The Radius Inflation Problem: Ditching Eclipsing Binaries

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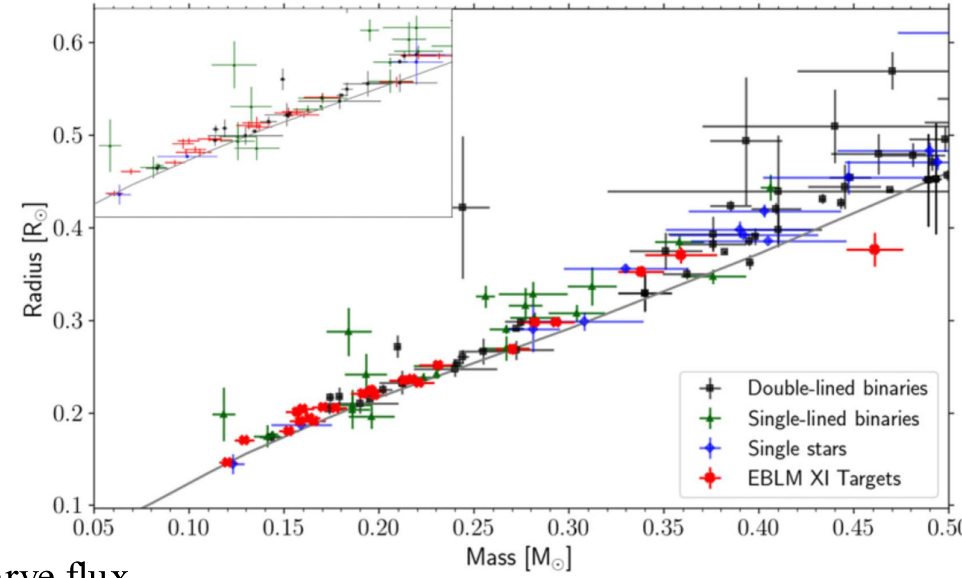
Swane et al. 2024



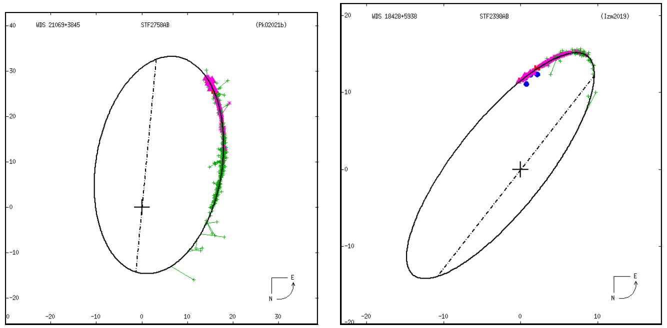
The Problem

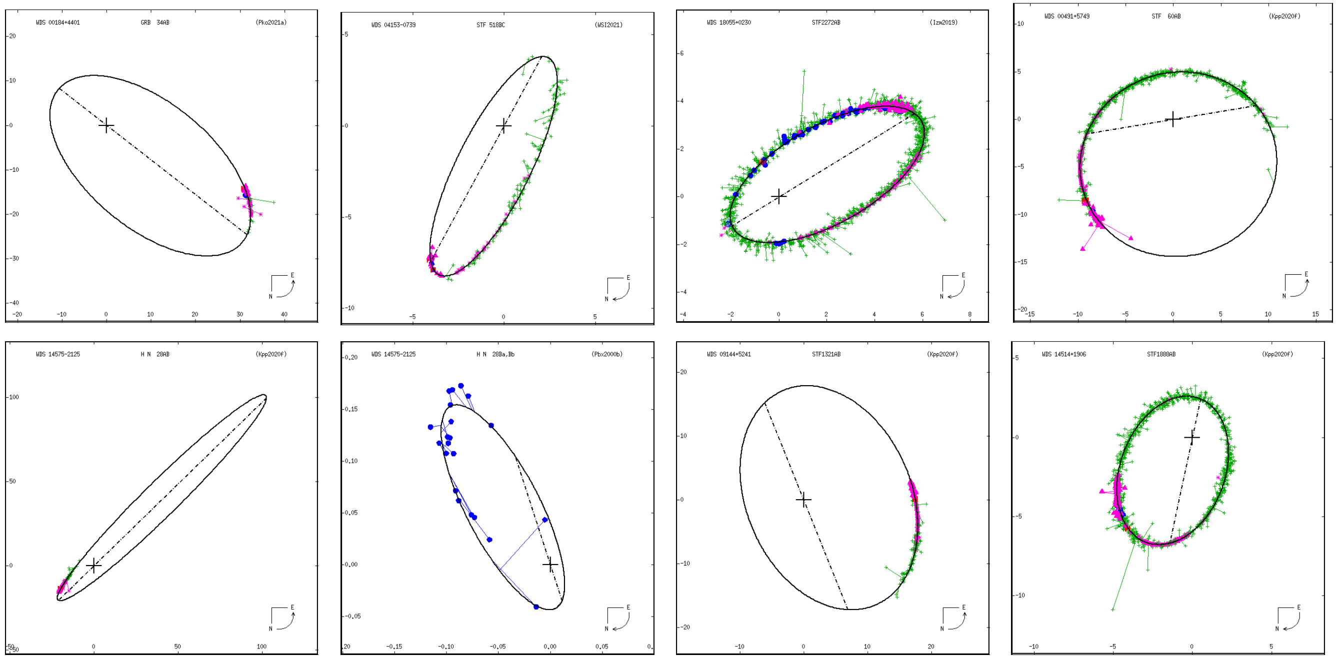
- Models don't match observations
- Different ideas
  - Stellar activity
    - Magnetic activity inhibits convection, leading to inflation to conserve flux
  - Star spots
    - Spots create variations flux and affects R by transit method
  - Tidal locking
    - Short Period Eclipsing Binaries
  - Metallicity
    - Models don't account for metallicity correctly – missing phyiscs/opacity affects R for a fixed mass

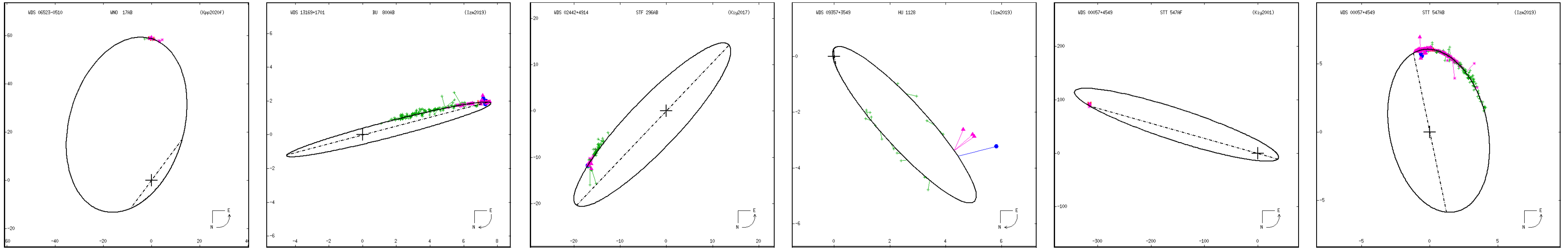
- >> Disagreement between various studies
  - Note: single stars, small metallicity ranges, short period EB's (<50 d).
  - Berger et al. 2006, Boyajian et al. 2012, von Boetticher et al. 2019, Swane et al. 2024…and more.

Motivation & Research Plan

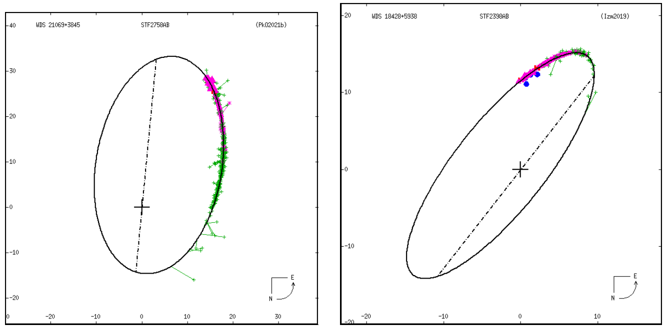
- Sample of new, precise M&R grids for testing stellar evolution models
    - Visual Doubles to represent single stars & free from tidal interactions
- Use MIRC-X/MYSTIC for precise angular diameters
- Masses from literature







Sample of Visual Doubles



Washington Double Star Catalog

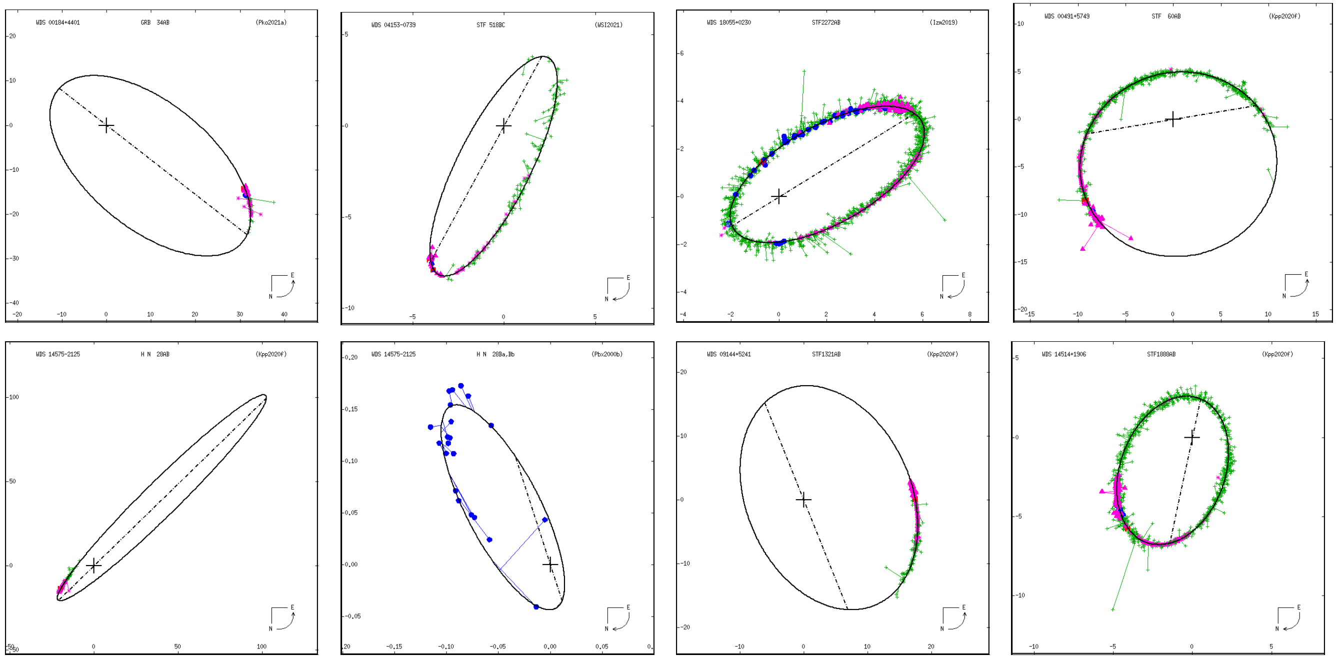
- ρ (last meas.) ≥ 4.5“

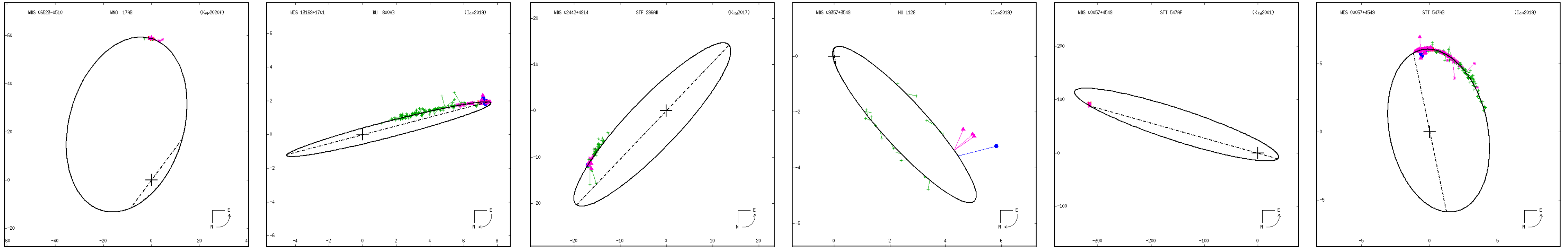
13 systems, 26 stars total

- 11 binaries, 1 triple
- exclude WD GJ 166 B

P > 88 yrs

D < 12 pc





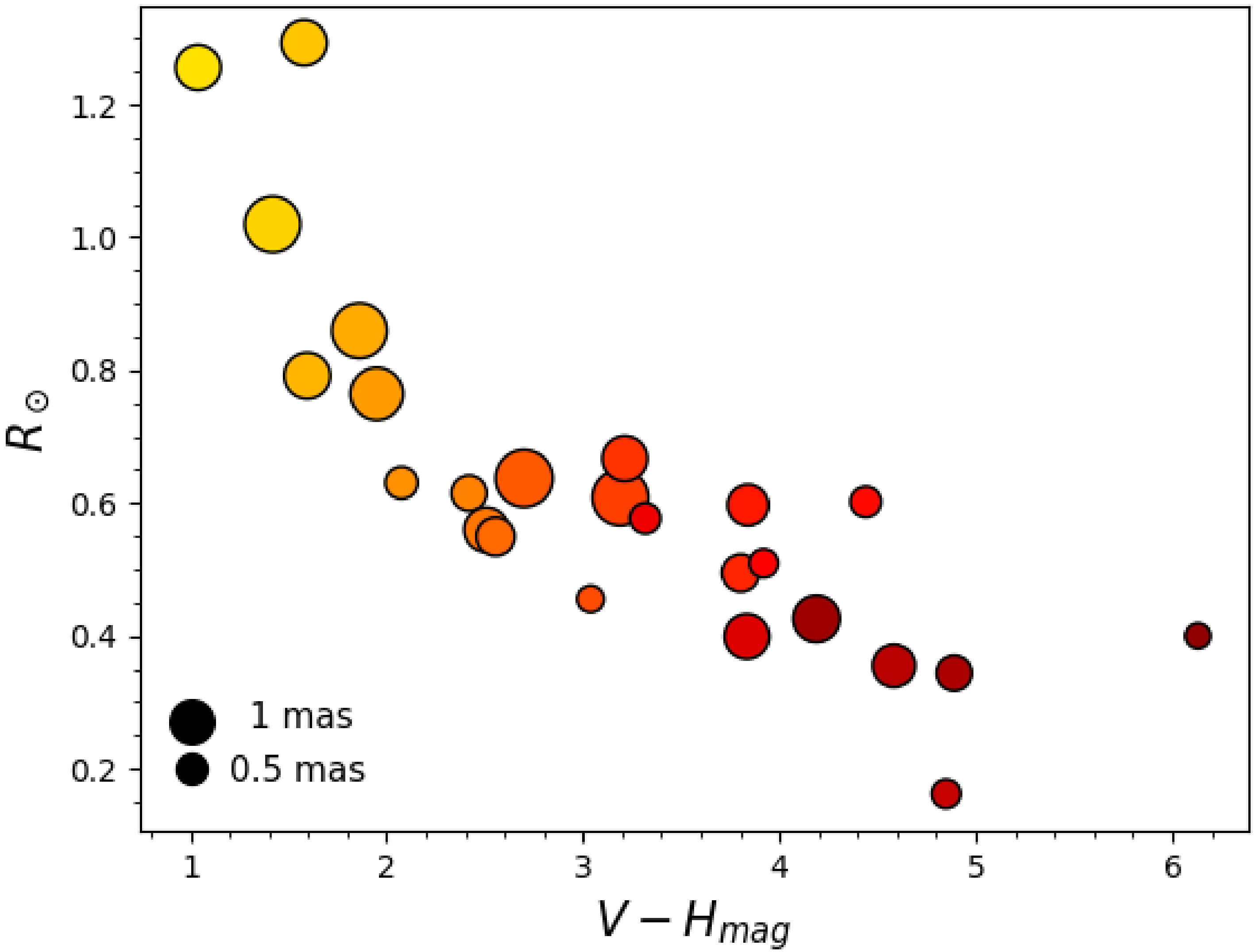
26 MS Stars

SpT cooler than F5

- 1 F7
- 3 G1, G8
- 9 K0-K7
- 13 M0-M5

Θ: 0.33 - 1.8 mas

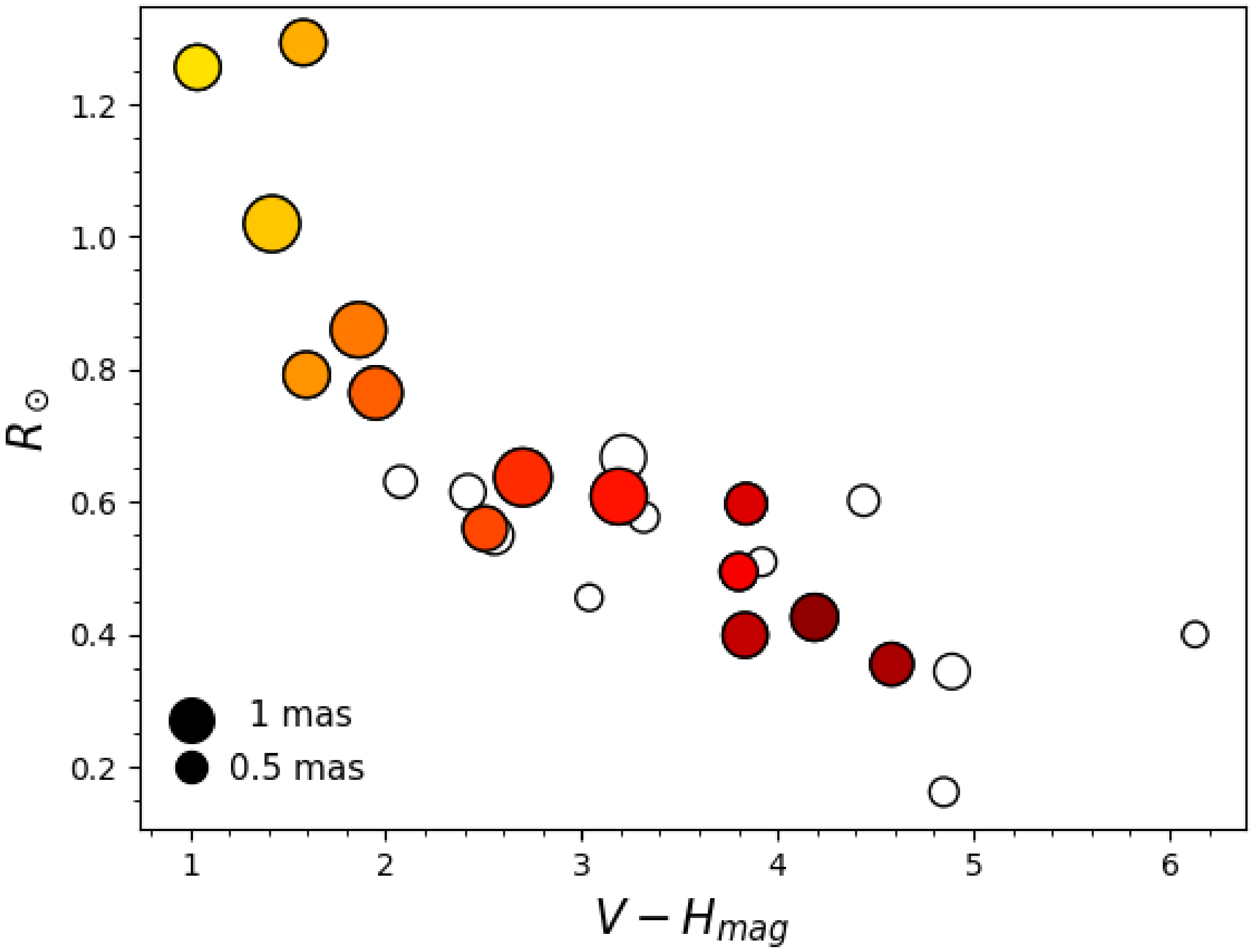
H: 2 – 6.8



14 CHARA Measurements

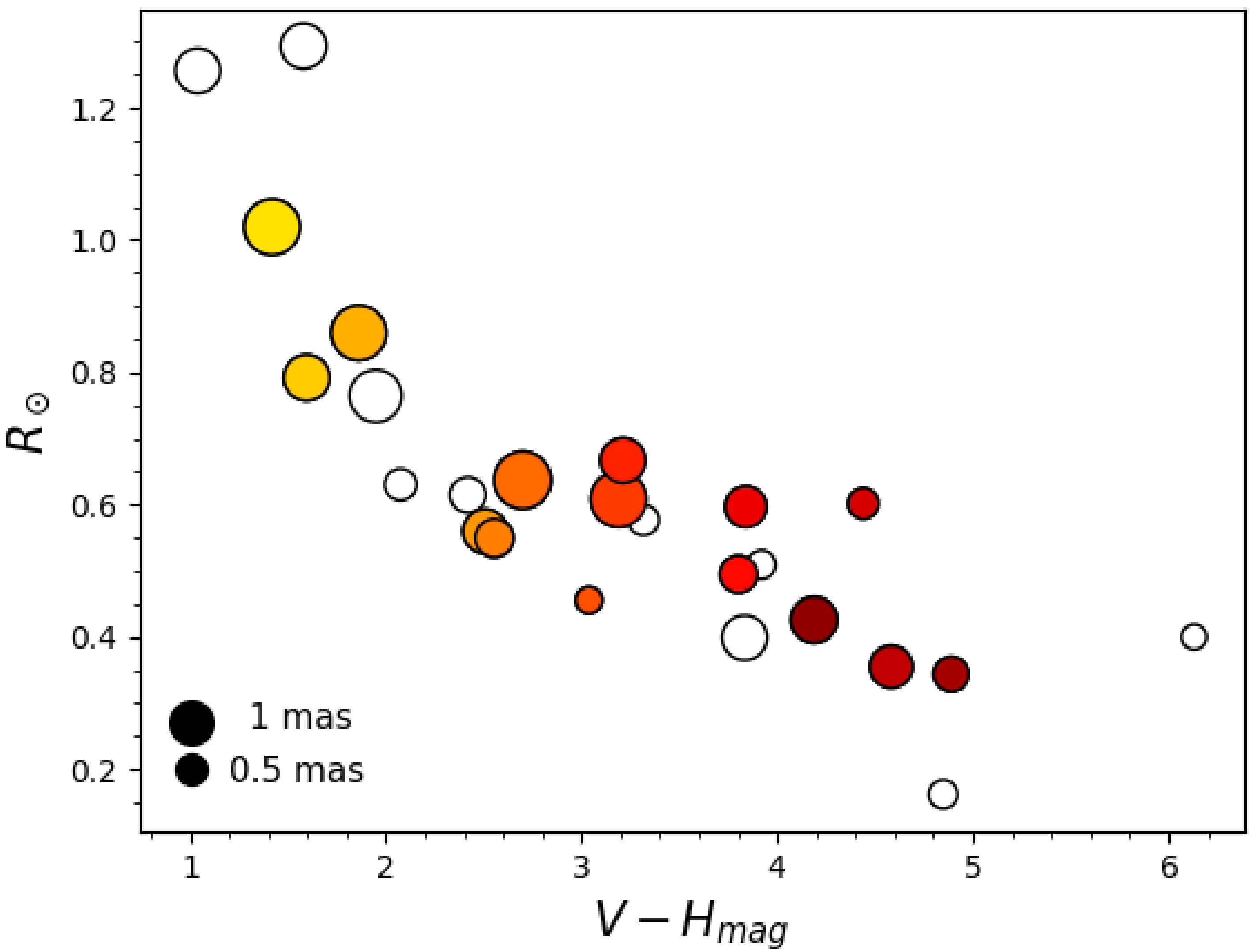
- Classic
- Pavo
- Flour

Valuable checks across beam combiners



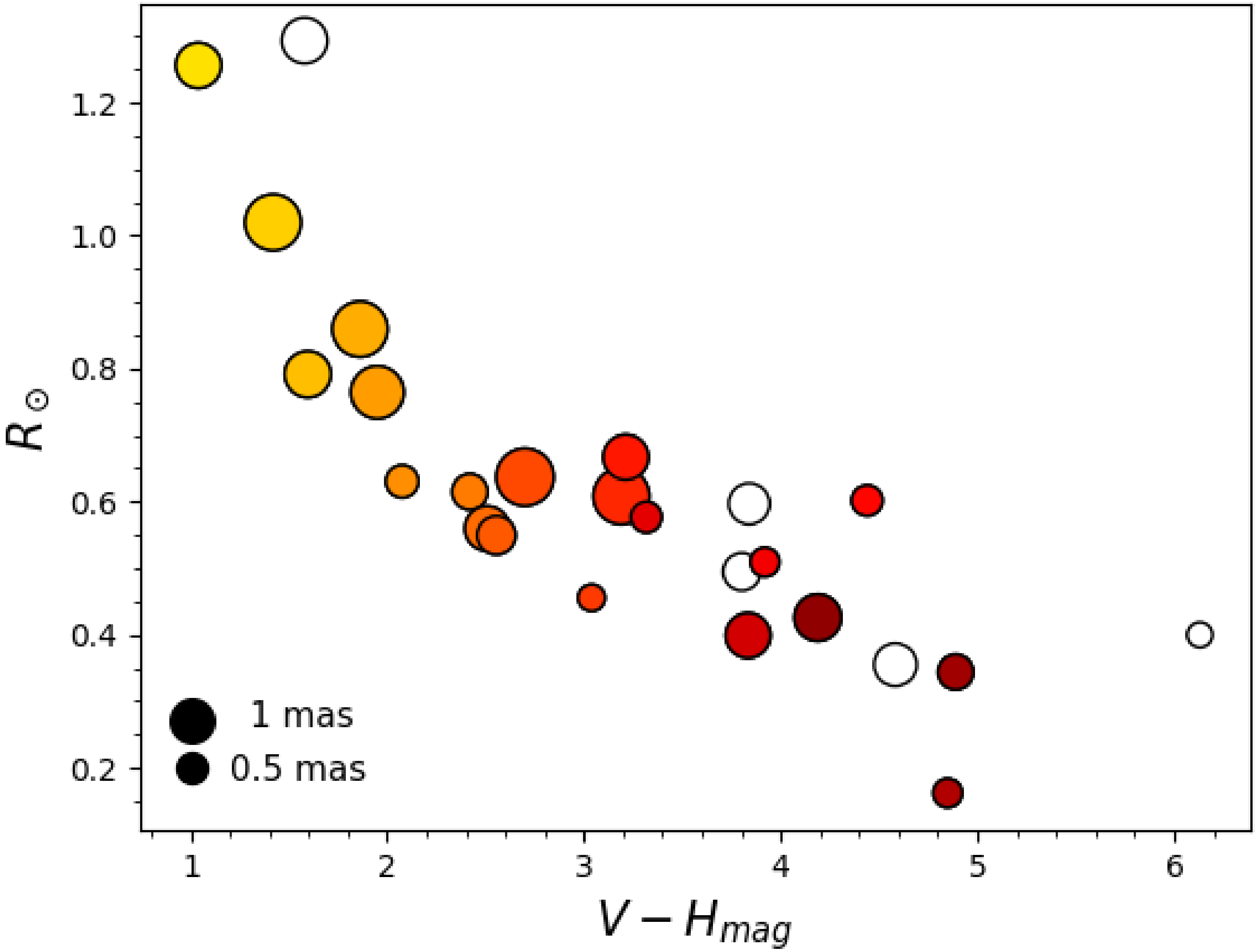
15 with Mass Info

- 11 dynamical mases
- 4 mass ratios



21 observed so far

- 1 left for 2025B
- 4 left for 2026A (March)



Sample of Visual Doubles

Common Name	GJ	D (pc)	SpT	P (yrs) a ('')	$M_\odot$
61 Cyg	820 A	3.497	K5V	618.7	0.6771 + 0.0052 - 0.0051
	820 B		K7V	25.25	0.6289 + 0.0094 - 0.0092
	725 A	3.523	M4V	653.3	M_b/M_a = 0.544 ± 0.030
	725 B		M4.5V	19.84	
GX & GQ And	**15 A**	3.562	M1V	1226	[0.59]
	15 B		M3.5V	26.95	
40 Eri	166 A	5.008	K0V	..	Und.
	166 B		DA2.9	233.2	0.573 ± 0.018
	166 C		M4.5V	6.888	0.204 ± 0.006
70 Oph	702 A	5.113	K0V	88.40	0.89 ± 0.02
	702 B		K4V	4.550	0.73 ± 0.01
eta Cas	34 A	5.923	G1V	471.3	1.0258 +0.007-0.0069
	34 B		M0V	11.90	0.5487 ± 0.0056
	338 A	6.334	M0V	933.0	0.69 ± 0.07
	338 B		M0V	19.20	0.64 ± 0.07

Common Name	GJ	D (pc)	SpT	P (yrs) a ('')	$M_\odot$
ksi Boo	566 A	6.754	G8V	152.0	0.954 + 0.073 - 0.050
	566 B		K5V	4.920	0.748 ± 0.011
	250 A	8.747	K3V	Und.	Und.
	250 B		M2V	[65.20]	
	505 A	10.99	K1V	607.0	[0.93]
	505 B		M1V	6.360	
13 Per	107 A	11.15	F7V	3327	[1.71]
	107 B		M1.5V	23.90	
11 Lmi	356 A	11.23	G8V	241.0	[0.90]
	356 B		M5V	7.180	
	4 A	11.52	K6V	516.0	M_b/M_a = 0.996 ± 0.026
	4 B		M0V	6.170	

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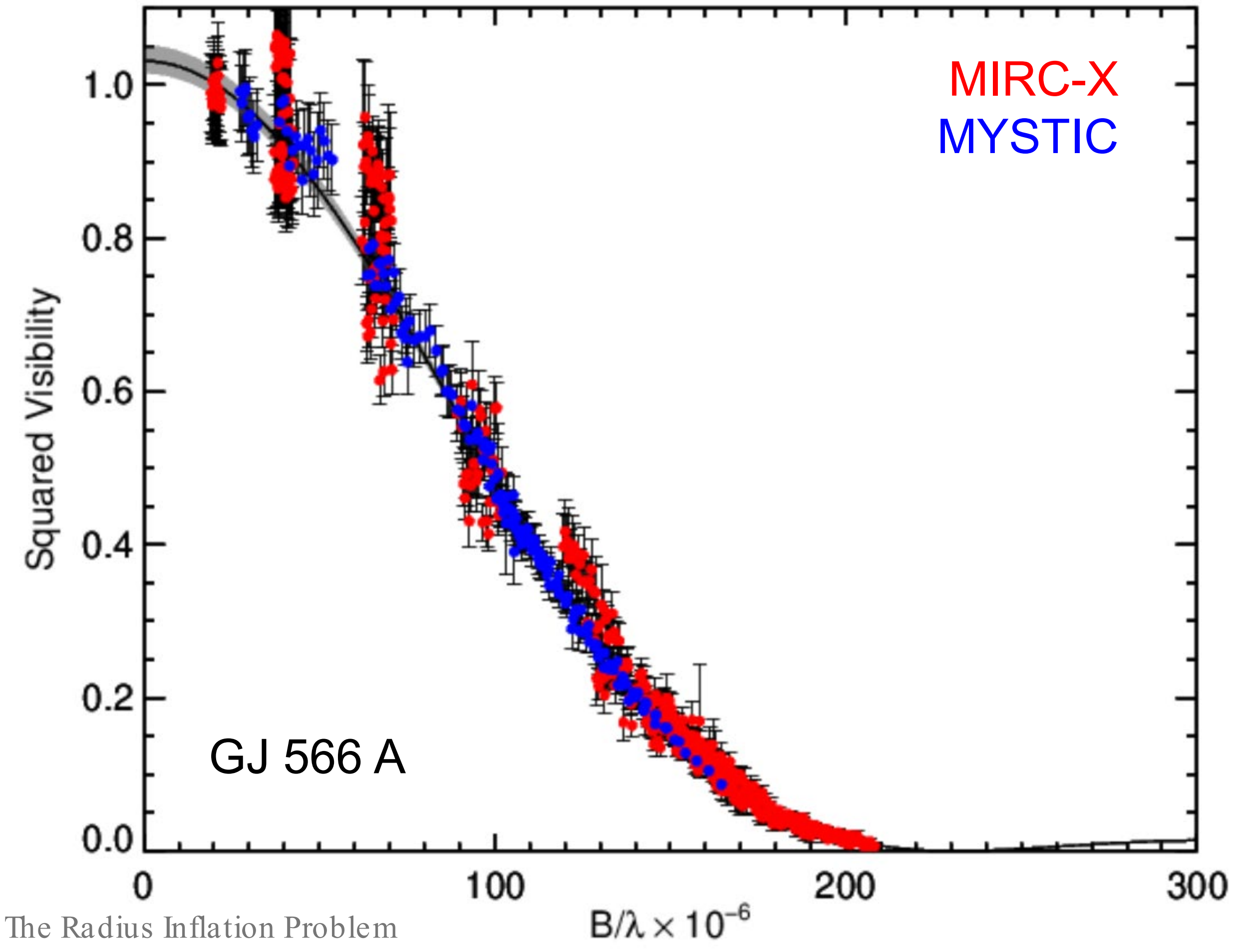
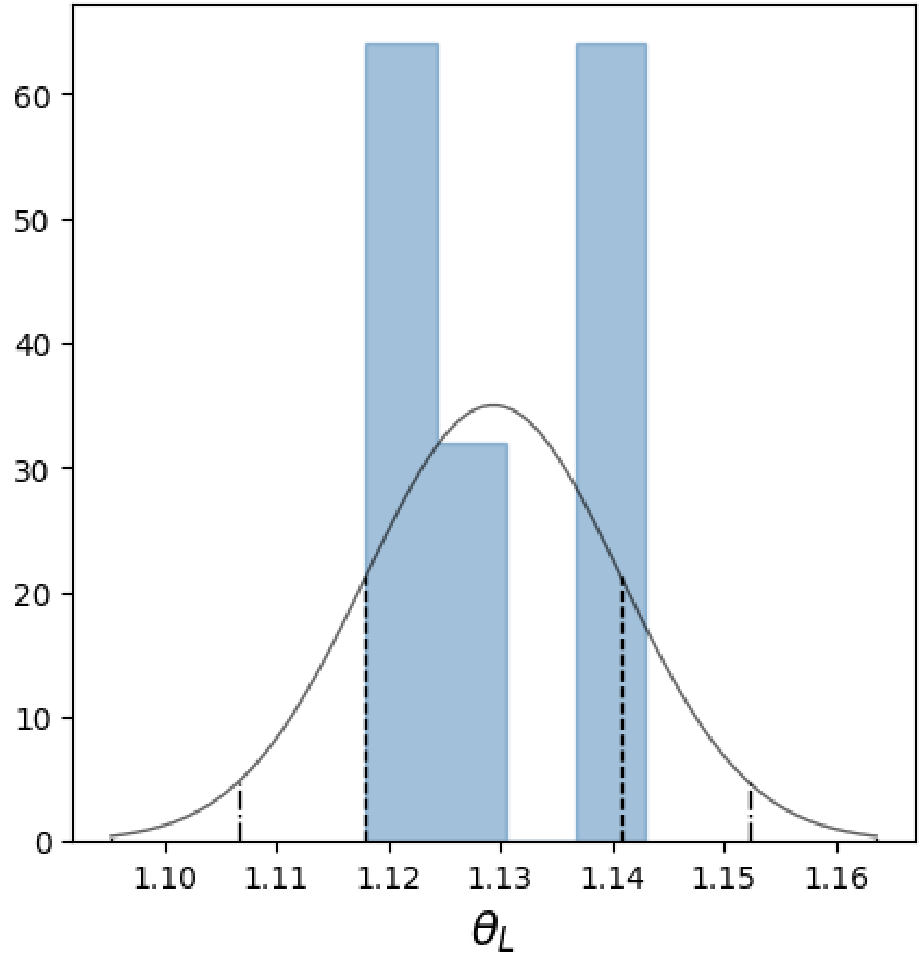
	4 B		M0V	6.170	

GJ 566 A

Obs. 3 Nights (2 in 2022, 2024)

$\theta_{LD} = 1.133 \pm 0.011$ mas (1%)



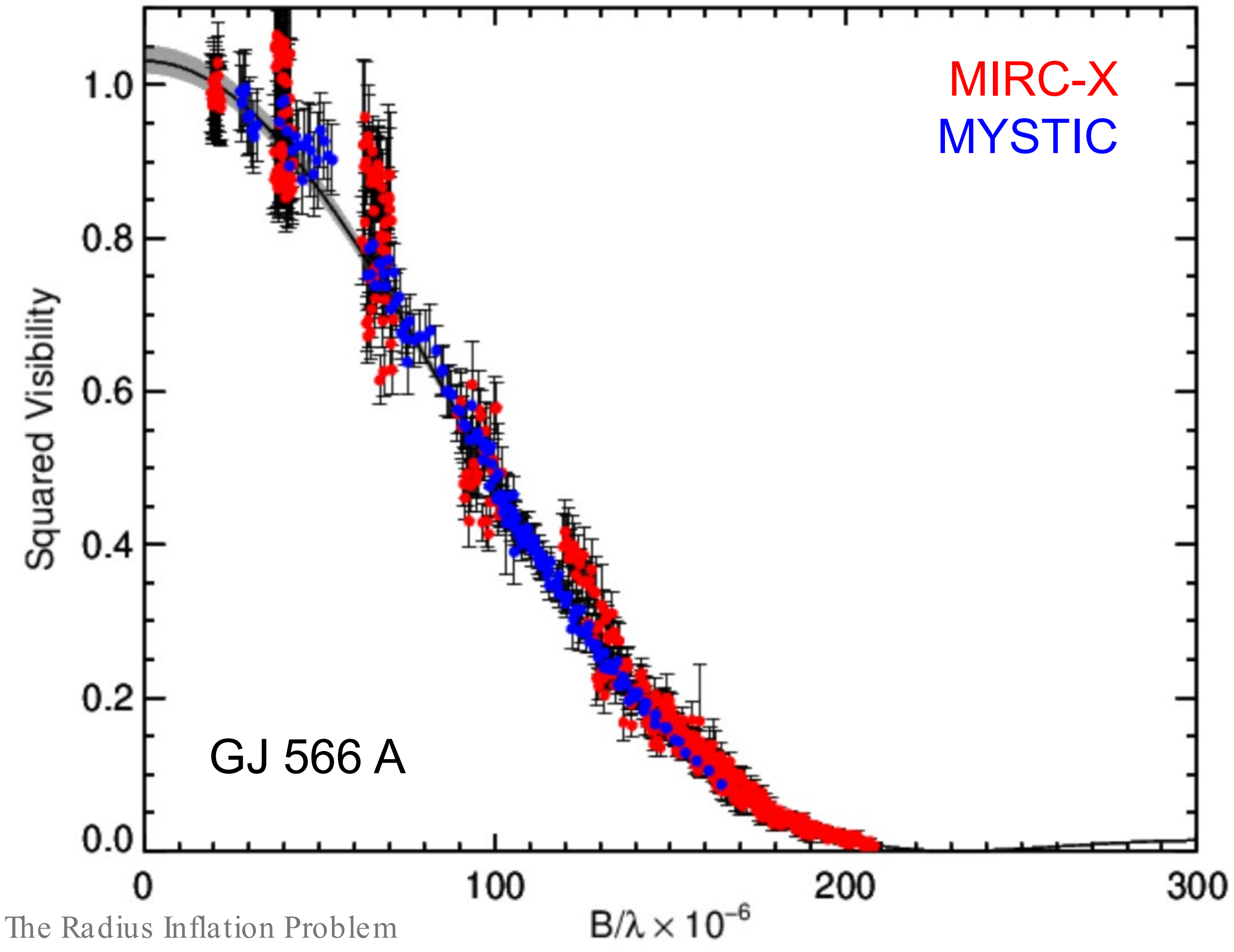


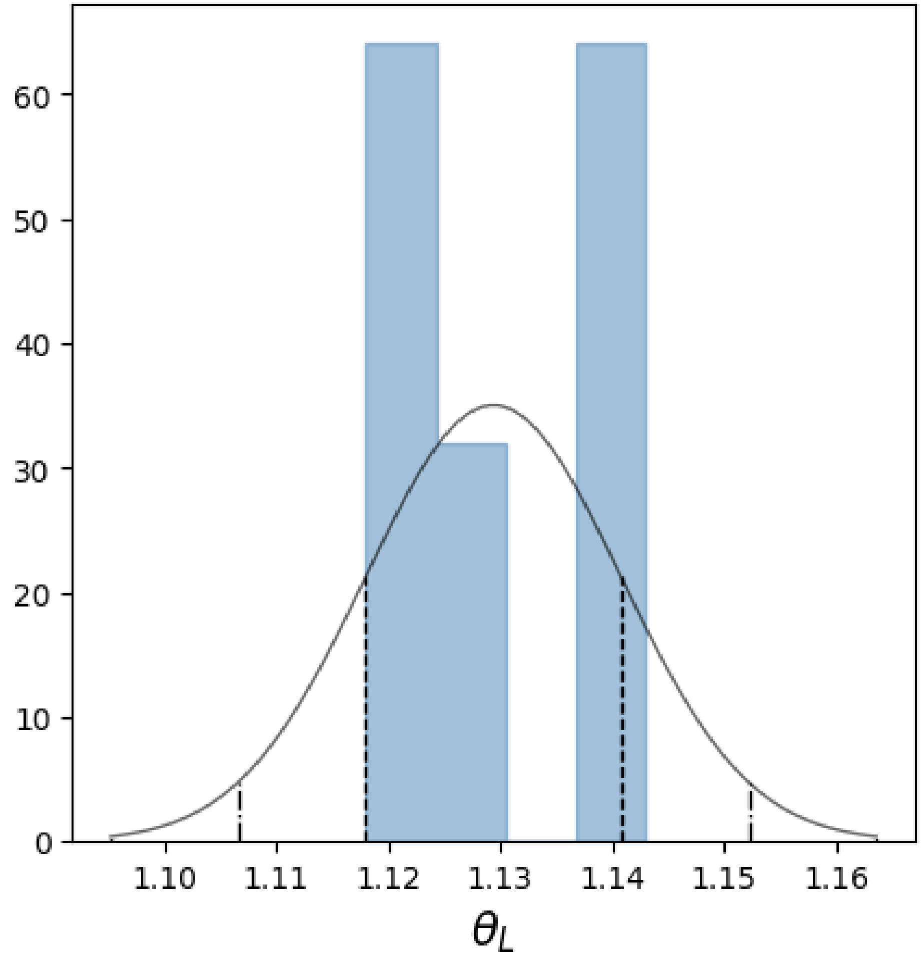
GJ 566 A

Obs. 3 Nights (2 in 2022, 2024)

$\theta_{LD} = 1.133 \pm 0.011$ mas (1%)

-	H	K	ALL
Nfiles	3	2	5
ldd	1.13	1.127	1.133



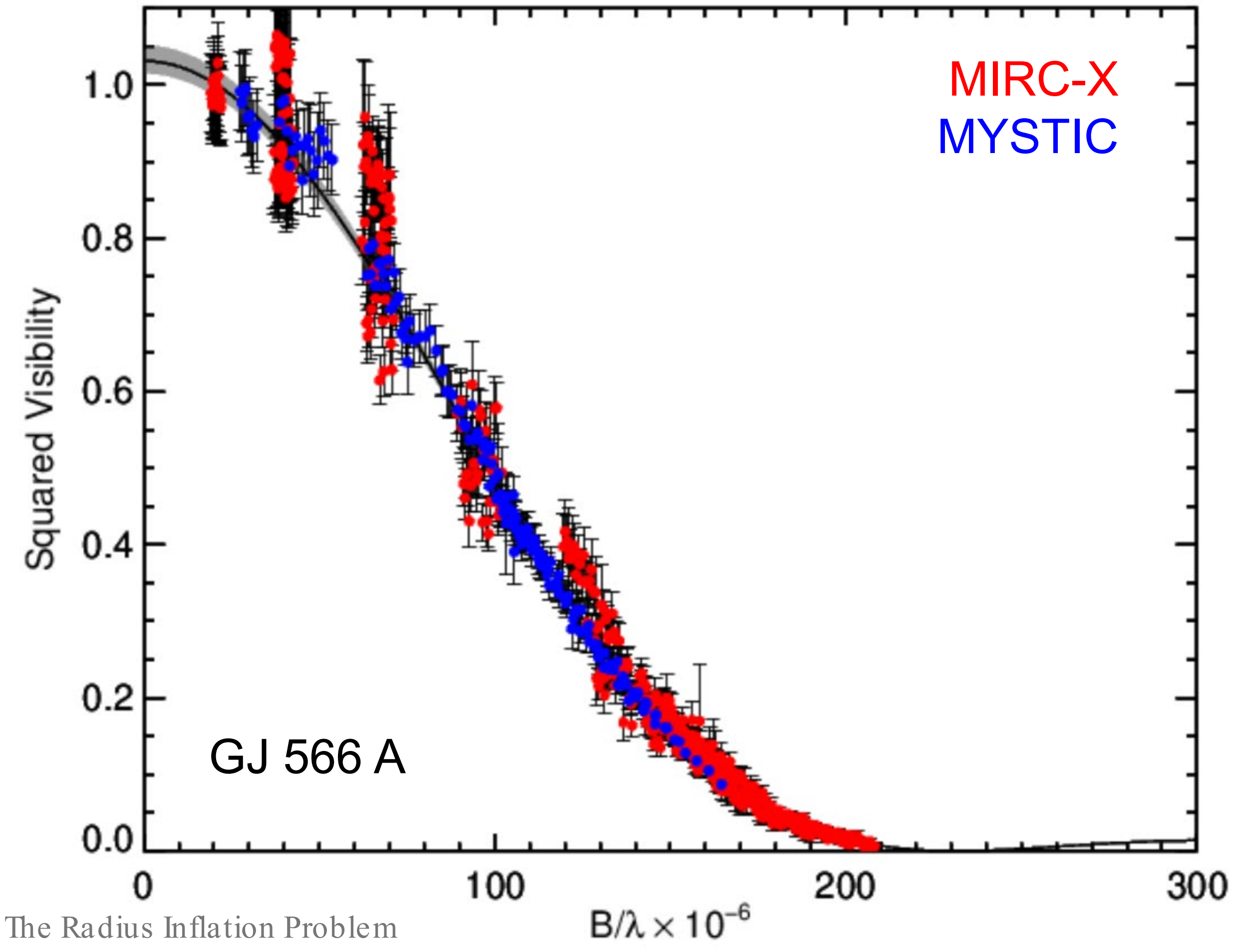


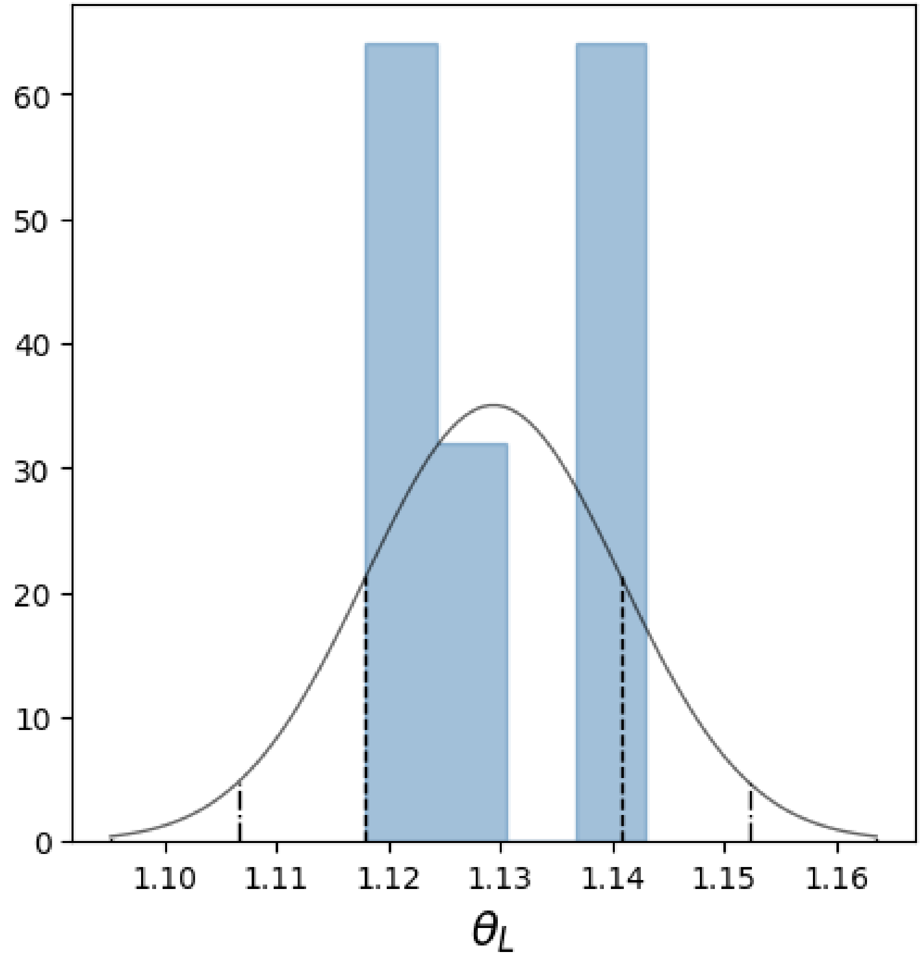
GJ 566 A

Obs. 3 Nights (2 in 2022, 2024)

$$\theta_{LD} = 1.133 \pm 0.011 \text{ mas } (1\%)$$

-	H	K	ALL
Nfiles	3	2	5
ldd	1.13	1.127	1.133
mean	1.133	1.124	1.129
sigma	0.013	0.008	0.011



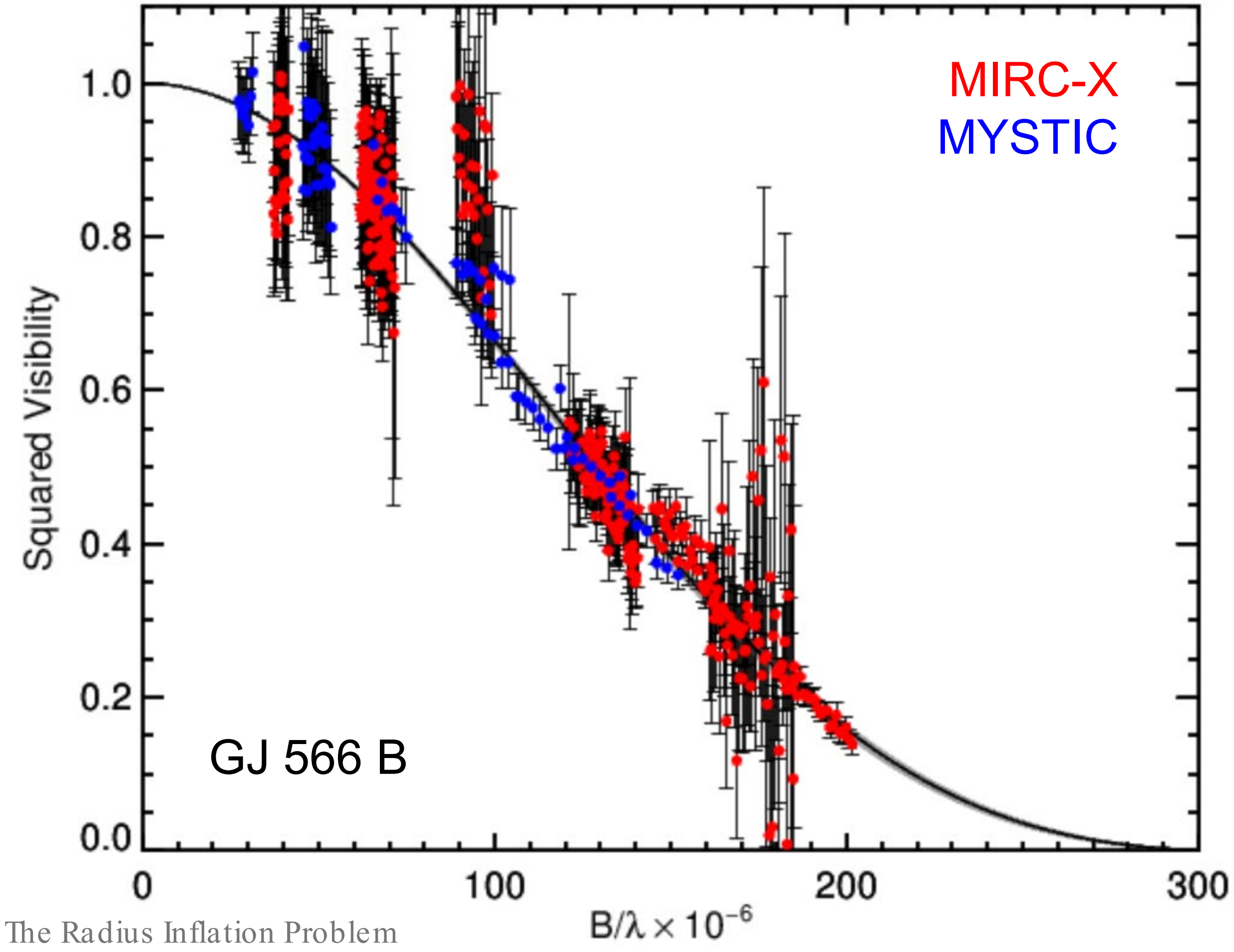


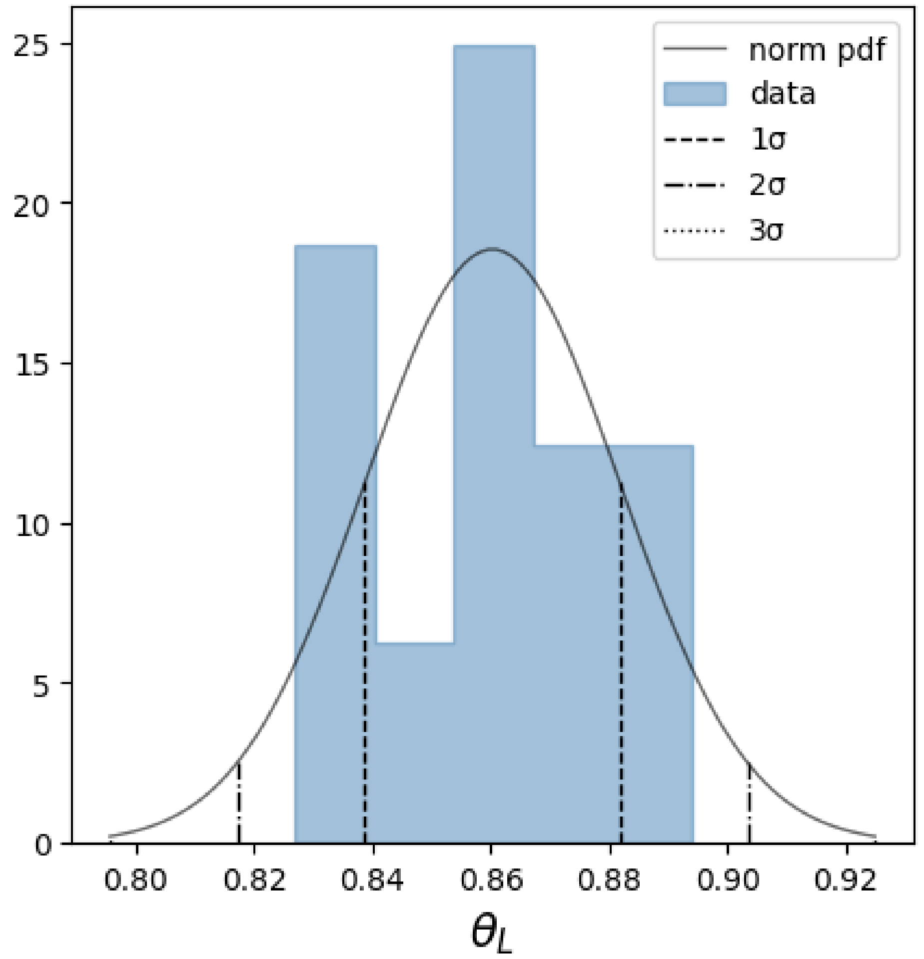
GJ 566 B

Obs. 2 Nights (2023, 2024)

$\theta_{LD} = 0.853 \pm 0.022$ mas (2.6%)

-	H	K	ALL
Nfiles	6	6	12
ldd	0.853	0.858	0.853

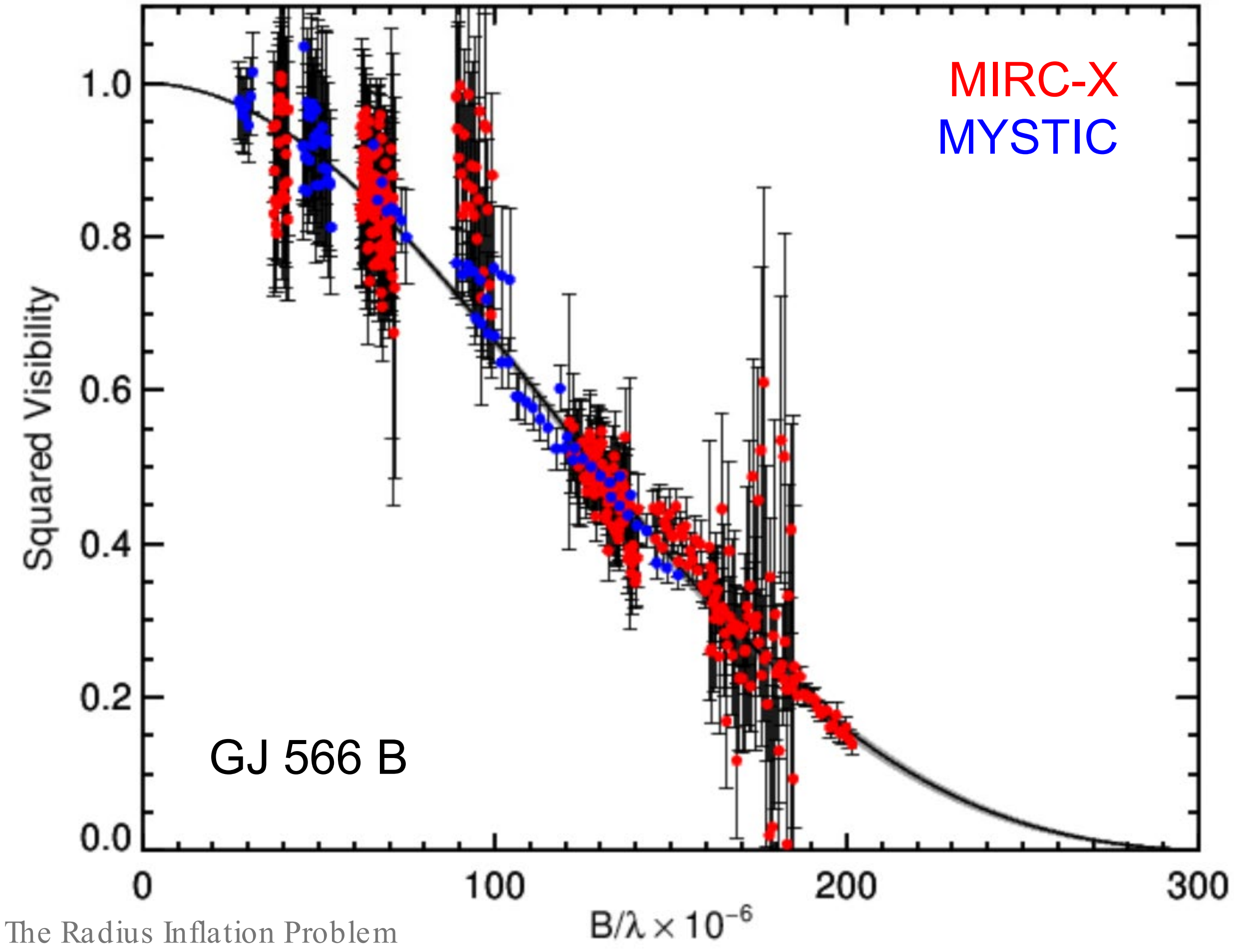




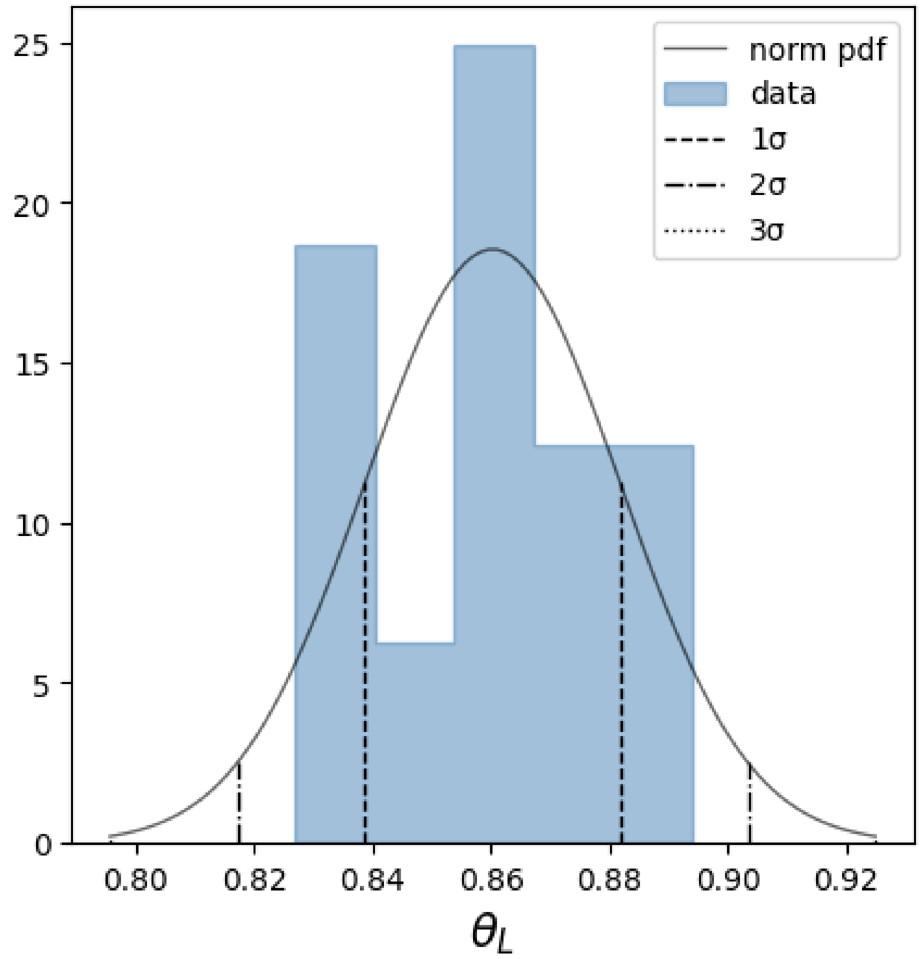
GJ 566 B

Obs. 2 Nights (2023, 2024)

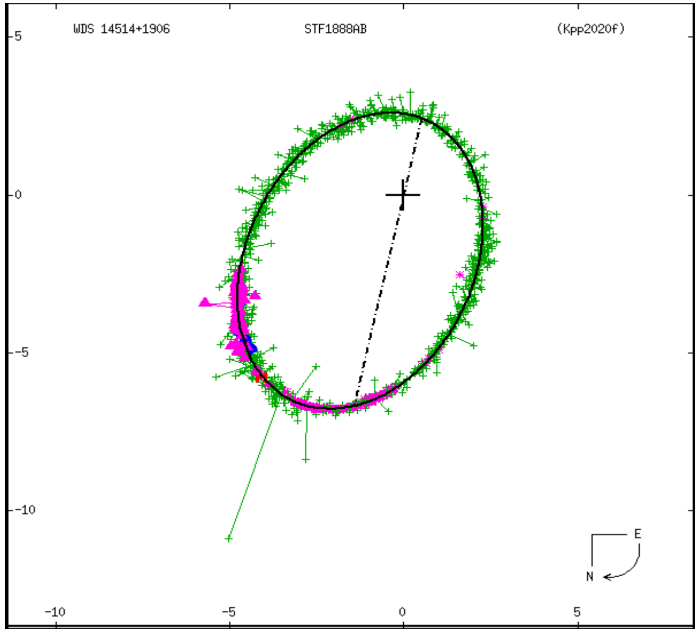
$\theta_{LD} = 0.853 \pm 0.022$ mas (2.6%)



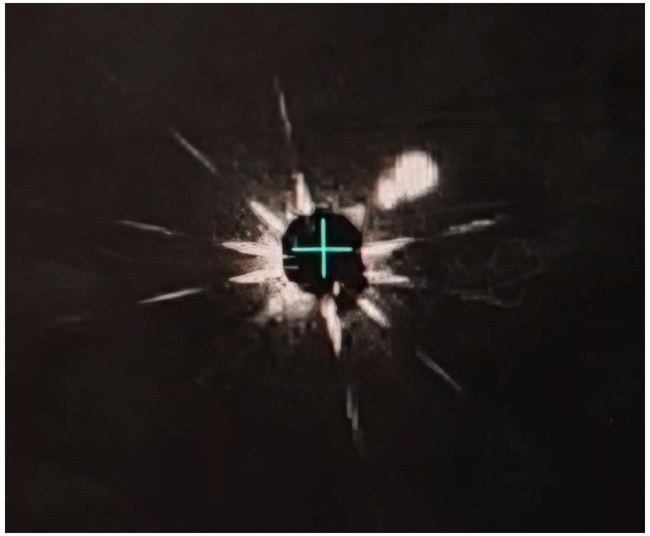
-	H	K	ALL
Nfiles	6	6	12
ldd	0.853	0.858	0.853
mean	0.865	0.855	0.860
sigma	0.009	0.030	0.022

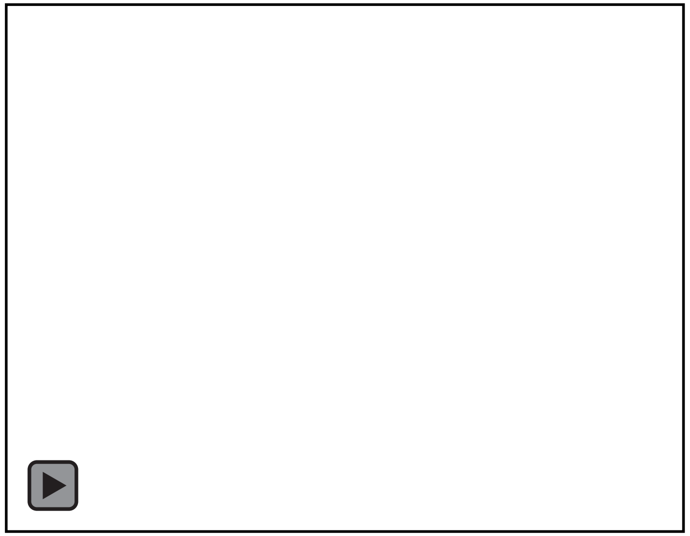


GJ 566 AB



P: 152 yrs, ρ: 4.5”
WDS





02/28/25

Flores et al. (in prep.)

GJ 566	A	B
θ_{LD} (mas)	1.133 ± 0.011	0.853 ± 0.022
$R_{\odot}$	0.823 ± 0.008	0.619 ± 0.016

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θ_{LD} (mas)	1.133 ± 0.011	0.853 ± 0.022
$R_\odot$	0.823 ± 0.008	0.619 ± 0.016
F_{bol} ($\times10^{-8}$ ergs/cm^{-2} s^{-1})	38.768 ± 0.189	9.081 ± 0.108
T_{eff} (K)	5487 ± 27	4399 ± 58

L: Harada et al. 2024

Fe/H: Hinkel et al. (2014)

$$F_{bol} = \frac{L}{4\pi d^2}$$

$$T_{Eff} = \left(\frac{4F_{bol}}{\sigma\theta^2}\right)^{0.25}$$

GJ 566	A	B
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T_{eff} (K)	5487 ± 27	4399 ± 58
$M_\odot$	0.954+0.073-0.050	0.748 ± 0.011
Fe/H	-0.11 ± 0.007	-0.14 ± 0.012

L: Harada et al. 2024

Fe/H: Hinkel et al. (2014)

$M_\odot$: priv. comm. Mark Giovinazzi, Amherst College

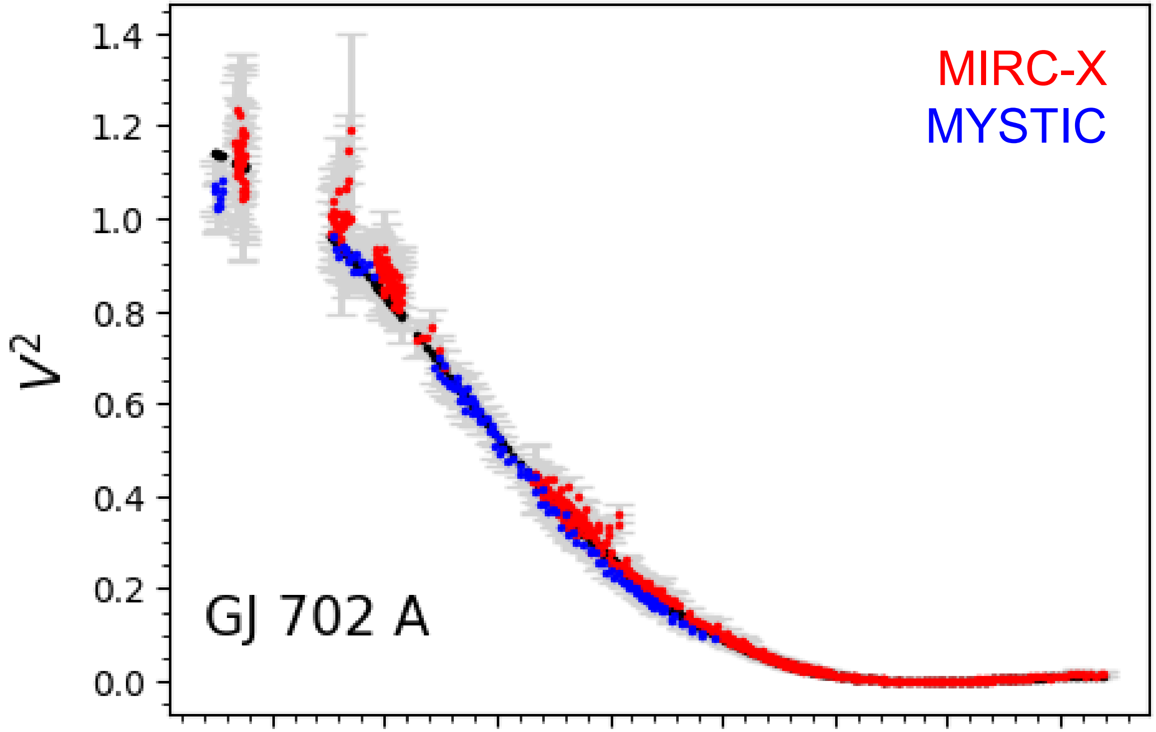
$$F_{bol} = \frac{L}{4\pi d^2}$$

$$T_{Eff} = \left(\frac{4F_{bol}}{\sigma\theta^2}\right)^{0.25}$$

GJ 702 AB

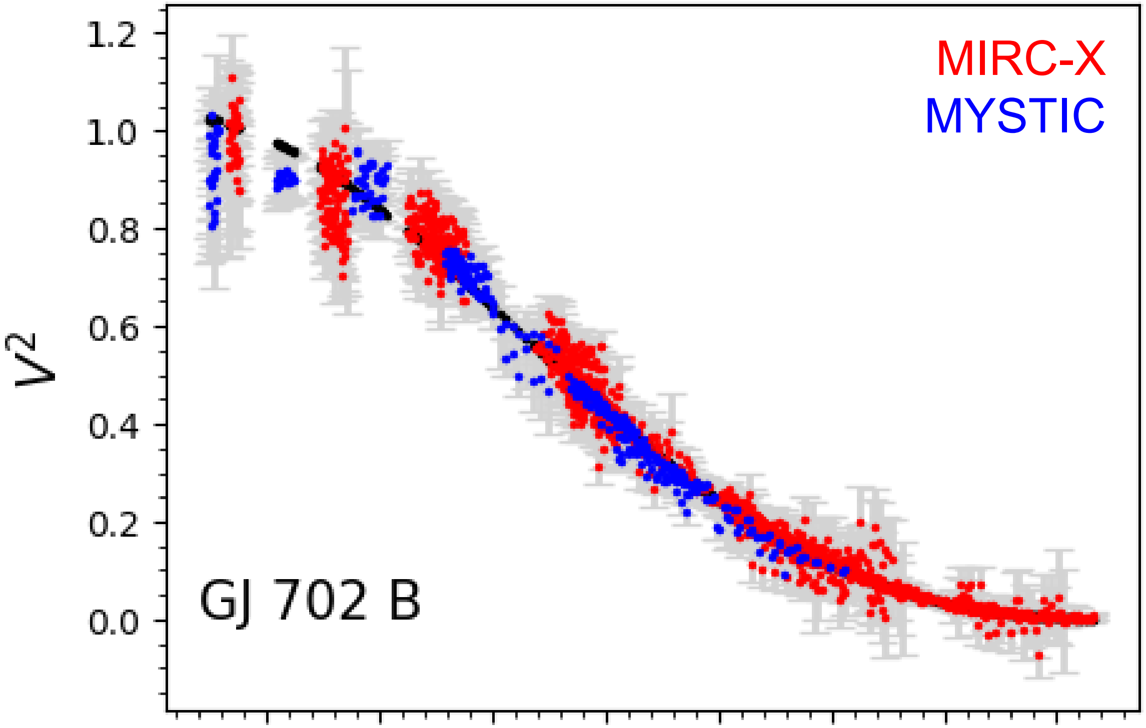
$\theta_{LD} = 1.538 \pm 0.001$ mas

$M = 0.890 \pm 0.020\ M_{\odot}$



$\theta_{LD} = 1.227 \pm 0.001$ mas

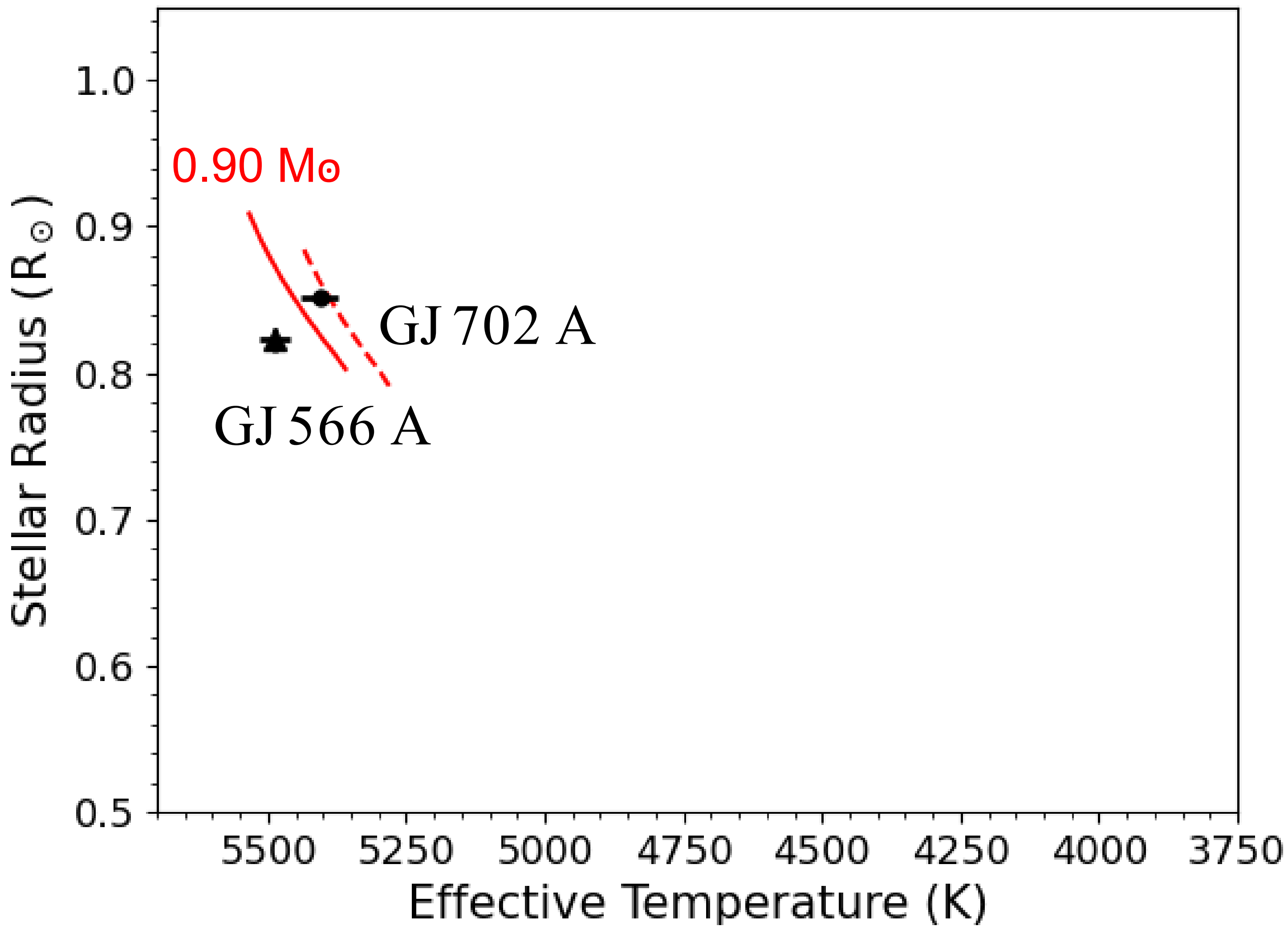
$M = 0.730 \pm 0.010\ M_{\odot}$



Masses from Eggenberger et al. 2008

Solar Metallicity Model Comparisons

- Primaries: 0.89, 0.95 $M_\odot$
- Secondaries: 0.73, 0.748 $M_\odot$



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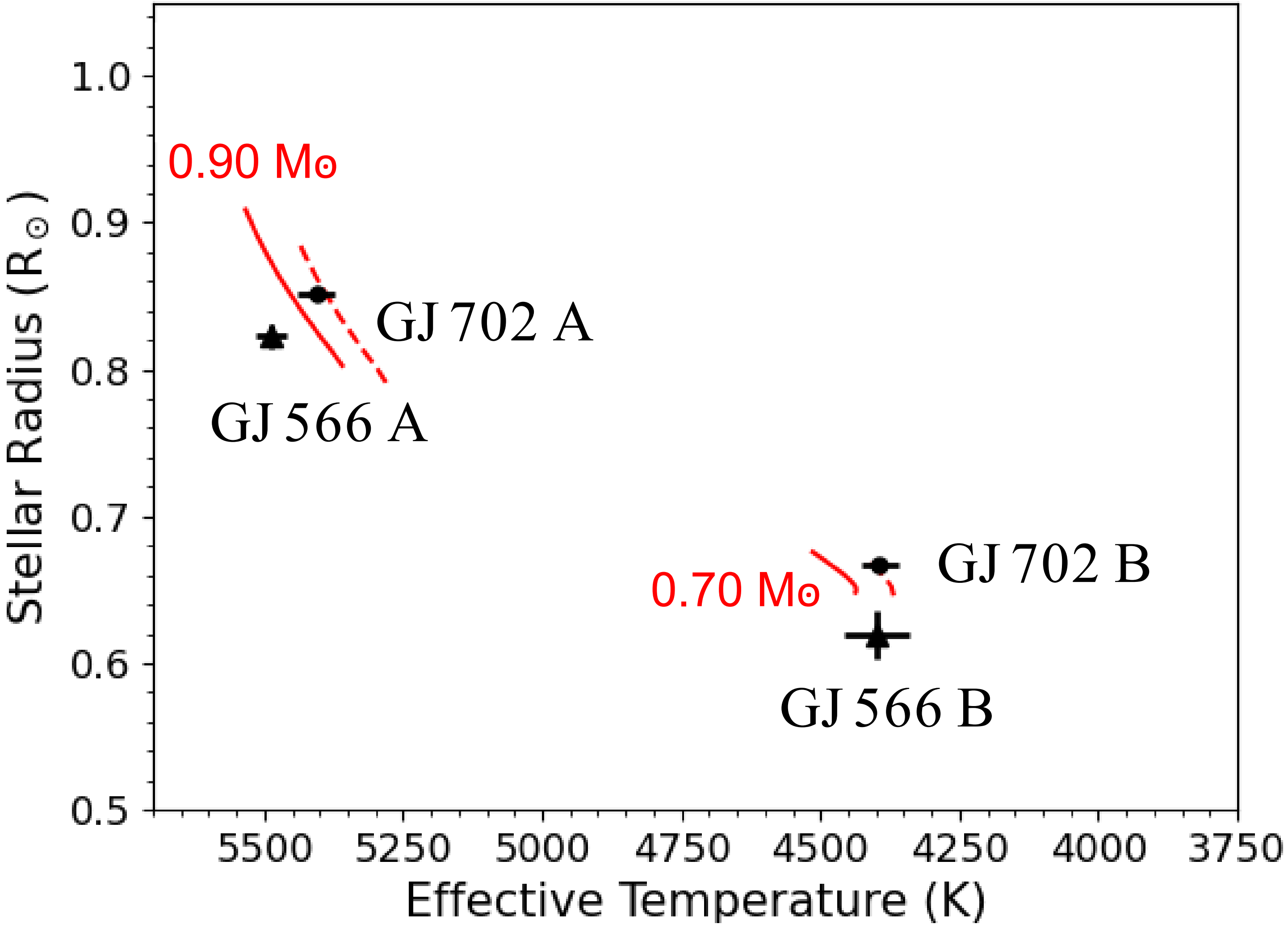

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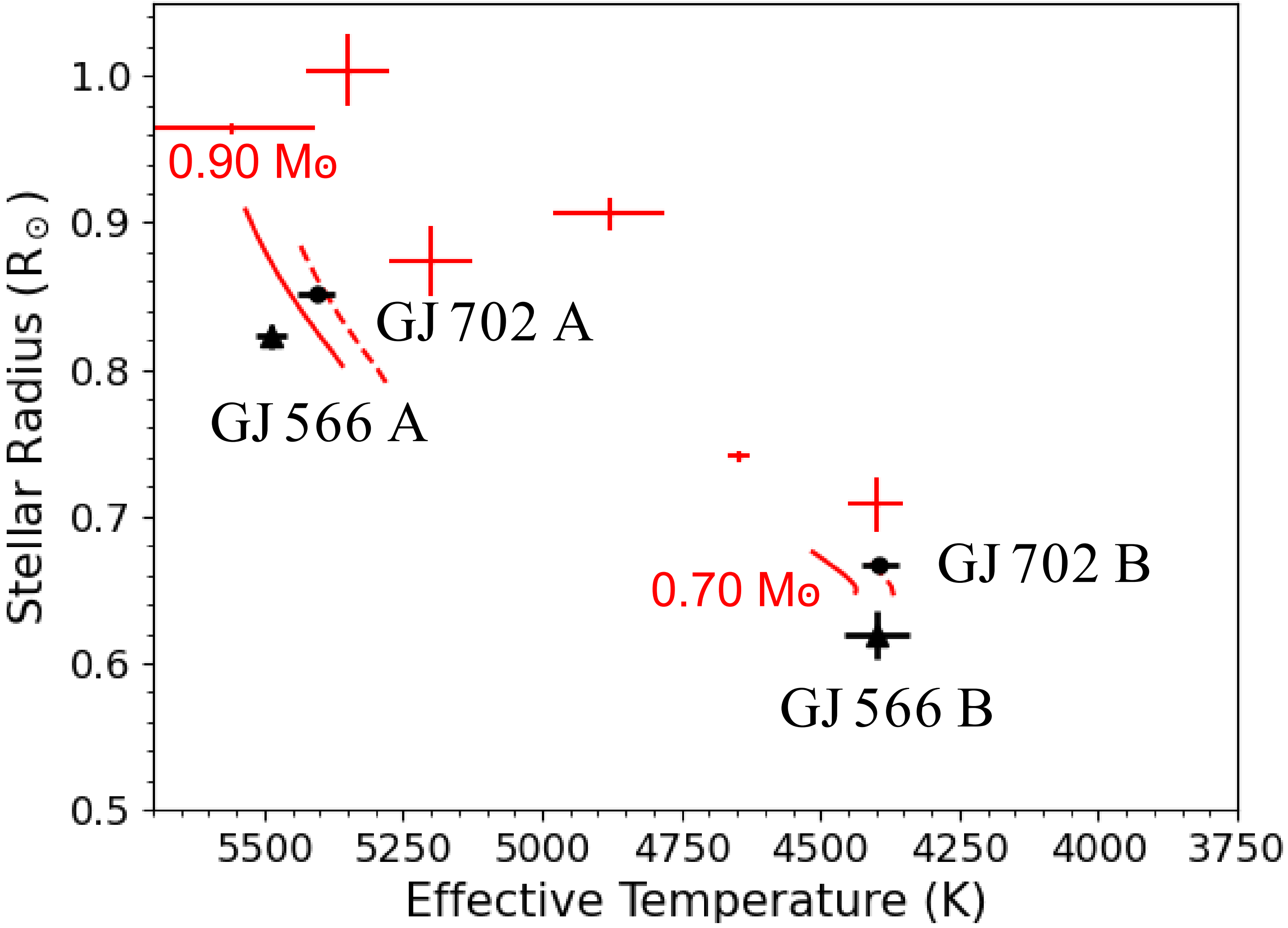
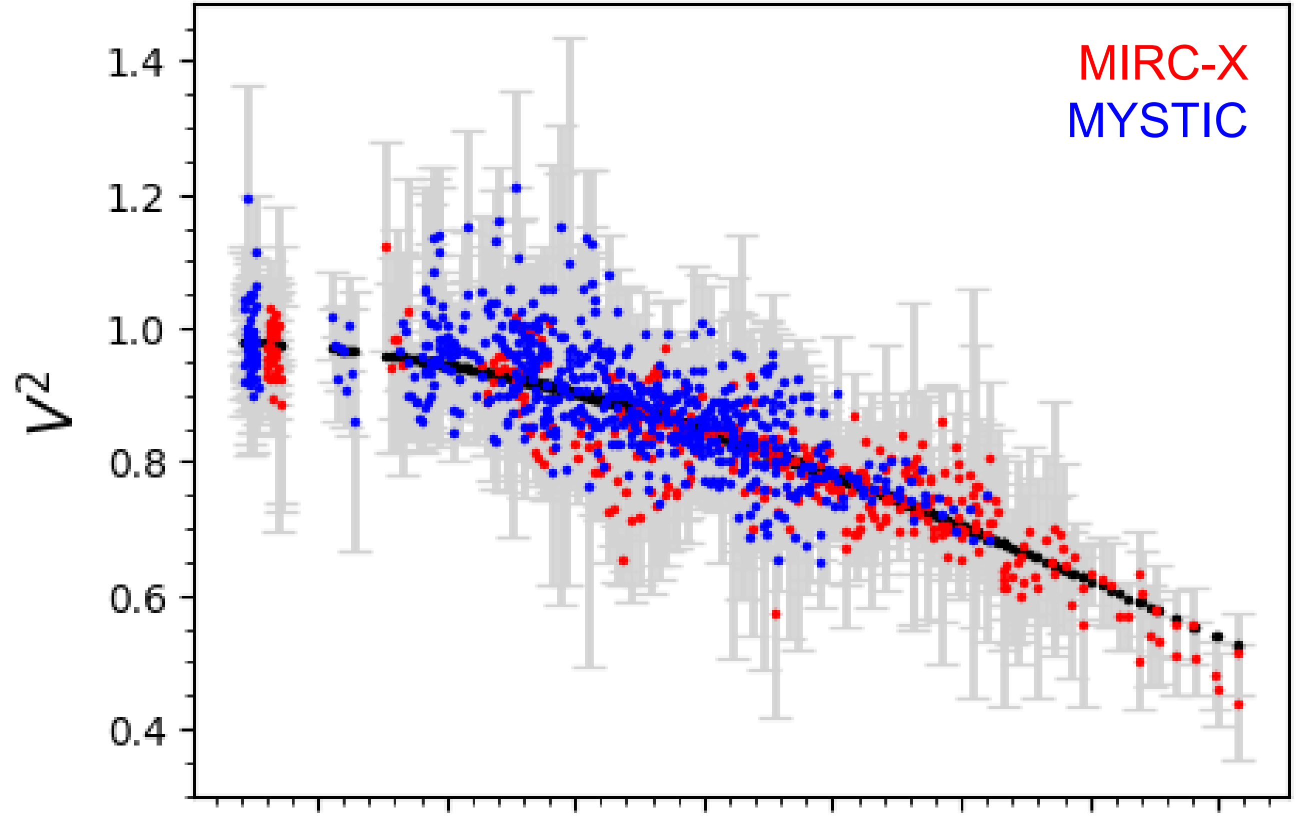


GJ 166 C

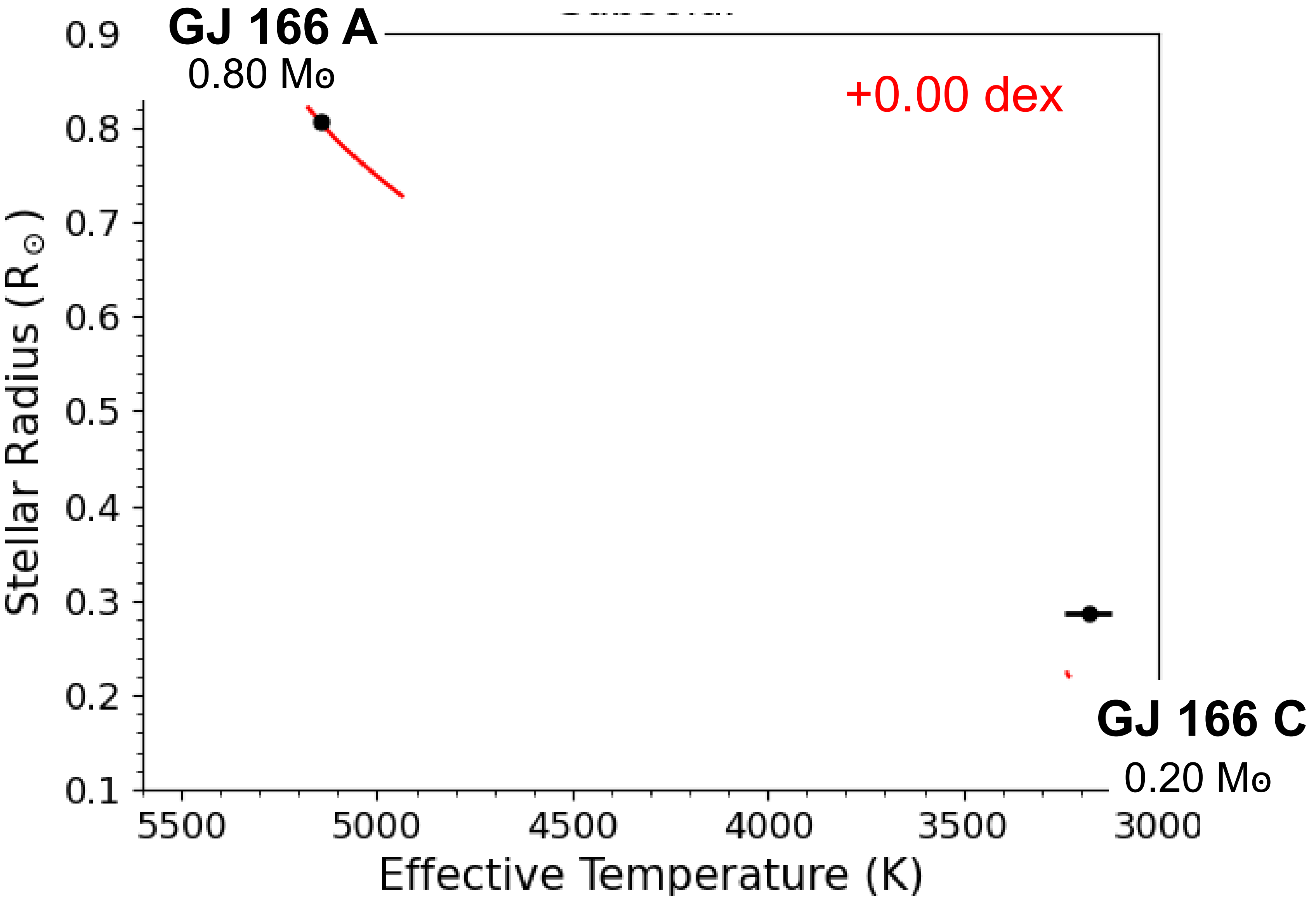
$\theta_{LD} = 0.534$ +/- 0.004 mas

$M = 0.2036$ +/- 0.0064 $M_{\odot}$

(Mason et al. 2017)



Model Comparisons



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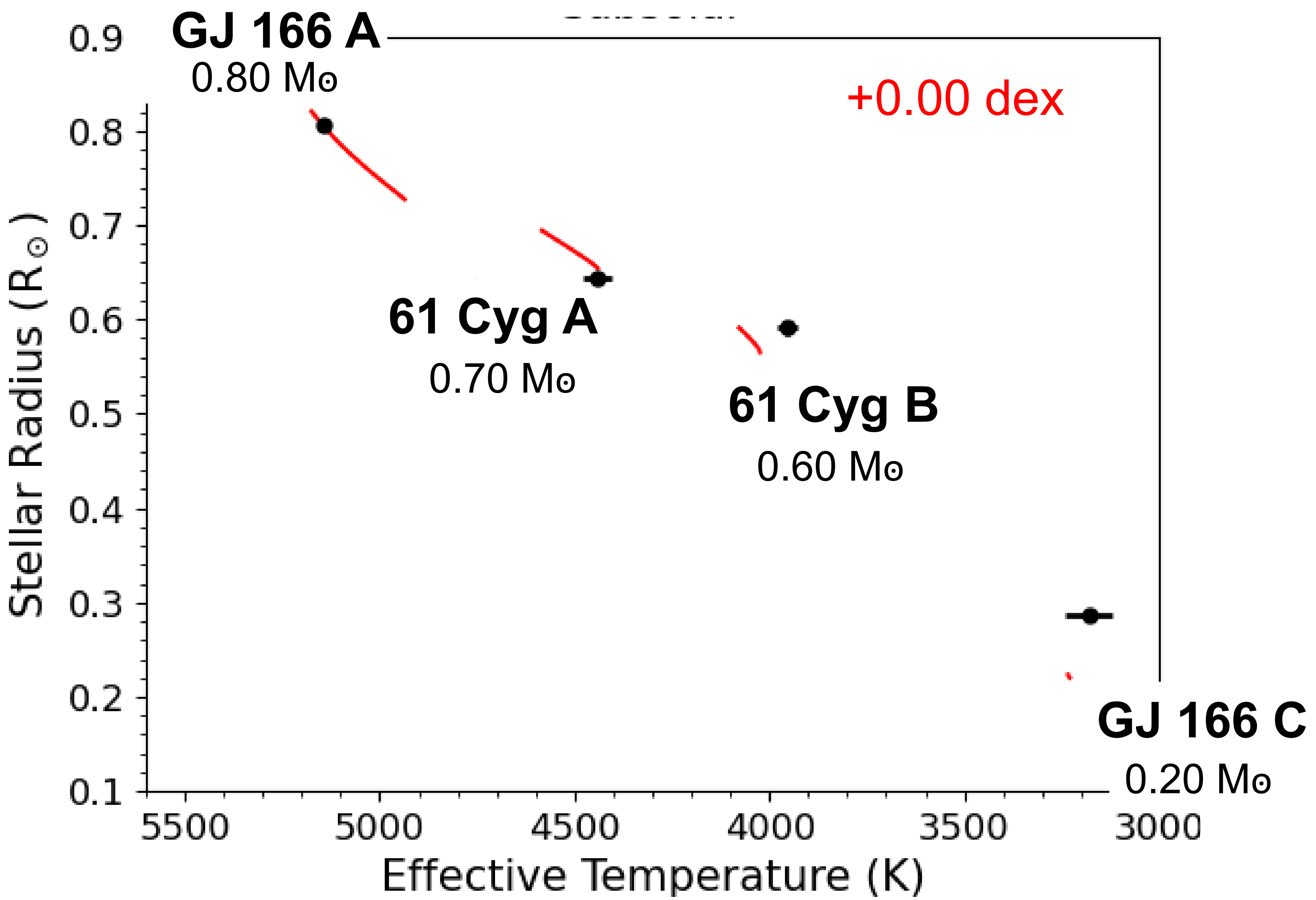

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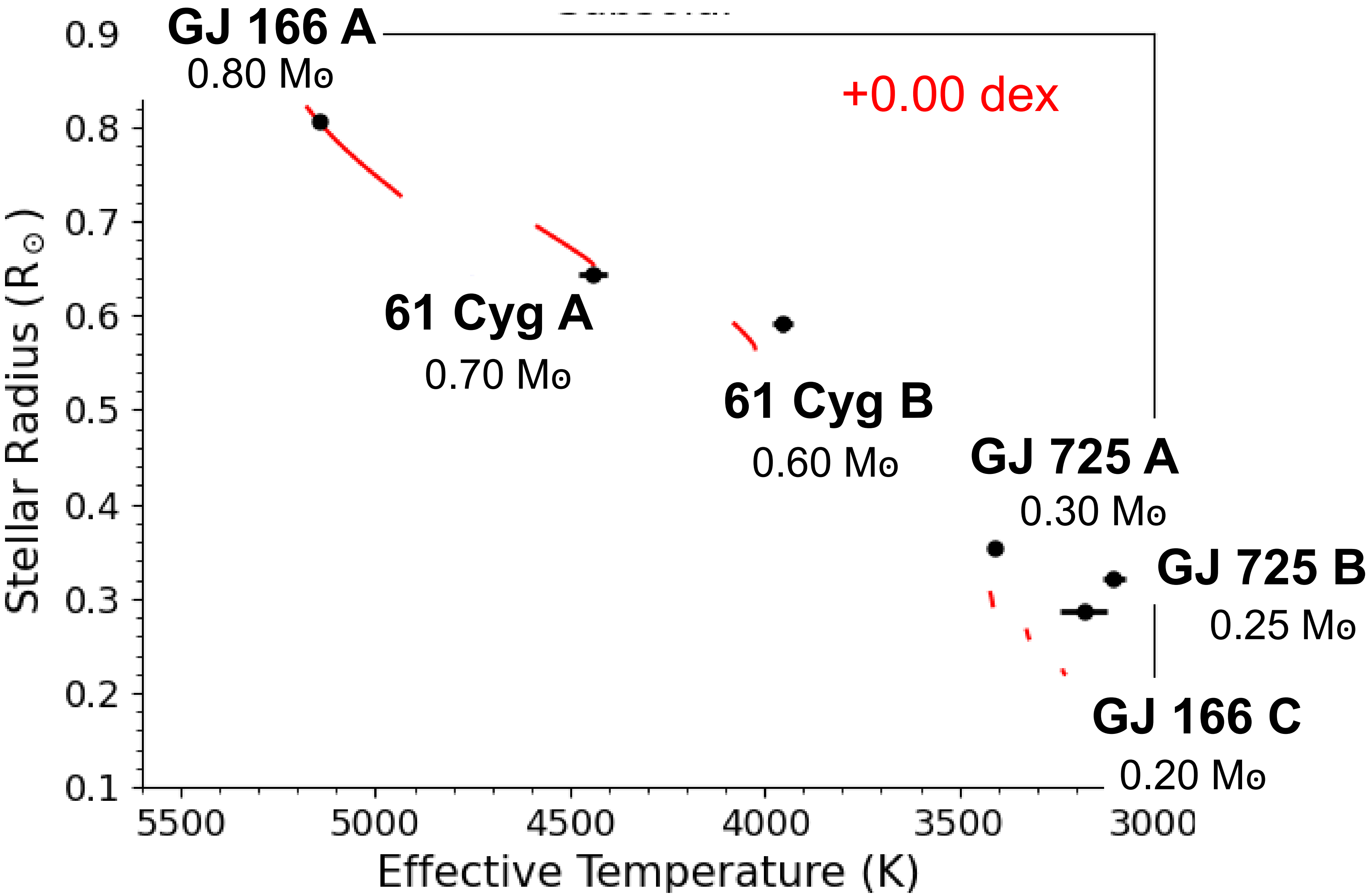
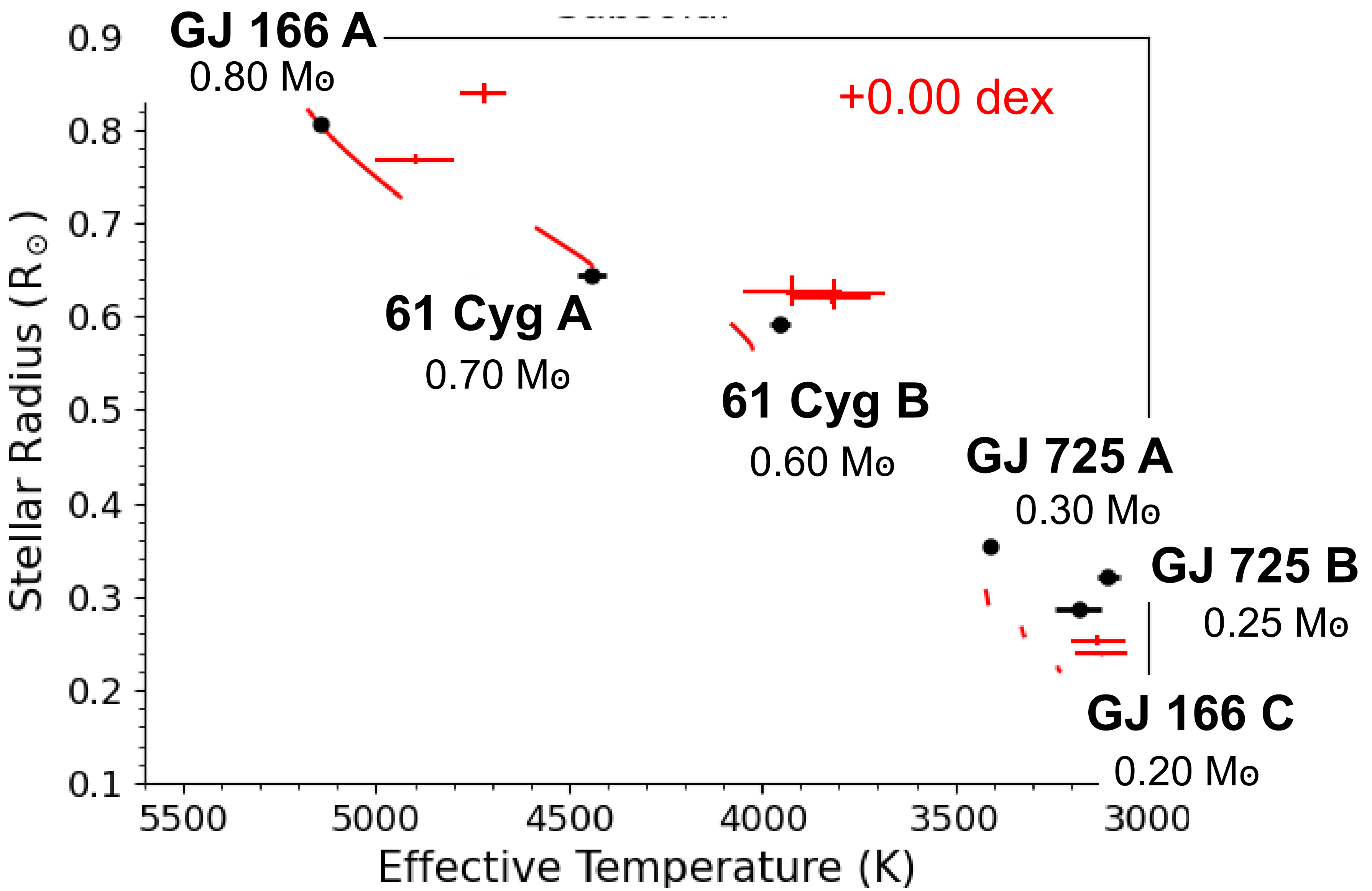
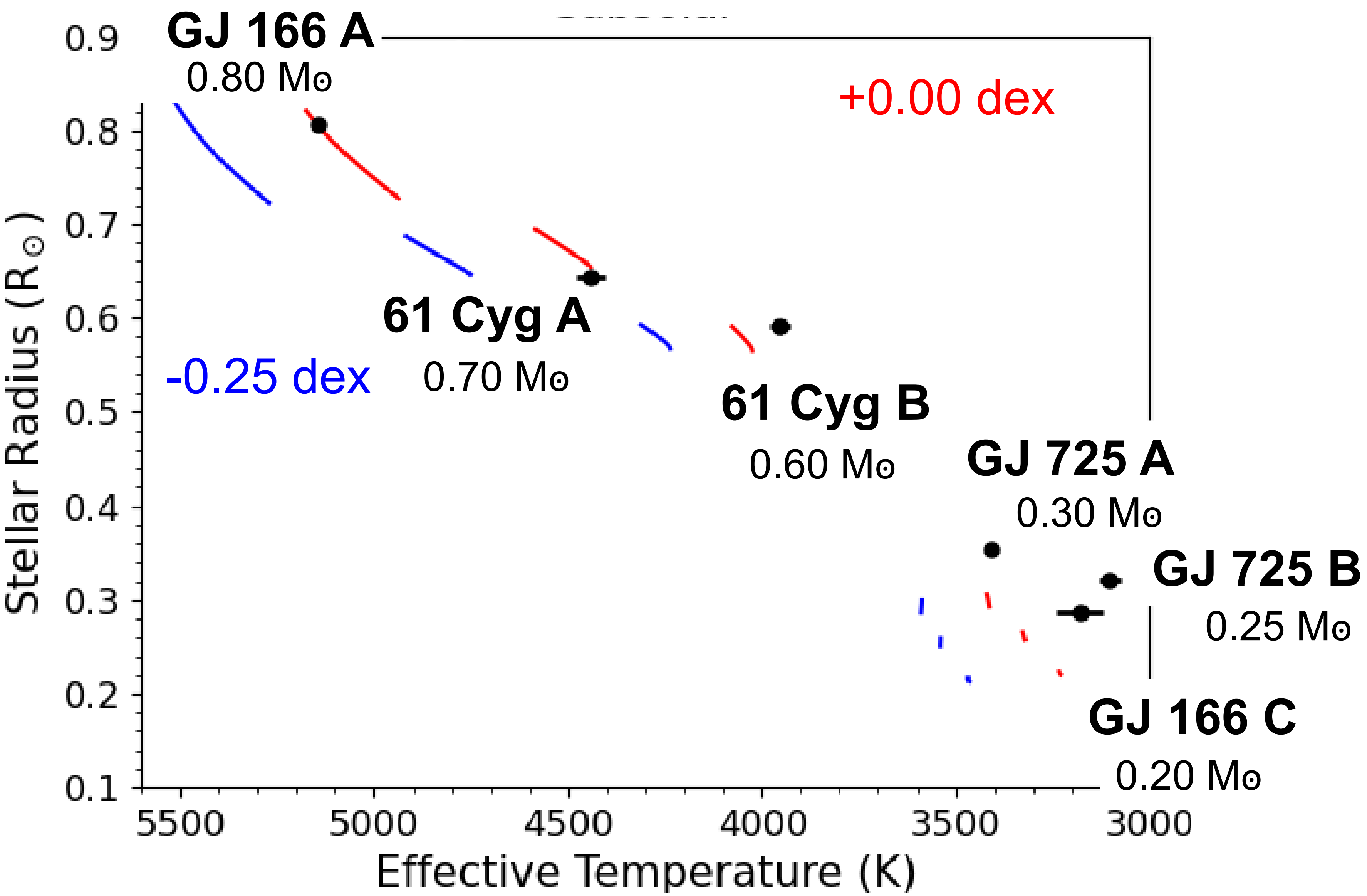


Model Comparisons



Metal Poor Model Comparisons



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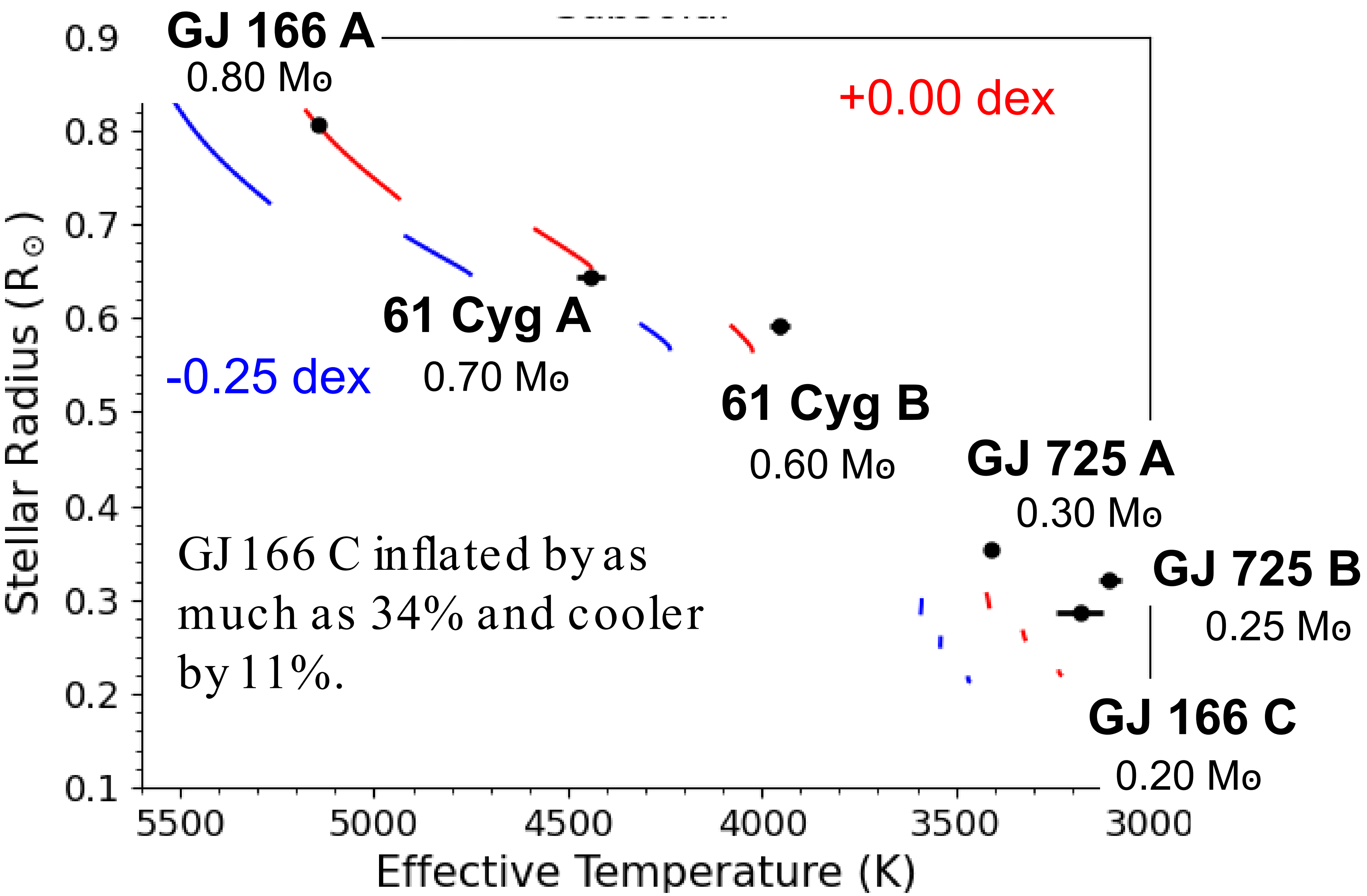

Final Remarks

Goal: Provide a sample of nearby low mass stars with precise M&R to test stellar evolution models

- ➢ Hope to get dynamical masses for most of the sample

So far, see a trend with metallicity once bias of short-period EB's removed

- Solar metallicity models agree well with observations
- Metal poor stars are significantly more inflated and/or cooler compared to models, likely unrecognized if assumed solar metallicity

- ➢ Results published soon ~Summer

- Expand sample with Dual Star Interferometry?