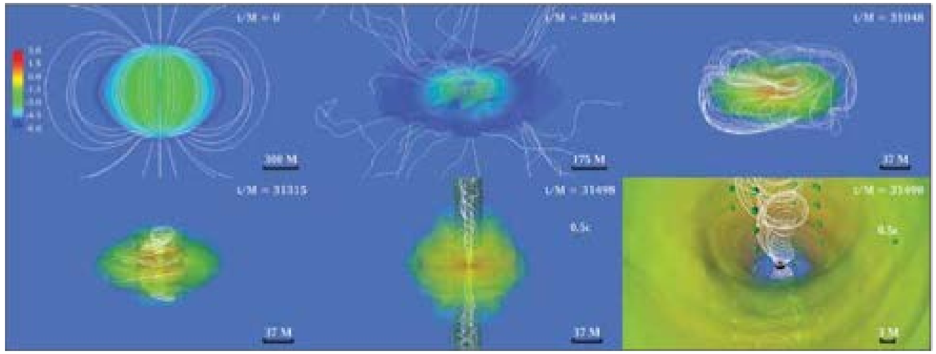
BLUE WATERS
SUSTAINED PETASCALE COMPUTING

Allocation: Illinois/990 Knh
PI: Stuart L. Shapiro
University of Illinois at Urbana-Champaign
Space Science

MAGNETOROTATIONAL COLLAPSE OF SUPERMASSIVE STARS: BLACK HOLE FORMATION, GRAVITATIONAL WAVES, AND JETS



Rendering of the evolution of a magnetized, spinning SMS through collapse and subsequent black hole formation . The outcome is a spinning black hole immersed in a magnetized accretion disk which forms a collimated magnetic field and launches an incipient, relativistic jet emerging from the poles of the black hole.

Research Challenge

Supermassive black holes (SMBHs) reside at the center of most galaxies, including our own. The formation and growth mechanisms for these SMBHs is not clear since, in the early universe, the rate of growth by gas accretion is limited and there is little time (less than a billion years) to grow the oldest and most massive ones if the first black holes were born no more than ten to a few hundred times the mass of the sun. It is quite plausible, therefore, that SMBHs formed from the direct collapse of supemassive stars (SMSs). This project solves the equations of general relativity to follow the collapse of a rotating, magnetized SMS to a SMBH.

Methods & Codes

The team used magnetohydrodynamic simulations (MHD) in full general relativity (GR) to determine the gravitational fields (including the gravitational waves), the matter flow and the electromagnetic fields. The equations were solved using their state-of-the-art Illinois GRMHD code , built on the Cactus infrastructure and using the Carpet code, but employing the team's own algorithms for integratiing Einstein's equations and the equationsf relativistic MHD. The central algorithm for the field equations was the BSSN scheme, which the group helped to develop. Shapiro's undergraduate research team helped to create visualizations and movies with the VisIT software on Blue Waters.

Results & Impacts

In typical cases, following black hole formation, the team observed the formation of magnetically dominated regions above the black hole's poles where the magnetic field lines wound into a funnel, within which the plasma flows outward. This outflow constitutes an incipient jet. Further analysis of the process powering the jets allowed the team to estimate that, for observation times of ~10^4 s, FERMI and SWIFT could detect ultra-long gamma ray burst phenomena from these stars. The gravitational wave busts also could be detected by future space-based gravitational wave instruments. Simulations also crudely modeled the collapse of first generation stars to massive black holes, which could power some of the long gamma-ray bursts observed by FERMI and SWIFT satellites. The analysis thus represents a significant advance in ``multimessenger astronomy".

Why Blue Waters

By adding OpenMP support to the researchers' code and taking advantage of Blue Waters interconnect and processors, the code exhibits greater scalability and performance than on any other supercomputer used by the team. Another recent effort, building the code with the Intel compilers on Blue Waters, resulted in a 30% performance boost, making Blue Waters unique for tackling the astrophysical problems the research team wanted to address. The ability to store and retrieve the data on Blue Waters efficiently and access handy visualization tools to probe simulations in progress also made Blue Waters very desireable.