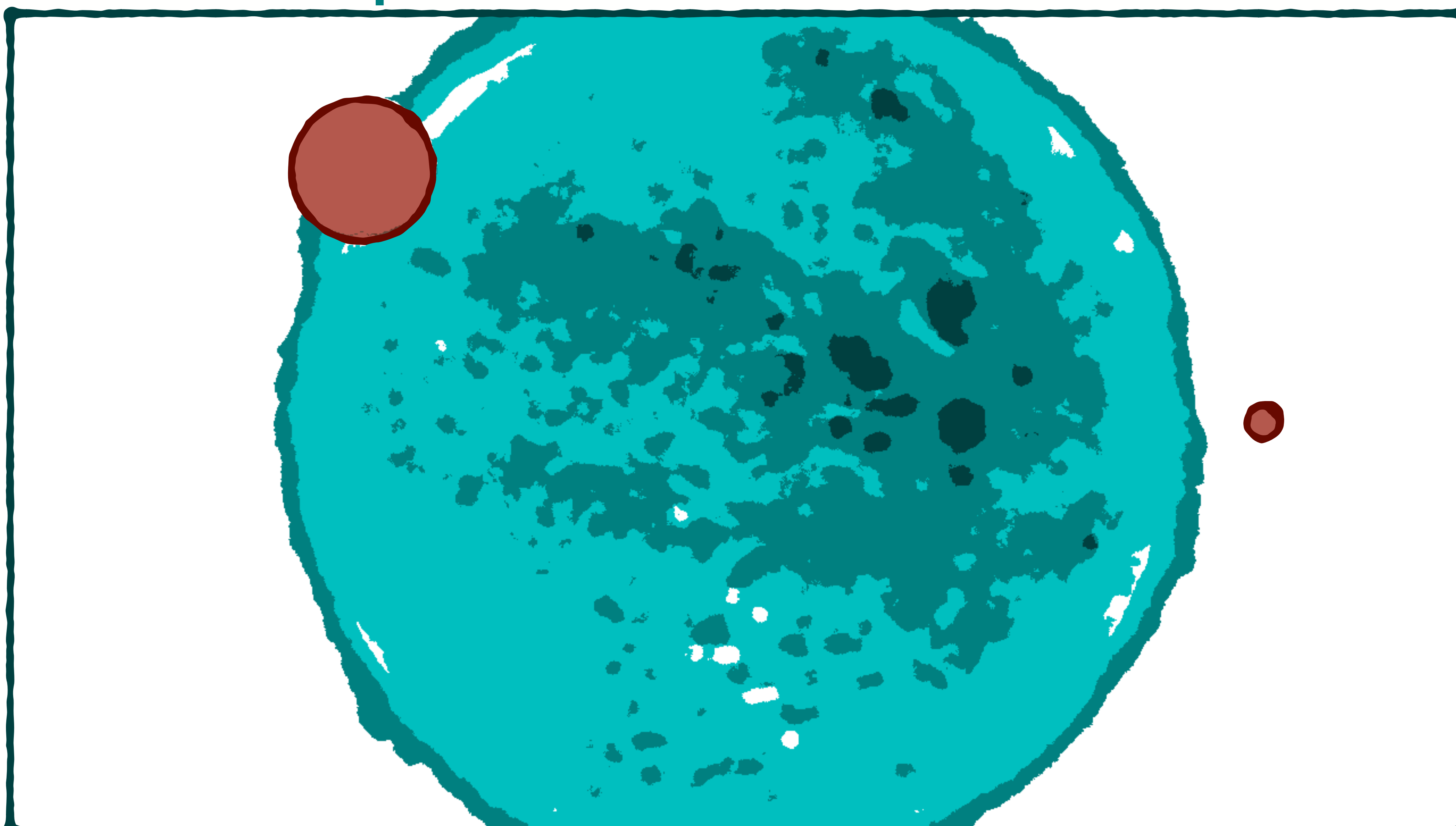
TRANSIT DETECTION
in the presence of stellar noise

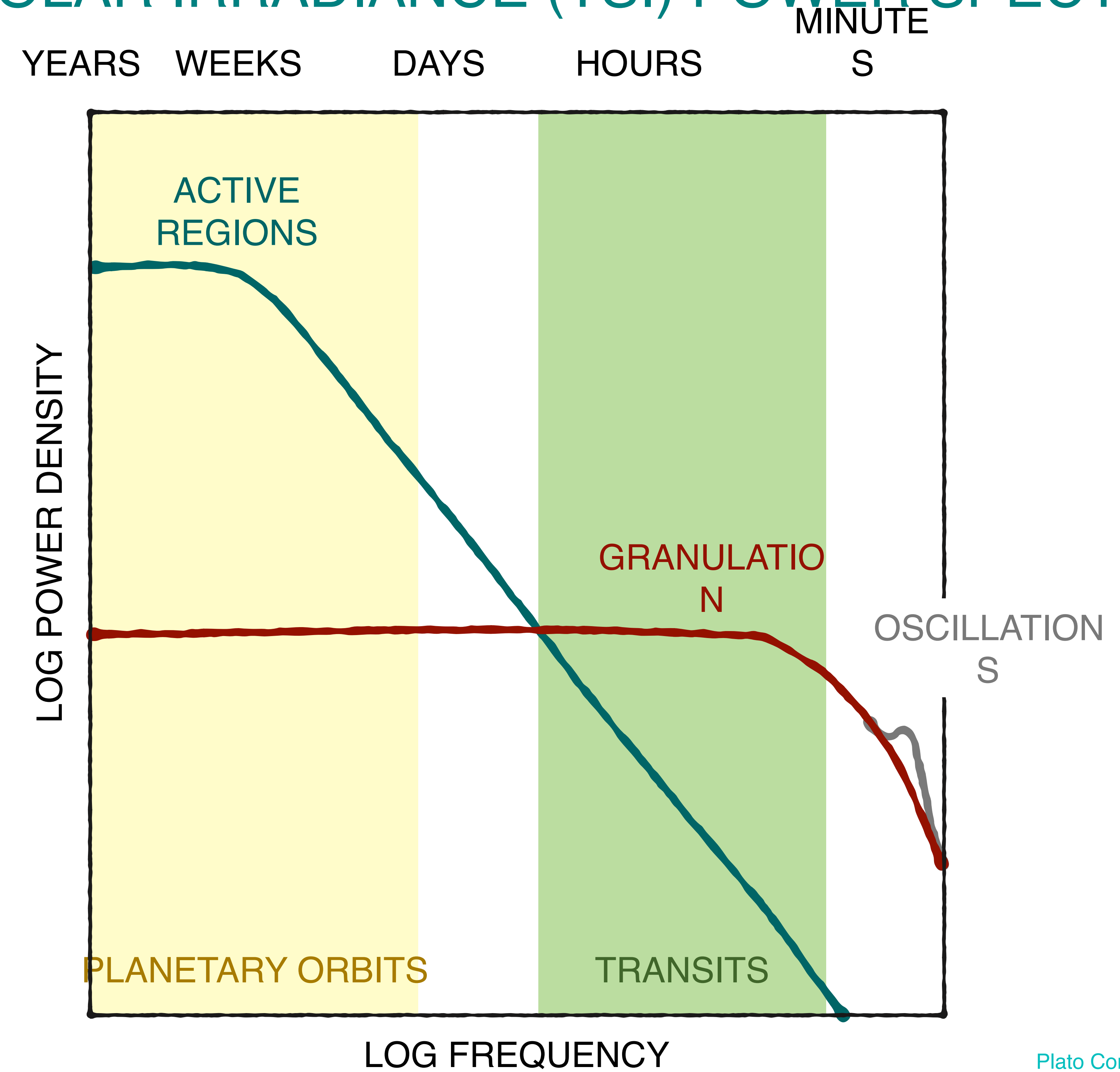


SUZANNE AIGRAIN (Oxford)
Steve Roberts, Hannu Parviainen, Vinesh Rajpaul, Ben Pope

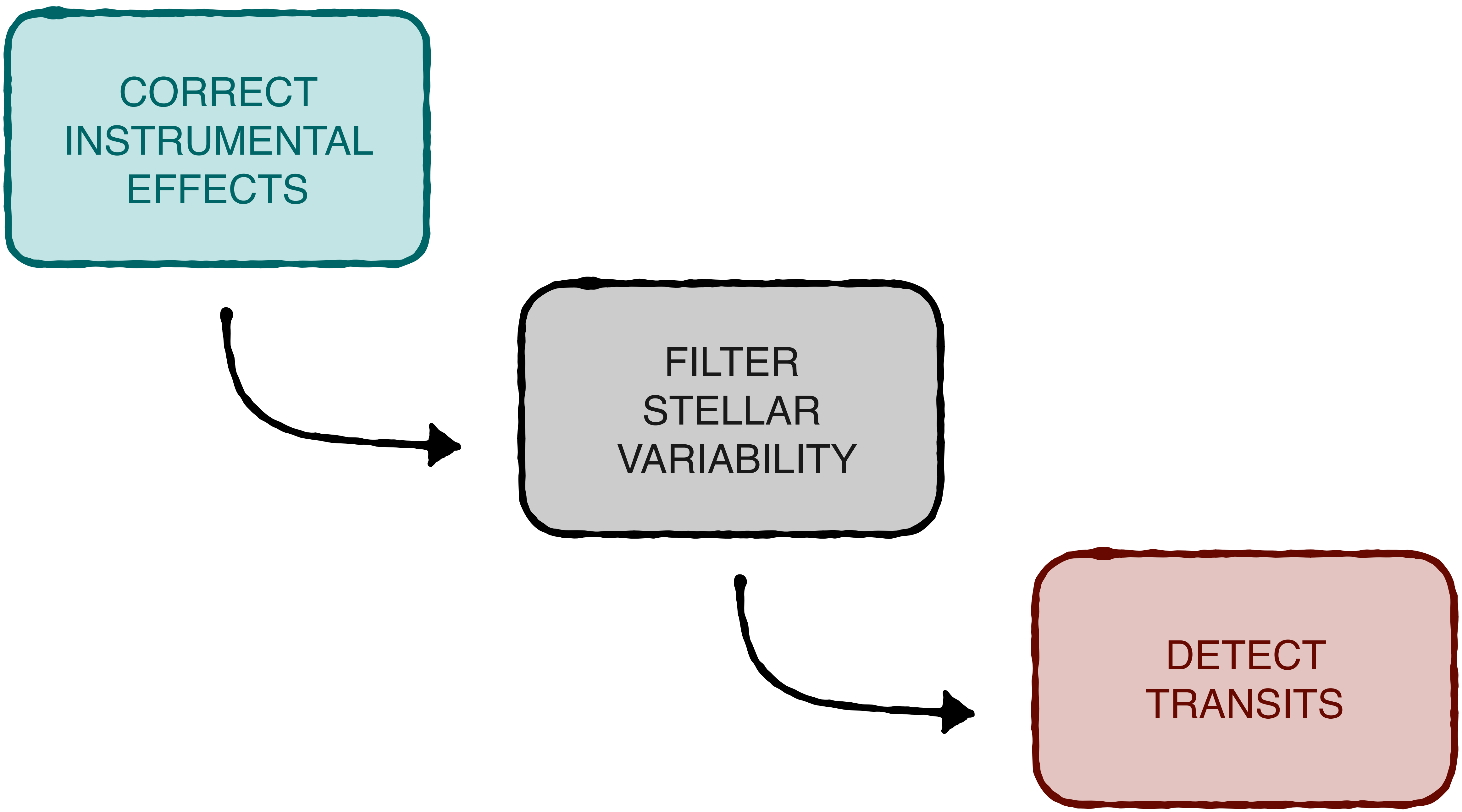
Plato Conference, Warwick, 05/09/2017

TIMESCALES

TOTAL SOLAR IRRADIANCE (TSI) POWER SPECTRUM

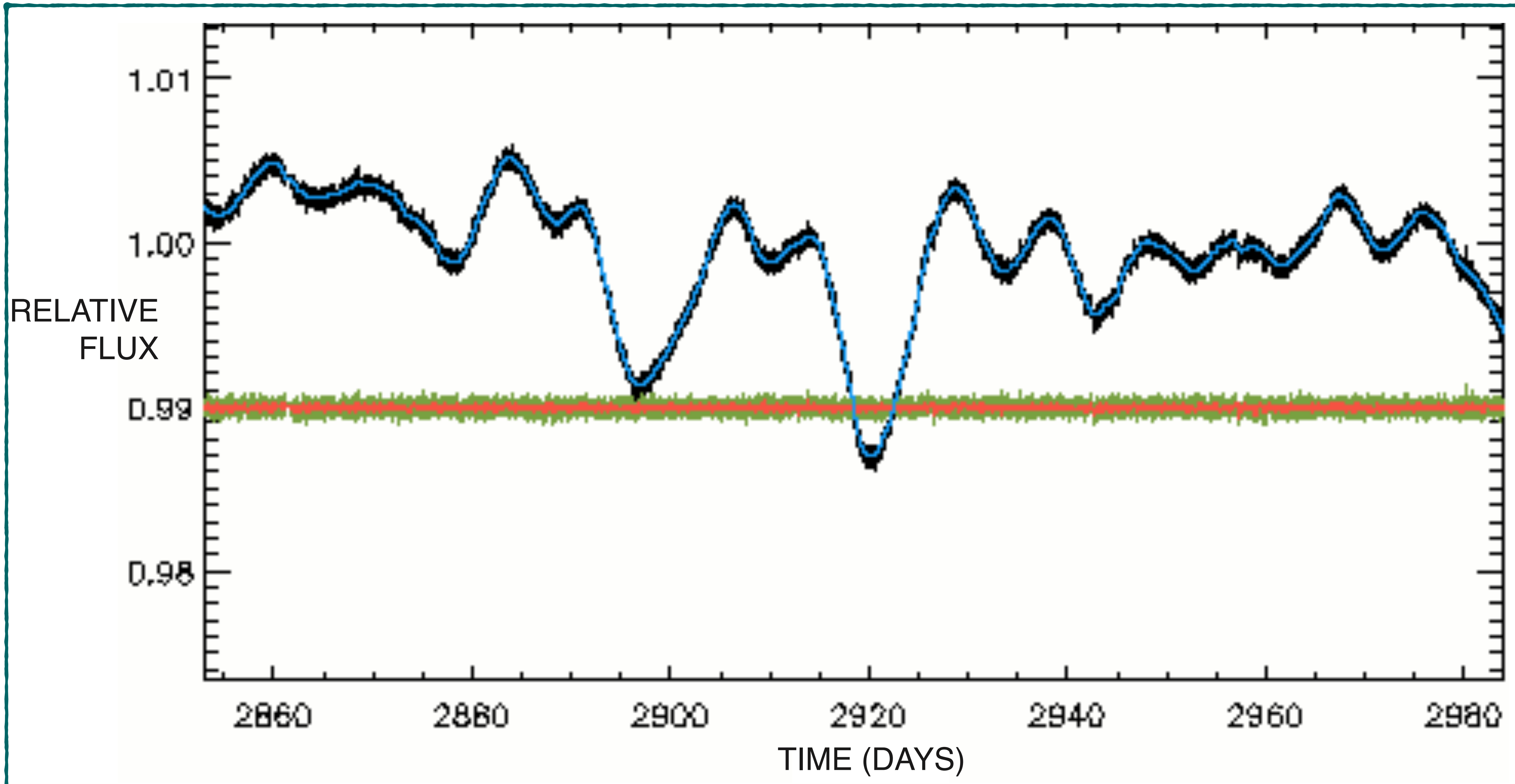


THE TRADITIONAL WAY



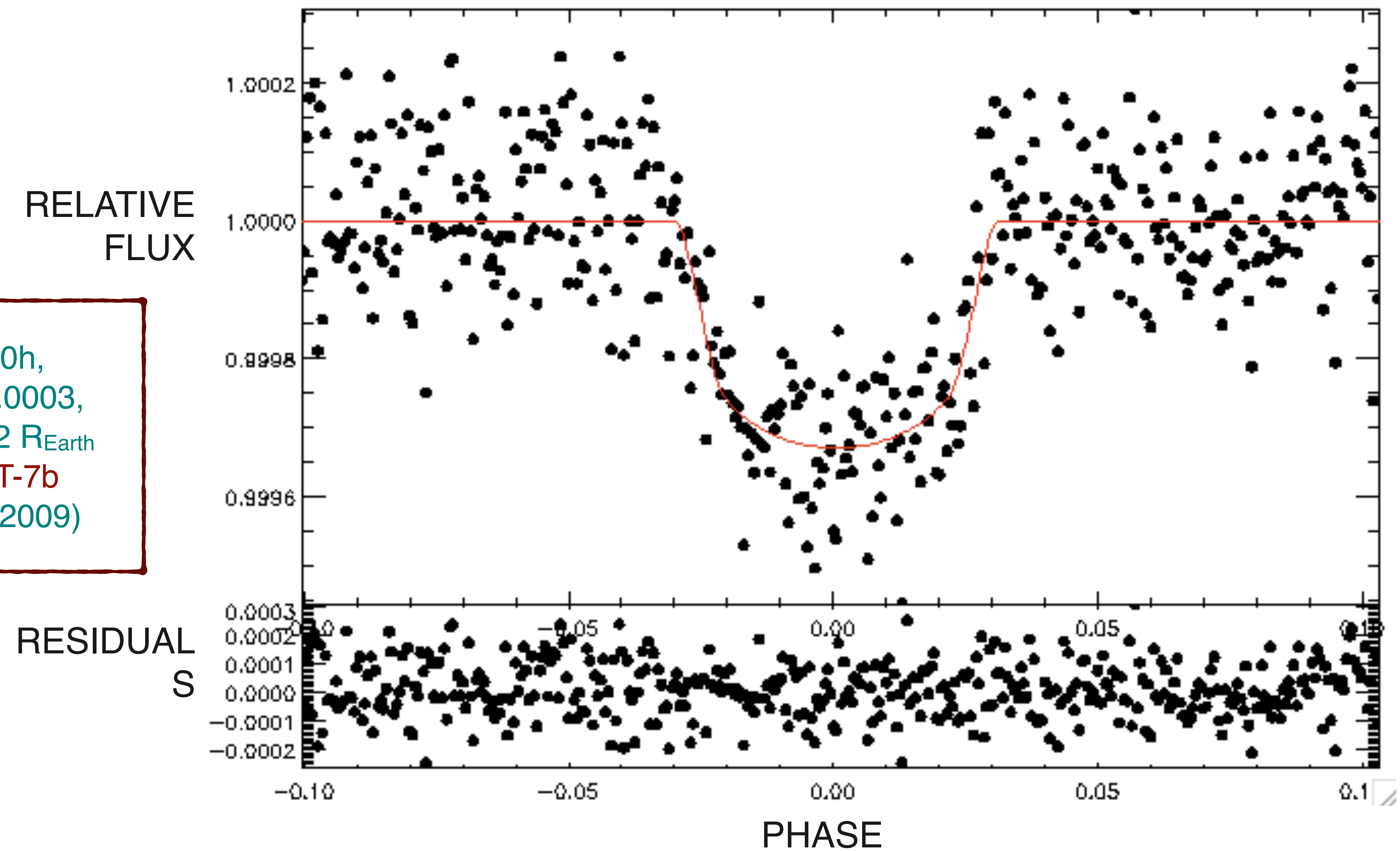
CoRoT EXAMPLE

ITERATIVE NON-LINEAR FILTER (Aigrain & Irwin 2004)



CoRoT EXAMPLE

BOX-LEAST SQUARES TRANSIT SEARCH (Kovacs, Zucker & Mazeh 2002)



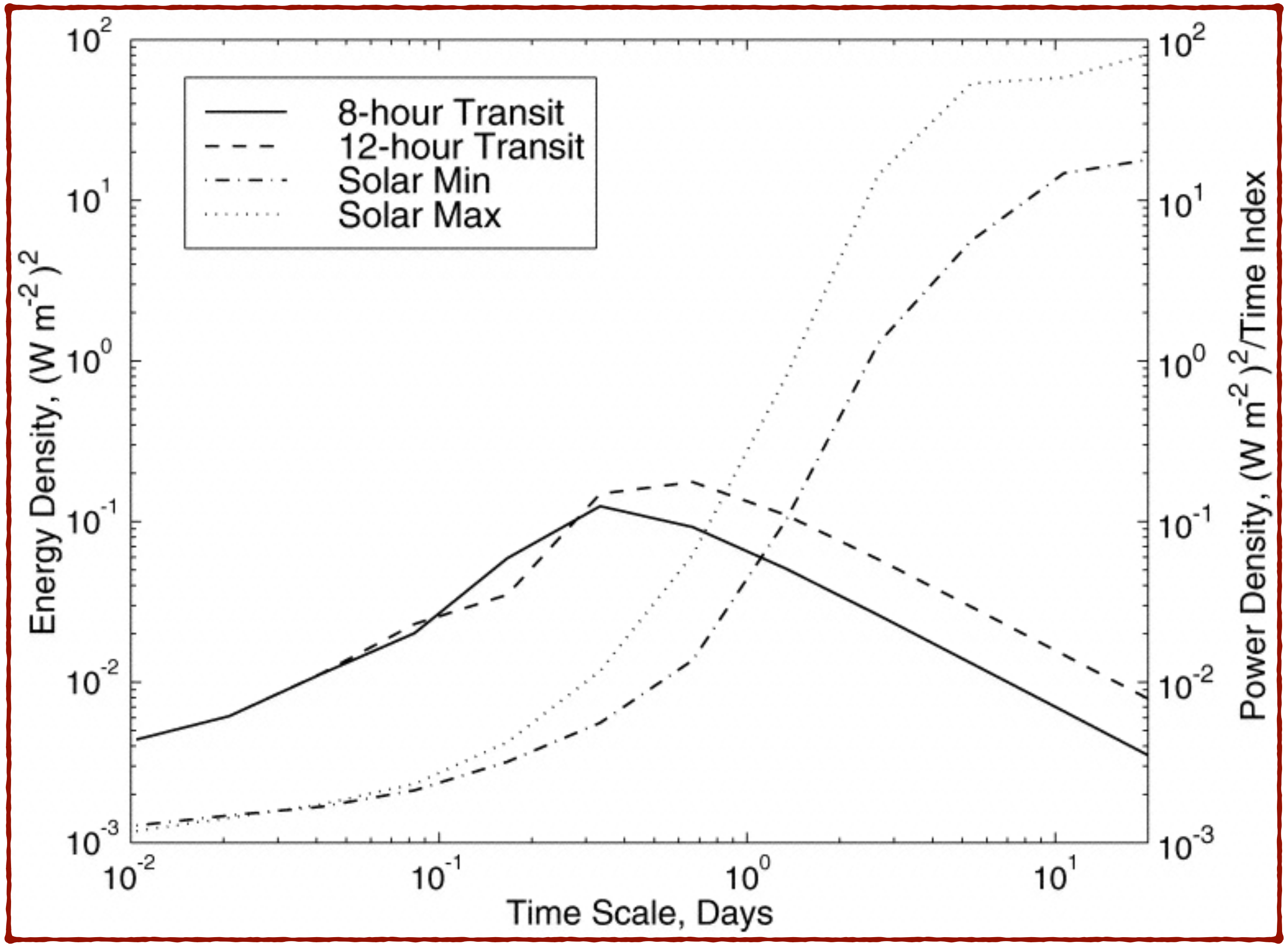
P ~ 20h,
depth 0.0003,
R_{planet} ~ 2 R_{Earth}
CoRoT-7b
(Leger+2009)

Sun-like activity doesn’t matter for warm Neptunes, hot Super-Earths, etc…

IT DOES FOR TEMPERATE EARTHS

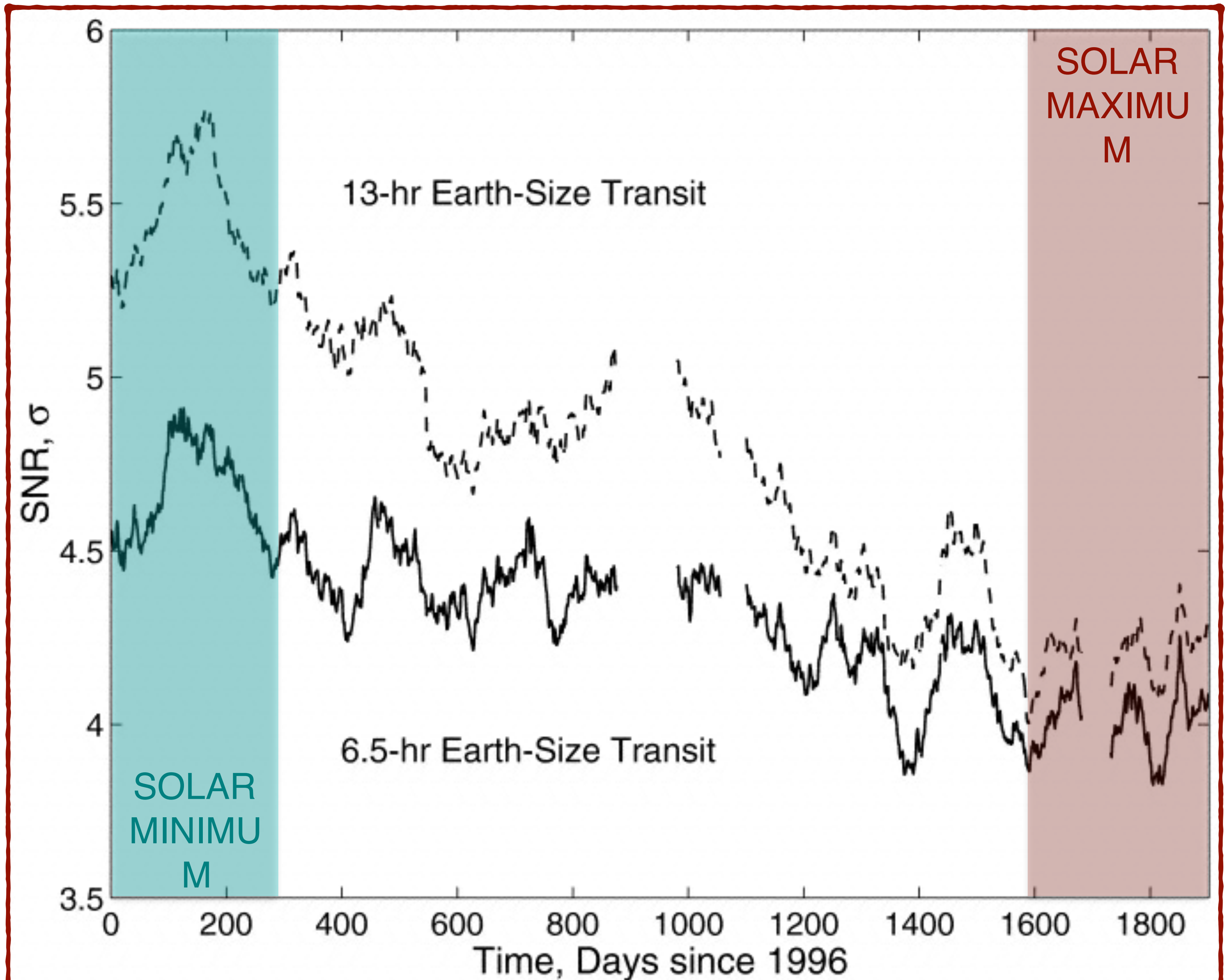
NEITHER WHITE NOR STATIONARY

FREQUENCY CONTENT of transits vs Total Solar Irradiance (TSI) variations



Jenkins(2002)

CHANGE IN SINGLE-TRANSIT SNR
over solar activity cycle



ADAPTIVE WAVELET-BASED MATCHED FILTER TRANSIT

Jenkins(2002)

SETTING THE THRESHOLD

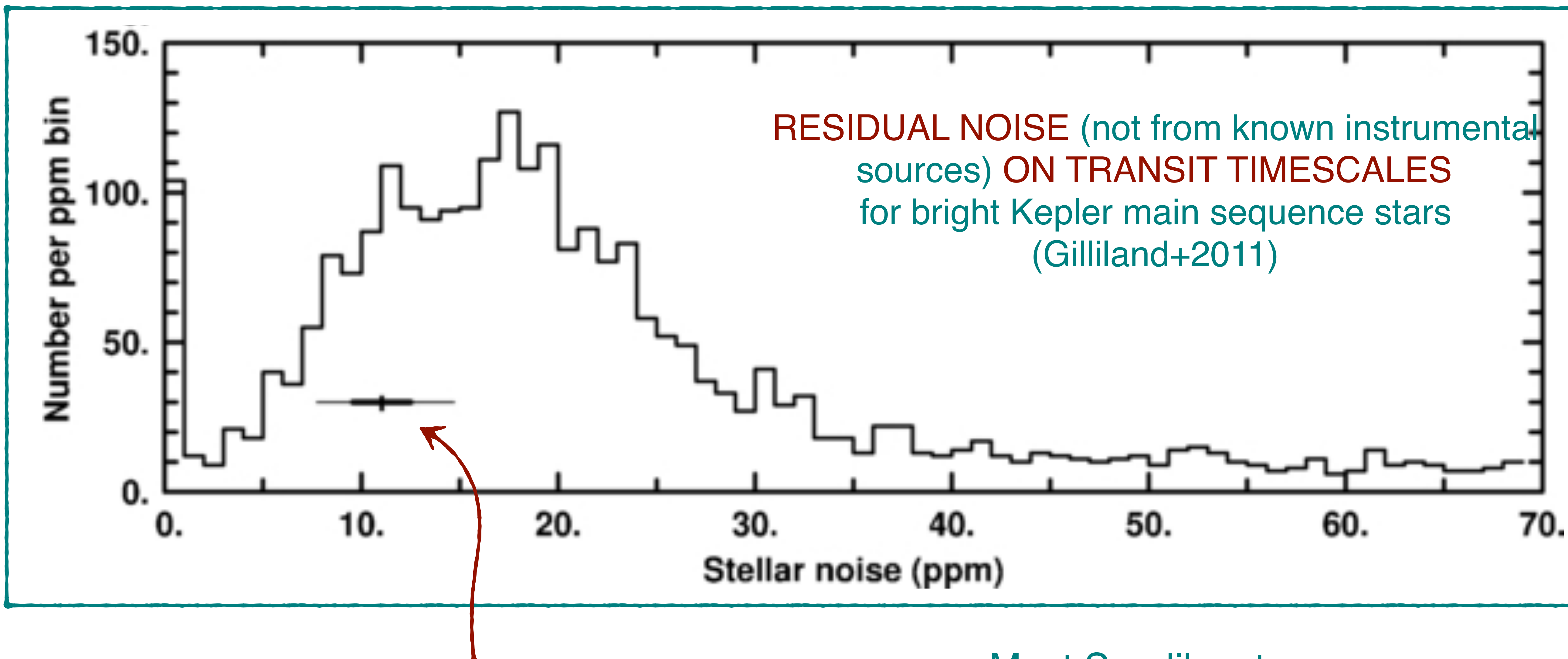
WANT <= 1 FALSE ALARMS over entire mission (1/600,000):

- threshold MES = 7.1
- expected sensitivity
  - ~80% for MES = 7.1
  - ~84% for MES = 8

KEPLER CATALOG GENERATION

- run transit search
- record all threshold crossing events (TCEs) - 100000's!!!
- vet them to weed out astrophysical and instrumental false alarms
- community follow-up and/or statistical validation

IS THE SUN TYPICAL?

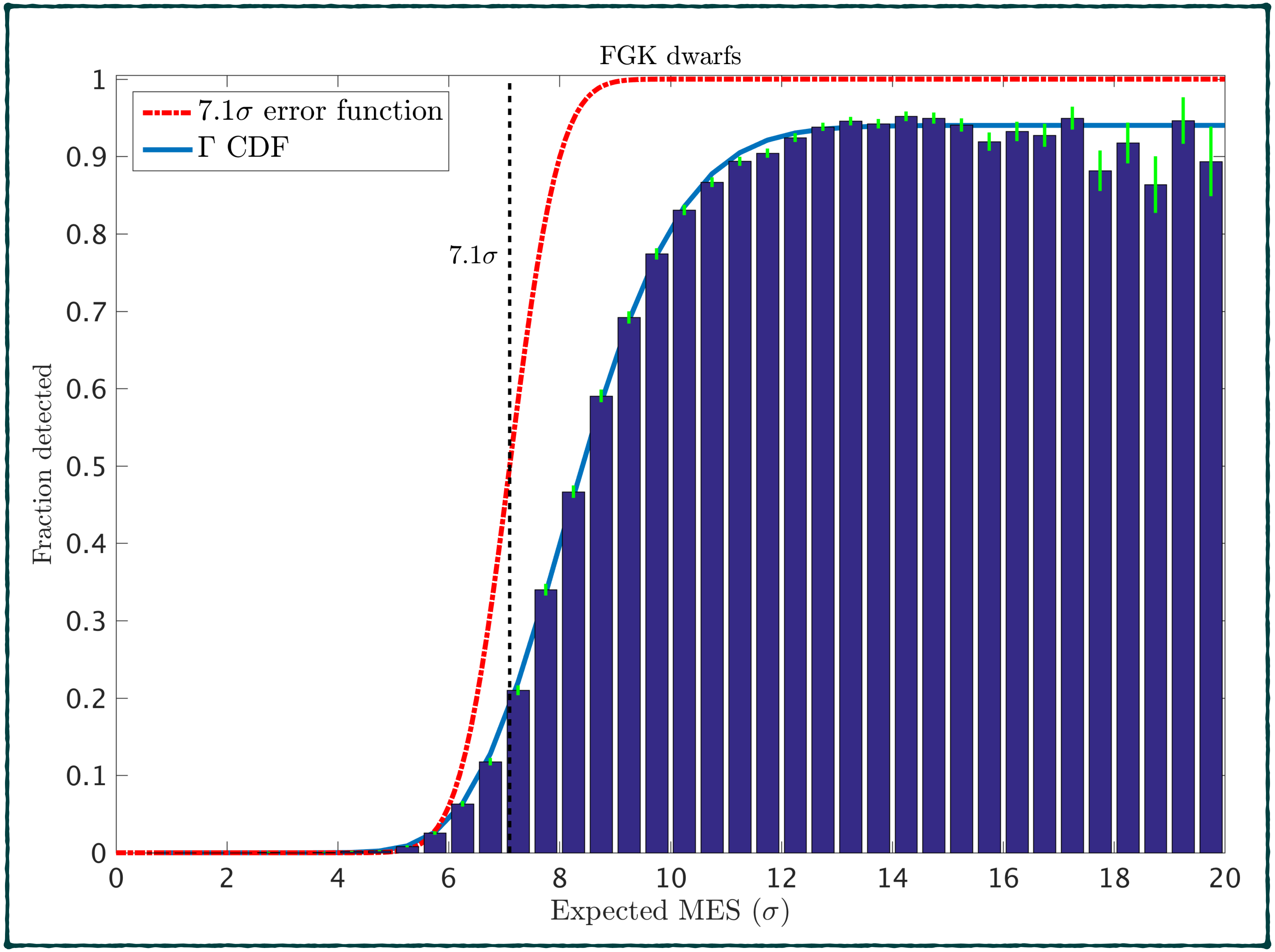


THE SUN

Most Sun-like stars
are MORE VARIABLE than the Sun

KEPLER TRANSIT INJECTION TESTS

Christiansen+(2013,2015a,b,2016,2017)



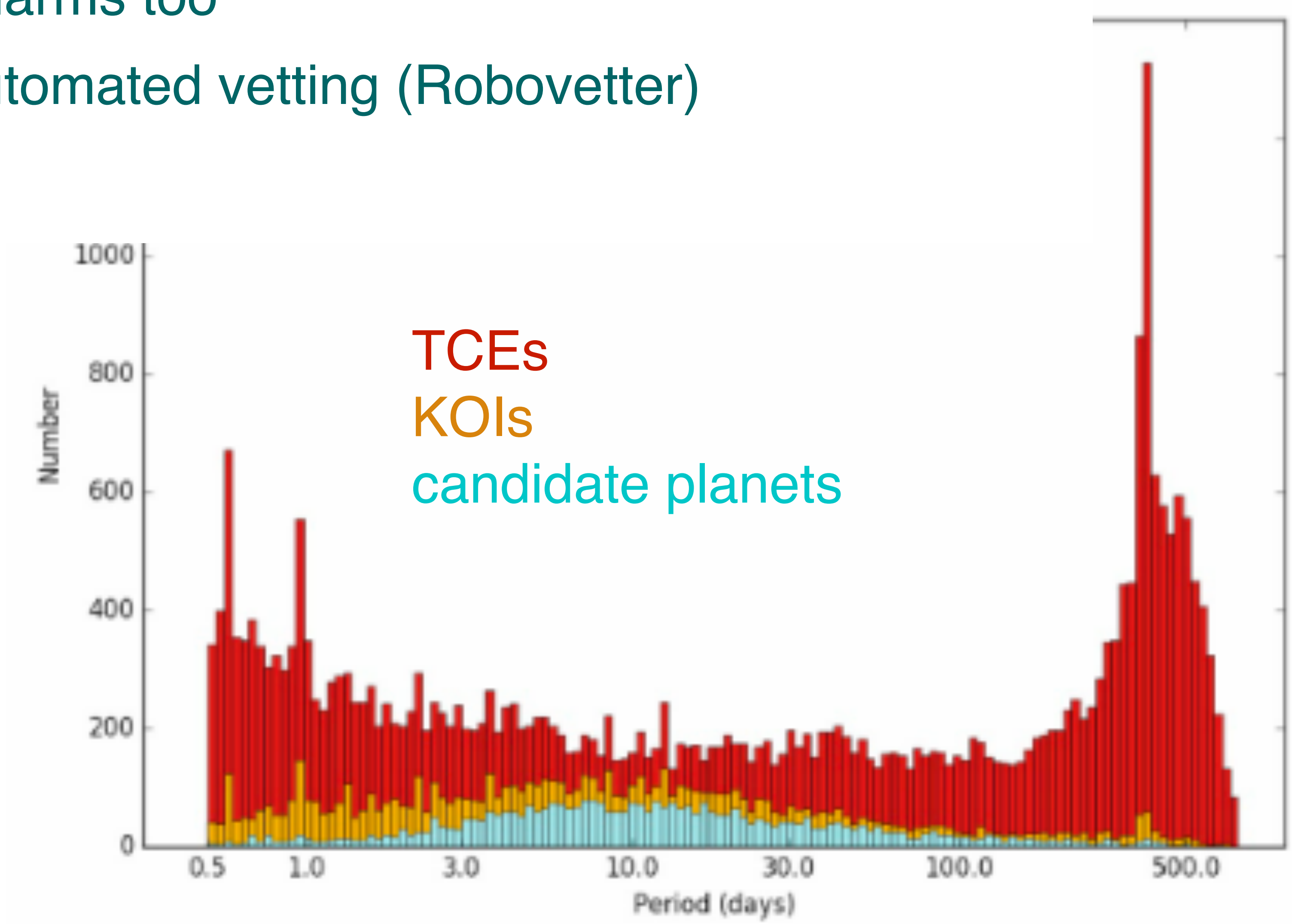
KEPLER "FINAL" CATALOG

Thompson+(2017)

ENHANCED VARIABILITY lowers the measured SNR of Earth-like transits

TO CATCH MORE EARTHS: lower the threshold

- means more false alarms too
- only feasible with automated vetting (Robovetter)

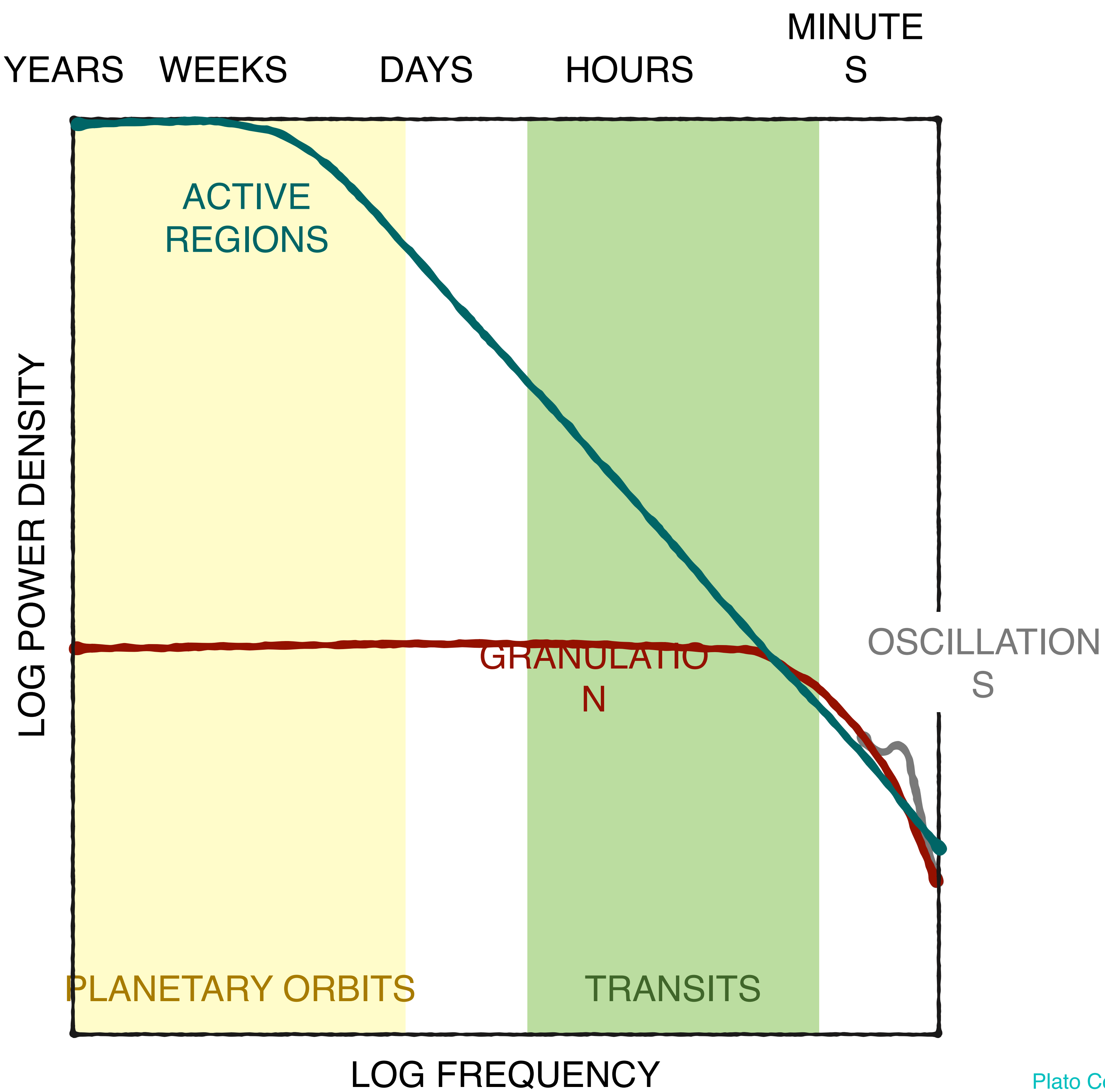


The latest Kepler catalog will yield improved estimates of η_{Earth}

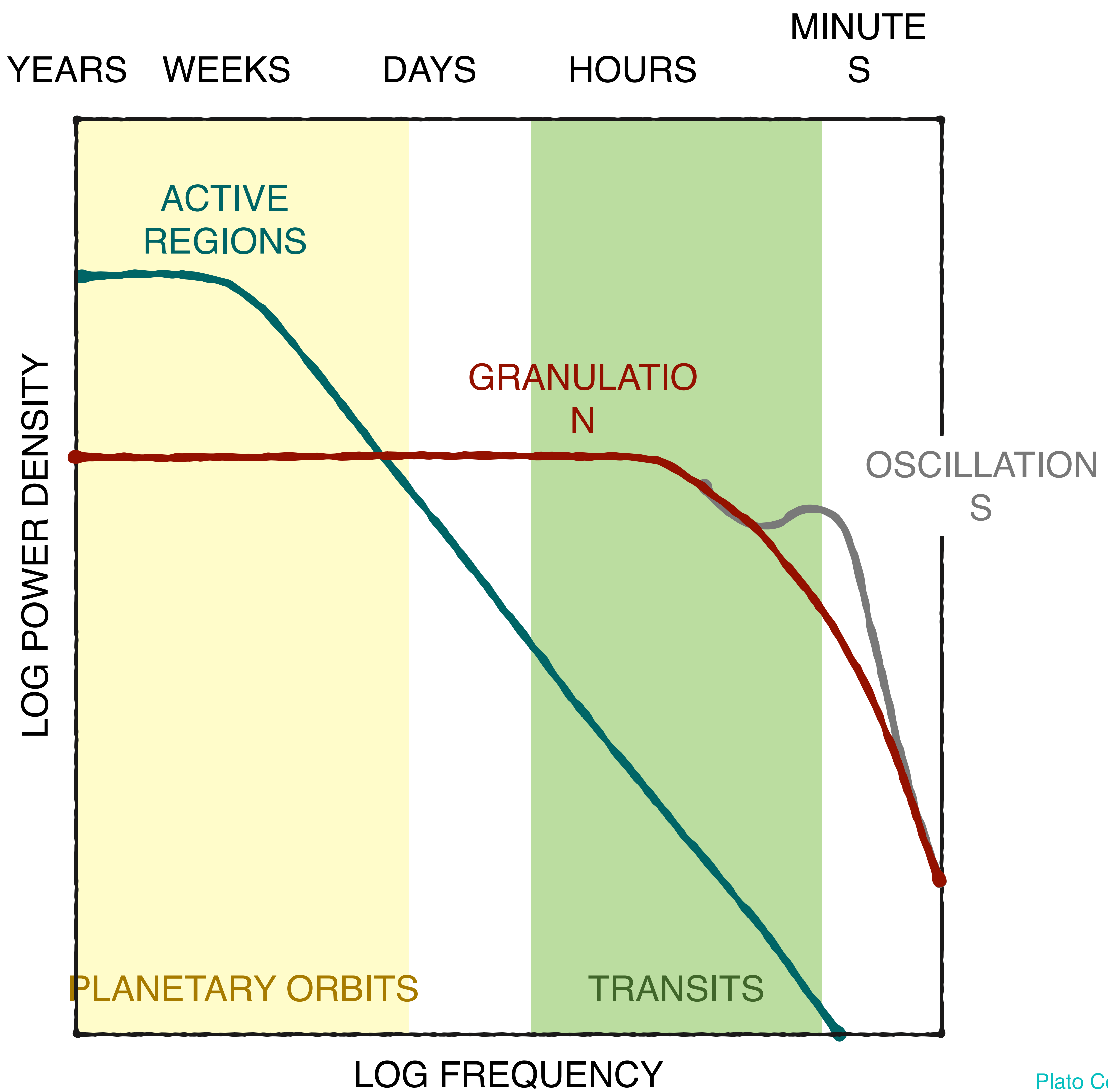
STILL BASED ON VERY SMALL NUMBER OF DETECTIONS

PLATO will survey brighter, more varied sample of stars

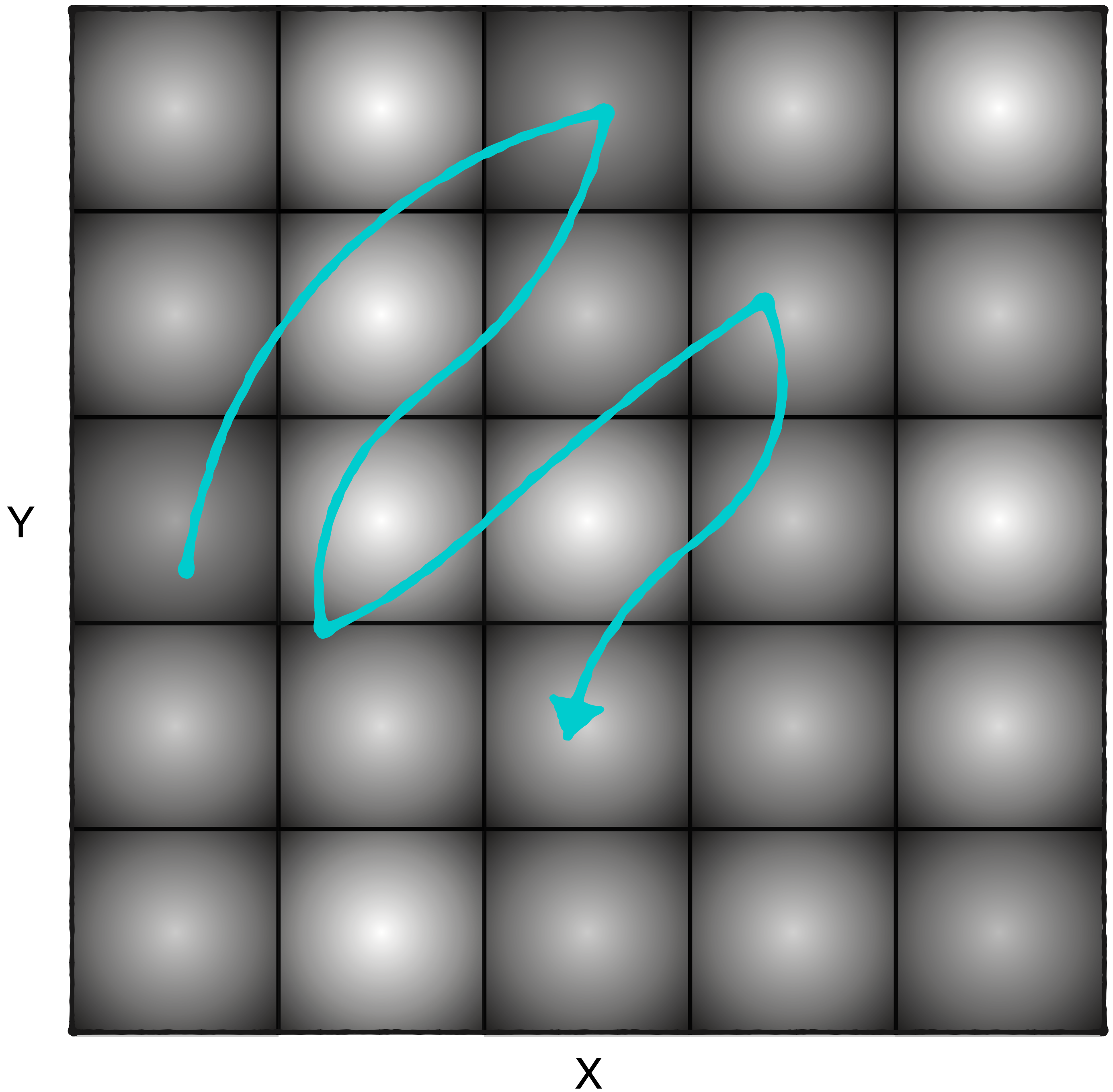
ACTIVE STAR

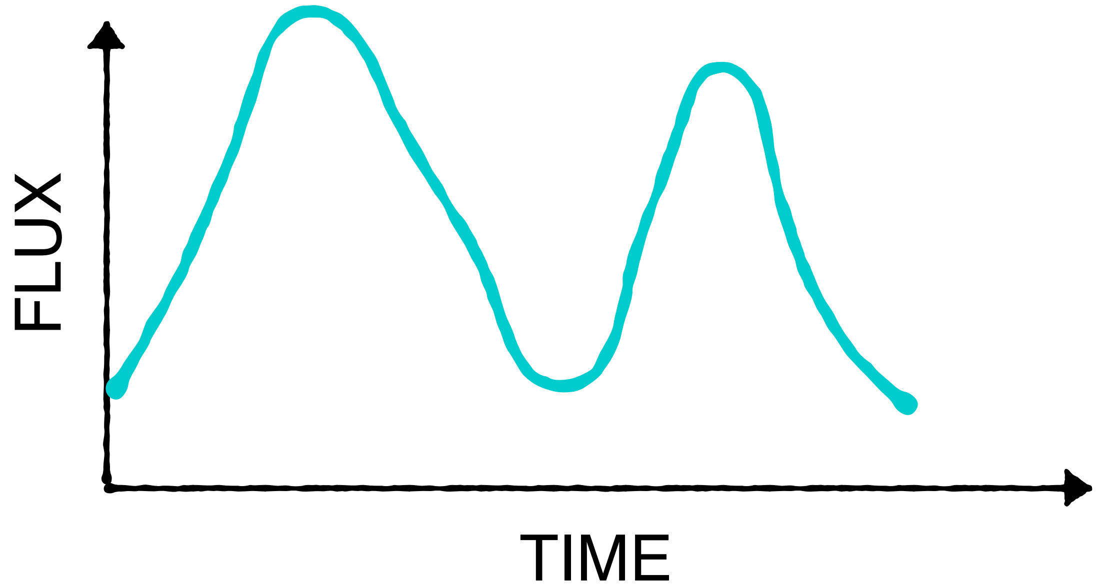

YEARS
WEEKS
DAYS
HOURS
MINUTE
S
ACTIVE
REGIONS
GRANULATIO
N
OSCILLATION
S
PLANETARY ORBITS
TRANSITS
LOG POWER DENSITY
LOG FREQUENCY

EVOLVED STAR



ITS NOT JUST STELLAR NOISE





STOCHASTIC PROCESSES

STELLAR VARIABILITY = INTERPLAY OF MAGNETISM & CONVECTION

- too complex / ill understood to predict analytically
- intrinsically STOCHASTIC

MODEL STOCHASTIC PROCESS EXPLICITLY

- parametrise statistical properties of data (mean, covariance)
- build any physical knowledge into model
- Bayesian framework - marginalise over nuisance parameters
- easily combined with deterministic phenomena (planets)

GAUSSIAN PROCESSES

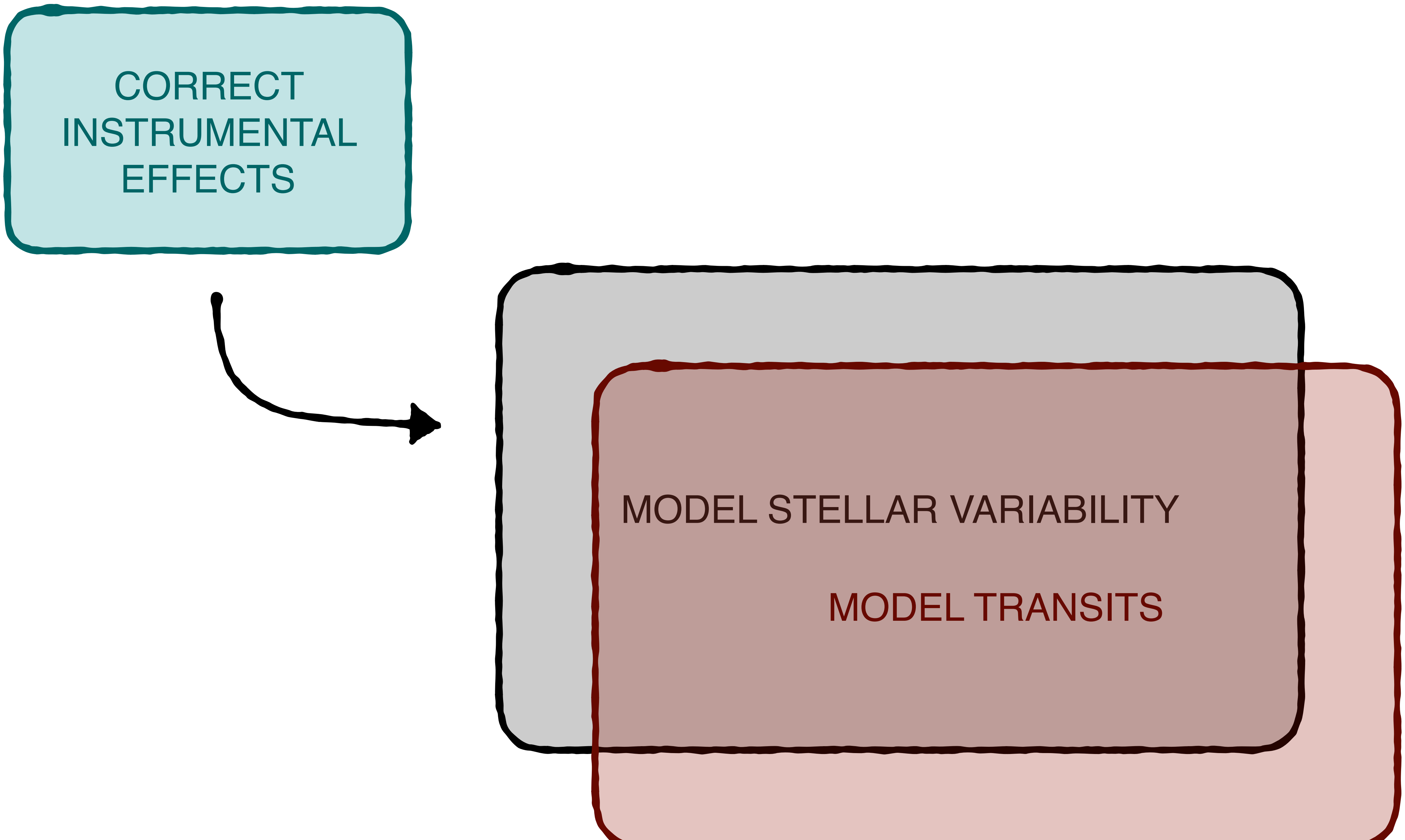
LIKELIHOOD: $p(\mathbf{y}|\mathbf{x},\mathrm{model}) = \mathcal{N}(\mathbf{y}|\mathbf{m},\mathbf{K})$

MEAN FUNCTION: $\mathbf{m}=f(\mathbf{x},\boldsymbol{\theta})$, COVARIANCE MATRIX: $K_{ij} = k(x_i,x_j,\boldsymbol{\Phi})$

TYPES OF GP

white noise: $\mathbf{K} = \sigma^2 \mathbf{I}$

GPs ARE ALREADY USED
in transit modelling



Kepler-91

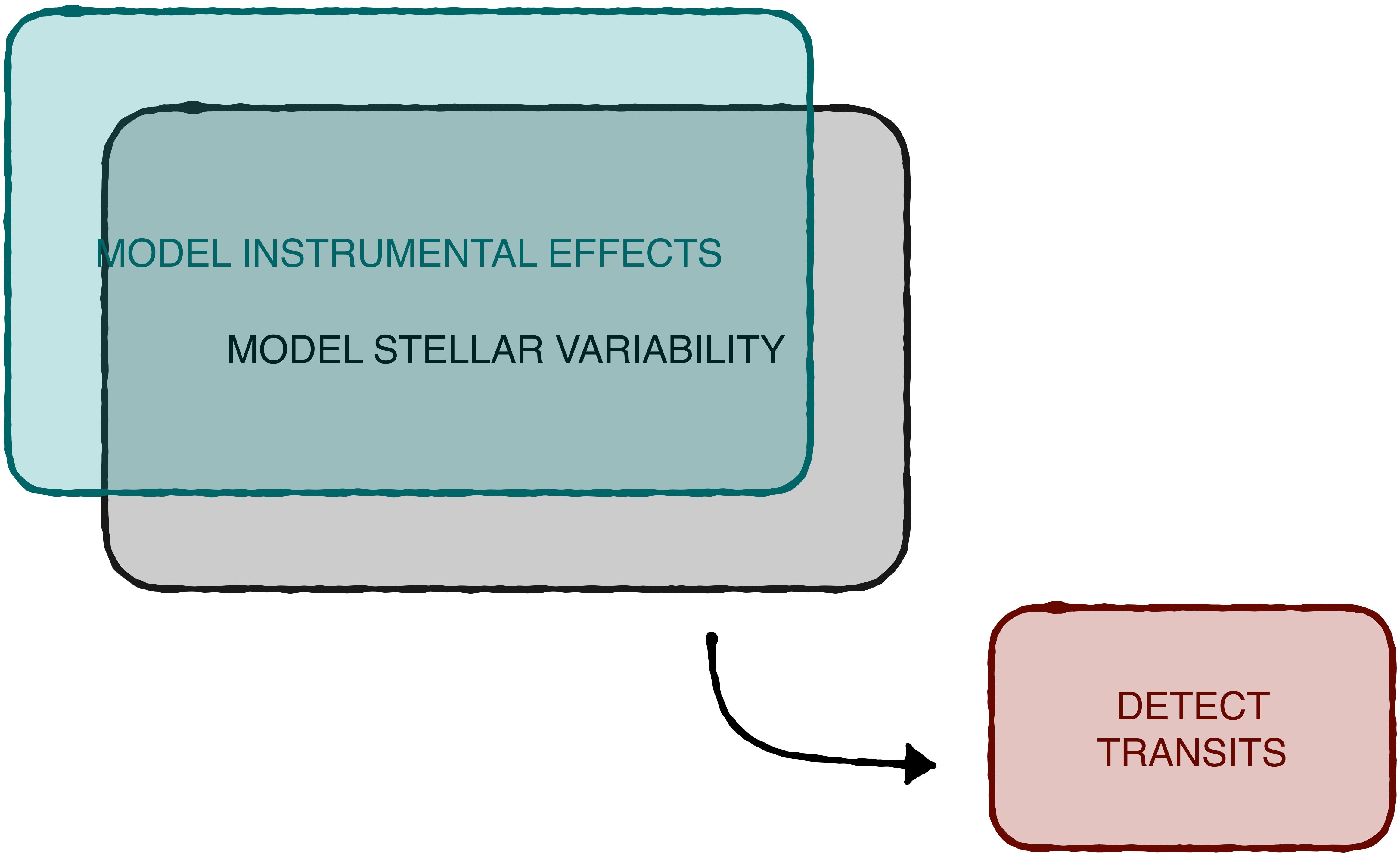
KOI 2133.01 (Bathala et al. 2013)

- red giant host star

CONFLICTING STUDIES

- Esteves et al. (2013): phase curve indicates self-luminous object
- Lillo-Box et al. (2014b) RV + phase curve confirm planet
- Sliski & Kipping (2014): stellar density from transit and asteroseismology inconsistent

GPs ARE ALREADY USED
in systematics correction



K2SC

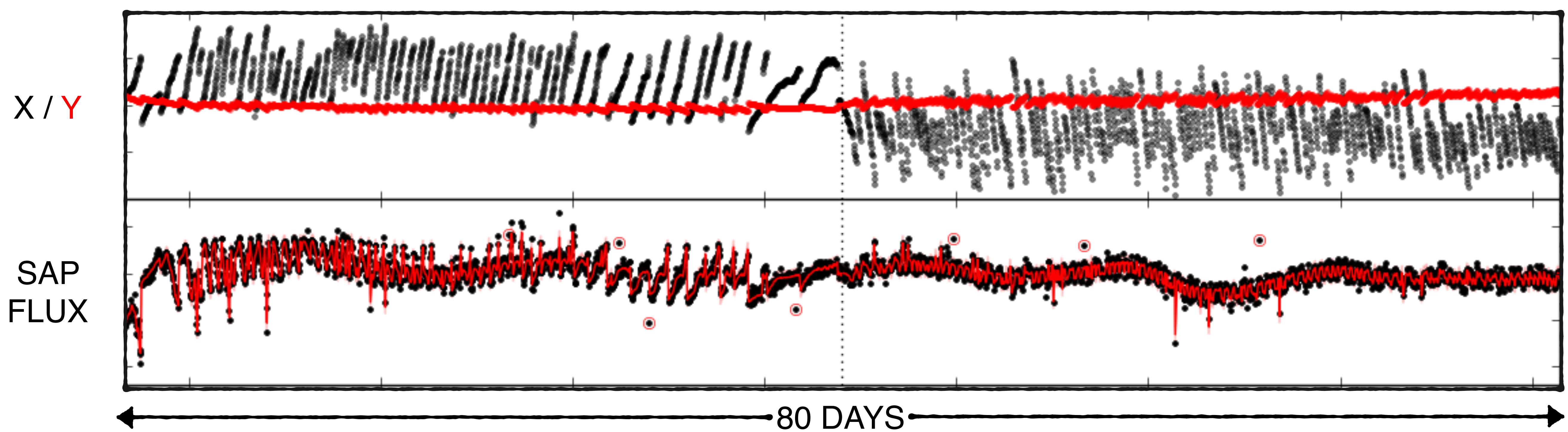
Aigrain+(2016)

K2 MISSION: pointing variations + intrapixel variations —> systematics

SYSTEMATICS: unknown 2-D function of star position

STELLAR VARIABILITY: unknown 1-D function of time

NEED FLEXIBLE, JOINT MODEL



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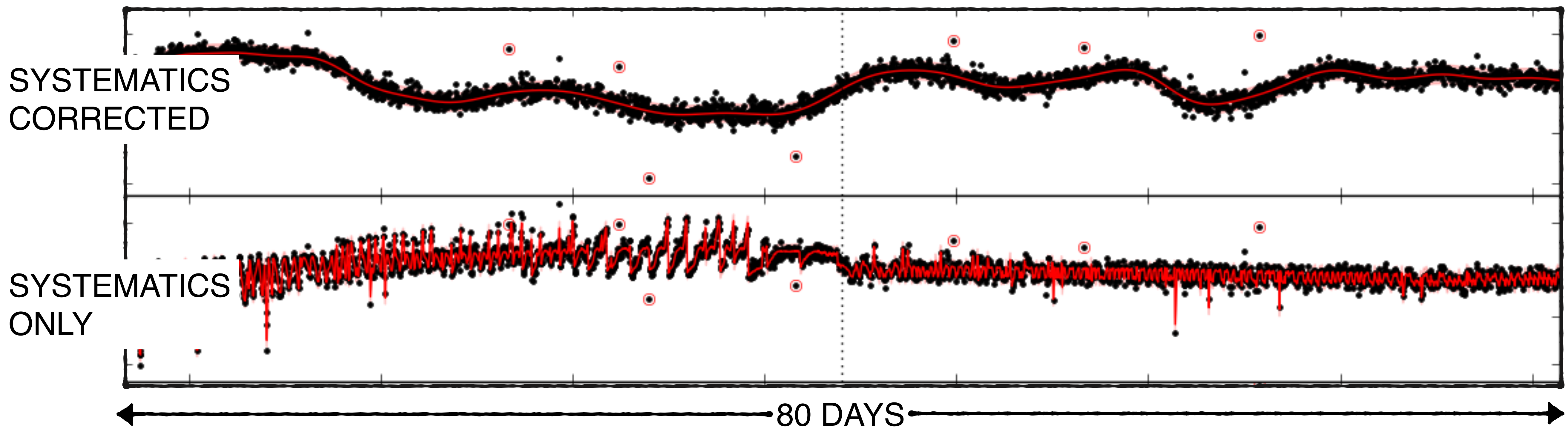
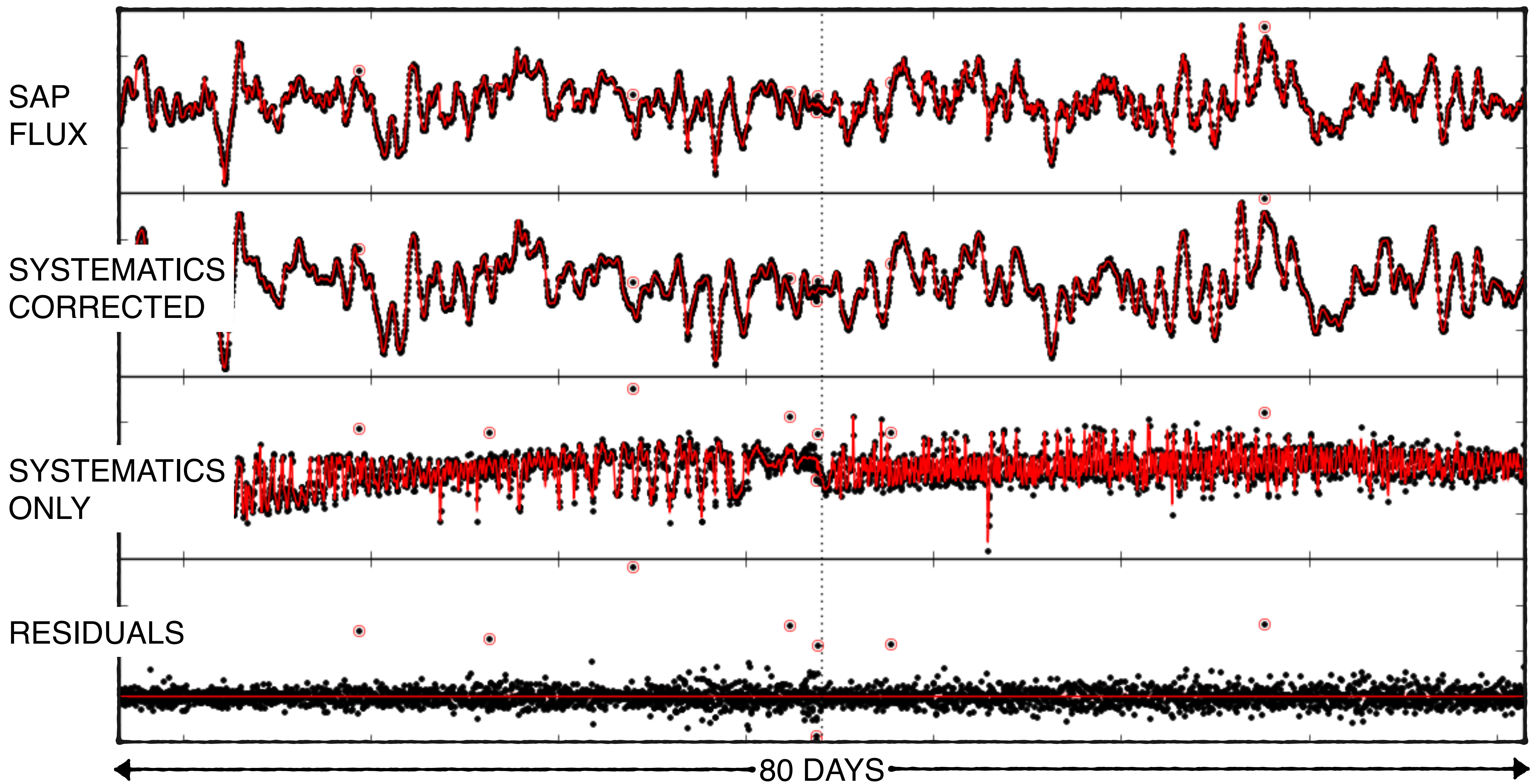


K2SC

Aigrain+(2016)



ADVERTISMENT BREAK

K2SC version 2 light curves now available at MAST
Campaigns 3-10

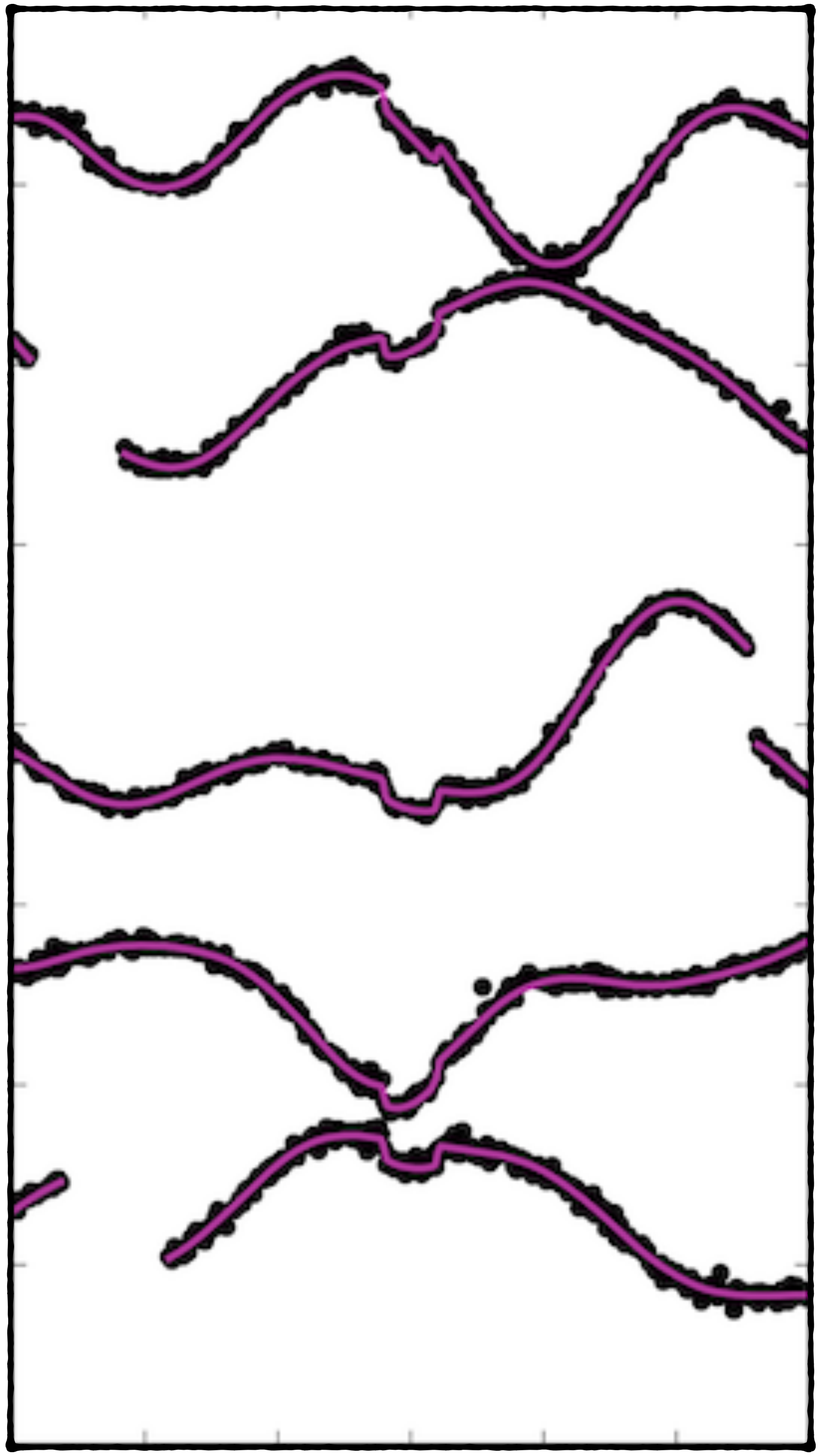
GPs for DETECTION?

CHALLENGING

- large datasets - GP regression is $O(N^3)$

POSSIBLE WITH FAST MATRIX INVERSION?

- e.g.: CELERITE (Foreman-Mackey+2017)



IMPLICATIONS FOR PLATO

DON'T FILTER, MODEL!

- correct known, predictable instrumental effects to best ability
- measure/model the rest, and the stars
- understand better relationship between existing algorithms/GPs
- PLATO pipeline is being defined now…

TEST ON KEPLER LIGHT CURVES

- we know much more about variability properties of target stars now

CAREFUL TREATMENT OF ACTIVITY WILL BE CRITICAL

- to maximise detection efficiency
- to UNDERSTAND detection efficiency and reliability
- for RADIAL VELOCITY follow-up