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Properties of Stars from High-Precision Photometry

Bill Chaplin, School of Physics & Astronomy
University of Birmingham, UK

SAGAN 2012, NExScI, 2012 July 27

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Properties of Stars from High-Precision *Kepler* Photometry

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High-precision photometry

$I(t_1), I(t_2), I(t_3), I(t_4), I(t_5), I(t_6)\ldots$

$\Downarrow$

properties

structure

dynamics

High-precision photometry

- Minutes to hours…
  - Oscillations
  - Granulation
- Days to months…
  - Rotation
  - Activity
  - Damping of solar-like oscillations

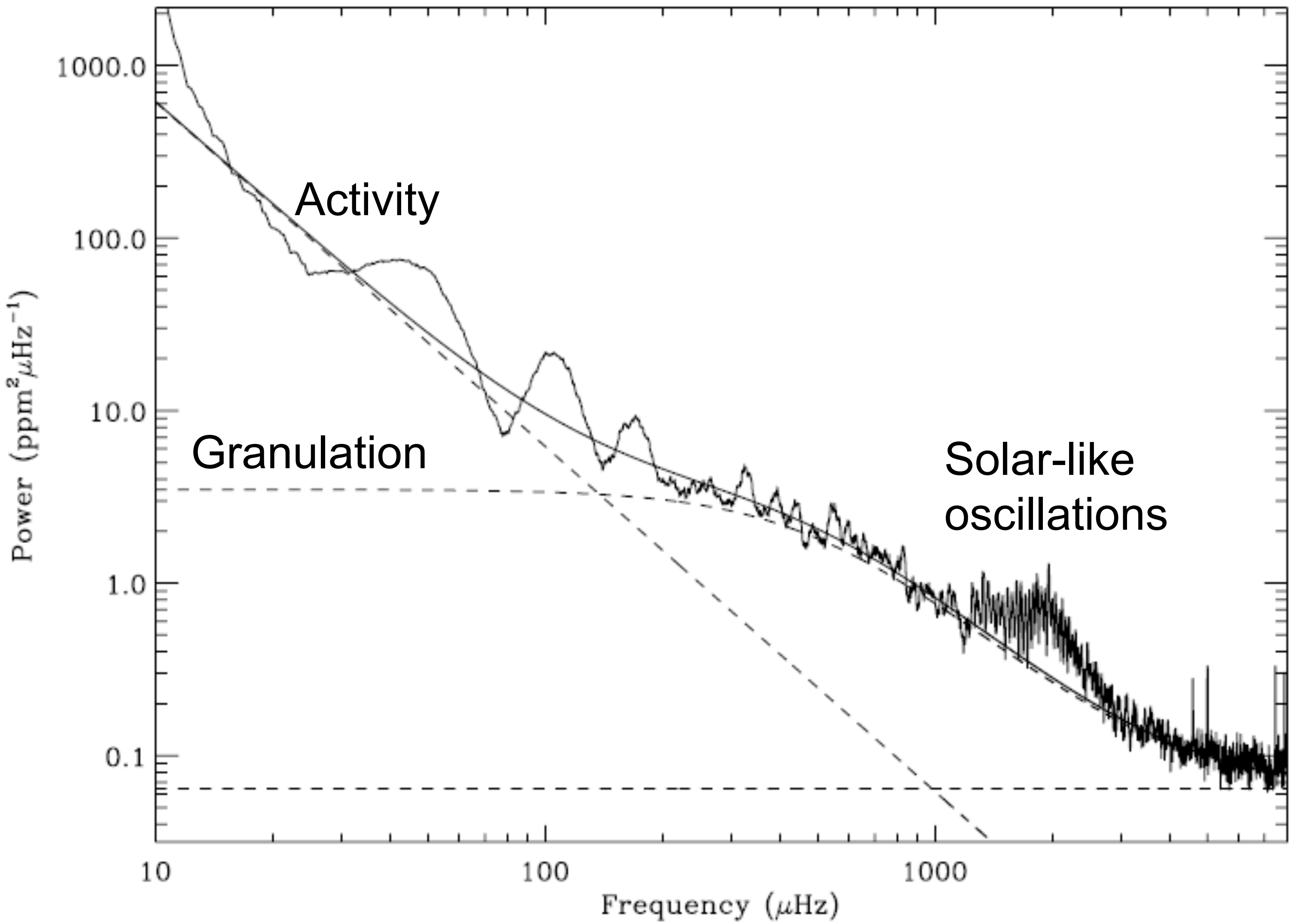
High-precision photometry

- Asteroseismology
  - Stellar properties (including precise ages)
  - Structure (depth BCZ)
  - Internal rotation, stellar inclination
  - Stellar cycles, surface activity
- Rotational modulation
  - Surface rotation, activity
  - Ages from gyrochronology

High-precision photometry

- Cross-checks and linkages…
  - Ages (asteroseismology & gyrochronology)
  - Rotation (internal & surface)
  - Belt-and-braces for inclination, dynamics
- Complementary ground-based data are essential for constraining stellar properties (e.g., from asteroseismology)

θ Cyg: The brightest *Kepler* target



Guzik et al. (2012), in preparation

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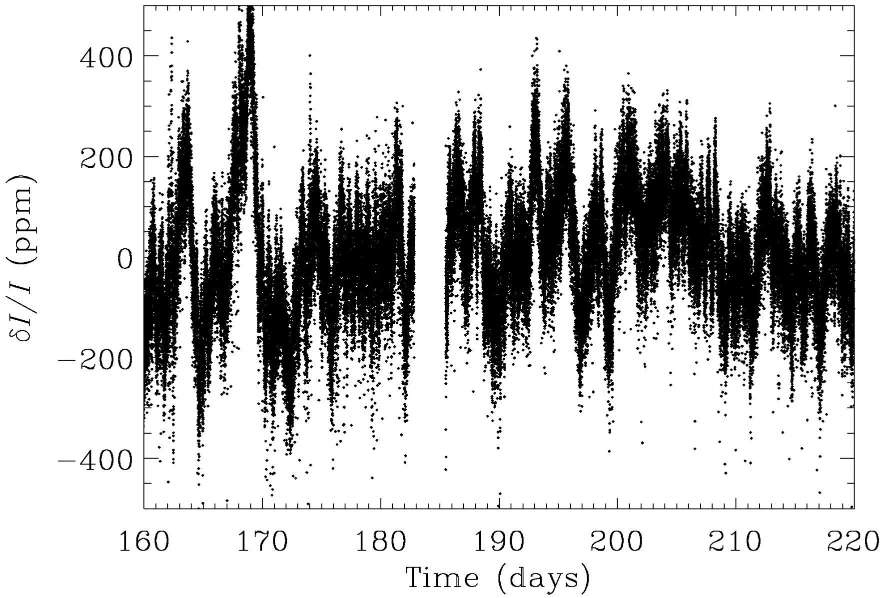
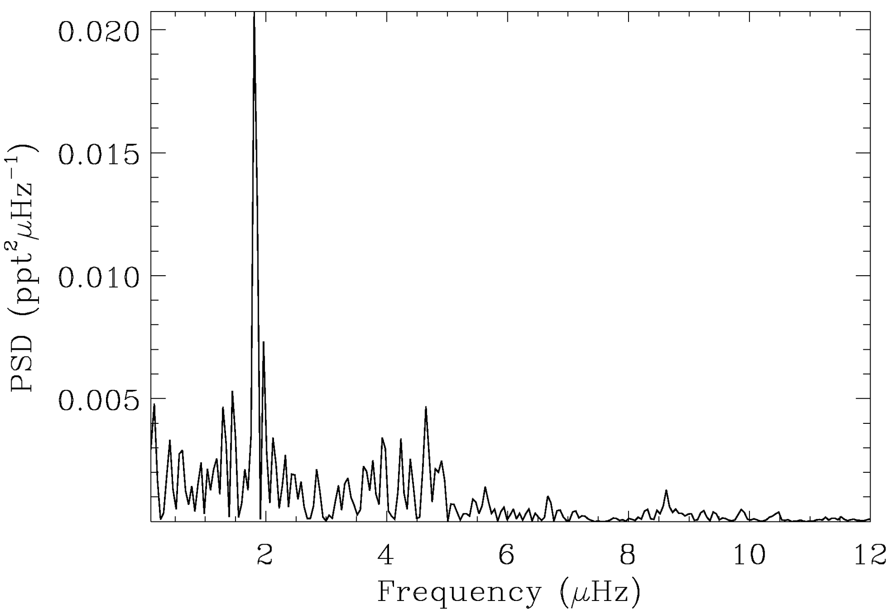
θ Cyg: The brightest *Kepler* target

Surface rotation…



Low-frequency signal



Guzik et al. (2012), in preparation

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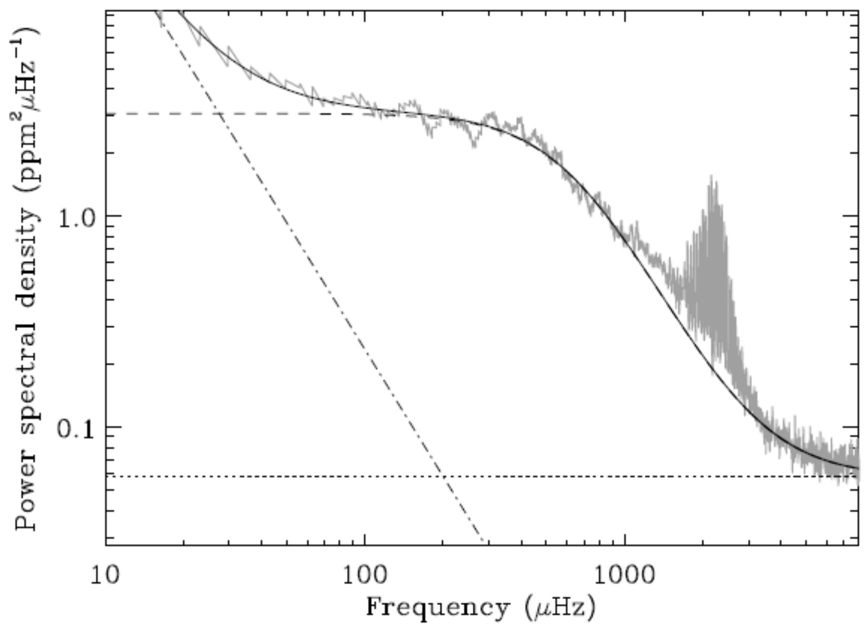
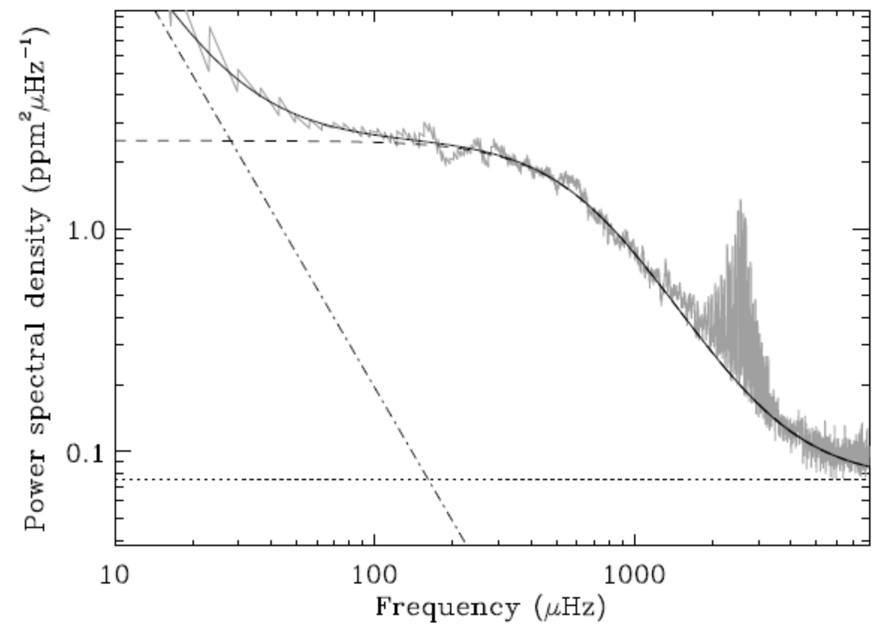
Kepler's "best in class"

Solar-type binary 16 Cyg (age 6.8 Gyr)

16 Cyg A $M = 1.11 M_{\odot}$



16 Cyg B $M = 1.07 M_{\odot}$



Metcalfe et al., 2012, ApJ, 748, L10

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Kepler's "best in class"

Solar-type binary 16 Cyg (age 6.8 Gyr)

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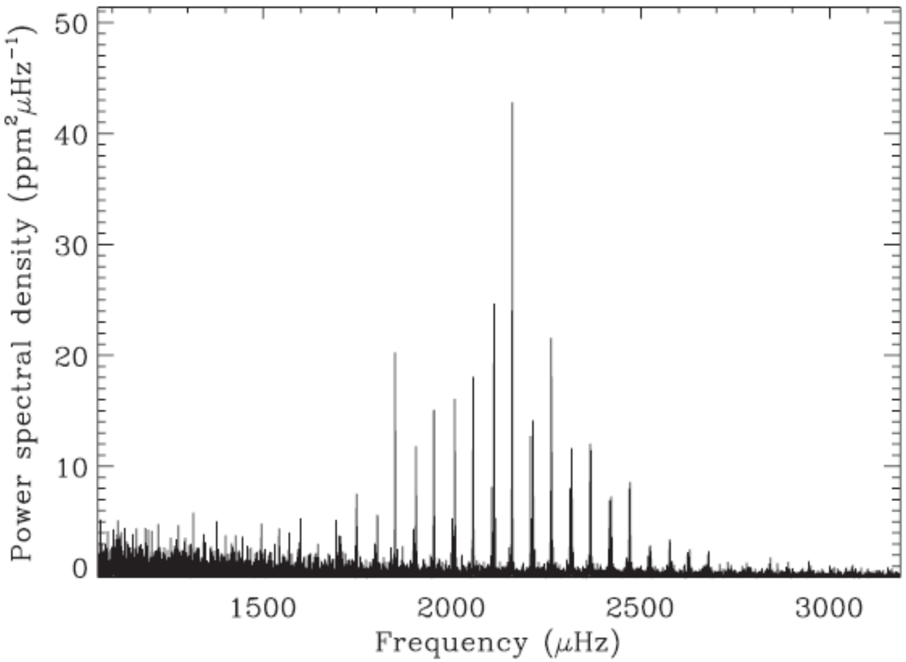
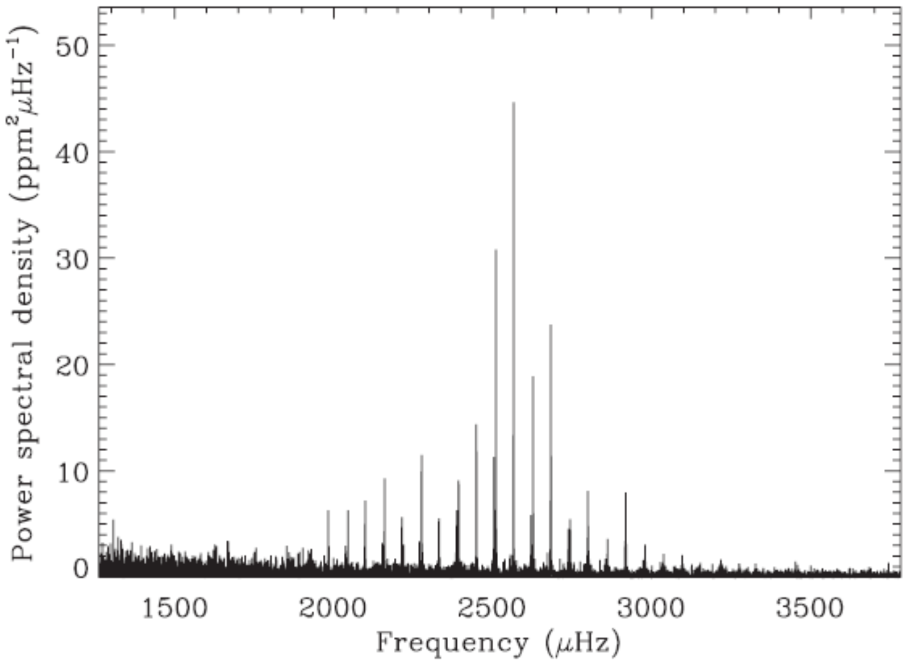


16 Cyg B $M = 1.07 M_{\odot}$



Metcalfe et al., 2012, ApJ, 748, L10

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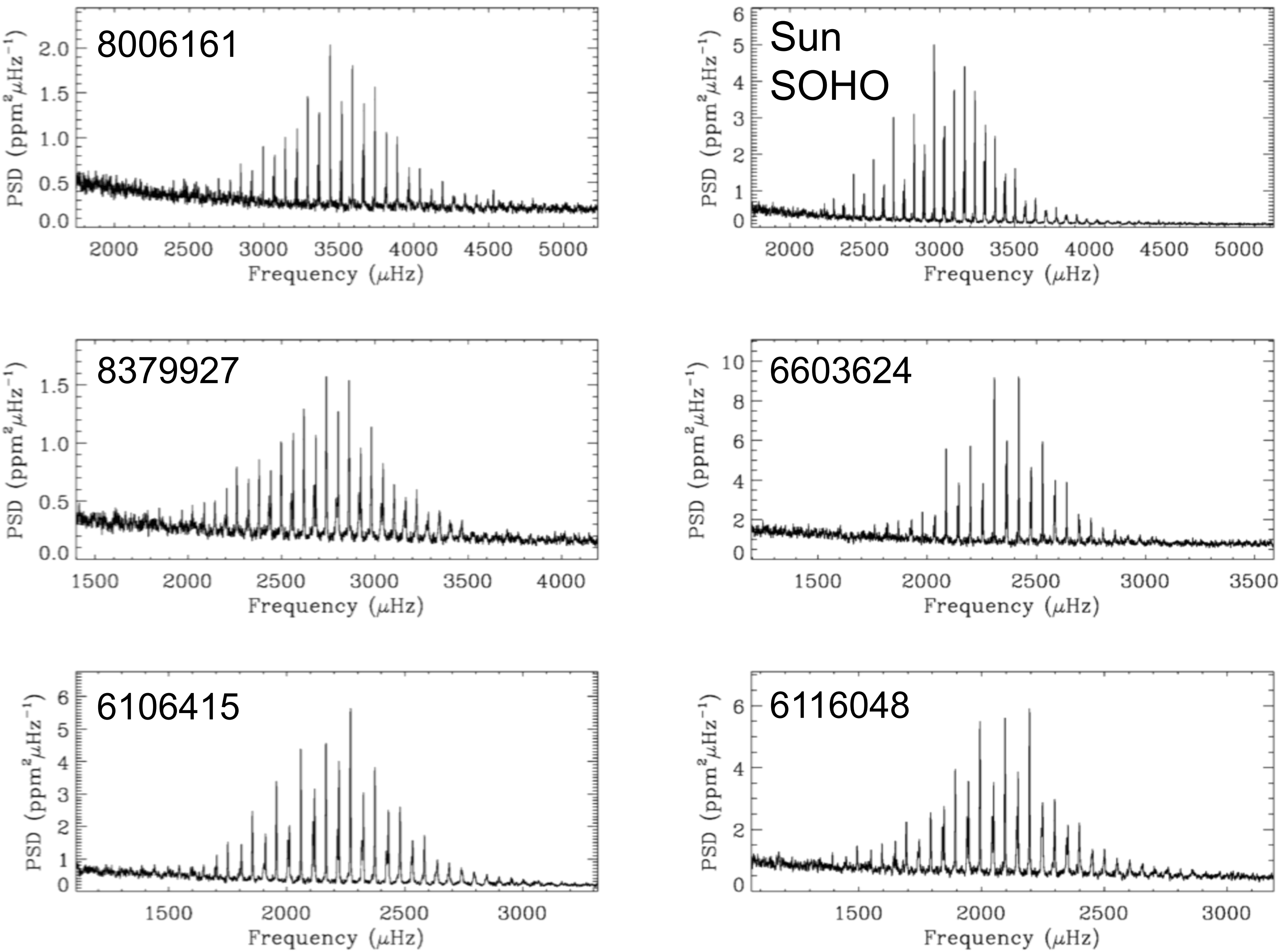

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Stellar properties from asteroseismology

- Precise, accurate fundamental stellar properties for modelling exoplanet systems:
  - Densities, radii, masses
  - log(*g*) for “boot strapping” spectroscopic analysis
  - Ages! Comparison with gyrochronology

Stellar properties from asteroseismology

- Internal rotation, stellar angle of inclination:
  - Constraints on dynamical histories of stellar systems

Stellar properties from asteroseismology

- Intrinsic activity, variability of host stars, influence on local environment:
  - “Sound” stellar activity cycles
  - Constrain distribution of near-surface activity
  - Depths of convective envelopes, tests of stellar dynamos

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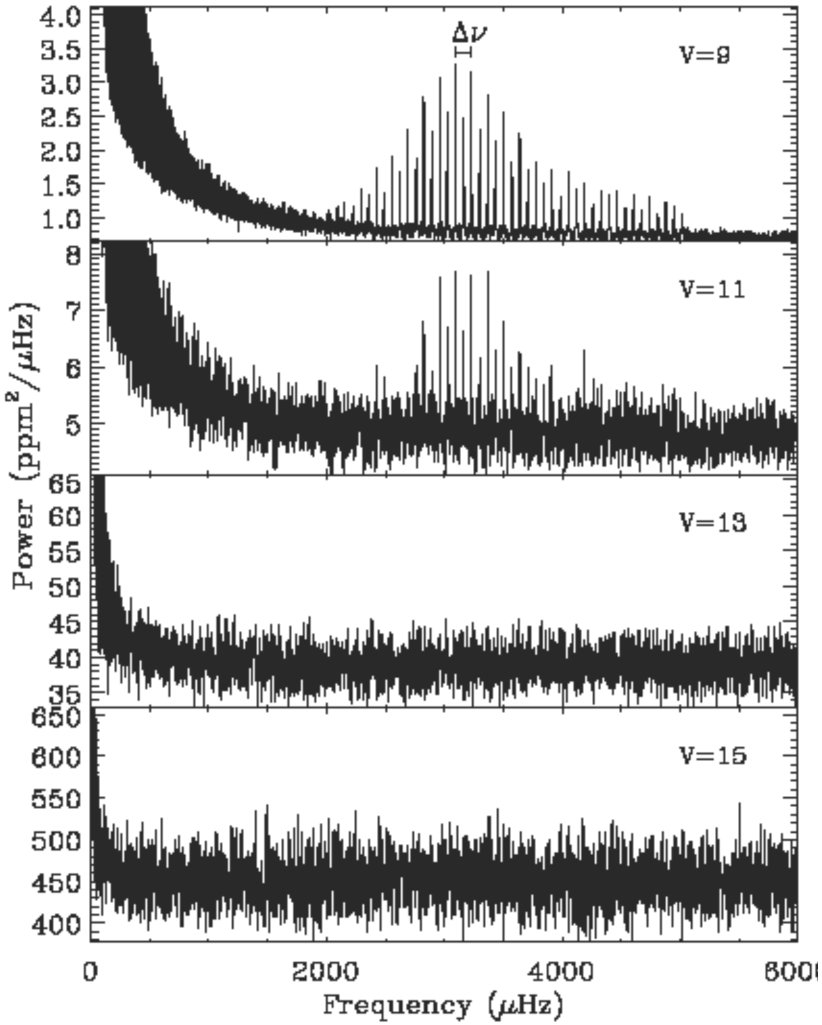
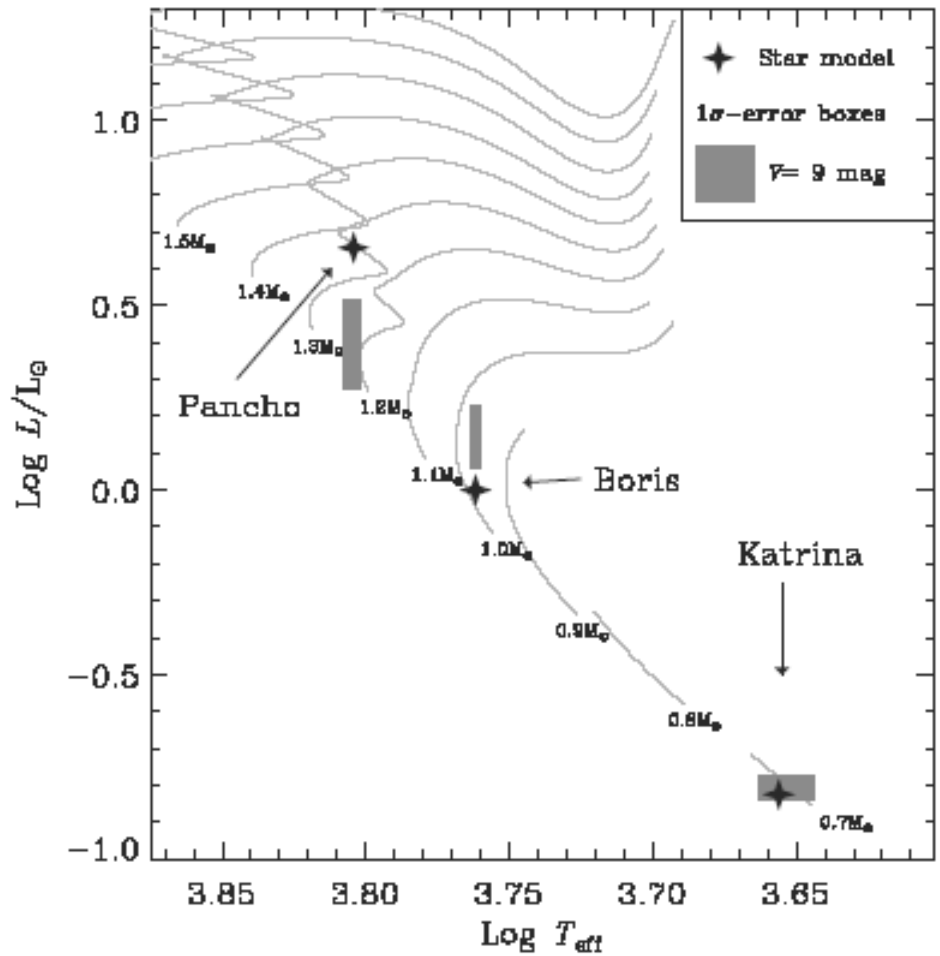
asteroFLAG Hare and Hounds





Stello, Chaplin et al. 2009, ApJ

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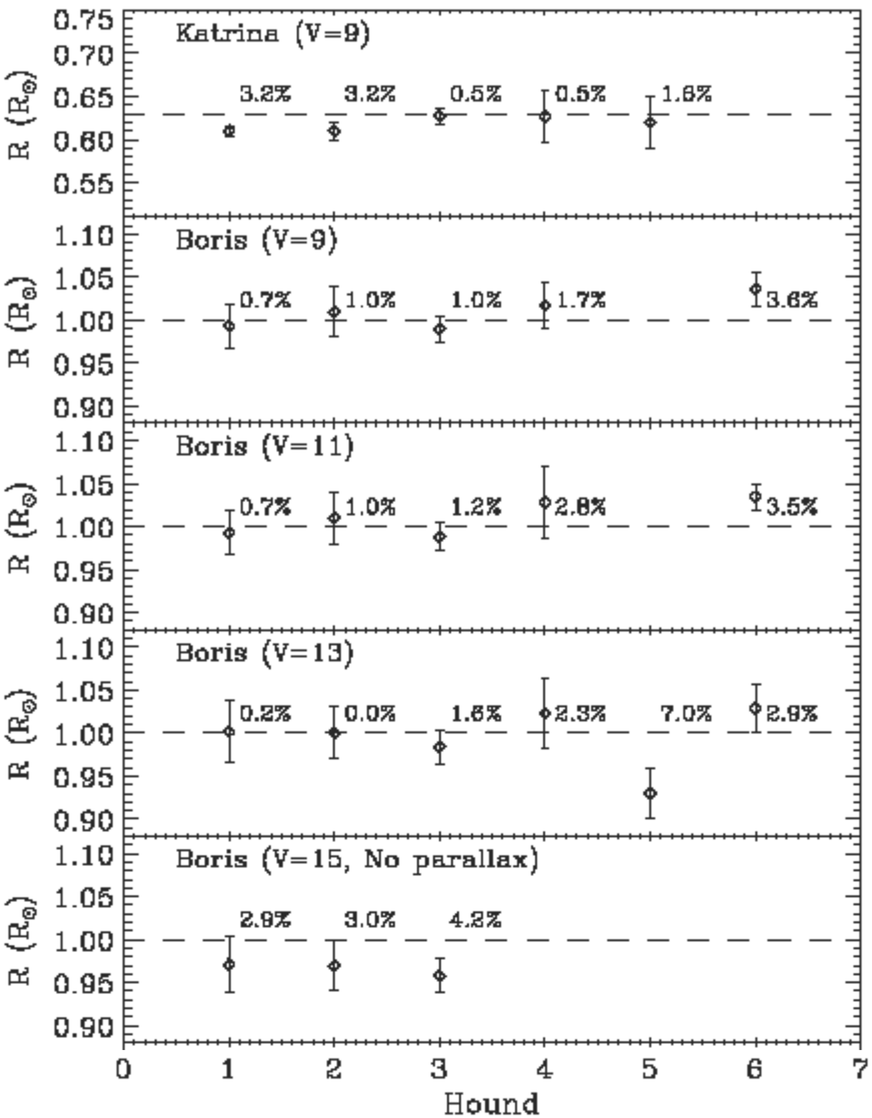
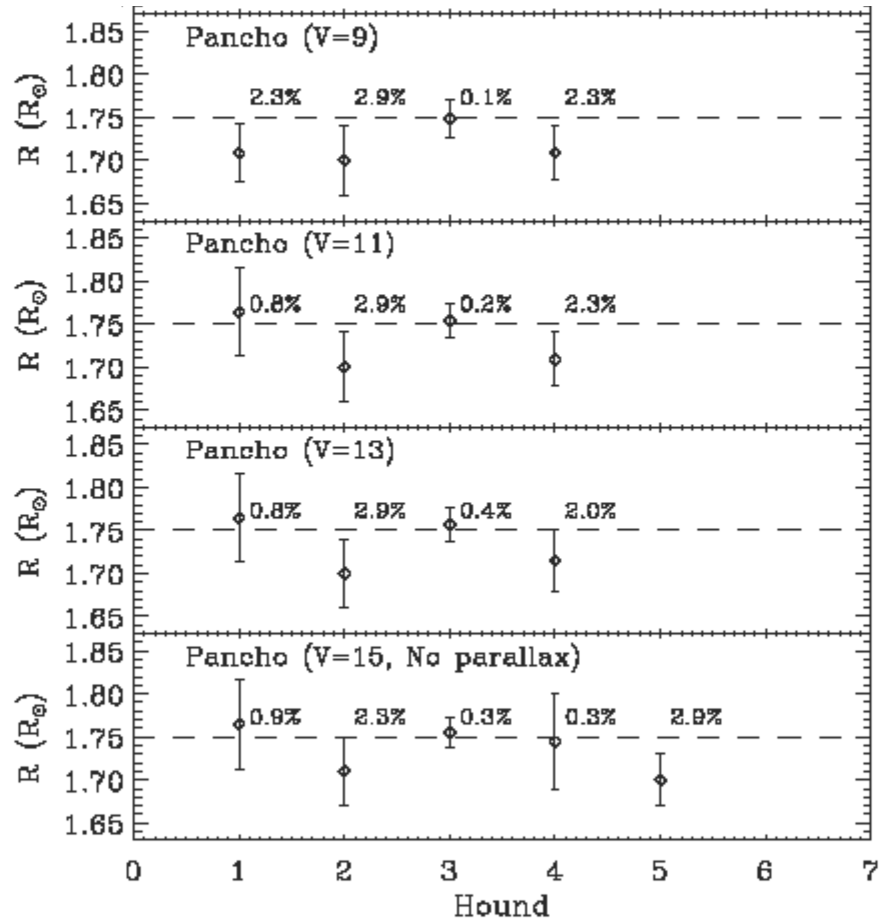
asteroFLAG Hare and Hounds





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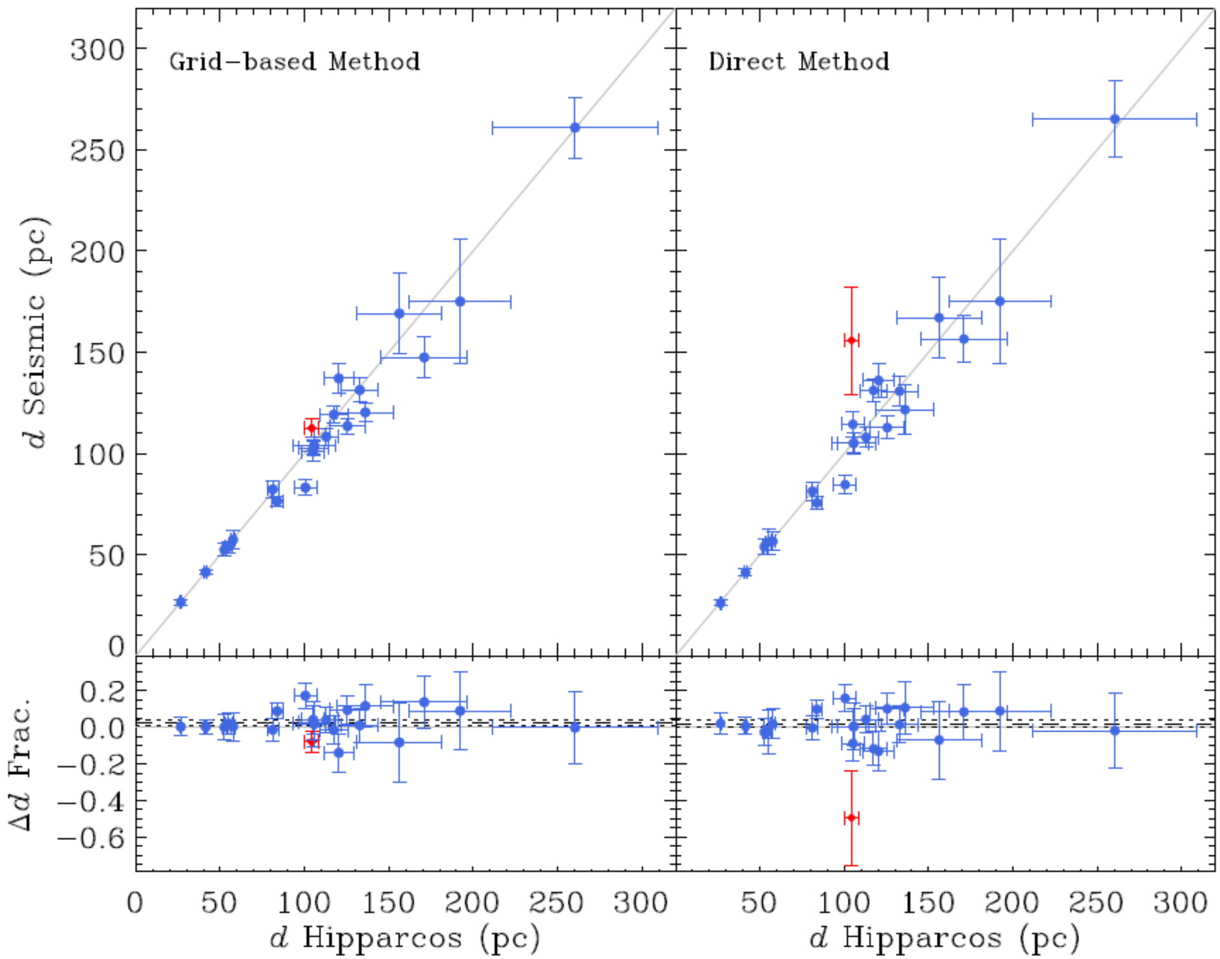
Testing asteroseismic inference

Hipparcos parallaxes



Silva-Aguirre et al., ApJ, 2012, submitted

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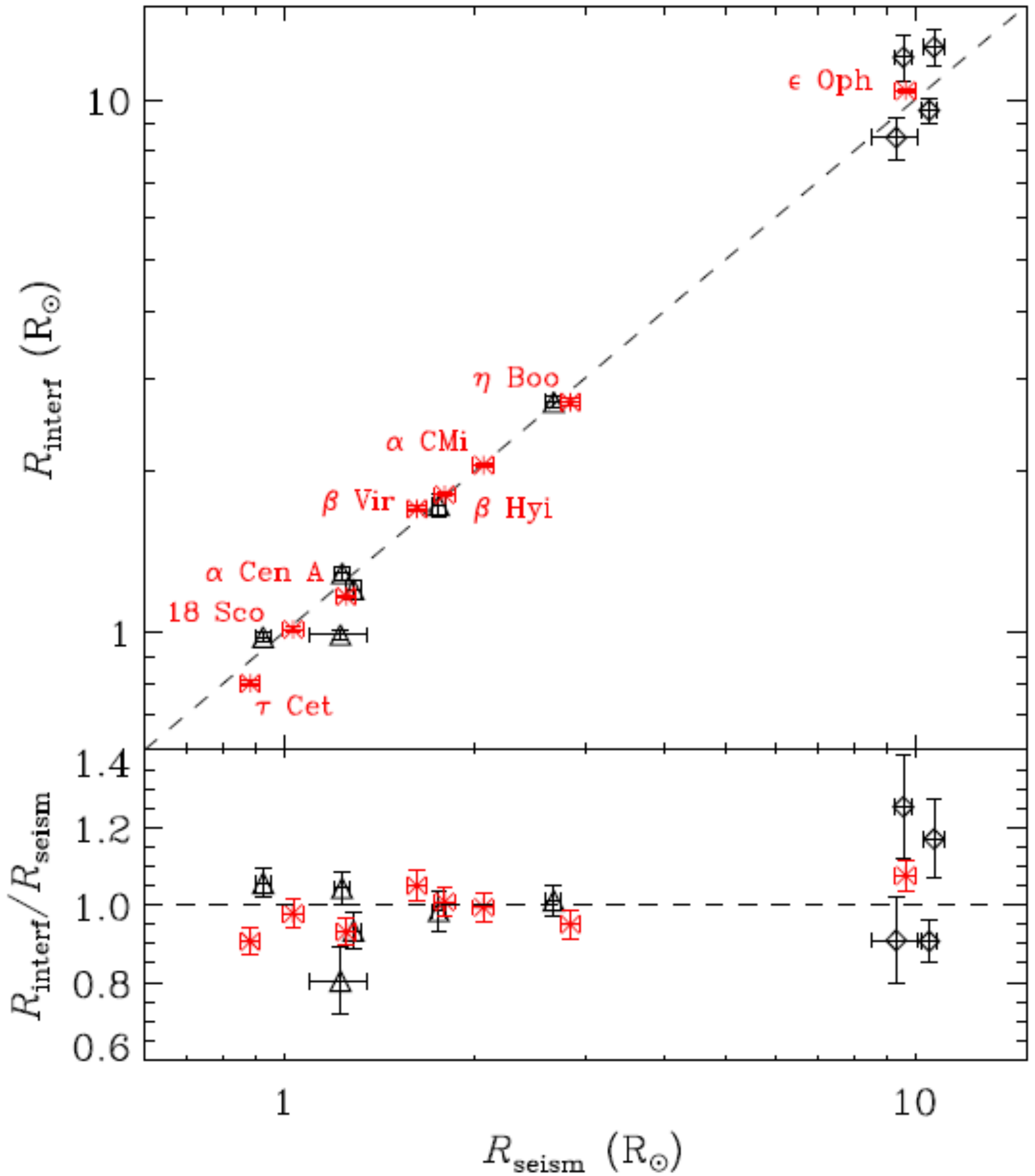

Testing asteroseismic inference with interferometry

Observations with CHARA

Huber et al., ApJ, 2012, submitted

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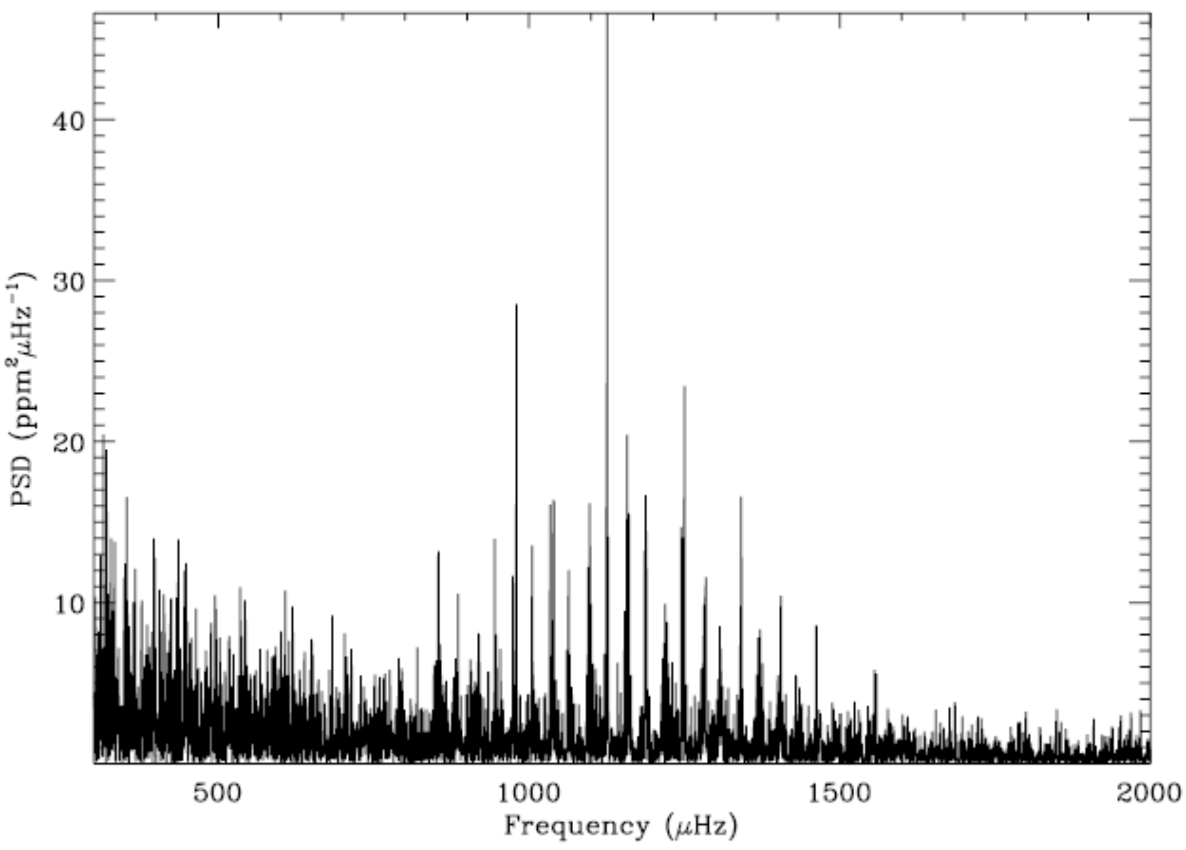
Kepler 21b $1.6R_E$ planet orbiting bright F-type sub-giant



Howell et al. (2012), ApJ, 746, 123

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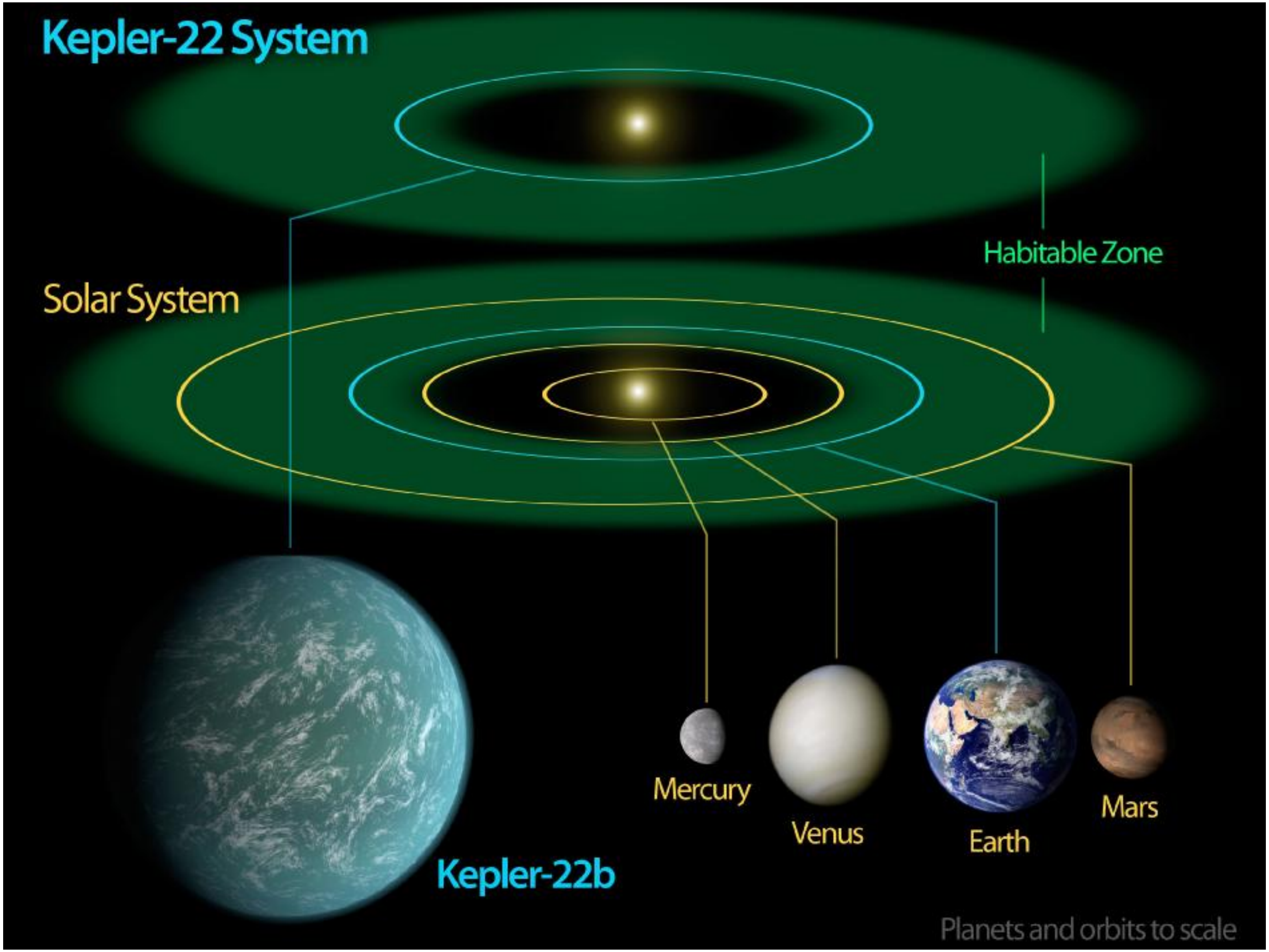
Kepler 21b $1.6R_E$ planet orbiting bright F-type sub-giant

- Brightest *Kepler* exoplanet host star
- High-precision stellar properties from asteroseismology:
  - Stellar radius to 2.2%
  - Stellar mass to 4.5%
  - Stellar age to 12%
- Planetary radius to 2.4%



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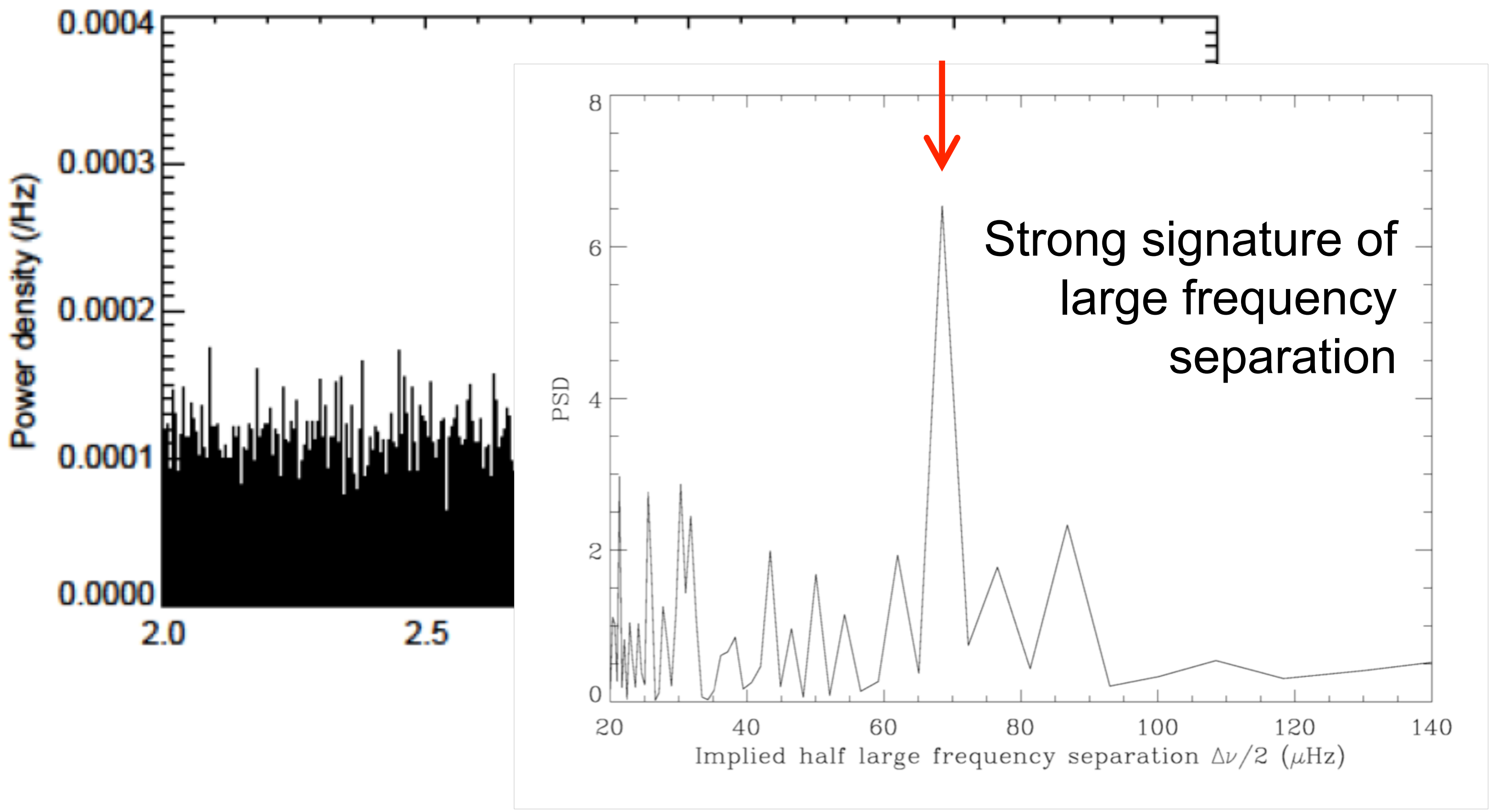
Kepler 22b 2.4R_E planet in habitable zone of Sun-like star



Borucki et al. (2012), ApJ, 745, 120

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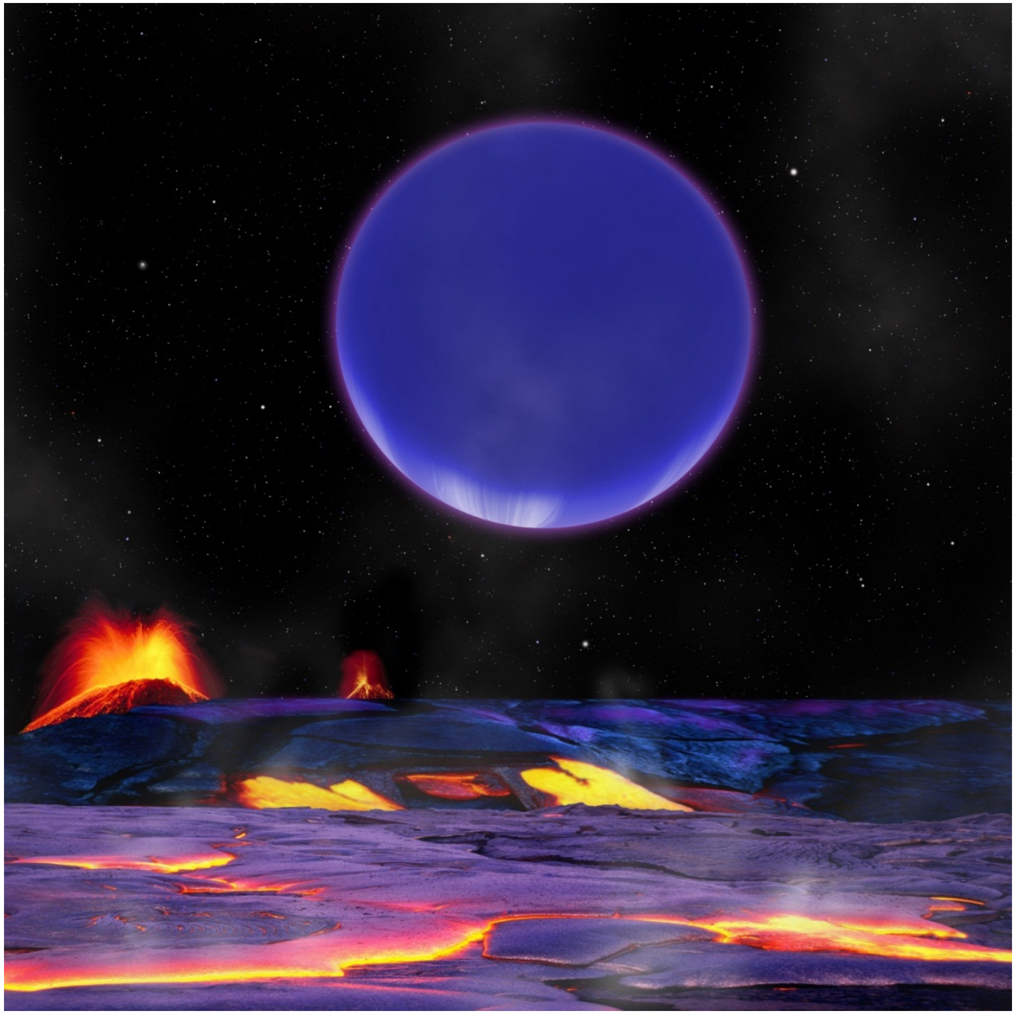
Kepler 36b and Kepler 36c



Carter et al. (2012), Science, in the press

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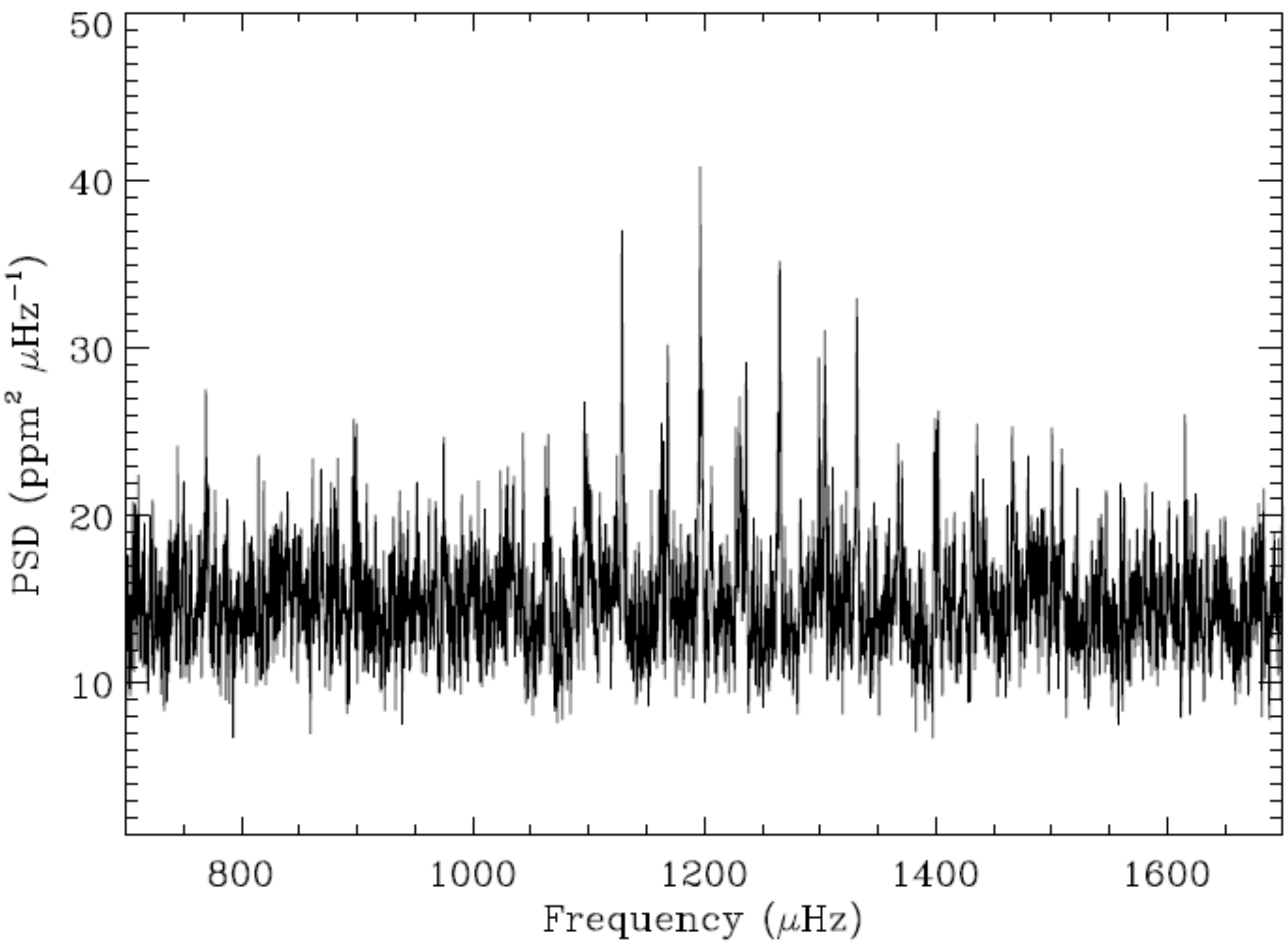
Kepler 36: G-type subgiant



Carter et al. (2012), Science, in the press

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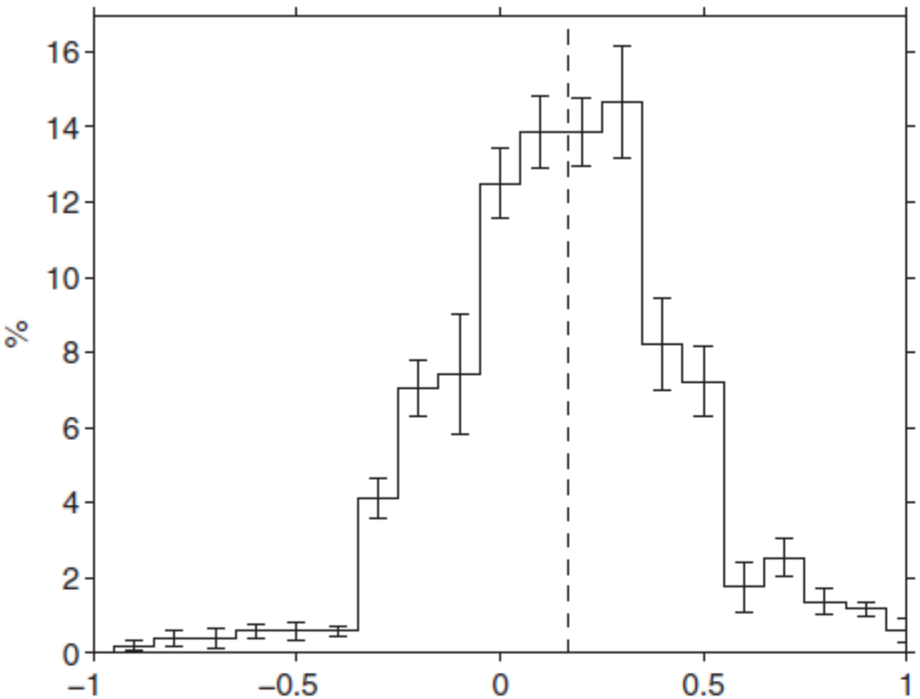
Kepler 36: G-type subgiant

- High-precision stellar properties from asteroseismology:
  - Stellar radius to 1.2%
  - Stellar mass to 4.0%
  - Stellar age to 15%
- Key to providing strong constraints on planetary properties

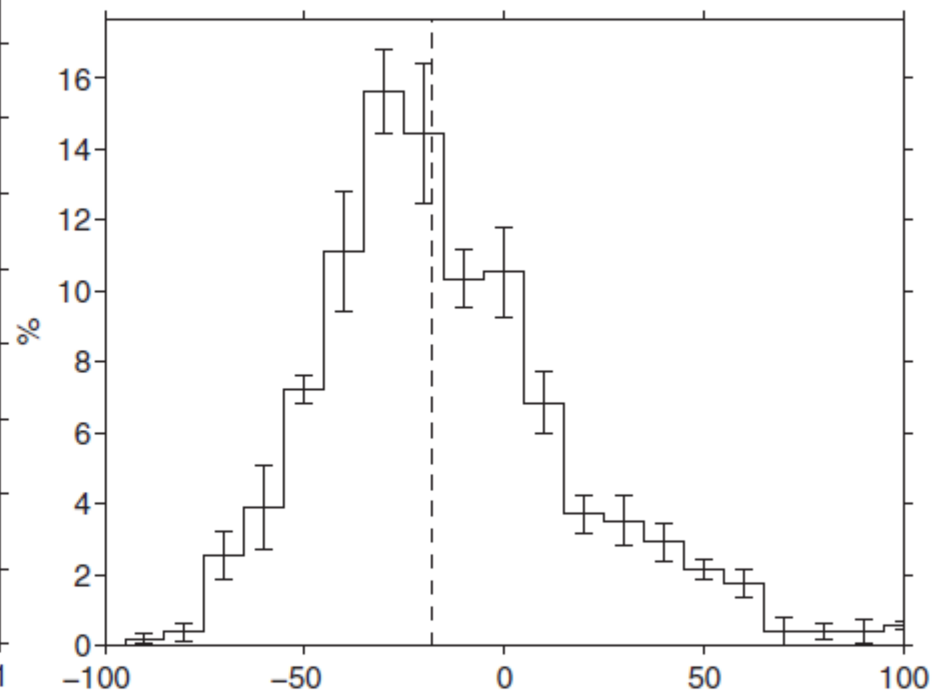
Carter et al. (2012), Science, in the press

Asteroseismic ensemble tests *Kepler* Input Catalogue

Finds an underestimation bias in KIC radii



KIC – seismic log *g* (dex)



KIC – seismic radii (%)

Verner et al., 2011, ApJ, 738, L28

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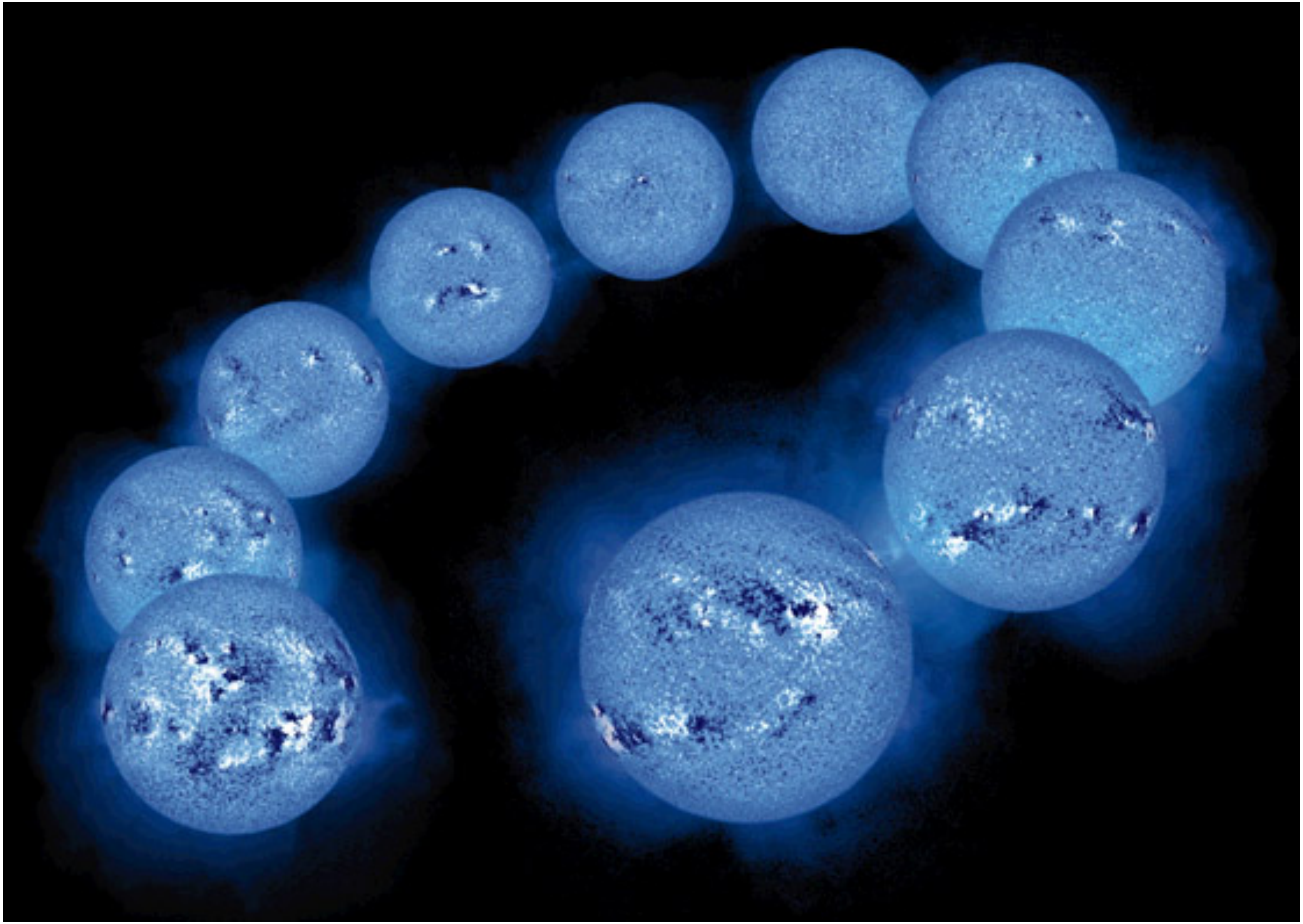
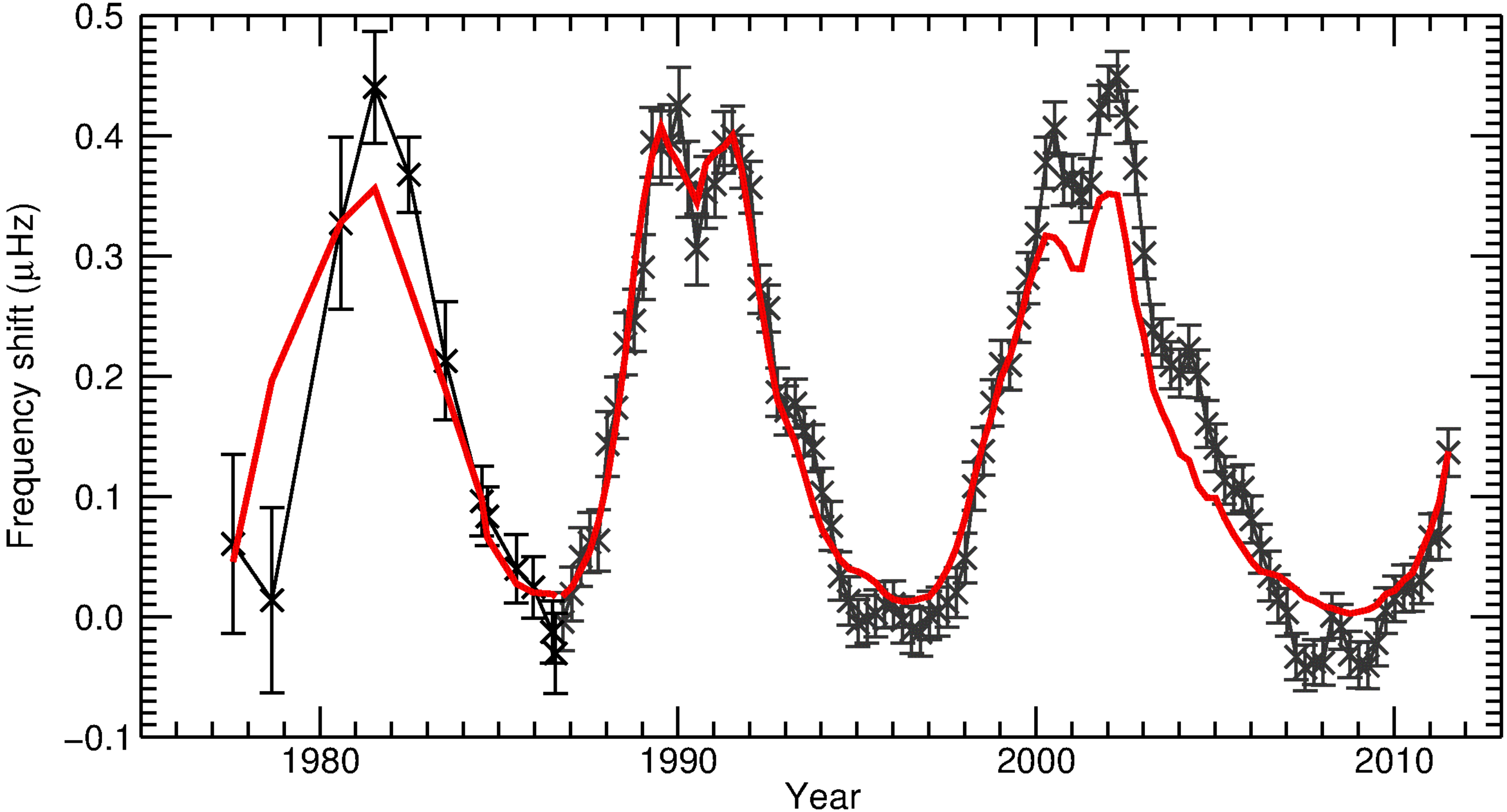


“Sounding” stellar activity cycles: Sun

Three solar cycles with BiSON Sun-as-a-star data



scaled 10.7-cm radio flux

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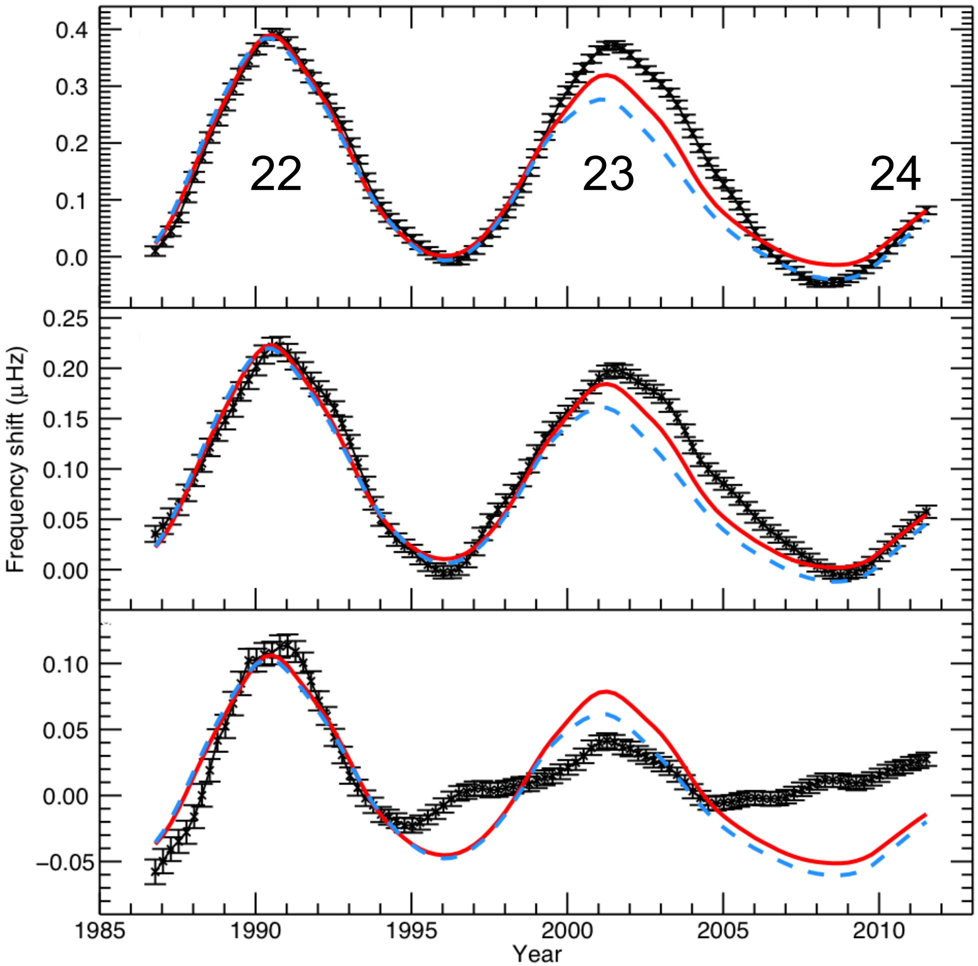
Cycles 22, 23… and rise of 24

BiSON Sun-as-a-star data



High-frequency modes

Intermediate-frequency modes

Low-frequency modes

scaled 10.7-cm radio flux

scaled ISN

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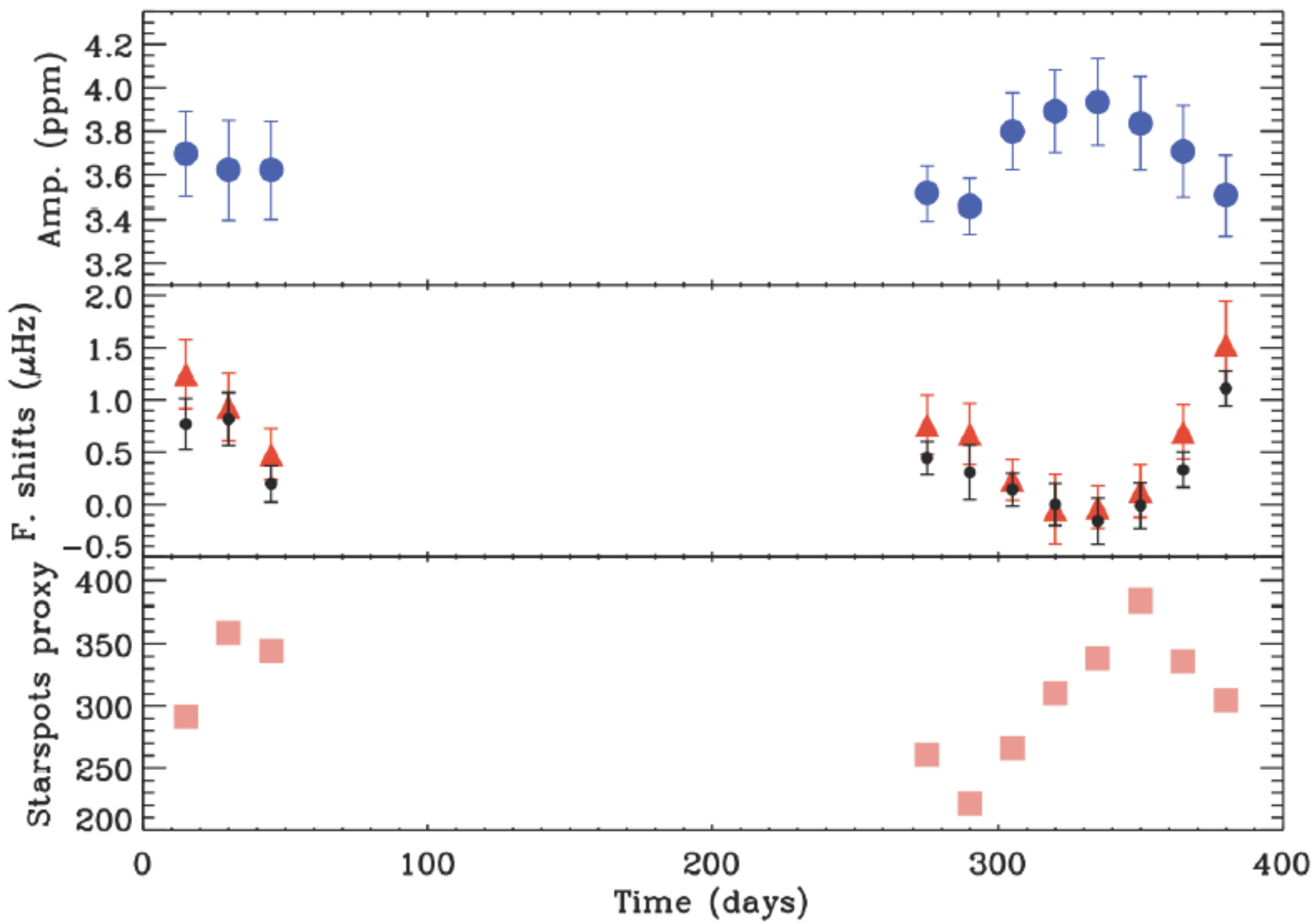
CoRoT reveals a short activity cycle in HD49933



García et al., 2010, Science, 329, 1032

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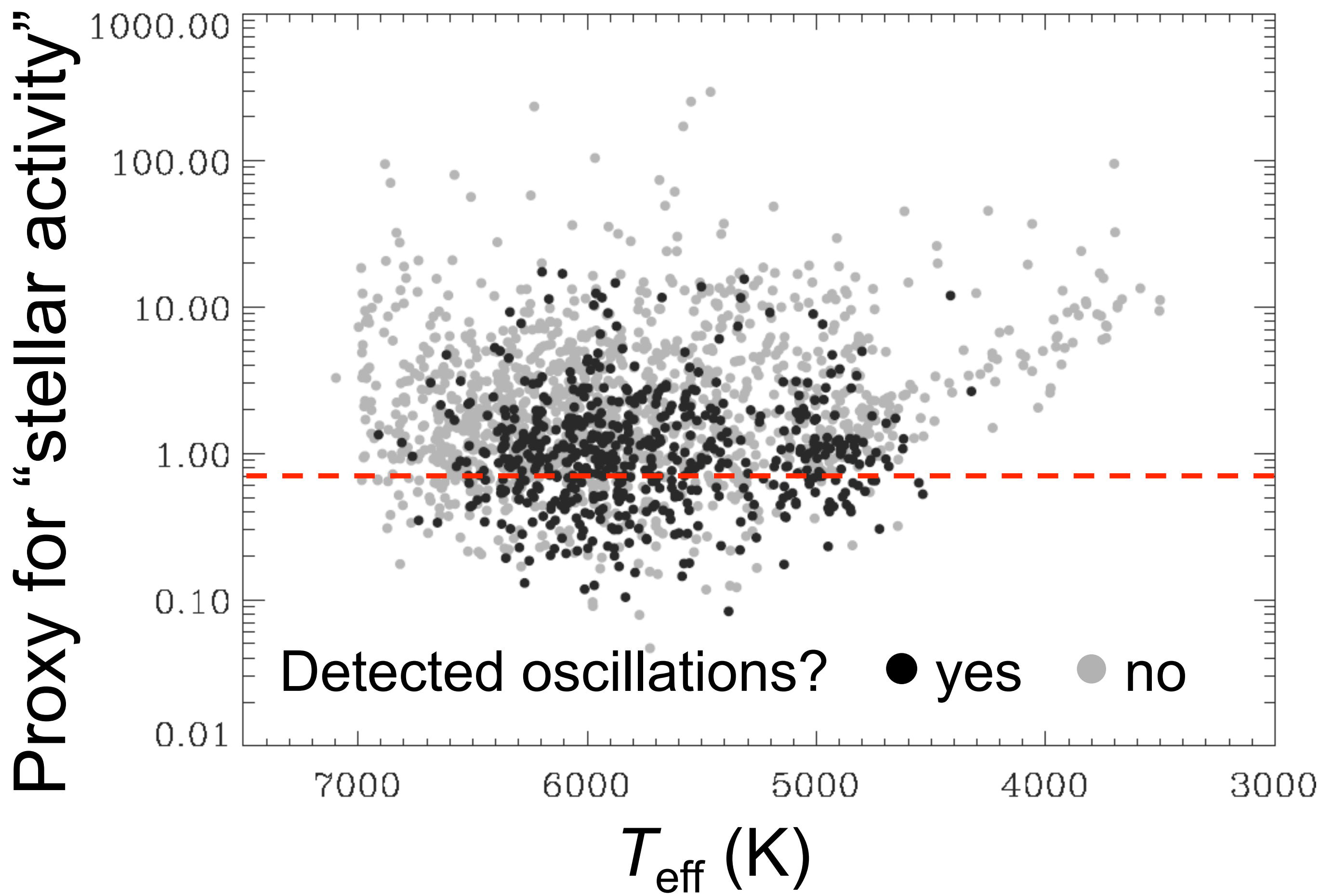
Stellar activity suppresses oscillations

Inference on magnetic fields and convection



Chaplin et al., 2011, ApJ, 732, 5L

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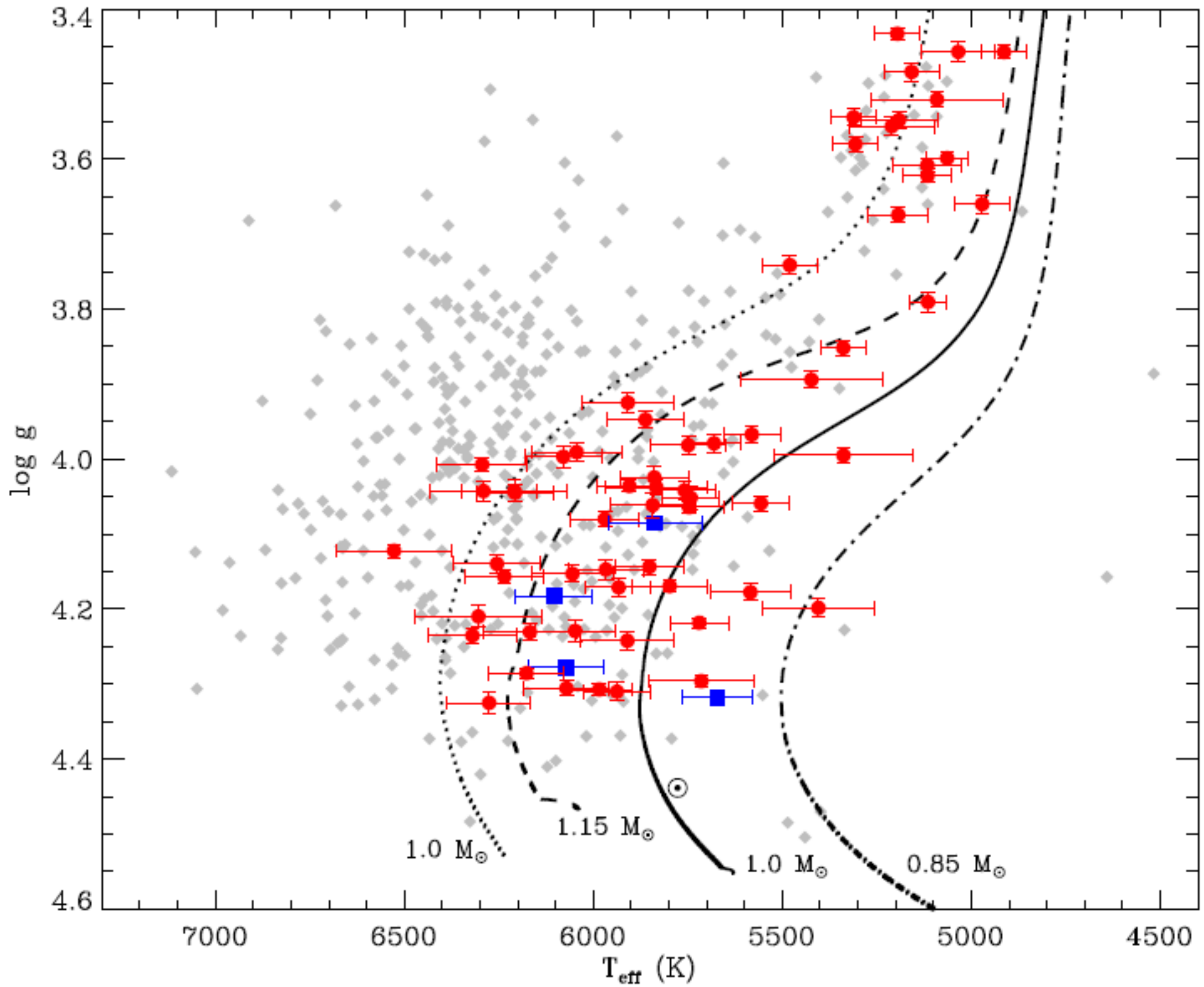
Stellar evolutionary sequences

The “Sun in time”—sequence of one solar mass stars



Silva-Aguirre et al., ApJ, 2011, 740, 2

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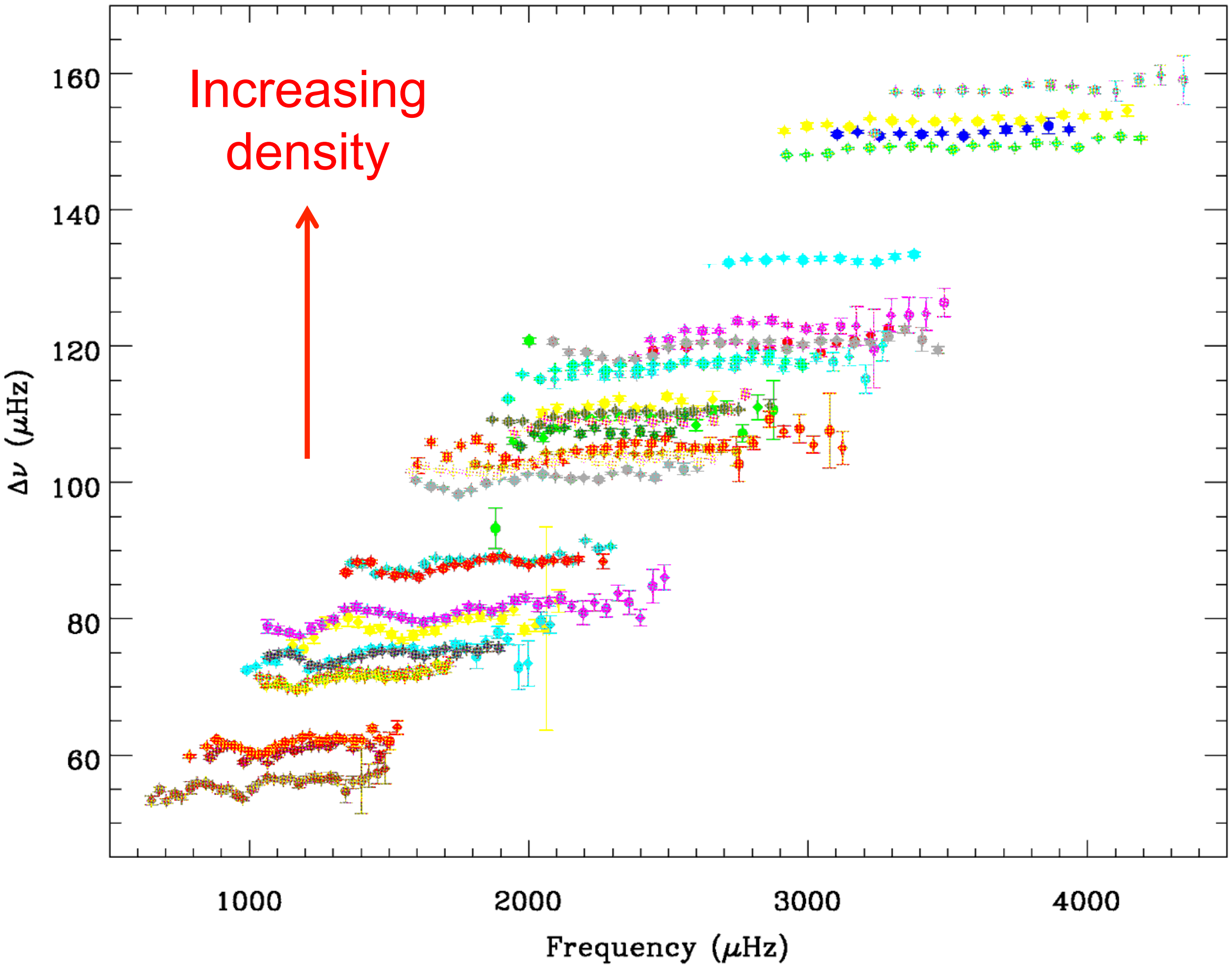
A selection of stars from Kepler's asteroseismic Zoo

Large frequency separations



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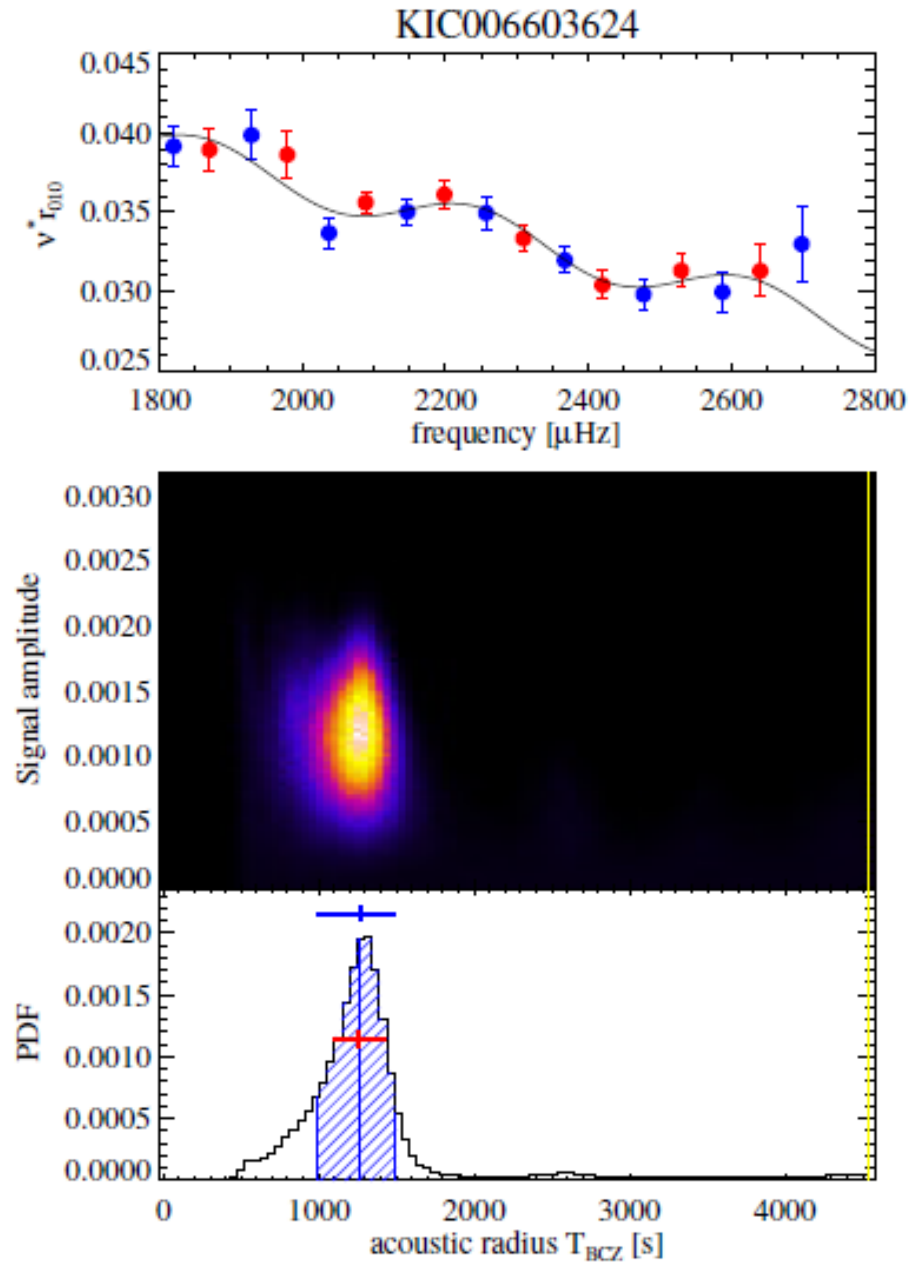
Convection zone depth

From acoustic glitches

- *Kepler* example: solar-type dwarf
- Signal present in particular combinations of frequencies



Mazumdar et al., 2012, in preparation

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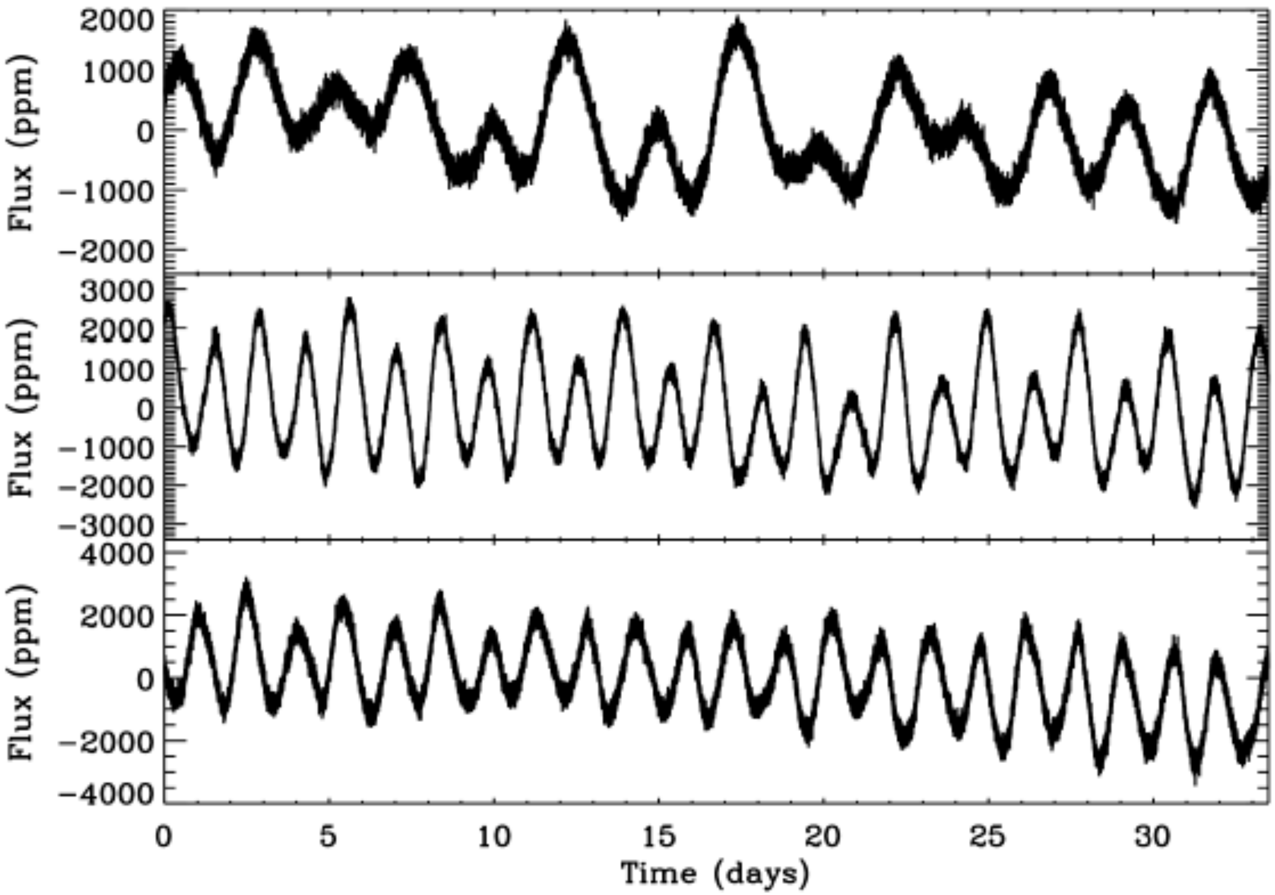
Surface rotation periods

Kepler lightcurves of solar-type stars



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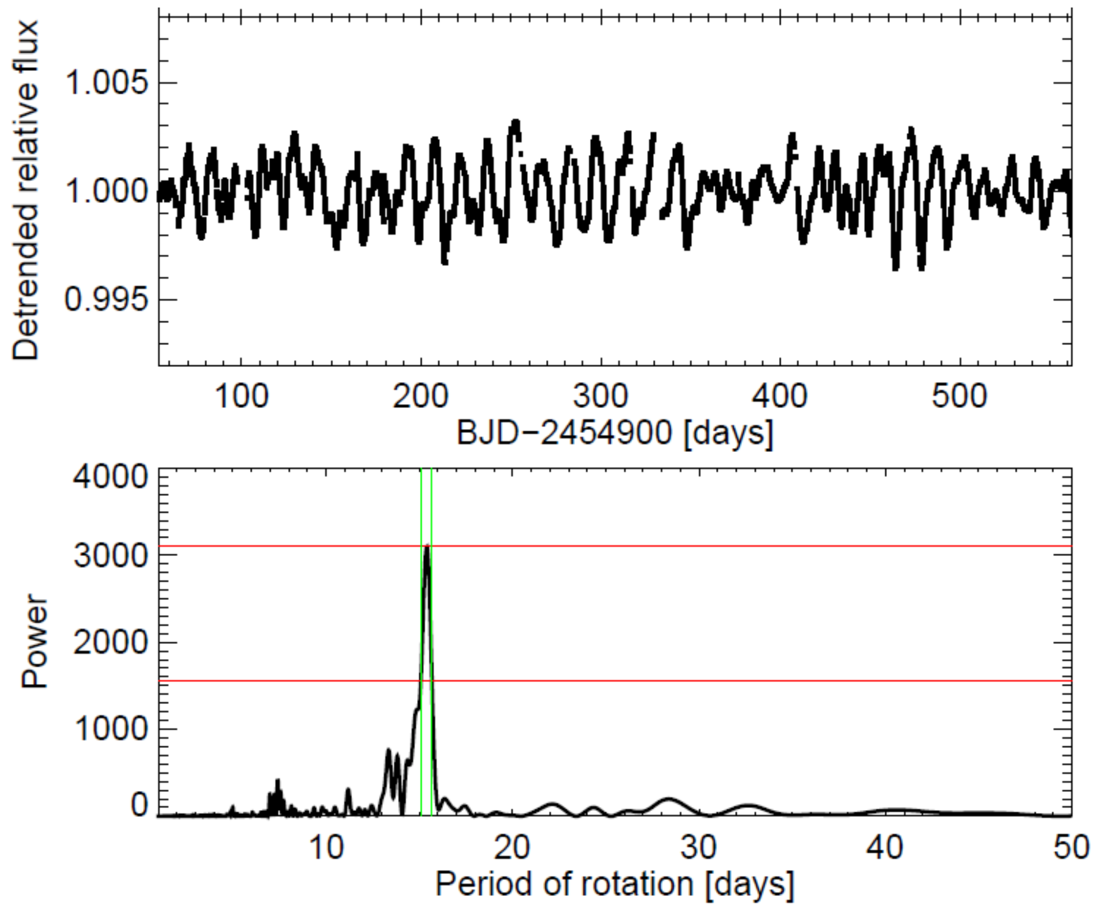
Surface rotation periods

Periodogramme analysis



Hirano et al., ApJ, 2012, submitted

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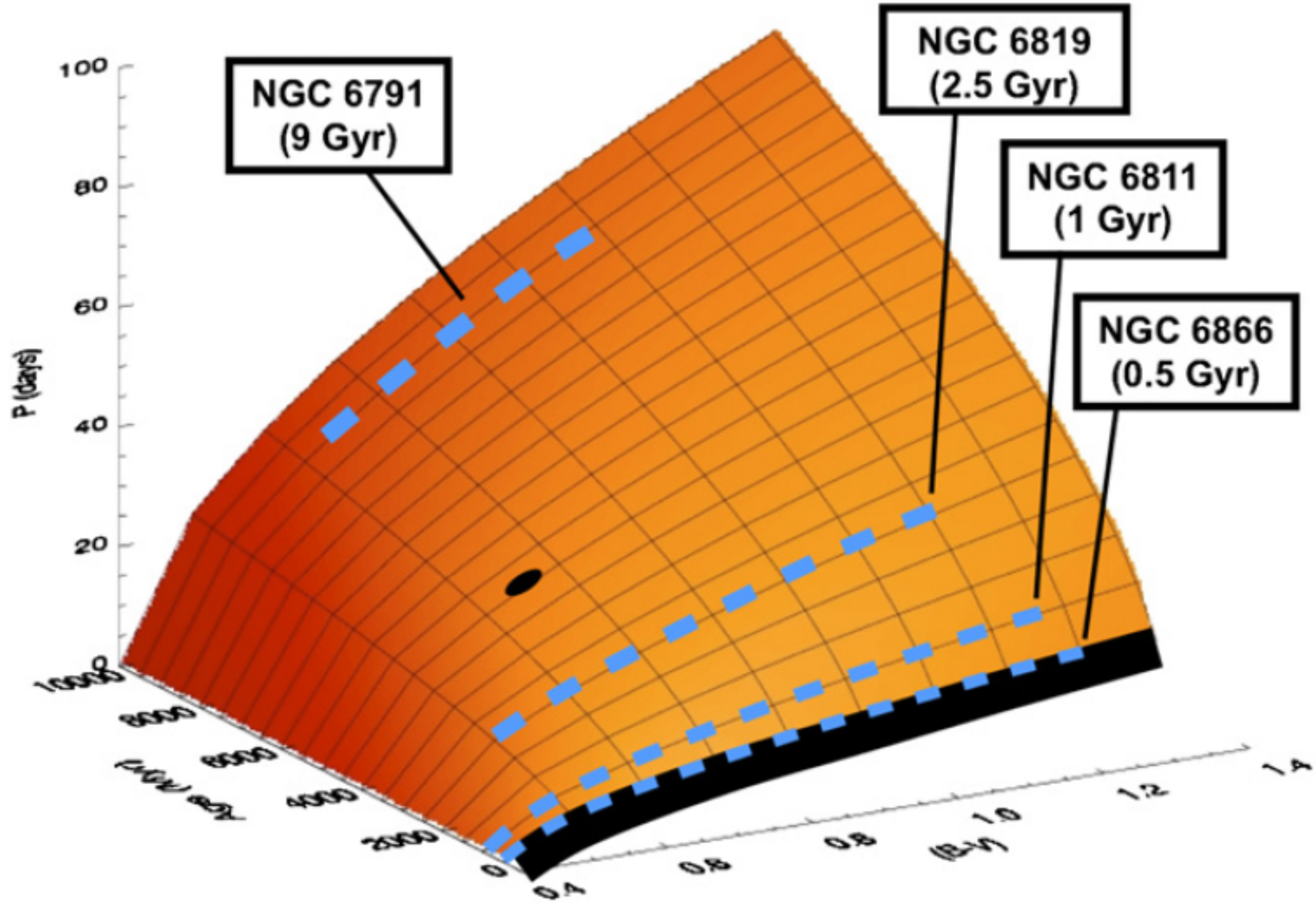
Gyrochronology



Meibom et al., ApJ, 2011, 733, L9

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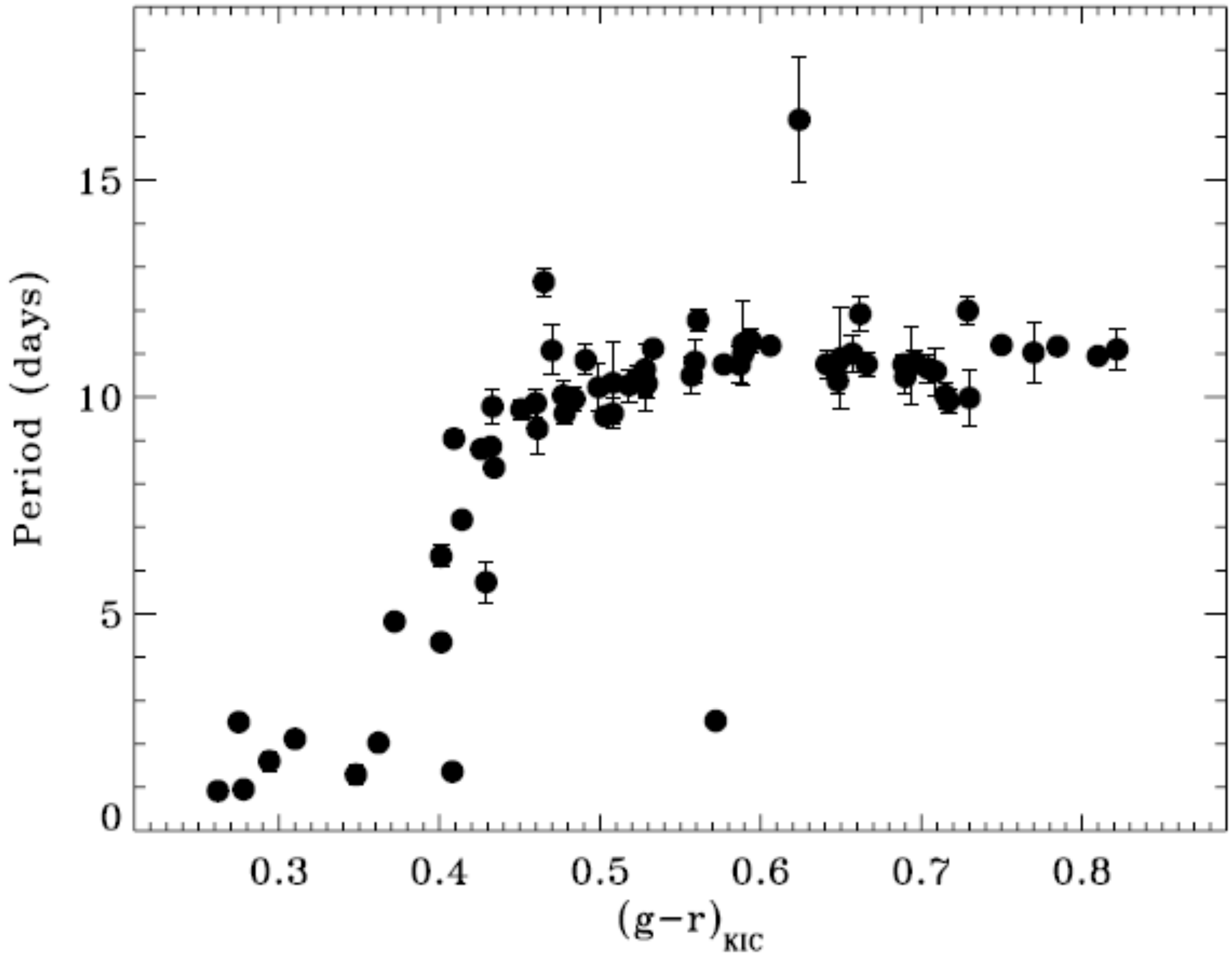
Gyrochronology



Meibom et al., ApJ, 2011, 733, L9

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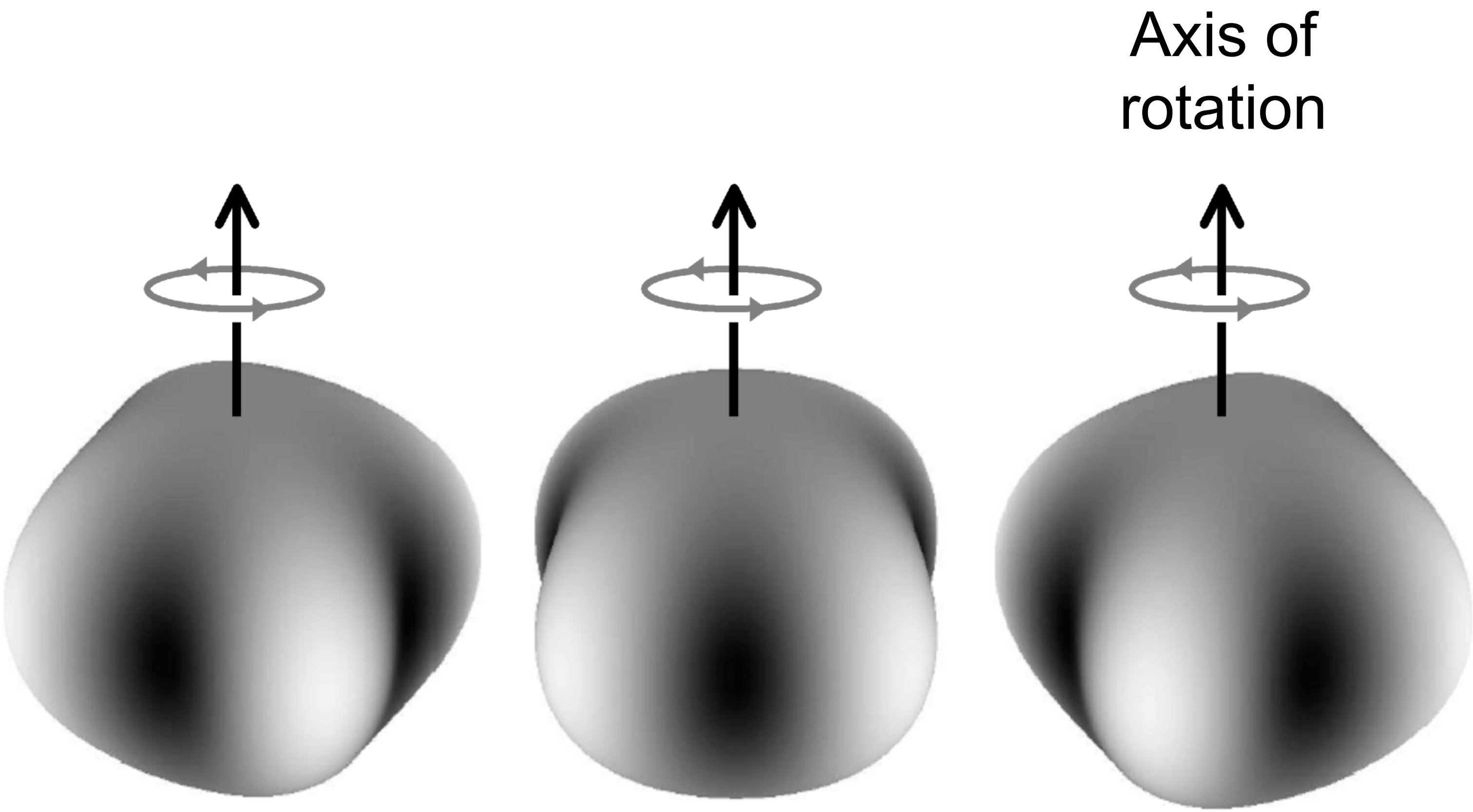
Rotational frequency splitting



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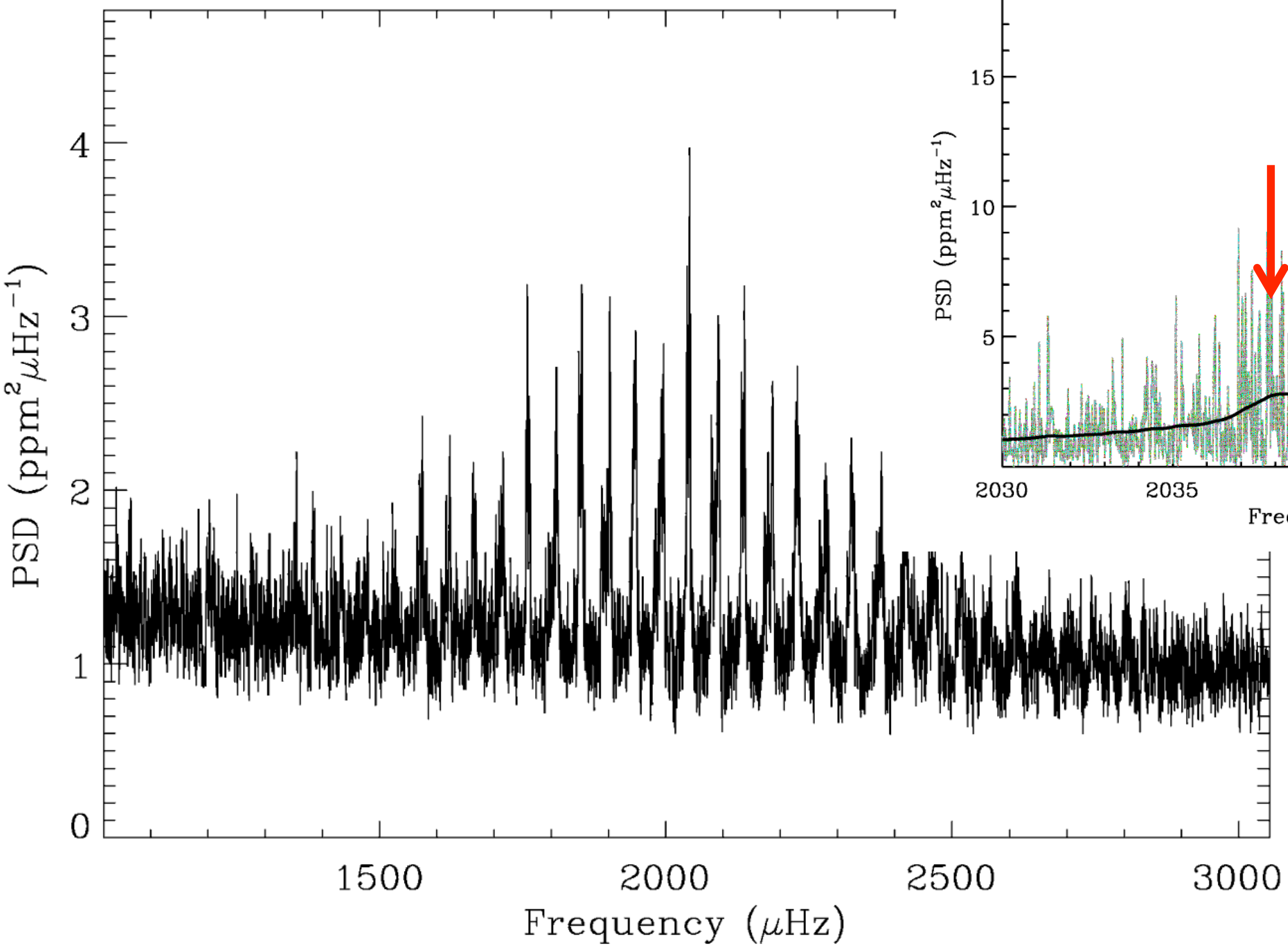
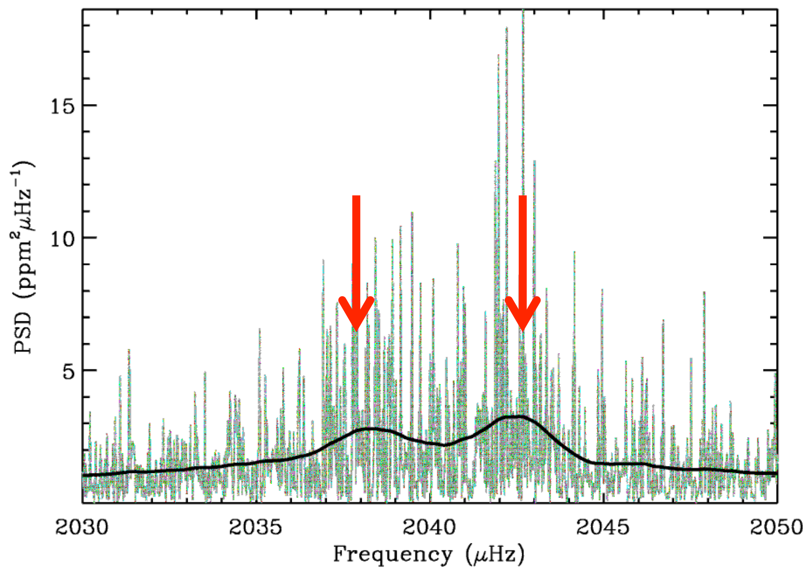
Rotational frequency splitting

Rotational frequency splitting



Dipole mode



Asteroseismic & surface signatures of rotation

Trivial conversion between convert between surface period and frequency splitting

$$P_{\mathrm{rot}} \; \square \; 1/\nu_{\mathrm{s}}$$

surface measure

equivalent splitting

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Asteroseismic & surface signatures of rotation

Given accurate stellar radius can convert between velocity and frequency splitting

$$v\sin(i) \; [?] \; 2\pi R\,\nu_{s}\,\sin(i)$$

surface measure

stellar radius

equivalent splitting

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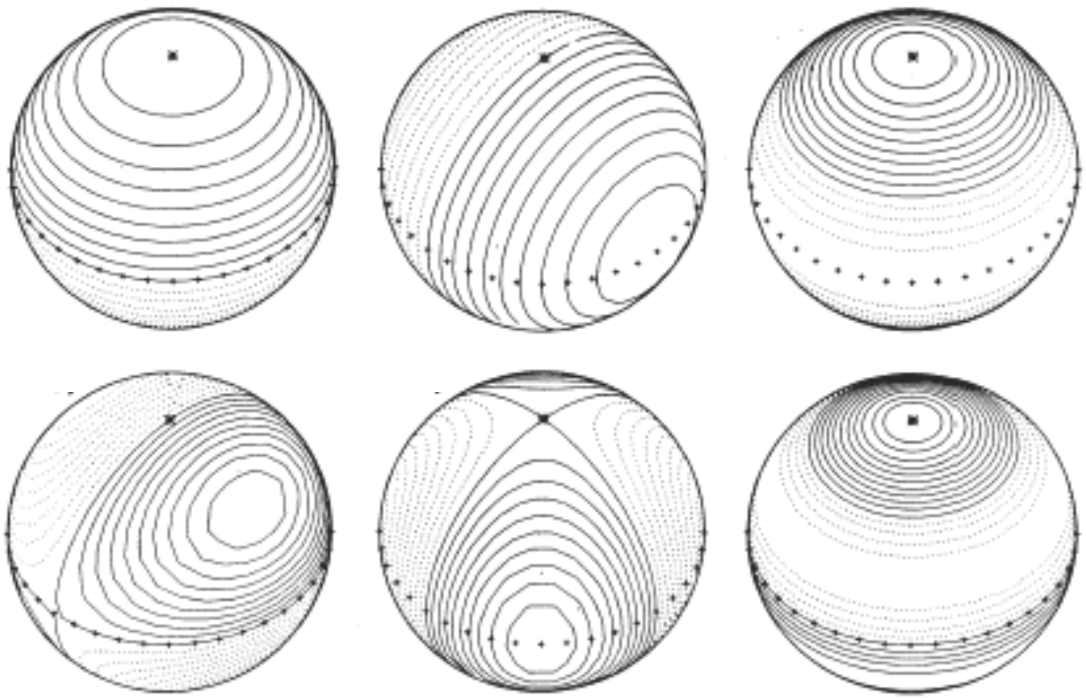
Asteroseismic & surface signatures of rotation

- In main-sequence stars frequency splittings weighted to rotation in envelopes
- Seems to be like Sun, i.e. internal rotation measured by splittings similar to surface rotation

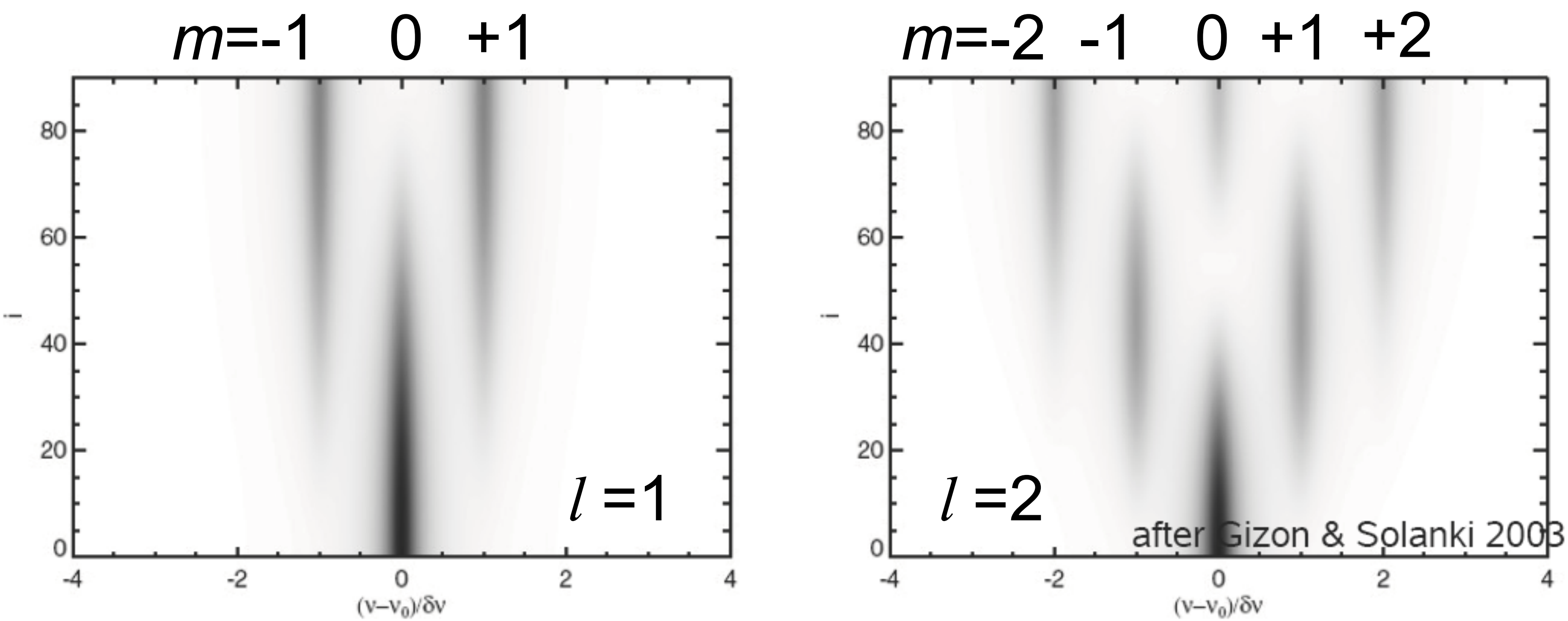
Inclination affects mode visibility

(1,0) (1,1) (2,0)



(2,1) (2,2) (3,0)

Inclination affects mode visibility



Gizon & Solanki, 2003, ApJ, 589, 1009

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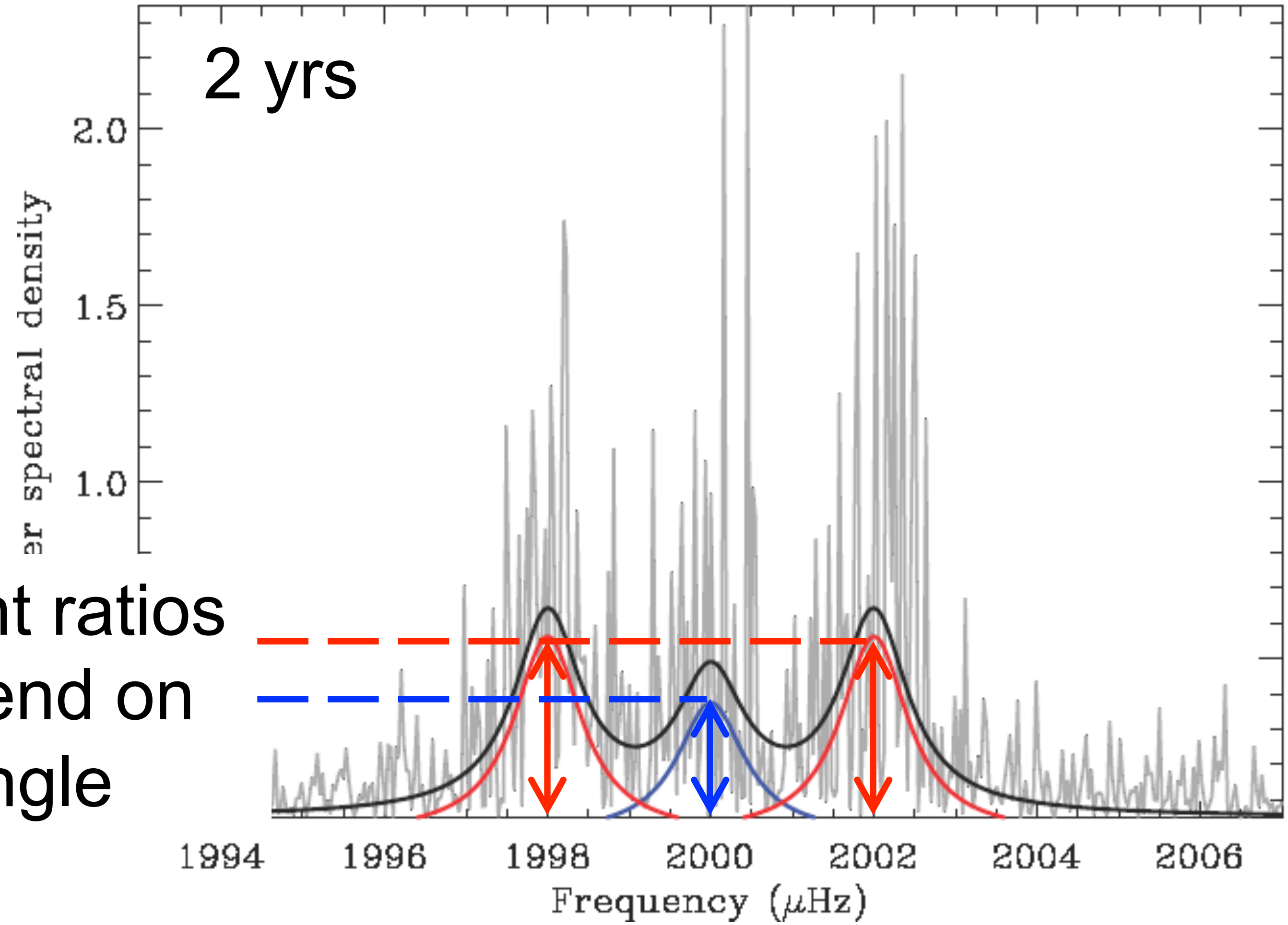
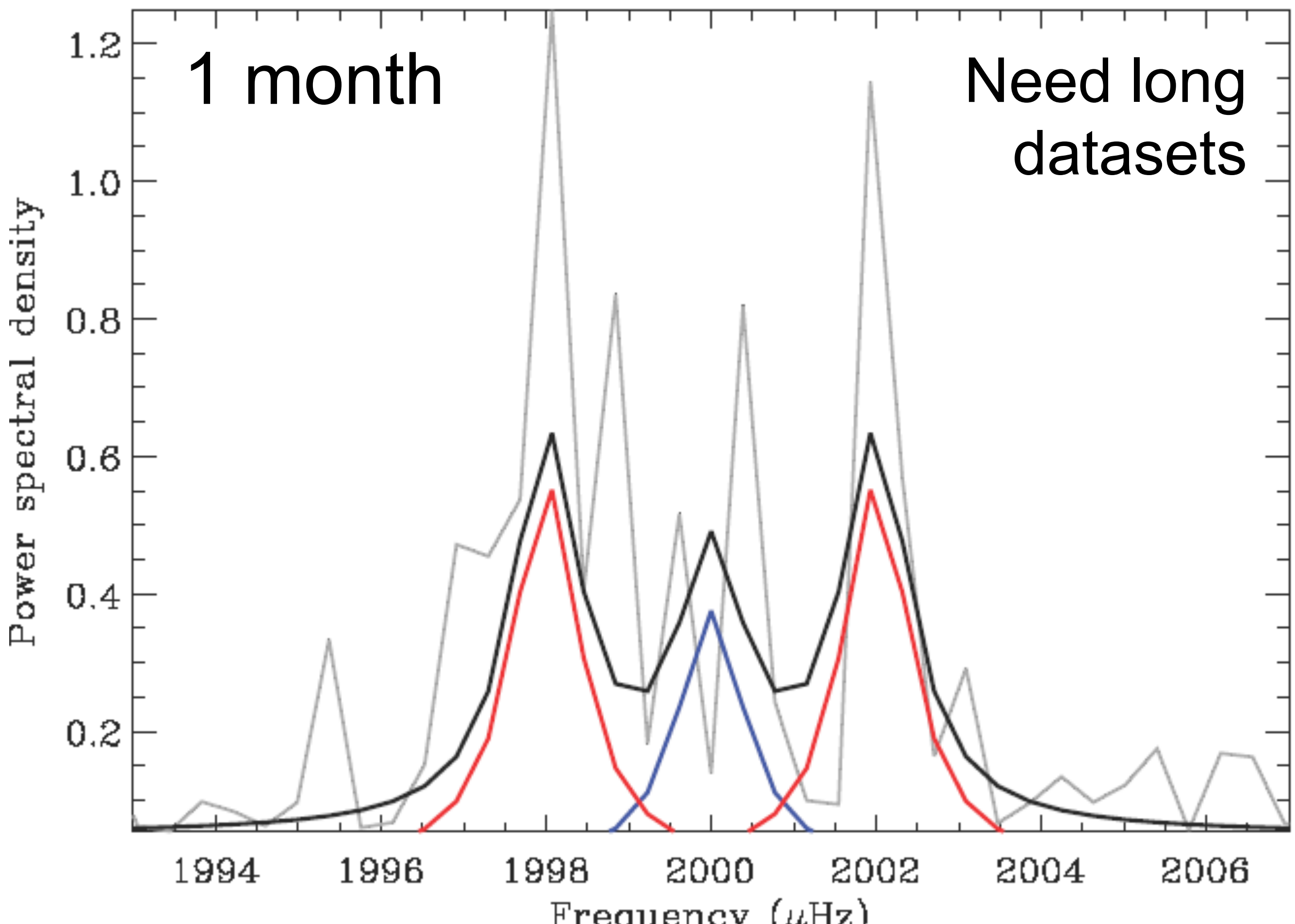
Inference on stellar inclination



Height ratios depend on angle

Inference on stellar inclination



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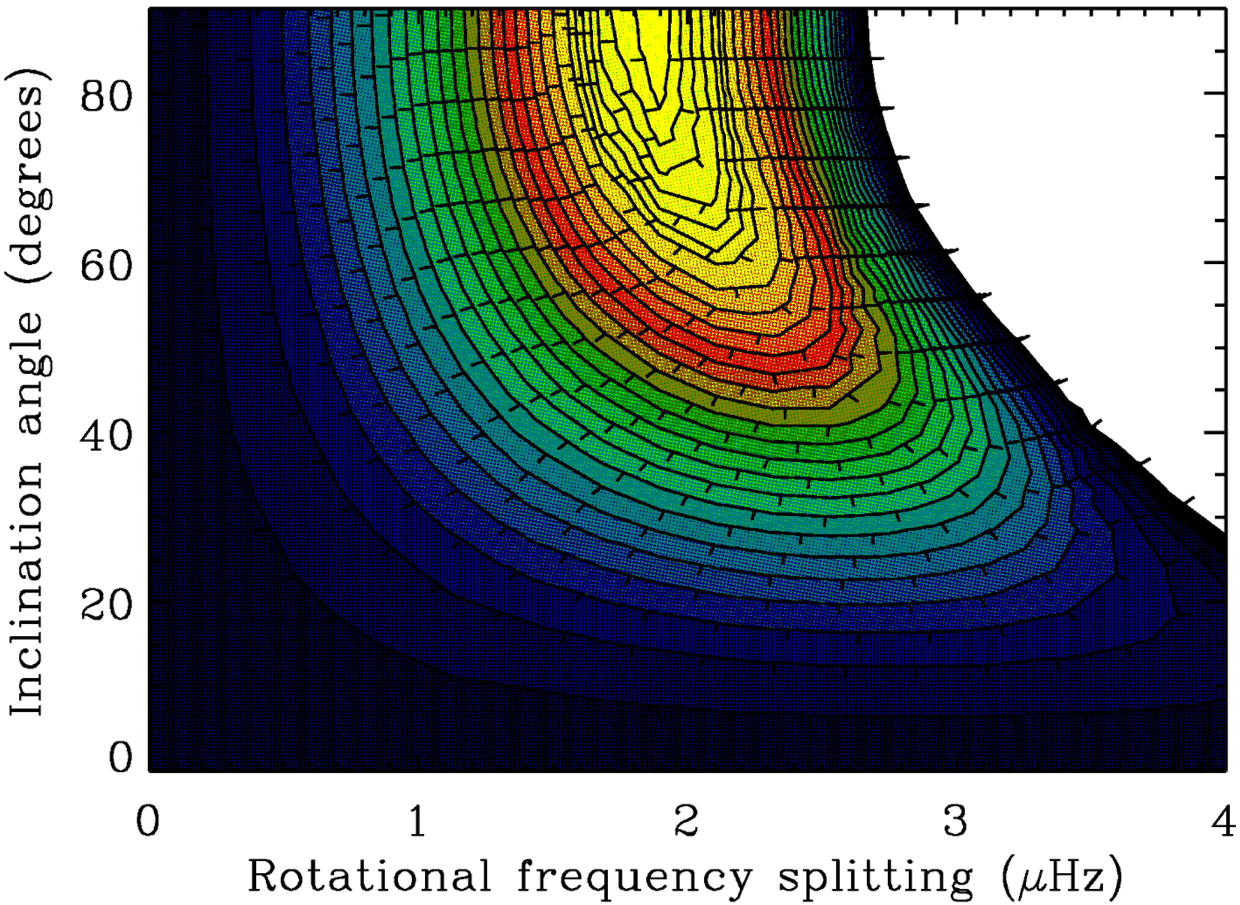
Inclination angle of ~90 degrees

Implies a well aligned system



End