Astrophysics with joint Fermi-LIGO detections

Daniel Holz

The University of Chicago

Worst case scenario

- We don’t detect any binaries at full sensitivity with years of observations
- What do we learn?
  - Gravitational waves don’t exist.

No way.

Worst case scenario

- We don’t detect any binaries at full sensitivity with years of observations
- What do we learn?
  - short GRBs are not binary systems
    - equivalent to beaming angle being larger than 90°
    - this takes 2 years for 90% confidence (HLV 2019)
  - puts pressure on population synthesis?
    - natal kicks are large?
    - binary does not survive common envelope evolution
    - constraints on star formation/evolution

Short GRBs are binary systems

- Plenty of evidence:
  - no supernova
  - far from centers of host galaxies
  - not associated with star formation
  - timescales appropriate
  - simulations might be consistent

In what follows we assume all short GRBs are the result of stellar mass compact binary progenitors

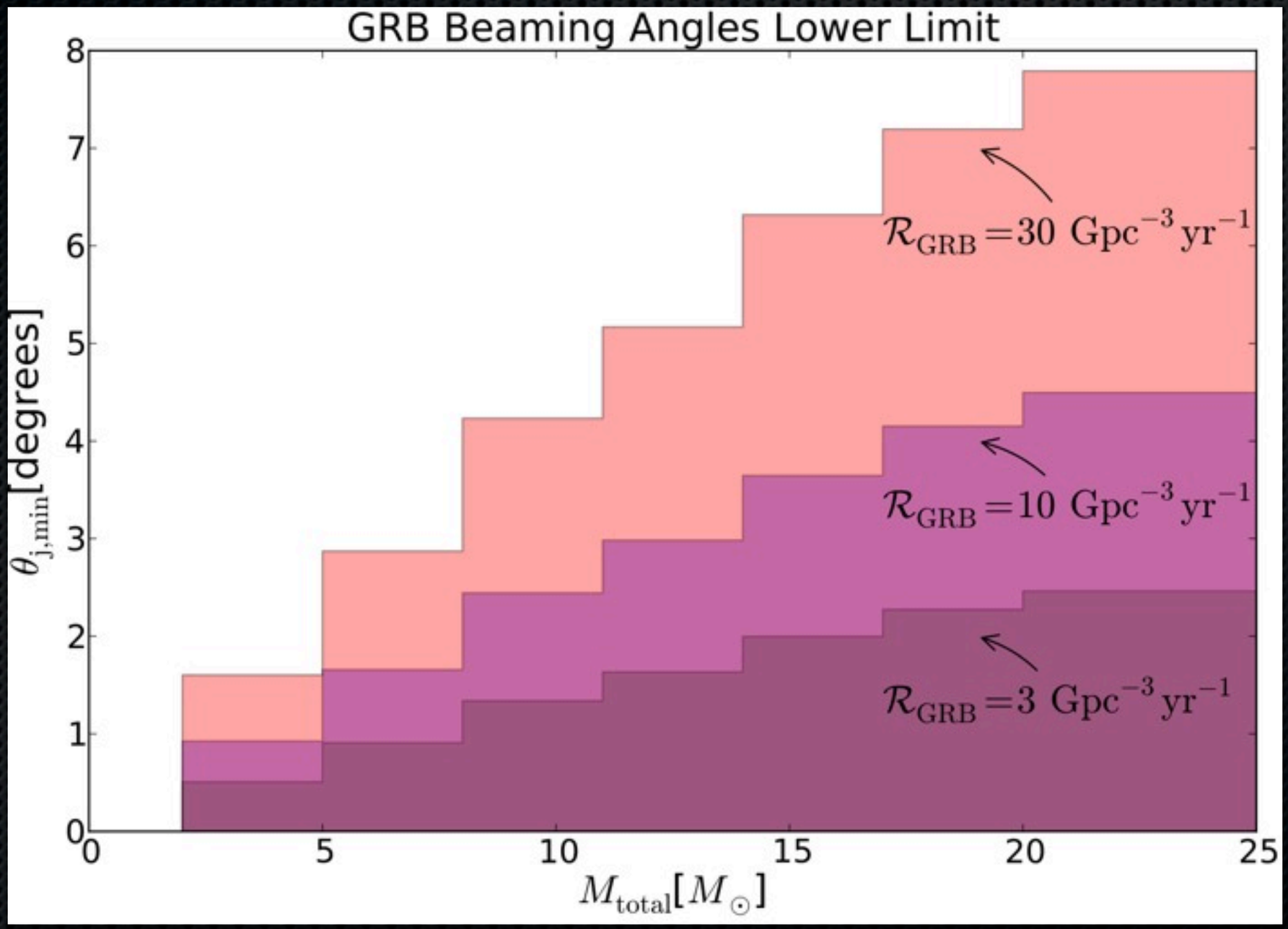
Short GRBs are binary systems

- Things we can learn from joint detections:
  - Which engine: NS-NS or NS-BH? Or maybe BH-BH?!
  - What distribution of masses? Correlation between masses and timescales? Total energy? Energy spectrum?
  - What is the beaming angle of the gamma rays?
  - Correlation of beaming angle with total energy? Spectrum? Timescale?
  - Distinguish popsyn models, and elucidate underlying astrophysics

Waiting for first detection

- Constantly improving upper limit on the event rate
- For a fixed configuration/sensitivity, the estimate of the upper limit to the rate scales as 1/time
  - This sets a lower limit to the beaming angle, which increases with time
  - At some point the beaming angle increases to 90^{o}, at which point BNS systems are ruled out as progenitors for short GRBs

LIGO limits on GRB beaming

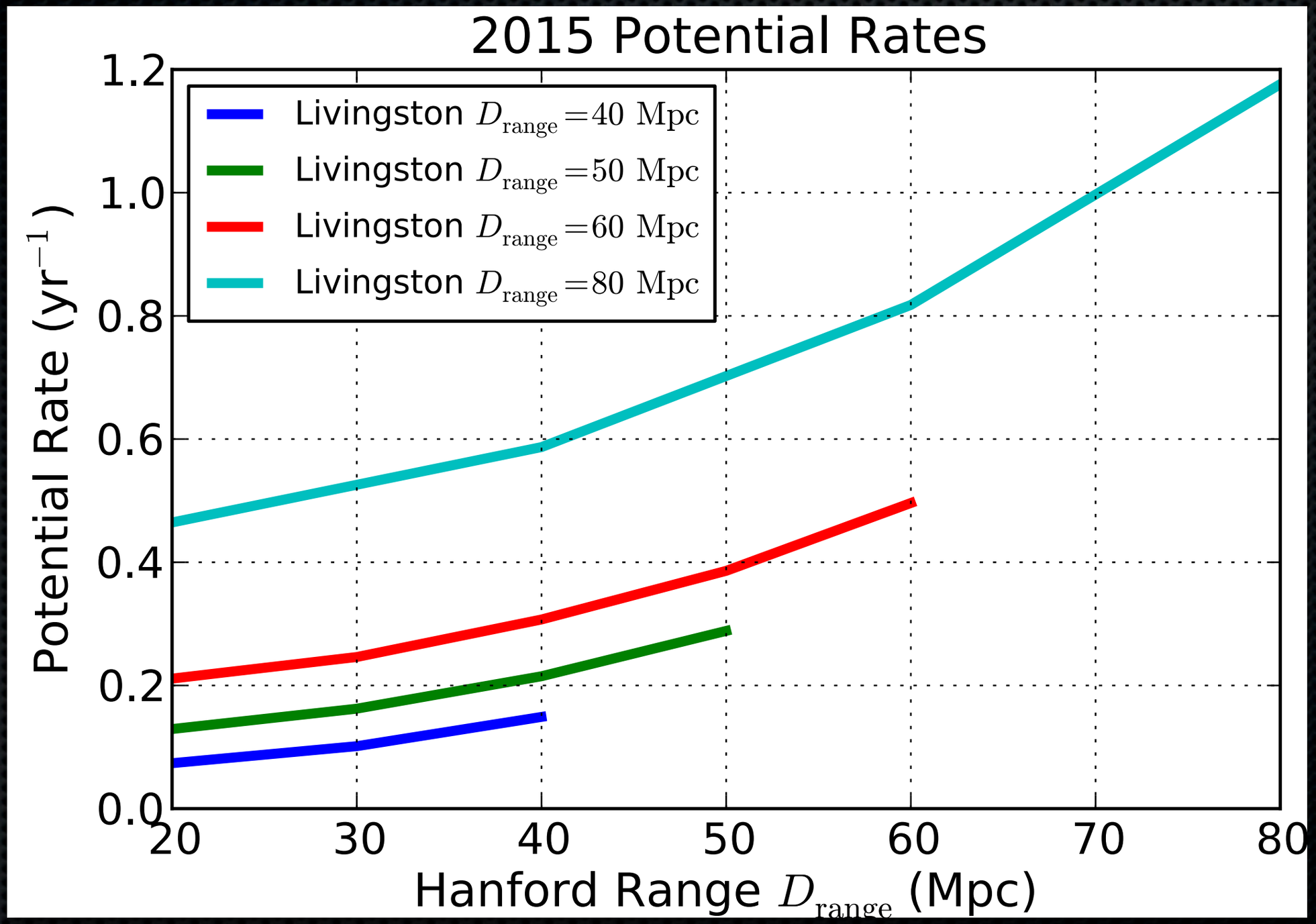


- LIGO S6/V2 didn't see any binaries: constrains beaming

How well do we know the short GRB rate?

- Significant improvements since Nakar, Gal Yam, & Fox 2006?
    - conservative lower limit: 10 /Gpc^3/year
- Can we do better?

Predicted rate this summer



- Rate can approach one per year!

Fermi trigger, no GW detection

- Sets a limit on a combination of distance, mass, sky position, and inclination angle of the binary
- Golden event:
  - Known redshift places it well within range of GW network, with all detectors operating and sensitive
  - No GW signal implies
    - Not face on?
    - Source is NOT a binary system

GW detection, no Fermi trigger

- Sets a limit on a combination of beaming angle (upper limit) and gamma ray flux (upper limit)
- Even if all short GRBs are BNS, this does not mean all BNS are short GRBs
- Lots of interesting physics in the discrepancies between these rates

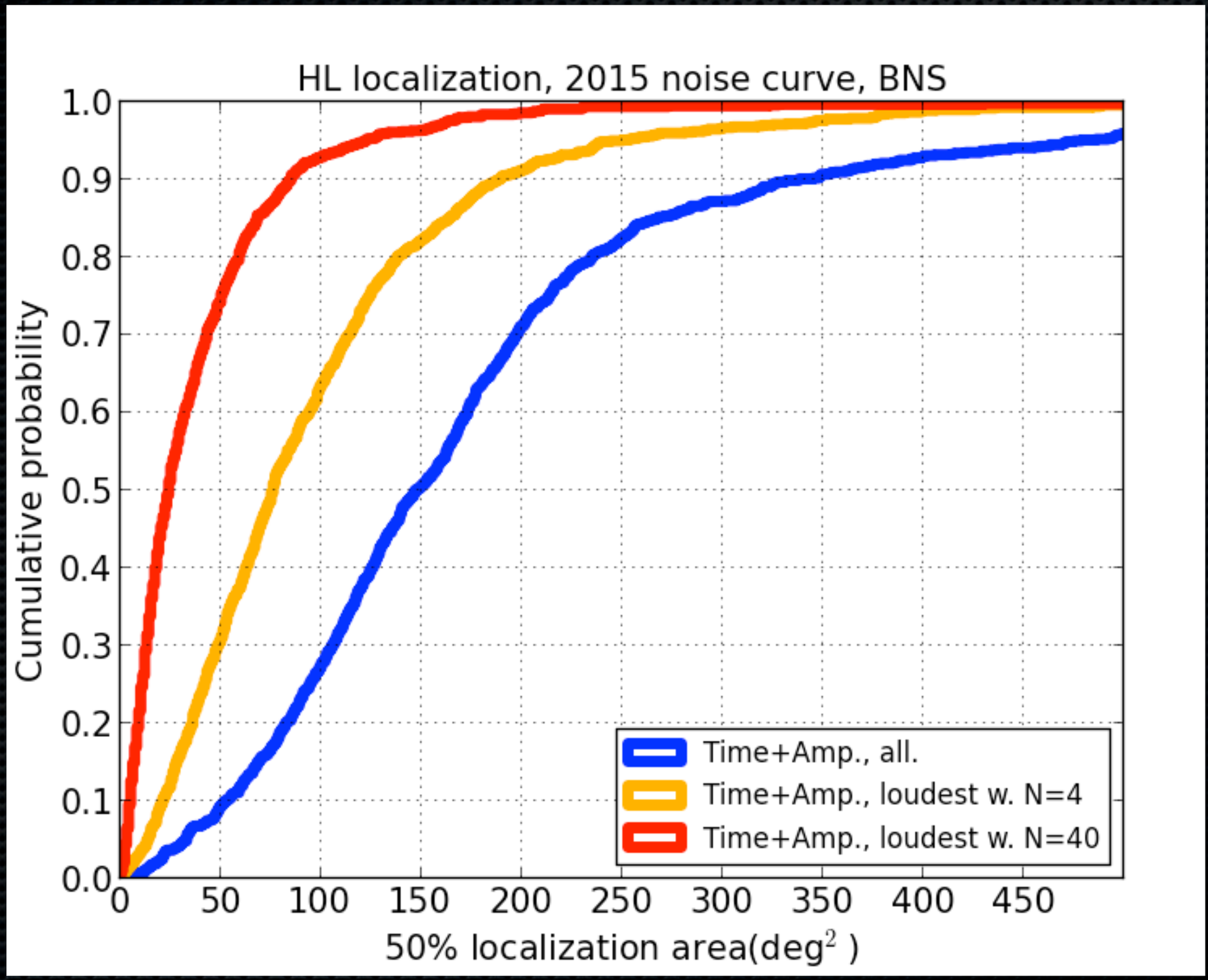
Blind search for EM counterparts

- Use theoretical models for kilonovae lightcurves
- Search existing observational data for these
- Lack of detection puts lower limit on beaming angle
- Preliminary version of this in process with DES SN data

Joint GW+Fermi sky localization

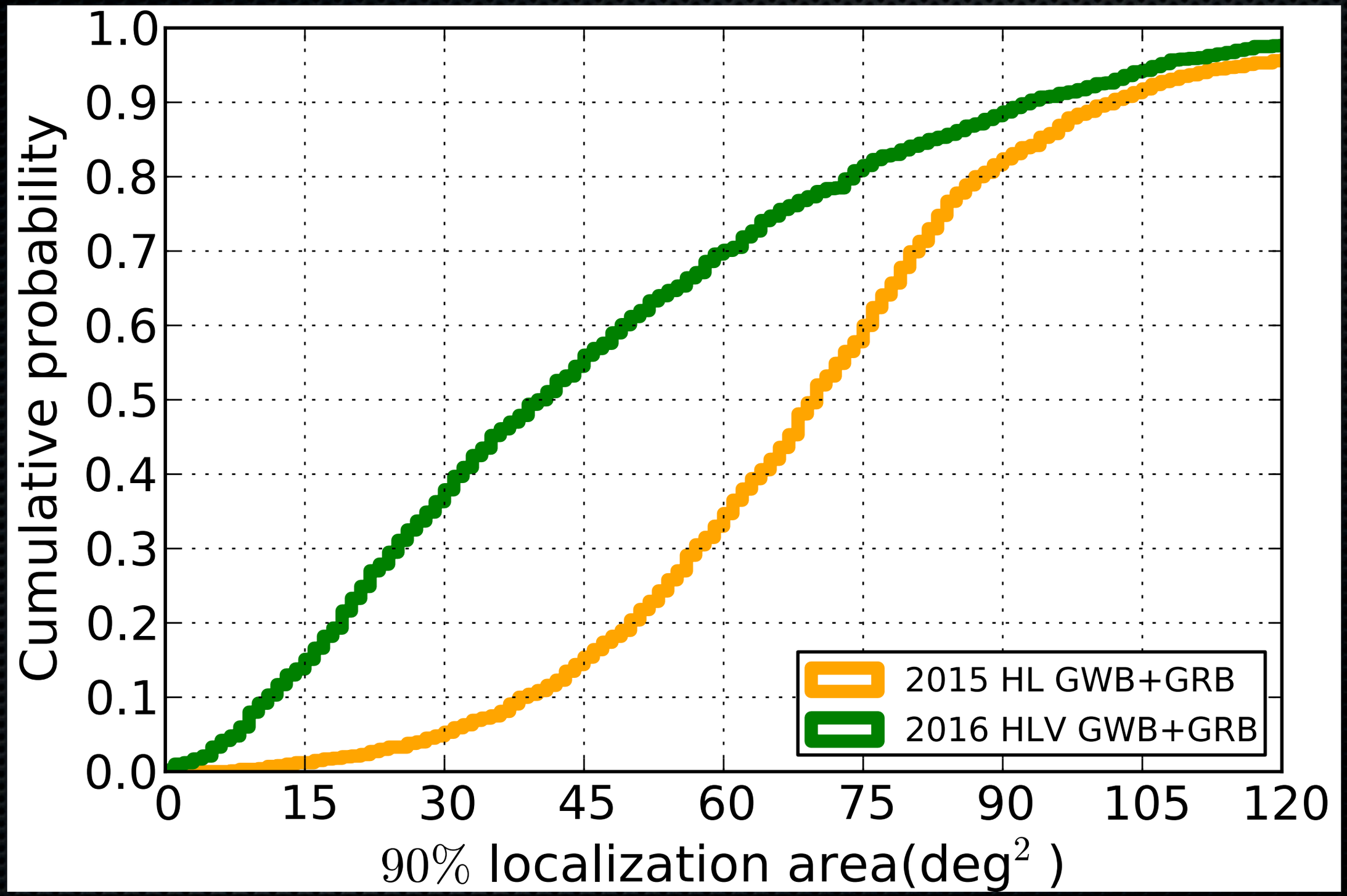
- Error boxes for LIGO can be large:
  - median: ~150 deg^2 (for 50% likelihood)
- Error boxes for GBM can be large:
  - ~100 deg^2 (for 50% likelihood)
- But these are bananas and oranges!
  - Joint approach significantly improves localization:
    - < 100 deg^2 (90% likelihood)

LIGO localization area



Chen & DH, in prep

Joint GW+Fermi sky localization



Chen & DH, in prep

First joint detection

- CBC in GWs and gamma-rays
- What do we learn?
  - Compact binary progenitor for short GRBs
  - Improved GW parameter fitting?:
    - sky position prior
    - jet break/inclination angle?
  - Event rates
    - relate to popsyn models
  - Host galaxies, environment, redshift

First joint detection

- In some cases can distinguish NS-NS from NS-BH
  - If you assume you know the underlying distribution of mass from population synthesis, then measuring chirp mass is sufficient
  - If anomalously high SNR, then single systems provide more information
    - Should follow universal distribution