Chance encounters in asteroseismology

Their impact on a scientific career

Peter De Cat

Royal Observatory of Belgium (Brussels, Belgium)

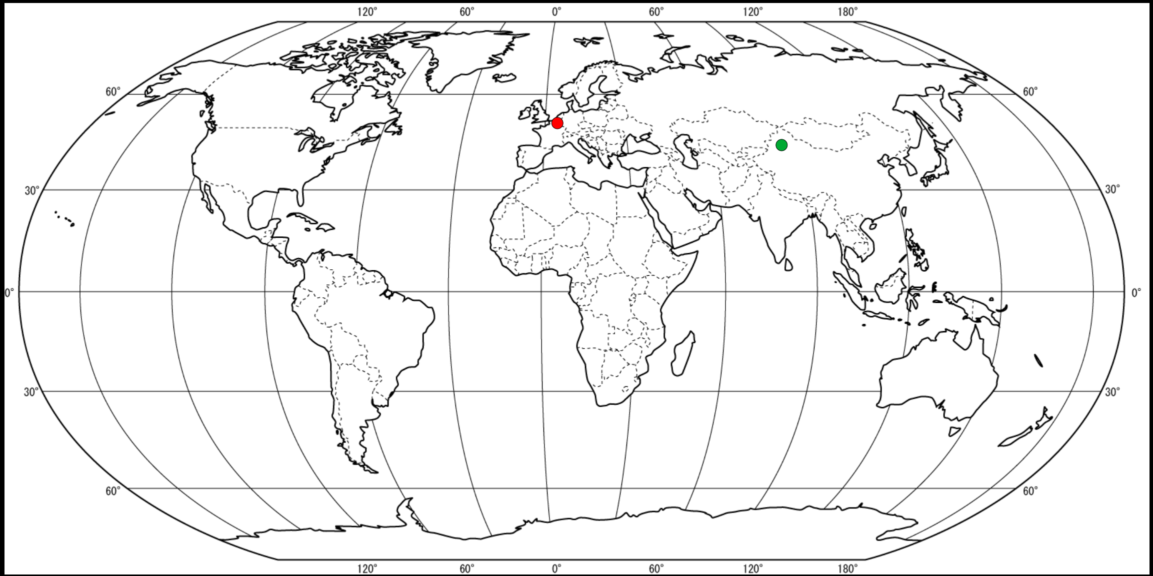
Personalia

- Date of Birth: 19/06/1974
- Sex: male (he/him)
- Martial status: married
- Children: Sien De Cat (29/01/2004)
  Nele De Cat (19/02/2007)
  Lore De Cat (19/02/2007)
- Affiliation: Royal Observatory of Belgium
  Ringlaan 3
  B-1180 Brussels
  Belgium
- E-mail: Peter.DeCat@oma.be

H-index: 44
- 122 papers in international refereed journals (7)
- 5 papers in international non-refereed journals
- 94 papers in proceedings of international conferences (21)

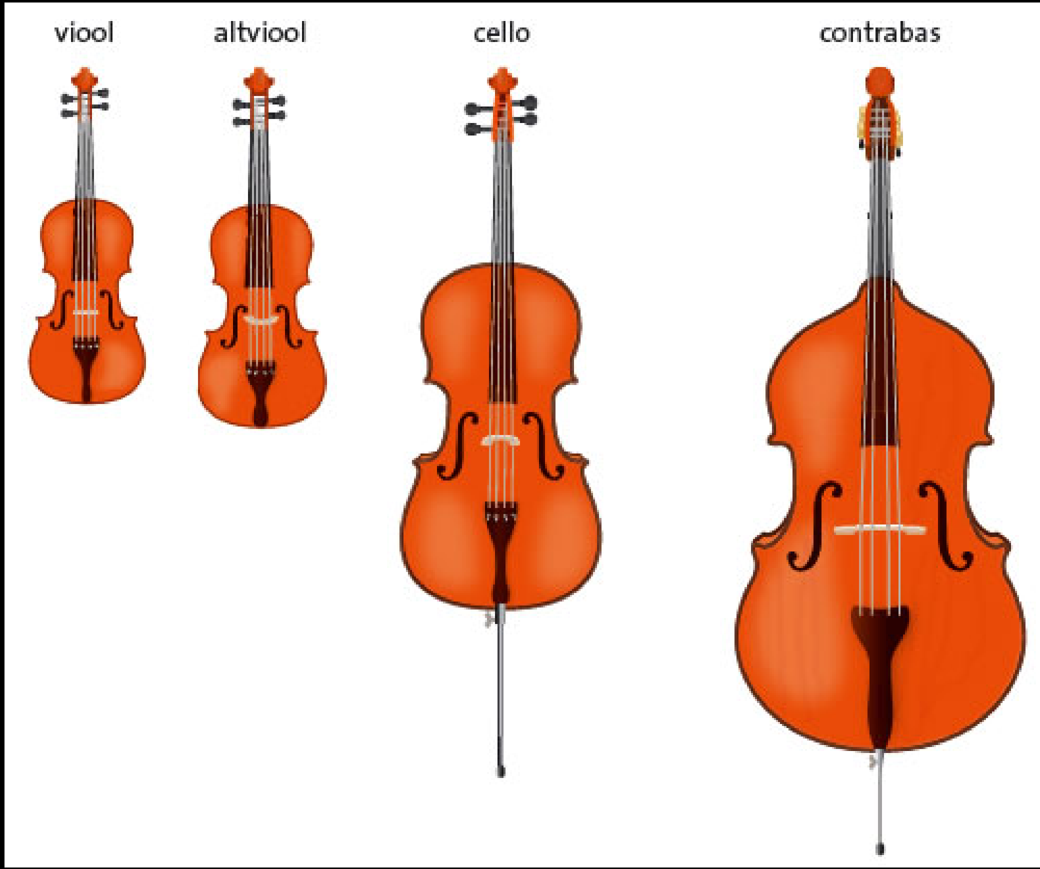
Outline

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



Musical instruments

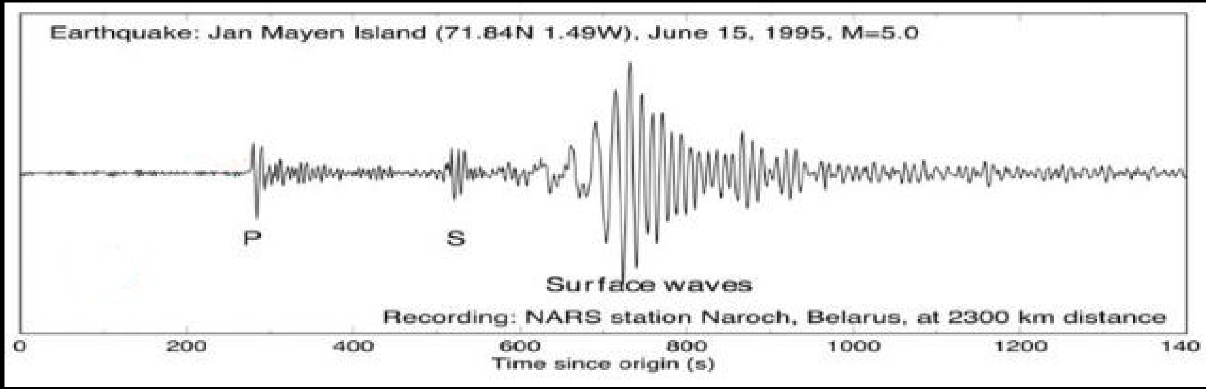
shape and material determines
the sound of the instrument



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,...

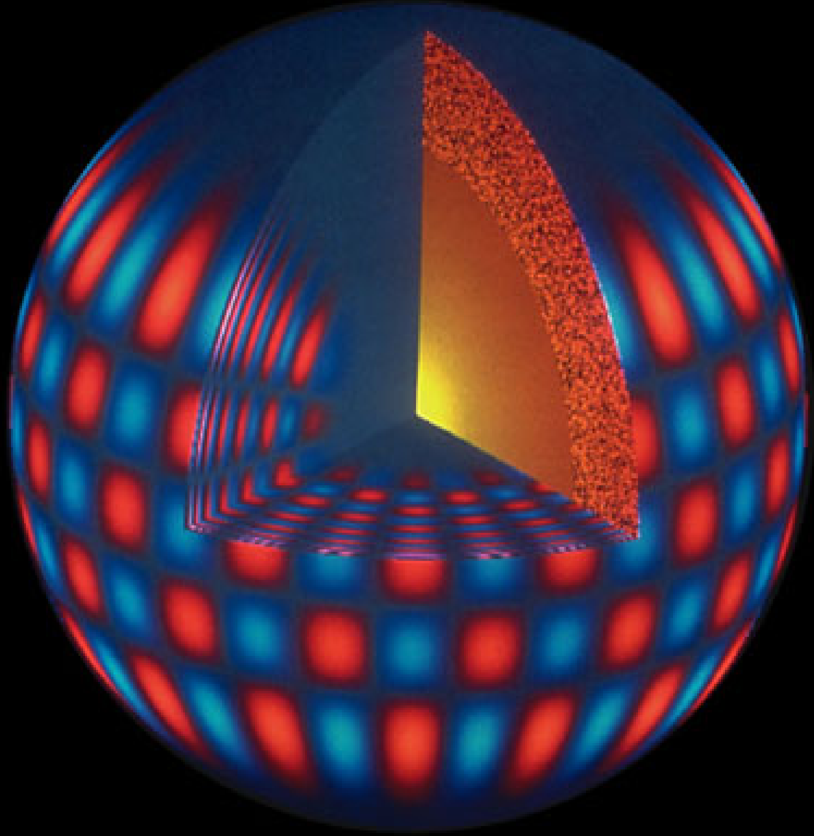
→ Convection
- size convective layers
- convective overshoot

→ Rotation
- surface versus core
- rigid versus differential

→ Internal mixing

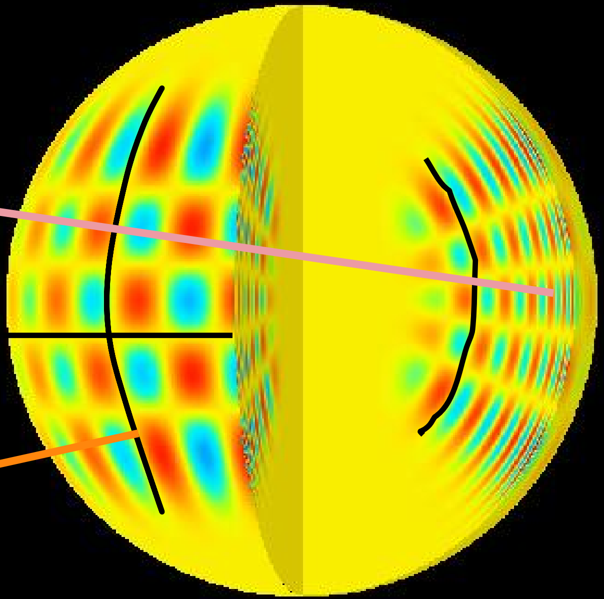
→ Diffusion

→ Internal structure
- layers
- composition



Pulsations

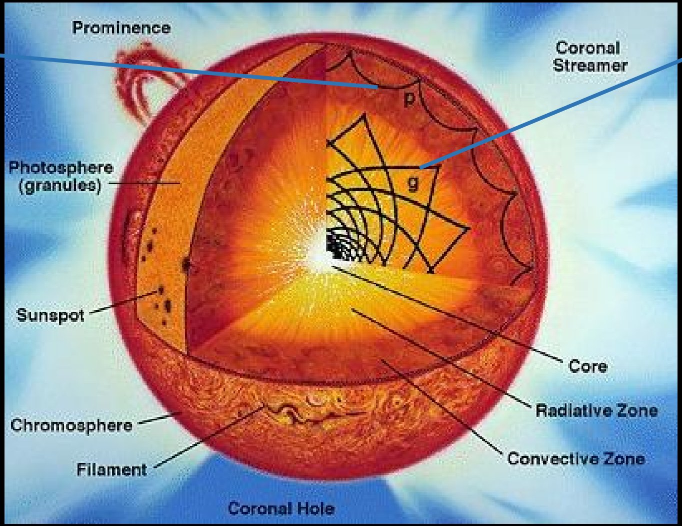
- f = frequency
- n = number of nodesurfaces between center and surface
- ℓ = total number of nodelines on surface
  - → $\ell = 0$: radial mode
  - → $\ell > 0$: non-radial mode
- $|m|$ = number of nodelines perpendicular to equator on surface
  - → $|m| \leq \ell$
  - → $m > 0$: prograde mode
  - →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

Asteroseismology

Pressure modes (p-modes)

- Restoring force: pressure
- Short periods
- Cavity near surface
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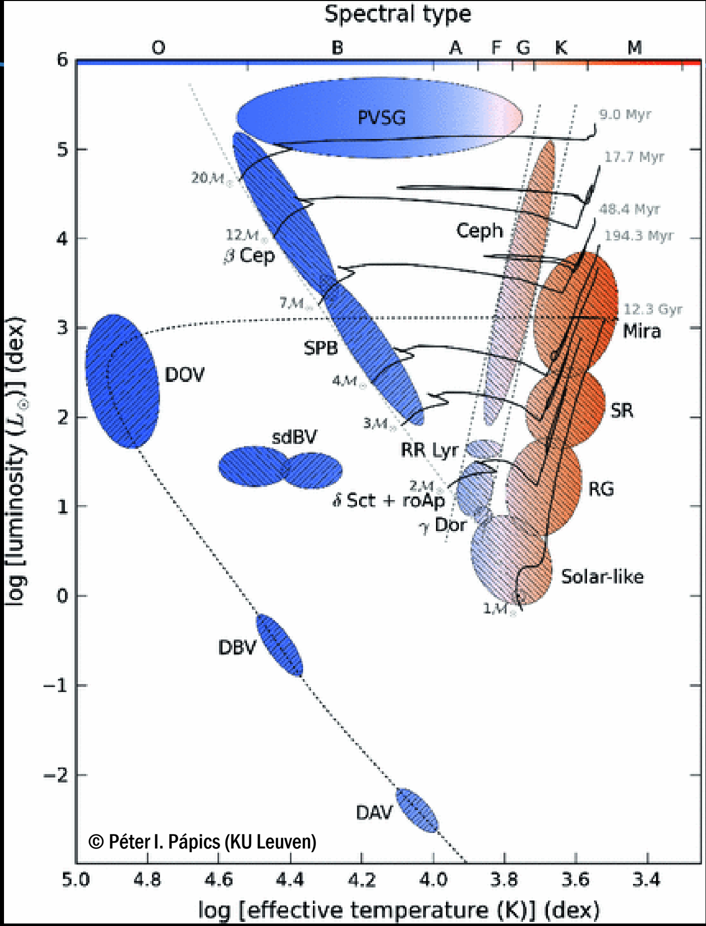
- \\\\



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2024/10/10, Xinjiang Astronomical Observatory (Ürümqi, China)

Asteroseismology

Pressure modes (p-modes)

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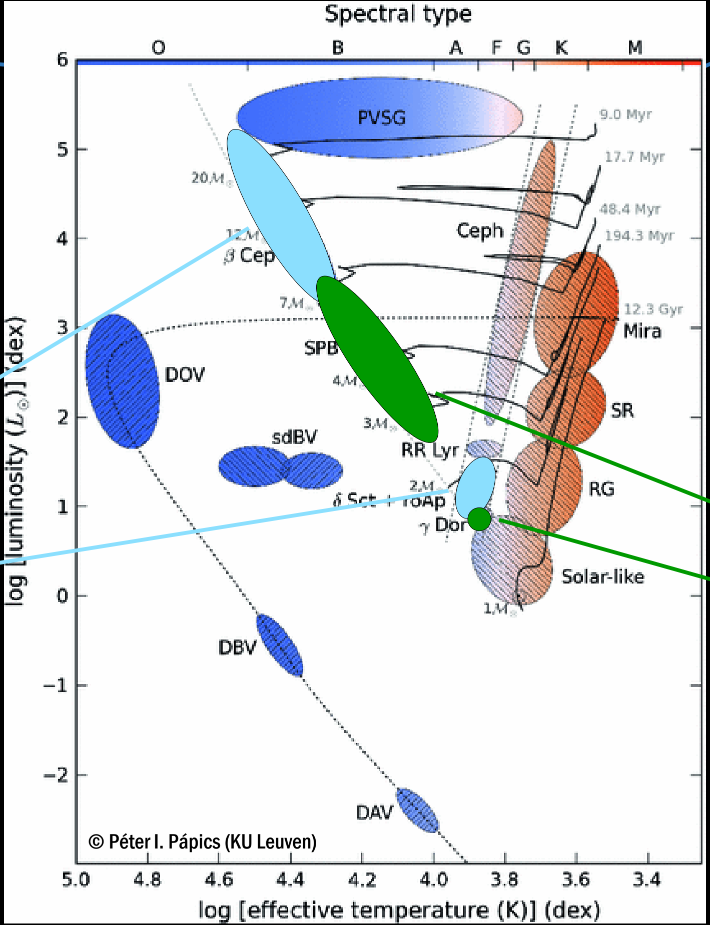


Gravity modes (g-modes)

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

β Cephei stars (βCep)

δ Scuti stars (δSct)

- Periods order of hours

(0.3-10 hours)

Slowly pulsating B stars (SPB)

γ Doradus stars (γDor)

- Periods order of days

(0.3-3 days)

What do we need?

- Star without rotation

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

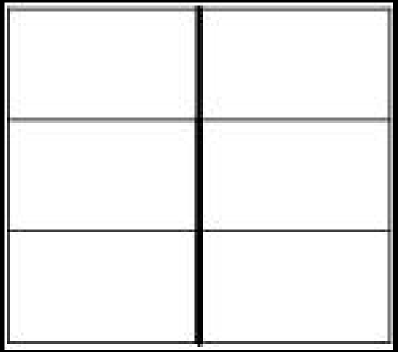
- Star with rotation

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

$\Longrightarrow$ **frequency multiplets** (Ledoux & Walraven 1958)

βCep δSct $C_{n,l} \approx 0$

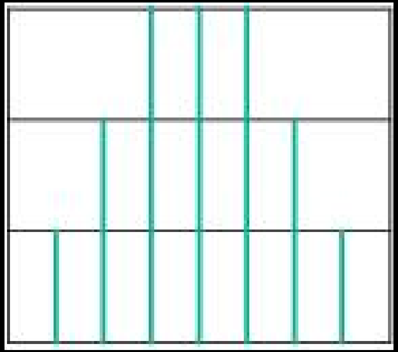
SPB γDor $C_{n,l} \approx \frac{1}{\ell(\ell+1)}$ + 2nd order term

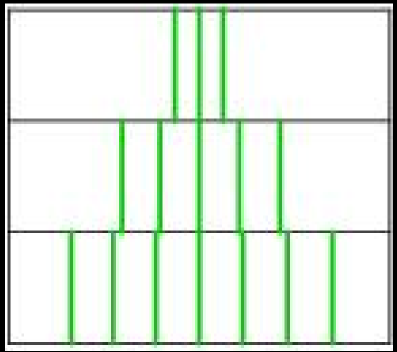


$\ell = 1$

$\ell = 2$

$\ell = 3$



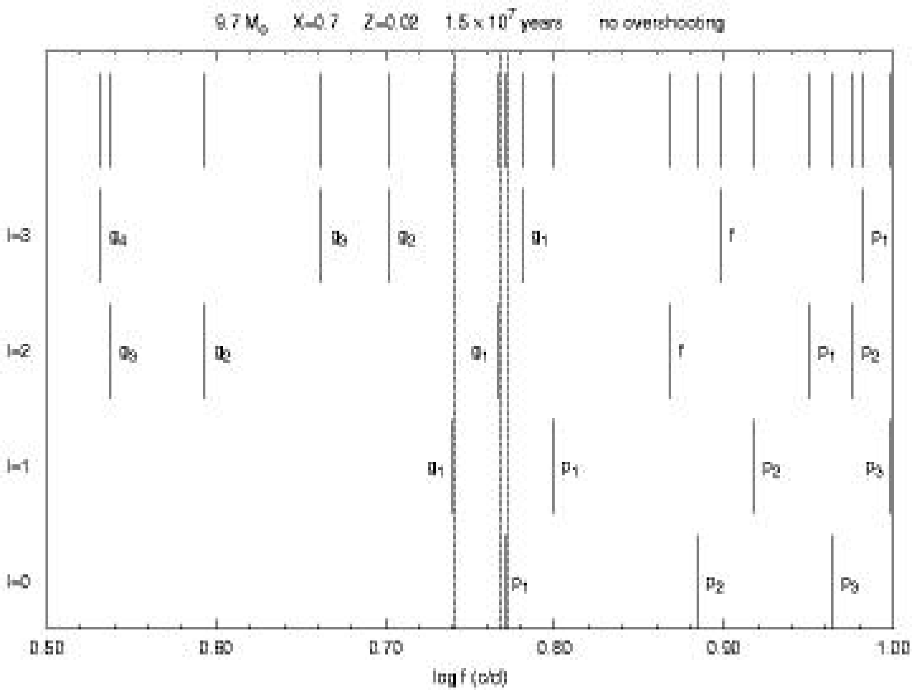


KSB - ORB

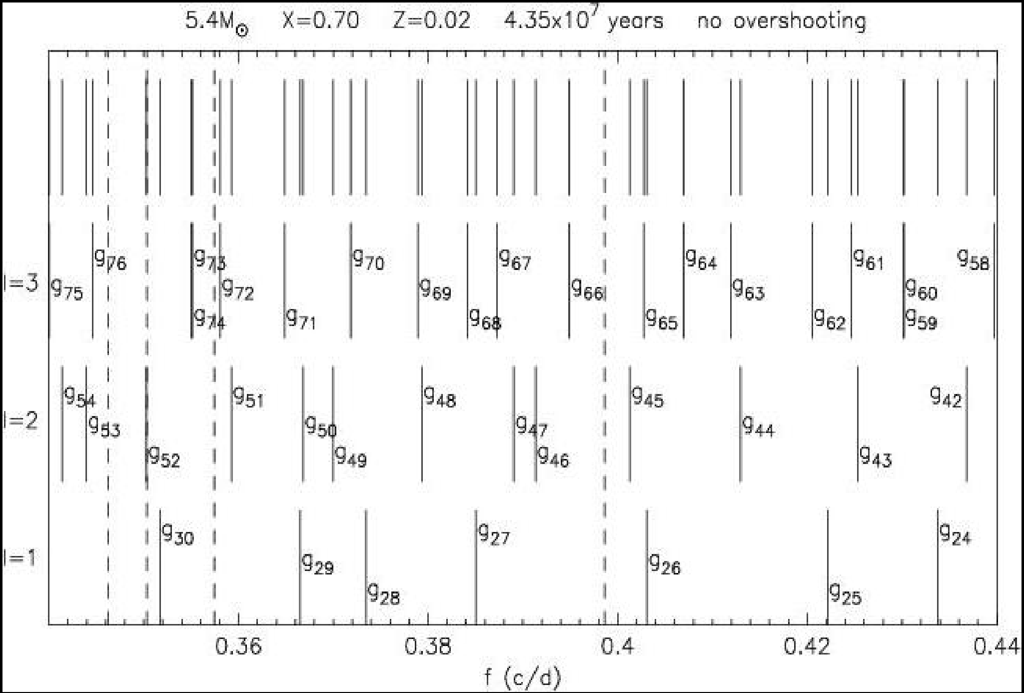
Peter De Cat (Royal Observatory of Belgium, Ringlaan 3, B-1180 Brussels, Belgium; Peter.DeCat@oma.be)
2024/10/10, Xinjiang Astronomical Observatory (Ürümqi, China)

What do we need?

- p-modes βCep star 16 Lacertae
  → Sparse frequency spectrum
- g-modes SPB star ο Velorum
  → Dense frequency spectrum



7 d^{-1}



0.1 d^{-1}

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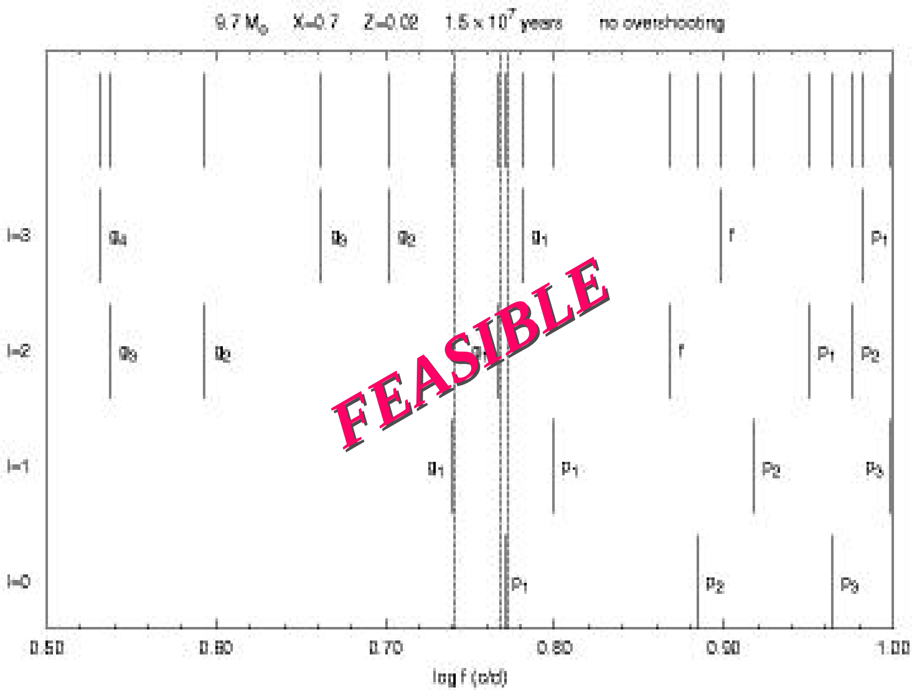
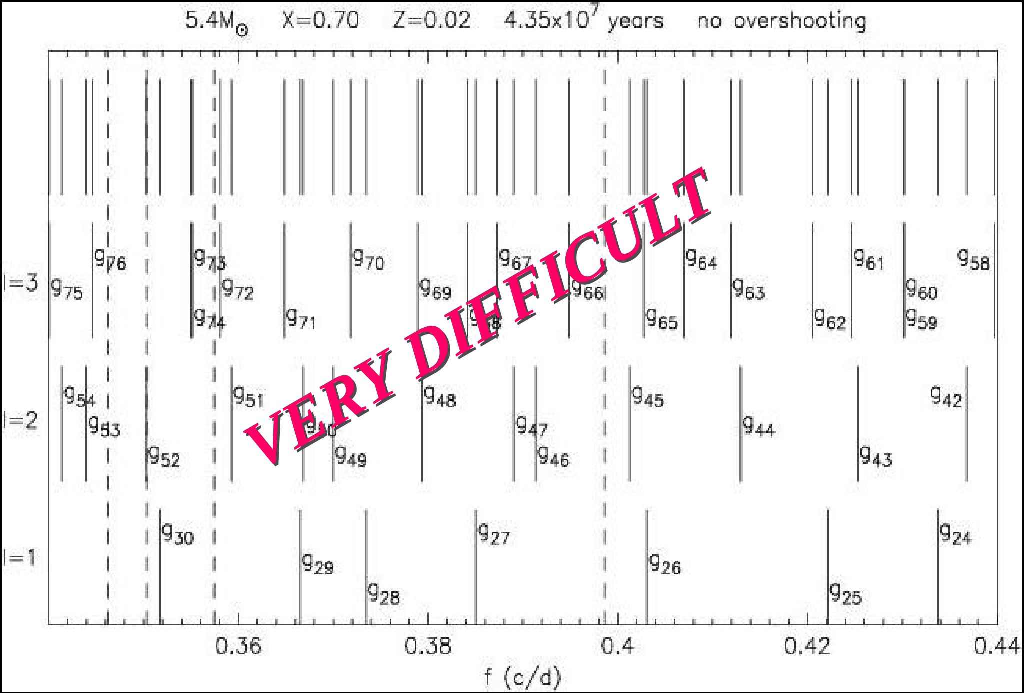


7 d^{-1}

no rotation



0.1 d^{-1}

What do we need?

- Many observed pulsation frequencies
- Frequency multiplets

Frequency analysis

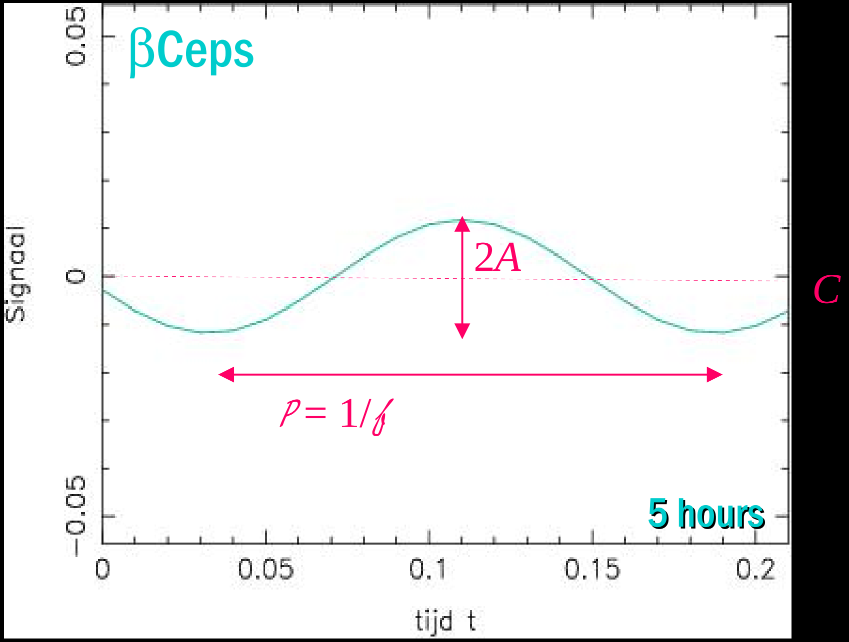
- Know which pulsation modes cause the observed variations

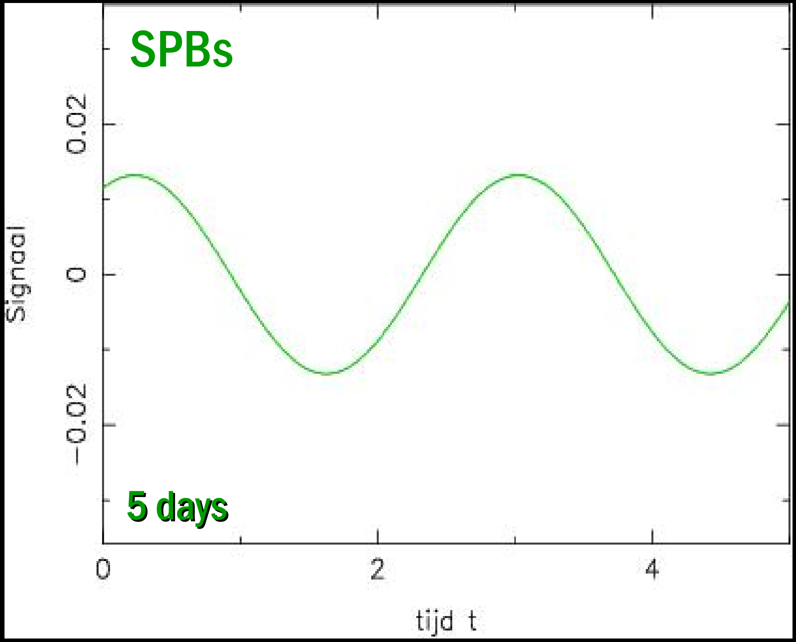
Mode identification

What do we observe?

- Time base
  - → Mono-periodic pulsator

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



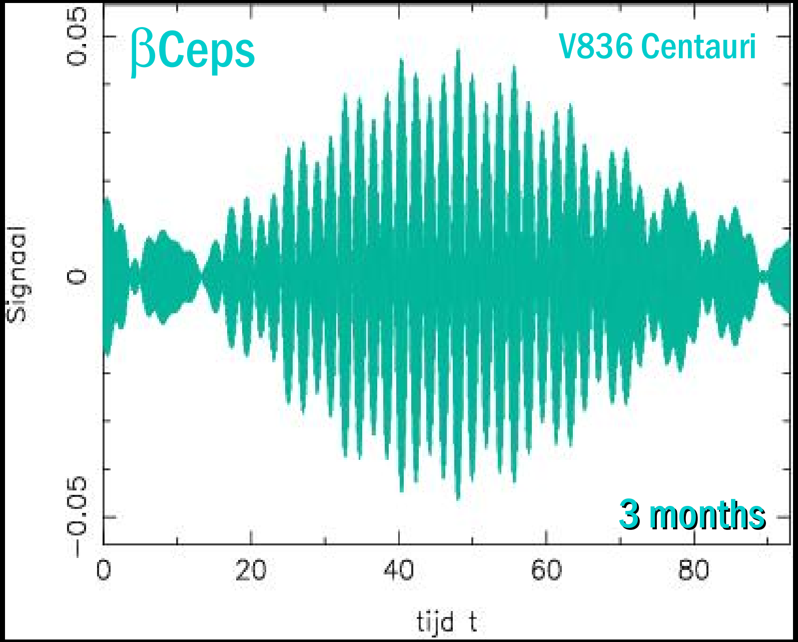


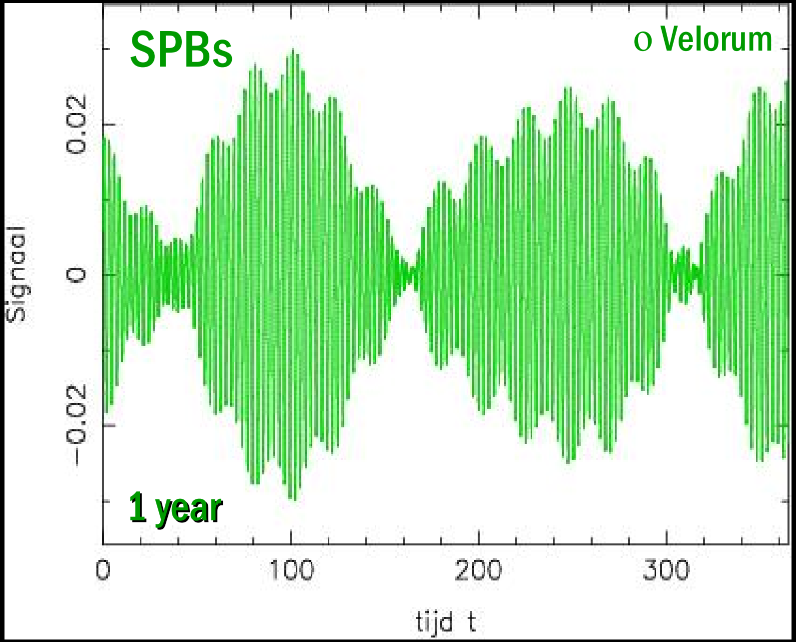
What do we observe?

- Time base

  → Mulit-periodic pulsator

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

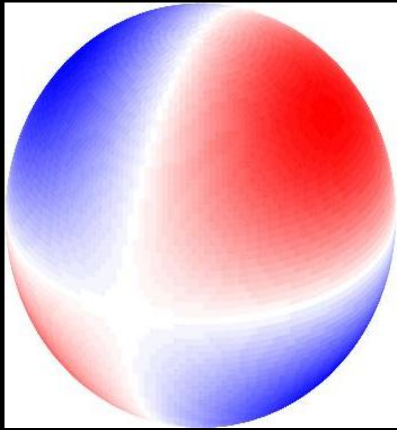


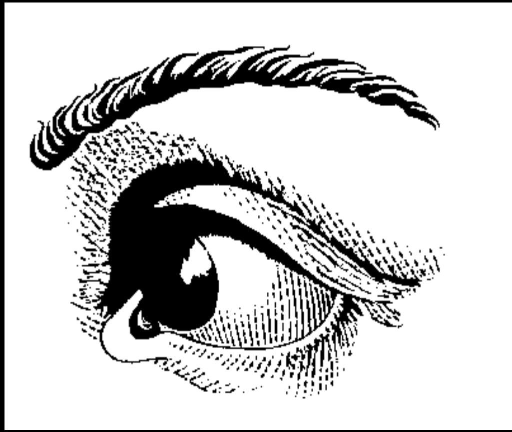


What do we observe?

- Instrument
  - → Naked eye

accuracy ~ 0.1 mag





eye (backyard)
~ 5 to 7 mm

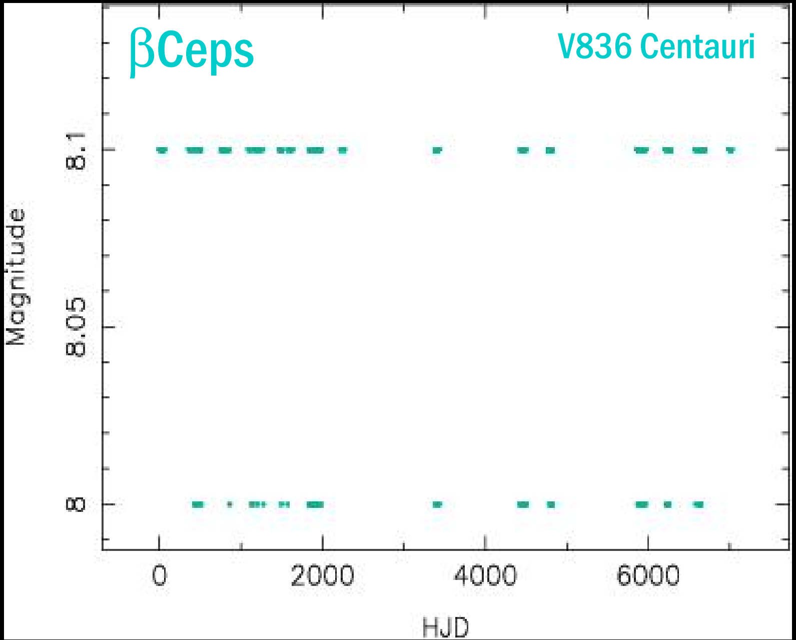
in 1 filter
(individual)

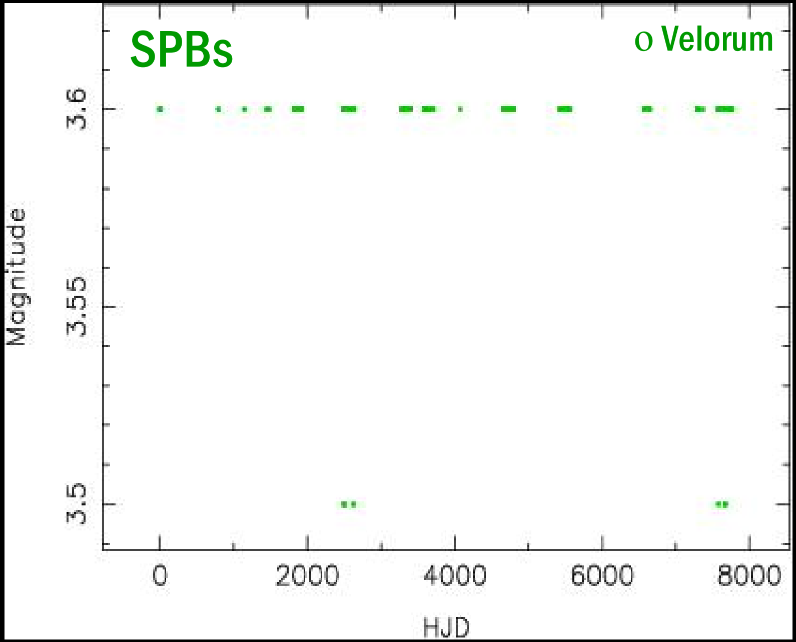
What do we observe?

- Instrument

  → Naked eye

accuracy ~ 0.1 mag





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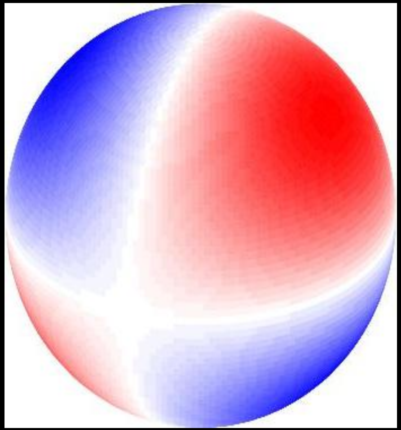
Peter De Cat (Royal Observatory of Belgium, Ringlaan 3, B-1180 Brussels, Belgium; Peter.DeCat@oma.be)

What do we observe?

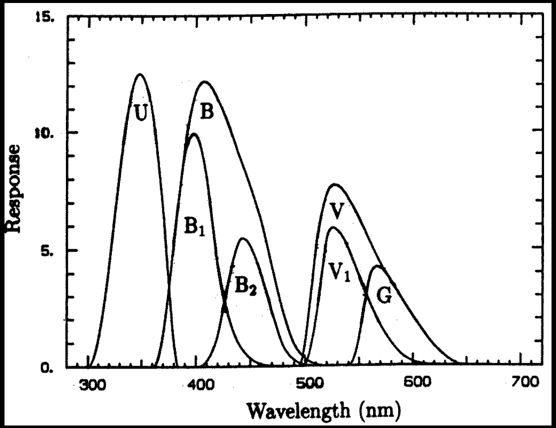
- Instrument

  → Photometer

accuracy ~ 0.005 mag



P7



Mercator telescope (La Palma)
~1.2 m

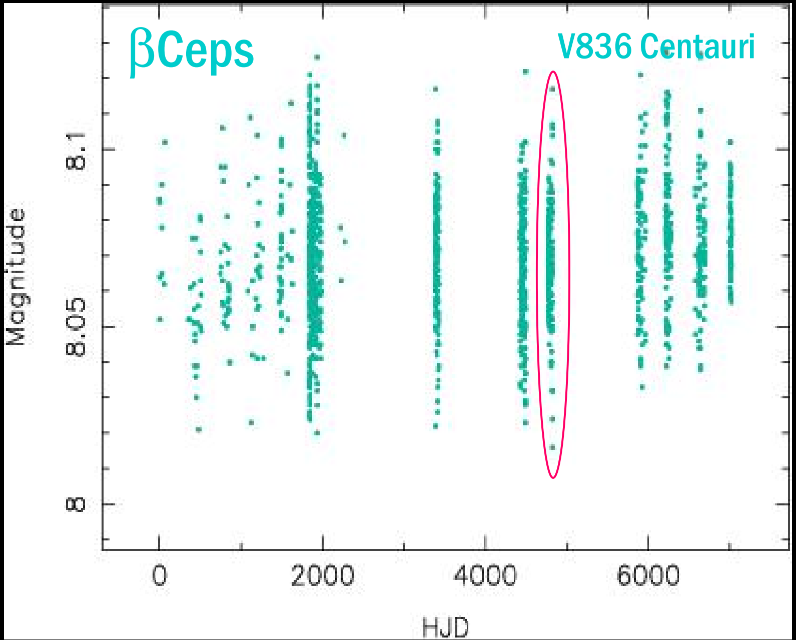
simultaneous in 7 filters
(very stable)

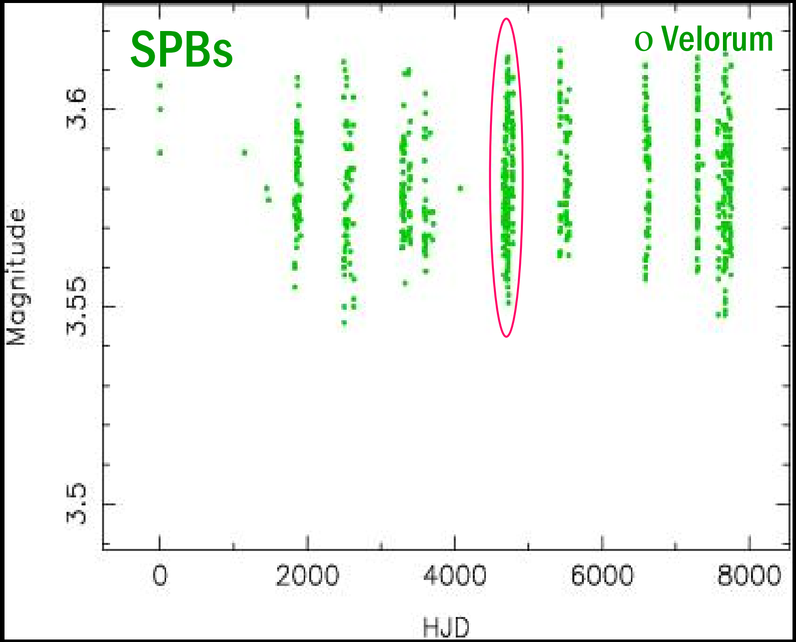
What do we observe?

- Instrument

  → Photometer

accuracy ~ 0.005 mag





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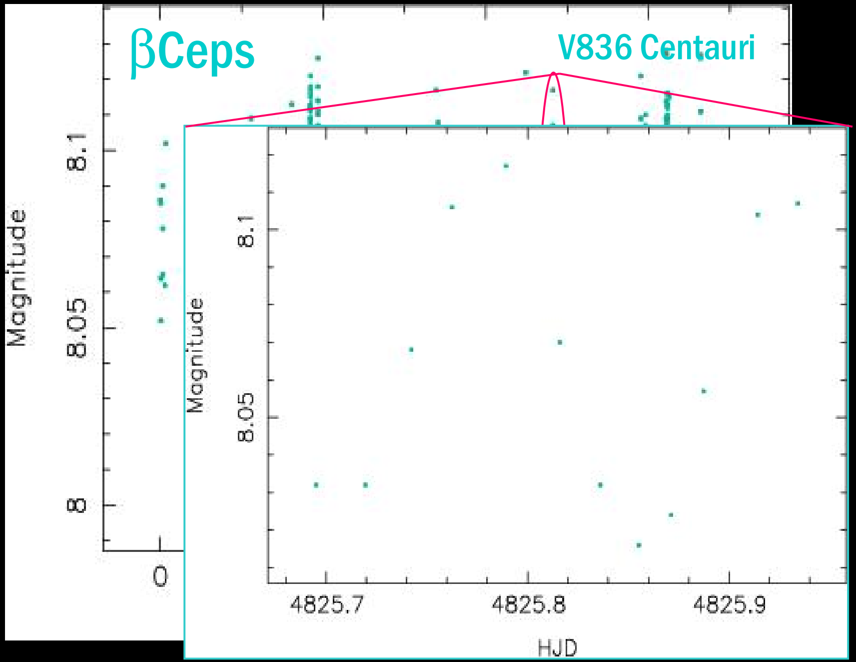
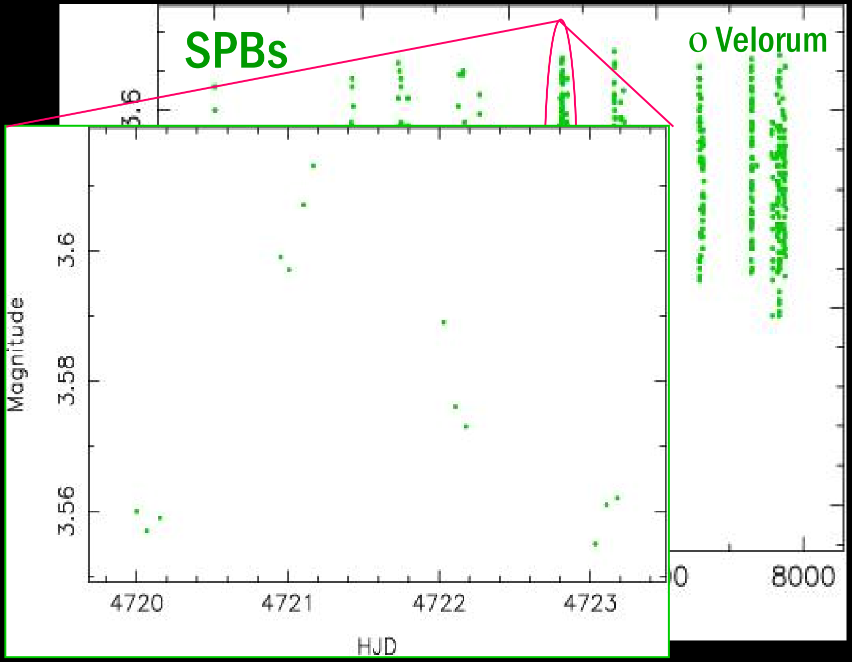
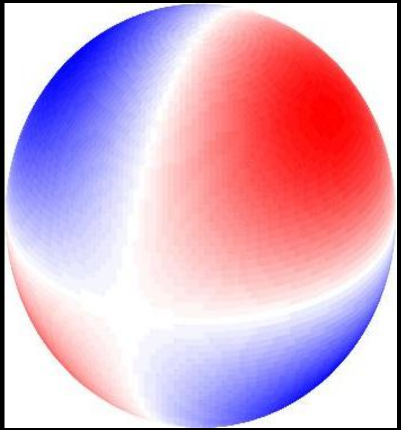




What do we observe?

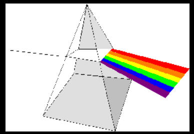
- Instrument

→ Spectrograph

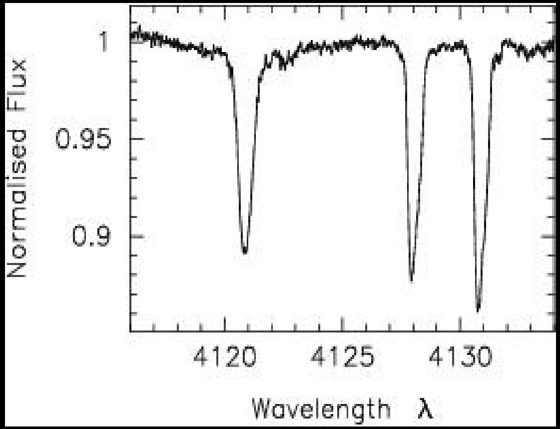


CAT telescoop (La Silla)

~ 1.4 m



CES



details of spectrum

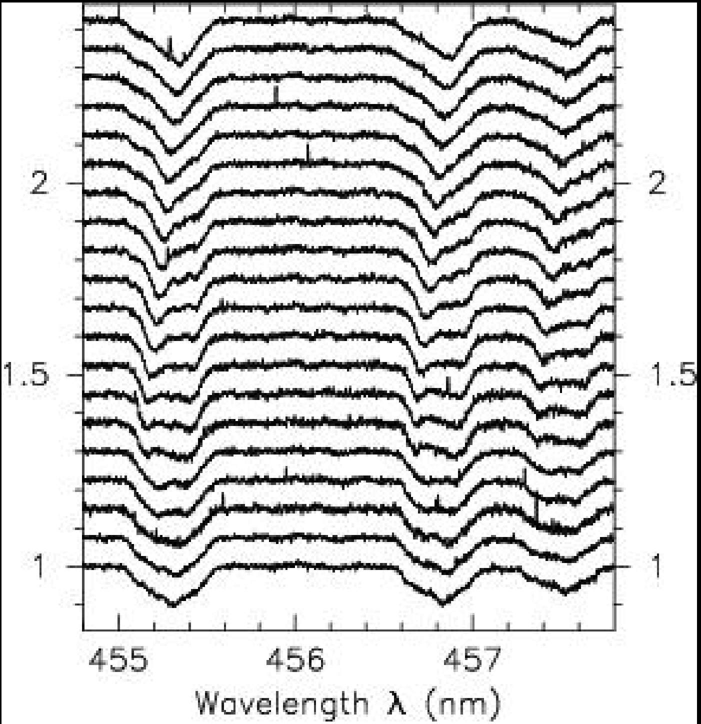
time series

line profile variations

What do we observe?

- Instrument

→ Spectrograph



βCeps

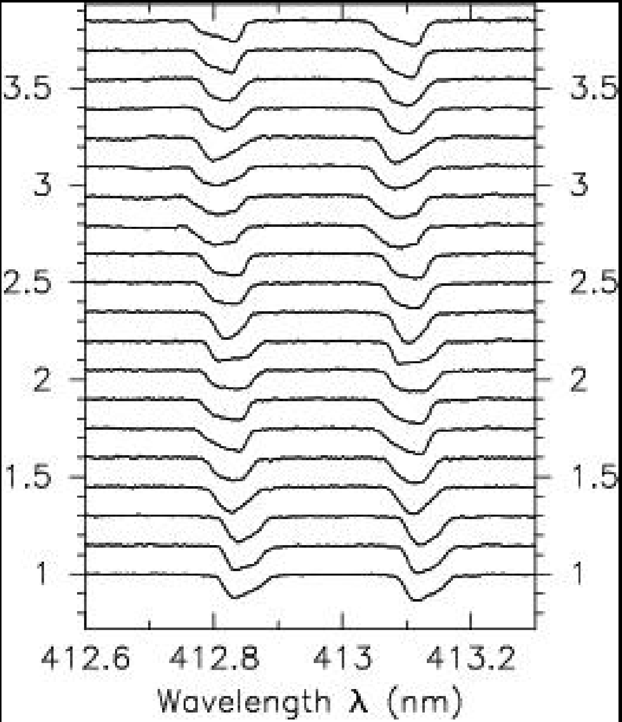
ε Persei (HD 24760)

456 nm SiIII-triplet

SPBs

33 Eridani (HD 24587)

413 nm SiII-doublet



What do we observe?

- Photometry
  - → Accuracy of few millimagnitudes
  - → In sever filters
- Spectroscopy
  - → High resolution
  - → High signal-to-noise
  - → Well-chosen line profile

Long enough time base

Peter De Cat (Royal Observatory of Belgium, Ringlaan 3, B-1180 Brussels, Belgium; Peter.DeCat@oma.be)

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- Photometry
  - → Accuracy of few micromagnitudes
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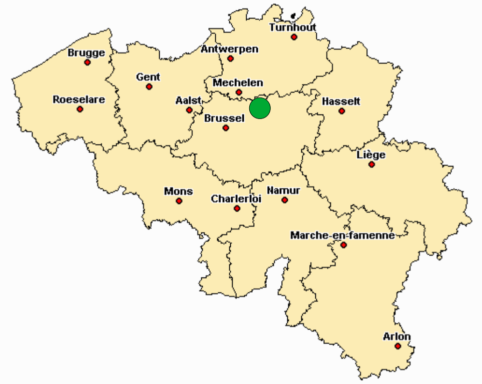
Long enough time base

Scientific background

KU Leuven

- Master student (physics)



KU Leuven

- Master student (physics)

Conny Aerts

Francqui award (2012)
Kavli prize in astrophysics (2022)

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)

Aerts, De Cat, Cuypers et al., 1998, A&A 329, 137

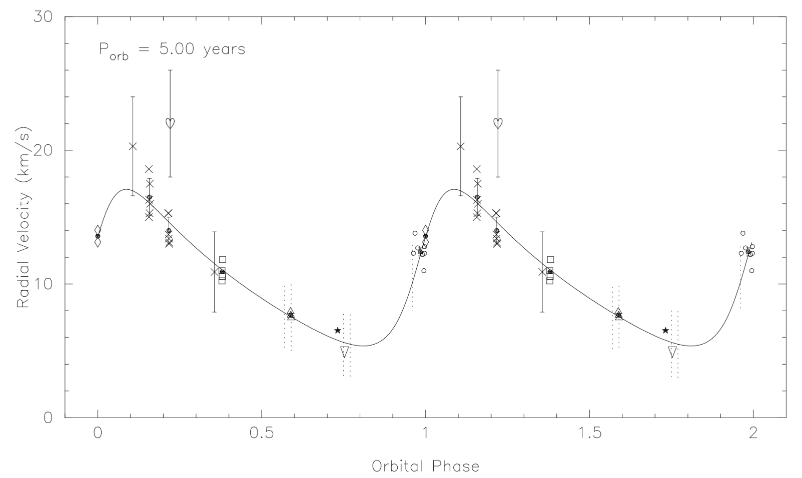
Multiperiodic pulsator

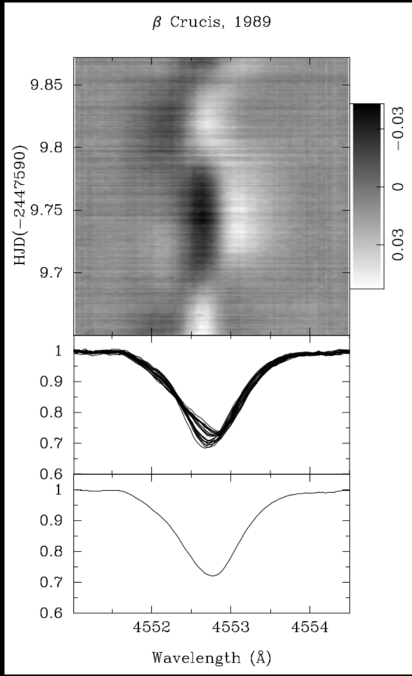
- f_1 = 5.2305468 d^{-1} (ℓ = 1)
- f_2 = 5.958666 d^{-1} ($\ell \geq 3$)
- f_3 = 5.472165 d^{-1} ($\ell \geq 3$)

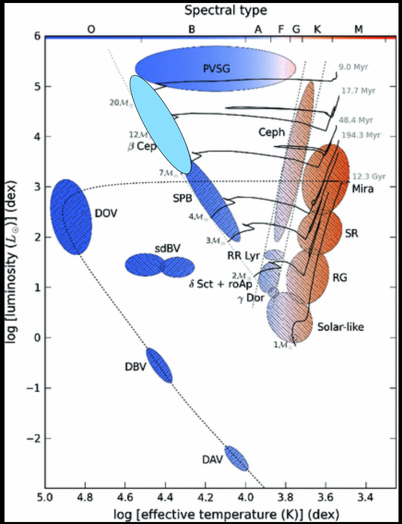
(moment method)

Single-lined binarity

- P_{orb} = 1828.0(25) 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

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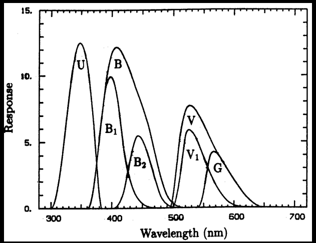
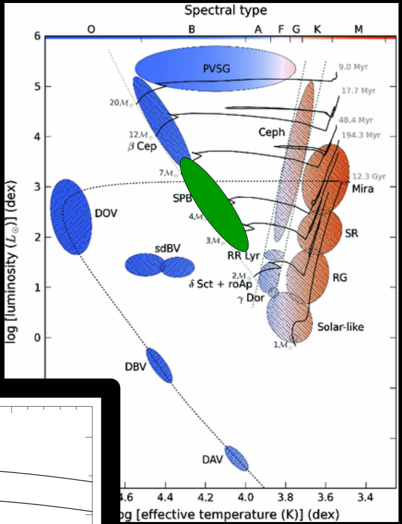
- PhD student (physics, group astronomy)

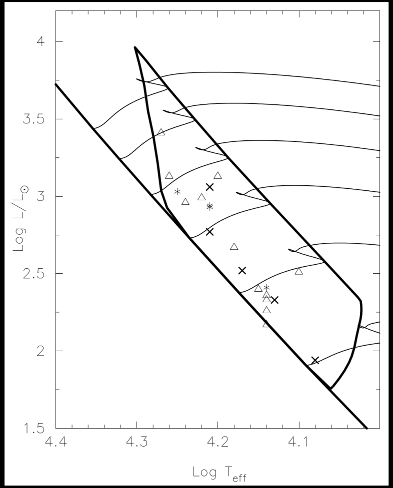


→ A study of bright southern slowly pulsating B stars

- 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 (SiII 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





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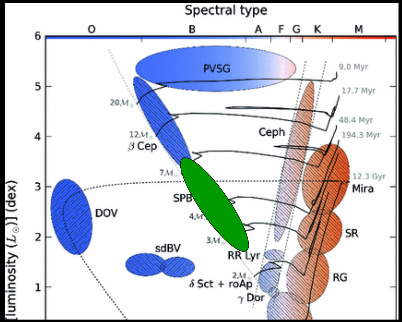
- PhD student (physics, group astronomy)

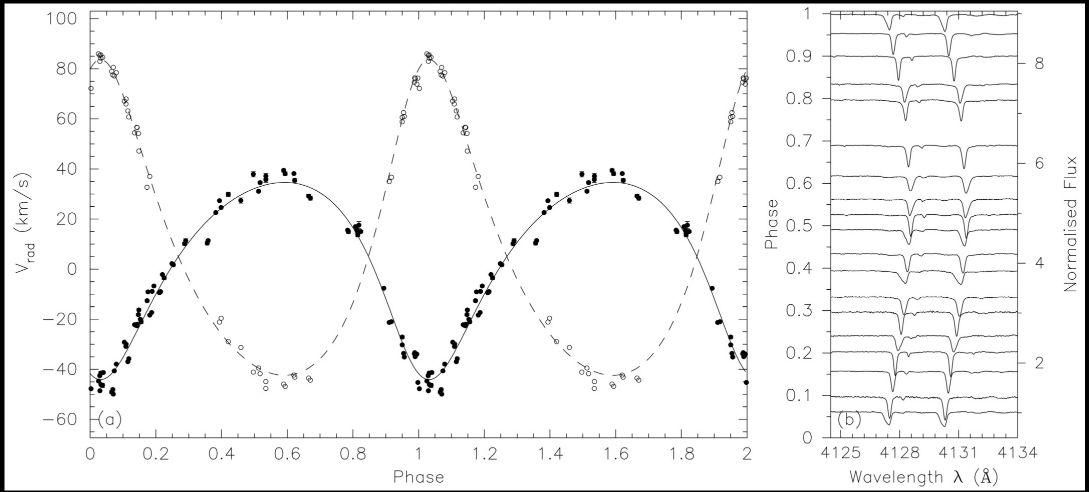
→ A study of bright southern slowly pulsating B stars

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

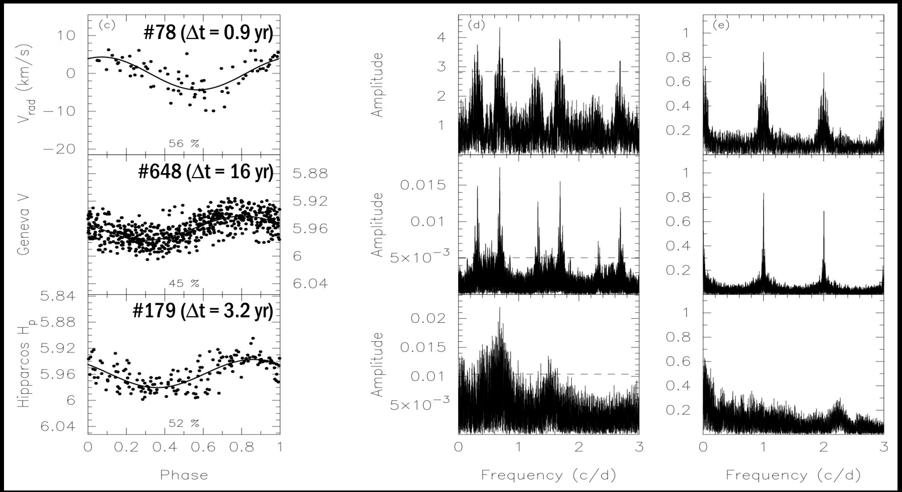
De Cat, Aerts, De Ridder et al., 2000, A&A 355, 1015



SPB star HD123515



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



KU Leuven

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

→ A study of bright southern slowly pulsating B stars

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

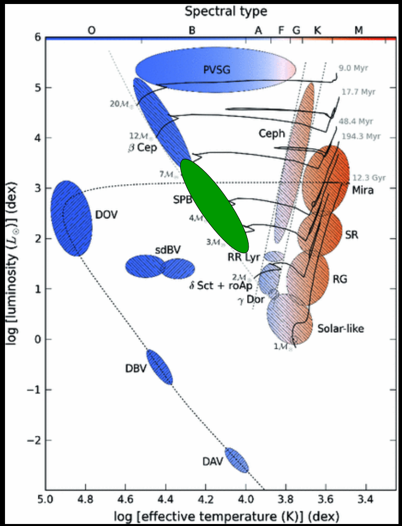
De Cat, Aerts, De Ridder et al., 2000, A&A 355, 1015

II. The instrinsic frequencies

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

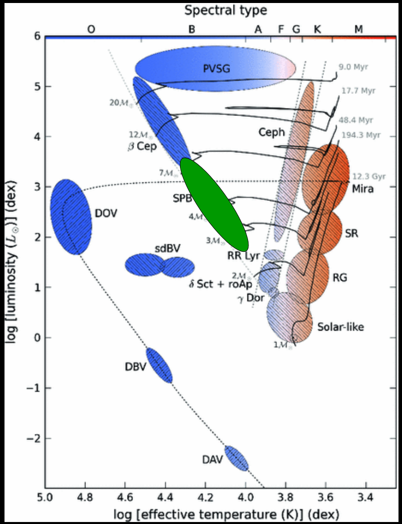
III. Mode-identification for singly-periodic targets in spectroscopy

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

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)

UC UNIVERSITY OF CANTERBURY Te Whare Wānanga o Waitaha CHRISTCHURCH NEW ZEALAND

Karen Pollard

Royal Observatory of Belgium

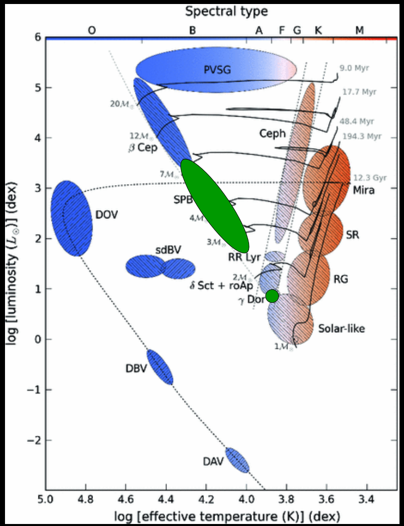
- Rotation and pulsations in main-sequence gravity mode pulsators (SPB and γDor stars)

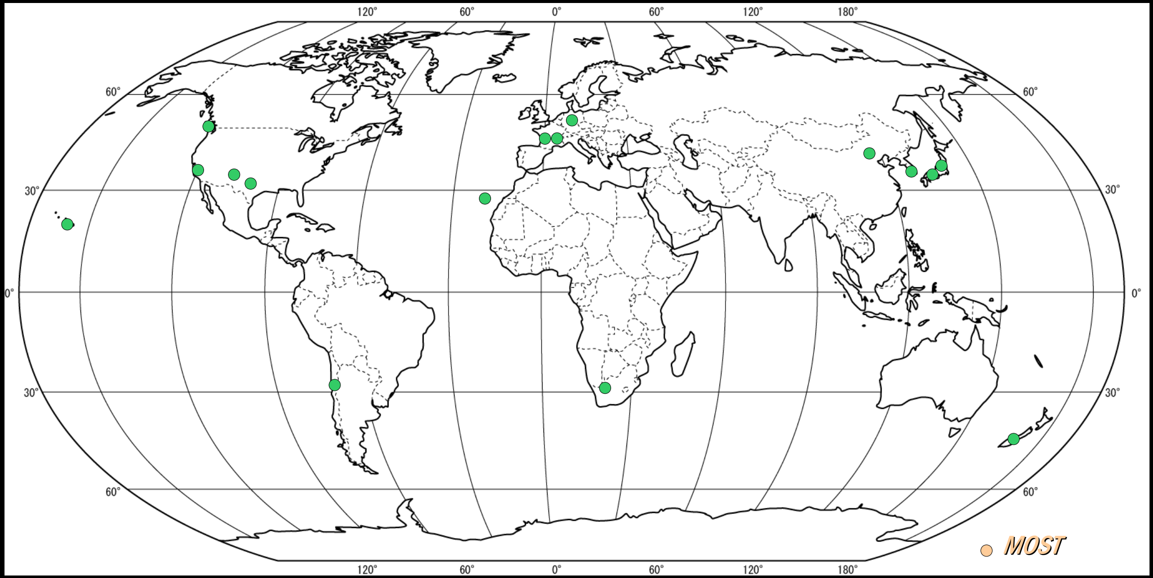
effect of rotation on pulsations?
→ isolated spectra for $v\sin i$ determination
→ spectroscopic multi-site campaigns
- ➢ 16 ground-based and 1 space-based observatories
- ➢ >11,000 high-resolution spectra

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

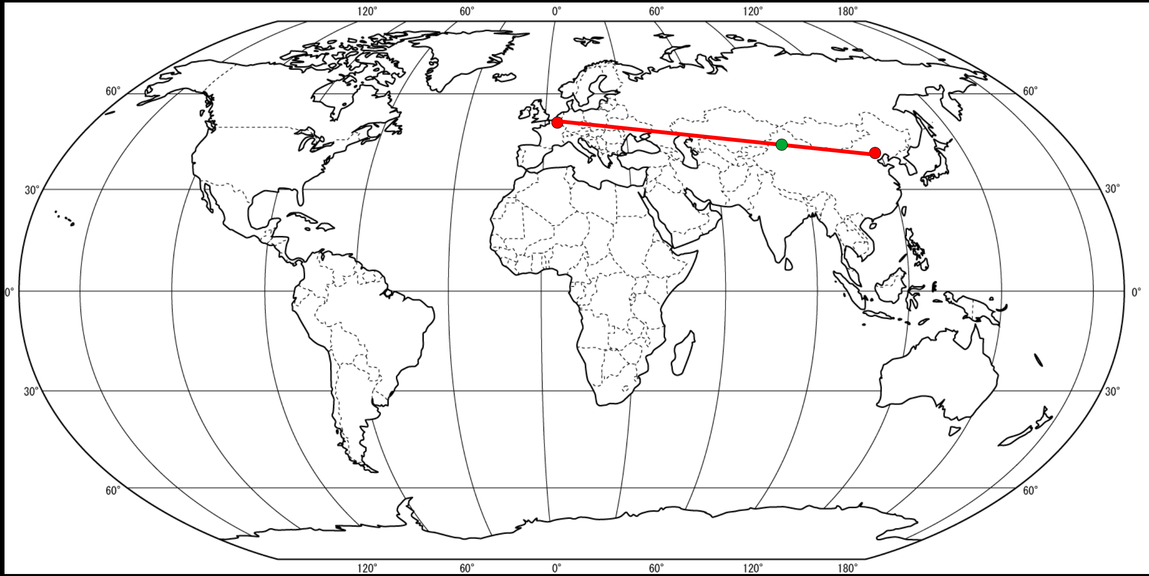

Duncan J. Wright


Ádám Sódor


21 days HD25558 (SPB star)
47 days HD218396 (γDor star)

Outline

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



Connection Belgium - China – Italy – Poland - USA   LAMOST-Kepler

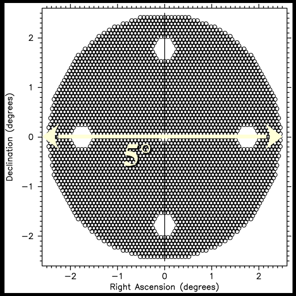
→ 2003/10/20: first contact with Jianning Fu (Dubrovnik, Croatia)

Jianning Fu

Connection Belgium - China – Italy – Poland - USA LAMOST-Kepler

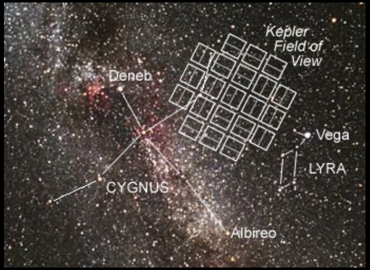
→ Large Sky Area Multi-Object Fiber Spectroscopic Telescope

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



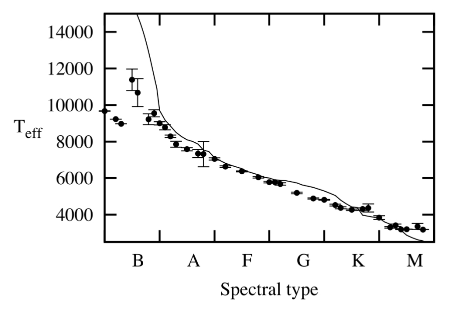
Unique combination of large multi-fiber telescope with wide field-of-view

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



Balona et al. (2011, MNRAS 413, 2403)

Need for accurarte stellar parameters

LAMOST-Kepler project

- Proposal submitted in 2010

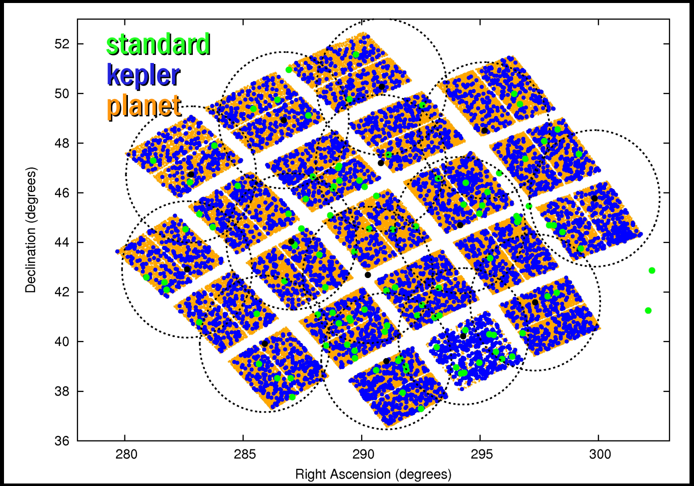
Collaboration with subchairs of Kepler Asteroseismic Science Consortium

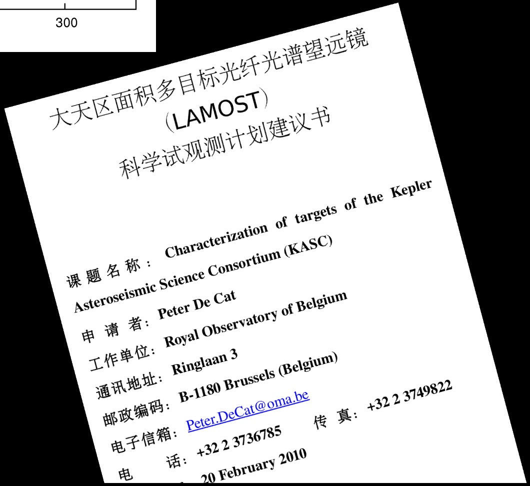
→ to cover whole Kepler field-of-view

→ to characterize targets in homogeneous way
  - spectral type
  - any peculiarities
  - T_{eff}, logg, metallicity

→ with low-resolution spectroscopy
  - radial velocity ⇒ binaries, cluster membership
  - rotation velocity ⇒ restriction on vsini

→ 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




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)
电子信箱： Peter.DeCat@oma.be
电话： +32 2 3736785 传真： +32 2 3749822
20 February 2010

Win-win opportunity for both LAMOST community and Kepler community

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

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

LAMOST-Kepler project

- Asian team

BNU (Beijing)

NAOC (Beijing)

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

BNU (Beijing)


NAOC (Beijing)



LASP (LRS)

temperature type

T_{eff} (2.75%)

$\log g$ (0.215 dex)

[Fe/H] (0.152 dex)

V_{rad} (18 km s^{-1})

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→ 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)

- ➢ Update of the statistics of the catalogue

KSB - ORB

Peter De Cat (Royal Observatory of Belgium, Ringlaan 3, B-1180 Brussels, Belgium; Peter.DeCat@oma.be)

2024/10/10, Xinjiang Astronomical Observatory (Ürümqi, China)

LAMOST-Kepler project

- Asian team

BNU (Beijing)

NAOC (Beijing)

LASP (LRS)

temperature type
$T_{\rm eff}$ (2.75%)
$\log g$ (0.215 dex)
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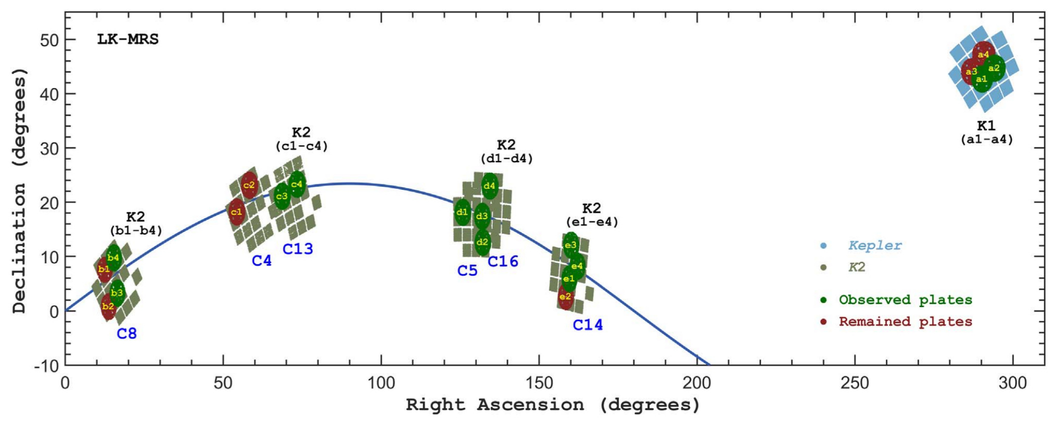
→ Fu et al., 2020, RAA 20, 167: "Overview of the LAMOST-Kepler project" (2011/05-2020/09)

→ 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
$T_{\rm eff}$ (100 K)
$\log g$ (0.15 dex)
[Fe/H] (0.09 dex)
$V_{\rm rad}$ (1 km s^{-1})



LAMOST-Kepler project

- Asian team

BNU (Beijing)

NAOC (Beijing)

LASP (LRS)

temperature type

$T_{\rm eff}$ (2.75%)

$\log g$ (0.215 dex)

[Fe/H] (0.152 dex)

$V_{\rm rad}$ (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)

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→ 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)

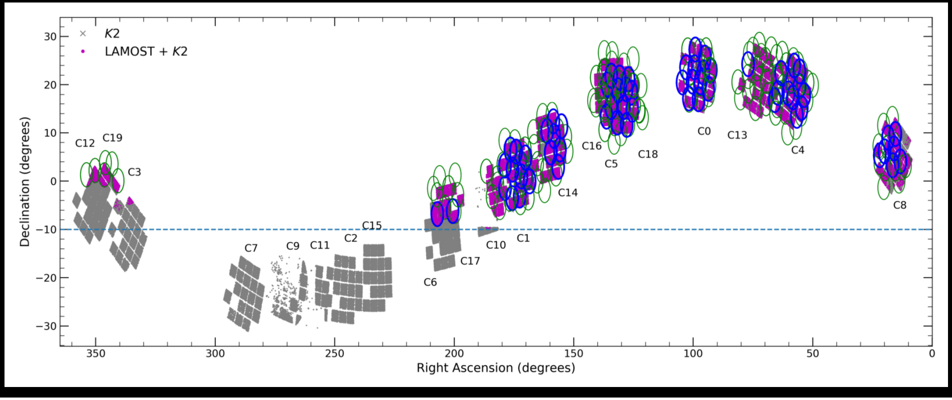
temperature type

$T_{\rm eff}$ (100 K)

$\log g$ (0.15 dex)

[Fe/H] (0.09 dex)

$V_{\rm rad}$ (1 km s^{-1})



LAMOST-Kepler project

- European team

Catania (Italy)



Wrocław (Poland)

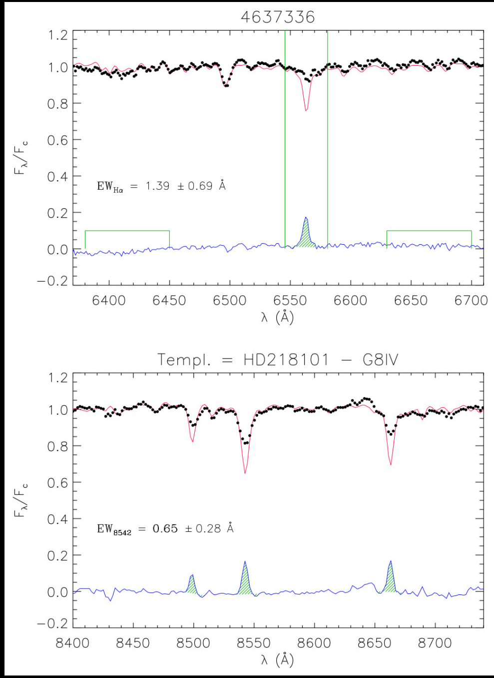
Brussels (Belgium)


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 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)



Peter De Cat (Royal Observatory of Belgium, Ringlaan 3, B-1180 Brussels, Belgium; Peter.DeCat@oma.be)

Connection Belgium - China – Italy – Poland - USA   LAMOST-Kepler

LAMOST-Kepler project

- European team

Catania (Italy)

Wrocław (Poland)

Brussels (Belgium)

ROTFIT (LRS)

temperature type
luminosity class
$T_{\rm eff}$ (3.5%)
$\log g$ (0.3 dex)
[Fe/H] (0.2 dex)
$V_{\rm rad}$ (14 km s^{-1})
$v\sin i$ > 120 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)

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- Detection of 442 chromospherically active stars
- Detection of accreting star KIC8749284 (K1V)

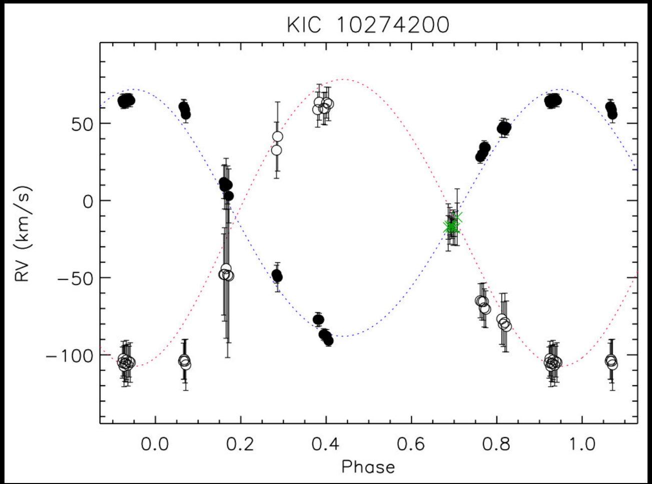
→ Frasca et al., 2022, A&A 664, A78: "Characterization of Kepler targets based on medium-resolution LAMOST spectra analysed with ROTFIT" (2017/09-2018/05)

- Detection of 327 chromospherically active stars
- Detection of 98 double-lined spectroscopic binaries (SB2) and 7 triple systems (SB3)
- EW measurement LiI λ6708 line for 1657 stars
  - ✔ 187 Li-rich giants (153 new ones)
  - ✔ fraction of 4-5% Li-rich giants
  - ✔ no relation between rotation and Li abundances (merging scenarios)

ROTFIT (MRS)

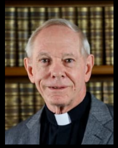
temperature type
luminosity class
$T_{\rm eff}$ (2.5%)
$\log g$ (0.25 dex)
[Fe/H] (0.15 dex)
$V_{\rm rad}$ (0.7 km s^{-1})
$v\sin i$ > 8 km s^{-1}

Parameter	Value
HJD0 $^{(a)}$	58020.45 ± 0.05
$P_{\rm orb}$ (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

- American team

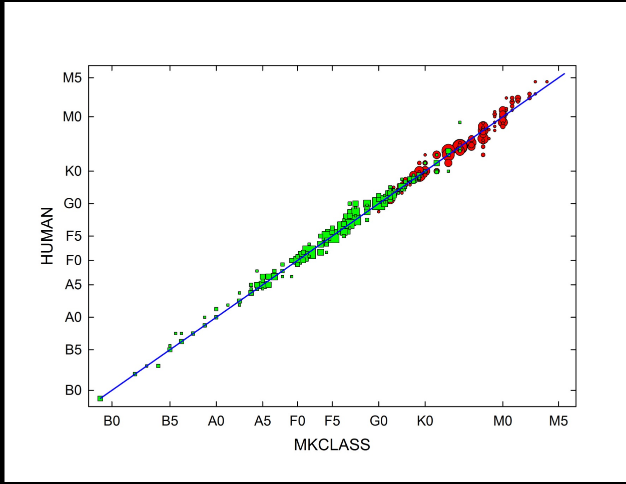


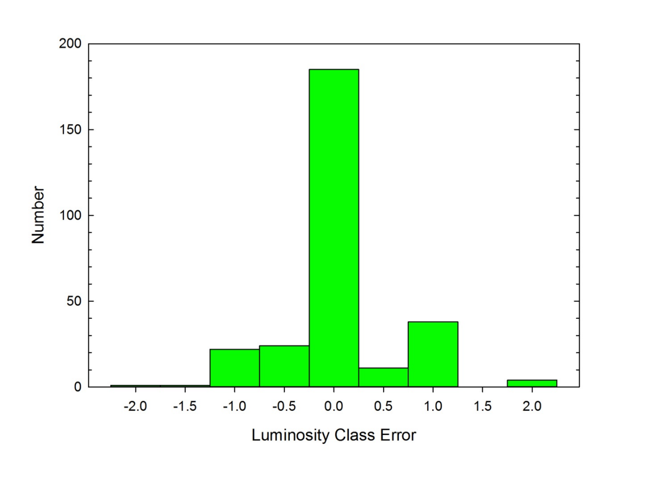
MKCLASS

temperature type (0.6)
luminosity class (0.5)

→ Grey et al., 2016, AJ 151, 13: "LAMOST observations in the Keperl 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

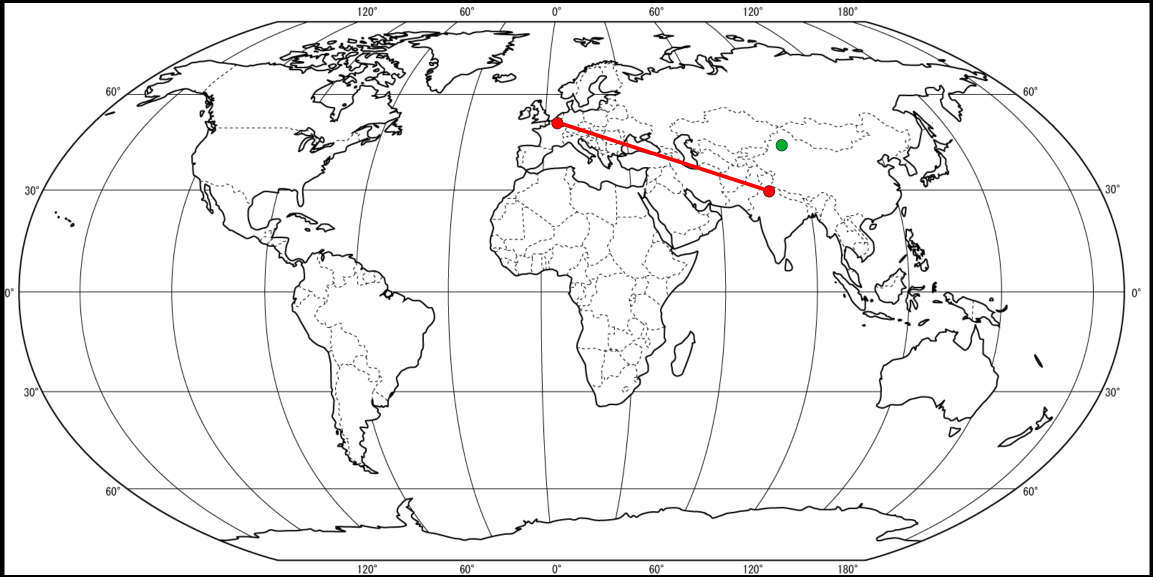
2024/05/21-24

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

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

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)

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

Indo-Belgian telescopes

Connection Belgium – India

BINA

Belgo-Indian Network for Astronomy and astrophysics

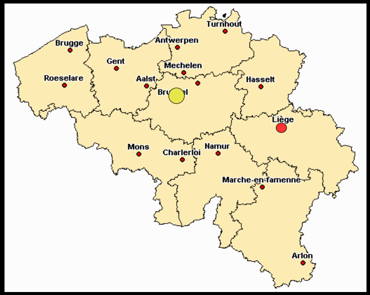
- **BINA-1** (2014-2018)

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)



→ Belgian partners (PI: Peter De Cat)

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

→ Indian partners (PI: Santosh Joshi)

- ARIES (Aryabhatta 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)
- SNBNCBS (S.N. Bose National Centre for Basic Sciences; Kolkata)
- TIFR (Tata Institute of Fundamental Research; Mumbai)

Peter De Cat (Royal Observatory of Belgium, Ringlaan 3, B-1180 Brussels, Belgium; Peter.DeCat@oma.be)

Connection Belgium – India

BINA

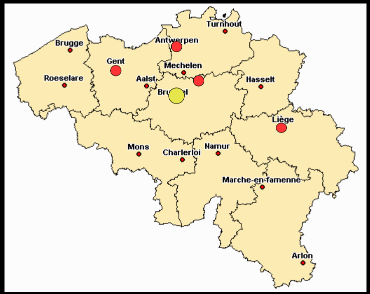
Belgo-Indian Network for Astronomy and astrophysics

- 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)



→ 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)

→ Indian partners (PI: Santosh Joshi)

- ➢ ARIES (Aryabhatta 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; Ahmadabad)
- ➢ RSU (Pt. Ravi Shankar University; Raipur)
- ➢ SNBNCBS (S.N. Bose National Centre for Basic Sciences; Kolkata)
- ➢ TIFR (Tata Institute of Fundamental Research; Mumbai)

Peter De Cat (Royal Observatory of Belgium, Ringlaan 3, B-1180 Brussels, Belgium; Peter.DeCat@oma.be)
2024/10/10, Xinjiang Astronomical Observatory (Ürümqi, China)

Connection Belgium – India

BINA

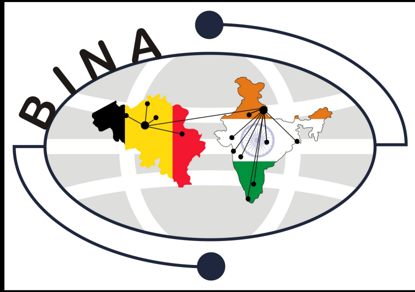
Belgo-Indian Network for Astronomy and astrophysics

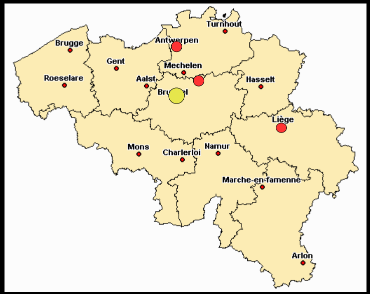
- BINA-1 (2014-2018) — Focus on instrument development (DOT+ILMT)
- BINA-2 (2018-2023) — Focus on scientific projects (telescopes of interest)
- BIPASS (2022-2025) — Focus on spectroscopy (data products and science)

Network activities

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

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





→ 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 (Aryabhatta 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; Ahmadabad)
- ➢ RSU (Pt. Ravi Shankar University; Raipur)
- ➢ SNBNCBS (S.N. Bose National Centre for Basic Sciences; Kolkata)
- ➢ TIFR (Tata Institute of Fundamental Research; Mumbai)
- ➢ UOC (University of Calicut; Calicut)

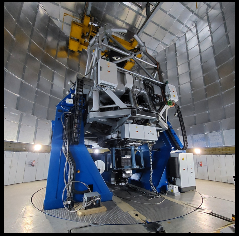
Connection Belgium – India

BINA

Belgo-Indian Network for Astronomy and astrophysics

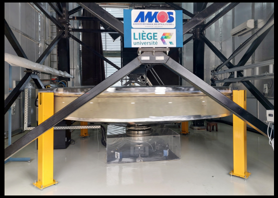
- Indo-Belgian telescopes

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

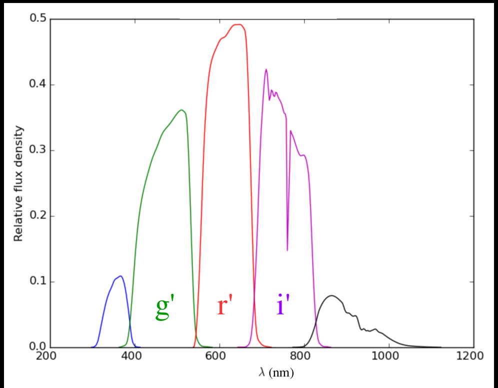


➢ IMAGER	optical imaging	2017A-Early-Science
➢ TIRCAM2	near-infrared imaging (permanent side-port1)	2017A-Early-Science
➢ ADFOSC	low-resolution spectroscopy + camera (main port)	DOT-2020-C1
➢ TANSPEC	medium-resolution spectroscopy + camera (main port)	DOT-2020-C1
➢ HRS	high-resolution spectrograph	DOT-2024-C2?
➢ Fast Photometer	multi-colour photometry	DOT-????-??

→ 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



KSB - ORB
Peter De Cat (Royal Observatory of Belgium, Ringlaan 3, B-1180 Brussels, Belgium; Peter.DeCat@oma.be)
2024/10/10, Xinjiang Astronomical Observatory (Ürümqi, China)

Connection Belgium – India

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 = 1.2-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

Peter De Cat (Royal Observatory of Belgium, Ringlaan 3, B-1180 Brussels, Belgium; Peter.DeCat@oma.be)

Connection Belgium – India

BINA

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 Sourthern Observatory, La Silla, Chile)
  - ✔ Multiband photometry (Johnson/Cousins BVRcIc, Sloan z, NIR exoplanet filter, NaI, H_2O+/OH, NH, CN, CO+, C3, BC, C2, GC, RC)

Search for habitable Planets Eclipsing Ultra-cOOl Star

- ➢ 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)

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Connection Belgium – India

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Long term view

Belgian partners

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

Indian partners

- ARIES (Santosh Joshi)
- DU
- HBCSE
- IIA
- IIST
- ISRO
- IUCCA
- KU
- NCRA
- PRL (Sashikiran Ganesh)
- RSU
- SNBNCBS
- TIFR
- UOC

Belgo-Indian Network for Astronomy and astrophysics

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

Network actvities
BINA-1
BINA-2
BIPASS
(DST/BELSPO)

Outreach
Citizen Science

PhD students

Mrinmoy Sarkar (ARIES)
Athul Dileep (ARIES)
Bhavya Ailawadhi (ARIES)
Naveen Dukiya (ARIES)
Vibhore Negi (ARIES)
Kumar Pranshu (ARIES)
Monalisa Dubey (ARIES)

Nikita Rawat (ARIES)
Anindya Saha (IIST)

Brajesh Kumar (ULiège)
Bikram Pradhan (ULiège)

Otto Trust (Mbarara, Uganda)

Post-docs

Bharti Arora (ULiège)
Priyanka Jalan (Warsaw)

Joint funding?

Connection Belgium – India

BINA

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

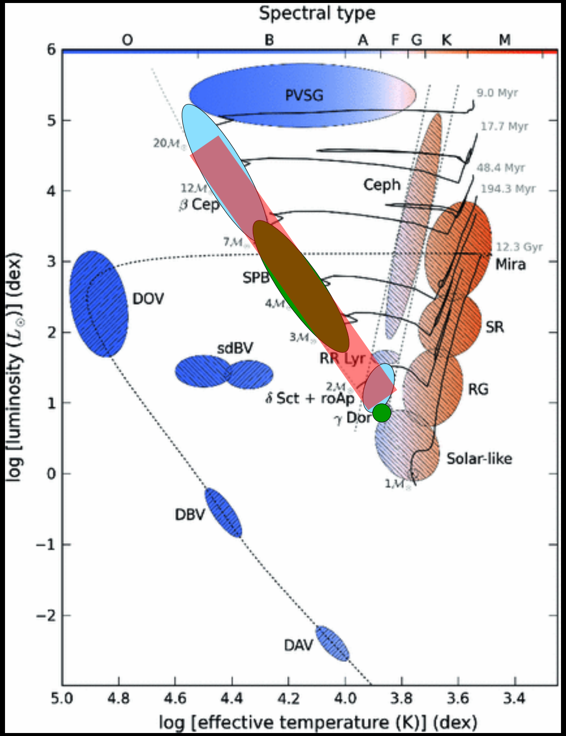
→ **CP2** (Ap stars)
- Overabundance Si, Cr, Sr, and rare-Earth elements (Sr, Cr, Eu, Nd, Pr,...)
- Magnetic field: strong (up to tens of kG)

→ **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; Martinez et al. 2001; Joshi et al. 2003, 2006, 2009, 2010, 2012, 2016, 2017)

Santosh Joshi (ARIES)



Joshi, Trust, Semenko et al., 2022, MNRAS 510, 5854

"High-resolution spectroscopy and K2 photometry of Am stars in the region of M44" (5 stars)

Connection Belgium – India

Science

Trust, 2022, PhD thesis (co-supervisors: Jurua, Joshi & De Cat)

Otto Trust (Mbarara)

Santosh Joshi (ARIES)

- “Hump-and-spike” stars (observed for normal A and Am/Fm stars)
  - → hump: unresolved Rossby modes (curly bracket)
  - → spike: rotational frequency (dashed line)
    - ➢ theoretical evindence for this interpretation

Trust, Jurua, De Cat & Joshi, 2020, MNRAS 492, 3143

- Kepler photometry (170 normal A and Am/Fm stars)

	Am/Fm stars	Normal A stars
No significant differences in spot radii	1.01(13) R_E	1.16(12) R_E
Significant difference in decay-time scale	3.6(2) days	1.5(2) days
Spots are smaller than GKM-type stars ⟶ weak magnetic fields?		

Trust, Jurua, De Cat et al., 2021, MNRAS 504, 5528

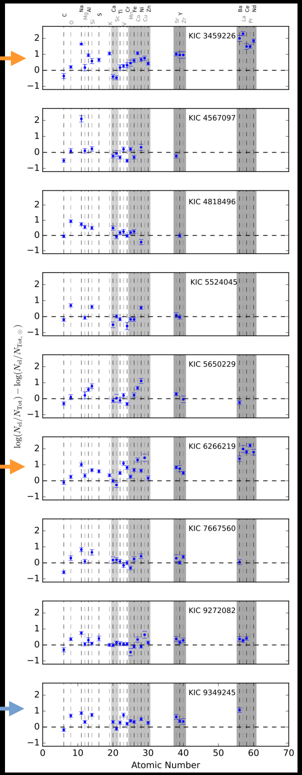
- HERMES spectroscopy (9 stars)

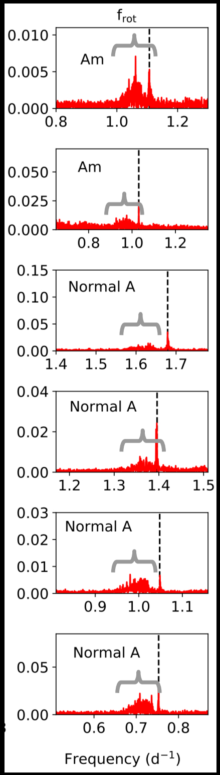
2 Am stars:	KIC3459226, KIC6266219
1 marginal Am star:	KIC 9349245

Trust, Jurua, De Cat et al., 2023, MNRAS 524, 1044

- HD180347

NLTE improves accuracy of derives abundances
Classification as Am (kA1hA8mA8) star





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KSB - ORB

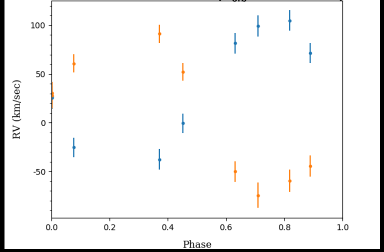
Science

Yogesh Joshi (ARIES)

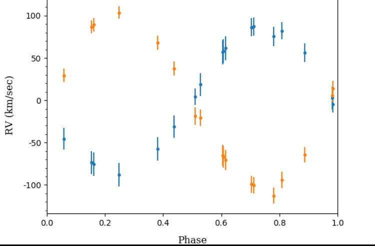
- **ORBIT** (Optical characterisation and Radial velocity monitoring with Belgian and Indian Telescopes) Joshi, De Cat, Panchal et al., 2019, BSRSL 88, 82
  - → Study of exoplanet and eclipsing binary candidates
    - ➢ Detection and characterisation of exoplanets (by determining accurate physical parameters through constraining the orbital inclination)
    - ➢ Alleviation of the mass-radius problem of the low-mass stars (by significantly increasing the number of low-mass eclipsing binaries with accurate masses, radii and metallicities)
  - → Observations
    - ➢ Photometry: TIRCAM2@DOT/3.6-m (Devasthal, India), DFOT@ARIES/1.3-m (Nainital, India), ASAS-3, K2
    - ➢ Spectroscopy: HERMES@Mercator/1.2-m (La Palma, Spain), HESP@HTC/2-m (Hanle, India
  - → Analysis EPIC211982753 and EPIC21191547 Panchal, Joshi, De Cat et al., 2019, BSRSL 88, 82

No evidence for orbital period changes over a timespan of 3.2 years
Spot on both components needed for EPIC21191547

EPIC 211982753 (P_{orb} = 5.3901 d)



EPIC 211915147 (P_{orb} = 3.62154 d)



Connection Belgium – India

BINA

Science

- Summary of publications
  - → Refereed: #40 published + #1 submitted
  - → Proceedings: #45 published

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

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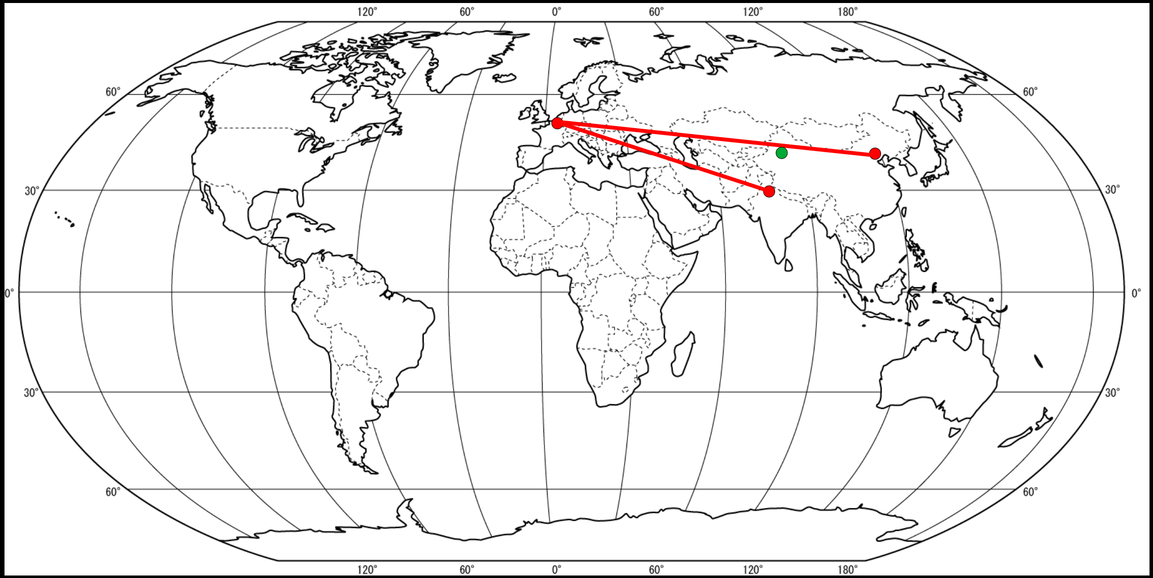
Outline

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
    - ➢ Chance 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!