Probing the Interior of the Nearby Supernova Progenitor: Rigel
ε-Mechanism exciting g-modes

Ehsan Moravveji
IASBS, Zanjan, Iran
Villanova University

Collaborators:
Edward F. Guinan, Villanova University, USA
Andres Moya, Madrid, Spain


Witch Head Nebula
≈ 300 pc away
size 3×1°
Illuminated by Rigel
Rigel (β Ori)
B8 Ia
T_{eff} = 12 100± 150
Mbol=-7.9±0.28
264±24 pc
M≈18.5 Msun
R≅79 Rsun
~10 Myr old
APOD: 29 December 2009

Introducing Rigel (B8 Ia, V=0.12)

Parameter	Measured	Modeled	Reference
Hipparcos Distanece	264 ± 24 pc		van Leeuwen (2007)
Effective Temperature T_{eff}	12100 ± 150 K	12077 K	Przybilla et al. (2010)
Surface Gravity log g	1.75 ± 0.10 dex	1.83	Przybilla et al. (2006, 2010)
Angular Diameter θ_{LD}	2.75 ± 0.01 mas		Aufdenberg et al. (2008)
Limb Darkened Radii	78.9 ± 7.4 $R_{\odot}$	80.6	This study
Luminosity log $(L/L_{\odot})$	5.08 ± 0.10 dex	5.09	This study
Metallicity [M/H]	-0.06 ± 0.10	0.00	Przybilla et al. (2006)
Surface Helium Y	0.32 ± 0.04	0.31	Przybilla et al. (2010)
Surface (N/C)	1.74 ± 0.60	1.86	Przybilla et al. (2010)
Surface (N/O)	0.52 ± 0.13	0.50	Przybilla et al. (2010)
Projected Velocity *v sin i*	24 ± 3 km s^{-1}	30	Simon-Diaz et al. (2010)
Mass Loss rate	1-2×10^{-7} $M_{\odot}$ yr^{-1}	3×10^{-8}	Chesneau et al. (2010)
Evolutionary Mass		18 $M_{\odot}$	This work

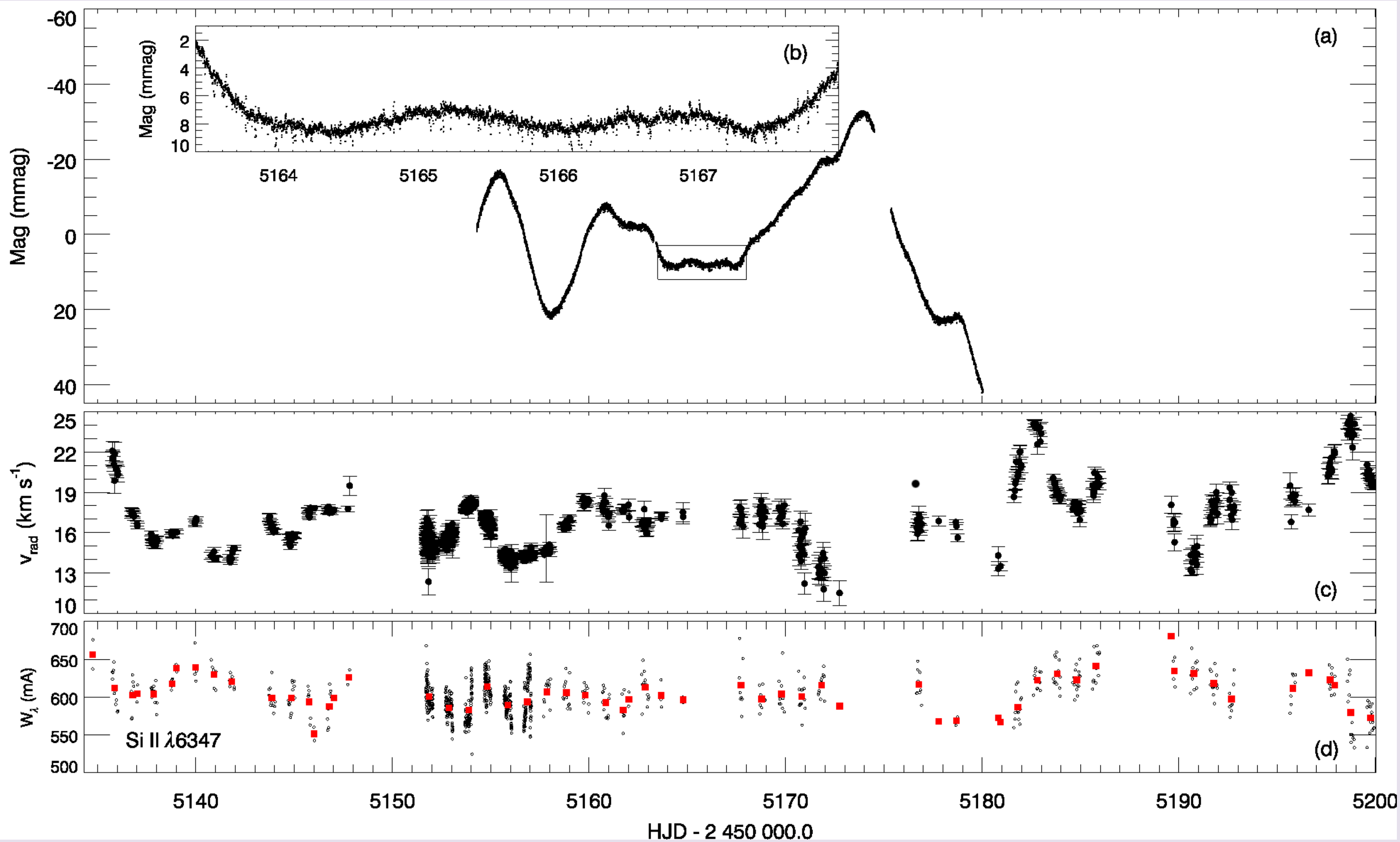
MOST Photometry

- 15 November to 13 December 2009
- Duration: **27.7** days
- **30 640** measurements
- Observed through Fabry lens
- Precision about 0.5 to 0.10 mmag.

AST/TSU Spectroscopy

- **2-m** AST at Fairborn Observatory, Arizona
- **2328** spectra taken over **6 years**, from December 2003 to February 2010
- R ≈ **30 000** to **20 000**; SNR ≈ **50** to **150**
- **442** spectra during MOST photometry
- **RV** measured from 29 metallic lines.

Simultaneous LC, RV and EW



Another Season

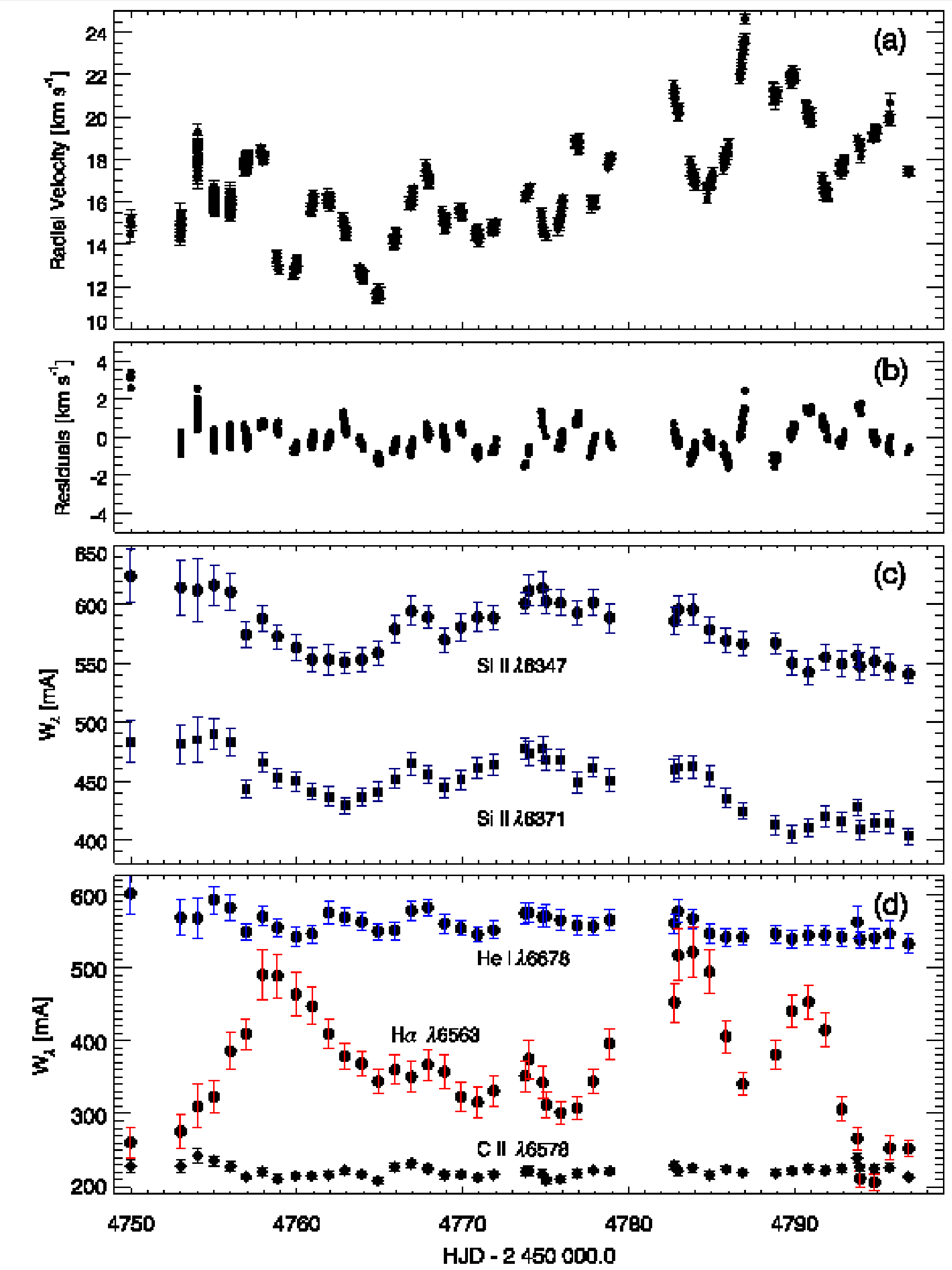
- A year before MOST photometry.
- Panel (a) is **50** day of radial velocity
- Panel (b) residuals.
- Panel (c) is equivalent widths of **Si II λ6347** and **Si II λ6371** lines.
- Panel (d) equivalent widths of **He I λ6678** and **Hα** and **C II λ6578**.

Any Correlation?

- Between equivalent widths almost NO.
- Between equivalent widths and radial velocity almost NO (De Ridder et al. 2002).
- Between photometry and radial velocity YES.

Strict Regularity?

Seems very likely in the radial velocity variations.

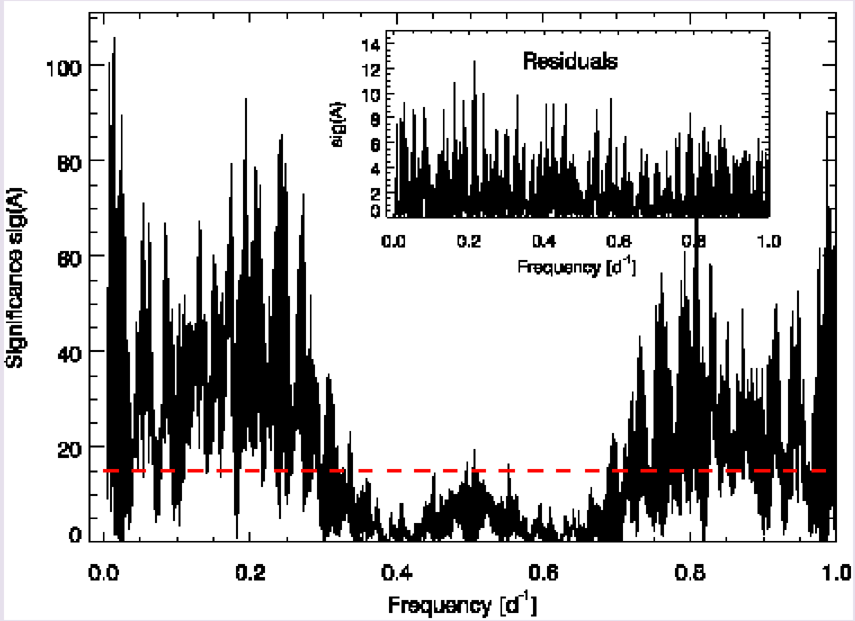


Frequency Analysis

SigSpec and **Period04**

Significance Spectrum

- Using **SigSpec** with the threshold significance of **sig = 15** (or SNR≅4.6) yields **19** frequencies.
- Same results with **Period04.**
- Shortest period and it's amplitude:
  (1.21 days, 0.404 km s^{-1})
- Longest period and it's amplitude:
- (74.74 days, 0.839 km s^{-1})

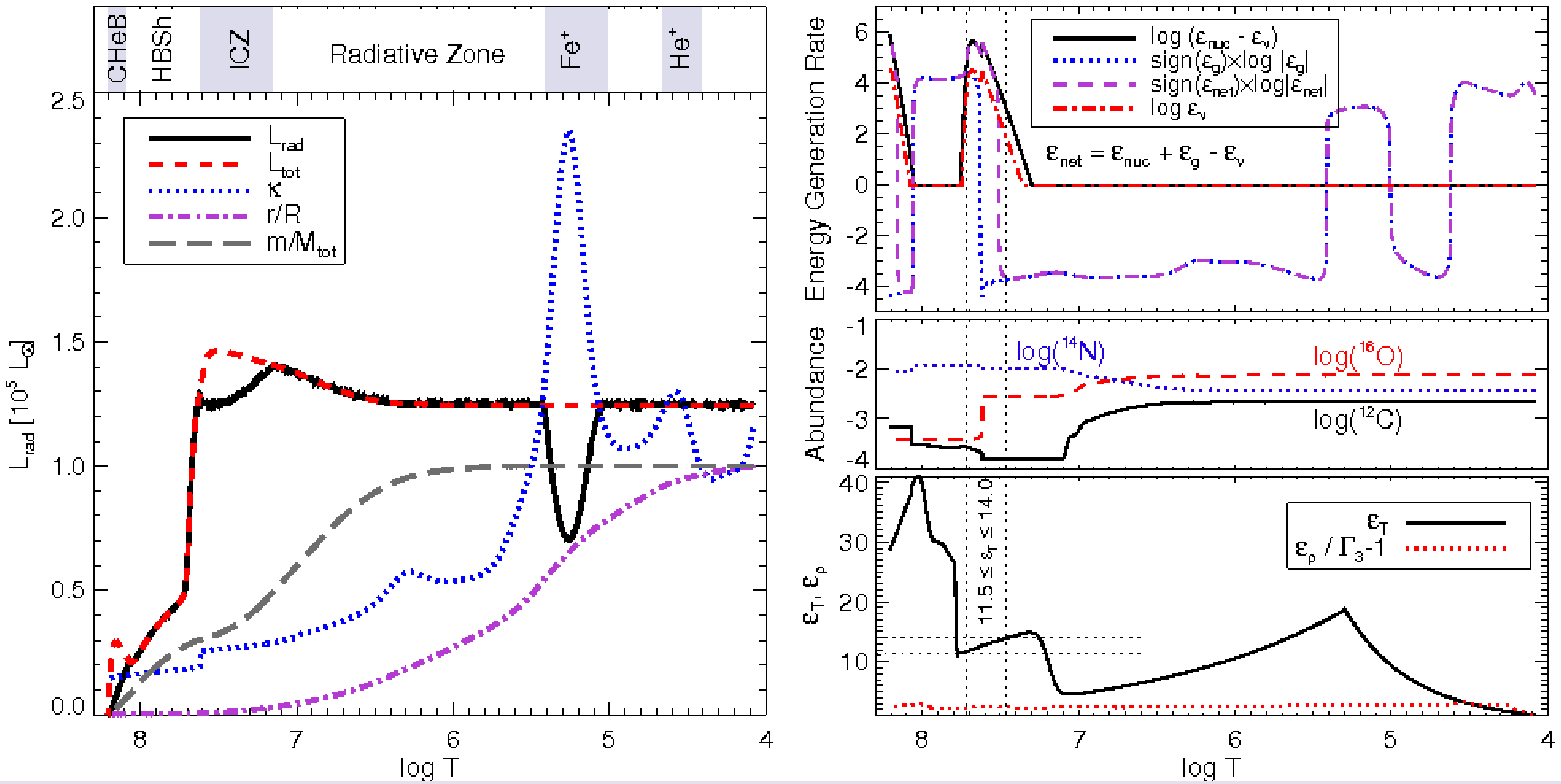


Modeling Internal Structure

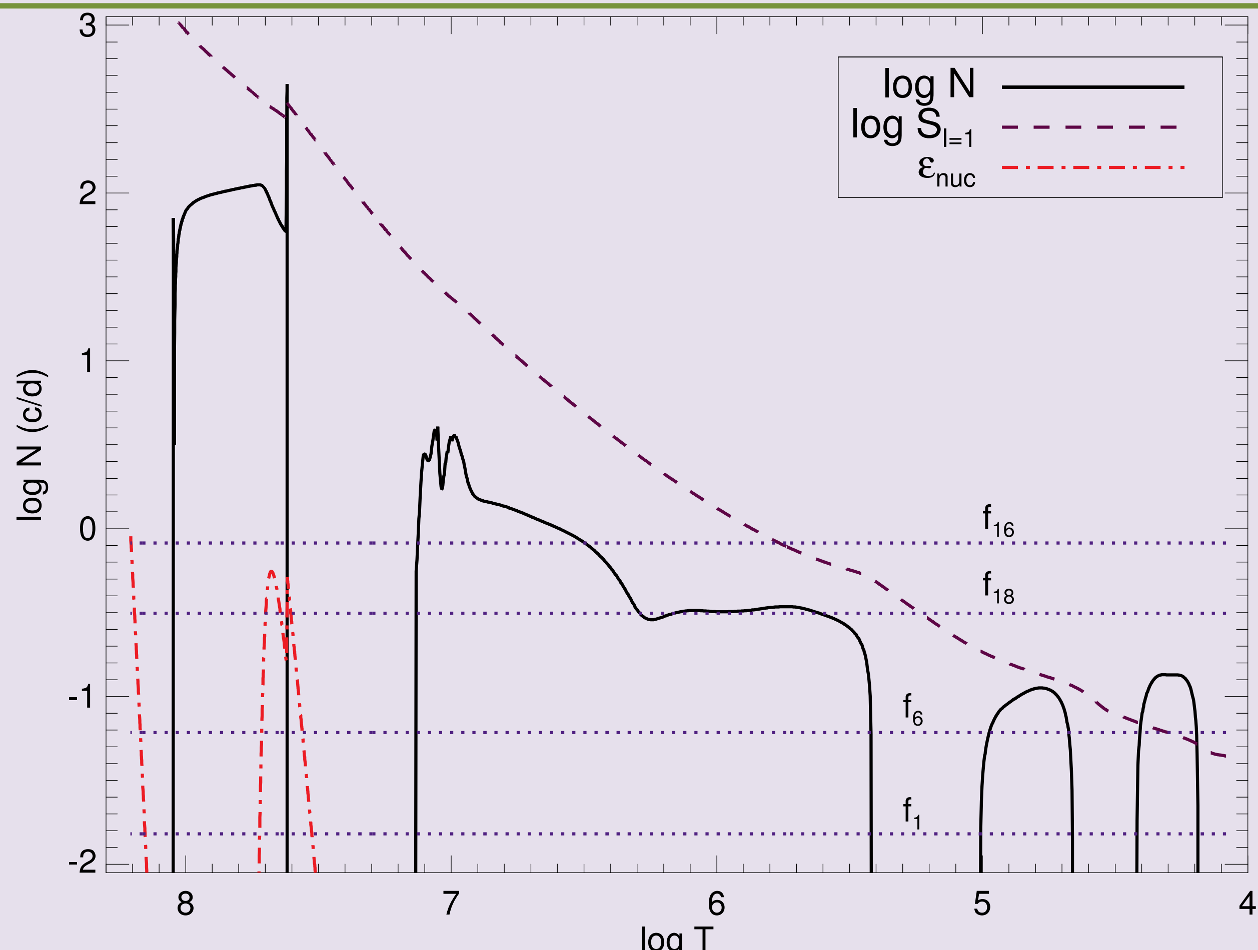
MESA

- Initial Mass: 19 $M_\odot$
- Initial v = 200 km s^{-1}
- Solar metallicity, GN93 Abundances.

- Rotational mixing as in Heger et al. 2005
- No overshooting
- Rotationally enhanced mass loss



Propagation Cavities

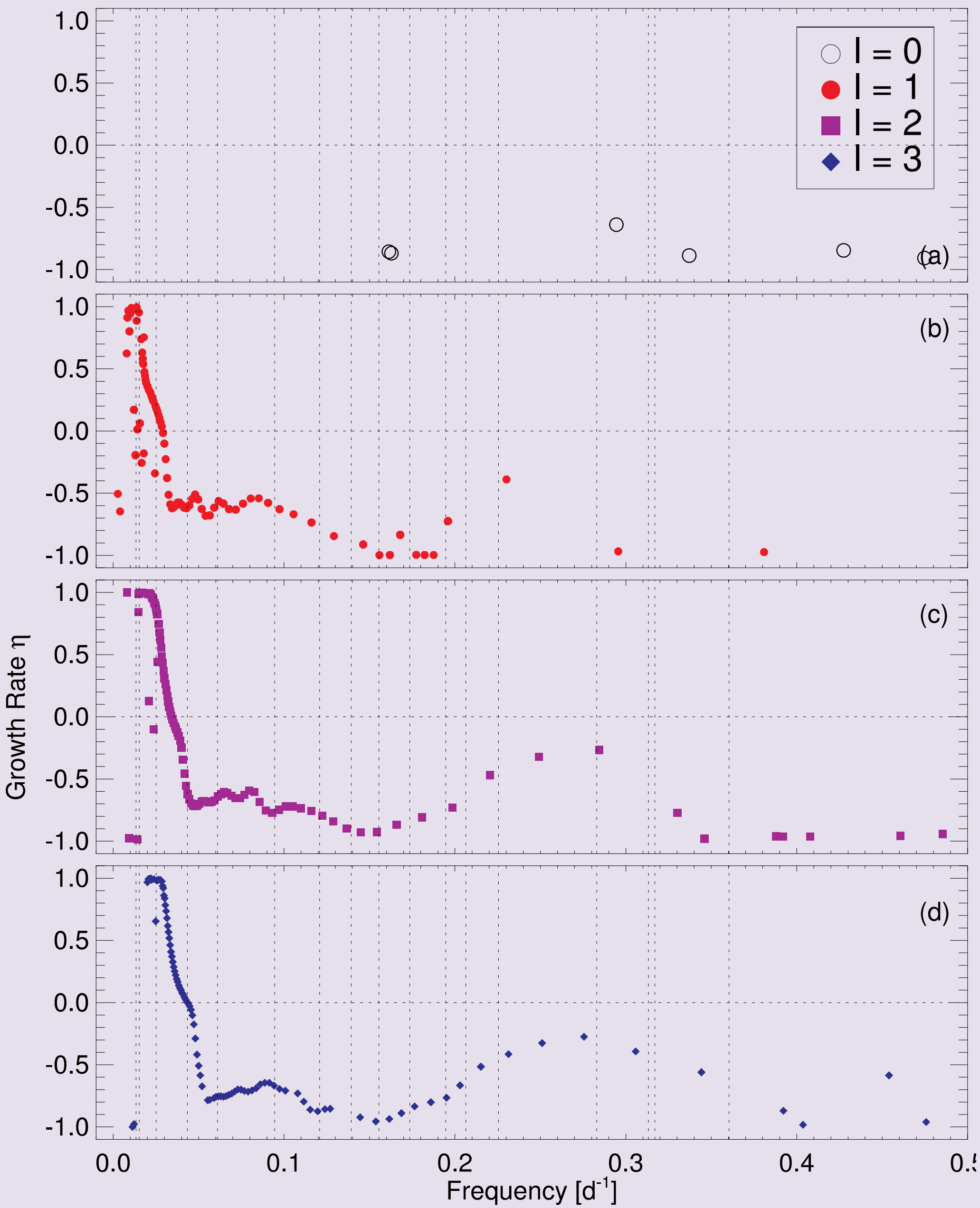


Stability Analysis

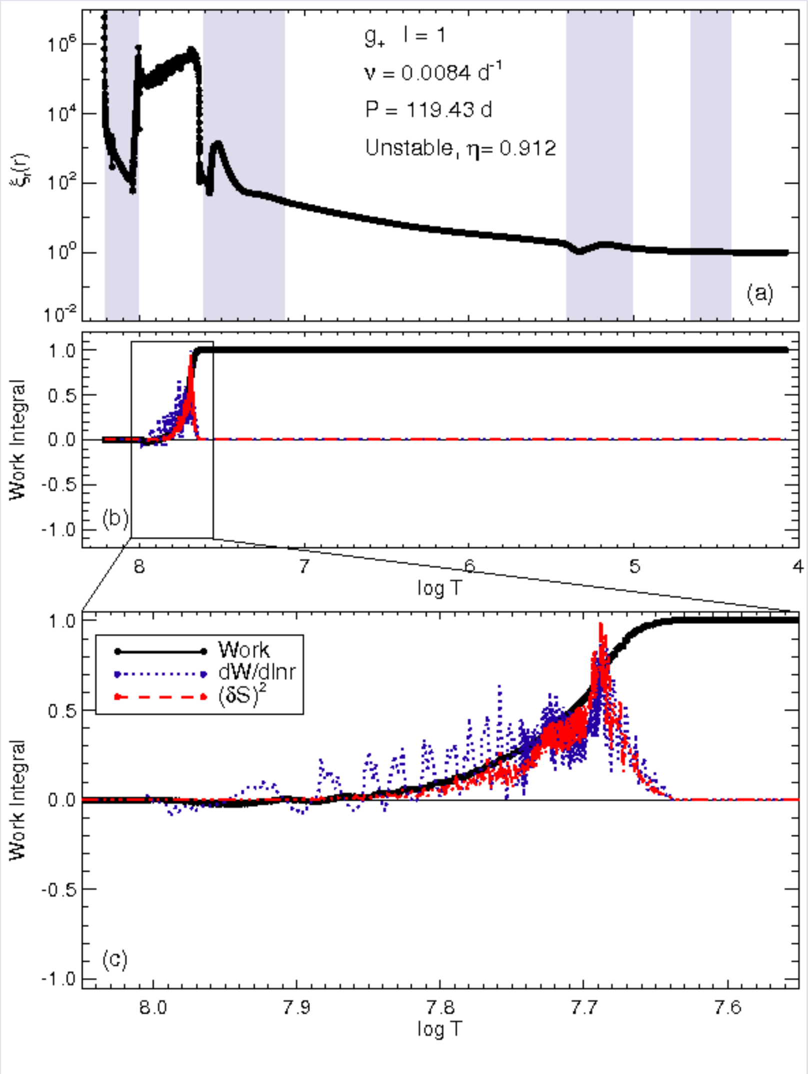
- **Gra**nada Oscillation **Co**de (**GraCo**, Moya et al. 2004),
- **Fully non-adiabatic** analysis,
- No pulsation-atmosphere interaction,
- Frozen convection is assumed.

Results:

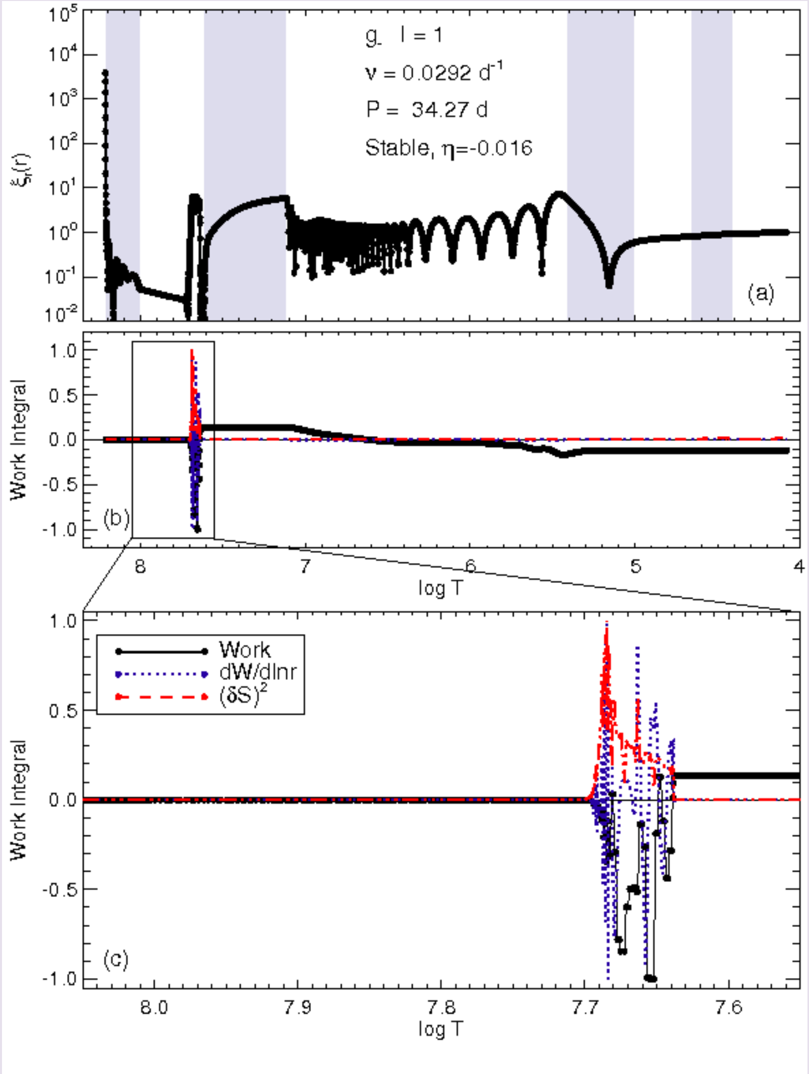
① Radial modes are stable,
② Low-frequency modes are destabilized by **ε-mechanism**,
③ Periods range from 26 to 120 d.
④ High-frequency modes are all stable,
⑤ Tendency towards instability around 0.3 d^{-1}.



Strong driving by ε-mechanism

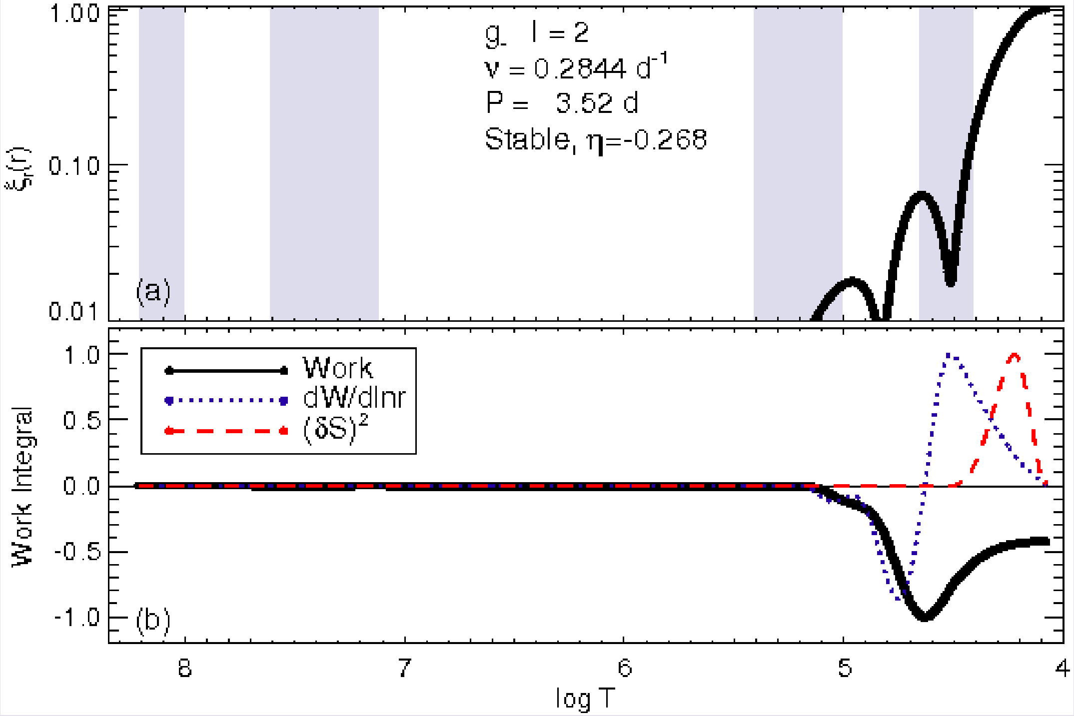


The Effect of Radiative Damping



The Role of κ-mechanism

- The tendency towards overstability raises from He^{+} opacity bump.
- No modes are excited.
- Further investigations are necessary to understand the nature of short-term periodicities.



Summary

- Long period (≈26 to 120 d) pulsations in the α Cyg type BA supergiants can be explained by the ε-mechanism.
- Our model (with rotational mixing) shows that the H-burning shell (HBSh) lies partly in the radiative zone below the intermediate convective zone.
- This helps overcoming the large radiative damping.
- Only g-modes with relatively high amplitudes at the HBSh can survive the huge radiative damping below ICZ.
- Shorter period modes are stabilized by the κ-mechanism operating at the Fe- and He-bumps of opacity.
- Our state-of-the-art model of Rigel predicts stability for this short period modes.

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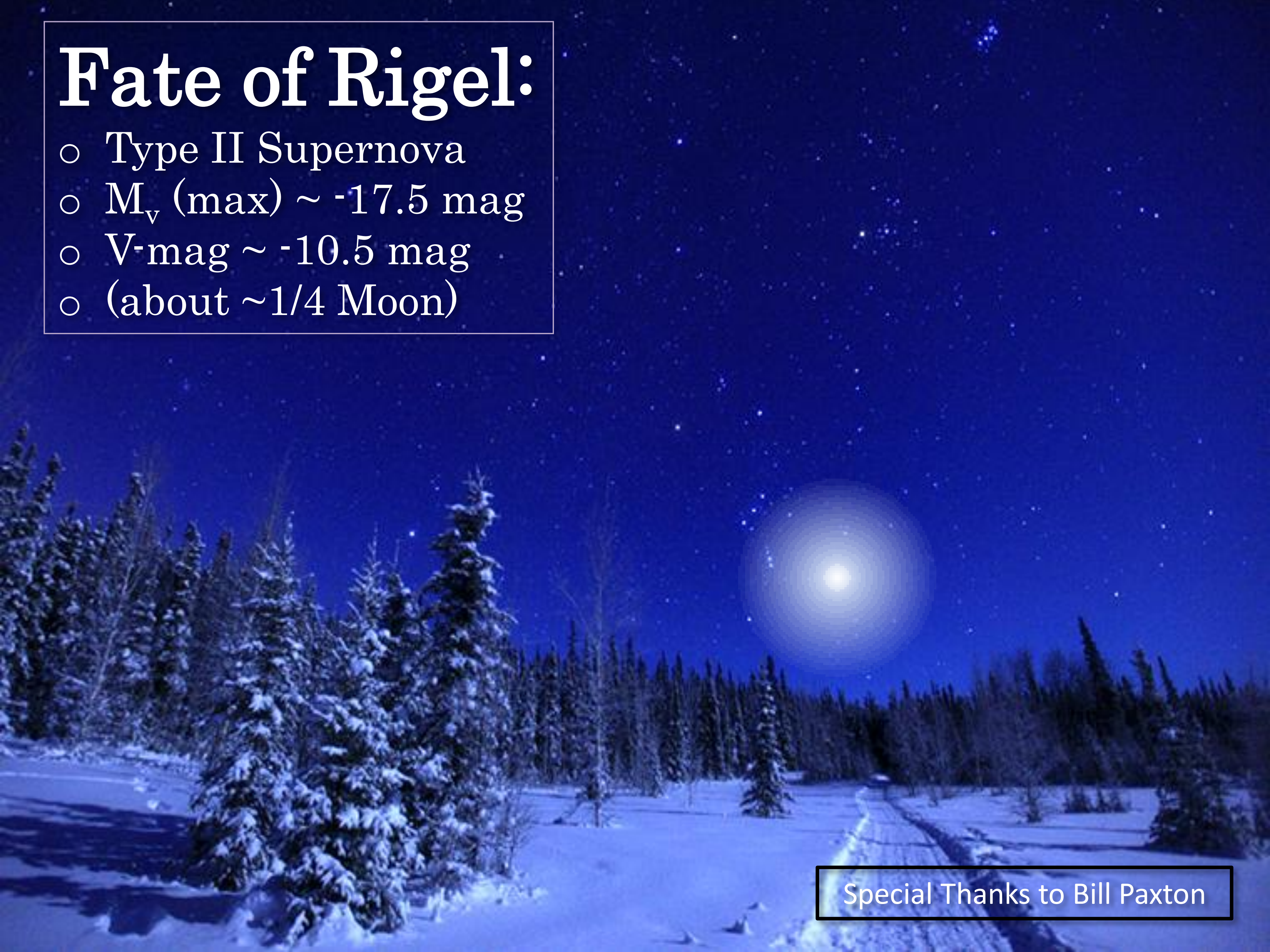
Fate of Rigel:

- Type II Supernova
- M_v (max) ~ -17.5 mag
- V-mag ~ -10.5 mag
- (about ~1/4 Moon)



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