High-resolution simulations of the Interaction between Nova/Supernova Ejecta and the nearby Accretion Disk

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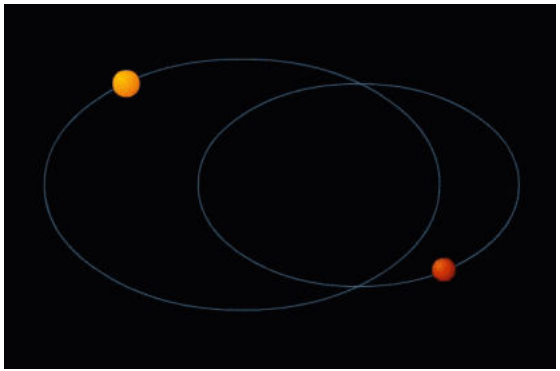
White Dwarfs in Binary Systems

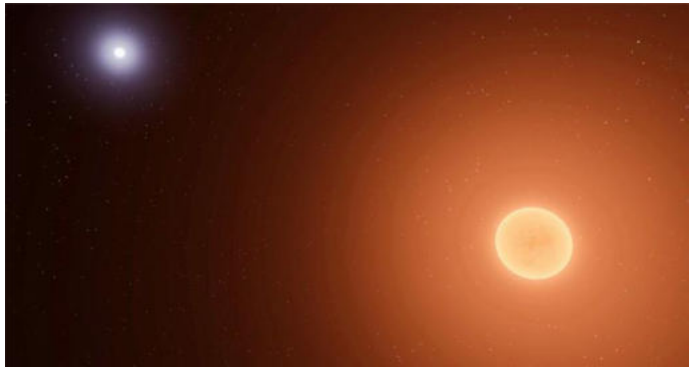
Approximately **30 to 50%** of stars are **binary** or multiple

Stars with different mass **evolve differently**, the lesser massive star outlives the other

After their main sequence life, stars **<8-10$M_{\odot}$** become **white dwarfs** (WDs)

We can find binary systems with either 1 or 2 white dwarfs (single or double degenerate scenarios)





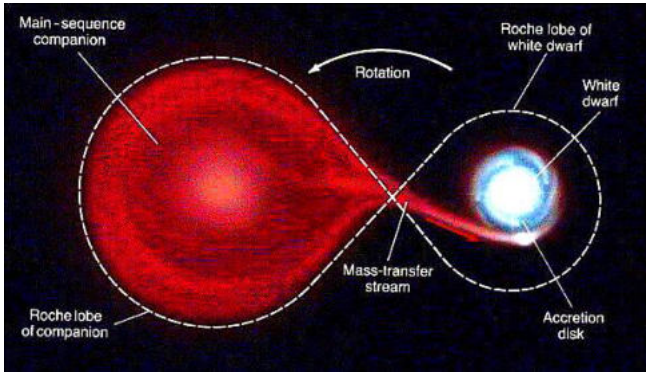
Mass transfer

The stars tend to get closer, the WD can receive mass from its **main sequence companion**.

The **accretion** takes place via **Roche Lobe overflow** (material surpass equipotential point)

More easily from **Red Giants** due to their size.

The material possess **angular momentum** and falls spiraling into the WD forming an **accretion disk**.



Nova & Type Ia Supernova Outbursts

The accreted material is mostly Hydrogen, which is heated (compressional heating) and nuclear burning occurs in the WD atmosphere.

Depending mainly on the rate of accretion, the new material added to the WD can lead to different explosive events: novae and supernovae

Nova: Hydrogen burning is unstable, temperature increases quickly and the whole envelope is blown up in a runaway reaction. Very bright events (10^4 - 10^5 LSun). *(Jose 2016, Starrfield et al. 2008)*

Type Ia Supernova: Hydrogen burning is stable, WD accumulates mass until ~1.4$M_\odot$, when density and temperature at the core is such that Carbon is ignited and the whole star is blown up from the inside. Extremely bright event (~10^{10} LSun). *(Hillebrandt, W., Kromer, M., Röpke, F.K. et al. 2013)*

Recurrent Novae

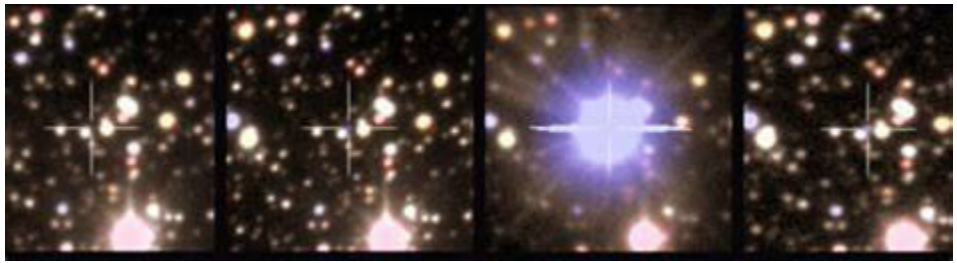
During Nova explosions only the outermost layers of the star are ejected, they do not disrupt the WD nor the binary system.

Novae can recur as enough material is again builded up into the WD, with periods around 10^4 - 10^5 years.

Those bursts observed multiple times within a short period ~1-100 years are called recurrent novae.

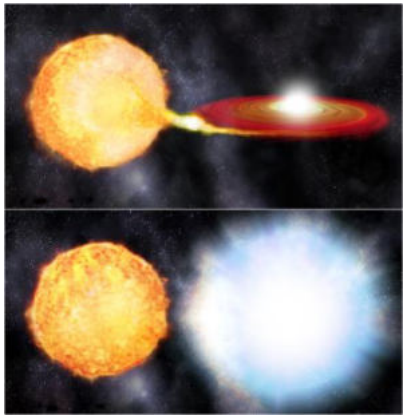
They are believed to originate from very massive White Dwarfs with high accretion rates.

In the Milky Way, only 10 recurrent nova have been discovered.



Observational cycle of recurrent novae

The goal: Study the role of the Disk



Typical novae studies focus on **early stages** of the explosion.

What happens to the accretion disk after a nova or supernova outburst?

Is the **disk destroyed**?

Is the ejected material **screened** by the disk?

Does the disk **distort the spherical geometry** of the ejecta?

Does the nova/supernova ejecta **impact the companion** star differently with or without the disk?

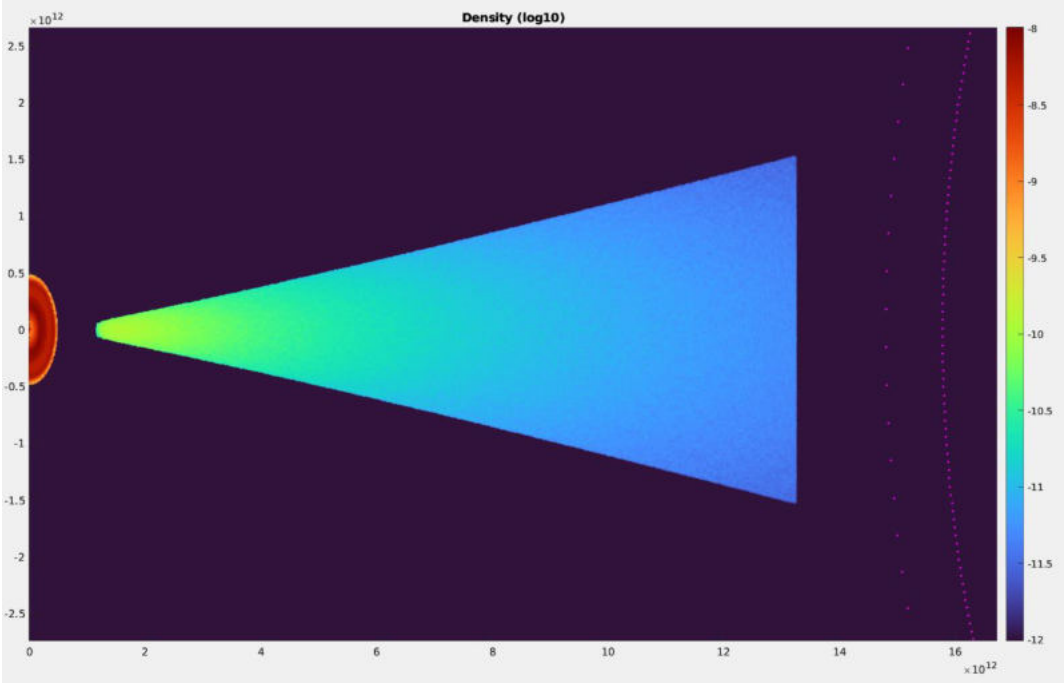
Does this impact **recurrence time**?

High Resolution Simulations: Axisymmetric SPH

Due to the **Rotational symmetry** of the WD-disk system, we can perform **2-D axisymmetric** simulations, which are much **faster and less expensive** than in full 3-D.

Hydrodynamic code → **Axis-SPHYNX** *(García-Senz 2022)*, a state-of-the-art axisymmetric **Smooth Particle Hydrodynamics** code

Effective resolution is $N_{3D} = (N_{2D})^{3/2}$, a calculation with 10^6 particles in 2-D equals 10^9 in 3-D



Planned Scenarios, Exploring Parameters

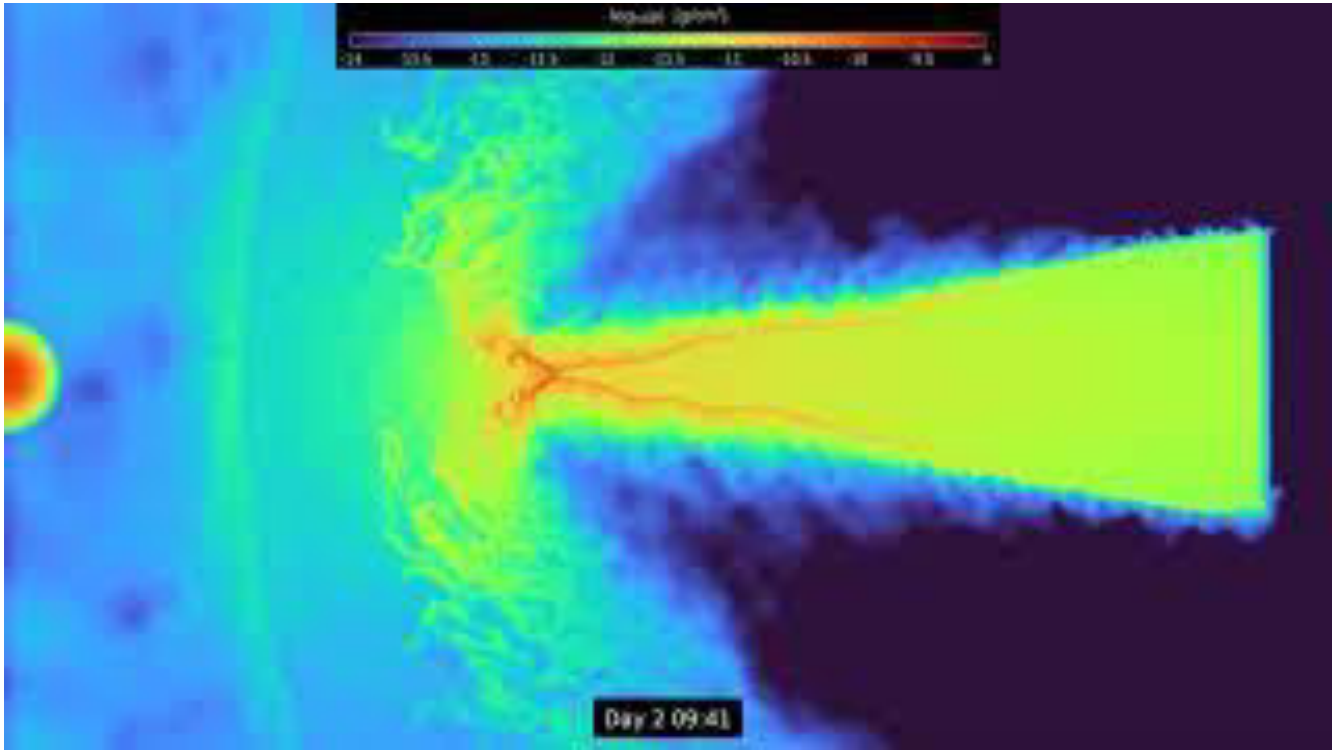
Name	WD mass	Ejecta mass	Velocity [km/s]	Orbital period	Accretion rate
Recurrent 1 (RS Oph)	1.38	1.2e-6	4200	454 days	2e-7
Recurrent Nova 2	1.38	1.2e-6	4200	5 days	2e-7
Classical Nova 1 (CO)	0.6	2e-4	1000	10 hours	2e-10
Classical Nova 2	1.25	2e-4	1000	10 hours	2e-10
Classical Nova 3	1.25	2e-5	1000	10 hours	2e-10
Classical Nova 4 (ONe)	1.25	2e-5	2600	10 hours	2e-10
Type Ia Supernova	1.36	1.36	7100	7.78 hours	5e-7

Recurrent Nova RS Ophiuchi (P. Orb = 454 days)

Resolution of 10^6 SPH particles, corresponds to a an effective 3D resolution of 10^9

Roughly 20 days running with 32 CPUs (~15.000 CPU hours)

Appearance of Kevin-Helmholtz instabilities due to shear flows

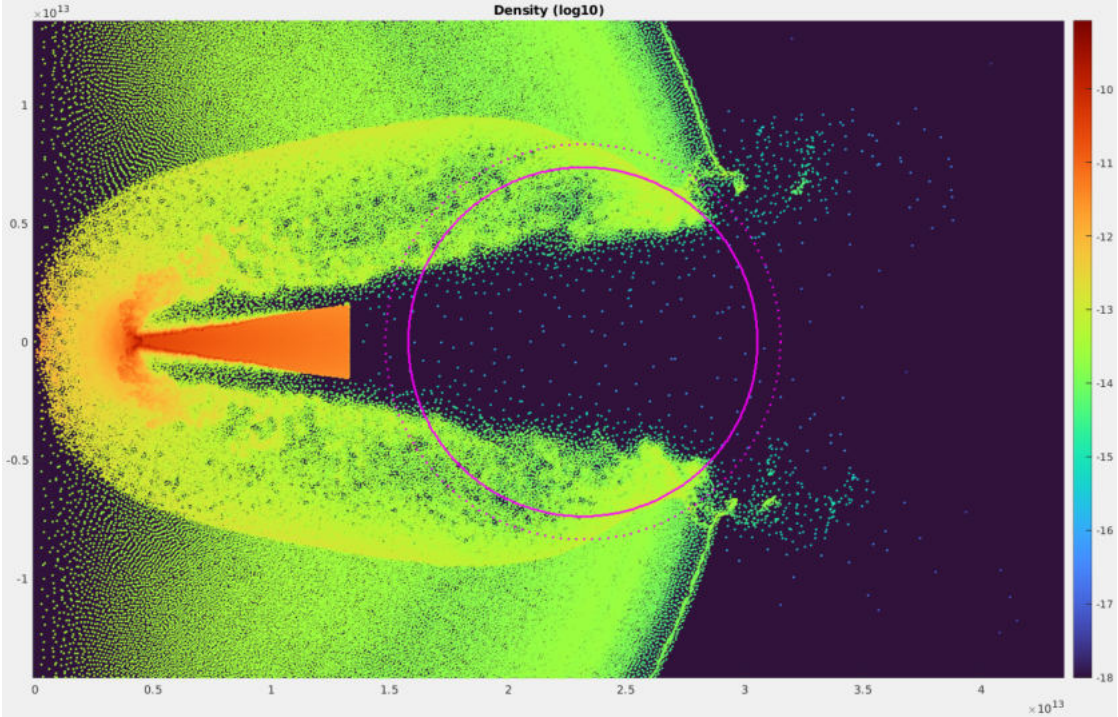


Disk Shielding/Screening

The disk survives and leaves a gap in the geometry of the ejecta

This impacts the chemical pollution onto the Red Giant companion, which is greatly reduced

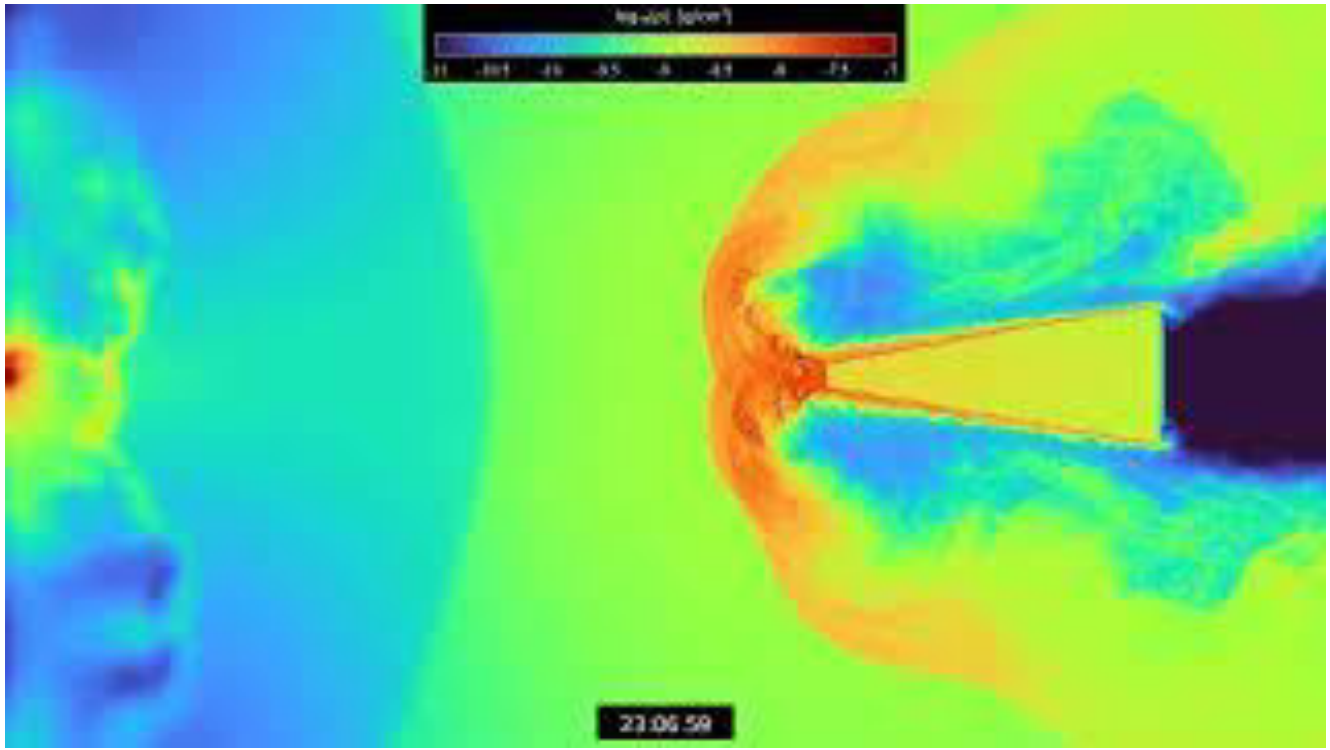
The survival of the disk favours recurrence, the disk is not build again from scratch



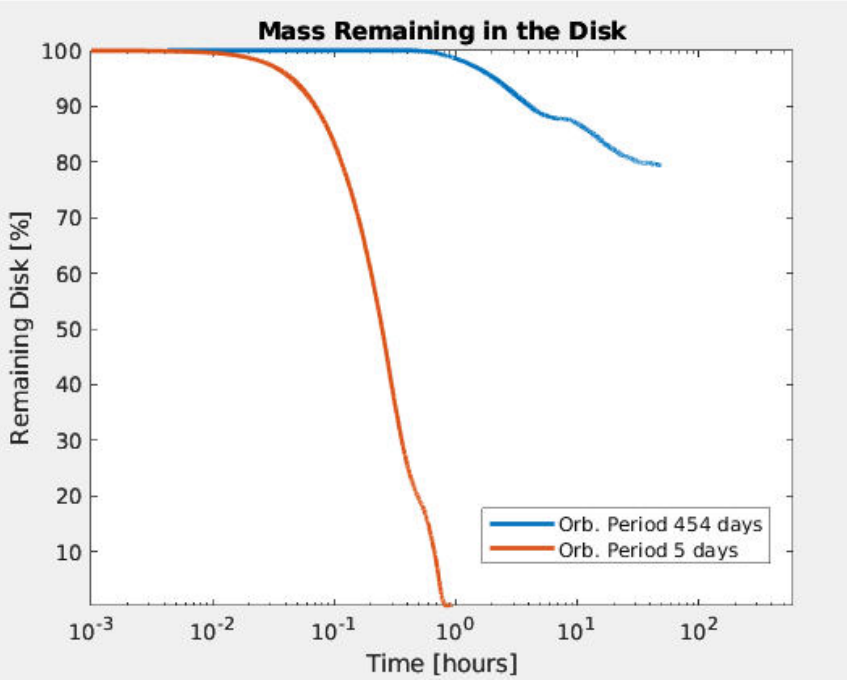
Recurrent Nova (P. Orb = 5 days)

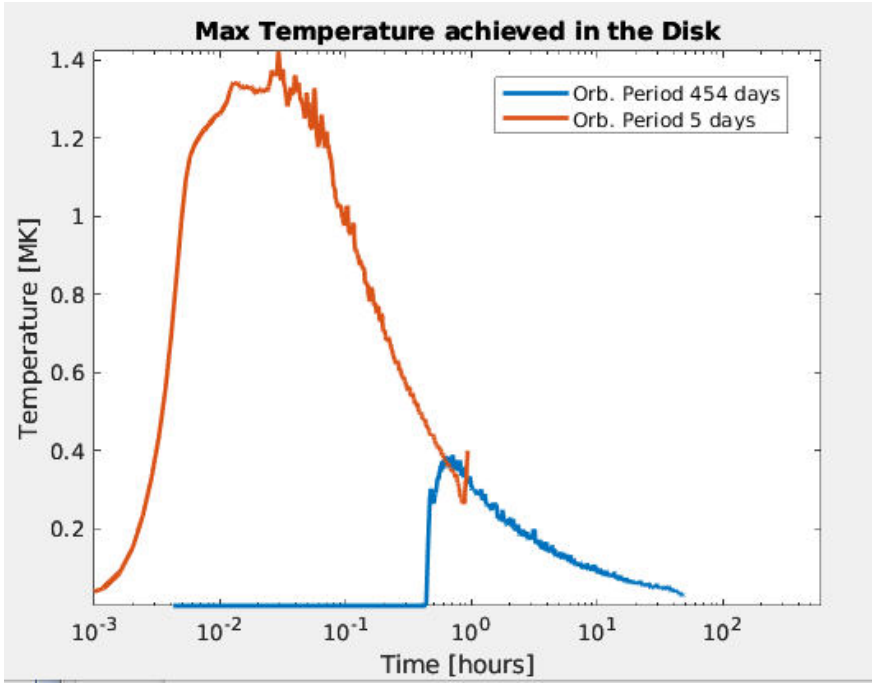
Much more reduced system, the disk is placed closer to the WD.

In this case the disk is completely destroyed, but it affects the geometry of the ejecta



Evolution of the Disk





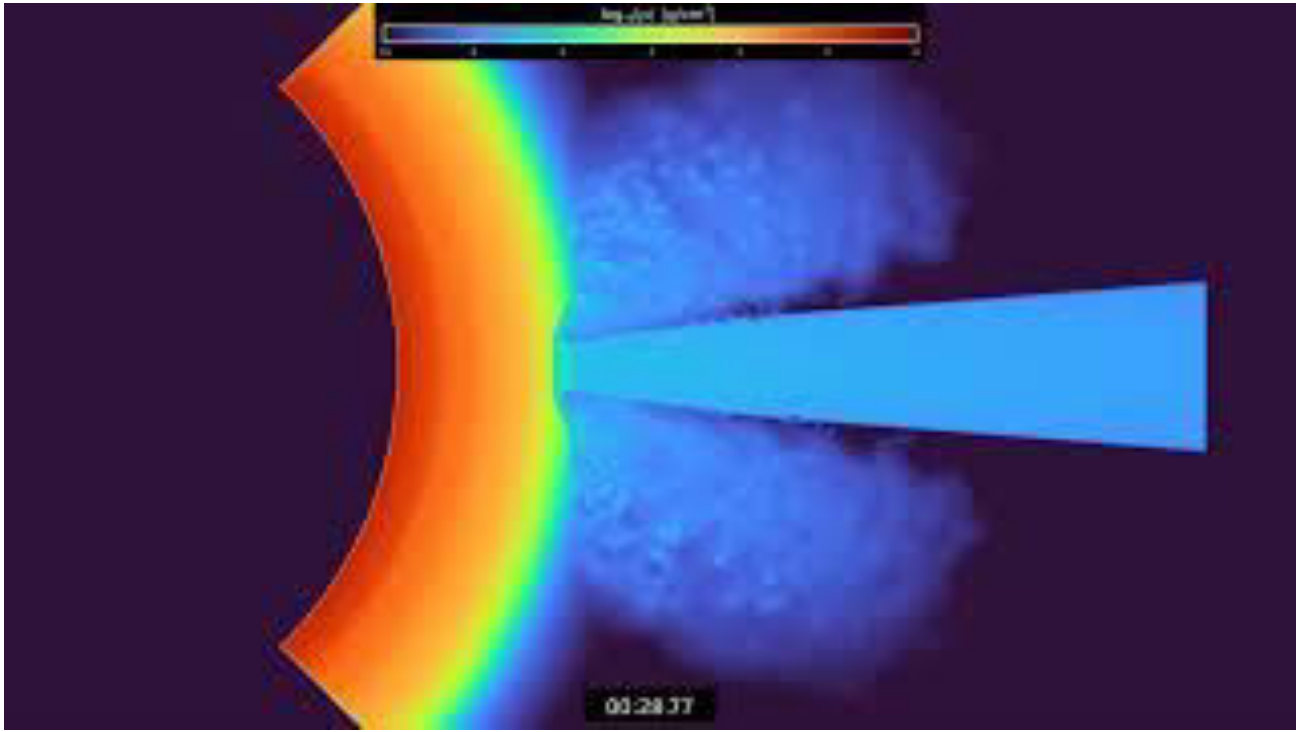
1 hour vs 2 days

Type Ia Supernova

The energy carried by the supernova ejecta is **orders of magnitude** superior than in a nova explosion.

Only the outermost shell with depth **~0.1 $M_\odot$** is simulated (~7% of total WD mass).

The disk is completely **obliterated** and its impact in the geometry of the ejecta is **negligible**



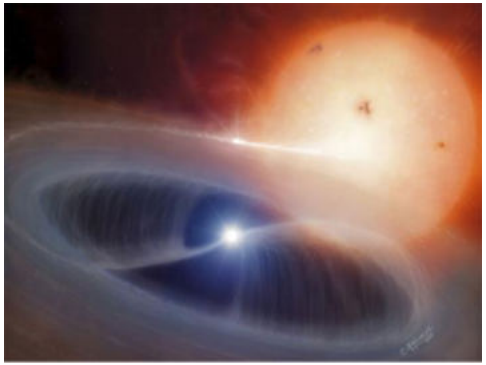
Future Work

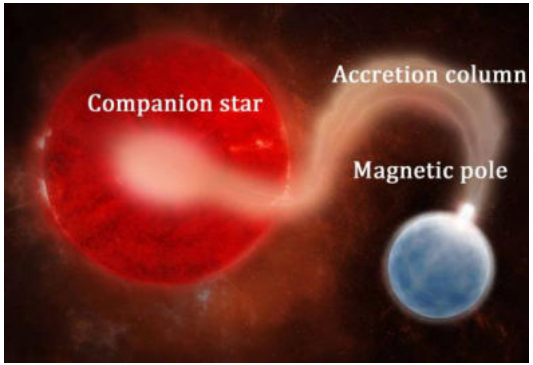
Rest of Classical Nova scenarios to study the impact of **different parameters**

Simulation of Nova caused by **stellar wind** instead of accretion

Full **3D magnetohydrodynamic** simulations to study the impact of **magnetic fields** in the disk geometry

Simulate **micronovae**: very dim outbursts taking place in the **magnetic poles** of the WD, caused by very **confined accretion** in presence of strong fields





Thank you :)