A Study of Rotation, Convection, and Activity Across the Kraft Break

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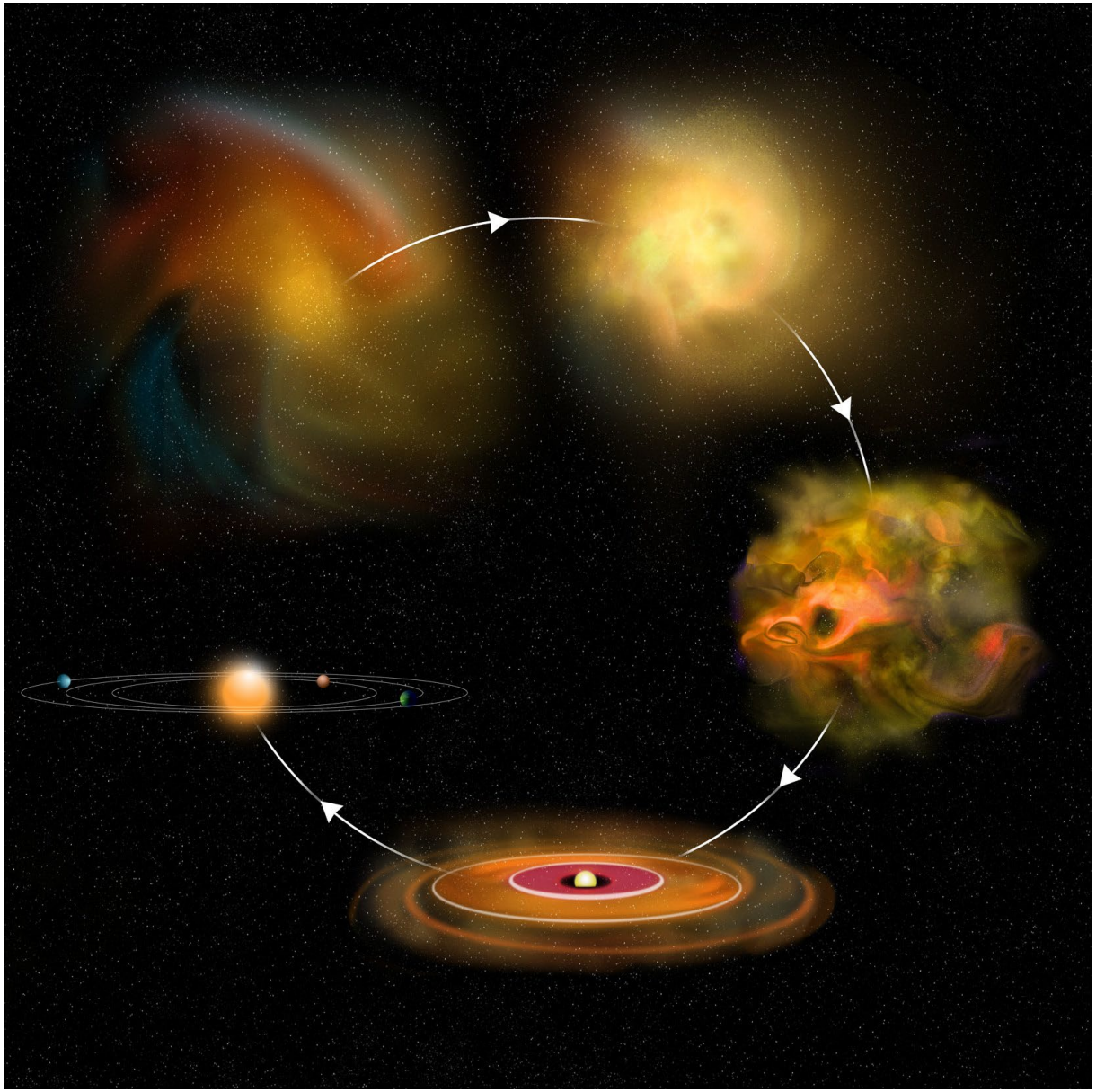
Rotation

Stars form from large gaseous nebula

Conservation of angular momentum causes stars to spin up



Courtesy of Bill Saxton, NRAO/AUI/NSF

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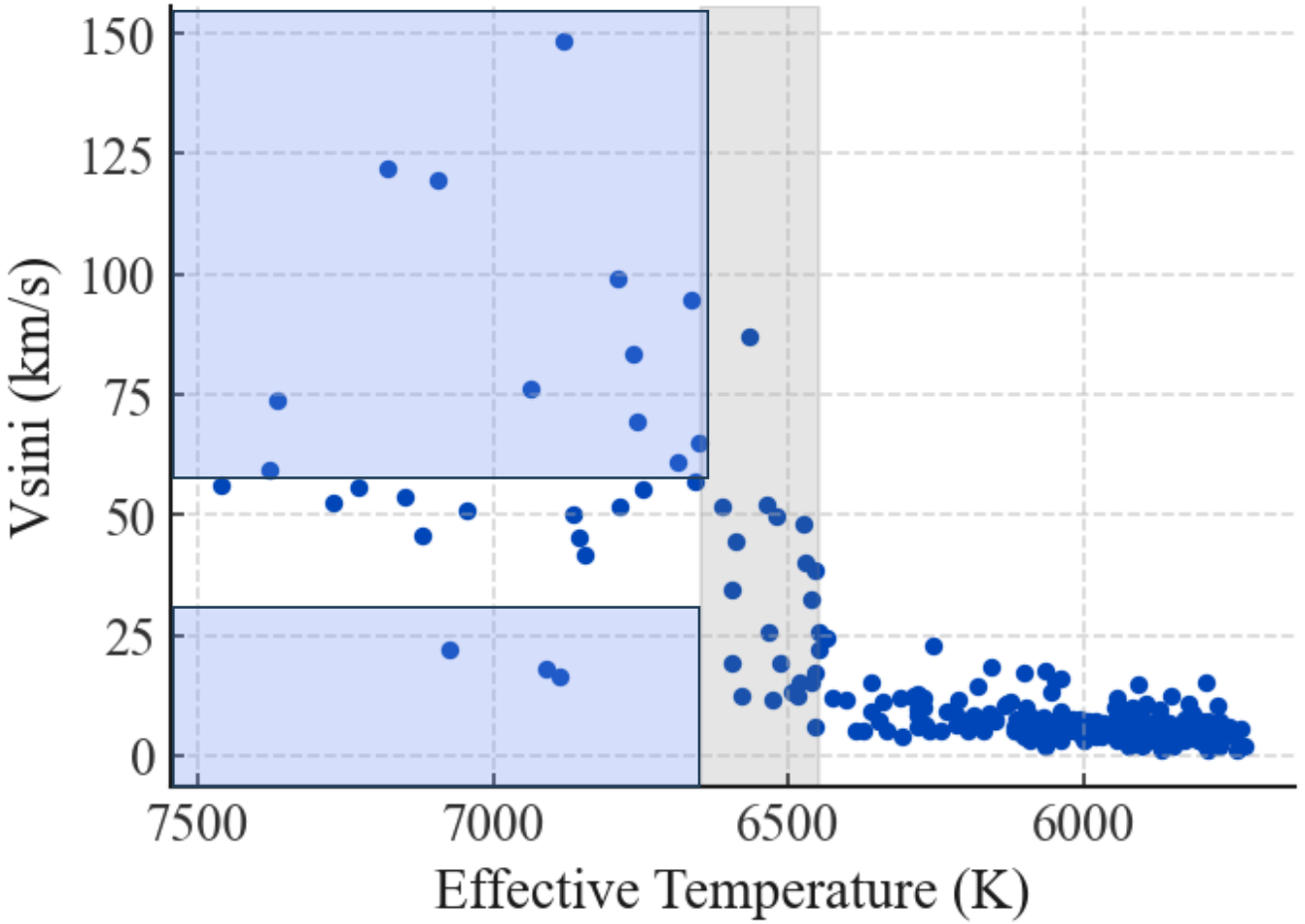
Rotation



- Not all stars remain rapidly rotating
- Separation between slow and rapid rotators at F4/F5
  - Kraft Break (Kraft 1967; Beyer & White 2024)
- The Coolest Rapid Rotators
- Some post-Kraft Break slow rotators

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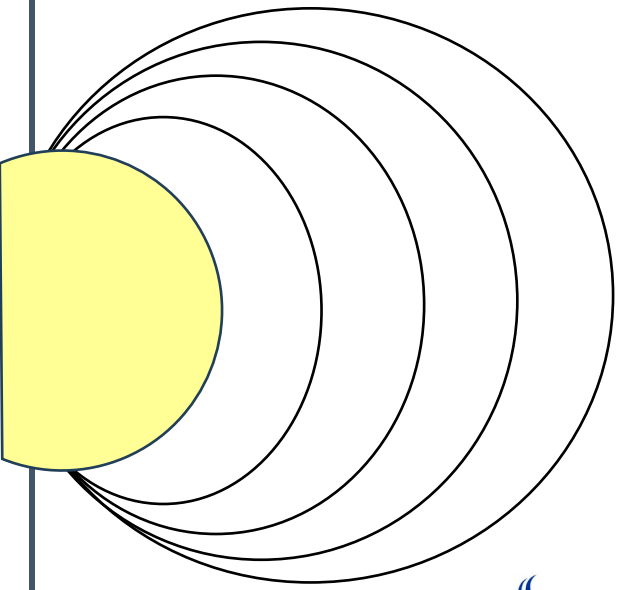
The Kraft Break and Convection

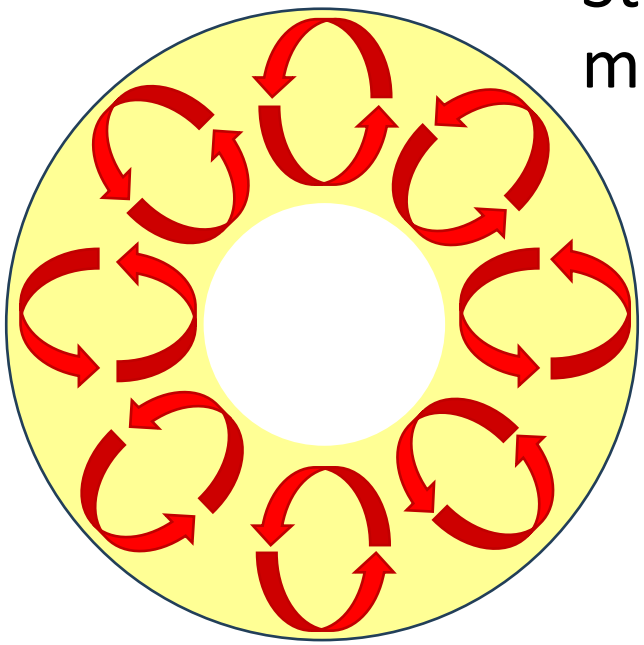
Why do stars spin down?

- Magnetic Braking
  - Stellar winds coupled with magnetic fields



Why does this only occur for stars cooler than F5?

- Convection
  - Stellar dynamo is necessary for magnetic field generation



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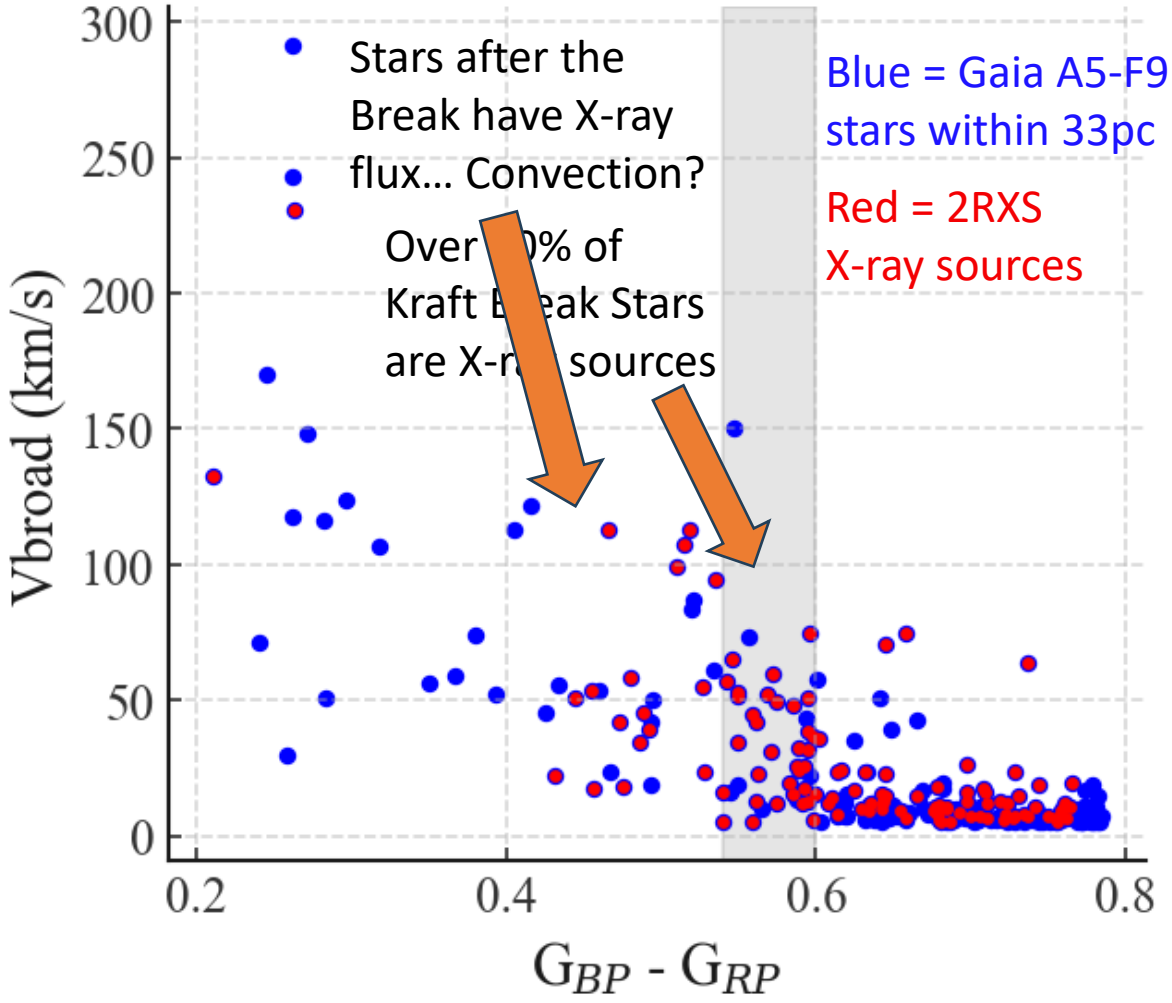
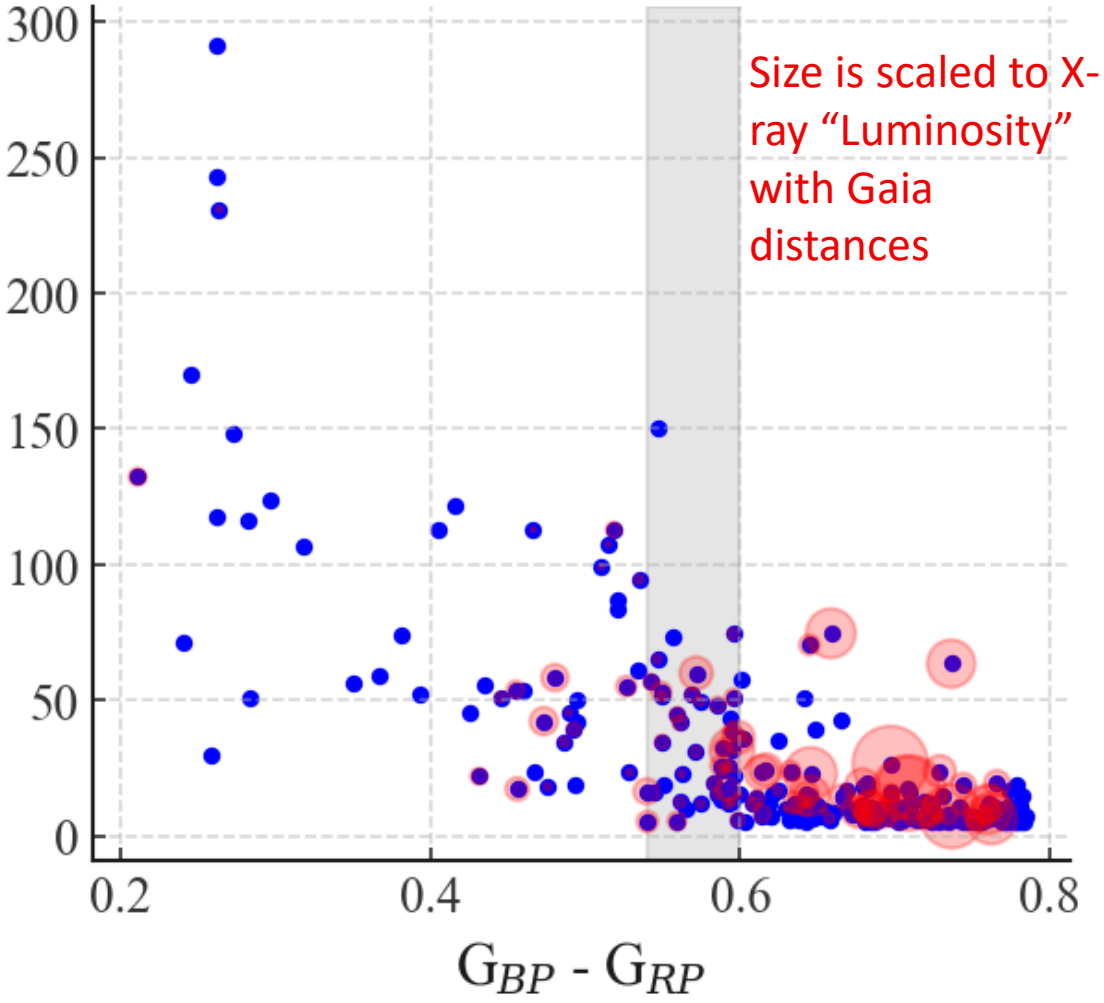
Convection and Activity





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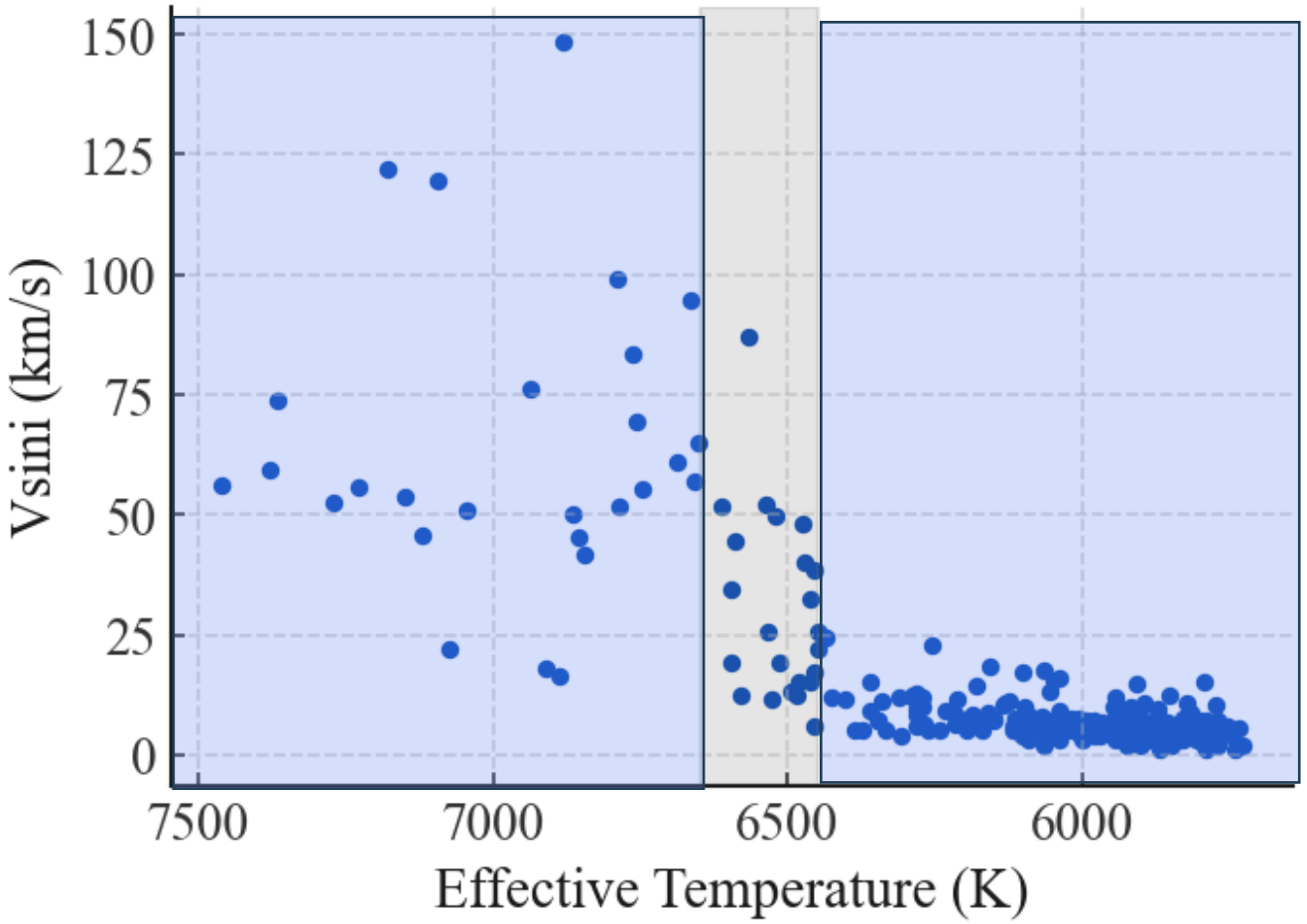
Why Stars spin slowly

What Happens When they spin fast



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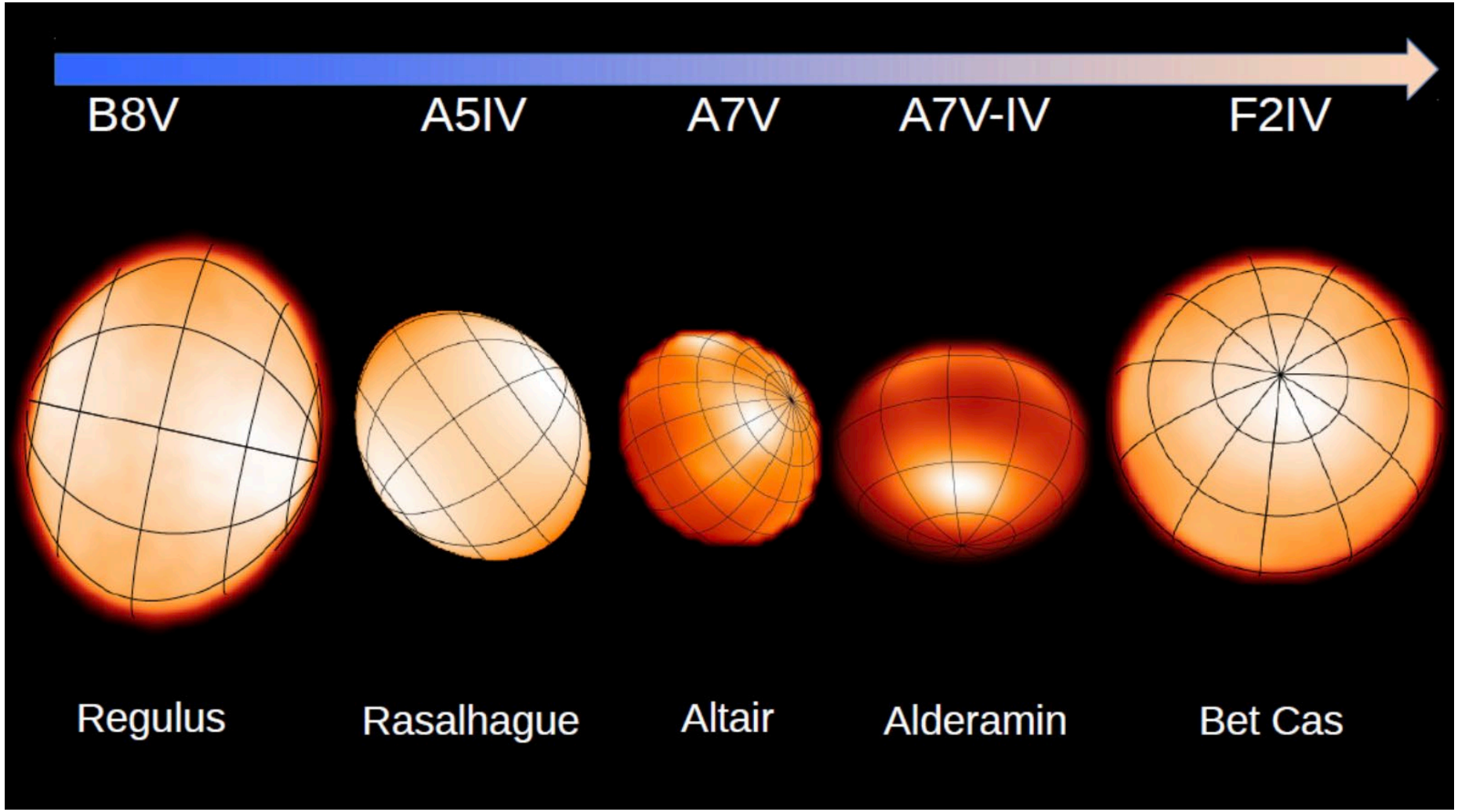
Gravity Darkening

Rapid rotation causes oblate stars

Equatorial regions are cooler and dimmer

Convection may be the reason behind discrepant gravity darkening profiles (e.g β Cas)



Credit: J. Monnier/CHARA

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Imaging the Coolest Rapid Rotators

Can gravity darkening cause convection and activity in the coolest rapidly rotating stars?

Search for Pole-on Rapid Rotators

Are hot slow rotators a product of inclination or a physical spin down mechanism?

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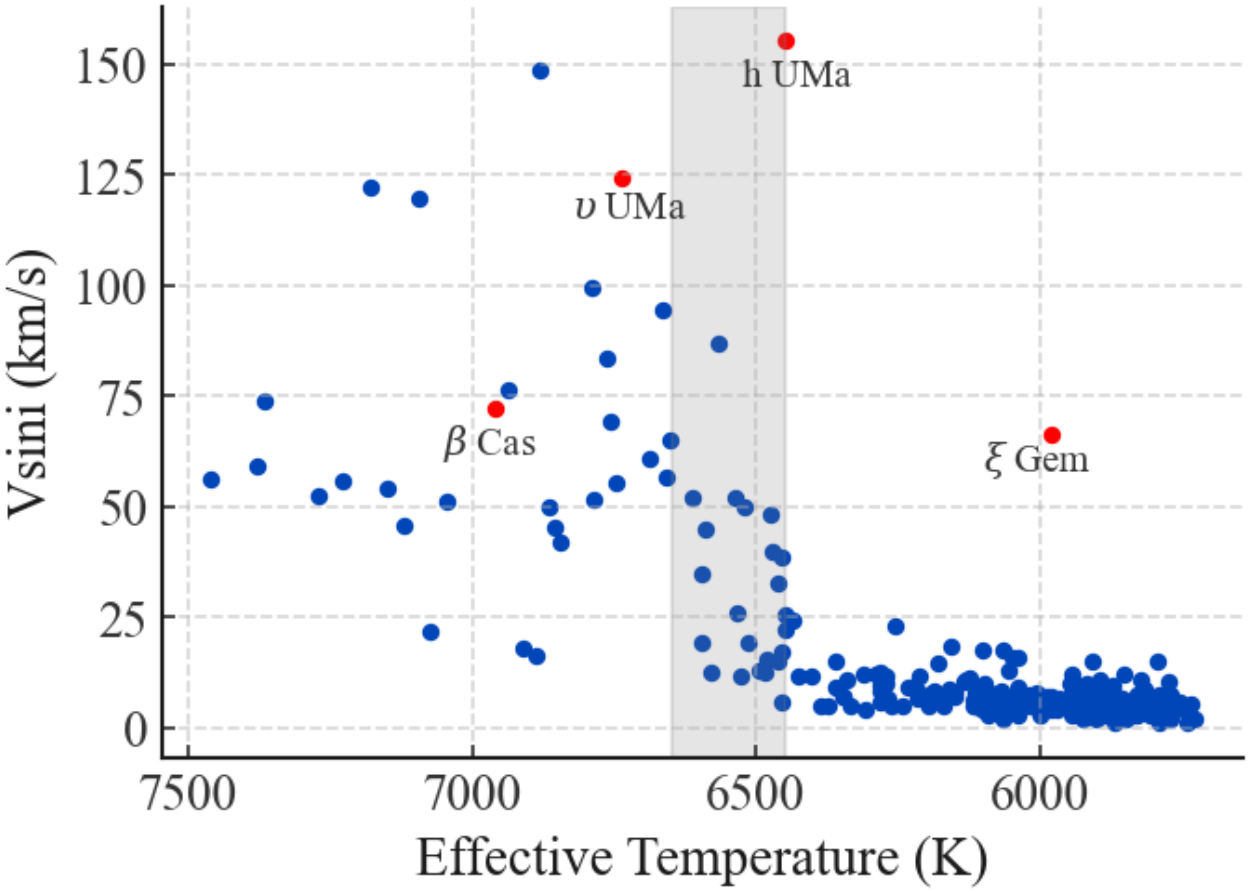
Imaging the Coolest Rapid Rotators

Sample

- F V & IV spectral types
- > 1.0 mas
  - Cruzalebes et al. 2019
- Vsini > 65 km/s
  - Shroder et al. 2009



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CHARA Observations

- This project had time:
  - March 2024
  - October 2024
  - March 2025
    - MIRC-X, MYSTIC, and SPICA
  - Were not able to get any usable on sky data

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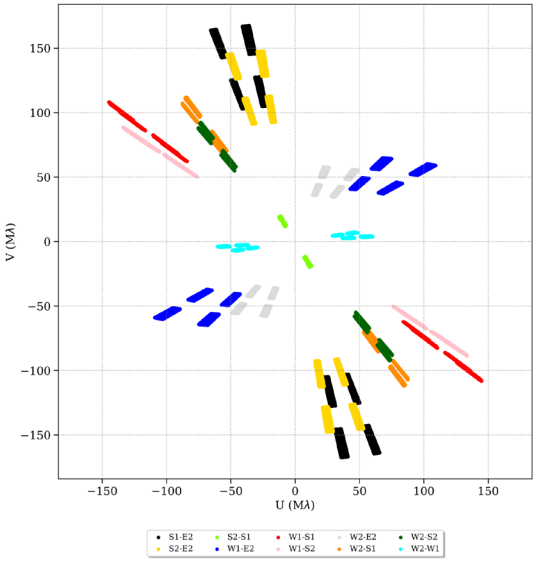
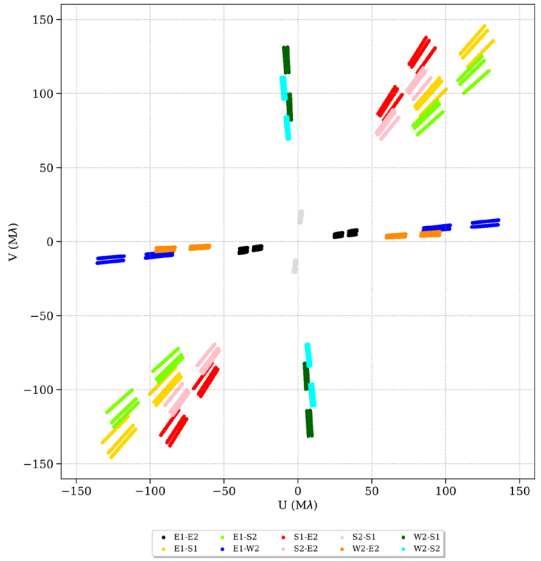
CHARA Observations

- December 2023
  - Jeremy Jones collected 2 brackets of 5T data ξ Gem
  - MIRC-X and MYSTIC
- Sept 2024 & Dec 2024
  - Justin Hom collected 1 bracket in Sept 2024 and 2 brackets in Dec 2024 on β Cas with 6T
  - MIRC-X and MYSTIC
- Special thank you to both for sharing their data





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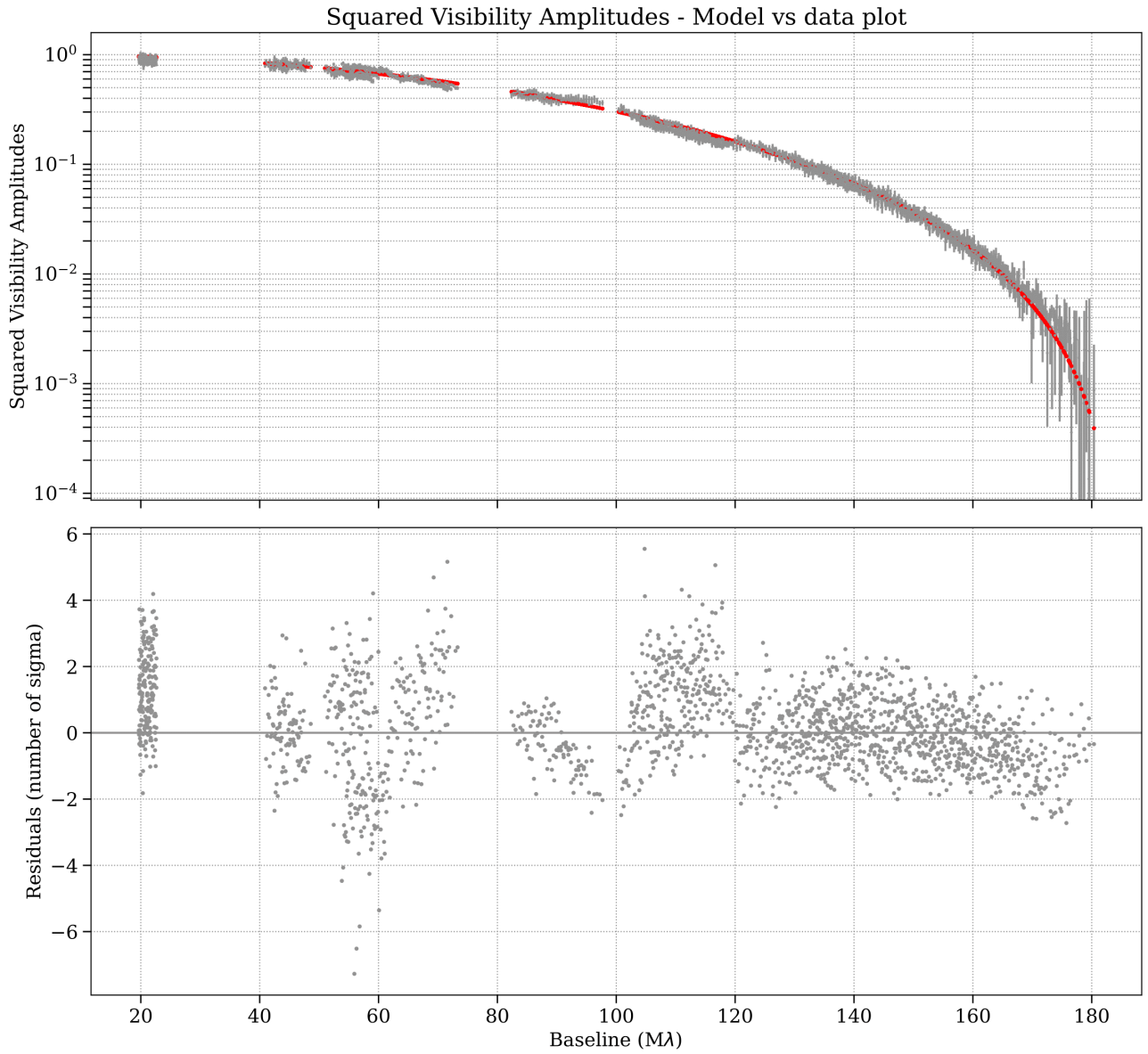
ξ Gem

- Measured UDD of 1.36 mas
  - Using OITOOLS model fitting routine
- Missing long baseline data
- 2nd lobe information necessary for determining darkening profiles



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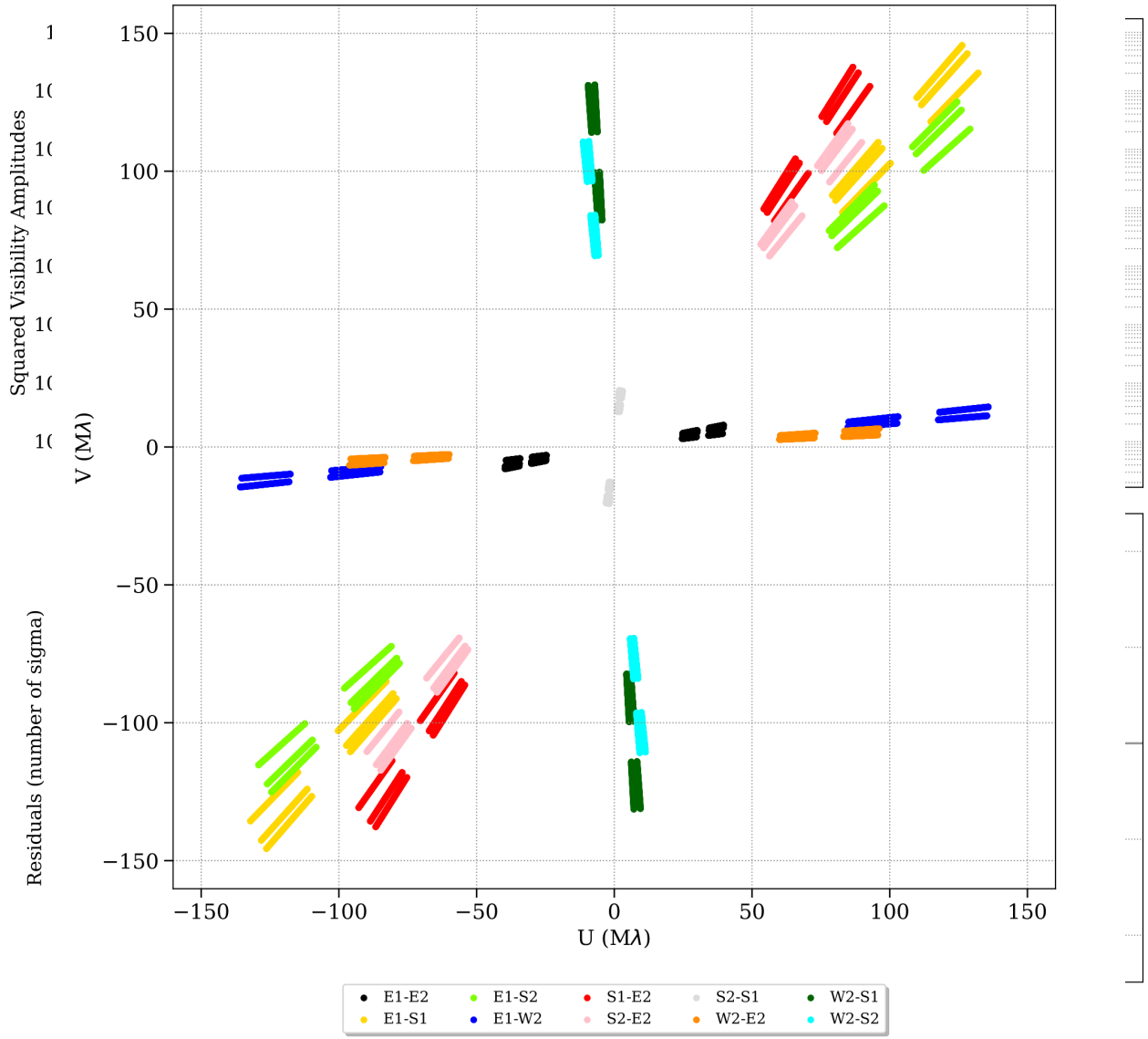
β Cas

- Noisy longer baseline data (Dec 2024)
  - Not used when measuring diameter/future image reconstructions
- Measured UDD of 1.98 mas
  - Using OITOOLS model fitting routine
  - Consistent with previous CHARA observations
    - Che et al. 2011



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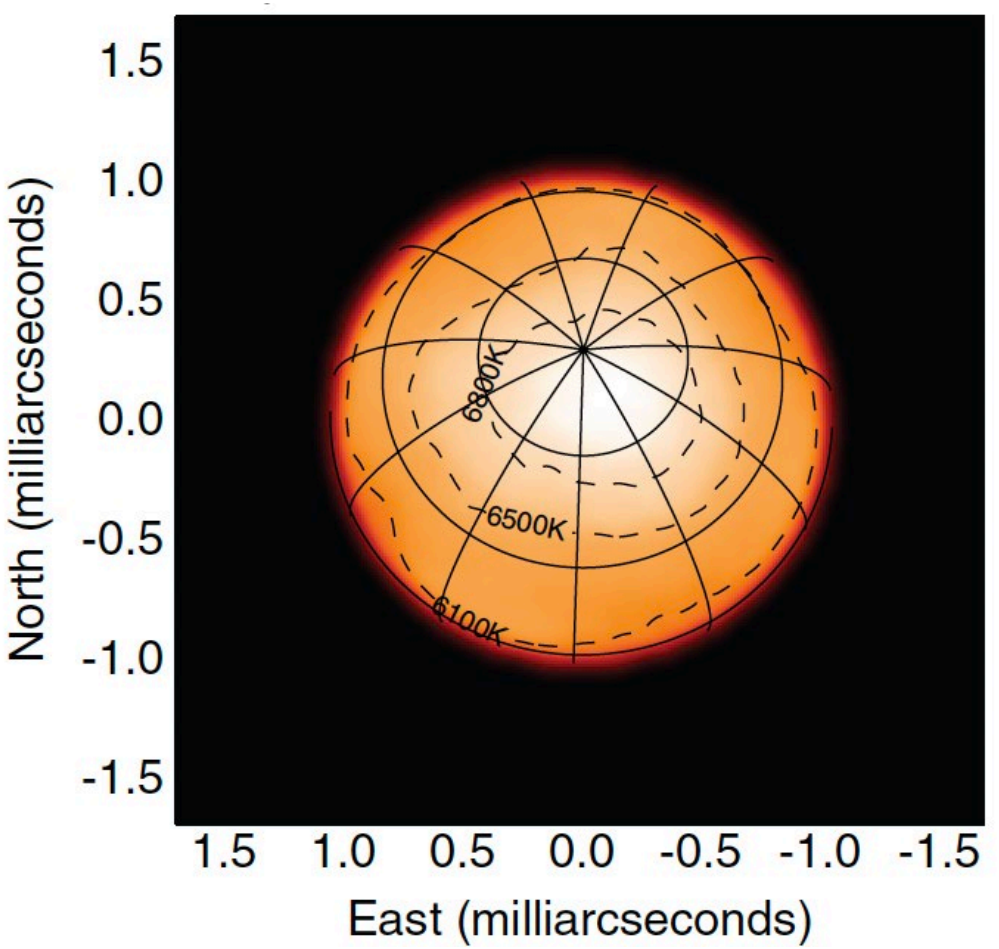
Future CHARA work

- Hopeful to get more observations
  - Trying to prioritize long baselines
- Use ROTIR2 to reconstruct images of the 4 Coolest Rapid Rotators (Thanks Fabien Baron)
- Separate limb darkening and gravity darkening
- Look for equatorial spots



Che et al. 2011

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The Search for Pole on Rapid Rotators

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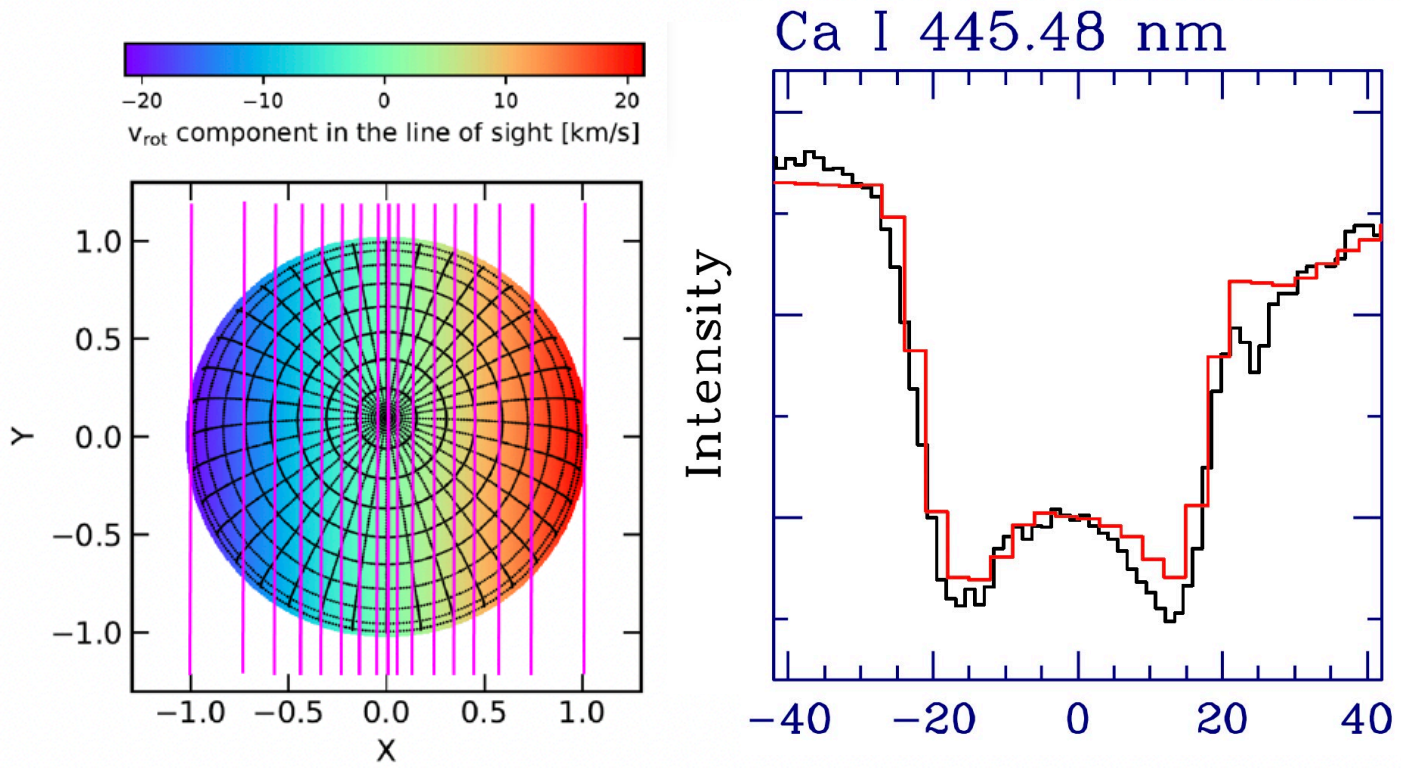
The Search for Pole on Rapid Rotators



Montesinos 2024

- Gravity darkening can cause changes in ionization fractions from the pole to the equator
- When seen near pole on this effect creates saddle shaped profile

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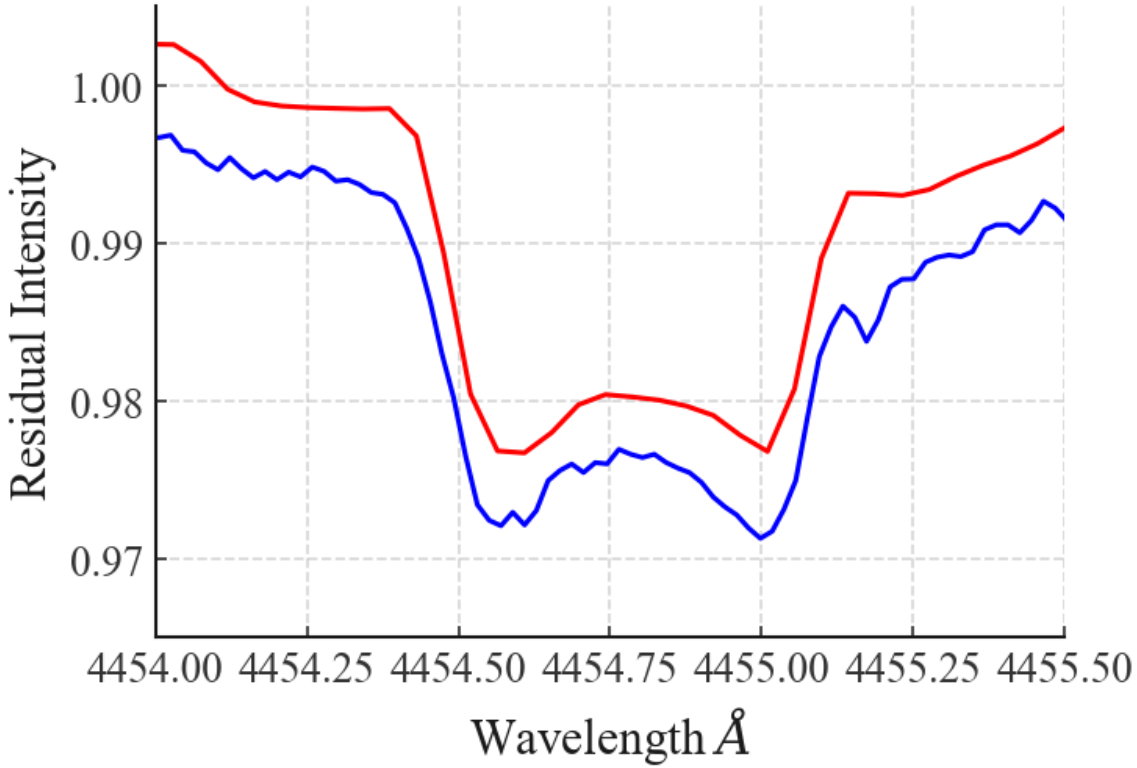
Vega the Known Pole-on Rapid Rotator

- Known Pole-on rapid rotator
  - Aufdenberg et al. 2006
  - Monnier et al. 2012
- Fastrot-spec able to model the saddle shaped profiles of Vega
- High S/N, high dispersion spectra shows the same profile
  - Takeda et al. 2007
- Can we find more like Vega?



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How Are We Looking for Them?

- Selected A and F stars with vsinis close to that of Vega (19 – 29 km/s)
  - Zorec & Royer 2012
- Excluded:
  - Close binaries
  - Chemically Peculiar stars
  - Stars dimmer G mag of 7.0

HD Number	SpTp	RA ^{o}	DEC ^{o}	G mag	vsini km s^{-1}	logT K	Observed?
197541	F0IV/V	311.34937	-30.47821	6.71	29	3.844 ± 0.002	
193432	B9IV	305.16590	-12.75908	4.75	24	4.004 ± 0.003	
161840	B8V	267.29365	-31.70321	4.76	24	4.044 ± 0.003	Y
101615	A0V	175.33246	-43.09567	5.53	19	3.982 ± 0.004	
96723	A1V	167.06574	-29.97249	6.47	23	3.956 ± 0.005	Y
87344	B8V	151.01171	-18.10141	6.25	28	4.029 ± 0.002	
80094	B7IV	138.82350	-58.38838	6.00	24	4.109 ± 0.003	Y
75469	A2Vs	132.68801	+18.83218	6.40	19	3.975 ± 0.007	
68423	B6Ve	122.10267	-63.80082	6.31	26	4.092 ± 0.003	Y
54834	A9V	107.46735	-16.23473	6.55	23	3.857 ± 0.002	Y
44783	B8Vn	096.00951	+08.88501	6.23	22	4.043 ± 0.002	Y
43179	B7V	093.38950	-29.39574	6.51	24	4.092 ± 0.003	
42035	B9V	092.19596	+08.66943	6.53	24	4.019 ± 0.002	
40446	A1Vs	089.70655	+00.55298	5.19	27	3.980 ± 0.007	Y
40136	F1V	089.10122	-14.16770	3.64	26	3.846 ± 0.003	Y
39985	A0IV	089.11681	+09.50940	5.96	28	4.011 ± 0.002	Y
39945	A5V	088.66316	-26.66027	6.82	20	3.914 ± 0.011	Y
37788	F0IV	085.27331	+00.33775	5.85	29	3.852 ± 0.002	Y
28114	B6IV	066.58793	+08.59027	6.03	24	4.150 ± 0.003	Y
10538	A0V	025.51247	-36.83231	5.70	20	3.985 ± 0.006	Y

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How Are We Looking for Them?

- SMARTS/CTIO 1.5m telescope with CHIRON echelle spectrograph
- Using the slit mode
  - (R ~ 90,000)
- 13 of the 20 have already been observed

HD Number	SpTp	RA ^{o}	DEC ^{o}	G mag	vsini km s^{-1}	logT K	Observed?
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28114	B6IV	066.58793	+08.59027	6.03	24	4.150 ± 0.003	Y
10538	A0V	025.51247	-36.83231	5.70	20	3.985 ± 0.006	Y

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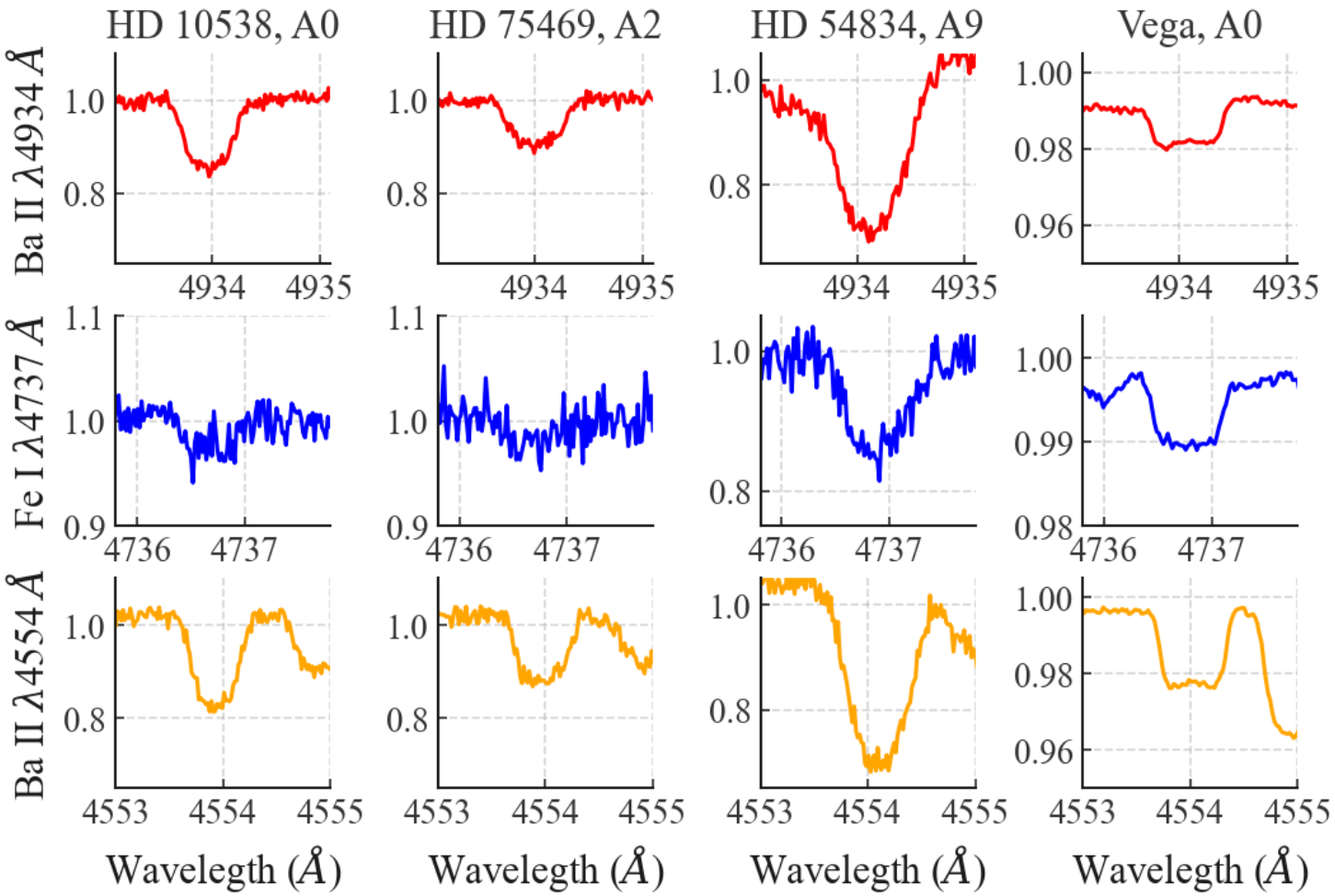
Results and Future Work



- None of the spectral lines examined have shown the saddle shaped profiles
- Still have stars in the observing queue

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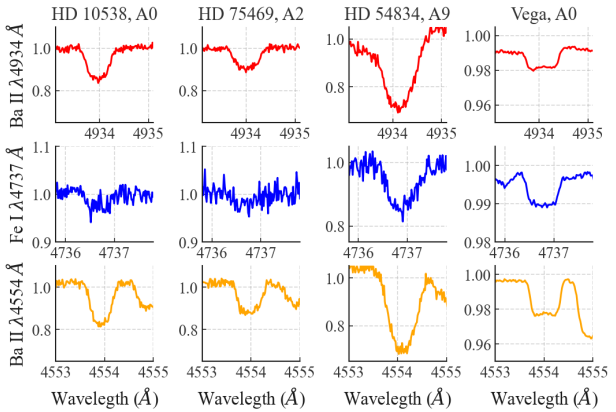
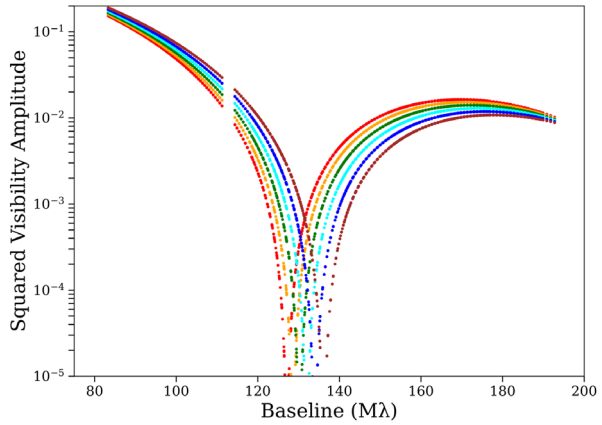
Summary



Imaging the Coolest Rapid Rotators

- Can gravity darkening induce convection, activity?
- More long baseline data is necessary to search for signatures (e.g. darkening profiles, spots)



The Search for Pole-on Rapid Rotators

- Saddle shape profiles of Vega are able to be modelled
- None of the 13 Vega like stars show this signature
- More spectra are in CHIRON observing queue

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Thank you

Question?

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