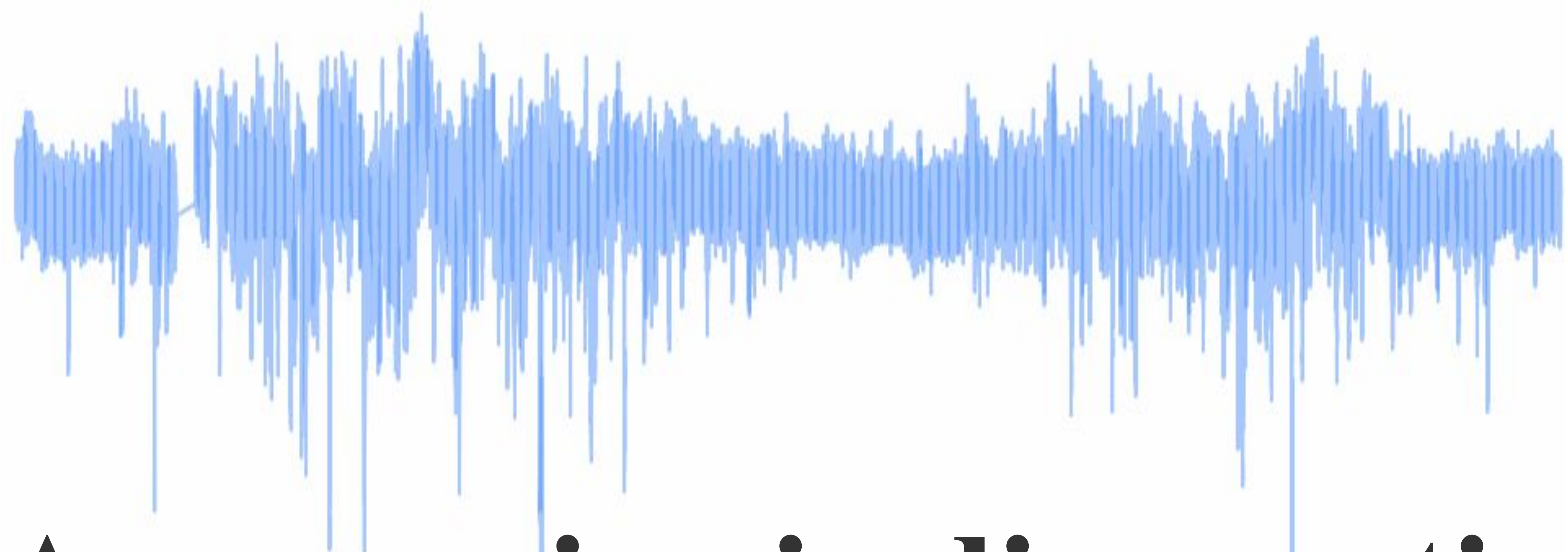

A new seismic diagnostics of stellar activity cycles

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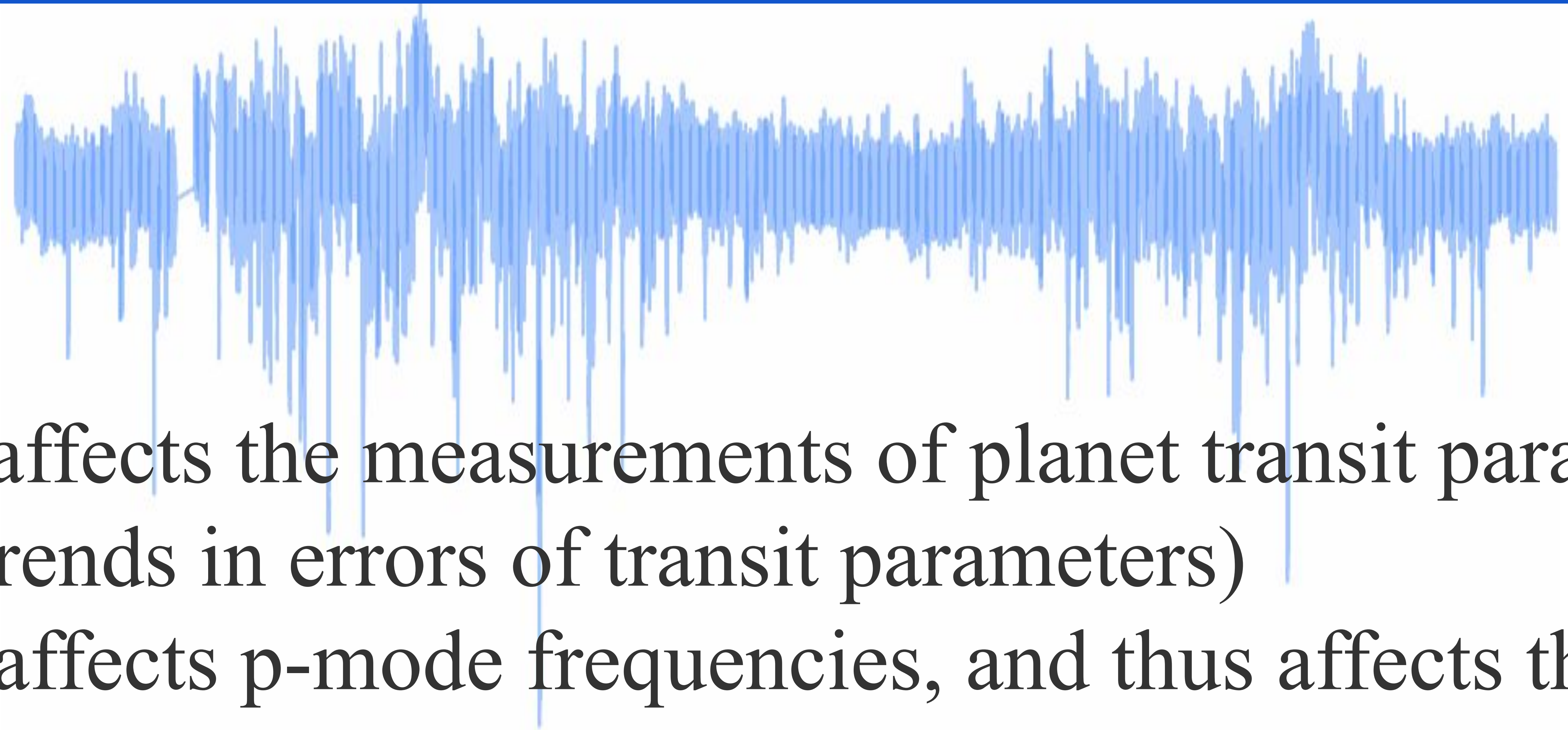
Long-term stellar activity variations: Why should we care?



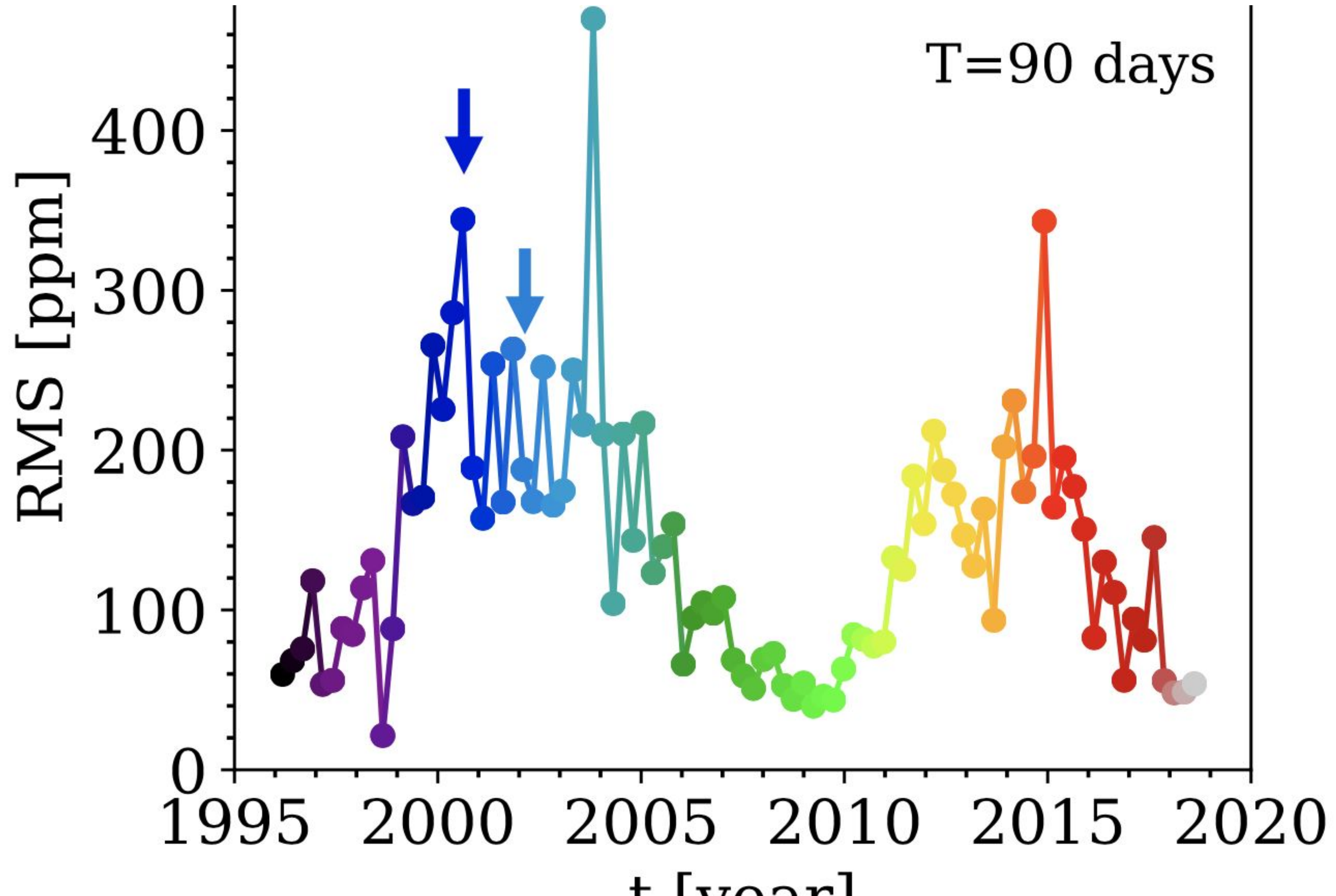
(22 years)

1. Stellar activity affects the measurements of planet transit parameters (including e.g. long-term trends in errors of transit parameters)
2. Stellar-activity affects p-mode frequencies, and thus affects the inferred stellar seismic parameters. Need to correct seismic parameters for activity effects

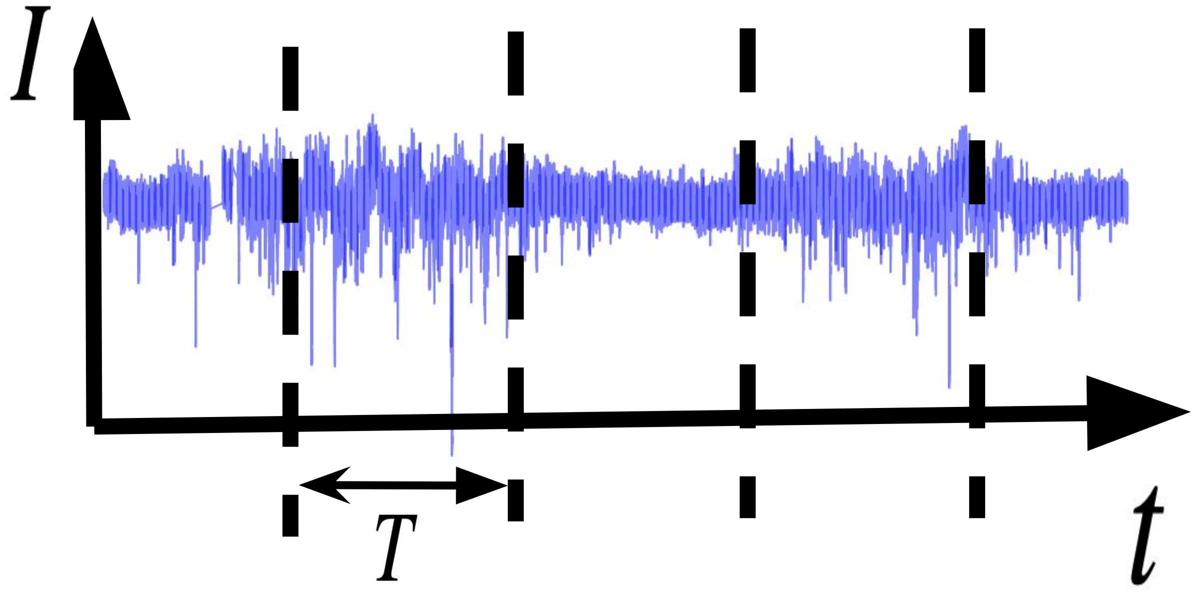
Long-term photometric variability for the Sun →

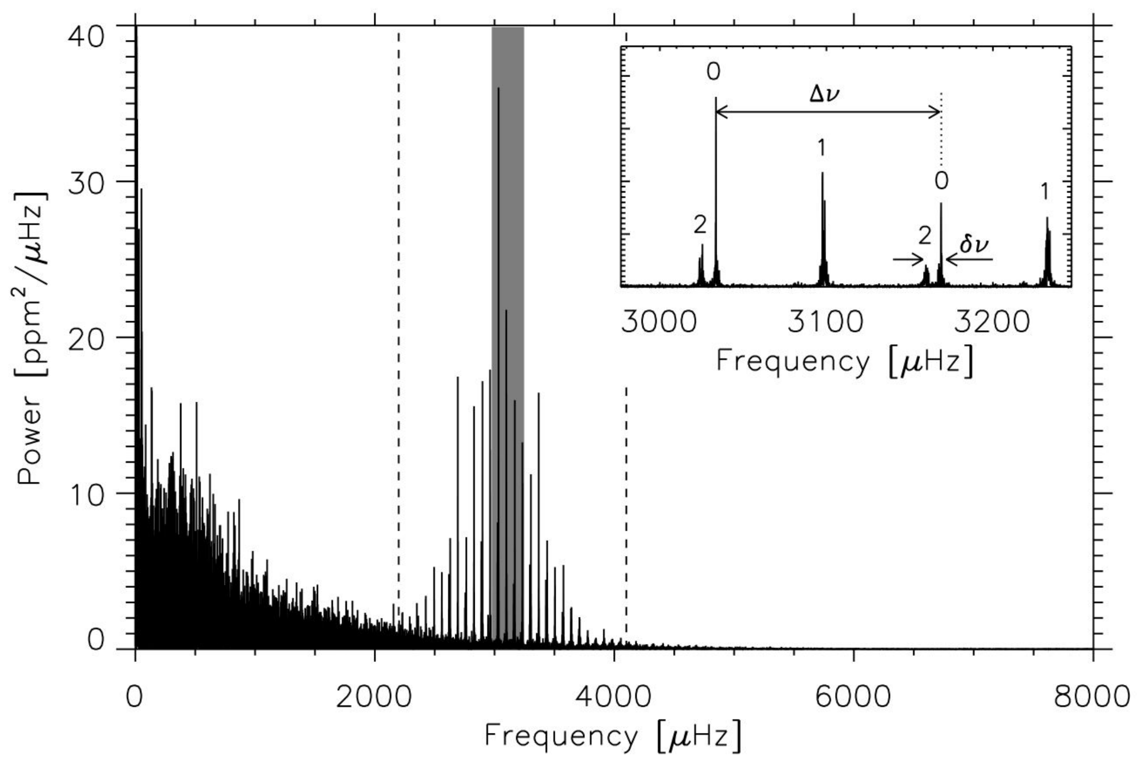
The Sun is a great laboratory thanks to availability of SOHO/VIRGO photometry
(1 min cadence over 22 years)

Activity variations on other stars may be much larger.

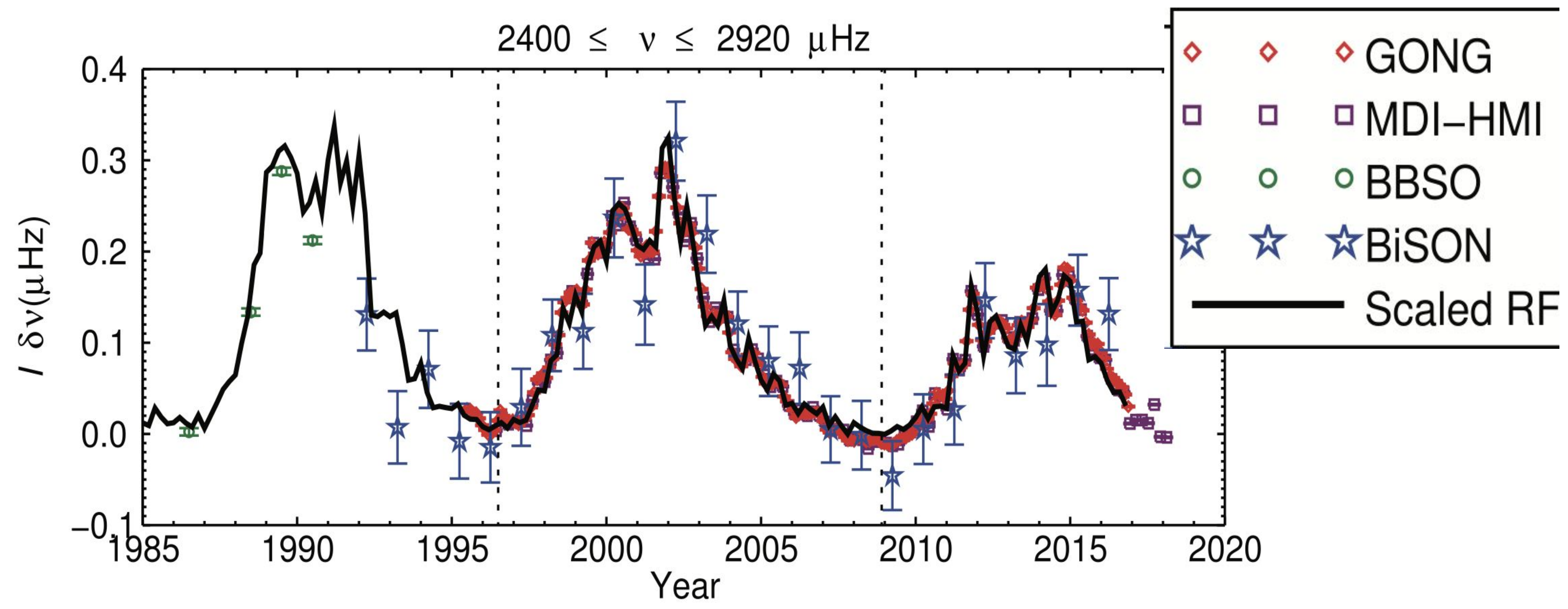


Measuring p-mode frequency shifts: standard methods





p-mode power spectrum for *T*=120 days



p-mode frequency shifts (Howe et al. 2017)

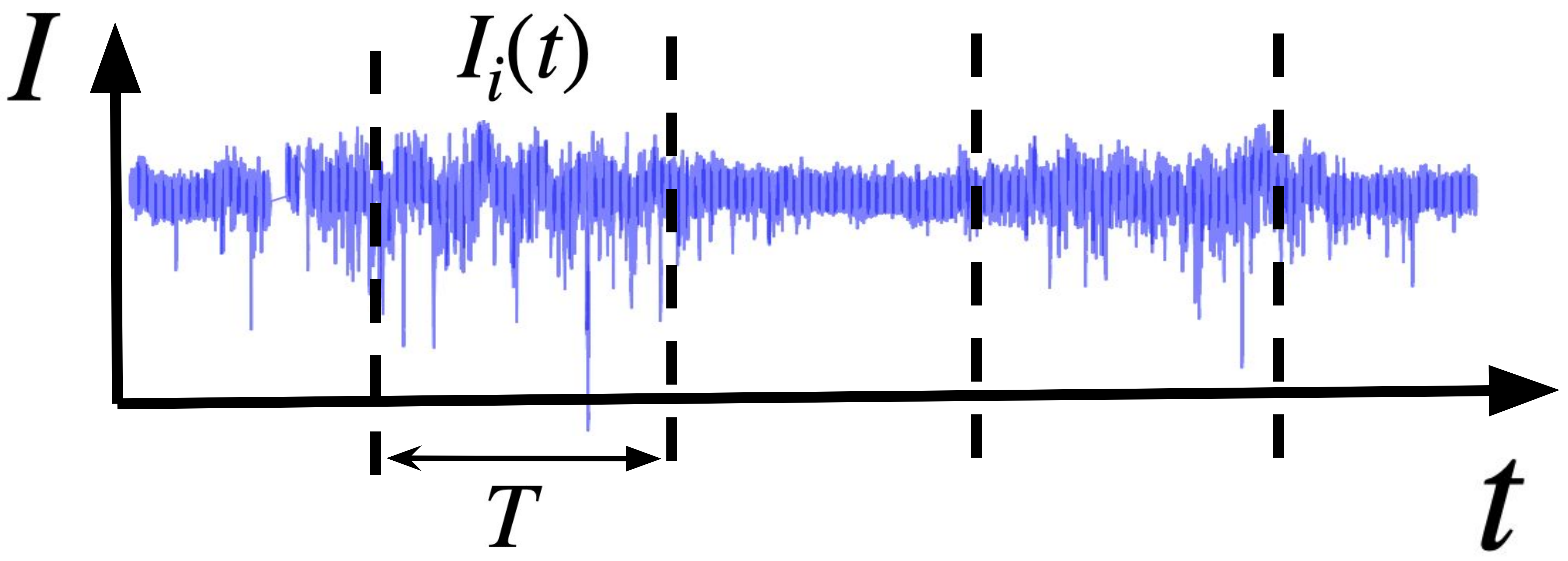
Goal here is to track the p-mode frequencies using smaller chunks of the data (*T* = a few months).

The standard methods:

1. Measuring a global frequency shift by cross-correlating the power-spectra from short periods with the average power spectrum from the full time series (Pallé et al. 1989, Régulo et al. 2016, Kiefer et al. 2017)
2. Measuring individual mode frequencies in each chunk, then average (e.g. Appourchaux et al. 2012, talk of Guy Davies)

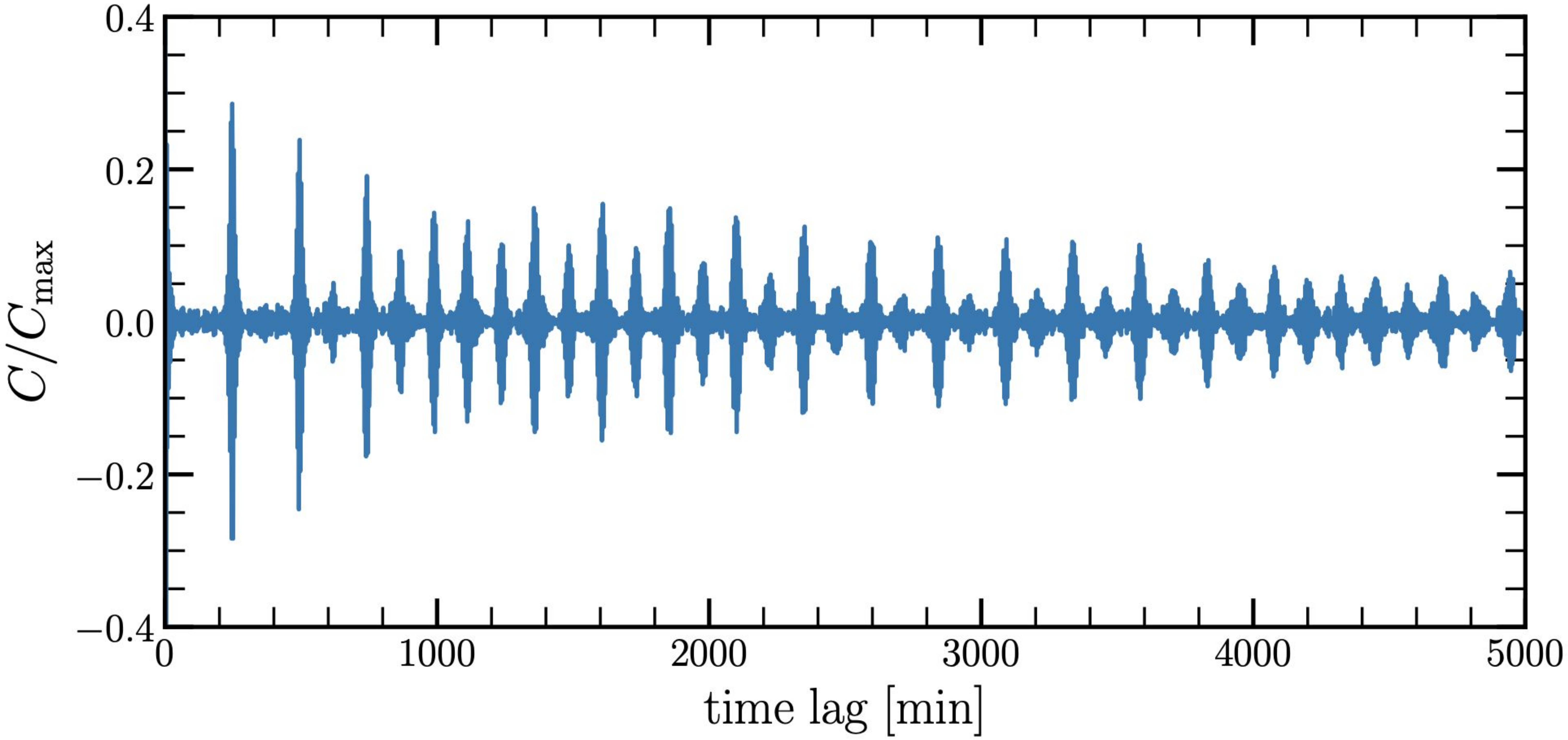
Potential issue with 1): physical interpretation is not straightforward.
Potential issue with 2): Lorentzian fits may fail for individual modes when time series are short.

New method

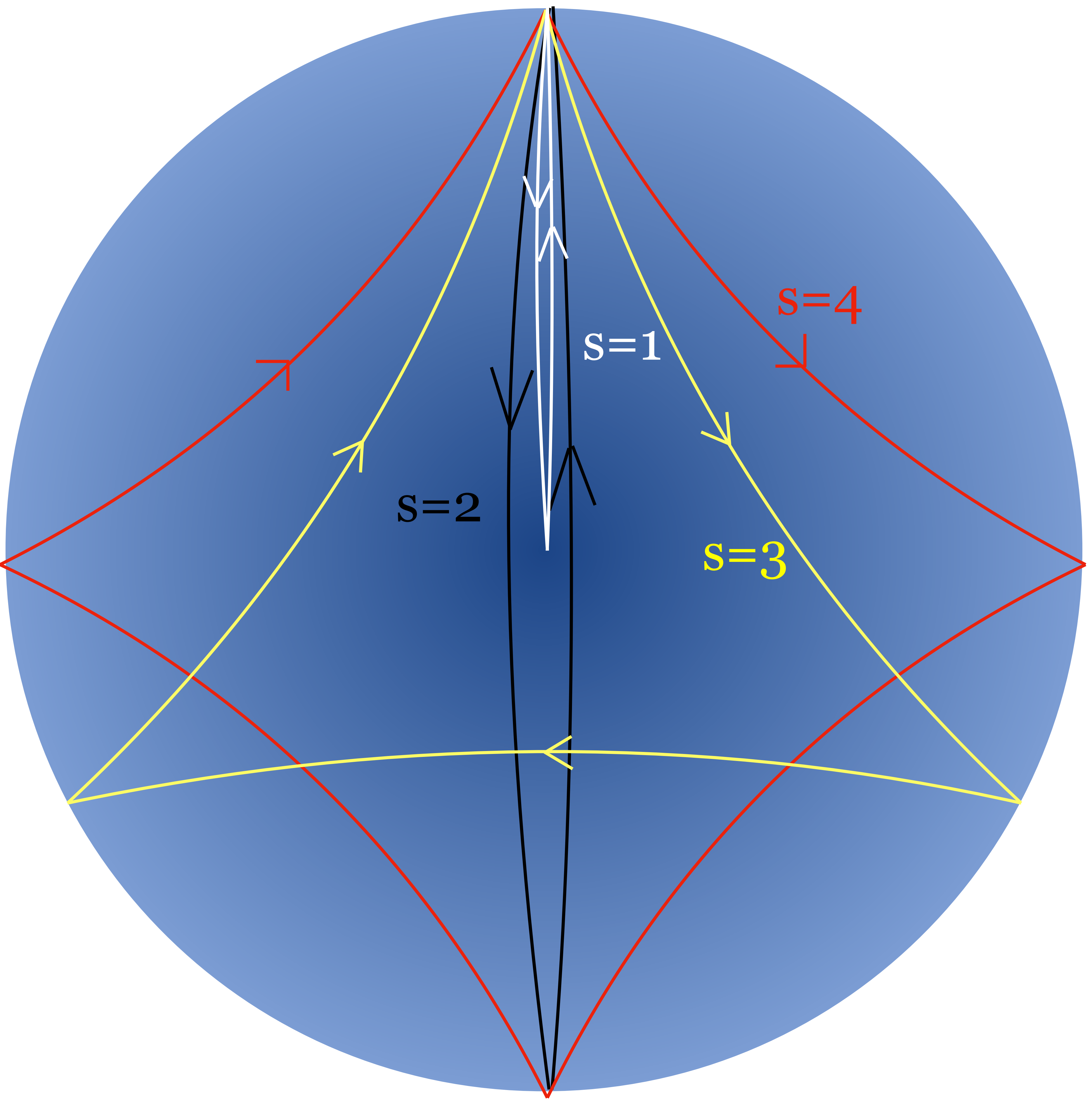


- Cut data set into chunks of length T
- Compute autocovariance of each chunk

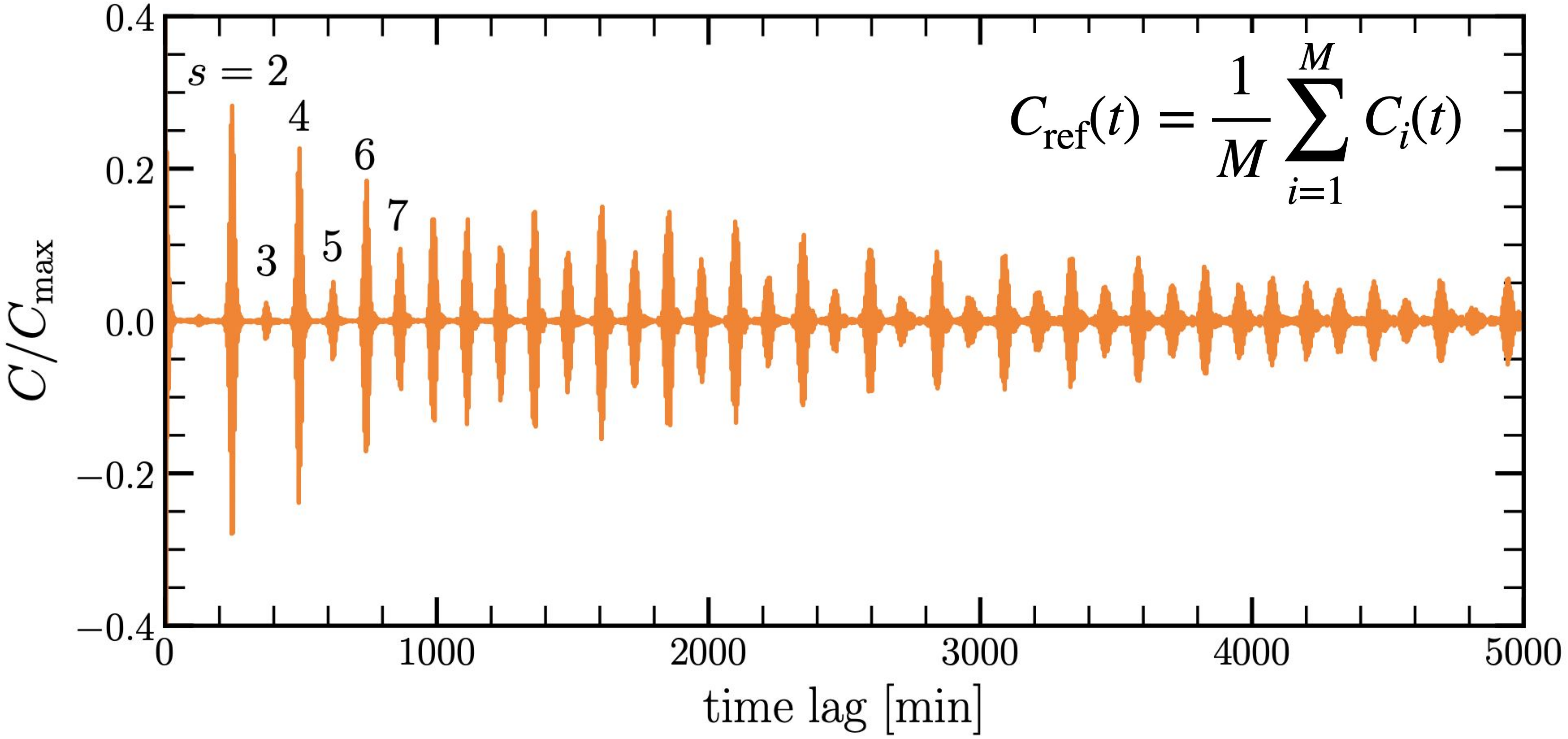
$$C_i(t) = \int_0^T I_i(t')I_i(t+t')dt'$$



Arrival times of p-mode wave packets



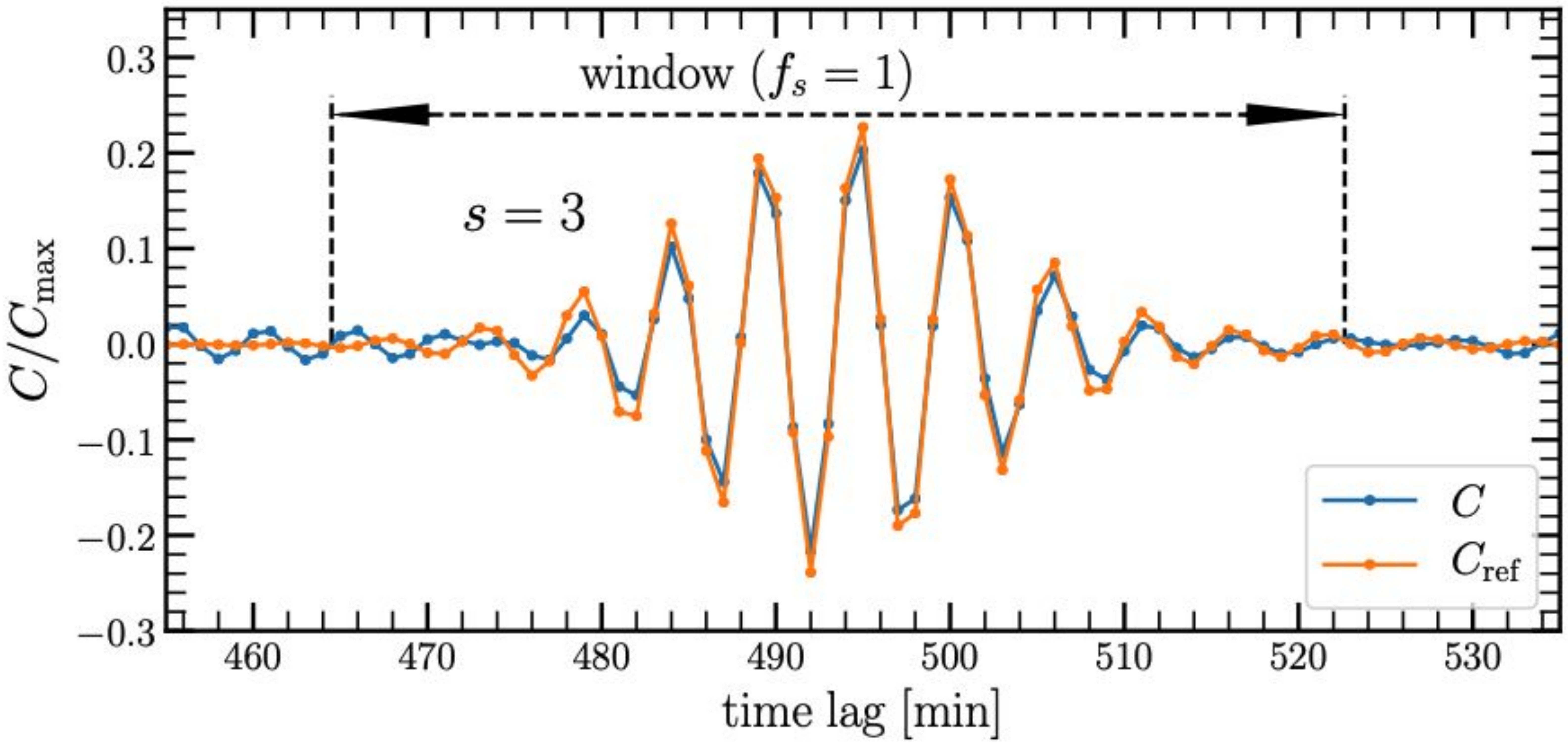
Ray paths of four different wave packets which take 1, 2, 3, and 4 bounces to travel around the Sun



Travel time measurements

- Measurement method developed in time-distance helioseismology (Gizon & Birch 2004)

- Very simple to implement
- For each skip, only one parameter to fit to the data: the phase travel time
- Very robust wrt noise



$$\tau_s = \int W_s(t)\,[C(t) - C_{\text{ref}}(t)]\,\mathrm{d}t$$

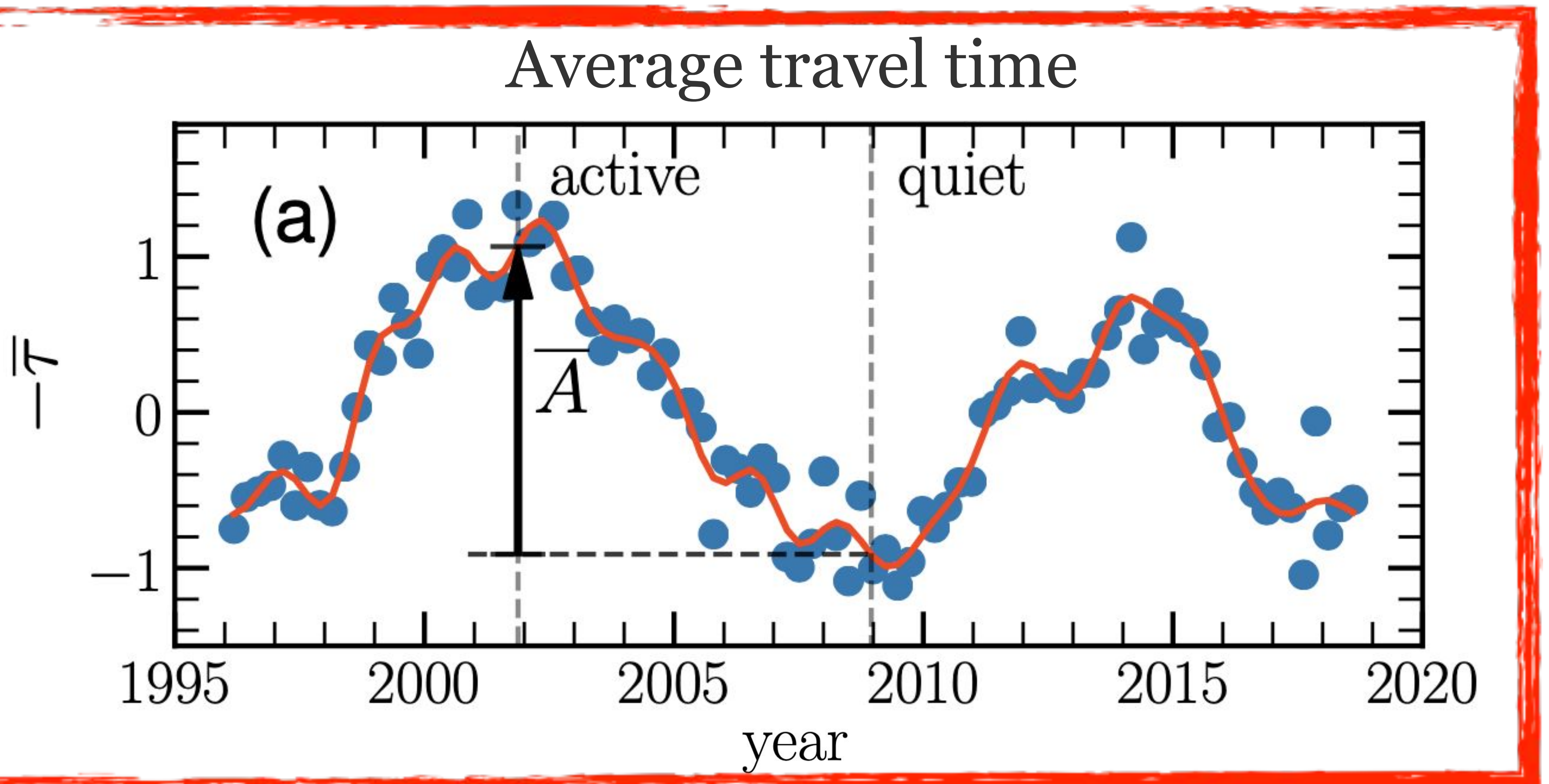
$$W_s(t) = -\frac{f_s(t)\, dC_{\text{ref}}(t)/dt}{\int f_s(t')\,[dC_{\text{ref}}(t')/dt']^2\, dt'}$$

Travel time measurements: the Sun

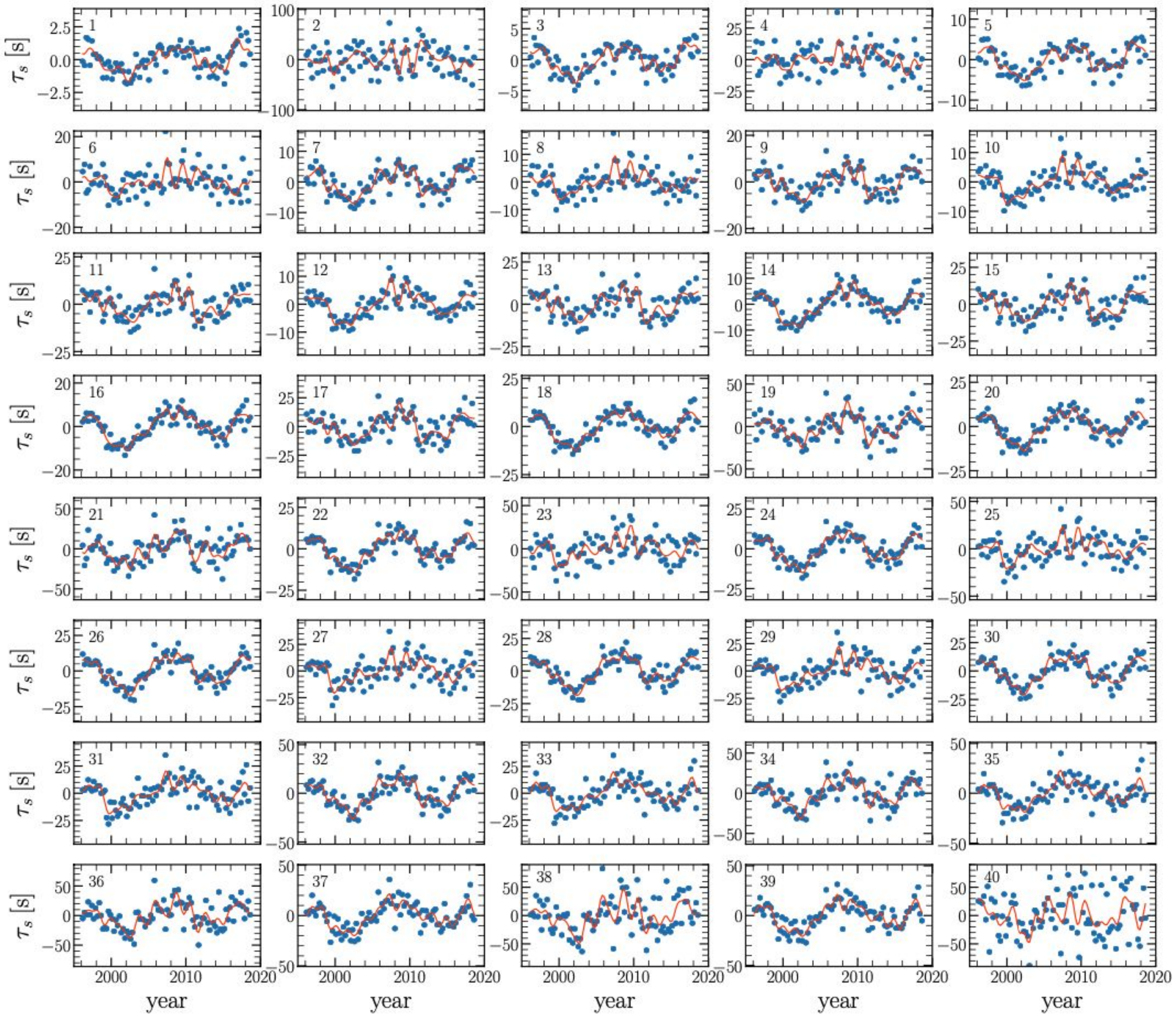
- Travel times for 40 p-mode wave packets
- Clear correlation with the activity cycle
- Strongest signal for s=18!

- Average travel time for s<= 40 (taking into account noise correlations):

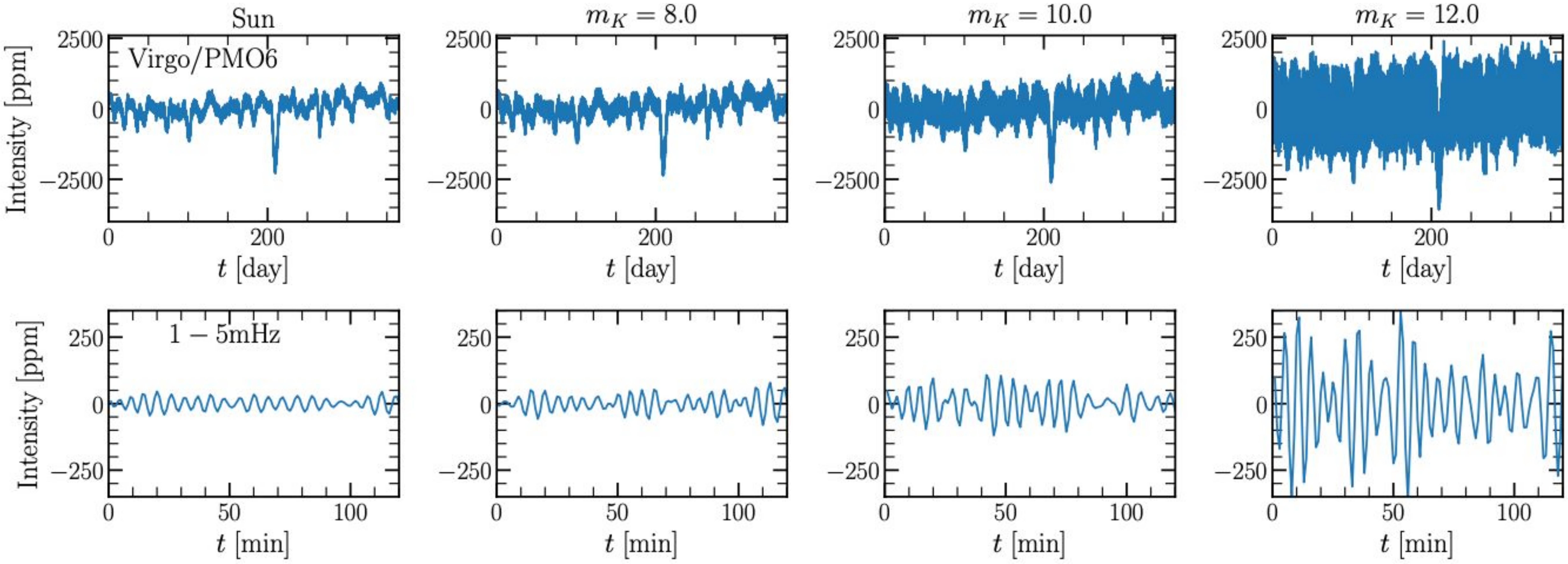
$$\overline{\tau}(t) = \sum_{s=1}^{N_{\text{packets}}} \alpha_s \tau_s(t) \qquad \alpha_s = \frac{1}{N_{\text{packets}}} \sum_{s'=1}^{N_{\text{packets}}} \Lambda_{ss'}^{-1/2}$$



Vasilyev & Gizon, in prep



Simulated Kepler-like data covering two full cycles

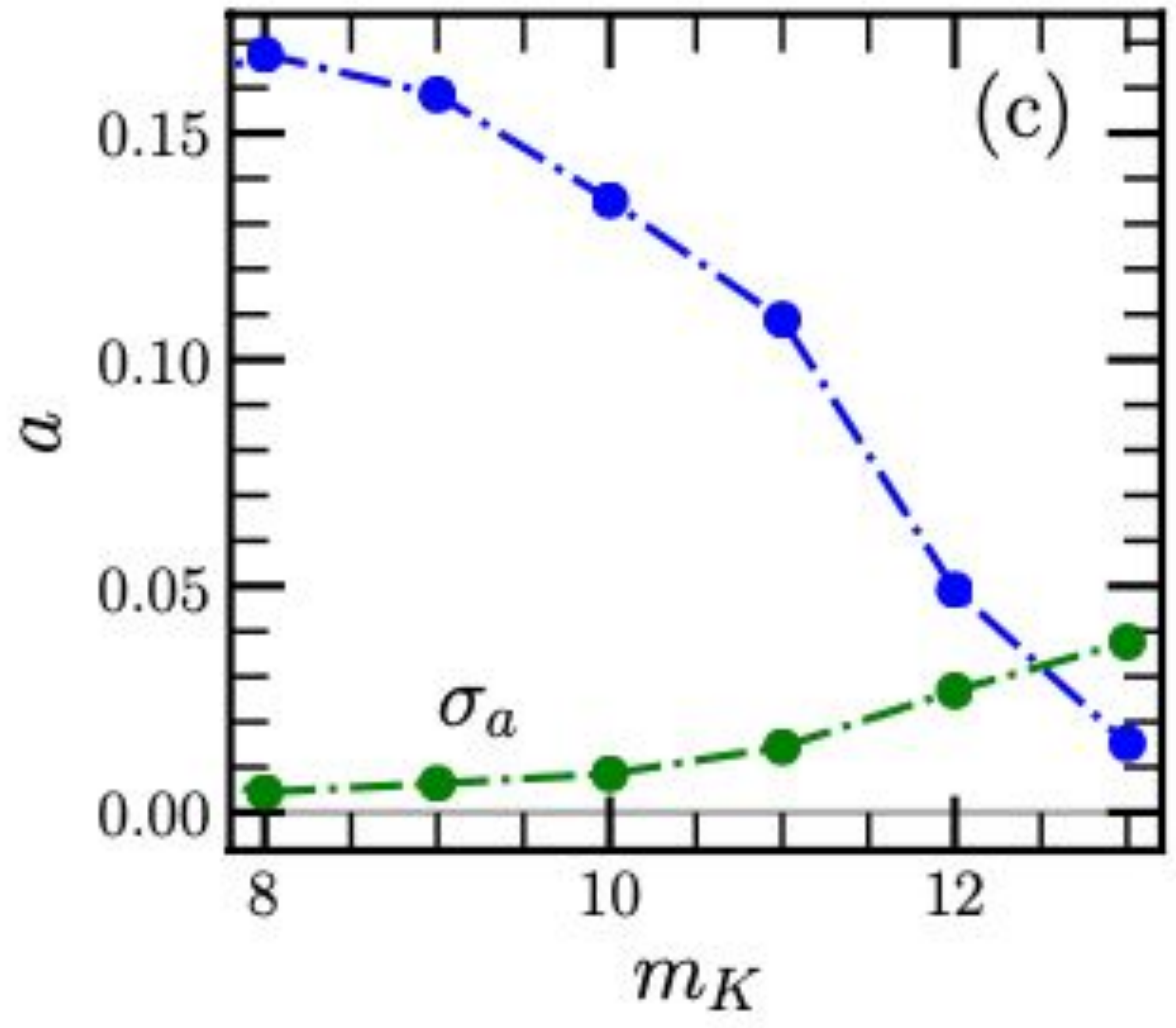


Vasilyev & Gizon, in prep

- Start from 22 years of VIRGO/TSI data
- Add noise such that S/N is Kepler-like for stars of different magnitudes
- measure average travel times each T=90 days

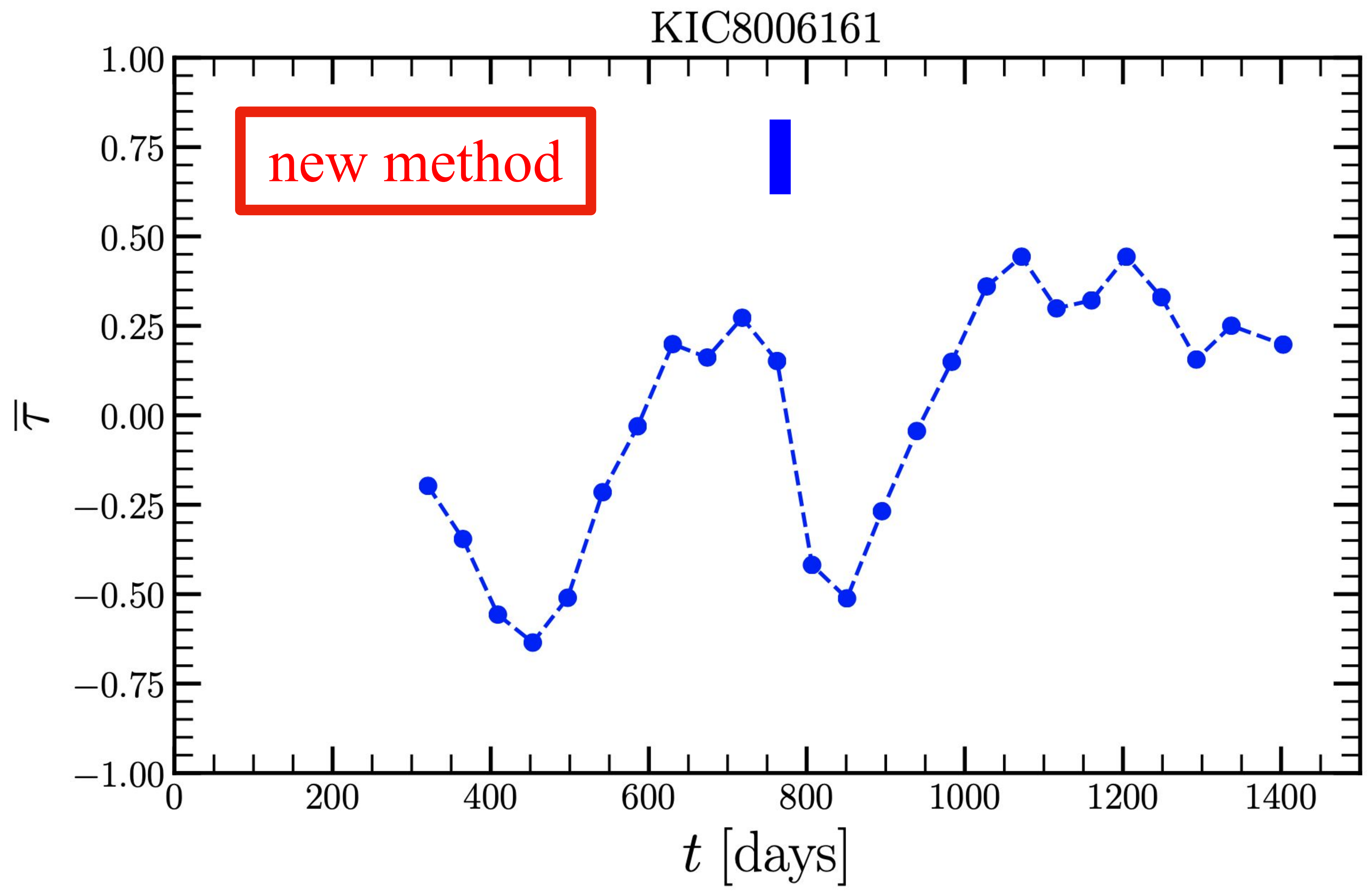
The method works well for mK≤11

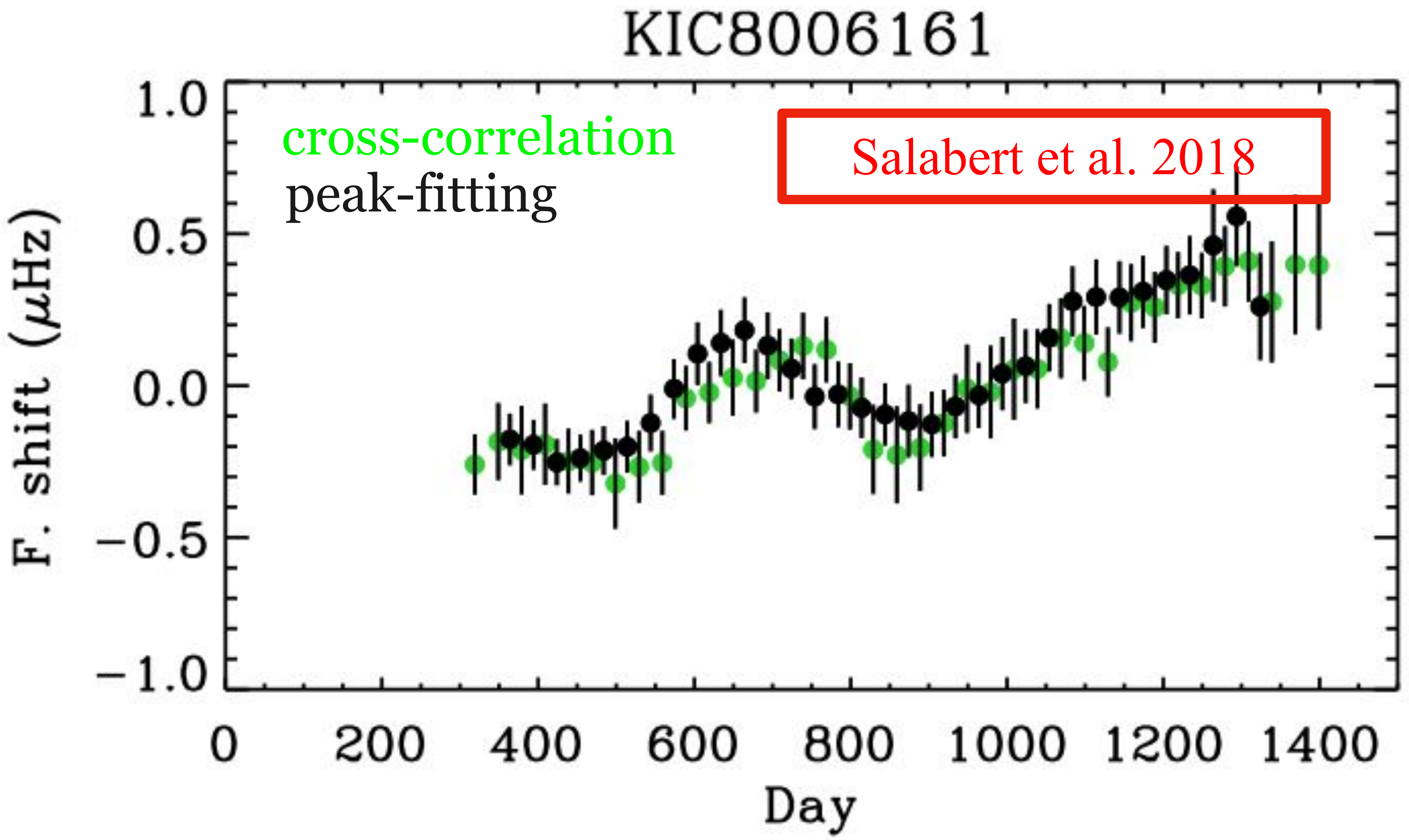
$$\widetilde{\tau}_{\rm fit}(t) = -a\cos\left(\frac{2\pi}{P_{\rm cyc}}(t-t_0)\right)$$



Example: Kepler KIC 8006161

Overlapping chunks of T=90 days





R=0.94 Rsun, M=1.01, Msun Age = 4.98 Gyr, Teff=5338 K, log g = 4.497, [Fe/H] = +0.64

Conclusions & Outlook

- We proposed **a simple method** to detect activity cycles in stars using p modes
- The method has been validated using the Sun (VIRGO data)
- It should work for PLATO stars in the P1 sample!

- In the future, we will interpret the extra information coming from the individual skips to further characterize activity.