Final Report on the Arizona Phase of SciDAC award DE-FC02-06ER41452 at the University of Arizona

A. Burrows[1]

1. INTRODUCTION

This document serves as the final report for the Arizona phase (DE-FC02-06ER41452) of my SciDAC award (entitled "SciDAC Computational Astrophysics Consortium" (CAC), overall PI Stan Woosley at UCSC). It includes a statement on personnel funded, science accomplished at Arizona, collaborations inaugurated and pursued, leverage provided by the SciDAC award, and publications generated. Should you require any further information, please don't hesitate to inquire of Adam Burrows (PI) at burrows@astro.princeton.edu. The project is now entering its second phase, now at Princeton University under award number DE-FC02-09ER41544, but has closed out as of March 14, 2008 at Arizona.

2. PERSONNEL

- University of Arizona - The co-PIs were Burrows and Hubeny. The postdoc supported by SciDAC was Dessart. Burrows moved to Princeton University this January 2008 and has moved the Arizona effort with him. Postdoc Dessart joined him in Princeton near the start of the grant year (March 15, 2008) and it is expected that Hubeny will join him later in 2008. Funds to support Hubeny in this SciDAC project will come from startup monies provided to Burrows by Princeton. An additional postdoc, Ott, was being paid by TINA to work on projects of interest to the CAC, in particular general relativistic hydrodynamics and r-process nucleosynthesis. During the last grant year, the SciDAC award at Arizona supported half time visualization specialist Fisher, who received such support under SciDAC through March 14, 2008. After that he was supported through June 2008 under an NSF award to Burrows that remained at Arizona, and will terminate June 30, 2008. After that at Princeton, the Burrows SciDAC projects will receive visualization support through the PICSciE computer cluster initiative there and through his startup funds. Graduate student Murphy was supported under SciDAC through March 14, 2008, after which he received support from the same

[1]Department of Astrophysical Sciences, Peyton Hall, Princeton University, Princeton, NJ 08544-1001, burrows@astro.princeton.edu; formerly at the University of Arizona

NSF young membership. He finishing his Ph. D. thesis (which is mostly to develop and employ the RFTHF-hydro code under SciDAC) on June 16, 2008. Recruitment is in progress for another SciDAC postdoc, to be hired by Princeton. Work at Arizona focused on core collapse supernovae and radiation transport and will be continued at Princeton the next three years.

3. SCIENCE

3.1. At the University of Arizona

Team members at the University of Arizona worked chiefly on radiation transport and models for core collapse supernovae, and have recently published papers on MHD jets from core collapse.

Burrows, Dessart, and Ott (along with collaborator Eli Livne of Hebrew University) have recently published state-of-the-art models of MHD-driven explosions of the rapidly rotating cores of massive stars. The code used is an upgraded version of VULCAN/2D that includes magnetic fields and magnetic torques. In the context of rapidly rotating Chandrasekhar cores, they have determined the jet powers, detailed driving mechanisms, critical rotation rates for MHD domination, spindown rates, and degree of collimation. The relative roles of Poynting and hydrodynamic flows were studied, and the possible connection with hypernova explosions was explored. Moreover, the proto-neutron star stage before black hole formation in the collapsar model of GRBs was investigated, and the possibility that a baryon loaded jet phase may always precede the collapsar phase was investigated. They also studied MHD-driven explosions after the accretion induced collapse of white dwarfs in binaries.

Hubeny and Burrows published an extensive paper on the RFTHF-transport scheme. Developed under SciDAC, RFTHF-transport is a multi-D, multi group, multi angle, velocity-dependent radiation transport code. The RFTHF-hydro code has been developed by Burrows and graduate student Murphy (whose Ph.D. thesis this is) and is an ALE code with an unstructured mesh. The coupling between the transport and hydro remains to create RFTHF is now underway and should be completed in the next six-eight months. The result will be the only fully multi-D, multi angle, multi group supernova code in existence and can be used for both neutrinos and photons.

Burrows and Hubeny have begun their collaboration with Bell at LLNL and Howell and Singer at LLNL to develop a 3D multi group flux limited diffusion rad/hydro code, CASTRO. One application of this code will be to further their multi-D study of core collapse supernovae and to create an all purpose 3D radiation/hydro capability for general astrophys-

ional simulation.

Burrows, Ott, Dessart, Livne, and Murphy are continuing their investigation of the acoustic mechanism they have seen in their long-term supernova simulations, in particular the progenitor dependence and the r-process nucleosynthesis. With K. Otsuki, they have calculated the r-process yields of these explosions and a paper is in progress.

Ott and Burrows are using the S_n multi-angle variant of VULCAN/2D to compare the neutrino heating rates and net gain behind the stalled shock using this more precise approach to what the multi-group, flux-limited diffusion (MGFLD) approach gives. This is the only multi-D ($2D_+$, multi-angle, multi-group exploration of the neutrino radiation field and emissions ever undertaken, except for an earlier paper by Livne et al. (2004) which covered only 22 milliseconds of evolution. This works covers hundreds of milliseconds of evolution. All the rest of the published work in the field has been flux-limited or ray-by-ray (multiple 1D calculations).

Murphy interacted with Dinesh Kaushik of TOPS to develop a robust Poisson solver for unstructured meshes that is now used in BETHE-hydro. Christian Ott partnered with FERM to optimize their 3D general relativistic collapse hydro code, Cactus/Carpet/Whisky ("CCW"), and Burrows and Fisher partnered with Janet Jacobsen of the VisIt visualization group at LBNL, under Wes Bethel to support and expand our visualization efforts.

Using the supernova spectral code, CMFGEN, Dessart has modeled numerous Type IIp and IIn supernovae and calibrated their use as distance standards. Recently, Dessart has incorporated time dependent level populations and ionization into CMFGEN and has used the updated code to compare with measured supernova spectra, obtaining unprecedently good fits. He, Hillier (Pittsburgh), and Burrows will soon generate theoretical Type Ia spectra in support of the overall Type Ia cosmological effort and spectral code comparison protocol planned under the SciDAC/CAC. Along with Burrows, Dessart is developing a general supernova light curve simulation capability to be applied to the analysis of supernova data obtained over the last 5 years and anticipated in the next.

4. COLLABORATIONS AND INTERACTIONS

4.1. With SciDAC Centers

The Arizona team also interacted with TOPS to develop a robust Poisson solver for unstructured meshes to be used in BETHE, and is starting to partner with FERM to optimize their 3D general relativistic collapse hydro code, Cactus/Carpet/Whisky ("CCW"). It

is partnered with the VisIt visualization group at LBNL under Wes Bethel (with Cristina Siegerist collaborating with Arizona's Tom Fisher) to support and expand Arizona's visualization efforts. The Arizona team collaborated with APDEC PI John Bell (LBNL), Louis Howell (LLNL), and Mike Singer (LLNL) to create the 3D CASTRO AMR radhydro code, in particular its transport module.

5. LEVERAGE AND COMPUTER TIME AWARDS

- Team members at Arizona (now at Princeton) have leveraged SciDAC funds with complementary NSF funds, in particular from the PFC TINA and through a direct individual investigator grant to PI Burrows. In addition, the Arizona team obtained a computer allocation on NASA's Columbia machine to perform supernova simulations of relevance to their SciDAC efforts. Finally, Burrows negotiated a startup package from Princeton University that provides computer clusters and visualization expertise in support of his SciDAC projects and a one to one match of SciDAC funds transferred to Princeton.

6. PUBLICATIONS

6.1. Adam Burrows, PI and Collaborators

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