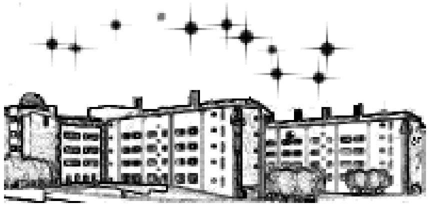
Observational Astrophysics Research in Uppsala

Nikolai Piskunov & IFA astronomers

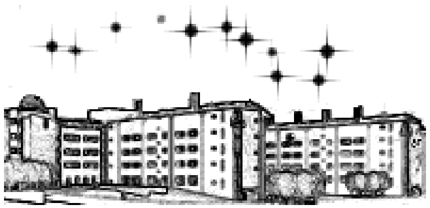
Research topics

- Re-ionization of the Universe and galactic evolution.
- Milky Way history, structure and chemical evolution.
- Stars: oldest stars, stellar surface structures, activity and magnetic fields, solar neighbourhood, solar twins, …
- Exoplanets: search for, studies of host stars, characterization of planetary atmospheres.
- Solar system (in collaboration with IRF).



Relations to Theoretical Program

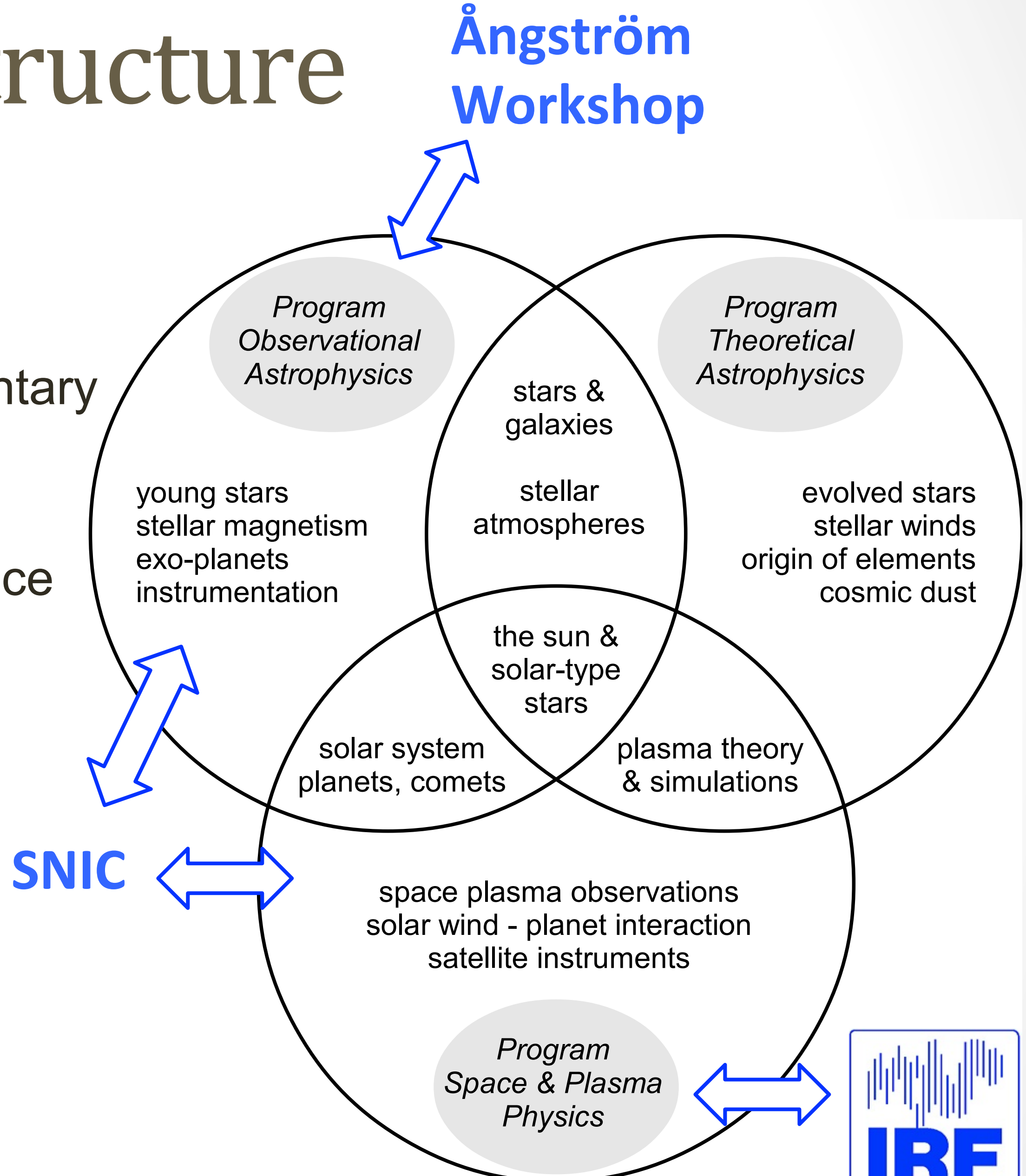
- Ab initio 1D and 3D models of stars.
- Departures from equilibrium (e.g. in level populations).
- Atomic and molecular data. Inelastic collisions.
- Spectral synthesis tools.
- Automated observation analysis tools.

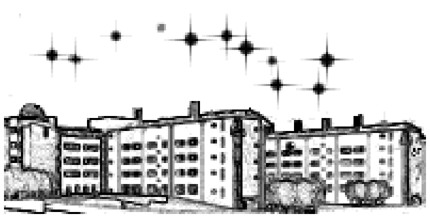


Division Structure

Three programs:

- Distinct but complementary areas of expertise.
- Several common science goals.
- Shared resources.





How we do it: observations from the ground

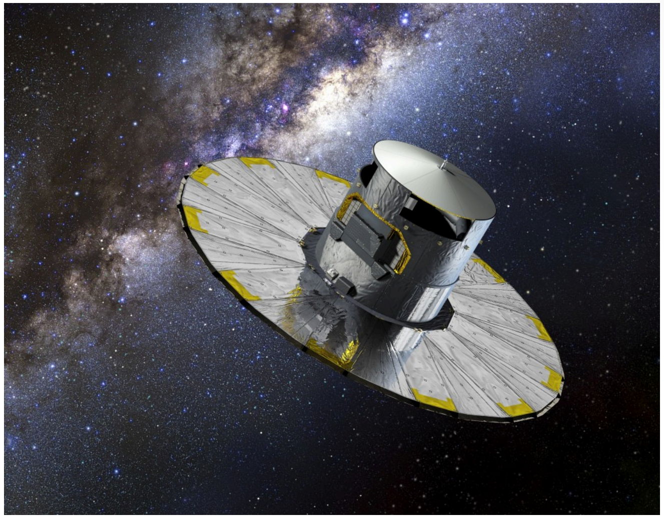
ESO Paranal

ESO La Silla

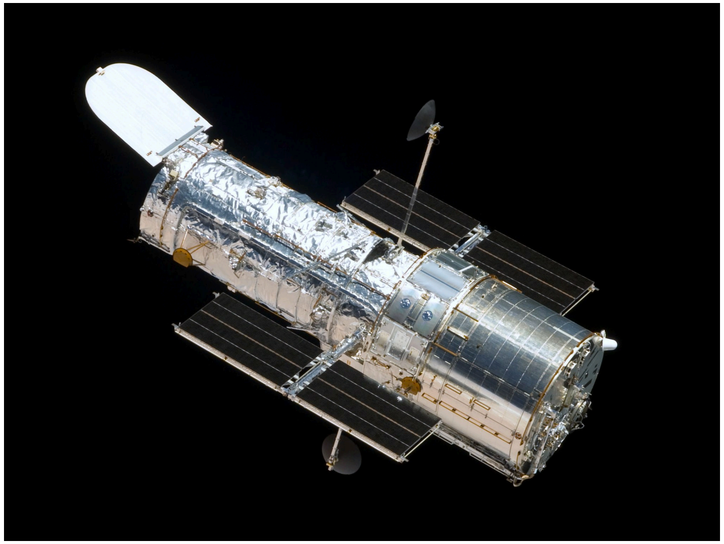
ESO ALMA, Chajnantor

How we do it: … and from space

ESA Rosetta



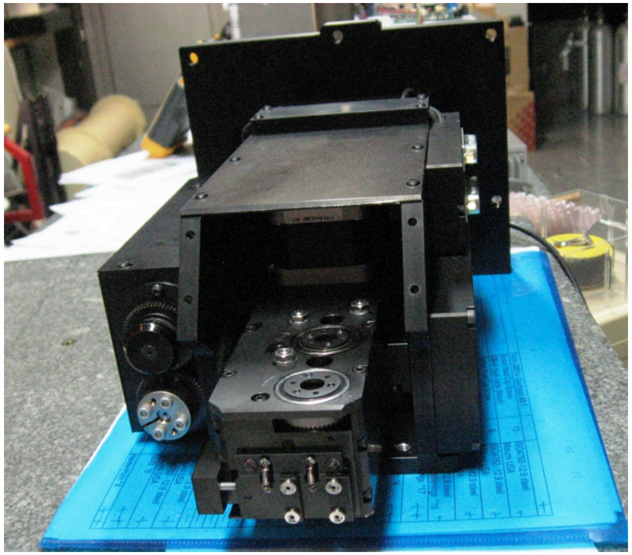
ESA Gaia



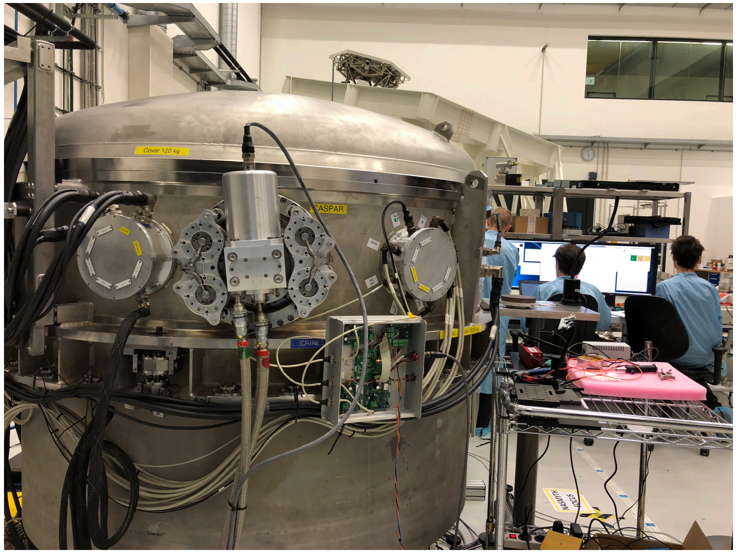
NASA HST

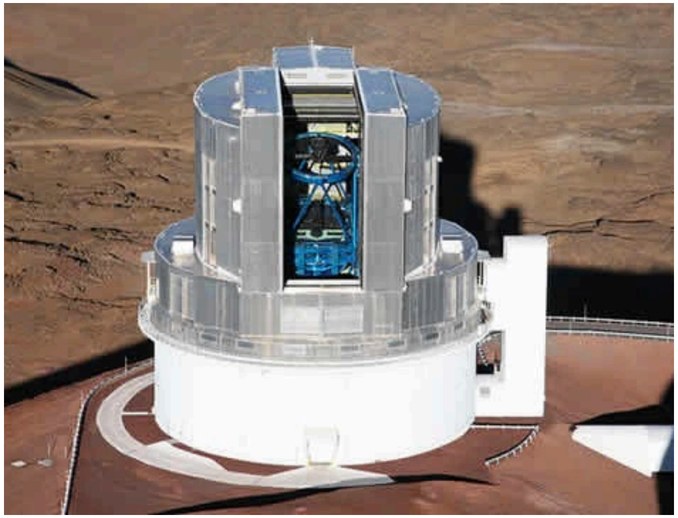
NASA JWST

How we do it: Instrument Development



ESO: HARPSpol



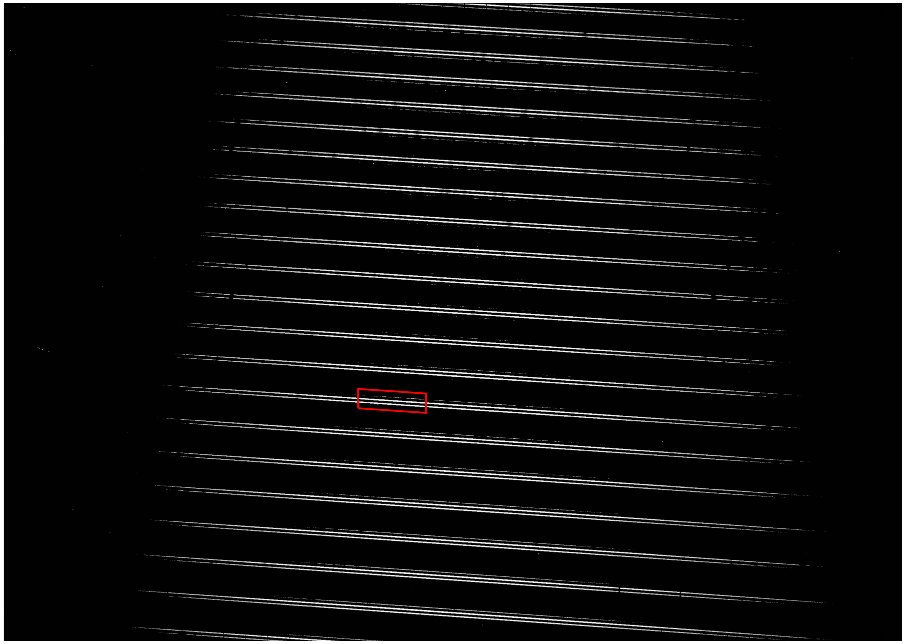


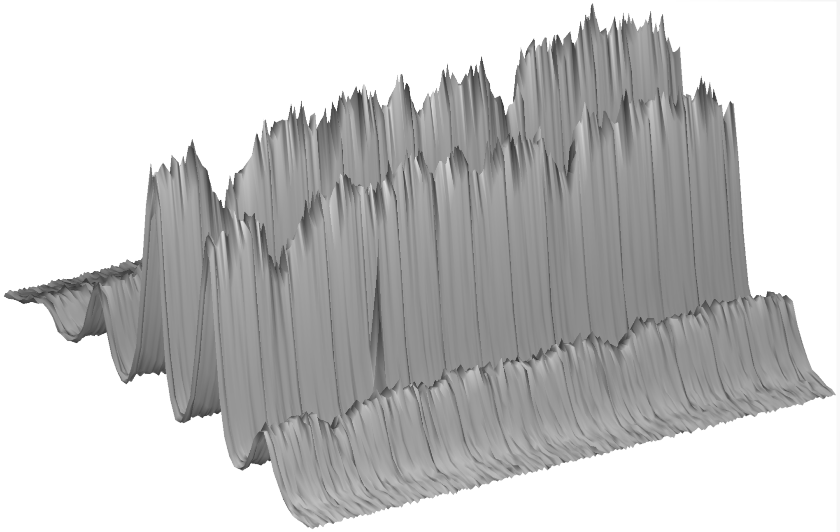
ESO: 4MOST

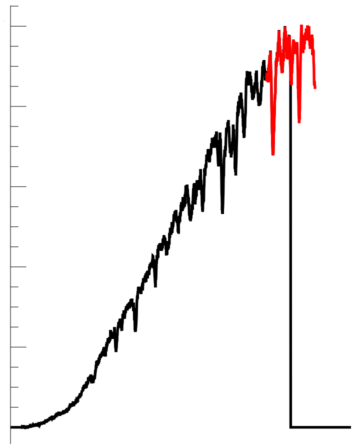
ESO: CRIRES+

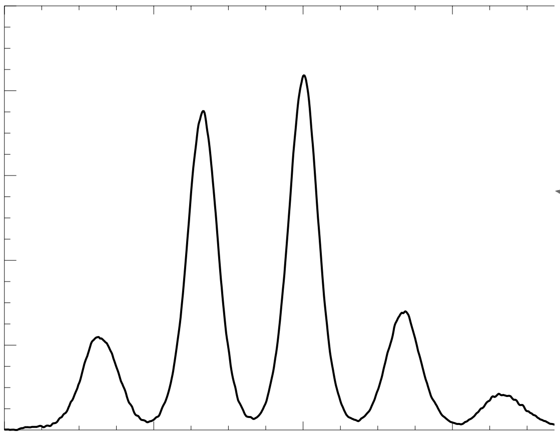
How we do it: Advanced Data Reduction

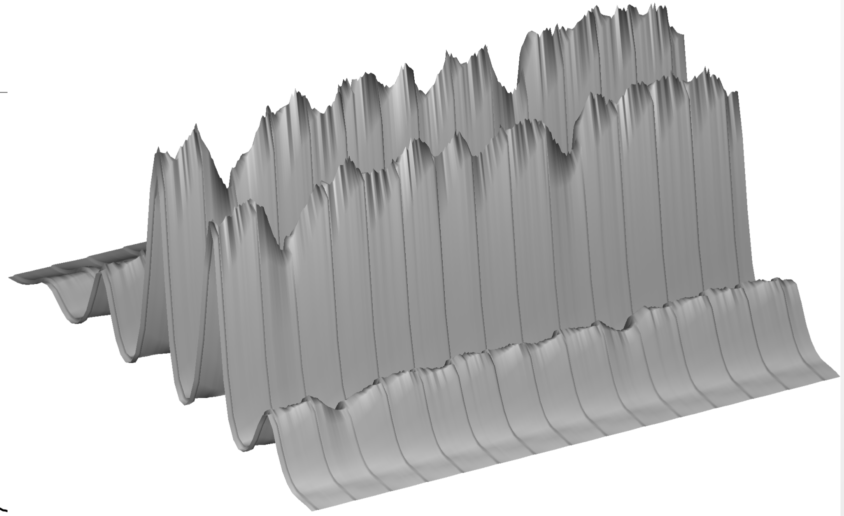
Echelle Spectrometer Slit Decomposition





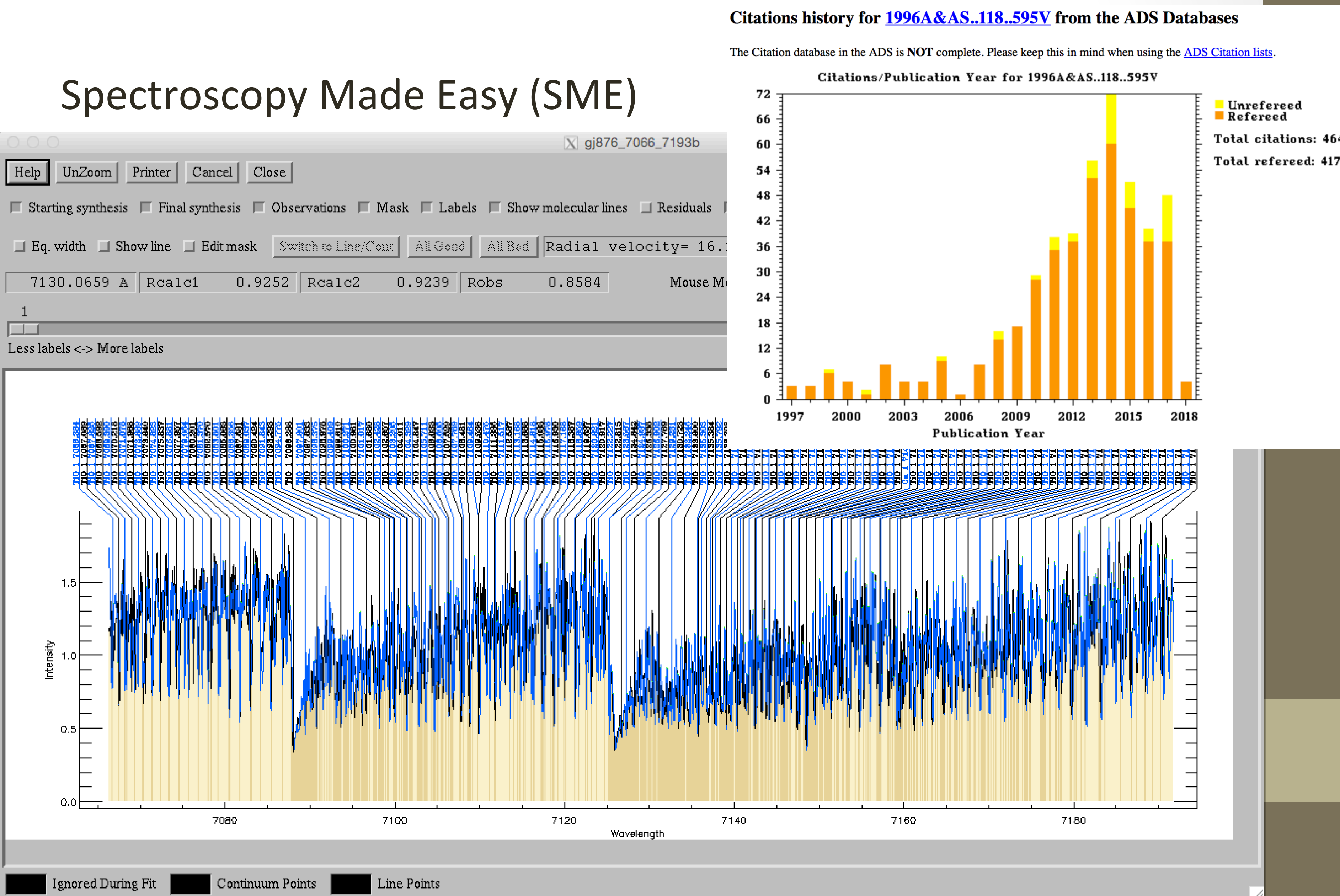






How we do it: Advanced Data Analysis

Spectroscopy Made Easy (SME)

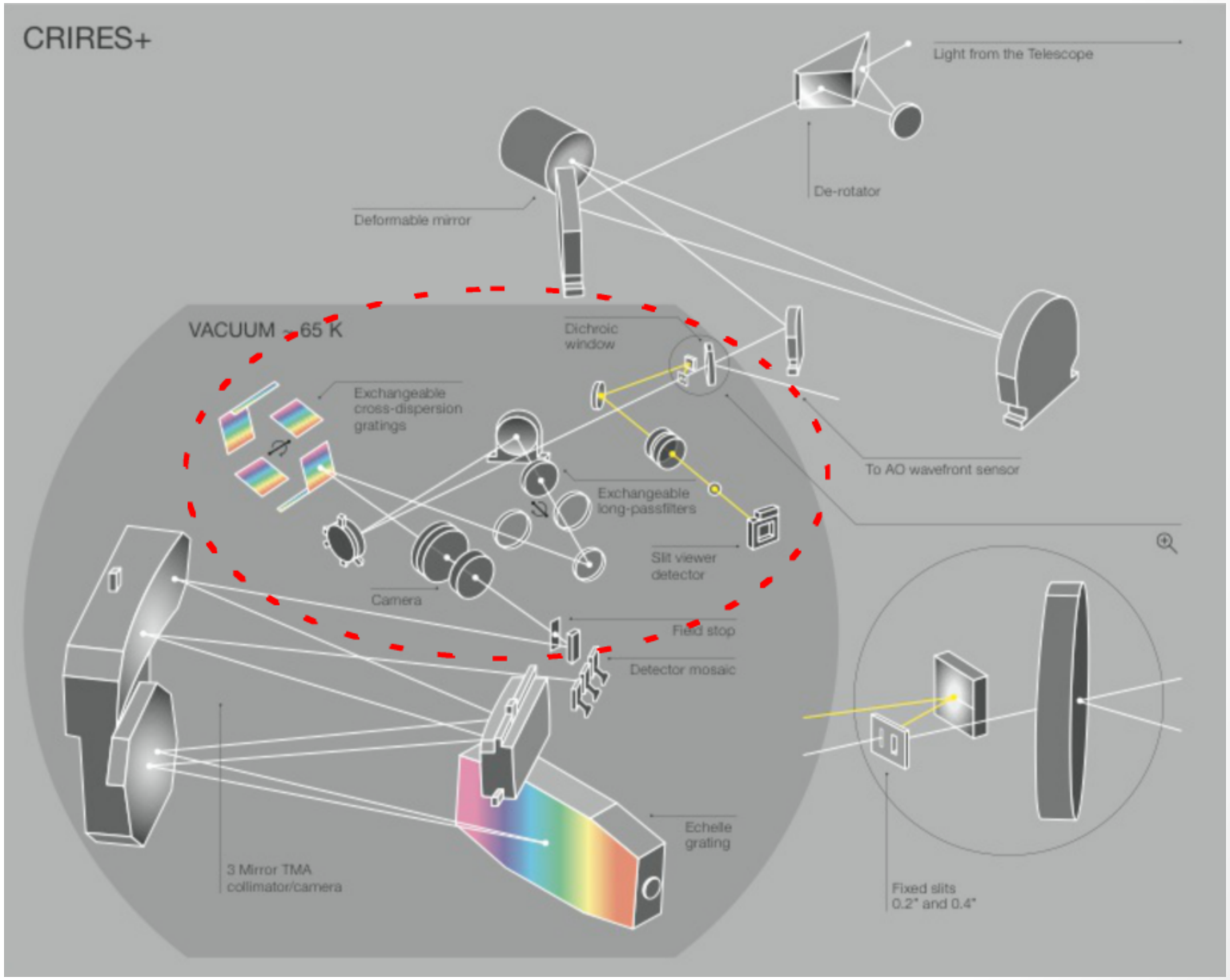


Four examples of our work

- CRIRES+ polarimeter.
- Gaia “big data” analysis.
- Magnetic Doppler Imaging.
- Exoplanet atmosphere characterisation.

CRIRES+ polarimeter

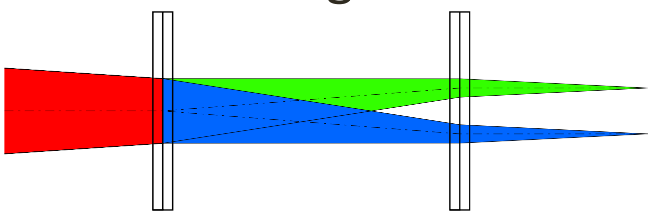
Problem: Adaptive optics works at wavelength < 1 µm and it gets confused when finding 2 polarised images instead of one.

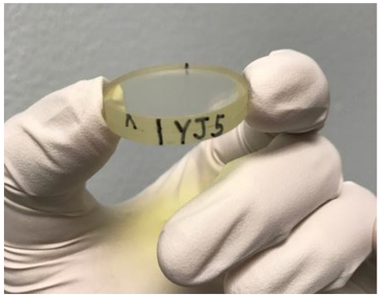


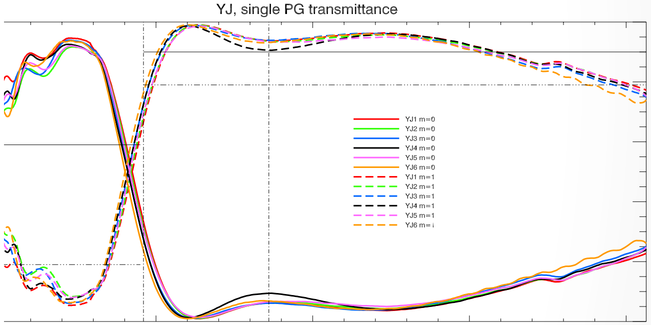
Echelle spectrometer has to see only polarised images for maximum sensitivity.

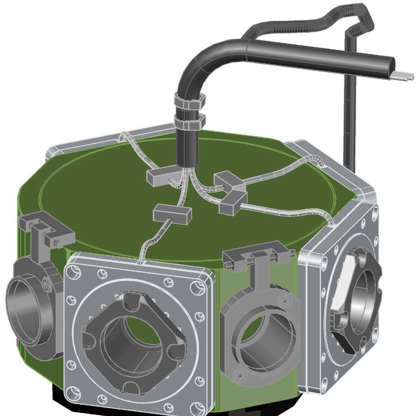
CRIRES+ polarimeter

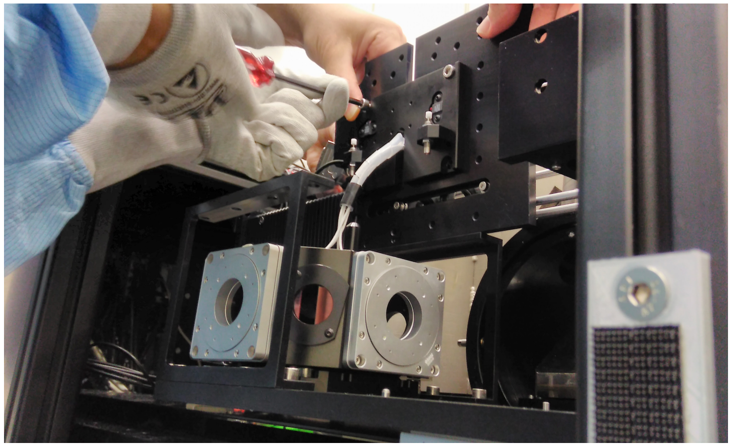
Solution: construct a beam-splitter out of two polarisation gratings with nano-pattern that creates constructive interference for circularly polarised light at wavelengths >1µm while acting as a simple transparent glass plate for shorter wavelengths.

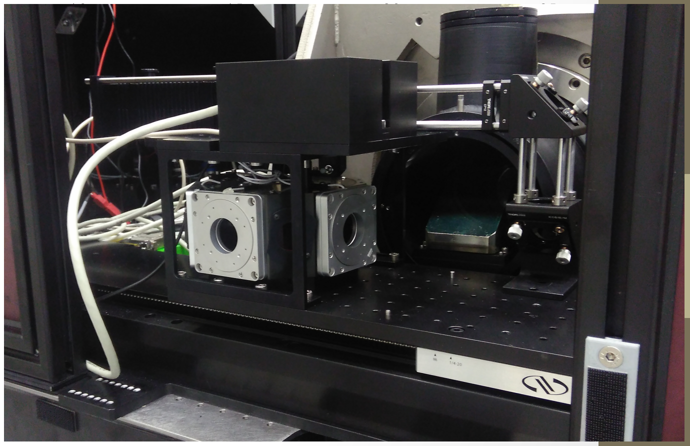




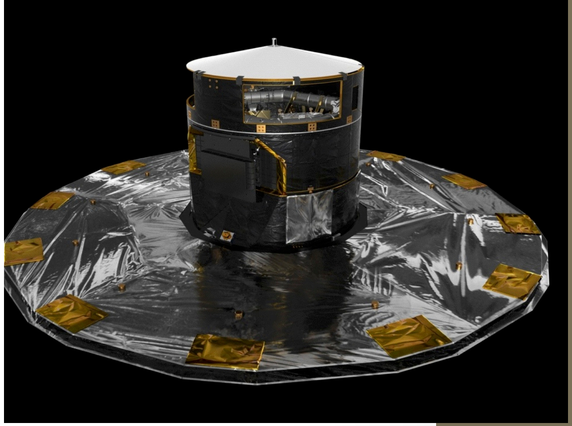








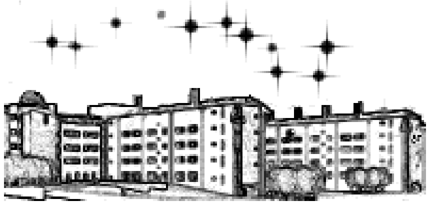
Gaia “big data”

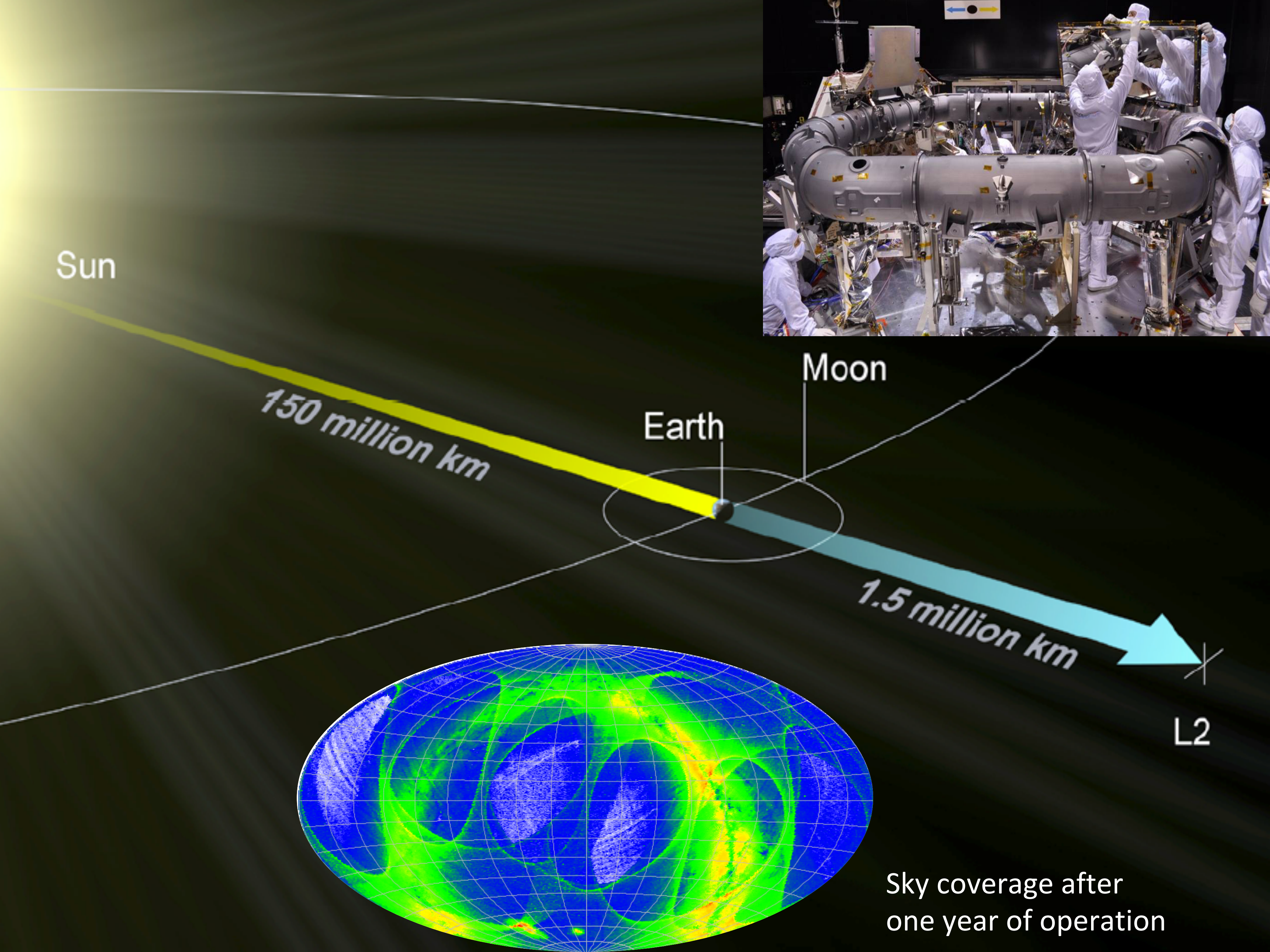


Goals: using **astrometric** and **spectroscopic** data measure **positions**, **velocities**, and **physical properties for** nearly **2 billion stars** in the Milky Way.

Launched in the end of 2013 Gaia collects about 50 GB of data per day. Originally planned for 5 years the mission is extended. Final catalogue is expected in 2022.

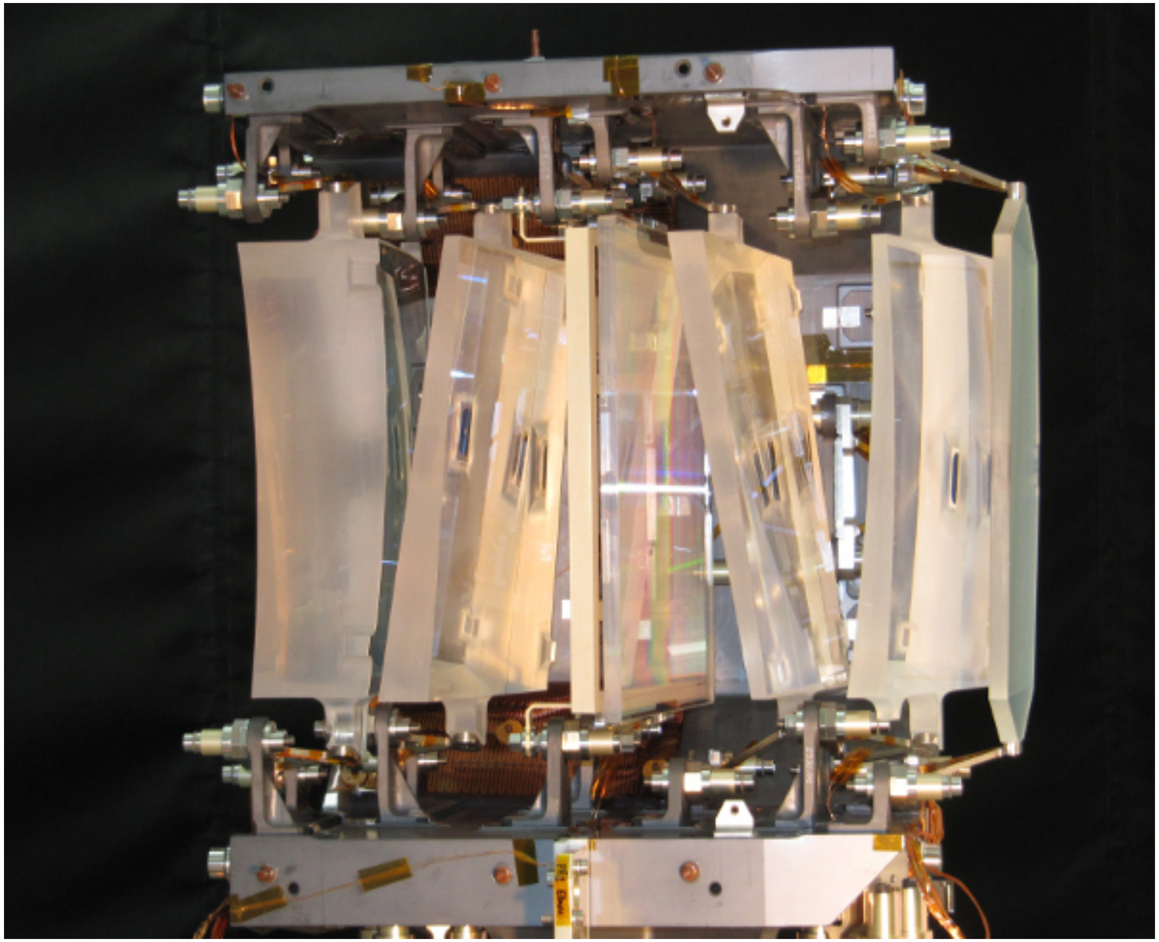
Each object is “visited” several times while a self-consisted solution for stars and Gaia position is constantly improving. By the end of the mission it will be sufficient to discover 20-30 thousand planets.





Sky coverage after one year of operation

Gaia spectroscopy



Gaia Radial-Velocity Spectrometer – EADS Astrium SAS, France

Gaia spectroscopy

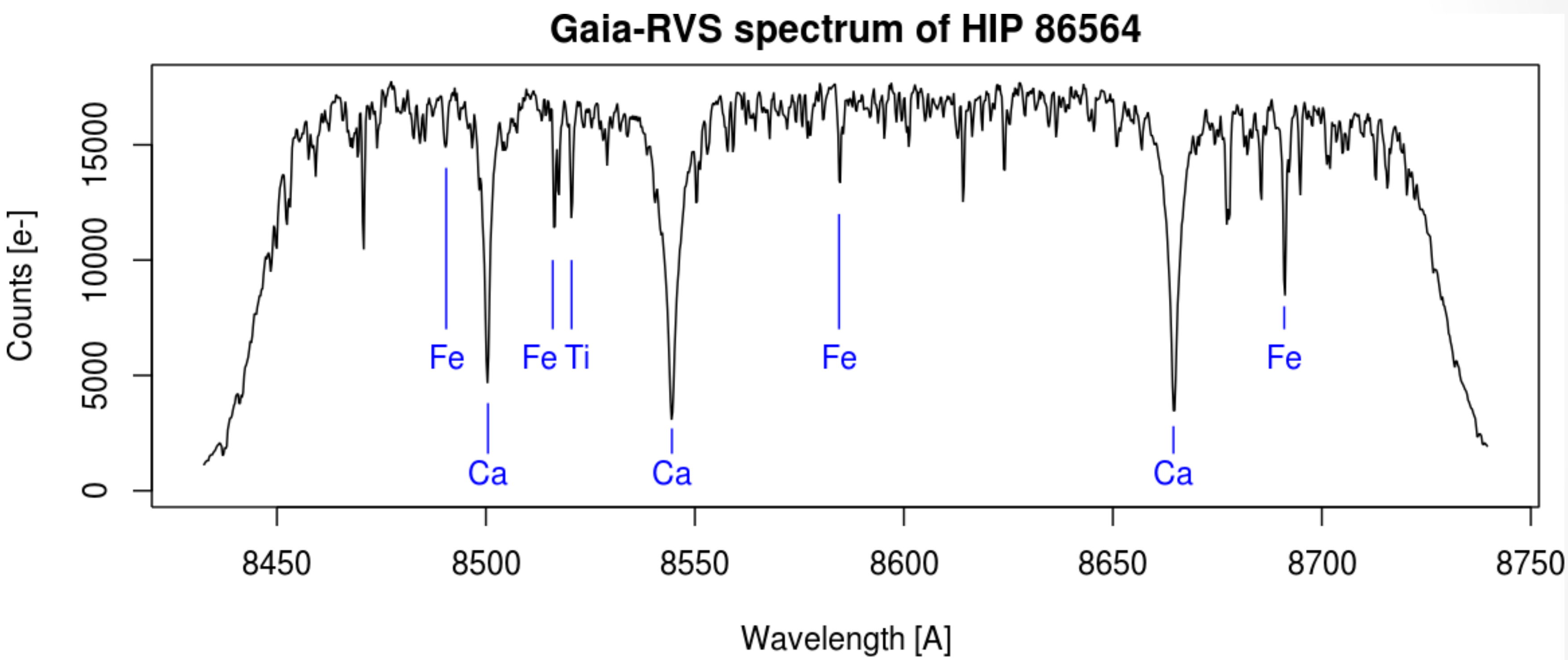
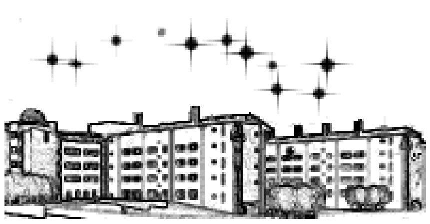
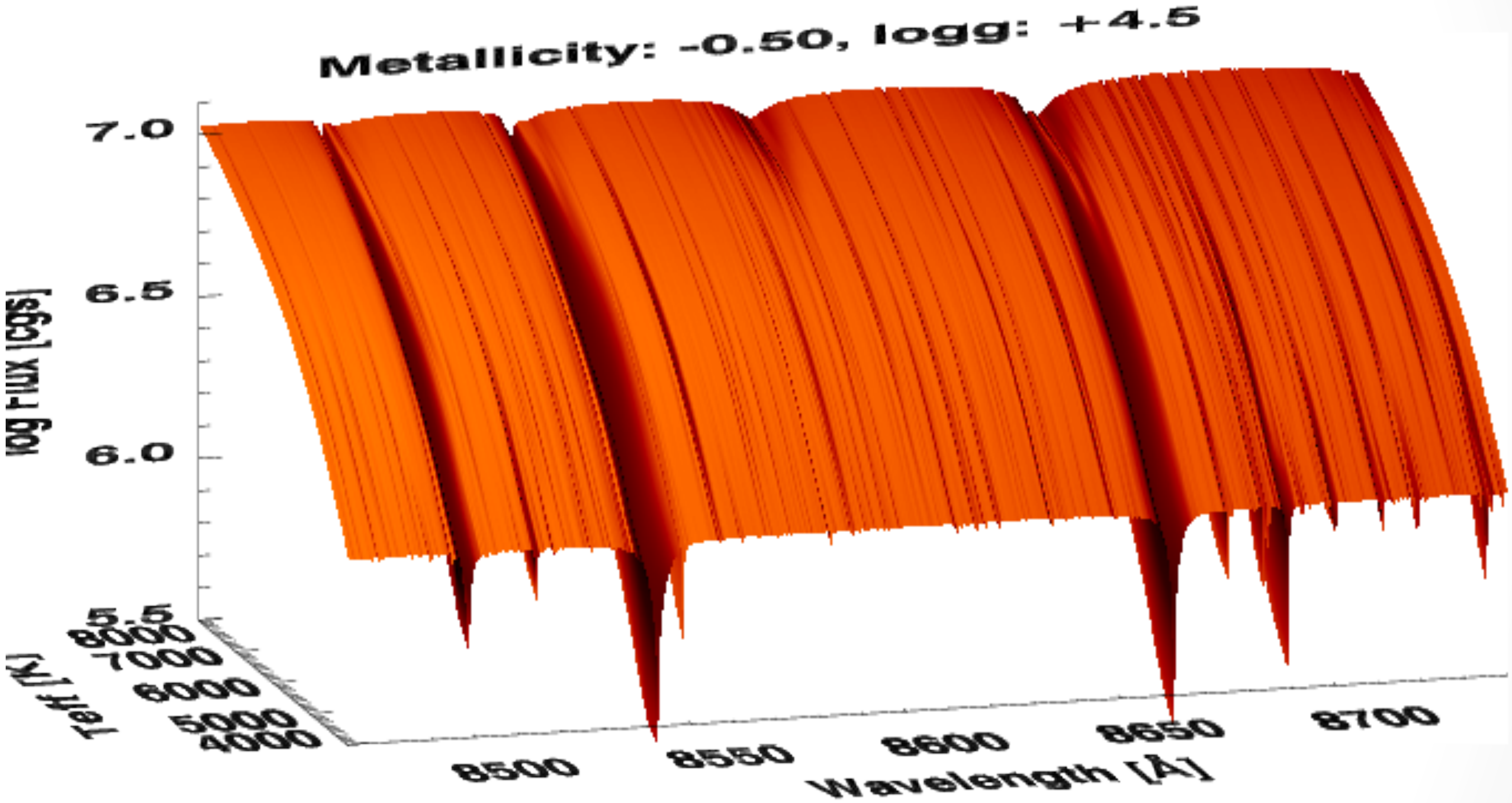
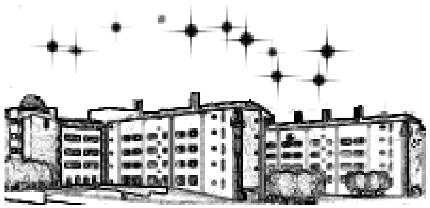


Figure courtesy D. Katz, O. Marchal, C. Soubiran



Gaia stellar parameters

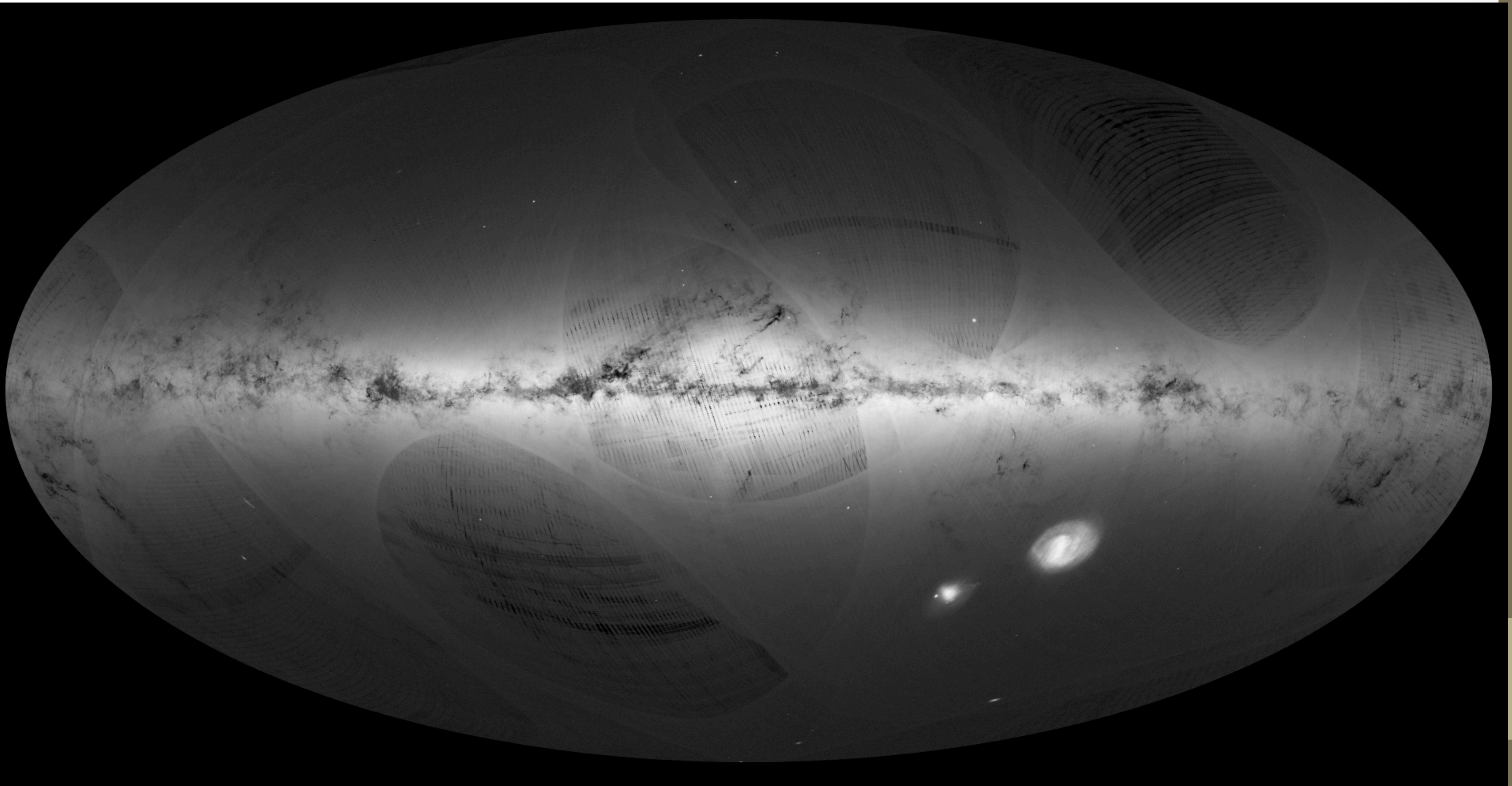




Uppsala contributed to creation of training data set for stellar parameter determination.

Gaia data release 1

Nearly 1.2 billion sources with more than 1/3 newly discovered.



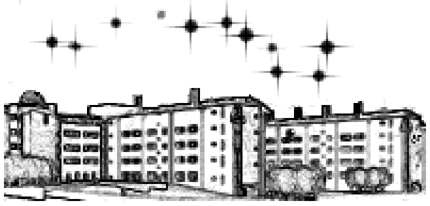
ESA/Gaia/DPAC/André Moitinho & Márcia Barros (CENTRA - University of Lisbon)

Gaia science

- While the data keeps coming and the astrometric solution keeps getting better the challenge is to process the data and derive physical parameters.

- Better geometrical data allows better interpretation of ground-base support spectroscopic surveys providing independent estimates of e.g. stellar radii.

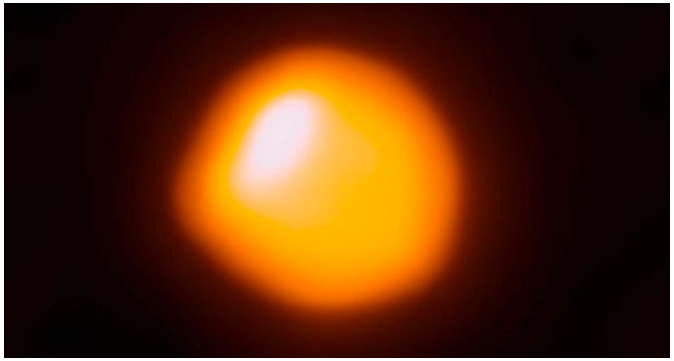
- There is also an opportunity to look for correlations between physical and dynamical parameters resulting from supernovae explosions, galactic mergers and star formation history of the Milky Way.



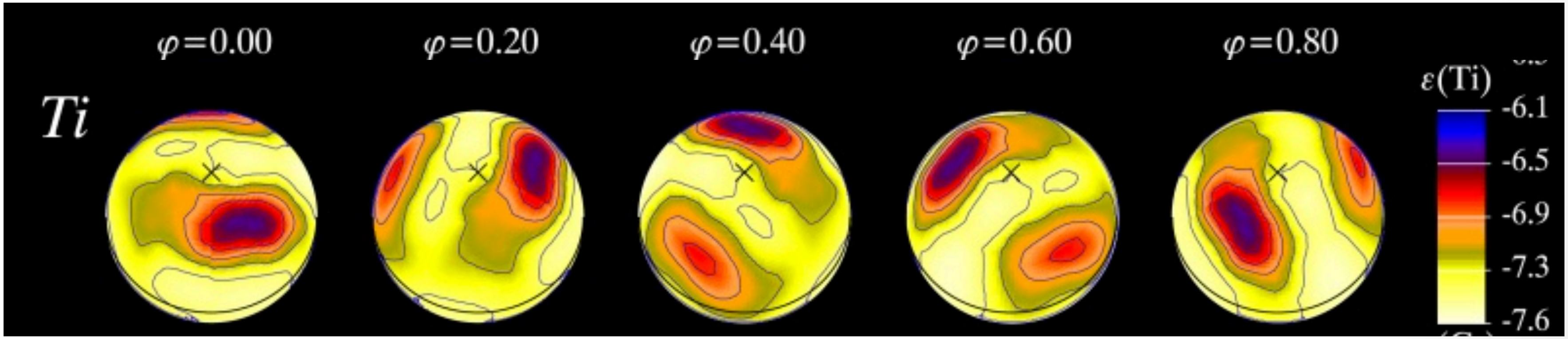
Magnetic Doppler Imaging

- **This is pure magic!**
- Even the largest telescopes or interferometers cannot resolve details on stellar surfaces (except for the Sun).

ALMA image of Betelgeuse



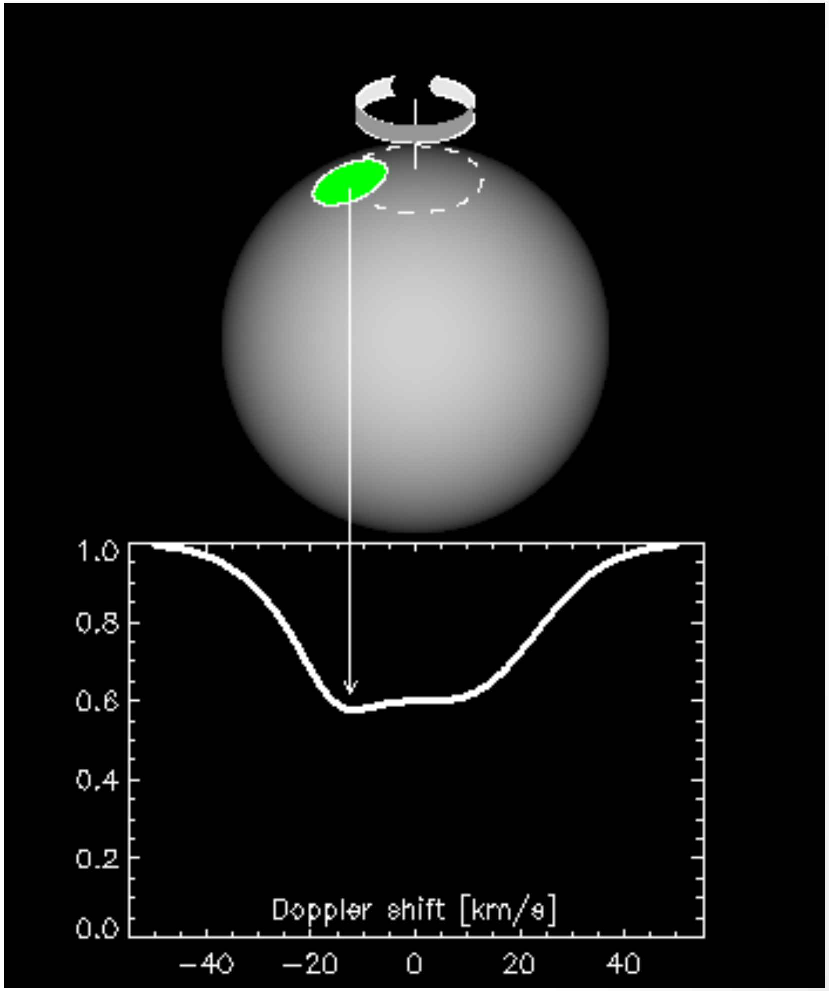
- Yet, we can construct maps of rotating stars!



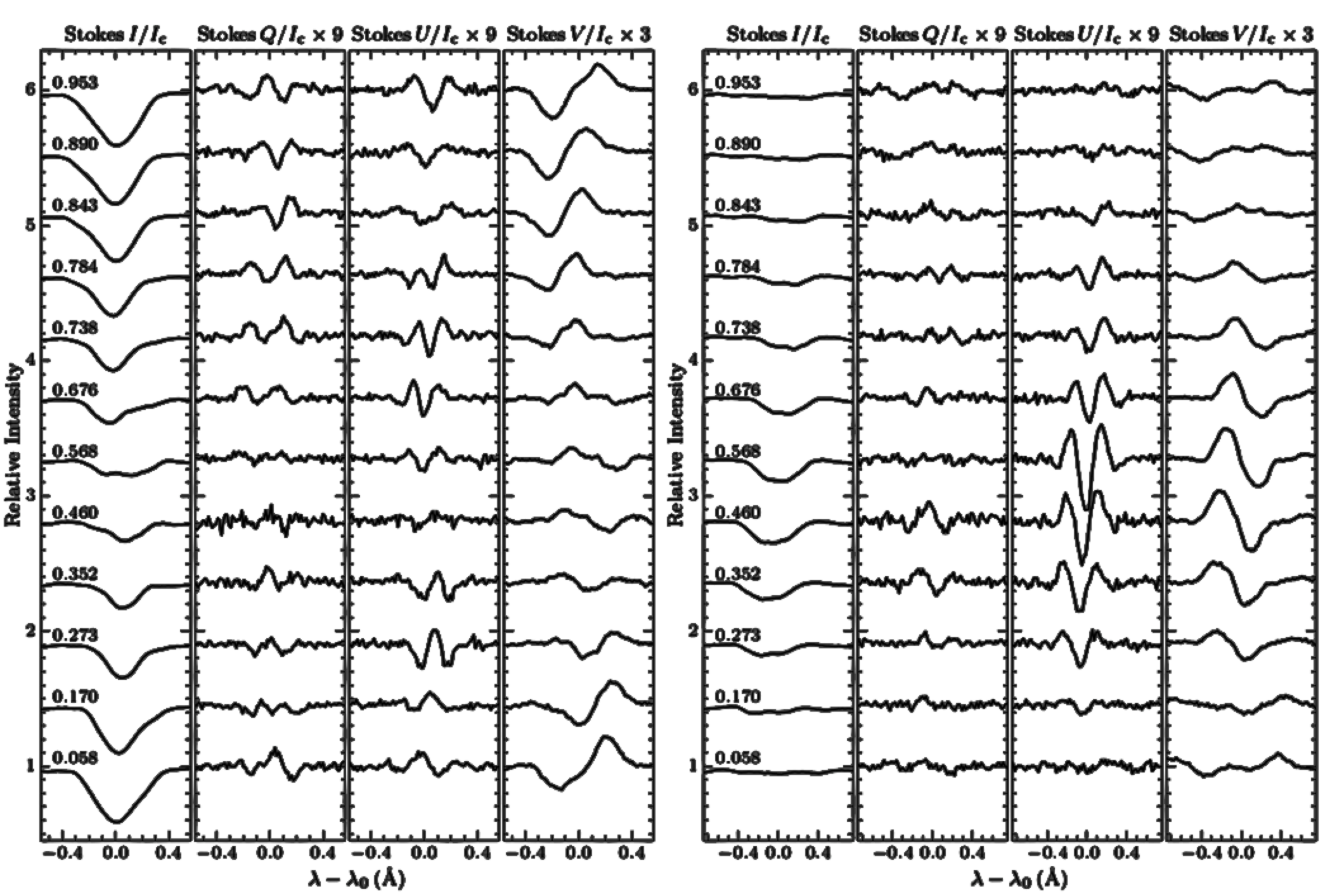
- This is how it is done.

Doppler Imaging

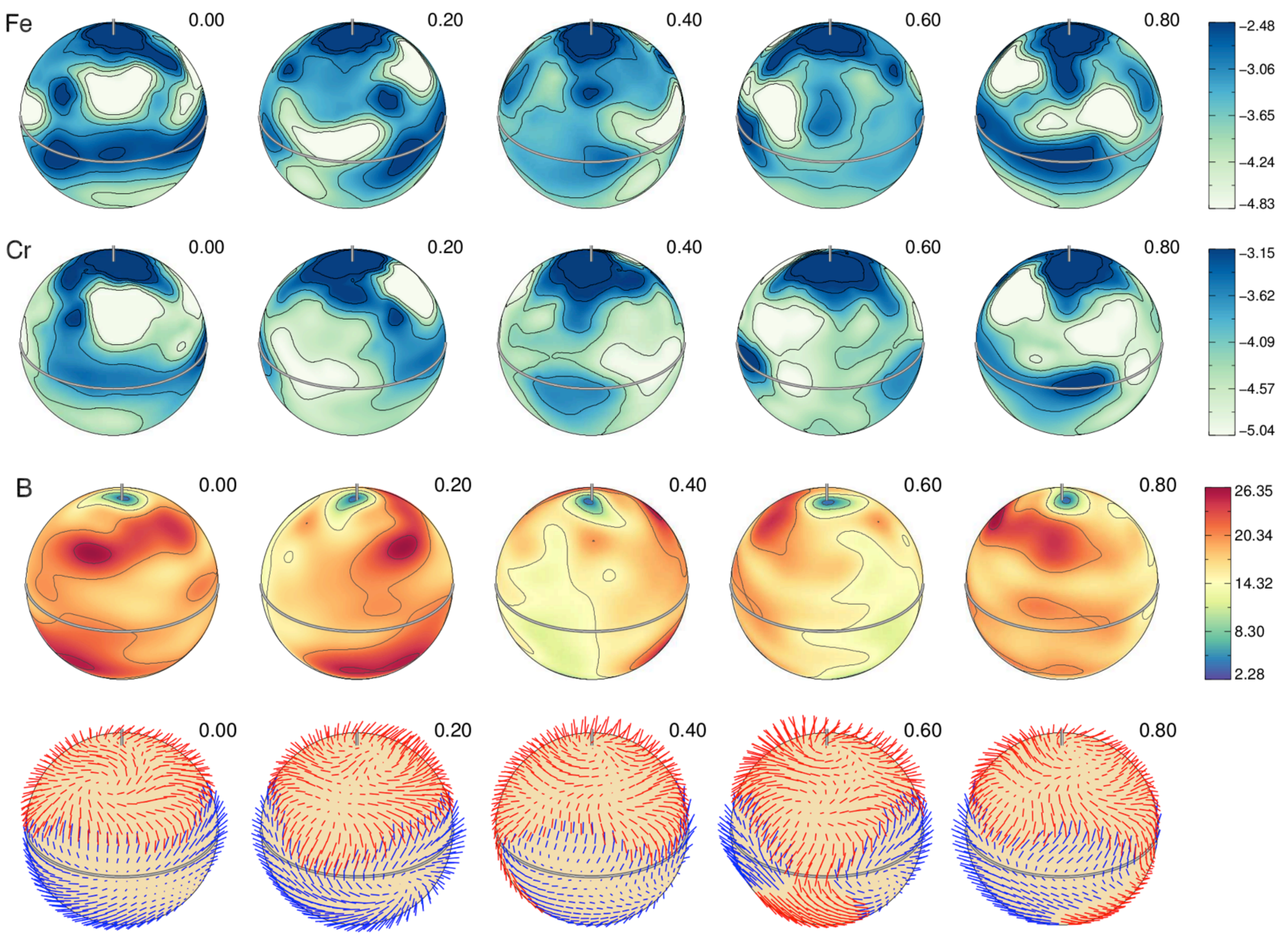
- Spectral lines that we observe are formed across the visible disk of a star.
- Locally absorption line strength depends on the emission level (continuum) and absorption strength. Both depend on the temperature and chemical composition.
- If local conditions differ from the rest of the surface (spot), deviations are imprinted in the disk-integrated profile:



MDI data for chemically peculiar star HD 24712 (Rusomarov et al. 2014)

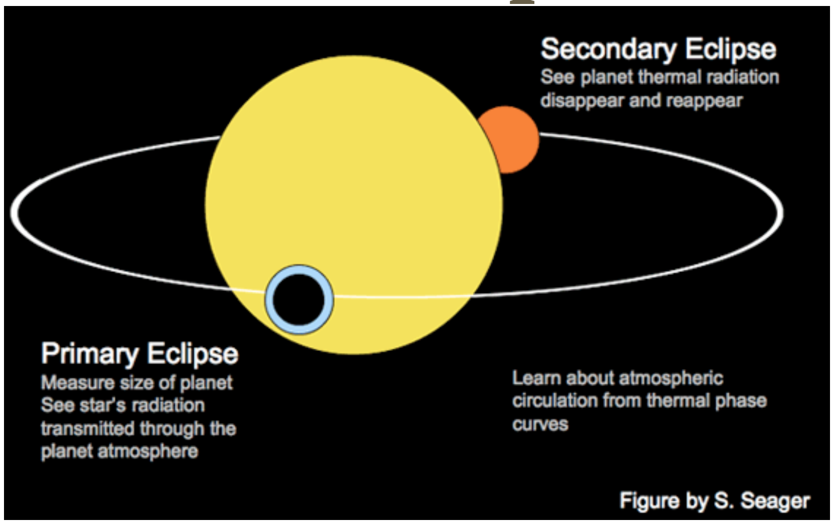


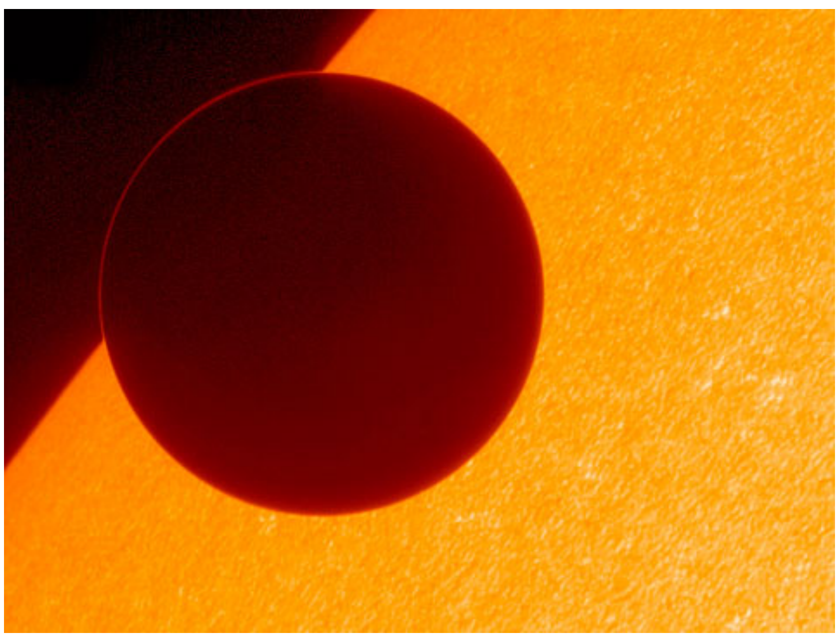
Magnetic Doppler Images

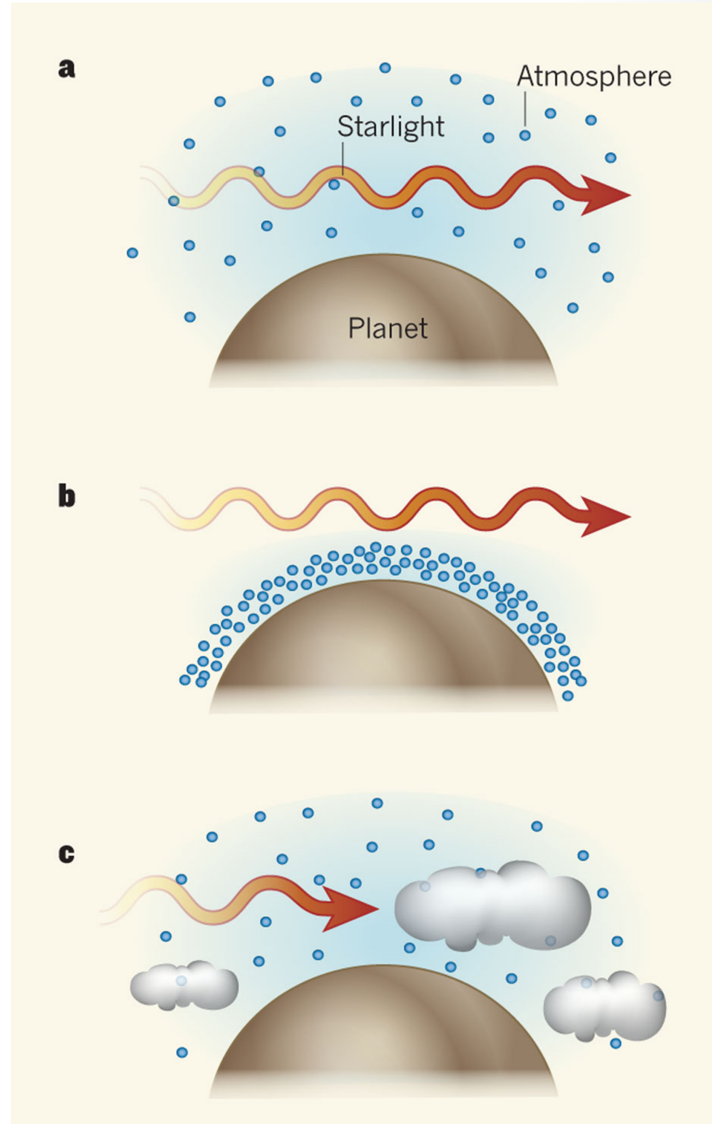


For more visit http://www.astro.uu.se/~oleg/di.html

Transit spectroscopy

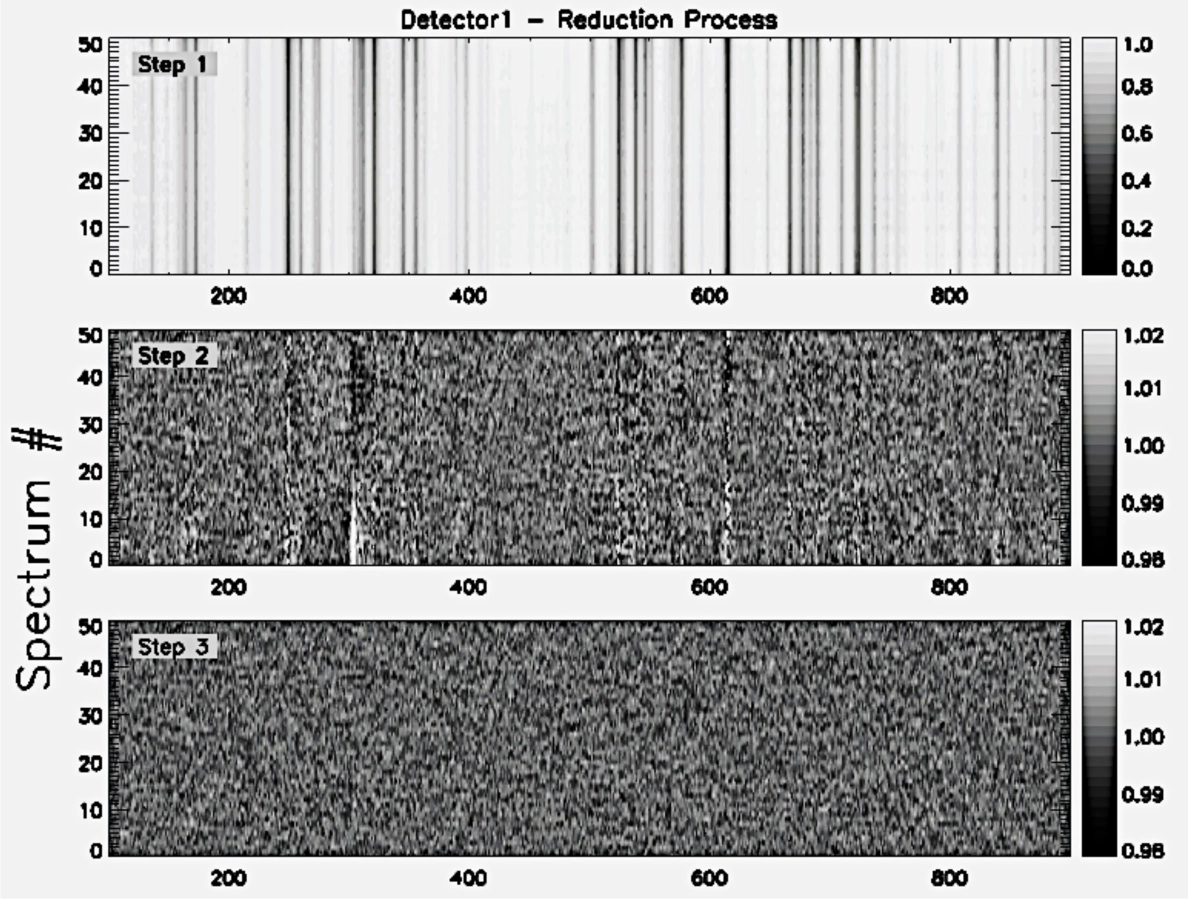






Transit spectroscopy

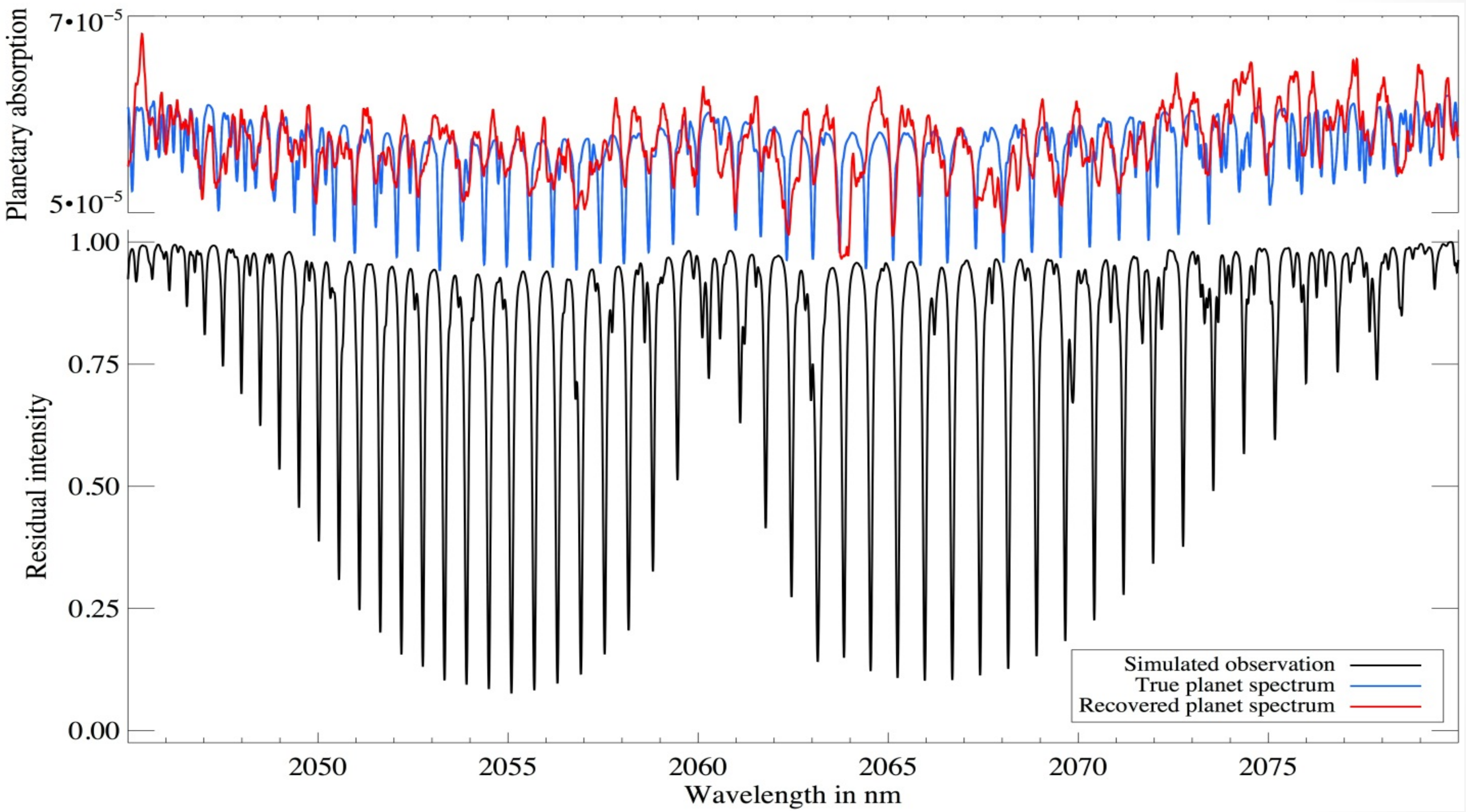
Observations of HD209458 (Snellen et al):



Iteratively removing telluric and stellar features

Cross-correlation with expected line positions in planetary atmosphere can give us detection but we must have a guess.

Numerical experiments



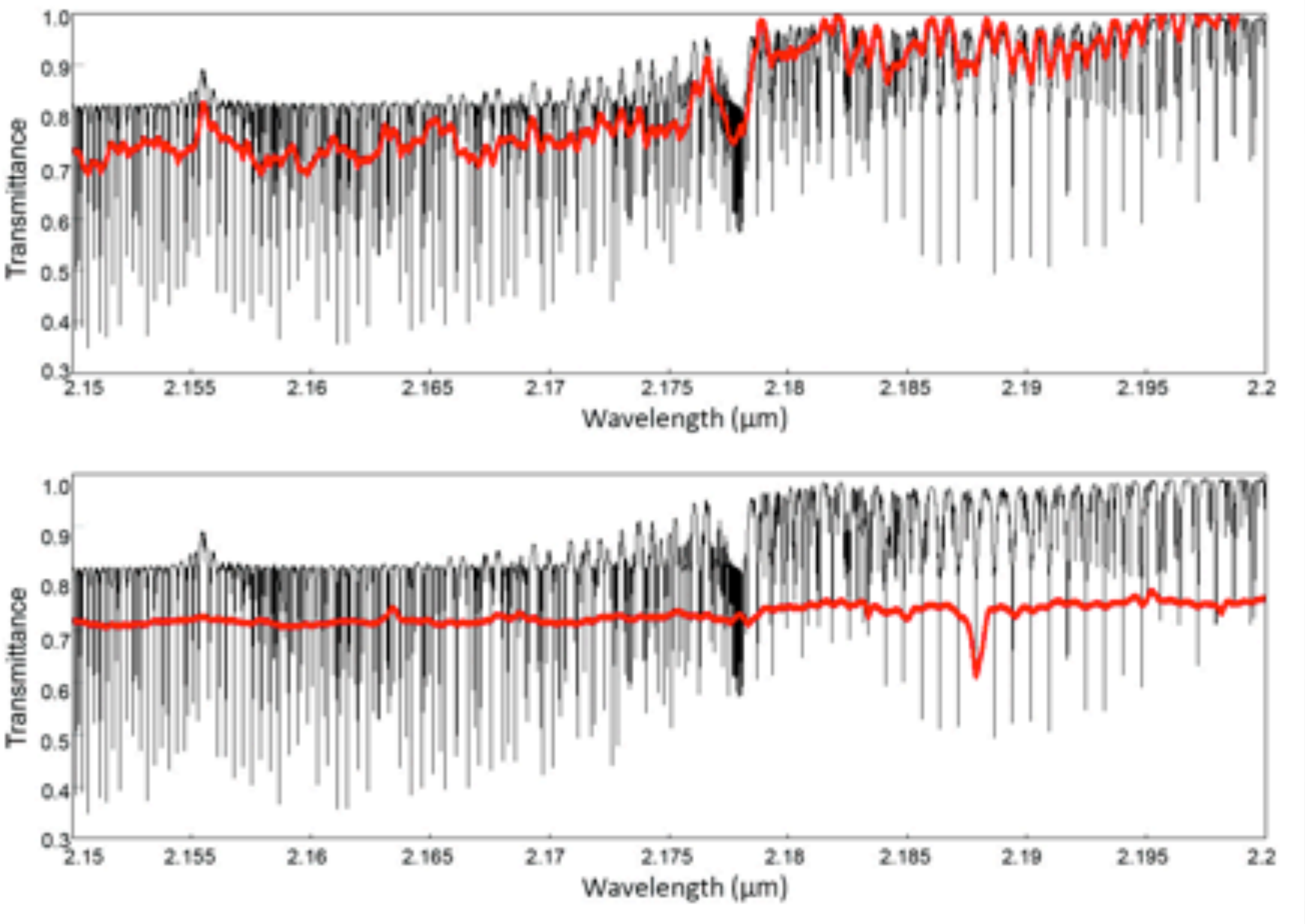
Earth-like planet passing in front of an M5 dwarf. Bottom panel: simulated observations with CRIRES+. Top panel: CO_2 spectrum in planet atmosphere (blue) and its reconstruction from 10 transits (red).

Spectral resolution is important

We can look “between” telluric lines by combining many transits

R=100000

R=10000



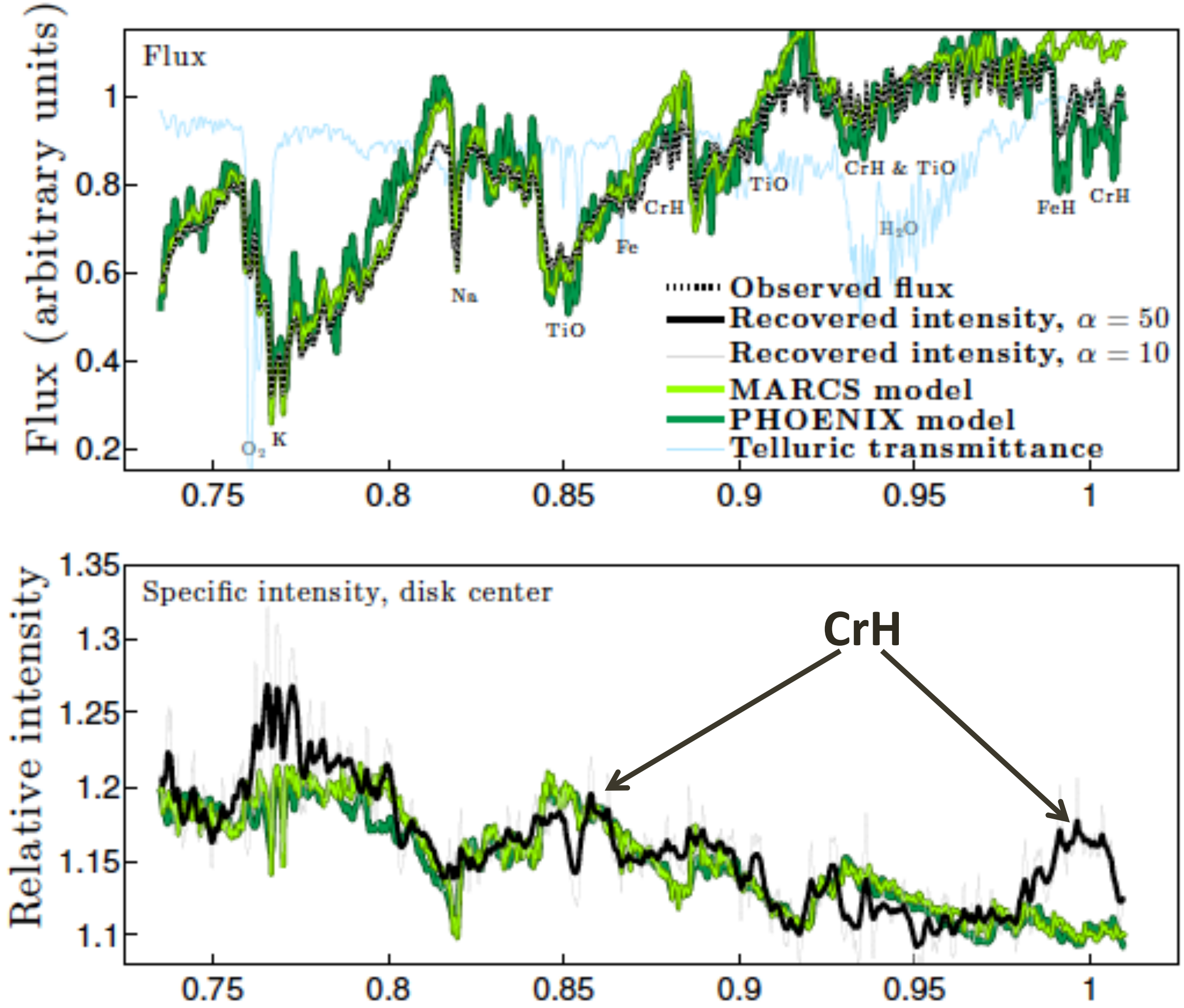
Real data: GJ1214b

- GJ1214b is a super-Earth orbiting an M-dwarf.
- Observations with the VLT FORS2 in multi-object spectroscopy mode.
- Eight transits spread over 3 years.
- 160 spectra with S/N around 130 on 0.7-1 μm range.

GJ1214: specific intensities

Stellar flux from observations and models

Specific intensity/ mean specific intensity from reconstruction and models. Found error in molecular data for CrH.



Outlook

- Gaia is working fine producing huge amount of data. It is complemented by ground-based spectroscopic surveys, like 4MOST. We focus now all the new science that is facilitated by these data.
- CRIRES+ is nearly ready to travel to Chile. It will be a unique instrument, specially for exoplanet characterization. You will hear more on that in the 2nd half of 2018.
- ELT HiReS − a fiber-fed super-stable echelle spectrometer is progressing well, aiming at first light in 2027-2028.
- The largest space telescope JWST will by launched in the end of 2018.

Conclusions

- In our fields we (UU) are on the cutting edge of research. In some − we are the cutting edge.
- We have developed methods and tools that are widely used all around the world.
- We have expertise and reputation in instrument development. This opens great perspectives for the future.
- Some of these instruments are already working or coming on-line very soon (e.g. CRIRES+). We are looking forward doing science with them.
- Some technologies we mastered can be useful for other groups in IFA: polarisation gratings, data analysis, atomic & molecular data.