The flow structure in the classical symbiotic system Z And during its active phase

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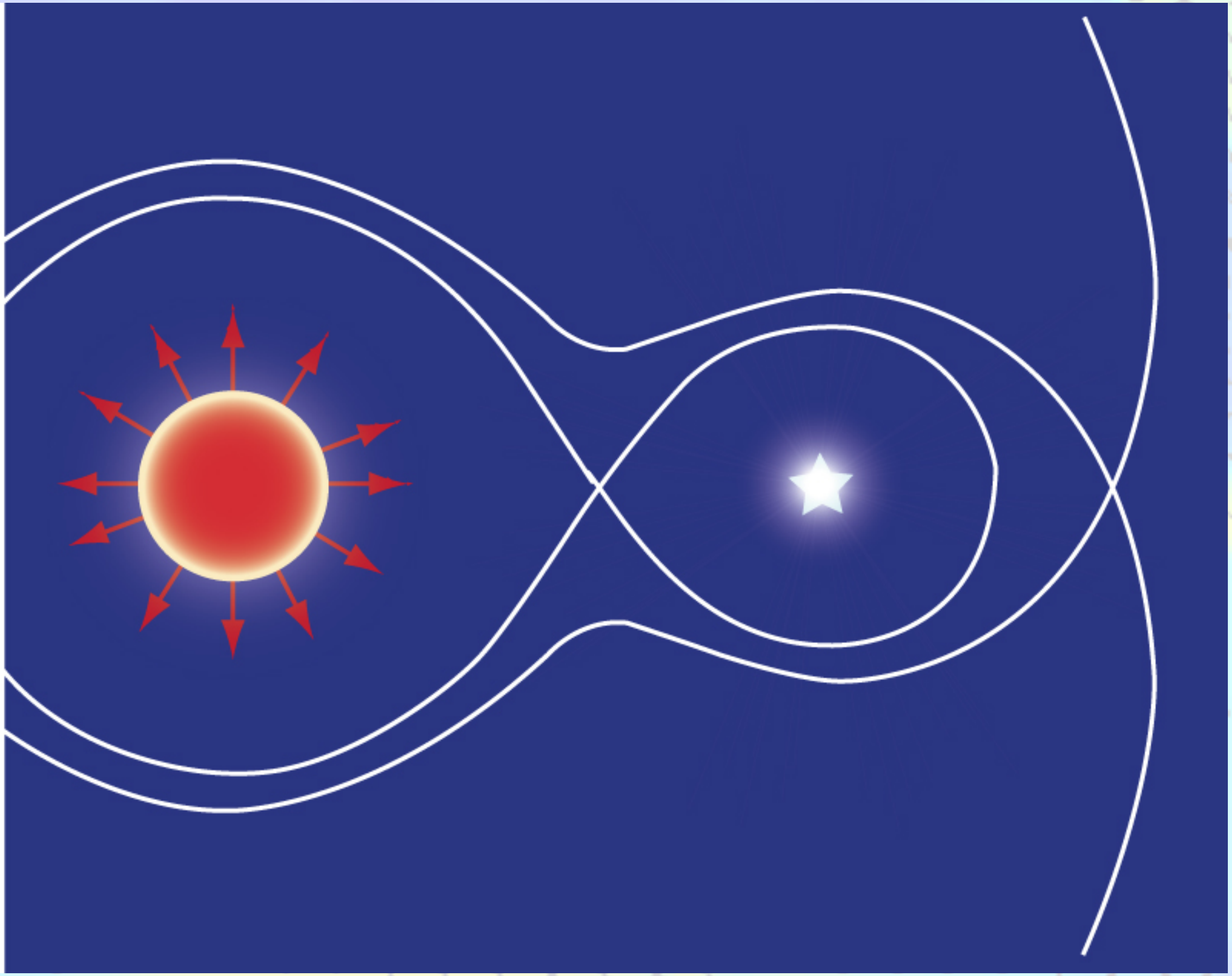


A typical symbiotic star is a detached system with mass exchange driven by stellar wind.

OUTBURSTS IN SYMBIOTIC STARS

Following the characteristics of their outbursts, symbiotic stars can be divided in two types:

1. **Symbiotic novae** ***(e.g. V1016 Cyg, V1329 Cyg, RS Oph, HM Sge).*** **These outbursts are longer and brighter. Their energetics can even exceed that of novae outbursts.**

2. **Classical symbiotic stars** ***(e.g. Z And, AG Peg, AG Dra, CI Cyg, AX Per).*** **Outbursts are typically last a few months and have amplitudes of 2-4^{m}.**

LEAVING THE STEADY BURNING RANGE

Case 1. Accretion rate becomes lower than the steady burning range:

Accreted material becomes exhausted → Burning termination → Matter accumulation on the surface → Hydrogen shell flash

Corresponds to the observational manifestations of symbiotic novae

Case 2. Accretion rate exceeds the steady burning range

Accreted matter accumulates above the burning shell → Expansion to giant's dimensions

Timescale and brightness changes correspond to classical symbiotic stars

This work deals with classical symbiotic stars using as example one of the most well-studied representatives of this class - Z And.

Part I

The structure of the gas flow in Z And in quiescence and during outburst

The Symbiotic System Z And

Components:

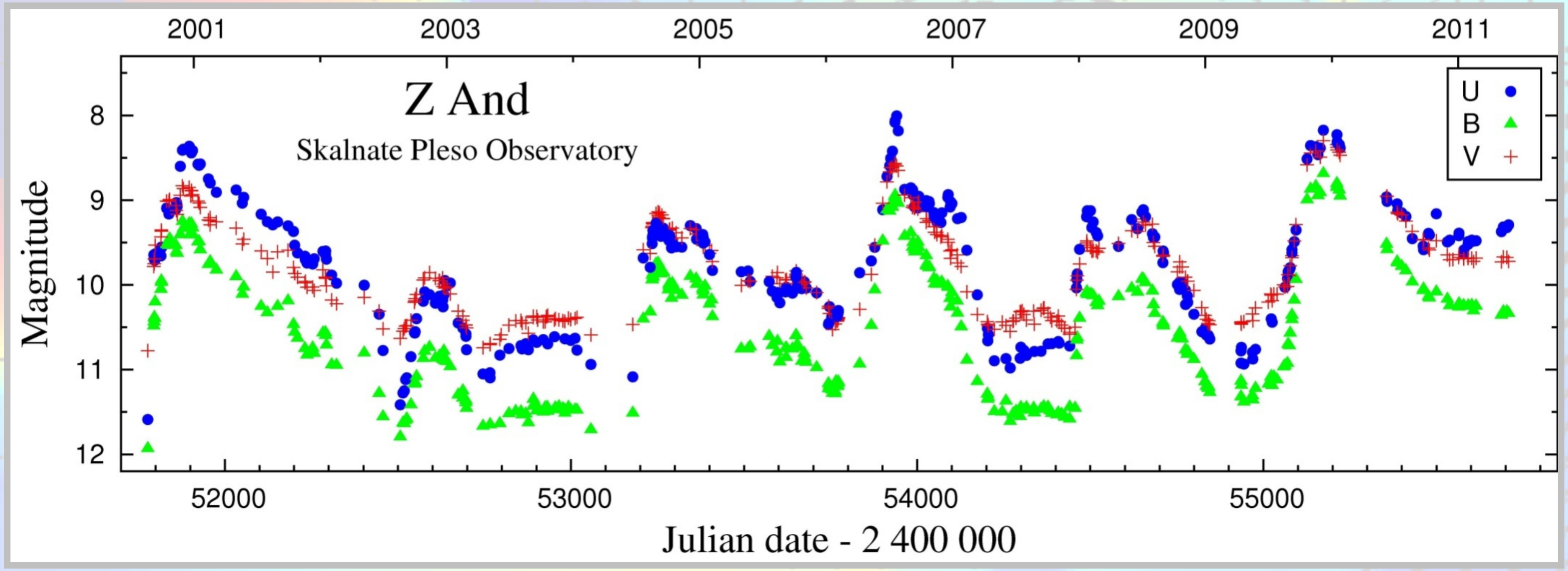
- A normal M4.5 III giant
- A white dwarf with $T_{eff} \geq 10^5$ K
- A partly photoionized surrounding nebula
- Orbital period P = 758.8^d

Active phases of Z And:

After 1915, 1939, 1960, 1984 and 2000.

Light Curve of Z And During Its Last Active Phase After 2000

1 2 3 4 5 6



Skopal et al. (2012)

OUTBURST IN A CLASSICAL SYMBIOTIC SYSTEM

- In quiescent state *accretion* rate is within the steady burning range
- At some moment accretion rate increases and oversteps the limits of the steady burning range.
- The time scale of the accretion rate increase should correspond to the characteristic time of outburst development.

What is the reason of the accretion rate growth?

REASON OF THE ACCRETION RATE GROWTH

In order to explain the accretion rate change several mechanisms were proposed:

- **Significant change of the donor's mass loss (Nussbaumer&Vogel, 1987) –** ***not confirmed by observations***
- **Accretion disk instabilities (Bath, 1977) –** ***no correspondence on scale and time***
- **Using the results of gasdynamic modeling we proposed the mechanism that can provide the accretion rate growth (Bisikalo et al., 2002)**

MECHANISM PROVIDING THE ACCRETION RATE GROWTH

Minor variations of giant's wind velocity → **Accretion regime change** → **Jump of the accretion rate**

Even minor variations in the donor's wind velocity is enough to lead to the accretion regime change - from disc accretion to wind accretion. During the transition period, namely during the disc destruction the accretion rate increases abruptly and exceeds the upper limit of the steady burning range.

THE MODEL

- The flow was described by the system of Euler equations in corotating coordinate frame.

EQUATIONS

$$\frac{\partial\rho}{\partial t}+\frac{\partial\rho u}{\partial x}+\frac{\partial\rho v}{\partial y}+\frac{\partial\rho w}{\partial z}=0$$

$$\frac{\partial\rho u}{\partial t}+\frac{\partial\left(\rho u^2+P\right)}{\partial x}+\frac{\partial\rho uv}{\partial y}+\frac{\partial\rho uw}{\partial z}=-\rho\frac{\partial\Phi}{\partial x}+2\Omega v\rho$$

$$\frac{\partial\rho v}{\partial t}+\frac{\partial\rho uv}{\partial x}+\frac{\partial\left(\rho v^2+P\right)}{\partial y}+\frac{\partial\rho vw}{\partial z}=-\rho\frac{\partial\Phi}{\partial y}-2\Omega u\rho$$

$$\frac{\partial\rho w}{\partial t}+\frac{\partial\rho uw}{\partial x}+\frac{\partial\rho vw}{\partial y}+\frac{\partial\left(\rho w^2+P\right)}{\partial z}=-\rho\frac{\partial\Phi}{\partial z}$$

$$\frac{\partial\rho E}{\partial t}+\frac{\partial\rho uh}{\partial x}+\frac{\partial\rho vh}{\partial y}+\frac{\partial\rho wh}{\partial z}=-\rho u\frac{\partial\Phi}{\partial x}-\rho v\frac{\partial\Phi}{\partial y}-\rho w\frac{\partial\Phi}{\partial z}$$

$$P=\left(\gamma-1\right)\rho\varepsilon$$

GRIDS

2D:

601×601cells

689×589 cells (condensed near the accretor)

3D: 253×253×85 cells

The Roe-Osher scheme has been used for 2D and SFS (simplified flux splitting) scheme for 3D.

THE MODEL

- The flow was described by the system of Euler equations in corotating coordinate frame.
- Since the mechanism of gas acceleration is poorly known for cool giants, we mimic the radiation pressure by reducing the gravitational attraction force to the donor star by a factor $1-\Gamma$.

MODELING OF A GIANT'S WIND

$$\mathbf{F} = \Gamma \frac{GM_1}{r^2} \frac{\mathbf{r}}{|\mathbf{r}|}$$

M_1 – mass of the donor, r – distance from the center of the donor, Γ – parameter.

The modified potential :

$$\Phi = -\frac{GM_1}{\left(x^2+y^2+z^2\right)^{1/2}} + \boxed{\Gamma \frac{GM_1}{\left(x^2+y^2+z^2\right)^{1/2}}} - \frac{GM_2}{\left((x-a)^2+y^2+z^2\right)^{1/2}} - \tfrac{1}{2}\Omega^2\left(\left(x-\frac{M_2}{M_1+M_2}a\right)^2+y^2\right)$$

THE MODEL

- The flow was described by the system of Euler equations in corotating coordinate frame.
- Since the mechanism of gas acceleration is poorly known for cool giants, we mimic the radiation pressure by reducing the gravitational attraction force to the donor star by a factor $1-\Gamma$.
- The value of adiabatic index has been accepted 1.01, that corresponds to the case close to the isothermal one.

PARAMETERS OF Z AND

Mass of the donor M_1	$2M_\odot$
Radius of the donor R_1	$77\ R_\odot$
Mass of the accretor M_2	$0.6M_\odot$
Radius of the accretor R_2	$0.07\ R_\odot$
Orbital period P_{orb}	758.8 days
Separation A	$482.53\ R_\odot$
Mass loss rate	$2\times10^{-7}\ M_\odot$
Donor's wind velocity	25 км/с

T.Fernandez-Castro, A.Cassatella, A.Gimenez et al., Astrophys. J., 324, 1016 (1988)

CALCULATIONS PERFORMED

1. $v = 25 - 5 = 20$ km/s:

- To study the possibility of disc formation in the system
- To estimate the accretion rate value
- To check if the accretion rate is indeed within the limits of the steady burning range

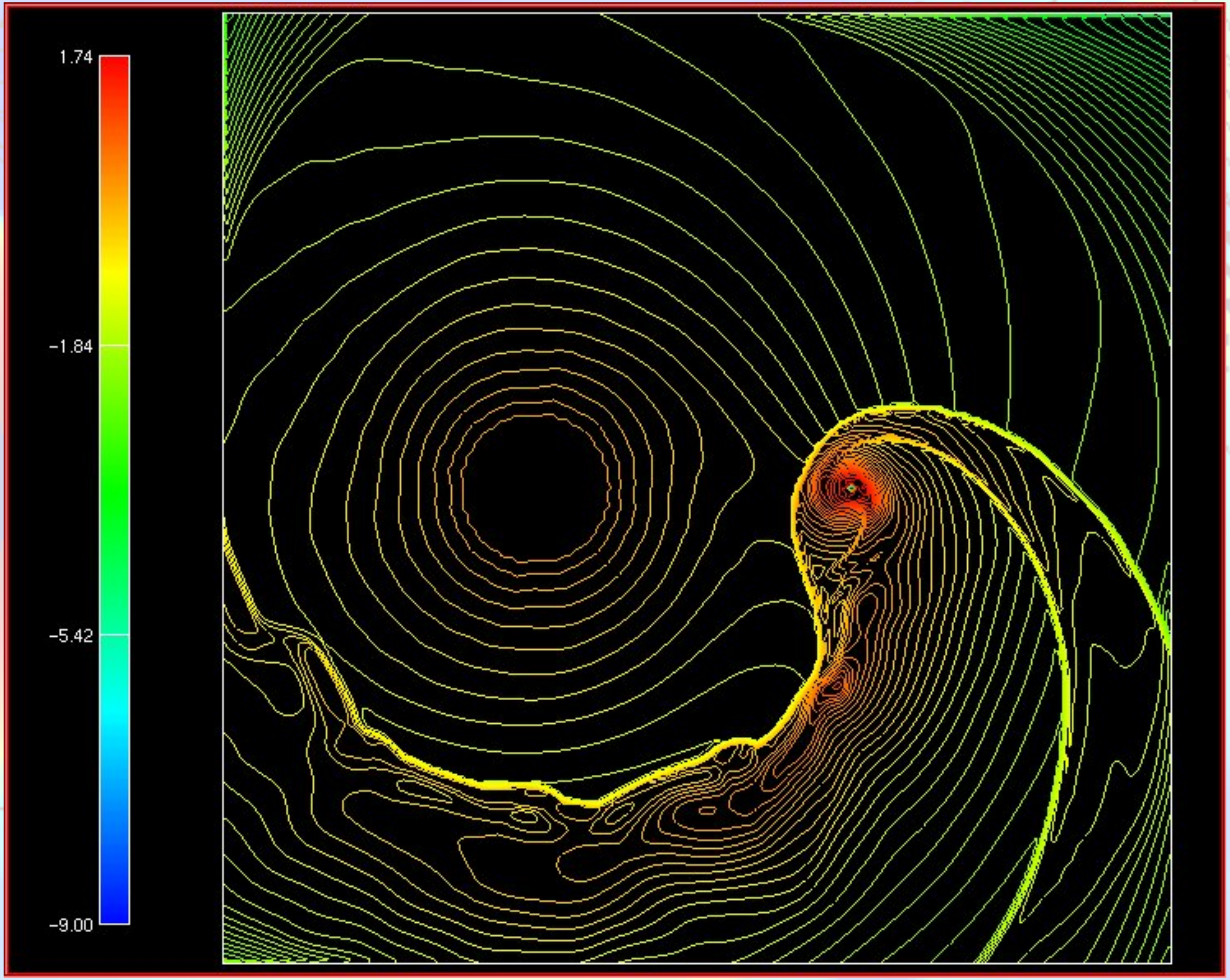
2. $v = 25 + 5 = 30$ km/s :

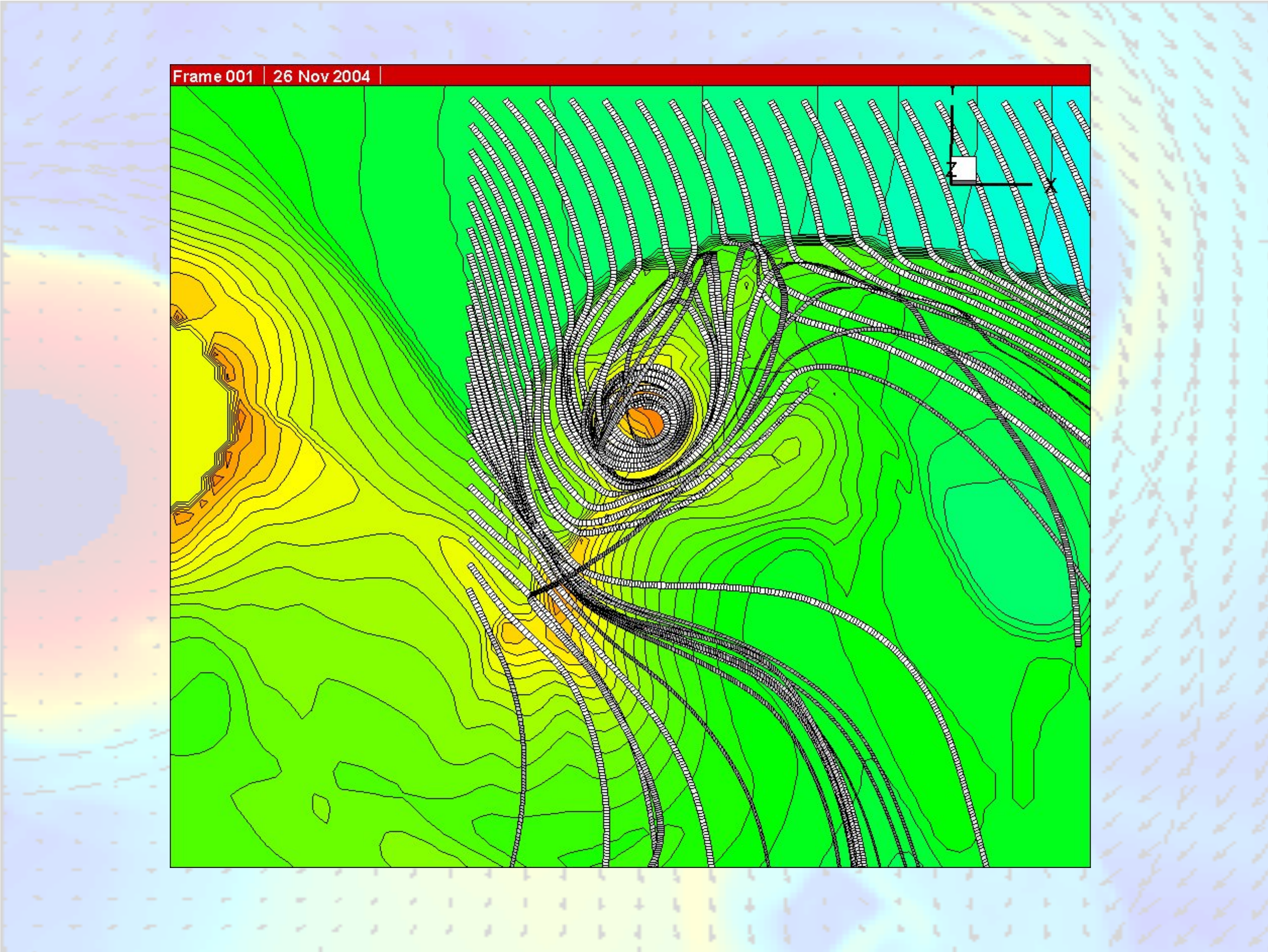
- To obtain parameters of the flow structure in the system without disc

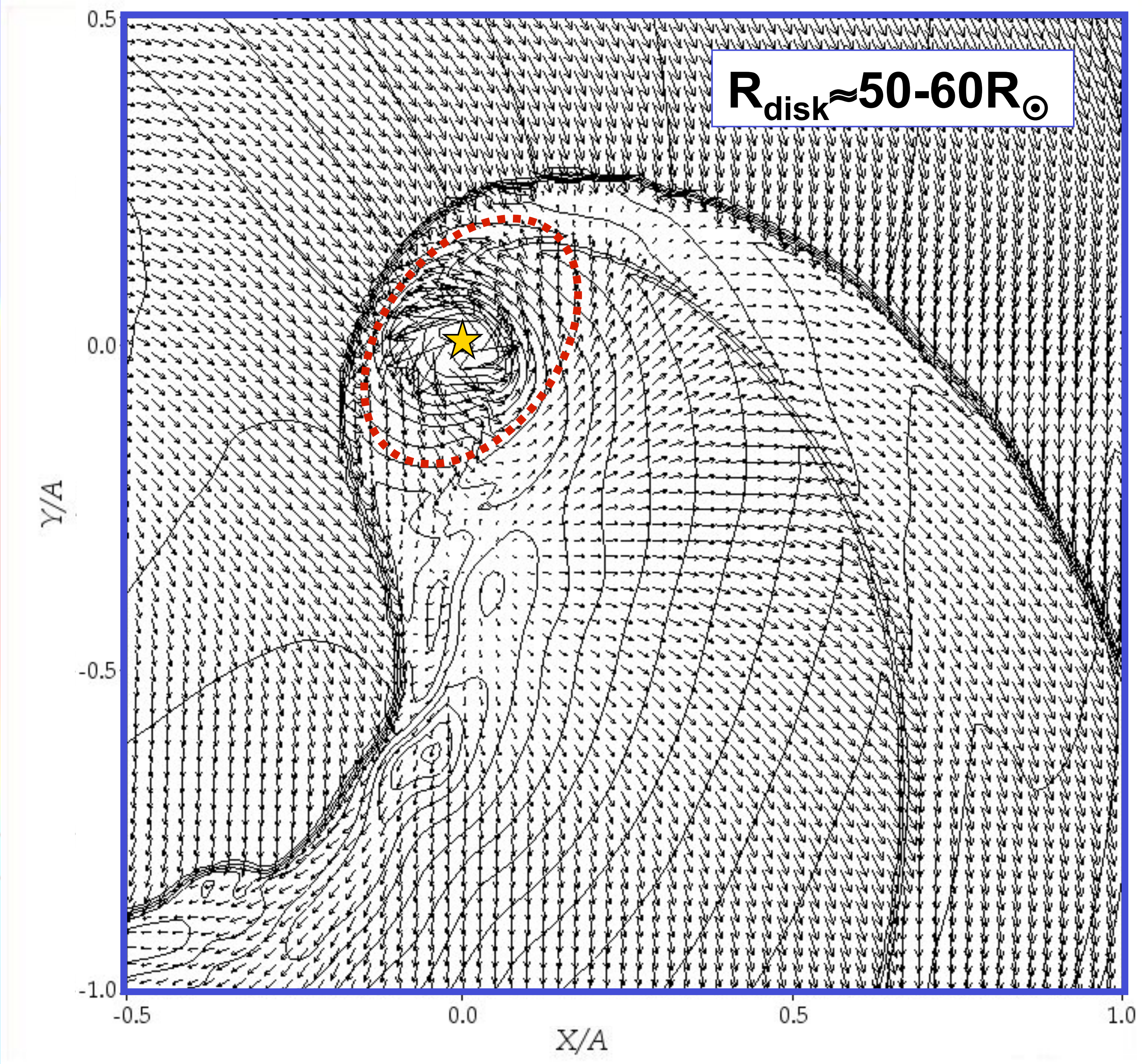
3. $v = 20 \rightarrow 30$ km/s :

- To study the process of disc destruction
- To estimate the accretion rate growth
- To find out if the accretion rate growth is enough to leave the steady burning range?

DONOR WIND VELOCITY V=20 КМ/С




Frame 001
26 Nov 2004
Y
Z
X



$R_{disk} \approx 50\text{-}60 R_\odot$
0.5
0.0
-0.5
-1.0
Y/A
-0.5
0.0
0.5
1.0
X/A

- For wind velocity v=20 km/s and values of the parameter $\Gamma \in [0.85-0.95]$ a steady accretion disc forms in the system.
- Accretion efficiency in this case is

$$\dot{M}_{accr} = 22.5-25\%$$

- For Z And where the mass loss rate is estimated to be $\sim 2\times10^{-7} M_{\odot}/yr$, and the accretion rate will be

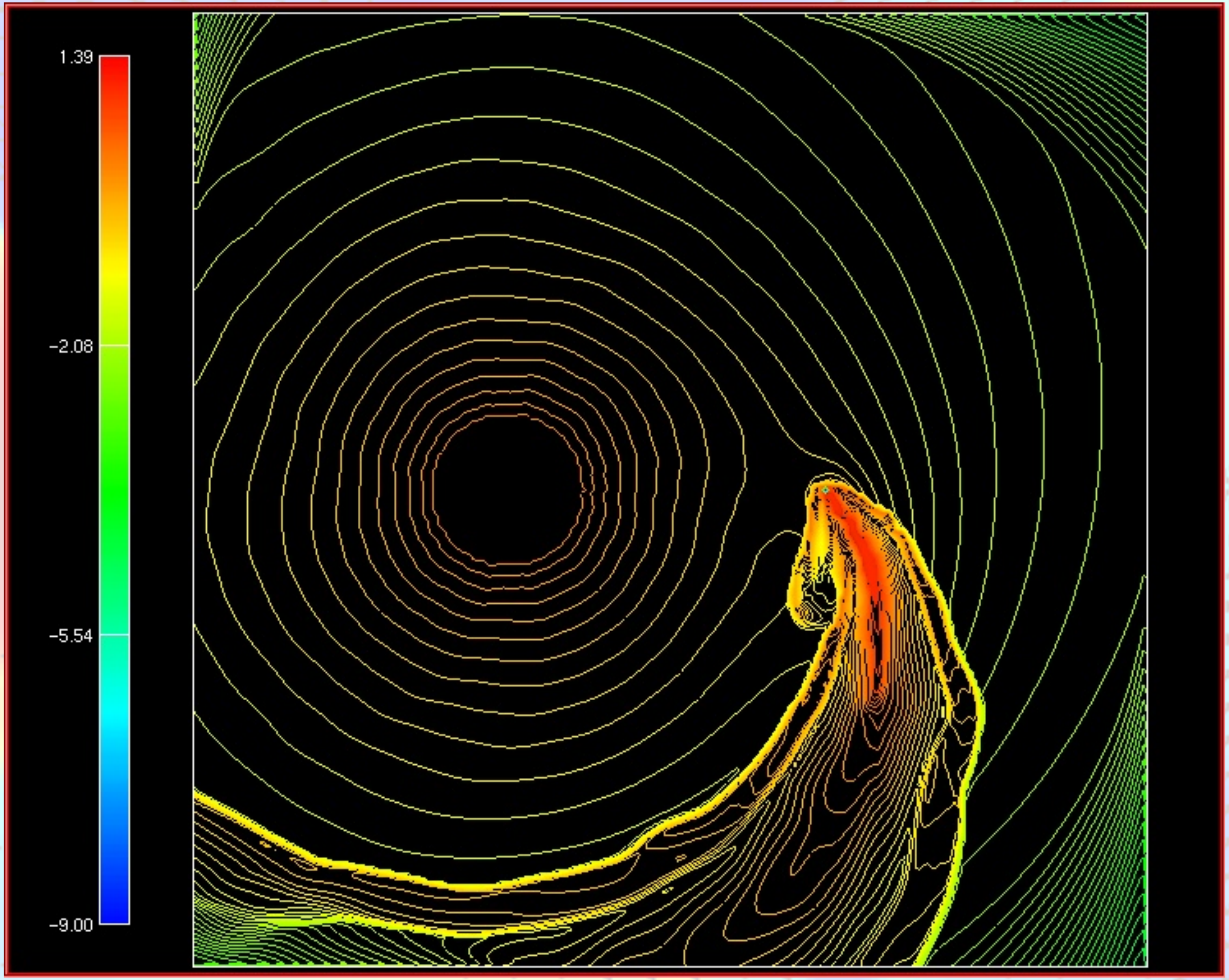
$$\dot{M}_{accr} = 4.5-5\times10^{-8} M_{\odot}/год$$

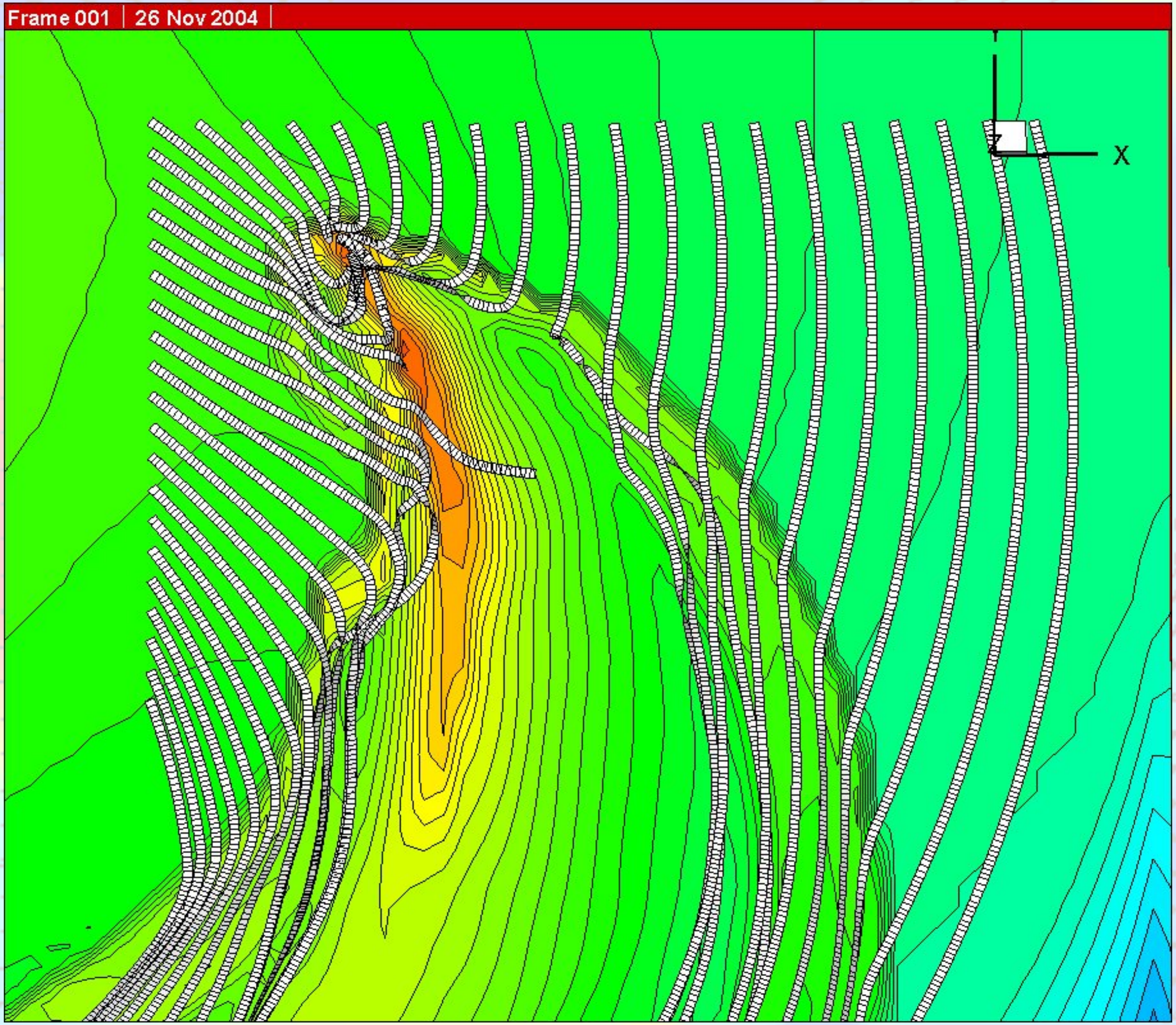
- For Z And ($M_{WD}=0.6M_{\odot}$) steady burning is possible if

$$2.1\times10^{-8} M_{\odot}/год \le \dot{M}_{accr} \le 4.7\times10^{-8} M_{\odot}/год$$

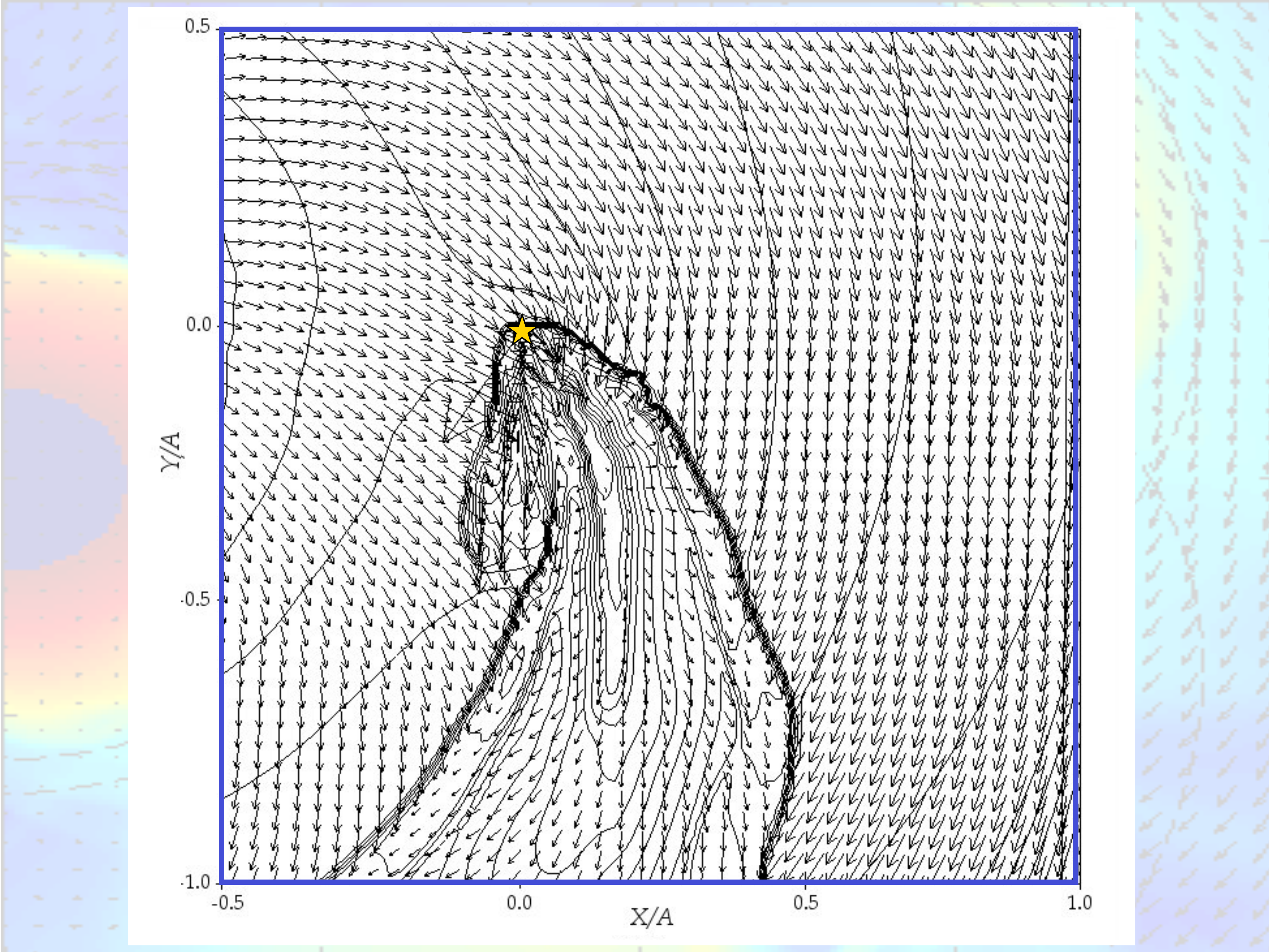
I.e. the accretion rate for the solution with the accretion disc corresponds to the steady burning range (near the upper limit).

DONOR WIND VELOCITY V=30 KM/S





Frame 001
26 Nov 2004
Z
X


0.5
0.0
-0.5
-1.0
Y/A
-0.5
0.0
0.5
1.0
X/A

- If the wind velocity equals 30 km/s the cone shock forms.
- Accretion efficiency in this case is $\dot{M}_{accr} = 11 - 13\%$

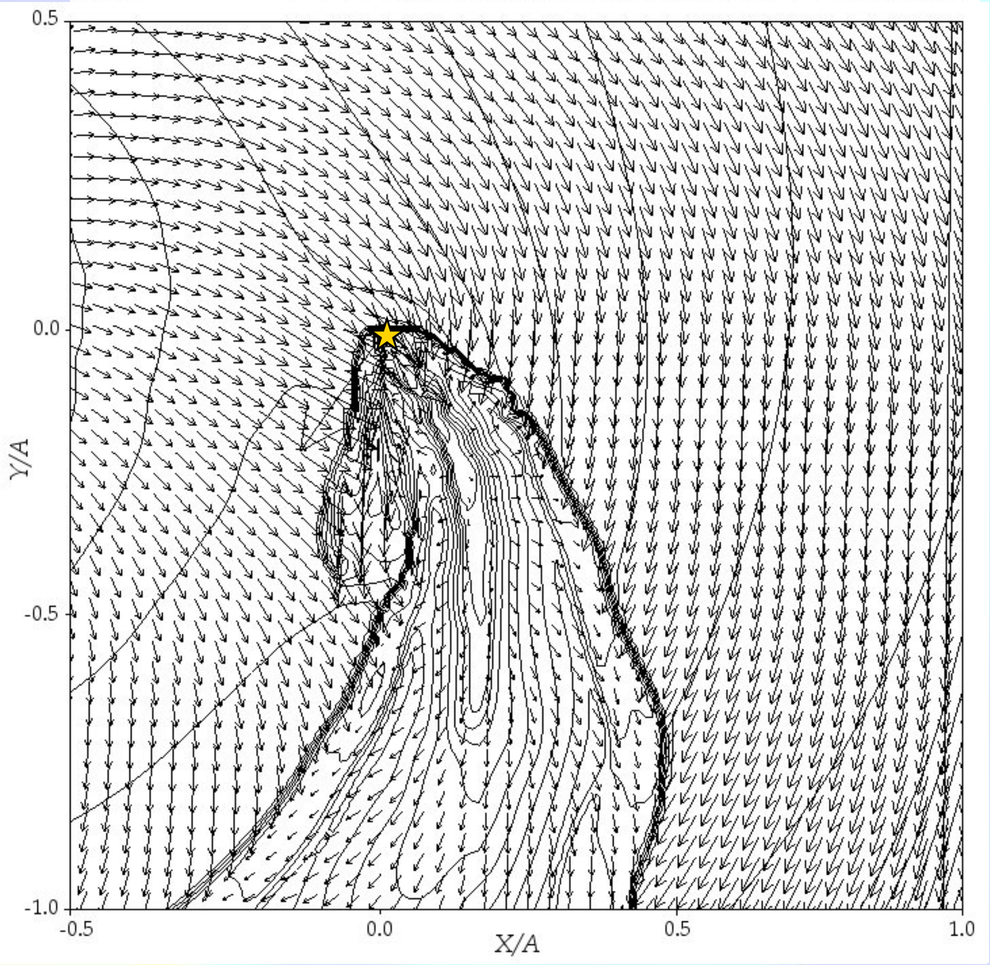
The analysis of results presented above allows to conclude that even small change in the donor's wind velocity (within ±5 km/s around the observed value 25 km/s) leads to a flow structure and accretion regime changeover, namely, to the transition from a disc to a wind accretion flow.

WIND VELOCITY CHANGE 20→30 KM/S

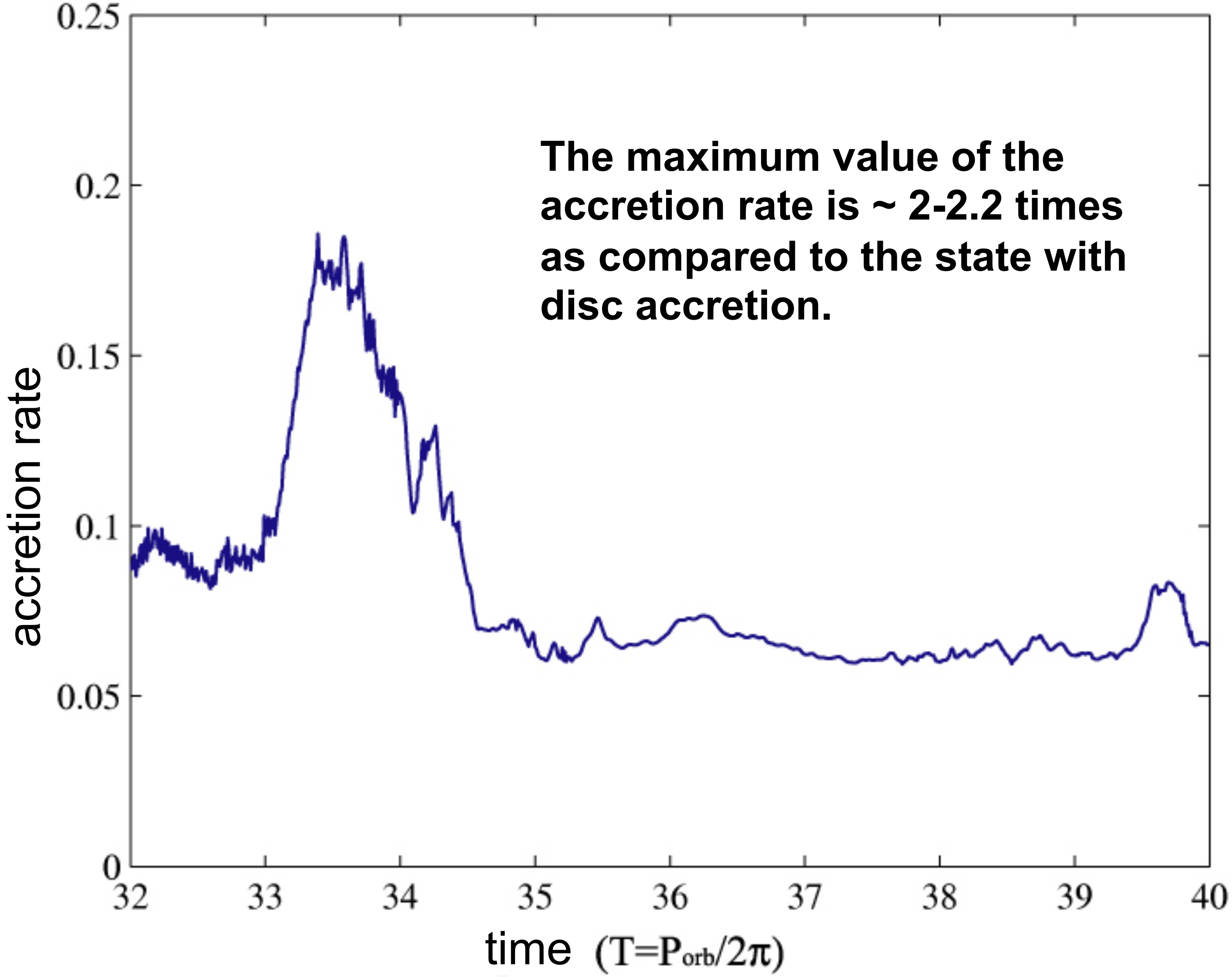
It takes about 133^d for the matter moving with increased velocity to reach the bow shock located in front of the accretor.

After that the wind moves further, crushes disk and makes the matter it contained to fall onto the surface of the accretor.

This results in the accretion rate jump.



ACRETION RATE CHANGE



Time scale:

For Z And the outburst development time is ~100^d.

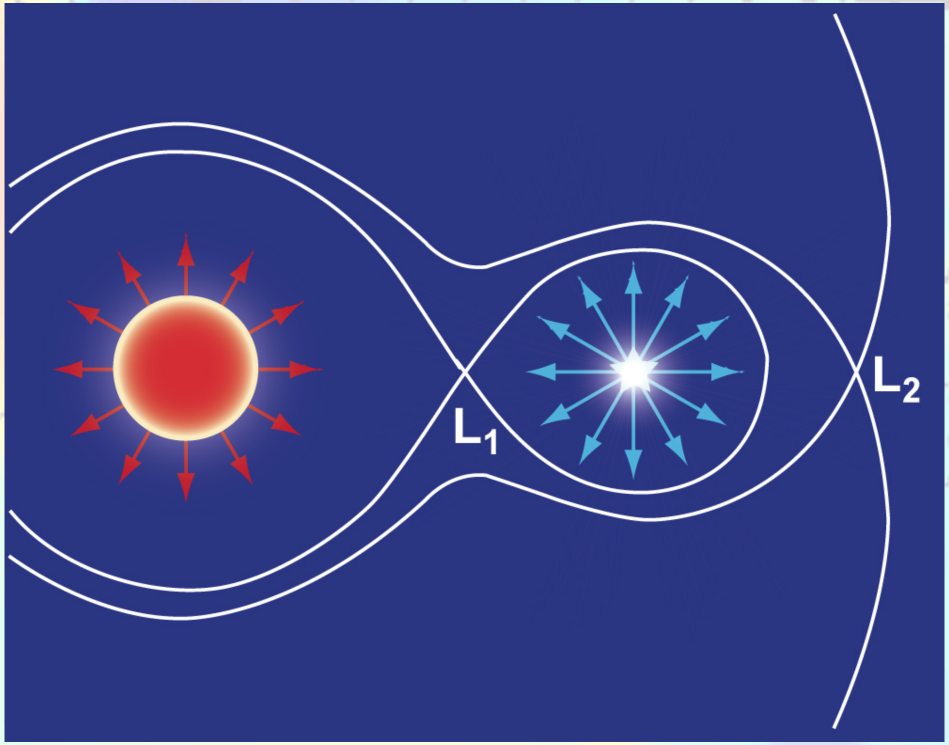
According to our results the full time of disc destruction is approximately ~180^d.

If we assume that the system leaves the steady burning range after the accretion rate increases in 1.5 times, the corresponding time will be ~100 days, in good agreement with observations.

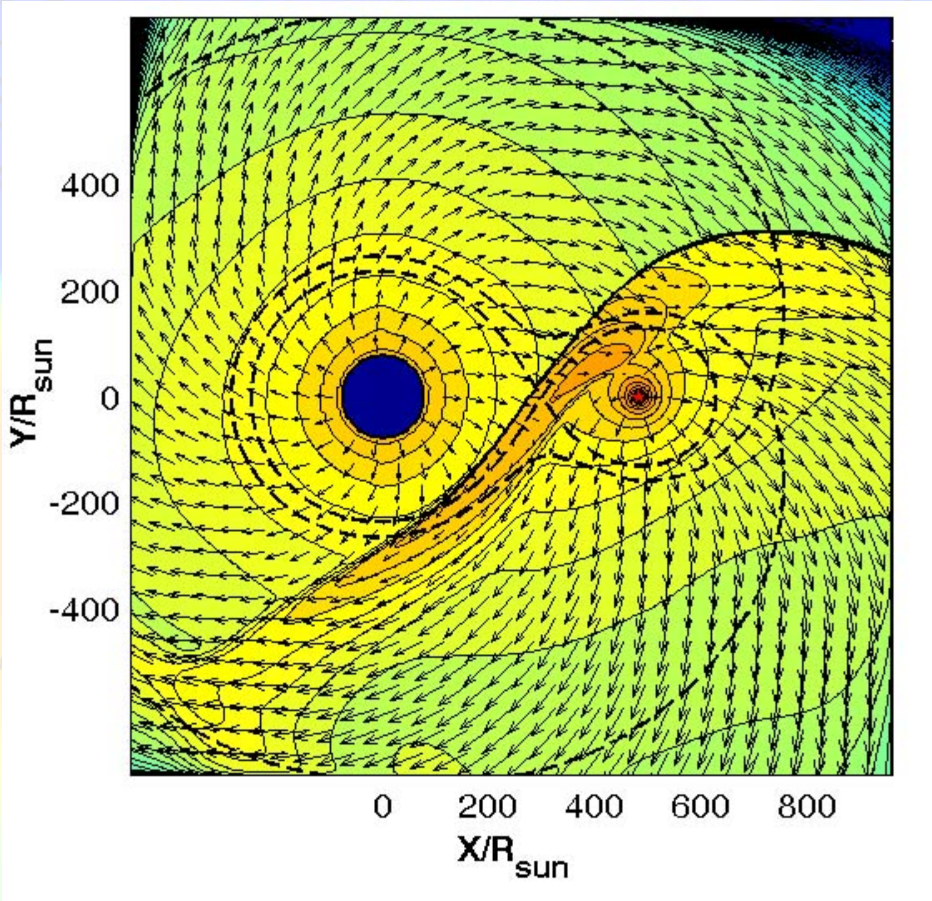
Part II

Colliding winds in classical symbiotic stars

There are a lot of symbiotics where the wind from the hot component has been observed at active stages of the system (e.g. Z And). In such a case winds from both components collide and form the complex structure with shocks.

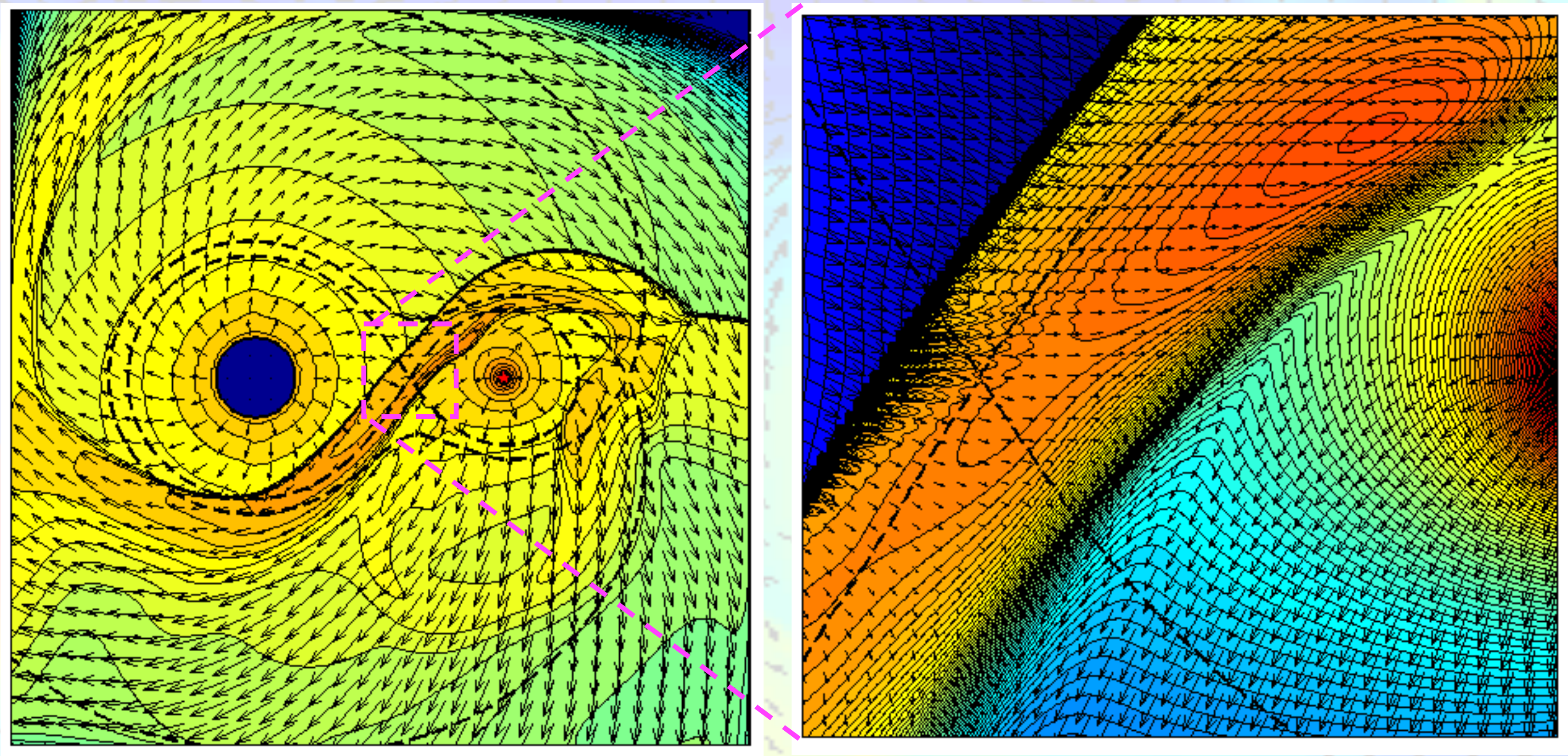


We took the stationary solution corresponding to the pre-outburst state and continued calculations with changed boundary conditions on the accretor's surface.



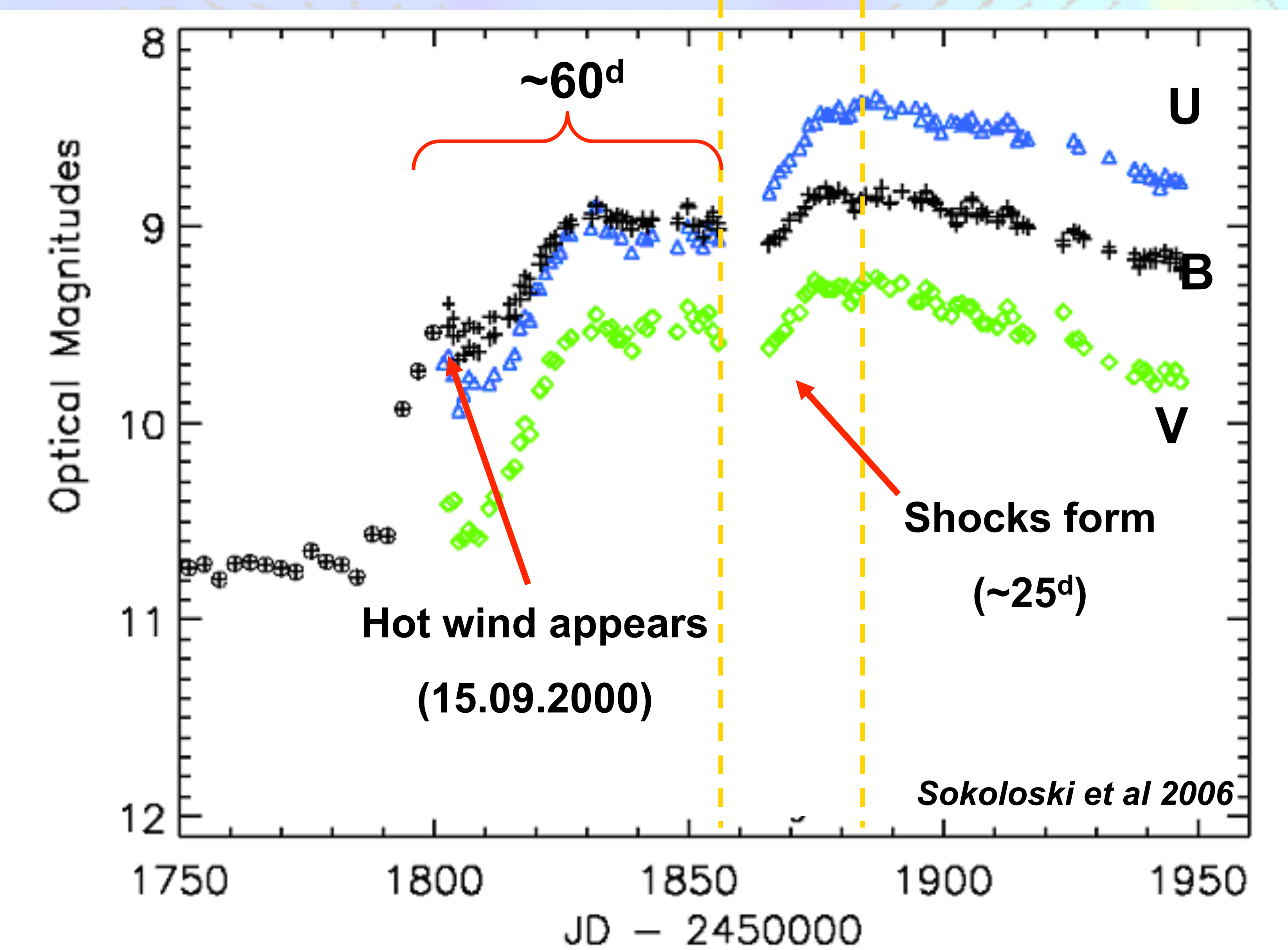
After 70^d the waves reach their final position between the system's components and it takes 20-30 days for the formation of shocks structure to be completed.

SHOCKS CONTRIBUTION TO THE BRIGHTNESS OF THE SYSTEM



Shocks formation can provide the brightness growth up to 1^m so it should be seen on the lightcurve.

Z AND LIGHT CURVE FOR THE OUTBURST AT 2000



SHOCK IONIZATION ESTIMATION

$$\mu = \frac{L}{n_e n_+ \alpha V}$$

The ratio of the number of ionizing photons to recombinations

Date (state of the system)	μ
15.09.1999 (quiescence)	1.12
22.11.2000 (outburst, rise to the second maximum)	1.00
06.12.2000 (outburst, near maximum)	0.76

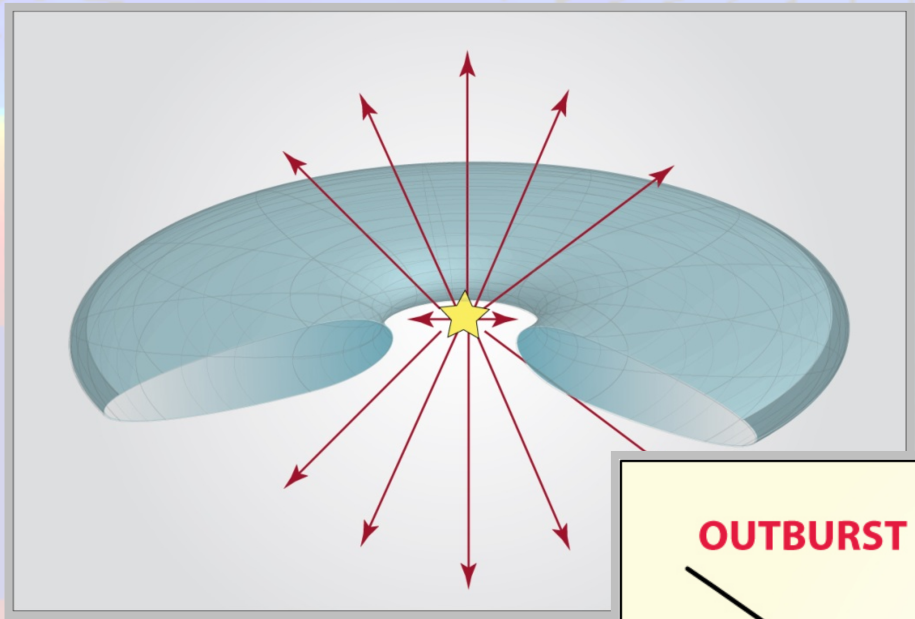
At the maximum of the outburst 24% of the emission of nebulosity can be the result of the shocks formed.

Conclusions

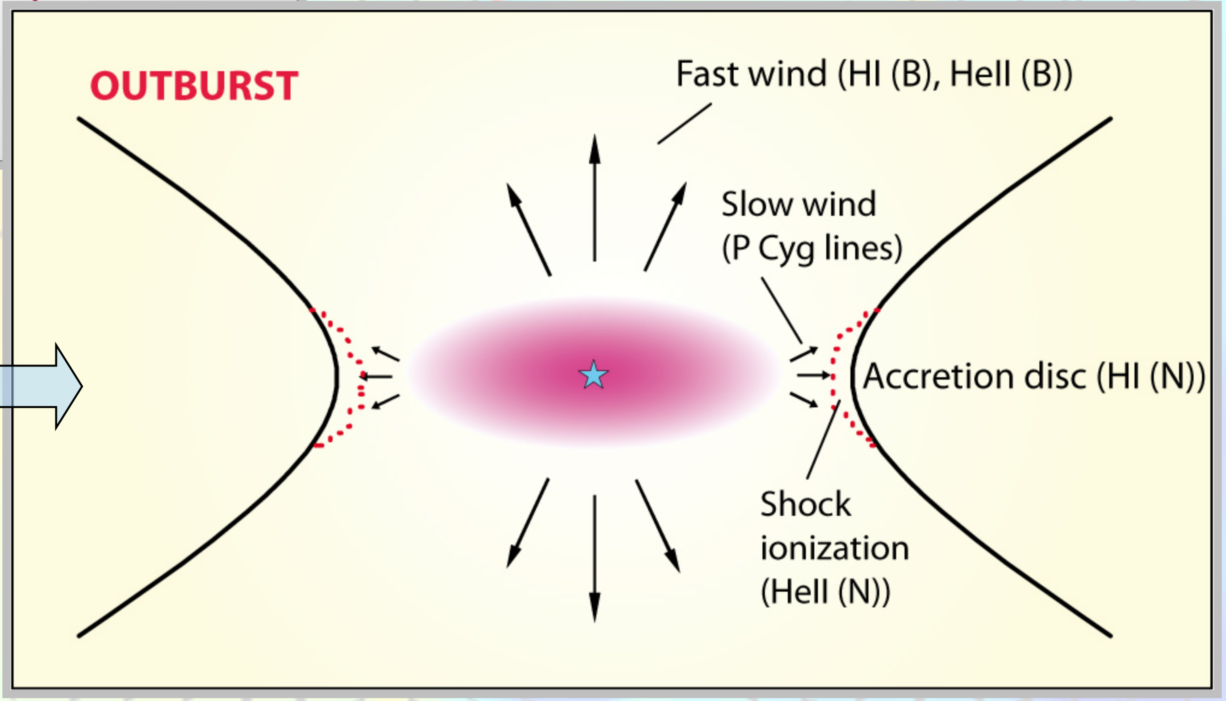
- ***The analysis of results presented here allows us to draw the main conclusion that the transition from quiescent to active state in symbiotic stars can be concerned with the accretion regime change (transition from the disc accretion to wind accretion) as the result of insignificant variations of donor's wind velocity.***

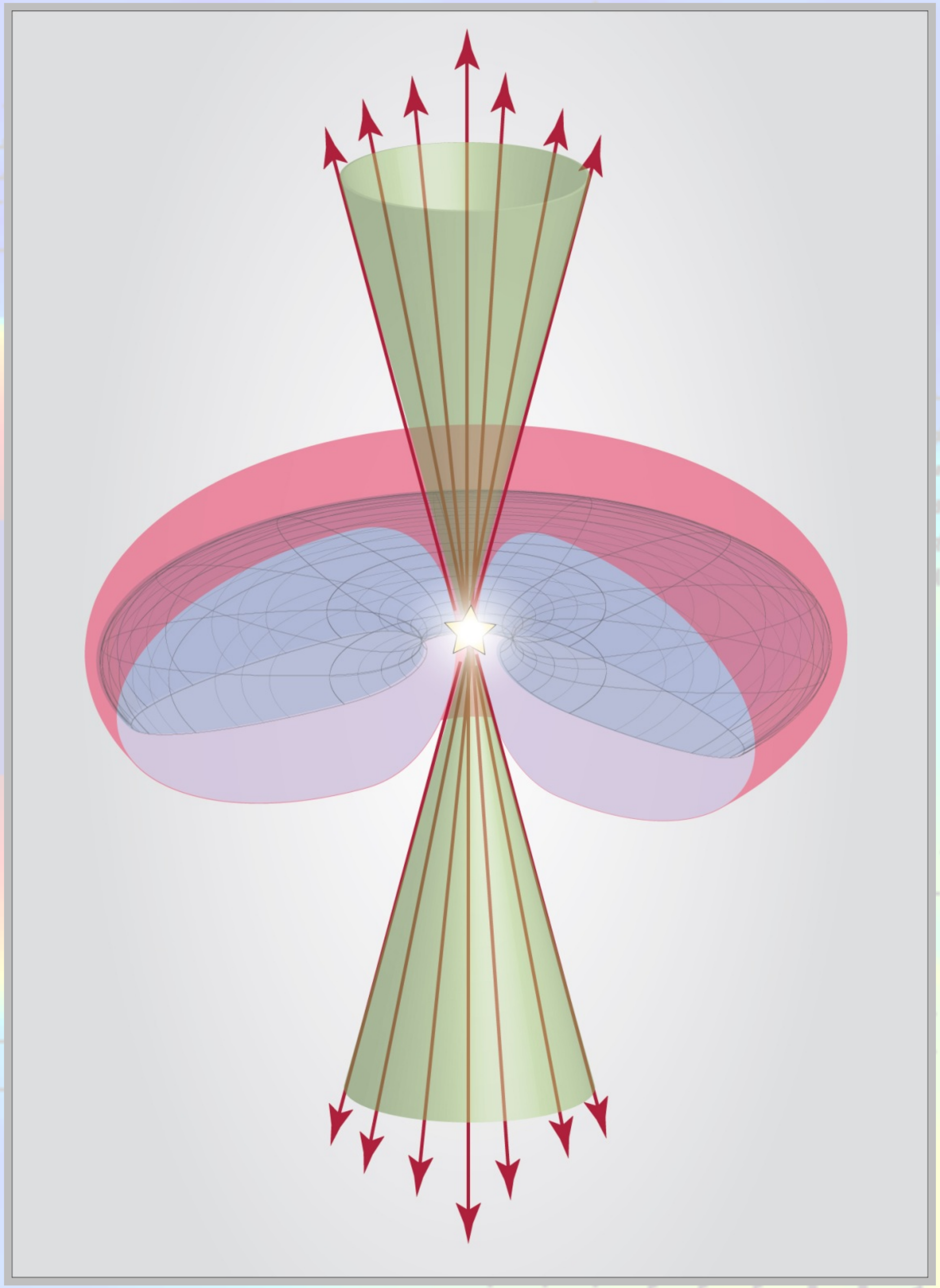
- ***Outburst development is well described in the framework of the colliding winds model.***

Schematic model of the region around the hot component during the first outburst



Schematic model
in the plane
perpendicular to the
orbital plane





Schematic model of the region around the hot component during a recurrent strong outburst (2006)