Compact binary coalescence events and Einstein Telescope

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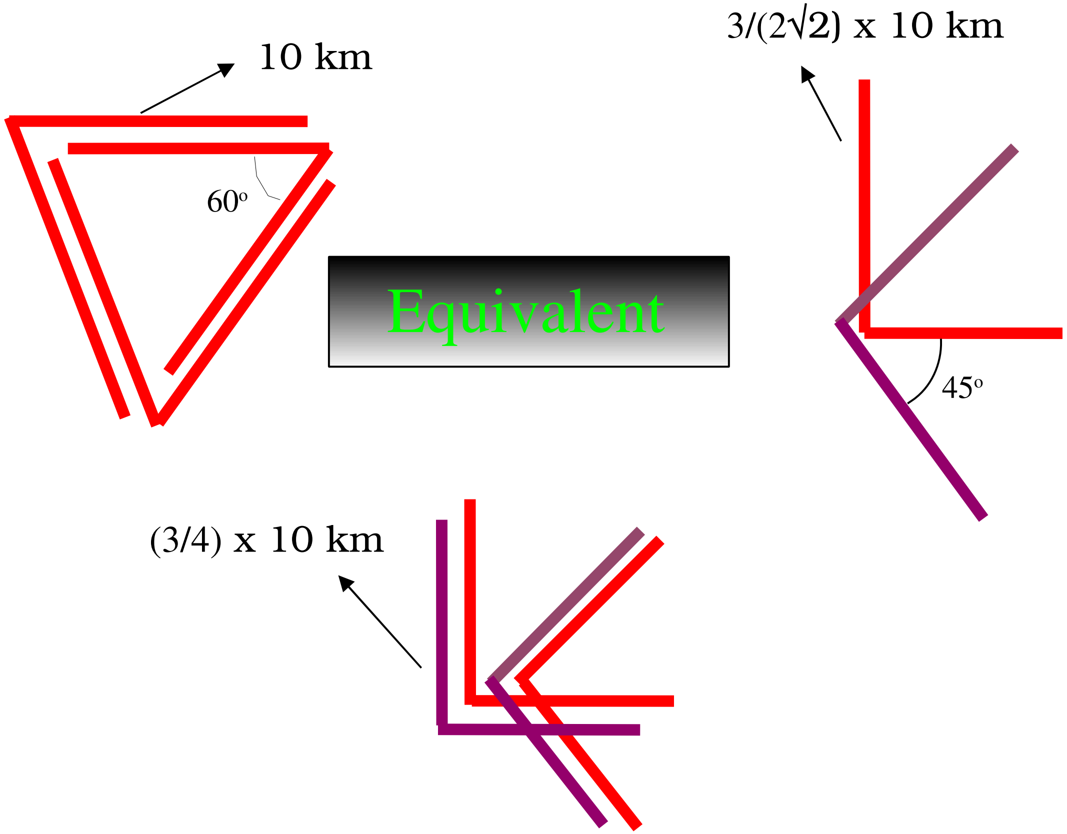
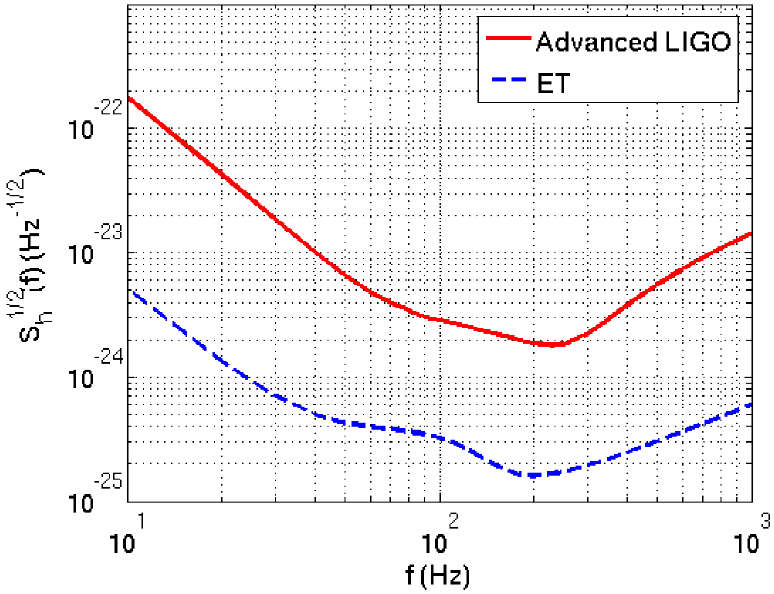
Overview

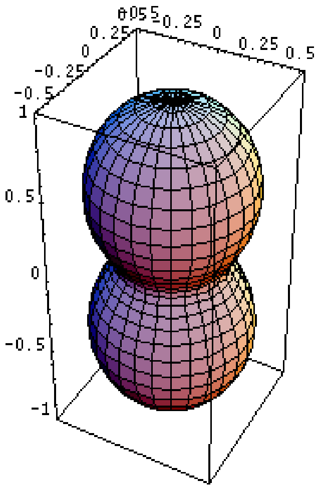
- Some assumptions about ET
- Compact binary coalescence as seen in ET
- Measuring the mass function of neutron stars and black holes
- Constraining inspiral models for GRBs
- Pointing accuracies
- Cosmology: Using inspirals as standard candles

Some assumptions about ET

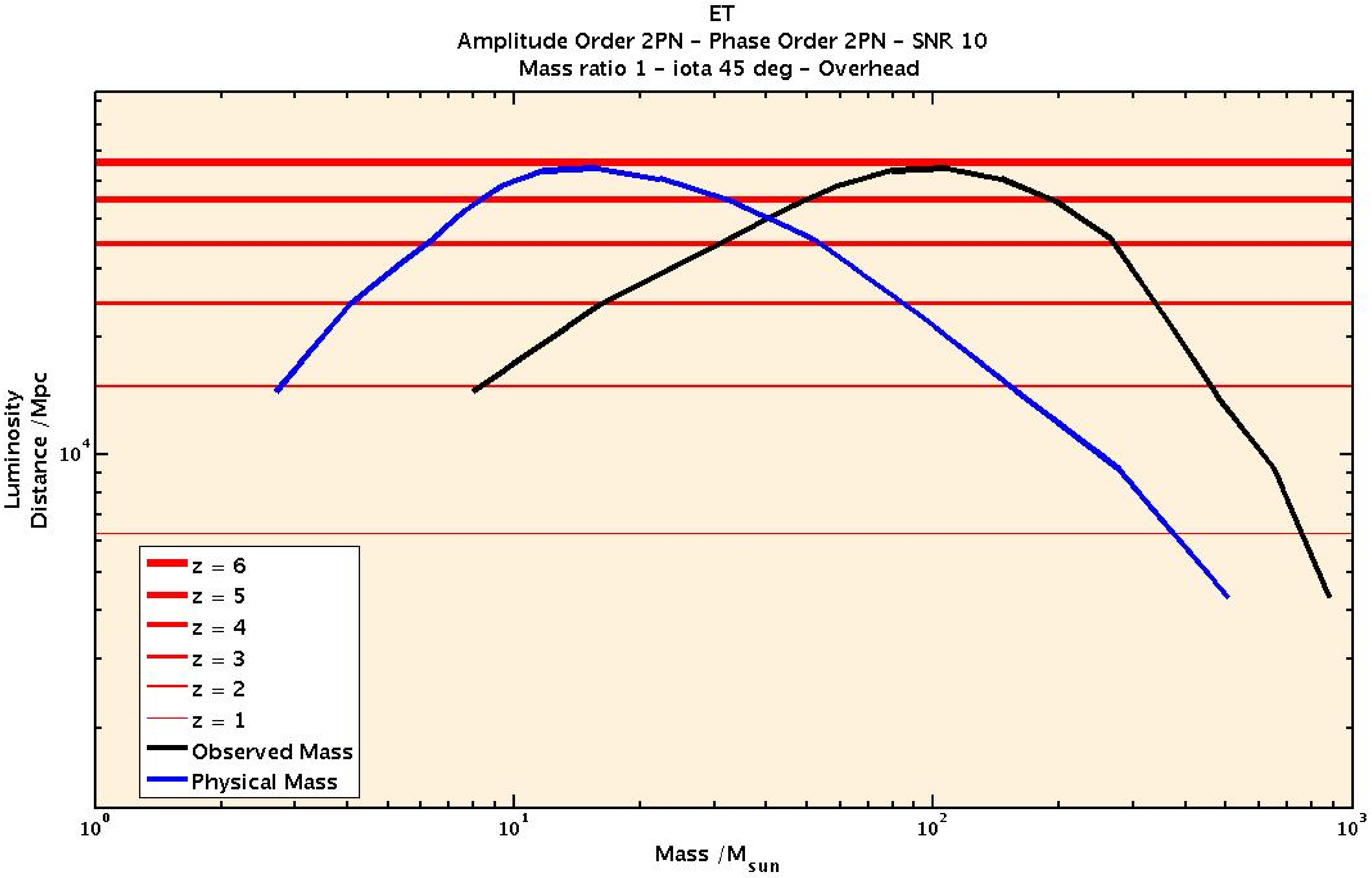
- Provisional noise curve
- 3 interferometers in equilateral triangle
- 30 km total tunnel length







Compact binary inspiral signals as seen in ET



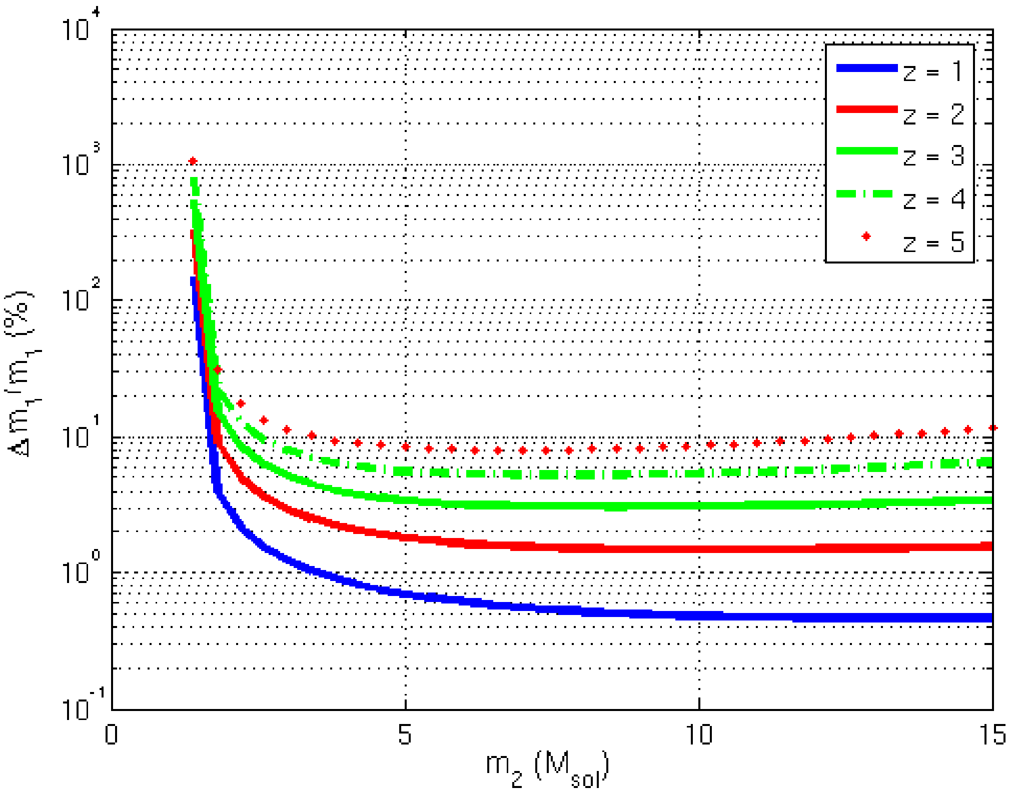
What can we learn?

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?

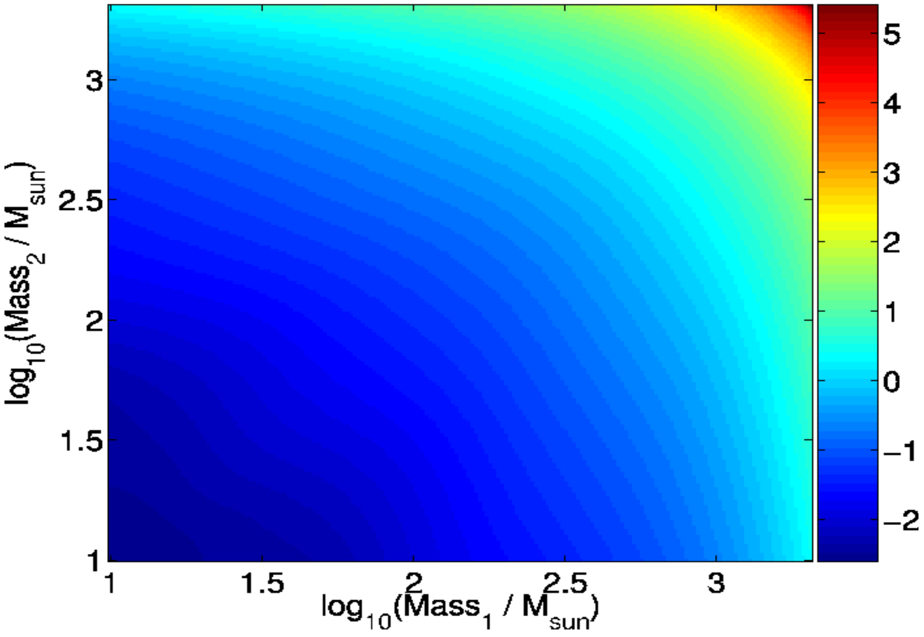
What is the mass range of neutron stars?

- 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 ~ 1
- Secondary object needs to be a black hole
- Asymmetric binaries: Can map the mass distribution out to redshift of several

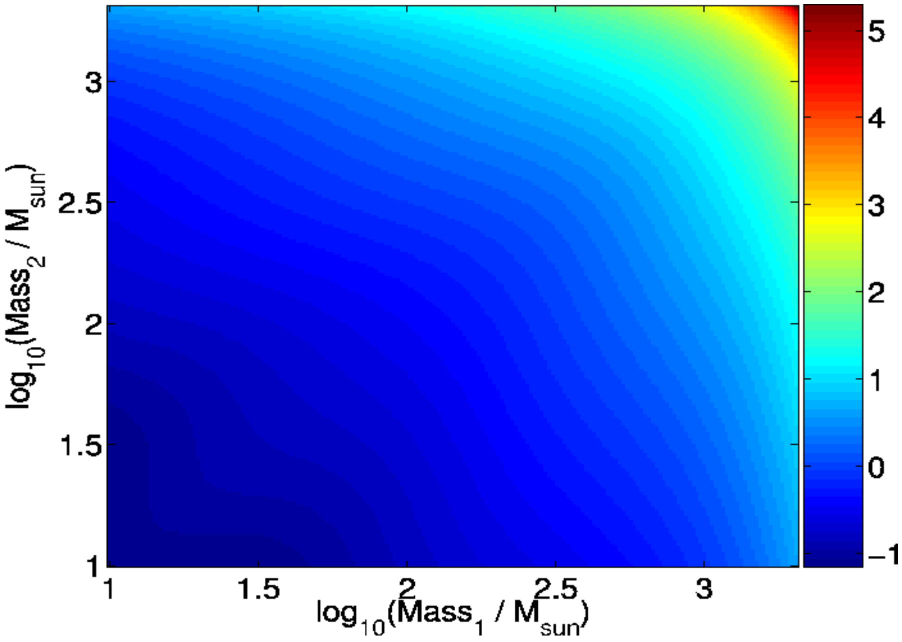


Weighing black holes over cosmological distances

- Estimation of mass parameters at a distance of 3 Gpc



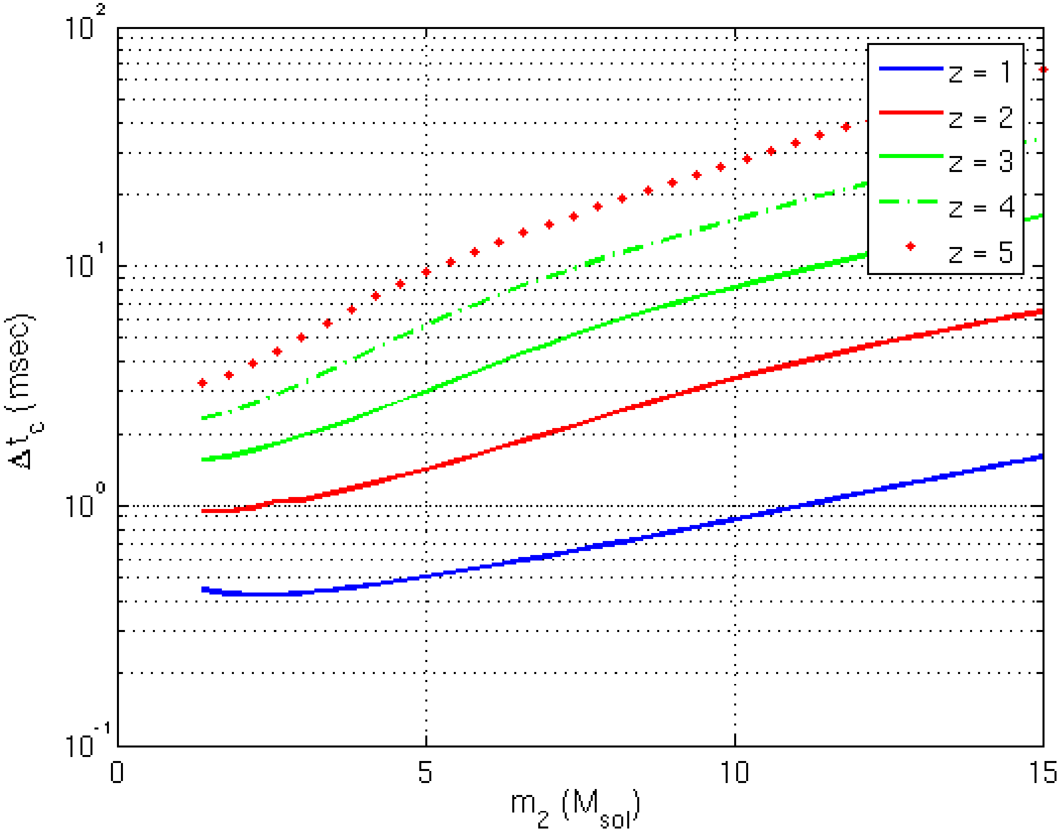
$\log_{10}$ of percentage error in chirp mass



$\log_{10}$ 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?



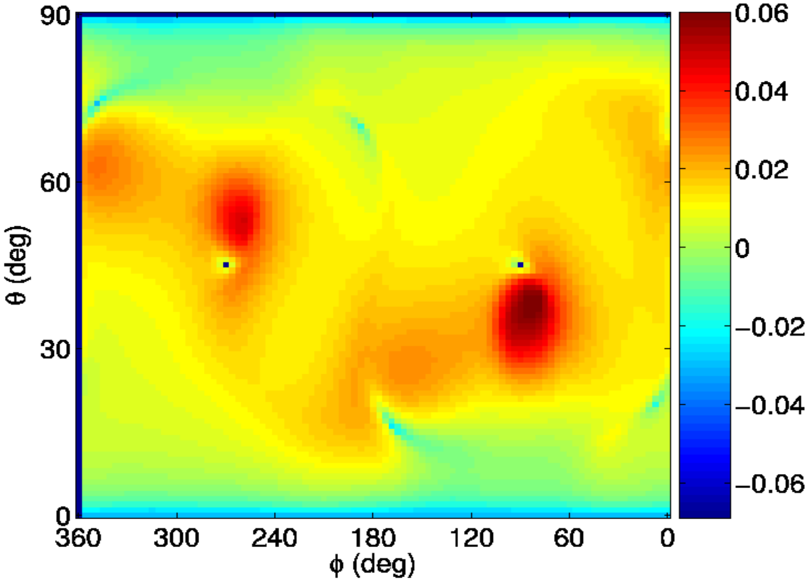
Pointing accuracies for ET as part of a network

- 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 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

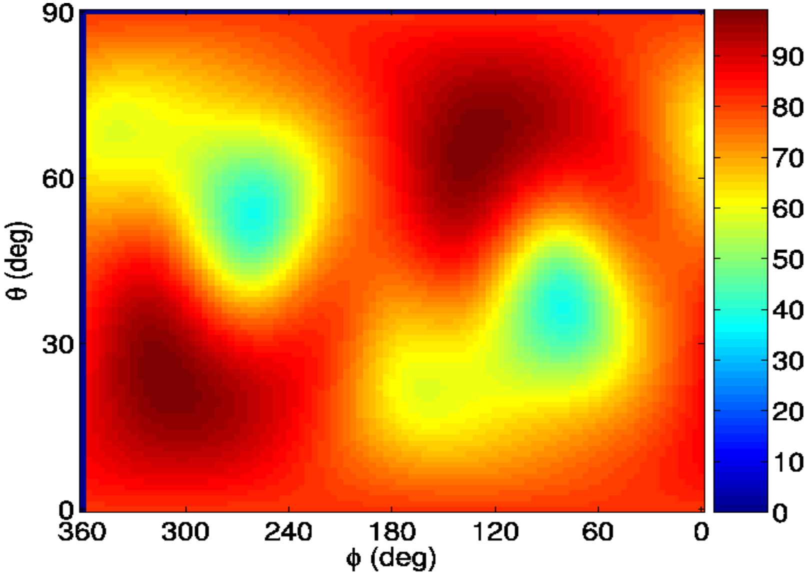
  → Possibility of finding the host galaxy
- Importance of pointing accuracy:
  - Even without EM counterparts, study whether the spatial distribution of binary coalescences follows distribution of visible matter
  - Definitive identification of (some or all) short GRBs as being compact binary coalescence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

Pointing accuracies

- Example: Three ETs, located at Cascina, Livingston and Hanford and a (10,20)M_{sun} system at 3 Gpc



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



SNR as a function of sky position

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:

    $p = w \rho$ $\quad$ $w = w(z)$ 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
- For simplicity, assume H_0, Ω_m, Ω_d known
- Estimate uncertainty on D_L using Fisher matrix formalism
- From error propagation formula:

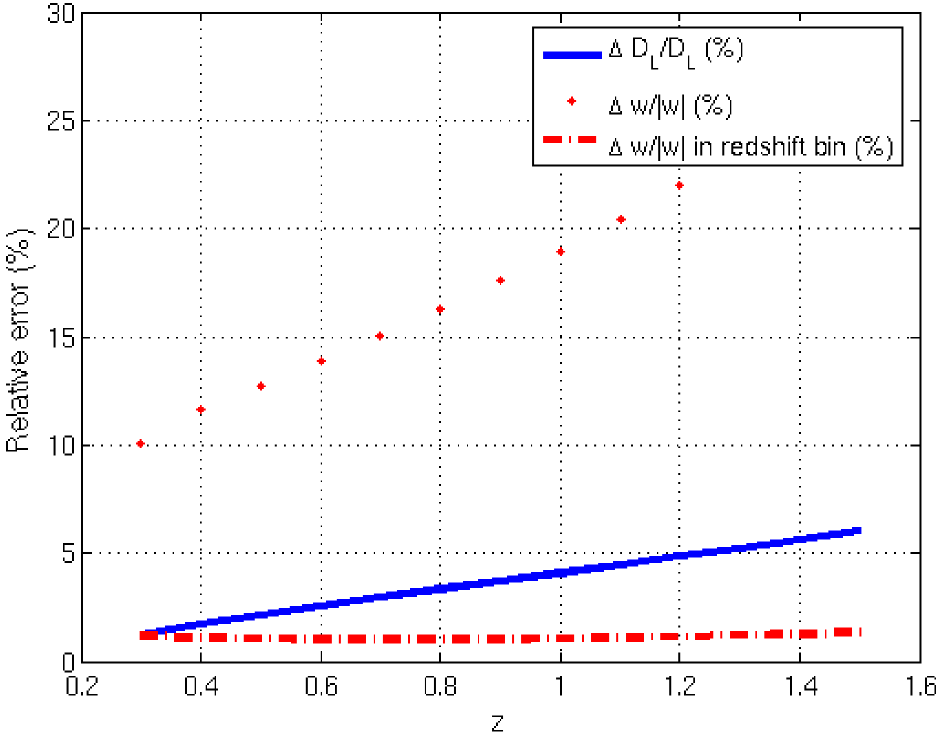
$$\Delta w = |\partial D_L/\partial w|^{-1}\,\Delta D_L$$

where $|\partial D_L/\partial w|^{-1}$ can be estimated from redshift and choices for H_0, Ω_m, Ω_d, w

Determining the dark energy equation of state

- Distance errors a few percent
- Individual errors in w large
- But: large numbers of sources
- Assume:

  - $(1.4,10)M_{sun}$ inspirals
  - Event rate 1 yr^{-1} in 300 Mpc radius
  - Each has identifiable host
  - w doesn't vary too much within bins of $\Delta z \sim 0.1$
  - Errors decrease with $\sqrt{n_{events}}$ where n_{events} number of events per bin



→ Trace evolution of w(z) with redshift coarseness 0.1

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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?
- More in-depth treatment of compact binary coalescences as standard sirens