Phase A review: Stars and Stellar Populations

Andrea Chiavassa

Outline

- Context, the team and the process
- Sciences cases: Cool stars
- Sciences cases: Dynamical and chemical composition of stellar atmospheres
- Sciences cases: Primitive stars
- Required TRLs

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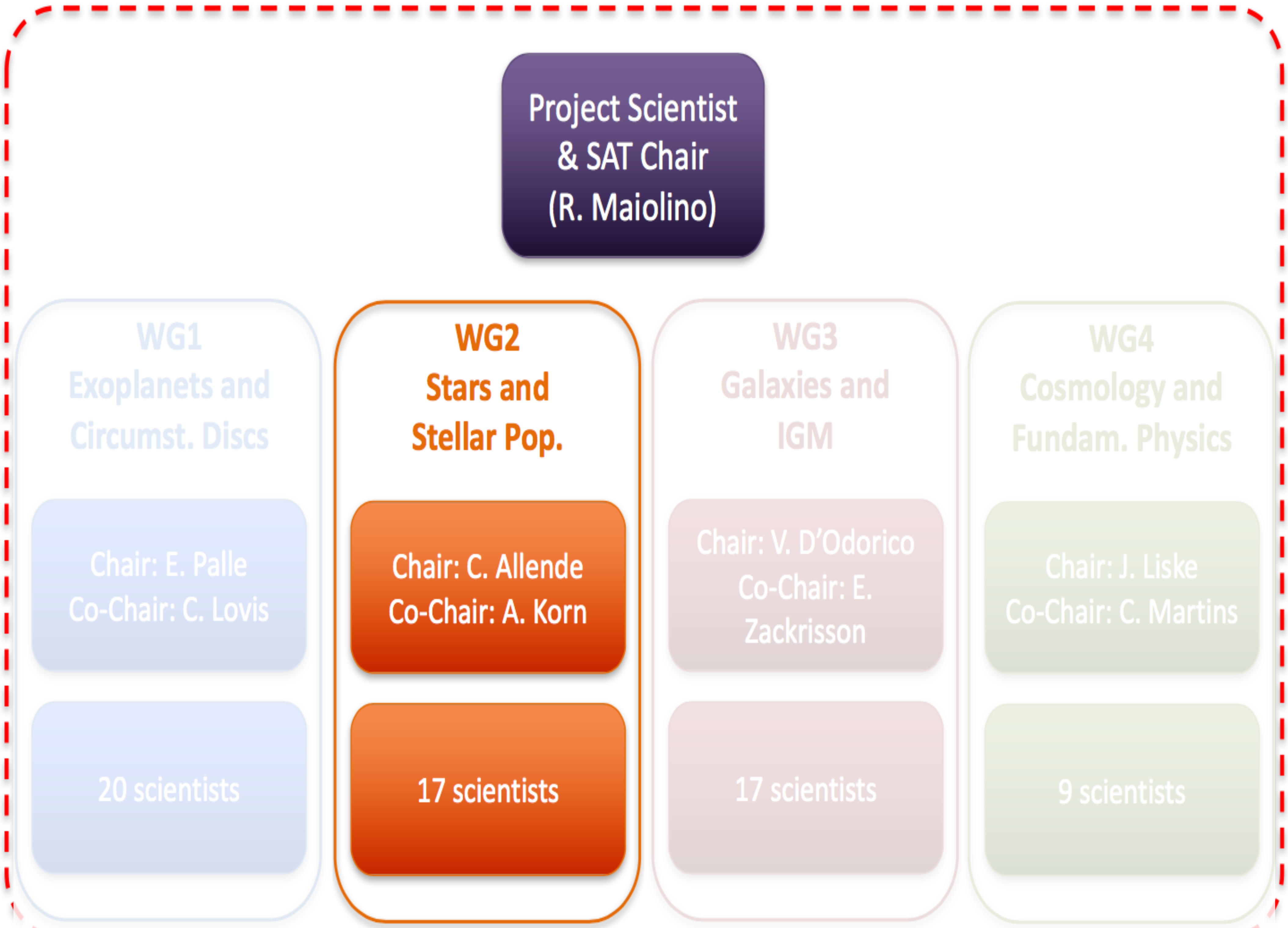
The team of Phase A

Science Advisory Committee (SAT): 63 experts in High-Res spectrosc.



The team of Phase A

Working group Stars and Stellar Populations

C. Allende (IAC, Spain - chair), A. Korn (Uppsala University, Sweden - co-chair)

V. Adibekyan (IACE, Portugal), J.-C. Bouret (LAM, France), A. Chiavassa (Lagrange, France), N. Christlieb (ZAH, Germany),
C. Juul Hansen (Niels Bohr Institute, Danemark), O. Kochukhov (Uppsala University, Sweden), J. R. de Medeiros, A. Mucciarelli (University of Bologna, Italy), E. Niemczura (University of Wroclaw, Poland) L. Pasquini (ESO), G. Pietrzynski (Polish Academy of Sciences, Poland), A. Reiners (University of Göttingen, Germany), D. Romano (University of Bologna, Italy), R. Schiavon (Liverpool John Moores University, UK), S. Sousa (IACE, Portugal)

The process

Starting point
Reviewing the science cases in the White paper of Maiolino et al. 2013 (arXiv:1310.3163)

Prioritization of Science Cases

Science Cases to TRL and advising for Technical solutions (Technical Team + ESO)

Estimation of costs and Phase A document

The process

Prioritization of Science Cases

Criteria:

A. Scientific impact (e.g., enabling new discoveries, importance for a broad scientific community, interdisciplinarity, Nobel prize potential)
B. Feasibility and time needed
C. Competitiveness with other instruments

The process

The winners are:

A. Cool stars (low mass, brown dwarf, red giant stars)

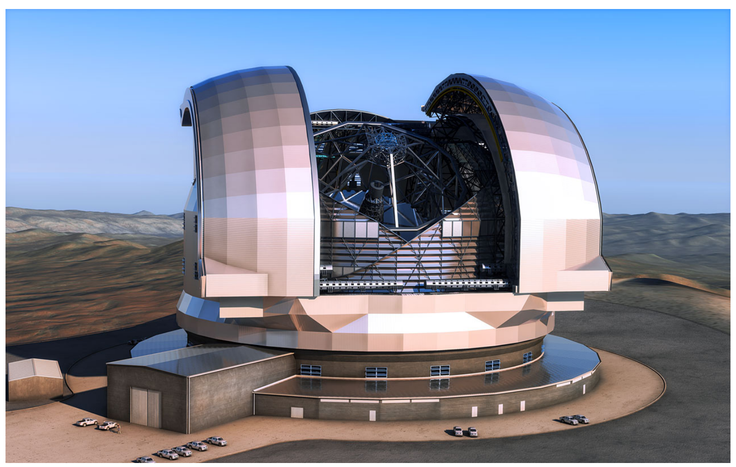
B. Primitive stars

C. Dynamical and chemical composition of stellar atmospheres

… + 15 additional science cases ranked lower, including stellar-population studies in the Local Group, via individual stars and extragalactic star clusters, pulsating stars, proto-planetary disks and pre-main sequence stars, asteroseismology in the Local Group, Gravity Darkening, Circumstellar disks, metals in white dwarfs

Take home message
What can be achieved with HIRES ?

The vast light-collecting power of the ELT



It will enable detailed high-resolution spectroscopy of individual stars (faint red dwarfs and distant red giants in nearby galaxies)

The high-resolution of HIRES

Measuring the absorption lines in stellar spectra, where the thermal and turbulent velocities may be as small as 1 km/s

Measuring the surface structures or anomalous chemistry

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Context

- Sciences cases: Cool stars
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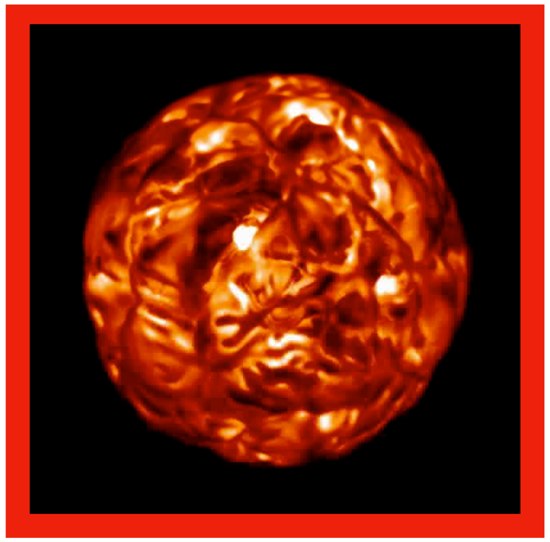
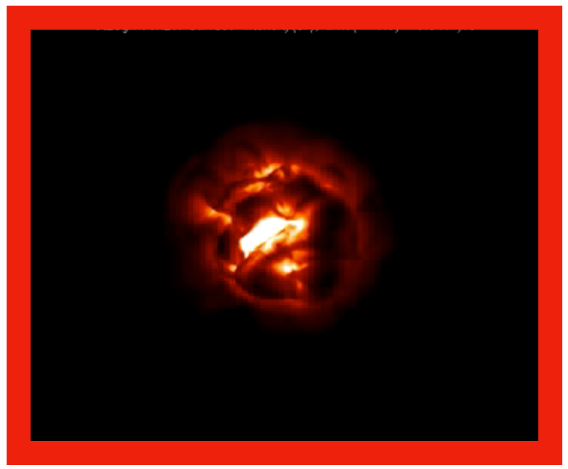
Science cases: Cool stars

RSG (Chiavassa et al. 2011)
M > 8 M☉



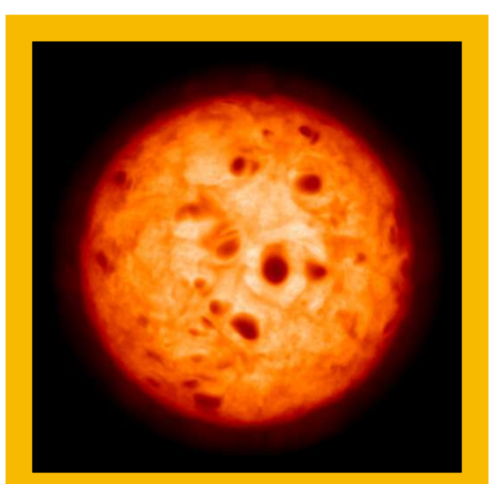
> 500 R☉

AGB (Freytag et al. 2017)
M = 1-8 M☉



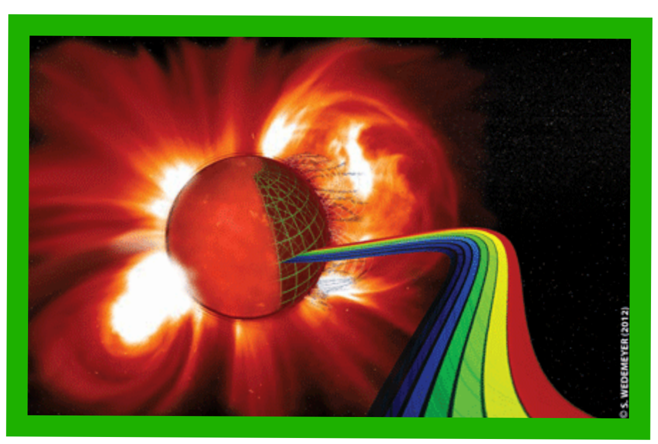
> 200 R☉

Brown Dwarf
(Freytag et al. 2013)
M = 13 Mj

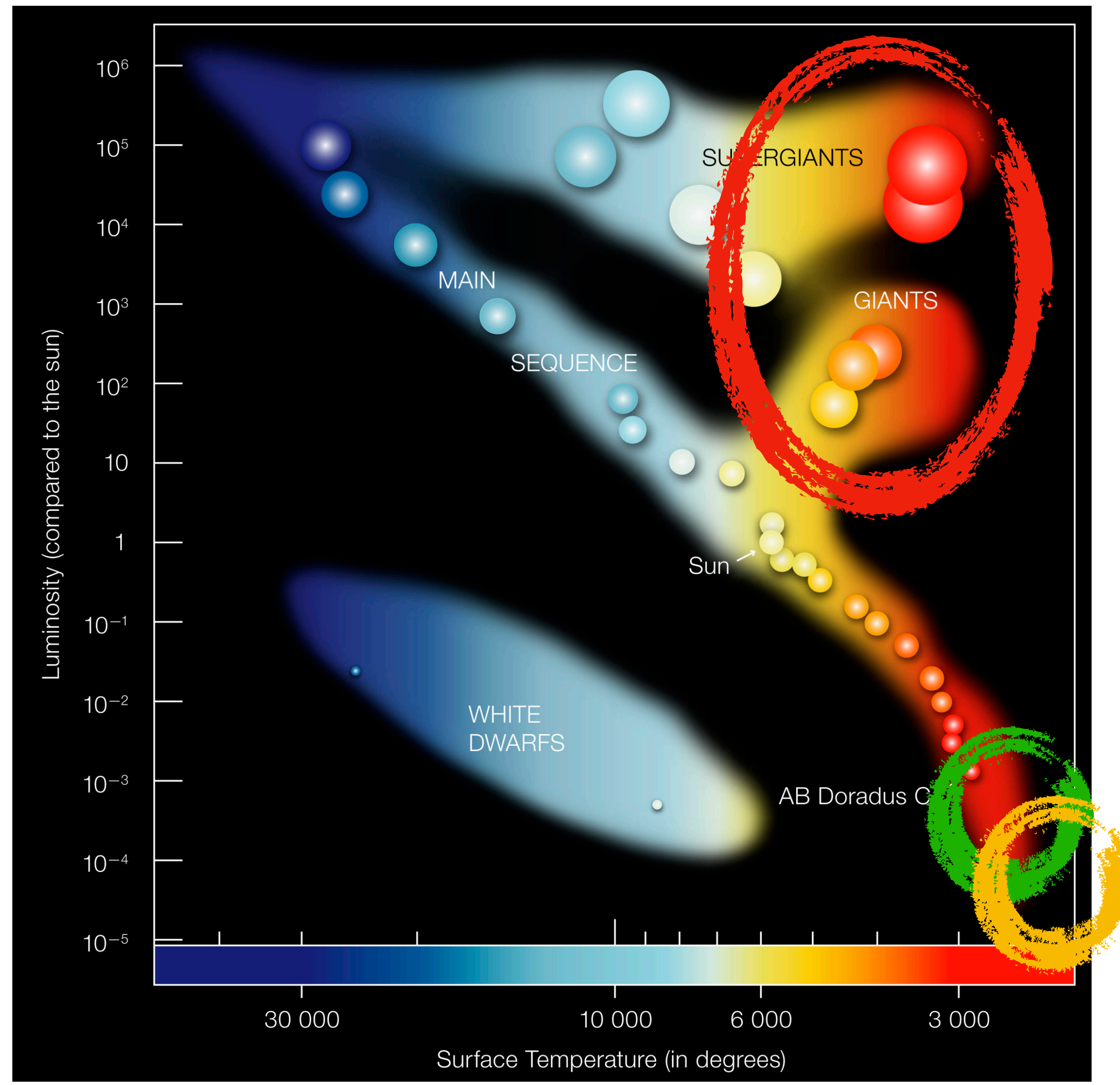


0.1 R☉

M Dwarf
(Wedemeyer et al. 2013)
M = 0.2 M☉



0.2 R☉



Science cases: Cool stars

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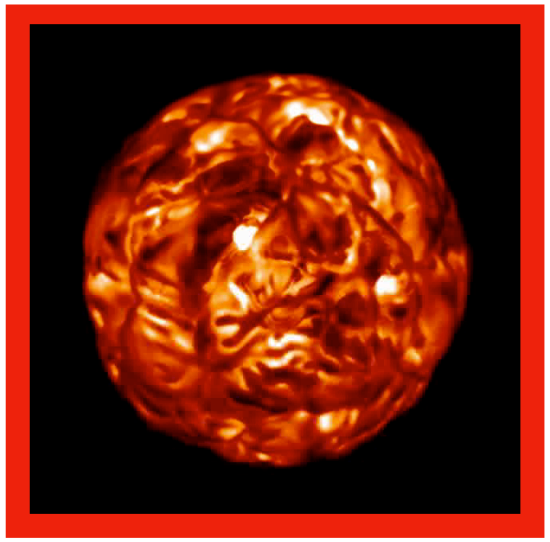

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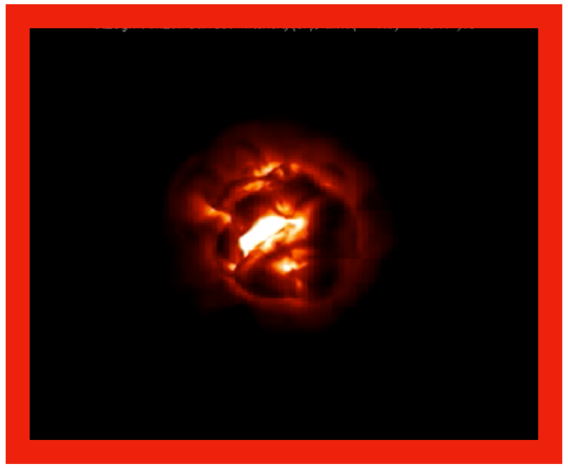

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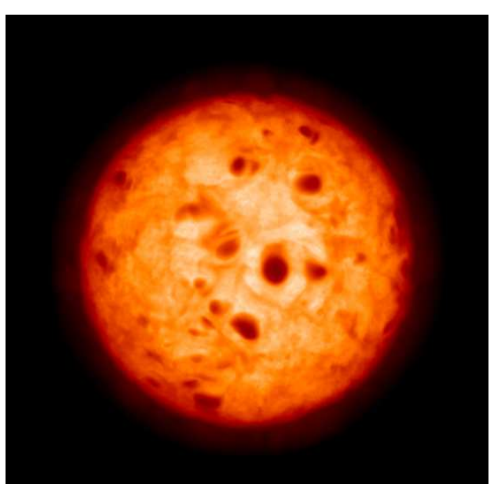

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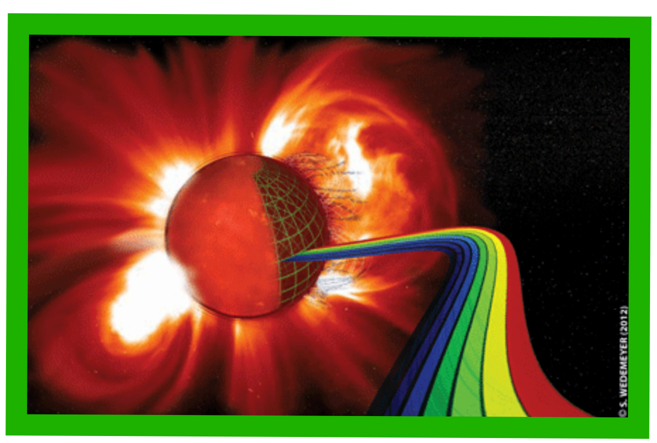

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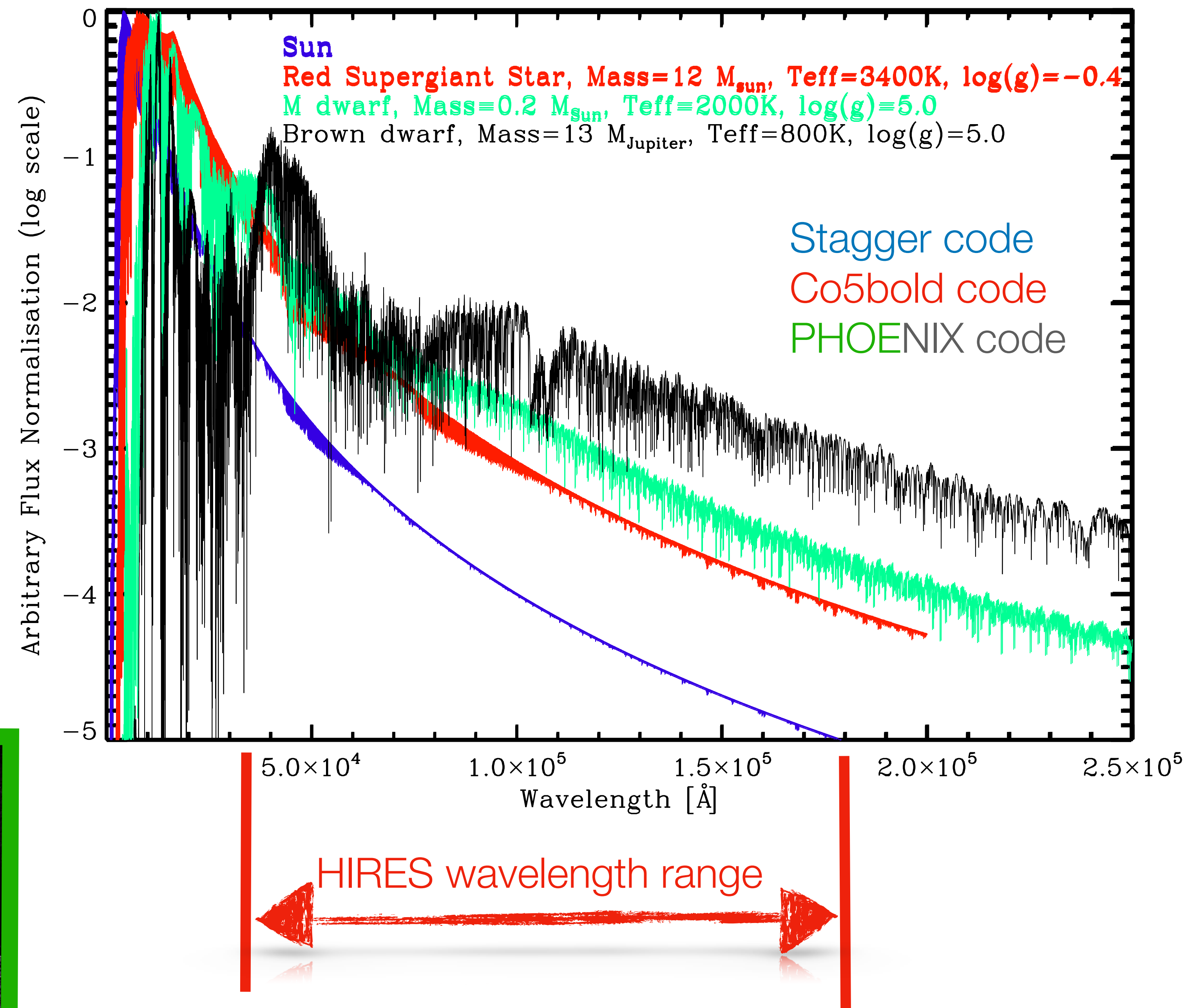
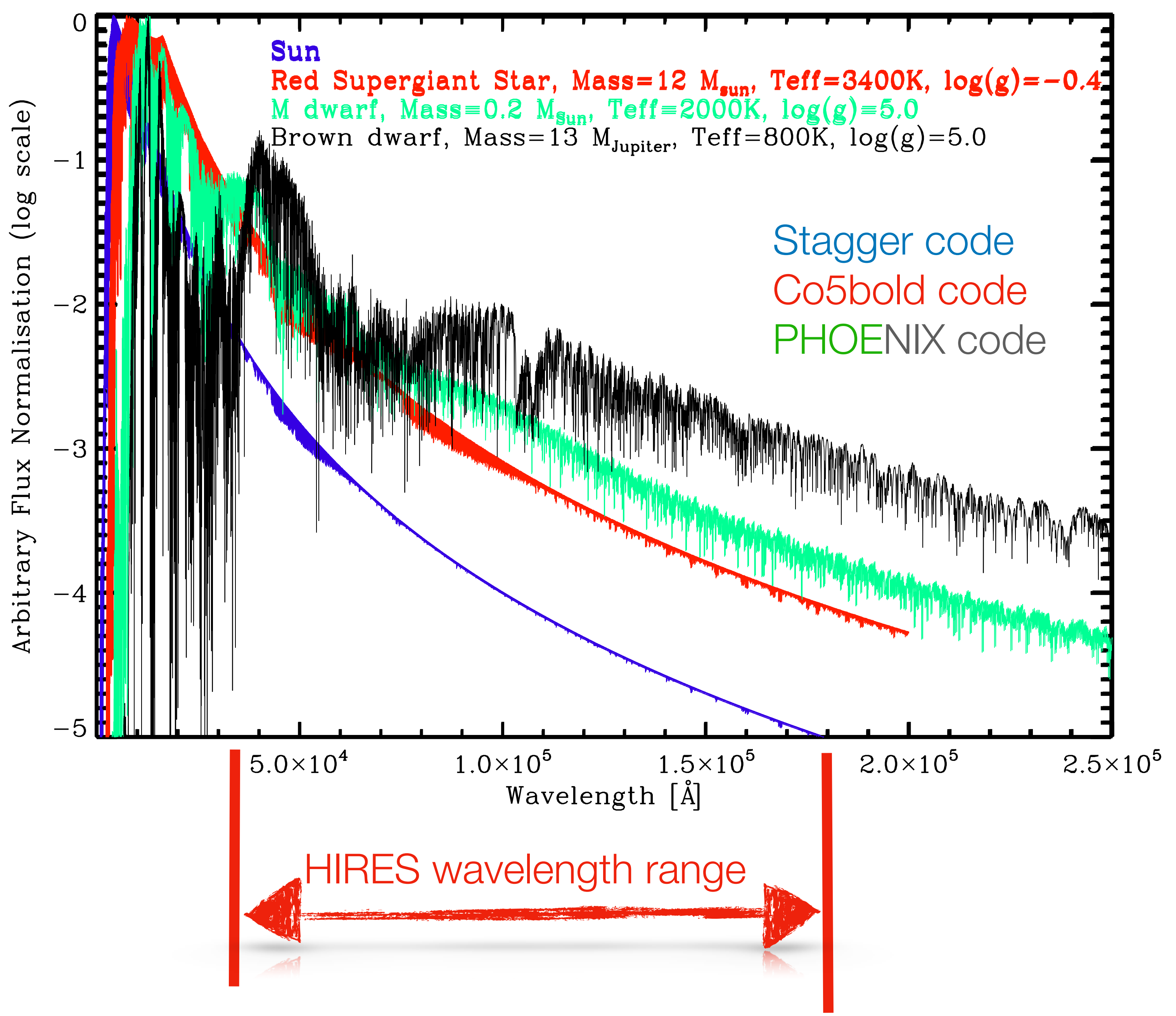


Science cases: Cool stars

At the low temperatures found in the atmospheres, the chemistry becomes complex, and a myriad of atomic and molecular transitions overlap in any given part of the spectrum.

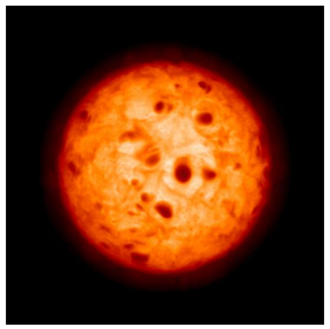
This spectral *crowding* causes serious difficulties to identify and interpret the observations.

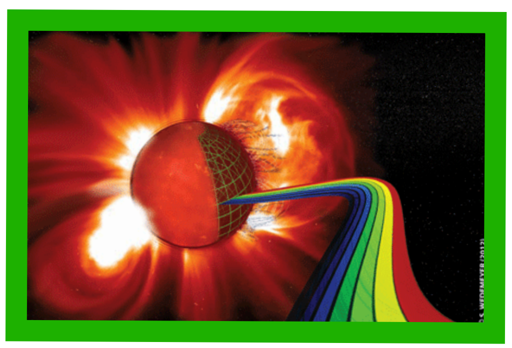
HIRES will observe at or beyond the limit imposed by the thermal and turbulent width of the spectral lines, and in the infrared, where there is a reduced density of transitions.

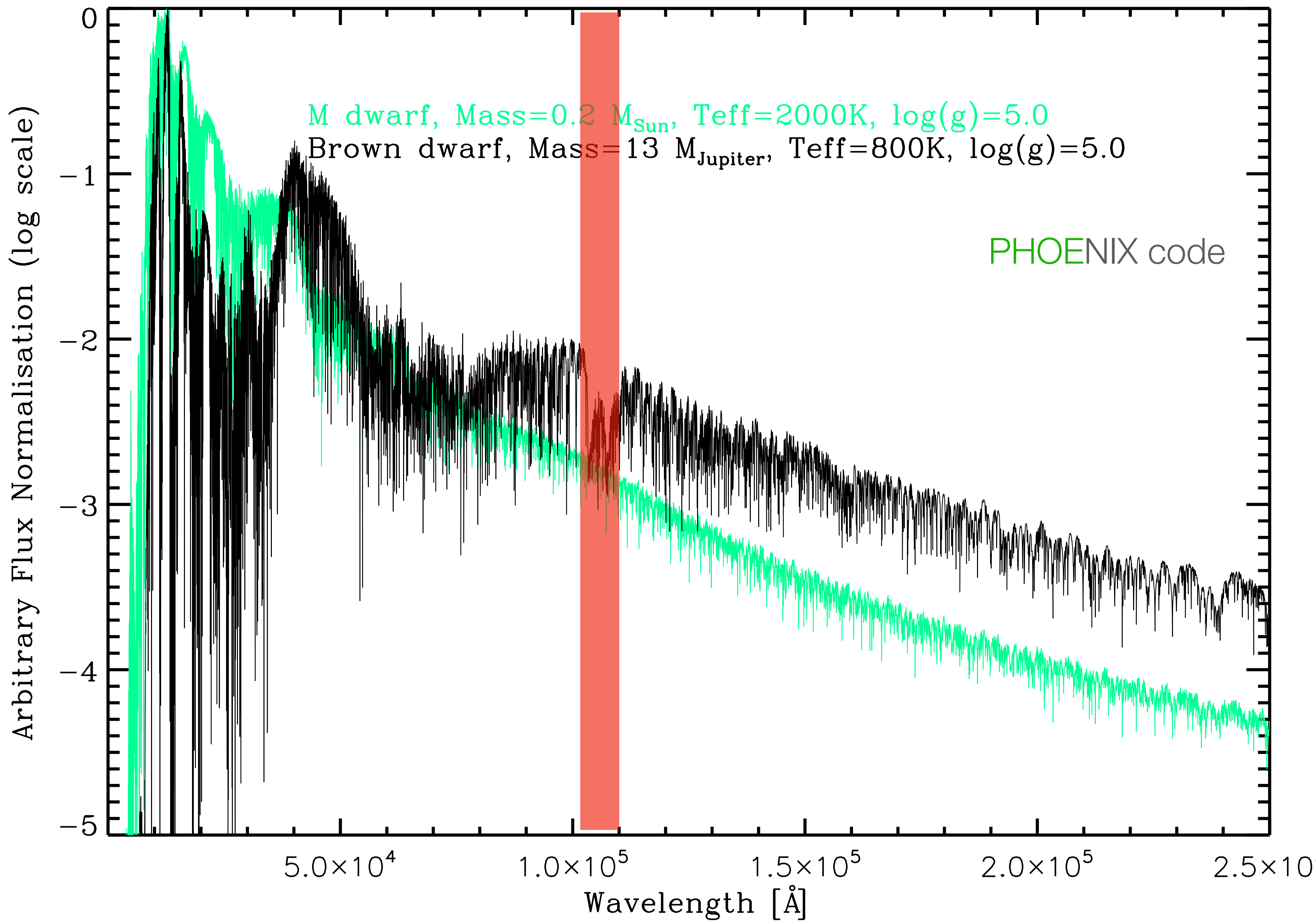


Science cases: Cool stars

Cool dwarf stars

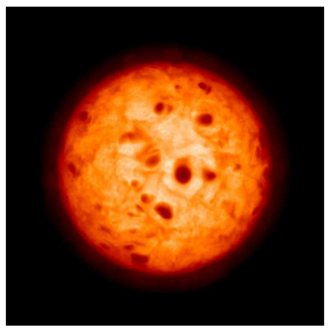


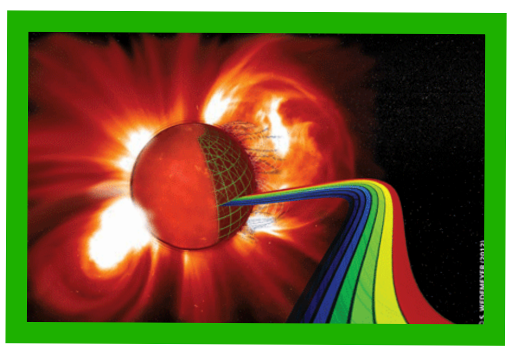




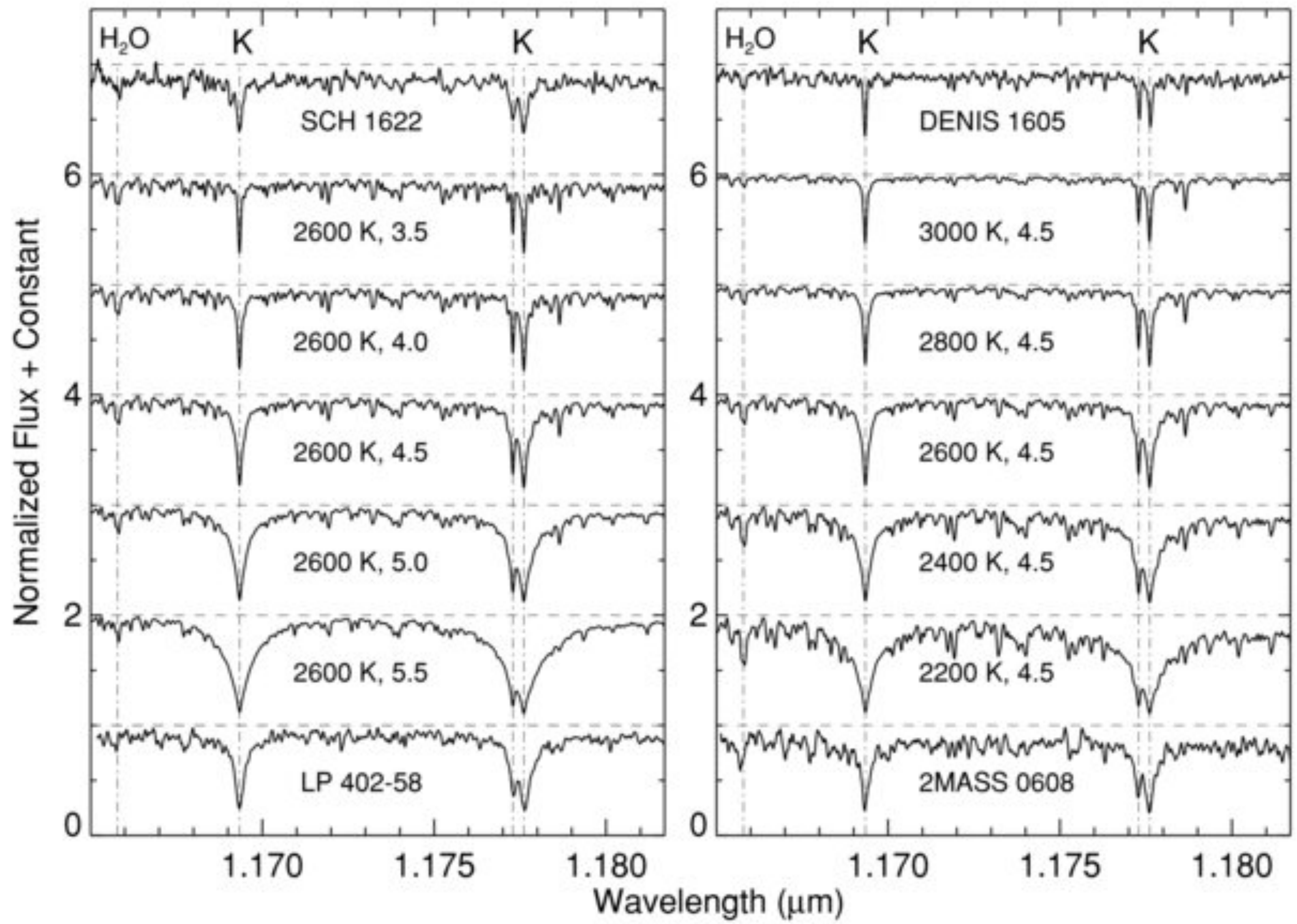
Science cases:
Cool stars

Cool dwarf stars





NIRSPEC spectra (Rice et al. 2010)



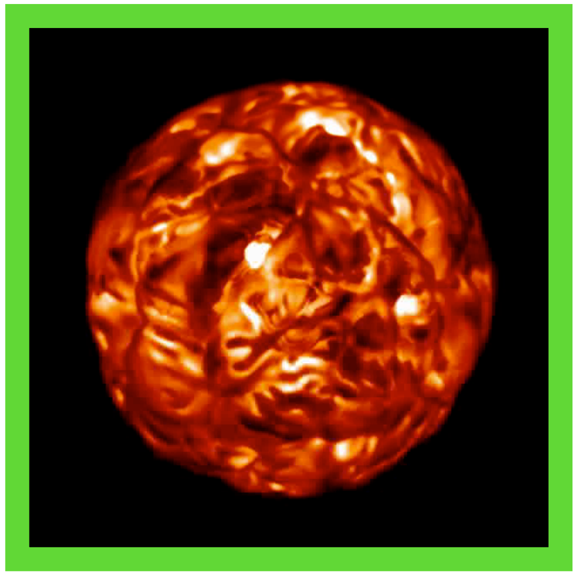
High-resolution spectroscopy provides detailed information, which complements photometric observations (synergy with PLATO and ARIEL).

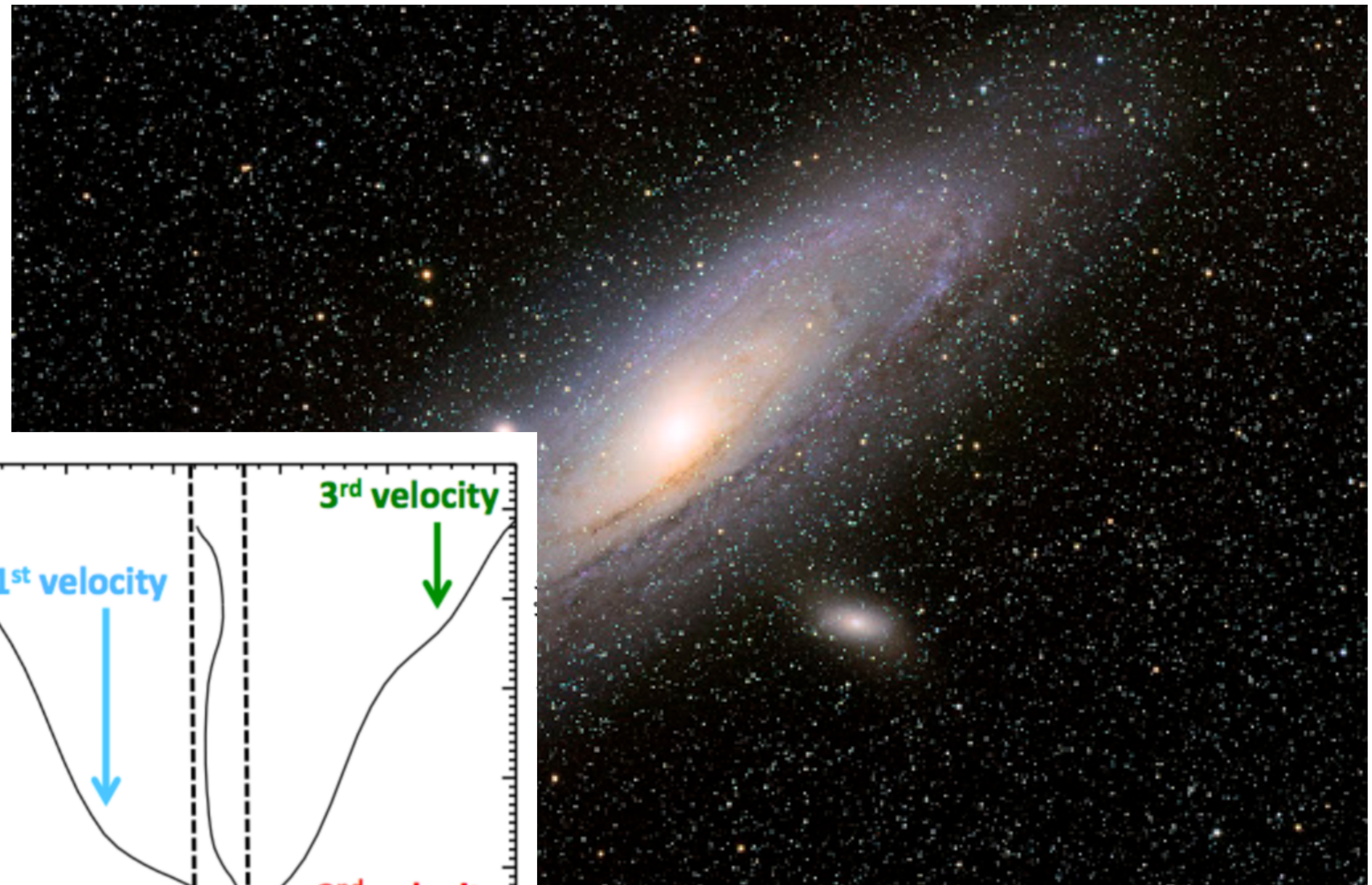
Atmospheric parameters of the star, in particular its chemical composition, or the presence of significant velocity fields, accretion from circumstellar material, or strong magnetic fields.

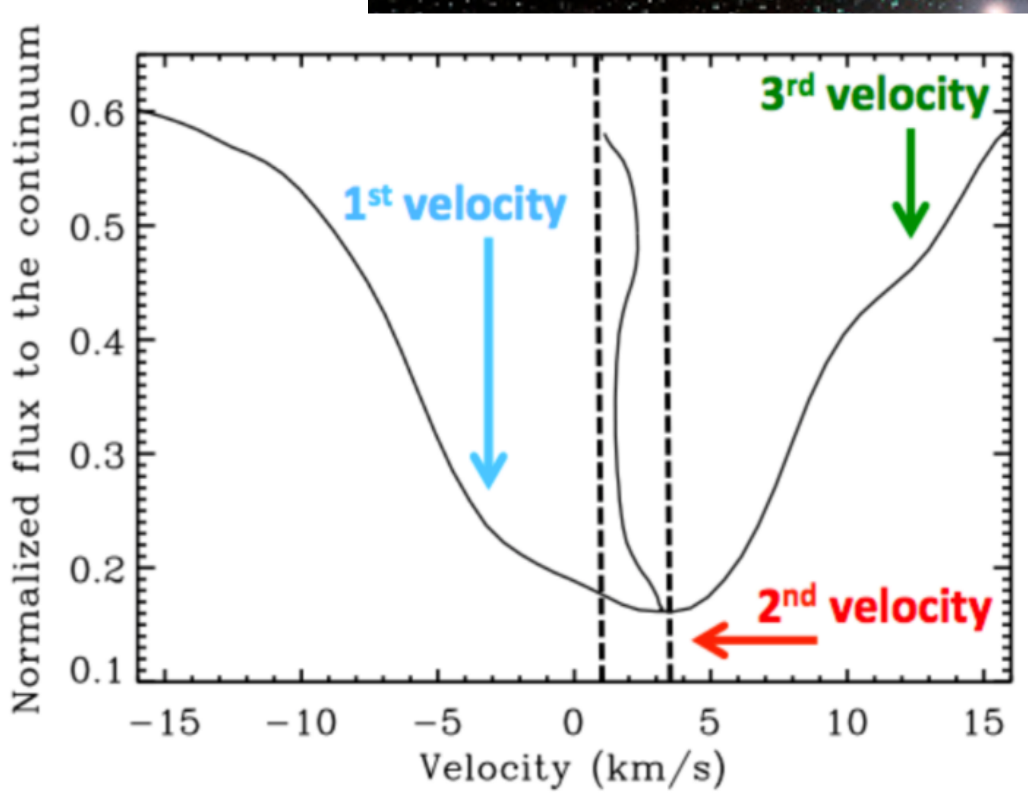
Strong sensitivity of potassium lines and H_2O absorption

Science cases: Cool stars

Cool evolved stars







Dynamics and chemical composition in nearby Galaxies (Davies et al. 2017)

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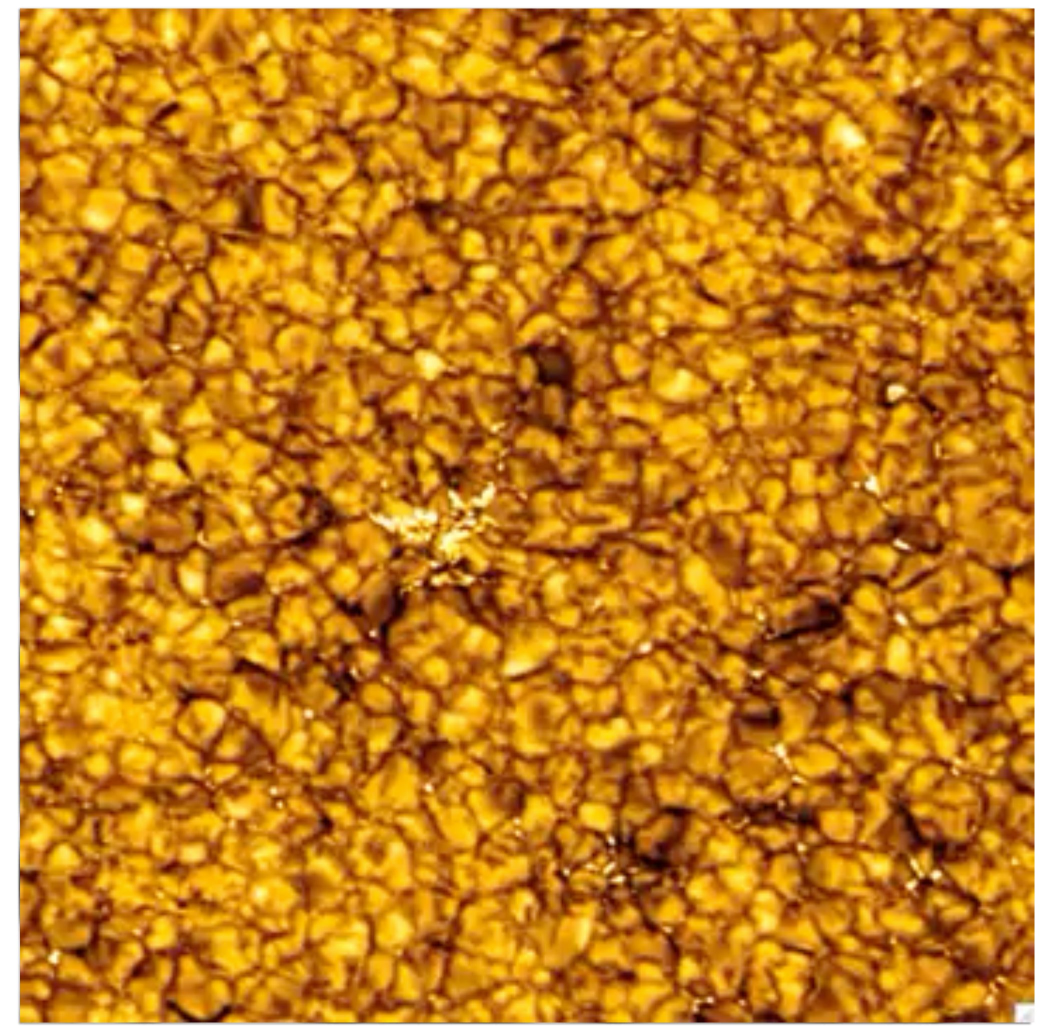
Science cases: Dynamical and chemical composition of stellar atmospheres

Bergemann et al. 2019

Synthetic Sun (Stagger code, Magic et al. 2013)

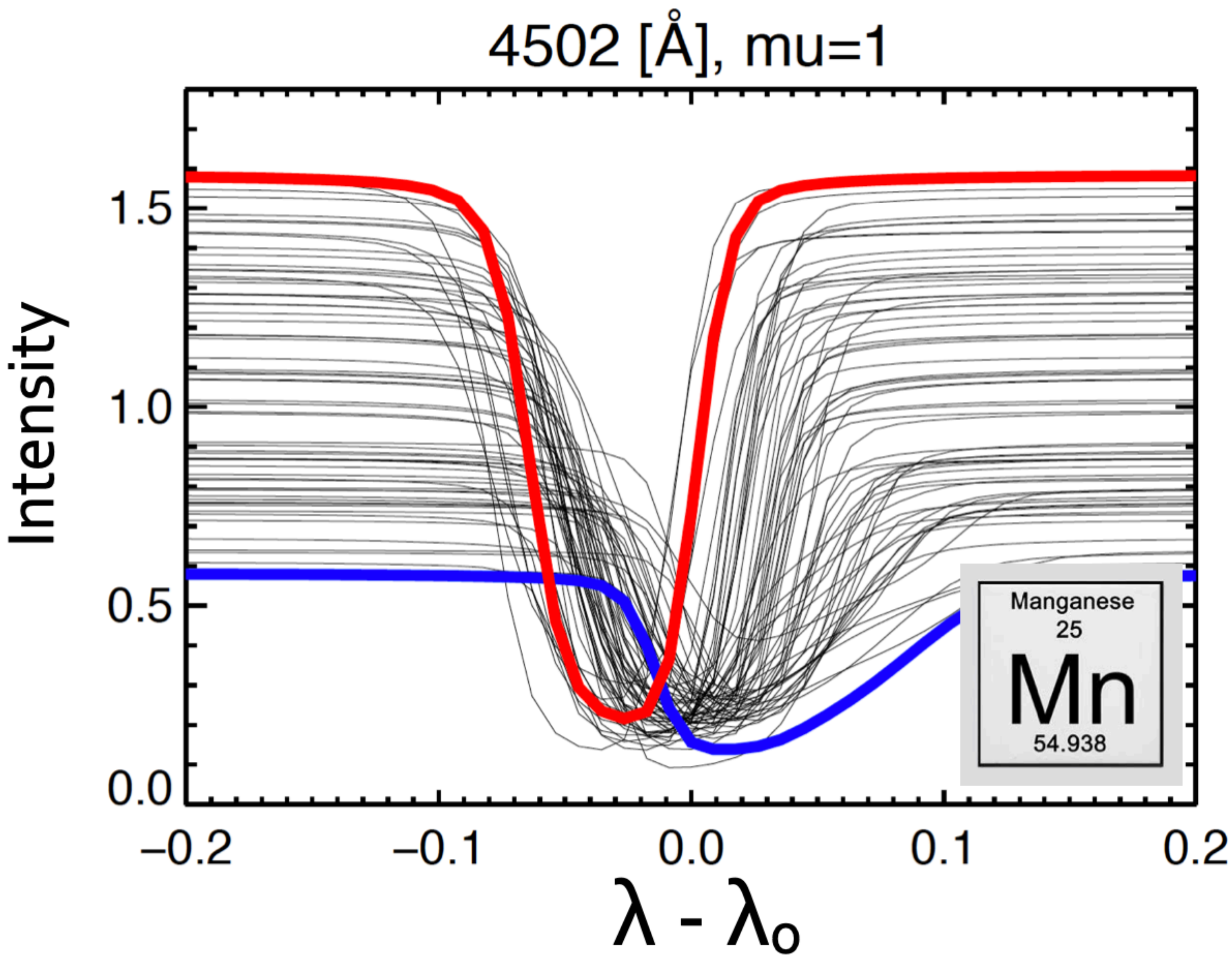
Observed Sun for 1 hour



Stellar surface inhomogeneities (caused by convection, magnetic fields, rotation, dust…) changes with time and affect line depth, position, width.

Science cases:
Dynamical and chemical composition of stellar atmospheres

Bergemann et al. 2019



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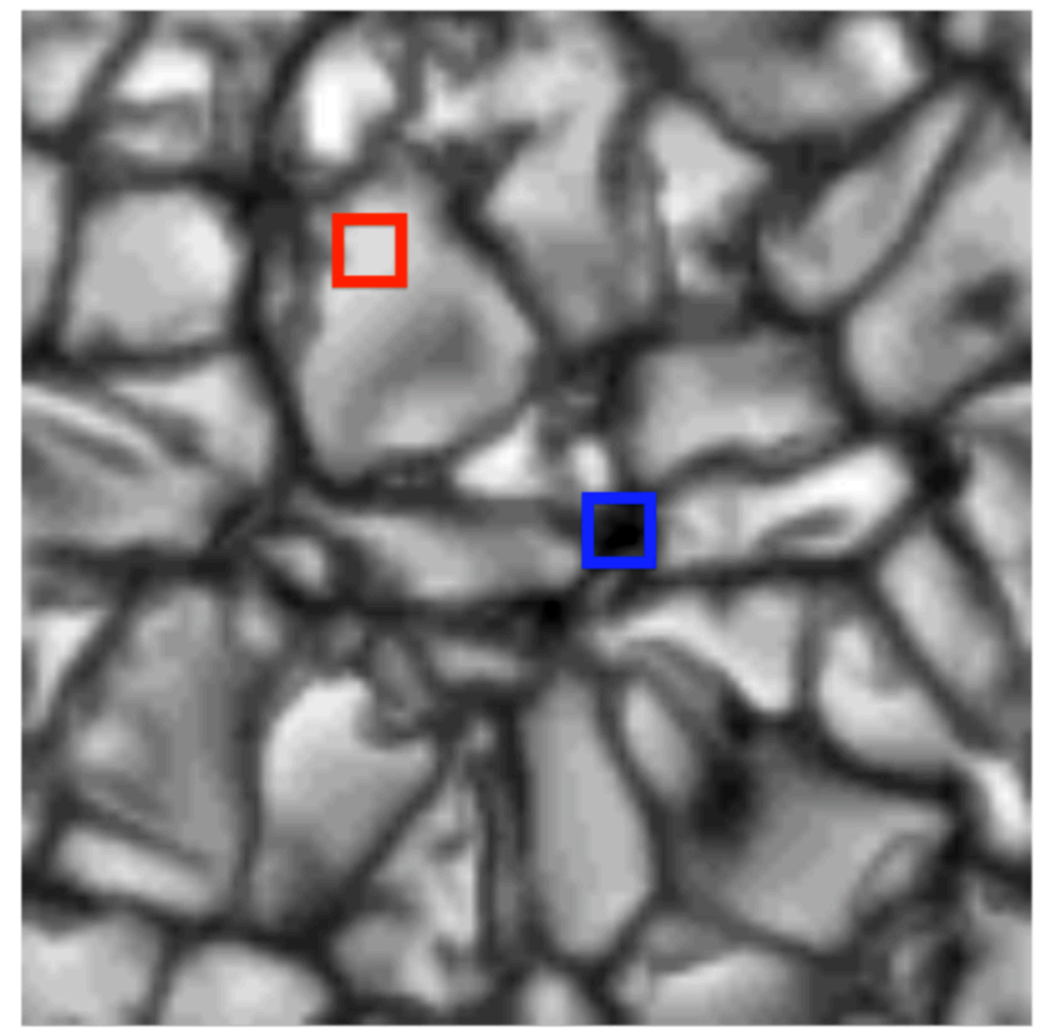

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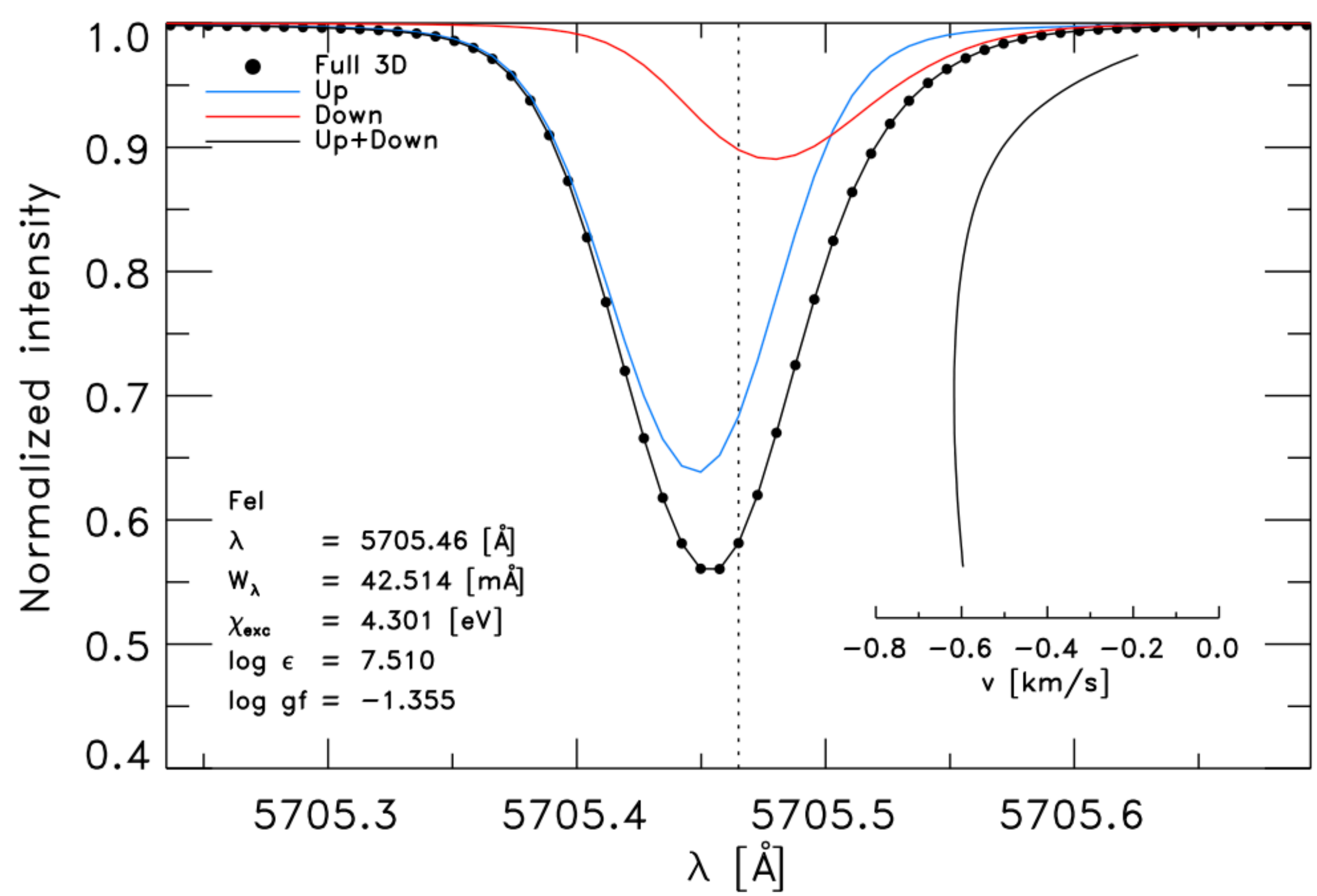
Science cases: Dynamical and chemical composition of stellar atmospheres

Extreme-precision studies of spectral line shapes and elemental and isotopic abundances (from ~ 0.1 dex to under 0.01 dex) :

- to reveal secular changes in surface composition of stars due to diffusion, mixing, or the accretion of interstellar or protoplanetary material onto the star (Melendez et al. 2009)
- of heavy elements (Z>30) in the blue (<430 nm) to understand the neutron-capture nucleosynthesis processes, and identifying their astrophysical site(s) (Sneden et al. 2008).

High Hand in hand, the application of state-of-the art 3D hydrodynamical model atmospheres and non-LTE modelling (e.g. Nordlander et al. 2017)



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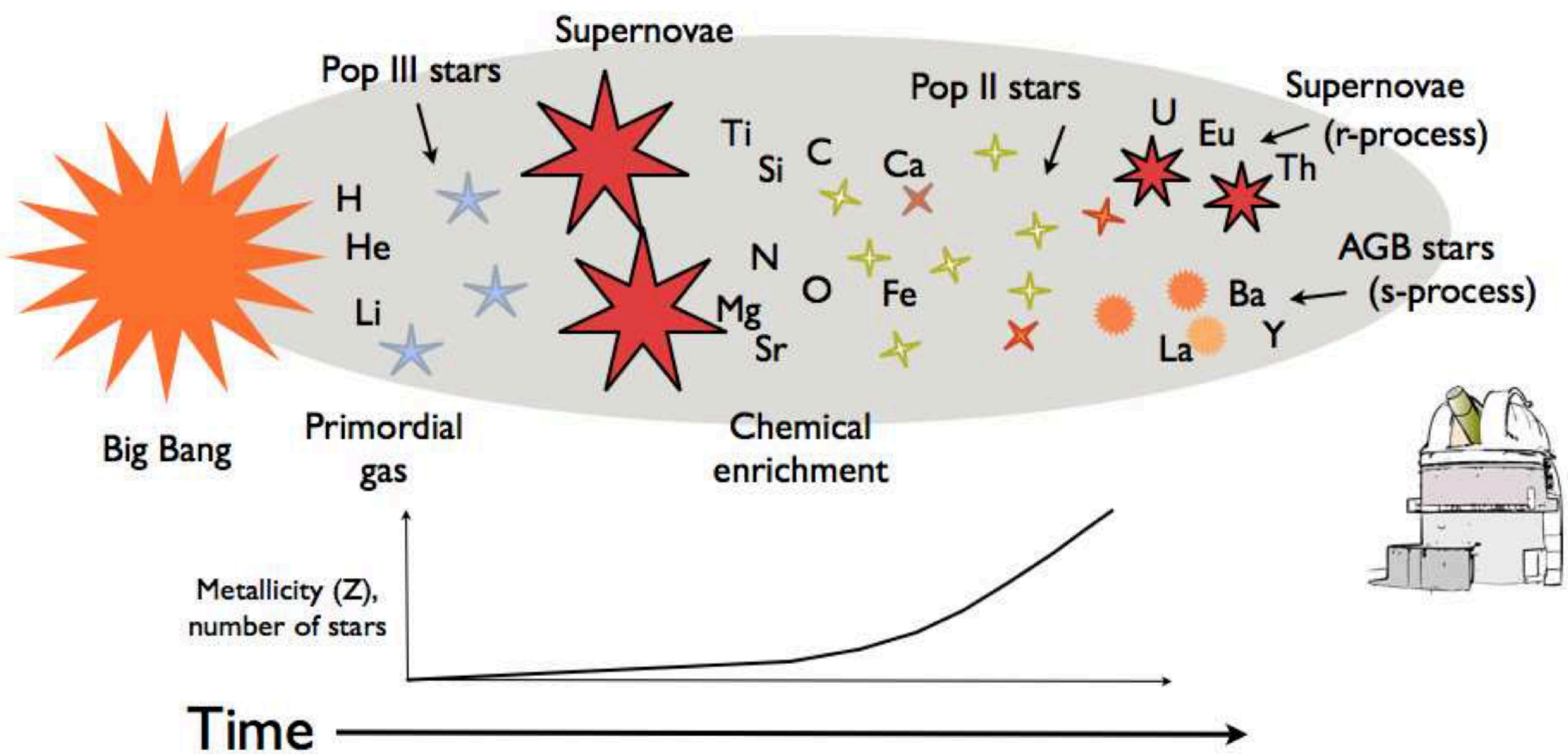
Science cases: Primitive stars

Sketch of the chemical enrichment of the Universe (Jacobson and Frebel 2014)



Understanding the nature of the very first generation of stars, determine the yields of early supernovae, and to constrain the lowest metallicity at which the gas can collapse to form low-mass stars.

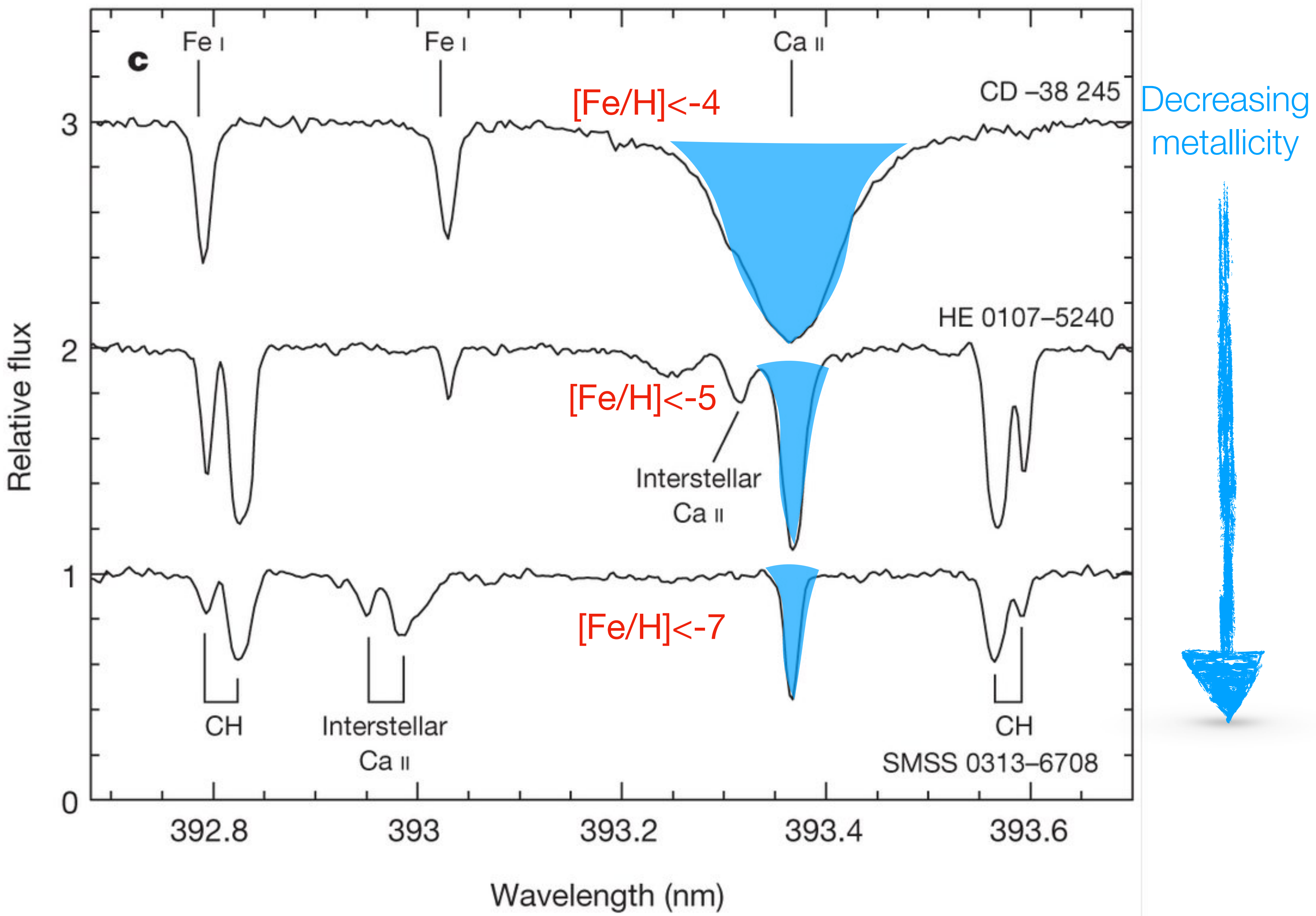
Science cases: Primitive stars

Detailed elemental abundances for dozens of elements to constrain models of supernovae and their progenitors.

Synergy with ongoing and planned surveys (SDSS, LAMOST, MOONS, DESI, WEAVE and 4MOST) that will identify targets down to V ~ 20, too faint to be followed-up at higher resolution with 10m-class telescope.

The blue (and near-UV) will be crucial, as this is where the atoms have their strongest (and only visible) transitions.

Most metal poor stars known (Keller et al. 2014)



Other Science cases

Pulsating stars - Cepheids as distance ladder

HIRES will allow us to observe fainter Cepheids in more galaxies, to constrain the dependence of the period-luminosity relationship on various stellar parameters.

Dynamical structure of their atmospheres throughout the Galaxy and also in lower-metallicity environments like the LMC/SMC

Proto-planetary disks and pre-main sequence stars

HIRES will be critical to measure at, high spectral resolution, line profiles and disentangle multiple components in the spectra (disks, circumstellar and interstellar gas, and light coming from the proto-star itself).

Powerful tool to identify stellar systems with rocky exoplanets via single-epoch high-quality spectroscopy.

Circumstellar disks, metals in white dwarfs

White dwarfs are intrinsically very faint, detailed follow up with HIRES will be crucial with to achieve extremely high signal-to-noise ratios and detect very weak lines from other metals that may be present in amounts that vary with time.

Other Science cases

Stellar-population studies in the Local Group, via individual stars and extragalactic star clusters

Spectroscopy of individual stars in other galaxies allow us to apply the same techniques used for Milky Way stars to study the formation and history of those galaxies, and therefore compare apples to apples.

Studi of Extra-Galactic clusters as tracer of the formation history and evolution of the galaxies harbouring them, they can be used to sample in detail the properties of their host galaxies.

Asteroseismology

Asteroseismology outside our Galaxy has never been done and will come as an excellent complement to the PLATO space mission which will explore our Galaxy.

Test of stellar evolution outside of our Galaxy and will provide very good constrain on the luminosity of and distance to these stars.

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Sciences cases: Pr

- Required TRLs

Science cases: Required TRLs

Science Case	Internal rank				Wavelength range (microns)									Spectral resolution (x 1,000)							Wavelength accuracy					Polarim.	Multiplex.			Backgr. Sub.	AO		IFU
					0.34-.037	0.37-0.4	0.4-0.50	0.50-0.67	0.67-0.8	0.8-0.9	0.9-1.3	1.5-1.8	2.0-2.4	5	10	20	50	80	100	150	2m/s	1m/s	10cm/s	2cm/s	1cm/s		2	5	10		SCAO	LTAO	
WG2: Stars and Stellar Populations																																	
Cool stars	1	9	10	7																													
Primitive stars	1	7	7	7																													
Stellar atmosph.	1	7	8	6																													

■ = Essential

■ = Desirable

Spectral resolution (x 1,000)						
5	10	20	50	80	100	150

To fully resolve the spectral line shapes (most of Science cases)

Science cases: Required TRLs

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The red-infrared is vital for cool stars, while the blue is inescapably needed for studying the most metal-poor stars.

Wavelength stability at levels of < 0.01 km/s on time scales of a few nights, as needed to ensure the accurate studies of stellar dynamics ans abundances

Science cases: Required TRLs

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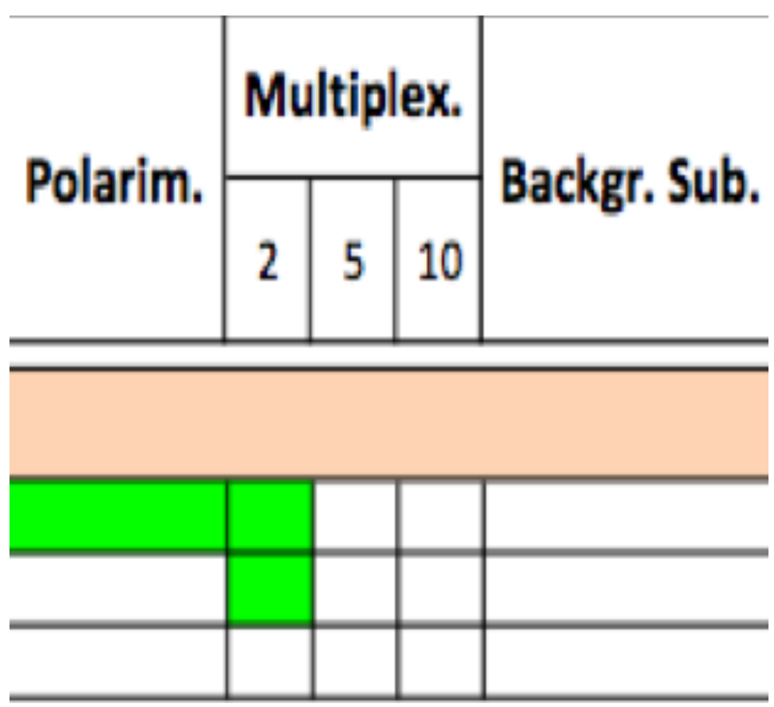

A background subtraction quality better than 0.1% in the optical and 0.5% in the infrared to avoid limiting the signal-to-noise ratio of observations

Relative flux calibration of better than 1% over spectral intervals of 20-30 nm, covering the broadest features in stellar spectra

Science cases: Required TRLs

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Primitive stars	1	7	7	7		Essential	Essential	Essential	Desirable										Essential	Desirable		Desirable					Desirable						
Stellar atmosph.	1	7	8	6				Desirable	Desirable	Essential	Essential	Essential							Essential	Desirable		Desirable									Essential		Essential

(Red) = Essential

(Green) = Desirable

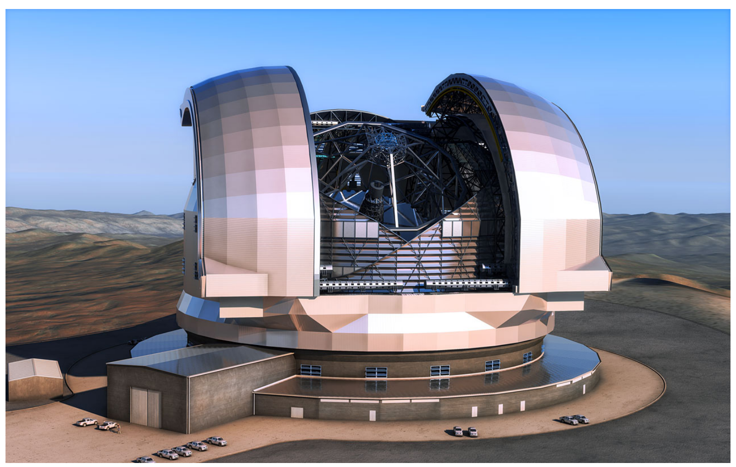
AO		IFU
SCAO	LTAO	
Essential		Essential

An IFU unit enabling spatial resolution close to 10 mas. This is a requirement for resolving stellar populations in nearby galaxies and circumstellar disks.

Take home message
What can be achieved with HIRES ?

The vast light-collecting power of the ELT

The high-resolution of HIRES



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Measuring the absorption lines in stellar spectra, where the thermal and turbulent velocities may be as small as 1 km/s

Measuring the surface structures or anomalous chemistry