Theoretical and Numerical Study of Colliding Supernovæ Remnants in the Laboratory

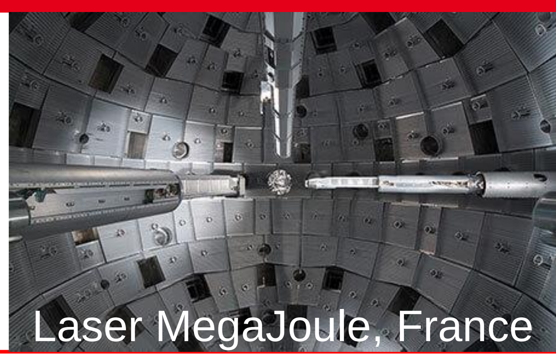
Marin Fontaine [1], Clotilde Busschaert [1] et Émeric Falize [1]

[1] *CEA, DAM, DIF, F-91297 Arpajon, France*

Experimental team: B. Albertazzi, P. Mabey, Th. Michel, G. Rigon, L. Van Box Som, J. Meinecke, N. Ozaki, J. R. Marques, S. Pikuz, S. Ryazantsev, G. Gregori and M. Koenig

Context: Laboratory Astrophysics Applied to the Study of Supernovæ Remnants

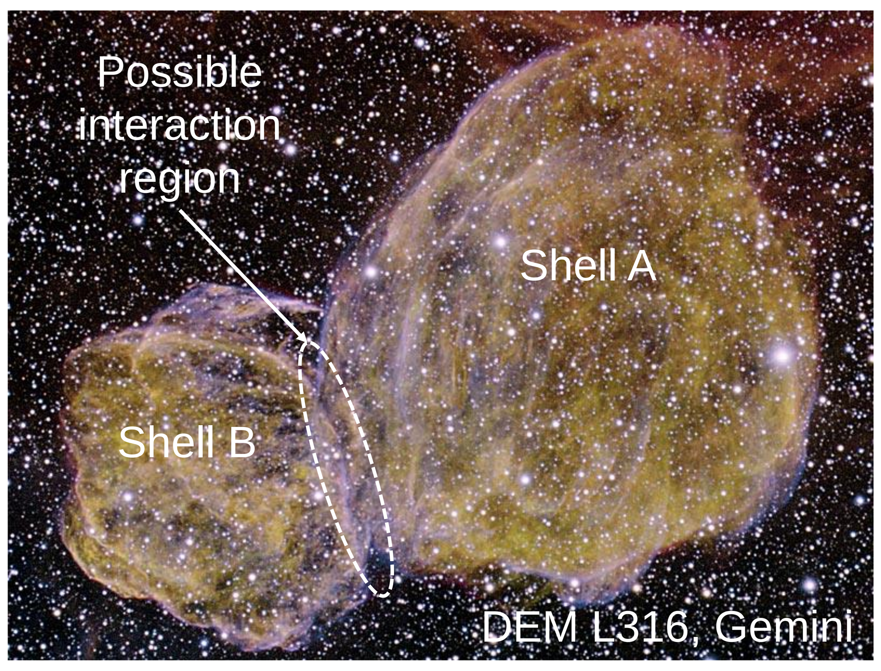
After the explosion, the supernova remnant (SNR) goes through different phases, dispersing its energy into the interstellar medium (Truelove & McKee 1999). When the SNR's mass becomes equal to the mass of the surrounding medium it has travelled through, the SNR is decelerating in the Sedov phase. During this phase, the SNR may collide with other objects, such as molecular clouds or other SNRs. The development of laboratory astrophysics using high-energy-density laser experiments has made it possible to reproduce and study many different astrophysical phenomena (Remington et al. 2006; Falize et al. 2011), such as a SNR in the Sedov phase.



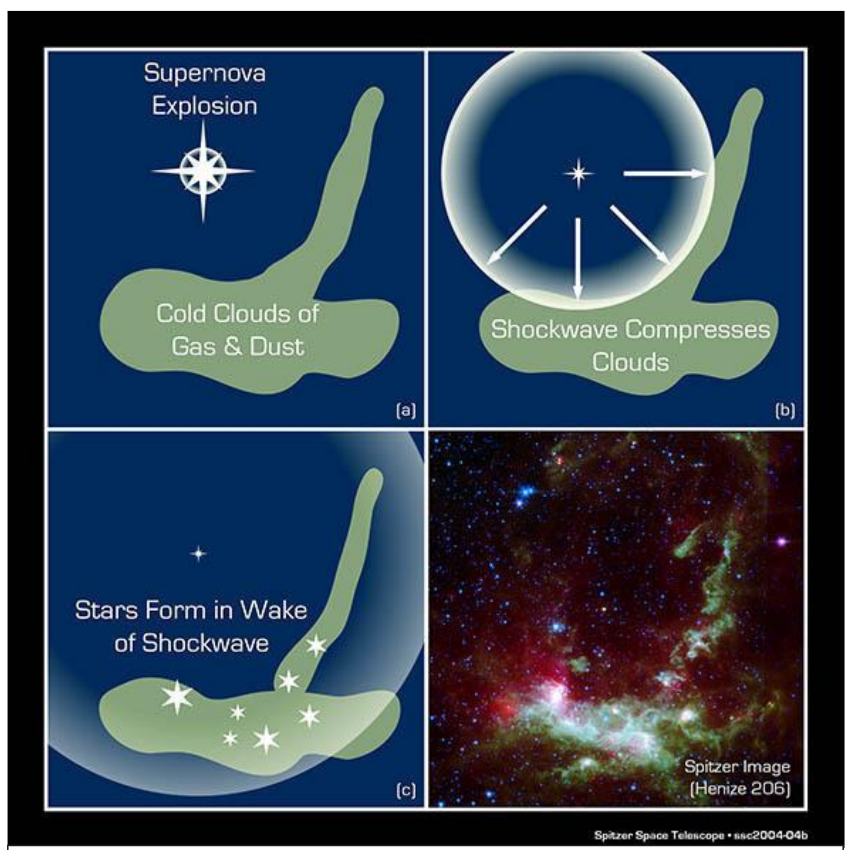
Laser MegaJoule, France

Collision of SNRs and the Triggering of Star Formation

McKee & Ostriker formulated in 1977 a model in which a SNR trigger new star formations. It collides with a molecular cloud or a dense clump, compresses it and leads to a collapse. A SNR can also collide with another SNR, forming turbulence in the interaction region of the shocks, one of the physical phenomena leading to the formation of new stars.



DEM L316, Gemini



McKee & Ostriker 1977's model

SNRs in the Laboratory: Scaling Laws

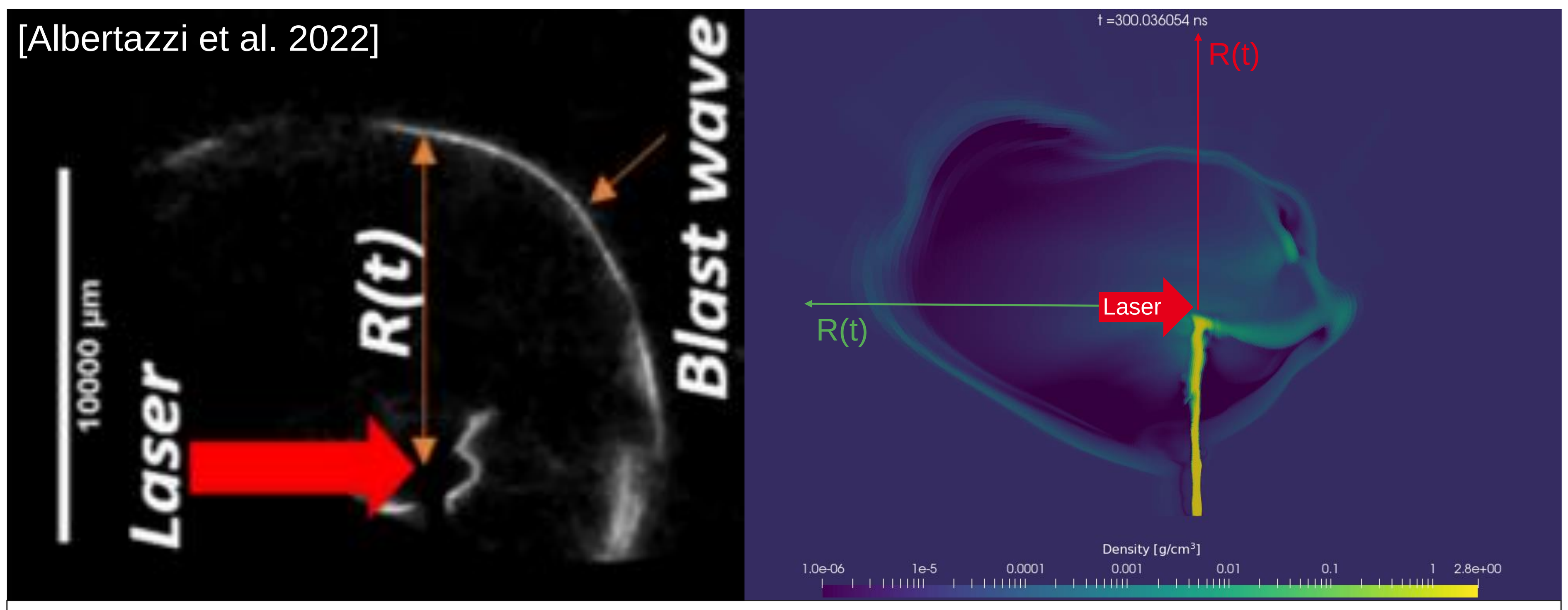
A scaling (eq. 1-2) of the hydrodynamic variables is introduced, preserving the hydrodynamic equations, ensuring the similarity between the laboratory and astrophysical systems.

$$r' = ar, \quad \rho' = b\rho, \quad P' = cP \quad (1) \qquad t' = a\sqrt{\frac{b}{c}}\,t, \quad v' = \sqrt{\frac{c}{b}}\,v \quad (2)$$

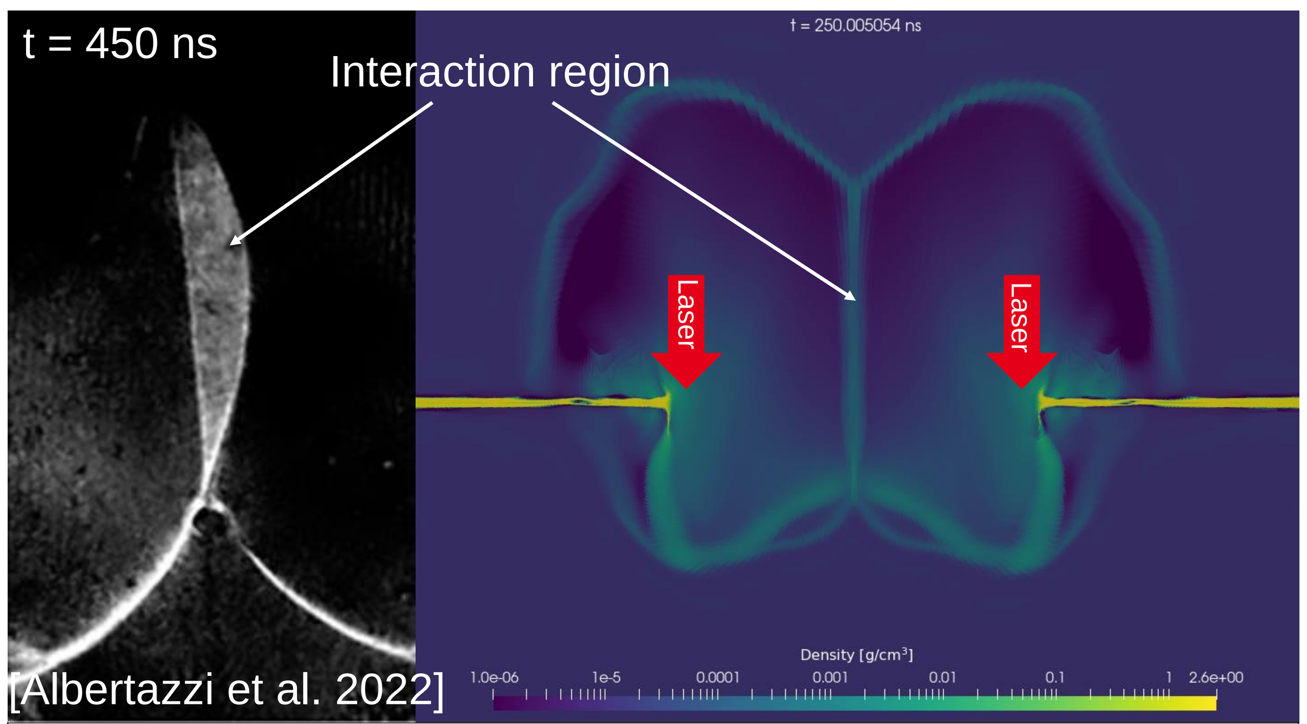
Quantities	Laboratory	Scaled lab.	SN1006
Radius	1 cm	7 pc	7 pc
Density [g/cm ^{3}]	$1{,}5.10^{-4}$	$\sim 3.10^{-20}$	$\sim 3.10^{-20}$
Pressure [dyn/cm²]	3.10^{7}	$\sim 6.10^{-12}$	$\sim 6.10^{-12}$
Time	300 ns	10^{5} yrs	~ 1000 yrs
Velocity [km/s]	$10-50$	1600	2890
Temperature [eV]	~ 5	-	~ 100
Mach number M	~ 5-10	-	~ 30
Density ratio η	10^{4}	-	10^{5}

Experiment's scaling laws (values for SN1006 taken from Chiad et al. 2015).

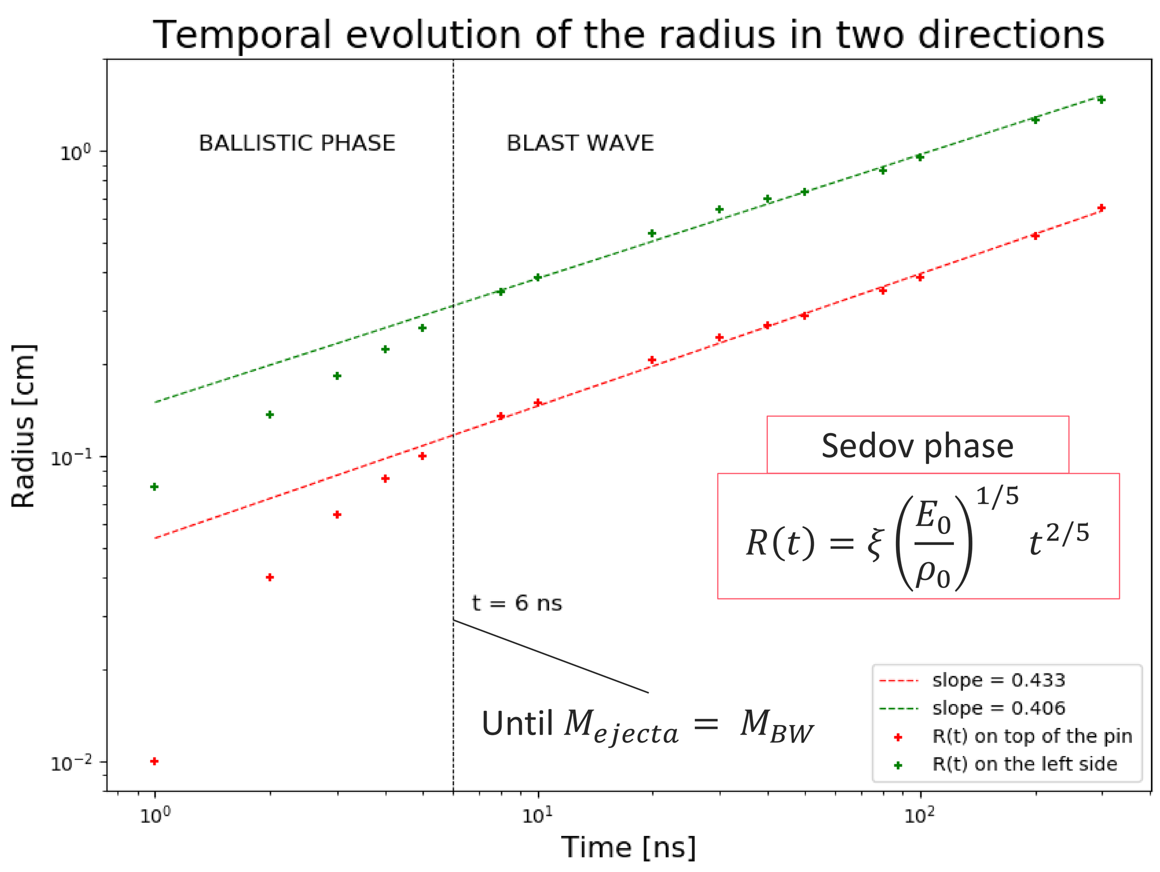
The Collision of SNRs in the Laboratory: 3D Hydrodynamics Simulations

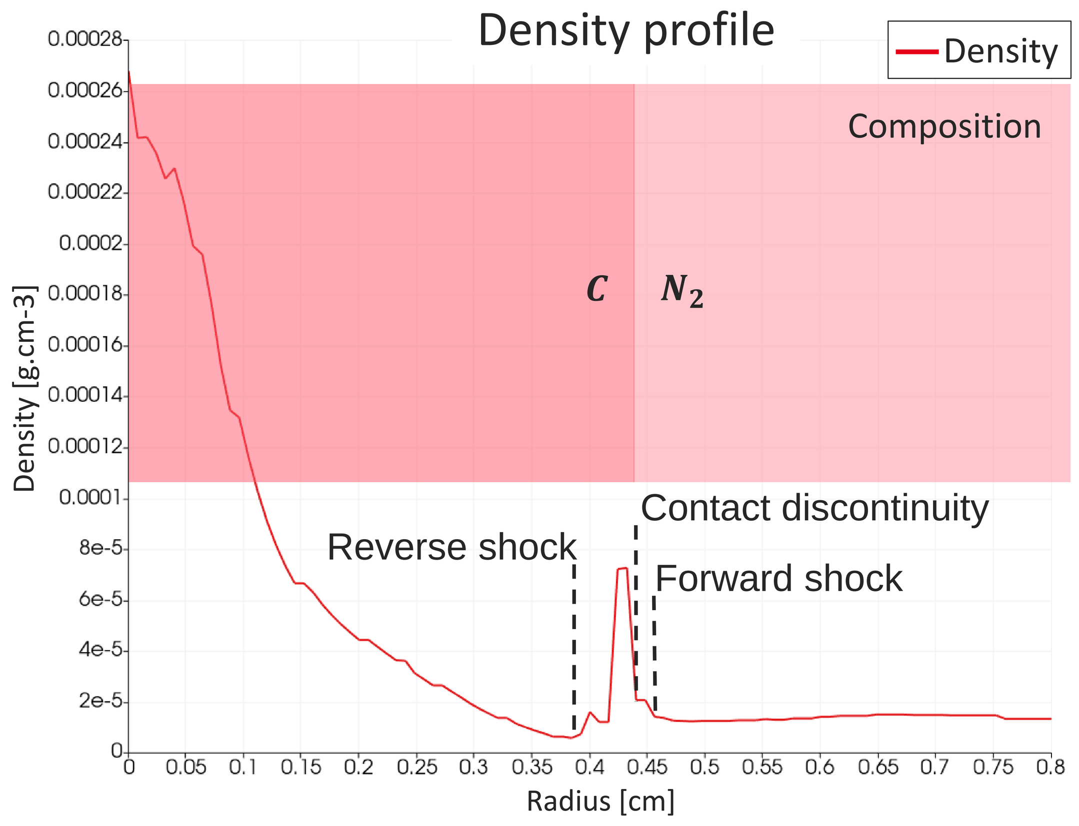


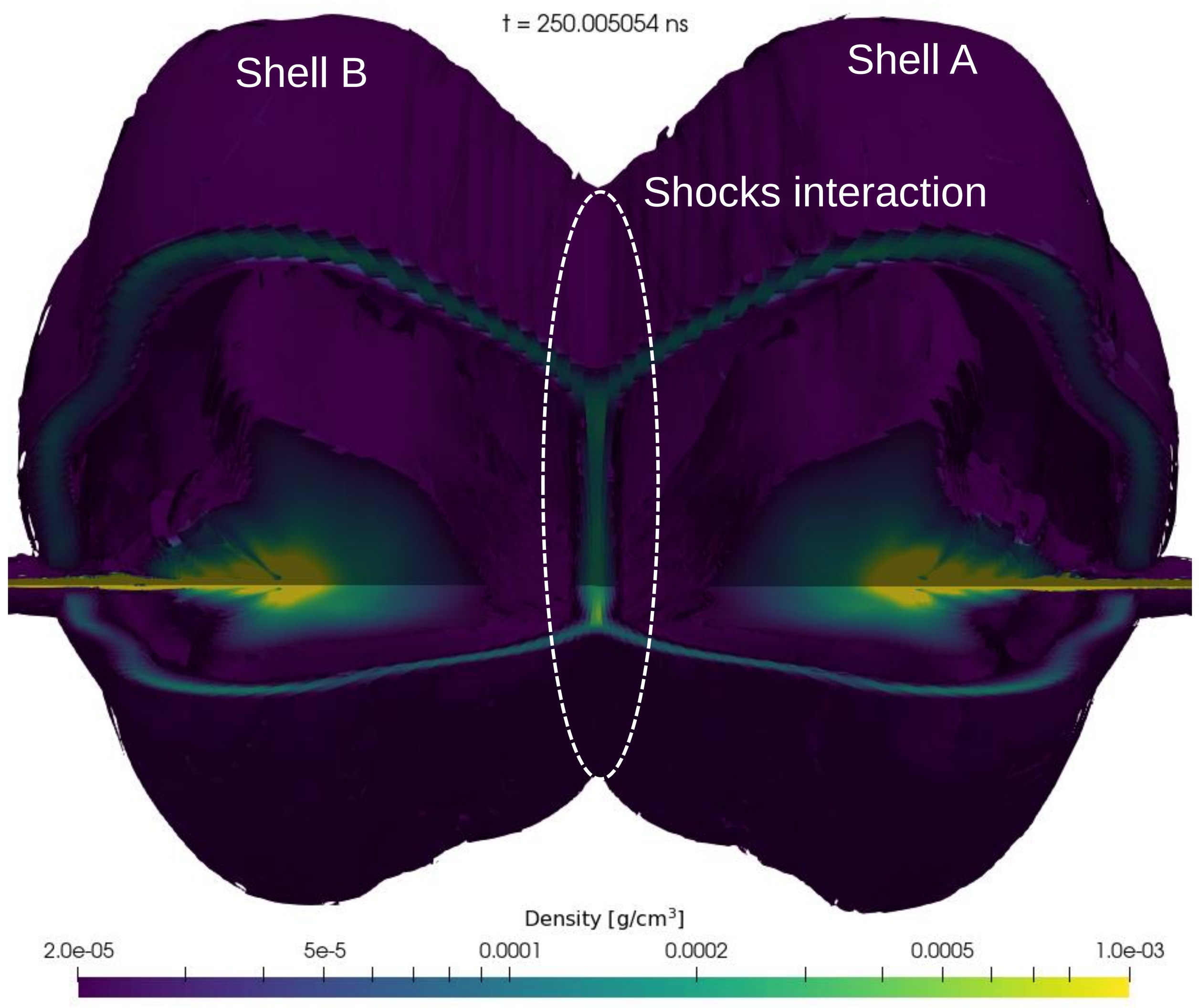
Experiment and 3D simulation of a single blastwave



Experiment and 3D simulation of a blastwaves collision







The ability to reproduce a SNR simulated at a laboratory scale is demonstrated. This allows the study of the collision of two SNRs. In the interaction zone, the compression ratio is around 1.75, the temperature increases by around 20% and vorticity is observed, that could generate a magnetic field.

Références

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- Falize, É., Michaut, C., & Bouquet, S. 2011, ApJ, 730, 96
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Perspectives

- An in-depth study of these simulations will be performed, especially for the interaction region, in order to get informations on the DEM L316 system and the possible collision of its two SNRs.
- In the laboratory, it is the possible to investigate the impact of a SNR on a molecular cloud. The simulation of this setup would give clues on the possible collapse it would trigger, leading to new star formations.