# Mass transfer in detached binaries

Ileyk El Mellah

L. Decin - R. Keppens - J. O. Sundqvist
The X-Wind and ATOMIUM collaborations

KU Leuven

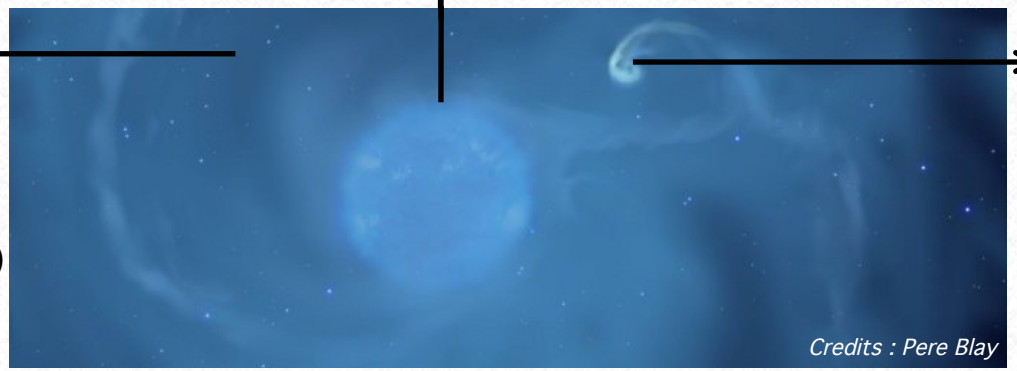
ESAC
April 2020

# Portrait – Detached binaries

## High-mass X-ray binaries

Be star

O/B supergiant




Radiation-driven wind

- UV line-absorption
- hot, fast, $10^{-6}$ $M_{\odot}$/yr
- inhomogeneous (“clumps”)
- ionized

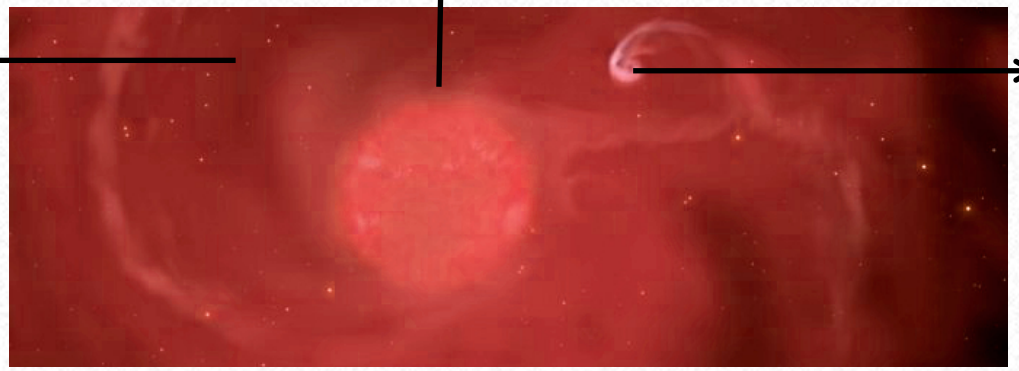
Compact object

- BH (Cyg X-1)
- NS (Vel X-1)

## Cool evolved binaries

Cool evolved star

- AGB (W Aql)
- RSG (31 Cyg)



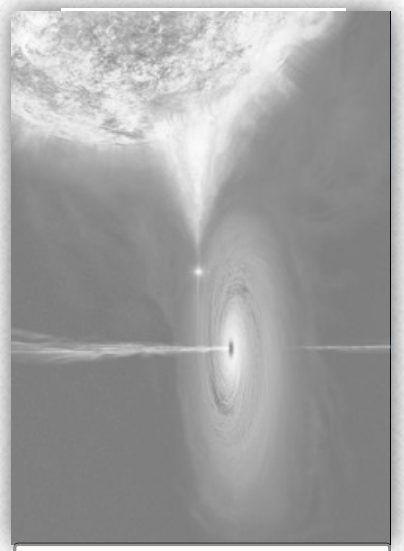
Dust-driven wind

- pulsations
- dust condensation
- cool, slow, $10^{-6}$ $M_{\odot}$/yr
- morphology

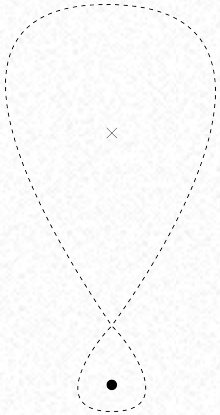
Lower mass companion

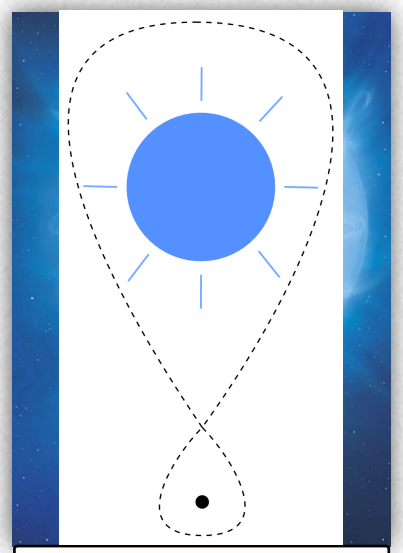
- MS
- WD
- exoplanet

# Portrait – Mass transfer mechanisms



RLOF





Wind accretion

Ex: low-mass X-ray binaries

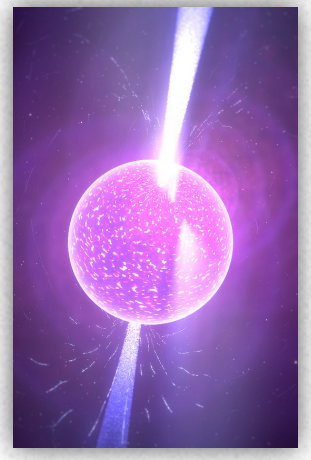
Permanent accretion disc
↳ multi-color black body

Ex: HMXBs & cool evolved binaries

Mass transfer via **stellar winds**

Disc? permanent?
Wind morphology?

# Motivations – High-mass X-ray binaries



## Compact objects

Neutron stars
- ↳ equation-of-state
- ↳ magnetic field

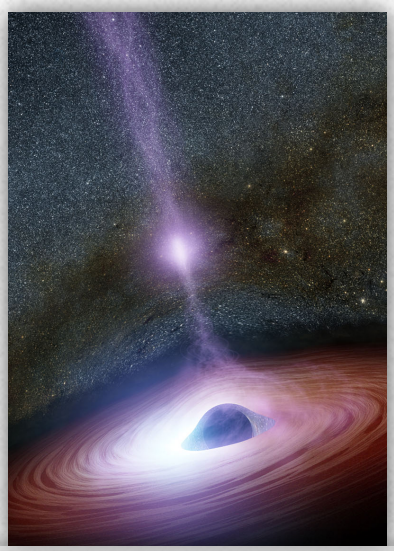
Black holes
- ↳ formation
- ↳ growth


## Gravitational waves

- ↳ progenitors?
- ↳ coalescence rates
- ↳ merger conditions

***Most massive stars***
***have at least one companion***
***whose presence impacts the evolution***

*Sana+2012*



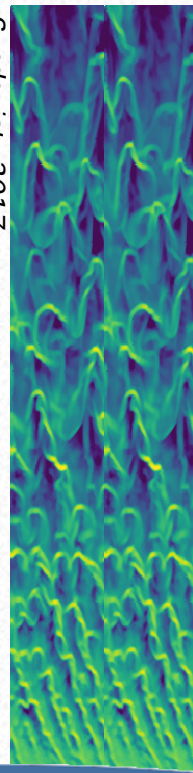
## High energies

- ↳ shocks & jets
- ↳ radiative processes
- ↳ magnetic reconnection
- ↳ particle acceleration

## Stellar evolution

- ↳ mass-loss rate
- ↳ wind micro-structure
- ↳ mass transfer
- ↳ wind morphology

*Sundqvist+2017*

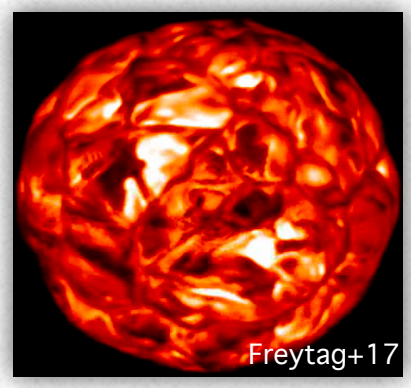


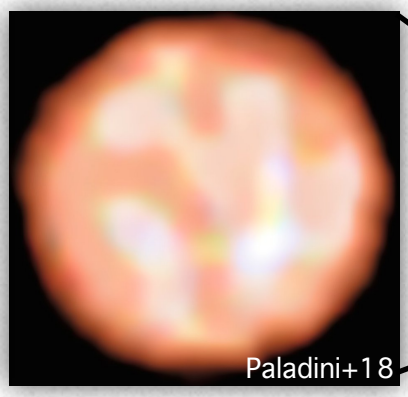
Blue Supergiant

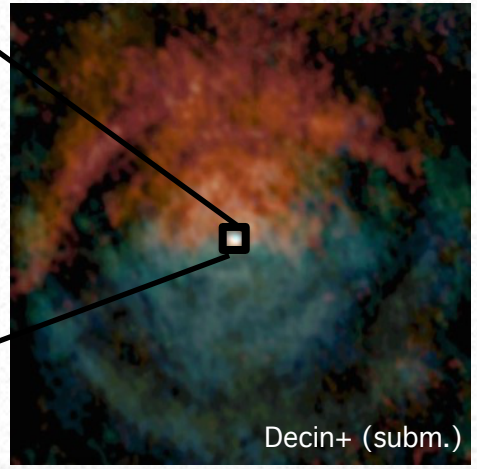
# Motivations – Cool evolved binaries

## Dust-driven winds

- wind **launching mechanism**
- chemical content: carbon ≠ oxygen-rich AGB?
- acceleration profile

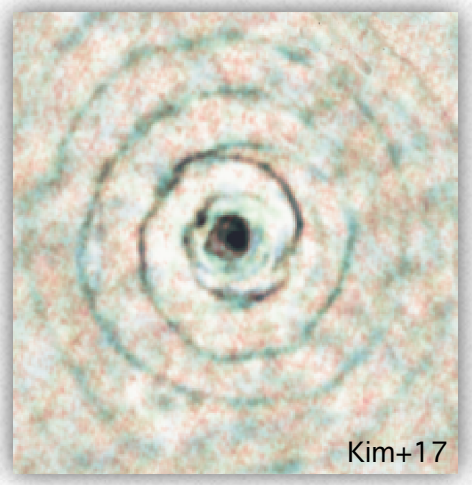


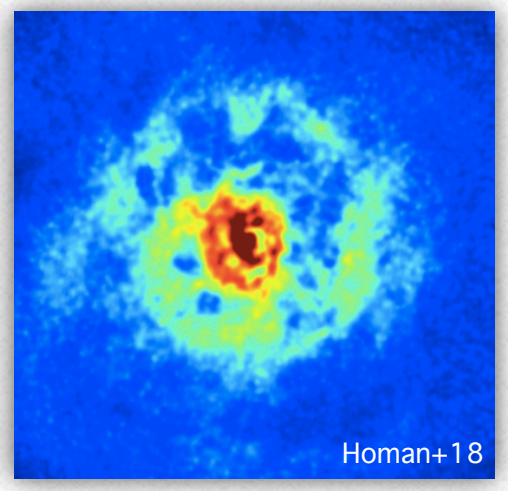



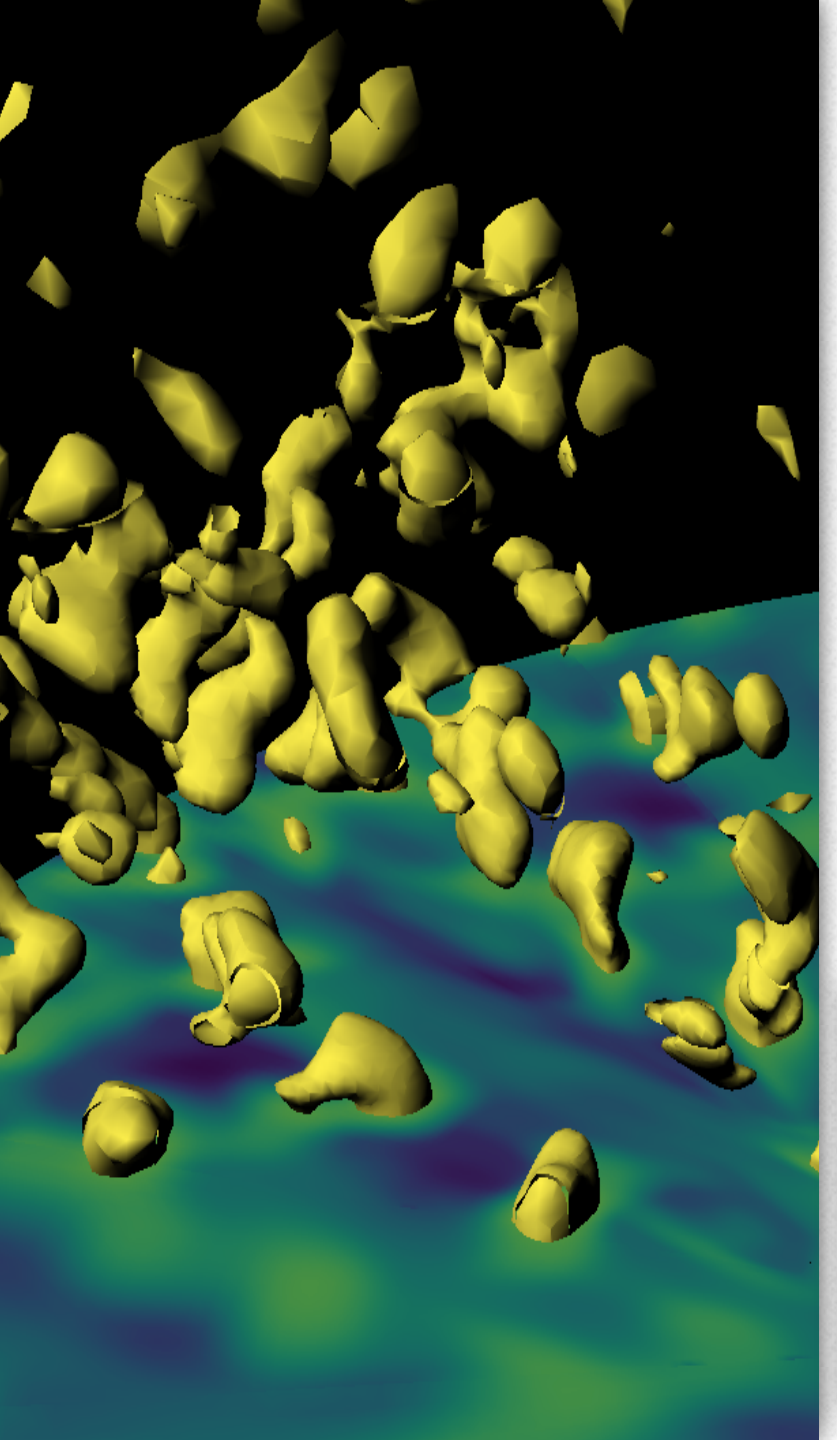




## Binarity rate

- non-spherical morphology
- companion on wide orbit?



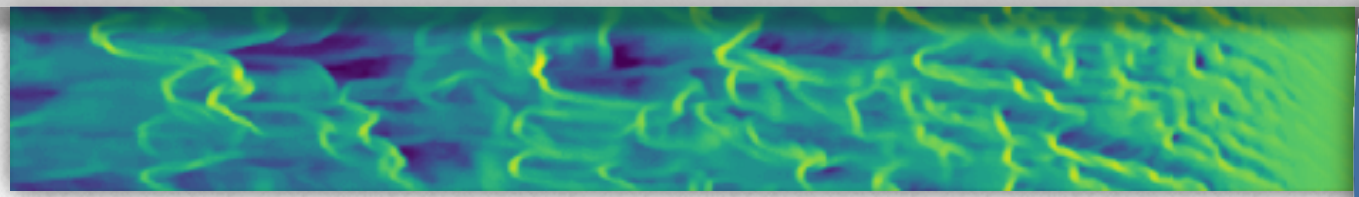


# Wind accretion in high-mass X-ray binaries

- *Accretion from a clumpy massive-star wind in supergiant X-ray binaries*, IEM, Sundqvist & Keppens MNRAS 2018
- *Wind-captured disks in SgXBs*, IEM, Sander, Sundqvist & Keppens A&A 2019

# Clump dimensions

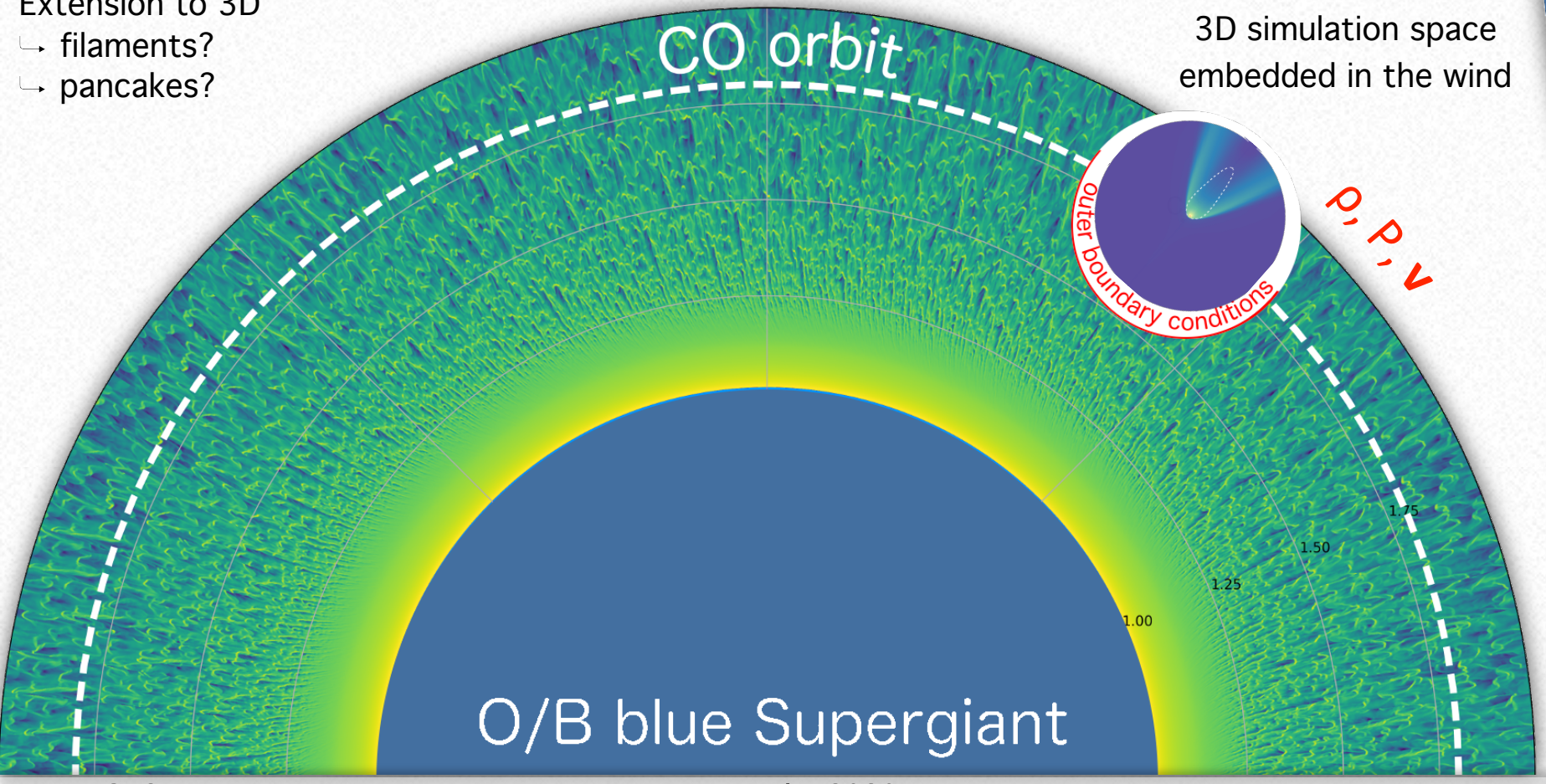
Radiative-HD
- 2D pseudo-planar
- long characteristics



*Sundqvist+17*

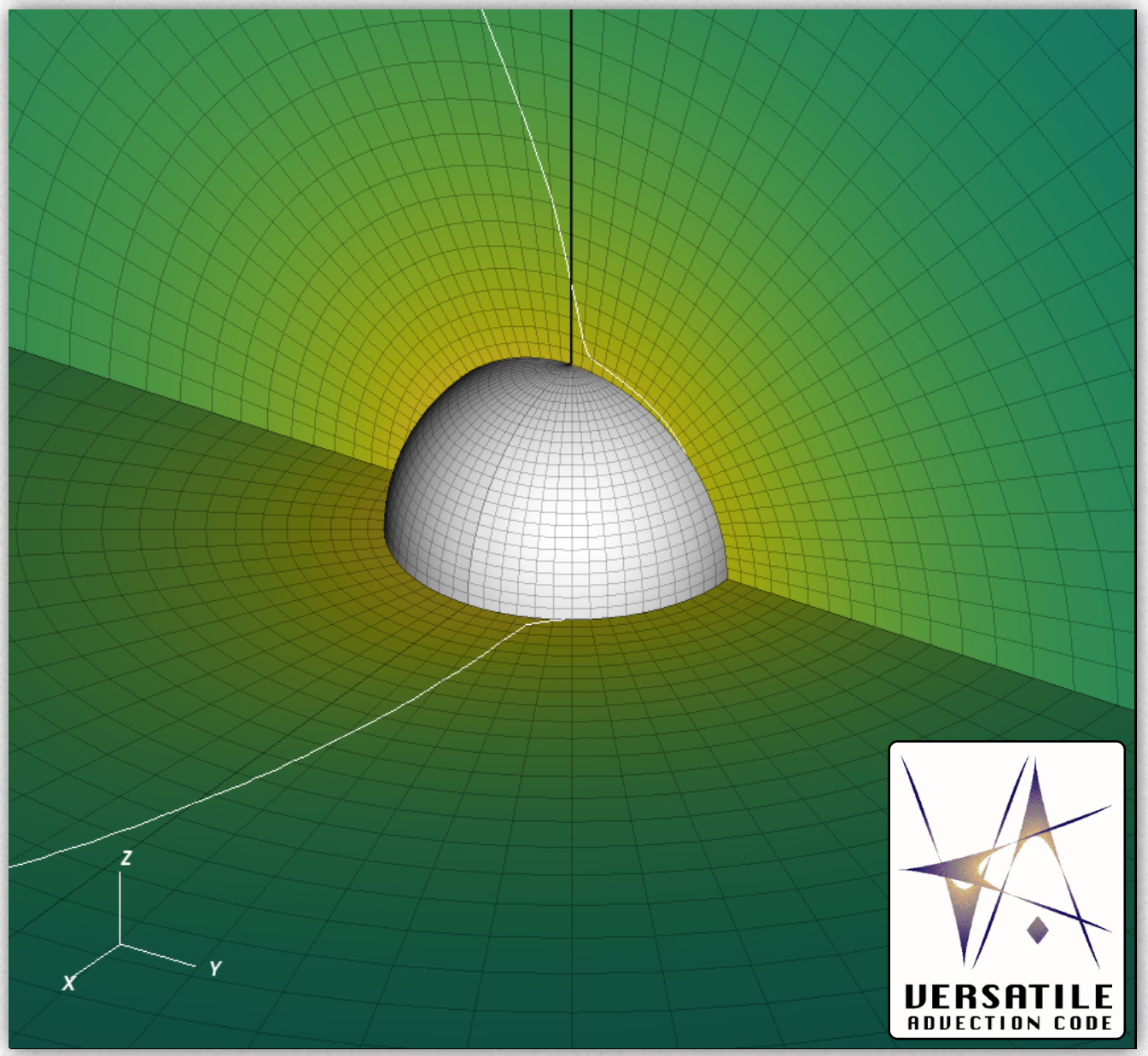
Line deshadowing instability => **clumps**

Extension to 3D
- filaments?
- pancakes?




Supergiant star

# Numerical setup : stretched spherical mesh




$$\frac{R_{out}}{R_{in}} = 800$$

Radially stretched grid

Resolution
64 x 48 x 64

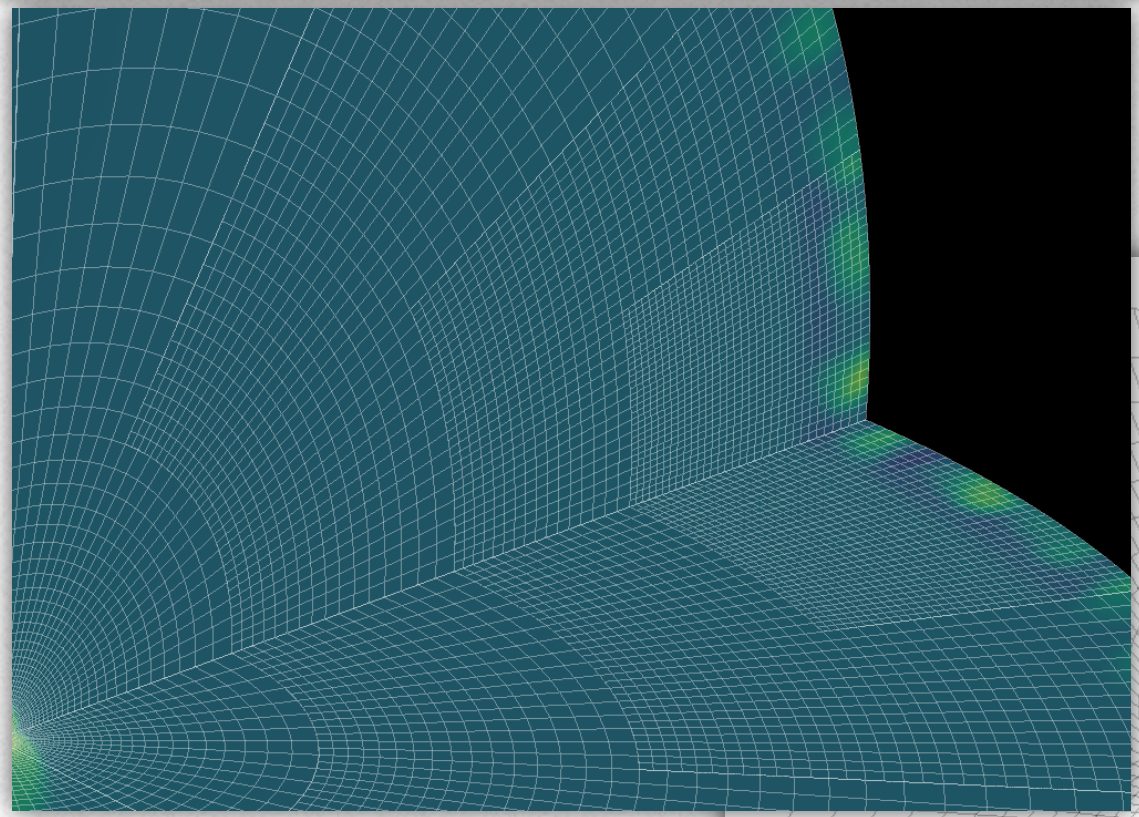
Axisymmetric flow

...

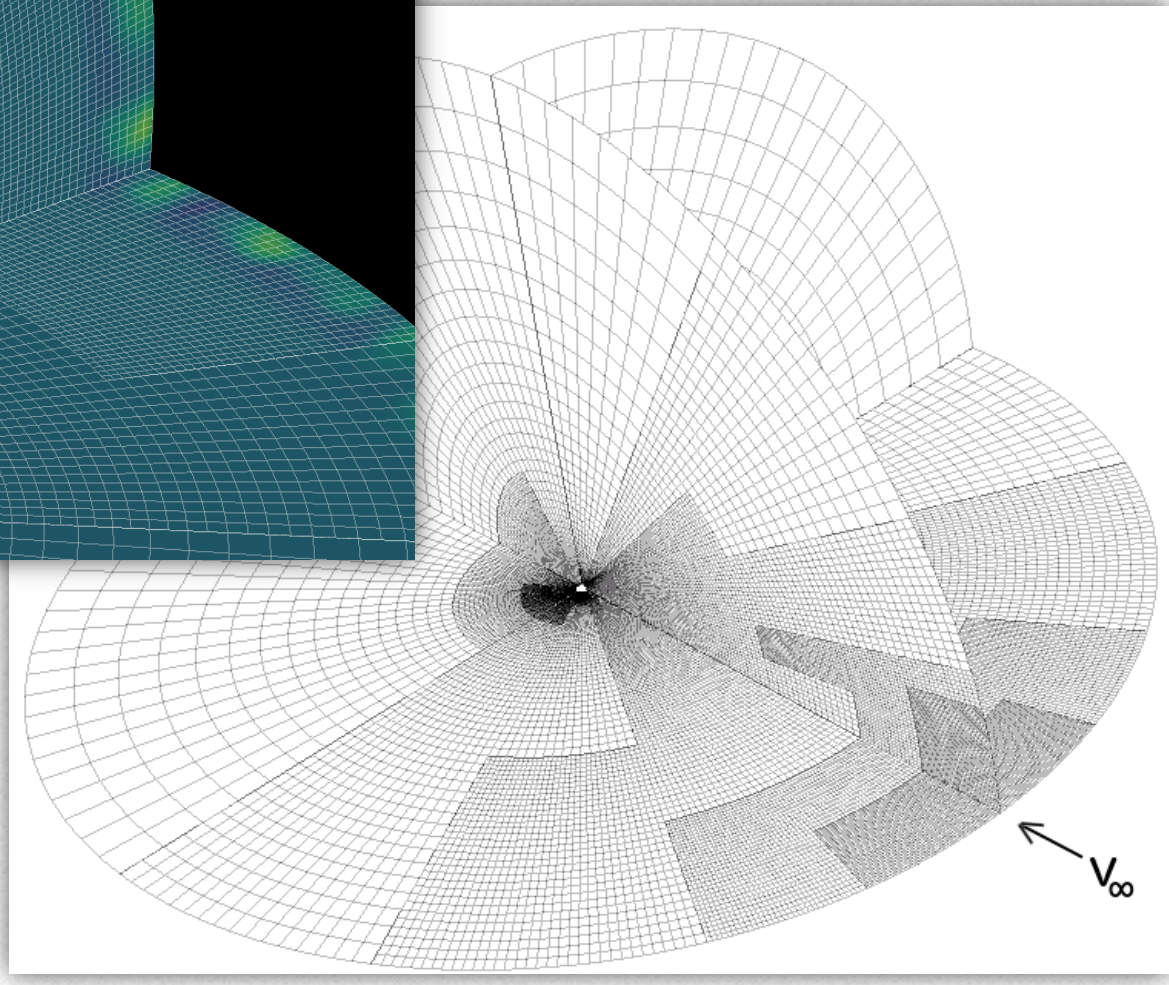
How to resolve small-scale off-centered features?

→ AMR

# Numerical setup : selective AMR



AMR
- 4 levels
- 9 effective AMR levels

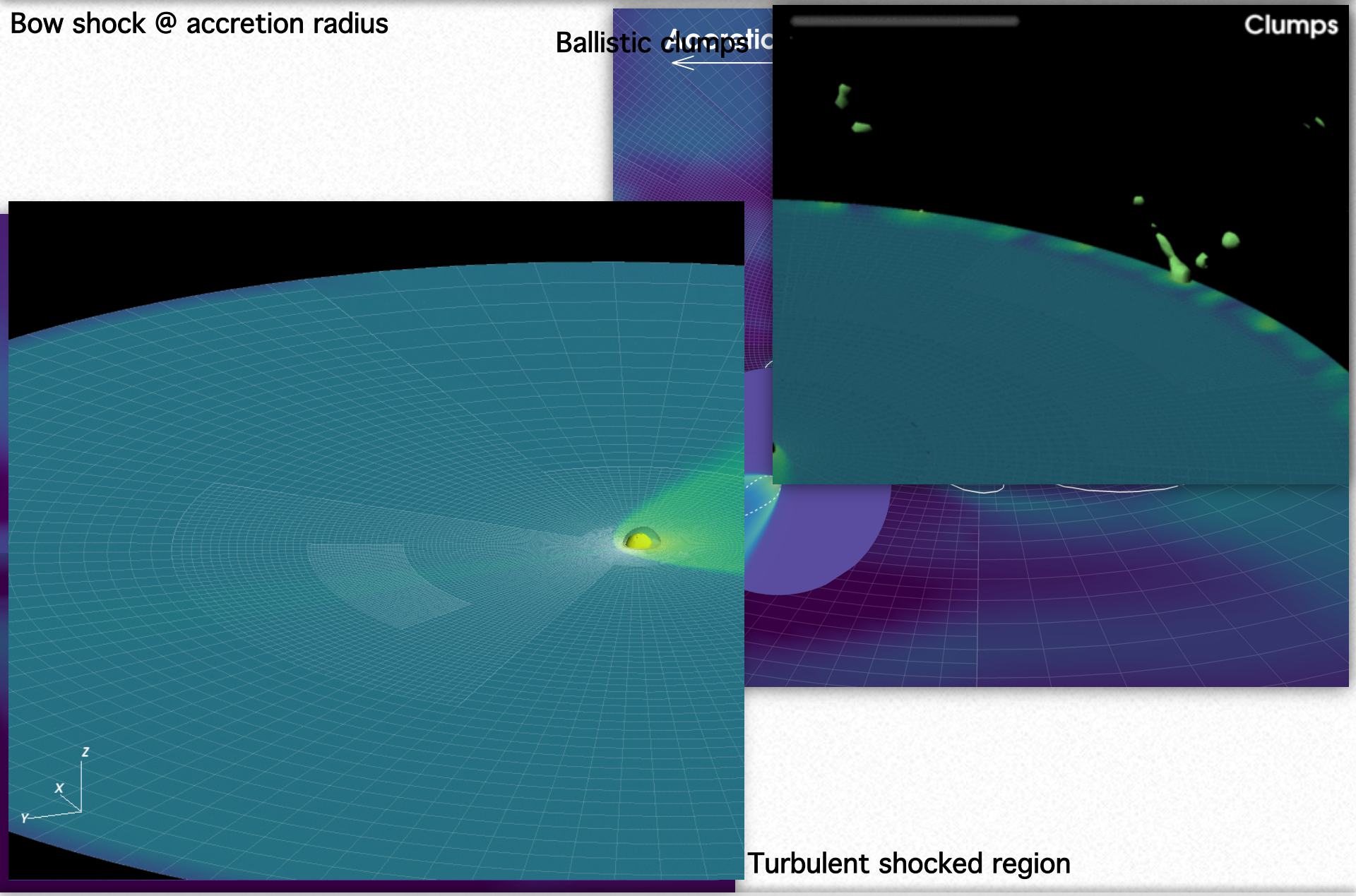



Selective AMR
- inhibited at the poles (CFL cond.)
- inhibited in the wake of the accretor
- **favored in the accretion cylinder**

# Structure of the flow

Bow shock @ accretion radius

Ballistic clumps



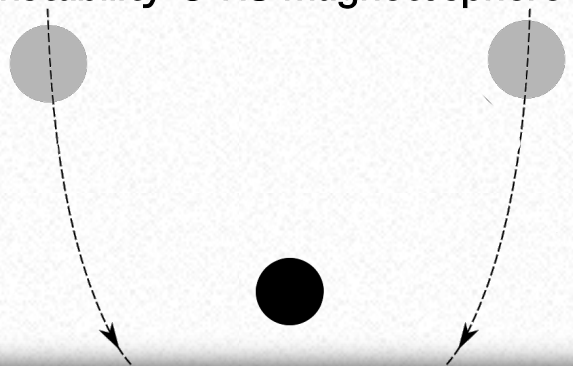

Turbulent shocked region

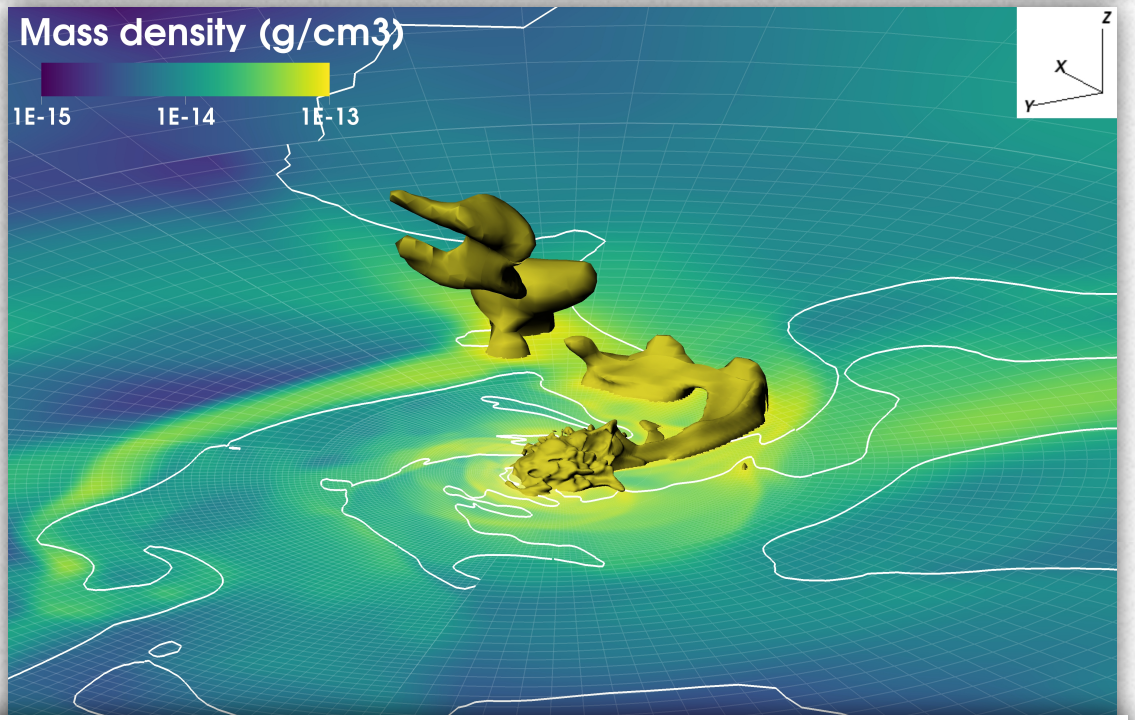
# Mass accretion rate : time variability

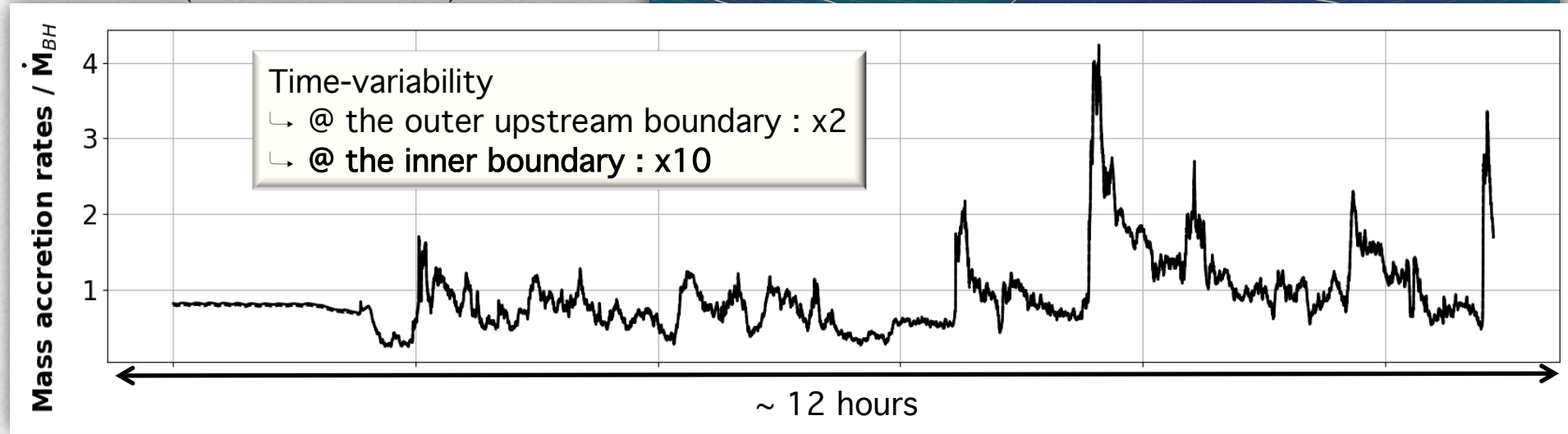
Cushioning role of the shock
↳ **prevents direct accretion of clumps**

Evacuation of angular momentum

Flares require other source of variability
↳ **instability @ NS magnetosphere**





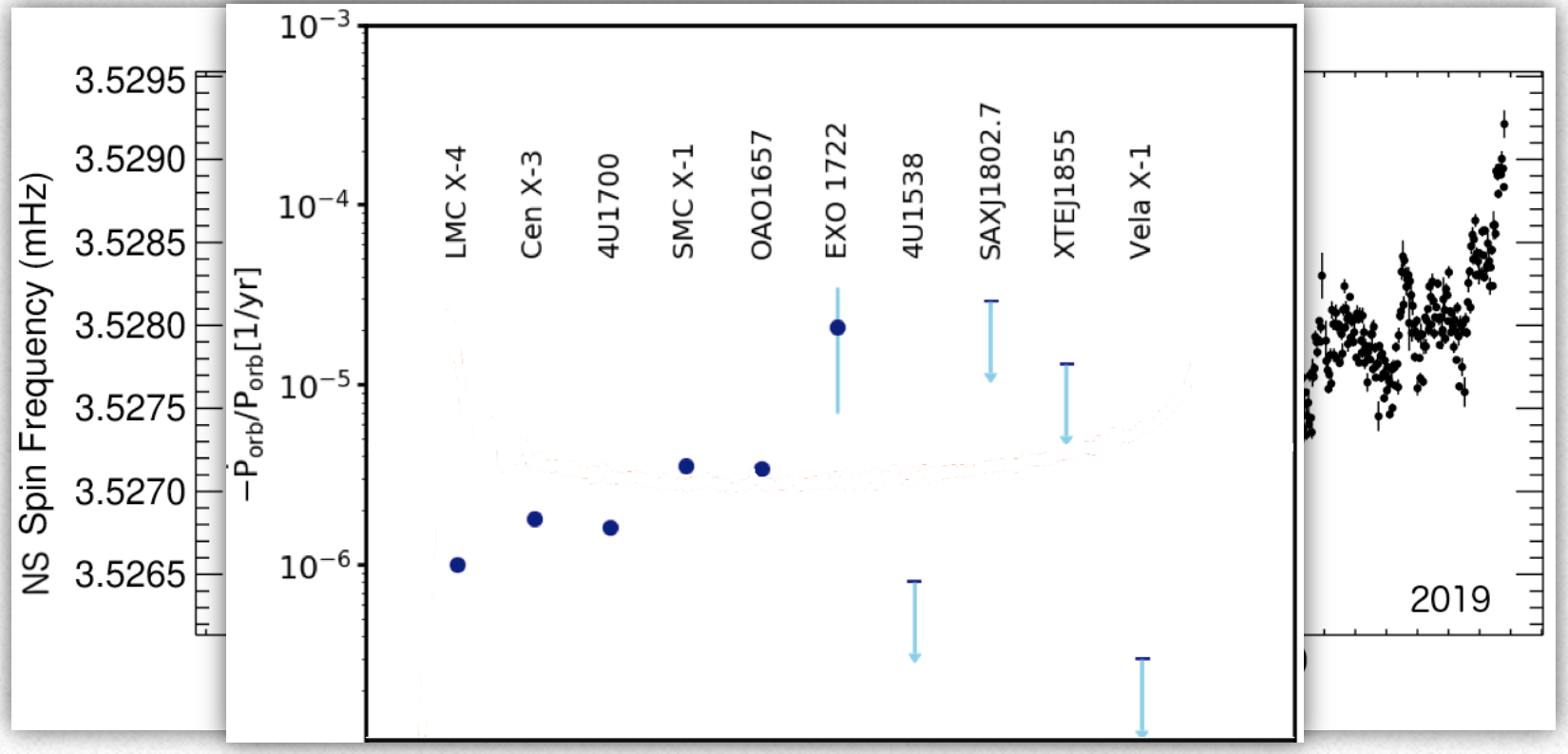
# Angular momentum transfers - observational diagnostics

**NS torques**

*Quast, Langer, Tauris 19*

**Orbital decay**

*Connaughton, Fermi GBM pulsar monitor 19*

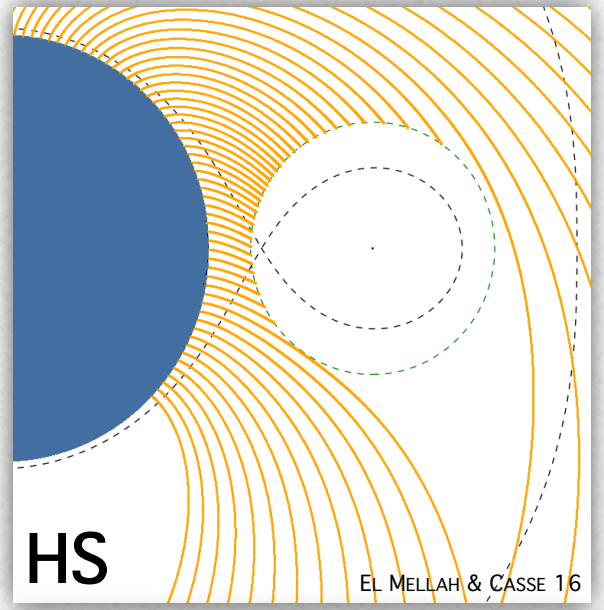


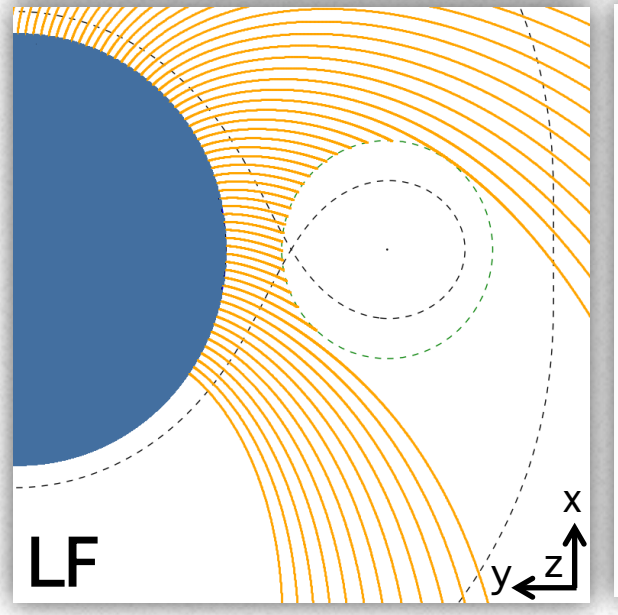

**Geometry** of the accretion flow

- disk
- spherical
- planar

**Morphology** of the wind

# Slow VS fast winds : where should we draw the line?



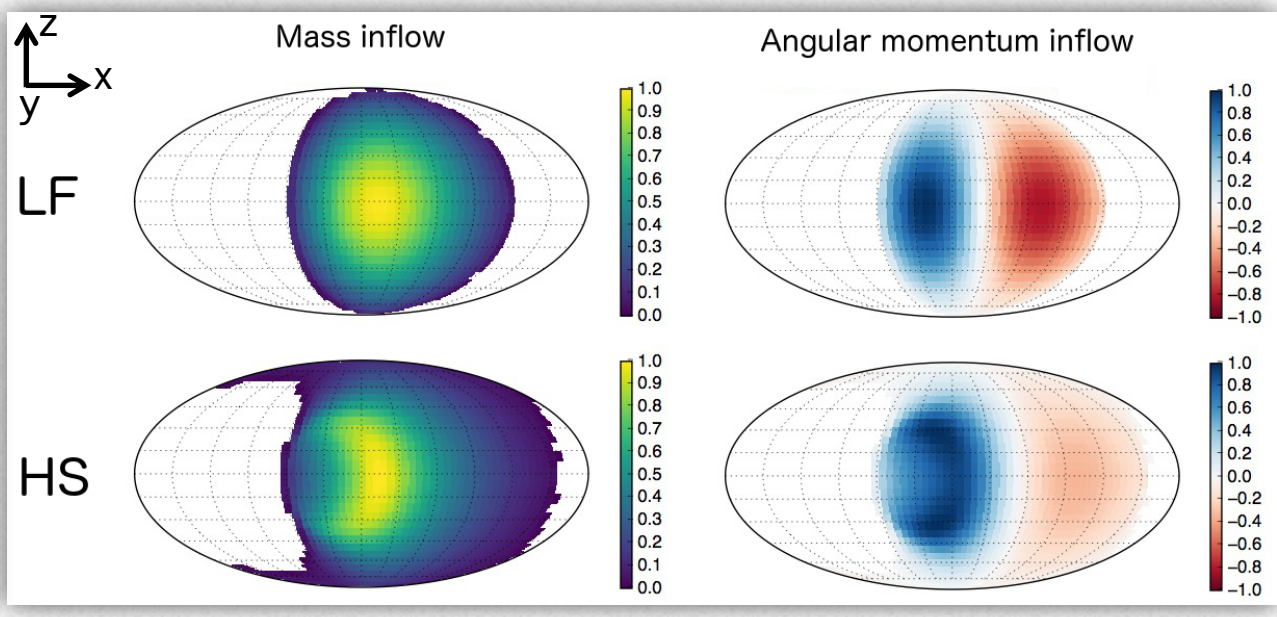




3D ballistic wind (RK4)
Stellar parameters fixed

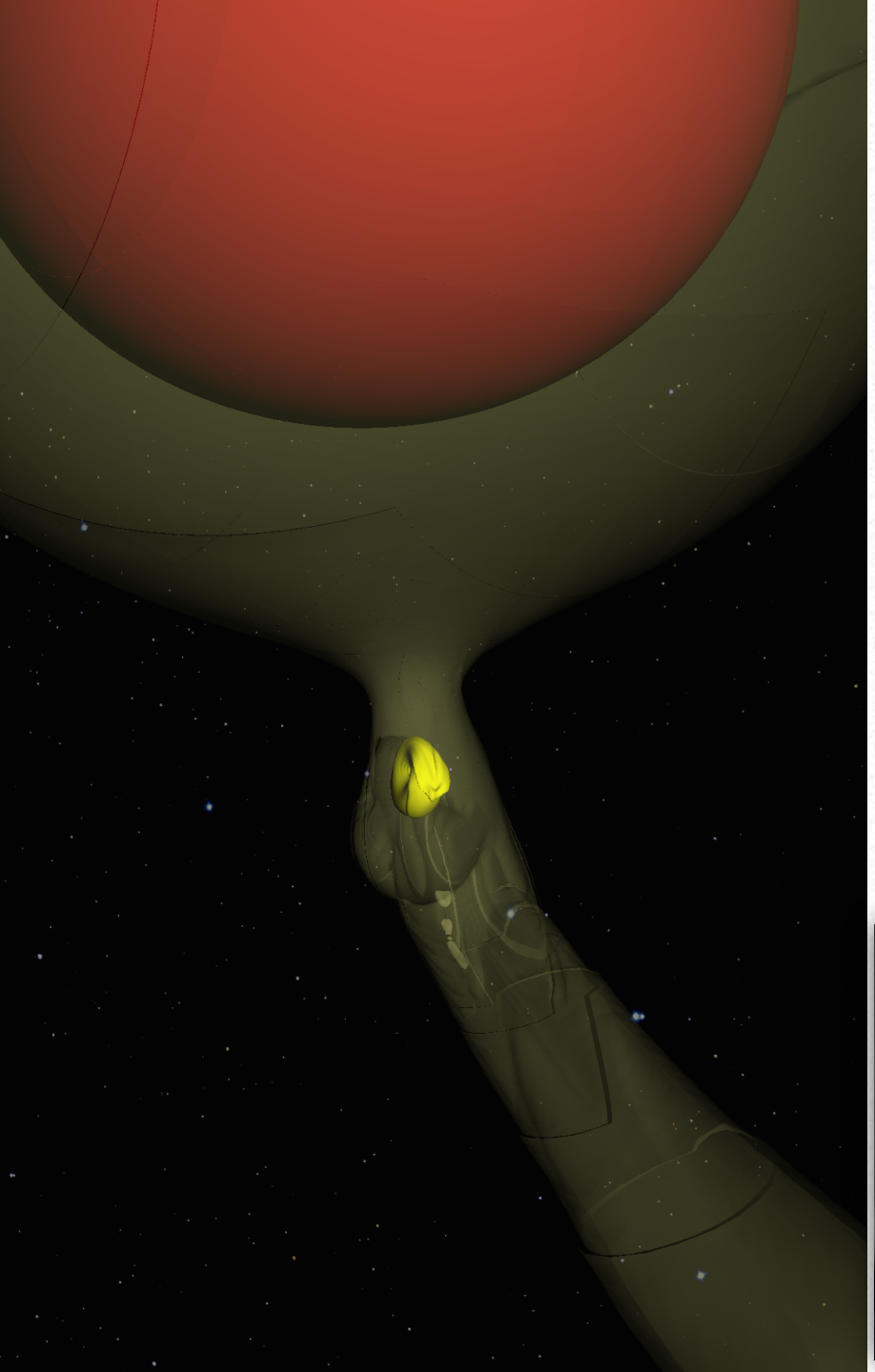
**Roche potential +**
**radiative acceleration (w/ X-rays)**

| Heavy Slow (HS) | Light Fast (LF) |
|---|---|
| NS mass : $2.5M_\odot$ | NS mass : $1.5M_\odot$ |
| Normal acceleration | Enhanced acceleration (50%) |
| => wind speed < orbital speed | => wind speed > orbital speed |

Similar mass inflow
BUT
**Net inflow of angular momentum non-zero for HS**



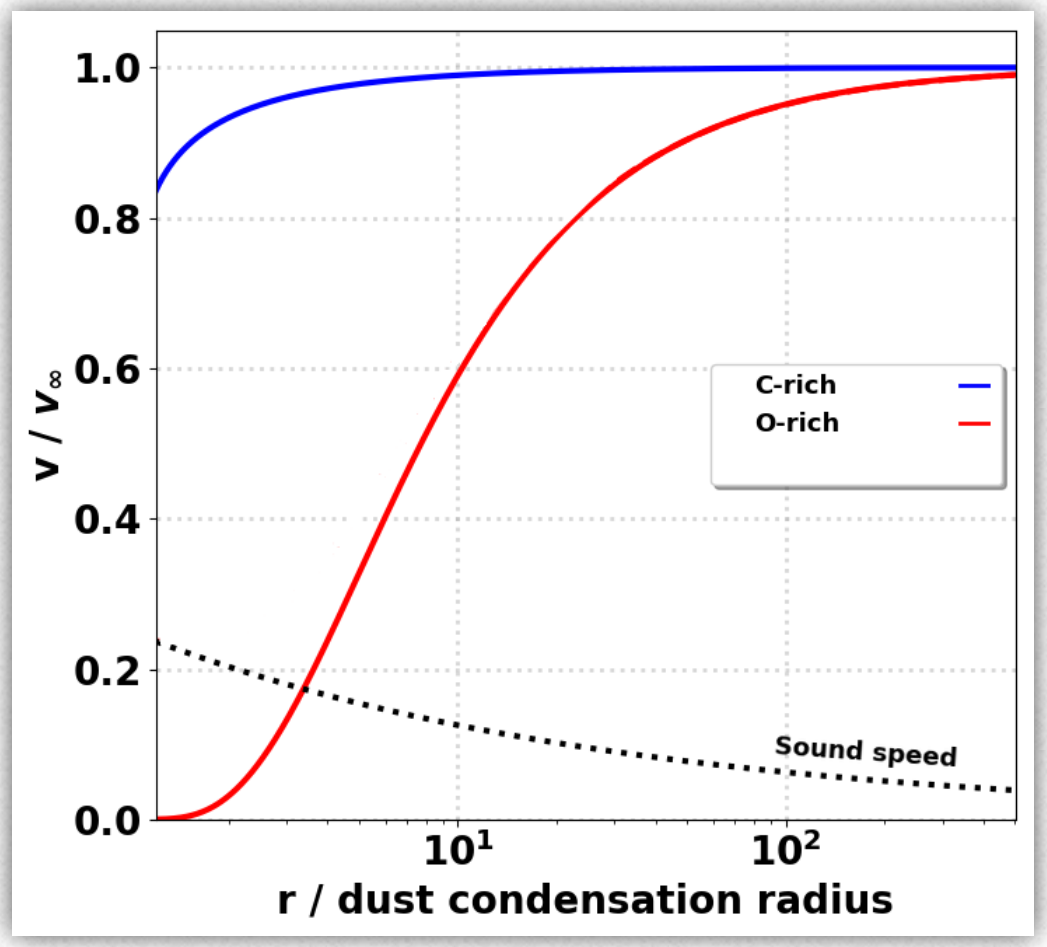
# Wind-captured disc



# Circumstellar envelope of cool evolved stars in binaries

- *Wind morphology around cool evolved stars in binaries – the case of slowly accelerating oxygen-rich outflows*, IEM, Bolte, Decin, Homan & Keppens A&A 2020

# Parametrized 1D radial wind




ß-velocity profile

$$v_\beta(r) = v_\infty(1 - R_0/r)^\beta$$

- dust condensation radius
- terminal velocity
- ß exponent

Sub or supersonic inflowing boundary?

- sonic point
- modified ß-wind

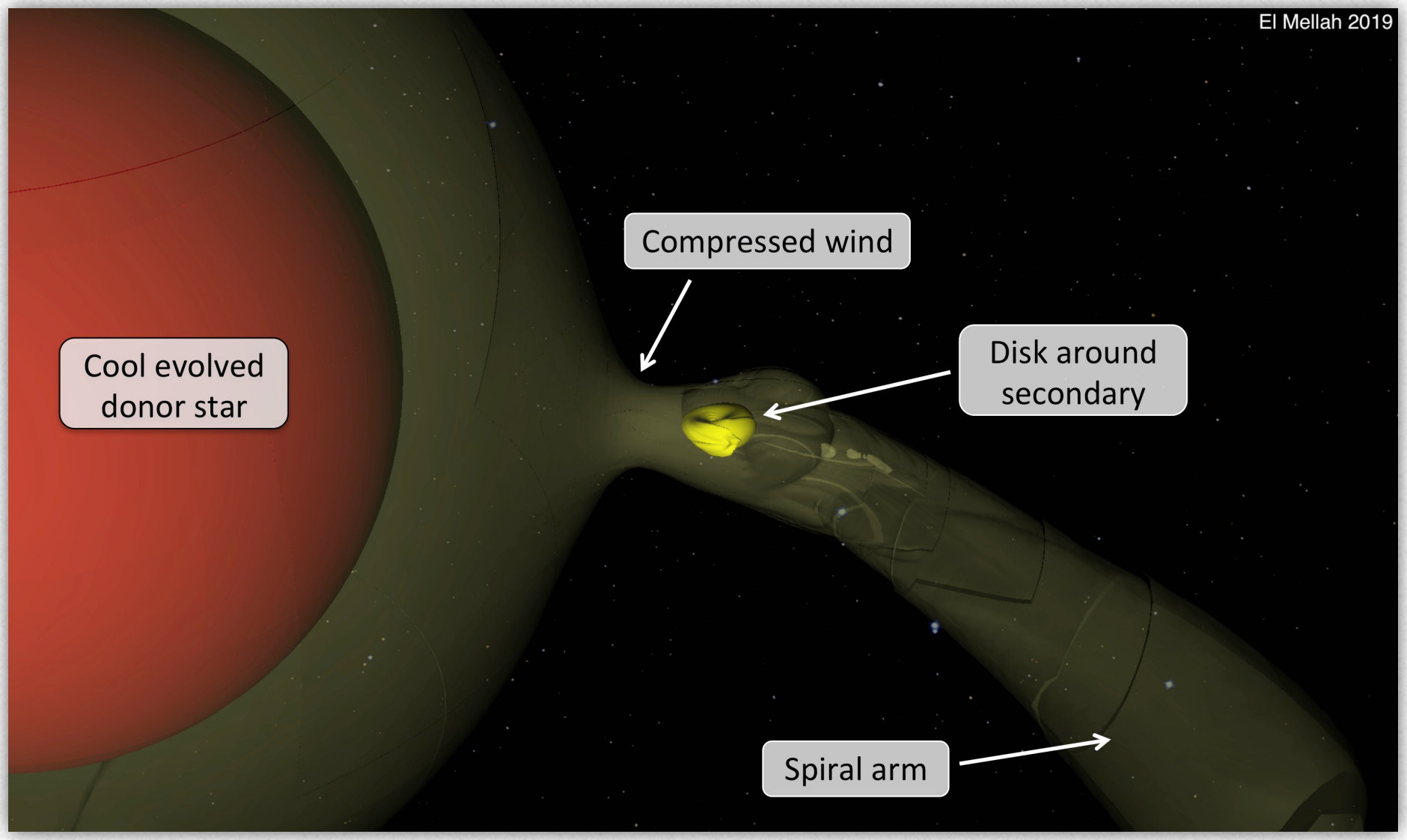
Effective acceleration

- stellar gravity
- radiative pressure

Co-rotating frame

- inertial forces
- non-spinning star

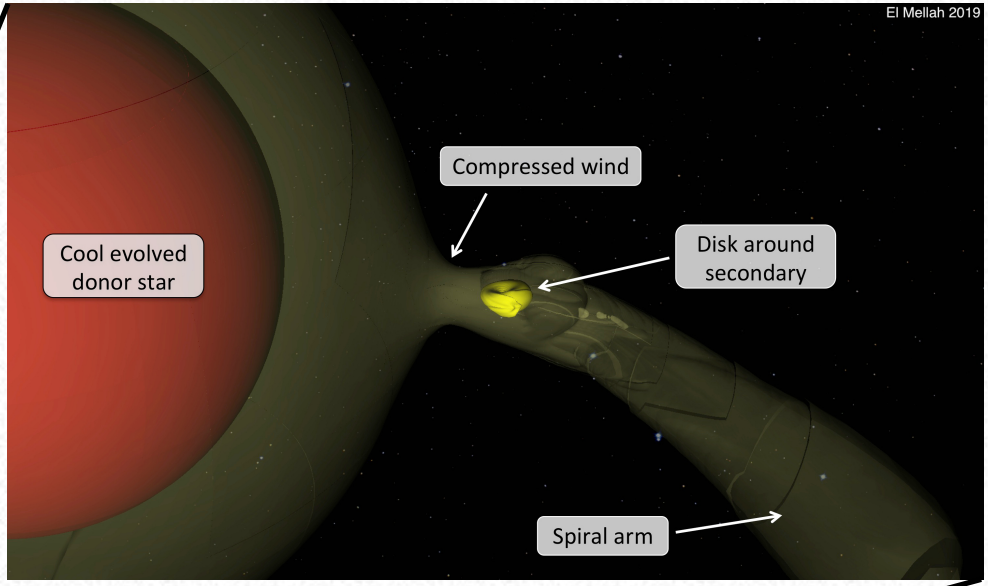
# Wind-captured disk

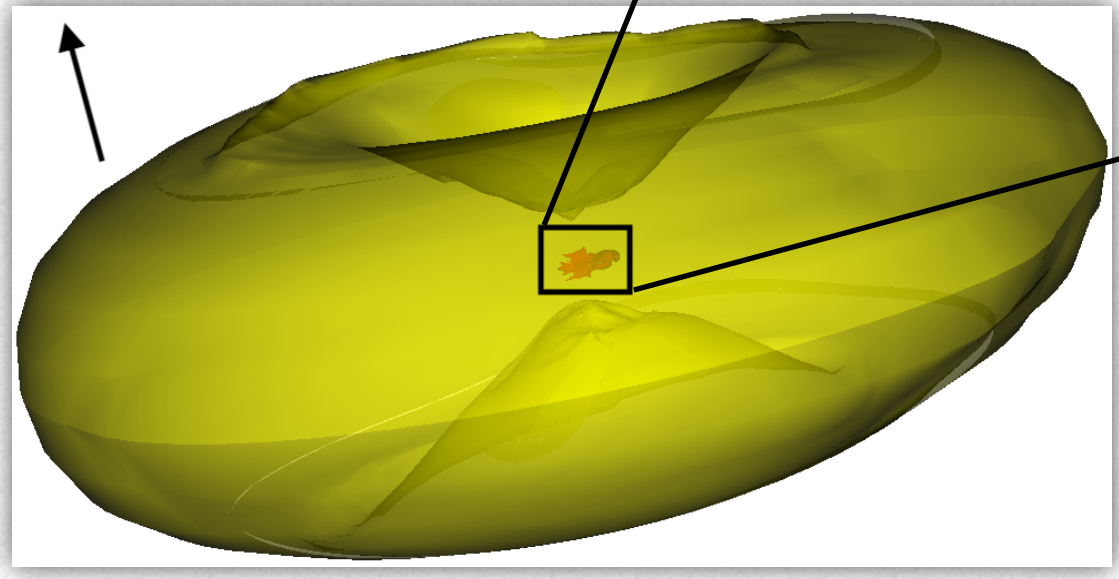


# Equatorial density enhancement

Key-parameters

- terminal wind speed / orbital speed
- mass ratio ($M_1/M_2$)
- filling factor
- ß exponent (C or O-rich AGB)



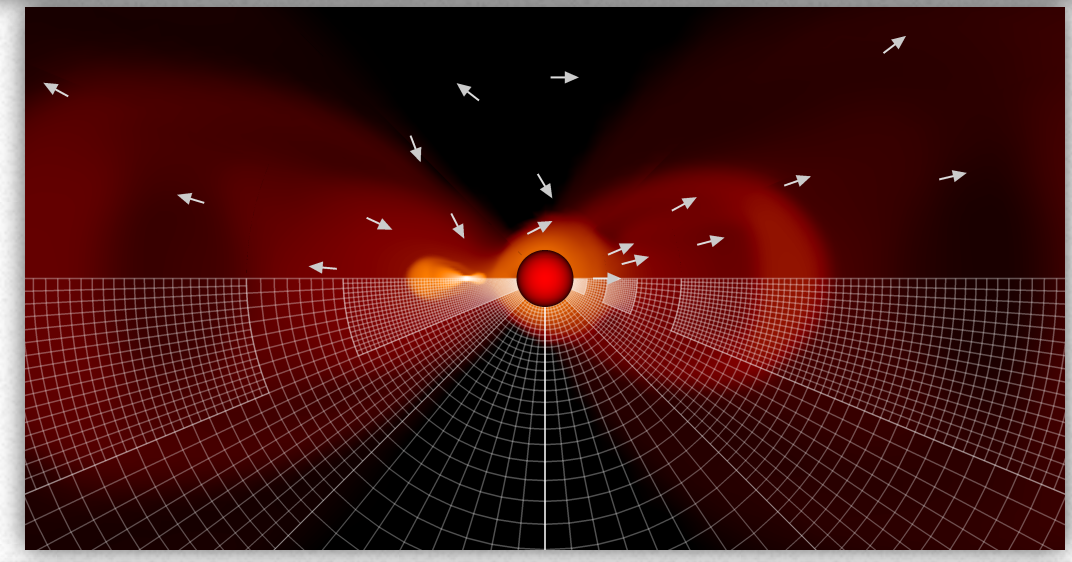



=> ~ 70 simulations

# Circumbinary envelope morphology

Spirals

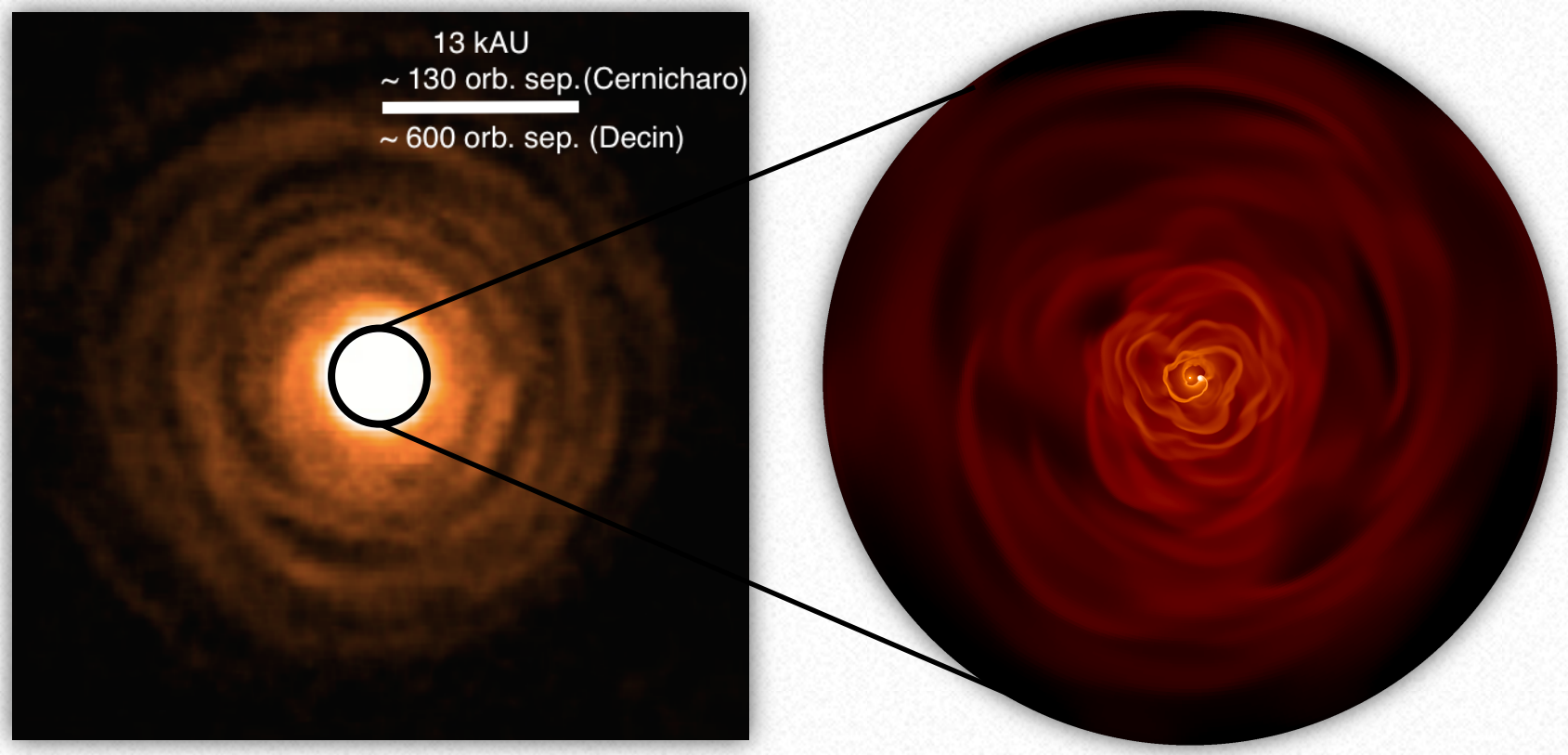

Line-of-sight



Arcs

# Circumbinary envelope morphology

Observations VS theory




- mass ratio ~ a few
- filling factor ~ a few 10%
- terminal / orbital speed ~ 1 (Decin+15)
- terminal / orbital speed ~ 4 (Cernicharo+15)
- C-rich AGB star

- mass ratio ~ 1
- filling factor ~ 20%
- terminal / orbital speed ~ 0.8
- C-rich AGB star

# Conclusion

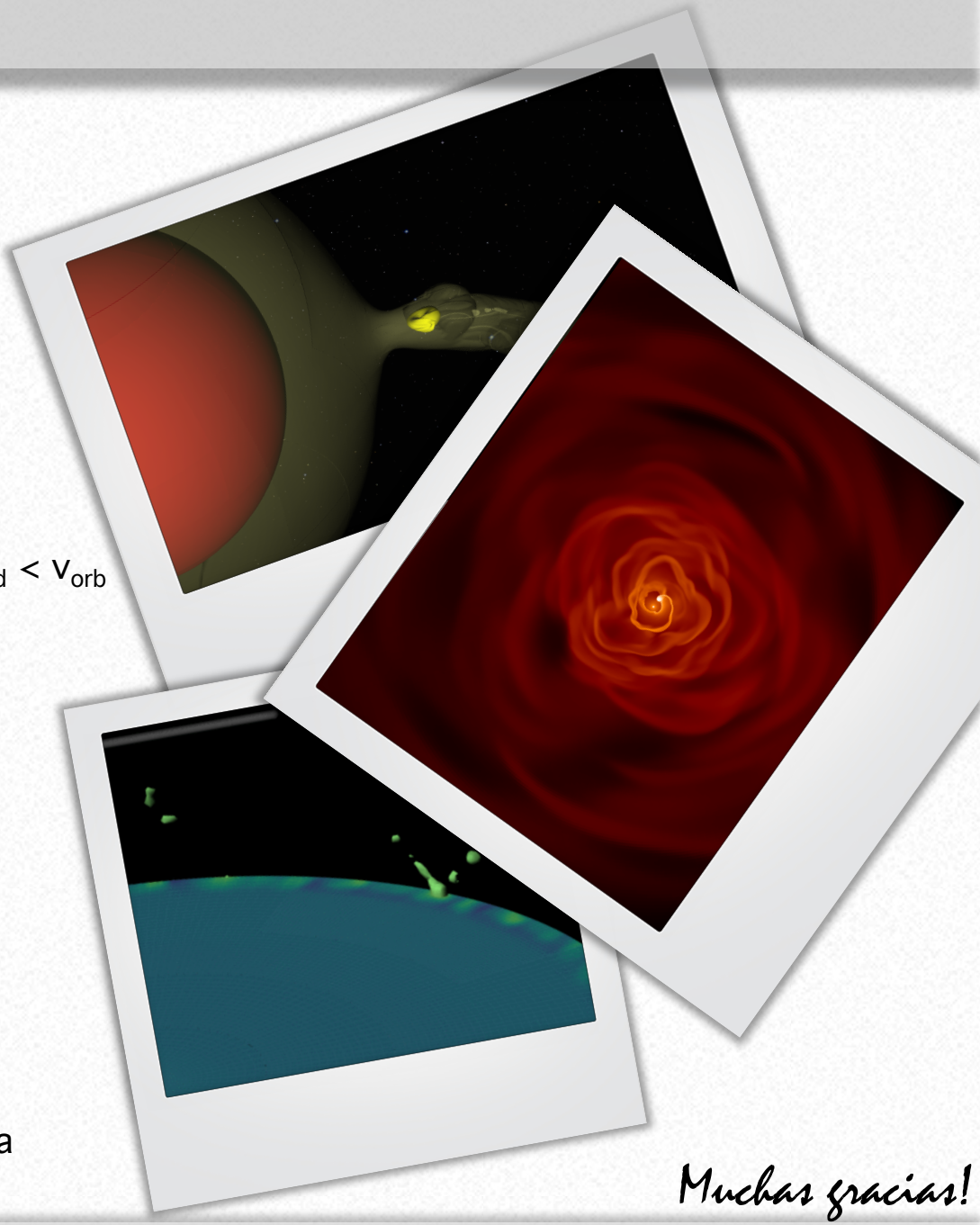
## Overview

High-mass X-ray binaries

- limited impact of clumps on $\dot{M}$ variability
- instabilities within a few 100 $R_{SCHW}$
- wind-captured disks for $v_{wind} < v_{orb}$

Cool evolved binaries

- significant non-isotropic features for $v_{wind} < v_{orb}$
- arcs, spirals, petals
- equatorial density enhancement



## Perspectives

- additional parameters (eg eccentricity)
- physical wind launching
- matter-radiation coupling
- orbital variability of column density
- synthetic emission maps & X-ray spectra

*Muchas gracias!*