Source Simulation Work in Italy

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A bit of geography...

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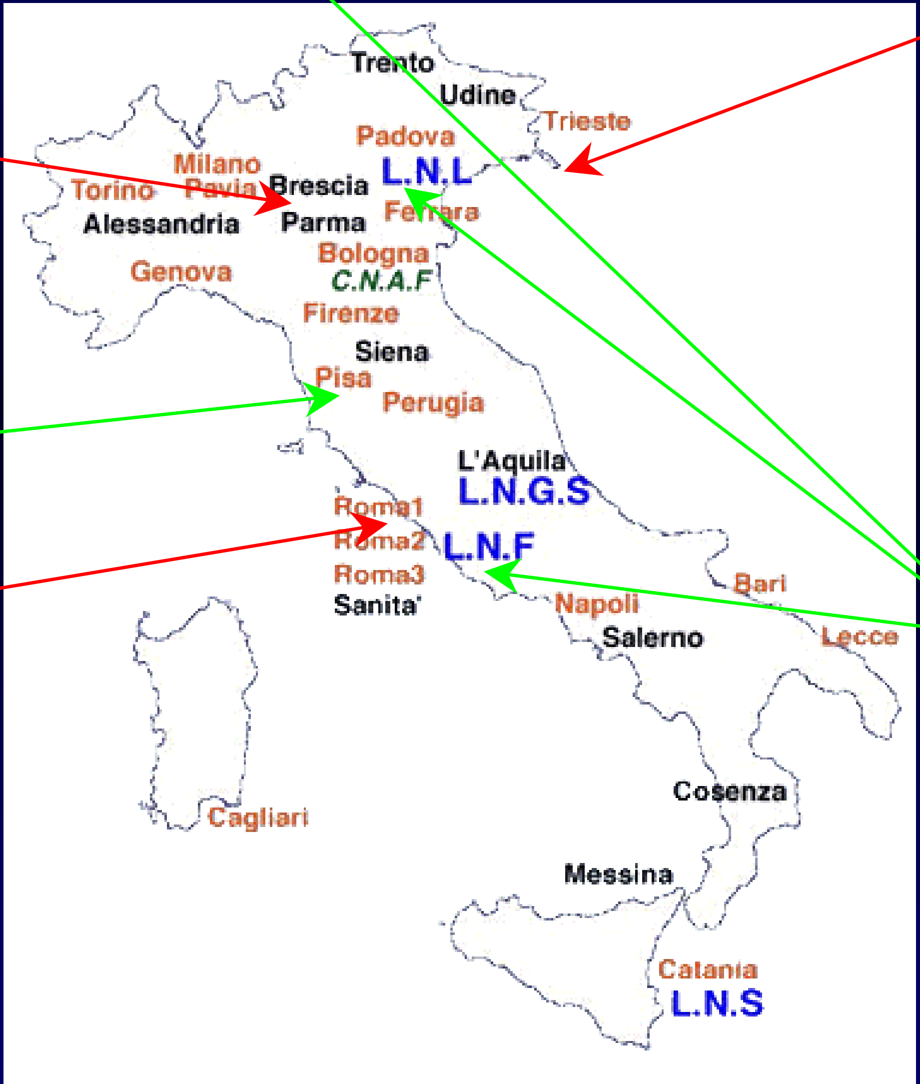
Omar BENHAR
Leonardo GUALTIERI
Jose PONS
Giovanni MINIUTTI
Alessandro NAGAR



SISSA Trieste
Luciano REZZOLLA
Luca BAIOTTI
Pedro MONTERO
Shin YOSHIDA
(Koji URYU)
John MILLER

Resonant Bars

Legnaro (Padova)
Frascati (Roma)
CERN (Geneve)

Source Simulation: the main projects

Relativistic hydrodynamics

- o Dynamics & Collapse of relativistic stars
- o Stellar normal modes (f-, r-, g-) & instabilities
- o Binary Inspiral

Perturbative Approaches

- o Normal modes & instabilities
- o Binary systems

Relativistic Hydrodynamics

An originally small collaboration between AEI and WashU led to a GR Hydrodynamics code coupled to the spacetime evolver in **Cactus**

The code was developed/tested jointly but primarily written by M. Miller (WashU); as a result, several papers have published jointly

In Dec 2001, with the EU effort at full steam, the need to tap local expertise and for a more compact working group has emerged, ie:

the need for a... **WHISKY!** (a EU, GR Hydrod. code)

- **SISSA (Trieste, I):** L. Baiotti, P. Montero, LR
- **AEI (Golm, D):** I. Hawke, S. Hawley, E. Seidel, T. Goodale
- **Univ. of Valencia (Valencia, E):** T. Font, JM. Ibanez, J. Frieben
- **AUTH (Thessaloniki, GR):** N. Stergioulas
- **OBSPM (Meudon, Paris): S. Bonazzola, E.**

Why invest in Whisky: yet another code?...

As the originating code (GR3D), **Whisky** makes use of High Resolution Shock Capturing methods leading to superior, high precision hydrodynamics

It's coupled to the **Cactus** spacetime evolver, possibly among the best available → exploits all of the "expertise" (gauge conditions, suitable reference frames and miscellaneous "tricks") developed for the binary black hole problem

The coupling of the spacetime and the of the hydrodynamics is made through the MOL (Method Of Lines) and is an important new feature. Given a grid and a spatial differencing L of the vector of variables q, the equations are written as ODEs in the form

$$\frac{d}{dt} q = L(q)$$

What does MOL do for you?

Any stable ODE method can be used (RK2, RK3, RK4, ICN,...) and the control of the truncation error is transparent

The coupling between different treatments in the hydro or spacetime is minimized: improvements in one code are instantly effective

Different numerical methods are easily implemented (just a change in the way the $L(q)$ is computed!)

Where are we now (2 ½ months later)?

SPACETIME: MOL is in place, ie full coupling with **CACTUS**

HYDRO: HLLE, Roe, Marquina Riemann solvers have been implemented. TVD and PPM reconstruction methods are in use. New interesting features have been found with PPM. ENO to come soon...

In other words: we are at the stage of simulating accurately isolated spherical and rotating stars (*cf. Font et al.*, PRD *2002*)

Perturbative Studies (more on Nils' talk)

One of the main goals of the EU-Network and considerable effort in both in SISSA and Rome: determine the quasi-normal modes of compact stellar objects and identify the presence of instabilities

Basic keyword these days: DIFFERENTIAL ROTATION

r-modes:

- determined the Newtonian eigenfreqs. in the Cowling approx.
- pointed out the generation of differential rotation as nonlinear effect; assessed the coupling with magnetic fields
- investigated the role of DR in the eigenfreqs. spectrum for toy problems

f-modes:

- determined that DR favours the instability in relativistic rapidly rotating stars within the Cowling approximation

binary systems:

- estimate gw emission from extrasolar planetary systems
- determined the structural effects in the tidal excitation of normal modes (f- & p-) in the final stages of the inspiral (*ie* $\nu > 0.2$, $\nu_{GW} > 200$ Hz). The energy output can be several orders of magnitude larger than the orbital one

Binary System:
one extended star + perturbating point-like star

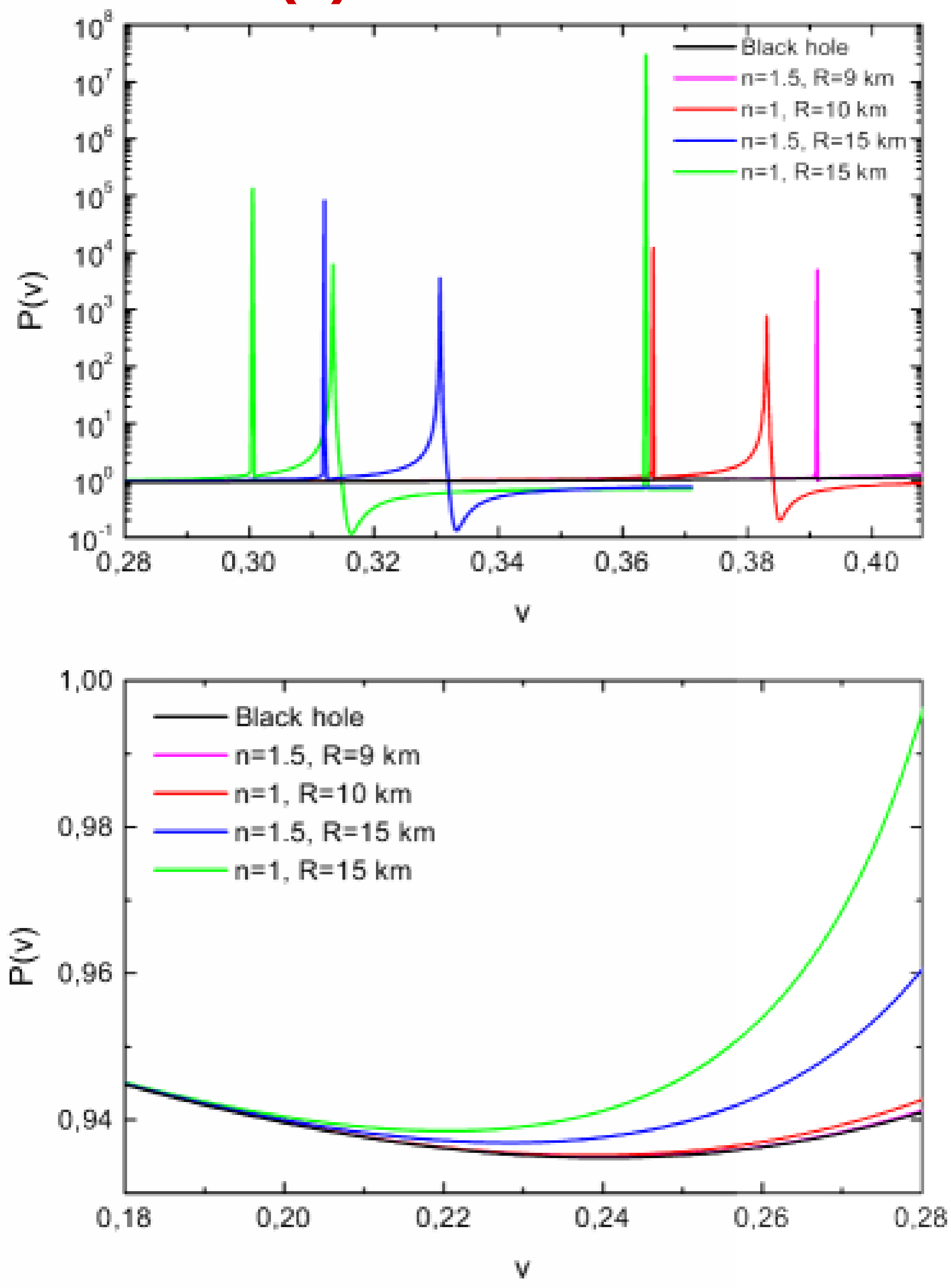
Einstein and hydrodynamic equations are perturbed and then solved numerically

The orbital evolution, the waveform and the energy emitted are calculated for several EOSs
Gualtieri et al. PRD 2001, 2002

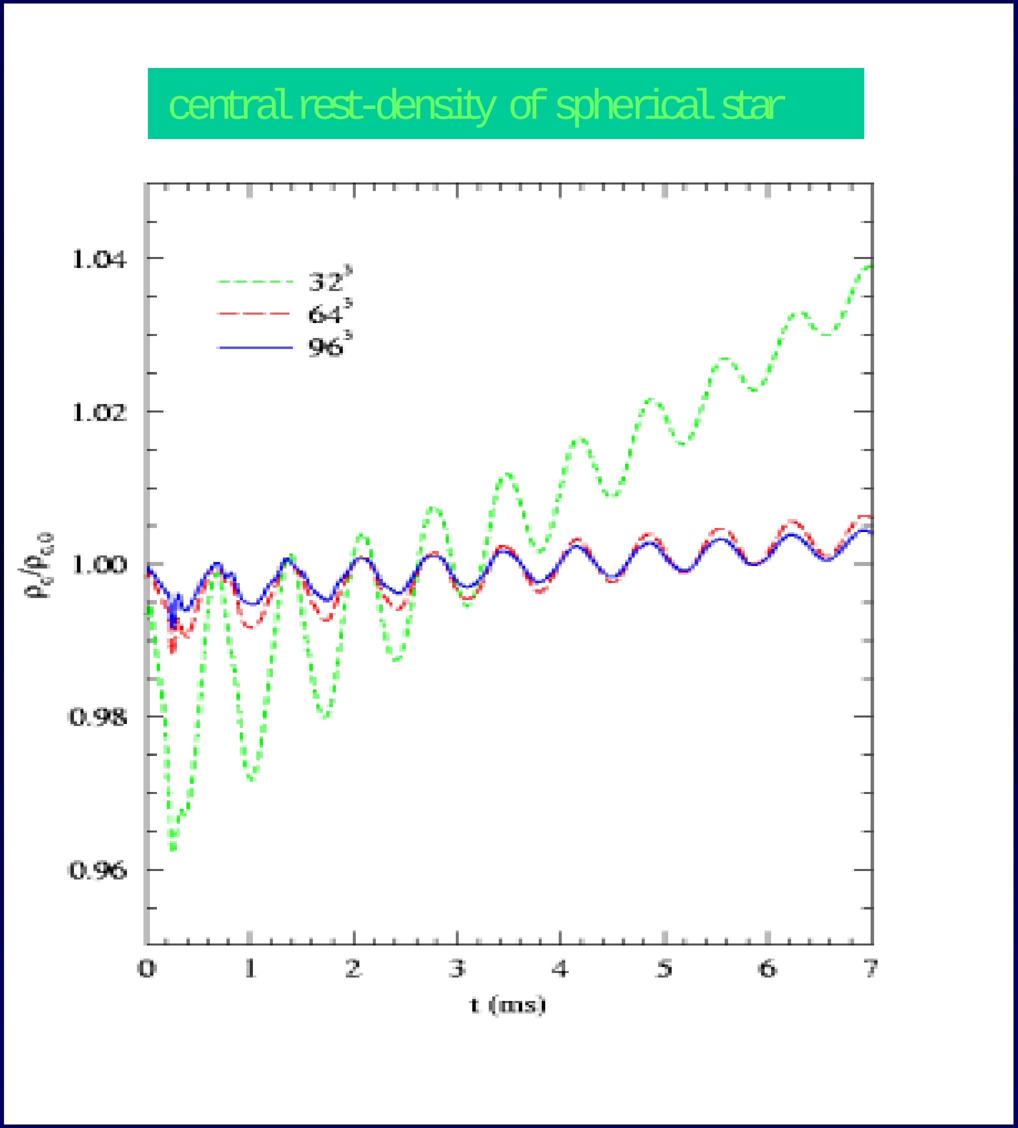
Main differences due to the internal structure become noticeble when $v/c > 0.2$

This happens 20-30 cycles before coalescence!

$P(v) = E^R / E^{ORB}$

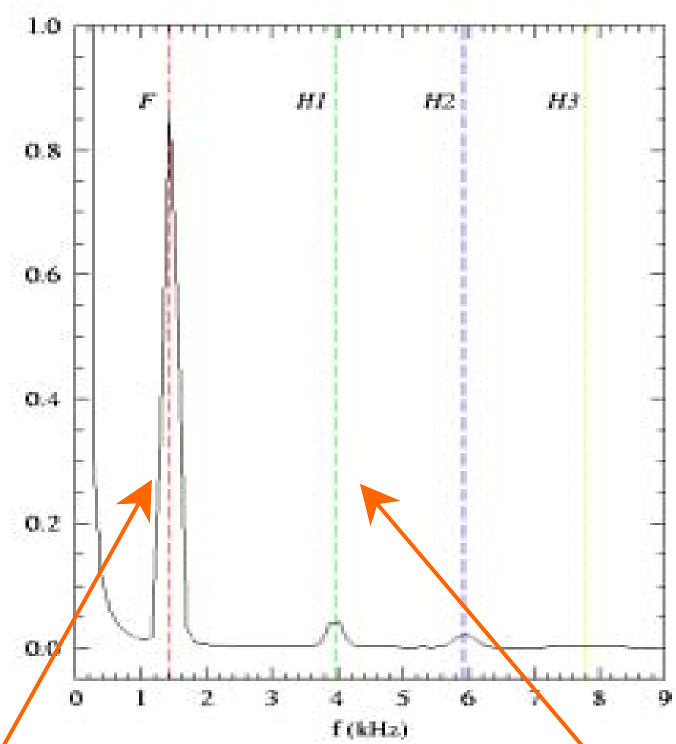


High Precision Hydrodynamics

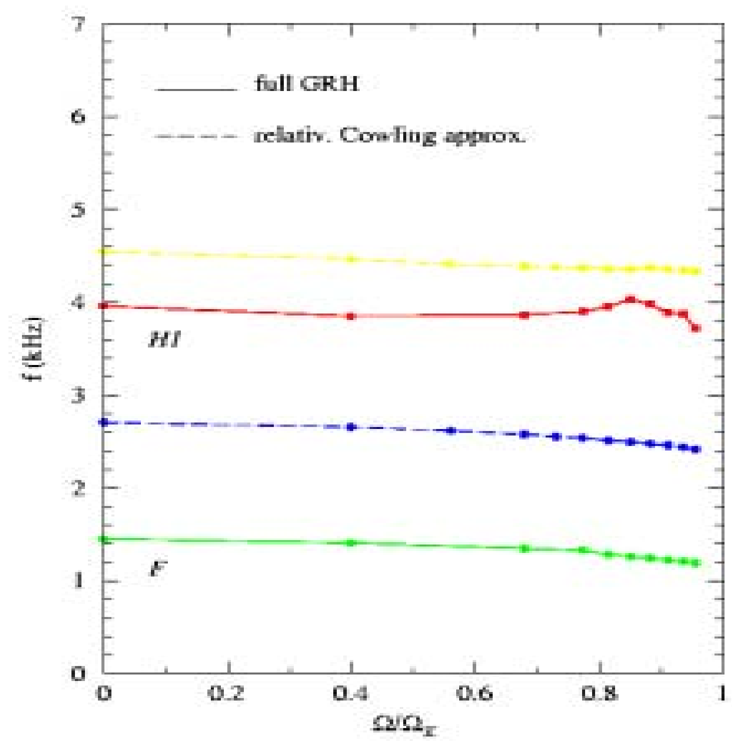


High Precision Hydrodynamics

Power Spectrum of central rest-density



Power Spectrum of central rest-density



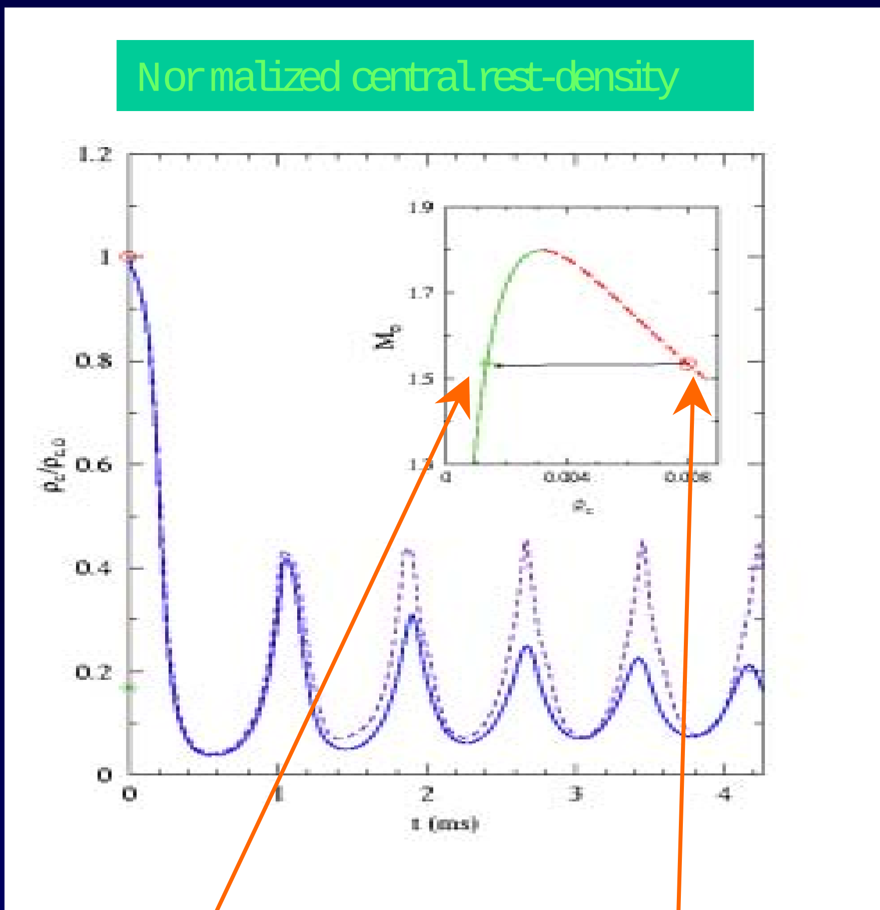
Fundamental mode: $\Delta f / f \sim 0.01$

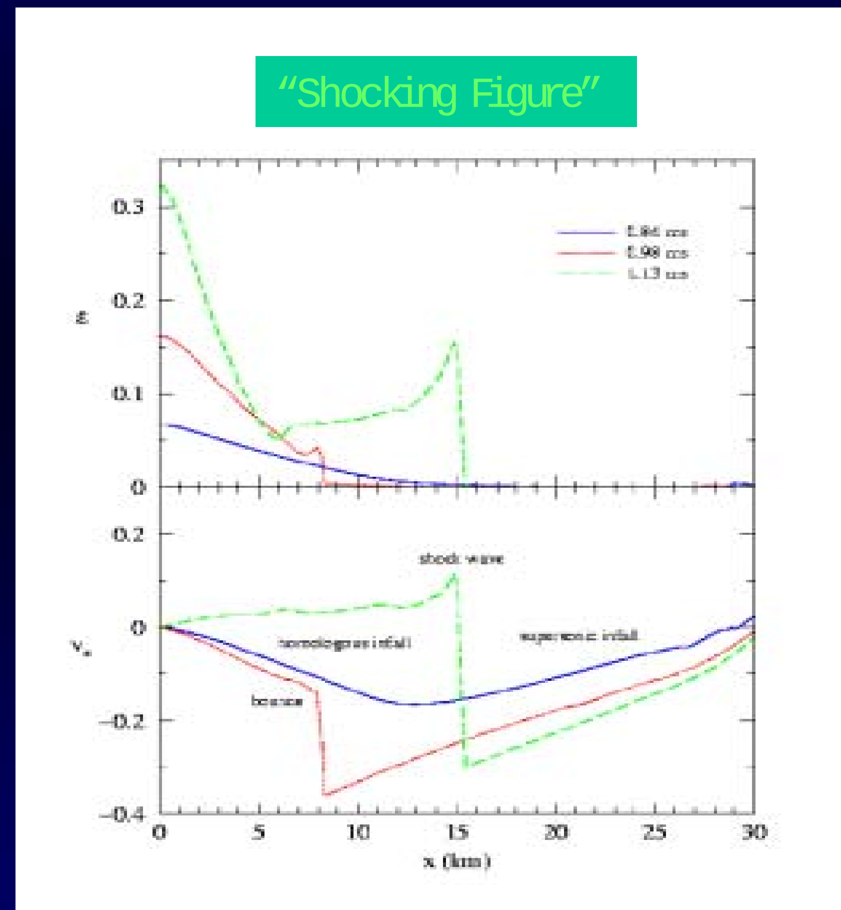
Overtones

These frequencies have not been computed before.
Numer. relativity anticipates perturbation theory!

Nonlinear dynamics: a “migrating” spherical star

Consider an unstable polytropic $\Gamma=2$ star, with $M=1.447M_{\odot}$





Stable config.   Unstable config.