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Variability and dusty winds of AGB stars

Sofie Liljegren

AGB stars

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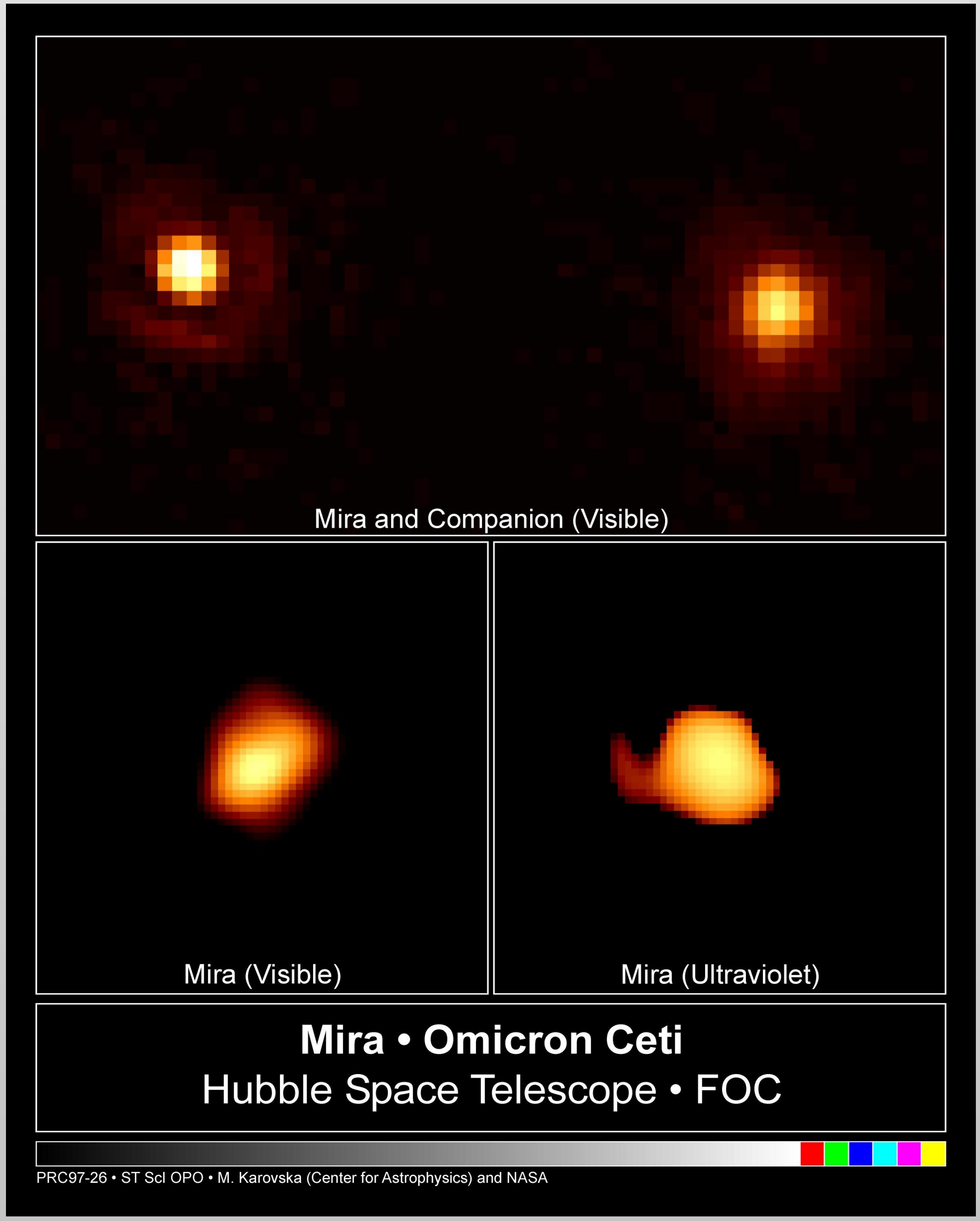
- Cool giants (T ~ 2500 - 3500K)
- Pulsates (100 - 1000 days)
- Luminous (L ~ 5000 - 10000 $L_\odot$)
- Significant mass loss (dm/dt ~ 10^{-8} - 10^{-4} $M_\odot$ yr^{-1})
- Slow wind (v ~ 10 - 30 km s^{-1})



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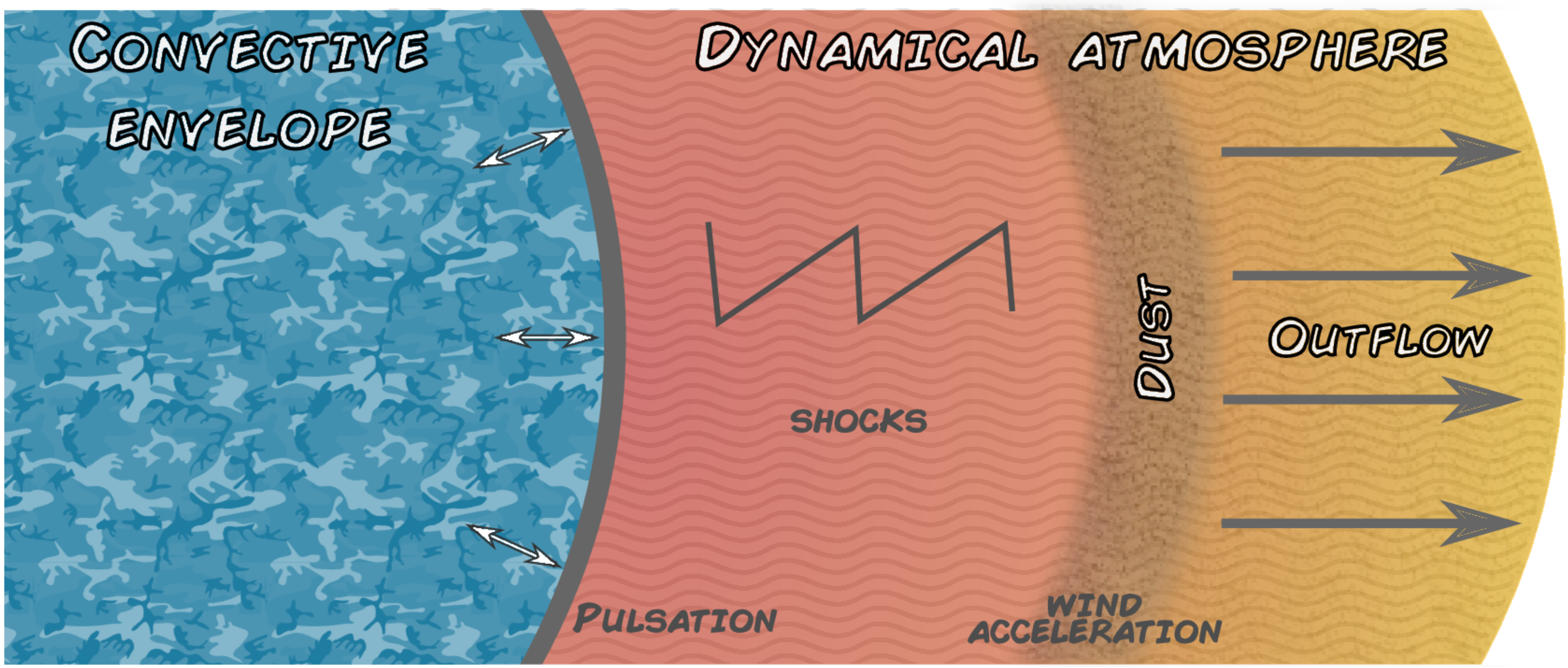
Structure - atmosphere



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Aim

- Connection between variability - stellar atmosphere - mass loss
- Is it possible to observe different pulsation properties?

(Liljegren et al., 2016, A&A, 589, 10)

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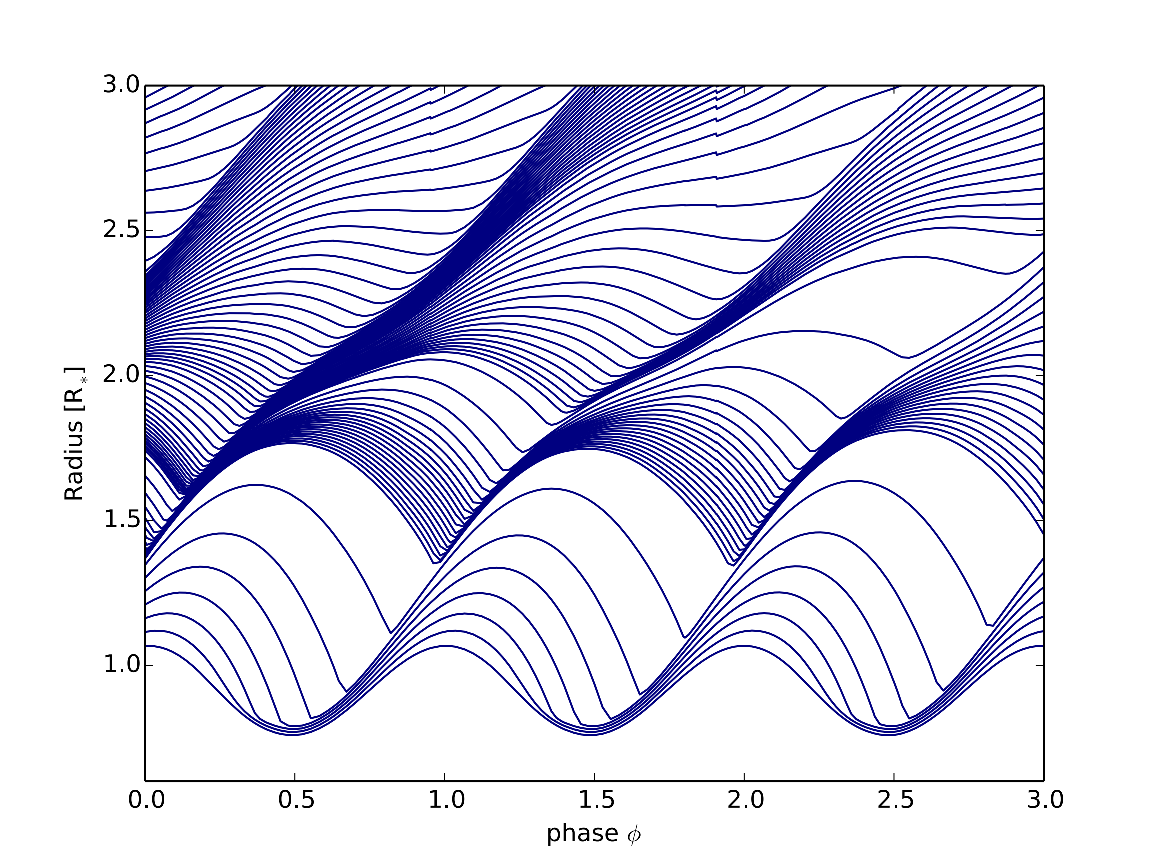
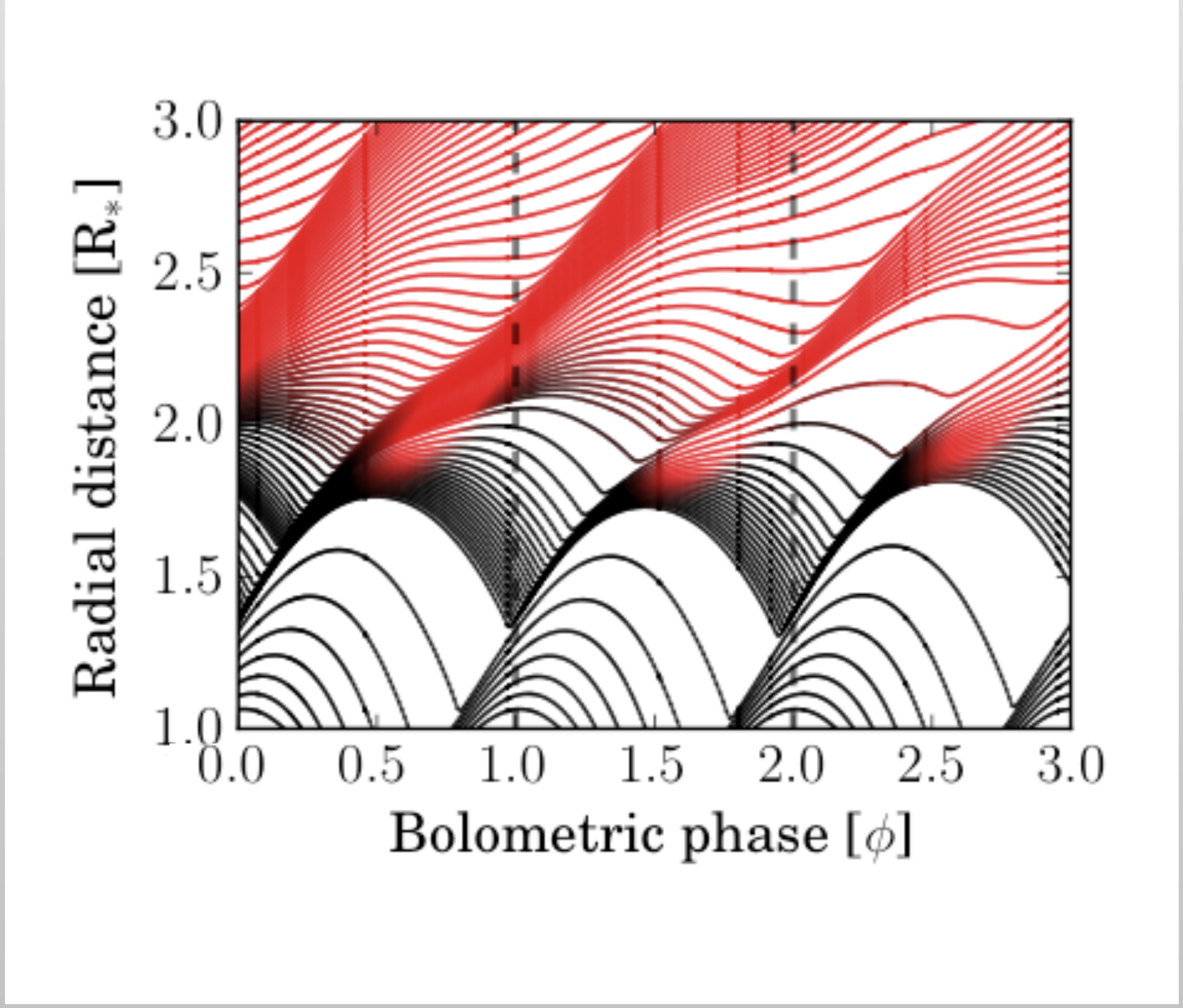
DARWIN

- 1D dynamical atmosphere and wind models
- Hydrodynamics eq. + frequency dependent radiative transfer
- Time-dependent description of dust grains
- Inner boundary: L_{in}, $R_{in} \propto \sin(t)$

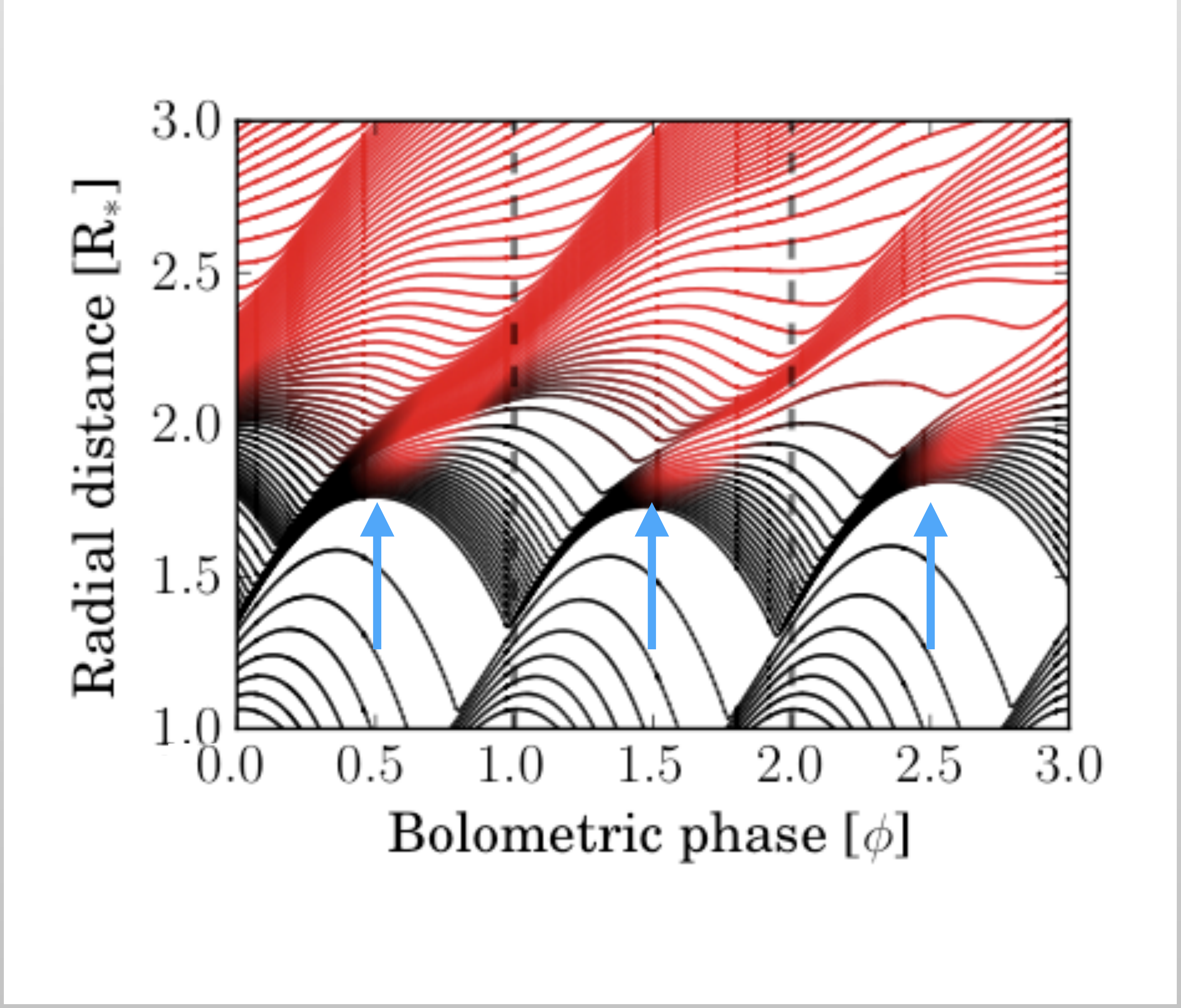


Atmosphere structure



Dust

Atmosphere structure



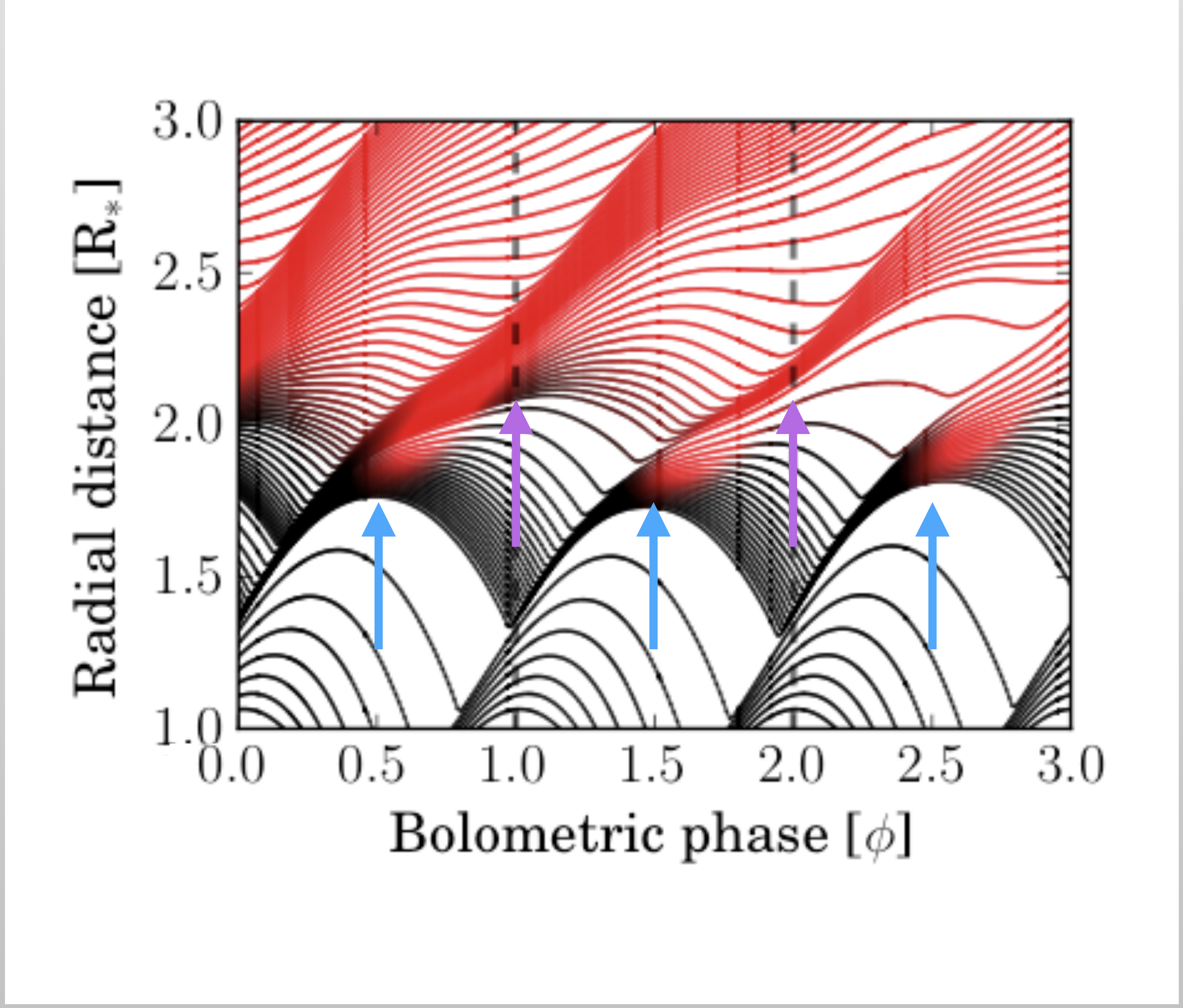
Dust

Lum minimum

-> low temp

-> dust = wind driving

Atmosphere structure



Dust

Lum minimum

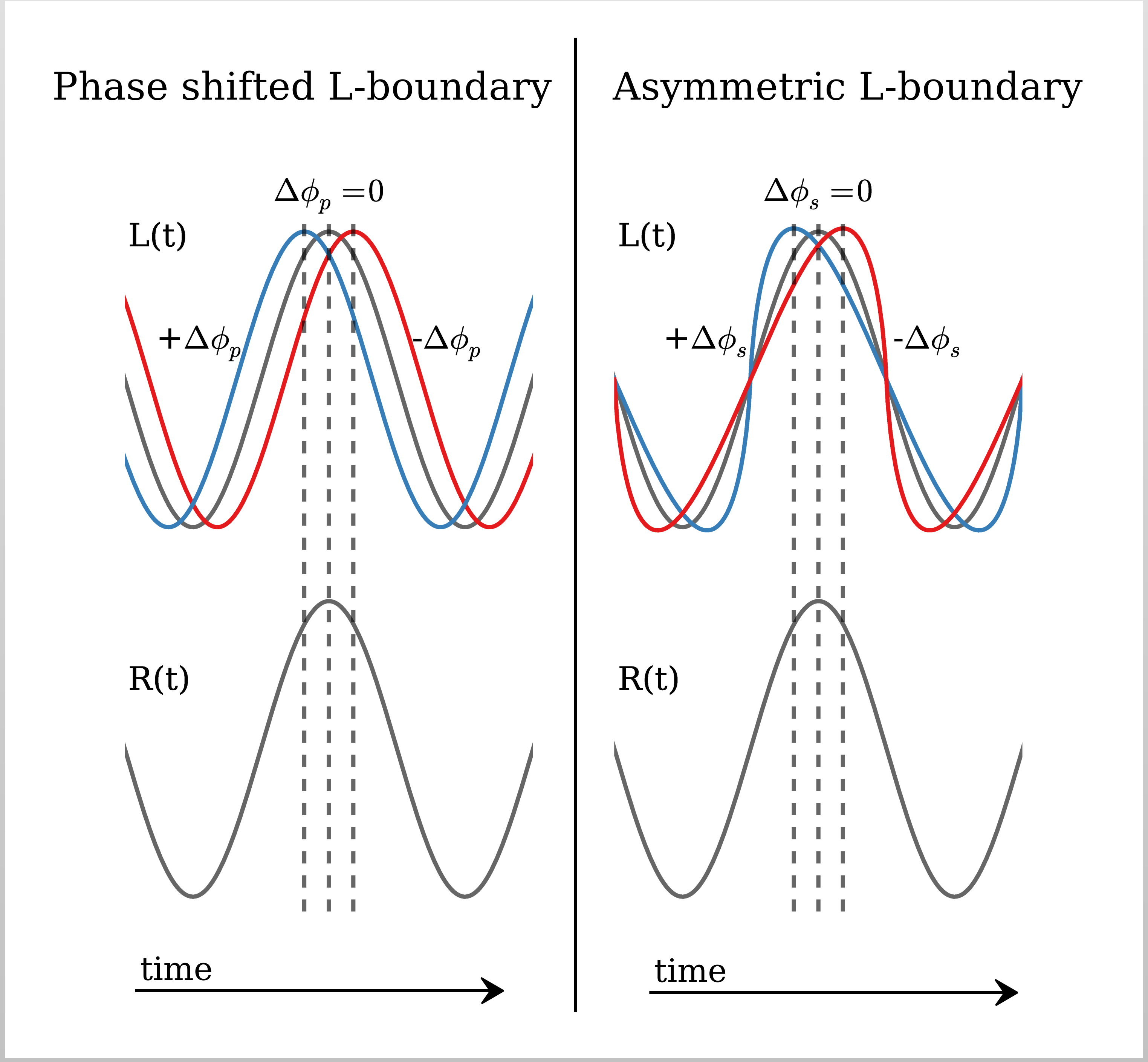
-> low temp

-> dust = wind driving

Lum maximum

-> radiative pressure on dust

New boundary conditions



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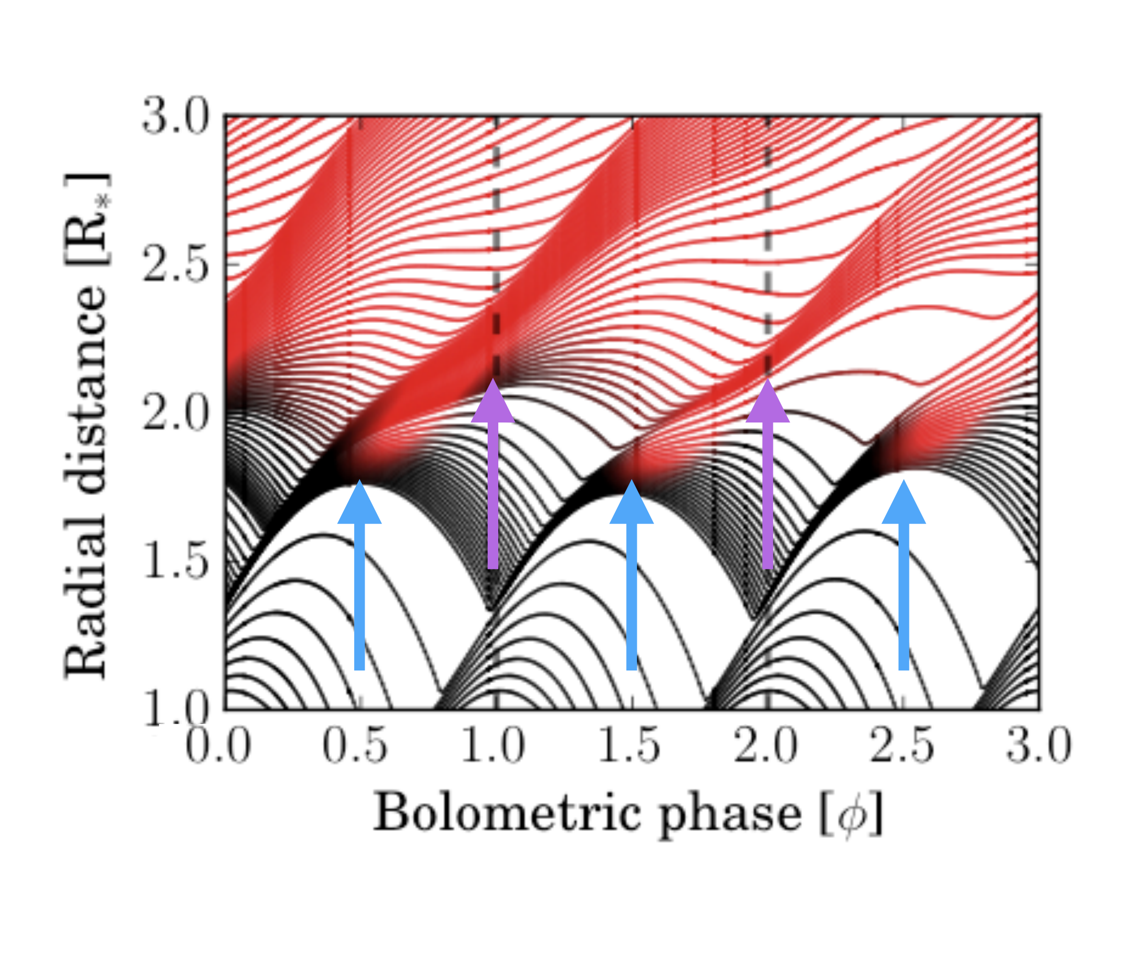
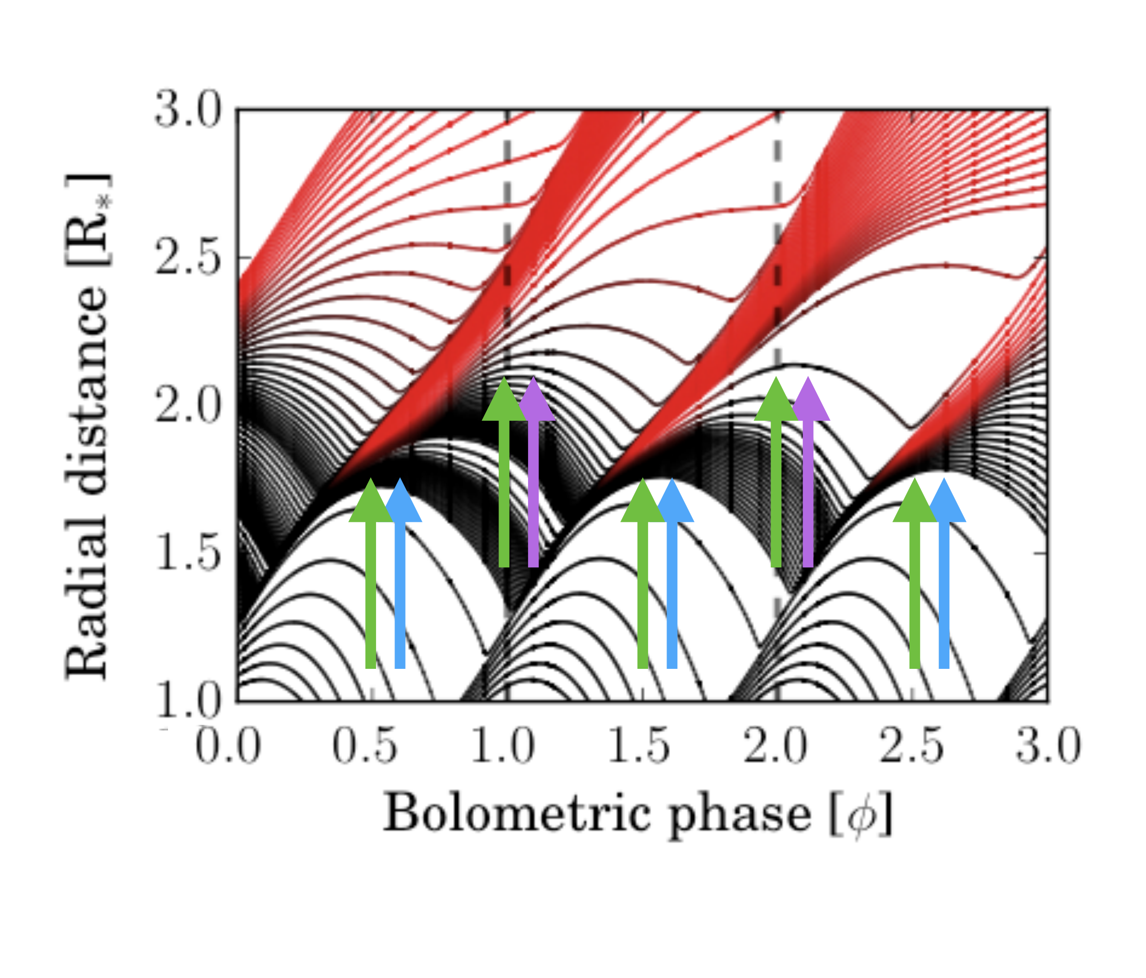
Positive phase shift

Original



Positive phase shift



-> Larger mass loss rate + higher wind velocity

Negative phase shift

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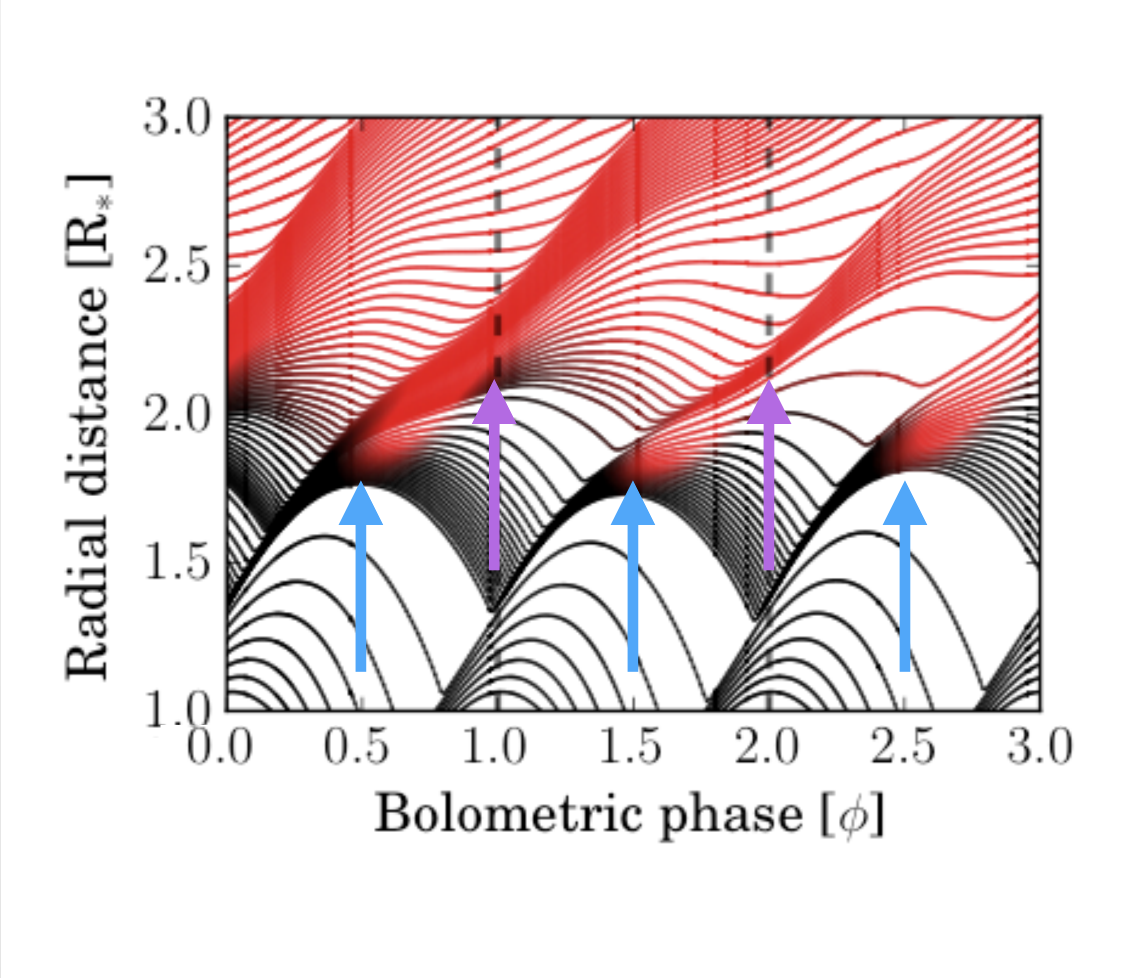
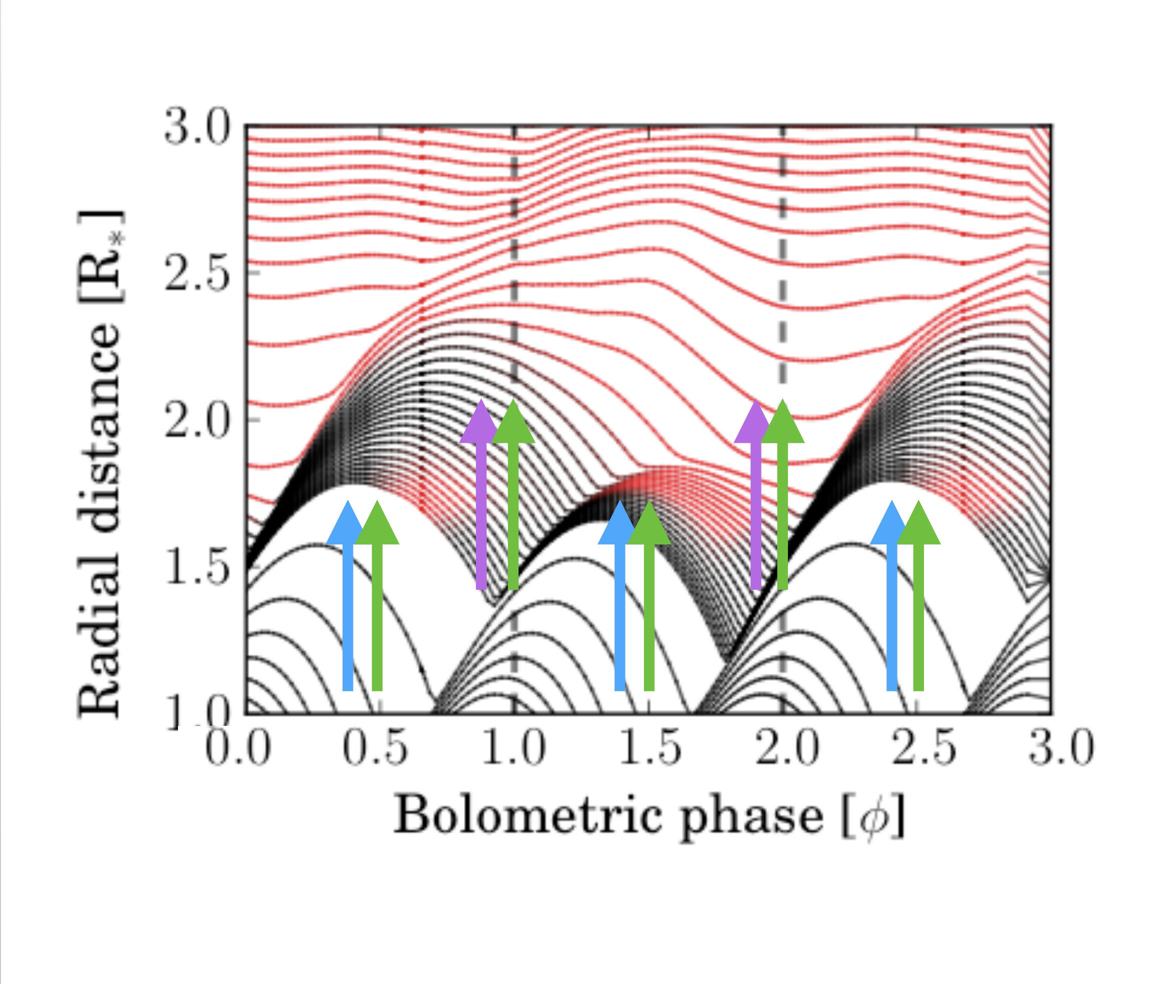
Original

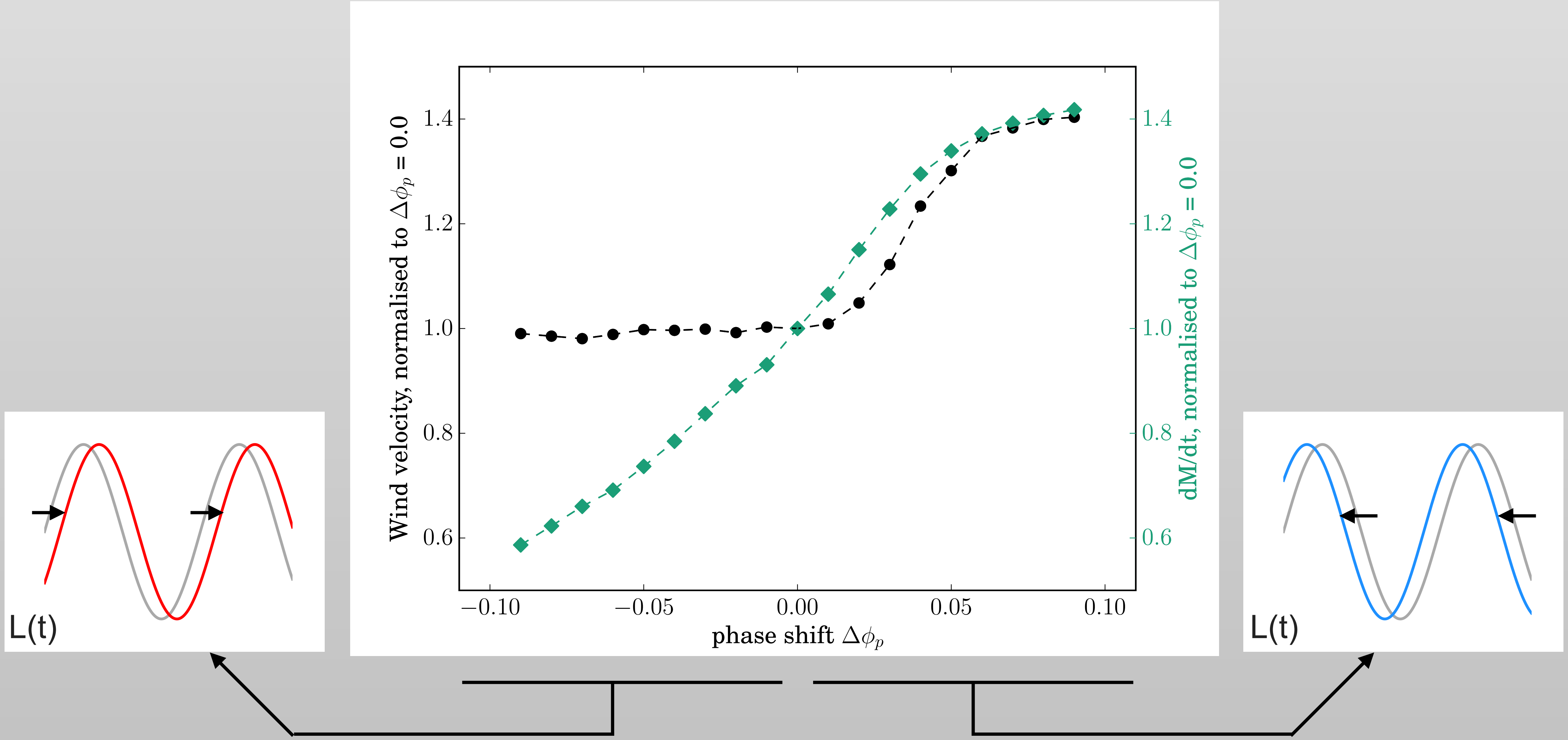


Negative phase shift



-> Lower mass loss rate

Wind properties vs Δϕ



Possible to observe?

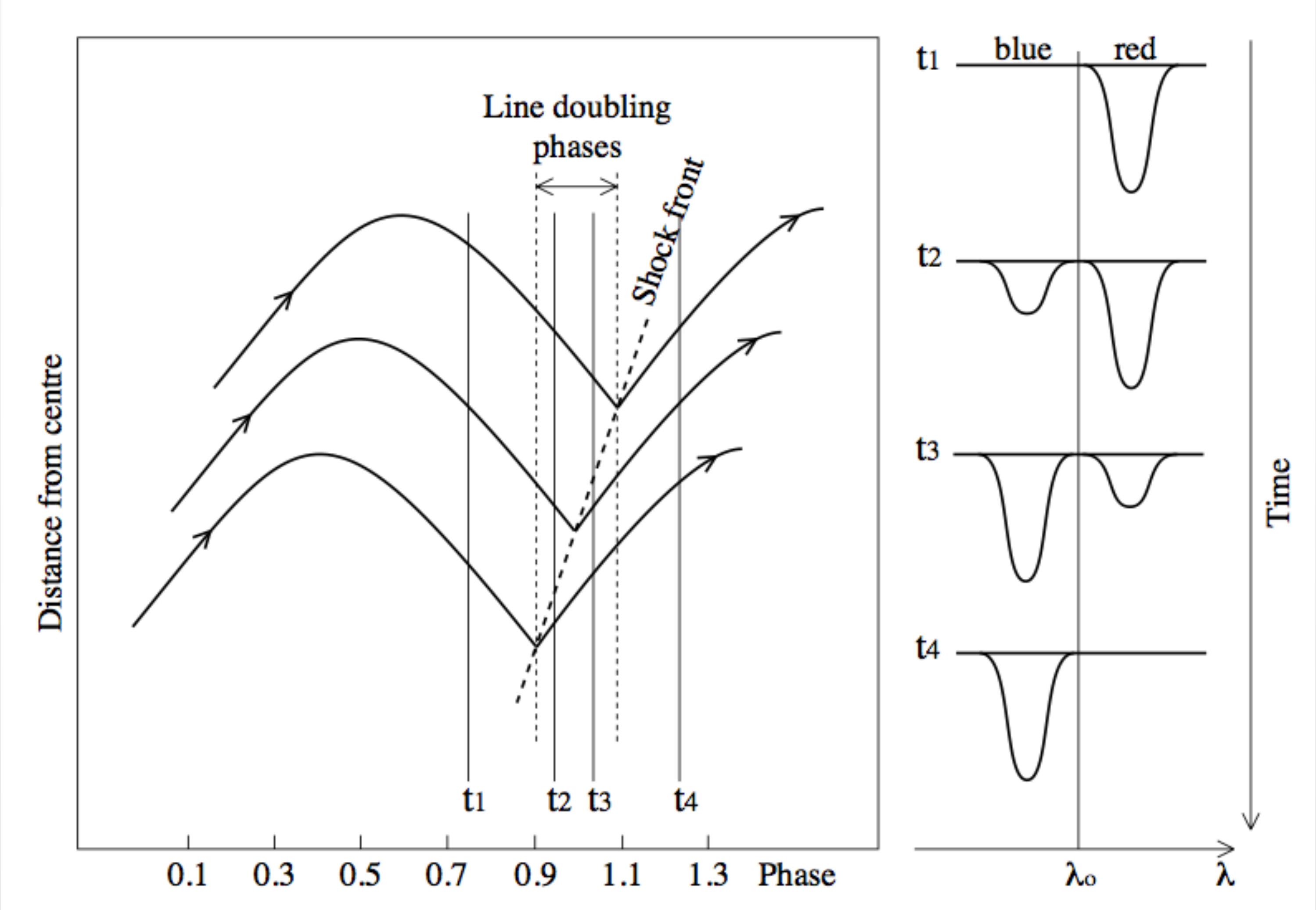
Light curves

-> variation in luminosity.

Molecular line profiles

-> information about the shockwaves

-> information about the radial variation



Alvarez et al., 2000

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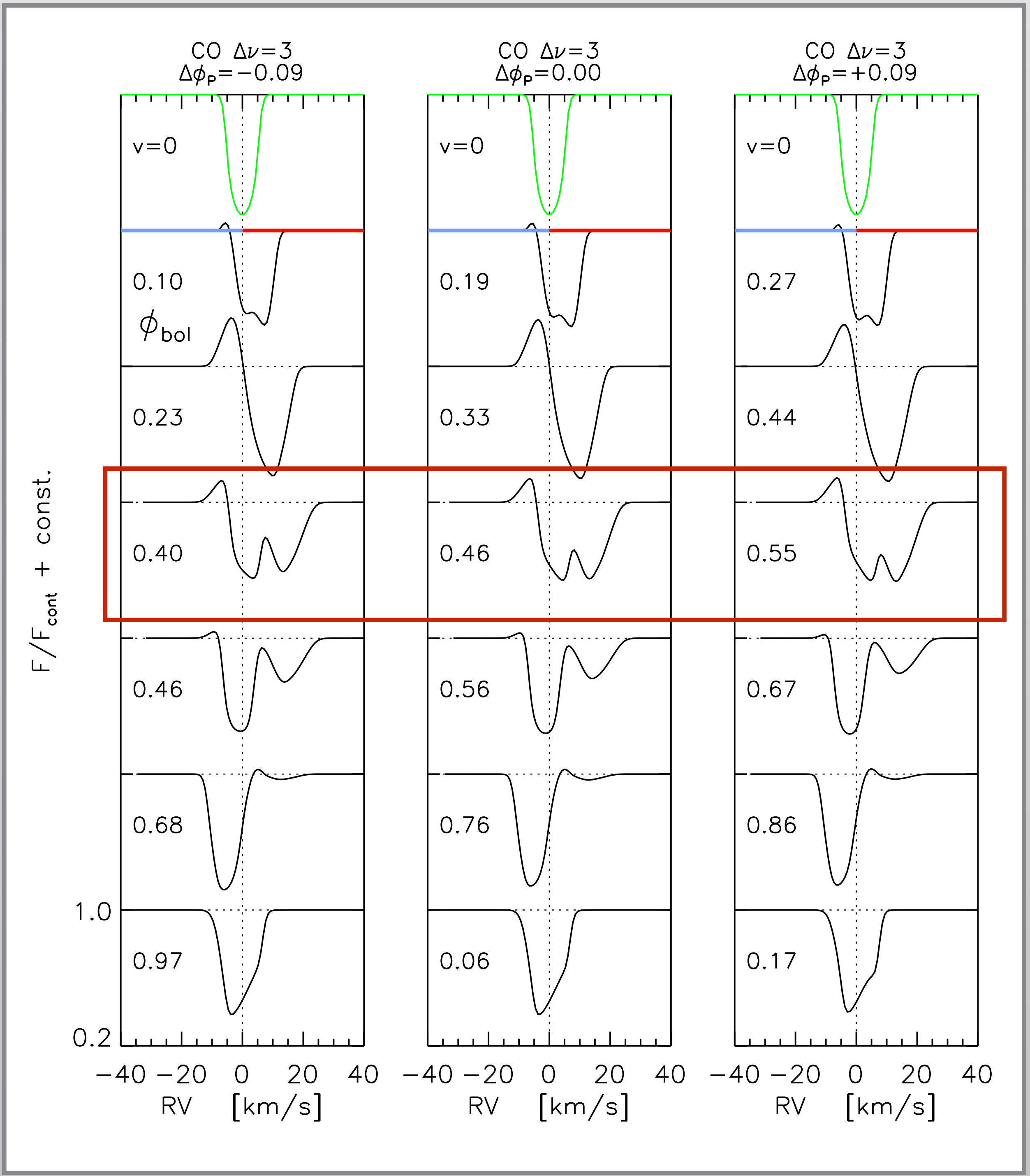
CO dv=3 line



- Line synthesis using COMA.
- CO vibration-rotation line (CO dv=3 5-2 P30 at 1.66 micron)
- Same features for different phase shift (e.g line doubling), at different bolometric phase

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Conclusions

- DARWIN models are sensitive to inner boundary condition
- Timing of both luminosity max and min matters
- Significant effects (± ~ 40%)
- Might be observable, by comparing high res spectra and light curves
- Use as a diagnostic tool for pulsation models(?)

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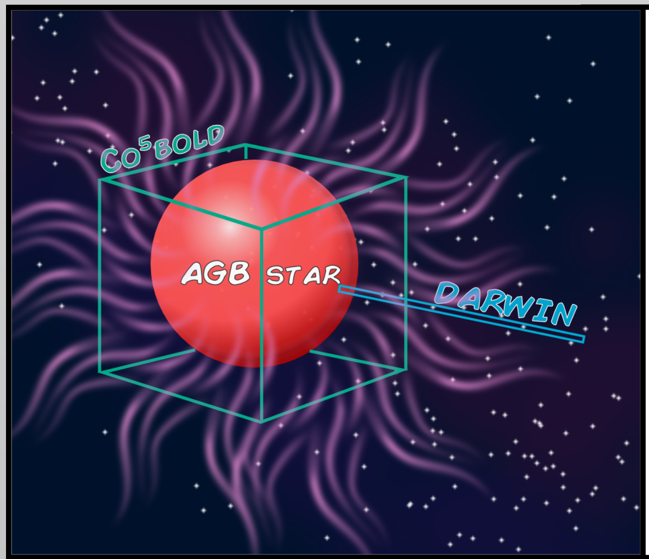
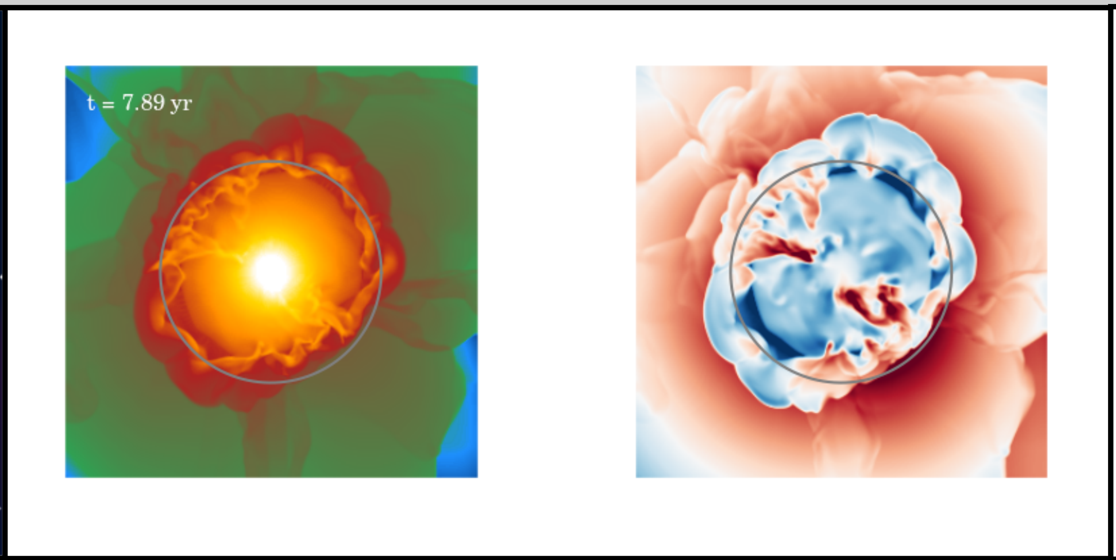
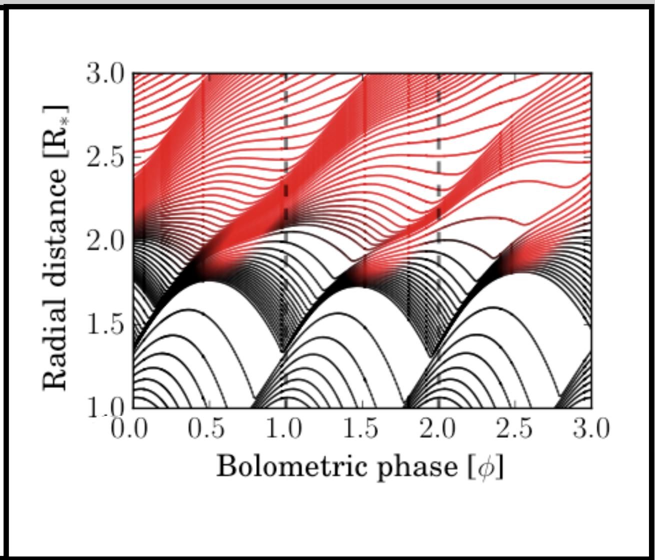
Outlook

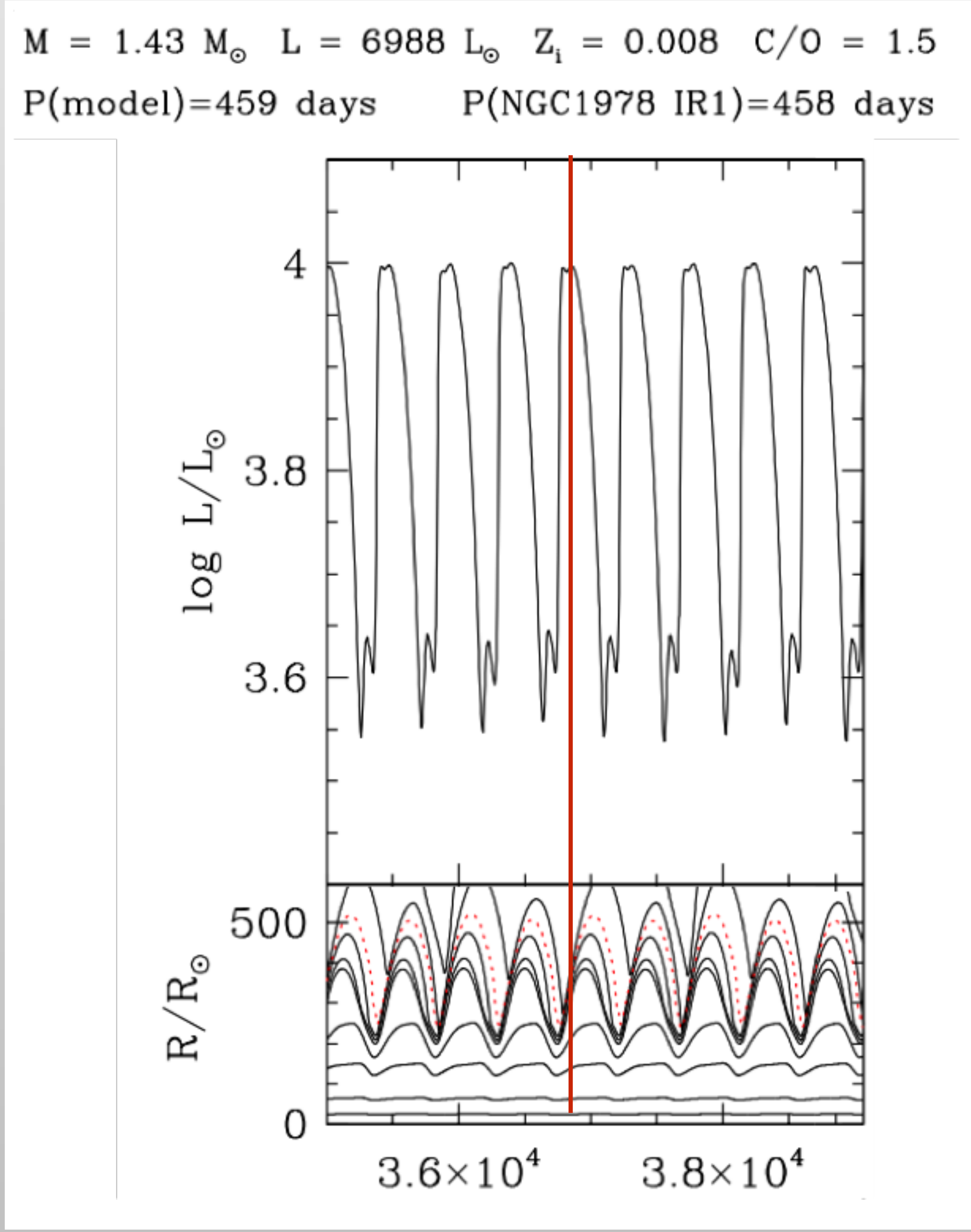
- Do same tests for m-stars
- Extract boundary conditions from the 3D models -> DARWIN





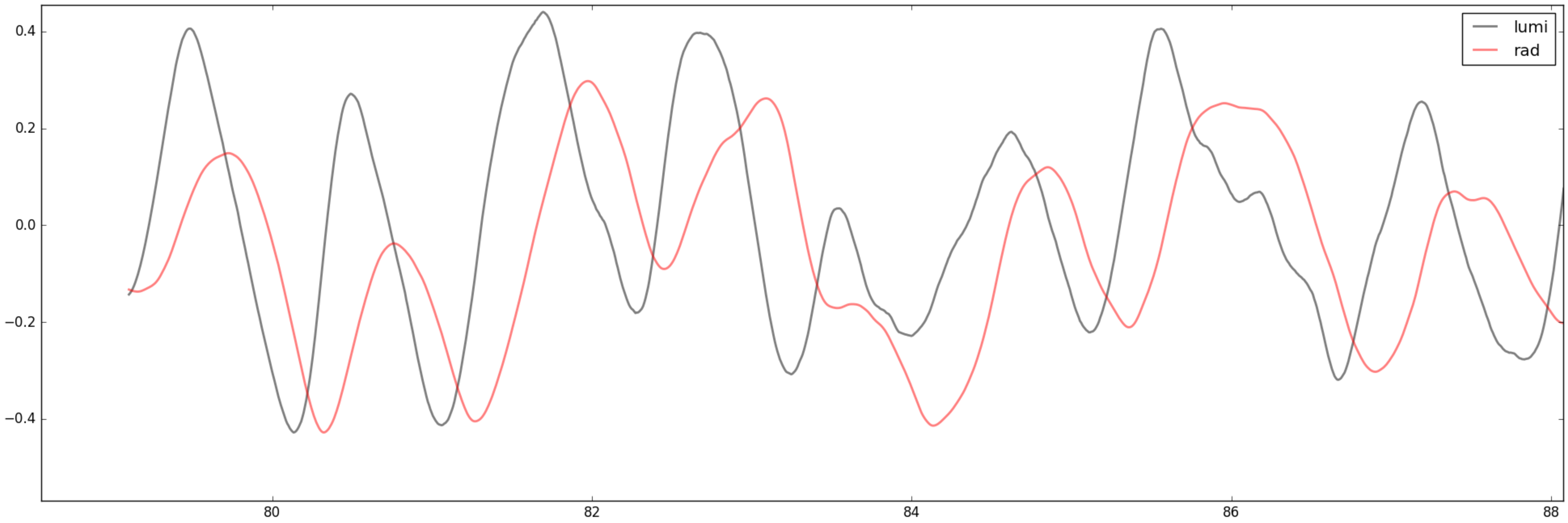


1D models



M = 1.43 M☉ L = 6988 L☉ Z_i = 0.008 C/O = 1.5
P(model)=459 days P(NGC1978 IR1)=458 days
log L/L☉
4
3.8
3.6
R/R☉
500
0
3.6×10^4
3.8×10^4

3d models



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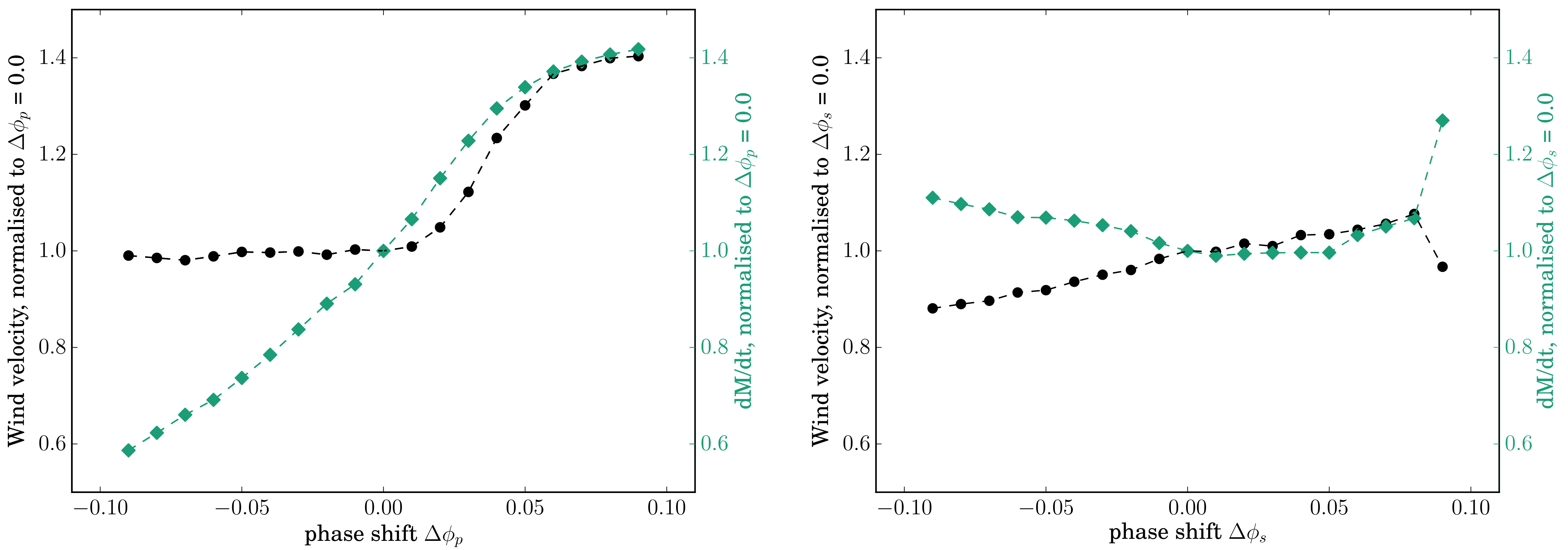
Setup

Model:	W	M
$L_\star$ [$L_\odot$]	7000	7000
$M_\star$ [$M_\odot$]	1.0	1.5
$T_\star$ [K]	2800	2600
$R_\star$ [$R_\odot$]	355	412
[Fe/H]	0	0
C/O [by number]	1.4	1.4
Period [days]	390	490
$\Delta u_{\rm p}$ [km s^{-1}]	2	6
f_L	1.0	1.5

Result


Wind velocity, normalised to $\Delta\phi_p = 0.0$
dM/dt, normalised to $\Delta\phi_p = 0.0$
phase shift $\Delta\phi_p$
Wind velocity, normalised to $\Delta\phi_s = 0.0$
dM/dt, normalised to $\Delta\phi_s = 0.0$
phase shift $\Delta\phi_s$

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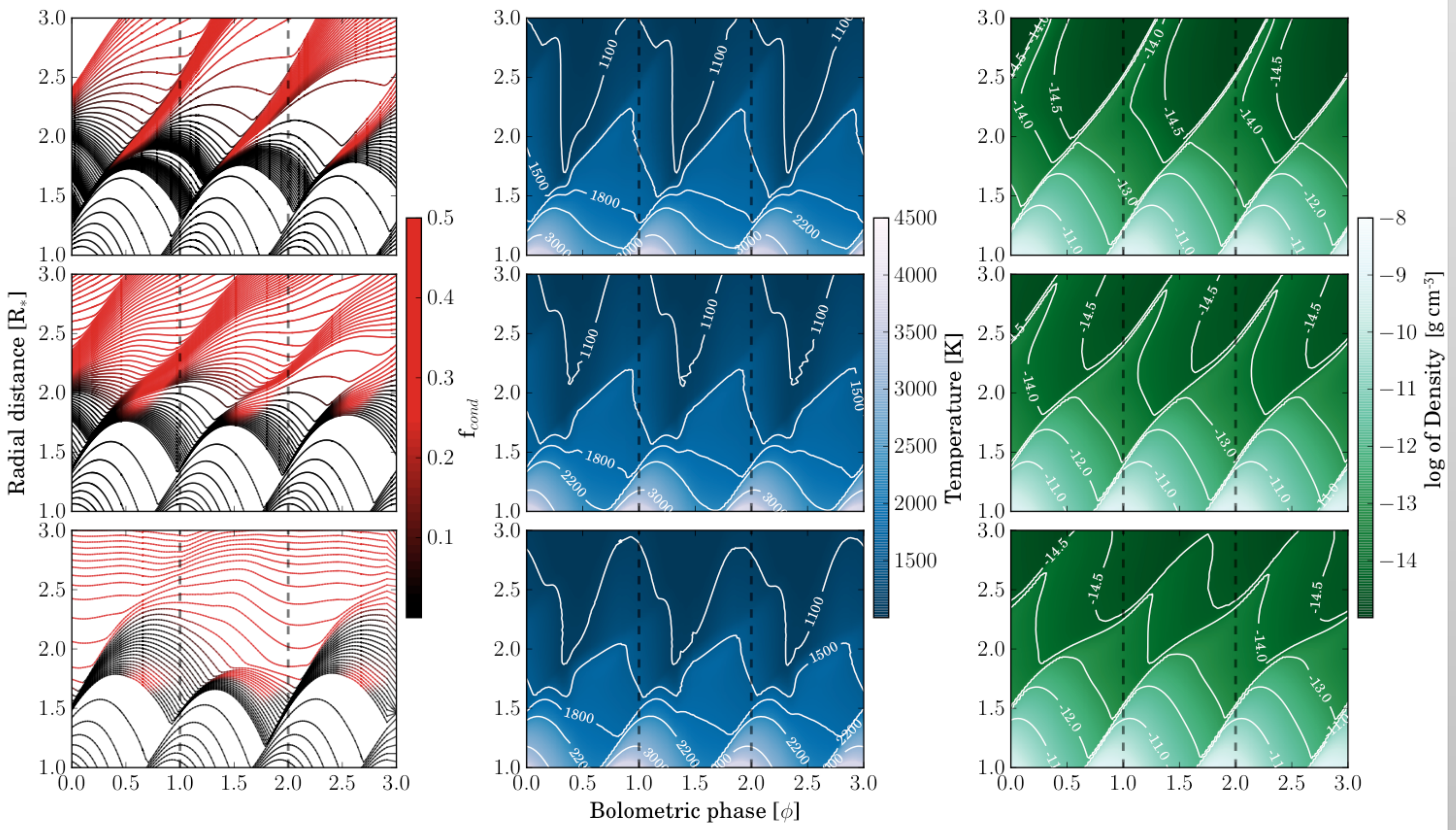
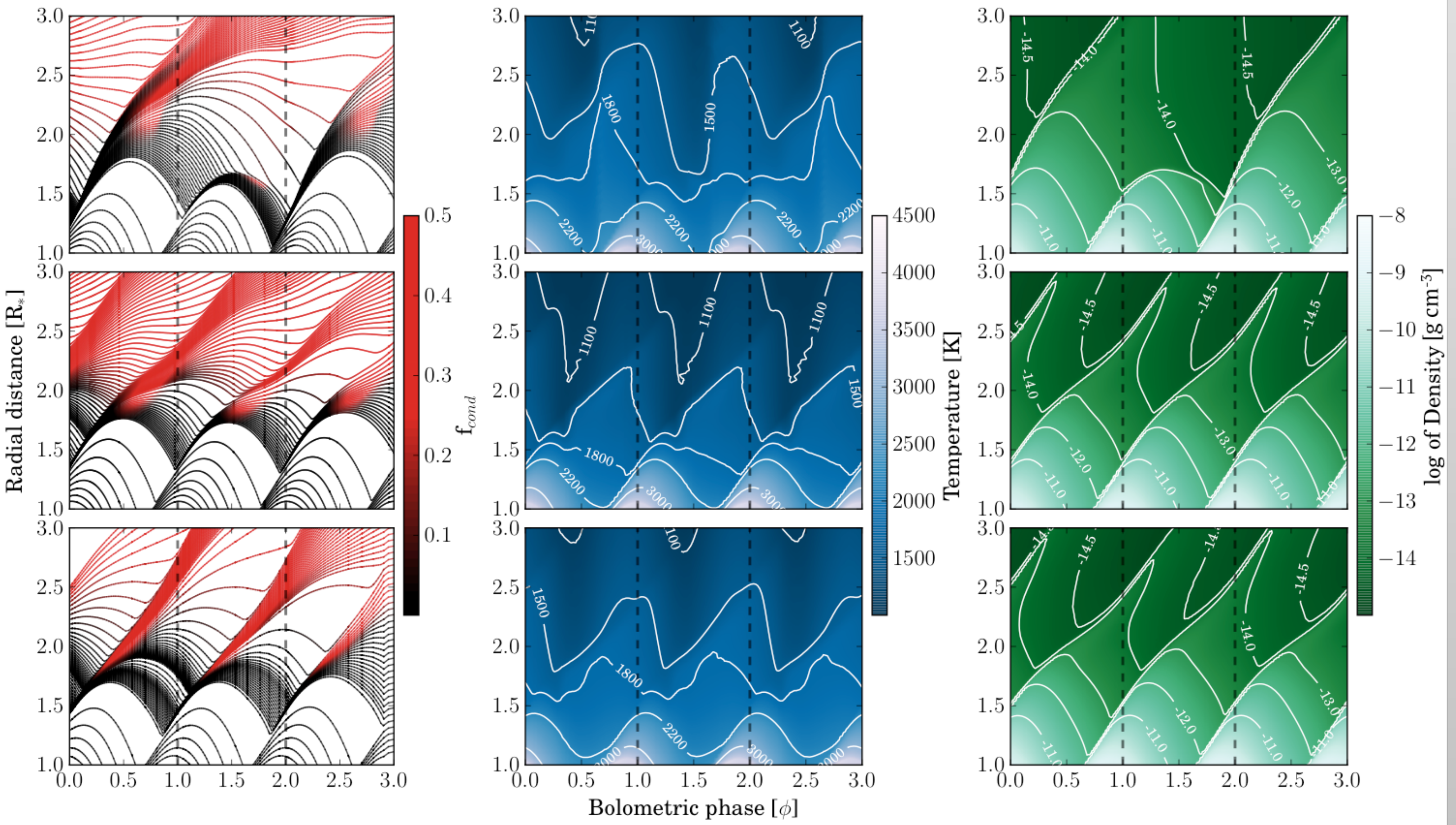
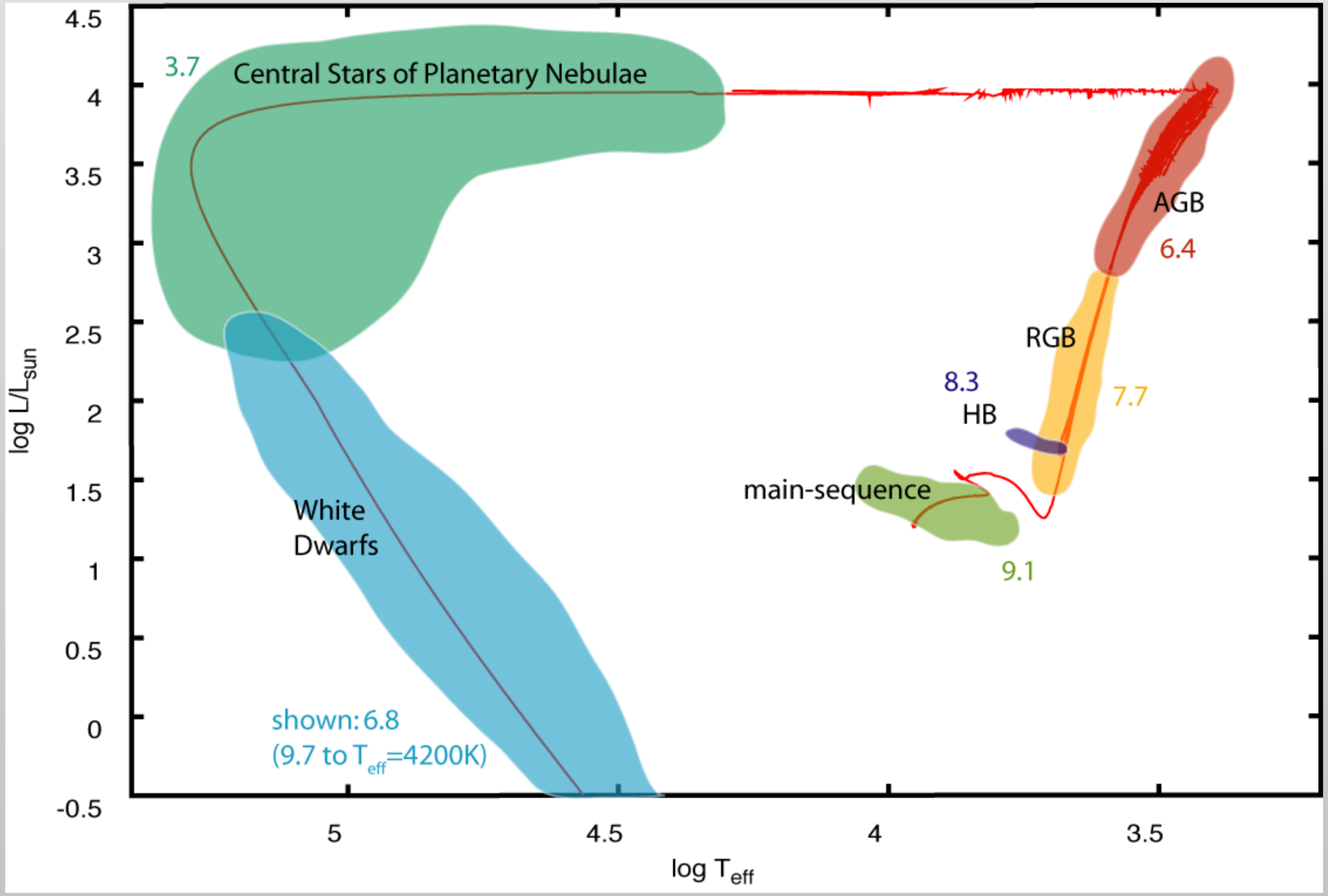
Result



Result


Radial distance [R$_*$]
Bolometric phase [ϕ]
f$_{cond}$
Temperature [K]
log of Density [g cm^{-3}]

Evolution



Herwig, 2005

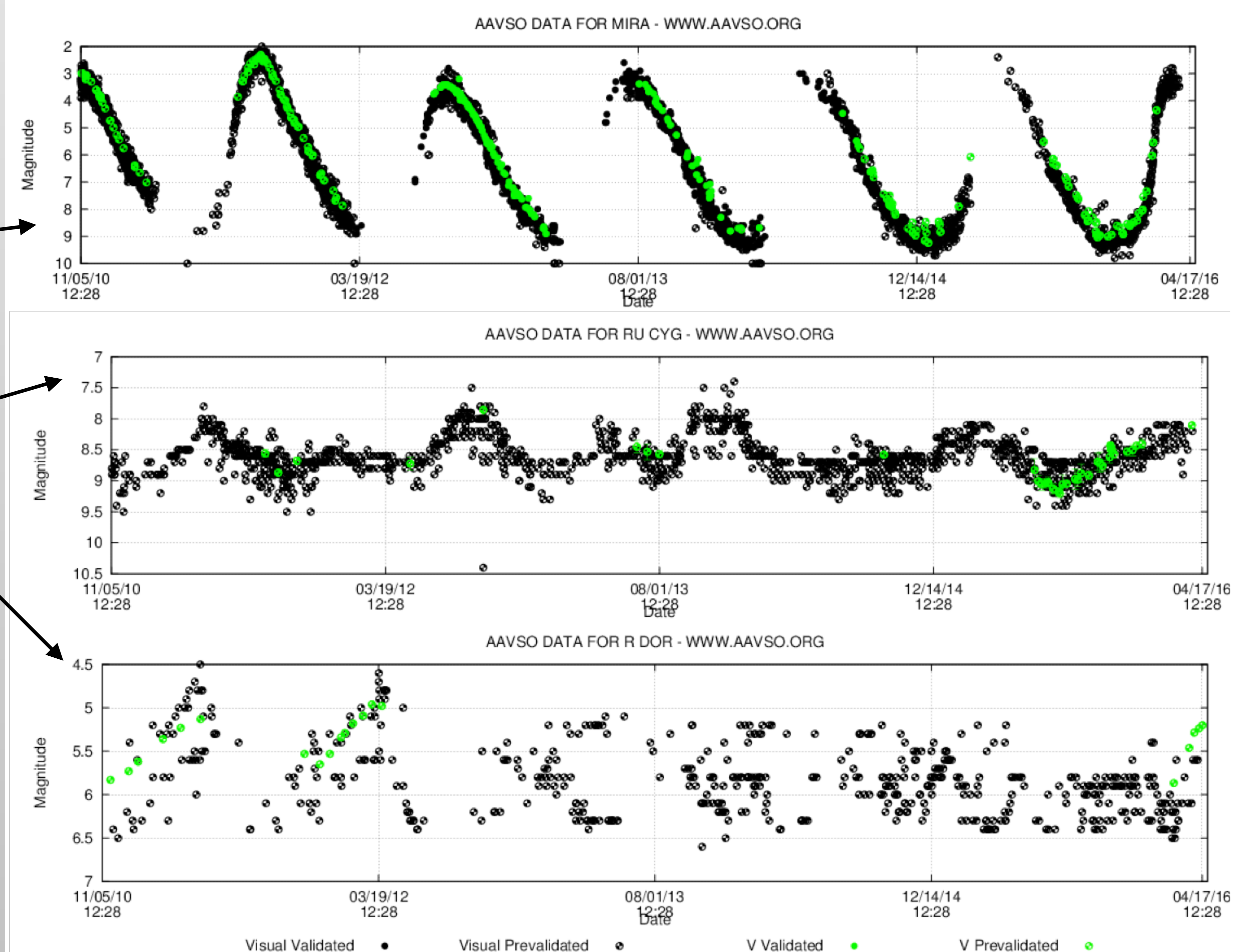
Light curves

Mira

Semi-regular, type a

Semi-regular, type b

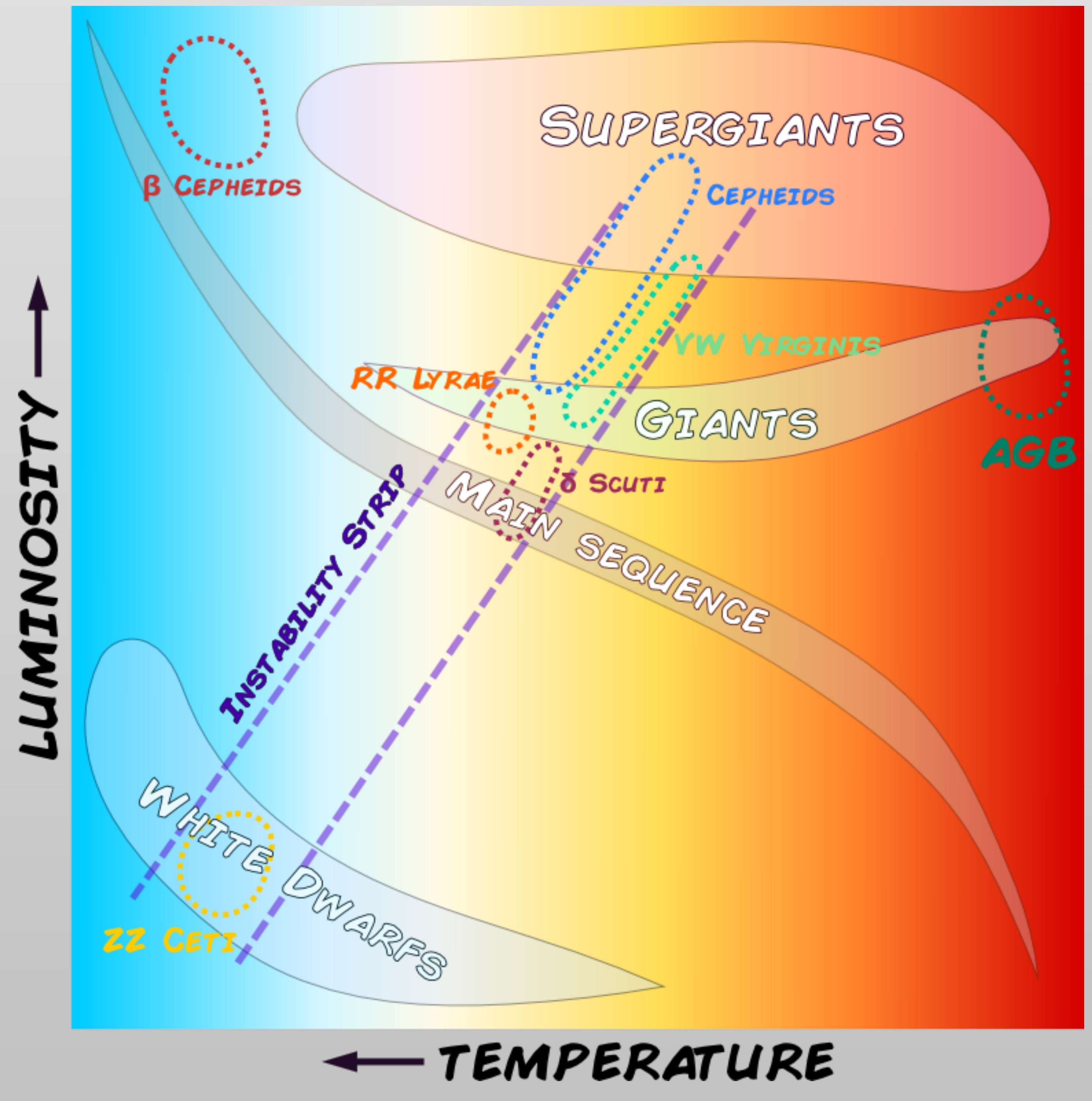
Irregular



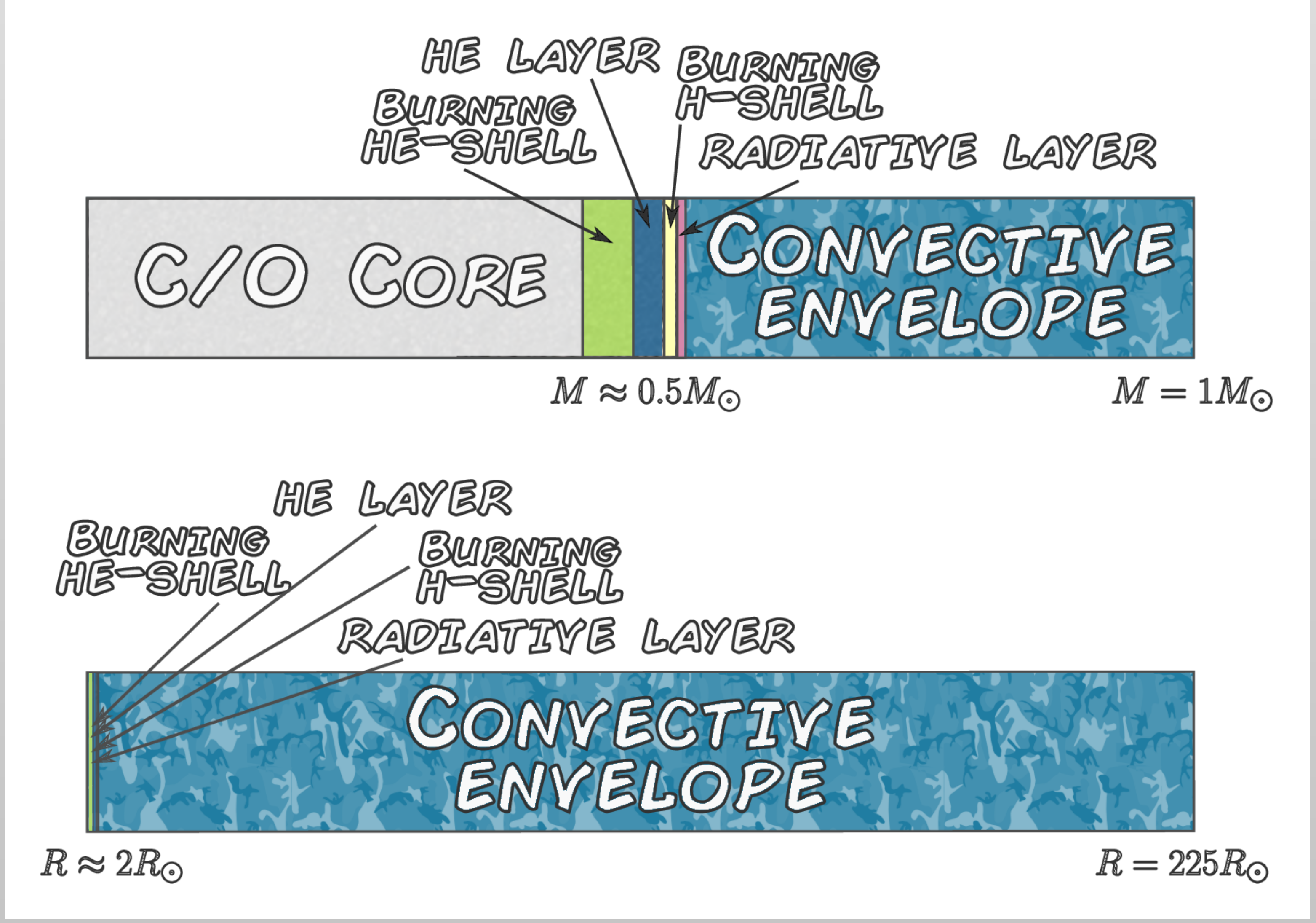
Observations from the AAVSO International Database, http://www.aavso.org)

AGB stars as pulsators

- Many classes of variable stars are on the instability strip -> kappa mechanism
- Driving of AGB stars poorly understood

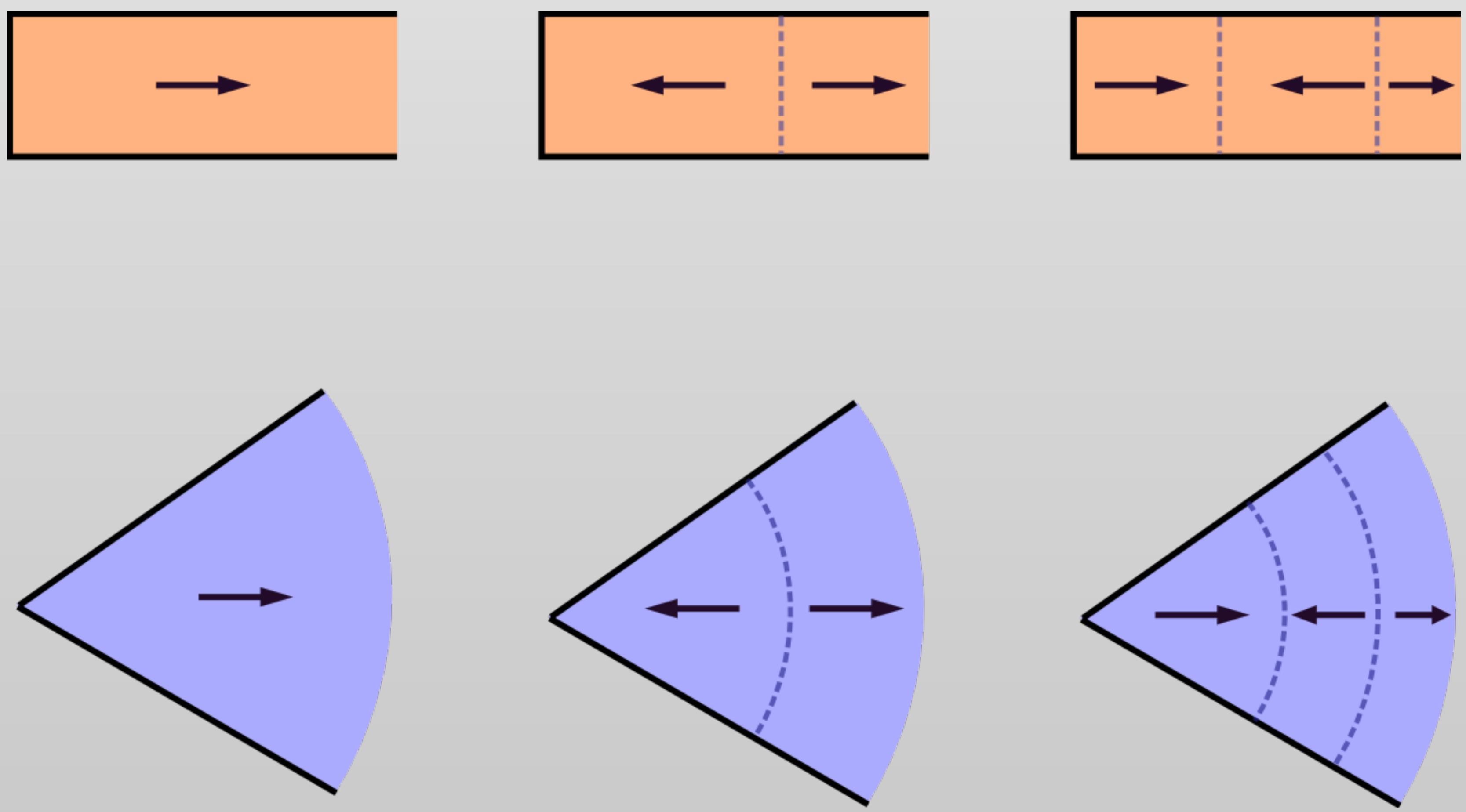


Structure - interior



- Pulsation driving takes place in convective envelope
- $\tau_{conv} \sim P$
- Driving of AGB stars poorly understood

Modes of pulsation



Fundamental 1st overtone 2nd overtone

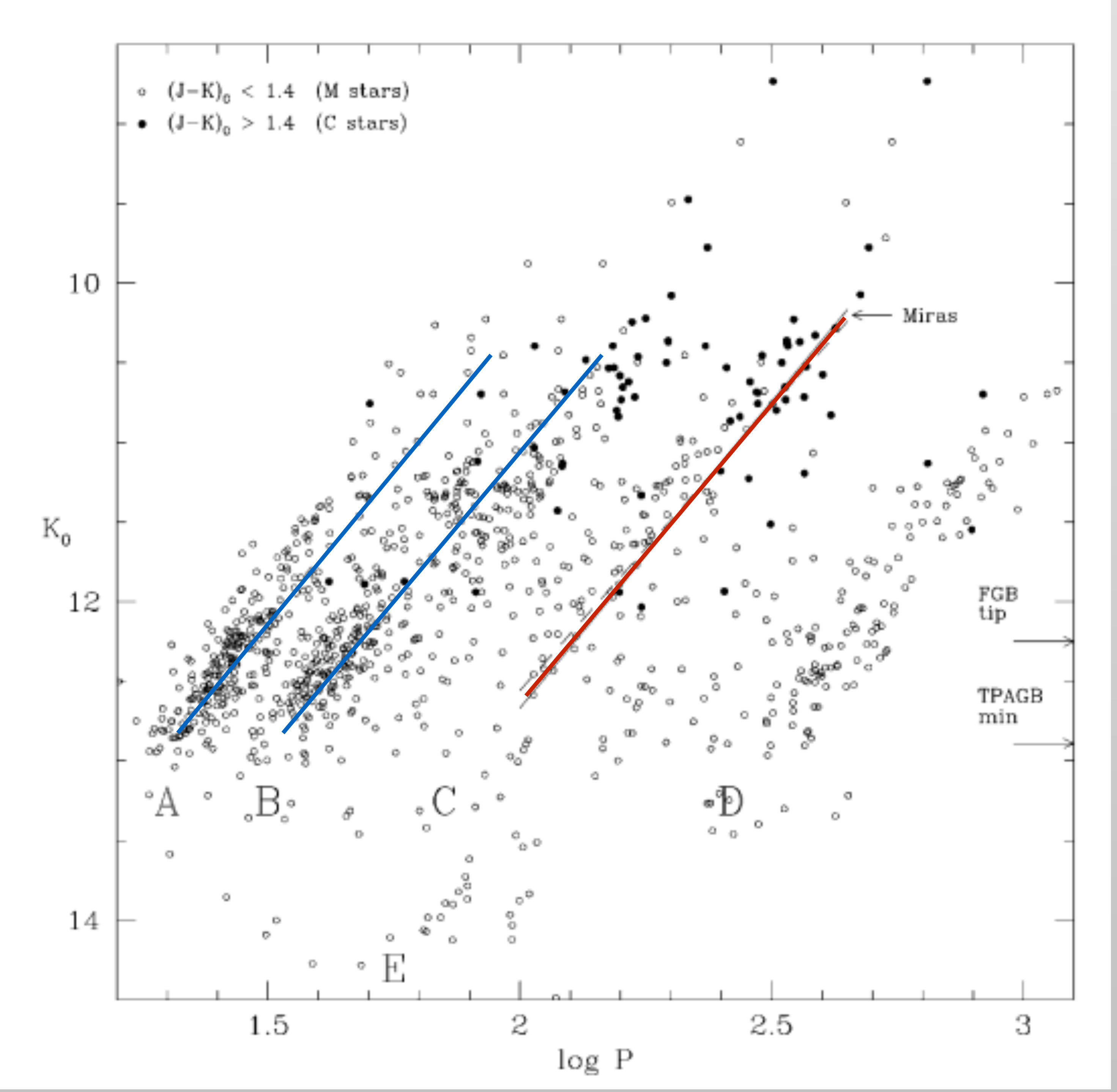
Period-Luminosity

C -> Miras

A, B -> SRVs, IRVs

E -> binaries with common envelope

D -> ??



AGB stars from the LMC, plotted in the P-L plane (Wood, 2000)

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Context

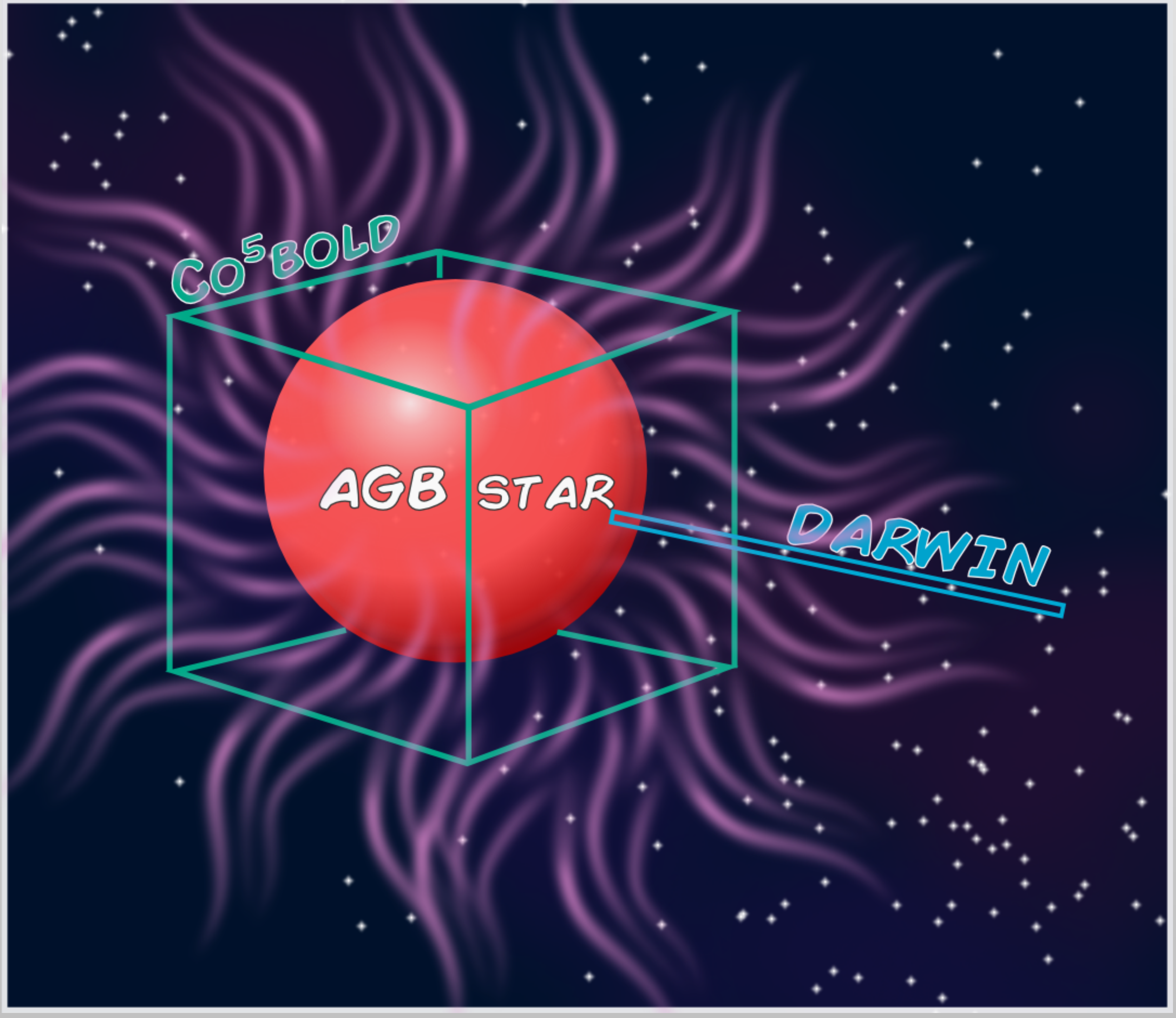
- Galactic chemistry - chemical yield of e.g. s-elements and dust yields depend on mass loss of AGB stars.

- Initial-final mass relation - depends on the mass loss during the AGB phase.

Aim

- Understand AGB star variability
- Connection between variability - stellar atmosphere - mass loss

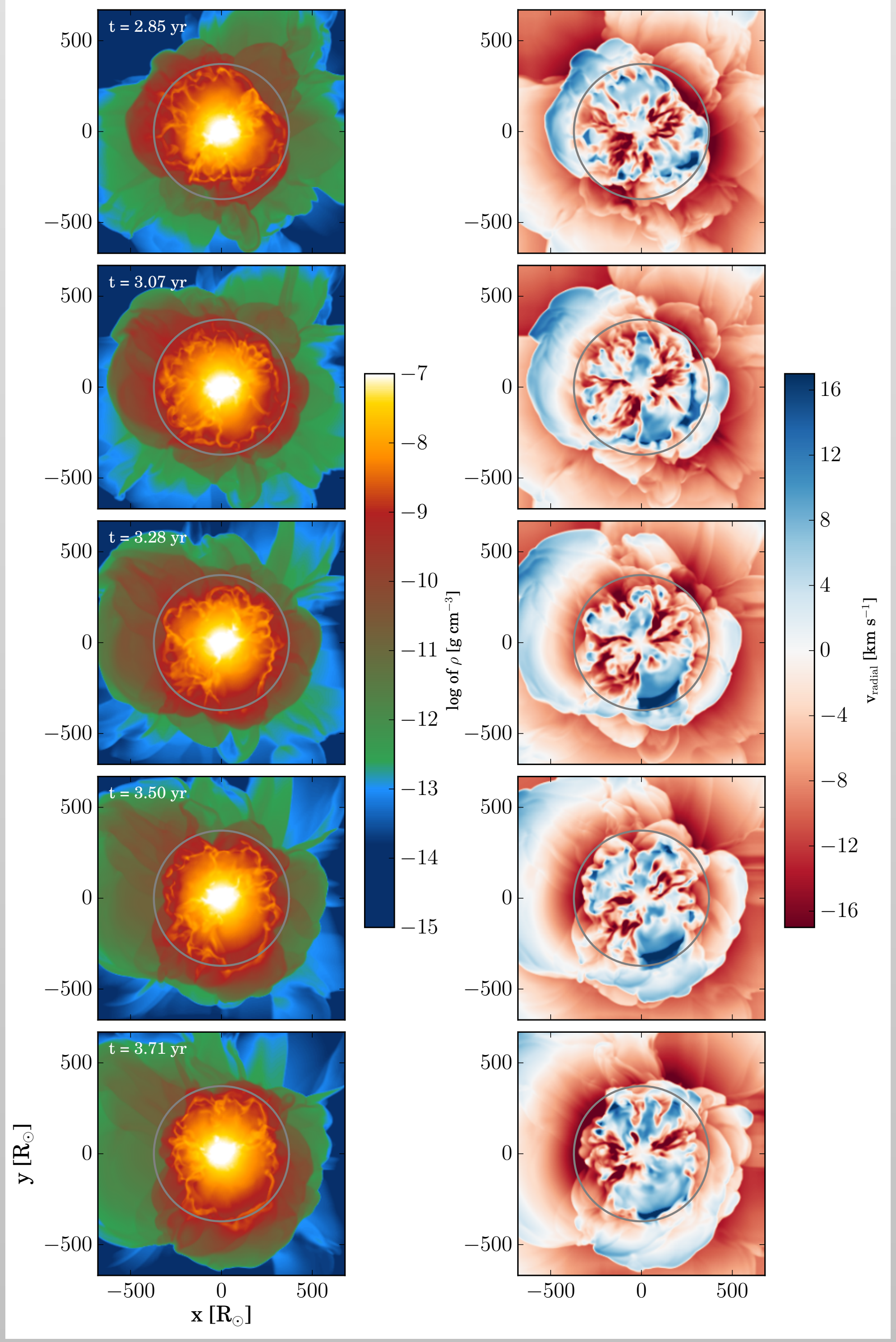
Modelling



CO⁵BOLD

- 3D star-in-a-box simulations
- Models convective envelope and lower atmosphere
- Compressible hydrodynamics eq. + grey radiative transfer

-> Paper II



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Paper I

A&A 589, A130 (2016)
DOI: 10.1051/0004-6361/201527885

Astronomy & Astrophysics

Dust-driven winds of AGB stars: The critical interplay of atmospheric shocks and luminosity variations

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Received 3 December 2015 / Accepted 8 March 2016

- Assess the effects on atmospheric structure, wind velocity and mass loss rate when using more realistic boundary conditions

- Investigate the implications for observables.

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Paper II

Astronomy & Astrophysics manuscript no. aaagb3dfirstgrid
May 11, 2016

Global 3D radiation-hydrodynamics models of AGB stars

Effects of convection and radial pulsations on atmospheric structures

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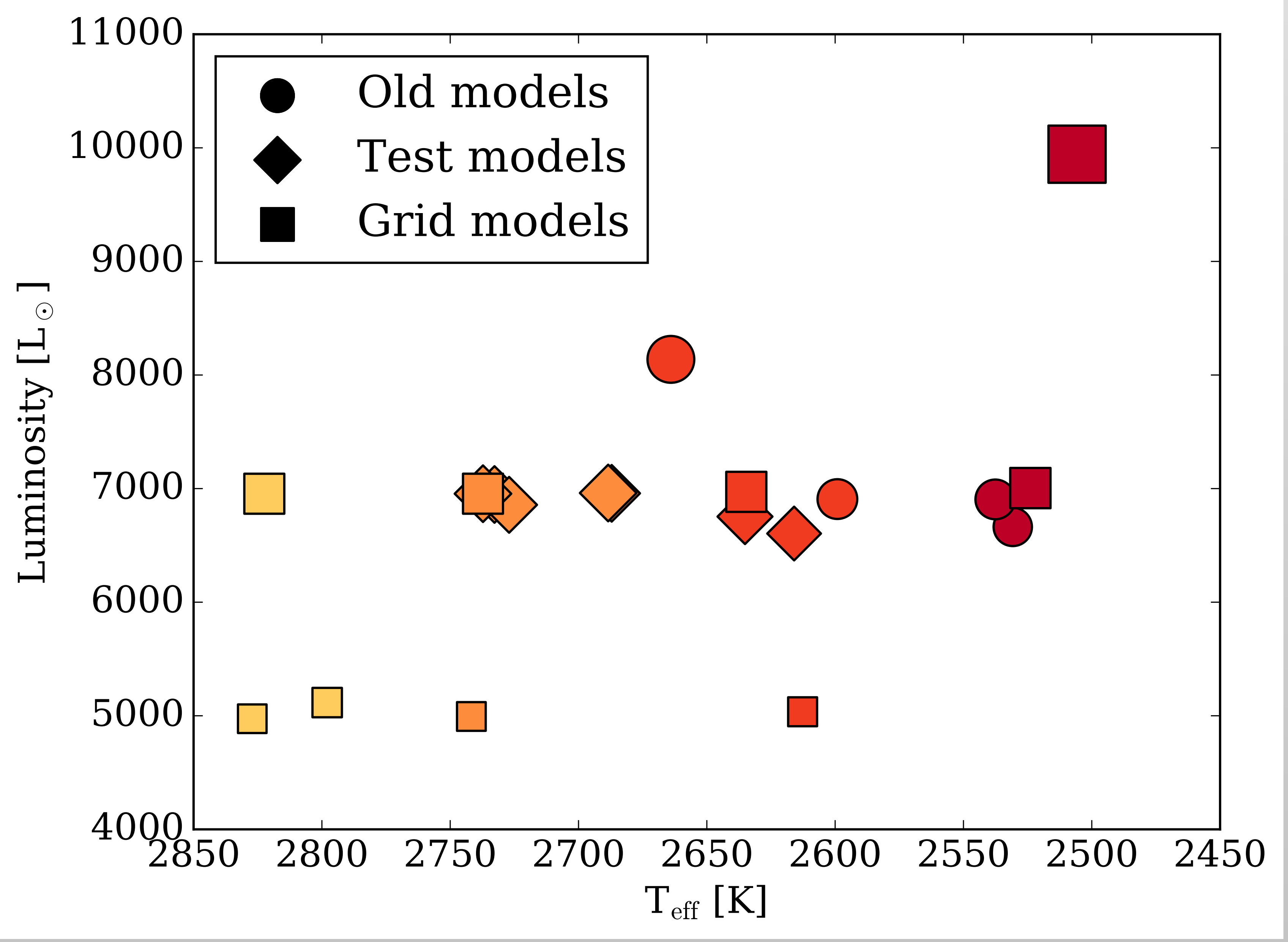
Started 2015-05-29; Received ...; accepted ...

- Grid of 3D models
- Investigate updated numerics, small scale structures and the influence of different stellar parameters

Setup and grid

- CO^{5}BOLD code used
- 3 groups of models



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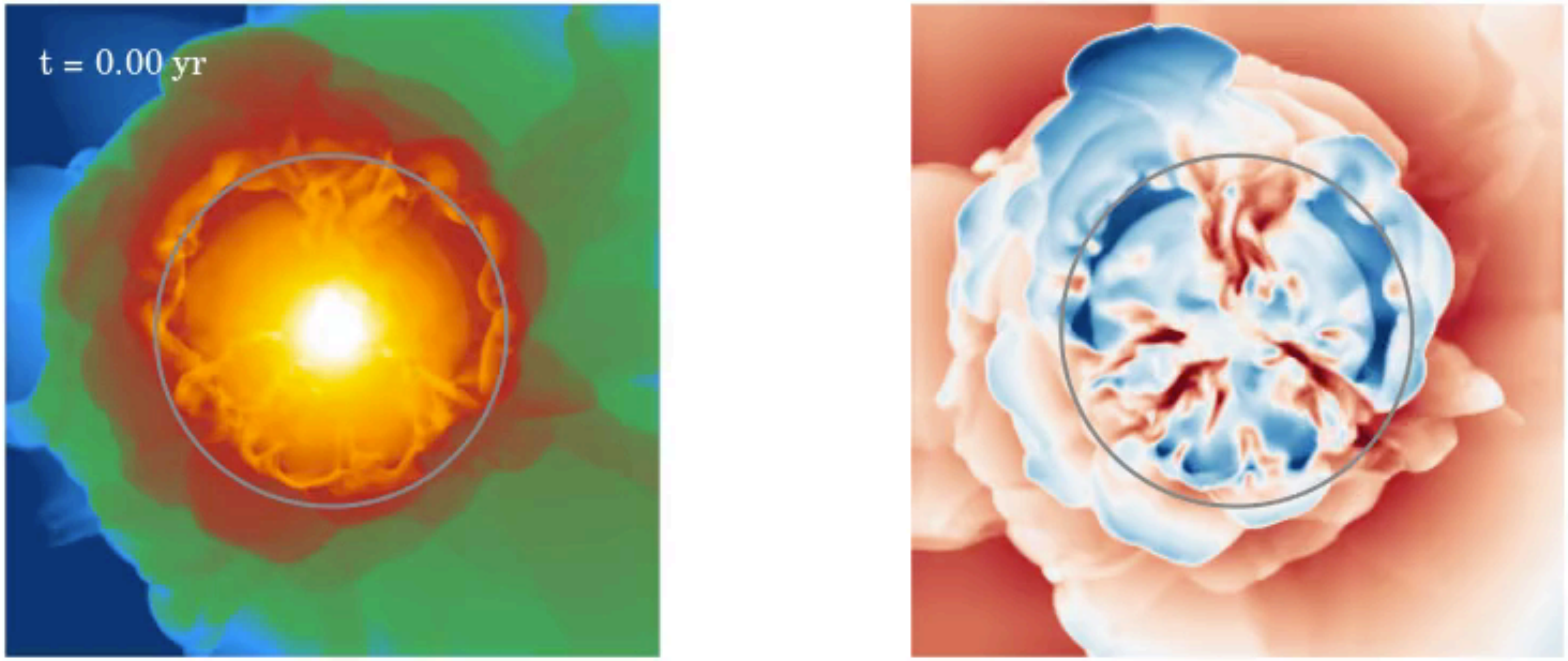
Movie



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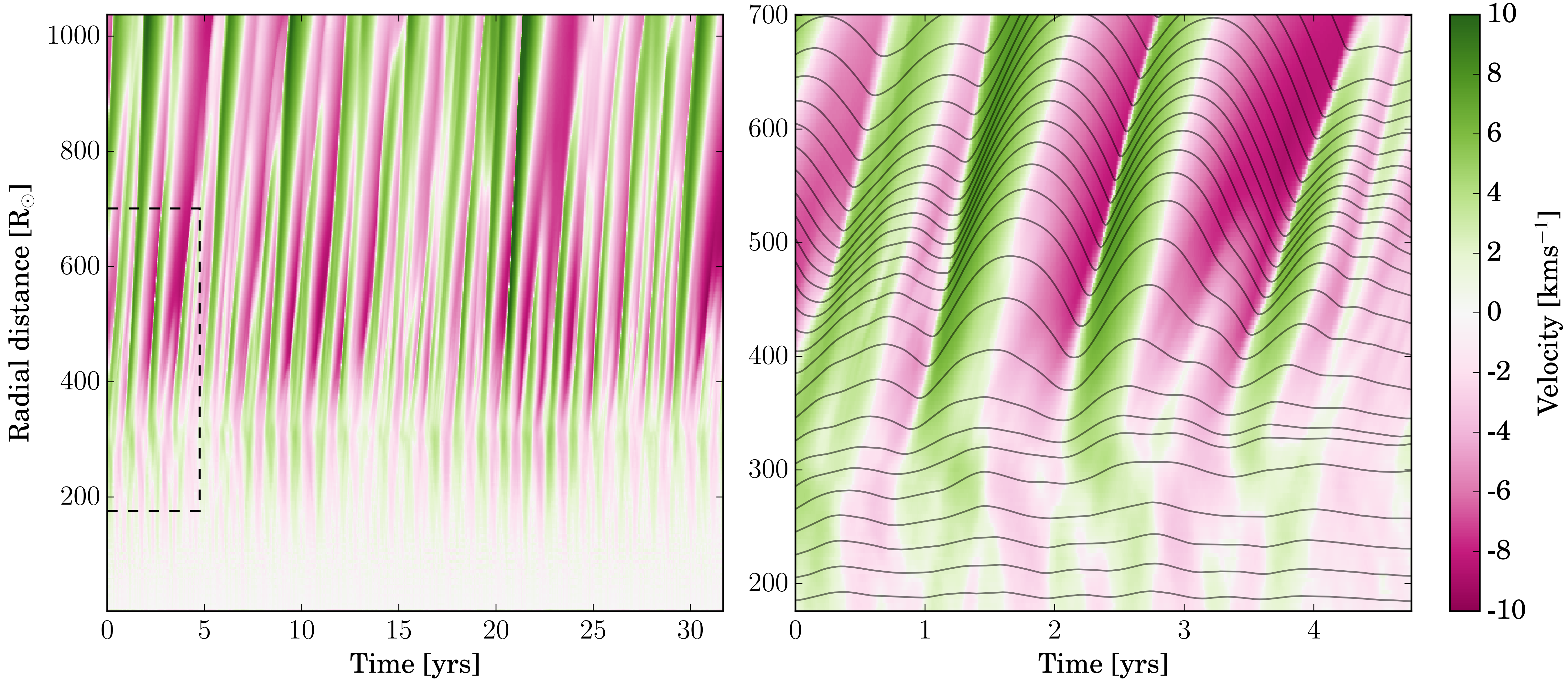
Radial velocity field



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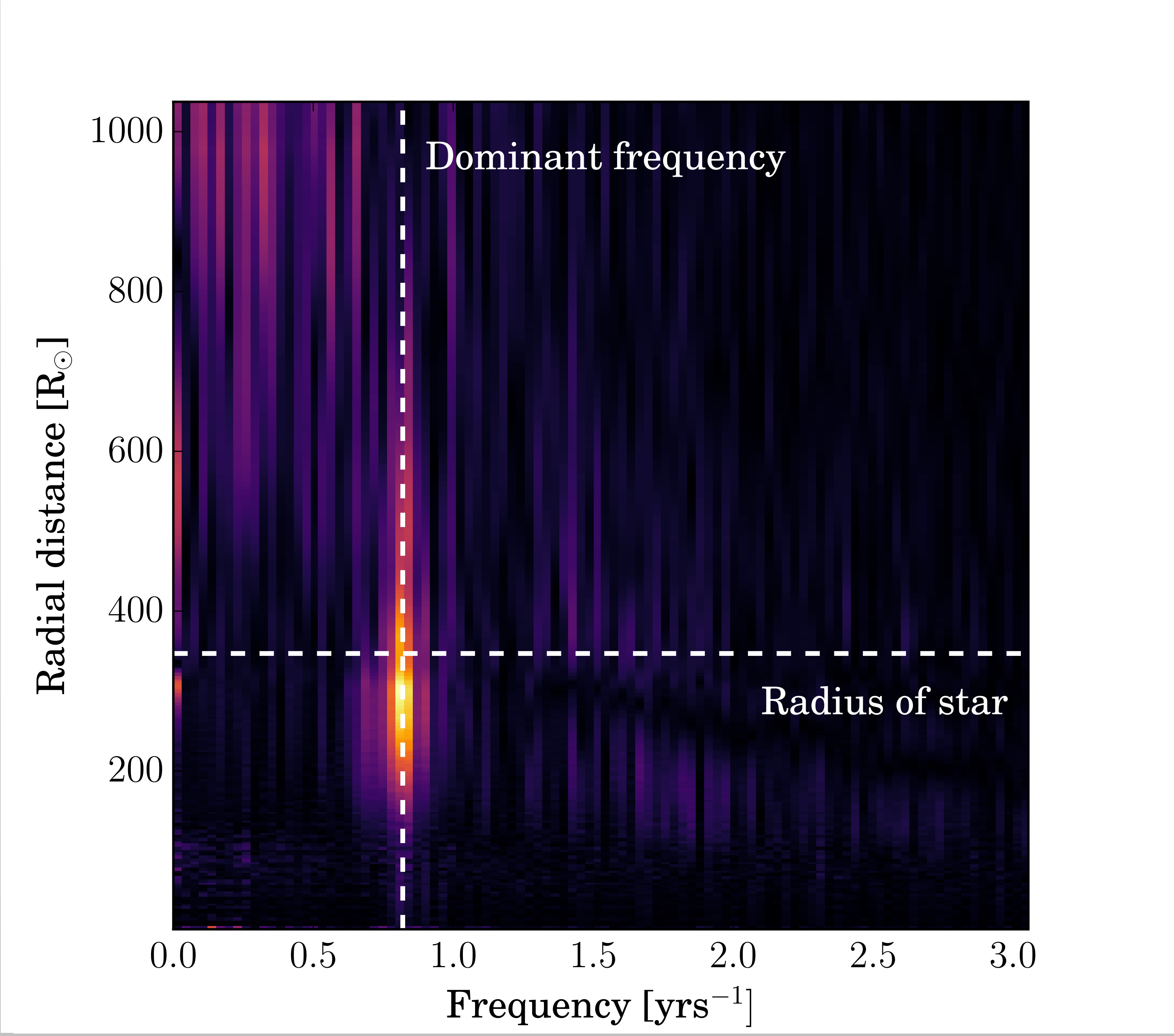
Fourier analysis



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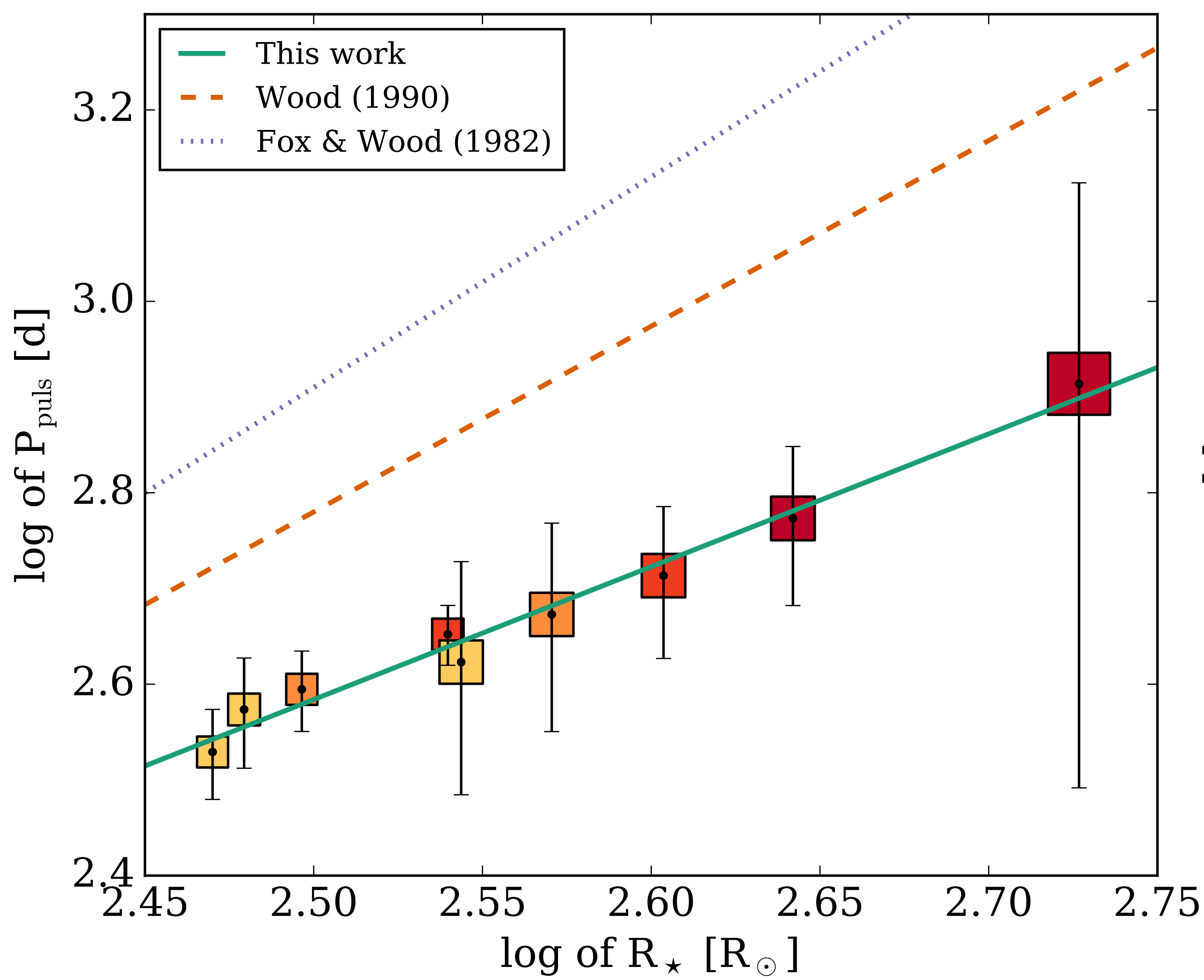
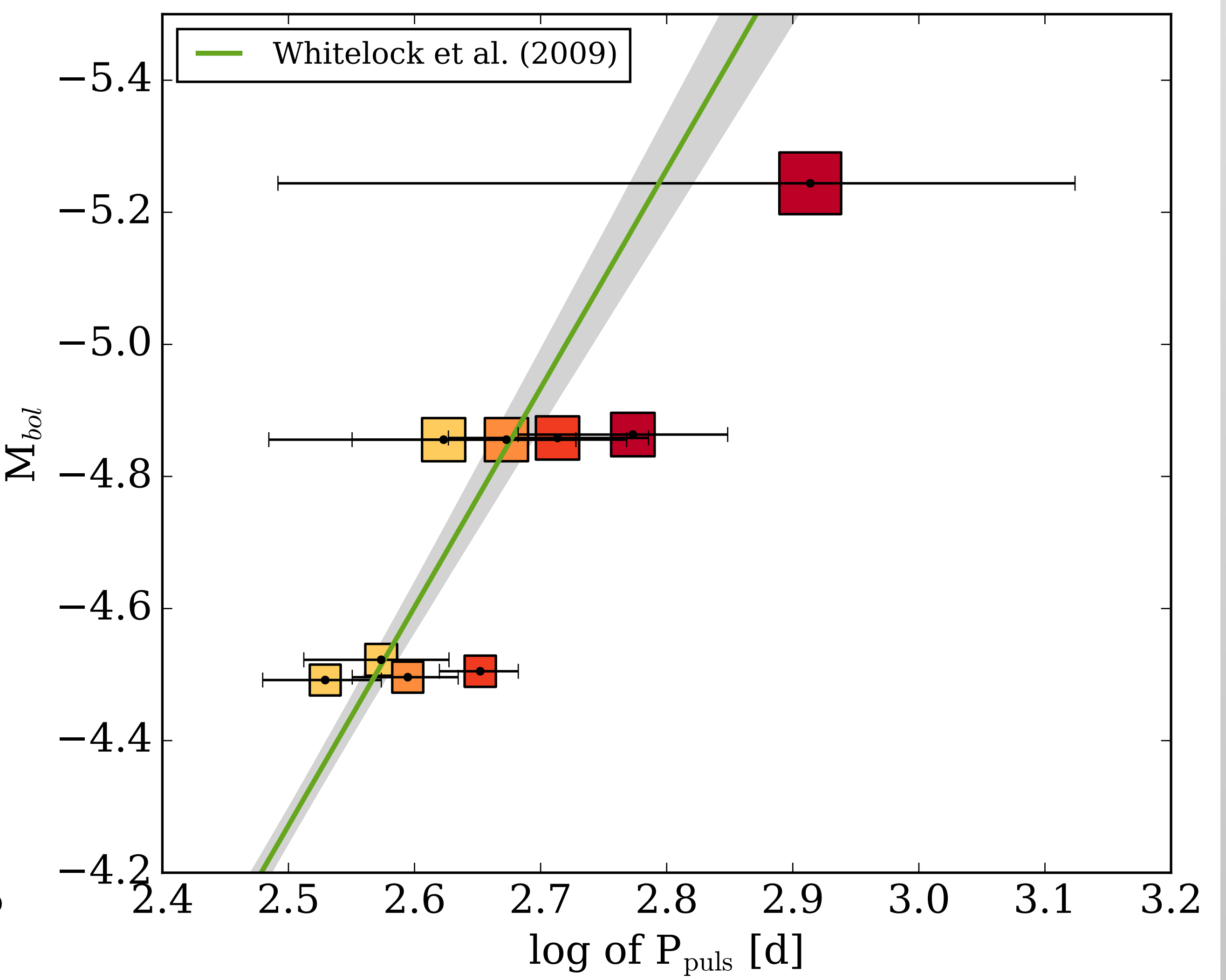
Comparison to other work

1D linear pulsation models



Observations



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Conclusions

- Self-excited radial pulsations
- Pulsates in the fundamental mode
- Produces realistic P-L relationship, consistent with observations
- Larger radius than 1D models

Classification - spectra

- M - stars -> C/O < 1, oxygen dominated chemistry (H_2O, SiO, TiO…), dust created are silicates and different oxides.
- S - stars -> C/O ~ 1, ZrO bands visible.
- C - stars -> C/O > 1, carbon - dominated chemistry (C_2, CN, HCN, C_2H_2). Amorphous carbon dust.

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Method comp