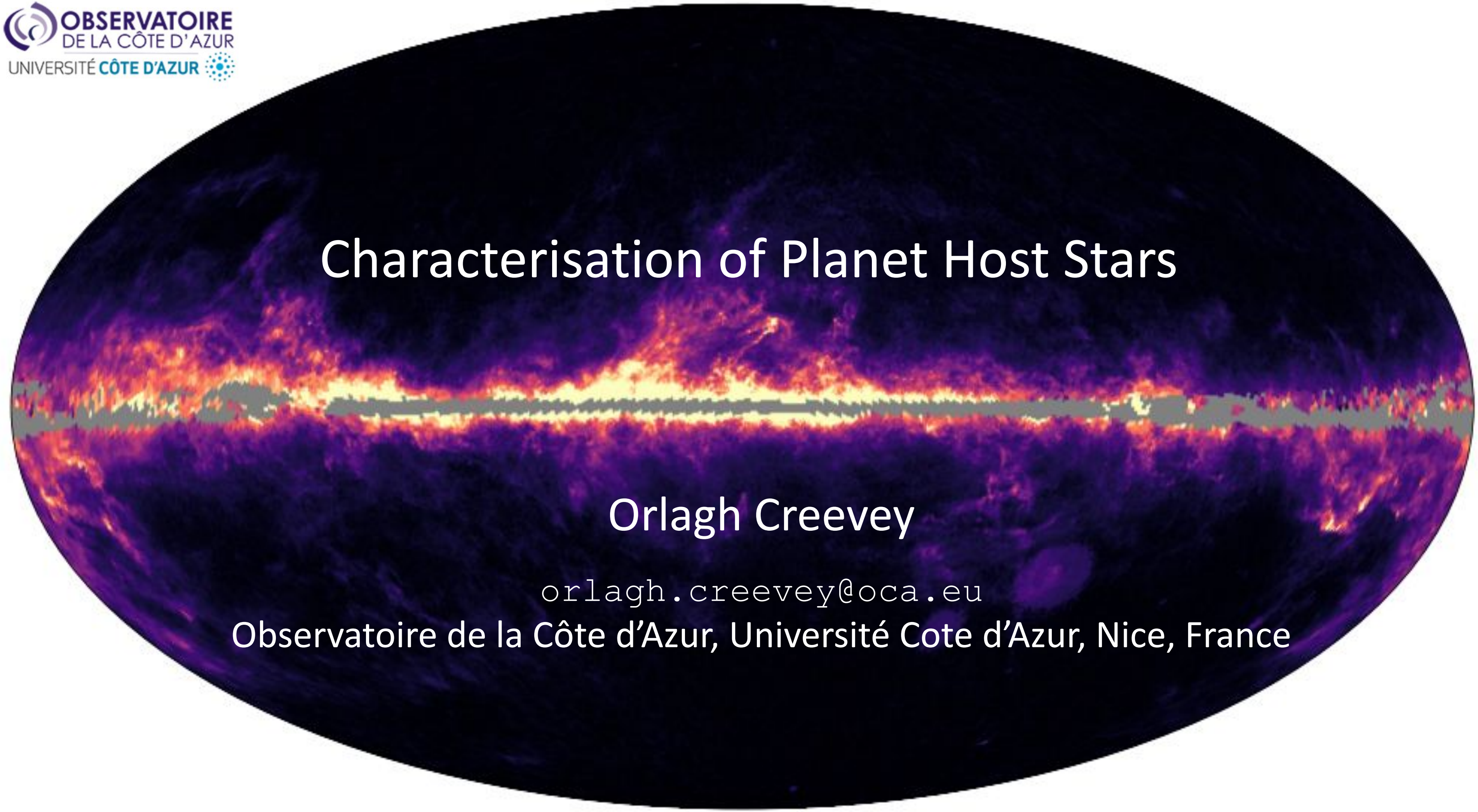

Characterisation of Planet Host Stars

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Outline

- Introduction (15)
  - Why we care
  - What is an observation and what is an inferred parameter
  - What are important stellar parameters and what are the measurements
- Classical determinations of each Individual parameter (30 mins)
- Asteroseismology (15)
- Exploiting Gaia DR3 (20)

Introduction: question to students

- What do we mean by characterisation of host stars?
- Why should you care about it?

Why (I think you should) care about stellar parameters for exoplanets

- Mass, radius, and effective temperature (Teff) of the planet host dictate the size and density of the planet, and amount of irradiation the planet receives (“too hot, too cold, just right”).
- Age:
  - Can we explain the known exoplanets distribution given our current knowledge of solar system evolution?
  - Has the system evolved long enough to be able to sustain life, and what kind of life? Is it like our Solar System?

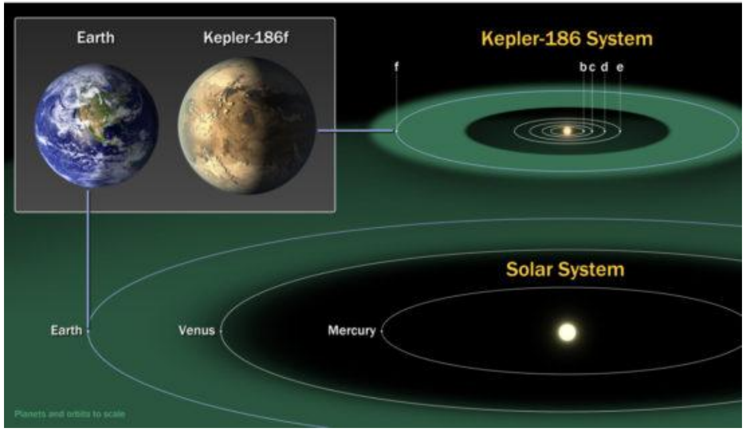

Image credit: NASA

Image credit: NASA/JPL-Caltech/Lizbeth B. De La Torre; adapted by O. Creevey

In particular for studies of atmospheres

- Teff, logg, [M/H], XYZ are fundamental stellar parameters and when the star+planet are observed together, one must understand how to remove the "stellar contamination"
- How fast does it spin? This affects the spectral lines
- what about magnetic storms / flares ? This affects habitability and ability to extract information
- What if the star has activity cycles? Are we sure to extract only the planet component? And how important can activity be to properly account for it?
- Is it a binary? The spectra will be contaminated.
- What about the affect of tides and winds?

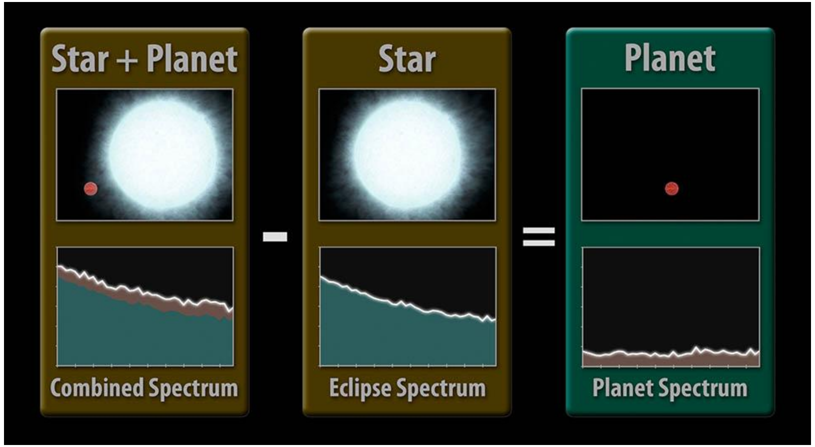

Image credit: NASA/JPL-Caltech/R. Hurt (SSC/Caltech);

- All these are the types of questions we need to know to correctly characterise exoplanets. This talk provides a broad general introduction to deriving stellar parameters, see later talks today and tomorrow for more details on some of the topics mentioned above.

What is a fundamental stellar parameter and what can we observe?

- Fundamental stellar parameter: ?
- Observation: … ?

What is a fundamental stellar parameter and what can we observe?

- Fundamental stellar parameter:
  - Radius
  - Luminosity
  - Effective temperature
  - surface gravity
  - chemical composition
  - Mass
  - Density
  - Age
  - rotation
- Observation:
  - Magnitudes
  - Colours
  - Luminosity class
  - Spectral type
  - Rotation period
  - Activity level
  - Binarity ….

What is a fundamental stellar parameter and what can we observe?

- Fundamental stellar parameter:
  - Radius, R
  - Luminosity, L
  - Effective temperature, T_{eff}
  - surface gravity, g
  - chemical composition
  - Mass, M
  - Density, ρ
  - Age
  - rotation
- Observation:
  - Magnitudes
  - Colours
  - Luminosity class
  - Spectral type
  - Rotation period
  - Activity level
  - Binarity ….

$$g \propto M/R^2$$

$$\rho \propto M/R^3$$

$$L \propto R^2/T_{\rm eff}^4$$

What is an observation and what is an inferred physical quantity?

- A true observation is a measurement of something
  - Amount of light, colours of stars, position on the sky, spectrum of star, light variations over time, interferometric visibilities
  - If we measure it over and over again we can define a "measurement error"
- Some quantities can be extracted directly from the measurements
  - radial velocities, oscillation frequencies, distances, orbits, rotation periods, chromospheric excess
- Inferred physical quantities use an assumption or a model along with the measurements
  - Teff
    - an observed spectrum and models of a stellar atmosphere
    - an interferometric diameter and bolometric flux fit
  - Age
    - any available measurements and stellar evolution models
    - members of clusters and use of isochrones

- In general, for most single stars, Teff, radius, mass, age are often <u>inferred quantities</u> and so we must <u>consider the assumptions in the model and account for this in our interpretation and estimation of uncertainties</u>

To derive stellar parameters accurately we need other things

- Fundamental Params: Radius, teff, logg, chemical composition, density, luminosity, mass, age, rotation
- Fundamental non-stellar params: Eccentricities, inclinations, distances, interstellar medium
- “Secondary Parameters”: Activity, limb-darkening, tides, winds, see later talks

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- Exploiting Gaia DR3 (20)

Spectral energy distribution

- The radiance of a star across different wavelengths (spectral distribution) depends on its temperature

- We can use the Planck Blackbody radiation law to describe this distribution

$$B_\nu(T) = \frac{2h\nu^3}{c^2}\frac{1}{e^{\frac{h\nu}{kT}} - 1}$$

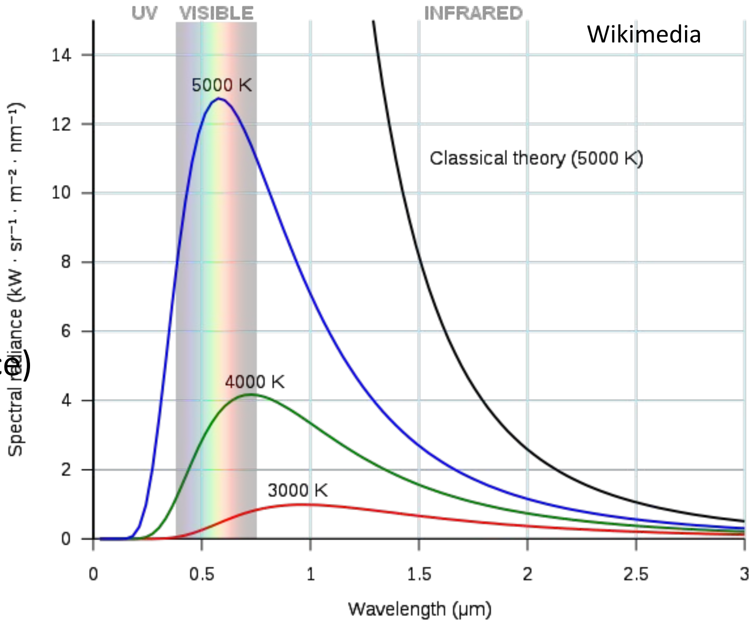
- In units of wavelength (λ) this is

$$B_\lambda = -B_\nu \frac{d\nu}{d\lambda} = \frac{c}{\lambda^2} B_\nu = \frac{2hc^2}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda kT}} - 1}$$

  - T = temperature, h = Planck's constant,
  - c = speed of light, k = Boltzmann constant,
  - ν = frequency

- Three main points to notice:
  - peak intensity wavelength (see also Wien's Law)
  - amount of radiation (higher temperature, more radiance)
  - spectral distribution shape (more peaky or flatter)

- This energy is the amount emitted at the surface per second (luminosity) but the stars are at different distances so the flux received on Earth depends on the distance



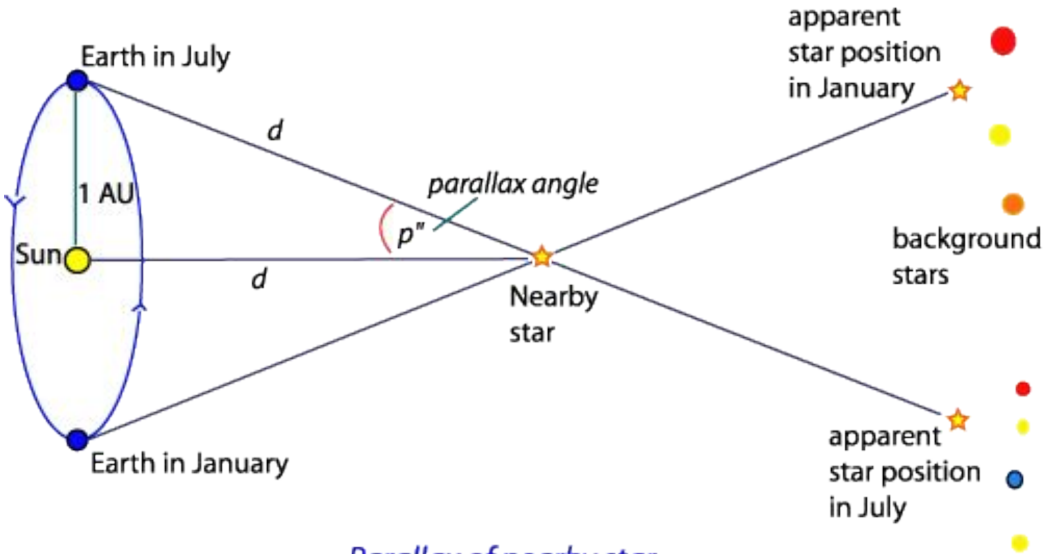
Wikimedia

Impact of distance and interstellar medium

Distances

- Hipparcos, Gaia, HST (most relevant for exoplanets)
- Photo-Geometric etc… (e.g. Bailer-Jones et al. 2018)
- Cepheids …

Credit: https://physics.stackexchange.com/questions/286309/how-is-the-parallax-angle-actually-measured



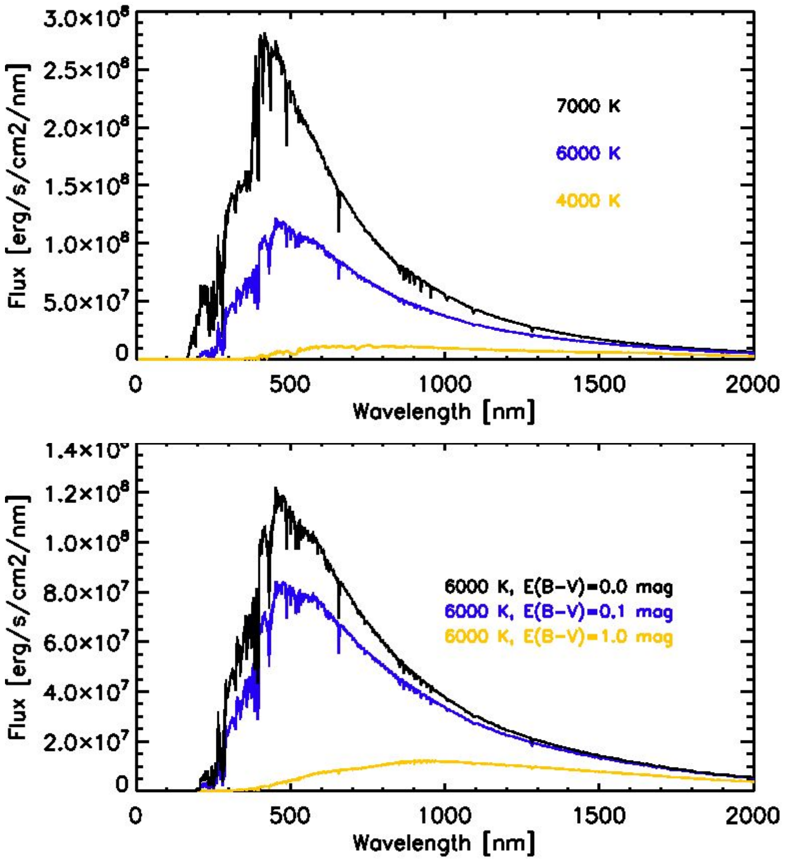
Parallax of nearby star

- Be careful distance (pc) = 1 / parallax (arcsec); uncertainties!
- See https://www.youtube.com/watch?v=KynOQRd5oLs

Interstellar medium

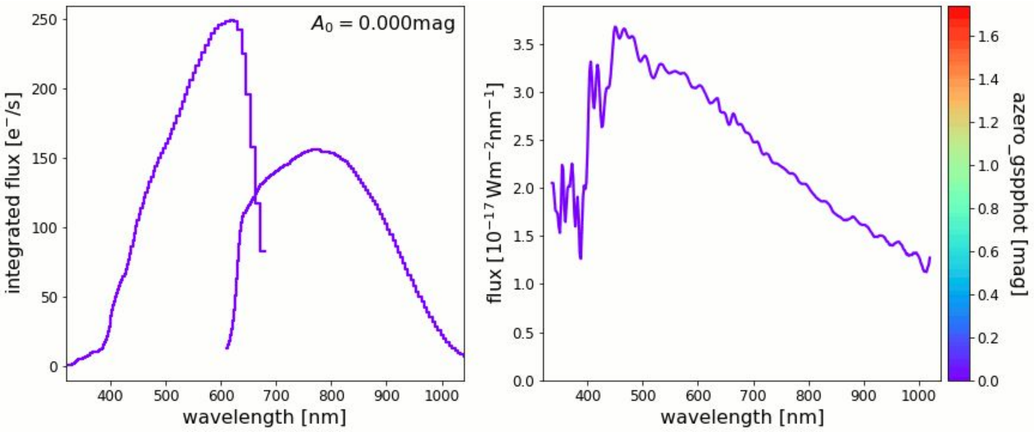
- Spectral energy distribution depends on Teff
- Amount received at Earth depends on distance
- The gas and dust between us and the star attenuate the light received from the star.
    - The star will appear dimmer
    - We call this extinction Aλ
    - Blue light is affected more than red light so the spectral shape will change
    - We also call it interstellar absorption or ‘reddening’
    - A_{BP} - A_{RP} = E(BP-RP) ‘reddening’ or E(B-V) measured in magnitudes
- Now we must consider
    - Teff
    - Distance
    - extinction

Figure produced by O. Creevey



GDR3 results from BP/RP spectra: effect of extinction

- By selecting ‘identical’ stars but with different amounts of extinction, we can investigate the impact of the dust on the spectral distribution
- The following are a selection of solar analogues i.e. similar Teff, log g, radius, mass to the Sun, with different values of extinction (left panel Gaia BP/RP spectra, right panel flux-calibrated BP/RP spectra)



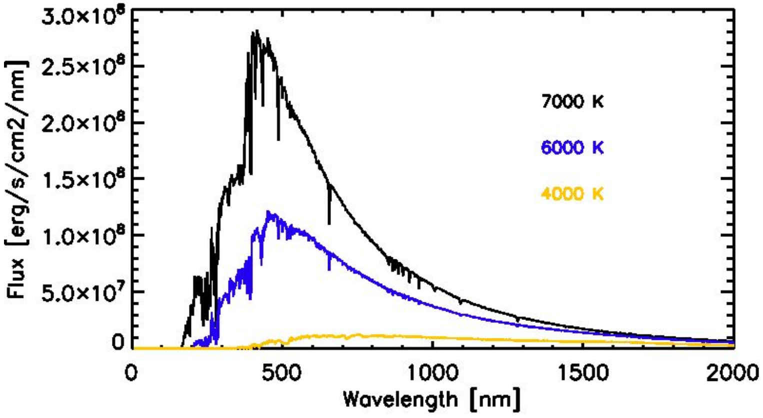
Gaia coll. Creevey et al. A&A 2022

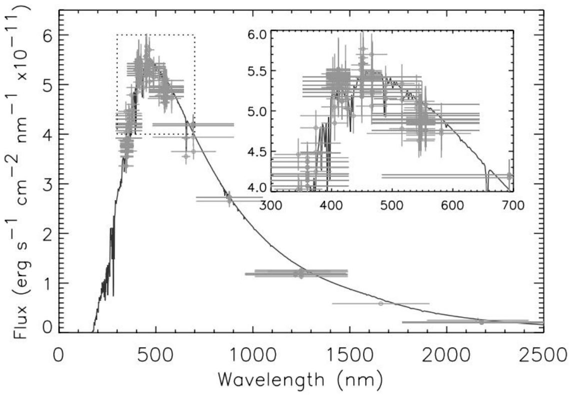
Luminosity

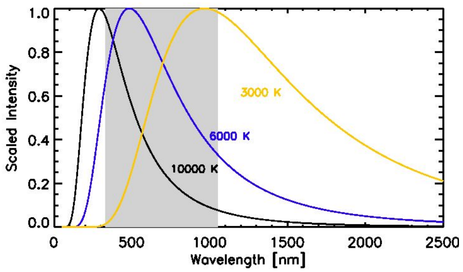
- Radiative power output (energy) of star (erg/s)
  - Integrate over stellar surface
  - Integrate over all wavelengths
  - Measure it at its surface

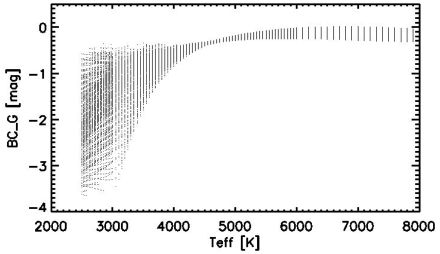
$$L_\star = 4\pi f_{\rm bol} d$$

- $f_{\rm bol}$ can be measured by
  - Collecting photometry and integrating (lower right)
    - careful with zeropoints and filters
    - using models to help integration
  - Measured magnitude and models of bolometric corrections (BC) – below the G magnitude and BCs
- Luminosity can have significant systematic errors









Radius

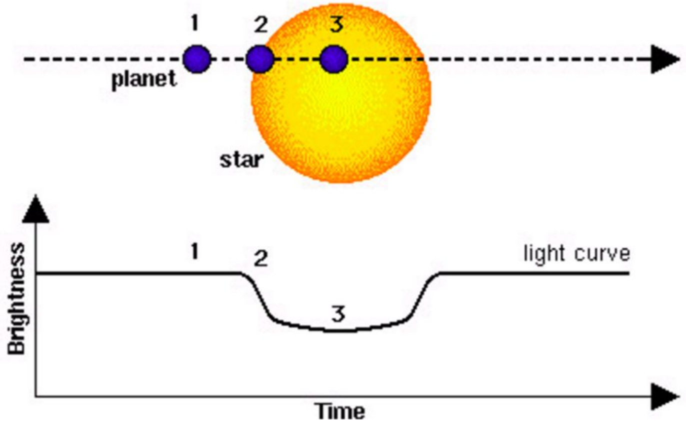
- Knowledge of the planet radius depends on the knowledge of the star radius where $d_{transit}$ = depth of the transit (we forget about the impact parameter for the moment)

$$d_{\text{transit}} = \left(\frac{R_{\text{planet}}}{R_{\text{star}}}\right)^2$$

- Rewriting R Rplanet on its own

$$R_{planet} = (d_{transit})^{0.5} \times R_{star}$$

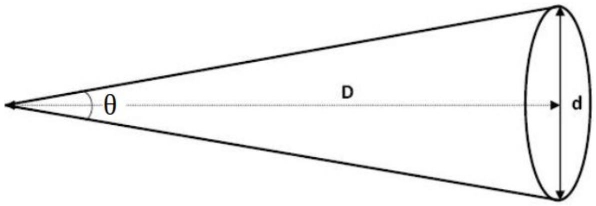
- 1% error on $R_{star} \longrightarrow$ > 1% error on R_{planet}
- 3% error on $R_{star} \longrightarrow$ > 3% error on R_{planet}



Radius

- The stellar angular diameter θ can be measured with interferometry

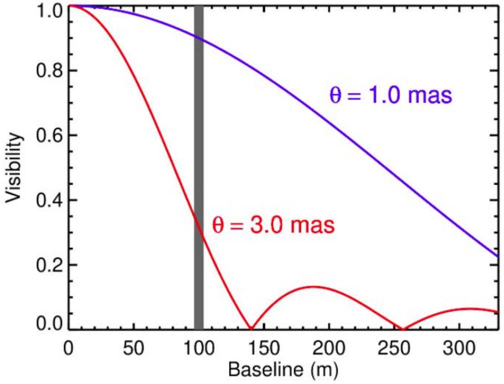
$$\theta = 2 \arcsin\left(\frac{d}{2D}\right)$$



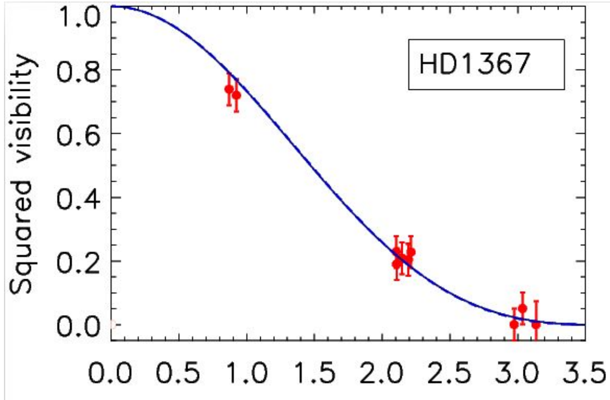
- where D = distance and d = diameter = 2*Rstar*
- But $\arcsin x \sim x \text{ for } D >> d$
- Need to convert radians to degrees, then arcsec
- Typically we use milliarcsec (1” = 1 arcsec = 1/3600 degrees)

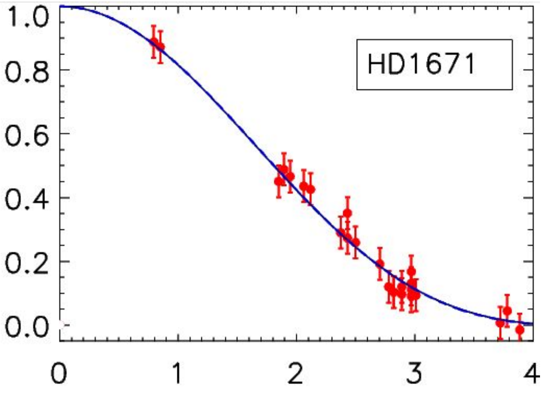
- What is the angular size of the Sun? What about the moon?
- Which star outside the solar system has the largest angular diameter?

- *Rstar* = θD/2 = θ / 2ϖ
- X% error on θ → >X% error on *Rstar*
- Careful, limb-darkening must be account for

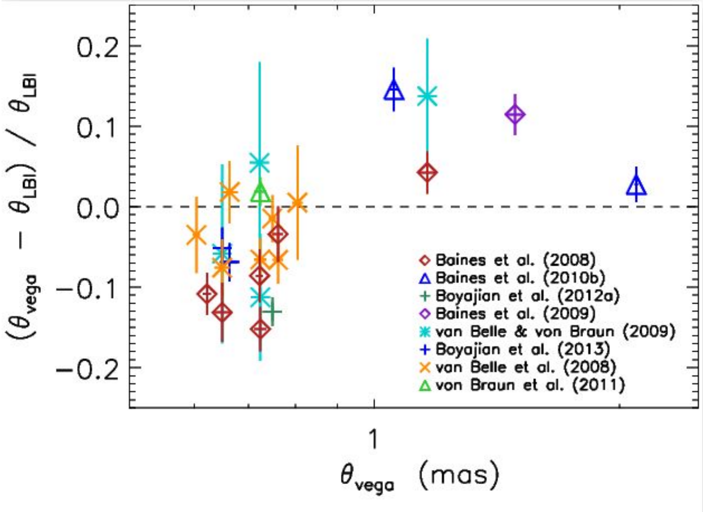


Radius





Ligi+2016 Properties of exoplanet host stars



Radius from other methods

- Stefan-Boltzmann Law
  - Needs L and Teff

$$R/R_\odot = \frac{\sqrt{L/L_\odot}}{(T_{\rm eff}/T_{\rm eff,\odot})^2}$$

- Using stellar evolution tracks and various observational constraints (Teff, Lum, + others)
  - The models will help to tighten the constraints even if only T, L and [M/H] are used (see later slide)

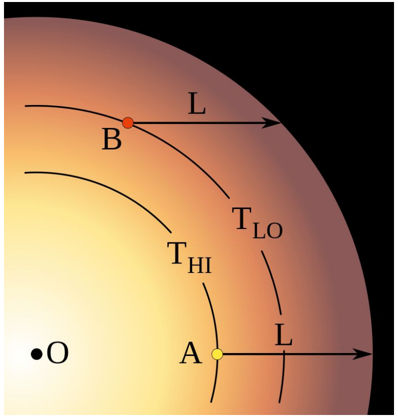
- Surface-brightness relations
  - Estimates the angular diameter θ from photometry and colours e.g. Salsi et al. 2021
  - Use distance along with estimated θ

$$\theta_{\rm LD} = 10^{8.4392-0.2V_0-2F_{V_0}}$$

$$\begin{array}{ll}
F_{V_0} = -0.1220_{\pm0.0006}(V-K)_0 + 3.9278_{\pm0.0016} & [1.80; 3.80] \\
F_{V_0} = -0.1374_{\pm0.0011}(V-K)_0 + 3.9581_{\pm0.0020} & [1.00; 3.30] \\
F_{V_0} = -0.1165_{\pm0.0012}(V-K)_0 + 3.9051_{\pm0.0055} & [3.70; 7.00] \\
F_{V_0} = -0.1240_{\pm0.0010}(V-K)_0 + 3.9148_{\pm0.0048} & [3.80; 7.50]
\end{array}$$

- Asteroseismology (see later slides)

Limb-darkening: an input or an observable in interferometric observations



– uniform disk:

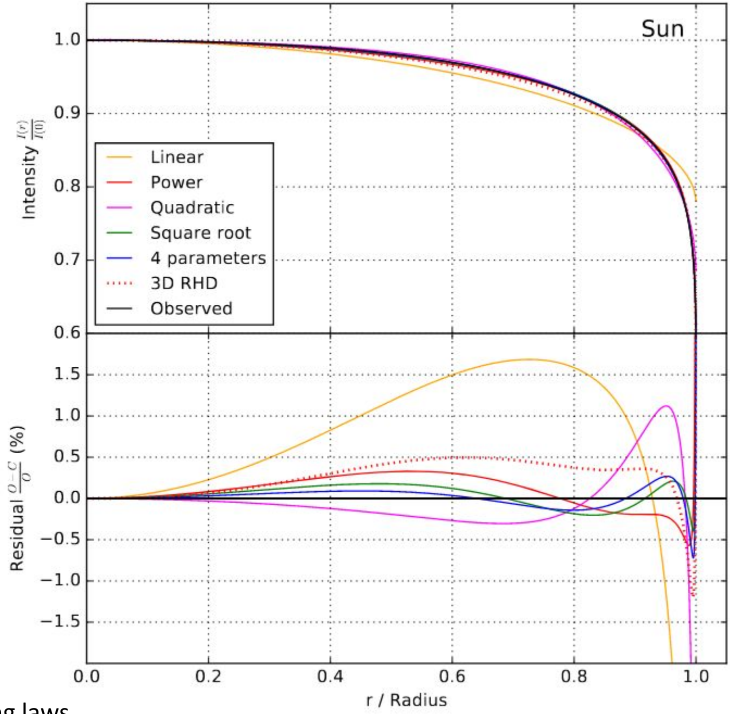
$$I(\mu)/I(1) = 1;$$

– linear:

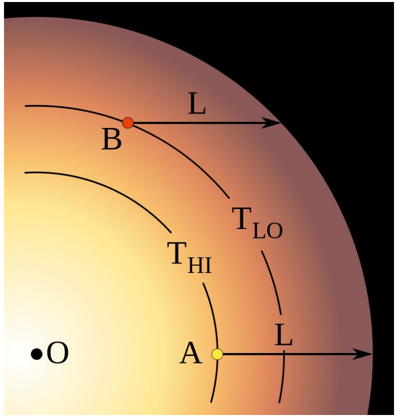
$$I(\mu)/I(1) = 1 - u\,(1 - \mu);$$

Two examples of simple limb-darkening laws

Kervella et al. 2016



Limb-darkening



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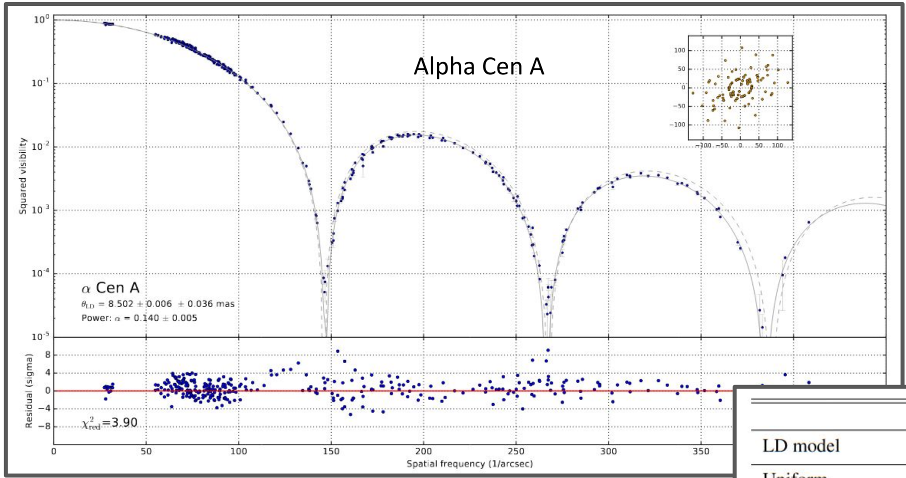


		α Cen A (G2V)	
LD model	LD parameters	$\theta_{LD}(A)$ [mas][a]	χ^2_{red}
Uniform	–	8.347 ± 0.004 ± 0.035	15.23
Linear (fixed)[b]	u = 0.2392 (fixed)	8.505 ± 0.003 ± 0.036	5.50
Linear (fit)	u = 0.1761 ± 0.0062	8.458 ± 0.005 ± 0.035	4.24
Quadratic	a = +0.191 ± 0.026 b = −0.031 ± 0.054	8.451 ± 0.013 ± 0.035	4.25
Square root	c = +0.29 ± 0.15 d = −0.19 ± 0.25	8.446 ± 0.017 ± 0.035	4.24
4 param. (fixed)[c]	a_1 = +0.7127 a_2 = −0.0452 a_3 = −0.2643 a_4 = +0.1311	8.540 ± 0.003 ± 0.036	4.98
3D	–	8.534 ± 0.003 ± 0.036	4.85
Power	α = 0.1404 ± 0.0050	8.502 ± 0.006 ± 0.036	3.90
Scaled solar	s_0 = 0.716 ± 0.042	8.498 ± 0.007 ± 0.036	4.38

– uniform disk:

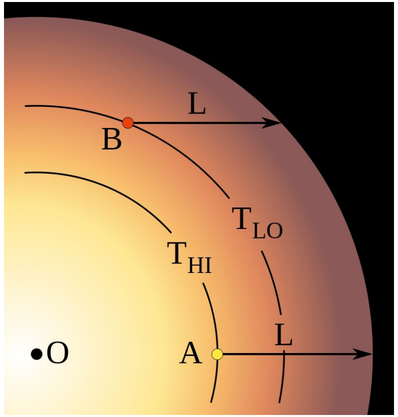
$$I(\mu)/I(1) = 1;$$

– linear:

$$I(\mu)/I(1) = 1 - u\,(1-\mu);$$

Two examples of simple limb-darkening laws
Using models for the parameters relies on the knowledge of stellar atmospheric parameters (includes v_turb)

Limb-darkening



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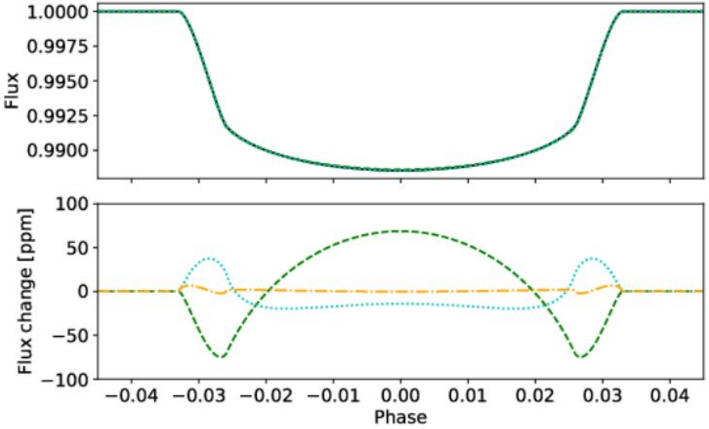
Two examples of simple limb-darkening laws

Maxted 2018



Comparison of transit profiles by changing the limb-darkening coefficients by 1-sigma

Biases introduced by limb-darkening coefficients is often larger than the quoted uncertainties in the fitting parameters, see e.g. Espinoza & Jordan, 2015, MNRAS

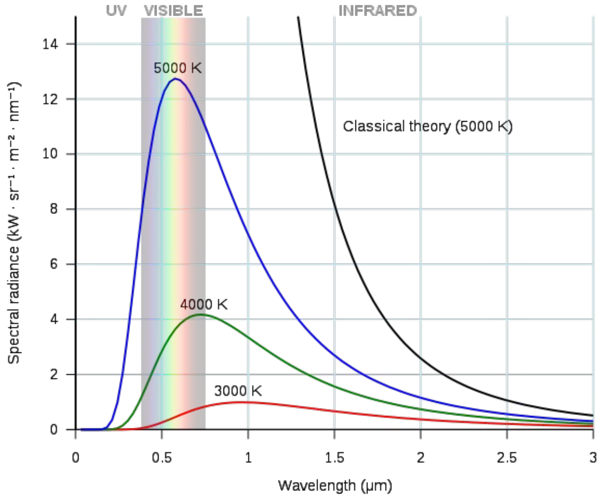
New instrument SPICA@CHARA to probe limb-darkening of stellar surfaces

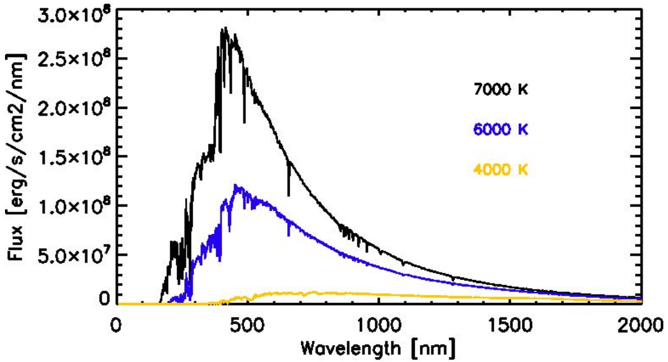
Effective temperature

- Teff characterizes the total flux transported through an atmosphere
- Average of the temperature in the atmosphere over depth
- Defined by the Stefan-Boltzmann Law
  - The temperature a star would have if the star were a pure blackbody
  - Obtain it directly from fbol and R*star*

$$T_{\text{eff}} = \left(\frac{L_\star}{4\pi R_\star^2 \sigma}\right)^{1/4}$$

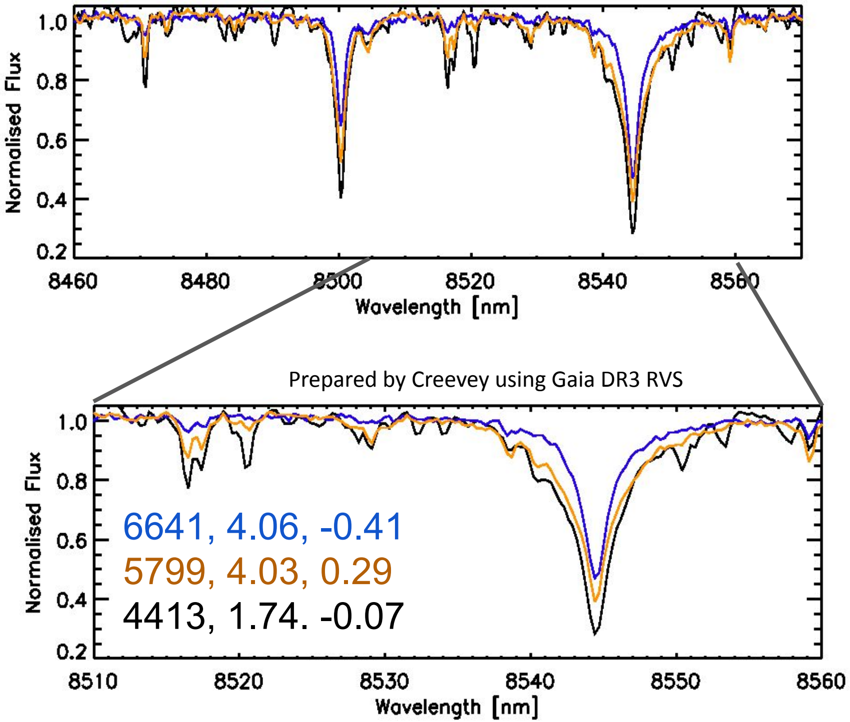
$$T_{\text{eff}} = \left(\frac{4 f_{\text{bol}}}{\sigma \theta}\right)^{1/4}$$

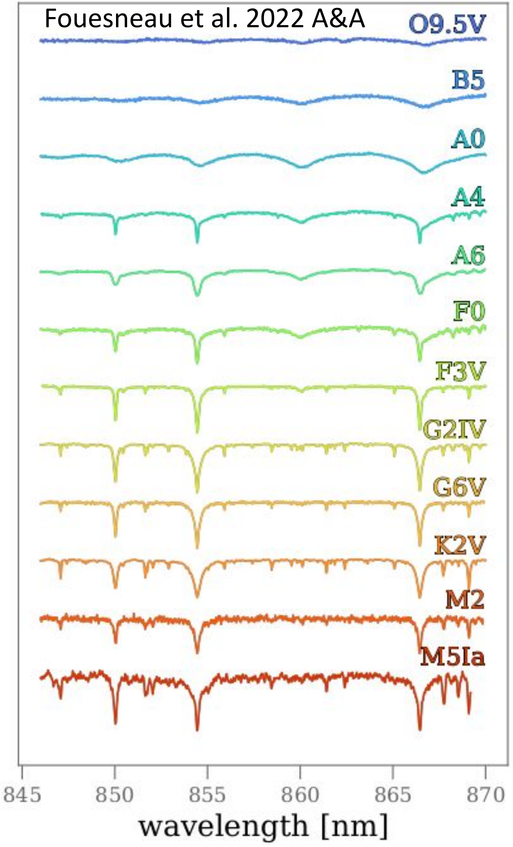




Effective temperature: high-resolution spectra

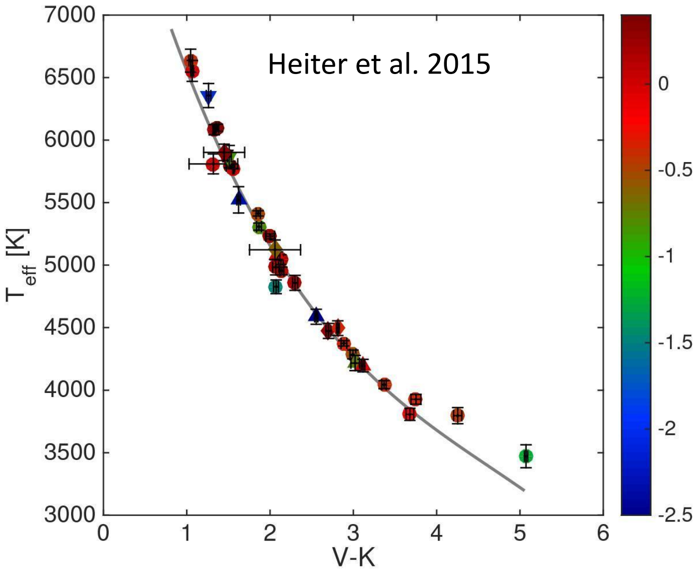
- High resolution spectra spectra allow one to estimate Teff, logg, [M/H]
- Require the use of atmospheric models and these can be subject to systematic errors and neglect of important physical processes (linelist!)

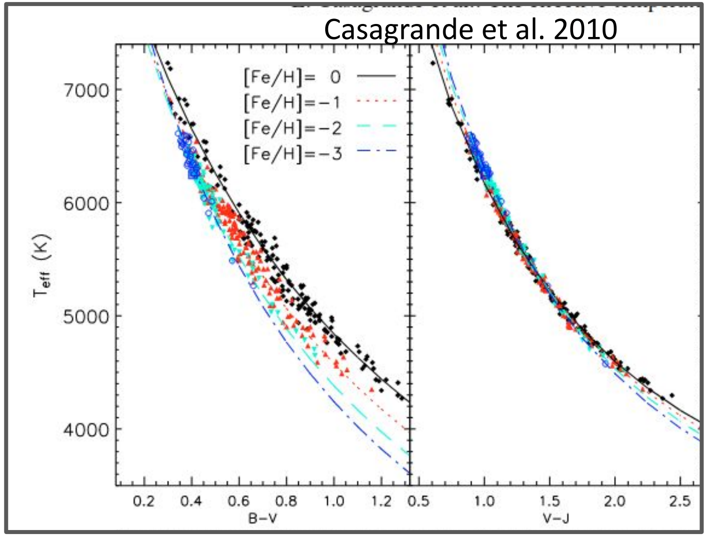




Effective temperature

- Alternative methods: colour-colour relations
  - Zero-point issues
  - Extinction effects



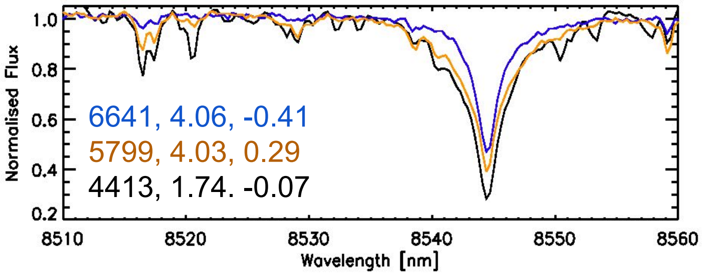


Surface gravity

- Usually expressed as $\log_{10} g$ or simply log g

$$g = \frac{GM}{R^2}$$

- Spectroscopic approaches:
  - Comparing a library of synthetic spectra with the observed one using a best-fitting approach
  - Measuring the equivalent widths of iron lines and requiring a balance between e.g. Fe I and II (or another species)
  - Metal-poor stars, physics often neglected e.g. NLTE and can cause a change in log g by 0.5 dex

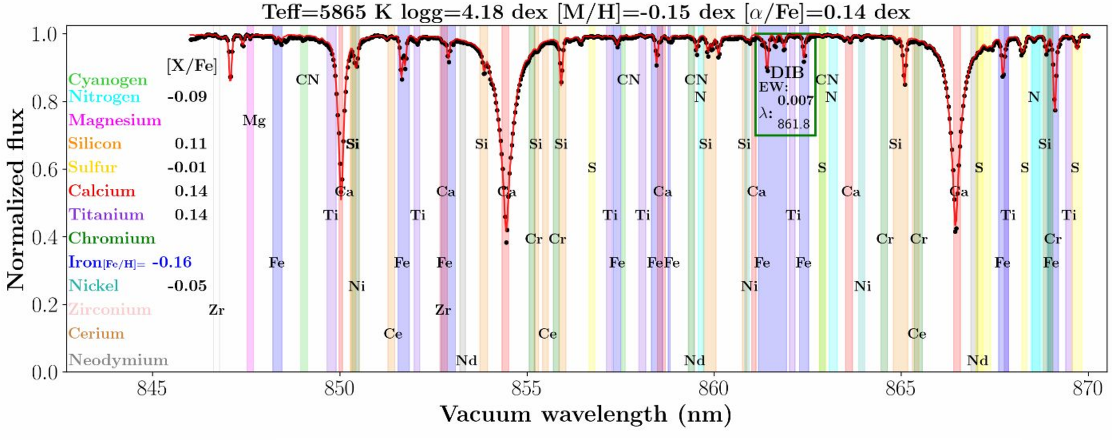


- Evolution track constraints
  - Using e.g. HR diagram constraints and isochrones or evolution models

- Flicker / FliPer: using time series to derive log g from stellar variability, e.g. Bugnet+2018, but see also Sulis+2020 for why you need to care about this for your observations

Metallicity and abundances

- High resolution spectra
  - depends also on T, g
  - Model-dependent

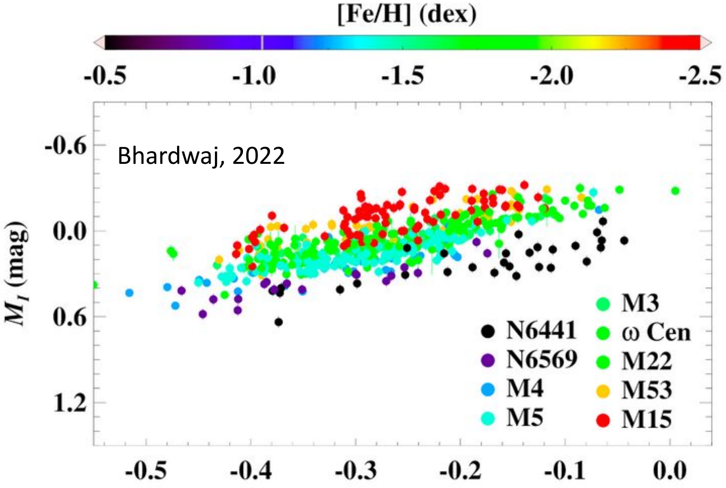


- Use of variable stars

$$M = \alpha + \beta \log (P) + \gamma [Fe/H]$$

  - α, slope of PL relation
  - □, zeropoint of PL relation
  - γ, coefficient

$$M_{K_{GC}} = -0.86 - 2.35 \log (P) + 0.17\,[\mathrm{Fe/H}] \quad (\sigma = 0.04)$$
$$M_{K_{TH}} = -0.82 - 2.25 \log (P) + 0.18\,[\mathrm{Fe/H}] \quad (\sigma = 0.04)$$



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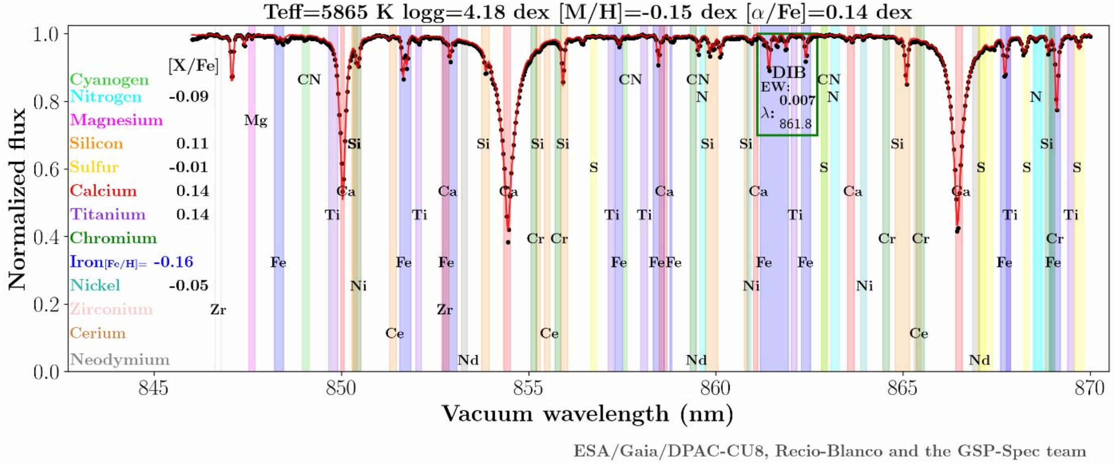

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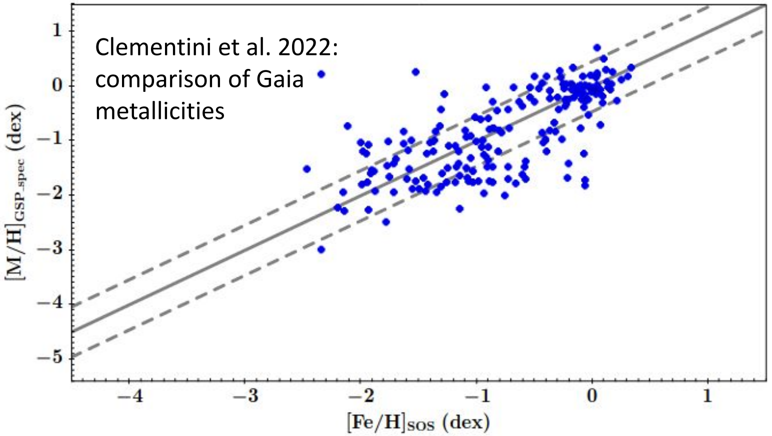


Mass of single stars

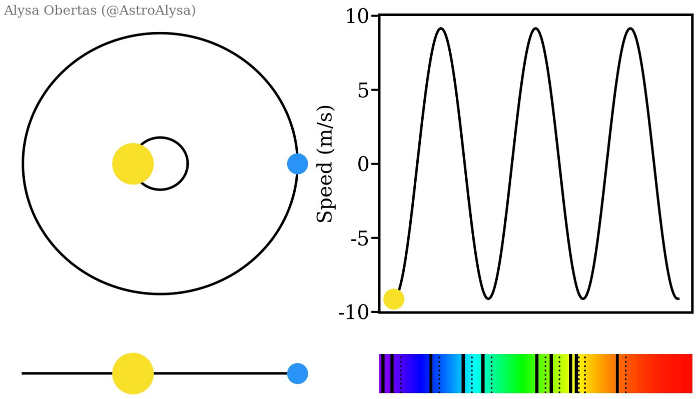
$$g = \frac{GM}{R^2}$$

- Measuring [density or log g] and radius
- Model-dependent (isochrones): fitting Teff, [M/H], Lum to stellar models (see later)
- Mass-luminosity relation (empirical)
- [Seismic] R, deltanu $\rightarrow$ mass

Mass in binary systems

- The movement of stars in binary systems (two stars that share a common center of gravity) can be described by Kepler's Third Law
- Their movement is detected by
    - radial velocities and the relative amplitude is related directly to the mass ratio

$$M_1 + M_2 = \frac{P}{2\pi G}\frac{(v_{r1}+v_{r2})^3}{\sin^3 i} \qquad \frac{M_2}{M_1} = \frac{v_{r1}}{v_{r2}}$$

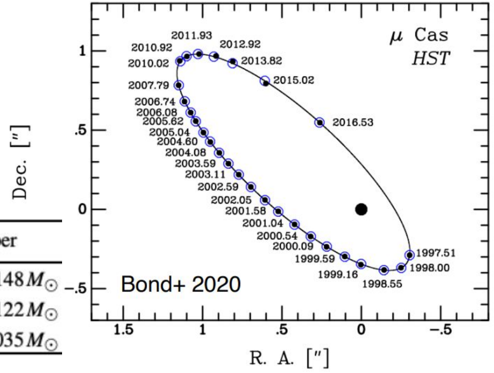


    - positional information (astrometry): masses depend on the flux ratio (F2/F1), P, parallax (omega) and separation (a)

$$(M_1 + M_2)\left(\frac{M_2}{M_1 + M_2} - \frac{F_2/F_1}{1 + F_2/F_1}\right)^3 = \frac{(a_0/\varpi)^3}{(P/365.25)^2}$$

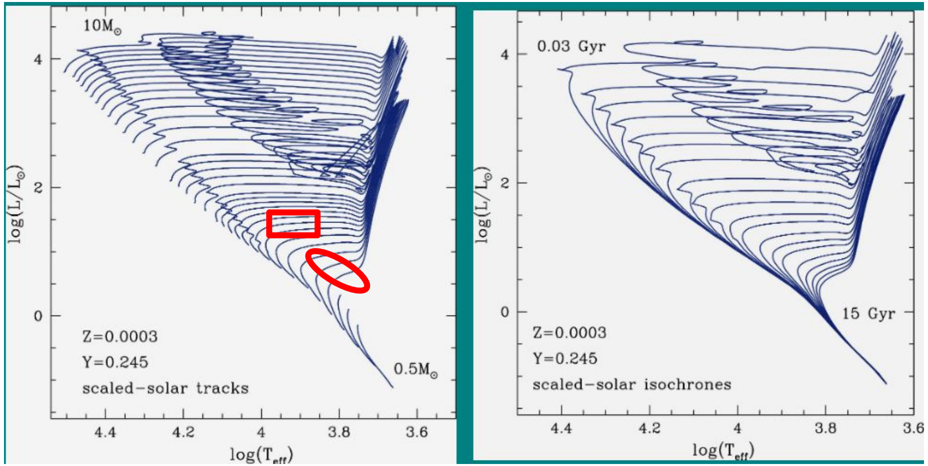
https://youtu.be/oGqSgBIJtZ0

Quantity	This paper
Total mass, $M_A + M_B$	$0.9168 \pm 0.0148 M_\odot$
Mass of μ Cas A, M_A	$0.7440 \pm 0.0122 M_\odot$
Mass of μ Cas B, M_B	$0.1728 \pm 0.0035 M_\odot$



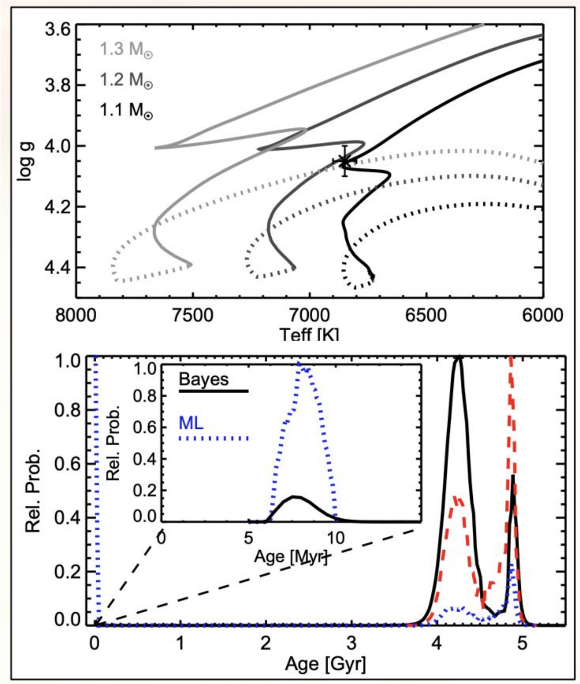
Isochrone Fitting (I)

- Using stellar evolution (or isochrones) to constrain stellar parameters



From presentation by S. Cassisi

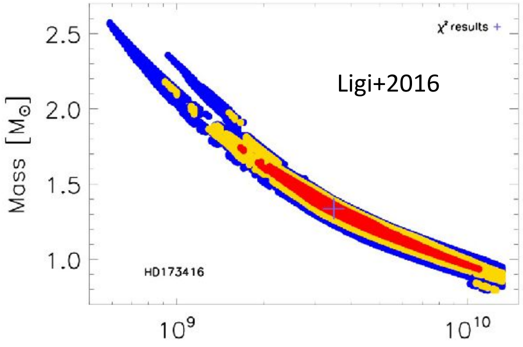
Serenelli et al. 2017

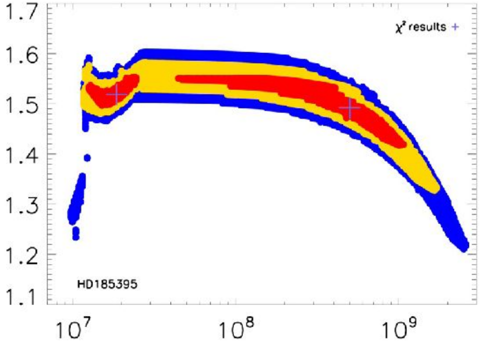


- The observables can be (L, T, [M/H]) or any other combination e.g. log g or colours (for colours, one must couple atmosphere models to evolution ones)

Isochrone Fitting (II)

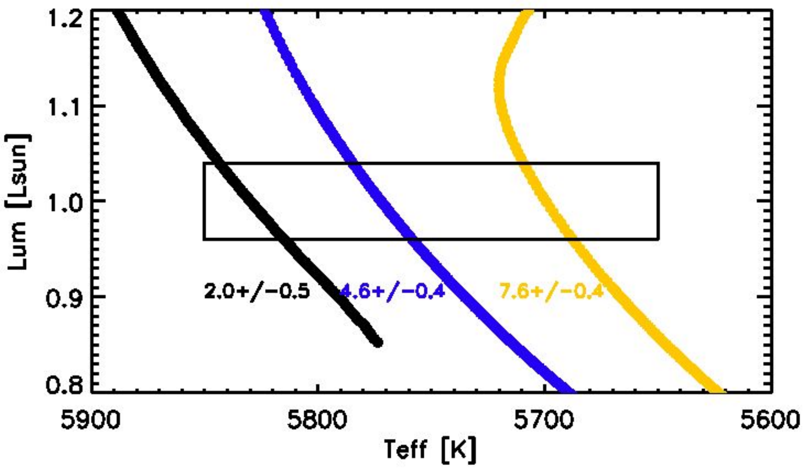
- Models are described using M, 2 of XYZ, alpha (mixing-length parameter) + age
- XYZ = initial mass fraction of hydrogen, helium + everything else with X+Y+Z=1
    - Careful: X/Z ≠ [M/H](surface)
- Distribution of metals often assumed solar “Solar-scaled”
- Some parameters fixed, e.g. Yi Important correlations among parameters
- Fixed input physics (equation of state, opacities, nuclear reaction rates)
- Include rotation? Magnetic fields? Atomic diffusion? “Exotic models”
- Results from isochrone fitting give uncertainties which do NOT consider these other issues
- Let’s forget about these issues and assume the models are right (!) we still have important correlations





Mass is the key to knowing the age

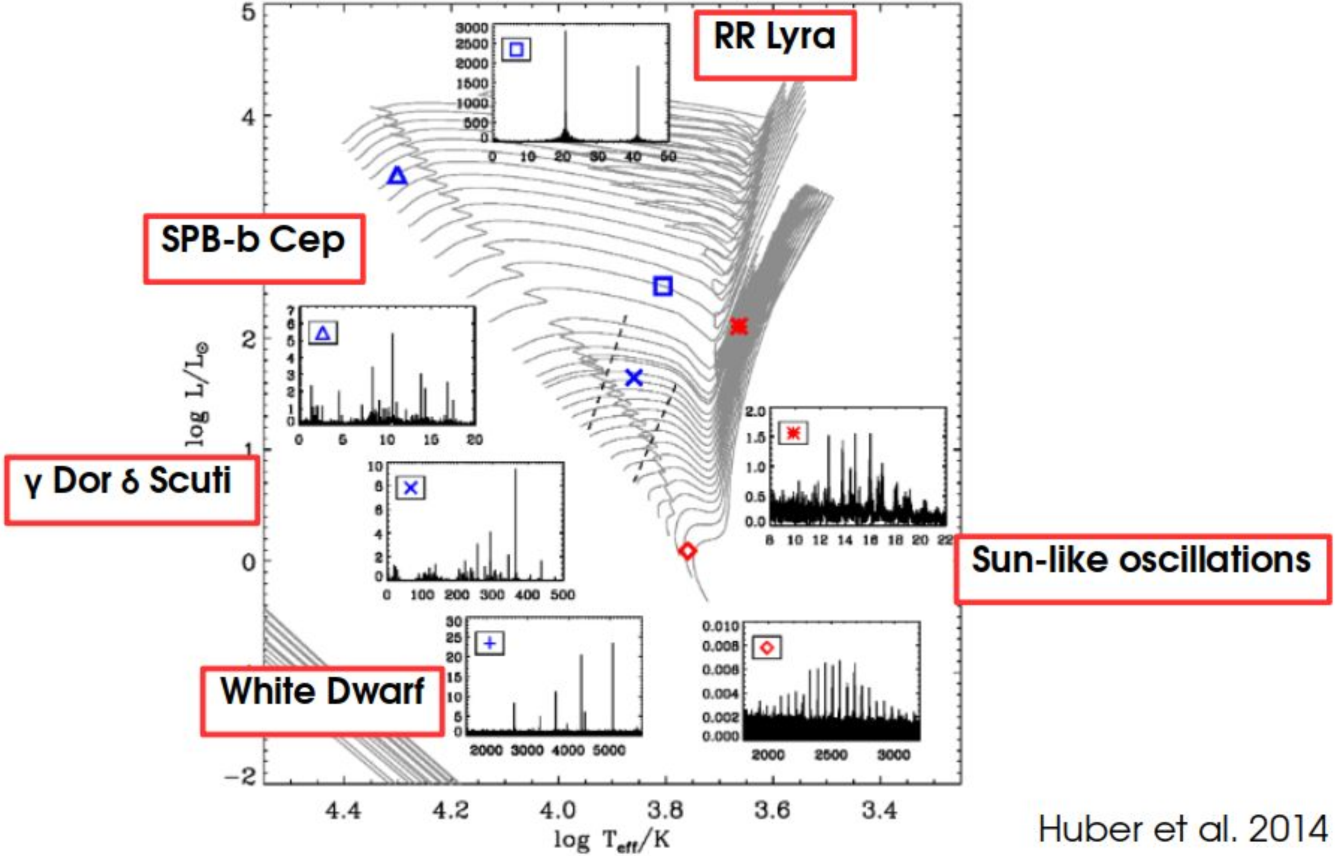
- The mass of the star is one of the key quantities that determines the structure of the star, hence its evolution
- Mass in this simulation goes from 0.96 - 1.04 Msolar (for a fixed Z)
- Age varies from 1.5 to 8.0 billion years even though the mass differs by 0.08 Msun
- An independent radius measurement can help!
  - 0.98 +/- 0.01 Rsun
  - 1.00 +/- 0.01 Rsun
  - 1.03 +/- 0.01 Rsun
- Or other observables sensitive to stellar structure:
  - seismology
- If the planet's host is in a binary or in a cluster, then things are much easier



Outline

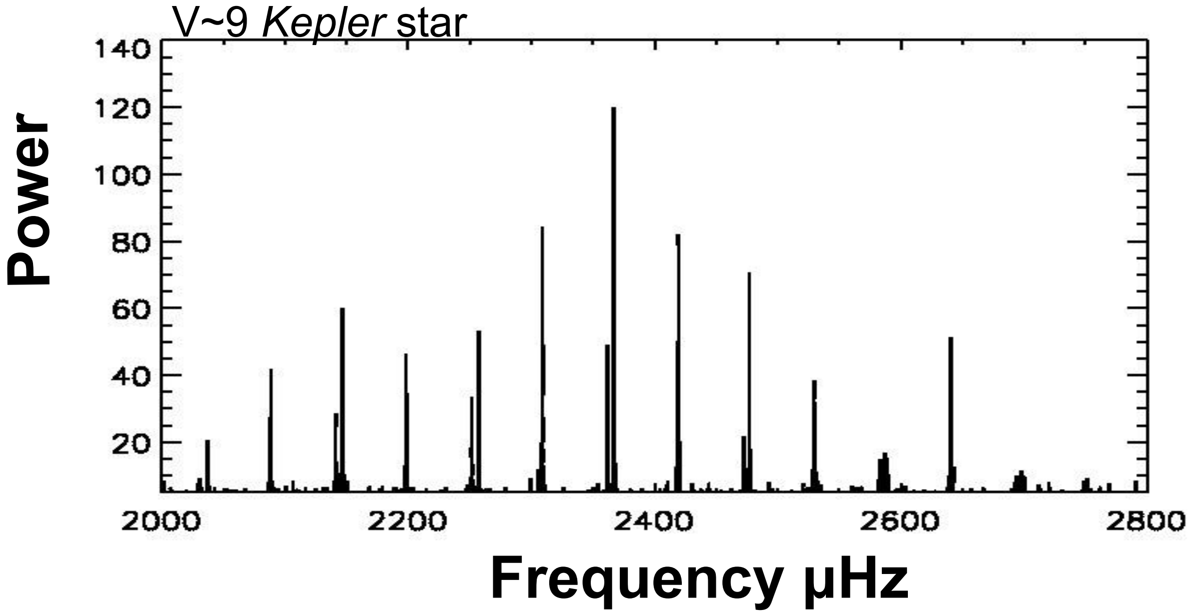
- Introduction (15)
  - Why we care
  - What is an observation and what is an inferred parameter
  - What are important stellar parameters and what are the measurements
- Classical determinations of each Individual parameter (30 mins)
- **Asteroseismology** (15)
- Exploiting Gaia DR3 (20)

Asteroseismology: study of stellar oscillations

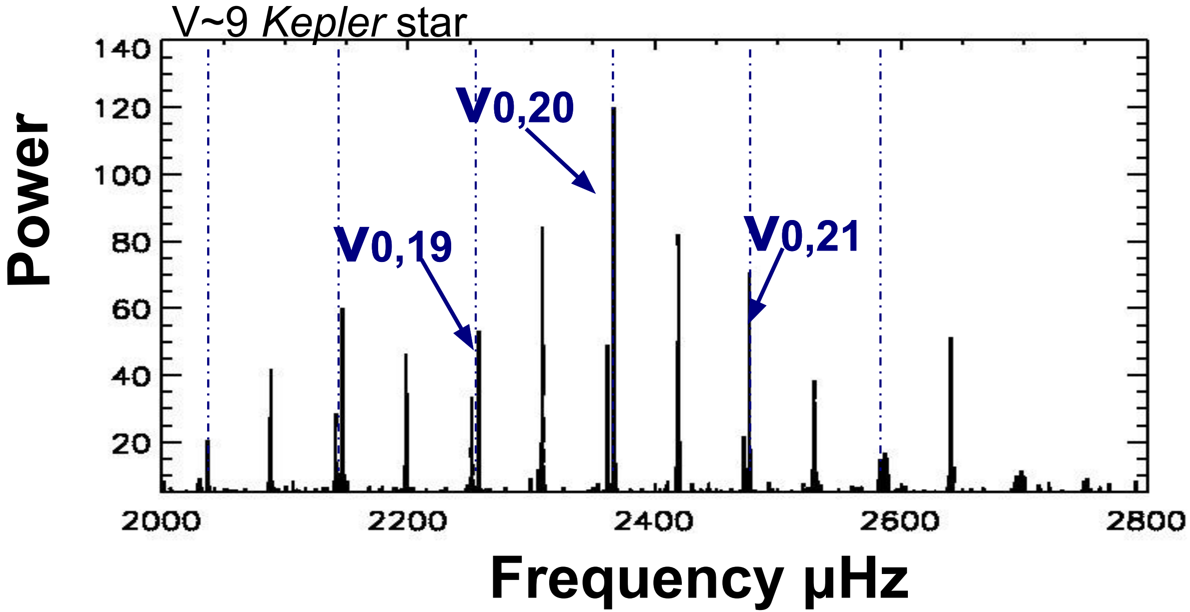


Huber et al. 2014

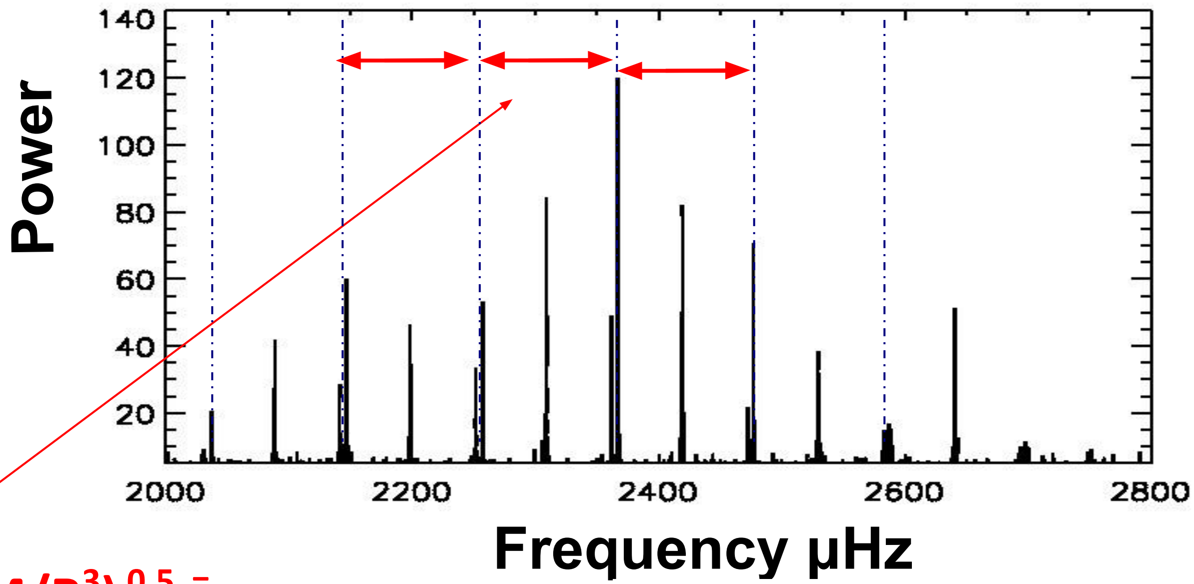
Asteroseismology of solar-like oscillators



Asteroseismology of solar-like oscillators



Asteroseismology of solar-like oscillators

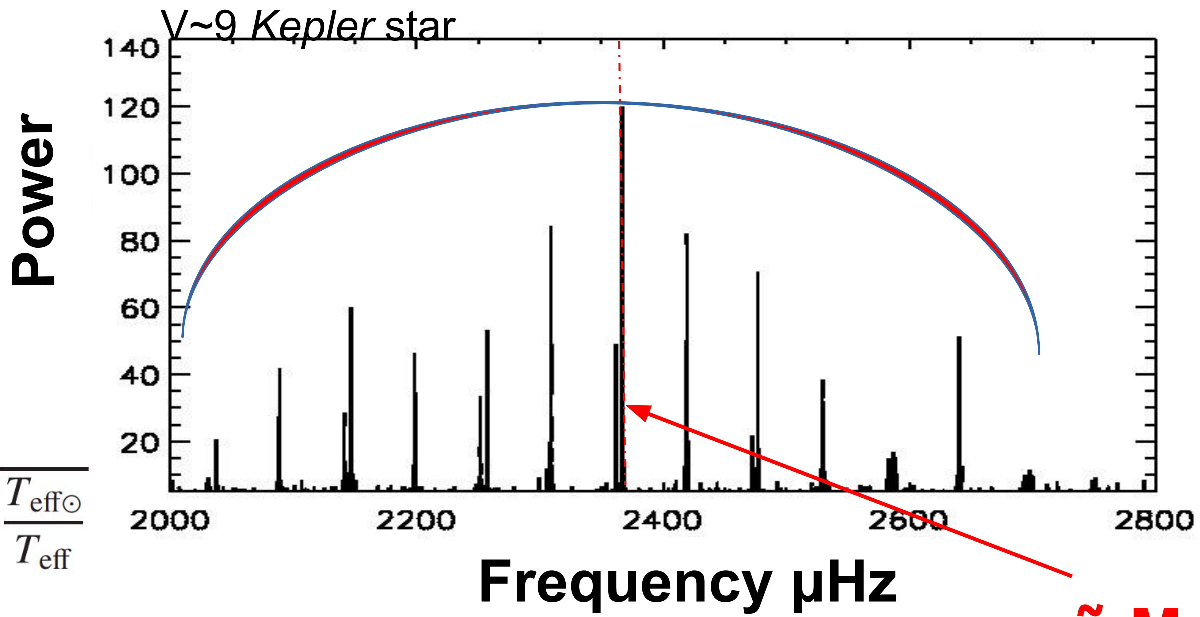


<$\Delta\nu$> = $(M/R^3)^{0.5}$ =

<Large frequency separations>

$$\frac{\langle\Delta\nu\rangle}{\langle\Delta\nu\rangle_\odot} \approx \sqrt{\frac{\rho}{\rho_\odot}} = \sqrt{(M/\mathrm{M}_\odot)/(R/\mathrm{R}_\odot)^3}$$

Asteroseismology of solar-like oscillators

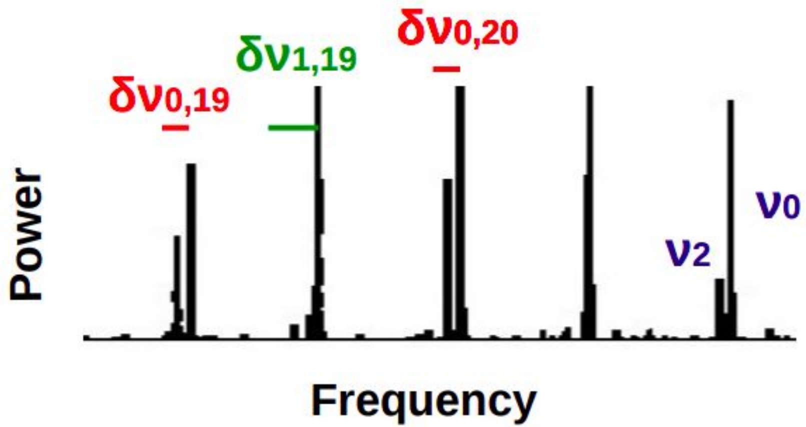


$$\frac{\nu_{\max}}{\nu_{\max\odot}} = f_{\nu_{\max}} \frac{g}{g_\odot} \sqrt{\frac{T_{\mathrm{eff}\odot}}{T_{\mathrm{eff}}}}$$

$$\nu_{max} \sim \frac{M}{R^2\, Teff^{0.5}}$$

Frequency of maximum power

Asteroseismology of solar-like oscillators



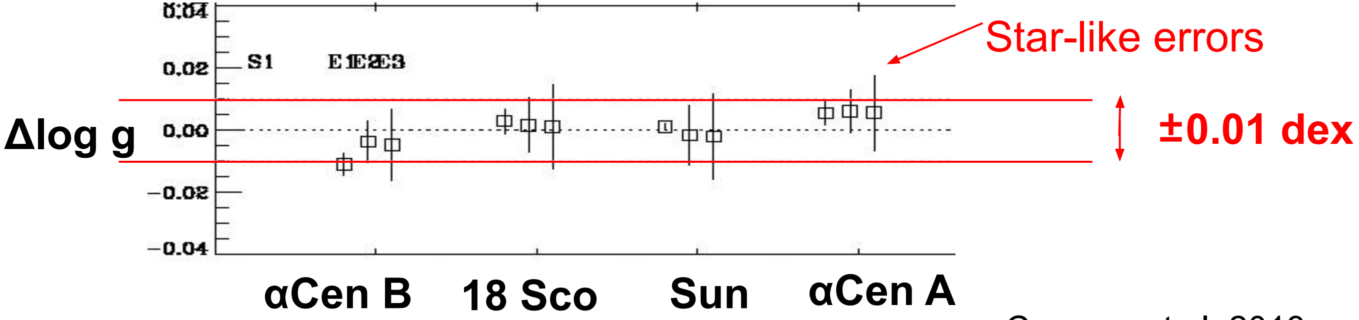
<Small frequency separations>

Asteroseismology of solar-like oscillators

$$R = \frac{\nu_{max}}{\Delta\nu^2} T_{eff}^{0.5}$$

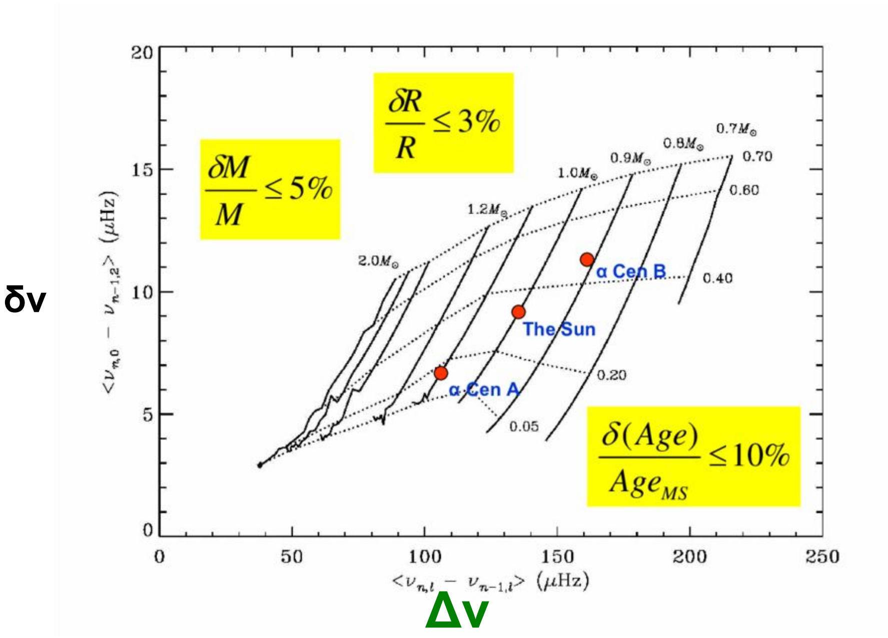
$$M = \frac{\nu_{max}^3}{\Delta\nu^4} T_{eff}^{1.5}$$

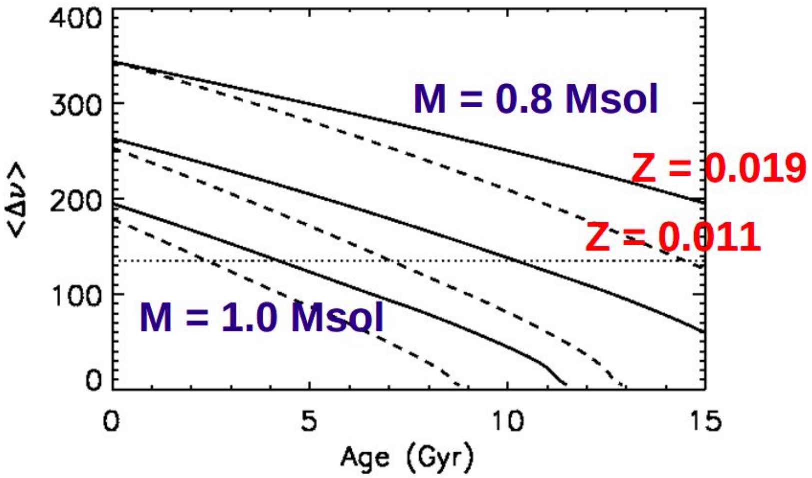
$$g = \nu_{max} T_{eff}^{-0.5}$$



Creevey et al. 2013

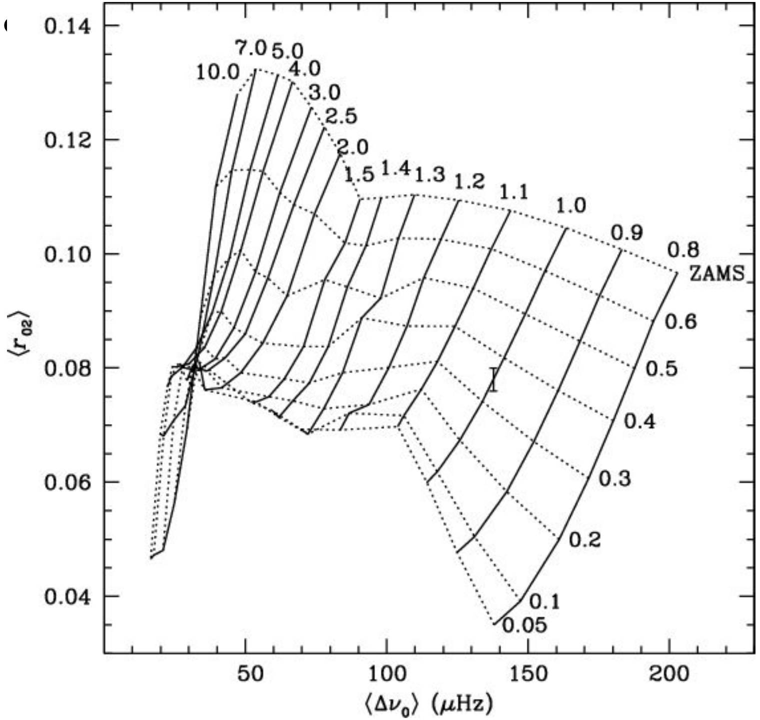
Asteroseismic diagnostic plots



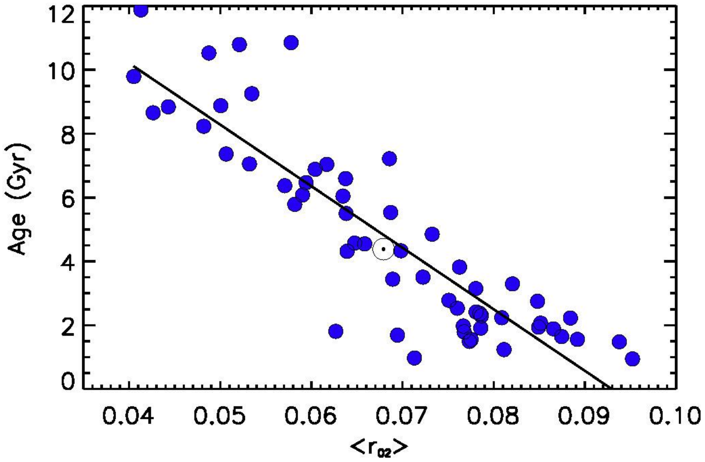


Asteroseismic diagnostic plots

r02



Δν



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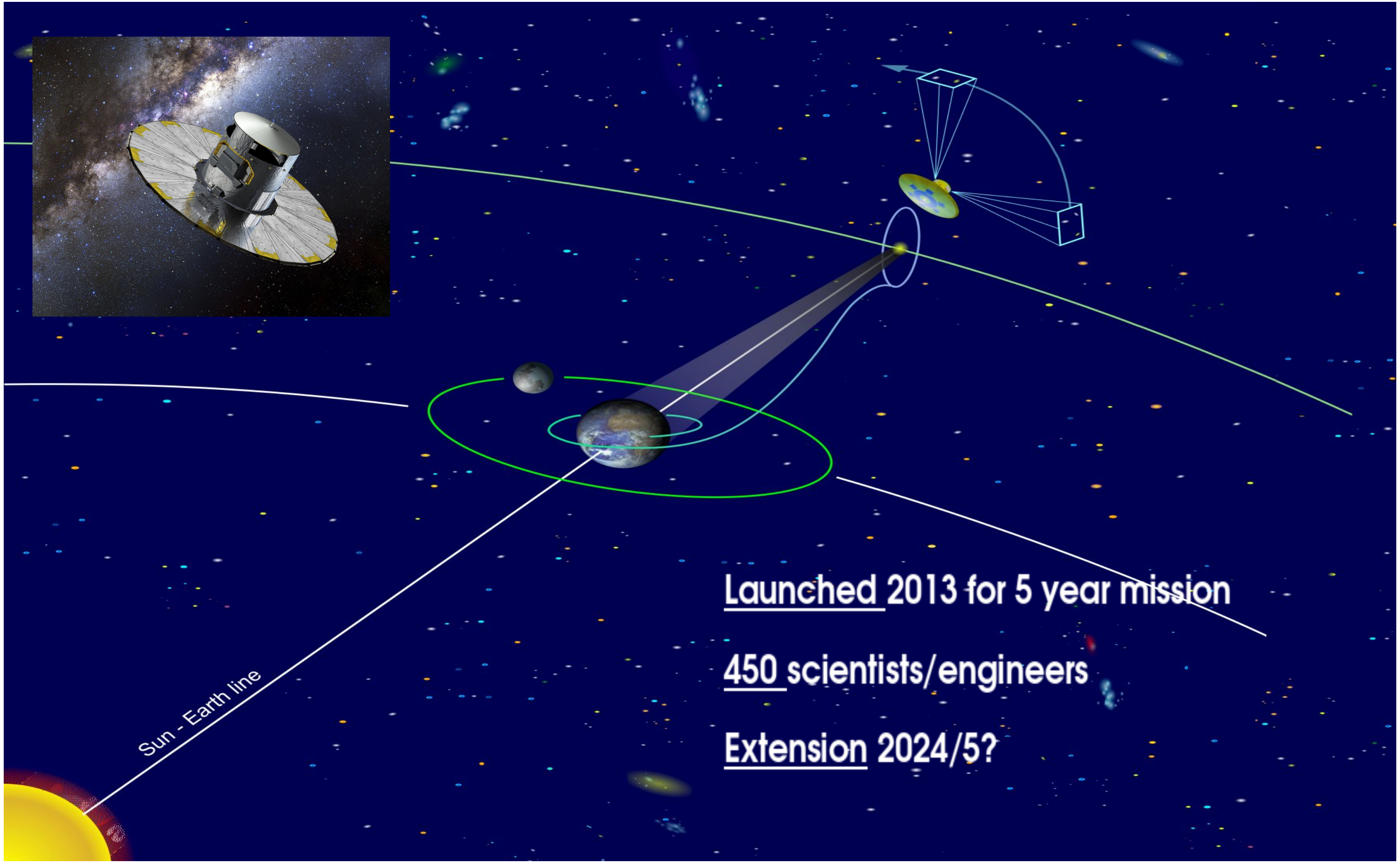
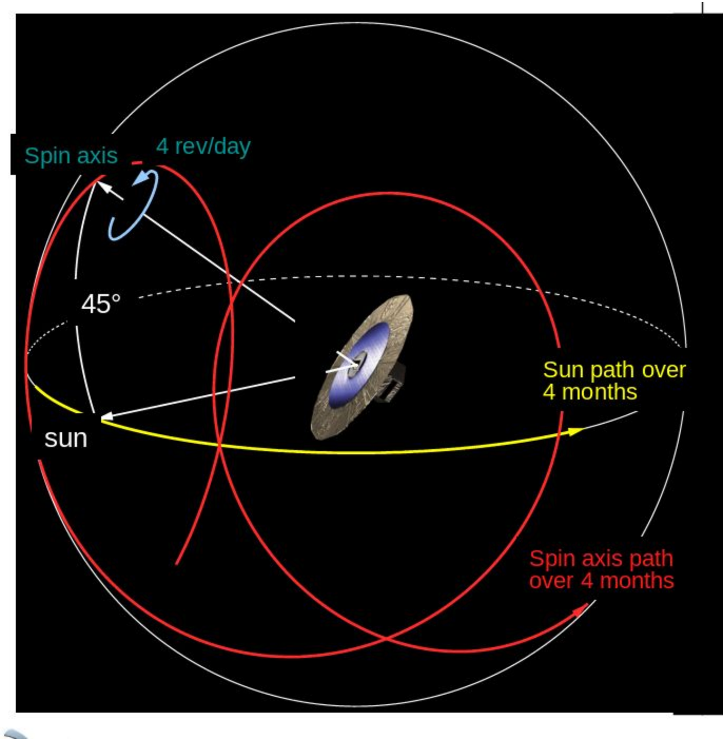
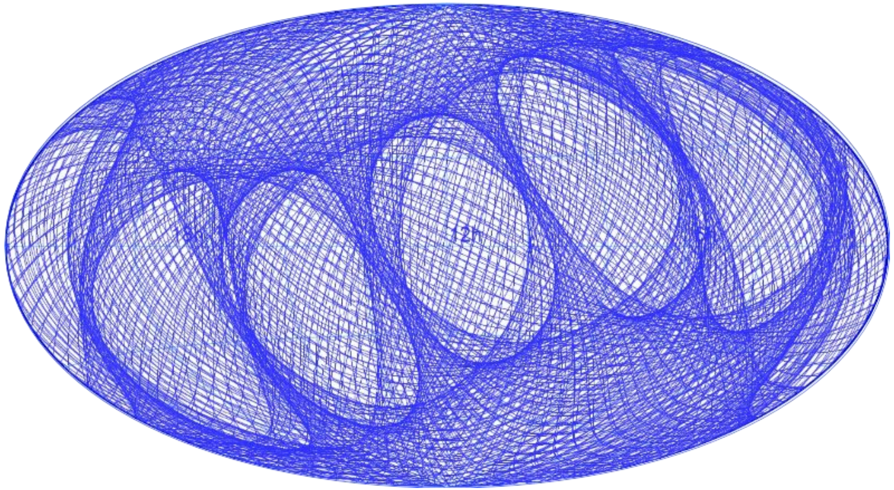
Gaia



Sun - Earth line
Launched 2013 for 5 year mission
450 scientists/engineers
Extension 2024/5?

Gaia





- All sky survey down to G<21 (bright limit ~ 3)
- Primary goal is to measure the positions and velocities of 2 billion stars (1% of the Milky Way) to study the 3D evolution of our Galaxy
- Understand the 3D dynamical evolution and trace back the formation our galaxy

  — but it does so much more than that!

Gaia observations

- Gaia measurements are <u>time series</u> of:
  - Positions of stars
  - ‘G’ band photometry
  - Low resolution spectro-photometry from the Blue and Red Prism
  - High resolution (R~11,000) spectra from the Radial Velocity Spectrometer

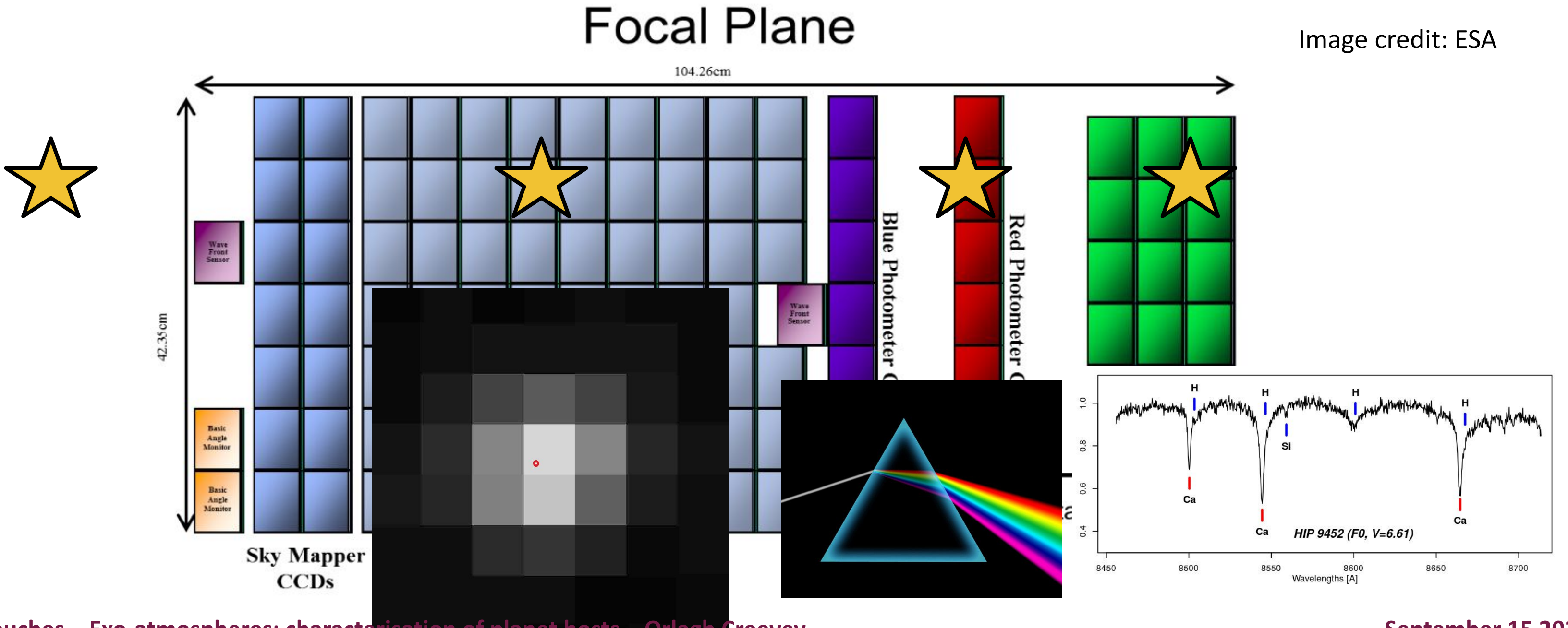


Image credit: ESA

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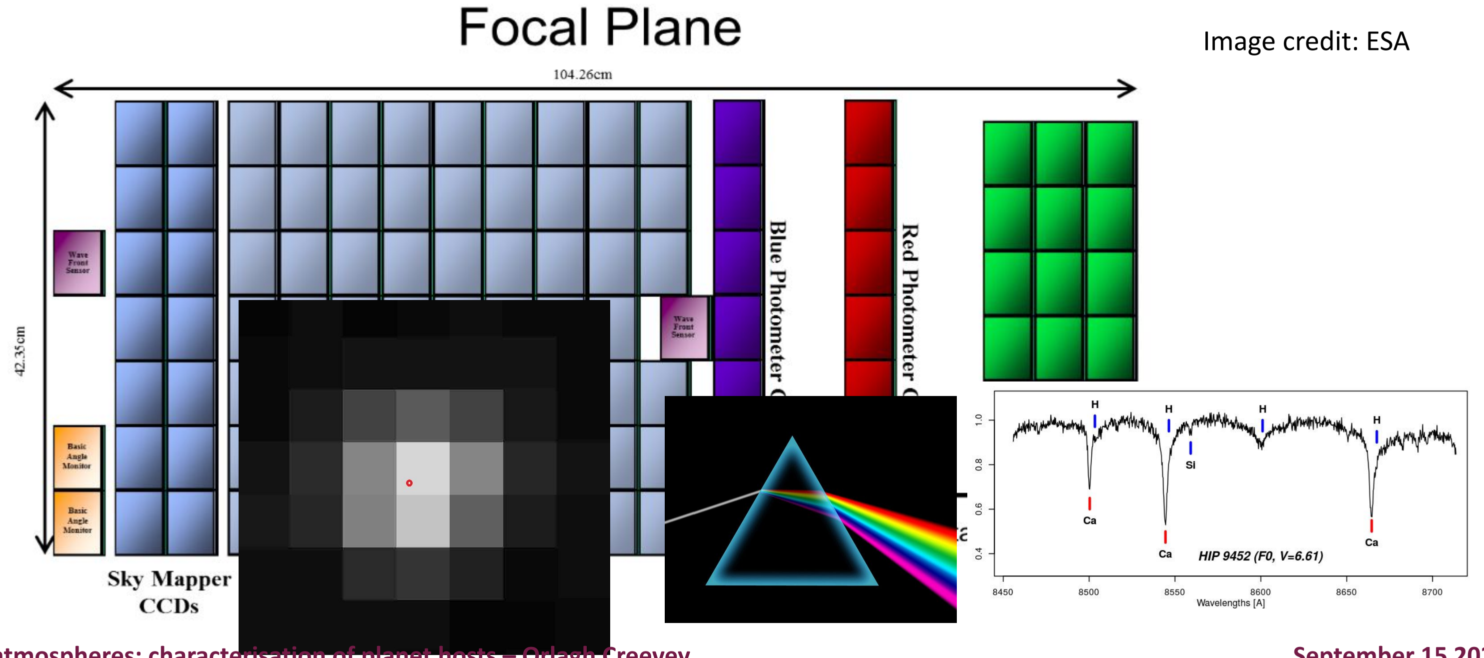


Image credit: ESA

Gaia Data Release 3: new products

- Gaia Data Release 3
  - Astrophysical parameters
  - Binary solutions, including planets
  - Activity and stellar rotation
  - Stellar variability
  - BP/RP and RVS spectra

Gaia Data Release 3: new products

- Gaia Data Release 3
  - **Astrophysical parameters**
  - Binary solutions, including planets
  - Activity and stellar rotation
  - Stellar variability
  - BP/RP and RVS spectra

Where?
https://gea.esac.esa.int/archive/
- Astrophysical parameters

- Other
- Gaia Data Release 1
- Gaia Data Release 2
- Gaia Data Release 3

- Gaia Data Release 3
  - gaiadr3.gaia_source
  - gaiadr3.gaia_source_lite
  - Astrophysical parameters
  - Auxiliary
  - Cross match
  - Extra-galactic
  - Non-single stars
  - Performance verification
  - Reference frame
  - Science alerts
  - Simulation
  - Solar system
  - Spectroscopy
  - Variability

- Astrophysical parameters
  - gaiadr3.astrophysical_parameters
  - gaiadr3.astrophysical_parameters_supp
  - gaiadr3.oa_neuron_information
  - gaiadr3.oa_neuron_xp_spectra
  - gaiadr3.total_galactic_extinction_map
  - gaiadr3.total_galactic_extinction_map_opt

- Non-single stars
  - gaiadr3.nss_acceleration_astro
  - gaiadr3.nss_non_linear_spectro
  - gaiadr3.nss_two_body_orbit
  - gaiadr3.nss_vim_fl

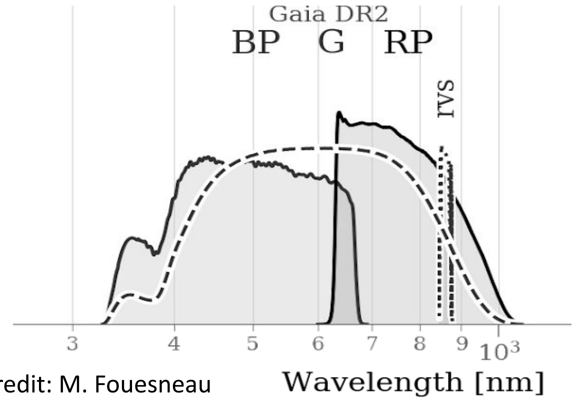
- Variability
  - gaiadr3.vari_agn
  - gaiadr3.vari_cepheid
  - gaiadr3.vari_classifier_class_definition
  - gaiadr3.vari_classifier_definition
  - gaiadr3.vari_classifier_result
  - gaiadr3.vari_compact_companion
  - gaiadr3.vari_eclipsing_binary
  - gaiadr3.vari_epoch_radial_velocity
  - gaiadr3.vari_long_period_variable
  - gaiadr3.vari_microlensing
  - gaiadr3.vari_ms_oscillator
  - gaiadr3.vari_planetary_transit
  - gaiadr3.vari_rad_vel_statistics
  - gaiadr3.vari_rotation_modulation
  - gaiadr3.vari_rrlyrae
  - gaiadr3.vari_short_timescale
  - gaiadr3.vari_summary

References: https://gea.esac.esa.int/archive/documentation/GDR3/Data_analysis/chap_cu8par/
Apsis I – overview of methods and content → *Creevey et al. 2022*
Apsis II – focus on stellar parameters → *Fouesneau et al. 2022*
Apsis III – focus on source classification and non-stellar parameters → *Delchambre et al. 2022*
Gaia DR3 Catalogue Validation → *Babusiaux et al. 2022*
GSP-Phot → *Andrae et al. 2022* GSP-Spec → *Recio-Blanco et al. 2022* ESP-CS → *Lanzafame et al. 2022*

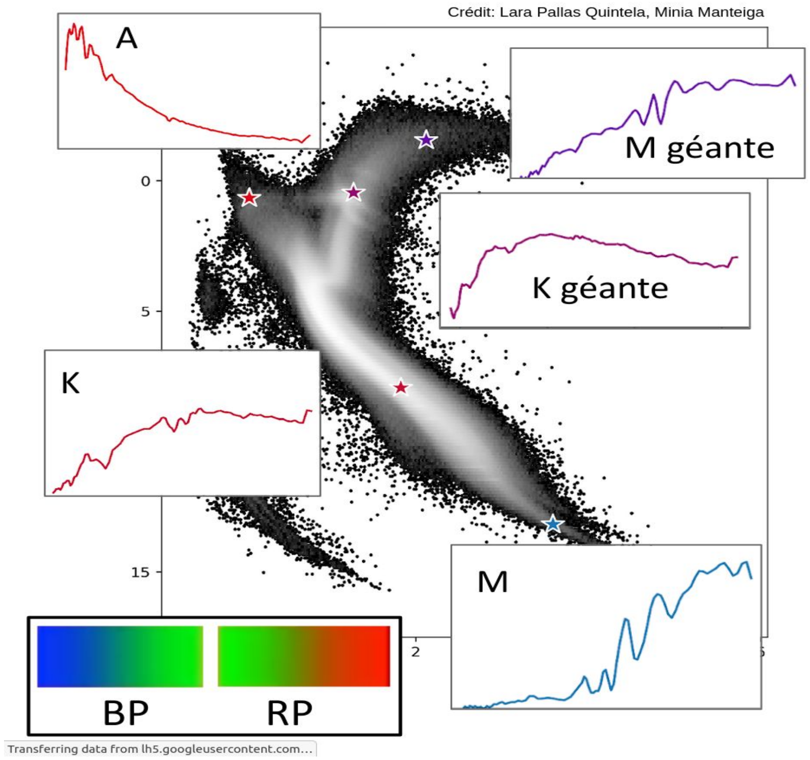
Low-resolution spectra: BP and RP

- Gaia produces BP and RP spectra, and these provide information about intensity distribution across wavelength (220 million published)

- The figure on the right shows examples of the flux distribution across the 330 – 1050 nm wavelength
  BP: 330nm – 680 nm
  RP: 640nm – 1050 nm

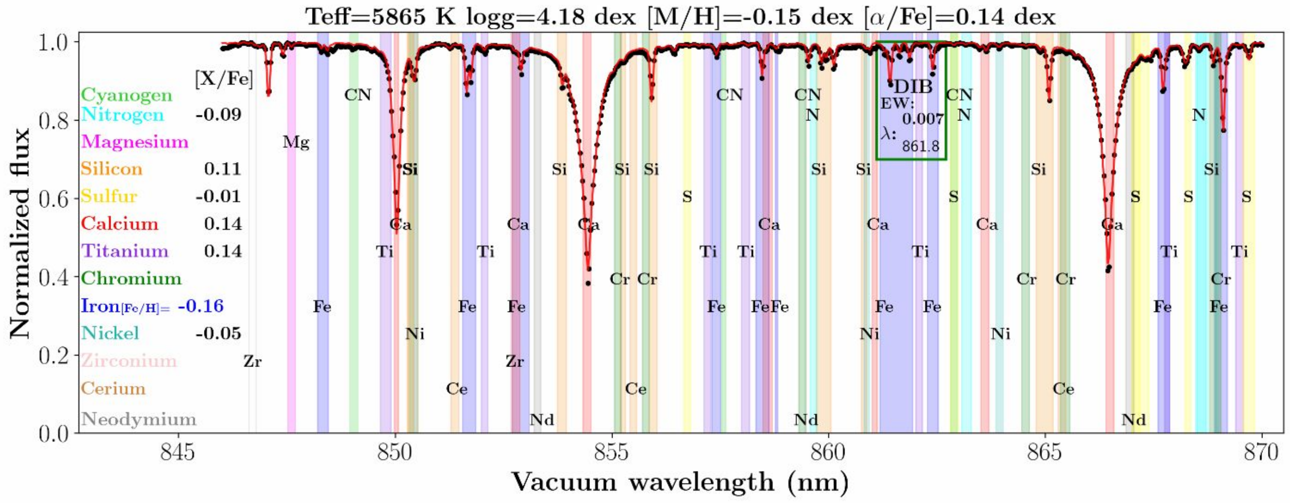


Credit: M. Fouesneau



RVS spectra: spectroscopic parameters and abundances

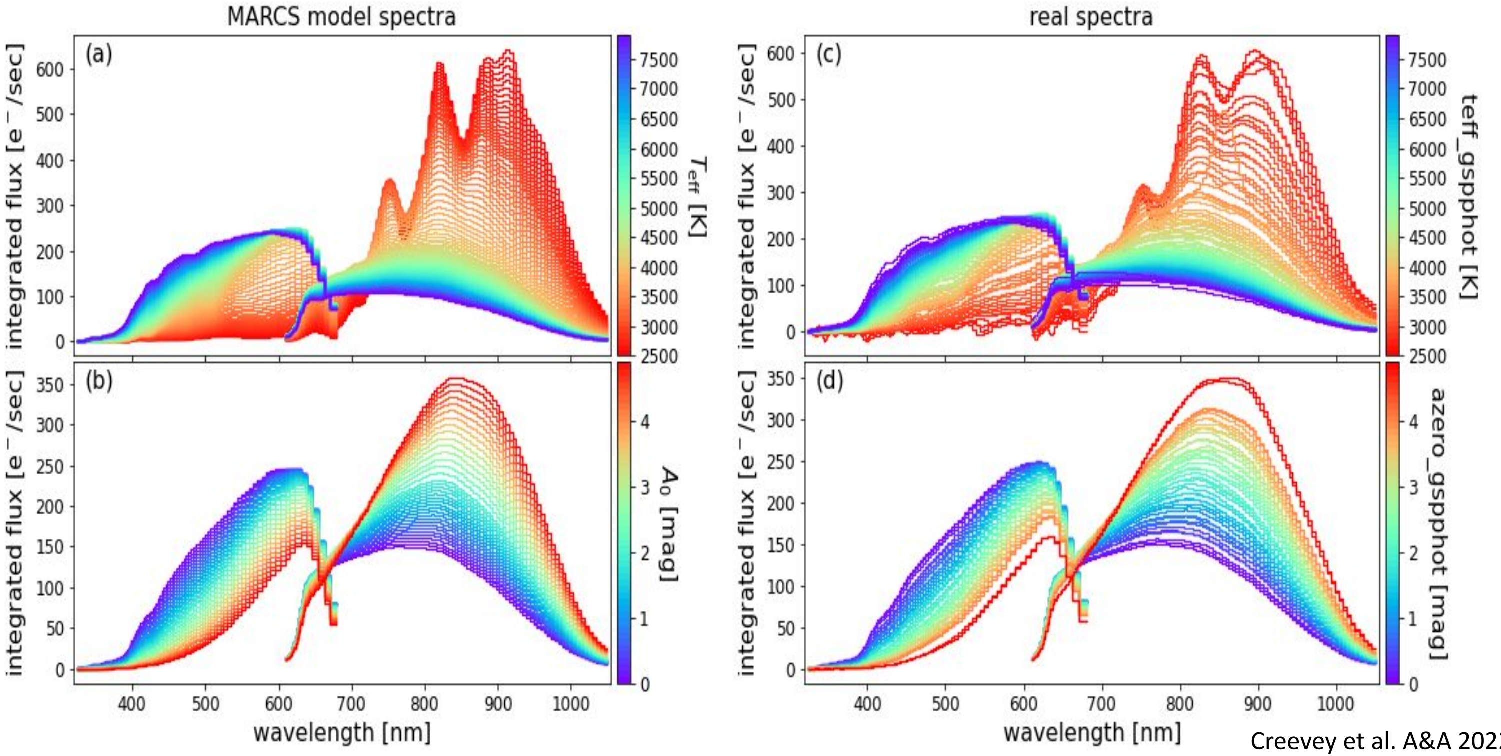
- The RVS spectra are used to derive radial velocities (3rd velocity component)
- They also contain a rich amount of astrophysical information: teff, log g , [M/H], alpha-abundance, individual chemical species (Fe, Mg, Ca, …) and even the diffuse interstellar band (DIB) feature which is related to the interstellar medium
- 1 million spectra published



ESA/Gaia/DPAC-CU8, Recio-Blanco and the GSP-Spec team

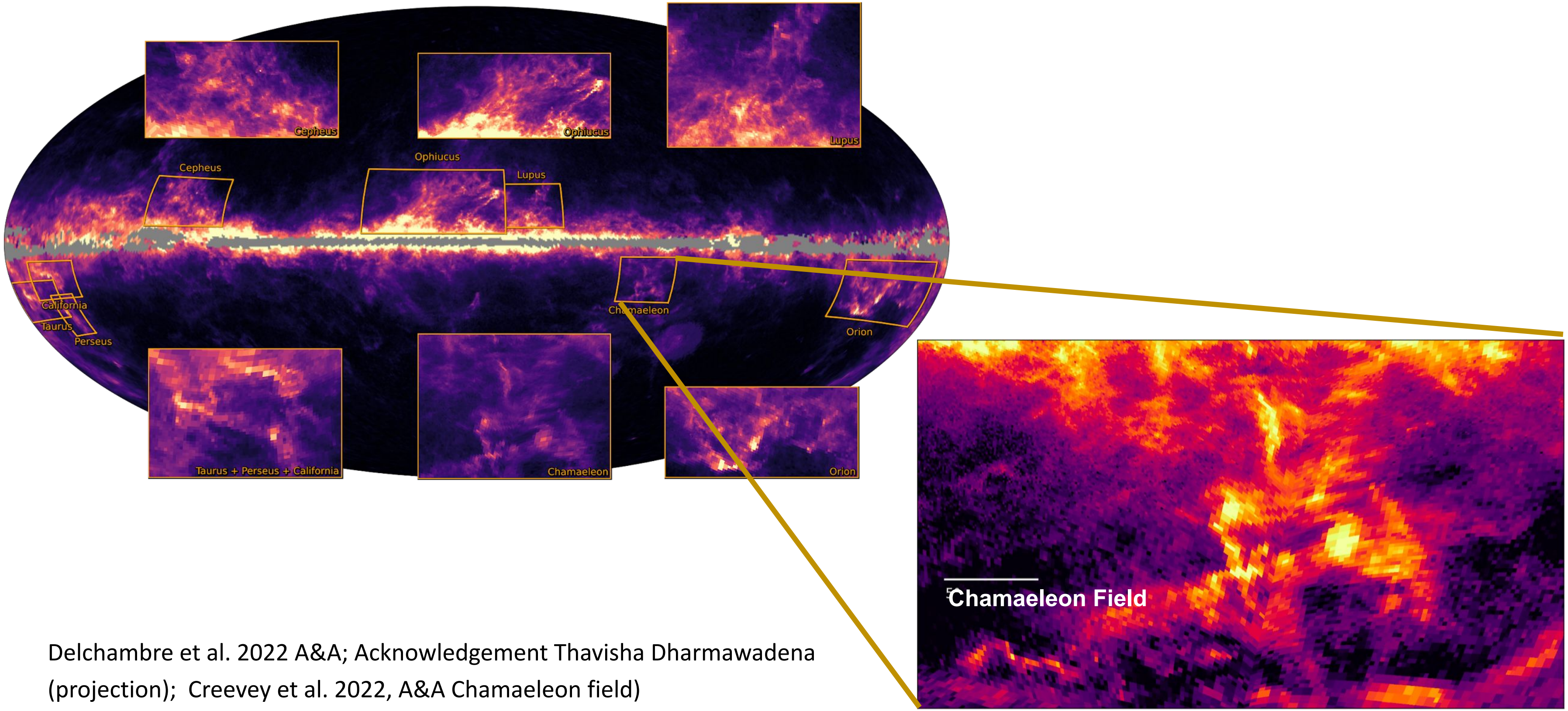
GDR3 results from BP/RP spectra: Teff and extinction

- Gaia DR3 contains 470 million estimates of Teff, AG, logg, [M/H] derived from the BP/RP spectra



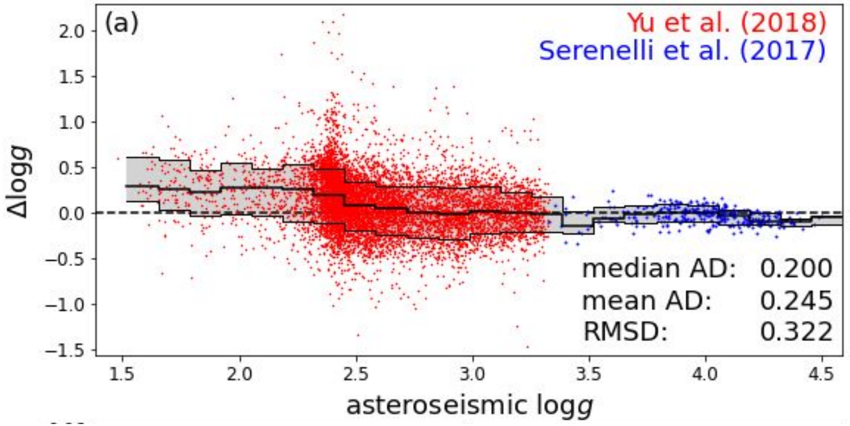
Creevey et al. A&A 2022

GDR3 results from BP/RP spectra: mapping the total galactic extinction



Delchambre et al. 2022 A&A; Acknowledgement Thavisha Dharmawadena (projection); Creevey et al. 2022, A&A Chamaeleon field)

GDR3 results from BP/RP spectra: surface gravities



Andrae et al. 2022: comparison of logg_gspphot with asteroseismic log g.

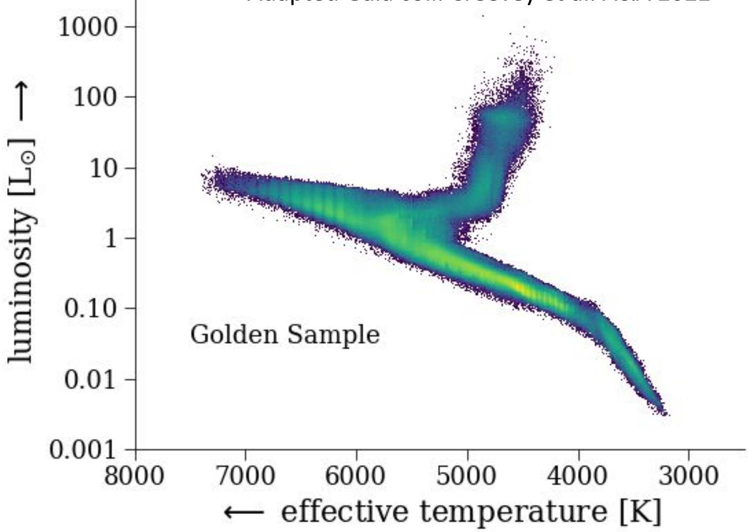
Precision for main sequence stars < 0.1 dex!

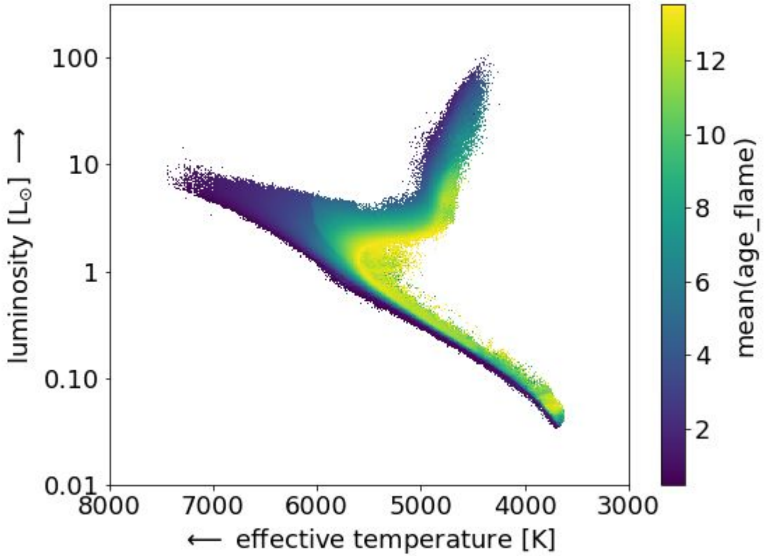
Teff, Lum, Ages of stars in Gaia DR3

- Golden Sample from Gaia coll. Creevey et al. 2022 showing a selection of high quality astrophysical parameters, colour-coded by number of sources

- Same diagram colour-coded by age – easily identify the main sequence and post-MS

Adapted Gaia coll. Creevey et al. A&A 2022



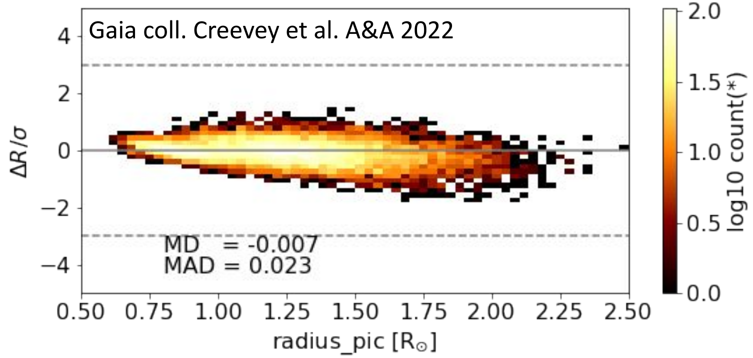


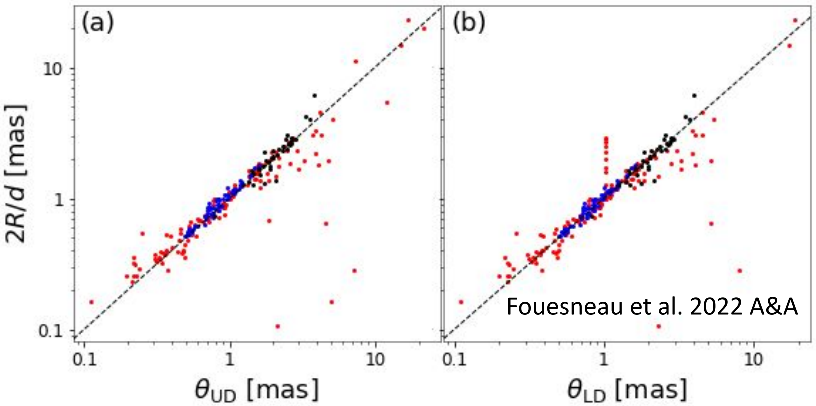
GDR3 results: Radius

- Gaia
  - radius_flame: use the Stefan-Boltzmann Law

$$L_\star = 4\pi R_\star^2 \sigma T_{\rm eff}^4$$

  - radius_gspphot: use the amplitude of the BP/RP spectra and distance (needs evolution models coupled to BP/RP spectra models



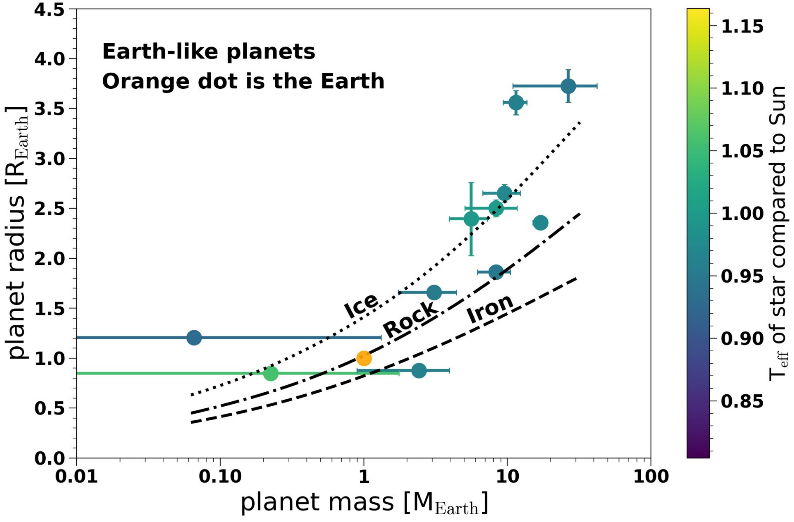


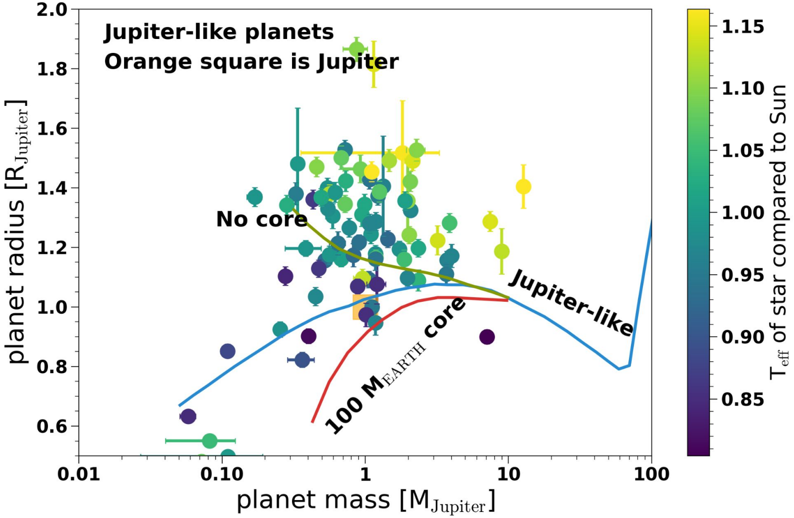
Masses, radii and ages of exoplanets using Gaia DR3

- Cross-match the Golden Sample with known exoplanet host stars
- Use the astrophysical parameters from Gaia DR3 (teff, radius, mass, age)

$$d_{\mathrm{tr}} = \left(\frac{R_p}{R_\star}\right)^2 \qquad M_p \sin(i) = \frac{M_\star^{2/3} P^{1/3} K (1-e^2)^{0.5}}{(2\pi G)^{1/3}}$$

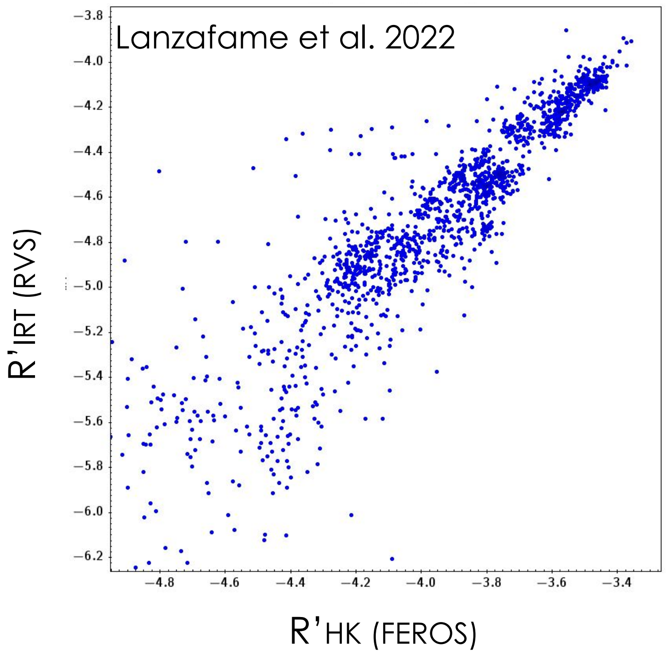
Adapted Gaia coll. Creevey et al. A&A 2022





Activity index in Gaia DR3

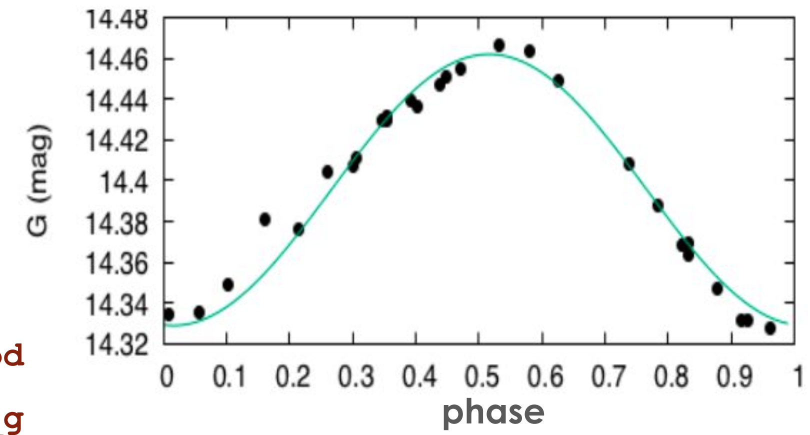
- Measures Ca IRT in RVS spectra (849.8, 854.2, 866.2 nm)
- Related to HK measurement
- 2M stars
- **astrophysical_parameters.activityindex_espcs**
- $\log R'_{\rm IRT} \simeq (C_0 + C_1\theta + C_2\theta^2 + C_3\theta^3) + \log\alpha$
- Theta = log (Teff), alpha = activityindex_espcs
- Two regimes
  - High values indicate saturated regime
    - Young objects
  - Unsaturated regime
    - Large uncertainties for low activity (less precise than H&K measurements)
    - “In-between” region is of interest here

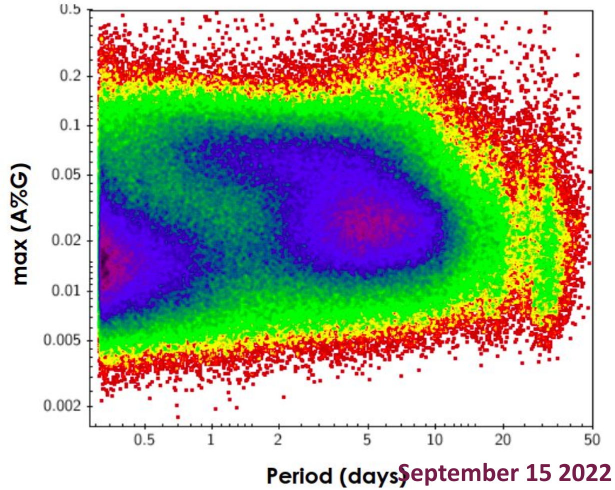


[M/H]	C_0	C_1	C_2	C_3
-0.50	-3.3391	-0.1564	-0.1046	0.0311
0.00	-3.3467	-0.1989	-0.1020	0.0349
0.25	-3.3501	-0.2137	-0.1029	0.0357
0.50	-3.3527	-0.2219	-0.1056	0.0353

Rotational period

- Rotation periods are available for about 0.5 M sources
- Use G time series data, 8 < G < 20
- Lomb-Scargle algorithm applied to 120 d segments
- Main sequence stars later than F5, T-Tauri and RS Cvn
- `vari_rotation_modulation.best_rotation_period`
- `vari_rotation_modulation.max_activity_index_g`





Distefano et al. 2022

Queries using the Gaia archive: https://gea.esac.esa.int/archive/

- Retrieve 100 random results of Teff, logg, and sourceID from Gaia DR3 with teff < 6000

```
select top 100 teff_gspphot, source_id
from gaiadr3.gaia_source
where teff_gspphot > 6000
and random_index < 10000
```

- Retrieve the same as above but also a spectroscopic determination of teff:

  (need to cross-match on the astrophysical_parameters table, and need to tell the query which tables teff_gspphot and source_id are from because they are present in both)

```
select top 100 gs.teff_gspphot, gs.source_id, ap.teff_gspspec
from gaiadr3.gaia_source as gs
inner join gaiadr3.astrophysical_parameters as ap on ap.source_id = gs.source_id
where gs.teff_gspphot > 6000 and gs.teff_gspphot < 8000 and teff_gspspec < 8000
and random_index < 10000000
```

- Using an external table (upload myfavouritetable.txt to my userspace)

```
○ Select gs.teff_gspphot, gs. source_id, xt.radius
○ inner join gaiadr3.astrophysical_parameters as ap on ap.source_id = gs.source_id
  →     inner join user_ocreevey.myfavouritetable.txt as xt on xt.source_id = gs.source_id
```

Summary

- You should care about stellar parametrisation
- Stellar observations ≠ stellar parameters
- Various methods for determining parameters, some model-independent, many not
- Characterisation of the interstellar medium and distance is critical
- Main parameters: teff, logg, [M/H], abundances, mass, radius, luminosity, age, rotation
- Mass, radius and age from “isochrone fitting” often neglects important systematic errors
- Important independent observations from asteroseismology to pin down density, logg, radius, mass, age
- Interest in Gaia observations for stellar characterisation
- Availability of many astrophysical parameters of interest in Gaia DR3 – but look beyond gaia_source, there are over 40 new tables in Gaia DR3 and gaia_source is only 1 table

https://youtu.be/oGqSgBIJtZ0