Coincidences between gravitational waves (with LIGO) and gamma-ray bursts (with HETE-2)

Should we look for coincidences between the two? Of course! (Why not?) We could see GRB's which are “off-axis”. But what exactly are we getting ourselves into...?

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GWDAW-9, December 2004

Outline

1) How many coincidences do we expect?

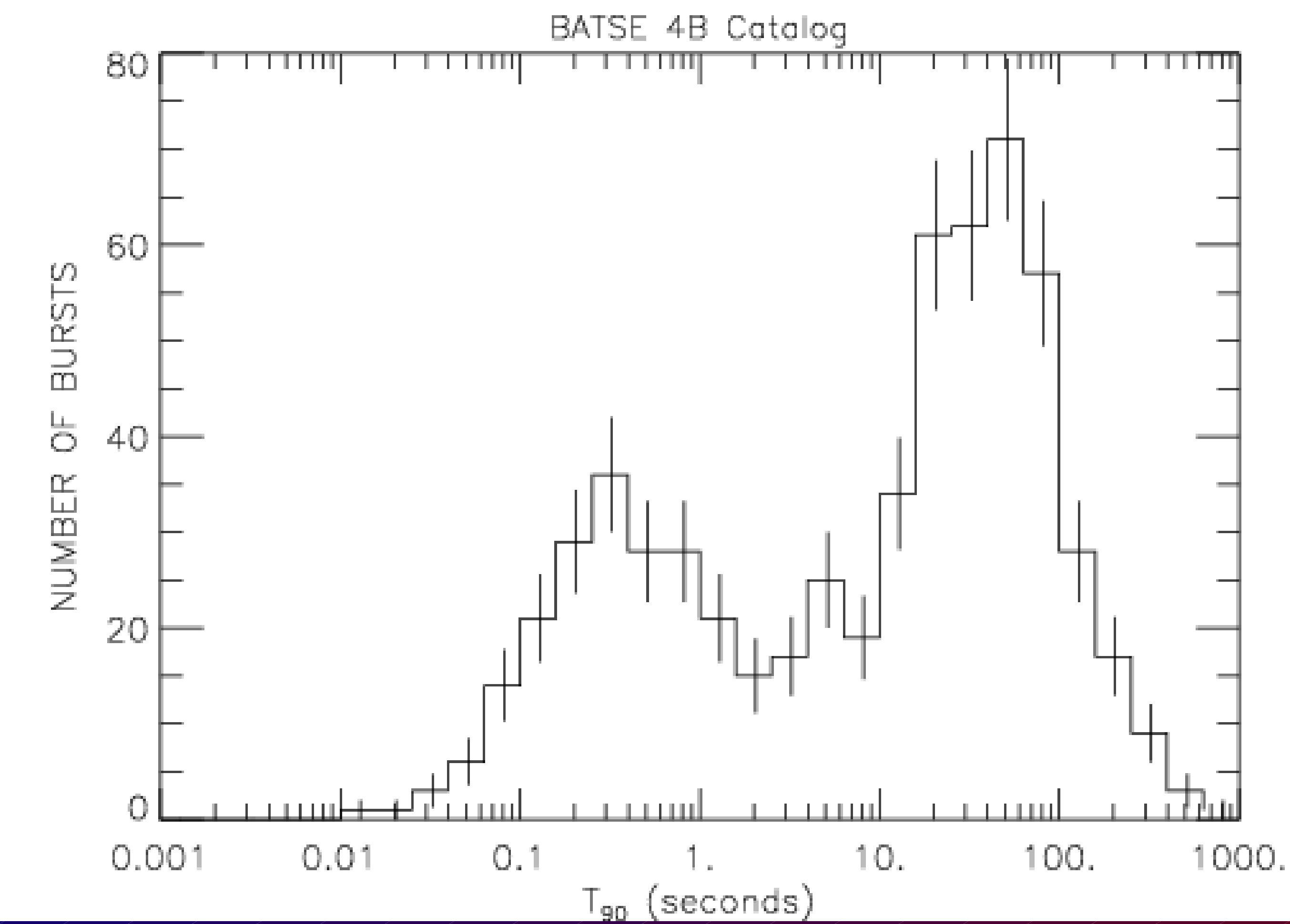
   – A Toy Monte-Carlo simulation throws events on the sky, using one model of long-duration GRB's

2) How might the answer to 1) be wrong?

   – Alternative models, or the lack thereof, could change what we expect

A little GRB backstory

- GRB's are generally divided into two categories:



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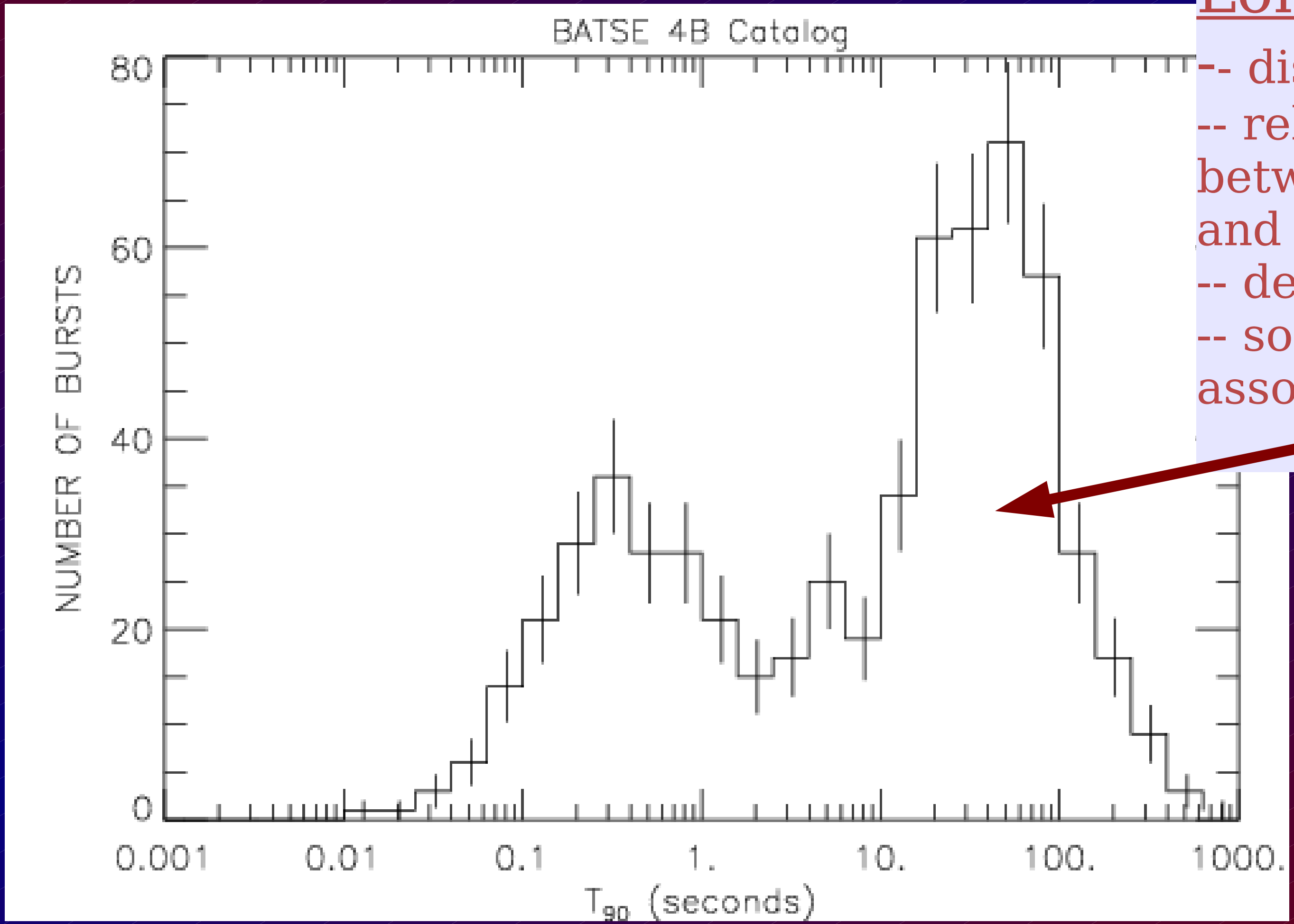


Long-duration:

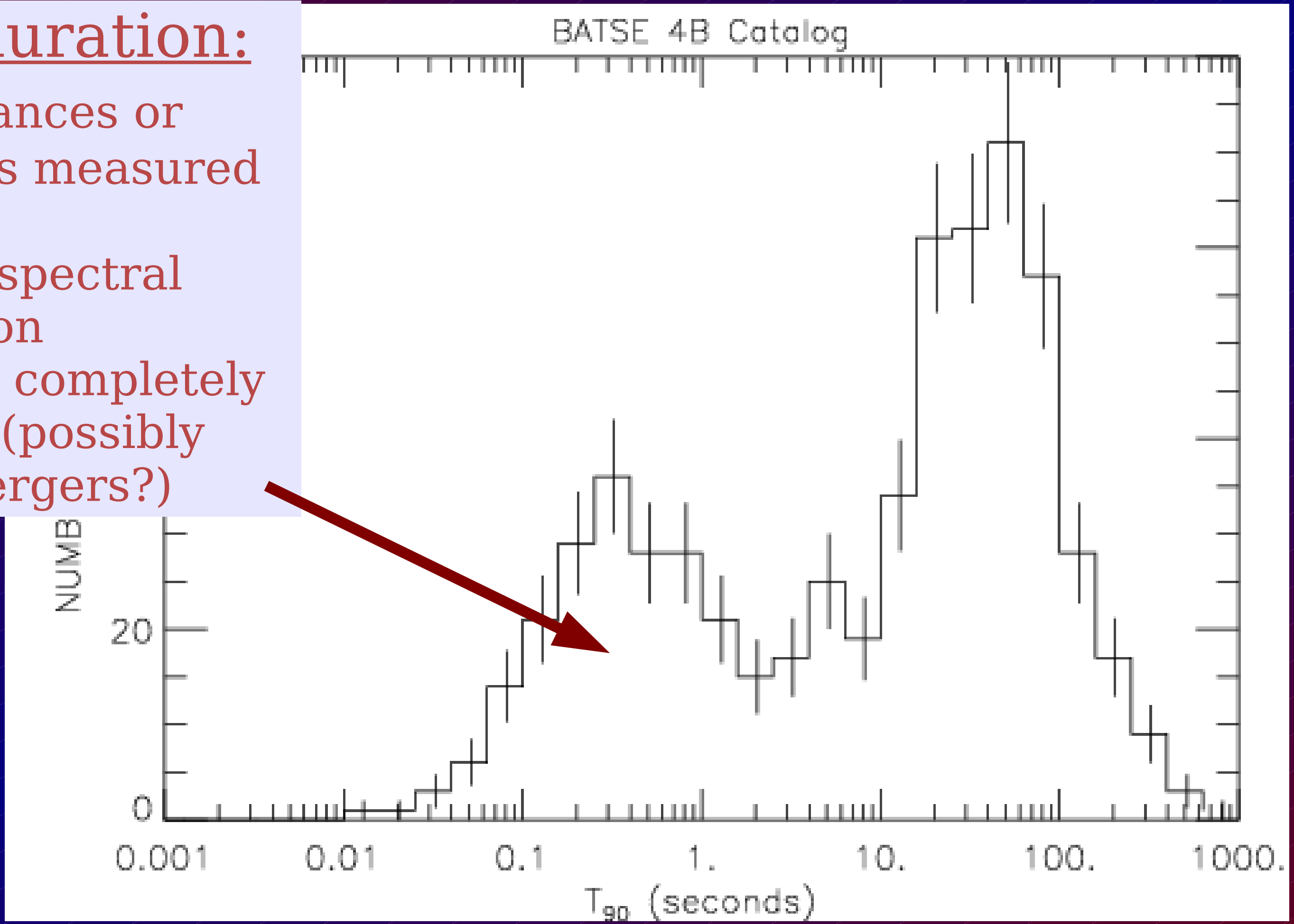
-- distances observed
-- relationships known between spectrum and energy
-- detailed jet models
-- some believed to be associated with SNe

A little GRB backstory

- GRB's are generally divided into two categories:

<u>Short-duration:</u>

-- no distances or afterglows measured yet
-- limited spectral information
-- sources completely unknown (possibly binary mergers?)

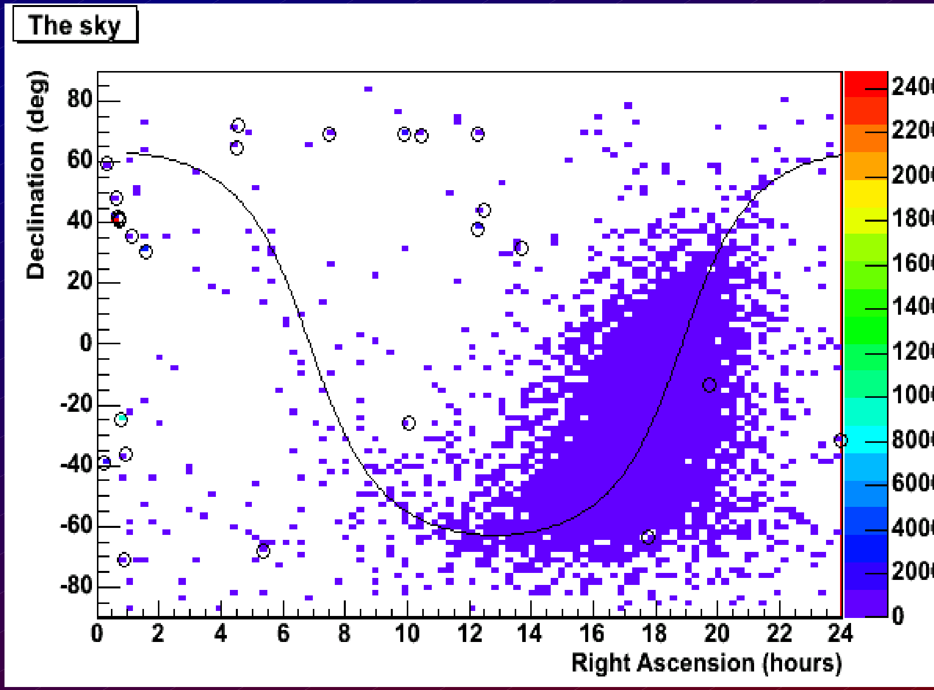


A Toy Monte Carlo for GRB's

- Simulate a population of GRB's, with distributions of:
  - Sky position
  - Distance
  - Orientation angle
  - Polarization angle (for GW's)
- ... and a model of:
  - gamma-ray emission properties
  - GW emission properties
  - cosmology and SFR
  - local event rate

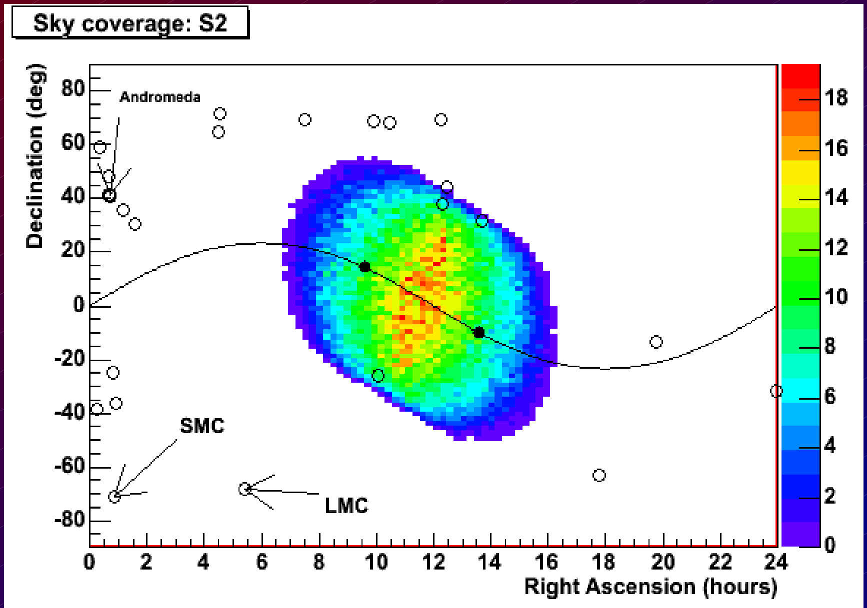
Distances

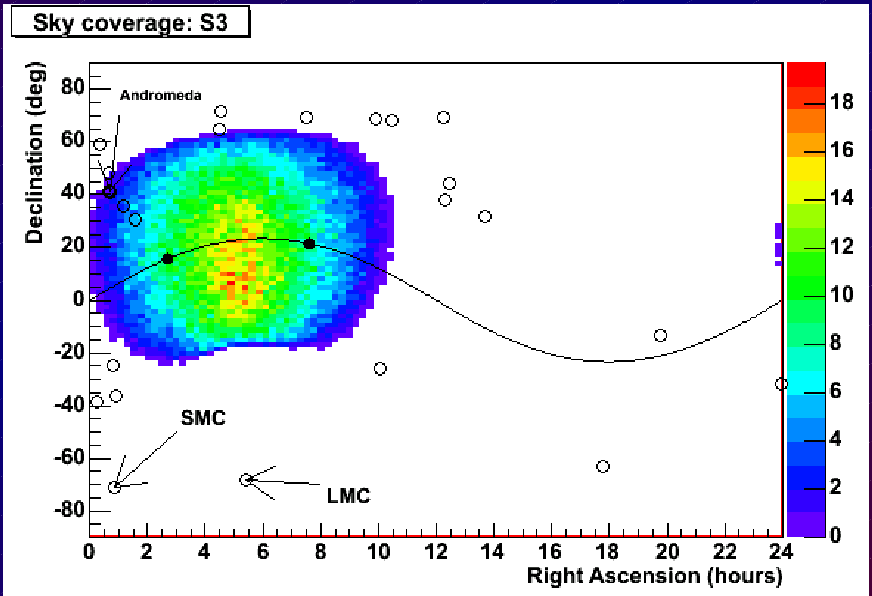
- Simulate events as though they were uniform in comoving distance D_c (and compute luminosity distance and z)
- Give each event a weight according to changing star formation rate as a function of z
- If D_c < 3 Mpc, draw from a list of known nearby galaxies
- If D_c < Milky Way, draw from a Galactic mass distribution:

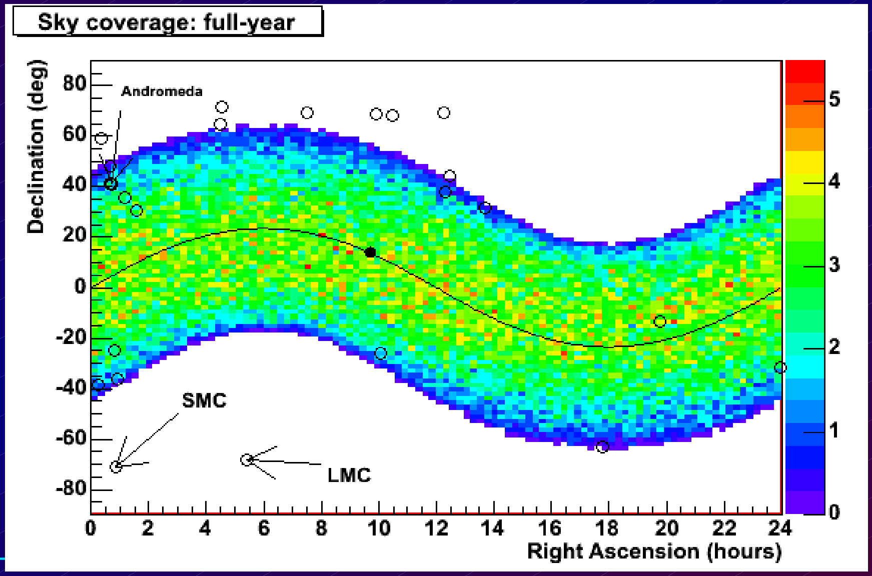


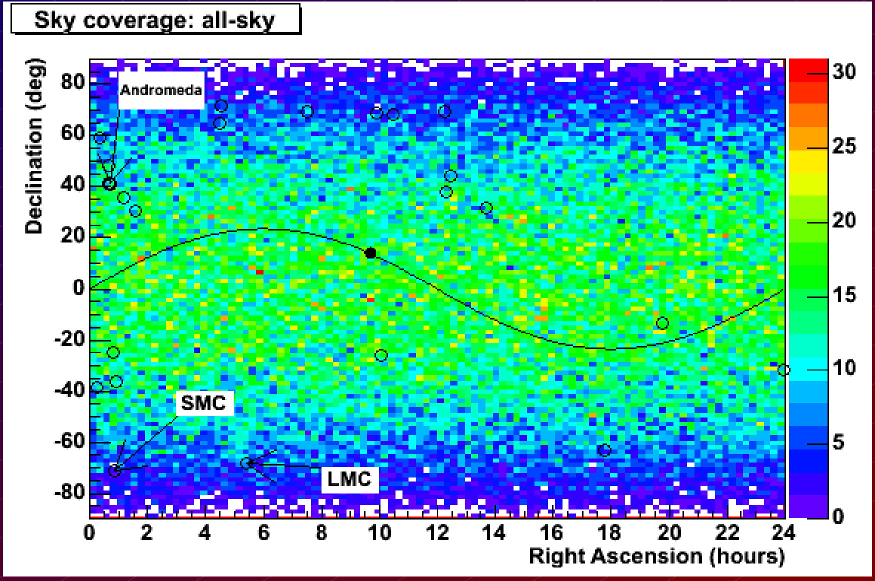
Sky position (RA,dec)

- Creates objects only within HETE field of view (~1.5 sr); can specify S2, S3, full-year, or all-sky.









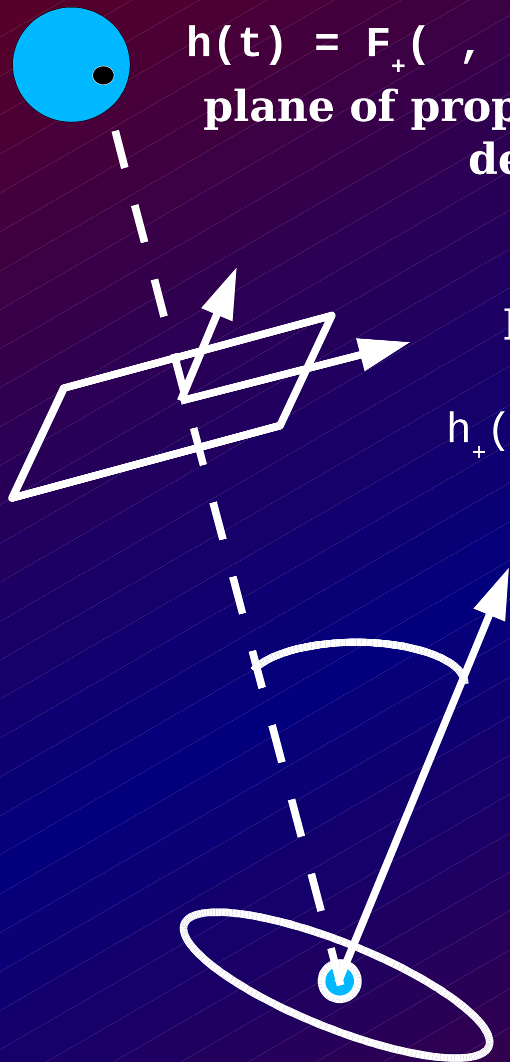
GW emission

- Two simple models: binary-like and supernova-like

At the detector:

$h(t) = F_+(\ ,\ ,\ ,t)h_+(t) + F_x(\ ,\ ,\ ,t)h_x(t)$

plane of propagation is rotated relative to detector by angle



In plane of propagation:

“binary-like”

$h_+(t) = 1/2(1+\cos^2\ )\ h0(t)$

$h_x(t) = \cos\ \ h0(t)$

“supernova-like”

$h_+(t) = \sin^2\ \ h0(t)$

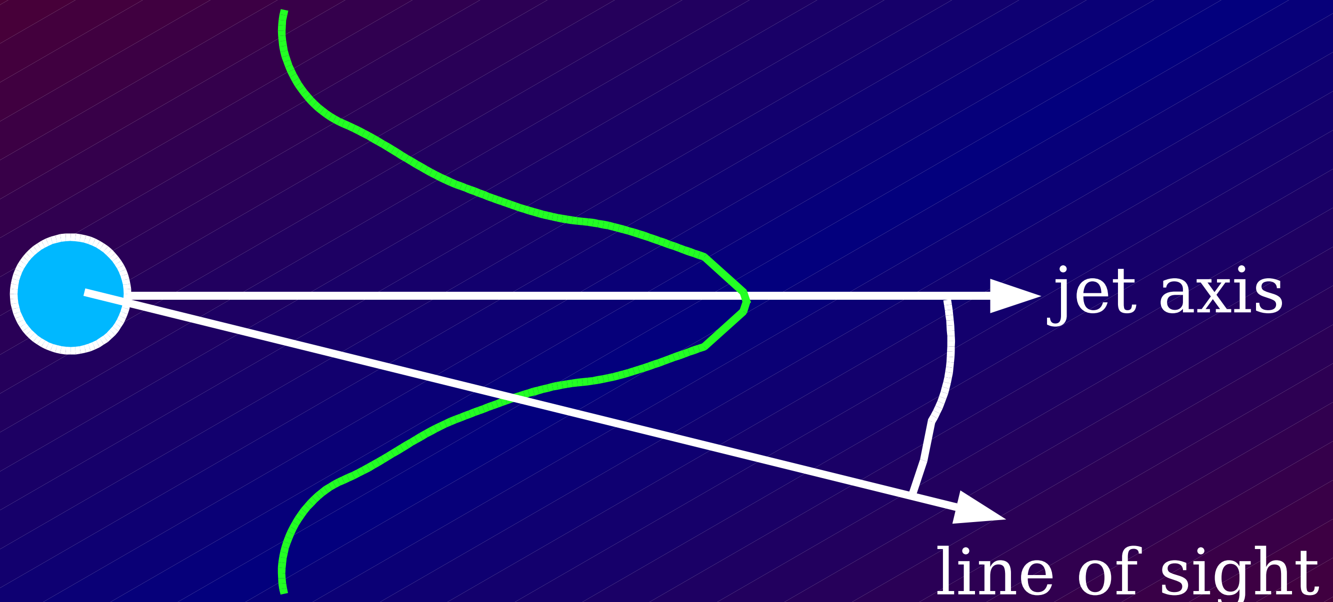
$h_x(t) = 0$

Source:

h0(t) = sine-Gaussians

Gamma-ray emission

- Two simple uniform-jet models: “Gaussian”, and “ -2”, candidates for long-duration GRB's:



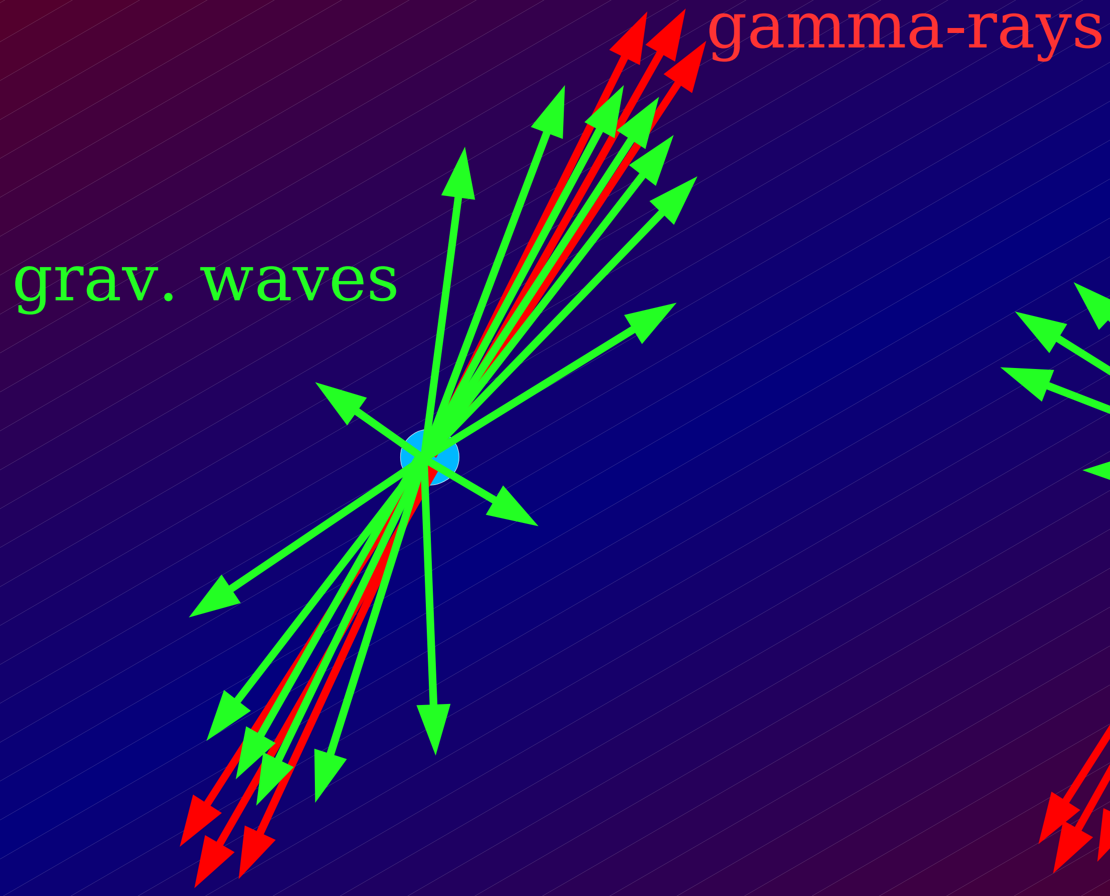
energy = f( ) = { -2
Gauss(,)

More assumptions

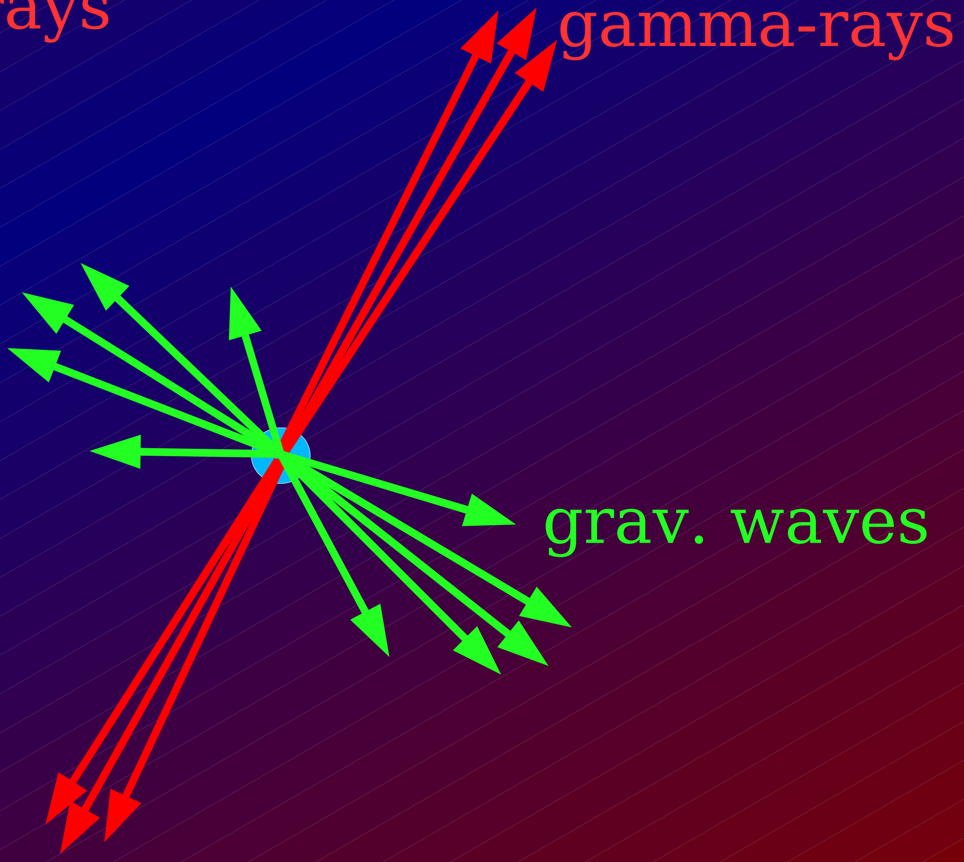
- polarization angle: randomized
- orientation angle: randomized
- For gamma-rays, GRB's are a standard candle of 10^{51} ergs
- For gravitational-waves, GRB's are a standard candle of $h_{rss} = 10^{-20}$ at 1kpc
- GW's produced are sine-Gaussian waveforms, with f=250 Hz and t=10ms
- Local rate of GRB's = local rate of SNe Ib/Ic / 100
- Importance sampling is used to enhance interesting regions of small angle and small distance

Effects: binary-like or supernova-like

<u>binary-like</u>



<u>supernova-like</u>

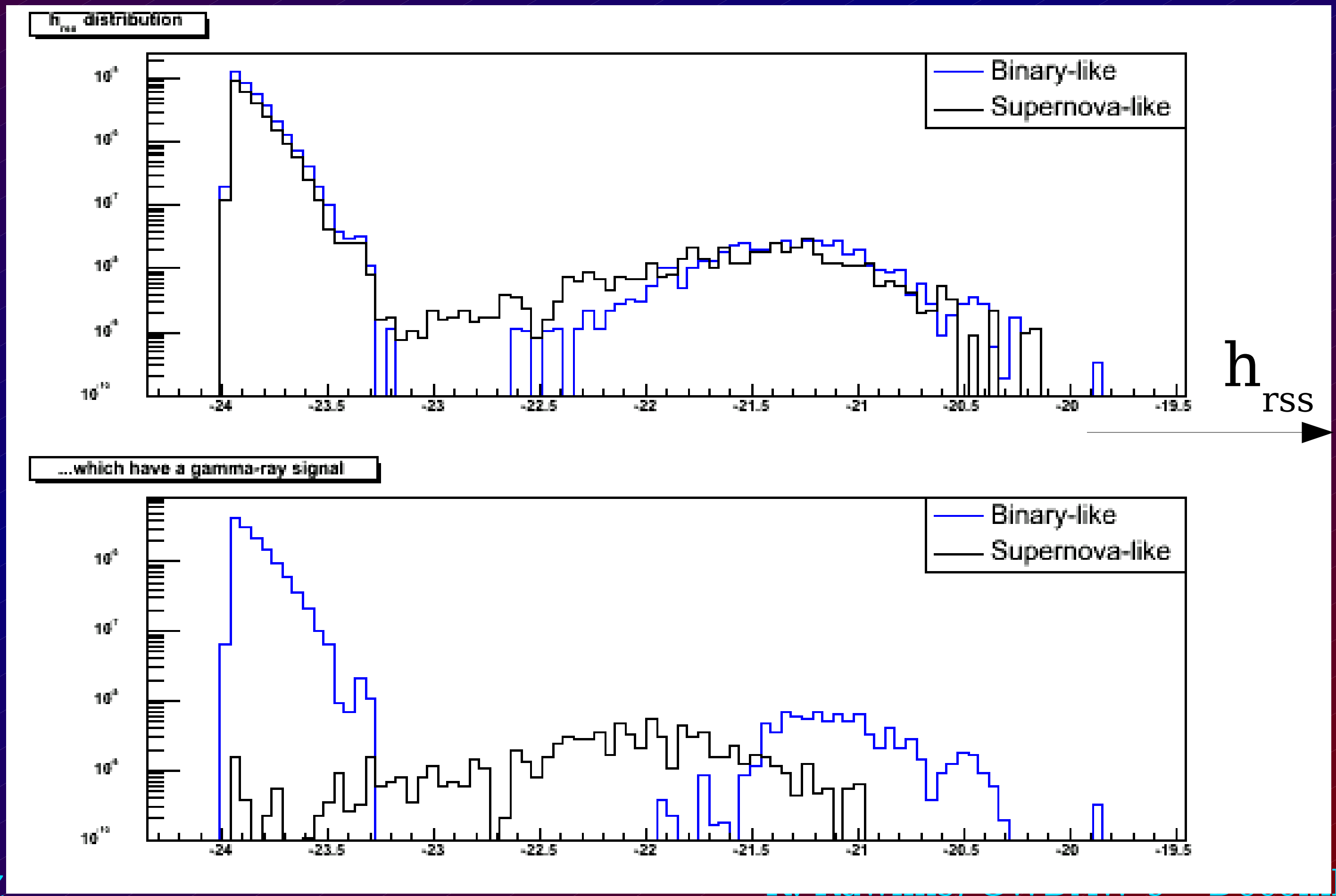


Effects: binary-like or supernova-like

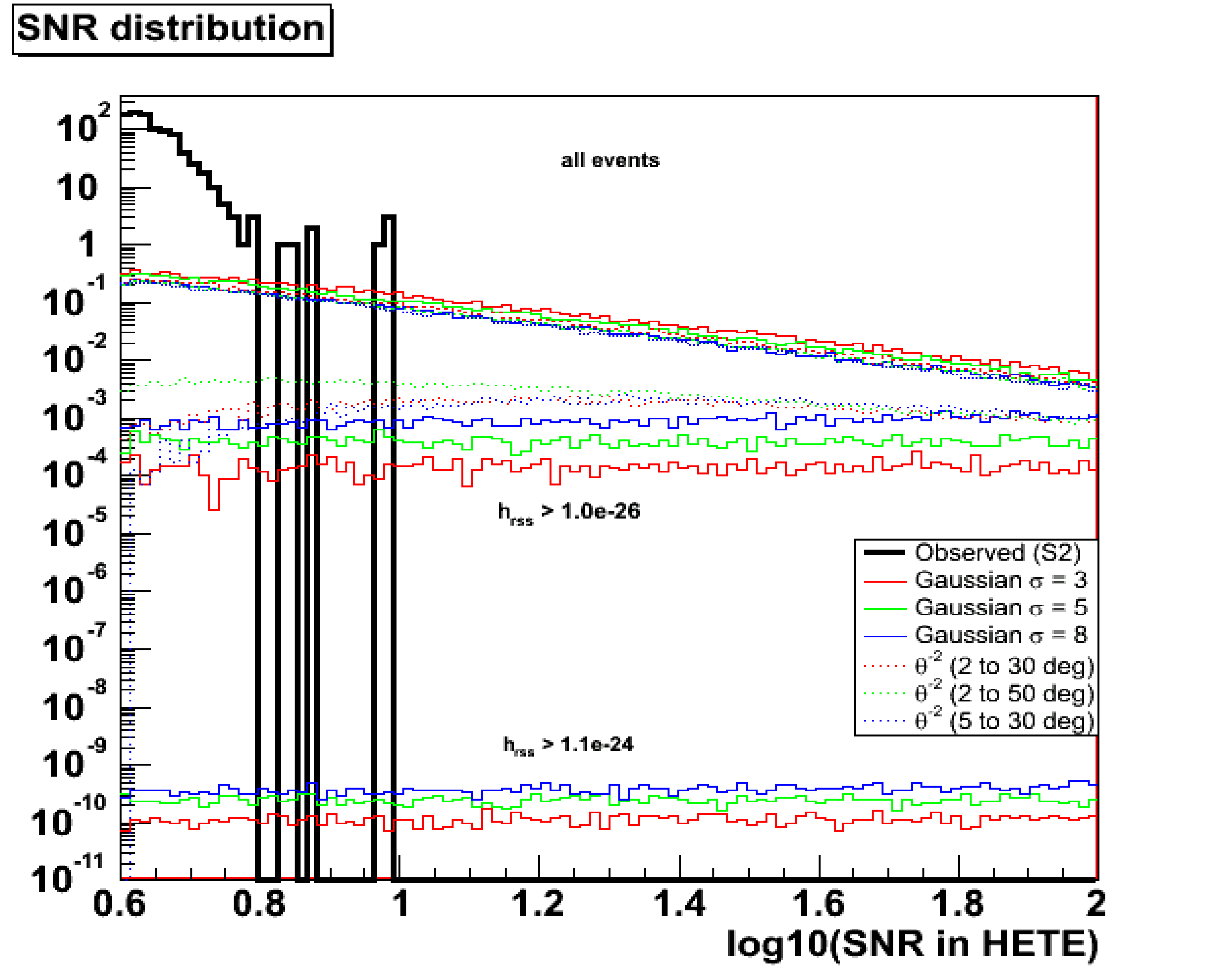
- Differences are minimal for all loud GW events, but if you apply a gamma-ray cut, the supernova-like events (whose GW point away from the jet axis) become rarer.

All events

Seen in gamma-rays



Predictions: different jet models

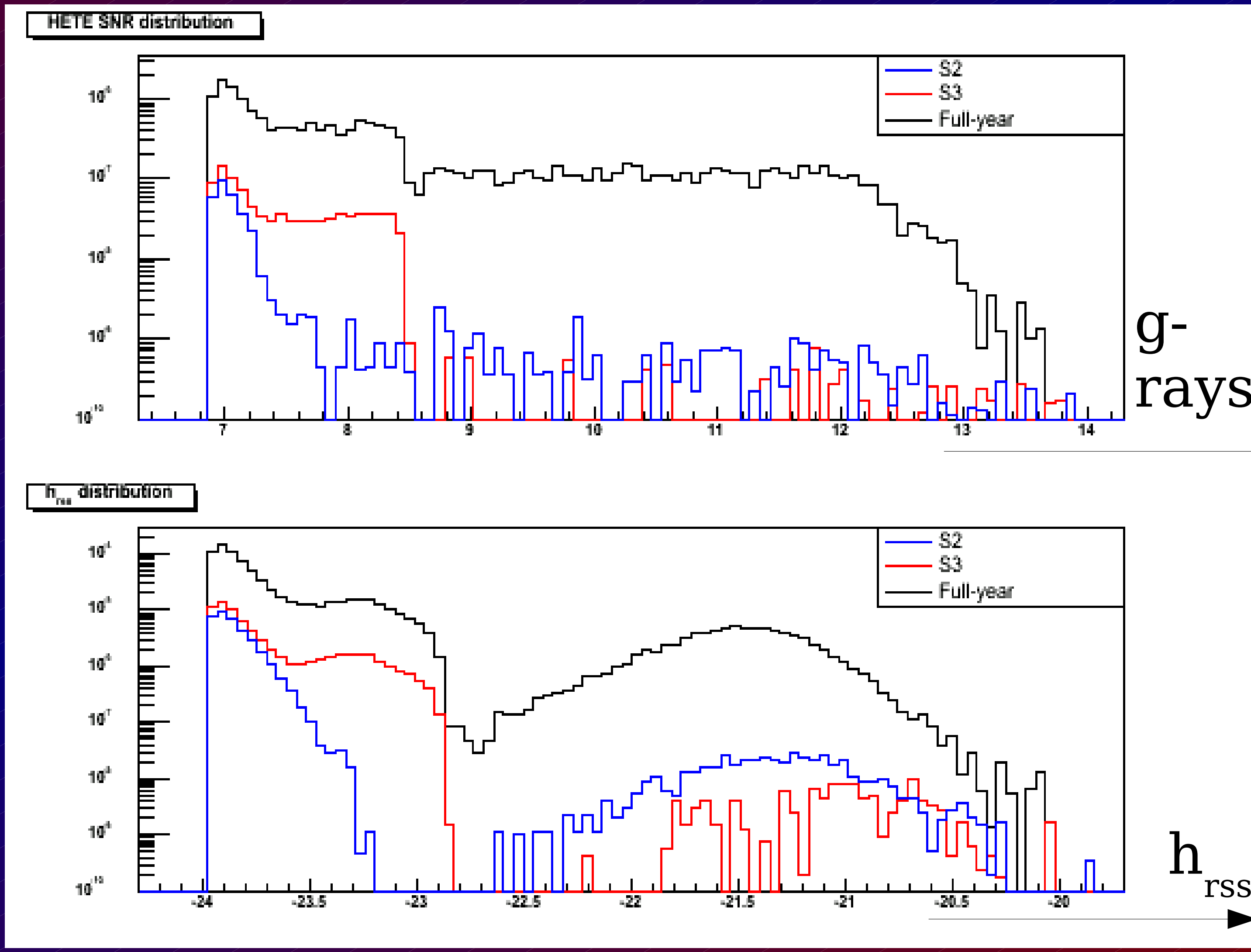


gamma-rays →

Predictions: which season?

- S2 observed closer to the Galactic Center
- S3 observed some of Andromeda

tails of distributions



g-rays

h_{rss}

Predictions: event rates

- Total events during S2 above HETE SNR=4:

  (optimal h_{rss} at 1 kpc = 10^{-20})

detector sens.	binary-like	SN-like	1e-20 in 1Mpc
• 10^{-26}:	6.8×10^{-2}	4.9×10^{-5}	
• 10^{-25}:	1.5×10^{-4}	1.4×10^{-7}	
• 10^{-24}:	1.9×10^{-7}	7.3×10^{-10}	
• 10^{-23}:	7.3×10^{-10}	6.8×10^{-10}	6.8×10^{-2}
• 10^{-22}:	7.3×10^{-10}	3.6×10^{-10}	1.5×10^{-4}
• 10^{-21}:	2.3×10^{-10}	2.2×10^{-11}	1.9×10^{-7}

Limitations

- No absorption of gamma-rays
- Hanford-only antenna pattern used
- Science run LIGO ontime assumed to be 100%
- Detector efficiency ->1 at a fixed h_{rss}
- GRB's are standard candles in GW's
- GRB's are standard candles in GR's
- Only “standard long-duration cosmological” bursts are modeled

Where to go from here?

- Are inspirals/short GRB's a better hope?
  - More favorable emission pattern
  - Better range in LIGO
  - Swift is expected to see many short GRB's
- "Third category" of GRB's?
  - Some bursts are underluminous in gamma-rays, have different spectral properties (i.e. GRB031203)
  - The bursts that look funny are the close-by ones
- Both these things are difficult to model

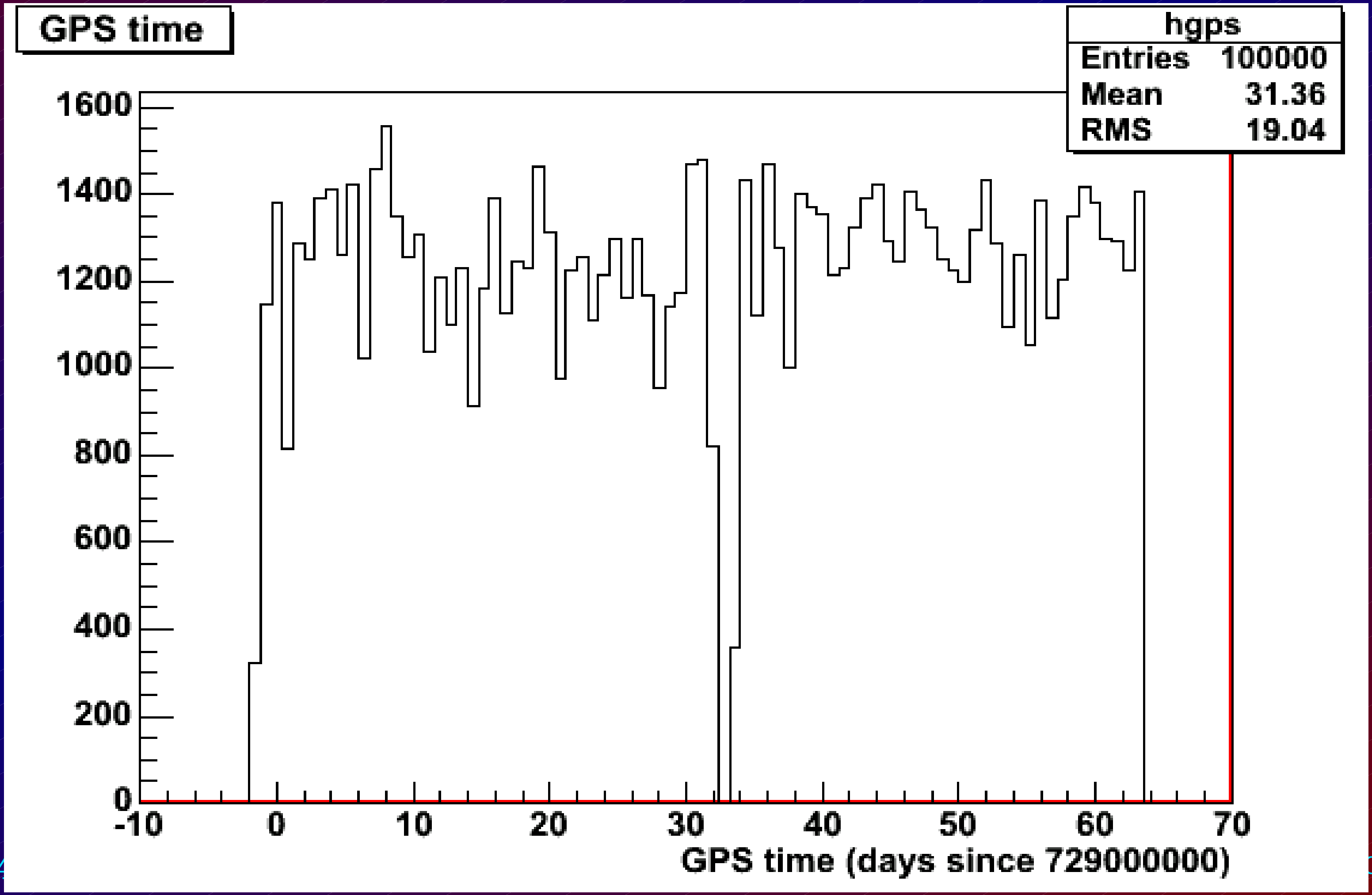
To-do list

- Expand GRB models; make some educated guesses and take a crack at short-duration and under-luminous
- Repeat for SWIFT satellite
- “Collect” triggers from both instruments, for S2, S3, (S4?) and compare

The End!

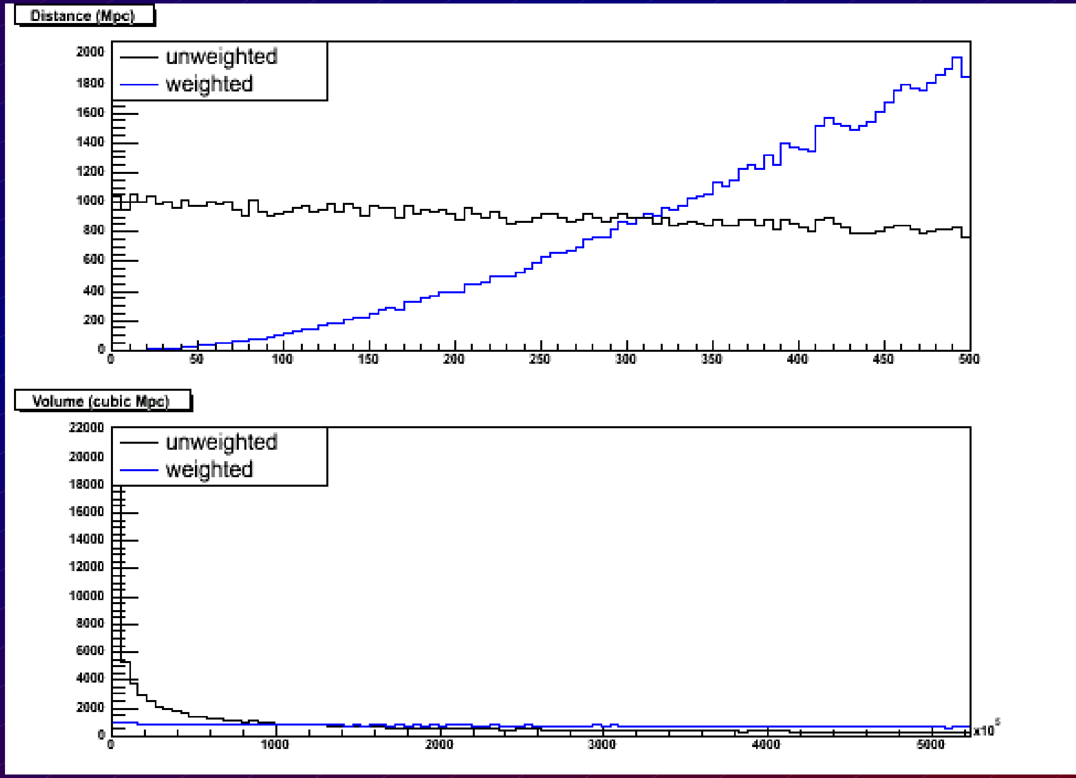
Inputs: GRB time

- For S2, use actual satellite on-times
- For S3 and others, hypothesize on-times based on orbital period



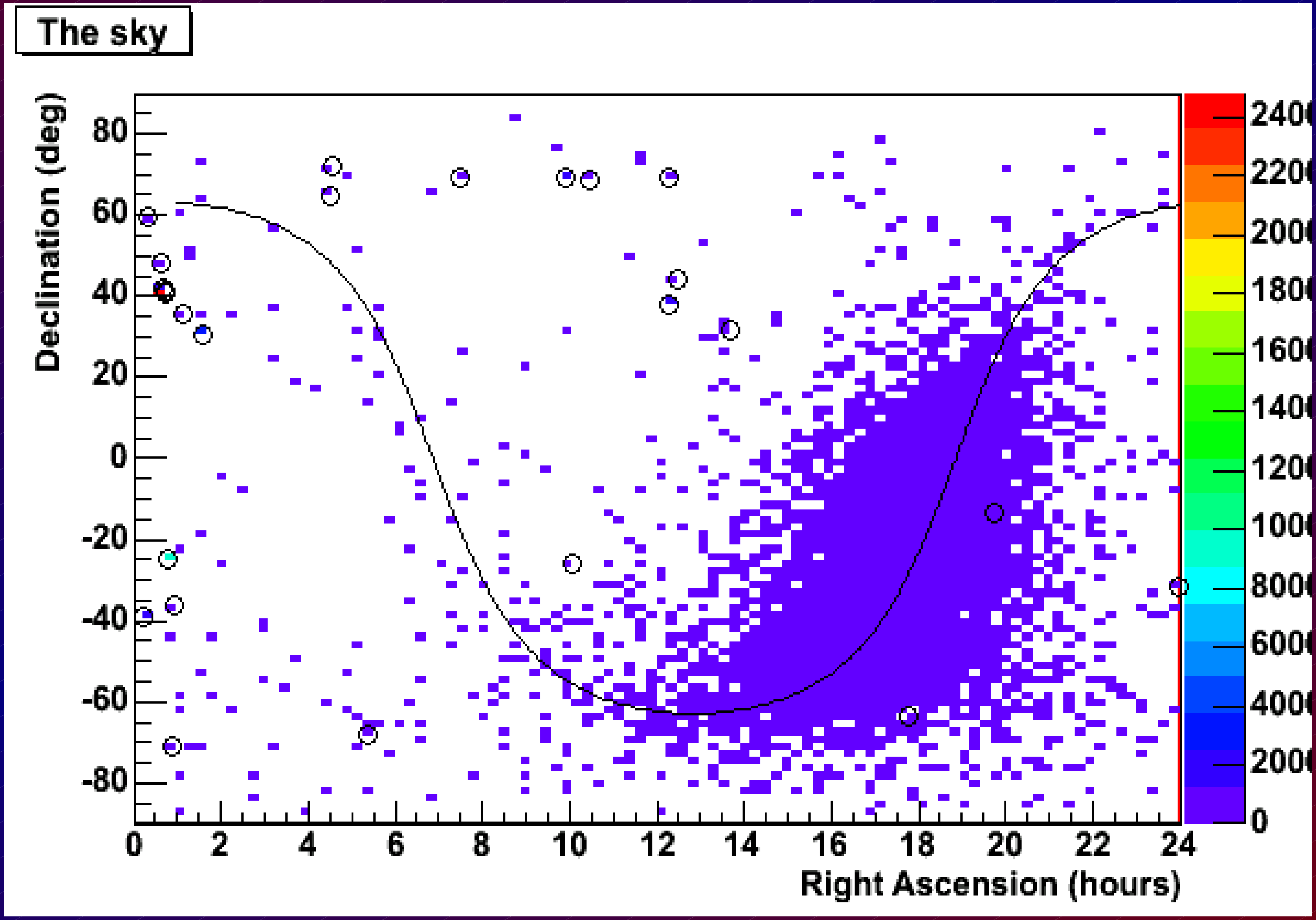
Inputs: Distance

- Simulate events as though they were uniform in comoving distance Dc
- From Dc, compute redshift z and luminosity distance DL
- Give each event a weight according to changing star formation rate as a function of z
- Importance-sample, to emphasize nearby (more insteresting) events



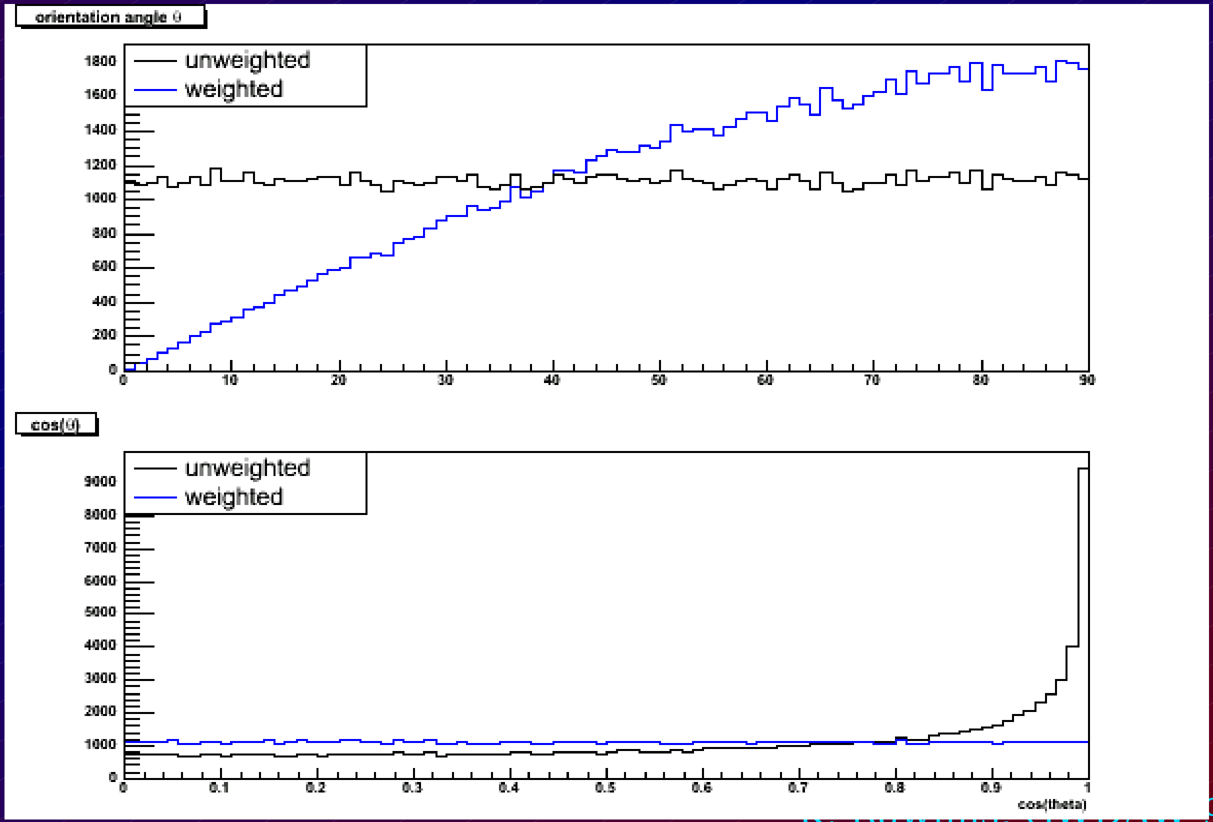
Nearby distances: the Galaxy

- If an event is generated in the Milky Way, it is pulled from a Galactic mass distribution:



Input: Orientation angle

- theta is the angle between the GRB jet axis (or angular momentum axis) and the line of sight
- Generate events uniformly in cos(theta). But because small-angles are most interesting, importance-sample to smoothen the distribution there.



Long vs. short-range simulations

- Need long-range simulations to know about low-SNR events, but short-range simulations are sufficient for loud-GW events.