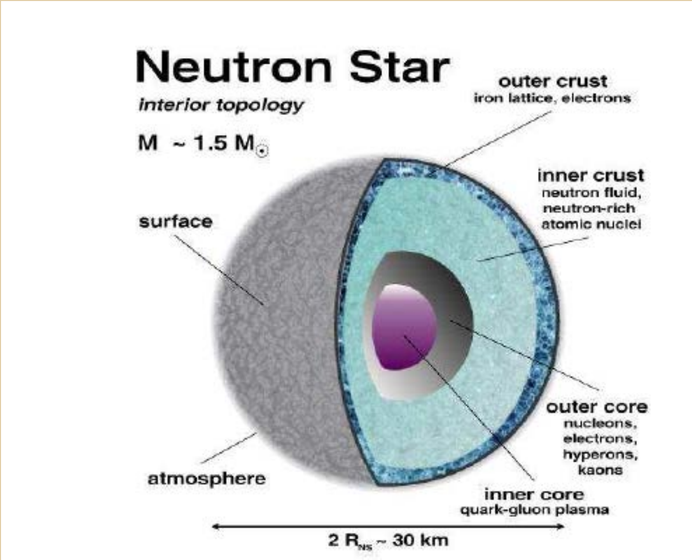
Deconfinement of quark content in Neutron Stars due to cosmic external agents

M Ángeles Pérez-García

Fundamental Physics Department & IUFFyM,
University of Salamanca
Spain

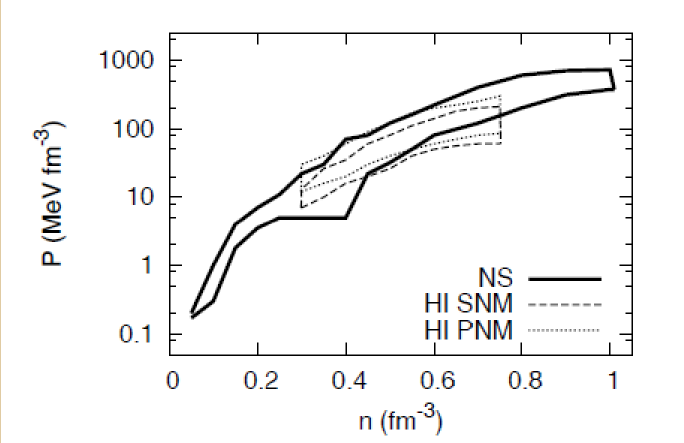
Neutron star EOS: from nuclear to ..quark matter?



Interior described using an EOS involving strong, electroweak and gravitational interaction for matter in Standard Model.

Many EOS in the literature, exp constraints come from HI collisions, M-R relation

Typically Mass <2.1 M_sun (is this really true?), R ≈ 12 km
Temperatures low, matter degenerate $T \ll E_{Fi}$



from Danielewicz et al. 2002, Steiner et al . 2010

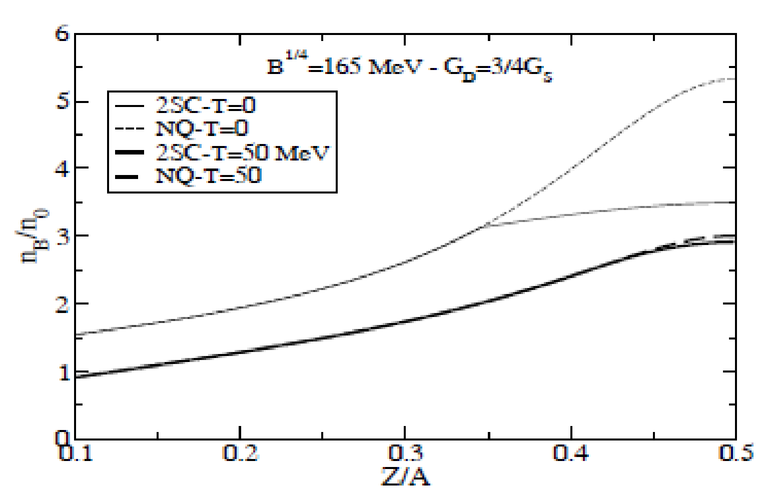
Deconfinement: how to seed quark matter

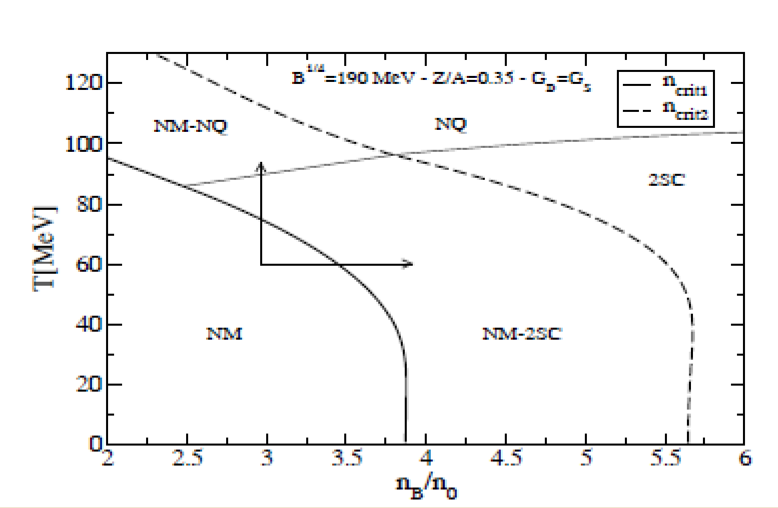
Feasibility on the phase transition has been explored relaying on variables: μ_i, m_i, T..

Superconducting phases possible, variety gaps Δ, ...

QCD phase-diagram is investigated, from 1 to $4n_0$, $n_0 \approx 0.16 fm^{-3}$ and temperature T ≈ 0-200 MeV

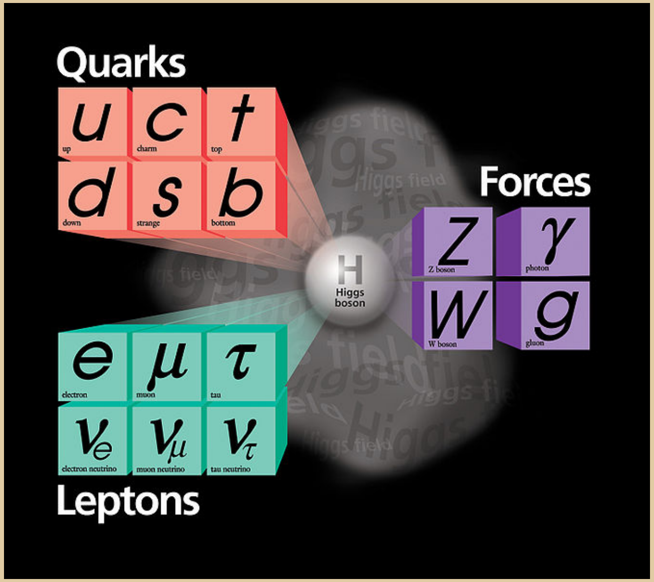
Isospin content, a_{sym} important to the onset of Q matter.

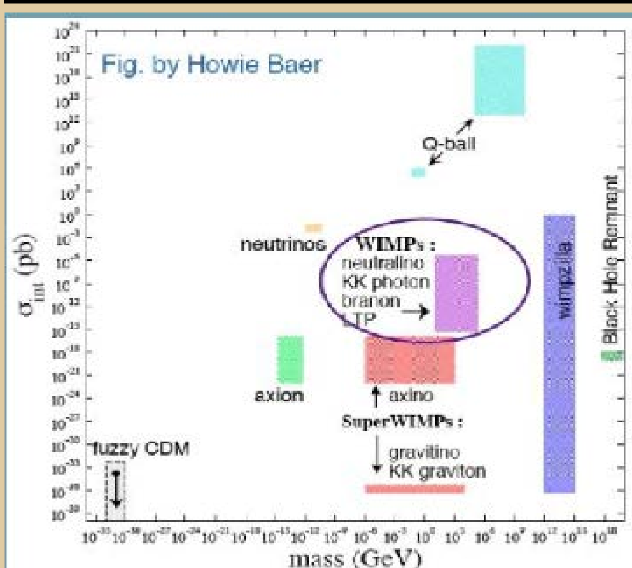




Pagliara & S-Bielich. 2010

SM matter & Dark matter





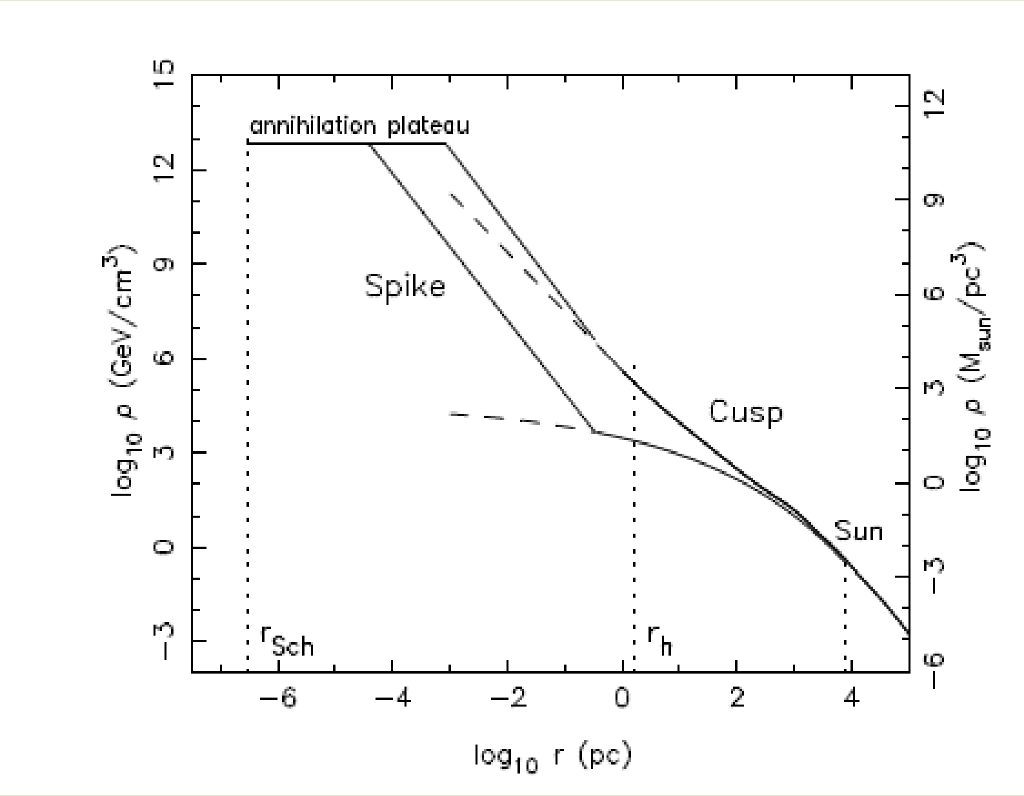
We already know what regular Standard model matter is

However another cosmological ingredient, Dark matter, remains yet undiscovered

DM is a major paradigm of modern Cosmology, indications from:

- -galaxy rotation curves
- -Gravitational lensing
- -CMB limits

DM profiles



Bertone et al 2009, arXiv: 0905.4736

DM particle could be accreted from the *galactic* halo

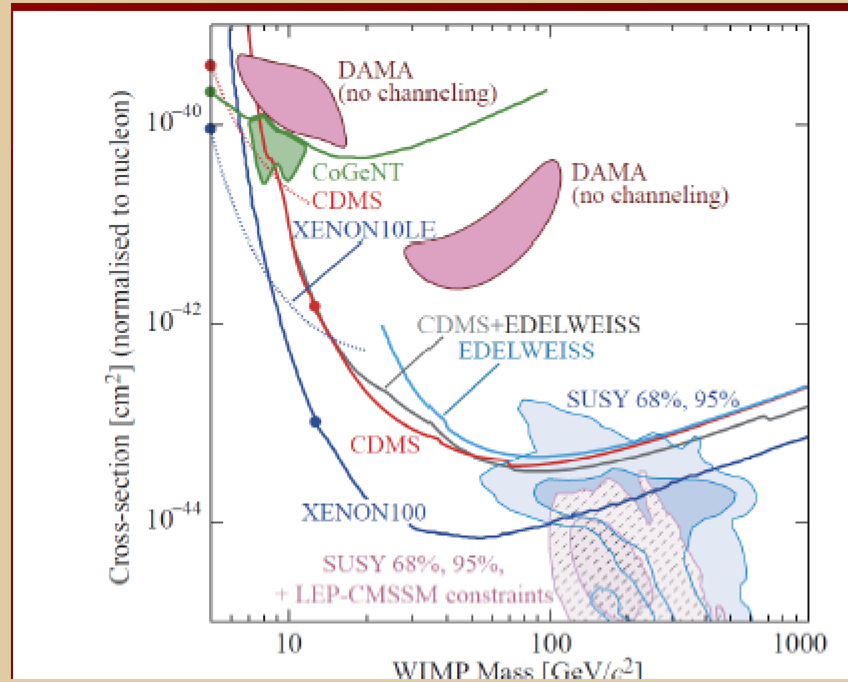
Pulsar profile peaks at
 ~3 Kpc, providing
local DM density ~8 Kpc of
$\rho_{DM,0}\approx 0.3$ GeV/c^2

A number of DM profiles exist in the literature with enhancement at the *galactic* center.

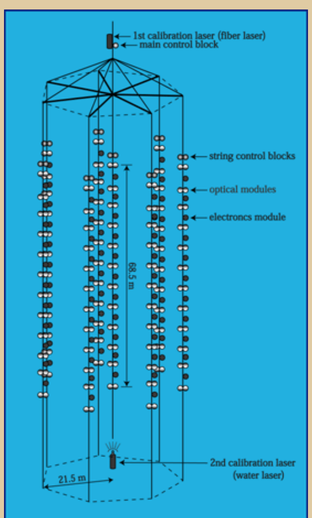
X-matter accretion

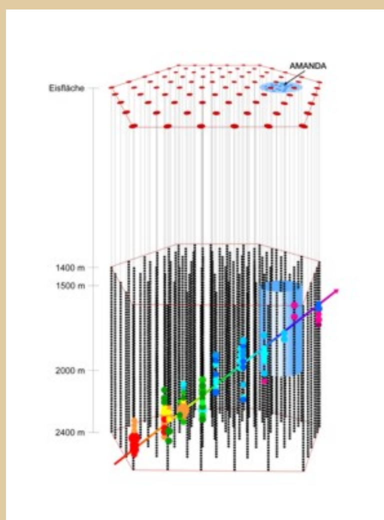
Currently a number of direct and indirect detection experiments looking for DM.

The efficiency of NS to capture DM is much larger than for the sun, experiments Baikal, IceCube look for ν production.



Drees et al, arxiv: 1204.2373





Direct detection (DAMA/LIBRA, COGENT, etc) m_X ~ 4-12 GeV/c^2

Indirect detection (interpretation of Fermi results): m_X ~ 130 GeV/c^2

X as Majorana particles

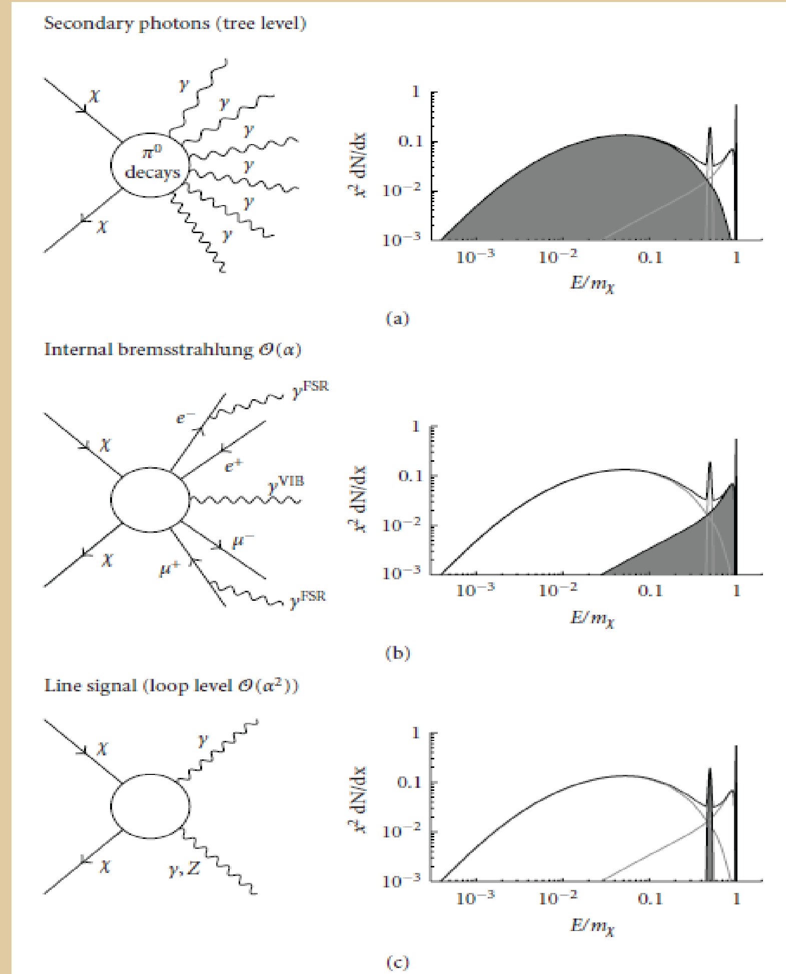
The energy deposition due to self-annihilation will depend on the allowed channels

Capture rate vs. processes removing DM: annihilation, evaporation, decay..

$$\dot{N}(t) = F - \Gamma_{annih} - \Gamma_{evap} - \Gamma_{decay}$$
$$\Gamma_{annih} = C_A N^2(t)$$
$$\Gamma_{evap} \approx e^{-GMm_X / RT}$$
$$\Gamma_{decay} = C_D N(t)$$

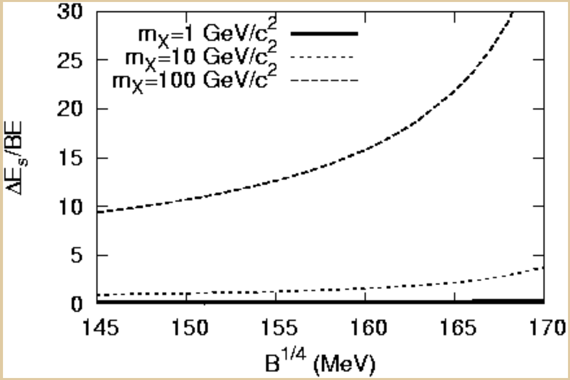
$$F = \frac{3.042 \quad 10^{25}}{m_X(GeV)} \rho_{DM} \Big/ \rho_{DM,0} \quad (s^{-1})$$

Capture rate for a typical NS at solar circle , Goldman & Nussinov 1989



Kuhlen 2010

NS transition to QS (HQS)



$$\dot{E} = f\,F\,\tau\,m_X c^2$$

$$f \approx 0.01-1$$

$$m_X \geq \frac{E_{slet}(\mu_i, m_i, A, B)}{2f}$$

Perez-Garcia, arXiv: 1205.2581

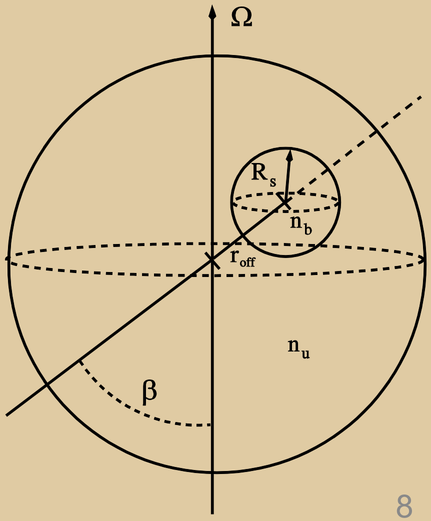
Perez-Garcia, Silk, Stone PRL 105, 141101 (2010)

Multi-spot spark coalescence is energetically allowed.

May cause off-center asymmetric burning front: Olinto, Horvath, Benvenuto 1988, Lugones et al 2002, Bombaci 2004, Drago et al 2004, Quark nova model by Ouyed et al

Quark deconfinement related to binding energy of the finite A-lump

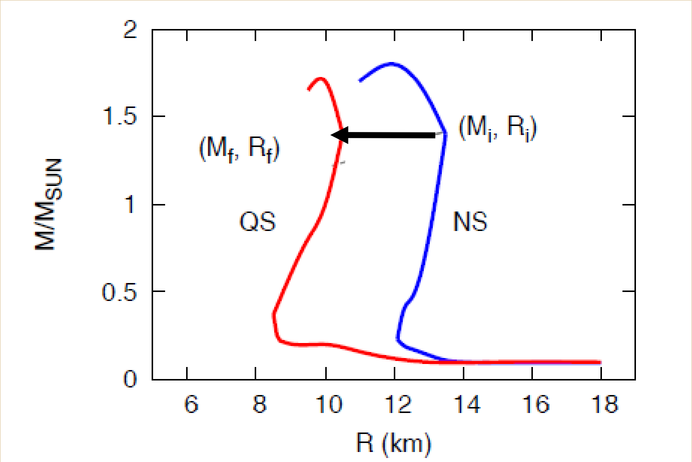
Side effect NS->QS: large recoiling



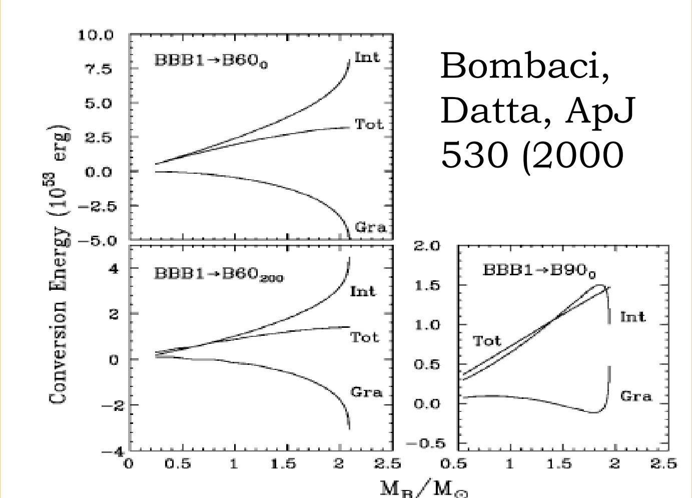
Perez-Garcia, Silk, PLB 711, 6 (2012)

$$\alpha = \frac{r_{off}}{R} \approx 10^{-2}$$

NS to QS: Short GRB emission expected



$$\Delta E \approx G M_{NS}^{2} \left(\frac{1}{R_{QS}} - \frac{1}{R_{NS}} \right) \approx 10^{53} \quad erg$$



- Quark deconfinement would vary the EOS (becoming softer) and releasing part of the gravitational/internal energy.
- Two configurations very similar in Mass (Bombaci et al 2000)
- A fraction of this energy is expected to be emitted producing an (ultra) short GRB (, t<0.1 s.
- This is different progenitor from usual NS+NS , NS+BH merger.

NS to HQS: Conversion energetics

Quark deconfinement would create a burning front, able to proceed in ms ($T_{90} < 2$ s).

Other duration depending on the burning ability to proceed.

Energy emitted will depend on the massive progenitor:

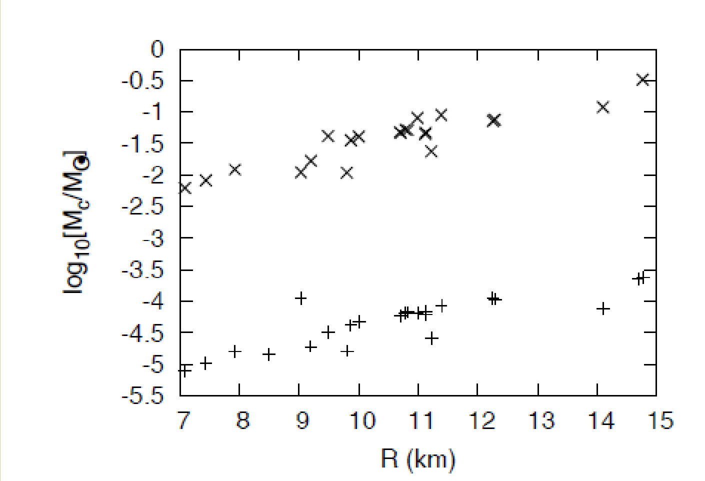
- beaming factor
- kinetic energy ejection factor
- gamma-ray energy production efficiency
- fraction of grav energy emitted in the relativistic ejecta

$$E_{\gamma,\mathrm{iso}} \simeq 3.5 \times 10^{52} \left(\frac{f_\mathrm{b}}{100}\right)\left(\frac{f_\gamma}{0.1}\right)\left(\frac{f_\mathrm{ej}}{0.01}\right)\left(\frac{R_{NS}}{12\,\mathrm{km}}\right)^{-1}\left(\frac{M}{1.5\,M_\odot}\right)^{2} \mathrm{erg}\,,$$

NS to HQS: Lorentz factors & duration

- Crust is typically below few % and signals the solid-liquid inter-phase at $n_0 \approx 10^{14}$ g/cc

- At lower densities , neutrons drip from nuclei, at about 10^{11} g/cc and this outer crust is a 1/100 of the whole crust.

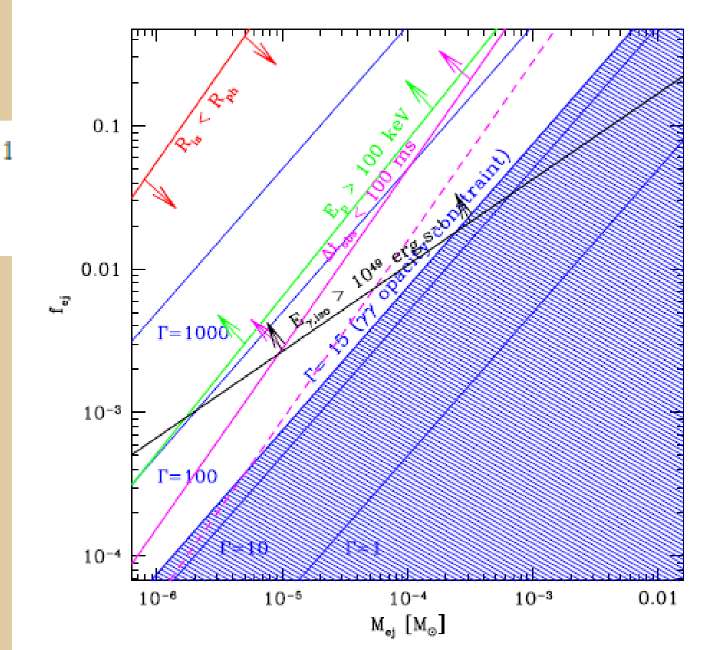


- Lorentz factors:

$$\Gamma_{\rm max} = \frac{E_{\rm kin}}{M_{\rm ej}c^2} \simeq 19 \left(\frac{f_{\rm ej}}{10^{-3}}\right)\left(\frac{R_{NS}}{12\,{\rm km}}\right)^{-1}\left(\frac{M}{1.5\,M_\odot}\right)^{2}\left(\frac{M_{\rm ej}}{10^{-5}\,M_\odot}\right)^{-1}$$

- Duration:

$$\Delta t_{\rm obs} \simeq \min\left(\frac{R_{\rm ph}}{2\Gamma^2 c}; \frac{\theta_{\rm j}^2 R_{\rm ph}}{2c}\right) \simeq \min\left(M_{\rm ej,-5}^2 f_{\rm ej,-3}^{-2}; \left(\frac{\theta_{\rm j}}{3^\circ}\right)^2\right) \times 0.8\, M_{\rm ej,-5}^{1/2}\,{\rm s}$$

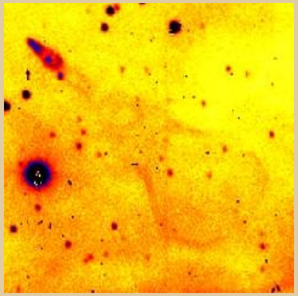


Perez-Garcia, Daigne, Silk, arXiv:1211.7018
Perez-Garcia, Daigne, Silk, submitted (2012)

Rate: NS to QS (HQS)

The rate would be small as it corresponds to a large delay between the end of the life of massive progenitor and emission of SGRB.

Transition would take place typically far from the center in a galaxy host, since NS natal kick and long lives



Guitar nebula, B2224+65

Time delays would have lower and upper limits based on DM steady accretion

$$\mathcal{R}_{\rm SGRB}/\mathcal{R}^{\rm (SNII)}_{\rm NS\to QS,max} \simeq \left(8\times10^{-4} \to 3\times10^{-3}\right)\left(\frac{\langle f_{\rm b}\rangle}{50}\right)$$

Perez-Garcia, Daigne, Silk, submitted (2012)

Conclusions

- We discussed the possibility that NS to QS transition driven by DM is a central engine for SGRBs with $\Delta t < 0.1$ s

- In this mechanism for SGRBs energies of 10^{48}-10^{52} erg can be injected, in agreement with observations

- High Lorentz factors attainable $\Gamma > 20$, if outer crust is ejected, $M < 10^{-4}$ solar masses.

- Natural short or large time delays arise in the model due to DM ingredient. Kicks allow NS transition in an off-center galaxy location and all types of galaxies.

- Weak afterglow is expected due to low external density

- A short (t<100 ms) hard signal $E_{peak} > 100$ KeV is expected.

mperezga@usal.es

New opportunities for:

Cooperation between:

University of Salamanca, Spain

Academic institutions in Brazil (especially Sao Paulo)

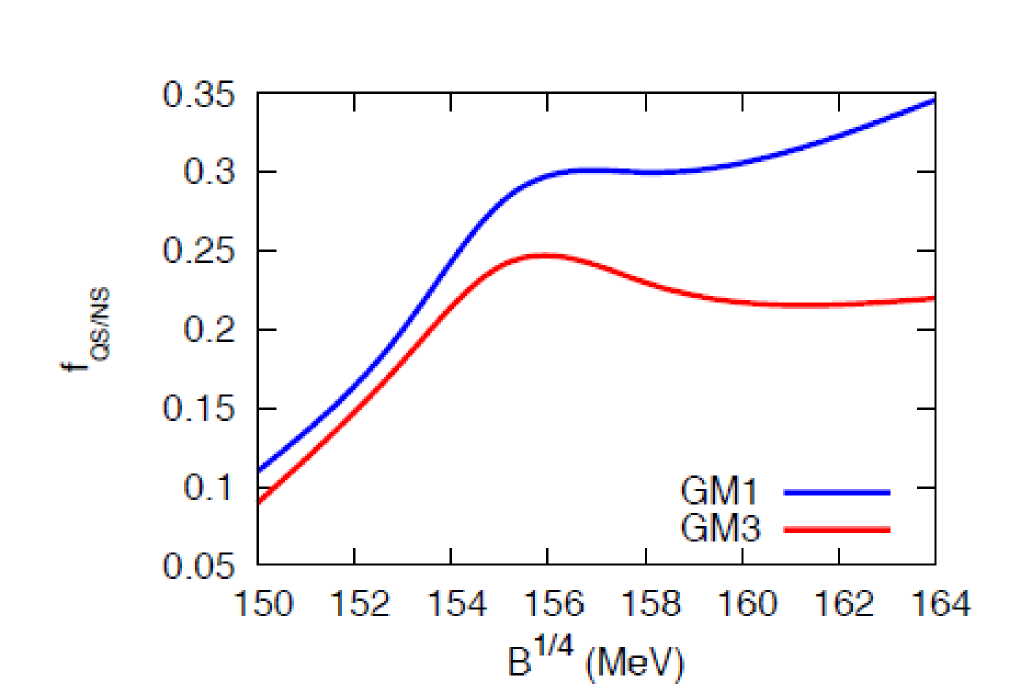
See more at Centro de Estudios Brasileños site: **http://www.cebusal.es/**

Offers research activities and cooperation for student exchange, postdocs, academic faculty, master and doctorate programs, meetings and advanced courses. mperezga@usal.es

Efficiency NS to QS (HQS)

It is expected a lower energy emitted, compared to LGRBs, with an efficiency factor

$$f_{\mathrm{QS/NS}} \approx |\Delta E_{\mathrm{grav,NS}\to\mathrm{QS}}/E_{\mathrm{grav,proj}\to\mathrm{NS}}| \approx \left| \left(\frac{M_{\mathrm{QS}}}{M_{\mathrm{NS}}}\right)^2 \left(\frac{R_{\mathrm{NS}}}{R_{\mathrm{QS}}}\right) - 1 \right|$$



Perez-Garcia, Daigne, Silk, submitted (2012)

Burning times

Olessen and Madsen, NPB (Proc. Suppl.) 24B (1991) 170-174 North-Holland

$B^{1/4}$/MeV	T/MeV	t_{burn}/sec $1.0M_\odot$	t_{burn}/sec $1.4M_\odot$
150	01	0.20$^+$	0.15$^+$
	05	0.89$^+$	0.65$^+$
	10	0.19$^+$	0.85$^+$
	20	0.06$^+$	0.05$^+$
155	01	2.1	1.7
	05	10.	8.4
	10	17.	14.
	20	11.$^+$	8.0
160	01	4.7	3.6
	05	23.	17.
	10	41.	32.
	20	56.	43.
165	01	12.	7.7
	05	55.	37.
	10	94.	63.
	20	117.	83.
170	01	23. (90)	7.4 (90)
	05	115. (91)	37. (91)
	10	206. (93)	64. (89)
	20	317. (98)	90. (88)
180	01	0. (00)	15. (50)
	05	0. (00)	70. (50)
	10	0. (00)	120. (44)
	20	1302. (61)	162. (49)