Large Scale computing at INFN:

TEONGRAV HPC activities.

Roberto De Pietri
INFN Parma e
Università di Parma
for the IS TEONGRAV

Our goals

- **TEONGRAV** stands for: **TE**oria delle **ON**de **GRAV**itazionali
- Our research is centered on the finding answers to the following questions:
  - Which are the features of the GW signal emitted by the main expected sources (such as, for instance, coalescing compact binaries, rotating non-axisymmetric NSs, oscillating BHs and NSs?
  - Which information on the emitting source could be extracted from a GW detection? For instance, what could we learn on the equation of state of the dense matter in the inner core of a NS?
  - Which information on the nature of gravity could be extracted from a GW detection? For instance, which could be the imprint of modifications or extensions of general relativity (GR) on the GW signal from astrophysical sources?
- **To reach our goals we need to simulate Astrophysical system on High Performance Computer**
- **In the era of gravitational observatory…..**

The case for a renewed support of computational theoretical physics at INFN (Proposal of 2014)

- Referring to the main INFN documents we estimated a request of 150M and 170M for the year 2016 and 2017 along way below the effective allocation on INFN machines.
- We integrated our resource through PRACE, ISCRA competitive allocations and the help of our international collaborators and we keep doing so.
- The number of INFN groups doing HPC research in Numerical General relativity is increasing as well as the request of HPC resources

Gruppo	Progetto (assegnazioni 2017)	Galileo	Marconi A2	Marconi A1
Trento	BNS with Magnetic Fields (Giacomazzo)		2.000.000	800.000
	Effetti relativistici grande scala (Bentivegna)	100.000	300.000	
Firenze	Magnetic winds in supernova (FIRENZE)		2.000.000	
Milano	Mass Stripping (Milano)	600.000		
	Massive Black Hole (Milano)	100.000	800.000	280.000
Parma	BNS (Parma - De Pietri)	1.260.000	4.900.000	20.000
	BNS (Parma - Bernuzzi)		4.000.000	200.000
Totale		**2.060.000**	**14.000.000**	**1.300.000**

Gruppo	Progetto (assegnazioni 2016)	Galileo	Fermi	Marconi A1
Trento	BNS with Magnetic Fields (Giacomazzo)	150.000	3.000.000	
	Effetti relativistici grande scala (Bentivegna)	50.000		300.000
Firenze	Magnetic winds in supernova (FIRENZE)		1.400.000	
Milano	Mass Stripping (Milano)	150.000		
	Massive Black Hole (Milano)	150.000		
Parma	BNS (Parma - De Pietri)	500.000	100.000	
	BNS (Parma - Bernuzzi)	50.000	2.500.000	100.000
Totale		**1.050.000**	**7.000.000**	**400.000**

The case for a renewed support of computational theoretical physics at INFN

S. Arezzini, L. Biferale*, M. Caselle*, A. Cea, A. Ciampa, L. Cosmai, G. de Divitiis, M. D'Elia, R. De Pietri*, C. Destri, P. Dimopoulos, F. Di Renzo, R. Frezzotti, L. Giusti*, G. La Penna, M. P. Lombardo*, V. Lubicz*, E. Marinari, G. Martinelli, V. Minicozzi, S. Morante*, M. Nicodemi*, A. Papa*, M. Papinutto, G. Parisi, F. Pederiva*, A. Pellissetto*, M. Pepe, F. Rapuano, C. Ratti, G. C. Rossi*, G. Salina, F. Schifano, S. Simula, N. Tantalo, C. Tarantino, R. Tripiccione*, E. Vicari, P. Vicini*, M. Viviani*, T. Vladikas

* *Conveners*

(Dated: February 18, 2015)

We outline a proposal for a strong and renewed support by INFN to its research groups active in theoretical computational physics. We argue that theoretical computational physics is important *per se* but it is also an important tool to understand in full the results and implications of present and future experiments. We describe a consistent line of action, review the physics area that would benefit from this line of support, and assess the level of resources needed to put this proposal in practice. We discuss several important advantages that this initiative would bring to all of INFN.

	2014	2016	2017
LGT: hadron physics	100	200	300
LGT: QGP and BSM	90	300	360
LGT: flavor physics	120	240	360
General relativity	60	140	170
Quantitative Biology	5	12	15
Fluid Dynamics	60	120	160
Nuclear Physics	10	15	20
Grand Total (Mcore-h)	**445**	**1027**	**1385**
Grand Total (Eq. Pflops)	**0.640**	**1.49**	**2.00**

Computational activity inside TEONGRAV

- **The research activity will be on various aspects and simulation methods in general relativity compact objects (Neutron Stars and Black Holes) and the modeling of the gravitational signal emitted by these systems. The main aspect of this activity is in the numerical simulation in time of the dynamics of binary systems consist of two stars of Neutrons in the final stage of the "Merger" and the following dynamic both with the presence of magnetic fields or without. In particular we intend to study the following systems:**

(1) Study in magneto-hydrodynamics general relativistic merger of binary stars of magnetized neutron and with different mass ratios and different equations of state. Signal calculation gravitational waves and estimation of possible electromagnetic counterparts. The study will focus in particular on two scenarios: (1a) Study of the possible formation of relativistic jets from the collision of binary neutron stars that produce a high-mass black hole after the merger (the "standard model" of short GRBs). (1b) Study of the possible formation of magnetars following the merger of binary stars of low mass neutrons ("time-reversal scenario" for short GRB).

(2) Simulations of many orbits in BNS systems and quantification of the difference due to tidal effects between simulations involving only the phase of merger than when the phase of "late-inspiral" is also simulated.

(3) Simulations of binary neutron stars using the BAM code to investigate the largest possible space of parameters covering total mass, microphysicsal EOS, mass-ratio, spins and temperature effect.

Computational activity inside TEONGRAV (2)

- **Other activities:**

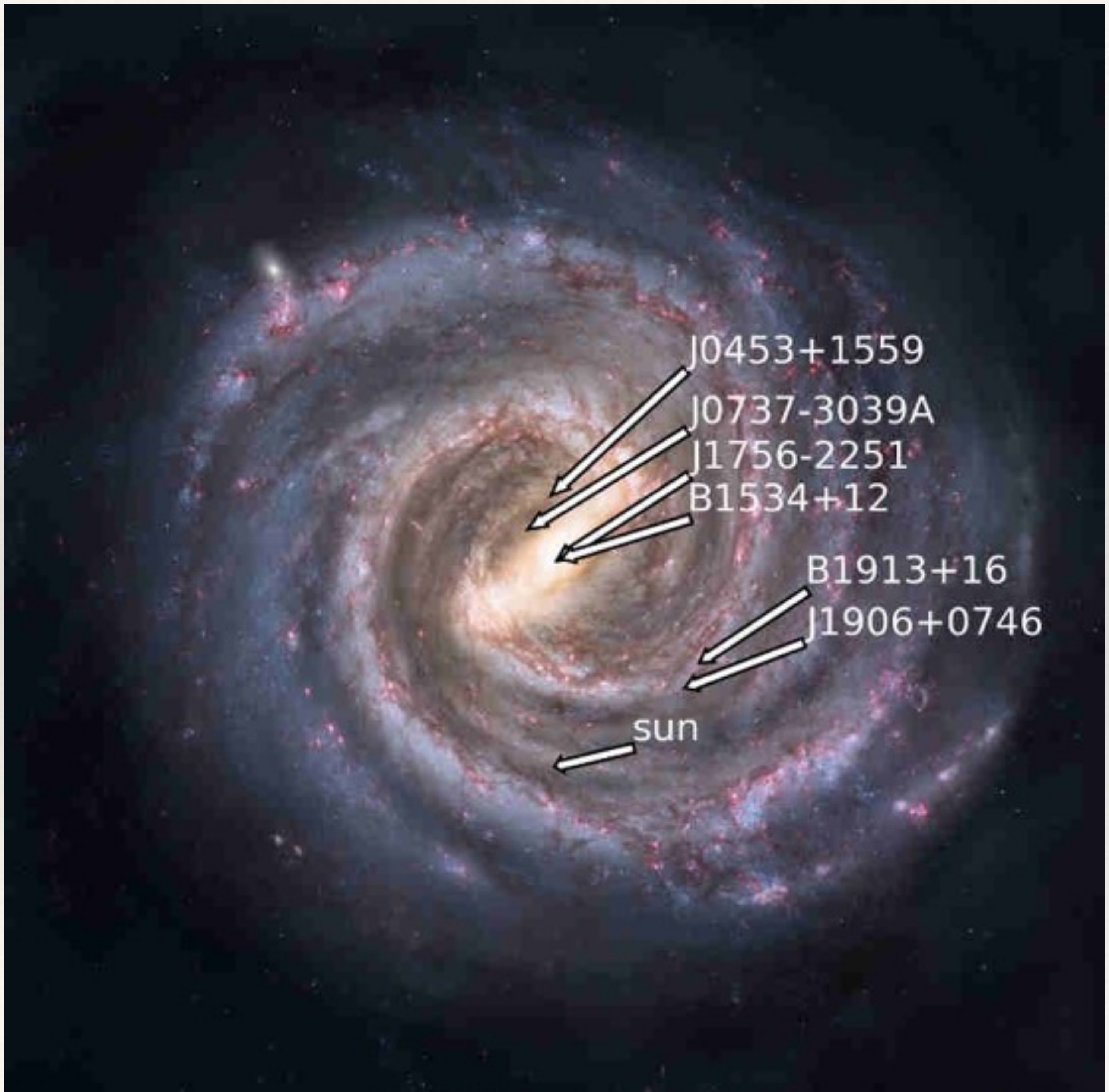
  (1) Phenomenological Waveform Modelling of GW signal using information coming from Numerical Simulation and Analytical Modeling.

  (2) 3D simulation of the interaction of winds from magnetized neutron stars rotating rapidly with the rest of the surrounding supernova (i.e. the class of sources known as pulsar wind nebulae). The simulations can expect made through the magnet-relativistic hydrodynamics code PLUTO using its AMR potential.

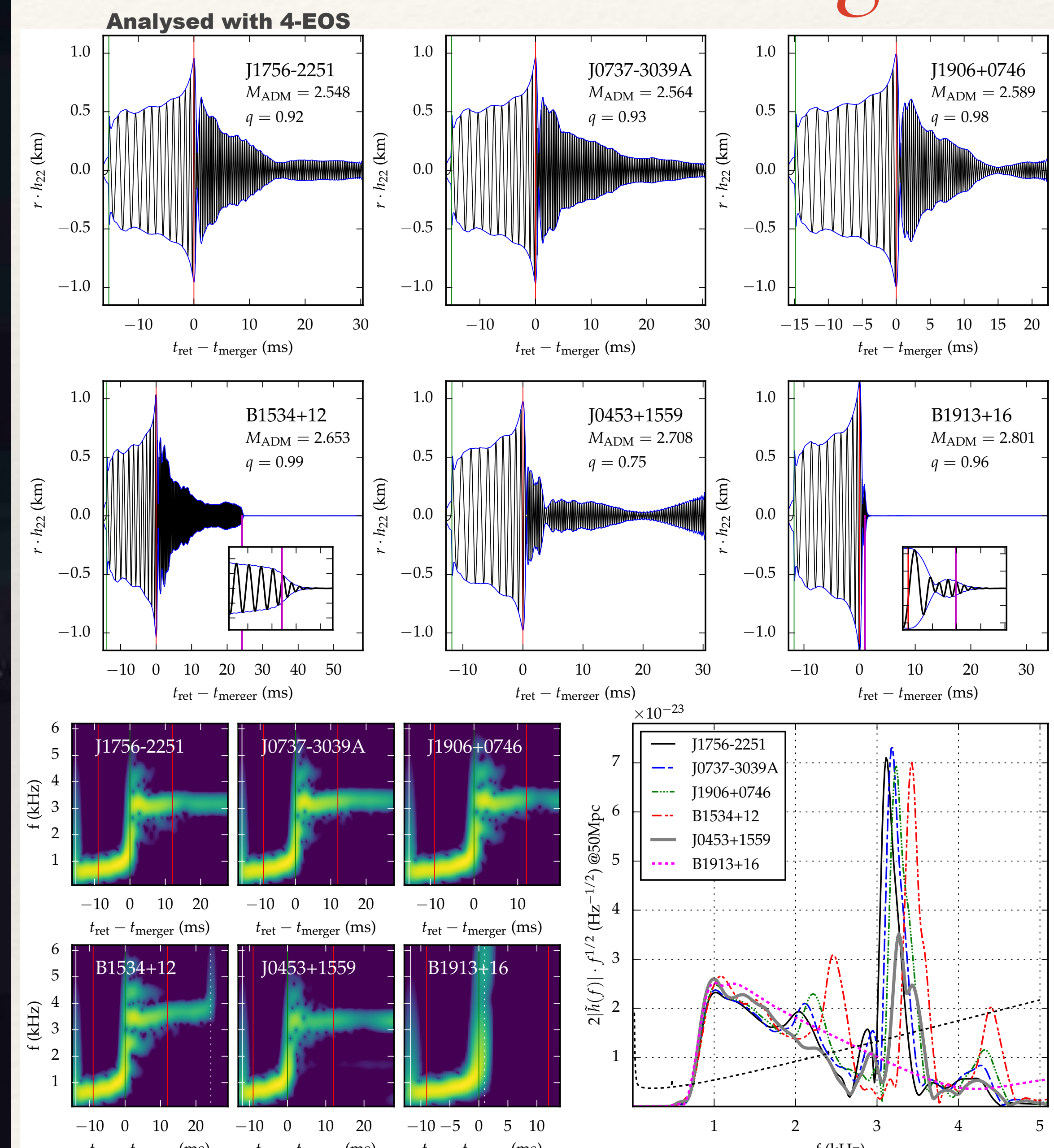
  (3) Investigation of the phenomenon of tidal destruction of stars from blacks holes in galactic numerical - test cores and analysis of physical interaction and relativistic effects; (B) the dynamics of blacks holes in binary galaxies in interaction and analysis of the role of gas and star formation evolution multi-orbital scale in relation to the target observational ELISA. Convergence test with the codes GADGET eGIZMO

  (4) The simulation of cosmological relevance spaces without approximations, by directly integrating the equation of Einstein, and the study of the stability and the optical properties of infinite lattices of blacks holes and cosmology with inhomogeneous fluid at zero pressure.

Binary Neutron Star Mergers are known source for gravitational wave observatory. In our Galaxy there are six know systems of this kind that will collapse emitting GW signal.

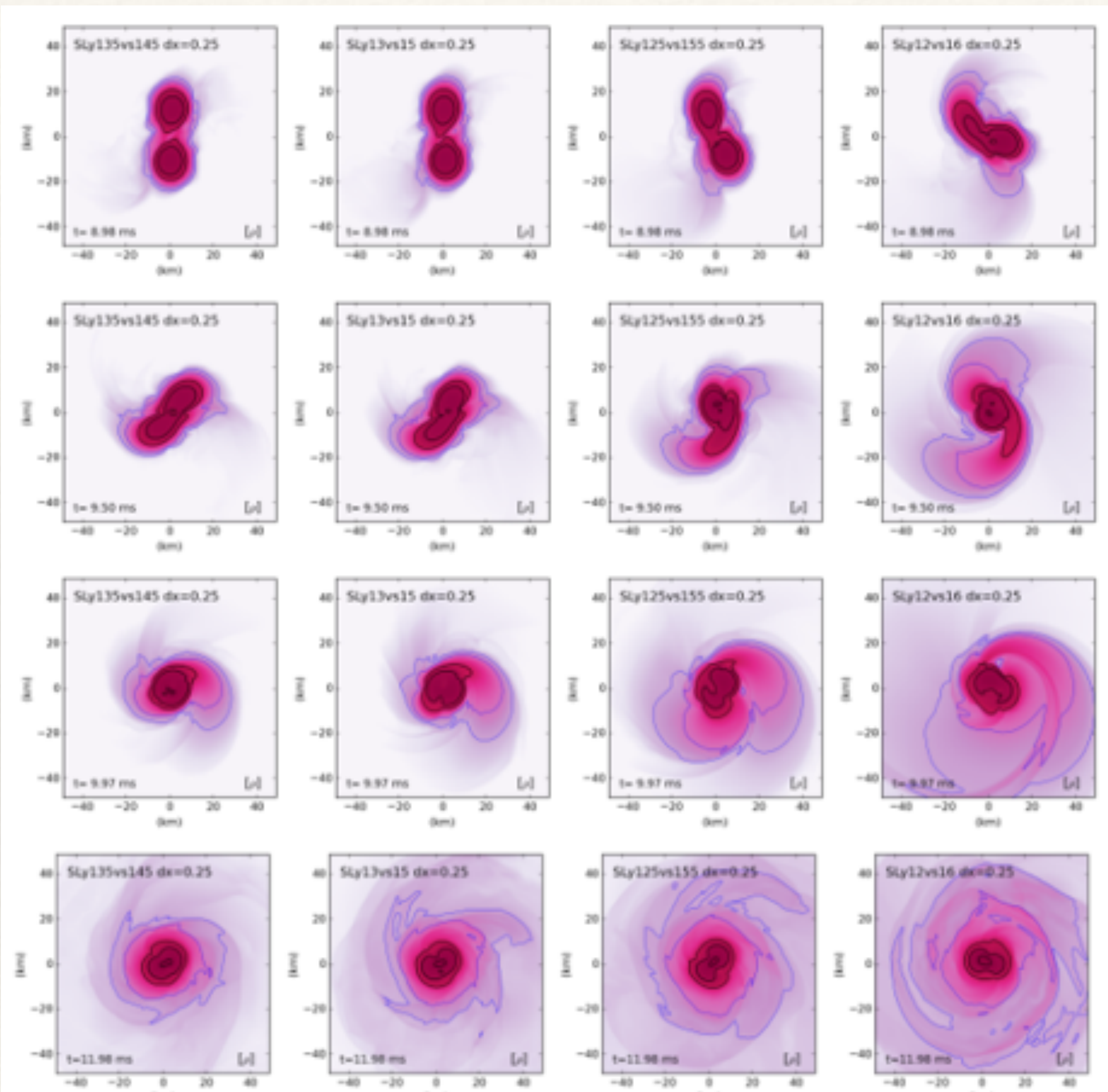


The simulated GW signal



Modeling Mergers of known Galactic Binary Neutron Stars,
A. Feo, R. De Pietri, F. Maione and F. Loeffler,
Classical and Quantum Gravity 34 (3), 034001 arXiv 1608.02810(2016)

Numerical Relativity in a nutshell



Modeling equal and unequal mass binary neutron star mergers using public codes,
R. De Pietri, A. Feo, F. Maione and F. Loeffler,
Physical Review D 93 (6), 064047, 034001 arXiv 1509.08804(2015)

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 8\pi G\, T_{\mu\nu}$$ Einstein Equations

$$\nabla_\mu T^{\mu\nu} = 0$$ Conservation of energy momentum

$$\nabla_\mu (\rho u^\mu) = 0$$ Conservation of baryon density

$$p = p(\rho, \epsilon)$$ Equation of state

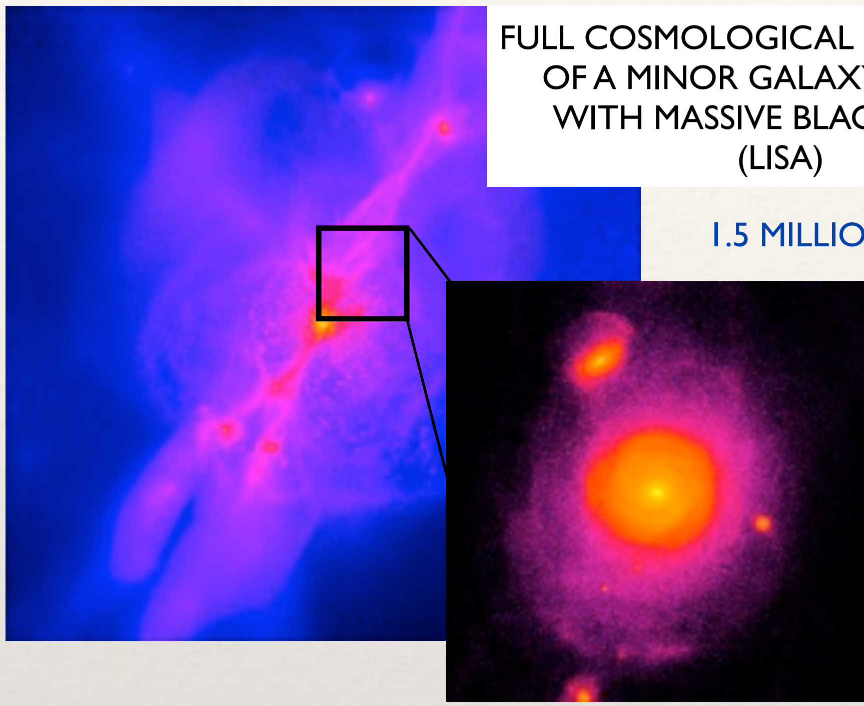
Ideal Fluid Matter
$$T^{\mu\nu} = (\rho(1+\epsilon) + p) u^\mu u^\nu + p g^{\mu\nu}$$

\+ Evolution of magnetic Fields (Trento and Firenze)

- Main goal: to study GW (and EM counterparts) from compact binaries
- Formation of compact binaries.
- Waveform modeling in NR + analytical relativity.
- Counterparts to BNS mergers: SGRB, Macronova,…

- Methods
- The fluid matter equations are a non linear a form a hyperbolic system and need HRSC Methods well-adapted to grid-methods and highly-scalable (Einstein Toolkit, WhiskyMHD, BAM code)
- Gasoline Tree-SPH code con adaptive individual time-stepping and ChaNGa that use Charm++ for load balancing.

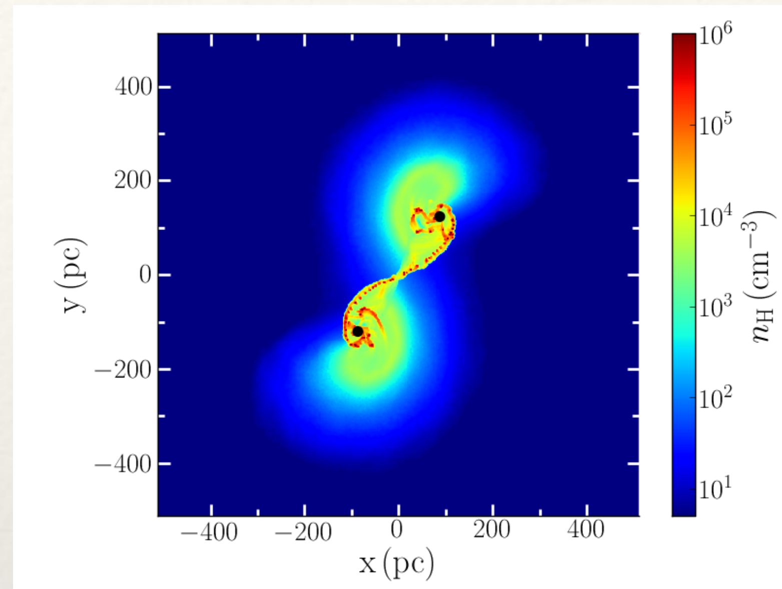
Activities ….
Teongrav@Milano: Multi-scale Black Hole Dynamics



FULL COSMOLOGICAL SIMULATION OF A MINOR GALAXY MERGER WITH MASSIVE BLACK HOLES (LISA)

1.5 MILLION CPU HOURS

SPINOSO, BONOLI, DOTTI, MAYER 2016

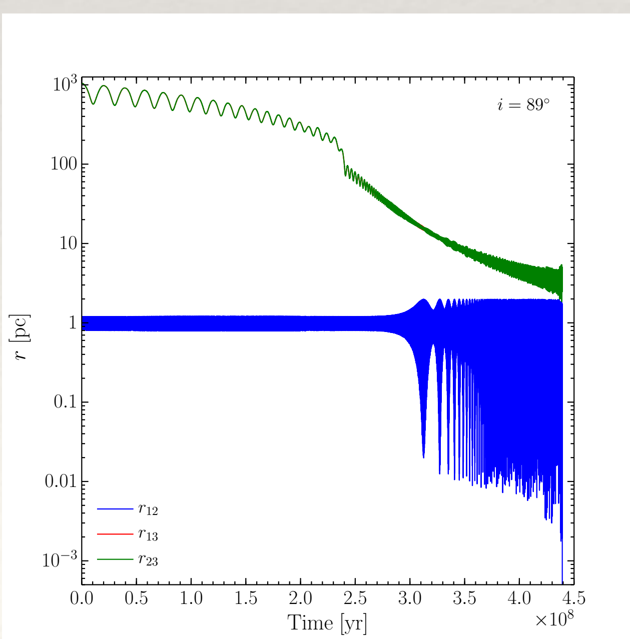


MASSIVE BLACK HOLES IN MERGING & STAR FORMING NUCLEAR DISCS
form ~ 100 pc down to 0.1 pc

(LISA)

300,000 CPU HOURS

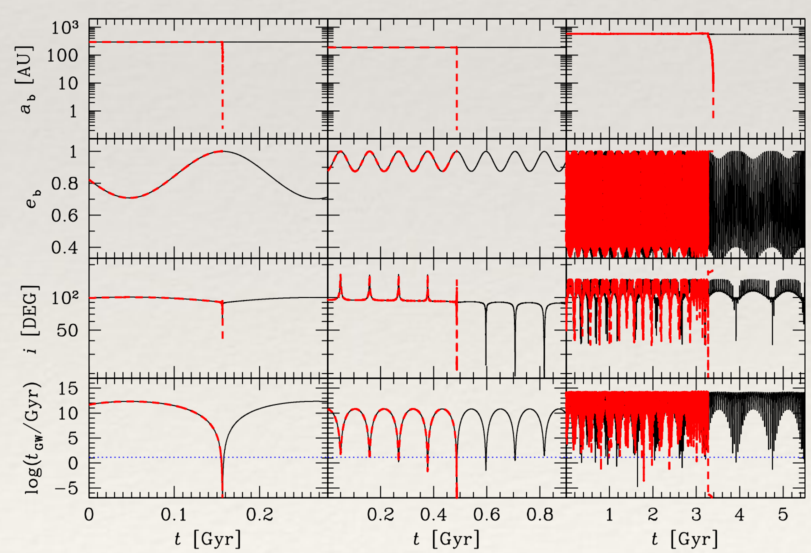
LUPI, HAARDT, DOTTI, COLPI, MNRAS, 2015



DYNAMICS OF MASSIVE BLACK HOLE TRIPLETS IN MERGING GALAXIES (PTA,LISA)

200,000 CPU HOURS

BONETTI, HAARDT, BARAUSSE, SESANA, MNARS, 2016



KOZAI-LIDOV RESONANCE ACTING ON STELLAR BLACK HOLES IN HIERARCHICAL TRIPLETS: THE PATH TO COALESCENCE OF THE INNER BINARY

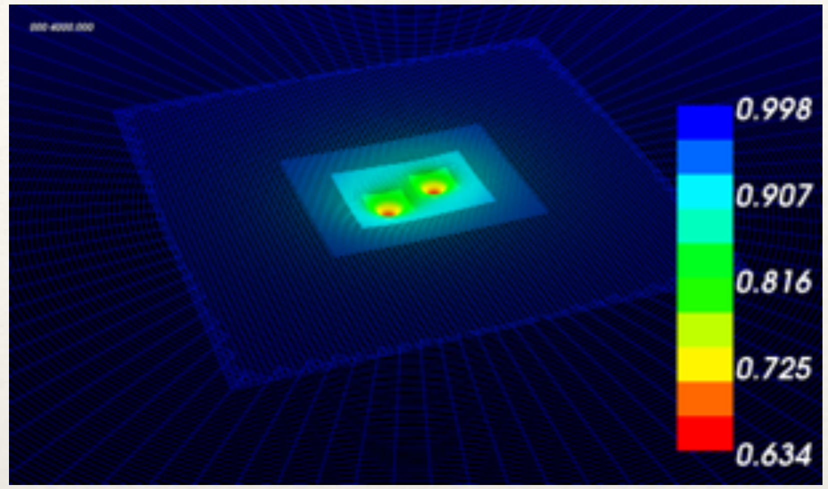
LIGO-VIRGO

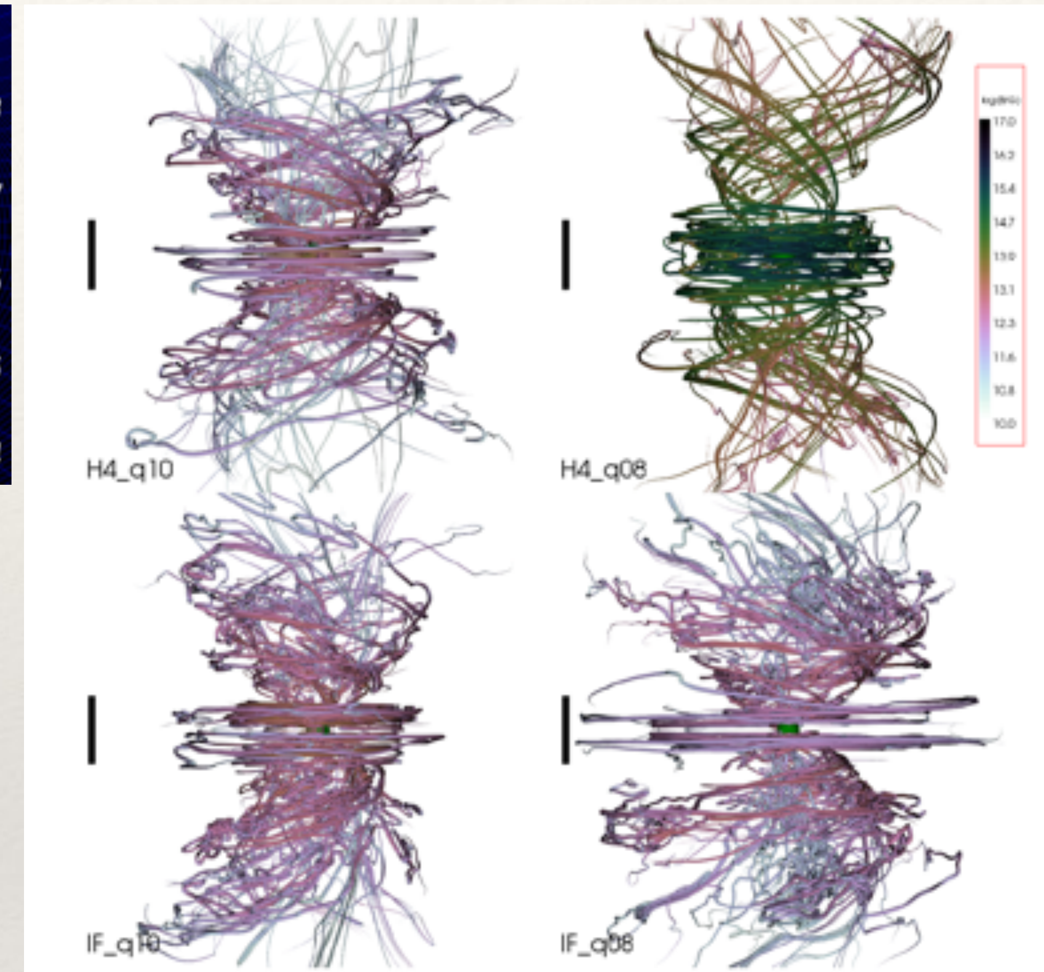
KIMPSON, SPERA,MAPELLI, ZIOSI, MNRAS, 2016

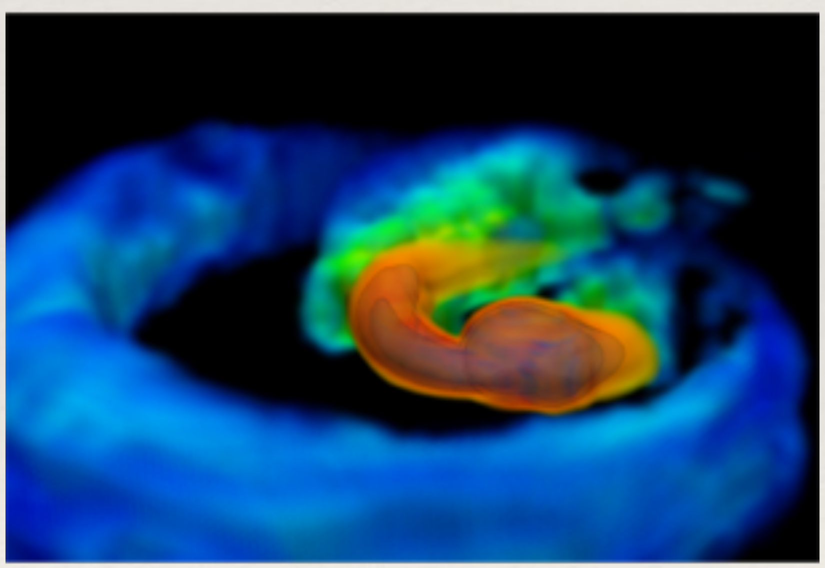
200,000 CPU HOURS

Activities …. Teongrav@Parma and Teongrav@Trento: Various aspect of – Binary Neutron Star Mergers

Typical GRID setup for simulation of BNS merger: (from Bernuzzi)



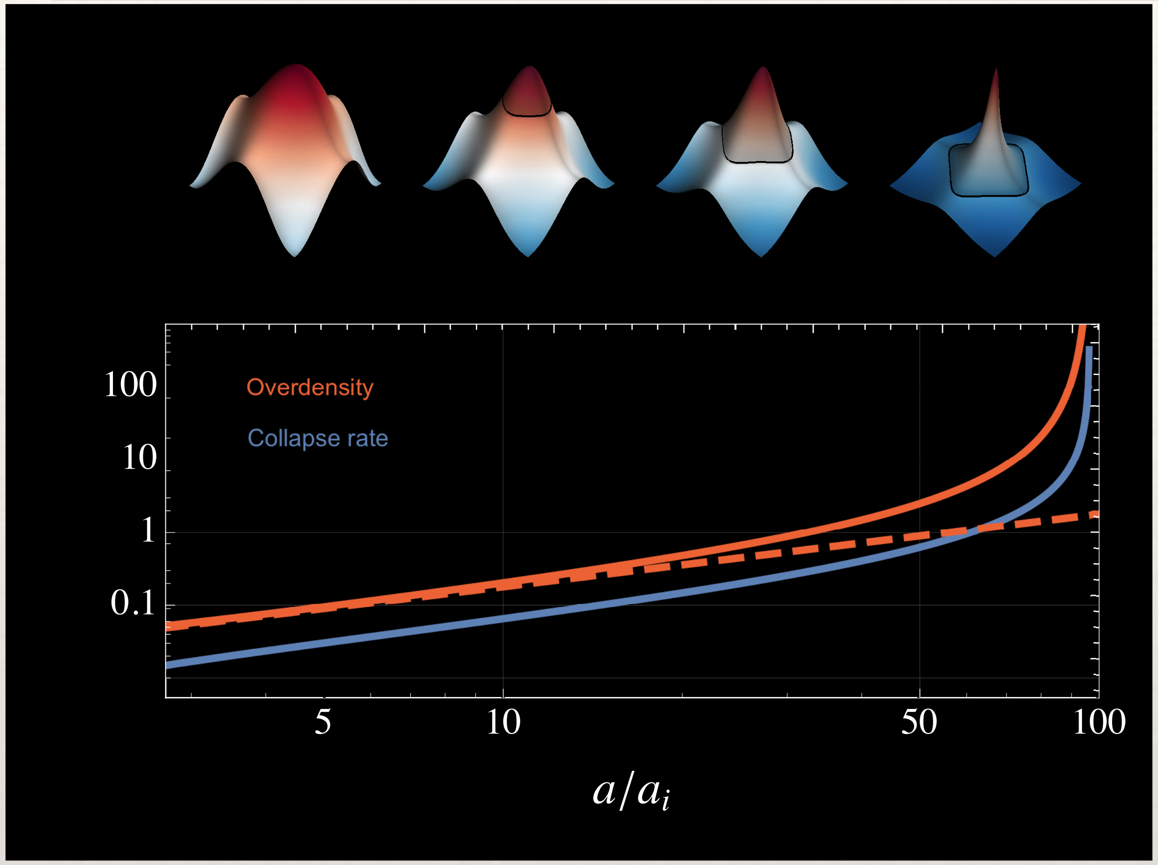




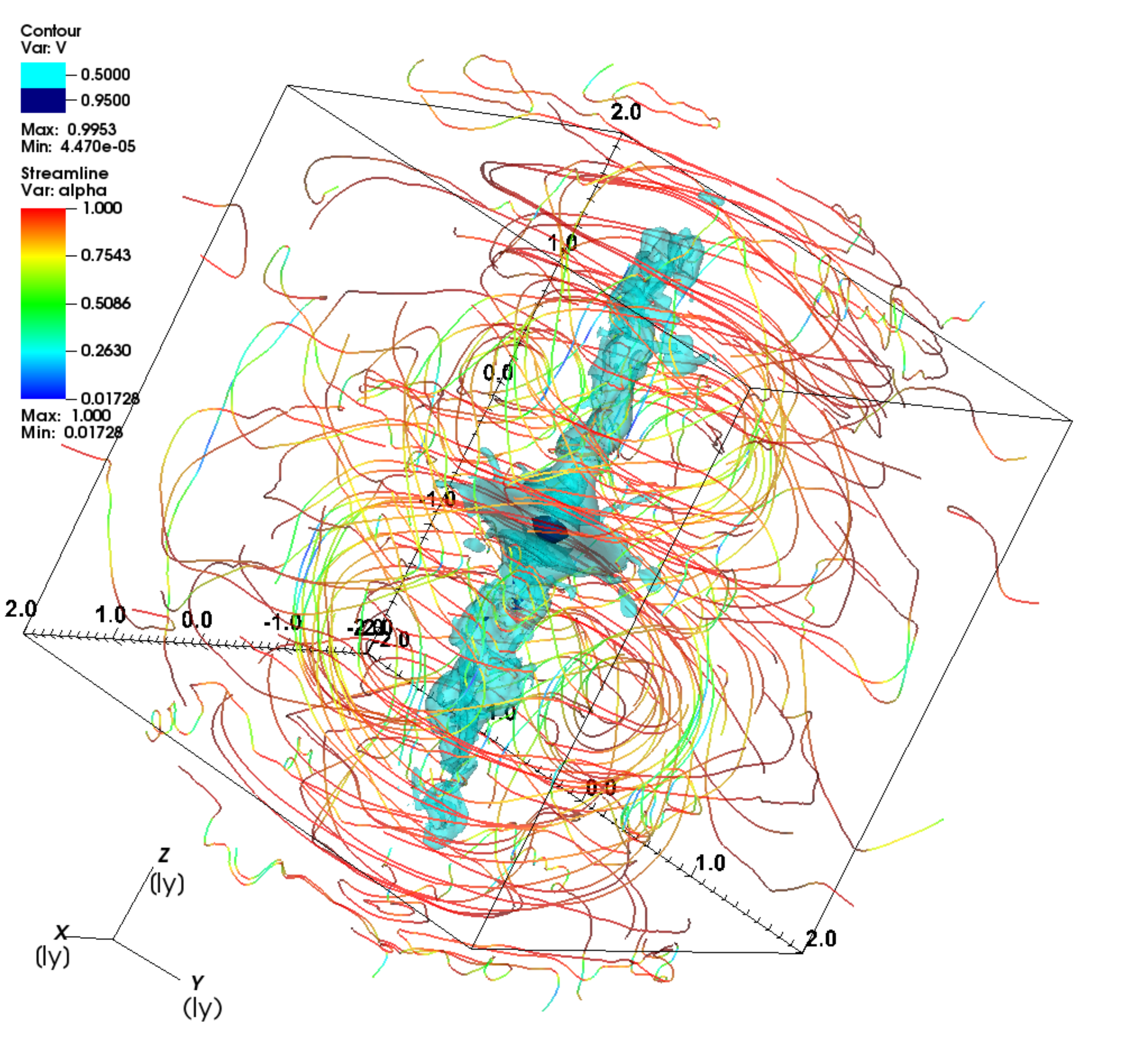
Gravitational waves and mass ejecta from binary neutron star mergers: Effect of the stars' rotation T.Dietrich, S. Bernuzzi, M.Ujevic, W.Tichy. ArXiv:1611.07367

Studied magnetic field evolution in NS-NS mergers and their link to short-gamma ray bursts. (Kawamura et al 2016, Ciolfi et al 2017)

Activities .... Teongrav@Catania and Teongrav@Firenze: Cosmological simulations and MHD simulations in Astrophysics



NONLINEAR INHOMOGENEOUS COSMOLOGIES WITH NUMERICAL RELATIVITY (BENTIVEGNA&BRUNI 2016)



3D relativistic MHD simulations of the Crab Nebula obtained with PLUTO-AMR. Isosurfaces of the velocity (0.5c and 0.95c) are shown to highlight the jet-torus structure, together with magnetic fieldlines. From Olmi et al., J. Plasma Phys. 82, id. 635820601 (2016).

Computing resources provided by the INFN and how they have allowed to develop the INFN research in the Gravitational Physics

- If there are research active in numerical gravitational physics in ITALY is due to the INFN efforts and its continued support to these activities.
- In 2001, the “Commissione IV” has funded a cluster for research in Numerical Relativity: the Albert100 cluster that was installed at the “gruppo collegato di Parma”.
- 2005, a PRIN was awarded to the Parma, Roma and Trieste groups that where operating inside the IS OG51 (now TEONGRAV). Realization of the **Albert2** cluster (installed in Parma).
- 2009 Cluster GRID-enabled **TRAMONTANA** (Commissione IV)
- 2012 Partnership CINECA INFN for the access to Tier-0 system in Bologna (FERMI)
- 2013 Cluster **ZEFIRO** (Commissione IV and SUMA).
- 2015 “Progetto premiale” and the realization of the Tier-1 **Galileo** (Joint effort CINECA-Progetto SUMA)
- **Our thanks to INFN !**

- **OUR ACTIVITY GREATLY EXPANDED IN THE LAST THREE YEARS WITH NEW PEOPLE AND NEW RESEARCH DEVELOPED.**
- **WE HOPE FOR CONTINUOUS INFN SUPPORT FOR COMPUTATIONAL ACTIVITY IN COMING YEARS .**
- **More that 60 publications of our groups related to numerical research in the last 3 years!**