What's in a Fermi Bubble:

numerical simulations of a quasar episode in the Galactic centre

Kastytis Zubovas*, Sergei Nayakshin, Andrew King

Theoretical Astrophysics group, University of Leicester, University Road, LE1 7RH, Leicester

Abstract

The recently observed gamma-ray emitting bubbles on either side of our Galaxy offer a chance to test several models of supermassive black hole (SMBH) evolution, feedback and relation with their host galaxies. We use a physical feedback model and novel numerical techniques to simulate a short burst of activity in the centre of our own Galaxy, which could have occured ~6 Myr ago, concurrently with the star formation event in the central parsec. We are able to reproduce the bubble morphology and energetics. These results provide strong support to the model, which was also used to simulate more extreme environments.

Introduction

The *Fermi* bubbles are two giant (~10 kpc high) gamma-ray emitting lobes discovered last year while analysing data from the *Fermi-LAT* telescope (see figure, right; Su et al. 2010). Their morphology suggests an association with the Galactic centre. We propose that the bubbles are a remnant of a wind outflow caused by a burst of activity in Sgr A*, the central SMBH of the Milky Way. As this picture is qualitatively similar to that of large-scale galactic wind outflows that are likely to have established the M-sigma relation (Ferrarese & Merritt 2000, King 2003, 2010), we use the same analytical and numerical (Nayakshin et al. 2009, Nayakshin & Power 2010, etc.) model to investigate the properties of this outflow. We find both analytical (Zubovas et al. 2011) and numerical (Zubovas & Nayakshin in prep) agreement with observation data and are able to constrain the outflow properties.

The physical model

As an accreting SMBH radiates away a lot of energy, the radiation pressure drives a wind outflow from its vicinity with a momentum flux

$$\dot{M}_{out} v \approx \frac{L_{Edd}}{c}; \quad v \approx \eta c \approx 0.1c$$

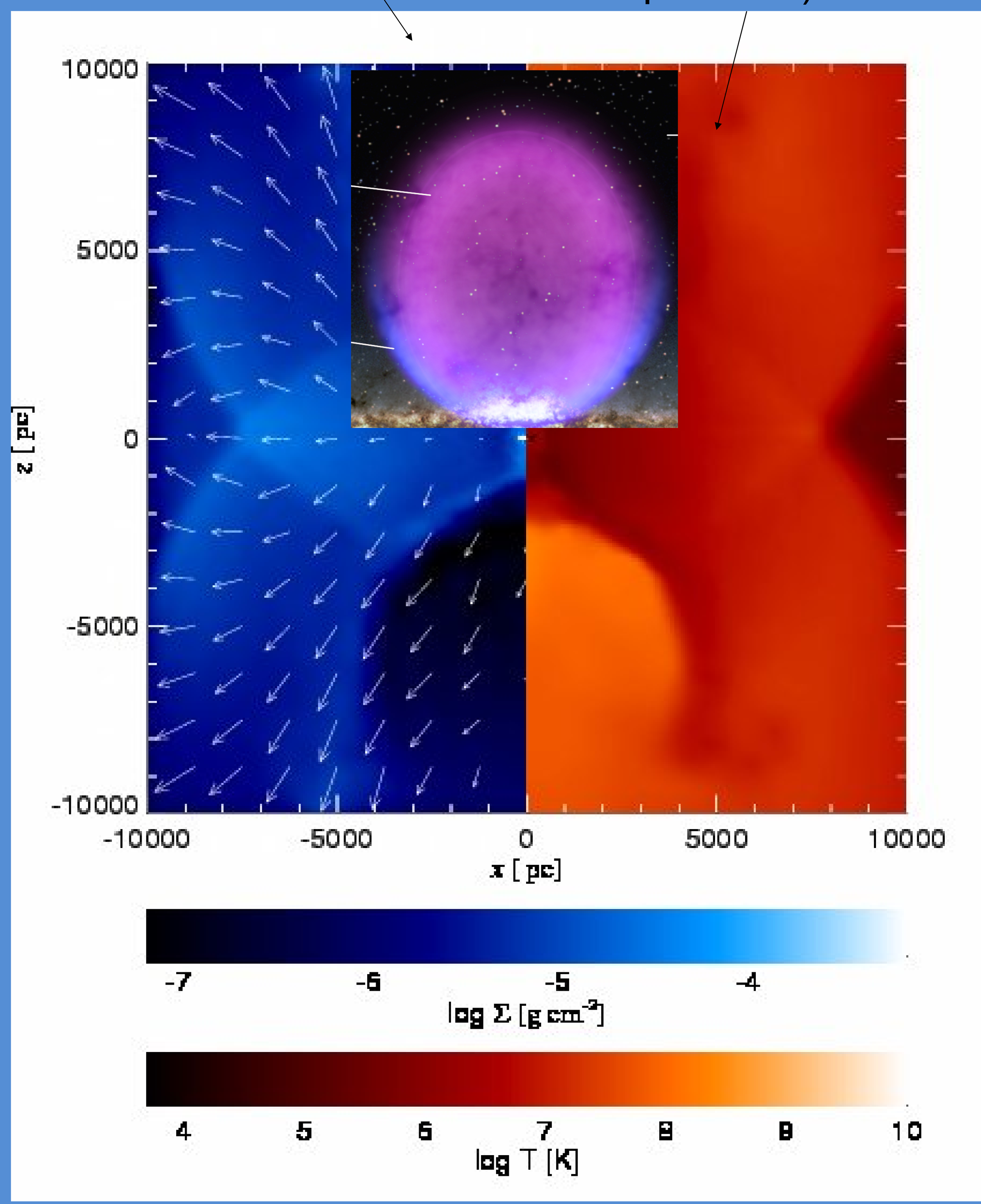
where $\eta \approx 0.1$ is the radiative efficiency. This wind shocks against the surrounding gas and pushes it away, forming an outflow. Its details depend on whether the shock cools efficiently, which in turn depends on its distance from the SMBH. Far enough (a few tens of parsecs in the case investigated here), the AGN radiation field cannot cool the shock, and so the surrounding gas may be accelerated to velocities >1000 km/s. This outflow persists for a time an order of magnitude longer than the duration of the AGN phase (King et al. 2011). In the Milky way, such an outflow is stalled in the Galactic plane by the ring of dense molecular gas, leading to formation of two teardrop-shaped bubbles perpendicular to the plane.

We fit the analytical equations to the properties of the bubble and then proceed to test the model numerically, using an SPH/N-body code GADGET (Springel 2005) with a Monte Carlo radiative transfer scheme (Nayakshin et al. 2009).

The Fermi bubbles

Observed *Fermi* bubble (artist impression, NASA)

Simulation result (density and temperature)



References

Ferrarese L. & Merritt D., 2000, ApJL, 539, 9

King A. R., 2003, ApJL, 596, 27

King A. R., 2010, MNRAS, 402, 1516

King A. R., Zubovas K., Power C., 2011, MNRAS, 415, 6

Nayakshin S., Cha S. H., Hobbs A., 2009, MNRAS, 397, 1314

Nayakshin S., Power C., 2010, MNRAS, 402, 789

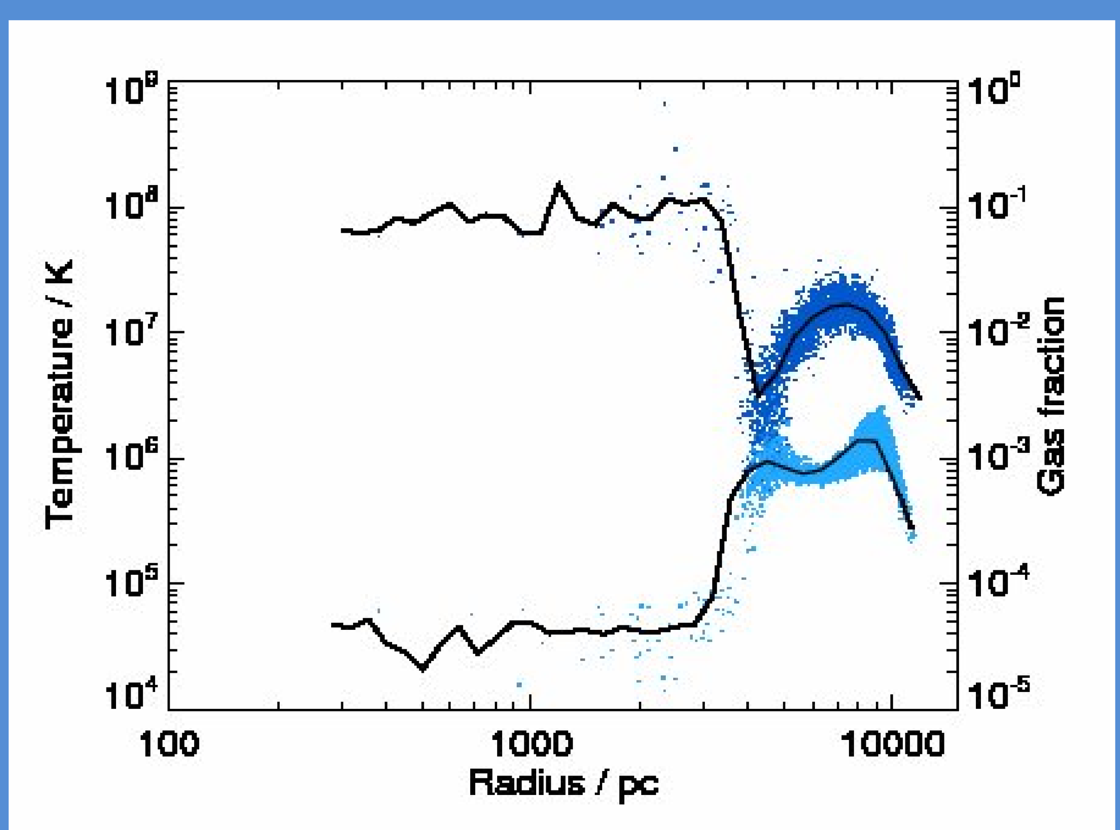
Springel V., 2005, MNRAS, 364, 1105

Su M., Slatyer T. R., Finkbeiner D. P., 2010, ApJ, 724, 1044

Zubovas K., King A. R., Nayakshin S., 2011, MNRAS, 415, 21

This research used the ALICE High Performance Computing Facility at the University of Leicester, part of the DiRAC Facility jointly funded by STFC and the Large Facilities Capital Fund of BIS.

Results and future prospects



Cross section of gas temperature (dark) and density (light) at z = [4;7] kpc from the midplane

The simulation results show that our physically motivated numerical model can explain the current observations of the Galactic centre. The two free parameters are the duration of the quasar outburst (≲1 Myr) and the ratio of diffuse gas density to background density (0.001). If the bubbles were inflated during the last star formation event in the central parsec 6 Myr ago, their current morphology (see fig., above) should be almost identical to that of the observed *Fermi* bubbles. The energy content of the bubbles is also consistent with observational constraints. The bubbles have almost reached pressure equilibrium with their surroundings by now (see fig., left).

The results have wider implications than just confirming the plausibility of this scenario of *Fermi* bubble formation. They also validate the use of this physical model, which is built from first principles and avoids any empirical numerical prescriptions. This is the first test of this model with realistic initial conditions, taking into account the non-spherical geometry of the gas distribution in the Galactic centre. In the future, we are planning to implement this model in cosmological simulations, thus investigating the early assembly of galaxies and the establishment of galaxy-SMBH correlations.

* E-mail: kastytis.zubovas@le.ac.uk