Investigating YSO Dippers With X-Shooter

Aaron Empey

Rebeca Garcia Lopez, Antonella Natta
University College Dublin (UCD)

UCD DUBLIN

IRISH RESEARCH COUNCIL
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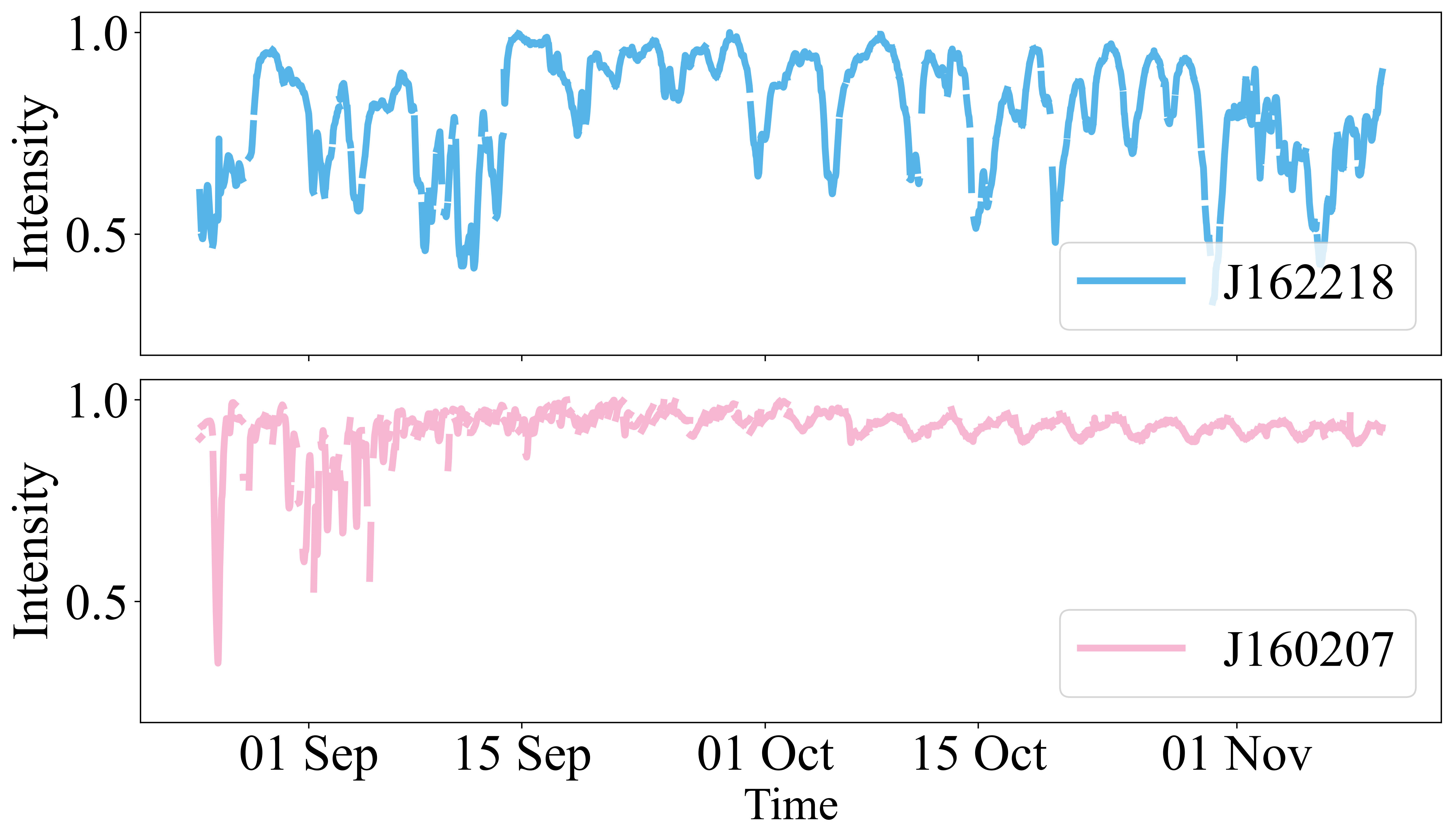
Why Dippers?

- Class of photometrically variable Young Stellar Objects (YSO)
- Account for ~30% of Classical T-Tauri Stars (CTTS)
- Frequent short term dips in their light curves at a range of wavelengths
- Irregular dippers believed to be due to changes in dust from inner circumstellar disc
- Unique insight into inner disc region and its dynamics

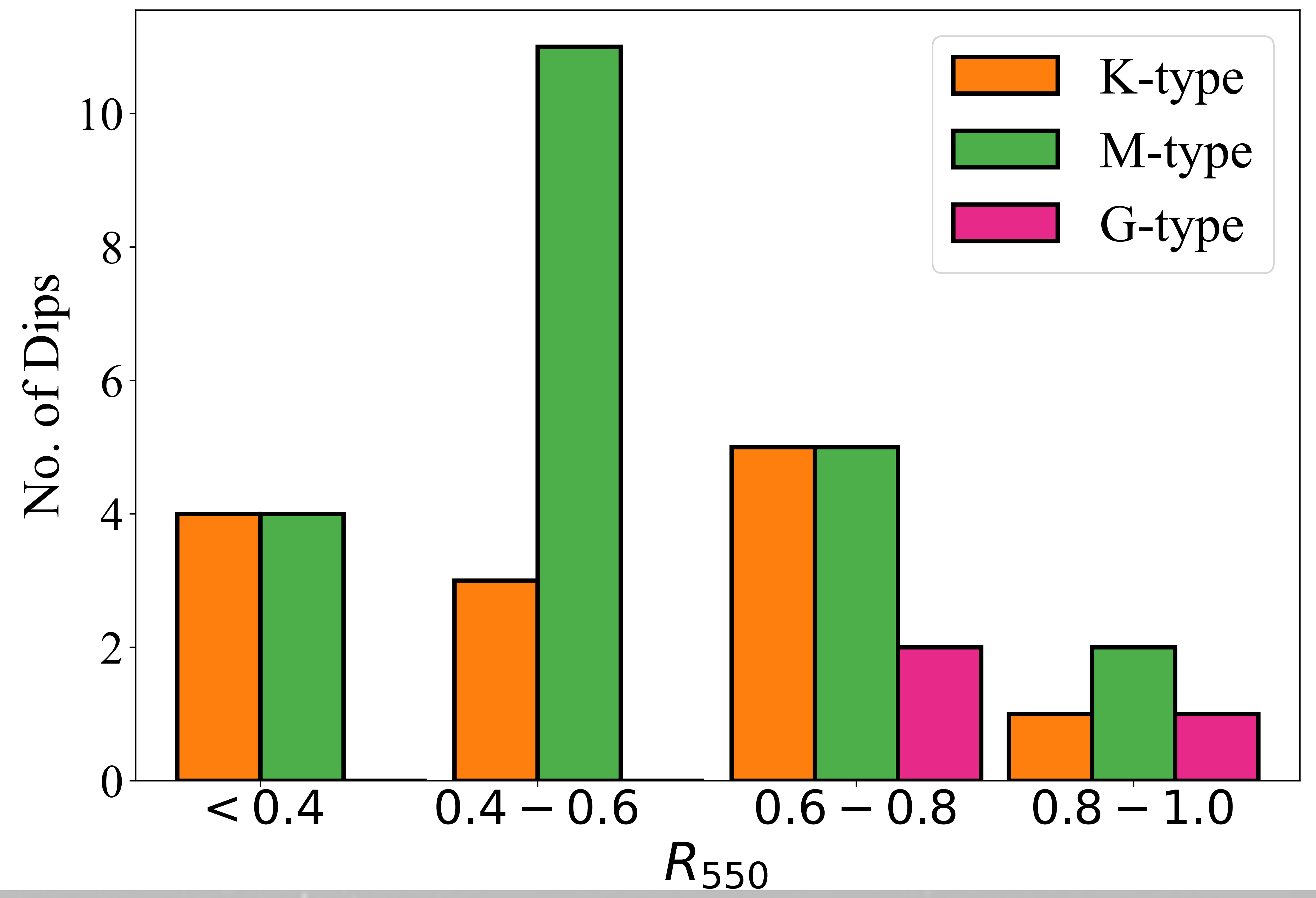


Example K2 Dipper light curves

What Do We Have?

- Survey of 16 irregular dippers from Upper Scorpius
- Targets are all K and M spectral types (+1 G type)
- X-Shooter spectra provide wide wavelength coverage
- Observations randomly sample each target
- 2 - 4 epochs per target with time intervals varying from 1 day to years apart
- 37 recorded dips

Empey et al., in prep



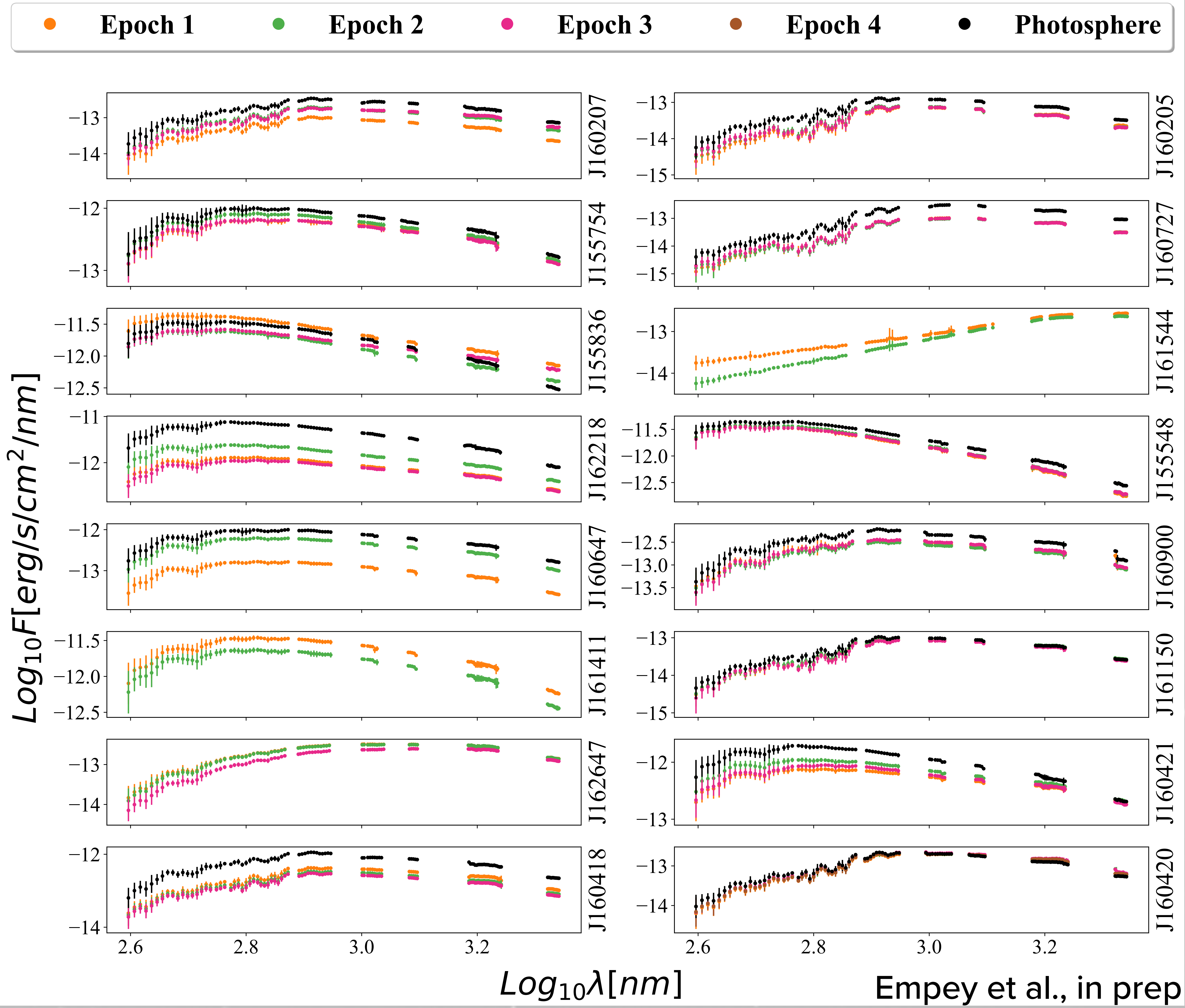
X-Shooter dipper sample spectral types, grouped by observed dip depth at 550nm

Stellar Photosphere

- Data sparsity means we cannot say if a system is in a stable state
- Combination of Class III templates and Gaia photometry to reproduce a photosphere
- Investigate dips with respect to this stable state

$$F_{obs} = F_{phot} e^{-\tau_\lambda}$$

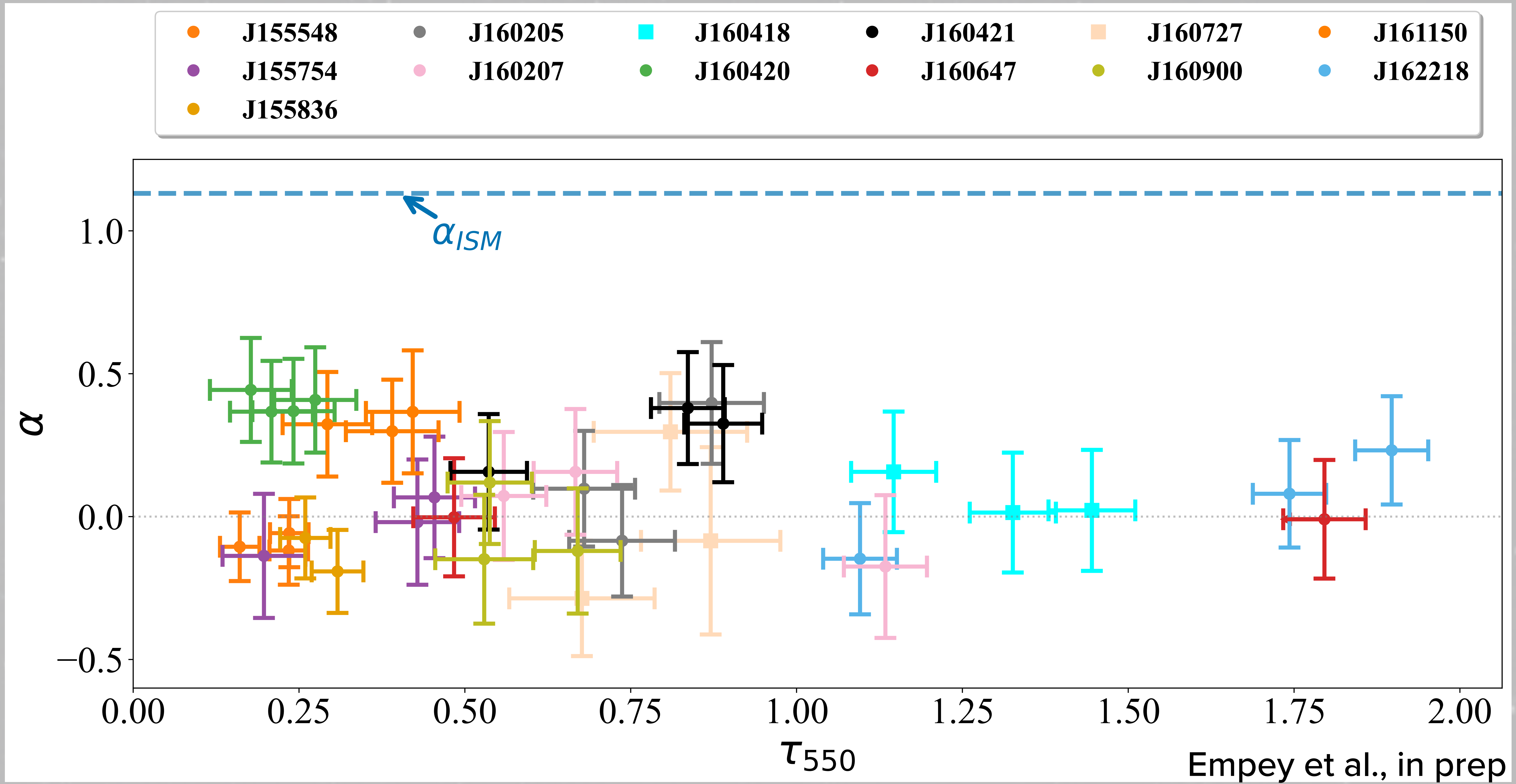
$$R_{550} = \left.\frac{F_{dip}}{F_{phot}}\right|_{550} = e^{-\tau_\lambda} \qquad \alpha = \frac{log\left(e^{\tau_{\lambda_2}}/e^{\tau_{\lambda_1}}\right)}{log(\lambda_2/\lambda_1)}$$



Empey et al., in prep

Dip Measurements

- Low dip optical depths
- All low α values that are below that of ISM reddening
- 80 % have "flat" optical depths - $\alpha \leq 0.2$

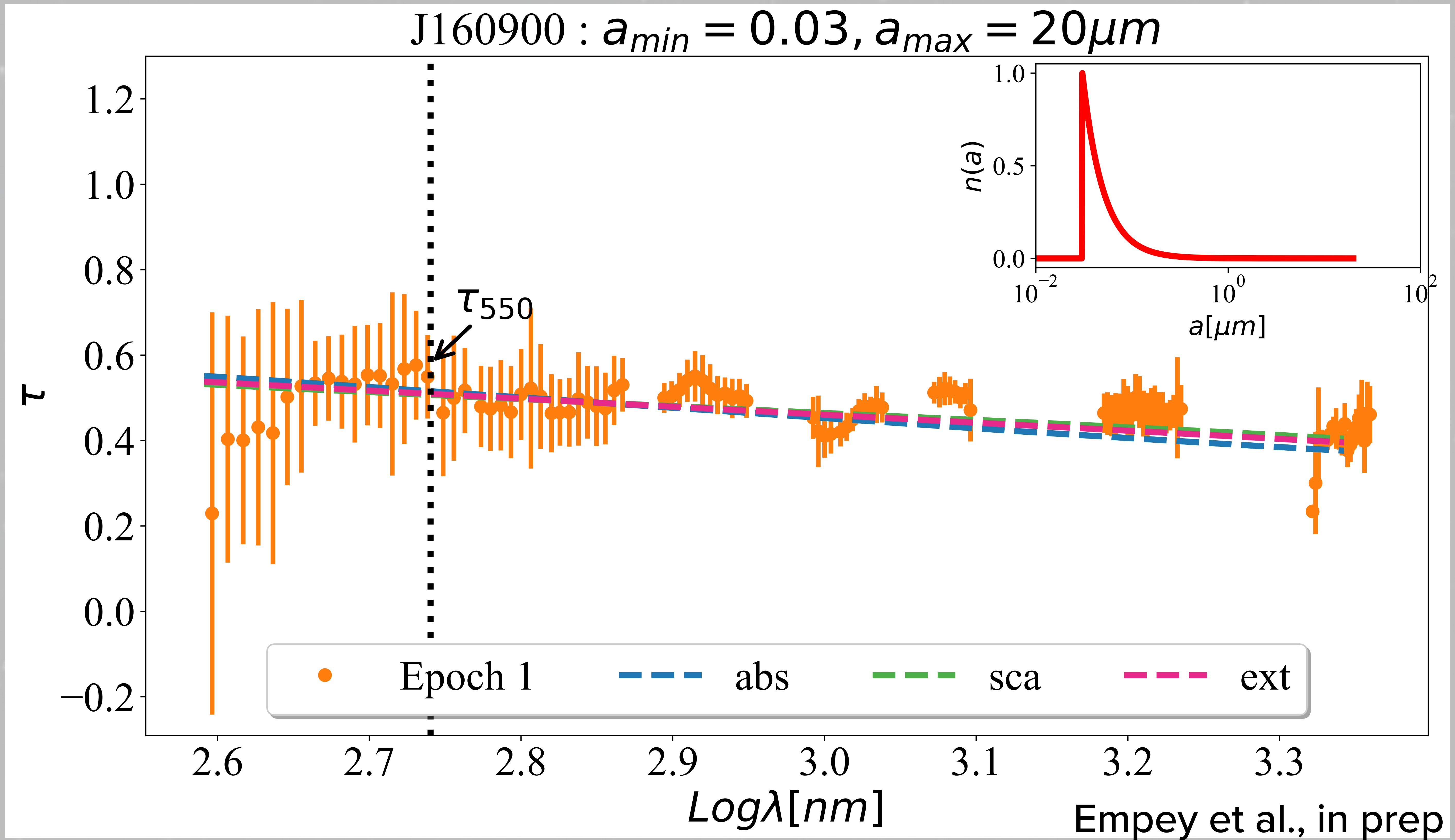


α, τ_{550} measurements for observed dips colour coded by object's 2MASS identifier

Dip Driving Mechanisms

- Results not consistent with presence of stellar spots or sudden accretion changes
- Dip properties are suggestive of variable extinction along LOS
- Consider τ_λ for all dips and compare alongside dust opacity models
- Apply lower limit on maximum size of dust grains

Dust Substructures



Empey et al., in prep

Dip showing grey-like extinction

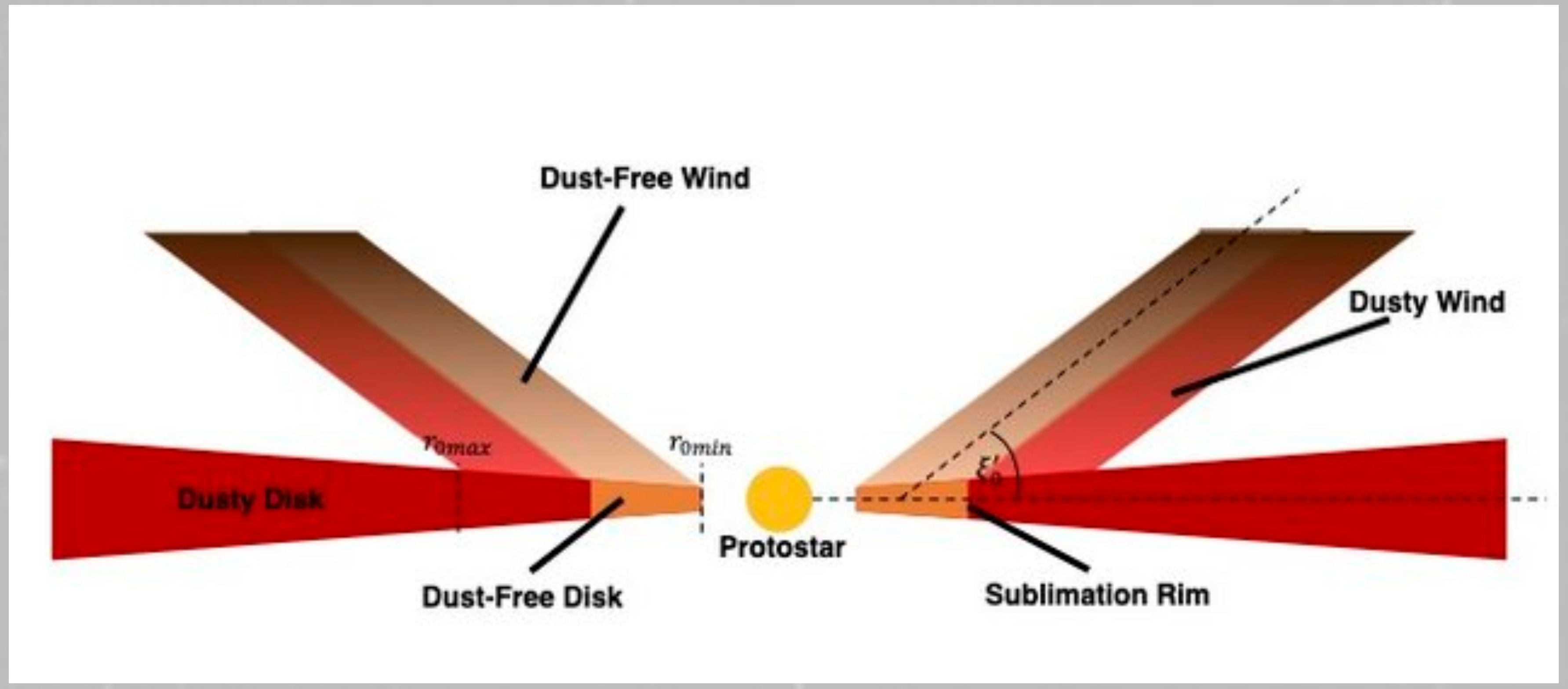
All cases require processed dust grains

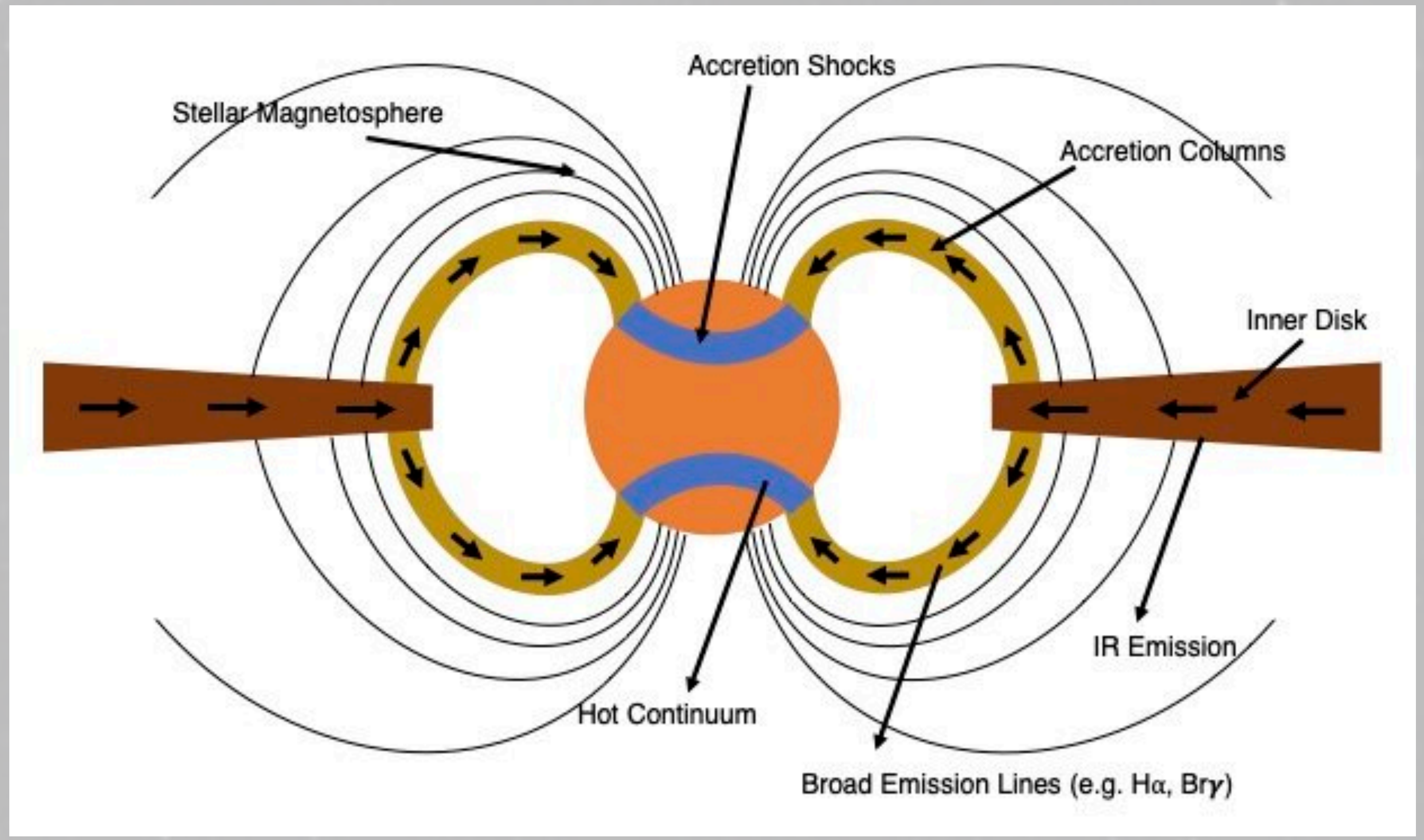
$$a_{min} = 0.03 - 0.3\mu m$$

$$a_{max} = 0.2 - 50\mu m$$

And so what…?

- Dip properties suggest dust substructures containing processed grains
- Grain growth in the innermost disc region
- Dust grains must be lifted into LOS:
  - Disk winds entraining surface grains (Miyake et al. 2016, Grinin et al. 2023)
  - Grains lifted into accretion columns (Sicilia Aguilar et al. 2020, Bodman et al. 2017)
  - Combination of effects





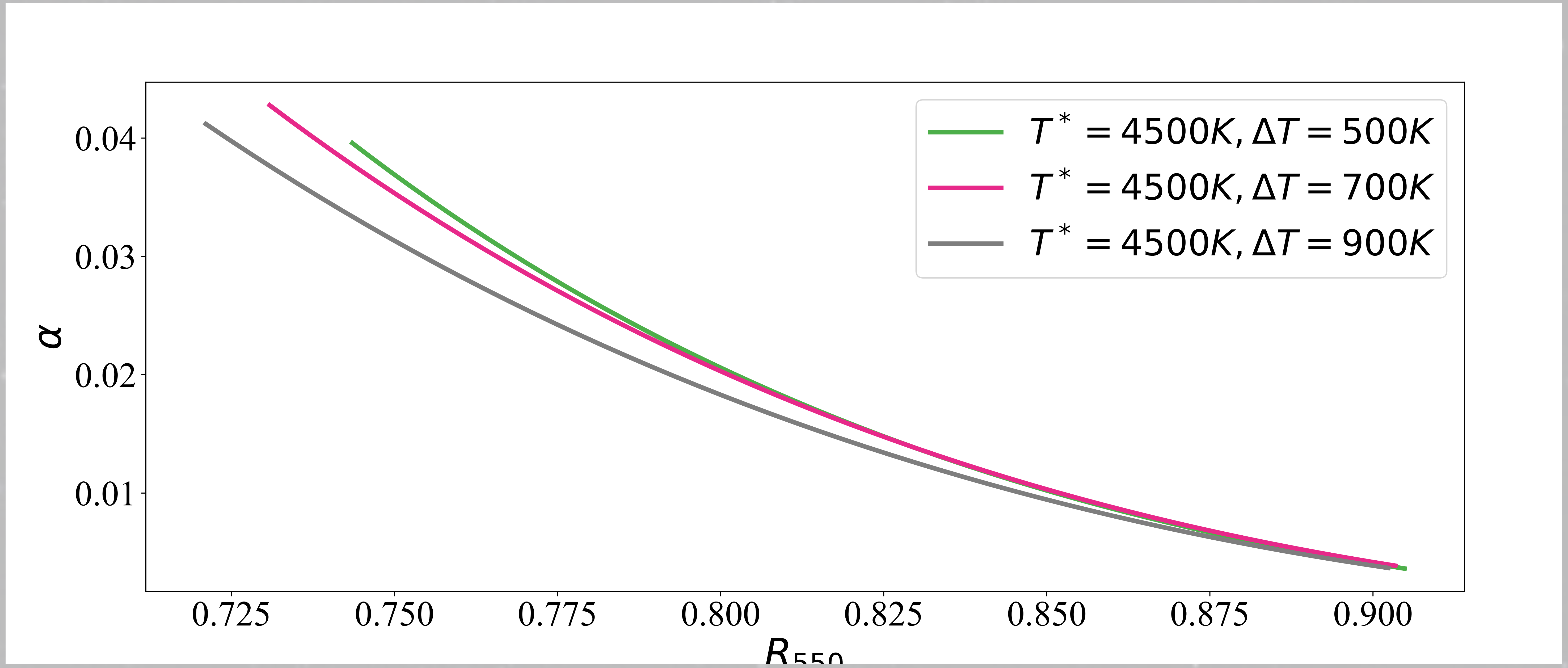
Credit: Labdon A., 2021

Concluding Remarks

- 37 Dips recorded from 16 targets with low optical depths
- Inner disc region very dynamic with dip properties changing between epochs
- Dips not consistent with presence of stellar spots or accretion variability
- Dust opacity models suggest processed grains are lifted above disc surface
- Possible mechanisms to lift dust grains:
    - Disc winds
    - Accretion columns
    - Combination of effects

Stellar Spots

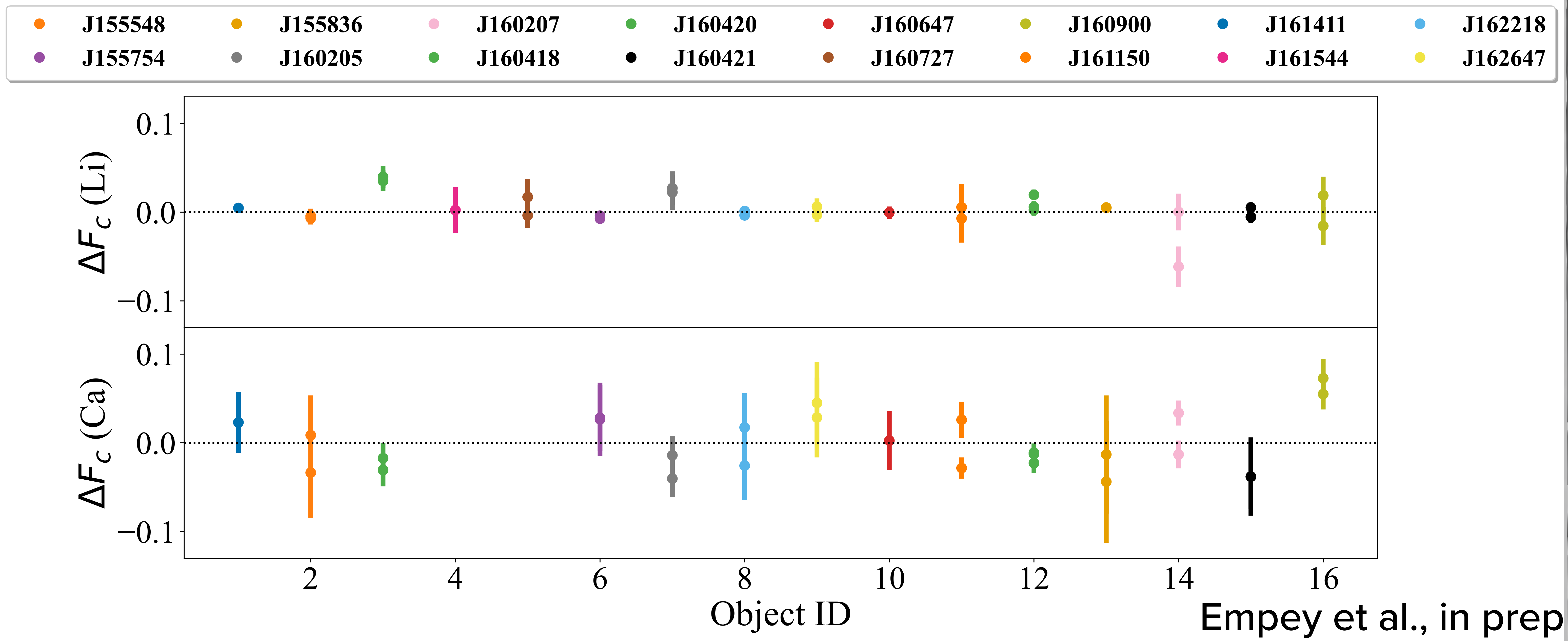
- Dark patches on stellar surface:
  - Temperatures ~500 K lower
  - Typical filling factors 5-30%
- Perform α, R_{550} analysis with clean and spotted blackbodies
- Unable to reproduce observations



Blackbody modelling of stellar spot dip parameters

Accretion Variability

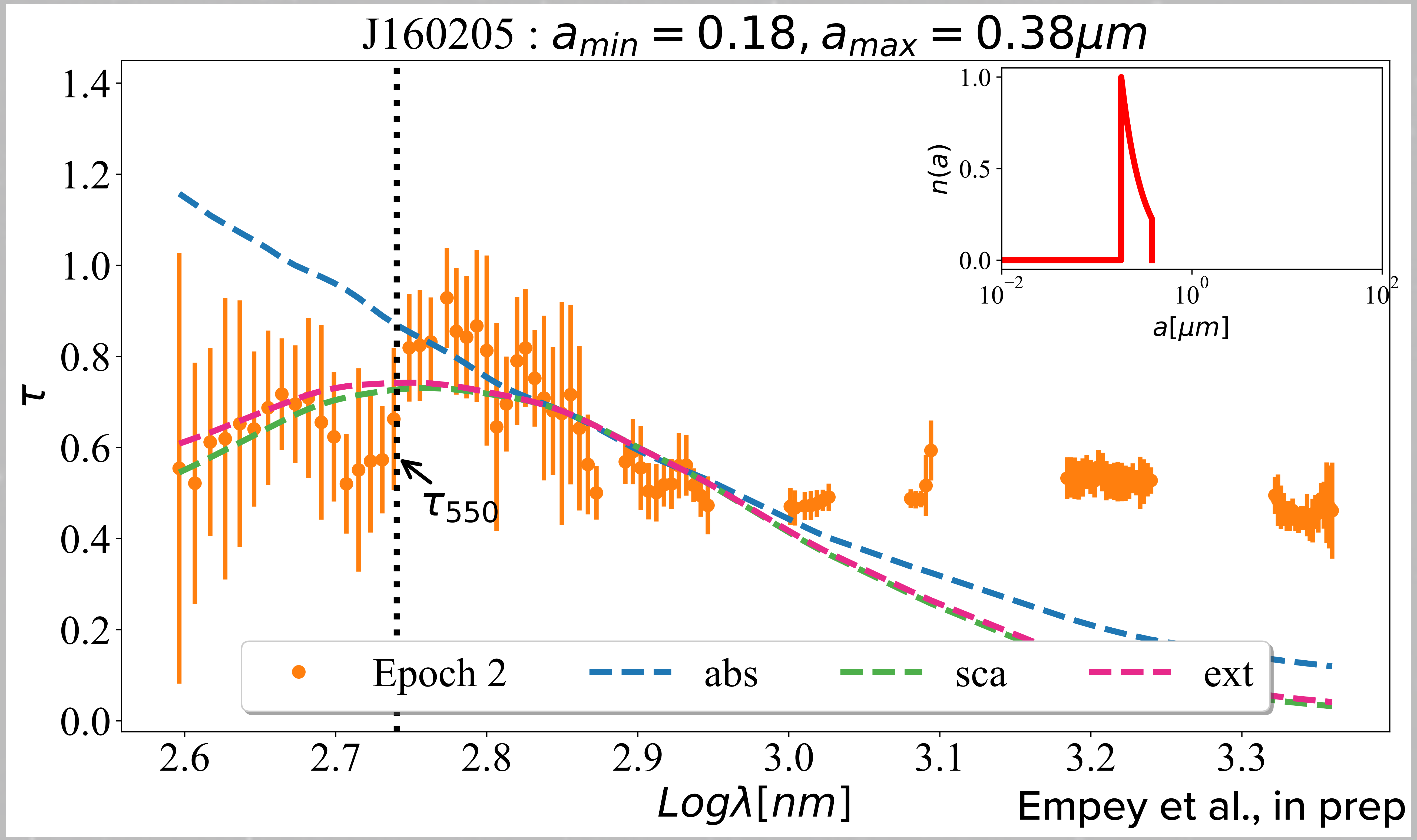
- Check for changes in photospheric line veiling between epochs
  - Ca I - 422.67 nm
  - Li I - 670.78 nm
- Measuring EWs to derive continuum level
- <10% change in continuum level for all targets
- No evidence for significant accretion variability



Empey et al., in prep

Relative changes in continua derived from line EWs

Dust Substructures



Dip showing “bumpy” extinction curve

Require narrow grain size distributions