Searching for Gamma Ray Bursts with the Einstein Telescope

ILIAS November 2008

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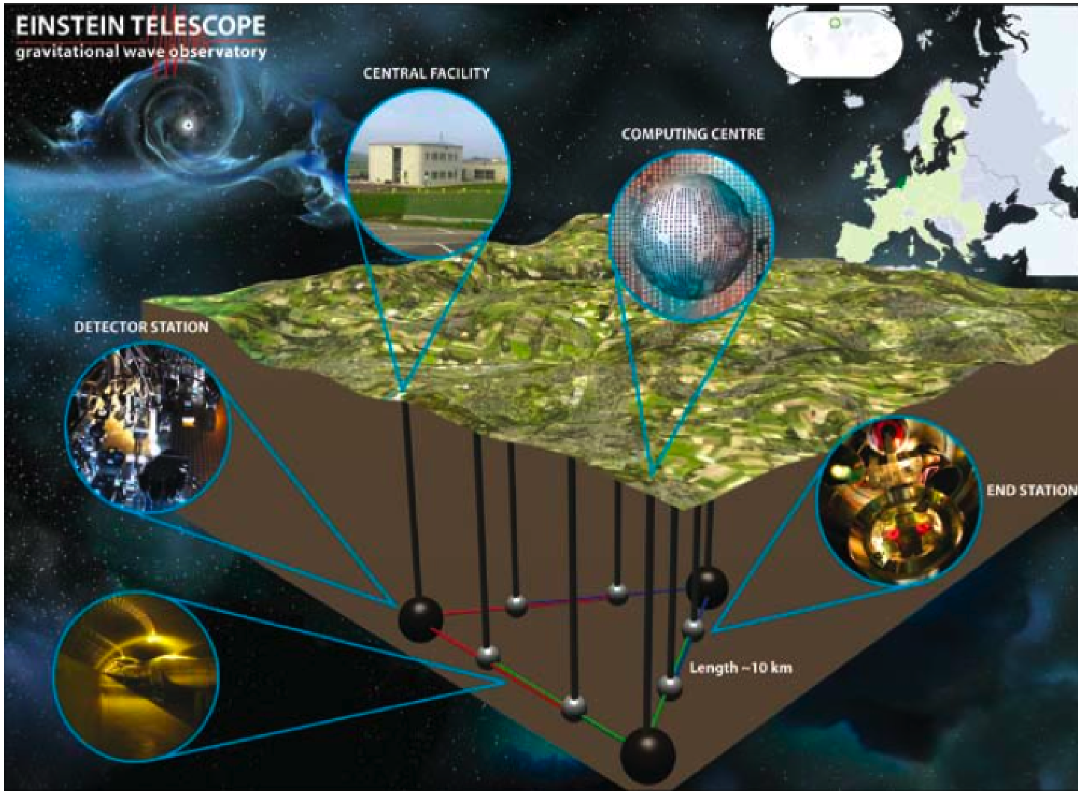
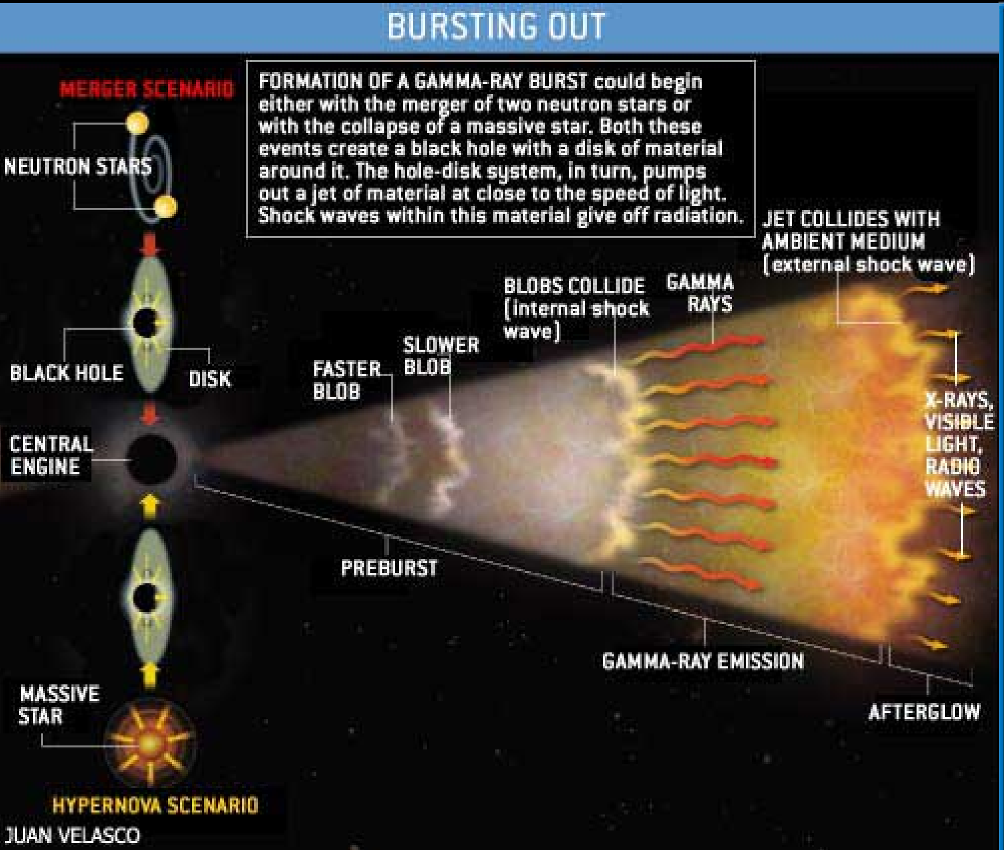
Overview

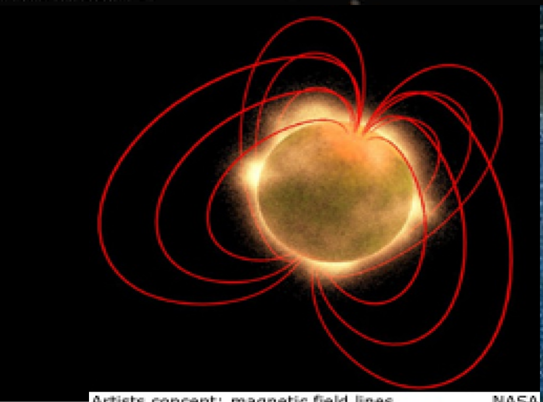
- How will multi-messenger astronomy benefit GRB searches?

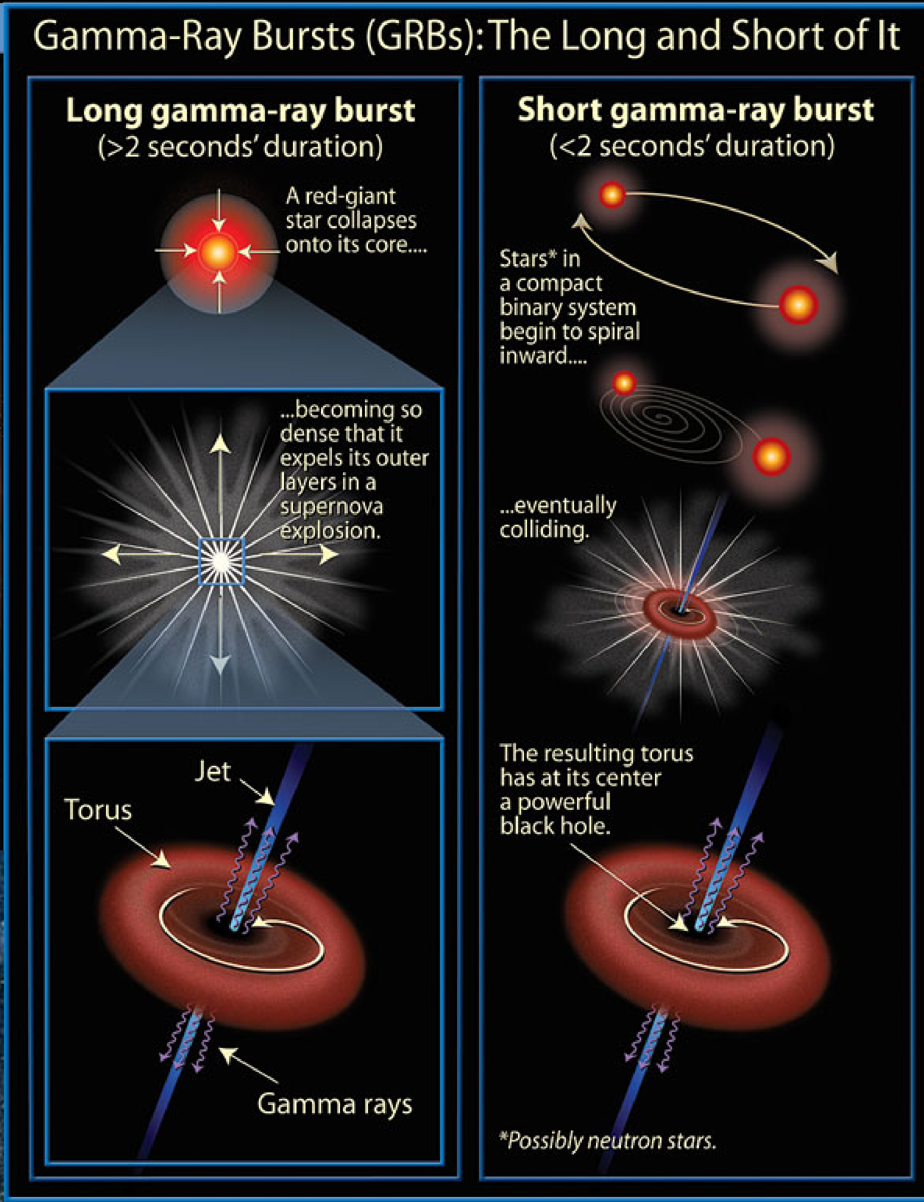
- Will focus on Einstein Telescope (ET), see Eric's talk for discussion of astro-particles and detectors
- Sensitivity of ET to inspiral of NS-BH binary systems
- Sensitivity of ET to unmodelled bursts
- Measuring the beaming of short GRBs?
- Supernova-GRB connection and sensitivity of ET to SNe



Gamma-ray bursts

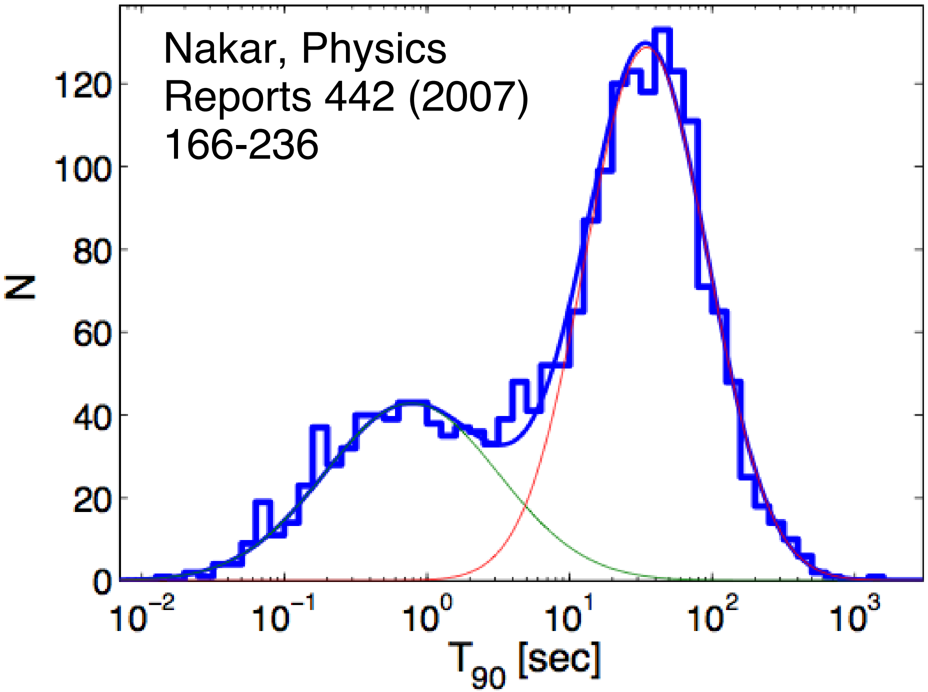






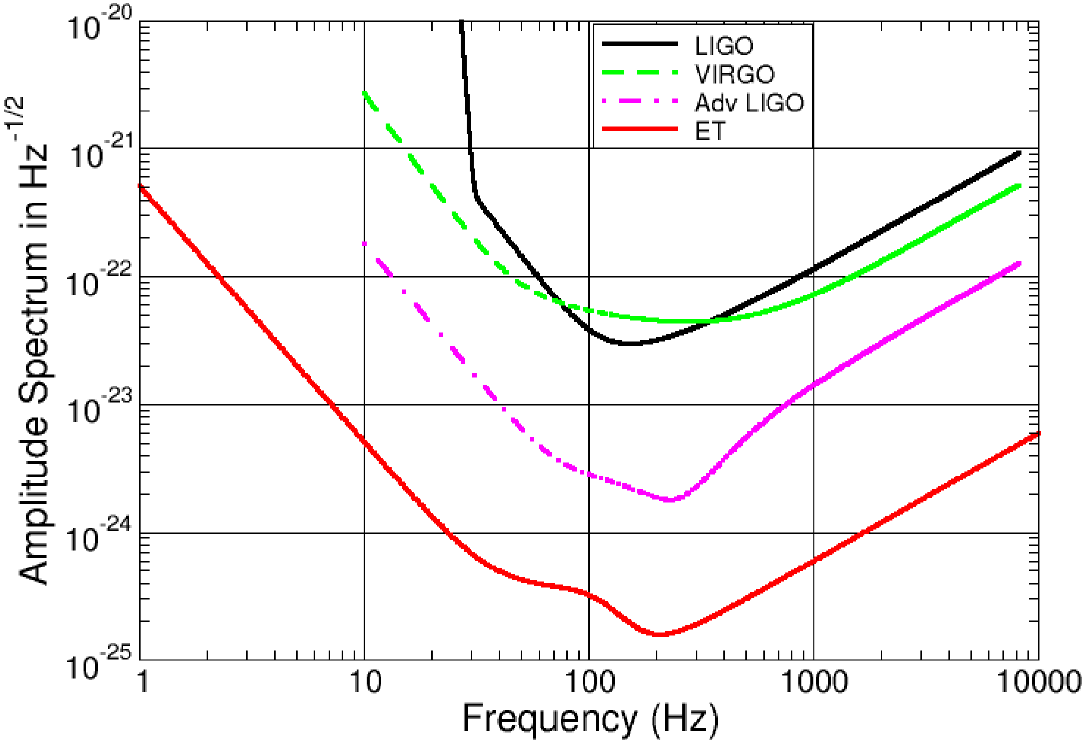
Gamma-ray bursts

- Traditionally divided into short/long categories based on duration
  - Some statistical evidence that long GRBs may be further divided into low- and high-fluence GRBs (Chattopadhyay et al. (2008))
  - Study of luminousity functions indicate that giant flares of soft gamma repeaters may contribute to population of short GRBs (Chapman et al. (2008))
- Use GW observations to perform a census of GRB progenitors
  - Associate GRB observation with inspiral, merger, core-collapse waveform
- GW observation can be used to constrain NS equation of state (Oechslin and Janka PRL **99**, 121102 (2007))



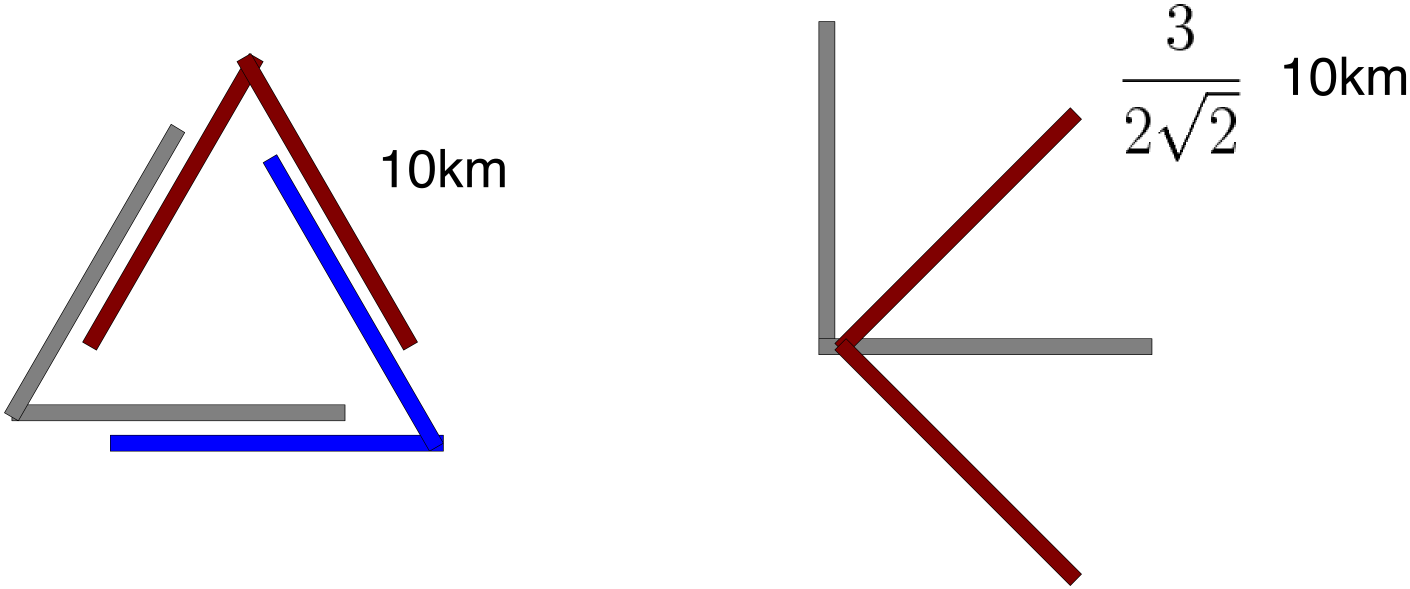
Einstein Telescope

- Einstein telescope
  - Proposed 3rd-generation ground-based interferometer GW detector
  - Sensitivity curve based upon projection for 3km EGO detector, scaled up for arm lengths of 10km, see CQG 24 (2007) 155-176:
    - Cryogenic optics
    - Underground
    - 100W laser power
- ~15 times more sensitive than Adv. LIGO
- Observes plus and cross polarization states



Einstein Telescope

- Geometry/topology Einstein telescope
  - Assume 3 ifos in equilateral triangle with 10km sides (working model rather than endorsement)
- Can be equivalently thought of as 2 L-shaped ifos with appropriately rescaled arms
  - See technical doc by Chris Van Den Broeck, <https://workarea.et-gw.eu/et/WG4-Astrophysics/base-sensitivity/>, “WG assumptions regarding ET and astrophysics”)



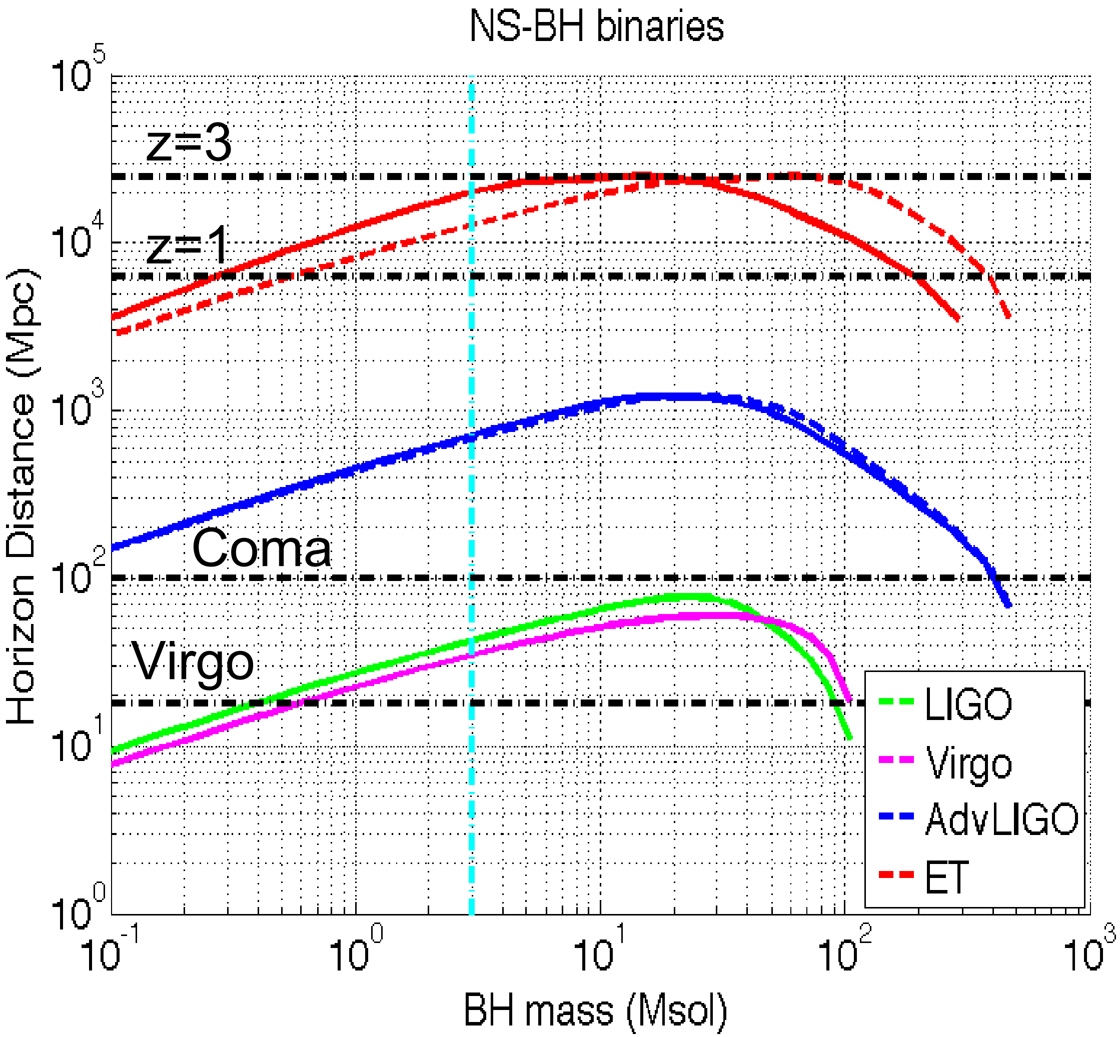
ET sensitivity to NS-BH inspirals

- Horizon distance
  - Distance at which we measure a matched-filter SNR=8 for optimally oriented and overheard sources

— — observed mass

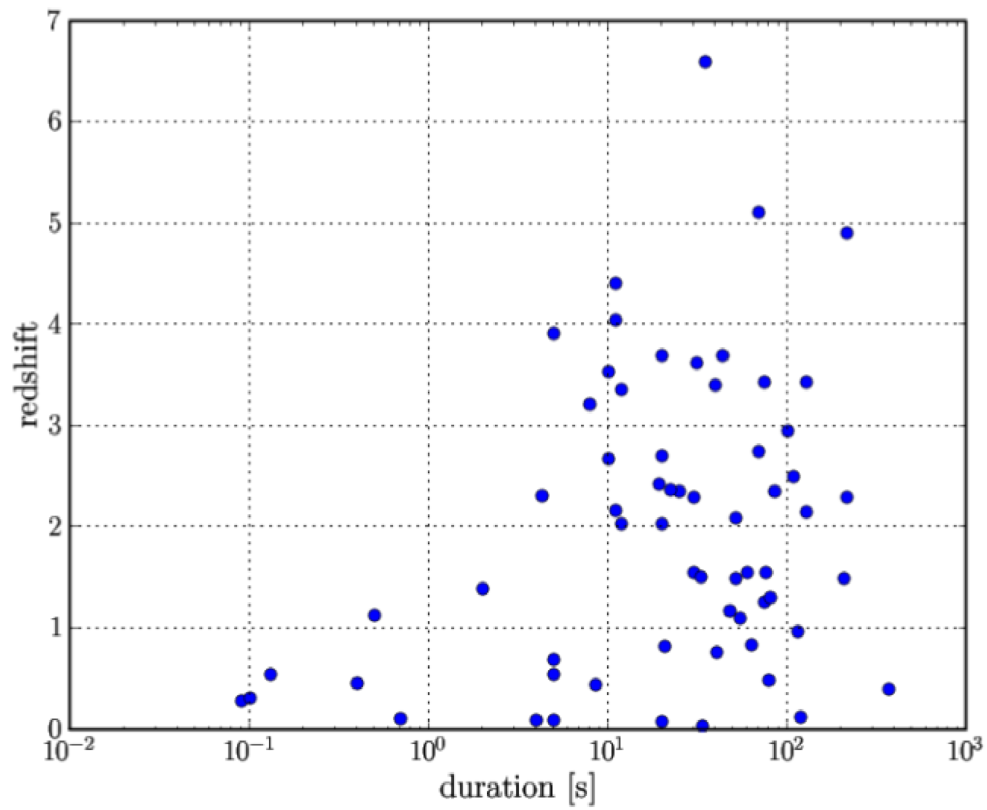
—— instrinsic mass

- Initial ifos: ~40Mpc
- ET: cosmology!
- See extra slides at end of talk for horizon distance plot for symmetric binaries



Cosmology with ET

- Principle:
  - Assuming inspiral progenitors for short GRBs
  - Measure redshift z from GRB's electromagnetic emission
  - Measure luminousity distance D_L from GW detection
  - z and D_L used to constrain cosmological parameters, H_0, Ω_m, Ω_d, w
  - See Arun et al. Phys. Rev. D 76, 104016 (2007) and arXiv:0810.5727



- Redshift of short GRBs
  - mean(z) ~ 0.5
  - GRB 080913 z~6.9! Perez-Ramırez et al. arXiv:0810.2107

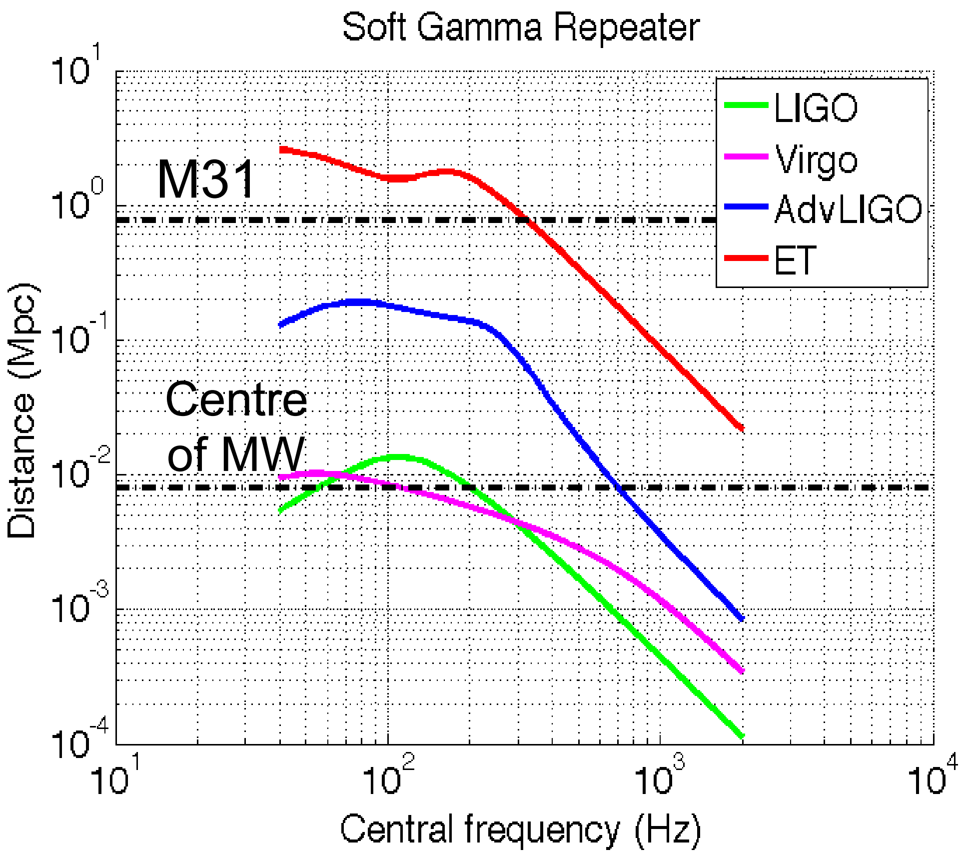
Unmodelled burst GWs

- Currently we set upper limits on hrss amplitude assuming circular polarized sine-Gaussian
  - 90% upper limit on hrss amplitude ~10 x $S_h(f)^{0.5}$
- Assume some intrinsic isotropic energies of GW sources:
  - Soft Gamma Repeaters, upper limit on E^{GW}_{iso} ~10^{46} erg (see refs in Astrophys. J. 681 (2008) 1419 and arXiv:0808.2050)
  - Core-collapse supernovae (rotating core and bounce), E^{GW}_{iso} ~10^{-8} $M_{Sol}c^2$ ~10^{46} erg (Table 1 of Ott (2008) arXiv:0809.0695)
  - Merger phase of compact body coalescence, E^{GW}_{iso} ~ 0.05 $M_{Sol}c^2$
  - Collapsar, E^{GW}_{iso} ~ 0.05 $M_{Sol}c^2$
- Calculate upper limit of observable distance using:

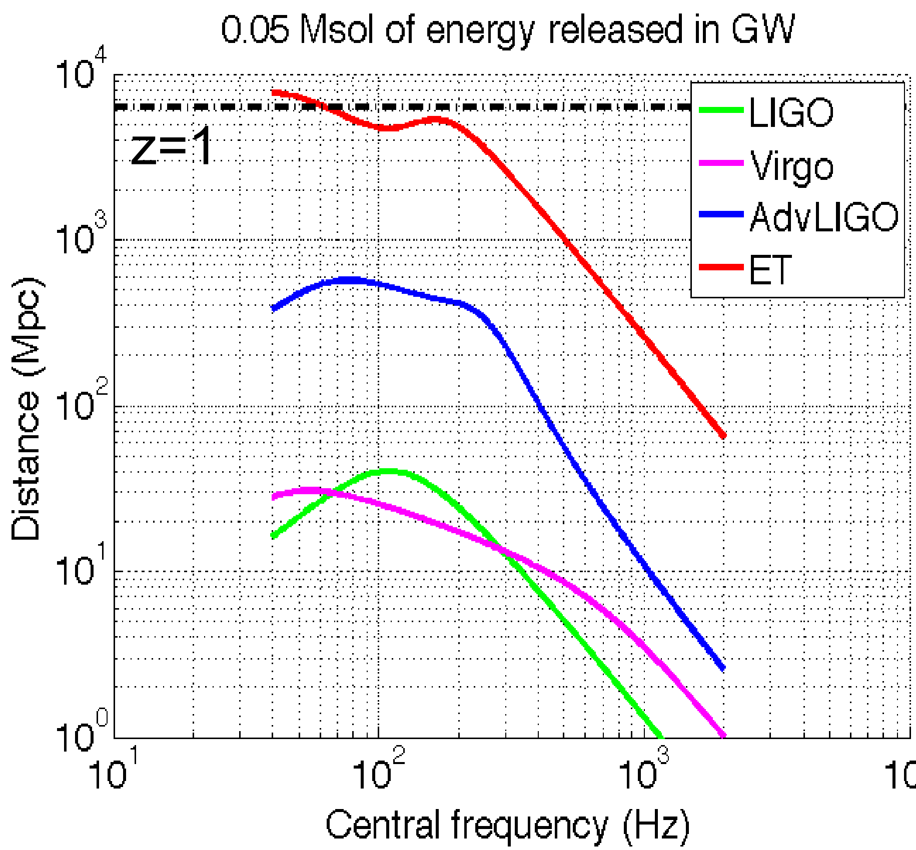
$$E_{\rm GW}^{\rm iso} \approx \frac{\pi^2 c^3}{G} D^2 f_0^2 h_{\rm rss}^2$$

Sensitivity of ET to unmodelled bursts

- $E^{GW}_{iso} \sim 10^{46}$ erg
- SGR giant flares and core collapse SN



- $E^{GW}_{iso} \sim 9\times10^{52}$ erg
- Merger phase of compact body coalescence, hypernovae



Einstein Telescope

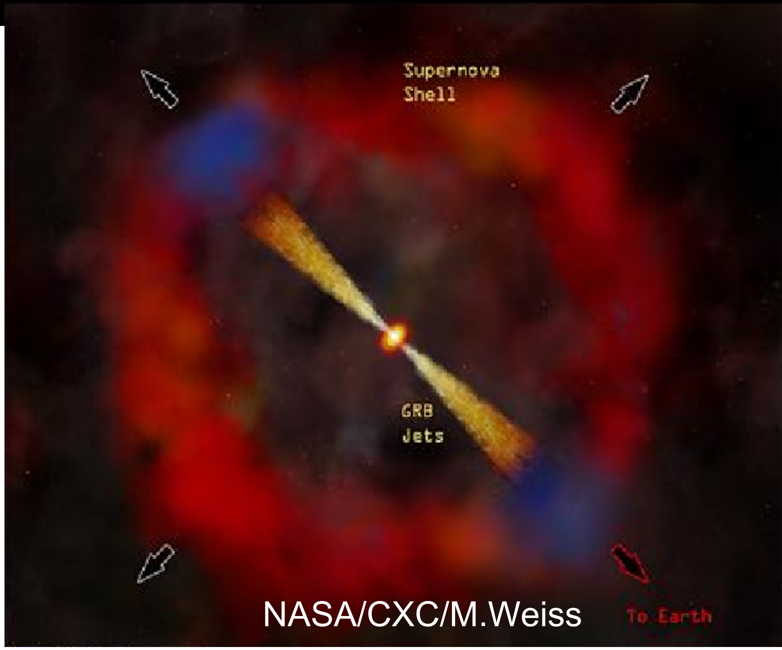
- Distance at which we can expect one progenitor formed per year:

	Formation Rate [Myr^{-1}galaxy^{-1}]		Distance [Mpc]		Optimal SNR		
	Standard	Range	Standard	Range	Initial ifo	Adv LIGO	ET
DNS	1.2	0.01-80	220	53-1100	~1	~18	~350
BH-NS(a)	2.6	0.001-50	170	62-2300	~2	~30	~600
(b)	0.55	0.001-50	280	62-2300	~1	~20	~380
BH-WD	0.15	0.0001-1	430	230-4900			
BH-He	14	0.1-50	95	62-490			
Collapsar	630	10-1000	27	23-110	<10	<160	<1000

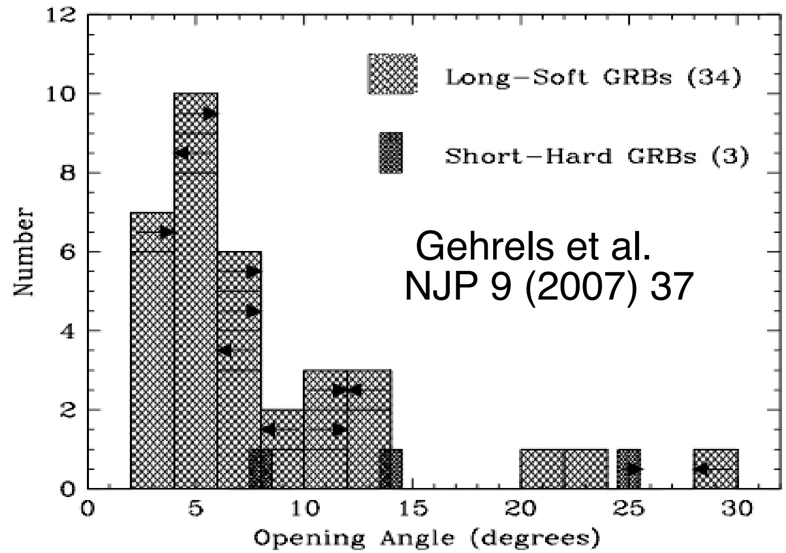
From: Kobayashi and Meszaros ApJ. 589 (2003) 861-870,
Based on: Fryer, C.L., Woosley,S.E. & Hartmann,D.H. 1999b, ApJ, 526, 152.

Beaming of short GRBs

- GRBs are expected to be beamed
  - See e.g., Frail et al. ApJ 562 L55 (2001)
- Einstein telescope
  - Measure both + and x polarization components of a GW
  - Possible to reconstruct (evolution of) inclination angle of inspiral
- Combine EM and GW observations to investigate beaming of short GRBs
  - Even with sky position and distance known it is difficult to untangle inclination and polarization angles, more in Chris Van Den Broeck's talk



NASA/CXC/M.Weiss



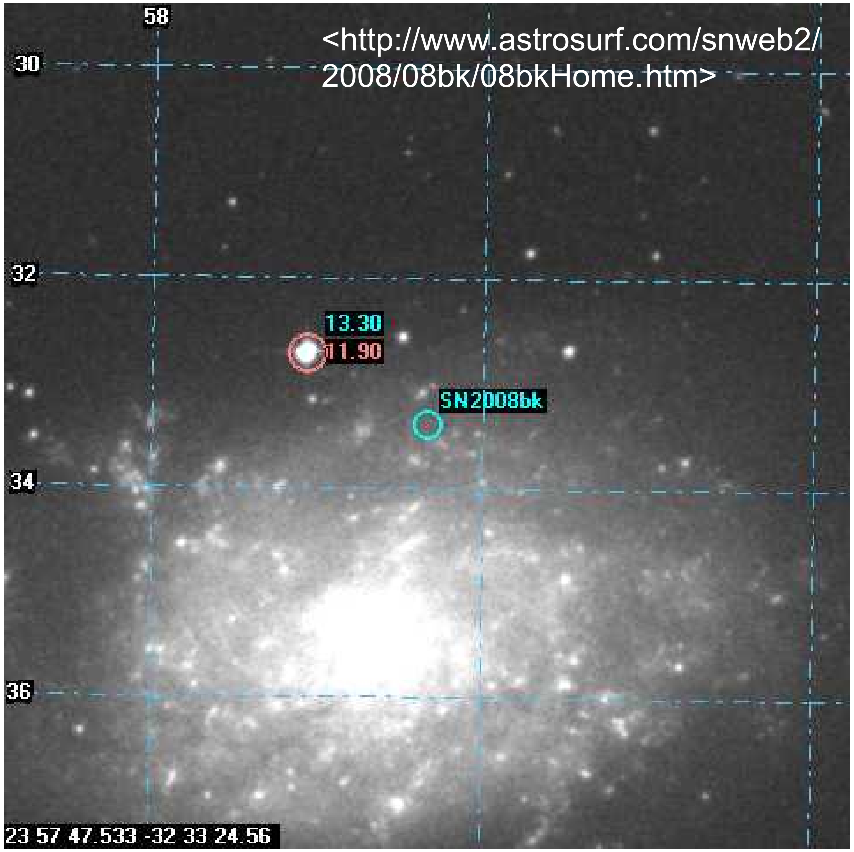
Gehrels et al. NJP 9 (2007) 37

SN-GRB connection

- "...most long-duration soft-spectrum GRBs are accompanied by massive stellar explosions (GRB-SNe)."
  - See Woosley and Bloom (2006) Ann. Rev. Astron. Astrophys. 44 (2006) 507-556
  - GRB 980425 - SN 1998bw coincident in time and sky location
- Long GRBs may be subset of Type Ic SNe
  - GRBs from only the more massive, highly rotating (~1%) stars
- Uncertainty in SN mechanism, core-bounce shock requires revival (Ott (2008) arXiv:0809.0695) and unbind the stellar envelope
  - Neutrino
  - Magneto-rotational, rapidly spinning progenitor, jet like emission, relevant to long GRB
  - Acoustic mechanism
  - Difficult to probe with traditional EM, use GWs and Neutrinos
  - Expect different mechanisms to have different GW signature

Supernovae

- SNe rates, Ott (2008) arXiv:0809.0695
  - < 1 core-collapse SN per 20 yrs in local group
  - < 1 core-collapse SN per ~2yrs in 3-5 Mpc
- SN 2008bk within NGC 7793 spiral galaxy, ~3.9Mpc



SN 2008bk

- Optimal SNRs for variety of SN progenitors at 3.9Mpc
- Multiply AdvLIGO SNRs x15 to find ET SNRs
  - Shaded progenitor models become detectable with SNR>8
  - Constrain progenitor model by (non)detection!

Process	Model	LIGO 2 4 km	LIGO L1/H1 4 km	LIGO H2 2 km	GEO600 600 m	VIRGO 3 km
Rotating Collapse	s11A2O13	0.124	0.008	0.005	0.001	0.009
& Bounce	s20A2O09	0.130	0.008	0.006	< 0.001	0.010
[99]	s40A3O12	0.214	0.024	0.013	< 0.001	0.018
Rotational Instability	s20A2B4	0.319	0.021	0.014	0.003	0.022
[42, 104, 105]	s20A2B4 ($\times 5$)	0.713	0.047	0.031	0.007	0.049
PNS g-modes	s11.2	0.147	0.006	0.005	0.002	0.009
[22, 23]	s15.0	0.454	0.021	0.015	0.006	0.027
and section 6.1	s25.0	0.612	0.029	0.020	0.007	0.037
	s25.0 ($\times 2$)	0.866	0.041	0.029	0.009	0.052
	s25WW	5.331	0.217	0.151	0.057	0.328

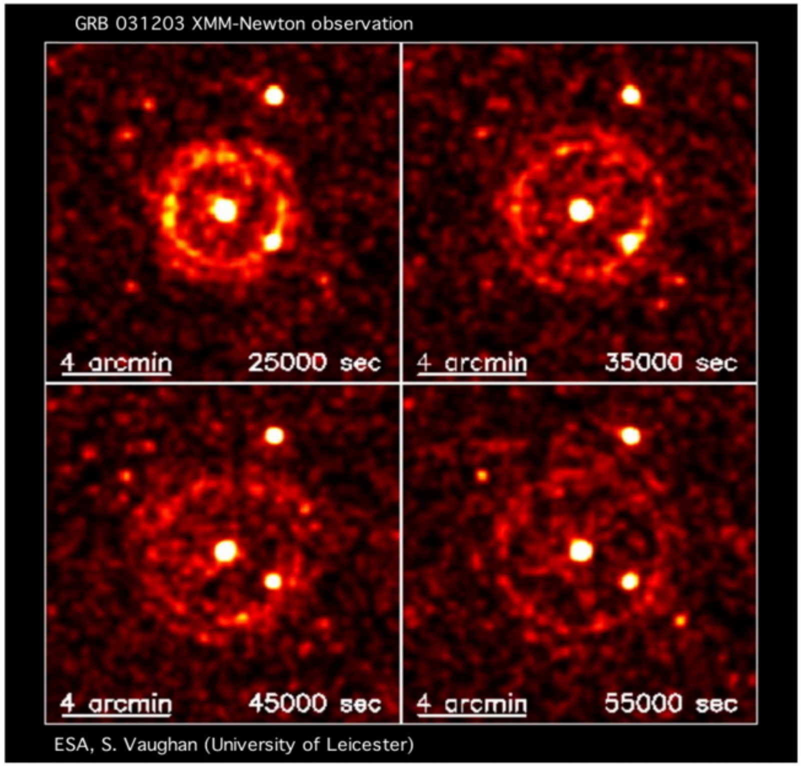
Ott (2008) arXiv:0809.0695

- Multiply SNRs x500 for SN in centre of Milky Way
  - All models detectable with high SNR for AdvLIGO and ET

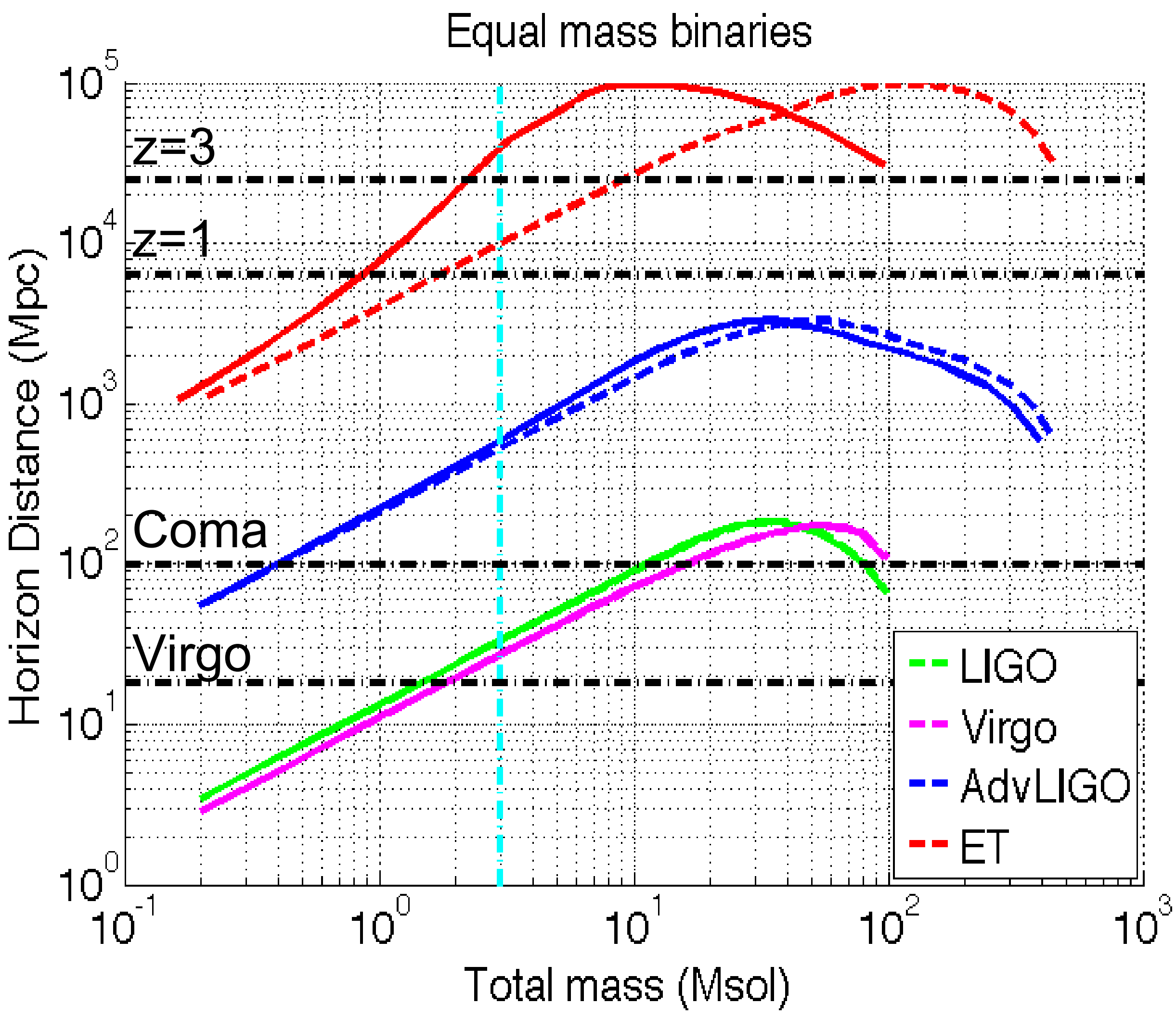
Conclusions

- ET will allow detection of short GRB progenitors to cosmological distances (z~3)
  - EM and GW observations can be used to constrain cosmological parameters
- Depending on progenitor model ET will detect a core-collapse SNe every few years
  - Non-detection will constrain progenitor model

Extra slides



ET sensitivity to equal mass binaries



Neutrinos

- Neutrinos....
  - <http://en.wikipedia.org/wiki/Neutrino_detector>
  - <http://en.wikipedia.org/wiki/List_of_neutrino_experiments>
  - What is current/predicted sensitivity? External trigger? Diagnostic?
  - Future detectors...