

Compact object simulations in 3D: BHs, NSs & BSs

Luis Lehner

(M. Anderson, E. Hirschmann, S. Liebling, P. Motl,
D. Neilsen, C. Palenzuela, O. Reula, J. Tohline)

LSU

NSF-ResCorp

Sources we care about

*Compact, dynamical & sources of gravitational waves
(and E&M signals)*

- GWs: common features in different binaries, degeneracies?, non-linear effects
- Understand other astrophysical systems, other sources of GWs

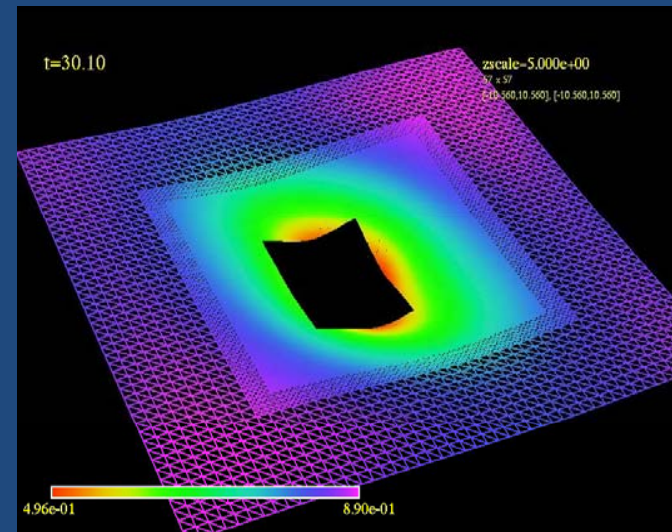
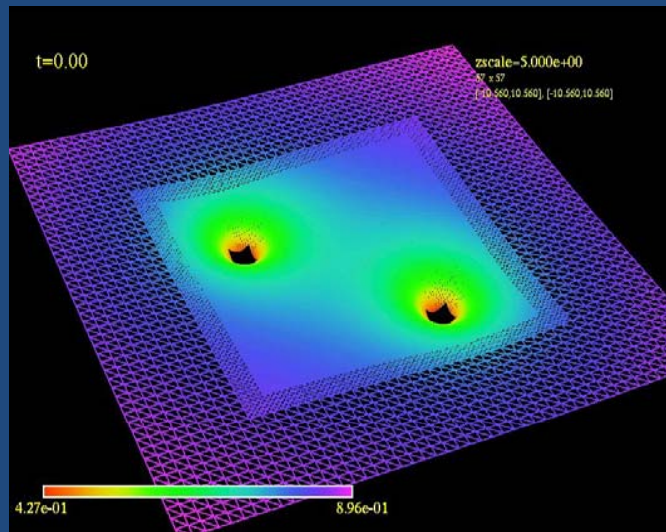
Systems:

- DRNS
- BH – BH (+ hydro)
- BH – NS
- BH – BS
- NS – NS
- BS – BS
- Cosmic strings (Liebling's talk)
- Critical phenomena in 3D (Liebling's talk)

Simulation

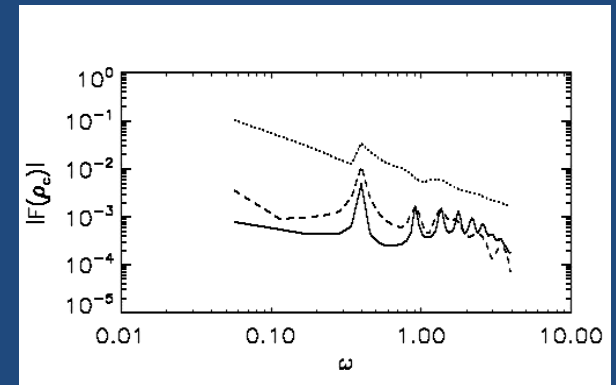
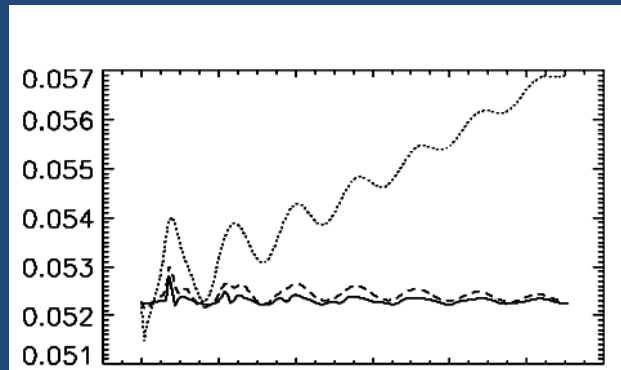
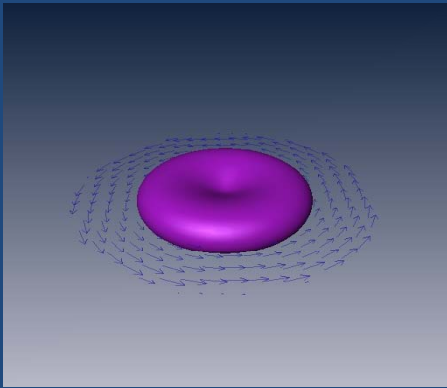
- Computational infrastructure: HAD [Liebling]
 - Provides: parallel AMR, deals with vertex & cell centered schemes, stability/reduce reflections through tapered boundary approach [LL,Liebling,Reula]. Combines transparently different systems.
- GR, scalar fields : 1st order generalized harmonic formulation
 - Implemented using summation by parts differential operators, RK3 time update (stability in linear problems). Maximally dissipative bdry conditions, CPBC available. [Palenzuela,LL]
- Magneto-Hydrodynamics:
 - High resoltn shock capturing scheme. Can use vertex (CENO) or cell centered algorithms. HLL flux and PPM reconstruction. Monopole constraint (and weak hyperbolicity! of MHD eqns) dealt with divergence cleaning. CPBC in progress. [Anderson,Neilsen,Hirschmann,Motl,Tohline]

Binaries, on and off the beaten path

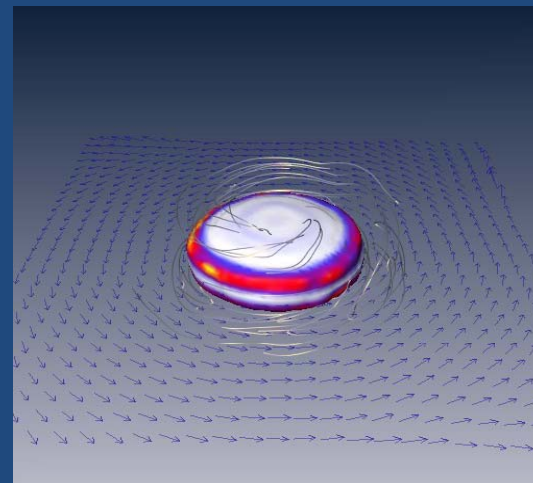
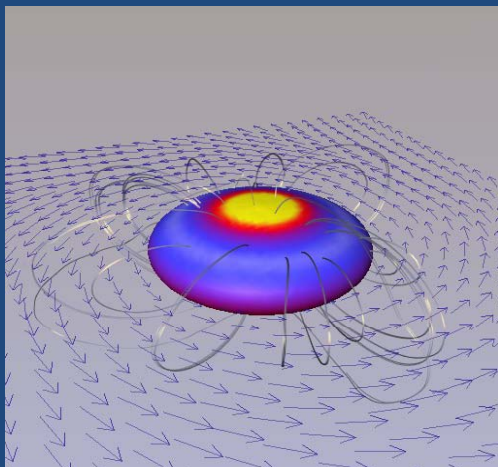


Single stars

- Normal mode of oscillations

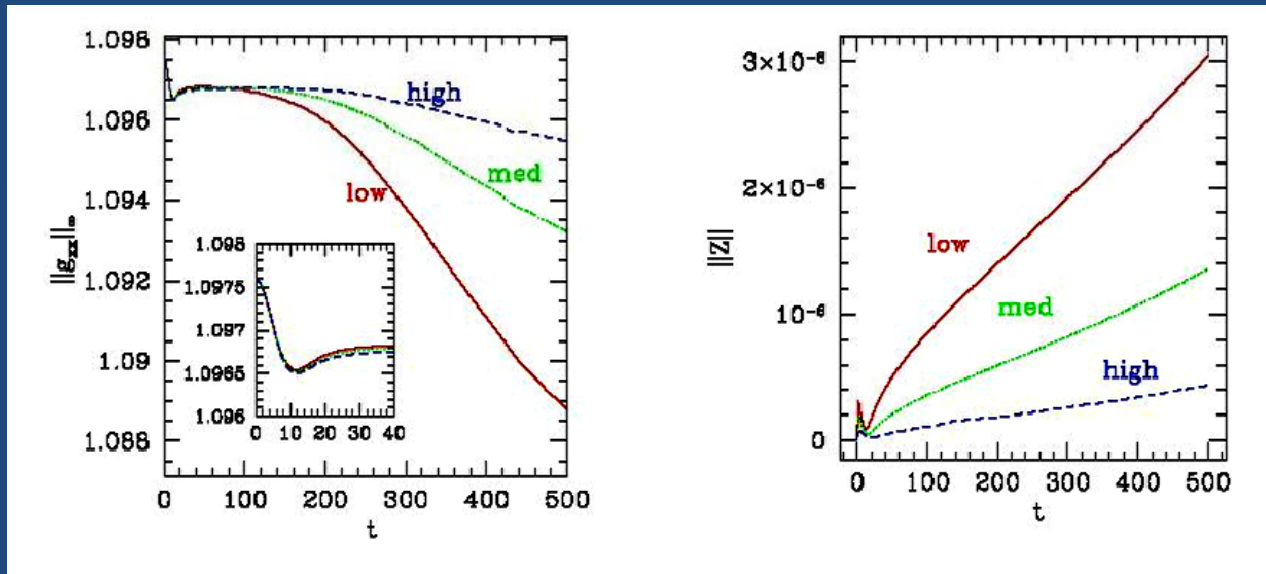
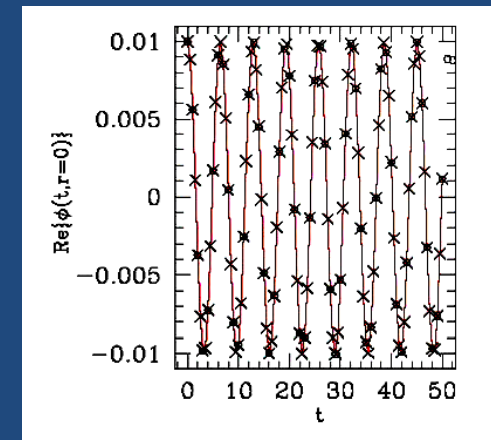


- Magnetic field effects (movie)



- Boson stars.

- Massive (complex) Klein Gordon field. Stationary spacetime solution ($\phi = \Phi(r) e^{i\omega t}$).
- Quantized angular momentum $J = n Q$

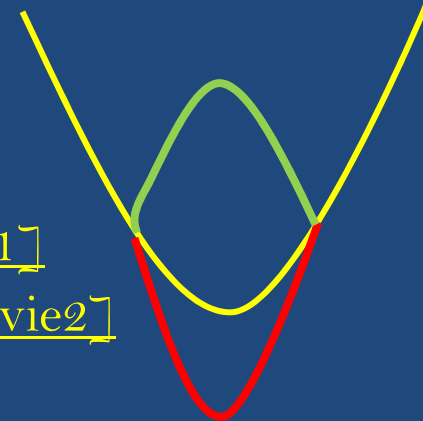


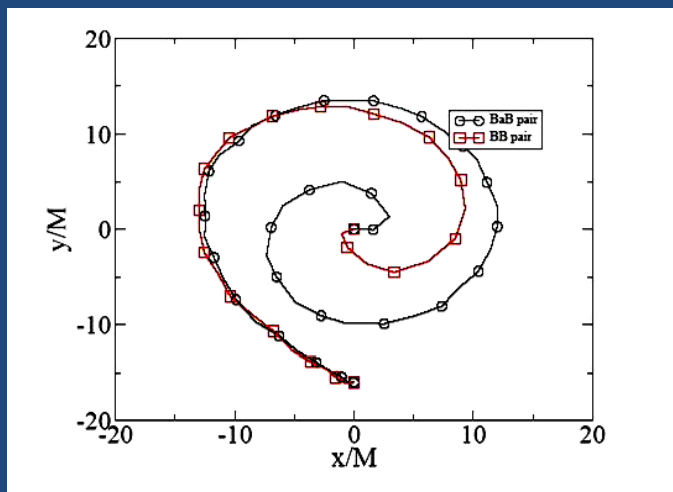
[Palenzuela, Olabarrieta, LL, Liebling 07]

- Binary boson stars (certainly off).
 - Where do internal properties start making a difference?.
 - What sort of signals are to be possible ?
 - Are there any surprises (at a fundamental level) ?
- Additional freedom $BS \rightarrow (BS)^* e^{i\kappa}$
- Simplistic analysis
 - $\rho \sim \rho_1 + \rho_2 + K \cos([1-e] [wt] + \kappa)$

– 3 cases of ‘interaction term’:

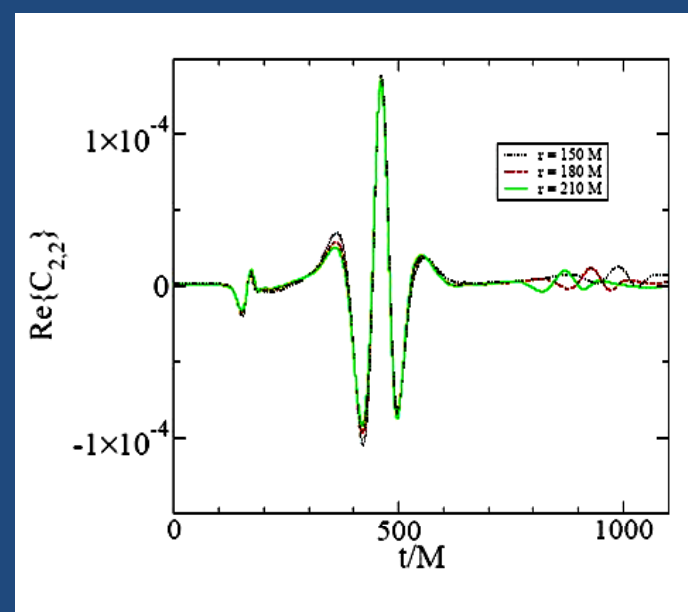
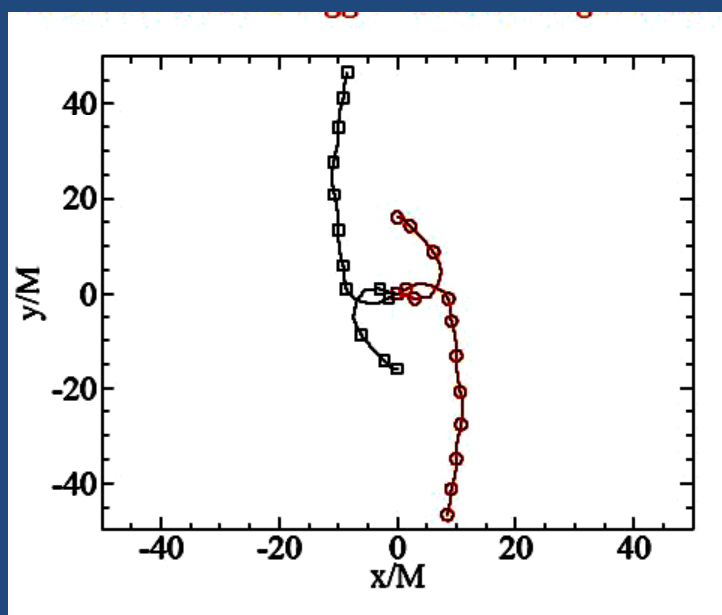
- ☐ Δ (boson – boson; $\kappa=0$) [[movie1](#)]
- ☐ $-\Delta$ (boson – PO boson; $\kappa=\pi$) [[movie2](#)]
- ☐ $\Delta \cos(2wt)$ (boson – antiboson*; $\kappa=0$)





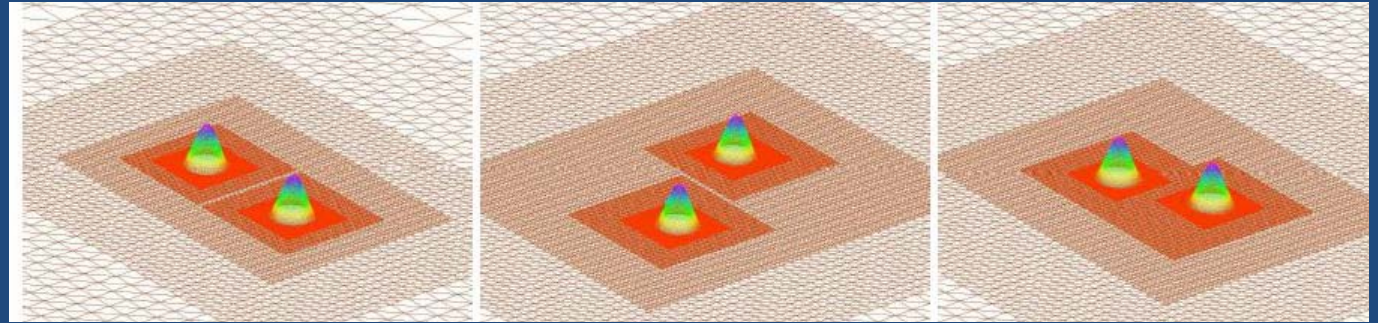
‘internal’ structure induced differences.

Zoom-whirl scenarios.



[Palenzuela,LL,Liebling 07]

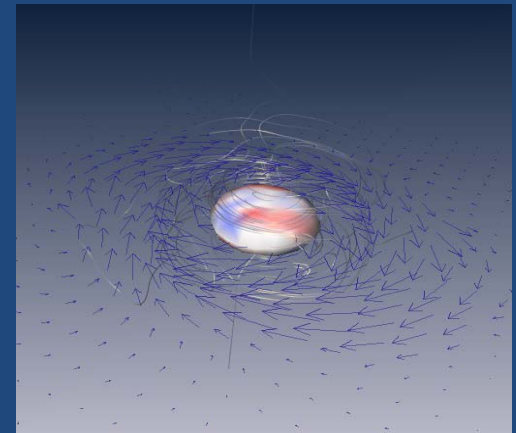
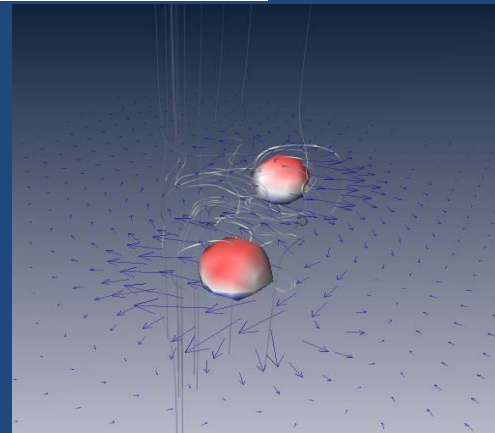
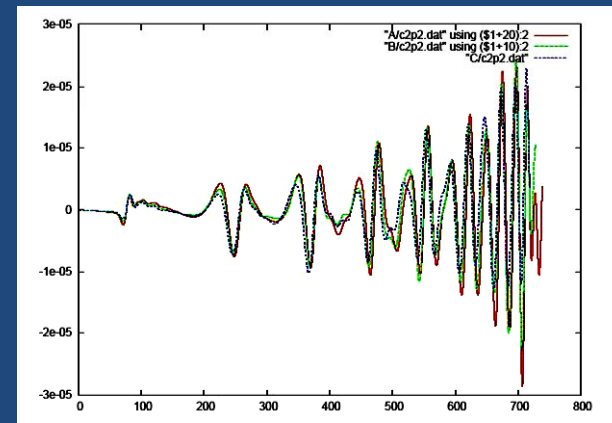
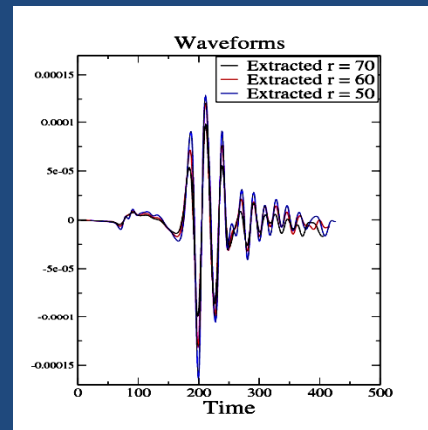
BNS (on, to some extent...)



- 1st movie

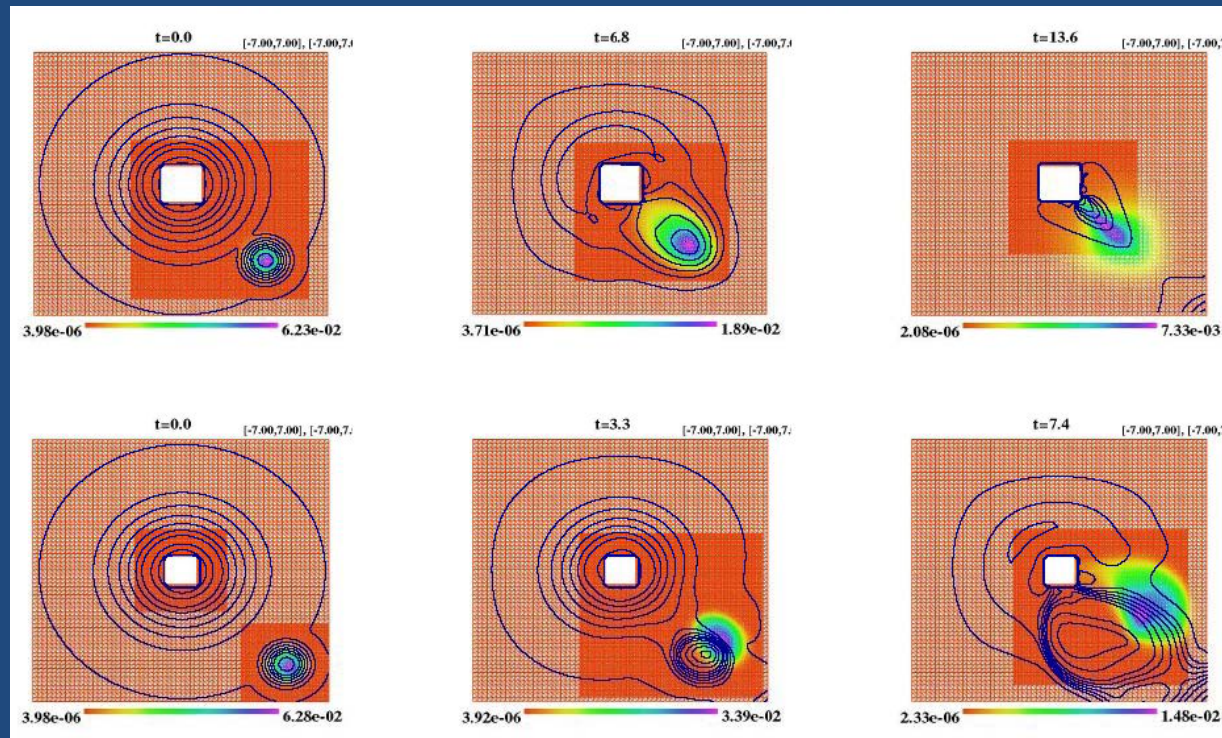
- 2nd movie

- 3rd movie



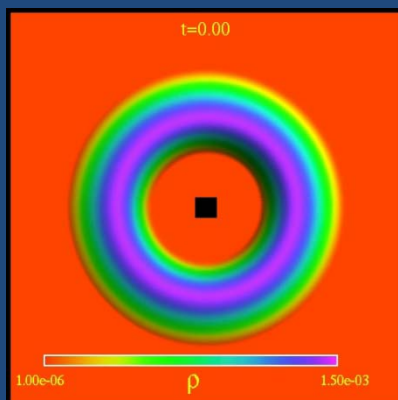
[Anderson, Palenzuela, Hirschmann, LL, Liebling, Neilsen, Motl]

BH-NS, BH-BS & accretion (in progress)



$$a = 0.2; M=1; \Gamma = 5/3$$

[Anderson, Palenzuela, Hirschmann, LL, Liebling, Neilsen]



[Megevand, Anderson, LL]

Next steps

- Non-linearities when/where & what is to be seen?
- Common features of waveforms.
 - PN gives much of the story, anything else in strong regimes?
 - Estimate size/effects of corrections to Ψ_4 in different cases [LL,Moreschi]
- Other effects roles?
 - MRI. Re-distribution of angular momentum, key differences.
 - ‘inner-structure’; environment (eqn of state, wet mergers)
- More ‘realistic’ data. Collaboration with Novak, Gourgoulhon, Grandclement.