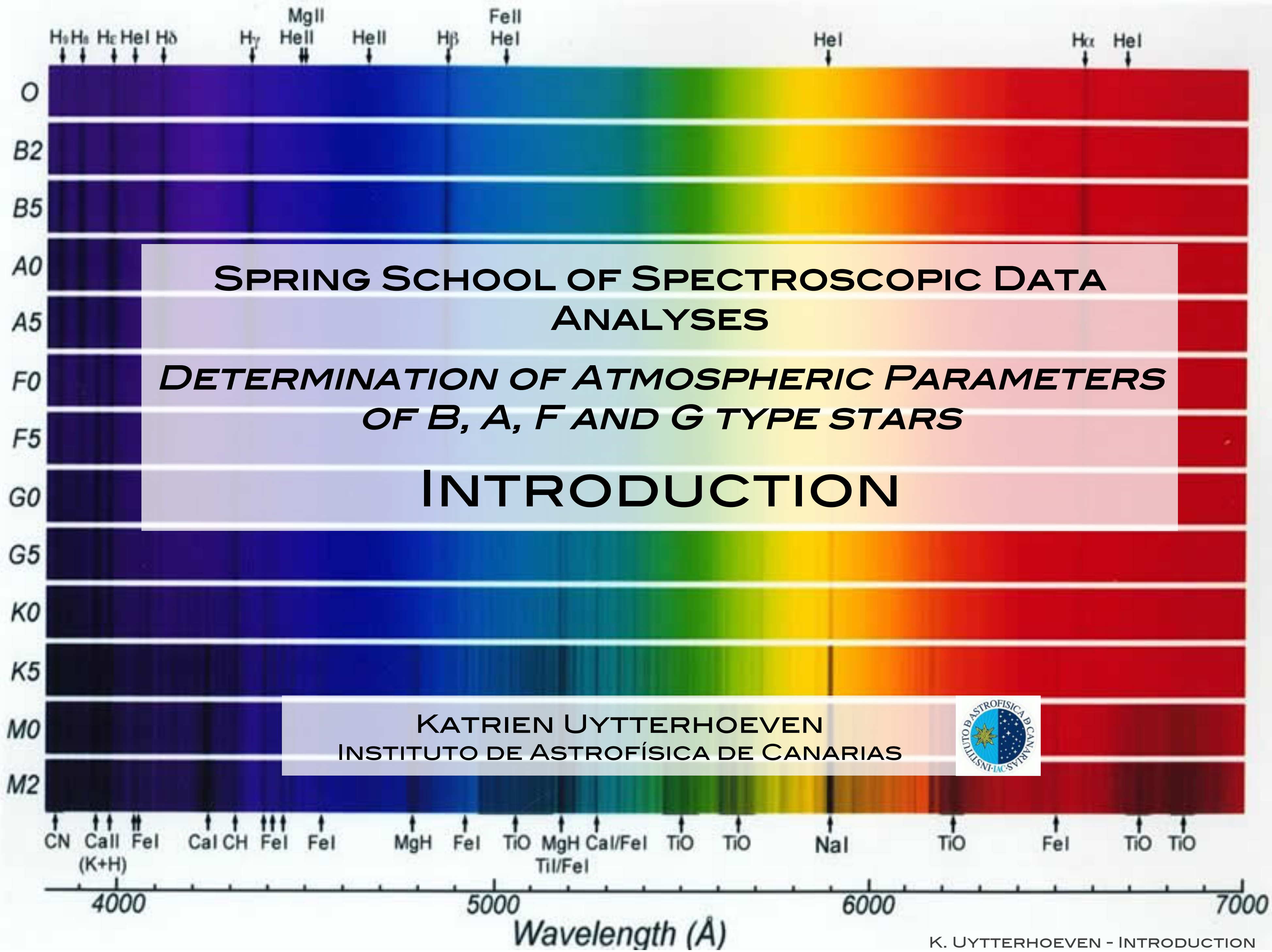


Spring School of Spectroscopic Data Analyses

Determination of Atmospheric Parameters of B, A, F and G type stars

Introduction

Katrien Uytterhoeven
Instituto de Astrofísica de Canarias

OUTLINE

- The need for accurate atmospheric parameters and abundances from an astrophysical point of view

- spectra as the ideal tool

- KASC and the characterization of asteroseismic Kepler targets

- motivation of the spring school

I. The need for accurate atmospheric parameters and abundances from an astrophysical point of view

Teff

logg

chemical abundances

vsini

microturbulence

Fundamental stellar parameters

To describe a star:

- mass (M)
- luminosity (L)
- radius (R)
- age
- chemical composition
- angular momentum
- magnetic field

Generally not directly observable!

Fundamental stellar parameters

To describe a star:

- mass (M)
- luminosity (L)
- radius (R)
- age
- chemical composition
- angular momentum
- magnetic field

Generally not directly observable!

effective temperature (Teff)
surface gravity (logg)

➔define physical conditions of the stellar atmosphere and directly related to M, L, and R

$$L = 4 \pi R^2 \sigma T_{eff}^4 \qquad g = G M/R^2$$

σ= Stefan-Boltzmann constant

G=gravitational constant

Fundamental stellar parameters

To describe a star:

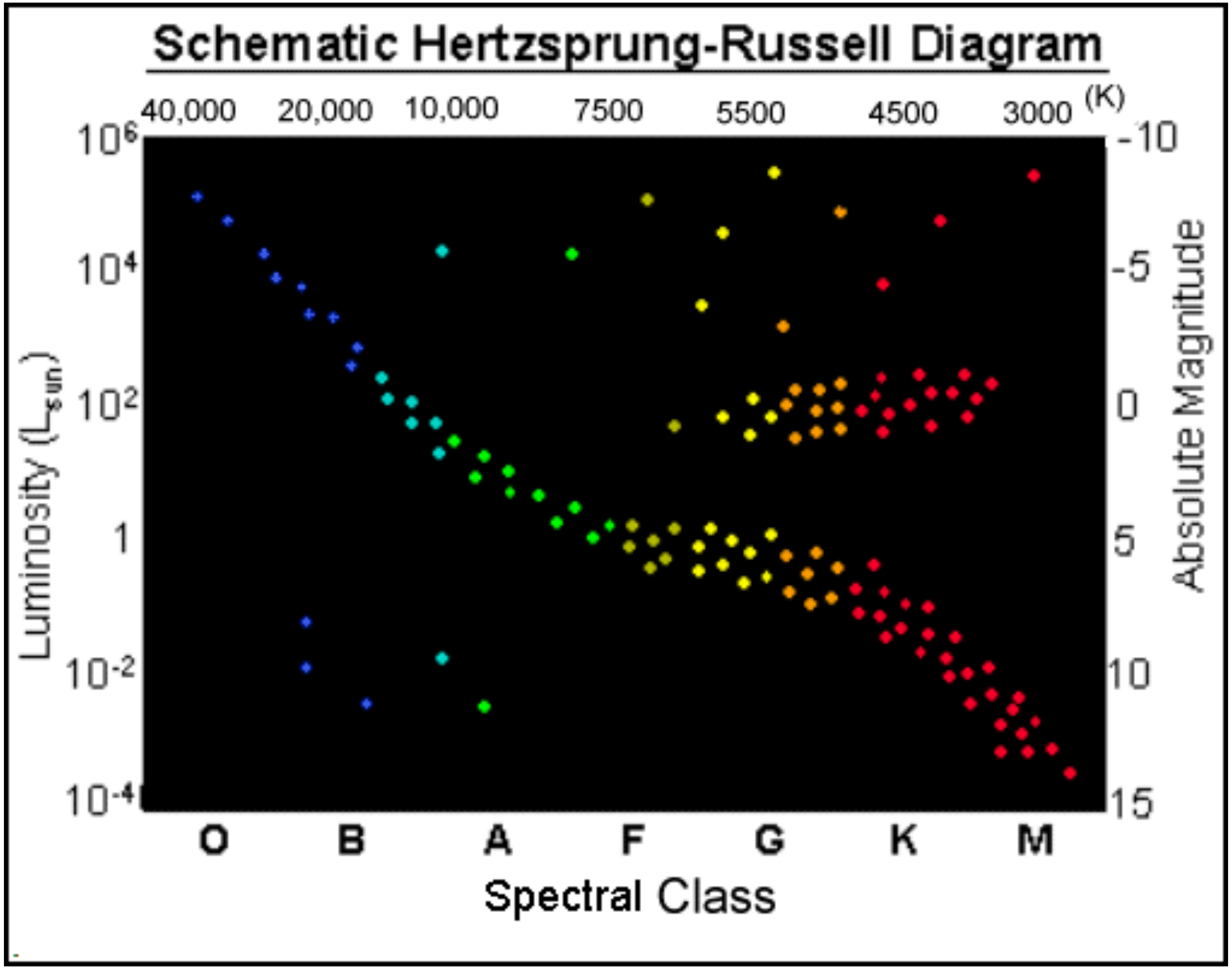
- mass (M)
- luminosity (L)
- radius (R)
- age
- chemical composition
- angular momentum
- magnetic field

Generally not directly observable!

effective temperature (Teff)
surface gravity (logg)

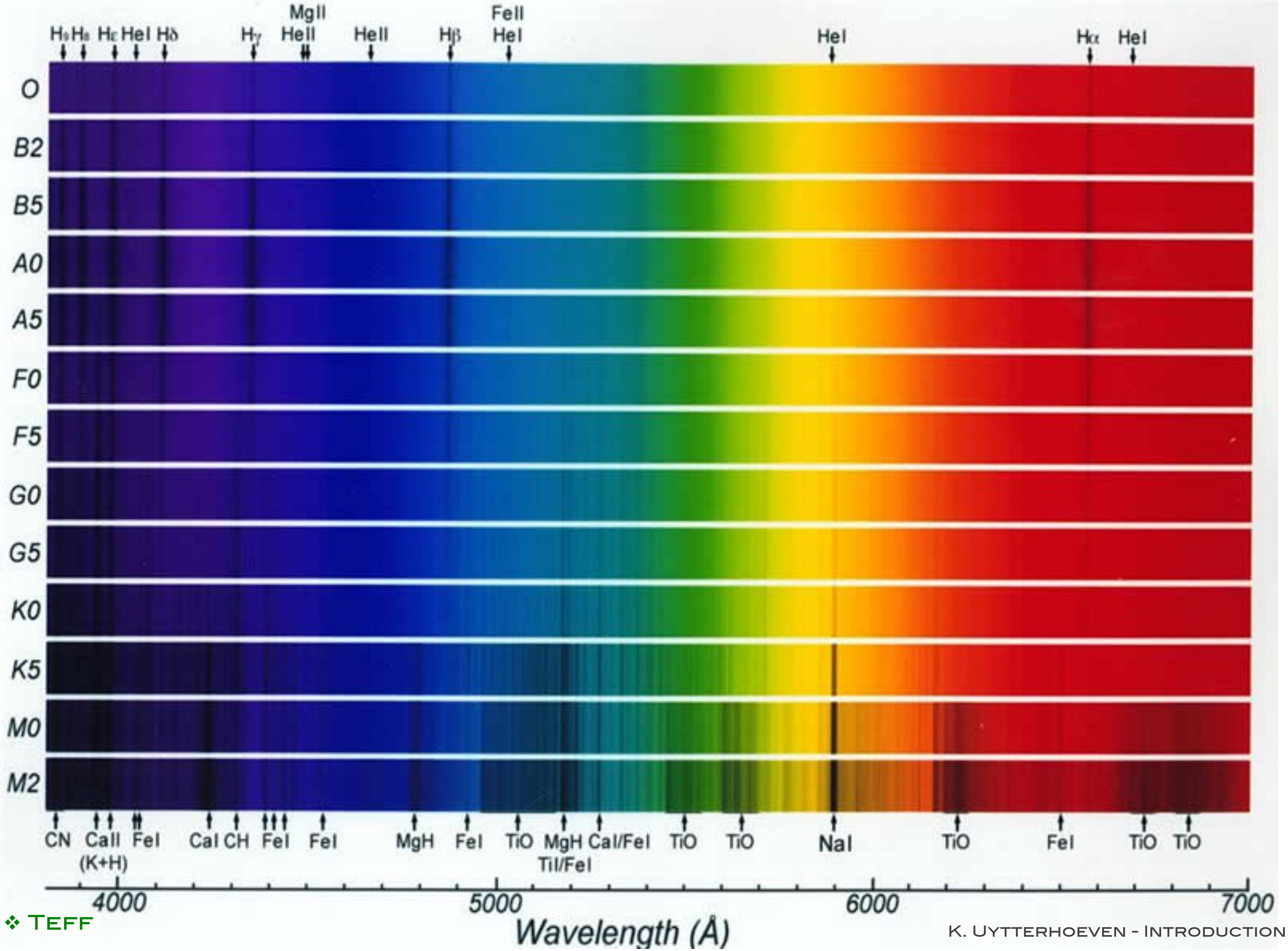
➔ Age estimated through theoretical evolutionary tracks in (Teff,L)- or (L, M)-diagram

Classification of stars



❖ Teff and logg

Classification of stars



❖ Teff

Study stellar structure and evolution of the Milky Way

REQUIRES DETAILED KNOWLEDGE OF PROPERTIES OF STELLAR POPULATIONS (MASS, AGES, KINEMATICS, CHEMICAL ABUNDANCES,...)

OBSERVATIONS NEEDED FOR STARS OF ALL AGES AND AT DIFFERENT POSITIONS IN THE HR-DIAGRAM

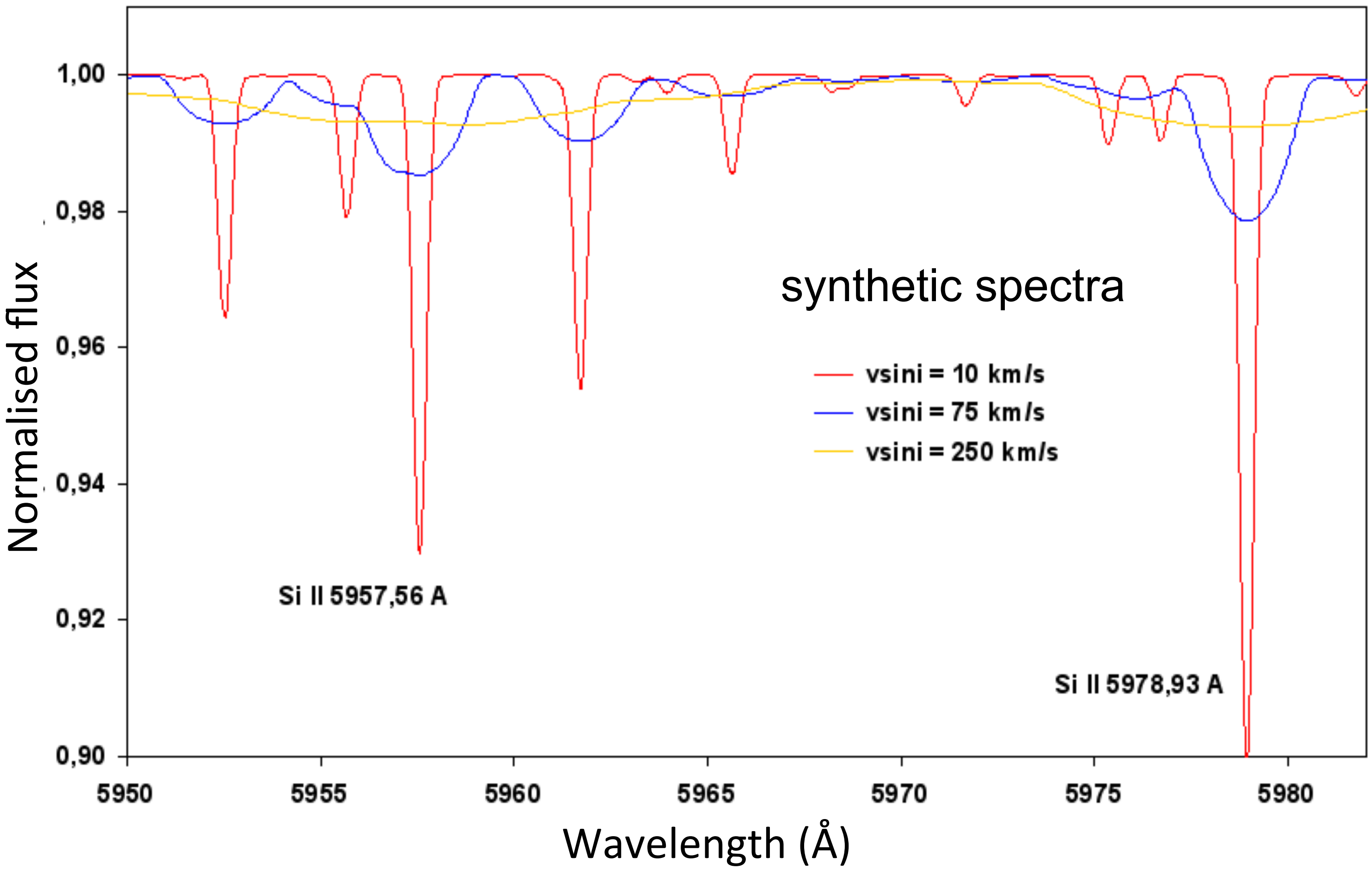
➔

CHARACTERIZATION OF STELLAR POPULATIONS

- Teff, logg, element abundances, rotation

Improve stellar atmosphere models

Compare observed spectra with synthetic spectra



Observations needed for stars of all ages and at different positions in the HR-diagram

- Teff, logg, element abundances, rotation, microturbulence ξ

DE CAT ET AL. 2007, A&A 463, 243

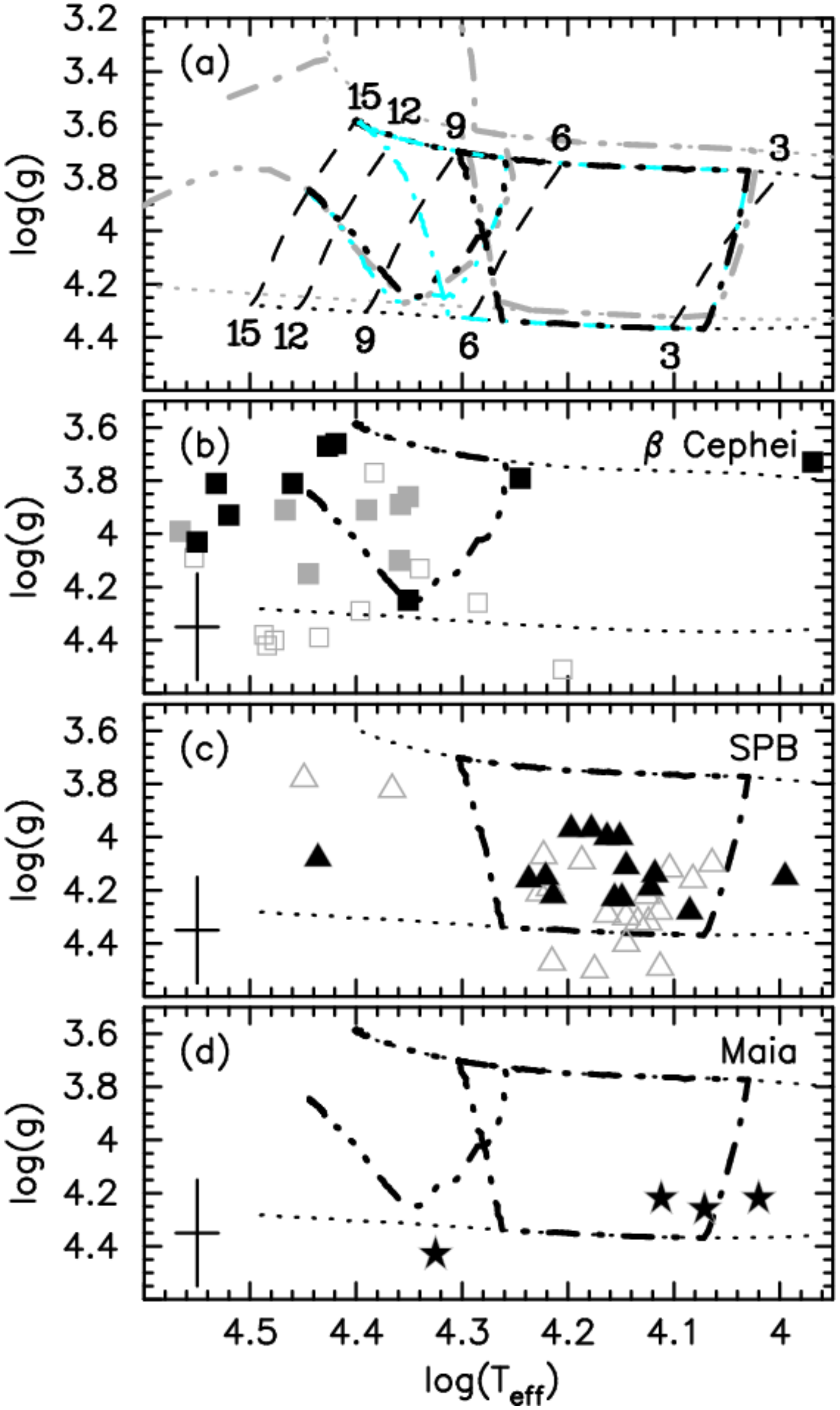
❖TEFF AND LOGG

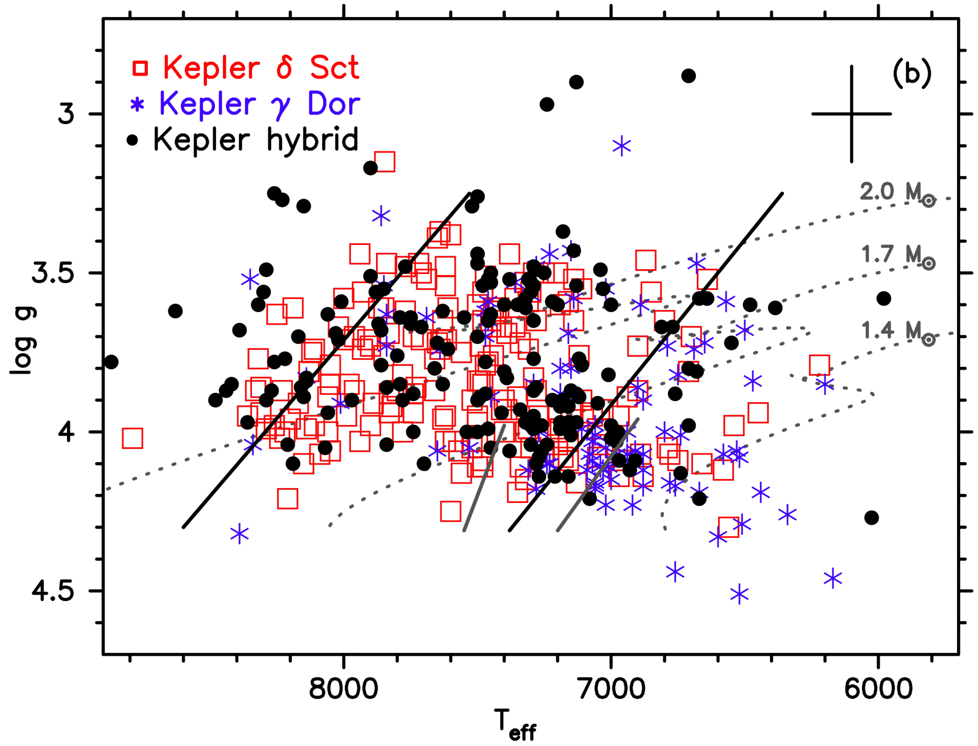
ASTEROSEISMIC STUDIES

TEST INSTABILITY STRIPS

←β CEP AND SPB STARS

↓δ SCT AND γ DOR STARS

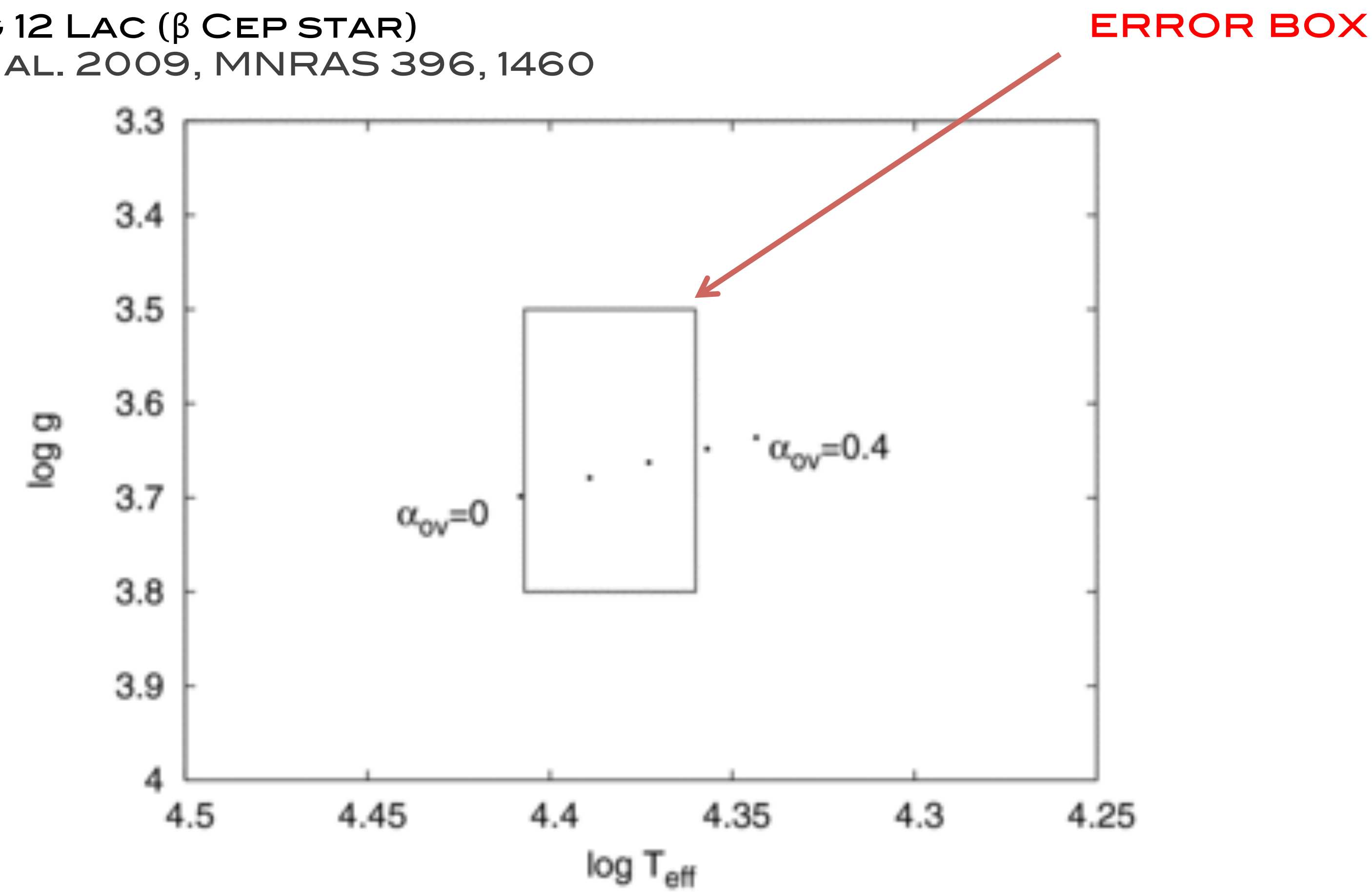




UYTTERHOEVEN ET AL. 2011, A&A 534, 125

Accurate values of Teff and logg needed to define unique asteroseismic model

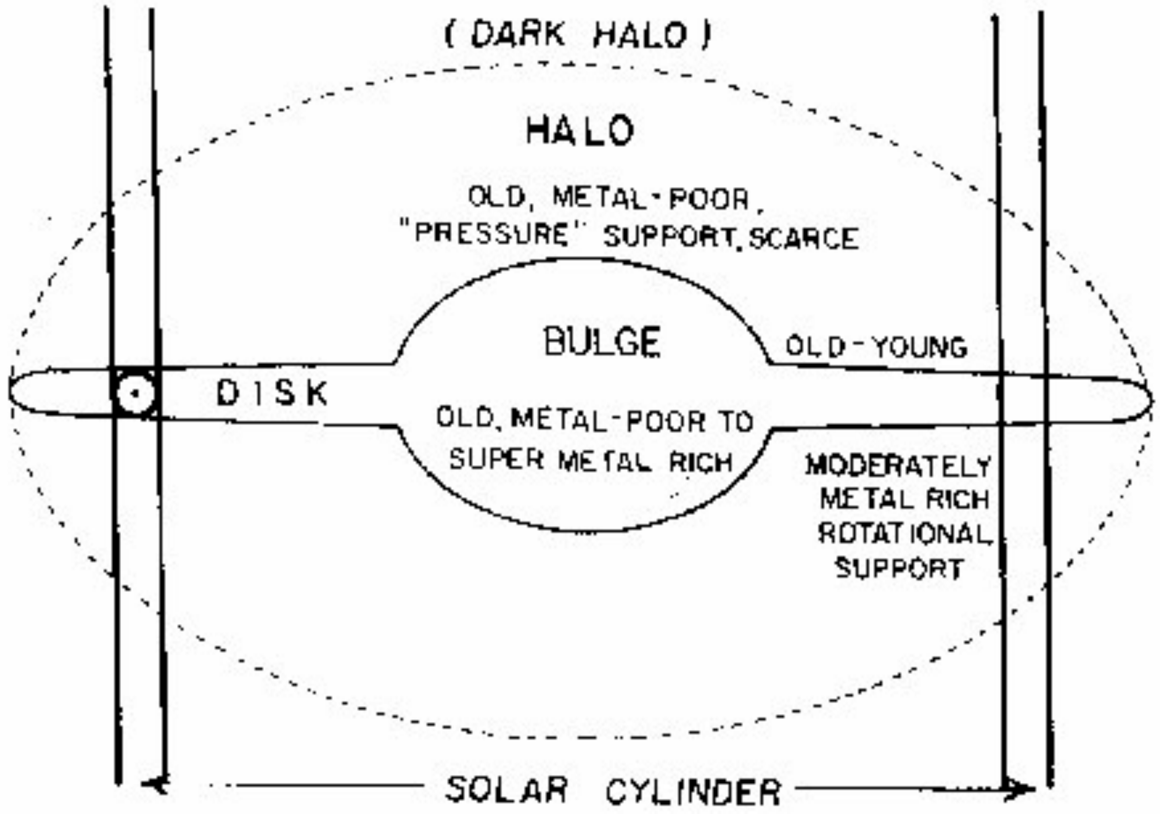
Modelling 12 Lac (β Cep star)
Desmet et al. 2009, MNRAS 396, 1460



The error box represents the position of 12 Lac in the log (T_{eff})−*log g diagram. The positions of the models which fit exactly* f_2 *(being the first overtone) and* f_3 *are also shown for different* α_{ov} *values.*

STUDIES OF THE CHEMICAL EVOLUTION OF THE MILKY WAY

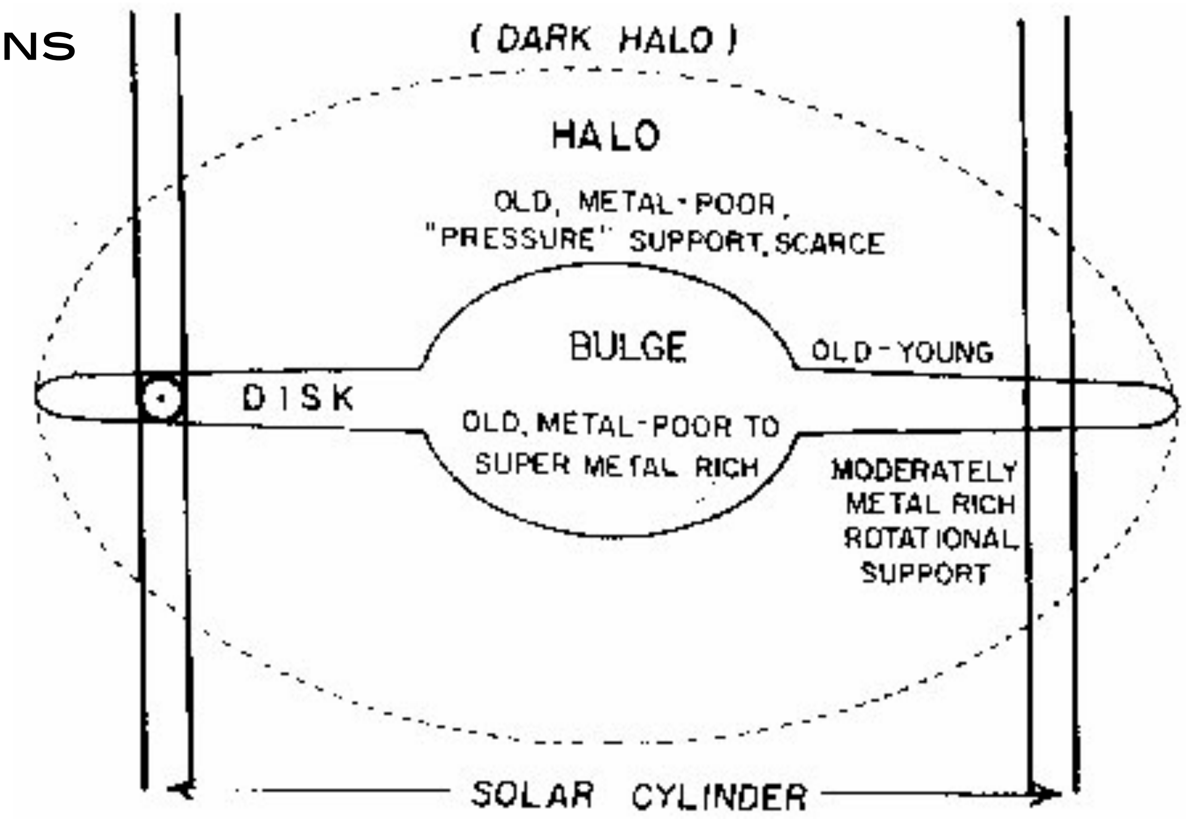
ORIGINAL CHEMICAL COMPOSITION:
H (70%)
HE (28%)
HEAVIER ELEMENTS (2%)



CAREFUL ANALYSIS OF CHEMICAL COMPOSITION OF DIFFERENT POPULATIONS OF STARS

= PROBE GALACTIC CHEMICAL EVOLUTION + TEST ELEMENT PRODUCTION BY THERMONUCLEAR REACTIONS IN STELLAR INTERIORS AND BY SUPERNOVAE.

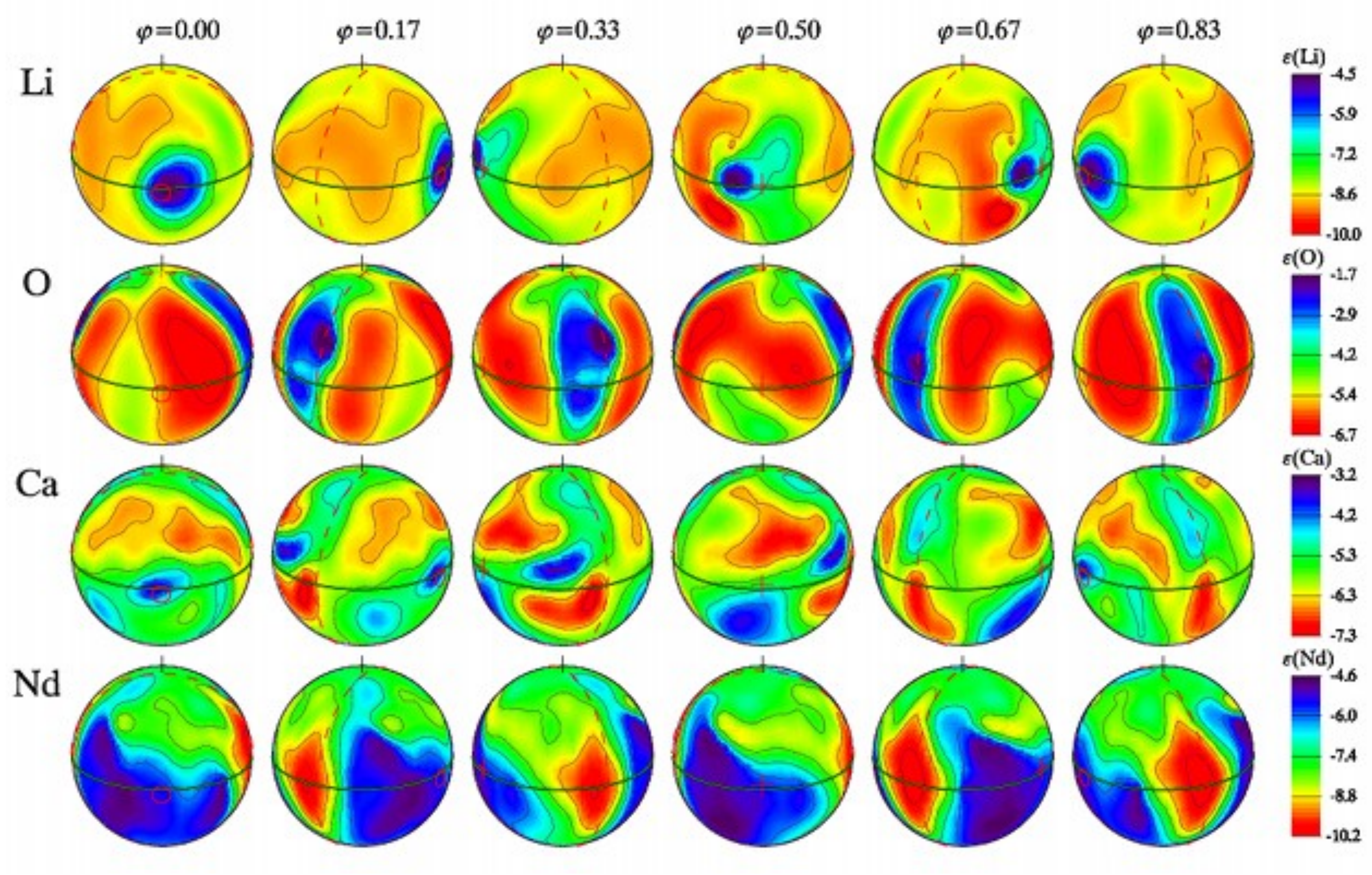
ADDITIONAL APPLICATIONS



FROM MODELS OF CHEMICAL EVOLUTION:

TEST ABUNDANCE GRADIENTS ACROSS THE MILKY WAY DISK, GAS INFALL EPISODES, AND STAR FORMATION RATES

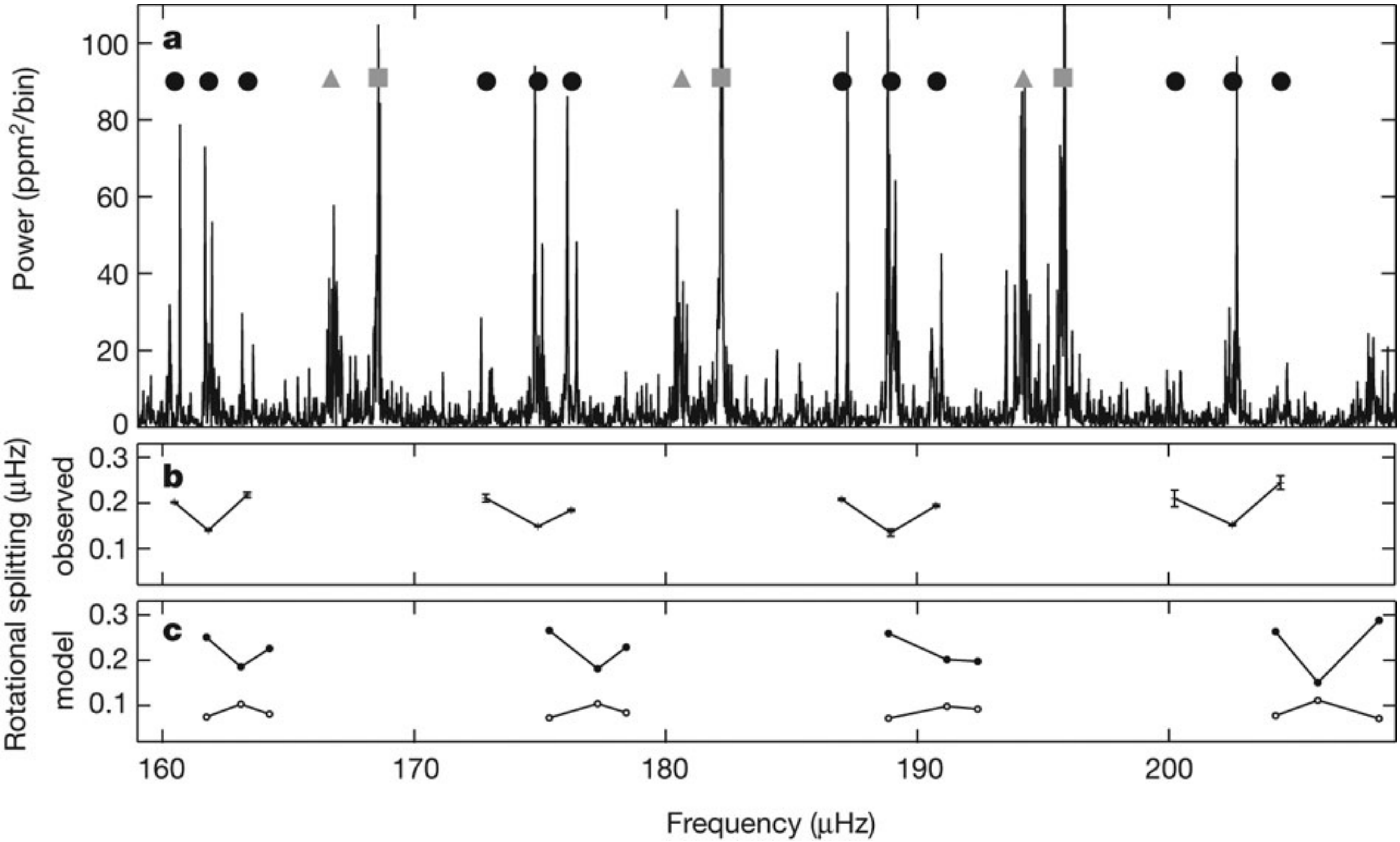
STUDY OF ABUNDANCE SURFACE INHOMOGENEITIES (SPOTS)



Kochukhov et al. 2004, A&A 424, 935 (RoAp star HR 3831)

❖ ELEMENT ABUNDANCES AND ROTATION

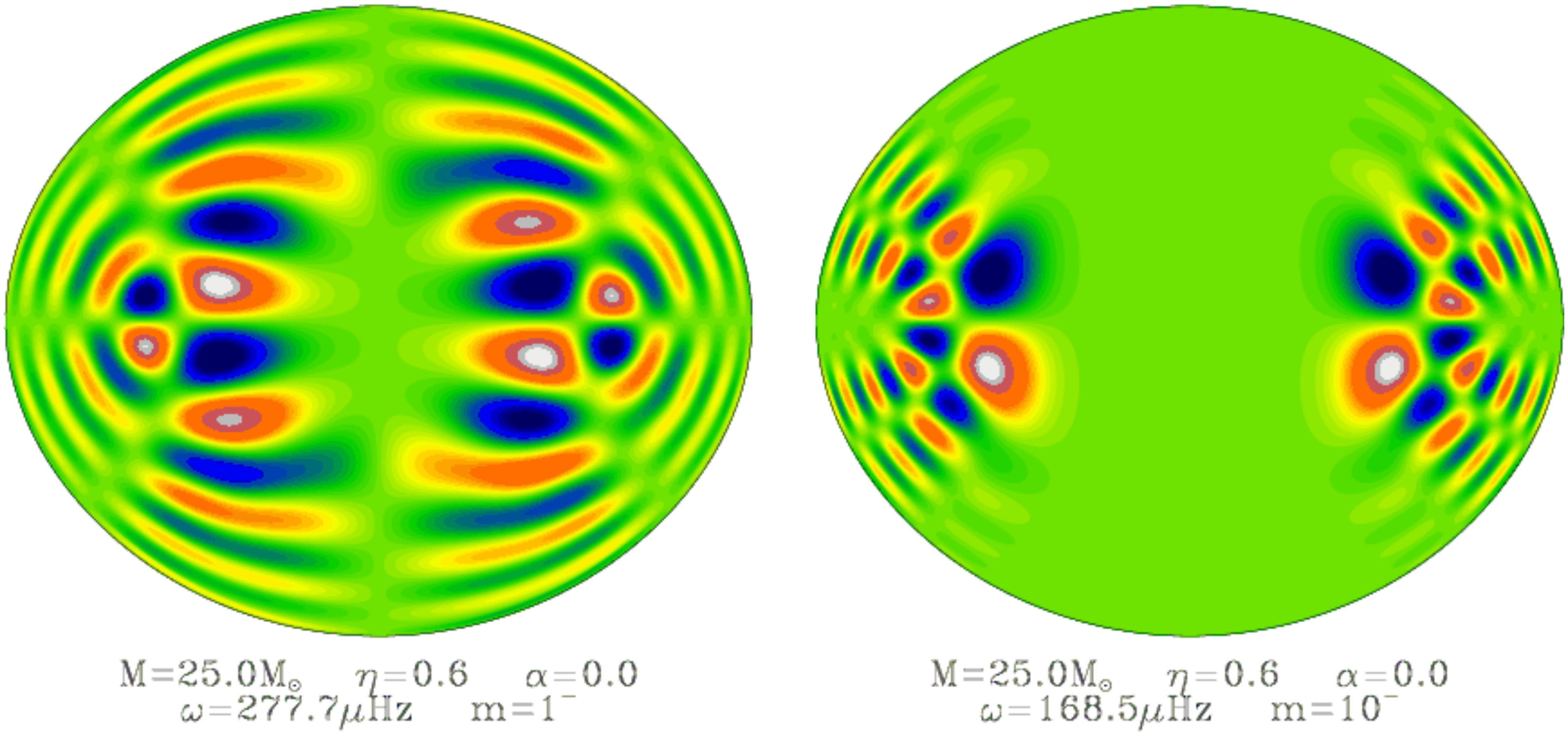
Rotational splitting of pulsation modes



Beck et al. 2012, Nature 481, 55 (red giant star)

TEST AND IMPROVE PULSATIONAL MODELS FOR RAPIDLY ROTATING PULSATING STARS

→ DEFORMATION OF SURFACE VELOCITY FIELDS



Reese et al. 2009, A&A 506, 189

❖ ROTATION

TEST AND IMPROVE MODELS OF CONVECTION

MICROTURBULENCE ξ

* ONE OF BROADING MECHANISMS OF ABSORPTION LINES

* MOST LIKELY CAUSED BY CONVECTION

(SUB-SURFACE CONVECTION ZONES IN CASE OF MASSIVE STARS; OUTER CONVECTION LAYER IN LESS MASSIVE STARS)

ACCURATE VALUES OF ξ IMPORTANT TO TEST
ATMOSPHERE MODELS
AND MODELS OF CONVECTION

AND MANY OTHER APPLICATIONS...

- STUDY OF CIRCUMSTELLAR MATTER
- RELATION BETWEEN CHEMICAL PECULIARITY AND ROTATION OR MAGNETIC FIELDS
- EFFECTS OF STELLAR ROTATION ON STAR FORMATION RATES
- ETC.

❖ Teff, logg, element abundances, rotation, microturbulence ξ

II. Spectra as the ideal tool to derive atmospheric parameters

II. Spectra as the ideal tool

Teff

logg

microturbulence ξ

abundances

vsini

Spectroscopy

Photometry
(Teff, logg, metallicity [M/H])

Spectrophotometry
(Teff, metallicity [M/H])

Infrared Flux Method
(Teff)

II. SPECTRA AS THE IDEAL TOOL

TEFF
LOGG
MICROTURBULENCE ξ
ABUNDANCES
VSINI

SPECTROSCOPY

PHOTOMETRY
(TEFF, LOGG, METALLICITY [M/H])

SPECTROPHOTOMETRY
(TEFF, METALLICITY [M/H])

INFRARED FLUX METHOD
(TEFF)

➔VALUES ALWAYS DERIVED BY COMPARISON WITH MODEL ATMOSPHERES!!!

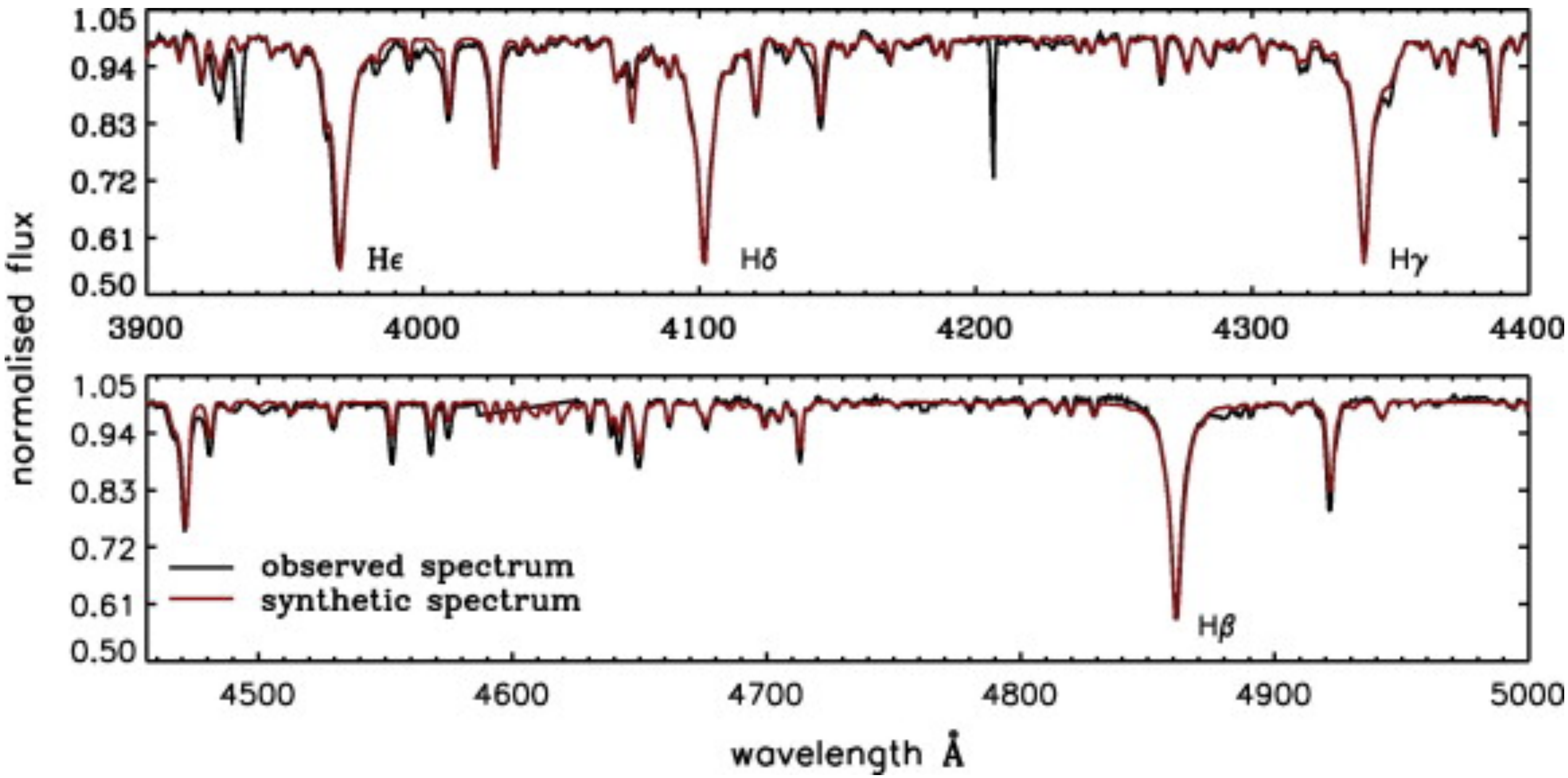
(EXCEPT WHEN MASS, RADIUS, AND ANGULAR DIAMETER ARE KNOWN)

How to choose the ideal spectrograph?

resolution

low-resolution (R<5000)
mid-resolution (5000<R<40000)
high-resolution (R>40000)

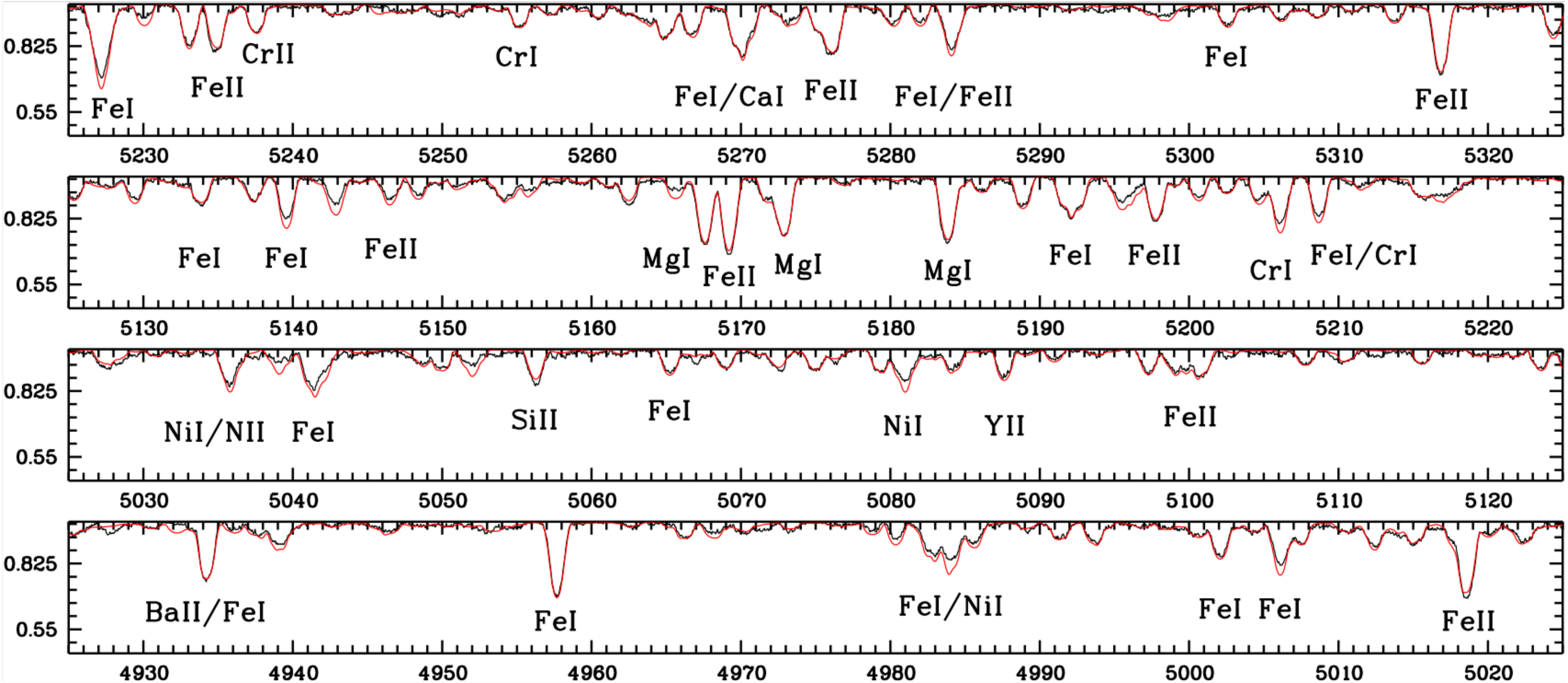
Ulusoy et al. 2013, New Astronomy 22, 51
(RSS longslit spectrograph (R=3000))



low resolution (R<5000)

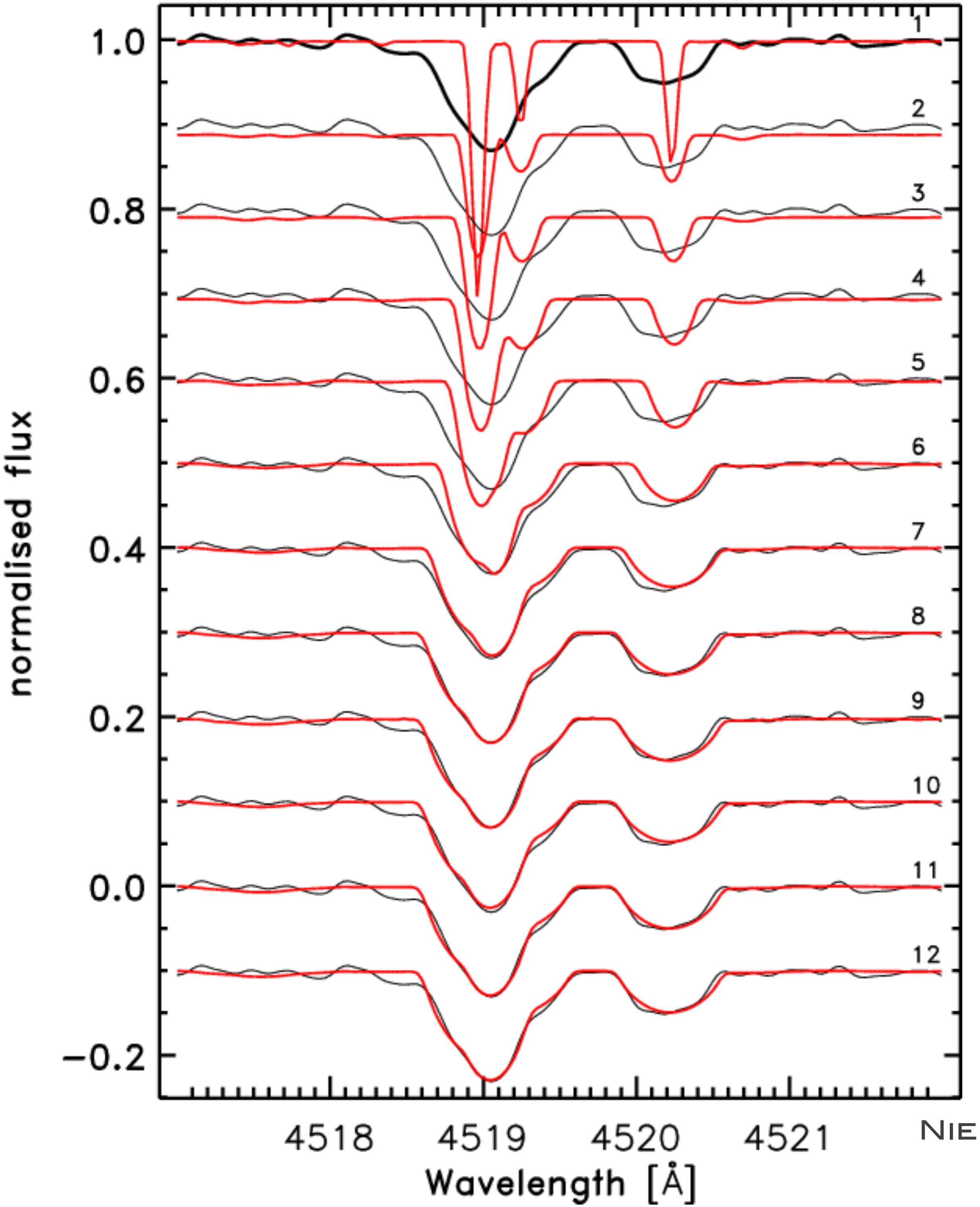
Mainly use of Balmer lines

Lehmann et al., 2011, A&A 526, A124
(Tautenburg spectrograph (R=32000))



medium resolution (5000<R<40000)

Select non-blended, well-resolved lines



HIGH RESOLUTION
R>40000

OPTIMAL!

NOTE:
HIGH-RES IN PARTICULAR
NEEDED FOR SLOW ROTATORS

Niemczura et al., 2009, A&A 506, 213

How to choose the ideal spectrograph?

resolution

low-resolution (R<5000)
mid-resolution (5000<R<40000)
high-resolution (R>40000)

Wavelength range

Are Balmer lines well-defined?
(interorder gaps / order definition)
Is a sufficient amount of element lines available for a reliable analysis?
(échelle spectrograph versus slit spectrograph)

How to choose the ideal spectrograph?

Resolution

low-resolution (R<5000)
mid-resolution (5000<R<40000)
high-resolution (R>40000)

Wavelength range

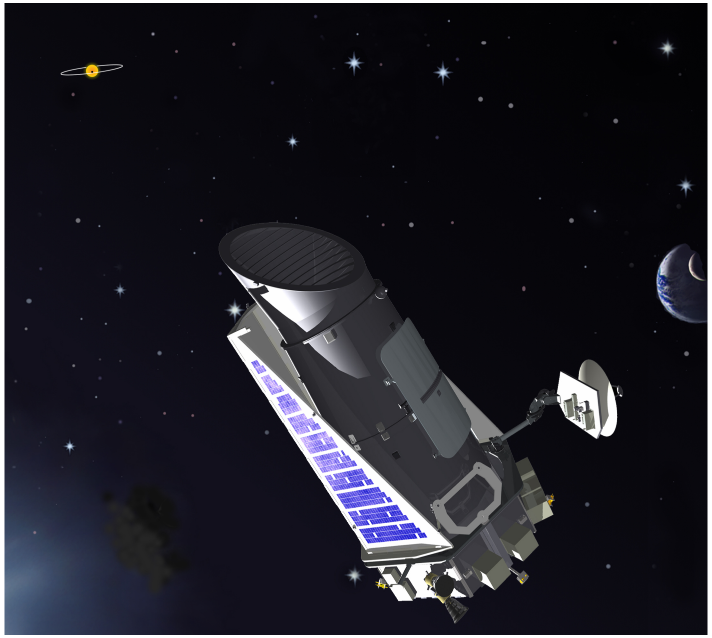
Are Balmer lines well-defined?
(interorder gaps / order definition)
Is a sufficient amount of element lines available for a reliable analysis?
(échelle spectrograph versus slit spectrograph)

Signal-to-noise ratio

at least SNR=100-150
The higher the SNR, the better!
(note: SNR versus faintness of the star)

III. KASC and the characterization of asteroseismic Kepler targets

KASC
(Kepler asteroseismic science consortium)



Kepler data does NOT provide information on Teff, logg, metallicity, vsini, chemical abundances

- To classify targets
- To provide input parameters for asteroseismic models

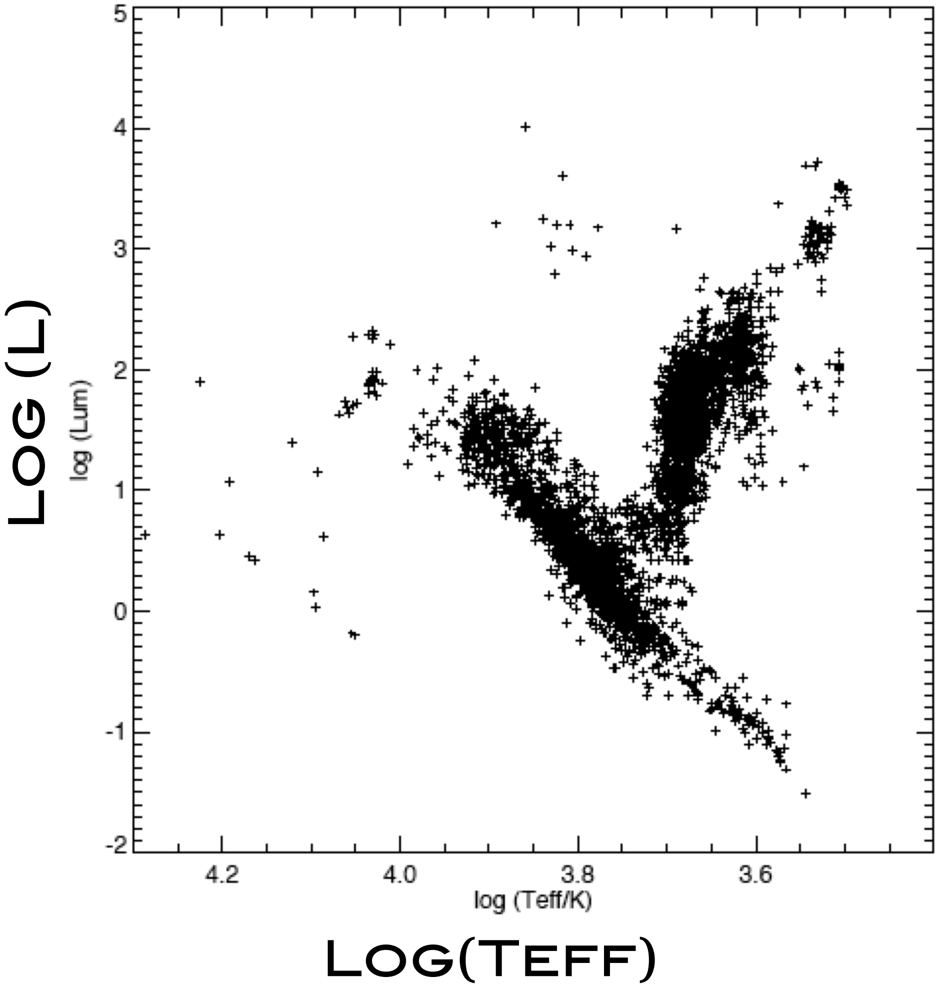
↓

ground-based follow-up for the Characterization of Kepler asteroseismic targets

see Uytterhoeven et al., 2010a,b

KIC - Kepler Input Catalogue

(Latham et al. 2005; Brown et al. 2011)

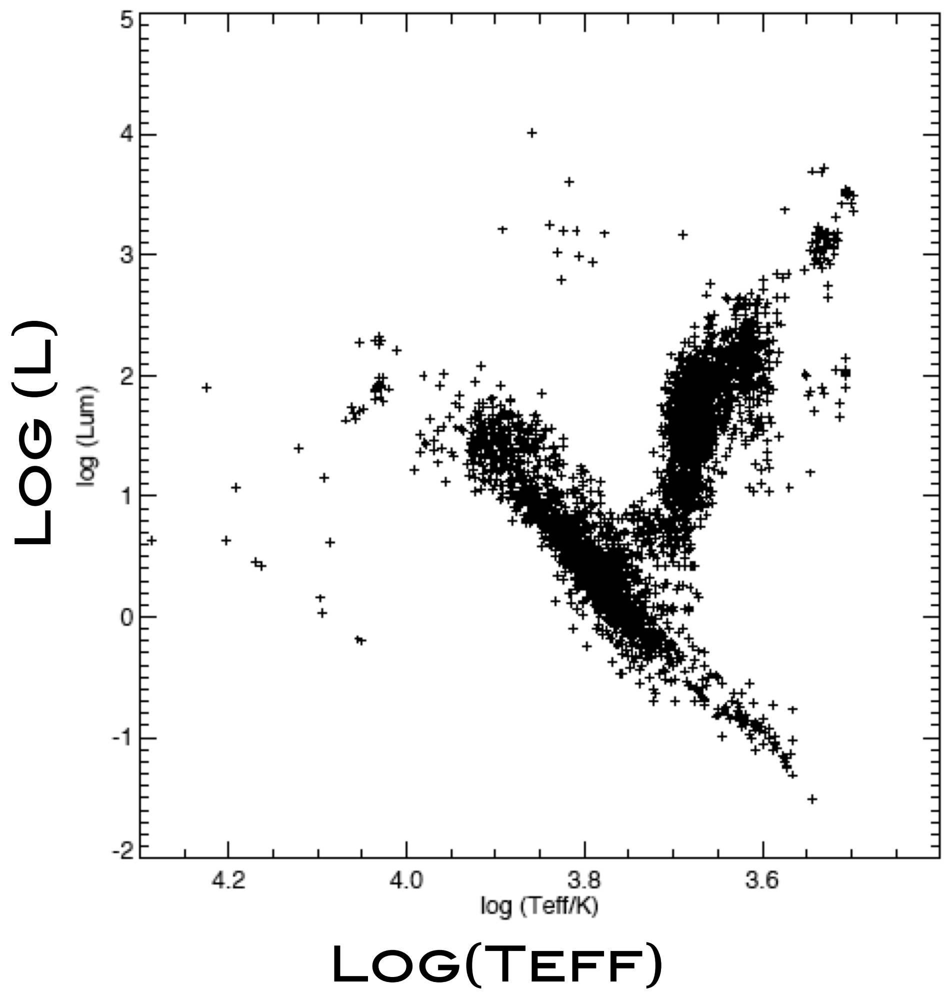


Multi-band photometry (Sloan filters and 2MASS HJK) for all Kepler stars

AIM:
distinguish dwarfs from giant stars

Focussed on F,G,K, and M dwarfs

KIC - Kepler Input Catalogue



Problem:
(Lehmann et al. 2011, A&A 526, A124
Molenda-Żakowicz et al., 2011, MNRAS 412, 1210)

- No accurate Teff for hotter stars (Teff>7000 K) as Sloan filters + 2MASS HJK do not include Balmer Jump

- Uncertainty logg = 0.5 dex

→ Not good enough for asteroseismic modeling

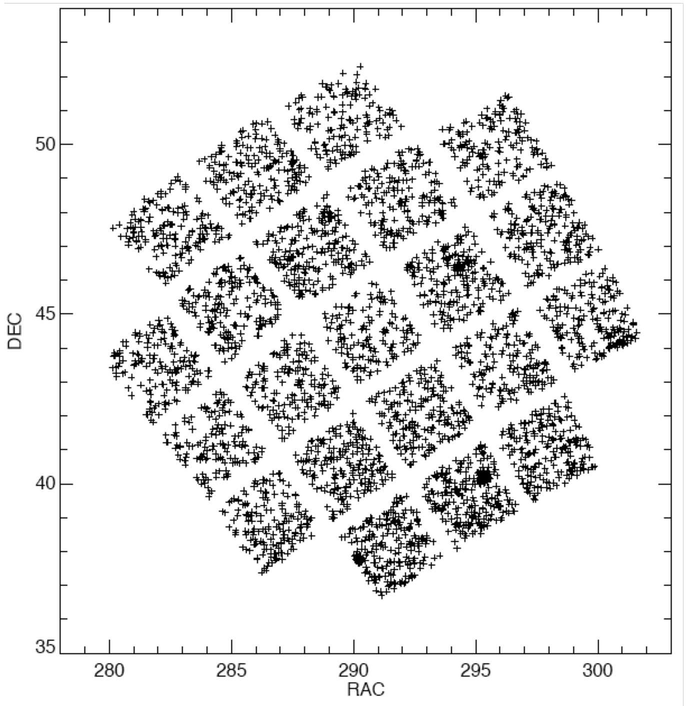
Independent and systematic characterization of Kepler stars needed!

Challenges...

★ Systematic characterisation of 5000+ KASC targets!!!

Facts:

≤14 targets can be observed per night with a 2m-class telescope



KASC targets on Kepler CCDs

➔ Many clear observing nights needed!

Challenges...

★ Kepler targets are relatively faint
(7<V<16; majority 12<V)

SNR>100 needed for characterization

<u>facts:</u> high-res, SNR=100 with 2.5m-tel.

V=9 Texp= 20min

V=10 Texp= 45min

V=11 Texp > 90min

Challenges...

★ Kepler targets are relatively faint

(7<V<16; majority 12<V)

SNR>100 needed for characterization

<u>facts:</u> high-res, SNR=100 with 2.5m-tel.

V=9 Texp= 20min

V=10 Texp= 45min

V=11 Texp > 90min

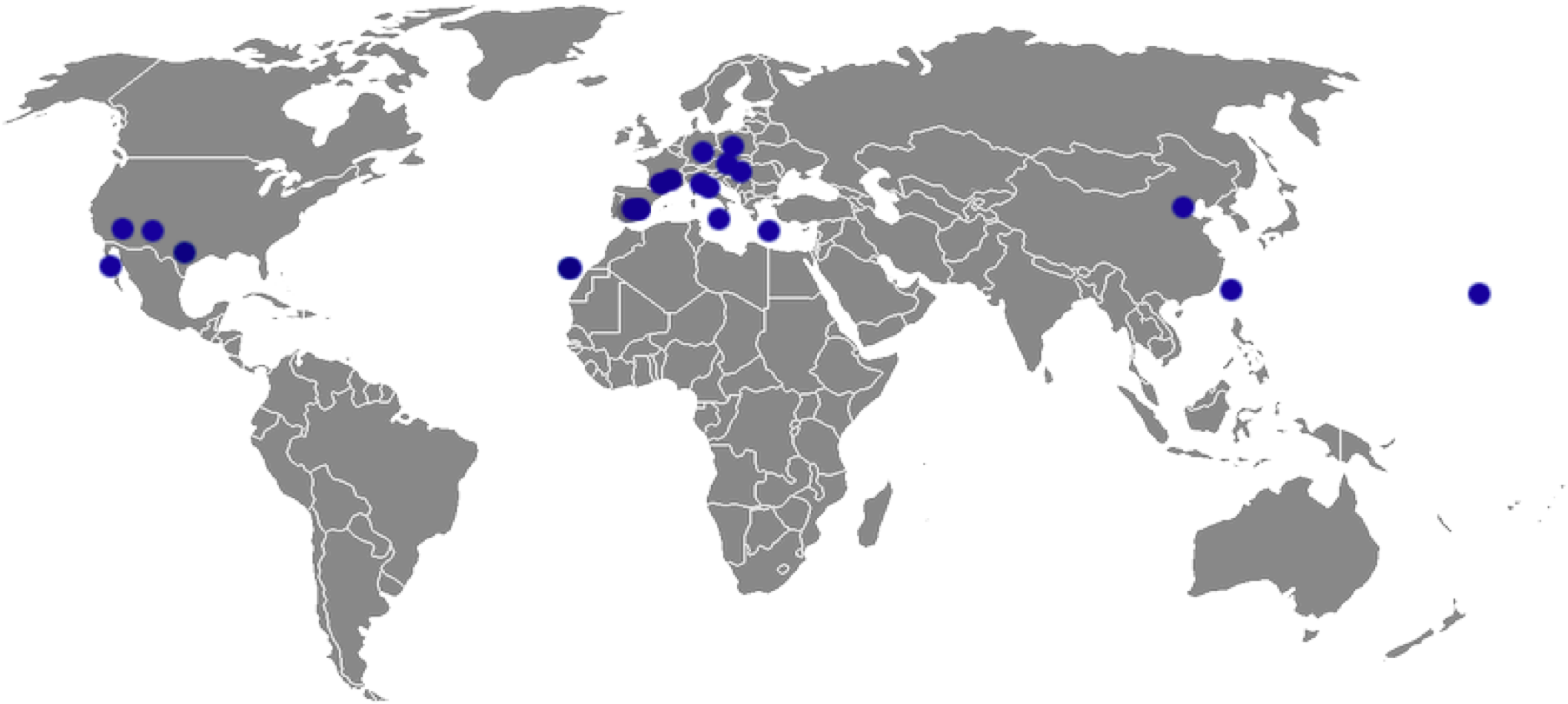
not many high-res spectrographs available at large telescopes

↓

only characterization of bright targets (V<11) feasible in a systematic way

observations of faint targets are very time consuming

KASC GROUND-BASED FOLLOW-UP, SO FAR



40 DIFFERENT INSTRUMENTS AT 35 TELESCOPES
ON 23 OBSERVATORIES IN 12 COUNTRIES
>1000 OBSERVING NIGHTS

SPECTROSCOPY, PHOTOMETRY AND INTERFEROMETRY high-res mid-res low-res

List of instruments

Below you will find lists of scientific instruments used to gather the ground based observations.
If an instrument (or instrument configuration) does not appear in the lists, please contact Rasmus Handberg.

Spectroscopy

Identifier	Name	Telescope size (m)	Resolution	Wavelength range (Å)
ALFOSC_SPEC	ALFOSC@NOT (low-res spectra) Nordic Optical Telescope, Roque de los Muchachos, La Palma, Spain.	2.5	600	3300 – 6200
ARCES	ARCES@ARC (mid-res spectra) 3.5m ARC telescope, Apache Point Observatory, New Mexico, USA.	3.5	33000	3200 – 10000
BCSPM	Boller & Chivens Spectrograph@2.12m OAN-SPM 2.12m Telescope, Observatorio Astronómico Nacional, San Pedro Mártir, Mexico.	2.12	2000	4000 – 5200
BFOSC_SPEC	BFOSC@Casini (low-res spectra) 1.51m G.D. Cassini Telescope, Osservatorio Astronomico di Bologna, Loiano, Italy.	1.51	5000	3300 – 11000
BOK	Boller & Chivens Spectrograph@BOK 90" BOK Telescope, Steward Observatory, Kitt Peak, Arizona, USA.	2.3	550	3620 – 6900
CS23	CS23@2.7m McDonald Harlan J. Smith Telescope, McDonald Observatory, Texas, USA.	2.7	60000	3960 – 9200
ESPADONS	ESPaDOnS@CHFT (high-res spectra) Canada-France-Hawaii Telescope, Mauna Kea, Hawaii, USA.	3.6	81000	3700 – 1050
FIES_HIGH	FIES@NOT (high-res spectra) Nordic Optical Telescope, Roque de los Muchachos, La Palma, Spain.	2.5	67000	3700 – 7300
FIES_LOW	FIES@NOT (low-res spectra) Nordic Optical Telescope, Roque de los Muchachos, La Palma, Spain.	2.5	25000	3700 – 7300
FIES_MID	FIES@NOT (mid-res spectra) Nordic Optical Telescope, Roque de los Muchachos, La Palma, Spain.	2.5	46000	3700 – 7300
FRESCO	FRESCO@91cm Catania 91cm telescope, Catania Astrophysical Observatory, Sicily, Italy.	0.91	21000	3800 – 8000
HERMES	HERMES@Mercator (high-res spectra) Mercator Telescope, Roque de los Muchachos, La Palma, Spain.	1.2	90000	3770 – 9000
HES	HES@Shane Shane 3m Telescope, Lick Observatory, California, USA.	3	60000	3800 – 9000
HIRES	HIRES@Keck (high-res spectra) Keck Telescope, W. M. Keck Observatory, Mauna Kea, Hawaii, USA.	10	45000	4250 – 8750
HRS_HIGH	HRS@HET (high-res spectra) Hobby-Eberly Telescope, McDonald Observatory, Texas, USA.	9.2	60000	4200 – 11000
HRS_MID	HRS@HET (mid-res spectra) Hobby-Eberly Telescope, McDonald Observatory, Texas, USA.	9.2	30000	4120 – 7850
IDS	IDS@INT Isaac Newton Telescope, Roque de los Muchachos, La Palma, Spain.	2.5	1400	3020 – 6650
ISIS_LOW	ISIS@WHT (low-res spectra) William Herschel telescope, Roque de los Muchachos, La Palma, Spain.	4.2	1600	3100 – 5300
ISIS_MID	ISIS@WHT (mid-res spectra) William Herschel telescope, Roque de los Muchachos, La Palma, Spain.	4.2	20000	3100 – 5300
LAMOST	Spectrograph@LAMOST (R=1000 or R=2000) Large Sky Area Multi-Object Fibre Spectroscopic Telescope, Xinglong Observatory, China.	4		3540 – 5900
LAMOST1	Spectrograph@LAMOST (R=1000) Large Sky Area Multi-Object Fibre Spectroscopic Telescope, Xinglong Observatory, China.	4	1000	3540 – 5900
LAMOST18	Spectrograph@LAMOST (R=1800) Large Sky Area Multi-Object Fibre Spectroscopic Telescope, Xinglong Observatory, China.	4	1800	3540 – 5900
LAMOST2	Spectrograph@LAMOST (R=2000) Large Sky Area Multi-Object Fibre Spectroscopic Telescope, Xinglong Observatory, China.	4	2000	3540 – 5900
NARVAL_SPEC	NARVAL@TBL (high-res spectra) Télescope Bernard Lyot, Observatoire Pic du Midi, France.	2	81000	3700 – 10000
RCSPEC	RC-spec@Mayall Mayall 4m Telescope, Kitt Peak National Observatory, Arizona, USA.	4	8000	
REOSC	REOSC@Nicolas Copernicus (mid-res spectra) 1.82m Nicolas Copernicus Telescope, Osservatorio Astrofisico di Asiago, Asiago, Italy.	1.82	20000	3700 – 7300
SARG	SARG@TNG (high-res spectra) Telescopio Nazionale Galileo, Roque de los Muchachos, La Palma, Spain.	3.58	57000	3700 – 10000
SES	SES@McDonald (high-res spectra) Otto Struve Telescope, McDonald Observatory, Texas, USA.	2.1	60000	4440 – 5030
SOPHIE	SOPHIE@1.92m OHP 1.92m Telescope, Observatoire de Haute Provence, France.	1.92	46000	3872 – 6943
specWG11	Unspecified WG11 Spectroscopy Low-resolution spectrospopy obtained with Bok (June-September 2008, EMG), INT (16 August 2008, CRL/MV; 5-10 June 2009, ROr, RO, TAO), NOT (20-24 September 2008, ROr; 14 August 2009, JHT, TL; 7 September 2009, JHT), WHT ISIS_low (11-12 April 2009, CA, RO; 14-16 July 2009, CA, TAO) (published in Østensen et al., 2010, MNRAS 409, 1470). Low resolution spectroscopy obtained with NOT (20-21 September 2008, JHT, AS; 22-26 September 2008, ROr; 7 September 2009, JHT, JL; 9 June 2010, JHT, AT; 27 September 2010, JHT, SFr, PAW) or WHT (11-12 April 2009, CA, RO; 14-16 July 2009, CA, TAO; 2-6 July 2010, CA, RO) (published in Østensen et al., 2011, MNRAS 414, 2860)..			
TLS_HIGH	Coudé echelle spectrograph@2.0m TLS (high-res spectra) Alfred Jensch Teleskop, Karl Schwarzschild Observatory, Tautenburg, Germany.	2	67000	4700 – 7400
TLS_MID	Coudé echelle spectrograph@2.0m TLS (mid-res spectra) Alfred Jensch Teleskop, Karl Schwarzschild Observatory, Tautenburg, Germany.	2	35000	4700 – 7400
TWIN	TWIN@3.5m CAHA (low-res spectra) 3.5m Telescope, Calar Alto Astronomical Observatory, Spain.	3.5	10000	3200 – 11000
UVES	UVES@VLT Very Large Telescope UT2, European Southern Observatory Paranal, Chile.	8.2	47000	4200 – 11000

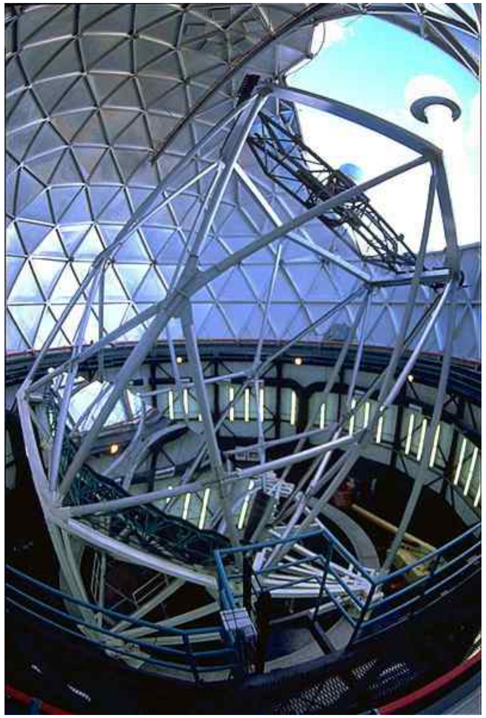
Photometry

Identifier	Name	Telescope size (m)	Filters
ALFOSC_PHOT	ALFOSC@NOT (Photometry) Nordic Optical Telescope, Roque de los Muchachos, La Palma, Spain.	2.5	
BFOSC_PHOT	BFOSC@Casini (Photometry)	1.51	Johnson

HERMES@Mercator

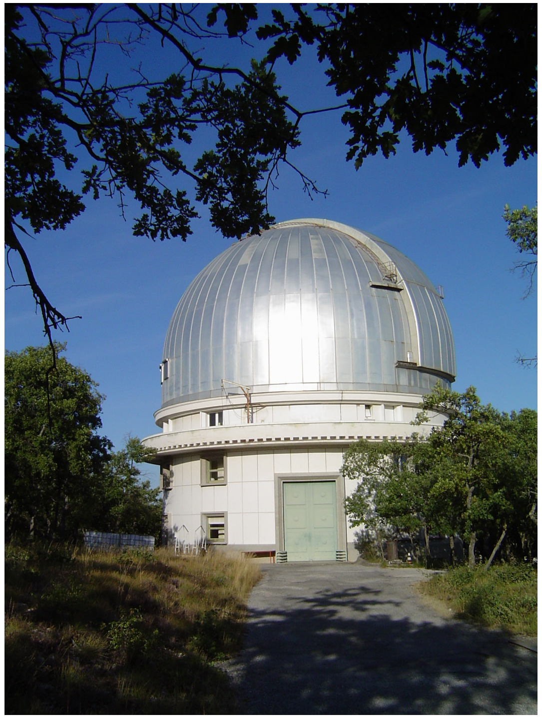
Guoshoujing (a.k.a. LAMOST)

(see poster Peter De Cat)



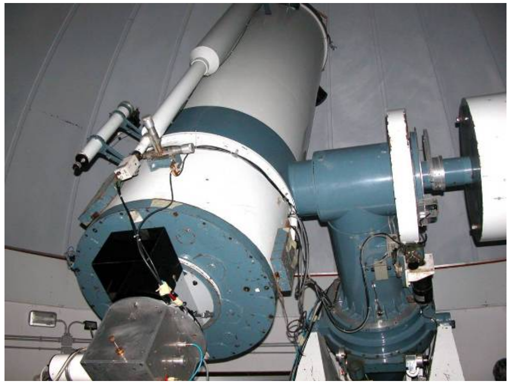
HRS@HET

2.7m & 2.1m McDonald



SOPHIE@1.9m OHP

SARG@TNG



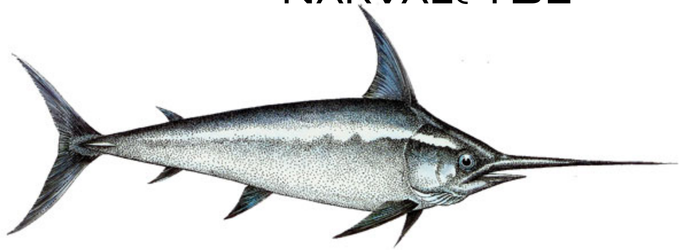
FRESCO@0.91M CATANIA

ISIS@WHT

FIES@NOT

B&C@2.3M BOK

NARVAL@TBL



ESPADONS@CFHT

Soon to come...

SONG network of 1m robotic telescopes

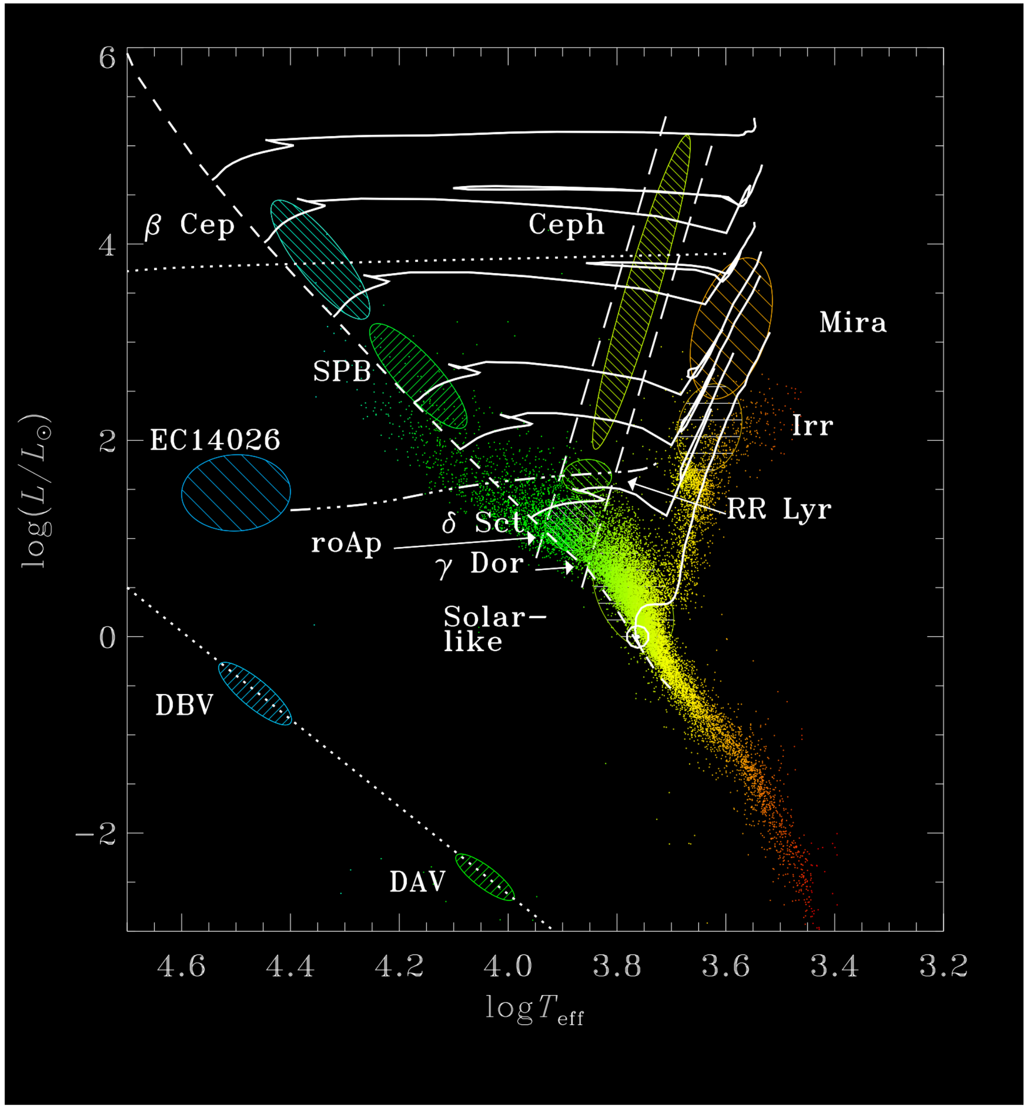
Proto-type SONG-OT (Tenerife)

High-res spectrograph (R~110000)
Dual-colour lucky imaging cameras

See poster by Andrea Triviño Hage!

IV. Motivation of the Spring School

IV. Motivation of the Spring School



KASC WG3
Main Sequence
Pulsators

KASC WG3
Main Sequence Pulsators

HUGE OBSERVATIONAL EFFORT FOR SYSTEMATIC CHARACTERISATION OF B-A-F TYPE STARS (β Cep, SPB, δ Sct, γ Dor, ...)

SPECTRA FOR 1014 OUT OF 3119 CLASSIFIED STARS! =33%

Lack of manpower with expertise to perform spectral analysis

↓

SPECTROSCOPIC SCHOOL

low-resolution spectrographs (R<5000)

BFOSC (1.5m Cassini, Loiano, I)
Boller & Chivens spectrograph (2m SPM, MX)
IDS (2.5m INT, ORM, E)
multi-object spectrograph (4m LAMOST, Xinglong, CN)

mid-resolution spectrographs (5000<R<40000)

ARCES (3.5m, APO, USA)
FIES (2.5m NOT, ORM, E)
FRESCO (0.91m Catania, I)
HRS (9.2m HET, McDonald, USA)
TWIN (3.5m, CaHa, E)

high-resolution spectrographs (R>40000)

CS23 (2.7m, McDonald, USA)
ESPADONS (3.6m CHFT, Mauna Kea, USA)
FIES (2.5m NOT, ORM, E)
HERMES (1.2m Mercator, ORM, E)
HES (3m Shane, Lick, USA)
HRS (9.2m HET, McDonald, USA)
NARVAL (2m TBL, Pic du Midi, F)
SARG (3.6m TNG, ORM, E)
SES (2.1m, McDonald, USA)
SOPHIE (1.9m, OHP, F)
spectrograph (2m, TLS, D)

B-type stars (#48)

spectra for 45 stars (94%)
low res: #13 ; mid-res: #15 ; high-res: #39

Note: bias towards V<11 stars
as faint targets are time-consuming

access to large telescopes with high-res
spectrographs needed!

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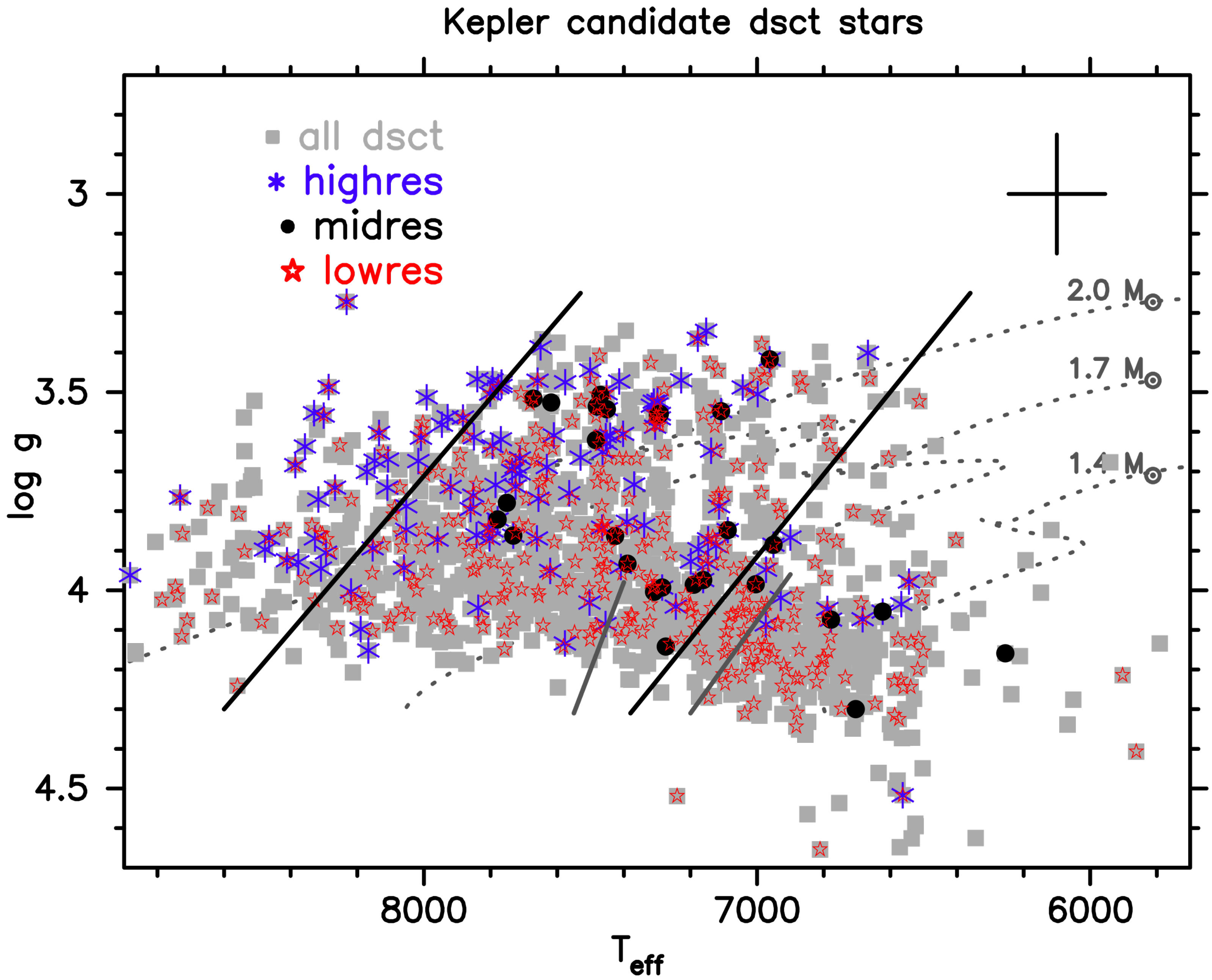
spectra for 45 stars (94%)
low res: #13 ; mid-res: #15 ; high-res: #39

δ Sct stars (#1607)

spectra for 513 stars (32%)
low res: #389 ; mid-res: #37 ; high-res: #151



Kepler candidate dsct stars
all dsct
highres
midres
lowres
2.0 M☉
1.7 M☉
1.4 M☉
3
3.5
4
4.5
log g
8000
7000
6000
T_{eff}

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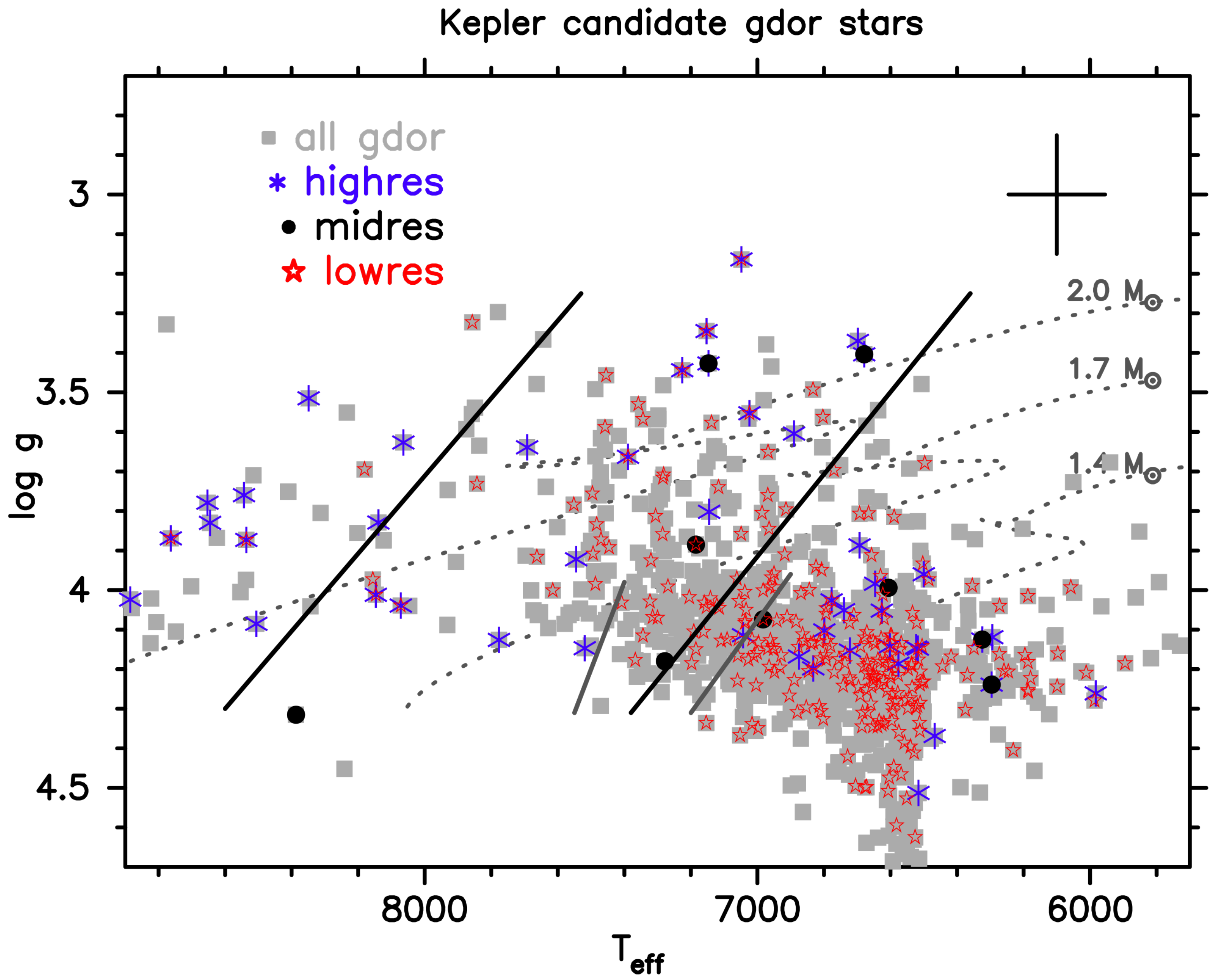
low res: #389 ; mid-res: #37 ; high-res: #151

γDor stars (#1205)

spectra for 331 stars (27%)
low res: #281 ; mid-res: #12 ; high-res: #70


Kepler candidate gdor stars
all gdor
highres
midres
lowres
2.0 M⊙
1.7 M⊙
1.4 M⊙
3
3.5
4
4.5
log g
8000
7000
6000
T_eff

B-type stars (#48)

spectra for 45 stars (94%)
low res: #13 ; mid-res: #15 ; high-res: #39

δ Sct stars (#1607)

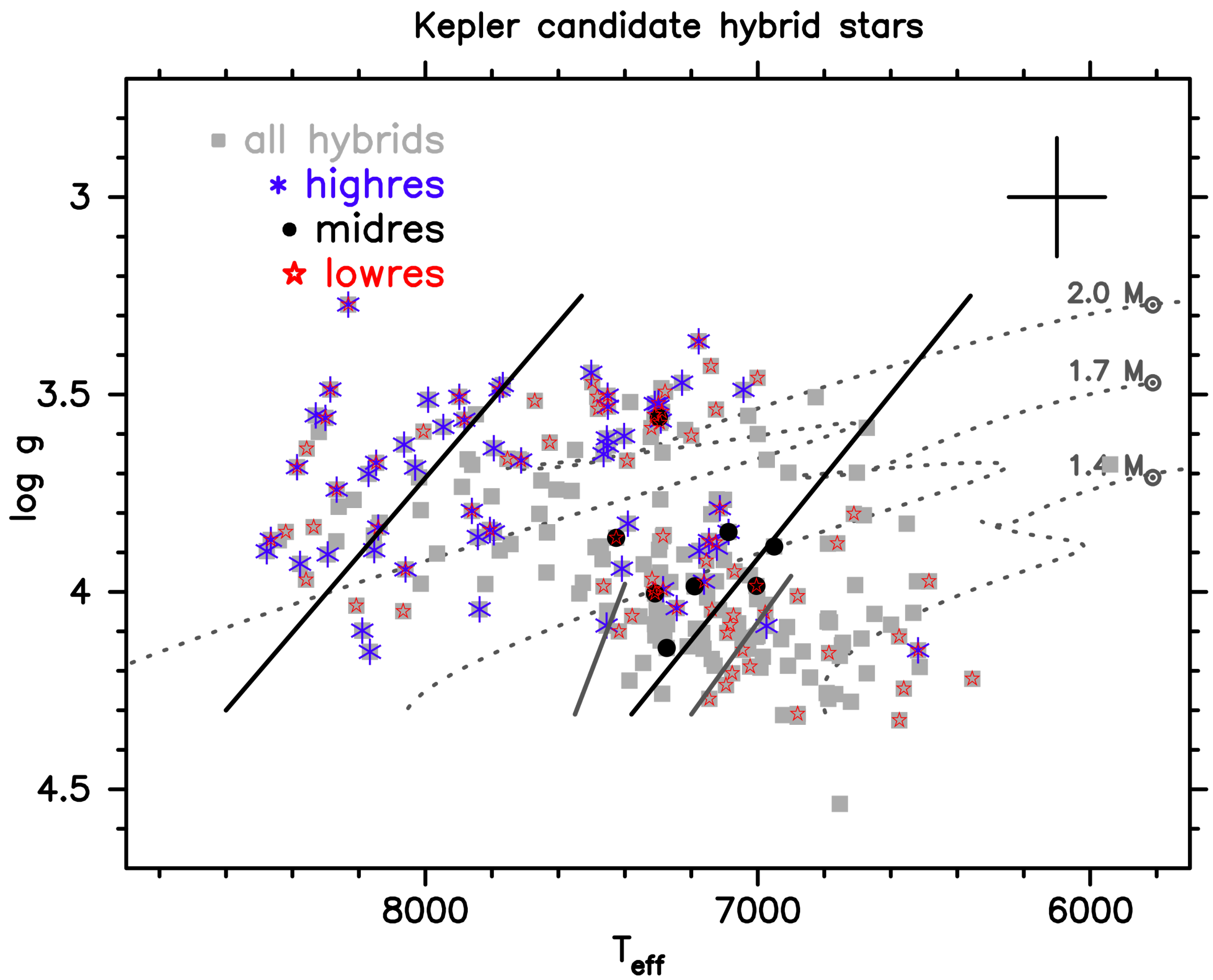
spectra for 513 stars (32%)
low res: #389 ; mid-res: #37 ; high-res: #151

γDor stars (#1205)

spectra for 331 stars (27%)
low res: #281 ; mid-res: #12 ; high-res: #70

hybrid δ Sct /γDor stars (#259)

spectra for 125 stars (48%)
low res: #84 ; mid-res: #10 ; high-res: #67


Kepler candidate hybrid stars
all hybrids
highres
midres
lowres
2.0 M⊙
1.7 M⊙
1.4 M⊙
3
3.5
4
4.5
log g
8000
7000
6000
T_eff

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spectra are a powerful tool to derive atmospheric parameters

high-resolution spectra are in particular very useful, but we need high-res spectrographs at larger telescopes (>4m) to observe faint stars

we need manpower to help analysing spectra for >1000 B-A-F Kepler asteroseismic targets!!!

Enjoy the spectroscopic spring school!