(Long and) short GRBs in the two-families scenario

Alessandro Drago - Ferrara

- 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

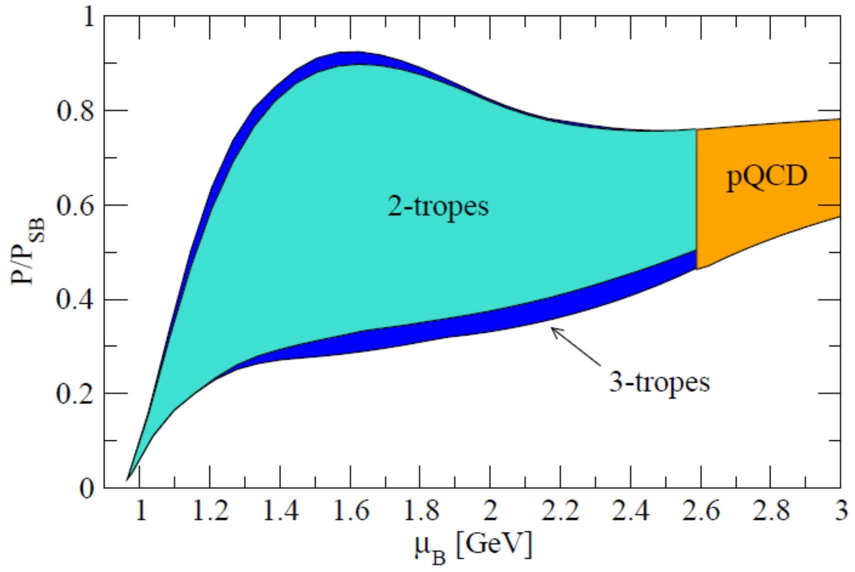
  Delta resonances and «delta-puzzle»
- A.D., G.Pagliara, arXiv:1506.08337

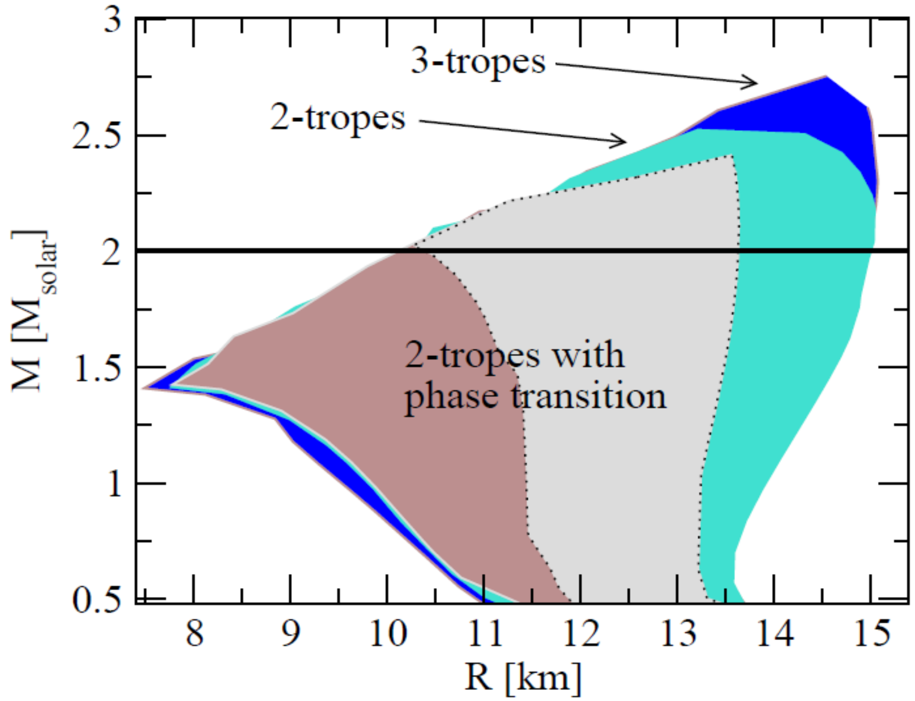
  Combustion of hadronic stars into quark stars: the turbulent and the diffusive regime
- A.D., A.Lavagno, B.Metzger, G.Pagliara, in preparation

  Quark deconfinement and duration of short GRBs

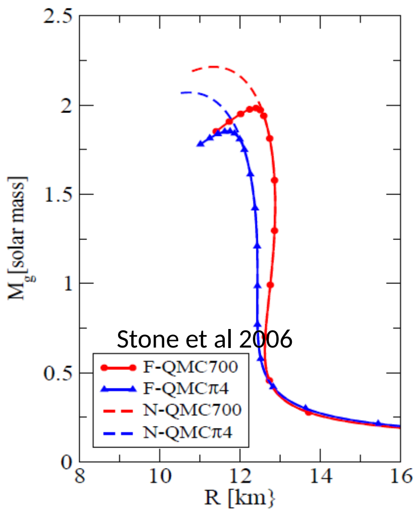
Connecting low densities to very high densities

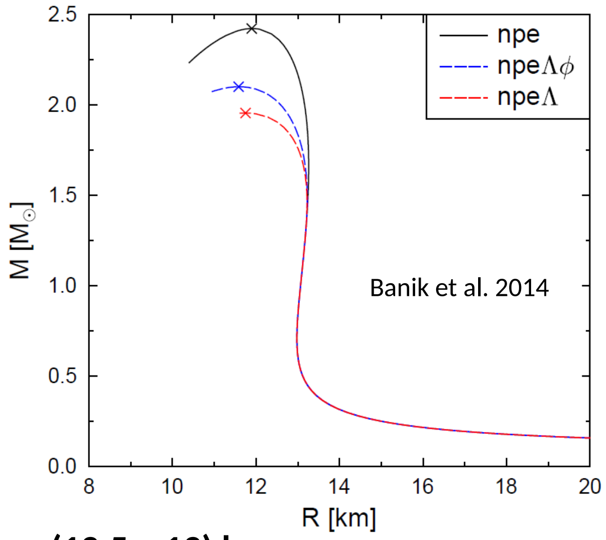
Kurkela, Fraga, Schaffner-Bielich, Vuorinen ApJ 789 (2014) 127



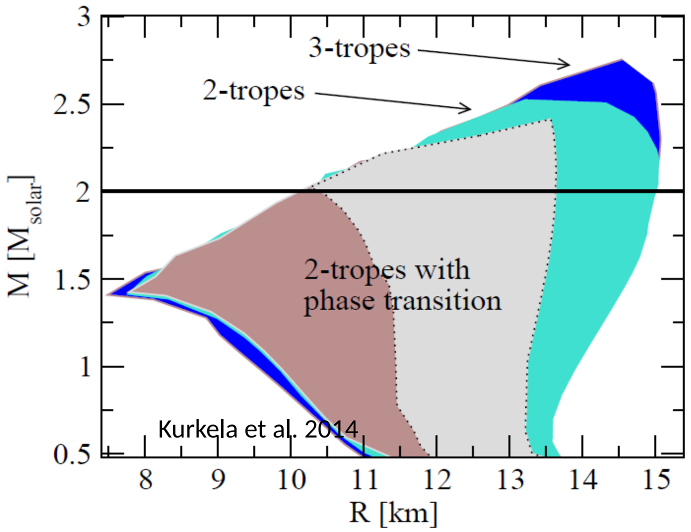


Minimum radius for a 1.4 M_s star

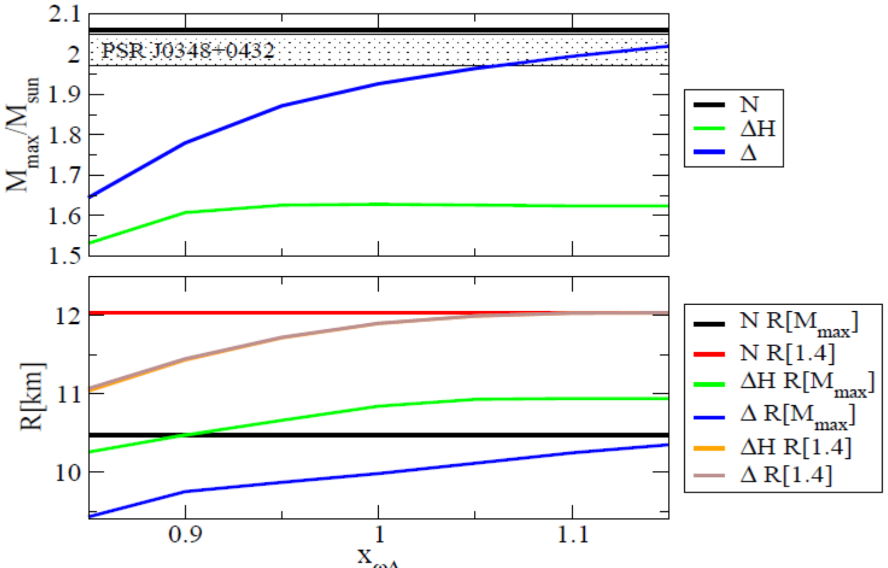




Hyperonic stars $R_{1.4}$ > (12.5 – 13) km

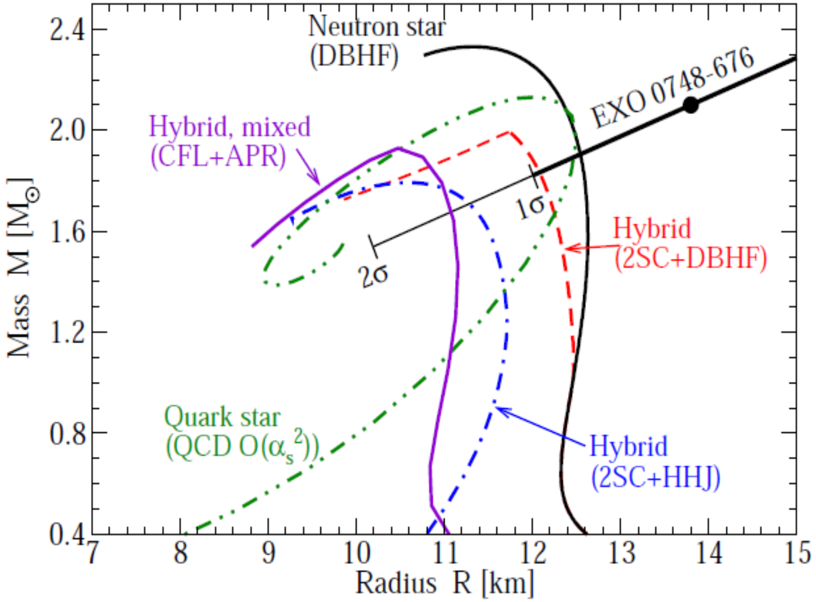


Hybrid stars $R_{1.4}$ > 11.5 km

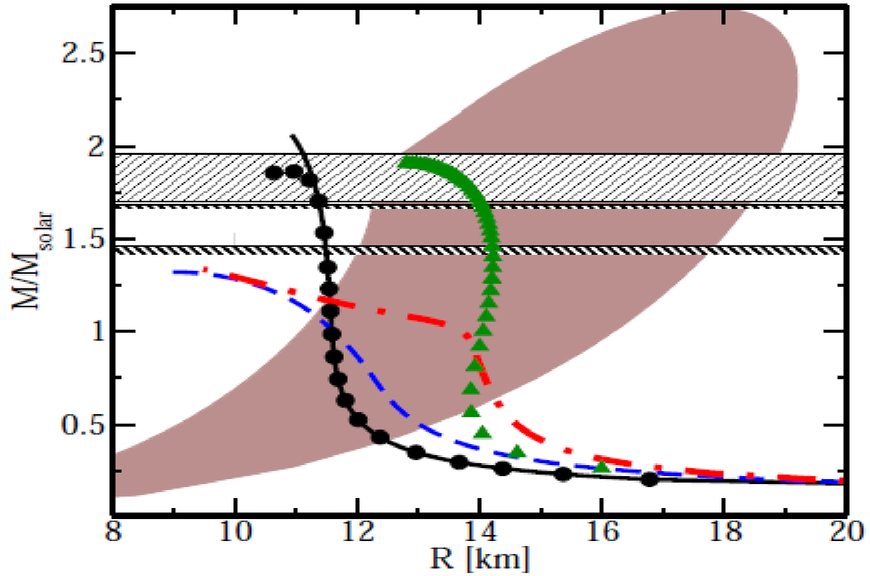


Delta – resonance stars
$R_{1.4}$ order of (10-11) km,
BUT the maximum mass
is smaller than 2 M_s

Hybrid stars or quark stars?



Alford et al Nature 2006



Kurkela et al PRD81(2010)105021

pQCD calculations: " … equations of state including quark matter lead to hybrid star masses up to 2Ms, in agreement with current observations.

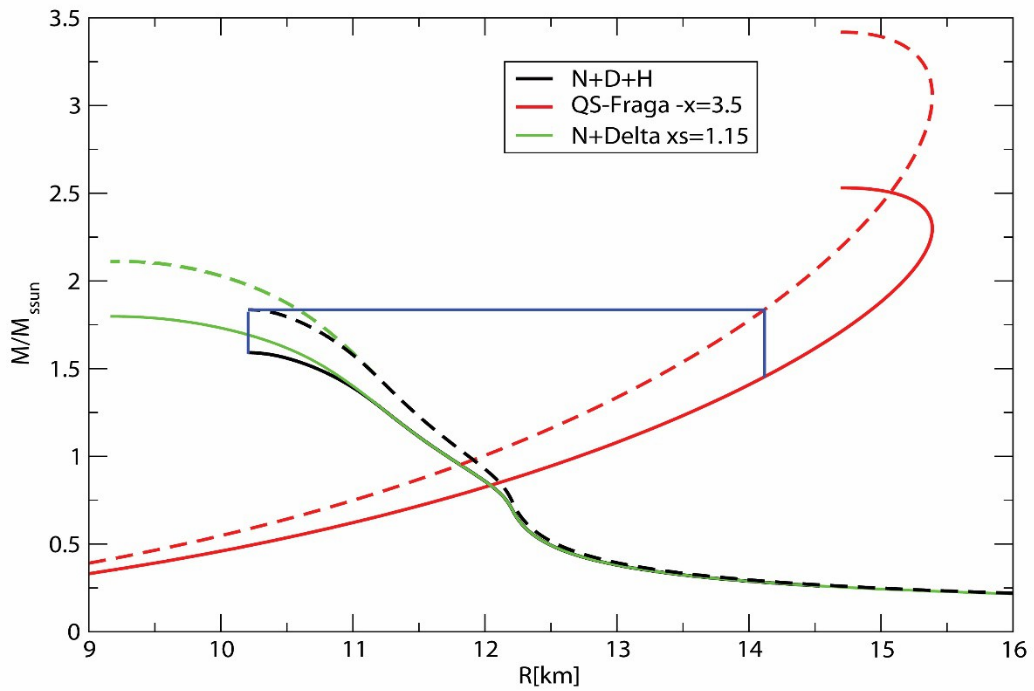
For strange stars, we find maximal masses of 2.75Ms and conclude that confirmed observations of compact stars with $M > 2M_s$ would strongly favor the existence of stable strange quark matter"

Before the discoveries of the $2M_s$ stars!!

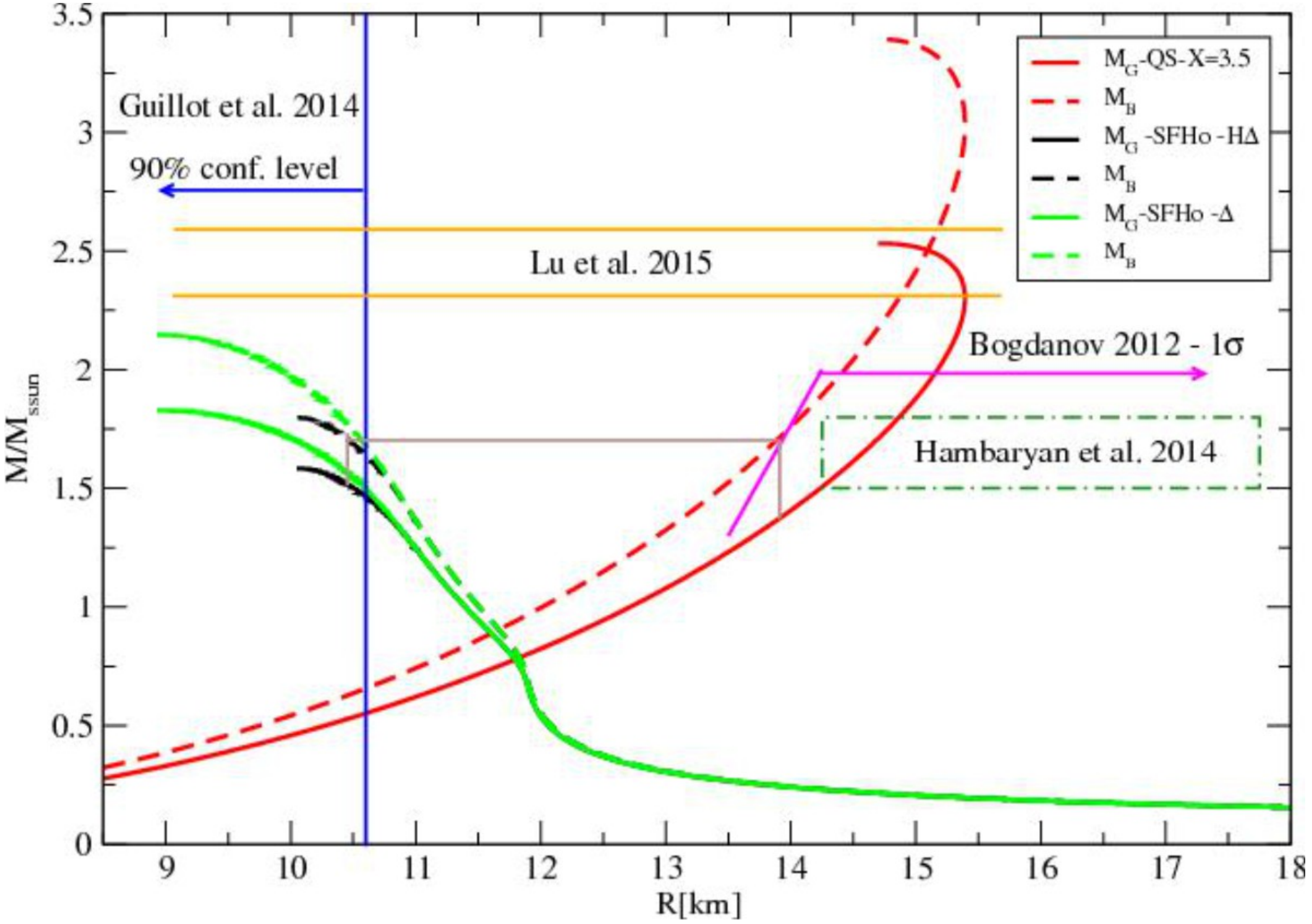
Why conversion should then occur?
Quark stars are more bound:
at a fixed total baryon number
they have a smaller gravitational
mass wrt hadronic stars.

The hadronic stars are stable
till when some strangeness
component (e.g. hyperons)
starts appearing in the core.
Only at that point quark matter
nucleation can start.

Finite size effects (surface tension)
can further delay the formation
of the first droplet of strange matter

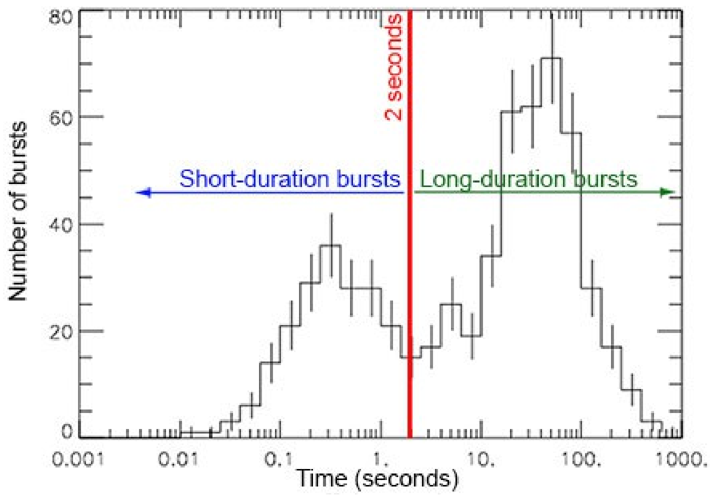


The maximum mass of a quark star can be as large as
2.75 $M_s \geq 2 \times (1.3 \div 1.4)\ M_s$.(Dynamically stable up to almost 1.3+1.3)
Therefore it is possible to have a ultra-massive quark star produced
by the merging of two normal-mass neutron stars.
The post-merging e.m. signal of the associated short GRB could show a
quasi-plateau emission, similar to the one observed in many long GRBs.

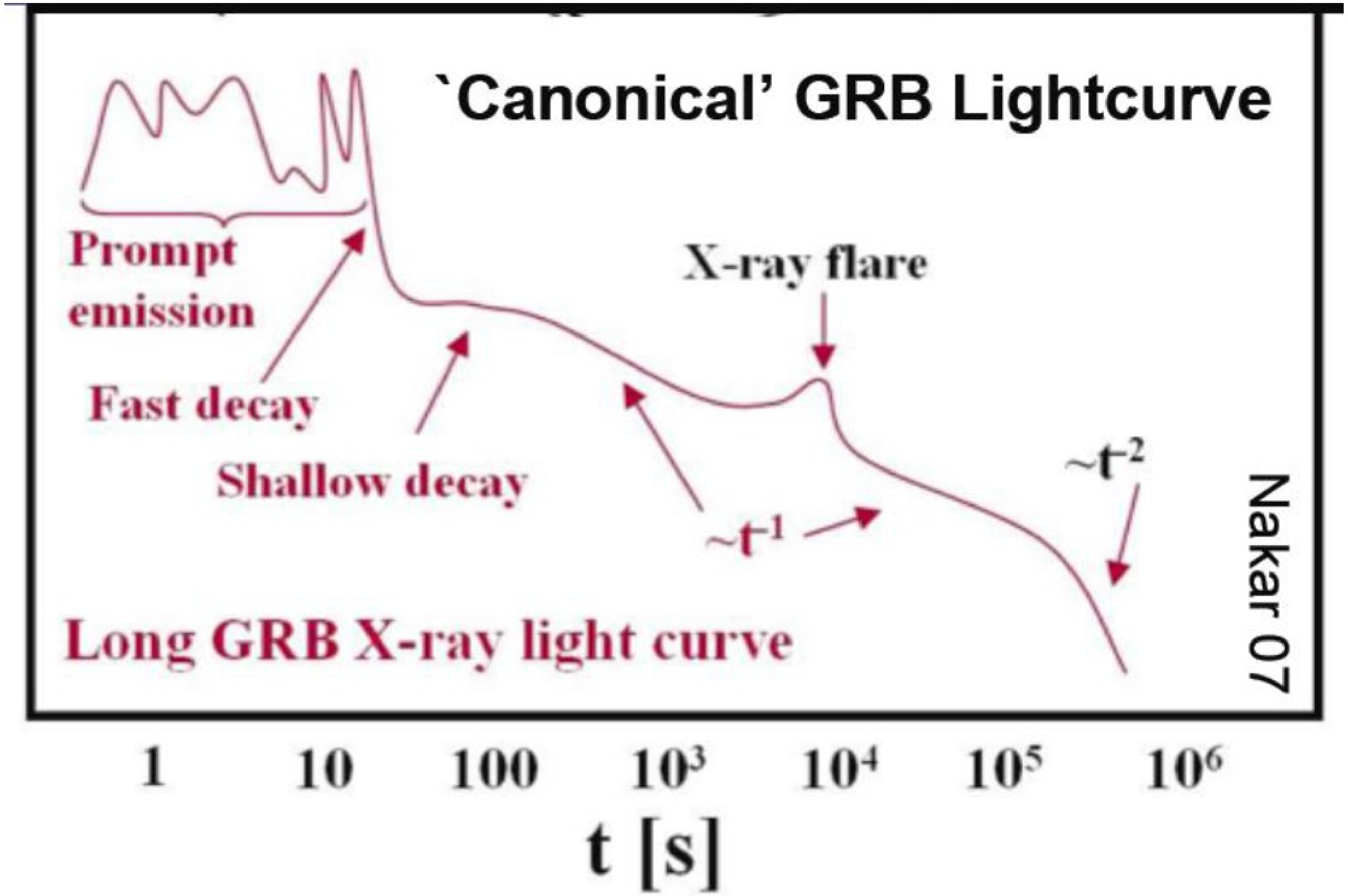


Guillot et al. 2014
90% conf. level
Lu et al. 2015
Bogdanov 2012 - 1σ
Hambaryan et al. 2014
M_G-QS-X=3.5
M_B
M_G -SFHo -HΔ
M_B
M_G-SFHo -Δ
M_B
M/M_ssun
R[km]

Long and short Gamma Ray Bursts

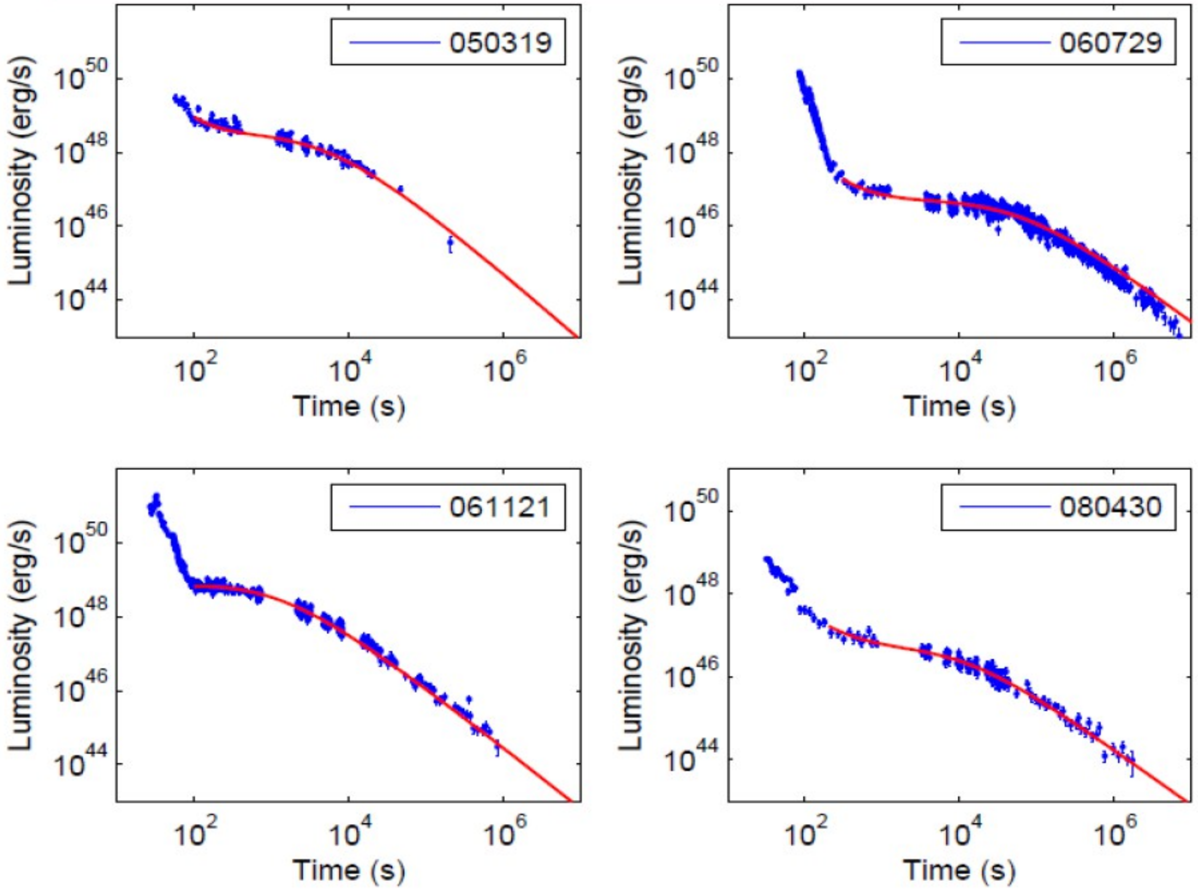


Long GRBs: collapse of a heavy progenitor
Short GRBs: merger of two neutron stars

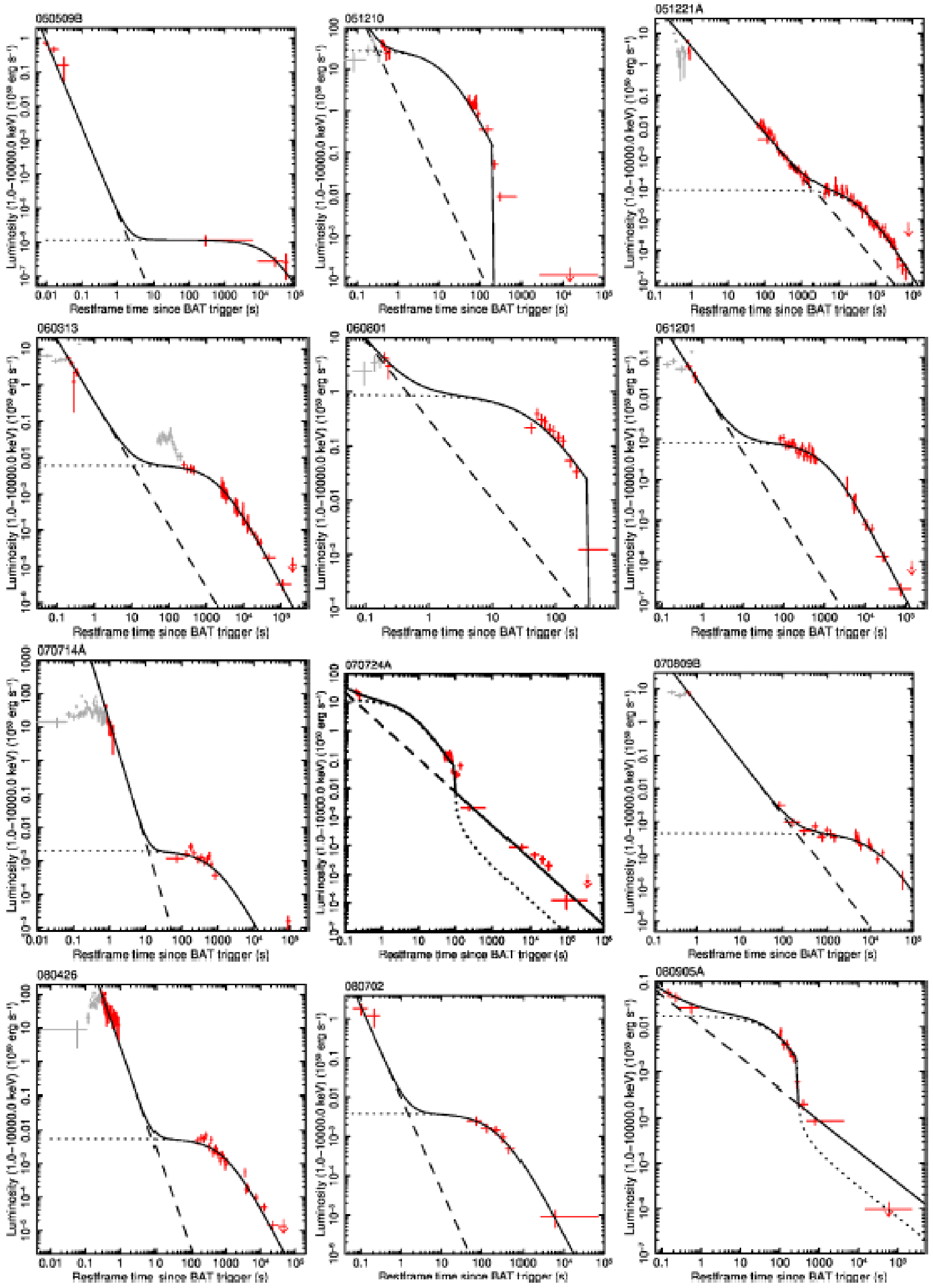

`Canonical' GRB Lightcurve
Prompt emission
Fast decay
Shallow decay
X-ray flare
~t-1
~t-2
Long GRB X-ray light curve
Nakar 07
1
10
100
10³
10⁴
10⁵
10⁶
t [s]

Modeling the quasi-plateau of **long** GRBs:
slow down of the protomagnetar

From Dall'Osso et al. 2010,
Quasi-plateau taking into account also the inter-stellar medium
B = (0.3 – 1) 10^{15} G, P = (1 – 3) ms



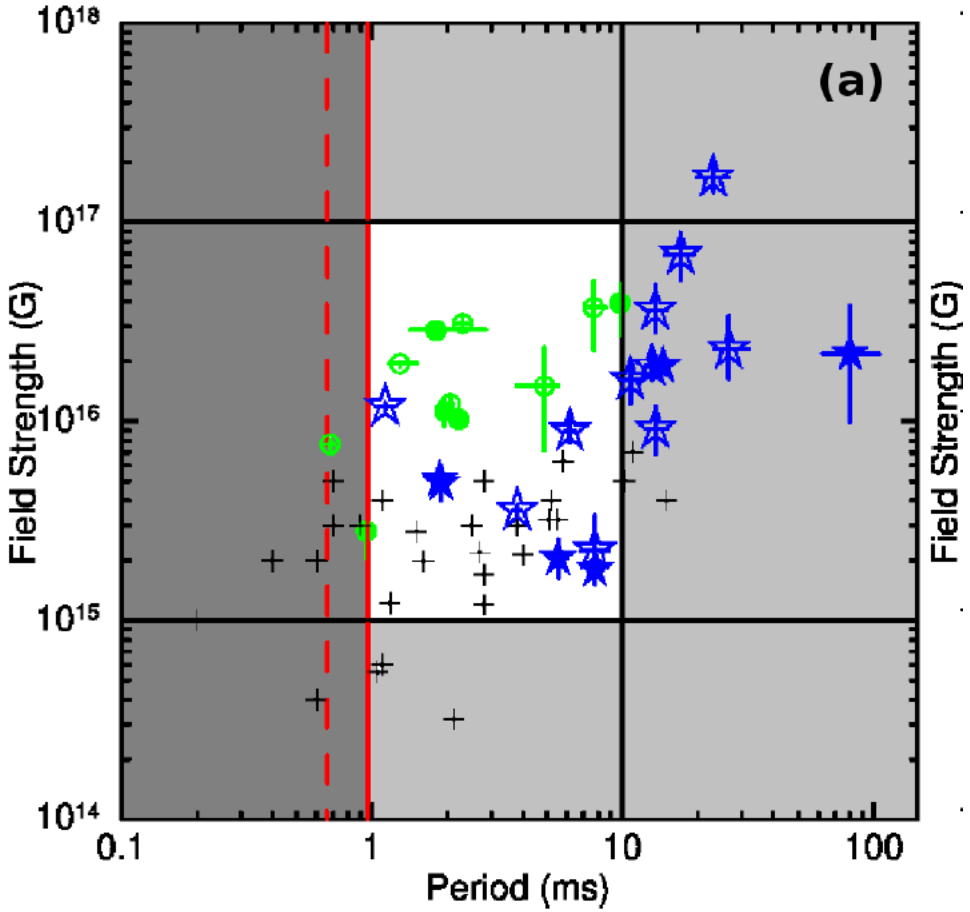
Rowlinson et al. 2013



Interpreting **short** GRBs extended emission in the same way as the quasi-plateau in long GRBs

Rowlinson et al. 2013: similarities between long and short GRBs

Similar values of B and P for long and short GRBs. B for sGRBs is roughly one order of magnitude larger than for lGRBs. Periods for sGRBs are slightly longer.



Analysis of short GRBs

Lasky, P. D., Haskell, B., Ravi, V., Howell, E. J., & Coward, D. M. 2014, Phys. Rev. D, 89, 047302
Ravi, V., & Lasky, P. D. 2014, MNRAS, 441, 2433
Hou-Jun Lu, Bing Zhang, Wei-Hua Lei, Ye Li, Paul D Lasky, 1501:02589

- **No plateau sample**: GRBs that do not have a significant plateau
- **2 NS → BH**

- **The internal plateau sample**: plateau followed by a decay with t^{-2} or steeper.
- **2 NS → supramassive → BH**

- **The external plateau sample**: plateau phase followed by a post-decay index close to -1.
- **2 NS → stable compact star**

- Maximum mass of a stable and not-rotating compact star: (2.46 +0.13 -0.15) M_s

- easy to explain if it is a quark star

How to describe 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).

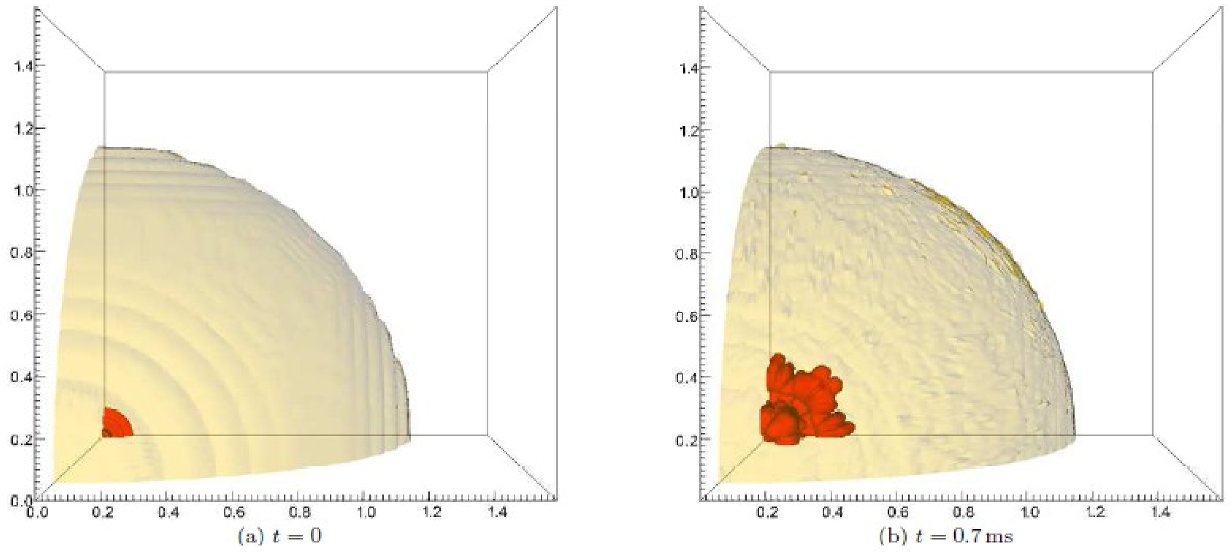
In other words, **if the central engine of a long GRB would stop after ~ 0.3 (1+z) seconds the resulting event would be indistinguishable from a short GRB** (Calderone et al. 2014).

Rapid conversion of the **core**
of a 1.4 Msun 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)

After the rapid burning the conversion proceeds via strangeness production and diffusion. The burning reaches the surface of the star after about 10 s.



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

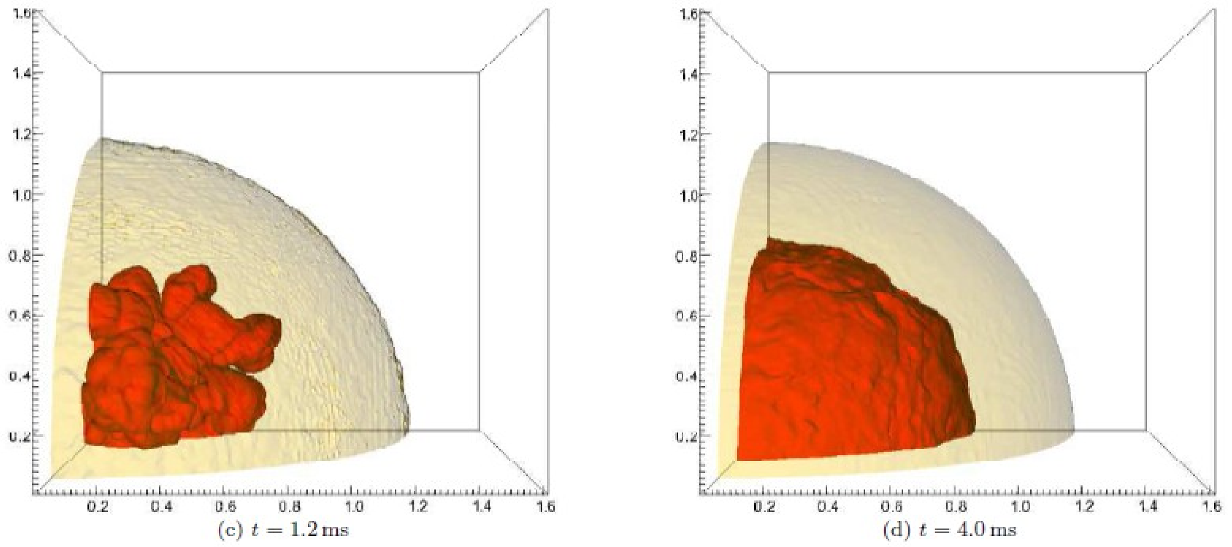
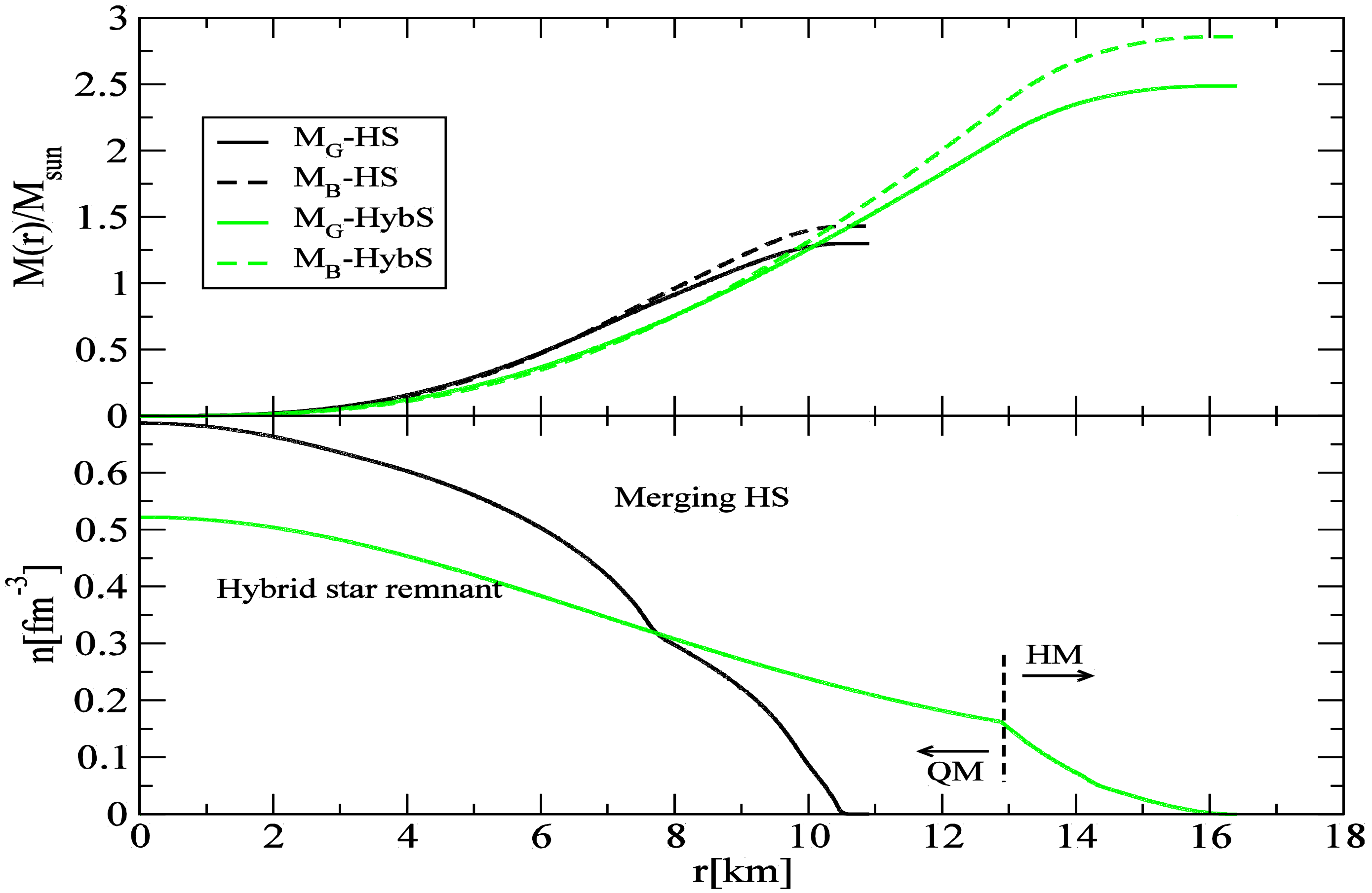


FIG. 1: (color online) Model: Set 1, $M = 1.4 M_\odot$. Conversion front (red) and surface of the neutron star (yellow) at different times t. Spatial units 10^6 cm.

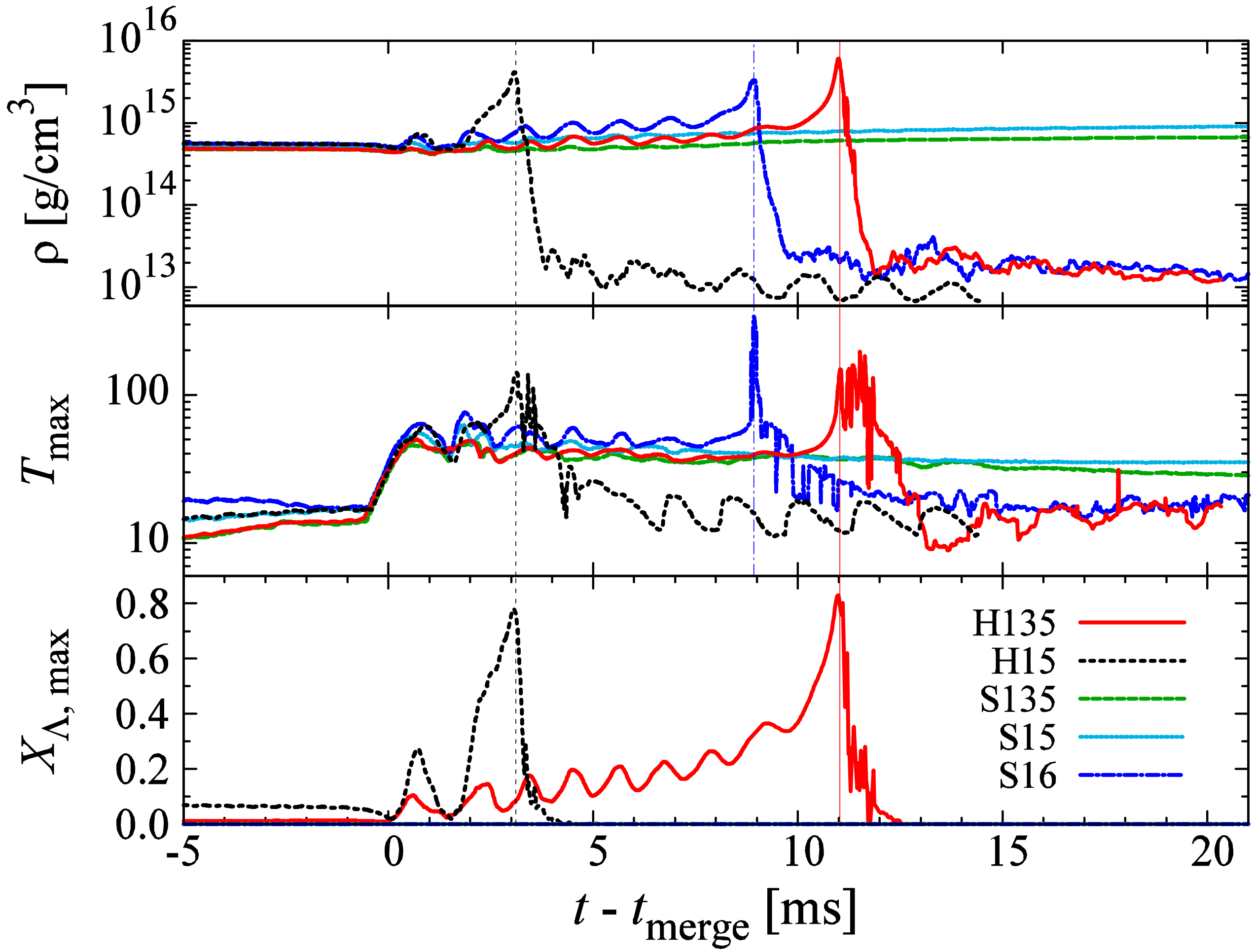
Structure of the stars before the merging and after the merging at the moment the fast burning halts



The configuration obtained after the rapid burning is mechanically stable although not yet in chemical equilibrium

Effects of hyperons in binary neutron star mergers

Sekiguchi, Kiuchi, Kyutoku and Shibata, Phys. Rev. Lett. **107**, 211101



Duration of the sGRB in the two-familes scenario

A.D., A.Lavagno, B.Metzger, G.Pagliara paper in preparation