SPHERLS: STELLAR CONVECTION AND PULSATION

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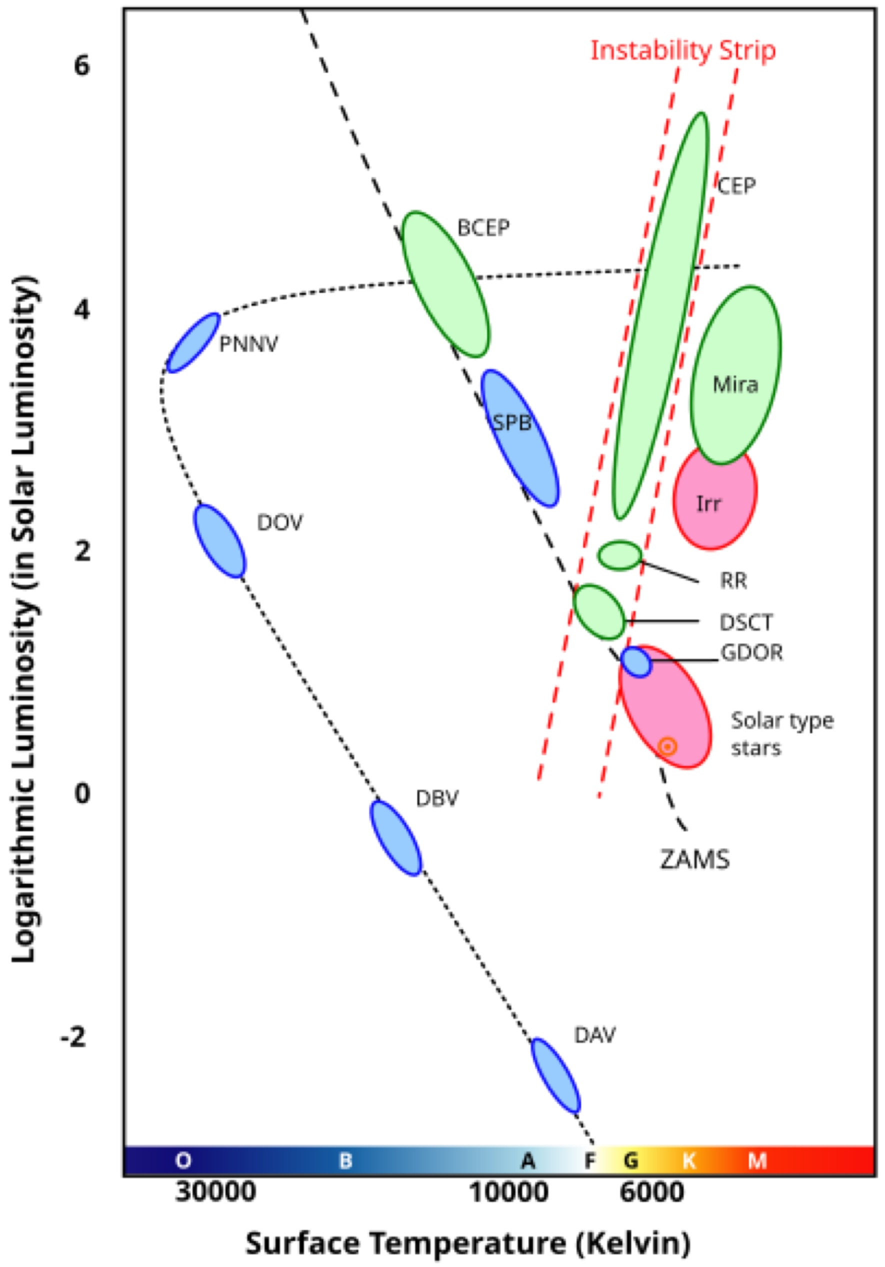
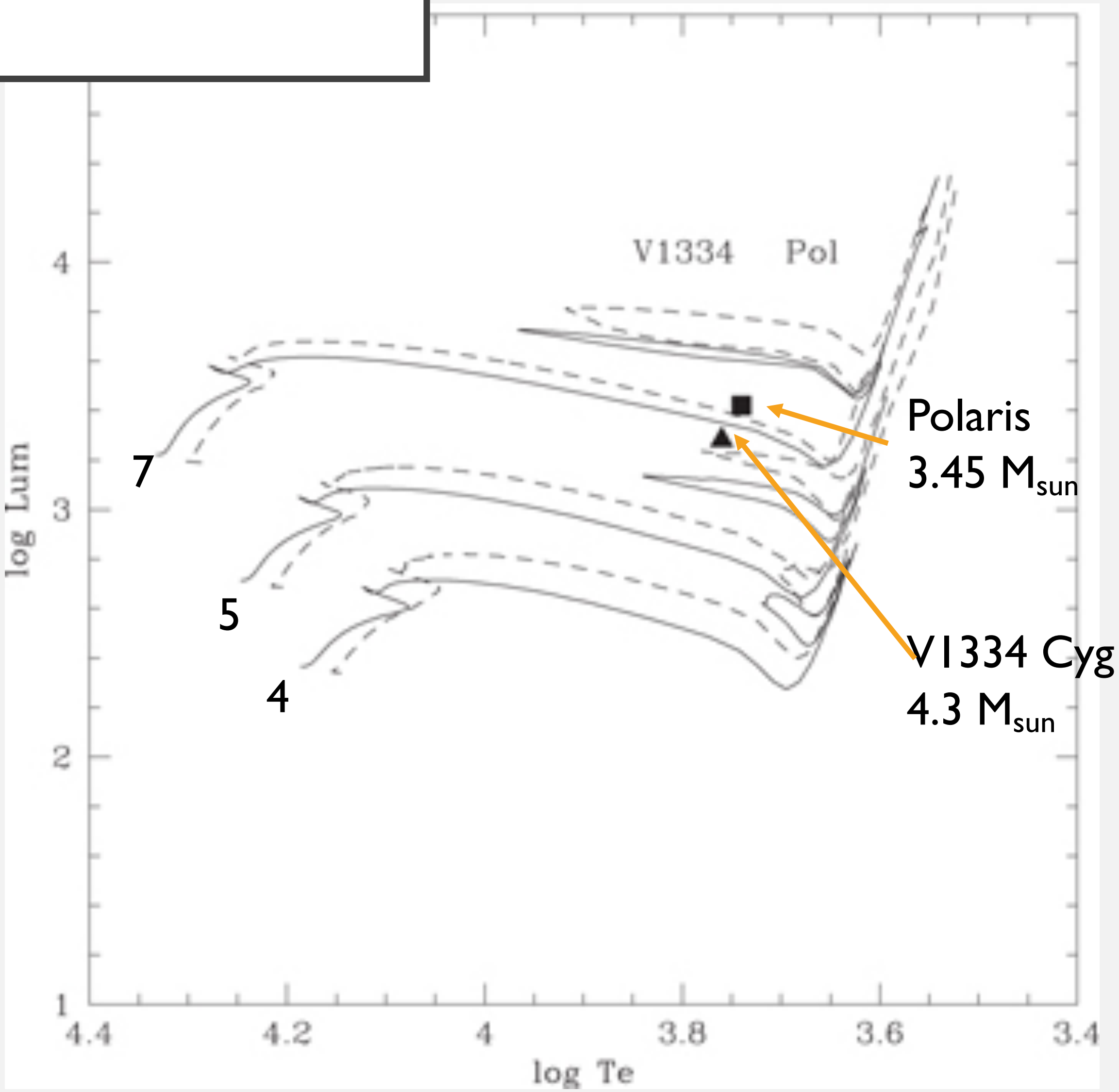
CLASSICAL VARIABLE STARS



CEPHEID VARIABLES

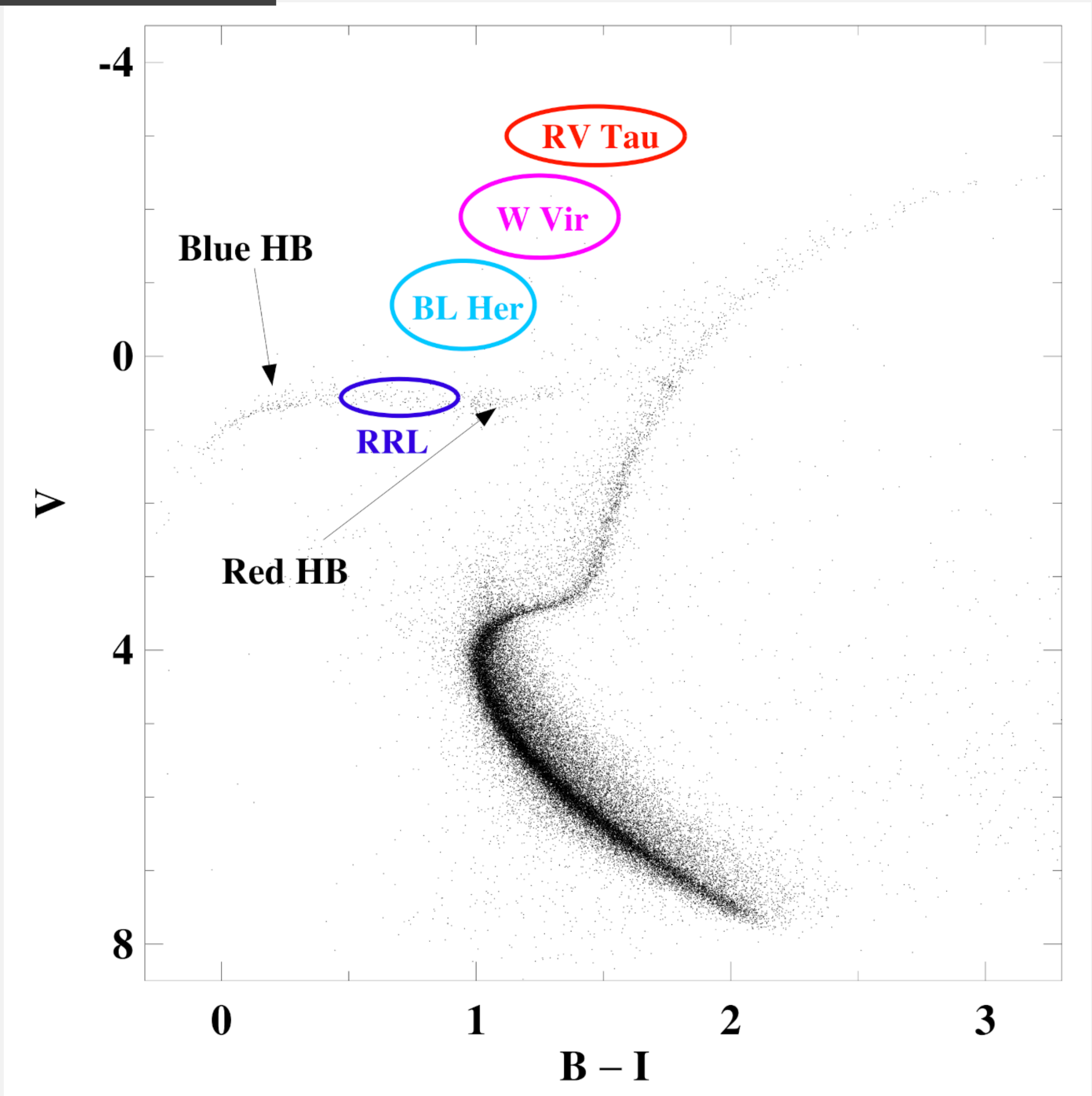
- Up to 3 crossings of instability strip
- Significant differences between evolution and dynamical masses



Evans et al., 2018

RR LYRA VARIABLES

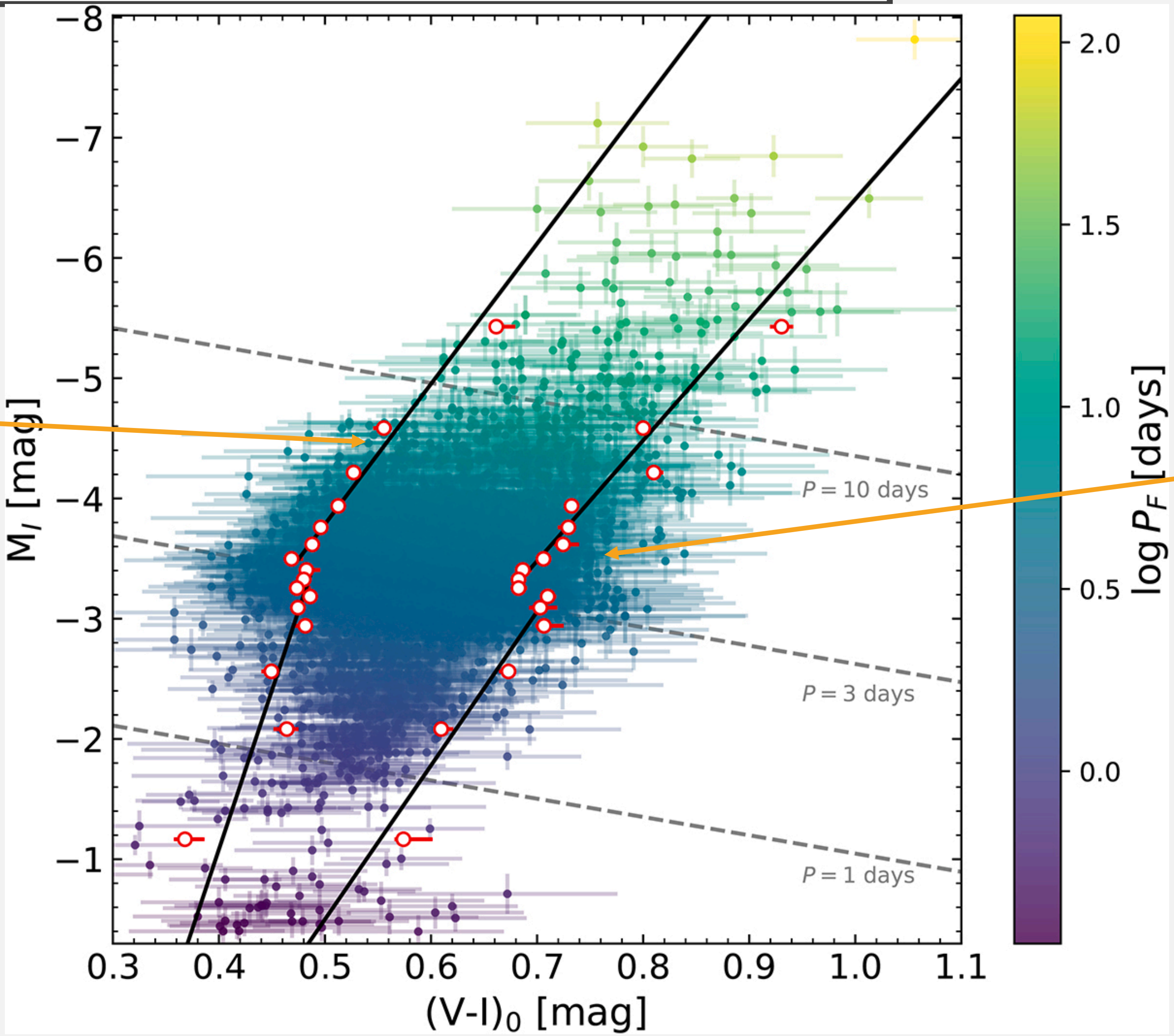
Evolved low mass stars



Bhardwaj, 2022

CEPHEIDS AND RR LYRAE VARIABLES

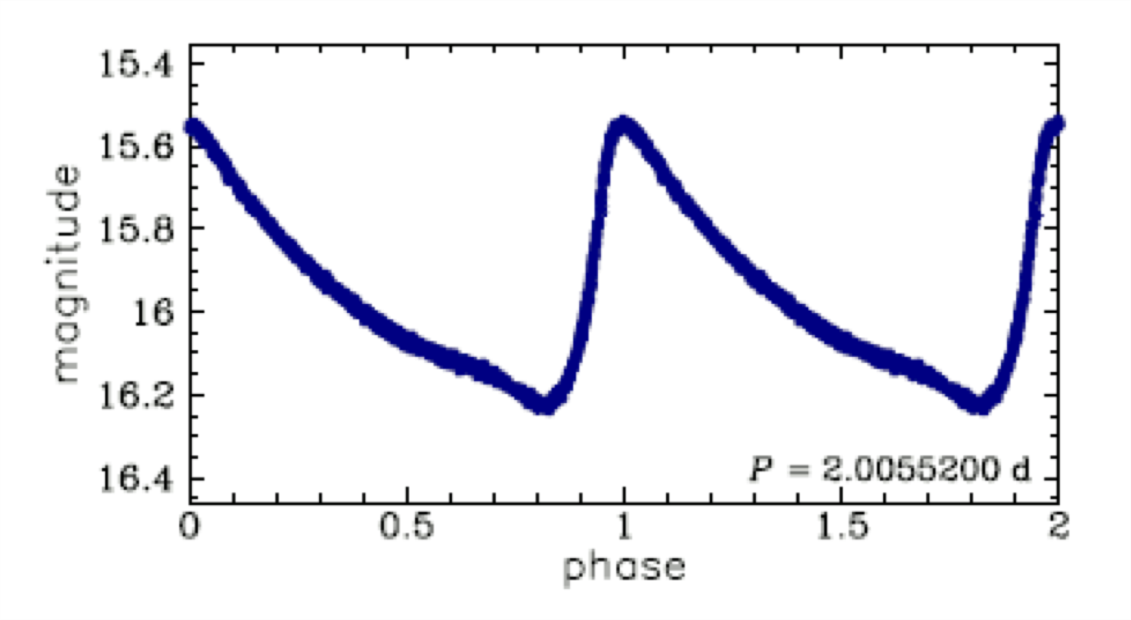
Blue edge: Ionization zone too close to stellar surface



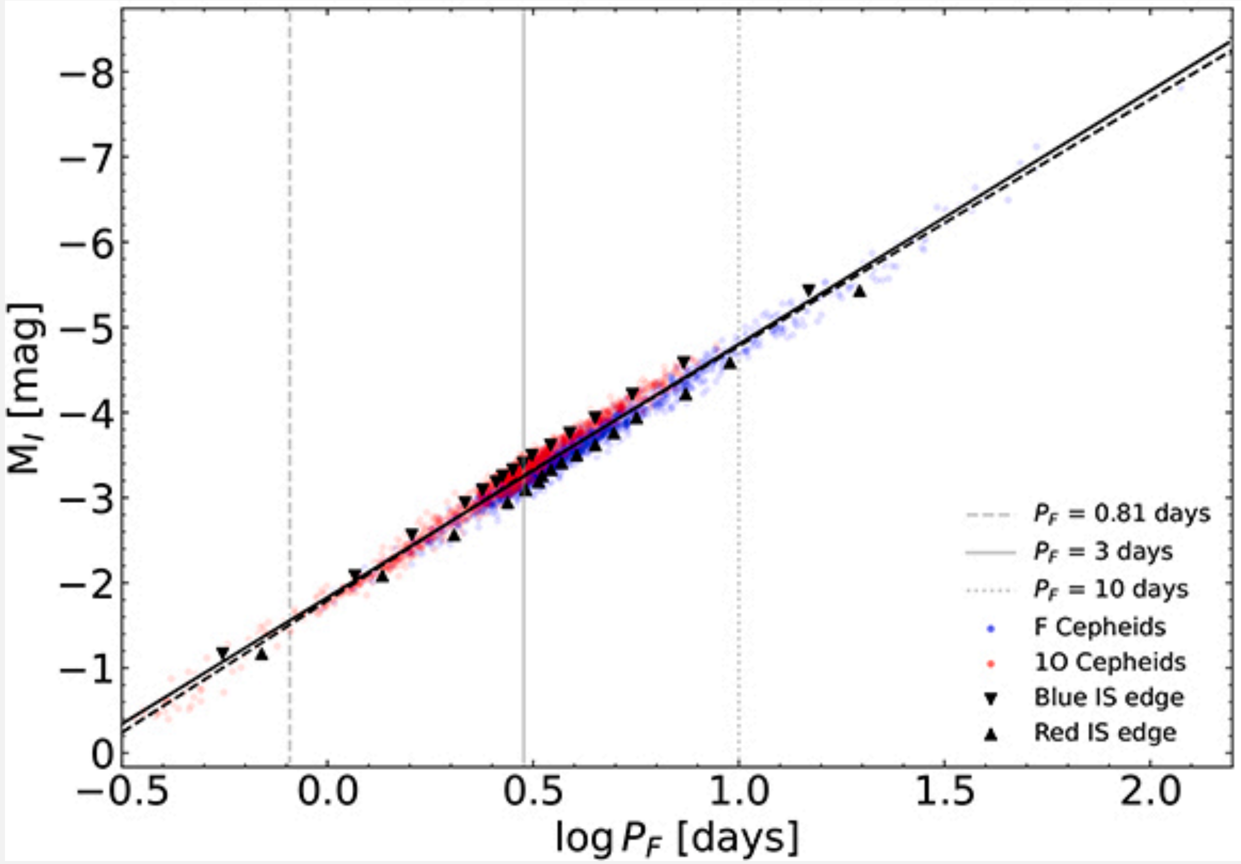
Red edge: Convection damps pulsation

Empirical Instability strip Espinoza-Aranciba et al., 2024

HV 12644
Fundamental mode pulsator

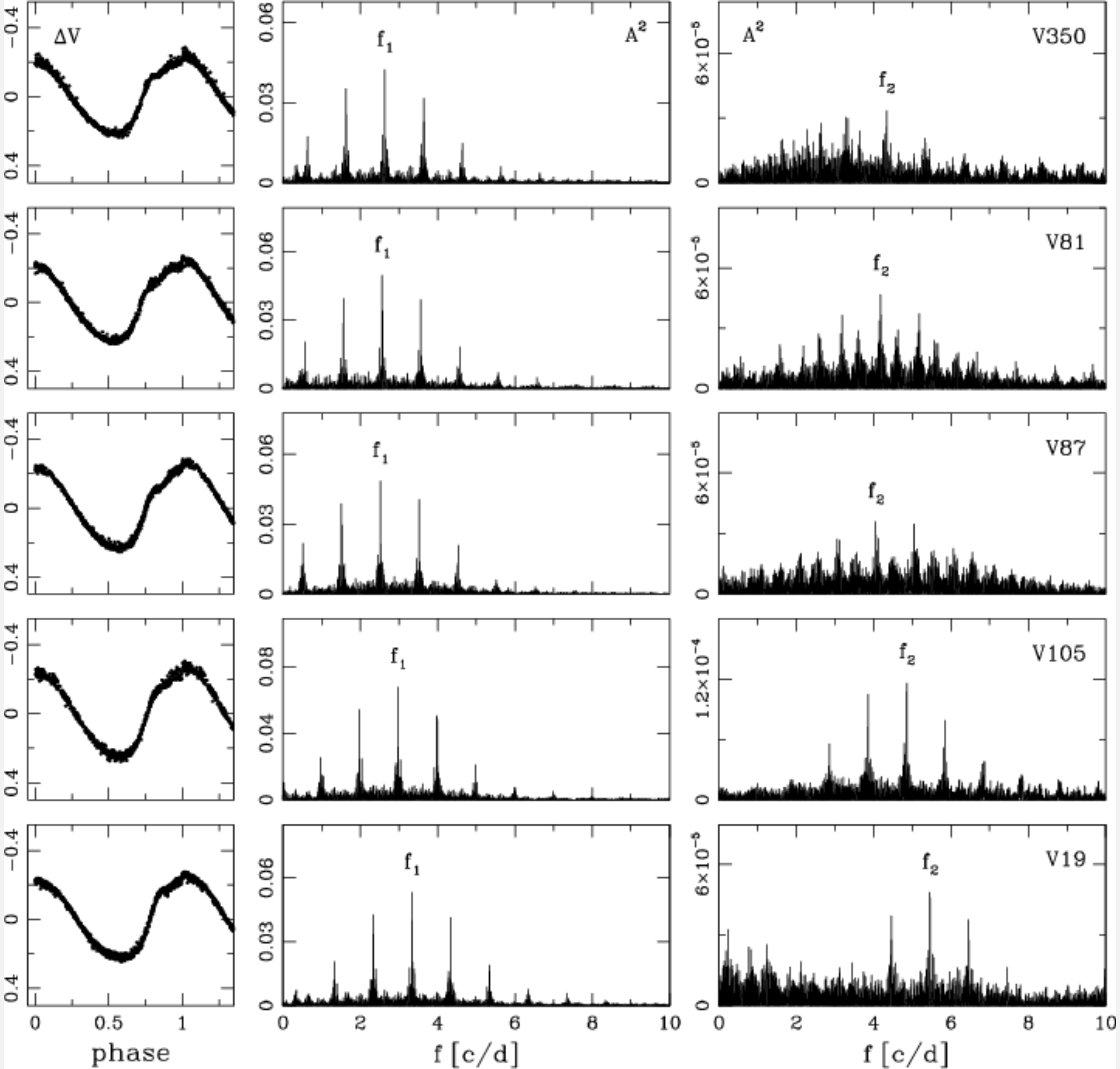


OGLE



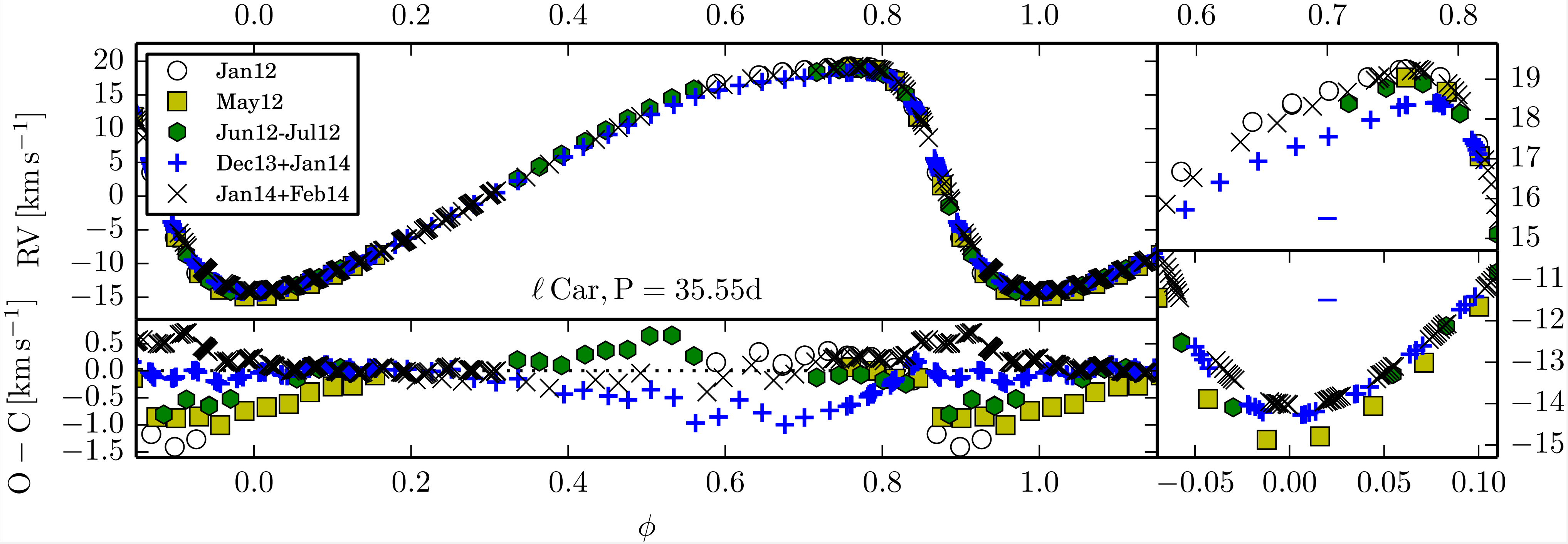
Espinoza-Aranciba et al., 2024

Double mode RR Lyra variables



Olech & Moskalsik, 2009

AMPLITUDE MODULATION

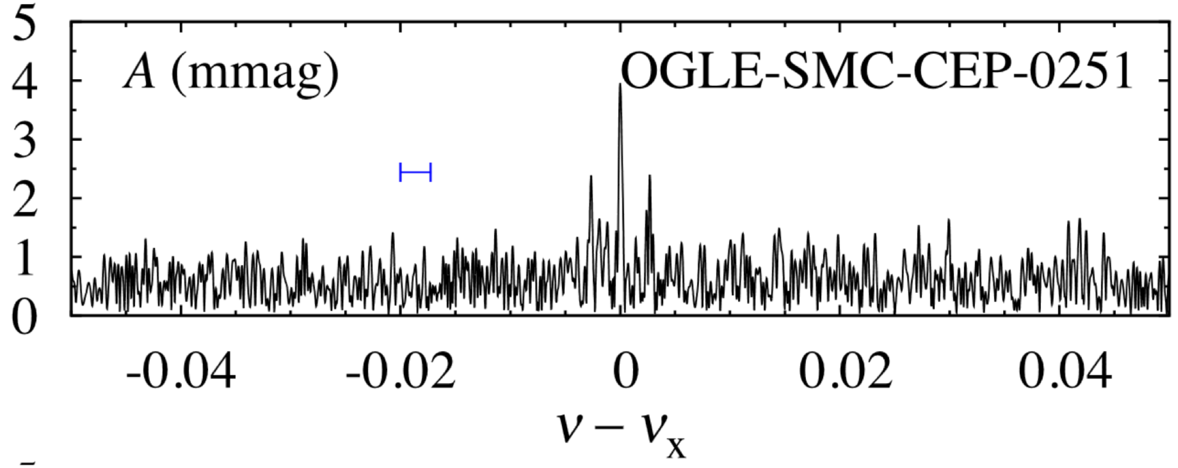


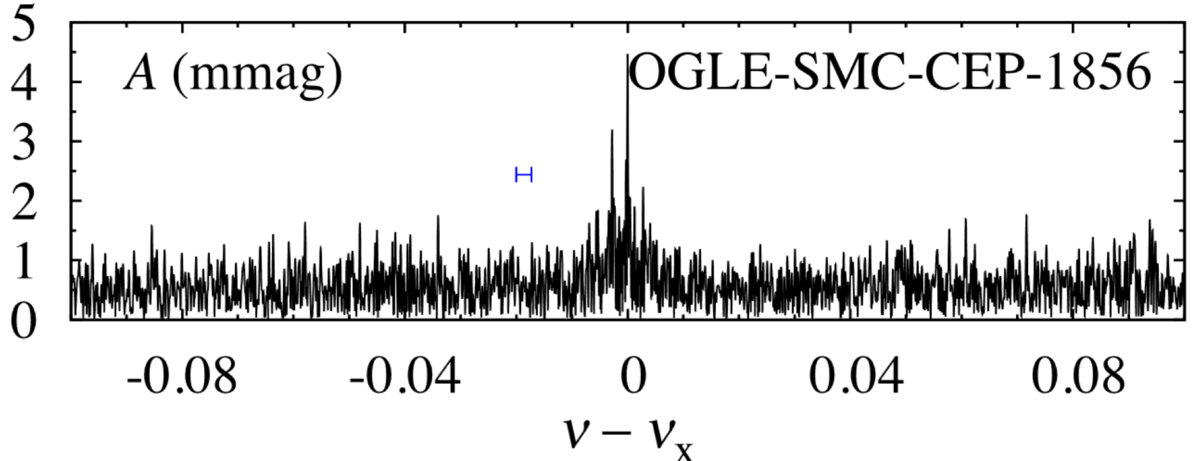
No clear mechanism

Variation time scale different for short and long period Cepheids

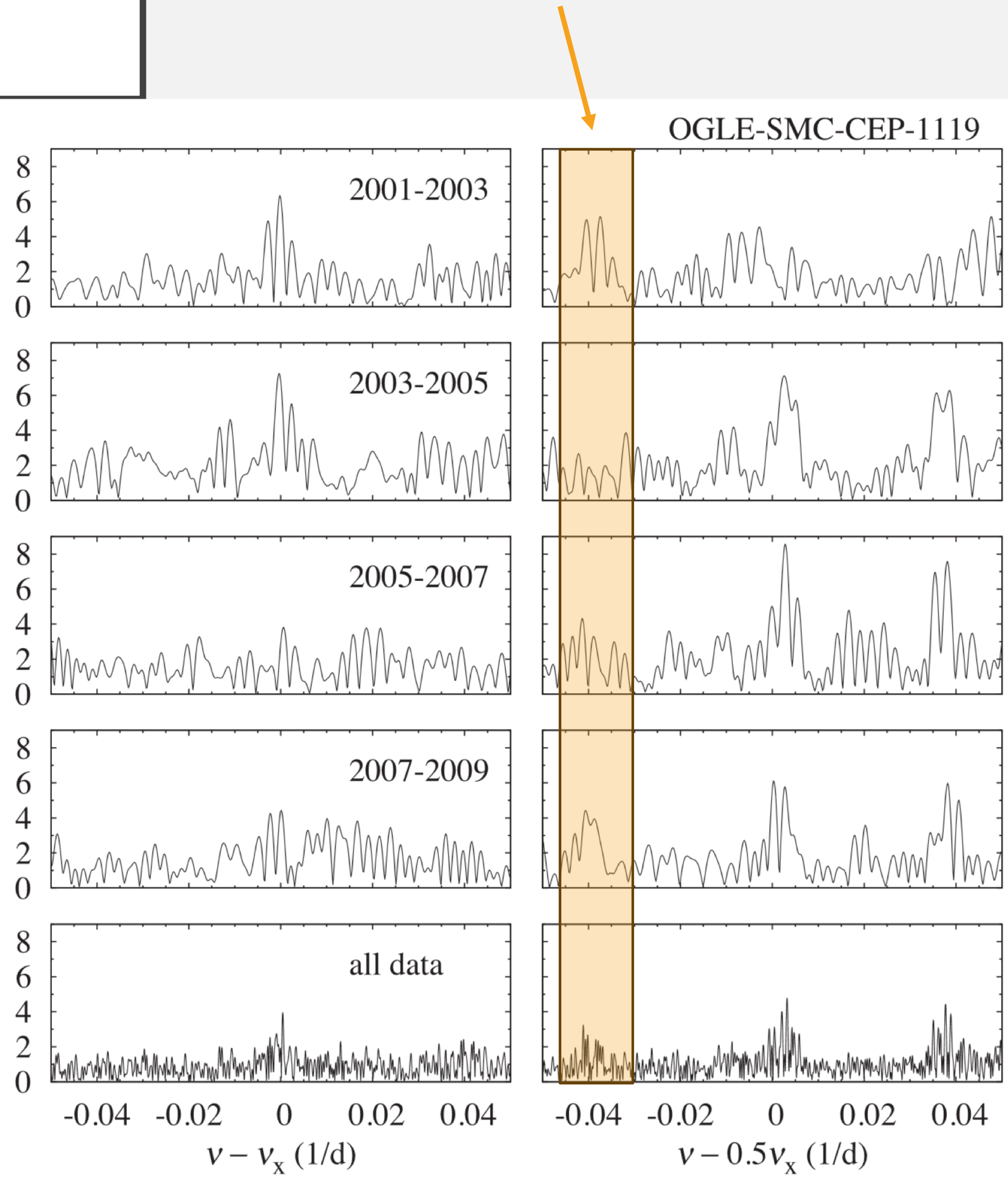
Anderson et al. 2014

NON-RADIAL OSCILLATIONS





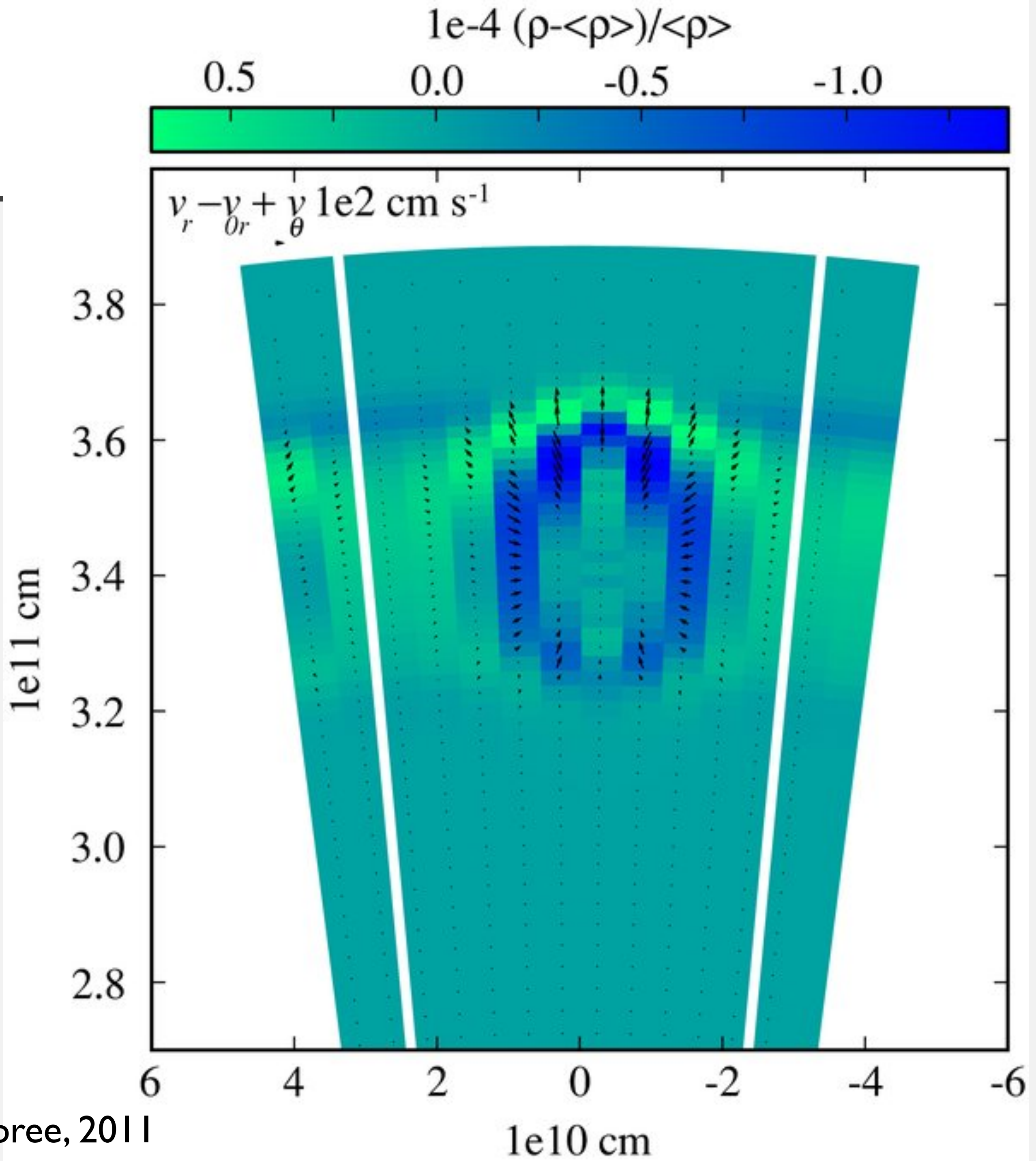
Daily alias



Smolec & Sniegowska, 2016

SPHERLS

- Stellar Pulsation with a Horizontal Eulerian Radial Lagrangian Scheme (Geroux and Deupree, 2011; 2013; 2014; 2015)
- 1, 2, or 3D calculations
- Calculation divided into radial regions and distributed among processors
- Periodic boundary conditions
- Initialize with eigenfunction from 1D calculation
- Toroidal perturbation to break spherical symmetry

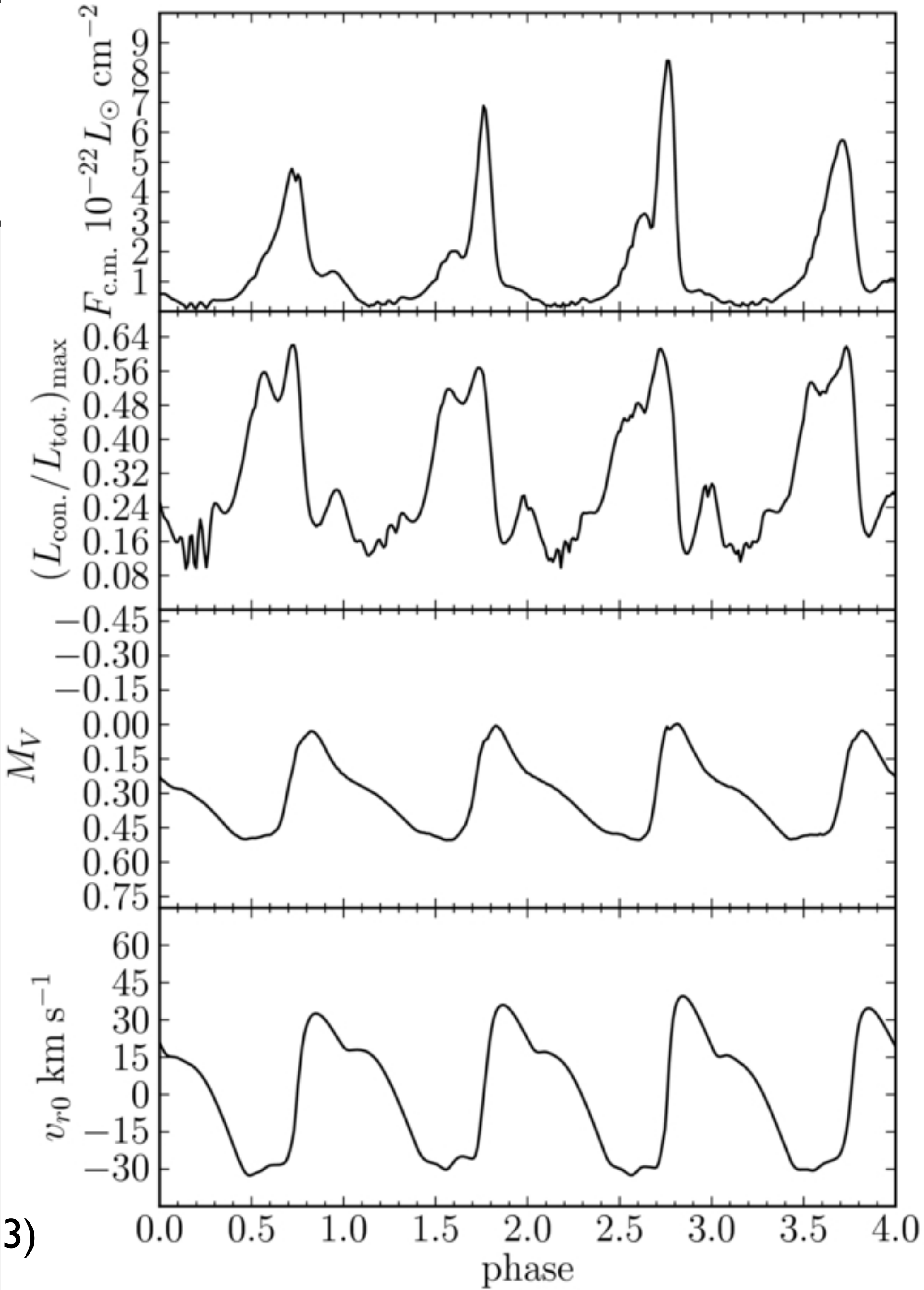


Geroux & Deupree, 2011

CONVECTION AND PULSATION

Written to explore connection between surface convection zones and stellar pulsation in RR Lyra stars

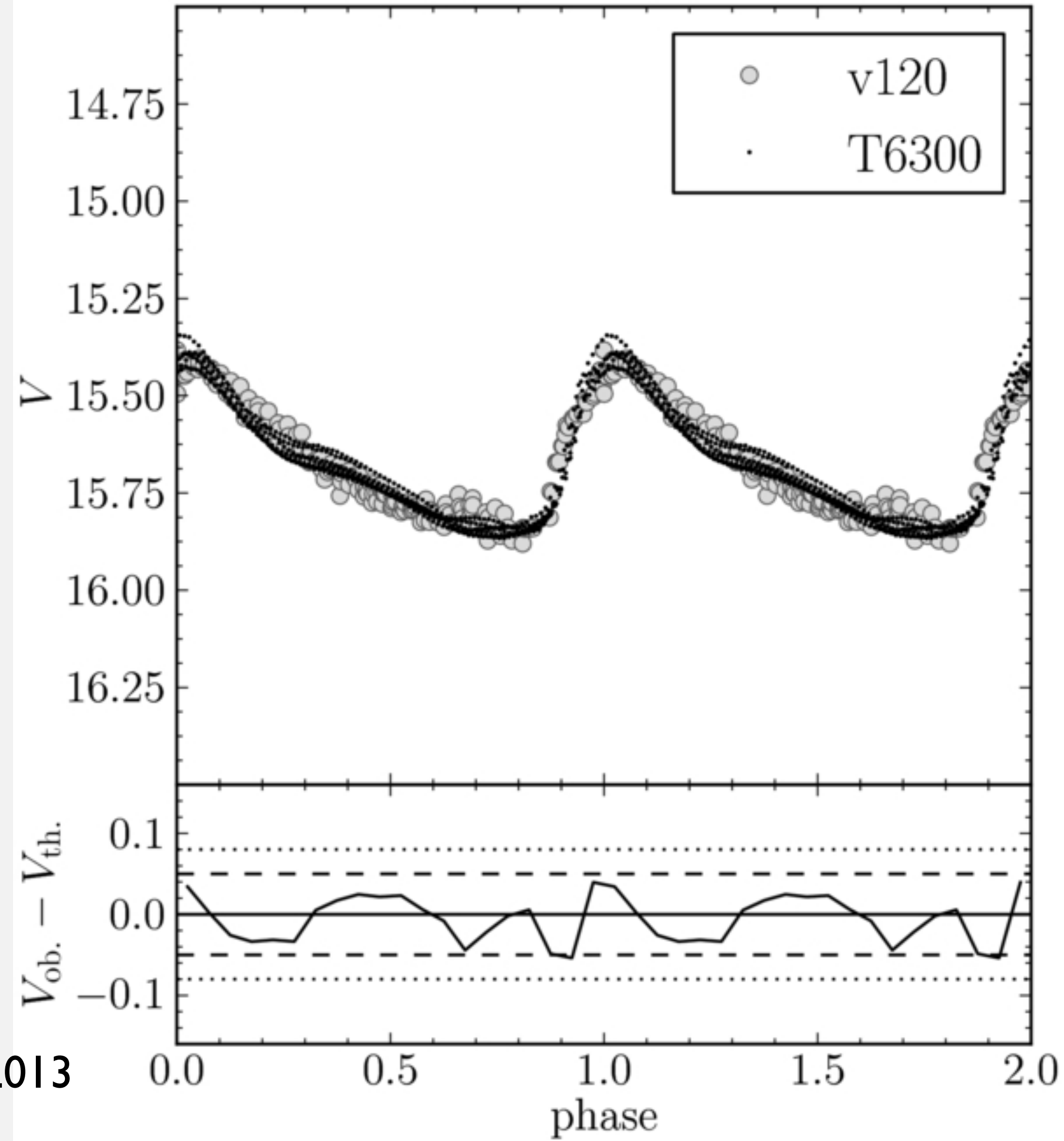
Model contracts ⟶ Convective flux grows
Model expands ⟶ Convective flux shrinks



Geroux & Deupree (2013)

COMPARISON TO OBSERVATIONS

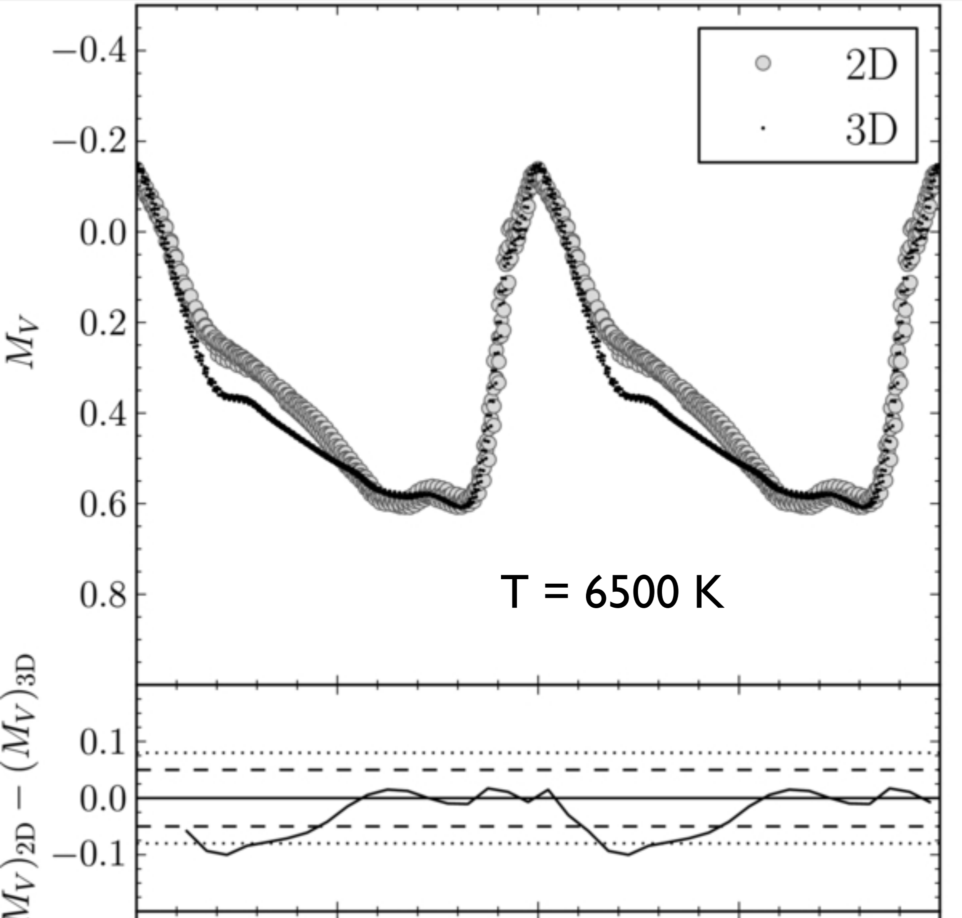
- Used model T and log g to calculate synthetic light curves
- Compared to several observed RR Lyrae
- V120 (Cacciari et al., 2005), RRab star with T_{eff} = 6300
- Able to reproduce broad features of light curve with 2D models



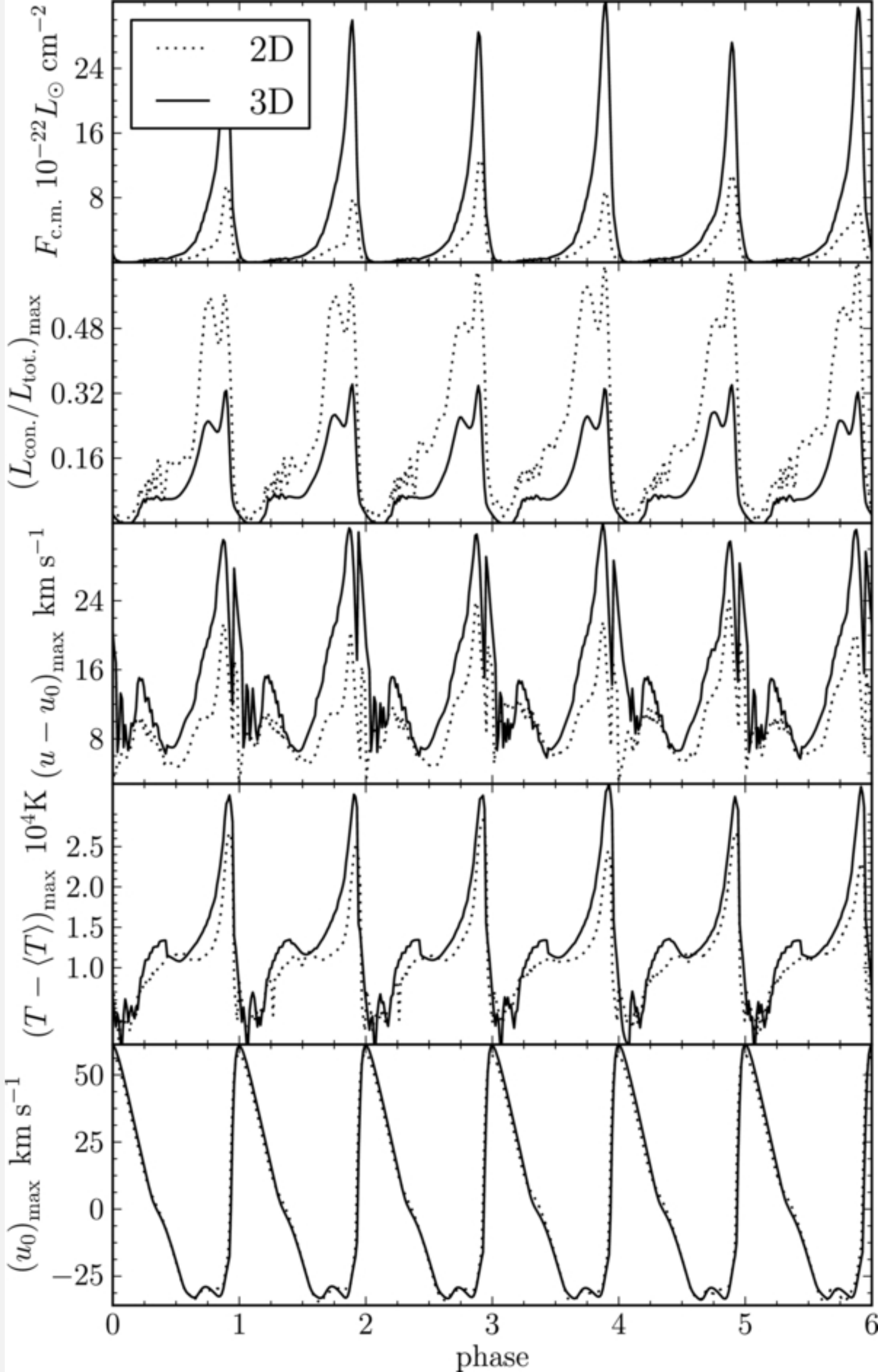
Geroux & Deupree, 2013

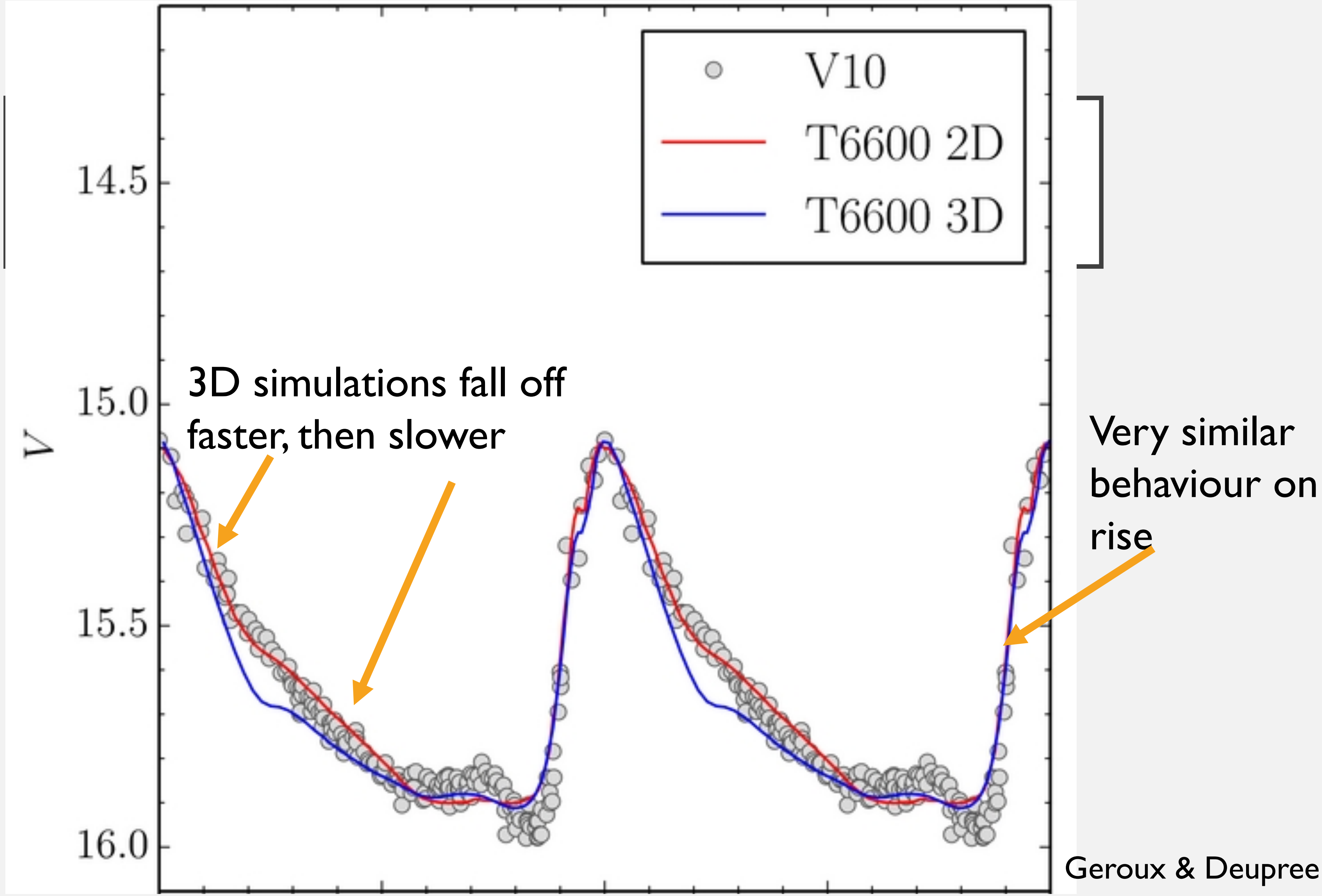
2D VS. 3D

2D and 3D calculations are broadly similar
Can map pulsation properties in 2D (faster!)



Geroux & Deupree, 2015



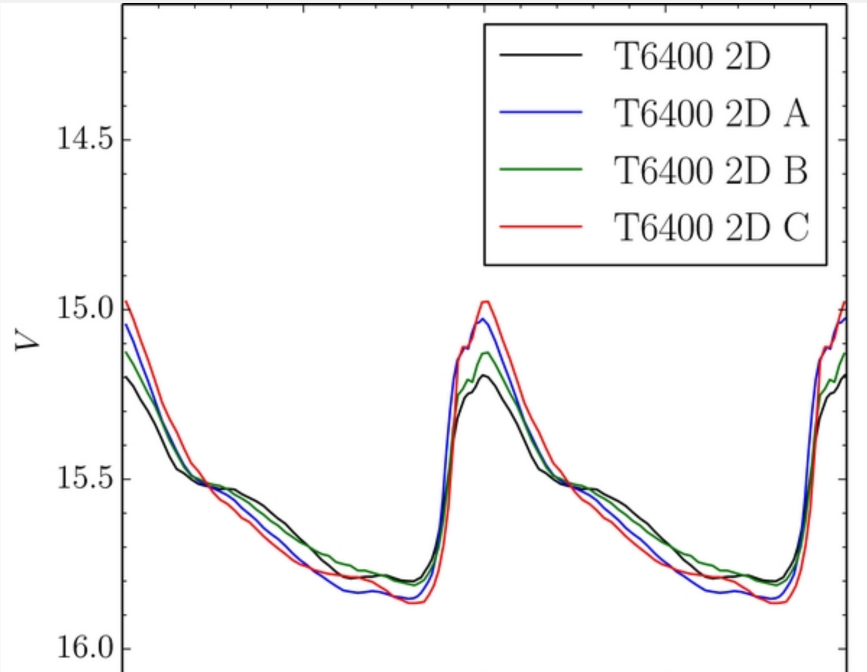


Geroux & Deupree 2014

RESOLUTION STUDY

Table 3
Angular Resolution Study of the 6400 K Model

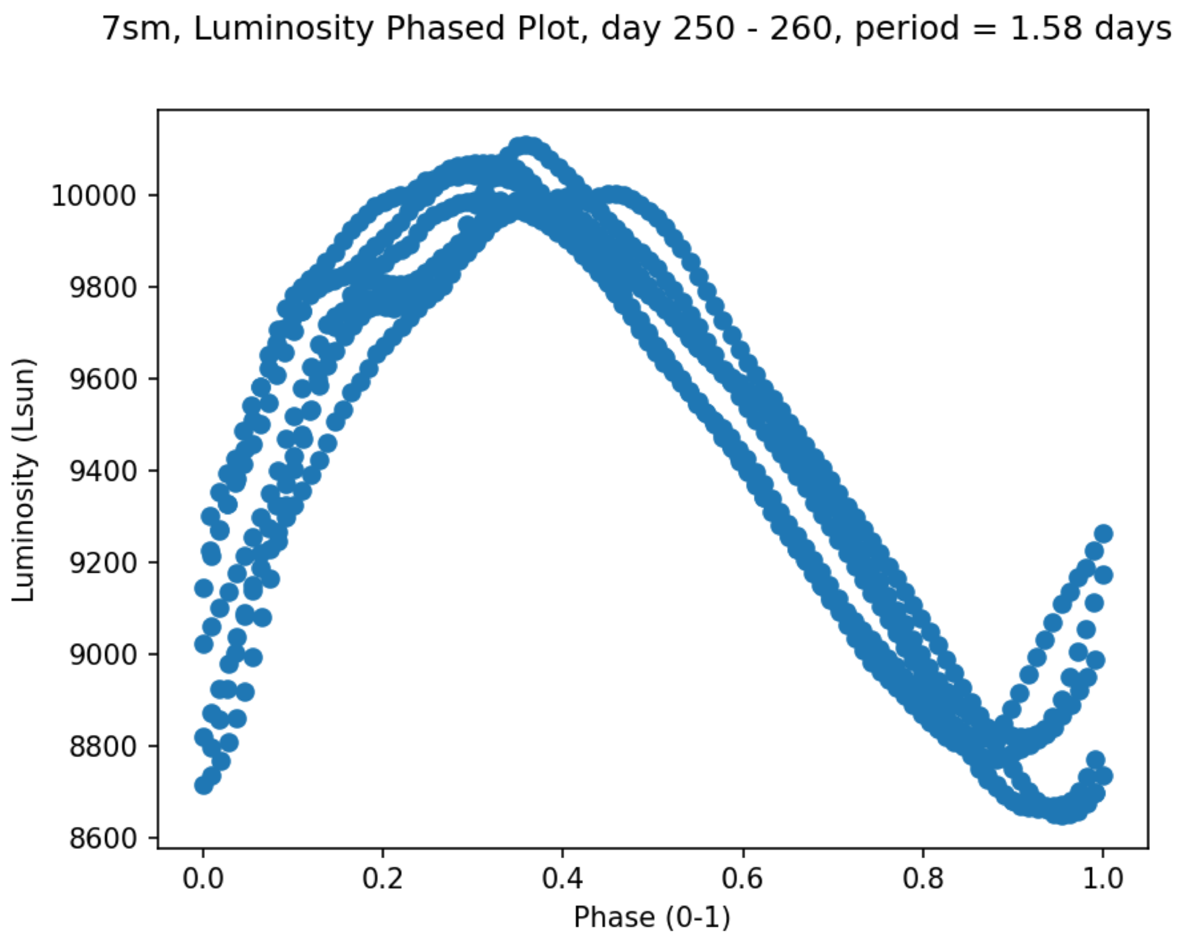
Case	Zones	Extent	Conv. Cells	A_V (mag)	$L_{conv.}/L_{tot.}$	ϕ_L	$\Delta\langle T\rangle/\langle T\rangle$	ϕ_T	$v_{conv.}$ (km s^{-1})	ϕ_v	$v_{amp.}$ (km s^{-1})
Baseline	20	6°	1	0.64	0.65 ± 0.01	0.73	0.65 ± 0.02	0.76	20 ± 2	0.71	82 ± 1
A	40	6°	1	0.83	0.61 ± 0.04	0.74	0.68 ± 0.01	0.75	25 ± 2	0.73	91 ± 3
B	40	12°	2	0.78	0.64 ± 0.03	0.73	0.68 ± 0.01	0.76	31 ± 1	0.72	88 ± 1
C	80	12°	2	0.94	0.56 ± 0.05	0.75	0.69 ± 0.01	0.76	31 ± 3	0.74	95 ± 1

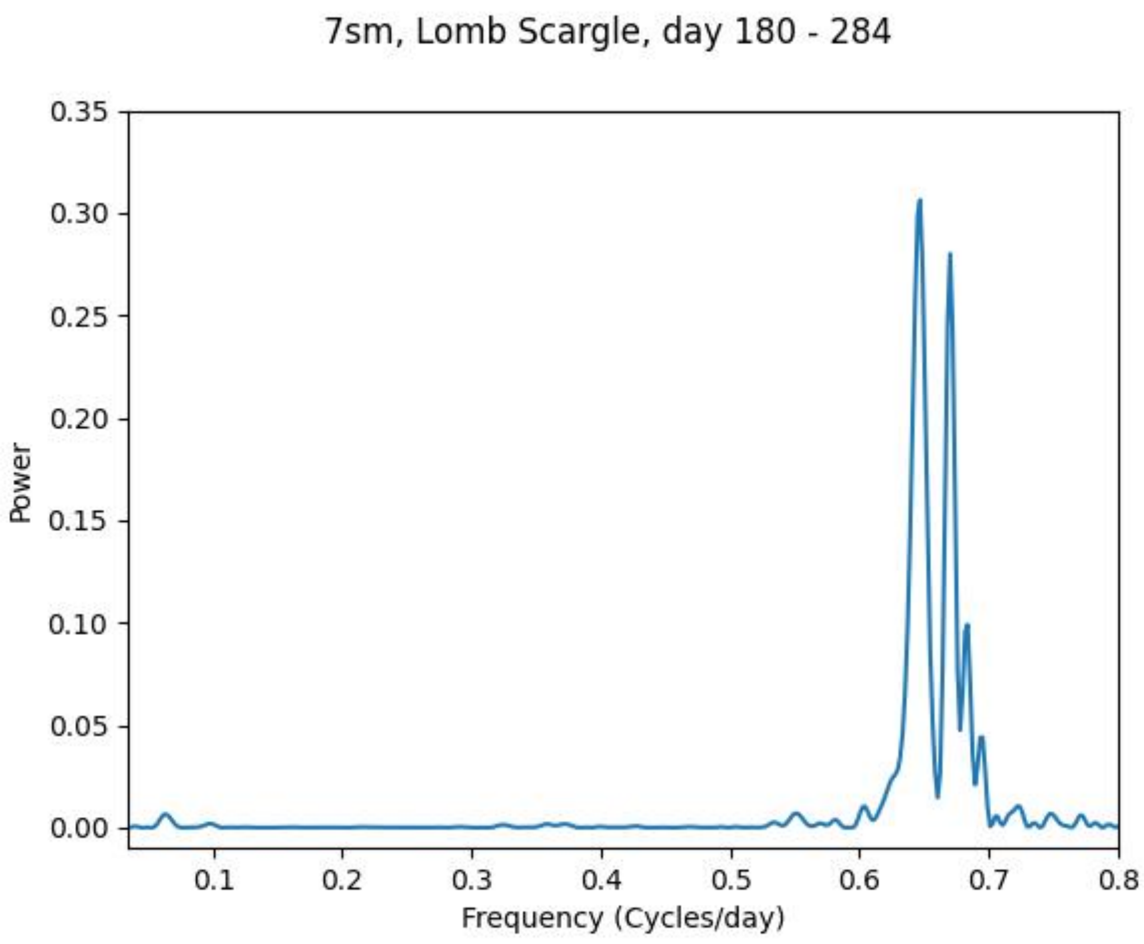


Geroux & Deupree 2015

Growth rates essentially the same in all four cases
Minor differences in shape of light curve
Low radial resolution
Peak performance @ 16 cores

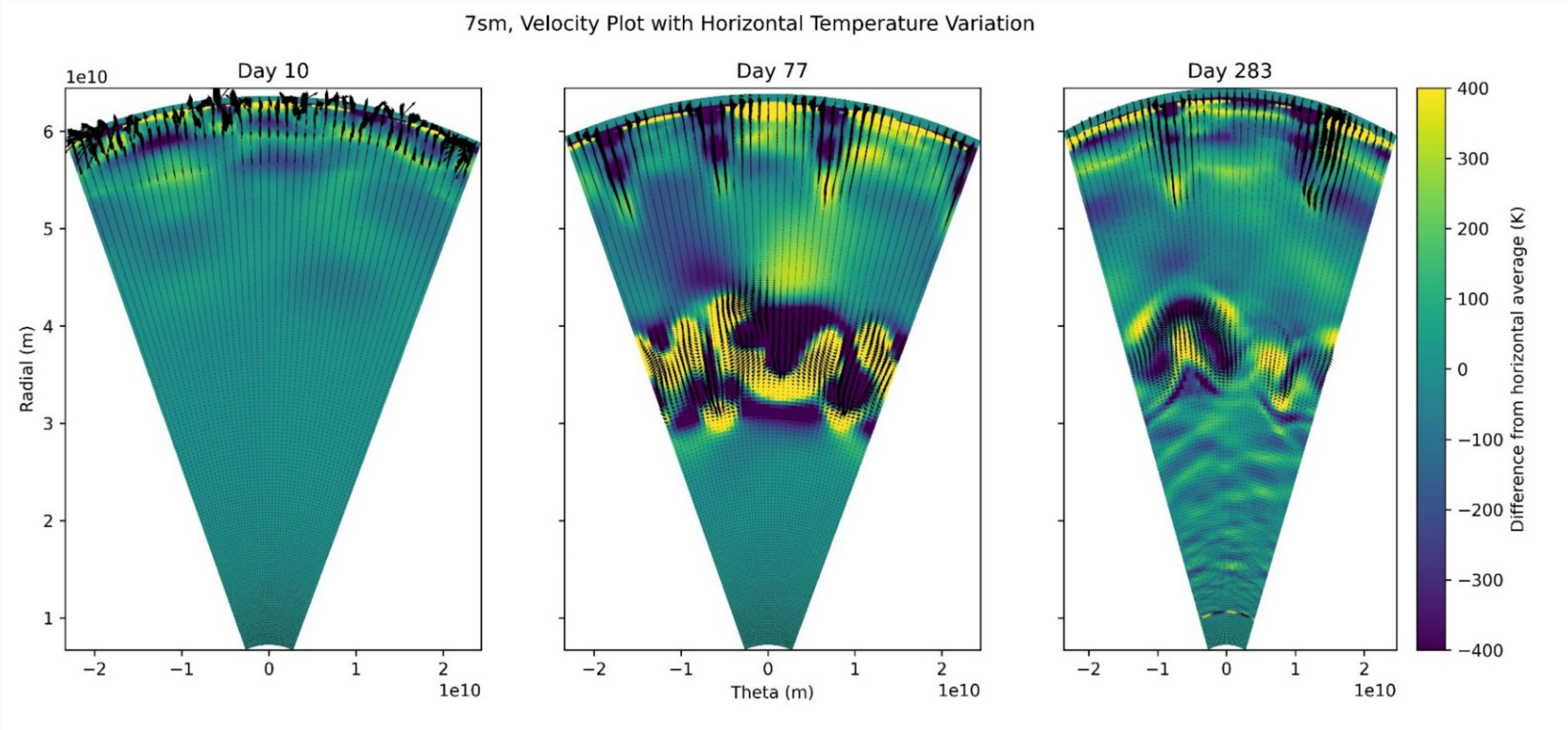
CEPHEID VARIABLES





J. Allison, BSc thesis (2023)

CEPHEID VARIABLES



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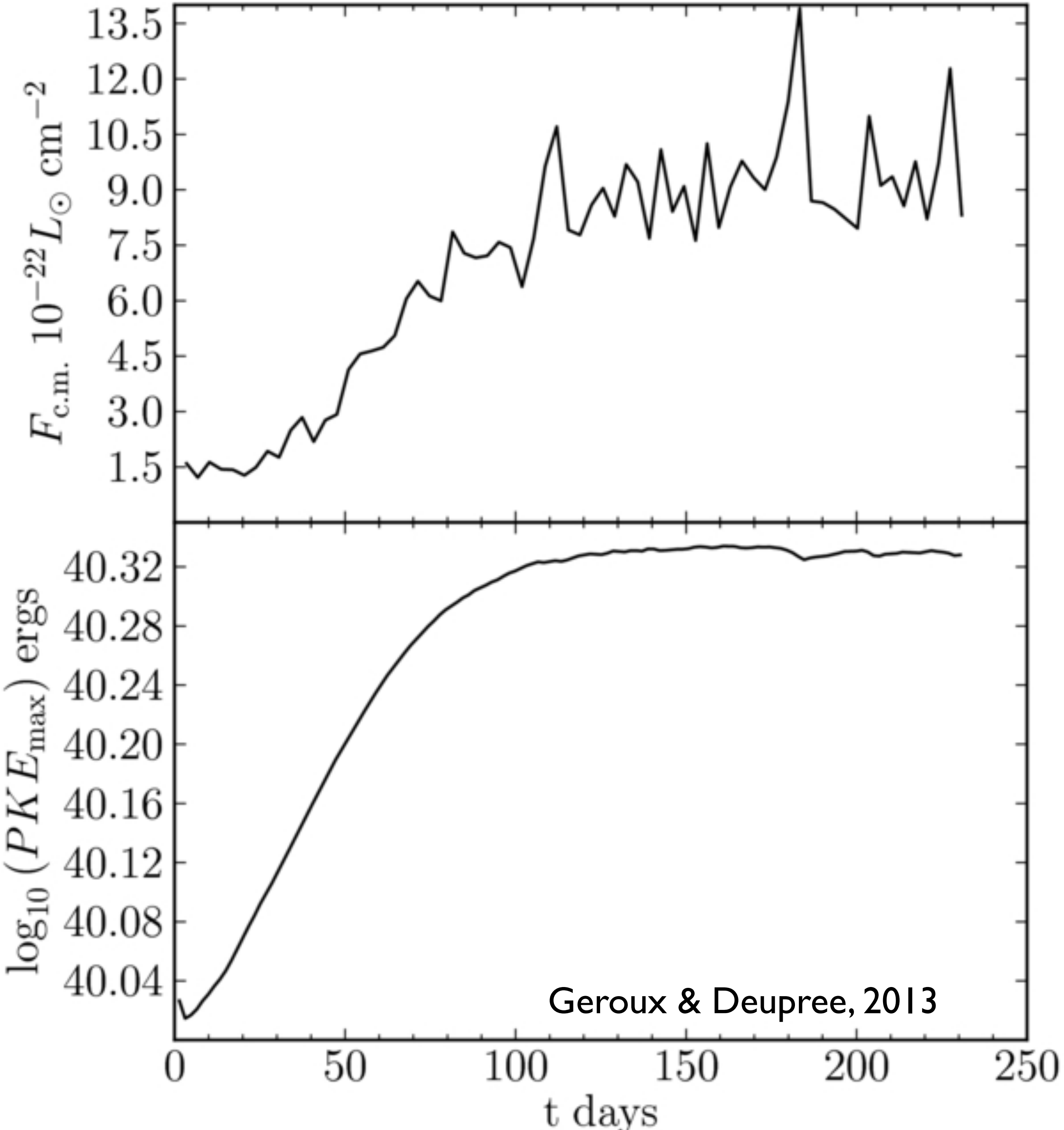
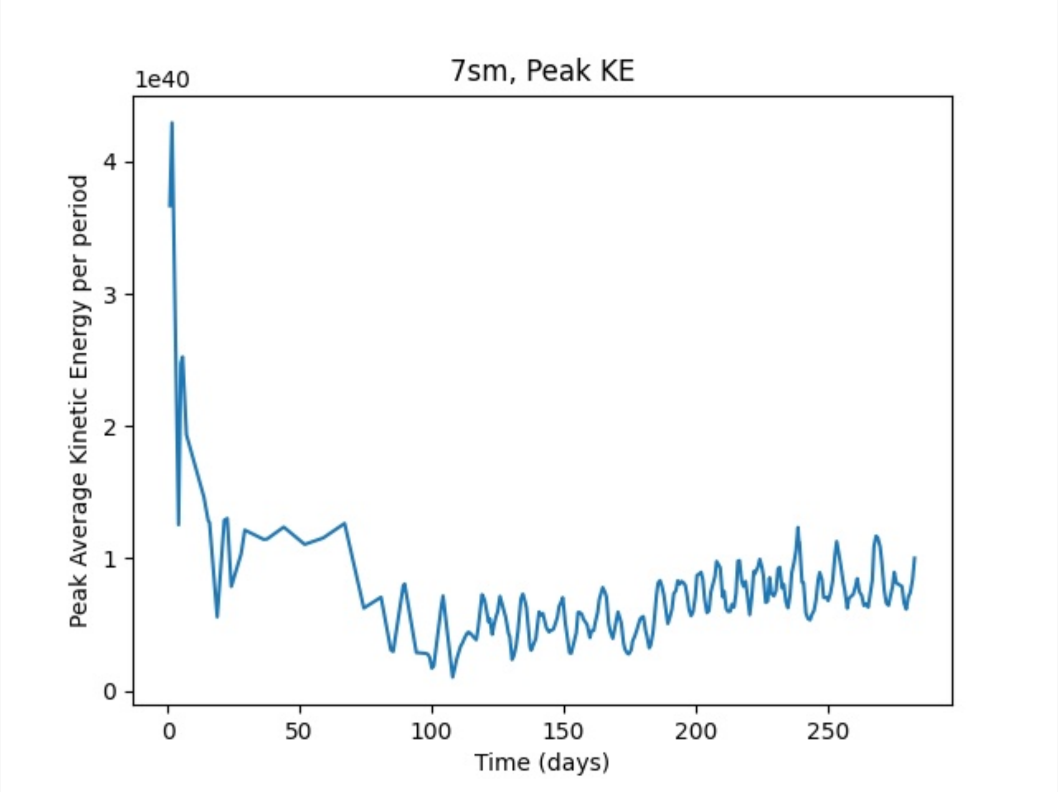


Geroux & Deupree, 2013

Long simulation times required to reach full amplitude



J. Allison, BSc thesis (2023)

UPDATING SPHERLS

- Updated outdated libraries
- Updated code to be compatible with modern libraries
- Streamlined calculations – object oriented design
- New version (hopefully) more efficient: Longer runs, larger simulations
- Less computation time required to reach full amplitude
- Easier to update with new physics in the future

RESULTS

FUTURE PLANS

- Verify new version reproduces results from Geroux & Deupree
- Theoretical instability strips for Cepheids and RR Lyrae
- Investigate double mode Cepheid driving

THANK YOU!

Collaborators: Padraic Odesse, Jay Allison, Duncan MacIsaac,