Gamma-Ray Bursts

Magnetars

UHECR/UHEV/GW

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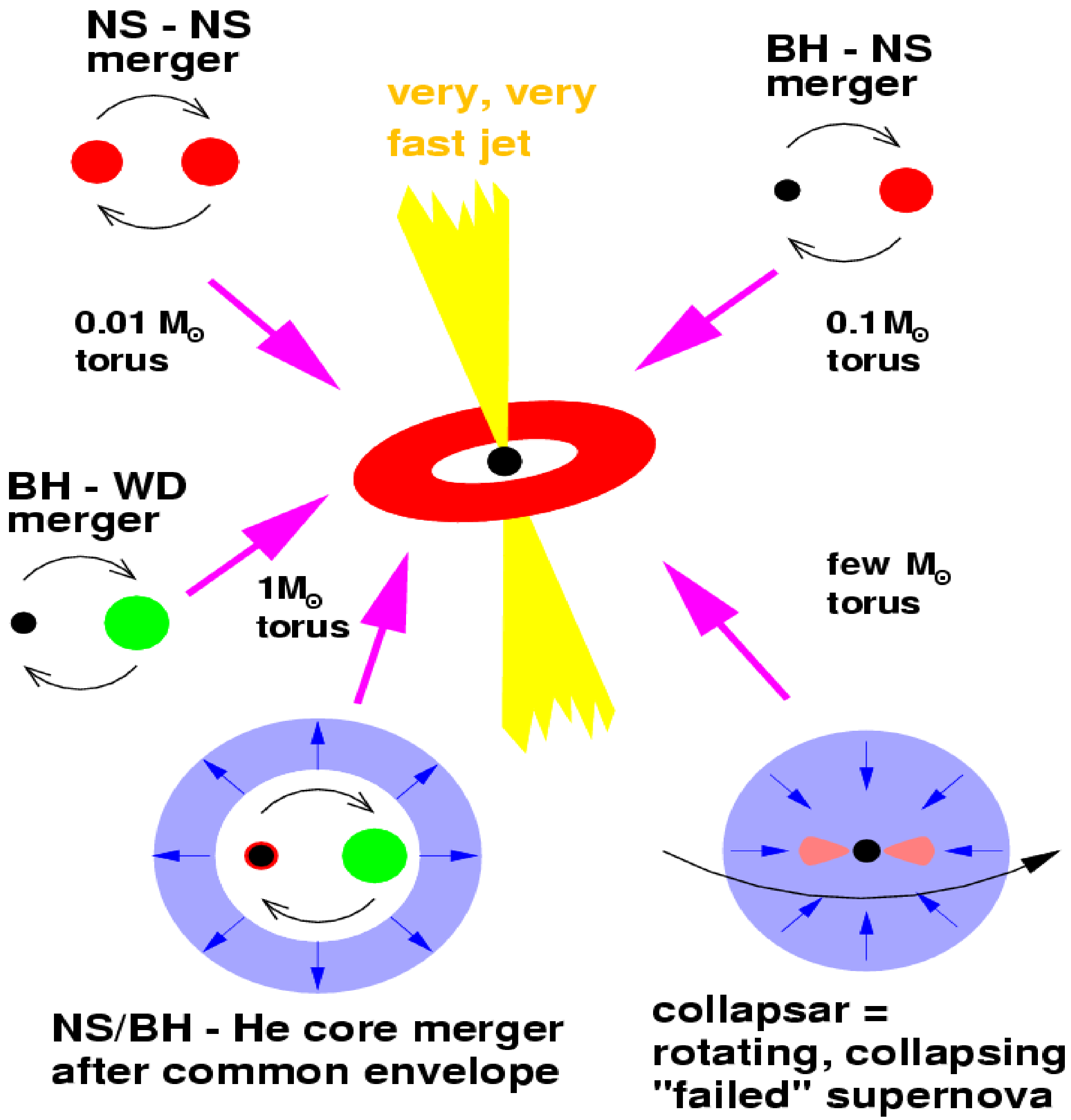
GRB:→ Hyperaccreting Black Holes (*via PNS?*)



NS - NS merger

very, very fast jet

BH - NS merger

short

0.01 $M_\odot$ torus

0.1 $M_\odot$ torus

BH - WD merger

$1M_\odot$ torus

few $M_\odot$ torus

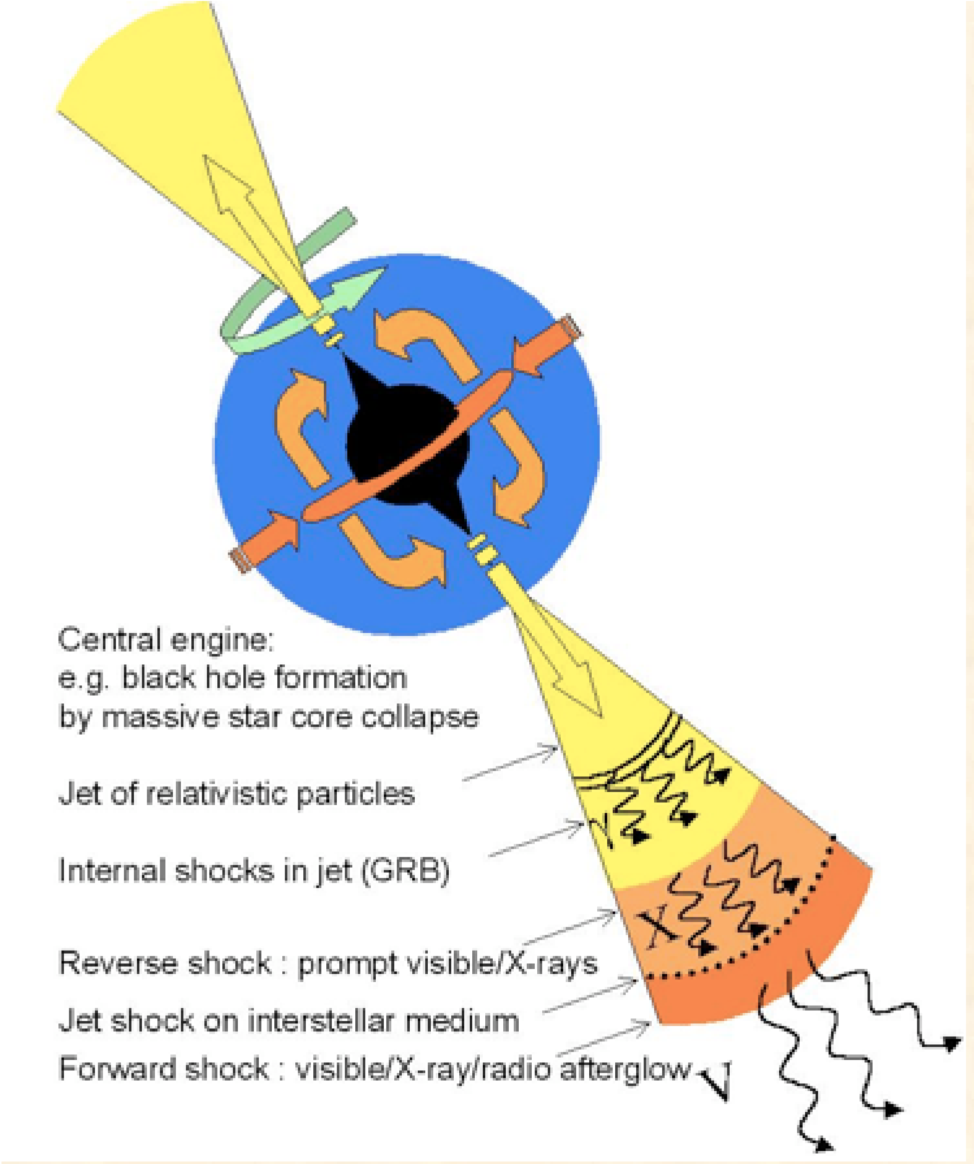
long

NS/BH - He core merger after common envelope

collapsar = rotating, collapsing "failed" supernova

M. Ruffert, H.-Th. Janka, 1998

GRB paradigm



Central engine:
e.g. black hole formation
by massive star core collapse

Jet of relativistic particles

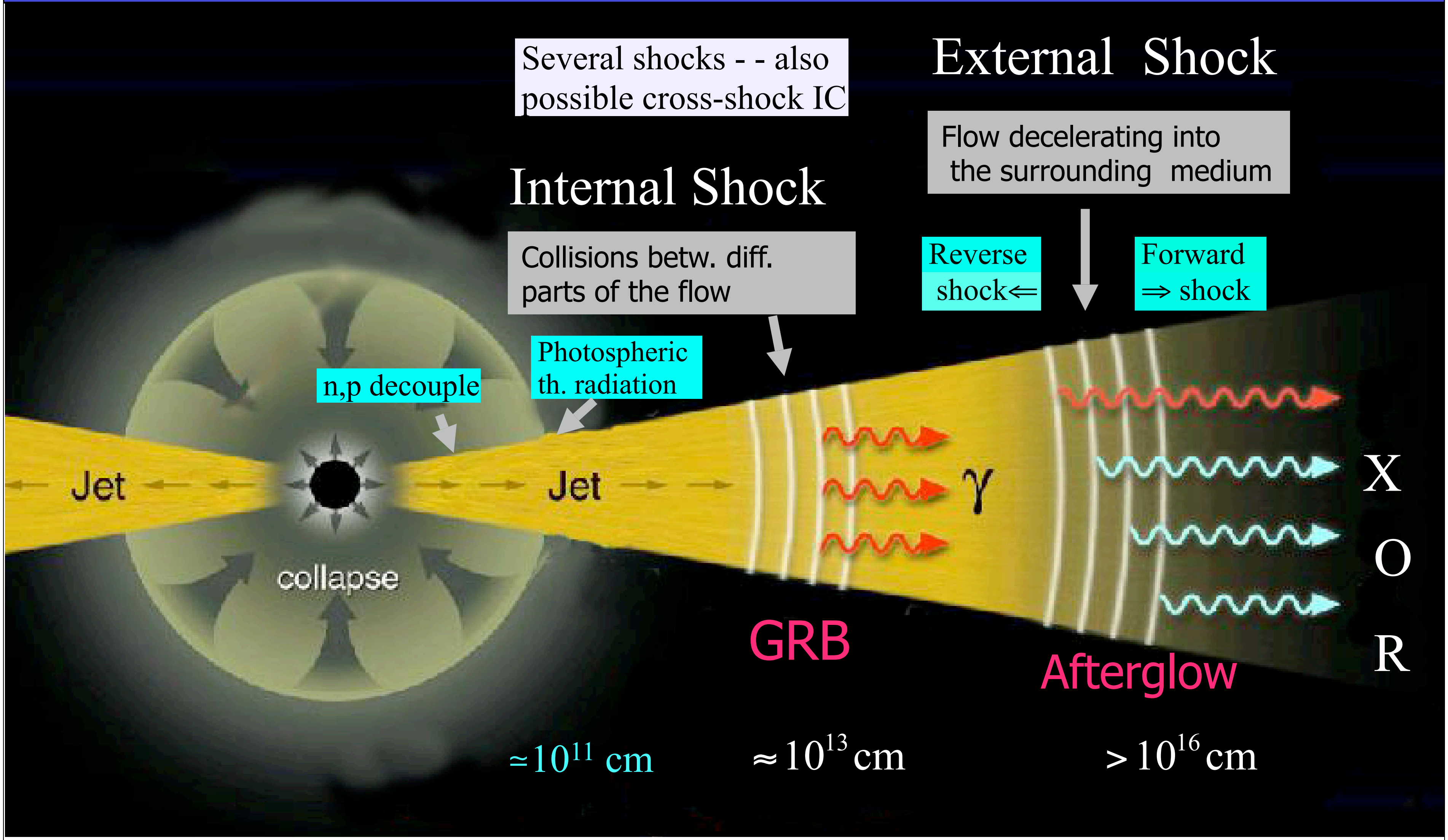
Internal shocks in jet (GRB)

Reverse shock : prompt visible/X-rays

Jet shock on interstellar medium

Forward shock : visible/X-ray/radio afterglow

Fireball Model of GRBs



Several shocks - - also
possible cross-shock IC

External Shock

Flow decelerating into
the surrounding medium

Internal Shock

Collisions betw. diff.
parts of the flow

Reverse
shock⇐

Forward
⇒ shock

Photospheric
th. radiation

n,p decouple

GRB

Afterglow

X
O
R

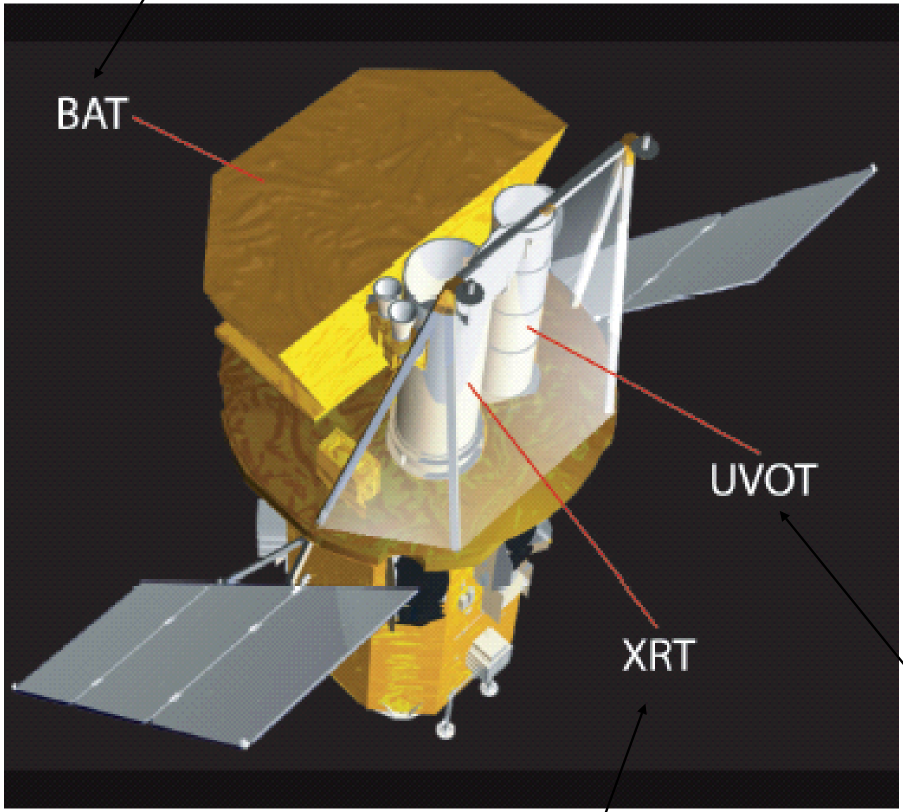
$\simeq 10^{11}$ cm

$\approx 10^{13}$ cm

$> 10^{16}$ cm

BAT: Energy Range: 15-150kev
FoV: 2.0 sr
Burst Detection Rate: 100 bursts/yr

SWIFT



Three instruments

Gamma-ray, X-ray and optical/UV

Slew time: 20-70 s !

>95% of triggers yield XRT det
>50% triggers yield UVOT det.

UVOT: Wavelength Range: 170-650nm

XRT: Energy Range: 0.2-10 keV

Launched Nov 04

Mission Operations Center: @ PSU
(Bristol Res. Park)

Mészáros, L'Aqu05

Simple astrophysical GRB GW model:

either bin.merger or collapsar:
⇒ as if blobs orbiting

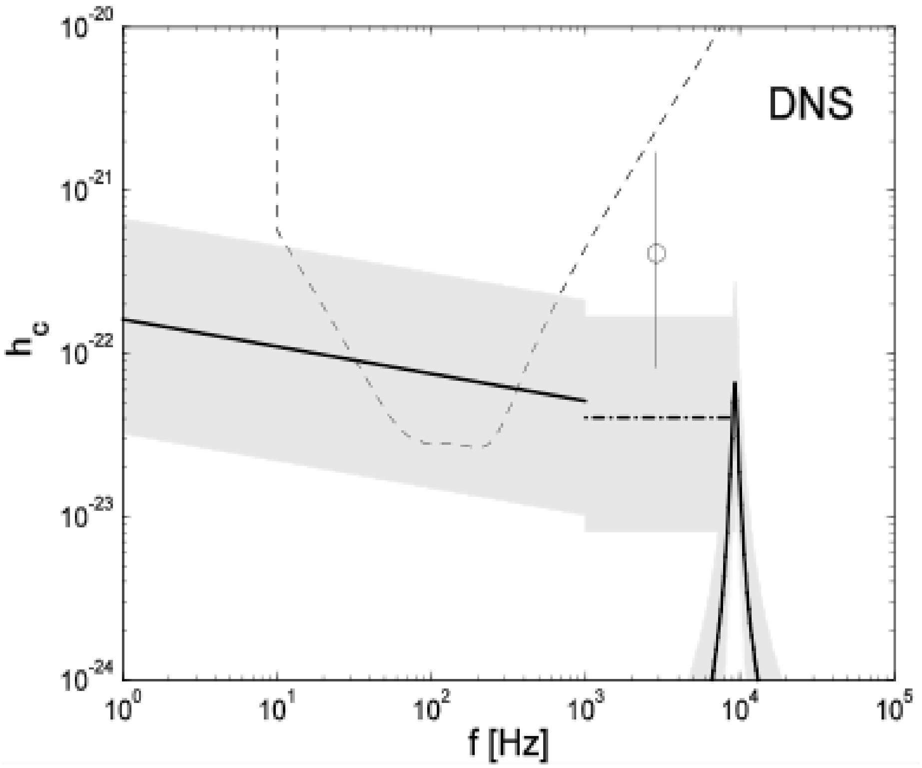
(fast rot. → instab. → blobs → merge ;

or: double NS, NS/BH: blobs → merge)

3 Usual Phases of Rotating Collapse

- In-spiral (binaries, or core blobs)
- Merger - central condensation + disk, subject to instabilities (again blobs?)
- Ring-down

GRB Progenitor GW Signals: DNS



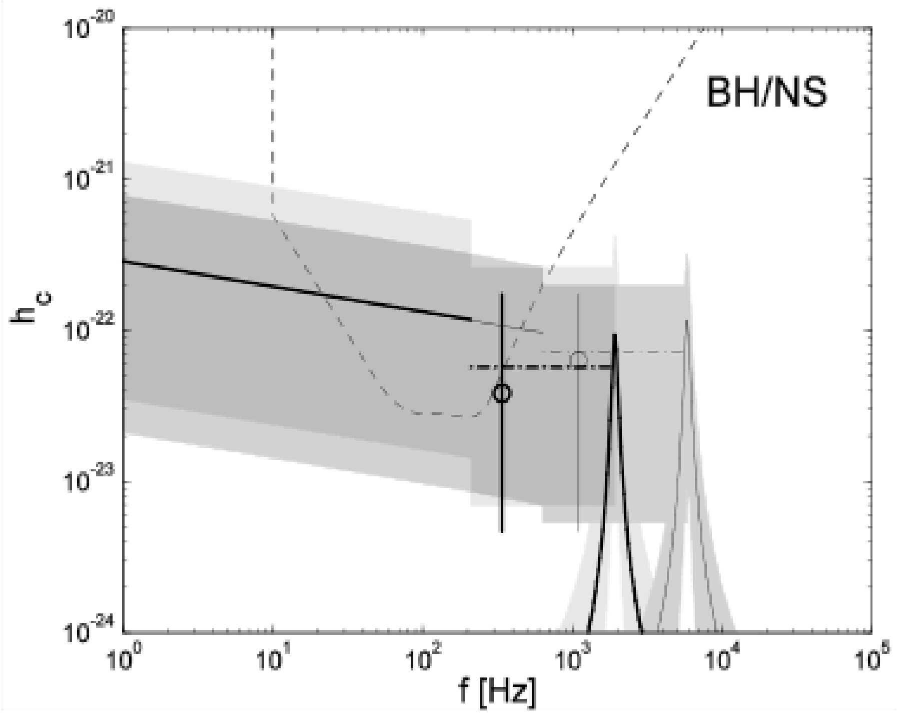
Dashed: LIGO II sensitivity

Double neutron star

Charact. Strain h_c
D (avg) =220 Mpc,
$m_1=m_2=1.4\ M_\odot$
$a=0.98$, $e_m=0.05$,
$m=m'=2.8\ M_\odot$, $N=10$,
$e_r=0.01$

Solid: inspiral; Dot-dash: merger;
Circle (bar inst); Spike: ring-down);
Shaded region: rate/distance uncertainty

GRB Progenitor GW Signals: **BHNS**

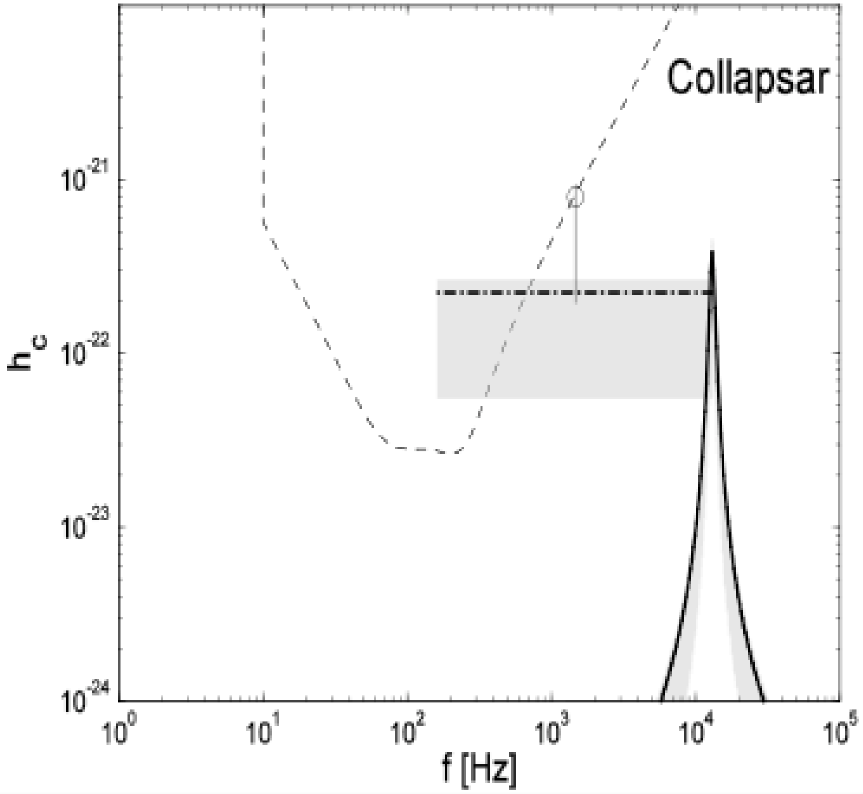


Solid: inspiral; Dot-dash: merger;
circle (bar inst); spike: ring-down);
shaded region: rate/dist uncertainty
Dashed: LIGO II noise $[f\ S_h(f)]^{1/2}$

Black hole-neutron star

thin: =170Mpc,
m_1=3.0 $M_\odot$, m_2=1.4 $M_\odot$,
m=0.5 $M_\odot$, m'=4 $M_\odot$
thick: d=280Mpc,
m_1=12 $M_\odot$, m_2=1.4 $M_\odot$
m=0.5 $M_\odot$, m'=13 $M_\odot$;
Both: a=0.98, e_m=0.05,
N=10, e_r =0.01

GRB Progenitor GW Signals: Collapsar



Collapsar w. core breakup, bar inst.

(optimistic numbers!)

d=270 Mpc,
$m_1=m_2=1\ M_\odot$, a=0.98,
e_m =0.05,
merge at r=10^7 cm;
m=1 $M_\odot$, m'= 3 $M_\odot$,
N=10, e_r =0.01

Dashed: LIGO II noise $[f\ S_h(f)]^{1/2}$

Kobayashi & Mészáros 02, ApJ 589, 861

Solid: inspiral; dot-dash: merger;
circle :bar inst; spike: ring-down);
shaded : rate/dist uncertainty

What is a Magnetar ?

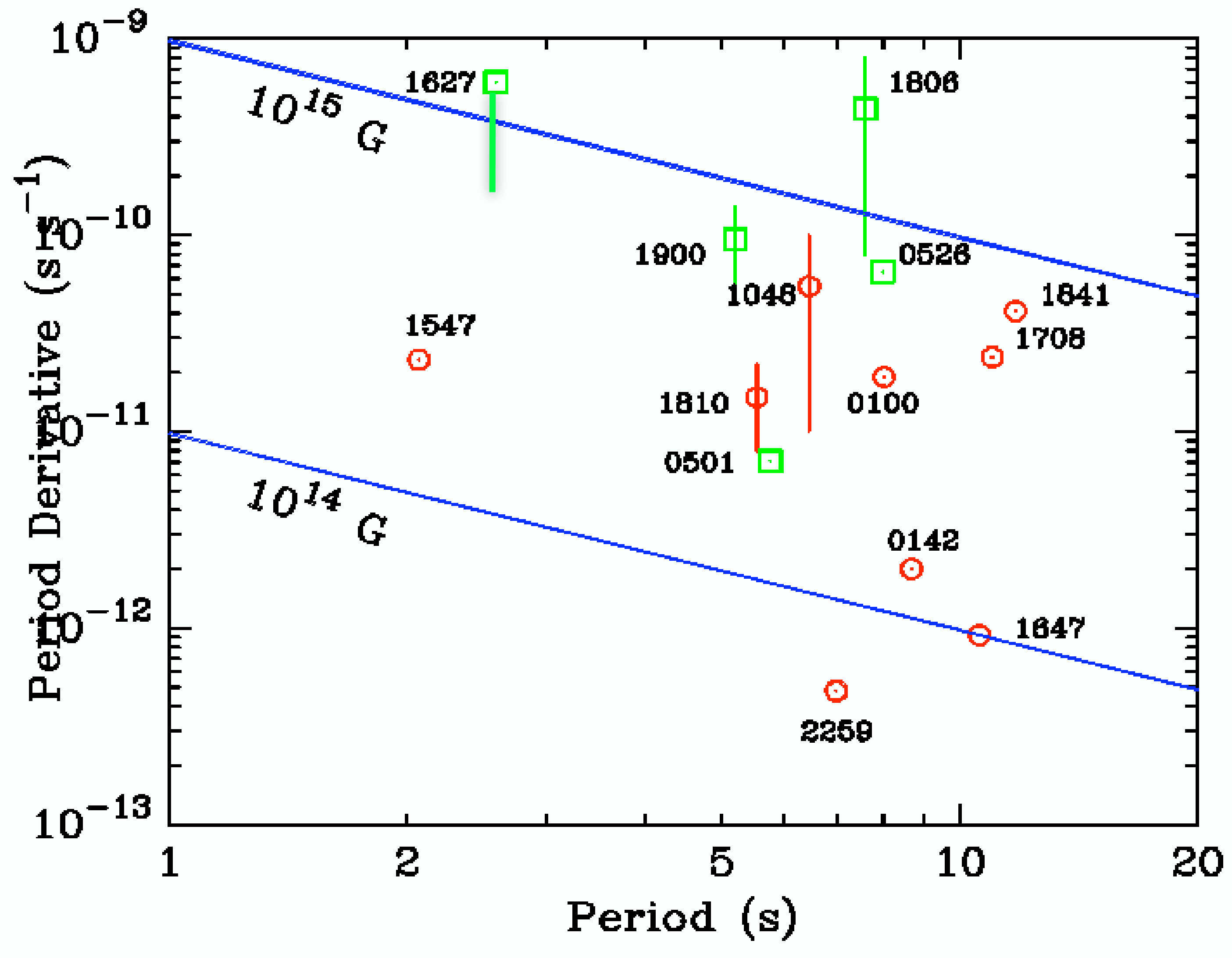
Isolated neutron stars where the main source of energy is the magnetic field

[most observed NS have $B = 10^9 - 10^{12}$ G and are powered by accretion, rotational energy, residual internal heat]

In Magnetars external field: $B = 10^{14} - 10^{15}$ G
internal field: $B > 10^{15}$ G

See review: Mereghetti 2008, A&A Rev. 15, 225
[arXiv:0804.0250]

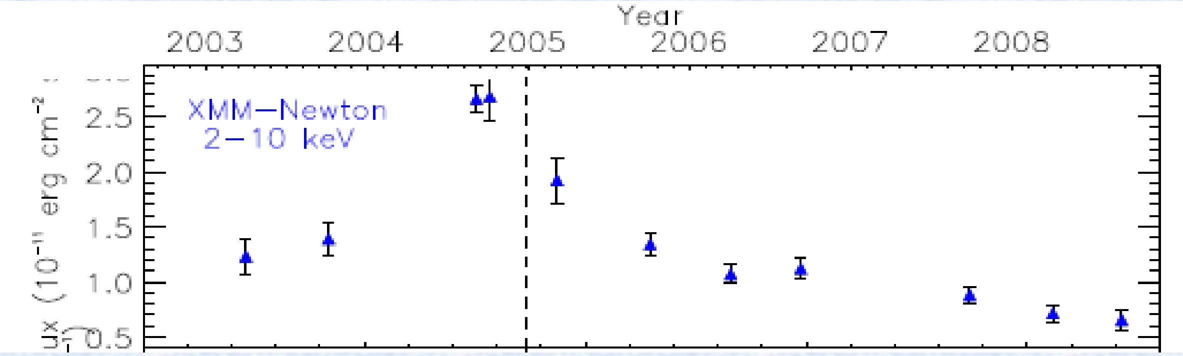
Period – Period derivative plot for Magnetars
(Anomalous X-ray Pulsars and Soft Gamma-ray Repeaters)



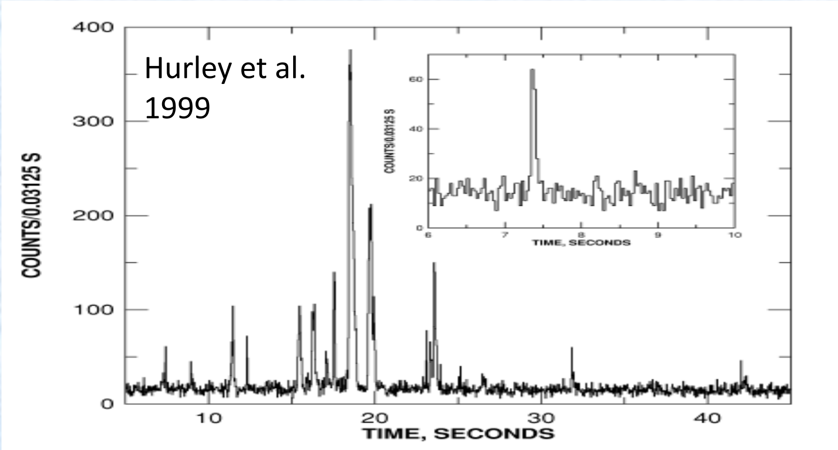
NOTE : vertical bars indicate Pdot variability range

Magnetars emit:

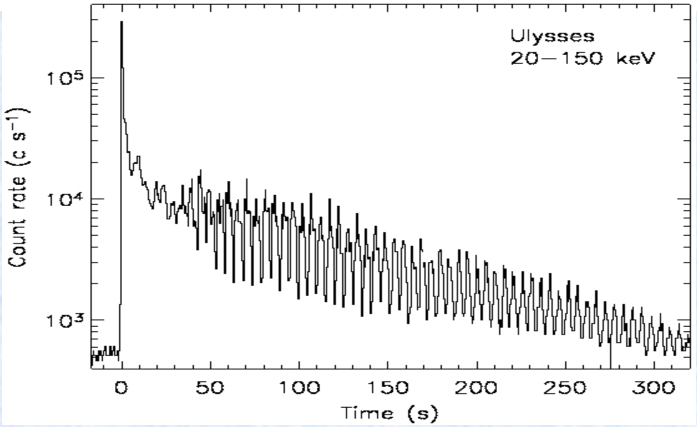
- "Persistent" X-rays
  - Lx~$10^{35\text{-}36}$ erg/s
  - ~1-200 keV
  - pulsed at few seconds,
  - spin-down



- short bursts of soft gamma-rays
  - Lx ~$10^{39\text{-}42}$ erg/s
  - kT~30-40 keV
  - durations ~0.1-1 sec


Hurley et al. 1999

- Giant Flares
  - Lx > 10^{44} erg/s
  - very rare events (only three observed)

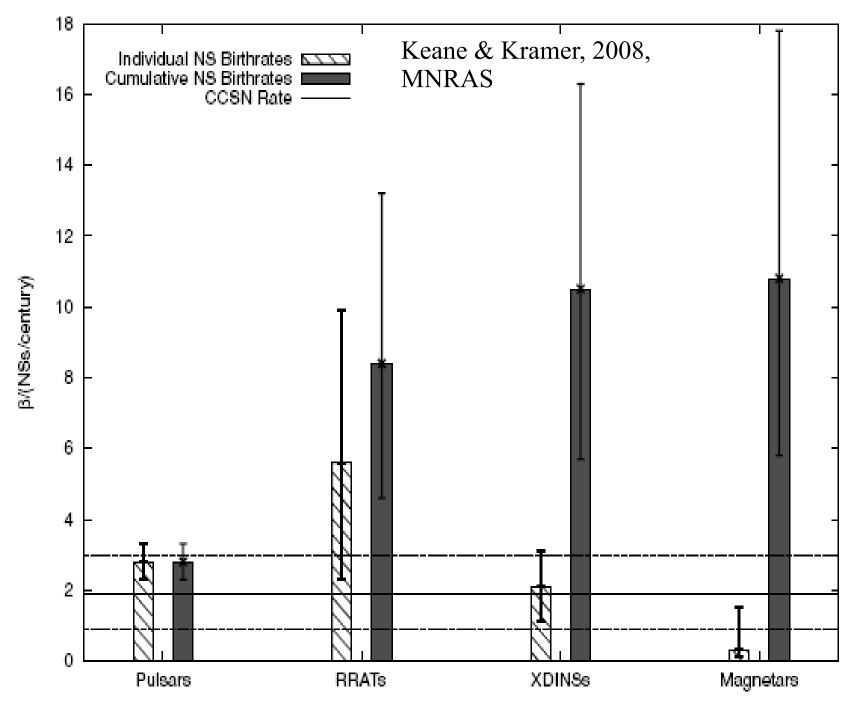


Magnetars birthrate

~ a few every 10^4 years

large uncertainties:

- small statistics (~10 persistent sources)
- uncertain lifetimes (~10^4 yrs ?),
- number and duty cycle of transient magnetars



Keane & Kramer, 2008, MNRAS

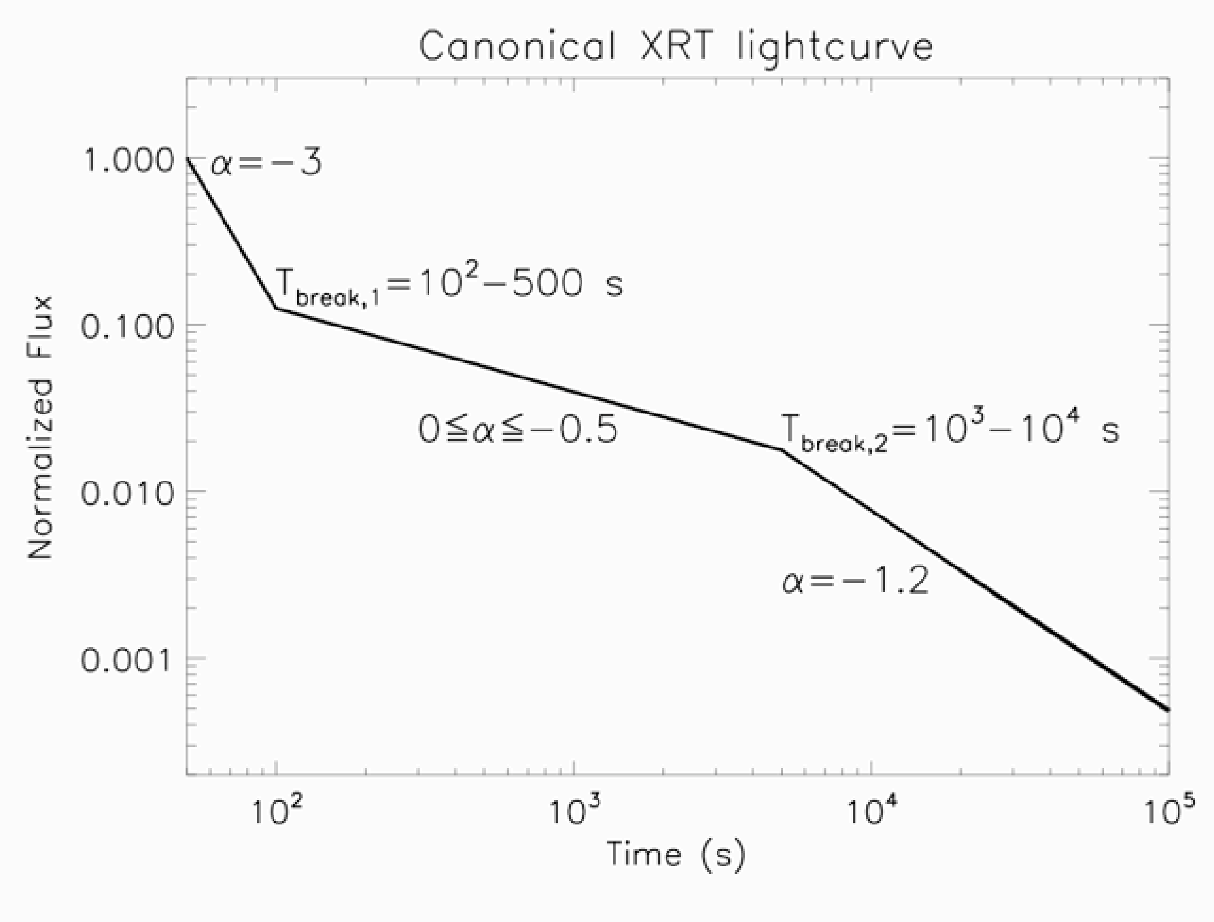
Birthrate of radio PSR and core collapse SN (1-3 / century) already in reasonable agreement → no much room for other populations of NS

Magnetars ~ 0.1-0.3 / century i.e. up to ~10% of radio PSRs

See also:
Gill & Heyl 2007, MNRAS 381,52 (~0.22 / century + transients)
Muno et al. 2008, ApJ 680, 639 (~0.3 – 6 / century)

Swift Era canonical X-ray afterglow plateau:

A temporary magnetar phase in GRB ?



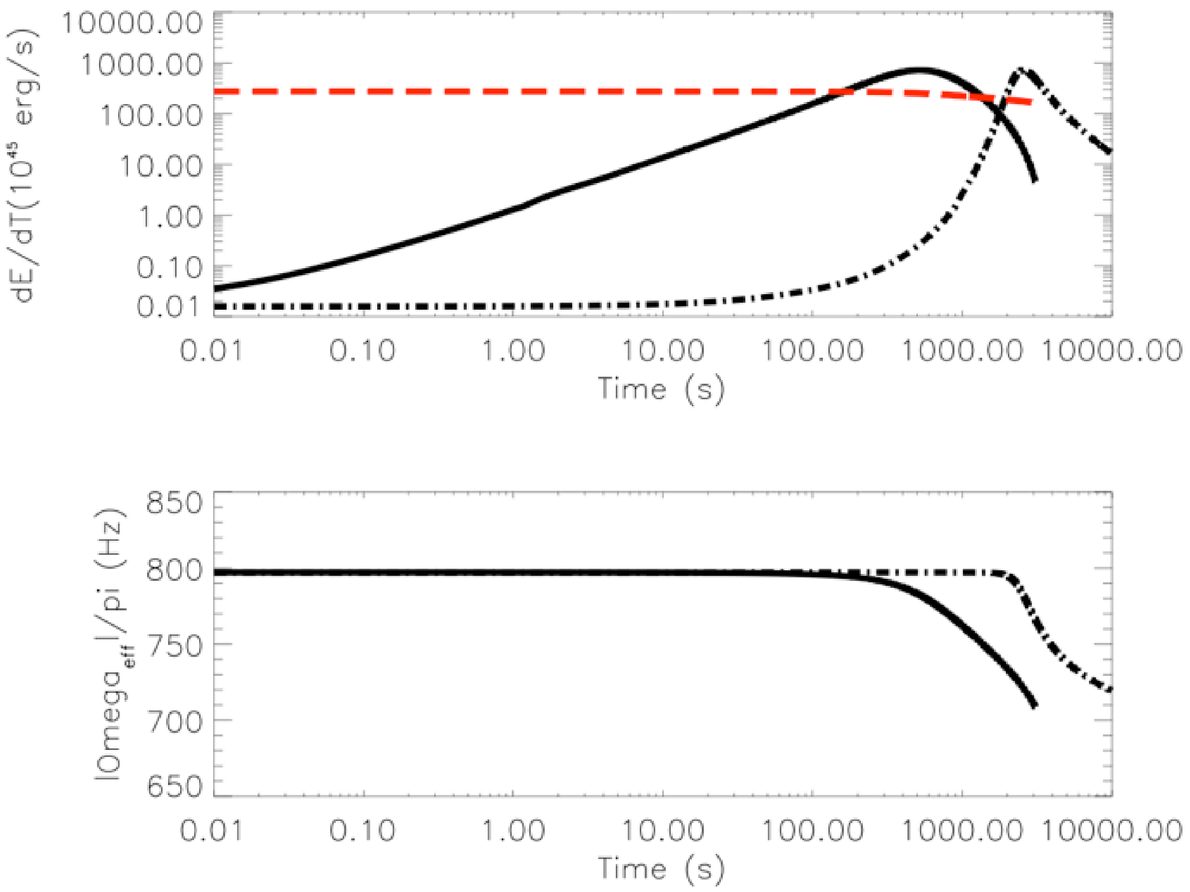
- It is one of the explanations for Swift X-ray plateaus (→energy injection)
- If so, magnetar must be fast rotating (collapsar paradigm)
- Fast rotation
  → bar instability?
- If so → GW emiss.

A. Corsi & P. Meszaros 09

GW + EM dipole losses

Bar instability → rotating ellipsoid

GW: with pattern Ω - EM: from frozen-in surface field

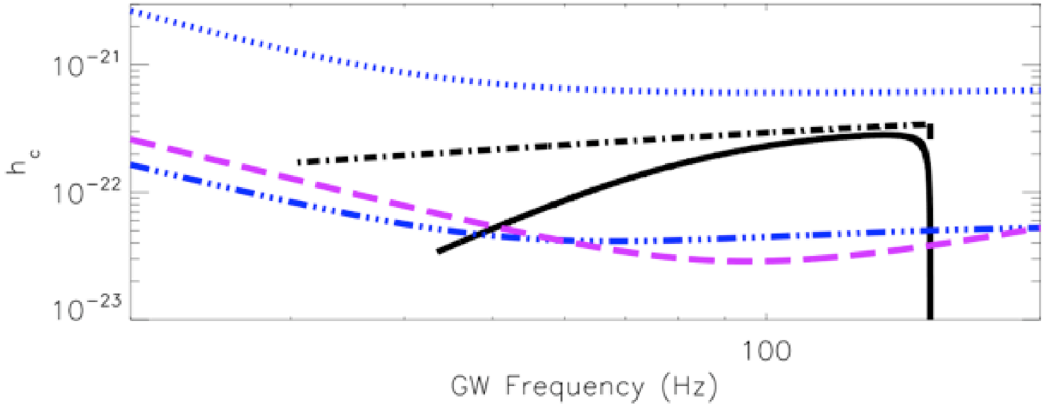


- Upper:
- Red: EM dipole energy losses ;
- Dot-dash: GW losses without EM loss term
- Solid black: GW losses with EM loss term
- Lower:
- Surface fluid effective angular velocity Ω_{eff}/π, where $\Omega_{eff} = \Omega - \Lambda$ (pattern minus peculiar) along a Riemann seq. (e.g. Lai-Shapiro)

Corsi & Mészáros

GW & EM loss effects

Upper: GW amplitude h_c
@ d=100 Mpc, for:



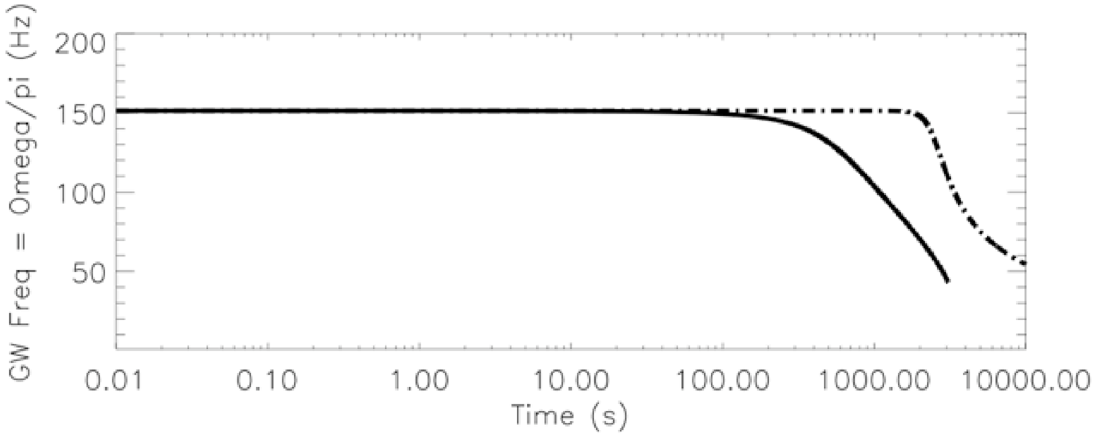
Black-solid: GW+EM

Black-dash-dot: GW only

Blue-dot: Virgo nom.

Purple dash: adv. LIGO/Virgo

Blue solid: Virgo adv.(bin)

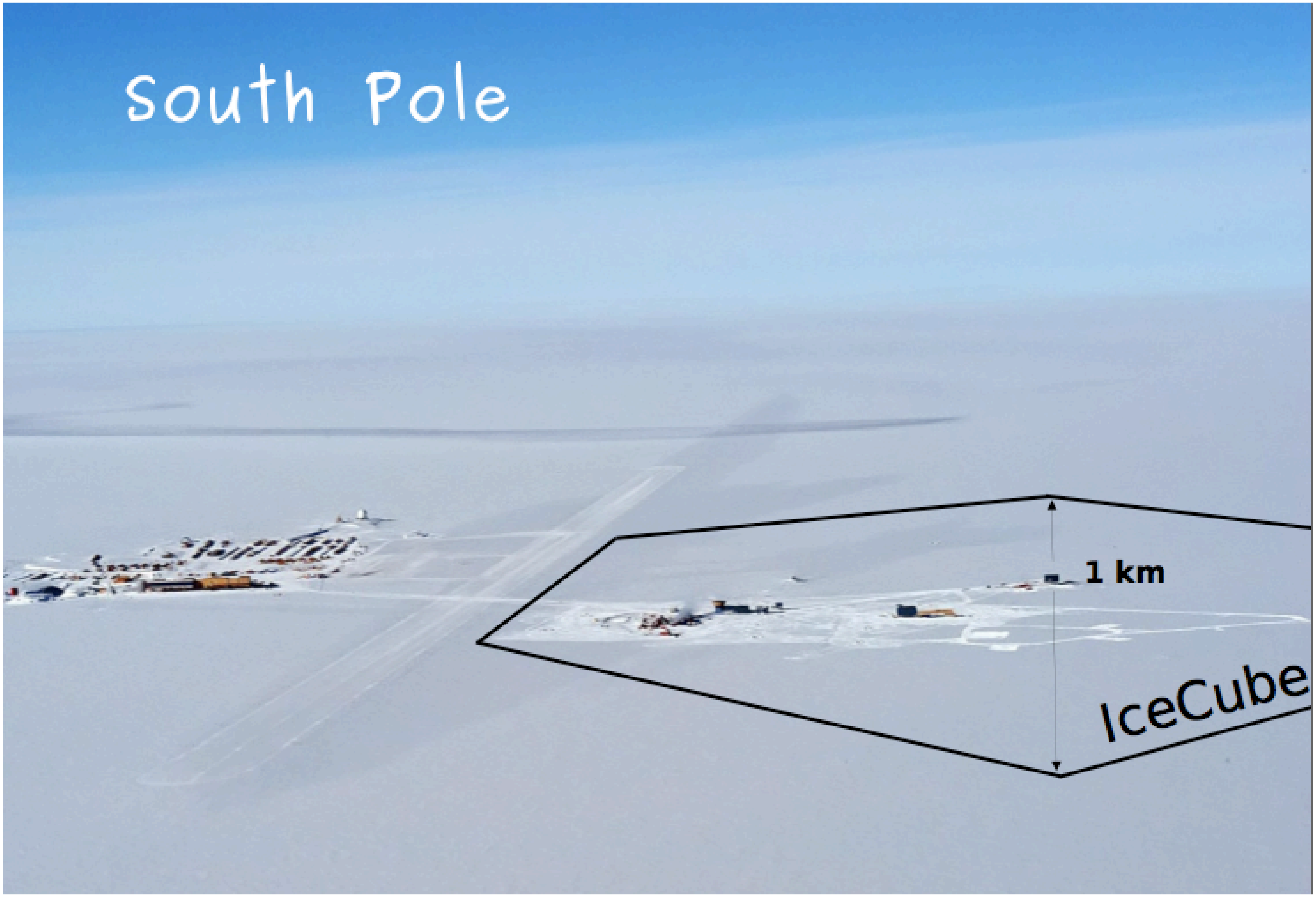


Lower:
W signal freq., for:

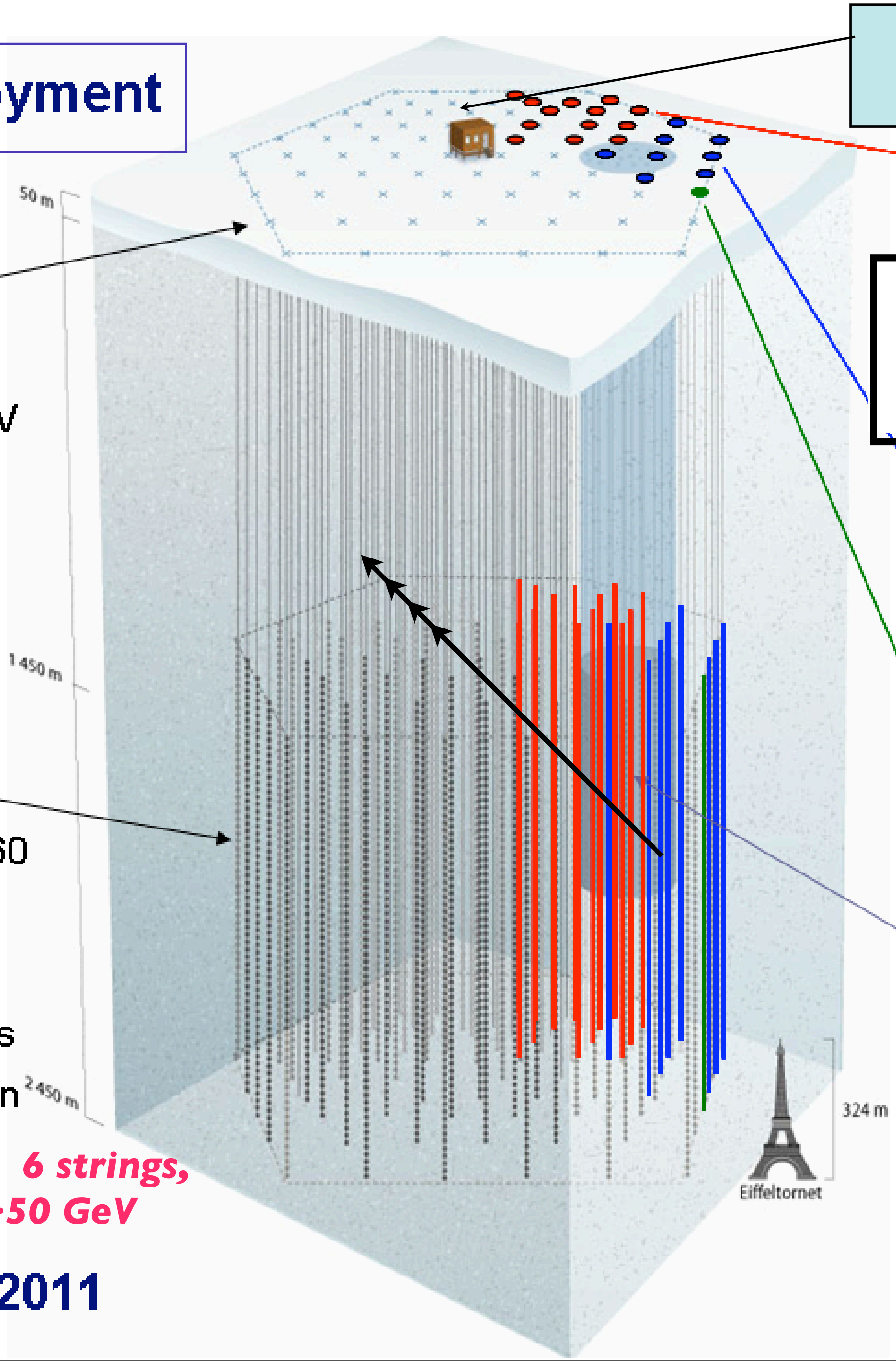
lack-solid: GW + EM losses
lack-dash: GW losses (only)

Corsi & Meszaros 09

ICECUBE



IceCube Deployment



2008-2009: 21 strings,
Total: ***59 strings (73%)***

2006-2007:
13 strings deployed

22 strings
1320 digital modules
52 surface detectors

2005-2006: 8 strings

2004-2005 : 1 string
First data in 2005
first upgoing muon:
July 18, 2005

AMANDA
19 strings
677 modules

IceTop

Air shower detector

Threshold ~ 300 TeV

InIce

planned 80 strings of 60 optical modules each

17 m between modules

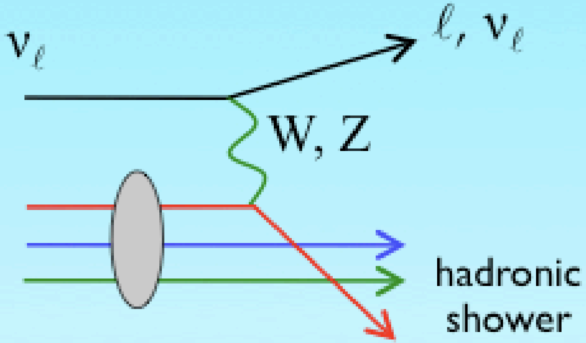
125 m string separation

Deep Core: 6 strings,
threshold >50 GeV

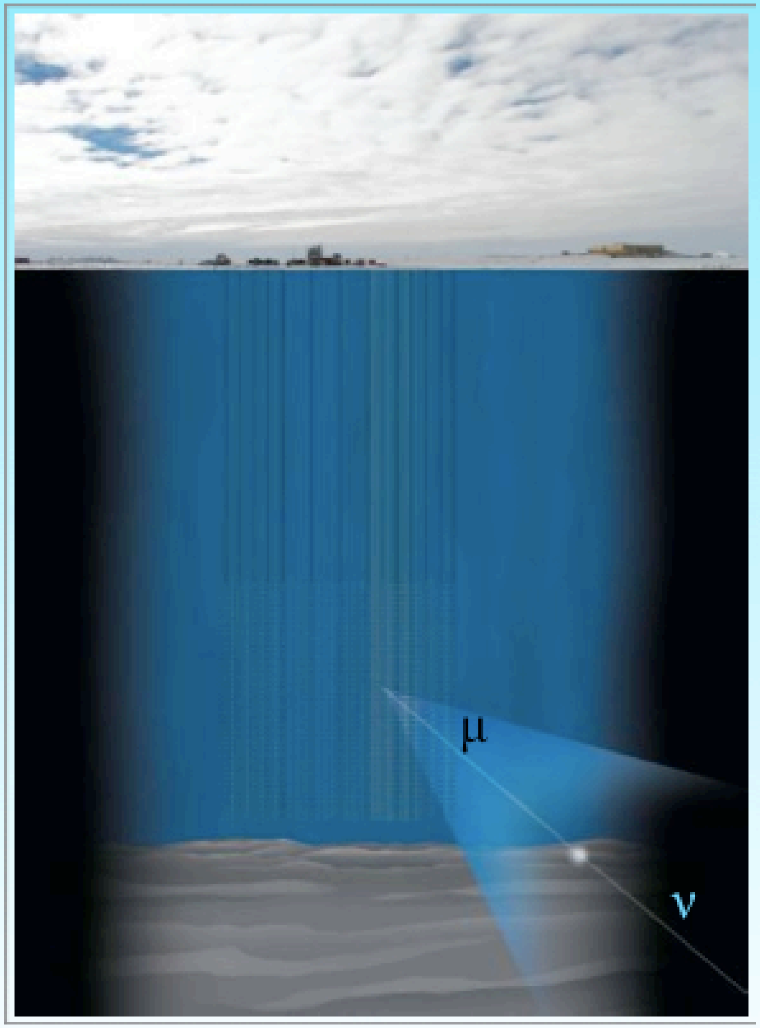
Completion by 2011

Neutrino Telescopes

- Neutrinos interact in or near the detector



  - $\mathcal{O}$(km) muons from ν_μ (CC)
  - $\mathcal{O}$(10 m) particle cascades from ν_e, low energy ν_τ, and NC interactions
  - Cherenkov radiation detected by optical sensors



Another magnetar signature?

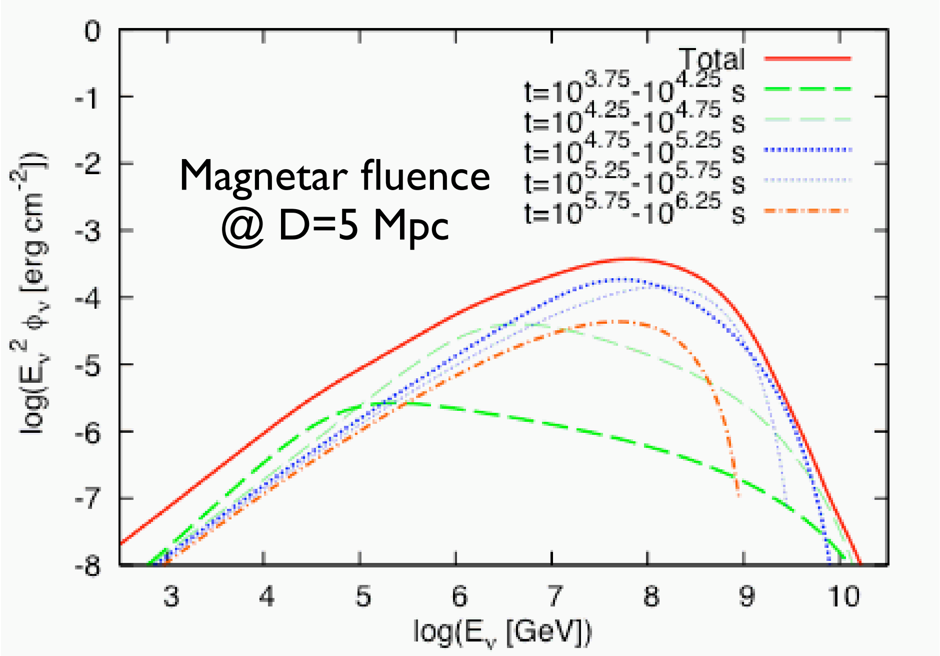
Magnetar birth ν-alert

Murase, Mészáros & Zhang, PRD in press; arXiv: 0904.2509

- Magnetars ($B \sim 10^{14}$-10^{15} G) may result from turbulent dynamo when born with fast (ms) rotation
- A fraction $\lesssim 0.1$ of CC SNe may result in magnetars
- In PNS wind, wake-field acceleration can lead to UHECR energies $E(t) \lesssim 10^{20}$ eV $Z\, \eta_{-1}\, \mu_{33}^{-1}\, t_4^{-1}$
- Surrounding ejecta provides cold proton targets for $pp \rightarrow \pi^{\pm} \rightarrow \nu$
- ν-fluence during time t_{int} first increases (strong initial π/μ cooling), then decreases (with the proton flux)

Magnetar birth ν-alert

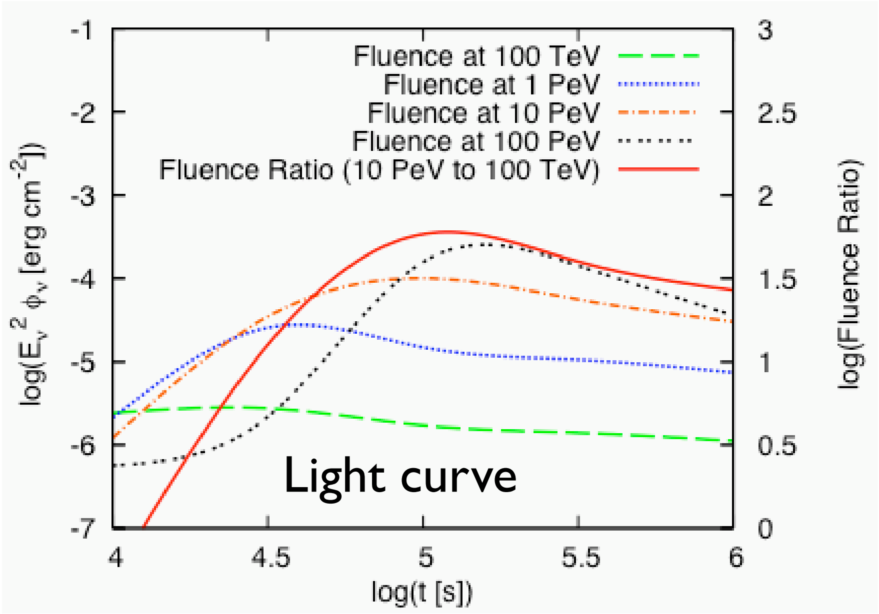
Murase, Mészáros & Zhang 09



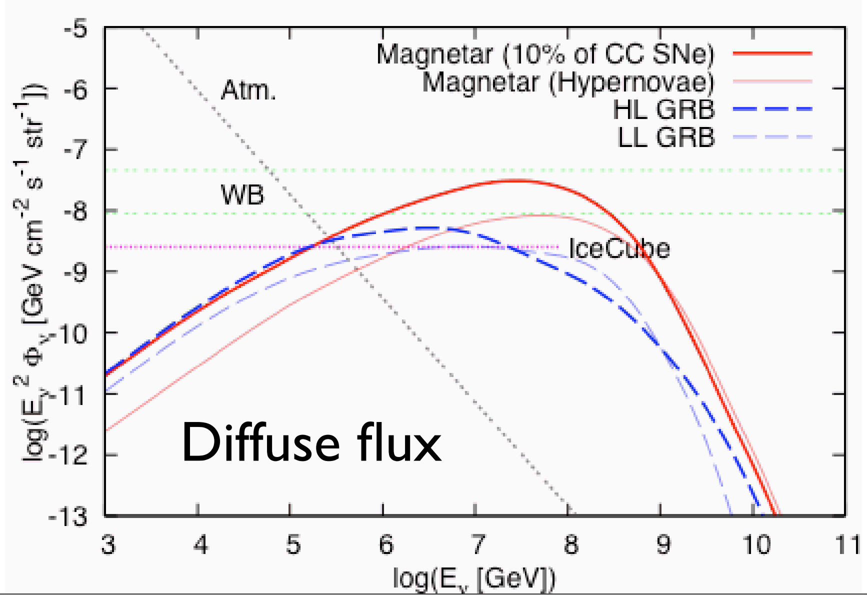
Magnetar fluence
@ D=5 Mpc

- Can signal birth of magnetar
- Test UHECR acc. in magnetar

-BUT: Not an explanation for Auger, because a) UHECR flux not sufficient, and b) UHECR spectrum not like Auger obs.



Light curve



Diffuse flux

Conclusions

- Will learn much from coordinated photon + GW and/or neutrino observations
- GW: reveal role of binaries (short) or instabilities (long) in GRB mechanism: real nature of the central engine?
- Reveal whether magnetars involved in GRB?
- Nus: reveal role of protons in GRB, whether outflow is MHD or hadronic, and whether GRB are source of some (all?) UHECR
- Nus reveal birth of magnetars in non-GRB SNRs? Other GW?