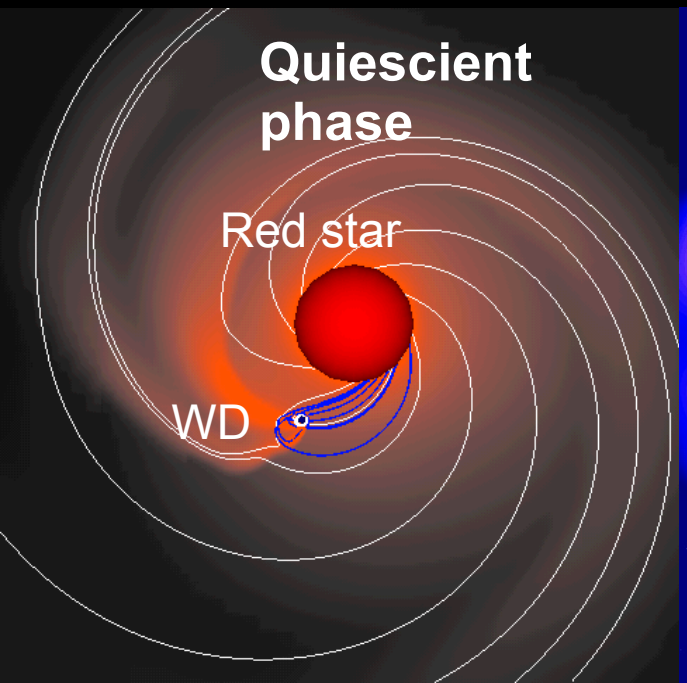
Recurrent novae: progenitors of SNIa?

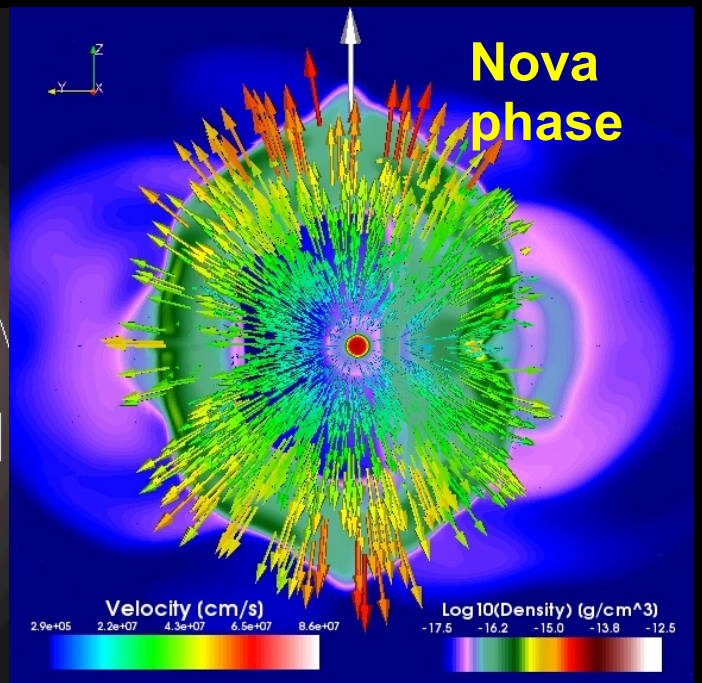
Rolf Walder, CRAL, ENS-Lyon, France

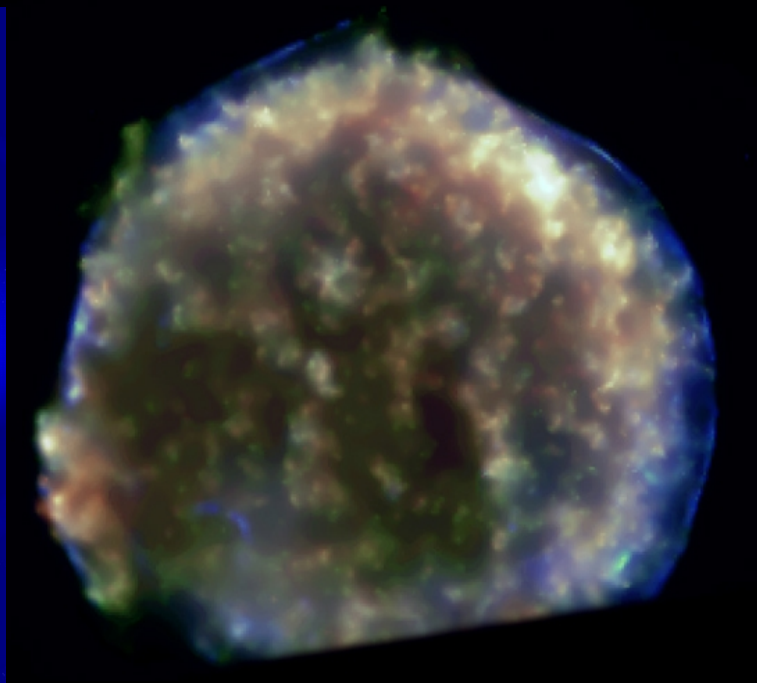
Doris Folini, CRAL, ENS-Lyon, France

Jean Favre, CSCS Manno, Switzerland (Visualization)

Steve Shore, Università di Pisa, Italy







Work is part of larger collaboration on stellar cosmic engines

Rolf Walder, Doris Folini, CRAL, ENS-Lyon

Georges Meynet , Cyril Georgy, Daniel Pfenniger, Observatoire de Genève

Steve Shore, Università di Pisa

Andrei Bykov, Russian Academy of Sciences, St. Petersburg

Randall LeVeque, University of Washington, Seattle

Jean Favre, Swiss Supercomputing Centre, CSCS, Manno

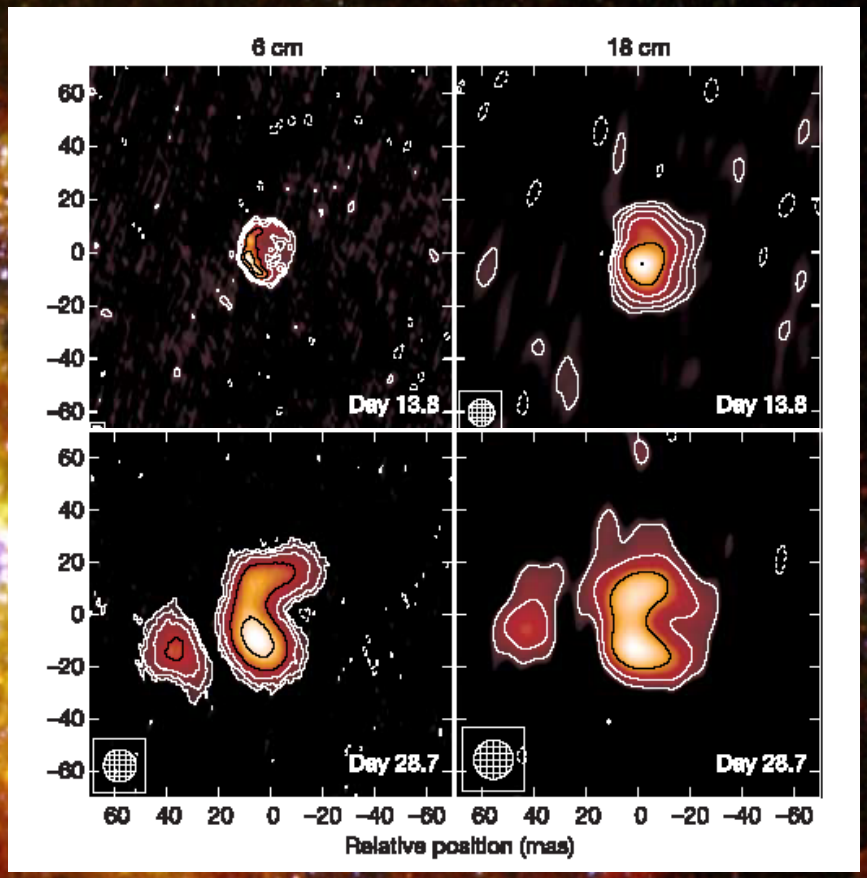
Keh-Ming Shyue, National Taiwan University, Taipeh

Presented computations were carried out at CSCS Manno and ETH Zurich

RS Ophiuchi

a recurrent nova with a 22 years cycle

Ophiuchi,
the one who carries the snake



O'Brian et al, Nature 2006

Outline

Why are recurrent novae promising candidates?

Some notes on wind accretion

Results: accretion and orbit-decay rates

Conclusion/Summary

First results:

Walder, Folini, Shore, AA 484, L9-L12, 2008

Two scenarios for SNIa:

both are based on binaries (WD + RS) !

A) Single degenerate scenario (SG)

Is there a way to transfer mass until WD reaches Chandrasekhar limit? Collapsing WD ignites C/O and star is disrupted.

B) Double degenerate scenario (DG)

Common envolope produces close WD+WD system.
WDs collide: C/O ignites and merger remnant explodes.

→ **SNIa progenitors:**

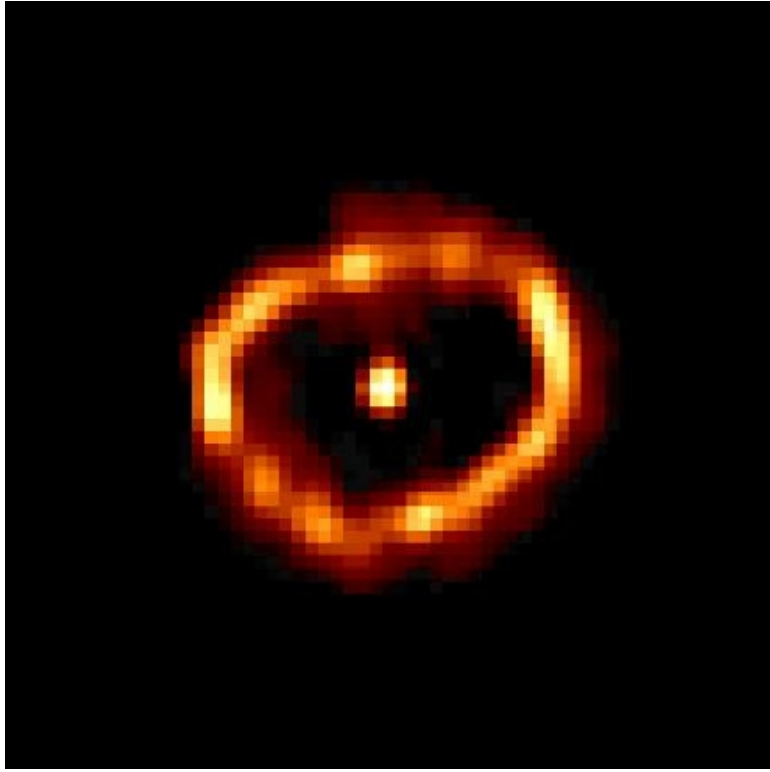
study mass-transfer and orbital evolution

Complication:

Novae: H-shell flashes on WD

The novae complication

can a WD grow in mass at all?



Hydrogen/helium is accumulated onto a hot WD by mass transfer:

- shell flashes are ignited from time to time
- flashes lead to mass ejection: ? $M_{ej} < M_{acc}$ or $M_{ej} > M_{acc}$?
- theory is very uncertain

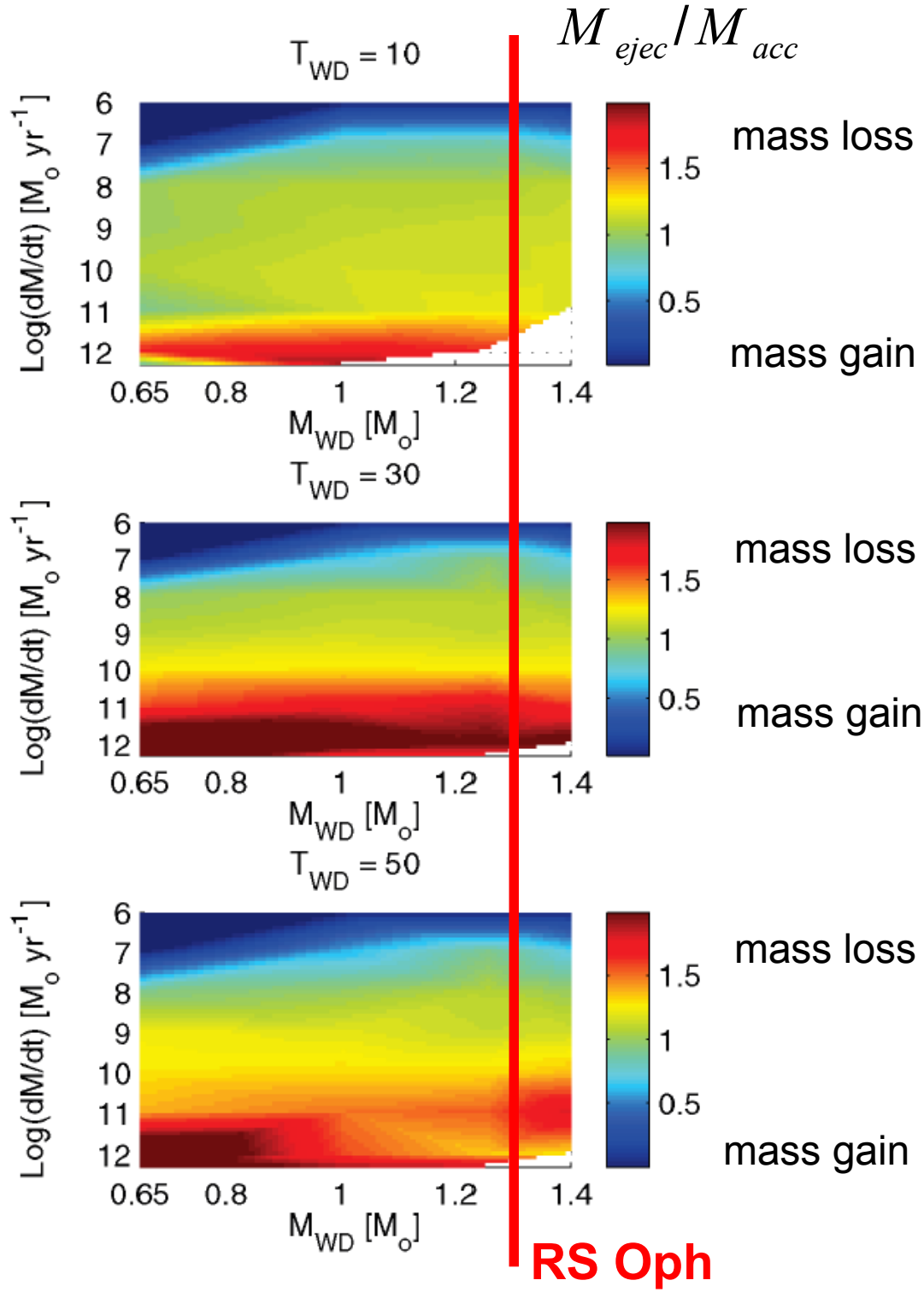
Mass bilance in nova systems

Limits

$\dot{M}$ >~ 1.e^{-8} $M_\odot$/yr to grow in mass

But: Eddington limit is ~ 1.e^{-6} $M_\odot$/y

Only a very small range of mass-accretion rates lead to WD mass increase



O.Yaron, D. Prialnik, M.M. Shara, & A. Kovetz, ApJ, 623 (2005)

The ten known recurrent novae

G.C.Anupama, 2002

	Name	m_{max}	m_{min}	t_3 days	$< t_{rec} >$ yrs	dist kpc	Secondary	P_{orb} days	Ref
S	T CrB	2.0p	10.2v	6.8	80	1.3	M3 III	227.67	[41]
	RS Oph	5.0v	11.5v	9.5	22	1.6	M0/2 III	455.72	[41], [46]
	V3890 Sgr	8.2v	17.0:	17.0	28	5.2	M5 III		[41]
	V745 Sco	9.6v	19.0:	14.9	52	4.6	M6 III		[41]
CV	U Sco	7.6v	18-19v	4.3	27	14	K2 IV	1.2305	[30], [24]
	V394 CrA	7.0v	18.8B	10,5.5	38	5	K	0.7577	[47]
	LMC 1990#2	10.9v	20:	5.26	22	49.4			[47]
	T Pyx	6.5v	15.2v	88	19	4.5:		0.0762	[32], [47]
	CI Aql	8.9v	17-17.8v	36	42		K-M IV:	0.6184	[11], [6]
	IM Nor	7.7v	19.5:	$\gtrsim 50$	82	1.9-2.4			[19], [21]

All massive WD > 1 $M_\odot$!

From theory: $t_3 \sim 1/M_{WD}$; $t_{rec} \sim M_{Acc}$ (week of M) **(Prialnik & Kovetz 1995)**

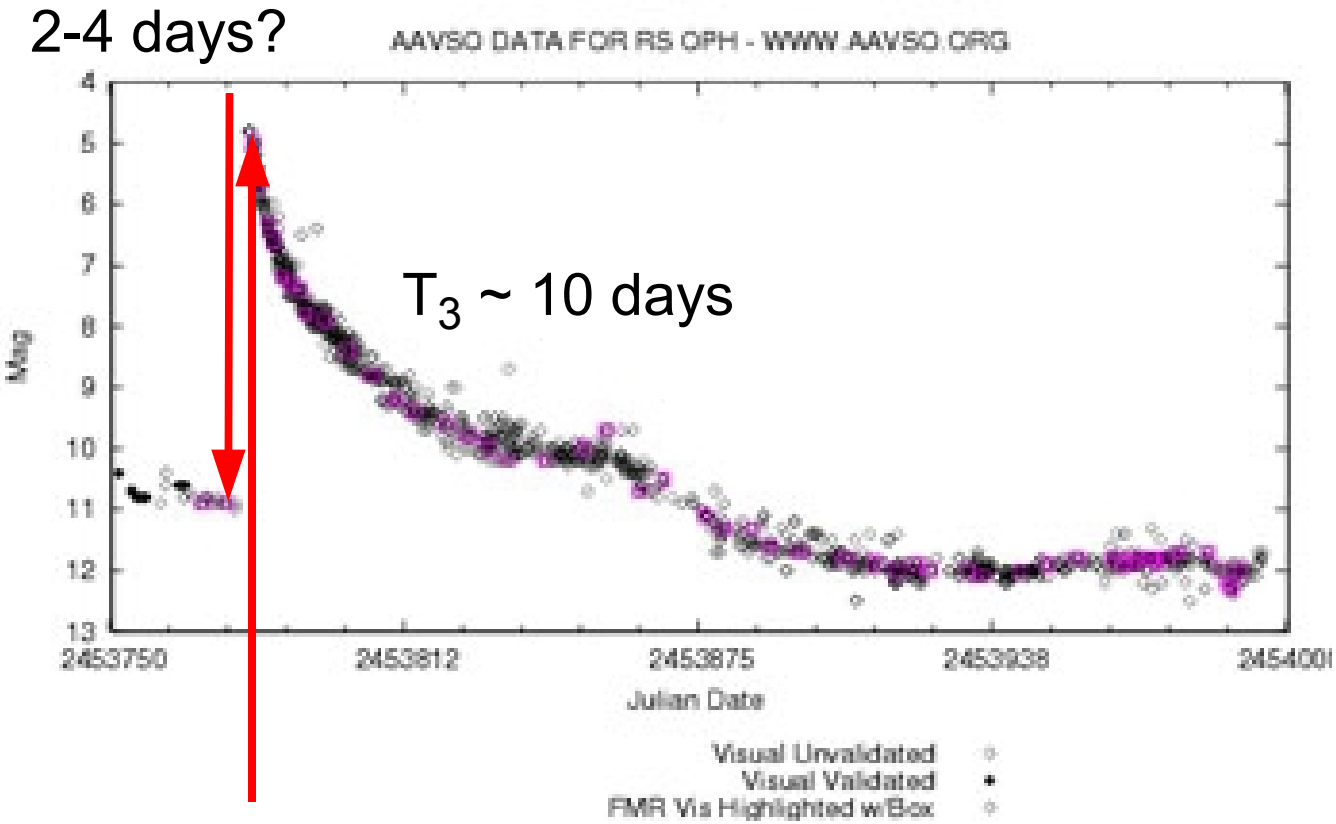
Good candidates to evolve into an SN Ia

Recurrent nova RS Oph, Outburst 2006

(one of the best observed system!)

Optical lightcurve

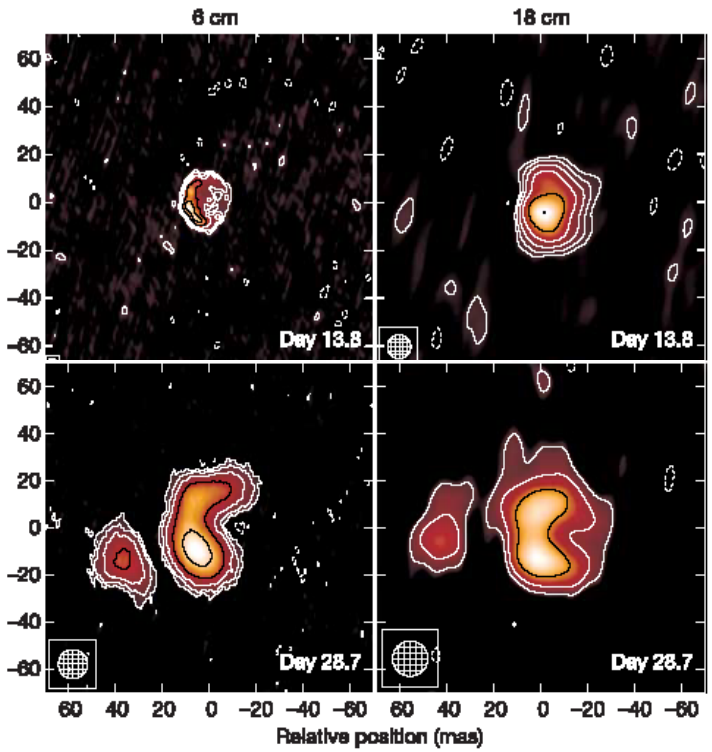
2-4 days?



T_3 ~ 10 days

February 12, 2006

Radio



O'Brian et al, Nature 2006

System Parameters

WD + M2 III (Fekel et al. AJ 119, 1375 (2000))

P_{orbit} = 455.72 d

ε = 0 (recently disputed)

M_{WD} = 1.35 – 1.4 $M_\odot$

M_{RG} = 0.4 – 2.3 $M_\odot$ (Fekel (2000); Dobrzycka&Kenyon (1994))

$Massloss_{RG}$: ~ 10^{-7} – 10^{-9} $M_\odot$/yr (10^{-5} $M_\odot$/yr, 10^{-10} $M_\odot$/yr) ?

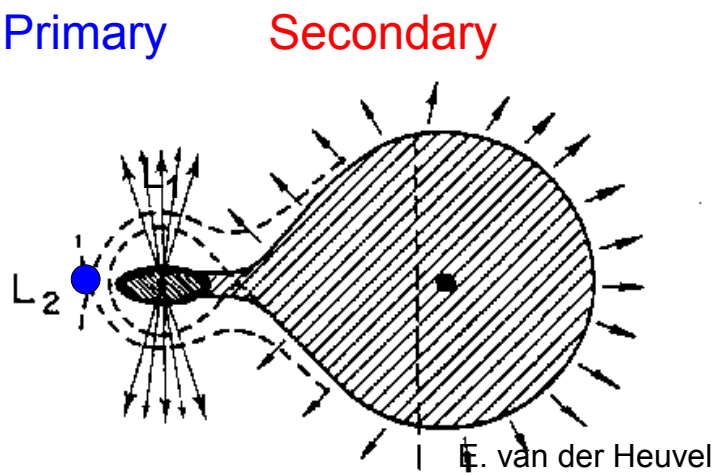
V_{RG} = 20 km/s; 36 km/s (Iijima 2007); 40-60 km/s (Shore et al. 1996)

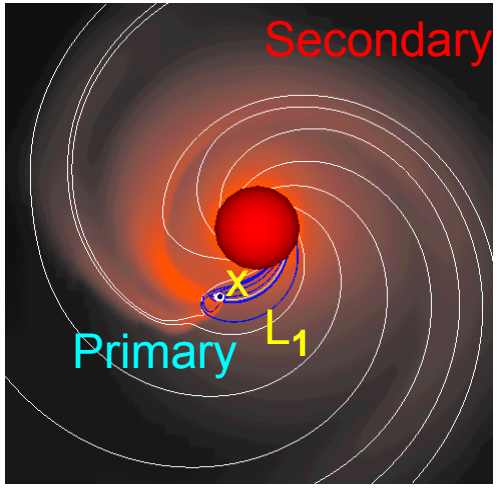
distance : 1.6 ± 0.3 kpc

Outburst history

2006, 1985, 1967, 1958, (1945), 1933, (1907), 1898

Two modes of mass transfer

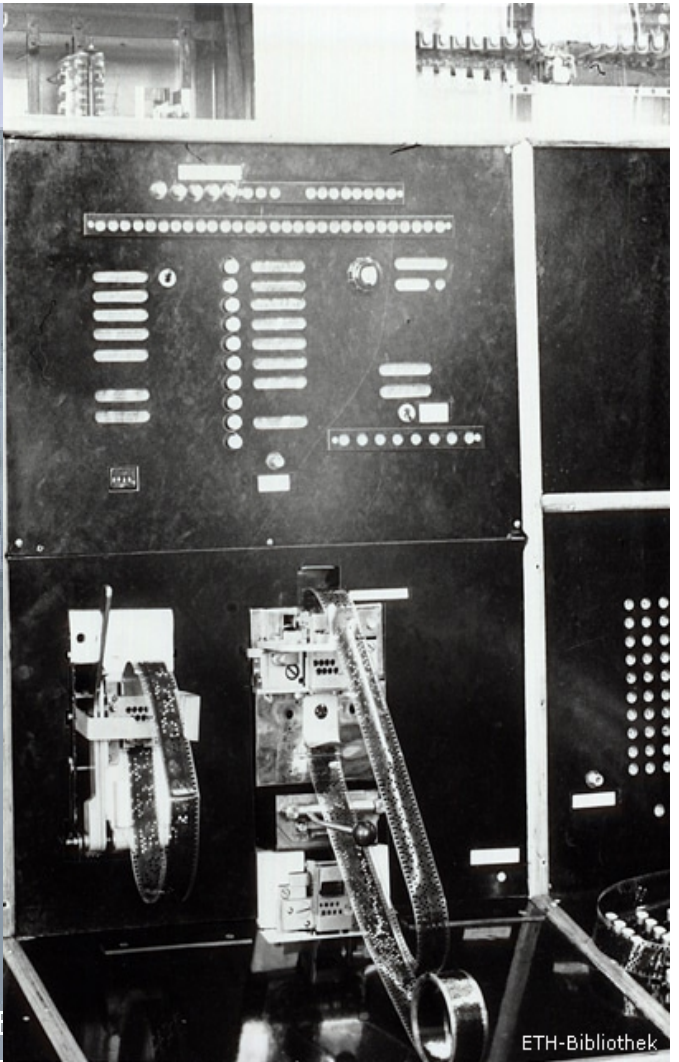




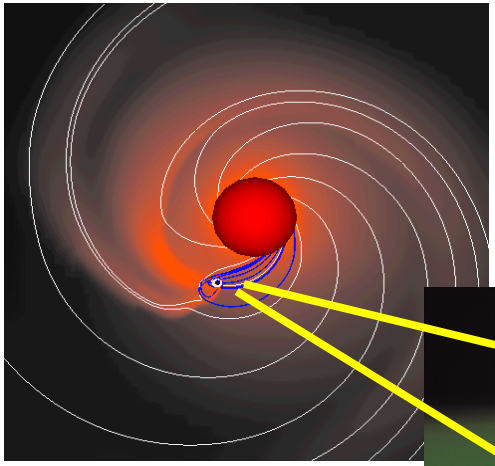
Mode	Roche lobe overflow	Wind accretion
Mass conservation	Conservative (no wind)	Non-conservative
In transfer	Non-conservative (wind)	
Accretion rate	Thermal expansion of secondary	Wind velocity of secondary
	Orbit decay (GRW, MB)	Orbital parameters
Primary: NS/BH	LMXRB	HMXRB
WD	Cataclysmic Variables (CV)	Symbiotics
Periods	Hours-days	Hours (high mass)
		Years (low mass)

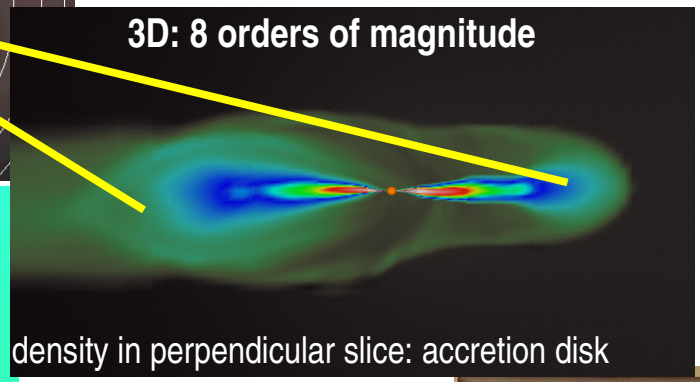
Computational tools

The Zuse Z4 at ETH Zürich



Computional toolbox A-MAZE+

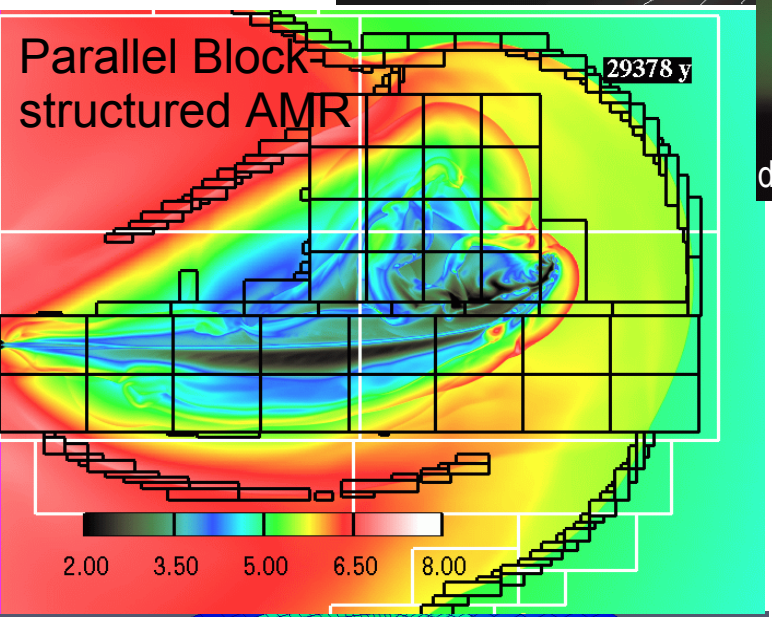


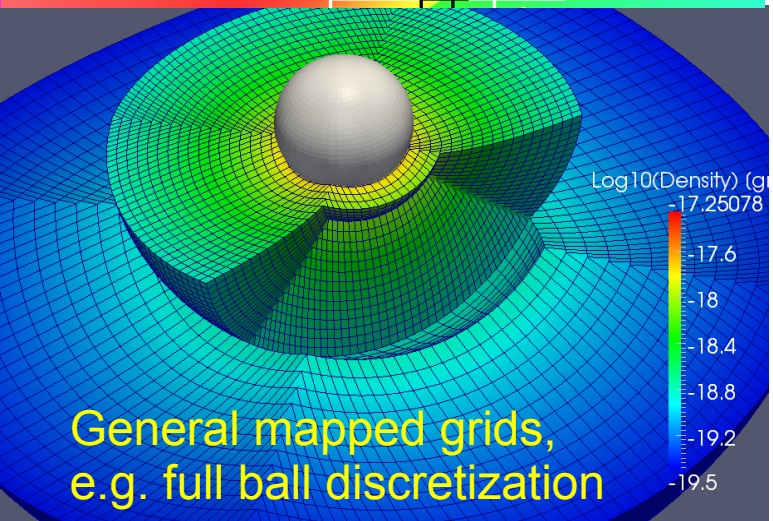


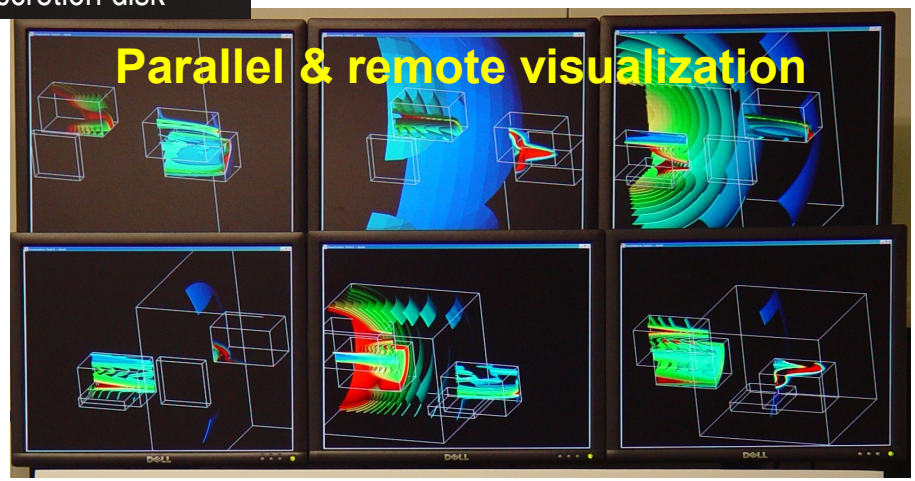
3D adaptive, high-resolution (M)HD schemes in parallel

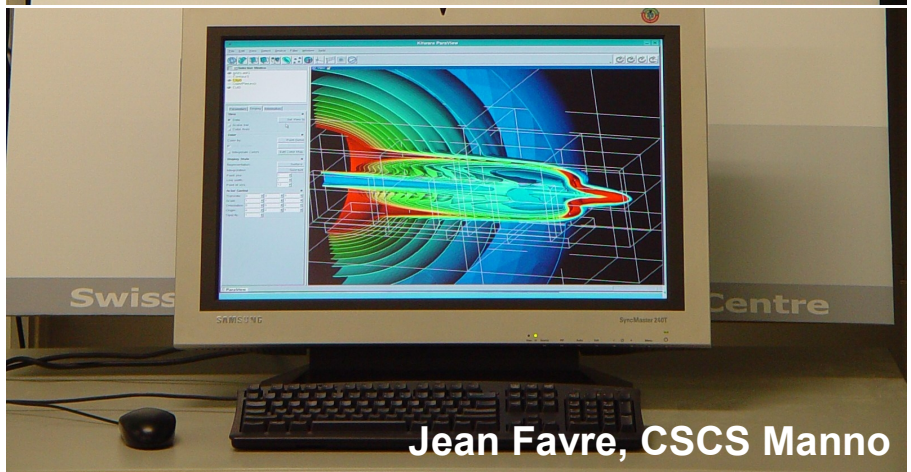
implicit schemes

Parallel 3D radiation transfer

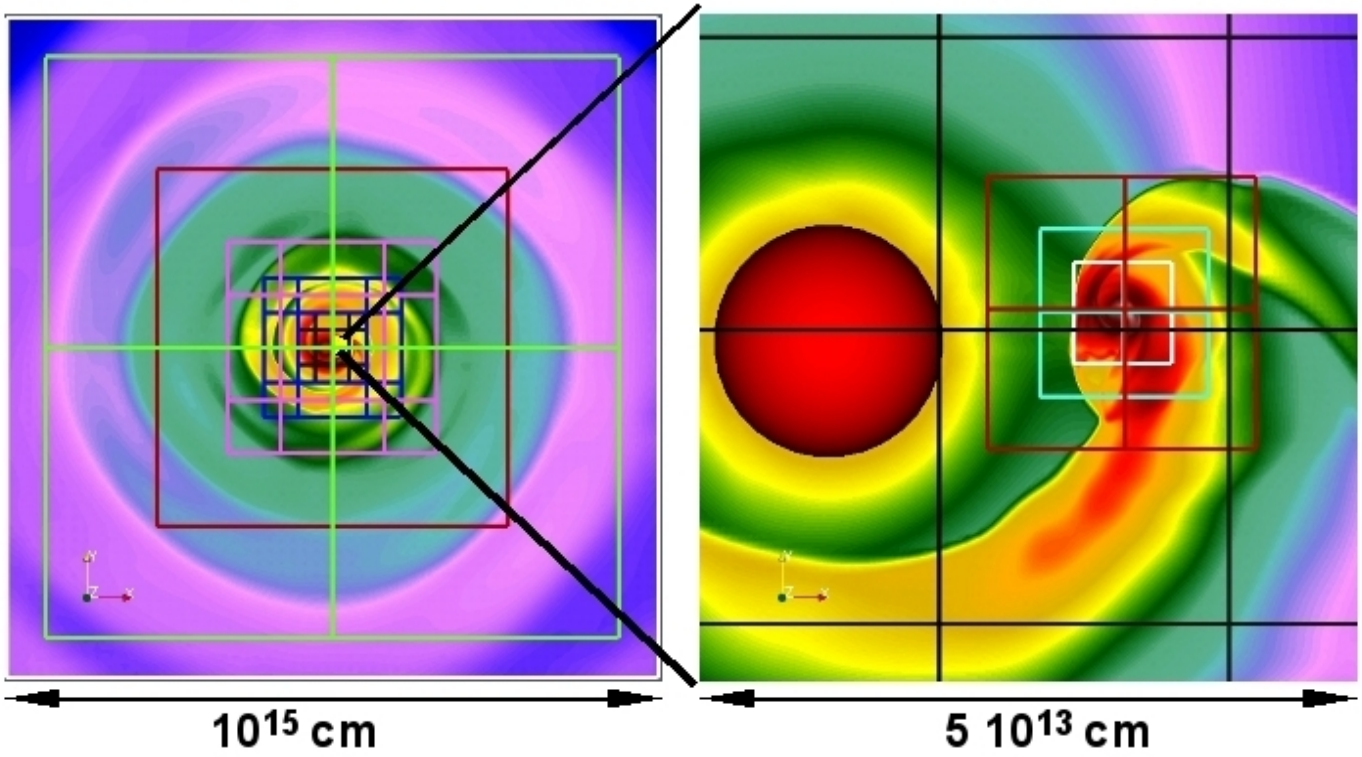








Simulations are carried out in an Eulerian frame of reference with the stars moving within the computational domain
9 (14) levels of refinement

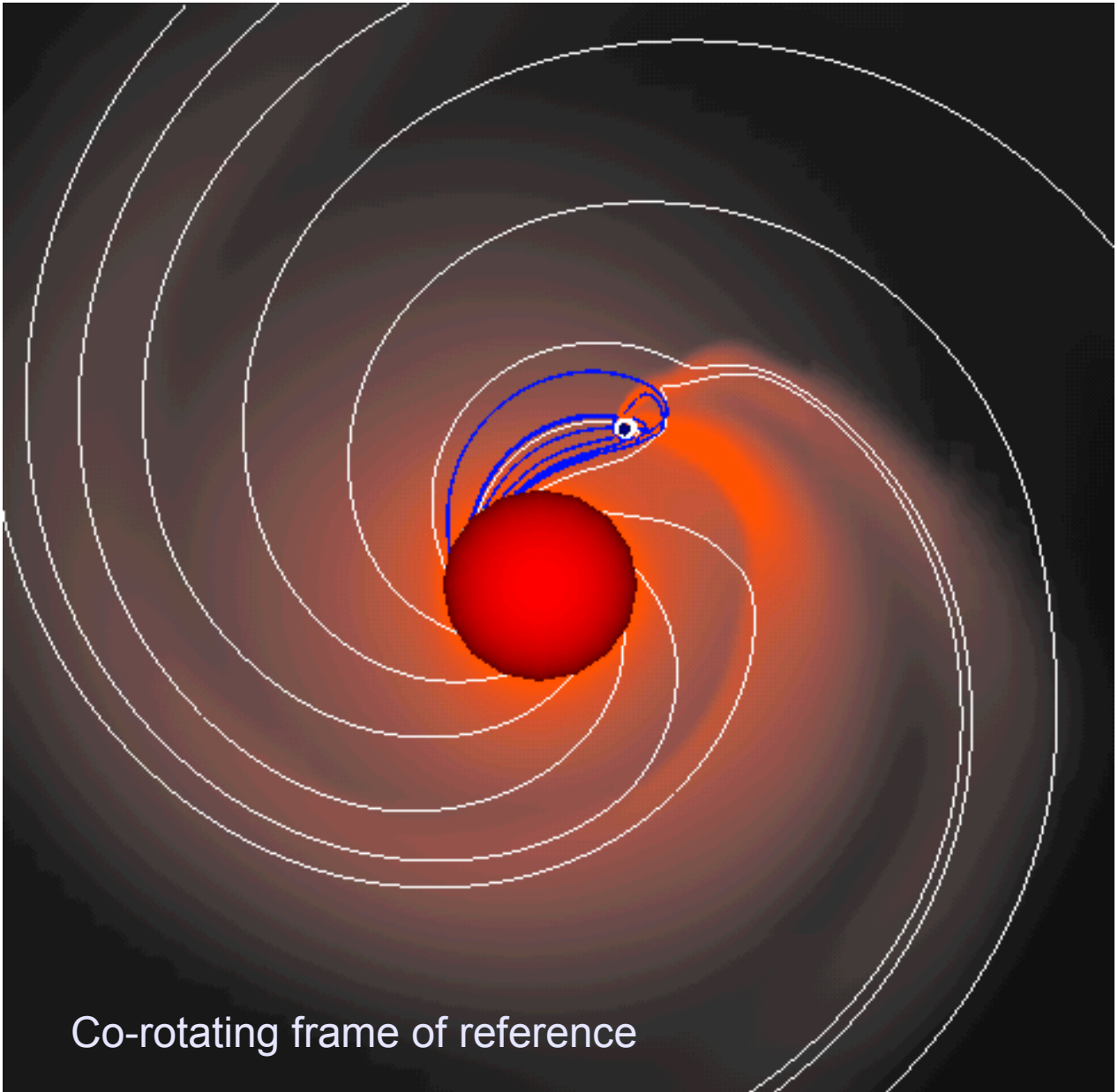


- ➔ From one level to the next, grid cells are refined by a factor of two
- ➔ Levels 1-6 are fixed in space, levels 7 to 10 move with the WD
- ➔ Each level comprises between 8 and 64 individual grids
- ➔ The entire mesh consists of 233 grids and $2 \cdot 10^7$ cells (498 grids/ 10^8 cells)

The decomposed grid structure is exploited for parallelization

Physics in quiescient phase:

takes places in the central region



Orbit scale . . : 1.4 – 1.7 AU
Physics scale : 2-3 orbit
more out . . . . : solely transport

1) Accretion physics in the vicinity of the WD.

2) Spiral shocks: transport of mass and angular momentum.

3) Spiral patterns are not always spiral shocks.

4) Roche theory has only limited significance in this case:
   - flow velocity
   - spiral shocks

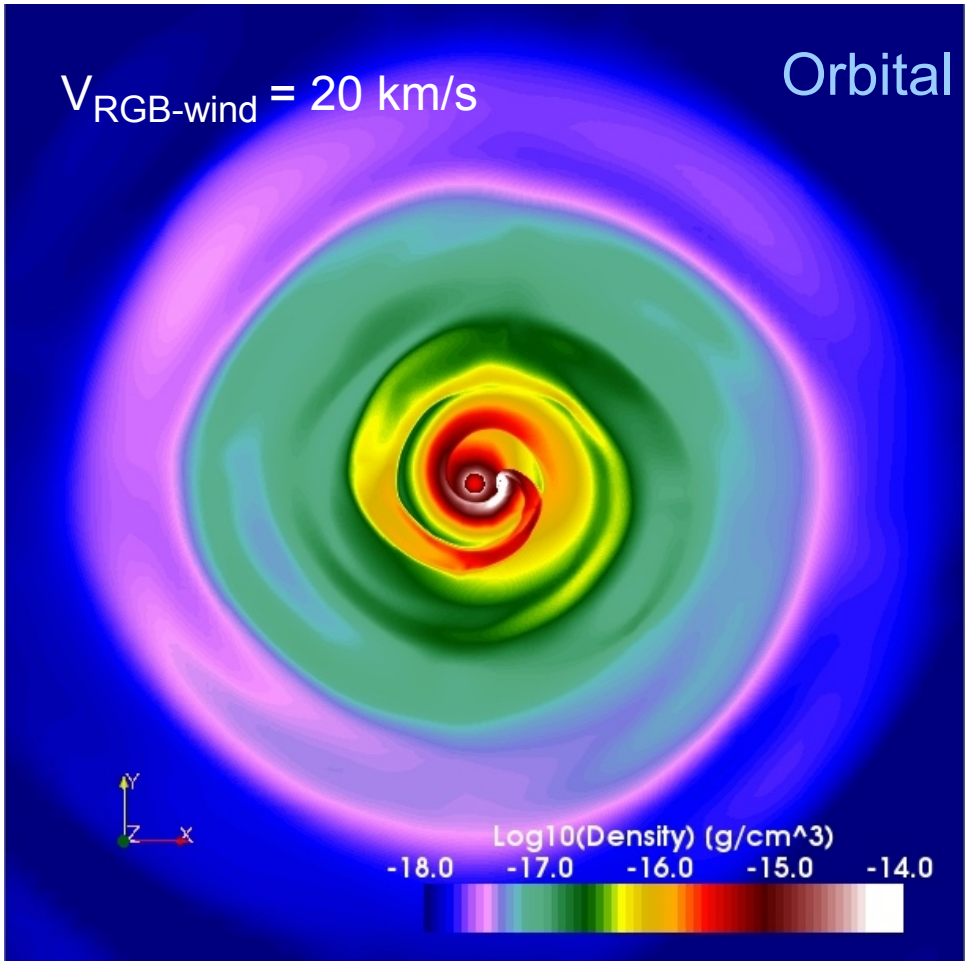
5) Bondi-Hoyle accretion is not application at all!

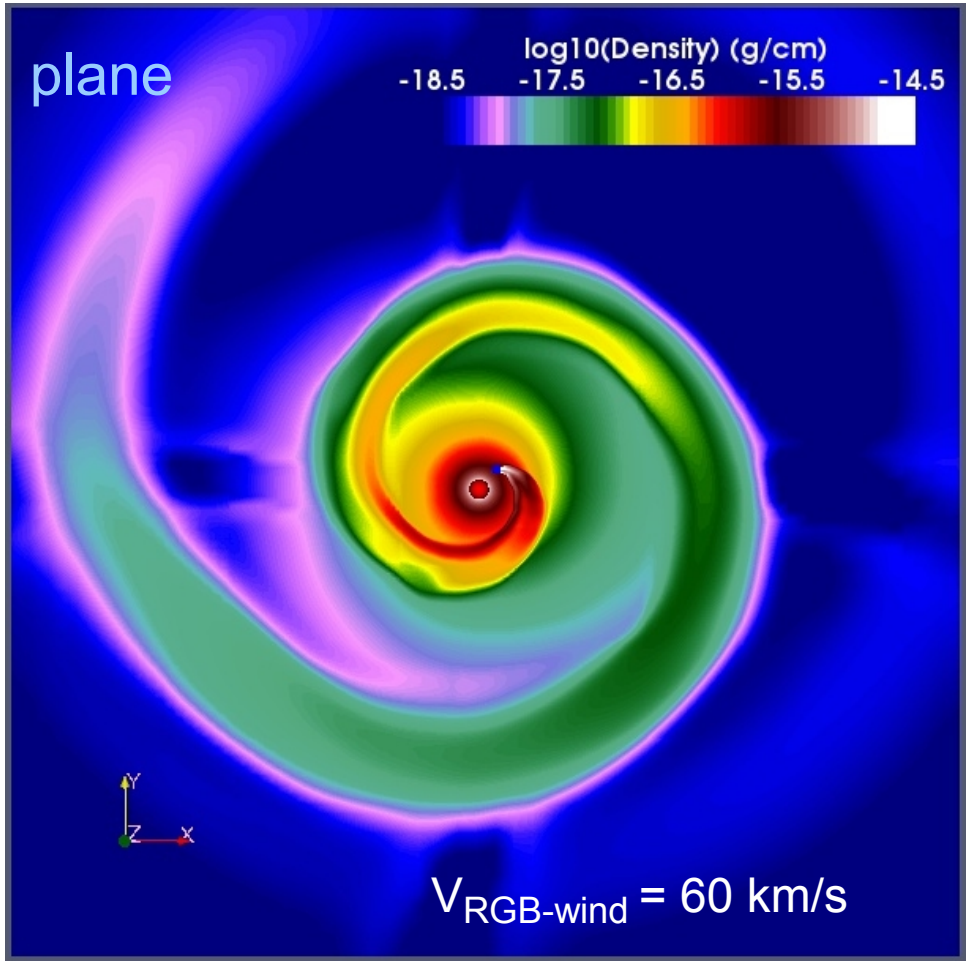
Circumstellar pattern determined by RGB-Wind

Spiral patterns are Archmedian (outside of the inner 'physics' region) and are caused by

- movement of RG star
- disturbance of RG wind by the accreting star

Opening angle of spiral depend mostly on wind velocity

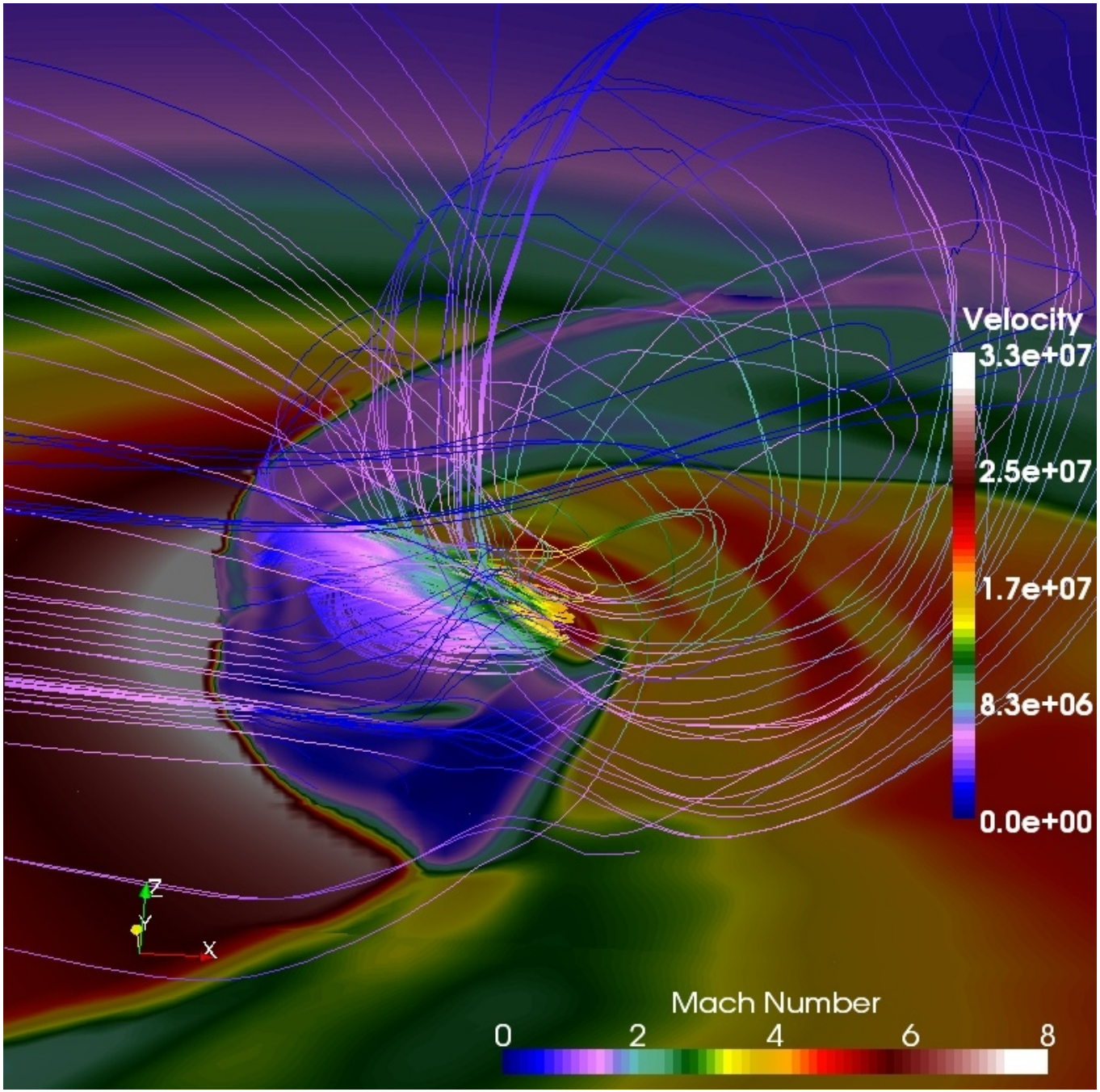




$1.e^{15}$ cm

$1.e^{15}$ cm

Complex accretion physics



Two dissipation regimes (transport of angular momentum)

1) Spiral shocks

2) Supersonic turbulence

Two Accretion Regimes

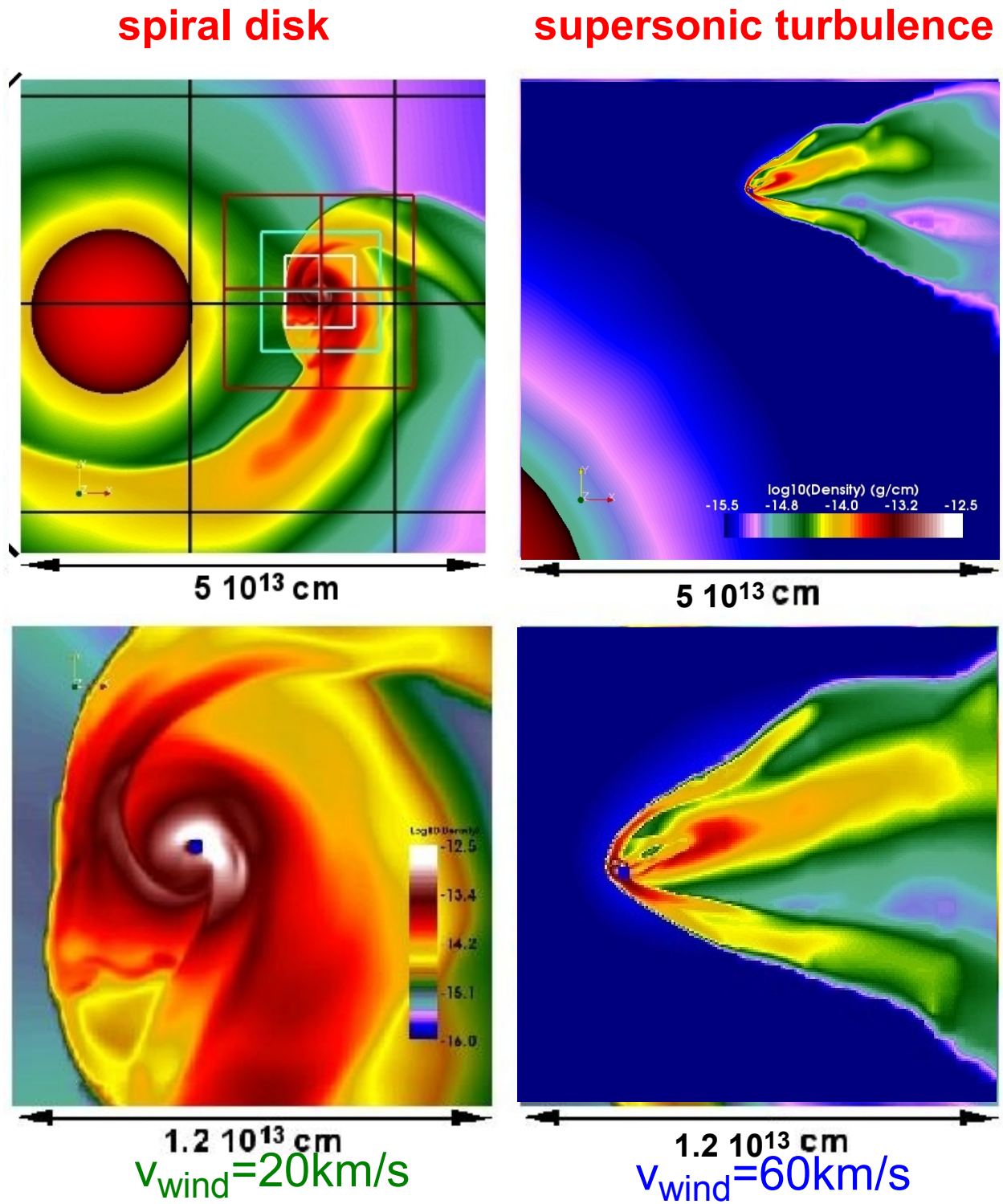
$M_{RG} = 2.3\ M_\odot$

$M_{WD} = 1.4\ M_\odot$

$\dot{M}_{RG} = 10^{-7}\ M_\odot/yr$

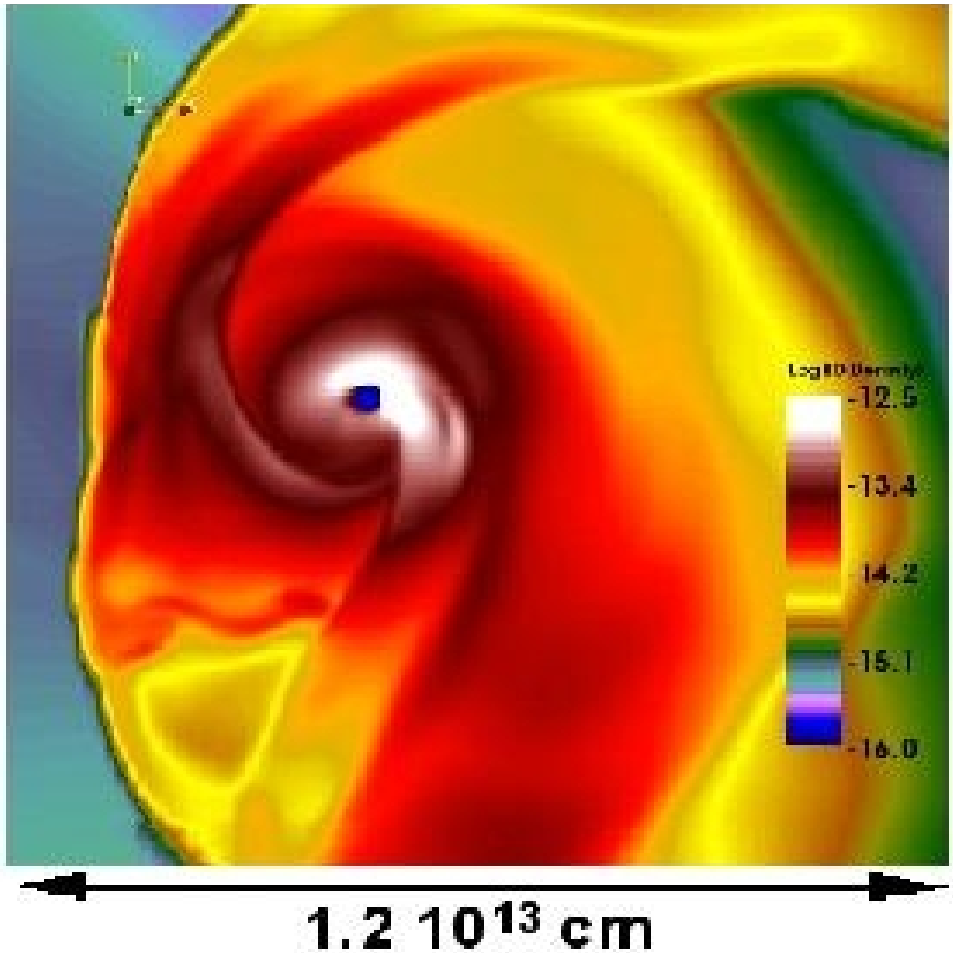
$V_{RG} = 20/60$ km/s

polytropic EOS
with = 1.1

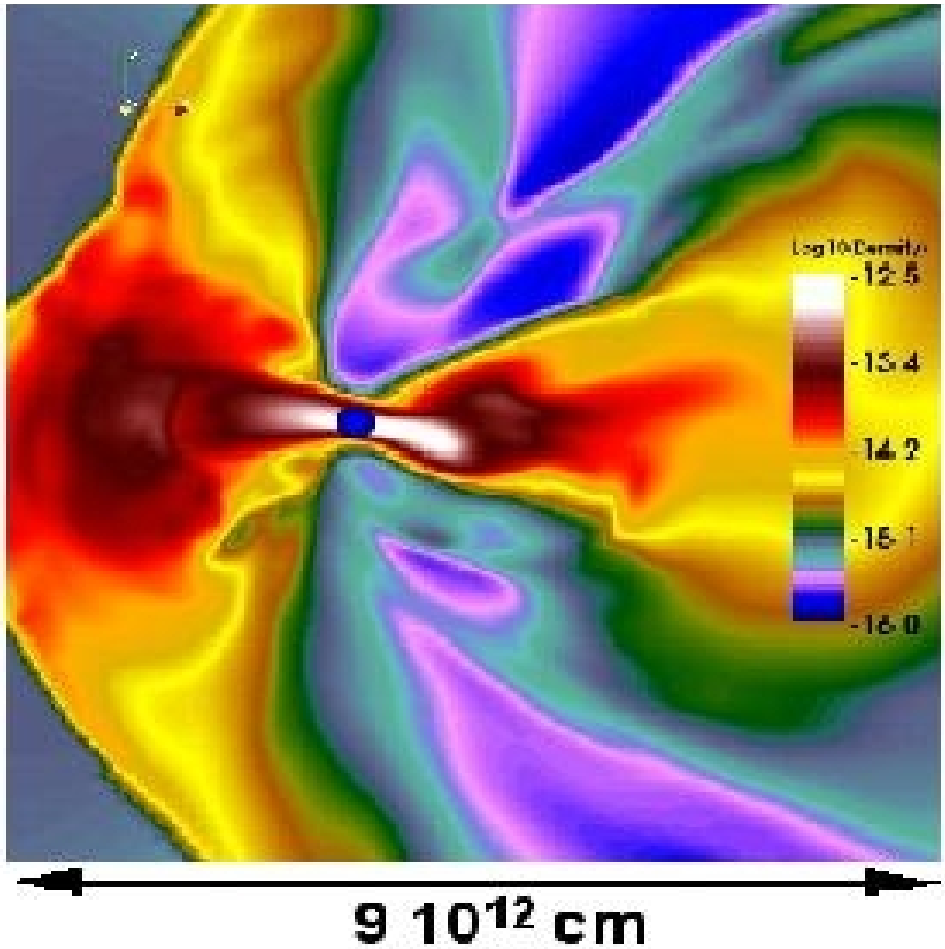


Spiral disk

Orbital plane

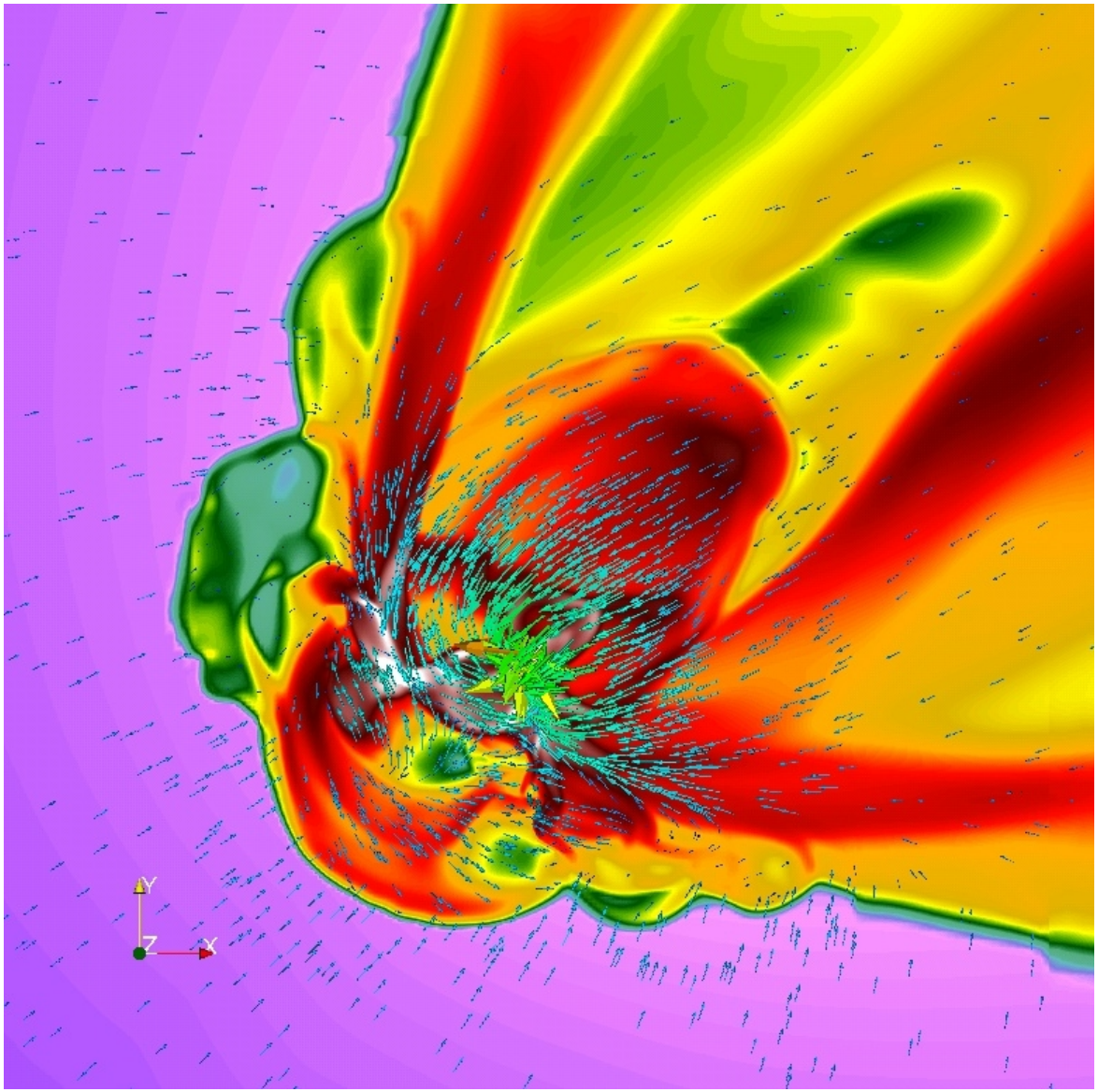


Normal to orbital plane



Accretion ball:

dissipation by supersonic turbulence

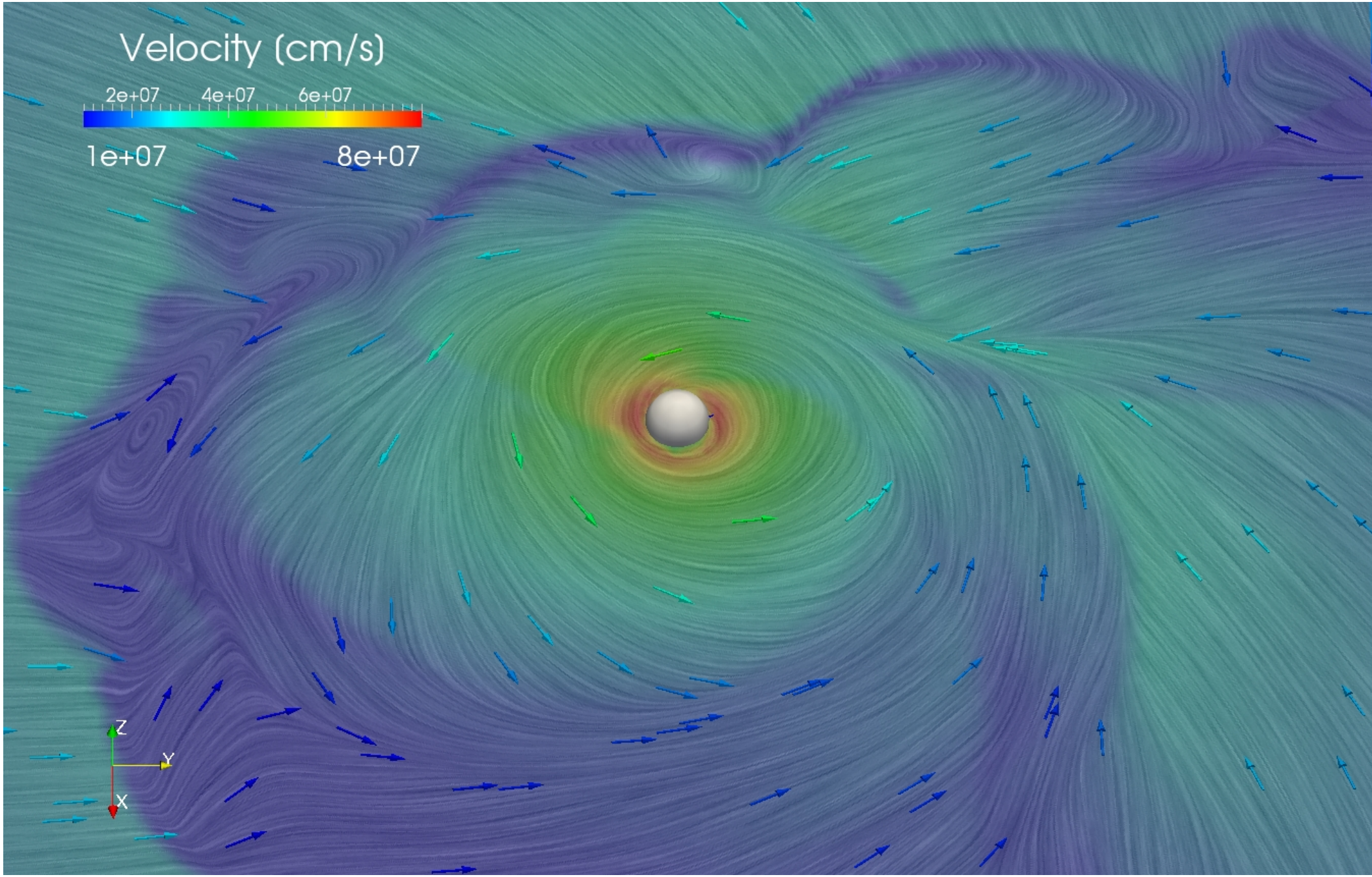


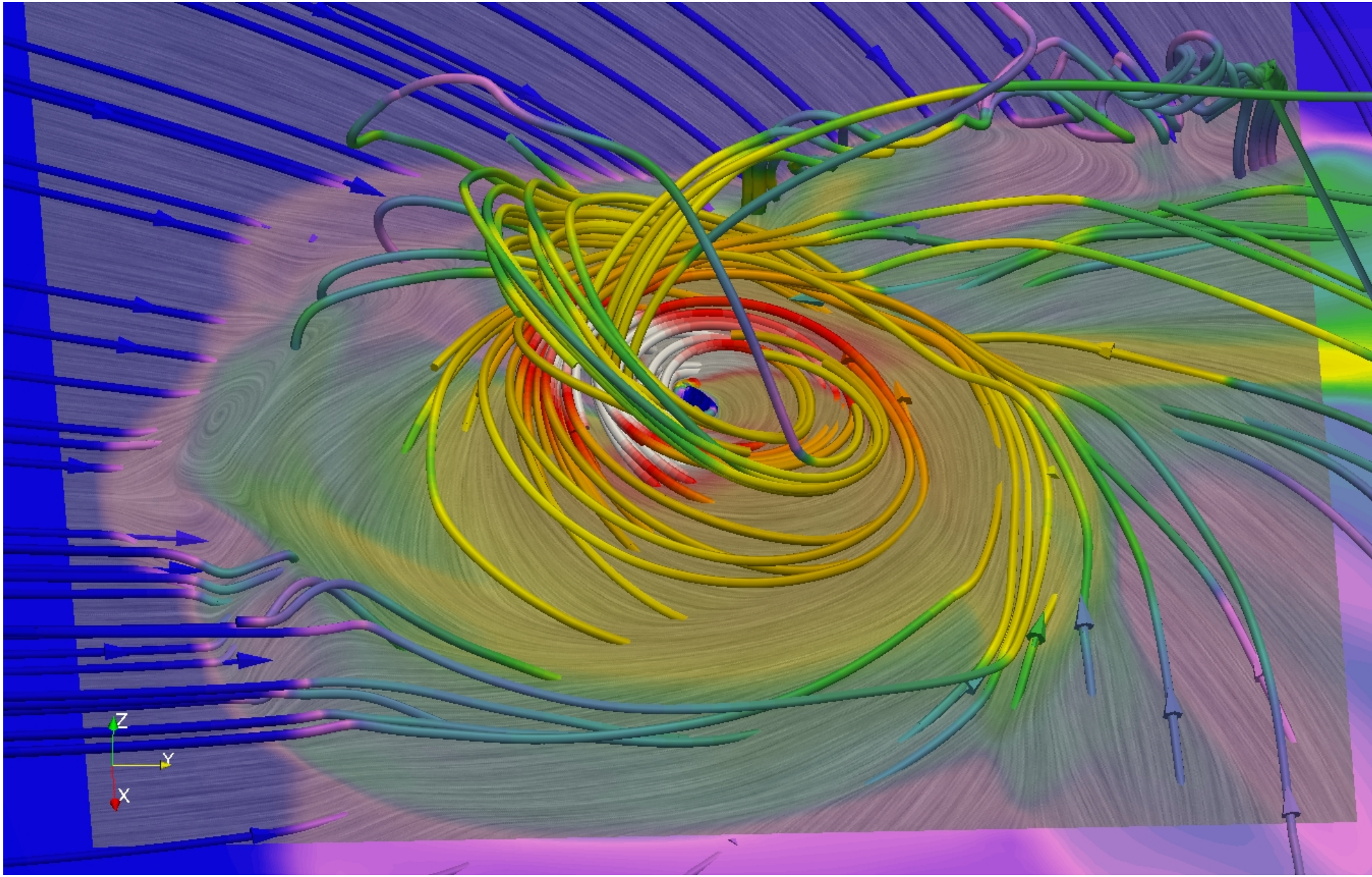
Supersonic streams from different direction collide.

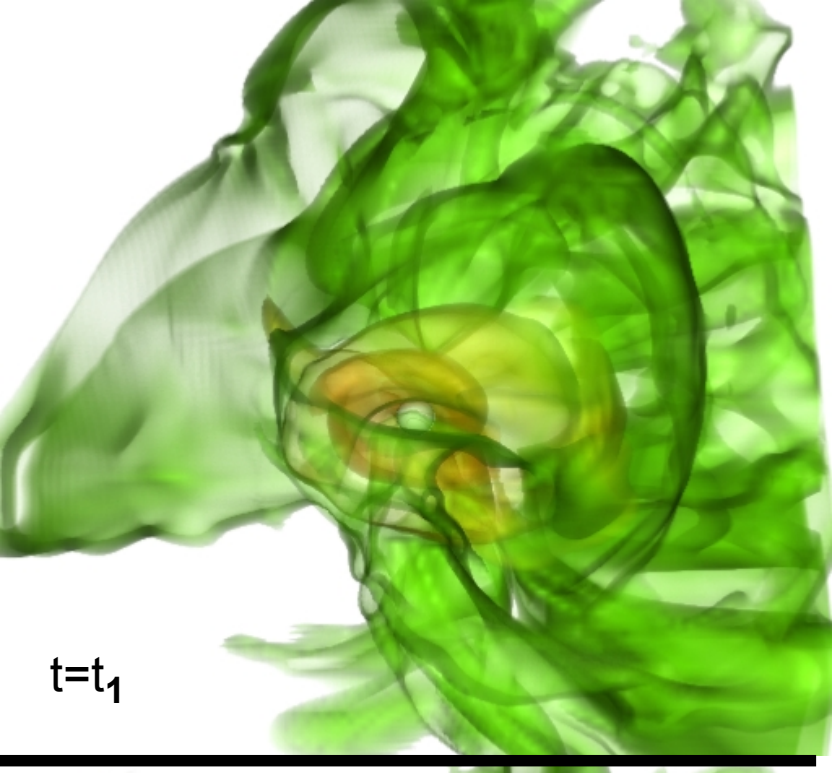
A network of shocks develops.

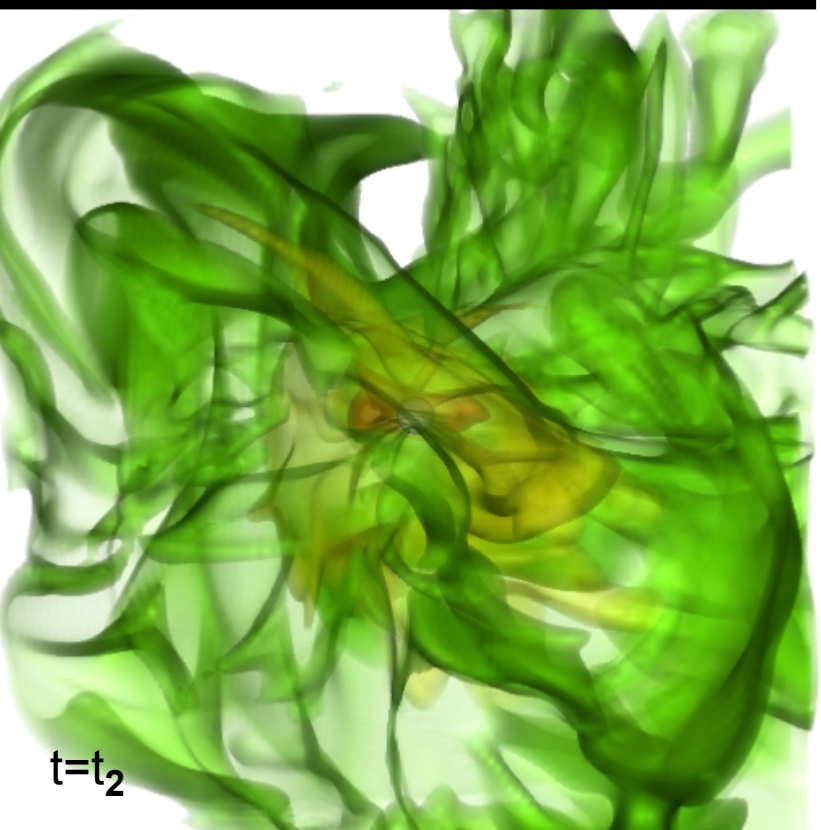
Angular momentum is transported outward by the shocks and material is able to fall.

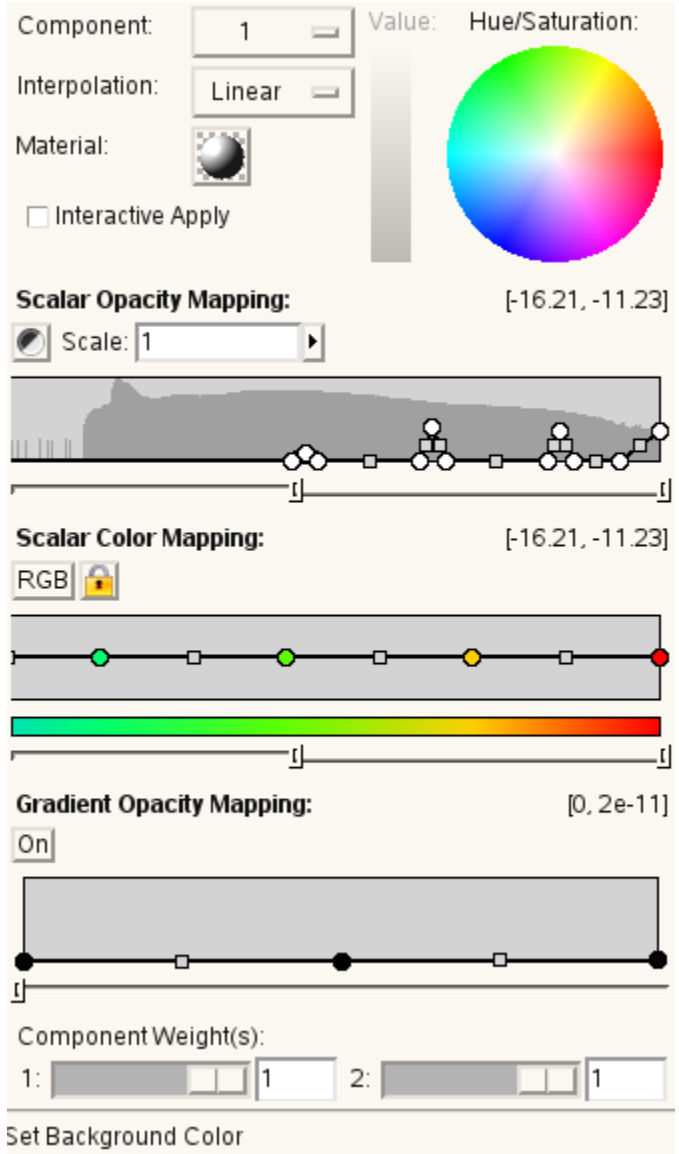
Max Ruffert (1994 ff)
T. Foglizzo, (2002)
Folini & Walder (2006)


Velocity (cm/s)
2e+07
4e+07
6e+07
1e+07
8e+07
Z
Y
X


Z
Y
X

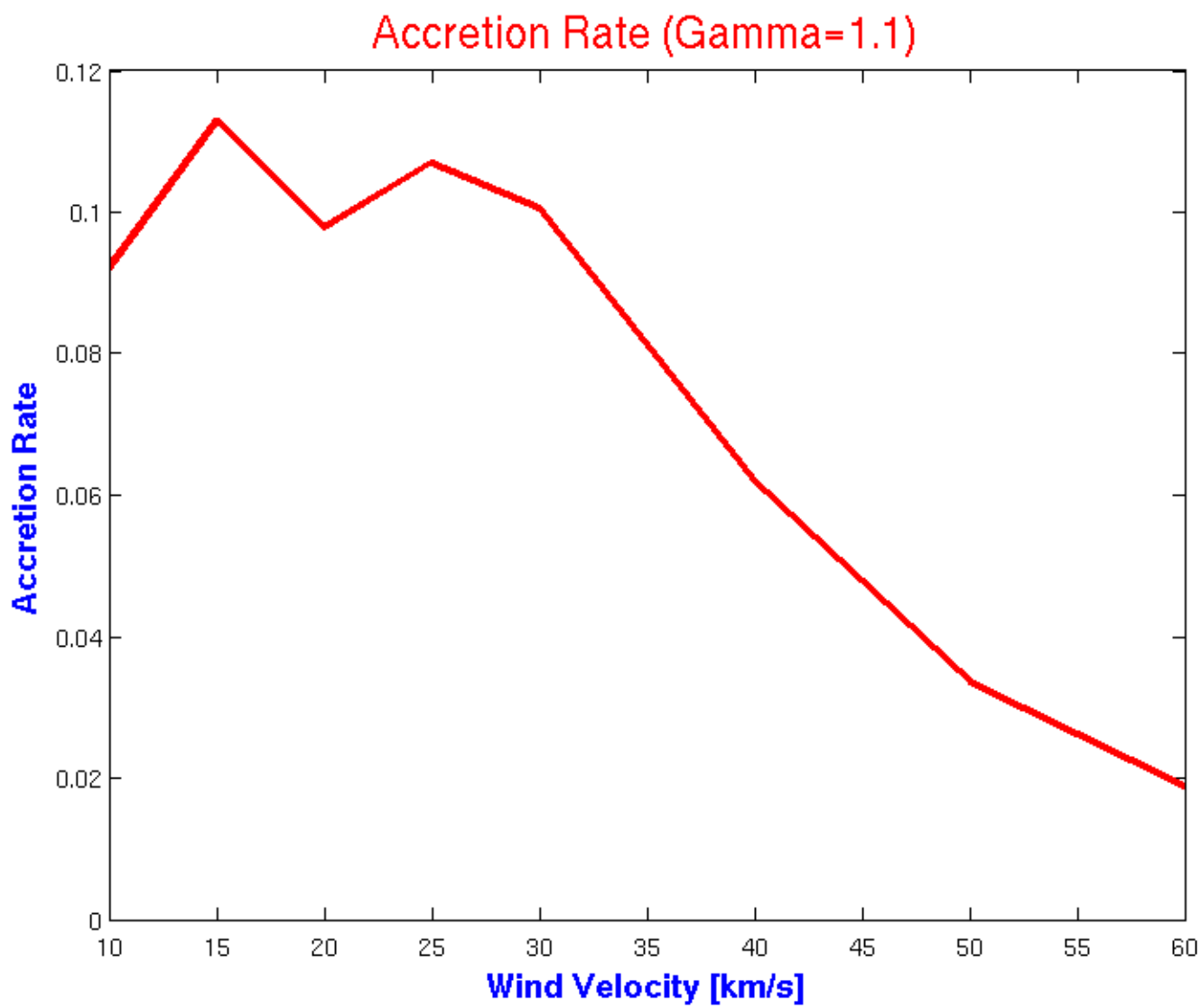






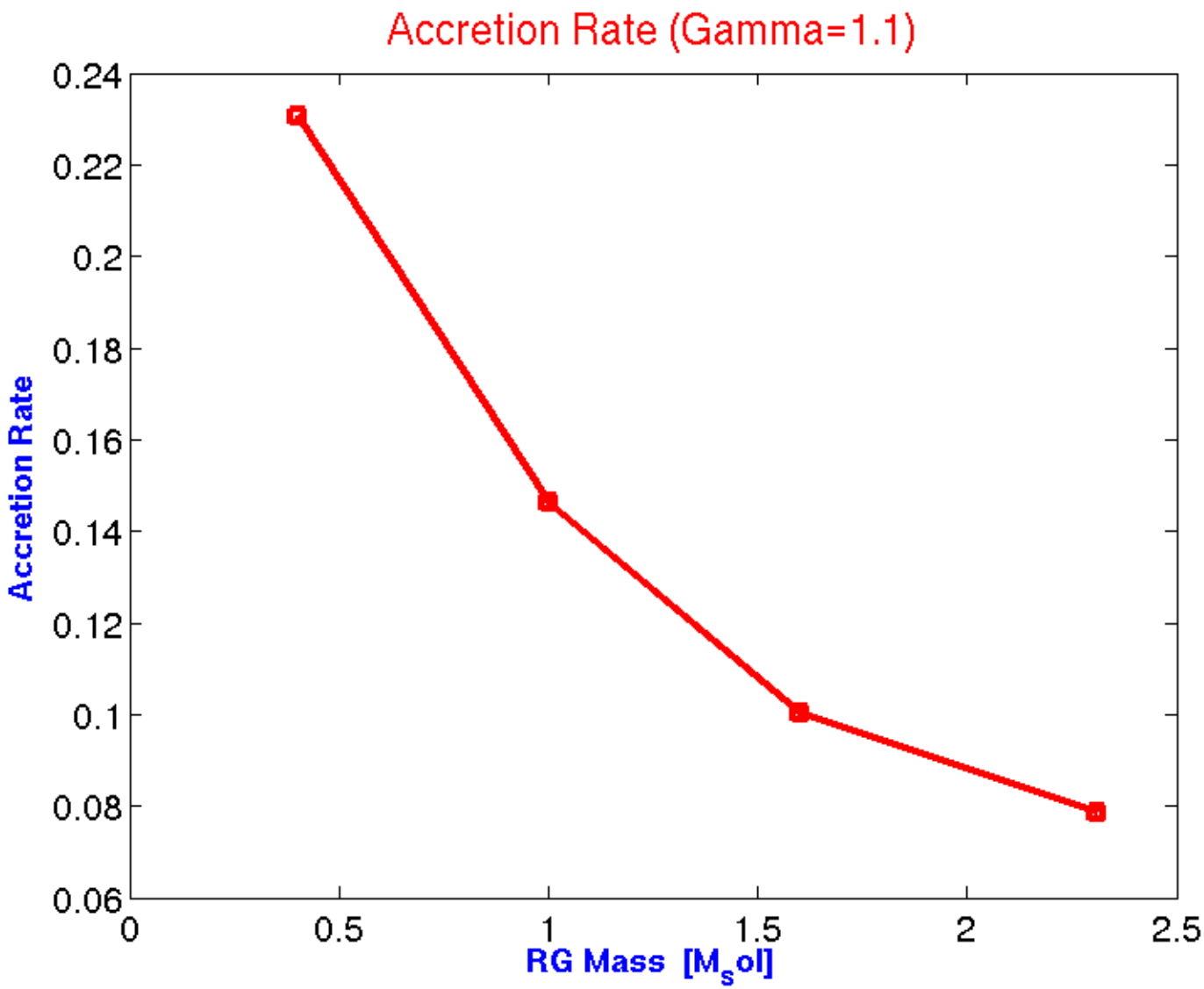
Opacity from different density values
red : log(ρ) = -11
green: log(ρ) = -14
blue : log(ρ) = -16

Opacity from gradients



RS Oph wind velocity is observationally not better confined

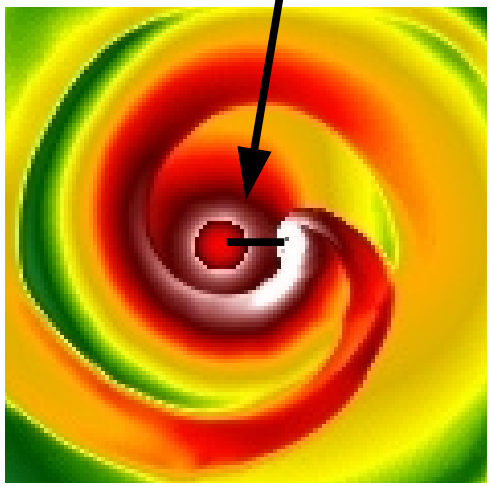
Thermodynamics: (20 km/s): 10.5 % (=1.0)
9.8 % (=1.1)
0.07 % (=1.666)

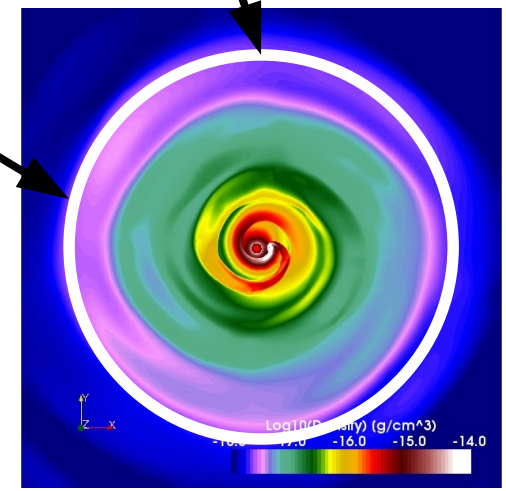


RS Oph RG mass is observationally notbetter confined

Evolution of the binary orbit

$$\frac{\dot{a}}{a} = \frac{(\dot{M}_1 + \dot{M}_2)}{(M_1 + M_2)} - 2\frac{\dot{M}_1}{M_1} - 2\frac{\dot{M}_2}{M_2} + 2\frac{\dot{J}}{J}$$



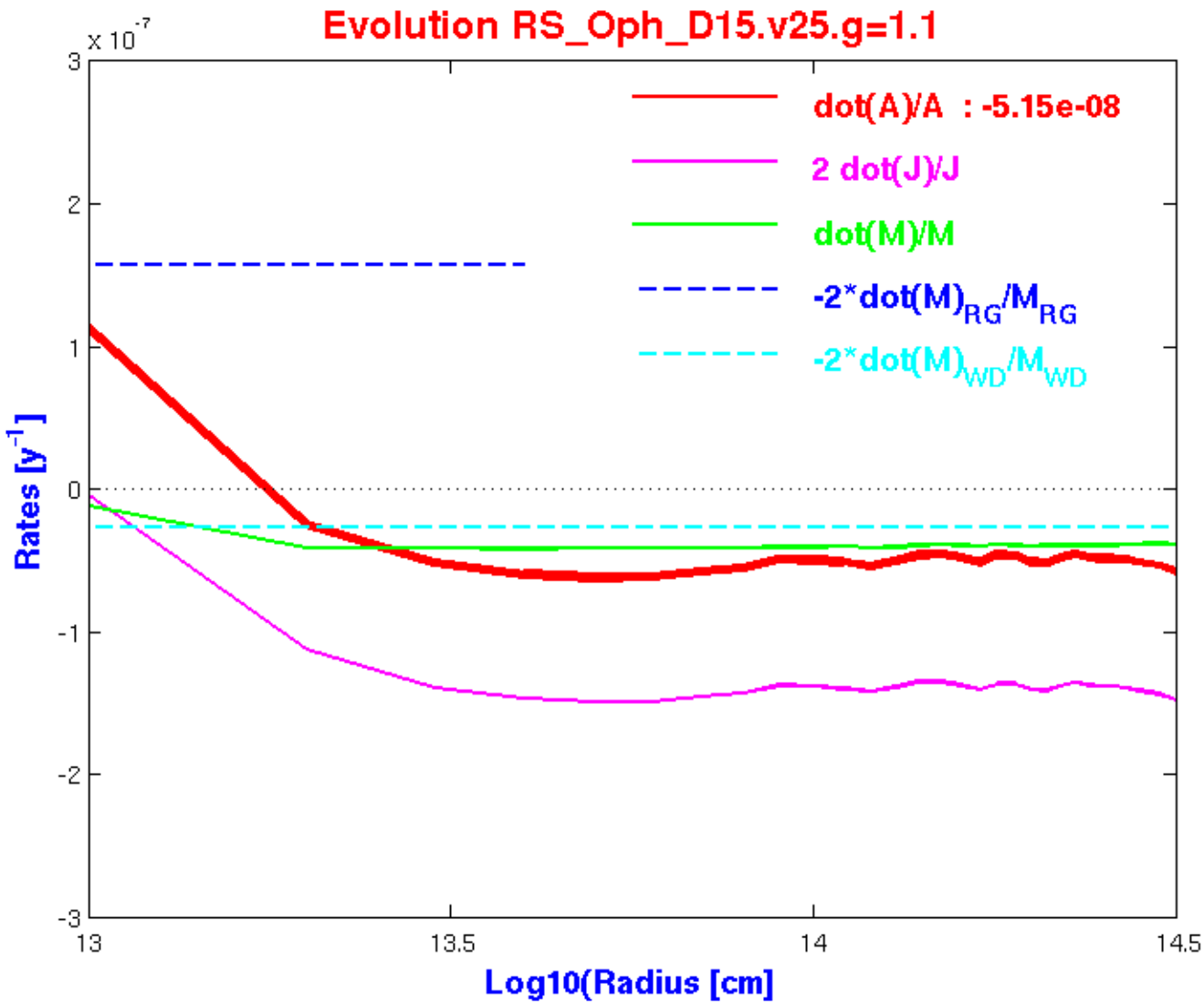


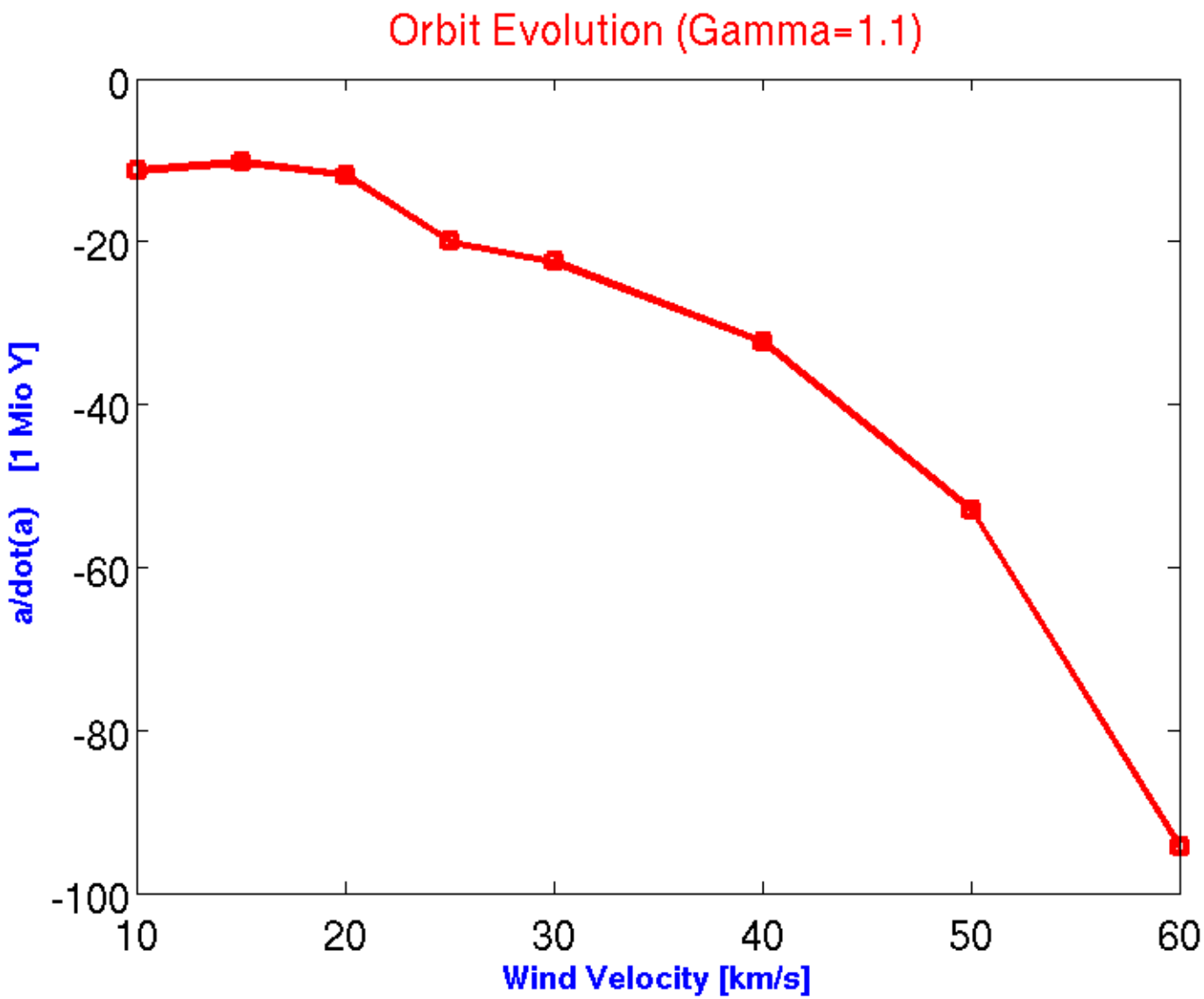
Far field: measure systemic mass and angular momentum losses

WD: measure accretion rate

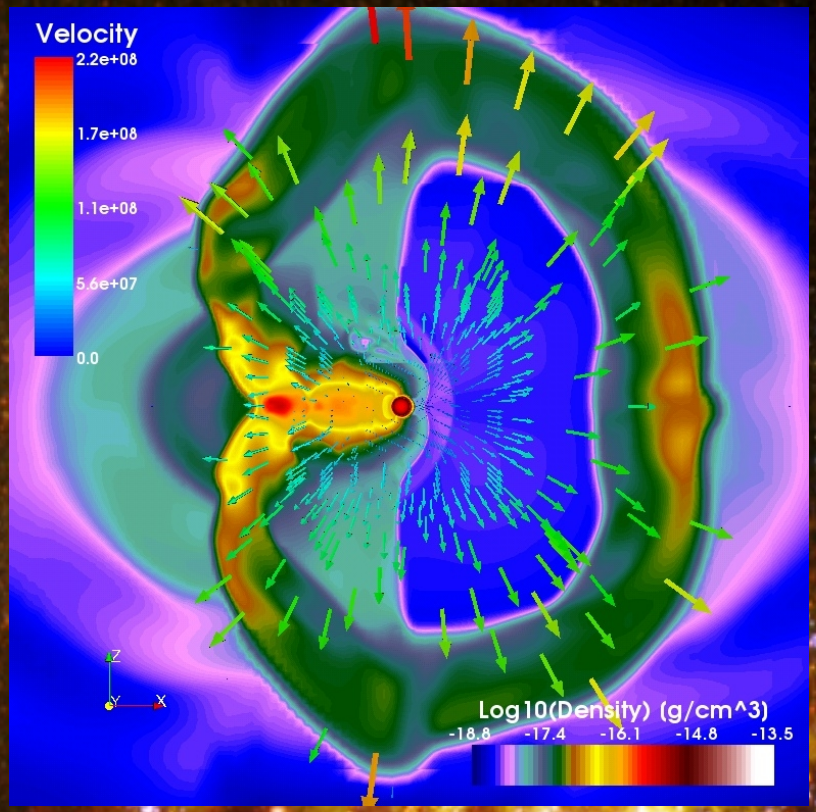
RG: control mass loss

TEST: systemic mass loss rate + accretion rate = given wind mass loss rate

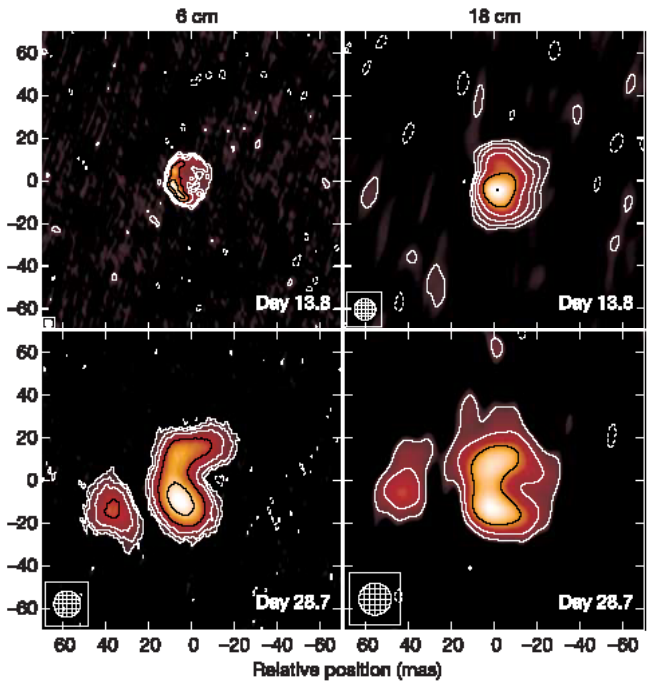

Evolution RS_Oph_D15.v25.g=1.1
x 10^-7
3
2
1
0
-1
-2
-3
Rates [y^-1]
13
13.5
14
14.5
Log10(Radius [cm]
dot(A)/A : -5.15e-08
2 dot(J)/J
dot(M)/M
-2*dot(M)RG/MRG
-2*dot(M)WD/MWD


Orbit Evolution (Gamma=1.1)
0
-20
-40
-60
-80
-100
10
20
30
40
50
60
a/dot(a) [1 Mio Y]
Wind Velocity [km/s]

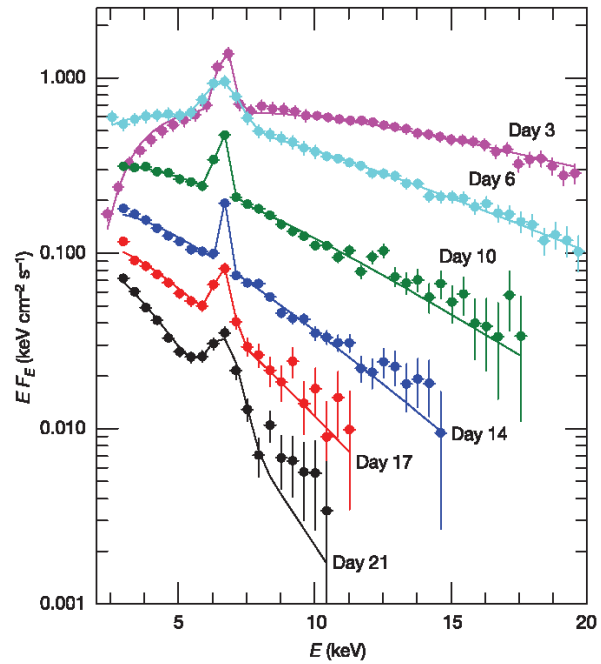
3D Simulations: the nova phase



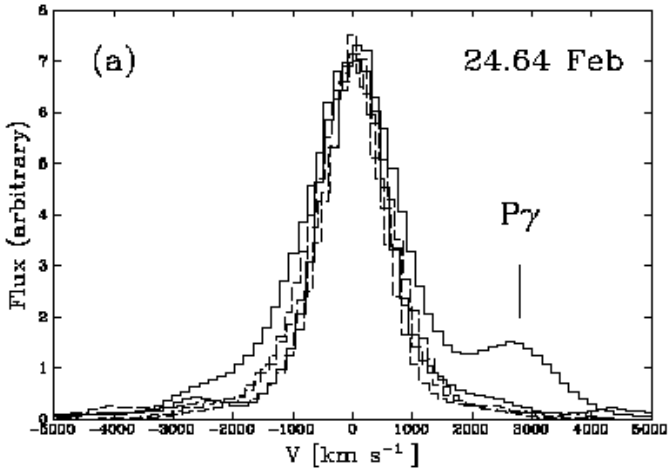
Observations of the last nova blast (2006)

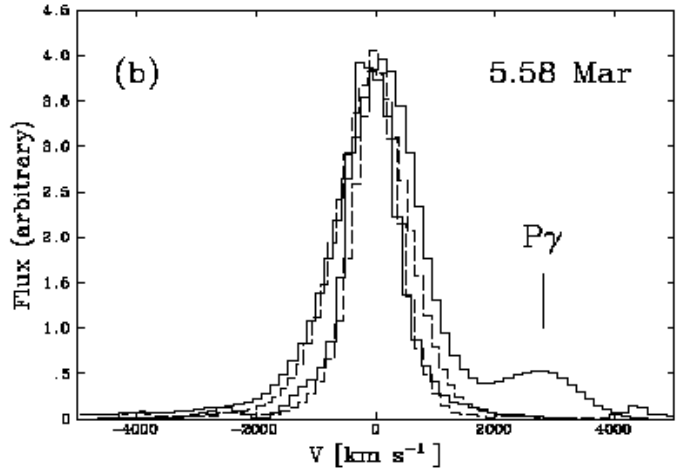


Radio, O'Brian et al., Nature 442 (2006)



X-ray, Sokoloski et al., Nature 442 (2006)





IR, Evans et al., MNRAS 2006 (astro-ph/0609394)

Summary and conclusions

We have computed for the first time in 3D the small and large scale density and velocity fields around the SNIa candidate RS Oph.

We have identified two different accretion regimes:

accretion ball (supersonic turbulence)
and a thick, non-Keplerian, disk with spiral shocks.

Accretion rate: 10 – 20 % of RG massloss rate, depending on the mass of the RG.
Flows must be close to isothermal.

Orbit decay: 3% per million years ($M_{RG} = 10^{-7}\ M_\odot$/yr; $M_{RG} = 2.3\ M_\odot$)
(with only a week dependence from M_{RG})

Massloss rate of RG: in combination with multi-cycle nova models not much less than $10^{-7}\ M_\odot$/yr.
Another, complete independent estimate!

Will RS Oph explode as an SNIa?

Quite possible; but many uncertainties remain.

1. Unknown: Nova models, what is ΔM_{cycle}?
Optimistically ΔM_{cycle} >~ + 10^{-8} $M_\odot$/cycle at (10 % of accreted)
for 0.01 $M_\odot$, we need ~10^6 cycles or <~10^7 yr at present stage.

2. Unknown: How long does the RG wind blow at this rate?
Typical time scales for RG winds are badly known, but
are perhaps on the order of 10^6 to 10^7 yr.

3. Unknown: What mass has the RG? And what evolutionary state has it?

4. Unknown: How does the decay of the orbit affect the accretion rate
and the orbit decay rate?
If mass decreases from 2.3 $M_\odot$ to 1 $M_\odot$ (~ 10^7 yr),
orbit shrinks from 2.68 10^{13} cm to 2.32 10^{13} cm.
This results in about the same decay rate but
doubled accretion rate.