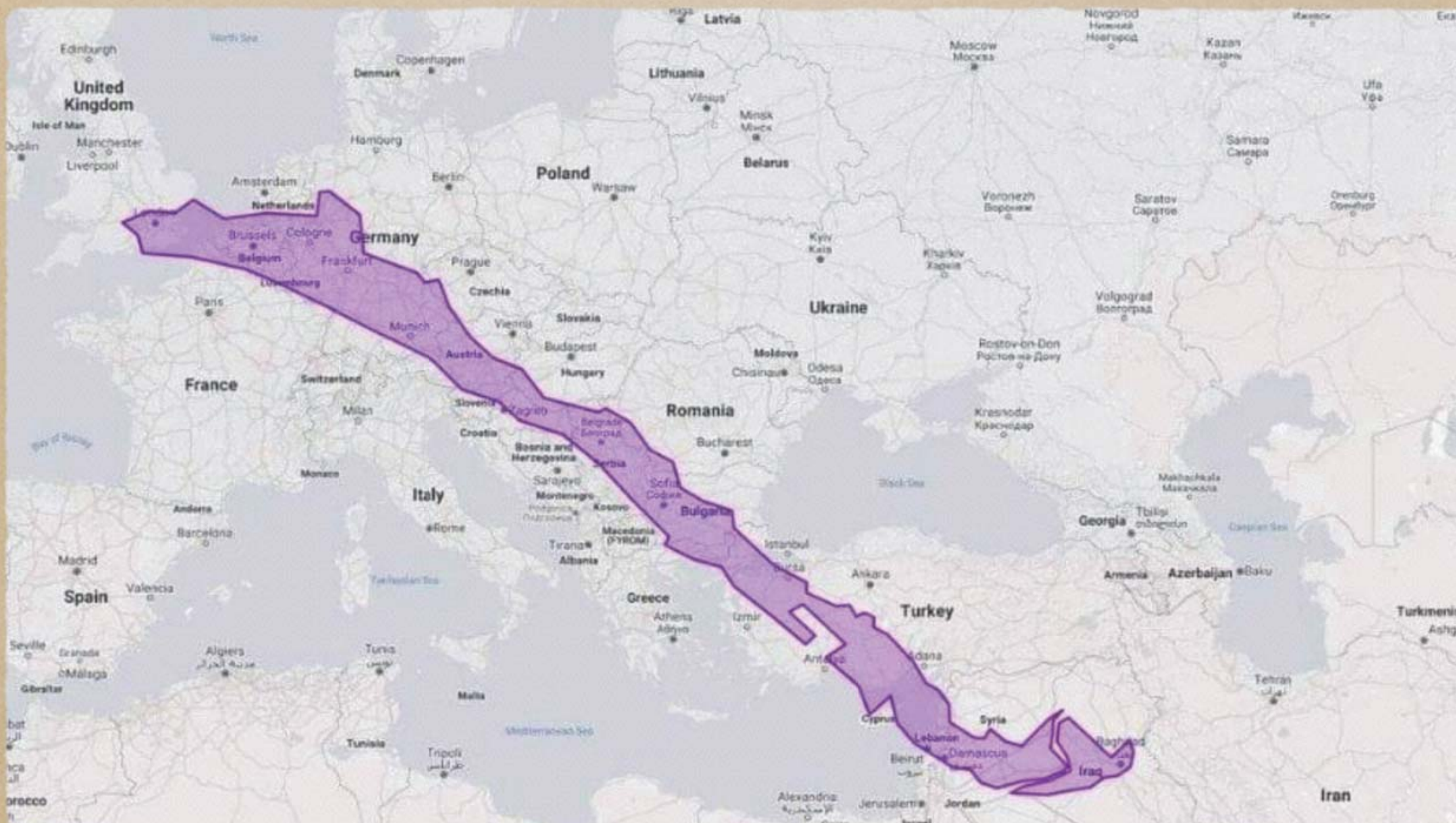
Vreli sub-patuljci ?

Maja Vučković,
Instituto de Física y Astronomía,
Universidad de Valparaíso,
Chile

16 Mart 2021



Latvia
Novgorod
Edinburgh
North Sea
Copenhagen
Denmark
Moscow
Kazan
United Kingdom
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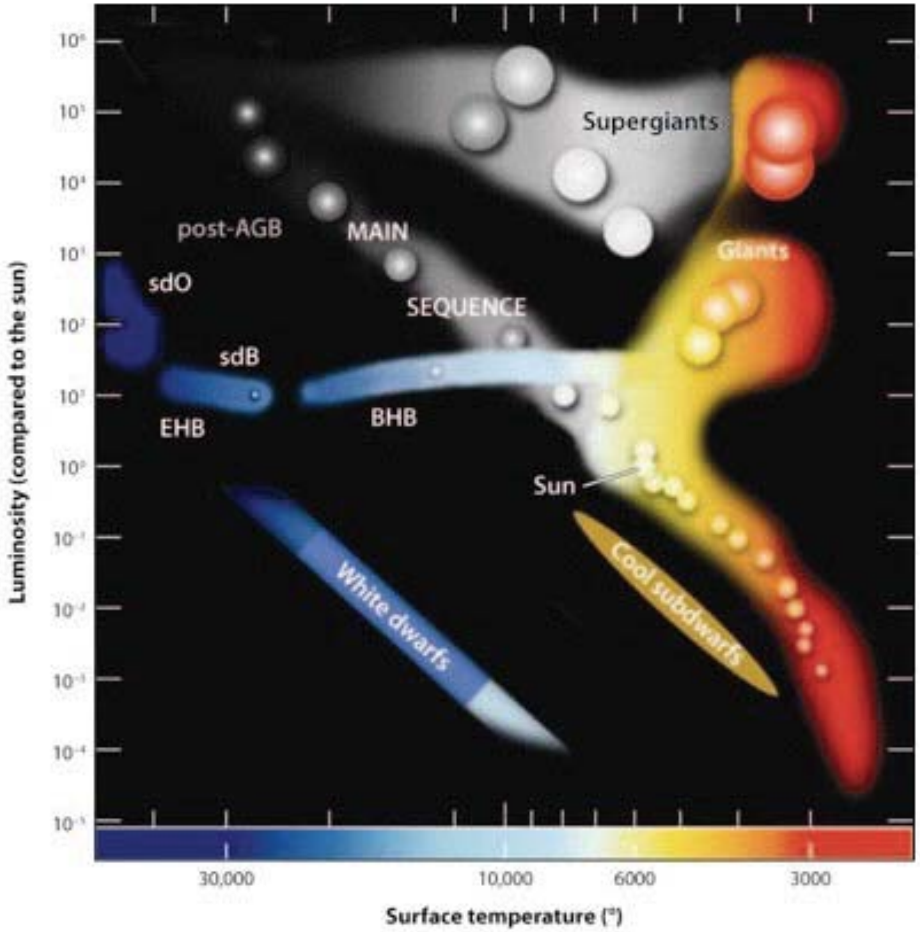
Isle of Man
Minsk
Dublin
Manchester
Hamburg
Samara
Liverpool
Belarus
Amsterdam
Berlin
Poland
Warsaw
Netherlands
Voronezh
Saratov
Orenburg
Brussels
Cologne
Germany
Kyiv
Belgium
Frankfurt
Prague
Kharkiv
Luxembourg
Czechia
Volgograd
Paris
Ukraine
Slovakia
Vienna
Munich
Austria
Budapest
Rostov-on-Don
Moldova
Hungary
Chisinau
Odesa
France
Switzerland
Slovenia
Milan
Zagreb
Romania
Krasnodar
Croatia
Belgrade
Bay of Biscay
Bosnia and Herzegovina
Bucharest
Serbia
Monaco
Sarajevo
Black Sea
Makhachkala
Montenegro
Sofia
Italy
Kosovo
Andorra
Bulgaria
Tbilisi
Georgia
Barcelona
Rome
Macedonia (FYROM)
Caspian Sea
Tirana
Istanbul
Madrid
Albania
Tyrrhenian Sea
Ankara
Armenia
Azerbaijan
Baku
Spain
Valencia
Greece
Turkey
Athens
Izmir
Seville
Granada
Algiers
Tunis
Antalya
Adana
Málaga
Gibraltar
Malta
Tehran
Syria
Cyprus
Mediterranean Sea
Lebanon
Baghdad
Tunisia
Tripoli
Beirut
Damascus
Iraq
Alexandria
Jerusalem
Jordan
Iran
Cairo
Israel

Outline

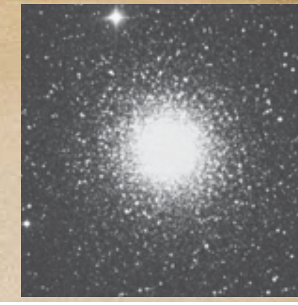
- www.hot-subdwarfs.com;
- binary evolution;
- asteroseismology;
- space missions;

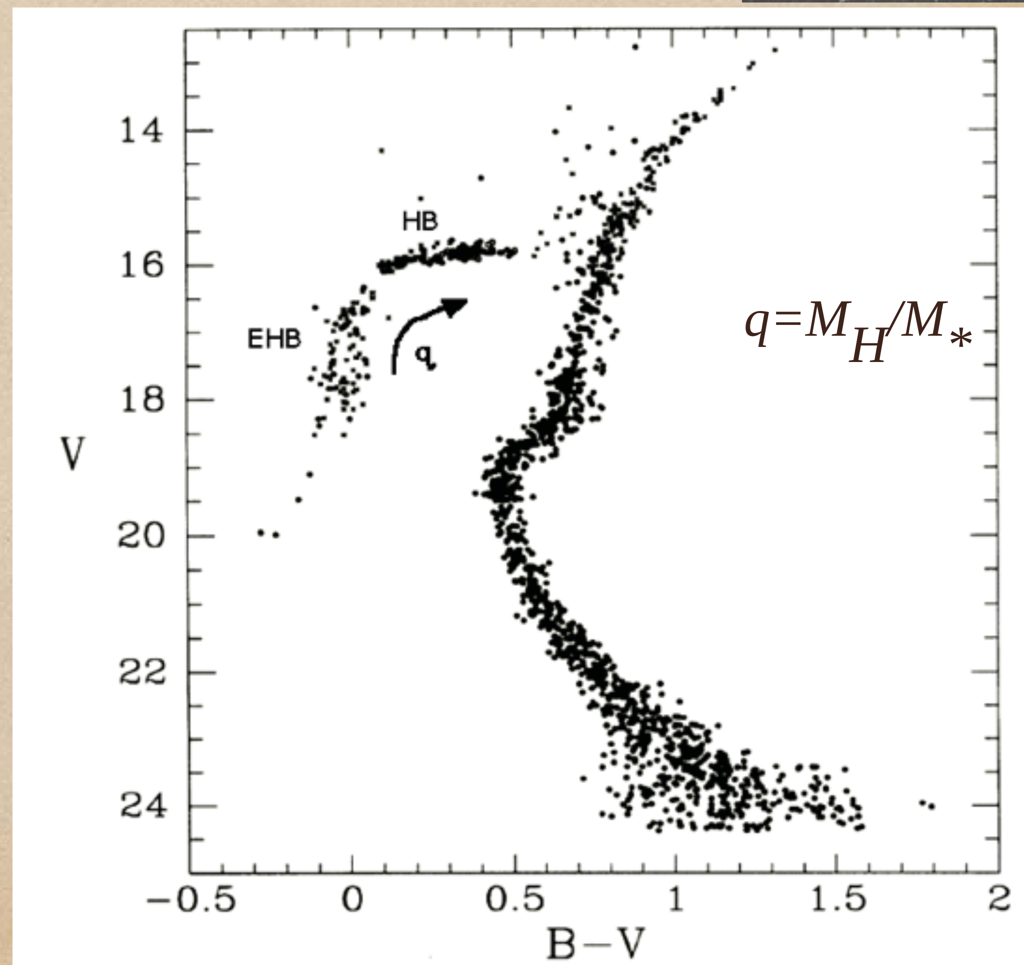
Where -sdB



Heber U. 2009.
Annu. Rev. Astron. Astrophys. 47:211–51

Where -sdB   M 15

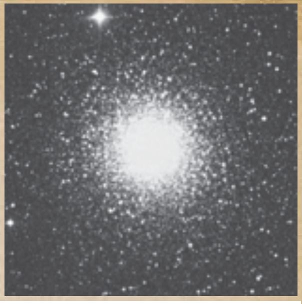


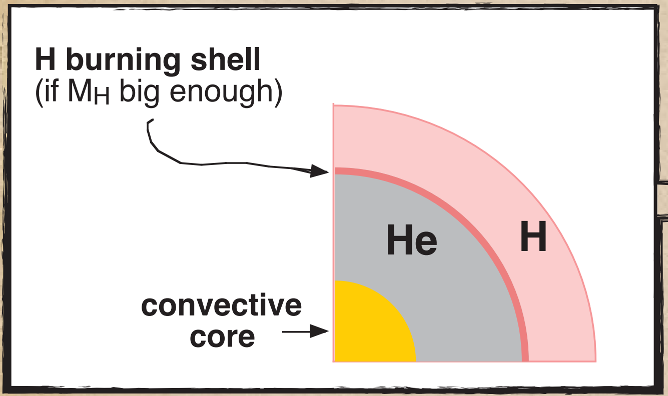


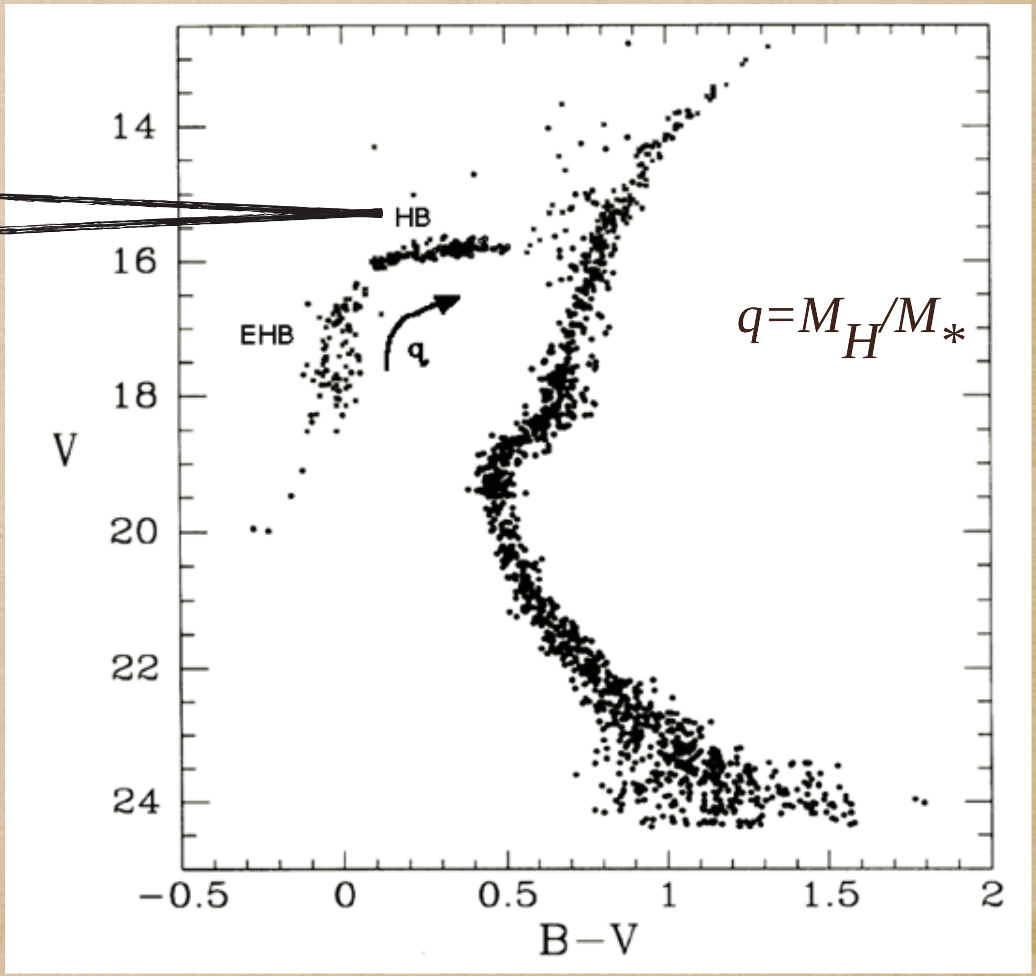
$q = M_H / M_*$

Where -sdB

M 15







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Where -sdB

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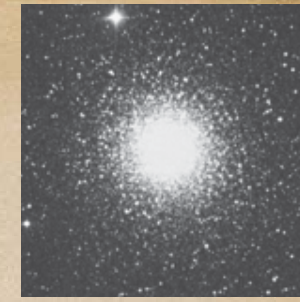
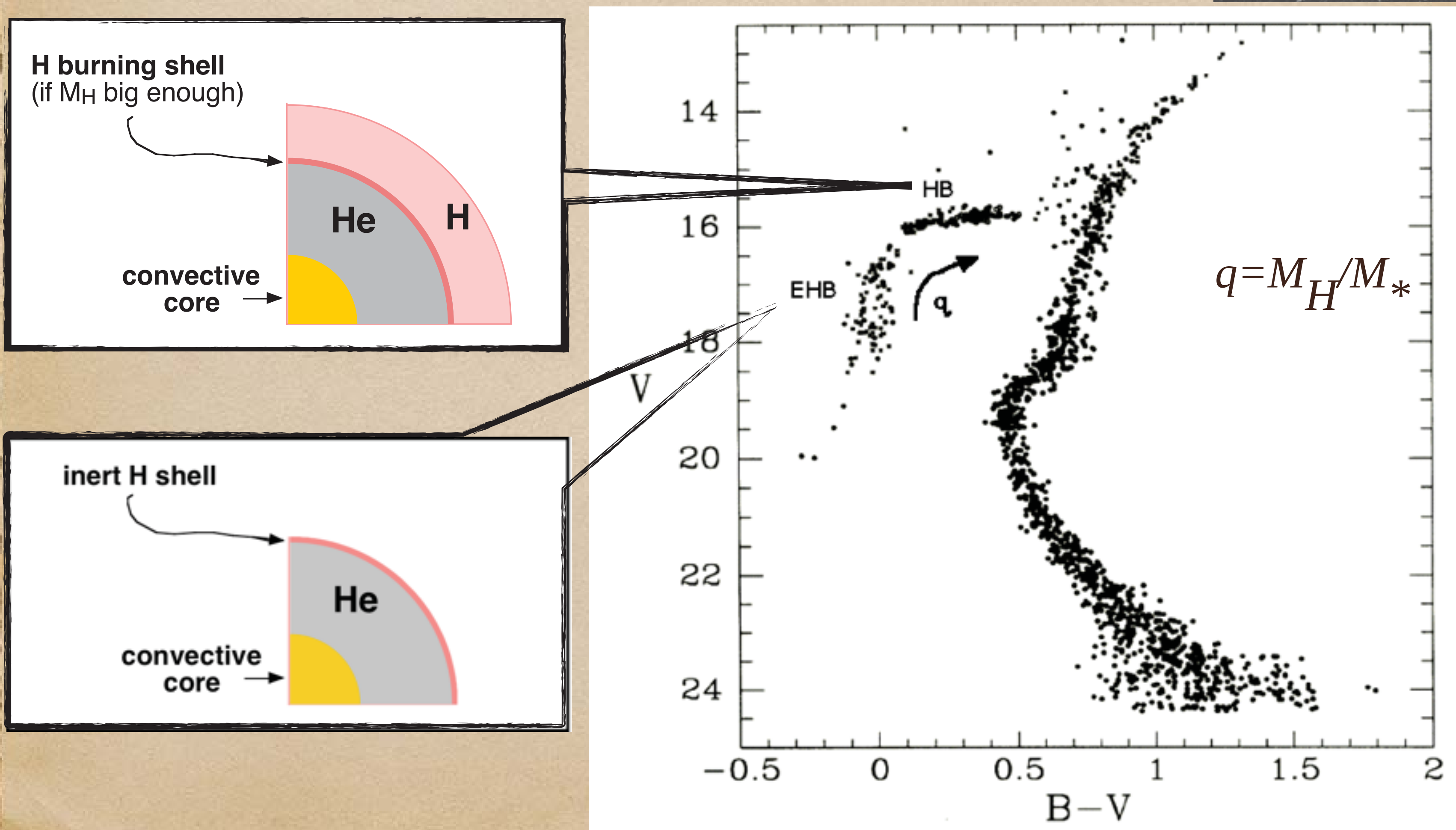




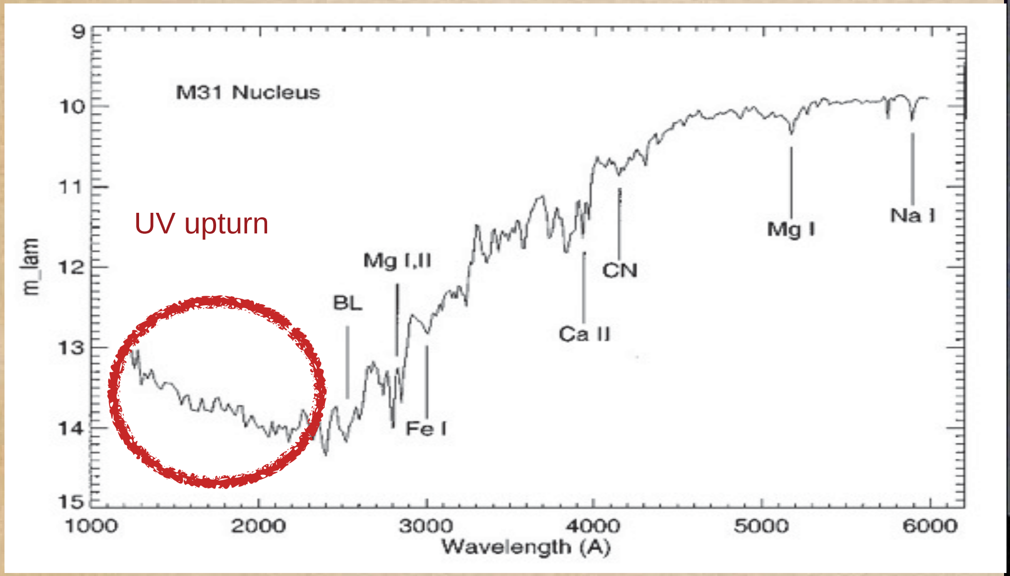
Where - sdB

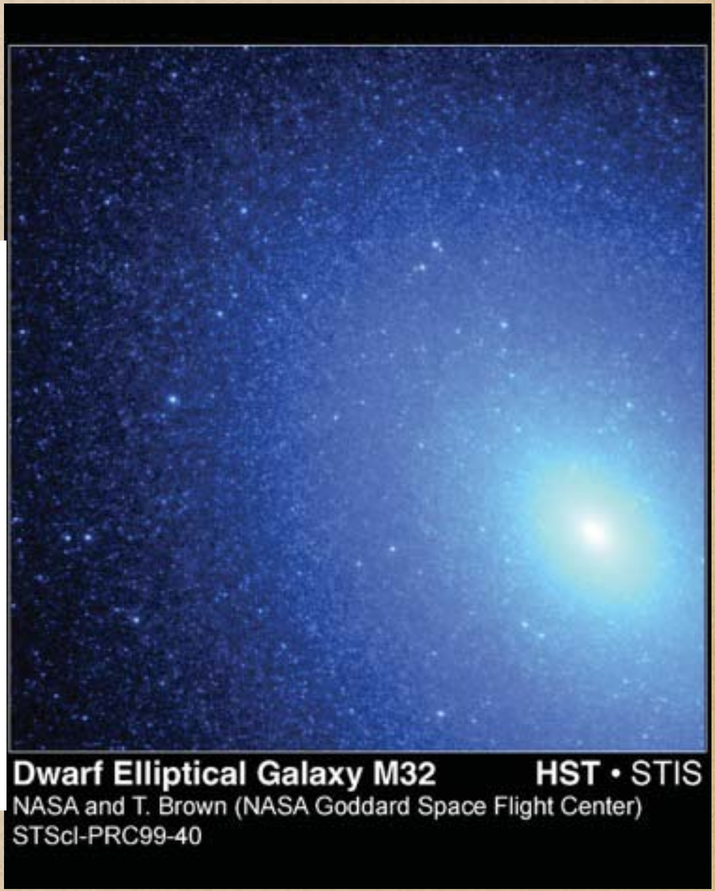
Humason & Zwicky 1947,
Greenstein & Sergent 1974

- globular clusters;
- disk Green et al. 1986;
- bulge Zoccali et al. 2003;
- elliptical galaxies Brown et al. 1997,2008;

Where - sdB

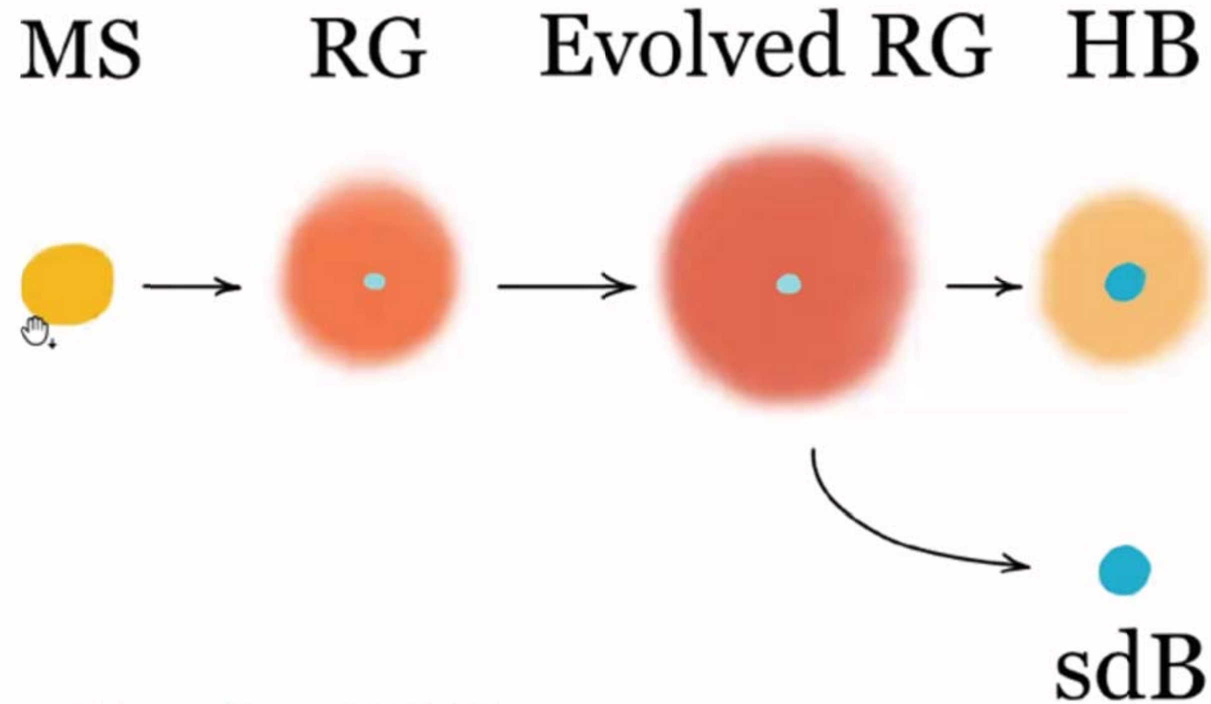
Humason & Zwicky 1947,
Greenstein & Sergent 1974





- UV-upturn O'Connell 1999;

What are sdB stars?

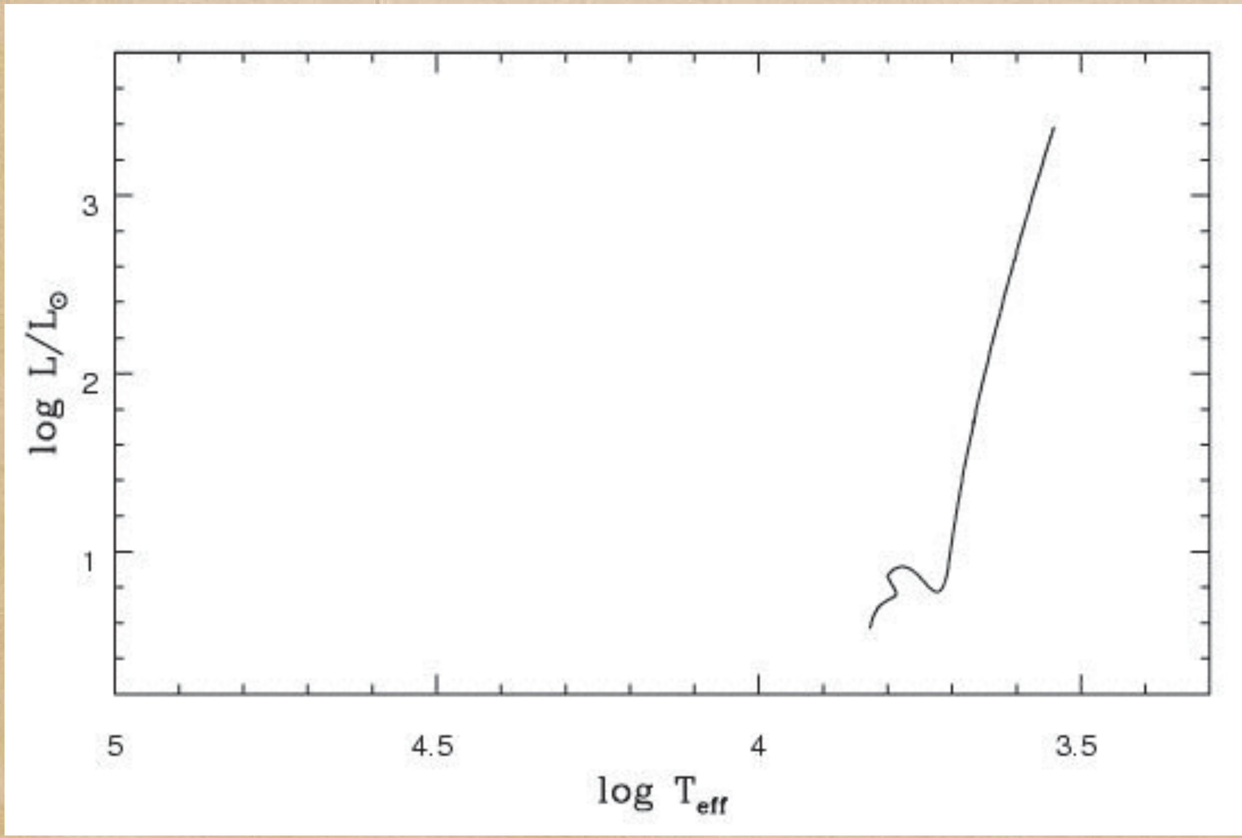


- B-stars
- Subdwarfs
- He-burning
- Hydrogen-poor: H less than 0.01MSun
- Typically ~0.1RSun, 0.40-0.48MSun
- Live for ~100Myr

(Heber, 2016) - review

Why - sdBs

- origin still under debate!



Why - sdBs

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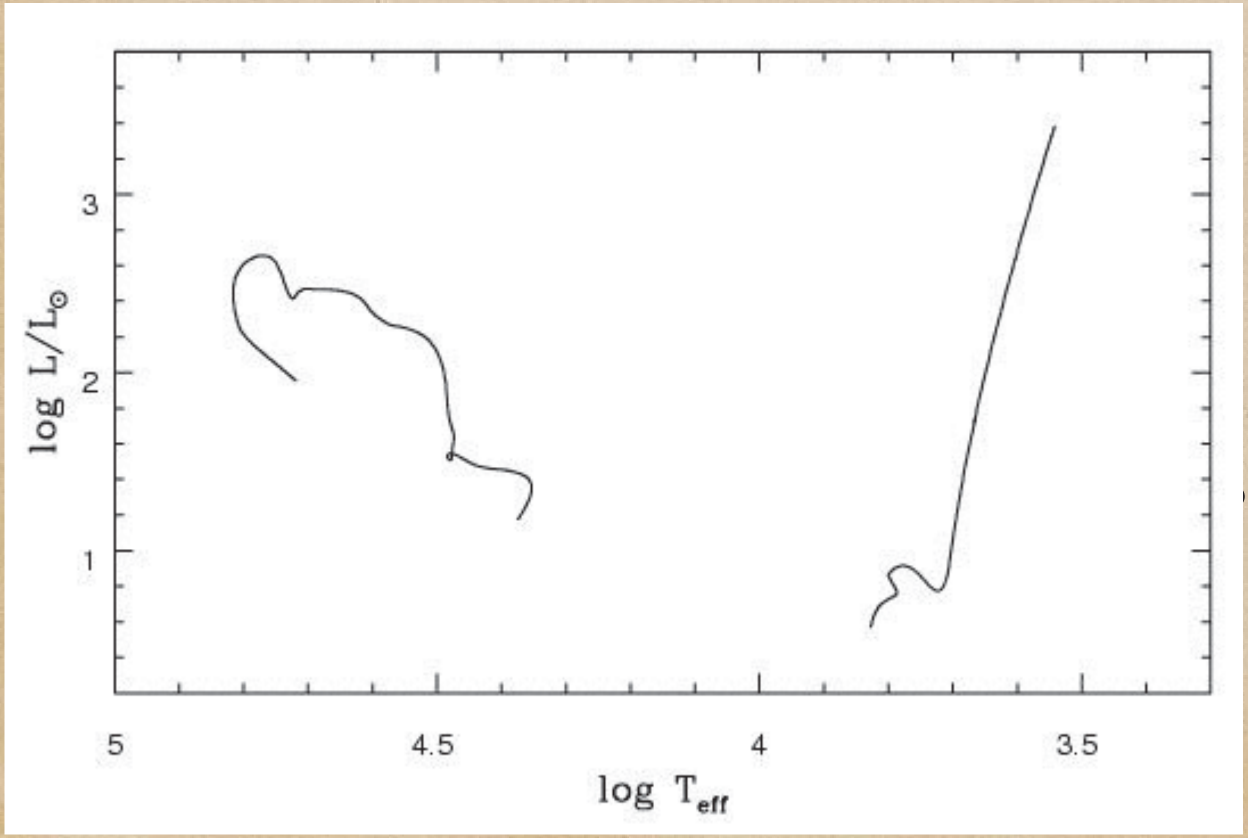

Why - sdBs

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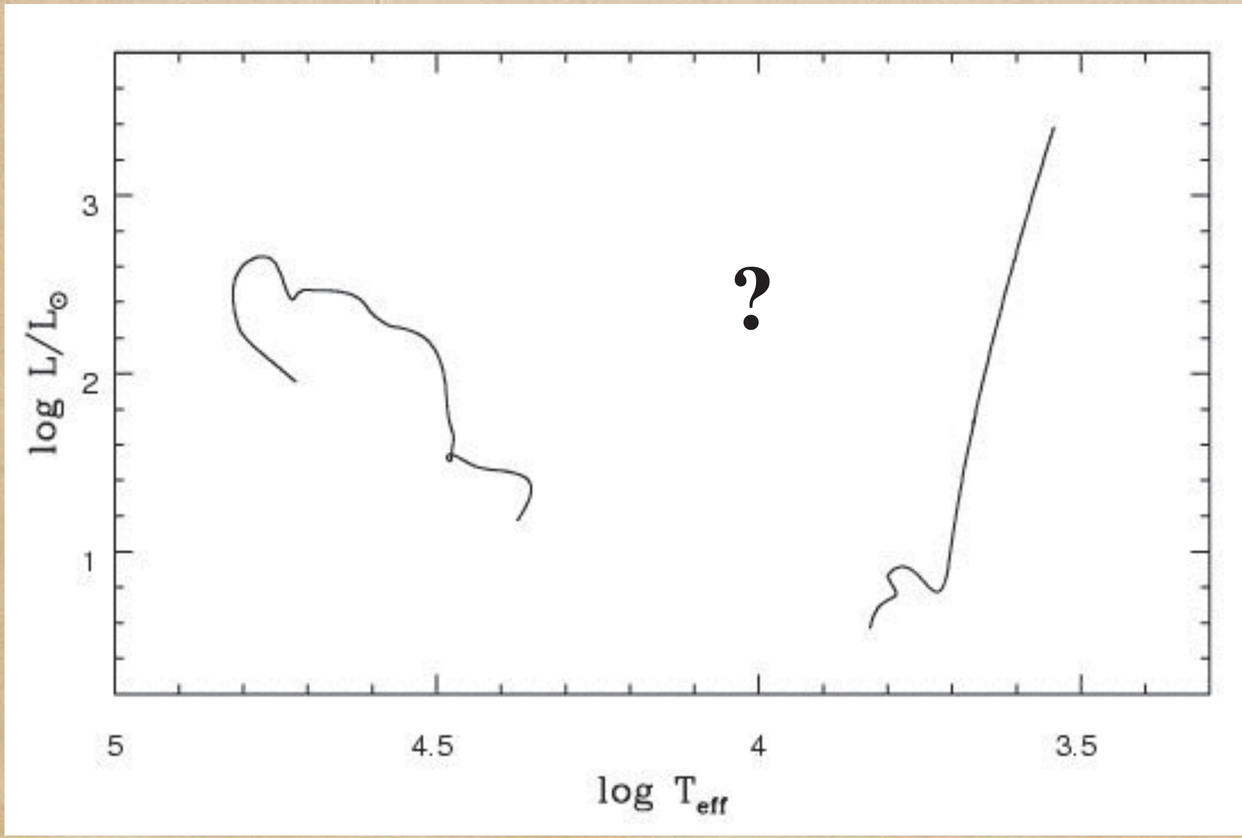
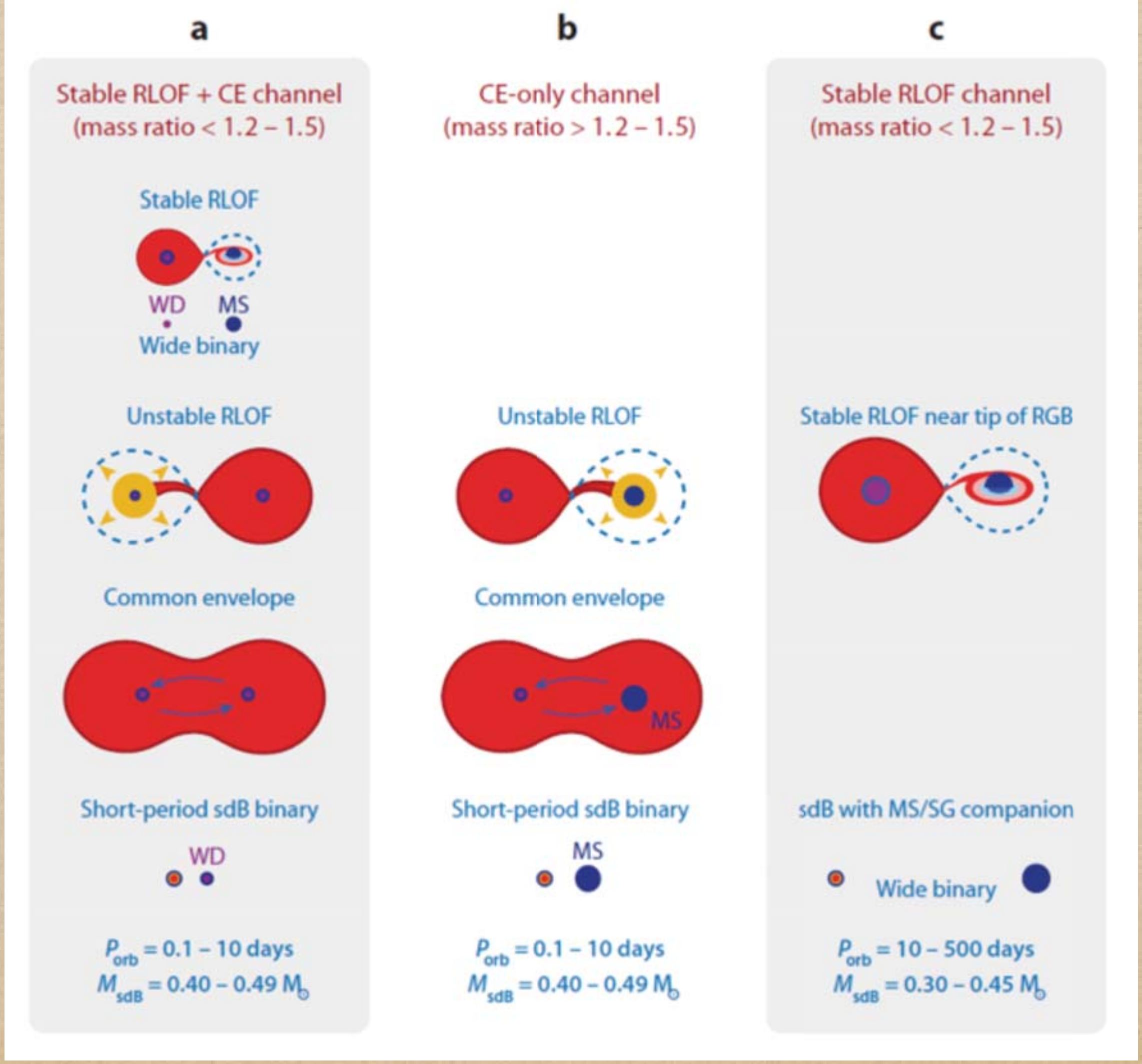
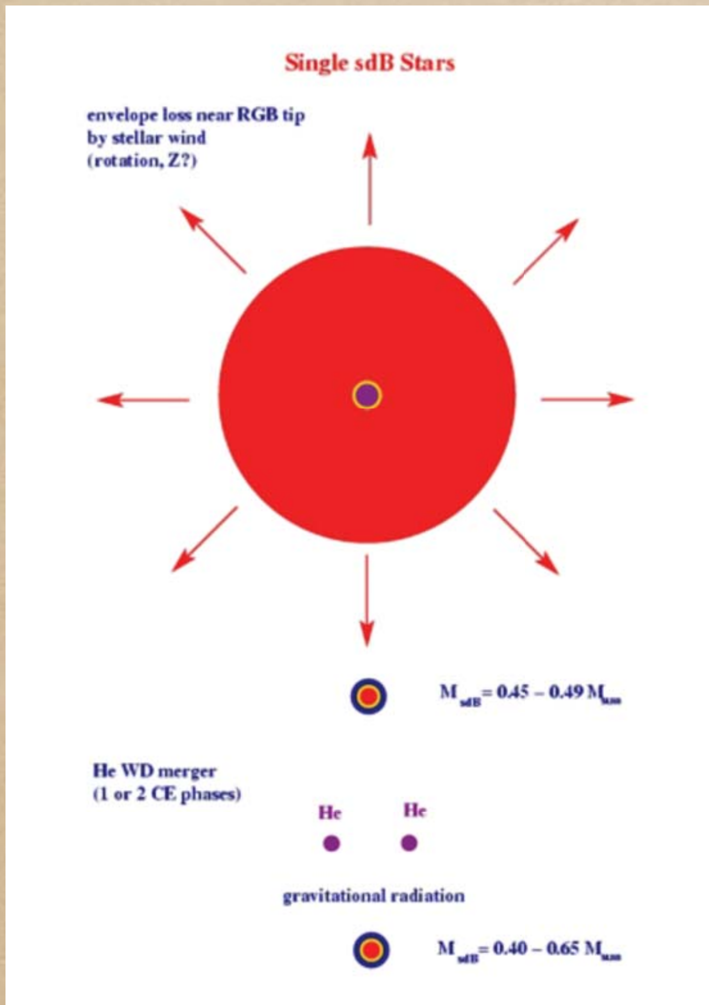


Formation channels



Podsiadlowski (2008)

Formation channels



Podsiadlowski (2008)

Proposed scenarios:

- ***enhanced stellar wind on the RGB*** *(D'Cruz et al. 1996)*
- ***merger of two He-core WD stars*** *(Iben 1990, Saio & Jeffery 2000)*
- ***CEE by giant planet that evaporates in the process*** *(Soker 1998)*
- ***low-mass brown dwarf merging along CE***
- ***a hierarchical triple (****Clausen & Wade 2011)*

- wide mass distribution up to 0.8 $M_\odot$;

Binary population synthesis

Han et al. 2002, 2003

- CEE :
  - P ~ 0.1-10 d, mass distribution @ 0.46 $M_\odot$;
- RLOF :
  - P ~ 10-500 d, mass distribution 0.3-0.49 $M_\odot$;

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Han et al. 2002, 2003

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  - P ~ 0.1-10 d, mass distribution @ 0.46 $M_\odot$;
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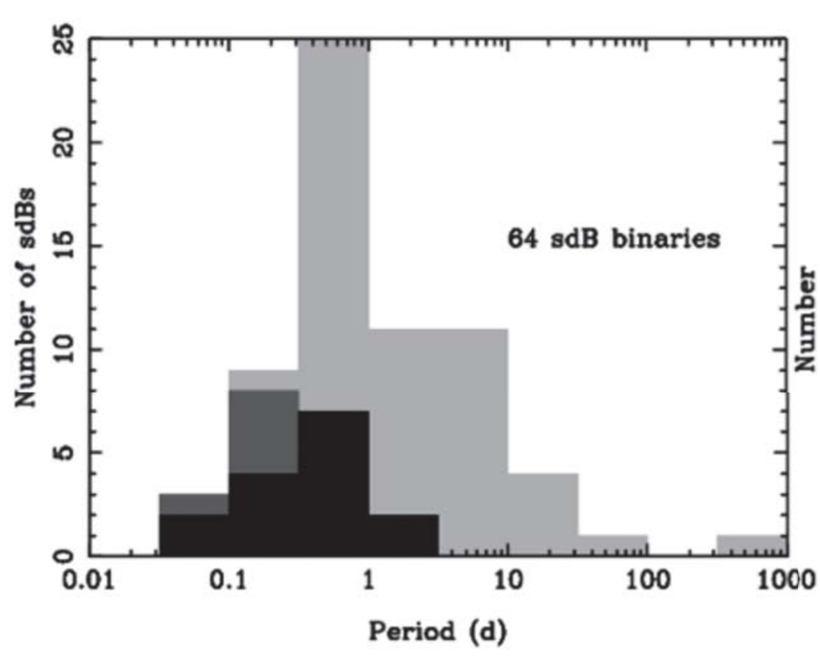
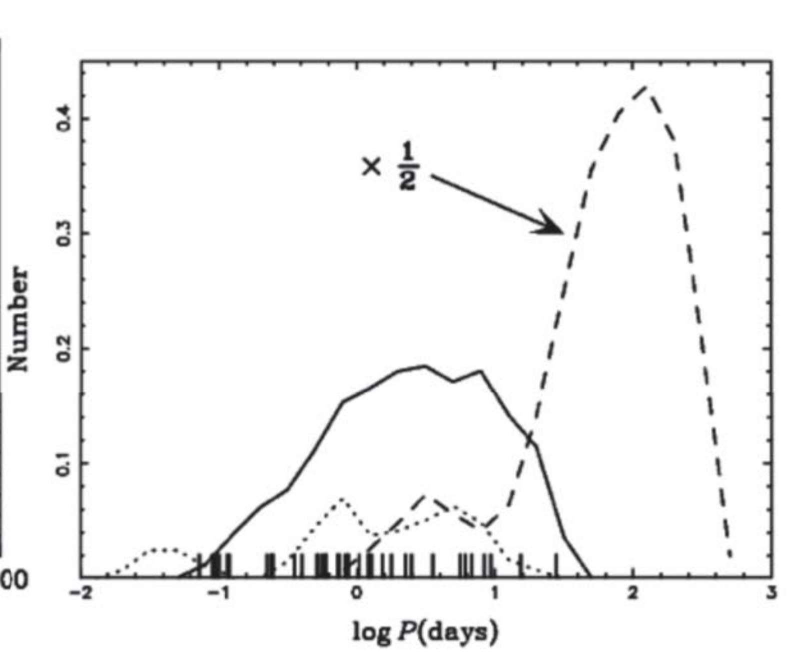
Tanks to observation !

Orbital period distribution

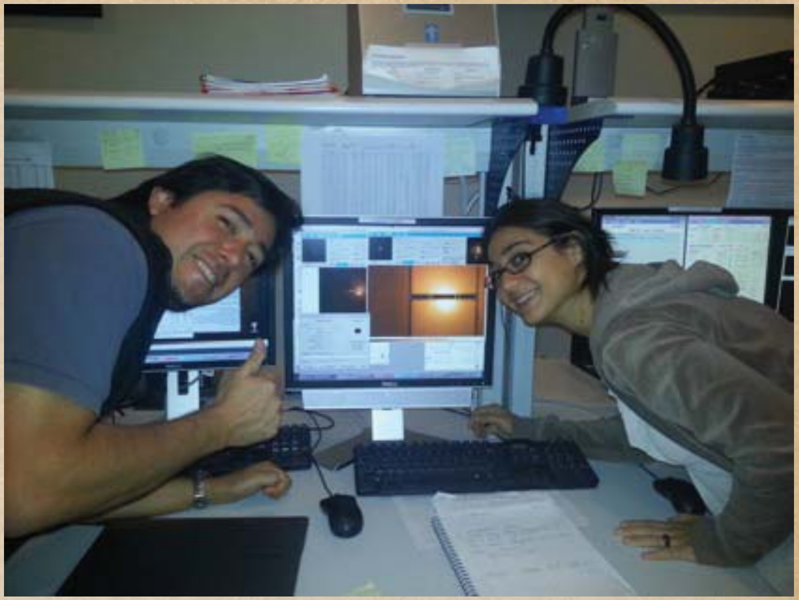
Observed



Theoretical



Han et al. 2003

PG1018-047

Deca et al. 2012, MNRAS, 421, 2798

PG 1018–047: the longest period subdwarf B binary

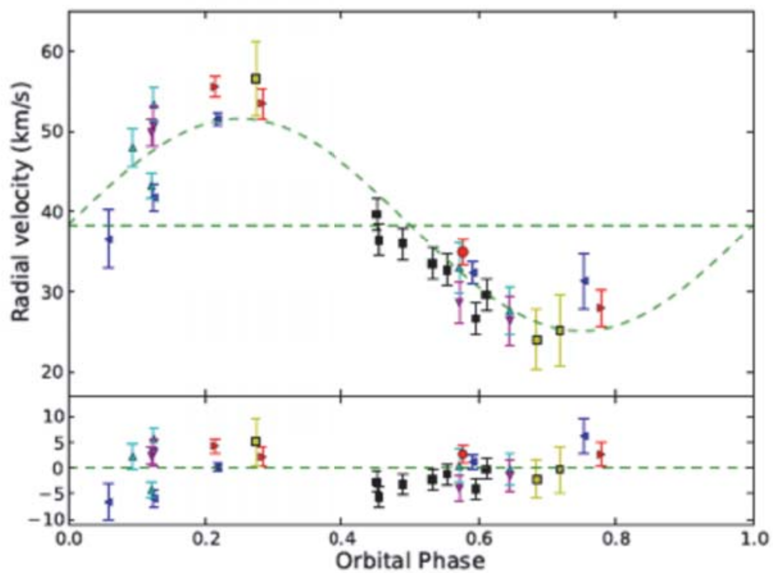


Figure 3. Radial velocity curve for the sdB component of PG 1018–047. We have averaged the RVs per observation run. The small lower panel shows the residuals. The black squares are the 7 RVs from the HET spectra, the red dot is the NOT/FIES data point, yellow squares are the SAAO observations, the blue left triangles and red right triangles are the respectively blue and red INT data points, and the cyan up and magenta down triangles correspond to the blue and red WHT radial velocities.

sdB + K5

- 10 years of spectroscopic monitoring
- INT, WHT, NOT, SAAO, HET

$P_{orb} = 760 \pm 6$ d

First results

Vos et al. 2015

First results

J. Vos et al.: The orbits of subdwarf-B + main-sequence binaries

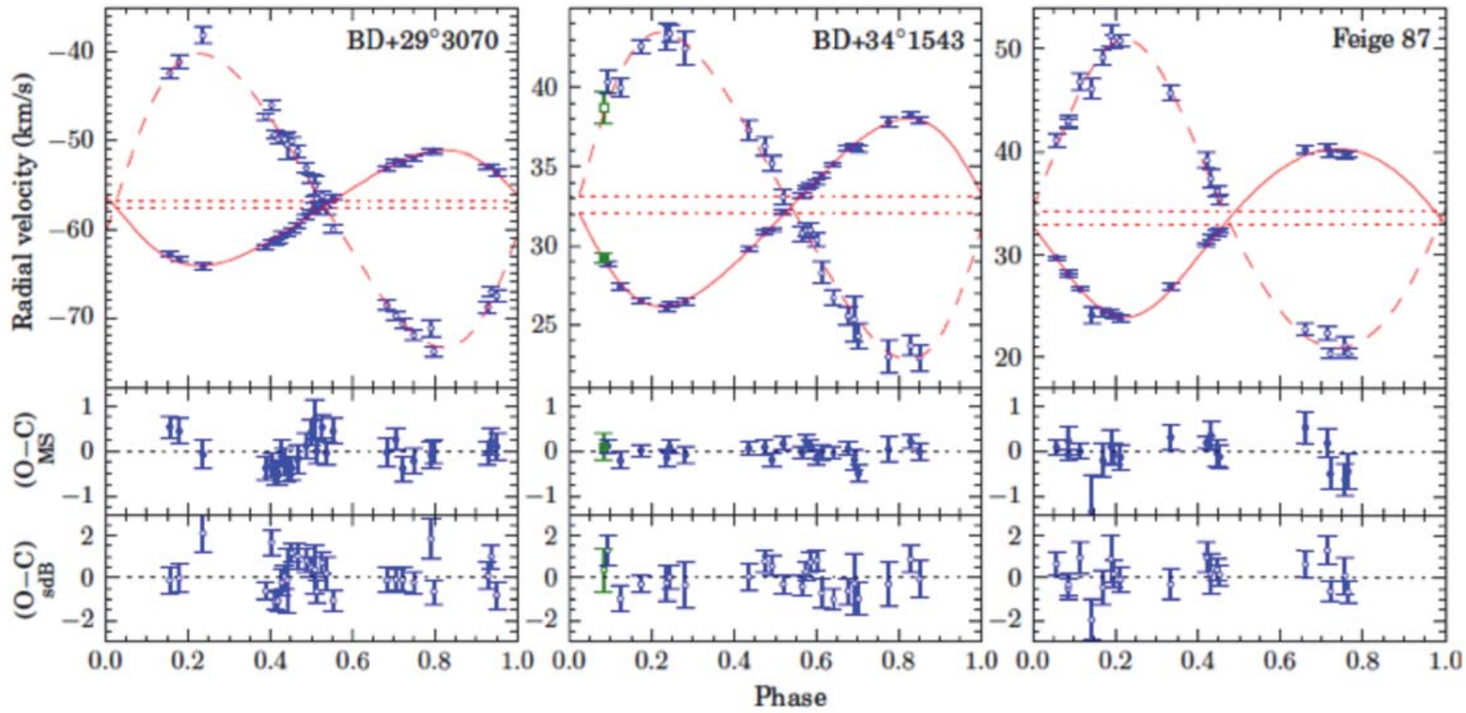
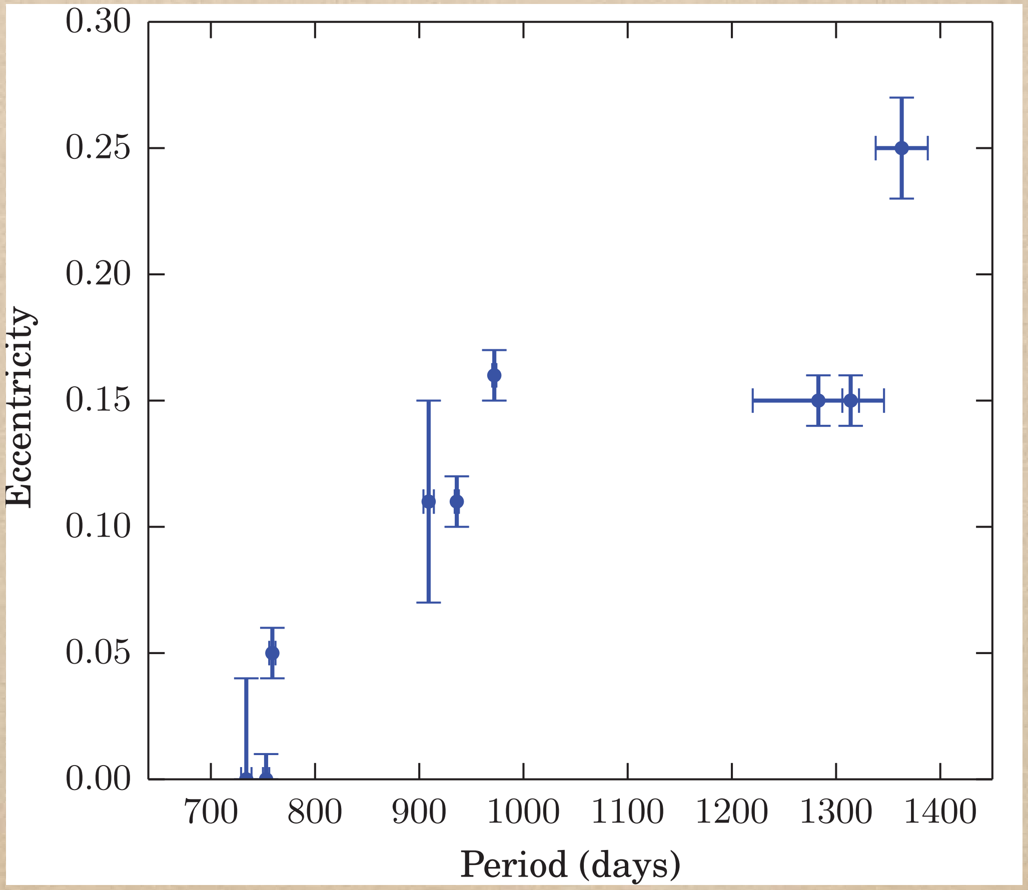


Fig. 1. The radial velocity curves for BD+29°3070 (left), BD+34°1543 (center) and Feige 87 (right). Top: spectroscopic orbital solution (solid line: MS, dashed line: sdB), and the observed radial velocities (HERMES: blue circles, FOCES: green squares, filled symbols: MS component, open symbols: sdB component). The measured system velocities of both components are shown by a dotted line. Middle: residuals of the MS component. Bottom: residuals of the sdB component.

Vos et al. 2015

First results

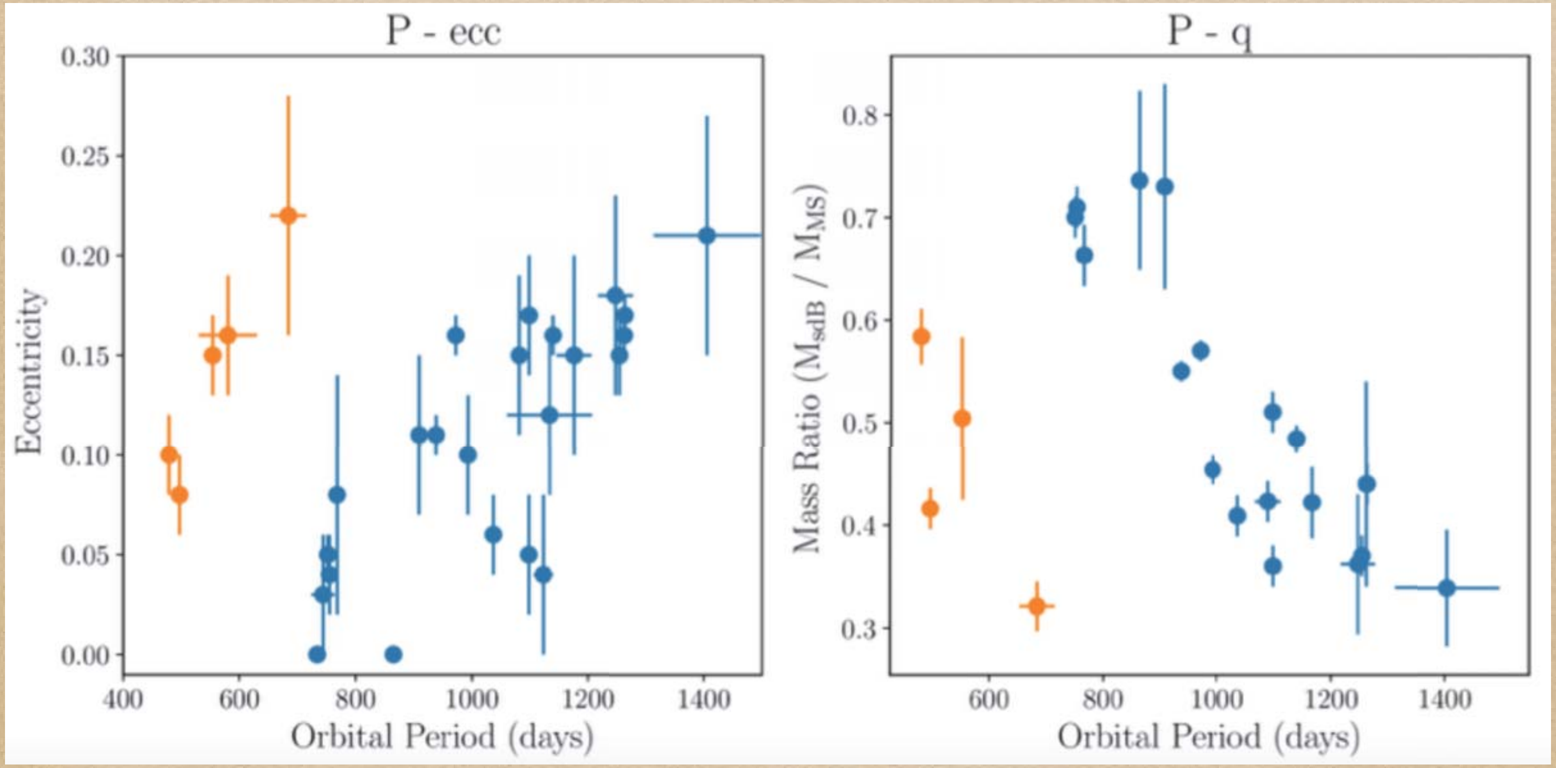
2009-2014



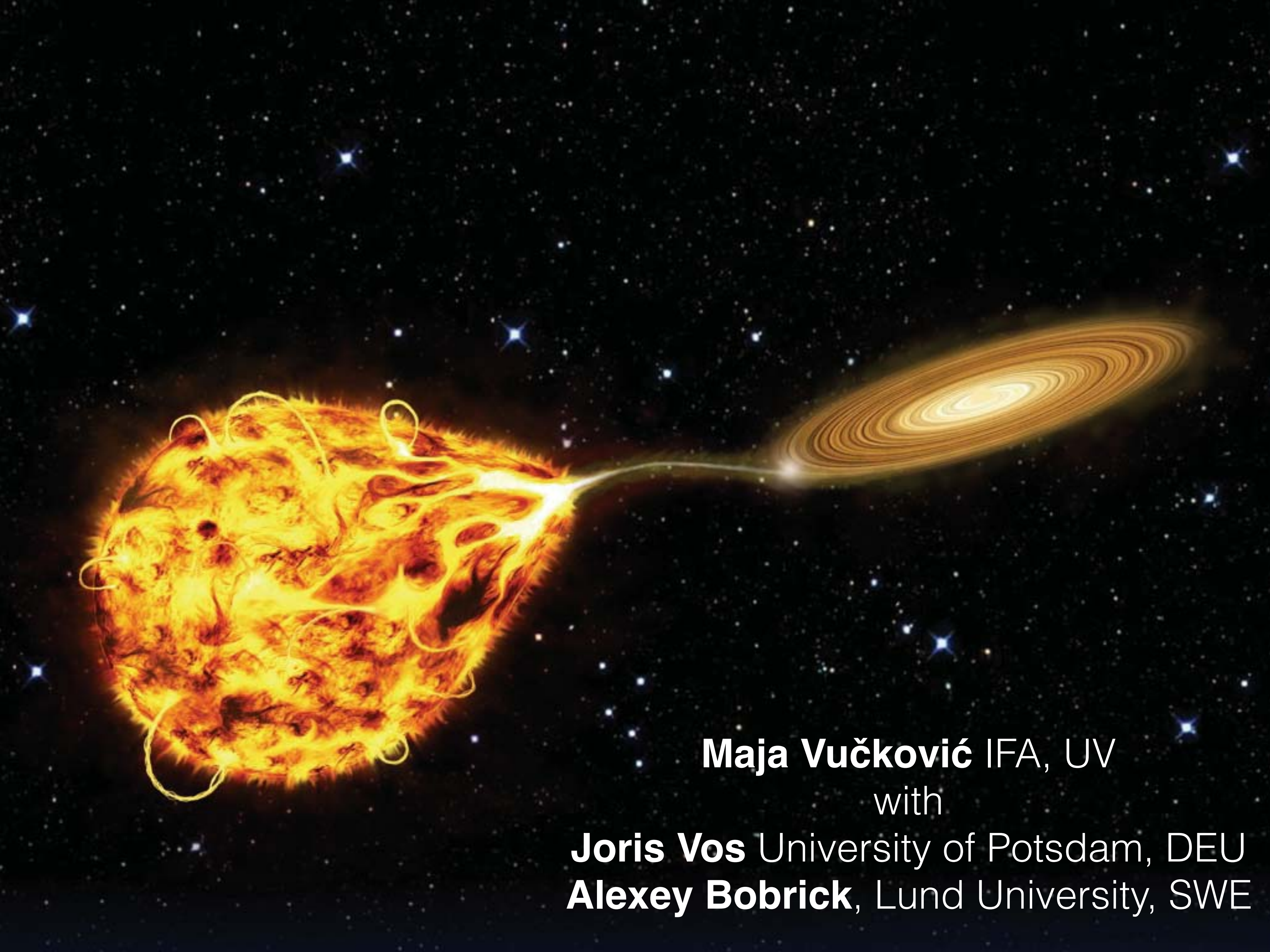
Vos et al. 2017

Observations

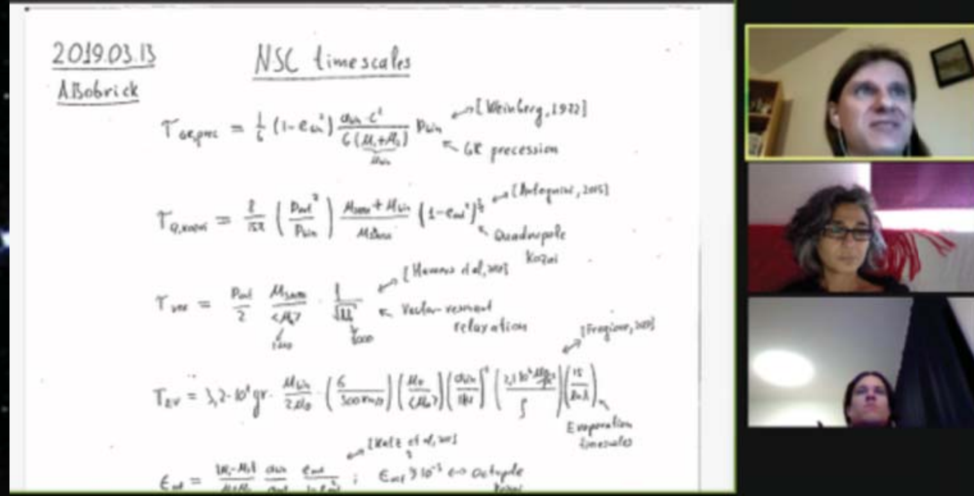
P_{orb} - eccentricity relation P_{orb} - mass ratio relation



Vos, Vučković et al. 2019

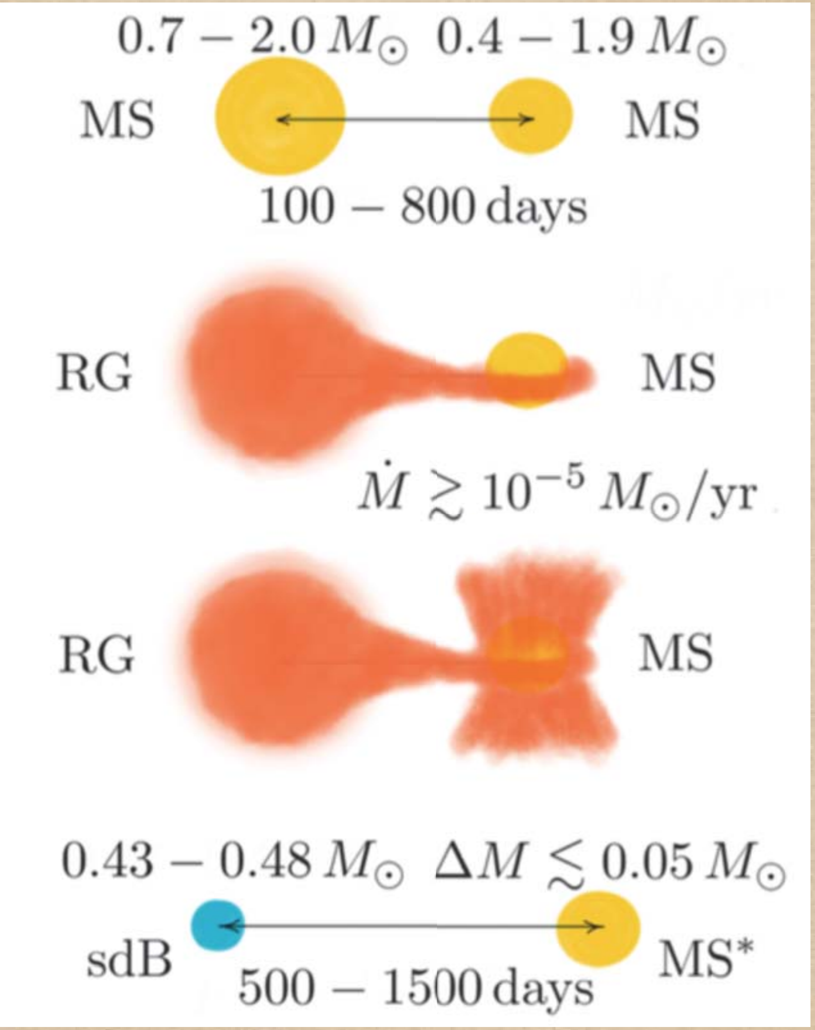


Maja Vučković IFA, UV
with
Joris Vos University of Potsdam, DEU
Alexey Bobrick, Lund University, SWE

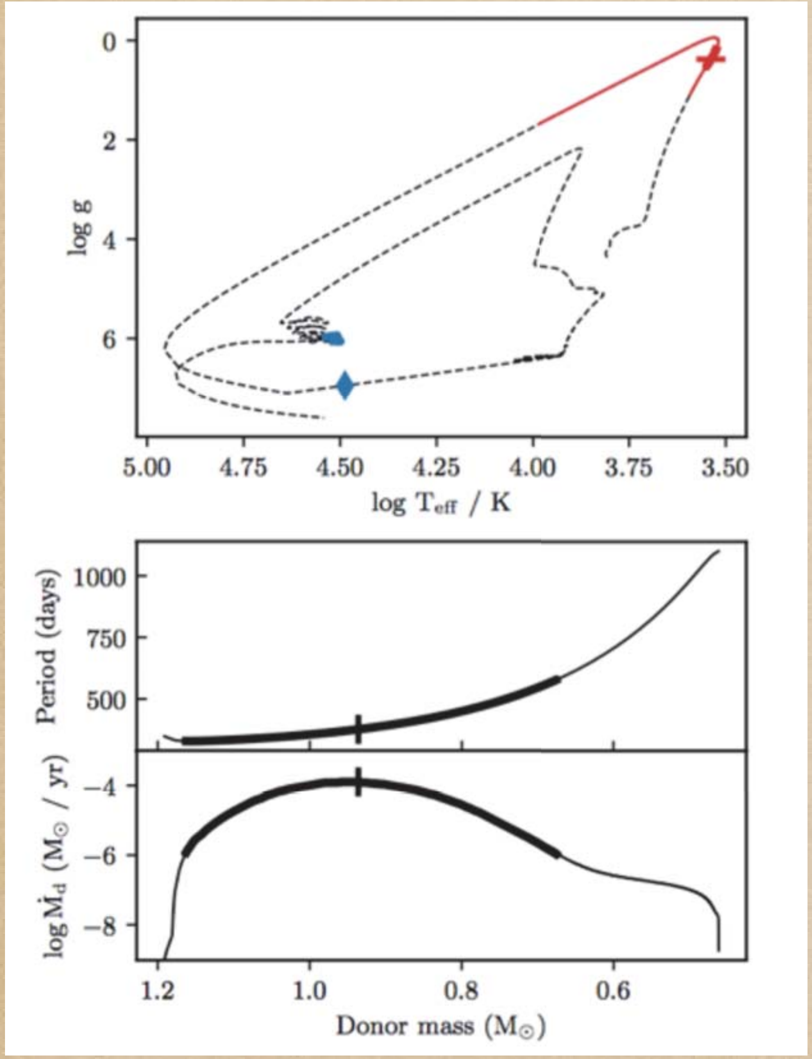


Maja Vučković IFA, UV
with
Joris Vos University of Potsdam, DEU
Alexey Bobrick, Lund University, SWE

Formation of wide sdB binaries



Vos et al. 2020



Vos et al. 2020

MESA

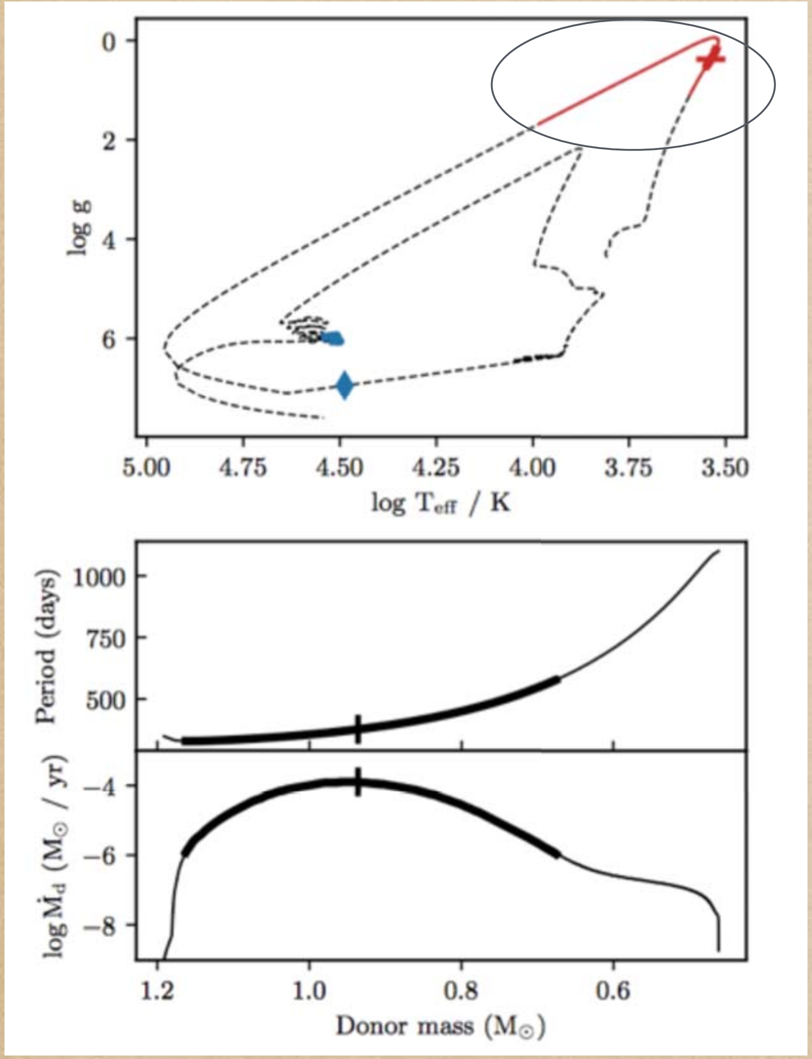
Paxton et al. 2015

$1.2\ M_{\odot} + 0.85\ M_{\odot}$

P_i=350 d

[Fe/H] = –0.15

-> thin disk



Vos et al. 2020

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Population properties

Mass distribution: Kroupa et al. 2004
Mass ratio: flat distribution
Orbital period: Log normal distribution

Metallicity:

- fixed
- uniform

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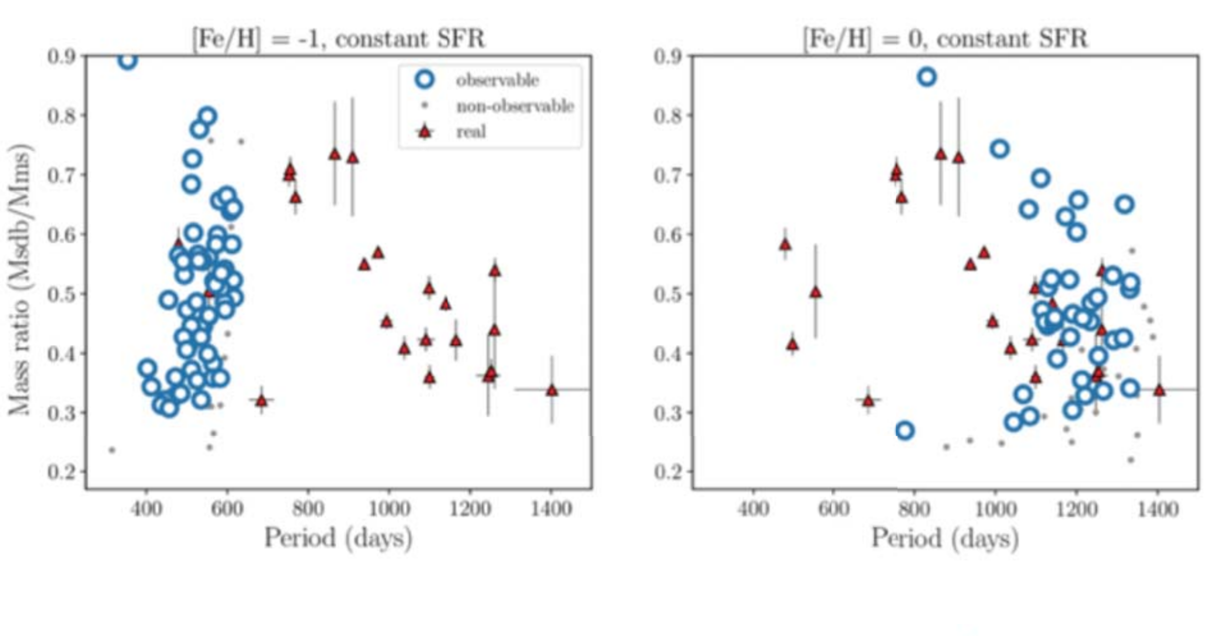

A single metallicity population does not work

Population properties

Mass distribution: Kroupa et al. 2004

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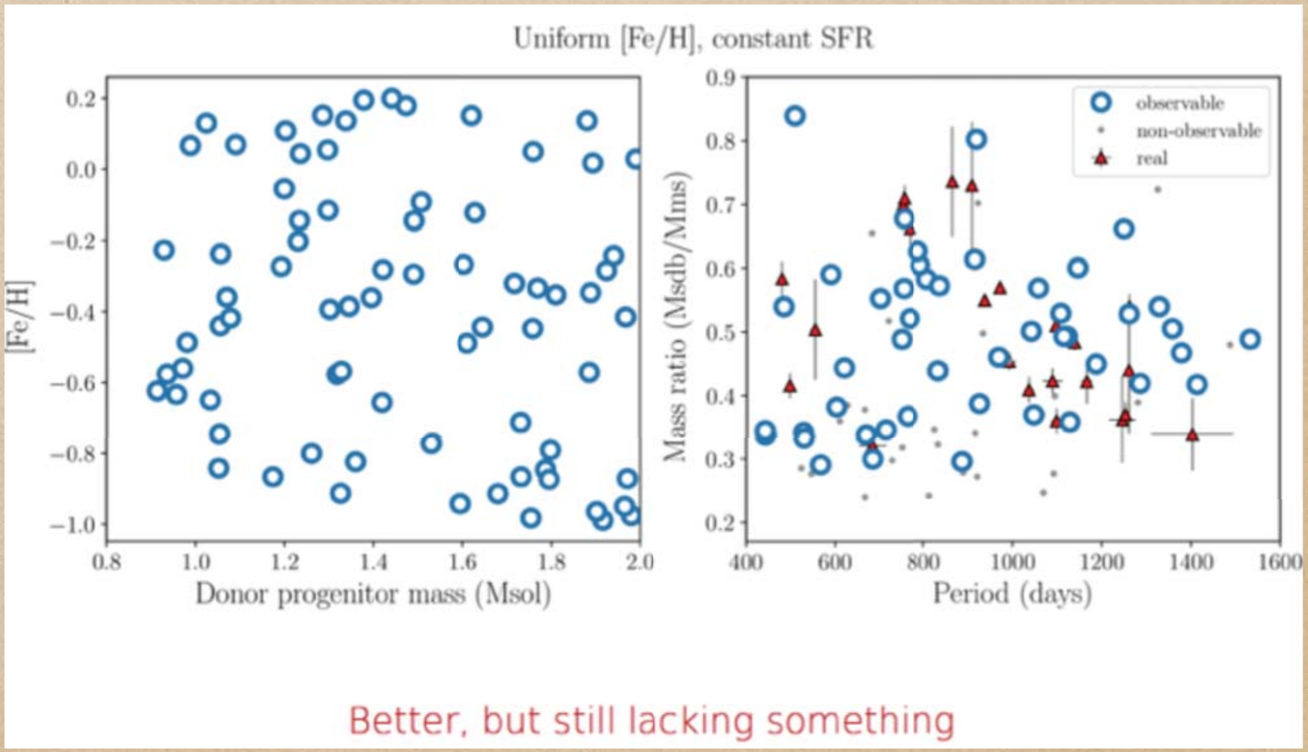
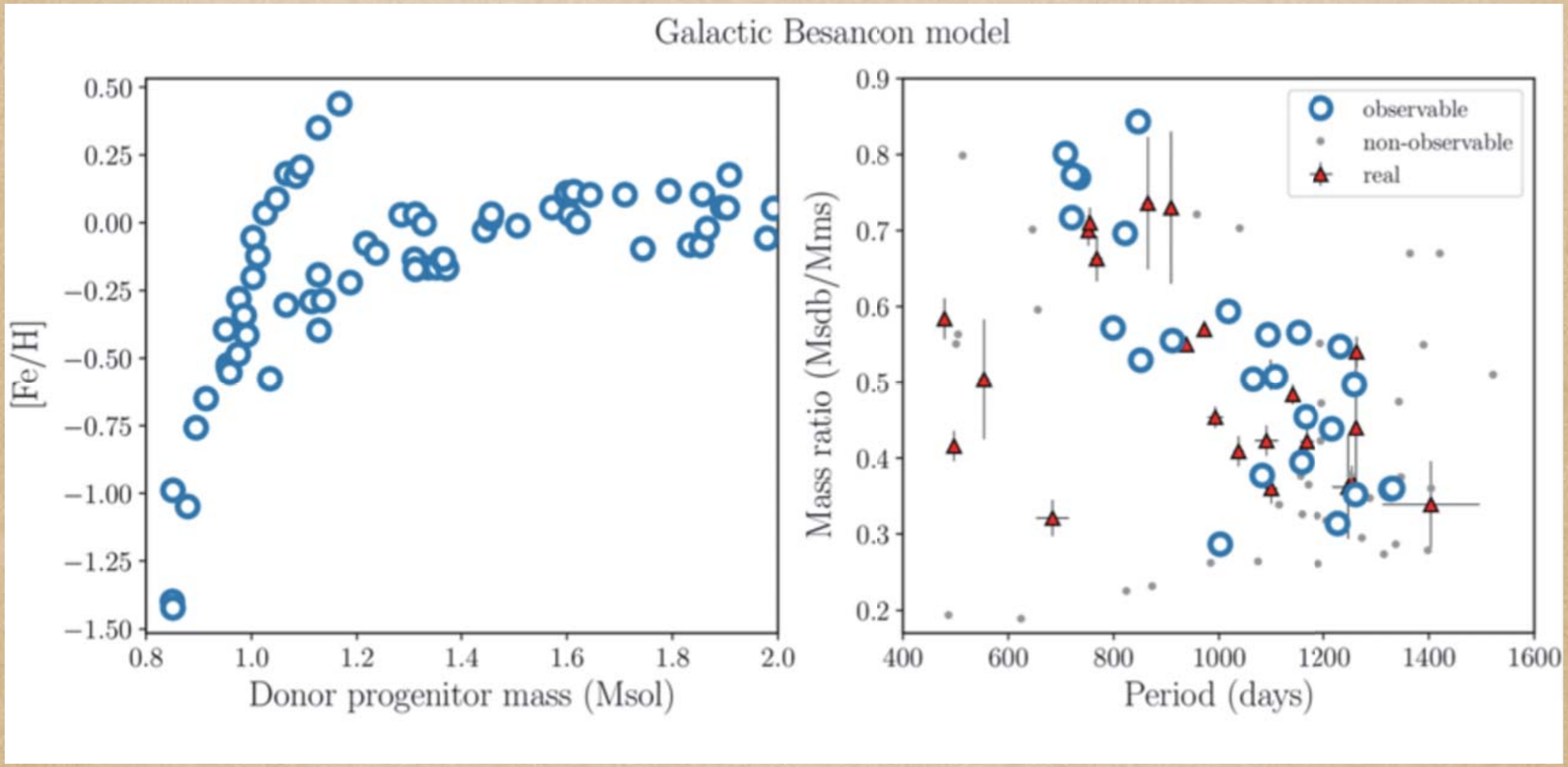


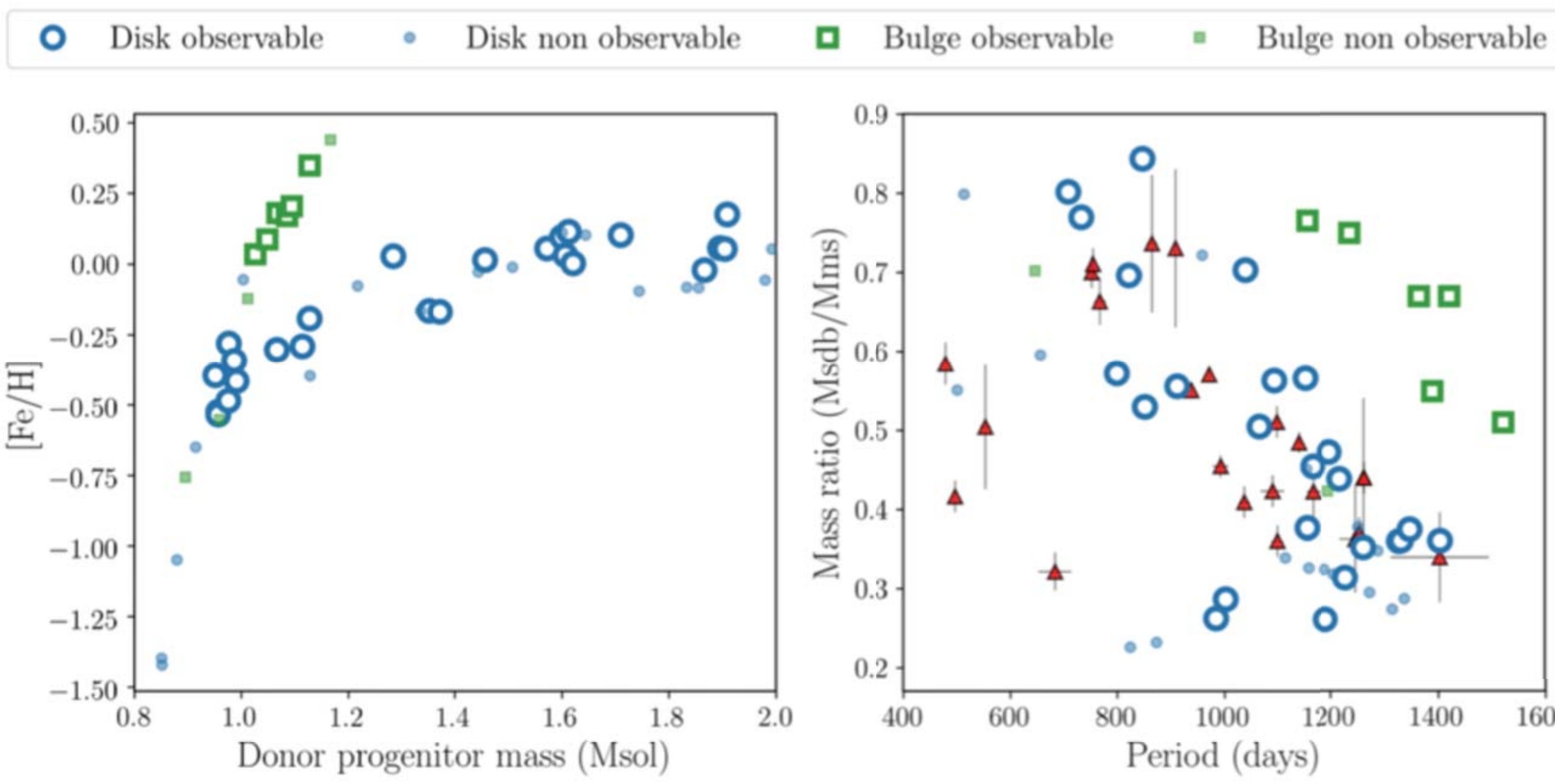
Besancon model for Galactic evolution (Robin et al. A&A 409 2003)

→ Aims to explain currently observed galaxy

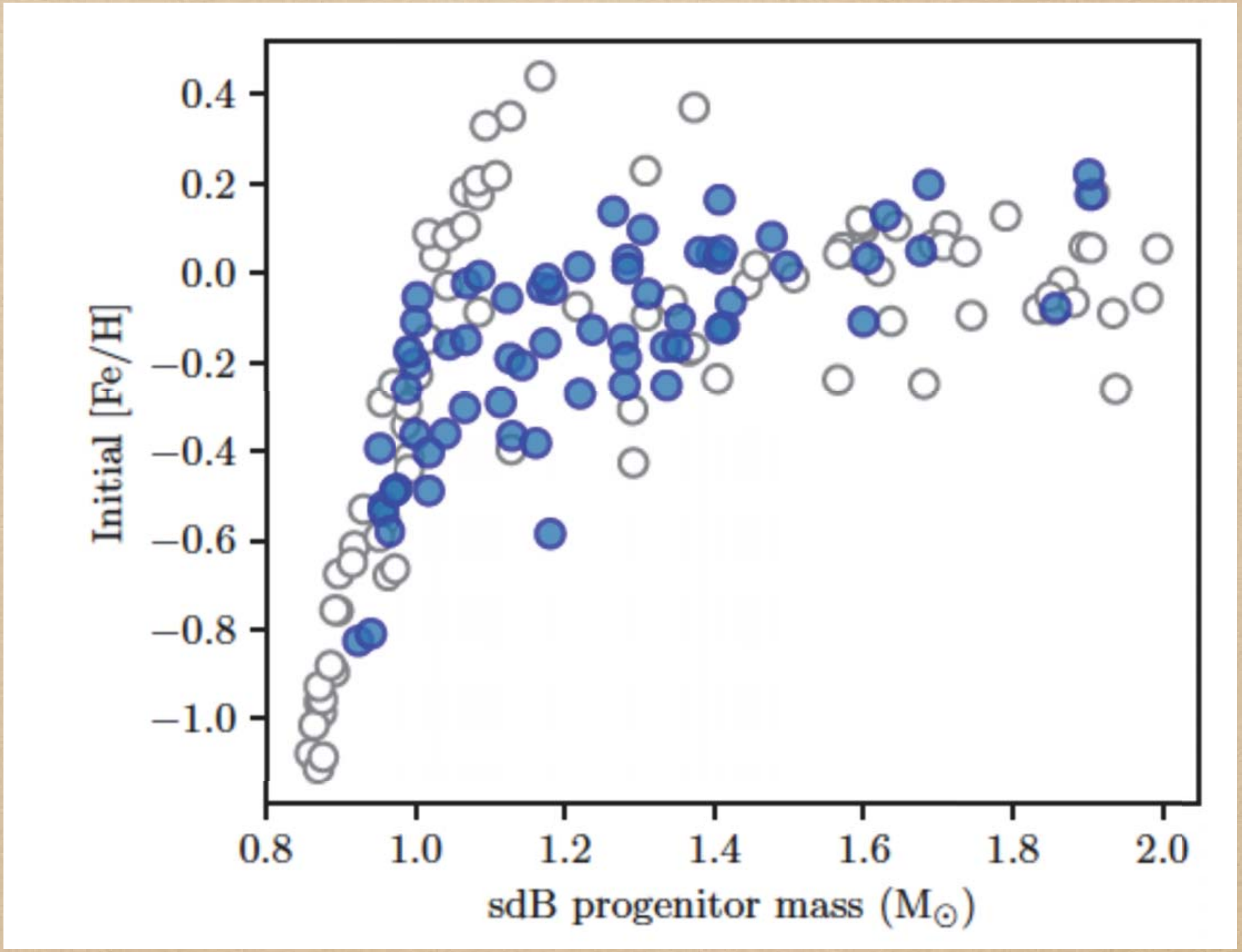


Voilà !

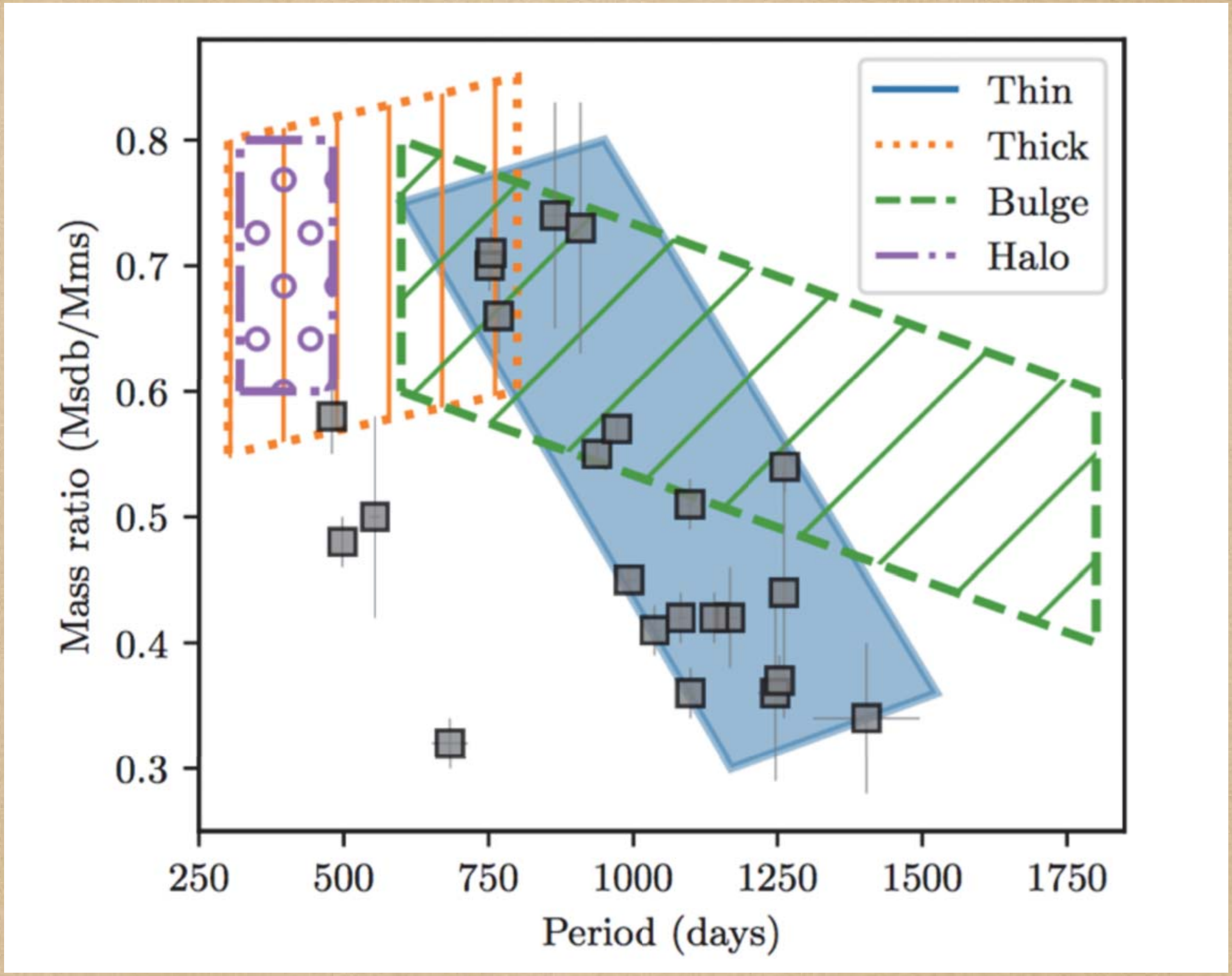
Galactic populations in P - q



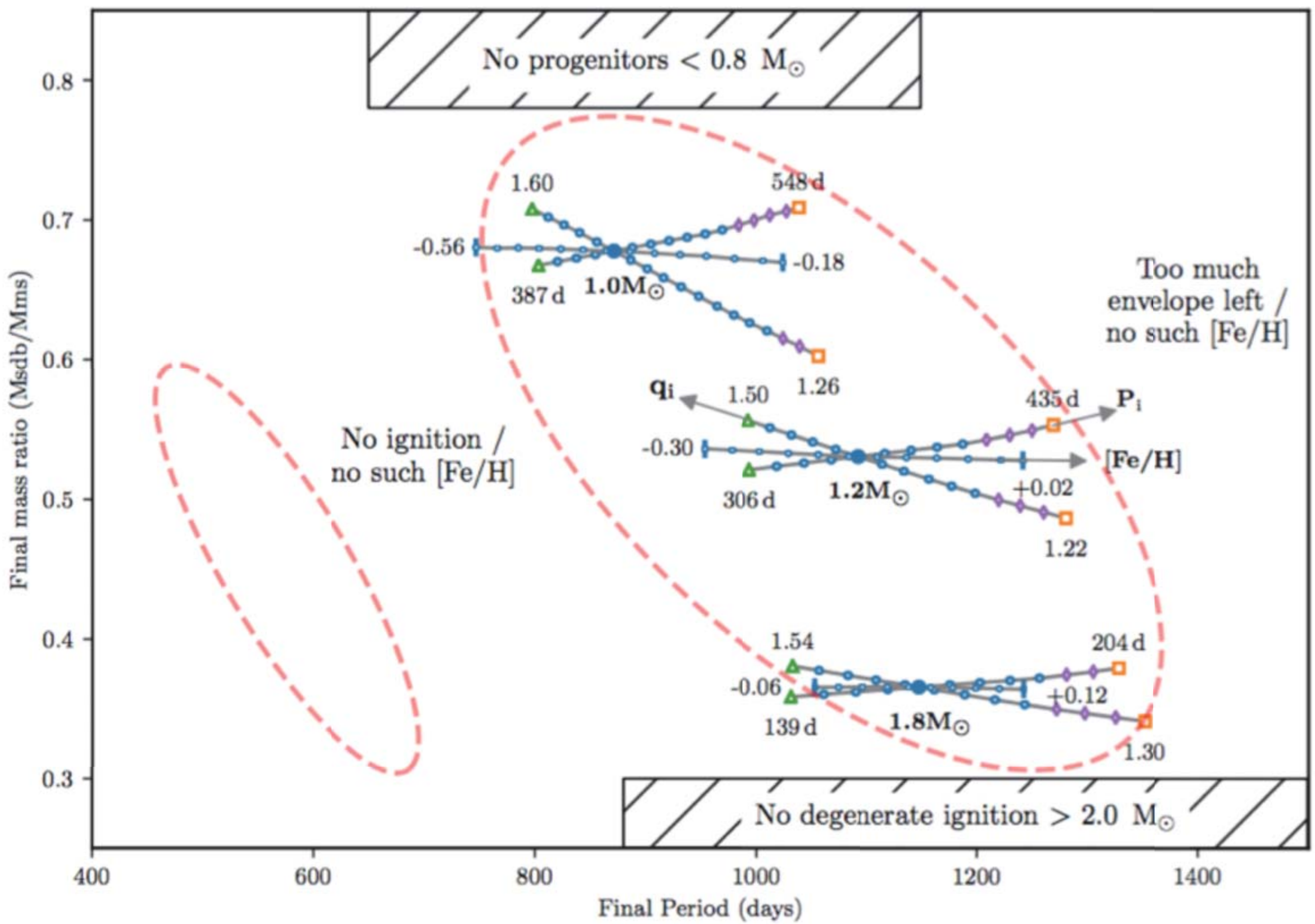
- Bulge is old with high [Fe/H] → thus longer periods
- Can be a test for the model



Vos et al. 2020



Vos et al. 2020



Vos et al. 2020

Take home message

Basic model for binary interaction

+

Besancon model for Galactic evolution

↓

P - q relation for wide sdB binaries

Galactic evolution is important for BPS studies!

Relavant for WDs, ELMs, sdAs, BHBs as well


Hvala na pažnji

some are pulsating !!!

SAAO 1m

Steward Observatory 1.54 m

1st sdOB conference @ La Palma 2005

pulsating sdB

EC14026 / V361 Hya

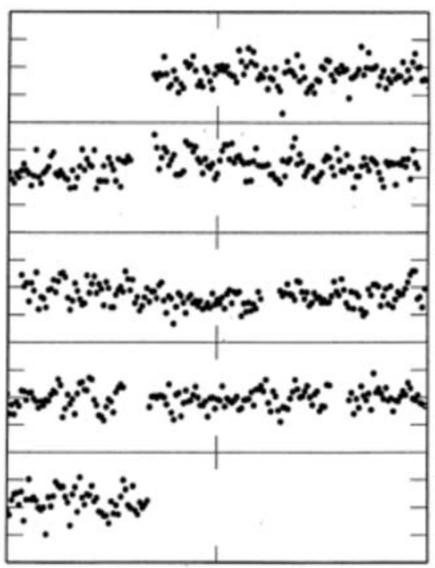


Figure 2. Continuous 10-s integrations in 'white light' for EC 14026 – 2647 for the night of 1994 May 16/17 – the discovery observations. The ordinate carets are separated by 0.05 mag and the abscissae by 0.01 d, so that the data read continuously from left to right and top to bottom, from fractional Julian date 0.307 to 0.387.

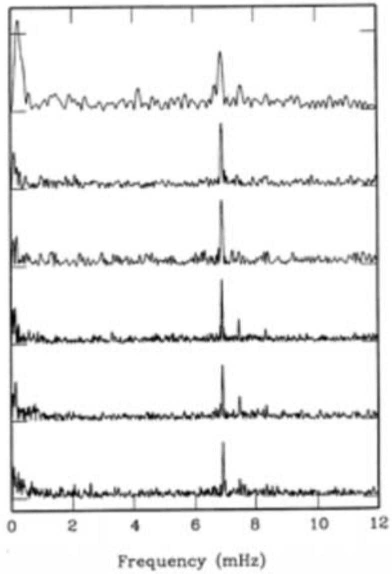


Figure 3. Amplitude spectra for EC 14026 – 2647 for (top to bottom) 1994 May 16/17 (data in Fig. 2), 1995 March 2/3 and 3/4, May 23/24, 24/25 and 25/26. Ordinate carets are separated by 0.015 mag. Note the secondary frequency near 7.5 mHz and the worm error frequency near 8.33 mHz. Conspicuous features at very low frequency are due to sky transparency variations.

Kilkenny et al. 1997 MNRAS, 285, 640

Betsy stars / V1093

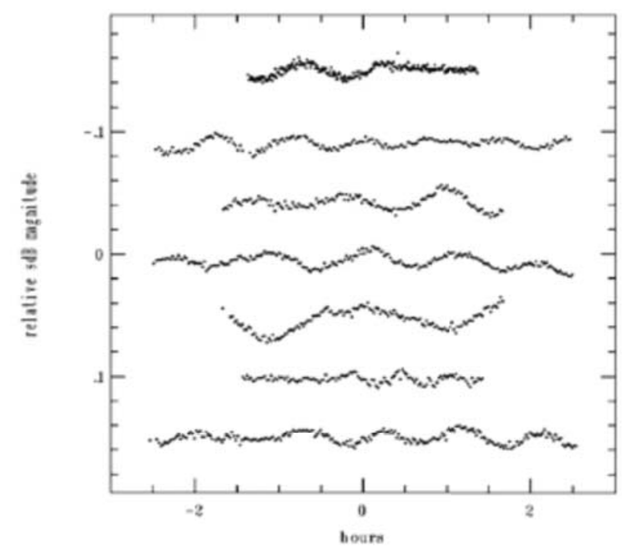


FIG. 1.—Discovery light curve for PG 1716+426 (*top*, observed with a *V* filter), followed by typical light curves for the largest amplitude long-period pulsators: PG 1716+426 (*R* filter), PG 0850+170 (*R*), PG 1338+481 (*B*), PG 1627+017 (*R*), PB 5450 (*R*), and PG 1739+489 (*V*). The time between peaks varies from about 35 to nearly 120 minutes.

Green et al. 2003 ApJ, 583, 31

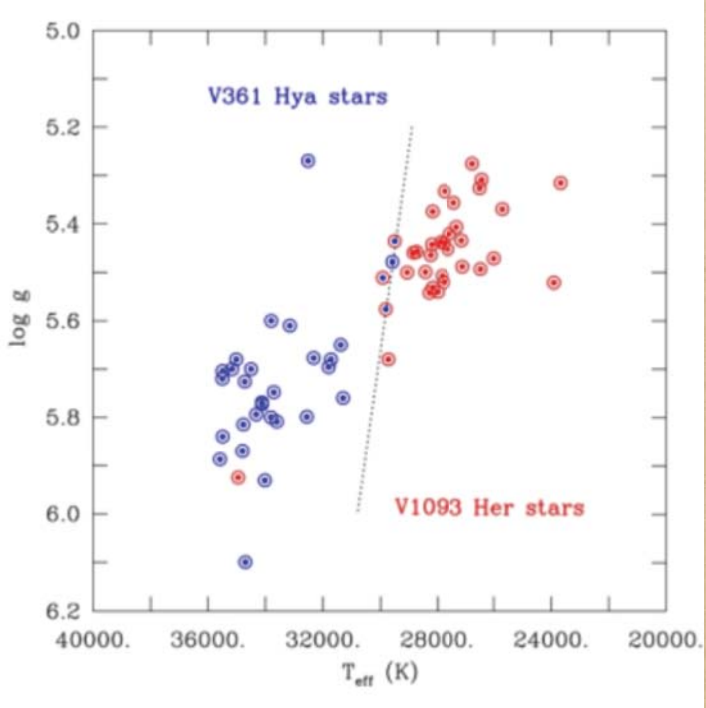
pulsating sdB

<u>EC 14096 or V361 Hya</u>
(Kilkenny et al. 1997):
P-mode pulsators, periods of 60-580 s, 0.3-64 mmag.

- 10% of the objects show pulsations.

<u>PG 1716 or V1093 Her</u>
(Green et al. (2003):
G-mode pulsators, periods 1000-14600 s, 0.4-4.1 mmag.

- 75% of the objects show pulsations.



Green et al. (2011)

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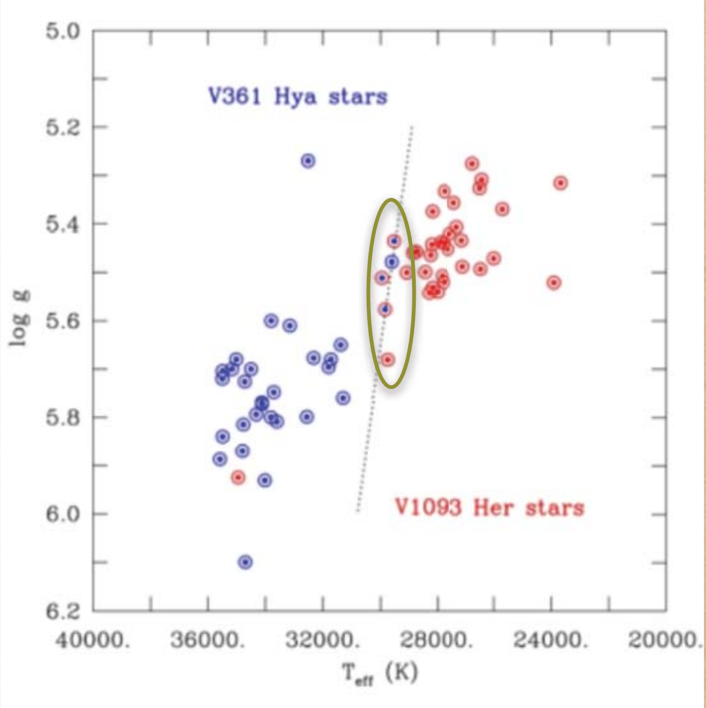
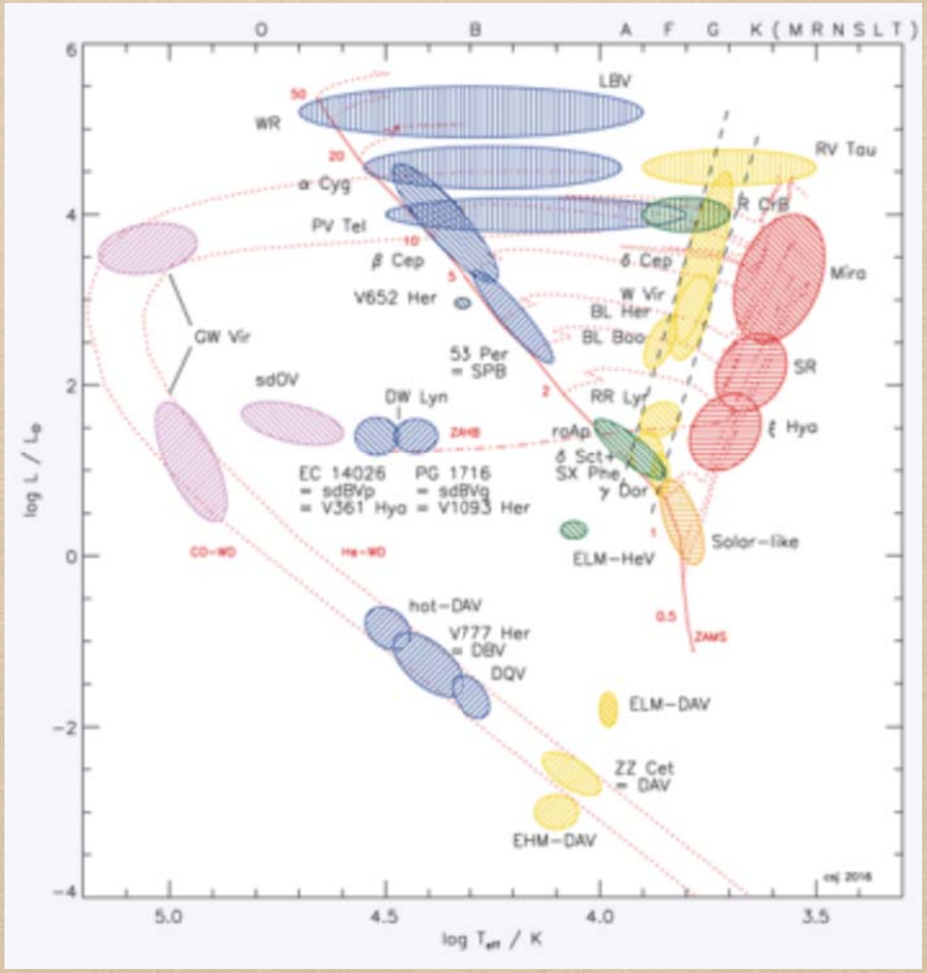
Hybrids (Schuh et al. 2006):
p - and g-modes.



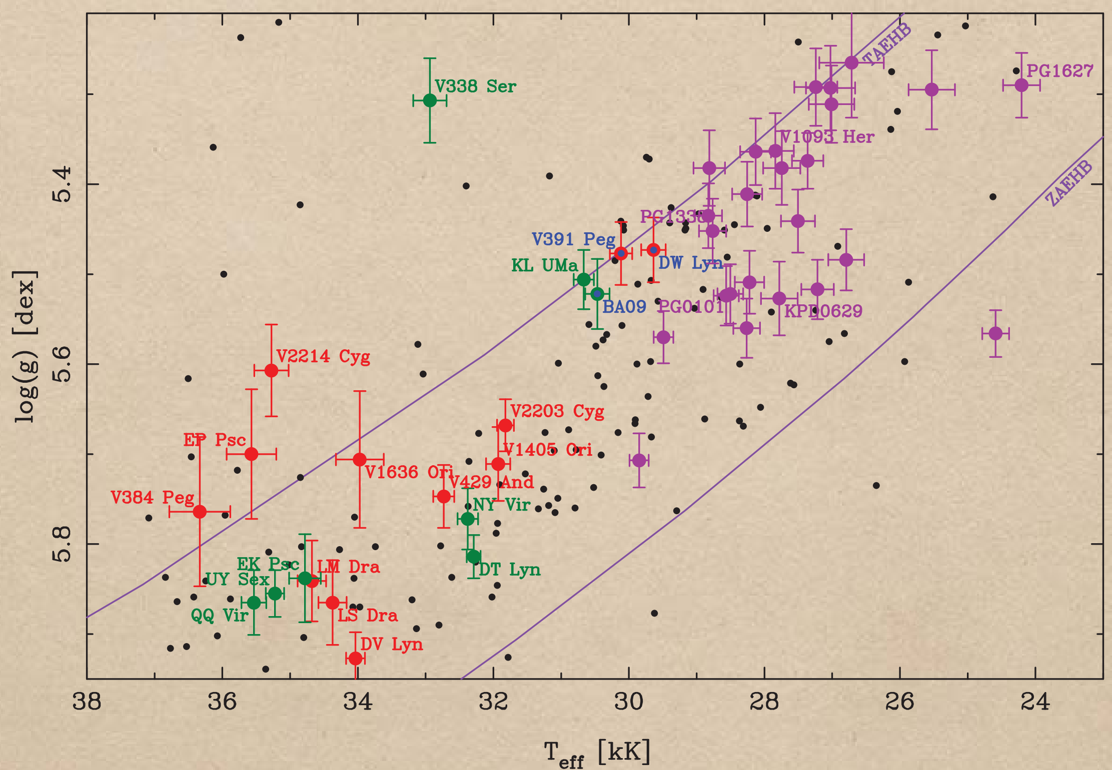
Green et al. (2011)

Pulsating stars across HRD



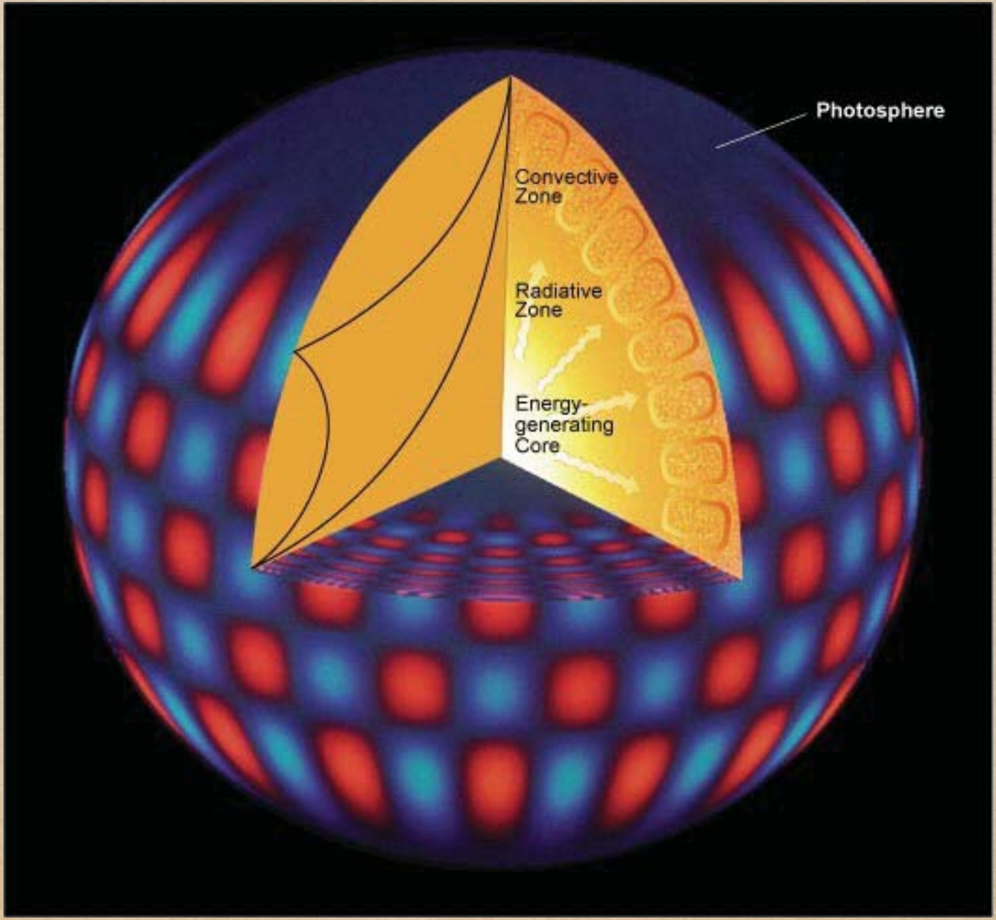
Jeffery & Saio (2016)

pulsating sdB

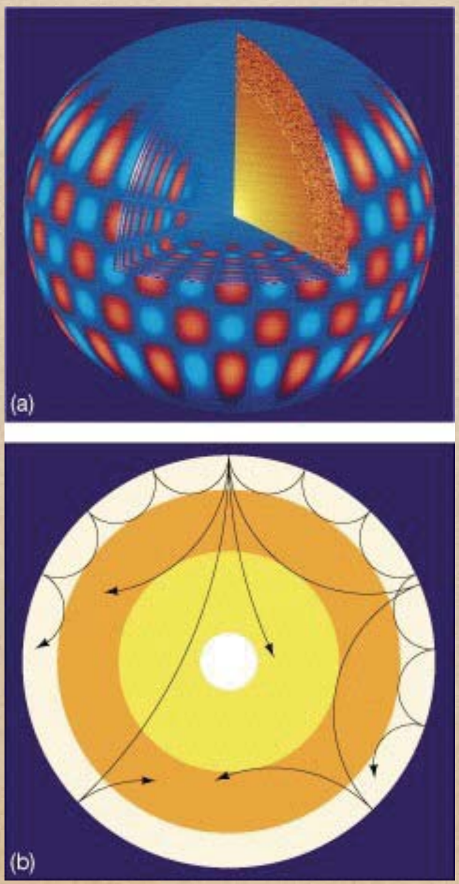


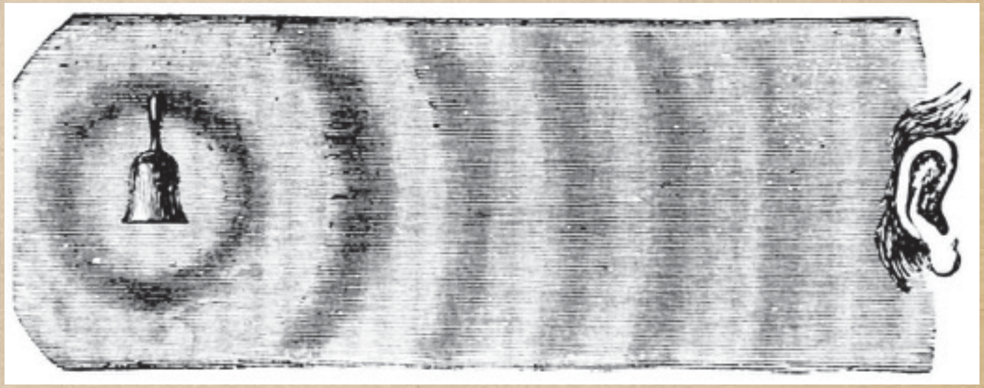
Betsy Green & Roy Østensen
private communication

Asteroseismology

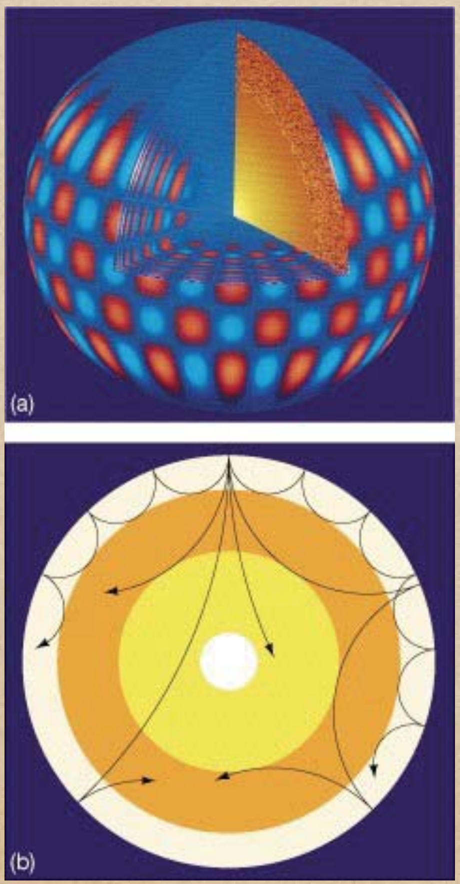


Asteroseismology





Asteroseismology



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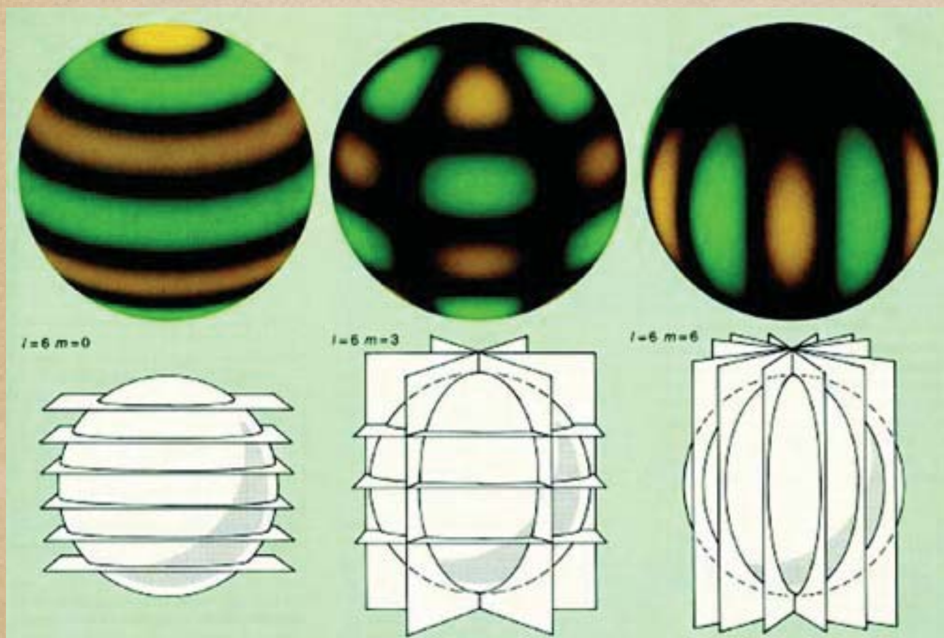
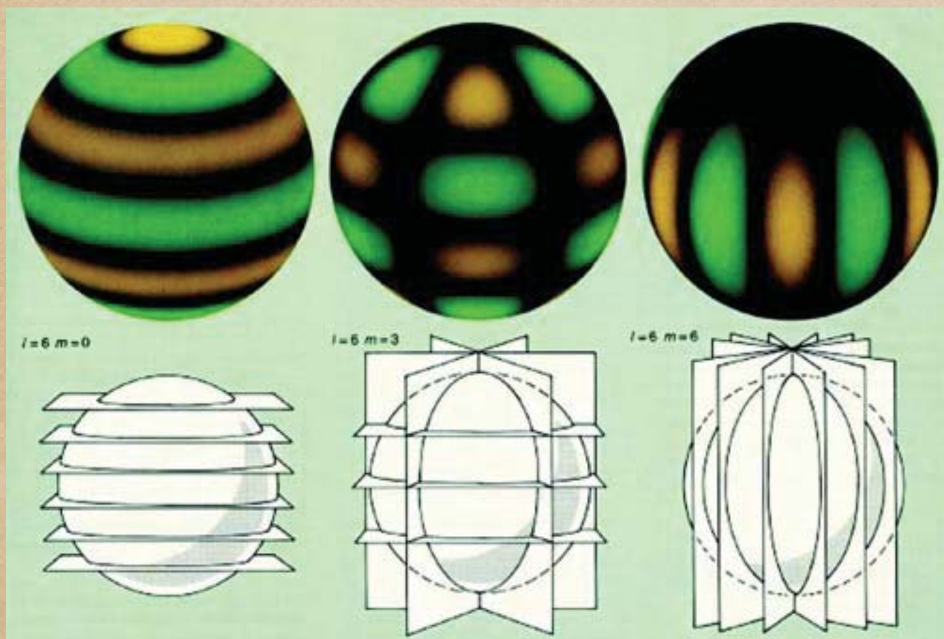
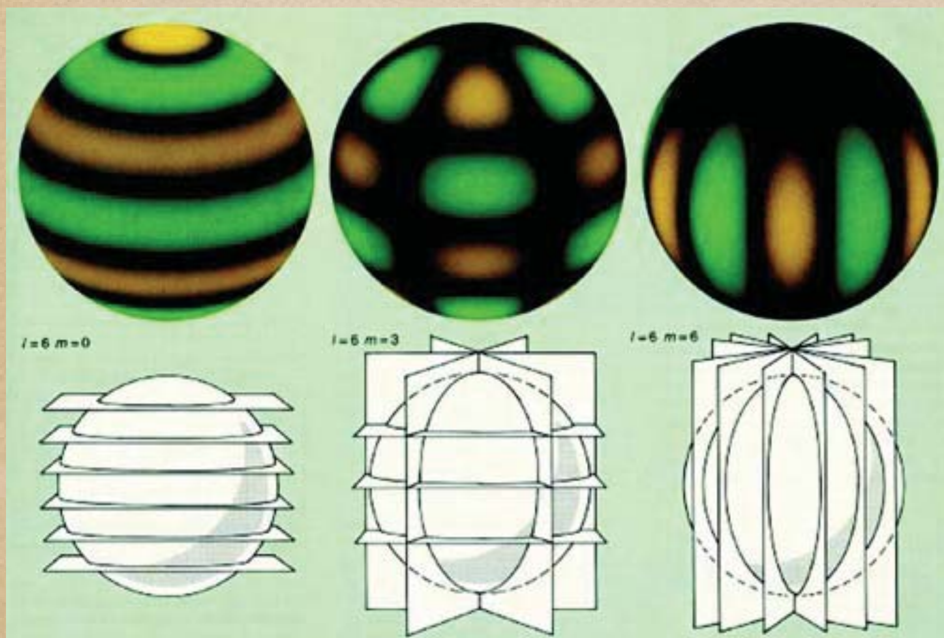


Asteroseismology



- each pulsation mode is explained with spherical harmonics $Y_{lm}(\theta,\phi)$;
- l degree of a mode;
- m azimuthal number;
- stars have unresolved disk;

Asteroseismology



- each pulsation mode is explained with spherical harmonics $Y_{lm}(\theta,\phi)$;
- l degree of a mode;
- m azimuthal number;
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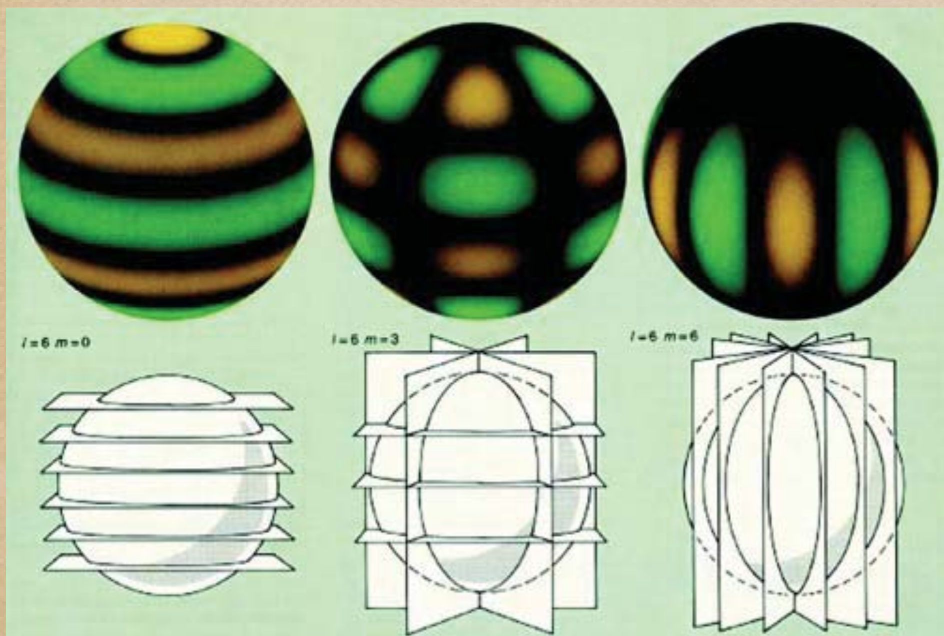
R & T & M_{tot} & M_{env}

Asteroseismology



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R & T & M_{tot} & M_{env}

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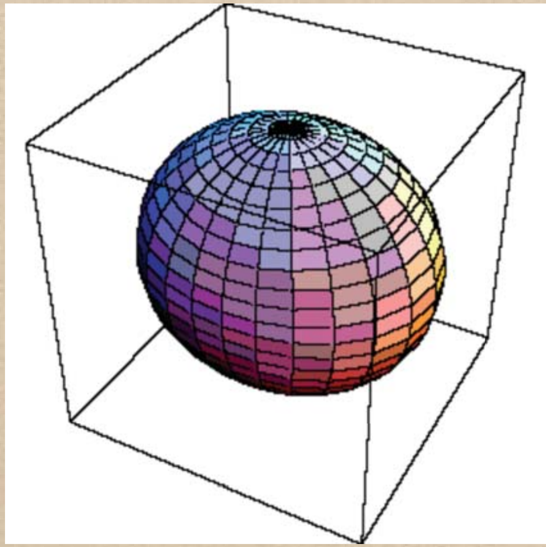

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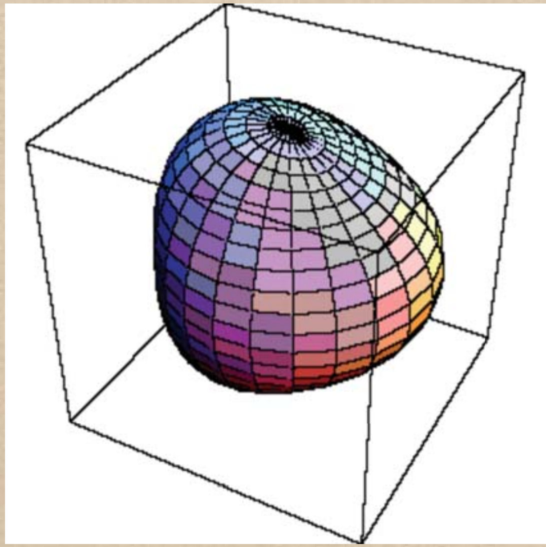

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R & T & M_{tot} & M_{env}

p-modes

Equal frequency spacings for *n* >> *l*

g-modes

Equal period spacings for *n* >> *l*

$$\Delta\Pi_\ell = \frac{\Pi_o}{\sqrt{\ell(\ell+1)}}$$

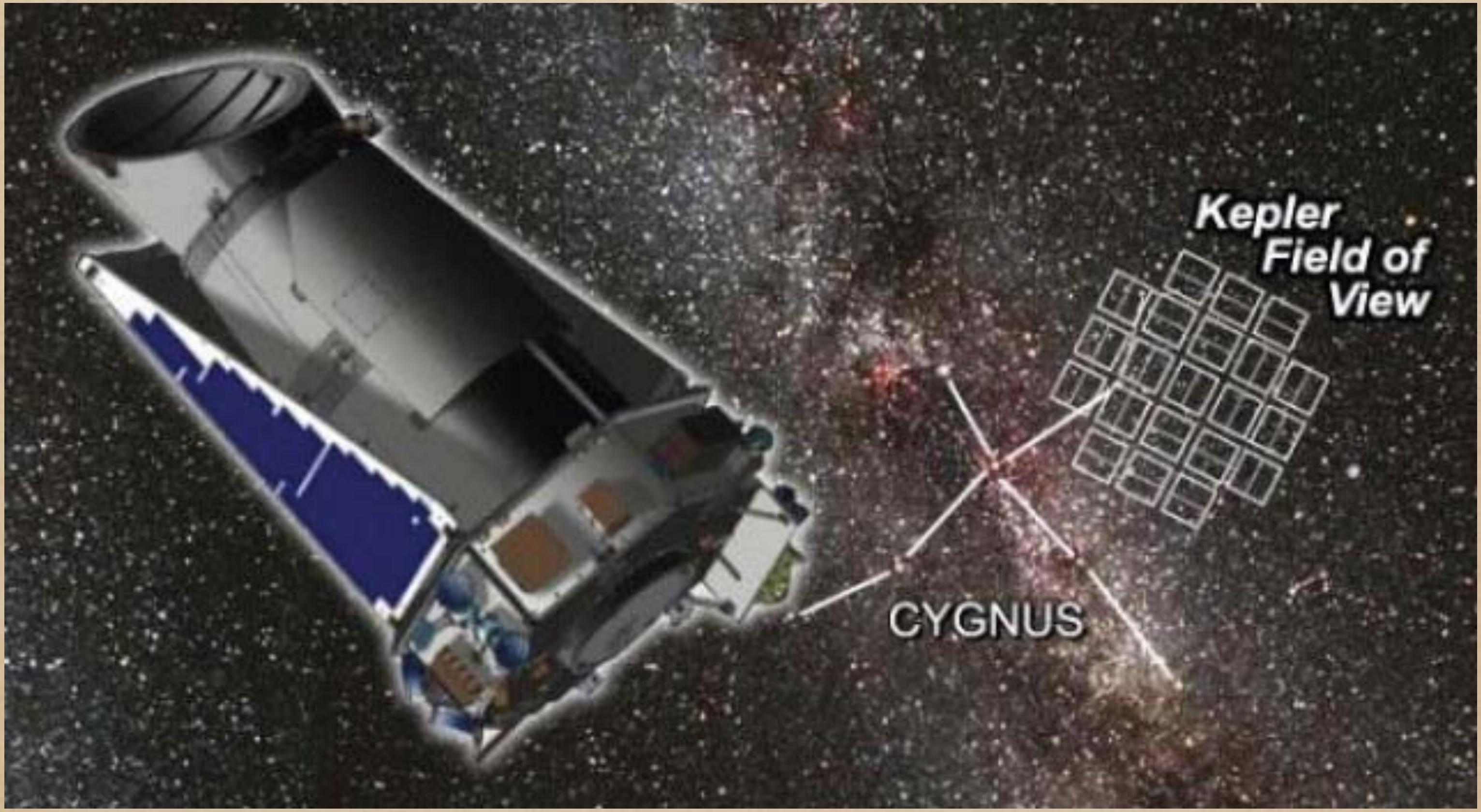
where

$$\Delta\Pi_\ell = \Pi_{\ell,n+1} - \Pi_{\ell,n}$$

=>

$$\Delta\Pi_{\ell=2} = \frac{\Delta\Pi_{\ell=1}}{\sqrt{3}}$$

good old KEPLER…



7 March 2009 -11 May 2013

good old KEPLER…

- 48 sdB stars observed
- 19 pulsators :
  - 100s frequencies/star
  - mostly g-mode
  - 1 pure p-mode
  - equal period spacings
    - l=1 and l=2 modes

7 March 2009 -11 May 2013

good old KEPLER…

- stellar rotation rates:
    - **too slow !**
- interior structure of g-mode pulsators:
    - **core too big !**

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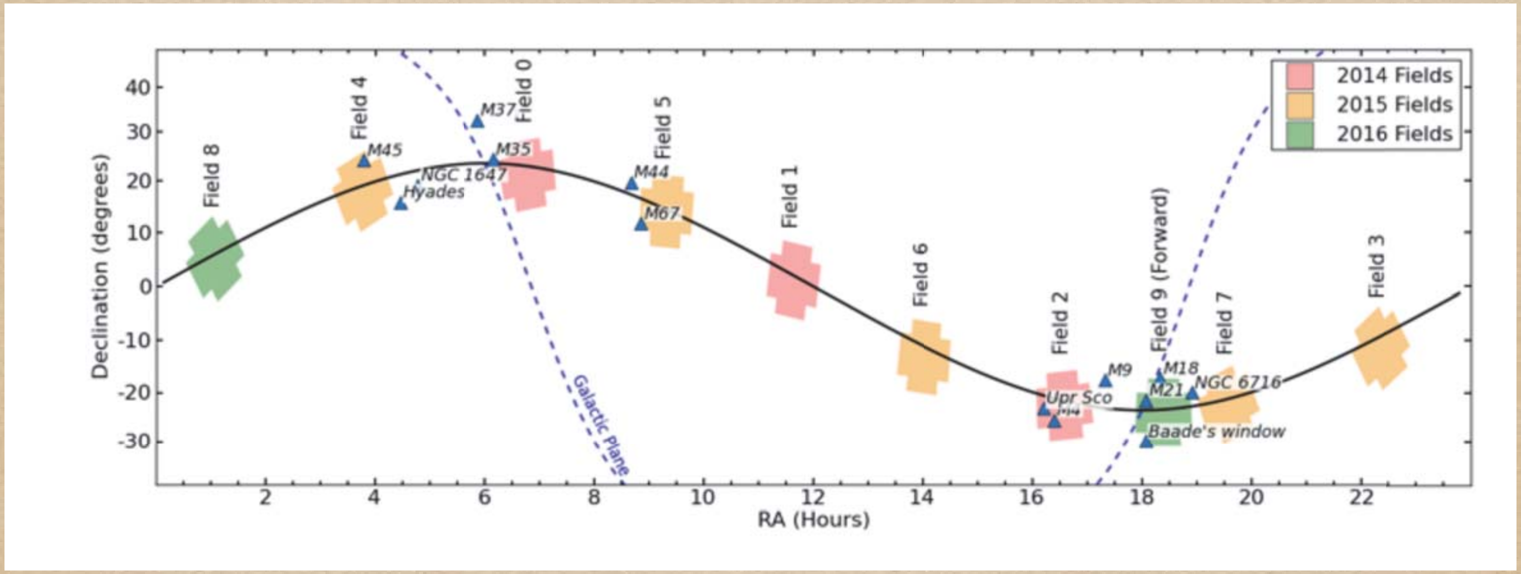
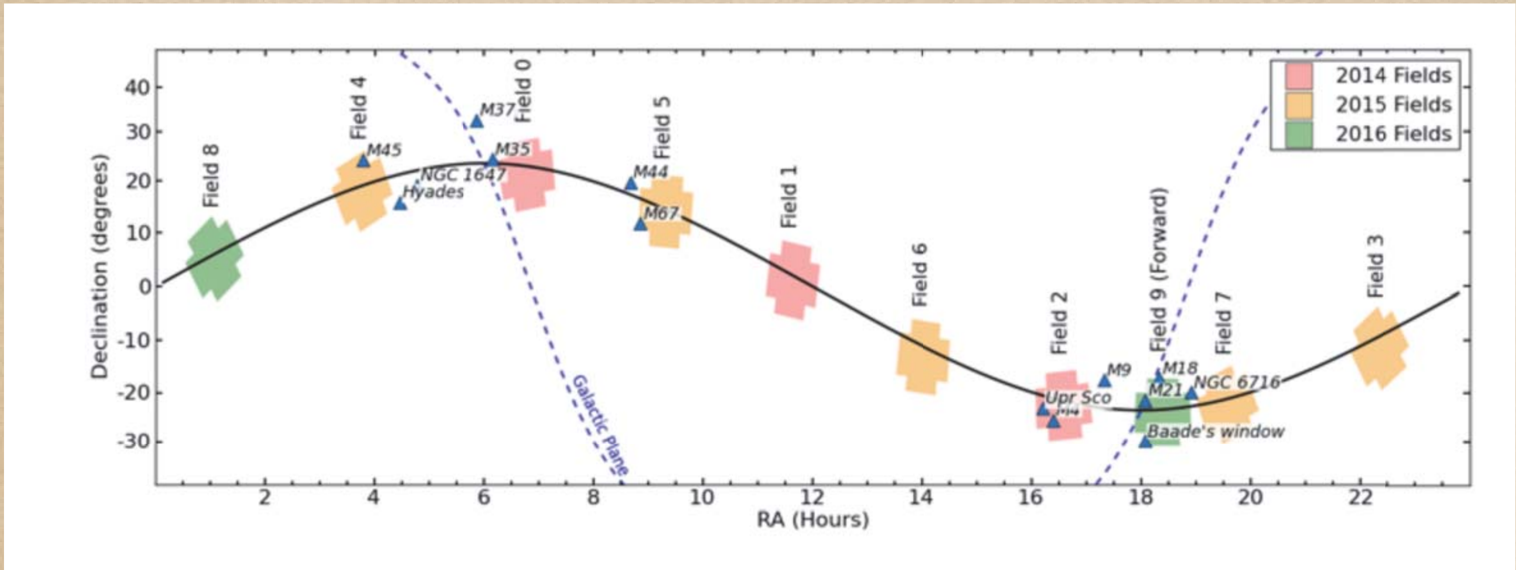
7 March 2009 -11 May 2013

KEPLER rebirth

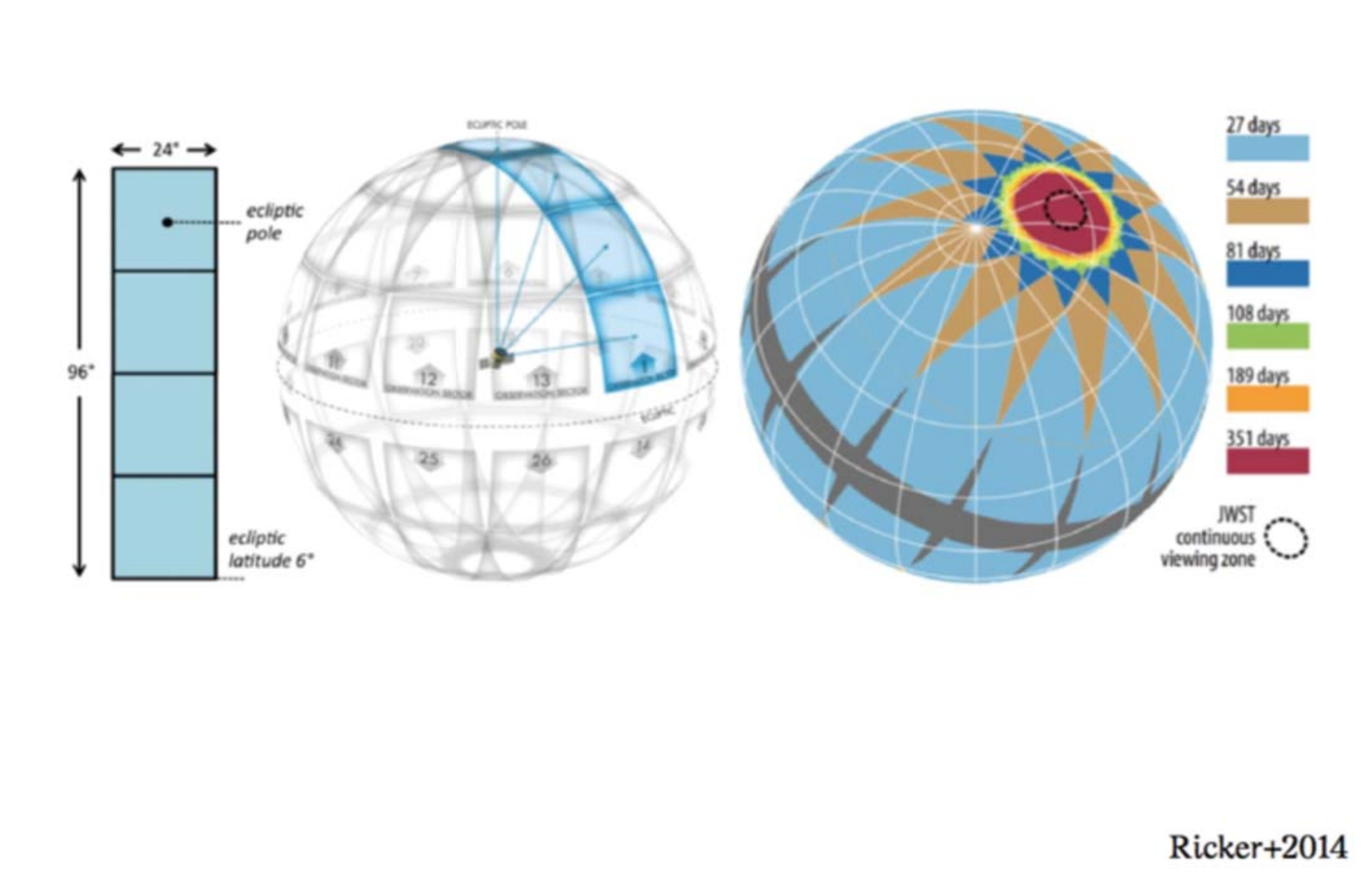


KEPLER rebirth



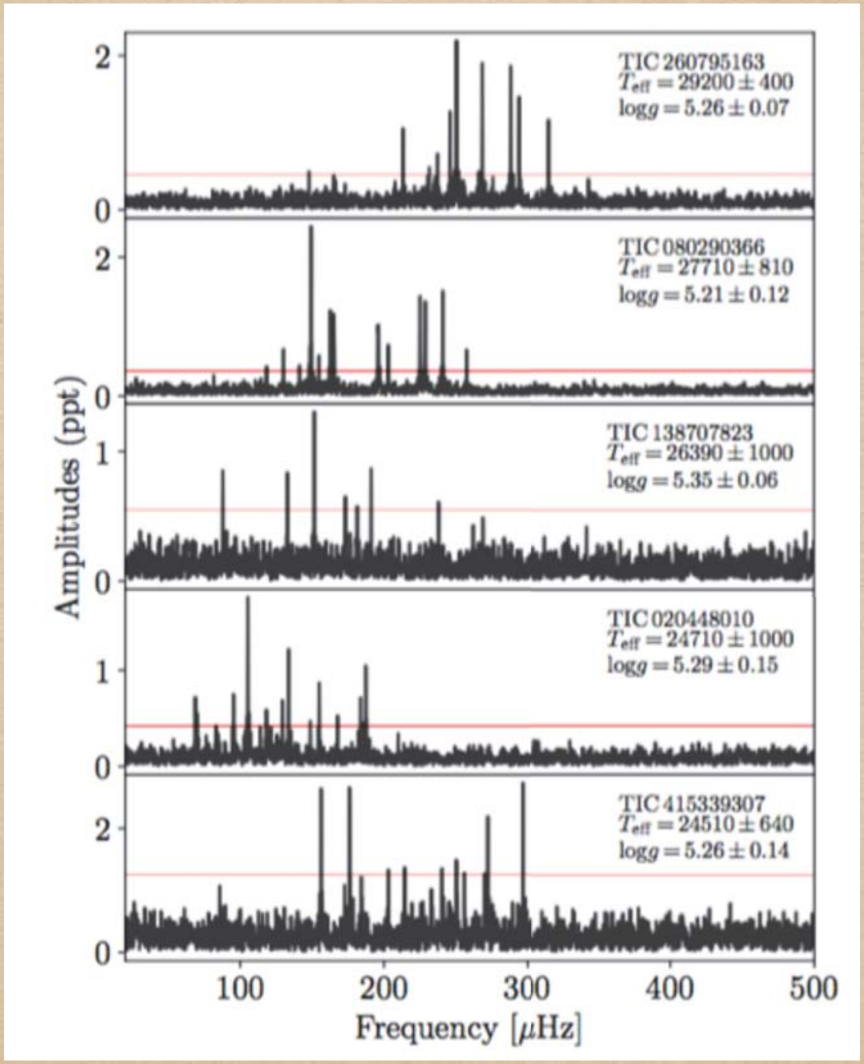
K2 mission

Transiting Exoplanet Survey Satellite



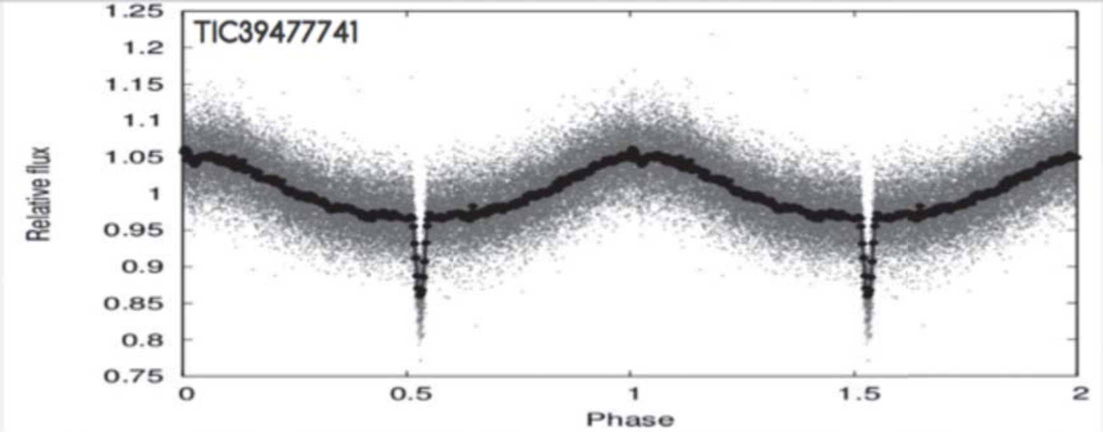
TESS mission

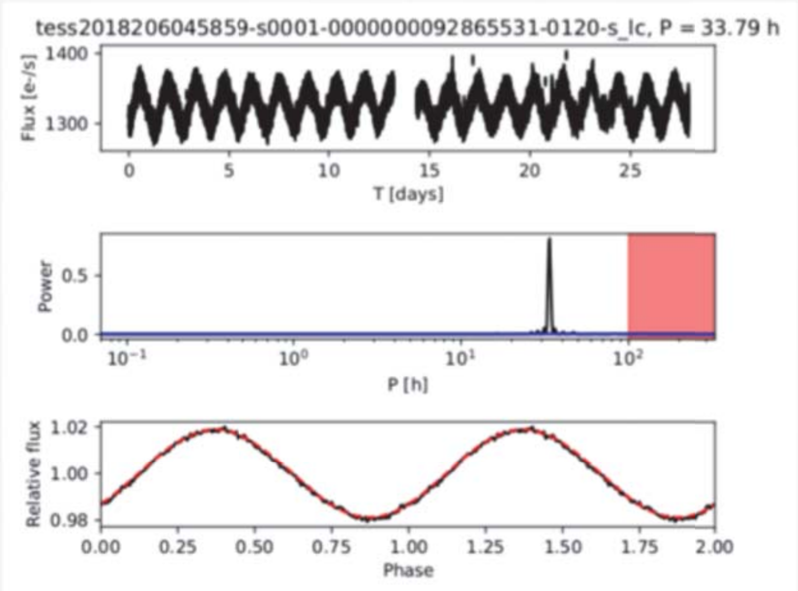
TESS mission



Uzundag et al. 2021

TESS mission





Conclusion on sdBs

- Stellar masses:
  - asteroseismology -> core !
  - binary characteristics
    - synchronisation (sub-synchronised rotation!)
- Binary stellar evolution
- Circumbinary planets ?
    - formation & survival


Hvala na pažnji