VSB TECHNICAL UNIVERSITY OF OSTRAVA | IT4INNOVATIONS NATIONAL SUPERCOMPUTING CENTER

HPCSE · 2026

VISUALISATION OF **MASSIVE BLACK HOLE ORBITAL DECAY**

IN DARK MATTER HALOS

A BLENDER + SPACECONVERTER WORKFLOW

MILAN JAROS[1], **ALICE DAMIANO**[2], **OSMAN YASAL**[1], **PETR STRAKOS**[1] and **LUBOMIR RIHA**[1]

1· IT4Innovations · VSB – Technical University of Ostrava
2· INAF – Osservatorio Astronomico di Trieste

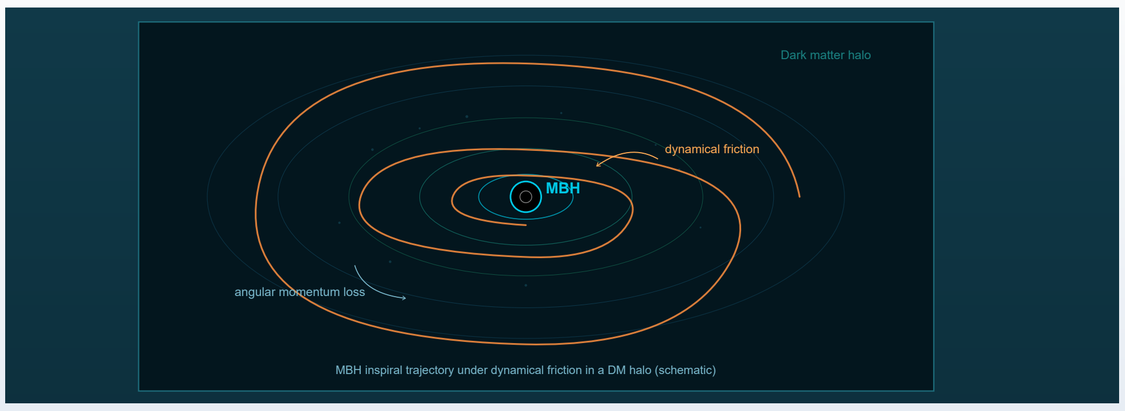
ABSTRACT

We present a visualisation workflow to analyse the orbital decay of a massive black hole (MBH) in dark matter (DM) halos using Blender. The workflow enables direct processing of simulation outputs from **OpenGADGET3** simulations into volumetric and geometric representations for interactive analysis and publication-quality rendering.

The underlying simulation models the MBH orbital decay under the influence of the **dynamical friction** effect, the gravitational drag exerted by the surrounding medium that leads to angular momentum loss and a gradual inspiral toward the centre of the halo. In cosmological-scale simulations, accurately capturing this process numerically is challenging due to limited resolution, therefore sub-resolution modelling of dynamical friction is required.

To enable consistent analysis across resolution levels, simulation outputs are processed using **SpaceConverter**, which performs distributed data loading, voxelization, and reduction on HPC systems. Particle-based data are converted into volumetric representations (OpenVDB) and into auxiliary geometric data for subsequent visualisation in Blender. MBH trajectories are reconstructed and visualised using Blender Geometry Nodes, while the underlying density field is obtained via SPH-based voxelization, enabling consistent coupling between particle dynamics and volumetric structure.

AT A GLANCE



MBH inspiral trajectory under dynamical friction in a DM halo (schematic)

VISUALISATION WORKFLOW

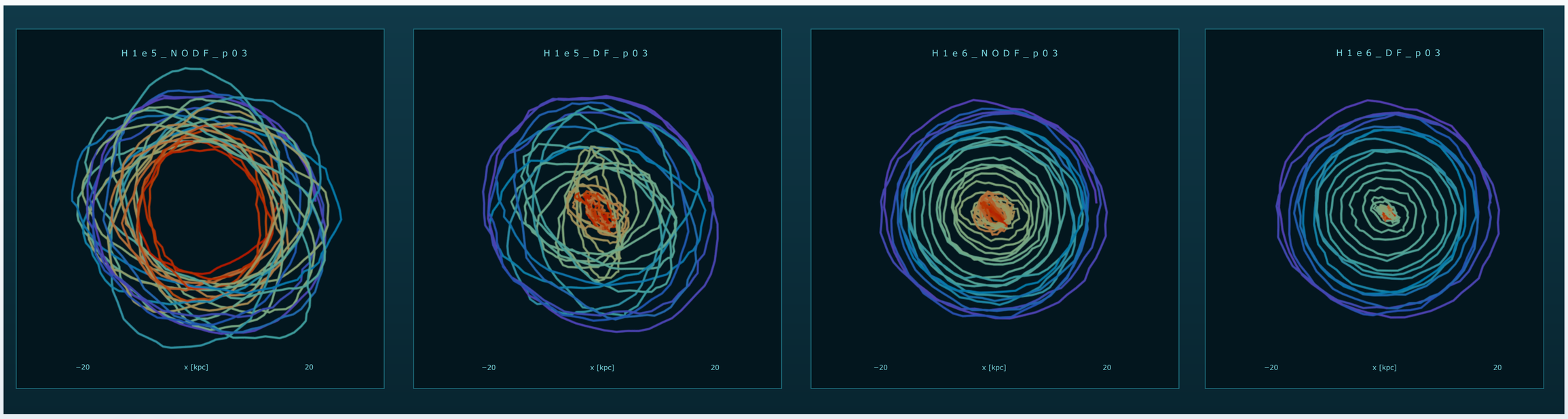
HPC PROCESSING ------ LOCAL EXPLORATION

01 **SIMULATION** — OpenGADGET3 — N-body Tree-PM
→ 02 **HPC PROCESSING** — SpaceConverter — MPI · SPH voxelisation · reduction
→ 03 **DATA FORMATS** — OpenVDB / NanoVDB — Volumes + particle exports
→ 04 **INTERACTIVE GUI** — BSpace add-on — Region select · density · radius
→ 05 **RENDERING** — Blender Cycles — Volumetric + Geometry Nodes
→ 06 **INSIGHT** — Science output — Inspiral analysis · figures

REMOTE · HPC NODES (MPI) | LOCAL · BLENDER WORKSTATION

MBH INSPIRAL TRAJECTORIES

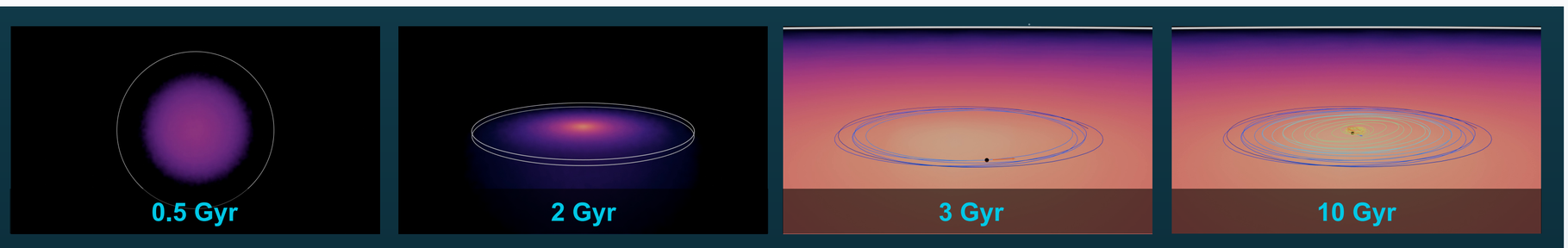
RENDERED IN BLENDER · OPENGADGET3 DATA



Projected BH trajectories for selected DM-only simulations, comparing resolution and the inclusion/exclusion of the sub-resolution DF correction. (**p03** stands for a particular softening choice of the BH and DM particles - C. Power et al., 2003, DOI: 10.1046/j.1365-8711.2003.05925.x)

Selected frames

RENDERED IN BLENDER · OPENGADGET3 DATA

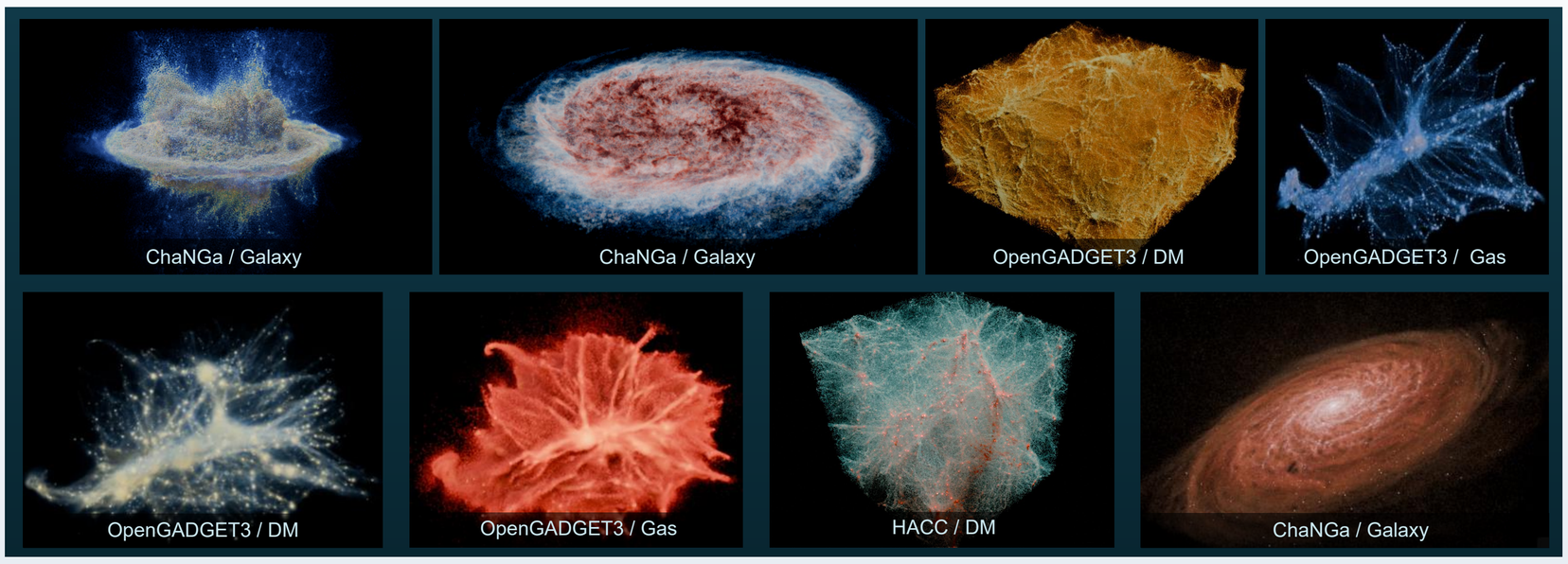


N-body simulation H1e7_NODF_p03 (10^7 particles, p03 softening, no DF correction) volumetric DM density + BH trajectory overlay

Massive black hole sinking

VISUALISATION GALLERY — SpaceConverter + BSpace results

RENDERED IN BLENDER



REFERENCES

1 Damiano A., Borgani S., Valentini M., Murante G., Tornatore L., Strakos P., Jaros M.
Dynamical friction and massive black hole orbits: Analytical predictions and numerical solutions
Astronomy & Astrophysics, 704 (2025) A83
DOI: https://doi.org/10.1051/0004-6361/202556054

2 Jaroš M., Strakos P., Barbosa J., Riha L., Rizzi S.
Visualizing the Cosmos: Bridging Astrophysical Simulations with Volume Rendering
VISGAP 2026
SpaceConverter / BSpace visualisation pipeline

Acknowledgments
This work was supported by the SPACE project under grant agreement No 101093441. The project is supported by the European High-Performance Computing Joint Undertaking and its members (including top-up funding by the Ministry of Education, Youth and Sports of the Czech Republic ID: MC2304). This work was also supported by the Ministry of Education, Youth and Sports of the Czech Republic through the e-INFRA CZ (ID:90254).