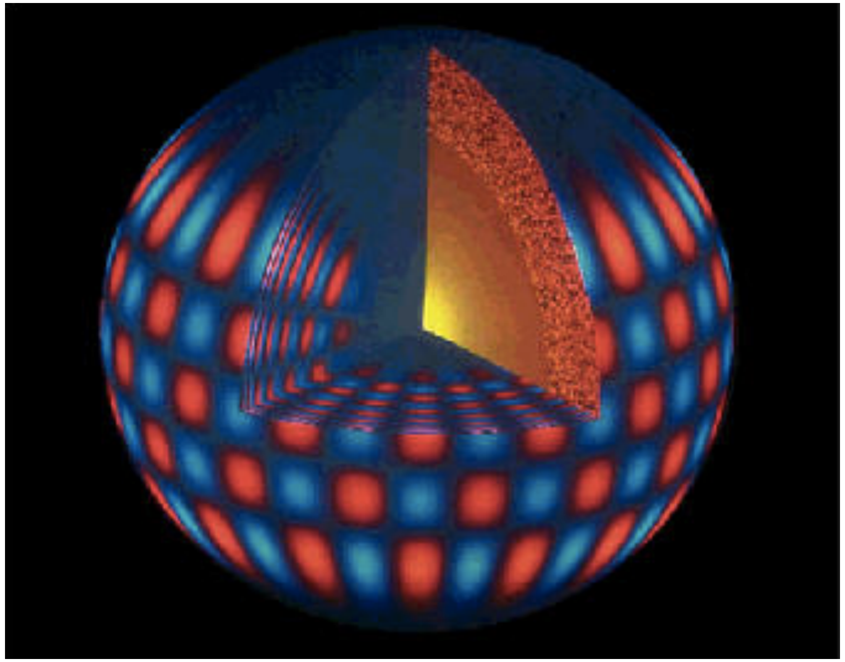
Asterseismology and Gaia

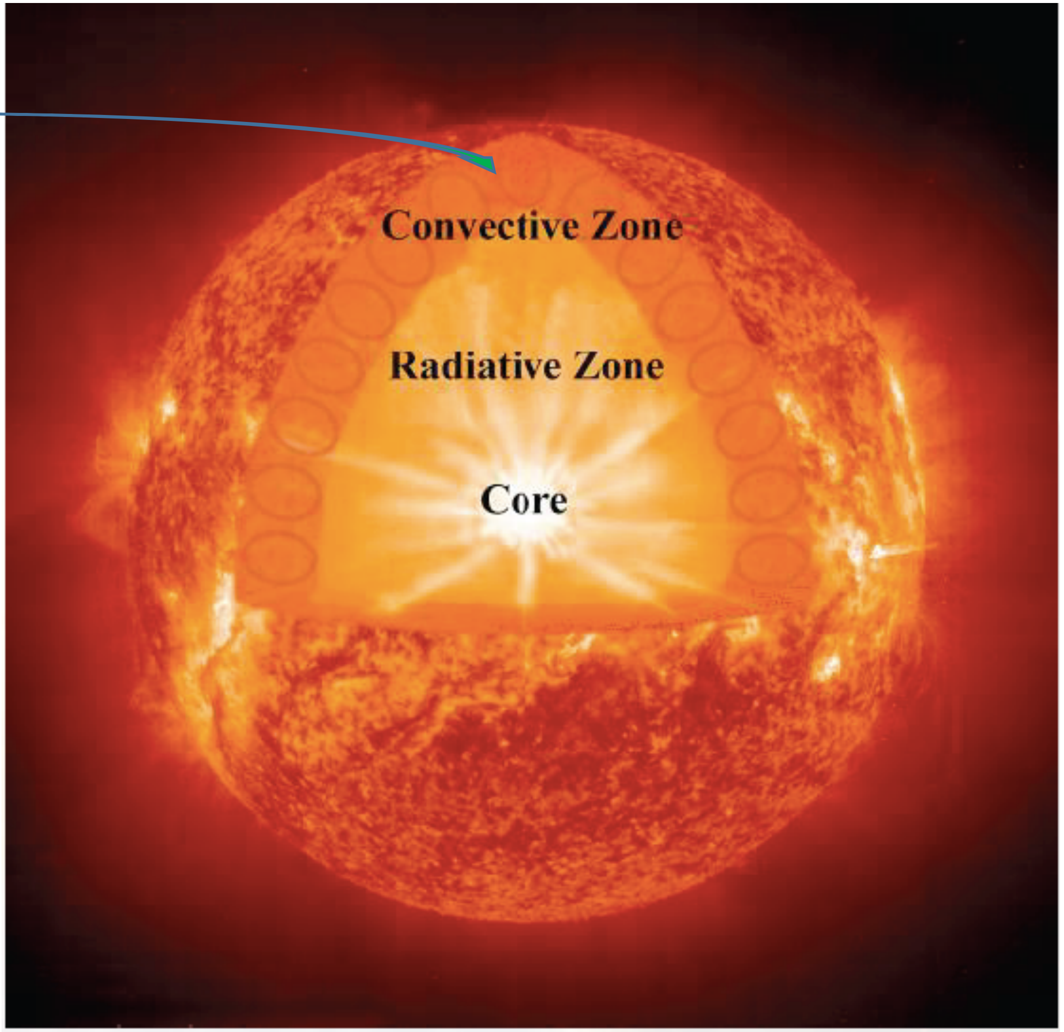
Asteroseismology can deliver accurate stellar radii and masses

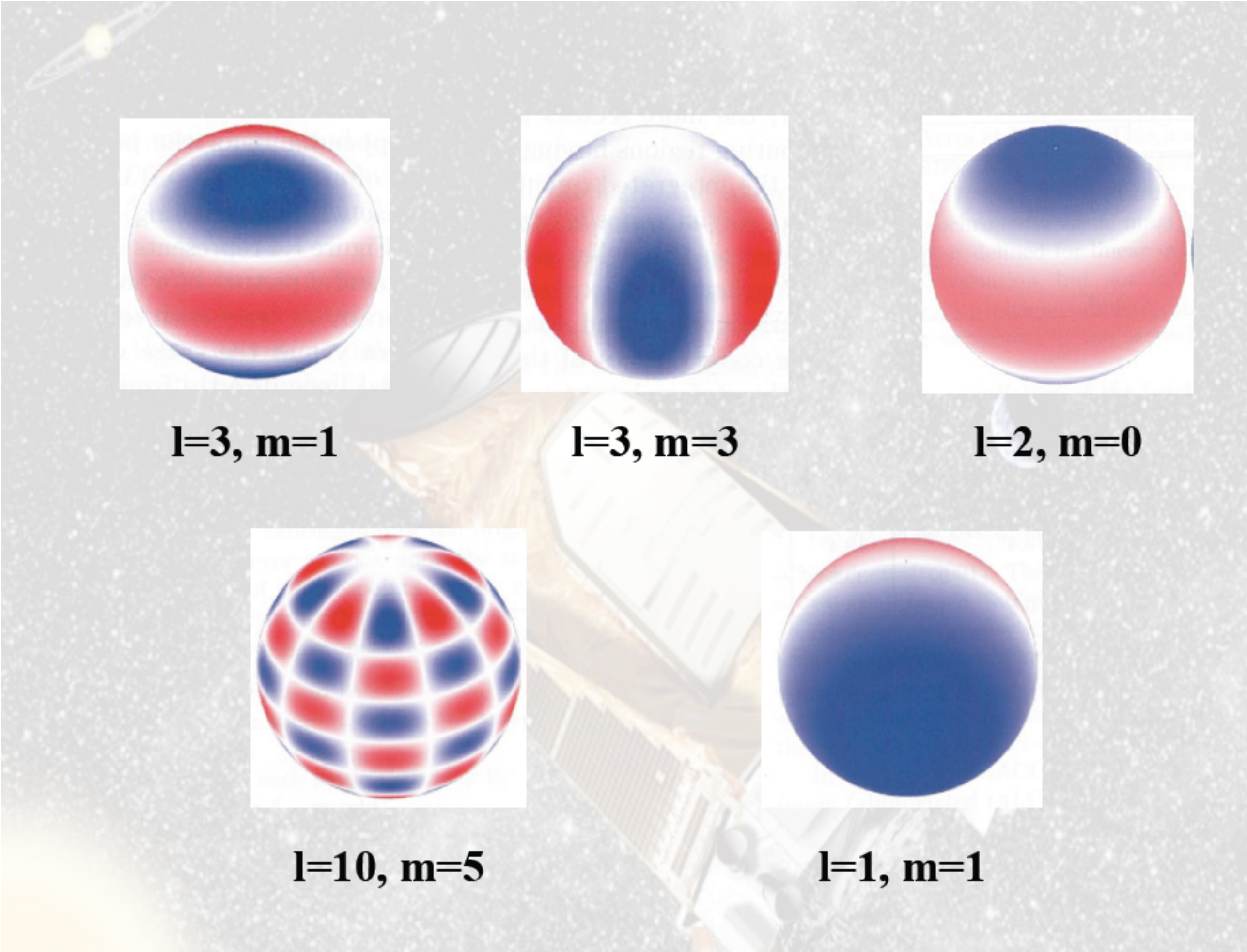
Huber et al 2017 compare results on distances from Gaia and asteroseismology for 2200 Kepler stars

Asteroseismology

Surface convection zones excite non-radial oscillations – standing sound waves







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Individual modes of oscillation are described in terms of spherical harmonics.
The oscillations are described by their frequency ν and three quantum numbers: the radial order *n* indicating the number of nodes in the radial direction, the spherical degree *l* indicating the number of nodal lines on the surface, and the azimuthal order *m* indicating the number of nodal lines that pass through the rotation axis.

Hekker 2017

The sound speed depends on the properties of the gas:

for an ideal gas: $$c \propto \sqrt{T/\mu}\,.$$

The measurement of frequencies of oscillations in stars allow us to probe the sound speed (and hence temperature and composition) in the stellar interior

T temperature, mu molecular weight

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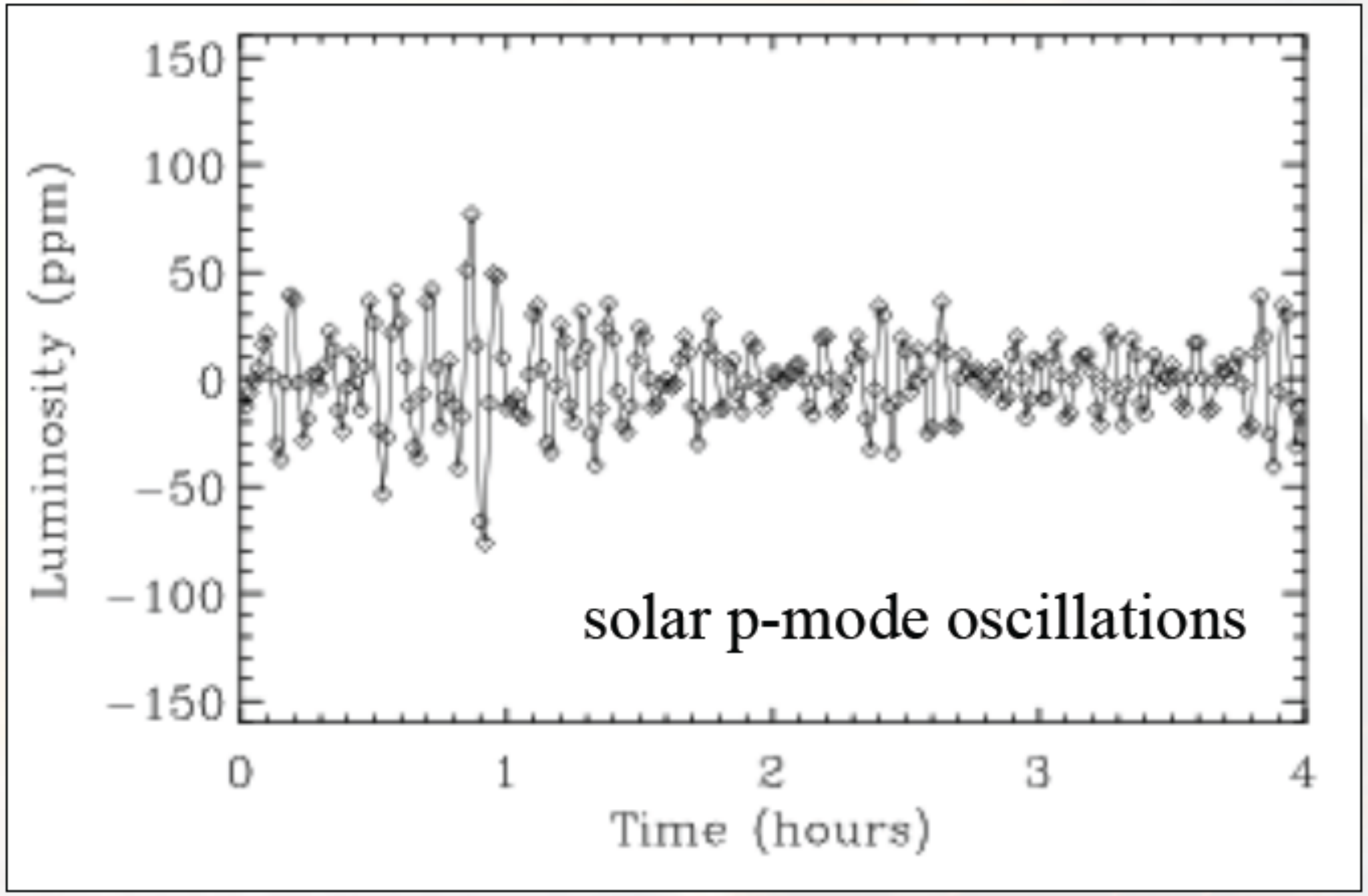
Stellar Oscillations cause Variations in Brightness



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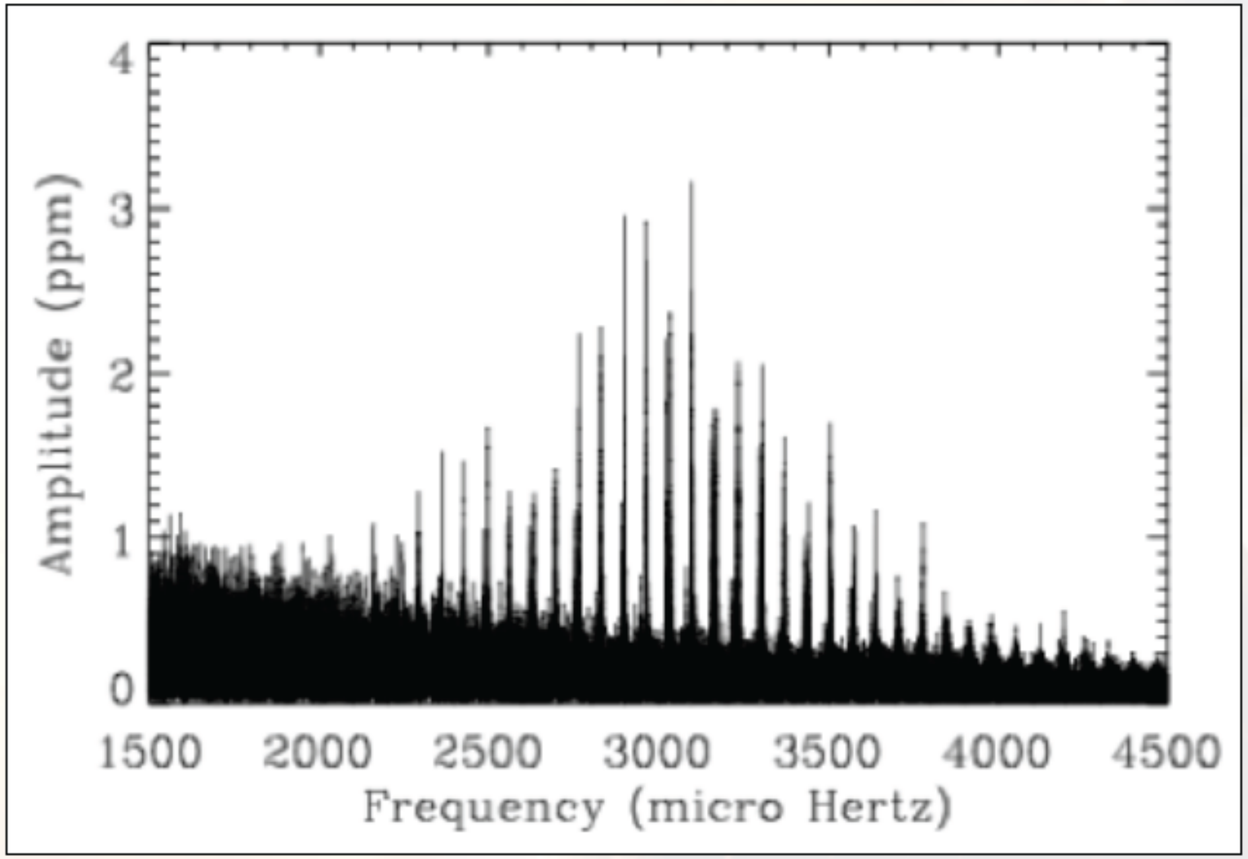
Fourier transform -> Frequency Spectrum



Oscillations driven by convection ("solar-like" oscillations) typically show a very rich spectrum of frequencies

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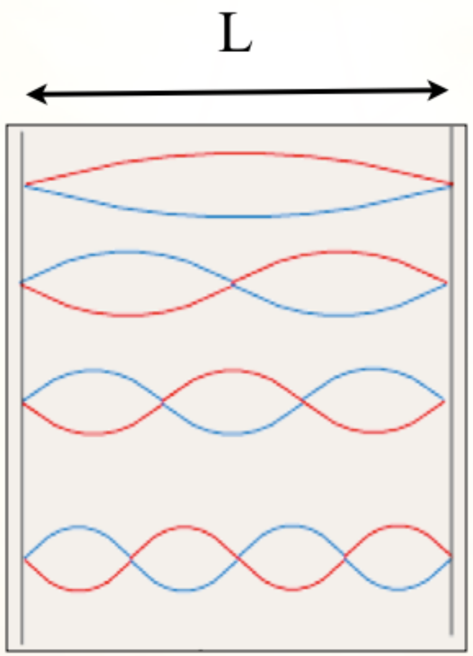
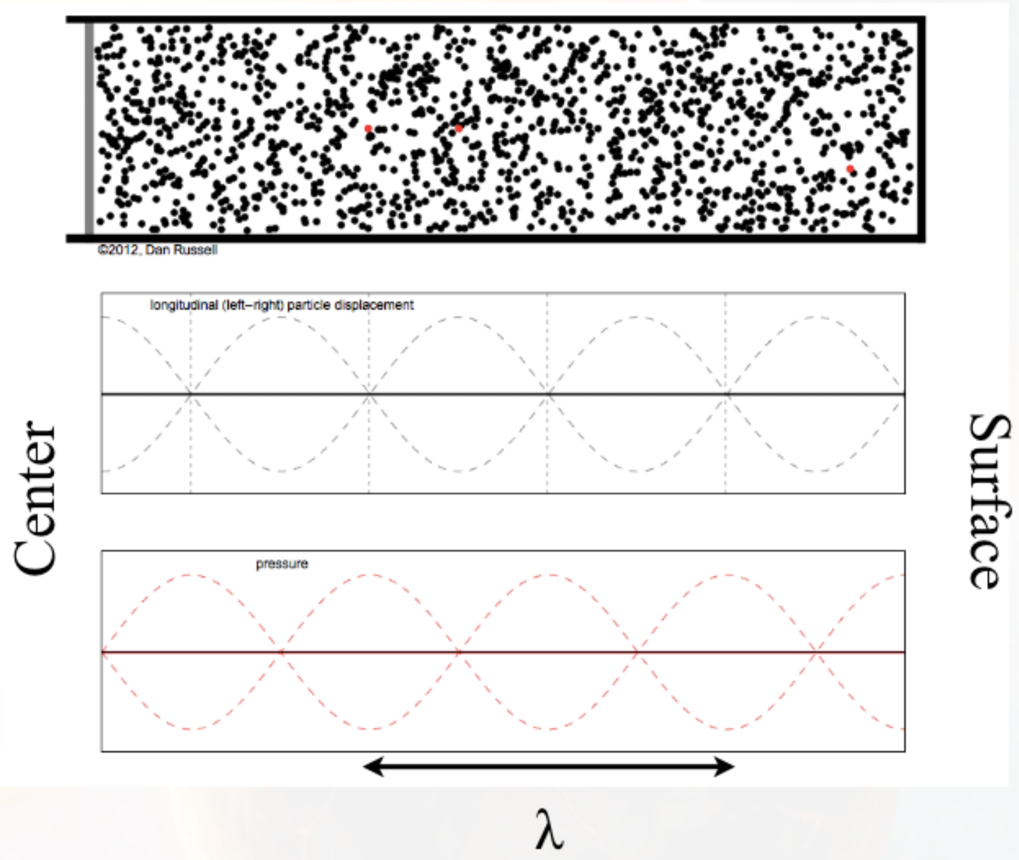
Oscillations are Standing Sound Waves





$L = n\,\lambda/2$

$L\,k = n\,\pi$

n = number of node lines

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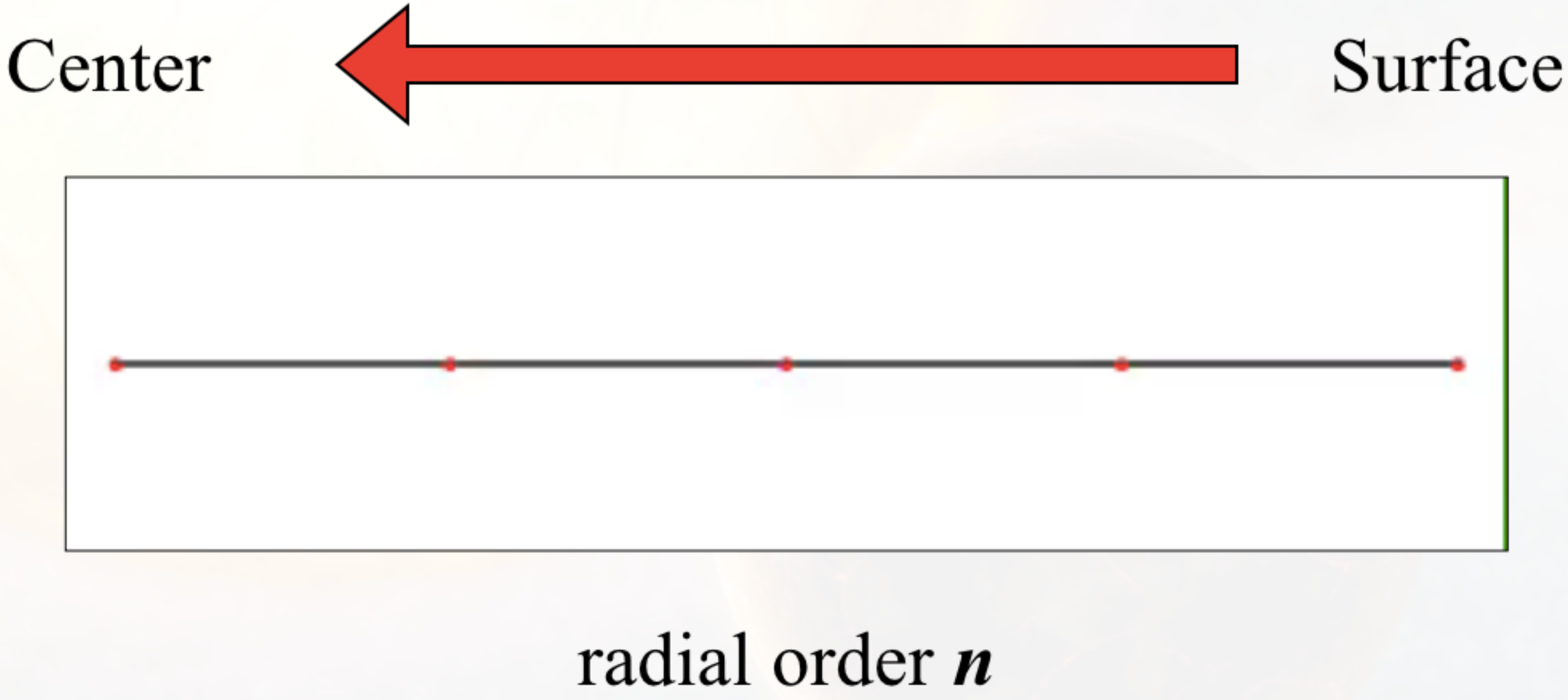
wavenumber $k = 2\pi/\lambda$.

Stellar Oscillations are Standing Sound Waves



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Size of cavity = stellar radius!

Dispersion relation

Applies when waves of different wavelengths have different velocities

- One example is propagation of light through glass
- Another is standing waves in a star

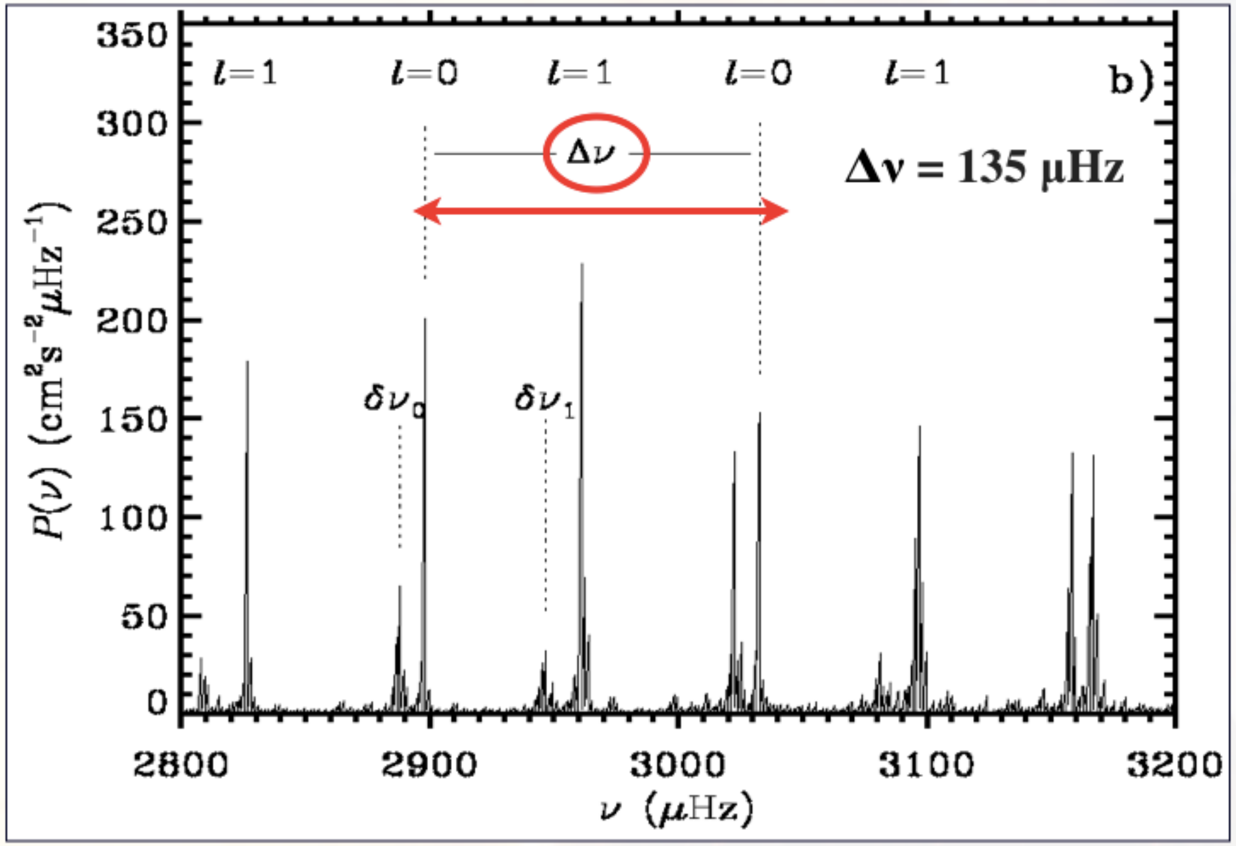
Frequency f related to angular frequency $\omega = 2\pi f$

dispersion relation: $\omega = c\, k$

sound speed = wavelength x frequency

$L\, k = n\, \pi \longrightarrow \omega = n\, \pi\, c\, /\, L$

Relates frequency, sound speed, radius



$$\Delta \mathbf{v} = (2 \int dr/c_s)^{-1}$$

$(\omega = n\, \pi\, c\, /\, L!)$

Integrate 1/(sound speed) through the star

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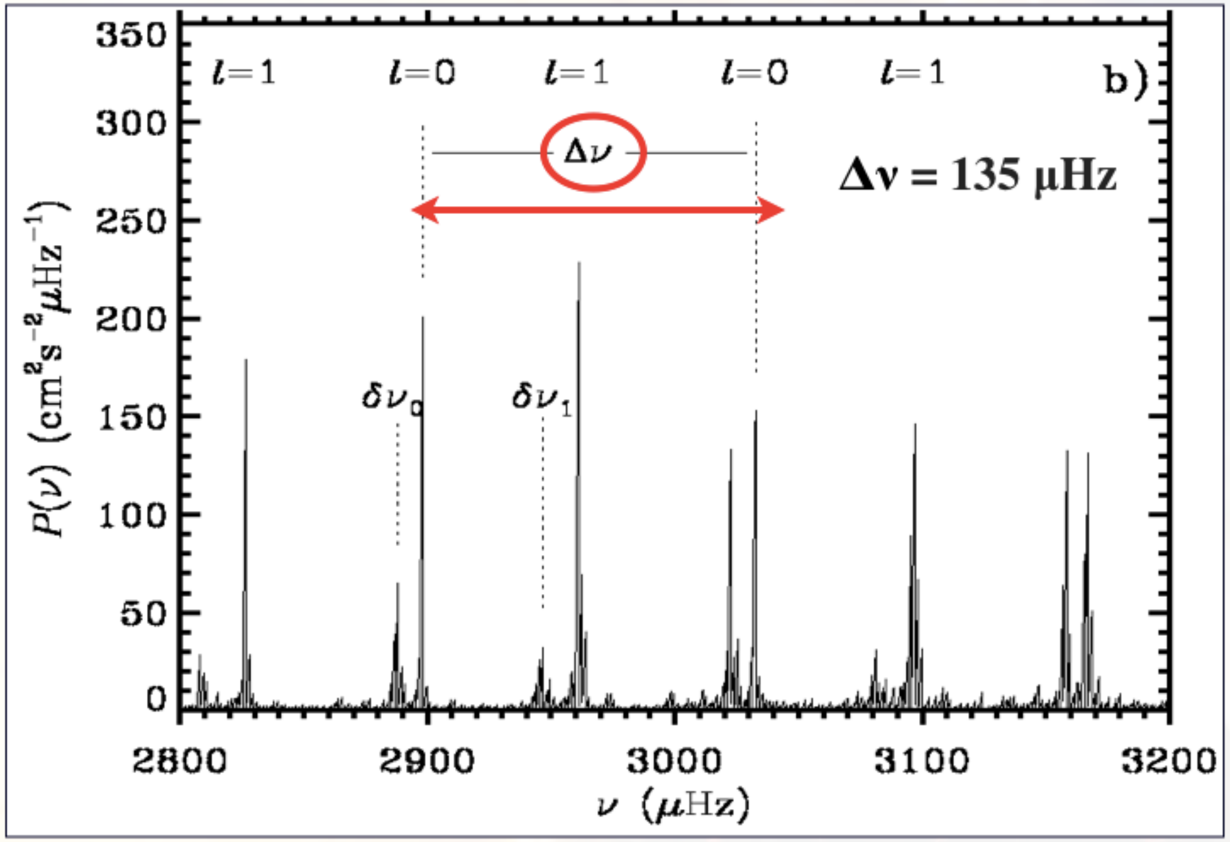

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sound speed c

$$c \propto \sqrt{T/\mu}\,.$$

$$T \propto \mu M/R$$

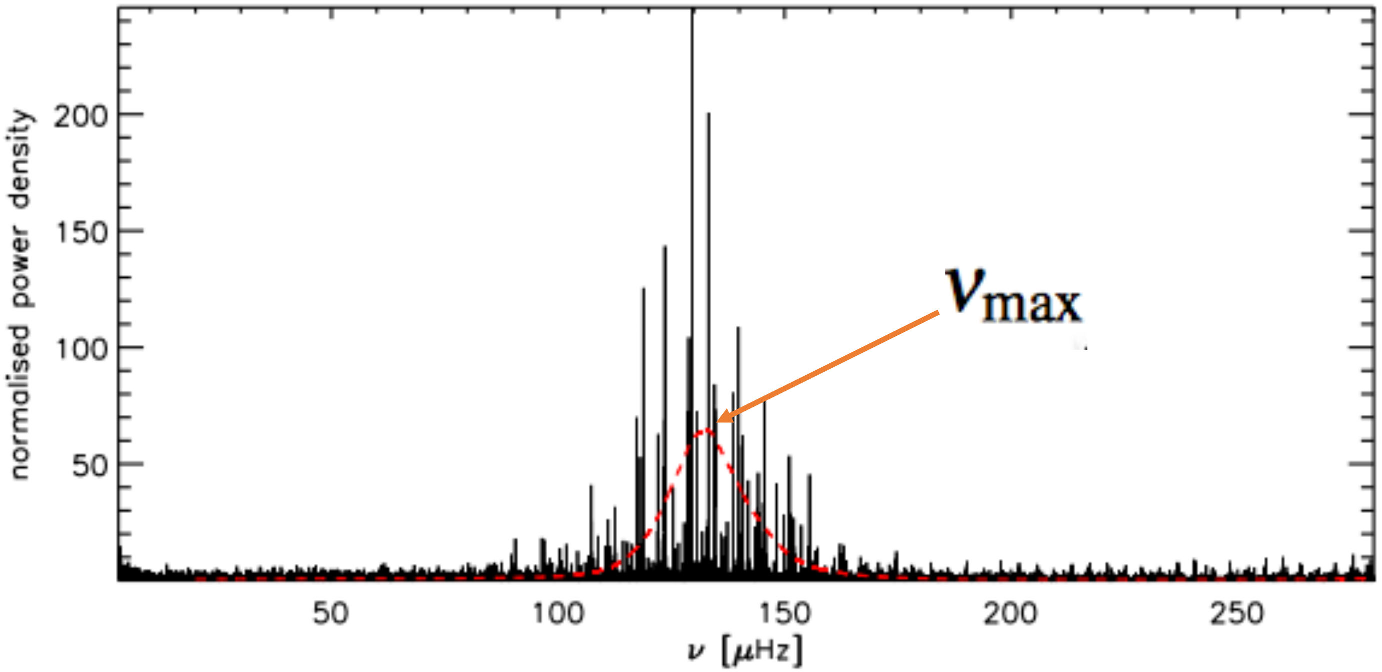
$$\Delta\nu = (2 \int dr/c_s)^{-1} \propto (M/R^3)^{1/2}$$

$(\omega = n\,\pi\,c\,/\,L!)$

The (average) frequency difference between modes of the same spherical degree and consecutive radial orders is a direct measure of the mean density of a star

Asteroseismology gives a direct measure of stellar mean density

Measuring log g



Hekker 2017

$$\nu_{max} \propto \frac{g}{\sqrt{T_{eff}}} \propto \frac{M}{R^2\sqrt{T_{eff}}}$$

If we can measure Teff, we can obtain log g, mass

Stellar radius from frequency data

$$\Delta\nu \propto \left(\frac{M}{R^3}\right)^{1/2}, \quad (1)$$

$$\nu_{\max} \propto \frac{M}{R^2\sqrt{T_{\text{eff}}}}. \quad (2)$$

Equations (1) and (2) can be rearranged to calculate radius as follows:

$$\frac{R}{R_\odot} \approx \left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right)\left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-2}\left(\frac{T_{\text{eff}}}{T_{\text{eff},\odot}}\right)^{1/2}. \quad (3)$$

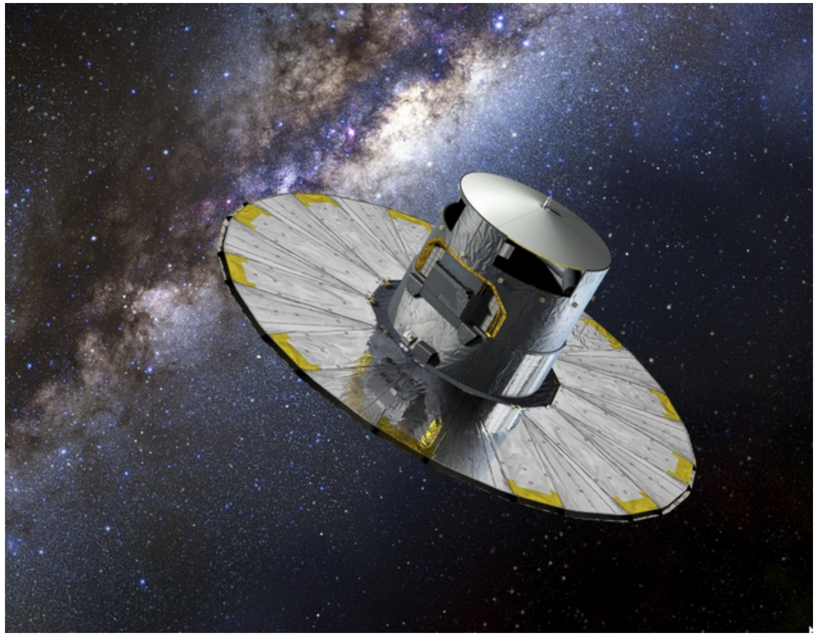
Huber et al 2017

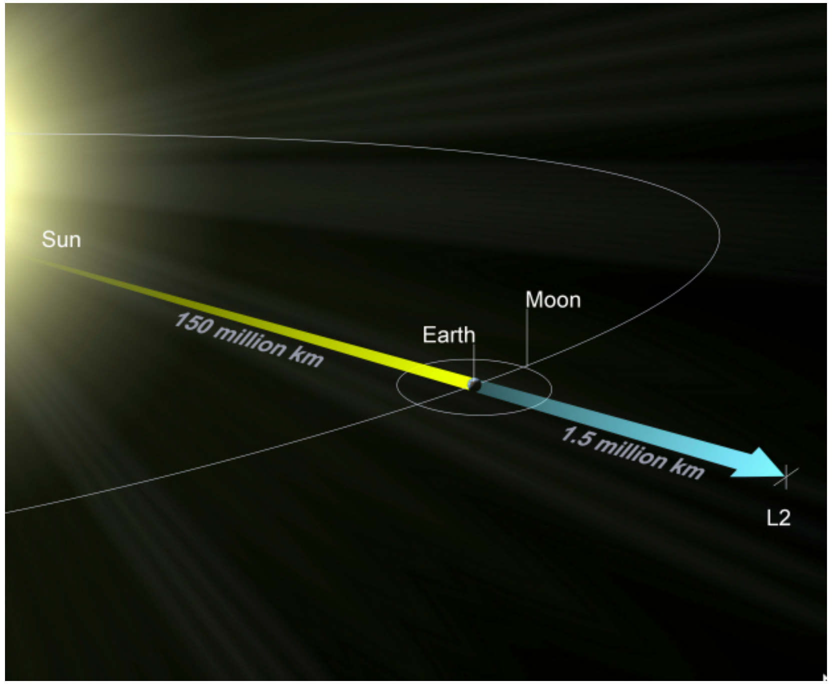
Asteroseismology summary

- Frequencies of Fourier spectrum of oscillations give stellar mean density and radius directly
- With the addition of Teff, we can also obtain log g and stellar mass

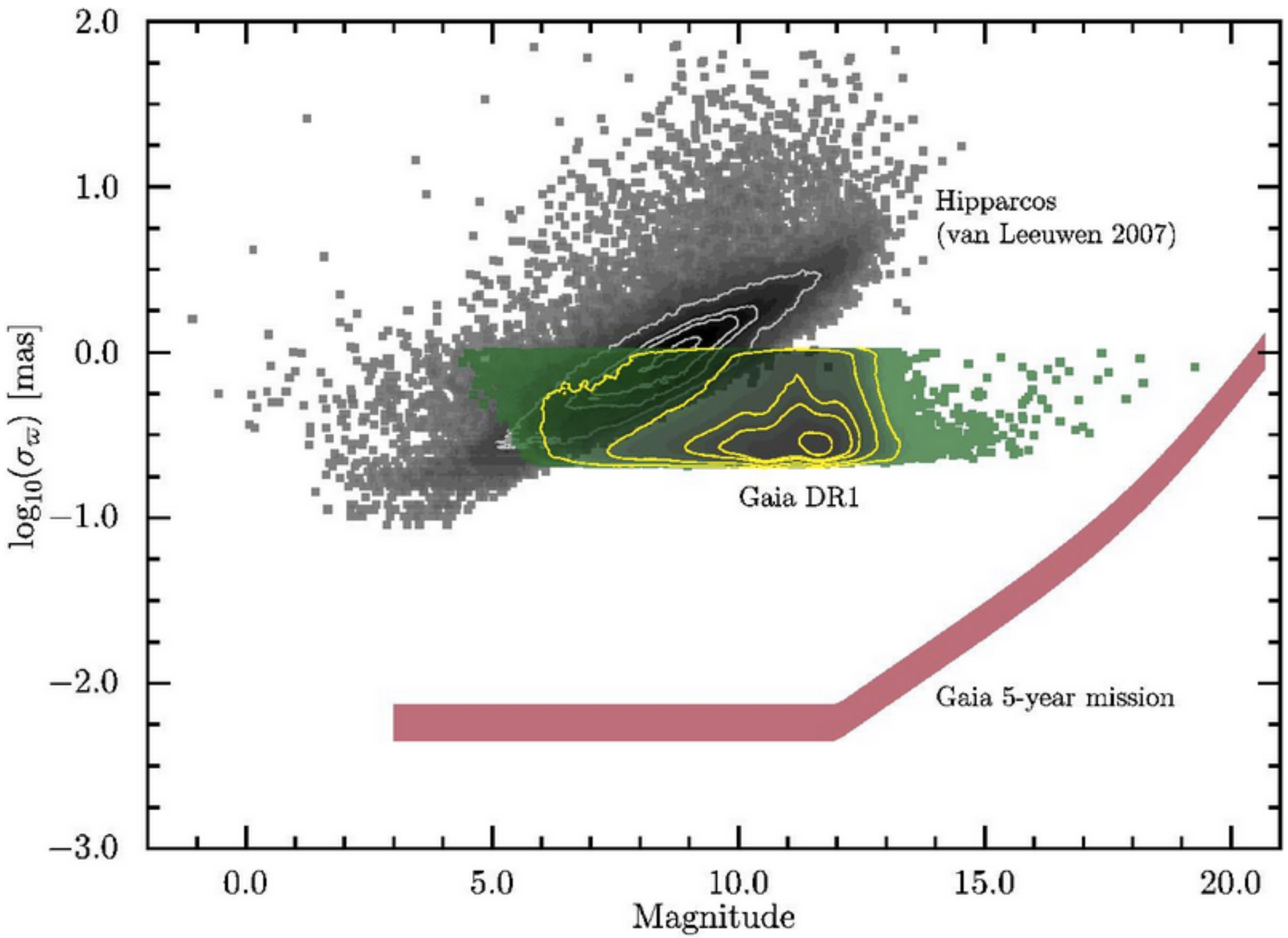
Gaia satellite

- Launched Dec 2013
- Orbits L2 (second Lagrange point, dynamically stable, no Earth occultation)
- Gaia Data Release 1(DR1), including TGAS (astrometric solution including proper motions derived from Tycho and DR1 positions) released 2016
- DR2 expected April 2018



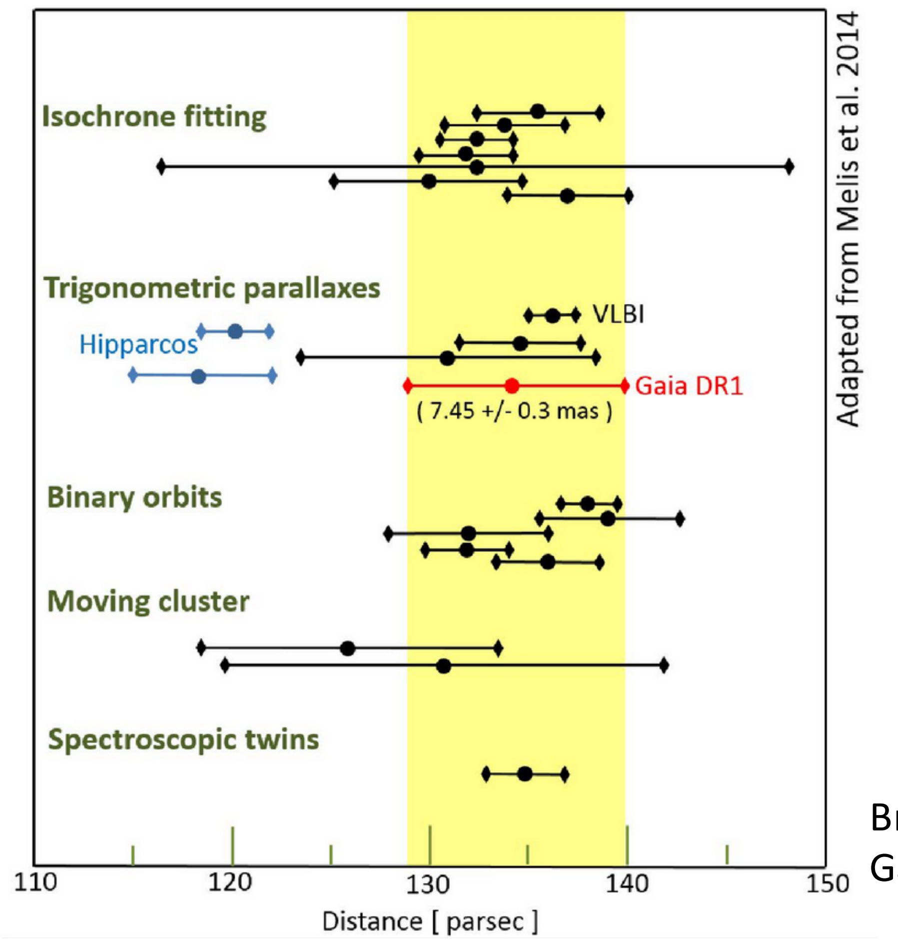


Gaia precision



Gaia DR1 paper 2016 – TGAS errors of order .3 mas

Hipparcos had geometric distortions in reference frame … much less with Gaia



Brown et al 17, Gaia DR1

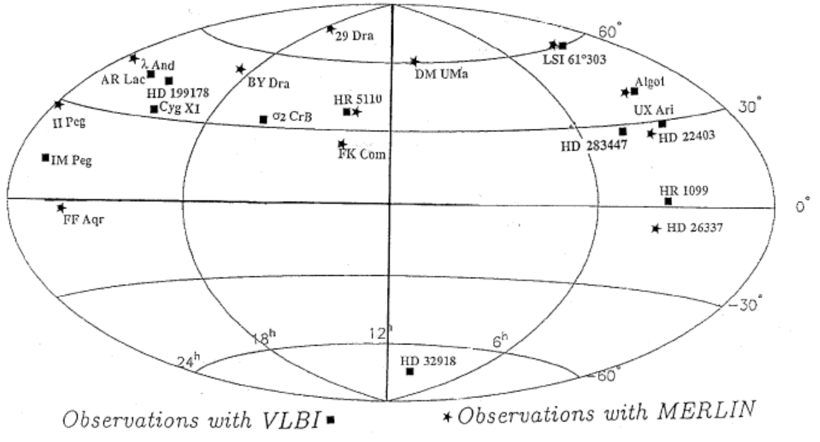


Fig. 2. Sky distribution of radio stars used for the link by VLBI (squares) and MERLIN (asterisks)

Kovalevsky et al 97

Hipparcos linked to accurate radio VLBI reference frame using only 12 radio stars! Gaia has 295 “defining” compact radio sources to tie it into the VLBI frame

THE ASTROPHYSICAL JOURNAL

Asteroseismology and *Gaia*: Testing Scaling Relations Using 2200 *Kepler* Stars with TGAS Parallaxes

Daniel Huber[1,2,3,4], Joel Zinn[5], Mathias Bojsen-Hansen[4], Marc Pinsonneault[5], Christian Sahlholdt[4], Aldo Serenelli[6], Victor Silva Aguirre[4], Keivan Stassun[7,8], Dennis Stello[9,2,4], Jamie Tayar[5]

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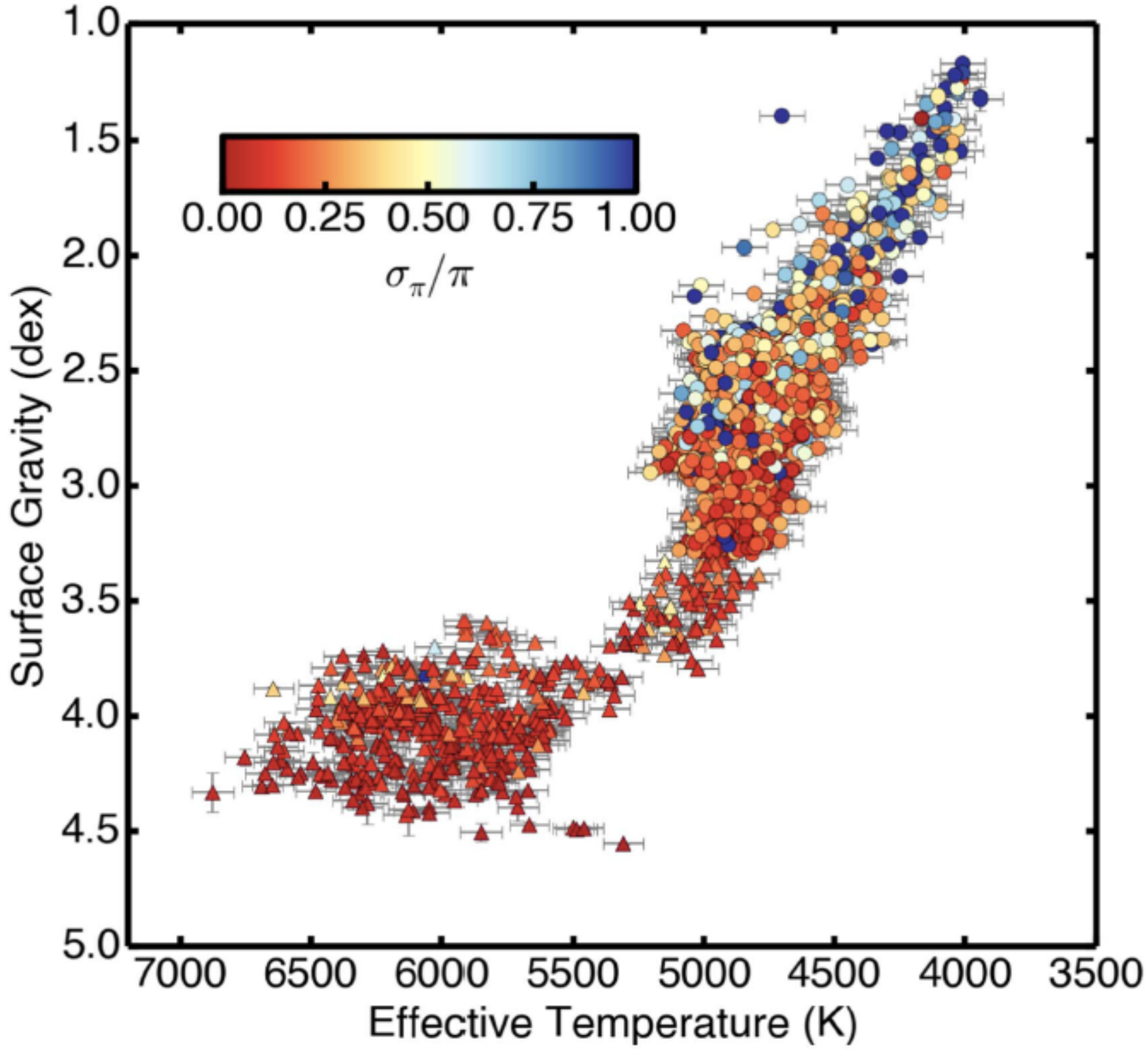


Figure 1. Surface gravity vs. effective temperature for ≈1800 red giants and ≈440 dwarfs and subgiants with TGAS parallaxes and detected oscillations

Radius and logg from Kepler Asteroseismic satellite

Spectroscopic Teff and [Fe/H] from SDSS APOGEE

griz photometry
2MASS JHKs

Parallax from asteroseismology?

Radius from asteroseismology

Teff from high-res spectra -> L

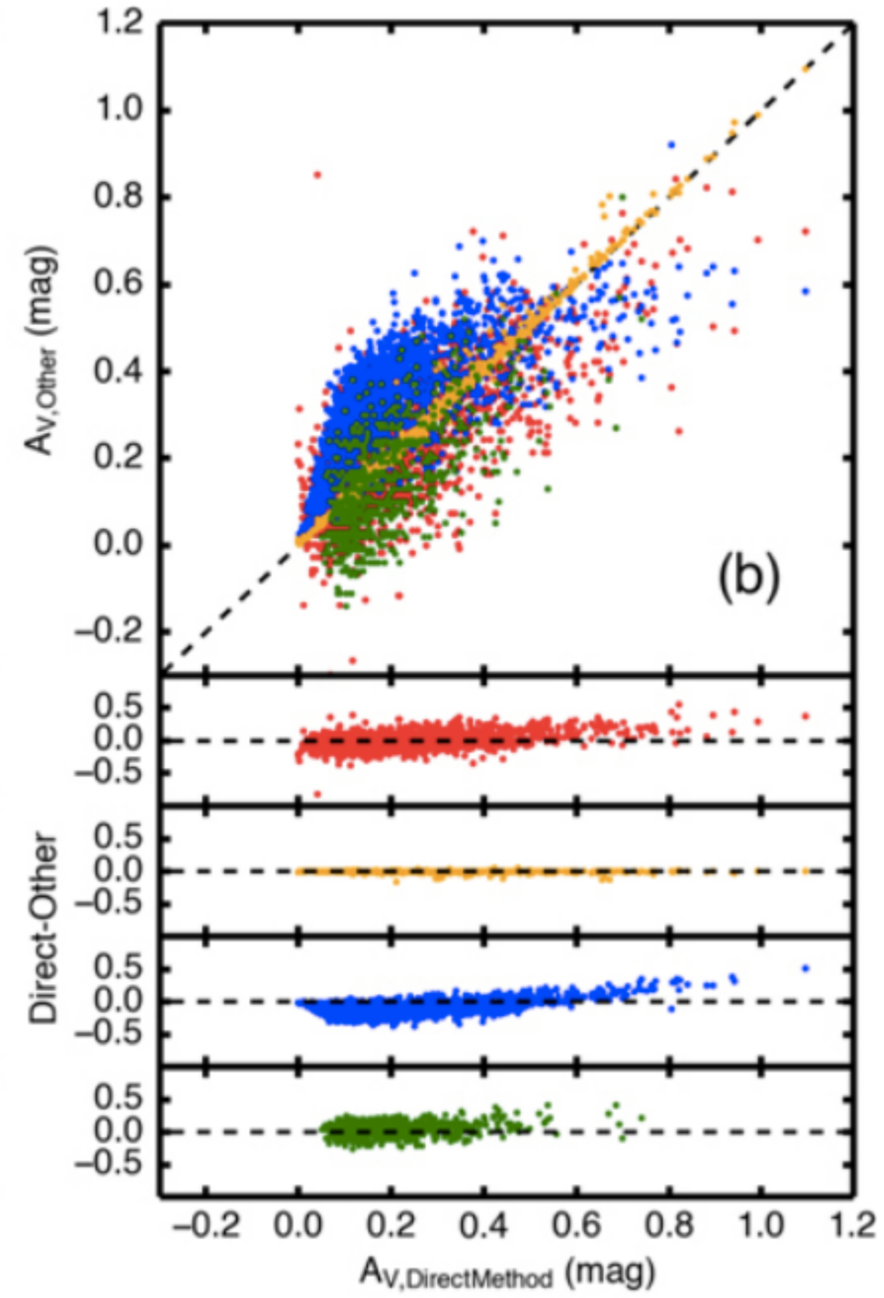
Bolometric correction from models using Teff, logg, [Fe/H],Av

L and BC give Mv, then use m-M=5 log d – 5 + Av

Radius from Gaia?

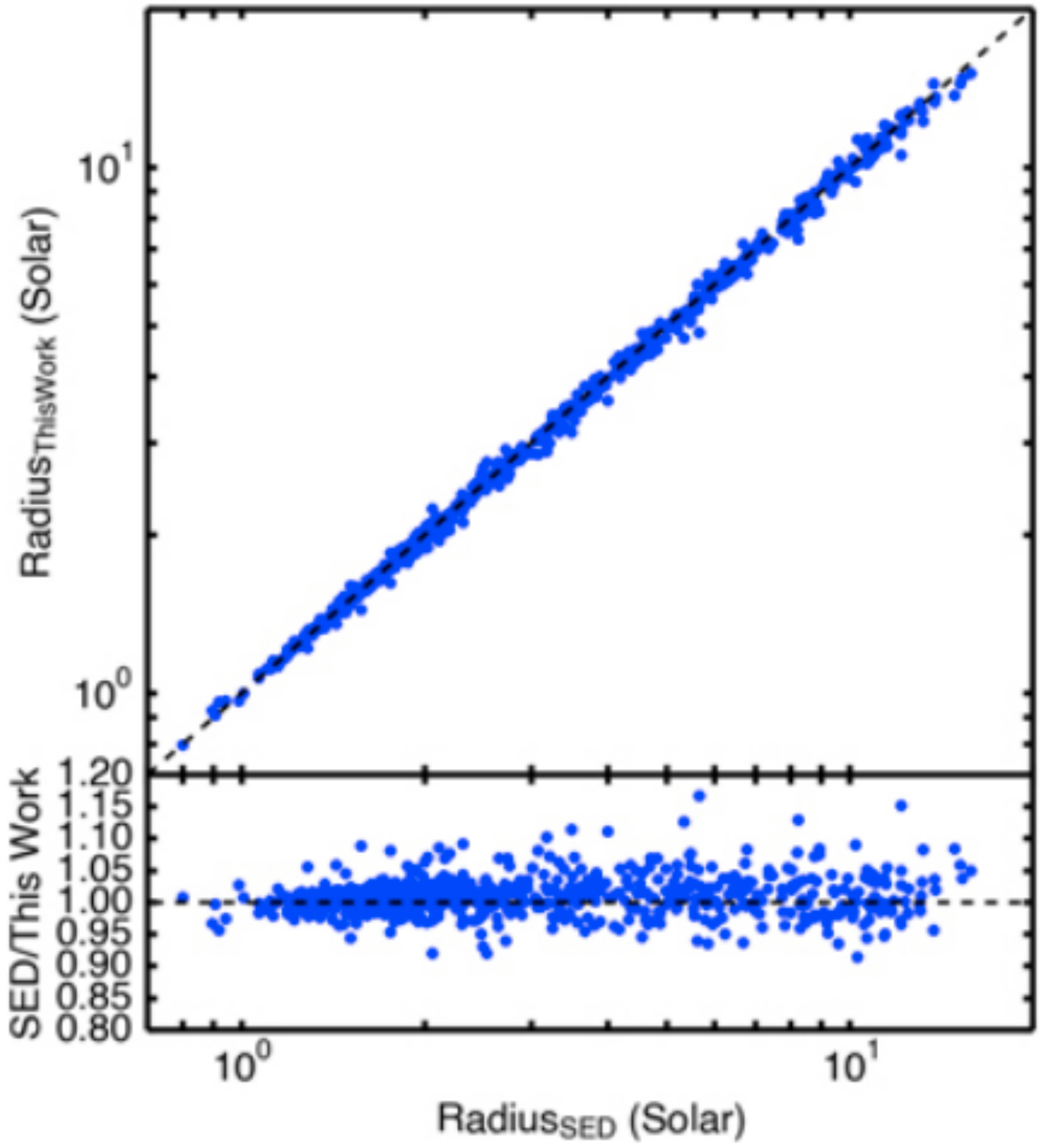
- Bayesian distances from 1/parallax
- Then do calculation in reverse

- OR estimate reddening using isochrones and synthetic photometry in *griz,* JHKs, compare with actual values of magnitudes/colors



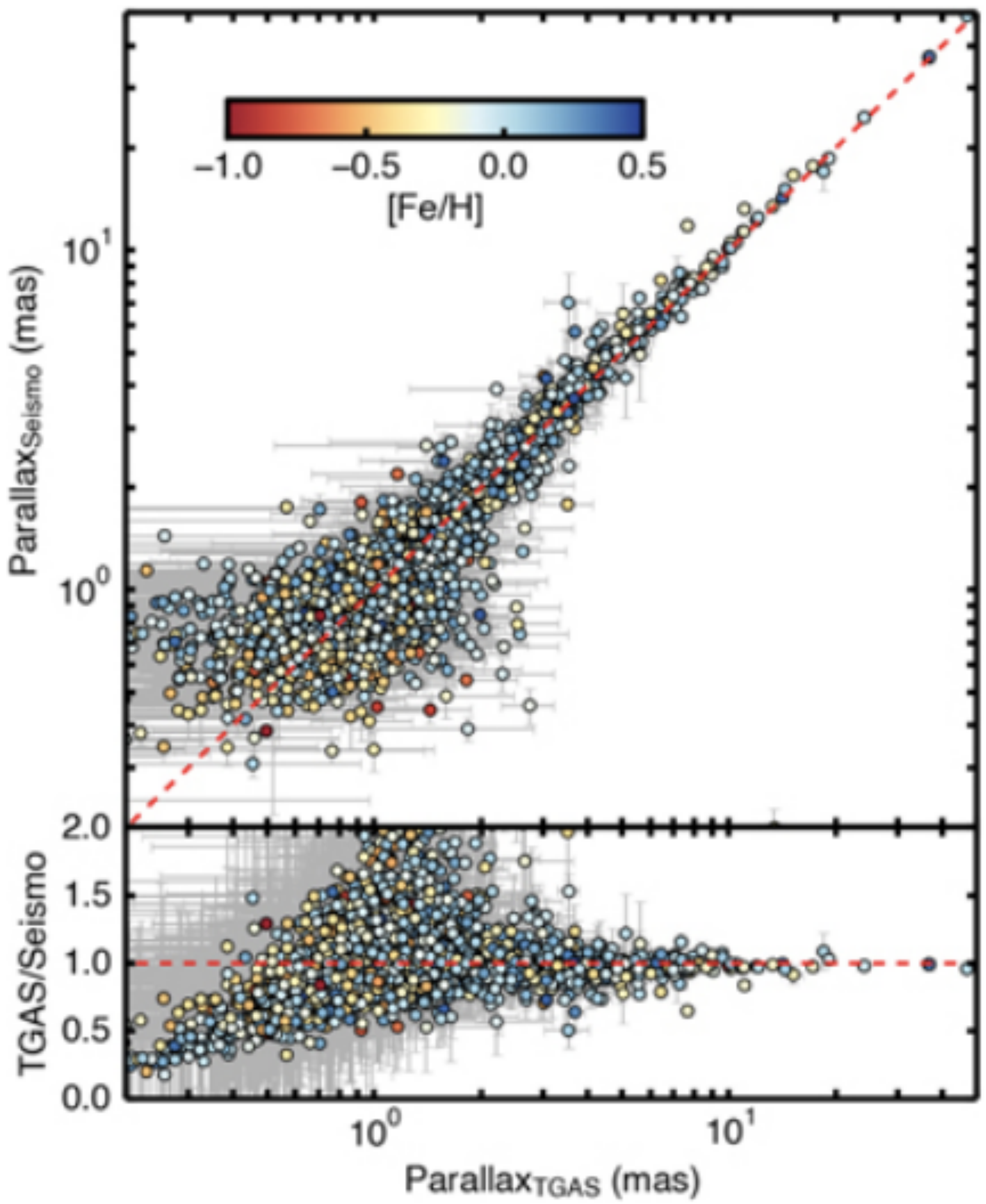
Extinction estimate from 3D model incl Schlafly correction

Note that these are small…..



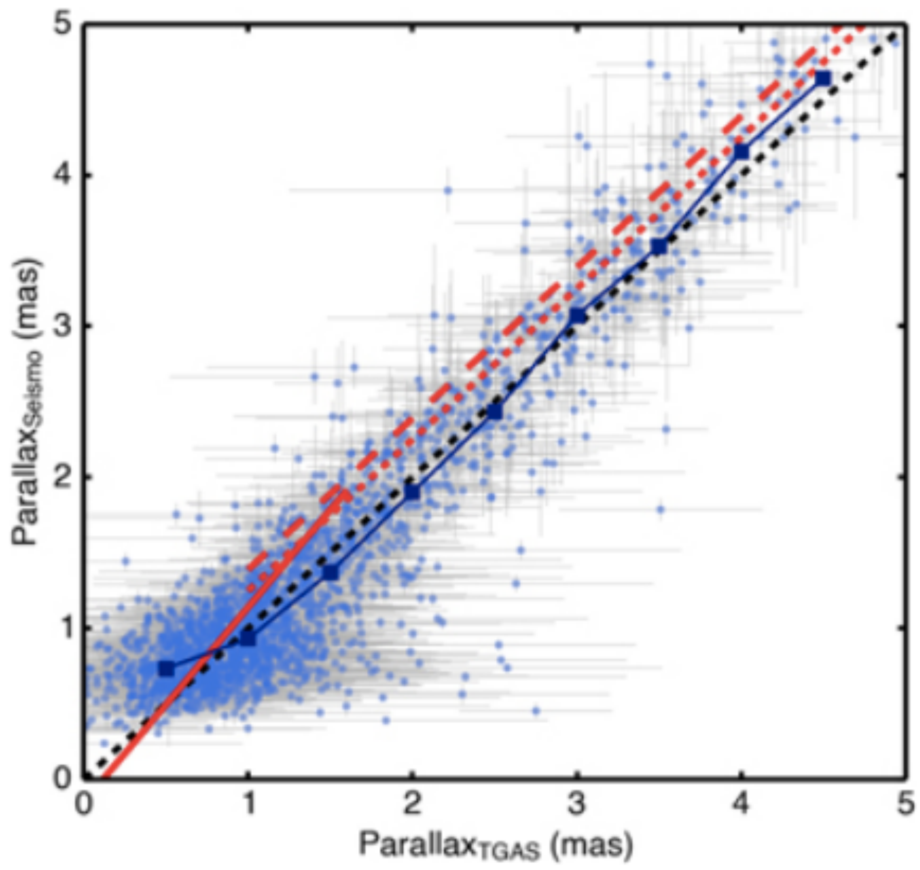
Test BCs using two methods

Systematic errors due to BCs
<1%



Gaia parallaxes vs Seismology derived ones

Asteroseismic-derived parallaxes are a little larger



Zoom In Zoom Out Reset image size

Figure 5. Asteroseismic vs. TGAS parallaxes for stars with $\pi < 5$ mas. The dashed black line shows the 1:1 relation. Light blue symbols are individual stars, while thick dark blue squares show median bins spaced by 0.5 mas. The red dashed and dotted lines show the predicted offsets from the TGAS parallax corrections by Stassun & Torres (2016b) with and without ecliptic latitude dependence,

Eclipsing binary result not supported (red dashes or dots)

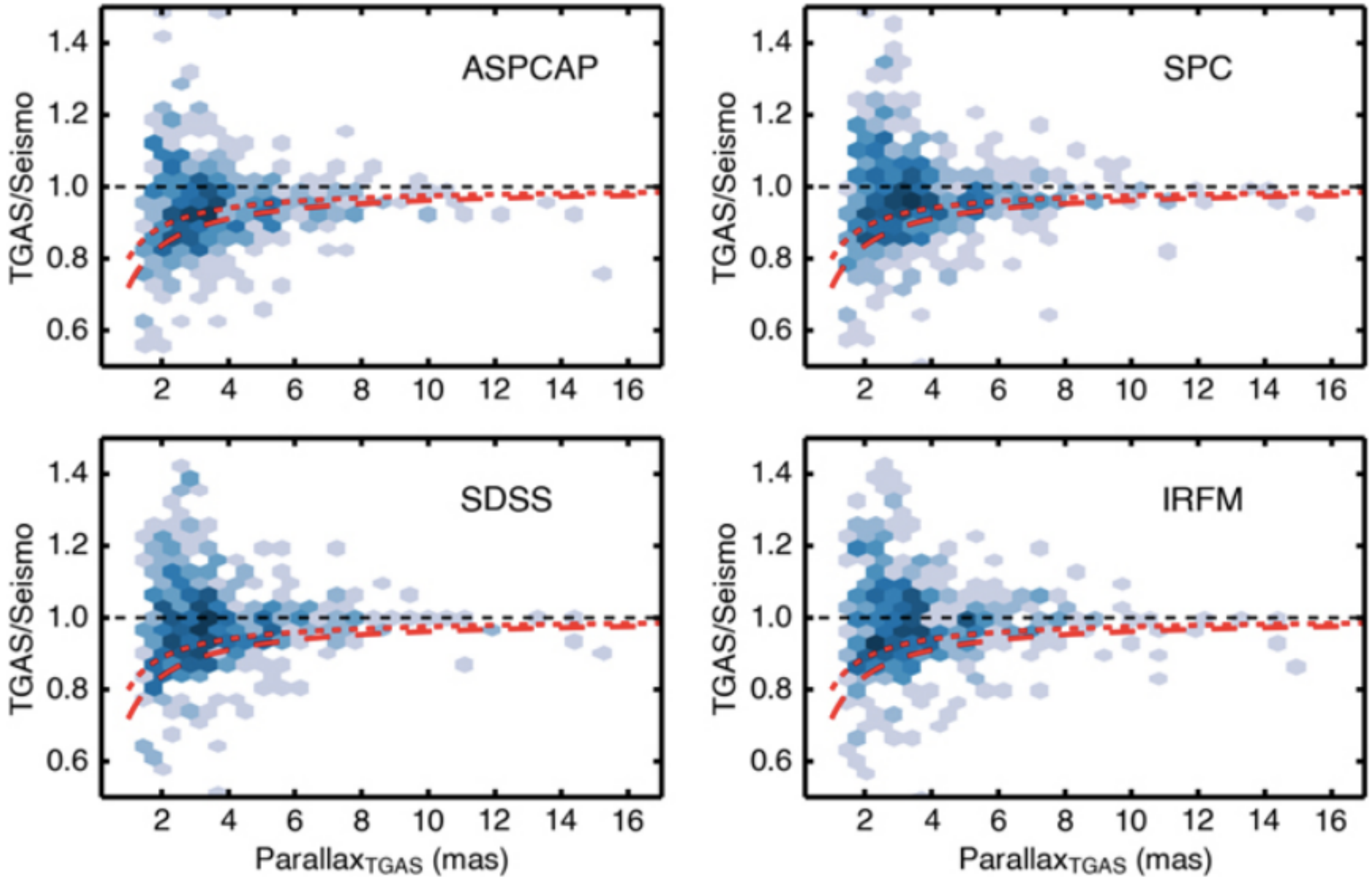
Strongest offset for large parallax (dwarfs)

Check out Teff : distances scale as Teff^2.5

Can derive Teff using spectroscopic methods (done here) OR photometric.

In particular, the InfraRed Flux Method (IRFM) is a photometric method which is well tied to fundamental physics but has an offset of order 100K from spectroscopic temperatures

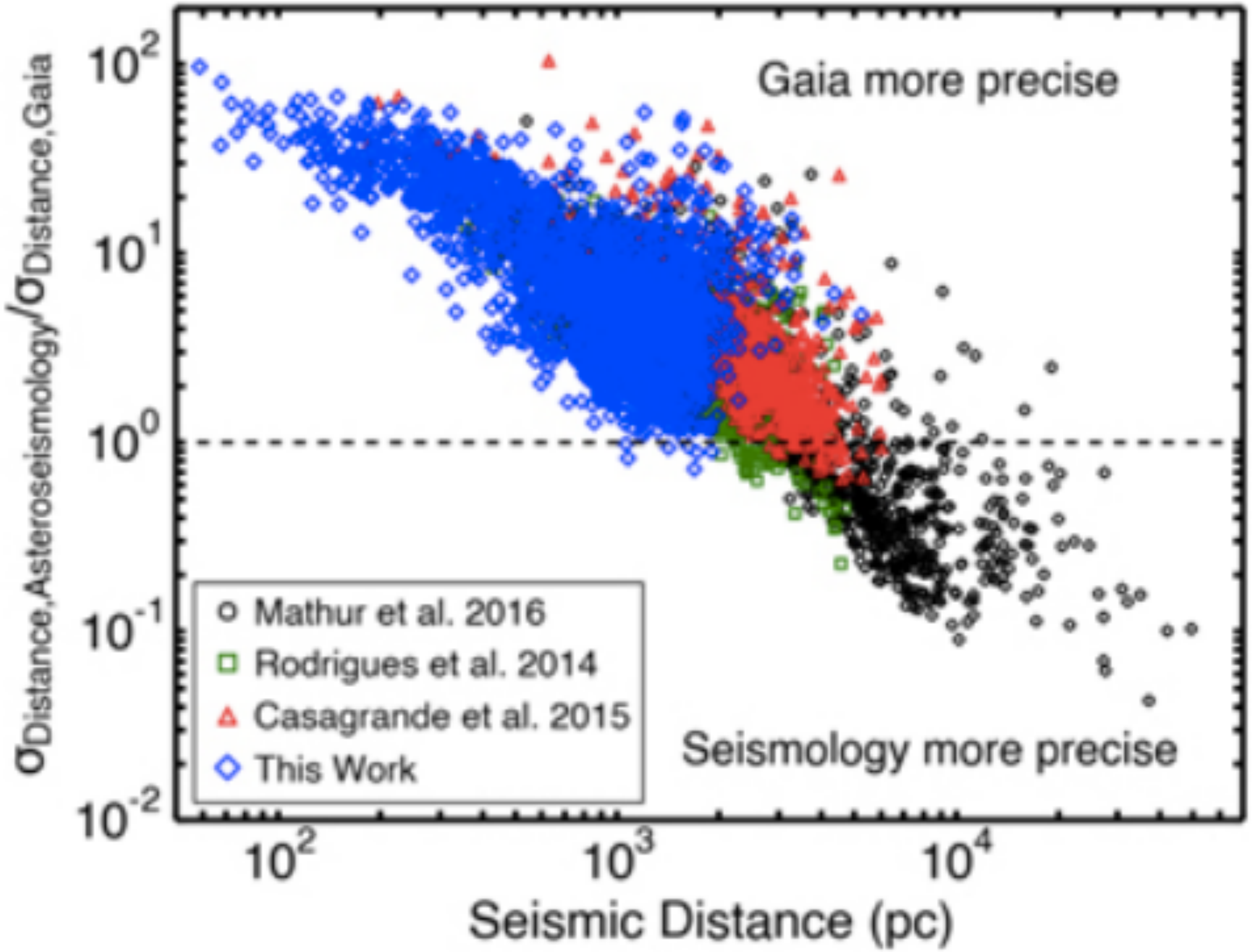
Redid asteroseismic parallax estimates using different temperature scale, for (more discrepant) dwarfs and subgiants only



Hotter Teff scale (IRFM) reduces difference between parallaxes to 2%

"Asteroseismic and TGAS distances agree within a few percent over several orders of magnitude"

The future: asteroseismic distances better than Gaia's end-of-mission ones for d>3 kpc



Summary

Gaia's TGAS parallaxes are pretty darn good … comparison with independently estimated asteroseismic parallaxes show differences at only a few percent

At the end of the Gaia mission, asteroseismic distances for red giants will still be more precise than Gaia parallaxes.