AGB Stars and Stellar Pulsation, Konkoly Observatory, Hungary

What can mass loss observations and models tell us about the properties of mass-losing AGB stars?

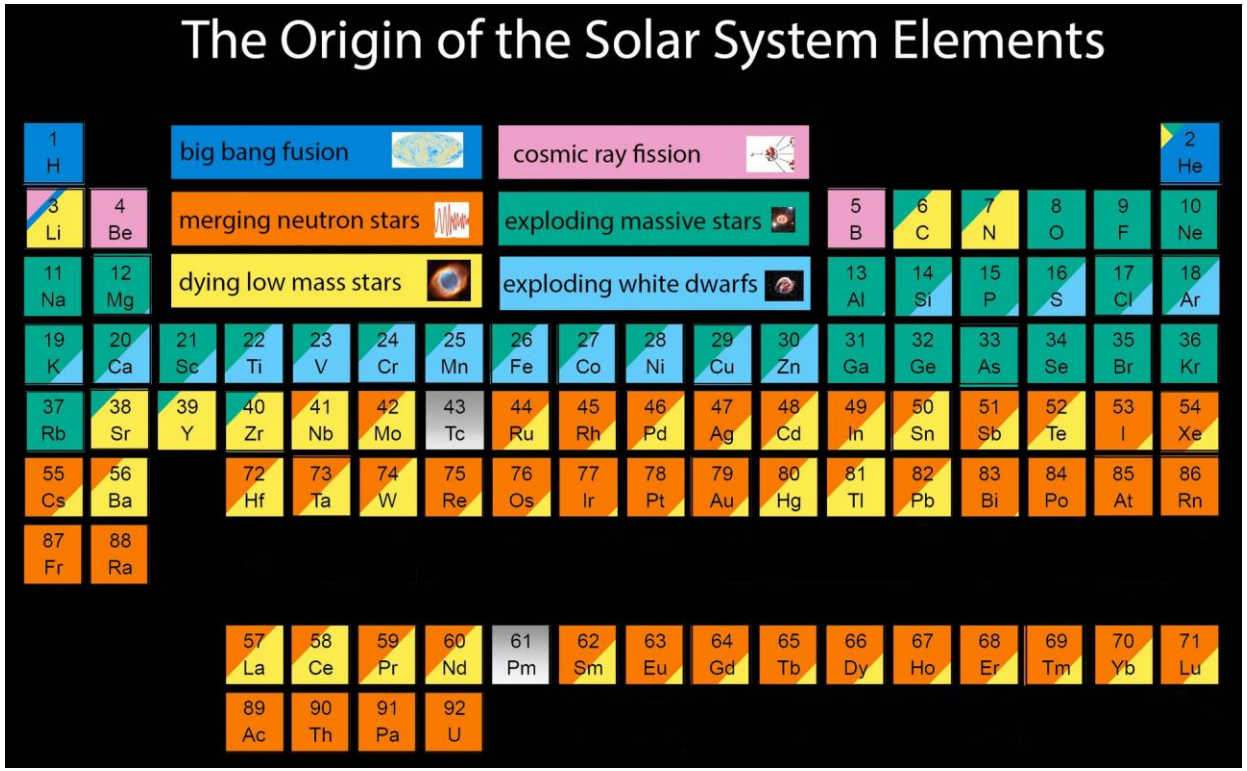
Speaker: Henry A. Prager (University of Iowa)

Collaborators: Lee Anne Willson (Iowa State University), Joyce Guzik (Los Alamos National Laboratory), Michelle Creech-Eakman (New Mexico Tech)

Oct 5, 2026

Why do we care about mass loss?

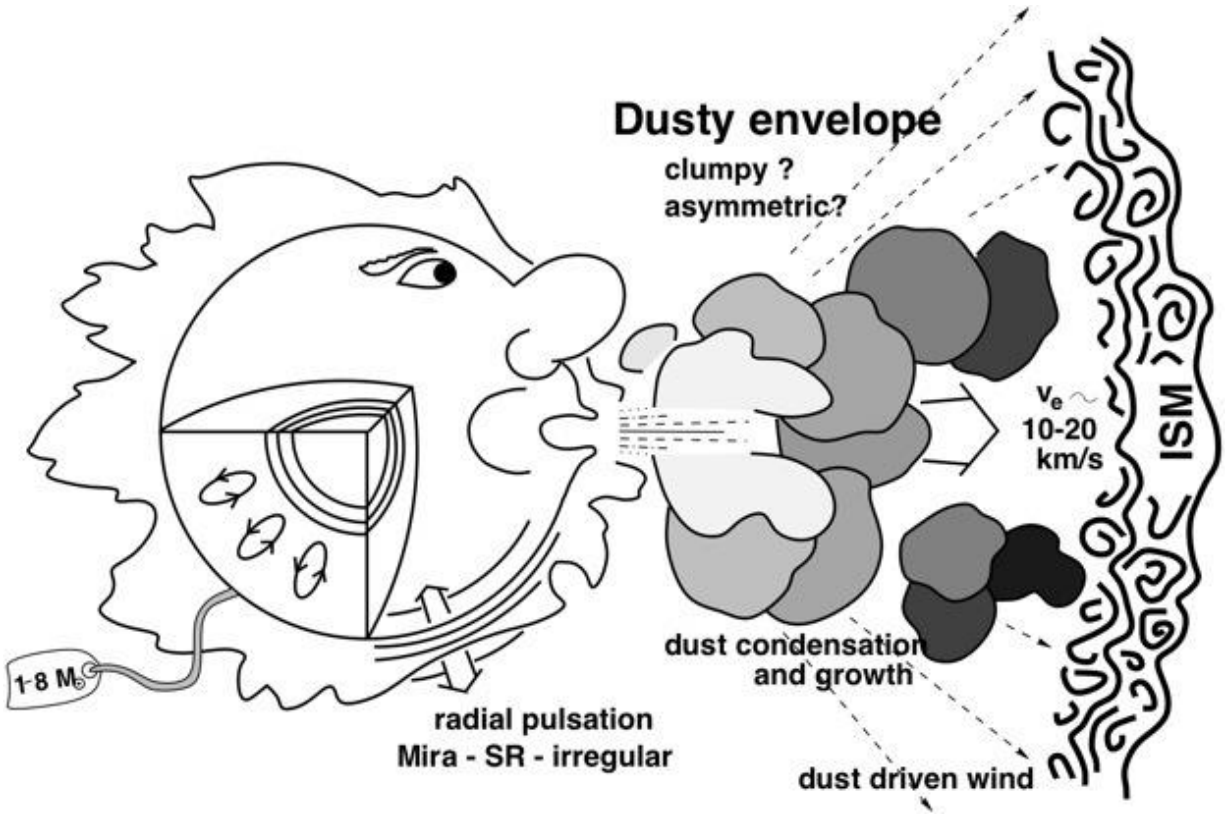
- AGB stars produce a whole bunch of stuff!
  - Carbon and Nitrogen primarily come from AGB stars
  - A lot of heavier elements are also produced there thanks to the s-process



Credit: Jenniffer Johnson, The Ohio State Univ.

Why do we care about mass loss?

- Our Sun will become one of these stars, so mass loss will impact the fate of our Sun
- A lot of astronomers care about white dwarfs! AGB stars can inform us about white dwarfs (and vice-versa as we will see!)



Credit: Massimo Marengo, Florida State Univ.

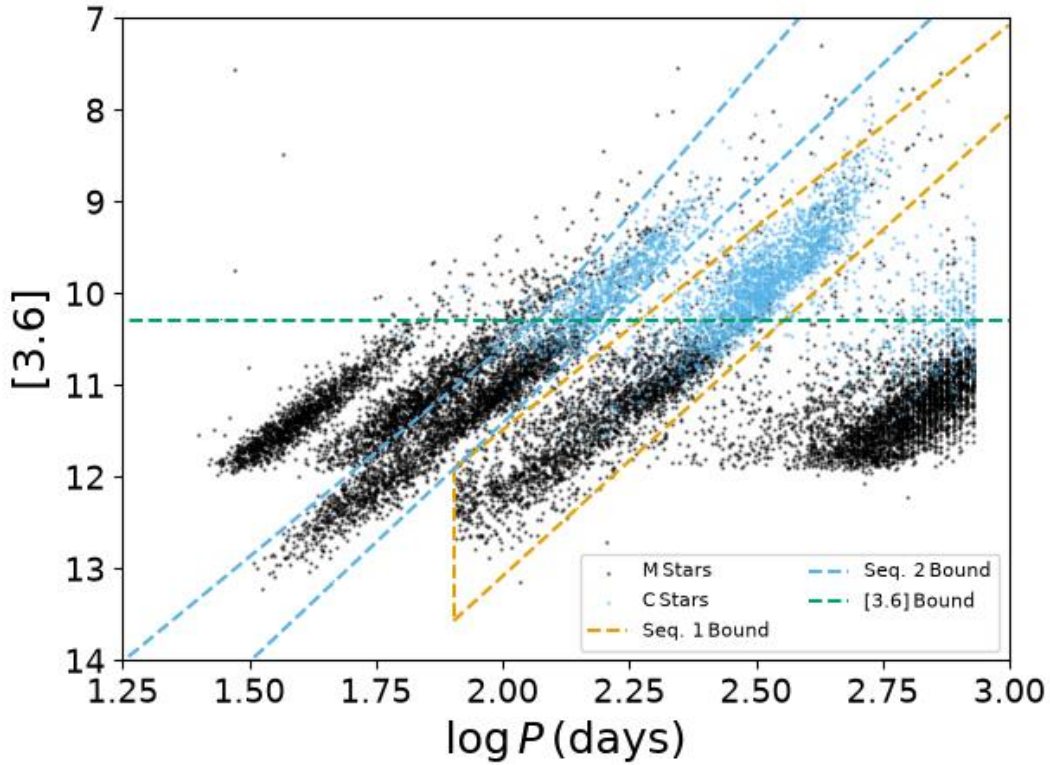
Mass losing stars in the LMC (Prager et al. 2022)

Part 1 https://ui.adsabs.harvard.edu/#abs/2022ApJ...941...44P

Which stars are AGB stars?

AGB Stars in the LMC

- Right: M, C stars as found in the Large Magellanic Cloud (Riebel et al. 2010, 2012)
- Seq.1 is fundamental mode, Seq. 2 is first-overtone mode



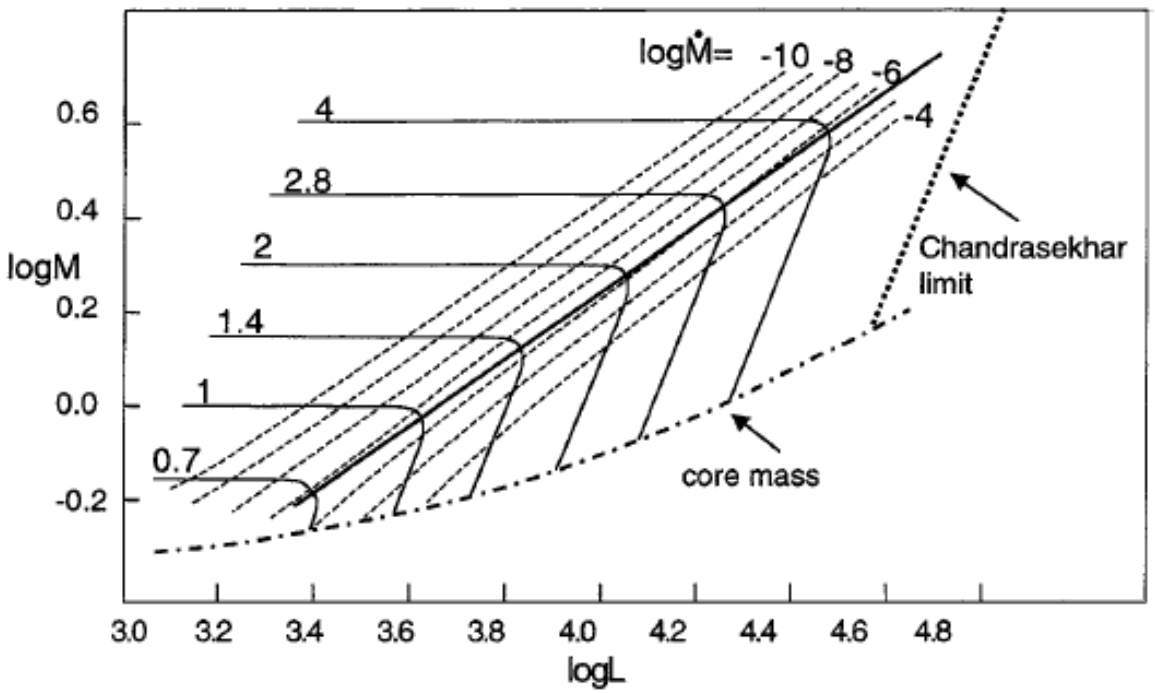
Which stars are AGB stars?

Results from Early Atmospheric Models

- Right: Evolution in mass and luminosity for solar-like stars (Willson 2000)
- We have a subtle bias: we classify stars as being at the AGB tip when they are near the cliff, or “death line” (solid black), where

$$\frac{1}{t_{ev}} = \frac{1}{M}\frac{dM}{dt} = \frac{1}{L}\frac{dL}{dt}$$

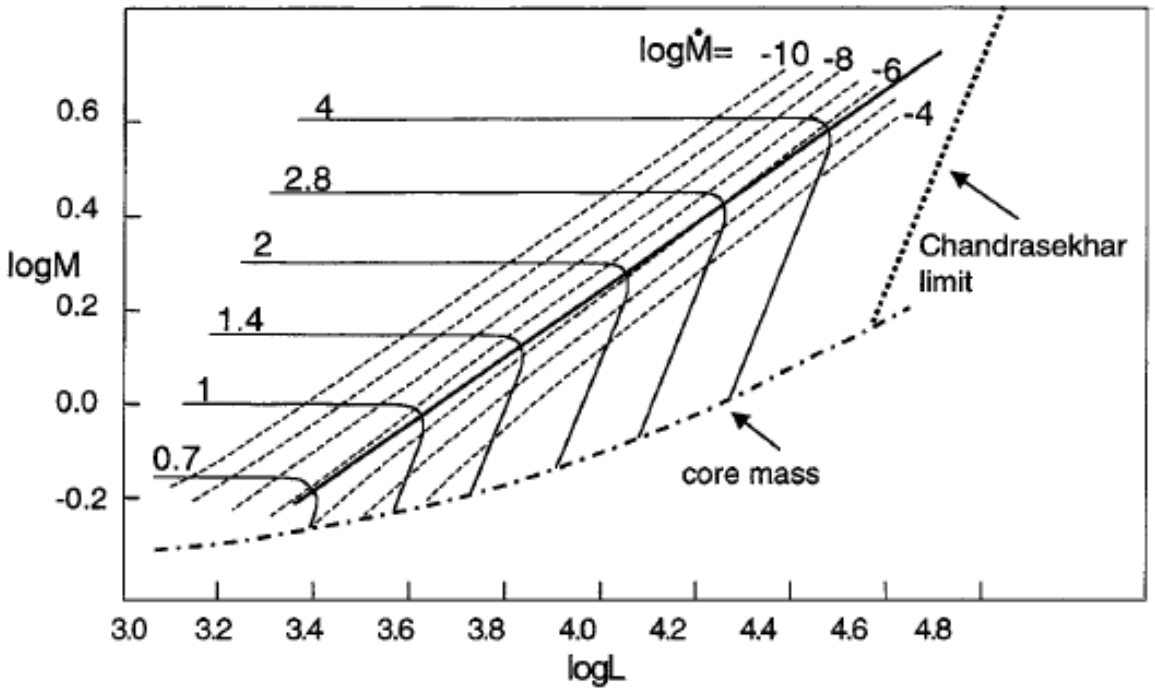
- Qualitatively, the death line is where evolution changes from predominantly in L to predominantly in M.



Which stars are AGB stars?

Results from Early Atmospheric Models

This bias poses a problem: *“empirical relations give us the properties of stars that are near a critical stage of losing mass, rather than telling us how to incorporate mass loss into evolutionary calculations.”* – Willson (2000)



How fast are AGB stars losing mass?

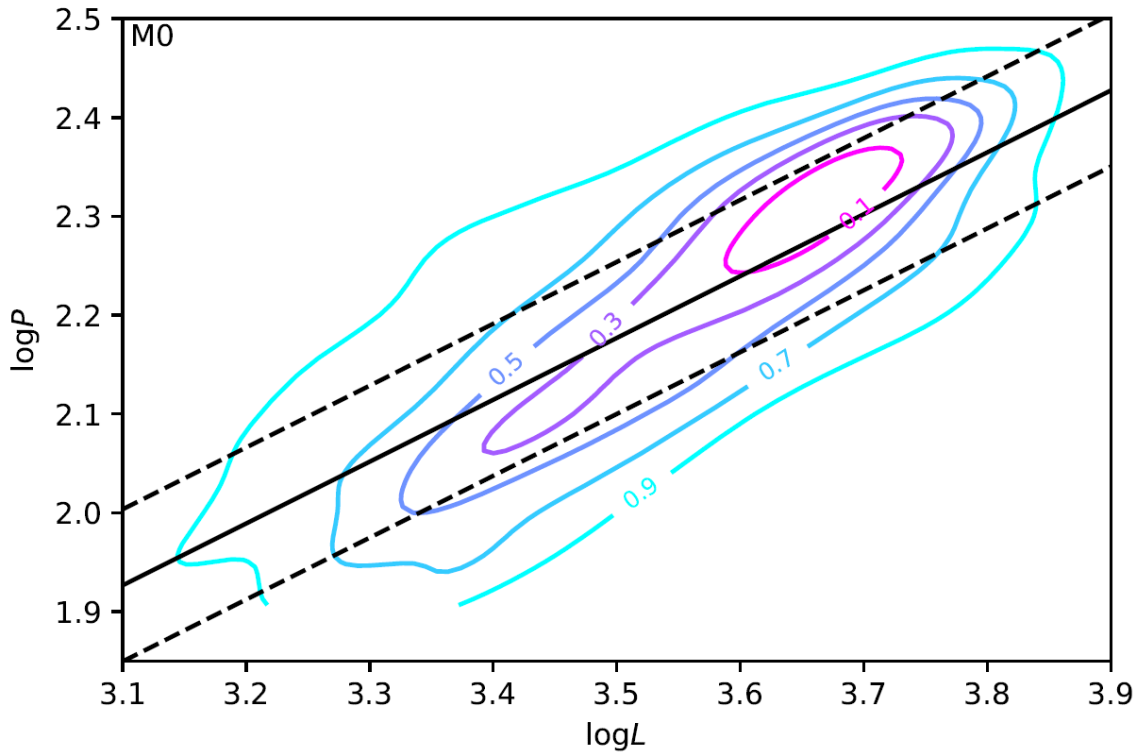
- Suppose a power law: $\log \dot{M} = \log A + B \log L + C \log M$
- A bit of quick math and we know $\frac{\partial \log \dot{M}}{\partial \log L} = B, \frac{\partial \log \dot{M}}{\partial \log M} = C$
- So, we can say $\frac{\Delta \log \dot{M}}{\Delta \log L} \approx B, \frac{\Delta \log \dot{M}}{\Delta \log M} \approx C$
- This approximation gets better as our exponents get larger.
- Evolutionary tracks and period-mass-radius relations let us do linear transformations between the above power law and $\log \dot{M} = \log \alpha + \beta \log L + \gamma \log P$

How fast are AGB stars losing mass?

Results from Early Atmospheric Models

- Right: approximation of the death line (solid black line) and death zone (dashed lines) of oxygen-rich, fundamental mode AGB stars in the LMC.
- We can measure $\Delta \log P$ and $\Delta \log L$, and thus find a formula:

$$\log \dot{M} = -35.2 + 8.24 \log L - 13.7 \log M$$

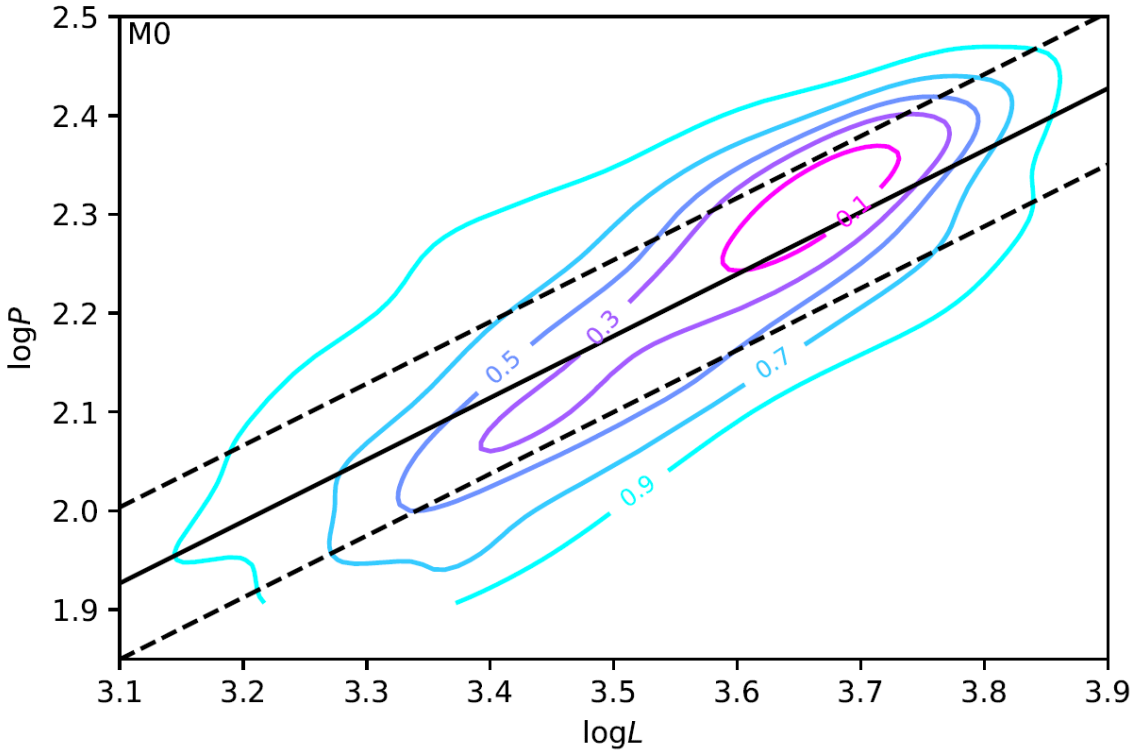


How fast are AGB stars losing mass?

Results from Early Atmospheric Models

$$\log \dot{M} = -35.2 + 8.24 \log L - 13.7 \log M$$

- This is a lower limit! Spread in the data tends to widen the strip
- We can do this for all 4 classifications presented so far, see Prager et al. 2022 for more details



Models of AGB Atmospheres: A Parameter Study (Prager et al. 2024)

Part 2 https://ui.adsabs.harvard.edu/#abs/2024Galax..12...81P

A Primer on Atmospheric Models

George Bowen's Atmospheric Pulsation Code - https://ui.adsabs.harvard.edu/abs/1988ApJ...329..299B/

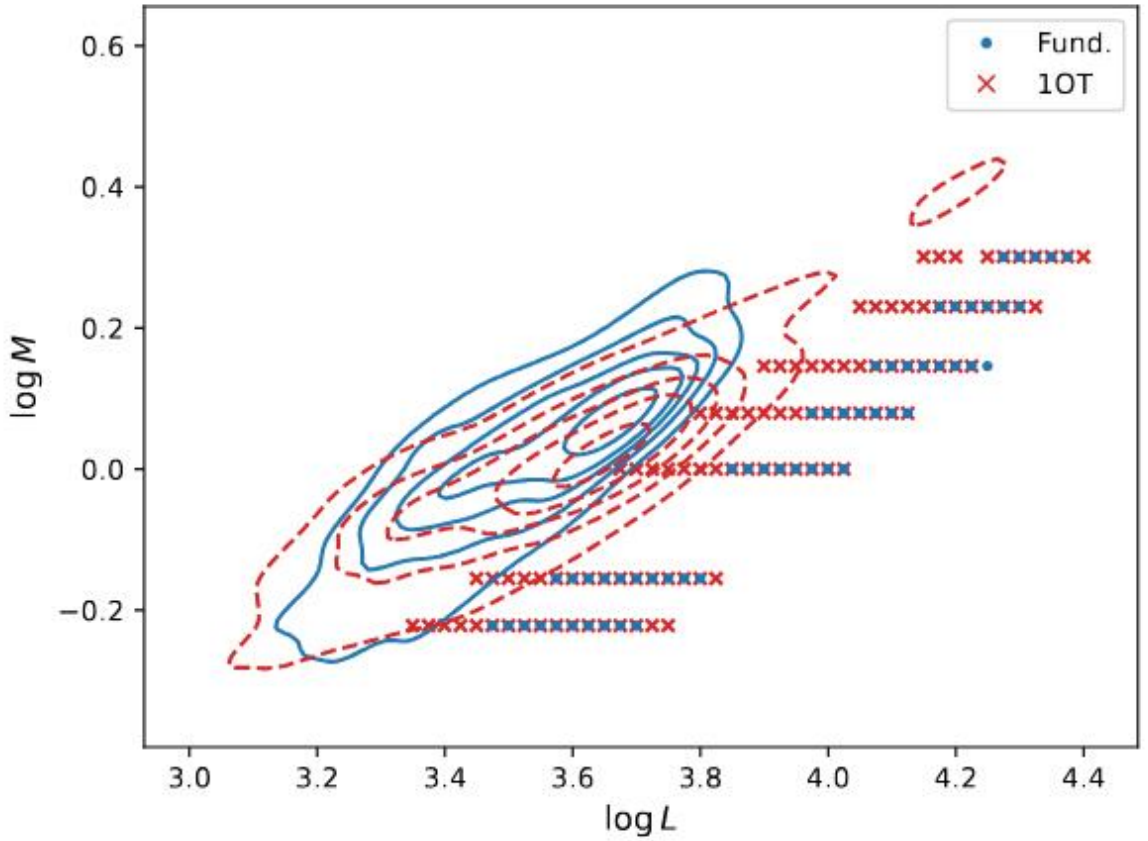
- Right: "Typical" input parameters, give or take
- Models establish a static atmosphere, it starts being driven at a prescribed frequency, dust is simulated as opacity changes in the atmosphere
- Very useful for checking a wide parameter space!

Input	Assumed Value
Piston Amplitude	**2 km/s**
Gas Opacity	2x10^-4 cm^2/g
Gas critical density	10^-12 g/cm^3
Pseudo viscosity pressure	4 dyn/cm^2
Electron-to-Hydrogen ratio	0.1%
Max. Dust Opacity	**2 cm^2/g**
Dust Condensation Temp.	**1450 K**
Dust Cond. Temp. Range	100 K
Molecular Opacity	0.4 cm^2/g
Molecular Cond. Temp.	2000 K
Molec. Dissoc. Energy	43 keV
Molec. Crit. Density	10^-7 g/cm^3

Results

What did we find?

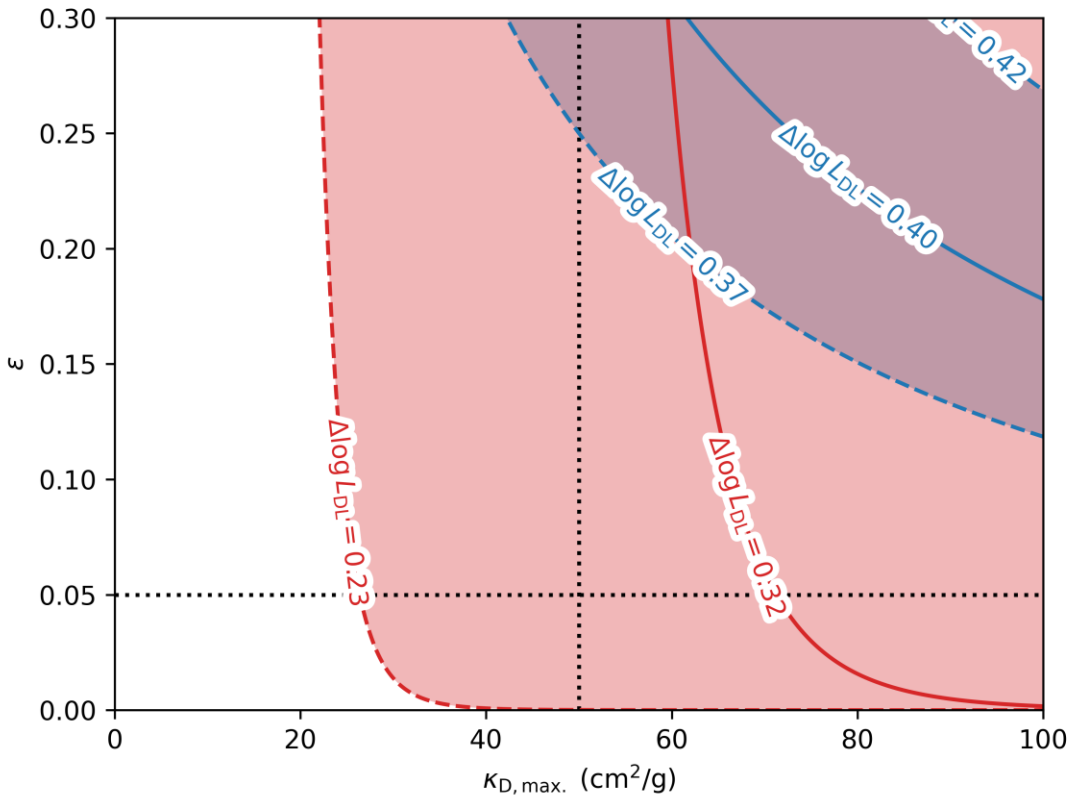
- Right: Comparison of observed stars in LMC (contours) to models with observed mass-loss rates (dots, crosses)
- If we only track models with mass-loss rates in the observed range, the death line is in the wrong place!



Results

What did we find?

- We determined the piston amplitude and dust opacity were the most important and flexible parameters for changing the mass-loss rate
- Right: Parameters needed to match (solid lines) or be within expected observational error (dashed lines)

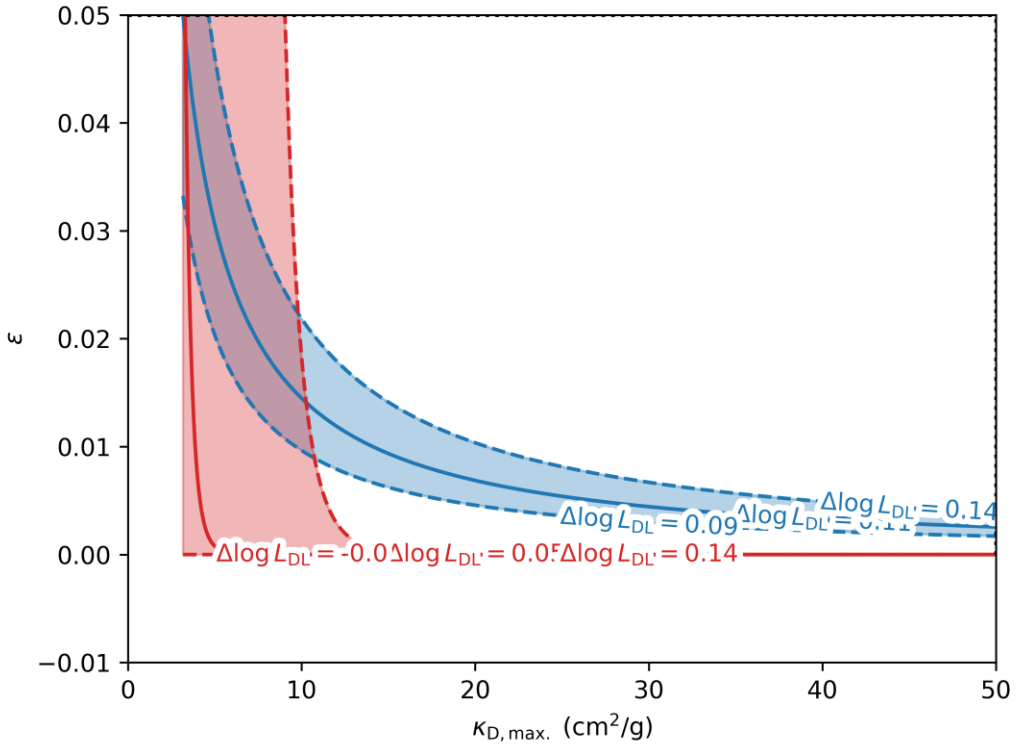


Results

What did we find?

- This is a big problem! I don't think AGB stars put 25% of their luminosity into pulsation or have dust with opacities of 80 cm^2/g!
- Either our understanding of mass loss is flawed, or one of our input assumptions must be flawed.

There is a way to get here…



A Consistent Determination of the Death Line (Prager et al. 2026)

Part 3 Submitted

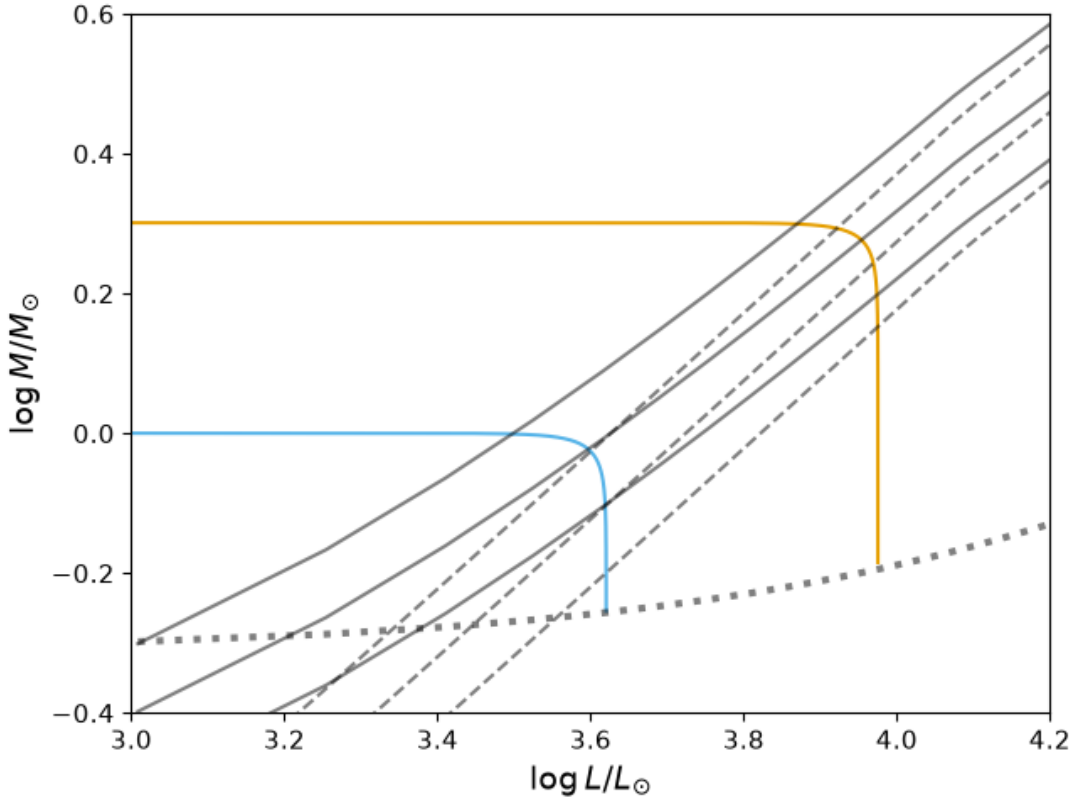
Wait… is it the models or the observations?

An Independent Determination of the Death Line

- Cunningham et al. (2024) used galactic white dwarfs to determine an initial-final mass relation

$$M_f = \begin{cases} 0.086M_i + 0.469 & \text{if } 0.5 < M_i/M_{sun} < 2.5 \\ 0.10M_i + 0.434 & \text{if } 2.5 < M_i/M_{sun} < 3.4 \\ 0.06M_i + 0.57 & \text{if } 3.4 < M_i/M_{sun} < 5.0 \end{cases}$$

- If we assume the final mass is the core mass of an AGB star, the initial mass is some percentage of initial AGB mass, and assume the final luminosity is approximately the death line luminosity, and combine with a core mass-luminosity relation… we get the figure on the right.



Wait… is it the models or the observations?

Radius-Mass-Luminosity Relations

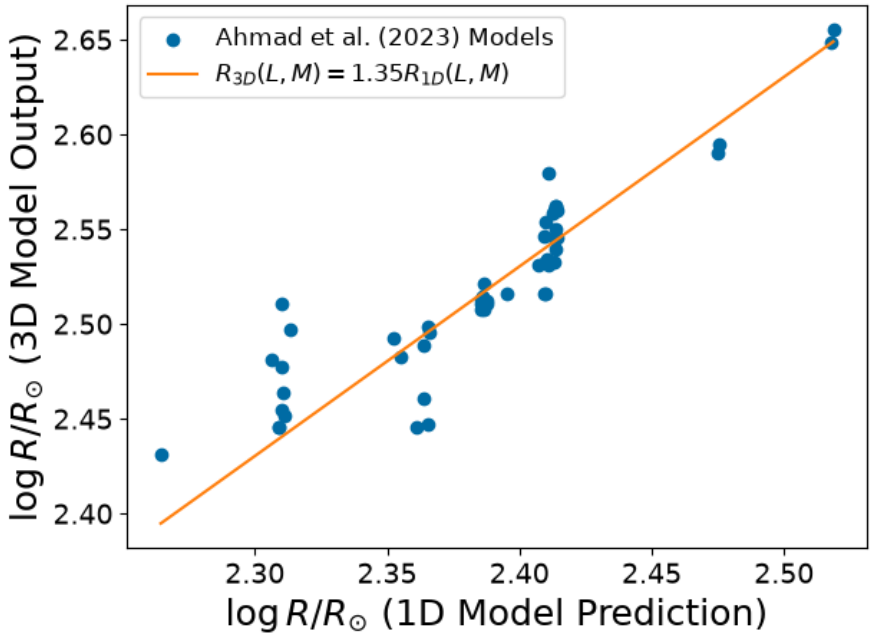
- 3D Models by Ahmad et al. (2023) generated using CO5BOLD suggest these stars are significantly larger when dynamics are taken into account

Period-Mass-Radius Relations

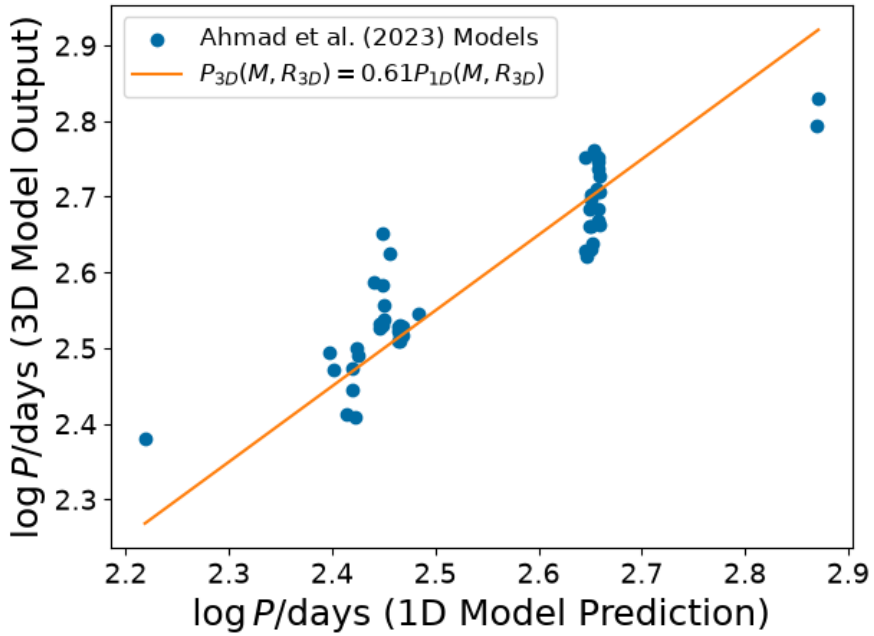
- 3D Models by Ahmad et al. (2023) generated using CO5BOLD suggest these stars have similar periods as 1D models

Wait… is it the models or the observations?

Radius-Mass-Luminosity Relations

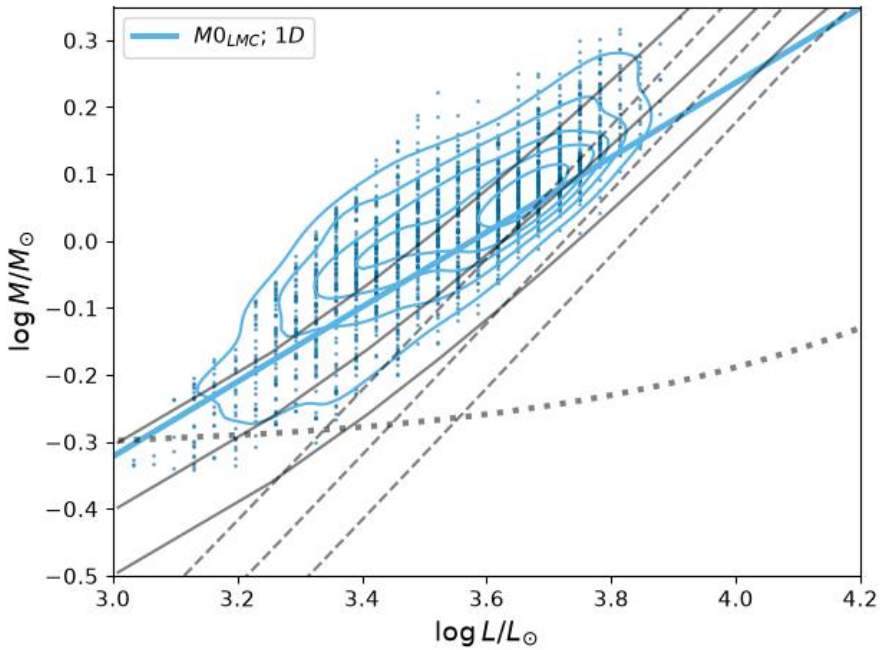


Period-Mass-Radius Relations

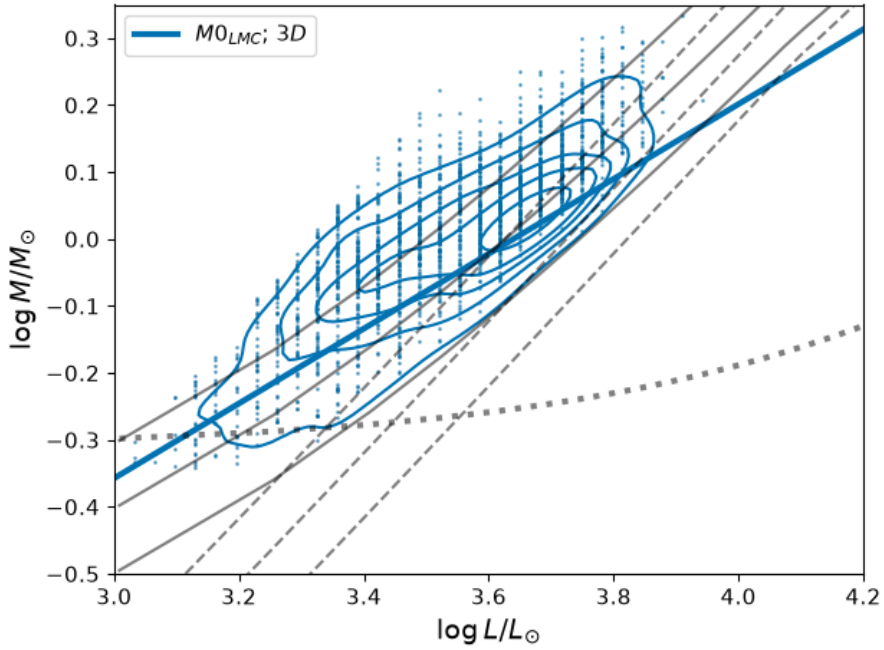


Death Lines from Observation

R1D, P1D

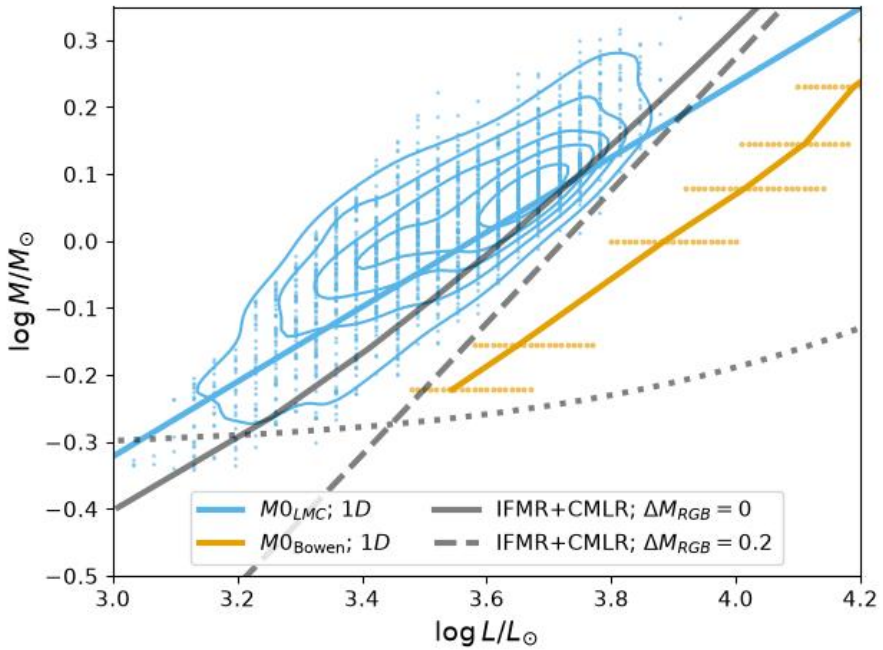


R3D, P3D

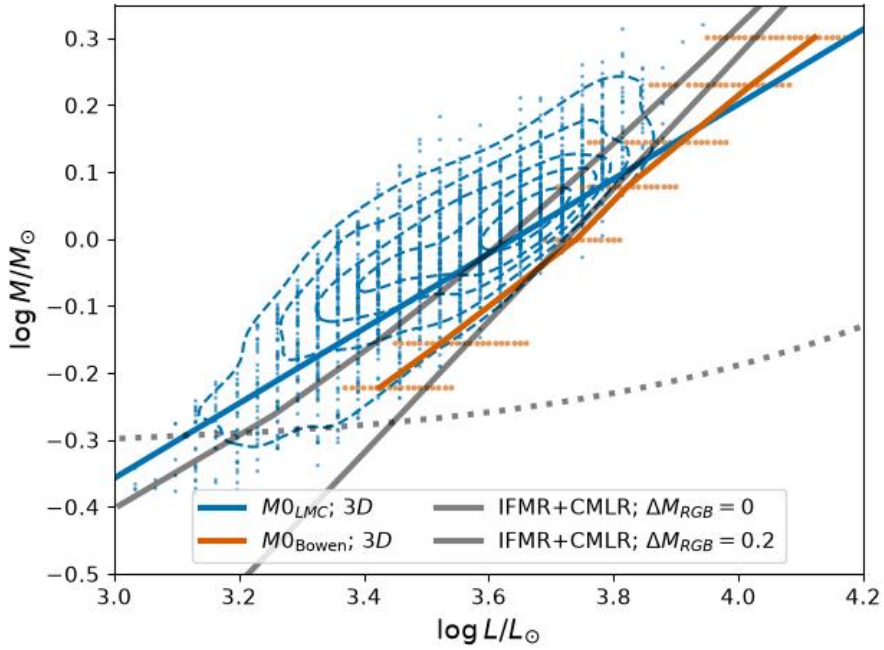


… Now add the models

R1D, P1D



R3D, P3D



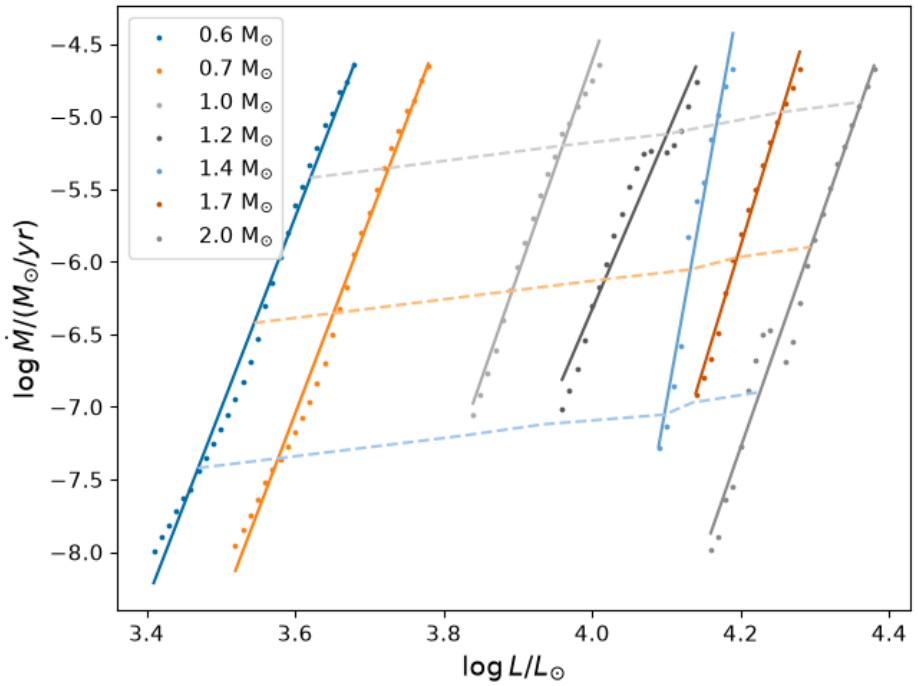
Mass-Loss Rates

- We see large exponents no matter which RML and PMR we use
- We do still need observations to determine the mass exponent *C*

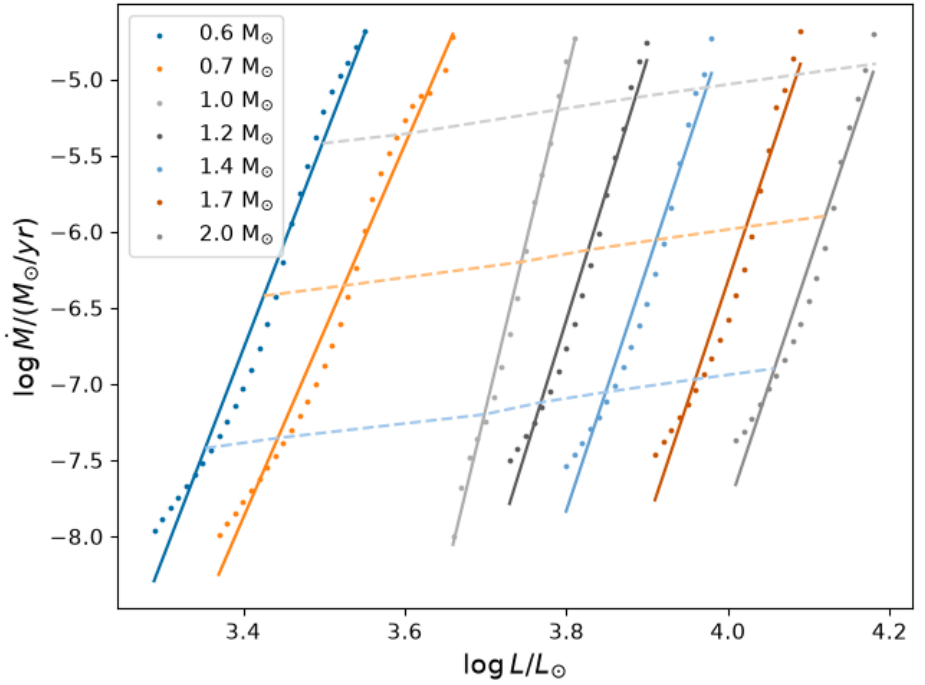
$R_{1D}(M,L)$ and $P_{1D}(M,R_{1D})$		$R_{3D}(M,L)$ and $P_{3D}(M,R_{3D})$	
$\log A$	B	$\log A$	B
-53.3403	13.2351	-48.880	12.408
-55.4485	13.4445	-48.030	11.828
-63.396	14.694	-88.379	21.949
-54.205	11.969	-71.624	17.117
-123.645	28.456	-68.534	15.975
-76.502	16.812	-69.892	15.892
-79.820	15.920	-71.492	15.920

Mass-Loss Rates

R1D, P1D

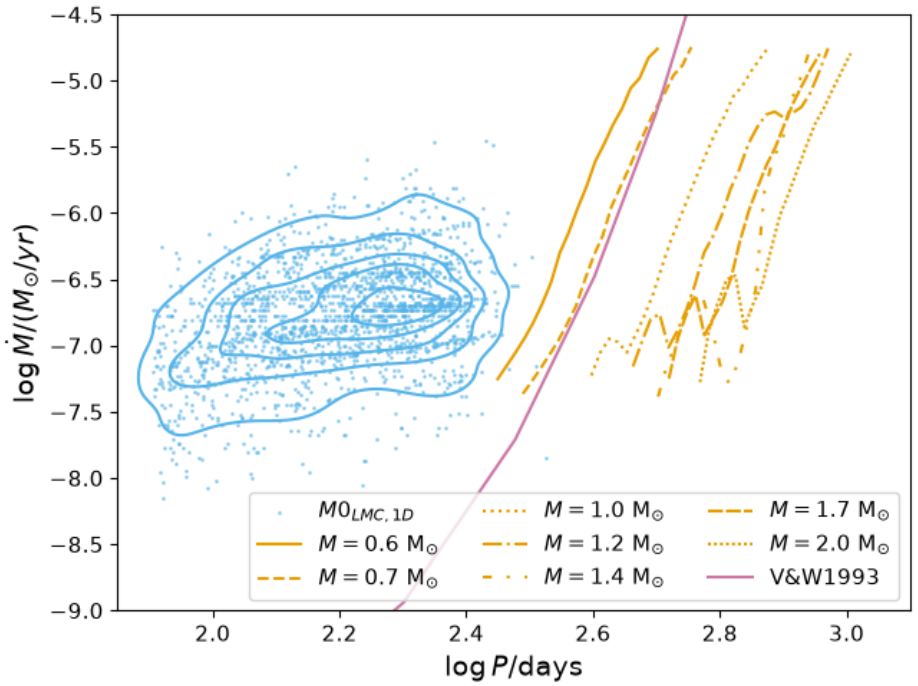


R3D, P3D

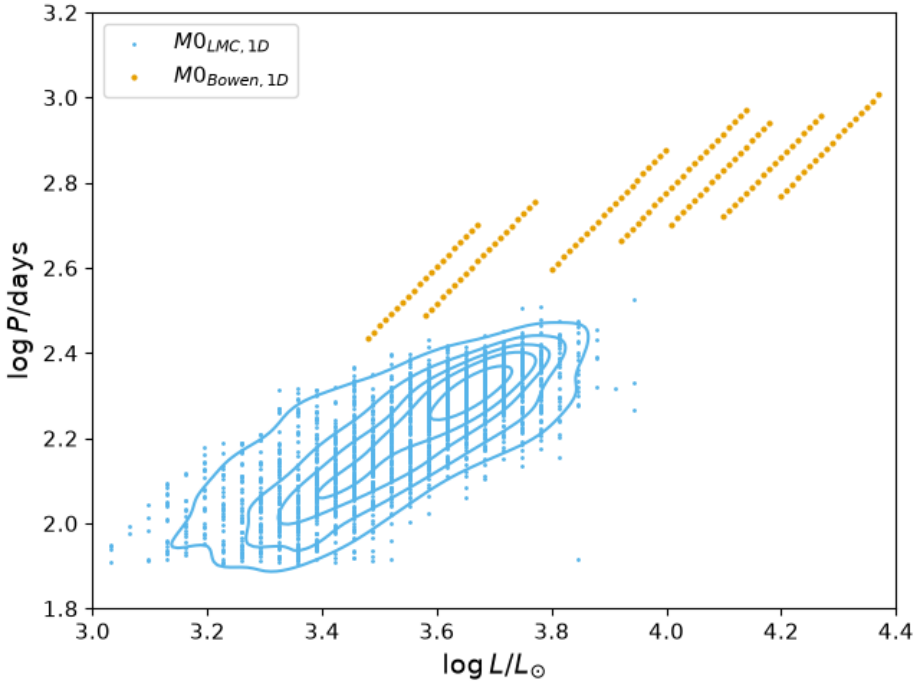


Are We Done?

Do mass-loss rates and periods match?

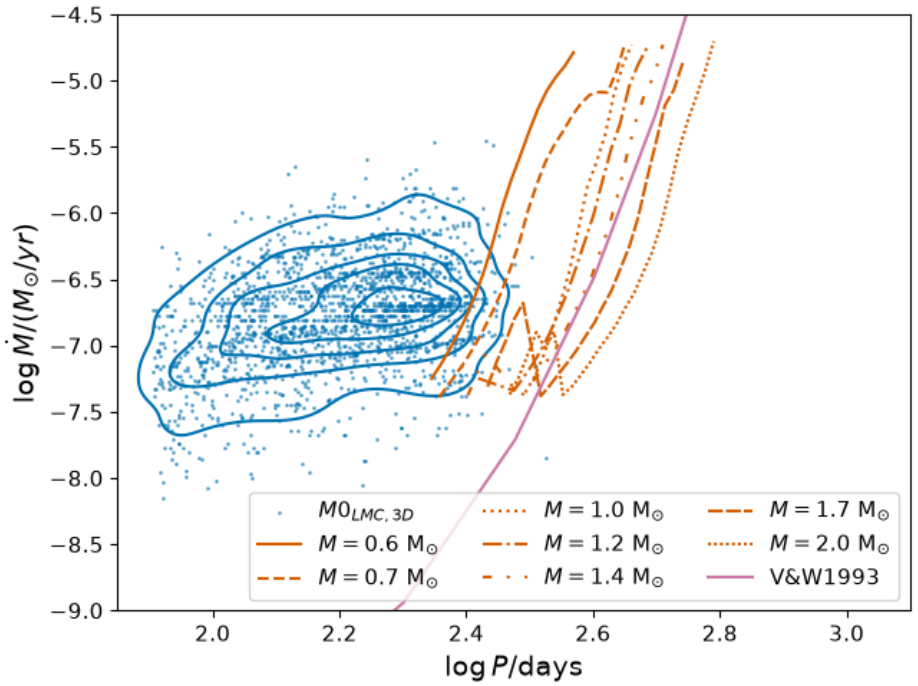


Are pulsating stars as bright as we expect?

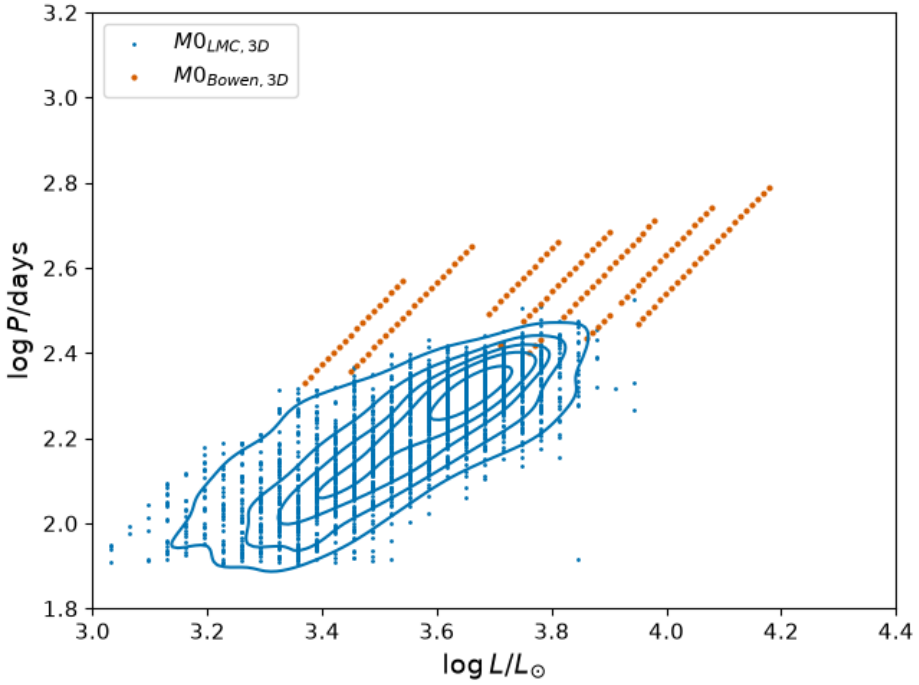


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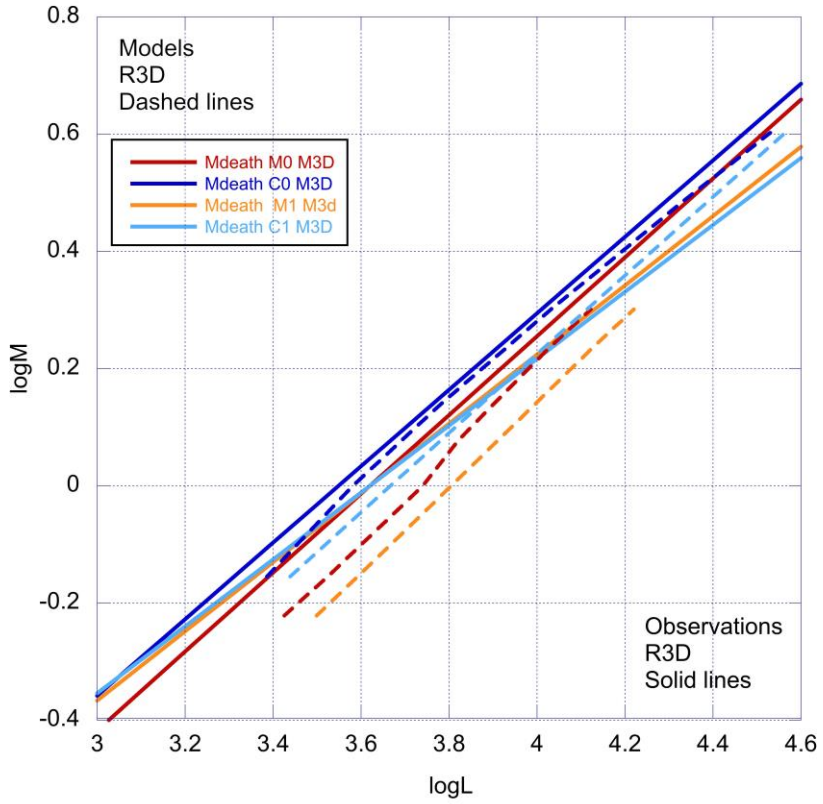


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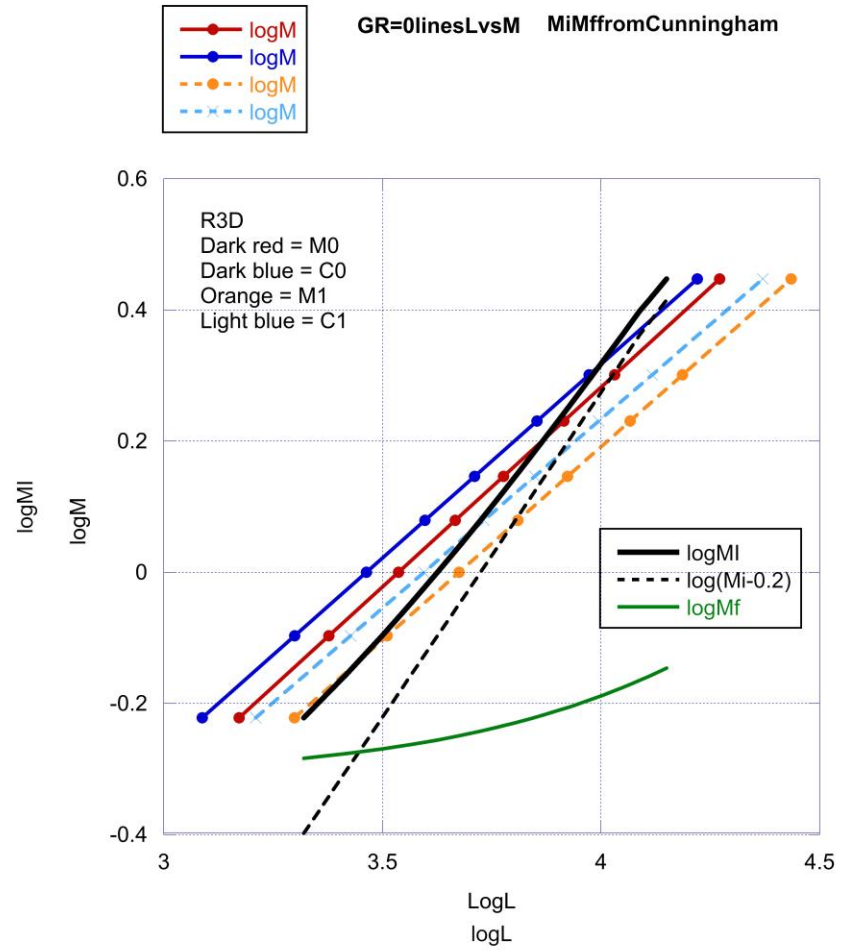
In Progress: Does this apply to more than just Miras? – (Coll.: L. A. Willson, J. Guzik, M. Creech-Eakman)

- Short Answer: Most likely yes
- Long Answer:
  - Limitation is we don't have 3D models into C star parameter space
  - Similar adjustments to R (M, L) relations as the M0 stars for the M1, C0, and C1 stars produce death lines in agreement with observations… and they all seem to have similar death lines



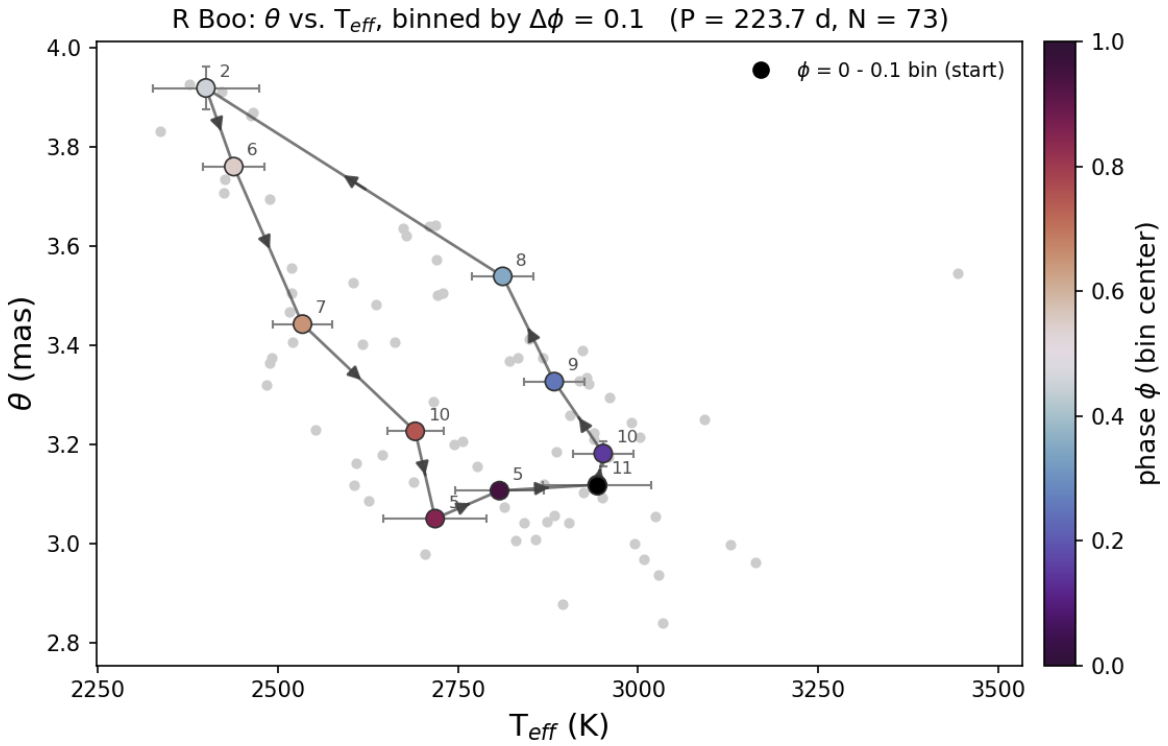
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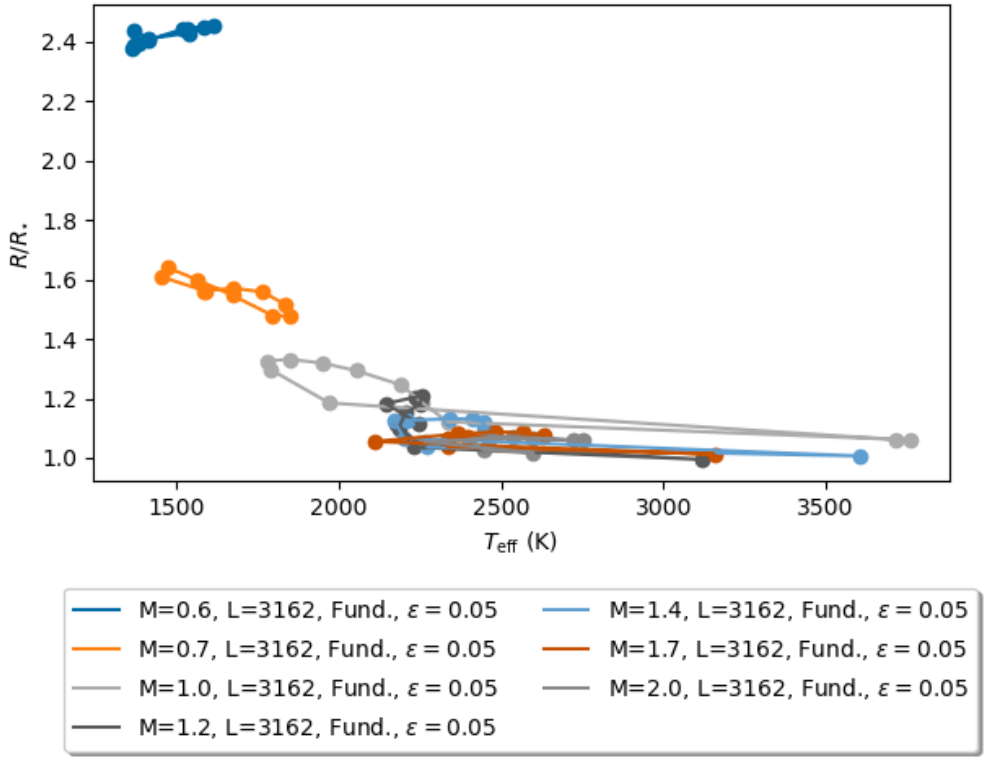


In Progress: What about individual stars? (Coll.: D. Baylis-Aguirre, G. van Belle, M. Creech-Eakman)

Observations

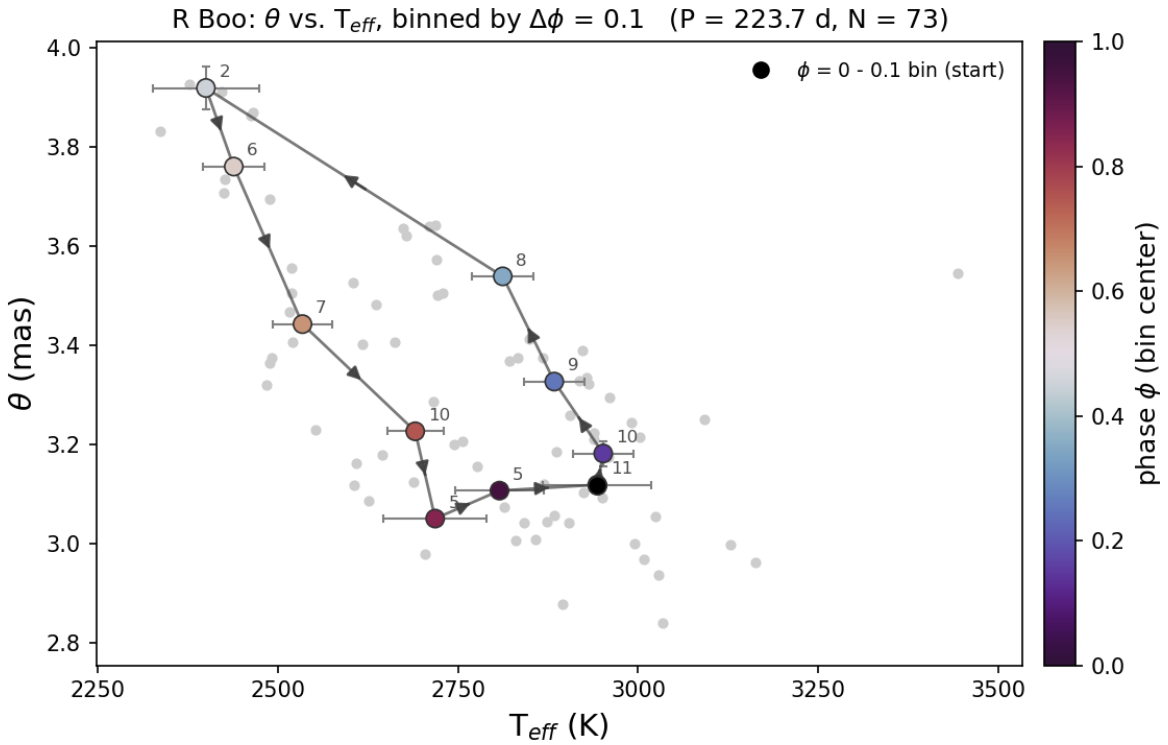


Atmospheric Models (F. Mode)

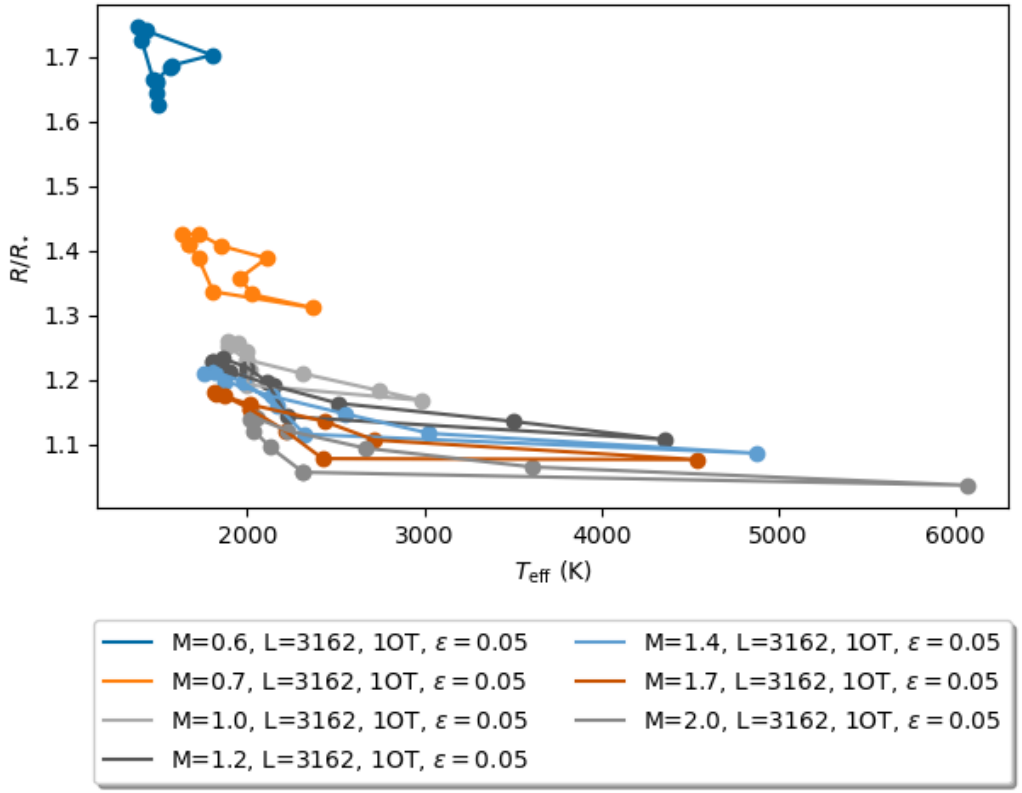


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Observations

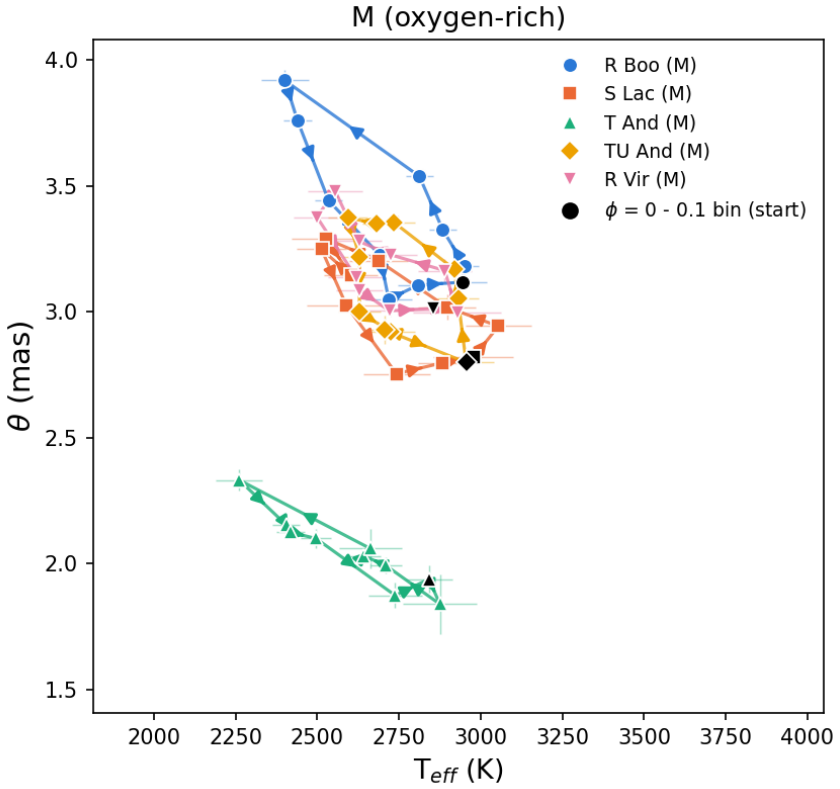


Atmospheric Models (1OT Mode)

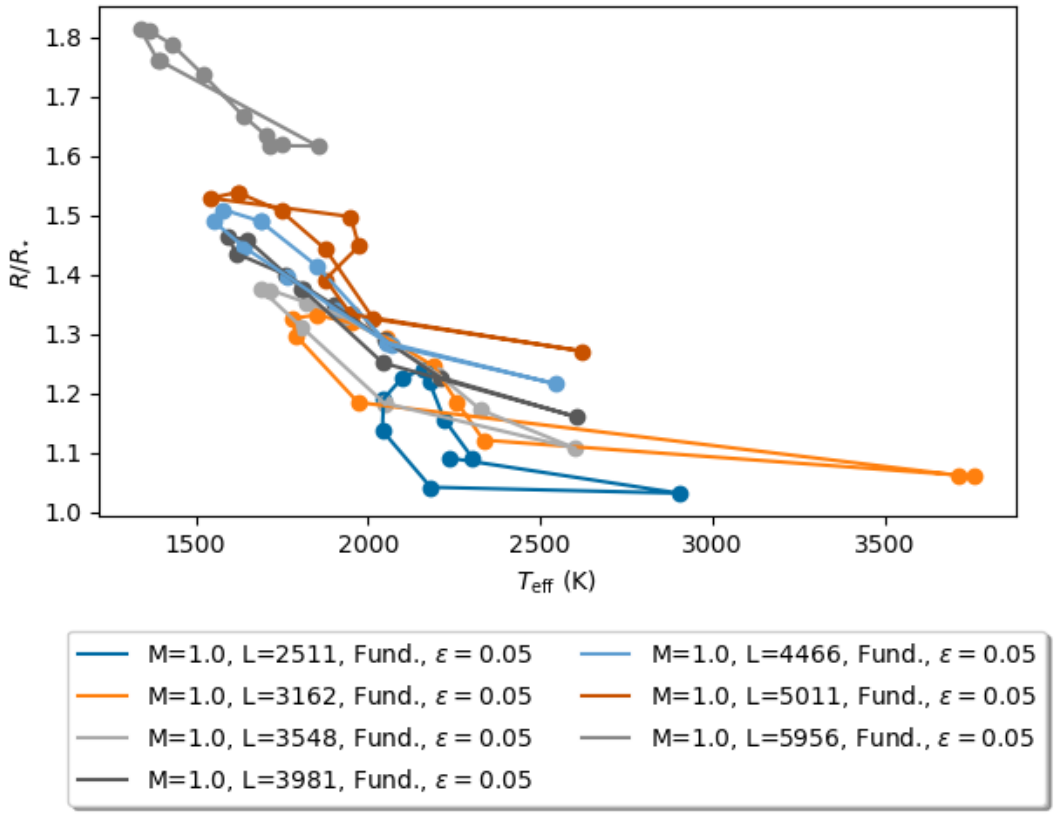


In Progress: What about individual stars? (Coll.: D. Baylis-Aguirre, G. van Belle, M. Creech-Eakman)

Observations

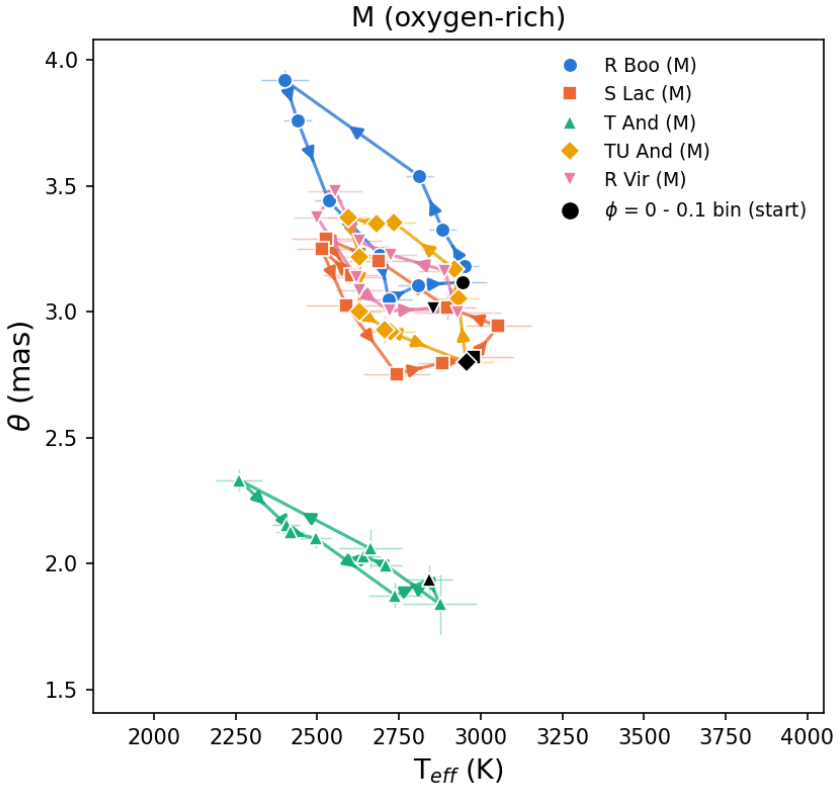


Atmospheric Models (F. Mode)

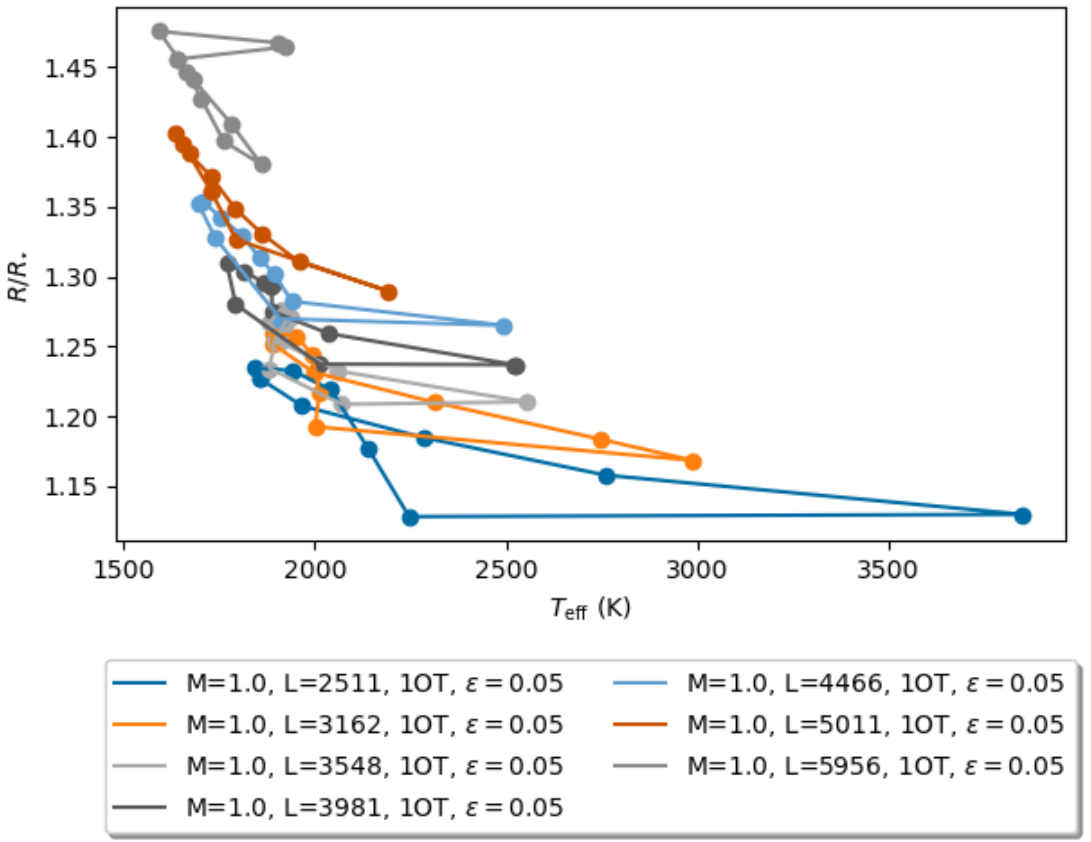


In Progress: What about individual stars? (Coll.: D. Baylis-Aguirre, G. van Belle, M. Creech-Eakman)

Observations



Atmospheric Models (1OT Mode)



AGB Stars and Stellar Pulsation, Konkoly Observatory, Hungary

Questions?

→ henry-prager@uiowa.edu

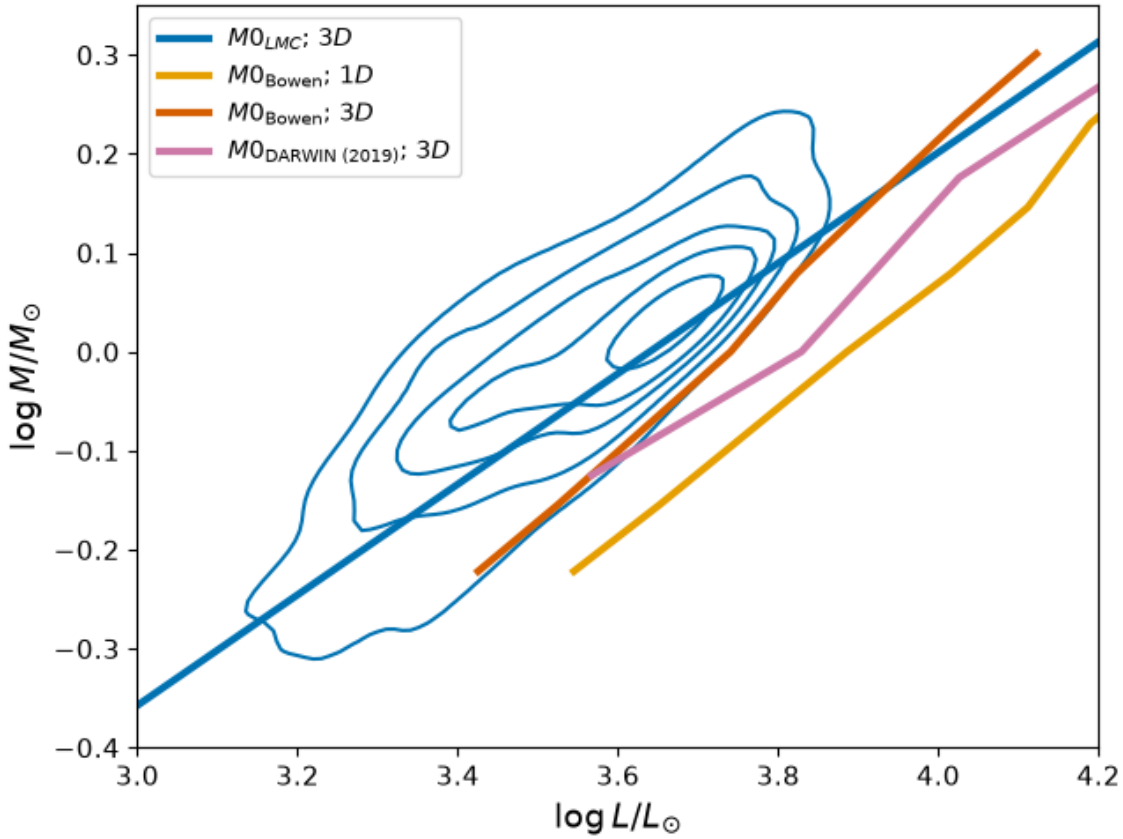


Bonus Slides

Part 3

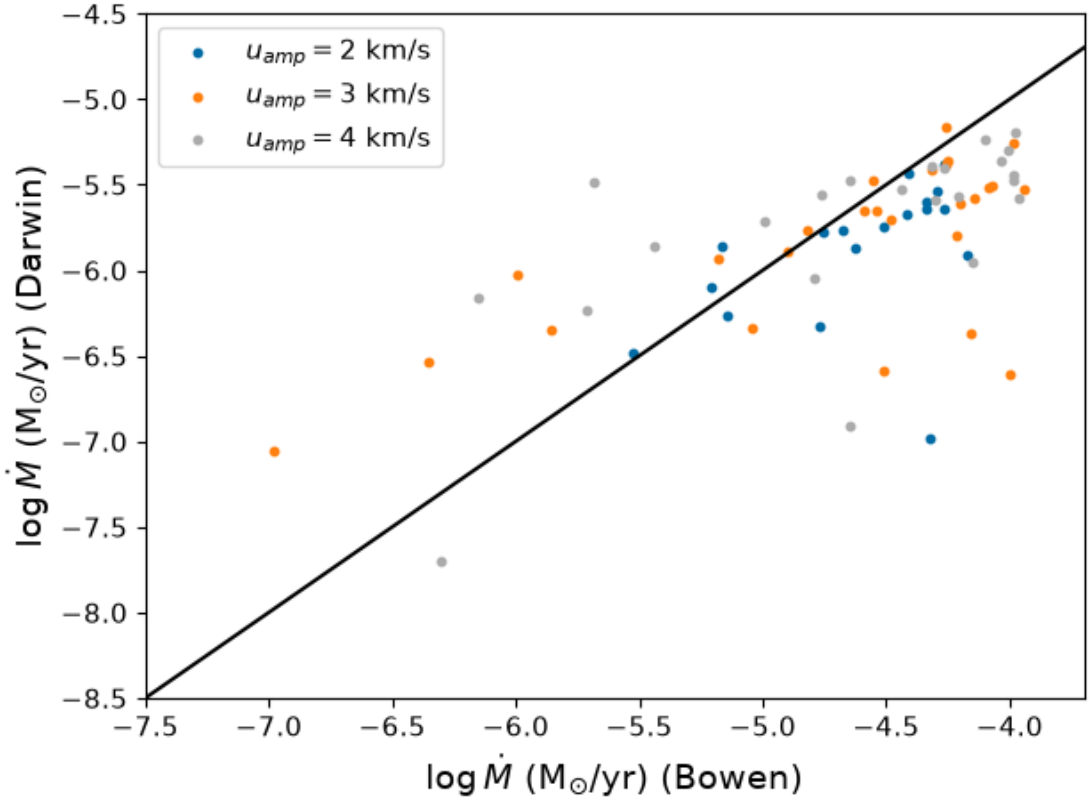
Is it our code?

- Short answer: no
- Long answer: Our code does make many simplifying assumptions. Improvements int the treatment of dust modeling and radiative transfer do move the death line closer to observations, but not enough.
- Right: Demonstration of the above statement



Is it our code?

- Short answer: no
- Long answer: Our code does make many simplifying assumptions. Improvements int the treatment of dust modeling and radiative transfer do move the death line closer to observations, but not enough.
- Right: Our models predict significantly higher mass-loss rates at given parameter combinations once new PMR and RML relations are used



Can you tell me about the PTI data?

- Disclaimer: I am much more in the modeling world, but I will do my best! (Thank you, Dana)
- PTI was a near-IR interferometer, single baseline
- Sensitive to objects 2-5 mas in diameter, resolving power of ~20
- Data on the AGB stars weas taken about once a month for 10 years between 1998 and 2008
- Sadly, no closure phases

