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

BH - WD merger

0.01 M☉ torus

1 M☉ torus

0.1 M☉ torus

collapsar = rotating, collapsing "failed" supernova

NS/BH - He core merger after common envelope

short

long

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

Internal Shock

Collisions betw. diff. parts of the flow

Photospheric th. radiation

n,p decouple

GRB

≈10^{11} \text{ cm}

GRB

≈10^{13} \text{ cm}

GRB

> 10^{16} \text{ cm}

External Shock

Flow decelerating into the surrounding medium

Reverse shock ⇐

Forward ⇒ shock
**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.

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

**Launched Nov 04**

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

**UVOT:** Wavelength Range: 170-650 nm

**XRT:** Energy Range: 0.2-10 keV
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

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: \textbf{BHNS}

\textbf{Black hole-neutron star}

thin: $d=170\text{Mpc}$,
$m_1=3.0\ M_\odot$, $m_2=1.4\ M_\odot$,
$m=0.5\ M_\odot$, $m'=4\ M_\odot$

thick: $d=280\text{Mpc}$,
$m_1=12\ M_\odot$, $m_2=1.4\ M_\odot$,
$m=0.5\ M_\odot$, $m'=13\ M_\odot$

Both: $a=0.98$, $e_m=0.05$,
$N=10$, $e_r=0.01$

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

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

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**
  - $L_x \sim 10^{35-36}\text{ erg/s}$
  - $\sim 1$-200 keV
  - pulsed at few seconds,
  - spin-down

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

- **Giant Flares**
  - $L_x > 10^{44}\text{ erg/s}$
  - very rare events (only three observed)
Magnetars birthrate

~ a few every $10^4$ years

large uncertainties:

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

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

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

See also:
Gill & Heyl 2007, MNRAS 381,52 (~0.22 / century + transients)
Swift Era canonical X-ray afterglow plateau: 
A temporary magnetar phase in GRB?

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

A. Corsi & P. Meszaros 09
GW + EM dipole losses

Bar instability $\rightarrow$ rotating ellipsoid

GW: with pattern $\Omega$ - 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 $\Omega_{\text{eff}}/\pi$, where $\Omega_{\text{eff}} = \Omega - \Lambda$
  (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:
GW signal freq., for:
- Black-solid: GW + EM losses
- Black-dash: GW losses (only)

Corsi & Meszaros 09
IceCube Deployment

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

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

2005-2006: 8 strings

2006-2007: 13 strings deployed

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

AMANDA
- 19 strings
- 677 modules

Completion by 2011
Neutrino Telescopes

- Neutrinos interact in or near the detector

\[ \nu_\ell \rightarrow \ell, \nu_\ell \]

- $\mathcal{O}(\text{km})$ muons from $\nu_\mu$ (CC)
- $\mathcal{O}(\text{10 m})$ particle cascades from $\nu_\mathrm{e}$, low energy $\nu_\tau$, and NC interactions
- Cherenkov radiation detected by optical sensors
Another magnetar signature?

**Magnetar birth ν-alert**

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

- Magnetars (B~10^{14}-10^{15} G) may result from turbulent dynamo when born with fast (ms) rotation

- A fraction ≲0.1 of CC SNe may result in magnetars

- In PNS wind, wake-field acceleration can lead to UHECR energies $E(t) \lesssim 10^{20} \text{ eV } Z \eta_{-1} \mu_{33^{-1}} t_4^{-1}$

- Surrounding ejecta provides cold proton targets for $pp \rightarrow \pi^\pm \rightarrow \nu$

- ν-fluence during time $t_{\text{int}}$ 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.
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?