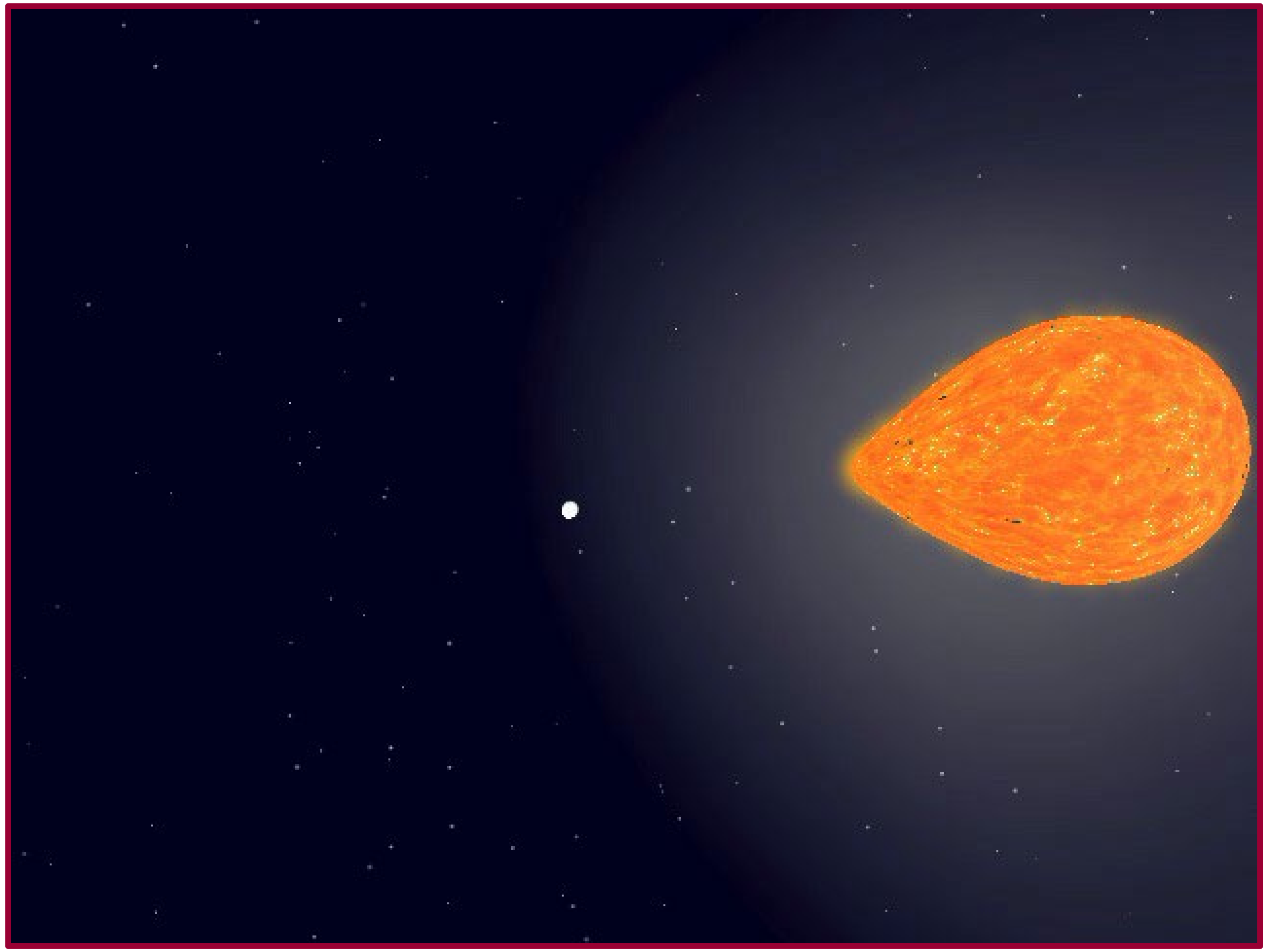
Recent Advances in the Modeling and Nucleosynthesis of Classical Novae & X-Ray Bursts

Jordi José

Dept. Física, Univ. Politècnica de Catalunya (UPC)
& Institut d'Estudis Espacials de Catalunya (IEEC), Barcelona

About 50% of the stars of our Galaxy form double or multiple systems (a fraction evolve into systems containing a WD or a NS)



Novae vs. X-Ray Bursts

Novae

Moderate rise times (<1 – 2 days)

$L_{Peak} \sim 10^4 - 10^5\ L_\odot$

$E_{output} \sim 10^{45}$ ergs

Mass ejected: $10^{-7} - 10^{-4}\ M_\odot$

($\sim 10^3$ km s^{-1})

Recurrence: ~ 1 – 100 yr (RNe)

~ $10^4 - 10^5$ yr (CNe)

Frequency: ~ 50 yr^{-1}

[Obs. ~ 10 yr^{-1}]

X-Ray Bursts (Type I)

Fast rise times (<1 – 10 s)

$L_{Peak} \sim 10^4 - 10^5\ L_\odot$

$E_{output} \sim 10^{39-40}$ ergs [in 10- 100 s]

$\alpha = L_{persistent}/L_{burst} \sim 100$

Mass ejected?

Recurrence: ~ hrs – days

Sources detected: ~ 100

Novae are XRBs in slow motion…

…XRBs are novae in fast forward

Type I X-Ray Bursts

Mass Ejection

The potential impact of XRB nucleosynthesis on **Galactic abundances** is still a matter of debate: **ejection** from a NS **unlikely** because of its large **gravitational potential** (ejection from the surface a NS of mass *M* and radius *R* requires $GMm_p/R \sim$ 200 MeV/nucleon, whereas only a few MeV/nucleon are released from thermonuclear fusion)

NS → $M_{NS} \sim 1.4\ M_{\odot}$, $R_{NS} \sim 10$ km → $v_{esc} = \sqrt{2G\ M_{NS}/R_{NS}} \sim$ **190 000 km s^{-1}**

[**WD** → $M_{WD} \sim 1\ M_{\odot}$, $R_{WD} \sim 6000$ km → $v_{esc} \sim$ **7000 km s^{-1}**]

➡ **XRBs are halted by fuel consumption** (due to efficient CNO–breakout reactions) rather than by expansion → nearly **constant pressure** at ignition depth

Some models achieve high pressures and densities at the envelope base → strong bursts, with short periods of **super–Eddington luminosities**, frequently accompanied by the presence of **precursors** in the X–ray light curve, together with mass–loss episodes through **radiation–driven winds** → ejection of a tiny fraction of the envelope (Weinberg et al. 2006a). It has been suggested that XRBs might account for the Galactic abundances of the problematic light ***p-nuclei*** (Schatz et al. 1998)

Radiation–driven wind models: Kato (1983), Ebisuzaki et al. (1983), and Quinn and Paczynski (1985). GR effects were introduced by Paczynski and Proszynski (1986), and Turolla et al. (1986)

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Astronomy & Astrophysics

Simulations of stellar winds from X-ray bursts

Characterization of solutions and observable variables

Y. Herrera[1,2], G. Sala[1,2], and J. José[1,2]

[1] Departament de Física, EEBE, Universitat Politècnica de Catalunya, c/Eduard Maristany 16, 08019 Barcelona, Spain
e-mail: gloria.sala@upc.edu
[2] Institut d'Estudis Espacials de Catalunya, c/Gran Capità 2-4, Ed. Nexus-201, 08034 Barcelona, Spain

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HYDRODYNAMIC MODELS OF TYPE I X-RAY BURSTS: METALLICITY EFFECTS

Jordi José[1,2], Fermín Moreno[1], Anuj Parikh[3], and Christian Iliadis[4,5]
[1] Departament de Física i Enginyeria Nuclear, EUETIB, Universitat Politècnica de Catalunya, C./ Comte d'Urgell 187, E-08036 Barcelona, Spain;
jordi.jose@upc.edu, moreno@ieec.fcr.es
[2] Institut d'Estudis Espacials de Catalunya (IEEC), Ed. Nexus-201, C/ Gran Capità 2-4, E-08034 Barcelona, Spain
[3] Physik Department E12, Technische Universität München, James-Franck-Strasse, D-85748 Garching, Germany; anuj.parikh@ph.tum.de
[4] Department of Physics and Astronomy, University of North Carolina, Chapel Hill, NC 27599-3255, USA; iliadis@unc.edu
[5] Triangle Universities Nuclear Laboratory, Durham, NC 27708-0308, USA
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Astronomy & Astrophysics

Mass-loss and composition of wind ejecta in type I X-ray bursts

Y. Herrera[1,2,3], G. Sala[1,2], and J. José[1,2]

[1] Departament de Física, EEBE, Universitat Politècnica de Catalunya, c/Eduard Maristany 16, 08019 Barcelona, Spain
[2] Institut d'Estudis Espacials de Catalunya, c/Gran Capità 2-4, Ed. Nexus-201, 08034 Barcelona, Spain
[3] Institute of Space Sciences, c/Can Magrans, 08193 Cerdanyola del Vallès, Barcelona, Spain
e-mail: herrera@ice.csic.es

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Y. Herrera

XRB Model with 1.4 M_{sun}, 13.1 km NS; $Z_{acc} = 0.02$, $M_{acc} \doteq 1.75\times10^{-9}$ M_{sun} yr^{-1})

→ $M_{ejec} = 3.1\times10^{-14}$ M_{sun}!

0.1% of the envelope is ejected per burst (mostly as ^{60}Ni, ^{64}Zn, [^{68}Ge], and ^{58}Ni). The ejecta also contains some tiny amounts of light **p-nuclei**, but **not enough** to account for their Galactic abundances

XRBs **do contribute** (to some extent!) to the Galactic abundances

Type I XRB Models with Rotation

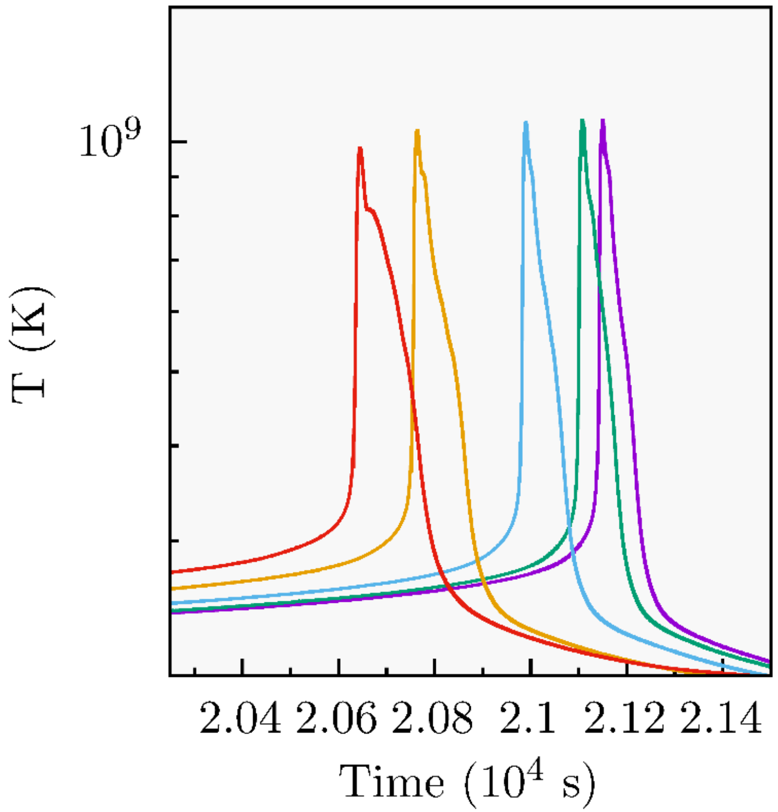
First models of XRB with Rotation (1D)

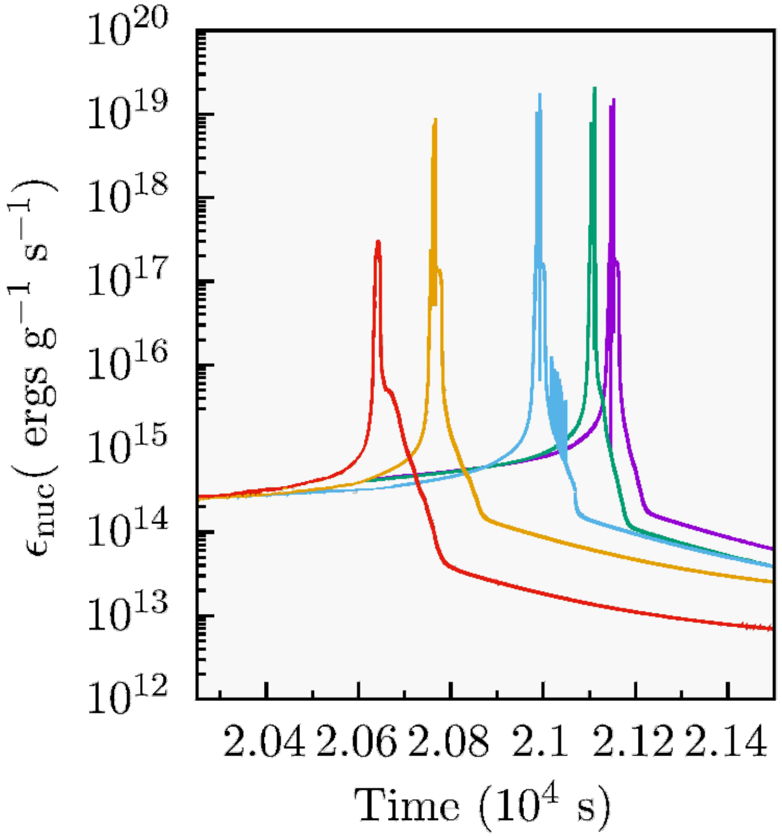
D. Martin
(PhD Thesis 2023)

Study of the effect of (**shellular**) **rotation** on type I XRB properties

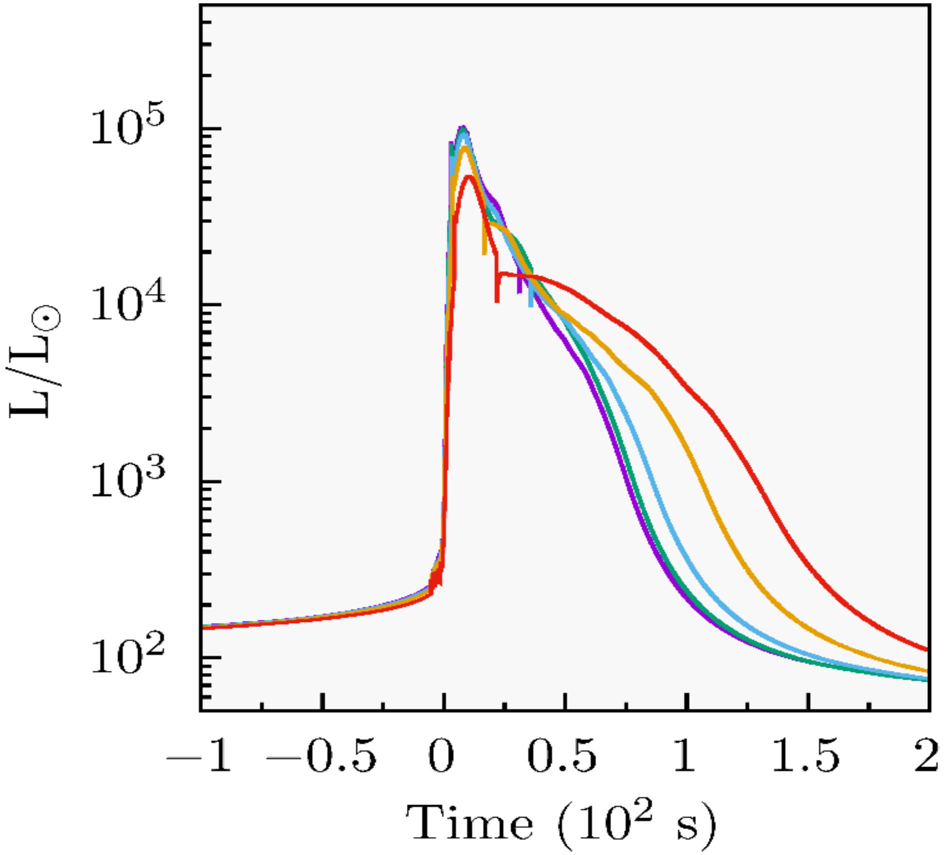
- **Pressure-lifting effect** caused by rotation: maximum density and pressure at the base of the envelope decrease as the angular velocity of the envelope increases
- The **size** of the **envelope shows a significant growth** with the increase of the angular velocity (up to 66% for the fastest rotation model considered)
- Bursts computed with **higher angular velocities have smaller recurrence times**

Temperature and nuclear energy generation rate of first burst for Model 1 (purple; Ω_0/Ω_{crit} = 0), Model 2 (green; Ω_0/Ω_{crit} = 0.2), Model 3 (blue; Ω_0/Ω_{crit} = 0.4), Model 4 (orange; Ω_0/Ω_{crit} = 0.6) and Model 5 (red; Ω_0/Ω_{crit} = 0.8). Models with larger angular velocity Ω_0 tend to achieve smaller peak temperatures and nuclear energy generation rates





Brightest bursts are those with smallest angular velocity Ω_0 (bursts with high rotation rates have long decays [increase up to 45%] and broad light curves)



Martin & JJ (2024, in preparation)

Classical (and Recurrent) Novae

Recurrent Novae

- long period binaries: very homogeneous class (WD + RG), ex: **RS Oph**
- short period binaries: heterogeneous class (WD + MS)

→ Subclasses: **U Sco, CI Aql, T Pyx** [Anupama 2007]

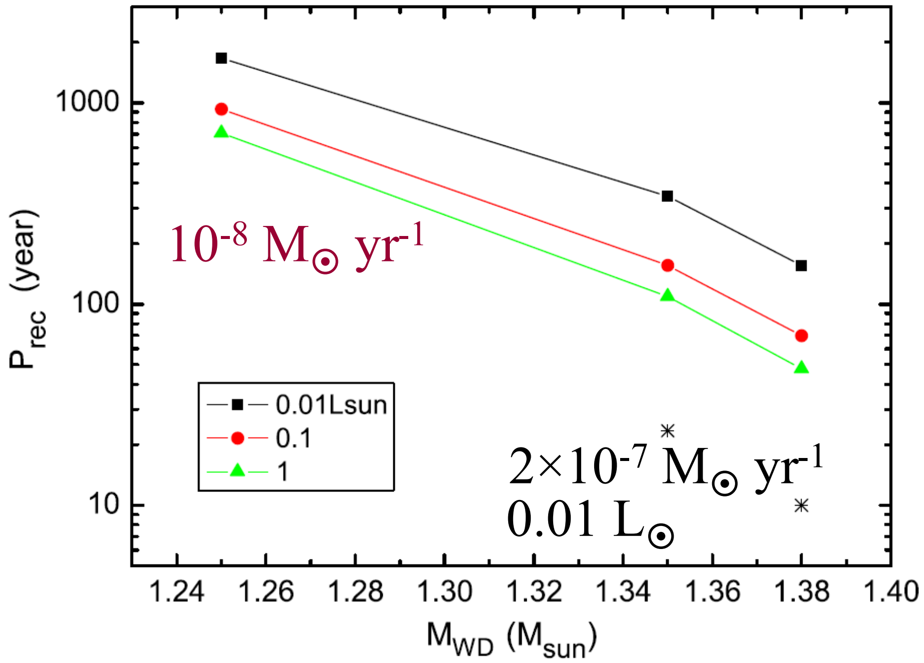
Recurrence time: 1 – 100 yr

NOT all the accreted material is ejected

→ **SN Ia progenitors**

Recurrence time: 1 – 100 yr →

M_{acc} ~ 10^{-7} – 10^{-8} $M_\odot$ yr^{-1}
M_{WD} close to Chandrasekhar limit
High initial L_{WD}



Hernanz & JJ (2008)
New Astr. Rev.

Hydrodynamic Simulations of the Recurrent Nova T Coronae Borealis (T CrB)

Jordi José[1,2] and Margarita Hernanz[2,3]

[1] Departament de Física, EEBE, Universitat Politècnica de Catalunya (UPC), c/Eduard Maristany 16, E-08019 Barcelona, Spain
[2] Institut d'Estudis Espacials de Catalunya (IEEC), c/Esteve Terradas 1, E-08860 Castelldefels, Spain
[3] Institut de Ciències de l'Espai (ICE-CSIC), Campus UAB, Camí de Can Magrans s/n, E-08193 Bellaterra, Spain
e-mail: jordi.jose@upc.edu

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A&A, in prep.

Interaction Between the Ejecta, the Accretion Disk, and the Secondary Star in the Recurrent Nova System U Sco

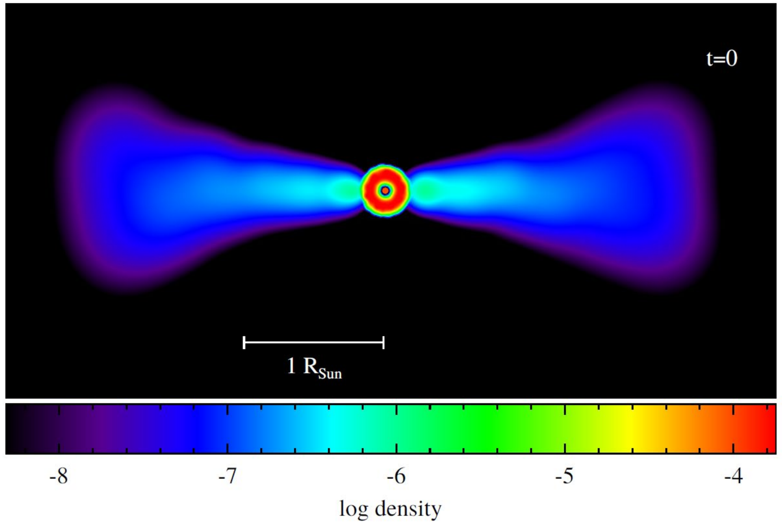
Joana Figueira[1,2], Jordi José[1,2], Rubén Cabezón[3], and Domingo García-Senz[1,2]

A&A, submitted

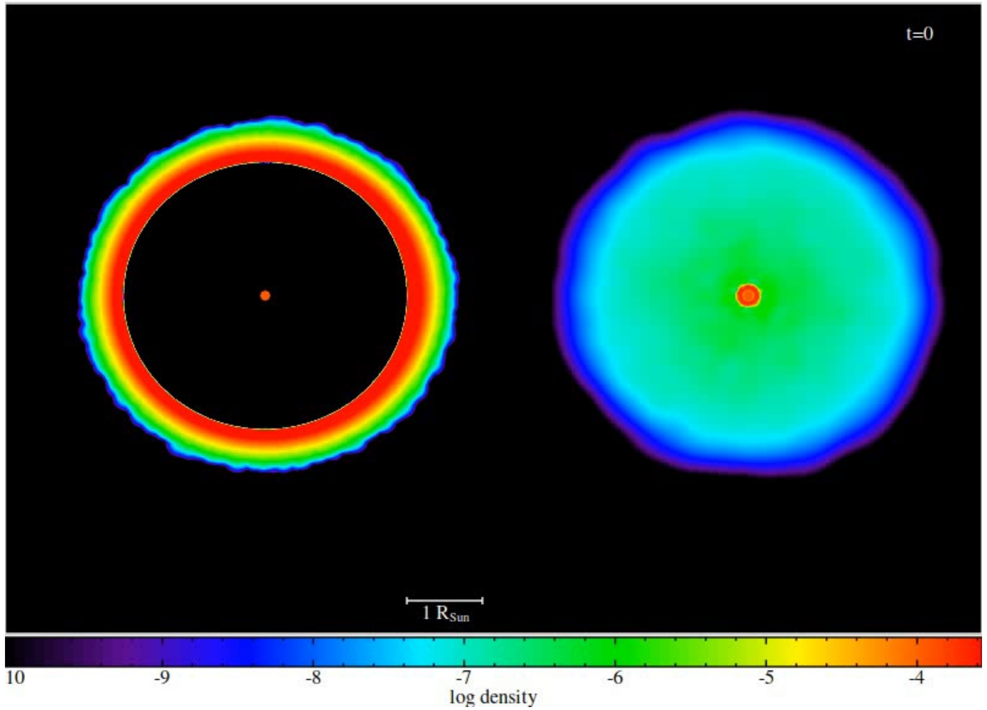
12000 ± 2000 pc from Earth

J. Figueira (PhD thesis 2023)

Seen in outburst in 1863, 1906, 1936, 1945?, 1969?, 1979, 1987, 1999, 2010…
and **June 6, 2022**

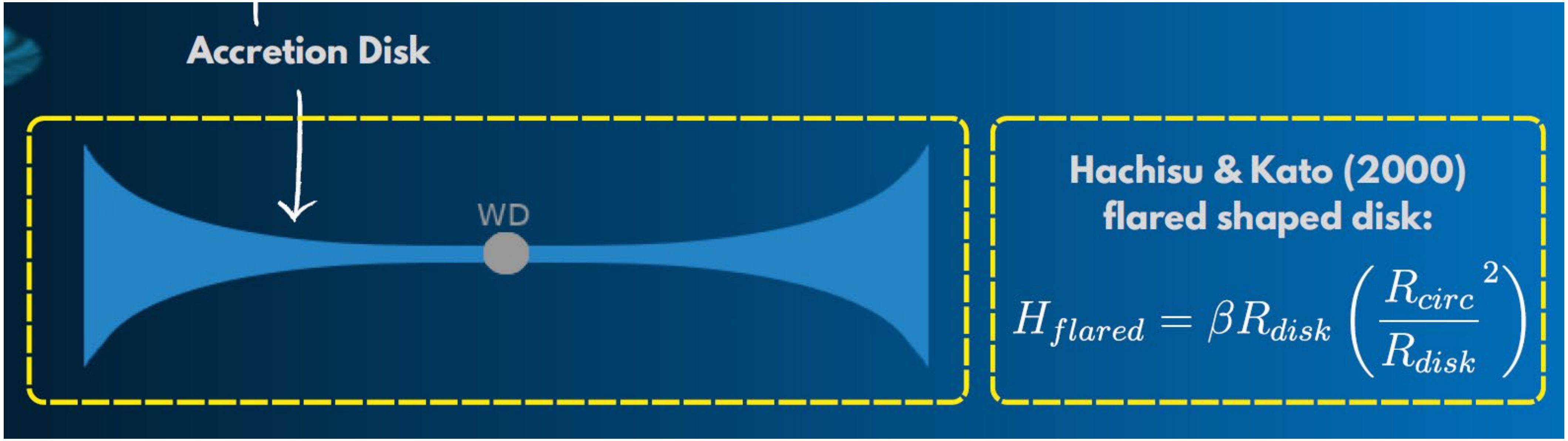


9.77×10^6 SPH particles
(disk ~ 2000 p.; ejecta ~3900 p.)



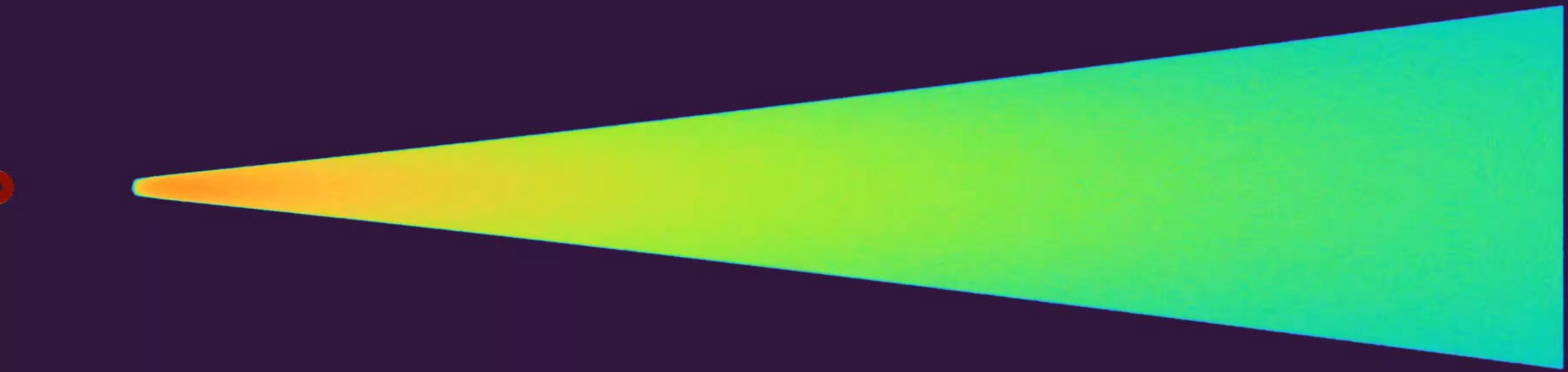
Rotation of the binary system was included

Analysis of the stability of the disk: in 6 out of 8 models computed, the disk gets **fully disrupted** and swept up. These models are characterized by **flared disks** and ratios $\mathbf{M_{ejecta}/M_{disk} \geq 1}$



Contamination of the secondary is **negligible** in recurrent novae with large P_{orb}

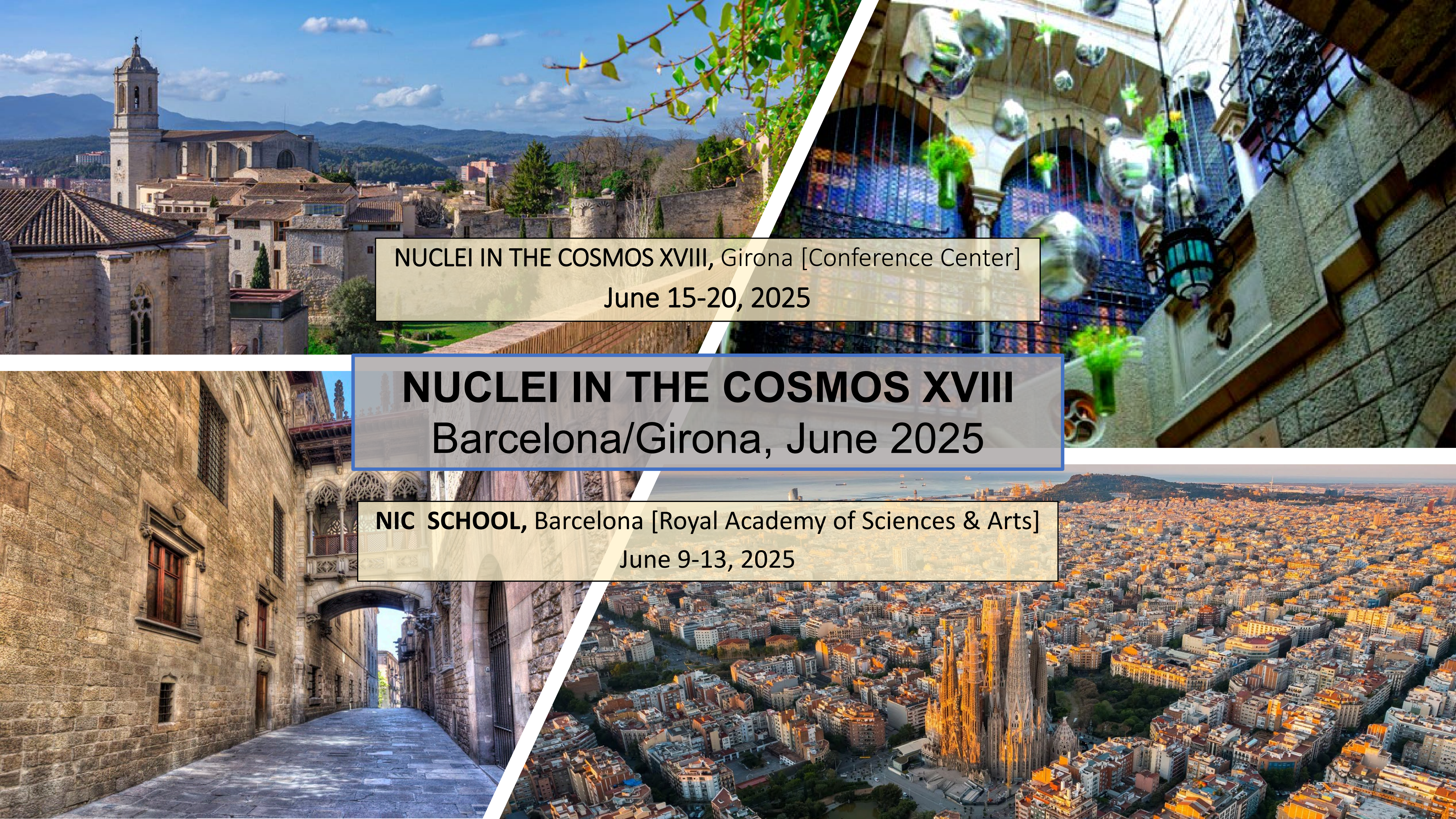
A. Sanz (PhD thesis)



10^6 SPH particles (2D axisym.) → **10^9 particles (3D)**

Day 1 00:00

Sanz, García-Senz & JJ (2024, in preparation)


NUCLEI IN THE COSMOS XVIII, Girona [Conference Center]
June 15-20, 2025
NUCLEI IN THE COSMOS XVIII
Barcelona/Girona, June 2025
NIC SCHOOL, Barcelona [Royal Academy of Sciences & Arts]
June 9-13, 2025

Thank you for your attention!

Jordi José

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