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NUMERICAL SIMULATIONS OF 2-D QUASI-SPHERICAL ACCRETION ONTO A BLACK HOLE

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ABSTRACT

We continue previous work done with state-of-the-art astrophysics computational code, Cosmos++. This code will be used to simulate black hole accretion disk systems with quasi-spherical symmetry in two dimensions using a general relativistic radiation magnetohydrodynamic framework. Numerical models of this type of system enable the investigation of the affect that the angular momentum of accretion flow has on the geometry of the disk.

1. INTRODUCTION

Despite the significant advances made in understanding black holes and black hole accretion disks in the past few decades, there are still a remarkable number of unanswered questions and aspects of these systems that require a better understanding. Numerical simulations and computational models are essentially the only tools available to study the processes associated with these extreme systems.

In an effort to better understand these systems, we will be employing the recently upgraded Cosmos++ computational astrophysics code to perform general relativistic radiation magnetohydrodynamic (GRRMHD) numerical simulations of black hole accretion disks. This proposal is just one step of a long-term project, the ultimate goal of which is to develop a method to perform global numerical simulations of radiation pressure dominated black hole accretion disks. Ultimately, our computational code will include gravitation, gas dynamics, magnetic fields, and radiation in a three-dimensional, relativistic framework.

In previous work (Fragile et al. 2012), spherically symmetric inflow onto a non-rotating black hole was considered in one dimension. These simulations suffered from drawbacks we have since corrected, the first being timestep restrictions due to the fully explicit GRRMHD scheme implemented, where the equations of radiation were solved and updated using a fully explicit method. To correct this, for the past year we have been developing Cosmos++ by adding a hybrid implicit-explicit numerical scheme (Turner & Stone 2011; Roedig et al. 2012), where an implicit step is used to solve for the radiation source terms and an explicit step is used to solve for the rest of the update. This increases the speed and efficiency of the simulations. The second restriction we have corrected for is the inclusion of a more general closure relation (Levermore 1984) combined with the M-1 model (Dubroca & Feugeas 1999; Ripoll et al. 2001), which enables Cosmos++ to treat both optically thin and thick regions of black hole accretion disks rather than just optically thick regions as before. In these types of simulations it is important to treat both regions, as the actual physical systems have a wide range of optical depth.

Now that these aspects have been added to the code, we are able to utilize it for more astrophysical applications and more realistic models of black hole accretion disks. In particular for this project it will be implemented for the modeling of two-dimensional quasi-spherical black hole accretion. Quasi-spherical accretion onto a black hole occurs when a relatively small amount of angular momentum is introduced into the system; this introduces a polar symmetry along the axis of rotation, though at large distances the system will appear spherical. The symmetry along the axis of rotation alters the geometry of the accretion flow, creating funnels at the poles that facilitate inflow and outflow. Inflowing matter with too much angular momentum to be accreted is pushed out by the centrifugal force along the funnel and collects along the equatorial region to form a torus.

2. METHOD

To produce these simulations we will be implementing the most updated version Cosmos++. We will first have to write a code that will describe a black hole accretion disk with a relatively small amount of angular momentum and quasi-spherical symmetry in two dimensions. This problem will include all the necessary physics: gravitation, magnetic fields, radiation, and gas dynamics all in the relativistic framework. The initial state of the disk will be modeled after Bondi's spherical accretion problem (Bondi 1952), but will contain gas imbued with enough angular momentum to introduce polar symmetry.

Previous modeling of these systems in the 2-D hyrdodynamic case (Proga & Begelman 2003, etc.) have shown that the properties of accretion flows are more dependent on the geometry of these tori (the non-accreted matter) than on the outer boundary conditions, such as amount and distribution of angular momentum. The size and shape of the torus formed constrains the geometry of the funnel along the poles and consequently the amount of in-falling matter onto the black hole, the mass accretion rate $\dot{M}$. To explore various geometries of these disks, we will consider a range of values for the mass accretion rates.

Due to the newly introduced polar symmetry in the system due to the angular momentum, the accretion flow will develop a latitude-dependent optical depth, where the equatorial regions in particular will have more optical depth. This means a latitude-dependent luminosity from an observer's perspective, which will vary depending on the geometry of the torus and polar funnel as well as the mass accretion rate. This property of accretion flow provides another parameter that can be tested over a range of values to enable us to explore the correlation between the properties of accretion flow and luminosity.

3. GOALS AND EXPECTED RESULTS

So far we have developed a GRRMHD astrophysical code that utilizes an implicit-explicit numerical scheme and by the time this project will begin, simulations endowed with angular momentum and magnetic fields will have been processed. The goals of this project will be modeling quasi-spherical disk accretion in two dimensions and preparing the Cosmos++ code for the next level of advanced 3-D simulations.

From these quasi-spherical disk models we can learn about effective (angle dependent) luminosity of these systems, as well as the strength of their jets. This enables the identification of various systems (gamma ray bursts, quasars, etc.) by observed latitude-dependent luminosity. We can also investigate the dependence of mass accretion rate on the geometry of the disk and the angular momentum of the inflow.

4. RESOURCES

This project is exclusively computational, centered around the Cosmos++ code. We will work with the already existing and newest version of the code, writing and testing problems using the C++ programming language. Small-scale test simulations will be done on the C of C campus cluster. Larger jobs will be sent to an Oak Ridge National Lab or other supercomputers/clusters to be run. Once the simulations have run, we will process the data using various programs that can graph or animate the results depending on the nature of the simulation.

5. BUDGET

No budget will be required for this project, as all necessary computer hardware belongs to the College of Charleston.

6. BIBLIOGRAPHY

Bondi, H. 1952, MNRAS, 112, 195

Dubroca, B., & Feugeas, J. 1999, Academie des Sciences Paris Comptes Rendus Serie SciencesMathematiques, 329, 915

Fragile, P. C., Gillespie, A., Monahan, T., Rodriguez, M., & Anninos, P. 2012, ApJS, 201, 9

Levermore, C. D. 1984, JQSRT, 31, 149

Proga, D., & Begelman M.C. 2003, ApJ, 582, 69

Ripoll, J.-F., Dubroca, B., & Duffa, G. 2001, Combustion Theory Modelling, 5, 261

Roedig, C., Zanotti, O., & Alic, D. 2012, ArXiv e-prints

Turner, N. J., & Stone, J. M. 2001, ApJS, 135, 95