Short GRBs and quark deconfinement

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- A.D., A.Lavagno, G.Pagliara, Phys.Rev. D89 (2014) 043014

  Two-families scenario

- A.D., A.Lavagno, G.Pagliara, D.Pigato, Phys.Rev. C90 (2014) 065809

  Delta resonances and «delta-puzzle»

- A.D., G.Pagliara, Phys. Rev. C 92 (2015) 045801

  Combustion of hadronic stars into quark stars: the turbulent and the diffusive regime

- A.D., A.Lavagno, G.Pagliara, D.Pigato, Eur.Phys.J. A52 (2016) 40

  A.D., G.Pagliara, Eur.Phys.J. A52 (2016) 41

  Review papers on the two-families scenario

- A.D., A.Lavagno, B.Metzger, G.Pagliara, Phys. Rev. D93 (2016) 103001

  Quark deconfinement and duration of short GRBs

- A.G.Pili, N.Bucciantini, A.D., G.Pagliara, L. del Zanna, MNRAS 462 (2016) L26

  Quark deconfinement and late-time activity in long GRBs

- G.Wiktorowicz, A.D., G.Pagliara, S.Popov, Astrophys.J. 846 (2017) 163

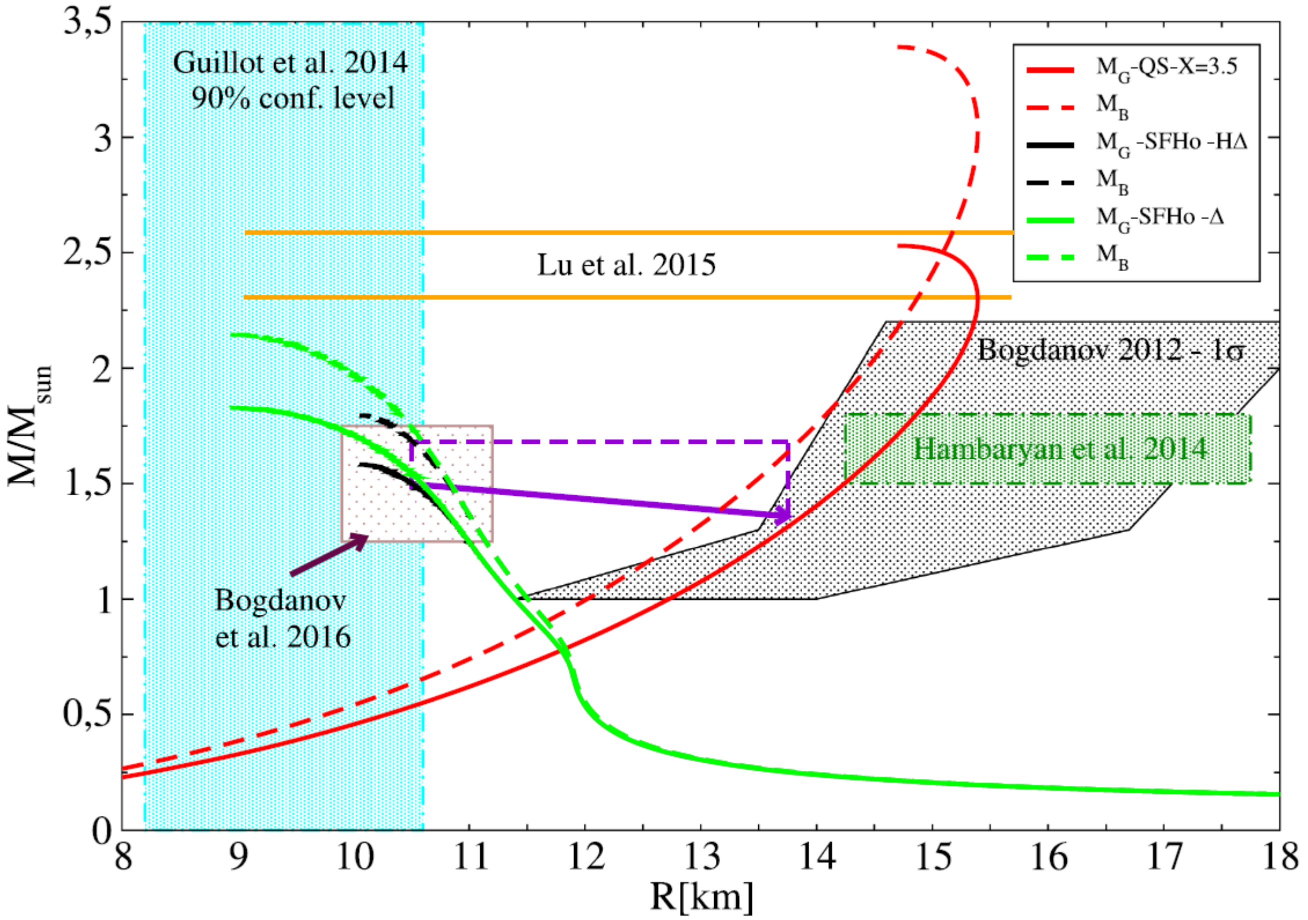
  Strange quark stars in binaries: formation rates, mergers and explosive phenomena

- A.D., G.Pagliara, 1710.02003

  Merger of two neutron stars: predictions from the two-families scenario

Two families of compact stars?

Suleimanov et al. 2017
4U 1820-30
«Best fit» R=11 km for M=(1.35-1.5) M_s



The merger of two NSs produces a strange quark star

Rayleigh-Taylor instabilities develop and **the conversion of the core occurs on the time scale of ms.**

The rapid burning stops before the whole hadronic matter has converted
(the process is no more exothermic as a hydrodynamical process, about 0.5 Msun of unburned material)

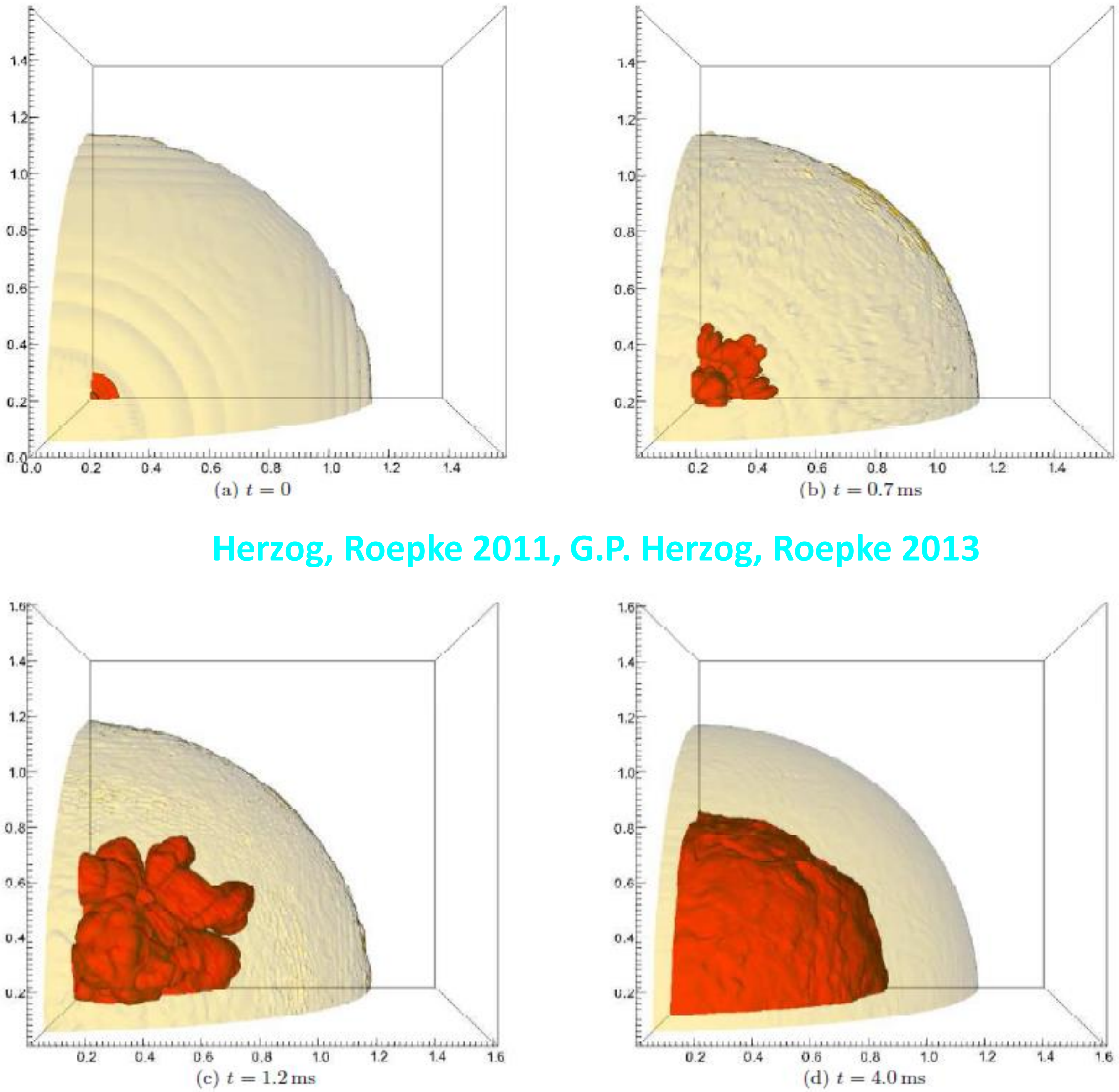
The configuration obtained after the rapid burning is

mechanically stable

although not yet in chemical equilibrium

After the rapid burning the conversion proceeds via strangeness production and diffusion.

The burning reaches the surface of the star after about 10s.



Herzog, Roepke 2011, G.P. Herzog, Roepke 2013

FIG. 1: (color online) Model: Set 1, $M = 1.4 M_{\odot}$. Conversion front (red) and surface of the neutron star (yellow) at different times t. Spatial units 10^6 cm.

How to describe within the protomagnetar model the prompt emission of short GRBs?

Long GRBs quasi-plateau **and short** GRBs extended emission are described very well by the spin-down of a rapidly rotating magnetar **with similar values of B and P**.

The promt emission of long GRBs is well described by the wind of a newly formed magnetar having values of B and P compatible with the description of the quasi-plateau. The duration of the prompt emission is of the order of the cooling time of the proto-magnetar, i.e. a few tens seconds.
During that time baryonic matter is ablated from the surface of the star by the neutrinos and accelerated by the radiation pressure.

Question: why the prompt emission of short GRBs lasts only a fraction of a second? What regulates the duration of ablation in that case?
Notice that the temperature in the short GRBs is even larger than in the long GRBs.

Prompt emission of long and short GRBs

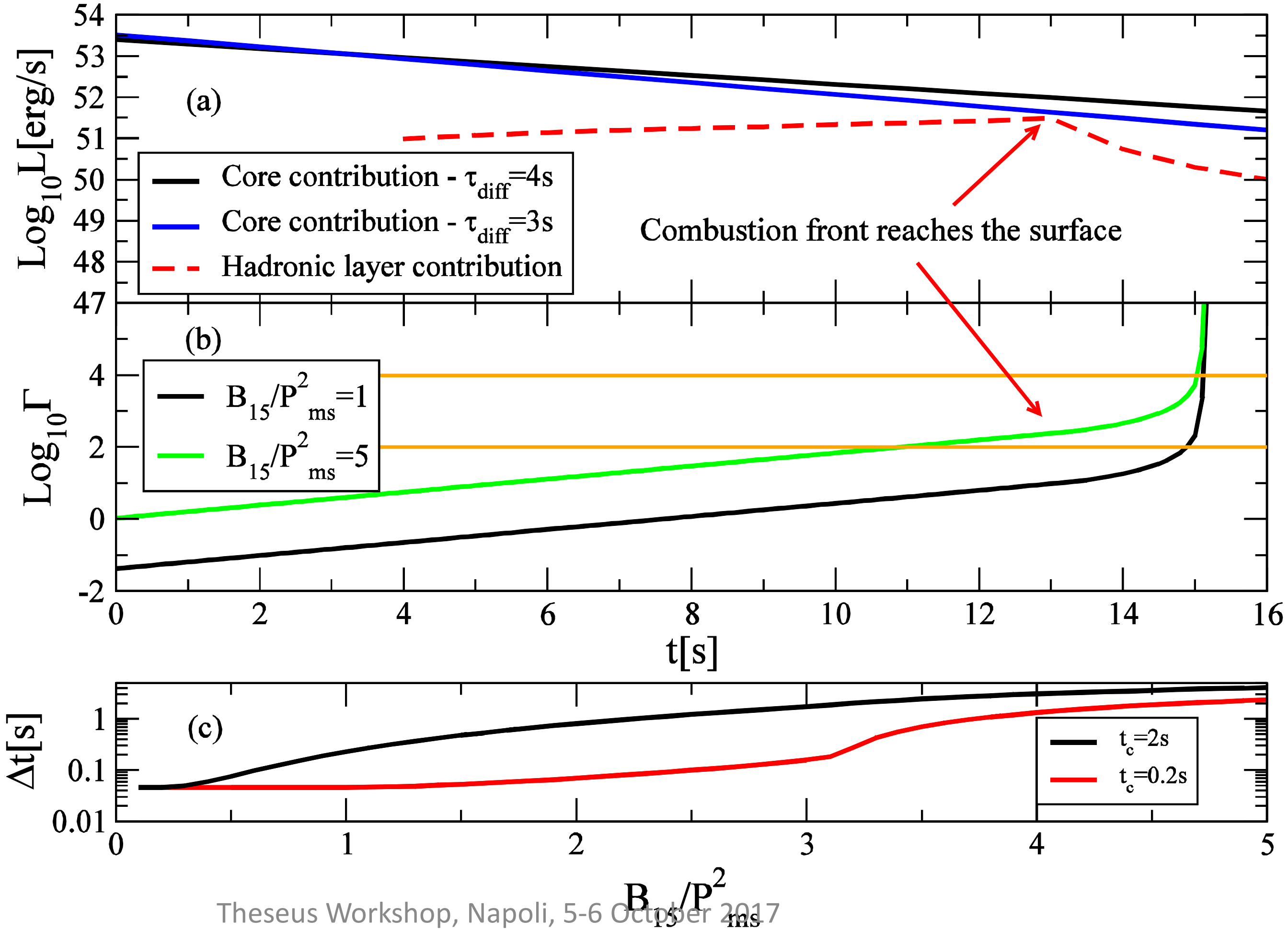
It was generally assumed that the prompt emission of short GRBs is spectrally harder than the one of long GRBs, but the differences are less evident when the sample is restricted to short GRBs with the highest peak fluxes (Kaneko et al. (2006)) or when considering only the first ~ 2 s of long GRBs light curves.

When comparing the prompt emission of short GRBs and the first seconds of long's one finds: (i) the same variability, (ii) the same spectrum, (iii) the same luminosity and (iv) the same $E_{peak} - L_{iso}$ correlation (Ghirlanda et al. 2009).

In other words, **if the central engine of a long GRB would stop after ~ 0.3 (1+z) seconds the resulting event would be indistinguishable from a short GRB** (Calderone et al. 2014).

Duration of the sGRB in the two-families scenario

A.D., A.Lavagno, B.Metzger, G.Pagliara PRD93 (2016) 103001



Neutrino luminosity

Magnetization or maximum Lorentz factor

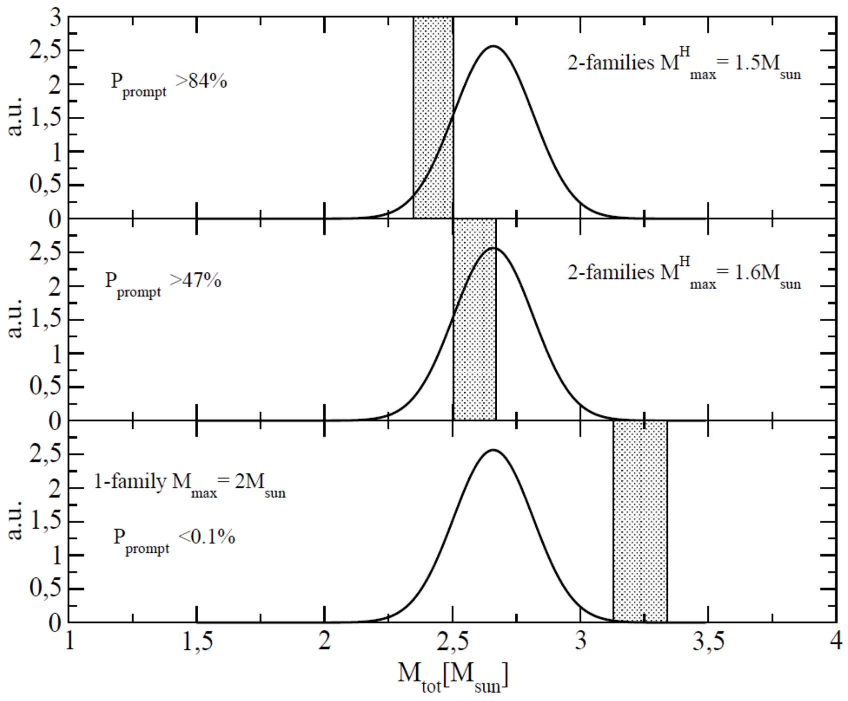
Duration of the burst

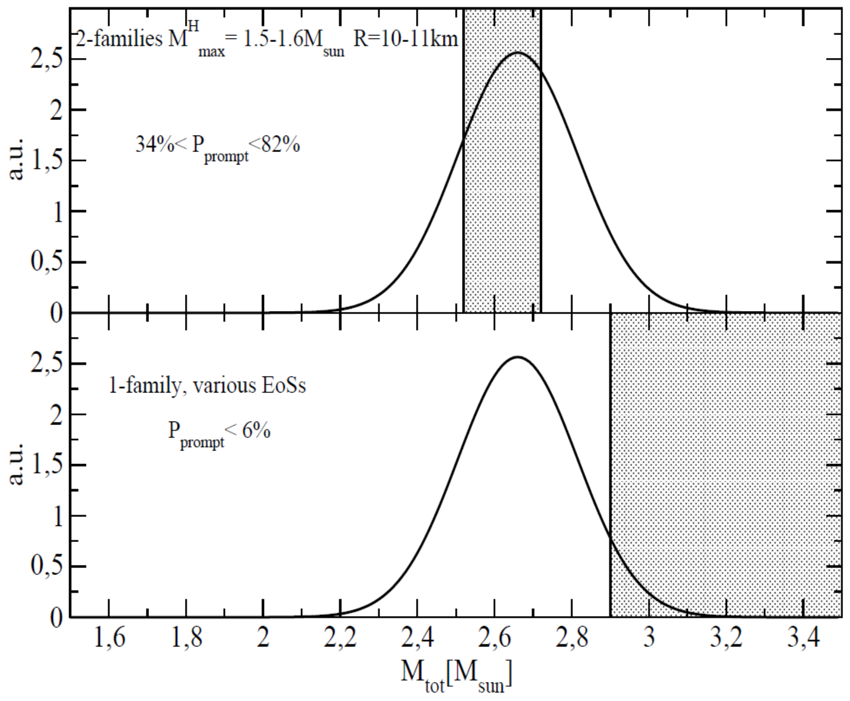
Strong correlation between duration and luminosity
as seen in the data
Shahmoradi, Nemiroff
MNRAS 451 (2015) 1

Strange quark star formation vs BH formation

- BH formation and Strange Quark Star formation BOTH help in reducing the baryon load thus allowing the formation of the jet associated with the prompt emission. There are differences in the time order of the events:
  - If a BH forms the activity of the protomagnetar needs to take place BEFORE that moment, so the «time-reversal» scenario of Ciolfi et al. and Rezzolla et al. is needed.
  - If a SQS forms the protomagnetar is active also after the formation of the SQS, so there is no need of a «time-reversal» scenario.
- Also the time delay between merger and prompt emission is different:
  - In the «time-reversal» scenario the prompt emission takes place after a supramassive star collapses to a BH and the time delay between merger and prompt can easily exceed 10^3 s.
  - In the SQS formation scenario the prompt emission takes place when quark deconfinement reaches the surface of the star, implying a delay between merger and prompt emission of the order of about 10 s.
- The combined analysis of GW and of EM signals will allow to discriminate betwen these two scenarios.

Prompt collapse to a BH: 2-families vs 1-family scenario





Distribution of M_{tot} = m1 + m2 (solid line). Range of values of $M_{threshold}$ is indicated by the shaded area.

The fraction of prompt collapses within the two-families scenario is MUCH larger than in the one-family case.

Mass of the mergers and short GRBs

An example:

$M^{H}_{TOV} = 1.6\ M_{\odot}$, $M^{Q}_{TOV} = 2\ M_{\odot}$

$M_{max,dr} = 1.6 \times M^{H}_{max} = 2.56\ M_{\odot}$

$M^{q}_{supra} = 1.2 \times M^{Q}_{TOV} = 2.4\ M_{\odot}$

a) if $M_g > M_{max,dr} = 2.56 M_{\odot}$ (approx. above $1.35\ M_{\odot} + 1.35\ M_{\odot}$)

direct collapse to a BH without any significant electromagnetic emission;

b) if $M^{q}_{supra} = 2.4\ M_{\odot} < Mg < M_{max,dr} = 2.56\ M_{\odot}$ (approx. from $1.25\ M_{\odot} + 1.25\ M_{\odot}$ to $1.35\ M_{\odot} + 1.35\ M_{\odot}$)

formation of a hypermassive SQS (sGRBs without extended emission);

c) if $Mg < M^{q}_{supra} = 2.4\ M_{\odot}$ (approx. below $1.25\ M_{\odot} + 1.25\ M_{\odot}$)

formation of supramassive SQSs → sGRBs with an extended emission.

Gravitational waves tests of the model

- **Tests falsifying the model:**
  - No evidence of rapid collapse to a BH (within a few ms from the merger) for a system having total mass larger than $M_{threshold}$, whose maximum value is of about $2.7M_{\odot}$. E.g., the merger of two $1.4M_{\odot}$ stars would rule out the two-families scenario if it does not collapse immediately into a BH.
  - Indications, during the inspiral and/or during the first milliseconds of the postmerger phase, of a very stiff EoS (low values of f2, smaller than about 3 kHz).
- **Tests against the model although not conclusive:**
  - No significant change of the spectrum during the first few tens milliseconds (the conversion to quark matter could occur at later times when the GWs signal is too weak to be detectable).
- **Validating (but not conclusive) tests:**
  - Very soft EoS during the inspiral or immediately after the merger (f_2 larger than about 3.3 kHz).
- **Strong confirmation tests:**
  - Rapid collapse to a BH of a merger having a total gravitational mass smaller than about $2.7M_{\odot}$.