# Investigating the circumstellar structures of B[e] Supergiants

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# The B[e] phenomenon

*" The B[e] classification designates those stars of spectral type B which show forbidden emission lines in their optical spectrum, where the notation "[e]" follows that for forbidden lines."*

*Conti 1976*

**Definition:**

*1. Strong Balmer emission lines.*

*2. Low excitation permitted emission lines of predominantly low ionization metals in the optical spectrum, e.g. Fe II.*

*3. Forbidden emission lines of [Fe II] and [O I] in the optical spectrum.*

*4. A strong near or mid-infrared excess due to hot circumstellar dust.*

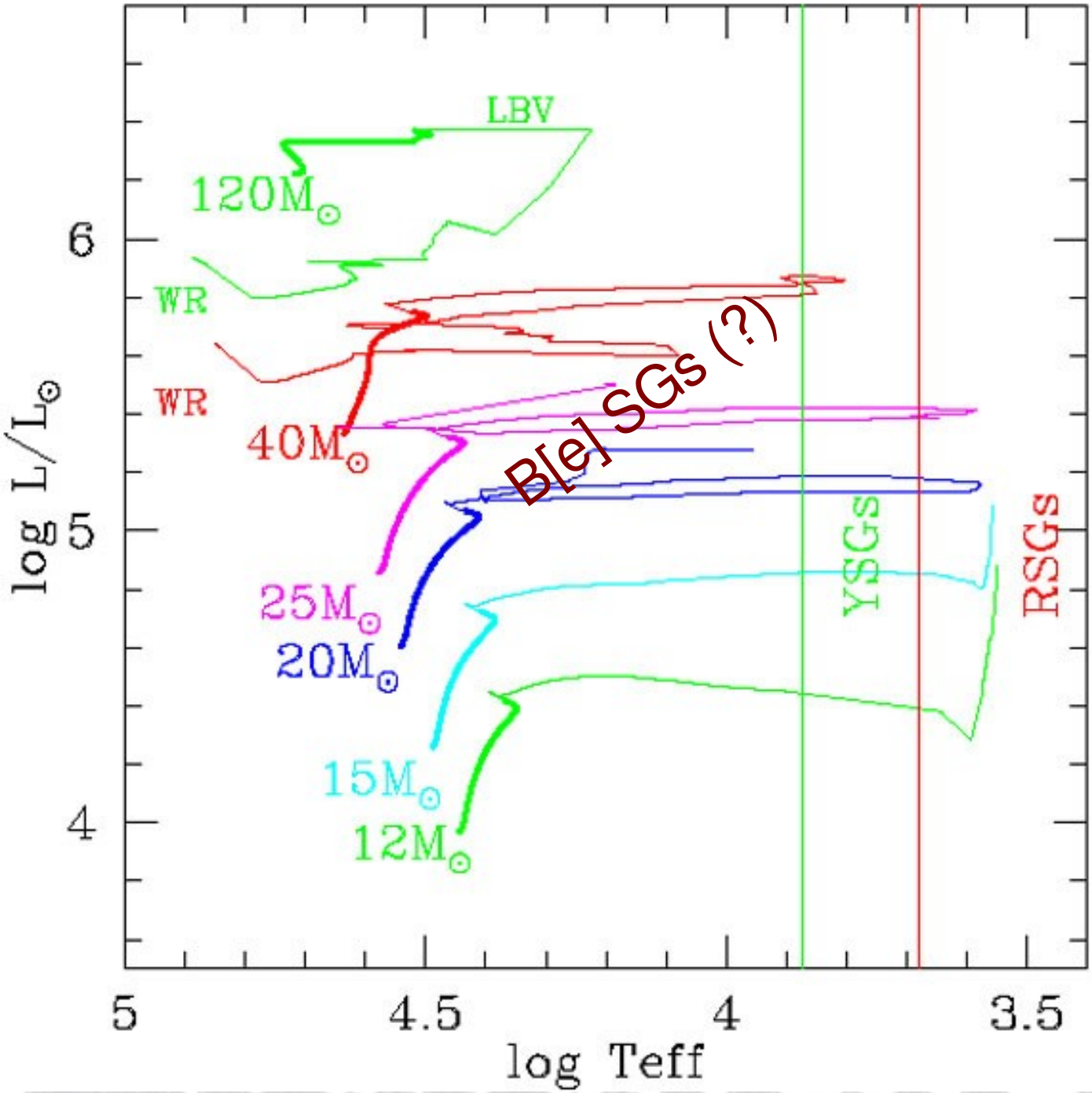
***Lamers et al. 1998 (Allen & Swings, 1976; Zickgraf, 1998)***

# Objects with the B[e] phenomenon

## at different evolutionary states:

- → Herbig AeBe
- → Compact Planetary Nebulae
- → Symbiotics
- → Supergiants
- → FS CMa type
- → Unclassified...

# Position in the Hertzsprung–Russell diagram




*Massey 2013*

# B[e] Supergiants – the observational properties

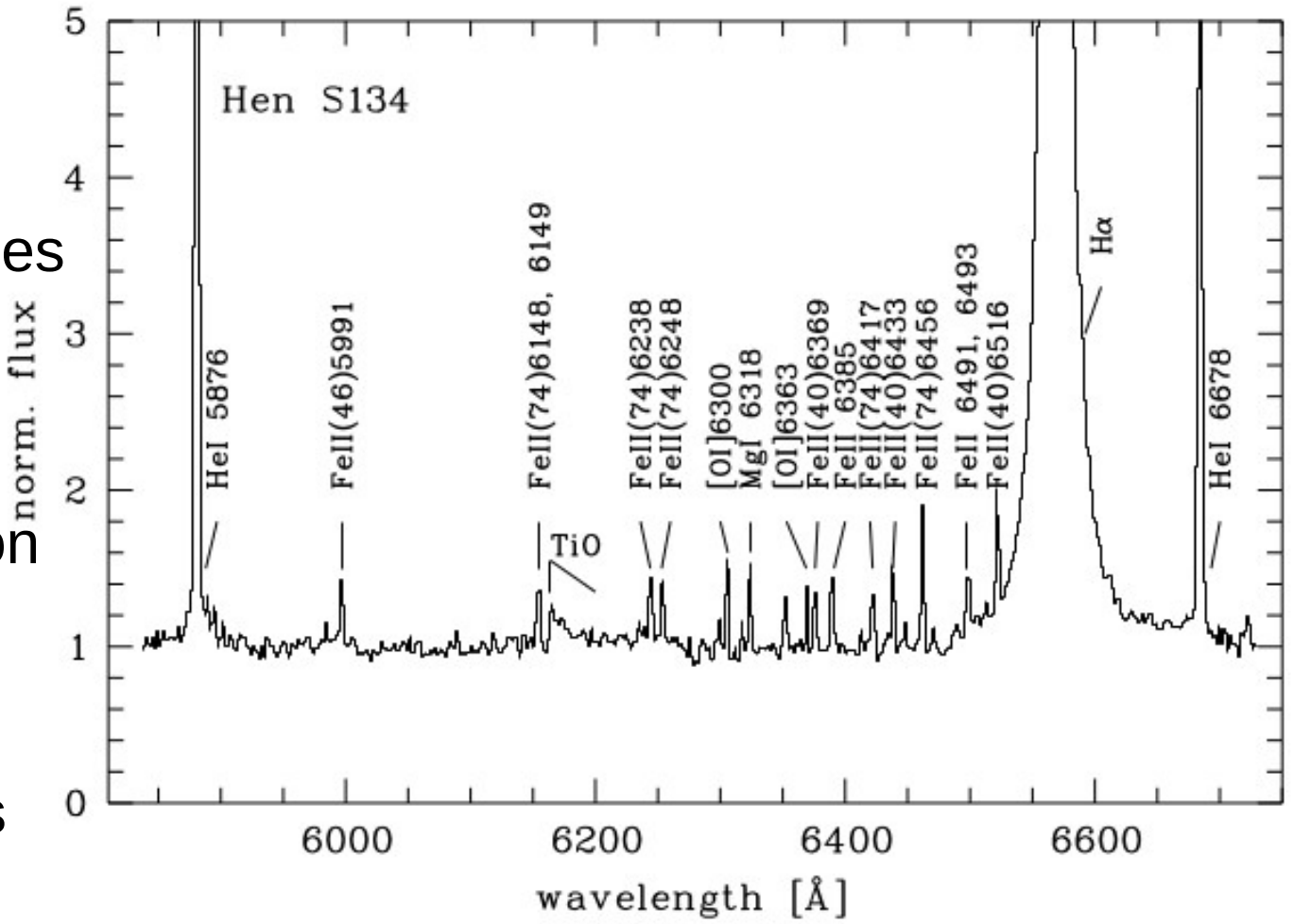
**1.** B[e] phenomenon

**2.** Strong Balmer lines,
+ usually P-Cygni profiles
($EQW_{H\alpha}$ ~ $10^2$-$10^3$ Å)

**3.** Narrow, low-excitation FeII, [FeII], and [OI]

**4.** Stars → Supergiants
Log ( $L_*/L$ > 4.0 )

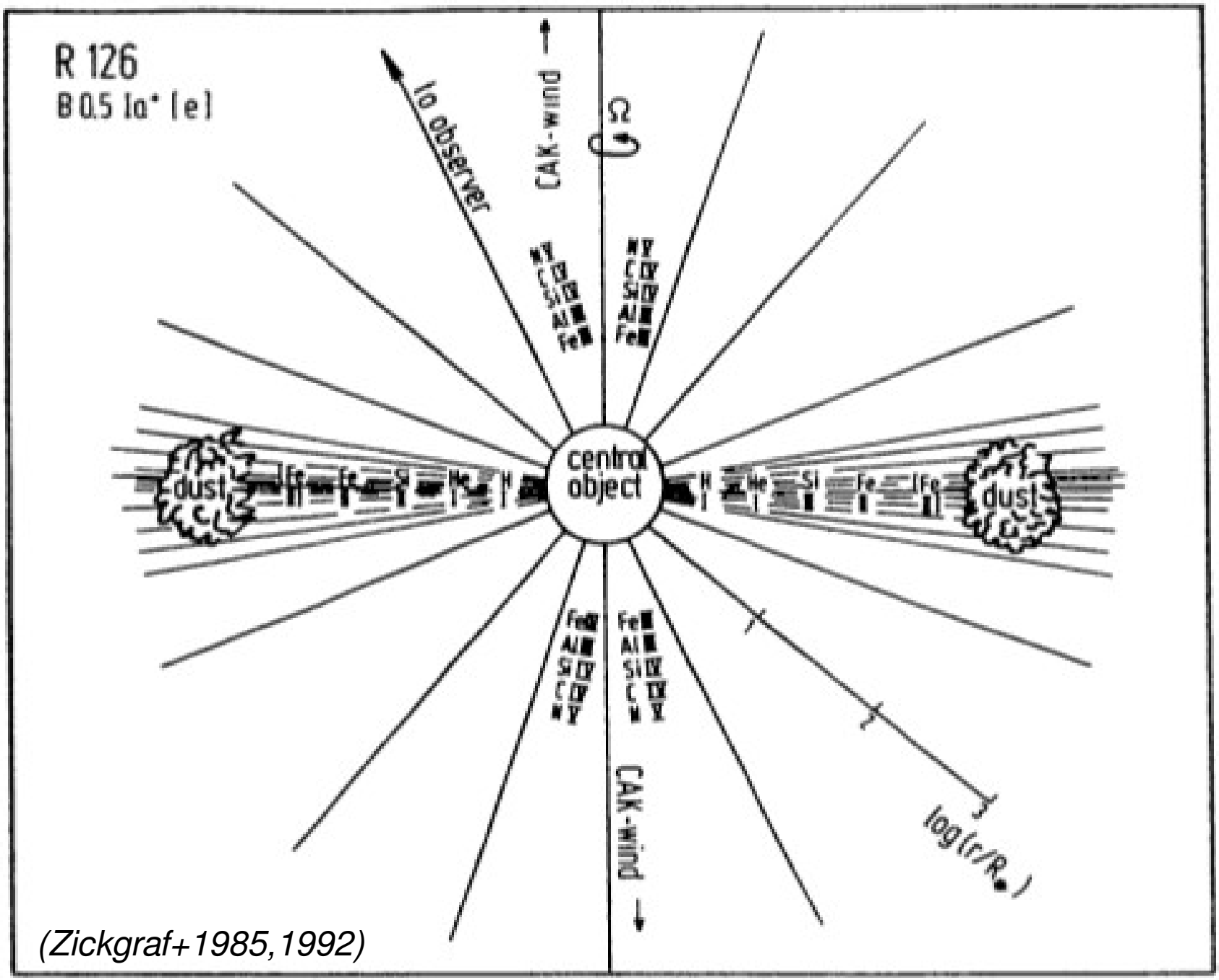
**5.** Chemically processed material → evolved evolutionary phase (e.g. $^{13}CO$ enrichment, TiO)




*Lamers+1998*

**See review by Kraus 2017, ASPC, 508, 219**

# “Classic” 2-component wind model




*(Zickgraf+1985,1992)*

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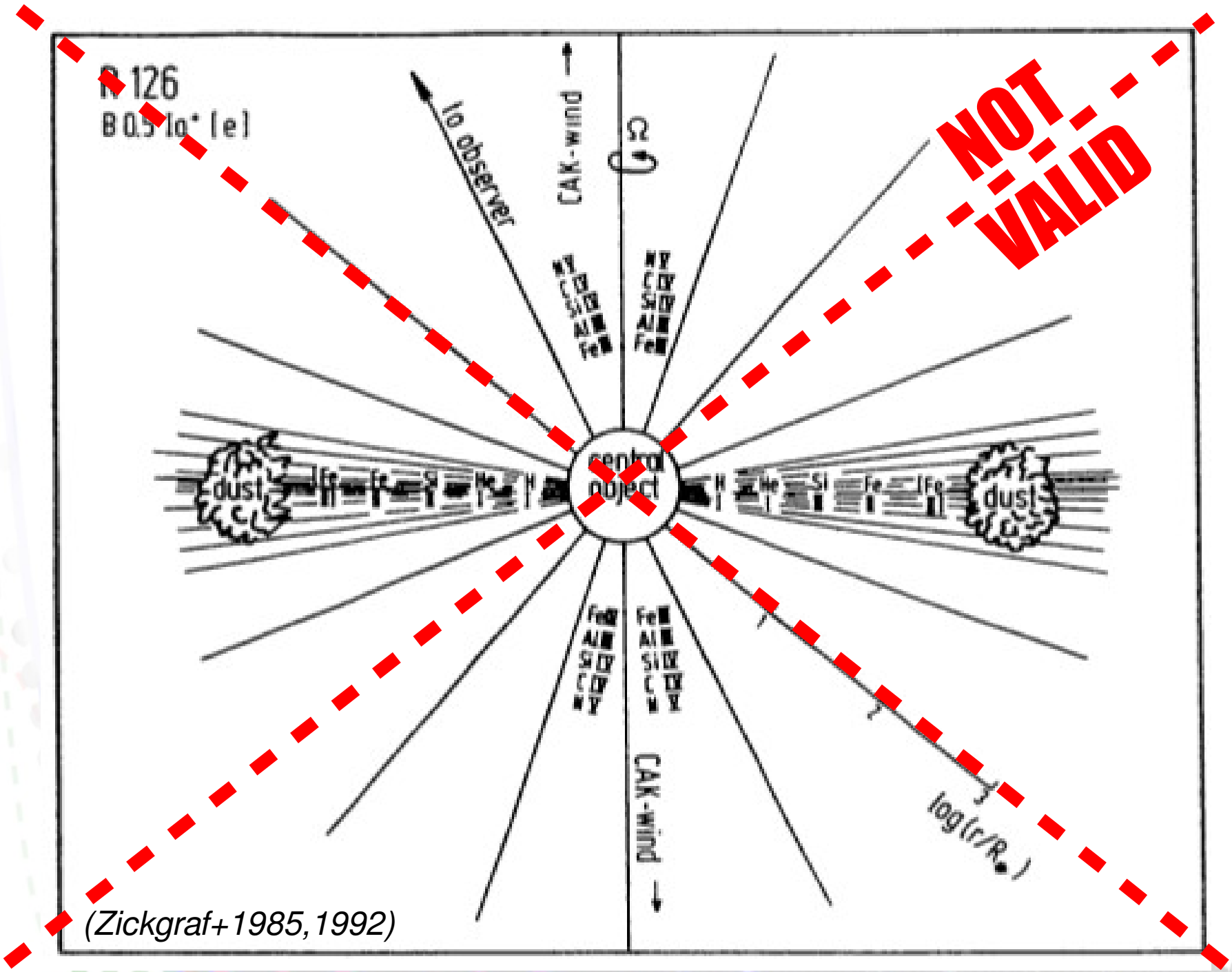
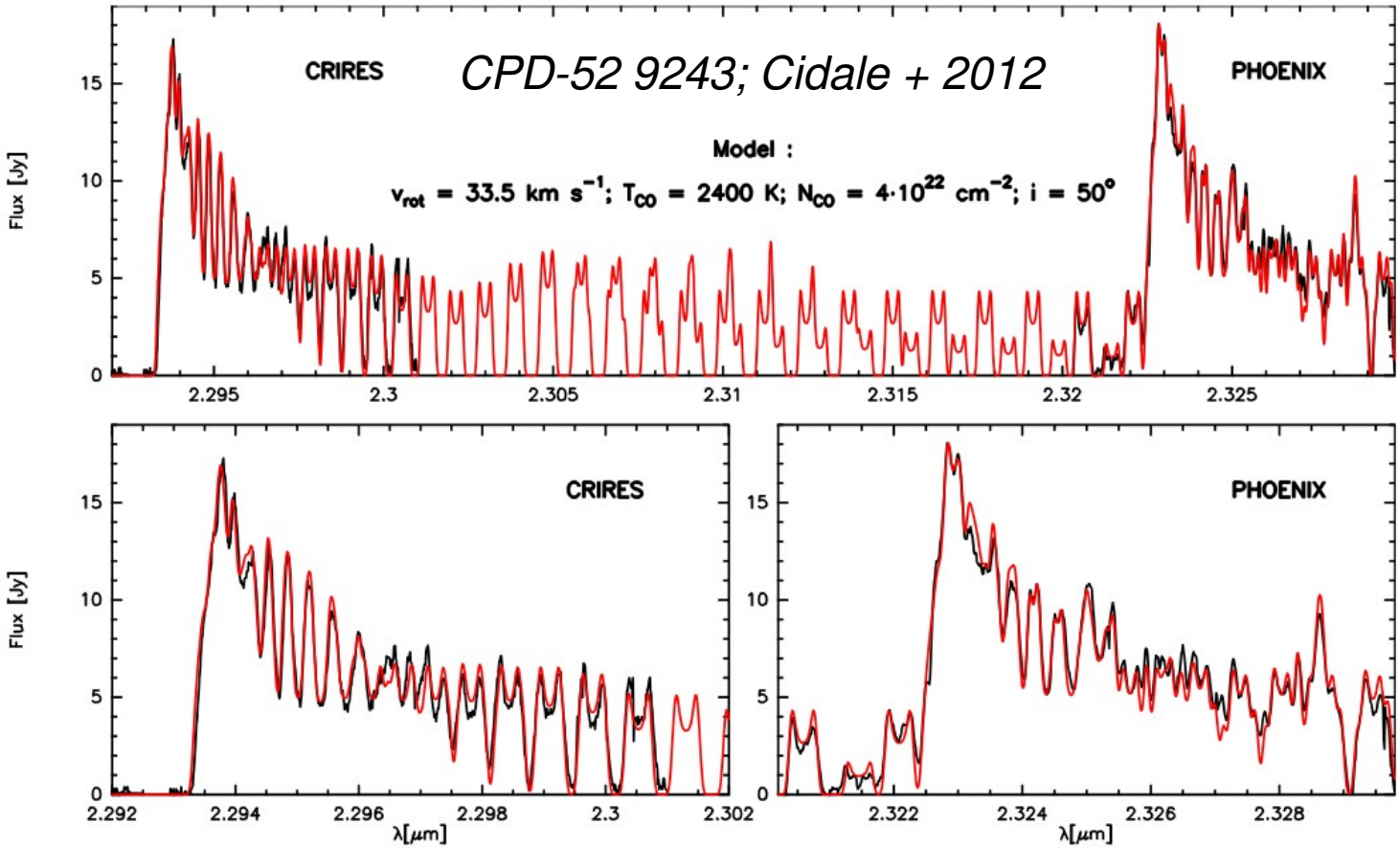



*(Zickgraf+1985,1992)*

# Towards a new model

→ Keplerian rotation
(e.g. Kraus+2010, Wheelwright+2012b)

→ Detached disks
(e.g. Millour+2011, Cidale+2012, Oksala+2013)



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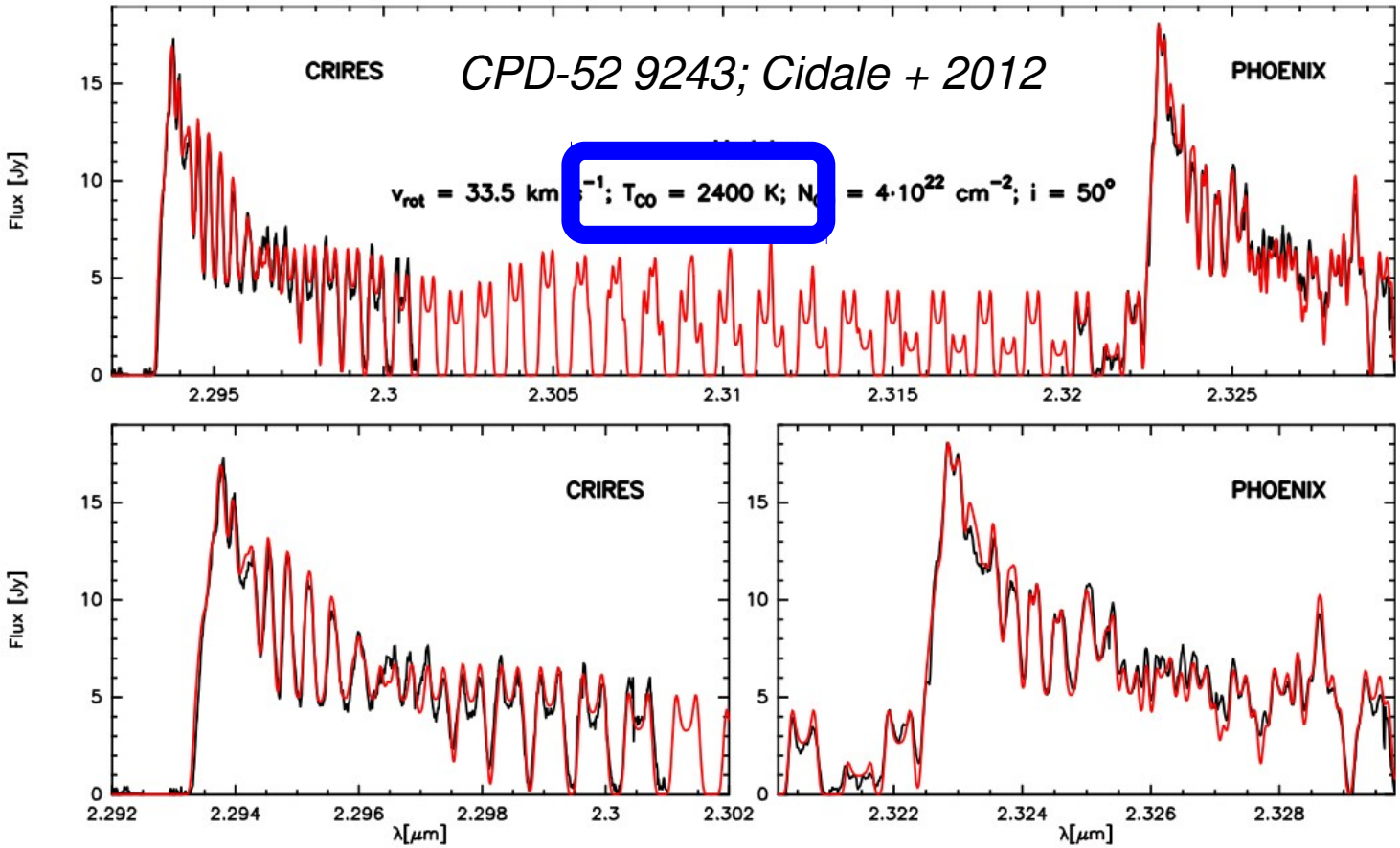
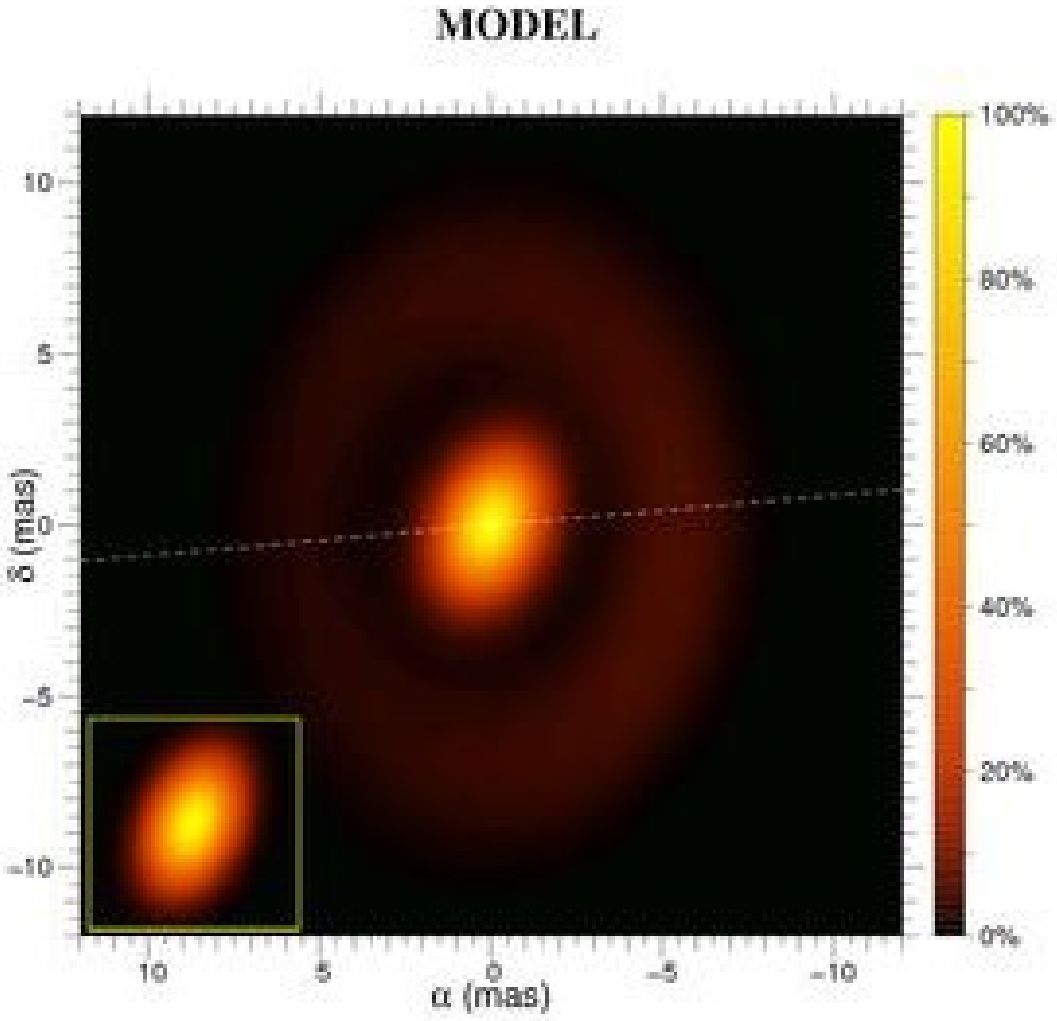


# Towards a new model

→ Keplerian rotation
(e.g. Kraus+2010, Wheelwright+2012b)

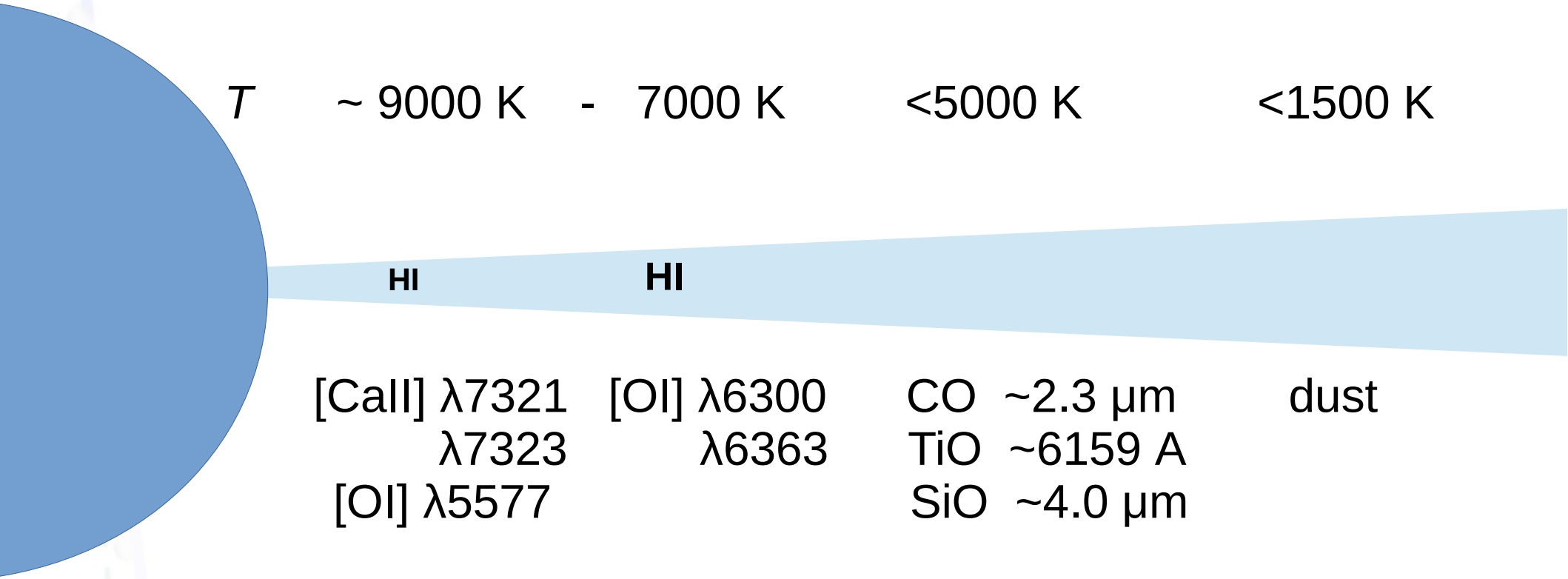
→ Detached disks
(e.g. Millour+2011, Cidale+2012, Oksala+2013)

→ Presence of rings
(e.g. Aret+2012, Kraus+2016)




*HD 62623*
*Millour + 2011*

# Disk tracing




*Kraus+2007,2010, Aret+2012*

Optical emission lines ([OI],[CaII]) are optically thin
Probe the kinematics of their forming regions

Tracers of different *temperatures / densities*
Probe different parts of the disk (structure)

# Observing campaign

**Goal:** **build** a homogeneous sample + **study** the global properties

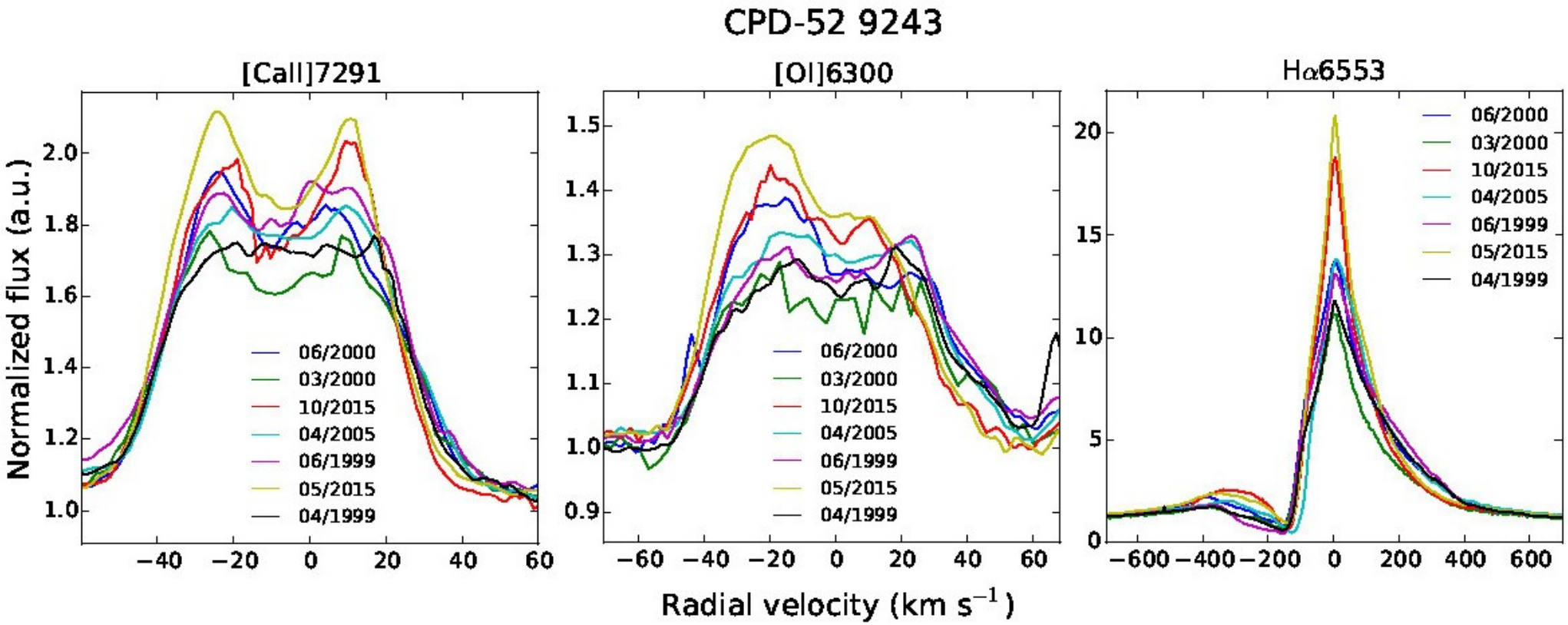
**High-resolution spectrographs:**

- FEROS @ 2.2m MPG/ESO, (*R*~48000, ~3600-9200 Å)
- echelle @ 2.5m du Pont, (*R*~45000, ~3600-9200 Å)
- SINFONI @ 8.2m UT4/ESO,
  (integral field spectrograph *R*~2000(J)-4000(K), 1.1-2.45μm)
- CRIRES @ 8.2m UT1/ESO, (*R*~100000, 1-5.3μm)
- Phoenix @ 8m Gemini South, (*R*~50000, 2.319-2.329μm)

**Time span:** **1999 – present**
better monitoring the last 4 years
Tycho Brahe program (CR, 2014 – 2016) + ESO programs

**Sample:** Galaxy = 12
Large Magellanic Cloud = 11
Small Magellanic Cloud = 5

# Observing campaign – an example




*Maravelias et al. (in prep.)*

# Kinematical model

Broadening of the line profile due to:

1. Emission from narrow rotating ring of gas
   (constant de-projected velocity Vrot)

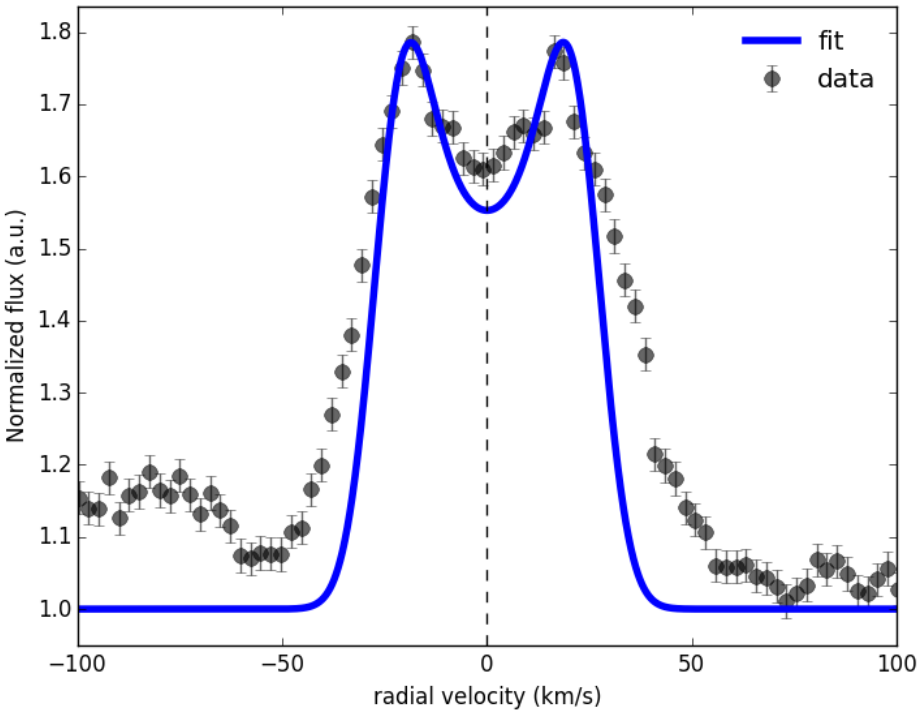
+

2. Gaussian component (Vg),
which is a combination of:
   a. spectral resolution (~5.5-6.5kms$^{-1}$),
   b. thermal velocity (~1-2 km s$^{-1}$)
   c. some random internal motion (~few km s$^{-1}$),
      implying a wider ring

*Free parameters:* velocities + flux

# Kinematical model

*Maravelias+2017*

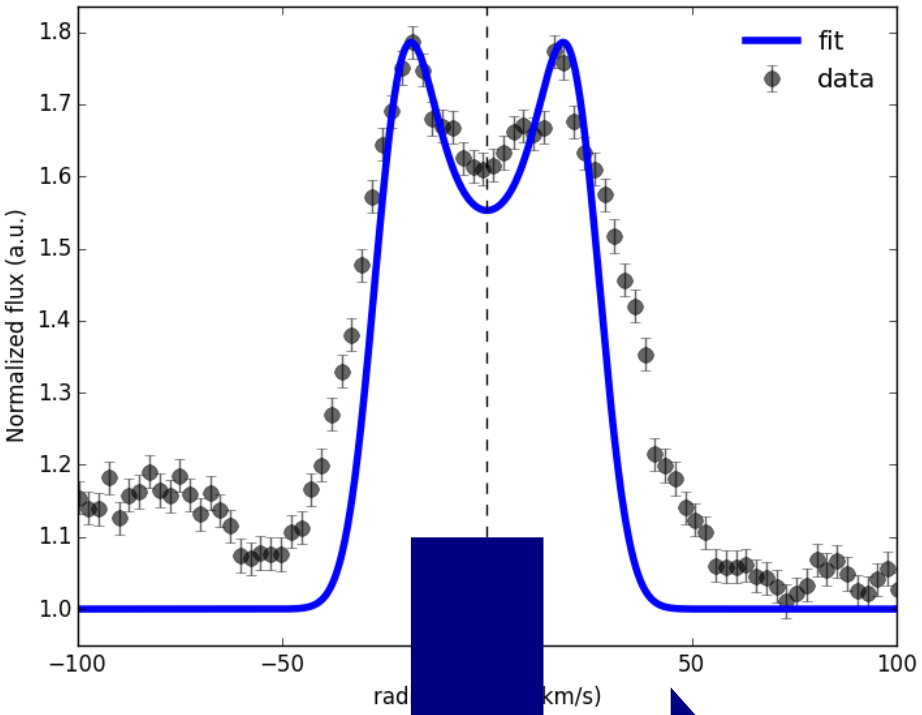



example: CPD-52 9243
[CaII] λ7291 in March 2000

Assuming same region with CO
Vrot = 33.5±2 Vg = 8±1 $kms^{-1}$

# Kinematical model

*Maravelias+2017*




2 rings

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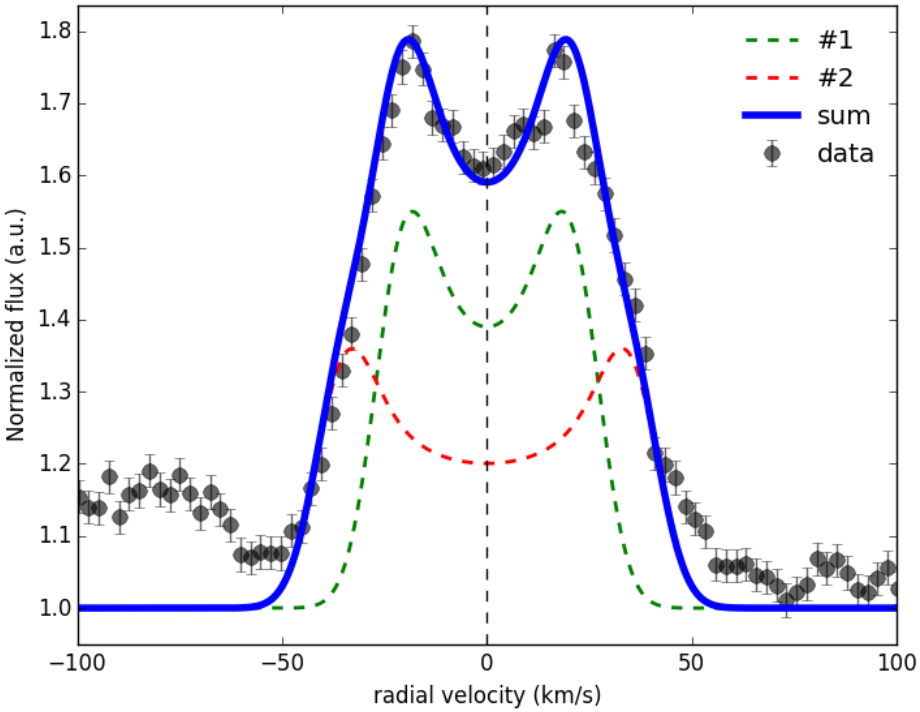
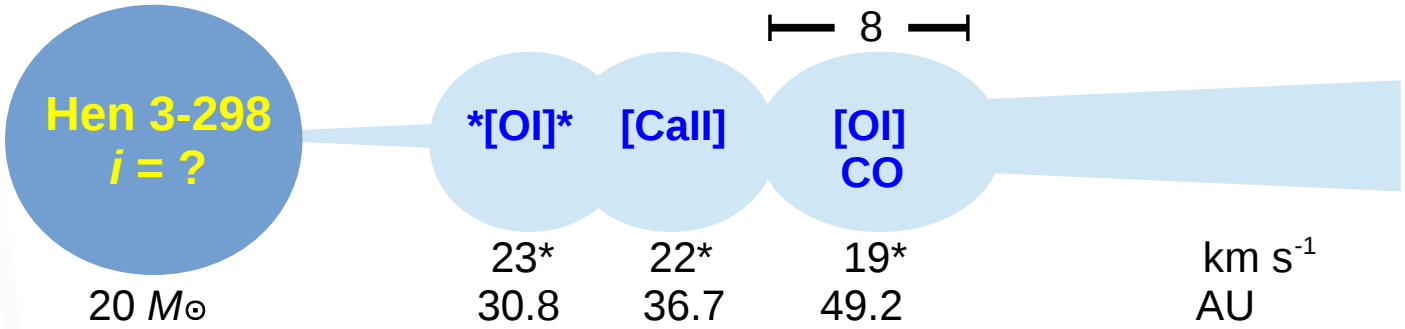



Vrot = 36±1 Vg = 9±1 kms$^{-1}$

Vrot = 52±1 Vg = 9±1 kms$^{-1}$

# Example cases

** line-of-sight velocities*
*[OI]* refers to [OI] λ5577, while [OI] to [OI] λλ6300, 6363




> 3 rings – although it could be a rather extended region
> T decreases away from the star

[ NOT to scale ]

*Maravelias+2017, Maravelias+,in prep.*

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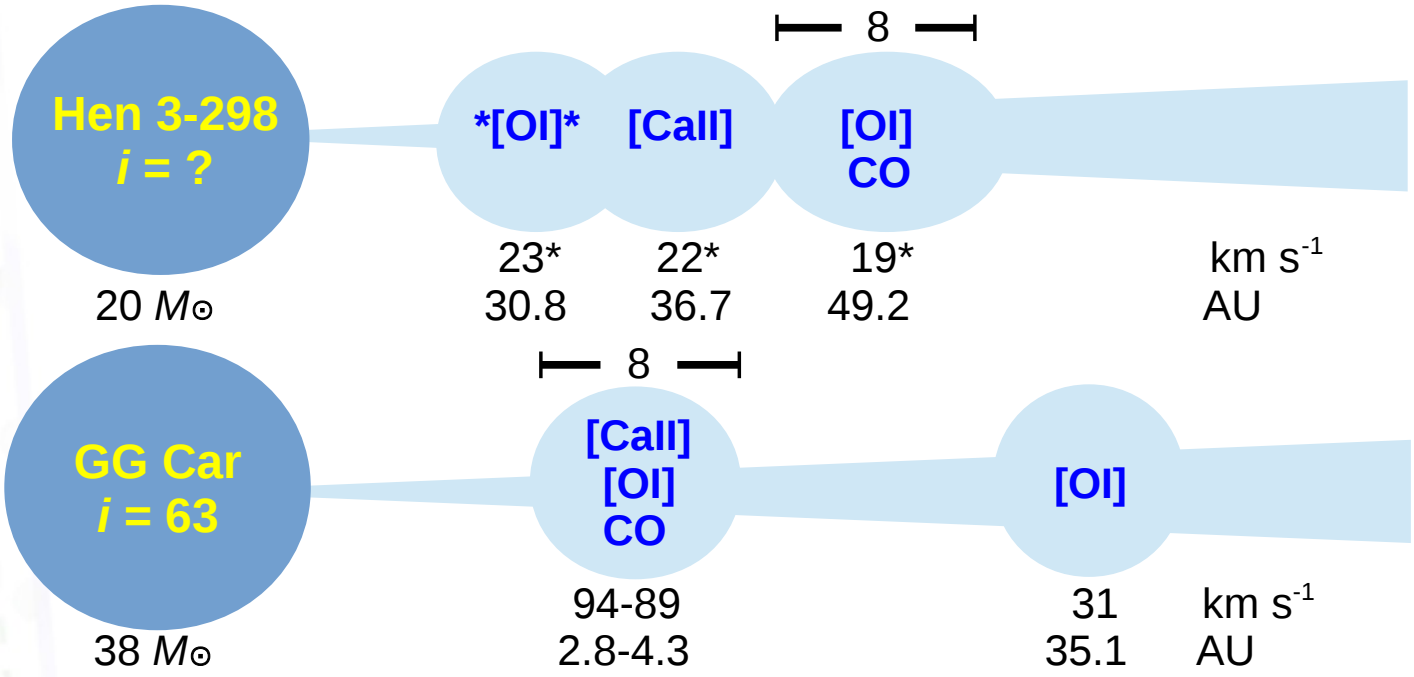


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> 2 rings
> Coexistence of molecular and atomic gas emitting regions
> Circumbinary structure

*Maravelias+2017, Maravelias+,in prep.*

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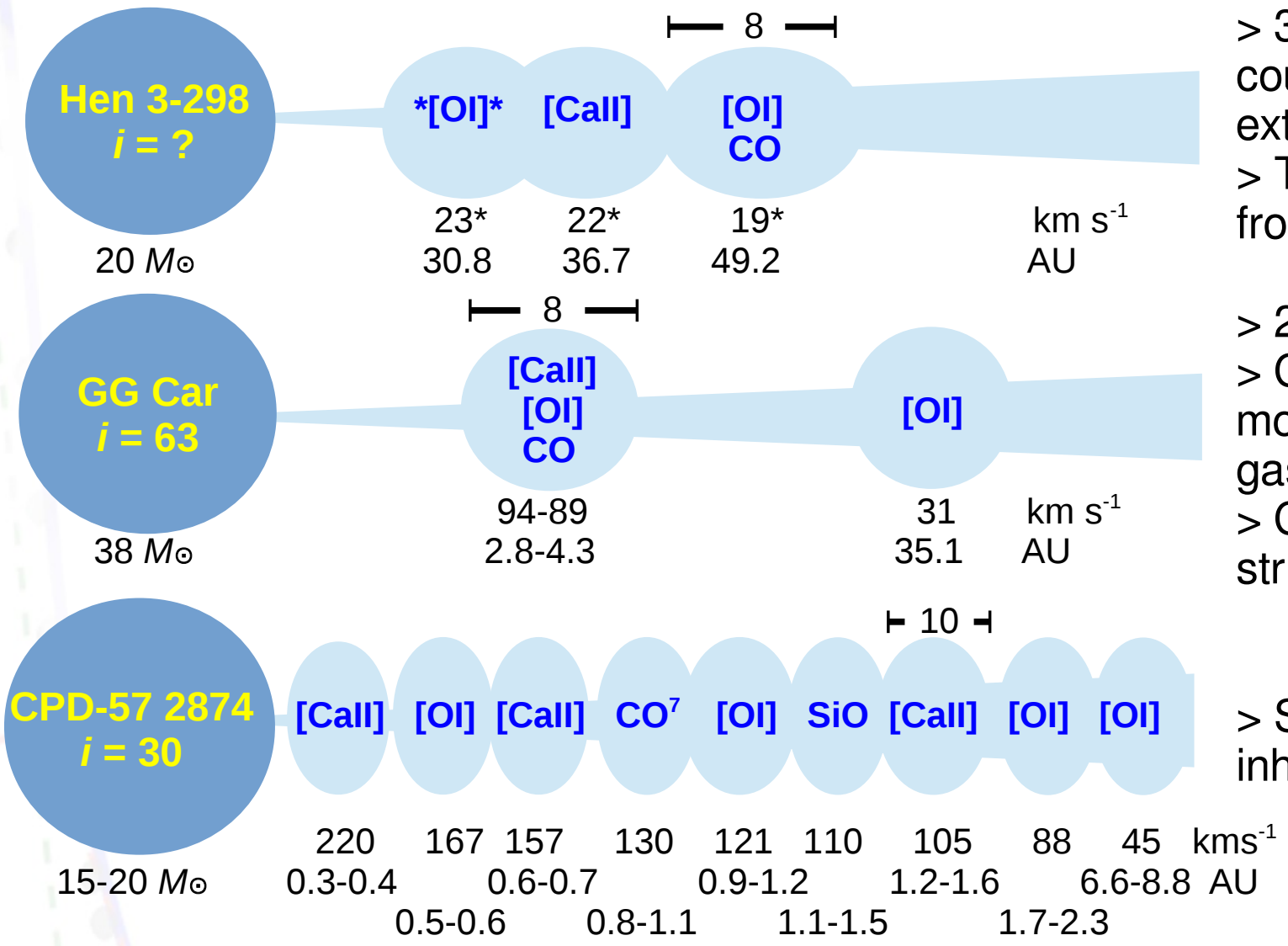


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> T decreases away from the star

> 2 rings
> Coexistence of molecular and atomic gas emitting regions
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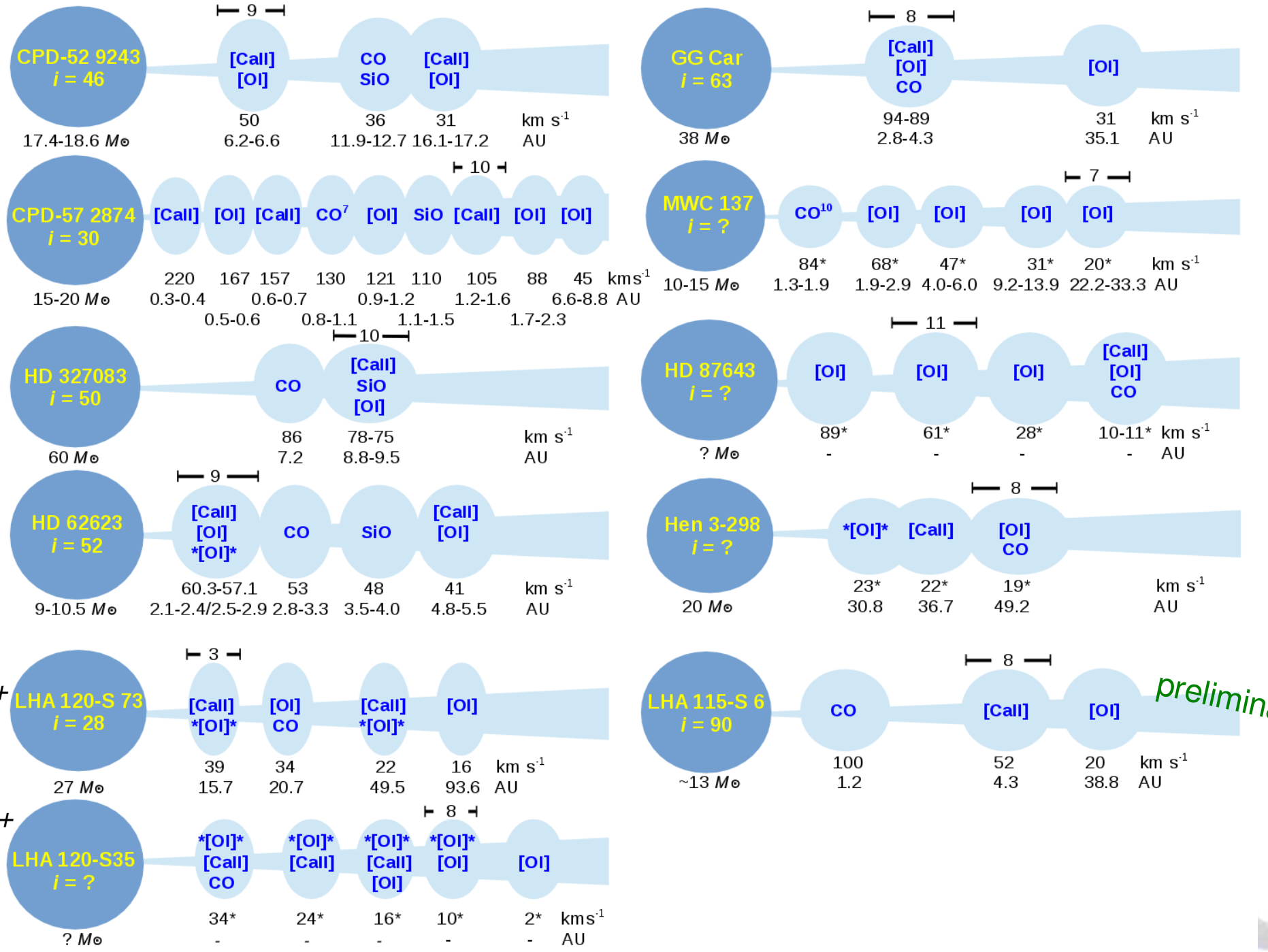
> Series of rings → inhomogeneous disk (?)

*Maravelias+2017, Maravelias+,in prep.*

# Exploring the results

*Maravelias+2017, Maravelias+,in prep.*

[ NOT to scale ]



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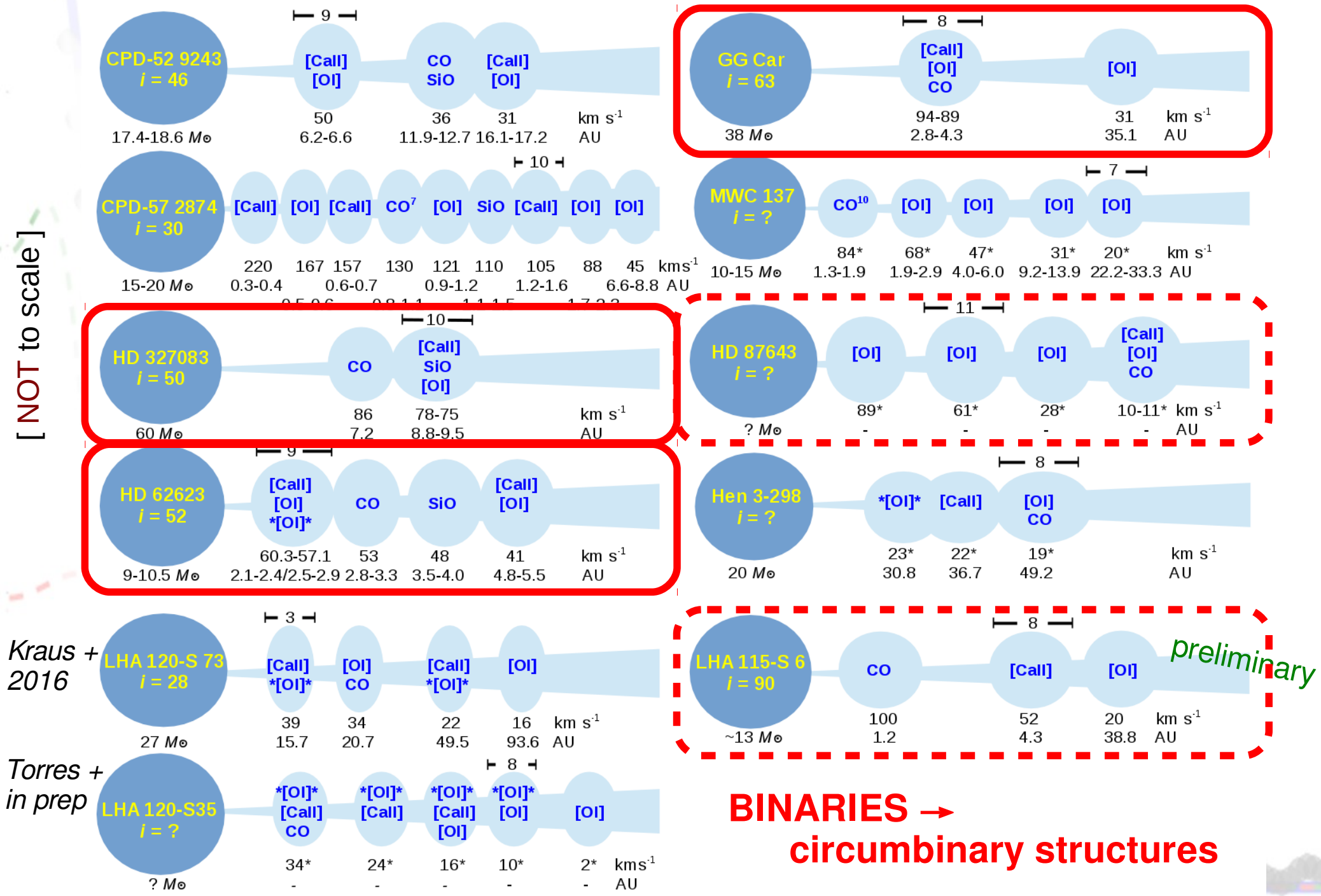
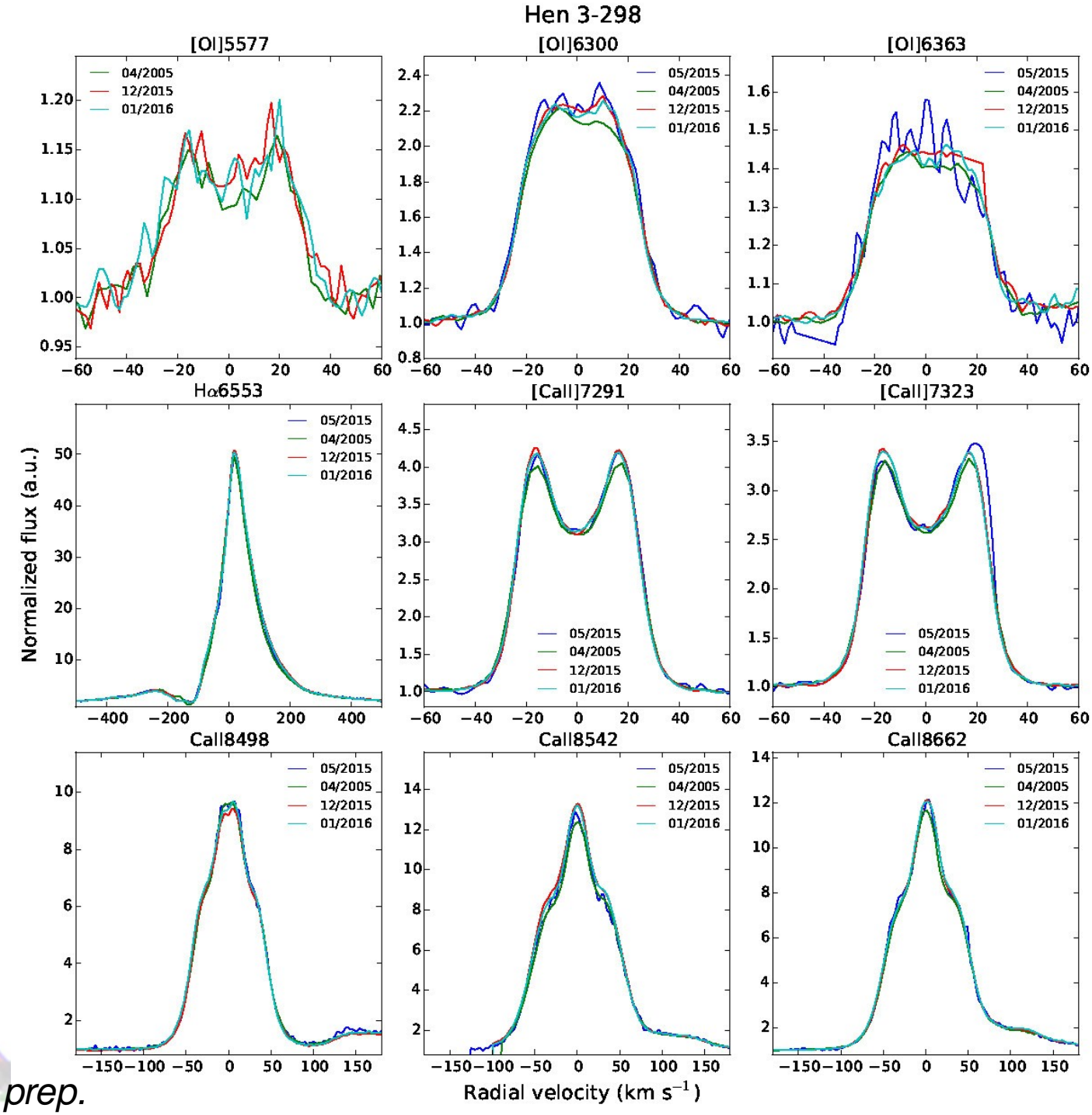


# About variability – stable structures

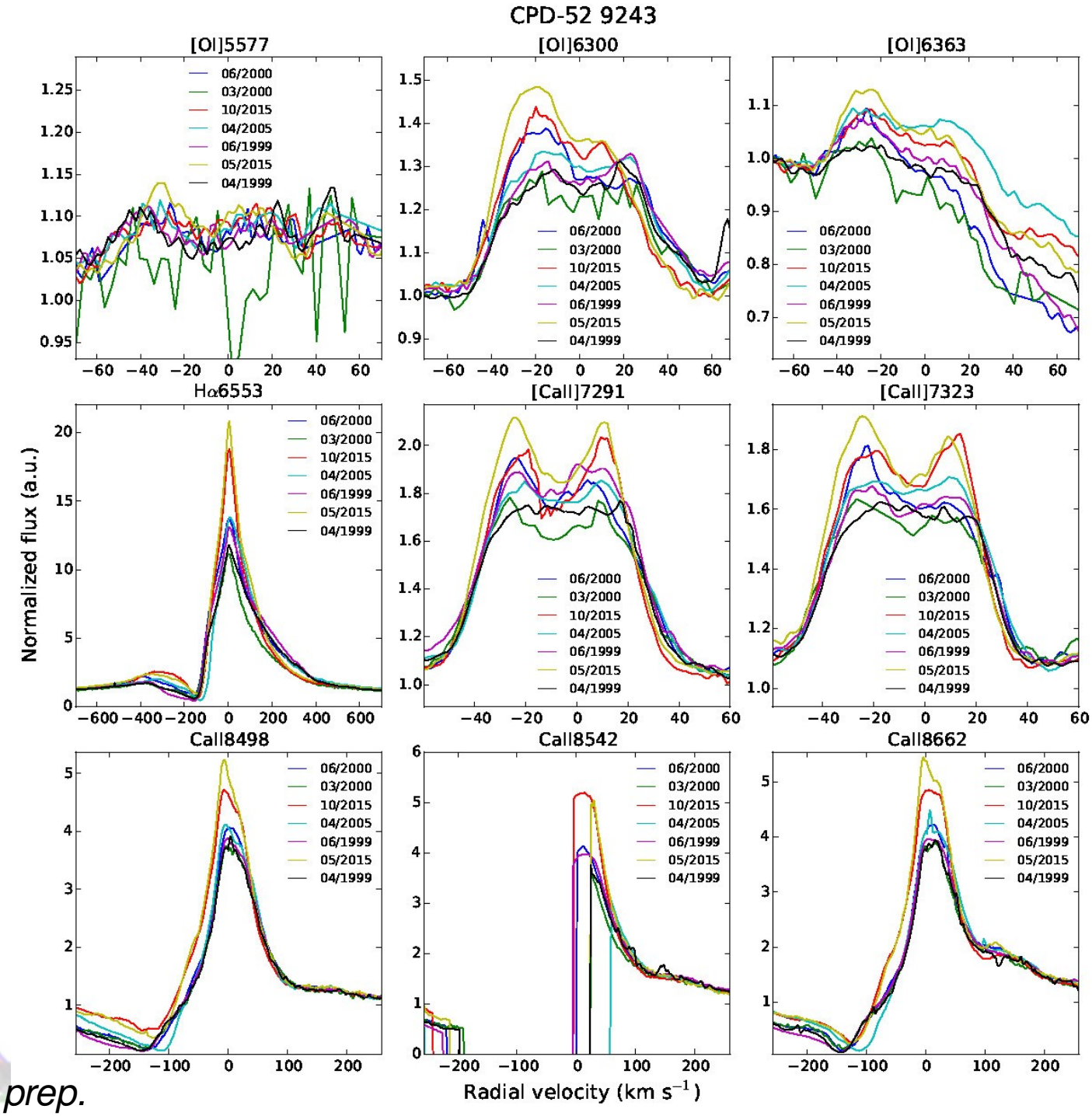
2005-2016




*Maravelias+,in prep.*

# About variability – active structures (binaries?)

1999-2015




*Maravelias+,in prep.*

# But ... how?

→ **binaries : mass-transfer**

*(e.g. Millour+2011, Wheelwright+2012)*

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→ **binaries : mass-transfer**
*(e.g. Millour+2011, Wheelwright+2012)*

→ **in single stars**

– **asymmetric winds ?**
*(e.g. Curé+2005, Kraus2006, Kurfürst+2017)*

– **mass-loss events ?**

– **objects that clear theirs paths ?**
*(e.g. Kraus+2016)*

# Summary

- Obtain high-resolution optical spectra for Galactic B[e]SGs:
  - CSE with inhomogeneous disks and ring-like structures
  - not a unique picture
  - detected variability in binaries (tentative trend)
- Need to understand:
  - how these structures form ?
  - what is the connection with other phases (e.g. YHGs) ?