Apples With Apples Workshop in Argentina

Sascha Husa, Friedrich Schiller University Jena sascha.husa-at-uni-jena.de

The third "Apples with Apples" workshop, which took place from March 14–25 2005 in Argentina, continued a series of roughly one two-week meeting per year to bring together numerical relativists in hands-on comparisons of formulations of the Einstein equations for numerical relativity. The meeting was organized by Oscar Reula in Villa General Belgrano, located in the beautiful Calamuchita Valley near Cordoba. The conference hotel that hosted all participants provided a very communicative setting for our purposes. Special thanks go to Oscar and the local students Florencia Parisi and Santiago Gomez for their help and support of the participants. The meeting followed the established patterns of previous apples with apples meetings, with talks and discussions in the first week, and working sessions and more discussions in the second week. Talks have been presented by Jeff Winicour, Osvaldo Moreschi, Tilman Vogel, Sascha Husa, Santiago Gomez, Bernd Reimann, Carles Bona, Bela Szilagyi, Yosef Zlochower and Pedro Maronetti, and all of these talks have been accompanied by rather lively discussions.

Jeff Winicour opened the meeting with a general introduction to the ideas and history of the project, and set the scene for the discussions to come. Carles Bona, Bela Szilagyi and Yosef Zlochower presented test results with their codes (the Z4 system, different versions of harmonic codes, and the LazEv BSSN code), and what they had learned from their tests and the discussions within the project. Sascha Husa presented results obtained with Calabrese and Hinder in [1] on second order in space hyperbolic evolution equations, and presented suggestions for revising the robust stability test. Bernd Reimann (see [2]) and Tilman Vogel (see [3]) discussed their promising approaches to deal with continuum instabilities. Pedro Marronetti presented his thoughts on setting up tests for binary neutron star evolutions, followed by a discussion on what could/should be done regarding tests for systems with matter. Santiago Gomez presented work of the Cordoba group on a new evolution system using components of the Weyl tensor as evolution variables, Osvaldo Moreschi talked about a new approach to the binary black hole problem, where interior and asymptotic region are matched with analytic methods. See [4] for abstracts and some slides.

The declared goal of the ApplesWithApples project is to develop a hierarchy of testbeds which should eventually include binary black hole problems. A natural hope is to progress rather quickly from the simple toy problems with periodic boundaries we had designed at the first meeting to actual black hole spacetimes – in particular since running 3D black hole simulations with advanced technology such as grid refinement or excision has become routine for several groups. However, another declared goal of this project is to significantly improve our level of actual understanding – believing that understanding is key to eventually develop robust simulation methods. More than for the previous meetings, the spirit of the Cordoba meeting has been one of digestion rather than accelerating the broadening of our scope – but this, I believe, has been achieved rather successfully! One of the main topics of the workshop was to incorporate recent theoretical progress into our practical program of designing test suites and in particular also into the interpretation of test results. Most notable here are the advances regarding the mathematical understanding of second order in space systems, of continuum instabilites (e.g. as signified in the talks of Reimann and Vogel), and in much work on particular evolution systems which has directly emanated from the apples project, such as the rather detailed studies of the Pittsburgh group.

Let me select a few points where our understanding has improved substantially: The instability exhibited for the ADM [5] system in the first "apples paper" [6] has finally been nailed down as an ordinary von Neumann instability. In order to properly understand this, progress with the theory of well-posedness and numerical stability for second order in space systems was required, see e.g. [1,7]. In fact, one of the misleading original ideas was to look for exponential growth in our "robust stability test", whereas weakly hyperbolic equations should be expected to only produce resolution dependent polynomial, e.g. linear, growth in the linear constant coefficient case (i.e. the robust stability test setup). This non-convergent behavior has in particular been verified for the ADM system.

Some confusion had been caused by the fact that numerical stability tests in the linear constant coefficient regime can show a rather complicated phenomenology due to the frequency dependent damping effects inherent in any finite difference scheme (with or without artificial dissipation). Depending on various parameters such as number of grid points, time step size or dissipation factor various effects with different inherent time scales may compete, and the proper interpretation of results may requires either extremely detailed and careful parameter studies – or some analytical modelling in addition to

numerical tests. As should be expected on theoretical grounds, most codes do require artificial dissipation (e.g. of Kreiss-Oliger type) beyond the linear constant coefficient regime in order to avoid high-frequency instabilities. Particularly clarifying in this respect were Yosef Zlochower's runs with the LazEv BSSN code, and Christiane Lechner's runs with various symmetric hyperbolic codes. As shown in [1], it turns out that for second order in space formulations the situation is somewhat more subtle than for first order systems: while the second derivatives in these systems typically help to damp out high grid frequencies, a mixing of first and second derivatives in the principal part may result in a numerical instability with standard discretizations of certain well posed systems (at least without artificial dissipation).

Since the meeting has taken place, several phone conferences have been organized to further coordinate our work, for information on how to join, news and how to access our data repositories with results see our web site [4]. Finally, let me mention that the steaks *are* indeed fabulous in Argentina, and that they are preferably accompanied by a Malbec from Mendoza.

References:

[1] G. Calabrese, I. Hinder and S. Husa, Numerical stability for finite difference approximations of Einstein's equations, gr-qc/0503056.

[2] B. Reimann, M. Alcubierre, J. A. González and D. Núnez, Constraint and gauge shocks in one-dimensional numerical relativity, *PRD* **71**, 064021 (2005).

[3] J. Frauendiener and T. Vogel, Algebraic stability analysis of constraint propagation, *Class. Quantum Grav.* **22**, 1769 (2005).

[4] See the project website at `http://www.appleswithapples.org` and the web pages of the meeting at `http://www.appleswithapples.org/Meetings/Cordoba2005` http://www.appleswithapples.org/Meetings/Cordoba2005

[5] Here the term ADM refers to the system presented in J. W. York, in Sources of Gravitational Radiation (Cambridge University Press, Cambridge, England, 1979).

[6] M. Alcubierre et al., Toward standard testbeds for numerical relativity, *Class. Quantum Grav.* **21**, 589 (2004).

[7] For an overview, new results and further references see Carsten Gundlach, Jose M. Martin-Garcia, Hyperbolicity of second-order in space systems of evolution equations, gr-qc/0506037.