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Binary Neutron Star rate predictions from observations of dwarf galaxies

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SIST Final Presentations

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MACALESTER COLLEGE

Motivation

Binary Neutron Stars (BNS) mergers are expected to produce:

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- Electromagnetic signatures, observable with telescopes (e.g. DECam at Blanco Telescope).

What is a Binary Neutron Star (BNS)?

NASA/Goddard Space Flight Center/Dana Berry

- Gravitationally bound system of two neutron stars.
- A neutron star is the remnant of a core-collapse supernova for $M_{ZAMS} < 25\ M_{\odot}$.

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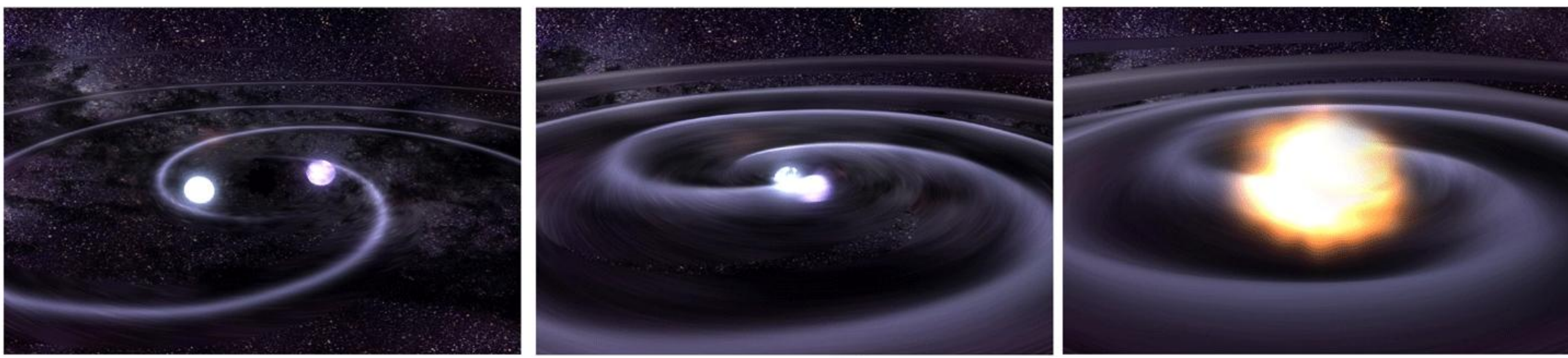
Binary Neutron Star Merger

Merger is the result of the shrinking of the distance between the neutron stars due to emission of gravitational waves.

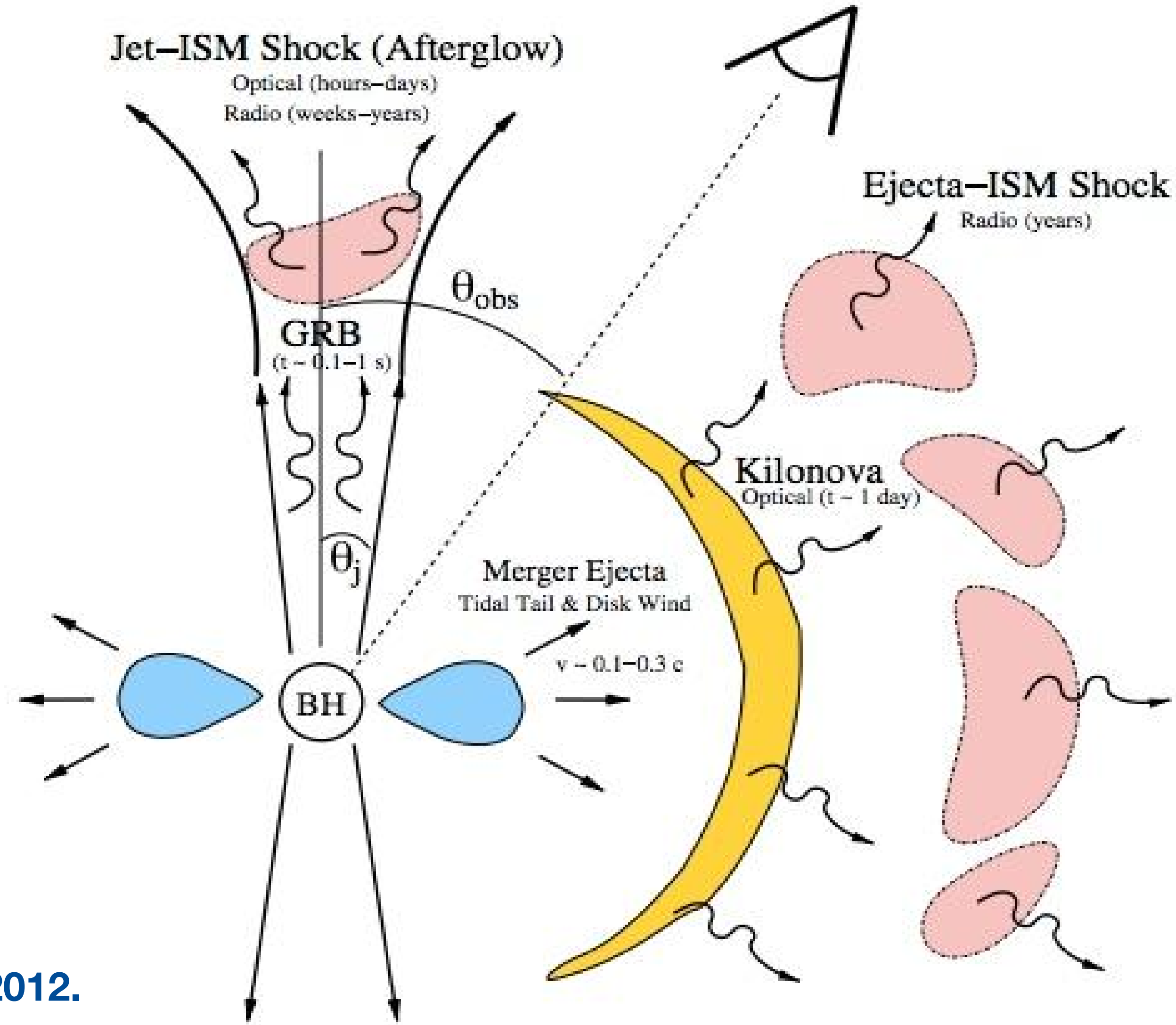
They are rare events (not detected yet).



NASA

Electromagnetic signatures of BNS

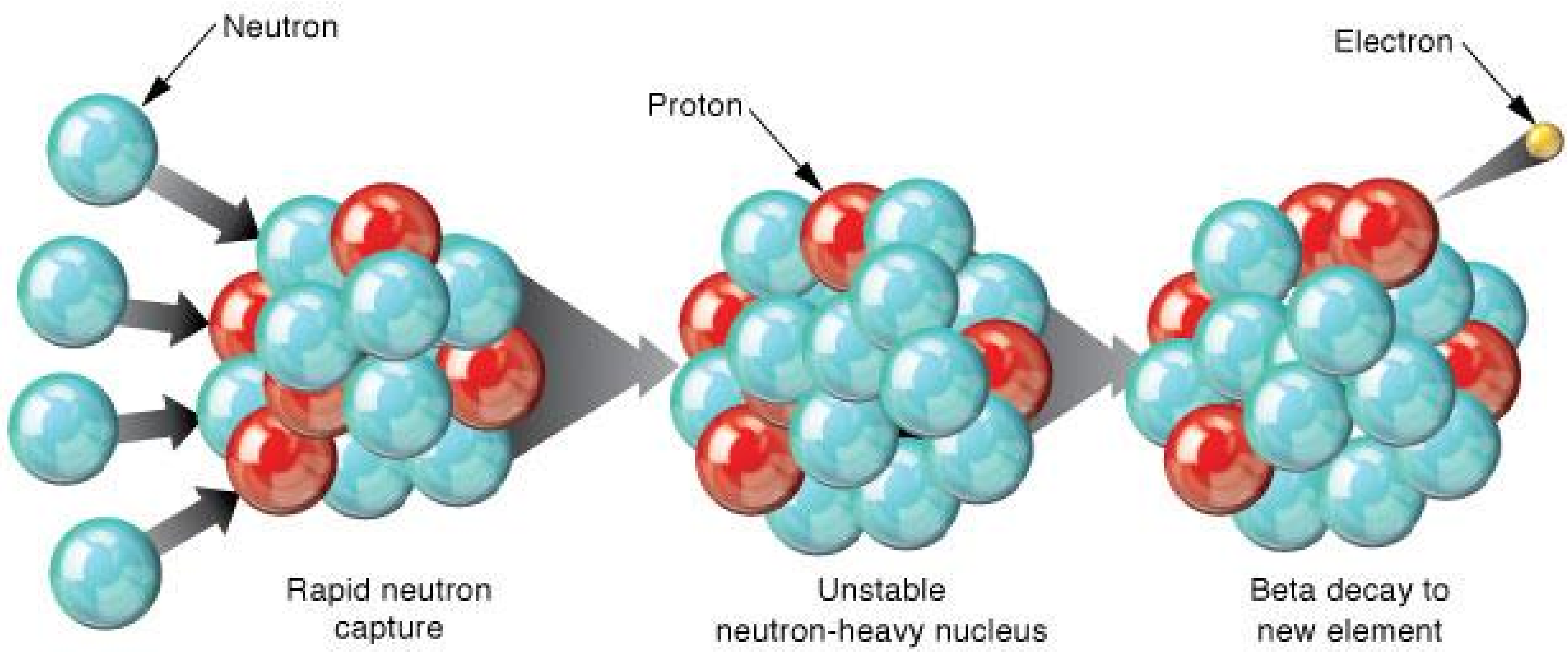
- Short Gamma Ray Burst (SGRB)
- **Kilonova**
- Afterglow



Metzger and Berger 2012.

R-process nucleosynthesis

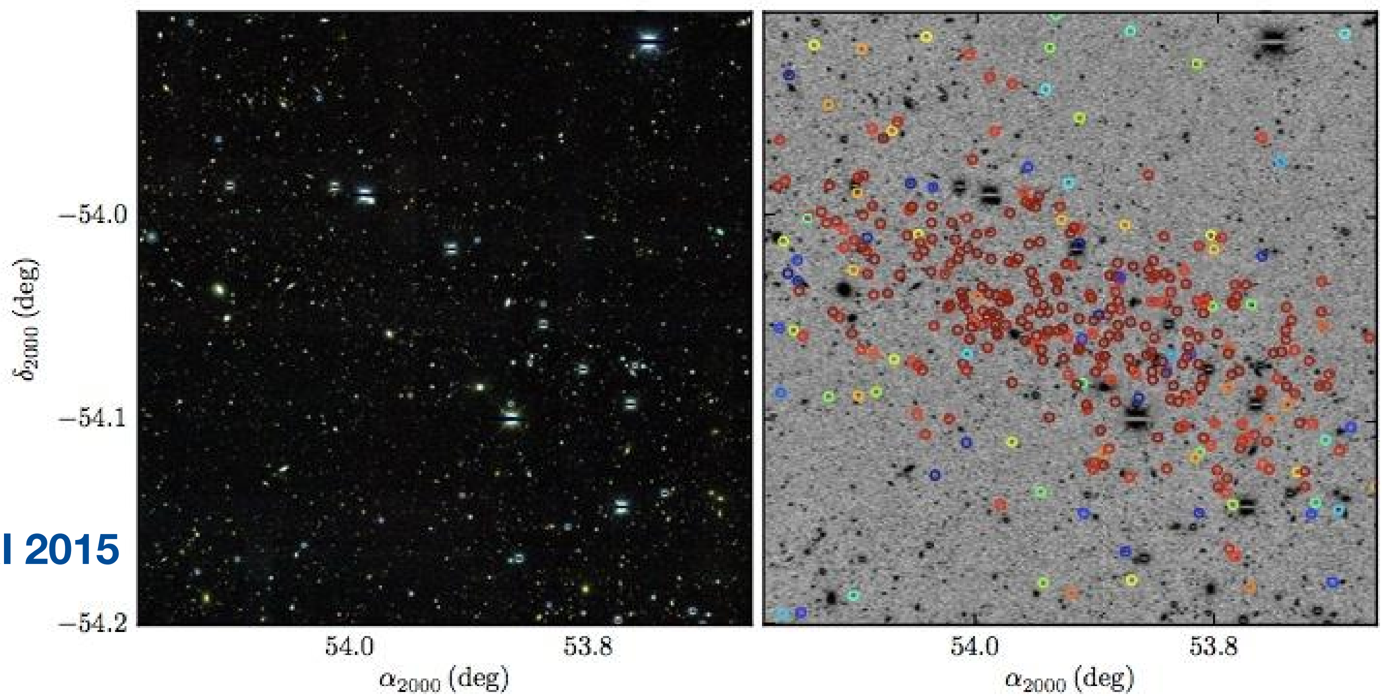
Rapid neutron capture (r-process) is the process by which heavy radioactive elements are formed (Metzger et al 2010).



Borg and Brennecka 2014.

Reticulum II

- Dwarf galaxy in the local group.
- High-resolution spectra analysis of the nine brightest members of Ret II done by Li et al 2016.
- A promising mechanism to explain metal abundance in Ret II is a binary neutron star merger.

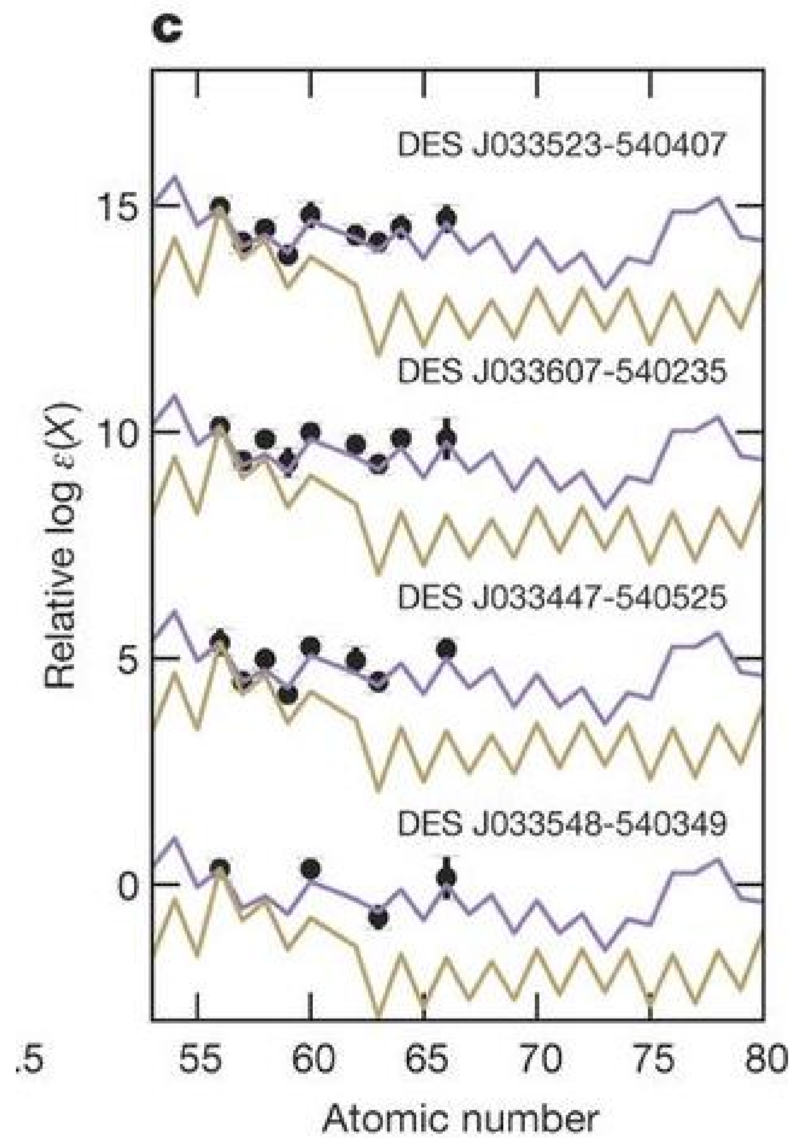


Bechtol et al 2015

High Resolution Spectroscopy on Reticulum II

Seven of the stars have high **neutron-capture element abundances, consistent with r-process pattern.**

Ji et al 2016



Goal

To calculate a lower limit to the **astrophysical rate** of **Binary Neutron Star Mergers** from the event in the dwarf galaxy Reticulum II.

+

To analyze the **observational selection effects of LIGO.**

=

Predict number of observable events with LIGO

Lower limit approximation for rate of BNS

Based on the event in Reticulum II: At least 1 event observed in 13 dwarf galaxies (galaxies with high-resolution spectroscopy analysis) in the timescale of a few Gyr.

$$\frac{1 event}{(\sum_{n=1}^{13} M_*) \times (T_{universe} - T_{event})} \approx 10^{-15} M_\odot^{-1} yr^{-1}$$

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Assumption: Number of BNS mergers scales up with stellar mass!

Two methods to approximate galactic stellar mass / luminosity

- **Schechter Mass Function:**

Yields spatial density of galaxies as a function of their stellar mass.

- **Galaxy catalog of nearby universe (<200 Mpc):**

To estimate luminosity (proxy for stellar mass) at different distances.

Schechter Mass Function

$$\phi(M) = b \times \phi^* \ln(10)[10^{b(M-M^*)}]^{(1+\alpha)} \exp[-10^{b(M-M^*)}]$$

- M^* determines where the mass function changes slope
- M is the mass
- ϕ^* is the normalization
- α is the slope for fainter, lower mass galaxies.

Multiplying the function by 10^M and integrating for the limits 10^6-10^{12} $M_\odot$ yields an estimate of the stellar mass in 1 Mpc^3.

Building galaxy catalog to estimate stellar mass

- Initial catalog put together by Jim Annis.
  - i-Band < 15.9 catalog of galaxies over the whole sky.
  - 4 catalogs used to update the distances:
    - EDD
    - NED-D
    - NED
    - SDSS DR12
  - The catalog has
    - RA, Dec, redshift
    - Distance
    - i-magnitude, g-i color
    - Absolute magnitude
    - Stellar mass

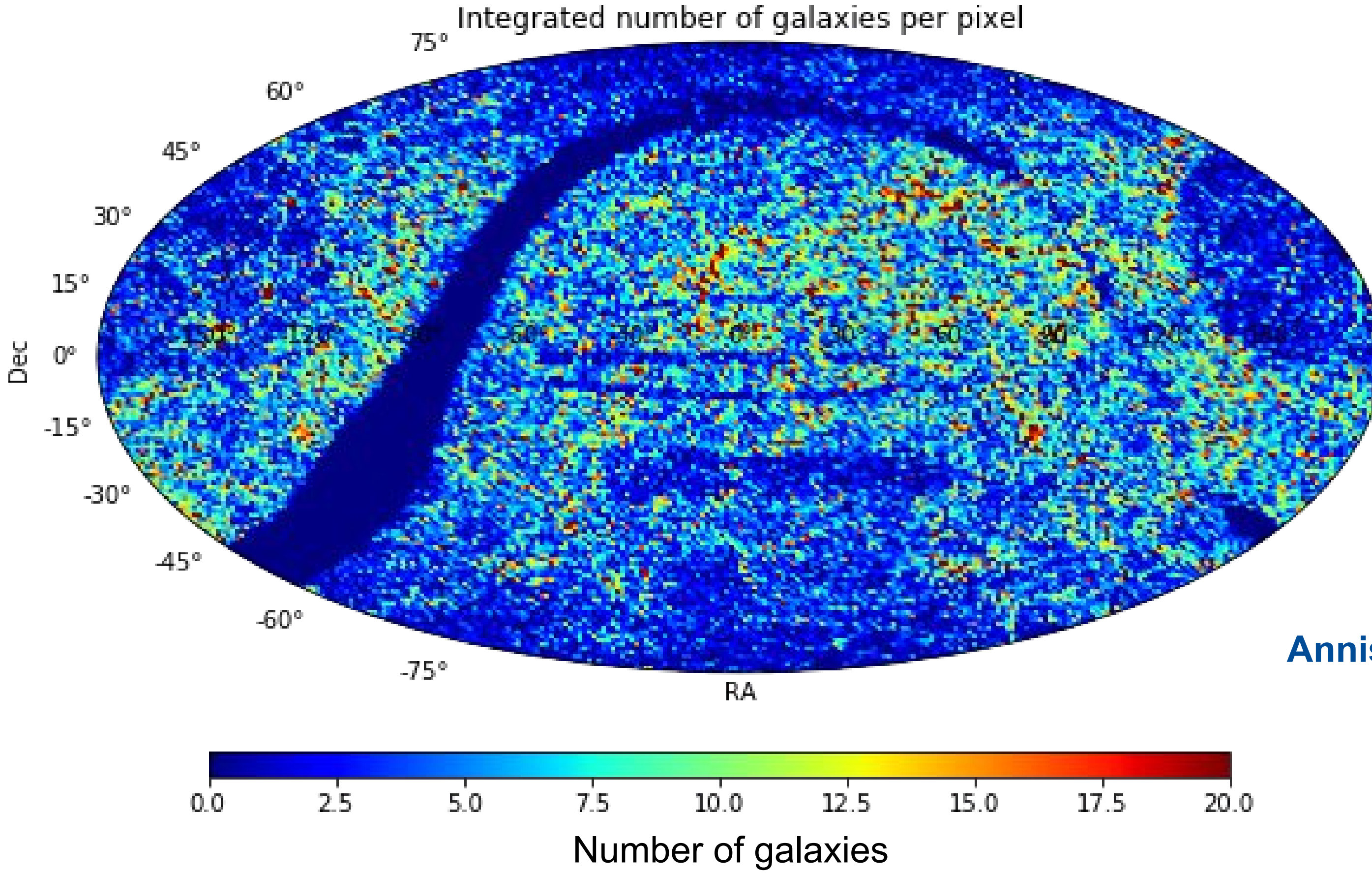
$$mass = \frac{M}{L} - 0.4(M - 4.58)$$

$$M/L = -0.68 + 0.7(g - i)$$

Taylor et al (2011)
Annis (2016)

Building galaxy catalog to estimate stellar mass

Artificial features around galactic plane and SDSS footprint due to difference in catalog source for redshift and color.



Annis 2016

Building galaxy catalog to estimate stellar mass

I worked on rebuilding the catalog (<200 Mpc) to eliminate artificial features:

I used 2MASS Extended Source Catalog as the base catalog and added distances from other surveys in the following preferential order:

1) **Distances** from **NED** and **EDD**

2) **Spectroscopic redshifts** from **NEDZ** and **SDSS**

3) **Photometric redshifts** from **2MPZ** catalog

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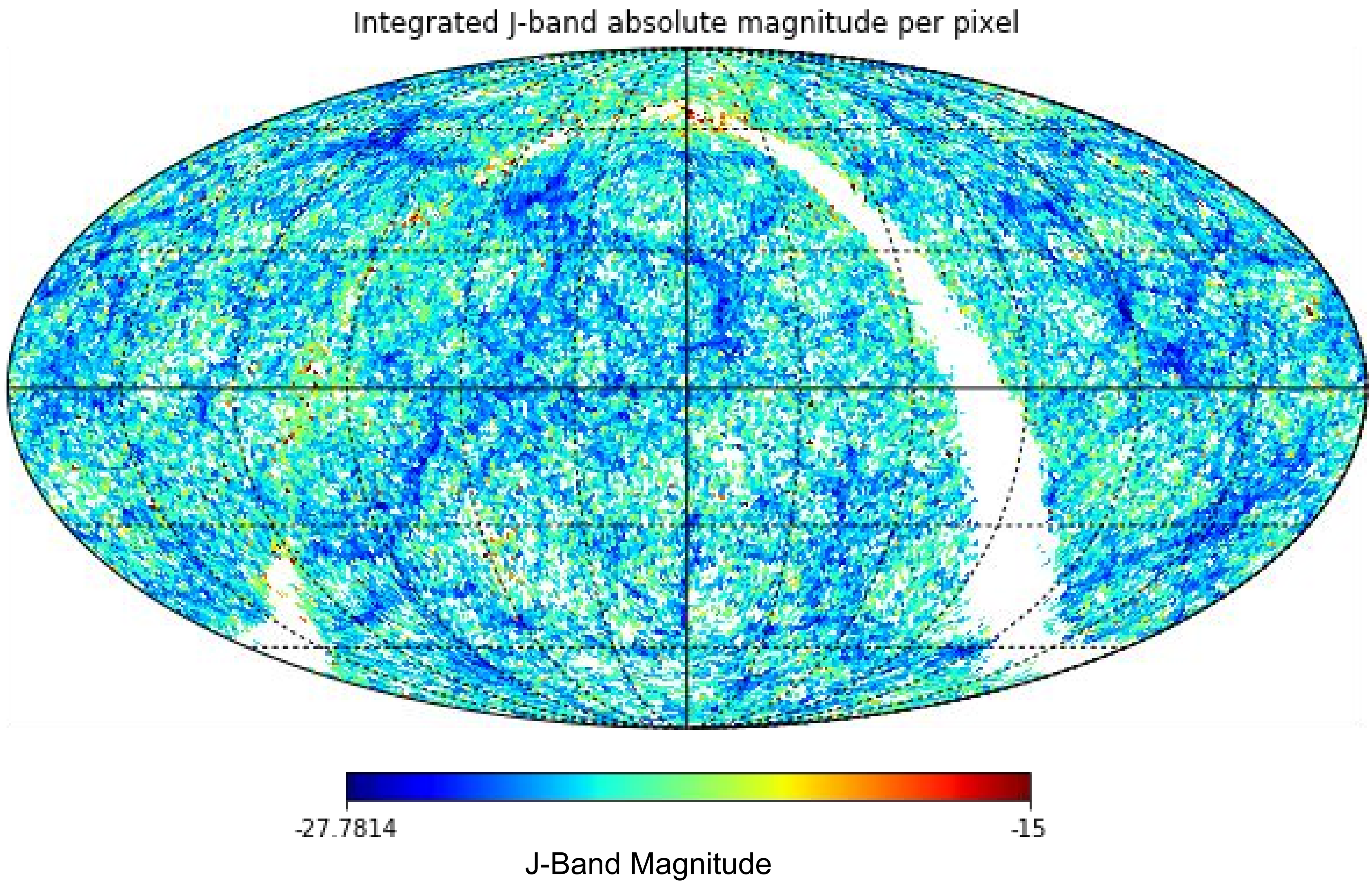
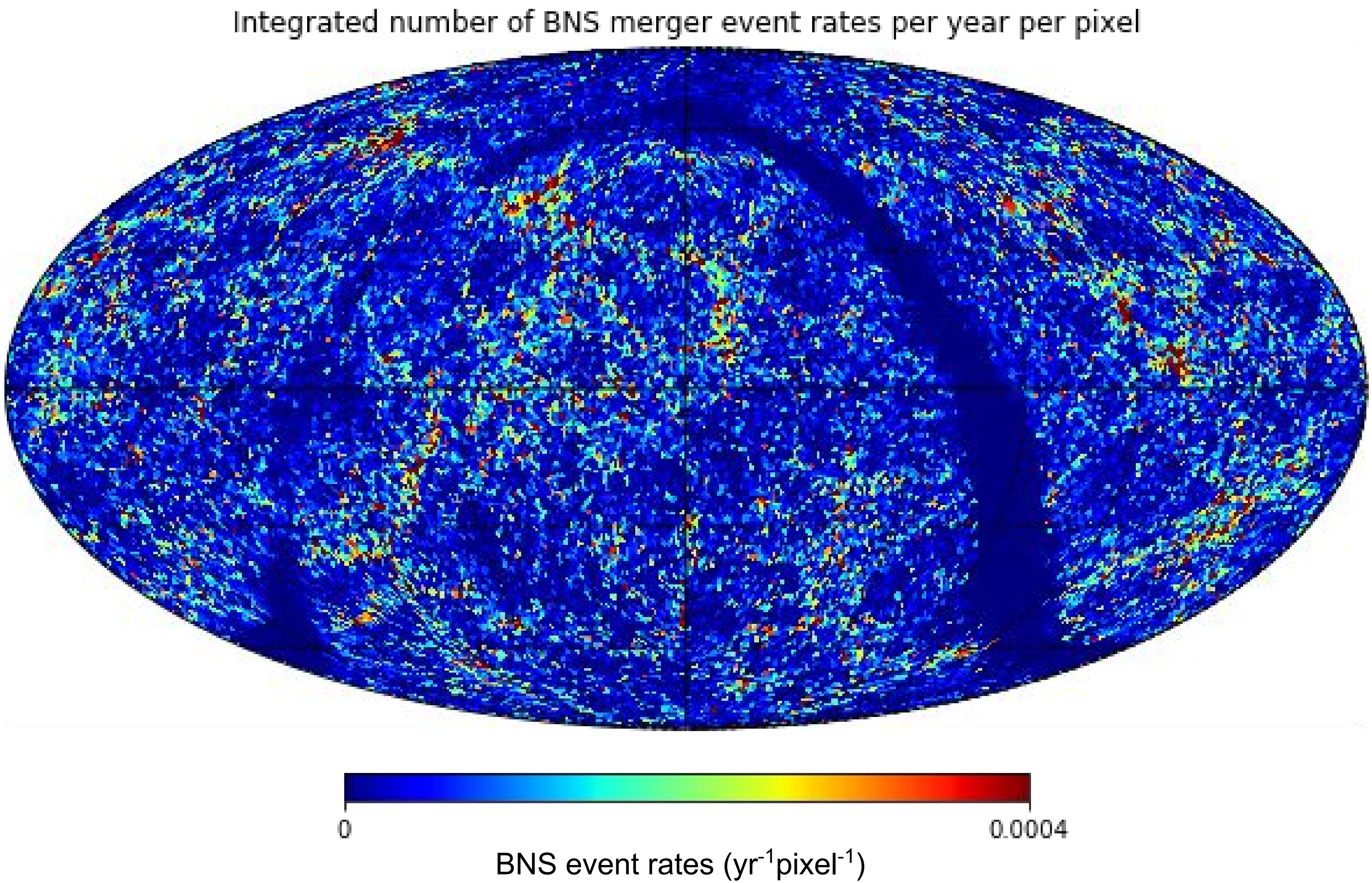
Results from New Galaxy Catalog

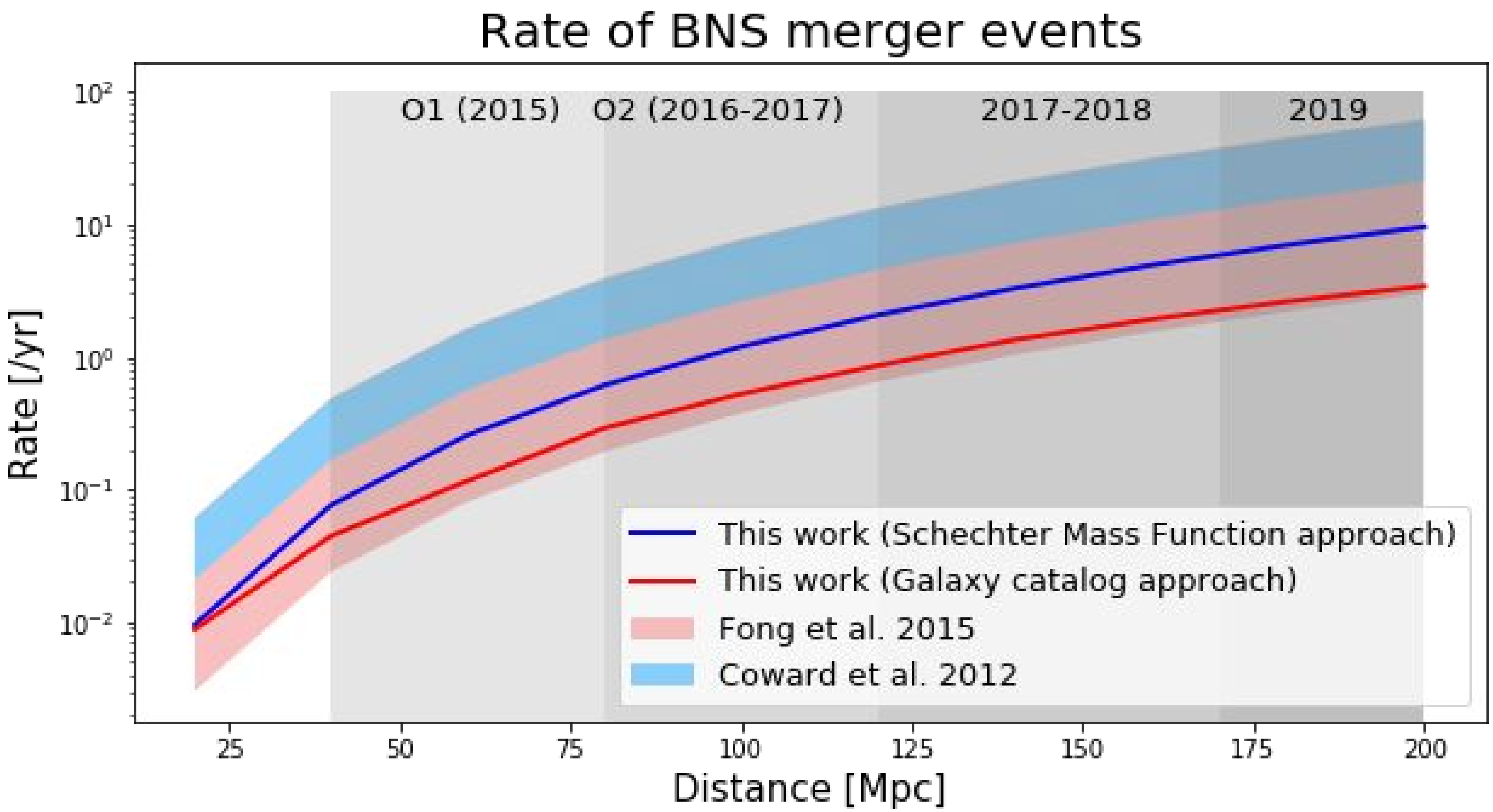


Results from New Galaxy Catalog



Comparison with literature values

- Rate with Schechter Function approach = 286 $Gpc^{-3}yr^{-1}$
- Rate with Galaxy catalog approach = 135 $Gpc^{-3}yr^{-1}$



LIGO observational selection effects

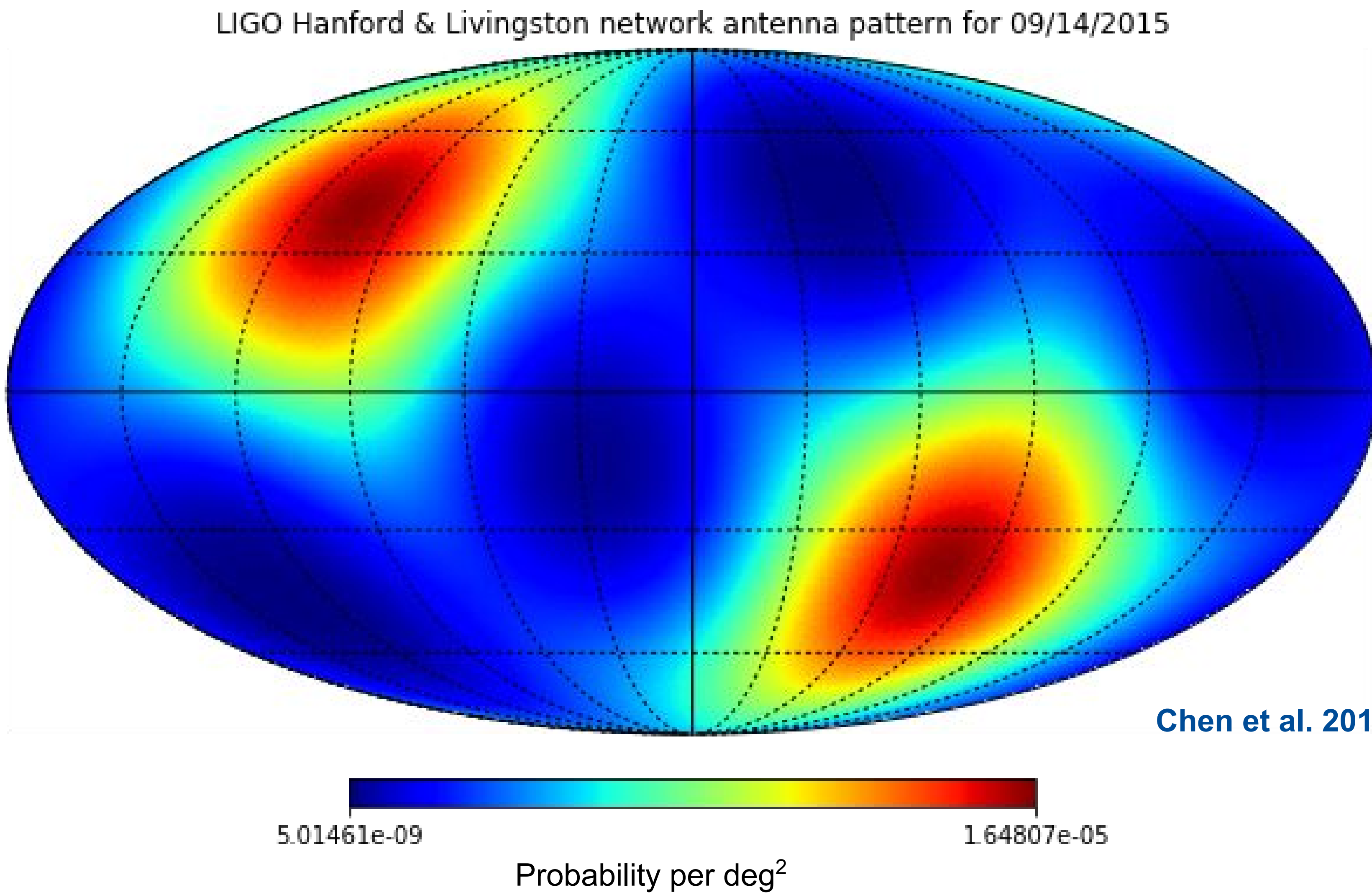
LIGO has observational selection effects for certain regions of the sky (Chen et al 2016) : **more sensitive to some regions of the celestial sphere than others.**

This depends on:

- Declination (latitude) due to location of interferometers

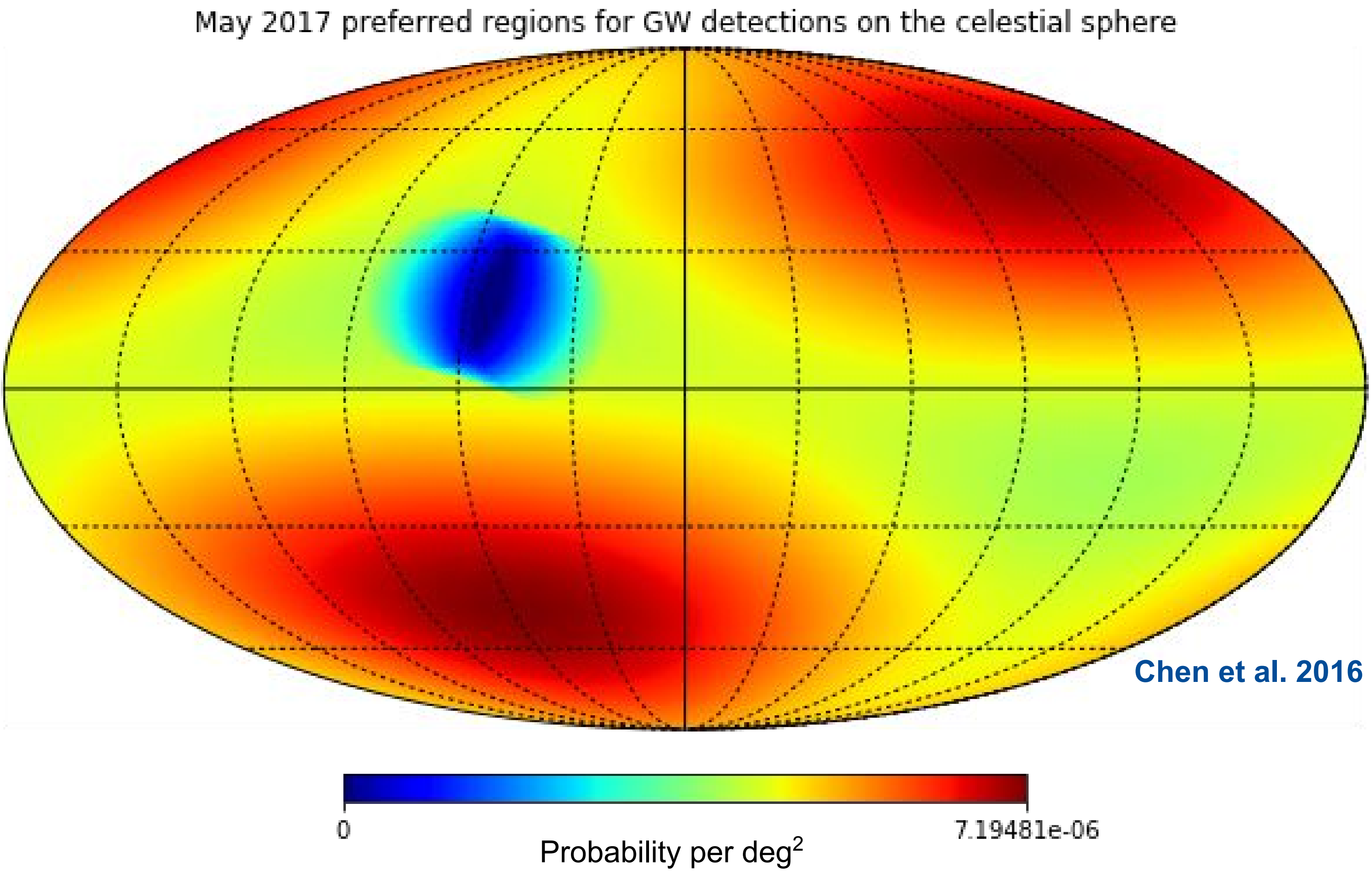
- Right Ascension (longitude) due to nonuniform daily and annual cycle.

LIGO observational selection effects



Chen et al. 2016

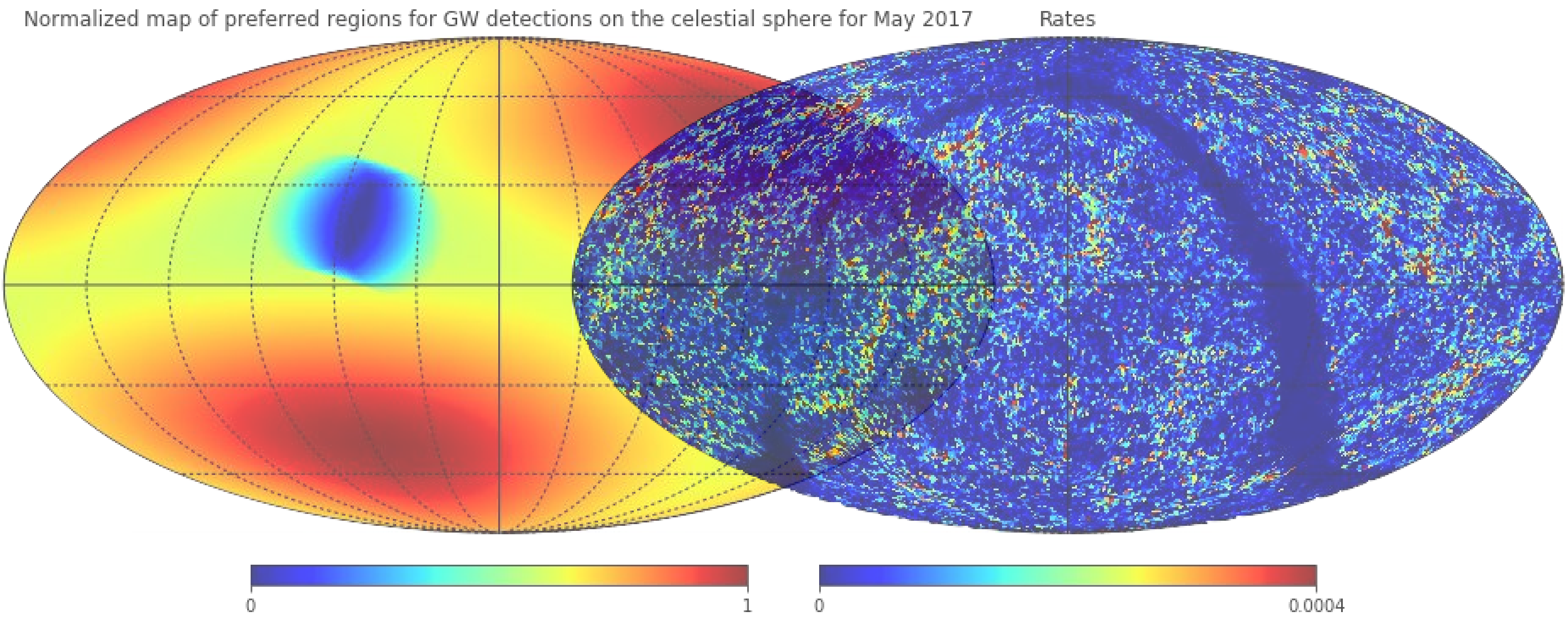
LIGO observational selection effects



Chen et al. 2016

Predicting observable rates of BNS with LIGO

Multiply LIGO sensitivity map (for every month and rates map.



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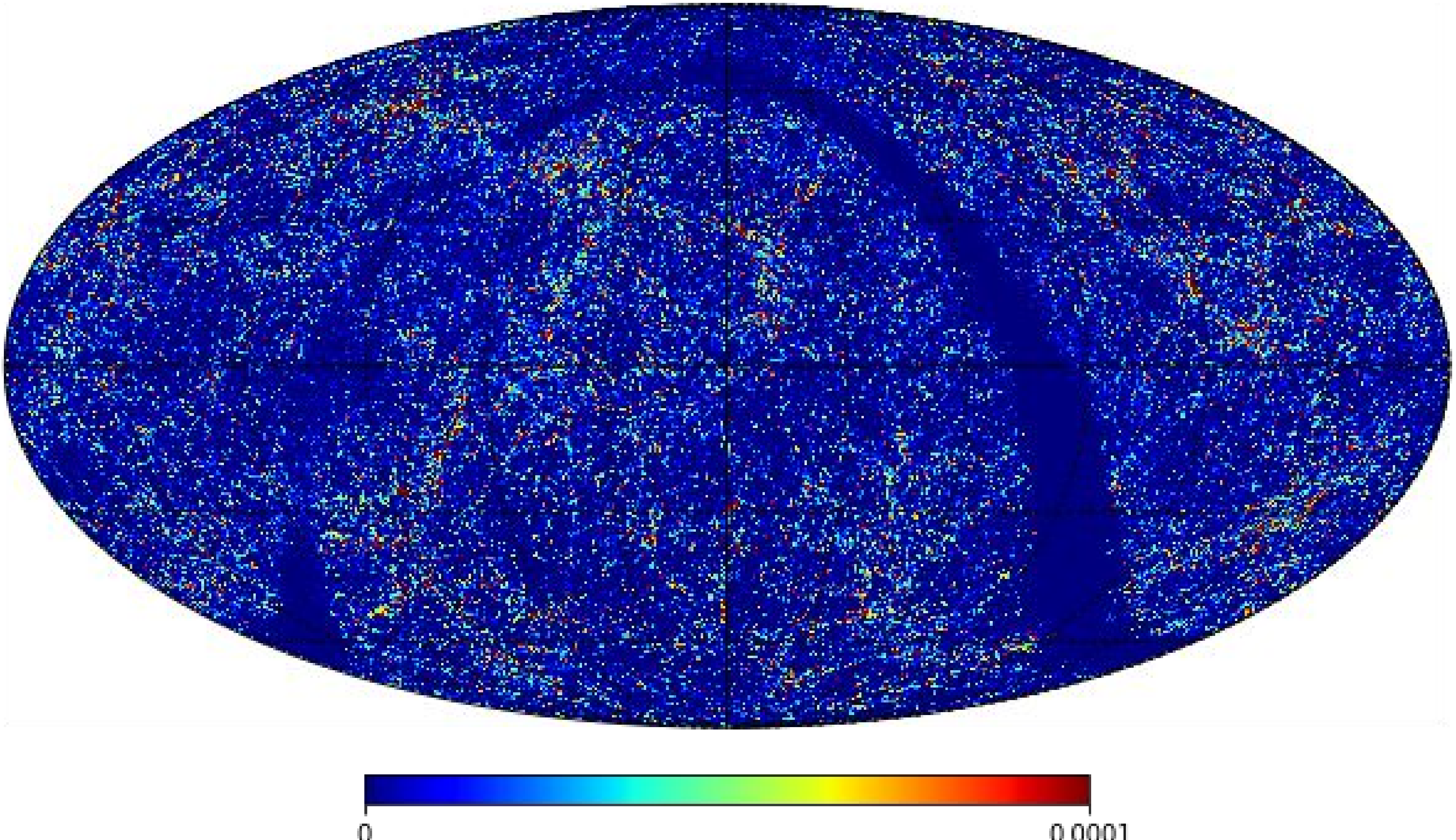
Predicting observable rates of BNS with LIGO

We get an expected number of observable events with LIGO of ~2.4 yr^{-1}.

Integrated observable number of BNS merger events with LIGO per pixel for 2017



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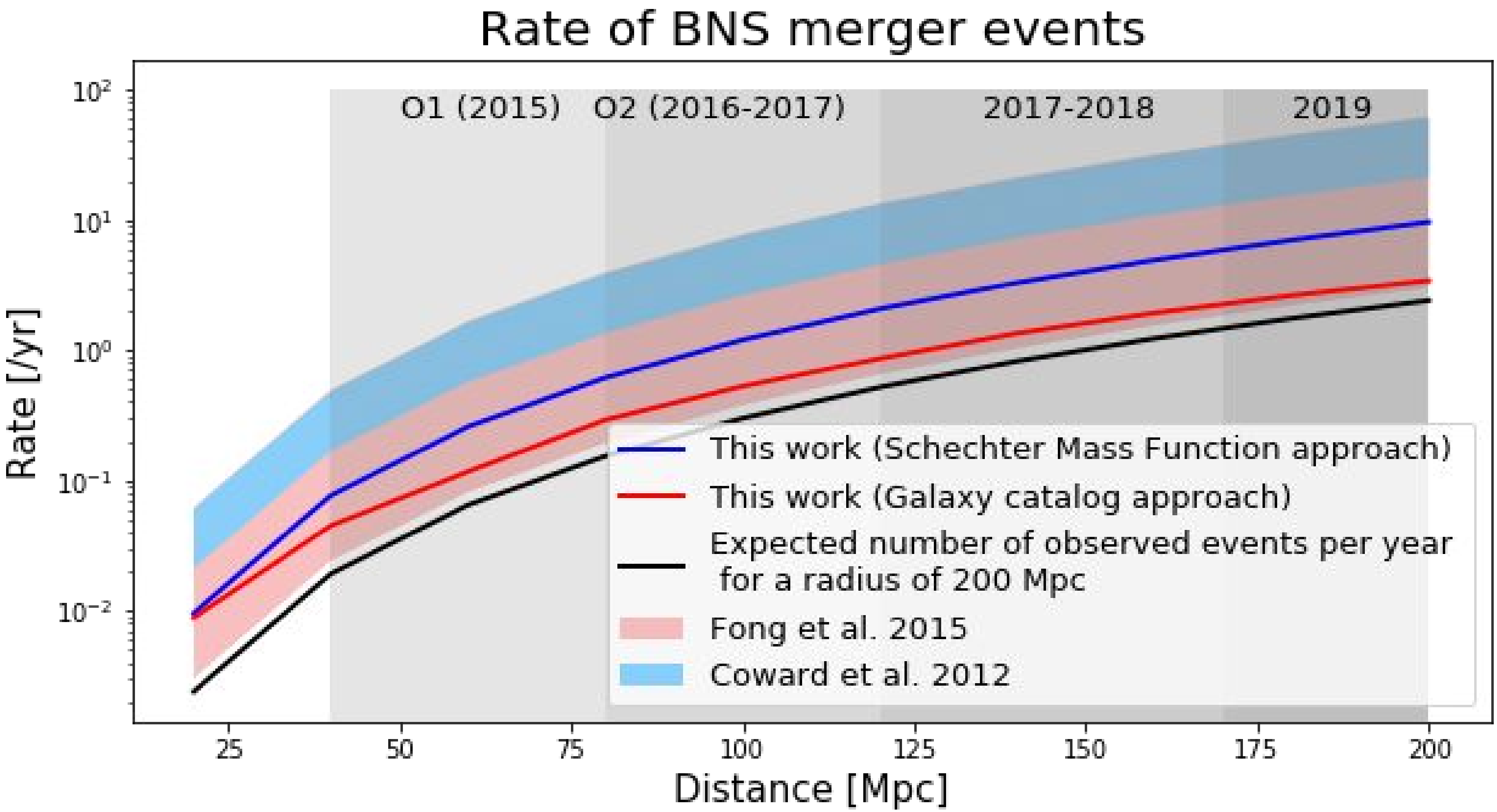
Literature comparison



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Future steps

- Build LIGO sensitivity maps for sources at different distances in order to make a better prediction of the number of observable BNS merger events.

- Consider DECam footprint and use this work to inform future EM follow-up.

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Collaborations / Partnerships

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