

Random encounters in asteroseismology

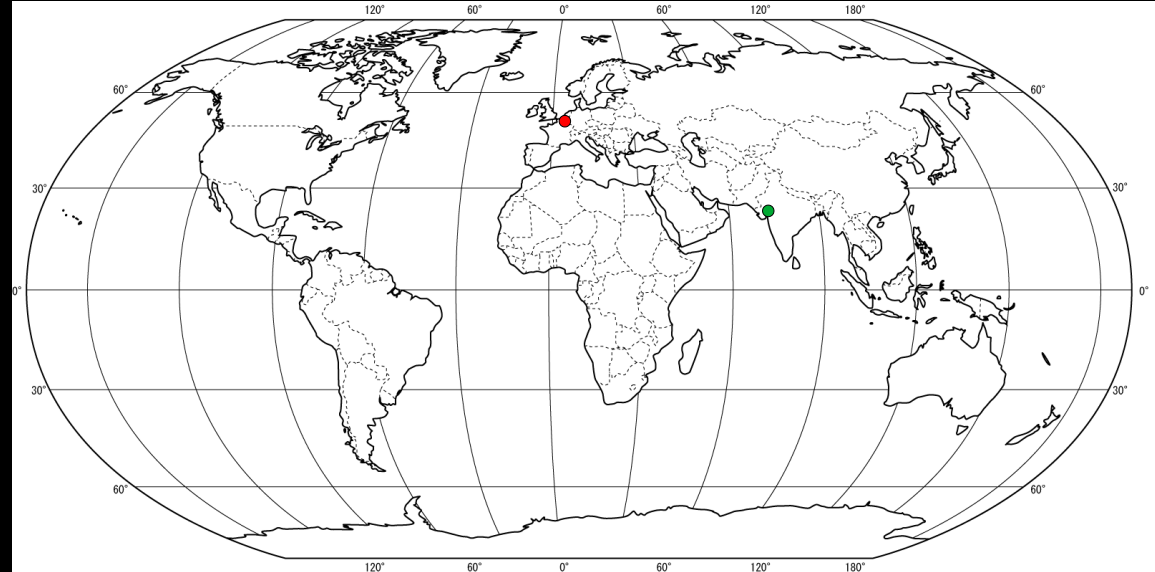
Their impact on a scientific career

Peter De Cat

Royal Observatory of Belgium (Brussels, Belgium)

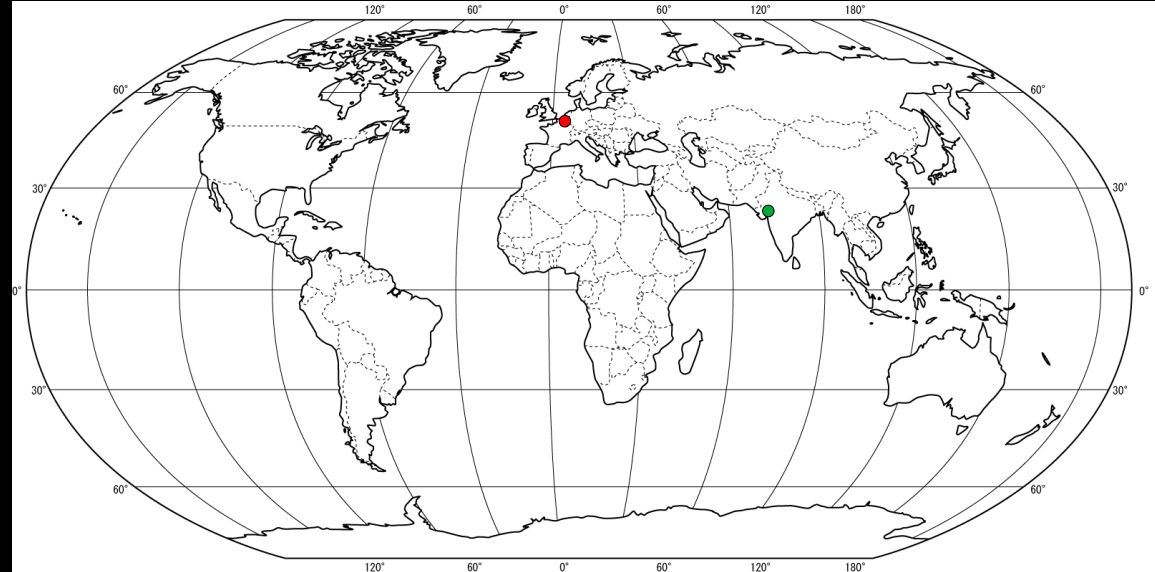
Outline

1. Scientific background
2. Connection Belgium – China
3. Connection Belgium – India
4. Conclusions and future prospects



Outline

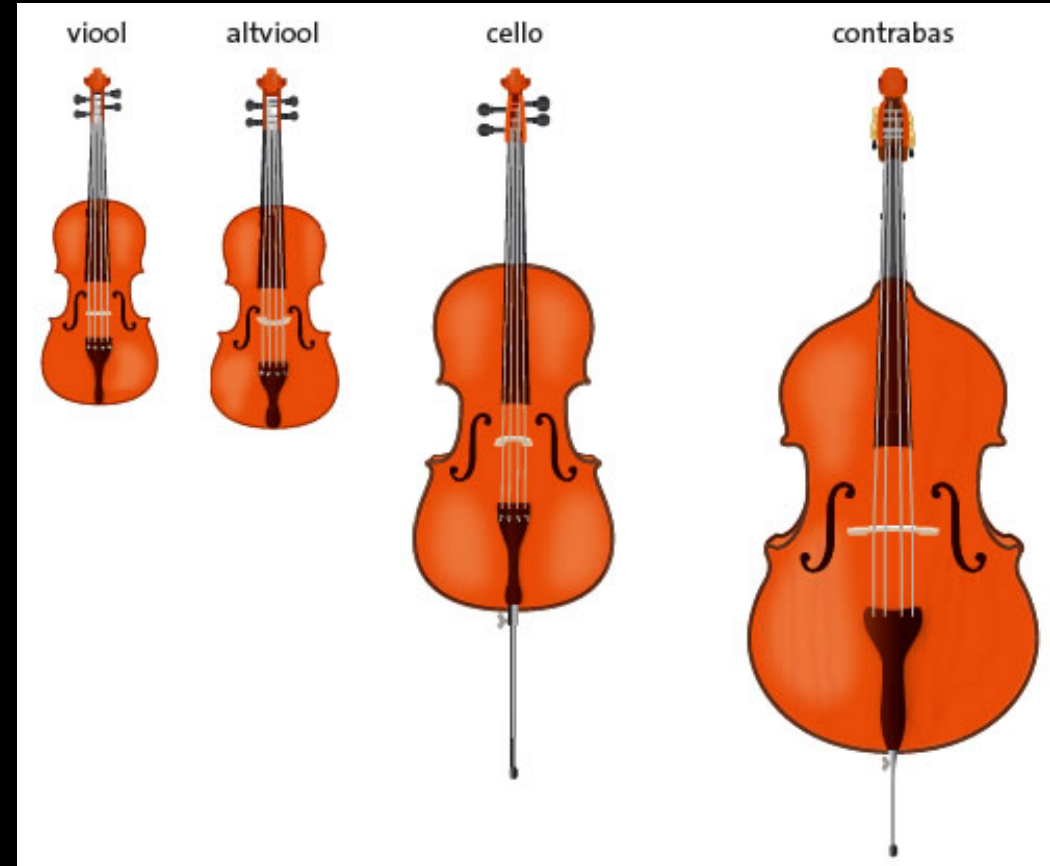
1. Scientific background
2. Connection Belgium – China
3. Connection Belgium – India
4. Conclusions and future prospects



Musical instruments



shape and material determines
the sound of the instrument

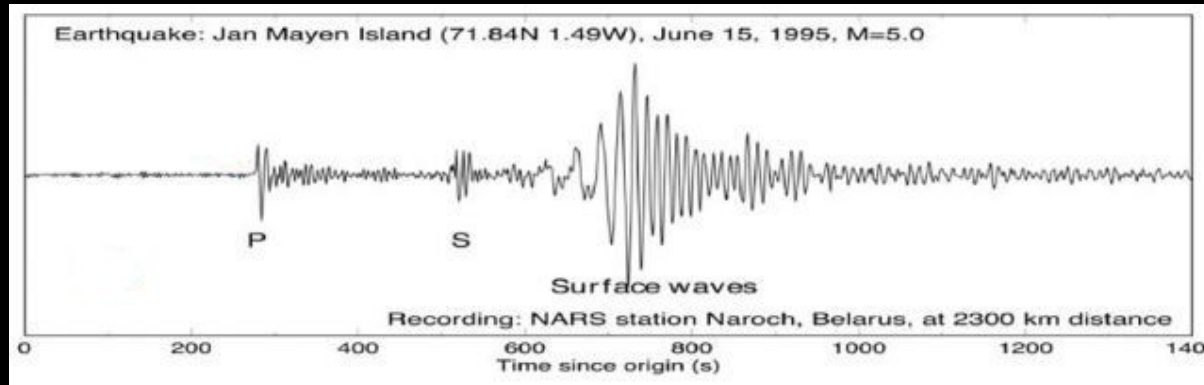


Seismology

- **seismo:** vibration, pulsation, oscillation,...
- **logy:** study of,...



use earthquakes to investigate
the interior of the Earth



Asteroseismology

- **aster:** star
- **seismo:** vibration, pulsation, oscillation,...
- **logy:** study of,...

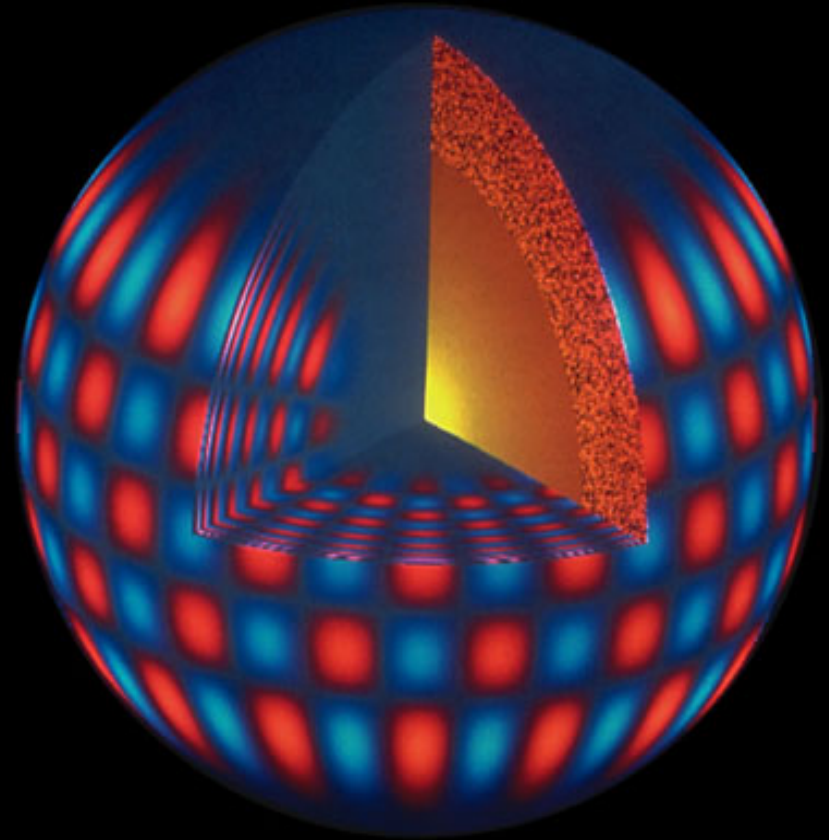


to investigate stars
by studying their pulsations and their interior!

Sun
 δ Scuti star HD31901

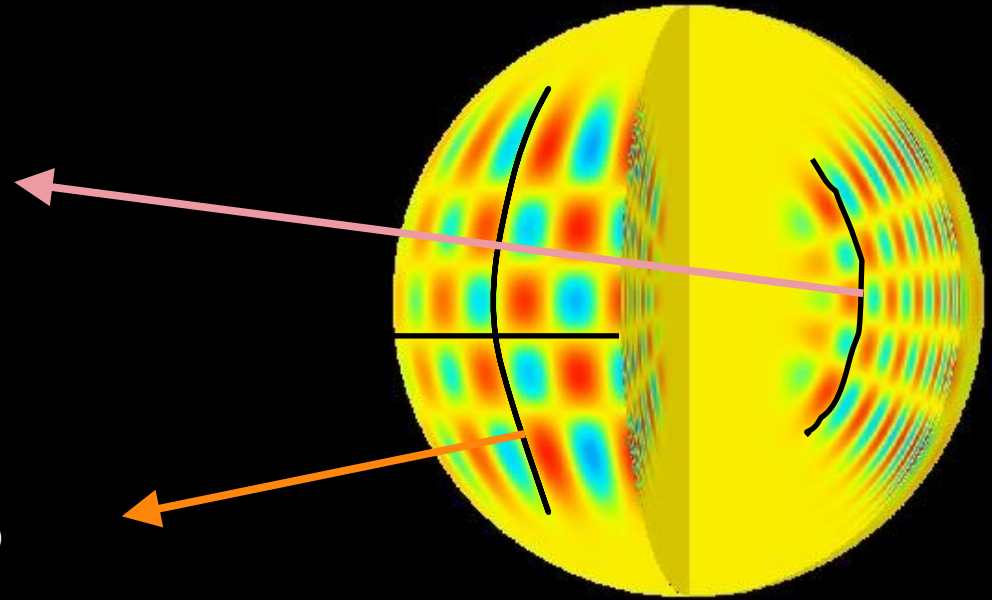
Asteroseismology

- **aster:** star
 - **seismo:** vibration, pulsation, oscillation,...
 - **logy:** study of,...
- Stellar parameters
 - M , age, X , Z ,...
 - Convection
 - size convective layers
 - convective overshoot
 - Rotation
 - surface versus core
 - rigid versus differential
 - Internal mixing
 - Diffusion
 - Internal structure
 - layers and their composition
 - Magnetic fields



Pulsations

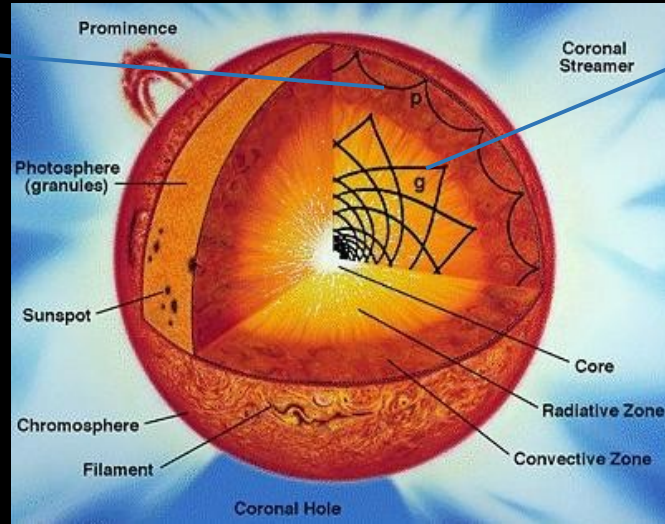
- σ = frequency
- n = number of nodesurfaces between center and surface
- ℓ = total number of nodelines on surface
 - $\ell = 0$: radial mode
 - $\ell > 0$: non-radial mode
- $|m|$ = number of nodelines perpendicular to equator on surface
 - $|m| \leq \ell$
 - $m > 0$: prograde mode
 - $m < 0$: retrograde mode



1. Frequency analysis
2. Mode identification
3. Theoretical modelling

Pressure modes (p-modes)

- Restoring force: pressure
- Short periods
- Cavity near surface
- Amplitude largest component in radial direction



Gravity modes (g-modes)

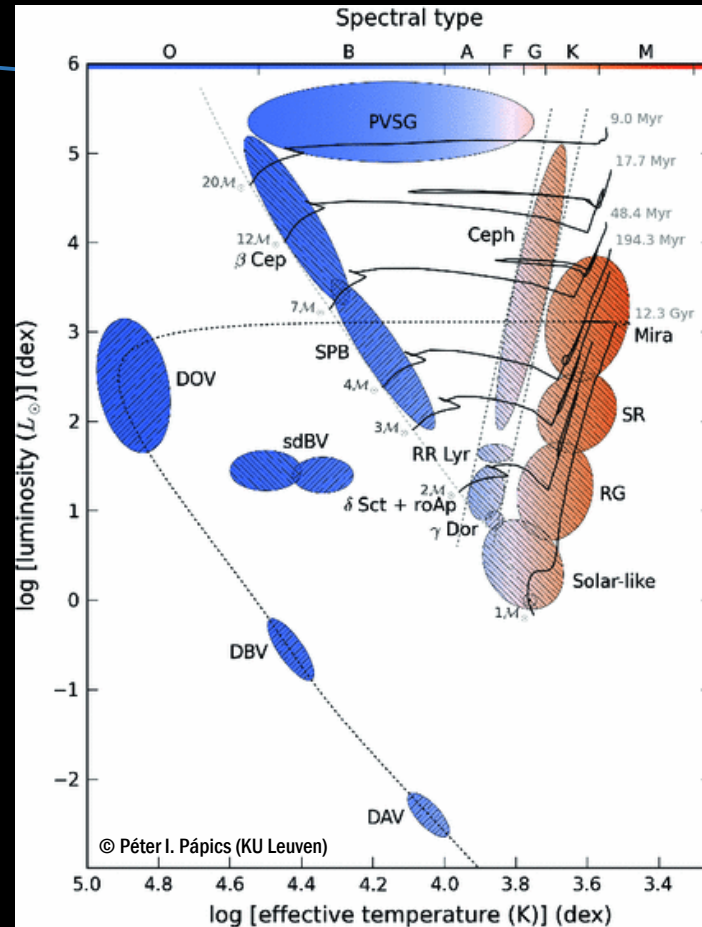
- Restoring force: buoyancy
- Long periods
- Cavity in deep interior
- Amplitude largest component in tangential direction

Pressure modes (p-modes)

- Restoring force: pressure
- Short periods
- Cavity near surface
- Amplitude largest component in radial direction
- \\\

Gravity modes (g-modes)

- Restoring force: buoyancy
- Long periods
- Cavity in deep interior
- Amplitude largest component in tangential direction
- \\\



Asteroseismology

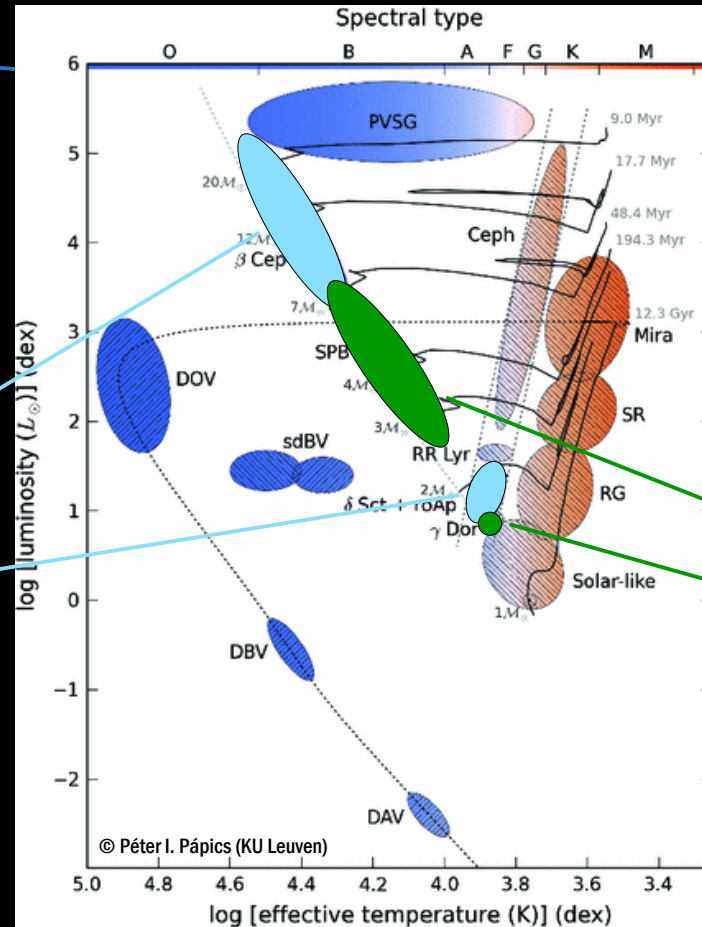
Pressure modes (p-modes)

- Restoring force: pressure
- Short periods
- Cavity near surface
- Amplitude largest component in radial direction
- \\\\\\\

β Cephei stars (β Cep)

δ Scuti stars (δ Sct)

- Periods order of hours
(0.3-10 hours)



Gravity modes (g-modes)

- Restoring force: buoyancy
- Long periods
- Cavity in deep interior
- Amplitude largest component in tangential direction
- \\\\\\\

Slowly pulsating B stars (SPB)

γ Doradus stars (γ Dor)

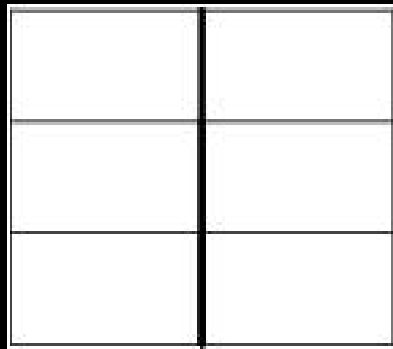
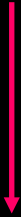
- Periods order of days
(0.3-3 days)

What do we need?

What do we need?

- Star without rotation

$$f_{n,\ell,m} = f_{n,\ell,0}$$



$\ell = 1$

$\ell = 2$

$\ell = 3$

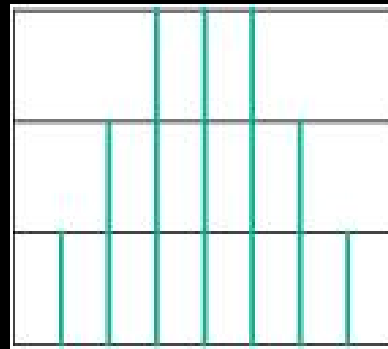
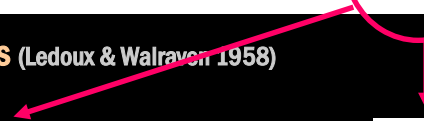
- Star with rotation

$$f_{n,\ell,m} \simeq f_{n,\ell,0} - m (1 - C_{n,\ell}) f_{\Omega} + \theta(f_{\Omega}^2)$$

⇒ **frequency multiplets** (Ledoux & Walraven 1958)

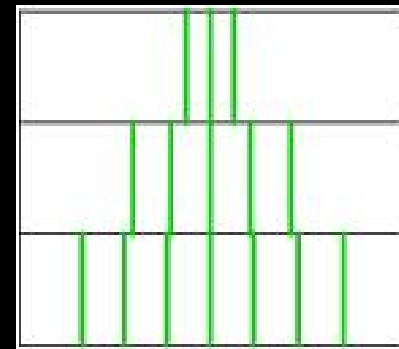
β Cep
 δ Sct

$$C_{n,\ell} \approx 0$$



SPB
 γ Dor

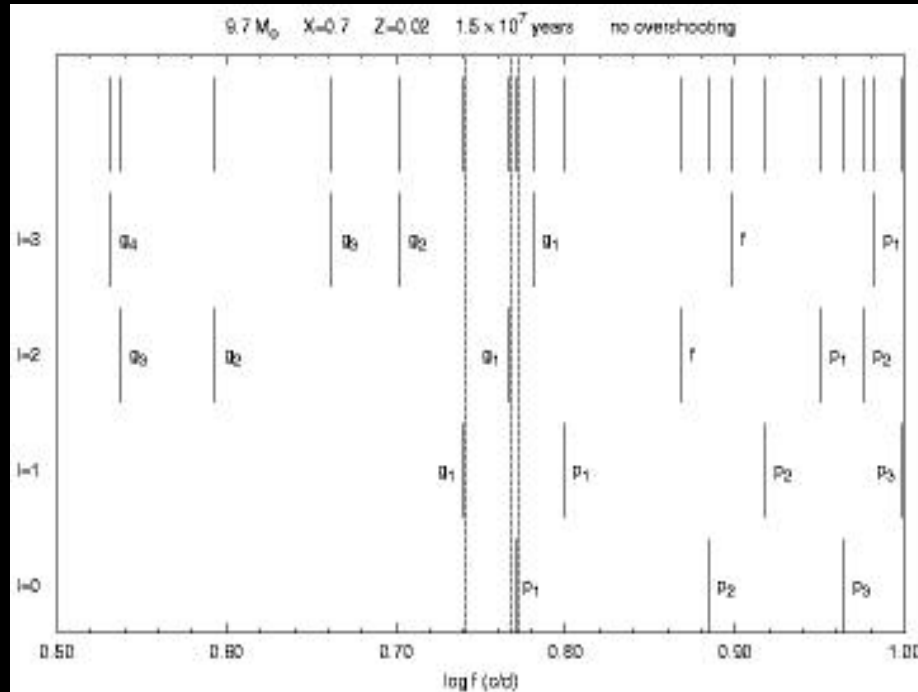
$$C_{n,\ell} \approx \frac{1}{\ell(\ell+1)} + \text{2nd order term}$$



What do we need?

- p-modes β Cep star 16 Lacertae

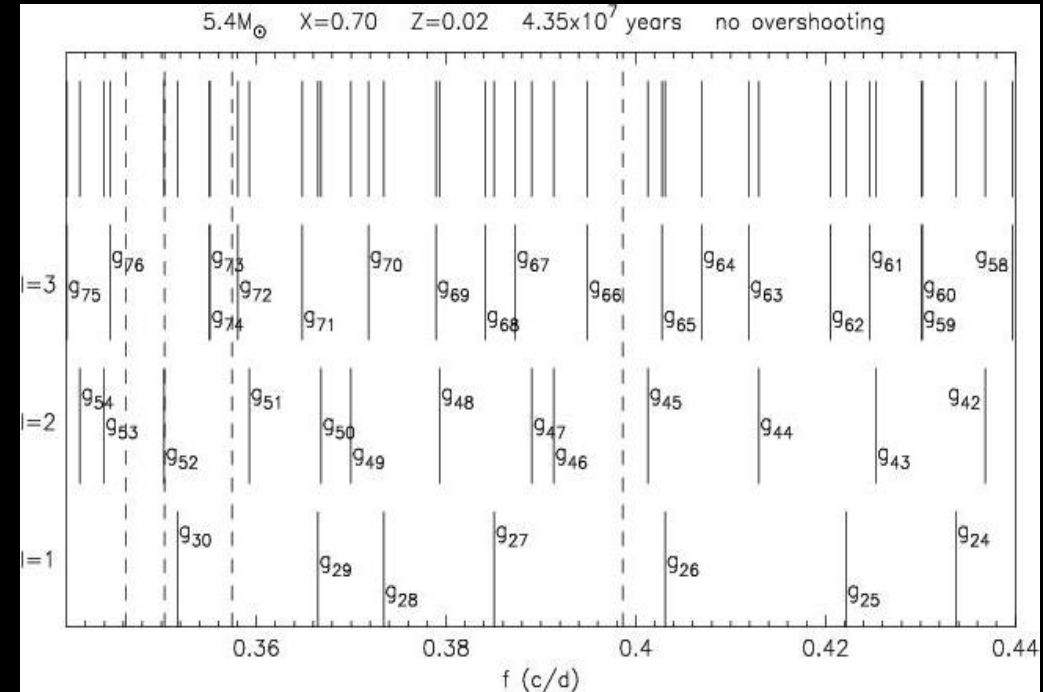
→ Sparse frequency spectrum



7 d^{-1}

- g-modes SPB star α Velorum

→ Dense frequency spectrum

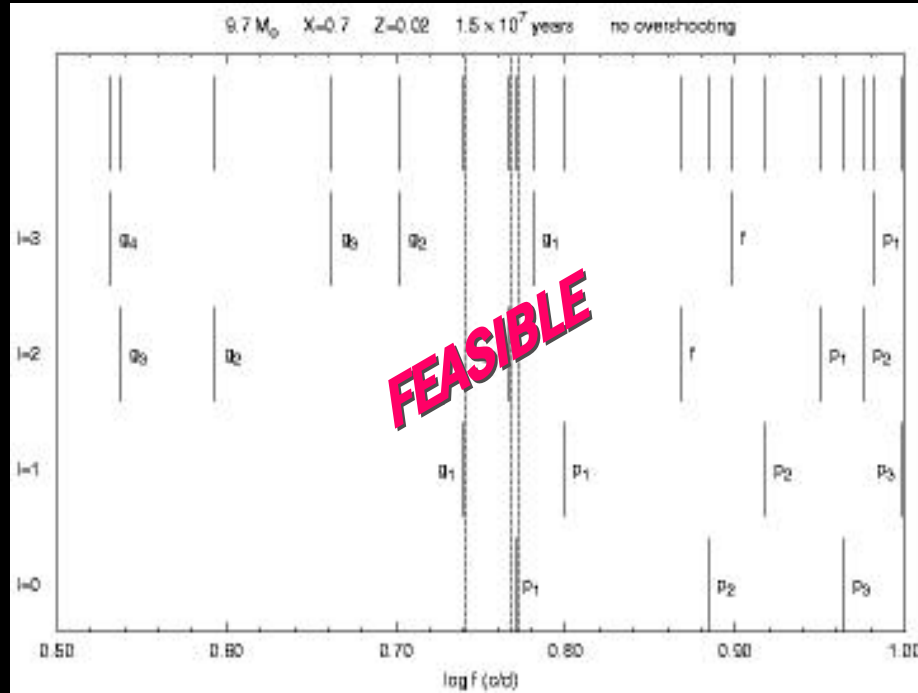


0.1 d^{-1}

What do we need?

- p-modes β Cep star 16 Lacertae

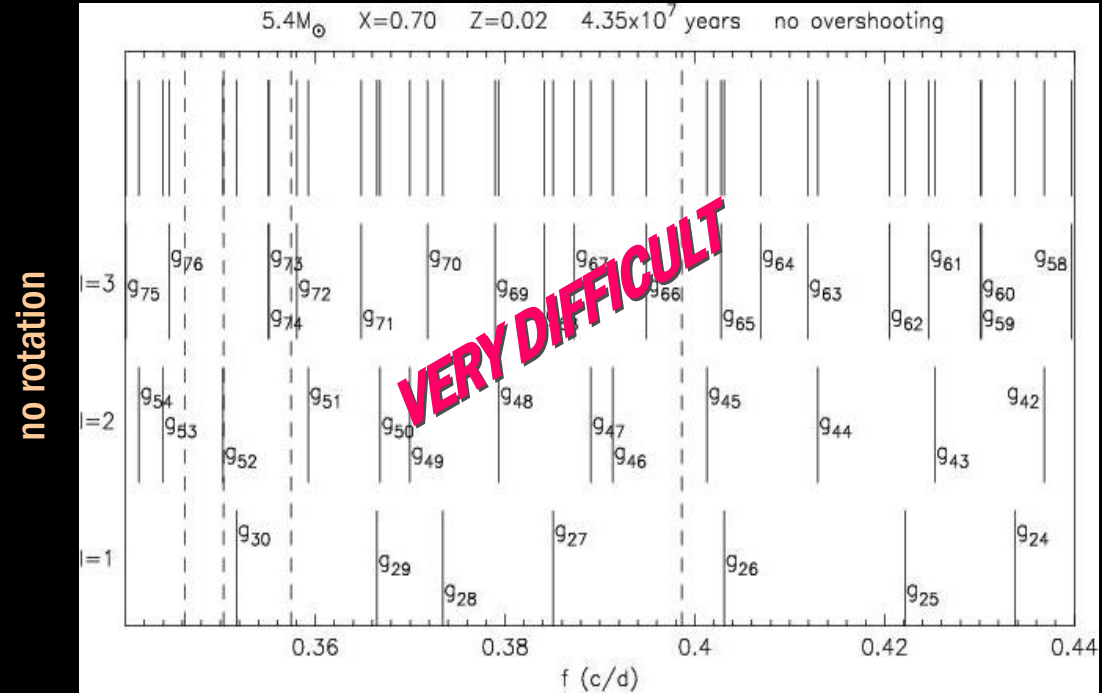
→ Sparse frequency spectrum



7 d^{-1}

- g-modes SPB star α Velorum

→ Dense frequency spectrum



0.1 d^{-1}

What do we need?

- Many observed pulsation frequencies
- Frequency multiplets

Frequency analysis

- Know which pulsation modes cause the observed variations

Mode identification

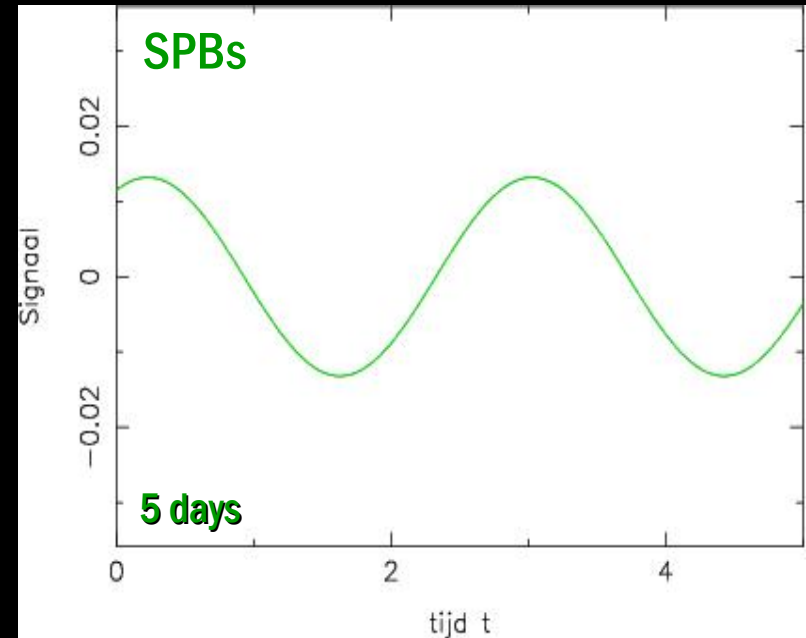
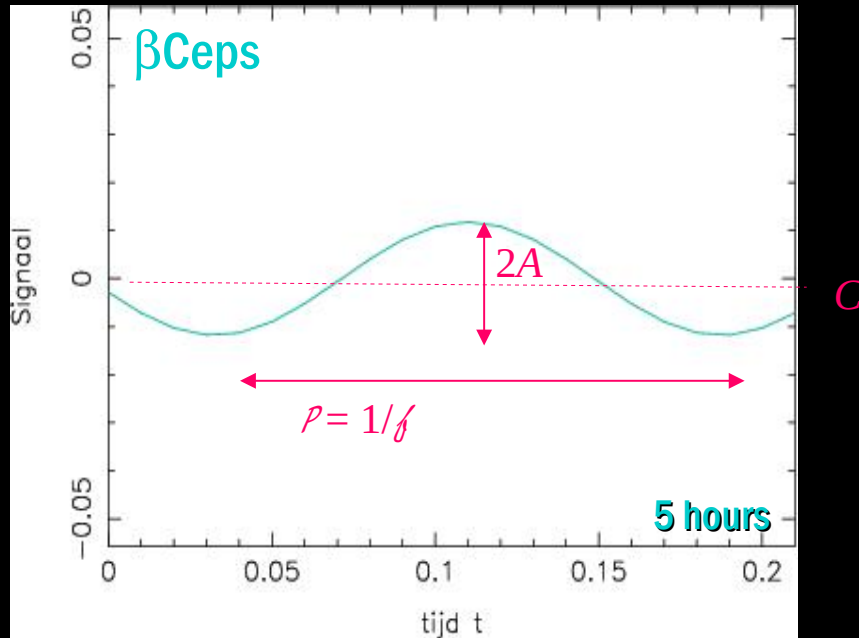
What do we observe?

What do we observe?

- Time base

→ Mono-periodic pulsator

$$\text{signal} = C + A \sin(2\pi f t + \phi)$$

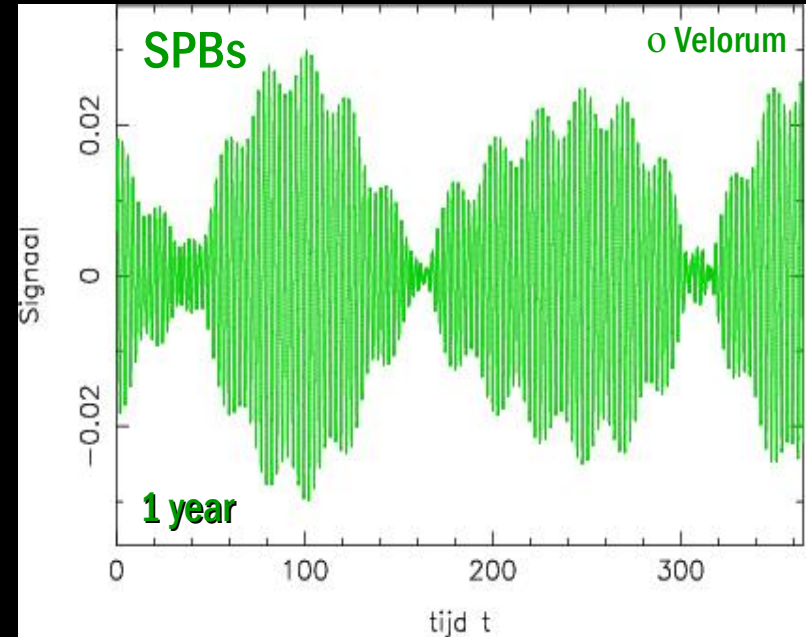
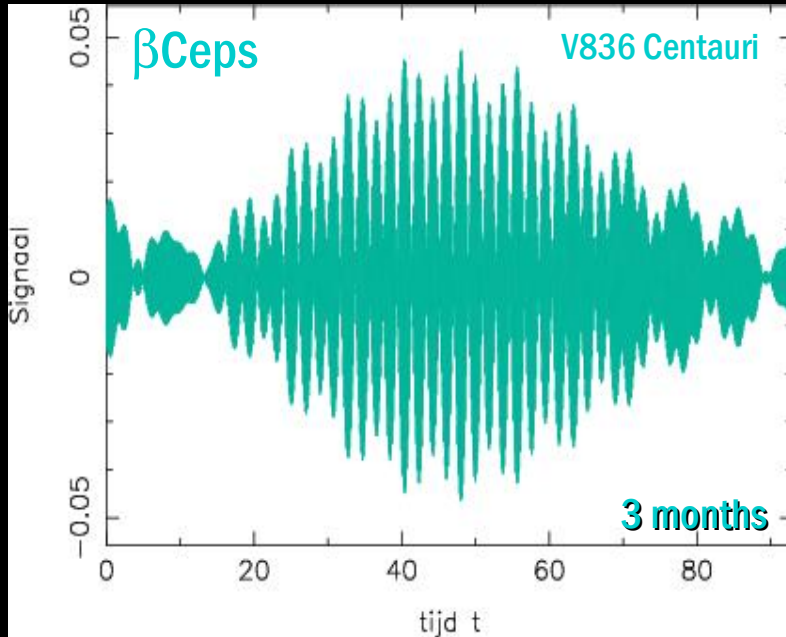


What do we observe?

- Time base

→ Multi-periodic pulsator

$$\text{signal} = C + \sum_i A_i \sin(2\pi f_i t + \phi_i)$$



What do we observe?

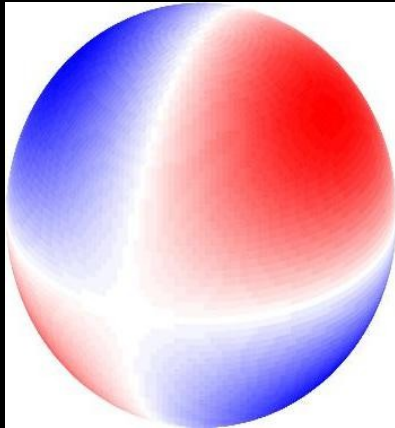
- Instrument

What do we observe?

- Instrument

→ Naked eye

accuracy ~ 0.1 mag



eye (backyard)
~ 5 to 7 mm

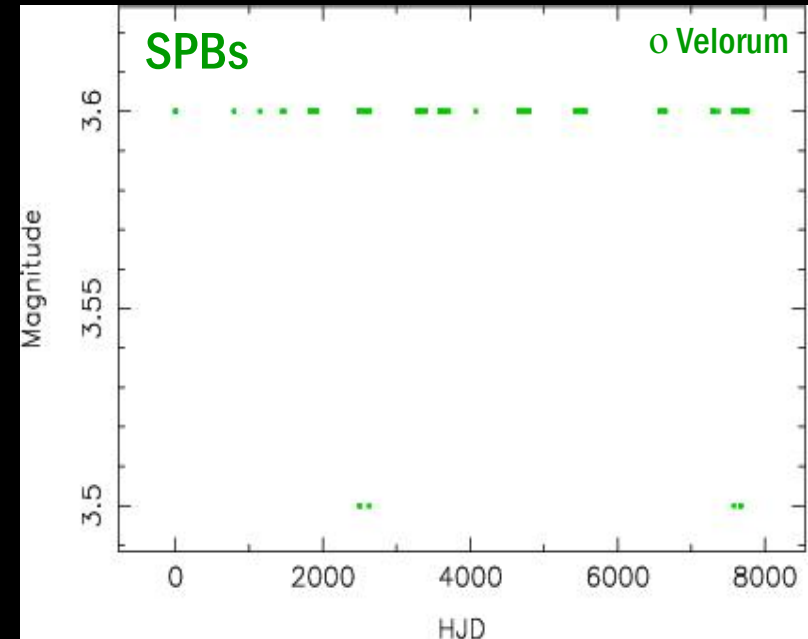
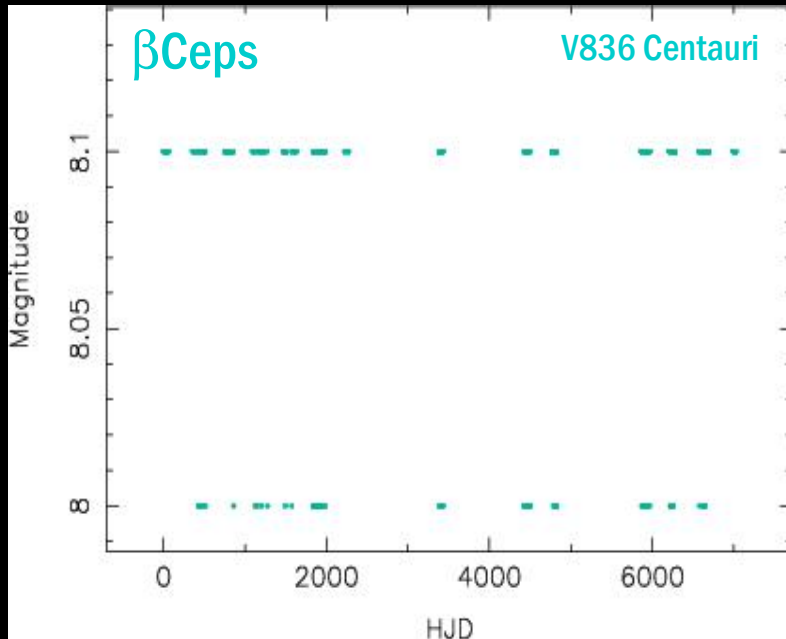
in 1 filter
(individual)

What do we observe?

- Instrument

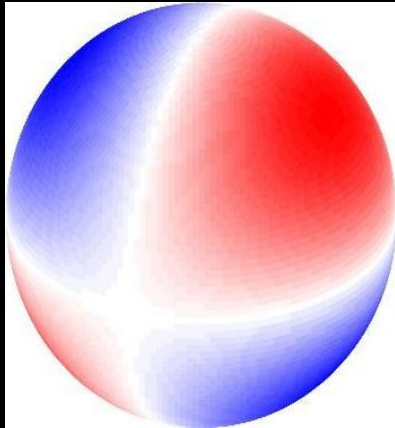
→ Naked eye

accuracy ~ 0.1 mag



What do we observe?

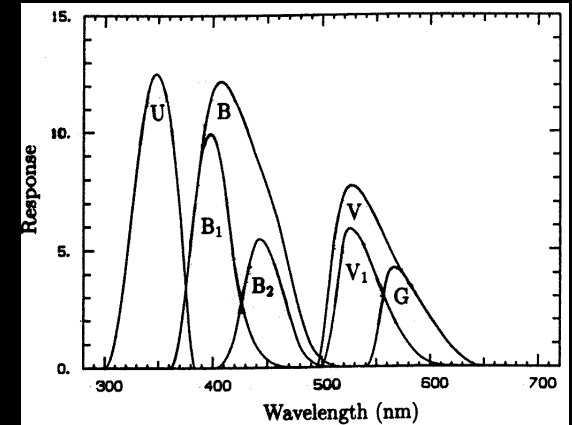
- Instrument
→ Photometer



Mercator telescope (La Palma)
~1.2 m



P7



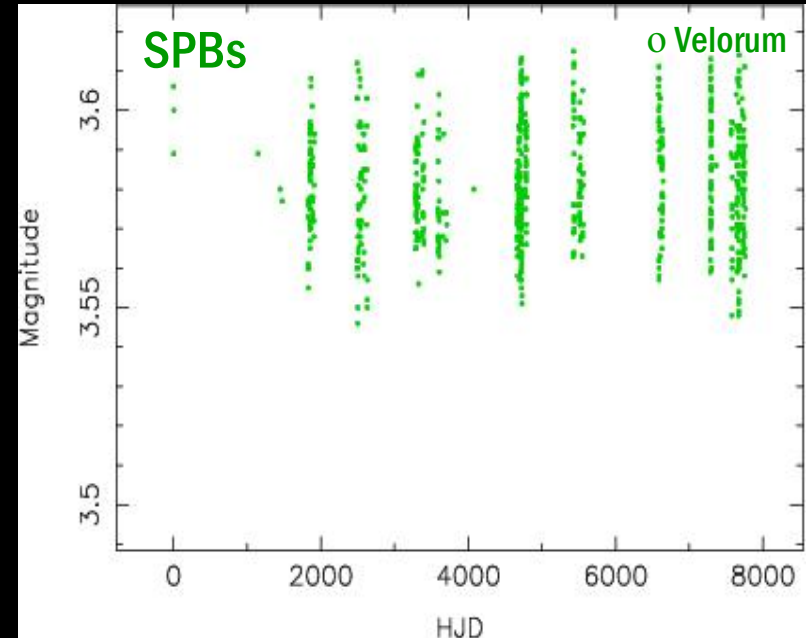
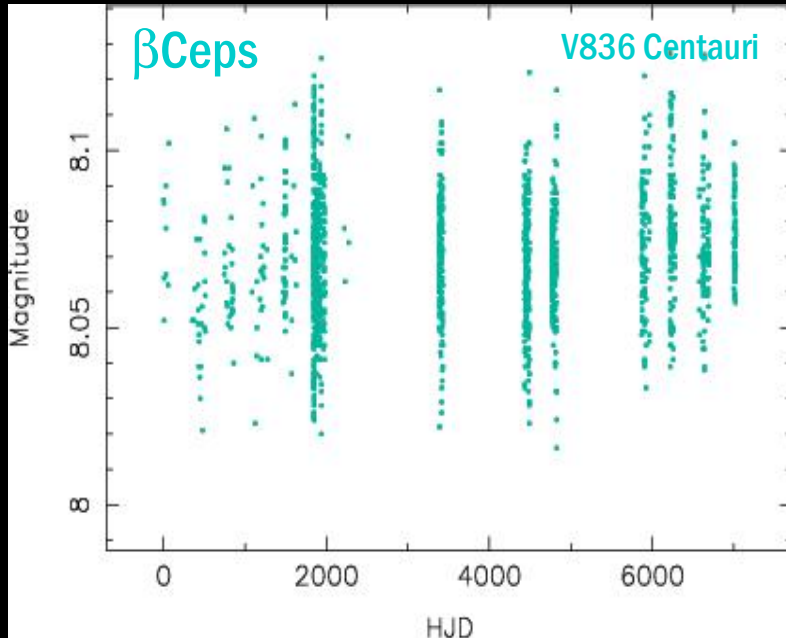
accuracy ~ 0.005 mag

simultaneous in 7 filters
(very stable)

What do we observe?

- Instrument
 - Photometer

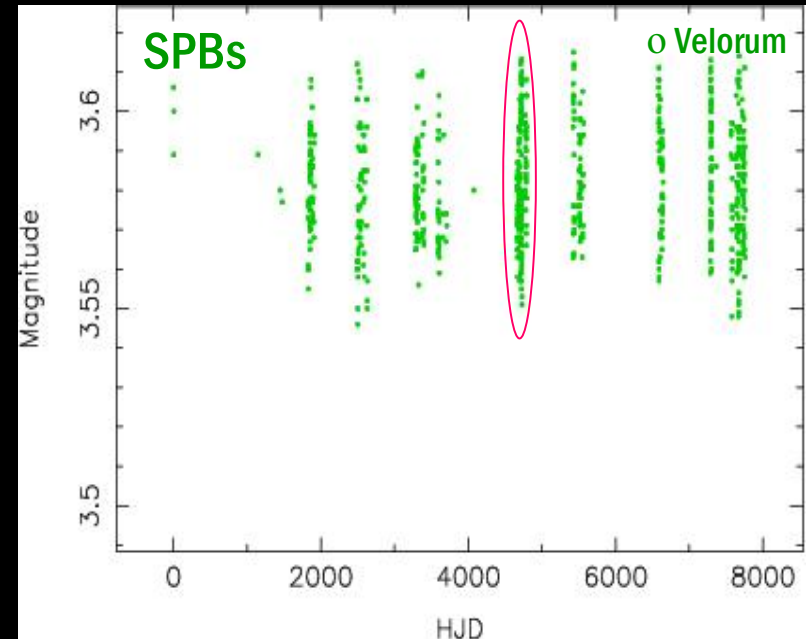
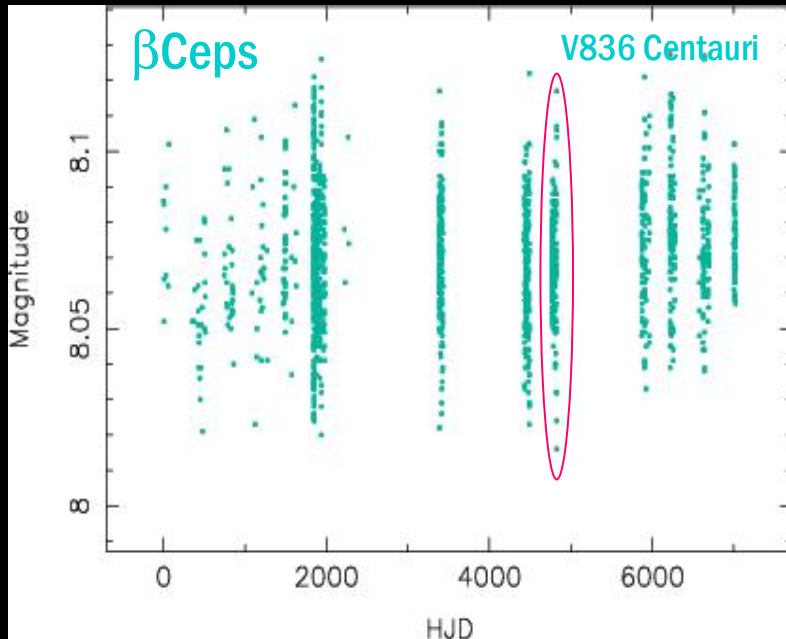
accuracy ~ 0.005 mag



What do we observe?

- Instrument
→ Photometer

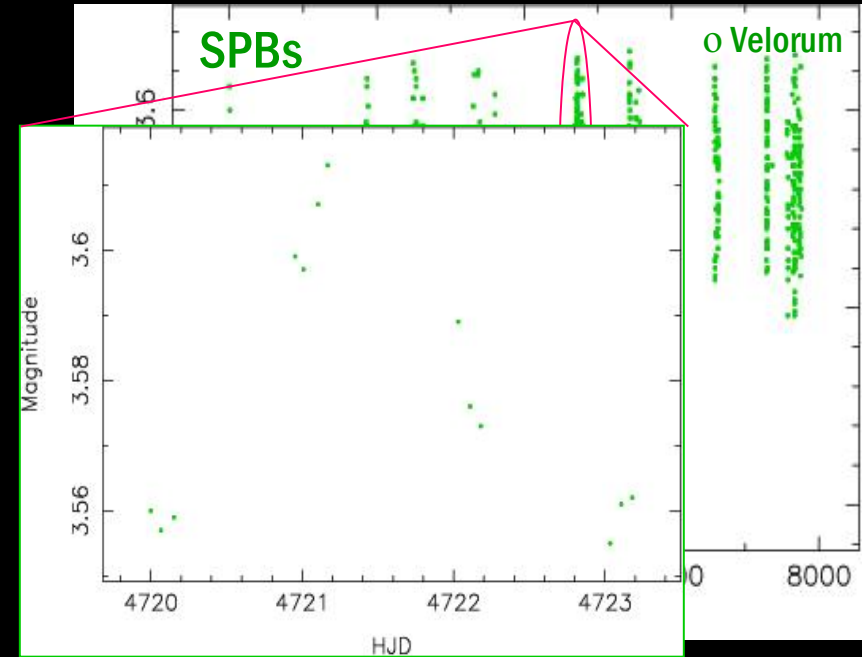
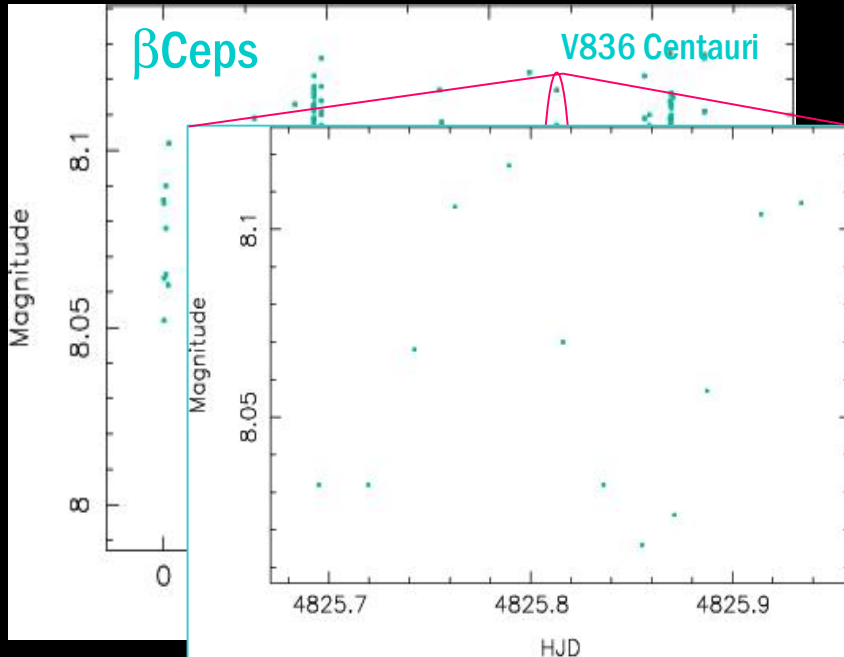
accuracy ~ 0.005 mag



What do we observe?

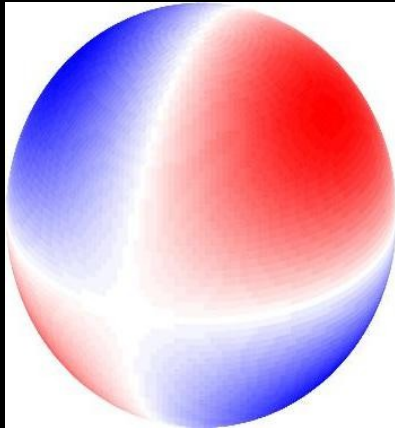
- Instrument
 - Photometer

accuracy ~ 0.005 mag

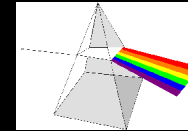


What do we observe?

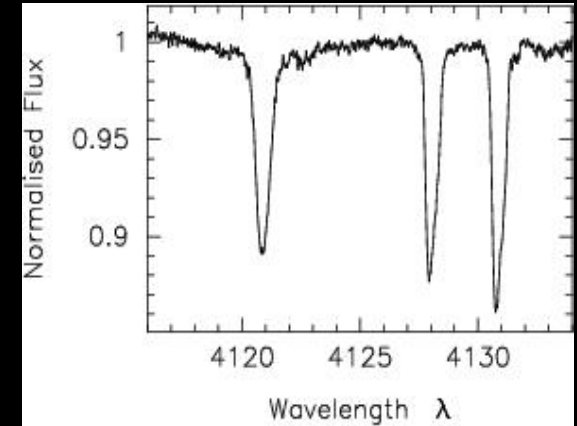
- Instrument
→ Spectrograph



CAT telescope (La Silla)
~ 1.4 m



CES



details of spectrum
time series

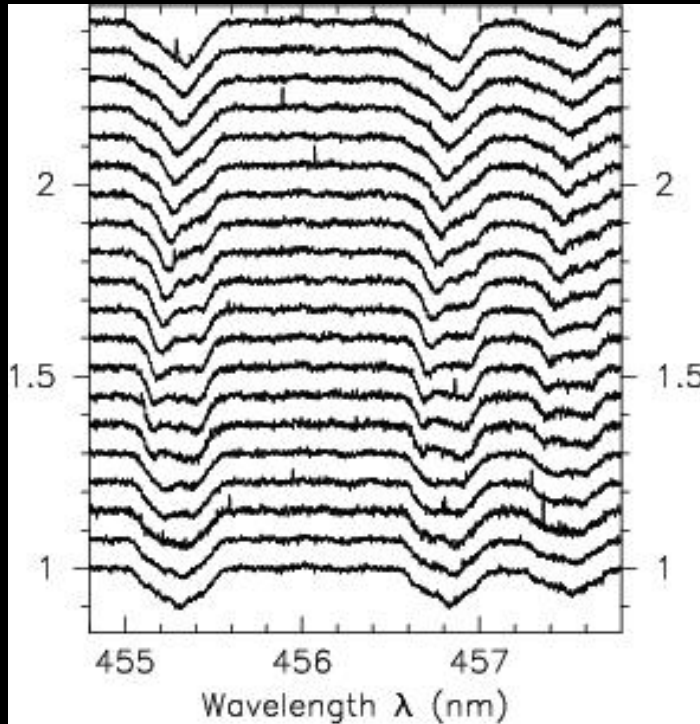


line profile variations

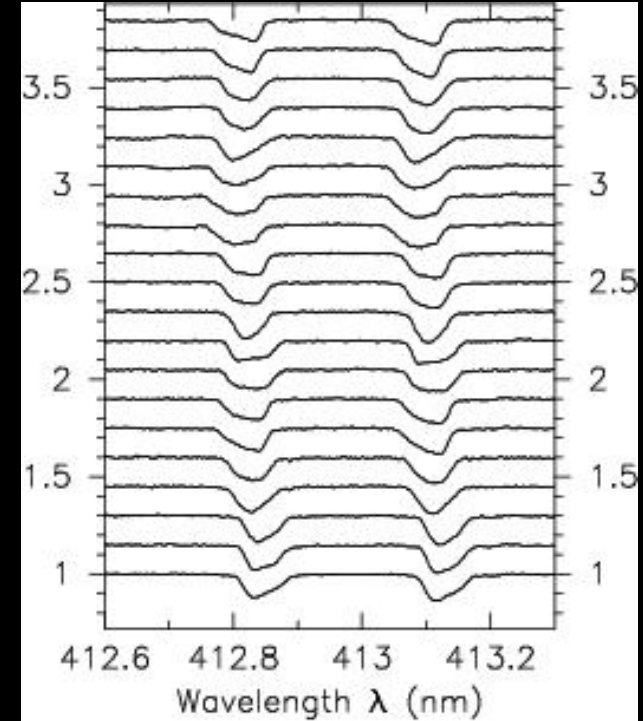
What do we observe?

- Instrument

→ Spectrograph



β Ceps
 ϵ Persei (HD 24760)
456 nm Sill-triplet



SPBs
33 Eridani (HD 24587)
413 nm Sill-doublet

Asteroseismic requirements and tools

Asteroseismic requirements and tools

- Time series
- Observed pulsation modes

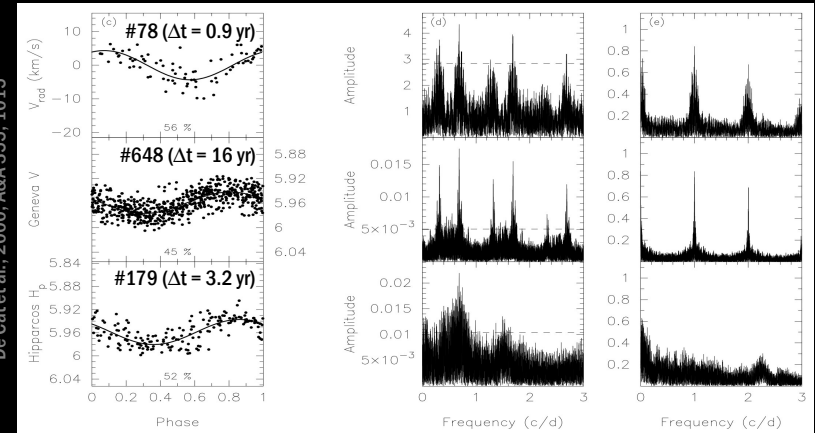
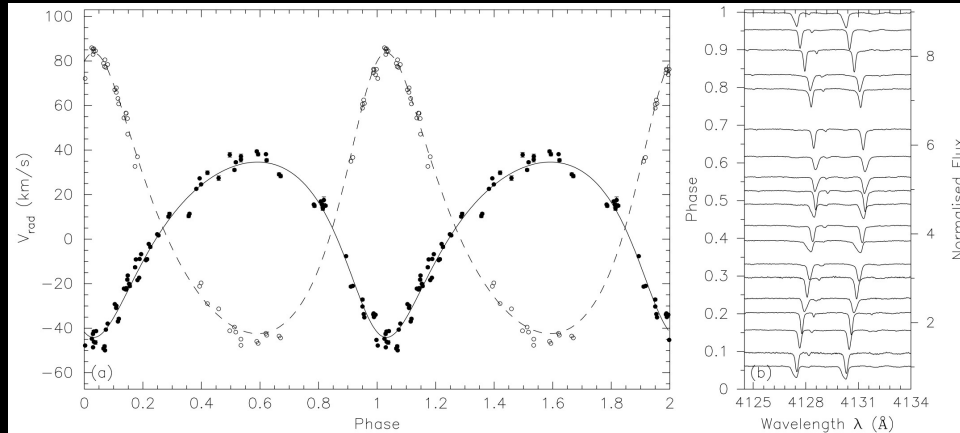
→ Frequency f → Frequency analysis

→ Degree ℓ
→ Azimuthal number m } Mode identification

➤ Spectroscopy: moment method (Aerts, 1992, A&A 266, 294; Briquet & Aerts, 2003, A&A 398, 687)

fourier parameter fit method (Zima, 2006, A&A 455, 227)

➤ Photometry: method of photometric amplitude ratios and phase shifts (Dupret et al., 2003, A&A 398, 677)



Asteroseismic requirements and tools

- Time series
- Observed pulsation modes

→ Frequency f → Frequency analysis

→ Degree ℓ
→ Azimuthal number m } Mode identification

- Spectroscopy: moment method (Aerts, 1992, A&A 266, 294; Briquet & Aerts, 2003, A&A 398, 687)
fourier parameter fit method (Zima, 2006, A&A 455, 227)
- Photometry: method of photometric amplitude ratios and phase shifts (Dupret et al., 2003, A&A 398, 677)

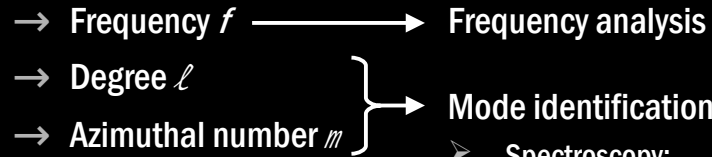


Status after arrival of
asteroseismic space missions



Asteroseismic requirements and tools

- Time series
- Observed pulsation modes



➤ Spectroscopy:

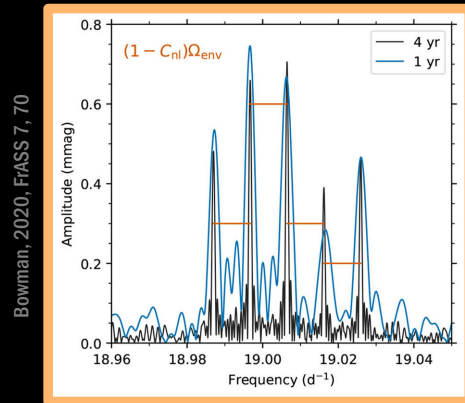
moment method (Aerts, 1992, A&A 266, 294; Briquet & Aerts, 2003, A&A 398, 687)

fourier parameter fit method (Zima, 2006, A&A 455, 227)

➤ Photometry:

method of photometric amplitude ratios and phase shifts (Dupret et al., 2003, A&A 398, 677)

rotational multiplets



Kepler
and K2

Status after arrival of
asteroseismic space missions



Asteroseismic requirements and tools

- Time series
- Observed pulsation modes

→ Frequency f → Frequency analysis

→ Degree ℓ

→ Azimuthal number m } Mode identification

➤ Spectroscopy:

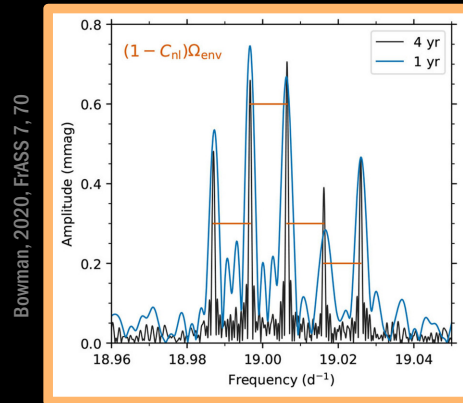
moment method (Aerts, 1992, A&A 266, 294; Briquet & Aerts, 2003, A&A 398, 687)

fourier parameter fit method (Zima, 2006, A&A 455, 227)

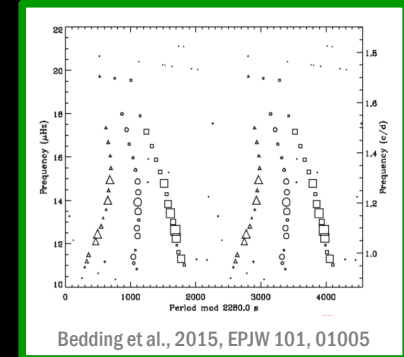
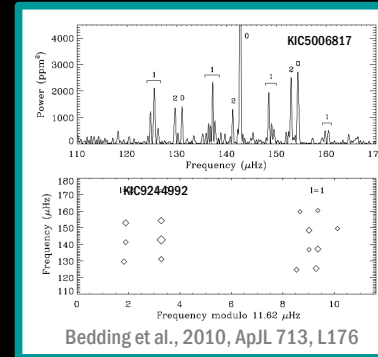
➤ Photometry: method of photometric amplitude ratios and phase shifts (Dupret et al., 2003, A&A 398, 677)

rotational multiplets

échelle diagram in frequency for **p-mode** and in period for **g-modes** (asymptotic regime)



Status after arrival of
asteroseismic space missions

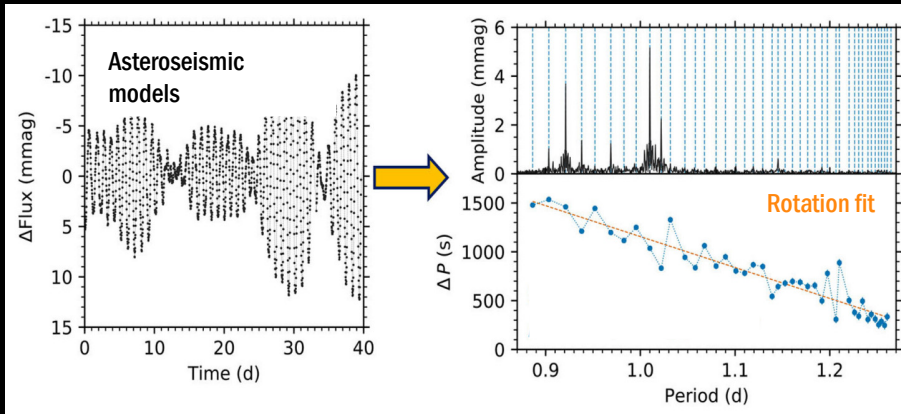


Asteroseismic requirements and tools

- Time series
- Observed pulsation modes
 - Frequency f → Frequency analysis
 - Degree ℓ
 - Azimuthal number m } Mode identification
 - Spectroscopy:
 - Photometry:



Status after arrival of
asteroseismic space missions



moment method (Aerts, 1992, A&A 266, 294; Briquet & Aerts, 2003, A&A 398, 687)

fourier parameter fit method (Zima, 2006, A&A 455, 227)

method of photometric amplitude ratios and phase shifts (Dupret et al., 2003, A&A 398, 677)

rotational multiplets

échelle diagram in frequency for p-mode and in period for g-modes (asymptotic regime)

g mode period spacing patterns (asymptotic regime)

Asteroseismic requirements and tools

- Time series
- Observed pulsation modes

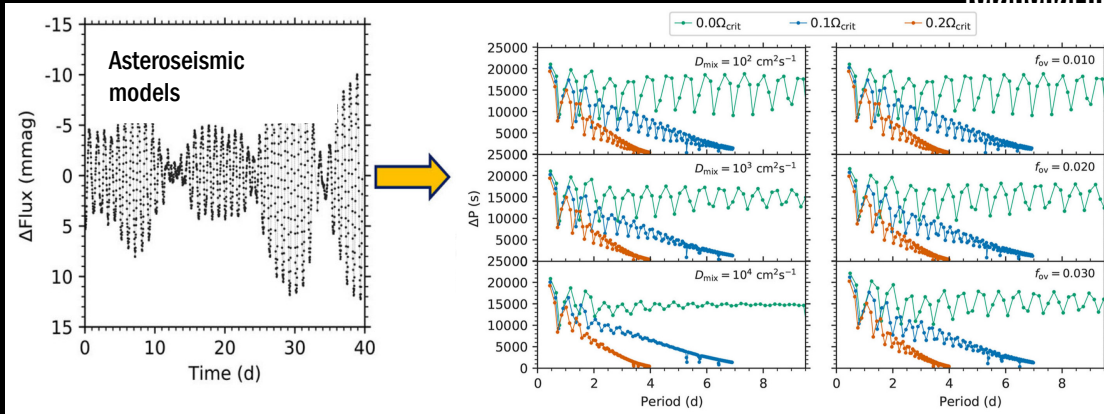
→ Frequency f → Frequency analysis

→ Degree ℓ
→ Azimuthal number m } Mode identification

- Spectroscopy: moment method (Aerts, 1992, A&A 266, 294; Briquet & Aerts, 2003, A&A 398, 687)
fourier parameter fit method (Zima, 2006, A&A 455, 227)
- Photometry: method of photometric amplitude ratios and phase shifts (Dupret et al., 2003, A&A 398, 677)
rotational multiplets



Status after arrival of
asteroseismic space missions



am in frequency for p-mode and in period for g-modes (asymptotic regime)
d spacing patterns (asymptotic regime)

Need for accurate stellar
parameters for modelling

Scientific background

KU Leuven

- Master student (physics)



KU LEUVEN



KU Leuven

- Master student (physics)

KU LEUVEN



Conny Aerts

Francqui award (2012)

Kavli prize in astrophysics (2022)

Scientific background

Asteroseismology

KU Leuven

● Master student (physics)



→ Evidence for binarity and multiplicity in the β Cephei star β Crucis

➤ CAT/CES@ESO(LaSilla)/1.4-m

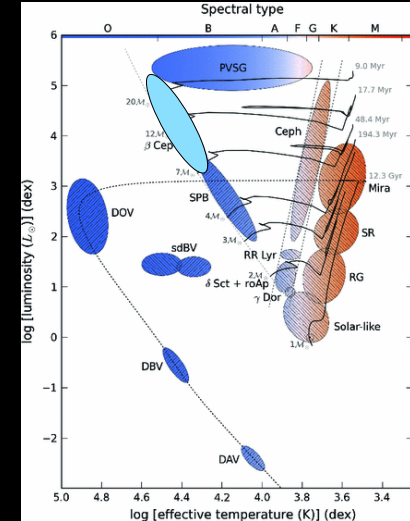
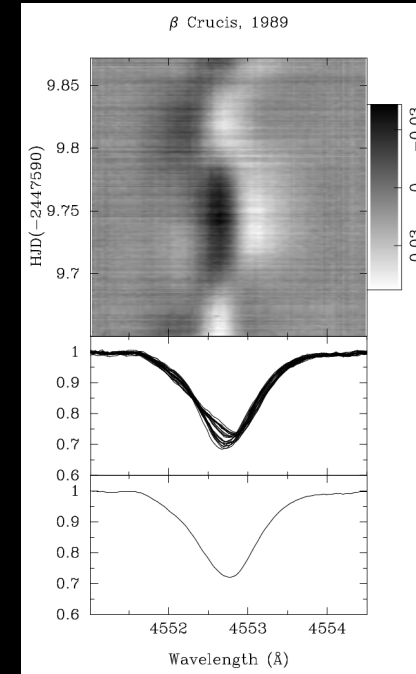
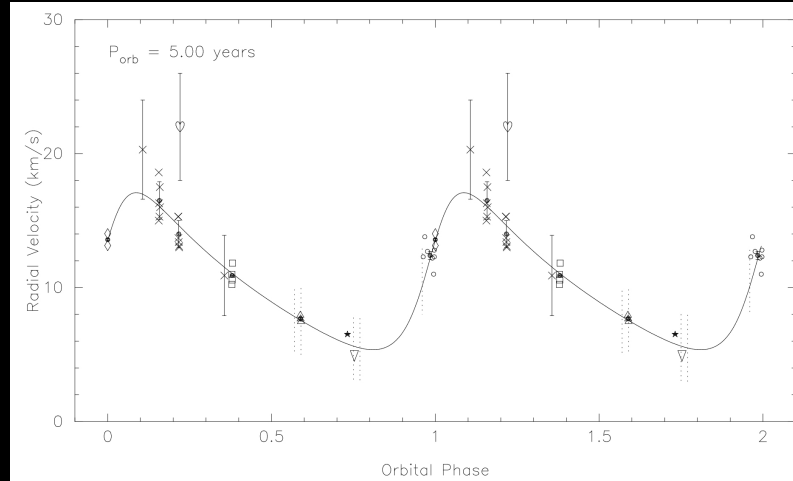
- ✓ high-resolution ($R=60000$), SiIII triplet (455.26, 456.78, 457.48 nm)
- ✓ time-series: 1193 spectra in 11 nights (1984-1995)
- ✓ isolated observations: 14 spectra in 14 nights (1996-1997)

Multiperiodic pulsator

- $f_1 = 5.2305468 \text{ d}^{-1}$ ($\ell=1$)
- $f_2 = 5.958666 \text{ d}^{-1}$ ($\ell \geq 3$)
- $f_3 = 5.472165 \text{ d}^{-1}$ ($\ell \geq 3$)
- (moment method)

Single-lined binarity

- $P_{\text{orb}} = 1828.0(25) \text{ days}$
- $e = 0.38(9)$
- B2V secondary



→ Polarimetric detection of non-radial oscillation modes in the β Cephei star β Crucis

Cotton, Buzasi, Aerts et al., 2021, NatAst 6, 154

KU Leuven

- Master student (physics)
- PhD student (physics, group astronomy)



→ A study of bright southern slowly pulsating B stars

➤ Sample

- ✓ 5 well-known SPBs (Waelkens, 1991, A&A 246, 539)
- ✓ 12 candidate SPBs (thanks to Hipparcos data)

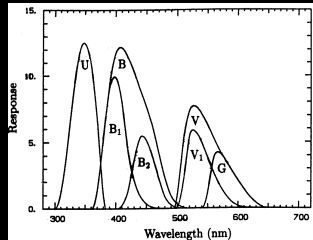
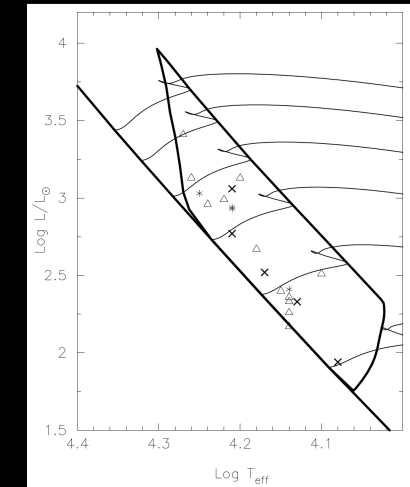
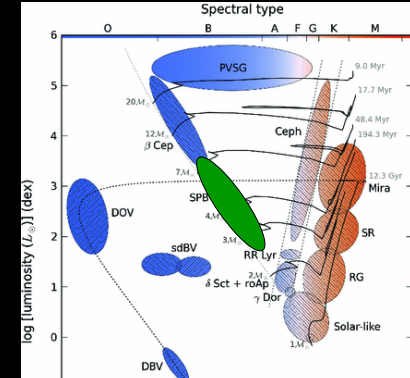
➤ Observations

- ✓ Spectroscopy: high-resolution CAT/CES@ESO/1.4-m (Sill doublet: 412.8, 413.0 nm)
- ✓ Photometry: Geneva photometry (U, B₁, B, B₂, V₁, V, G)
Hipparcos photometry (H_p)

➤ Analysis

- ✓ Frequency analysis
- ✓ Mode identification
 - moment method and photometric amplitude ratios

Observational characterisation of class of SPB stars



KU Leuven

- Master student (physics)
- PhD student (physics, group astronomy)



→ A study of bright southern slowly pulsating B stars

➤ Sample

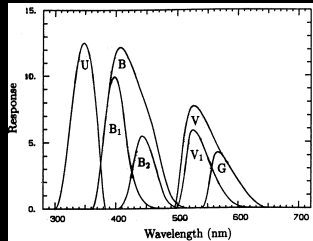
- ✓ 5 well-known SPBs (Waelkens, 1991, A&A 246, 539)
- ✓ 12 candidate SPBs (thanks to Hipparcos data)

➤ Observations

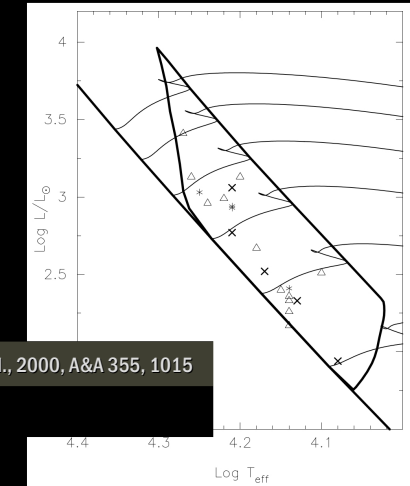
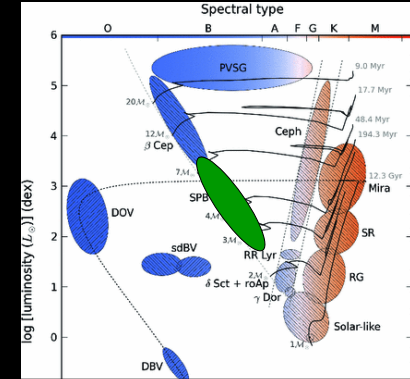
- ✓ Spectroscopy: high-resolution CAT/CES@ESO/1.4-m (Sill doublet: 412.8, 413.0 nm)
- ✓ Photometry: Geneva photometry (U, B₁, B, B₂, V₁, V, G)
Hipparcos photometry (H_p)

➤ Analysis

- ✓ Frequency analysis
- ✓ Mode identification
→ moment method and photometric amplitude ratios



Observational characterisation of class of SPB stars



I. Determination of the orbital parameters and of the main frequency of the spectroscopic binaries

De Cat, Aerts, De Ridder et al., 2000, A&A 355, 1015

II. The intrinsic frequencies

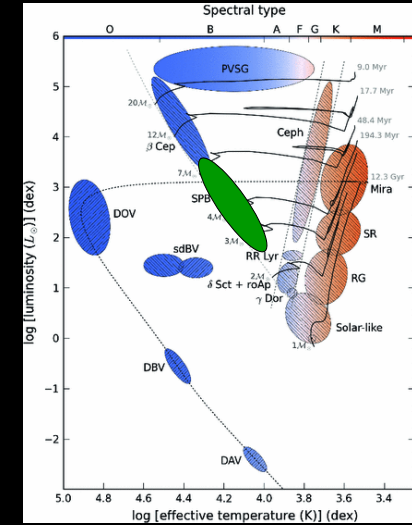
De Cat & Aerts, 2002, A&A 393, 965

III. Mode-identification for singly-periodic targets in spectroscopy

De Cat, Briquet, Daszyńska-Daszkiewicz et al., 2005, A&A 432, 1013

KU Leuven

- Master student (physics)
- PhD student (physics, group astronomy)
- Post-doctoral fellow



KU Leuven

- Master student (physics)
 - PhD student (physics, group astronomy)
 - Post-doctoral fellow
- 2003/10/20: first contact with Jianning Fu (Dubrovnik, Croatia)



Jianning Fu

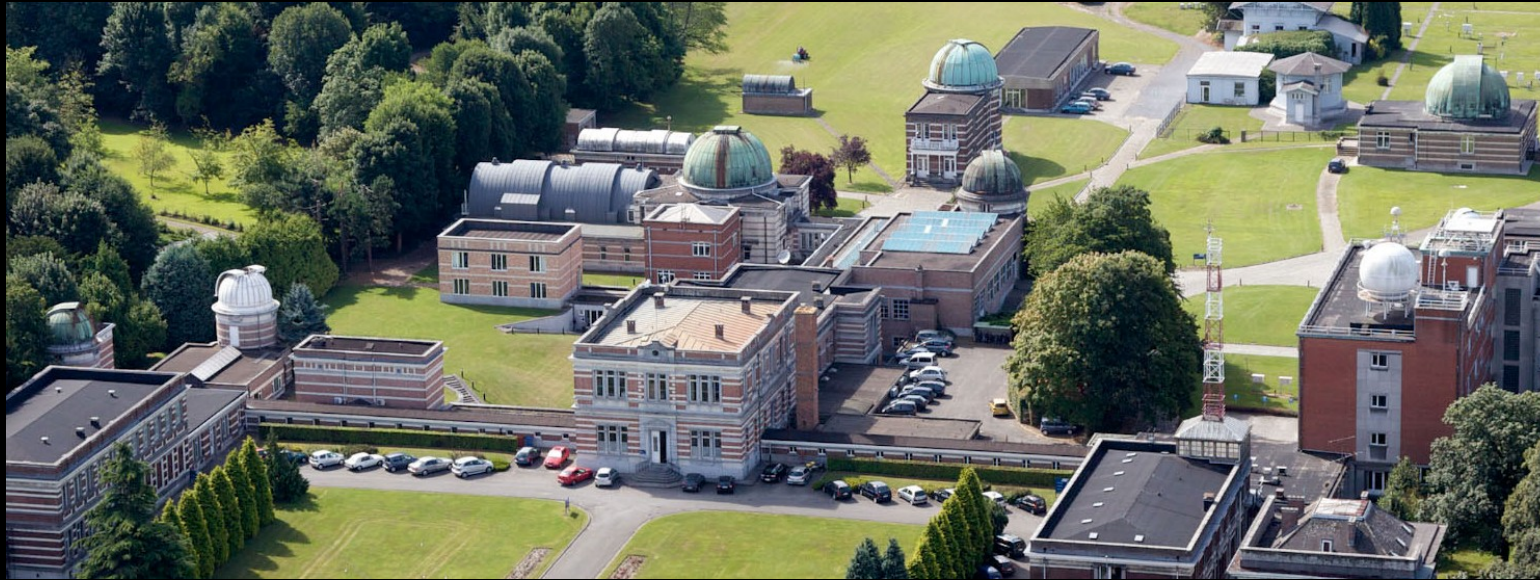


Scientific background

Asteroseismology

Royal Observatory of Belgium

- Scientific researcher



Patricia Lampens



Jan Cuypers



Martin Groenewegen



Royal Observatory of Belgium

- Scientific researcher

→ 2005/06/20: First contact with Karen Pollard (Rome, Italy)



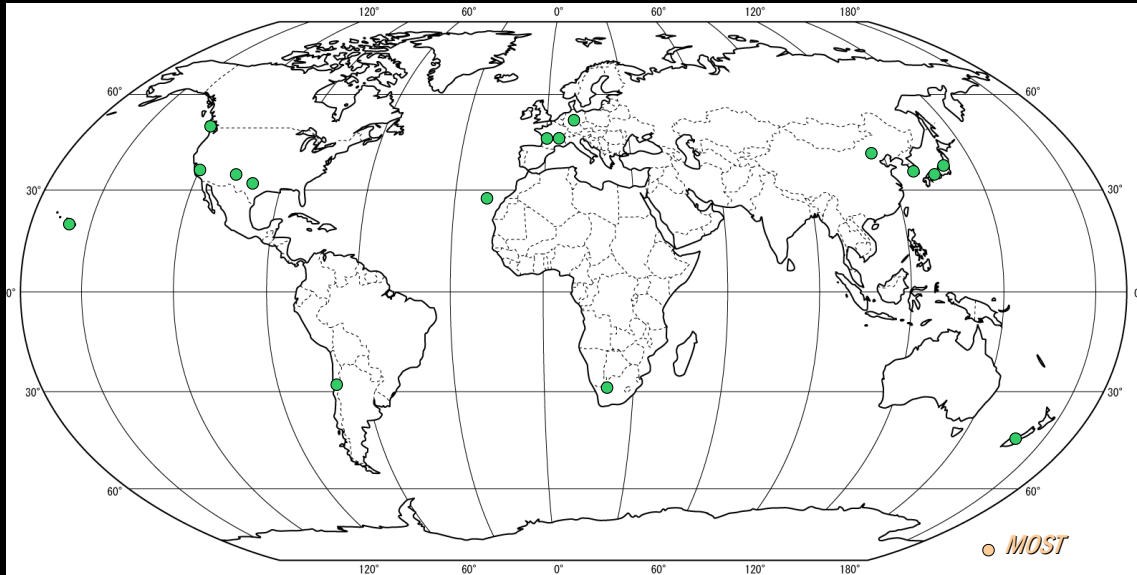
Karen Pollard

Scientific background

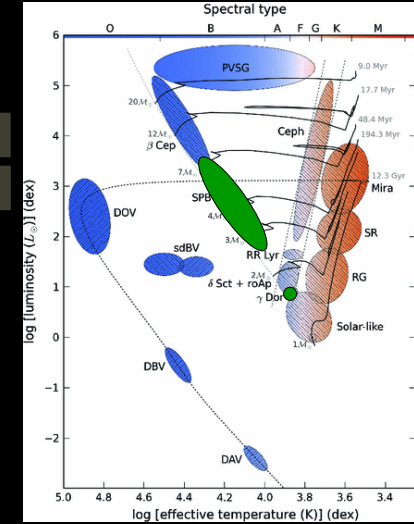
Royal Observatory of Belgium

● Rotation and pulsations in main-sequence gravity mode pulsators (SPB and γ Dor stars)

- effect of rotation on pulsations? {
- isolated spectra for $v \sin i$ /determination
 - spectroscopic multi-site campaigns
- 16 ground-based and 1 space-based observatories
 - >11,000 high-resolution spectra



Asteroseismology



Action 1 project (2008-2011): Duncan J. Wright

Action 1 project (2012-2014): Ádám Sódor

De Cat, Wright, Pollard et al., 2009, AIPC 1170, 480

ESPaDOnS@CFHT/3.58-m
 Hamilton@Lick/3-m
 9682M@DAO/1.2-m
 RA2@McDonald/2.1-m
 Echelle@Fairborn/2-m
 HARPS@ESO/3.6-m
 FEROS@ESO/2.2-m
 FIES@RMO/2.6-m
 HERMES@RMO/1.2-m
 SOPHIE@OHP/1.93-m
 NARVAL@TBL/2-m
 CES@TLS/2.0-m
 GIRAFFE@SAAO/1.9-m
 COUDE@Xinglong/2.16-m
 BOES@BOA/1.8-m
 HIDES@OAO/1.88-m
 HERCULES@MJUO/1.0-m

jianning fu



21 days HD25558 (SPB star)
 47 days HD218396 (γ Dor star)

Duncan J. Wright

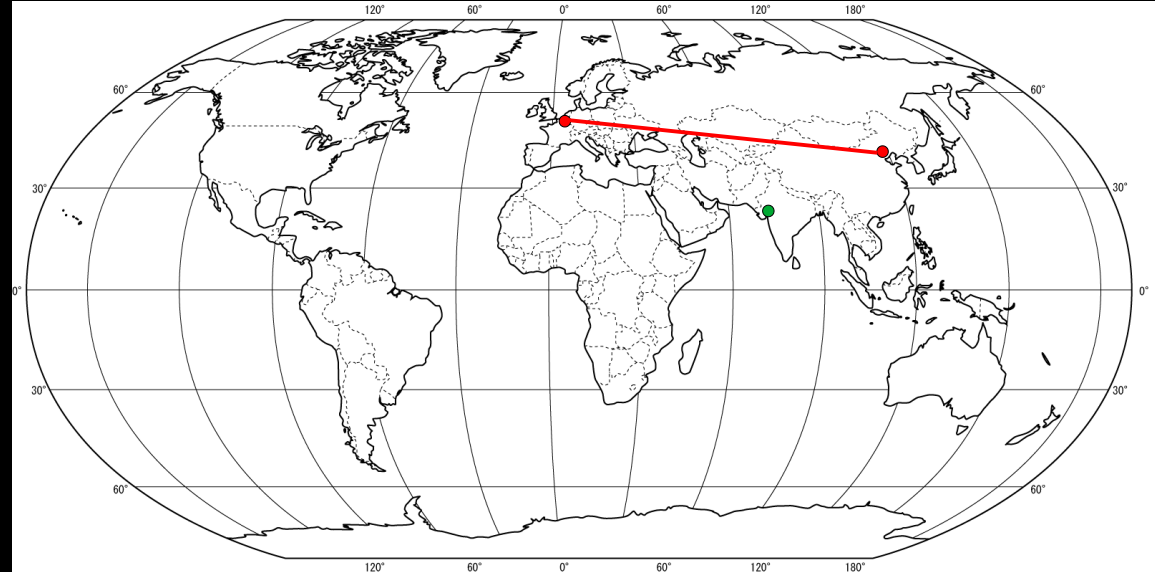


Ádám Sódor



Outline

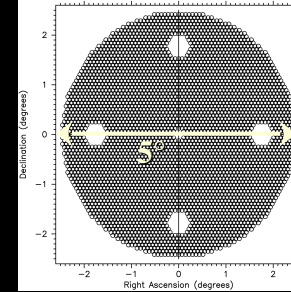
1. Scientific background
2. Connection Belgium – China
3. Connection Belgium – India
4. Conclusions and future prospects





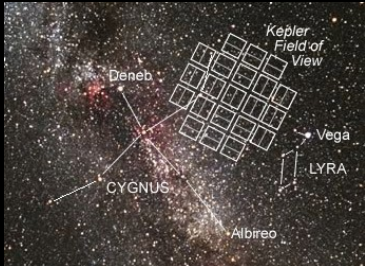
→ Large Sky Area Multi-Object Fiber Spectroscopic Telescope

- Size: 4.0-m telescope
- Field of View: circular with diameter of 5° on sky ($\sim 20 \text{ deg}^2$)
- Fibers: #4000
- Wavelengths: 370 – 900 nm
- Resolution: ~ 1800 (LRS) / ~ 7500 (MRS)
- Targets: $> 5\,000\,000$ (stars, galaxies, QSOs)



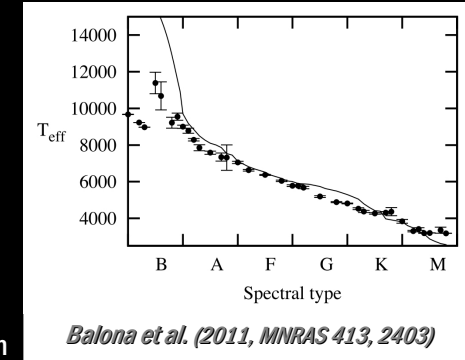
Unique combination
of large multi-fiber
telescope with wide
field-of-view

Kepler



→ NASA mission Kepler

- primary mirror: 1.2-m
- launch on 2009/03/07 (lifetime ~ 3.8 years after failure on 2013/05/14)
- continuous monitoring of 1 star field in Cygnus-Lyra region
- broad band photometry with accuracy of few ppm
- main scientific goals
 - ✓ discover Earth-size planets (transit method)
 - ✓ characterizing planet-hosting stars by means of asteroseismic methods
 - ✓ opportunity for asteroseismic investigation of stars covering H-R diagram



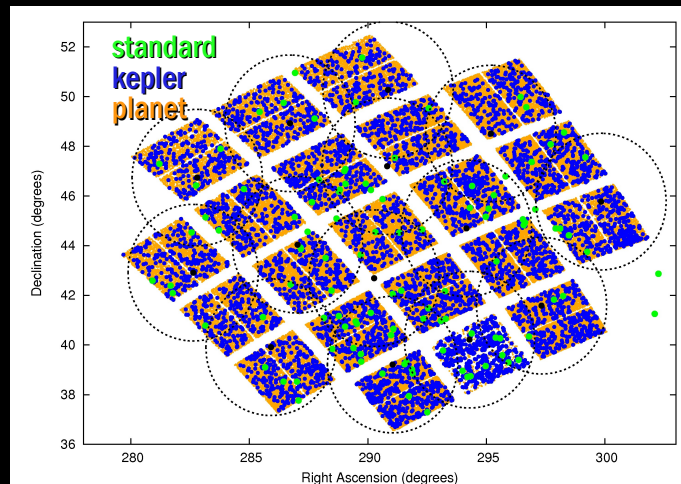
Need for accurate stellar
parameters

LAMOST-Kepler project

- **Proposal submitted in 2010**

Collaboration with subchairs of
Kepler Asteroseismic Science Consortium

- to cover whole Kepler field-of-view
- to characterize targets in homogeneous way
 - spectral type
 - any peculiarities
 - T_{eff} , $\log g$, metallicity
- with low-resolution spectroscopy
 - radial velocity $\Rightarrow$ binaries, cluster membership
 - rotation velocity $\Rightarrow$ restriction on $v \sin i$
- because it is the only instrument to observe thousands of targets efficiently
 - brightest targets ($K_p \leq 10.5$ mag): with 2-m class telescopes
 - LAMOST: focus on fainter targets



- **First observations on 2011/05/30**
- **First reduced spectra distributed in 2012/05**
- **First publication with introduction of project in 2015**

Win-win opportunity for both
LAMOST community and Kepler community

De Cat, Fu, Ren et al., 2015, ApJS 220, 19

大天区面积多目标光纤光谱望远镜
(LAMOST)
科学试观测计划建议书

课题名称: Characterization of targets of the Kepler
Asteroseismic Science Consortium (KASC)
申请者: Peter De Cat
工作单位: Royal Observatory of Belgium
通讯地址: Ringlaan 3
邮政编码: B-1180 Brussels (Belgium)
电子邮箱: Peter.DeCat@oma.be
电话: +32 2 3736785 传真: +32 2 3749822
20 February 2010

LAMOST-Kepler project

- Asian team



LASP (LRS)

temperature type

T_{eff} (2.75%)

$\log g$ (0.215 dex)

[Fe/H] (0.152 dex)

V_{rad} (18 km s⁻¹)

→ Ren et al., 2016, ApJS 225, 28: “LAMOST observations in the Kepler field: Analysis of the stellar parameters measured with LASP based on low-resolution spectra” (2012/06-2014/09)

- Detection of 115 candidate metal poor stars (106 with [Fe/H] < -1.0 dex; 9 with [Fe/H] < -2.0 dex)
- Detection of 18 high-velocity stars (V_{rad} < -300 km s⁻¹)

LAMOST-Kepler project

- Asian team



LASP (LRS)

→ Ren et al., 2016, ApJS 225, 28: “LAMOST observations in the Kepler field: Analysis of the stellar parameters measured with LASP based on low-resolution spectra” (2012/06-2014/09)

temperature type

T_{eff} (2.75%)

→ Zong et al., 2018, ApJS 238, 30: “LAMOST observations in the Kepler field: II. Database of the low-resolution spectra from the five-year regular survey” (2015/05-2017/05)

$\log g$ (0.215 dex)

[Fe/H] (0.152 dex)

→ Fu et al., 2020, RAA 20, 167: “Overview of the LAMOST-Kepler project” (2011/05-2020/09)

V_{rad} (18 km s⁻¹)

➤ Update of the statistics of the catalogue

LAMOST-Kepler project

Asian team



LASP (LRS)

temperature type

T_{eff} (2.75%)

$\log g$ (0.215 dex)

[Fe/H] (0.152 dex)

V_{rad} (18 km s⁻¹)

→ Ren et al., 2016, ApJS 225, 28: "LAMOST observations in the Kepler field: Analysis of the stellar parameters measured with LASP based on low-resolution spectra" (2012/06-2014/09)

→ Zong et al., 2018, ApJS 238, 30: "LAMOST observations in the Kepler field: II. Database of the low-resolution spectra from the five-year regular survey" (2015/05-2017/05)

→ Fu et al., 2020, RAA 20, 167: "Overview of the LAMOST-Kepler project" (2011/05-2020/09)

→ Zong et al., 2020, ApJS 251, 15: "Phase II of the LAMOST-Kepler/K2 survey: I. Time series of medium-resolution spectroscopic observations" (2019/01-2019/06)

LASP (MRS)

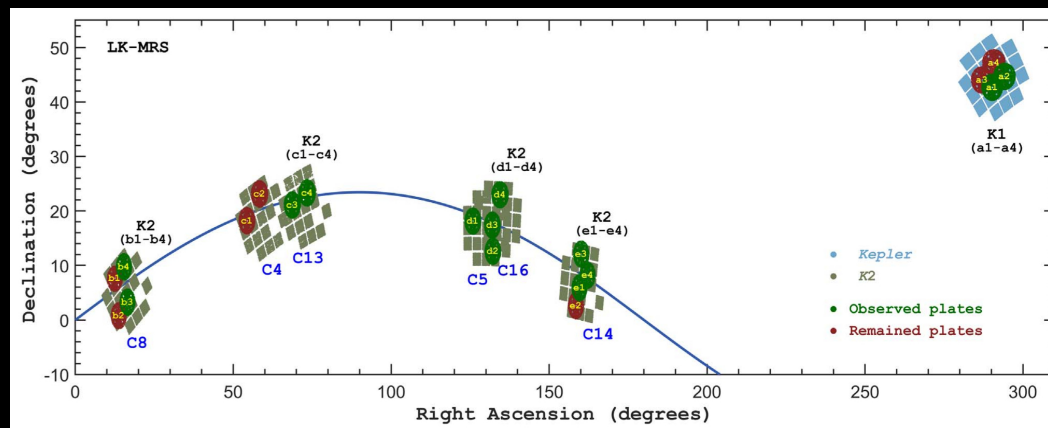
temperature type

T_{eff} (100 K)

$\log g$ (0.15 dex)

[Fe/H] (0.09 dex)

V_{rad} (1 km s⁻¹)



LAMOST-Kepler project

- Asian team



LASP (LRS)

temperature type

T_{eff} (2.75%)

$\log g$ (0.215 dex)

[Fe/H] (0.152 dex)

V_{rad} (18 km s⁻¹)

- Ren et al., 2016, ApJS 225, 28: "LAMOST observations in the Kepler field: Analysis of the stellar parameters measured with LASP based on low-resolution spectra" (2012/06-2014/09)
- Zong et al., 2018, ApJS 238, 30: "LAMOST observations in the Kepler field: II. Database of the low-resolution spectra from the five-year regular survey" (2015/05-2017/05)
- Fu et al., 2020, RAA 20, 167: "Overview of the LAMOST-Kepler project" (2011/05-2020/09)
- Zong et al., 2020, ApJS 251, 15: "Phase II of the LAMOST-Kepler/K2 survey: I. Time series of medium-resolution spectroscopic observations" (2019/01-2019/06)
- Wang et al., 2020, ApJS 251, 27: "LAMOST observations in 15 K2 campaigns: I. Low-resolution spectra from LAMOST DR6" (2015/12-2018/01)

LASP (MRS)

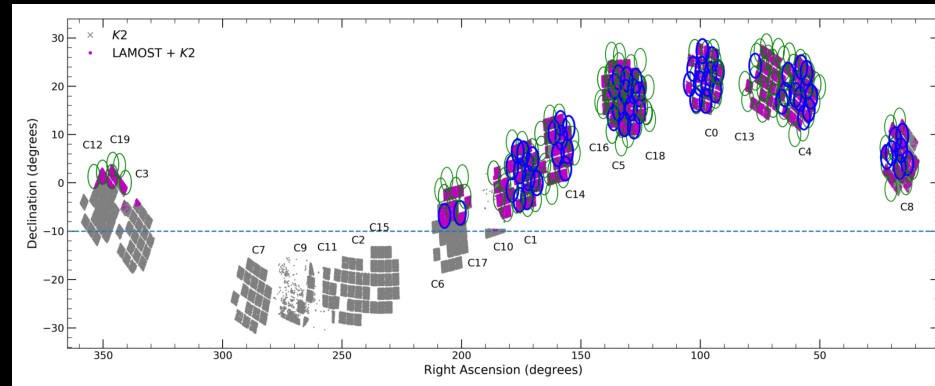
temperature type

T_{eff} (100 K)

$\log g$ (0.15 dex)

[Fe/H] (0.09 dex)

V_{rad} (1 km s⁻¹)



LAMOST-Kepler project

● European team

ROTFIT (LRS)

temperature type

luminosity class

T_{eff} (3.5%)

$\log g$ (0.3 dex)

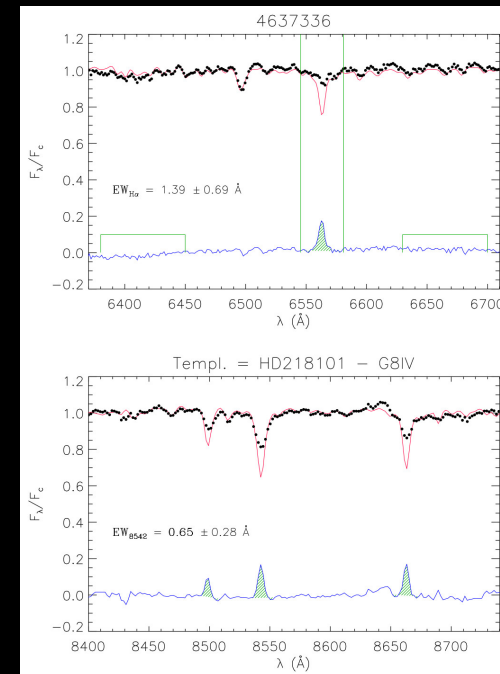
[Fe/H] (0.2 dex)

V_{rad} (14 km s⁻¹)

$v \sin i > 120 \text{ km s}^{-1}$

→ Frasca et al., 2016 A&A 594, A39: “Activity indicators and stellar parameters of the Kepler targets: An application of the ROTFIT pipeline to LAMOST-Kepler stellar spectra” (2011/05-2014/09)

- Search for emission line objects
- Detection of 442 chromospherically active stars
- Detection of accreting star KIC8749284 (K1V)



LAMOST-Kepler project

European team



ROTFIT (LRS)

temperature type

luminosity class

T_{eff} (3.5%)

$\log g$ (0.3 dex)

[Fe/H] (0.2 dex)

V_{rad} (14 km s⁻¹)

$v \sin i > 120 \text{ km s}^{-1}$

→ Frasca et al., 2016 A&A 594, A39: “Activity indicators and stellar parameters of the Kepler targets: An application of the ROTFIT pipeline to LAMOST-Kepler stellar spectra” (2011/05-2014/09)

- Search for emission line objects
- Detection of 442 chromospherically active stars
- Detection of accreting star KIC8749284 (K1V)

→ Frasca et al., 2022, A&A 664, A78: “Characterization of Kepler targets based on medium-resolution LAMOST spectra analysed with ROTFIT” (2017/09-2018/05)

- Detection of 327 chromospherically active stars
- Detection of 98 double-lined spectroscopic binaries (SB2) and 7 triple systems (SB3)
- EW measurement Lil λ 6708 line for 1657 stars

ROTFIT (MRS)

temperature type

luminosity class

T_{eff} (2.5%)

$\log g$ (0.25 dex)

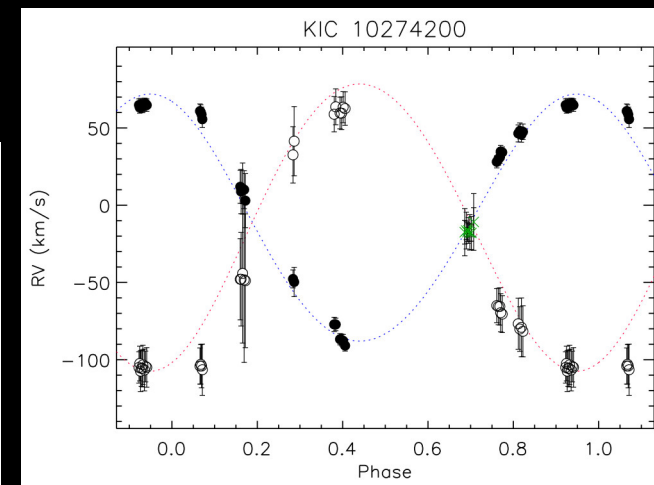
[Fe/H] (0.15 dex)

V_{rad} (0.7 km s⁻¹)

$v \sin i > 8 \text{ km s}^{-1}$

- ✓ 187 Li-rich giants (153 new ones)
- ✓ fraction of 4-5% Li-rich giants
- ✓ no relation between rotation and Li abundances (merging scenarios)

Parameter	Value
HJD0 ^(a)	58020.45 ± 0.05
P_{orb} (d)	4.278 ± 0.001
e	0.04 ± 0.04
ω (°)	20.0 ± 0.5
γ (km s ⁻¹)	-11 ± 3
K_1 (km s ⁻¹)	80 ± 1
K_2 (km s ⁻¹)	93 ± 3
$M_1 \sin^3 i$ ($M_{\odot}$)	1.23 ± 0.08
$M_2 \sin^3 i$ ($M_{\odot}$)	1.06 ± 0.05
M_2/M_1	0.86 ± 0.03
$a \sin i$ ($R_{\odot}$)	14.6 ± 0.2



LAMOST-Kepler project

European team



ROTFIT (LRS)

temperature type

luminosity class

T_{eff} (3.5%)

$\log g$ (0.3 dex)

[Fe/H] (0.2 dex)

V_{rad} (14 km s⁻¹)

$\sin i > 120 \text{ km s}^{-1}$

→ Frasca et al., 2016 A&A 594, A39: “Activity indicators and stellar parameters of the Kepler targets: An application of the ROTFIT pipeline to LAMOST-Kepler stellar spectra” (2011/05-2014/09)

- Search for emission line objects
- Detection of 442 chromospherically active stars
- Detection of accreting star KIC8749284 (K1V)

→ Frasca et al., 2022, A&A 664, A78: “Characterization of Kepler targets based on medium-resolution LAMOST spectra analysed with ROTFIT” (2017/09-2018/05)

- Detection of 327 chromospherically active stars
- Detection of 98 double-lined spectroscopic binaries (SB2) and 7 triple systems (SB3)
- EW measurement Lil λ 6708 line for 1657 stars

ROTFIT (MRS)

temperature type

luminosity class

T_{eff} (2.5%)

$\log g$ (0.25 dex)

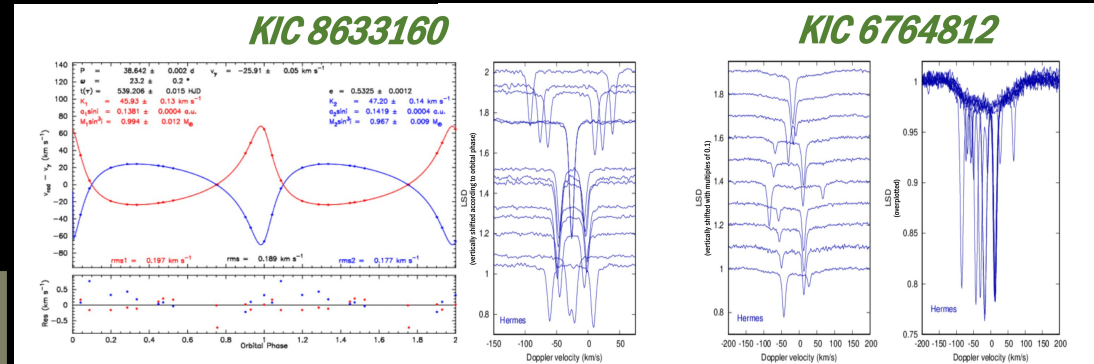
[Fe/H] (0.15 dex)

V_{rad} (0.7 km s⁻¹)

$\sin i > 8 \text{ km s}^{-1}$

- ✓ 187 Li-rich giants (153 new ones)
- ✓ fraction of 4-5% Li-rich giants
- ✓ no relation between rotation and Li abundances (merging scenarios)

Follow-up high-resolution spectroscopy with HERMES@ORM/1.2-m Mercator telescope



LAMOST-Kepler project

- American team



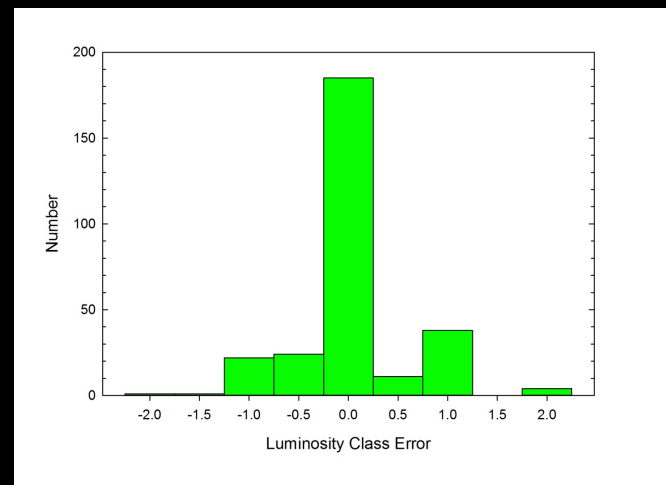
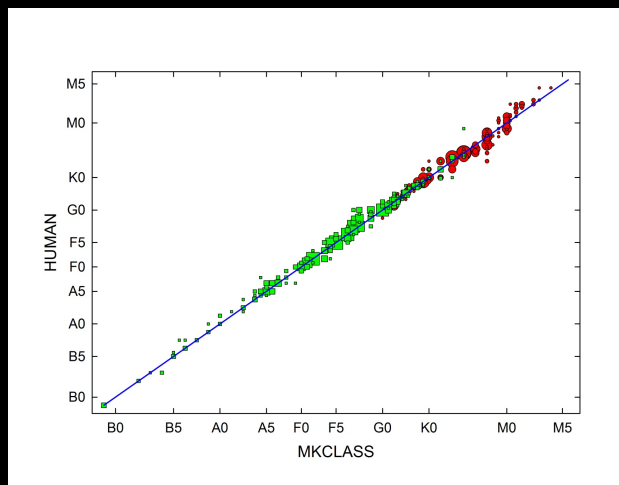
MKCLASS

temperature type (0.6)

luminosity class (0.5)

→ Grey et al., 2016, AJ 151, 13: “LAMOST observations in the Kepler field: Spectral classification with the MKCLASS code” (2011/05-2014/09)

- Classification on MK system (direct comparison with MK standards)
- Identification of peculiar and astrophysically interesting stars
 - ✓ 32 candidate Barium dwarfs (s-process enhances G-type dwarfs)
 - ✓ 34.6% of A stars are Am
 - ✓ 132 candidate λ Bootis stars (chemically peculiar late B to early-F stars: surface underabundances of most iron-peak elements, near-solar abundances of C, N, O, and S)



LAMOST-Kepler project

- LRS and MRS LAMOST spectra have shown to be useful in many different scientific fields, including:
 - Stellar parameter determination
 - Asteroseismology
 - Binary stars
 - Stellar activity
 - Peculiar stars
 - Exoplanets

2024/05/21-24

Third LAMOST-Kepler/TESS workshop (Beijing, China)

"Synergies between ground-based spectroscopic surveys and space-based photometric missions"

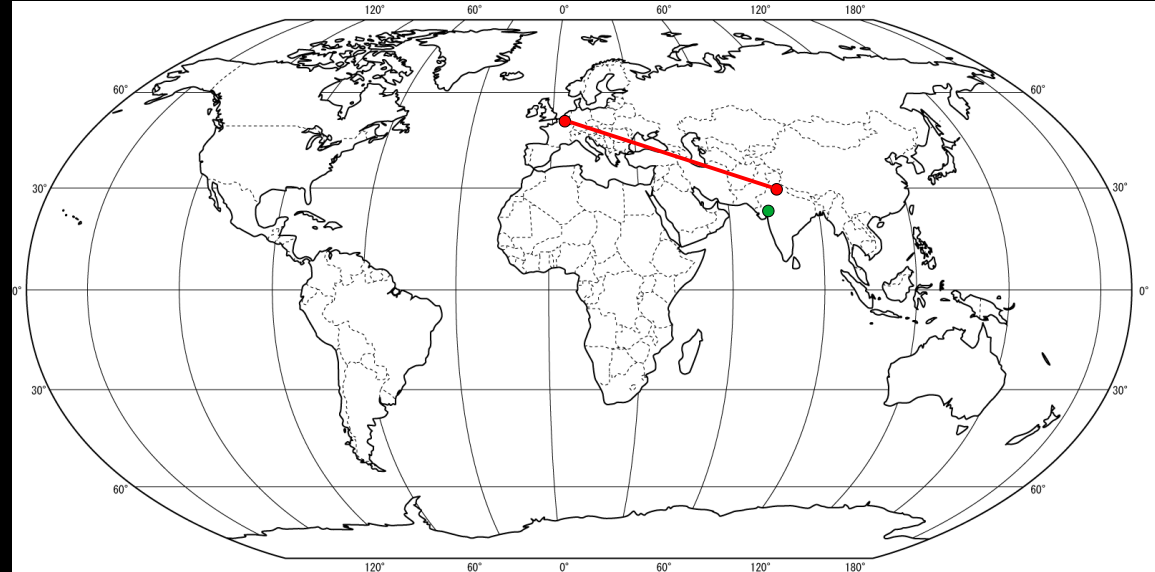
The 3rd LAMOST-Kepler/TESS Workshop

Beijing, 2024.05.21-24



Outline

1. Scientific background
2. Connection Belgium – China
3. Connection Belgium – India
4. Conclusions and future prospects



Connection Belgium – India

BINA

→ 2014/01/27: first contact with Santosh Joshi (e-mail)

Subject: Re: KASC WG3: K2 mission and other updates (reminder)
Date: Mon, 27 Jan 2014 09:25:19 +0530 (IST)
From: Dr. Santosh Joshi <santosh@aries.res.in>
To: Peter De Cat <Peter.DeCat@oma.be>

Hi Peter,
Please let me know if you are interested in the following programme:
http://www.dst.gov.in/whats_new/whats_new13/cop_belcall2014.pdf

Regards
Santosh
<http://www.aries.res.in>

Indo-Belgian telescopes



Subject: Indo-Belgian Research and Technology Cooperation
Date: Tue, 28 Jan 2014 10:59:37
From: Peter De Cat <Peter.DeCat@oma.be>
To: Dr. Santosh Joshi <santosh@aries.res.in>

Dear Dr. Santosh Joshi,

Thank you very much for your message! Unfortunately it ended up in the spam mail so I didn't see it immediately! (to be on the safe side, please also send a copy to my private e-mail: peter-ke@telenet.be)

Yes, we would be very interested to submit such a proposal! We already submitted a proposal last year in collaboration with Prof. Ram Sagar in view of the DOT telescope (and the Belgian guaranteed time) but unfortunately our proposal was not successful... However, we would like to try again this year so it would be very nice to collaborate with you!

From the Belgian side, two institutes are participating:
* Royal Observatory of Belgium (Patricia Lampens, Yves Frémat and myself),
* Université de Liège (Jean Surdej).

Is there anybody else from your institute that would like to join our team? Do you know colleagues from other Indian institutes that would be interested? What are the main scientific topics you are working on? What kind of network activities would you like to introduce in the proposal?

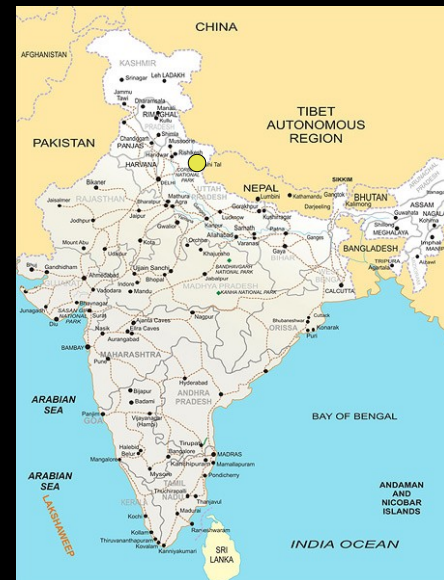
Thanks again for your proposition. We still have one month to prepare a proposal. Let's hope we will have the opportunity to start a fruitful collaboration!

Kind regards,
Peter

cc. Patricia Lampens, Yves Frémat, Jean Surdej



Santosh Joshi



Connection Belgium – India

BINA

Belgo-Indian Network for Astronomy and astrophysics

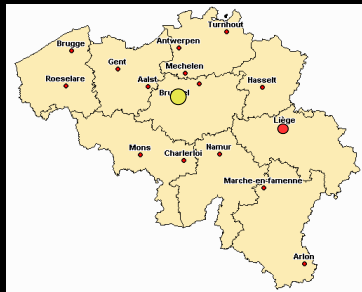
● BINA-1 (2014-2018)

Focus on instrument development (DOT+ILMT)

Network activities

Belgian Science Policy Office
(BELSPO; Govt. of Belgium)

International Division,
Department of Science and Technology
(DST; Govt. of India)



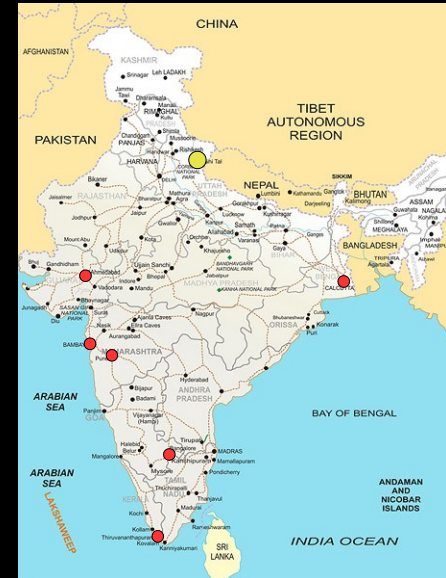
Indian partners (PI: Santosh Joshi)

- ARIES (Aryabhata Research Institute of Observational Sciences; Nainital)
- IIA (Indian Institute of Astrophysics; Bangalore)
- IIST (Indian Institute of Space Science & Technology; Trivandrum)
- IUCAA (Inter-University Centre for Astronomy and Astrophysics; Pune)
- PRL (Physical Research Laboratory; Ahmadabad)
- SBNCBS (S.N. Bose National Centre for Basic Sciences; Kolkata)
- TIFR (Tata Institute of Fundamental Research; Mumbai)



Belgian partners (PI: Peter De Cat)

- ROB (Royal Observatory of Belgium; Brussels)
- ULiège (Université de Liège; Liège)



Connection Belgium – India

BINA

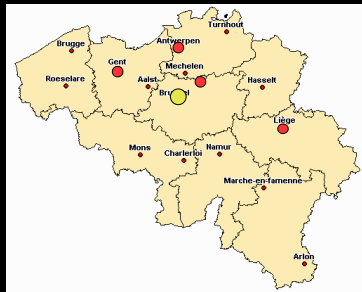
Belgo-Indian Network for Astronomy and astrophysics

- BINA-1 (2014-2018) Focus on instrument development (DOT+ILMT)
- BINA-2 (2018-2023) Focus on scientific projects (telescopes of interest)

Network activities

Belgian Science Policy Office
(BELSPO; Govt. of Belgium)

International Division,
Department of Science and Technology
(DST; Govt. of India)



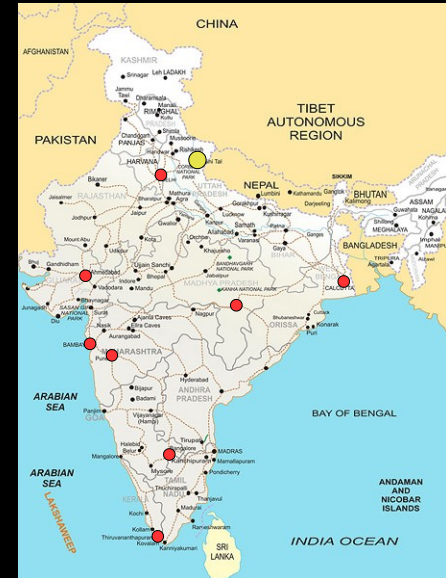
Indian partners (PI: Santosh Joshi)

- ARIES (Aryabhata Research Institute of Observational Sciences; Nainital)
- DU (Delhi University; Delhi)
- HBCSE (Homi Bhabha Centre for Science Education; Mumbai)
- IIA (Indian Institute of Astrophysics; Bangalore)
- IIST (Indian Institute of Space Science & Technology; Trivandrum)
- ISRO (ISRO Satellite Centre; Bangalore)
- IUCAA (Inter-University Centre for Astronomy and Astrophysics; Pune)
- KU (Kumaun University; Nainital)
- NCRA (National Center for Radio Astrophysics; Pune)
- PRL (Physical Research Laboratory; Ahmedabad)
- RSU (Pt. Ravi Shankar University; Raipur)
- SBNCBS (S.N. Bose National Centre for Basic Sciences; Kolkata)
- TIFR (Tata Institute of Fundamental Research; Mumbai)



Belgian partners (PI: Peter De Cat)

- ROB (Royal Observatory of Belgium; Brussels)
- KU Leuven (Katholieke Universiteit Leuven; Leuven)
- UAntwerp (Universiteit Antwerpen; Antwerp)
- UGent (Universiteit Gent; Ghent)
- ULB (Université Libre de Bruxelles; Brussels)
- ULiège (Université de Liège; Liège)

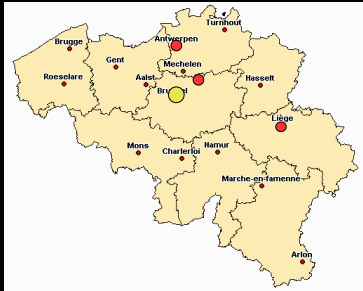


Connection Belgium – India

BINA

Belgo-Indian Network for Astronomy and astrophysics

- BINA-1 (2014-2018) Focus on instrument development (DOT+ILMT)
- BINA-2 (2018-2023) Focus on scientific projects (telescopes of interest)
- BIPASS (2022-2025) Focus on spectroscopy (data products and science)



→ Belgian partners (PI: Laurent Mahy)

- ROB (Royal Observatory of Belgium; Brussels)
- KU Leuven (Katholieke Universiteit Leuven; Leuven)
- UAntwerp (Universiteit Antwerpen; Antwerp)
- UGent (Universiteit Gent; Ghent)
- ULB (Université Libre de Bruxelles; Brussels)
- ULiège (Université de Liège; Liège)
- VUB (Vrije Universiteit Brussel; Brussels)



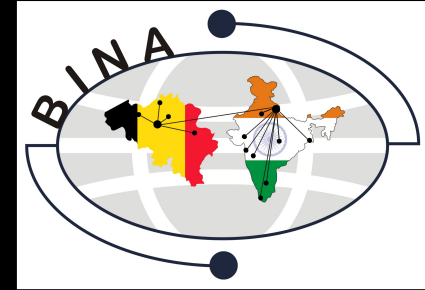
Indian partners (PI: Sashikiran Ganesh)

- ARIES (Aryabhata Research Institute of Observational Sciences; Nainital)
- DU (Delhi University; Delhi)
- HBCSE (Homi Bhabha Centre for Science Education; Mumbai)
- IIA (Indian Institute of Astrophysics; Bangalore)
- IIST (Indian Institute of Space Science & Technology; Trivandrum)
- ISRO (ISRO Satellite Centre; Bangalore)
- IUCAA (Inter-University Centre for Astronomy and Astrophysics; Pune)
- KU (Kumaun University; Nainital)
- NCRA (National Center for Radio Astrophysics; Pune)
- PRL (Physical Research Laboratory; Ahmedabad)
- RSU (Pt. Ravi Shankar University; Raipur)
- SBNCBS (S.N. Bose National Centre for Basic Sciences; Kolkata)
- TIFR (Tata Institute of Fundamental Research; Mumbai)
- UOC (University of Calicut; Calicut)

Network activities

Belgian Science Policy Office
(BELSPO; Govt. of Belgium)

International Division,
Department of Science and Technology
(DST; Govt. of India)



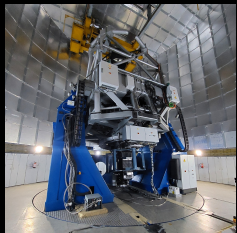
Connection Belgium – India

BINA

Belgo-Indian Network for Astronomy and astrophysics

● Indo-Belgian telescopes

→ 3.6-m Devasthal Optical telescope (DOT) (Operational since 2017/04/01)



- IMAGER optical imaging
- TIRCAM2 near-infrared imaging (permanent side-port1)
- ADFOSC low-resolution spectroscopy + camera (main port)
- TANSPEC medium-resolution spectroscopy + camera (main port)
- SPIM optical imaging
- HRS high-resolution spectrograph

2017A-Early-Science

2017A-Early-Science

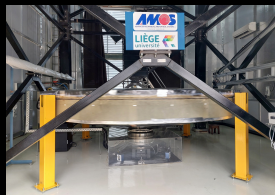
DOT-2020-C1

DOT-2020-C1

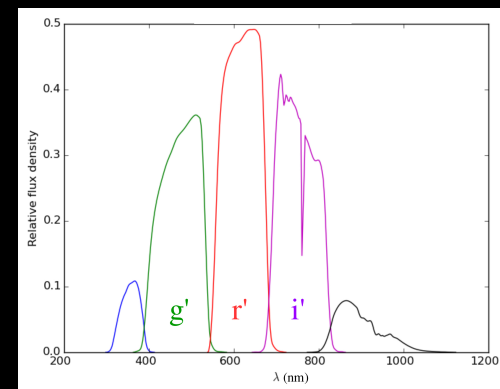
DOT-2025-C1

DOT-2027?

→ 4-m International Liquid Mirror telescope (ILMT) (First light: 2022/04/29; Inauguration: 2023/03/21)



- Rotating container with liquid mercury
- Zenithal telescope
- Nominal phase: 5 years of scientific operations



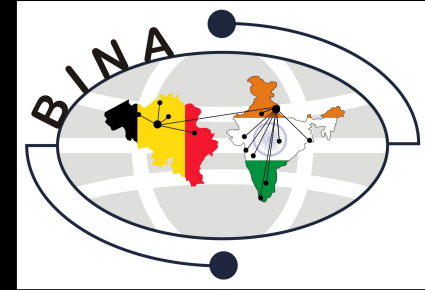
Belgo-Indian Network for Astronomy and astrophysics

- Indo-Belgian telescopes
- Telescopes of interest

→ Access through Indian Partners

- 1.04-m@ARIES = 1.04-m telescope (Nainital, India)
 - ✓ CCD & polarimeter
- 1.3-m@ARIES = 1.3-m Robotic Telescope (Devasthal Observatory, Devasthal, India)
 - ✓ multi-colour photometry
- 2.01-m@IIA = 2.01-m Himalayan Chandra Telescope (Indian Astronomical Observatory, Leh, Ladakh, India)
 - ✓ Himalaya faint object spectrograph, near-IR imager & optical CCD imager
- 2.5-m@PRL = 2.5-m Infrared Telescope (Mount Abu Observatory, Rajasthan, India)
- 1.2-m@PRL = 1.2-m Infrared Telescope (Mount Abu Observatory, Rajasthan, India)
 - ✓ NICMOS Infrared Camera and Spectrograph, Imaging Fabry-Perot Spectrometer, high time resolution Infrared Photometer, Optical Polarimeter, Fibre-linked Grating Spectrograph & high resolution optical spectrometer 'PRL Advanced Radial-velocity All-sky Search'
- GMRT@NCRA-TIFR= Giant Metrewave Radio Telescope (Pune, India)
 - ✓ 30 parabolic 45-m dishes spread over up to 25 km for radio interferometry
- ASTROSAT@ISRO = Satellite (Space)
 - ✓ Ultra Violet Imaging Telescope, Soft X-ray imaging telescope, Large Area X-ray Proportional Counter, Cadmium Zinc Telluride Imager, Scanning Sky Monitor, Charged Particle Monitor (observations from far UltraViolet to hard X-rays)

India's first dedicated
multi-wavelength space
telescope



Belgo-Indian Network for Astronomy and astrophysics

- Indo-Belgian telescopes
- Telescopes of interest

→ Access through Indian partners

→ Access through Belgian partners

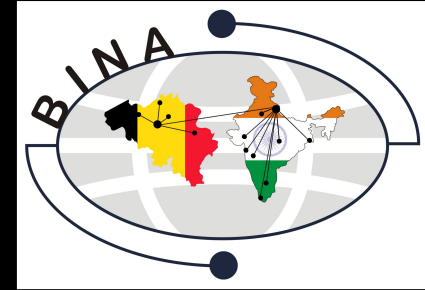
- 1.2-m@KULeuven = 1.2-m Mercator telescope (Roque de los Muchachos Observatory, La Palma, Canary Islands, Spain)
 - ✓ HERMES: high-resolution spectroscopy

Transiting Planets and
Planetesimals Small
Telescope

- 0.6-m@ULiège = 0.6-m TRAPPIST-North telescope (Oukaïmeden Observatory, Maroc)
- 0.6-m@ULiège = 0.6-m TRAPPIST-South telescope (European Southern Observatory, La Silla, Chile)
 - ✓ Multiband photometry (Johnson/Cousins BVRcl, Sloan z, NIR exoplanet filter, NaI, H₂O⁺/OH, NH, CN, CO⁺, C3, BC, C2, GC, RC)

Search for habitable
Planets Eclipsing Ultra-
cool Stars

- 1.0-m@ULiège = 4x1.0-m SPECULOOS-North telescope (Teide Observatory, Tenerife, Canary Islands, Spain)
- 1.0-m@ULiège = 1x1.0-m SPECULOOS-South telescope (European Southern Observatory, Paranal, Chile)
- 1.0-m@ULiège = 1x1.0-m SAINT-EX telescope (National Astronomical Observatory of Mexico, San Pedro Mártin, Mexico)
 - ✓ Camera sensitive in the very-near-infrared
- many@ESO = European Southern Observatory (Chile)



Long term view

Belgian partners

- ROB (Peter De Cat & Laurent Mahy)
- ULiège (Michaël De Becker)
- UAntwerpen
- KULeuven
- ULB



Indian partners

- ARIES (Santosh Joshi)
- DU
- IIA
- IIST
- IUCCA
- KU
- MANUU
- NCRA-TIFR
- NIT-Rourkela
- PRL (Sashikiran Ganesh)
- PRSU
- SNBNCBS
- TIFR
- UOC
- URSC

Belgo-Indian Network for Astronomy and astrophysics

Gather all joint Indo-Belgian initiatives related to astronomy and space science

Network activities

Research visits
Conferences
Workshops
Seminars

PhD students

Post-docs

Outreach Citizen Science

Bharti Arora (ULiège)

Otto Trust (Mbarara, Uganda)

Joint funding?

Science

- Chemically peculiar stars (main-sequence BAF-stars stars with abnormal surface abundances)

→ CP1 (Am/Fm stars)

- Overabundance iron group elements
- Underabundance He, Ca, Sc
- Magnetic field: weak or non-detectable

→ CP2 (Ap stars)

- Overabundance Si, Cr, Sr, and rare-Earth elements (Sr, Cr, Eu, Nd, Pr,...)
- Magnetic field: strong (up to tens of kG)

→ CP3 (HgMn stars)

- Overabundance HgII and/or MnII
- Underabundance light elements (He, Al, N)
- Magnetic field: weak or non-detectable
- Slow rotators

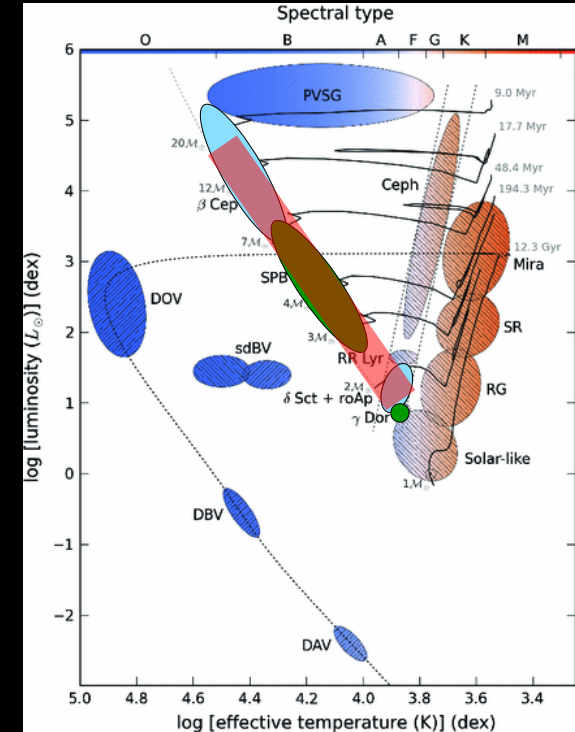
→ CP4 (He weak stars)

- Underabundance HeI
- Magnetic field: moderate (order 1kG)
- Slow rotators

Nainital–Cape survey project

(Ashoka et al. 2000; Martínez et al. 2001; Joshi et al. 2003, 2006, 2009, 2010, 2012, 2016, 2017, 2022, 2025)

Santosh Joshi (ARIES)



Science

Joshi, Dileep, Semenko et al., 2025, MNRAS 554, 640

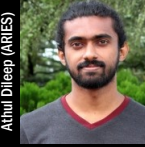
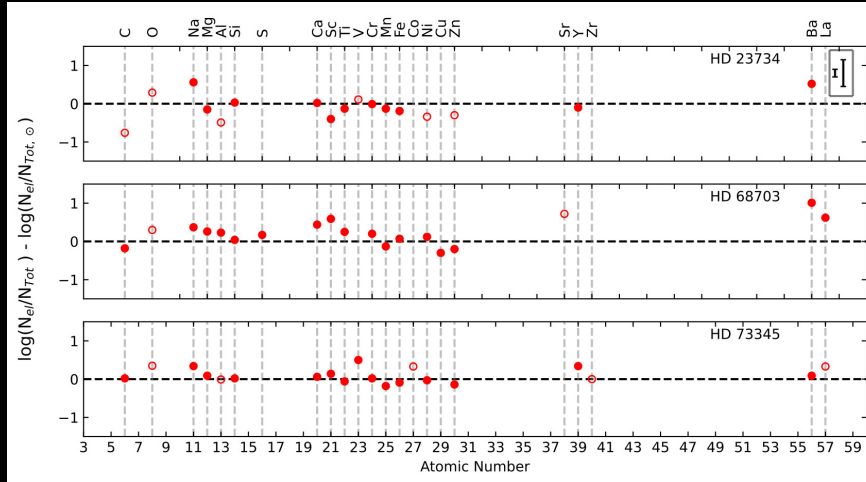
- “Asteroseismology of HD23734, HD68703, and HD73345 using K2-TESS space-based photometry and high-resolution spectroscopy”

- candidate **chemically peculiar stars** in Nainital-Cape survey
- photometry: co-existence of rotational modulation & pulsation
 - radial modes (evidence for preference $n > 1$)
- spectroscopy: likely **chemically normal stars**

- How pure is the CP classification within the Nainital-Cape survey?

Spectroscopic Tracking and Abundance Research Survey of Chemically Peculiar stars (STARS-CP)

- one high-resolution spectrum with SNR ~ 100
 - Fundamental stellar parameters
 - Detailed abundance analysis
 - Evidence for binarity (multiple lines)
 - Evidence for pulsational/rotational modulation (line asymmetries)
- few follow-up spectra with SNR ~ 30
 - Search for and study of multiple systems (radial velocities)

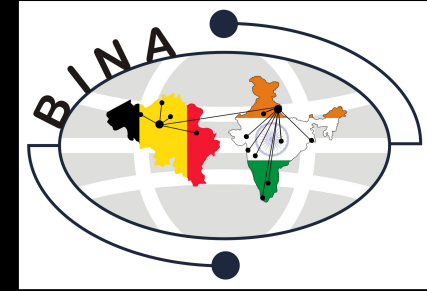
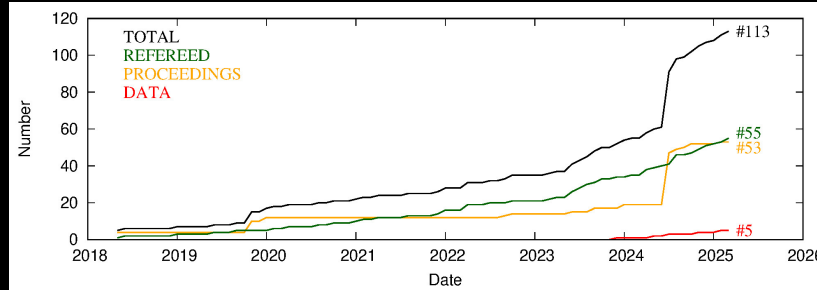


Connection Belgium – India

BINA

Science

● Publications



2024/11/4-7

4th BINA workshop (Calicut, India)

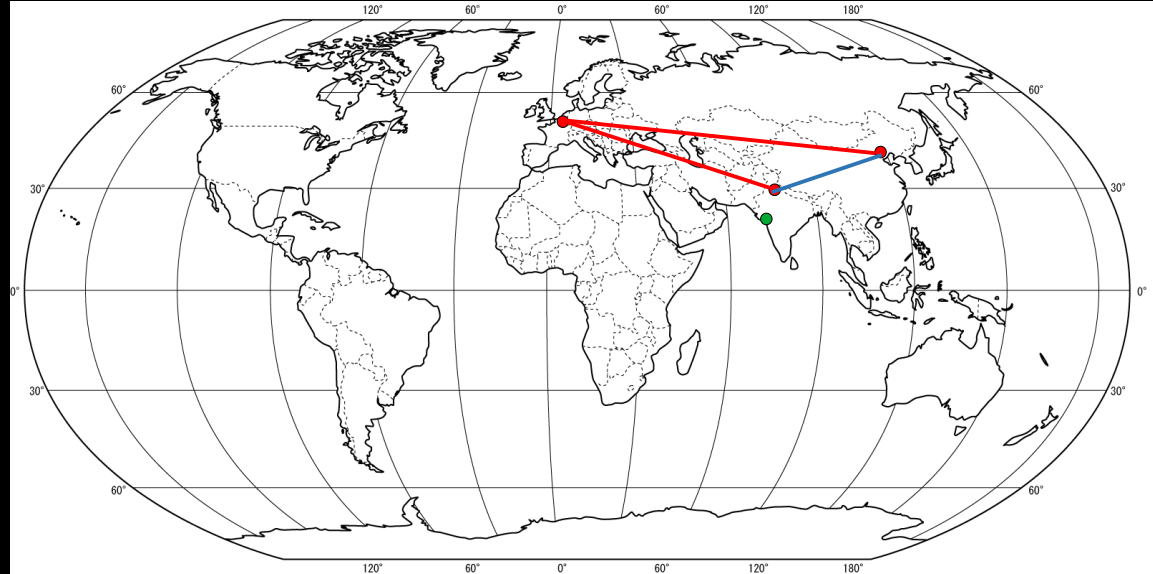
"Moving forward with the Indo-Belgian Cooperation in Astronomy"



- Instrumentation ULiège – ROB – ARIES
- Solar physics ROB – ARIES - PRL
- Solar system objects ULiège – PRL
- Exoplanets ROB – ARIES and ULiège – PRL
- Peculiar stars ROB – ULiège - ARIES
- Multiple systems ROB – ARIES
- Abundances ULB – UOC - IIA
- Massive stars ULiège – IIST
- Star forming regions
- Compact objects
- Transients ULiège – ARIES - PRL
- Extragalactic astrophysics

Outline

1. Scientific background
2. Connection Belgium – China
3. Connection Belgium – India
4. Conclusions and future prospects



Conclusions and future prospects

Take away messages

- Network activities are extremely important
 - New collaborations
 - Random encounters can lead to the start of new scientific endeavours
 - New scientific ideas
 - Deepen your view
 - Broaden your view
 - Meet your peers
 - It might open opportunities in the future
 - Present your results (write papers, progress results for collaborators, talks at international conferences)
 - Treat your colleagues as your collaborators (not as your opponents) because $1 + 1 > 2$
- Know your own strengths and weaknesses
 - Use your strong points and keep them strong
 - Search for collaborators to improve your weak points
- Work to live (not live to work)
 - Take time to reload and relax

Conclusions and future prospects

Take away messages

- Network activities are extremely important
 - New collaborations
 - Random encounters can lead to the start of new scientific endeavours
 - New scientific ideas
 - Deepen your view
 - Broaden your view
 - Meet your peers
 - It might open opportunities in the future
 - Present your results (write papers, progress results for collaborators, talks at international conferences)
 - Treat your colleagues as your collaborators (not as your opponents) because $1 + 1 > 2$
- Know your own strengths and weaknesses
 - Use your strong points and keep them strong
 - Search for collaborators to improve your weak points
- Work to live (not live to work)
 - Take time to reload and relax

Thank you for your attention!

