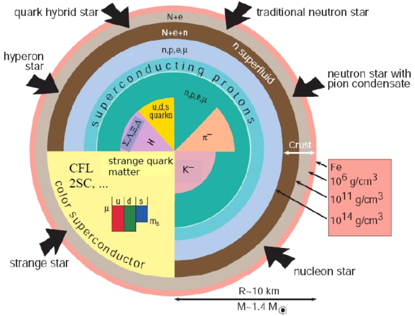
Two branches of neutron stars: reconciling massive pulsars and SN 1987A

collaboration with

P. Haensel & J.L. Zdunik (CAMK, Warsaw)



Brown-Bethe hypothesis for SN1987A

Bethe & Brown 1994, 1995

Explain the observable amount of $\sim 0.075 M_{\odot}$ of radioactive ^{56}Ni AND in the same time lack of a pulsar in the SN remnant

Solution (?)

- Kaon condensation: dense matter EOS becomes soft $\longrightarrow$ stars' maximum mass $M_{max} \sim 1.5 M_{\odot}$
- Fallback, delayed collapse to black hole: enough time to eject the radioactive material

Two birth scenarios: "cold" vs "hot"

Cold scenario

No exotic phase is produced (star too cold/not sufficiently dense)

$\Downarrow$

accretion of matter

$\Downarrow$

Production of PSR J0751+1807 (Nice et al. 2005)

$$2.1 \pm 0.2 M_\odot$$

Hot scenario

Exotic phase appears

$\Downarrow$

EOS softens, small M_{max}

$\Downarrow$

Star may collapse to a black hole (SN1987A?)

But...

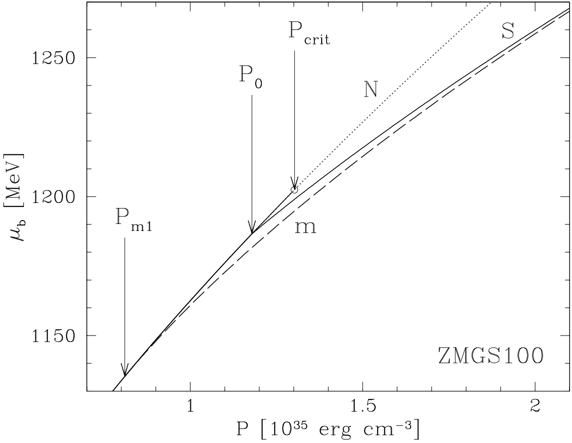
what exotic phase? Kaons, quarks?

First order phase transition to kaon condensate

Example EOS:

phase N: Zimanyi & Moszkowski (1990)
phase S: Glendenning & Schaffner-Bielich (1999) with $U_K^{lin} = -100\text{MeV}$

- P_{m1}: onset of the mixed phase
- P_0: equilibrium pressure of pure phases
- P_{crit}: pressure at which kaons spontaneously appear
- chemical potential $\mu_b = (\mathcal{E} + P)/n_b$



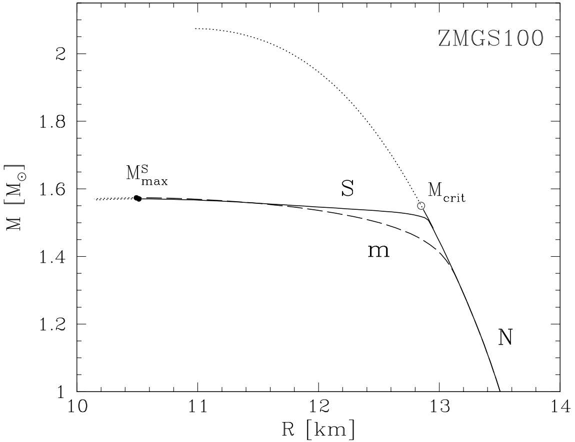
Stars with kaon-condensed cores: M(R) relation

TOV solutions

- Maximum masses M^S_{max} for mixed and pure phases EOSs almost identical
- $M^S_{max} \simeq M_{crit}$
- Cannot go above M_{crit}!

:-(

Unfortunately, maximum mass M^S_{max} or M_{crit} too low to explain observations of $\sim 2M_\odot$ pulsars...



Quark de-confinement: *ud* matter

Low-temperature regime:

$T < 1MeV$: transition to *ud* (then to *uds* matter), lepton fraction as in $\beta-$equilibrated N phase

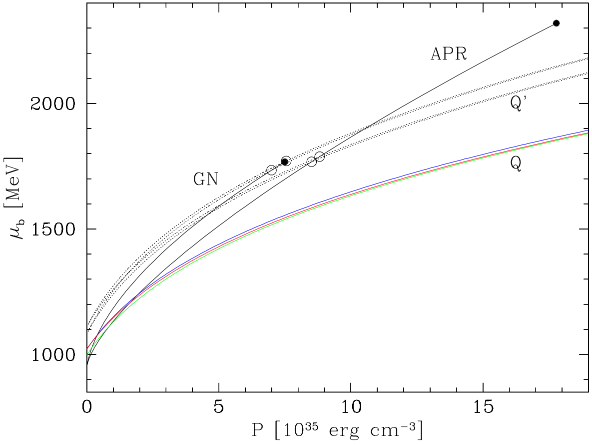
Example EOSs:

- APR (Akmal, Pandharipande & Ravenhall 1998)
- GN (Glendenning 1985)

$+$

MIT Bag model:
$B = 90,\ 100 MeV/fm^3$,
$m_s = 150,\ 200 MeV$, $\alpha_s = 0.2$

- Q': non-strange *ud* quark matter
- Q: strange *uds* quark matter



Quark de-confinement: *uds* matter

High-temperature regime:

For $T \simeq 50 MeV$ *uds* matter created at lower P, thermal fluctuations & existence of strange particles (hyperons)

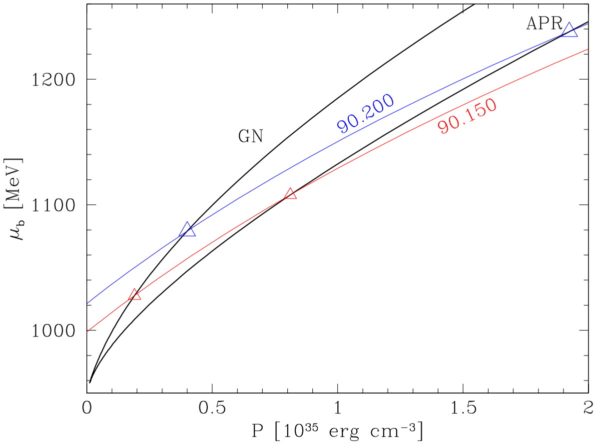
Example EOSs:

- APR (Akmal, Pandharipande & Ravenhall 1998)
- GN (Glendenning 1985)

+

MIT Bag model:
$B = 90,\ 100 MeV/fm^3$,
$m_s = 150,\ 200 MeV$, $\alpha_s = 0.2$

Shown here: the dependence on the quark mass m_s

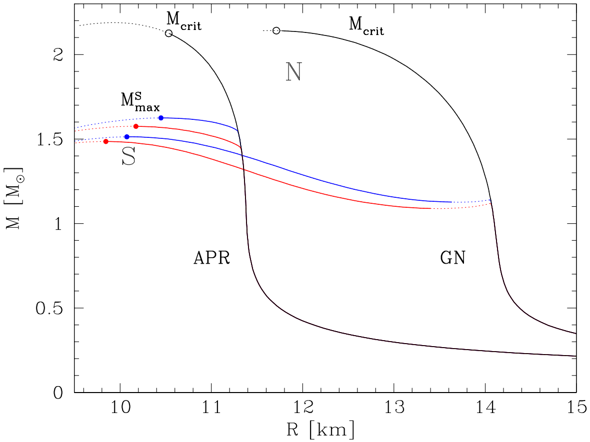


Stars with quark cores: M(R) relation

:-)

- **"Hot branch"** Q, with $M_{max} \sim 1.5 M_{\odot}$
- **"Cold branch"** Q' which appear near the maximum mass, above $2M_{\odot}$
- They are no "twin" stars, but rather "different-M_{max} siblings"

model	$M^{S}_{\rm max}$	$M_{\rm crit}$
APR.100.150	1.57	2.13
APR.90.200	1.62	2.13
GN.100.150	1.48	2.145
GN.90.200	1.51	2.14



Summary

More than one EOS of dense matter?

- Massive pulsars were born without exotic cores and acquired the mass later, by accretion
- SN1987A produced proto-neutron star with exotic core that subsequently collapsed into a black hole
- The original Brown-Bethe hypothesis fails for a kaon condensate EOS, but works well with quark de-confinement

Ockham wielding razor