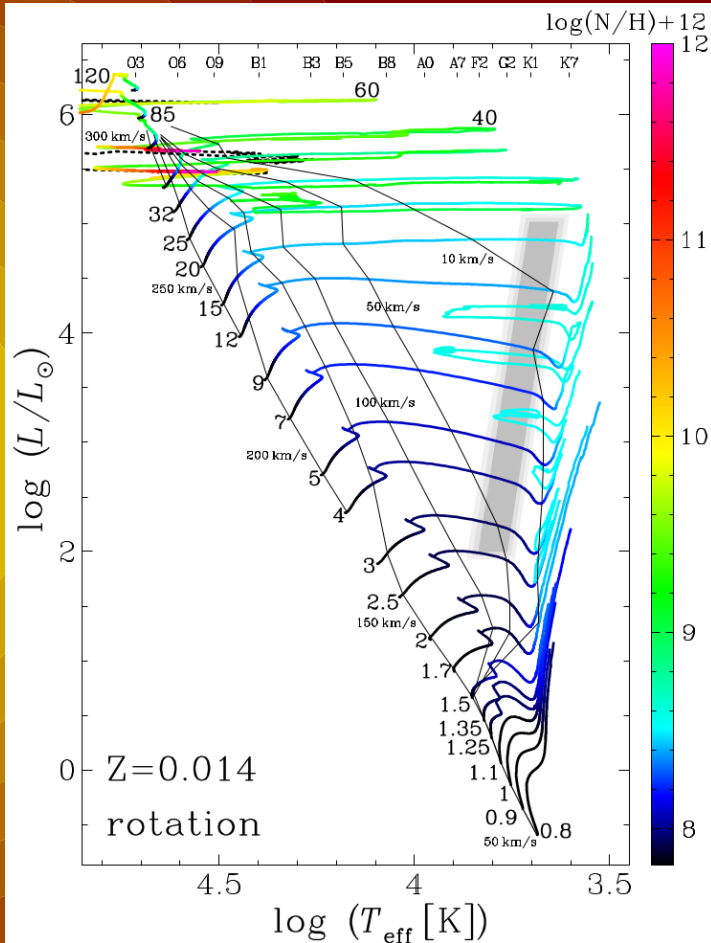


The mass-loss activity of yellow hypergiants

Michalis Kourniotis
Astronomical Institute
Czech Academy of Sciences

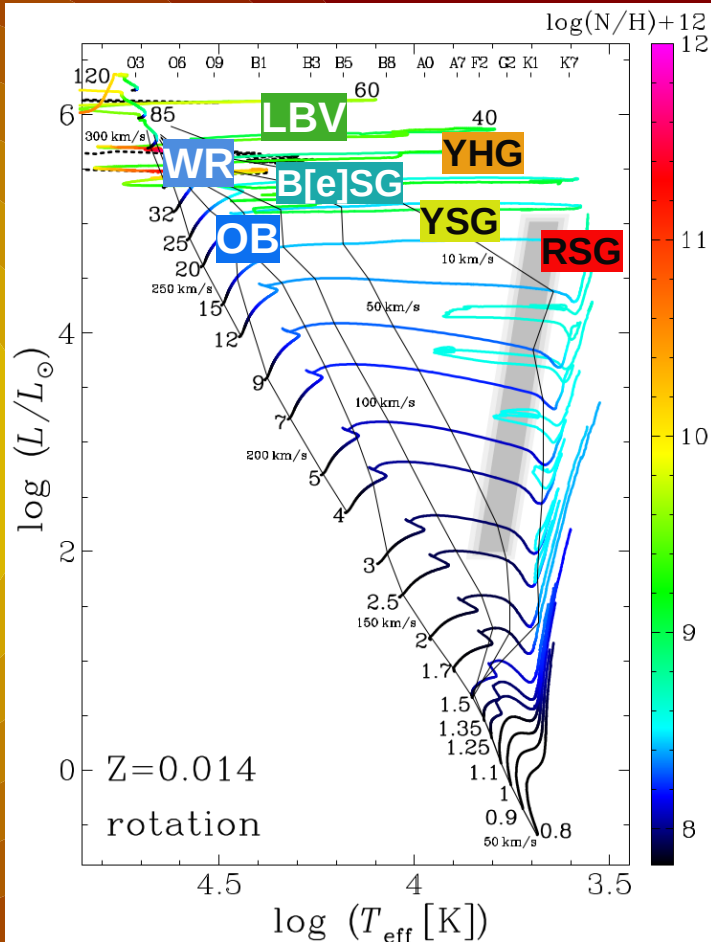
Summer school on Stellar Winds and Outflows
Harrachov – 13/09/2023

Massive star evolution



- ✓ Massive stars ($> 8 M_{\odot}$) display short but impacting life
- ✓ Different channels give rise to the various stellar types
- ✓ The mass-loss mechanisms vary throughout evolution; their physics are associated to the stellar parameters
- ✓ Post-RSG evolution remains a missing piece of the puzzle

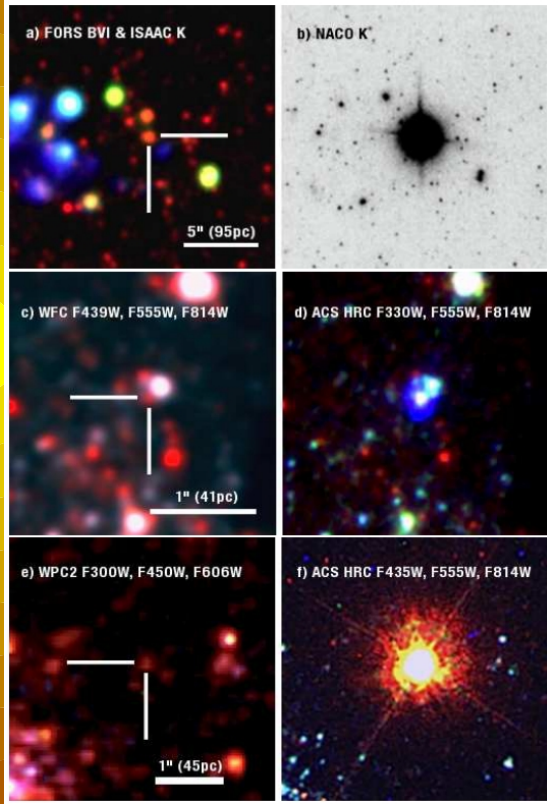
Massive star evolution



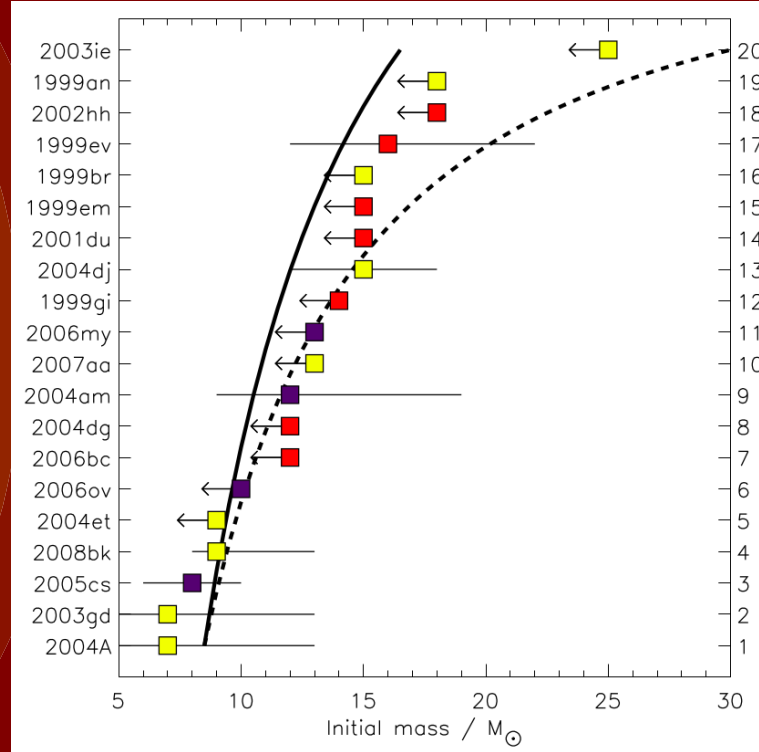
- ✓ Massive stars ($> 8 M_{\odot}$) display short but impacting life
- ✓ Different channels give rise to the various stellar types
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The RSG problem

or... how do RSGs with $M > 17 M_{\odot}$ die?



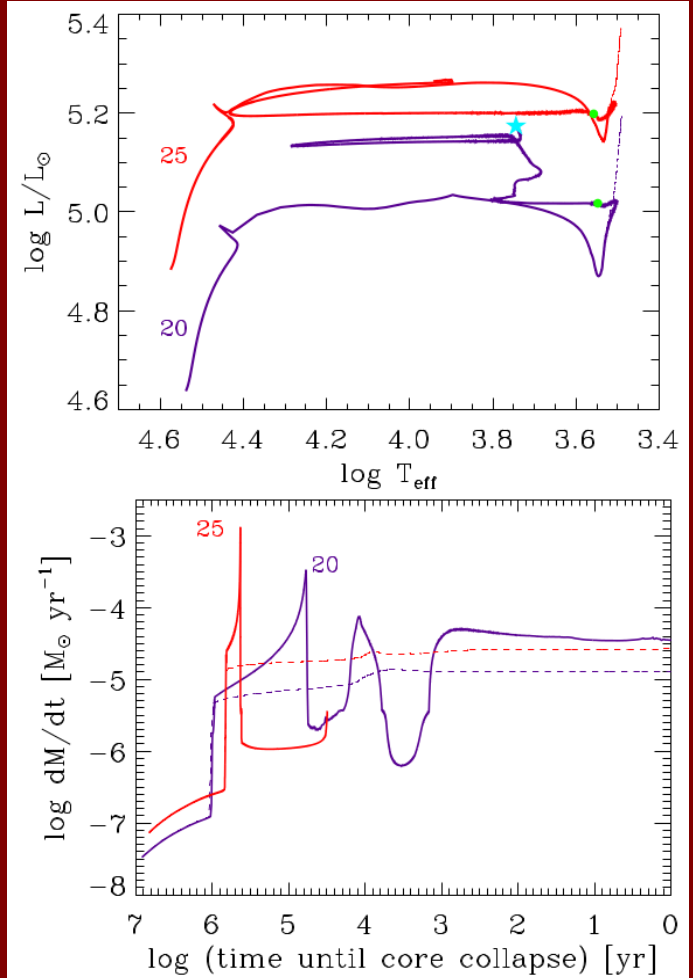
pre/post-SN imaging



Smartt 2009

School on Stellar Winds and Outflows

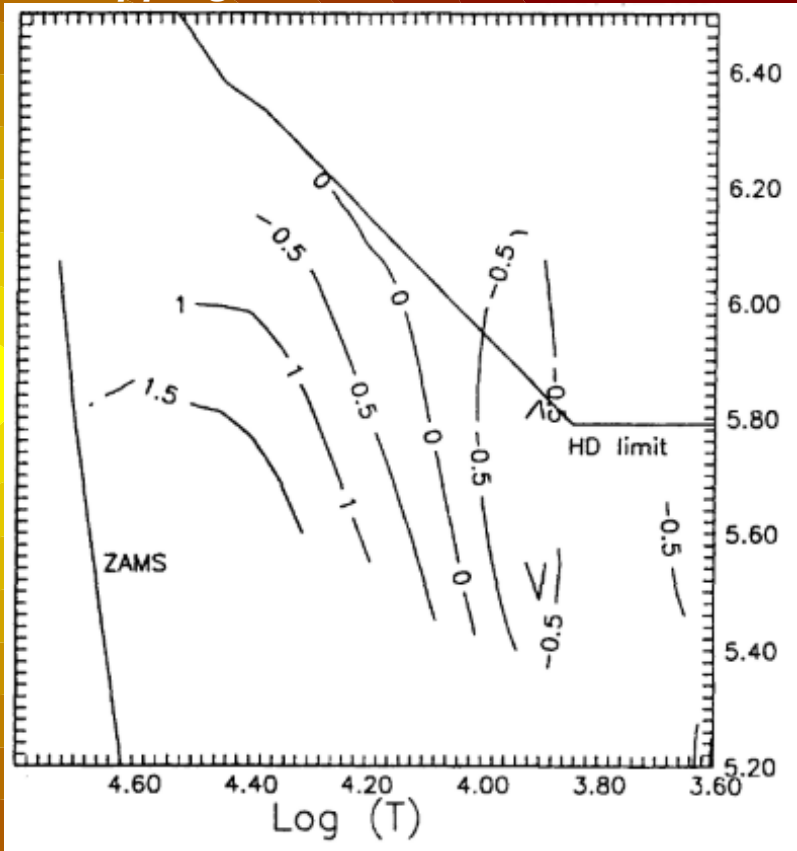
High mass-losses during RSG phase



Yoon & Cantiello 2010

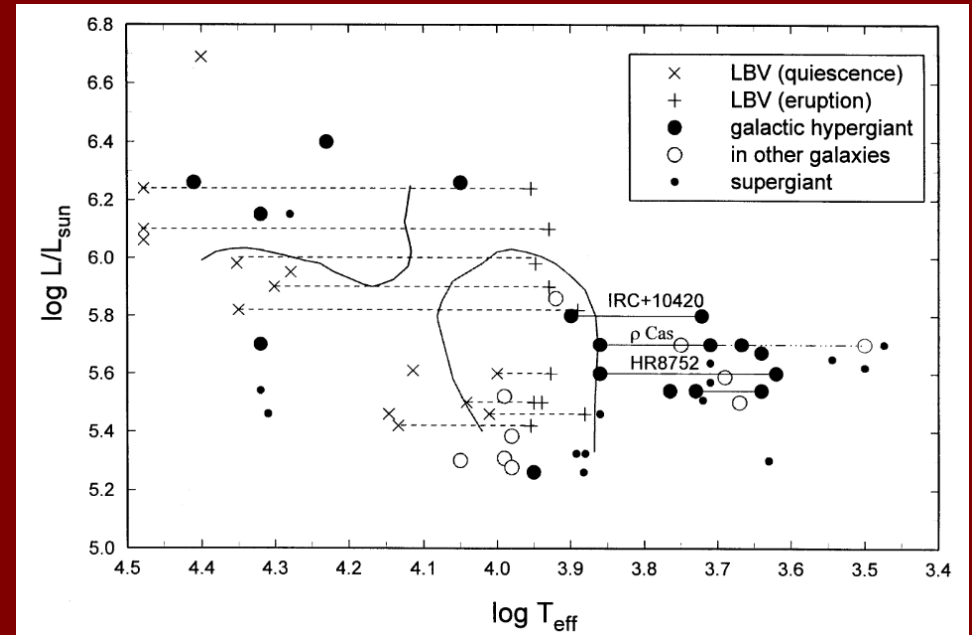
Atmospheric instability

Mapping the effective acceleration



Nieuwenhuijzen et al. 1995

Regions of atmospheric instability

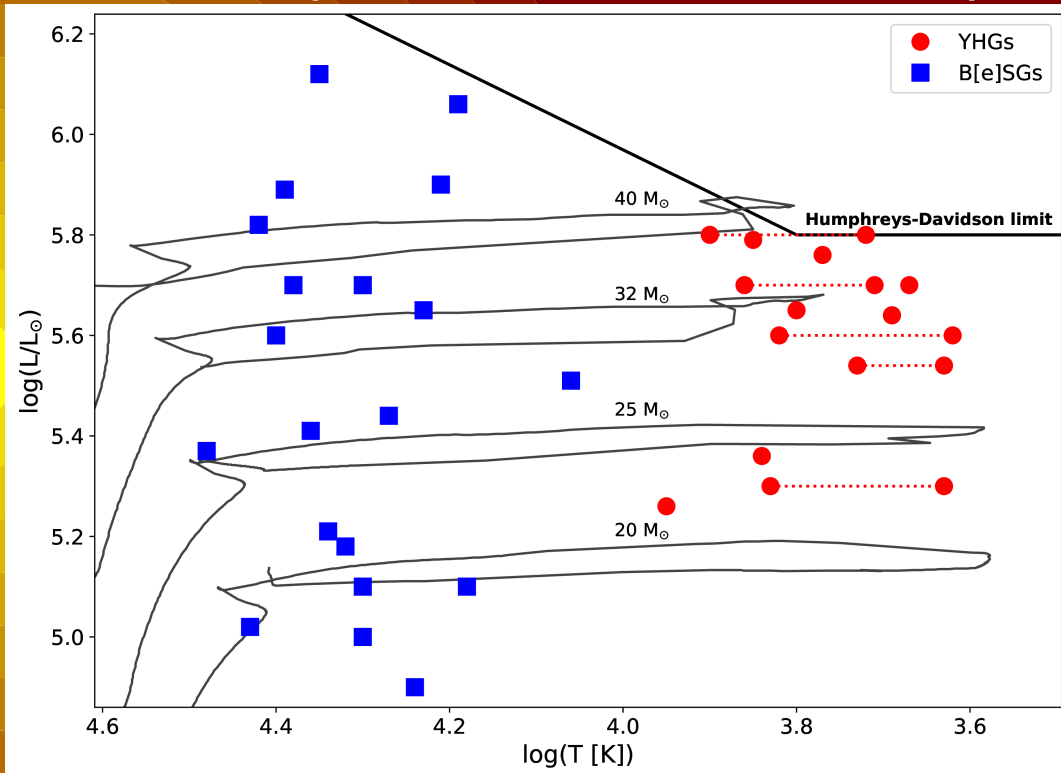


de Jager 1998

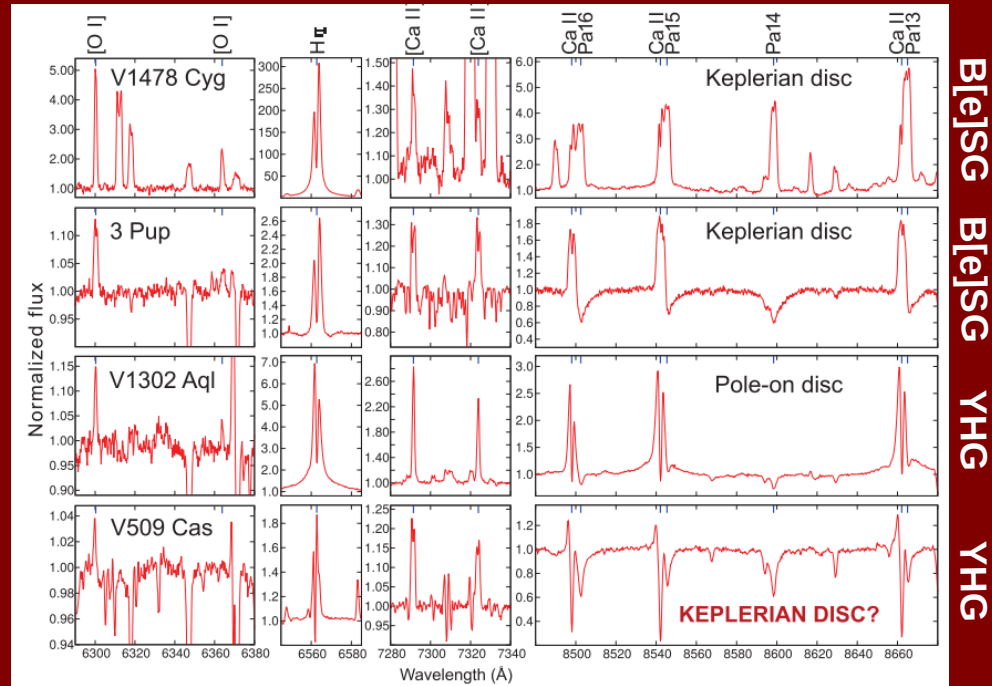
- ✓ The “Yellow Void” (YV) is modeled as area of very low g_{eff} values
- ✓ It is situated within $T_{\text{eff}} \sim 6000\text{--}10000\text{ K}$ with $\log(L/L_{\odot}) > 5.5$
- ✓ YHGs are believed to exhibit outbursts when approaching YV

The post-RSGs: YHG and the B[e]SGs

A census of post-RSGs classes in the Local Group

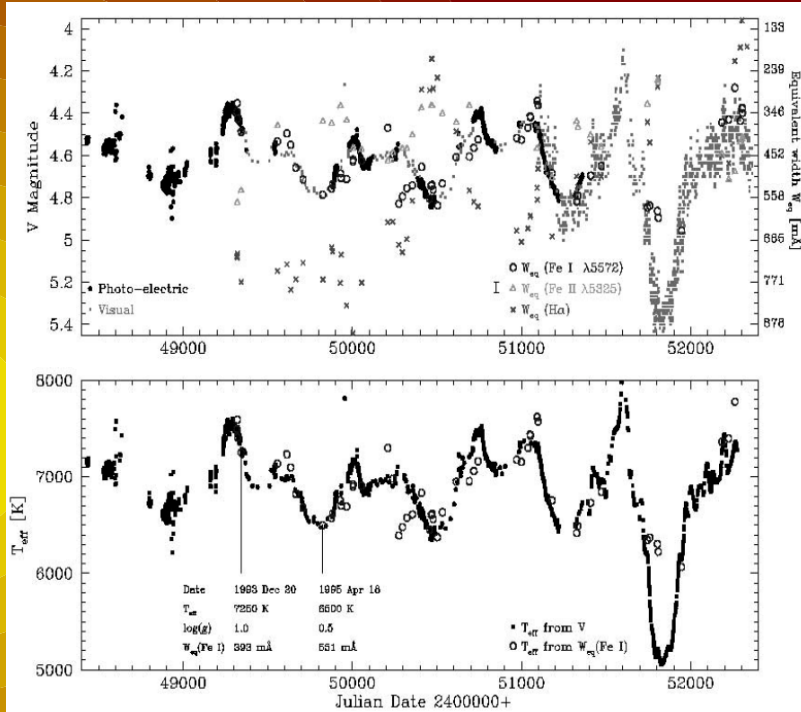


...is the evolutionary kinship between YHG & B[e]SGs ?



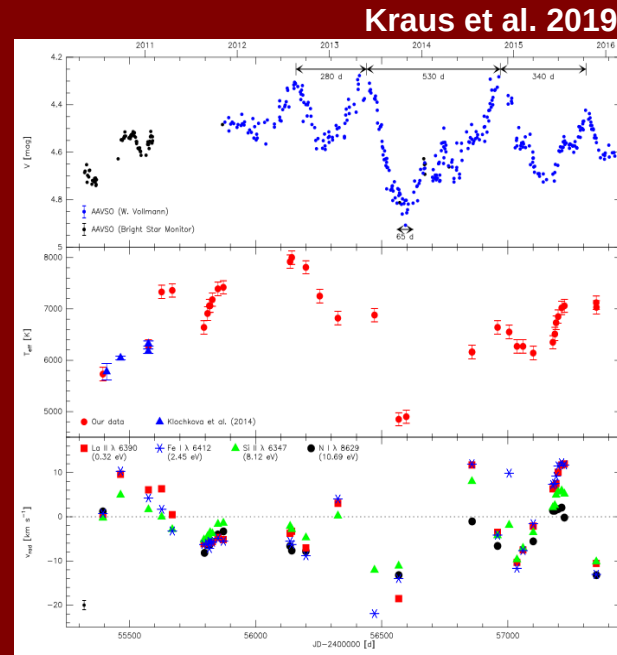
Aret et al. 2017

The prototype ρ Cas



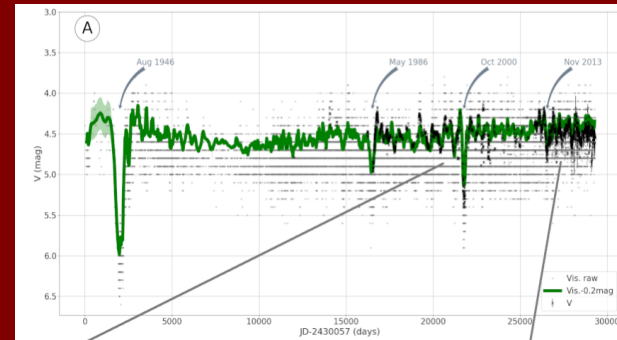
Lobel et al. 2003

- ✓ Ejection of a $3 \times 10^{-2} M_{\odot}$ shell
- ✓ Formation of TiO lines during the outburst
- ✓ Extended, velocity-stratified atmosphere



Kraus et al. 2019

- ✓ Temperature decrease of ~ 3000 K in 2013
- ✓ Asymmetric lines
- ✓ Circumstellar emission
- ✓ Evidence of gas remnant from RSG phase

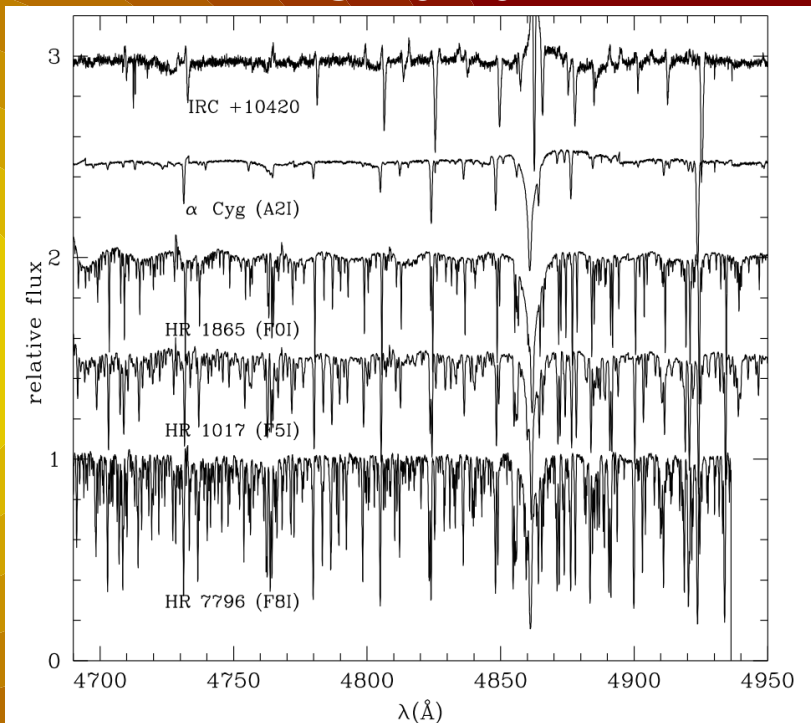


Maravelias & Kraus 2021

- ✓ The star underwent its most dramatic recorded outburst in 1946
- ✓ Decreasing duration and increasing frequency of the events

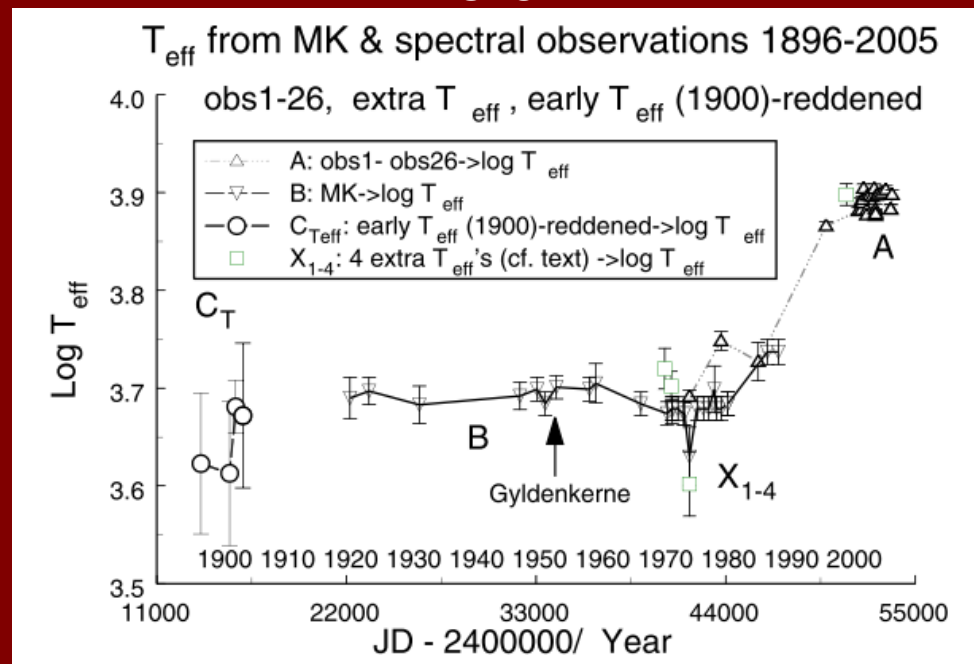
Other YHG variables

IRC+10420



UES/WHT spectrum, 1994 (Oudmaijer 1998)

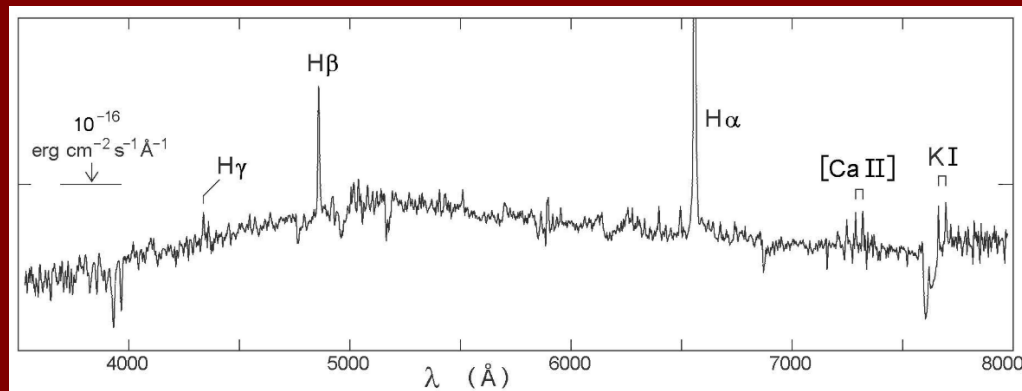
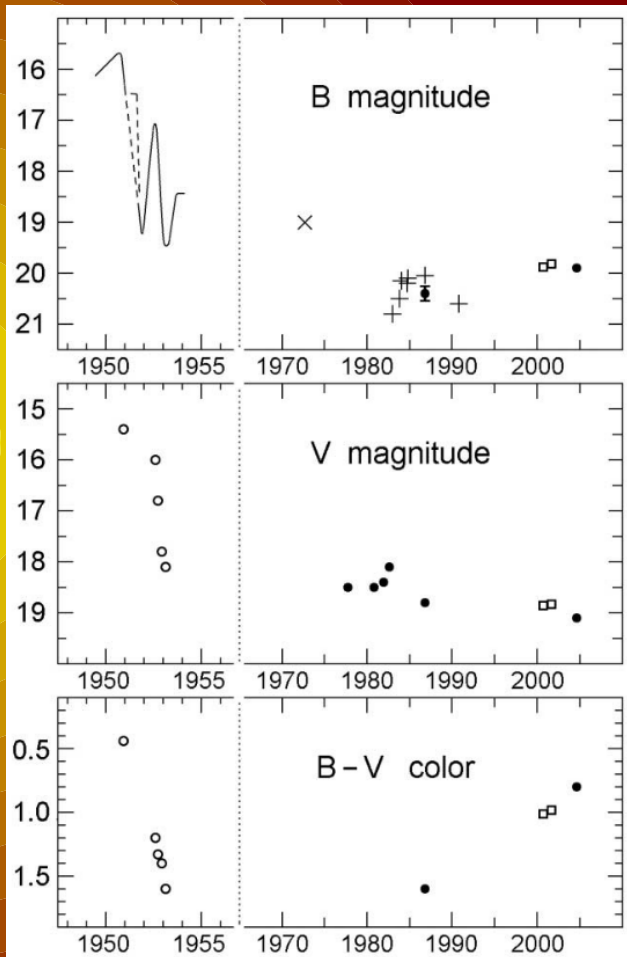
HR8752



1973-2005; Nieuwenhuijzen et al. (2012)

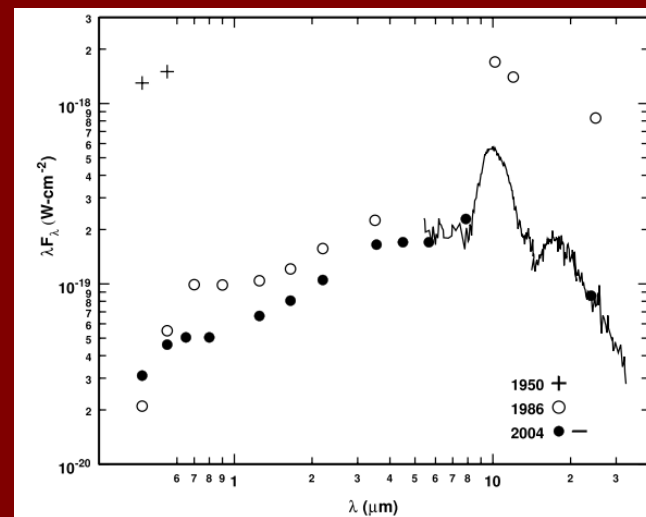
- ✓ **IRC+10420: Change in spectral type from F8 to A2, blueshifted emission, and high extinction**
- ✓ **HR8752: The dispersion of past ejected shells in 1973 revealed the compact hot photosphere**

Beyond the Galaxy: Var A



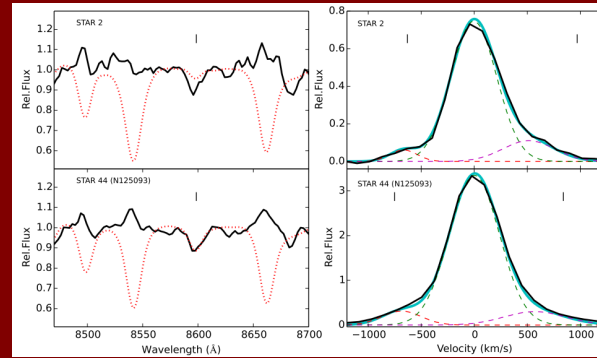
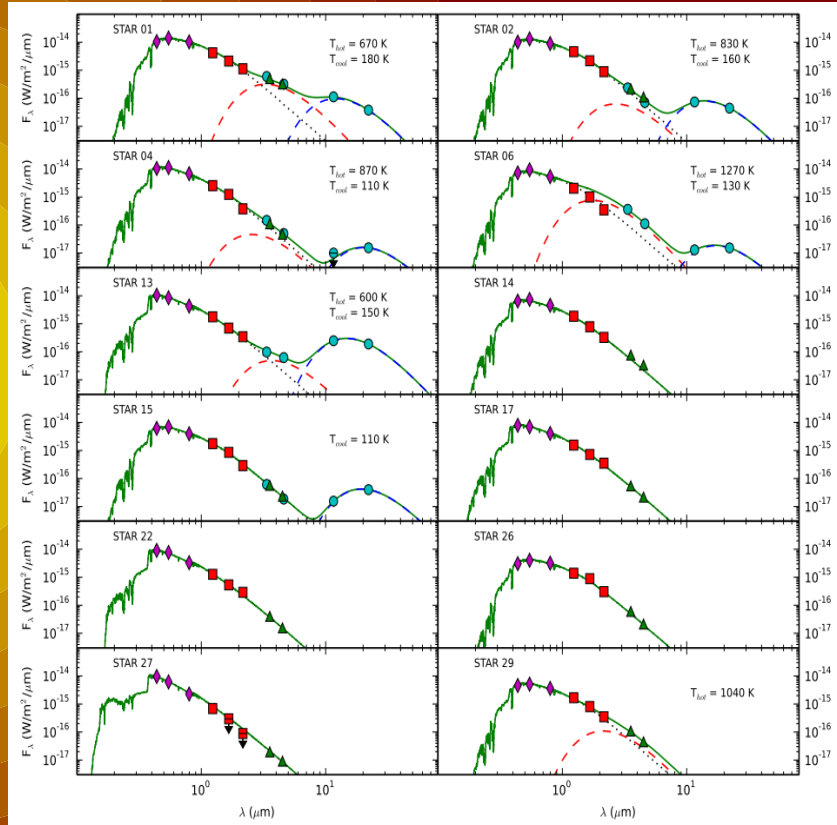
- ✓ *Change in the spectral type from F to M*
- ✓ *Variability with timescale of > 50 years*
- ✓ *Heavy dust obscuration*

Humphreys et al. 2006



Searching for YHGs

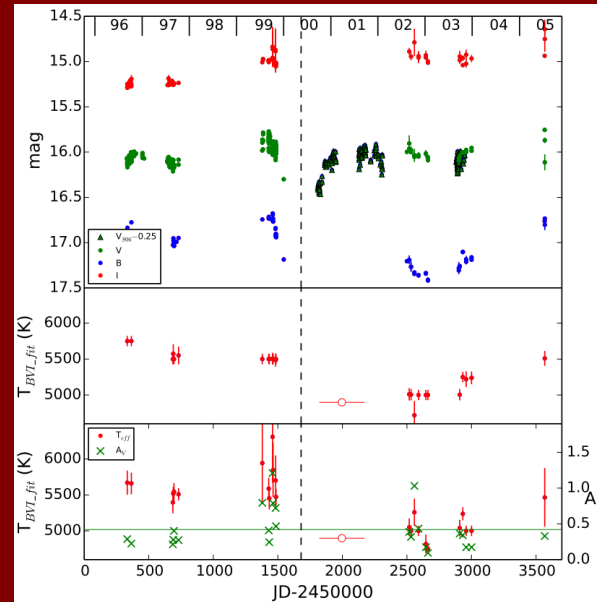
Exploring the surroundings of YHG candidates



✓ Broad H α wings

✓ Call emission

Kourniotis et al. 2017

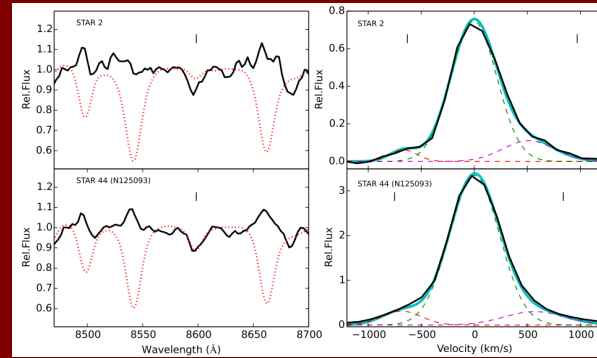
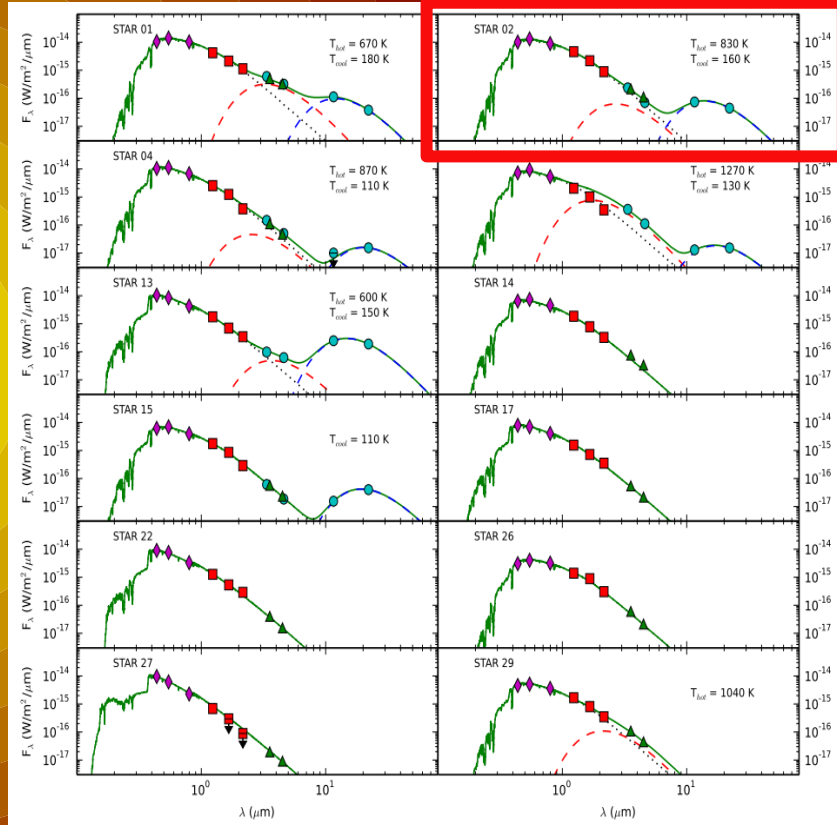


✓ Dimming event

✓ Drop by $\Delta T_{\text{eff}} > 500 \text{ K}$

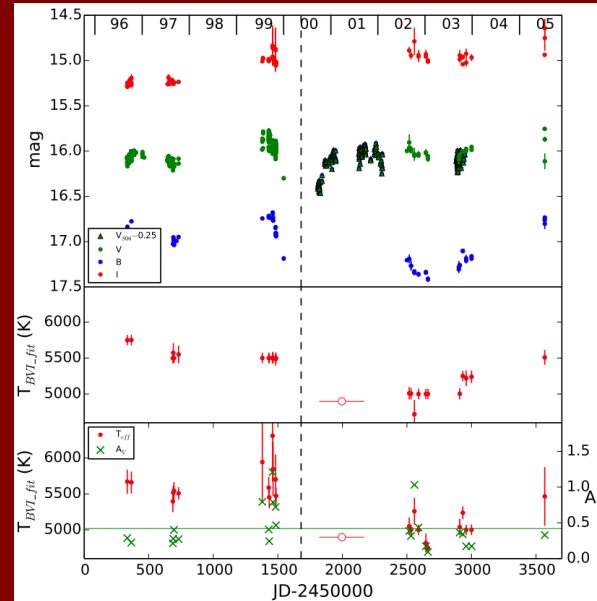
Searching for YHGs

Exploring the surroundings of YHG candidates



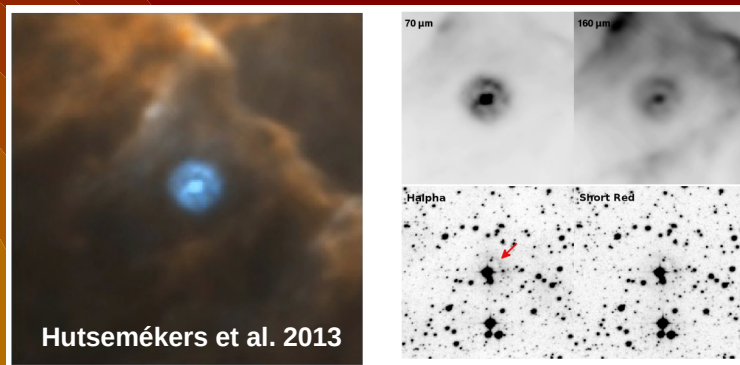
- ✓ Broad H α wings
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Kourniotis et al. 2017



- ✓ Dimming event
- ✓ Drop by $\Delta T_{eff} > 500$ K

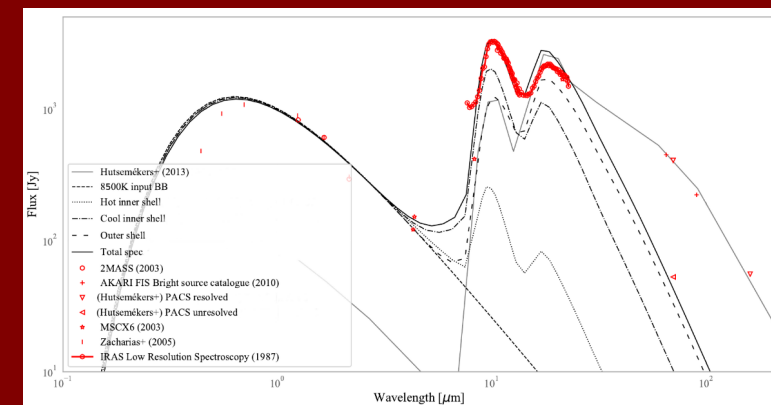
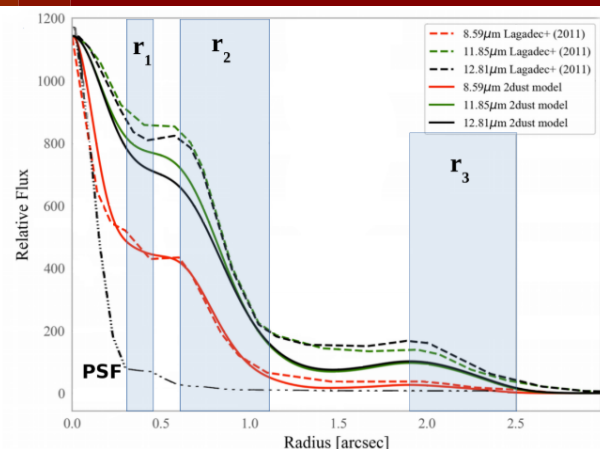
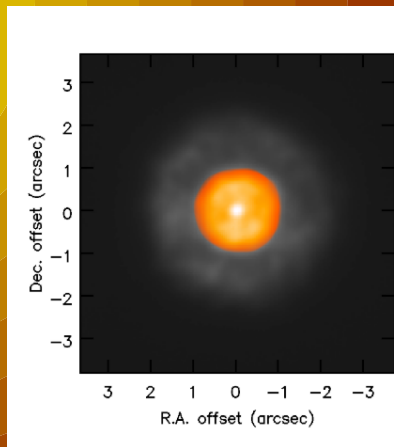
Nebulosity and shells of YHG: Hen 3-1379



The Fried Egg nebula

Fried Egg Nebula	M_{gas} ($10^{-3} M_{\odot}$)	T_{d} (K)	r_{d} ($''$)	t_{kin} (yr)	\dot{M} ($M_{\odot} \text{ yr}^{-1}$)
Hot inner shell	0.021	620–480	0.3–0.45	30.8	6×10^{-7}
Intermediate shell	0.90	460–320	0.6–1.1	102.7	9×10^{-4}
Outer shell	5.6	240–200	1.9–2.5	123.2	5×10^{-5}

IRAS 17163	$\log(L_{\star}/L_{\odot})$	T_{\star} (K)	d (kpc)
	5.7	8500	1.2

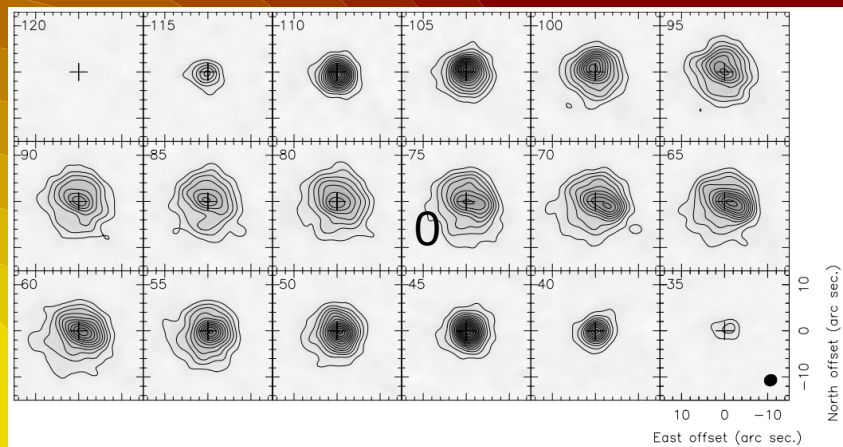


Koumpia et al. 2020

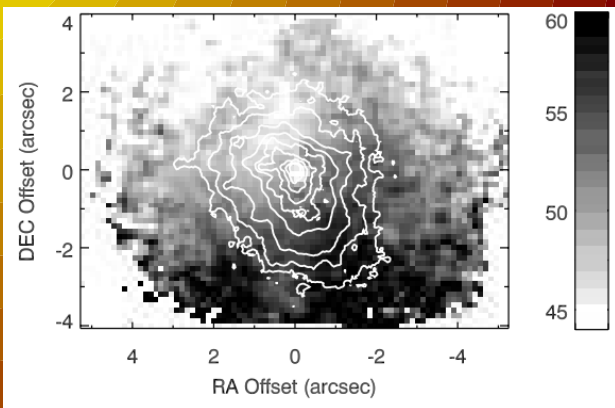
Koumpia et al. 2020

Nebulosity and shells of YHG: IRC+10420

Maps of the ^{12}CO J = 1–0 emission from IRAM

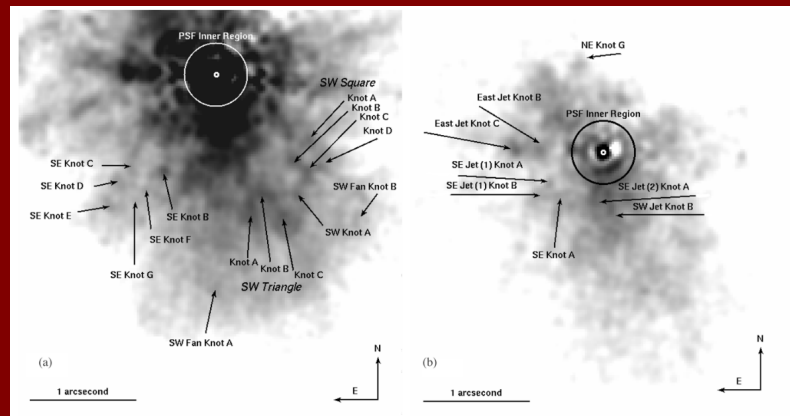


Castro-Carrizo et al. 2007



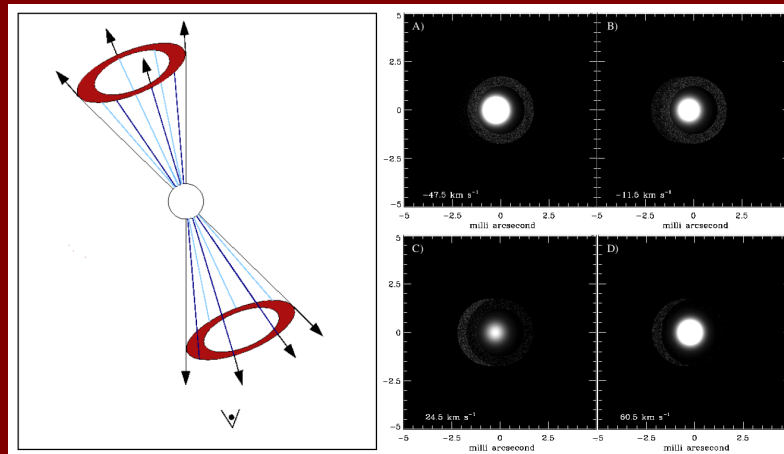
Davies et al. 2007

Map of the Ha EW overlaid with a contour map of the B-band HST image



Tiffany et al. 2010

HST/WFPC2 imaging

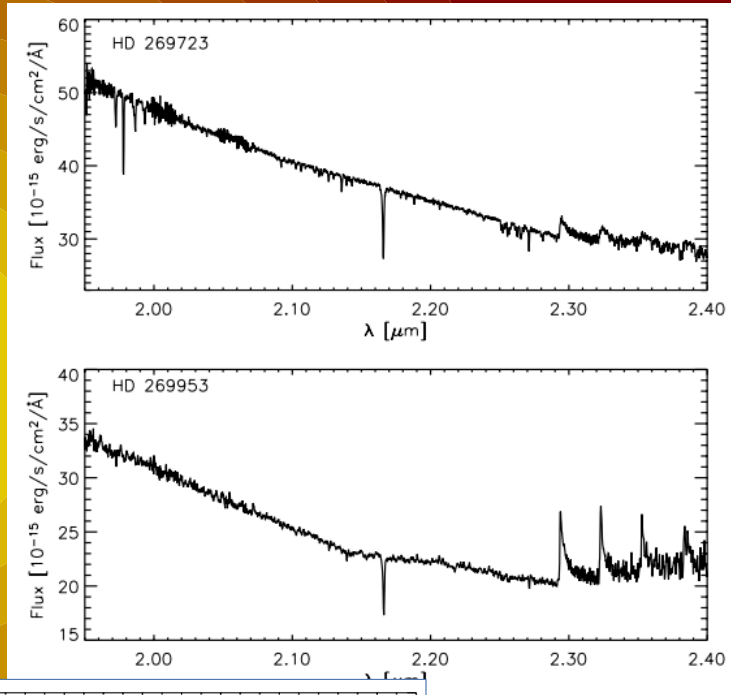


Geometry model based on AMBER observations

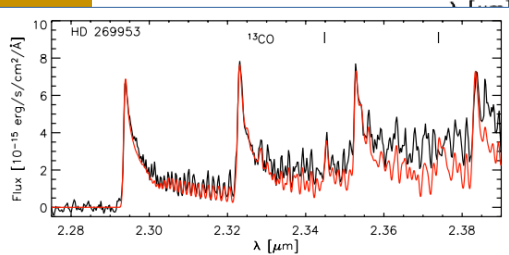
Oudmaijer & de Wit 2013

Ejecta in the K-band

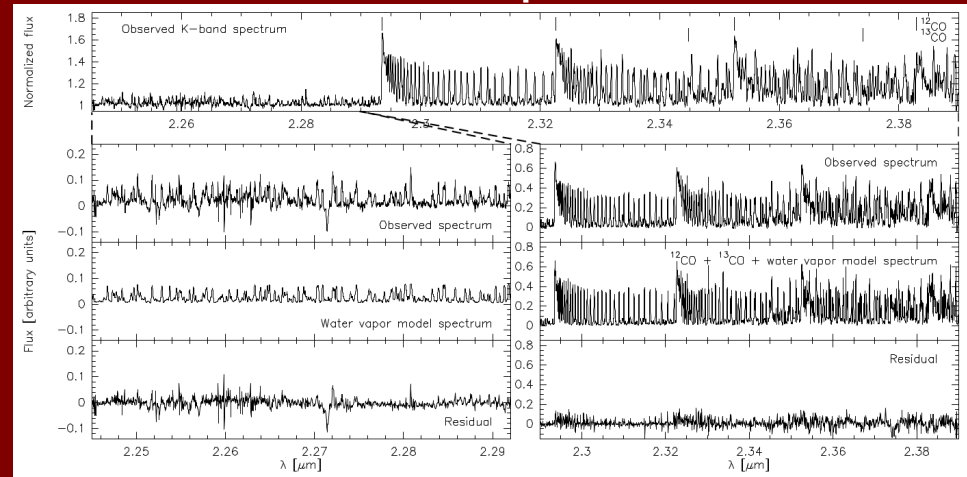
Processed material around YHGs



Oksala et al. 2013

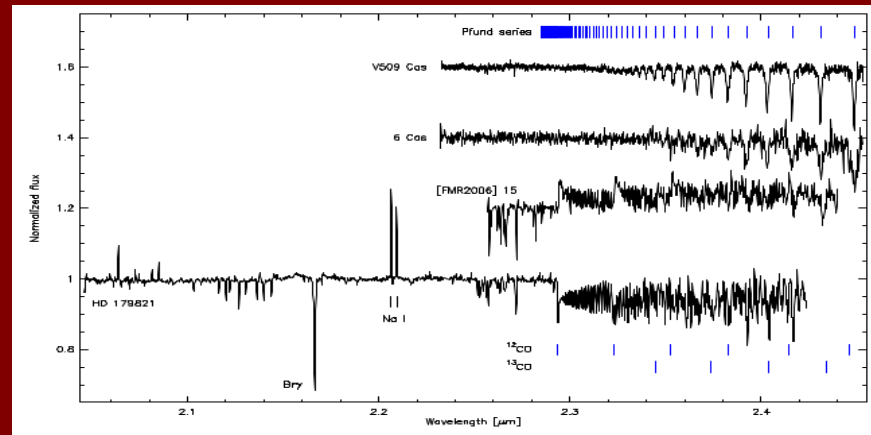


First detection of water vapor around HD269953



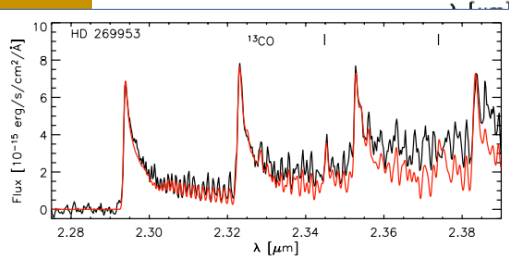
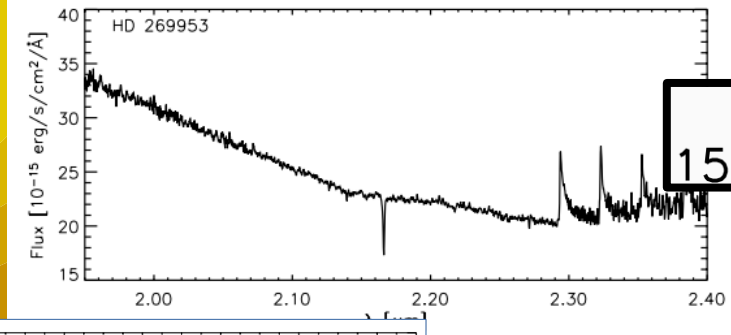
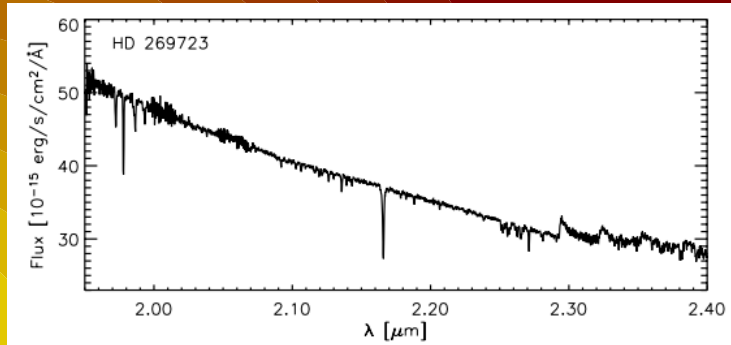
Kraus et al. 2022

Kraus et al. 2023



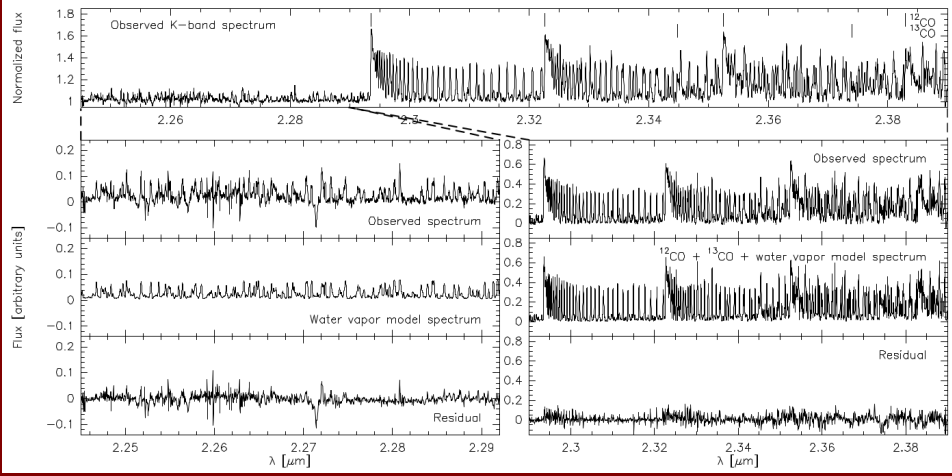
Ejecta in the K-band

Processed material around YHGs



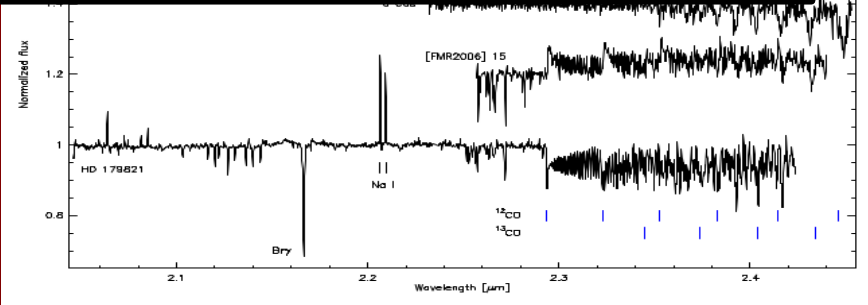
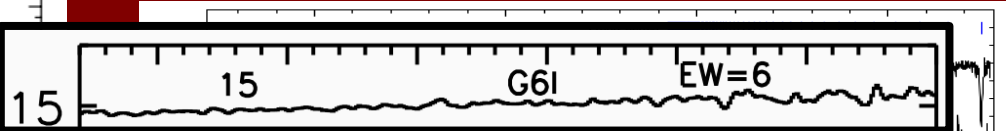
Oksala et al. 2013

First detection of water vapor around HD269953



Kraus et al. 2022

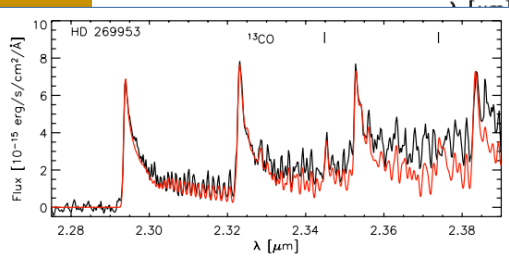
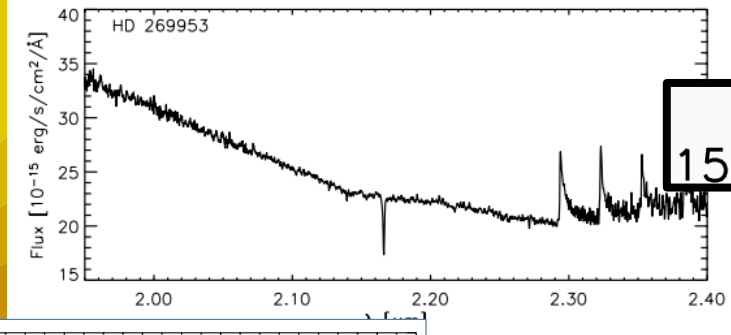
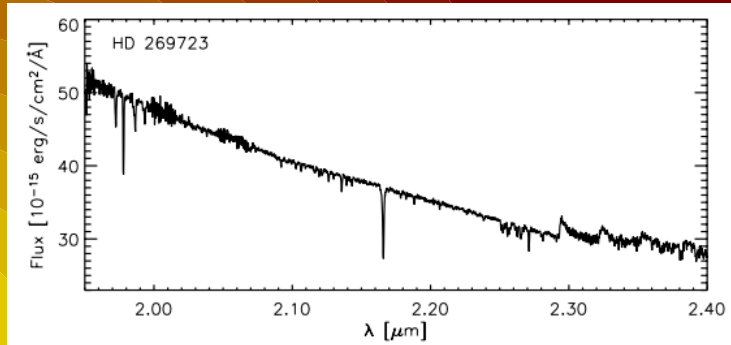
Kraus et al. 2023



[FMR2006] 15 (2005)
Finger et al. 2006

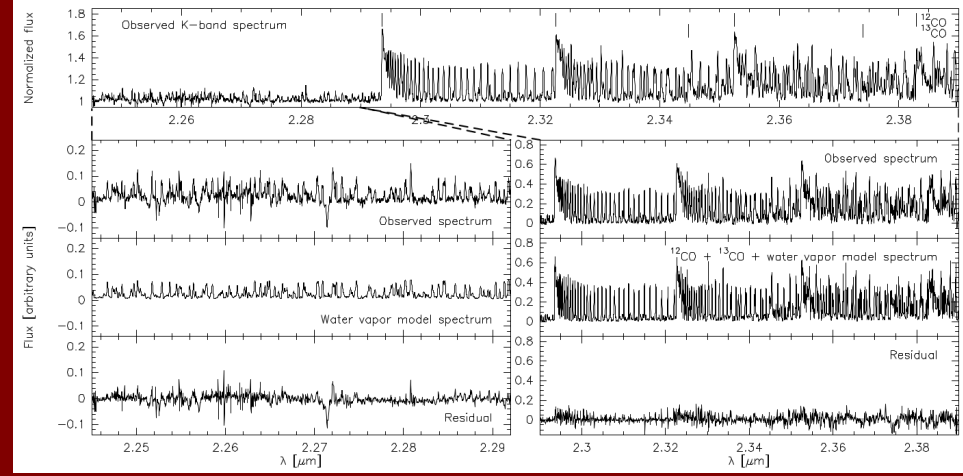
Ejecta in the K-band

Processed material around YHGs



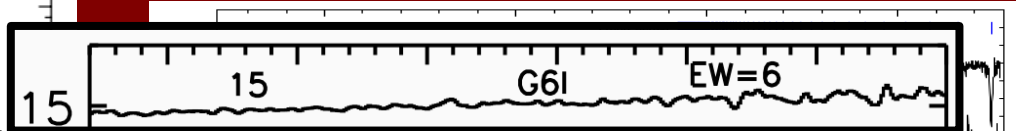
Oksala et al. 2013

First detection of water vapor around HD269953

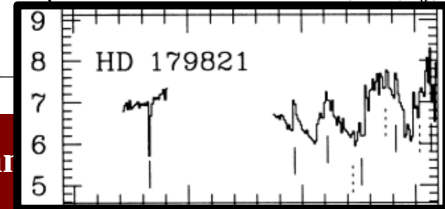
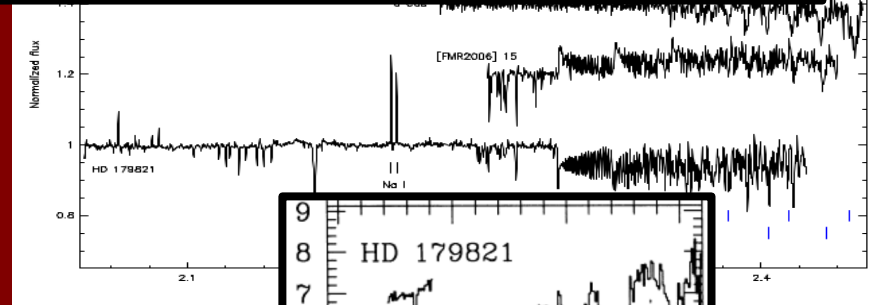


Kraus et al. 2022

Kraus et al. 2023



[FMR2006] 15 (2005)
Finger et al. 2006

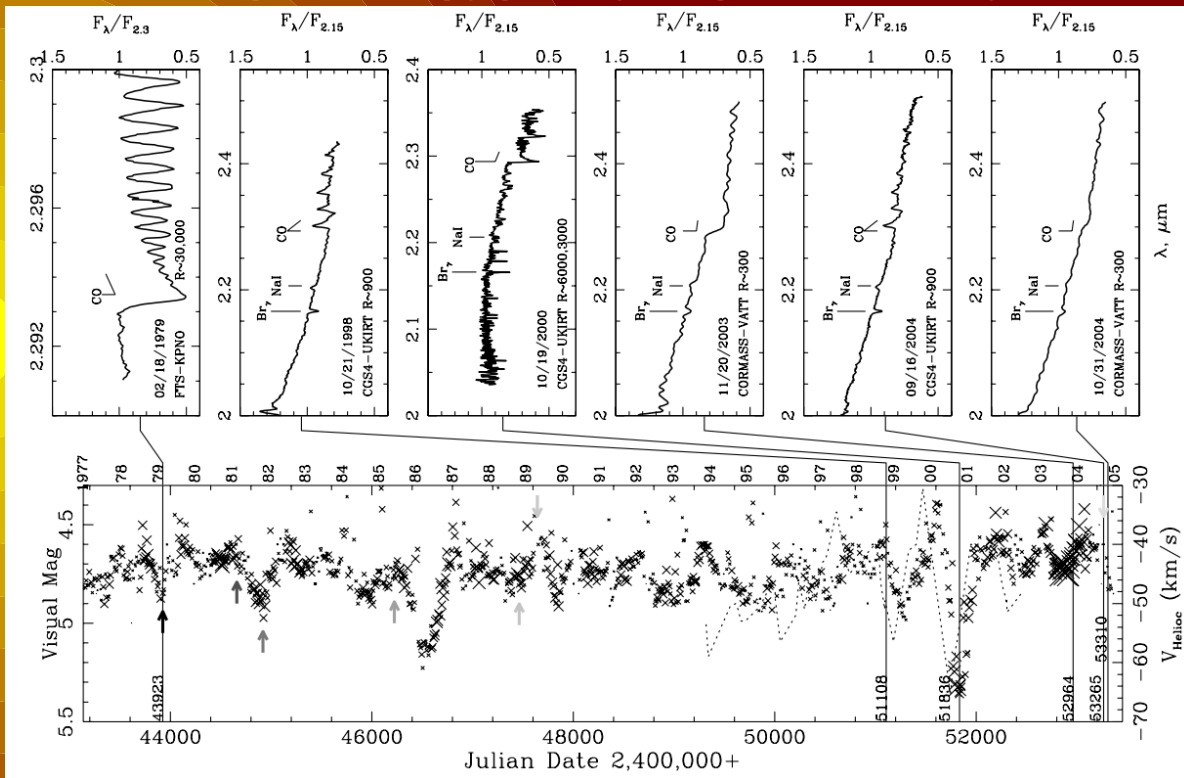


HD179821 (1989)
Oudmajer et al. 1995

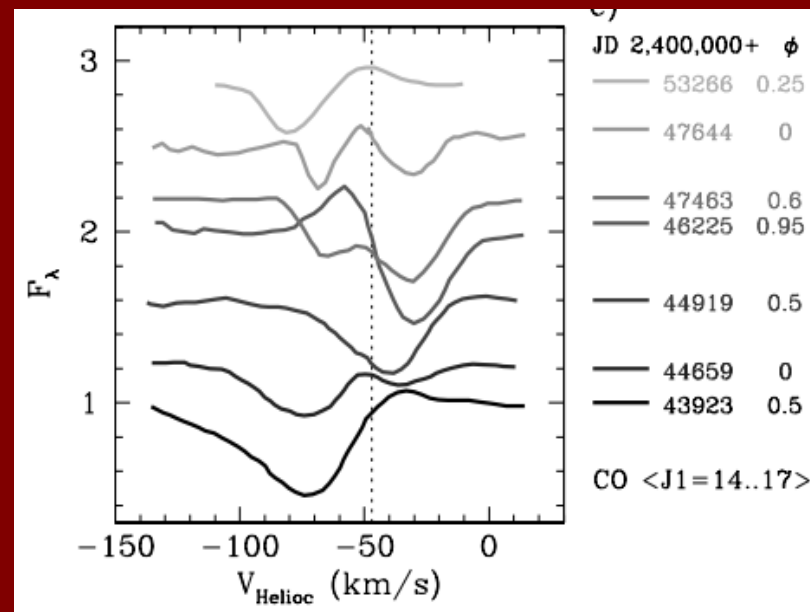
School on Stellar Winds and

Circumstellar variability

K-band spectroscopy pairing the photometric lightcurve



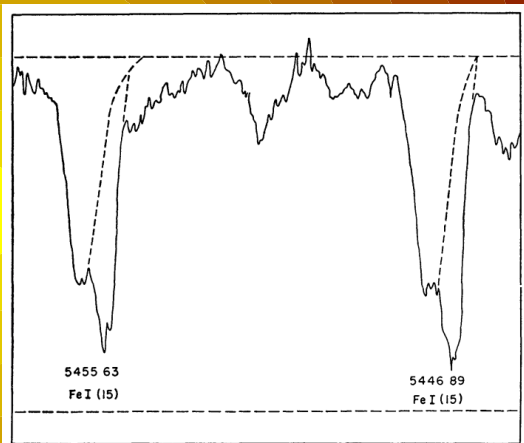
Gorlova et al. 2006



- ✓ *A variable K-band appearance*
- ✓ *Correlates with stellar activity*
- ✓ *CO is found to be in emission at high mass-loss phases*
- ✓ *Line profile of a pulsating photosphere*

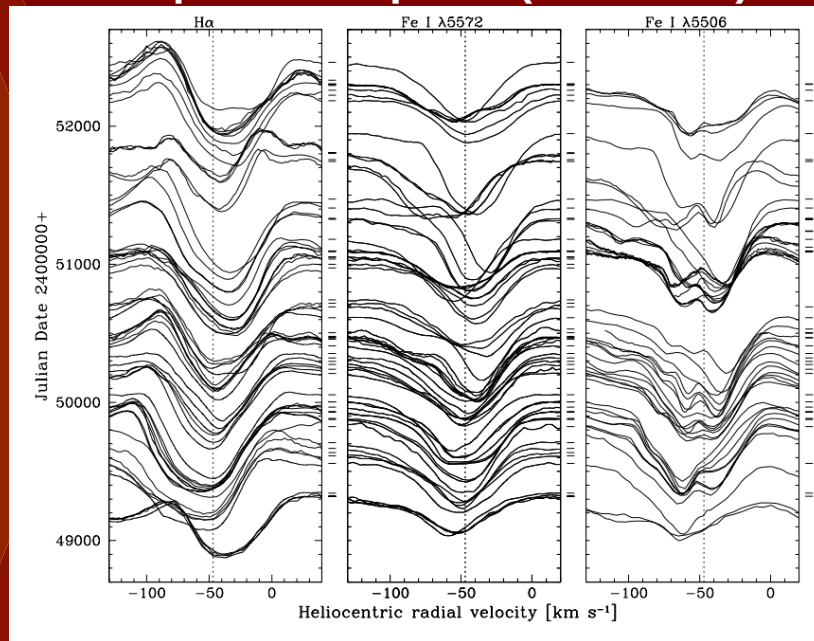
Line dynamics in the optical

ρ Cas: Asymmetric lines trace circumstellar shells



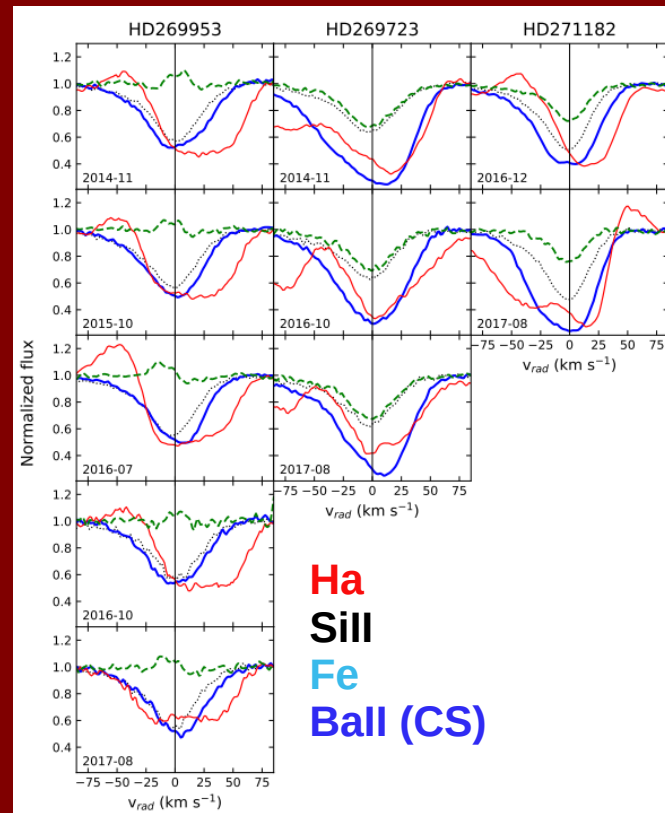
Sargent 1961

Line profiles of ρ Cas (1993-2002)



Lobel et al. 2003

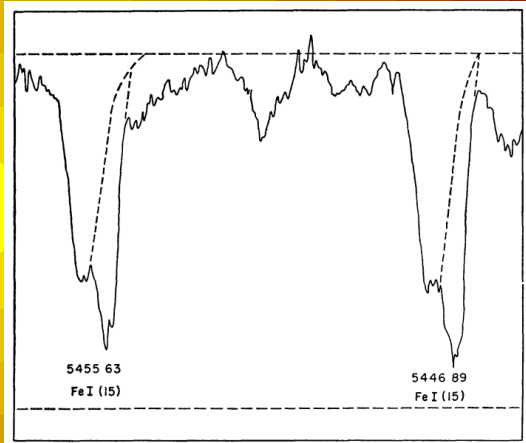
Lines of YHGs in the LMC



Kourniotis et al. 2022

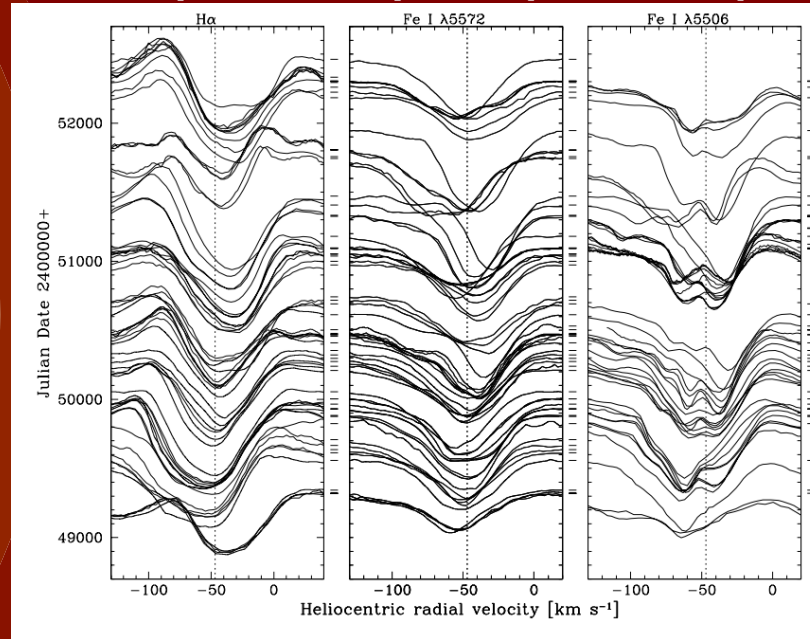
Line dynamics in the optical

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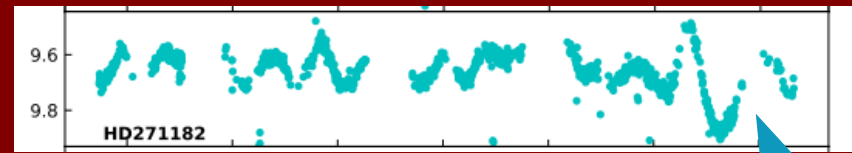


Sargent 1961

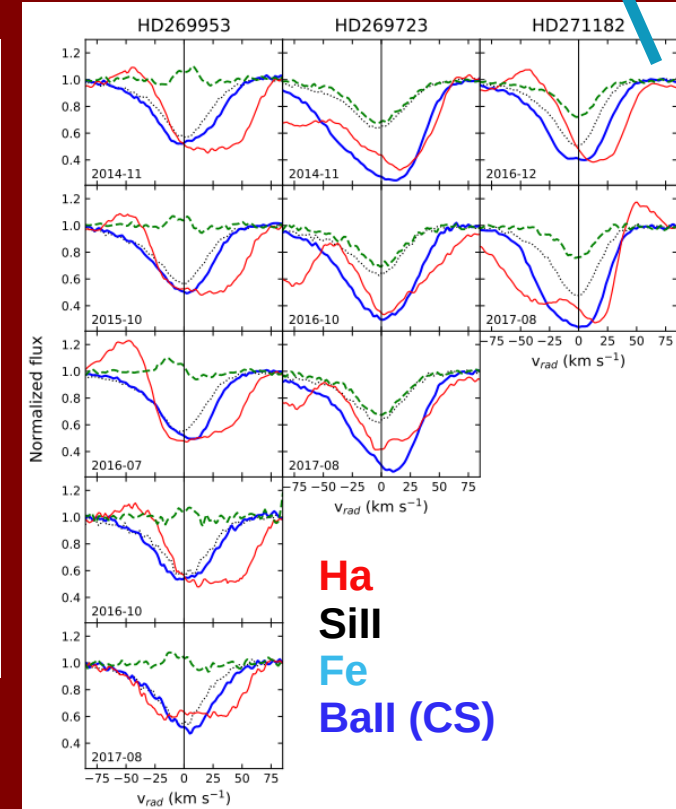
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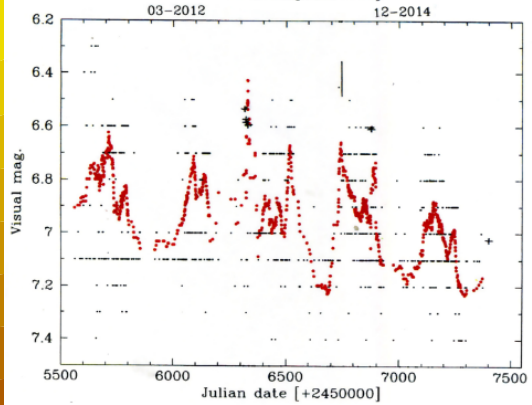
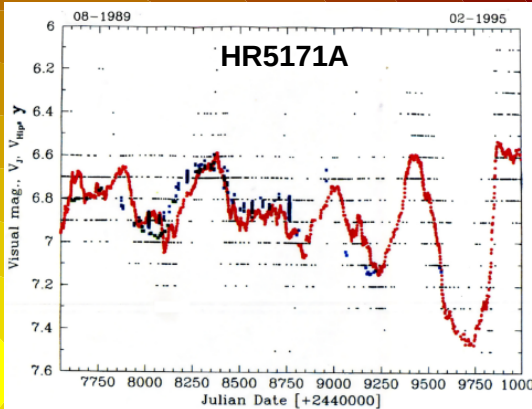


Lines of YHGs in the LMC

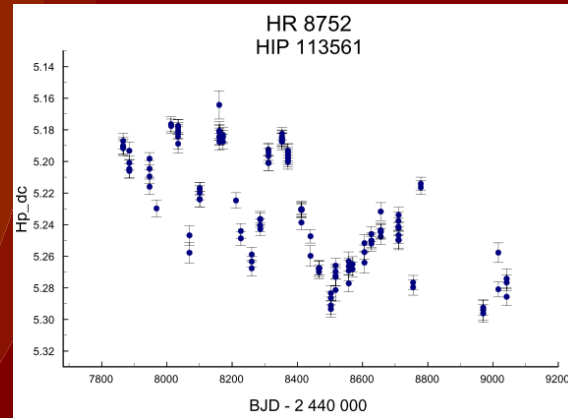
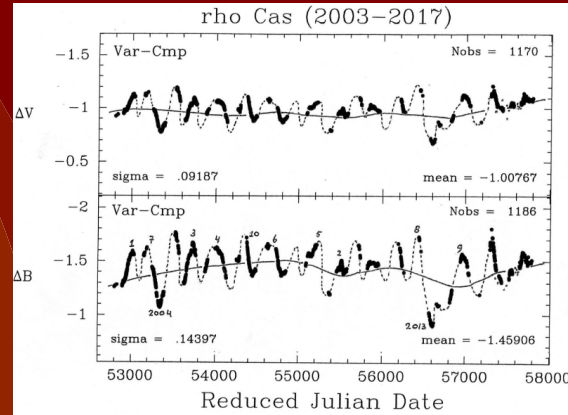


Kourniotis et al. 2022

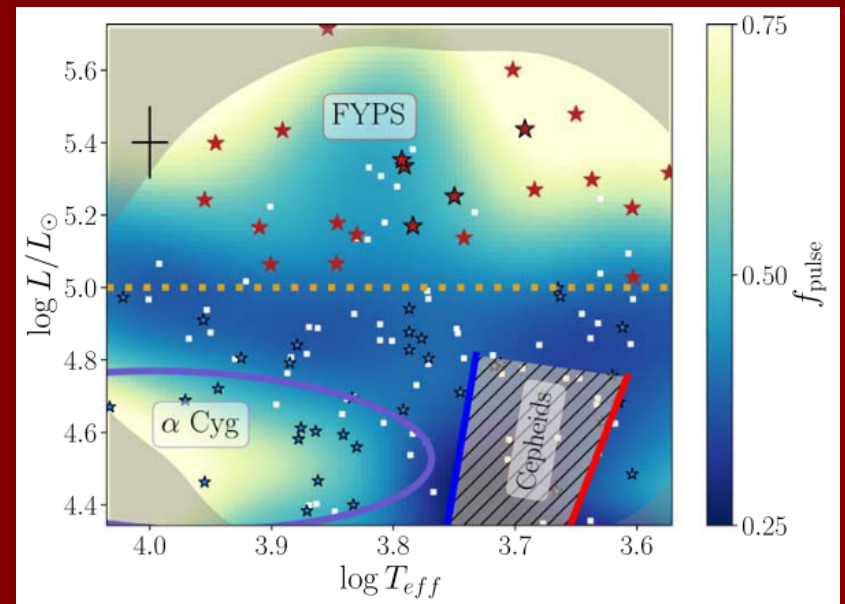
Pulsational variability



van Genderen et al. 2019



Nieuwenhuijzen & de Jager 2000

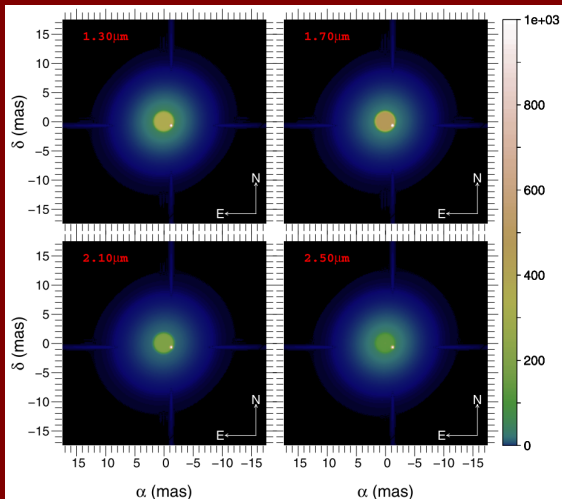
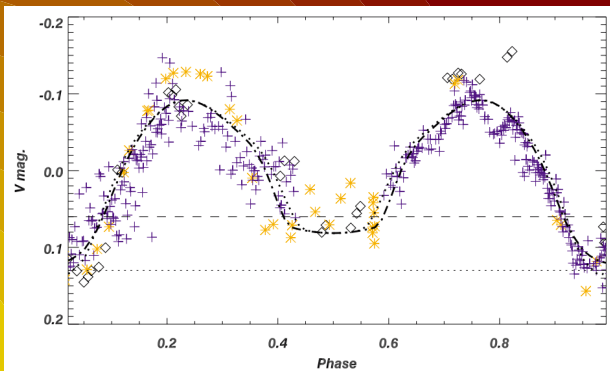


Dorn-Wallenstein et al. 2022

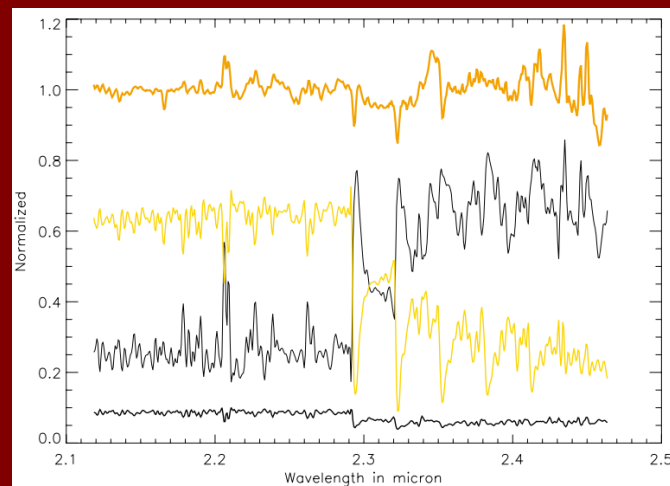
- ✓ Most, if not all, YHG exhibit semi-regular pulsations with poorly-understood nature
- ✓ Pulsational properties change based on the location/direction of the YHG on the HRD
- ✓ How does the pulsating activity change in YHG compared to YSGs ?

Binarity: HR5171A

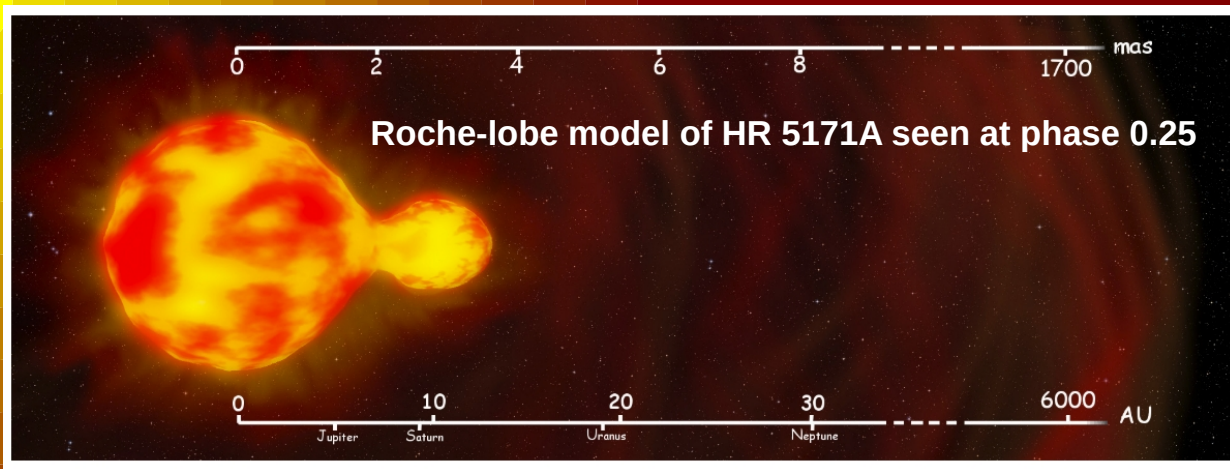
Phased LCs (HIPPARCHOS/ASAS)



Models fitting AMBER/VLTI interferometry



K-band comp. spectrum from AMBER/VLTI



Roche-lobe model of HR 5171A seen at phase 0.25

- ✓ *HR5171A is very physically extended*
- ✓ *Extended nebulosity / flux asymmetry*
- ✓ *Eclipsing LC reveals system ($P_{orb} \sim 3.5\text{yr}$)*
- ✓ *Possibly in Wind Roche-Lobe Overflow*

Chesneau et al. 2014

The *astroquery* package

hands on

- ✓ *astroquery* is a package for querying astronomical web forms and databases.
- ✓ Contains modules for querying web services for MAST, Simbad, Gaia, ESO, NASA ADS, VizieR etc, bringing the web interface to the scripting level.
- ✓ ***HANDS-ON: learning to query the VizieR service getting access to the published photometric catalogs, building the SED of a star.***
 - ***Query the 2MASS catalog around the coordinates of YHG V382 Car***
 - ***Converting magnitudes into fluxes using passband properties available from <http://svo2.cab.inta-csic.es/theory/fps3/>***
 - ***Student task: complement with Gaia 2 and WISE observations to assemble the optical/IR SED***
 - ***Student task: build SEDs for YHGs V509 Cas, IRC+10420, and ρ Cas***

Exercise slide

hands on

Radmm IR  J H K S

2MASS All-Sky Catalog of Point Sources (Cutri+ 2003)

II/246

Post annotation

1.II/246/out

Filter ID	λ_{ref}	λ_{mean}	λ_{eff}	λ_{min}	λ_{max}	W_{eff}	ZP_{v}
2MASS/2MASS.J	12350.00	12350.00	12350.00	10806.47	14067.97	1624.32	1594.00
2MASS/2MASS.H	16620.00	16620.00	16620.00	14787.38	18231.02	2509.40	1024.00
2MASS/2MASS.Ks	21590.00	21590.00	21590.00	19543.69	23552.40	2618.87	666.80

Radmm IR  J H K S

WISE All-Sky Data Release (Cutri+ 2012)

II/311

Post annotation

1.II/311/wise

Filter ID	λ_{ref}	λ_{mean}	λ_{eff}	λ_{min}	λ_{max}	W_{eff}	ZP_{v}
WISE/WISE.W1	33526.00	33526.00	33526.00	27540.97	38723.88	6626.42	309.54
WISE/WISE.W2	46028.00	46028.00	46028.00	39633.26	53413.60	10422.66	171.79
WISE/WISE.W3	115608.00	115608.00	115608.00	74430.44	172613.43	55055.23	31.67
WISE/WISE.W4	220883.00	220883.00	220883.00	195200.83	279107.24	41016.80	8.36

Radmm IR  G Bp G Grp

Gaia DR2 (Gaia Collaboration, 2018) [acknowledge](#)

I/345

1 annotation(s) on 1 specific record(s)

1.I/345/gaia2

Filter ID	λ_{ref}	λ_{mean}	λ_{eff}	λ_{min}	λ_{max}	W_{eff}	ZP_{v}
GAIA/GAIA2.Gbp	5050.00	5279.89	5050.00	3280.45	6719.03	2347.38	3534.74
GAIA/GAIA2.G	6230.00	6742.51	6230.00	3306.60	10450.65	4182.96	3296.20
GAIA/GAIA2.Grp	7730.00	7883.71	7730.00	6254.97	10605.79	2756.78	2620.25

School on Stellar Winds and Outflows

The AAVSO database

hands on

- ✓ The *American Association of Variable Star Observers (1911)* is an international non-profit organization of observers, which enables anyone to participate in the scientific discovery in the field of variable star astronomy.
- ✓ It is based in Cambridge, Massachusetts, with active participants from more than 100 countries, hosting more than 34 million observations of variable stars.

<https://www.aavso.org/>

- ✓ *HANDS-ON: learning to query, visualize and analyze a light curve from the AAVSO database*
 - *Online lightcurve generator - Accessing the data*
 - *VStar tool for analysis of time-series*
 - *Student task: periodic analysis of Eta Aql, ASAS 182611+1212.6, T UMi*

Exercise slide

hands on



For Observers

LCG
Light Curve Generator

VPhot
Photometry Tool

VSP
Variable Star Plotter

VStar
Data Analysis

VSX
Variable Star Index

WebObs
Data Entry

Plot a light curve

Your Star History ▾

Star Name:

:All Bands :Select Bands

Standardized Magnitude ▾

Julian Day ▾

From Date:

To Date:

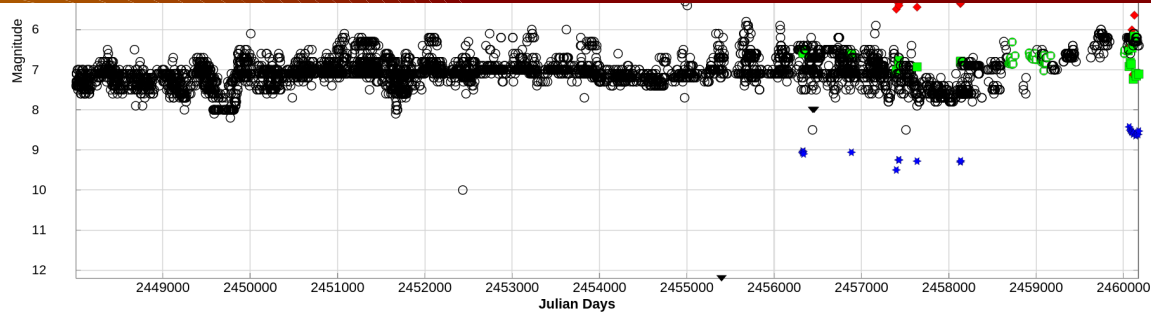
Plot Previous: Days All:

Observer(s): ?

?

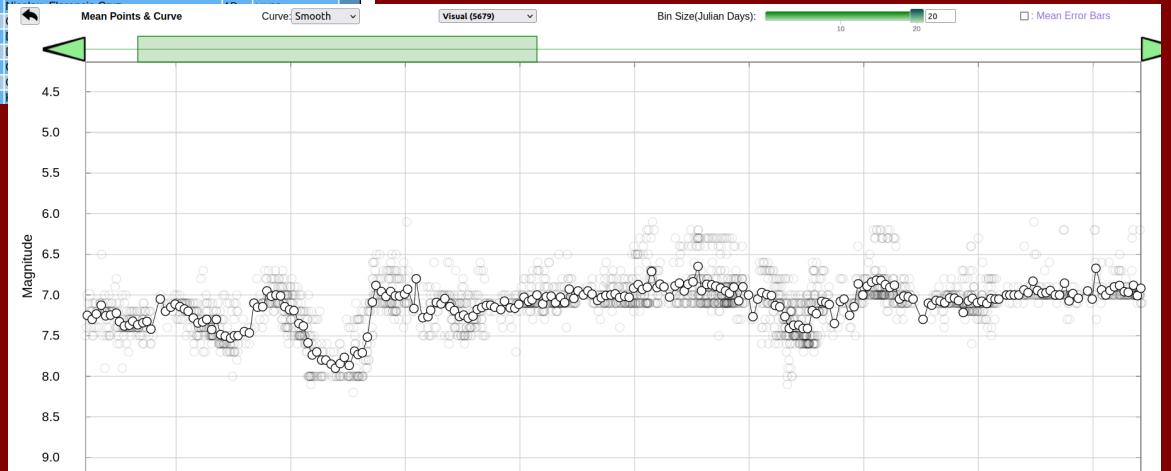
Exercise slide

hands on



Contributors to this Plot
5,792 observations of the 5,792 total observations for this star.

<input checked="" type="checkbox"/> All Contributors	<input checked="" type="checkbox"/> AAF (5) : Vis	<input checked="" type="checkbox"/> Abbott, Patrick	CA	<input checked="" type="checkbox"/> AAX (256) : Vis	<input checked="" type="checkbox"/> Amorim, Alexandre	BR	REA
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/> ACN (1) : Vis	<input checked="" type="checkbox"/> Adib, Carlos	BR	<input checked="" type="checkbox"/> AJC (8) : Vis	<input checked="" type="checkbox"/> Almeida, Joao	BR	
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/> ANAB (1) : Vis	<input checked="" type="checkbox"/> Arias, Nicolás	AR	<input checked="" type="checkbox"/> ARL (1) : Vis	<input checked="" type="checkbox"/> Alencar Caldas, Romualdo	BR	
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/> AWY (1) : Vis	<input checked="" type="checkbox"/> Araujo, Wesley	BR	<input checked="" type="checkbox"/> BWZ (216) : Vis	<input checked="" type="checkbox"/> Blown, Eric	NZ	
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/> BYU (22) : Vis	<input checked="" type="checkbox"/> Brandie, J.	NZ	<input checked="" type="checkbox"/> CFL (5) : Vis	<input checked="" type="checkbox"/>		
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/> COM (15) : Vis	<input checked="" type="checkbox"/> Cooper, Tim	ZA	<input checked="" type="checkbox"/> CR (2) : Vis	<input checked="" type="checkbox"/>		
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/> DCMA (1) : Vis	<input checked="" type="checkbox"/> da Silva, Cledison	BR	<input checked="" type="checkbox"/> DSI (46) : B,H,I,J,R,V	<input checked="" type="checkbox"/>		
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/> DVC (2) : Vis	<input checked="" type="checkbox"/> Devillers, Chris	ZA	<input checked="" type="checkbox"/> DXX (18) : Vis	<input checked="" type="checkbox"/>		
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/> FMX (45) : Vis	<input checked="" type="checkbox"/> Farrell, Fraser	AU	<input checked="" type="checkbox"/> GAJ (13) : Vis	<input checked="" type="checkbox"/>		
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/> GED (9) : Vis	<input checked="" type="checkbox"/> Gonçalves, Eduardo Henrique Cordeiro	BR	<input checked="" type="checkbox"/> GFE (1) : Vis	<input checked="" type="checkbox"/>		
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/> GPX (53) : Vis	<input checked="" type="checkbox"/> Goltz, William	AU	<input checked="" type="checkbox"/> HEN (73) : Vis	<input checked="" type="checkbox"/>		



Exercise slide

hands on



Home

Download Data

Please complete this form to download variable star data from the AAVSO International Variable Star List. For very large datasets or further assistance, please contact AAVSO HQ (aavso@aavso.org).

WHAT IS THE AUID, NAME, OR DESIGNATION OF THE OBJECT? *

V766 CEN

WHAT DATE RANGE WOULD YOU LIKE TO USE?

Enter Julian date or Gregorian Date (MM/DD/YYYY)

START DATE *

2448000

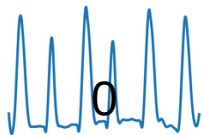
END DATE *

2460155.5

HOW SHALL WE CONTACT YOU?

FIRST NAME

LAST NAME



Submit and Access Data

Variable Star Plotter

[VSP Help Guide](#) [Request a Sequence](#) [Report chart errors](#) [Standard](#)

PLOT A QUICK CHART

WHAT IS THE NAME, DESIGNATION OR AUID OF THE OBJECT?

V766 CEN

Required if no coordinates are provided below

RIGHT ASCENSION

Allowed Formats: HH:MM:SS, HH MM SS, DDD.XXXX. Required if no name is given above

CHOOSE A PREDEFINED CHART SCALE

Select one...

A is larger, slower; G is smaller, faster

CHOOSE A CHART ORIENTATION

Visual Reversed CCD

PLOT A FINDER CHART OR A TABLE OF FIELD PHOTOMETRY? *

Chart Photometry

CHART ID

A Chart ID will allow you to reproduce prior charts. Overrides all other fields in this form.

ADVANCED OPTIONS

FIELD OF VIEW

300

In Arcminutes. Must be between 0' and 1200'

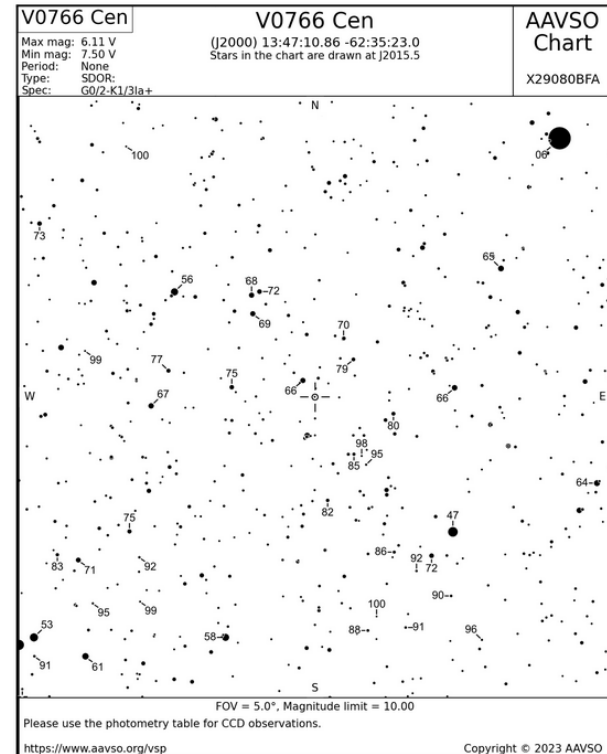
MAGNITUDE LIMIT

10.0

Stars fainter than this magnitude will not be displayed

Variable Star Plotter

[Plot Another Chart](#) [Photometry Table for This Chart](#)



School on Stellar Winds and Outflows