Imaging of Massive Evolved Stars at CHARA

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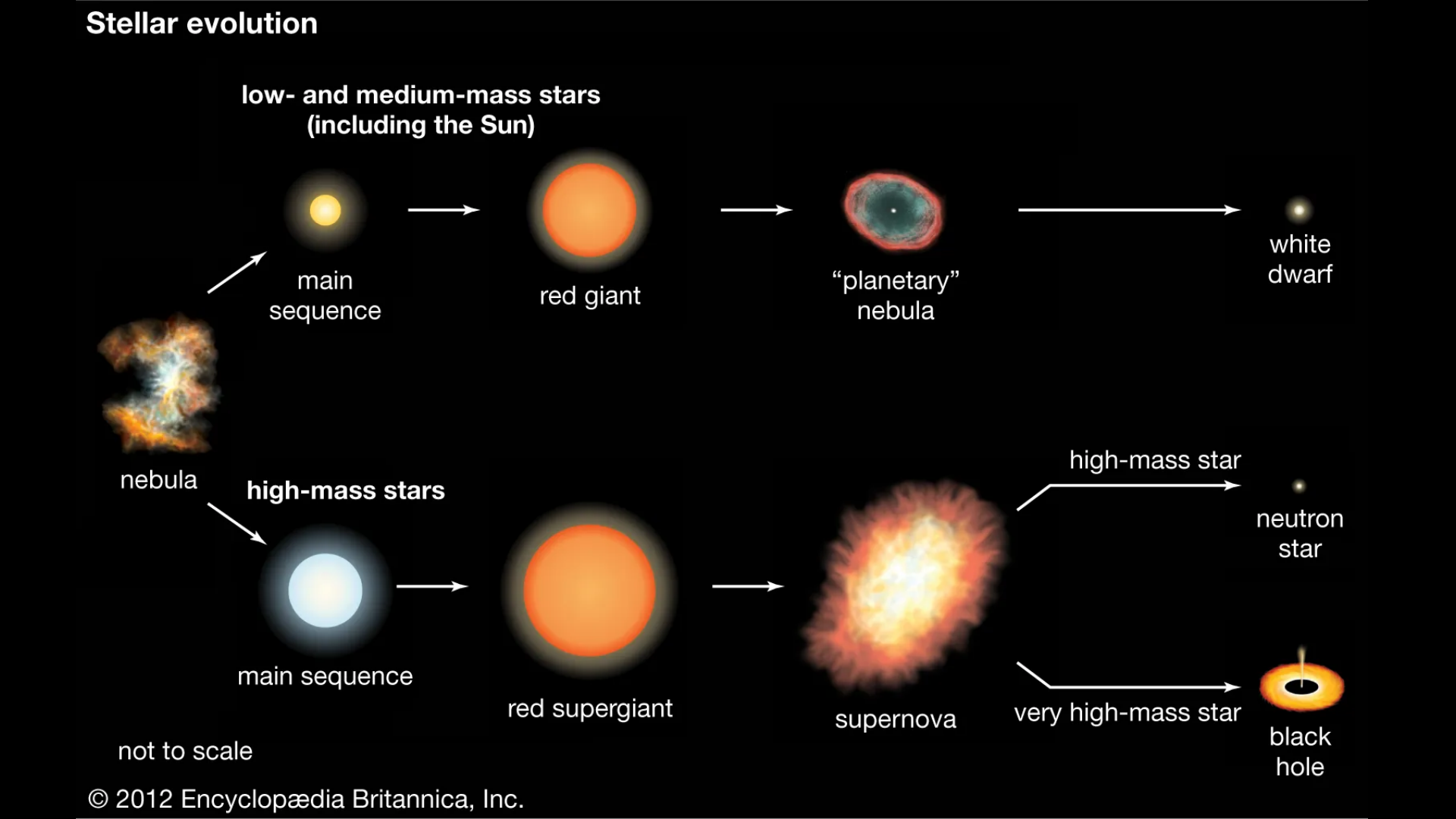
CHARA Science Meeting 2025, Apr 28-30, Nice, France


Stellar evolution
low- and medium-mass stars
(including the Sun)
main
sequence
red giant
“planetary”
nebula
white
dwarf
nebula
high-mass stars
high-mass star
neutron
star
main sequence
red supergiant
supernova
very high-mass star
black
hole
not to scale
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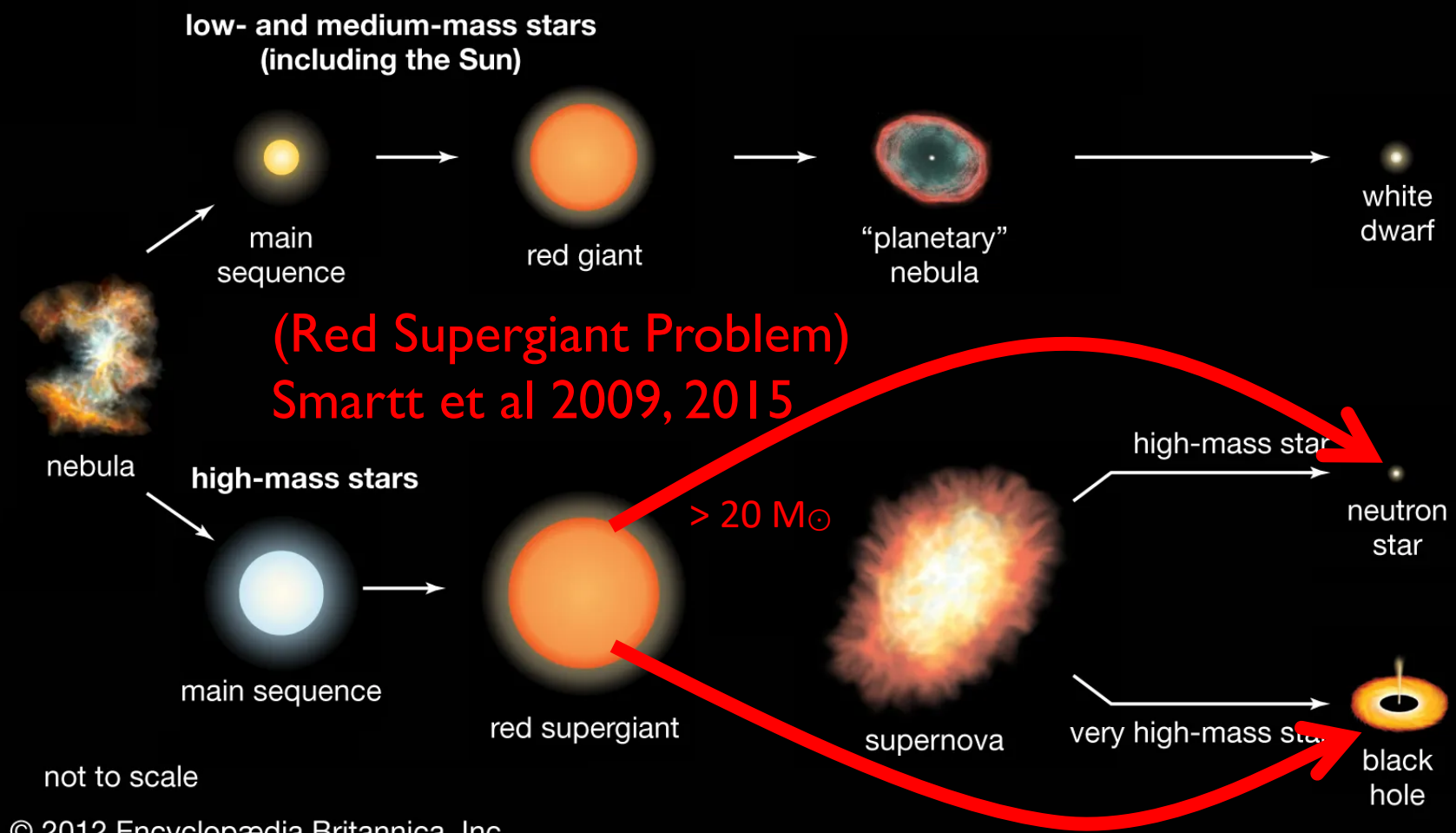
Stellar evolution
low- and medium-mass stars
(including the Sun)
main
sequence
red giant
"planetary"
nebula
white
dwarf
nebula
(Red Supergiant Problem)
Smartt et al 2009, 2015
high-mass stars
> 20 M⊙
high-mass star
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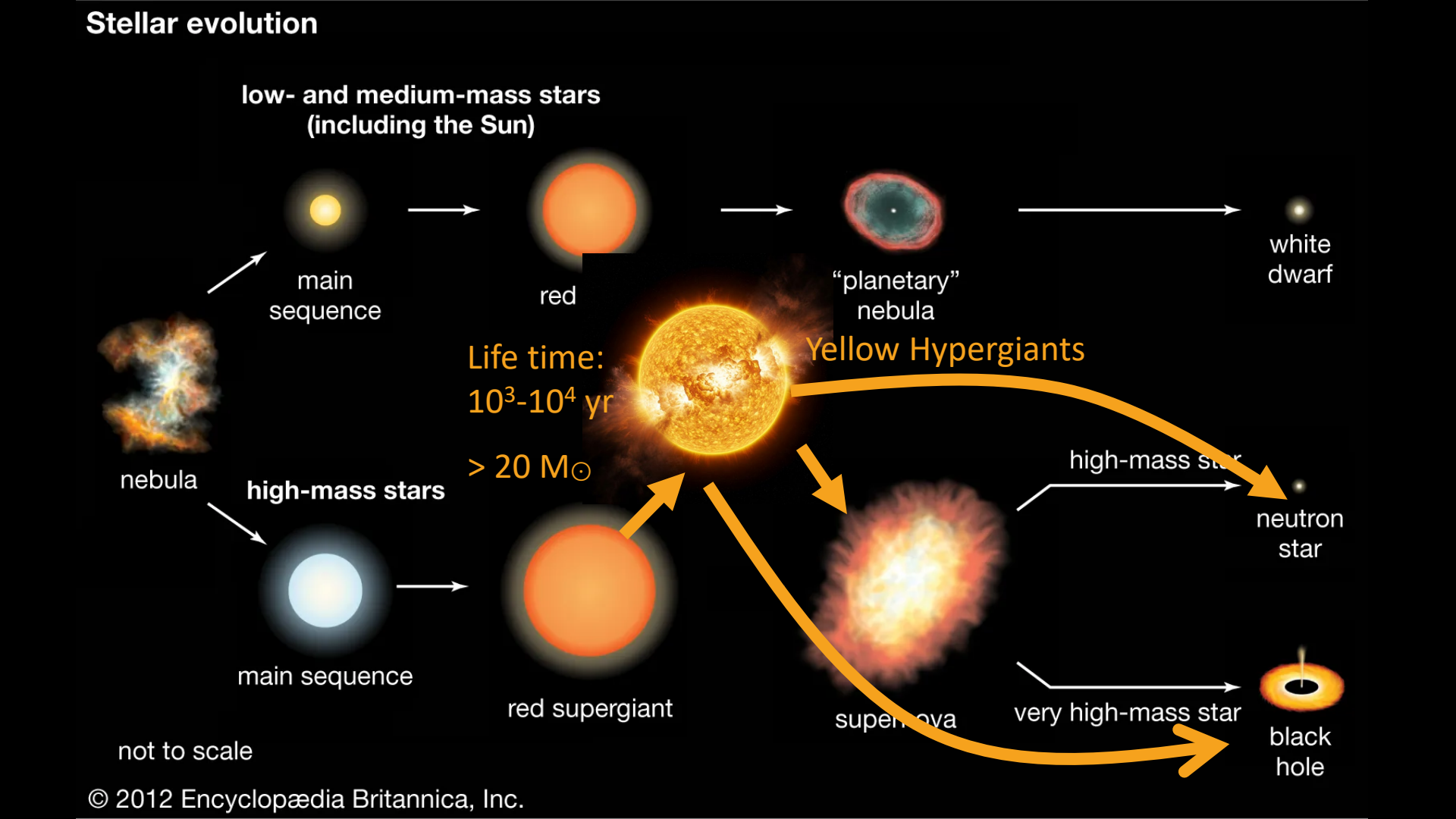
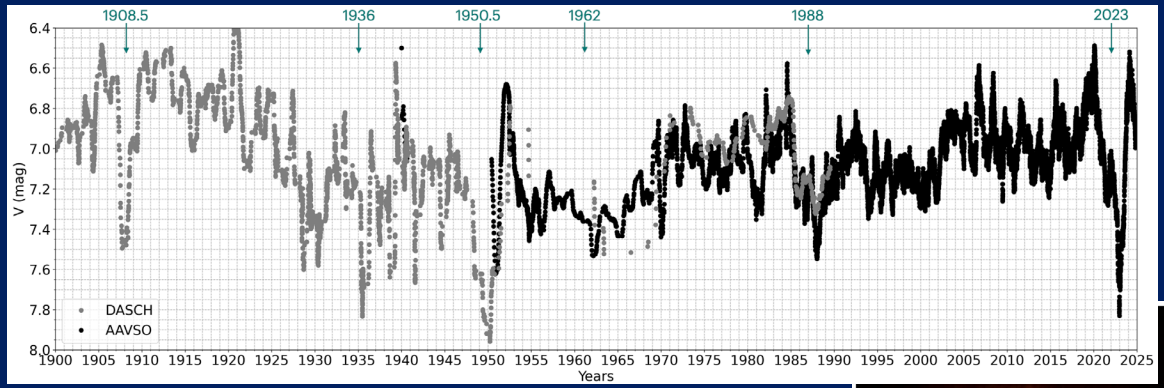


YELLOW HYPERGAINTS

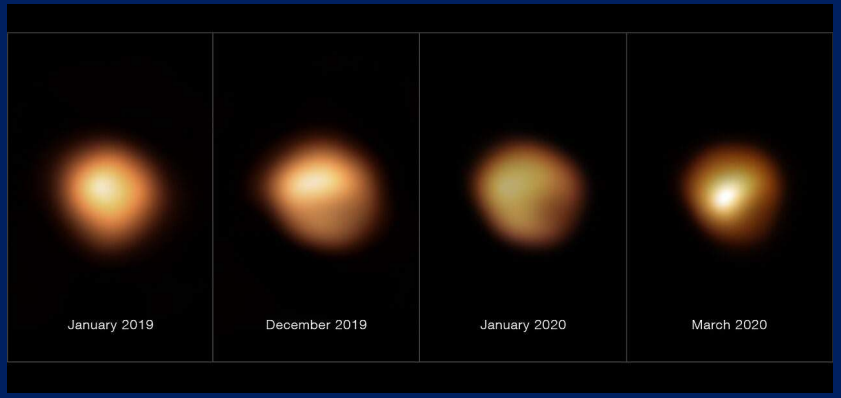
- Massive stars > 20 $M_\odot$
- High mass loss rates: from ≈10^{-4} to 10^{-2} $M_\odot$ yr^{-1}
- Higher temperatures: close to 7000K

Pulsational instabilities, large-scale surface activity, or changes in the wind may trigger this transition from RSG to YHG

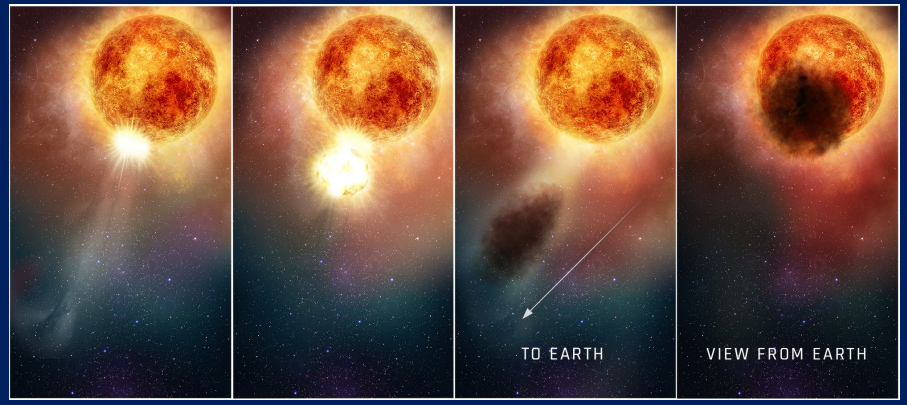


HST images of the yellow hypergiants IRC+10420, VY Cma, NML Cyg (see review by Humphreys 2025)

PREVIOUS INTERFEROMETRIC STUDIES



Betelgeuse
Montarg`es et al. 2021

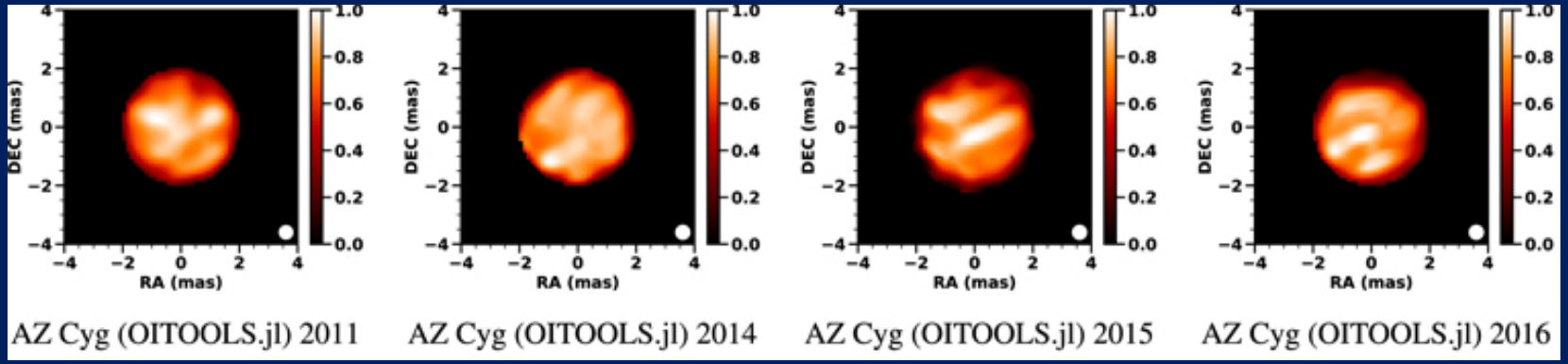


- Vast gas cloud ejection
- Cloud cools and forms dust
- dust blocks starlight

Illustration credit: NASA, ESA, and E. Wheatley (STScI)
Montarg`es et al. 2021, Dupree et al. 2022

PREVIOUS INTERFEROMETRIC STUDIES

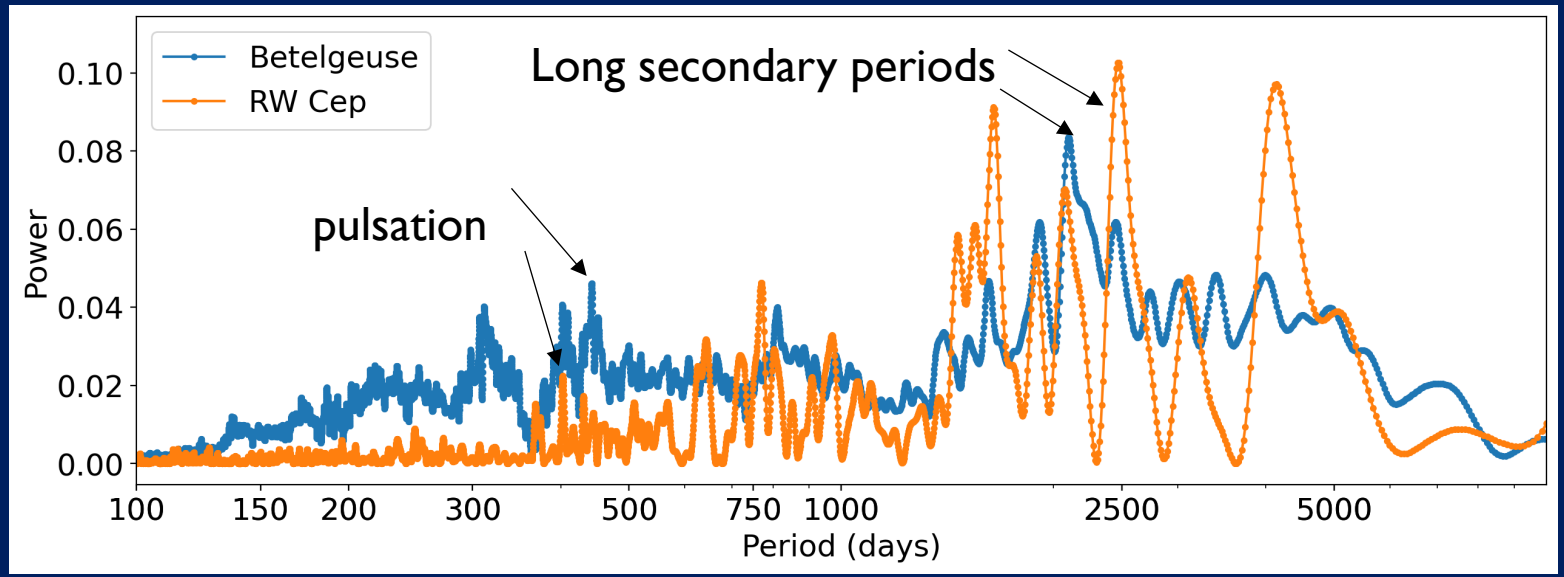
- Red Supergaints are famous targets for interferometry
- There are several images of red supergaints revealing convection cells and their evolution epoch to epoch.



Norris et al 2021, CHARA/MIRC images

MASS-LOSS CONNCTION TO PULSATION AND CONVECTION CELLS ACTIVITY

Connection between convection activity to the time-series photometry is still missing. We need monitoring of stellar surface and convection cells at regular intervals.

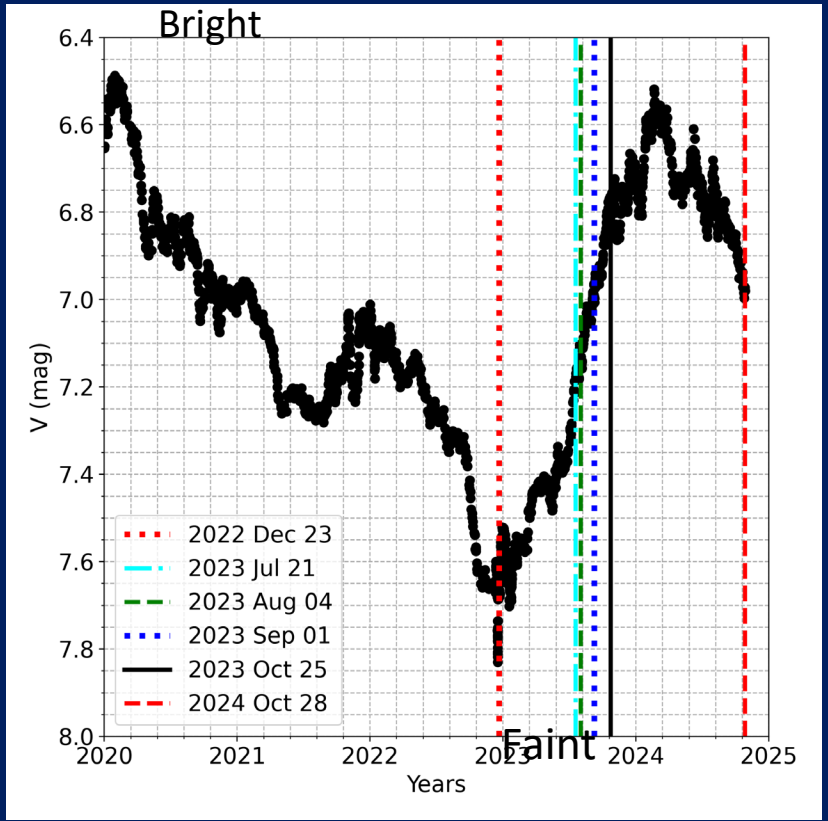


OUR RESEARCH

- *We image these peculiar yellow hypergiants*
- *We aim to understand mass loss mechanisms by studying stellar surfaces.*
- *We aim to understand fundamental properties such as long secondary periods, rotation, and convection cell lifetimes by combining CHARA imaging with AAVSO time-series photometry.*

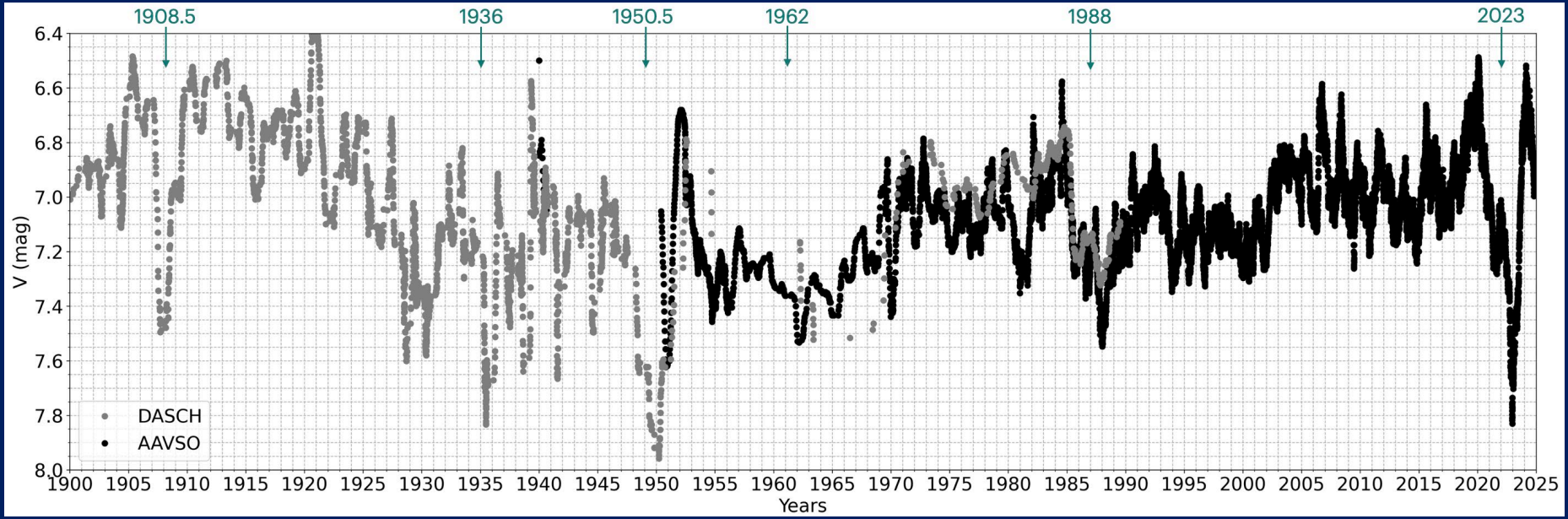
FIRST YHG: GREAT DIMMING OF RW CEPHEI

What happened to cause the star to fade?



Credit: Data from AAVSO observers

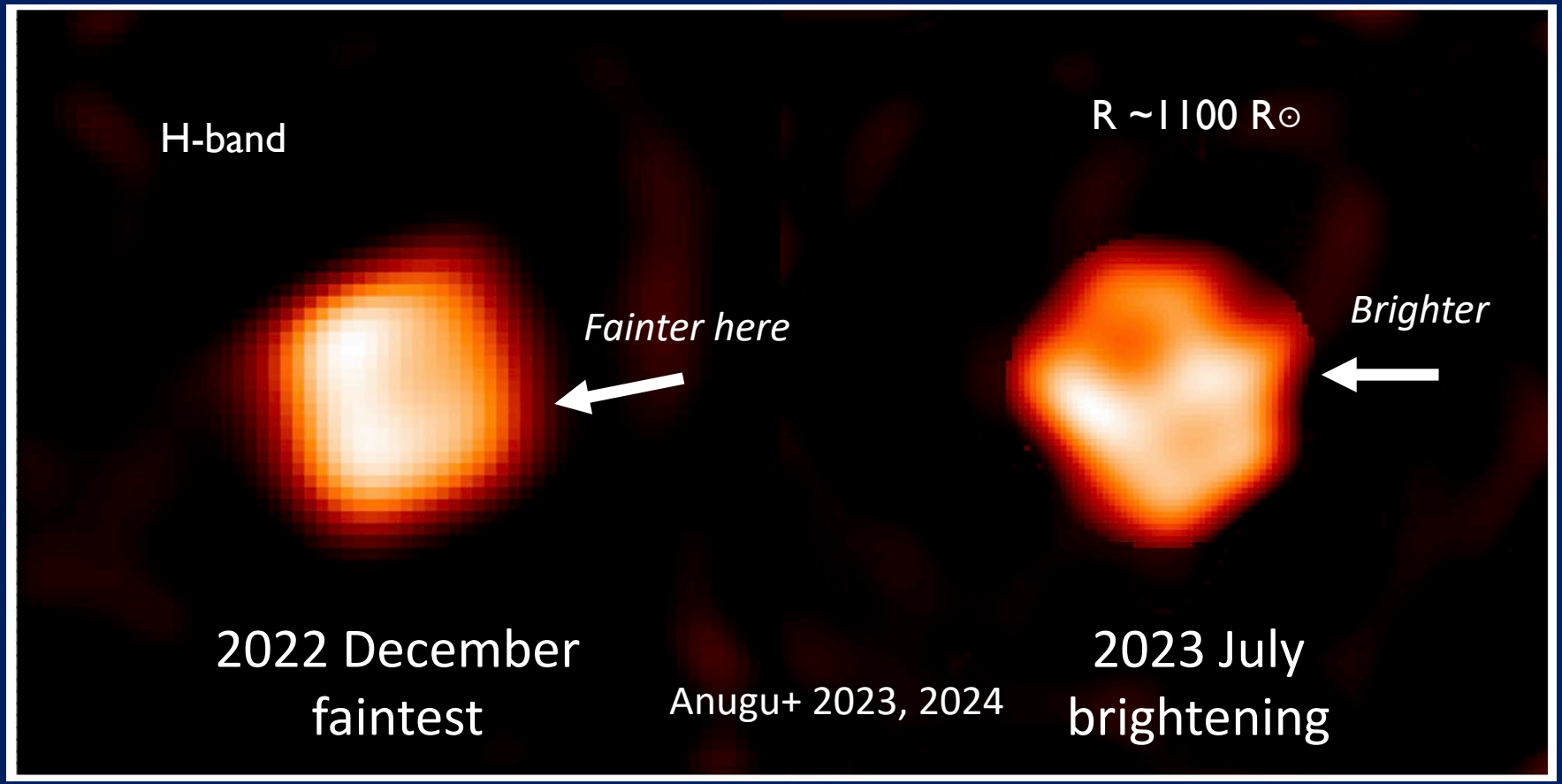
MASS LOSS HISTORY OF RW CEP



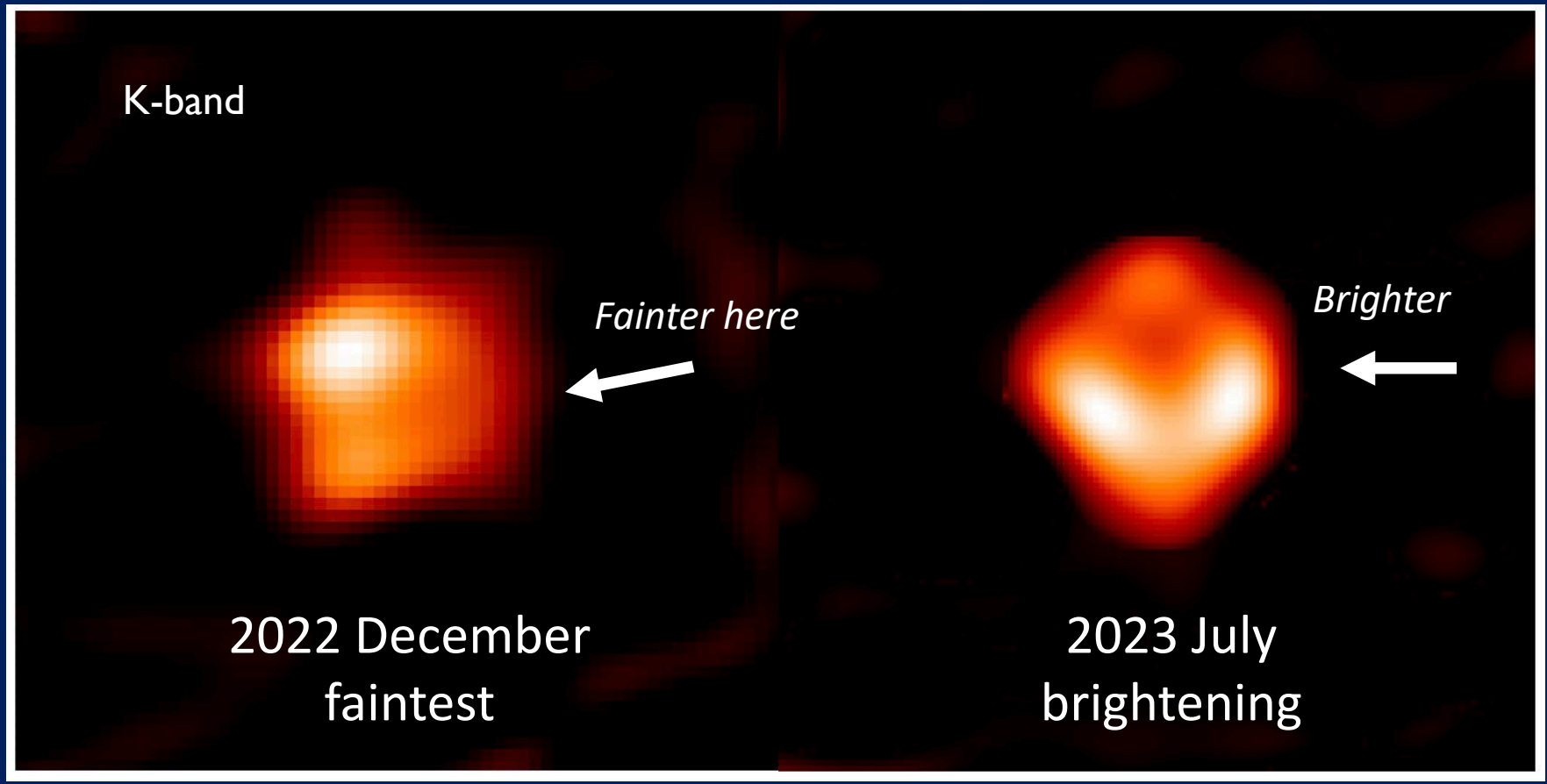
RW Cep experiencing intense mass loss through episodic outbursts

Credit: Data from AAVSO observers

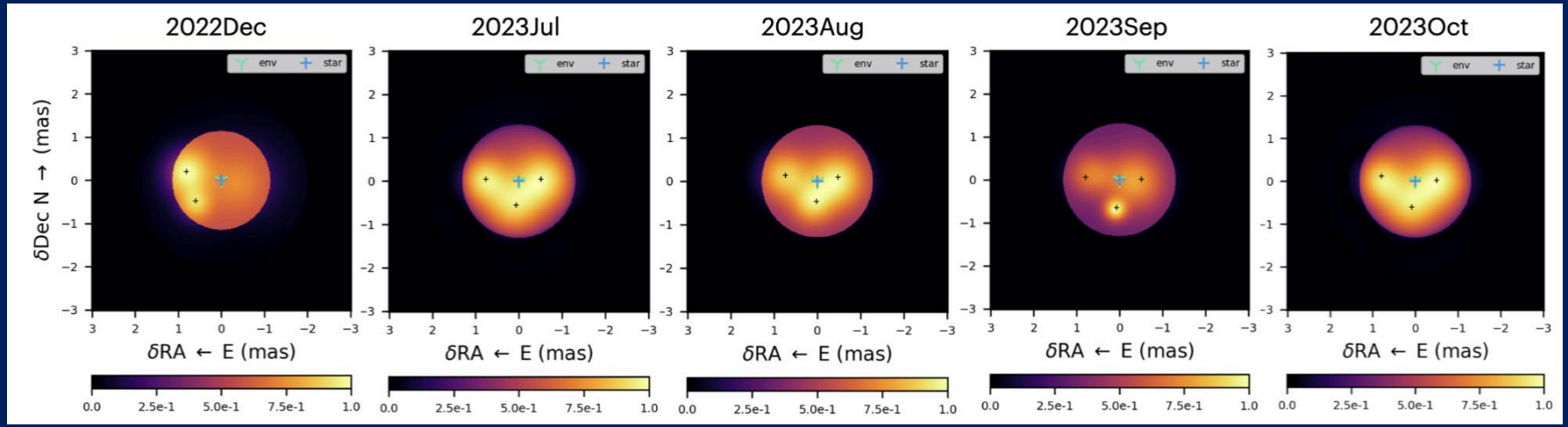
CHARA IMAGES OF RW CEPHEI



CHARA IMAGES OF RW CEPHEI



CHARA IMAGES OF RW CEPHEI



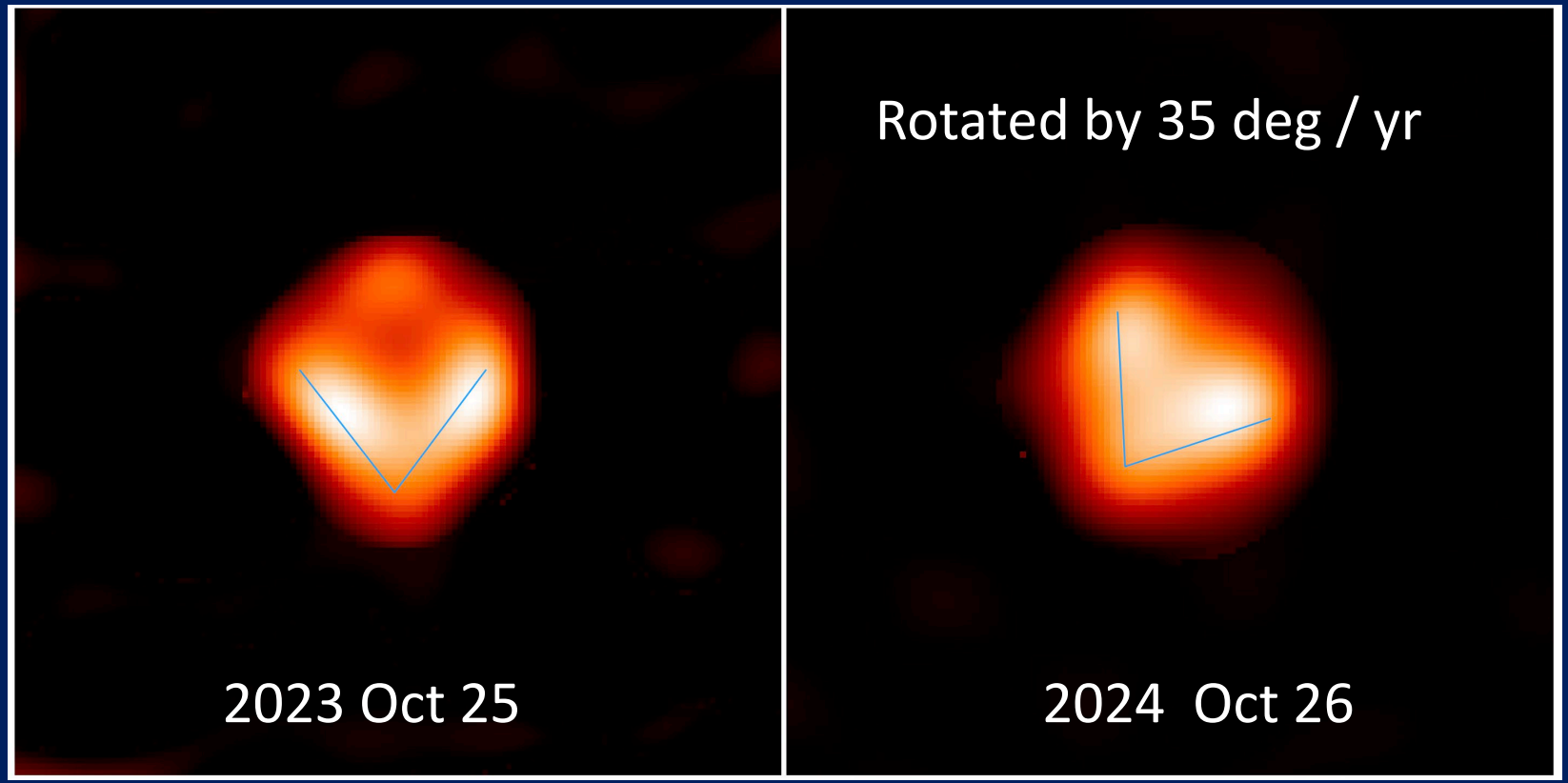
2022 December faintest

PMOIRED

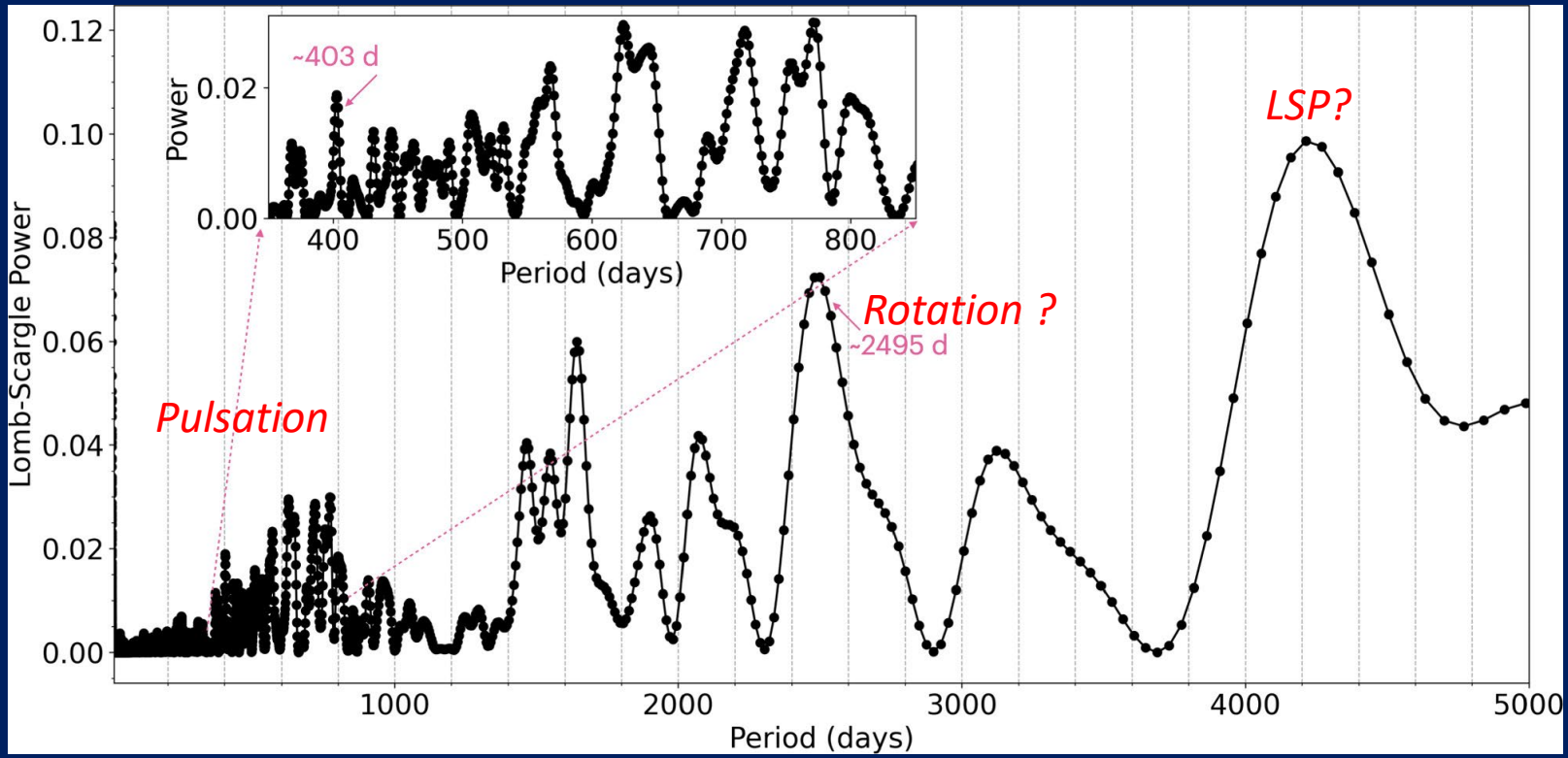
2023 Jul-Oct Started brightening

POST DIMMING IMAGES

K-band

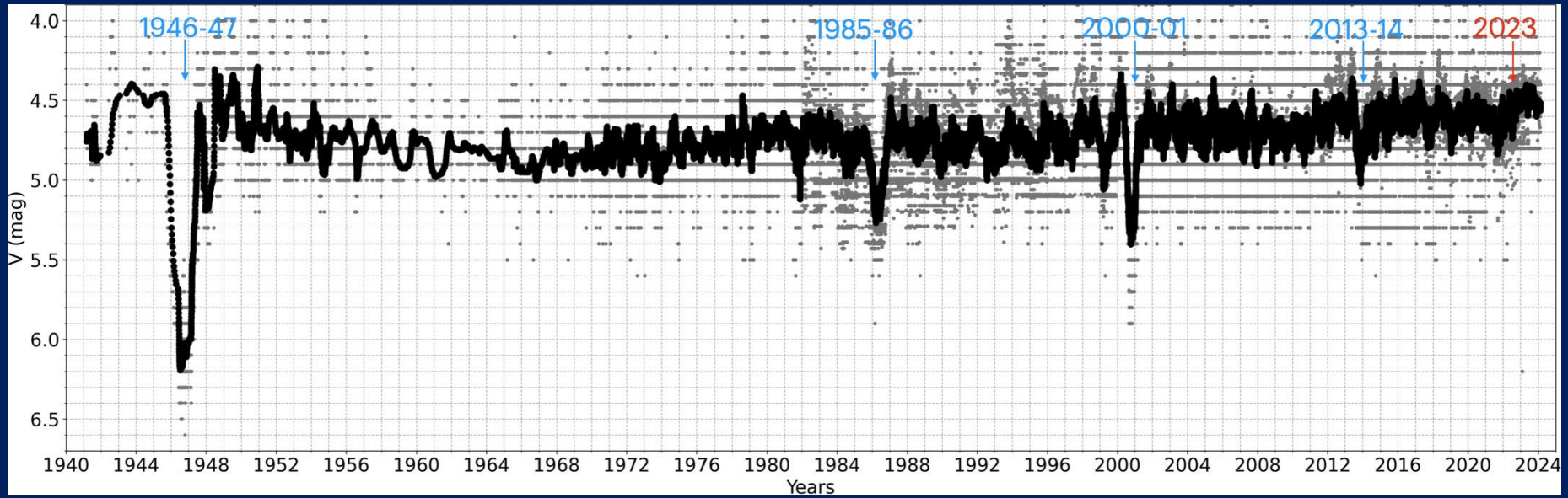


RW CEP LOMB–SCARGLE PERIODOGRAM



Credit: Data from AAVSO observers

SECOND YHG: RHO CAS



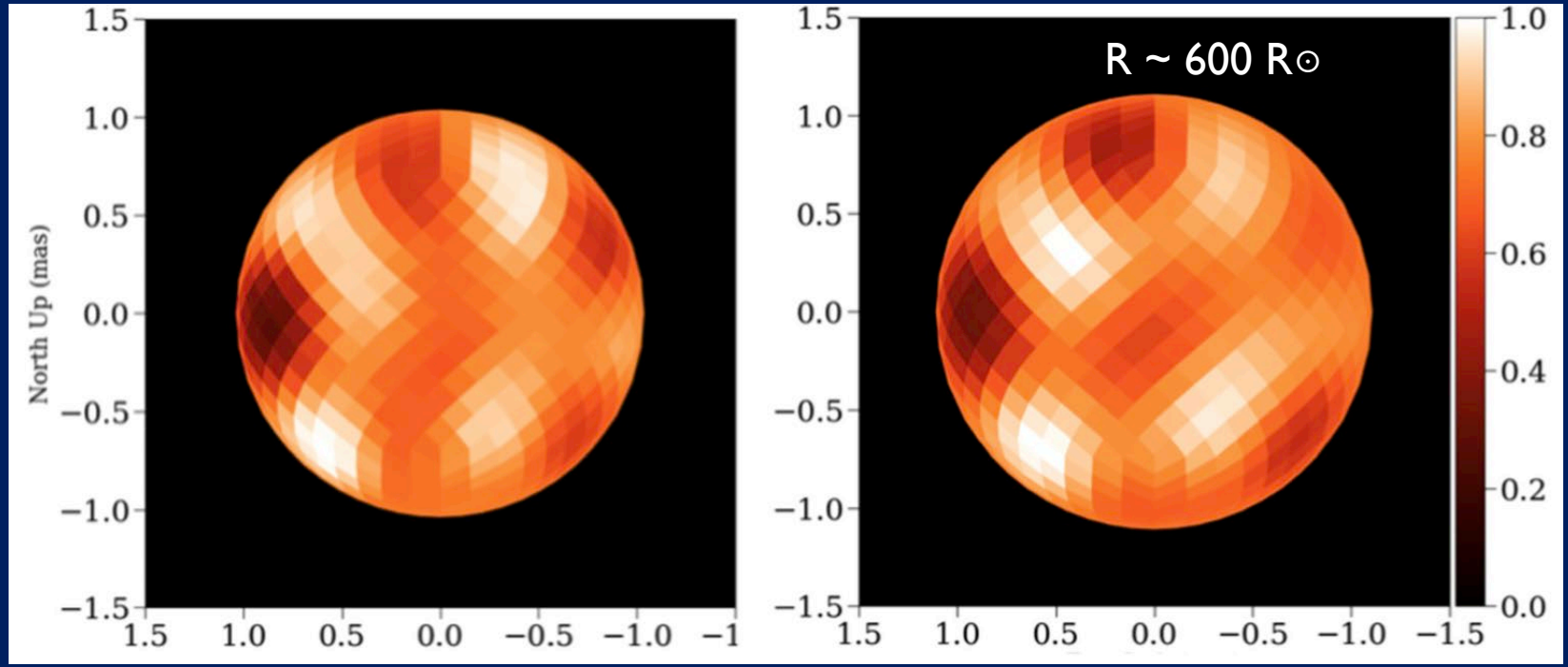
- *Rho Cas, yellow hypergiant*
- *Experiencing intense mass loss through episodic outbursts*

Credit: Data from AAVSO observers

CHARA IMAGES OF RHO CAS

H-band

K-band

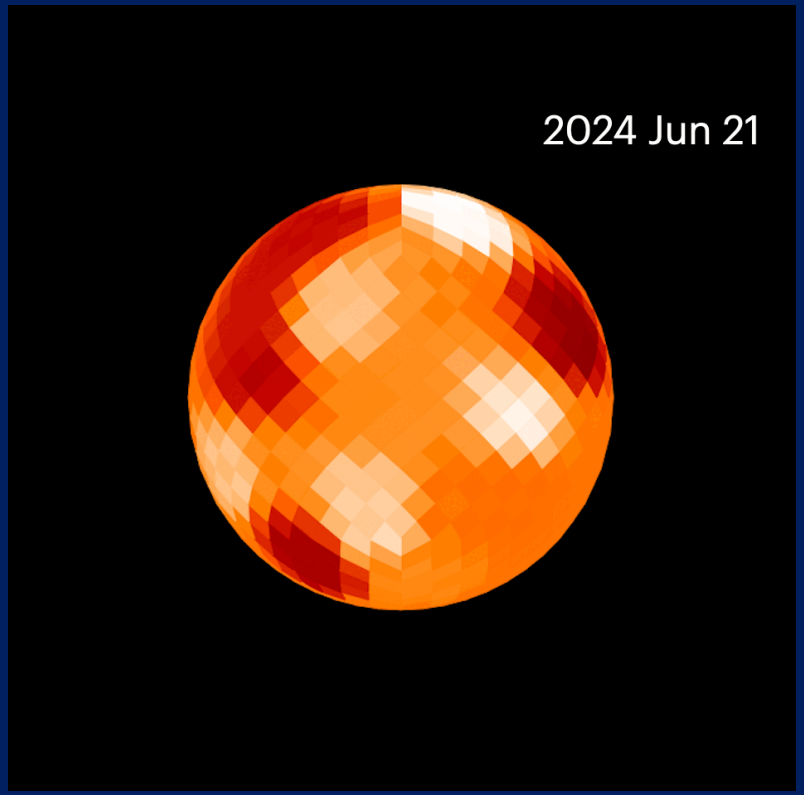


2023 Oct

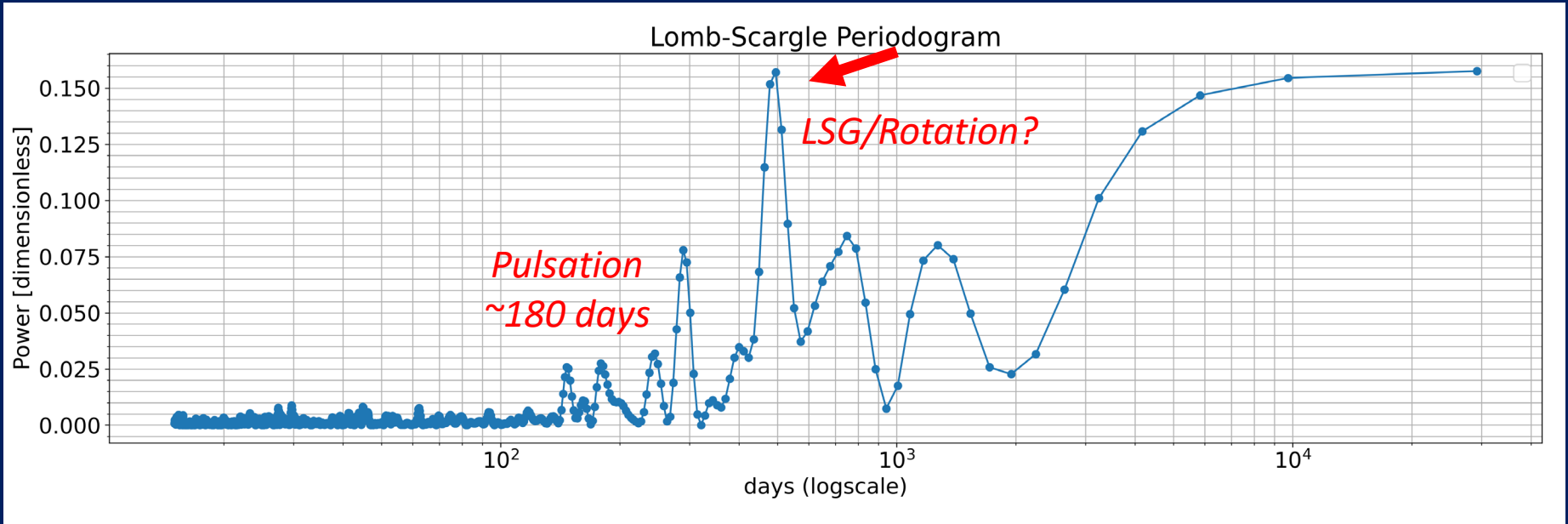
Anugu+ 2024

RHO CAS ROTATIONAL MOTION

- *A fast rotator ?*
- *Dynamics of convection cells?*
- *Vsini = 25 km/s*
- *Radius = 564 – 700 R⊙*



RHO CAS: LOMB–SCARGLE PERIODOGRAM

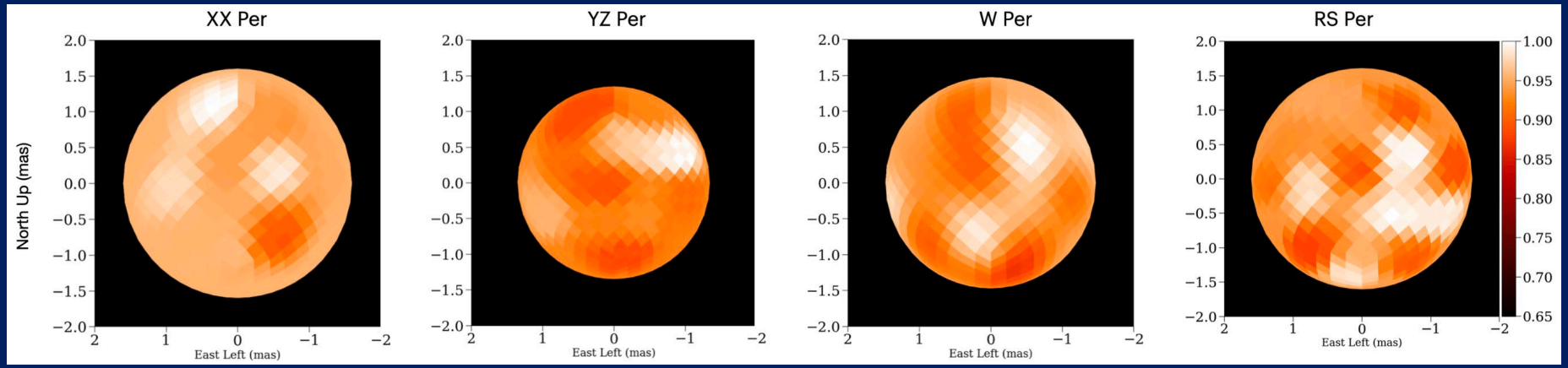


We imaged 5 epochs covering 1-year
Working on the rotational period from the images.

Credit: Data from AAVSO observers

To compare we also image RSGs surface activity

K-band



For baseline comparison with yellow hypergiants, we are also monitoring four red supergiants.

Do they evolve in similar time scale?

SUMMARY

- We combine CHARA images and AAVSO data to understand fundamental parameters of peculiar yellow hypergiant stars.
- We explain the Great dimming episodes in these stars using direct images
- Combined analysis of CHARA and AAVSO reveal the rotational periods

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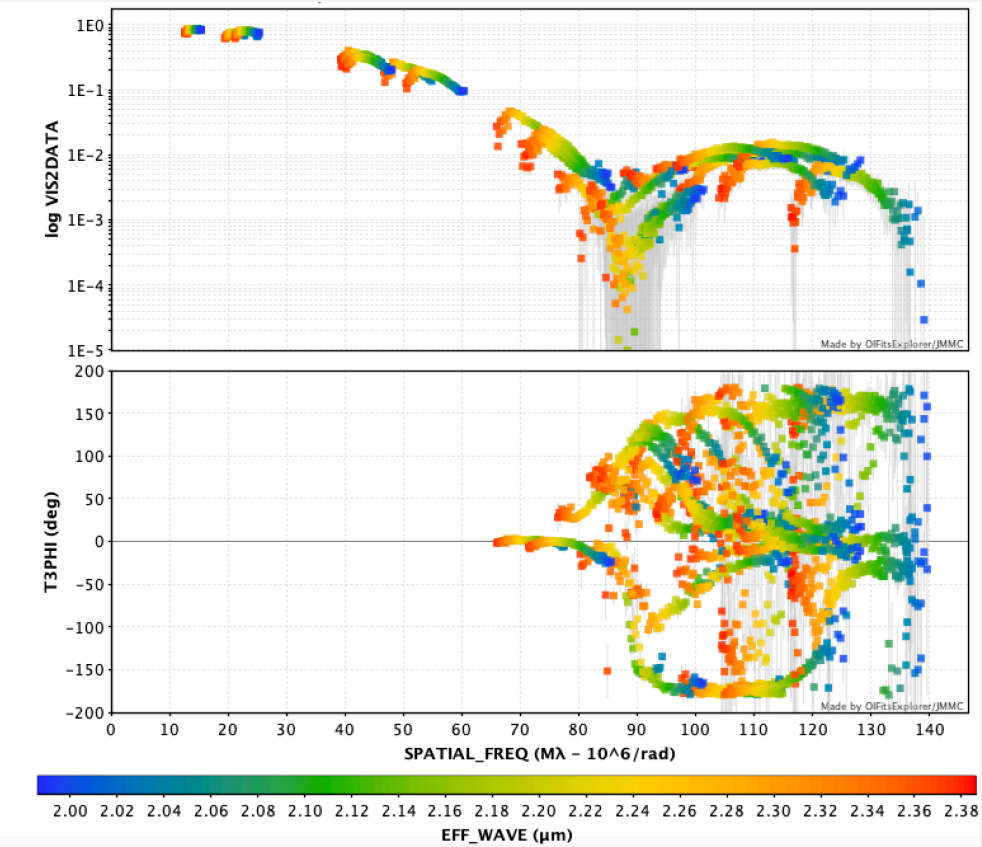
CHARA DATA K-BAND



CURRENT RESEARCH

- **Red Supergiant (RSG) Problem:**
  The direct collapse of RSGs with masses > 20 $M_\odot$ into black holes, without the explosive signature of a supernova, is referred to as a failed supernova (Smartt et al 2009, 2015).
- **Episodic Mass Loss and Post Red Supergiants:**
  High mass-loss rates in massive stars > 20 $M_\odot$, leads warmer temperatures, phases such as yellow hypergiants (YHG) and luminous blue variables (LBV) (Humphreys et al 2006, 2025). Pulsational instabilities, large-scale surface activity, or changes in the wind may trigger this transition from RSG to YHG.

Betelgeuse mass is around 16-19 $M_\odot$, will it go supernovae or collapse into directly black hole? Not massive enough to become yellow hypergiant.

COMPARISON TO BETELGEUSE

	Betelgeuse	RW Cep	Rho Cas
Size (Solar radii)	764-996	1100 ± 44	564 - 700
Teff (k)	3650	3900-4200	7000
Mass loss (solar mass)	$\sim 10^{-7}$	10^{-6}	5×10^{-3} - 10^{-5}
Size in sky (mas)	~42 mas	~2.6 mas	2.1 mas
Distance	153-222 pc	3.9 kpc	2.5–3.1 kpc