Gaia - physical parameters for one billion stars

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Summary

- Gaia catalogue will contain physical parameters for ~1 billion sources
- parameters mostly stellar T_{eff}, log g, metallicity
- based on large grid of model stellar spectra assuming 1D+LTE
- Gaia-SAM group explores more realistic Stellar Atmosphere Models for benchmark stars
  - solar type metal-poor star HD 19445: Ca II 850 nm abundance in non-LTE is ~0.1 dex lower than in in LTE
  - solar type metal-rich star α Cen A: Fe abundance in 3D is ~0.1 dex lower than in 1D

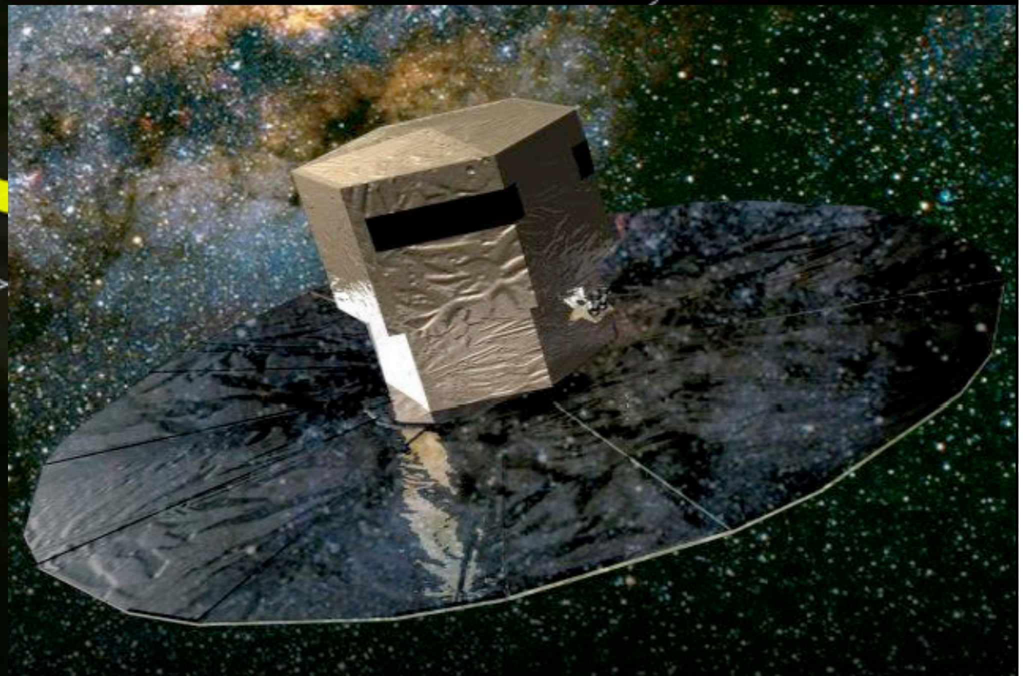
I – Gaia

- Gaia mission
- Gaia science goals
- Gaia instruments and observations

Gaia mission objectives

- Mapping the Milky Way Galaxy in **six dimensions**
- **Positions** of ~1 billion stars
  - scanning satellite with two viewing directions
  - limiting magnitude = 20
  - accuracy down to 20 μas
- **Space velocities** of Galactic stars
  - proper motions for all stars
  - radial velocities for objects brighter than 17th mag
- **Physical parameters** for all stars

Gaia mission characteristics



- ESA cornerstone mission
- Launch date: 2012
- Lissajous-type orbit around second Lagrange point
- Mission duration: 5 years, final catalogue ~2020

Science with Gaia

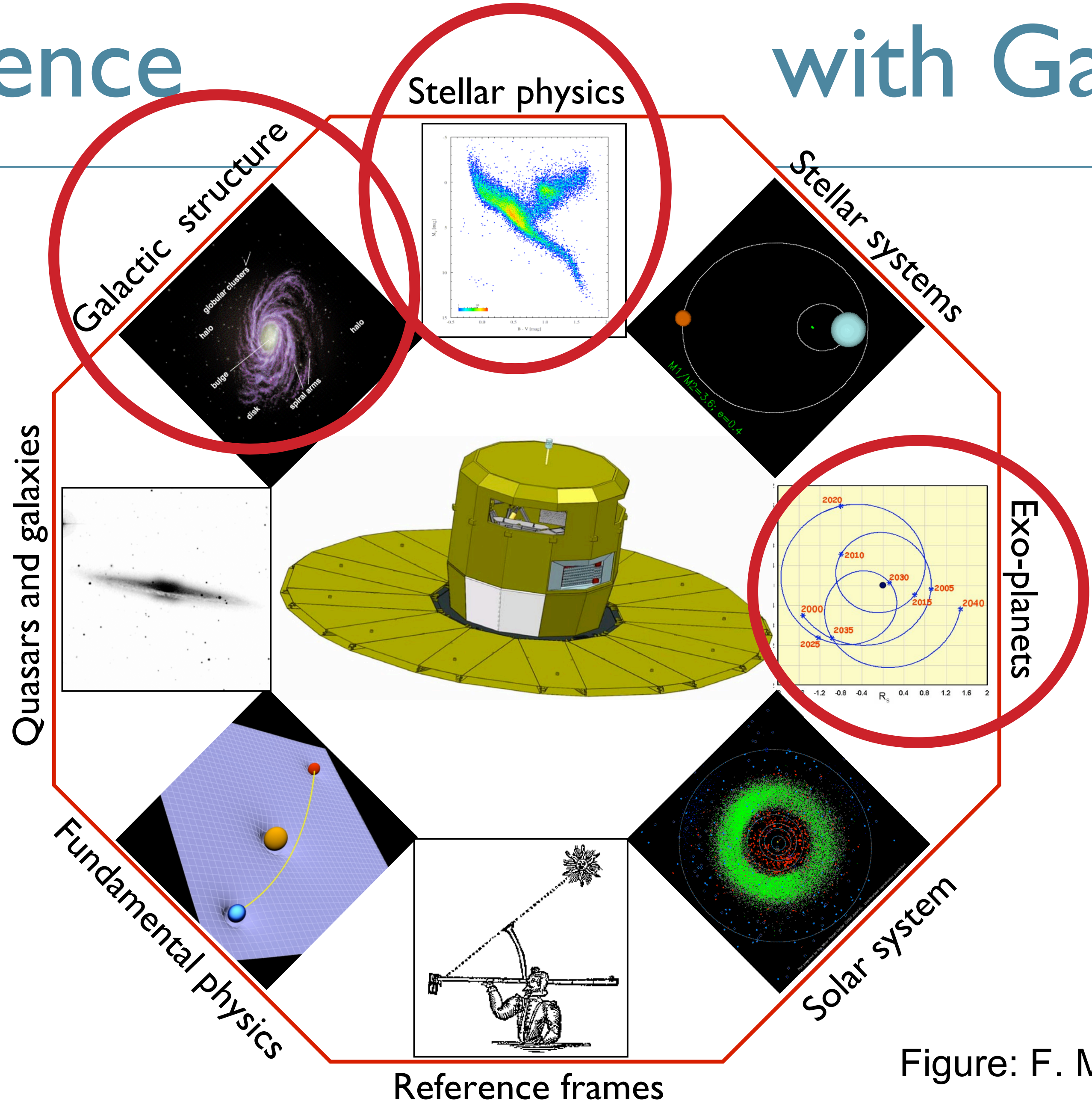
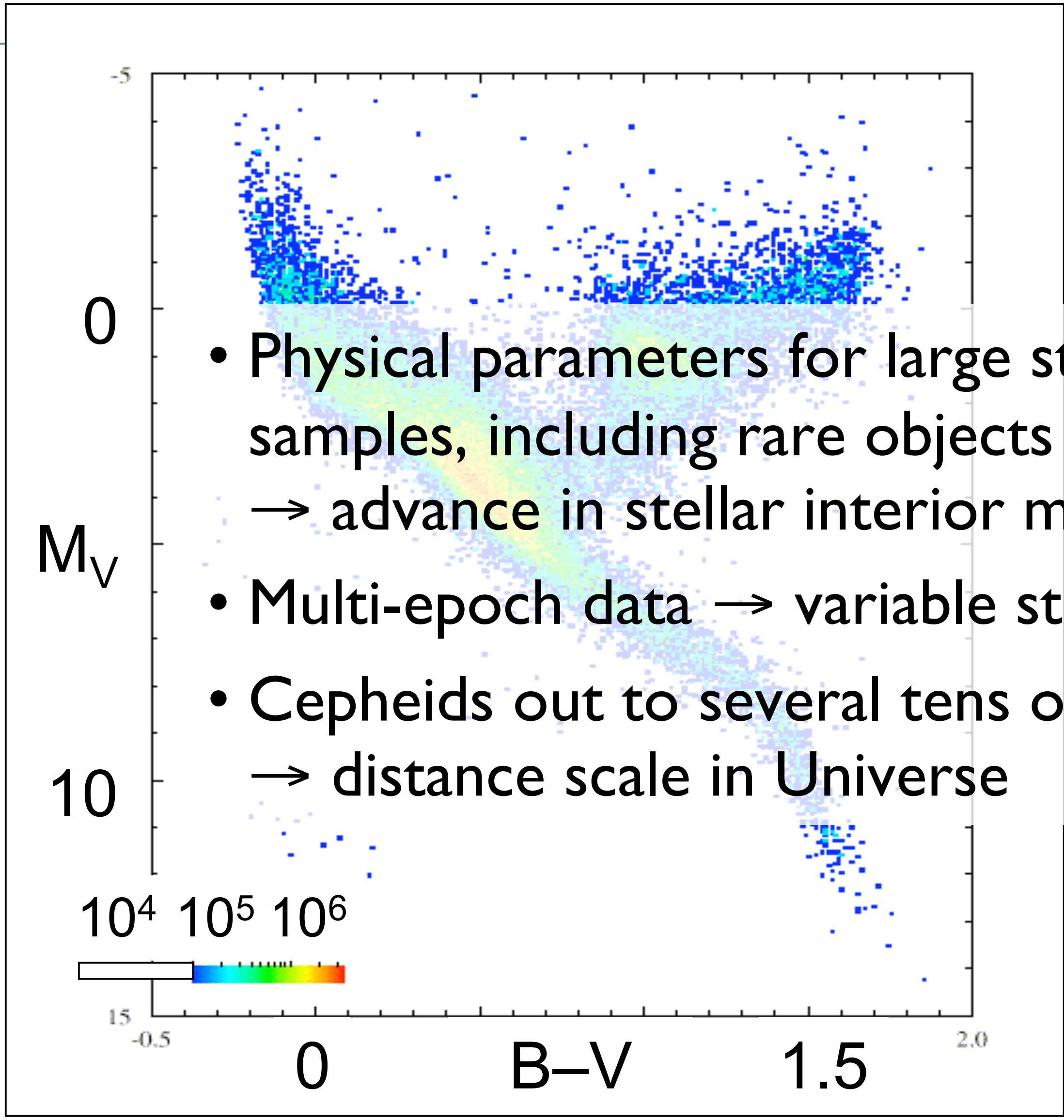


Figure: F. Mignard

Stellar physics



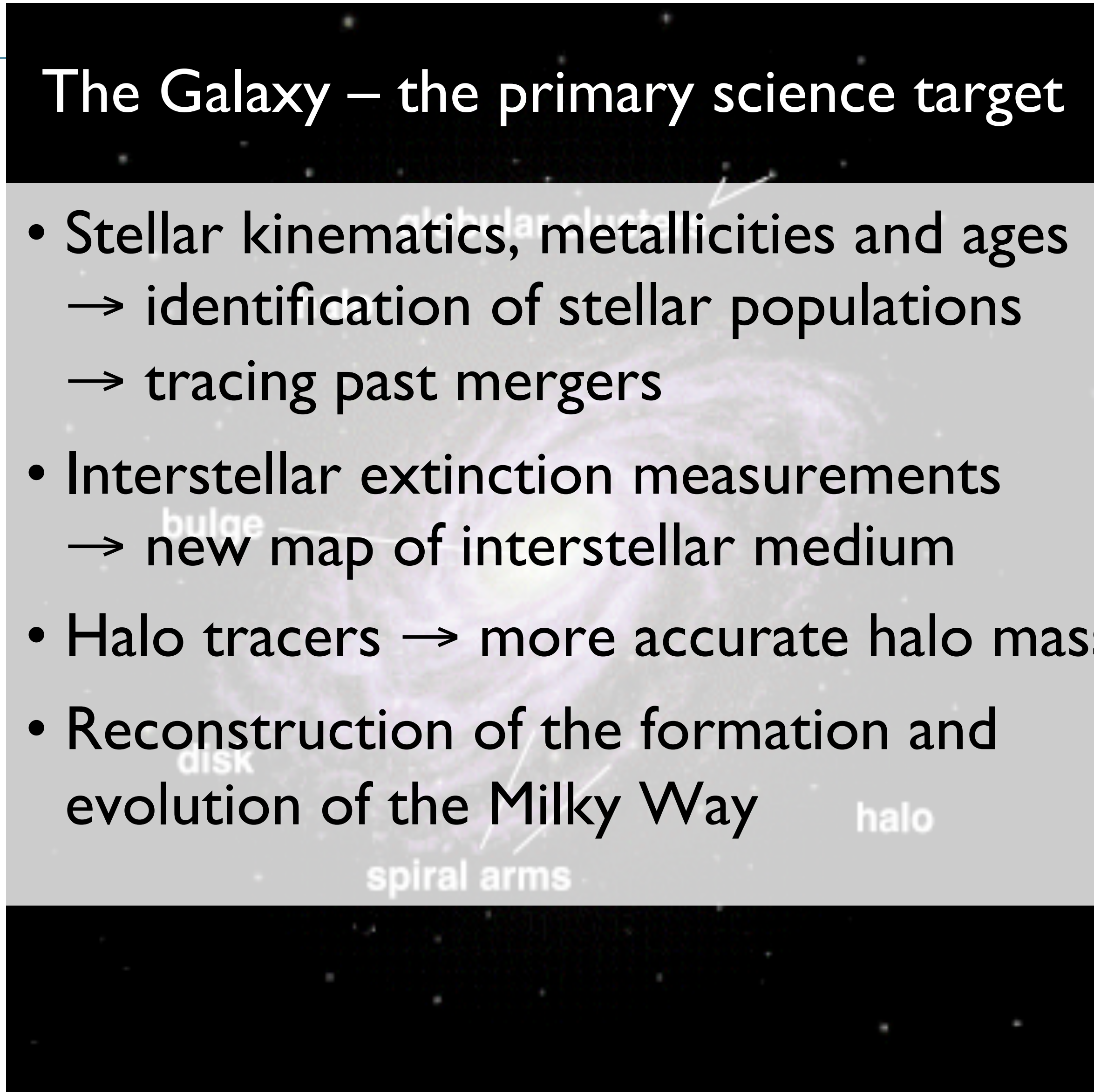
- Physical parameters for large stellar samples, including rare objects
  → advance in stellar interior models
- Multi-epoch data → variable star physics
- Cepheids out to several tens of kpc
  → distance scale in Universe

Gaia?

Stars with parallax error <20%

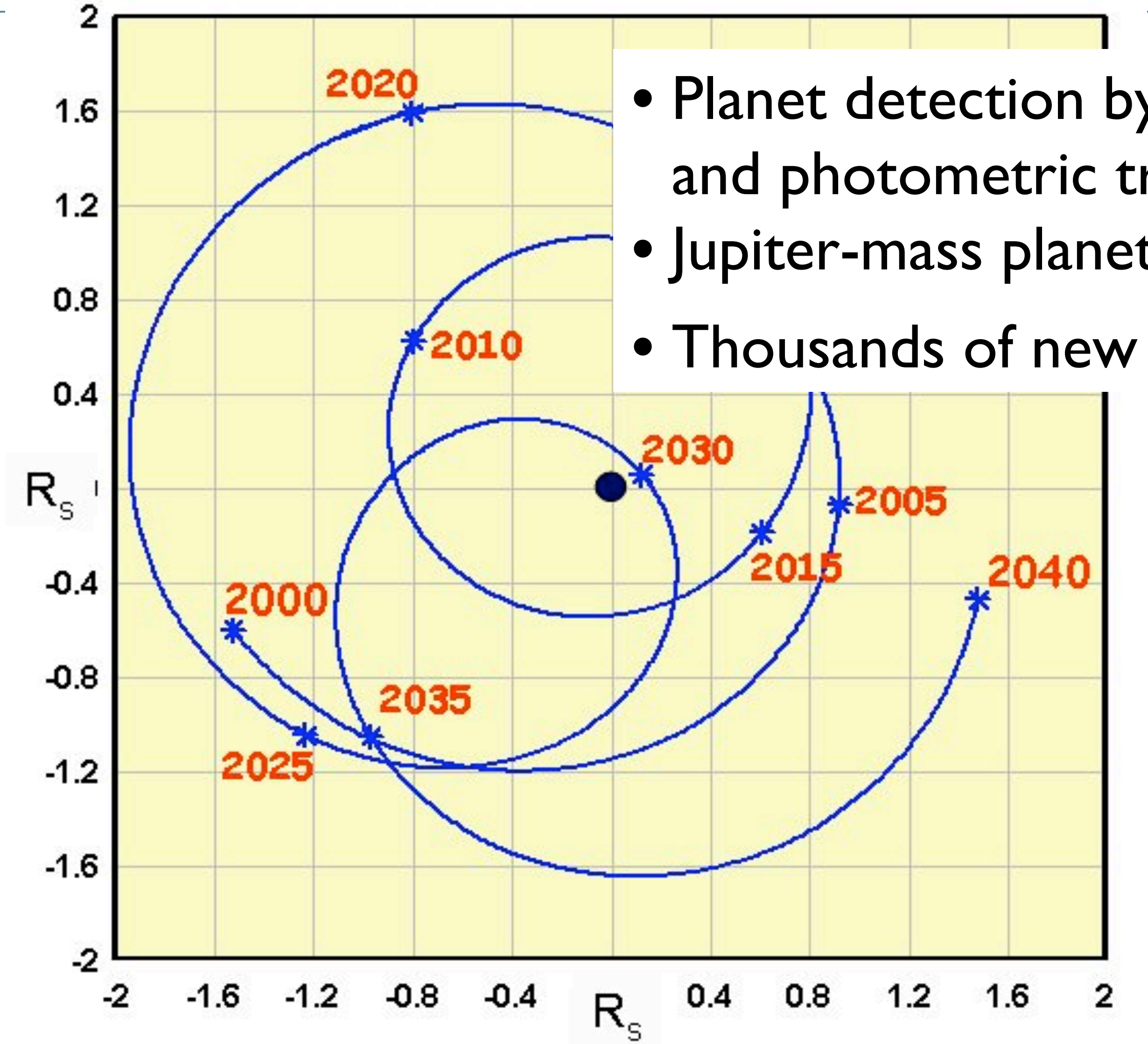
Galactic structure

The Galaxy – the primary science target



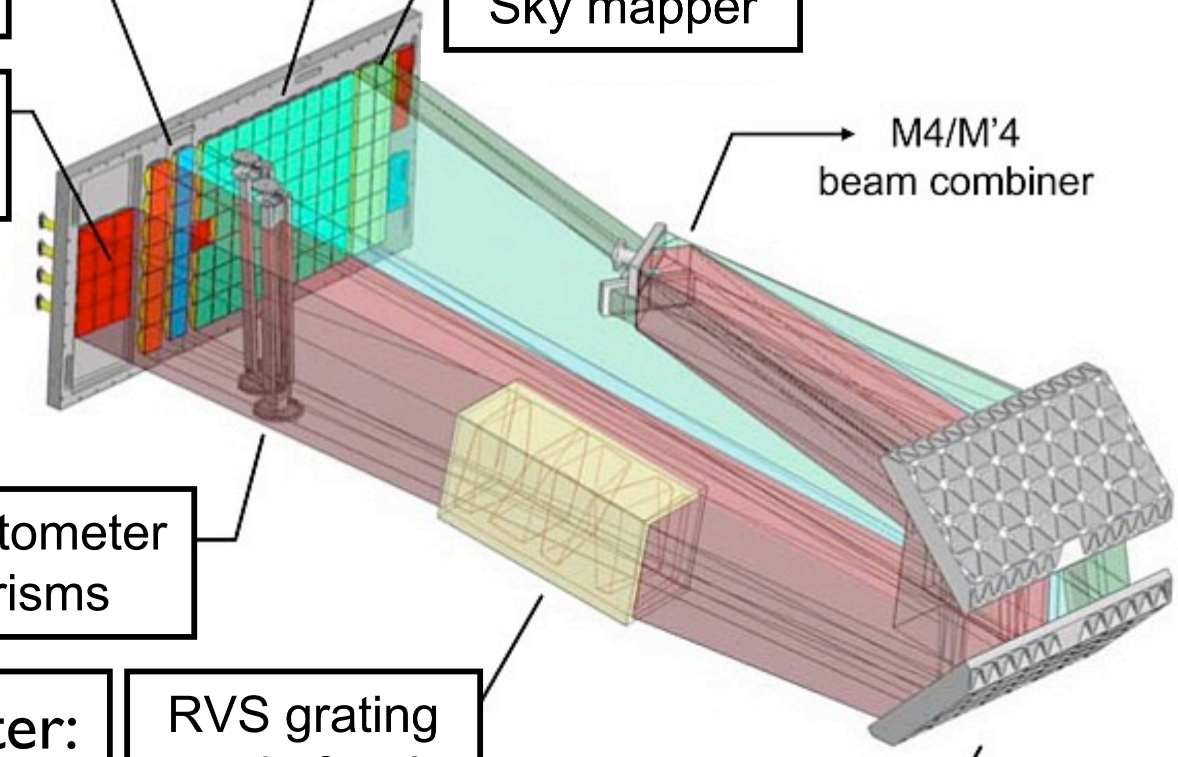
- Stellar kinematics, metallicities and ages
  → identification of stellar populations
  → tracing past mergers
- Interstellar extinction measurements
  → new map of interstellar medium
- Halo tracers → more accurate halo mass
- Reconstruction of the formation and evolution of the Milky Way

Extrasolar planets



- Planet detection by astrometry and photometric transits
- Jupiter-mass planets out to 200 pc
- Thousands of new planets

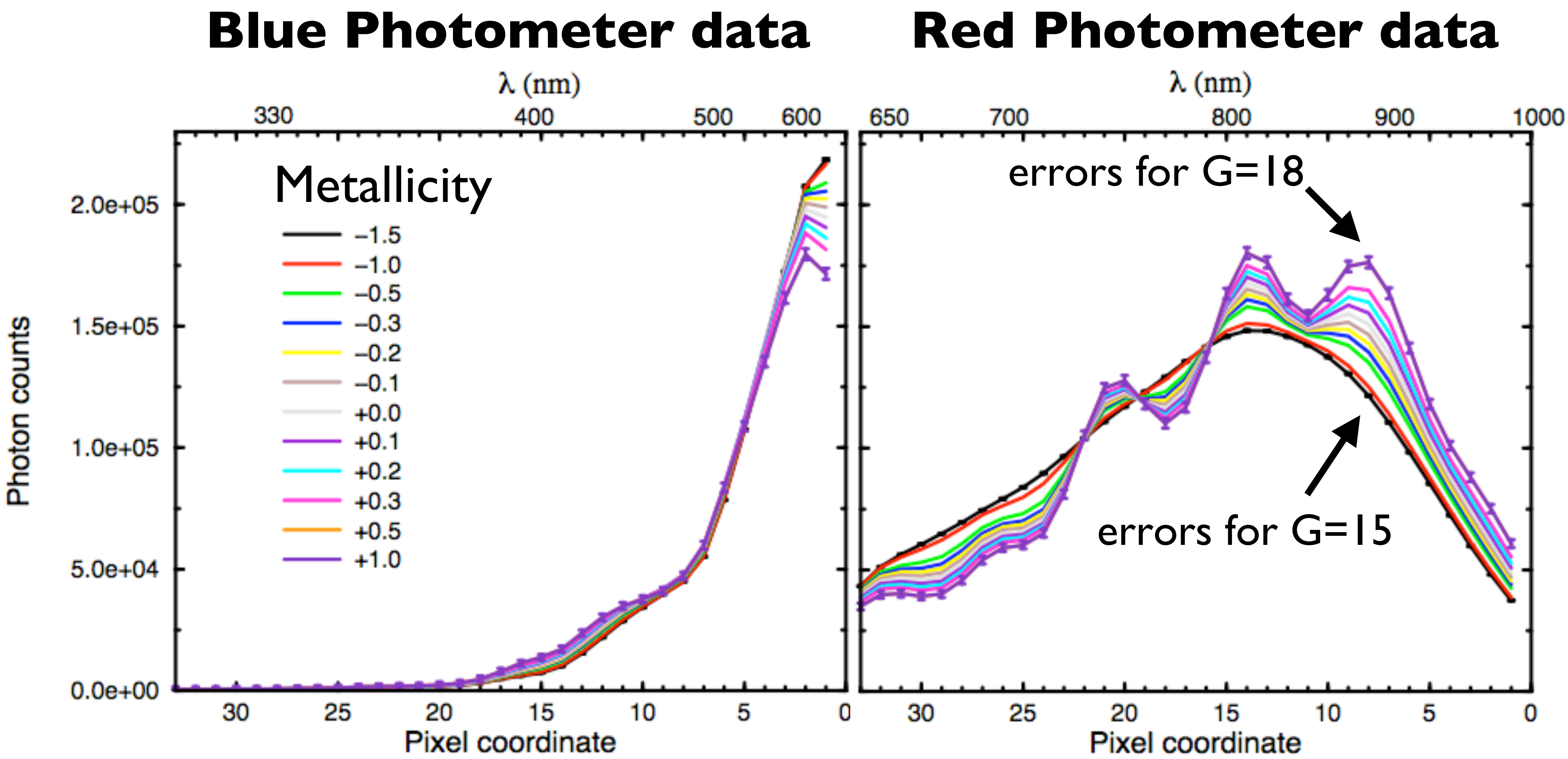
Gaia instruments



Blue photometer:
330–660 nm
Red photometer:
650–1000 nm

Radial Velocity Spectrometer:
847–874 nm (CaII triplet)
resolution 11,500

Simulated PB/RP data for T_{eff}=3500 K



Figures: Carme Jordi et al.

Simulated RVS data

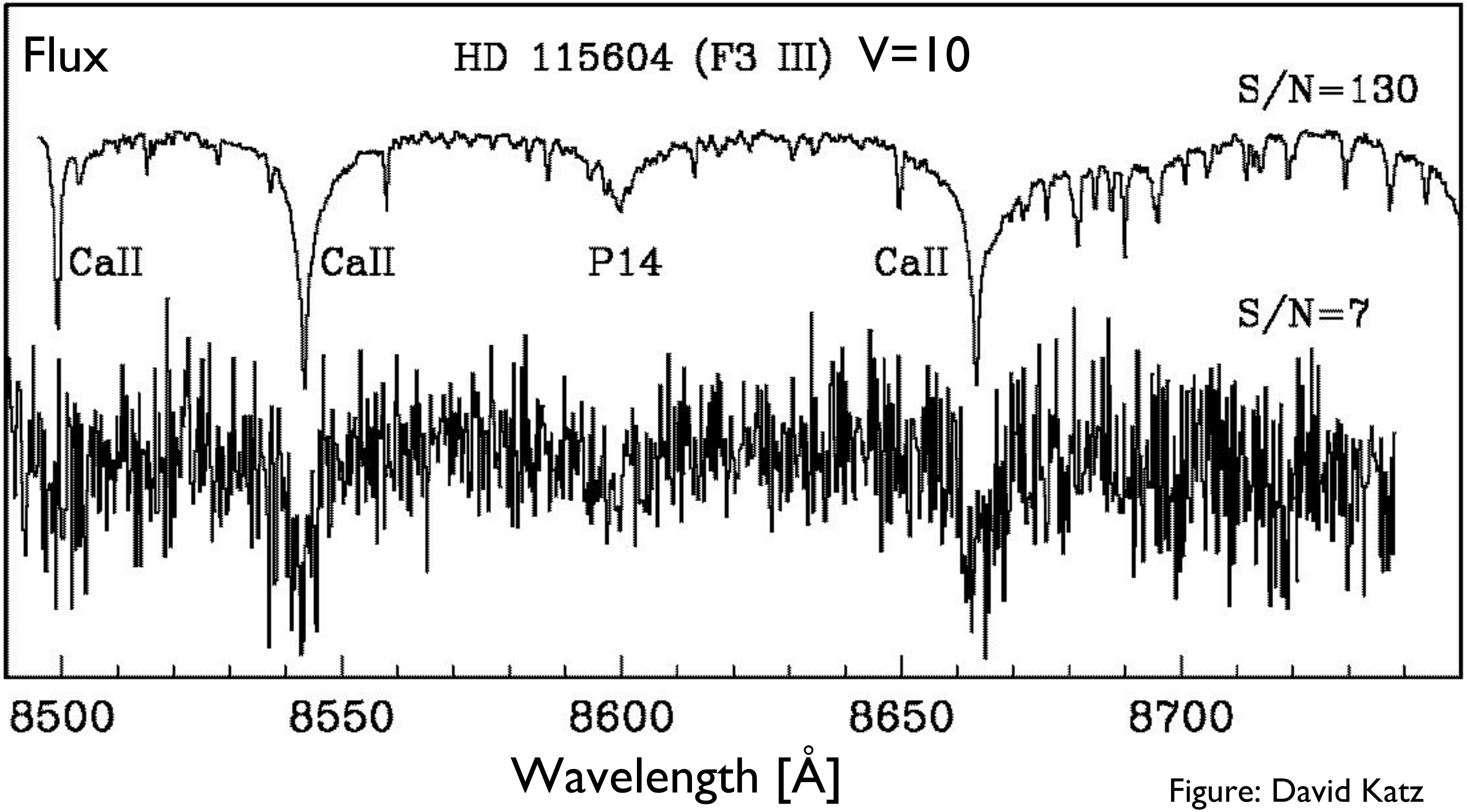
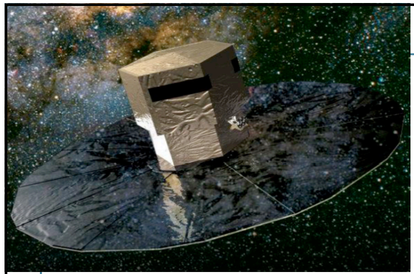
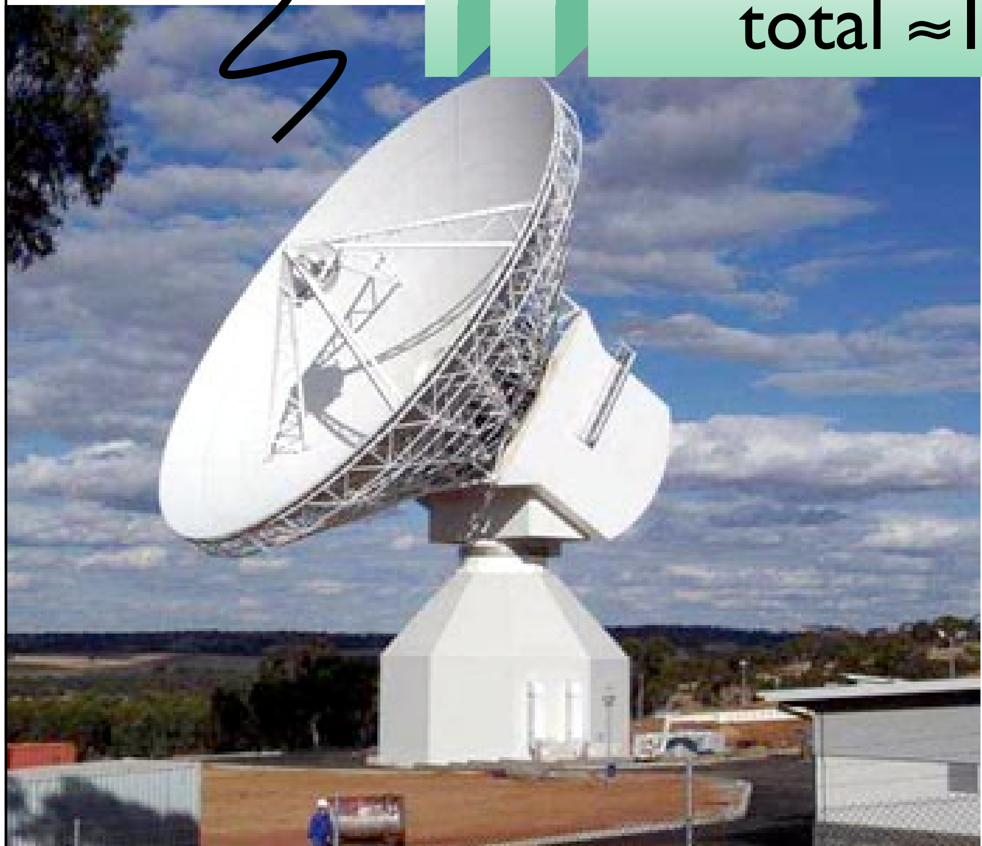


Figure: David Katz

Data processing and analysis





Raw data, 50 GB/day
total ≈100 TB

Gaia Main Data Base

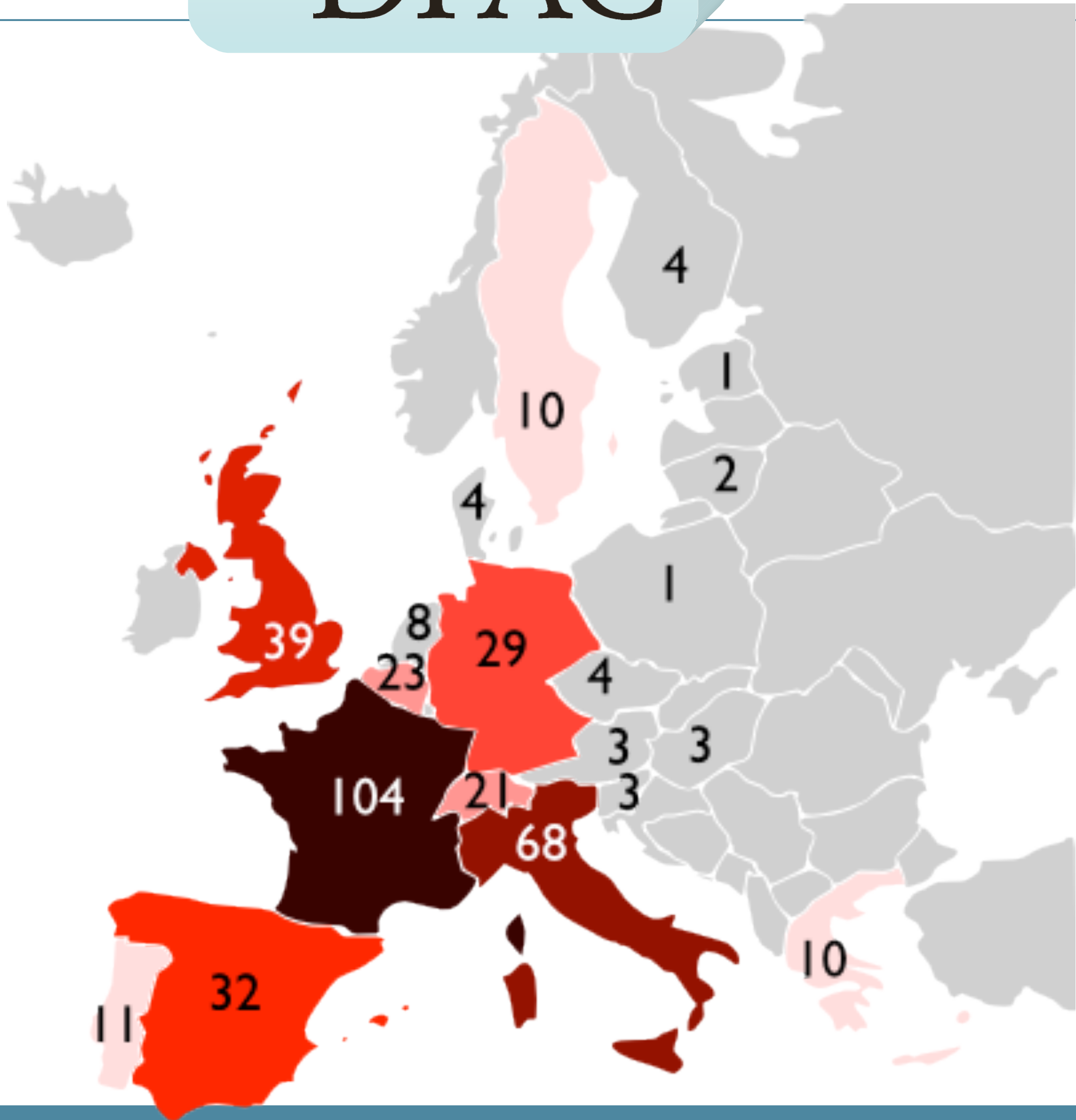
Gaia DPAC

Data Processing and Analysis Consortium

Final scientific data

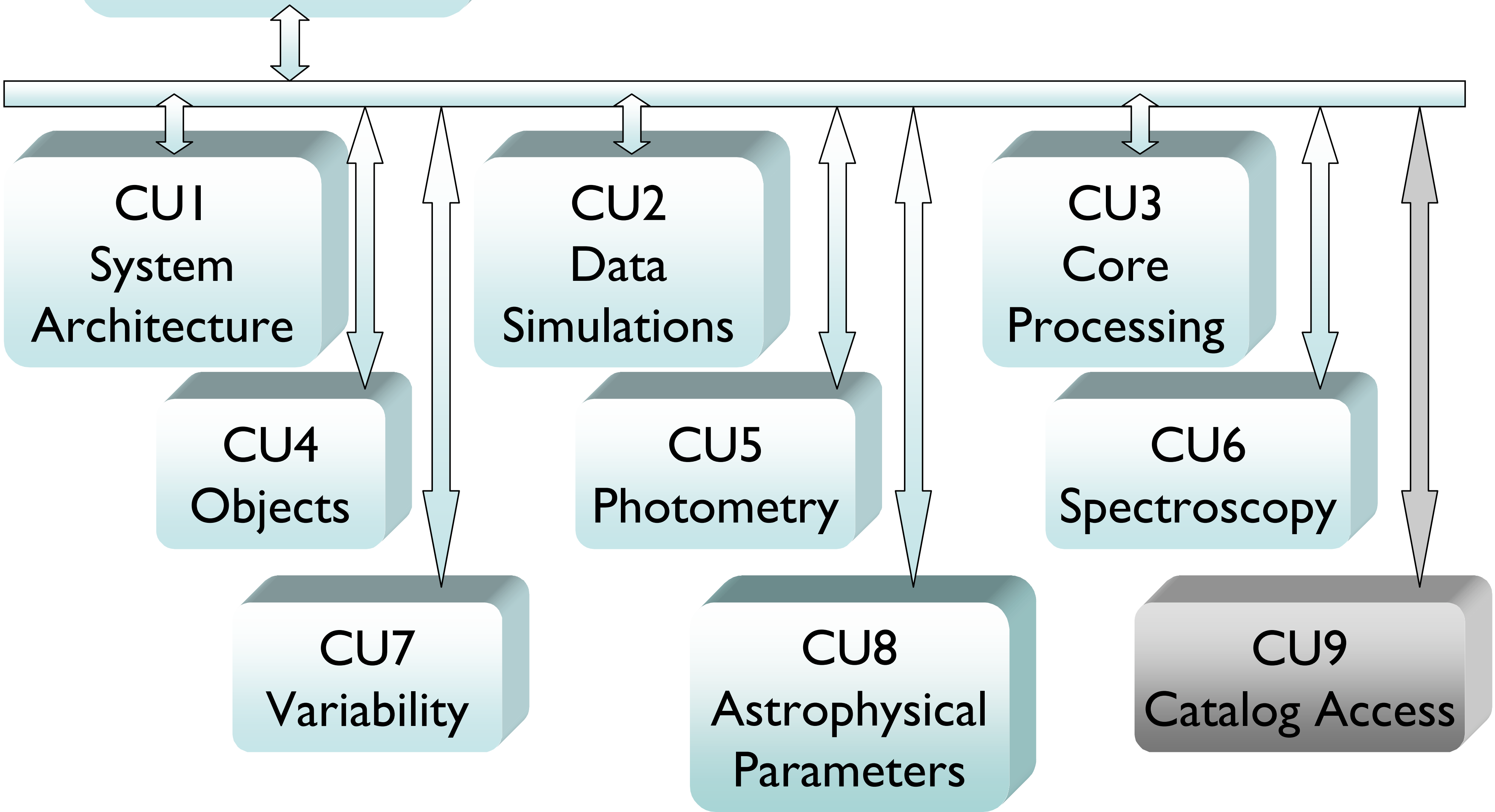
Gaia DPAC

members

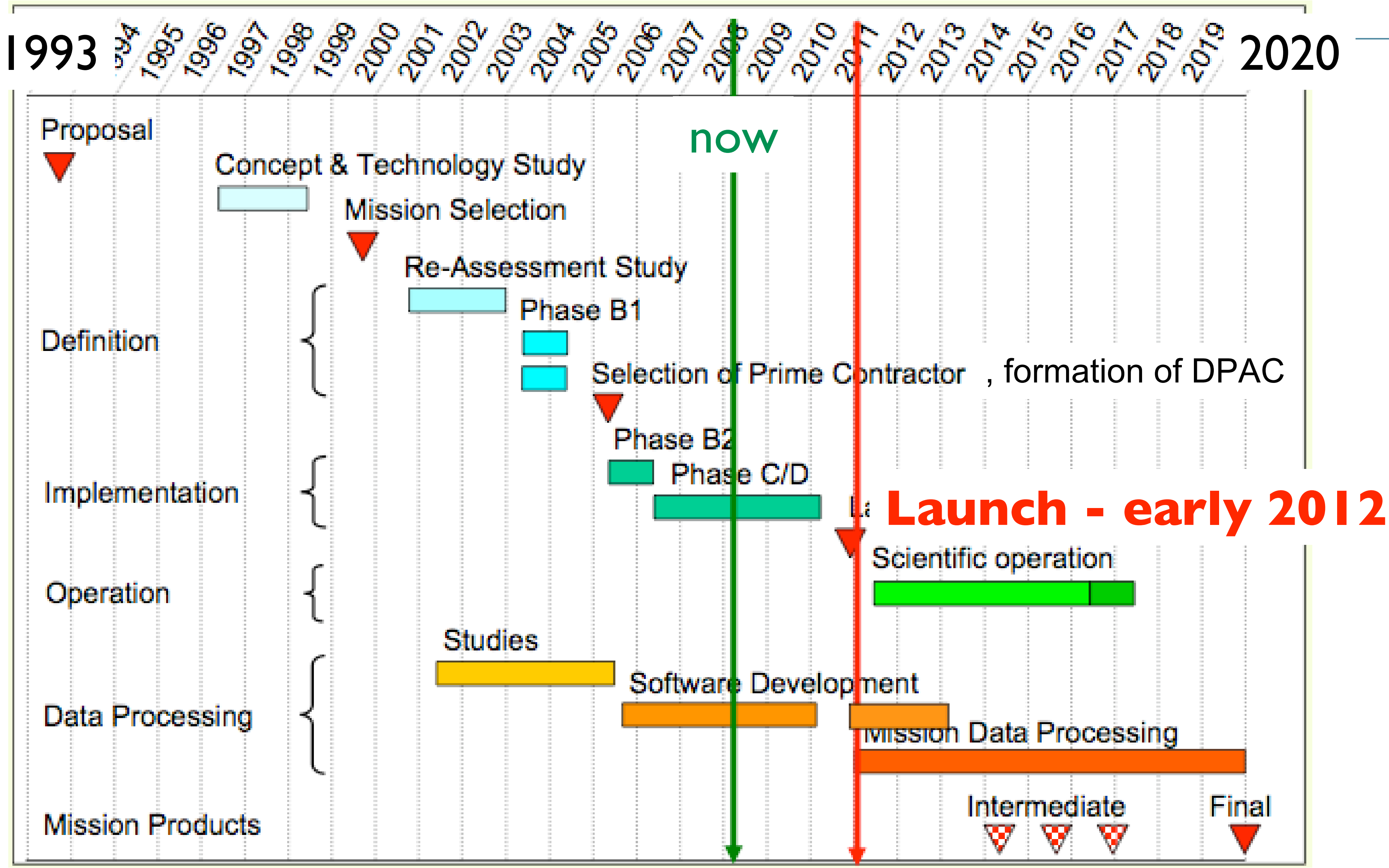


+ 29 at ESA
+ 10 outside Europe

Gaia DPAC organization



Gaia schedule



II – Astrophysical Parameters

- Astrophysical parameter determination for Gaia sources
- Gaia grid of synthetic stellar spectra
- MARCS grid of spectra

CU8 – Astrophysical Parameters

- **Objectives**
  - **Classify** all sources → probabilities for being star, galaxy, quasar, etc.
  - Determine **astrophysical parameters** → T_{eff}, log g, metallicity, α elements, extinction, …
- ***Software development***
  - "General Stellar Parametrizer" will use BP/RP and RVS spectra, trained on model stellar spectra
- ***Provide data for training and calibration***
  - e.g. synthetic and observed stellar spectra

Gaia grid of synthetic stellar spectra

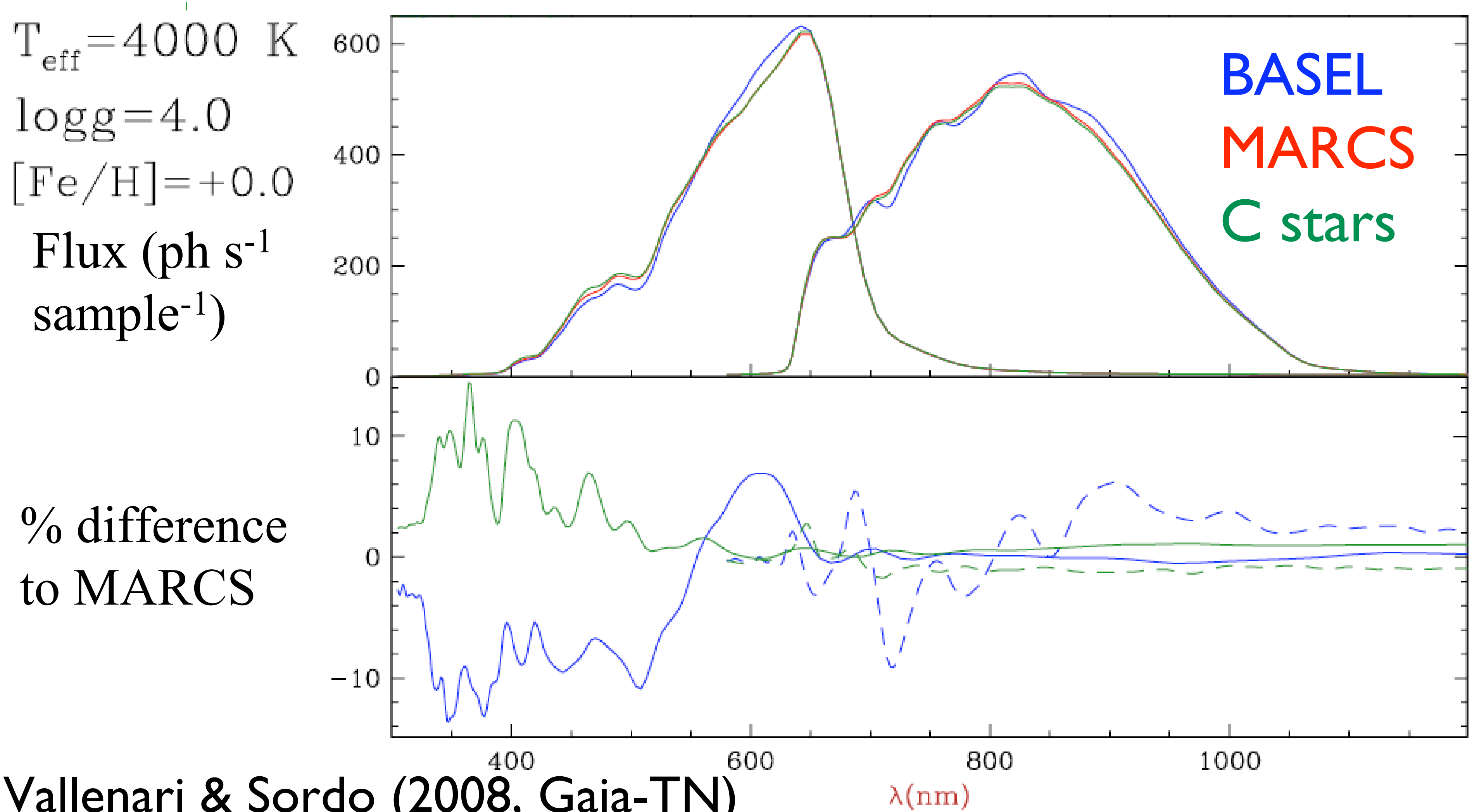
- Covering HR diagram and large metallicity range

	Teff	logg	[Fe/H]
min	3000 K	–0.5	–5
max	50000 K	+5.5	+1

+ white dwarfs

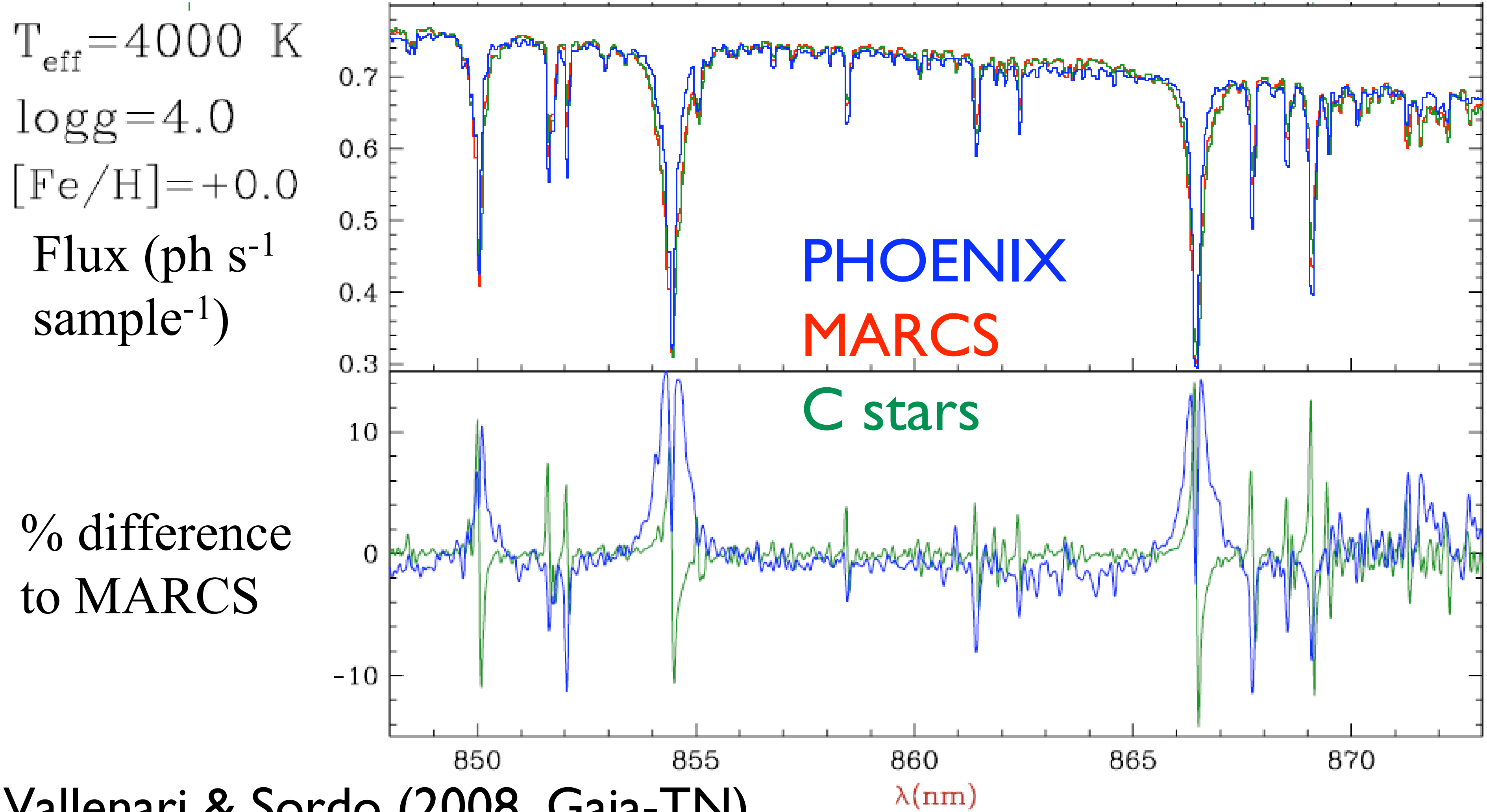
- Spectra for 2 wavelength ranges and resolutions: BP/RP and RVS, most in 1D and LTE
- Provided by several different groups and codes
- Cool stars (4000–8000 K): BASEL, MARCS, C stars (older MARCS), PHOENIX

Gaia spectra simulations – BP/RP



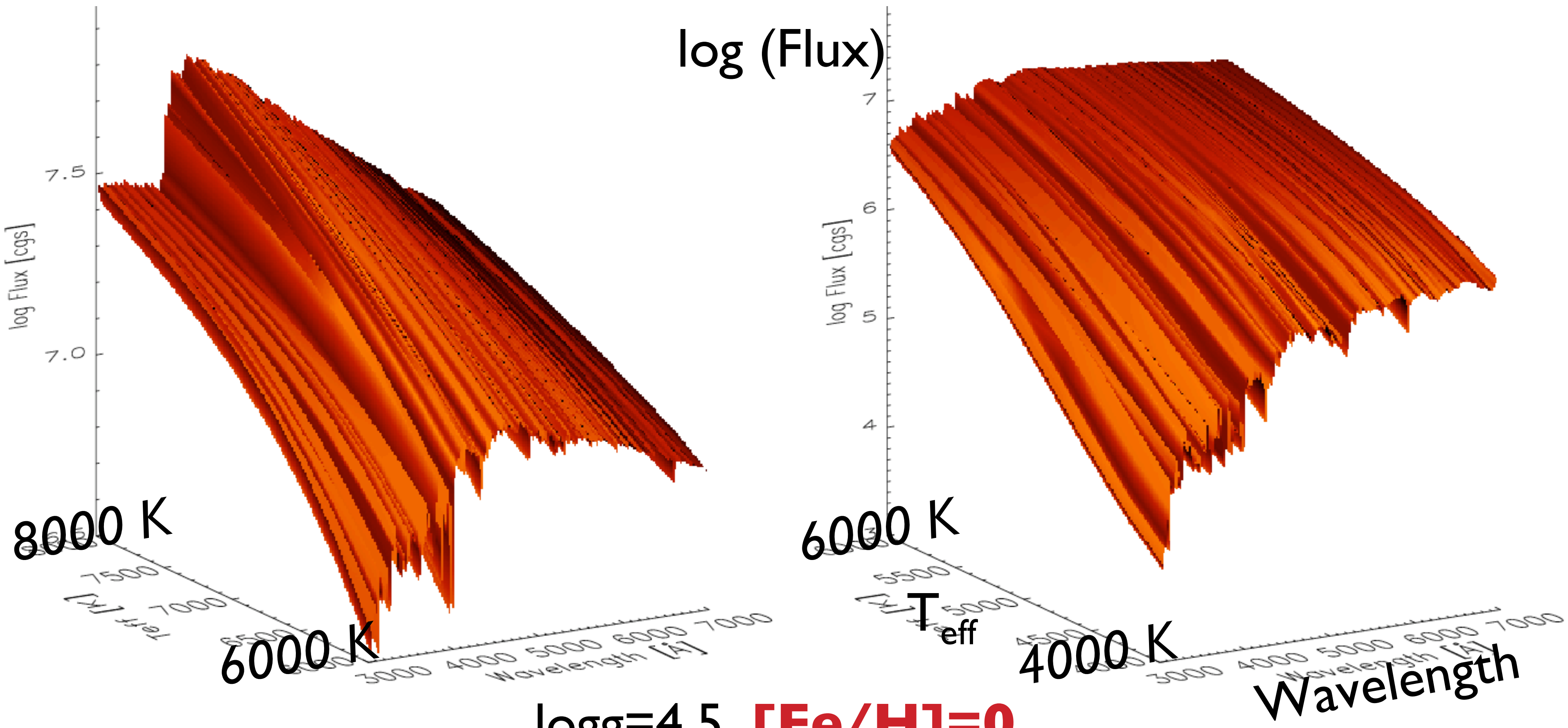
Vallenari & Sordo (2008, Gaia-TN)

Gaia spectra simulations – RVS



Vallenari & Sordo (2008, Gaia-TN)

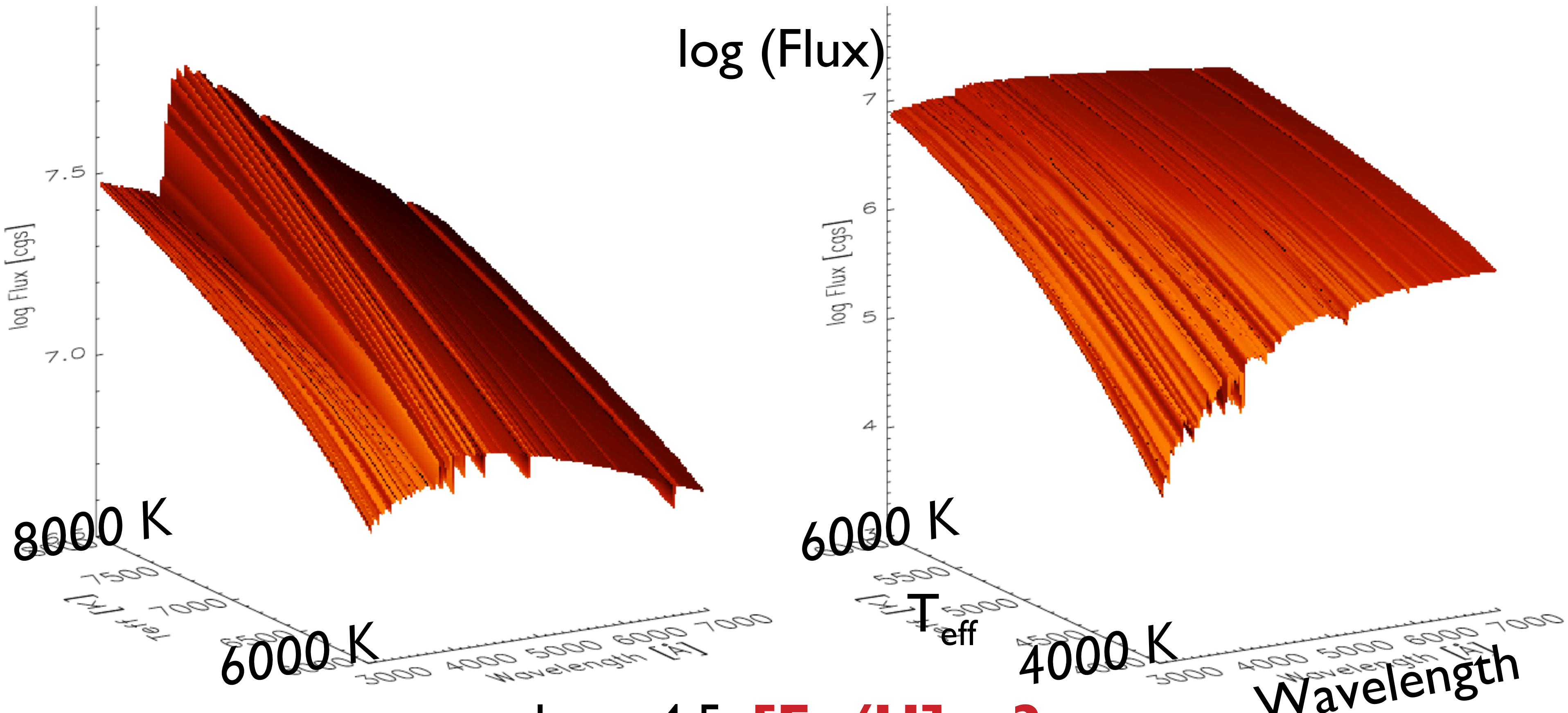
MARCS grid of stellar spectra



logg=4.5, **[Fe/H]=0**

Gustafsson et al. (2008), http://marcs.astro.uu.se

MARCS grid of stellar spectra



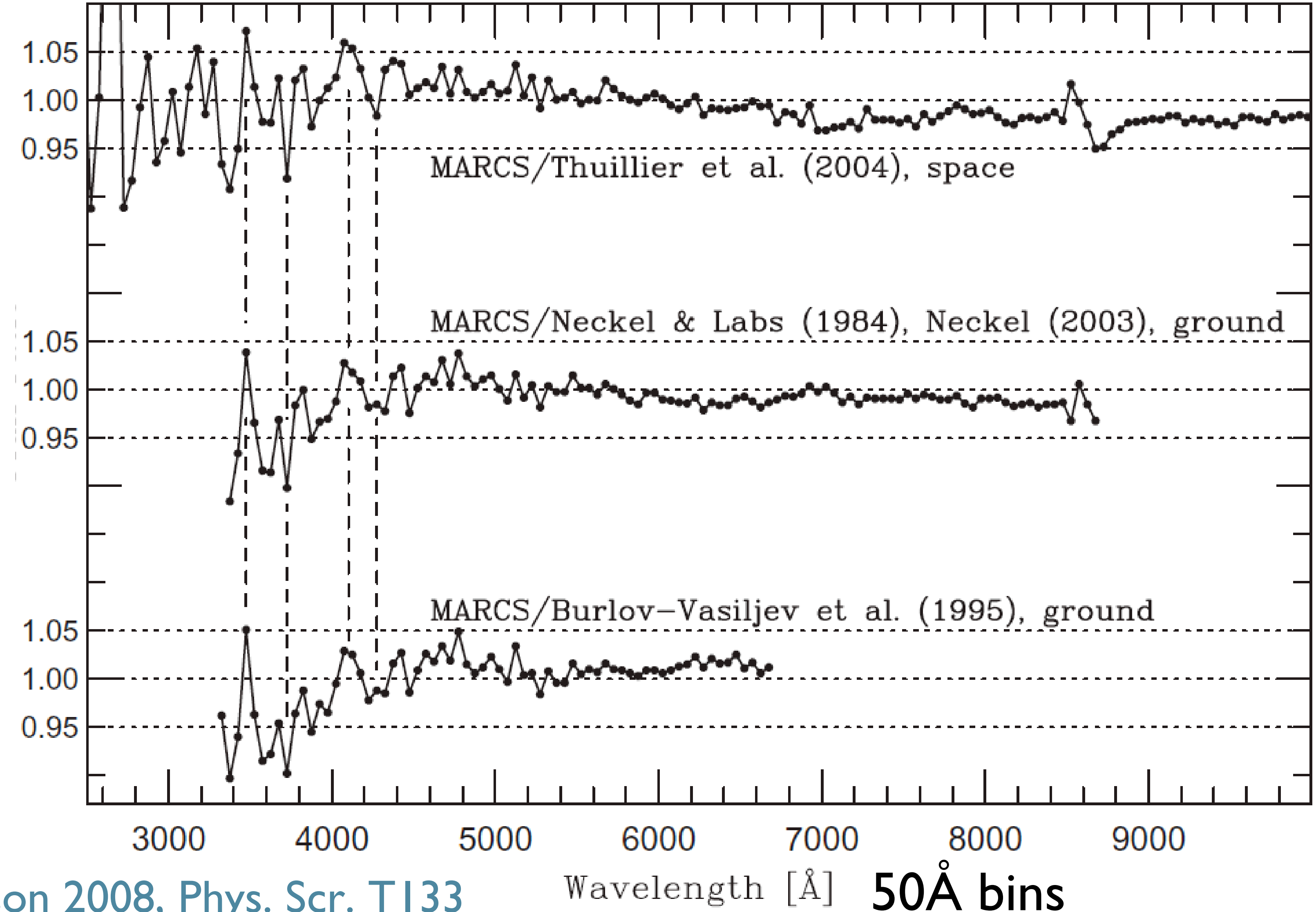
logg=4.5, **[Fe/H]=–3**

Gustafsson et al. (2008), http://marcs.astro.uu.se

MARCS model flux ↔ observations

Sun

Flux ratio

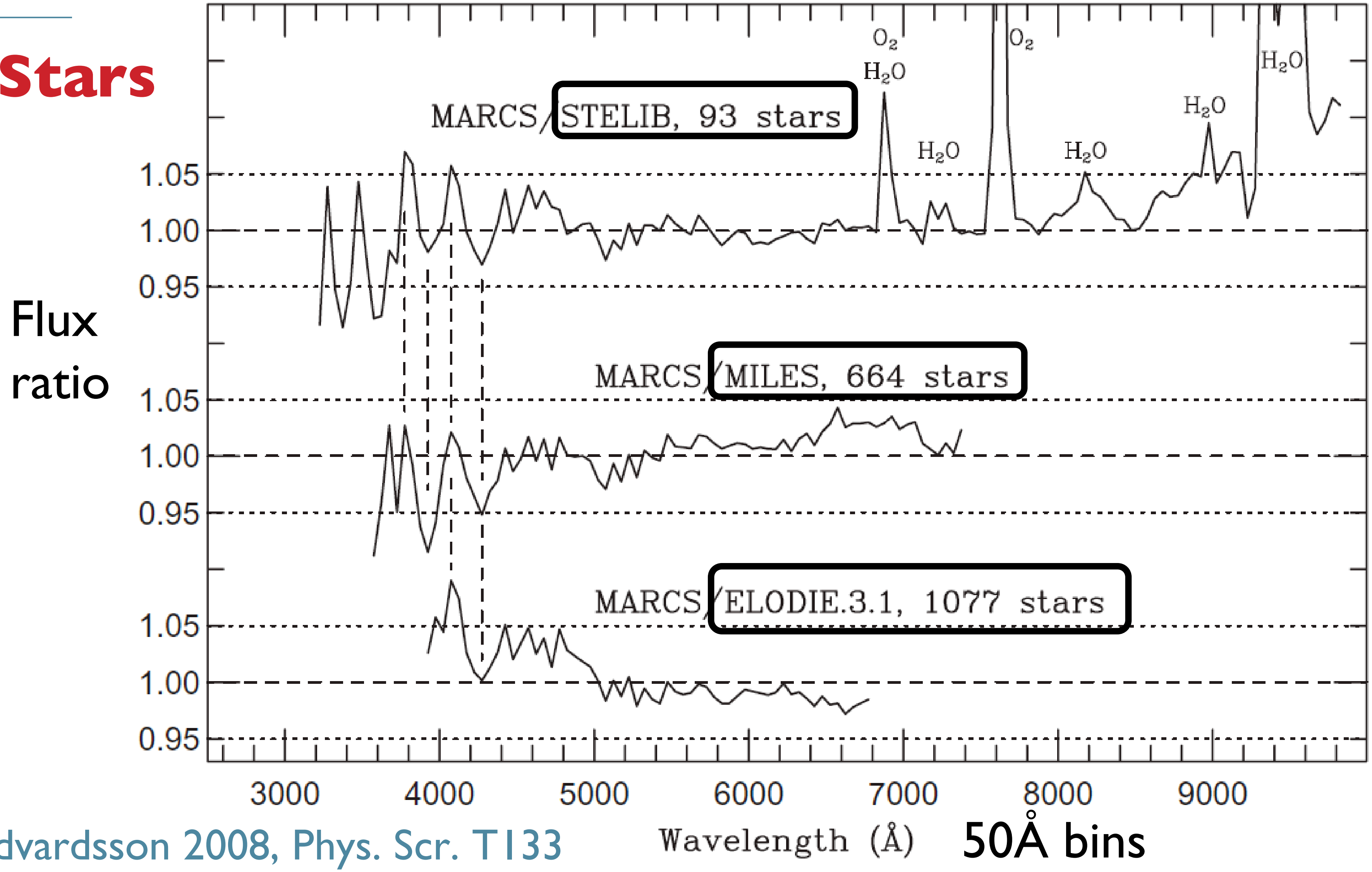


Edvardsson 2008, Phys. Scr. T133

50Å bins

Example: MARCS flux distributions

Stars



Edvardsson 2008, Phys. Scr. T133

III – Validation of stellar models

- Benchmark stars program – Gaia-SAM group
- Benchmark star candidates
- Model validation methods
- Available observations – archives and new
- Examples
  - 1D non-LTE: metal-poor stars
  - 3D-LTE: α Cen A
  - 1D-LTE, optical vs RVS: δ Eri

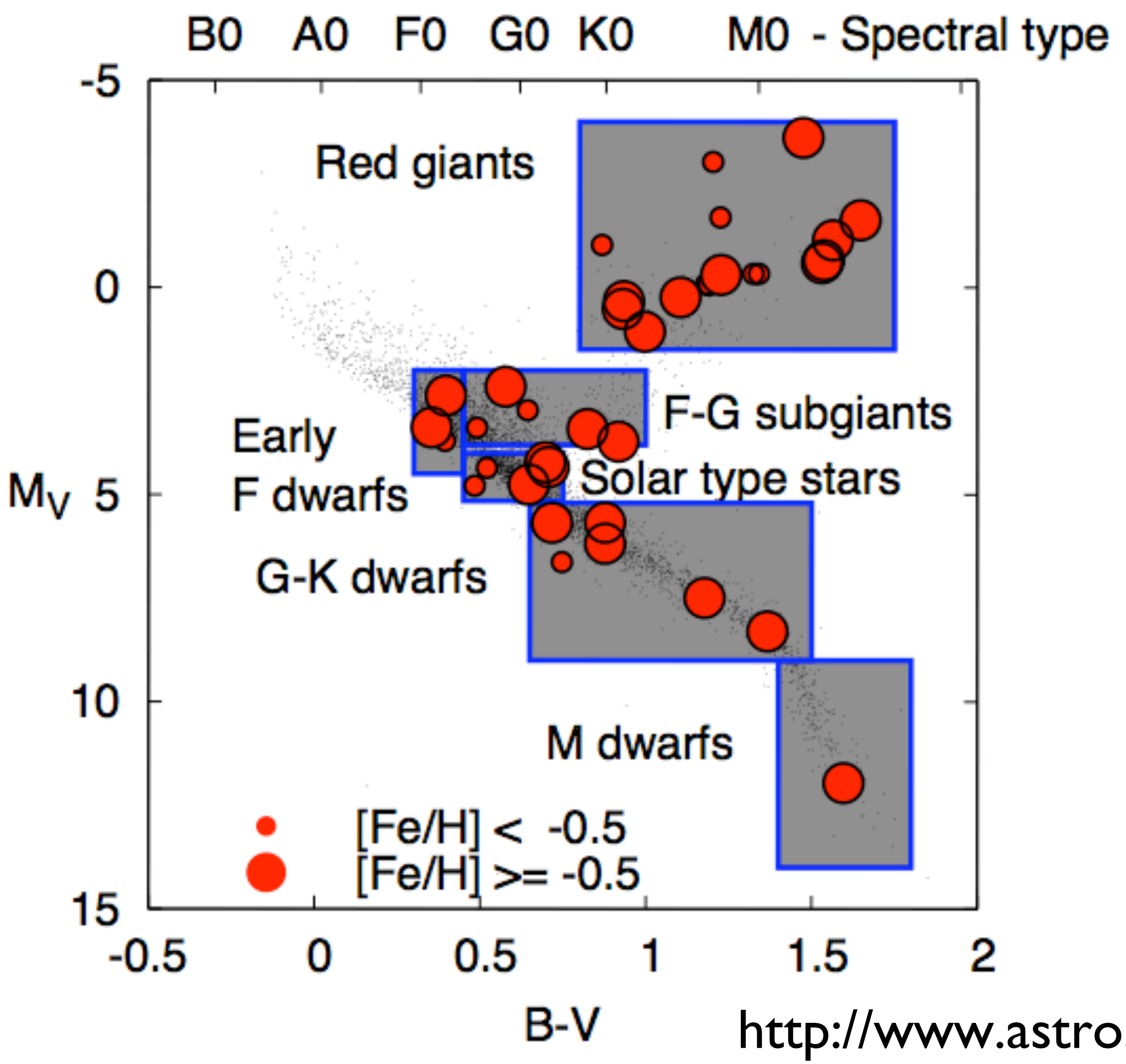
Benchmark stars

- **are carefully selected bright stars**
  - well-known physical properties;
    astrophysical parameters determined with high precision,
    several independent methods
- **are used for validation of models**
  - compare dedicated high-quality observations with synthetic spectra and other observables
  - decide on changes of stellar atmosphere models and synthetic spectra
  - derive error estimates for current models

Gaia-SAM group

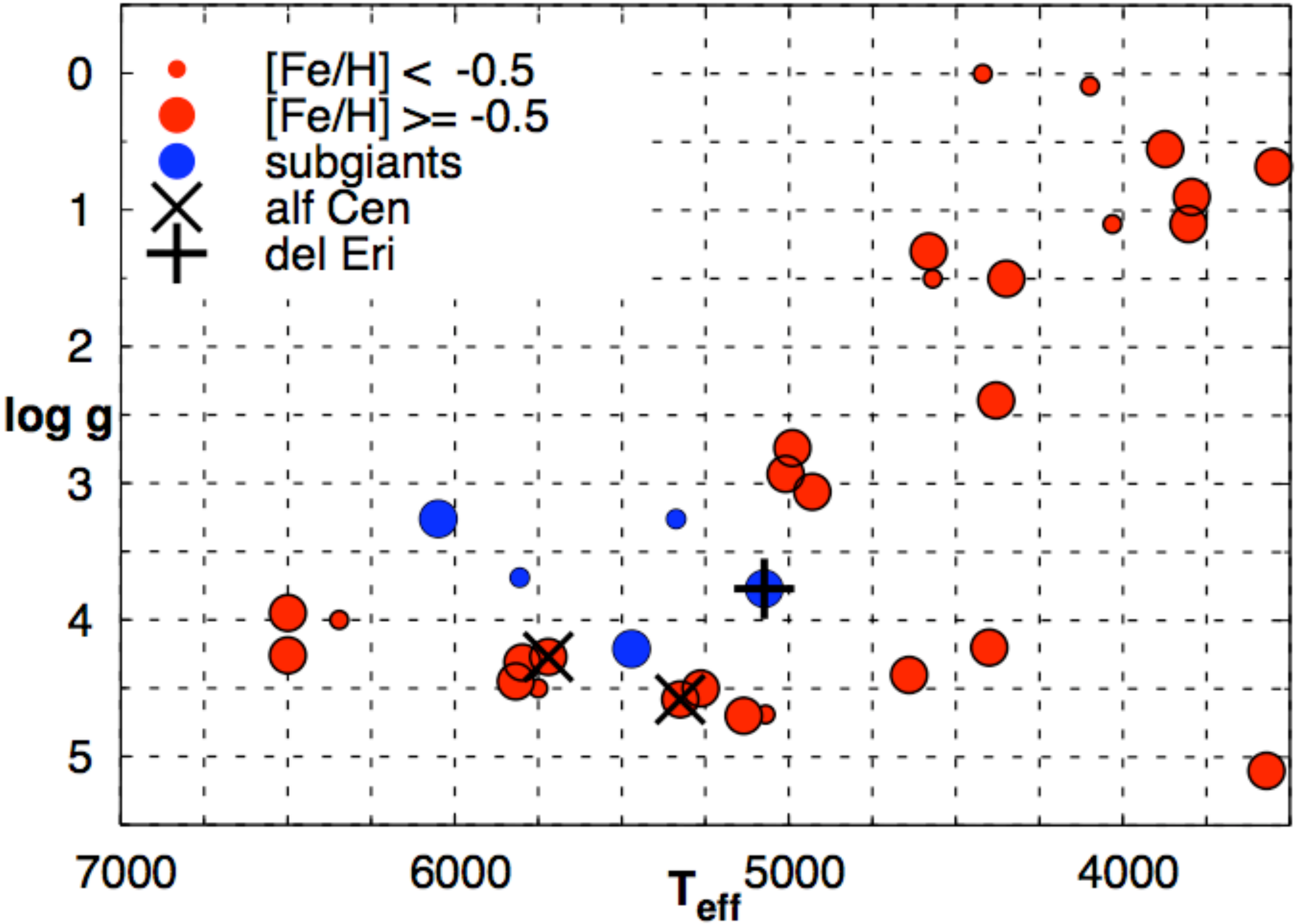
- Identify and develop realistic *stellar atmosphere models* applicable to Gaia, using **benchmark stars**
- **Model physics – focusing on**
  - radiation-hydrodynamics in 3D
  - non-LTE spectral line formation
  - improved spectral line data
- Parameters – focusing on **cool stars** – $T_{eff} \leq 6500$ K
- **People**: *Uppsala* – A. Korn, P. Barklem, B. Edvardsson, B. Gustafsson, *Nice* – F. Thévénin, L. Bigot, *Paris-Meudon* – N. Feautrier et al., P. Kervella

Benchmark star candidates



http://www.astro.uu.se/~ulrike/GaiaSAM

Benchmark star candidates



Model validation

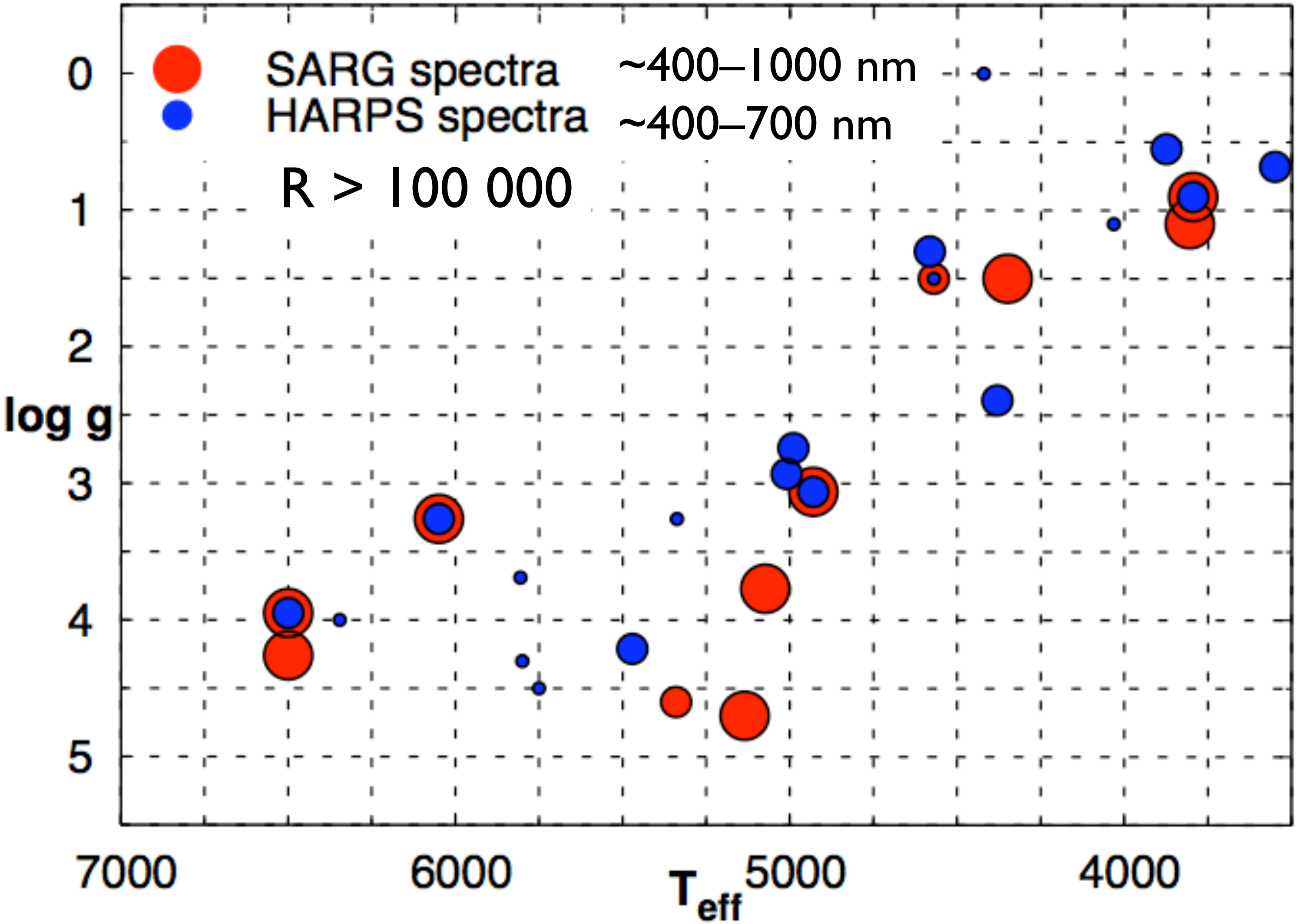
tests planned and observations needed

- **Flux calibrated spectra**
  - flux distributions
  - individual strong features – spectral indices
- **High-res spectra + interferometry**
  - **metallicity / abundances**
  - limb darkening
  - line profiles

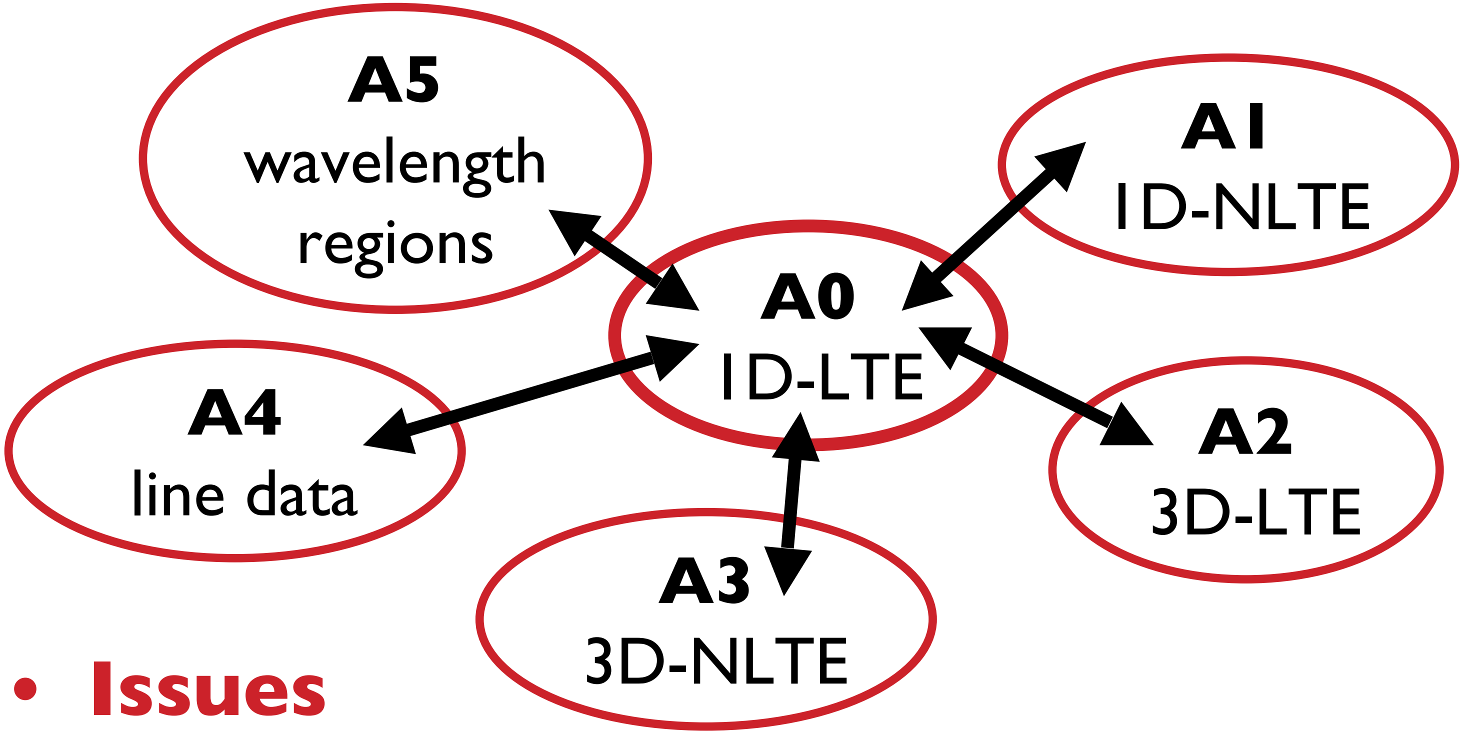
Observations

- **Archives:**
  - high-res spectroscopy (R >50 000) for most stars, mostly R <100 000 and wavelength < 800 nm
  - flux libraries – ELODIE, MILES, STELIB, CFLIB, Gray, …
- **New:** very high-res spectroscopy
  - HARPS – 3.6m – ESO – 21 stars, 2007/2008
  - SARG – TNG – La Palma – 11 stars, 2007+2009
- **New - planned**
  - high-res spectroscopy: NARVAL – TBL – Pic du Midi
  - spectrophotometry and photometry

New observations - high-res spectra

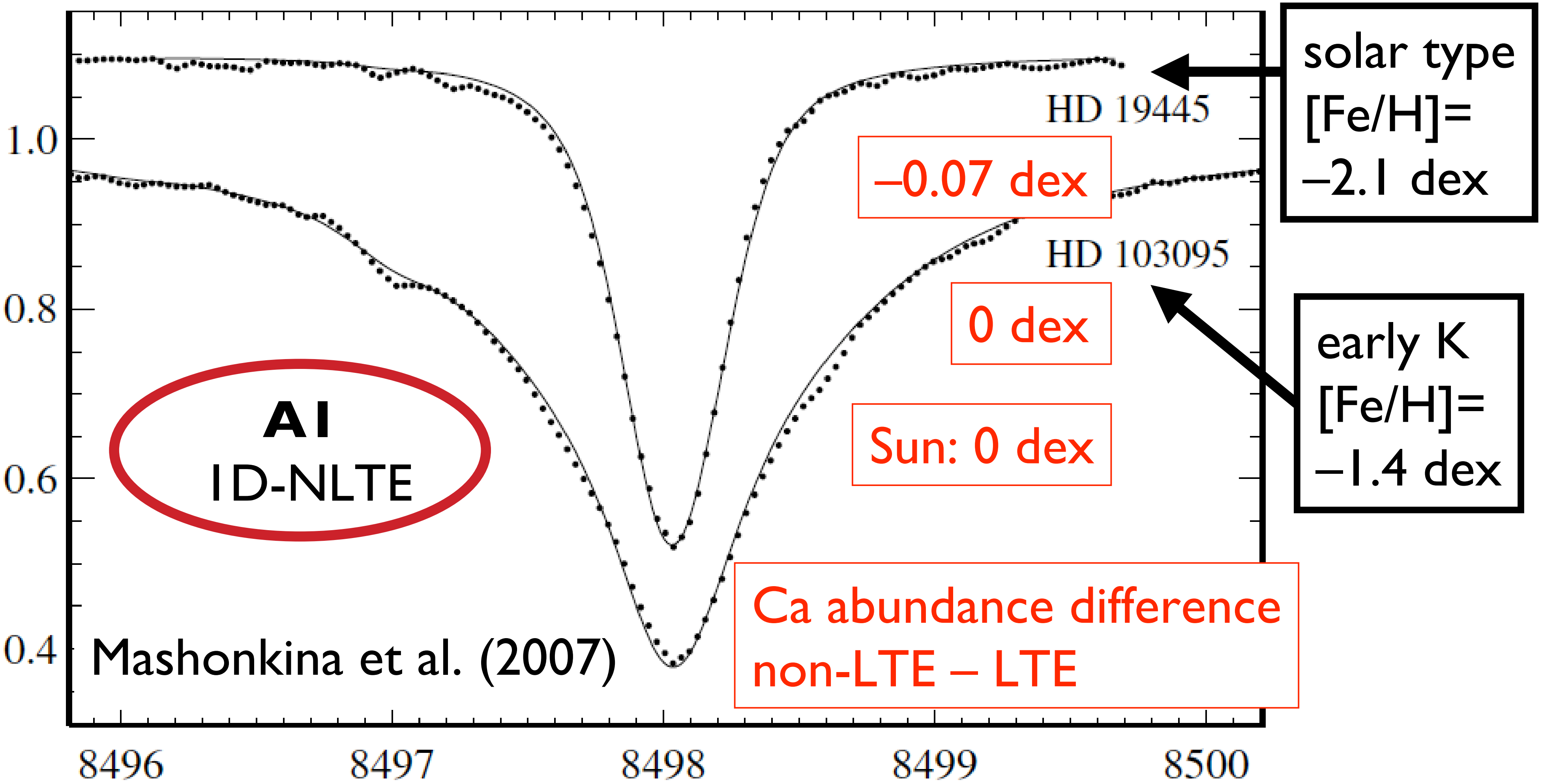


Abundance tests



- **Issues**
  - consistency in codes – must aim for real differential analysis, e.g. opacities 1D-3D
  - coupling effects (do effects add up or cancel?)

Example 1: Ca II 850 nm non-LTE

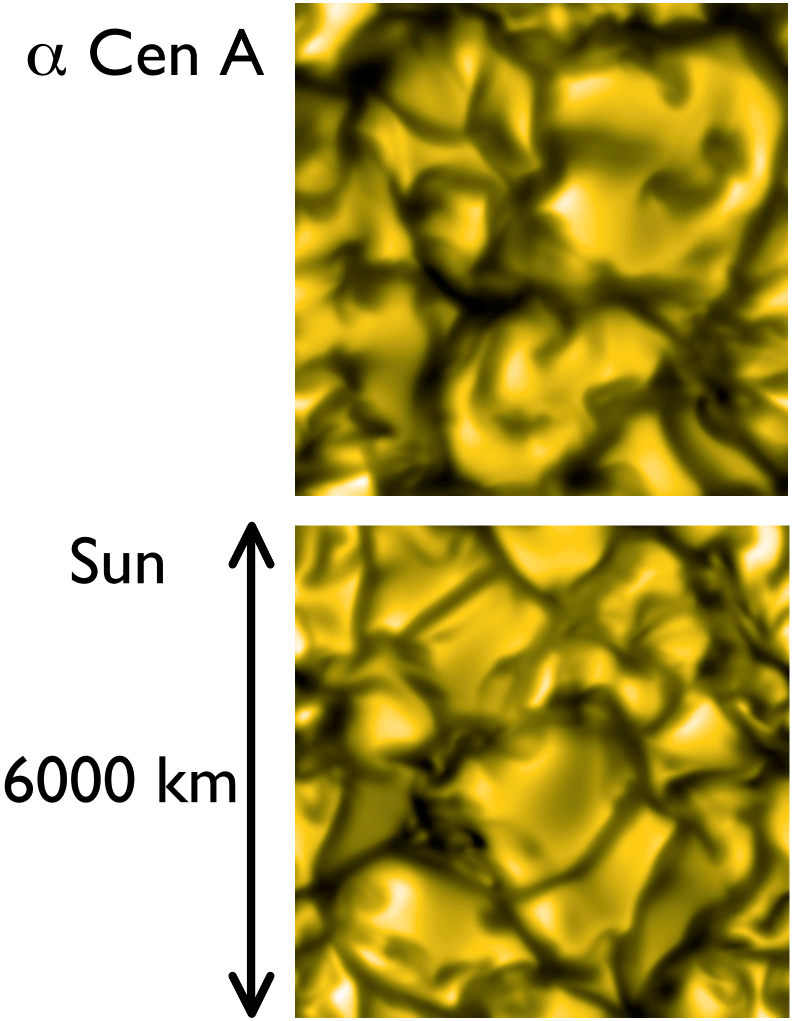


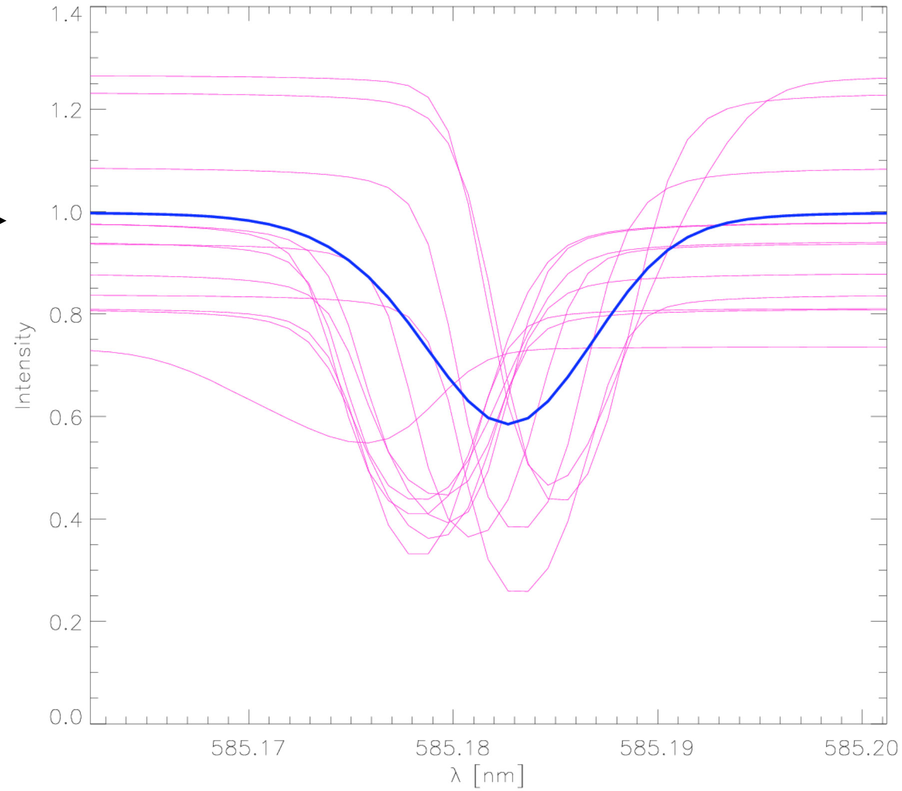
Example 2: α Cen A

- T_{eff}=5780 K, logg = 4.3, [Fe/H]>0
- HARPS spectrum
- **1D LTE** analysis (MARCS) + **3D LTE** analysis
- **Preliminary results**
  - Better fit to line profiles in 3D, without micro- or macroturbulence parameters
  - Fe abundance somewhat lower in 3D than in 1D
  - Bigot et al. (2008, Mem. S.A.It. Vol. 79, 670)

3D-RHD models

α Cen A





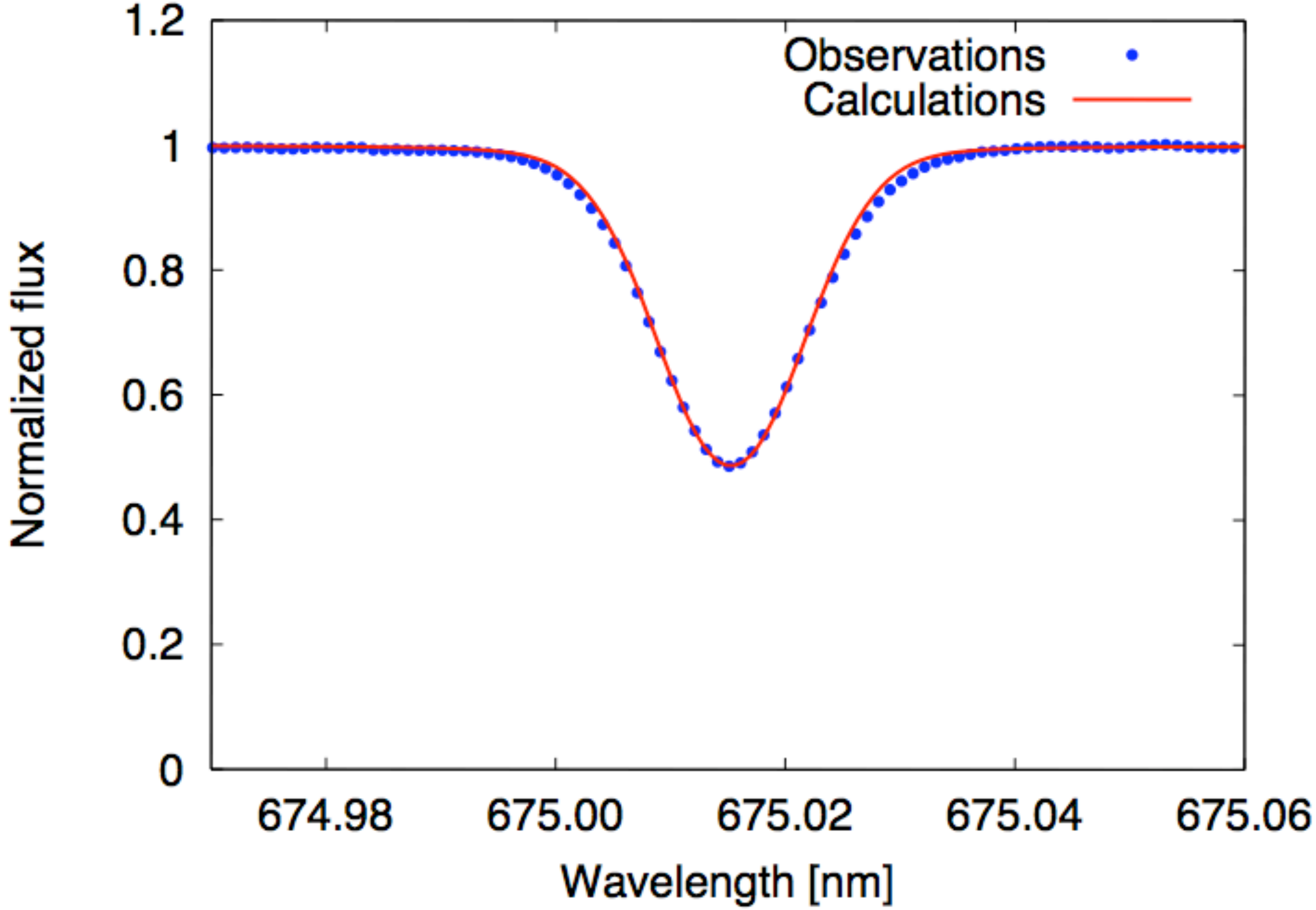
Disk-center line profiles

Disk-center surface intensity

Figures: L. Bigot

α Cen A

A0
1D-LTE

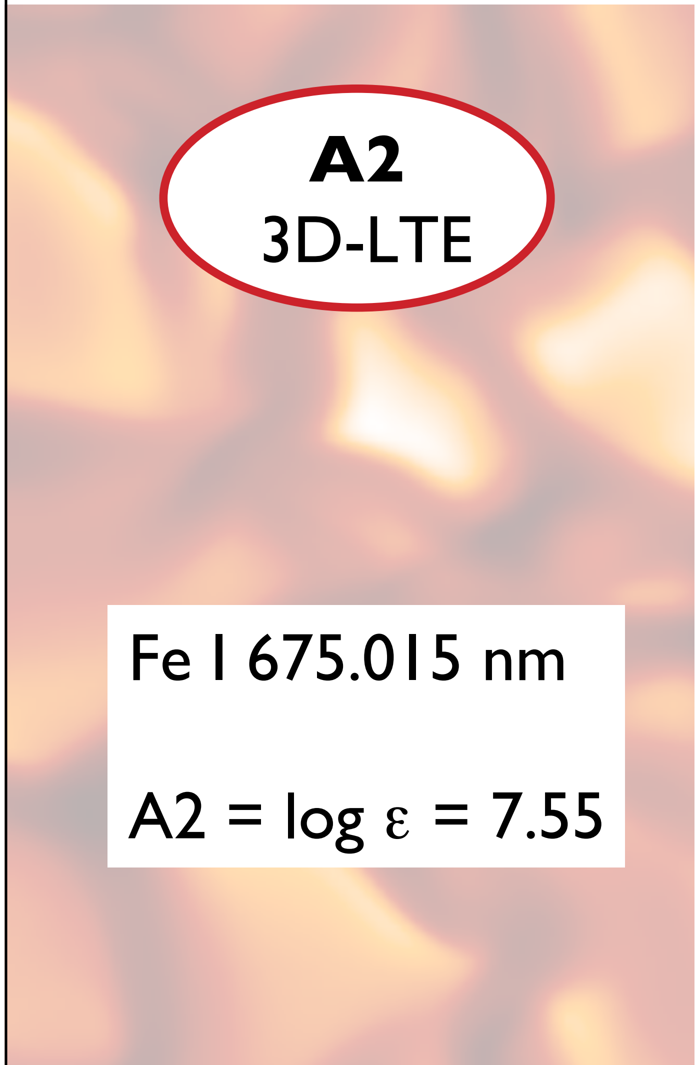


Fe I 675.015 nm

A0 = log ε = 7.82

Vmicro = 0.8 km/s, Vmacro = 3.3 km/s

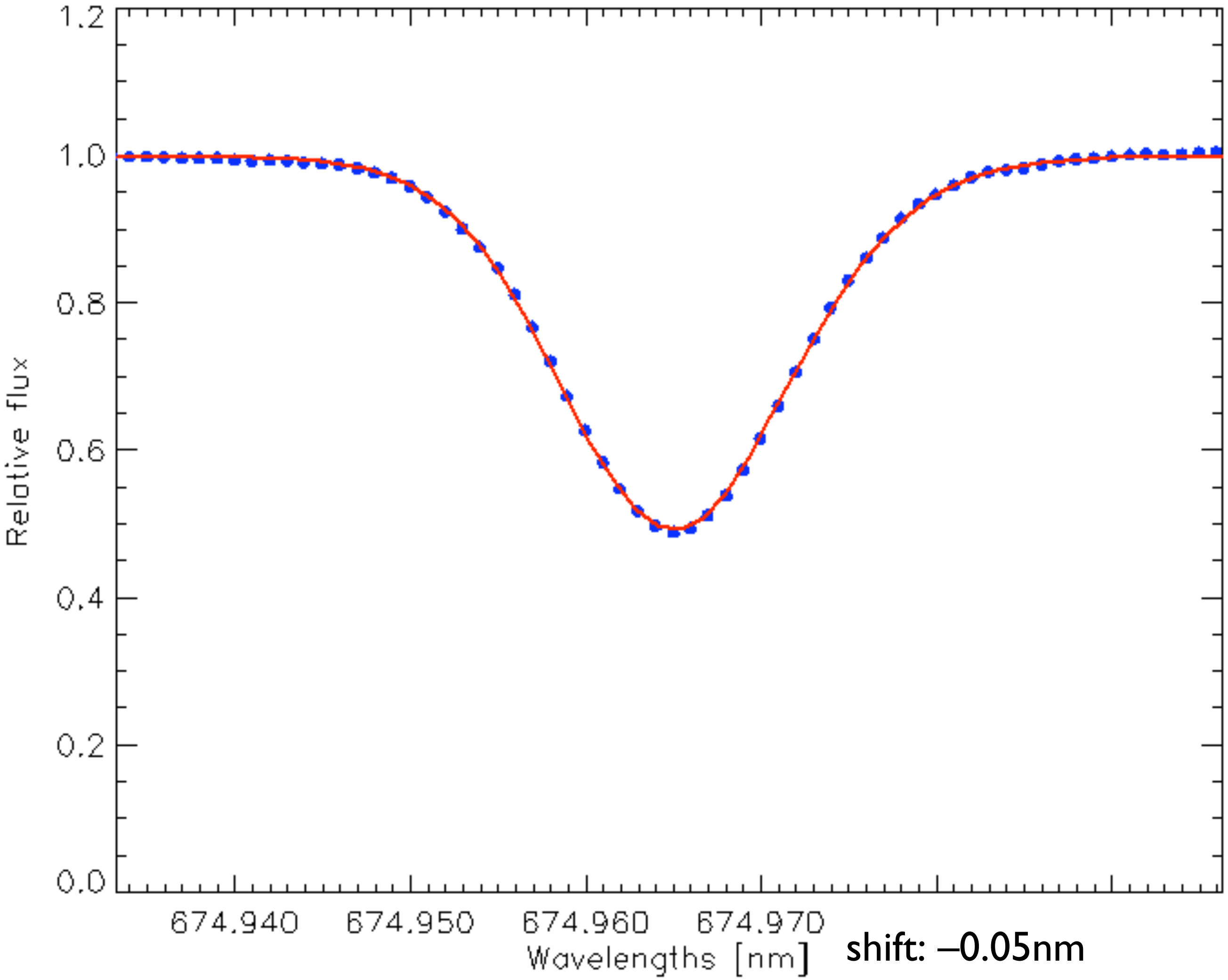
α Cen A



A2
3D-LTE

Fe I 675.015 nm

A2 = log ε = 7.55



shift: –0.05nm

Example 3: δ Eri

- T_{eff} = 5035 K, log g = 3.8, [Fe/H] = 0
- V. Makaganiuk (PhD student, Uppsala)
- **SARG spectrum**
- MARCS models, **1D LTE analysis**
- **Fe** I, Fe II, **Ca** I lines – fit → T_{eff} and abundances
- **optical** (555–675nm) and **RVS** wavelength regions analysed separately
- **Result:** no difference between abundances

A5
wavelength regions

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