Modeling The Triple System α Herculis: Estimation of Primary AGB Star Mass

Ehsan Moravveji[1], Edward F. Guinan[2], and Rick Wasatonic[2]

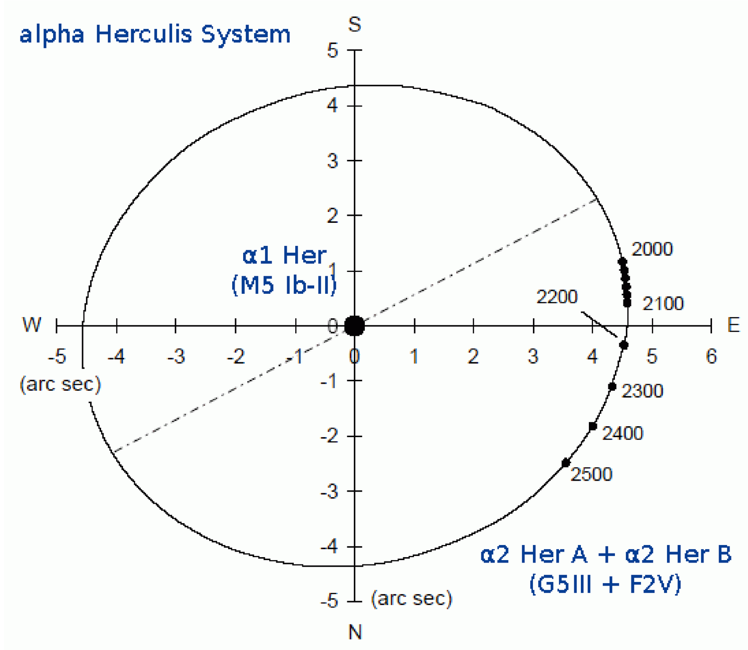
[1]Institute for Advanced Studies in Basic Science, Iran.
[2]Department of Astronomy, Villanova University, USA.

Institute for Advanced Studies in Basic Sciences
Gava Zang, Zanjan, Iran

VILLANOVA UNIVERSITY

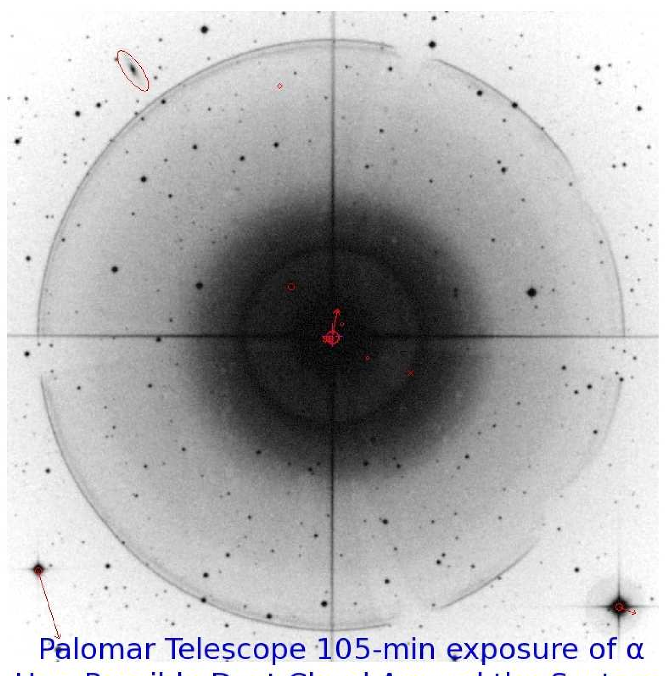
Introducing α Herculis System

- α Herculis is a *triple* stellar system. The primary α^1 **Her** (M5 Ib-II) and the secondary α^2 **Her** form a visual binary of seperation $\tilde{\alpha} \approx 4.7''$, and orbital period of $P \approx 3600$ yr. The primary is an AGB star while the secondary is a spectroscopic binary itself (α^2 Her A, B).
- The distance derived from Hipparcos parallax is $d_{\rm Hip} = 110 \pm 16$ pc, so the projected semi-major axis between α^1 Her and α^2 Her is ~520 AU.



Why Do We Care About α^1 Her?

- **Bright** ($m_V = 3.5$ mag), **nearby** ($d_{\rm Hip} = 110$ pc) AGB star,
- Controversy in the literature around it's **mass** ranges from 1.7 to 17 $M_\odot$,
- The first star whose mass loss rate was measured ($\dot{M} = 3 \times 10^{-7} M_\odot {\rm yr}^{-1}$) [8],
- Stochastically excited **pulsations** like Red Giants (around $\Pi = 126$ d) [5],
- **Long Secondary Period** ($\Pi_{\rm LSP} \approx 1400$ d),



Palomar Telescope 105-min exposure of α Her: Possible Dust Cloud Around the System.

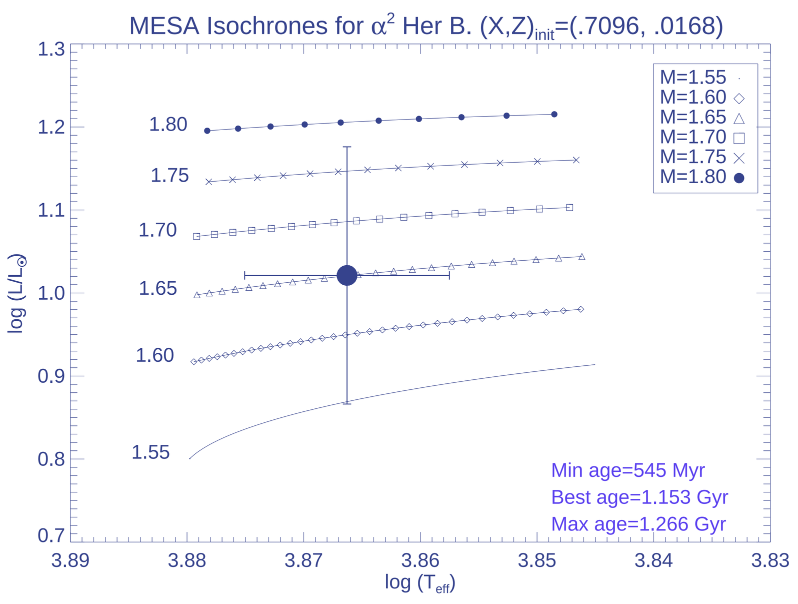
- **We are interested in the pulsations of this star, and deriving its physical properties from modeling the internal structure.**
- Here is our first assessment of α^1 Her mass, based on three independent methods: (1) from $\log g$ with radii coming from Wing C calibration [5, 8], (2) from an age constraint and isochrone fitting [4], (3) from extending the asteroseismic mass and radius determination from red giants to semi-regular pulsating stars [3].
- **Observations:** We have more than two decades of VRI and Wing ABC photometry carried out at Villanova University and Tennessee State University, starting from March 1986. The maximum of peak-to-peak light variability in V, for instance, is 0.98 mag, typical of an **SRc** pulsating star.

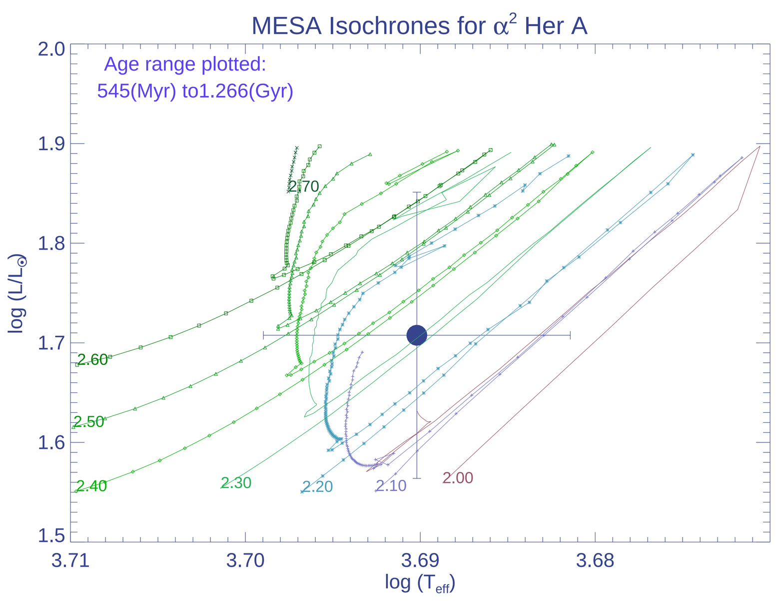
Table 1. Physical Properties of the System

	α^1 Her	α^2 Her A	α^2 Her B	Reference
Spec. Class	M5 Ib-II	G8 III	A9 IV-V	[8]
$T_{\rm eff}$ [K]	3270 ± 65	4900 ± 100	7350 ± 150	[5], [8]
$\log(L/L_\odot)$	3.92 ± 0.30	1.71 ± 0.39	1.02 ± 0.43	[5]
$\log(g/g_\odot)$	-4.27	-2.1	-0.11	[8]
Mass [$M_\odot$]	see Table 2	2.30 ± 0.20	1.65 ± 0.10	this work
Radius [$R_\odot$]	286 ± 31			[5]

Masses of Individual Members

- Based on observed $\log L/L_\odot$ and $\log g/g_\odot$ (Thiering and Reimers 1993) we locate α^2 Her A and B on the HR diagram, with MESA evolutionary tracks [6], and look for the possible ranges of mass and age (see Table 1).

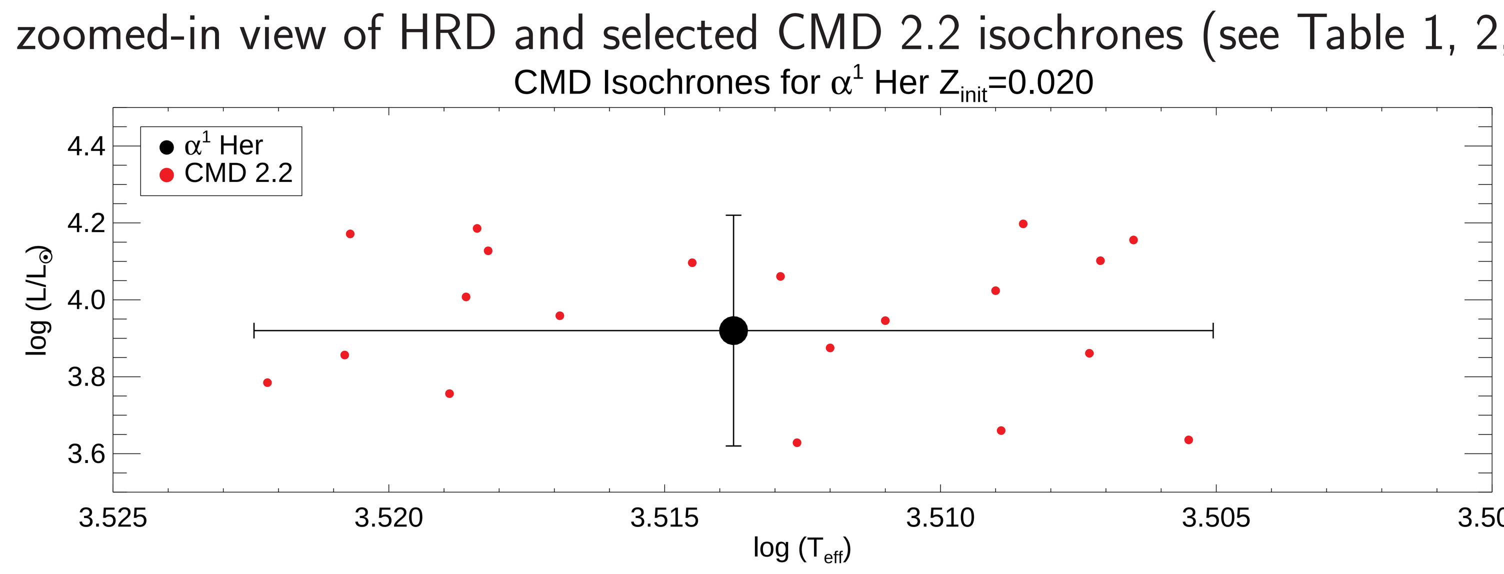




- Q: What is the allowed **age** and **mass** of binary companions?
  A: The best age is $\tau_2 = 1.15$ Gyr, and the total mass of the binary is $m_2 = 3.95 \pm 0.30 M_\odot$.
- From binary system membership, it is unclear that α^1 Her is a *low-mass AGB* or a *super-AGB* star. The reason is large uncertainties in $\tilde{\alpha}$, $d_{\rm Hip}$, and P.
- **Assuming** that all three stars are **coeval**, forming from the same contracting cloud, then $\tau_1 \simeq \tau_2$. Based on this *age constraint*, and CMD 2.2 isochrones for models meeting conditions in Table 1, α^1 Her mass is $2.1 \lesssim m_1 \lesssim 3.0\ M_\odot$.

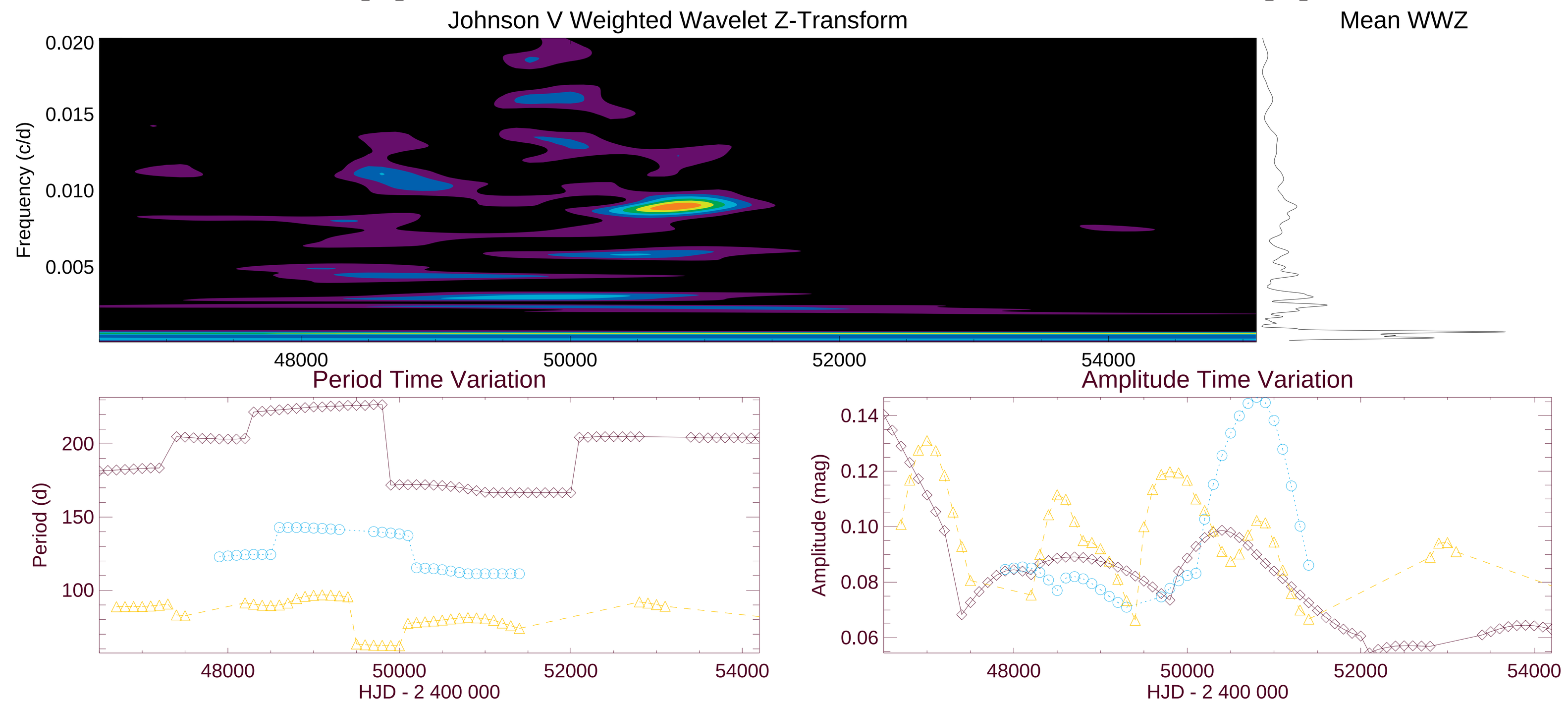
CMD 2.2 Isochrones and α^1 Her on HR Diagram

A zoomed-in view of HRD and selected CMD 2.2 isochrones (see Table 1, 2, [4]).



Semi-Regularity and Weighted Wavelet Z-Transform (WWZ)

- To demonstrate the temporal change in frequency and amplitude of three selected modes, WWZ [2] with binsize of $\Delta t = 100$ d is employed [5].

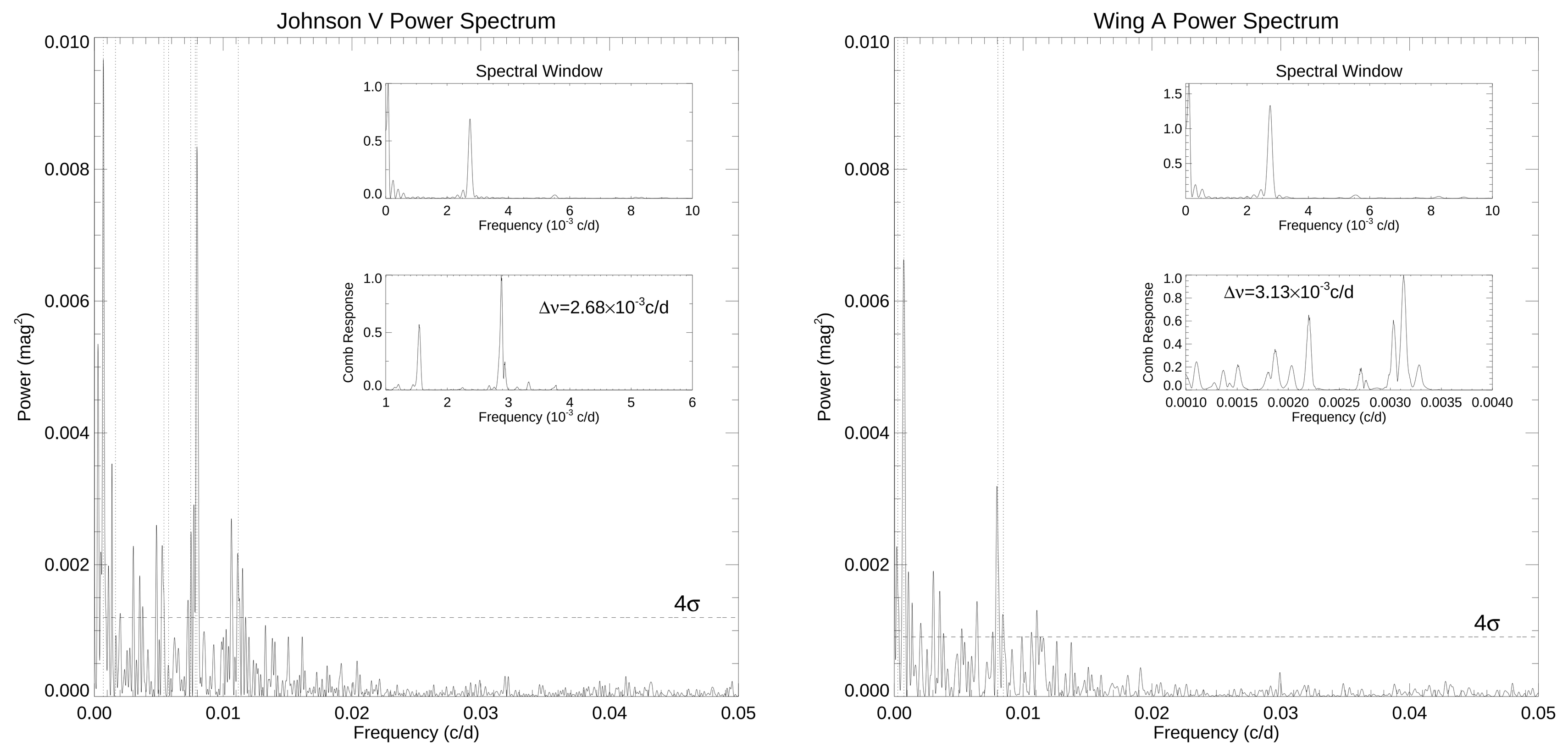


Scaling Mass and Radius From Asteroseismology

- Stochastically excited oscillations by turbulent convection is predicted in semi-regular pulsating stars [1]. Based on the large frequency spacing $\Delta\nu$ and the central frequency in the DFT hump $\nu_{\rm max}$, mass and radius scale as [3]

$$R/R_\odot = (\nu_{\rm max}/\nu_{\rm max,\odot}) \cdot (\Delta\nu/\Delta\nu_\odot)^{-2} \cdot (T_{\rm eff}/T_\odot)^{1/2}, \quad (1)$$

$$M/M_\odot = (R/R_\odot)^3 \cdot (\Delta\nu/\Delta\nu_\odot)^2. \quad (2)$$



- $\overline{\Delta\nu} = 0.22 \times 10^{-3}$ and $\nu_{\rm max} \simeq 0.080$ cd^{-1} yield $M = 2.9 \pm 1.8 M_\odot$.

Table 2. Summary of α^1 Her Mass (m_1)

$m_1\,(M_\odot)$	Method	Remark
4.4 ± 1.3	$\log g$	Mean radii used is $286 \pm 31 R_\odot$ [5], but from Eq. 2 is $355 \pm 58 R_\odot$,
2.9 ± 1.8	$\Delta\nu$	From Eq. 3 with mean radii from Eq. 2 (see above),
2.1 to 3.0	Isochrones	See Marigo et al. (2008)
	Pulsation	Prospective study, based on Xiong et al. (1998)

References

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Mail: moravveji@iasbs.ac.ir WWW: http://iasbs.ac.ir/students/moravveji/