Compact Binary Inspiral and the Science Potential of Einstein Telescope

Sukanta Bose, Richard O'Shaughnessy, B.F. Schutz, B.S. Sathyaprakash, Chris Van Den Broeck

APP 2009, Edinburgh, 9 June 2009

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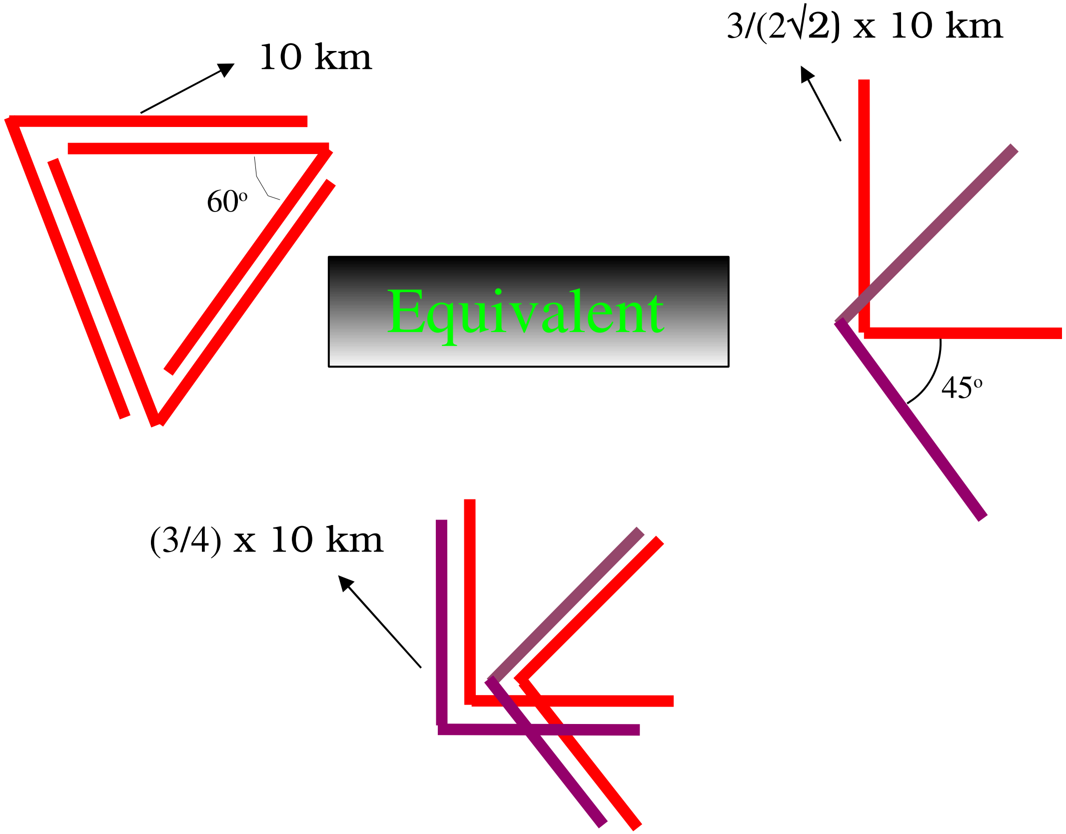
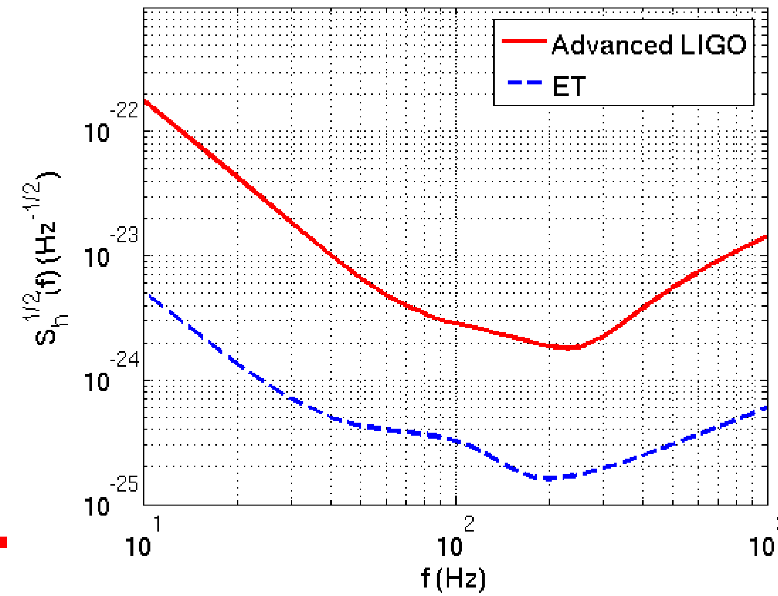
Overview

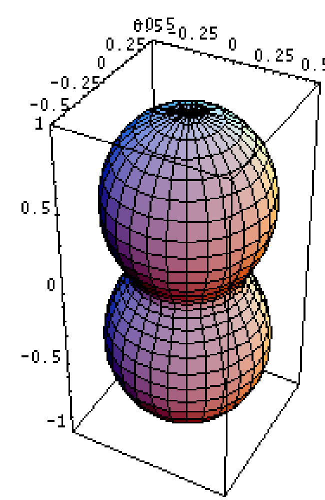
- What could ET look like?
- Compact binary coalescence as seen in ET
- What can we learn?

Some assumptions about ET

- Provisional noise curve
- 3 interferometers in equilateral triangle
- 30 km total tunnel length







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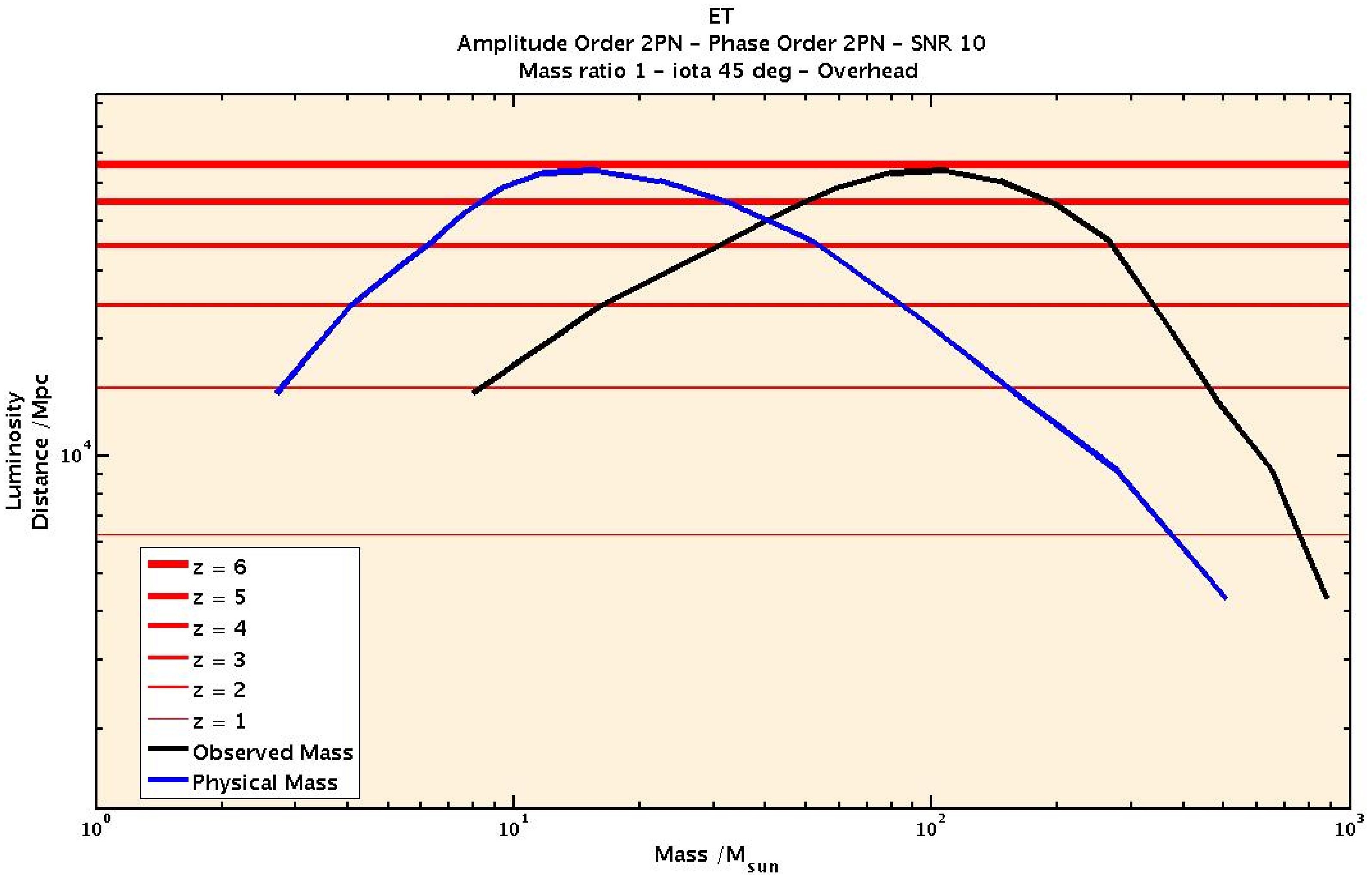
Compact binary inspiral signals as seen in ET



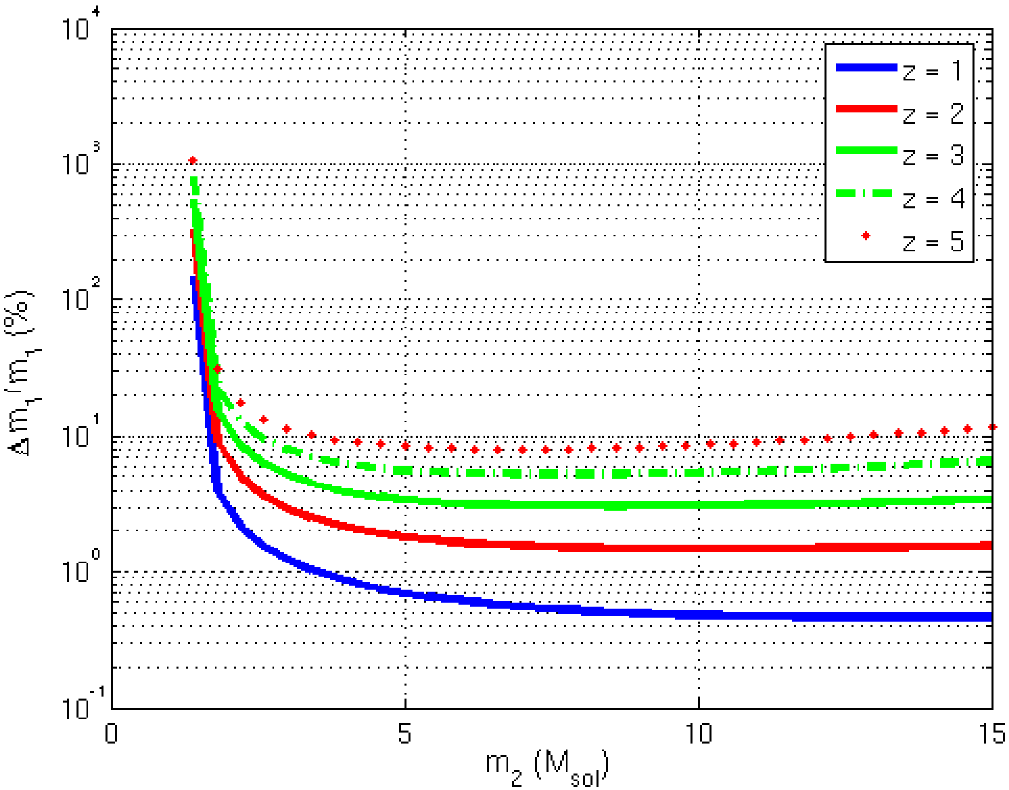
What can we learn?

Some questions we can hope to address:

- What is the mass distribution of compact objects, and how has this distribution evolved over cosmological timescales?
- In particular, what is the mass range for neutron stars?
- What is the lowest mass a black hole can have?
  (Is there an intermediate state between neutron stars and black holes?)
- What is the mechanism behind gamma ray bursts (GRBs)?
- Can we use compact binary inspiral events as standard sirens and use them to do cosmology?

What is the mass range of neutron stars?

- Let one object in a binary be a neutron star; how well can we measure its mass as a function of the other object's mass?
- Mass measurement better than a percent out to $z \sim 1$
- Secondary object needs to be a black hole
- Asymmetric binaries: Can map the mass distribution out to redshift of several



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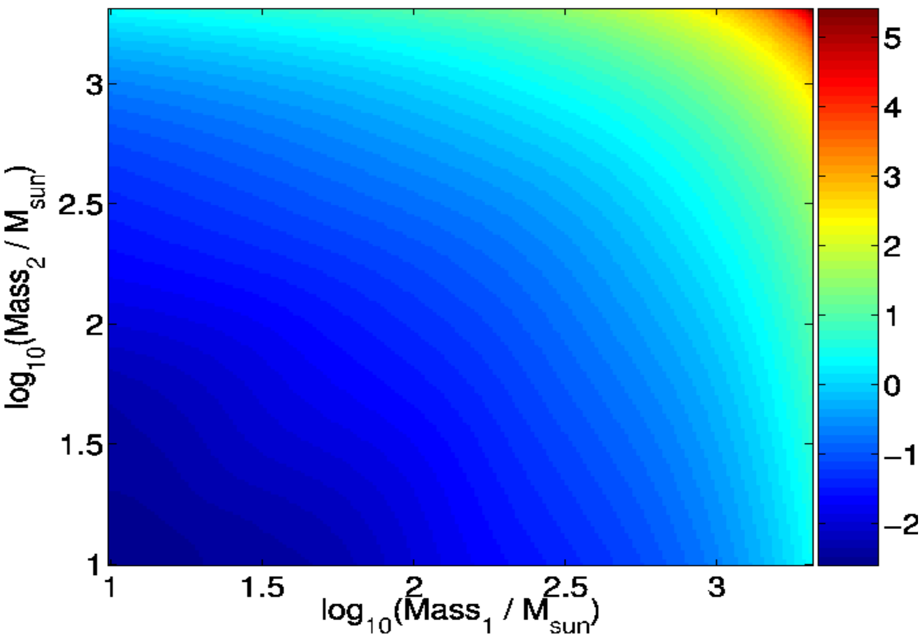
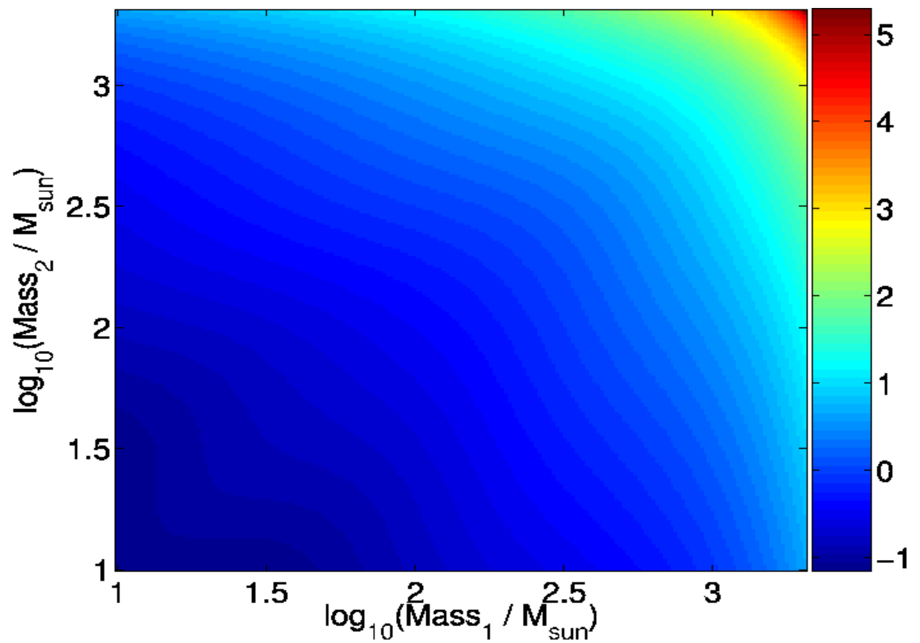
Weighing black holes over cosmological distances

- Estimation of mass parameters at a distance of 3 Gpc

$\log_{10}$ of percentage error in chirp mass

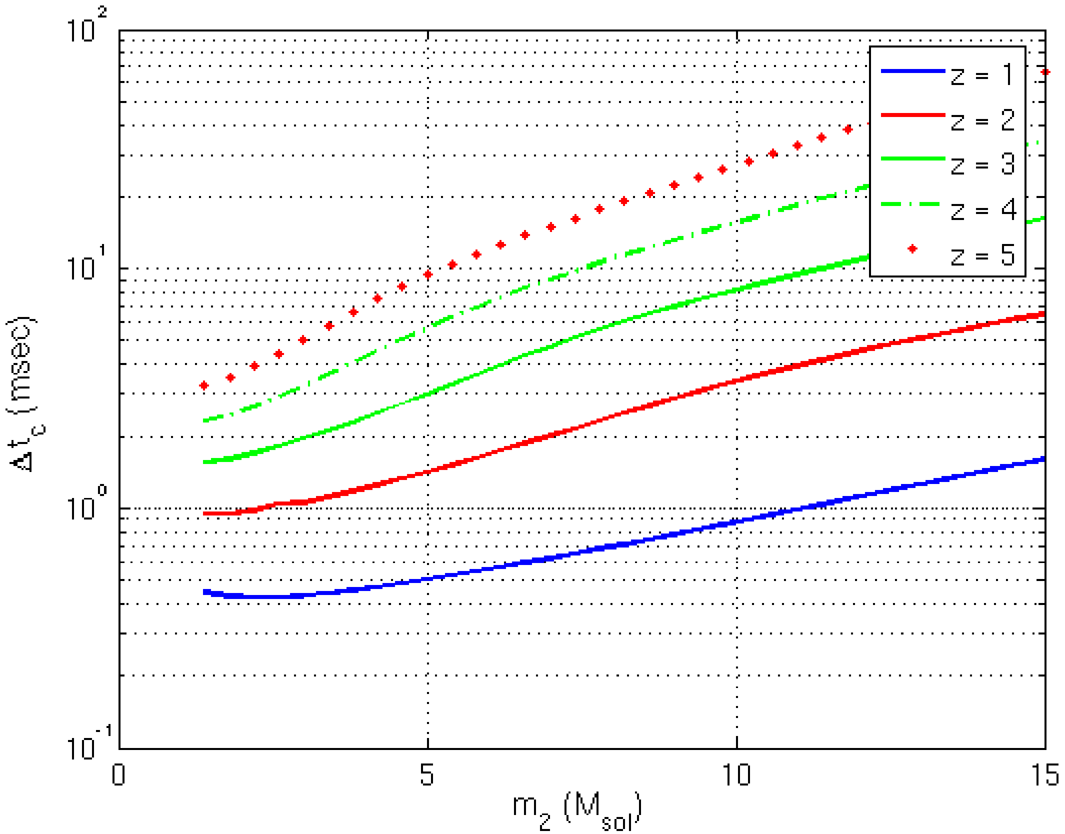


$\log_{10}$ of percentage error in η



What is the mechanism behind GRBs?

- Some short, hard GRBs could be caused by the inspiral of two neutron stars, or a neutron star and a black hole
- Beamed gamma ray emission perpendicular to the inspiral plane
- Constrain such models by:
  - Measuring the promptness of gravitational radiation compared to the gamma radiation
  - Constraining the opening angles of the beams by measuring inclination angle?



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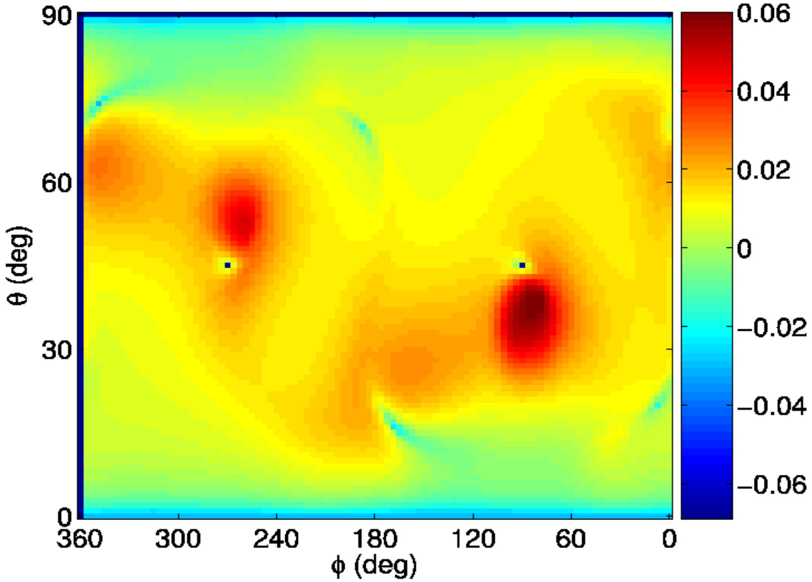
Pointing accuracies for ET as part of a network

- If ET part of a network of at least three detectors, will be able to infer sky position from differences in times of arrival
- For ET together with two L-shaped detectors with AdvLIGO or ET noise curve, typical pointing accuracies of a few square degrees
- Coalescences involving a neutron star will have EM counterparts:
  - Strongly beamed GRB-like signature
  - Infrared/optical afterglow

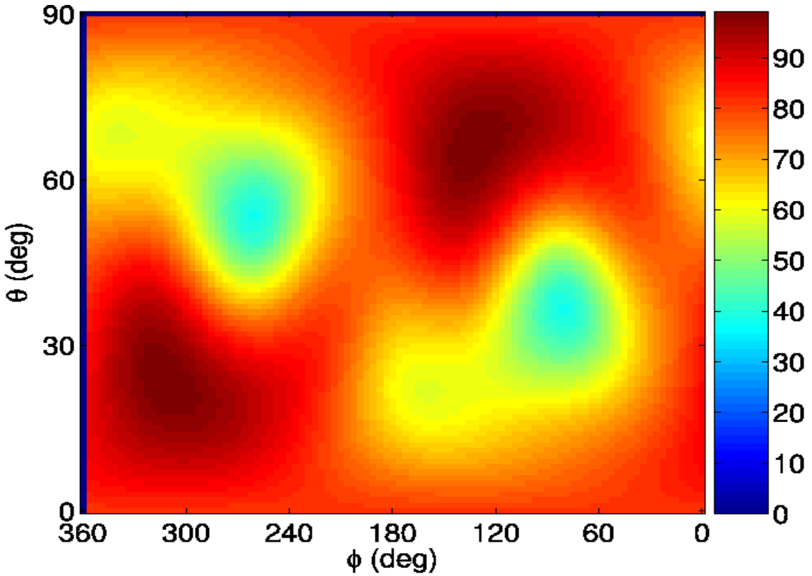
  $\rightarrow$ Possibility of finding the host galaxy
- Importance of pointing accuracy:
  - Even without EM counterparts, study whether the spatial distribution of binary coalescences follows distribution of visible matter
  - Definitive identification of (some or all) short GRBs as being compact binary coalescence events
  - Use of binary coalescence as "standard sirens"

Pointing accuracies

- Example: An ET located in Cascina and two L-shaped ifos with ET PSD at Livingston and Hanford and a $(10,20)M_{sun}$ system



Sky position accuracy in $\log_{10}(\deg^2)$



SNR as a function of sky position

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Determining the dark energy equation of state

- From supernovae studies: Universe appears to be accelerating
- Possible explanations:
  - General relativity inadequate at large length scales
  - Cosmological constant
  - Dark energy
- Dark energy:
  - New form of matter with positive density, negative pressure
  - FRW Universe, model dark energy as perfect fluid:

    $p = w\,\rho$ $\qquad$ $w = w(z)$ equation of state parameter
  - If $w = -1$ then cosmological constant
  - Current constraints from 5 year WMAP and supernovae studies:

    $-1.11 < w < -0.86$
  - Following Schutz '86: Use inspiral GW events as "standard sirens"

Determining the dark energy equation of state

- Compact binary coalescences as "standard sirens":
  - From the gravitational-wave signal, get luminosity distance D_L
  - If sky position can be obtained, identify host galaxy and get redshift z
  - Relationship $D_L(z)$ depends sensitively on cosmological parameters

    H_0, Ω_m, Ω_d, w
- With large number of sources, fit $D_L(z)$
- Need to take into account instrumental errors as well as weak lensing errors
  - Instrumental: $\Delta D_L / D_L \sim 1/SNR$
  - Weak lensing: linear in z (and ~5% at z=1)

  $\rightarrow$ Combine as sum of quadratures to get 1-sigma uncertainty in $D_L(z)$

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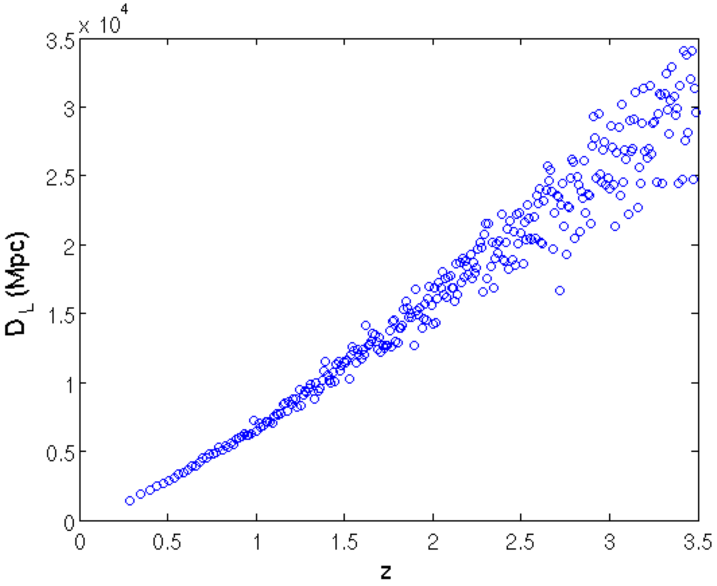
Determining the dark energy equation of state

- Place 1000 binary neutron star sources uniformly in comoving volume, assume strong EM counterparts so that hosts can be found, redshifts known
- For each, take "measured distance" to be

  $D_L + \delta D_L$ where

  - D_L computed from fiducial, "true" cosmological model
  - δD_L drawn from Gaussian distribution (with 1-sigma spread as in previous slide)



- Assume H_0 known, $\Omega_m + \Omega_d = 1$: need only fit $D_L[\Omega_m, w](z)$
- Repeat 5000 times (different "realizations") $\rightarrow$ get 5000 values for Ω_m, w
- 1-sigma spreads: $\Delta\Omega_m = 9.4\%$, $\Delta w = 7.6\%$
- *Circumvents cosmic distance ladder!*

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Summary and future work

Using inspiral events:

- Find out what is the mass distribution of compact objects, and how this distribution has evolved over cosmological timescales
- Study the mass range for neutron stars
- Find out the mechanism behind short gamma ray bursts
- Use compact binary inspiral events as standard sirens to do cosmology

Future work:

- What about merger and ringdown?
- How can we constrain detailed inspiral models for GRBs?
- What do NS and BH mass distributions tell us about progenitor channels?