Multimessenger Astronomy with the Einstein Telescope

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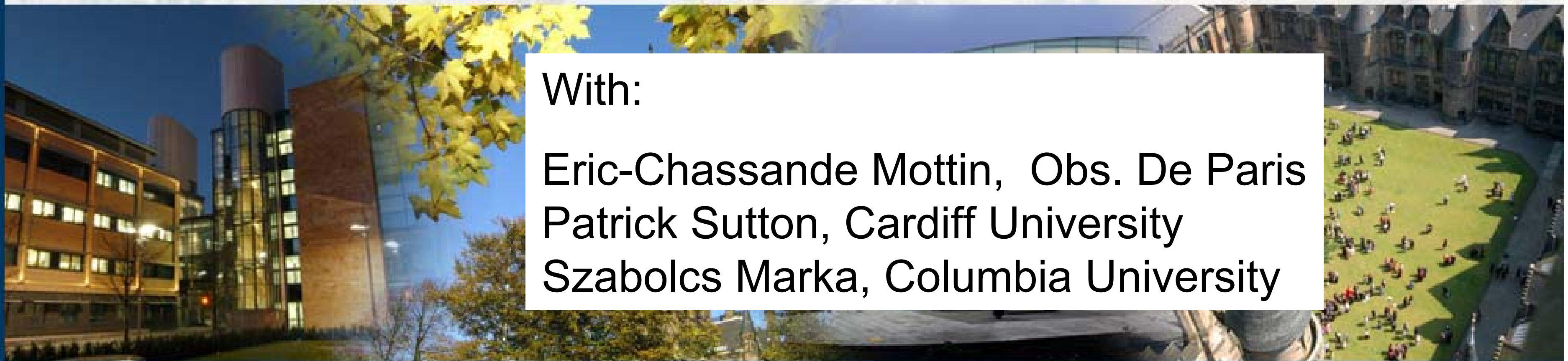
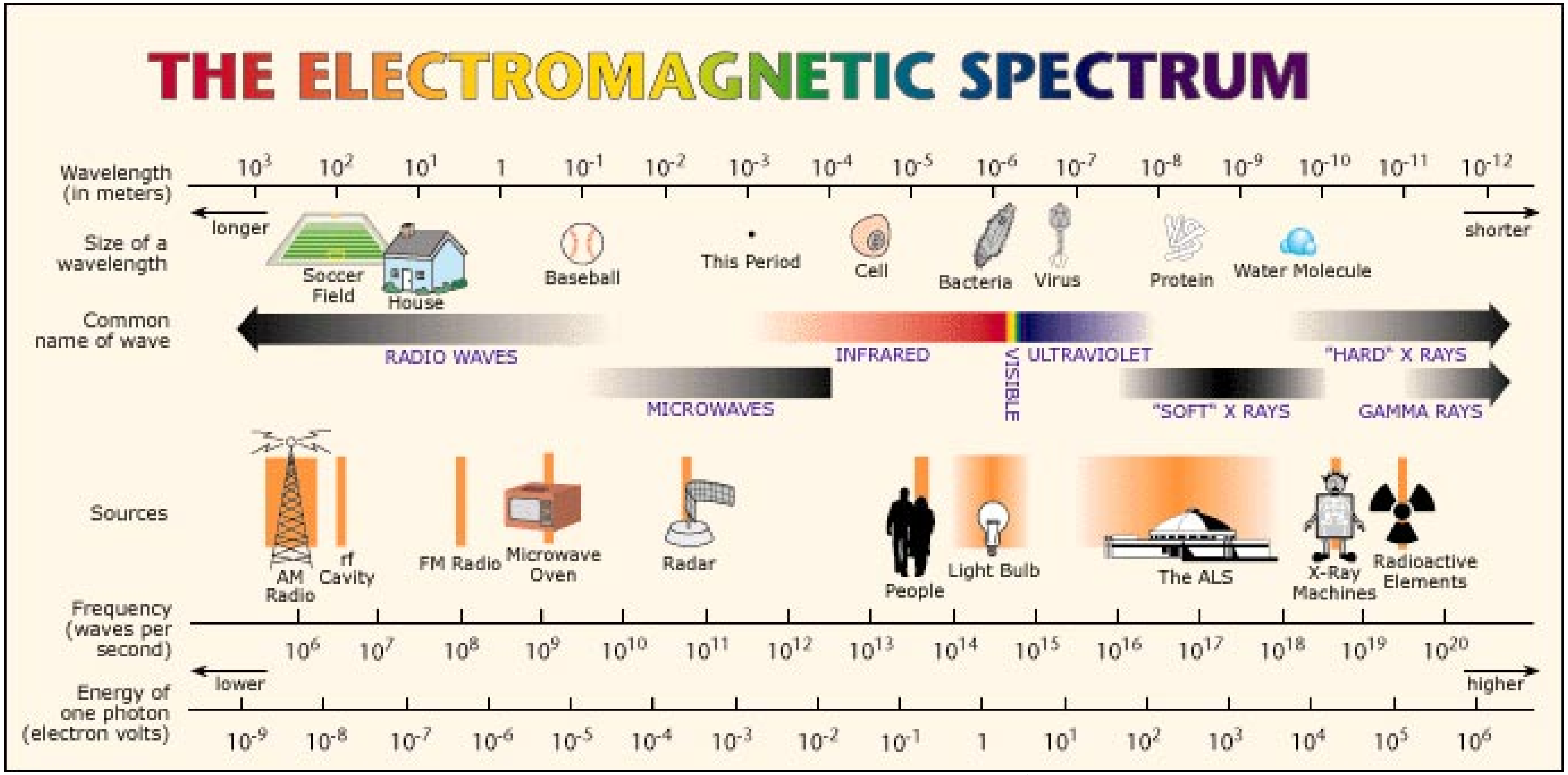
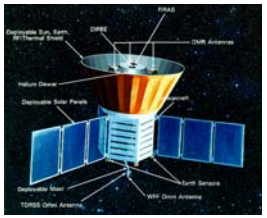
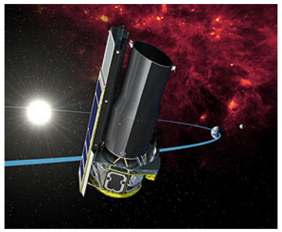


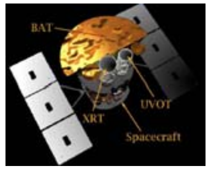
With:

Eric-Chassande Mottin, Obs. De Paris
Patrick Sutton, Cardiff University
Szabolcs Marka, Columbia University


THE ELECTROMAGNETIC SPECTRUM
Wavelength (in meters)
10^3 10^2 10^1 1 10^-1 10^-2 10^-3 10^-4 10^-5 10^-6 10^-7 10^-8 10^-9 10^-10 10^-11 10^-12
longer
shorter
Size of a wavelength
Soccer Field
House
Baseball
This Period
Cell
Bacteria
Virus
Protein
Water Molecule
Common name of wave
RADIO WAVES
MICROWAVES
INFRARED
VISIBLE
ULTRAVIOLET
"SOFT" X RAYS
"HARD" X RAYS
GAMMA RAYS
Sources
AM Radio
rf Cavity
FM Radio
Microwave Oven
Radar
People
Light Bulb
The ALS
X-Ray Machines
Radioactive Elements
Frequency (waves per second)
10^6 10^7 10^8 10^9 10^10 10^11 10^12 10^13 10^14 10^15 10^16 10^17 10^18 10^19 10^20
lower
higher
Energy of one photon (electron volts)
10^-9 10^-8 10^-7 10^-6 10^-5 10^-4 10^-3 10^-2 10^-1 1 10^1 10^2 10^3 10^4 10^5 10^6






BAT
XRT
UVOT
Spacecraft

Multi-messenger Astronomy

A multi-messenger approach is particularly important for GW astronomy, and can:

- increase confidence in GW detections
- optimise GW search strategies
- Answer specific science questions about emission mechanisms, as well as harnessing sources as astrophysical probes.

Here we consider only MMA issues for transient sources.
See also Andersson et al (2009) for a discussion of CW sources.

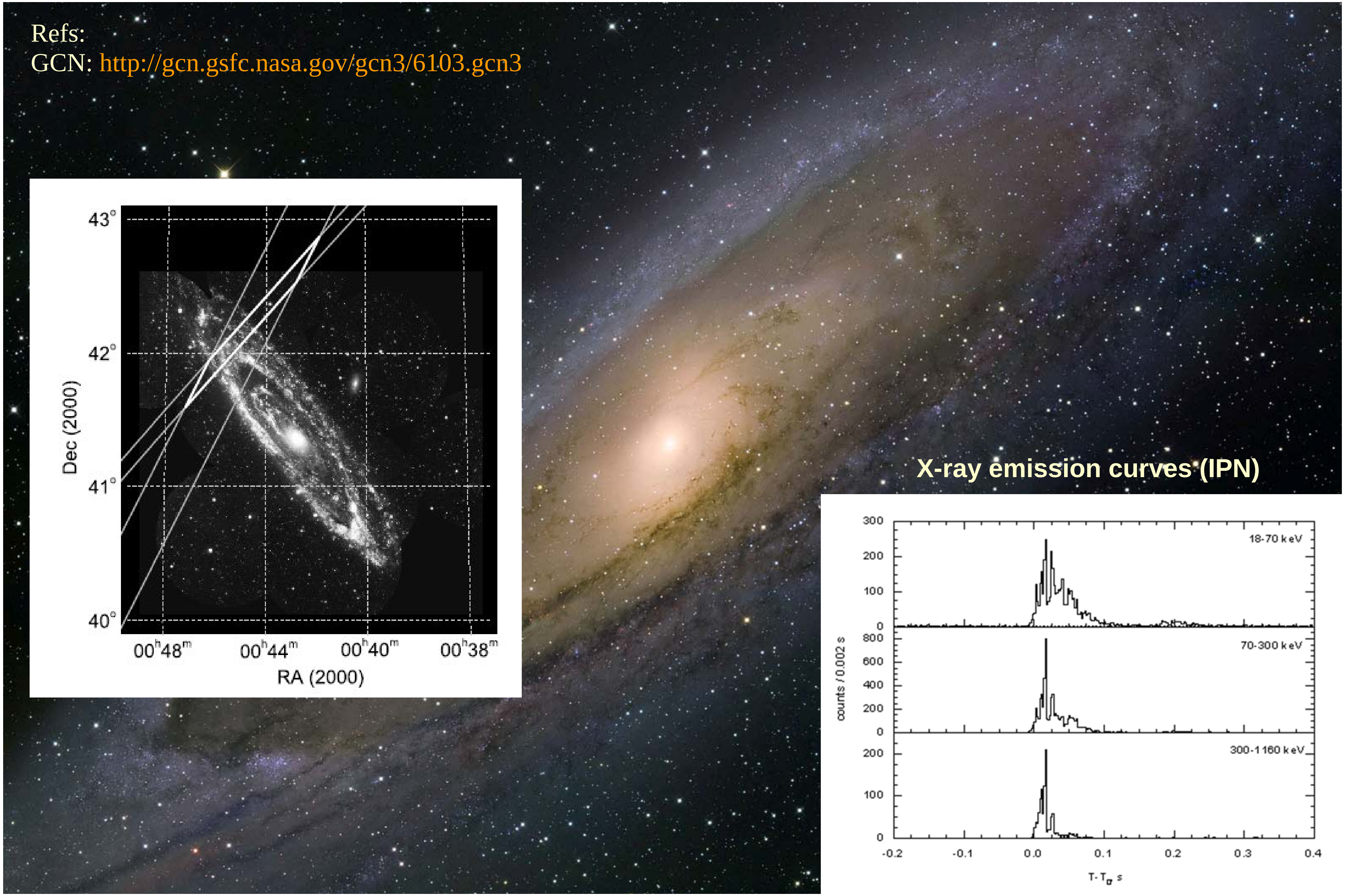
Current multi-messenger approach

Mode of interaction: **E-M** observation triggers GW search

(see e.g. Abbott et al 2008)

Approach adopted in many searches by ground-based detectors, particularly resulting from gamma-ray and/or x-ray observations.

Example: GRB070201, *Not a Binary Merger in M31*



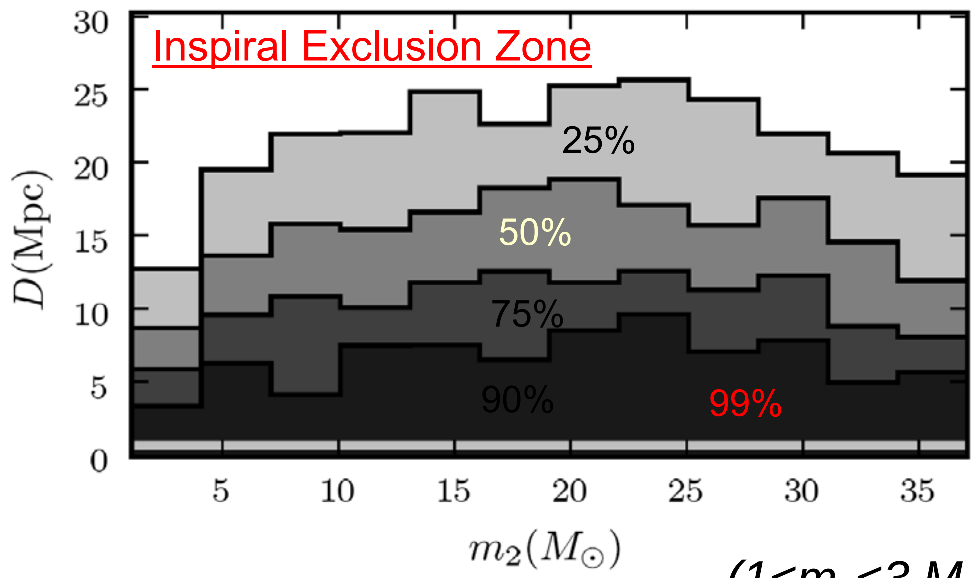
Refs:
GCN: http://gcn.gsfc.nasa.gov/gcn3/6103.gcn3

X-ray emission curves (IPN)

Example: GRB070201, *Not a Binary Merger in M31*

- **Inspiral (matched filter search:**
  - **Binary merger in M31 scenario excluded at >99% level**
  - **Exclusion of merger at larger distances**

Abbott, et al. "Implications for the Origin of GRB 070201 from LIGO Observations", Ap. J., 681:1419–1430 (2008).



($1<m_1<3\ M_{sun}$)

- **Burst search:**
  - **Cannot exclude an SGR in M31**

    SGR in M31 is the current best explanation for this emission

  - **Upper limit: 8×10^{50} ergs ($4\times10^{-4}\ M_\odot c^2$) (emitted within 100 ms for**

Current multi-messenger approach

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E-M trigger mode natural:

- GW detector networks all-sky monitors, low angular resolution
- GW detectors operate at low data rate, O(10^4 samples/sec).
  → all data archived. (c.f. LOFAR, SKA)
- EM observations highly directional, with FOV of arcminutes or less

Future multi-messenger approach

Nascent efforts towards GW triggers: Bloom et al (2009)
Kanner et al. (2008)

In the ET era, we can expect GW detections as a routine occurrence $\Rightarrow$ *both* ***E-M*** $\rightarrow$ ***GW***

and ***GW*** $\rightarrow$ ***E-M*** *searches*

Prospects for the Einstein Telescope…

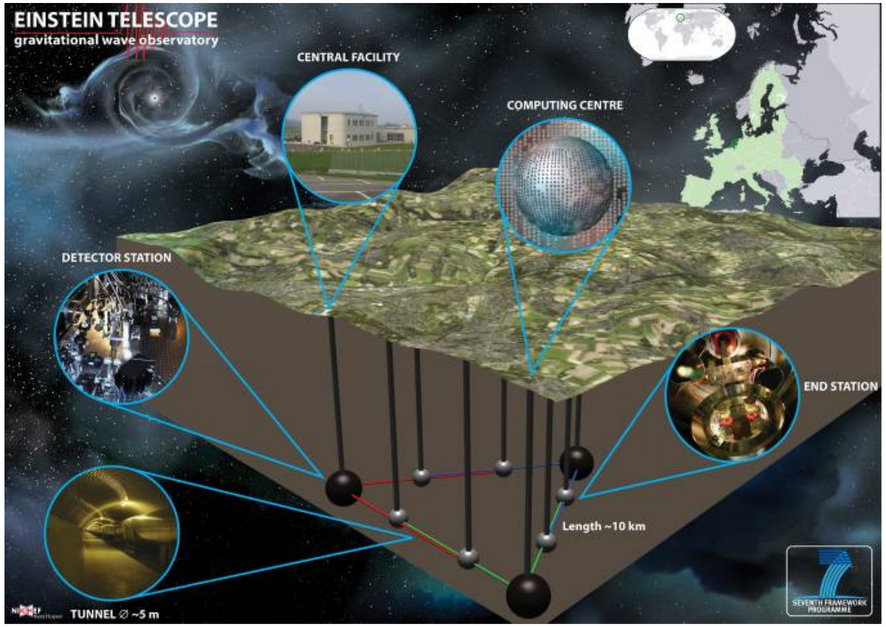
Third Generation Network — Incorporating Low Frequency Detectors

- Third-generation underground facilities are aimed at having excellent sensitivity from ~1 Hz to ~10^4 Hz.
- This will greatly expand the new frontier of gravitational wave astrophysics.

Recently begun:

Three year-long European design study, with EU funding, underway for a 3rd-generation gravitational wave facility, the **Einstein Telescope** (ET).

Goal: **100 times** better sensitivity than first generation instruments.



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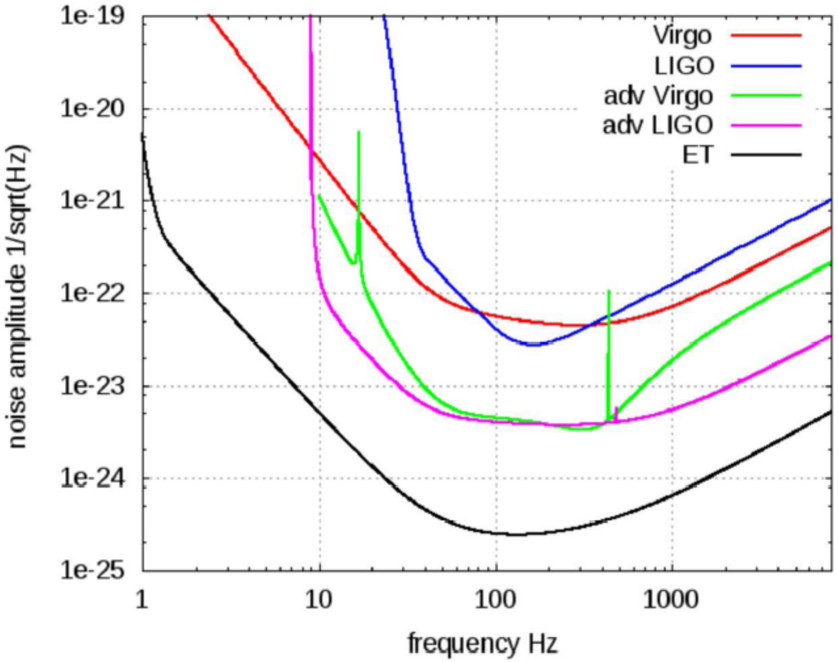


High Energy Photons / Neutrinos

Many potential sources:

- Gamma ray bursts
- Soft gamma repeaters
- Ultra-luminous X-ray sources
- Micro-quasar flares

Rule-of-thumb for the reach of ET:

$$D_{\mathrm{L}} \simeq \sqrt{\frac{3G\,(1+z)\,E_{\mathrm{GW}}}{\pi^2 c^3\,S(f)}}\,\frac{F_{\mathrm{rms}}}{\rho_{\mathrm{det}}\,f}$$

$$\simeq 5\ \mathrm{Gpc}\,(1+z)^{1/2}\,\frac{10}{\rho_{\mathrm{det}}}\,\frac{100\,\mathrm{Hz}}{f}\left(\frac{E_{\mathrm{GW}}}{10^{-2}M_{\odot}c^2}\right)^{1/2}\frac{2.5\times10^{-25}/\sqrt{\mathrm{Hz}}}{S(f)^{1/2}}\,F_{\mathrm{rms}}$$

High Energy Photons / Neutrinos

Key requirement:

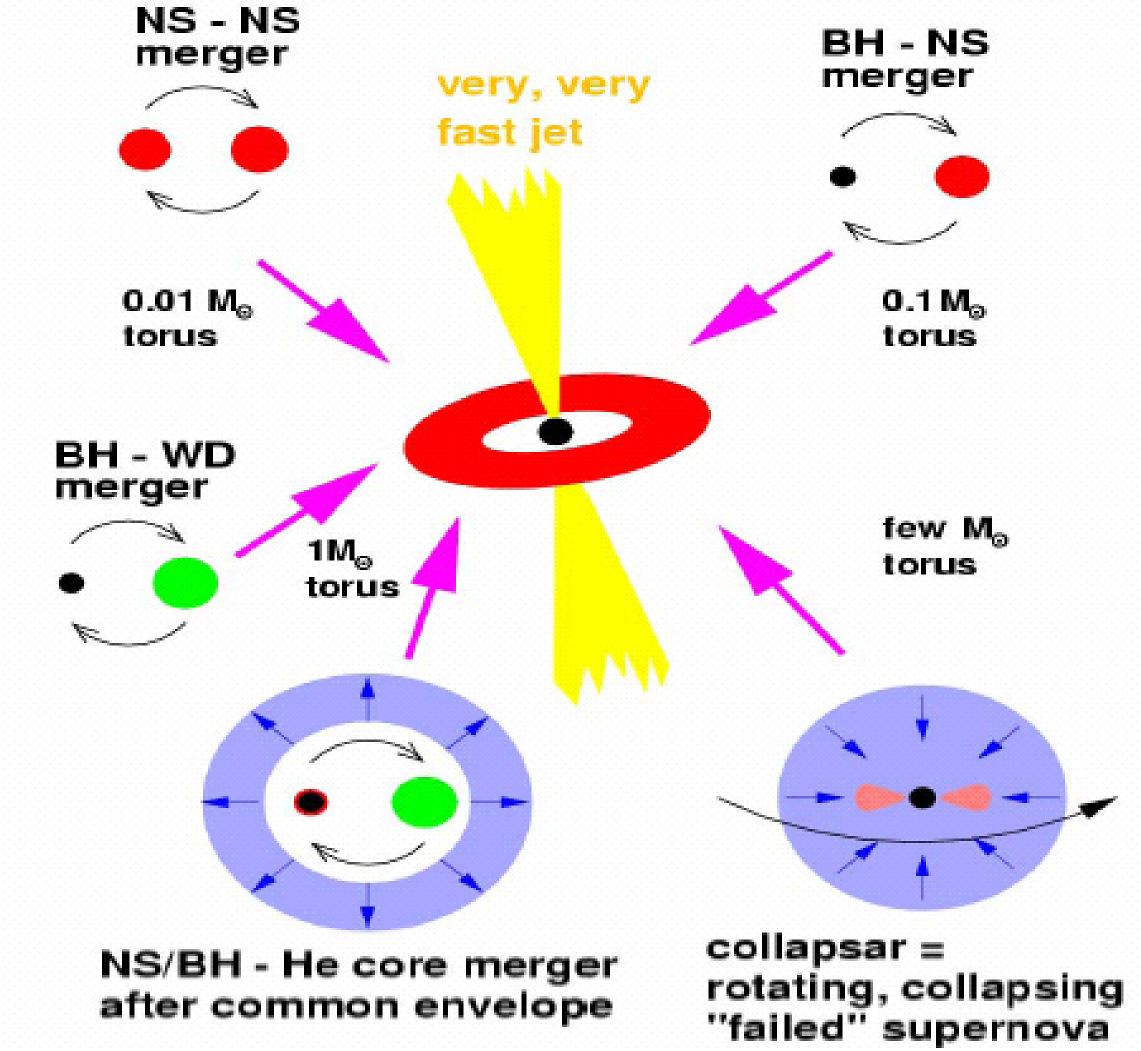
> All-sky burst monitoring satellite operational during the ET era.

Current: SWIFT, INTEGRAL, GLAST

Planned: ASTROSAT (India), MAXI (Japan), SVOM (France/China)

Drawing board: IXO, EXIST ← Optimised for detecting high-z GRBs, 600 / yr

GRB: → Hyperaccreting Black Holes (current paradigm)



Short
($t_\gamma \lesssim 2$ s)

Long
($t_\gamma \gtrsim 2$ s)

High Energy Photons / Neutrinos

Long Duration GRBs

Progenitor – Wolf-Rayet star $> 25\mathrm{M}_\odot$

Rate ~ $0.5\,\mathrm{Gpc}^{-3}\,\mathrm{yr}^{-1}$

Details of collapsar model uncertain:

- Rapidly rotating stellar core; accretion disk centrifugally supported; Non-axisymmetric instabilities $\rightarrow$ GWs?

e.g. van Putten et al (2008) Suspended accretion model

$E_{\mathrm{GW}} \simeq 0.2\mathrm{M}_\odot$ at 500 Hz. Observable to ~1Gpc with ET

High Energy Photons / Neutrinos

Sub-class of low-L Long Duration GRBs?

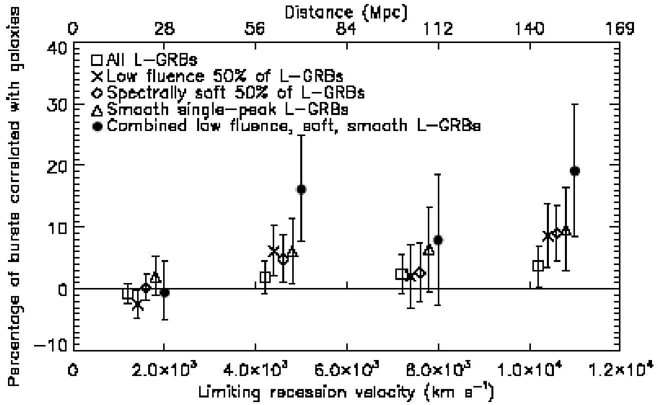
e.g. GRB980425 / SN1998bw at $z = 0.0085$

Chapman et al (2007)

Liang et al (2007)

Local rate up to 1000x

that of the high-L population.



Believed to be associated with particularly energetic core-collapse SN.

Extreme end of a continuum, with the same underlying physical model?...

Medium Energy Photons

Two clear opportunities for multi-messenger astronomy:

Optically selected core-collapse supernovae

NS-NS 'Standard Sirens'

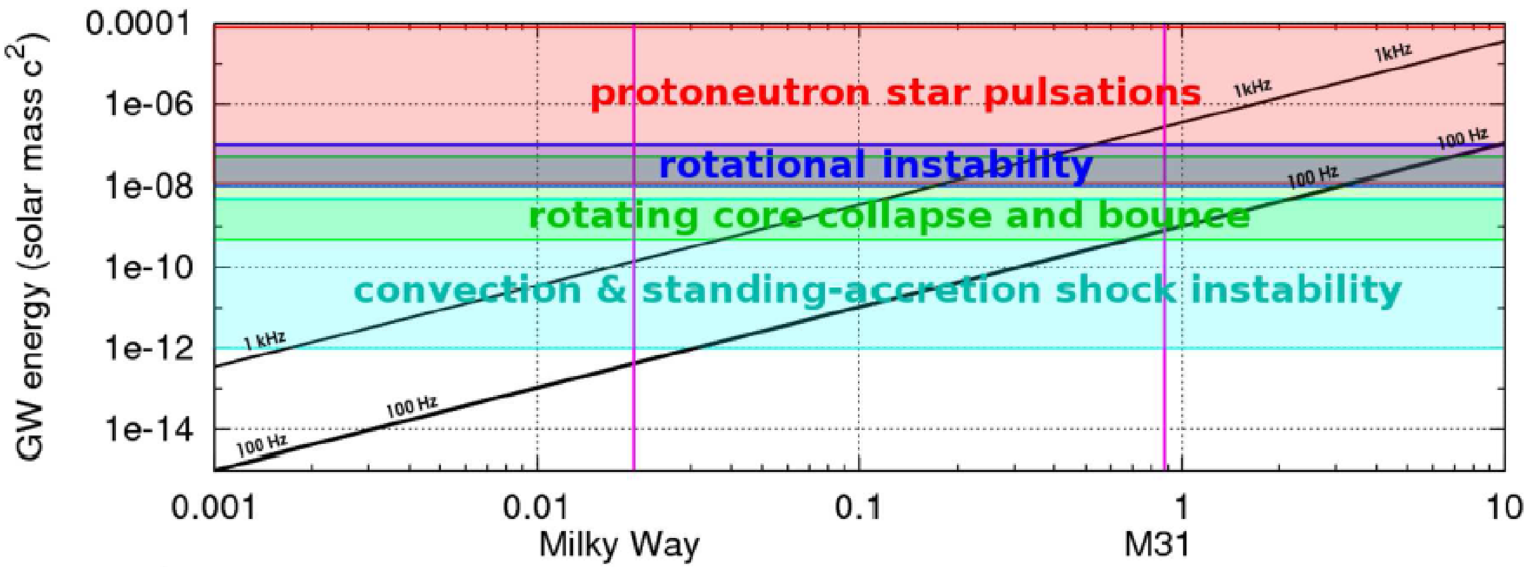
=

Medium Energy Photons

Two clear opportunities for multi-messenger astronomy:

Optically selected core-collapse supernovae

Even 2nd generation detectors only able to detect GWs from galactic SN.
Expected galactic SN rate ~ 0.02 / year!

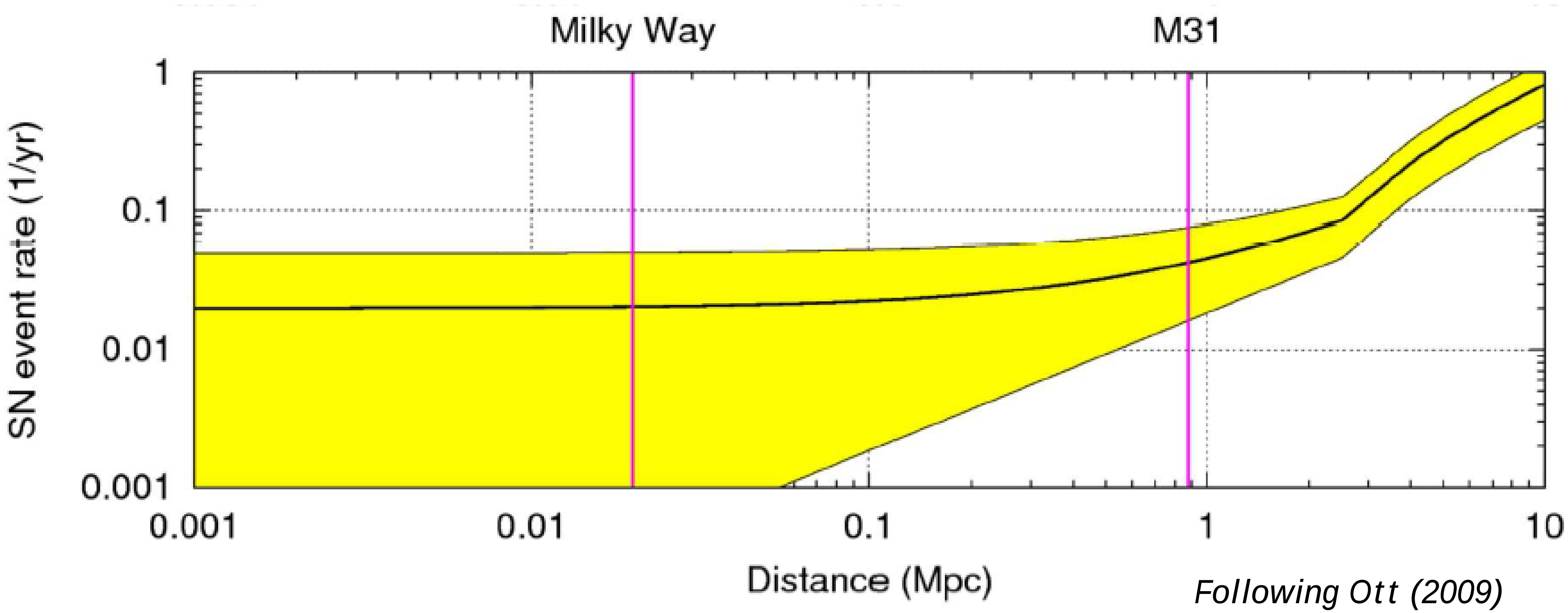


Following Ott (2009)

Medium Energy Photons

Two clear opportunities for multi-messenger astronomy:

Optically selected core-collapse supernovae



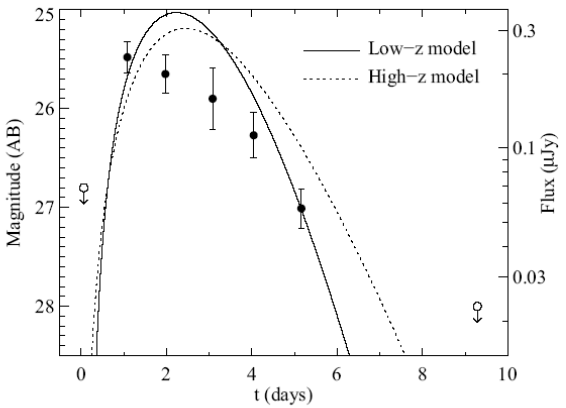
Following Ott (2009)

ET should be able to constrain *some* more energetic GW-processes

Medium Energy Photons

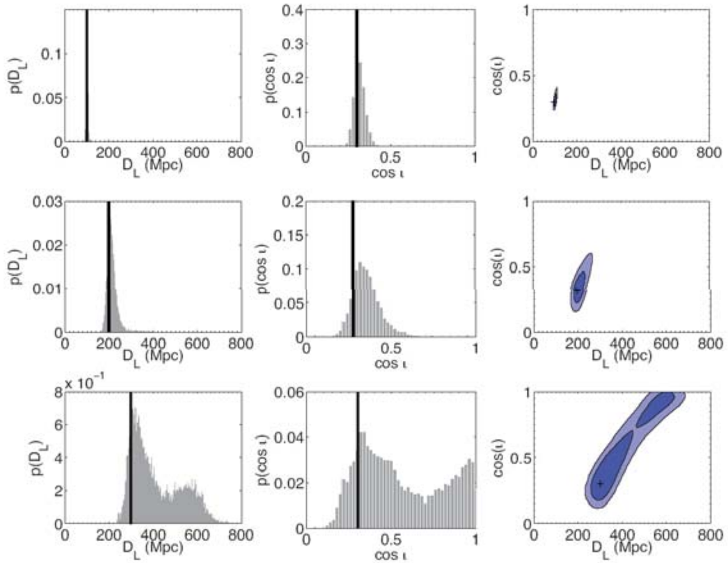
Two clear opportunities for multi-messenger astronomy:

NS-NS 'Standard Sirens': potential high-precision distance indicators.



First optical observation of a NS-NS merger?

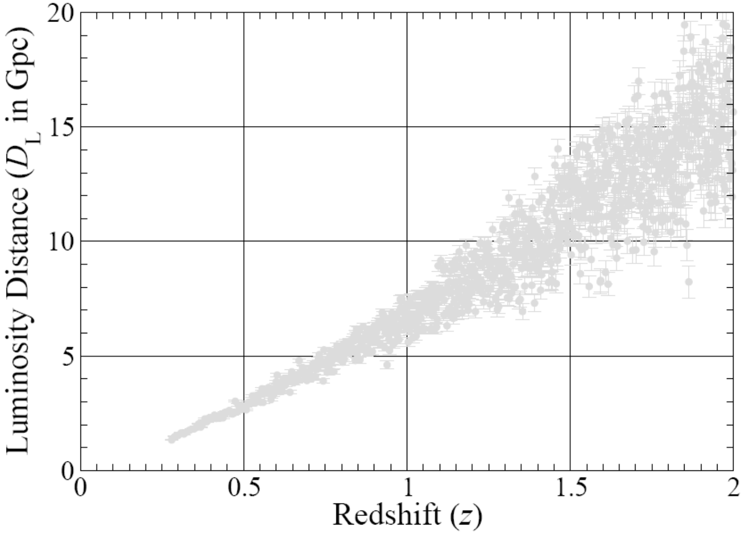
GRB 080503 (Perley et al 2008)



Nissanke et al (2009)

MMA challenge: redshift from E-M counterpart

Medium Energy Photons



Sathyaprakash et al. (2009):

~10^6 NS-NS mergers observed by ET. Assume that E-M counterparts observed for ~1000 sources, 0 < z < 2.

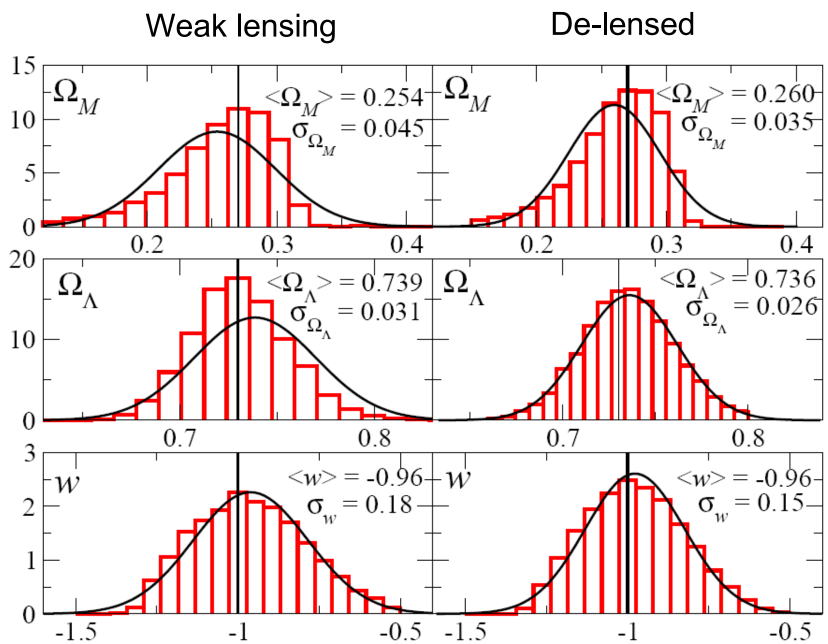
Fit $\Omega_M, \Omega_\Lambda, w$

$$\sigma_{\Omega_M} = 0.035$$

$$\sigma_{\Omega_\Lambda} = 0.026$$

$$\sigma_w = 0.15$$

Competitive with 'traditional' methods

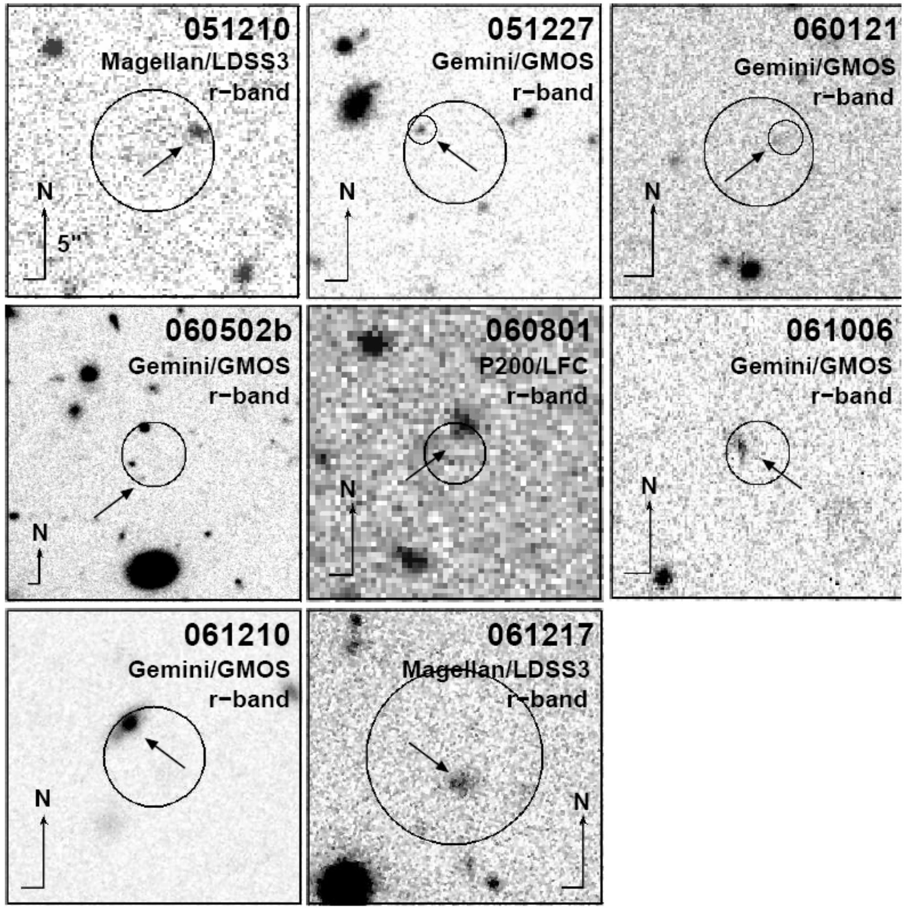


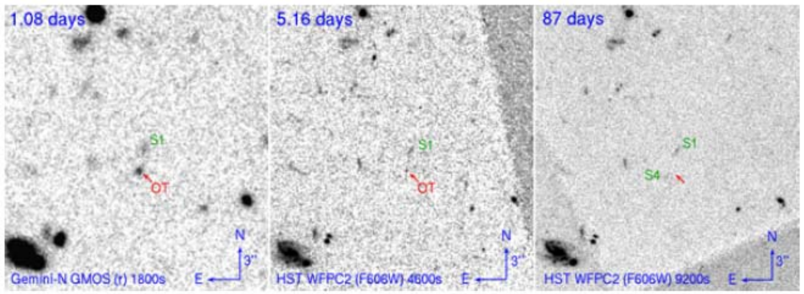
Medium Energy Photons

Berger et al. (2007) present optical observations of 9 short-hard GRBs. Obtained spectrosopic redshifts for 4.

8/9 host galaxies, with R-band mag. 23 – 26.5

Also, *no* HST optical host galaxy for GRB080503



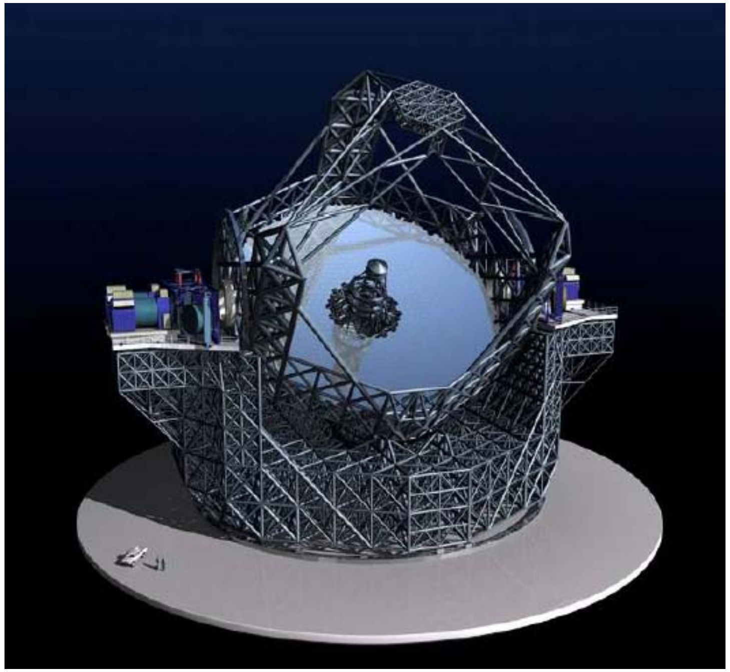


Medium Energy Photons

By the ET era there should be Extremely Large optical Telescopes operating on the ground.

See e.g. the 30-m EELT
http://www.eso.org/sci/facilities/eelt/

EELT will be capable of obtaining high quality spectra at **z ~ 6**.



EELT

⇒ Follow-up spectroscopic observations should be straightforward

Medium Energy Photons

BUT Still strong case for a wide-spectrum high-energy monitoring satellite.

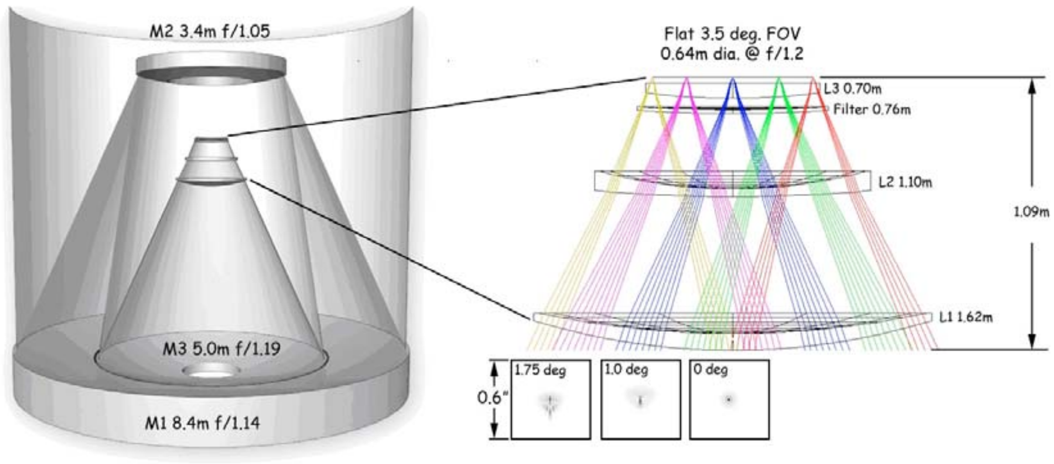
e.g. 5 of the 9 SGBs in Berger et al (2007) had only X-ray positions, but these were measured to ~6 arcseconds.

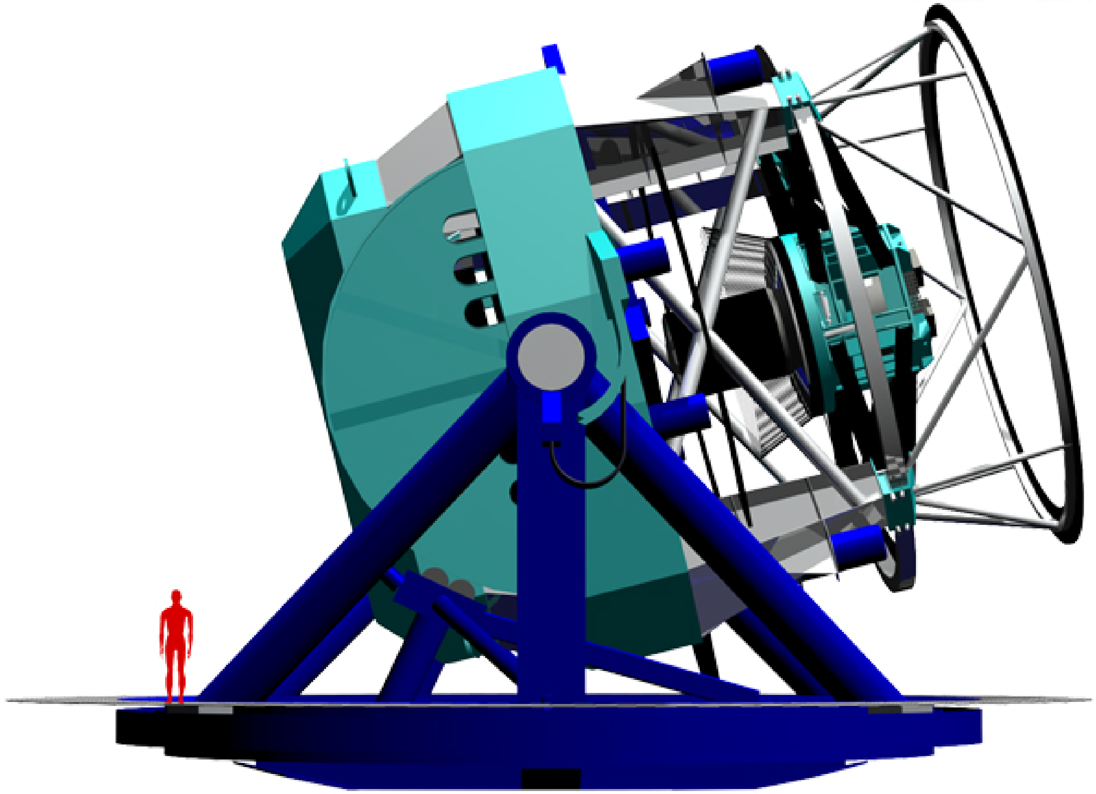
GW triggers from ET network would locate source to ~10 sq. deg.

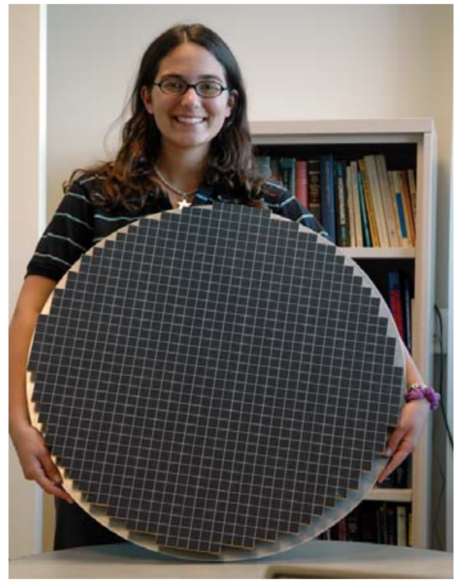
With *only* optical afterglows, that leaves ~10^7 galaxies!

LSST

Large Synoptic Survey Telescope







SUPA IGR

Erice, Oct 2009

University of Glasgow

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CHALLENGE Use 2nd generation NS-NS merger detections to better understand optical (and radio) signatures.

Medium Energy Photons

e.g. Hansen & Lyutikov (2001)

Discuss prospects for detecting radio *pre-cursor* of short-hard GRBs, due to magnetospheric interactions of a NS-NS binary.

At 400 MHz

$$F_\nu \sim 2.1\mathrm{mJy}\,\frac{\epsilon}{0.1}\left(\frac{D}{100\mathrm{Mpc}}\right)^{-2} B_{15}^{2/3}\, a_7^{-5/2}$$

Already detectable by largest radio telescopes, out to few x 100 Mpc.

Observable with SKA to cosmological distances.

Medium Energy Photons

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CHALLENGE Use 2nd generation NS-NS merger detections to better understand optical (and radio) signatures.

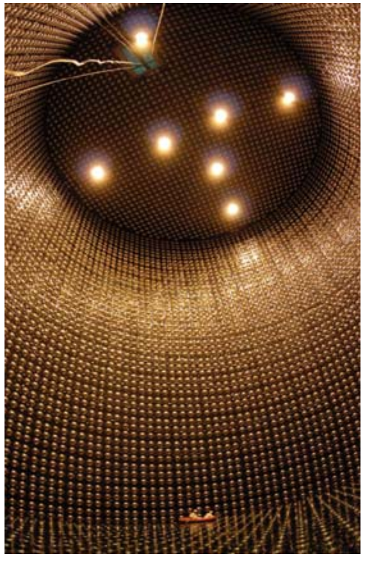
Could this open up entire NS-NS merger population detected by ET?

Neutrinos

Many targets of ET will also be strong neutrino emitters.

Two energy ranges of interest:

$E_\nu \lesssim 10\,\mathrm{MeV}$ ‘Low’ energies – vessel filled with water, or liquid scintillator.



Current: e.g. Super-Kamiokande
50 kTon of pure water

LVD, SNO+
1 kTon of liquid scintillator

Future: ASPERA roadmap includes Megaton detector.

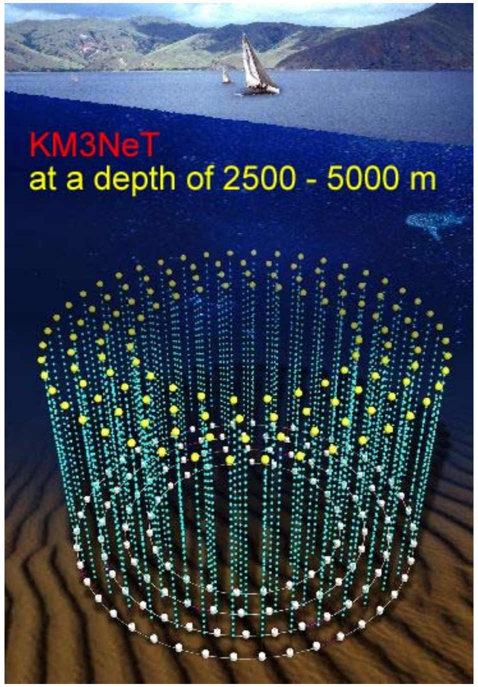
Plans for multi-megaton (e.g. Deep-TITAND)

Neutrinos

Many targets of ET will also be strong neutrino emitters.

Two energy ranges of interest:

$E_\nu \gtrsim 100\ \mathrm{GeV}$. 'High' energies – need much larger volume.



Current: e.g. IceCube
km^3-scale, at South Pole

ANTARES

0.01 km^3-scale, at 2.5km depth

Future: ASPERA roadmap includes KM3NeT.

Conclusions

Many and varied MMA science opportunities with ET:

- Long GRBs to ~1Gpc; constraints on low-L population?
- E-M counterparts of SHB ‘standard sirens’ (possibly extending to full NS-NS merger population?)
- Coincident GWs and neutrinos from GRBs and core-collapse SN, improving understanding of physical mechanisms
- GW triggers of E-M searches to become routine?

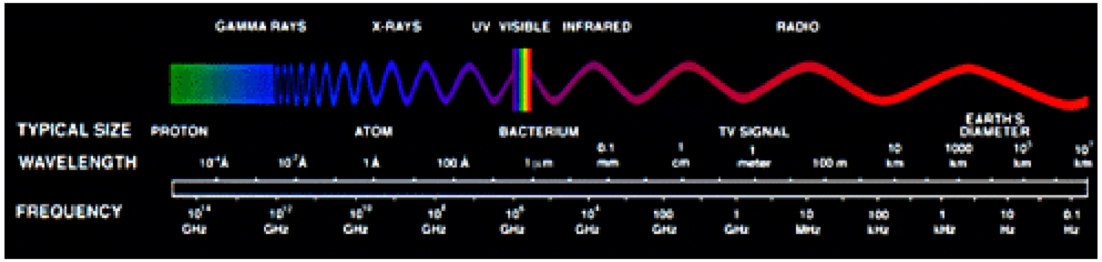
All needs strong collaboration and synchronicity with other messengers.

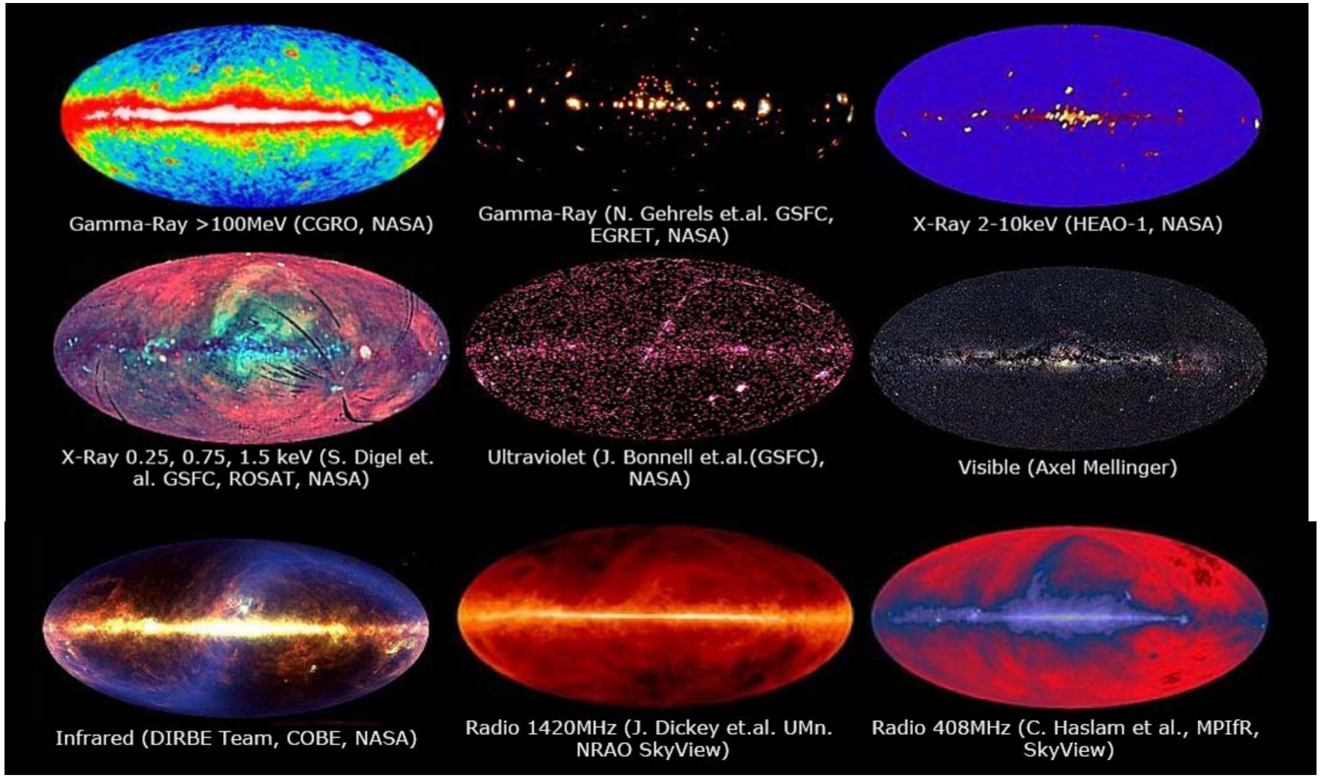
Multi-messenger facilities post-2020?

photons	radio		SKA (LOFAR)
	IR/visible/UV		LSST, GAIA, survey subproduct of JDEM/Euclid
	X-ray	~ keV	symbol-X, XEUS (narrow-field)
	gamma-ray	~ MeV	ASTROSAT, MAXI
		~ GeV	Fermi (2008+10?, wide-field mon.) CTA (HESS, narrow-field)
neutrinos	low-e		mega-ton detector
	high-e	> 100 GeV	Km3Net
GW			LISA

(following Chassande-Mottin, 2008)

Opening a new window on the Universe





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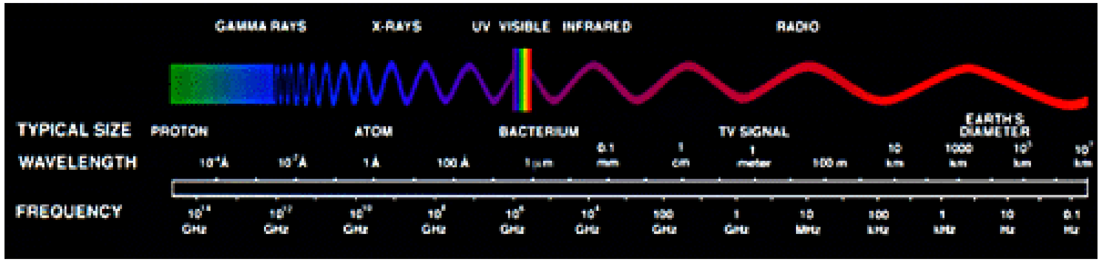

Gravitational Waves

????

Infrared (DIRBE Team, COBE, NASA)

Radio 1420MHz (J. Dickey et.al. UMn. NRAO SkyView)

Radio 408MHz (C. Haslam et al., MPIfR, SkyView)