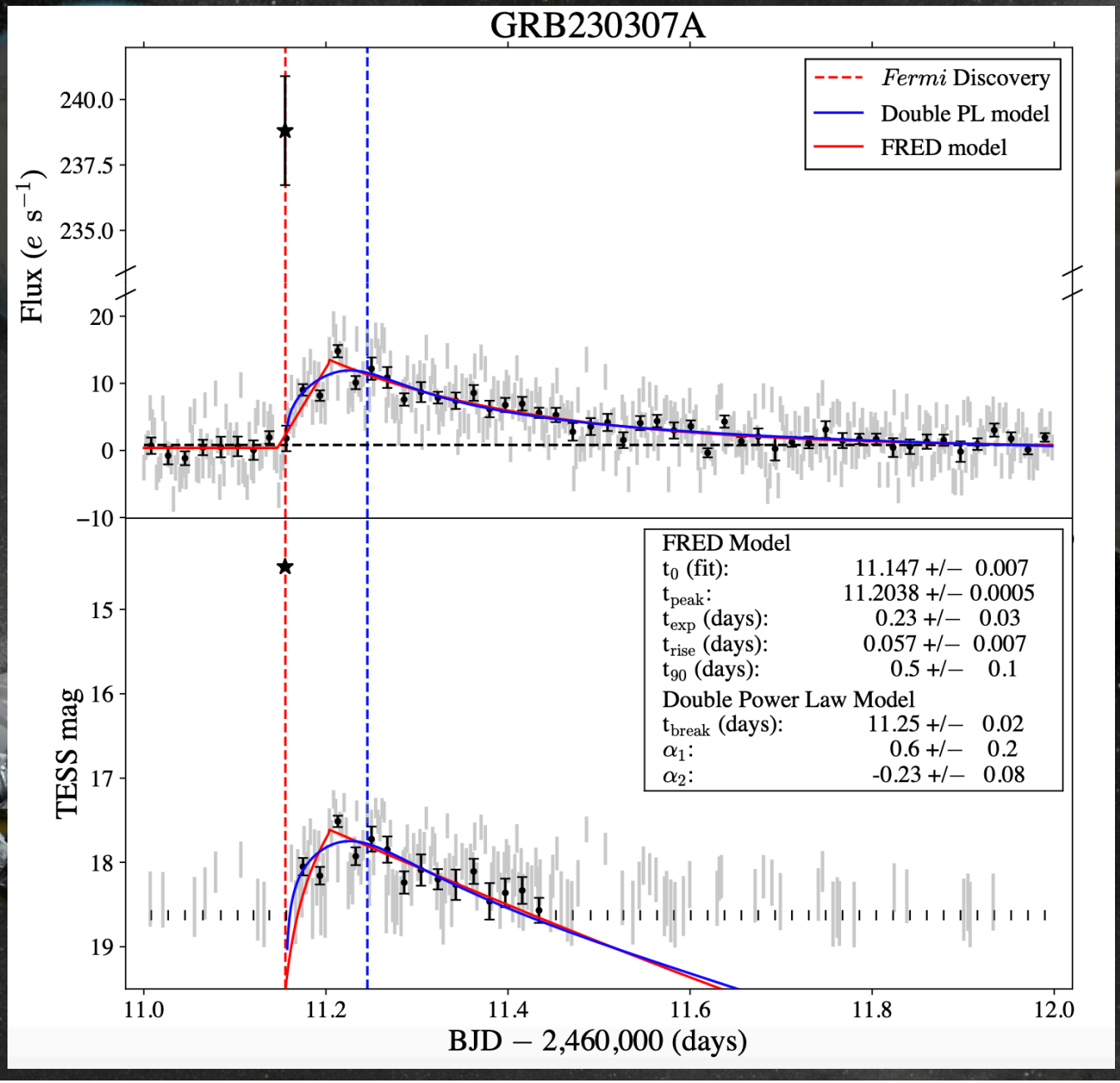






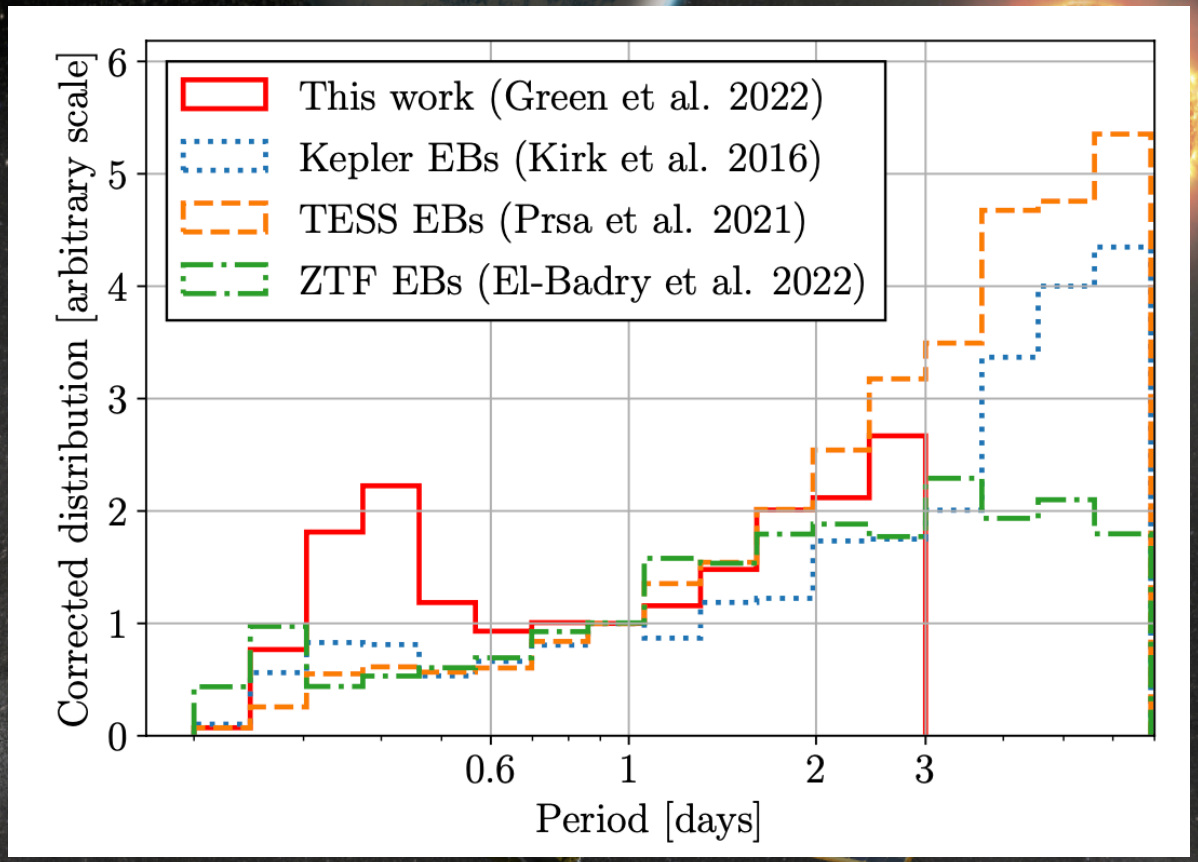
Stars and Stellar Astrophysics

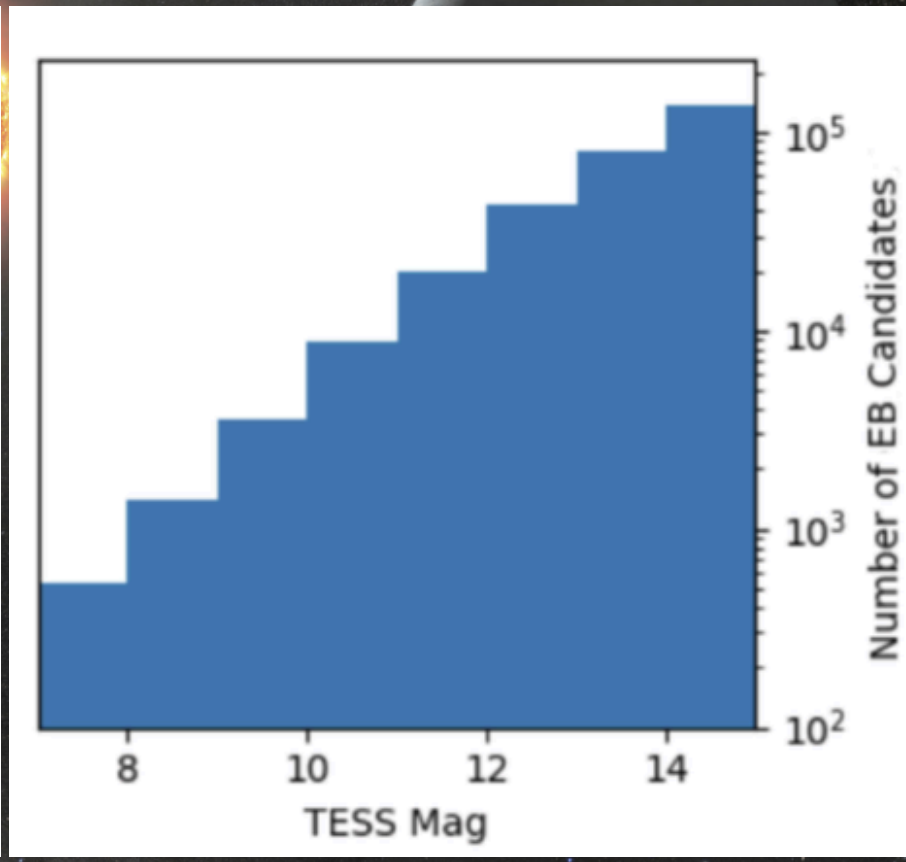
GRBs: Rapid follow-up just days after detection (GRB 230307A, Fausnaugh et al. 2023)



Stars and Stellar Astrophysics

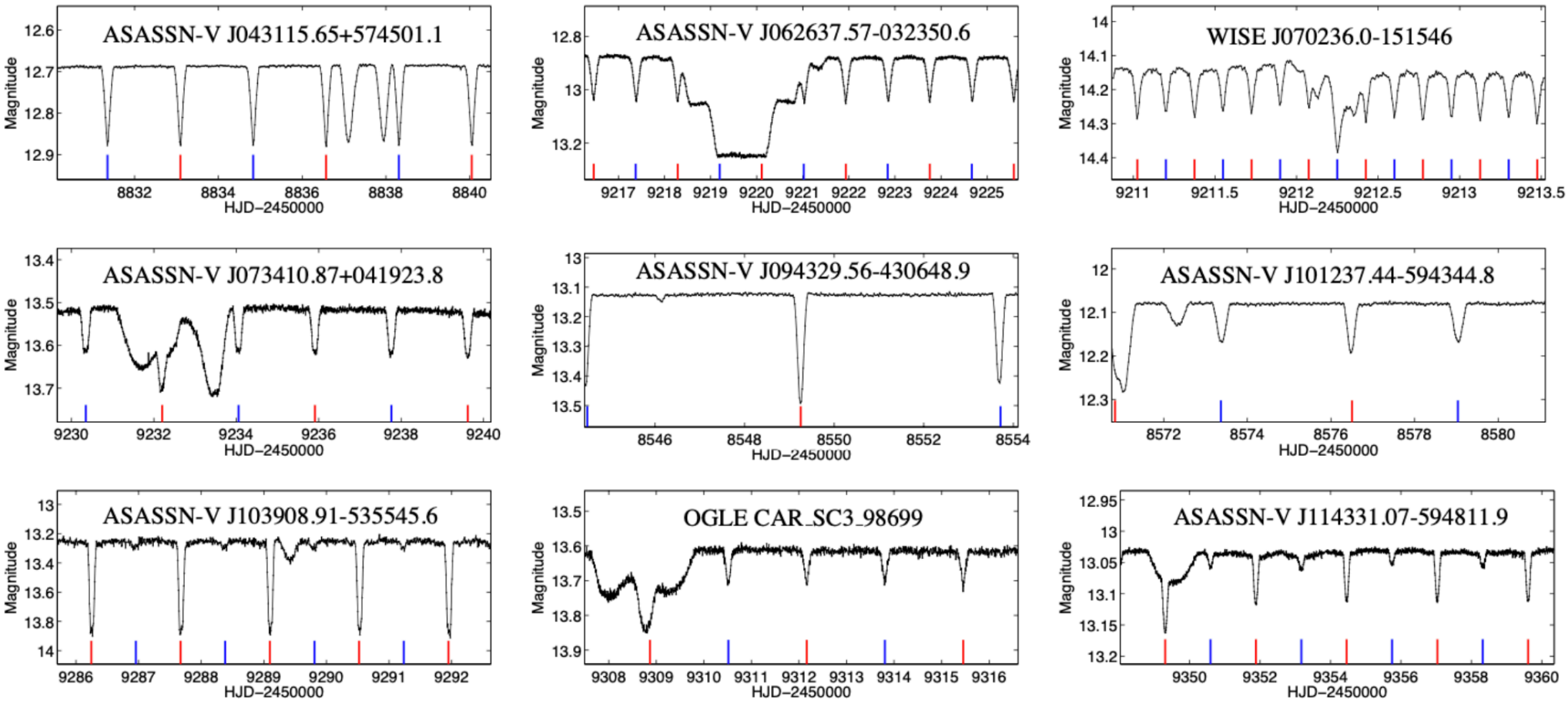
Eclipsing binary stars: Hundreds of thousands of systems (e.g. Prsa et al. 2022; Green et al. 2023, Kruse et al. in prep)





Stars and Stellar Astrophysics

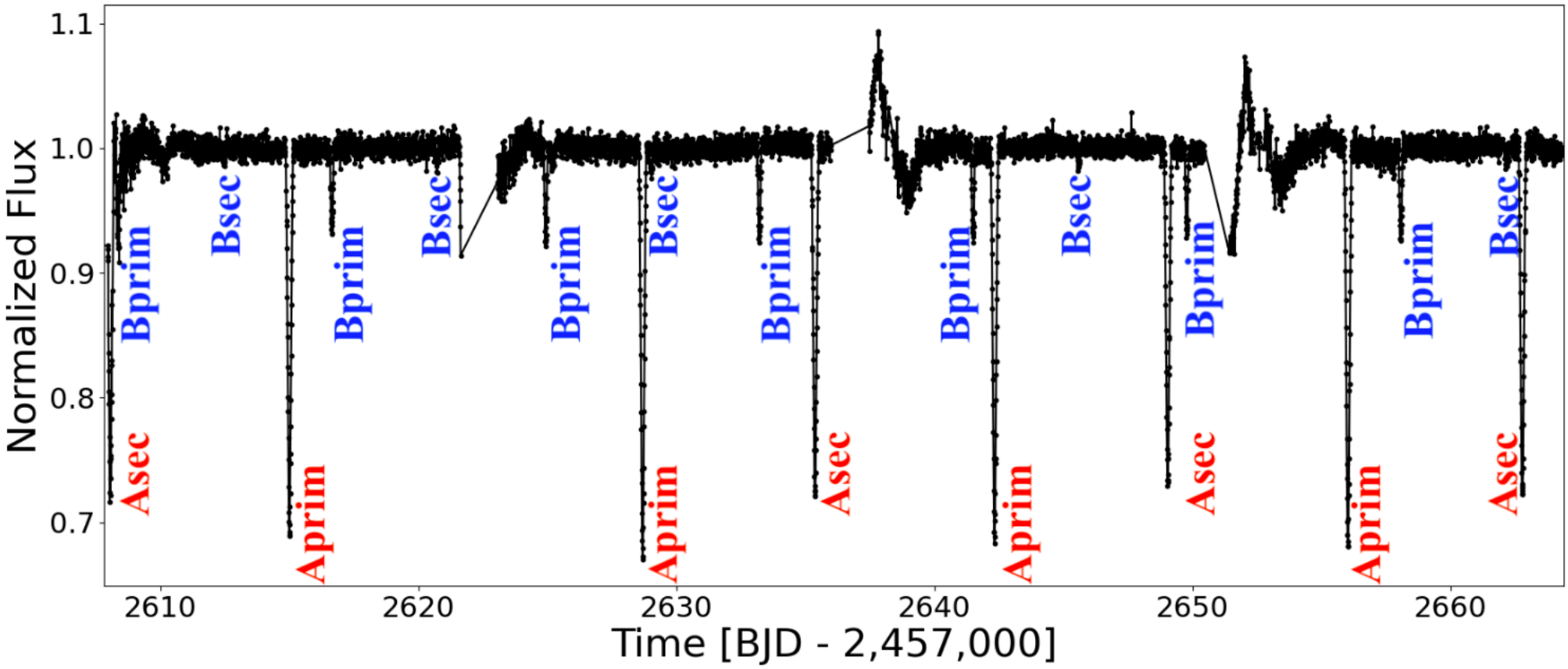
Multiple Stars: Hundreds of multiply-eclipsing stellar triples and quadruples (e.g. Borkovits et al. 2023; Kostov et al. 2023, 2024; Rappaport et al. 2023; Zasche et al. 2023)



Triply-eclipsing triples

Stars and Stellar Astrophysics

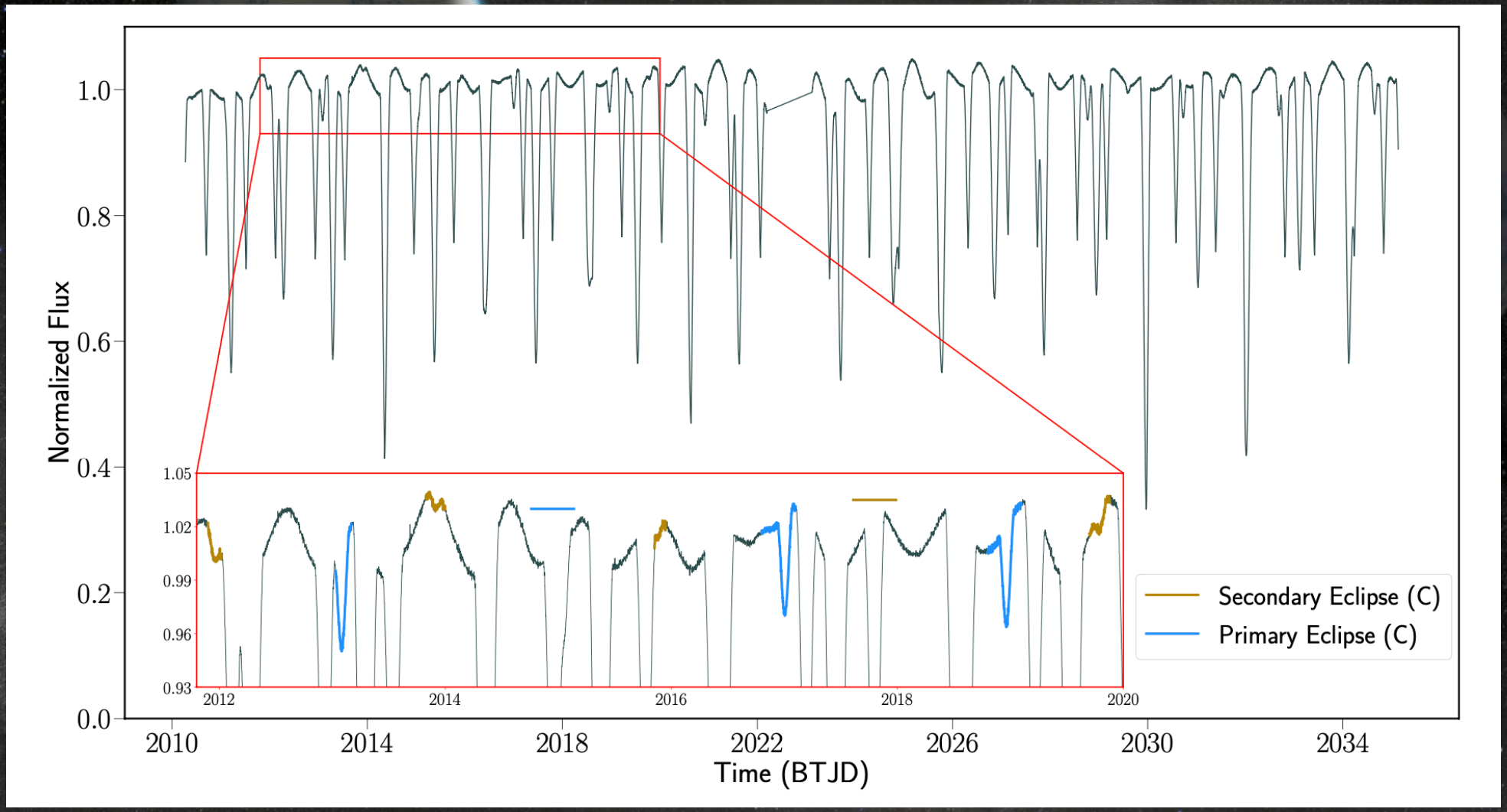
Multiple Stars: Hundreds of multiply-eclipsing stellar triples and quadruples (e.g. Borkovits et al. 2023; Kostov et al. 2023, 2024; Rappaport et al. 2023; Zasche et al. 2023)



TESS lightcurve of TIC 219006972

Stars and Stellar Astrophysics

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



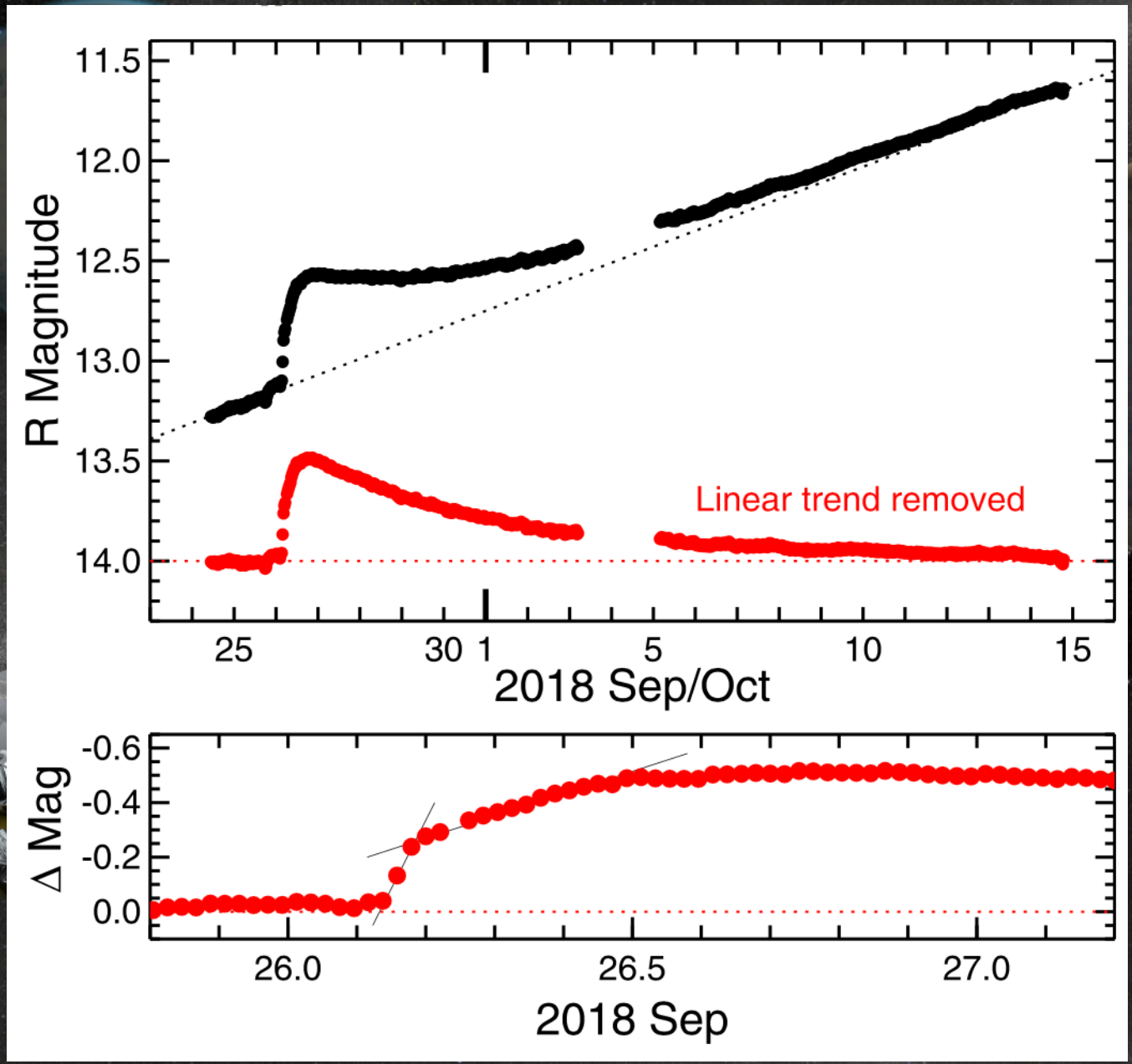
TESS lightcurve of V994 Her

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

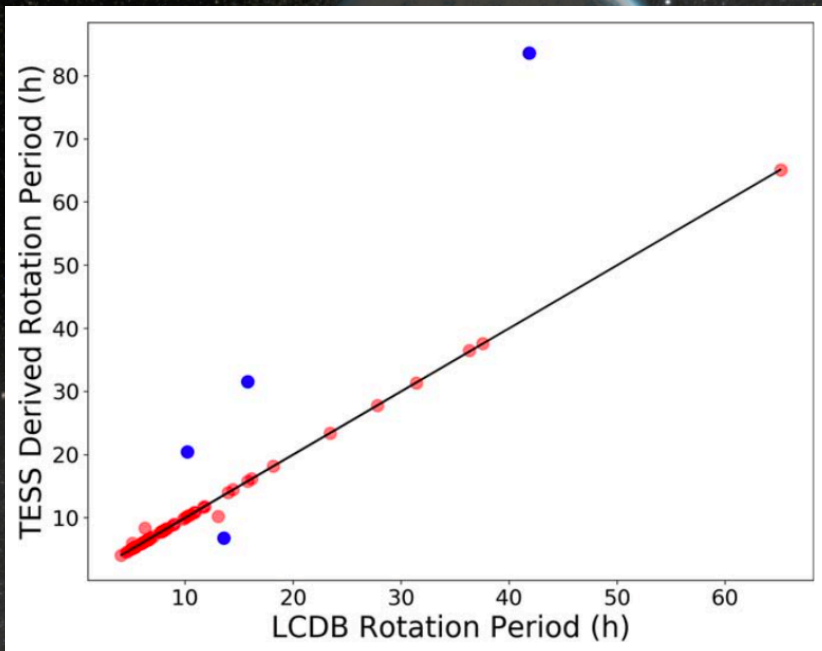
- **Comets: outburst from 46P/Wirtanen (Farnham et al. 2022)**

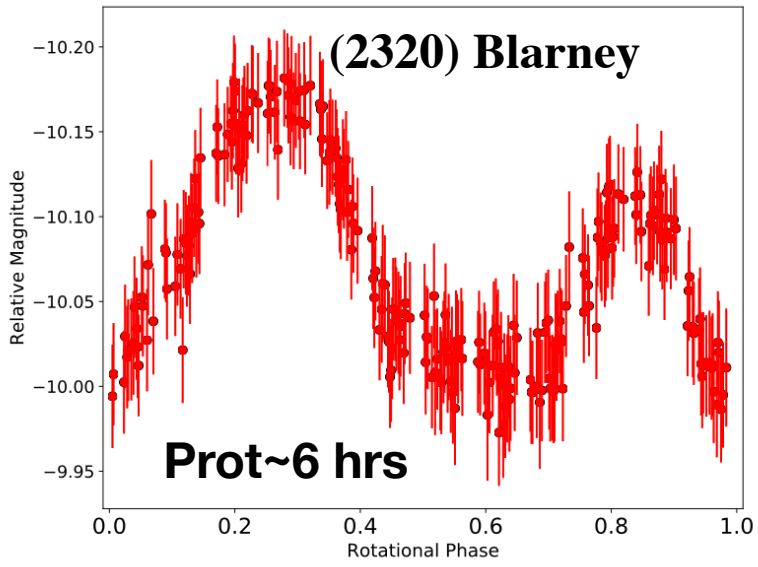


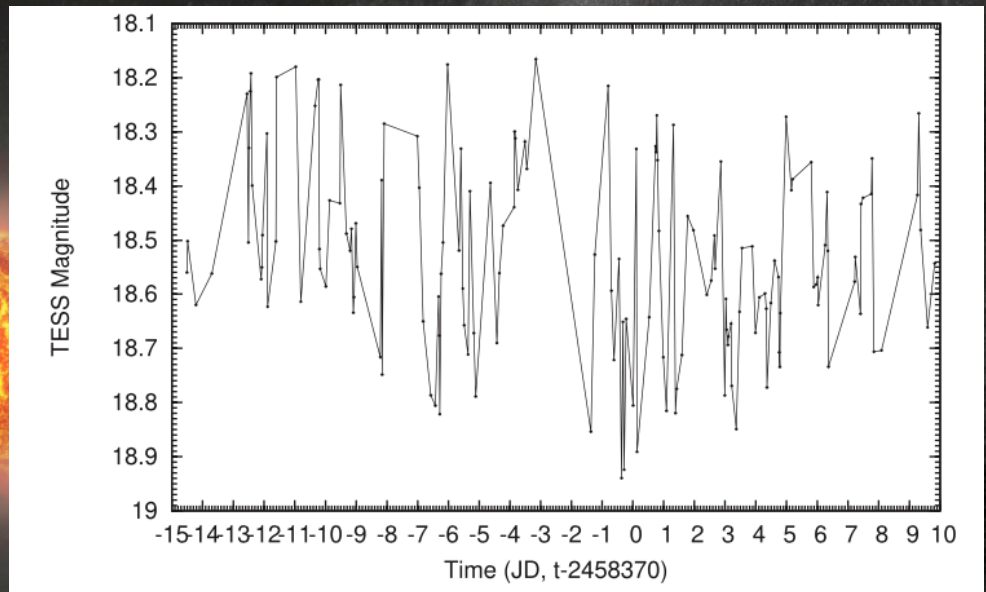
FFI detection of previously unknown dust trail

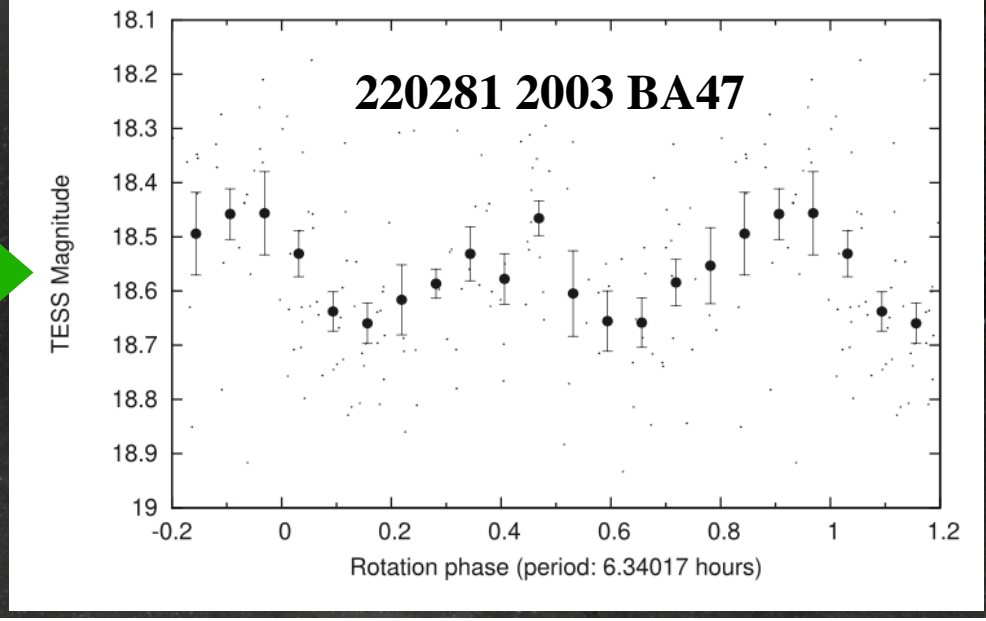
Solar System

- **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)**



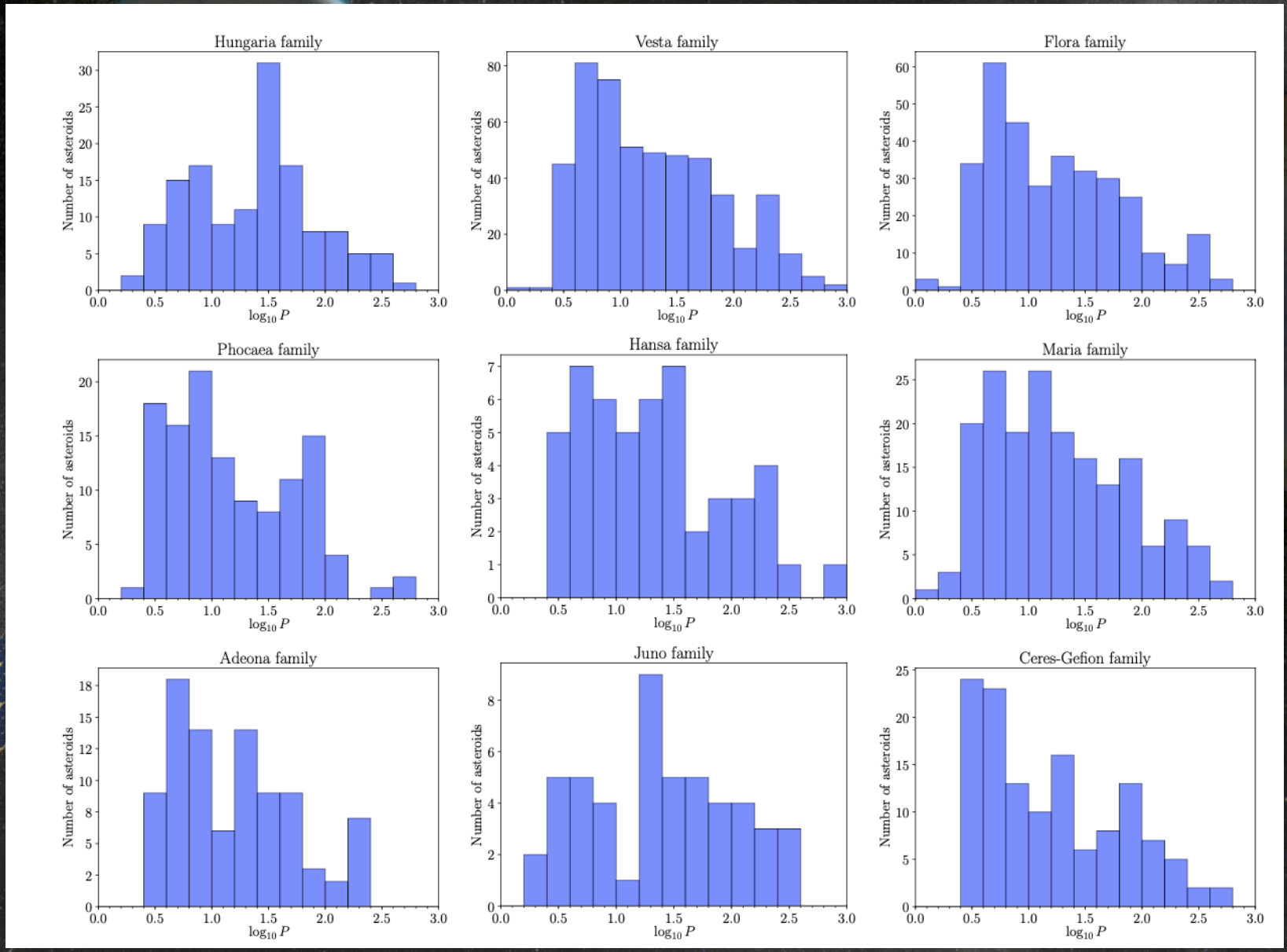






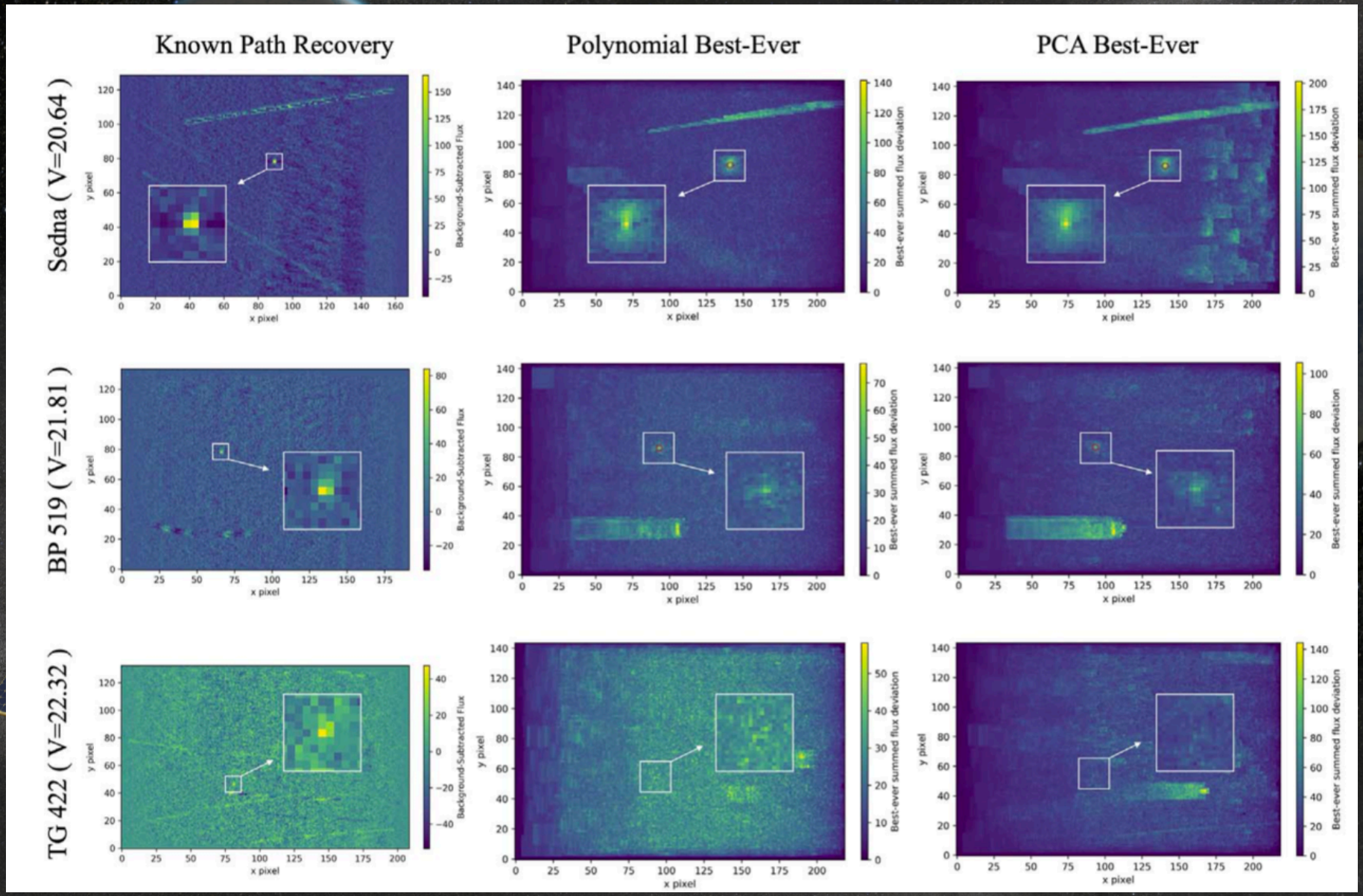
Solar System

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



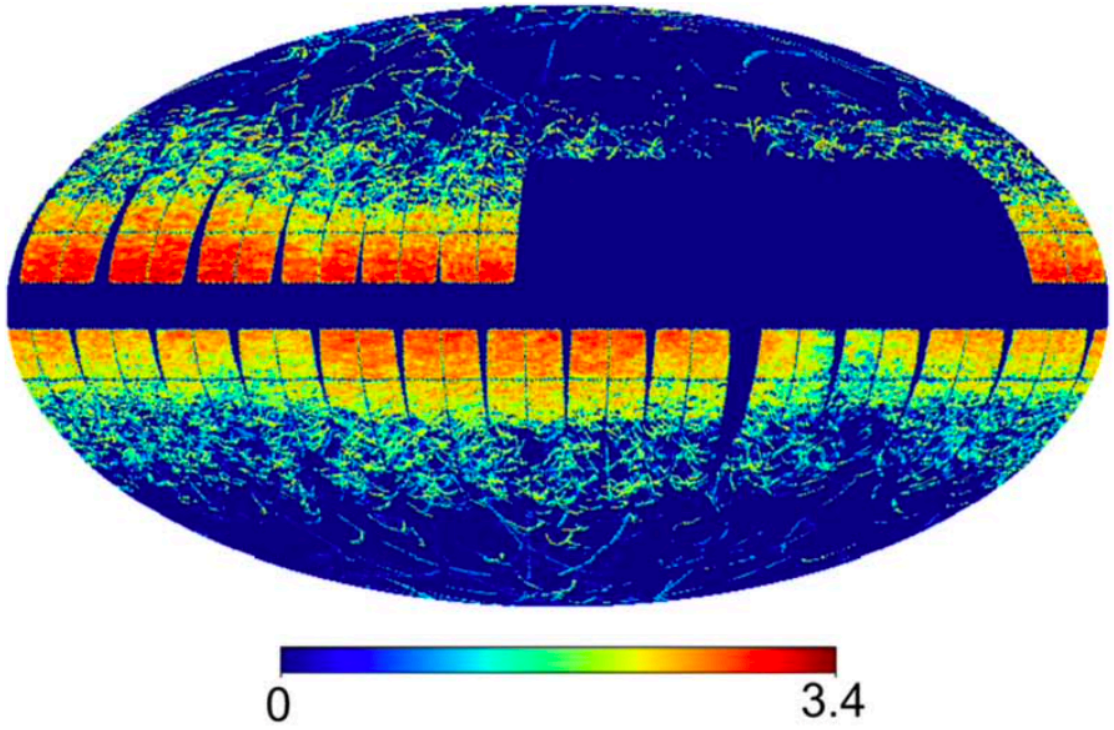
Solar System

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

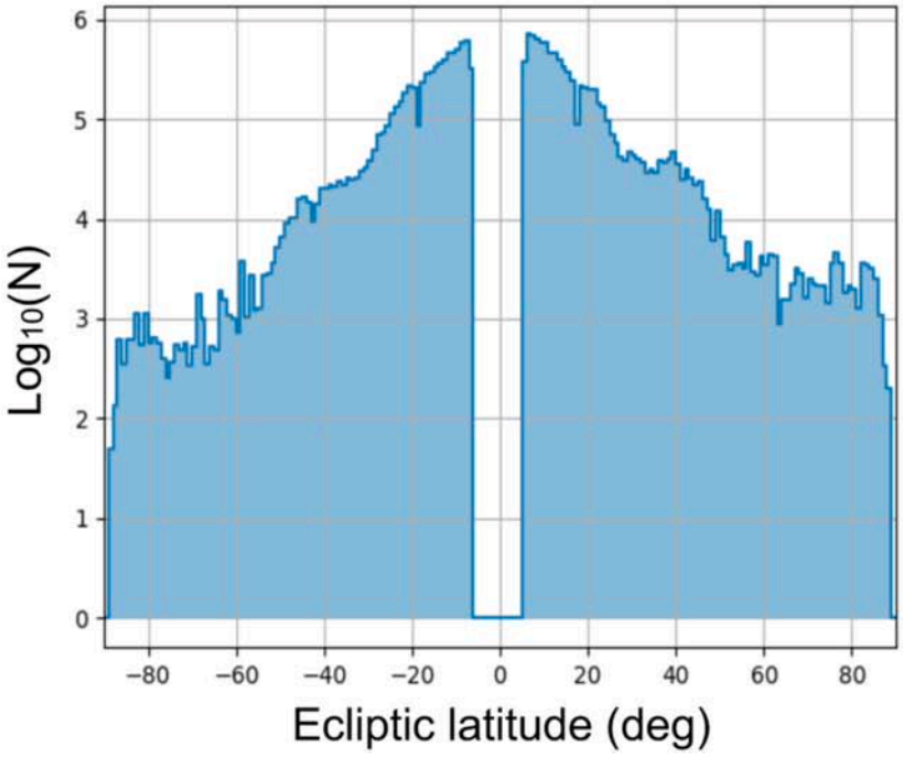


Solar System

- **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



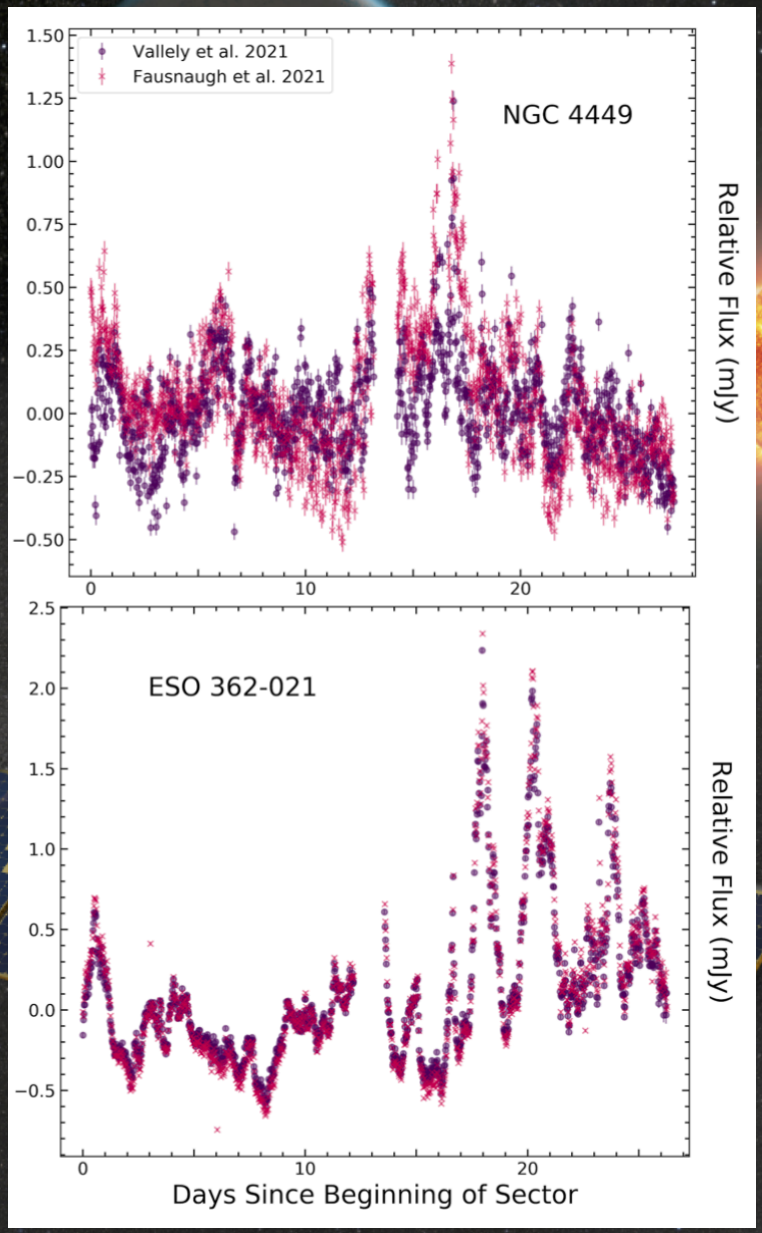
Number of objects as a function of ecliptic latitude (TESS Year 1 and 2)

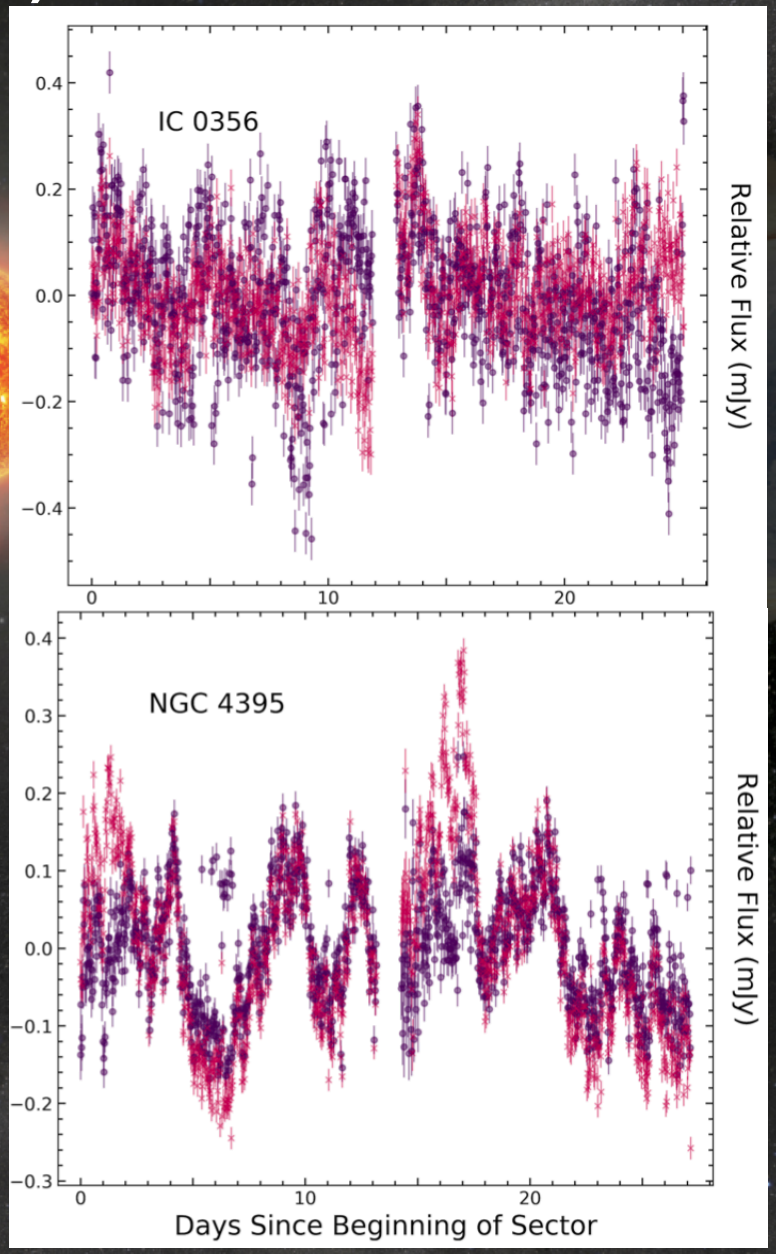
Galaxies

- *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

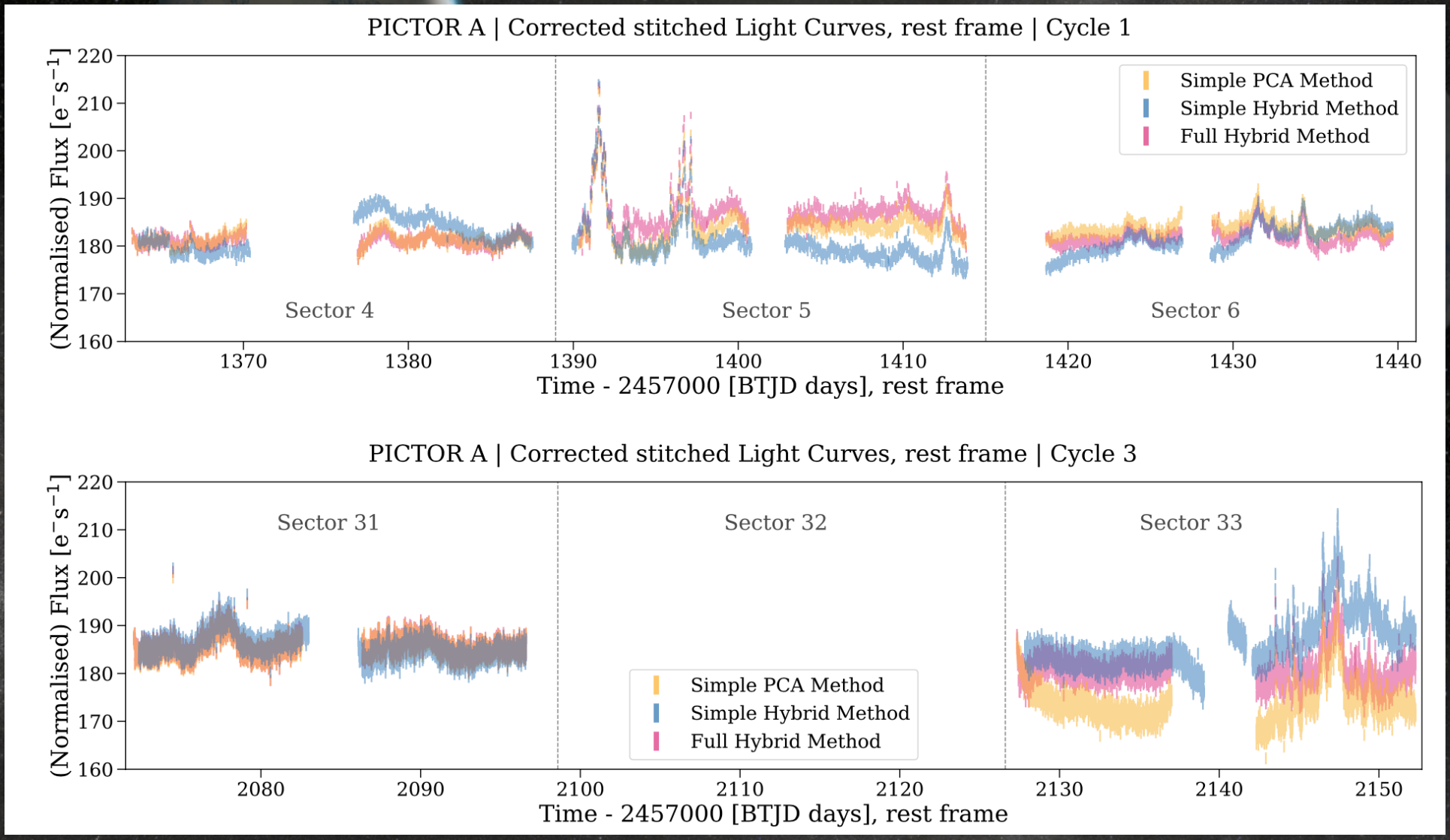
- **<u>AGN Variability</u>: Identify dozens of AGNs from variability in TESS data (e.g. Burke et al. 2021, Treibel et al. 2022). Timescales ~hours to ~days**





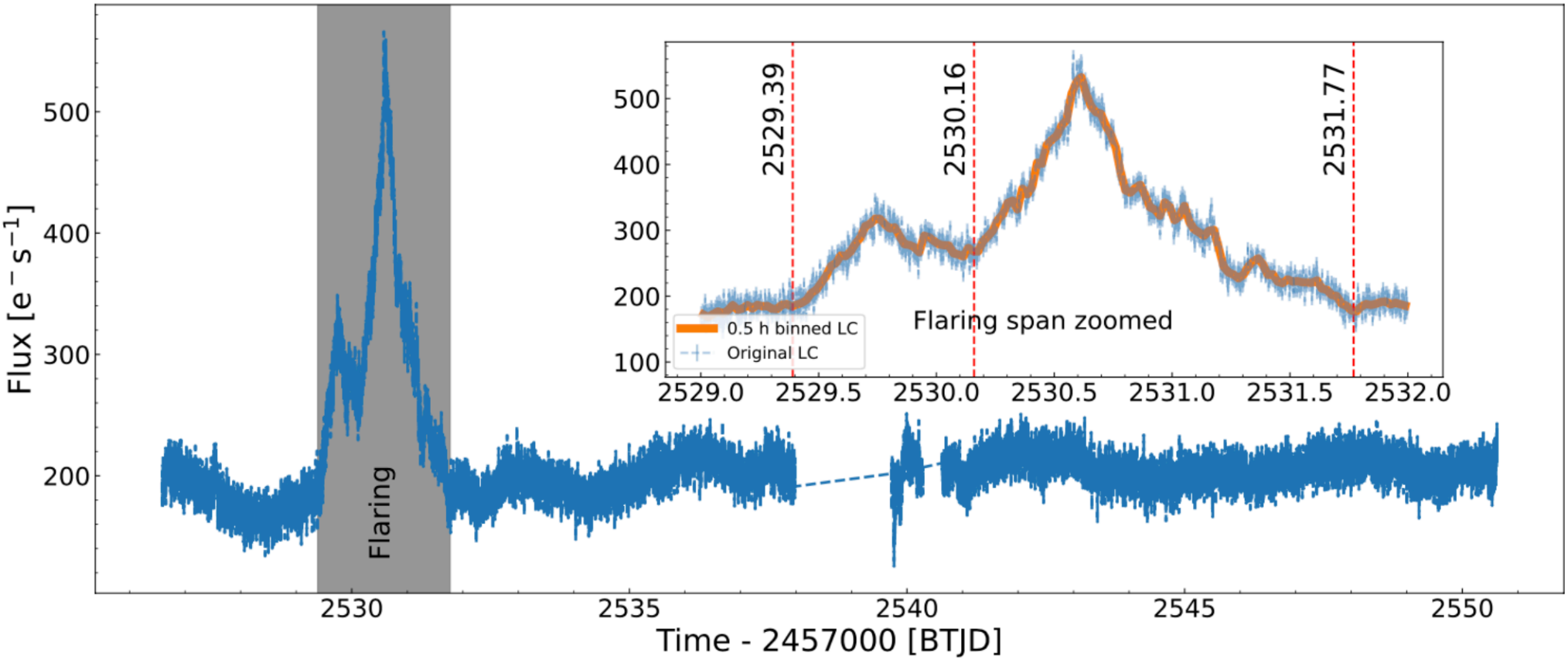
Galaxies

- **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):**



TESS data of radio-loud blazar OJ 287; doubling rise time of ~0.4 days

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)