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The Rotational Puzzle of Cygnus OB2

3D modelling of non-spherical massive stars

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Massive blue star credit: ESO/M. Kornmesser

Principal Characteristics

- $M_* \geq 8 M_{\odot}$
- Most powerful & luminous phenomena
- Rapid evolution
 - Crucial role in cosmos
 - Mechanical & radiative feedback

Langer (2012); Geen et al. (2015)



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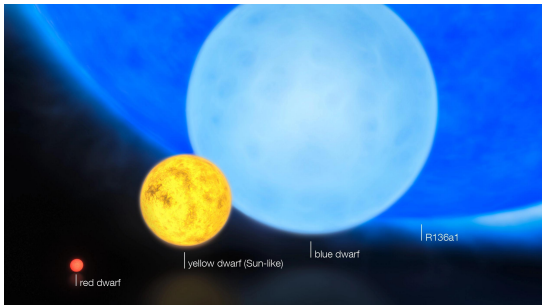
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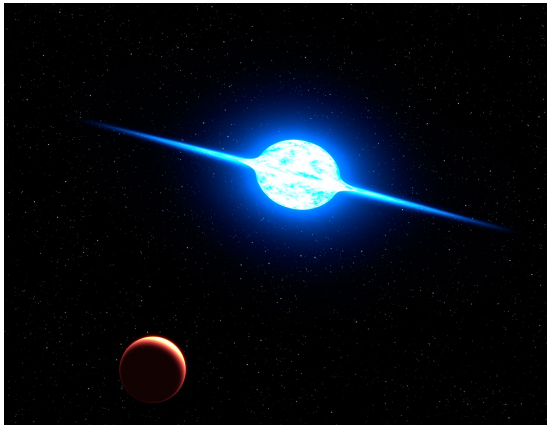
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Importance of rotation

- Rotation key element
 - Evolution
 - Fate
- Similar
 - Stellar mass
 - Metallicity
- 3D Geometry
 - Non spherical
 - Internal processes

Maeder & Meynet (2000)



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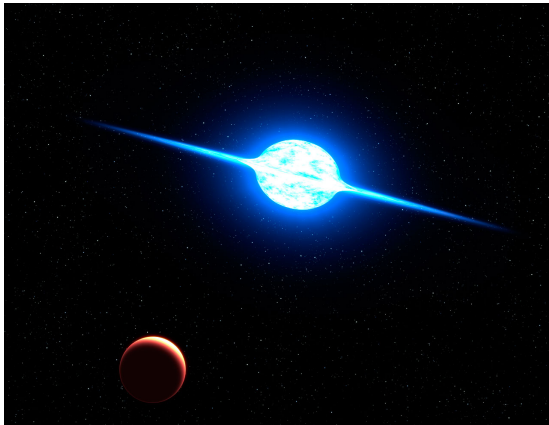
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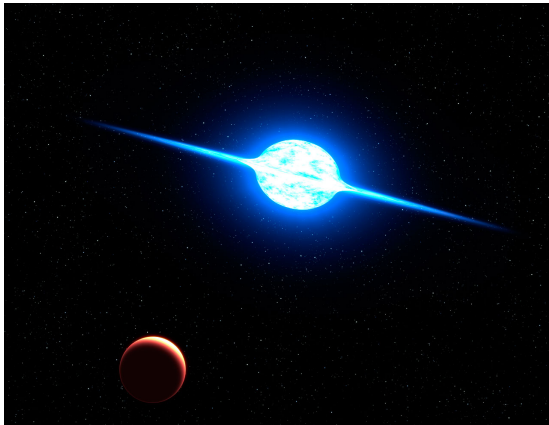
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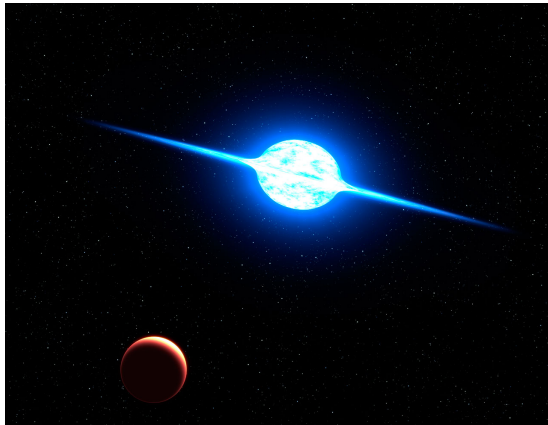
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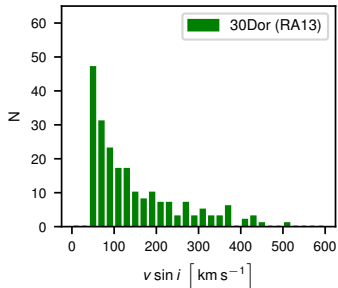
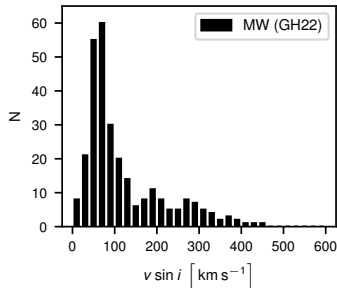
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Distributions of rotational velocities

- O-type stars

Milky Way Holgado et al. (2022)

30 Doradus Ramírez-Agudelo et al. (2013)

- Bimodal distribution

Peak slow rotators ($v \sin i \sim 80 \text{ km s}^{-1}$)

Tail fast rotators ($v \sin i > 200 \text{ km s}^{-1}$)



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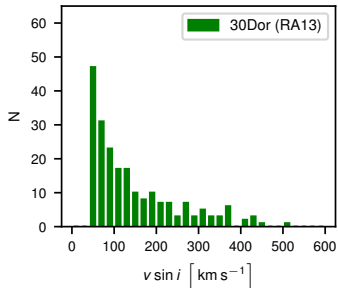
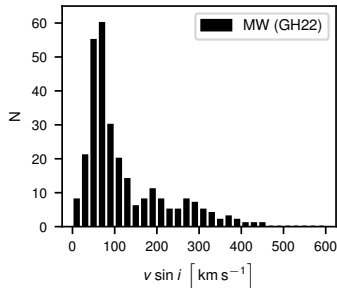
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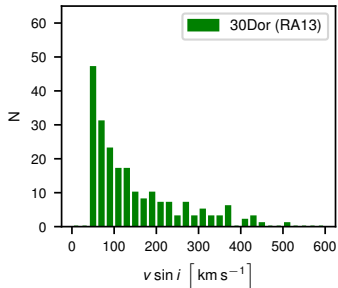
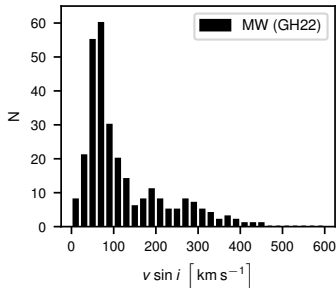
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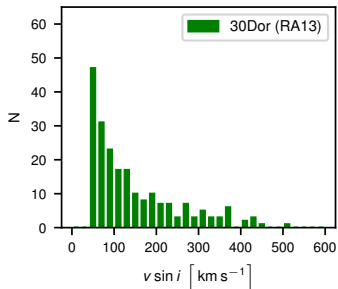
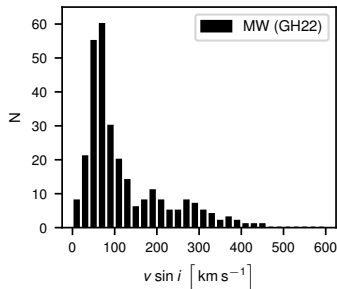
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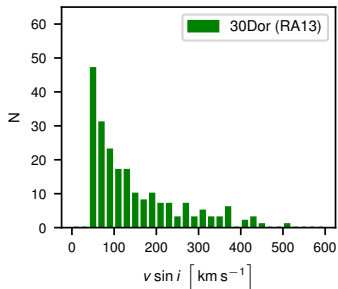
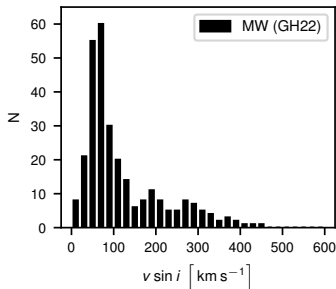
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VFTS 352 animation credit: SPAMMS, Michael Abdul-Masih

Massive stars systems

- **Most found in multiple systems**
- Interaction between members systems
 - Evolution & Fate

Sana et al. (2014)

Interactions in massive stars systems

- Different interactions
 - Tides, mass-exchange, ...
- Rotation rate change

de Mink et al. (2013); Holgado et al. (2022)



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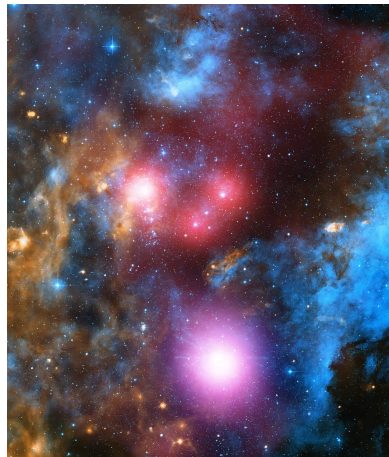
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Key Region

- One of the richest areas of massive star formation in MW
- Nearest from Earth
 ~ 1.7 kpc
- Understanding of massive stars
 - formation and evolution of massive stars
 - dynamics of star clusters
 - feedback processes



Cygnus OB2 image credit: X-ray: NASA/CXC/SAO/J. Drake et al; H-alpha: Univ. of Hertfordshire/INT/IPHAS; Infrared: NASA/JPL-Caltech/Spitzer



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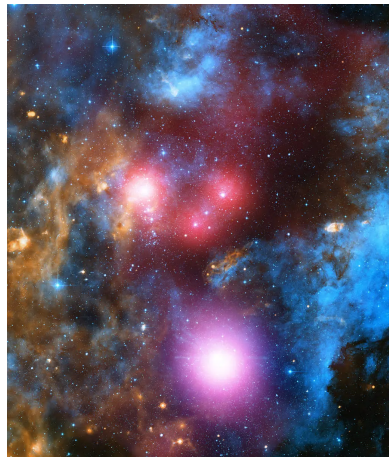
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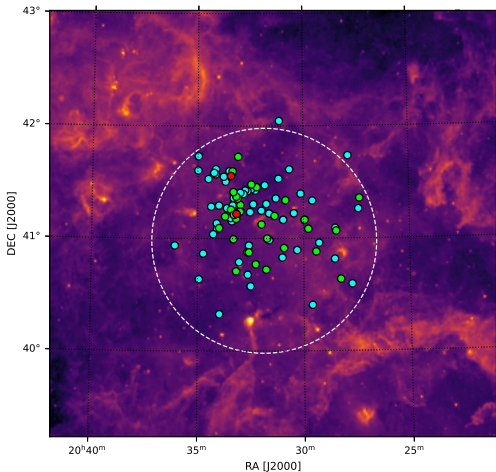
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Galán-Diéguez et al. (prep)

- OB-type stars
 - 112 stars
- ORM Observations
 - 10.4-m GTC
 - 4.2-m WHT
 - 2.56-m NOT
 - 2.54-m INT
- $v \sin i$ distribution



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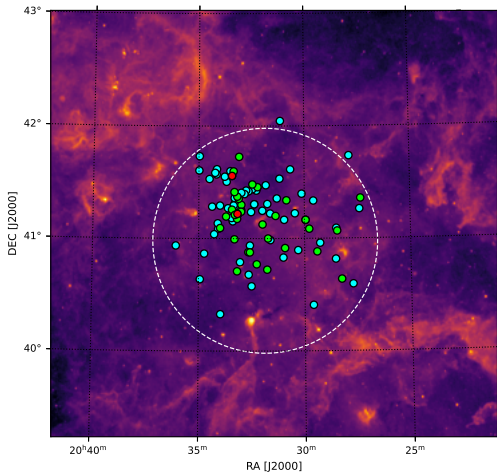
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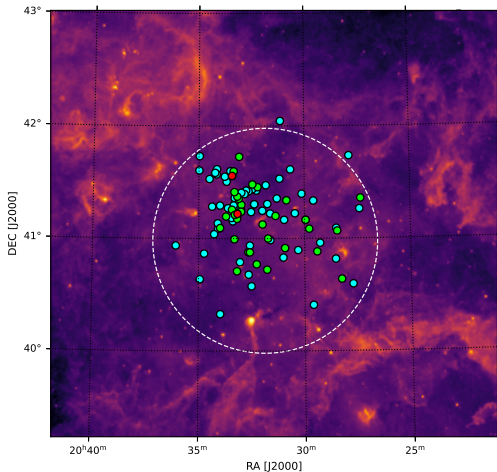
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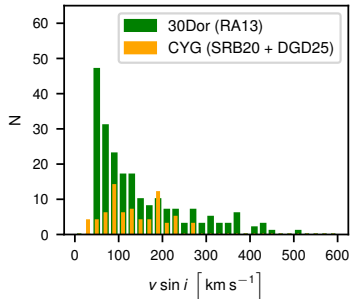
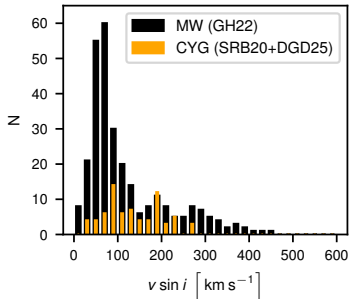
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- 30 Doradus (Ramírez-Agudelo et al. (2013))

- Lack of fast rotators

- $v \sin i \geq 200 - 250 \text{ km s}^{-1}$



$v \sin i$ distribution in Cygnus OB2

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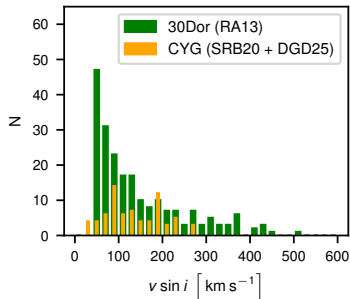
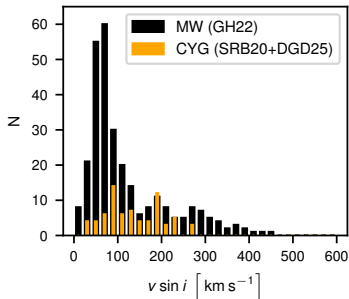
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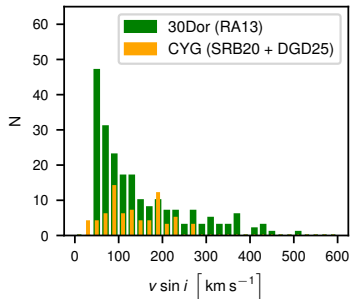
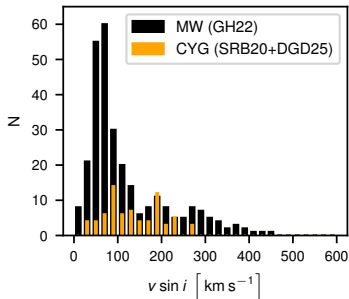
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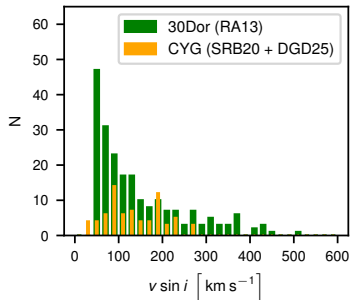
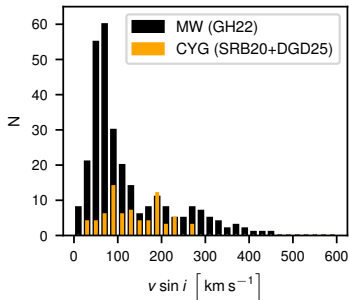
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Lack of fast rotators!

- **Problem:**
 - Multiple systems
 - Binary interactions → fast rotators [de Mink et al. \(2013\)](#)
- WHAT'S GOING ON IN CYGNUS OB2?
 - Fast-rotators expected: 10-12



$v \sin i$ distribution in Cygnus OB2

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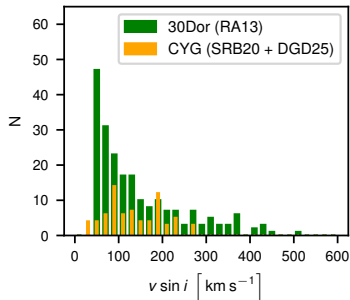
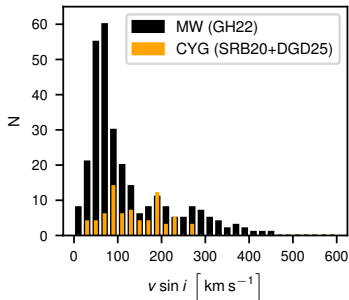
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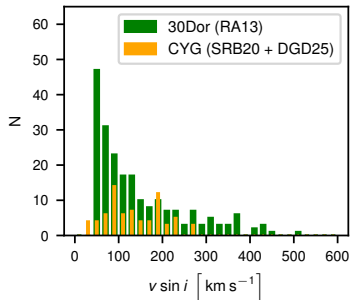
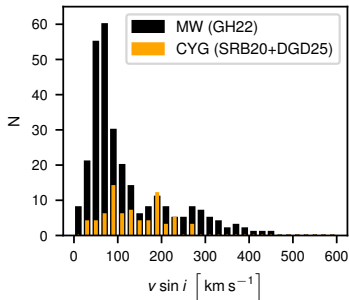
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Lack of fast rotators!

- Problem:
 - Multiple systems
 - **Binary interactions** → **fast rotators** [de Mink et al. \(2013\)](#)
- WHAT'S GOING ON IN CYGNUS OB2?
 - Fast-rotators expected: 10-12



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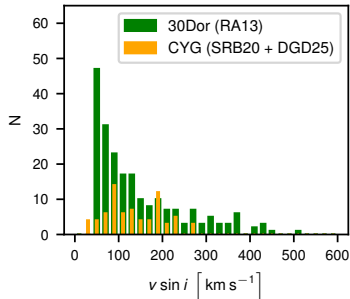
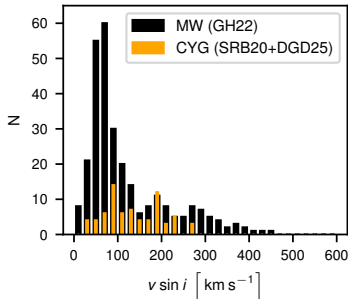
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Lack of fast rotators!

- Problem:
 - Multiple systems
 - Binary interactions → fast rotators [de Mink et al. \(2013\)](#)
- **WHAT'S GOING ON IN CYGNUS OB2?**
 - Fast-rotators expected: **10-12**



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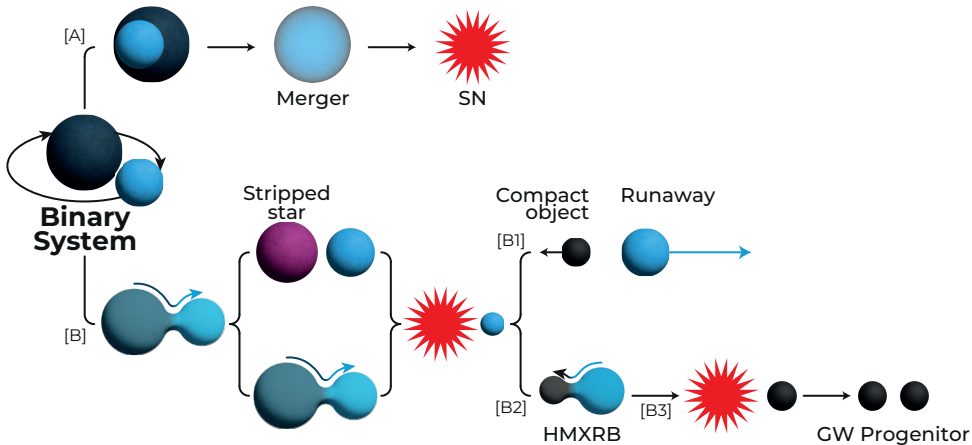
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WORK IN PROGRESS!

- **Runaways**
 - Fast-rotators ejected by SN explosion





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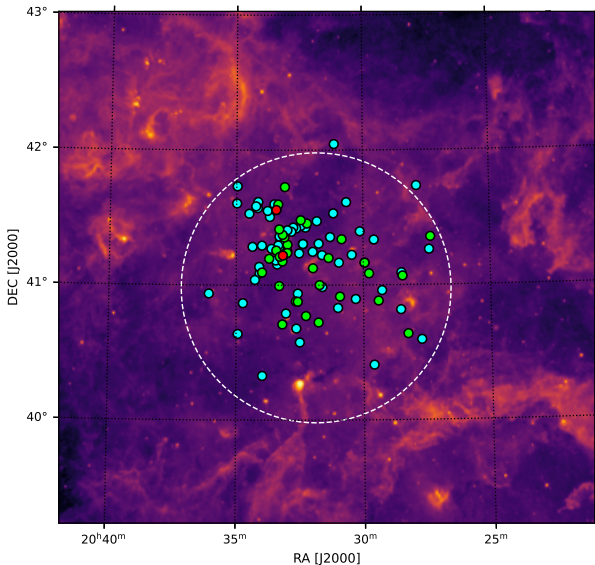
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WORK IN PROGRESS!

- **Cygnus OB2 age**
 - No enough time for binary interactions



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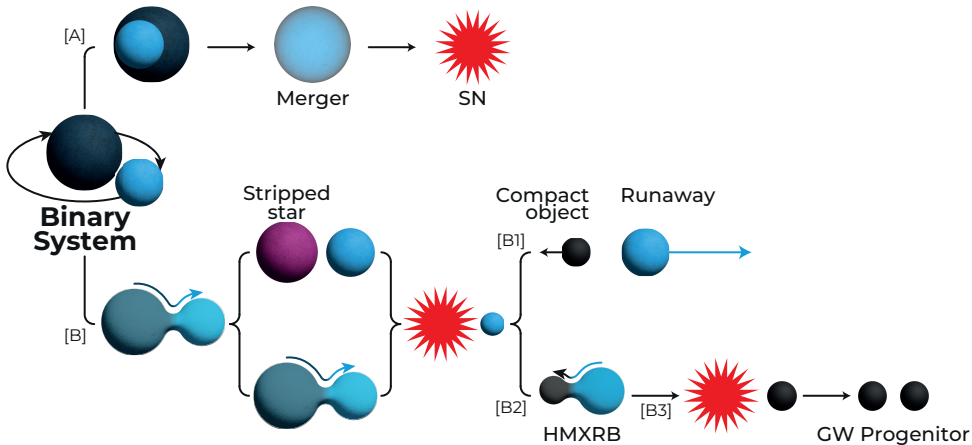
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WORK IN PROGRESS!

- **Spin rotation direction**
 - Fast-rotators from the front



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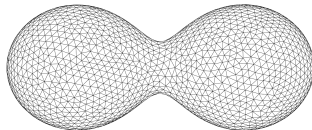
Cygnus OB2 age

Rotational spin

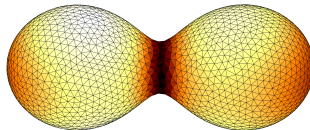
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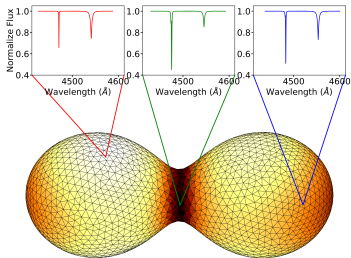
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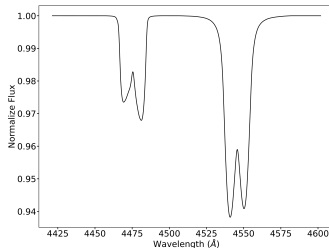
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3)



4)





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WORK IN PROGRESS!

- **Molecular cloud density**
 - No formation enough binary systems



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The Rotational Puzzle of Cygnus OB2

3D modelling of non-spherical massive stars

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