A- MAZE: An introduction on the possibilities and limitations

Contents

- What A- MAZE comprises
- What A- MAZE can do
- What is not (yet) implemented

What A-MAZE comprises

Codes for ideal hydrodynamics and MHD in 1D- 3D
with source terms

Codes for NLTE radiative transfer under nebular
conditions in 1D- 3D

A code for NLTE radiative transfer in 3D

Visulization software for these codes

Various scripts for data management

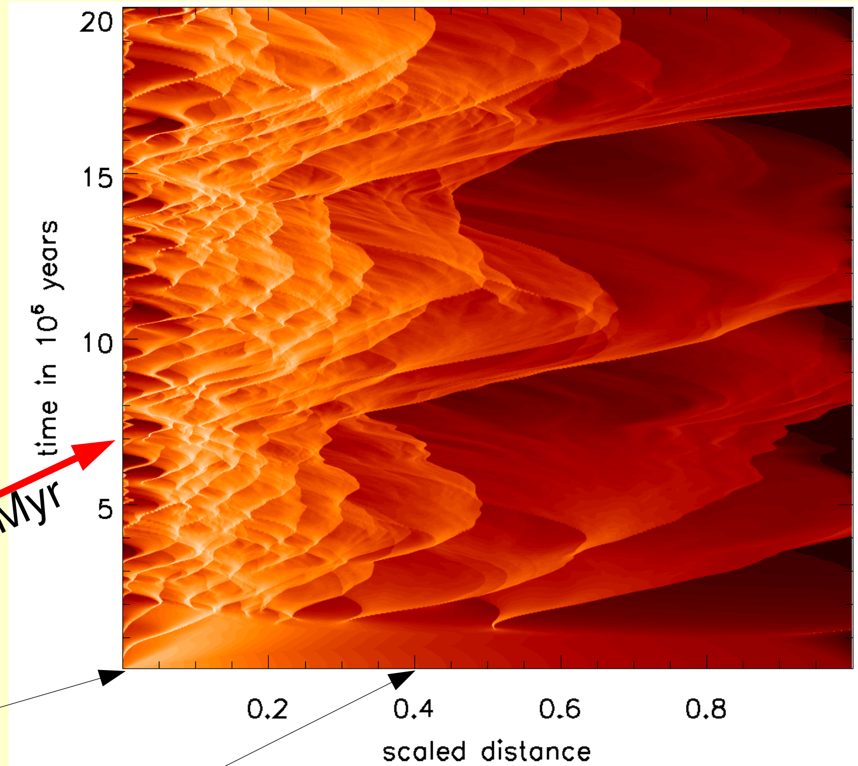
What A- MAZE can do

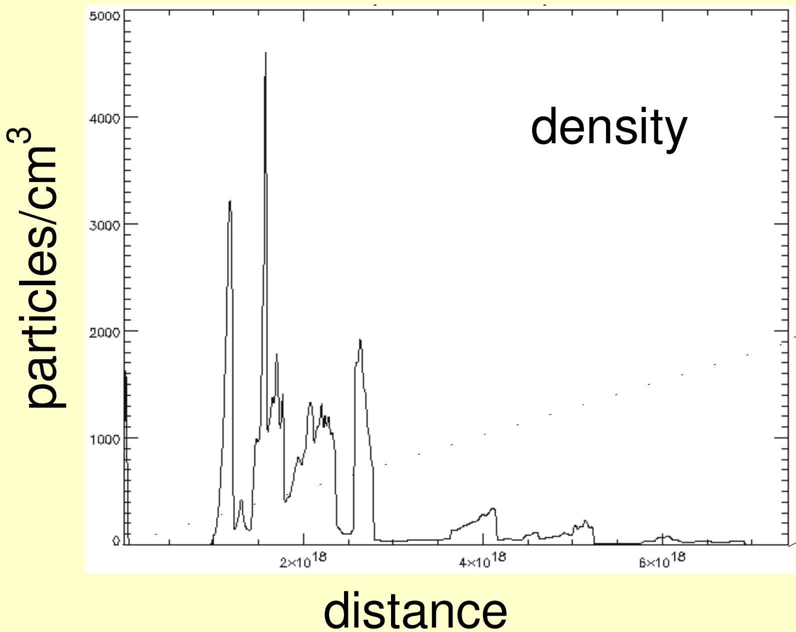
1D MHD: self-gravitating slab + Alfvén- wave

Use:
ideal isothermal MHD equations with a source term for self- gravity, 3^{rd} order stabilized Lax- Friedrich type solver

Study:
structuring and support of environment of pre- stellar cores by Alfvén- waves

time- series of 1D plots
color- coded, white = high density





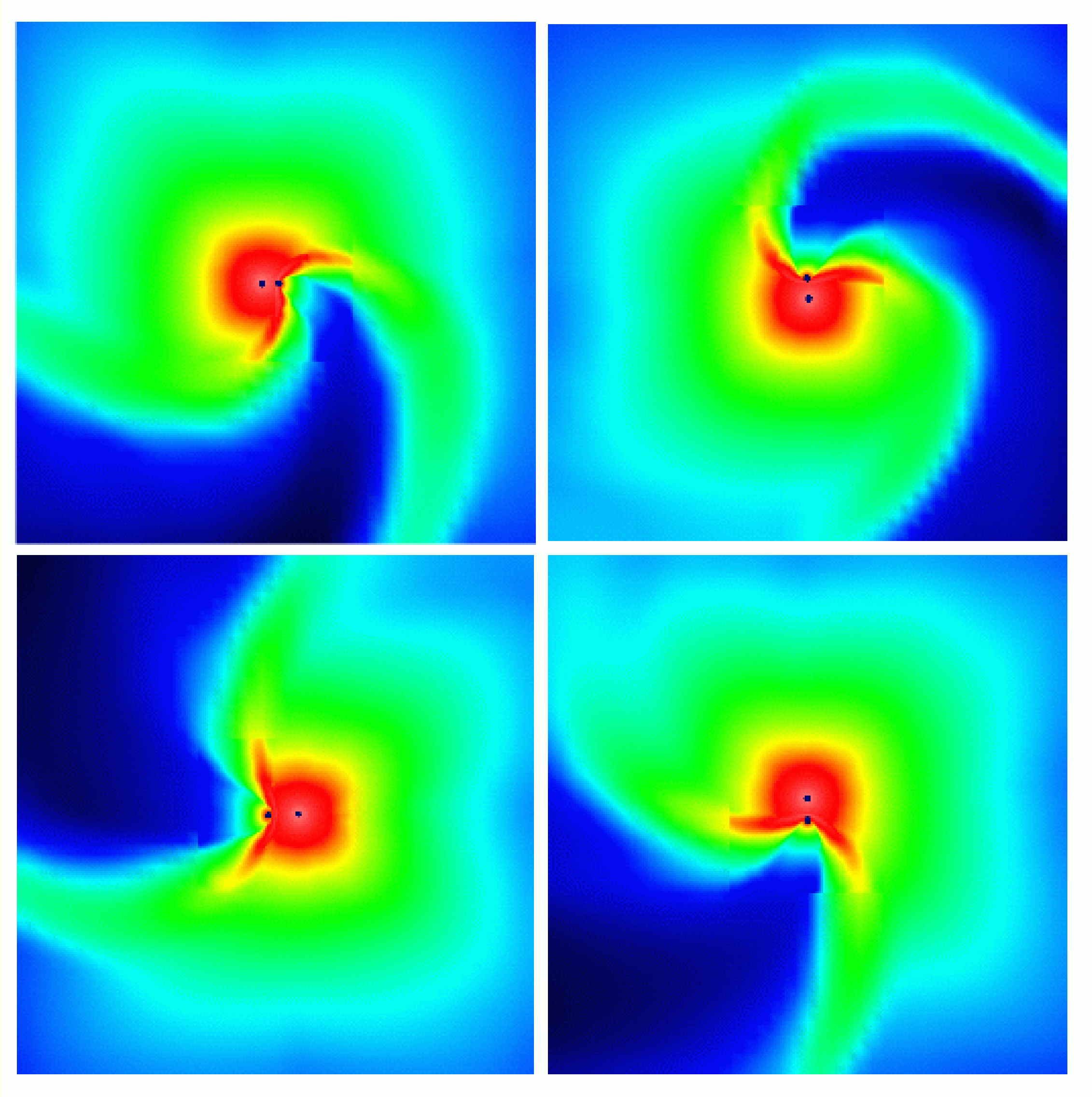
with Jean Heyvaerts,
Observatoire de Strasbourg

3D hydrodynamics: WR+O binary γ Velorum

Use:
ideal Euler equations with an adiabatic equation of state, no radiative cooling, stars orbiting around each other on eccentric orbits

Study:
3D density distribution as a function of phase, X-ray light curve as a funciton of phase and position of observer

logarithmic density in orbital plane, red = high

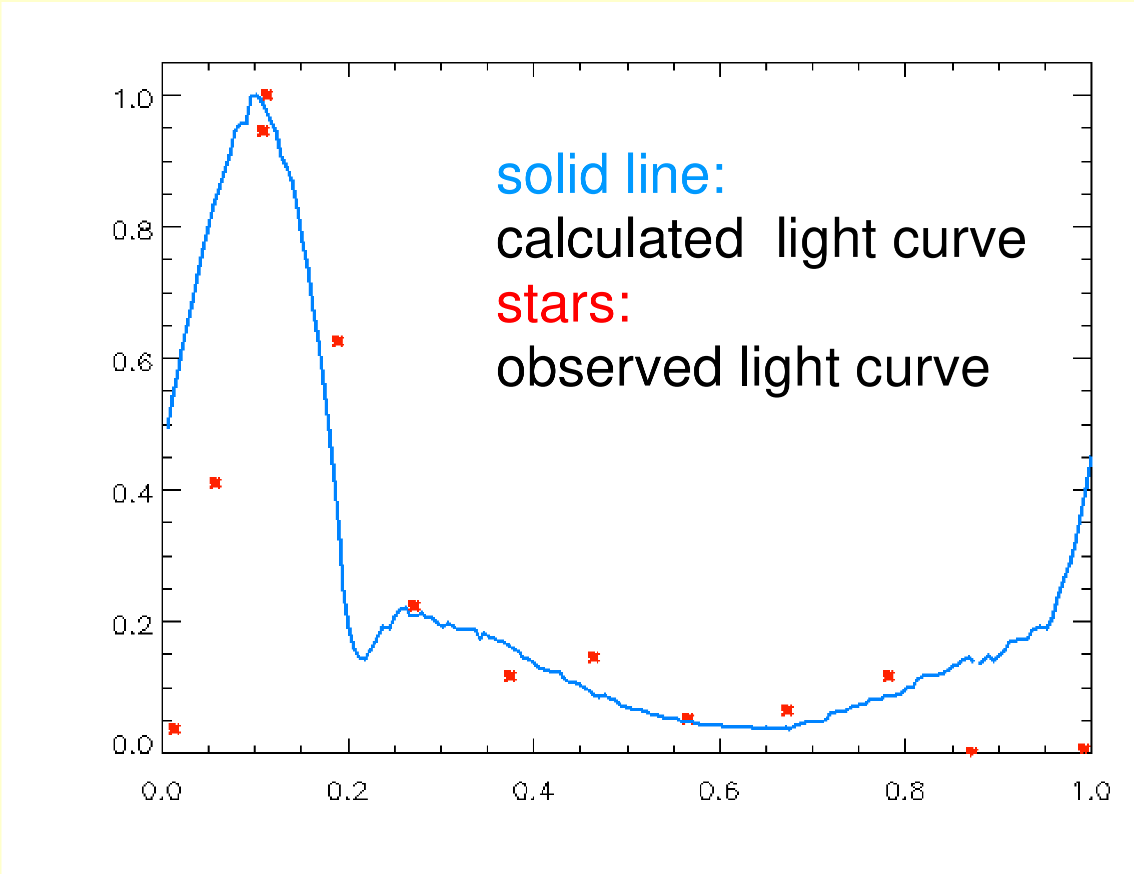


3D hydrodynamics: WR+O binary γ Velorum

From 3D hydro model, calculate X-ray light curve:

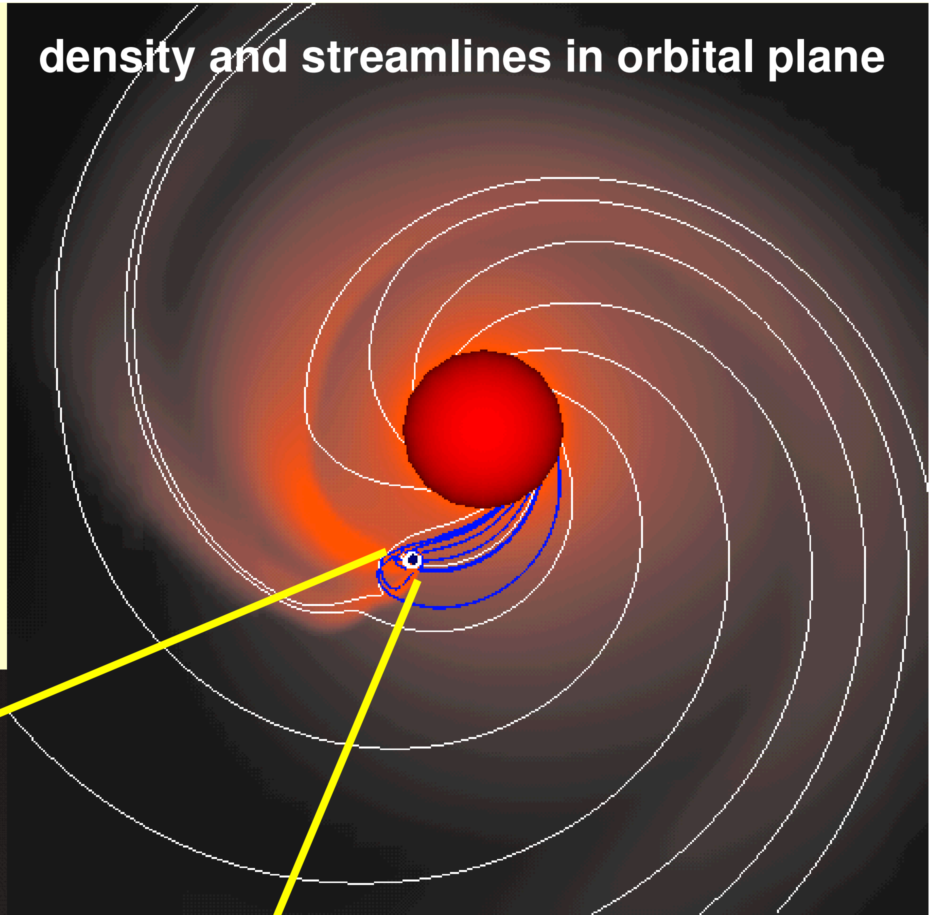
- Assume X- ray sources in central region of the wind- wind collision zone (sources not further specified)

- Assume attenuation of emitted X-rays as
  flux = exp(- κ*col.dens.)
  where = $5*10^{-23}$ cm^{-2}

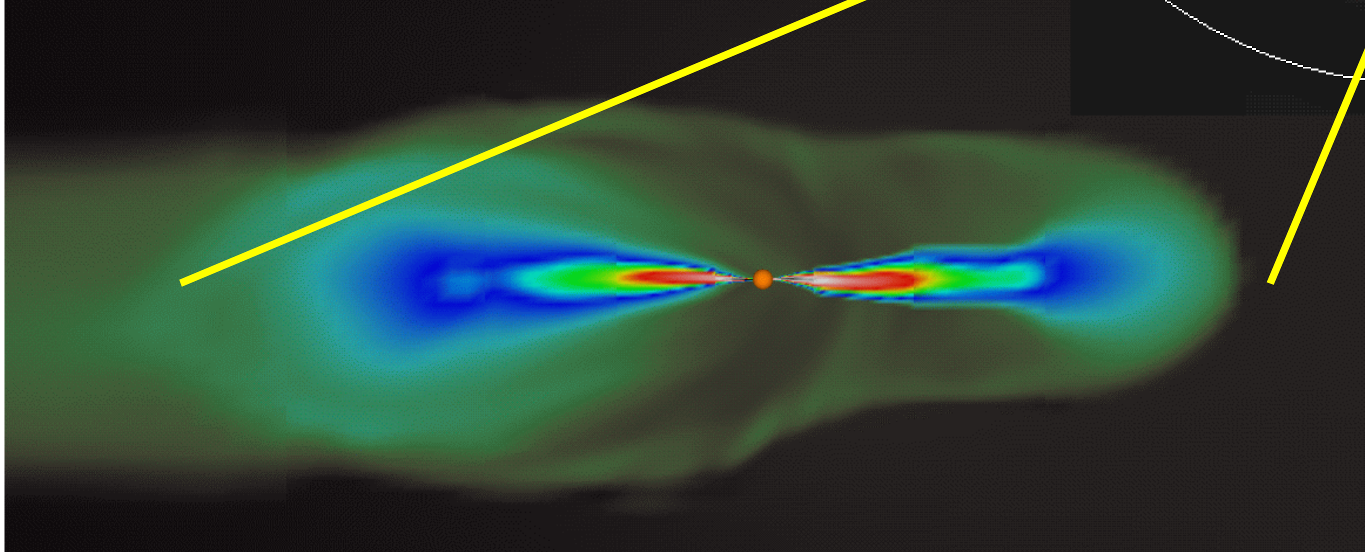


3D hydrodynamics: accreation wake in RW Hya?

Use:
Euler equations with an adiabatic equation of state, radiative cooling, stars orbiting around each other on spherical orbits



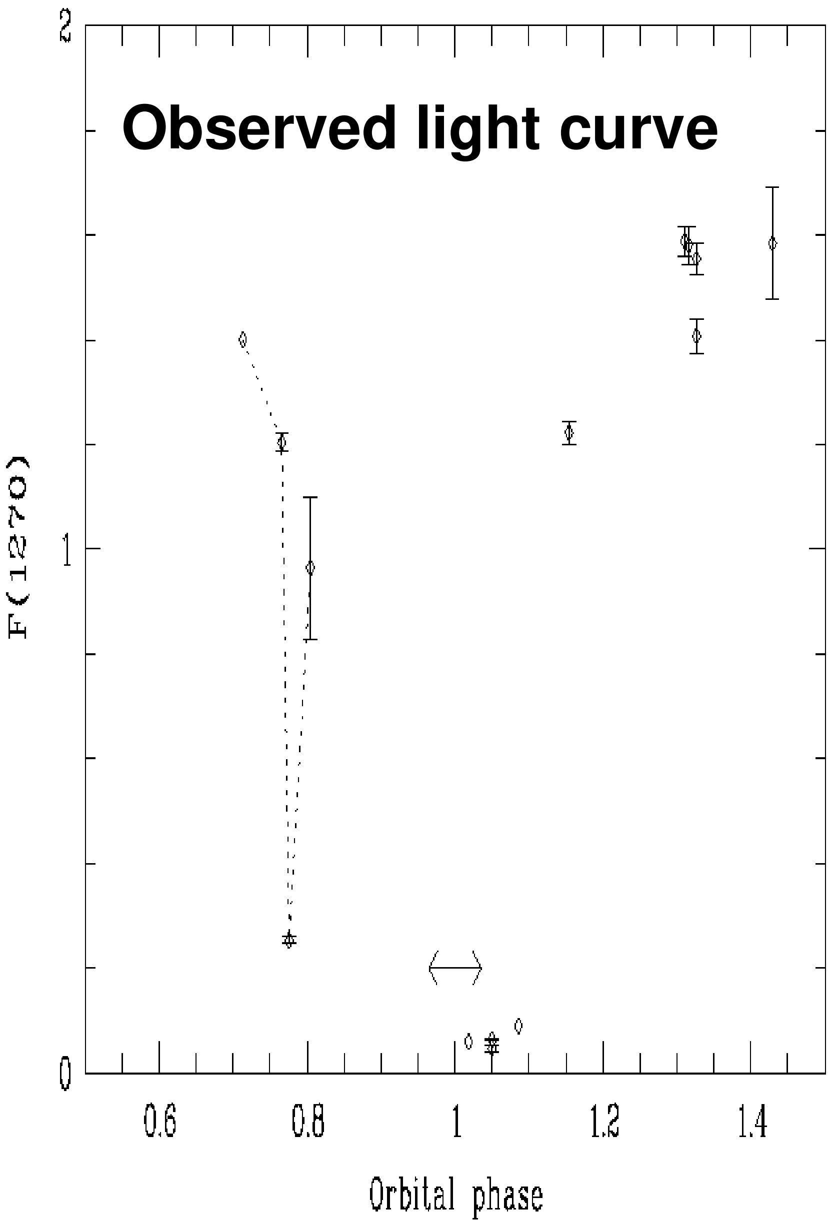
with T. Dumm, H. Nussbaumer,H. Schild, W. Schmutz, ETH Zürich

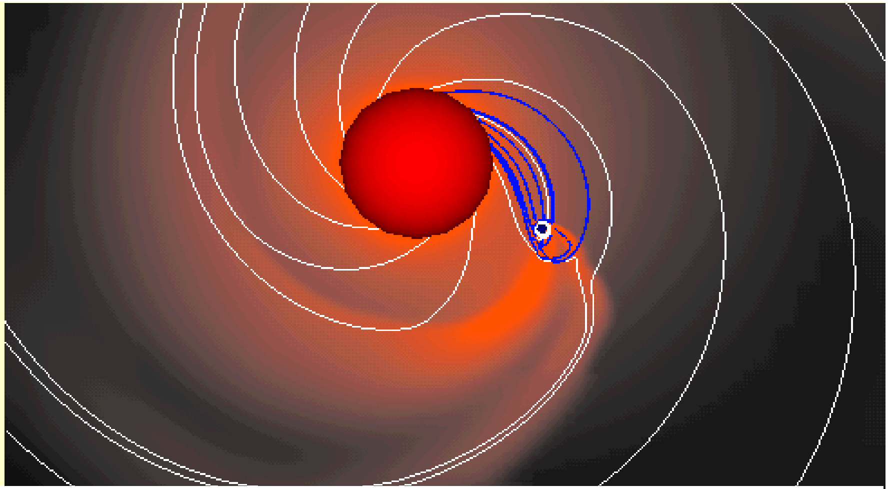


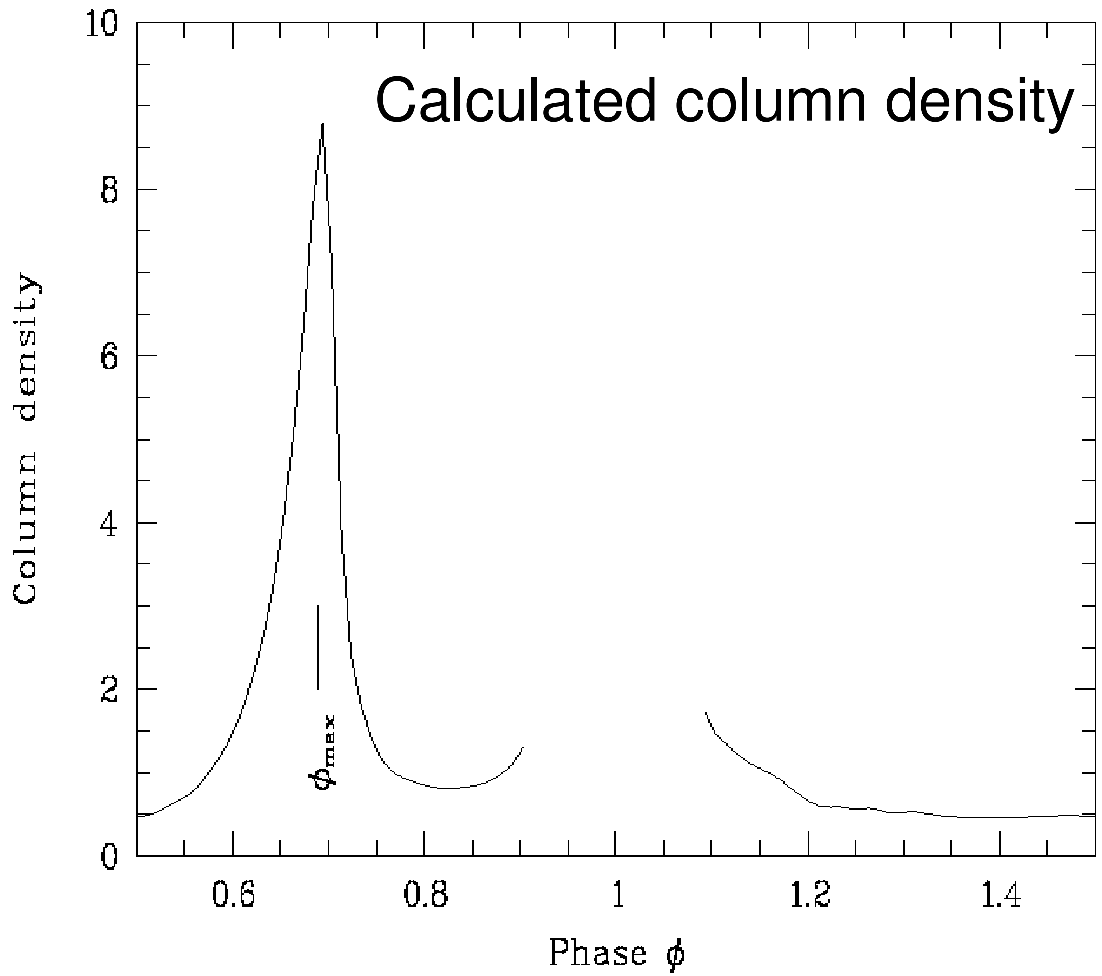
density in perpendicular slice: formation of disk

Study:
Can accreation lead to a narrow wake of high column density, explaining the dip in the observed light cureve at $\phi = 0.78$?

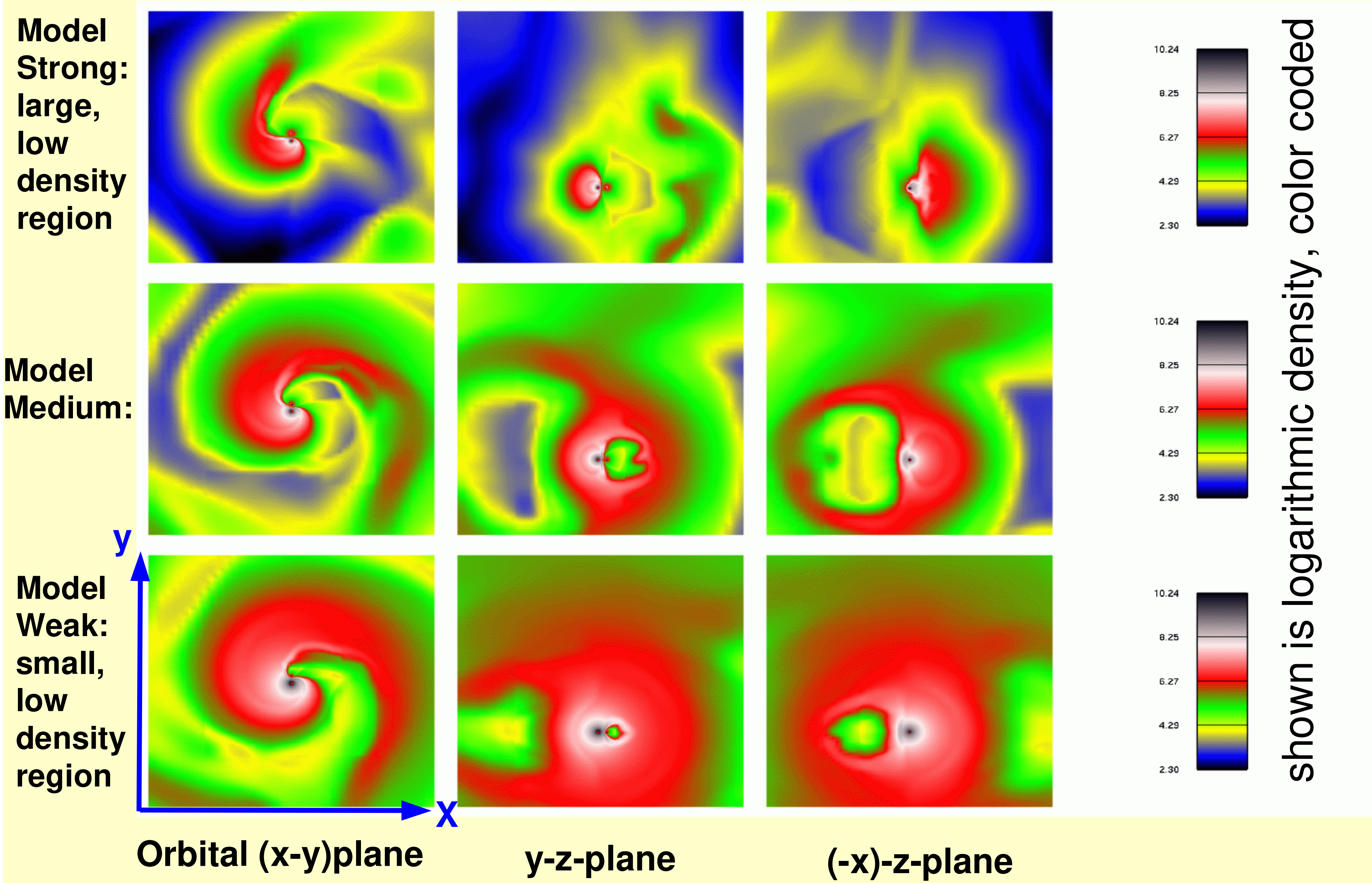
3D hydrodynamics: accreation wake in RW Hya?







3D hydrodynamics and 3D NLTE rad. transf., nebular cond.: Circum- stellar matter distribution of colliding wind models



Taking the right ion, line profiles vary differently over orbit in model weak and strong, mirroring the different 3D density distribution:

- 3D distribution, model weak
- red giant wind only, model weak
- red giant + 3D distribution
- 3D distribution, model strong

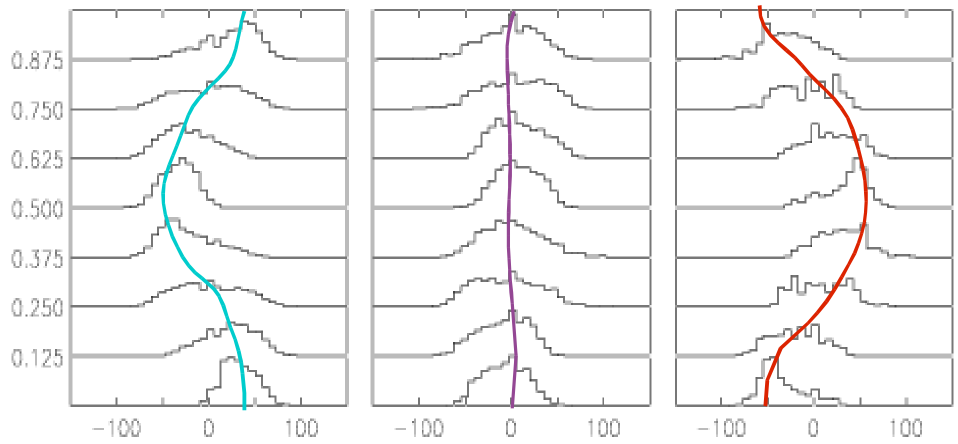


Figure 2. Line profile variation as computed for an observer in the orbital plane for the OIII line at 5008 Å for model *weak* with radiation sources of T = 90000 K and L = 100 $L_\odot$ (left), L = 1000 $L_\odot$ (middle), L = 10000 $L_\odot$ (right) for eight different phases (y-axis) and against relative velocity in km/s (x-axis). While for L = 100 $L_\odot$ the profile variation stems from the re-shaped circumstellar matter it merely reflects the undisturbed red giant wind for L = 10000 $L_\odot$.

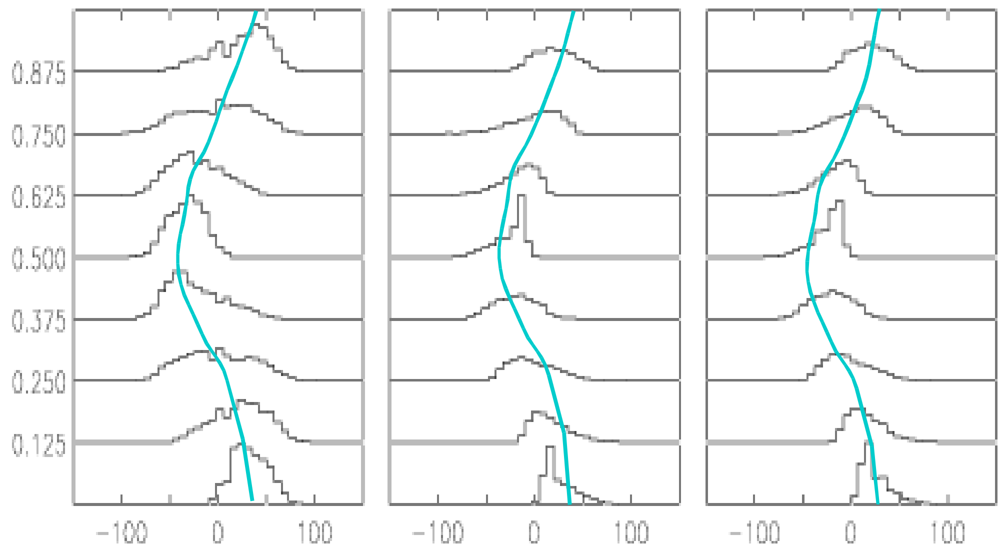


Figure 3. Probing the colliding winds interaction zone. The right ion makes it possible. From left to right: L=100 $L_\odot$, L=1000 $L_\odot$,L=10000 $L_\odot$ for model weak and T = 90000 K. The lines are 5008 OIII, 1242 NV, and 1031 OVI.

weak $\phi_{min} \approx 0.5$

strong $\phi_{min} \approx 0.25$

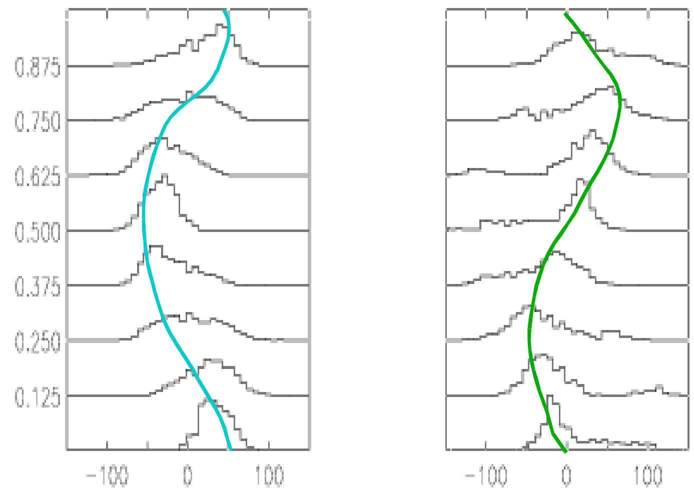
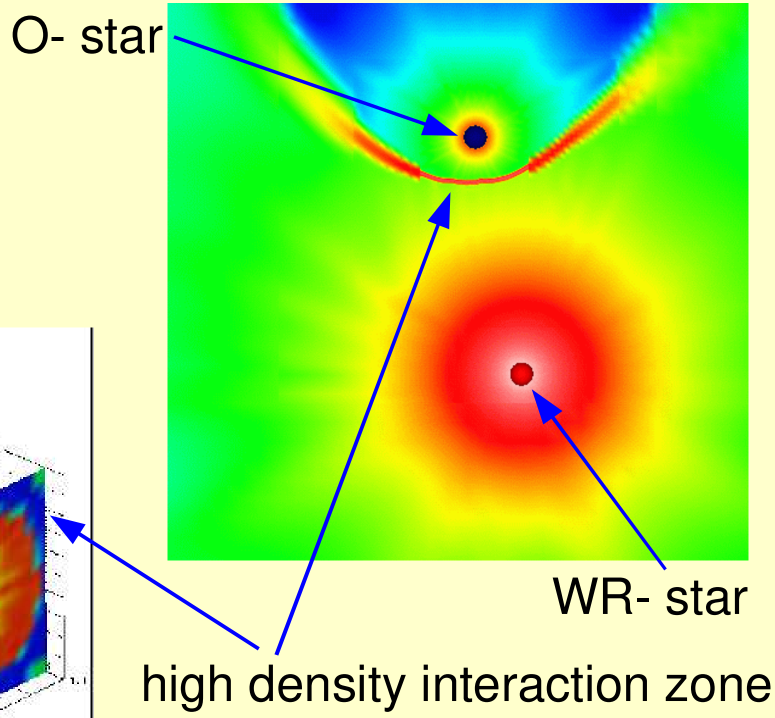
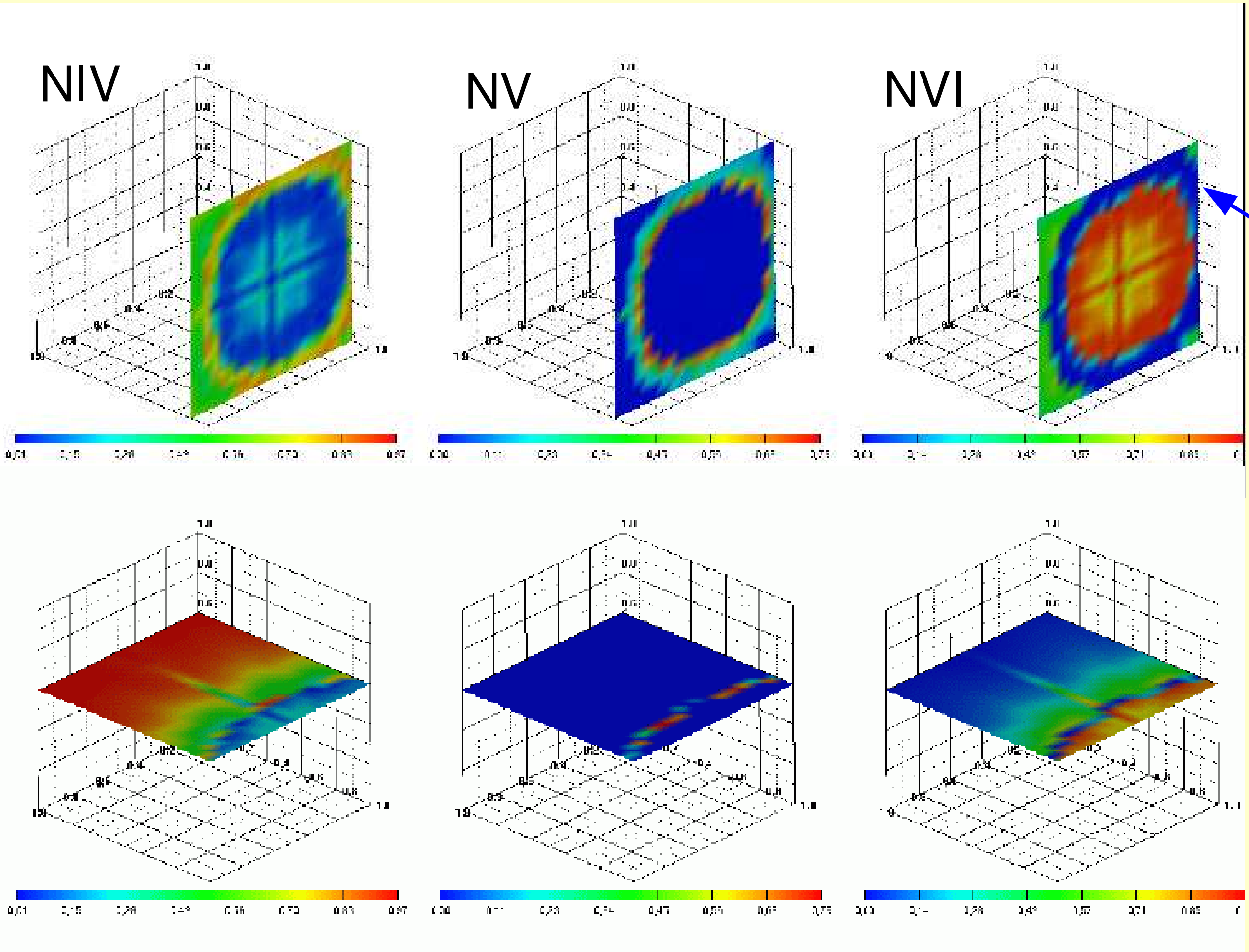


Figure 4. Considering the right ion, the phase at which maximum blue shift of the line profile is reached allows to distinguish between model strong and model weak. Shown is the OIII line at 5008 Å for model *weak* (left) and model *strong* (right) for a radiation source with L = 100 $L_\odot$ and T= 60000 K. The maximum blue shift for model *weak* occurs around phase 0.5, for model *strong* it occurs around phase 0.25.

3D hydrodynamics and 3D optically thick NLTE rad. transf.: ionization state of wind- wind collision zone in γ Velorum

Use:
isothermal Euler equations, stars orbiting around each other on excentric orbits,
3D optically thick NLTE radiative transfer



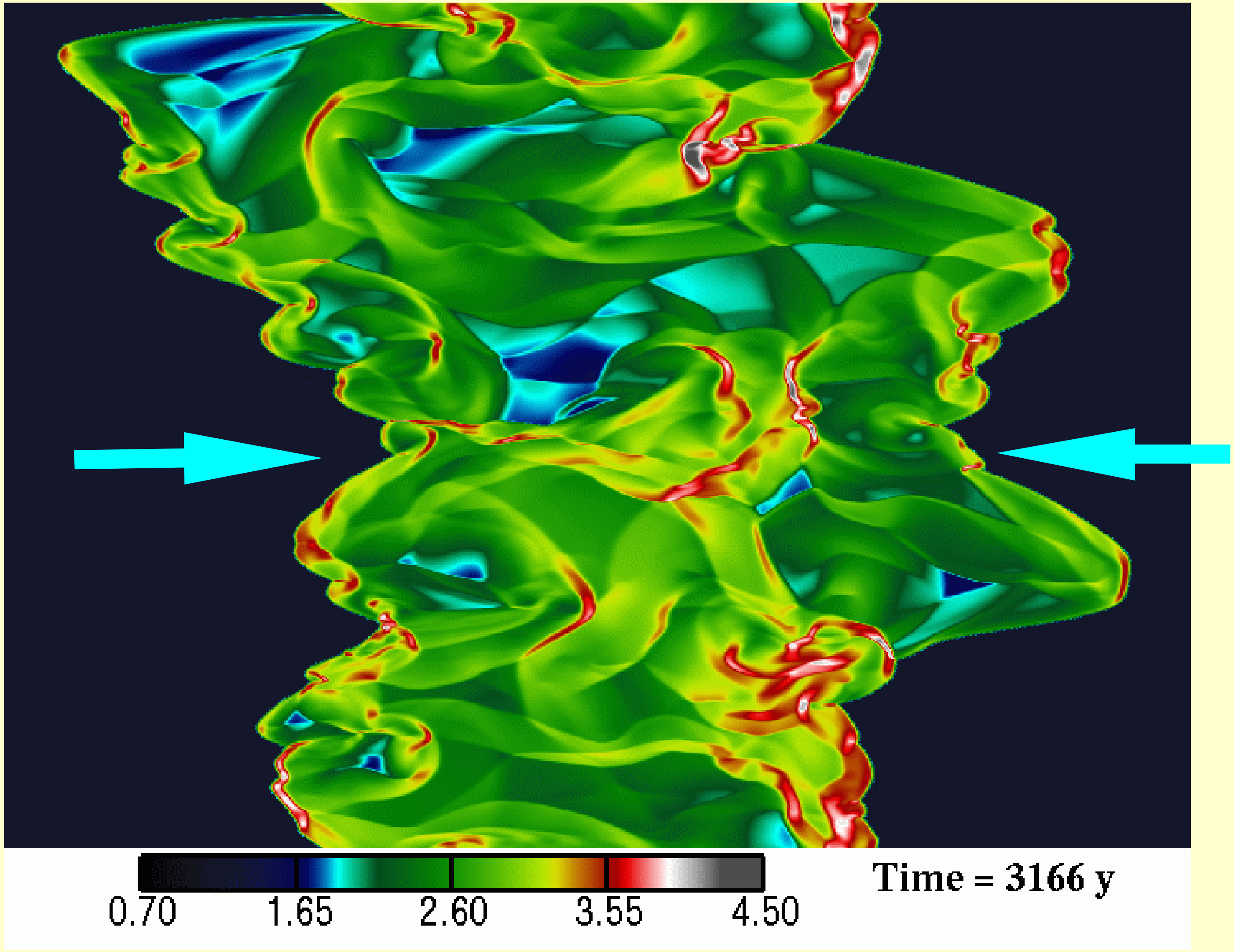


Study:
What is the ionization state of the cold, high density wind- wind collision zone?

2D hydro: supersonic turbulence in shock bound slab

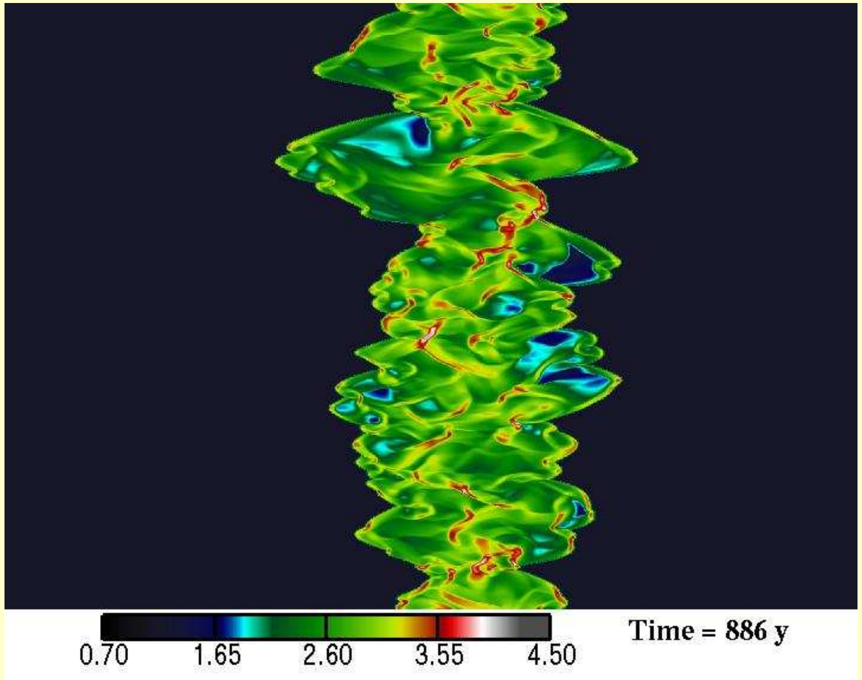
Use:
isothermal Euler equations, two flows colliding head on, both Mach 20

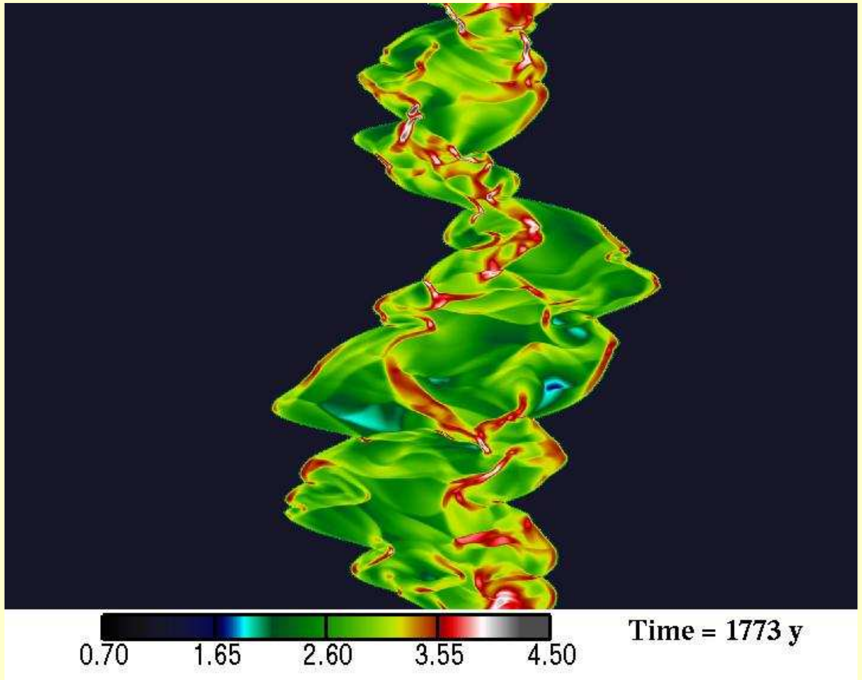
Study:
How turbulent is the interior of the slab?
What determines the structure scale in the slab?



Fully developed turbulent shell: density

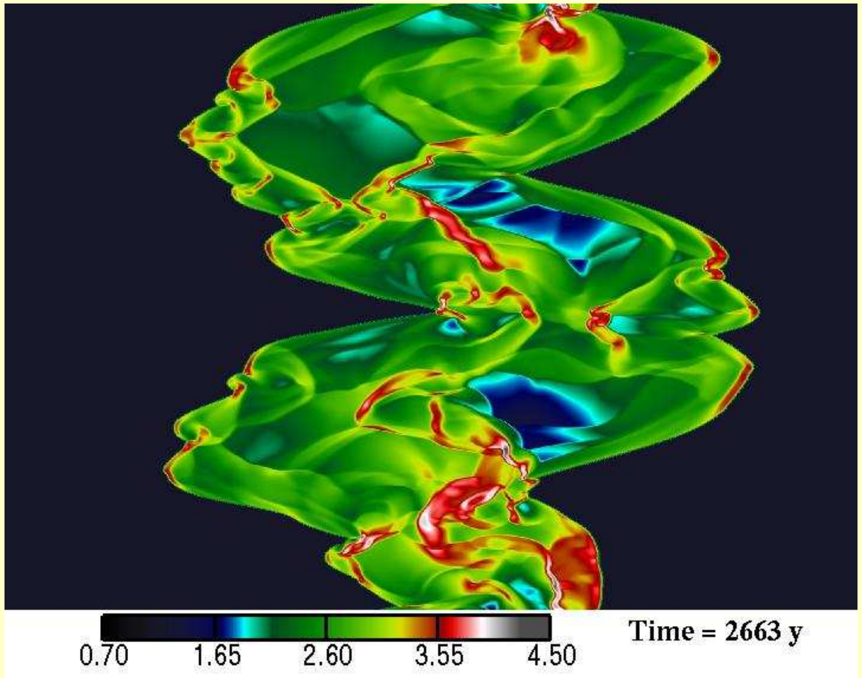
2D hydro: supersonic turbulence in shock bound slab





Density for three different times, time increasing clockwise.

As time increases, the driving wave- length increases. The structure size in the slab seems to be larger.

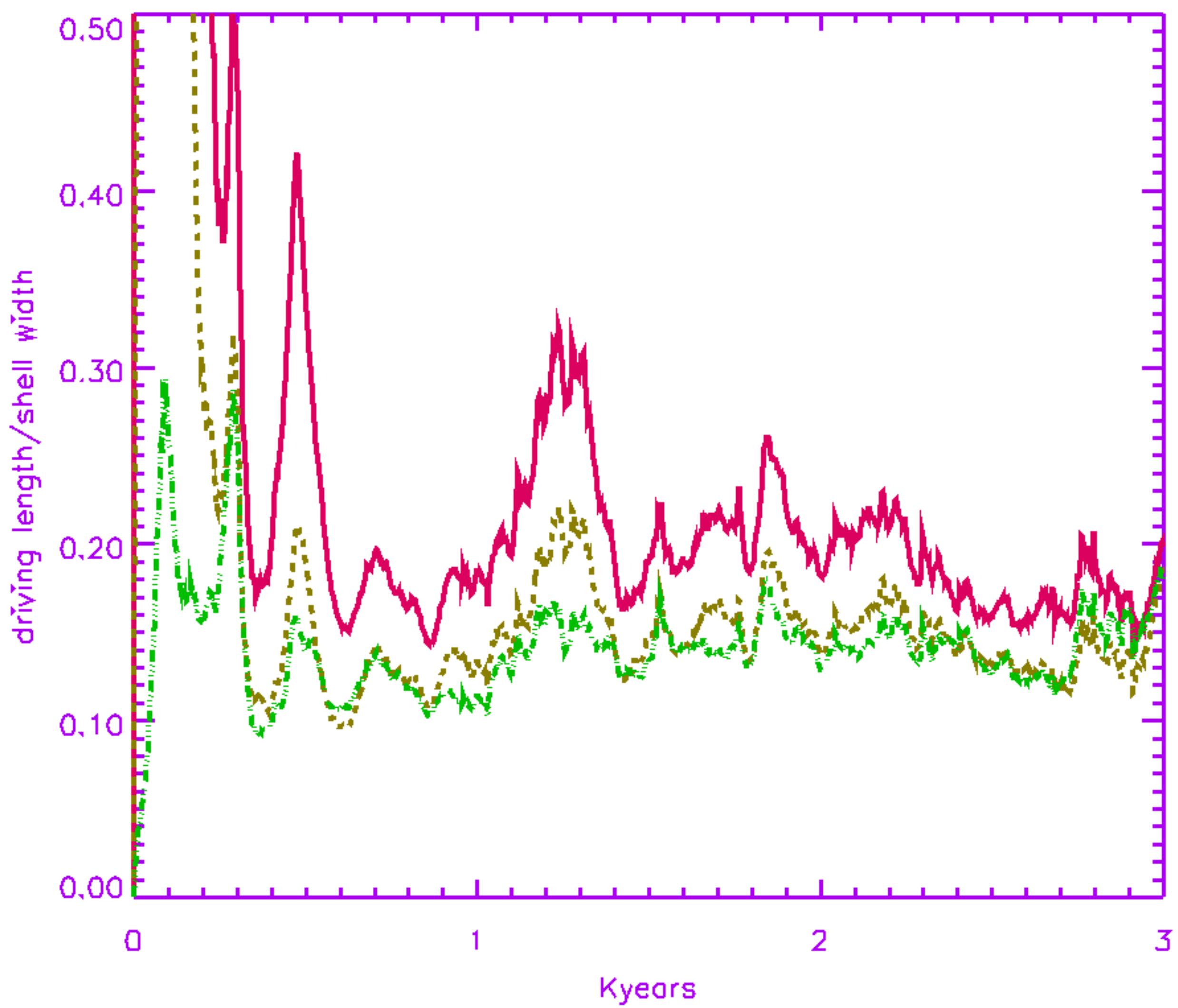


Driving wave-length measured at slab thickness

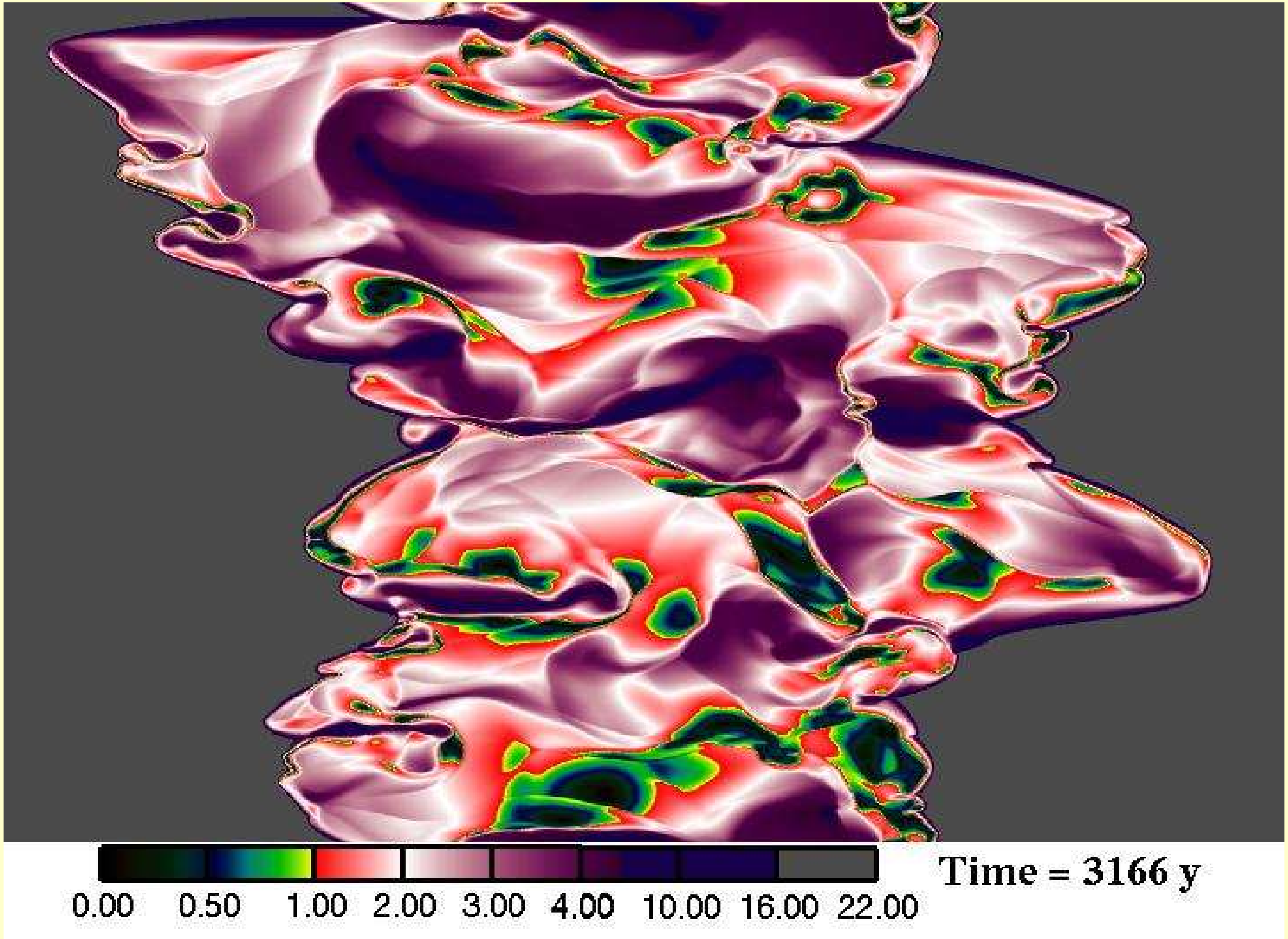
Slab thickness = $(1/ny)\sum_{i=1}^{i=ny} d_{slab}(i)$

In these units,
$\mathcal{L}$ remains constant

Driving wave- length selected by slab thickness?



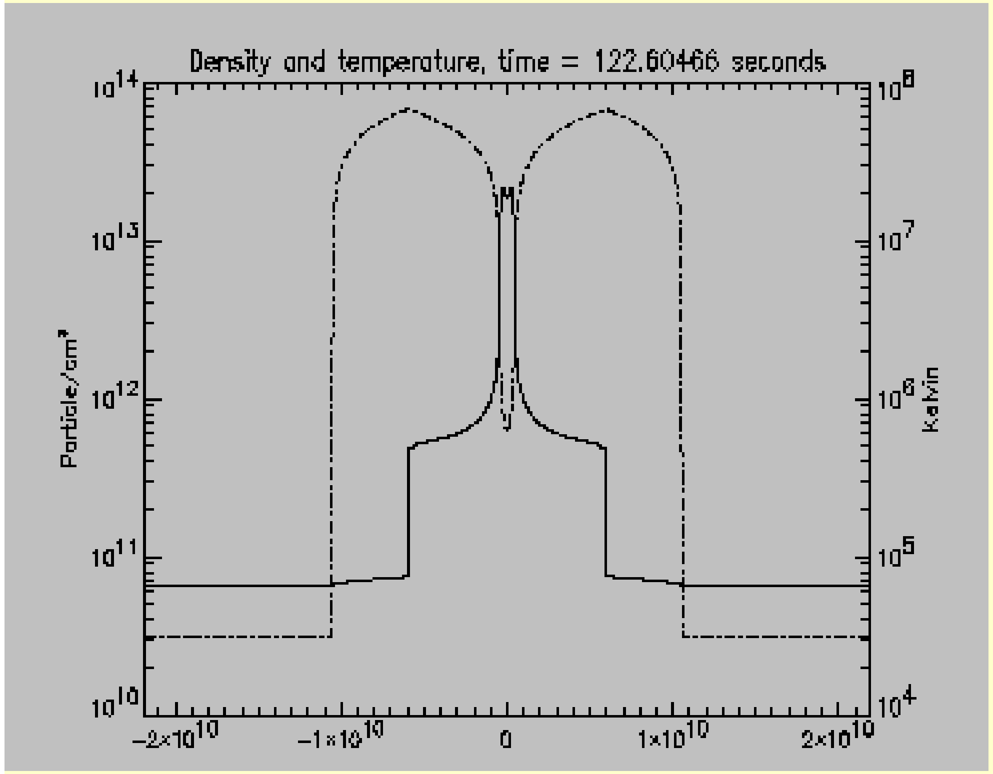
Fully developed turbulent shell: Mach number

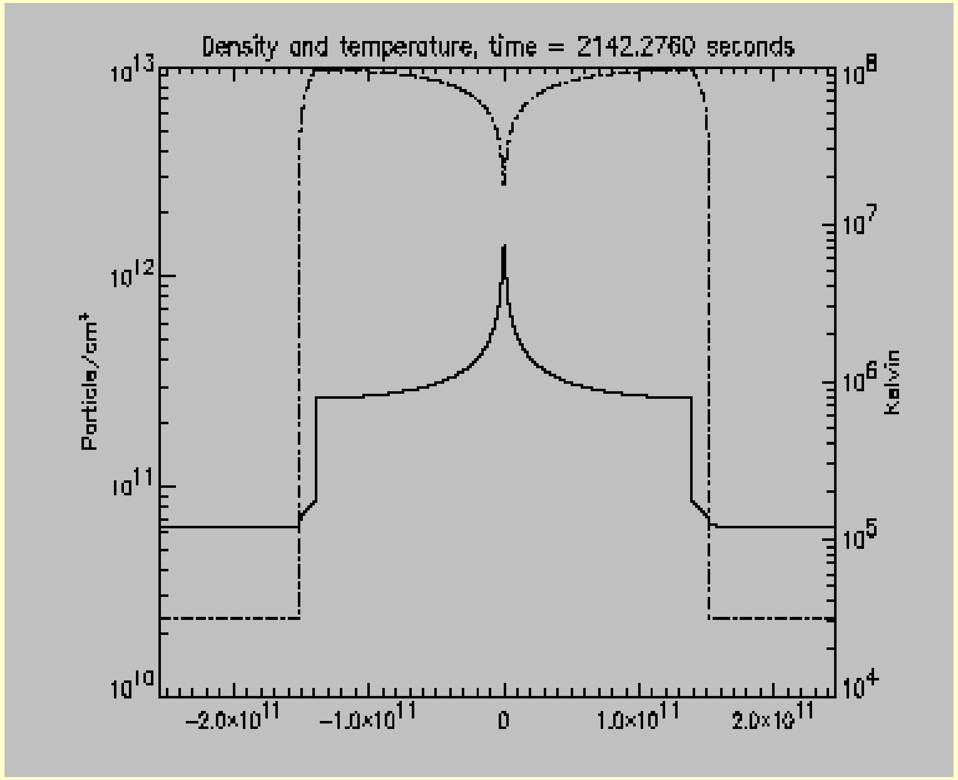


1D hydro with heat conduction

Use: 1D Euler equations with heat conduction, adiabatic equation of state

Study: How does heat conduction affect the temperature- and density- structure of colliding flows; stability



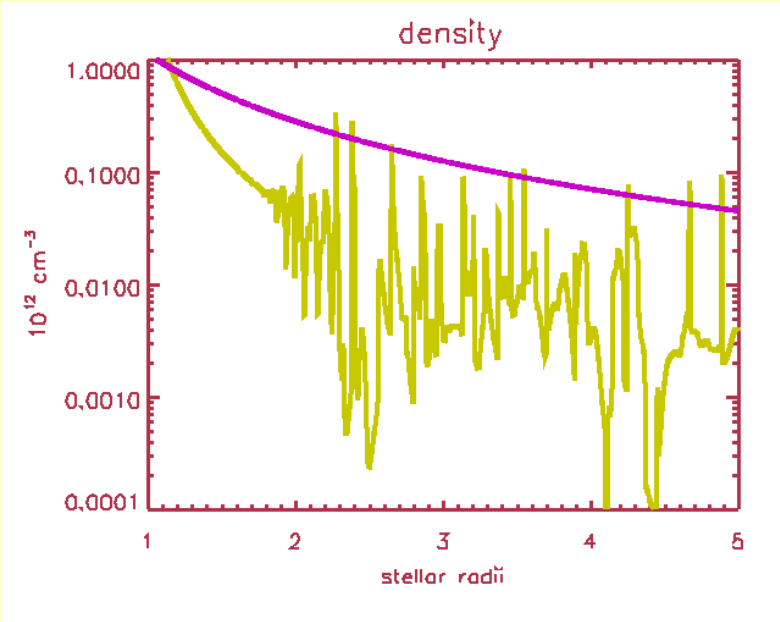


with Simin Motamen, ETH Zürich

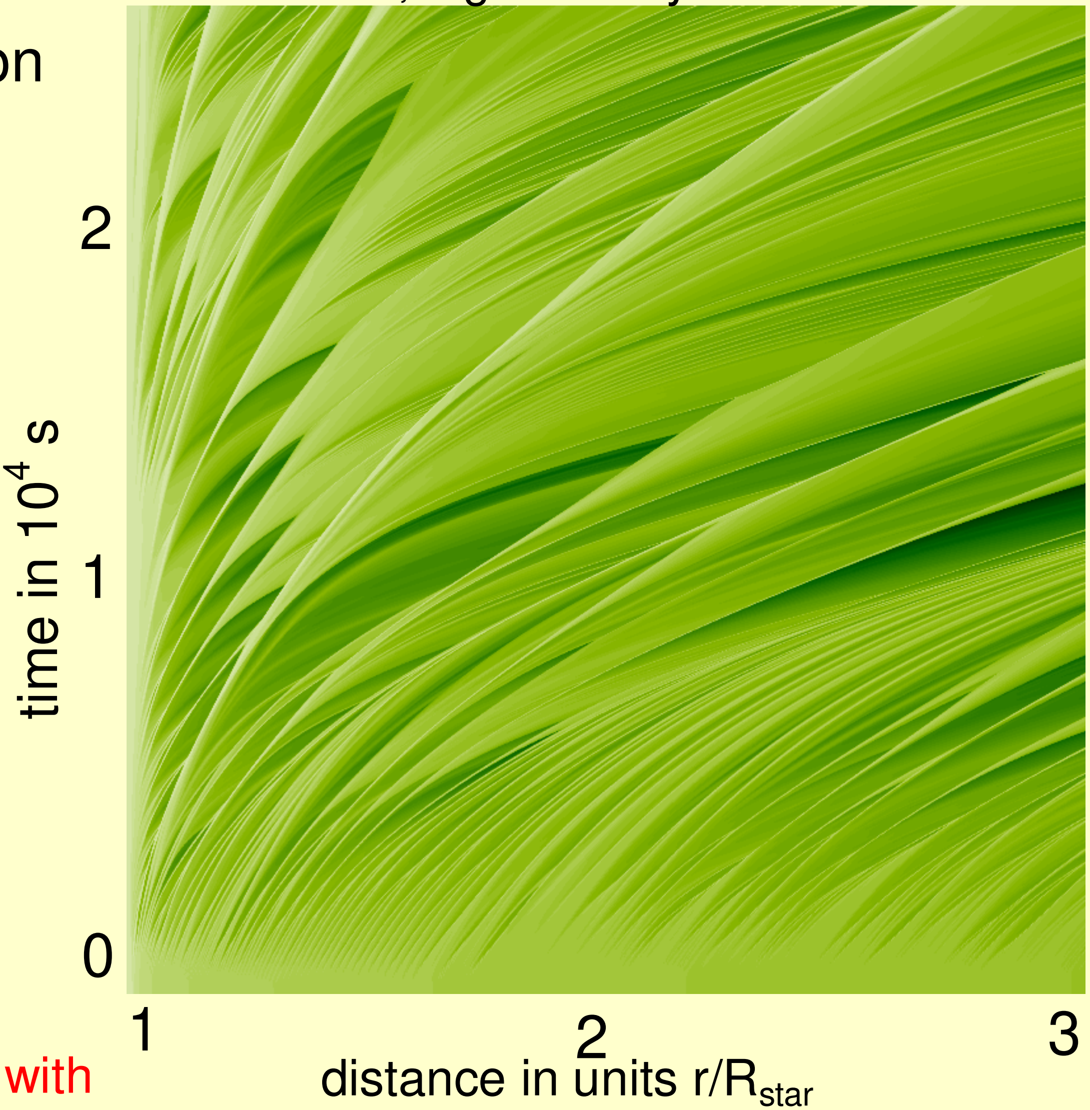
1D hydro + radiative forces: unstable hot star winds

Use:
Euler equations, isothermal eq. of state, source term for radiation force, radiative transfer with parameterized opacities

Study:
time evolution of stellar wind, mass loss, terminal velocity, wind structure



time series of 1D density distribution, color coded, high density = white



with
Franziska Widmer, diploma student, ETH Zürich
courtesy Stan Owocki, university of Delaware

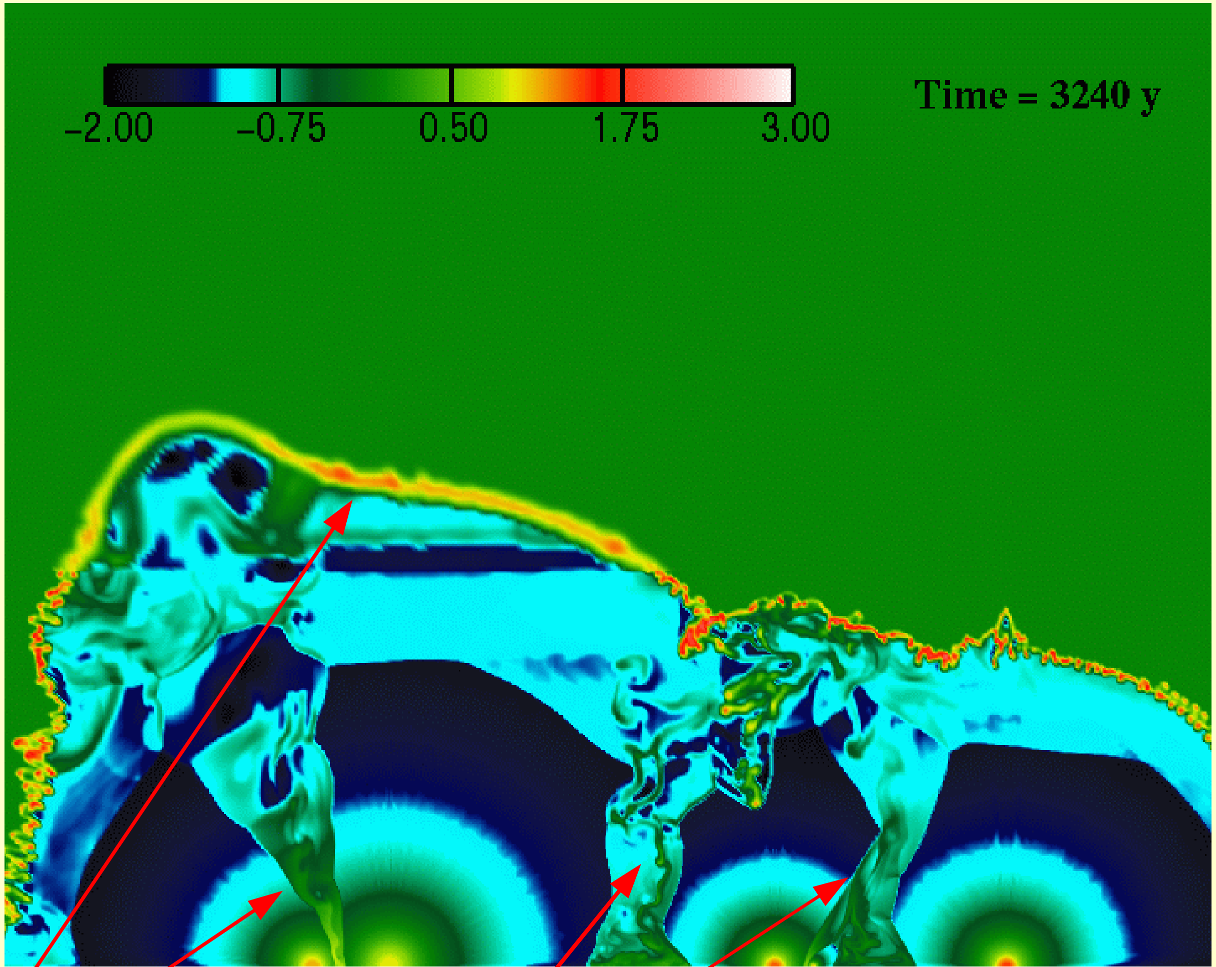
2.5 D hydrodynamics: galactic wind bubbles

Use:
Euler equations, adiabatic equation of state, radiative cooling, 5 hot star winds

Study:
interaction of hot star winds, can they trigger star formation?

with Marielle Stegeman and Henny Lamers, University of Utrecht

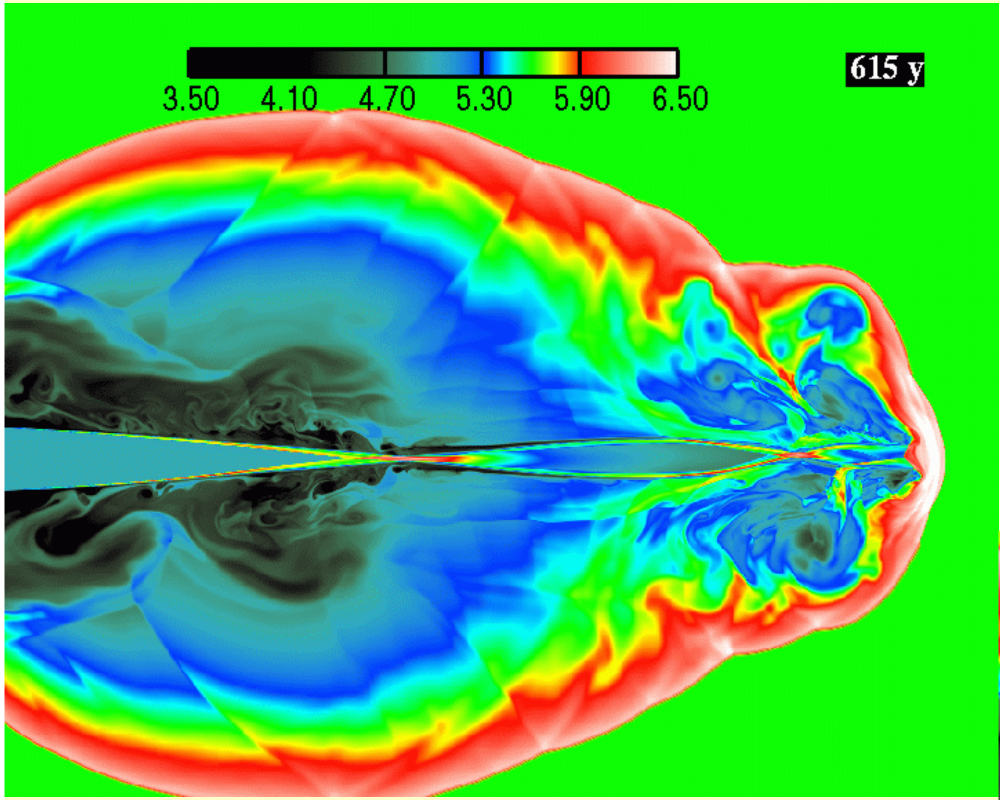
density distribution



the five hot stars

high density interaction zones

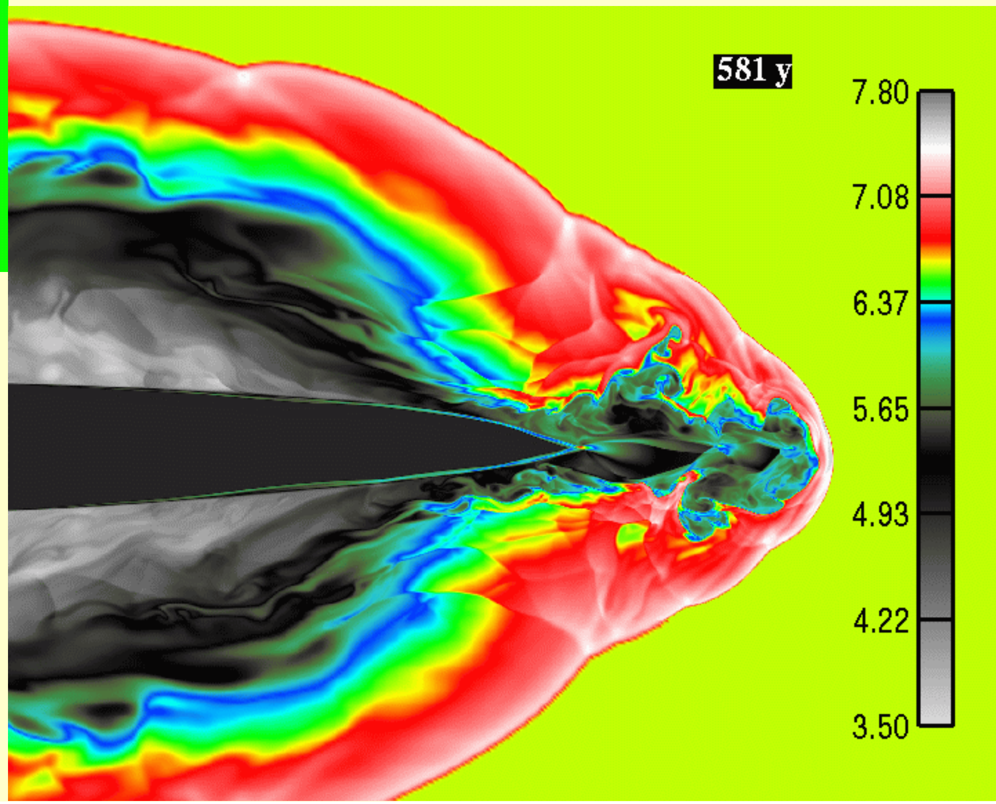
2D MHD: jets from young stellar objects



density, $\gamma = 1.4$, $\eta = 4$

Use:
ideal MHD equations, adiabatic equation of state, no radiative cooling, $\eta = \rho_{ambient} / \rho_{jet}$

density, $\gamma = 1.4$, $\eta = 40$

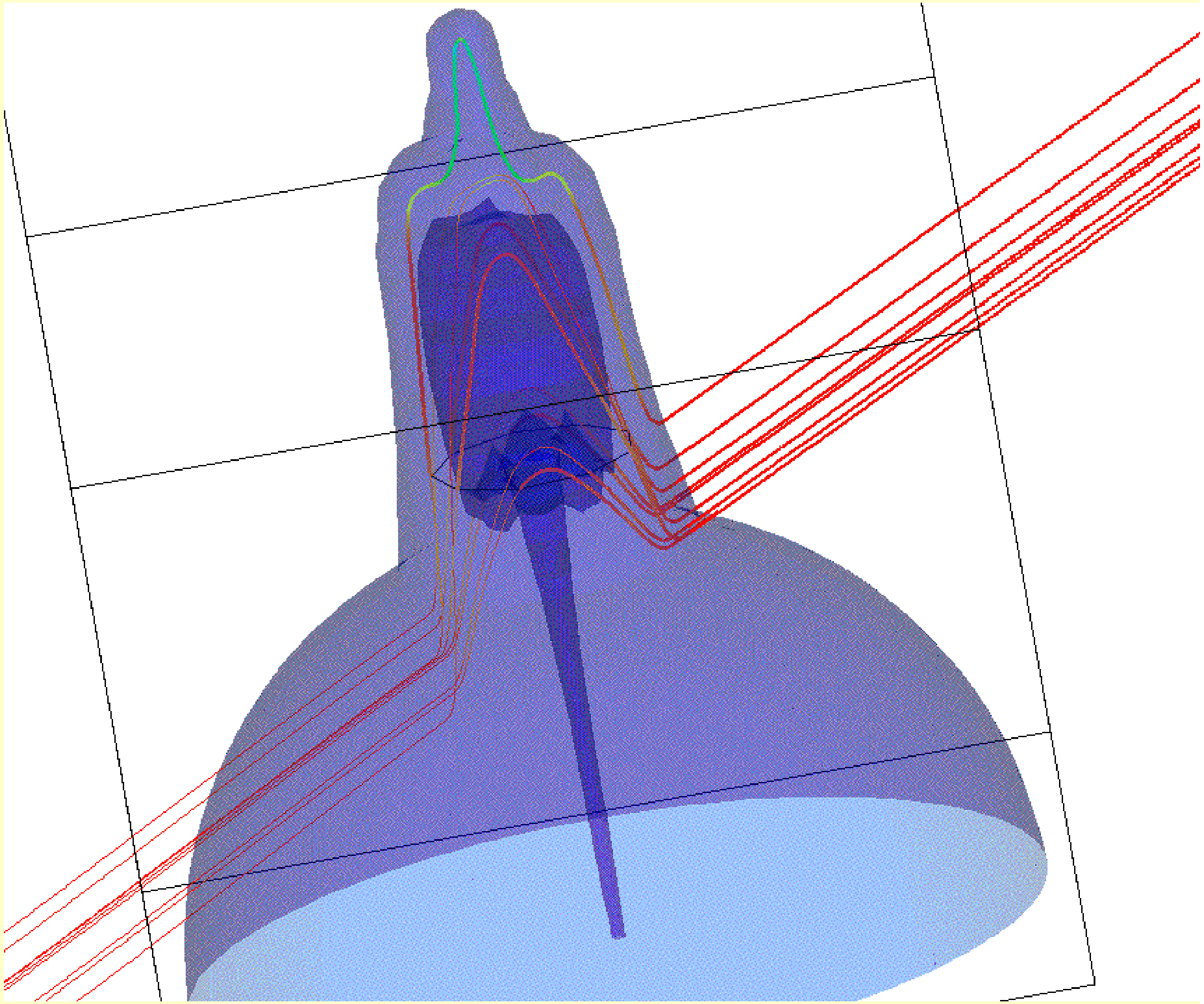


Study:
shape of jet, time evolution, stability

with Jean Heyvaerts, Observatoire de Strasbourg

3D MHD: jets from young stellar objects

blue faces: two density iso-surfaces
lines: (stretched) field lines of $B_{background}$



Use:
ideal MHD, adiabatic equation of state, no radiative cooling

Study:
shape of jet, time evolution, stability

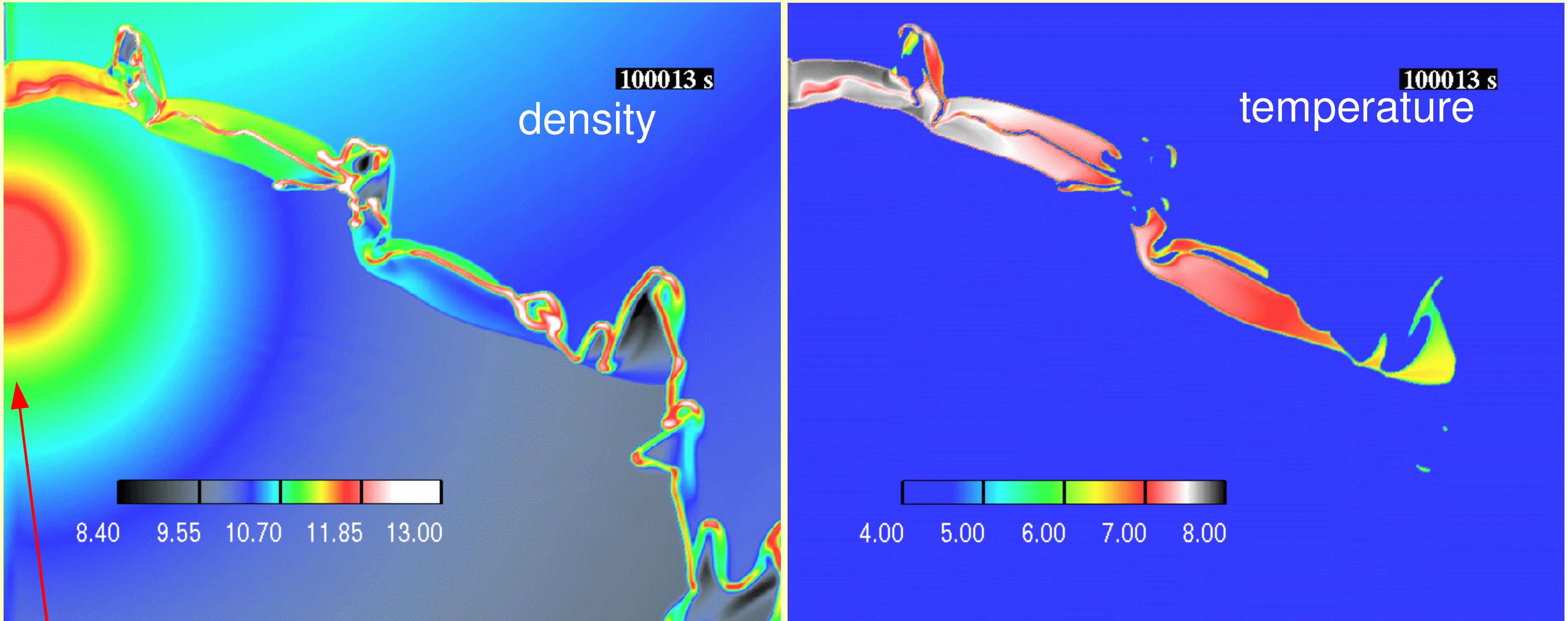
with Jean Heyvaerts,
Observatoire de Strasbourg

2D hydro: stability of colliding wind interaction zone

Use:
Euler equations, adiabatic equation of state, radiative cooling

Study:
Stability of wind- wind interaction zone, temperature distribution, apparent extension of zone

WR- star



O- star

Summary

- 1D MHD: self-gravitating slab + Alfvén- wave
- 3D hydrodynamics: WR+O binary γ Velorum
- 3D hydrodynamics:
  accreation wake in RW Hya?
- 3D hydrodynamics and 3D NLTE rad. transf., nebular cond.:
  Circum- stellar matter distribution of colliding wind models
- 3D hydrodynamics and 3D optically thick NLTE rad. transf.:
  ionization state of wind- wind collision zone in γ Velorum
- 2D hydro: supersonic turbulence in shock bound slab
- 1D hydro + radiative forces: unstable hot star winds
- 2.5 D hydrodynamics: galactic wind bubbles
- 2D MHD: jets from young stellar objects
- 3D MHD: jets from young stellar objects
- 2D hydro: stability of colliding wind interaction zone

- Not implemented:
  Hydro/MHD: self- gravity, heat- conduction, resistivity
  TR3D: large optical thickness, anisotropic scattering,
  efficient coupling to rate equations