Hydrodynamic model of the Sgr A East supernova remnant

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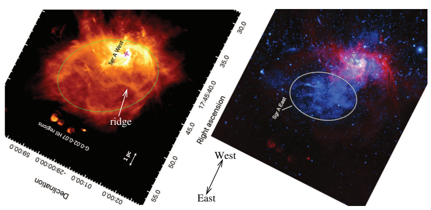
Abstract

We present a hydrodynamic model describing the evolution of a supernova remnant within the vicinity of a galactic centre, influenced by the wind of a young nuclear star cluster. The aim of this model is to test the hypothesis that such remnants can deliver mass accreted onto their expanding shells to supermassive black holes, thereby contributing to their rapid growth (see Palouš et al., 2020). We apply this model to study Sgr A East, the supernova remnant closest to the centre of the Milky Way. Firstly, we explore parameter space using a simplified hydrodynamic code called RING, based on the thin shell approximation. Subsequently, we use the adaptive mesh refinement code FLASH to perform detailed simulations of the most promising scenarios and compare them to the observations of Sgr A East.

Observations of Sgr A East

Sgr A East is the supernova remnant closest to Sgr A⋆ (supermassive black hole in the Galactic centre), with projected distance $\sim 1'$ (2.3 pc).

- eliptical shape 8.3×6 pc
- interacts with the molecular cloud M50 at the East side (bottom)
- shell-like appearance in radio (**Left below:** 6 cm radio cont.; Zhao et al., 2016)
- centrally bright in X-rays (**Right below:** Chandra 2-8 keV (blue), VLA 8.3 GHz (red); Zhou et al., 2021)

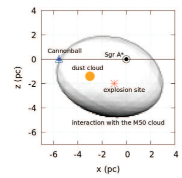


Parameter study with thin-shell code RING

See Ehlerová et al. (2022) for details.

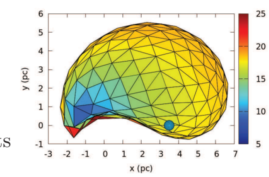
Physical model:

- reproducing Sgr A East properties by assuming that it interacts with:
  - Young Nuclear Star Cluster wind on top (West on the sky)
  - Molecular cloud M50 on bottom (East on the sky)



Thin shell code RING

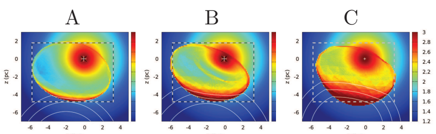
- follows SNR in pressure/momentum driven thin shell phase
- models the shell using infinitesimally thin triangular segments
- accelerations due to gravity and pressure forces act on segments



Results of the parameter study

- cloud position (x_{cl},y_{cl},z_{cl}) and radius (r_{cl}) and SN explosion position (x_0,y_0,z_0) for the three best models:

model	$x_{\rm cl}$ pc	$y_{\rm cl}$ pc	$z_{\rm cl}$ pc	$r_{\rm cl}$ pc	x_0 pc	y_0 pc	z_0 pc	age kyr
A	-2	+2	-10	5	-1	+3	-2	10
B	-2	0	-10	6	-1	+1	-2	19
C	-2	+4	-8	5	-1	+2	-3	29



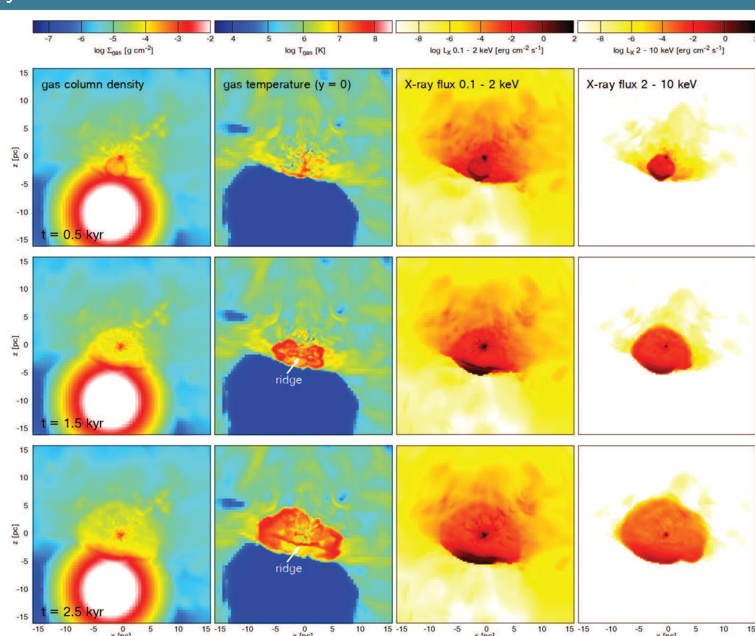
Hydrodynamic simulations

Simulation setup:

- based on public AMR code Flash
- wind of Young Nuclear Star Cluster (YNSC):
  - energy dominated by 30 WR stars
  - mass loading ×10 to mimic gas inflow from Circumnuclear Disk (CND)
- fixed gravity of SMBH and Nuclear Star Cluster
- optically thin radiative cooling (Schure et al. 2009)
- 9 levels of refinement (smallest grid cell: 0.015 pc)

Results for model A (right):

- columns: column density (1), gas temperature at y = 0 (2), X-ray flux 0.1-2 keV (3), X-ray flux 2-10 keV (4)
- supernova remnant (SNR) is traced well with 2-10 keV X-ray emission
- its shape agrees well with observations and with RING calculations
- SN shock reflected from the cloud interacts with the wind and leads to a feature resembling a ridge observed in radio (see temperature at 1.5 kyr)



Conclusions and Future Work

- the presented model of the SNR interacting with YNSC wind and M50 cloud reproduces well the Sgr A East shape and some other observed features (e.g. the ridge)
- the thin shell code RING and the hydrodynamic code Flash simulations are in a good agreement
- we shall add the CND and evaluate the impact of SN explosion on the SMBH accretion rate (see Barna et. al, 2025)

References

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