Wind accretion in Supergiant X-ray Binaries

Ileyk El Mellah

Rony Keppens
& the X-Wind collaboration

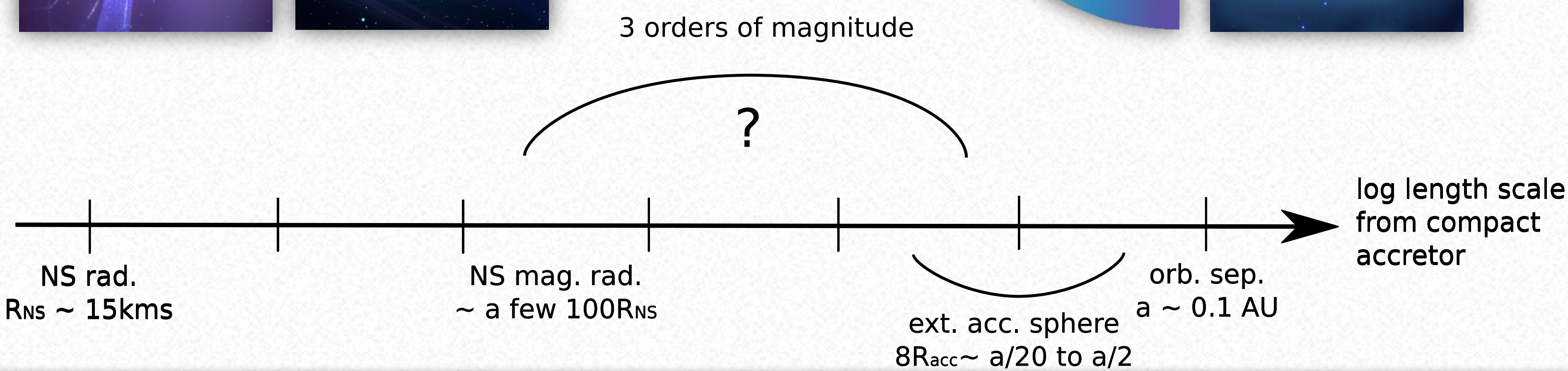
CmPA – KU Leuven

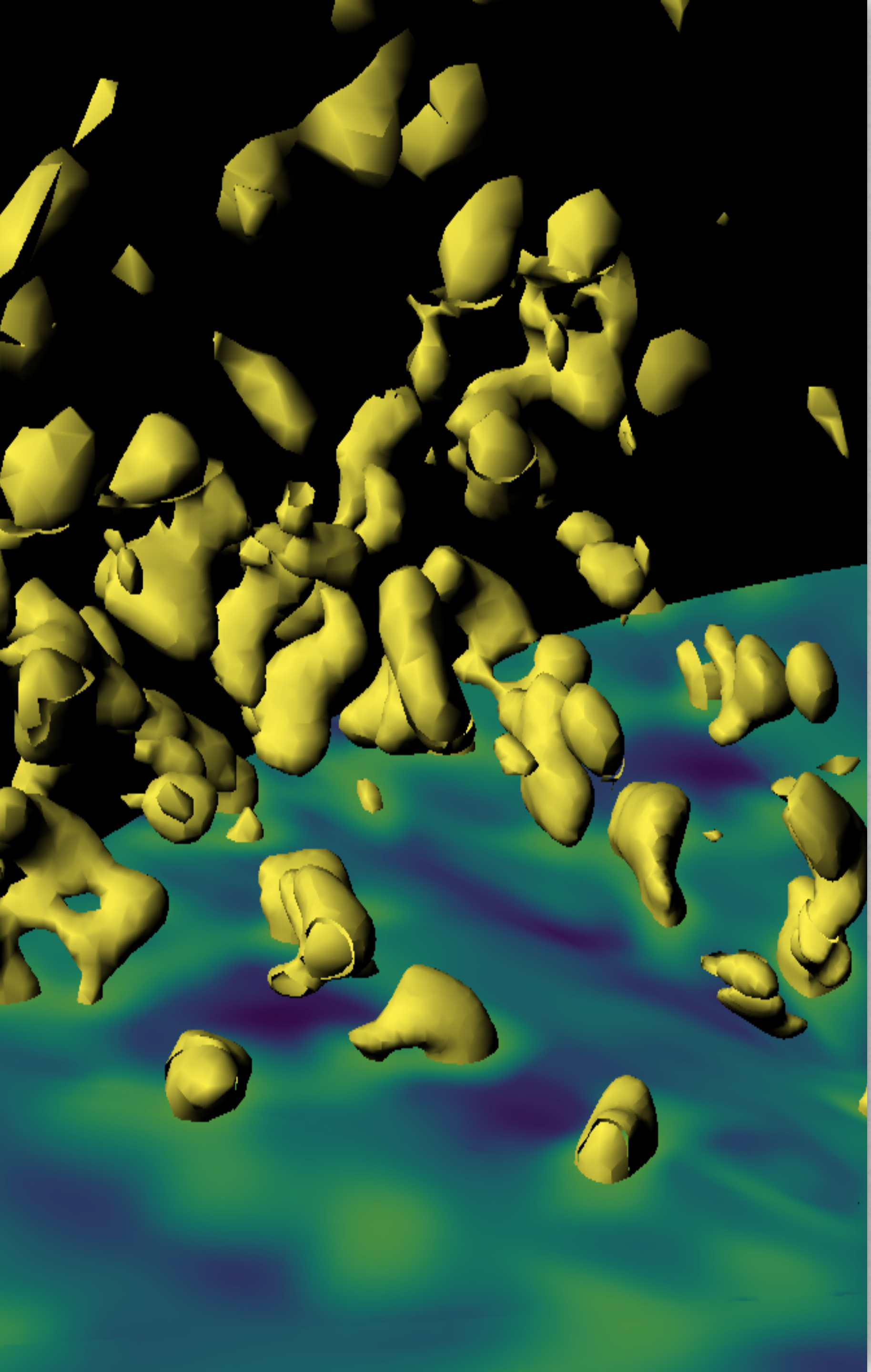
Geneva
February 2019

The challenge of scales

1. clumps capture?

2. disc-like structure?





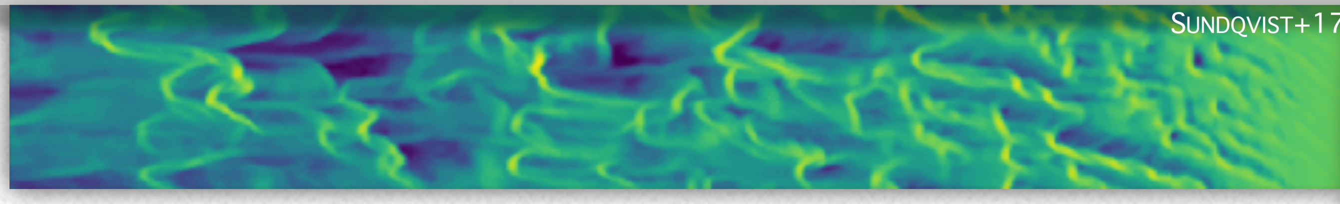
Clumps in the wind

Accretion from a clumpy massive-star wind in SgXB,

MNRAS 2018

IEM, Jon Sundqvist, Rony Keppens

Clump dimensions

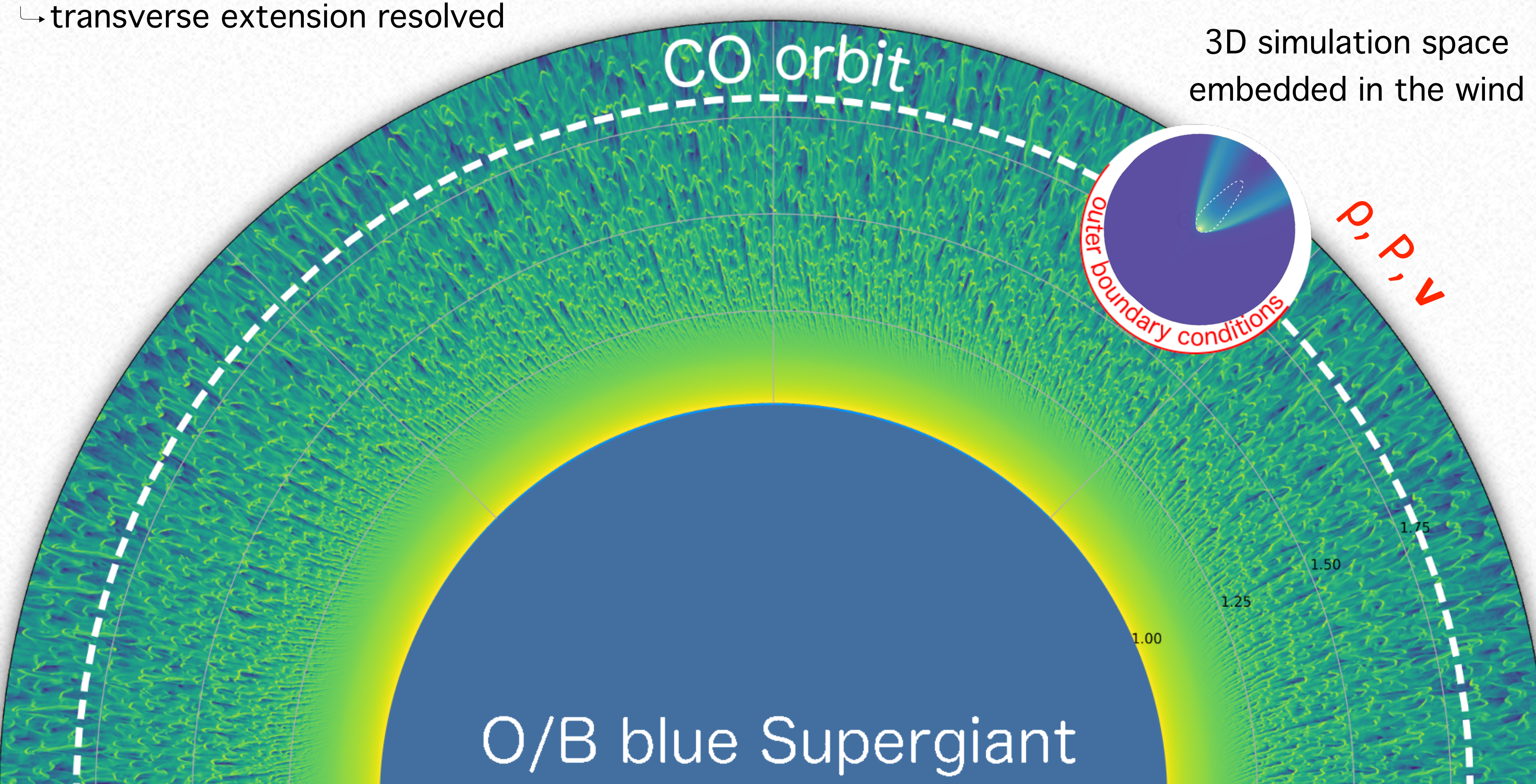


Line-driven winds

Internal shocks
=> **clumps**

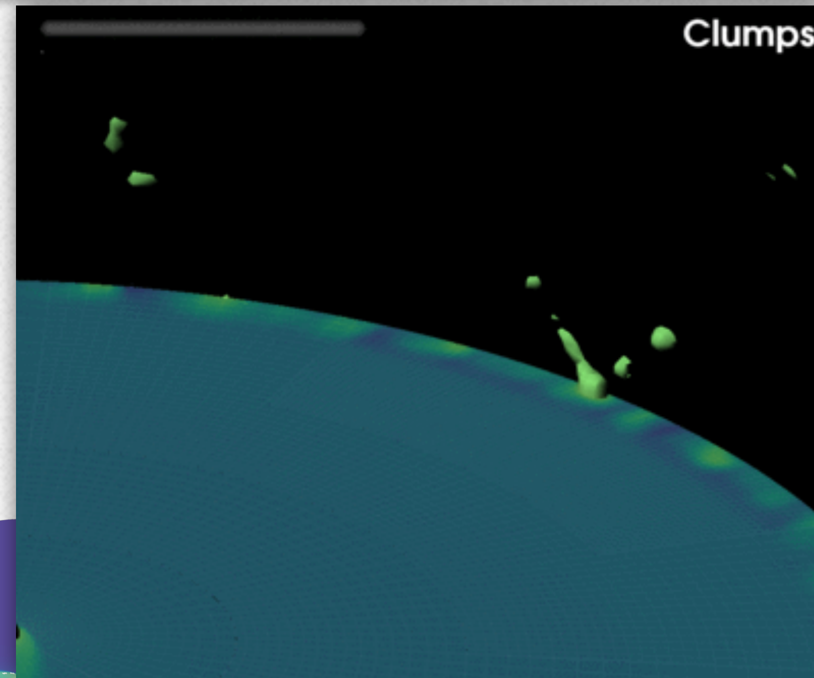
Pseudo-planar 2D simulations
↳ transverse extension resolved

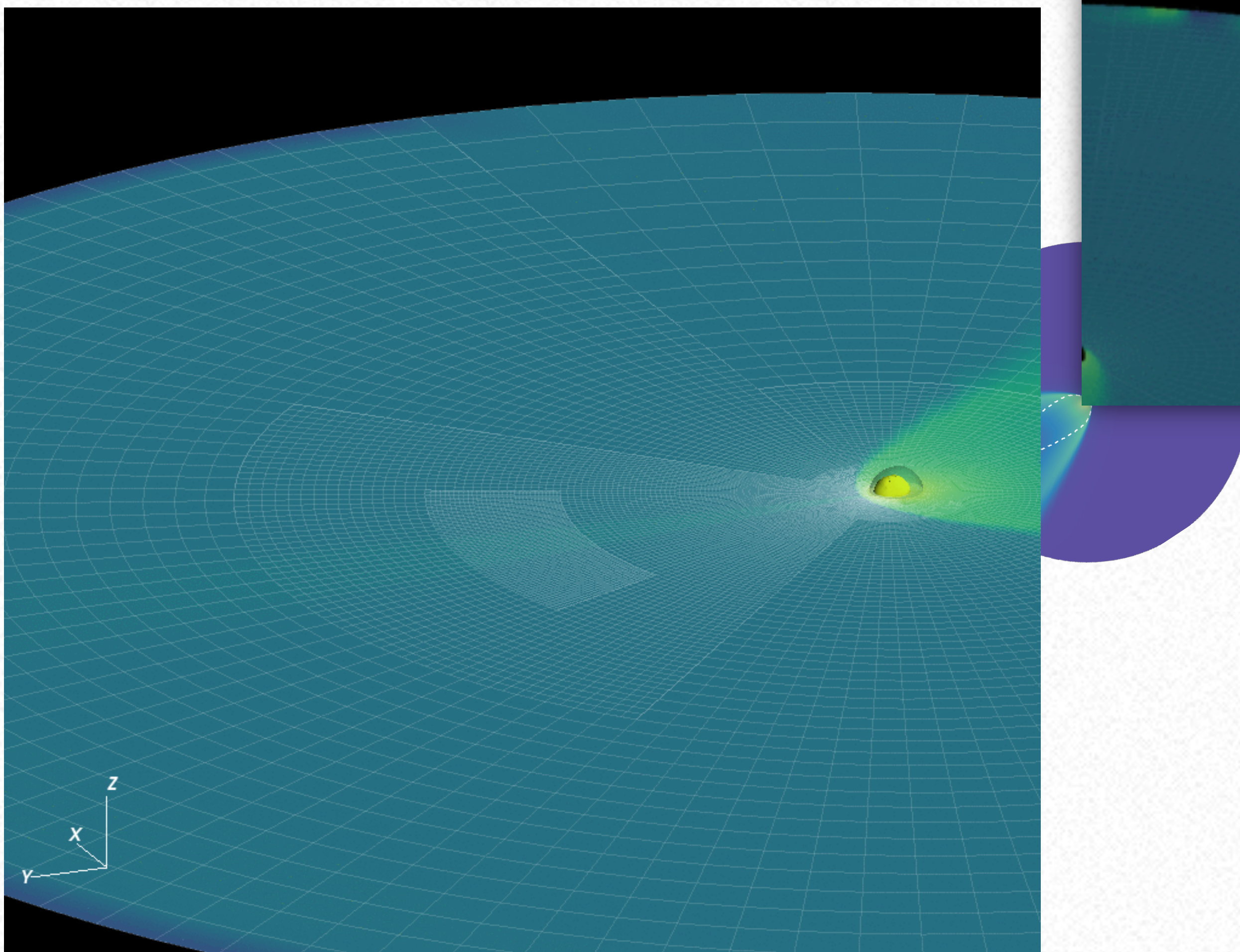
3D simulation space
embedded in the wind



Structure of the flow and time variability of the mass accretion rate

Ballistic clumps



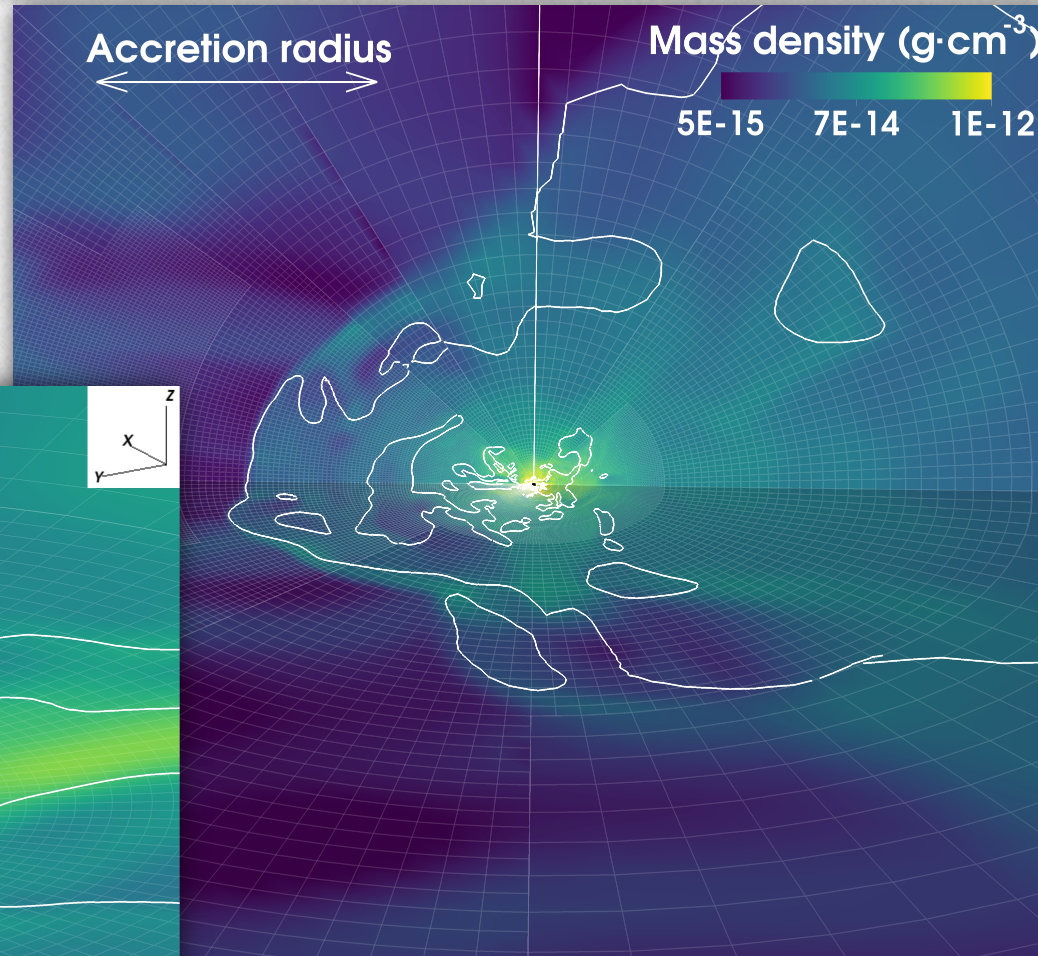


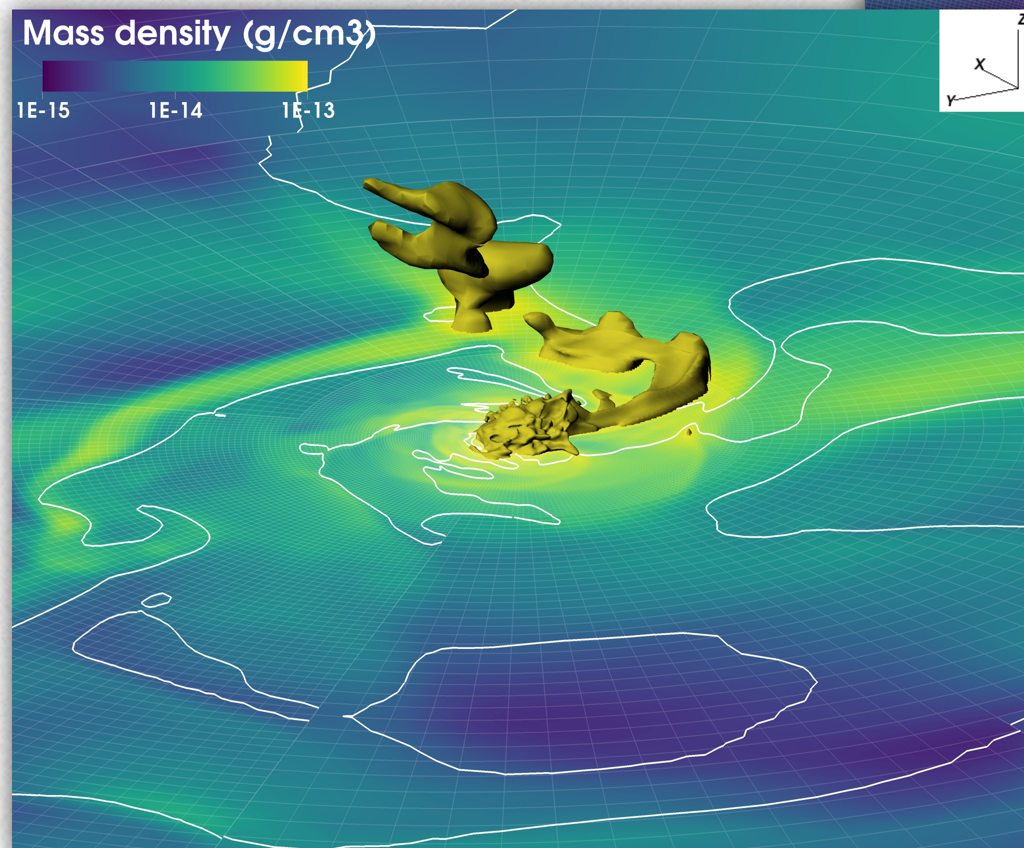
Structure of the flow and time variability of the mass accretion rate

Bow shock @ accretion radius

↳ **prevents direct accretion** of clumps

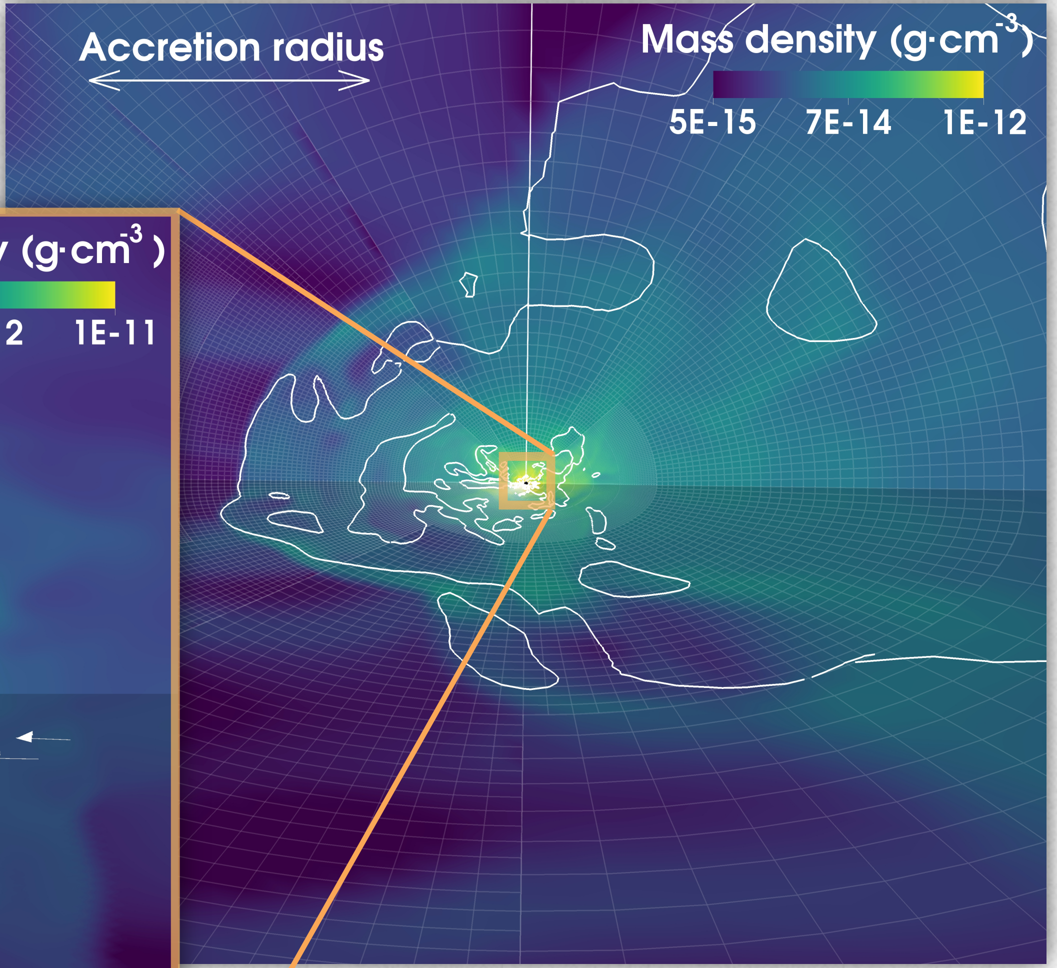
↳ evacuation of angular momentum

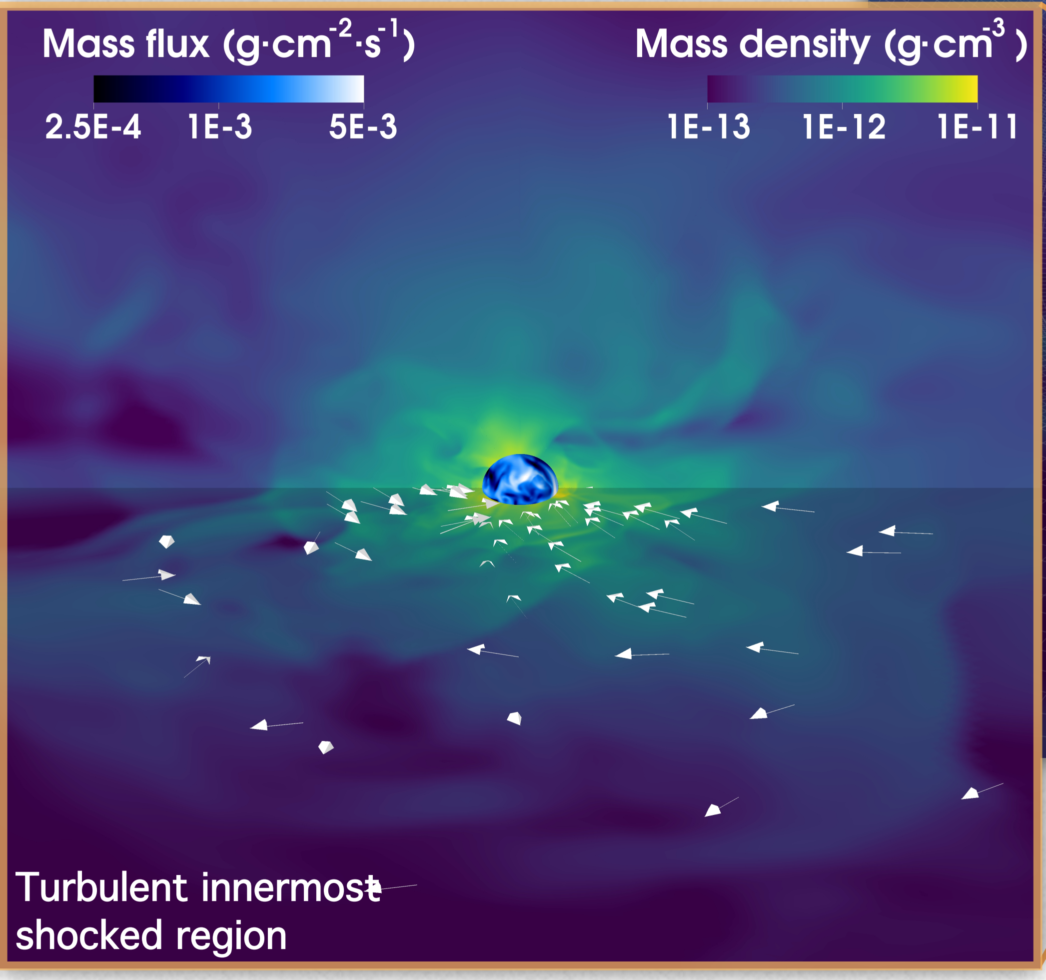




Structure of the flow and time variability of the mass accretion rate

Bow shock @ accretion radius
↳ **prevents direct accretion** of clumps
↳ evacuation of angular momentum





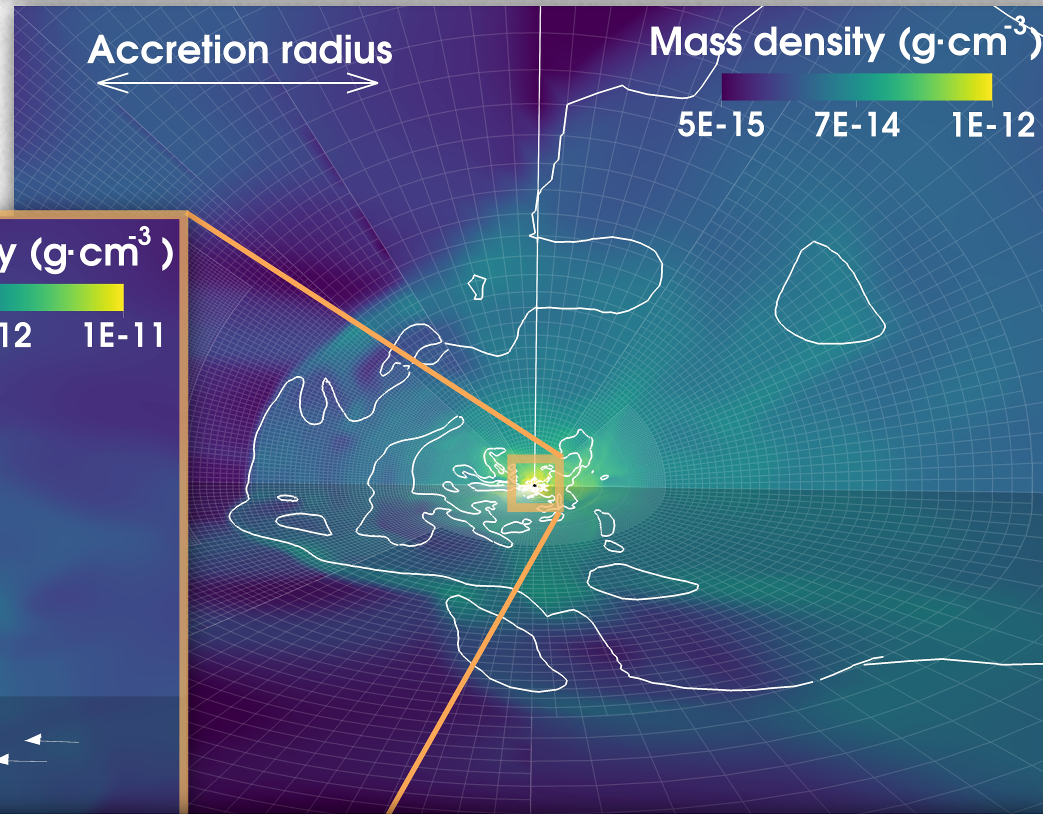
Structure of the flow and time variability of the mass accretion rate

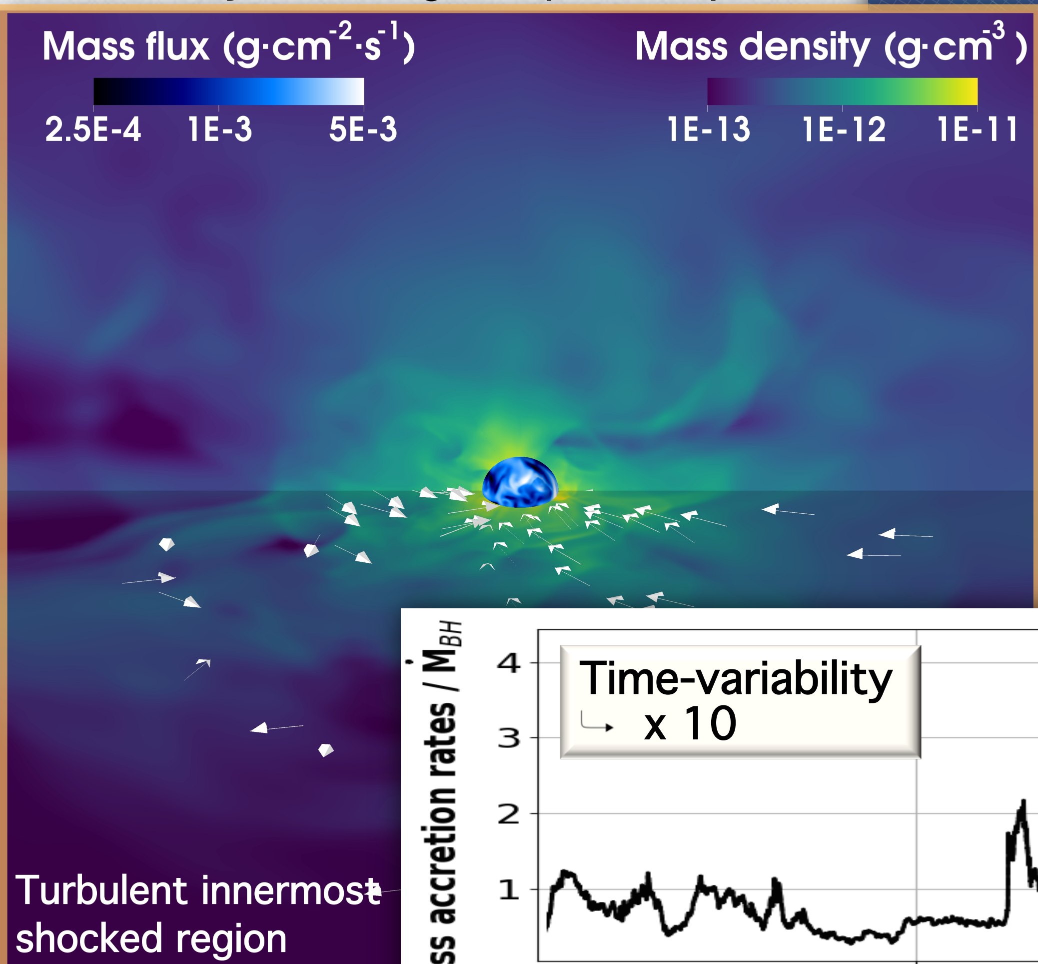
Bow shock @ accretion radius

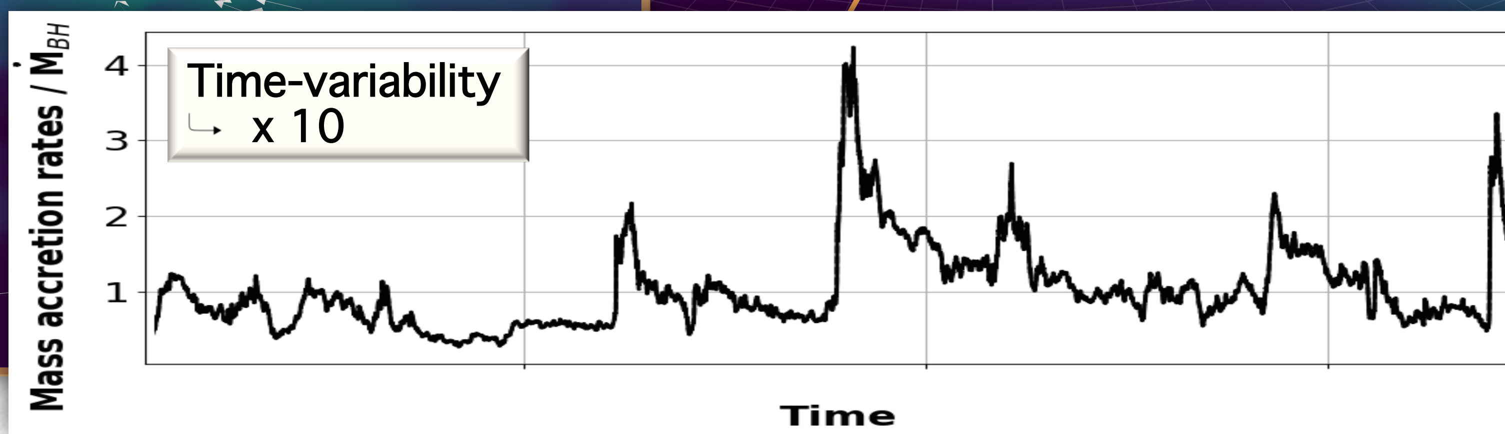
↳ **prevents direct accretion** of clumps

↳ evacuation of angular momentum

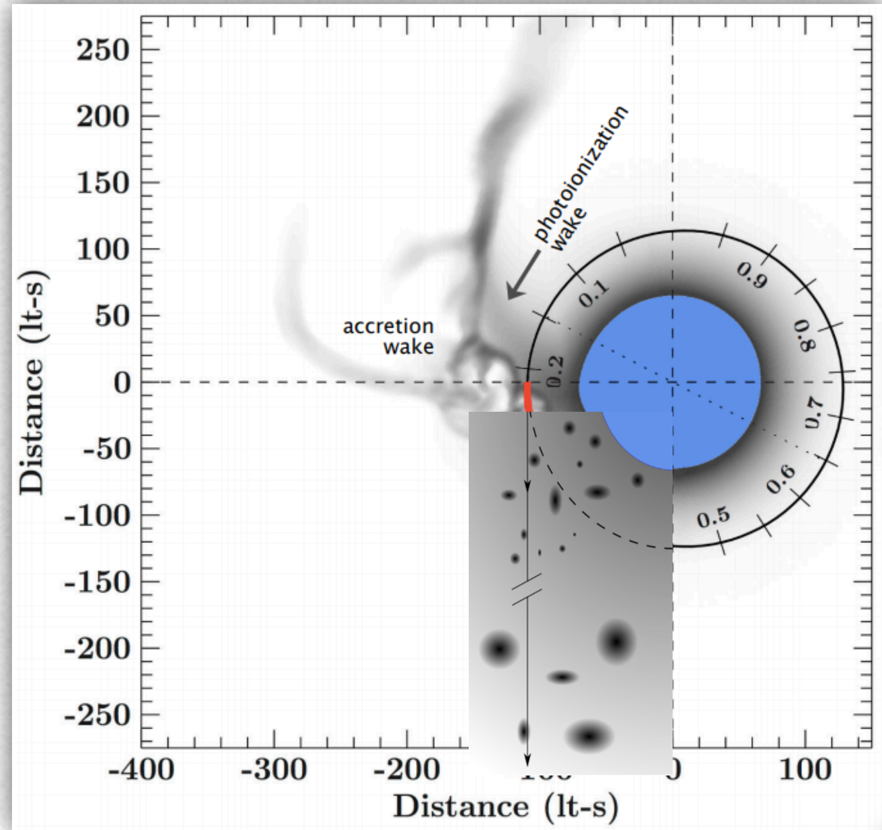
↳ **instability @ NS magnetosphere required**







Observations of Vela X-1



Phase ~ 0.25

↳ no tail in the L.O.S

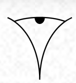
Hardness enhanced

↳ not from source

↳ increase in N_H (x7)

↳ 1h long

Grinberg et al. 2017

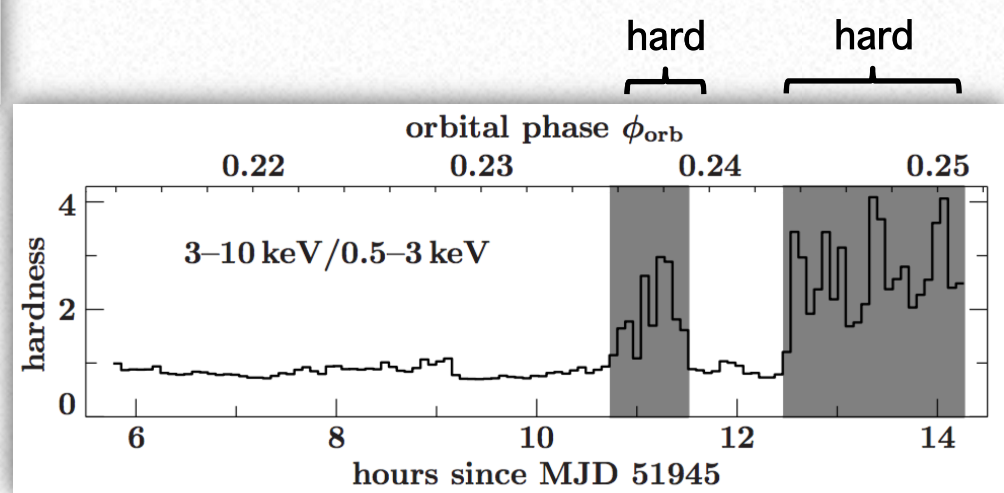


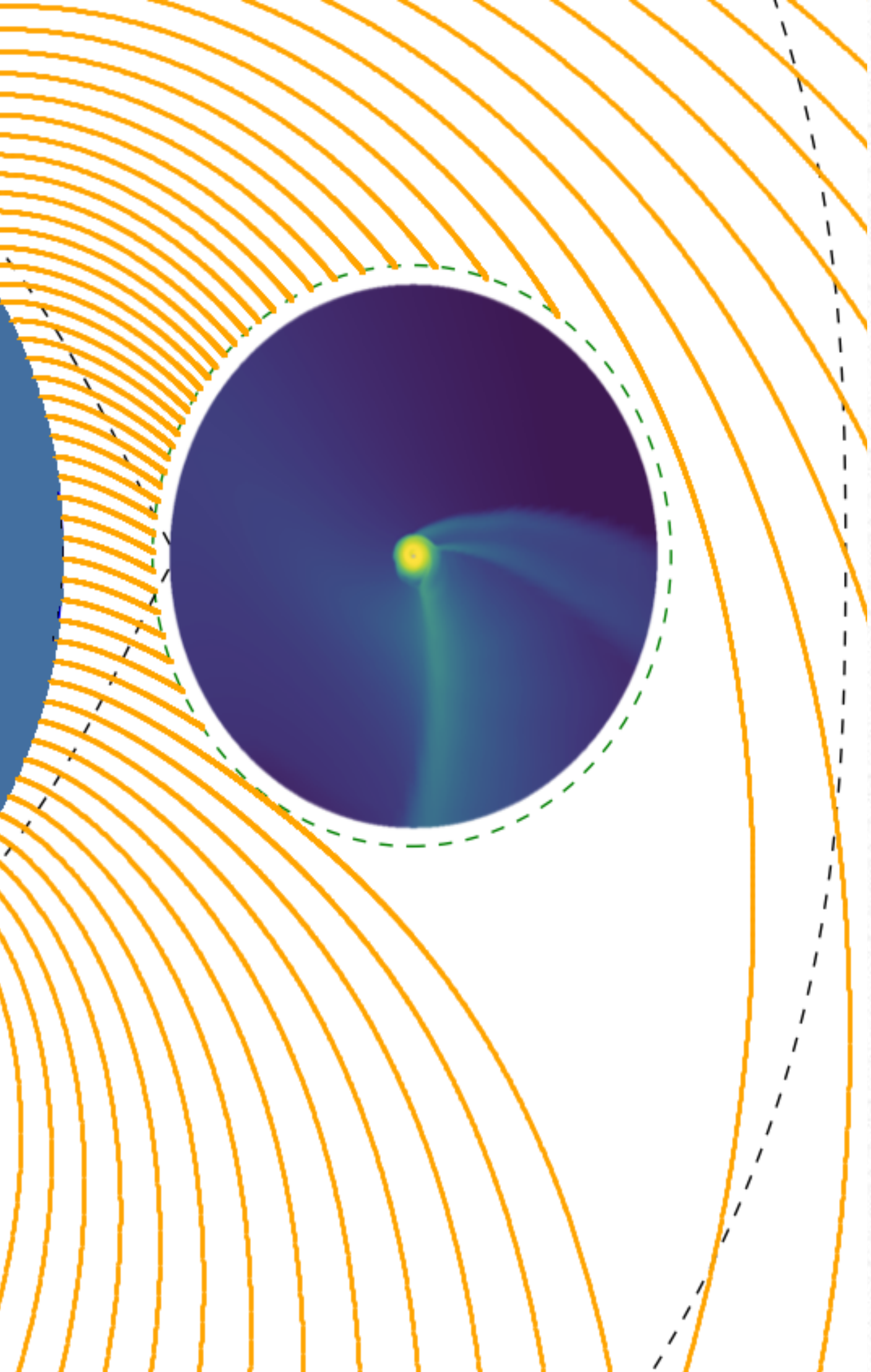
Due to clump event?

↳ too small (1% of R_{star})

↳ too packed

↳ too fast (~1,000km/s)



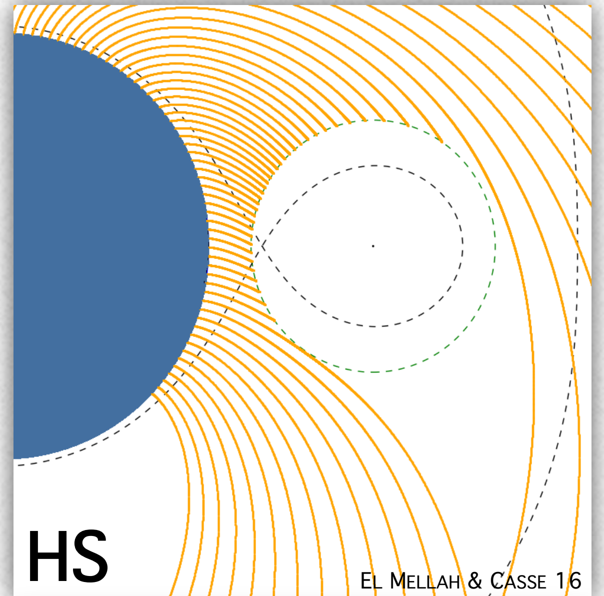


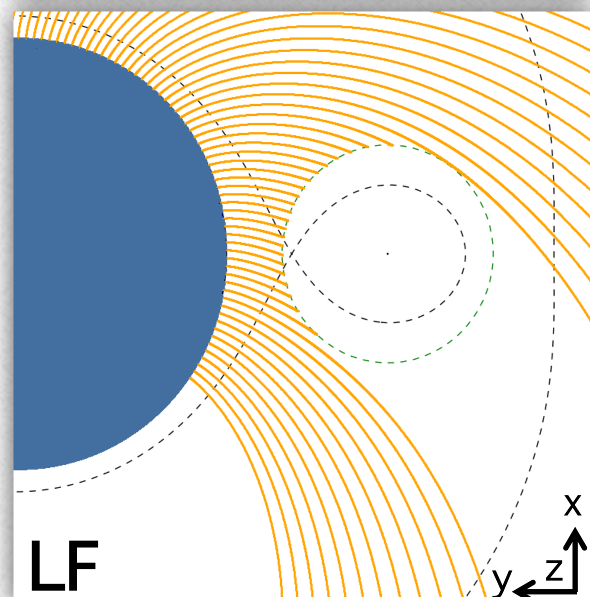
Orbital bending

Wind-capture discs in SgXB, A&A 2019

IEM, Andreas Sander, Jon Sundqvist, Rony Keppens

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



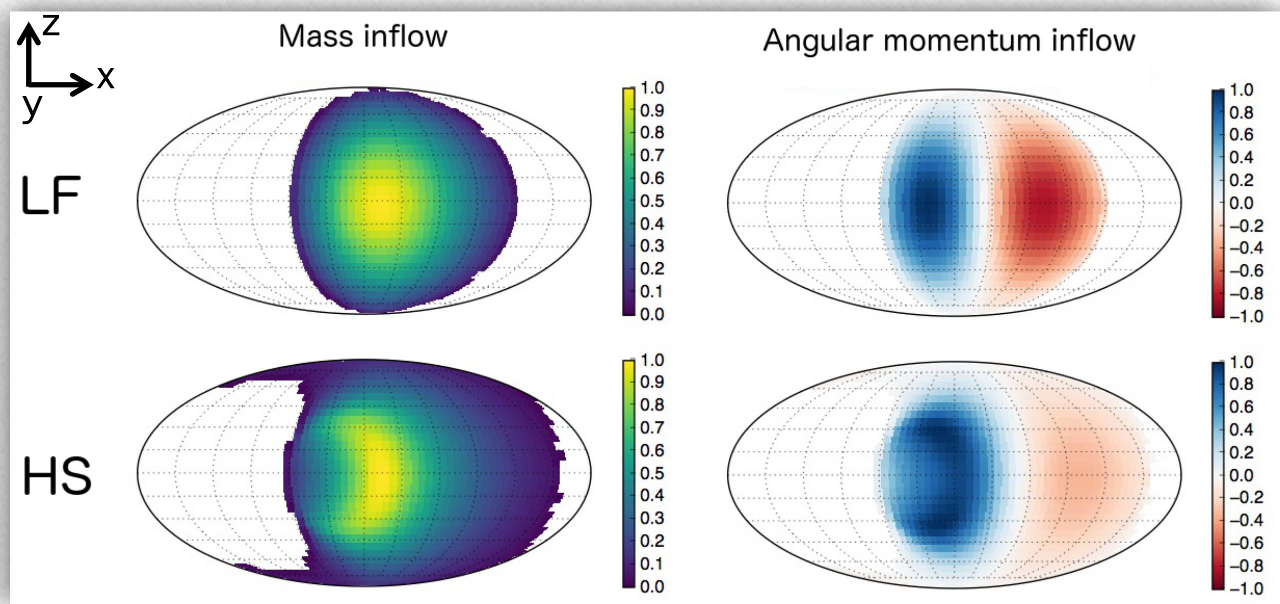


3D ballistic wind (RK4)
Stellar parameters fixed

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

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

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



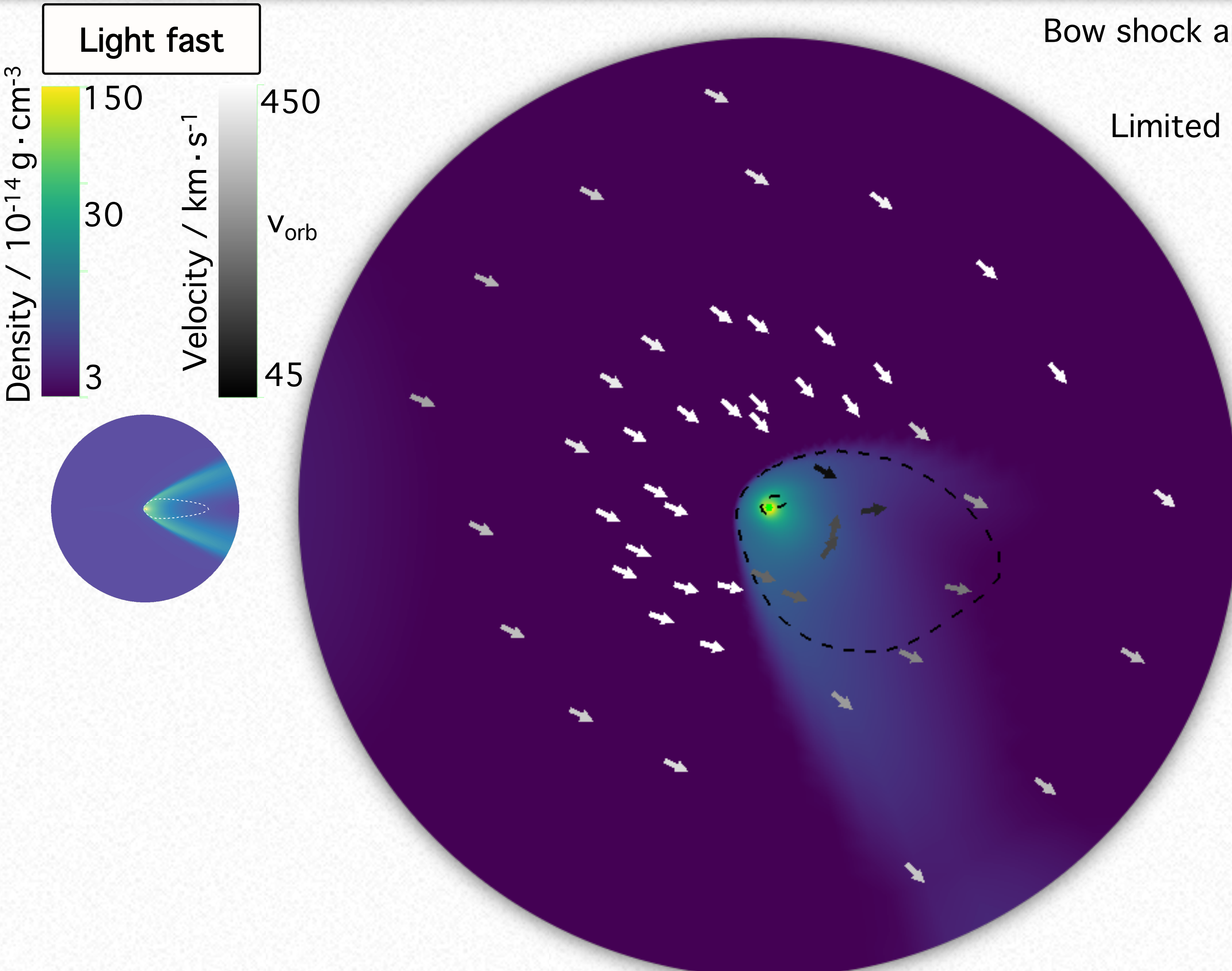
Wind-RLOF configuration

Bow shock and Mach-1 misaligned

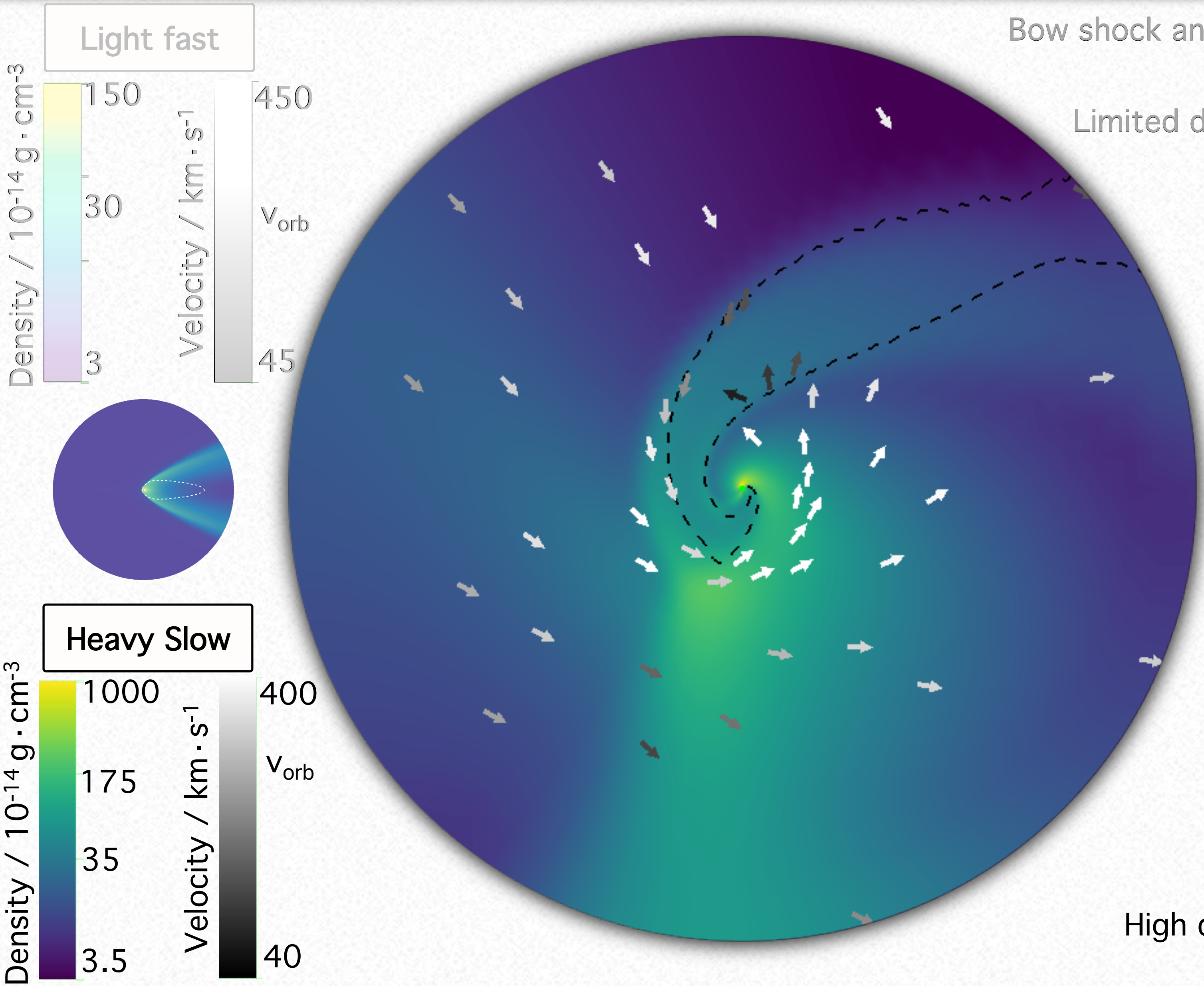
Sonic surface

Limited density enhancement

No disc



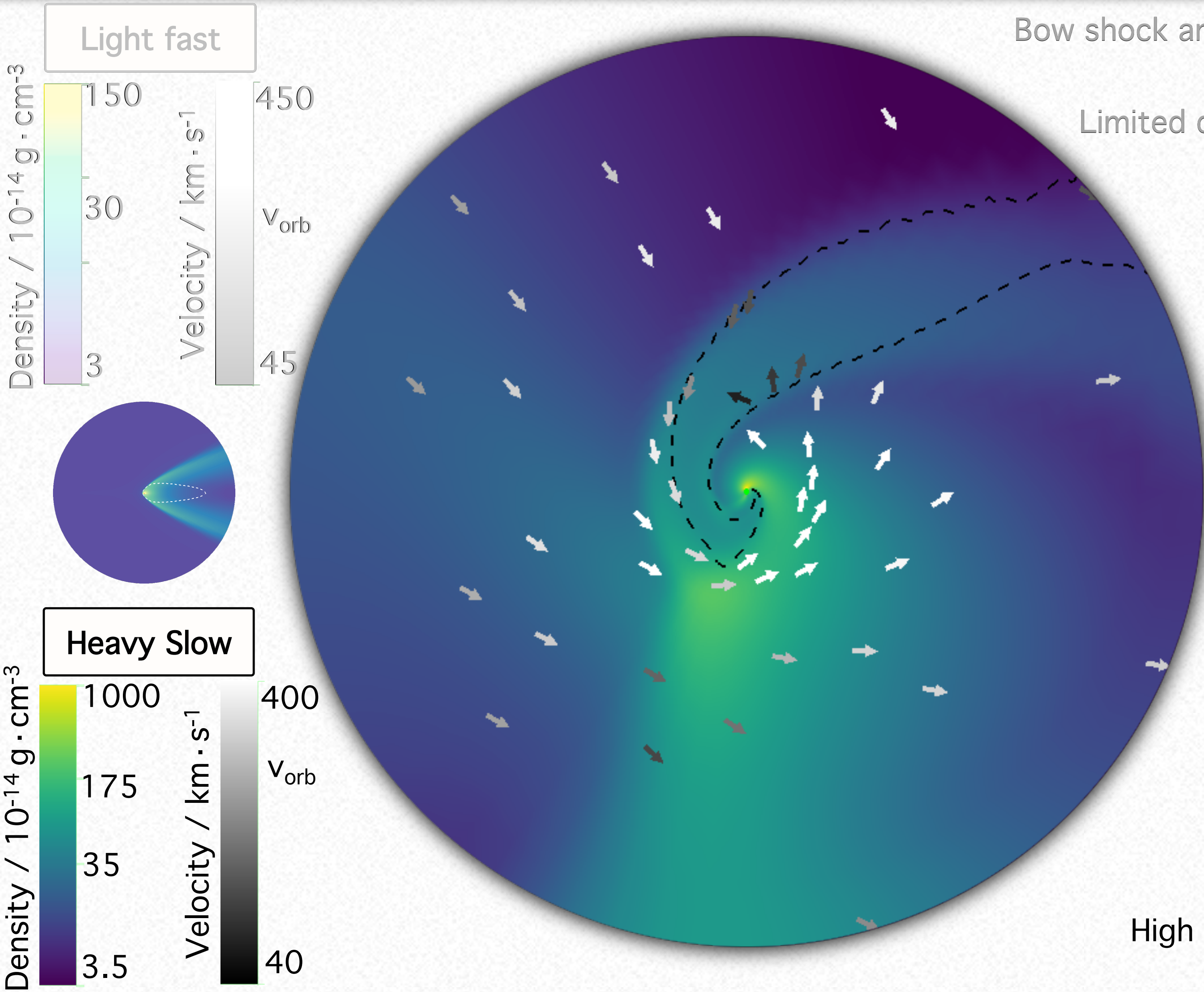
Wind-RLOF configuration



Bow shock and Mach-1 misaligned
Sonic surface
Limited density enhancement
No disc

Asymmetric shock
Orbital compression
High density enhancement
Spiral structure

Wind-RLOF configuration



Bow shock and Mach-1 misaligned

Sonic surface

Limited density enhancement

No disc

Temperature increase by factor x5,000

⇓

cooling required

Asymmetric shock

Orbital compression

High density enhancement

Spiral structure

Cooling prescriptions and wind-capture disc

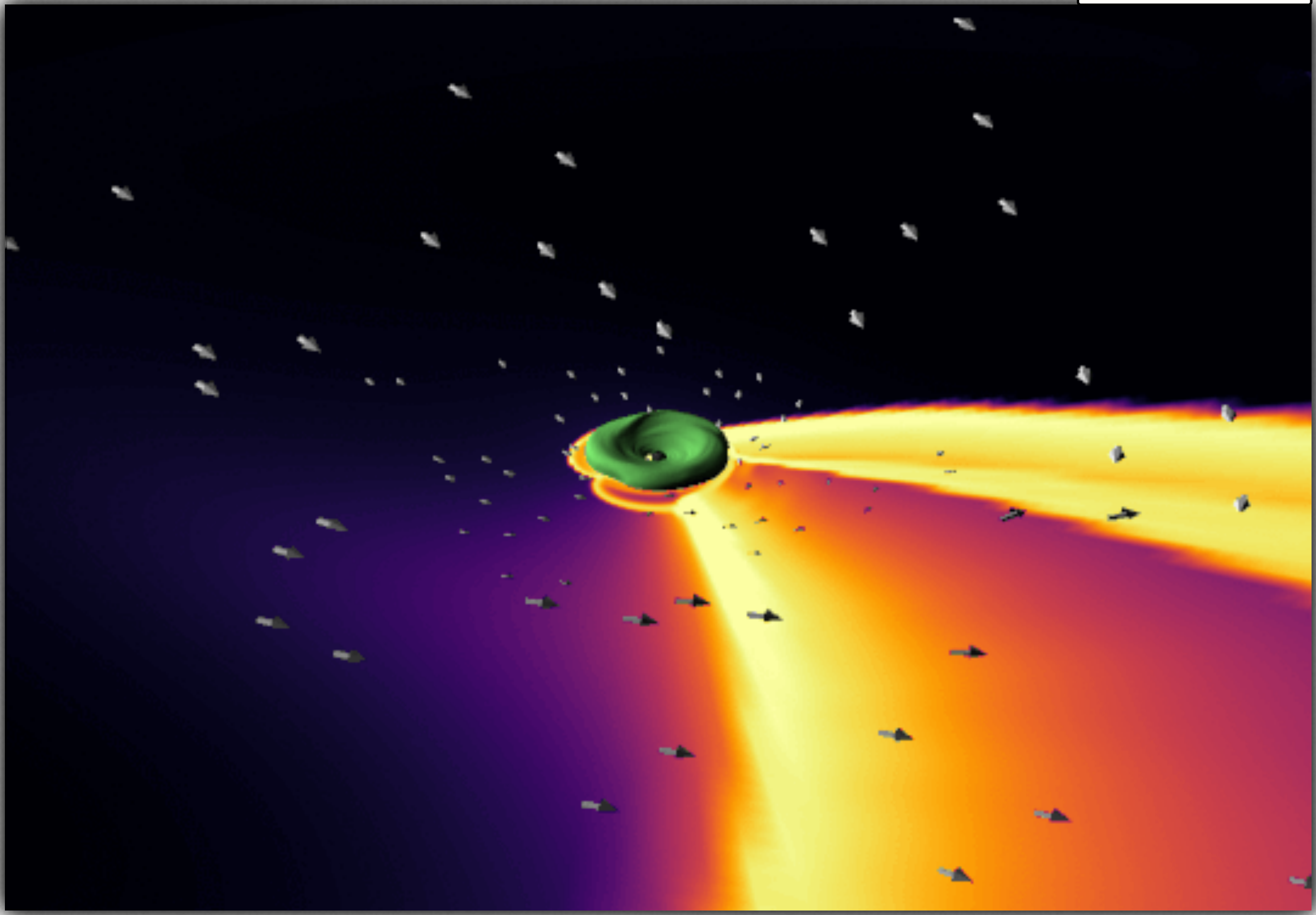
Polytropic prescription to reproduce cooling

Heavy Slow

Constant entropy

Constant high temperature

Constant low temperature



Light fast

↳no disc

Conclusion

Overview

Impact of clumps on time-variability

↳ **lower** than ballistic prediction

↳ cushioning **shock**

↳ limited absorption variability along LOS

↳ **instabilities within a few 100 R_{SCHW}**

↳ dependence on orbital separation (SFXT)

Orbital shearing and disc formation

↳ provided $v_{wind} < v_{orb}$ …

↳ … and efficient cooling

↳ beyond NS magnetosphere

Perspectives

↳ the case of Cygnus X-1

↳ disc-like structure => disc wind? transient?

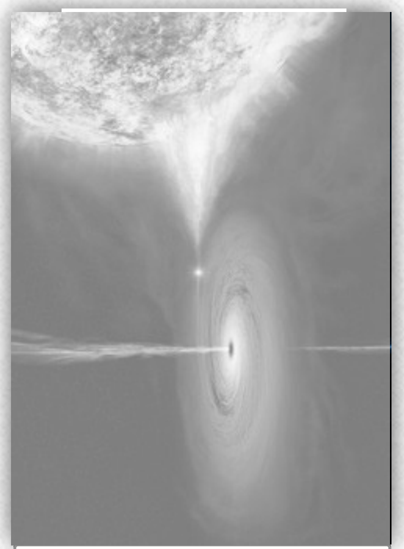
↳ NS (or BH) spinning-up

↳ **Enhanced mass transfer => ULX (IEM, Sundqvist, Keppens, A&A 2019)**

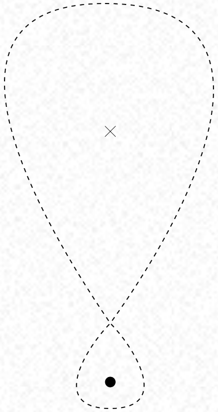
Merci!

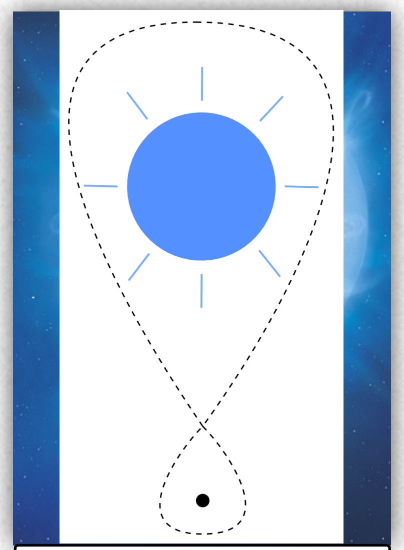
Introduction

Mass transfer



Roche lobe overflow





Wind accretion

Low-mass stellar companion

Permanent accretion disc

↳ multi-color black body

↳ support on top of which grows various instabilities

High-mass stellar companion

Intense radiatively driven **stellar winds**

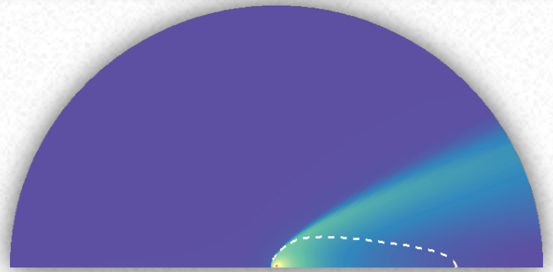
↳ terminal velocity ~ 1000 km/s

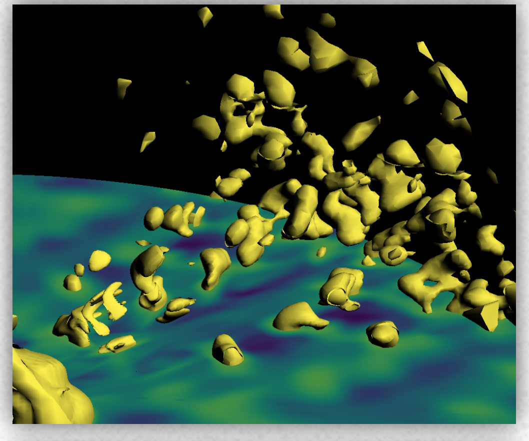
↳ mass outflows ~ 10^{-6} $M_{\odot}$/yr

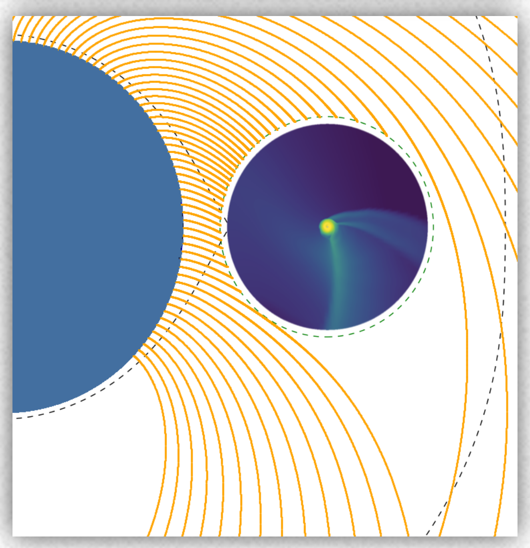
Low angular momentum flow => disc? permanent?

Clumpy winds => time variability?

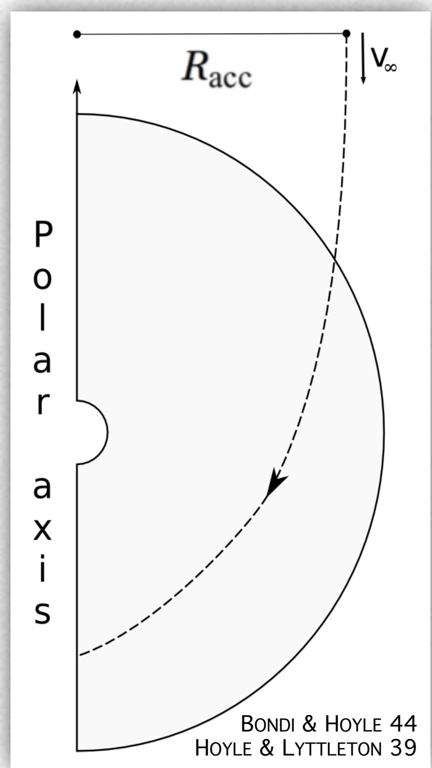
Contents



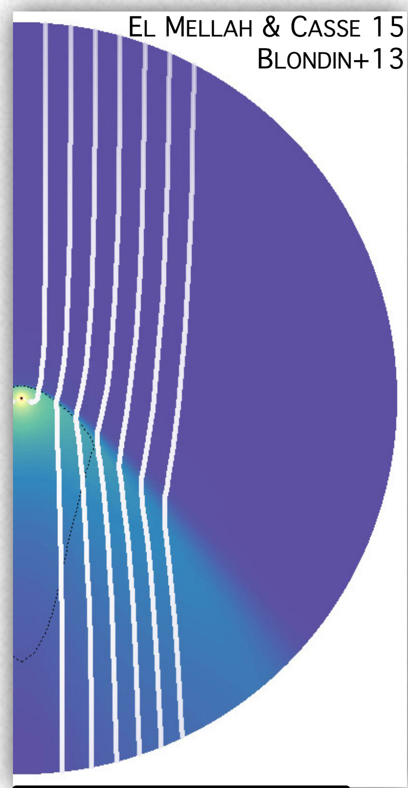




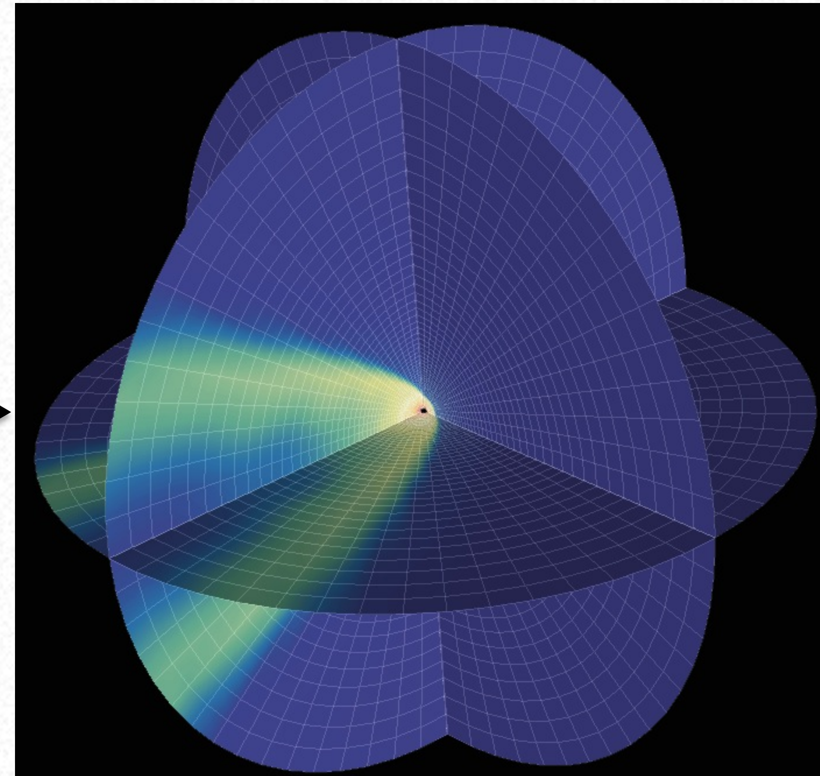
Theory



Axisymm. BHL



Axisymm. HD



Relaxed 3D initial state

Empirical mass acc. rate

$$\frac{R_{acc}}{R_{Schw}} = \left(\frac{c}{v_{\infty}}\right)^2$$

Structure of the flow

Influence of the Mach #

Inner sonic surface

Inhomogeneous outer boundary conditions

Sheared inflow

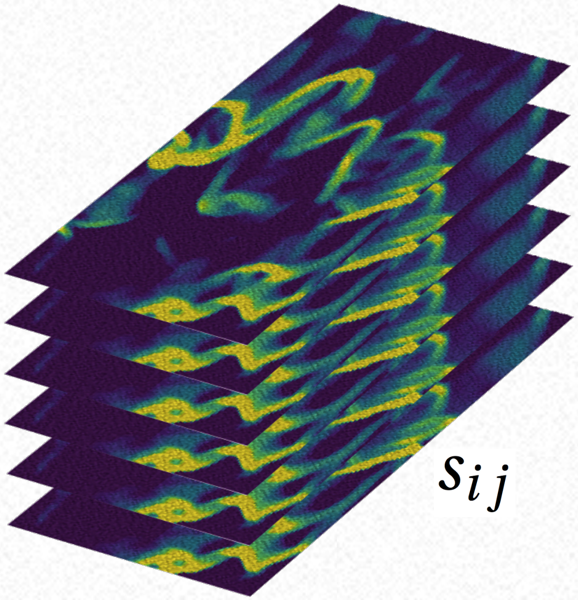
Orbital effects

Xia + 18

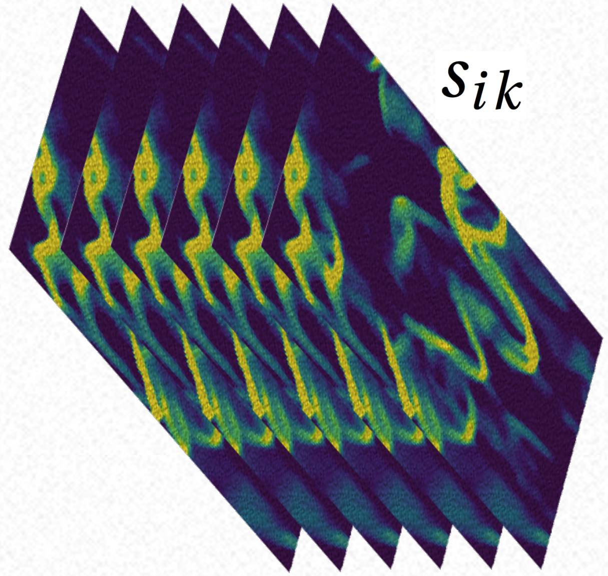
VERSATILE ADVECTION CODE

Clump dimensions : 3D reconstruction

Stacking of a 2D time stripe...



... in both transverse directions

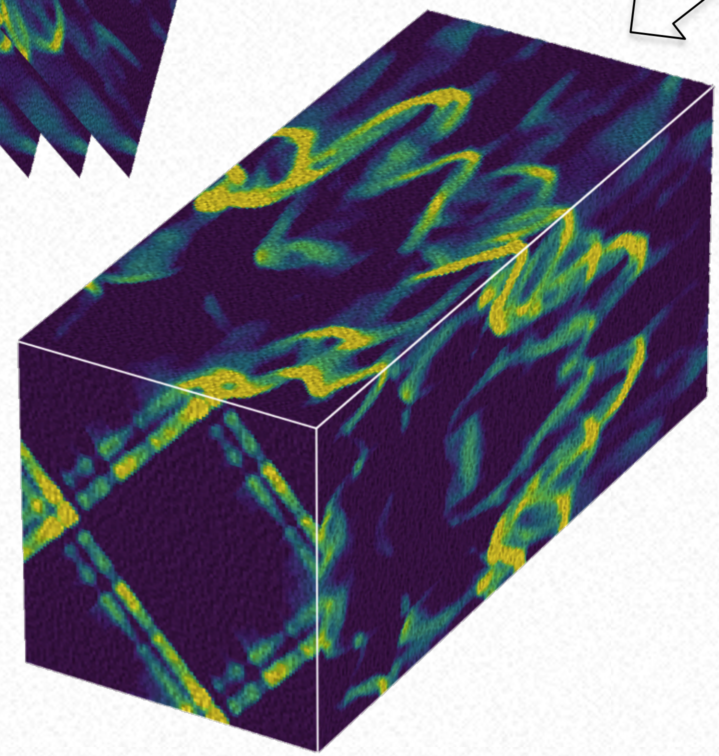


Combined with
arithmetic or geometric average

$$S_{ijk} = \overline{s_{ij} \cdot s_{ik}}$$

+ histogram correction

45 degrees
rotation



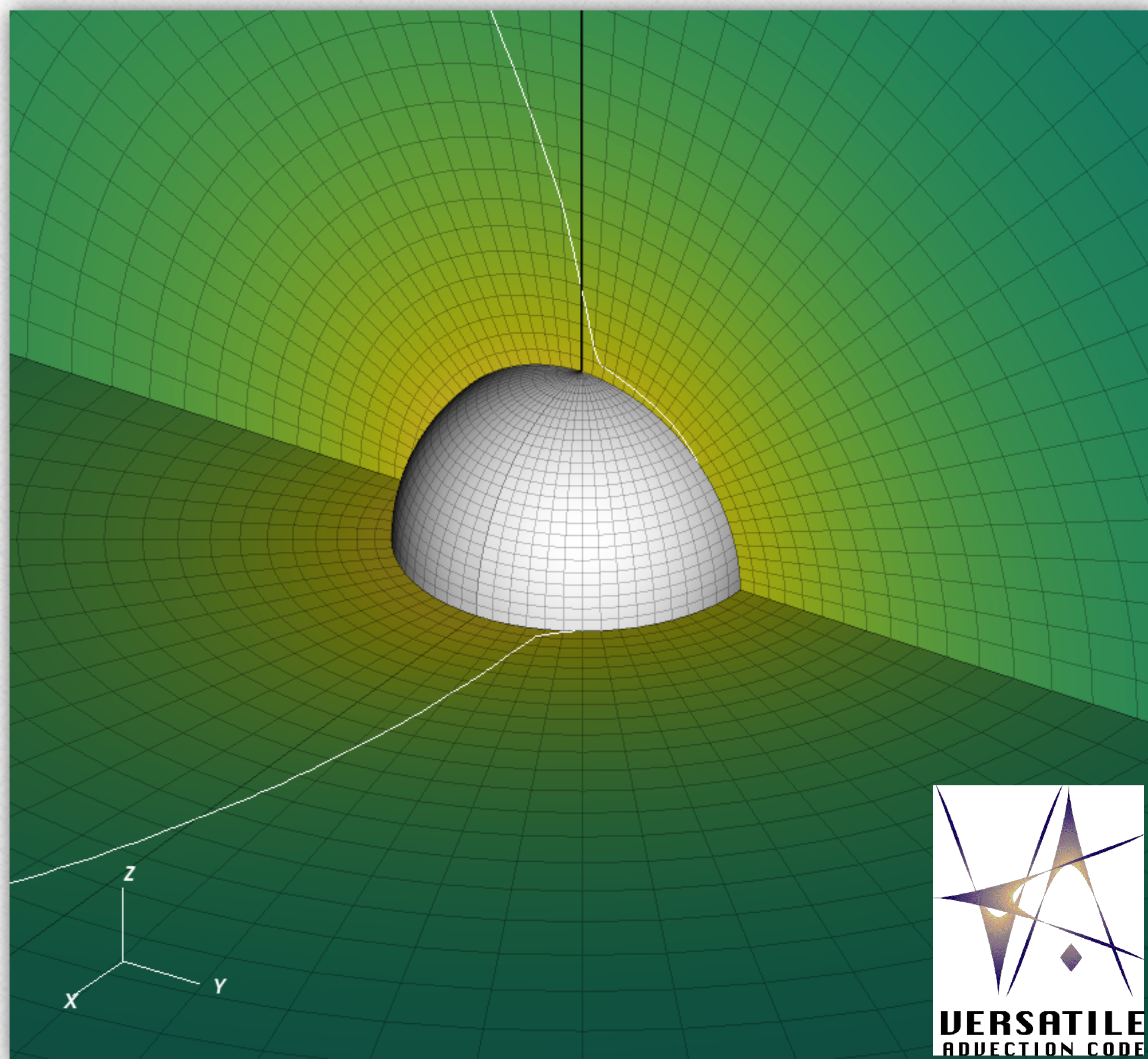
Same stochastic properties

+/- z symmetry

Original signal retrieved on central slice

Spherical clumps

Numerical setup : stretched spherical mesh



XIA + 18

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

Radially stretched grid

Resolution
64 x 48 x 64

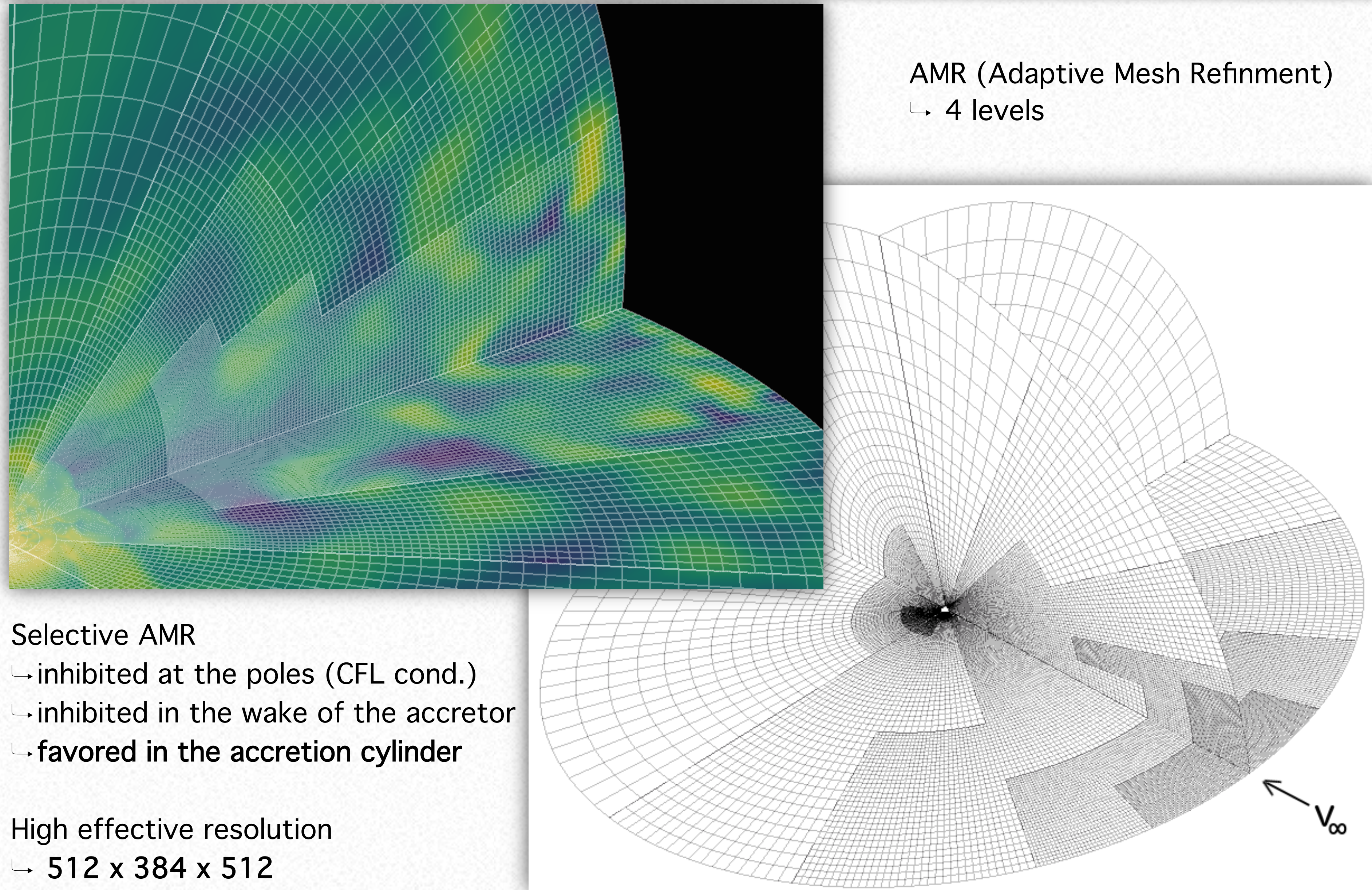
Axisymmetric flow

...

How to resolve small-scale off-centered features?

⟶ AMR

Numerical setup : selective AMR

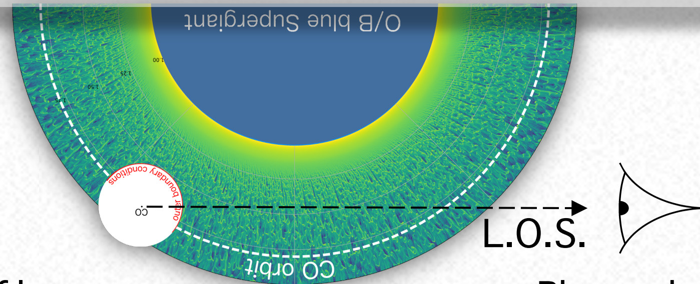


AMR (Adaptive Mesh Refinment)
↳ 4 levels

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

High effective resolution
↳ 512 x 384 x 512

Column density : model

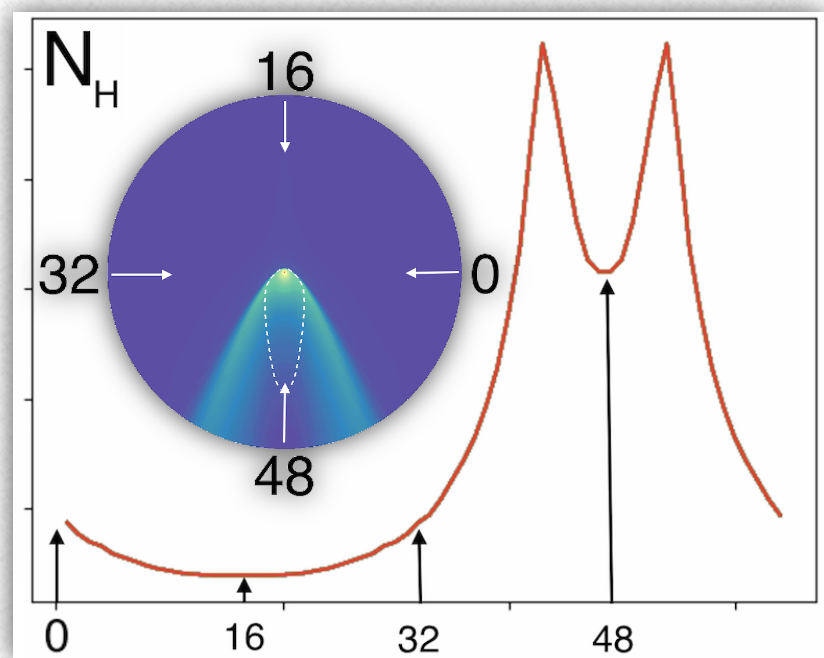


Local column density

Time varying column density profile

Dependence on inclination angle

N_H in every 3D direction at each time step

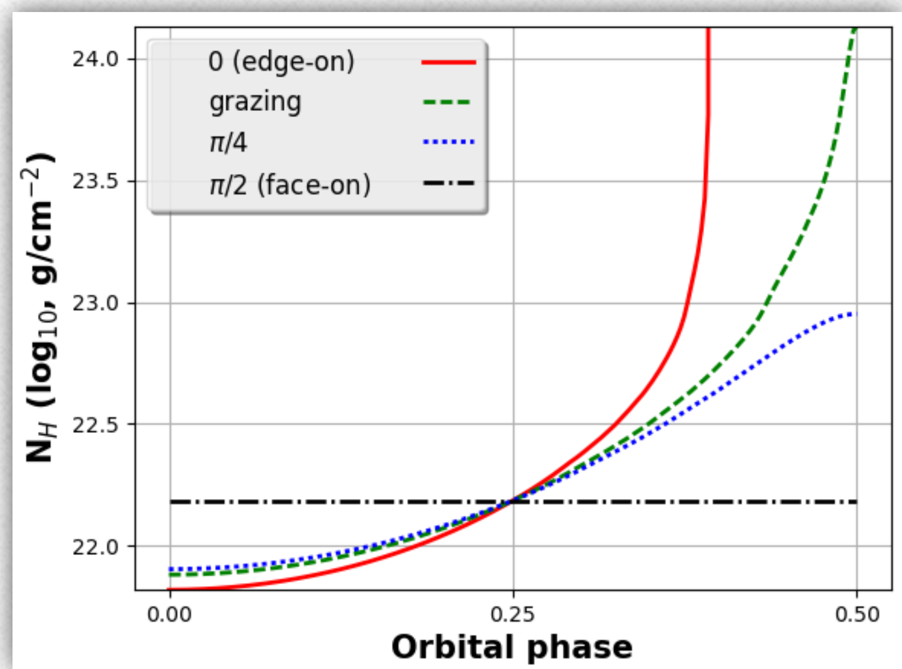


Orbital column density

Phase dependent column density profile

Dependence on **inclination angle**

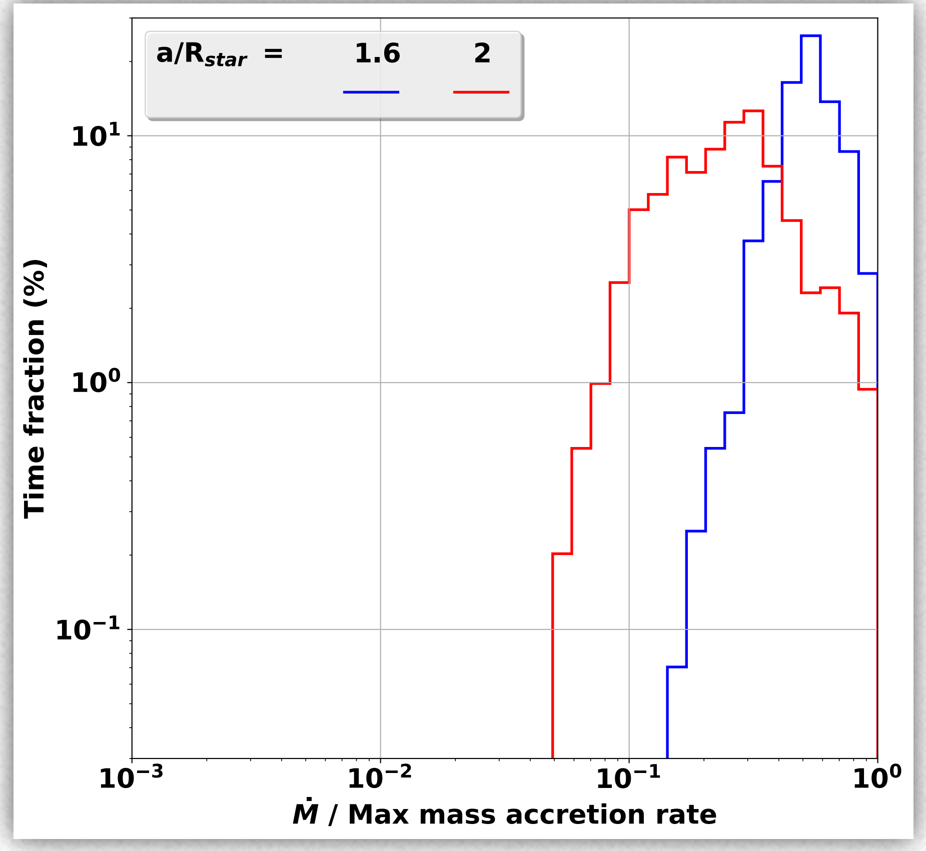
Isotropic or clumpy wind

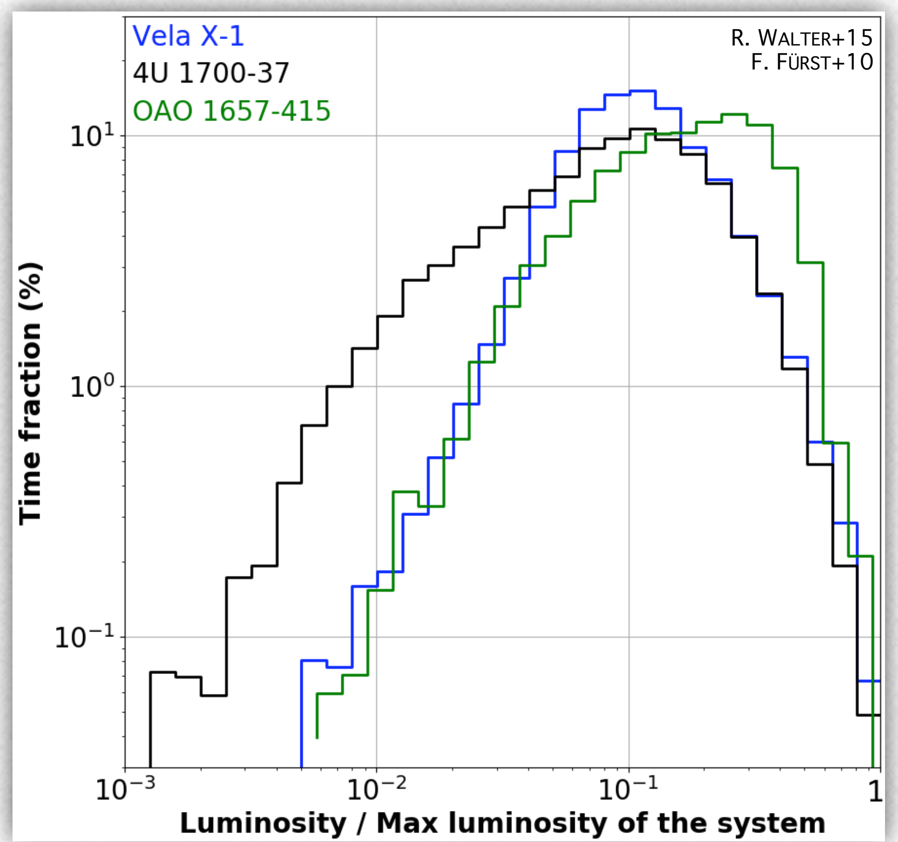


Mass accretion rate : activity diagram

Luminosity diagram : histogram of activity levels
↳ X-ray luminosity observed
↳ numerical mass accretion rate

Role of orbital separation

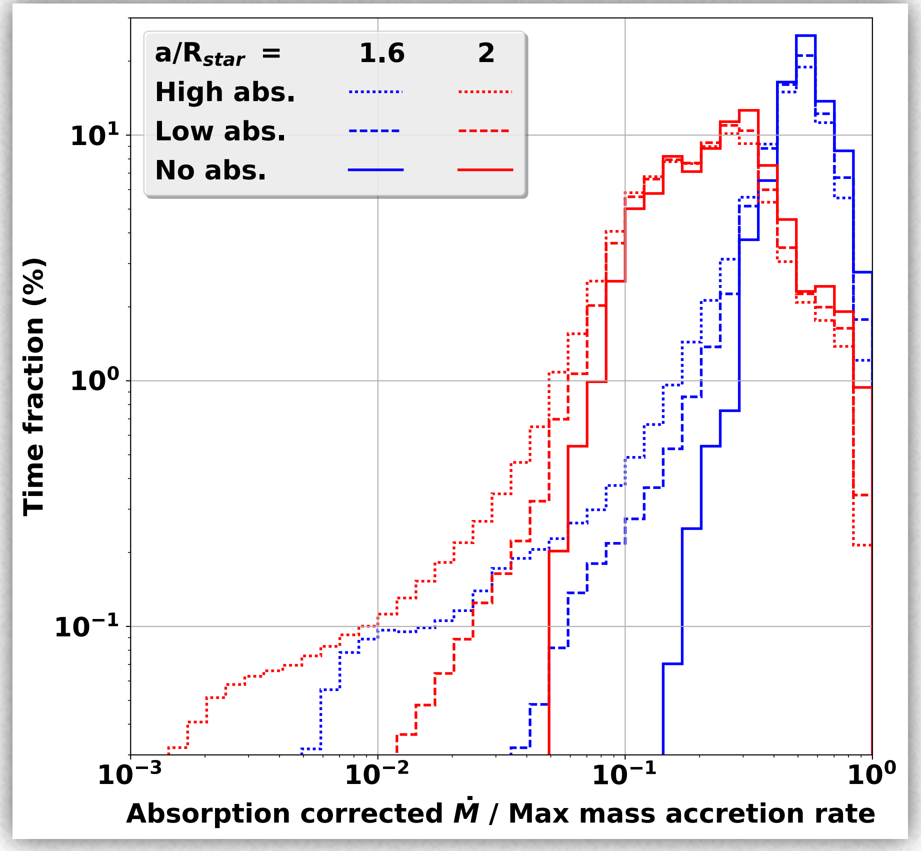


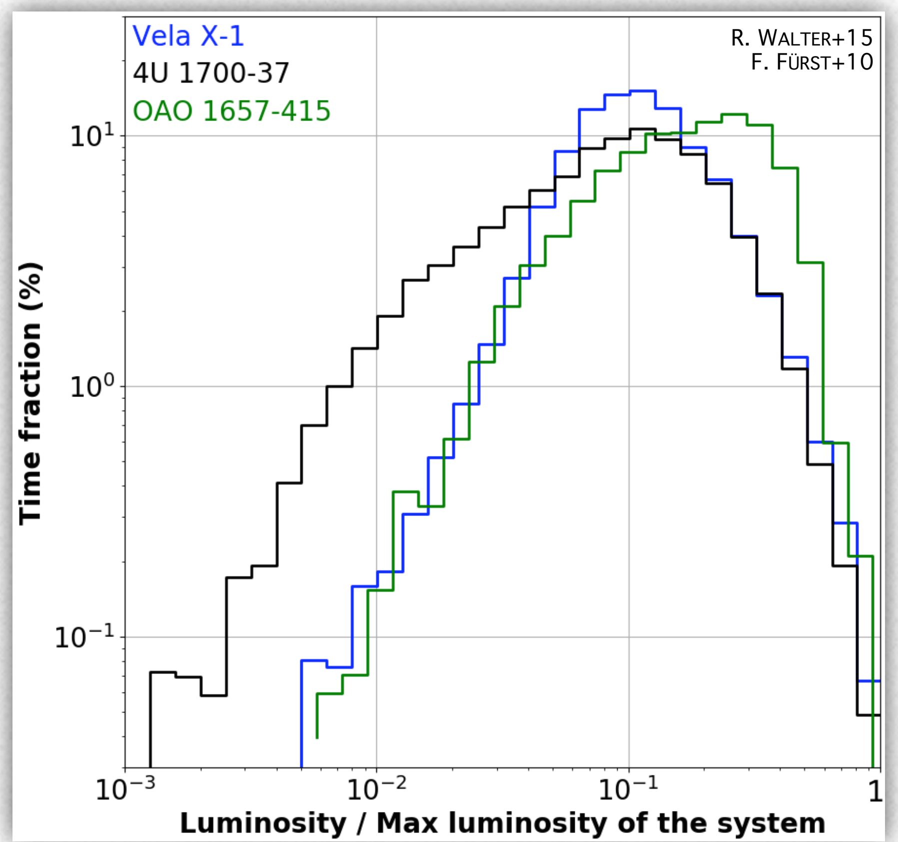


Activity levels
↳ high levels cut off
↳ main activity ~ 10%
↳ max/min ~ 10 to 20

Column density : absorption corrected activity diagram

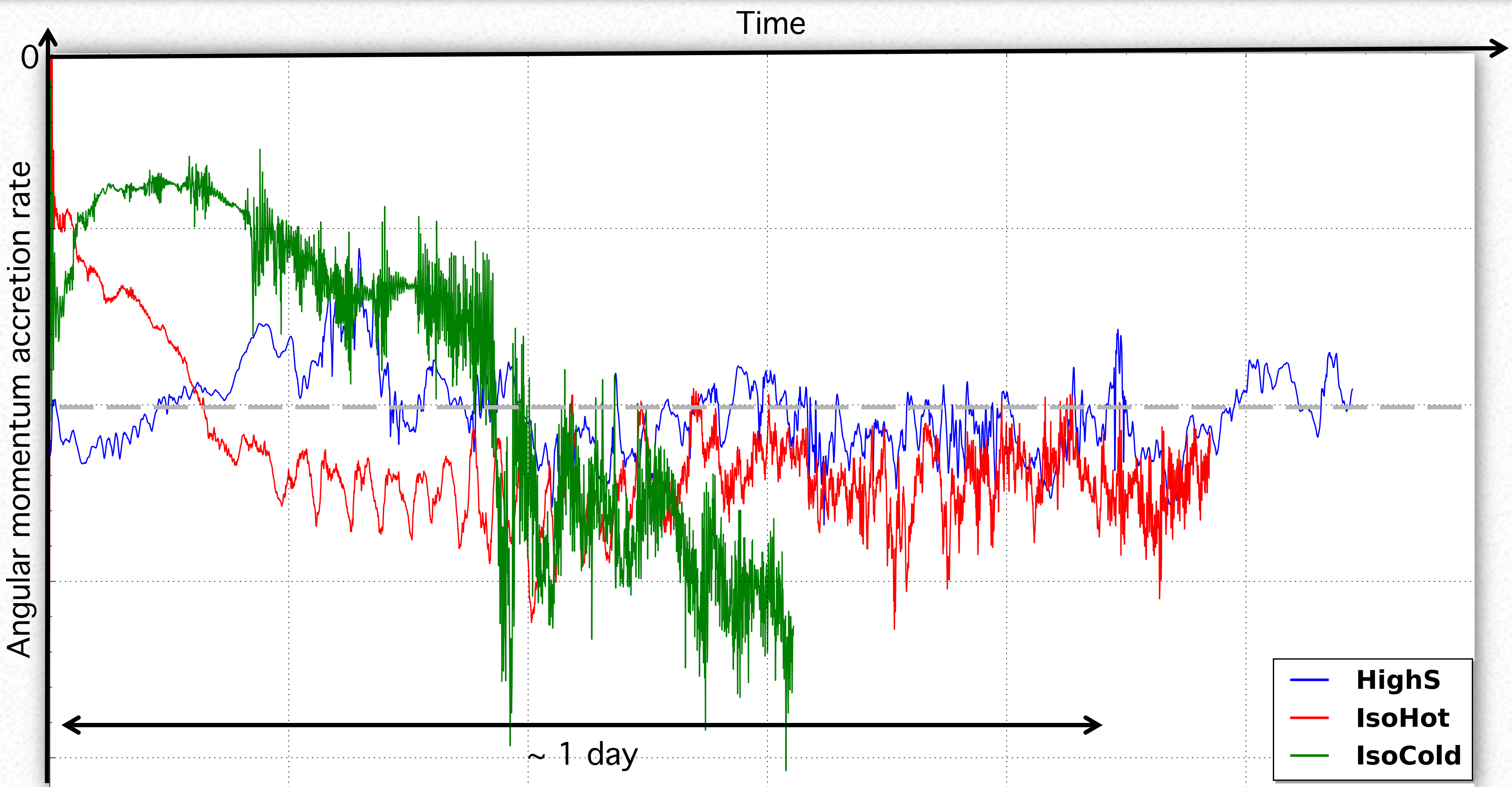
Absorption => enrichment of low-level activity





High luminosity flares unexplained by clumps alone

Angular momentum accretion rate



NS spin period in Vela X-1 ~ 283s

=> characteristic spin-up time as low as ~ **10 kyrs**

N.B. : high mass accretion rate