Accuracy and Precision of industrial stellar abundances

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Nucleo de Astronomia
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NÚCLEO DE ASTRONOMÍA udp
FACULTAD DE INGENIERÍA Y CIENCIAS

We  stellar spectra

We ❤ stellar spectra

Stellar spectroscopists have the “best data” about stars - know “the best” about them

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Stellar spectroscopists have the “best data” about stars - know “the best” about them

We suffer from the “too much information effect”

We  stellar spectra

- Radial velocities
- Atmospheric physics

- Chemical makeup

We ❤ stellar spectra

- Radial velocities
  - Travel velocities across the Galaxy
  - Variations due to oscillations or presence of companions

SONG, HARPS, PFS…

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  - Turbulent motions, magnetohydrodynamics
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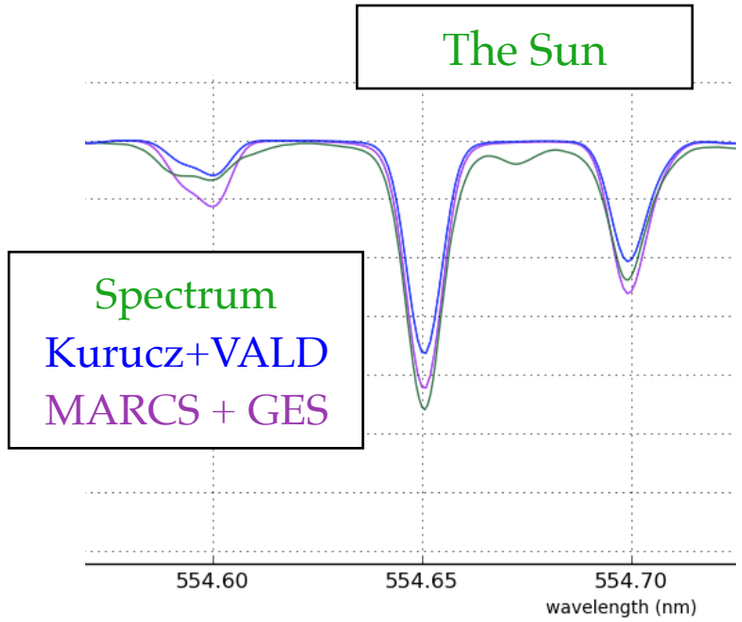

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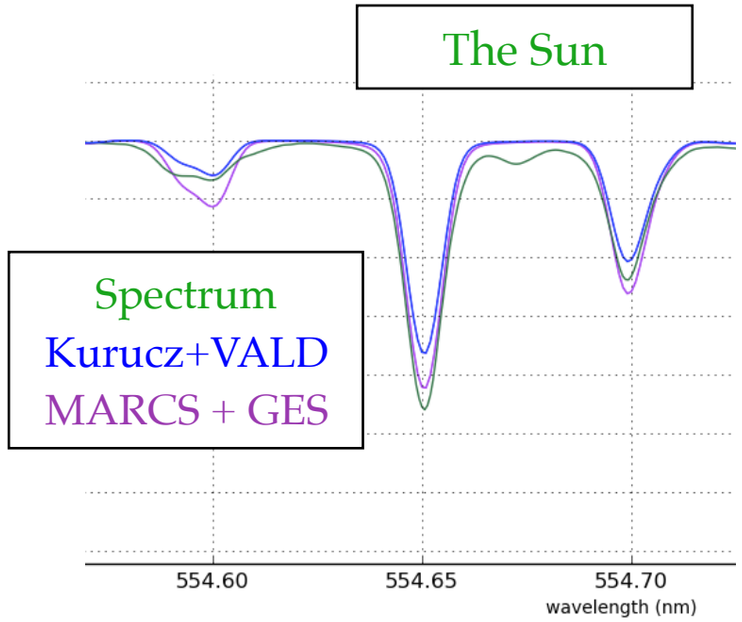
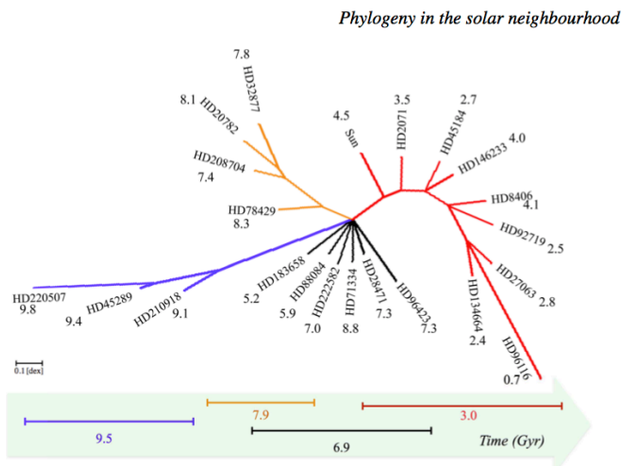
  - Chemical anomalies
  - Stellar DNA





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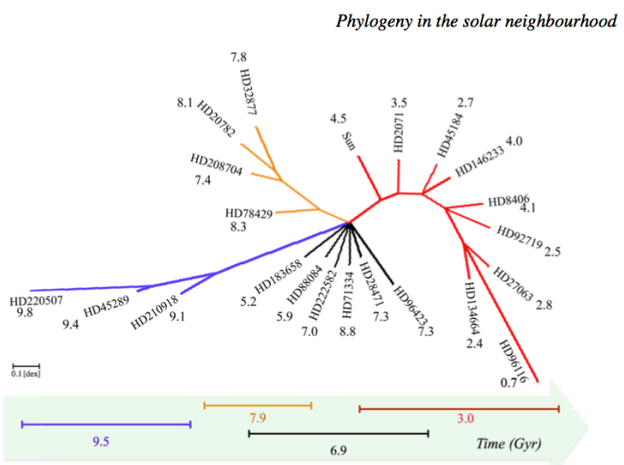

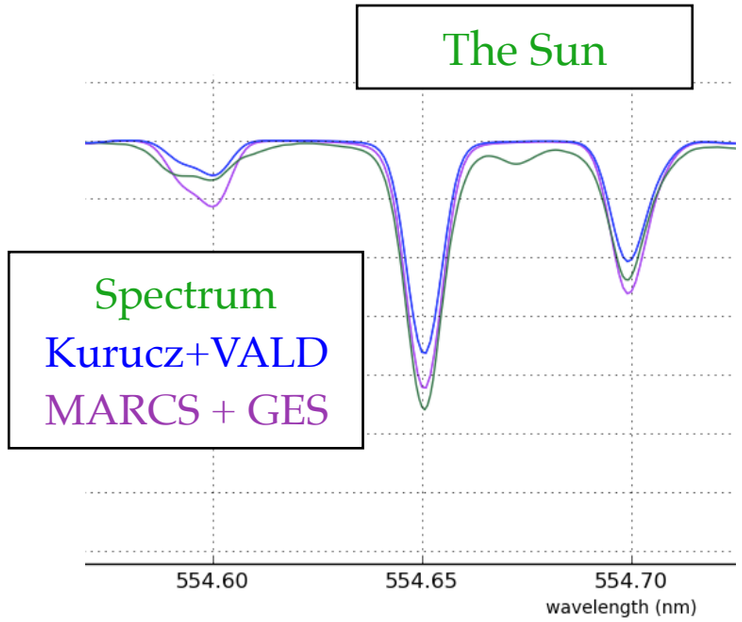

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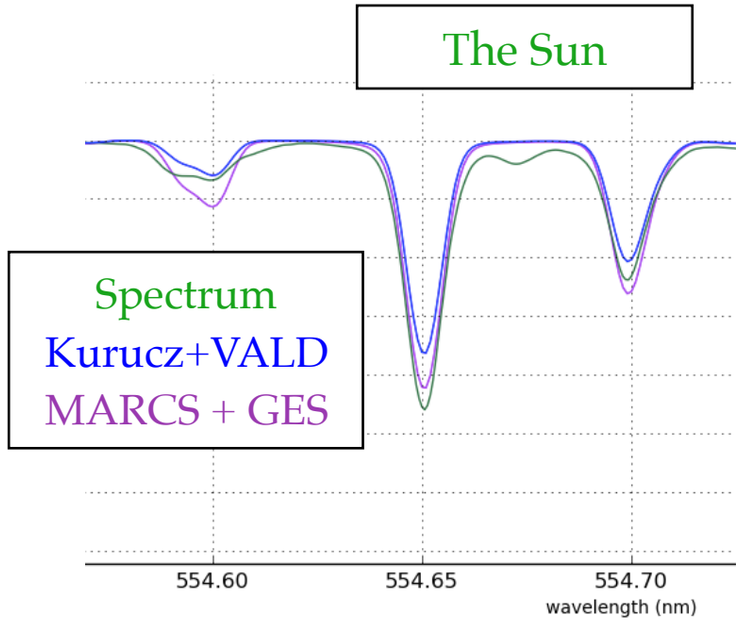
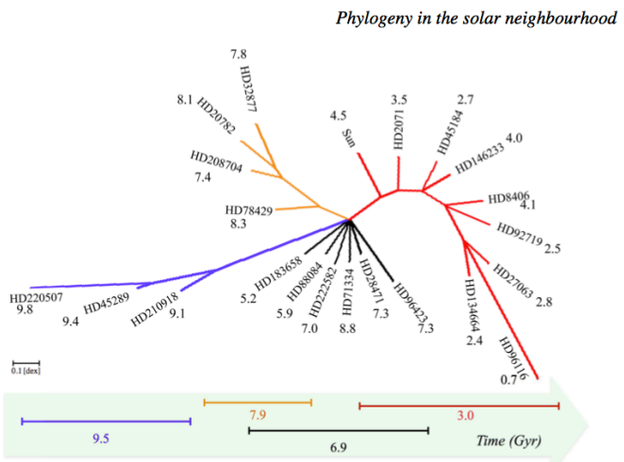
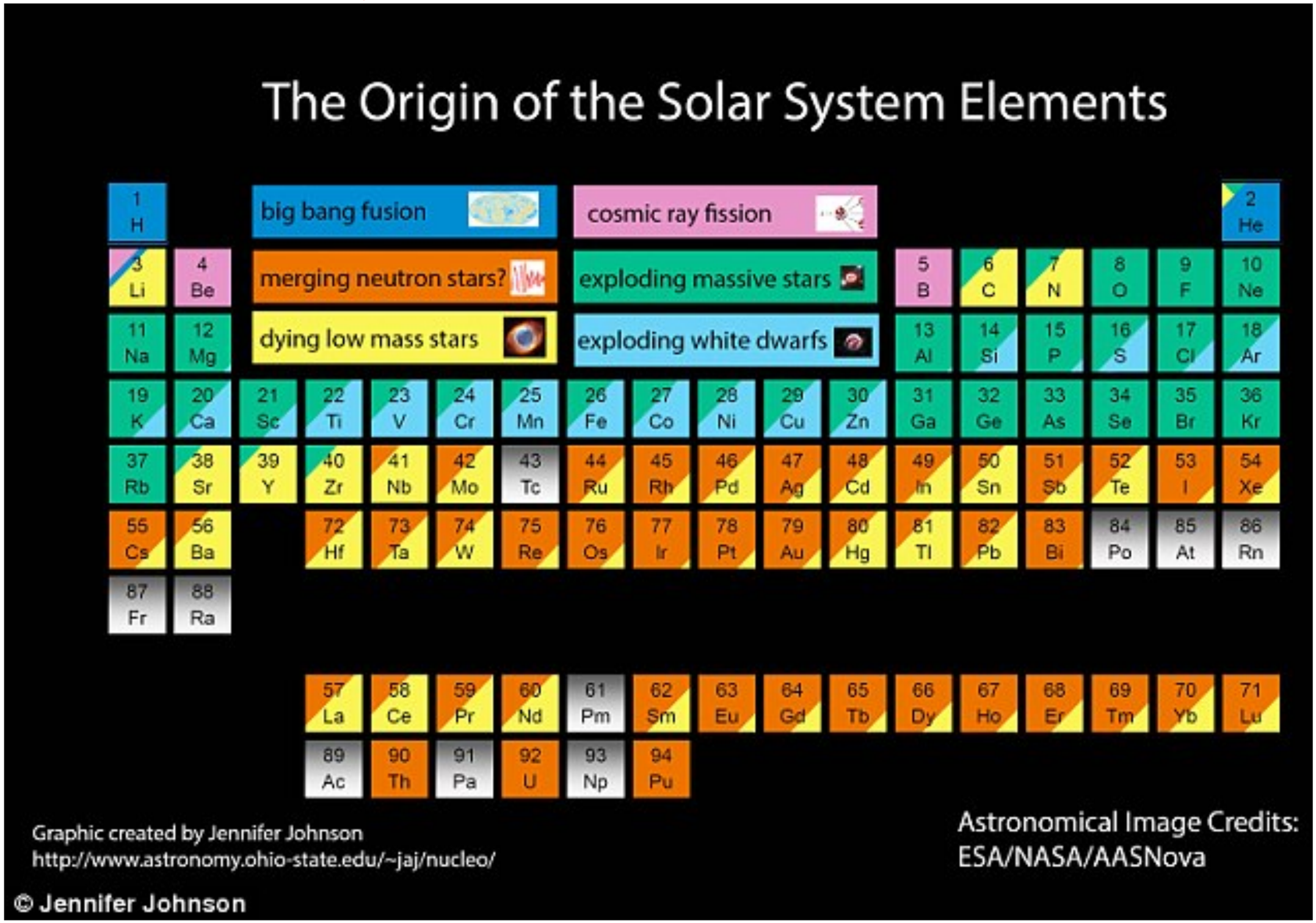




We ❤ stellar DNA



We ❤ stellar DNA

Elements potentially detected in spectroscopic surveys of the Milky Way

Gaia - ESO
GALAH
APOGEE
RAVE
LAMOST
Included in Hypatia

1 H Hydrogen 1.008																	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
11 Na Sodium 22.990	12 Mg Magnesium 24.305											13 Al Aluminium 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.631	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 83.798
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.711	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.294
55 Cs Cesium 132.905	56 Ba Barium 137.328	57-71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.085	79 Au Gold 196.967	80 Hg Mercury 200.592	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [208.982]	85 At Astatine 209.987	86 Rn Radon 222.018
87 Fr Francium 223.020	88 Ra Radium 226.025	89-103	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [278]	110 Ds Darmstadtium [281]	111 Rg Roentgenium [280]	112 Cn Copernicium [285]	113 Nh Nihonium [286]	114 Fl Flerovium [289]	115 Mc Moscovium [289]	116 Lv Livermorium [293]	117 Ts Tennessine [294]	118 Og Oganesson [294]

57 La Lanthanum 138.905	58 Ce Cerium 140.116	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.243	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.500	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.055	71 Lu Lutetium 174.967
89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	94 Pu Plutonium 244.064	95 Am Americium 243.061	96 Cm Curium 247.070	97 Bk Berkelium 247.070	98 Cf Californium 251.080	99 Es Einsteinium [254]	100 Fm Fermium 257.095	101 Md Mendelevium 258.1	102 No Nobelium 259.101	103 Lr Lawrencium [262]

Jofre, Heiter & Soubiran (in prep)

Annual Reviews of Astronomy and Astrophysics, 2019, Vol 57, coming soon

Accuracy and precision of industrial stellar abundances

Paula Jofré,[1] Ulrike Heiter,[2] and Caroline Soubiran[3]

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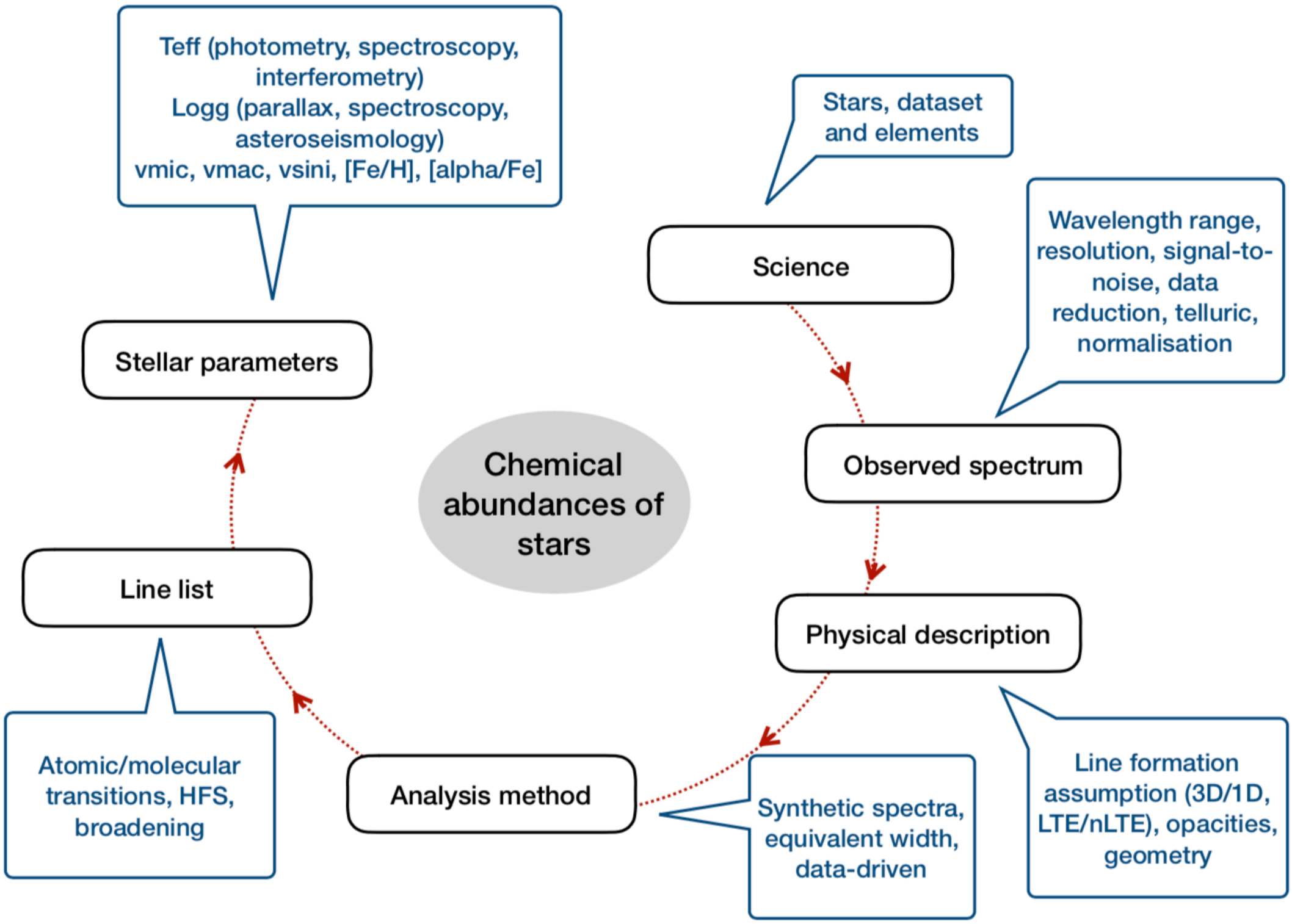
[2]Observational Astrophysics, Department of Physics and Astronomy, Uppsala University, Box 516, 75120 Uppsala, Sweden
[3]Laboratoire d'Astrophysique de Bordeaux, Univ. Bordeaux, CNRS, B18N, allée Geoffroy Saint-Hilaire, F-33615, Pessac, France

Steps and issues



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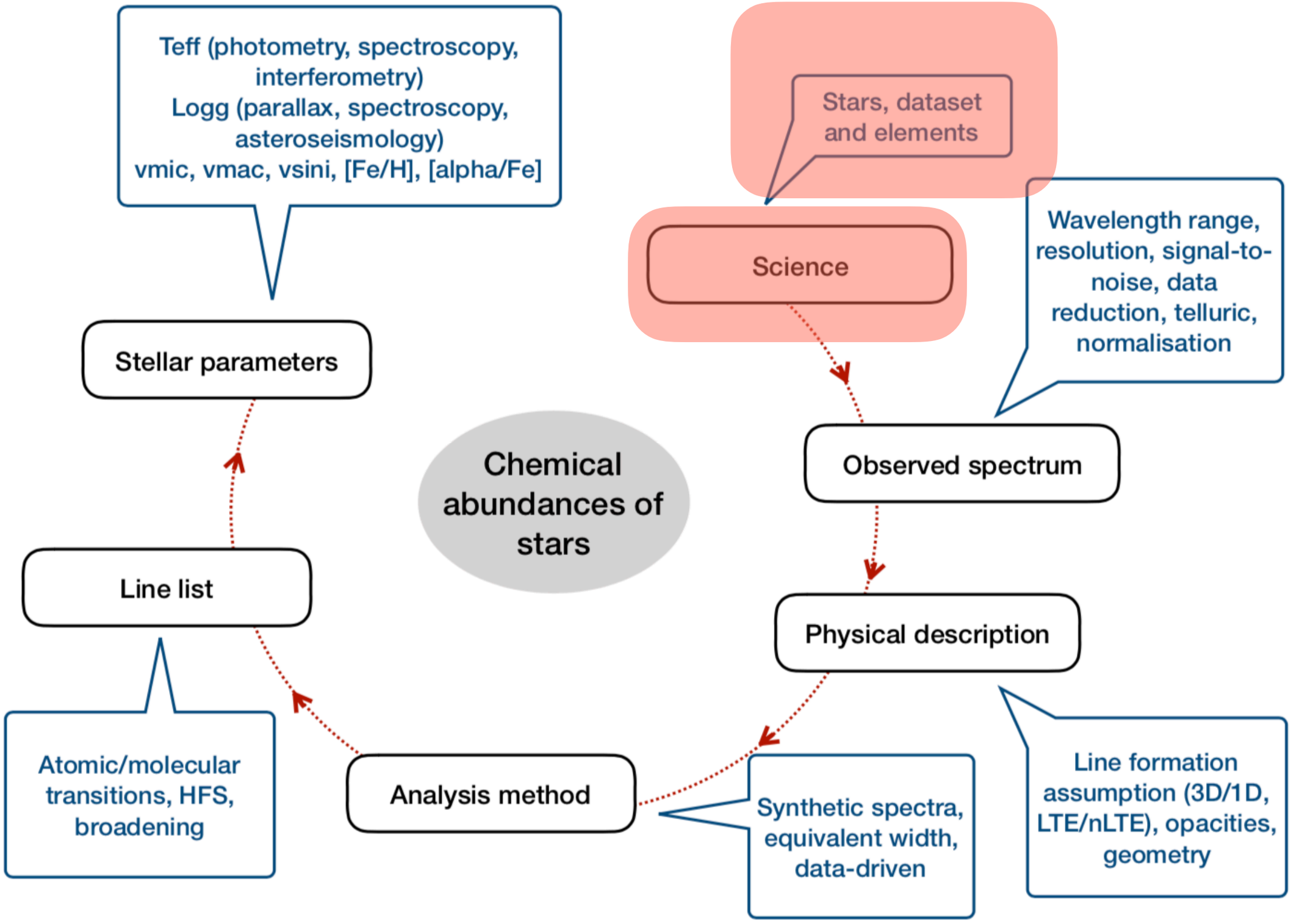

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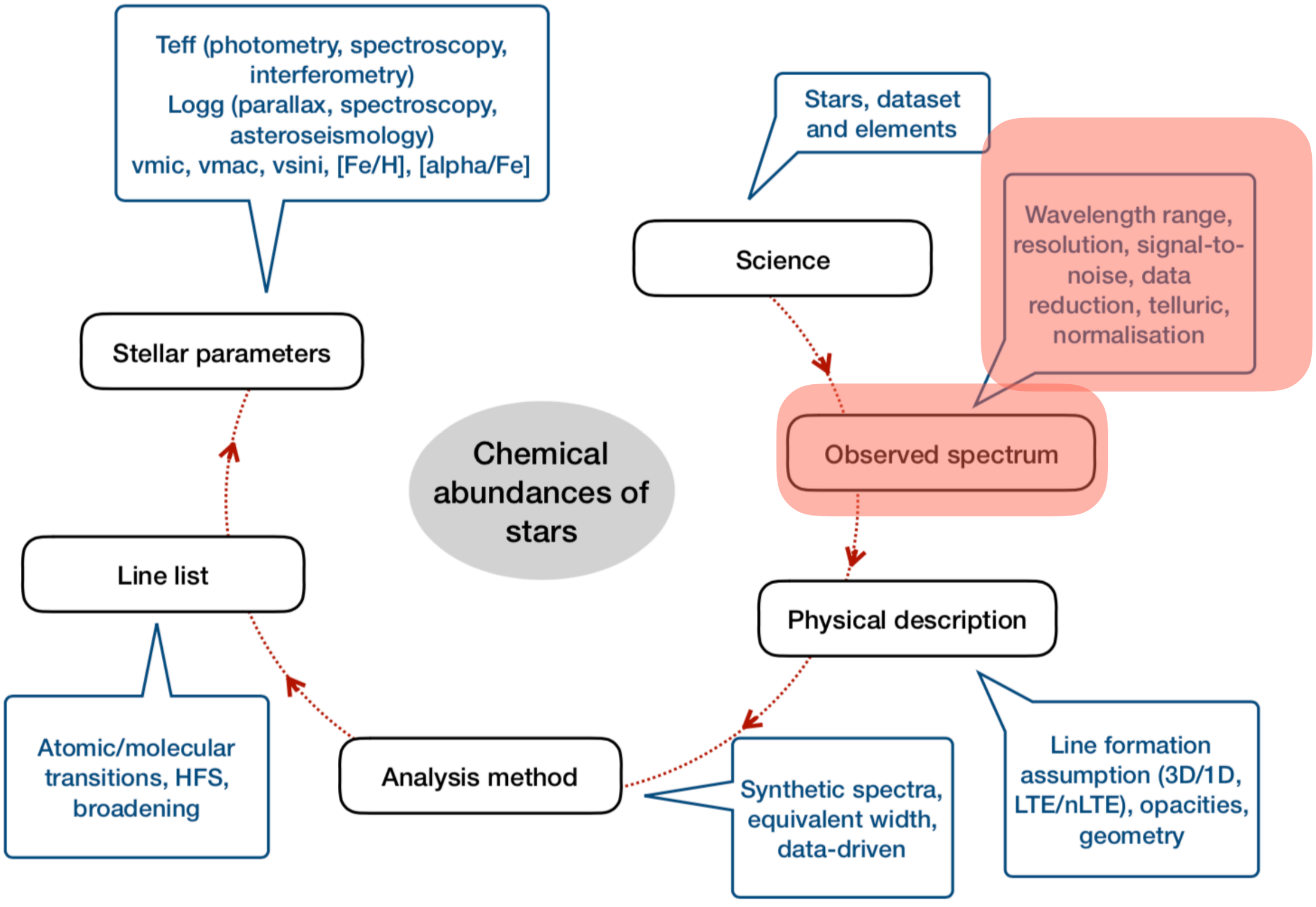

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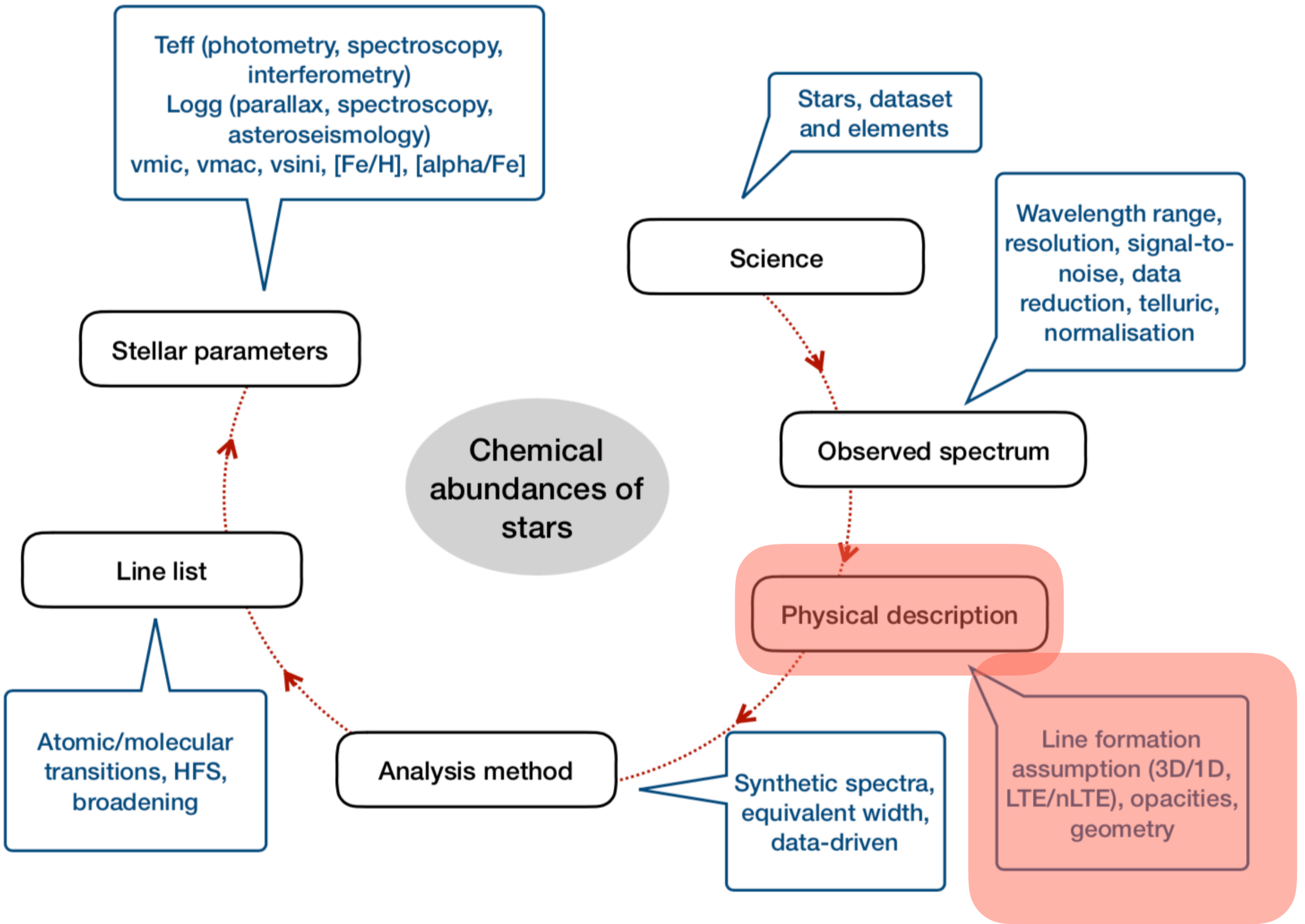
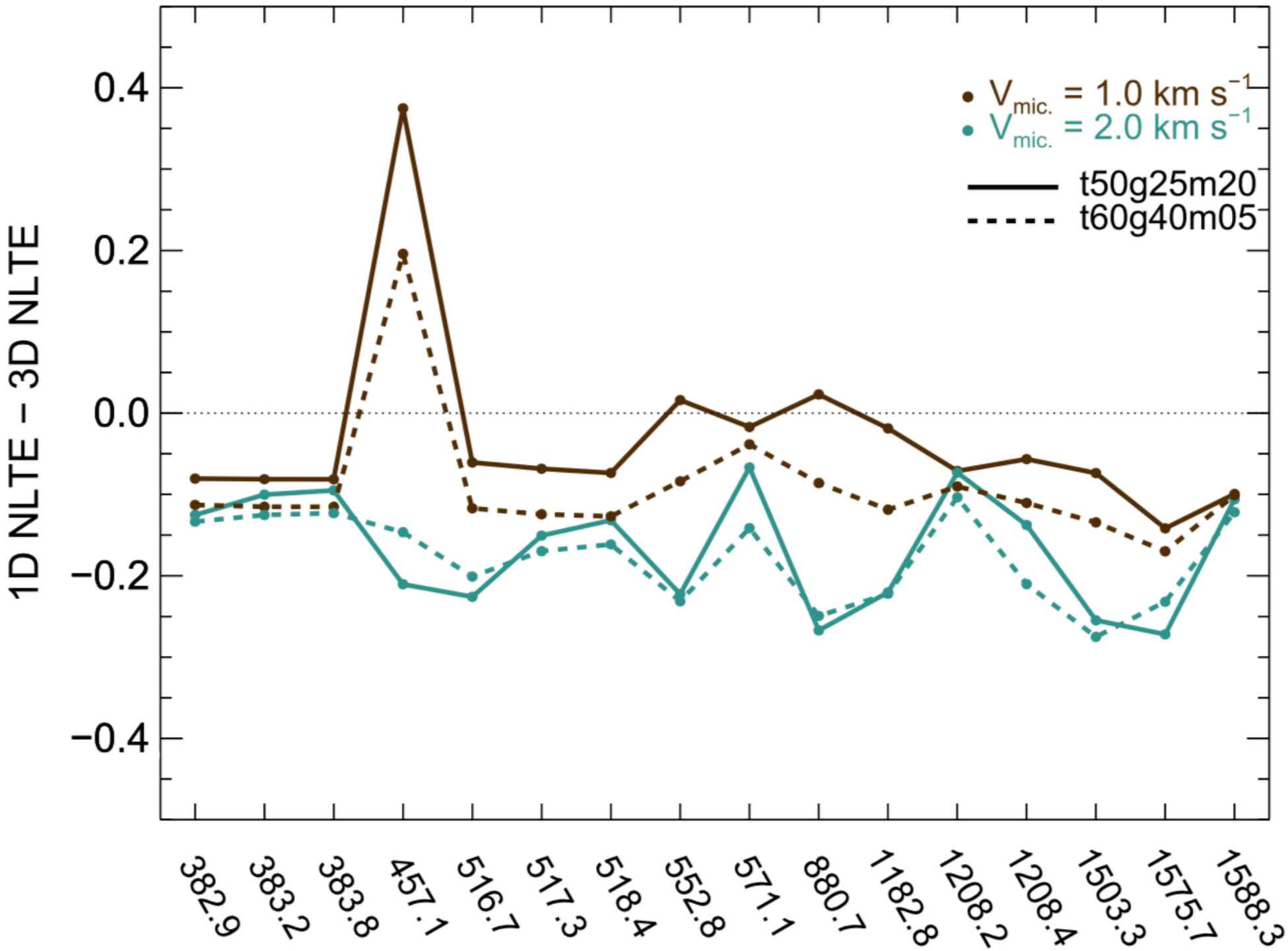


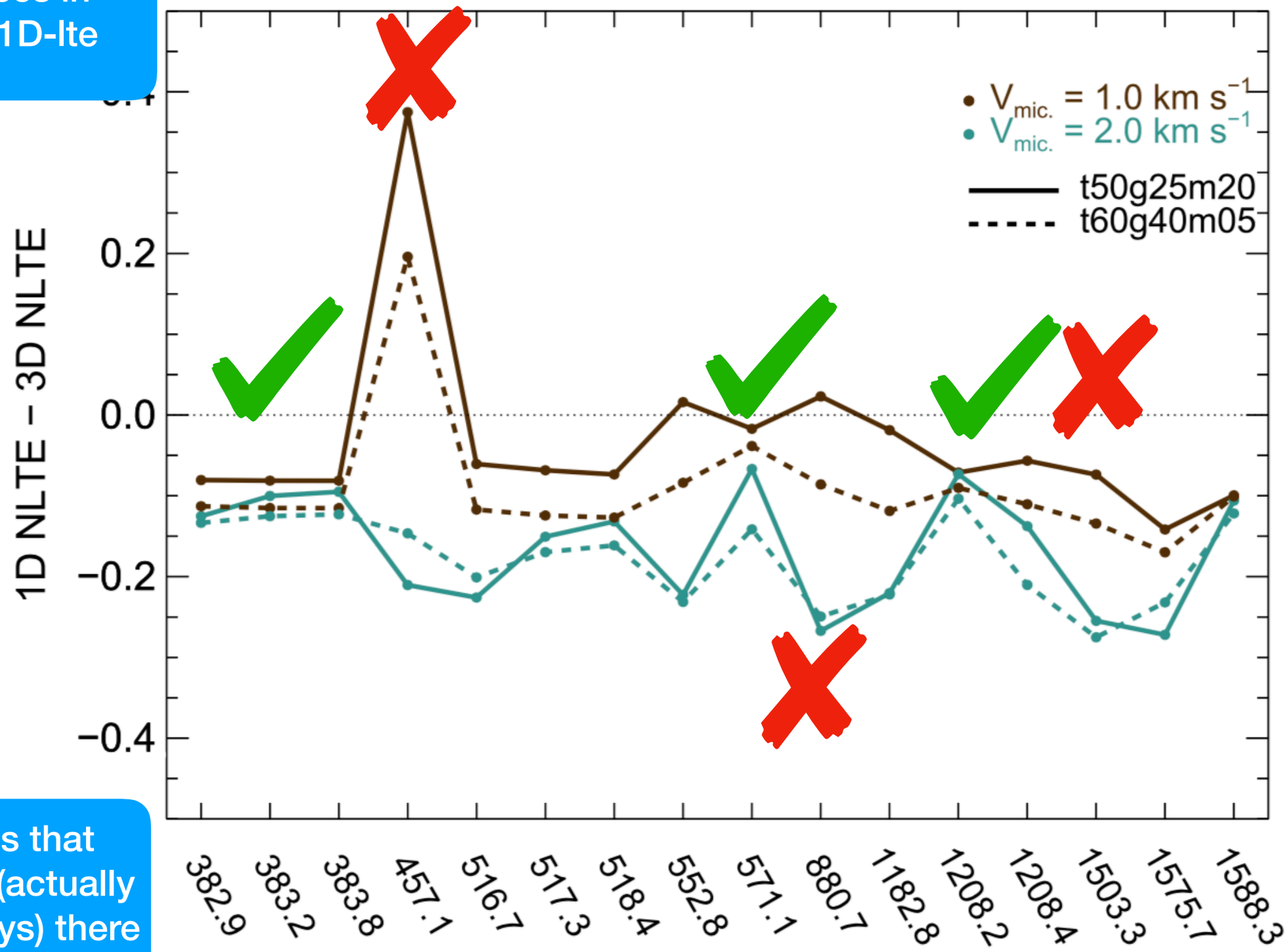
Mg abundances in stars



Bergemann et al 2017

When many lines are available, we could get ~accurate abundances in standard 1D-lte

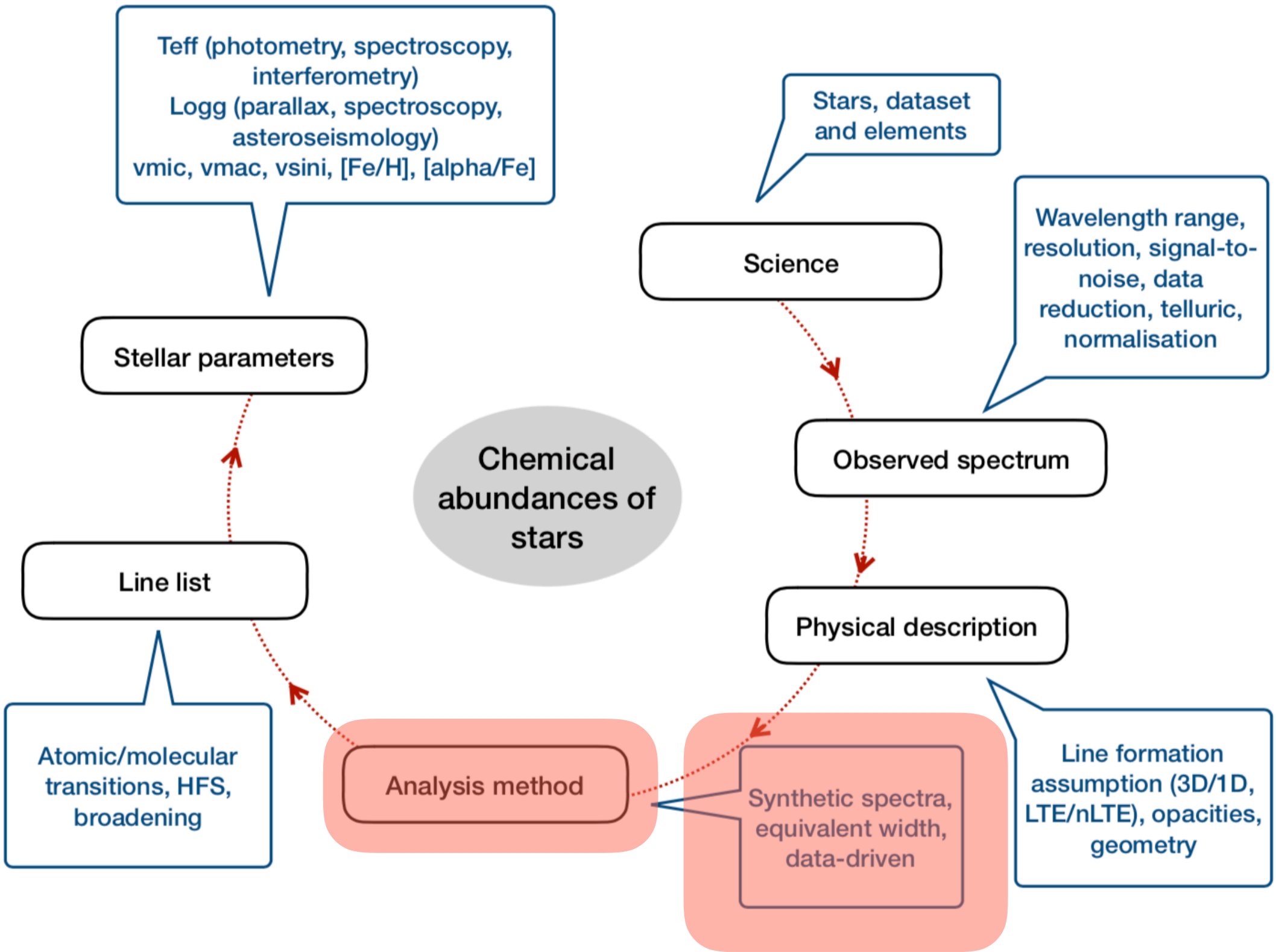
Mg abundances in stars



Bergemann et al 2017

Problem is that sometimes (actually almost always) there are no good lines

Steps and issues



Classical methods

EWs / Syntheses

“Modern” methods

data-driven/neural networks

Classical methods

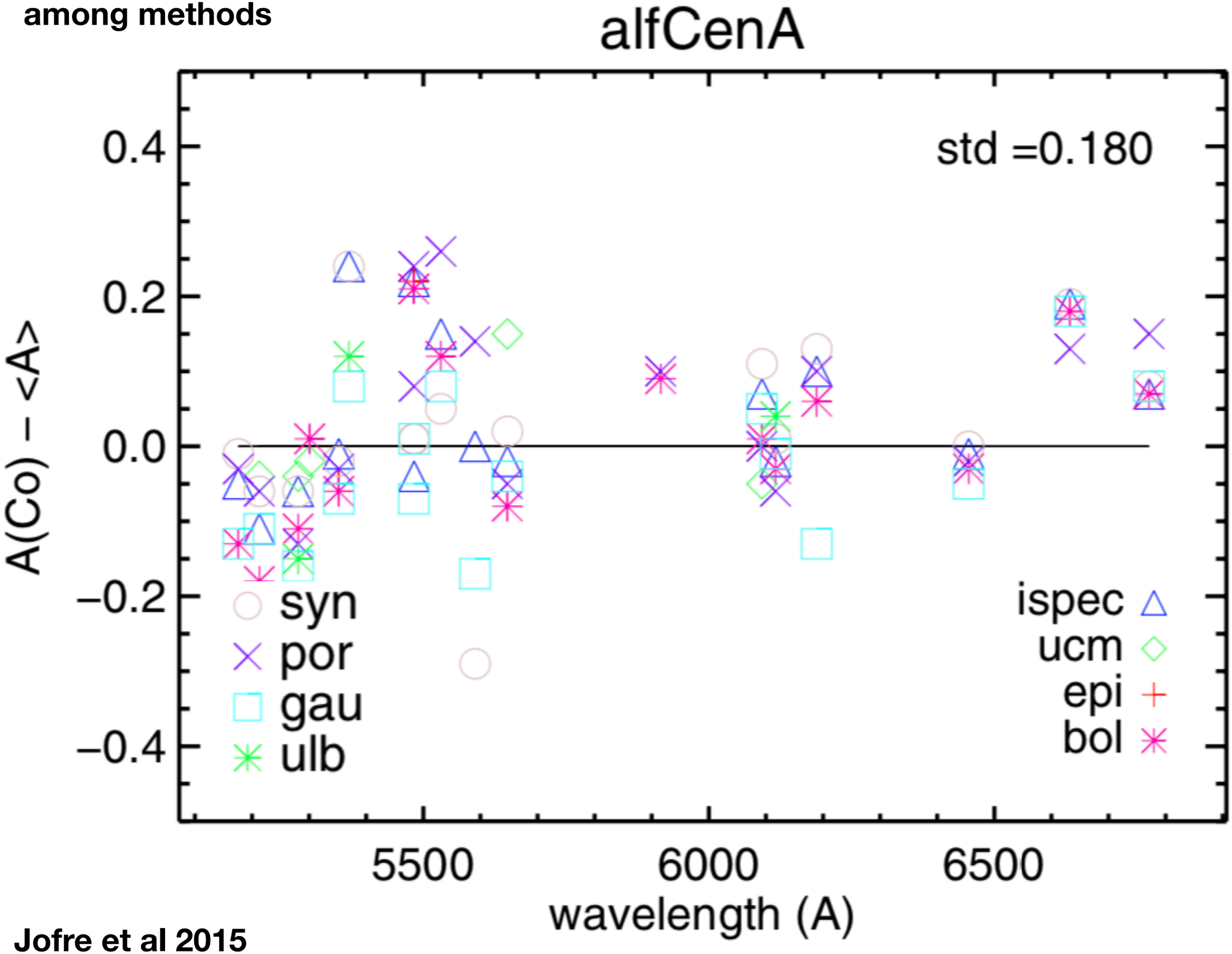
EWs / Syntheses

"Modern" methods

data-driven/neural networks

Training set

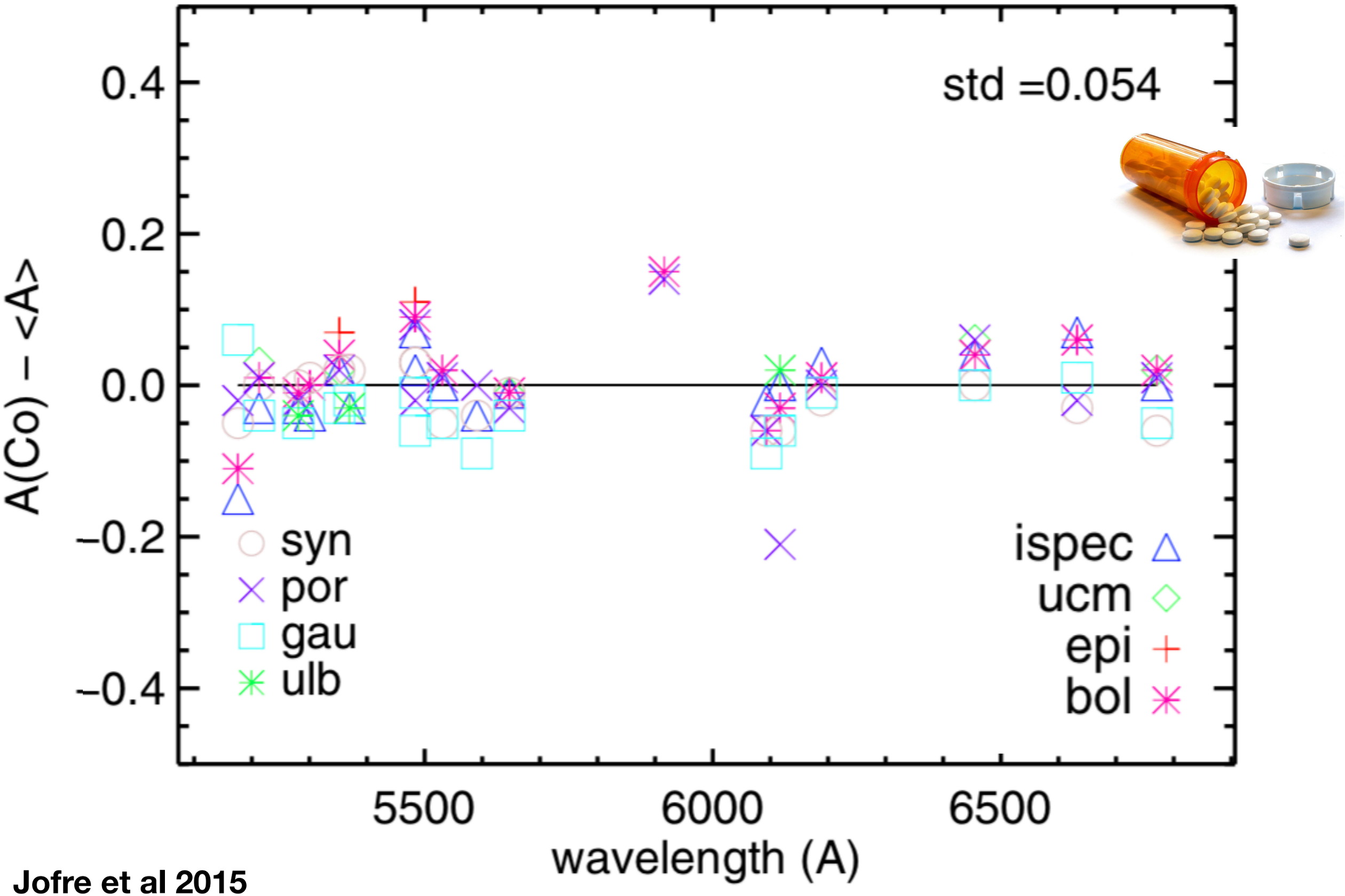
Large difference among methods



Jofre et al 2015

Large difference among methods

Differential analyses are great pain killer



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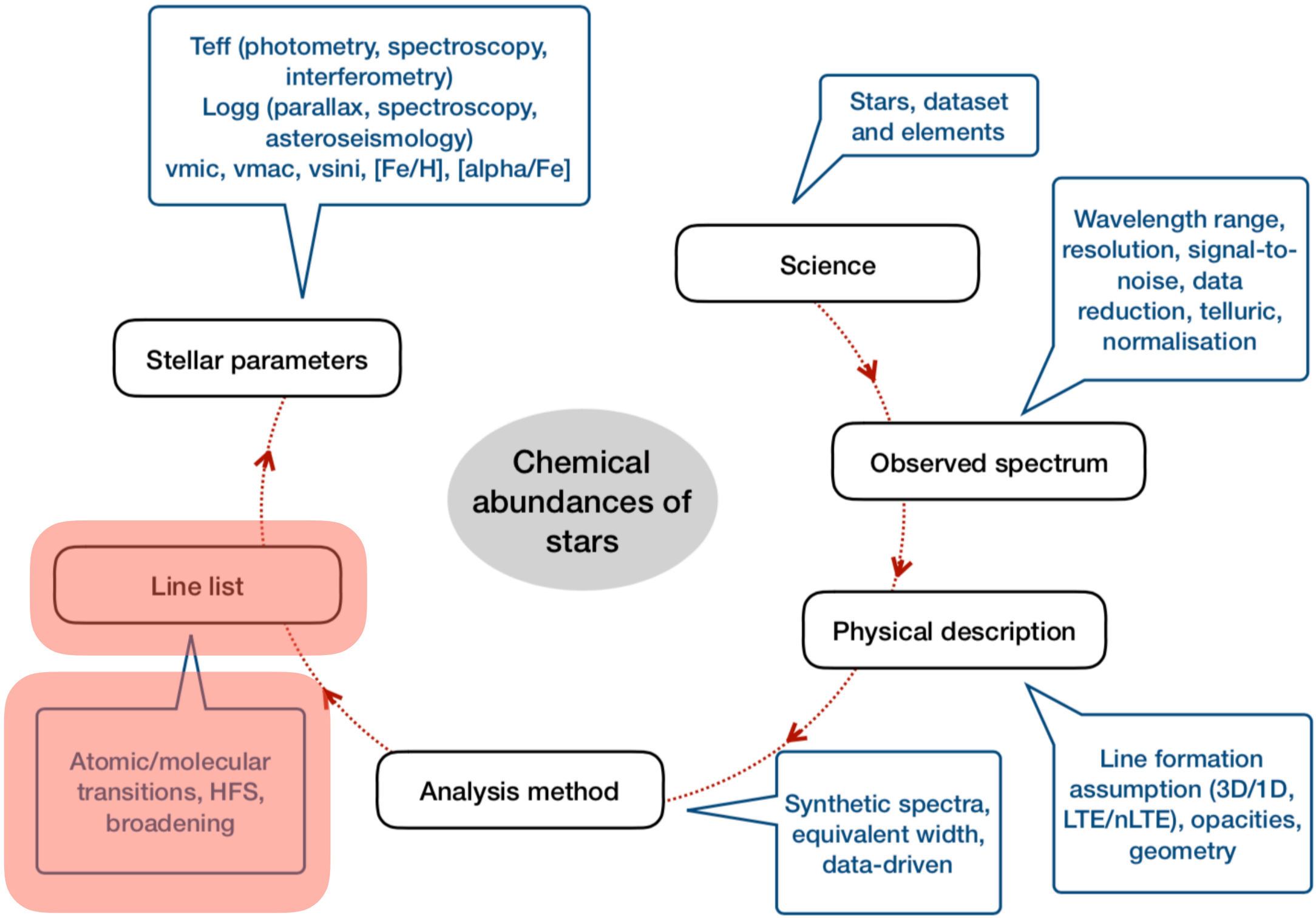
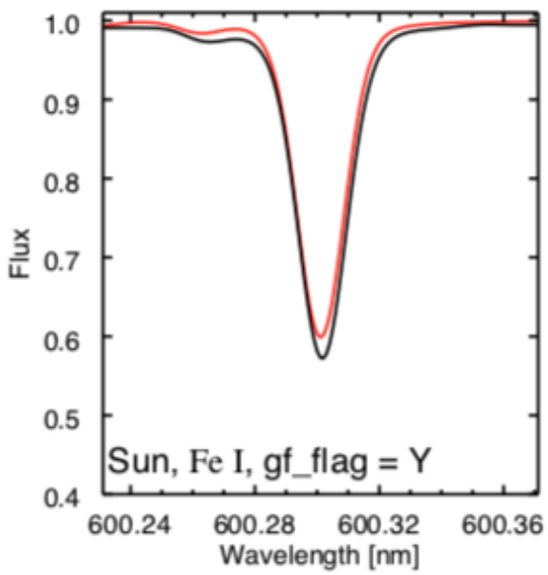
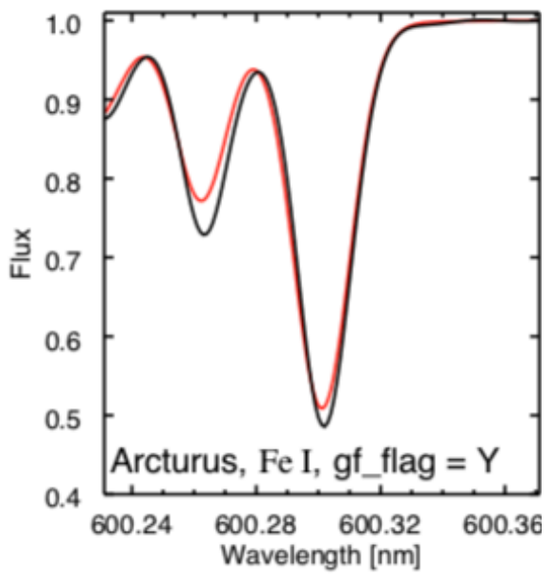
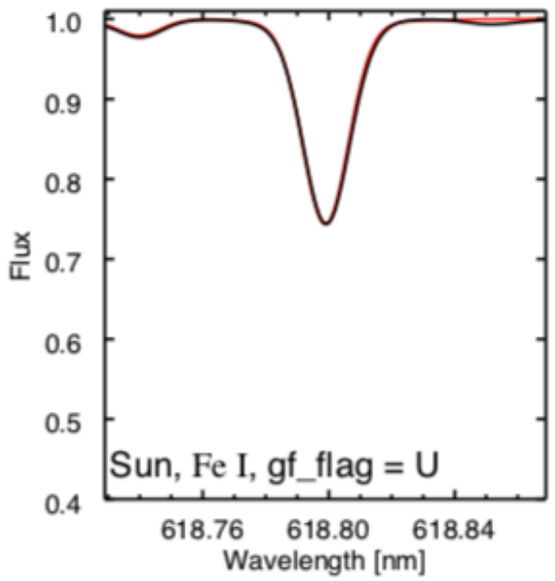
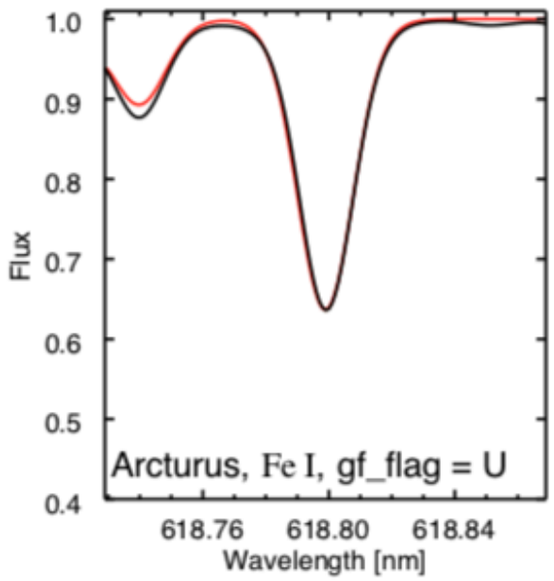


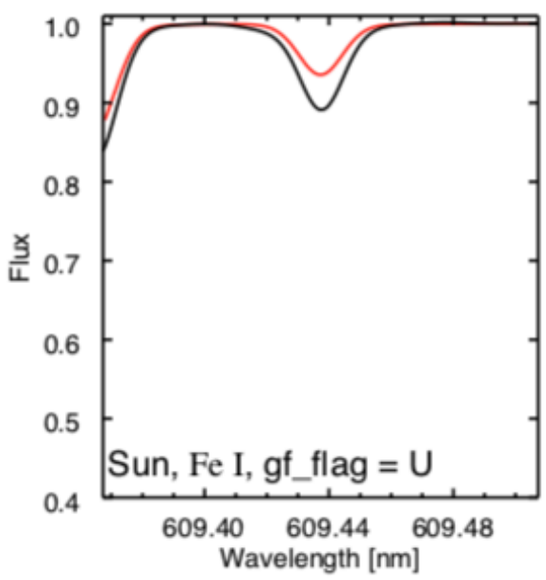
Line list - oscillator strengths

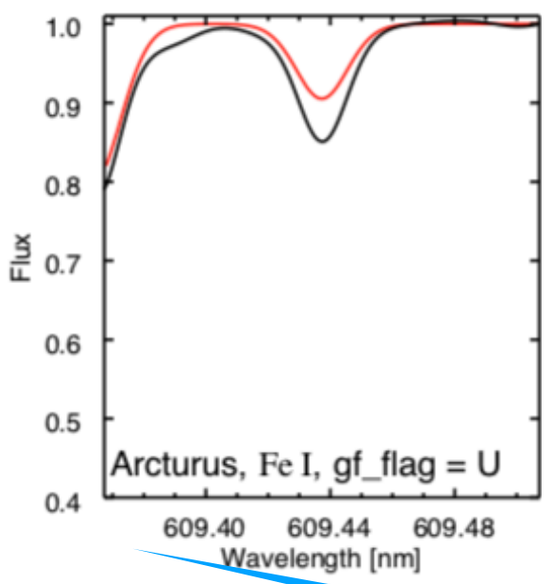


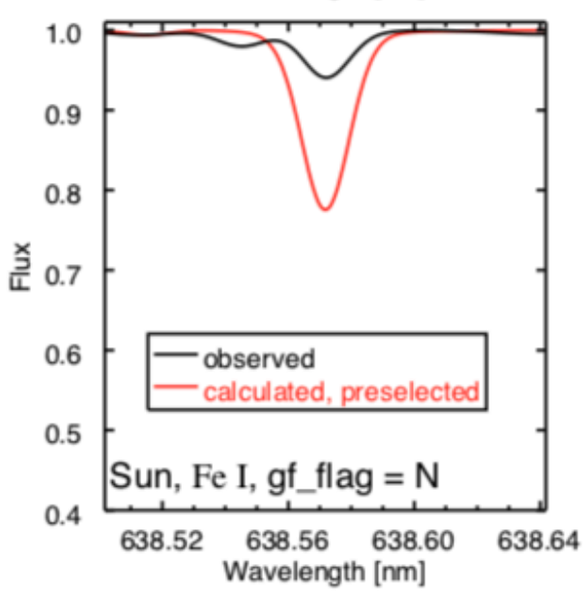


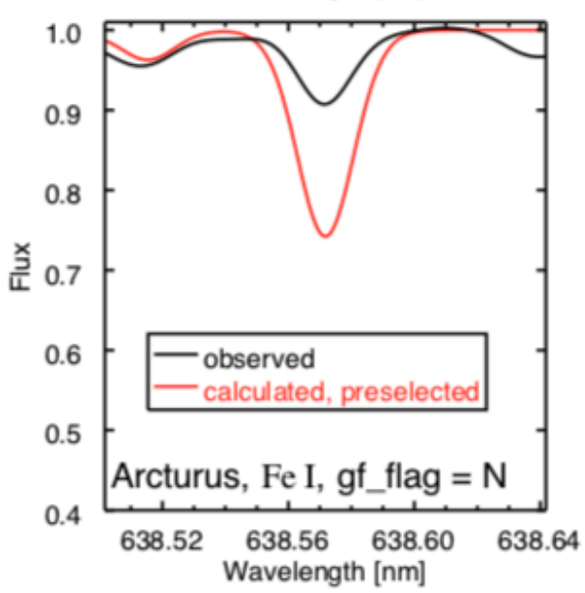








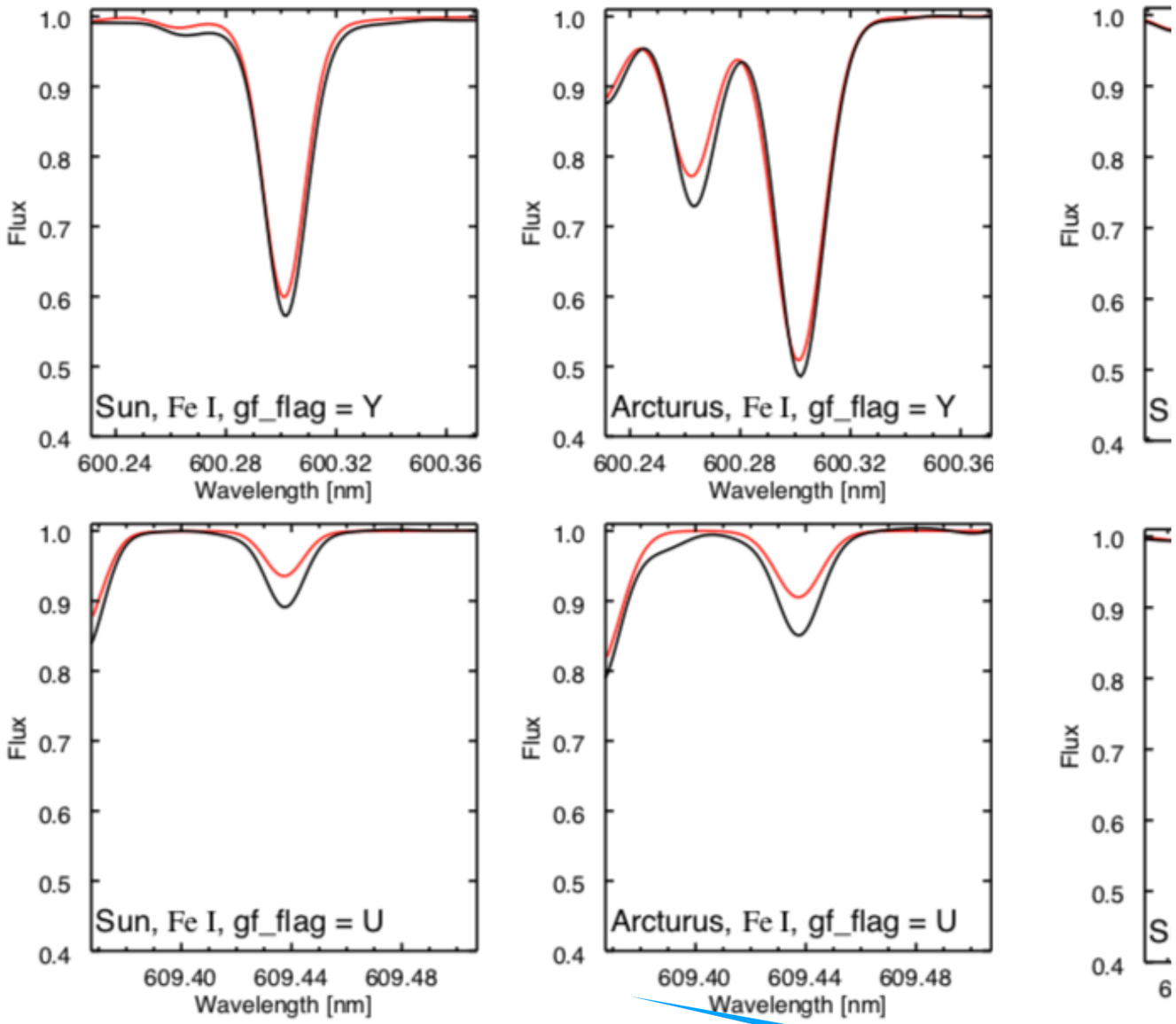


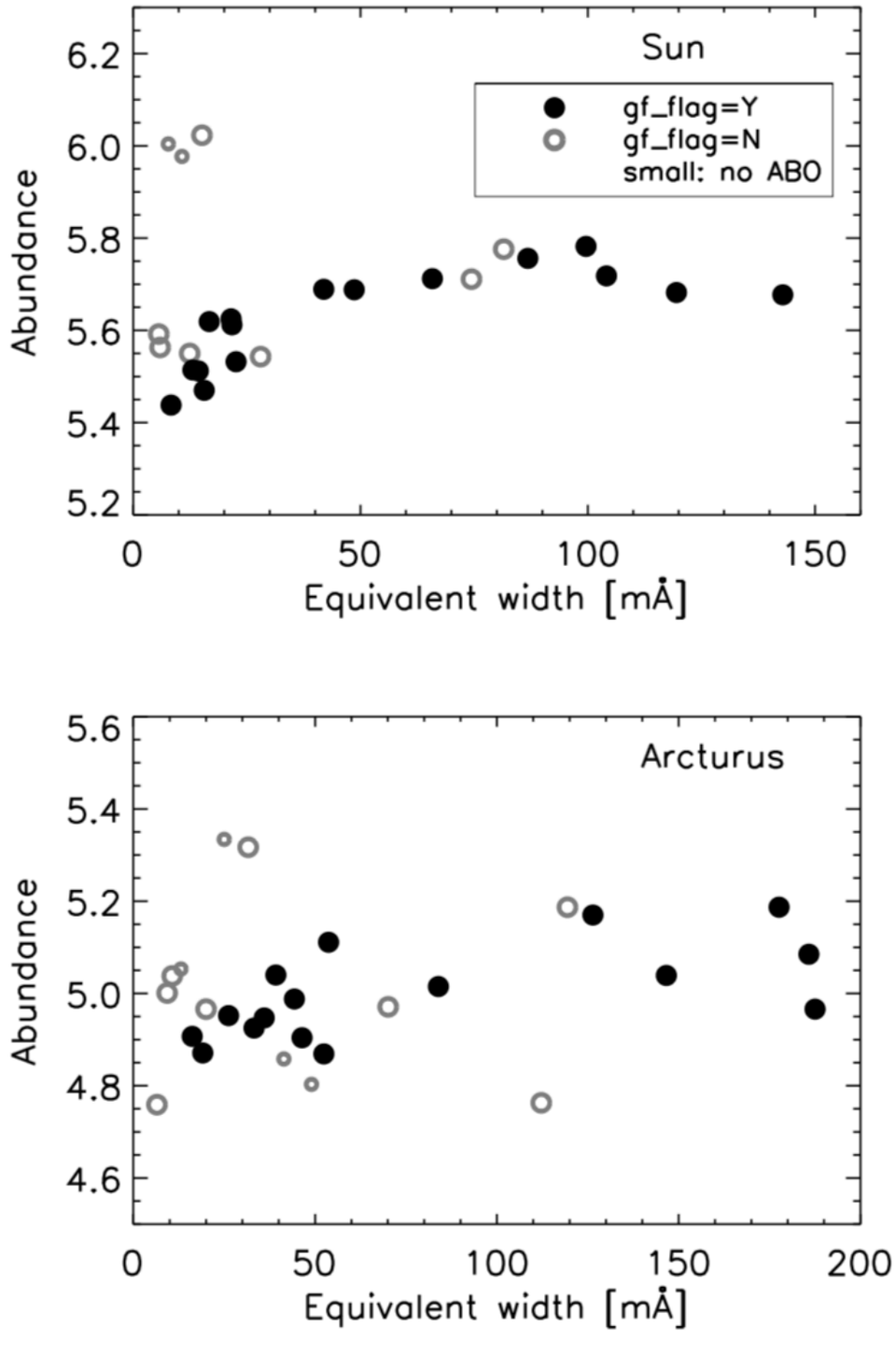


Heiter et al (in prep)

For GES, flagging system of all identified lines

Line list - oscillator strengths





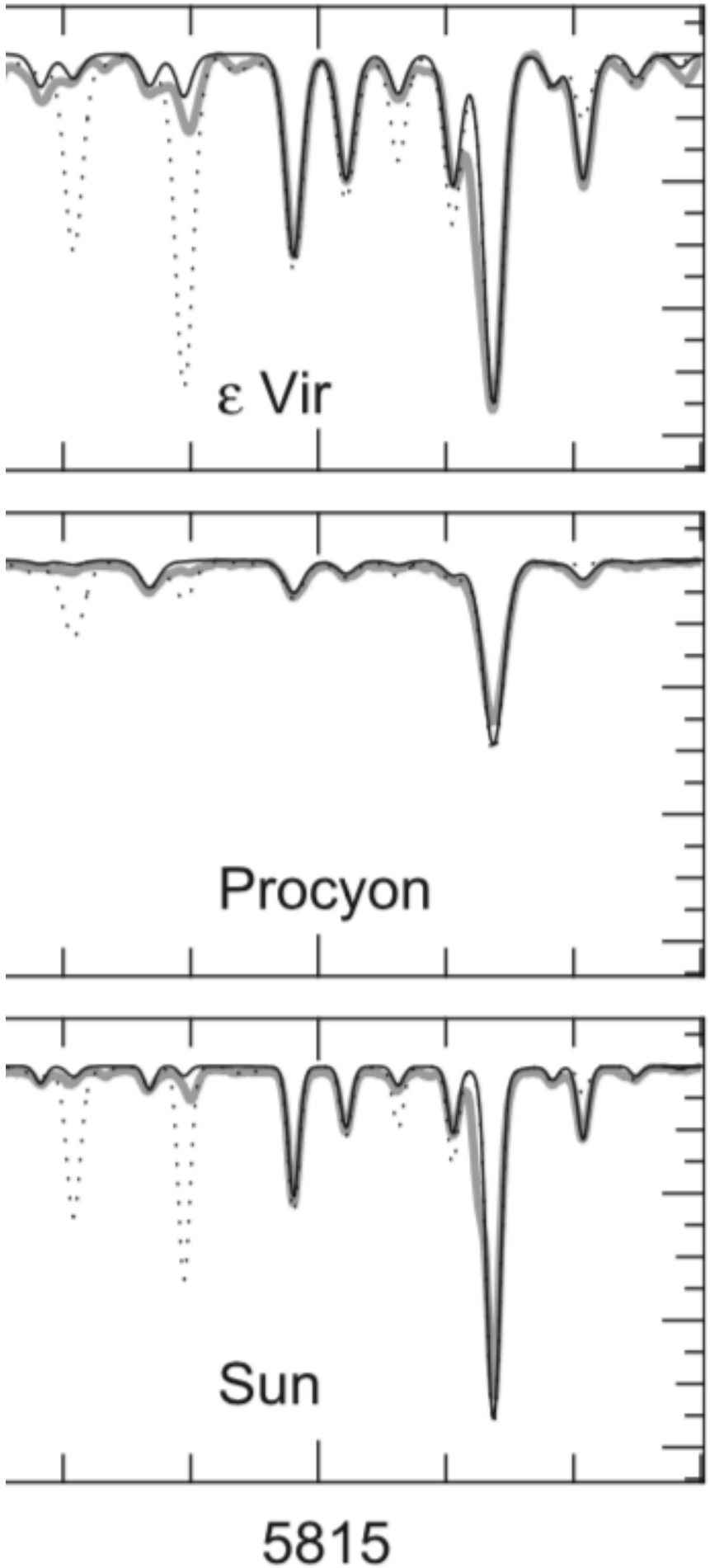
Heiter et al (in prep)

For GES, flagging system of all identified lines

Line list - oscillator strengths

"Astrophysical calibration"
Fit log(gf) for fixed abundances
in benchmark stars

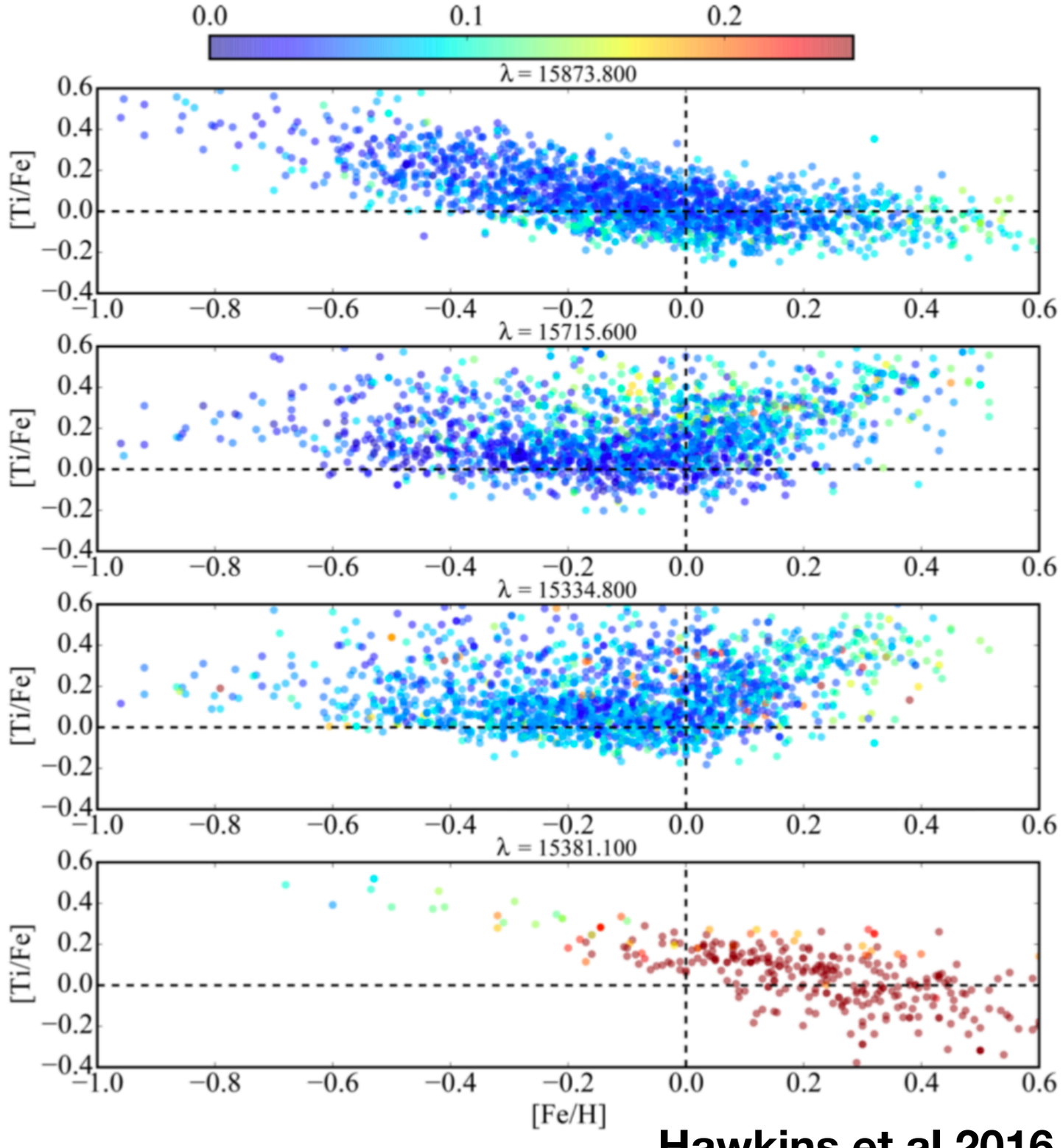
Done in surveys like
APOGEE since IR lines would all have
flag N (in GES system)
This is other excellent pain killer to
improve precision



Boeche & Grebel 2016

Line selection

Expected MW trend



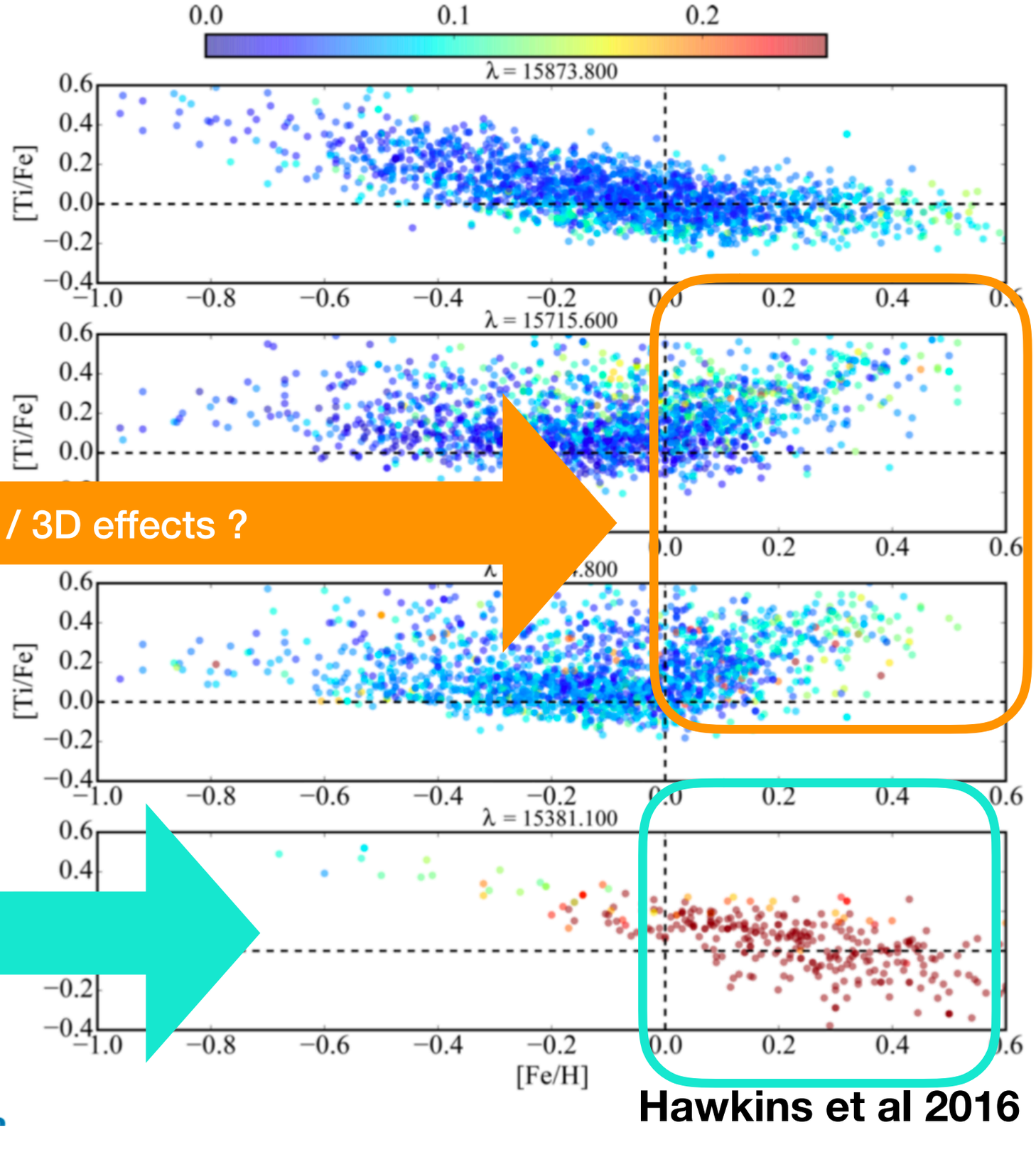
Hawkins et al 2016

Line selection

Expected MW trend

Saturation / 3D effects ?

Blends



Hawkins et al 2016

Line selection and effect on methods

GES comparison of 5 methods analysing Ca of UVES spectra

Blends/saturation/3D/non-LTE/ continuum/log-gf… all affect different leading to different line selection criteria

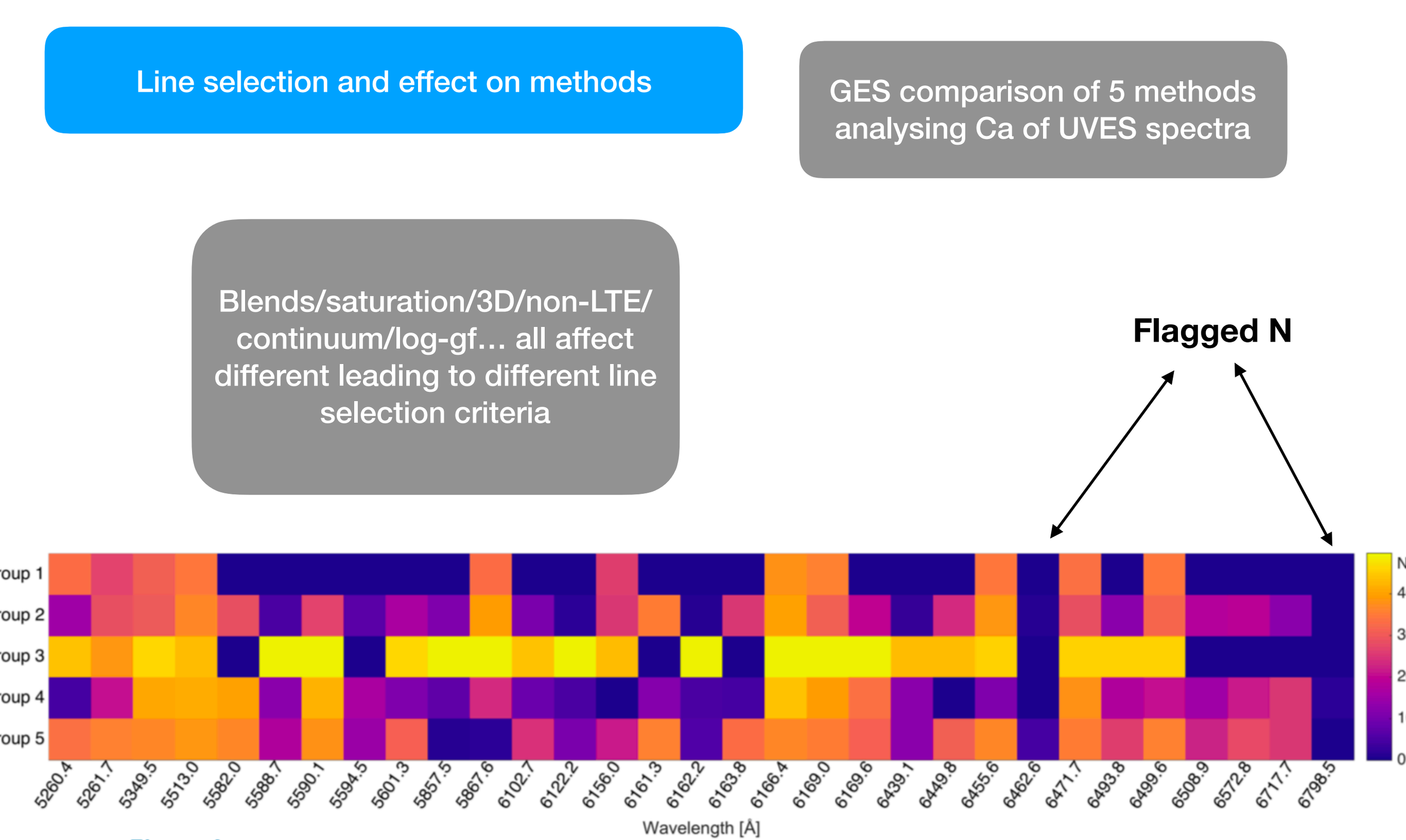
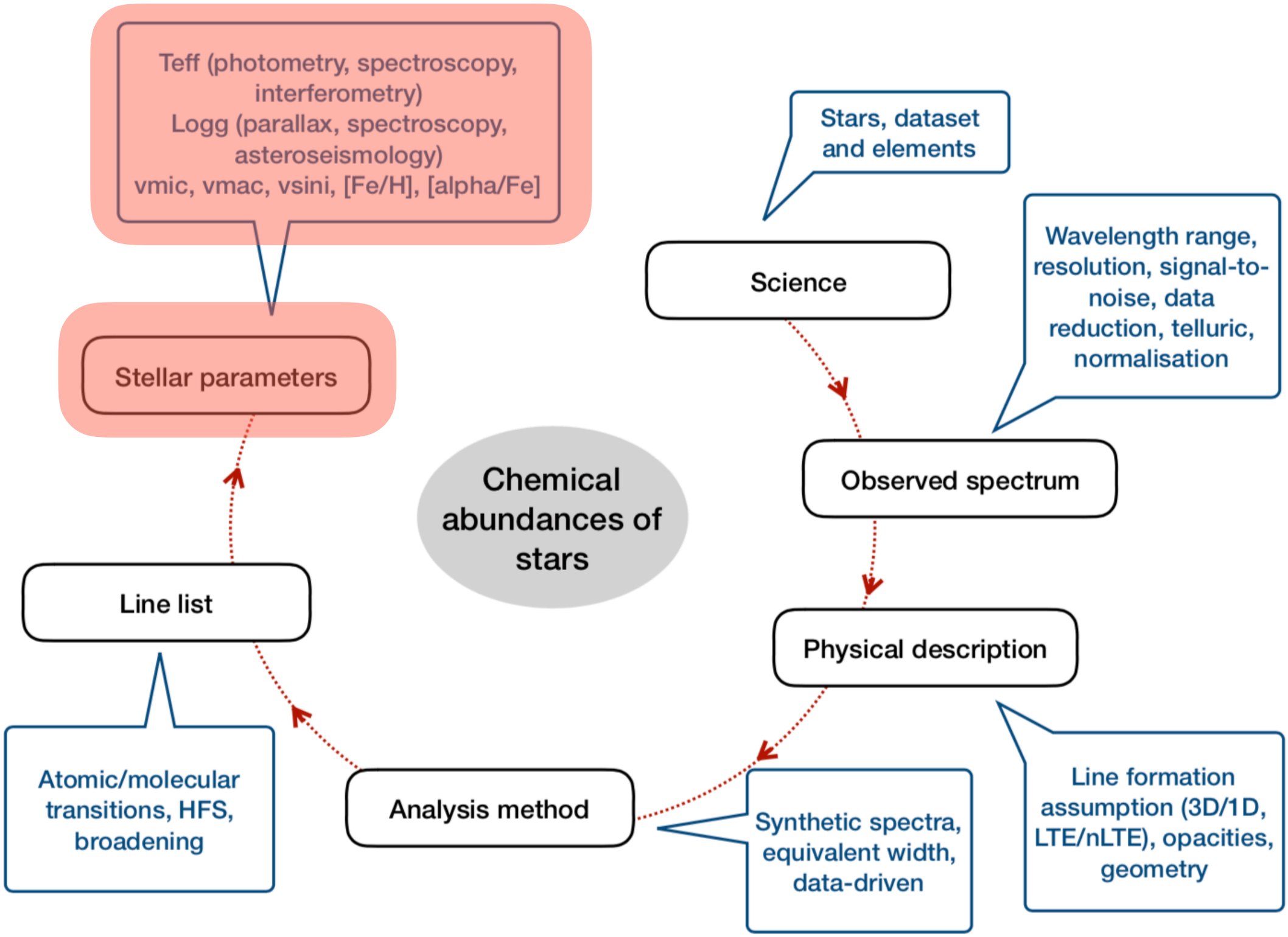


Figure 4

Ca I-line selection in the Gaia-ESO survey. Colour coding represents the number of stars for which an abundance was determined for each line by different analysis groups participating in the internal data release 5. Based on data provided by R. Smiljanic (priv. comm.).

Steps and issues



Special Request

Delivering Your Happiness

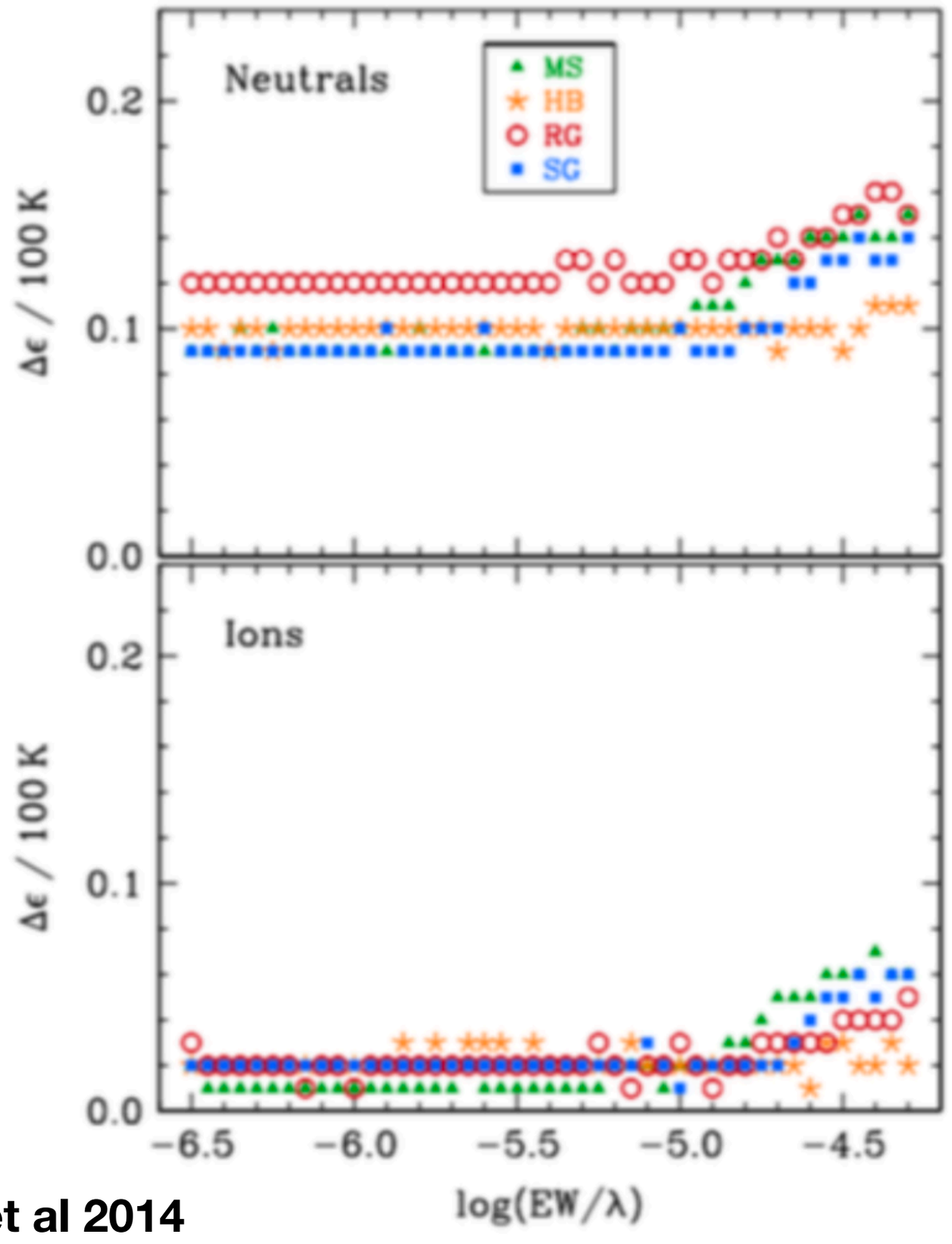
Effective temperature

Special
Request

Delivering Your
Happiness

Abundances are affected, especially those measured from neutral lines

Effective temperature



Roederer et al 2014

Special

Delivering Your

Happiness

Effective temperature

IRFM

Excitation balance

H lines

Interferometry

At least 4 different current popular photometric relations using different colours, bolometric corrections, and extinction laws (100 K)

Effective temperature

Chemical anomalies?

IRFM

Excitation balance

Blackwell & Shallis 1977: Near black body in Infrared

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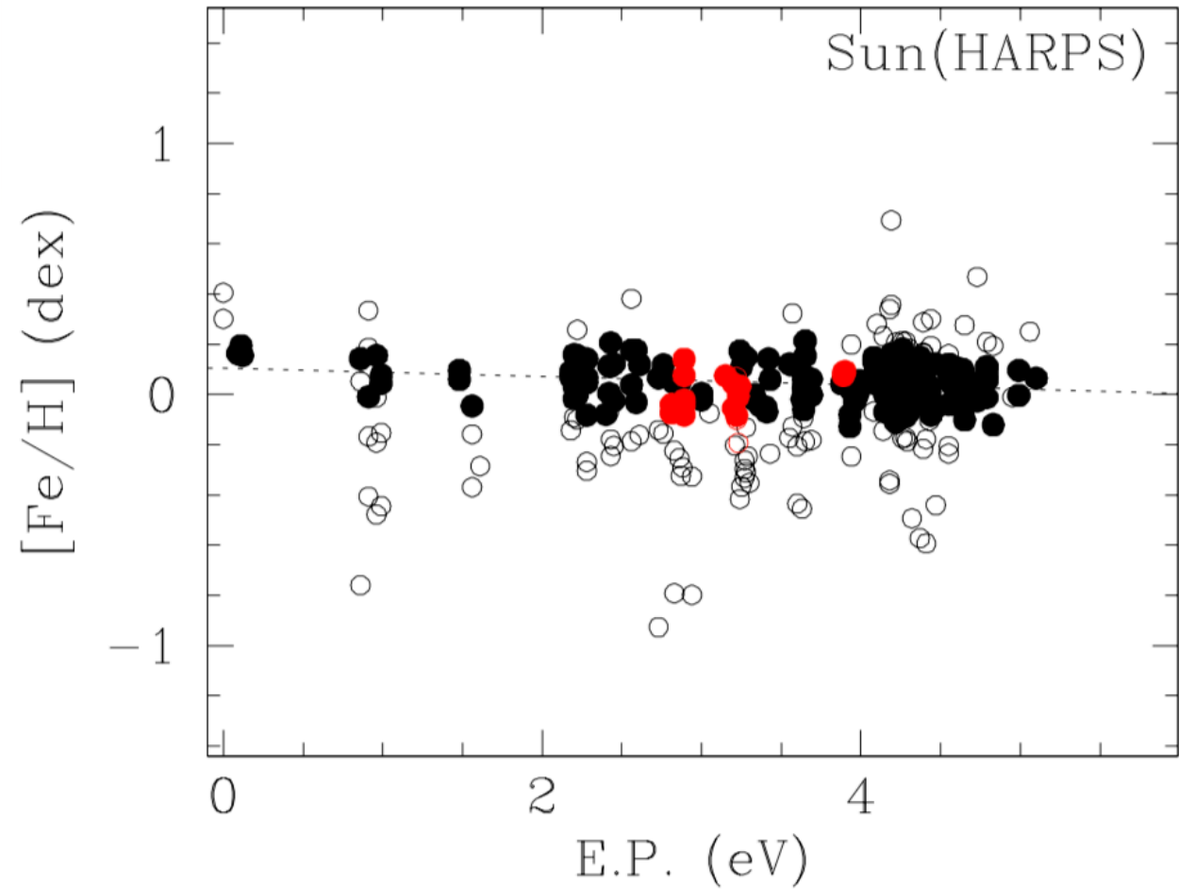
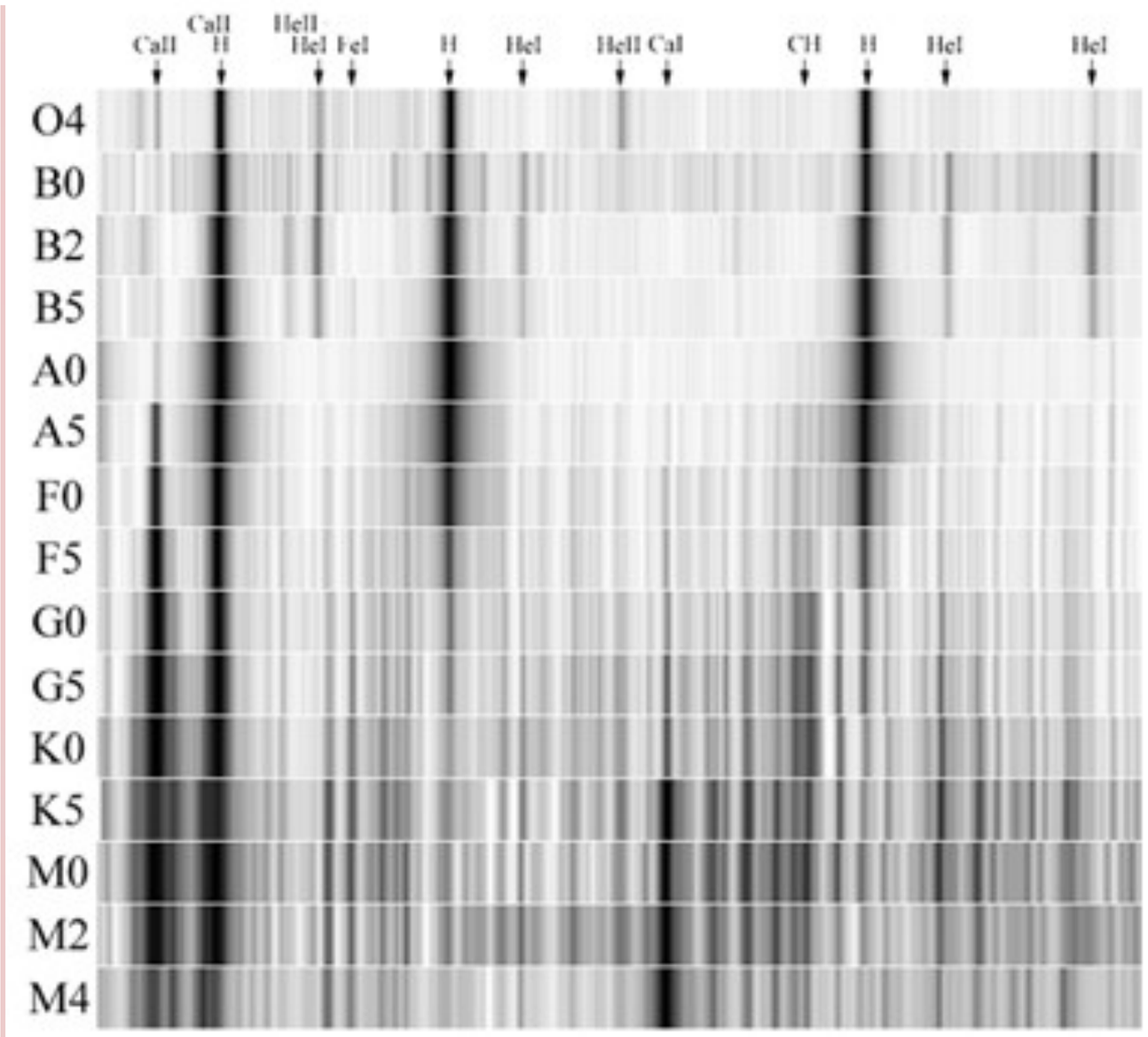


No abundance vs excitation potential is found.
Teff is subject to line selection (30 K - too many lines) and LTE (50 K- Bensby et al 2014).

Excitation balance

Boltzmann:
line strength of neutrals is dependent on
1) the temperature of the atmosphere layer where absorption is produced and
2) Excitation state of the atom.

Interferometry



Effective temperature

Excitation balance

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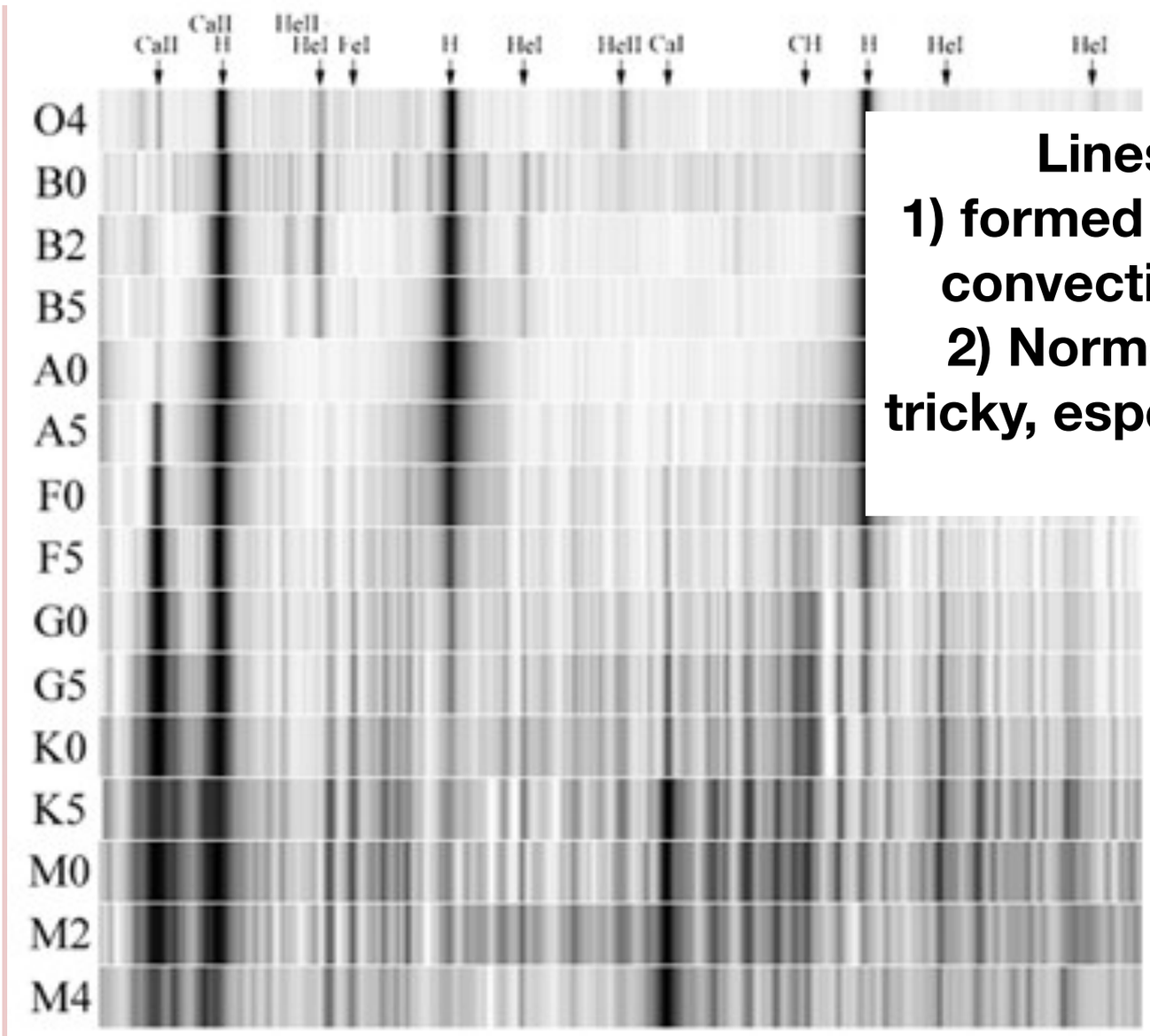
Interferometry



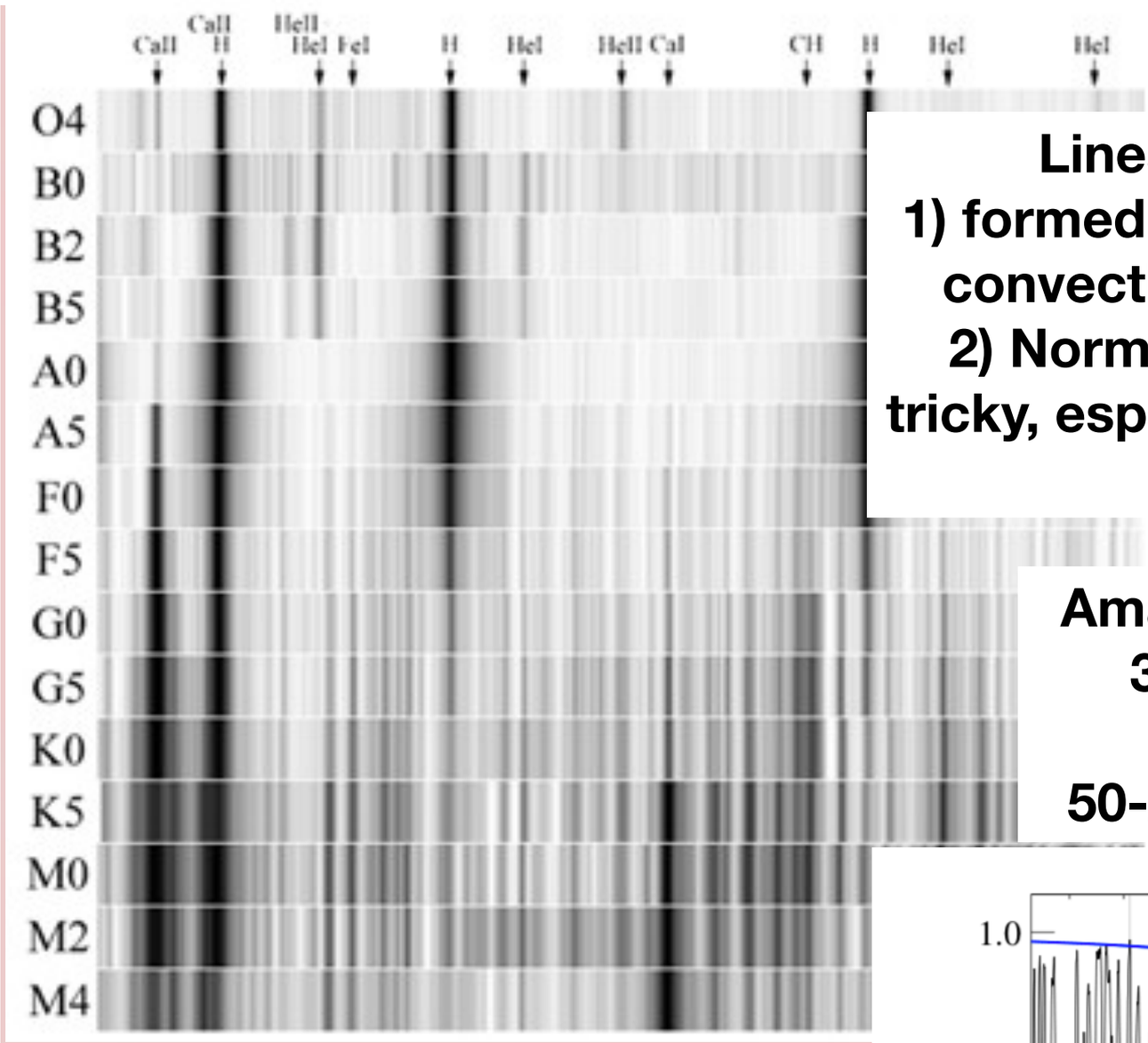
Effective temperature

Lines are so strong that
1) formed deep in spectrum where convection (3D-LTE) is an issue
2) Normalising spectra can get tricky, especially at high-res echelle spectra

Excitation balance

H lines

Interferometry



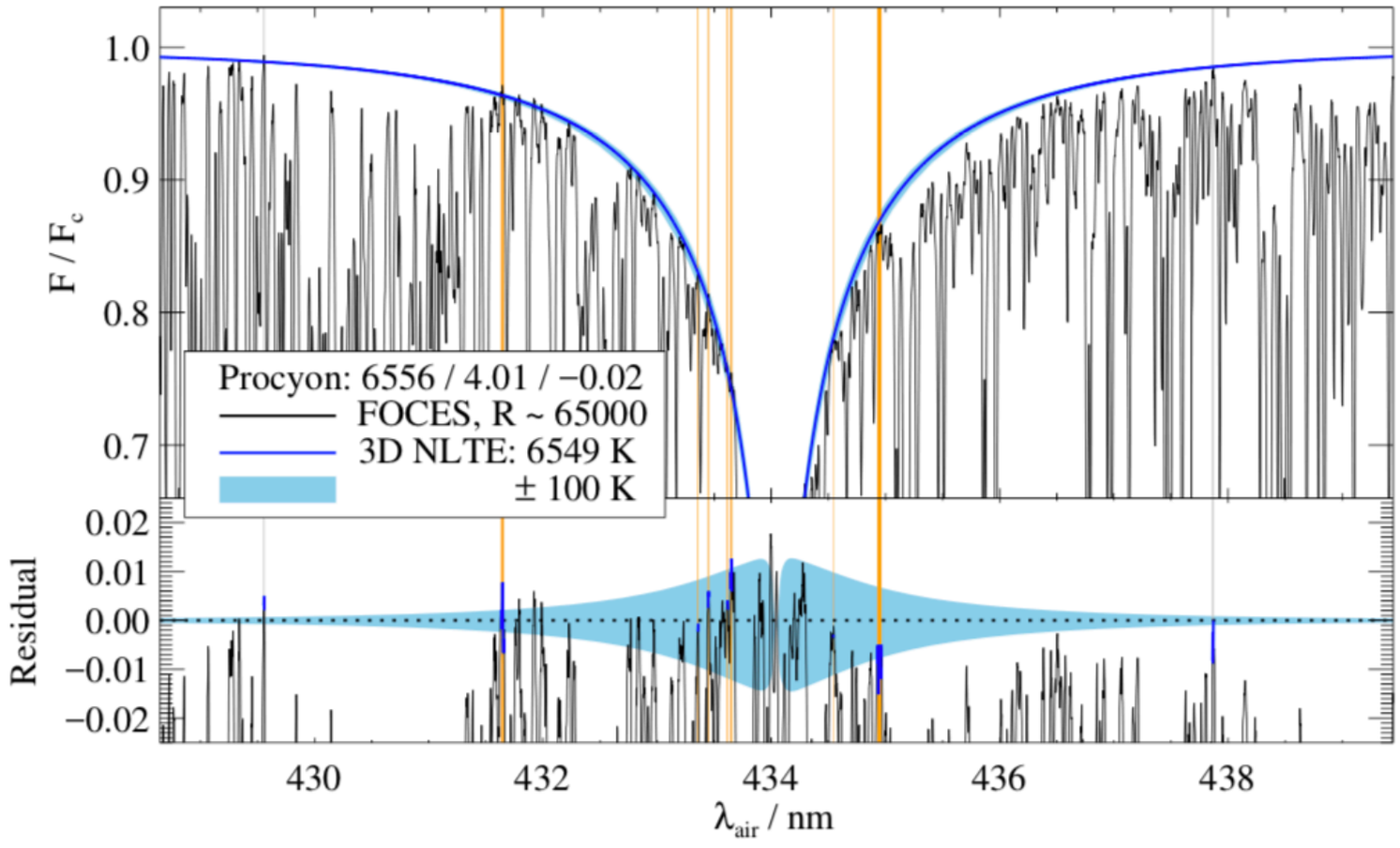
H lines

Effective temperature

Lines are so strong that
1) formed deep in spectrum where convection (3D-LTE) is an issue
2) Normalising spectra can get tricky, especially at high-res echelle spectra

Excitation balance

Amarsi et al 2018 has a grid of full 3D-non-LTE spectra publicly available
50-200 K differences with 1D-LTE



Special

Delivering Your

Happiness

Effective temperature

IRFM

Excitation balance

H lines

Interferometry

$$T_{\rm eff} = \left(\frac{F_{\rm bol}}{\sigma} \right)^{0.25} (0.5\,\theta_{\rm LD})^{-0.5}.$$

Special

R t

Delivering Your

Happiness

IRFM

Effective temperature

Tim White's kingdom!
Not really one with fairy tales!

H lines

Interferome

$$T_{\rm eff} = \left(\frac{F_{\rm bol}}{\sigma}\right)^{0.25} (0.5\,\theta_{\rm LD})^{-0.5}.$$

My kingdom - also not really of fairy tales

Gaia FGK benchmark stars

Effective temperature

Tim White's kingdom!
Not really one with fairy tales!

H lines

Interferome

$$T_{\rm eff} = \left(\frac{F_{\rm bol}}{\sigma}\right)^{0.25} (0.5\,\theta_{\rm LD})^{-0.5}.$$

Special

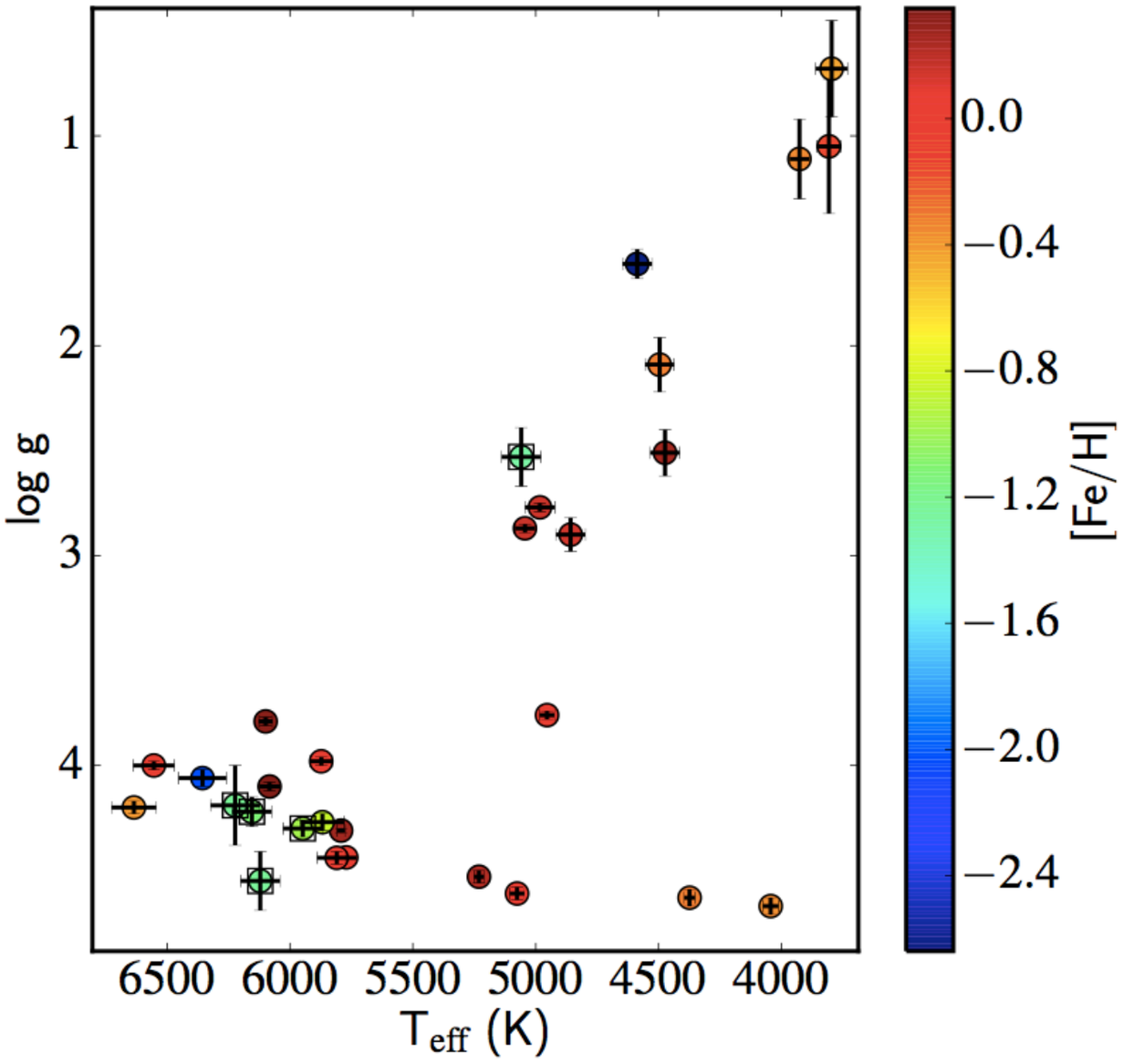
My kingdom - also not really of fairy tales

Effective temperature

Tim White's kingdom!
Not really one with fairy tales!

Interferome

Gaia FGK benchmark stars



Hawkins et al 2016

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Gaia FGK benchmark stars

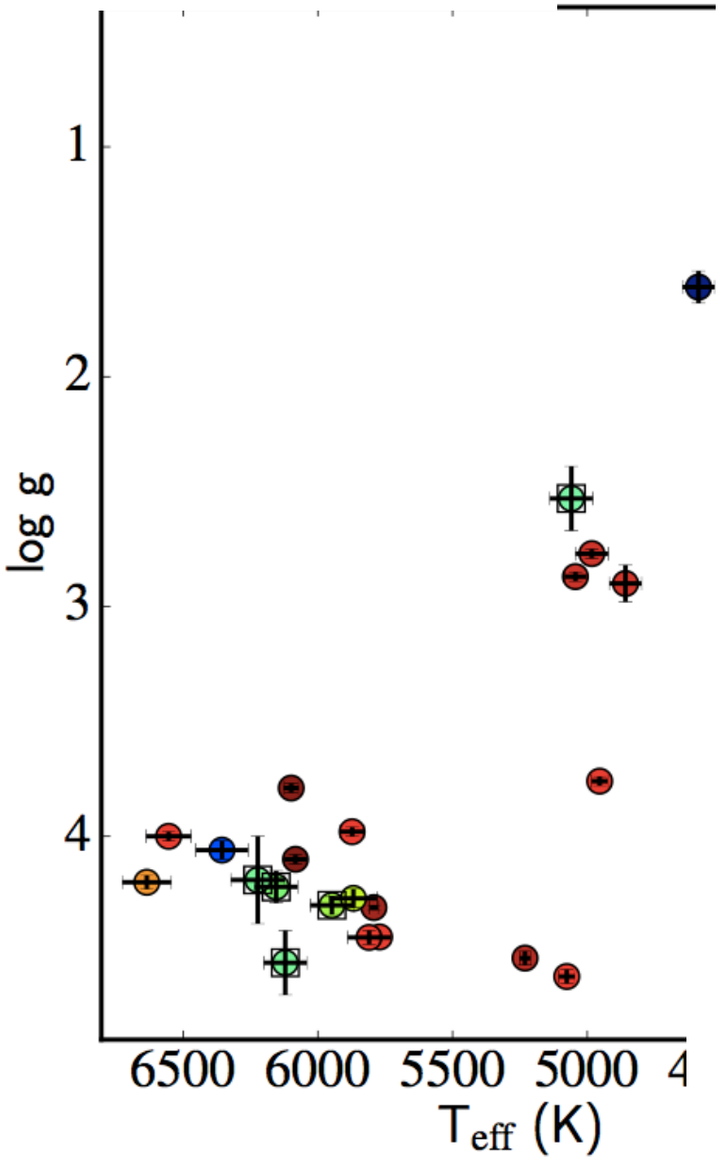
nperature

My kingdom - also not really of fairy tales

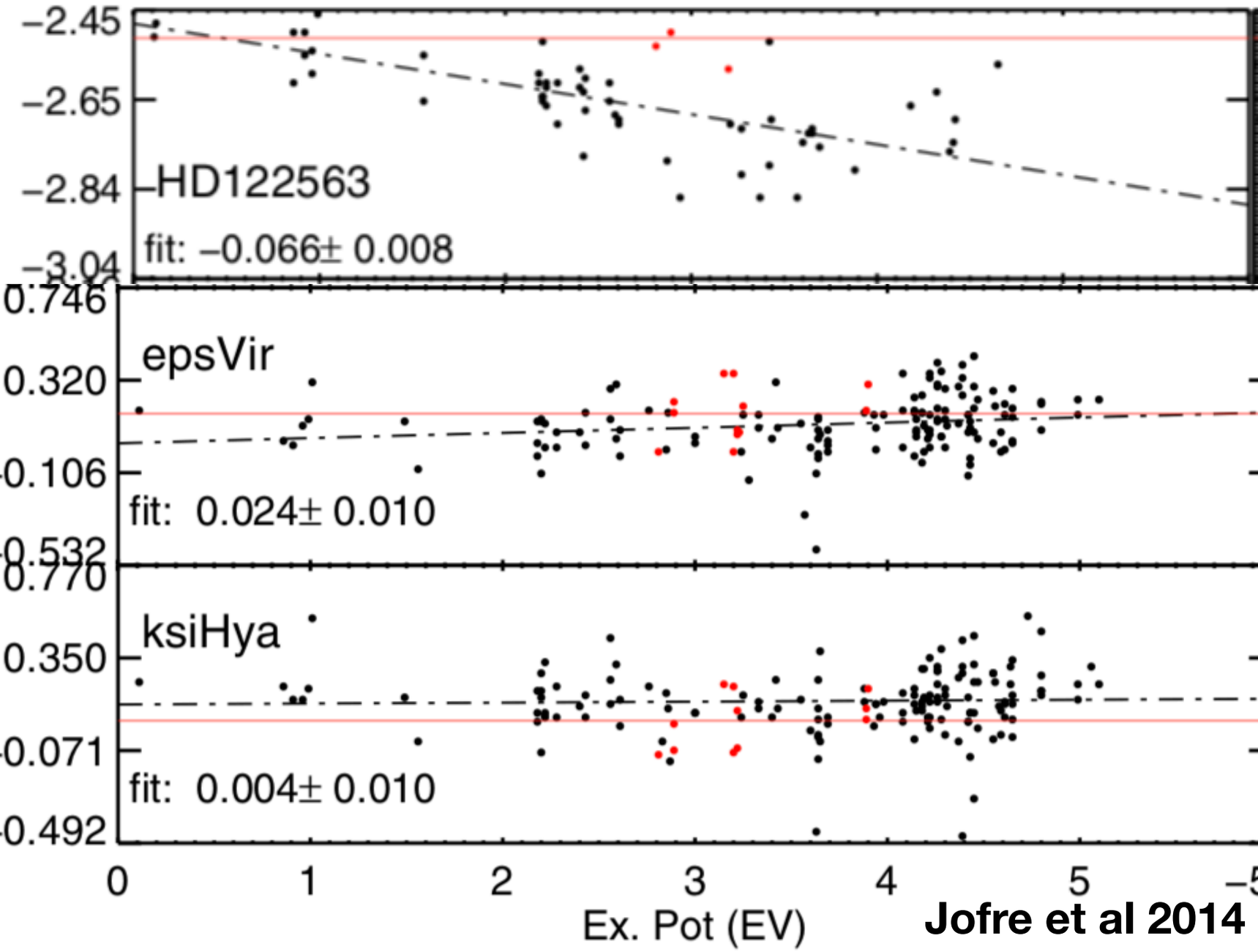
P. Jo

Bolometric flux and angular diameters have errors which mean 100~K in Teff

IRFM



Hawkins et al 2016

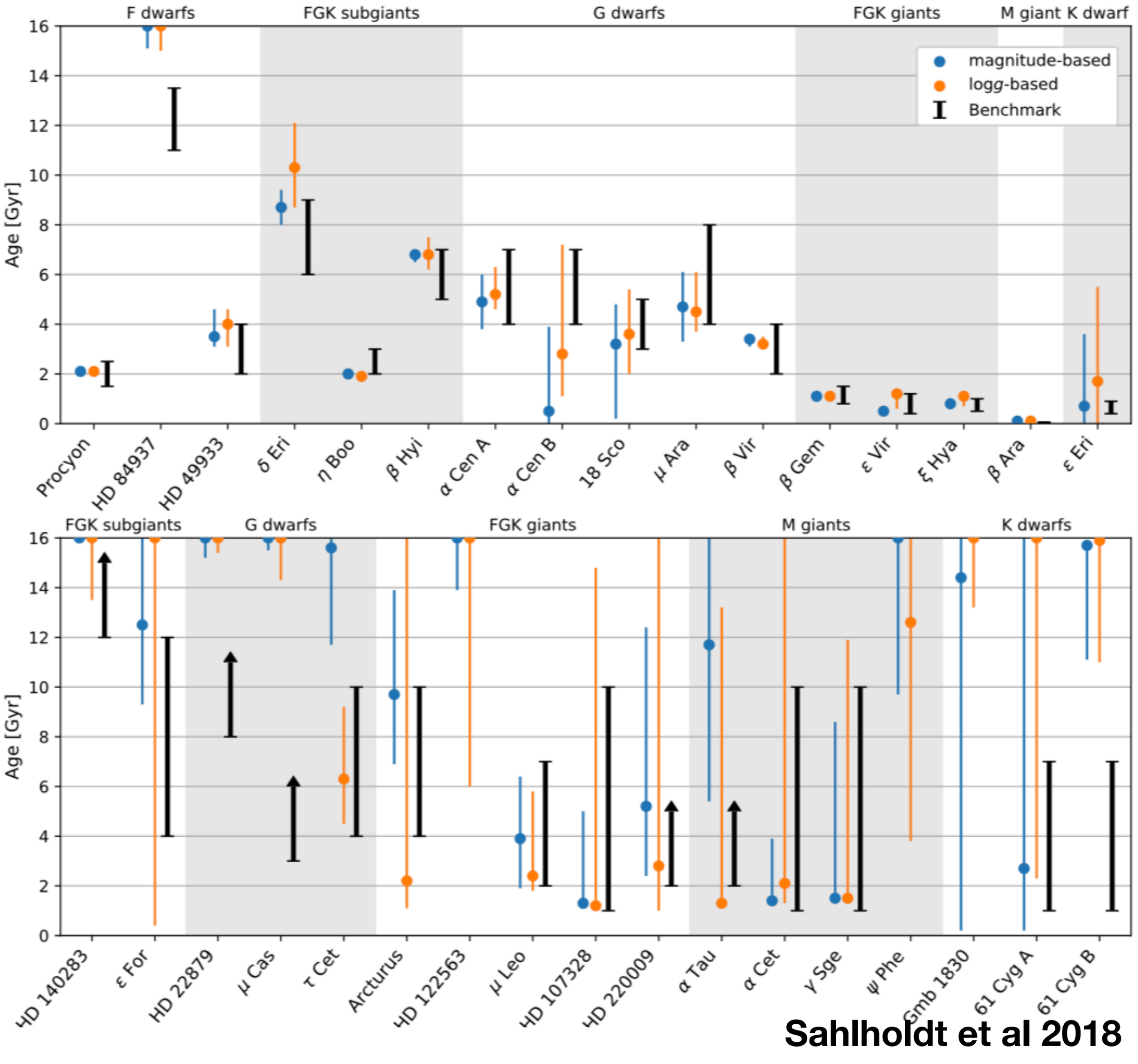


Jofre et al 2014

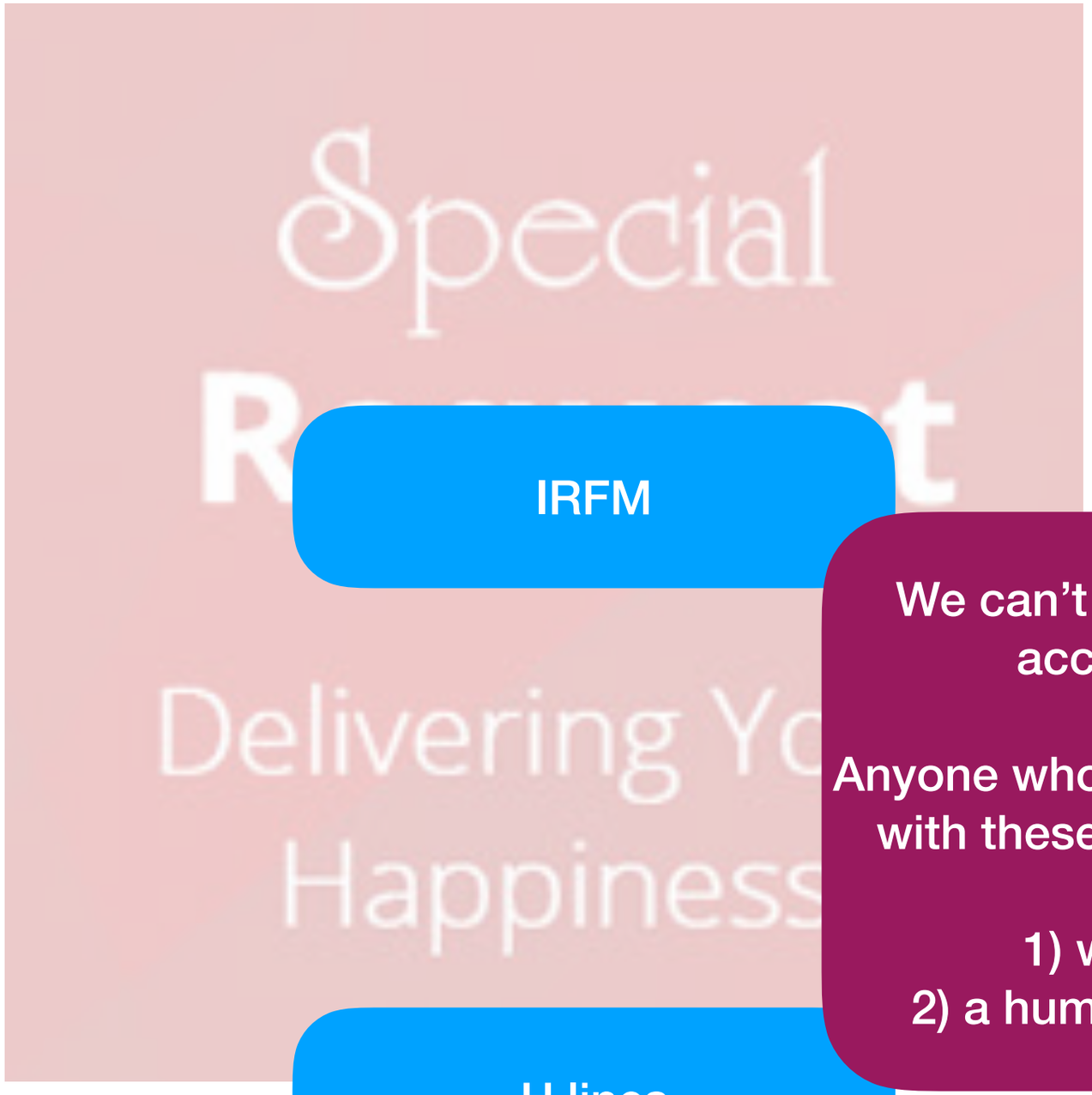
Gaia FGK benchmark stars

My kingdom - als
really of fairy ta

Ages



Sahlholdt et al 2018



Effective temperature

IRFM

Excitation balance

We can’t beat 100 K accuracy

Anyone who claims better with these methods is

1) wrong
2) a humble genius

H lines

Interferometry

Sorry, don’t think this special request delivers happiness…

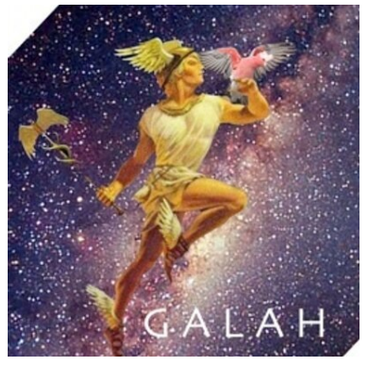
LINK BETWEEN THE "BROAD SWEEPER" AND THE "ULTIMATE REFINER"

Gaia benchmarks

clusters

seismic fields

Hipparcos & Gaia



We  stellar DNA

Chemical elements are made in stars

We ❤ stellar DNA

Chemical elements are made in stars

Stellar generations *inherit* the chemical makeup of previous generations

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Chemical elements are made in stars

Stellar generations *inherit* the chemical makeup of previous generations

Galactic archaeology is about using low-mass stars's ages and chemical elements to trace the evolution of the MW

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A fun “interdisciplinary" discussion with a biological anthropologist over many dinners at King’s Cambridge

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Science News Scientist-to-Watch 2018

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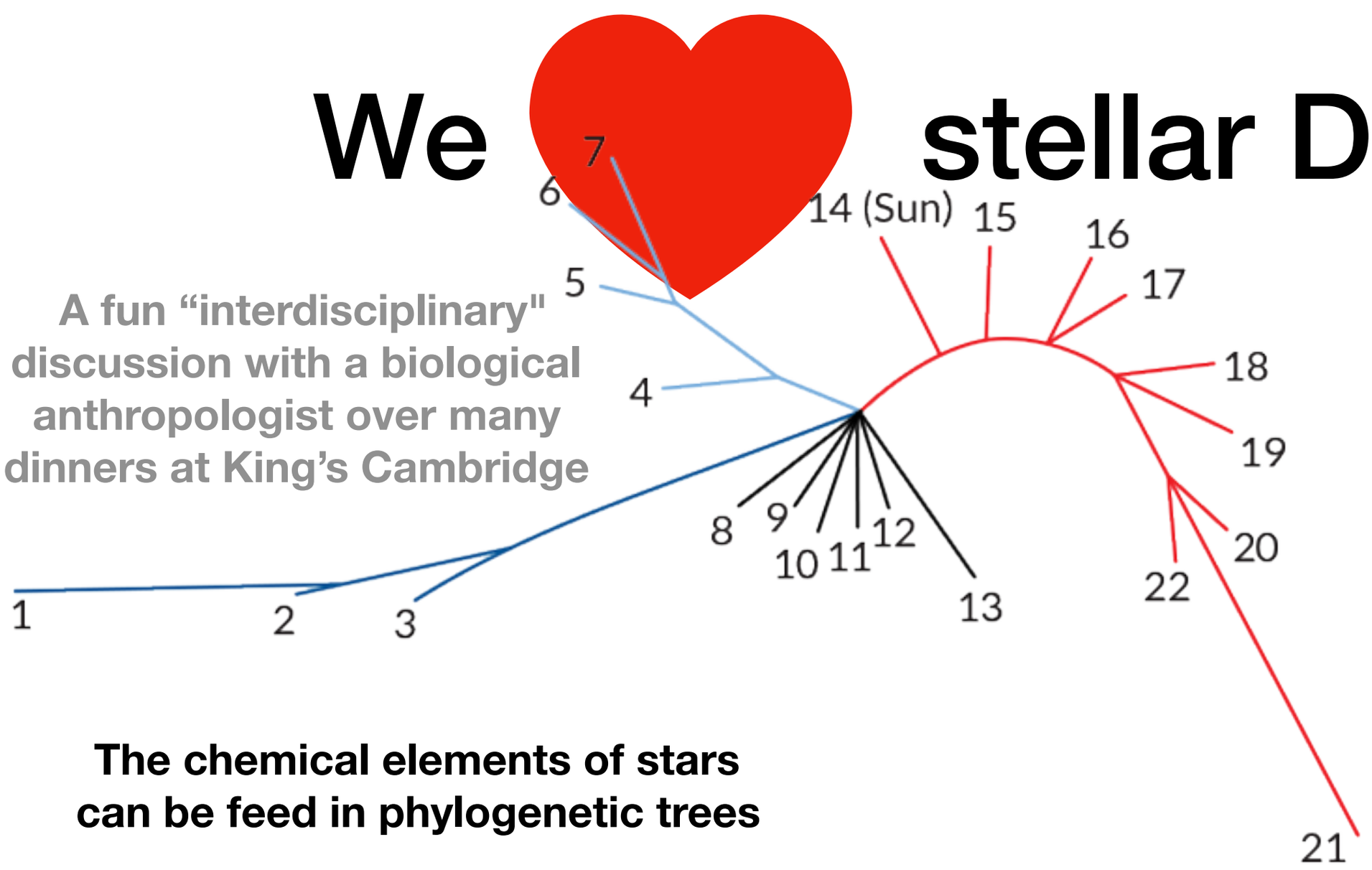

The chemical elements of stars can be feed in phylogenetic trees

This method works with putting closest stars in neighbouring branches

Jofre et al 2017

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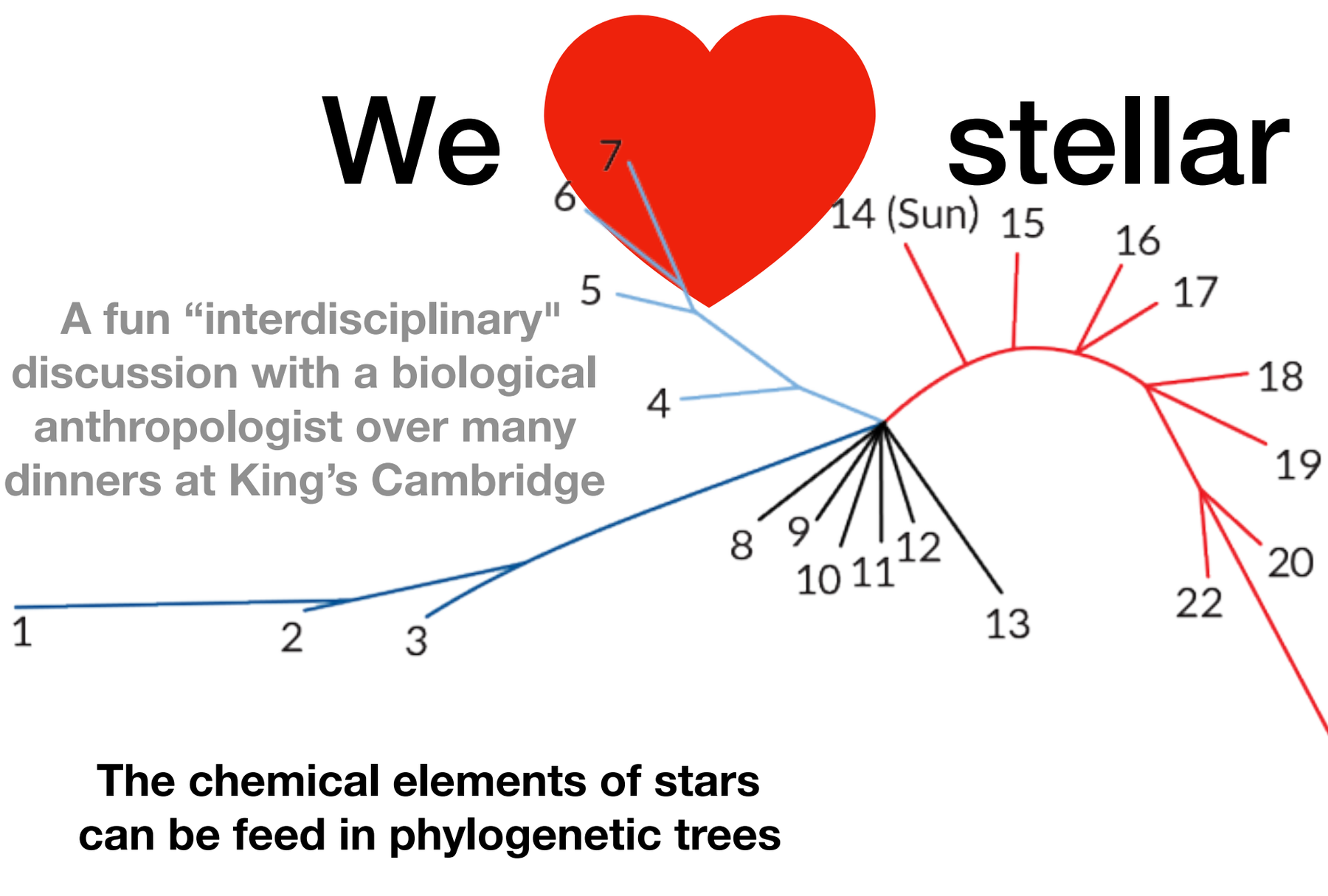

Only possible (now) with the best-of-the-best data (SONG would do?)

The chemical elements of stars can be feed in phylogenetic trees

This method works with putting closest stars in neighbouring branches

Jofre et al 2017

-22 solar twins of Nissen2015/16
-3 populations in the Solar Neighbourhood (different in age)
-each has different branch length - age relation (chemical evolution rate)
- First proof of concept we can use phylogenetic trees to reconstruct history of stars

Nucleo de Astronomia, UDP

- Chile's astronomy is perhaps the community that is growing the fastest - no wonder, so are the facilities that are being installed in the dessert. Chile is investing in the development of astronomy like few countries.

- Astronomy Nucleus, UDP, Santiago de Chile - started 2013 - I joined as 5th Faculty in 2017 (the stellar/galactic person), now we are 7 faculty + 6 post-docs, 1 outreach coordinator.

    - 1 more faculty to join **(and search)** in next 2 years.

    - **Next year PhD program starting.** Stay tuned and encourage adventurous candidates to come, we trust we have all necessary stuff to form young scientists!

    - Telescopes, many funding programmes (ESO-Chile, ALMA/CAS/ECOS/ Belgium/STINT/Gemini…-Conicyt, Fondecyt, etc), international networks, etc

    - We are a new group of scientists, with new ideas and ambitions we've collected from our experiences abroad. Chile is liking it, I hope the rest does it too!