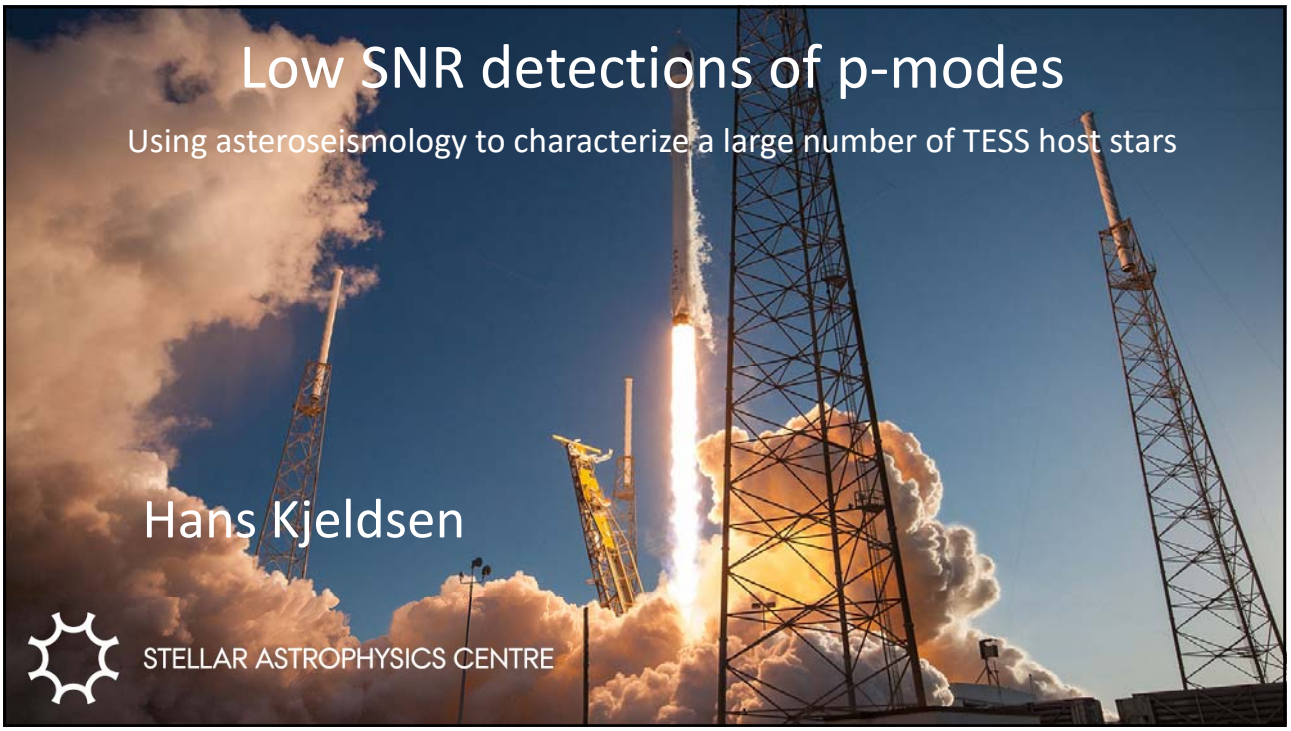
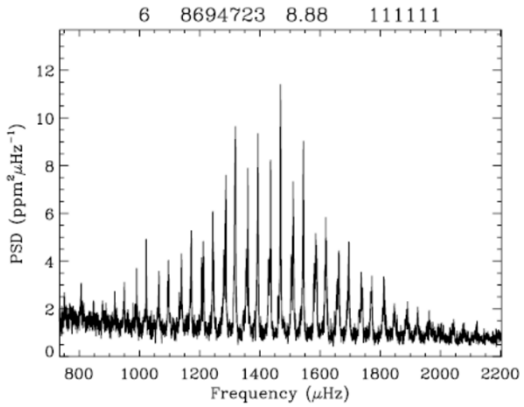


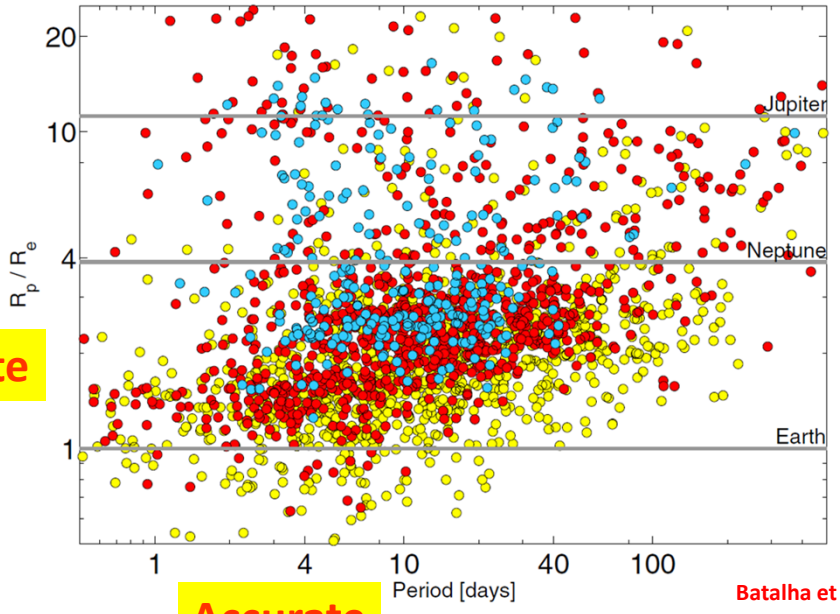
Properties of exoplanet host stars using Asteroseismology



- Time series data
- Low amplitude
- Multi-mode oscillations
- High frequencies

- Detection of a transit (exoplanet):
  Radius ratio, Orbital period
- **Asteroseismology (host star):**
  Stellar Properties: Mass, Radius, Density, Age, Rotation (spin-orbit)
- Ground-based follow-up (exoplanet):
  Velocity signature: Mass ratio

Kepler transits



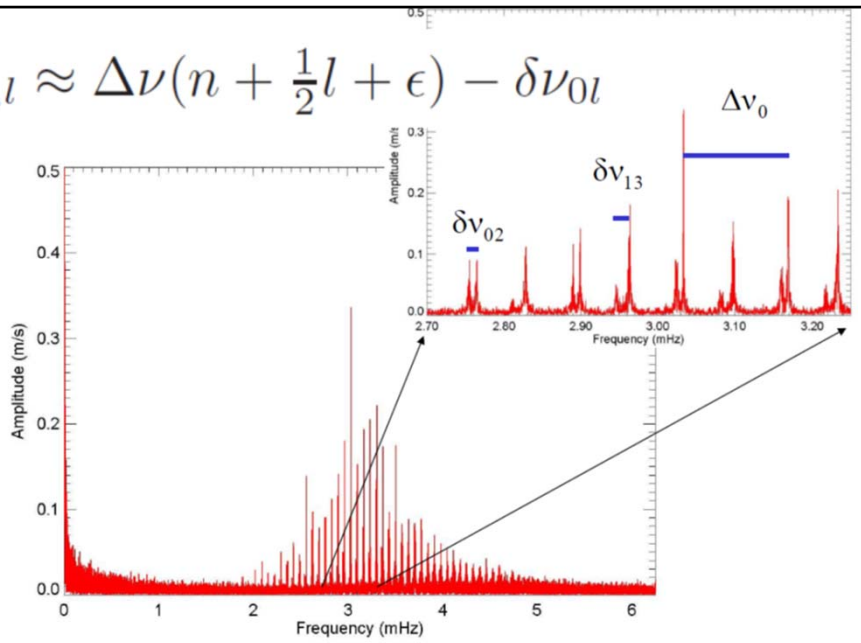
Batalha et al. 2013

Less accurate

Accurate

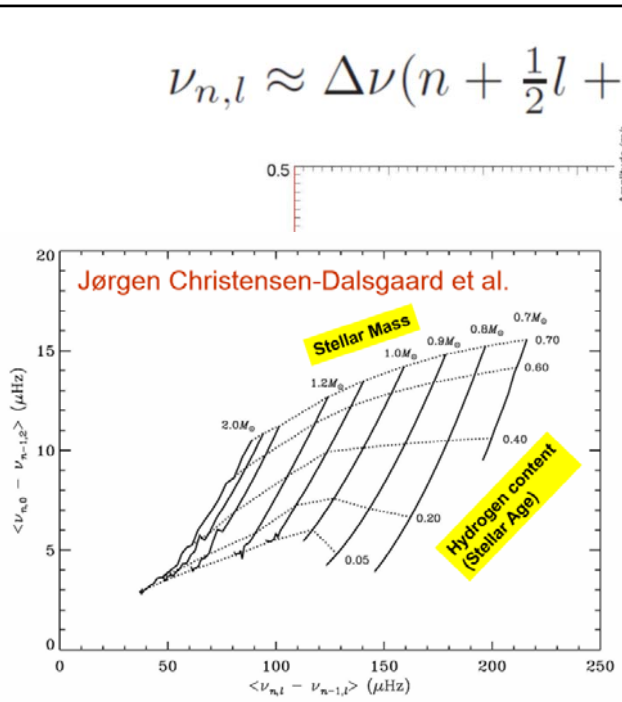
Figure 3. Radius vs. orbital p… es in the B10 (Borucki et al. 2011a) catalog (blue points), the B11 (Borucki et al. 2011b) catalog (red points), and this contribution (yellow points). Horizontal lines marking the radius of Jupiter, Neptune, and Earth are included for reference.

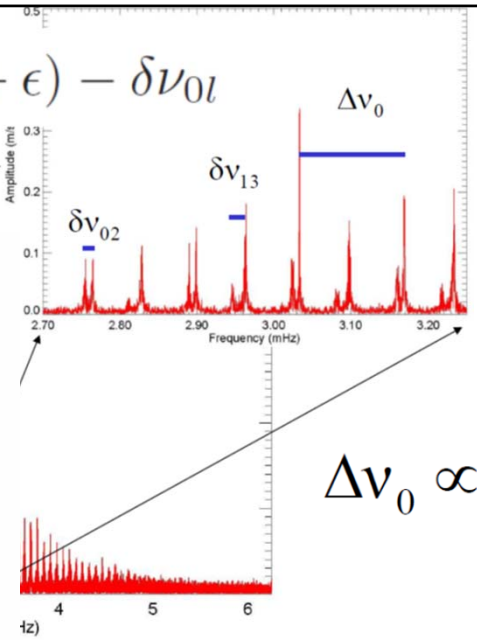
$$\nu_{n,l} \approx \Delta\nu\left(n + \frac{1}{2}l + \epsilon\right) - \delta\nu_{0l}$$



Solar oscillation spectrum

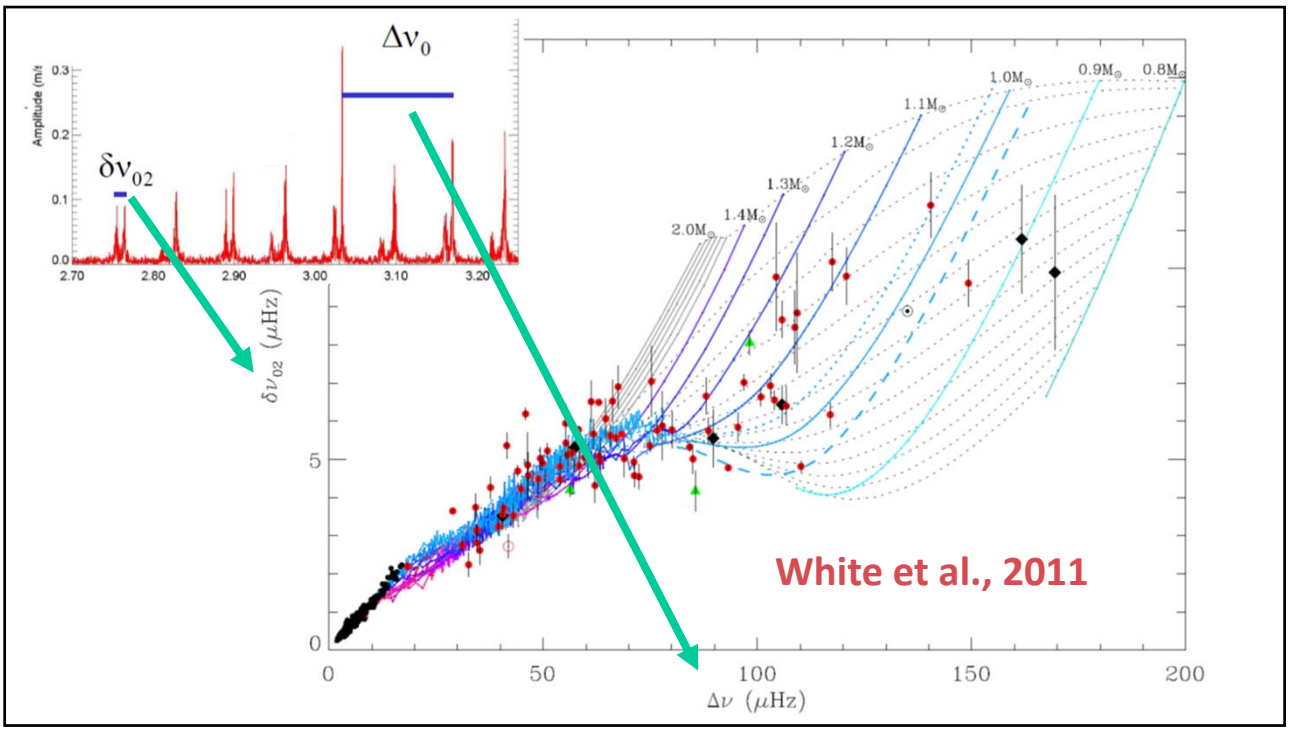
$$\nu_{n,l} \approx \Delta\nu\left(n + \frac{1}{2}l + \epsilon\right) - \delta\nu_{0l}$$

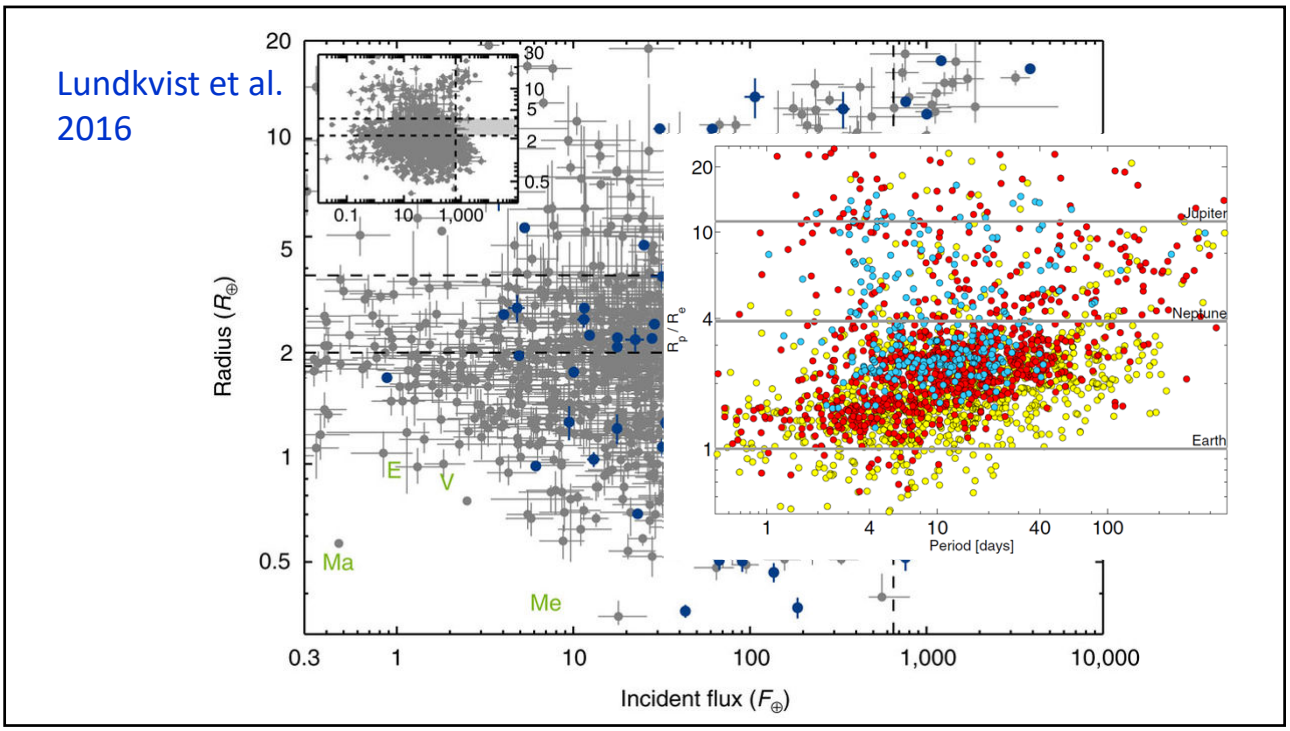




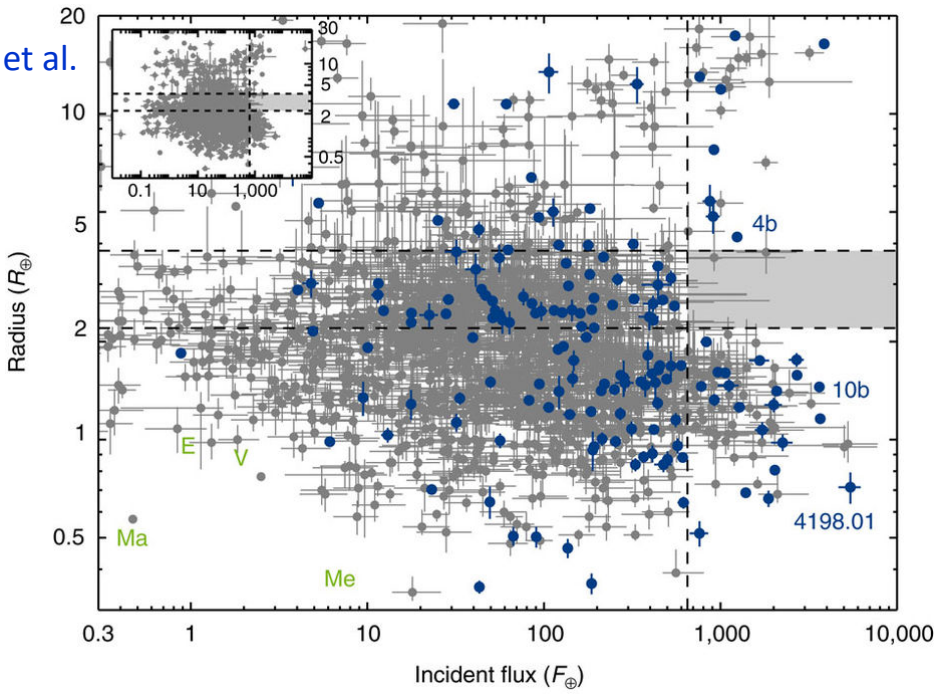
$$\Delta\nu_0 \propto \sqrt{\bar{\rho}}$$

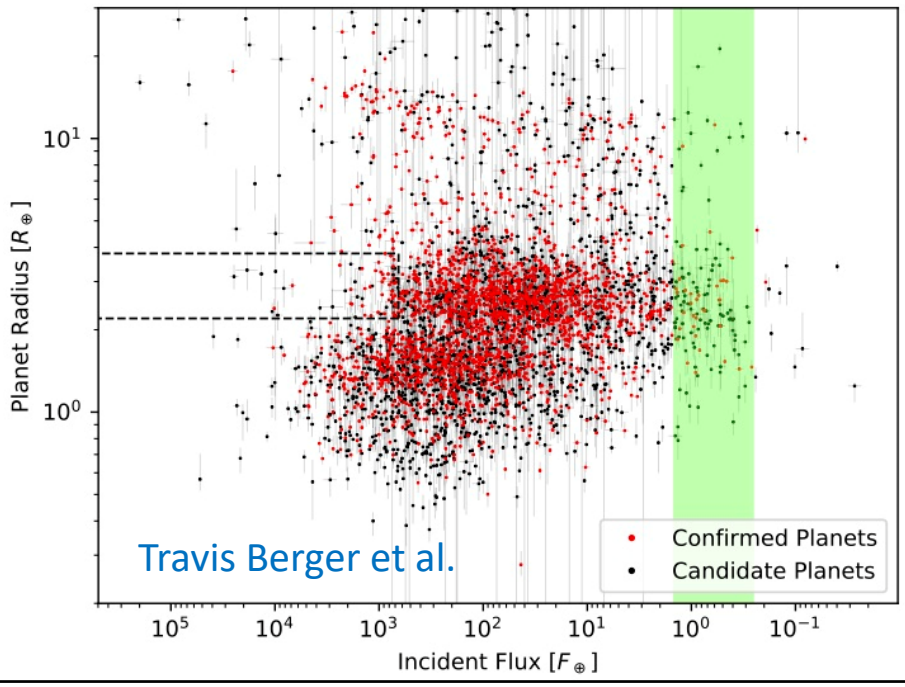
spectrum


$\Delta\nu_0$
$\delta\nu_{02}$
Amplitude (m/s)
0.3
0.2
0.1
0.0
2.70
2.80
2.90
3.00
3.10
3.20
1.0M⊙
0.9M⊙
0.8M⊙
1.1M⊙
1.2M⊙
1.3M⊙
1.4M⊙
2.0M⊙
$\delta\nu_{02}$ (μHz)
5
0
0
50
100
150
200
$\Delta\nu$ (μHz)
White et al., 2011


Lundkvist et al. 2016
Radius ($R_\oplus$)
20
10
5
2
1
0.5
30
10
5
2
0.5
0.1
10
1,000
E
V
Ma
Me
0.3
1
10
100
1,000
10,000
Incident flux ($F_\oplus$)
R_p / R_e
20
10
4
1
Jupiter
Neptune
Earth
1
4
10
40
100
Period [days]

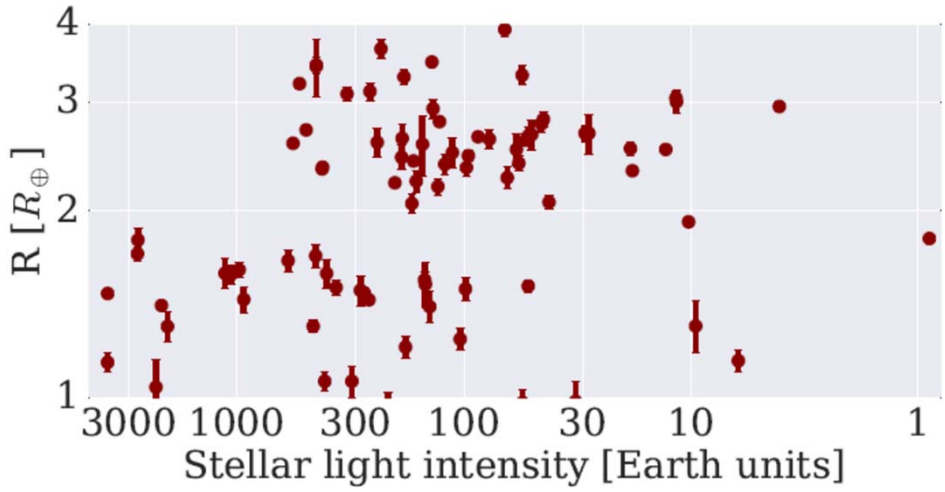
Lundkvist et al. 2016





Travis Berger et al.

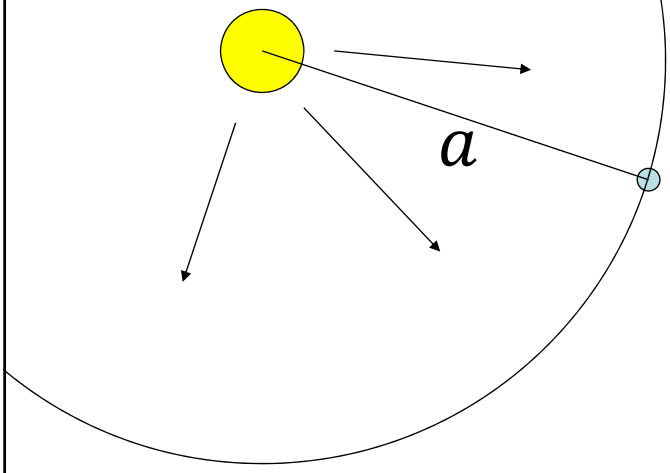
Van Eylen, Agentoft, Lundkvist, et al. 2018



Luminosity

$$L = R^2 \cdot T_{eff}^4$$

Solar units



Flux at distance *a*

$$\boldsymbol{F} = \frac{L}{a^2}$$

Solar and Earth units

$$a^3 = M \cdot P^2$$

Solar and Earth units

Planet Radius

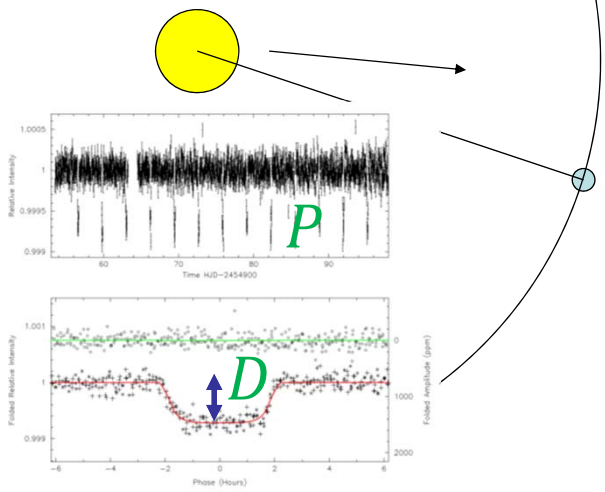
$$\boldsymbol{r_p} = 109 \cdot R \cdot \sqrt{D}$$

Solar and Earth units

Luminosity

$$L = R^2 \cdot T_{eff}^4$$

Solar units



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Planet Radius

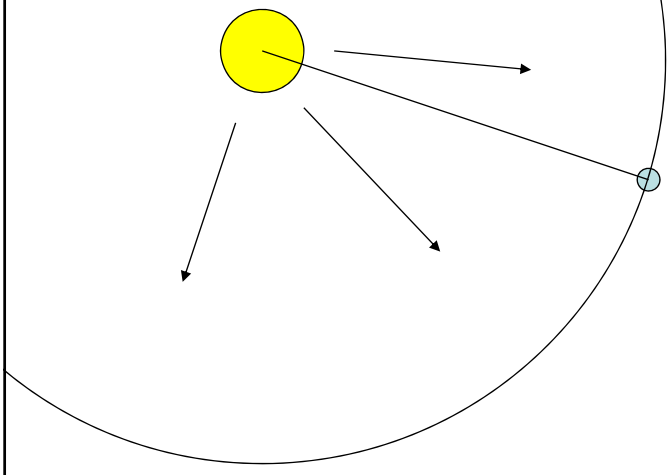
$$r_p = 109 \cdot R \cdot \sqrt{D}$$

Solar and Earth units

Luminosity

$$L = R^2 \cdot T_{eff}^4$$

Solar units



Flux at distance *a*

Solar and Earth units

$$F = \frac{R^2 \cdot T_{eff}^4}{M^{2/3} \cdot P^{4/3}}$$

Planet Radius

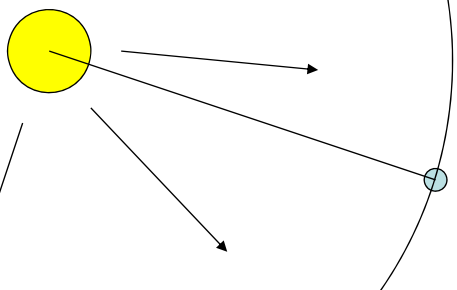
$$r_p = 109 \cdot R \cdot \sqrt{D}$$

Solar and Earth units

Luminosity

$$L = R^2 \cdot T_{eff}^4$$

Solar units



Talk by Travis Berger

Flux at distance *a*

Gaia

Solar and Earth units

$$F = \frac{R^2 \cdot T_{eff}^4}{M^{2/3} \cdot P^{4/3}}$$

25%

Planet Radius

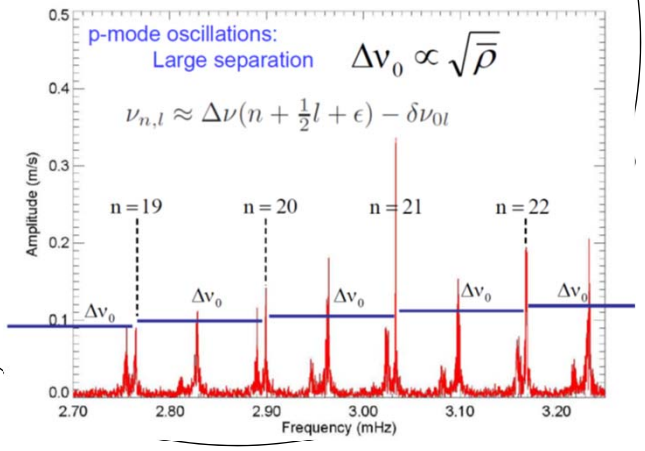
$$r_p = 109 \cdot R \cdot \sqrt{D}$$

8%

Solar and Earth units

Asteroseismology

$$R, \Delta\nu_0$$



Flux at distance *a*

$$F = \frac{T_{eff}^4}{\Delta\nu_0^{4/3} \cdot P^{4/3}}$$

Solar and Earth units

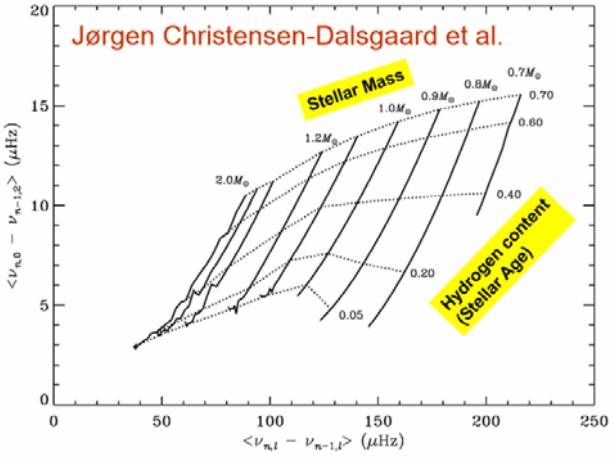
Planet Radius

$$r_p = 109 \cdot R \cdot \sqrt{D}$$

Solar and Earth units

Asteroseismology

$R, \Delta\nu_0$



Flux at distance *a*

$$F = \frac{T_{eff}^4}{\Delta\nu_0^{4/3} \cdot P^{4/3}}$$

Solar and Earth units

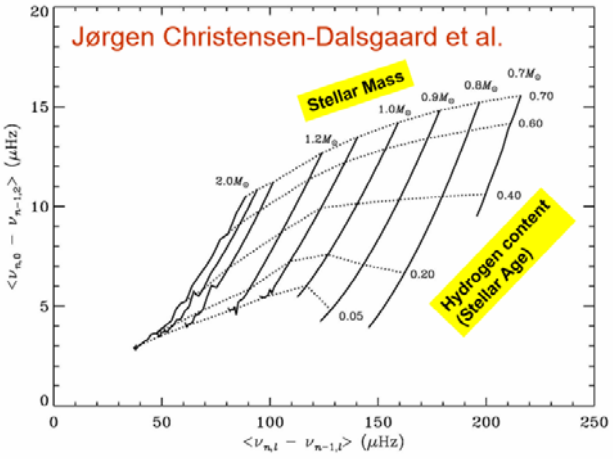
Planet Radius

$$r_p = 109 \cdot R \cdot \sqrt{D}$$

Solar and Earth units

Asteroseismology

$R, \Delta\nu_0,\ \rho$ 1%



Flux at distance *a*

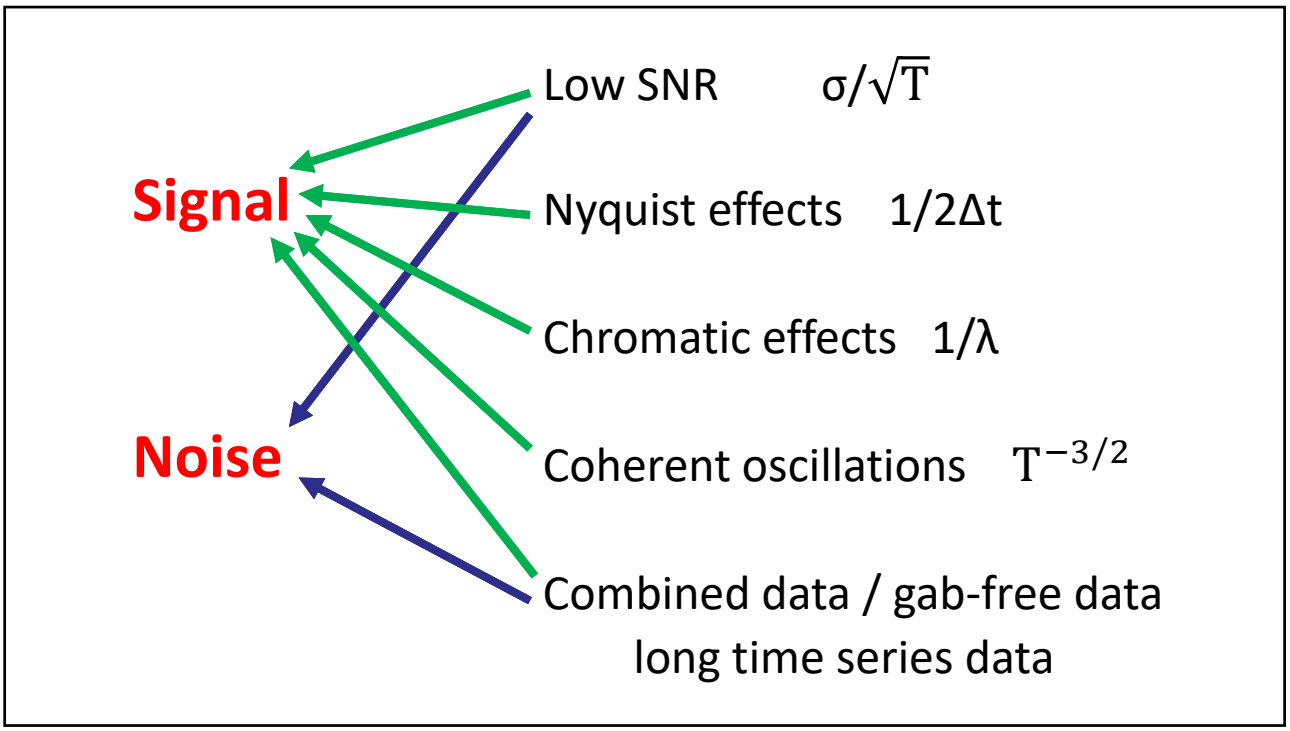
$$F = \frac{T_{eff}^4}{\Delta\nu_0^{4/3} \cdot P^{4/3}}$$

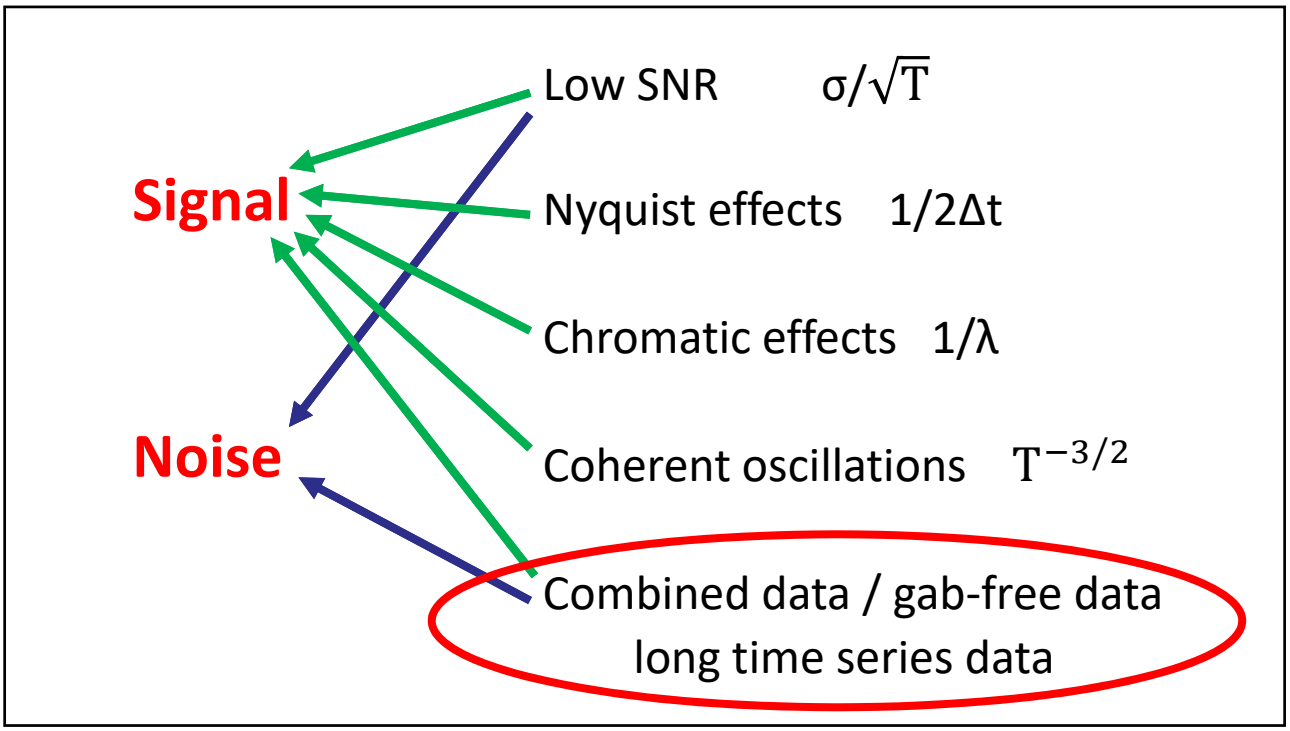
7% Solar and Earth units

Planet Radius

$$r_p = 109 \cdot R \cdot \sqrt{D}$$

2% Solar and Earth units


Signal
Noise
Low SNR $\sigma/\sqrt{T}$
Nyquist effects 1/2Δt
Chromatic effects 1/λ
Coherent oscillations $T^{-3/2}$
Combined data / gab-free data
long time series data


Signal
Noise
Low SNR $\sigma/\sqrt{T}$
Nyquist effects 1/2Δt
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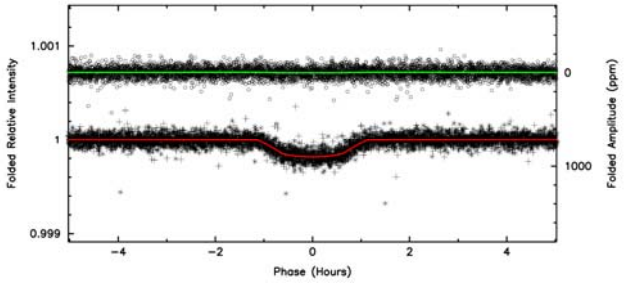
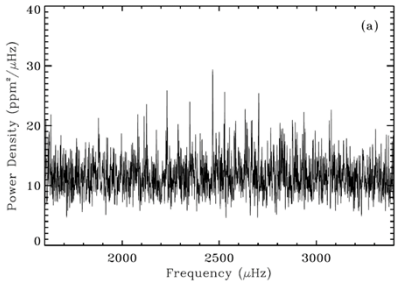
long time series data

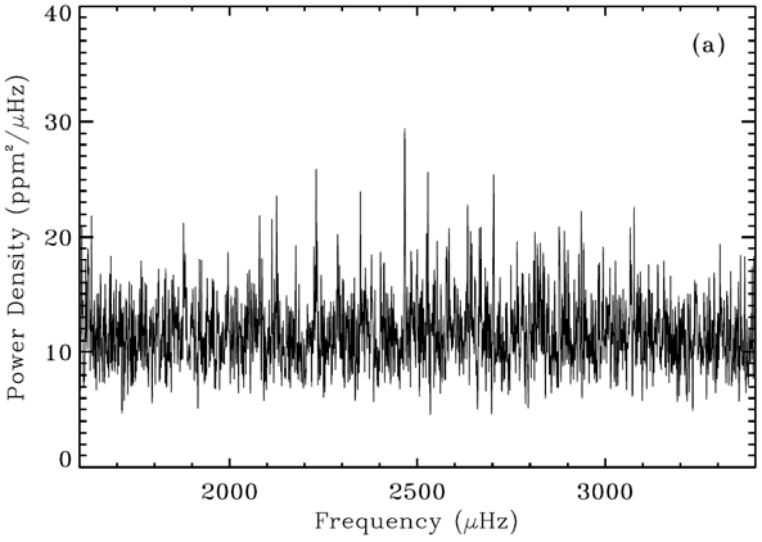
THE ASTROPHYSICAL JOURNAL, 729:27 (21pp), 2011 March 1 doi:10.1088/0004-637X/729/1/27

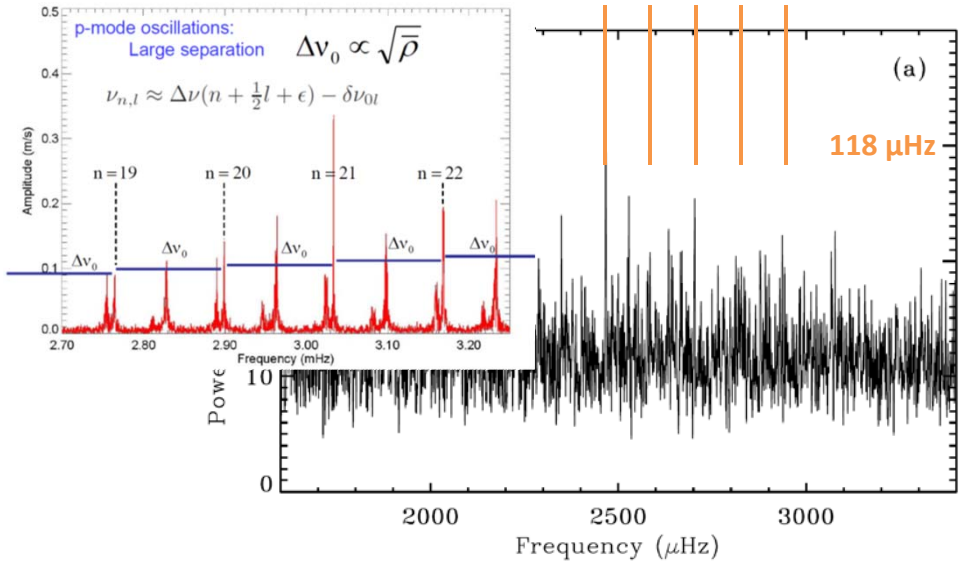
KEPLER'S FIRST ROCKY PLANET: KEPLER-10b*

NATALIE M. BATALHA[1], WILLIAM J. BORUCKI[2], STEPHEN T. BRYSON[2], LARS A. BUCHHAVE[3], DOUGLAS A. CALDWELL[4], JØRGEN CHRISTENSEN-DALSGAARD[5,6], DAVID CIARDI[7], EDWARD W. DUNHAM[8], FRANCOIS FRESSIN[3], THOMAS N. GAUTIER III[9], RONALD L. GILLILAND[10], MICHAEL R. HAAS[2], STEVE B. HOWELL[11], JON M. JENKINS[4], HANS KJELDSEN[5], DAVID G. KOCH[2], DAVID W. LATHAM[3], JACK J. LISSAUER[2], GEOFFREY W. MARCY[12], JASON F. ROWE[2], DIMITAR D. SASSELOV[3], SARA SEAGER[13], JASON H. STEFFEN[14], GUILLERMO TORRES[3], GIBOR S. BASRI[12], TIMOTHY M. BROWN[15], DAVID CHARBONNEAU[3], JESSIE CHRISTIANSEN[2], BRUCE CLARKE[4], WILLIAM D. COCHRAN[16], ANDREA DUPREE[3], DANIEL C. FABRYCKY[3], DEBRA FISCHER[17], ERIC B. FORD[18], JONATHAN FORTNEY[19], FORREST R. GIROUARD[20], MATTHEW J. HOLMAN[3], JOHN JOHNSON[21], HOWARD ISAACSON[12], TODD C. KLAUS[20], PAVEL MACHALEK[4], ALTHEA V. MOOREHEAD[18], ROBERT C. MOREHEAD[18], DARIN RAGOZZINE[3], PETER TENENBAUM[4], JOSEPH TWICKEN[4], SAMUEL QUINN[3], JEFFREY VANCLEVE[4], LUCIANNE M. WALKOWICZ[12], WILLIAM F. WELSH[22], EDNA DEVORE[4], AND ALAN GOULD[23]







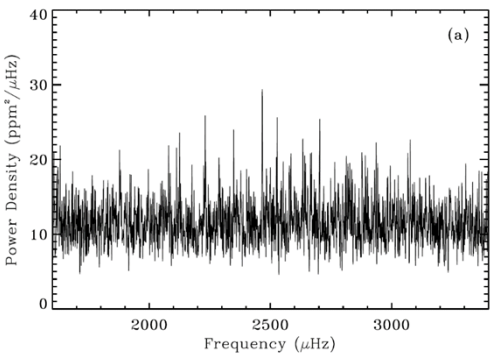


Large frequency separation

Kepler-10

Mass (Msun)	0.995 ± 0.060	(6%)
Radius (Rsun)	1.056 ± 0.021	(2 %)
Age (Gyr)	11.9 ± 4.5	(38%)

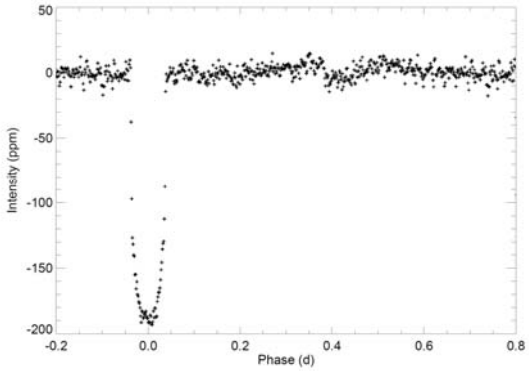
- Batalha et al. 2011

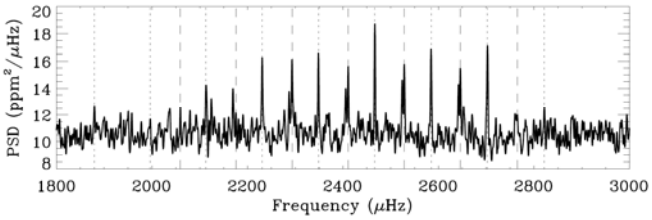


The Astrophysical Journal, 781:67 (8pp), 2014 February 1 doi:10.1088/0004-637X/781/2/67

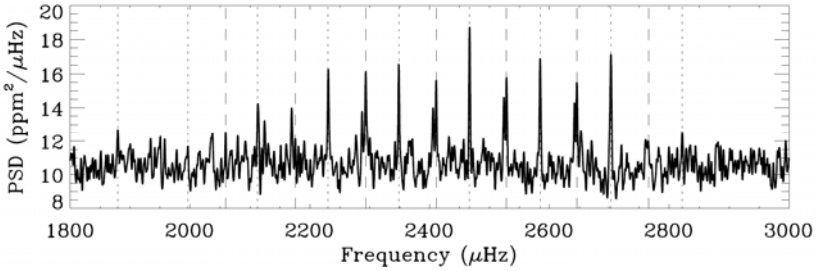
ACCURATE PARAMETERS OF THE OLDEST KNOWN ROCKY-EXOPLANET HOSTING SYSTEM: KEPLER-10 REVISITED

Alexandra Fogtmann-Schulz, Brian Hinrup, Vincent Van Eylen, Jørgen Christensen-Dalsgaard, Hans Kjeldsen, Víctor Silva Aguirre, and Brandon Tingley
Stellar Astrophysics Centre, Department of Physics and Astronomy, Aarhus University, Ny Munkegade 120, DK-8000 Aarhus C, Denmark; alfosc@phys.au.dk
Received 2013 August 28; accepted 2013 December 3; published 2014 January 9

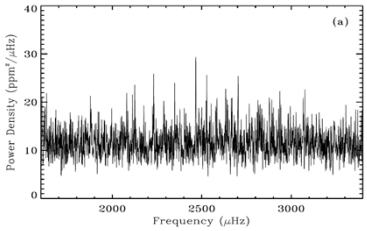




~ 850 days



Mass (Msun)	0.913 ± 0.022	(2.4 %)
Radius (Rsun)	1.065 ± 0.009	(0.8 %)
Age (Gyr)	10.4 ± 1.4	(13.5 %)



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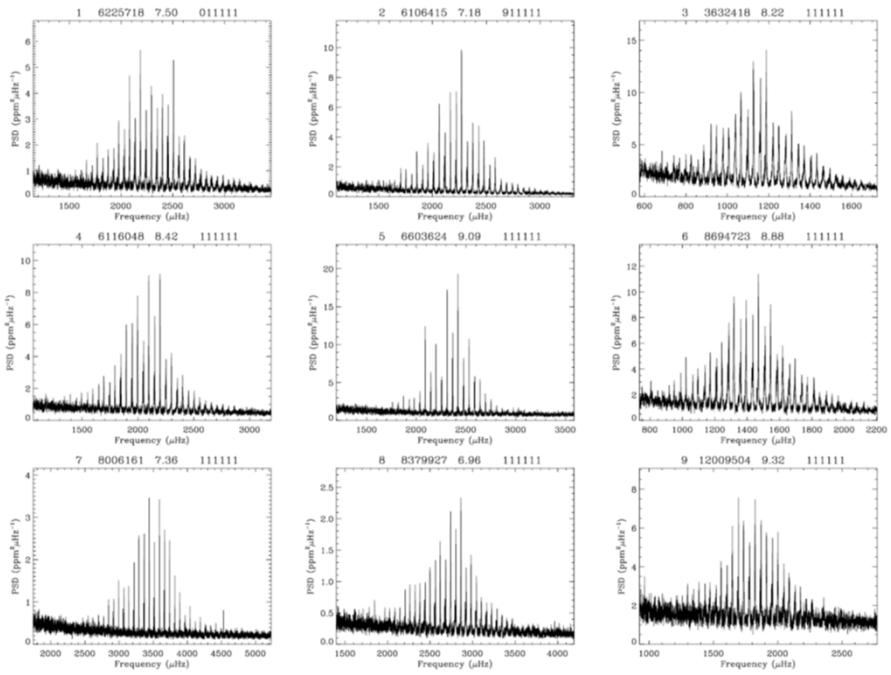
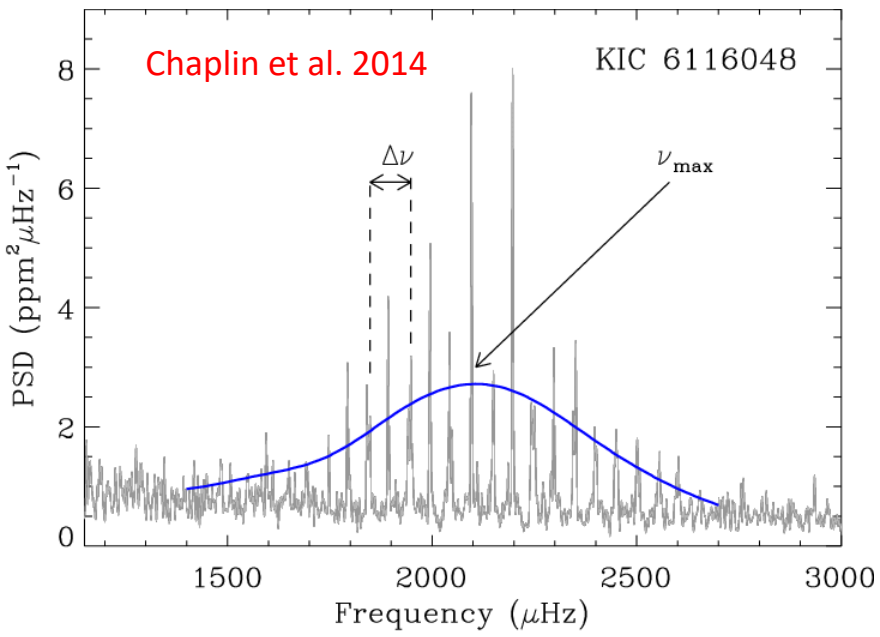
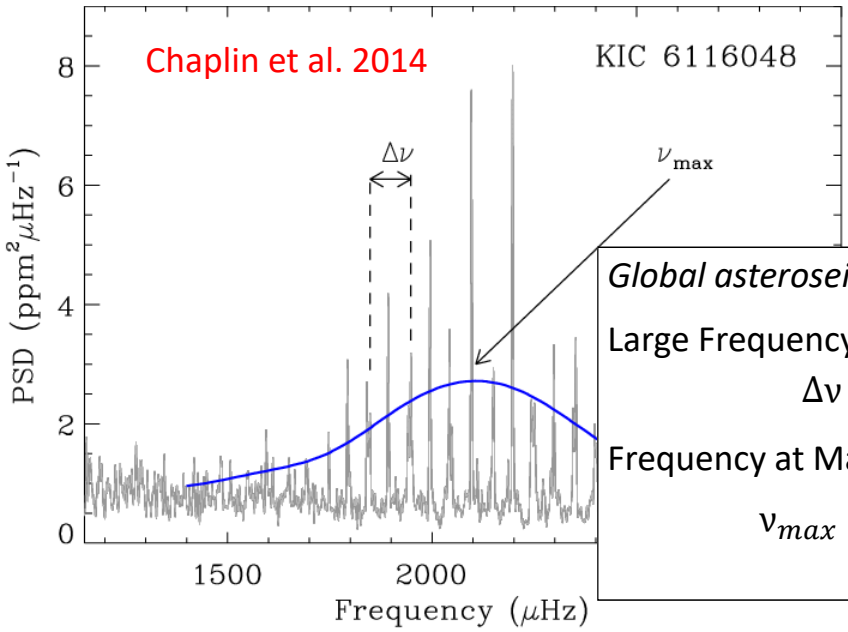
Age (Gyr)	11.9 ± 4.5	(38 %)

- Batalha et al. 2011

Chaplin et al. 2011







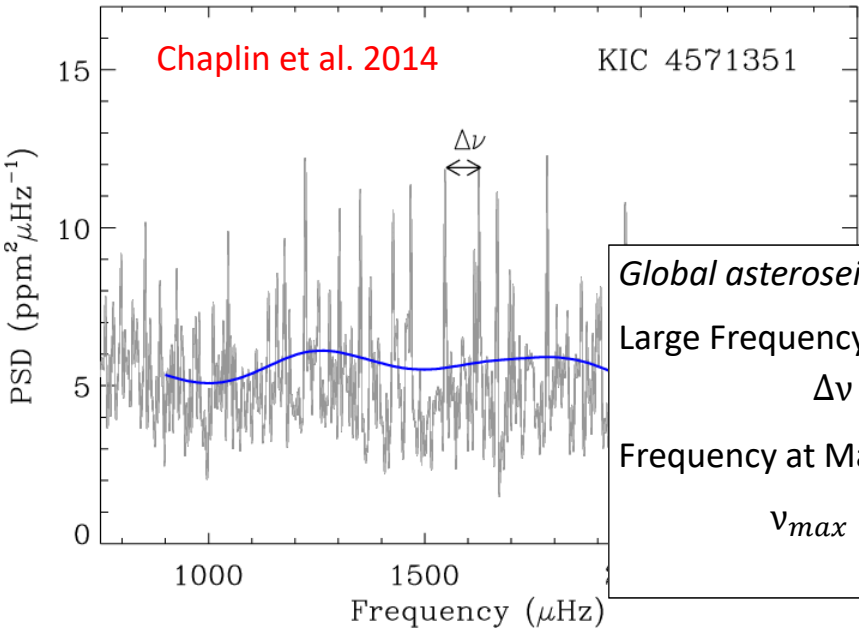
Global asteroseismic parameters:

Large Frequency Separation

$$\Delta\nu \propto \sqrt{\bar{\rho}}$$

Frequency at Maximum Power

$$\nu_{max} \propto \frac{g}{\sqrt{T_{eff}}}$$



Global asteroseismic parameters:

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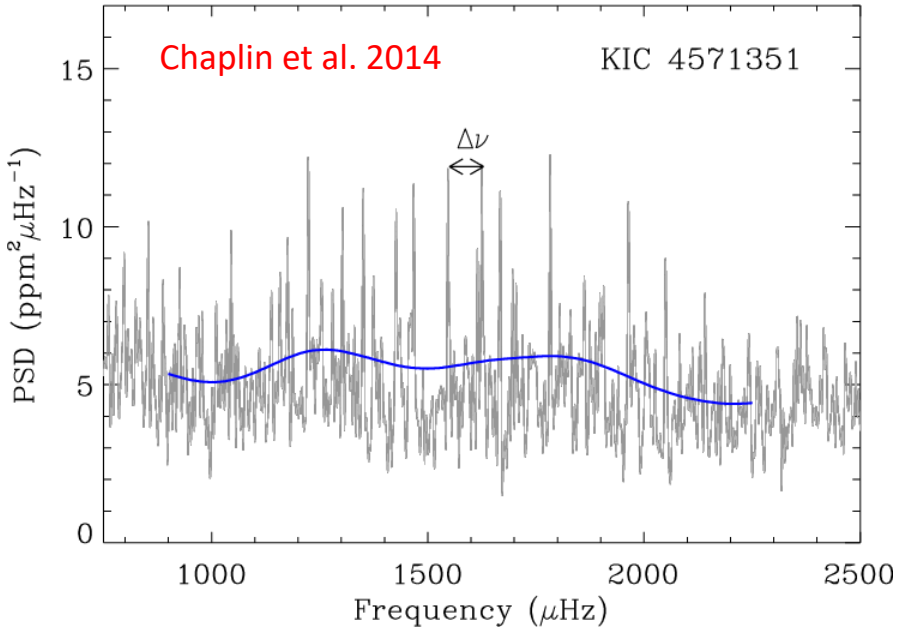
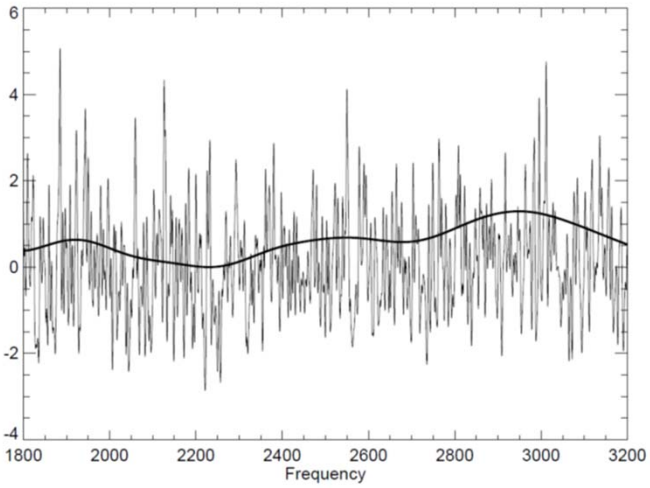
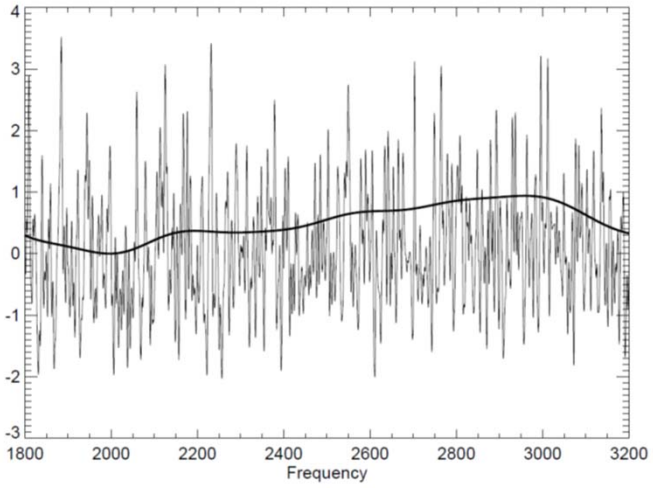

Chaplin et al. 2014
KIC 4571351
$\Delta\nu$
PSD (ppm^2 μHz^{-1})
15
10
5
0
1000
1500
2000
2500
Frequency (μHz)

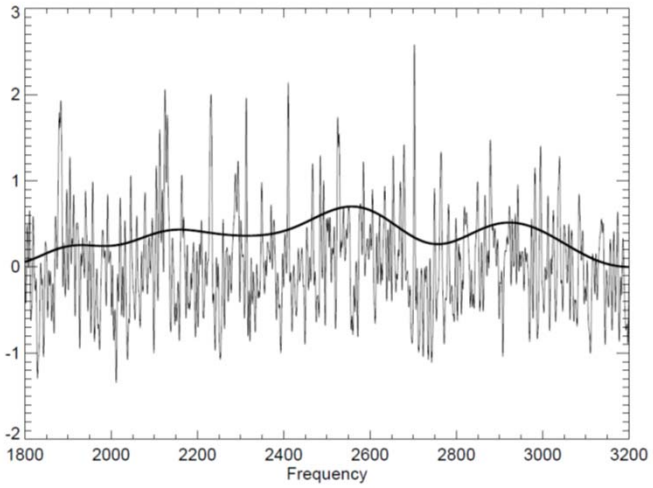
1 Kepler-10


6
4
2
0
-2
-4
1800
2000
2200
2400
2600
2800
3000
3200
Frequency

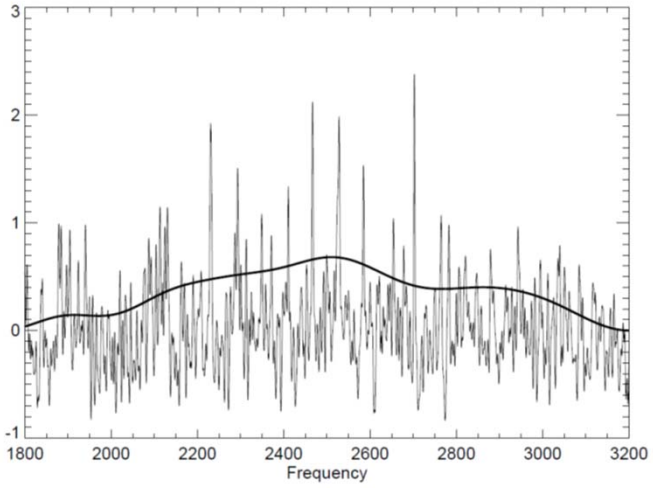
2 Kepler-10



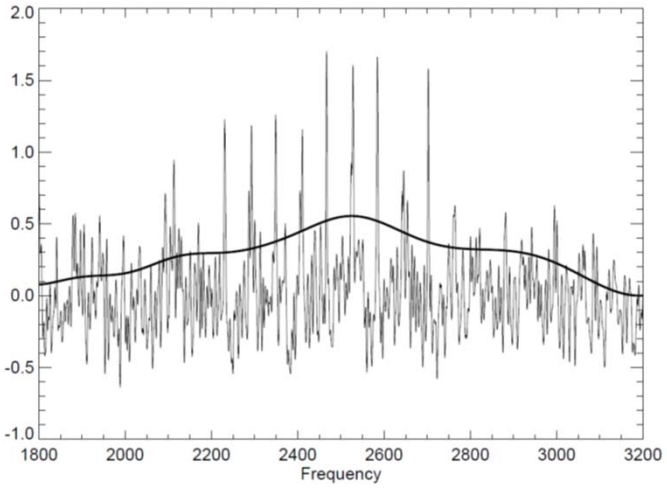
8 Kepler-10



16 Kepler-10

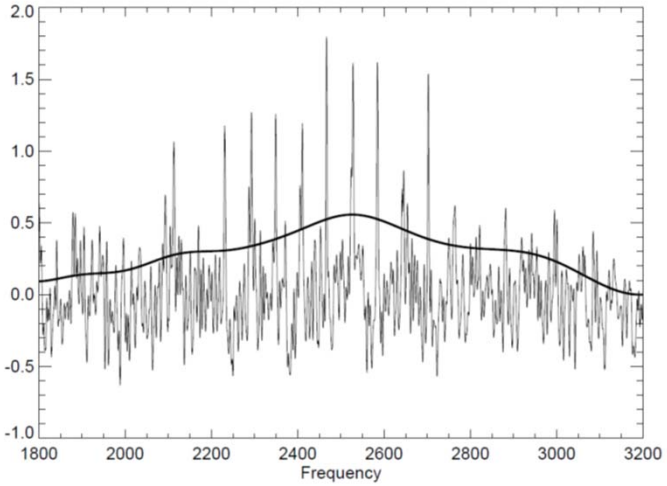


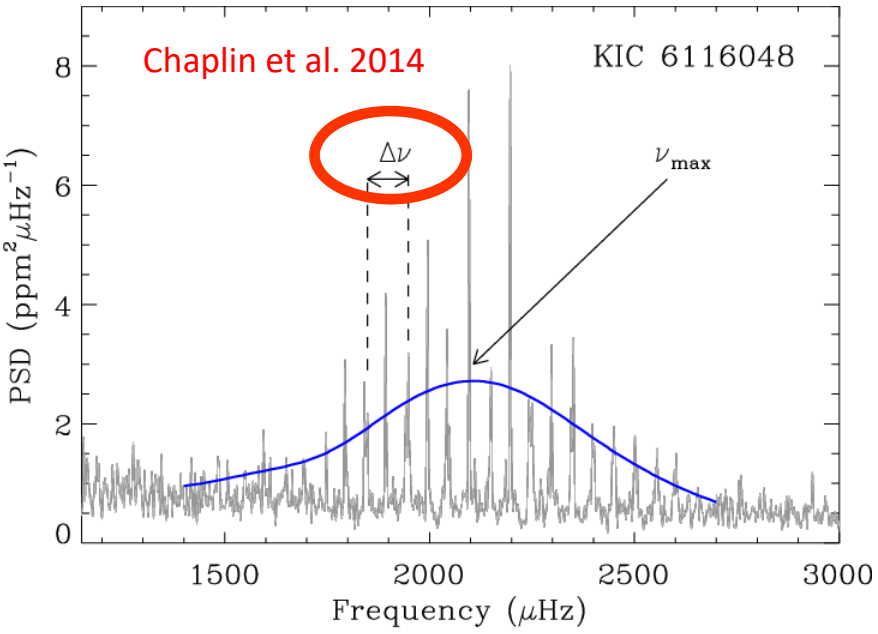
32 Kepler-10

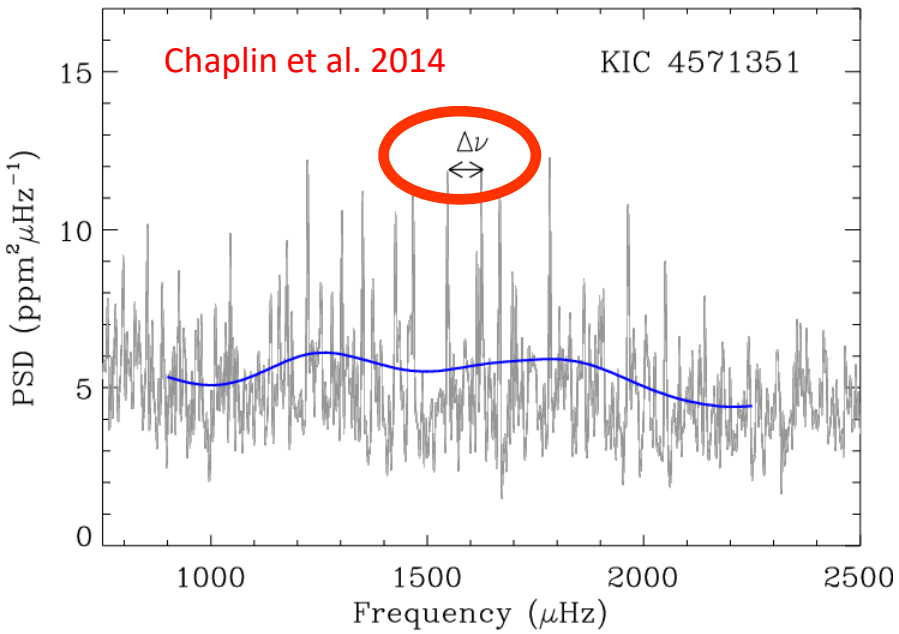


34

Kepler-10

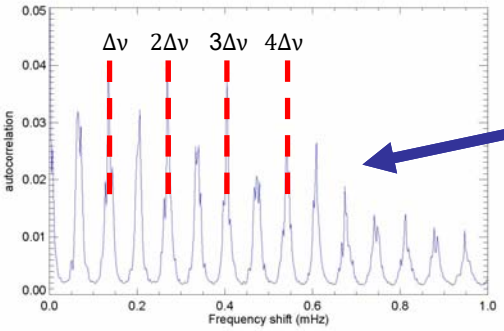

2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
1800
2000
2200
2400
2600
2800
3000
3200
Frequency

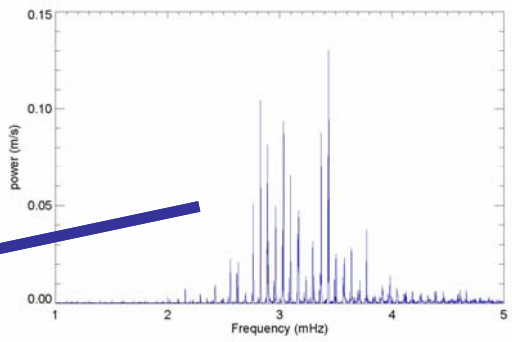

Chaplin et al. 2014
KIC 6116048
$\Delta\nu$
ν_{max}
PSD (ppm^2 μHz^{-1})
0
2
4
6
8
1500
2000
2500
3000
Frequency (μHz)



Measuring the large frequency separation and detecting the p-mode signal

- Power of power
- Auto-Correlation (AC)

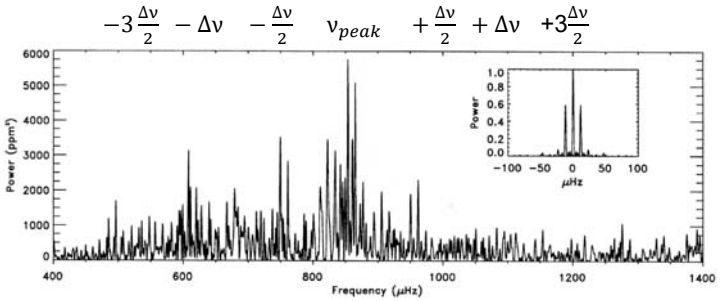


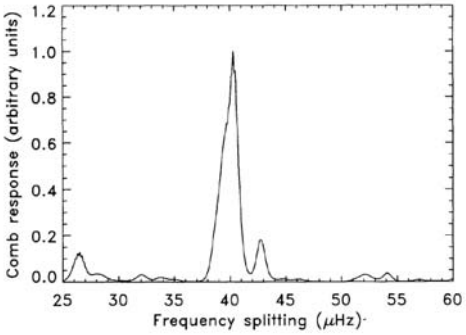


GOLF (sun) used as an example

Measuring the large frequency separation and detecting the p-mode signal

- Power of power
- Auto-Correlation (AC)
- Comb Response



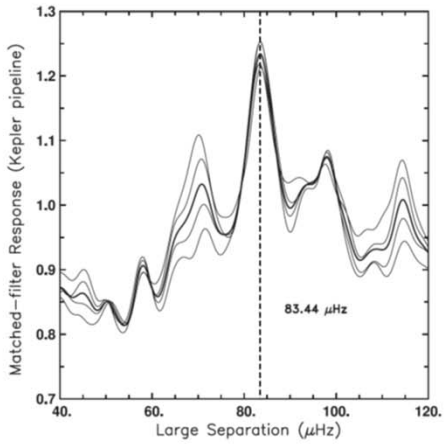


Kjeldsen, Bedding, Viskum, Frandsen, 1995

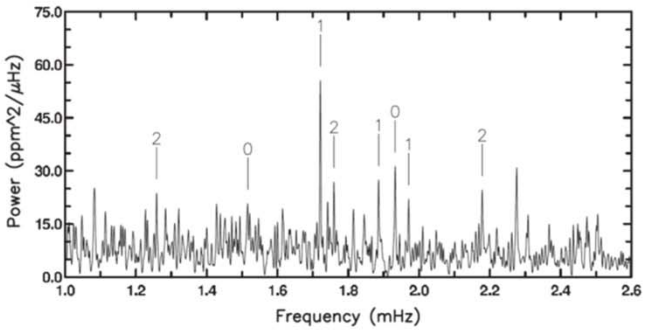
THE ASTROPHYSICAL JOURNAL, 726:2 (17pp), 2011 January 1 doi:10.1088/0004-637X/726/1/2

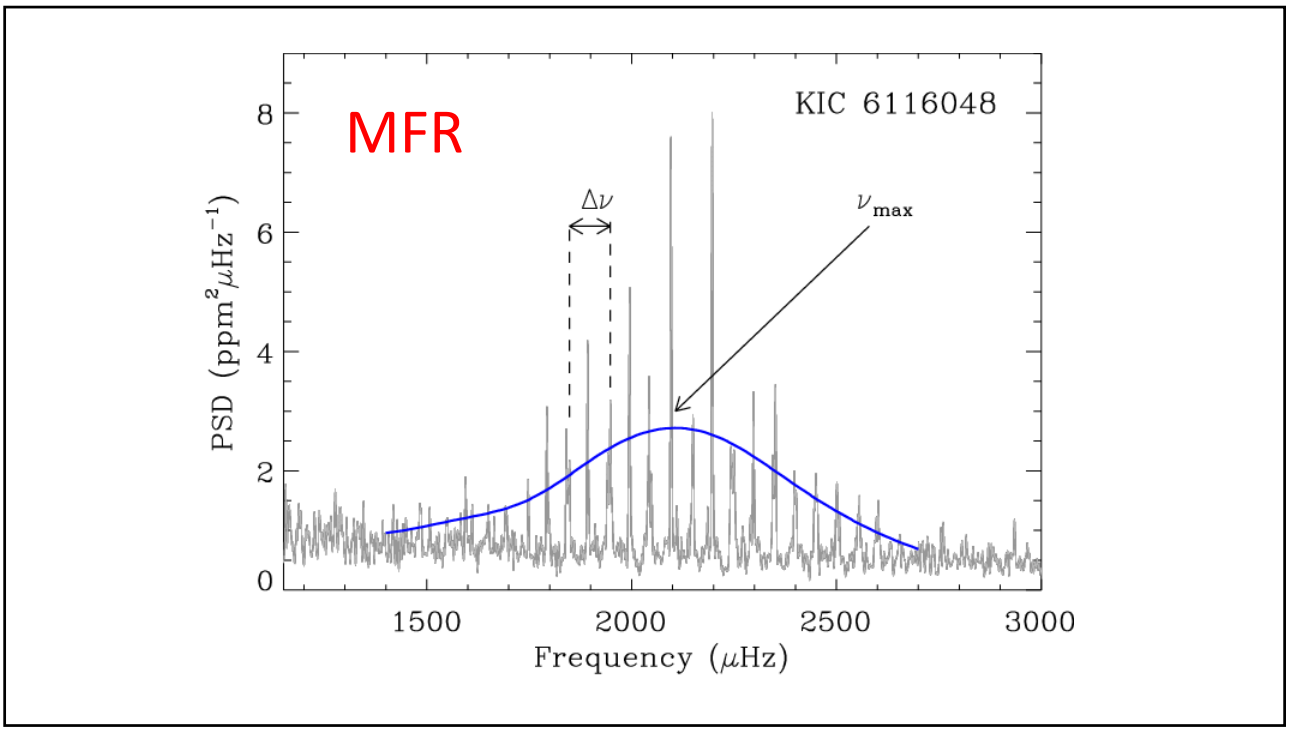
ASTEROSEISMOLOGY OF THE TRANSITING EXOPLANET HOST HD 17156 WITH *HUBBLE SPACE TELESCOPE* FINE GUIDANCE SENSOR*

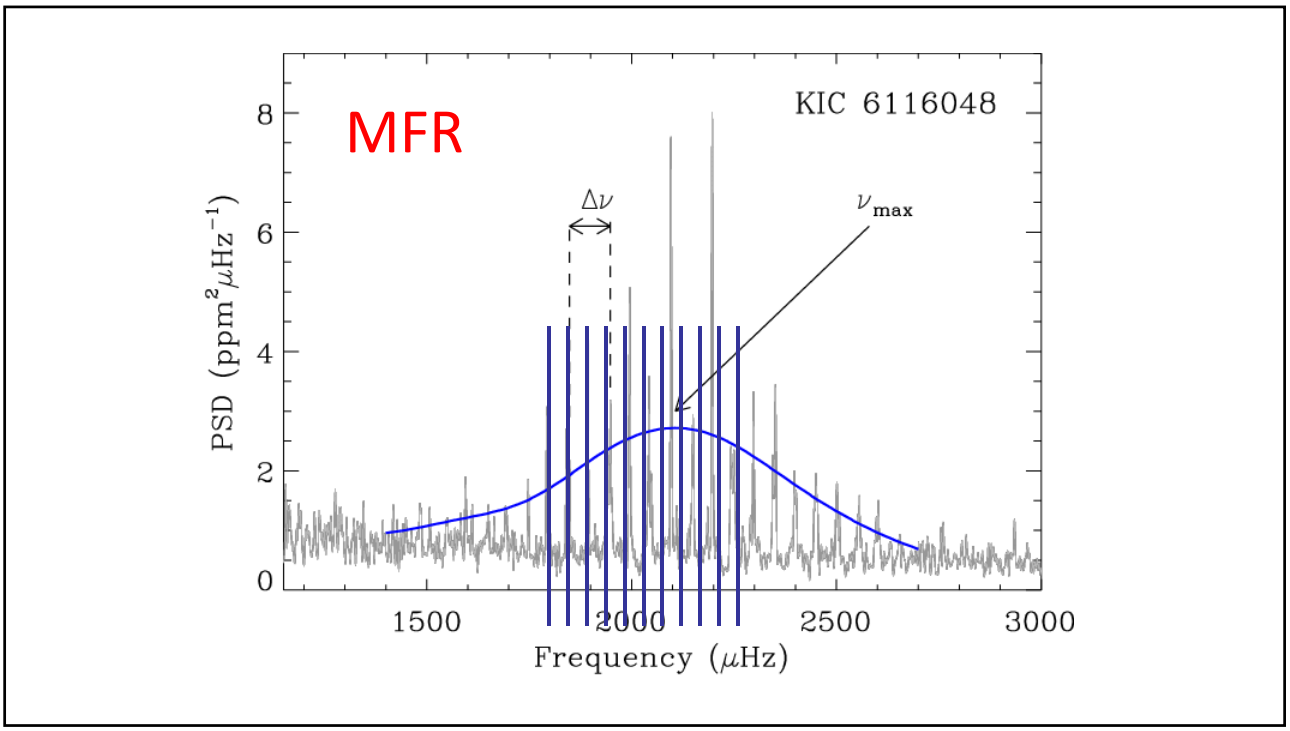
RONALD L. GILLILAND[1], PETER R. MCCULLOUGH[1], EDMUND P. NELAN[1], TIMOTHY M. BROWN[2], DAVID CHARBONNEAU[3], PHILIP NUTZMAN[3], JØRGEN CHRISTENSEN-DALSGAARD[4], AND HANS KJELDSEN[4]

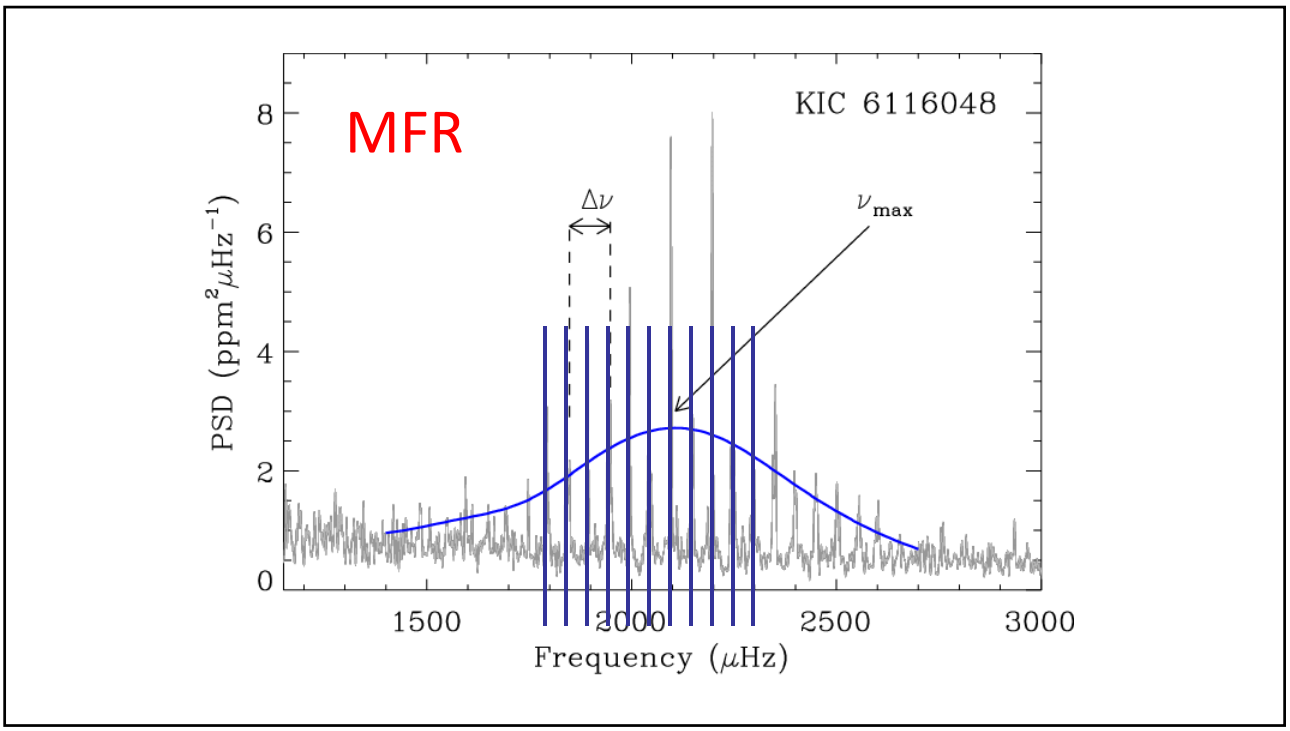


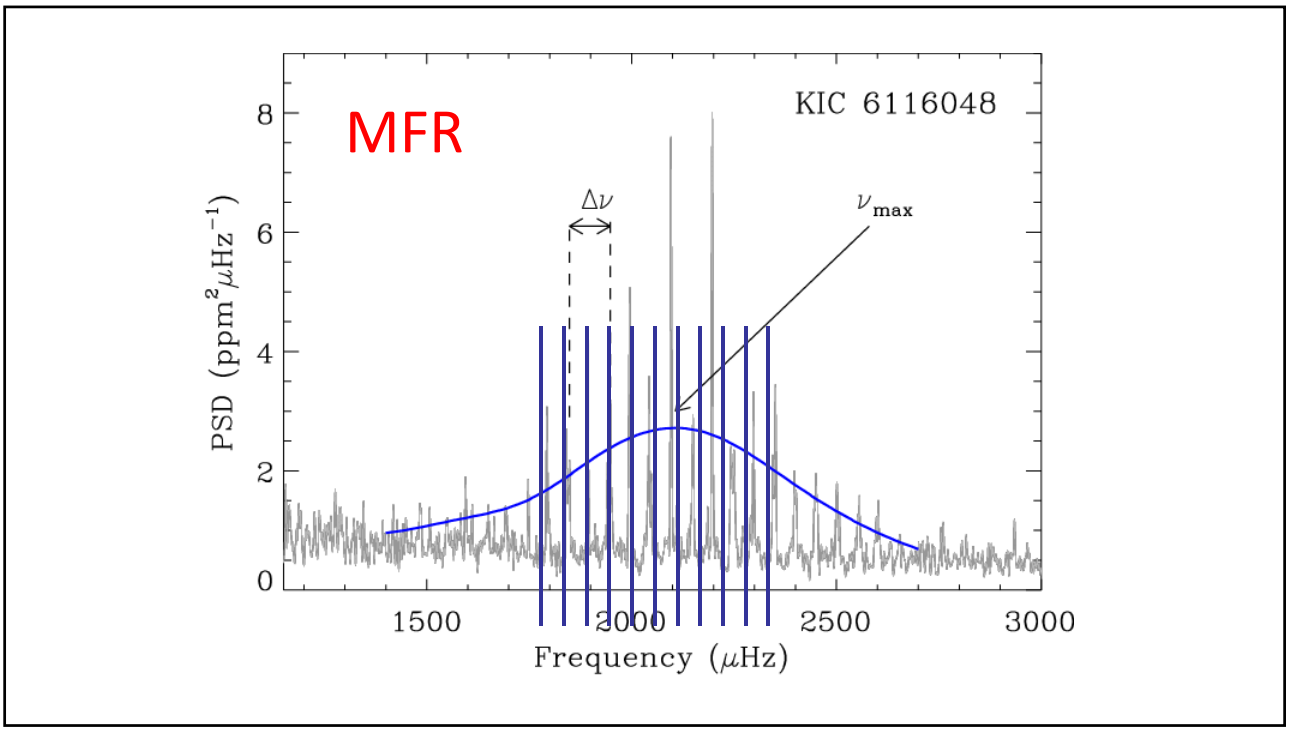
MFR: Matched-filter Response

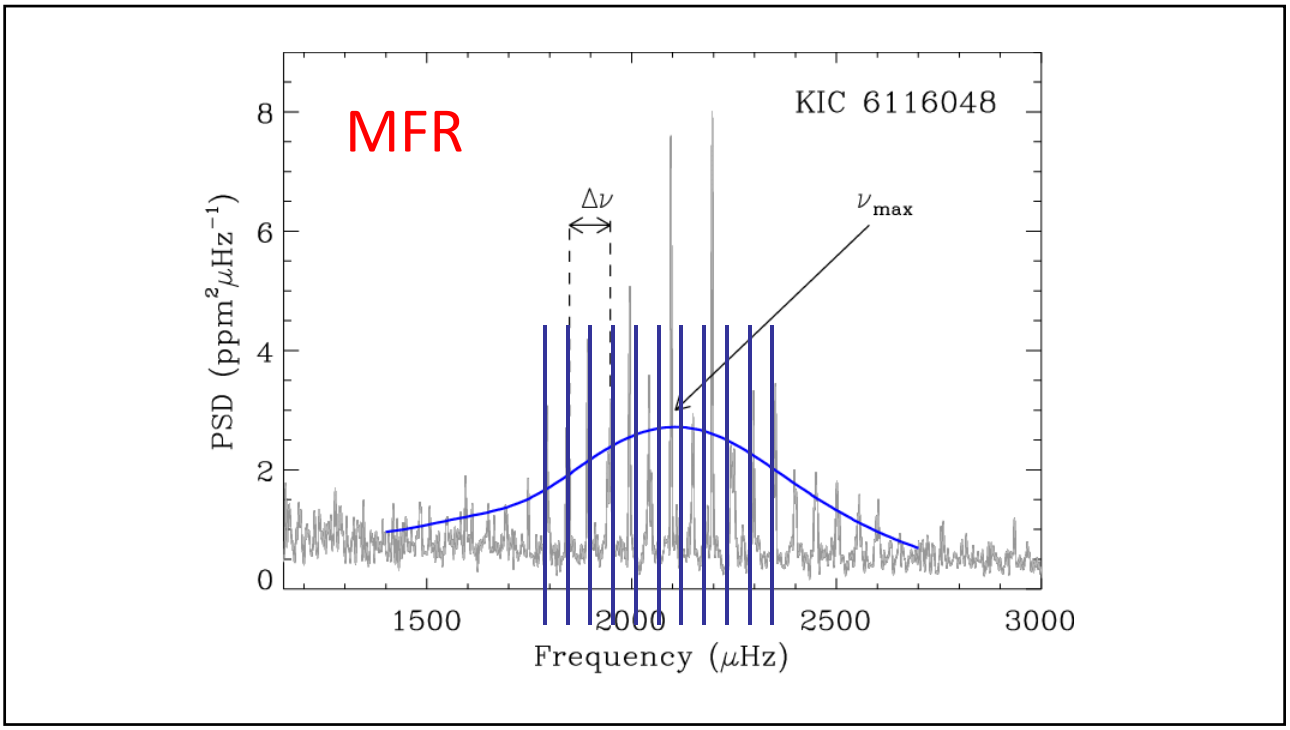


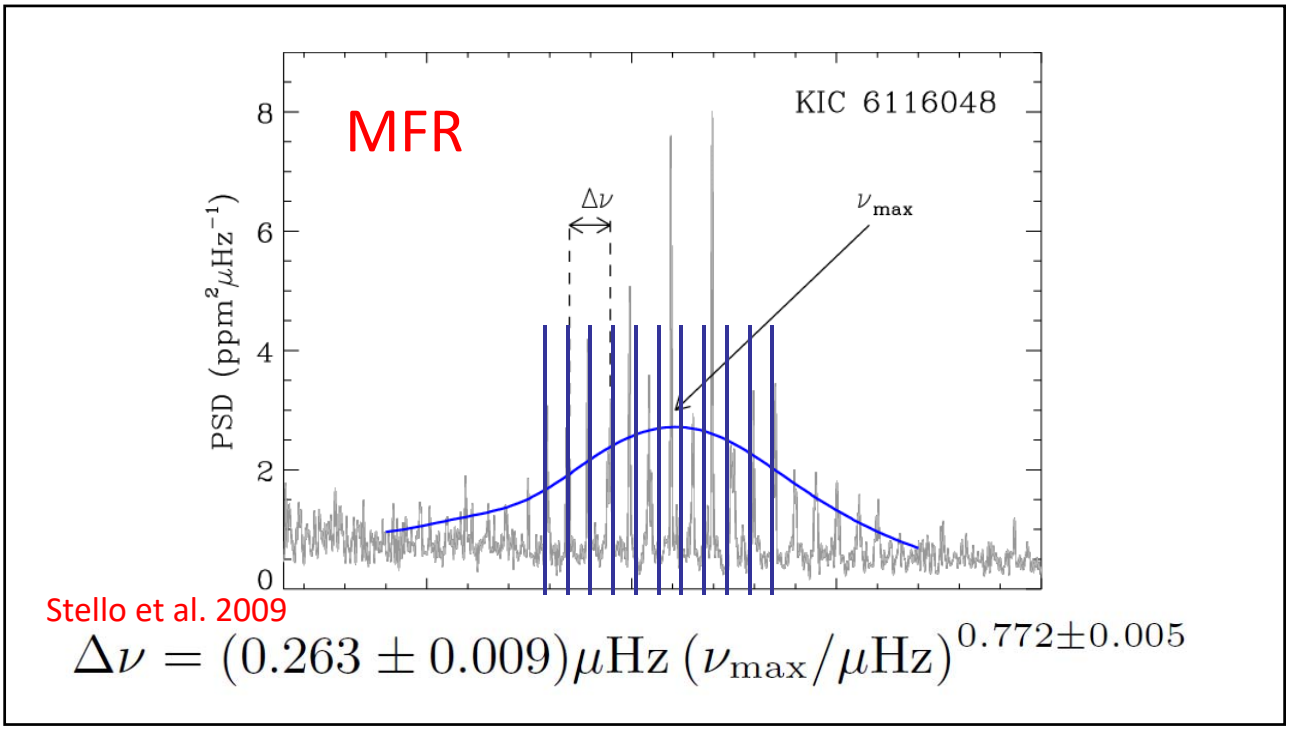

MFR
KIC 6116048
$\Delta\nu$
ν_{max}
PSD (ppm^2 μHz^{-1})
0
2
4
6
8
1500
2000
2500
3000
Frequency (μHz)


MFR
KIC 6116048
$\Delta\nu$
ν_{max}
PSD (ppm^2 μHz^{-1})
0
2
4
6
8
1500
2000
2500
3000
Frequency (μHz)


MFR
KIC 6116048
$\Delta\nu$
ν_{max}
PSD (ppm^2 μHz^{-1})
0
2
4
6
8
1500
2000
2500
3000
Frequency (μHz)


MFR
KIC 6116048
$\Delta\nu$
ν_{max}
PSD (ppm^2 μHz^{-1})
0
2
4
6
8
1500
2000
2500
3000
Frequency (μHz)

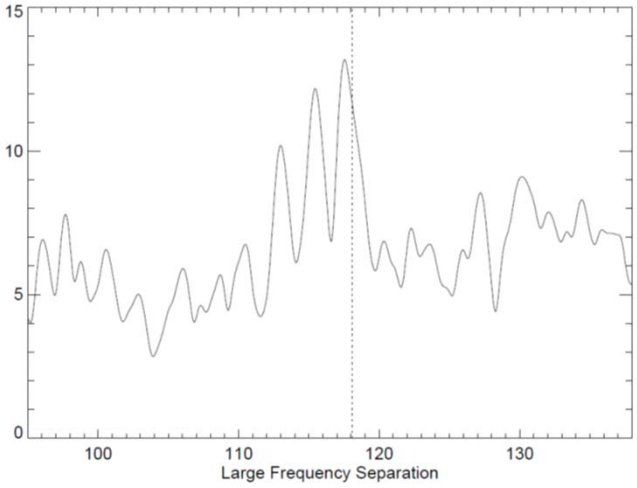




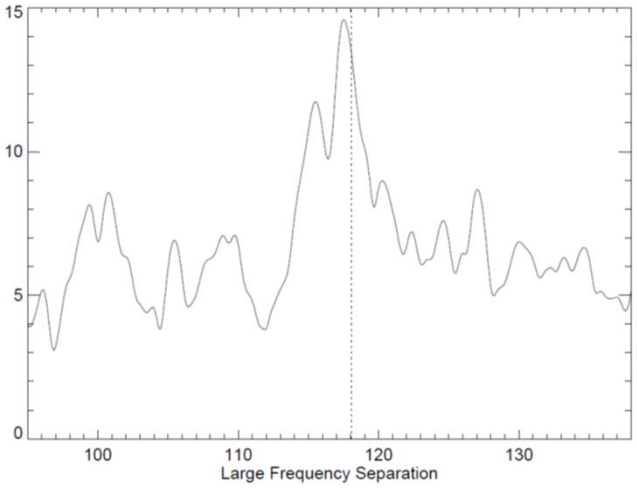
Stello et al. 2009

$$\Delta\nu = (0.263 \pm 0.009)\mu\mathrm{Hz}\,(\nu_{\mathrm{max}}/\mu\mathrm{Hz})^{0.772\pm0.005}$$

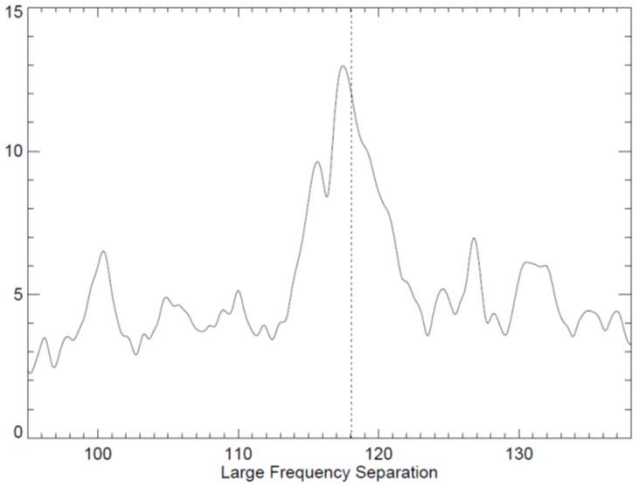
1 Kepler-10



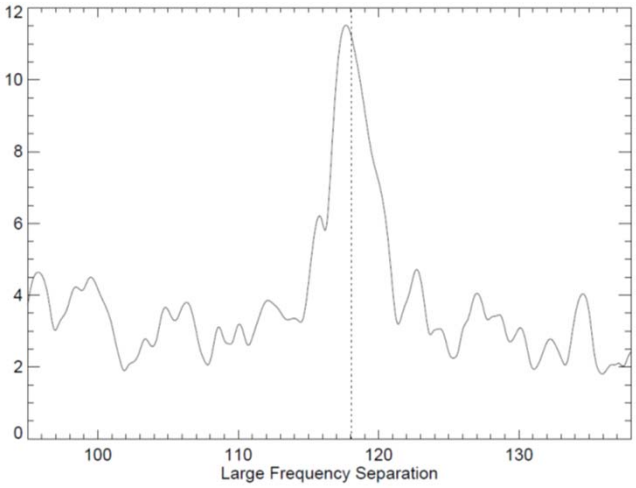
2 Kepler-10



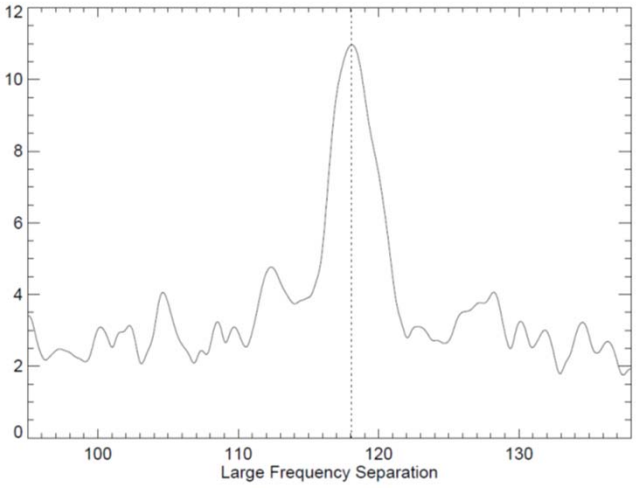
4 Kepler-10



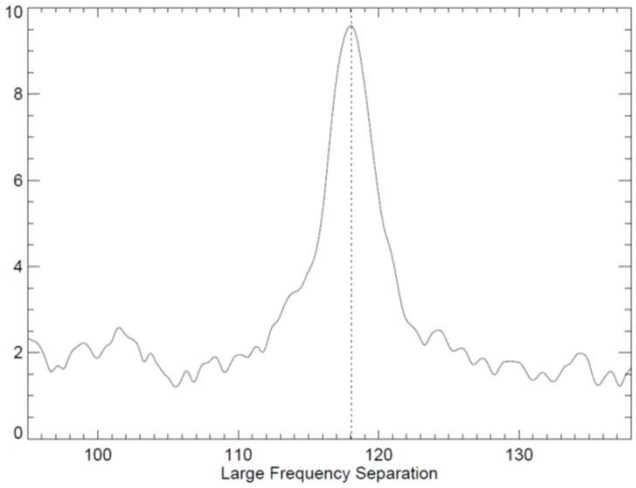
8 Kepler-10



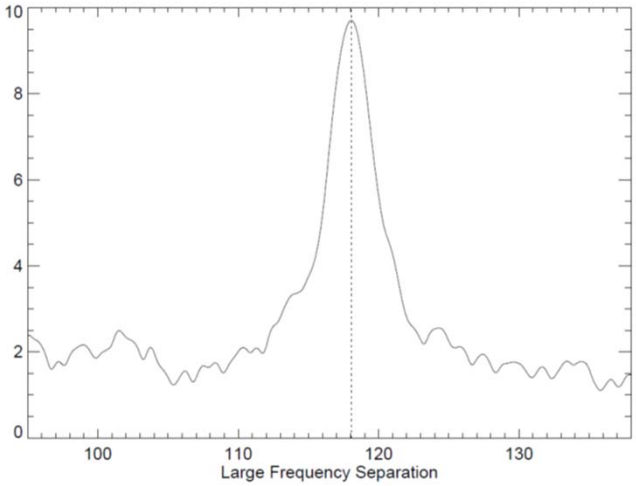
16 Kepler-10



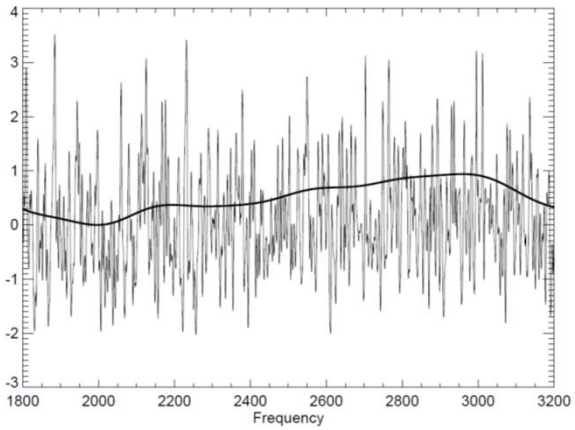
32 Kepler-10

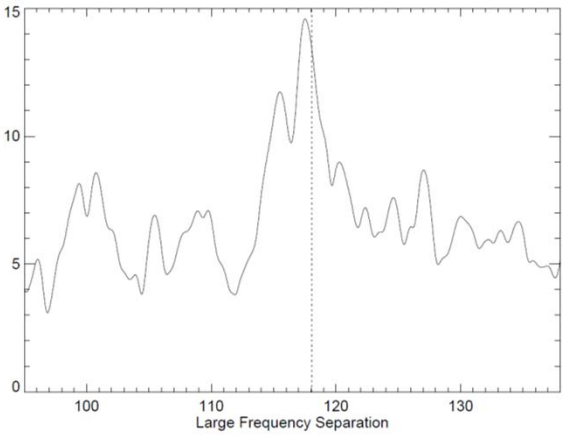


34 Kepler-10

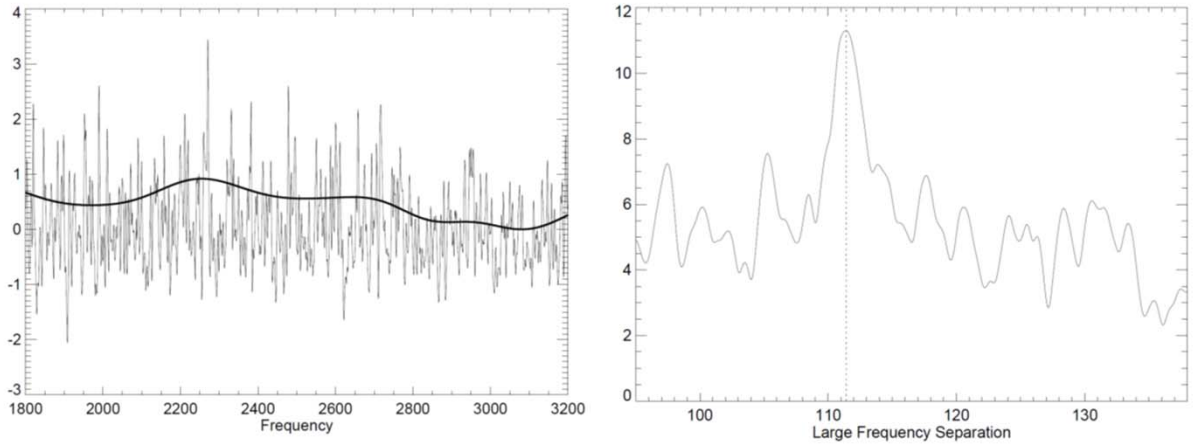


60 d Kepler-10 V=11.16 TESS=6.0

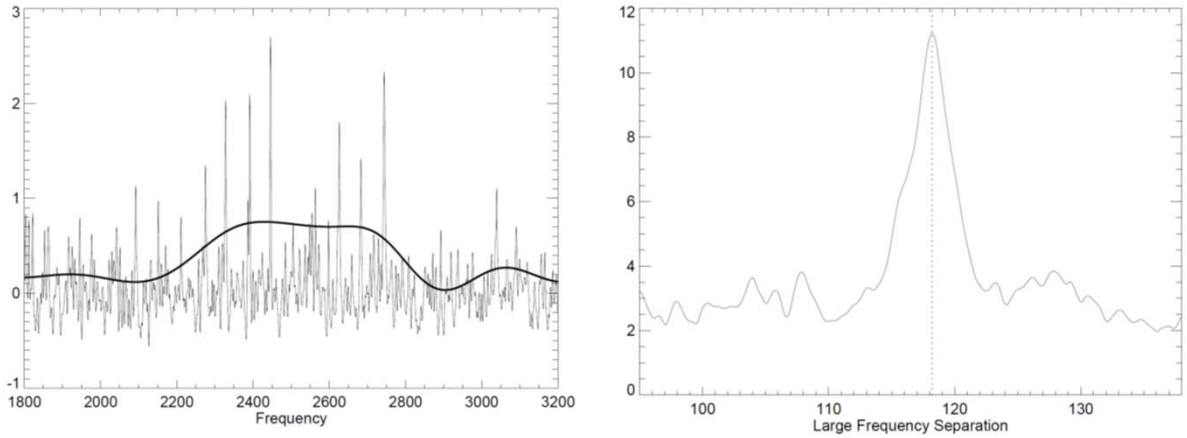


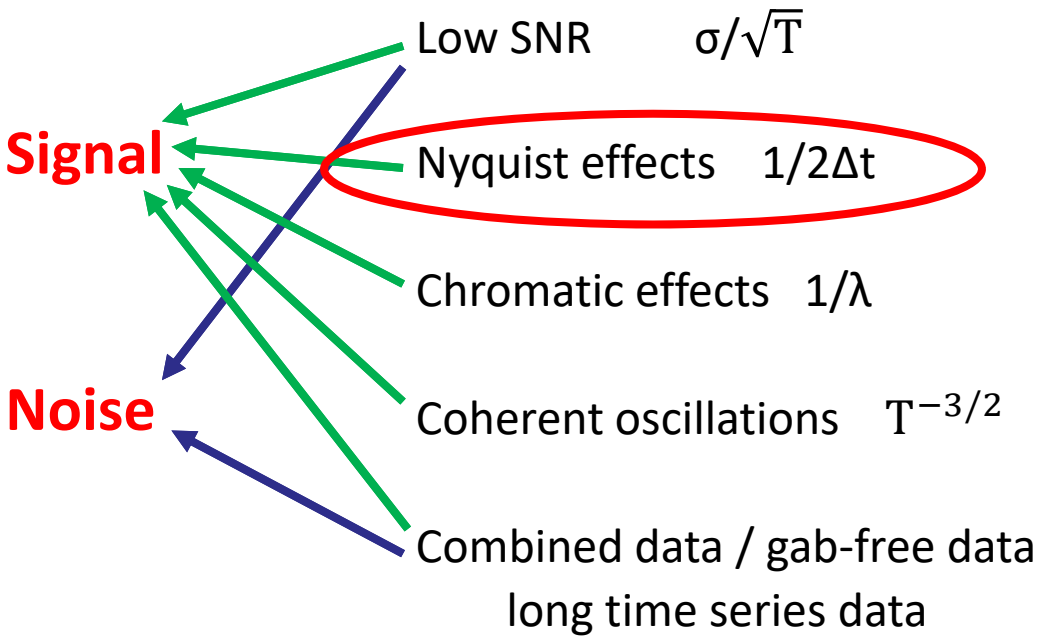


30 d KIC 7106245 V=10.81 TESS=5.8



30 d KIC 8760414 V=9.79 TESS=4.8

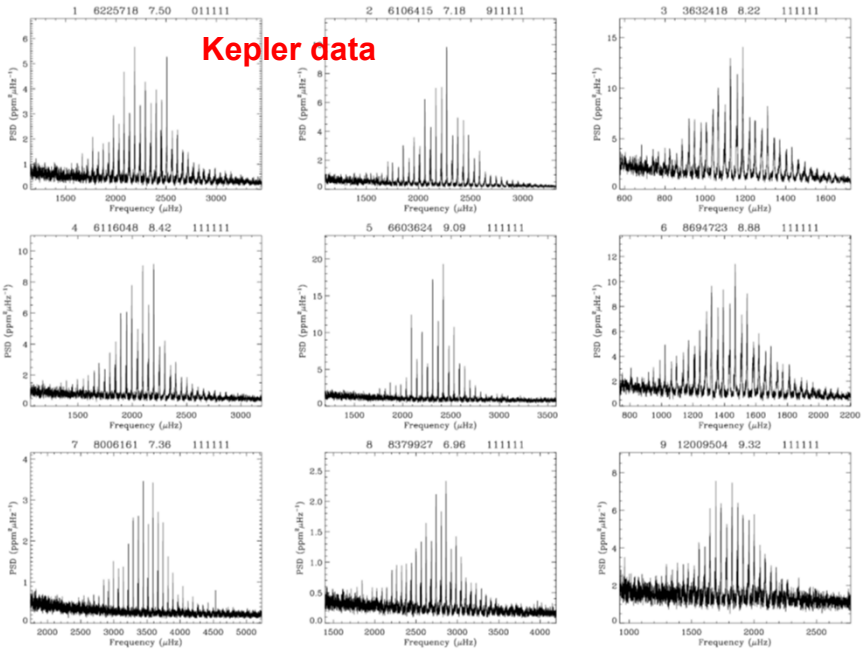




Sampling effects

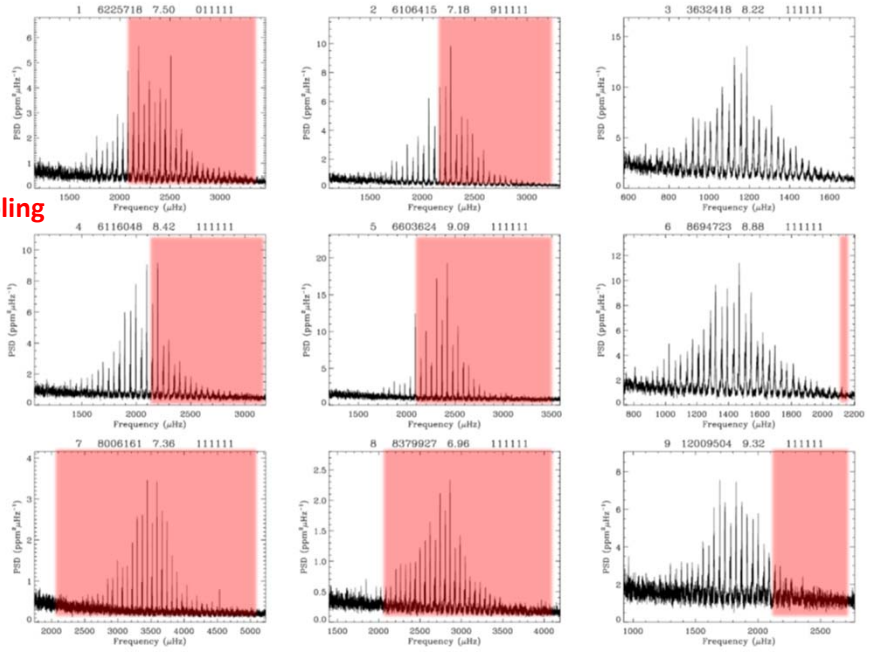
- Useful frequency domain: $0 \rightarrow \nu_{Nyq} \equiv \frac{1}{2\Delta t}$ where Δt is the sampling time
- Frequency resolution: $\frac{1}{T_{obs}}$
- If data are taken as the integration over Δt one will see a decrease in amplitude of coherent oscillations (which will depend on the phase of the specific oscillation)

Kepler data

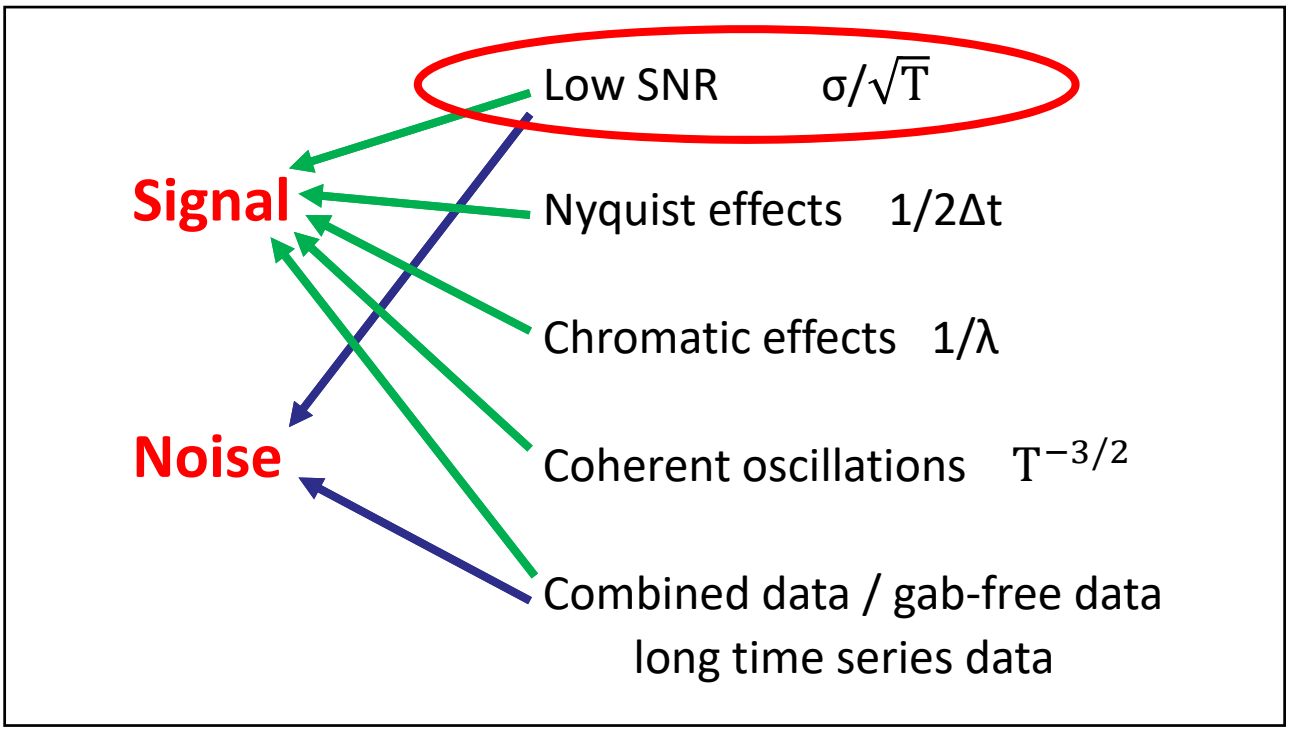


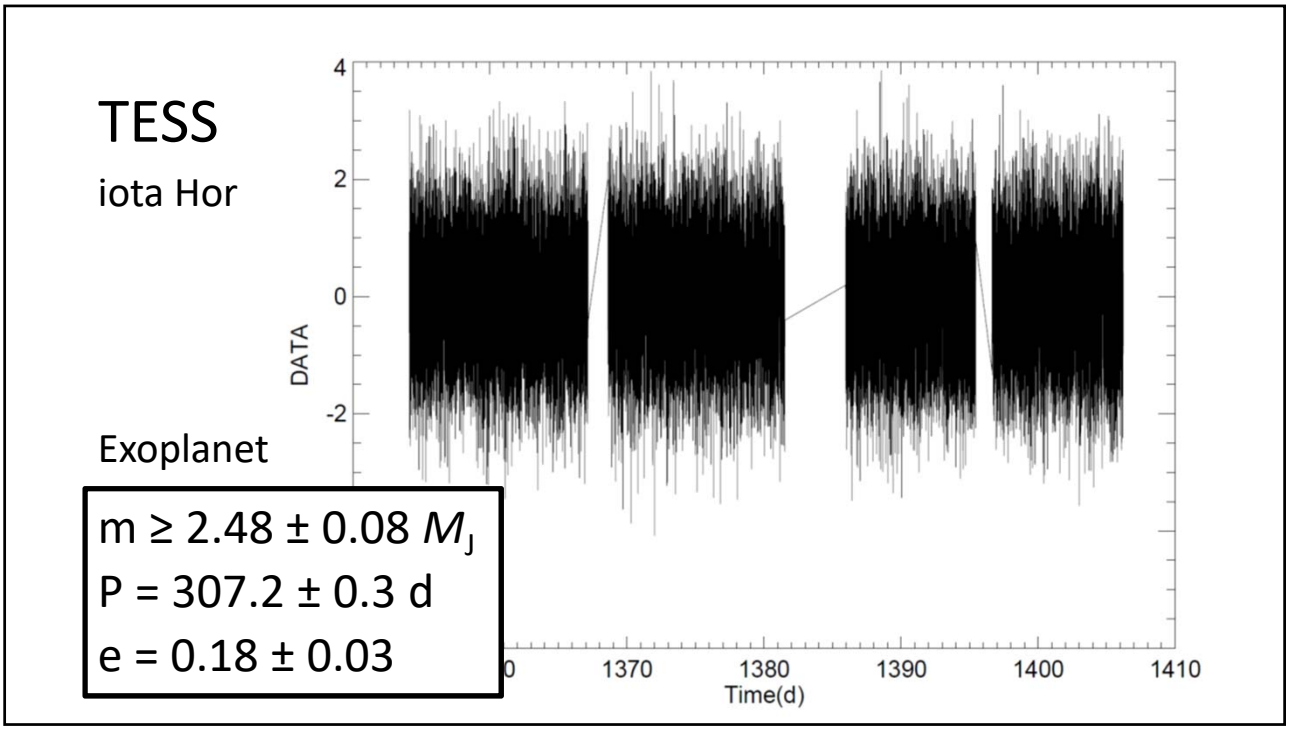
Chaplin et al.

2 min sampling



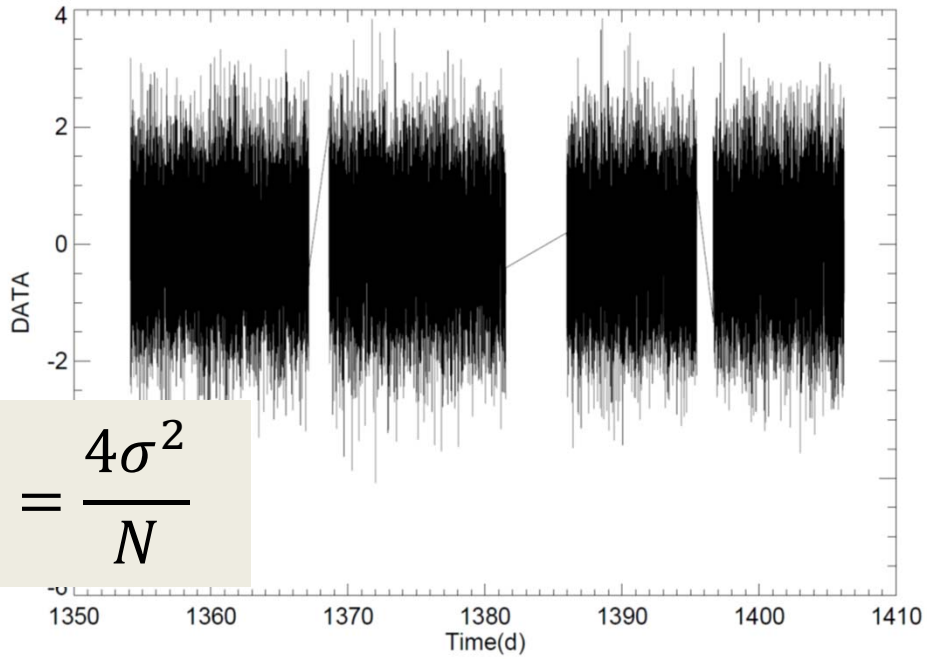
Chaplin et al.


Low SNR $\sigma/\sqrt{T}$
Signal
Nyquist effects 1/2Δt
Chromatic effects 1/λ
Noise
Coherent oscillations $T^{-3/2}$
Combined data / gab-free data
long time series data


TESS
iota Hor
Exoplanet
m ≥ 2.48 ± 0.08 M_J
P = 307.2 ± 0.3 d
e = 0.18 ± 0.03
DATA
4
2
0
-2
1370
1380
1390
1400
1410
Time(d)

TESS

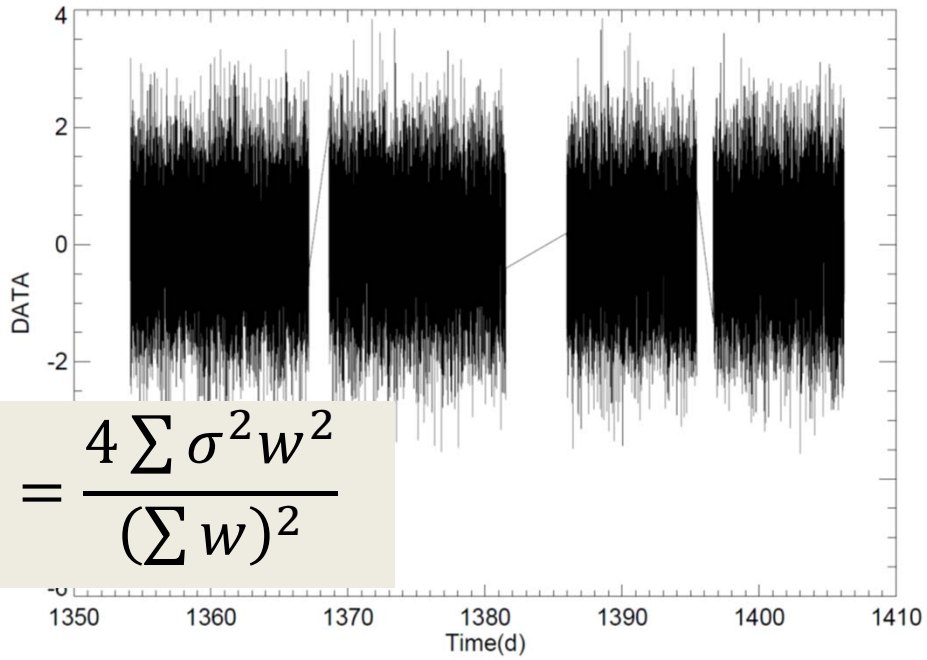
iota Hor



$$P_{noise} = \frac{4\sigma^2}{N}$$

TESS

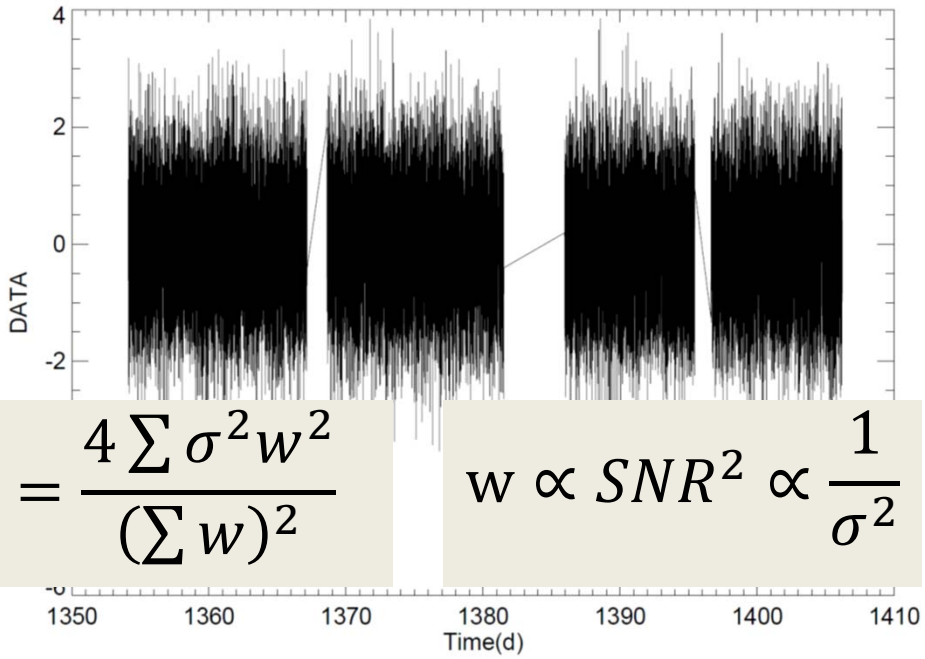
iota Hor



$$P_{noise} = \frac{4\sum \sigma^2 w^2}{(\sum w)^2}$$

TESS

iota Hor

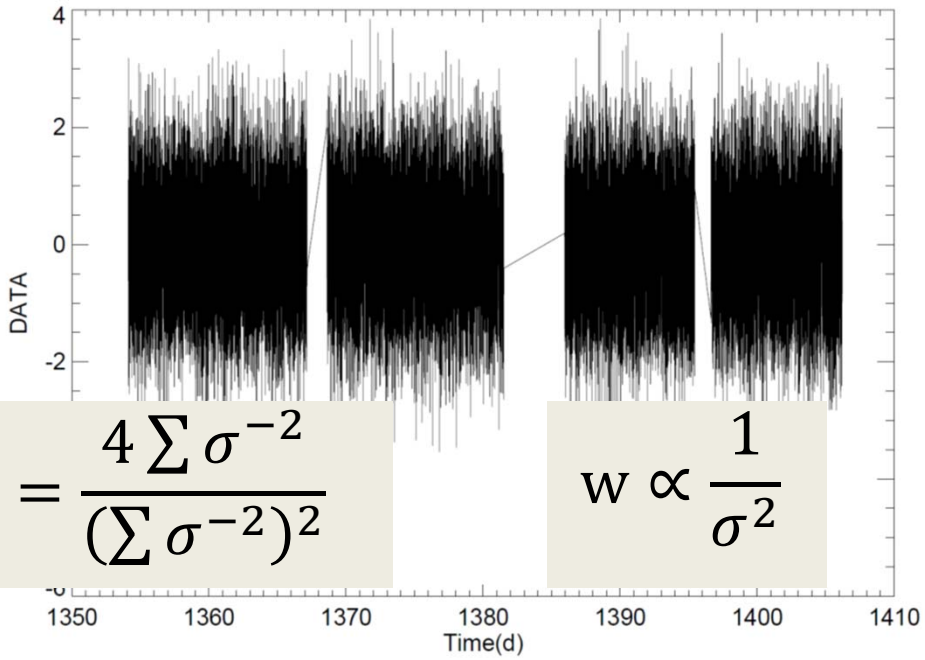


$$P_{noise} = \frac{4\sum \sigma^2 w^2}{(\sum w)^2}$$

$$\mathrm{w} \propto SNR^2 \propto \frac{1}{\sigma^2}$$

TESS

iota Hor

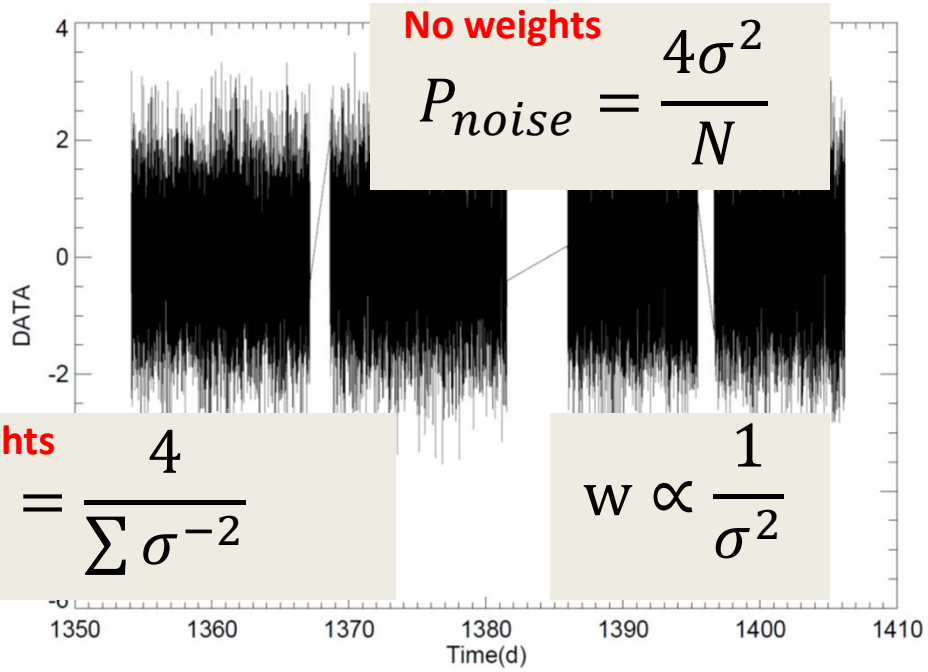


$$P_{noise} = \frac{4\sum \sigma^{-2}}{(\sum \sigma^{-2})^2}$$

$$\mathrm{w} \propto \frac{1}{\sigma^2}$$

TESS

iota Hor



No weights

$$P_{noise} = \frac{4\sigma^2}{N}$$

Weights

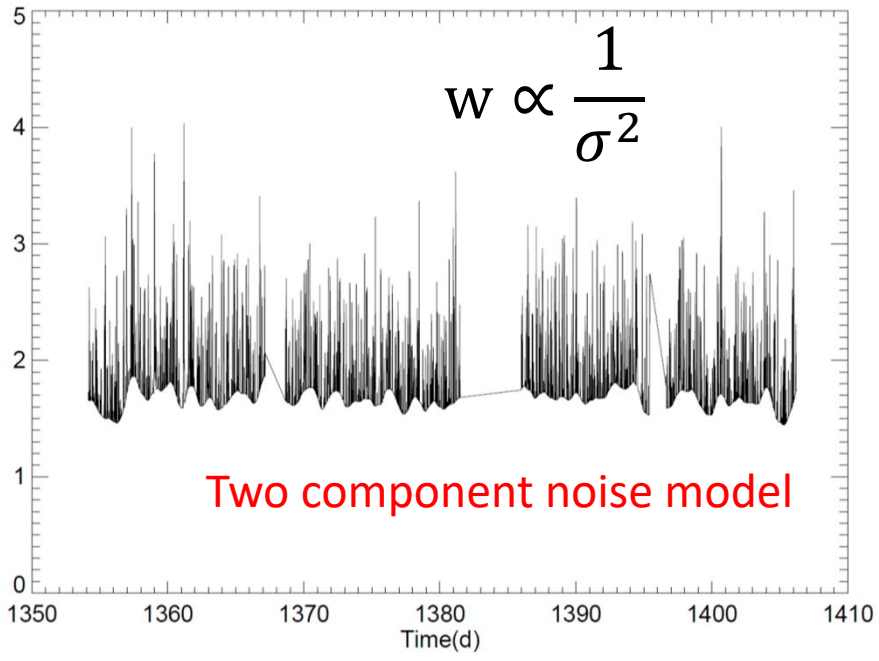
$$P_{noise} = \frac{4}{\sum \sigma^{-2}}$$

$$w \propto \frac{1}{\sigma^2}$$

TESS

iota Hor

Scatter and Statistical weights



$$w \propto \frac{1}{\sigma^2}$$

Two component noise model

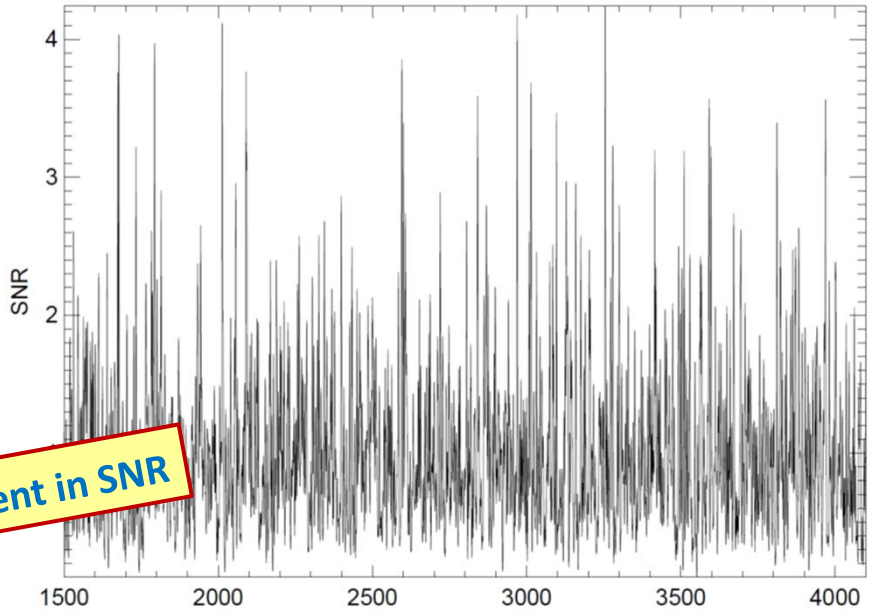
p-modes ?

TESS

iota Hor

$$w \propto \frac{1}{\sigma^2}$$

30 % improvement in SNR



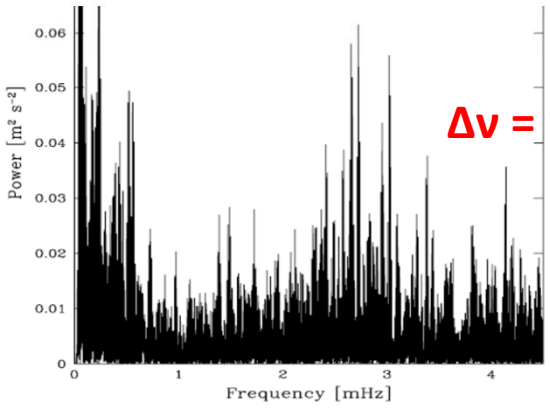
A&A 482, L5–L8 (2008)
DOI: 10.1051/0004-6361:20079342

Astronomy & Astrophysics

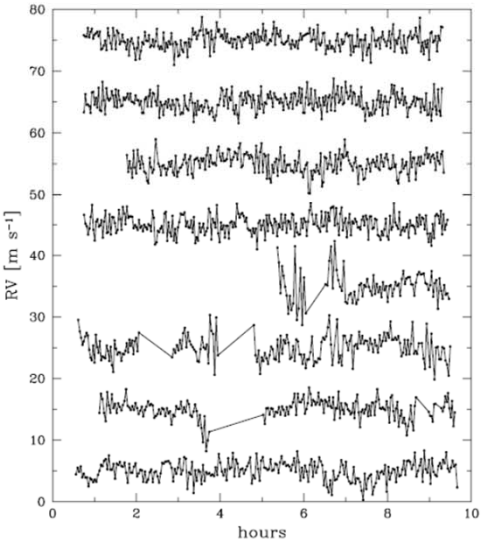
LETTER TO THE EDITOR

The exoplanet-host star ι Horologii: an evaporated member of the primordial Hyades cluster

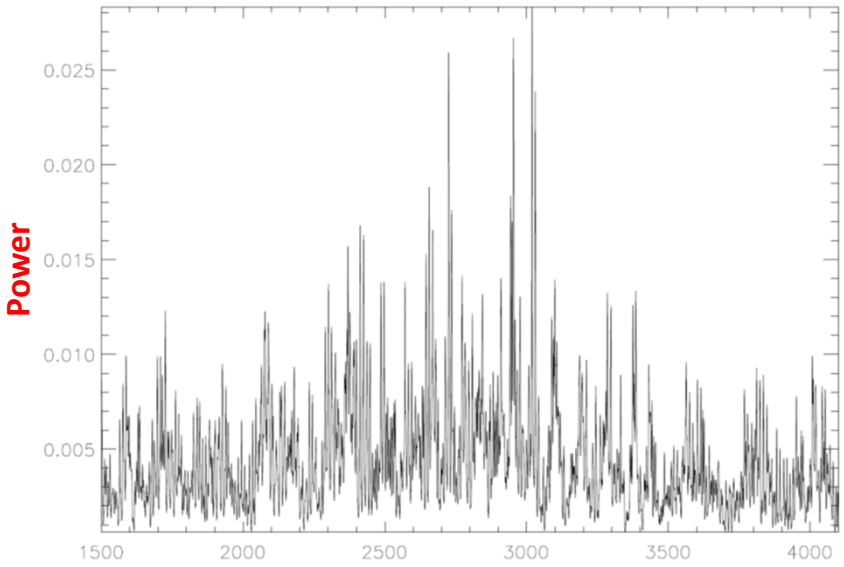
S. Vauclair[1], M. Laymand[1], F. Bouchy[2], G. Vauclair[1], A. Hui Bon Hoa[1], S. Charpinet[1], and M. Bazot[3]

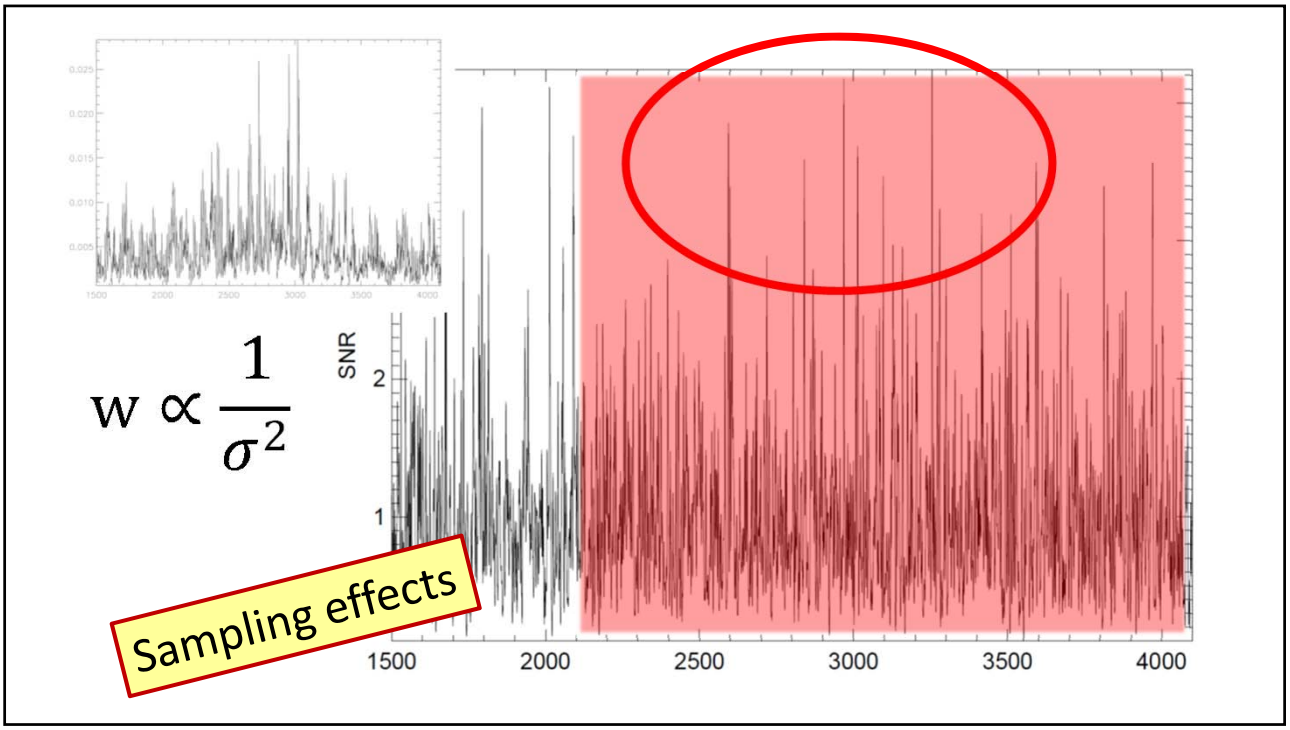


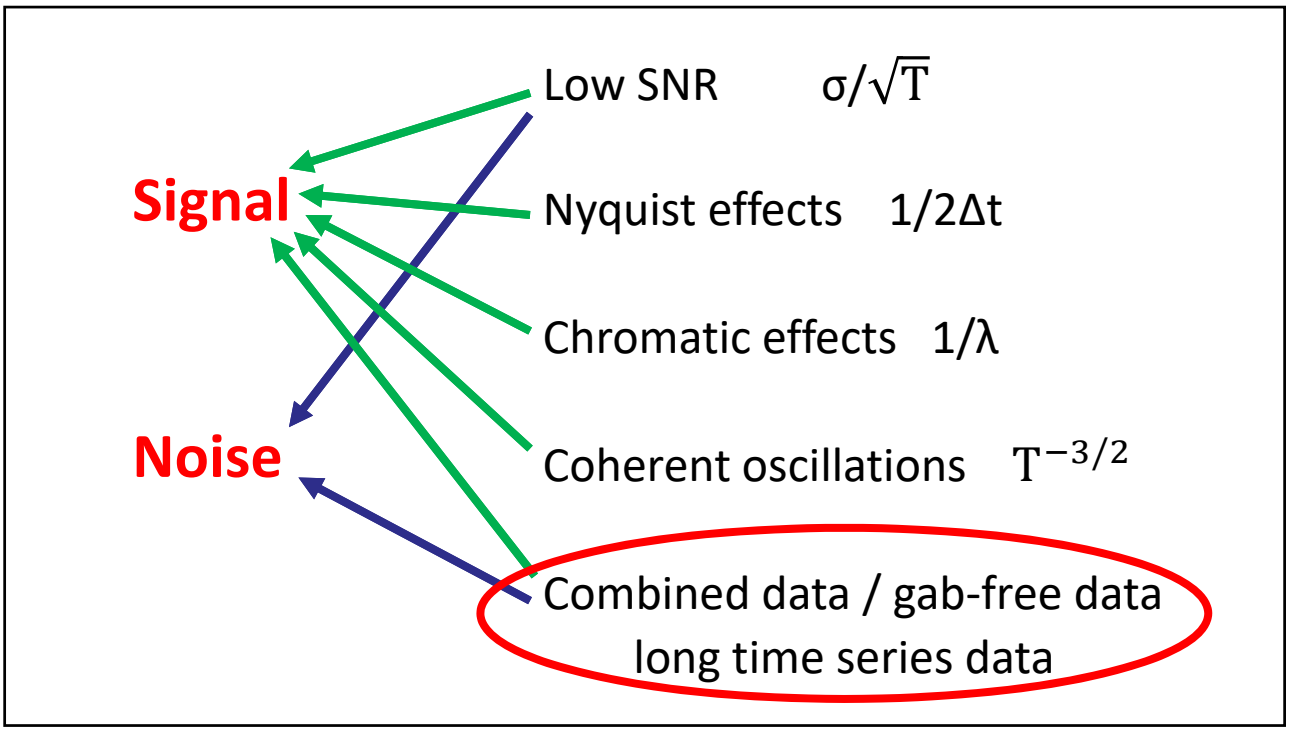
Δν = 120 μHz



iota Hor – TESS and HARPS






Signal
Noise
Low SNR $\sigma/\sqrt{T}$
Nyquist effects 1/2Δt
Chromatic effects 1/λ
Coherent oscillations $T^{-3/2}$
Combined data / gab-free data
long time series data


SONG: Stellar Observations Network Group