(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, Phys. Rev. C 92 (2015) 045801

  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

Review papers on the two-families scenario:

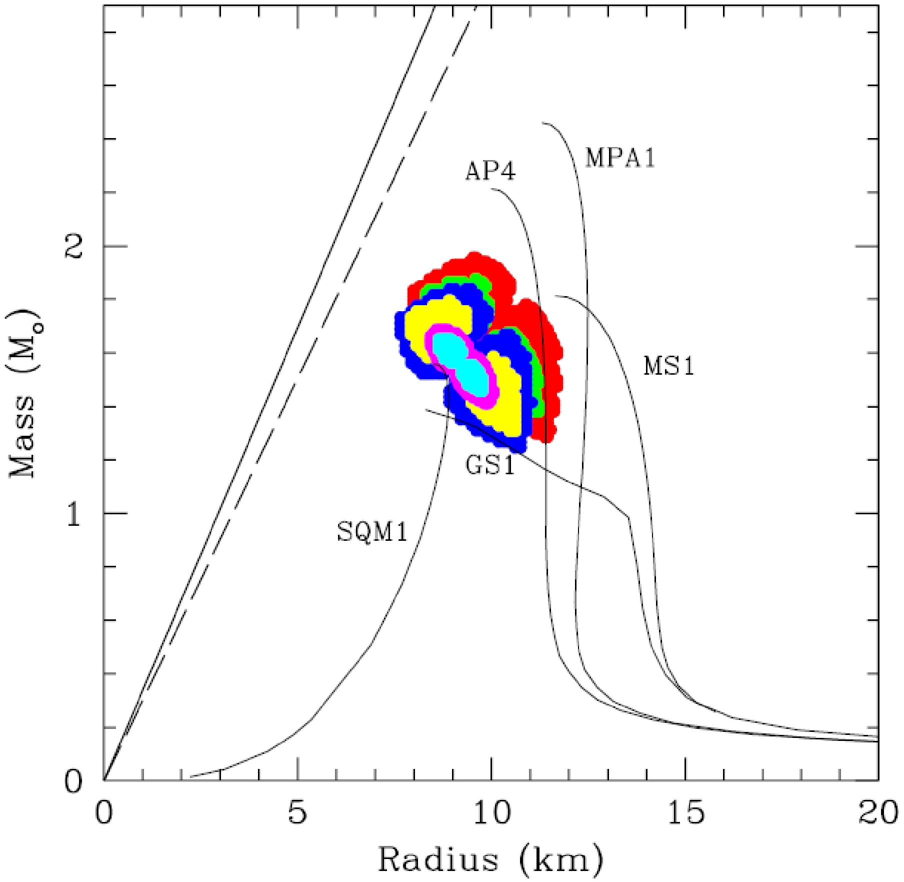
arXiv: 1509.02131 and 1509.02134 accepted for publication

Why a two-families scenario?

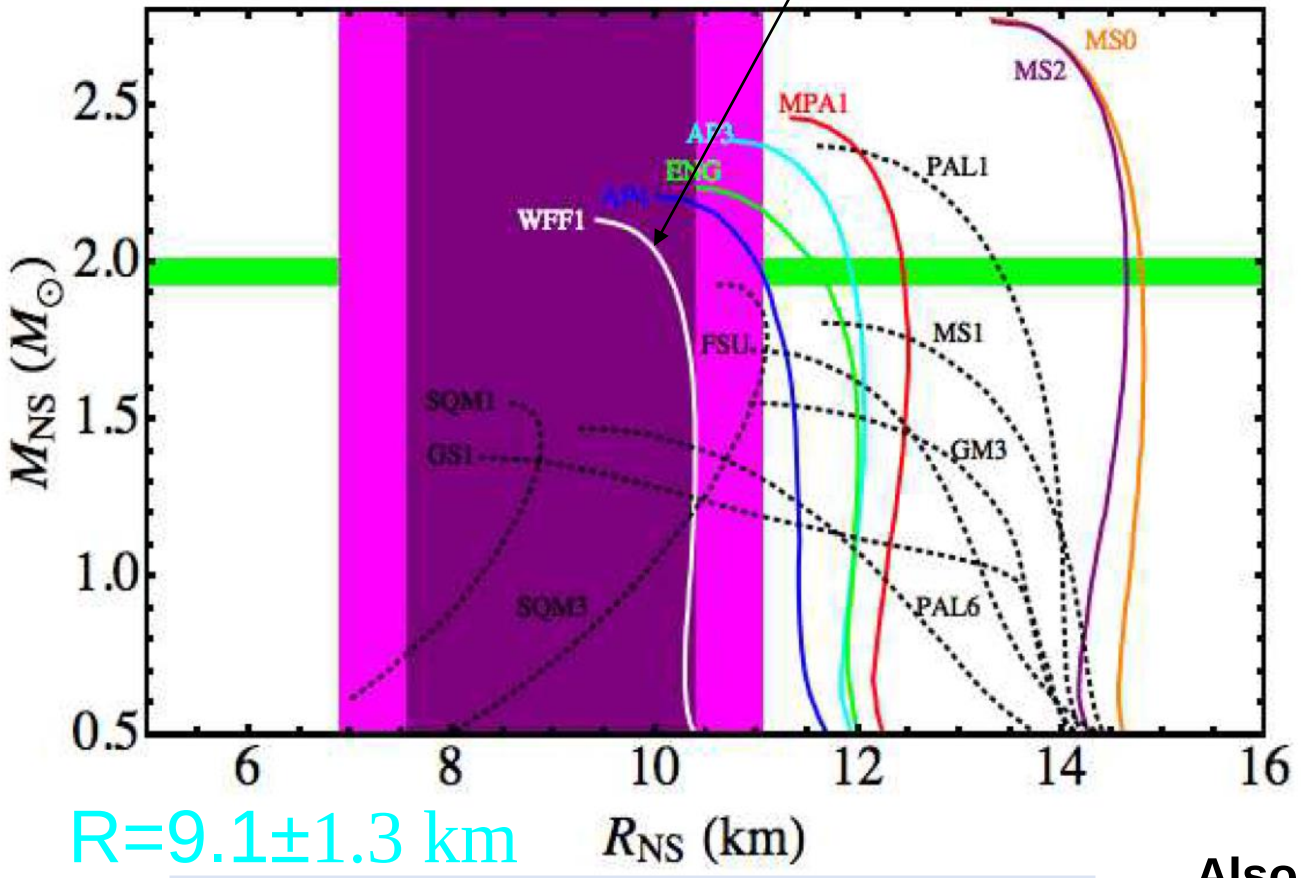
The problem of the radii of compact stars

Indications for SMALL radii:
a VERY controversial result

Oezel, Baym, Guever PRD82 (2010) 101301



Nice, but just nucleons,
And it violates causality!

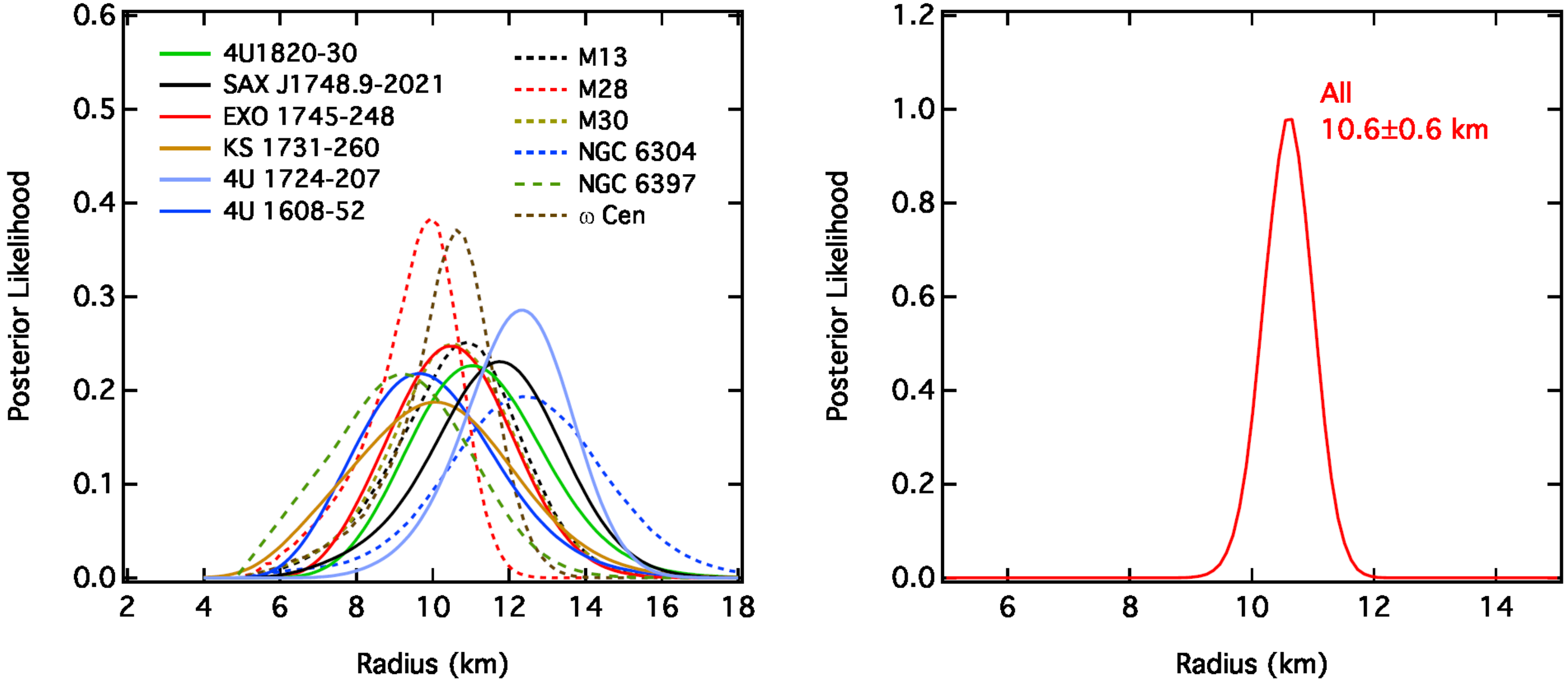


R=9.1±1.3 km

Guillot et al. ApJ772(2013)7
analysis of 5 QLMXBs

Also Guillot and Rutledge 1409.4306
R=(9.4 ± 1.2)km

Oezel, Psaltis, Guever, Baym, Heinke, Guillot, arXiv:1505.15155



Indications for LARGE radii

Hambaryan et al 2014

RXJ1856.5-3754

Is the nearest INS and the distance (d = 123+11-15 pc) is known with relatively good accuracy.

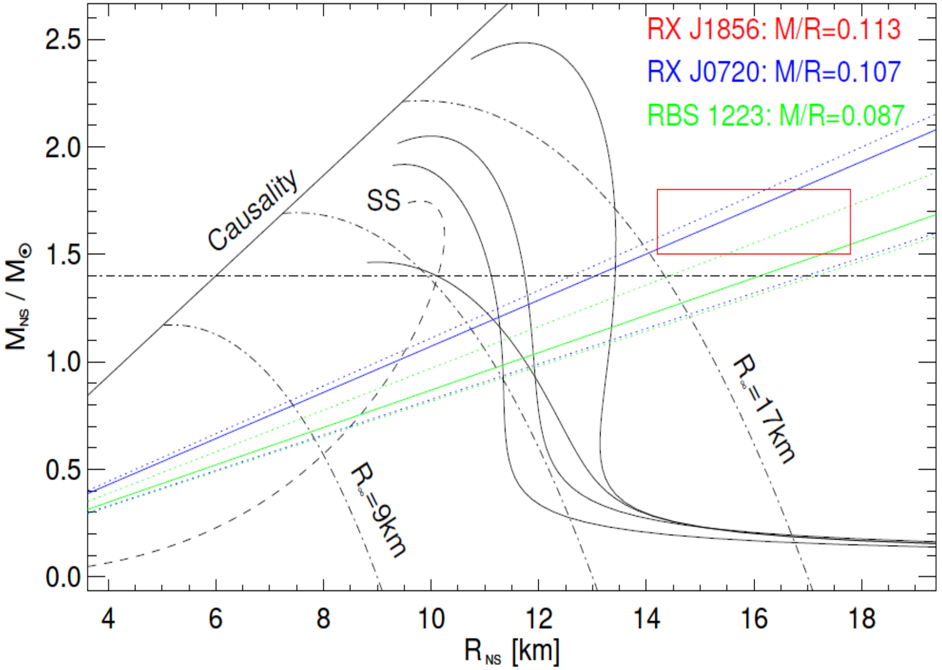
The X-ray spectrum does not show any signicant absorption feature and the pulsed fraction is quite low (1.5%).

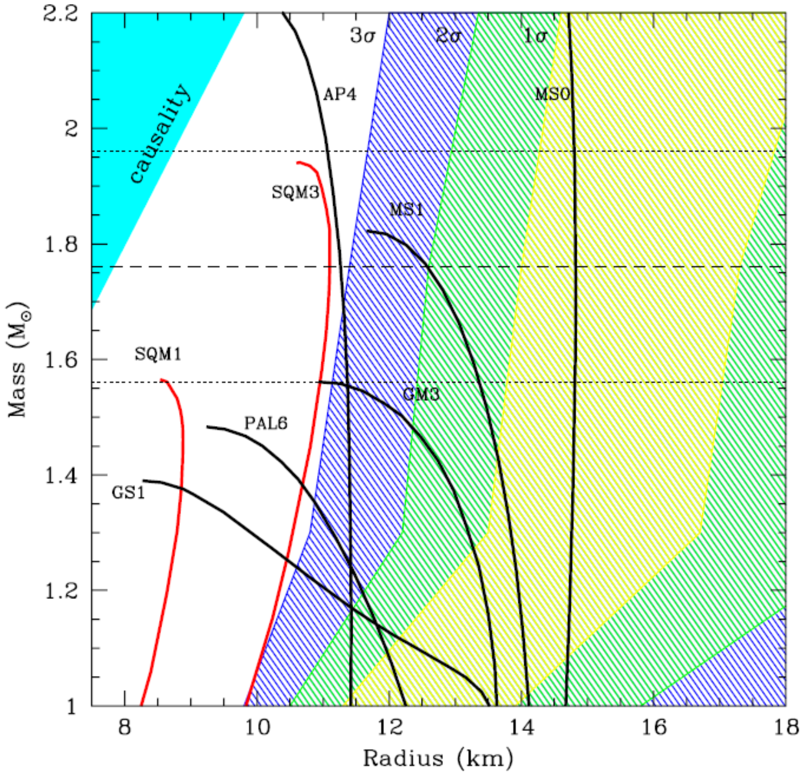
Bogdanov 2013

PSR J0437–4715, *XMM-Newton*

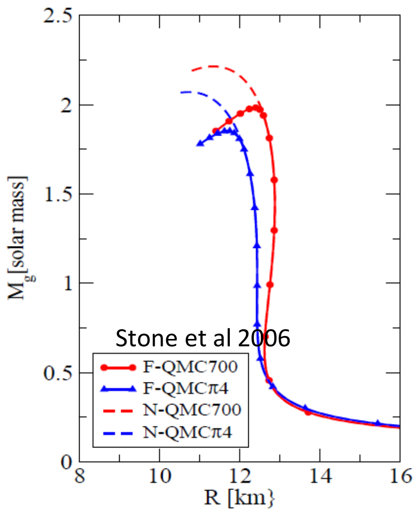
The thermal radiation exhibits at least three components, with the hottest two having total effective areas consistent with the expected polar cap size.

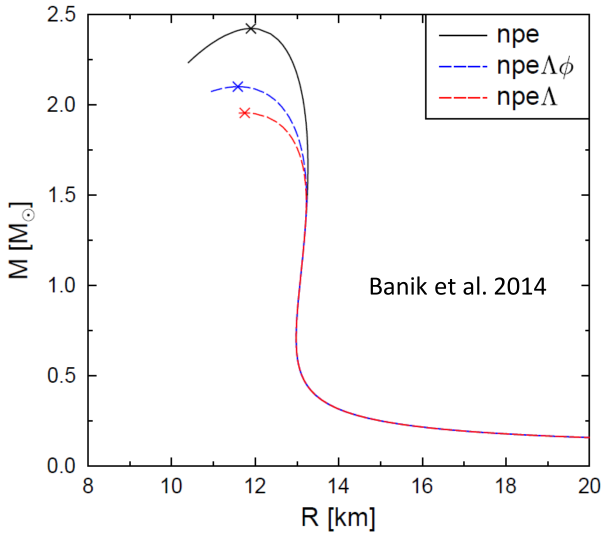
The coolest component, on the other hand, appears to cover a significant portion of the stellar surface



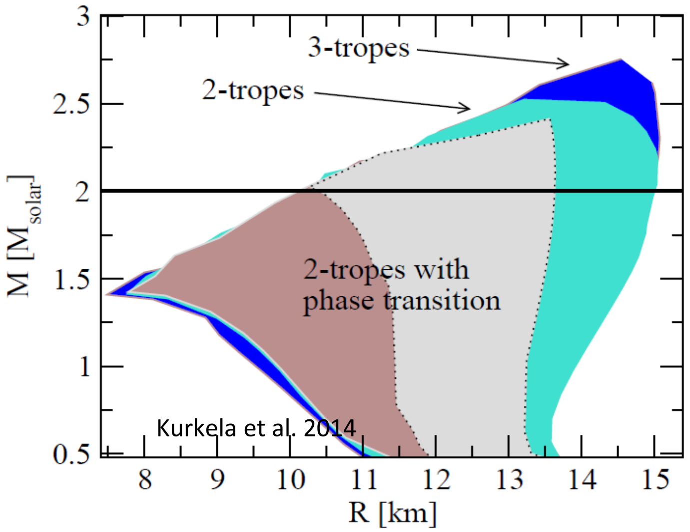


Minimum radius for a 1.4 M_s star

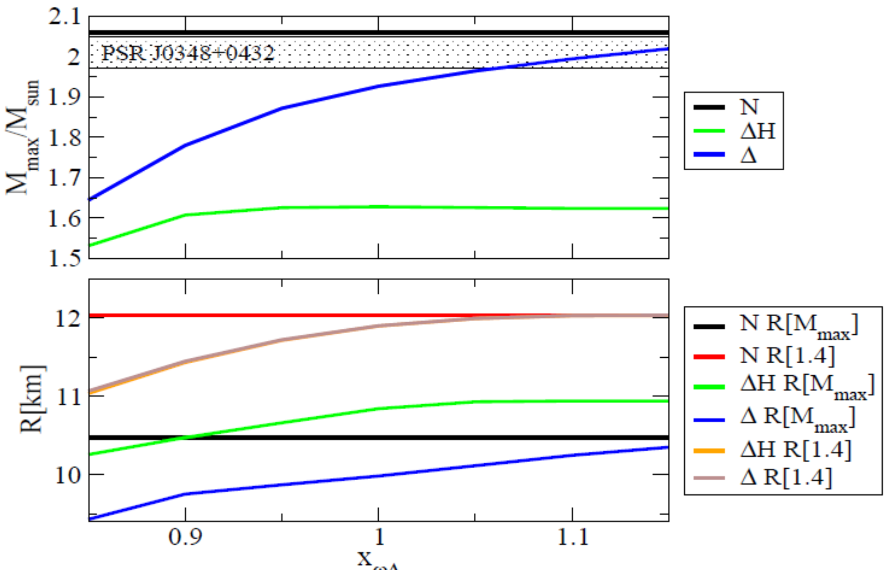




Hyperonic stars $R_{1.4}$ > (12.5 – 13) km



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

Strong softening… is this surprising?

Heavy ions physics:

(Kolb & Heinz 2003)

Also at finite density the quark matter equation of state should be stiffer than the hadronic equation of state in which new particles are produced as the density increases

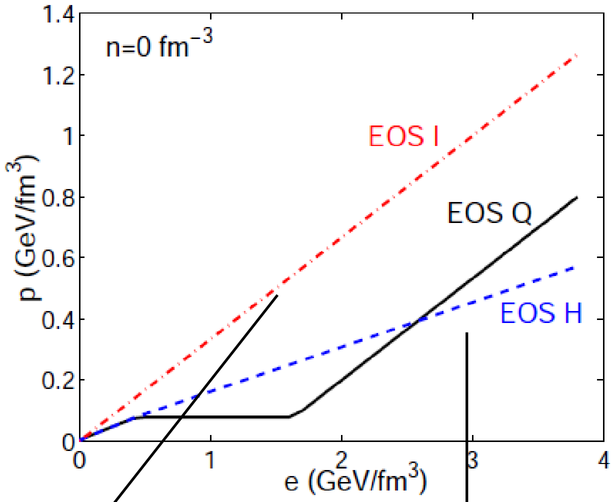
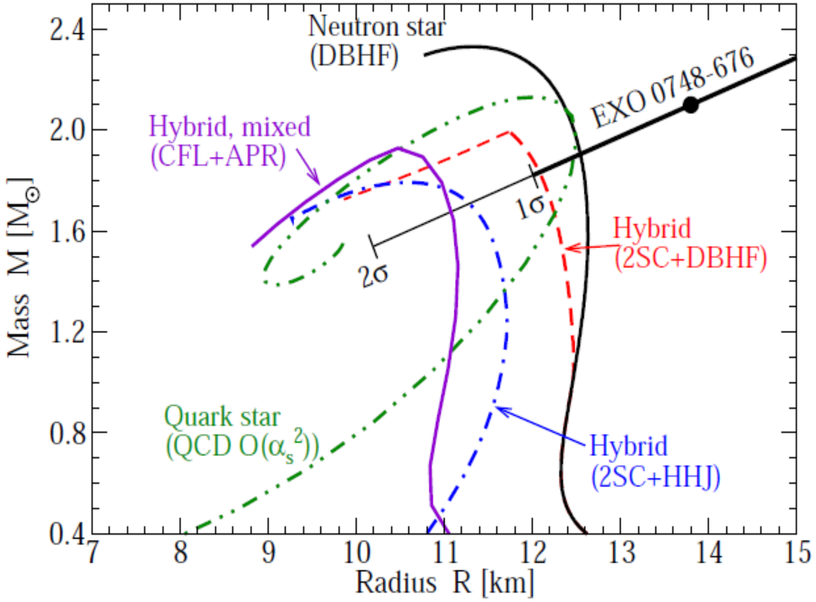
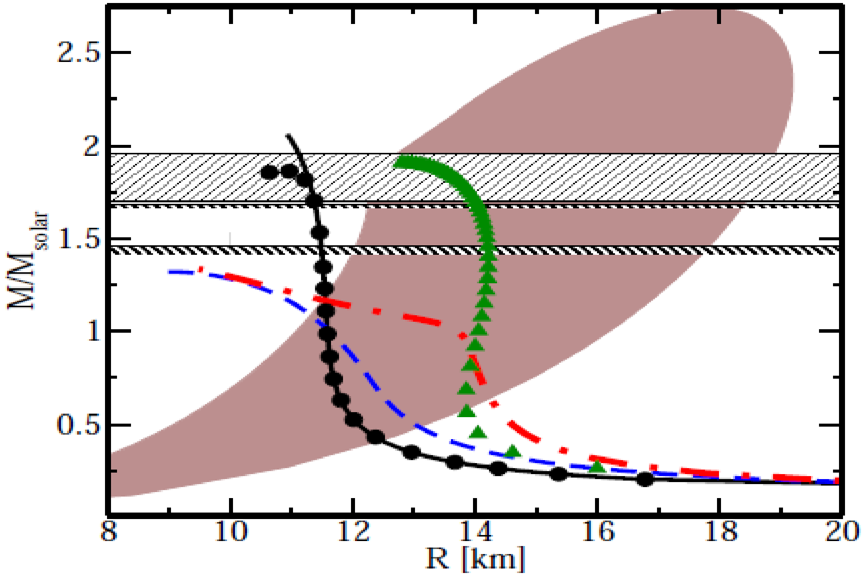


Fig. 1. Equation of state of the Hagedorn resonance gas (EOS H), an ideal gas of massless particles (EOS I) and the Maxwellian connection of those two as discussed in the text (EOS Q). The figure shows the pressure as function or energy density at vanishing net baryon density.

p=e/3 massless quarks **Hadron resonance gas p=e/6**

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.

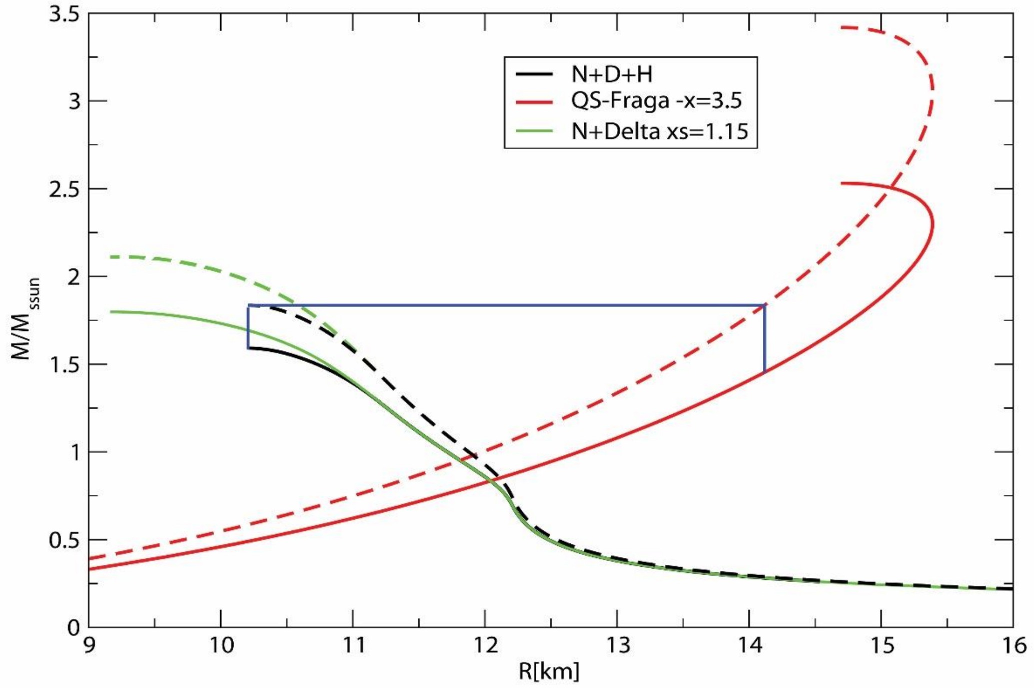
For strange stars, we find maximal masses of 2.75Ms and conclude that confirmed observations of compact stars with $M > 2M_s$ would strongly favor the existence of stable strange quark matter"

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.

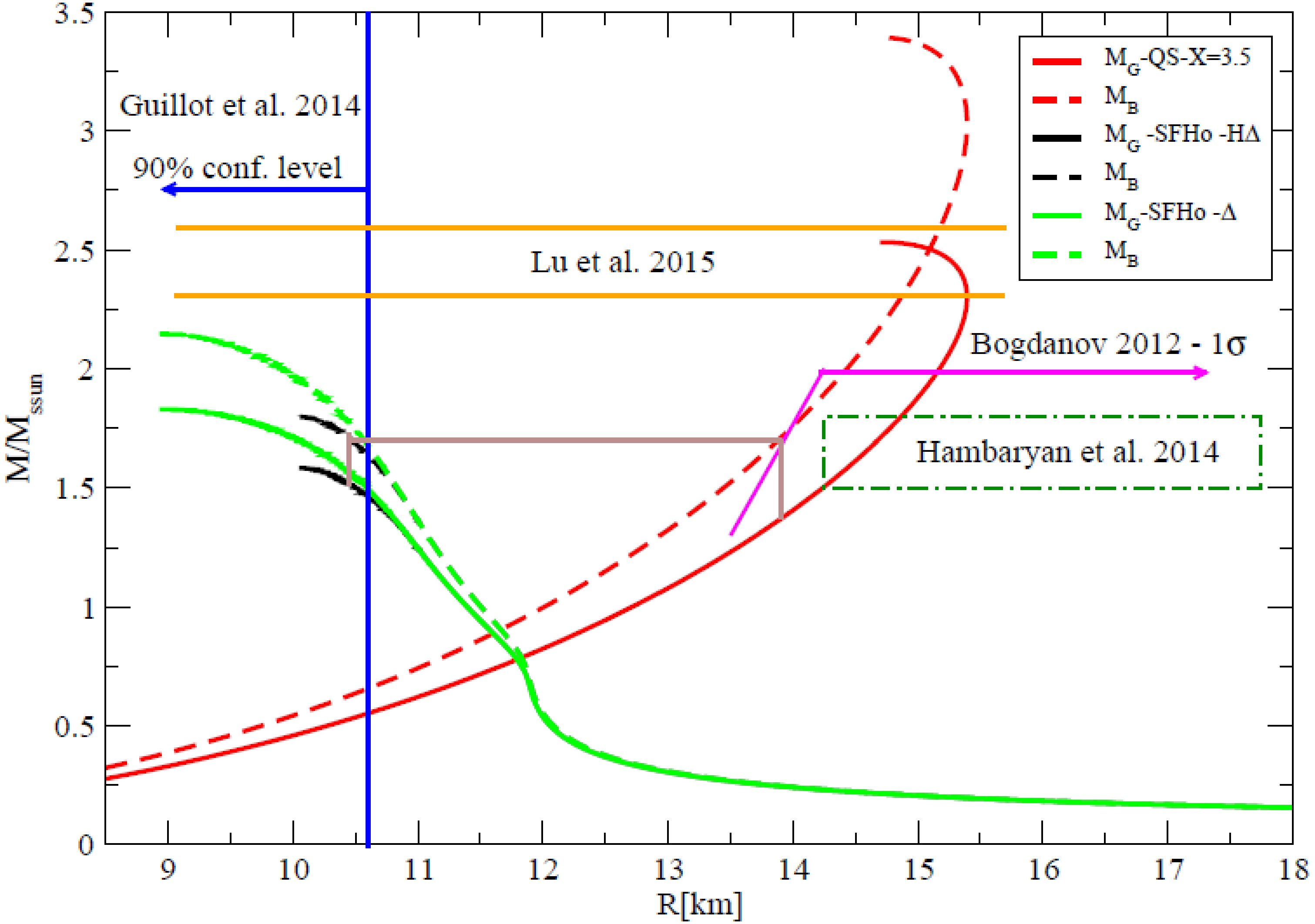
The hadronic stars are stable
till when some strangeness
component (e.g. hyperons)
starts appearing in the core.
Only at that point quark matter
nucleation can start.

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.

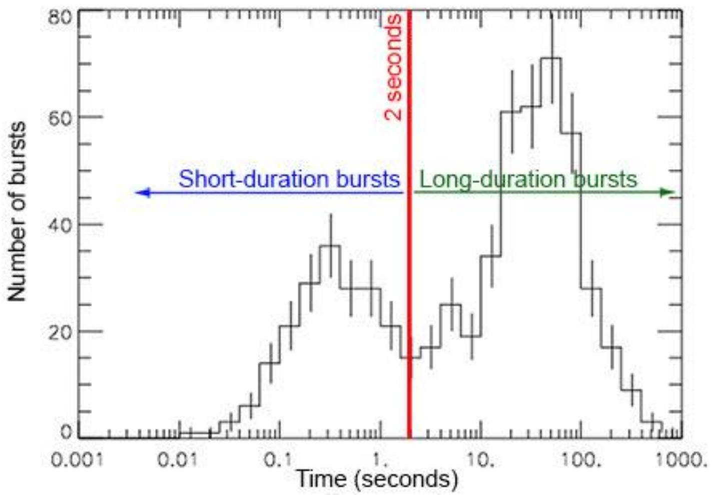
Small and large radii within the two-families scenario



Gamma Ray Bursts

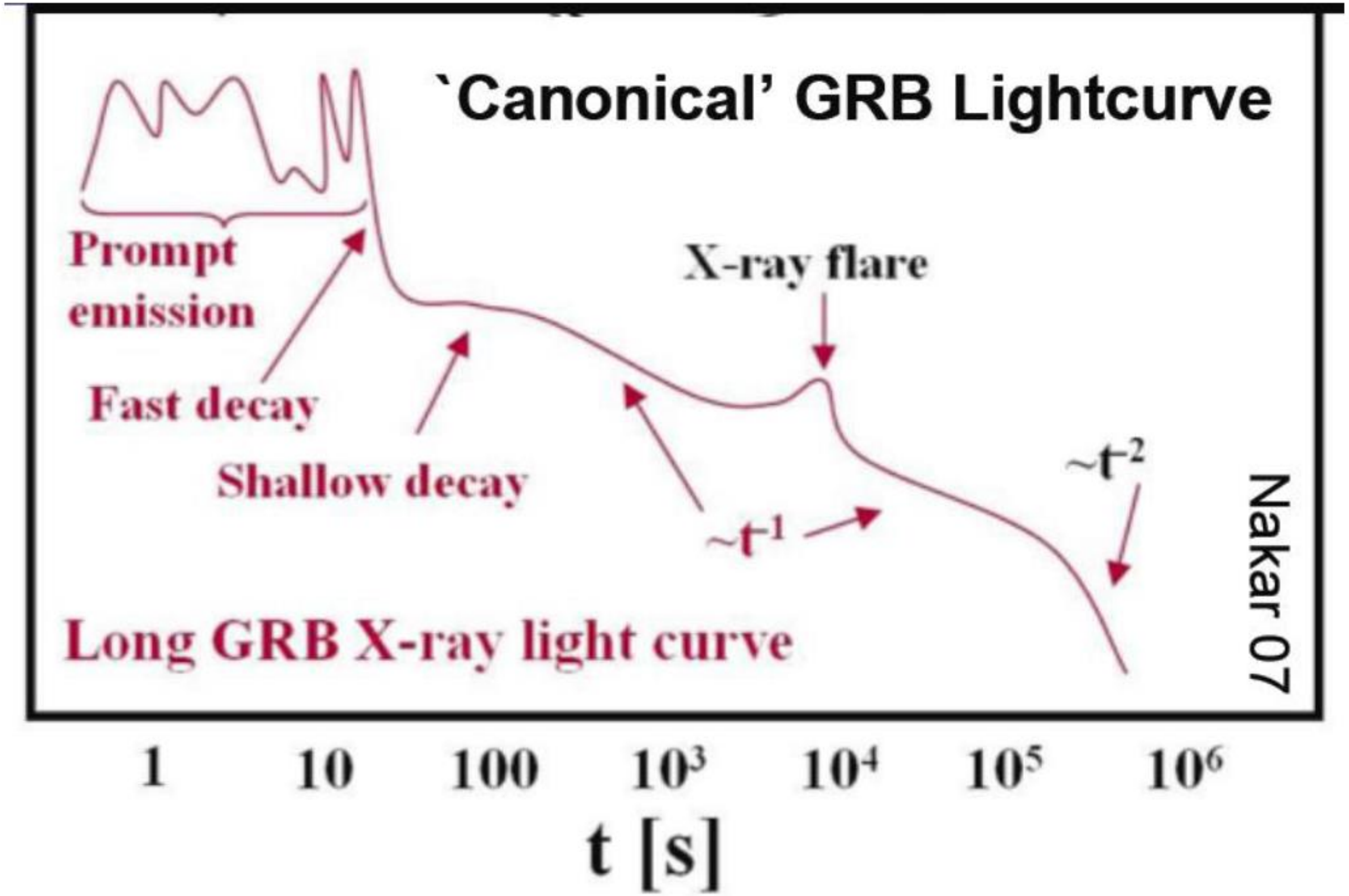
The role of quark deconfinement in short GRBs

Long and short Gamma Ray Bursts



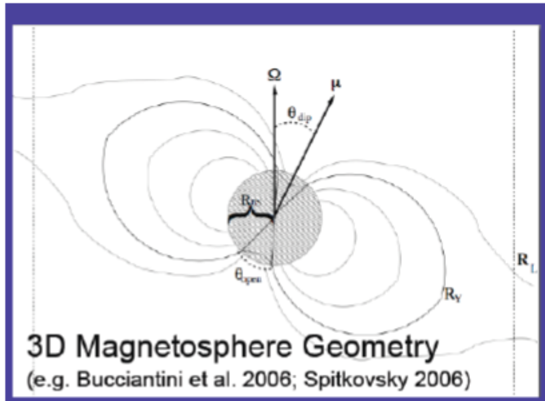
Long GRBs: collapse of a heavy progenitor
Short GRBs: merger of two neutron stars

`Canonical' GRB Lightcurve



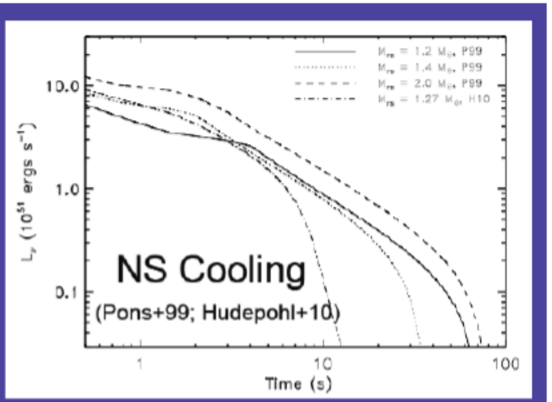
Nakar 07

Evolutionary wind model



3D Magnetosphere Geometry

(e.g. Bucciantini et al. 2006; Spitkovsky 2006)



NS Cooling

(Pons+99; Hudepohl+10)

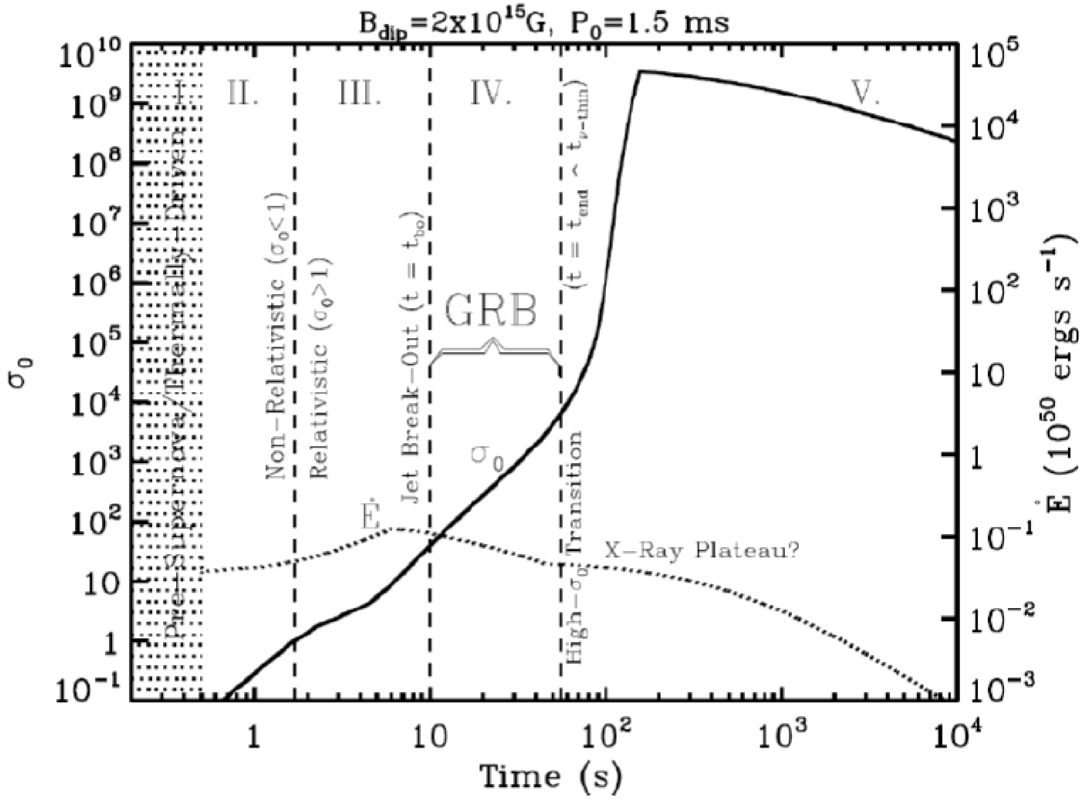
Calculate: Wind Power $\dot{E}(\mathrm{t})$, Mass Loss Rate $\dot{M}(\mathrm{t})$,

$$\Rightarrow \text{'Magnetization'}\ \sigma(\mathrm{t}) \sim \dot{E}/\dot{M}c^2 = \Gamma_{\max}(\mathrm{t})$$

In terms of

Initial Rotation Period P_0 , **Dipole Field Strength** B_{dip} & **Obliquity** θ_{dip}

Magnetar model of GRBs (Metzger et al.)

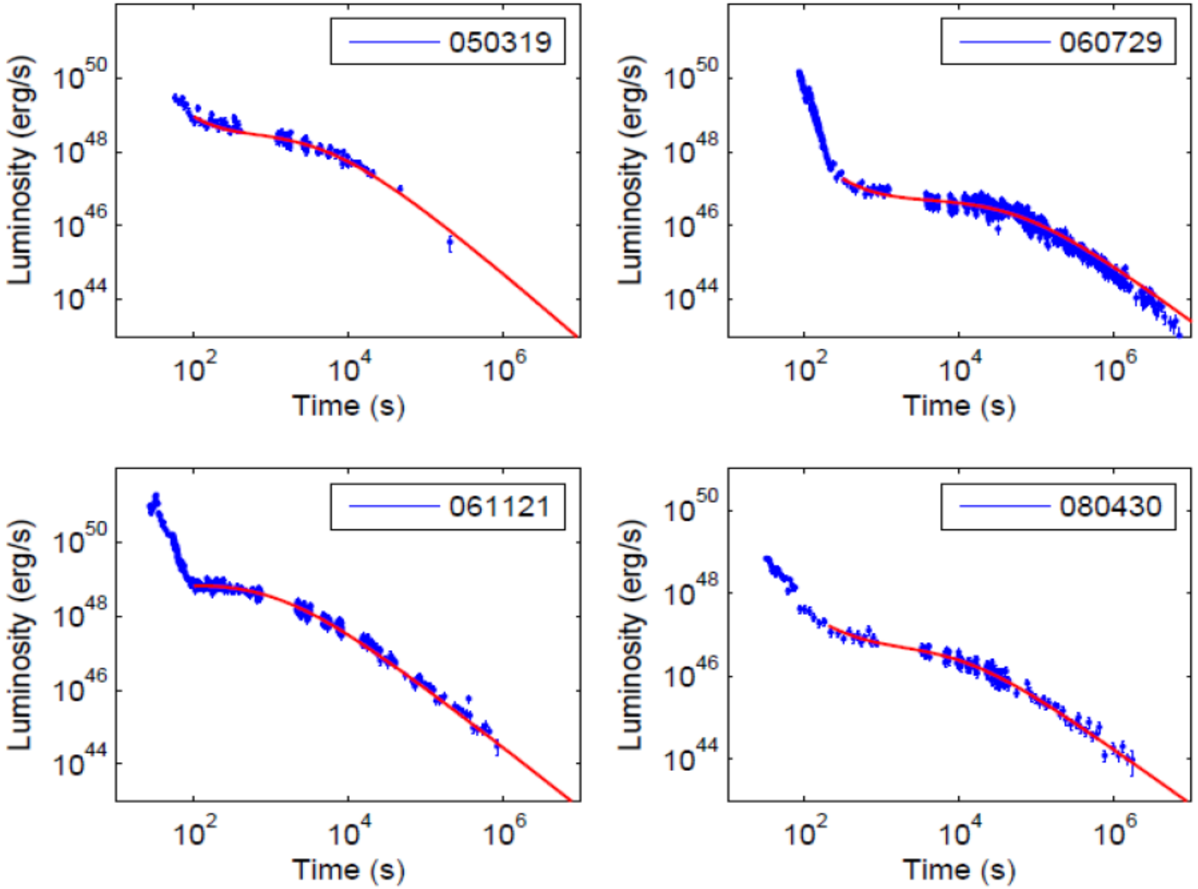


$$\sigma_0 \equiv \frac{\phi^2\Omega^2}{\dot{M}c^3} \qquad \phi \equiv B_r r^2$$

Quark deconfinement would reheat the star and generate a new mass ejection

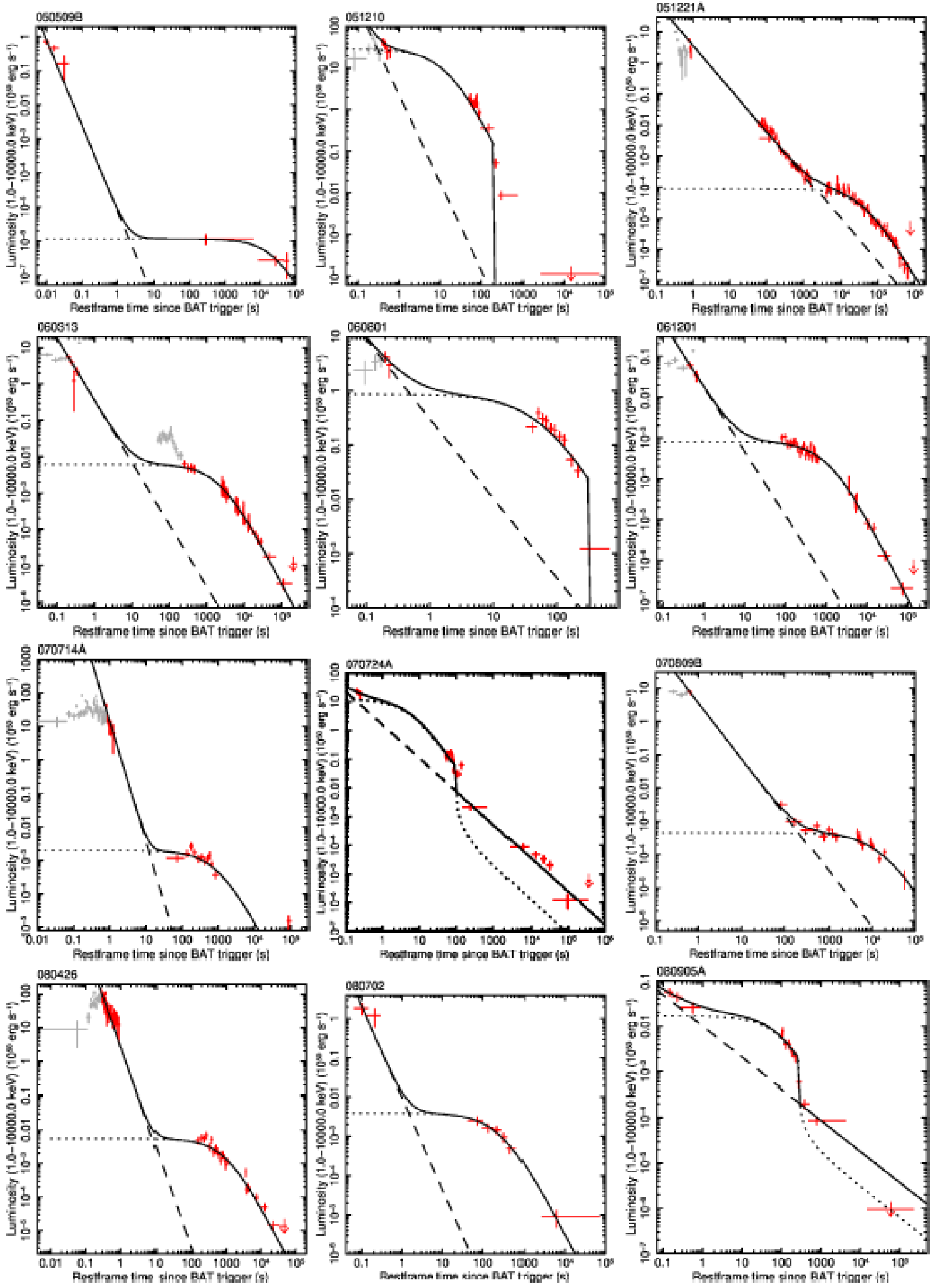
Modeling the quasi-plateau of **long** GRBs:
slow down of the protomagnetar

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



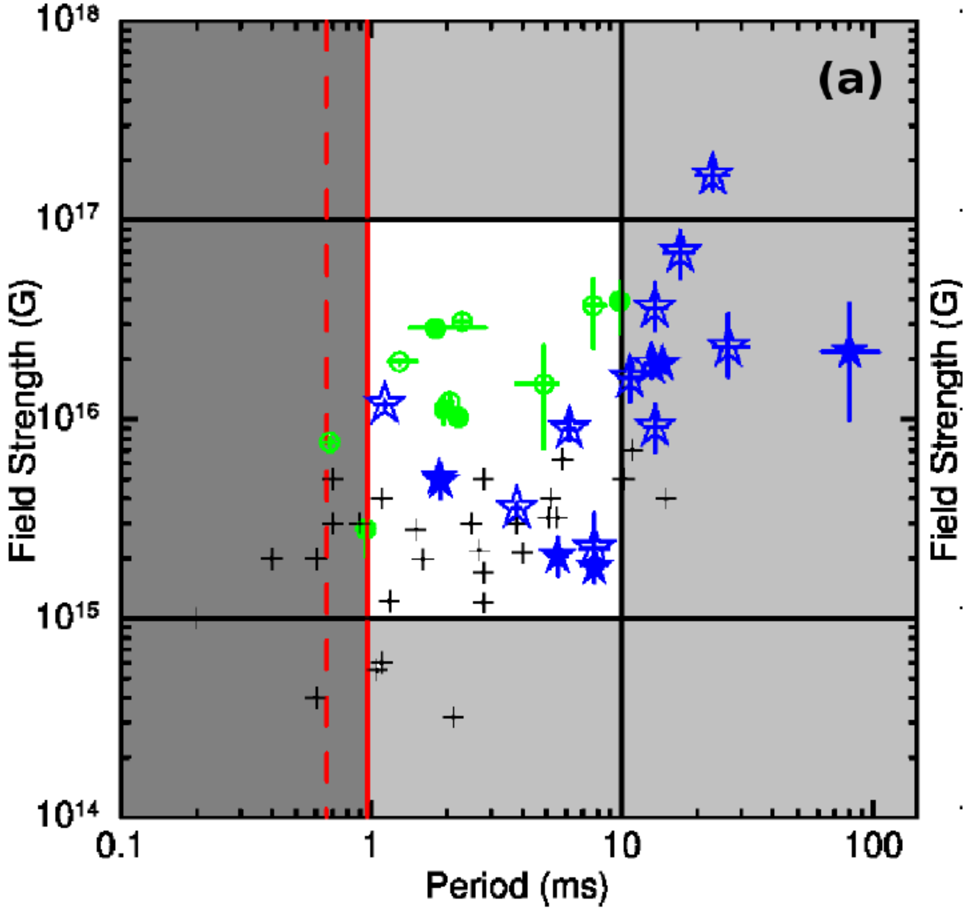
Rowlinson et al.
2013

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.



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

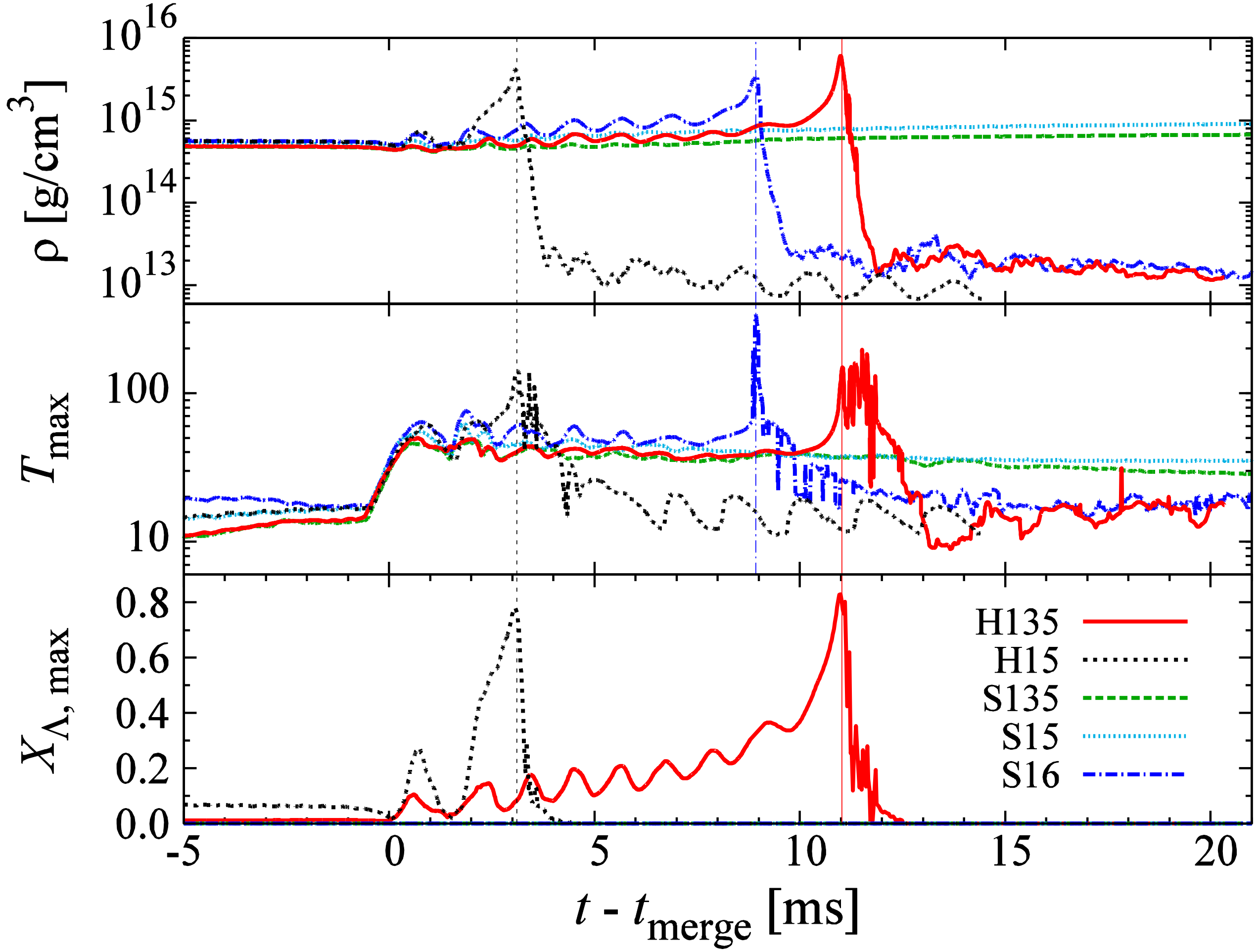
It was generally assumed that the prompt emission of short GRBs is spectrally harder than the one of long GRBs, but the differences are less evident when the sample is restricted to short GRBs with the highest peak fluxes (Kaneko et al. (2006)) or when considering only the first ~ 2 s of long GRBs light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

Effects of hyperons in binary neutron star mergers

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

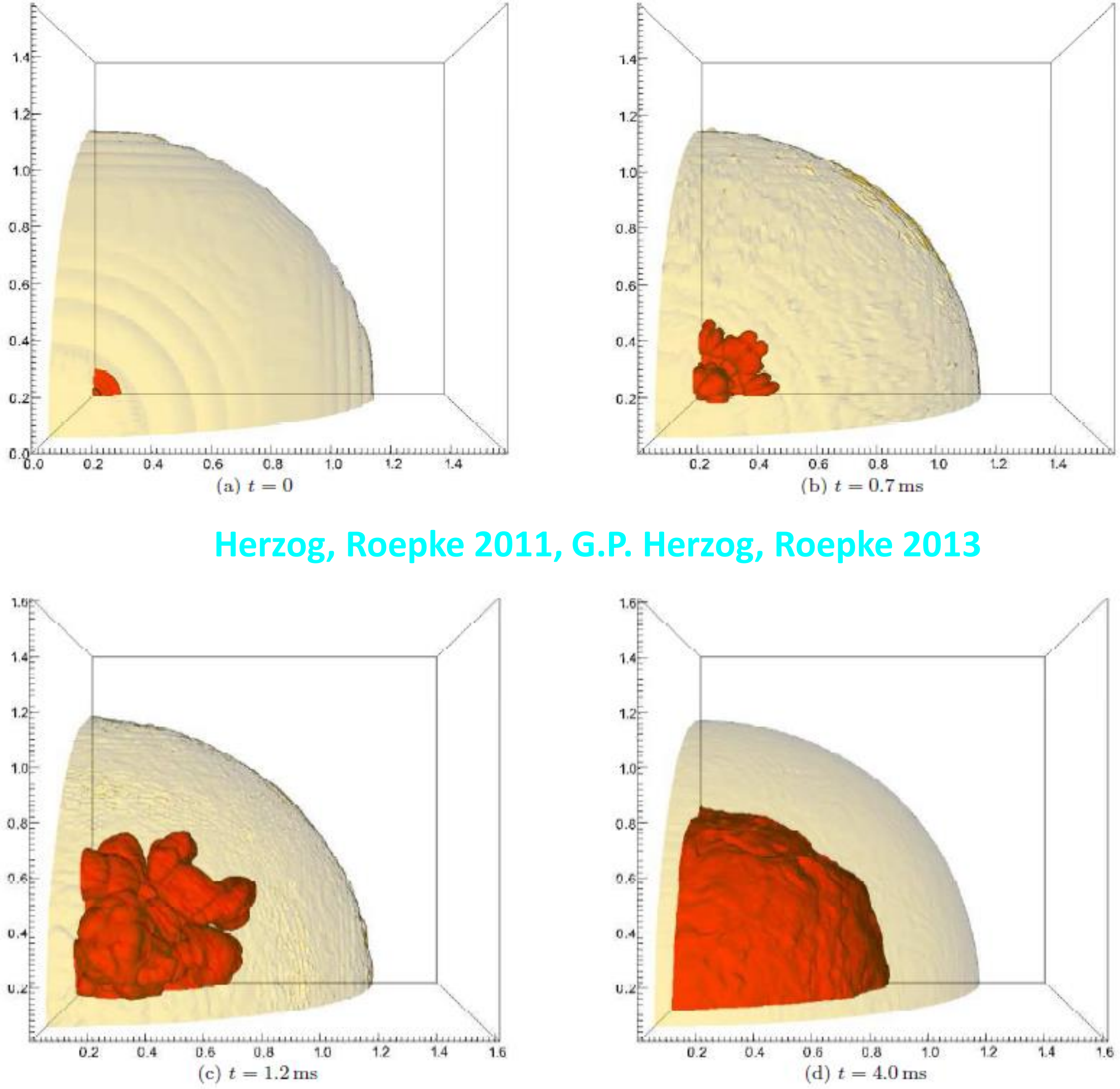


Rapid conversion of the **core**
of a 1.4 Msun star

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.



(a) $t = 0$

(b) $t = 0.7\,\mathrm{ms}$

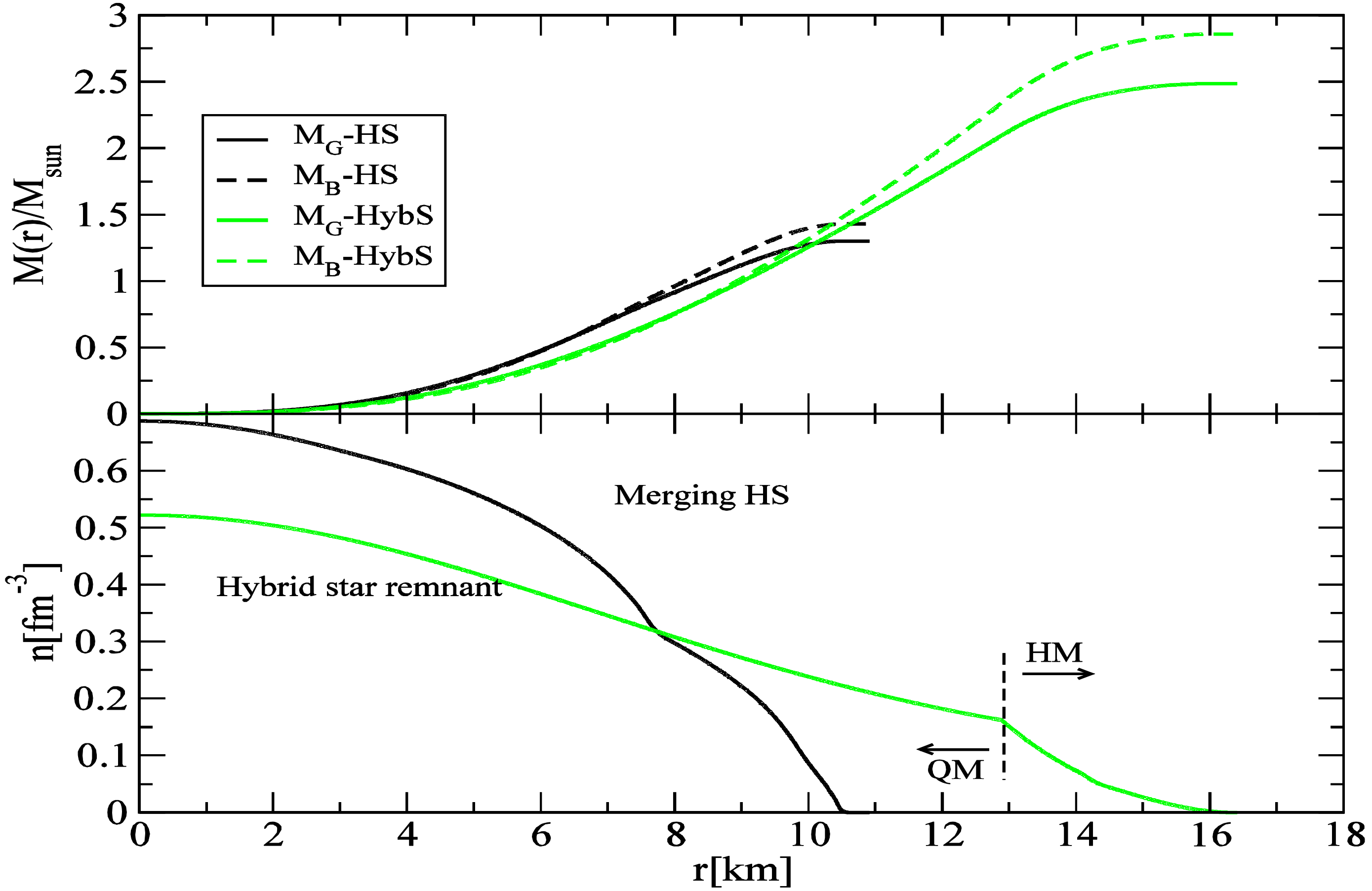
Herzog, Roepke 2011, G.P. Herzog, Roepke 2013

(c) $t = 1.2\,\mathrm{ms}$

(d) $t = 4.0\,\mathrm{ms}$

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.

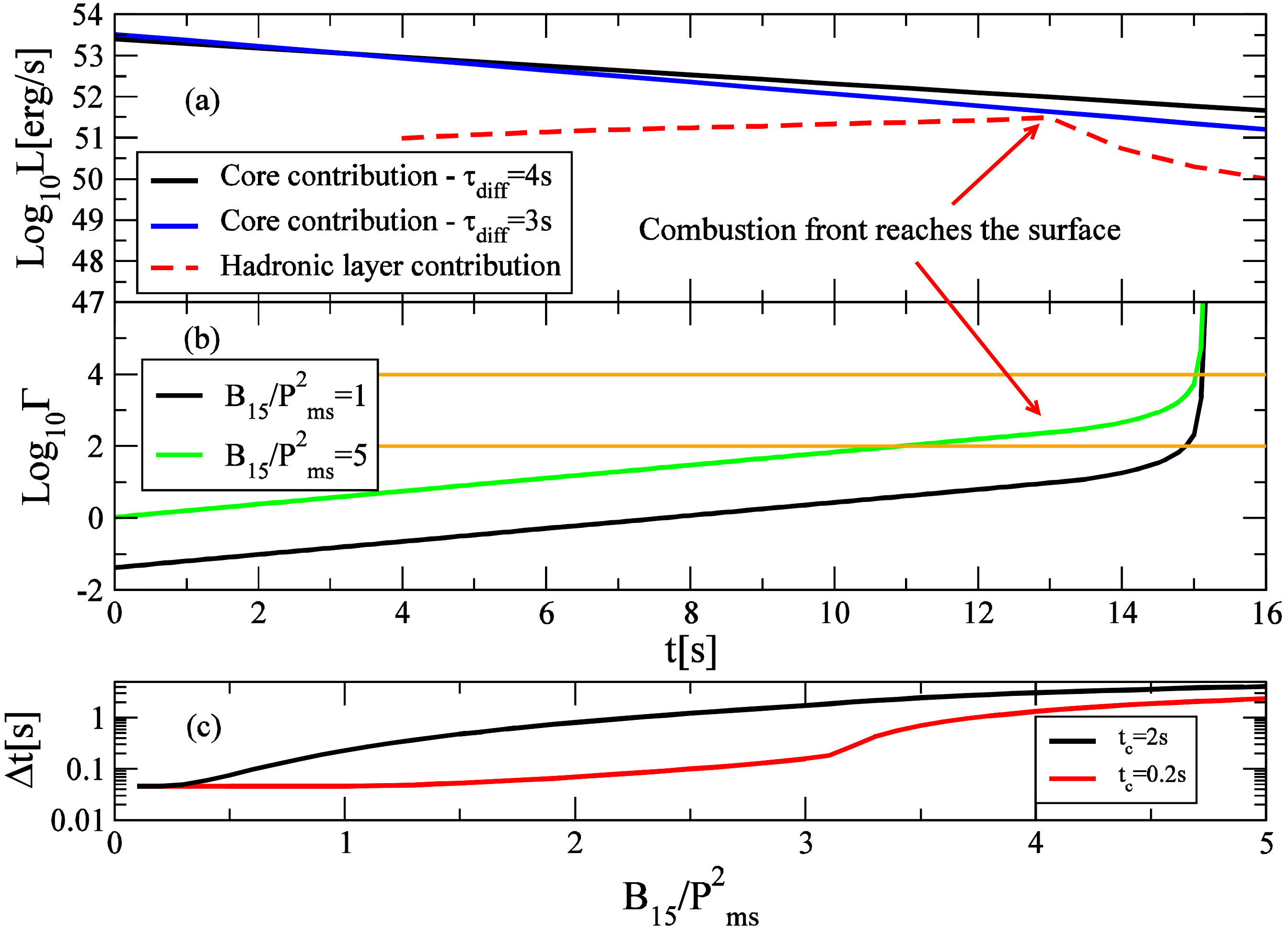
Structure of the stars before the merging and after the merging at the moment the fast burning halts



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

Duration of the sGRB in the two-families scenario

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



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