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Cosmic "collisions" (and explosions) in the ngVLA Era

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Developing the ngVLA Science Program Workshop – 27 June 2017 - Socorro

Collaborators for this study

Science collaborators:
- Dale Frail (NRAO)
- Benjamin Owen (TTU)
- David Sand (TTU)
- Richard O'Shaughnessy (RIT)

Technical advisors:
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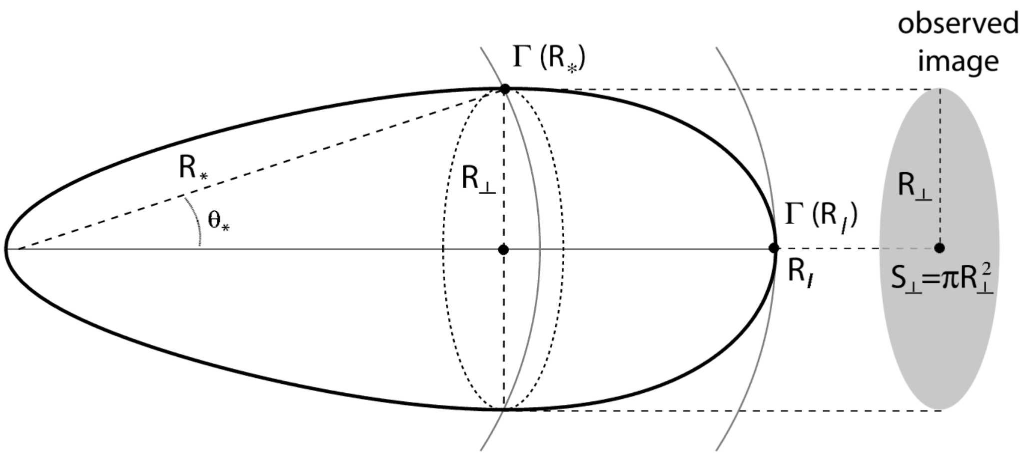
- Remy Indebetouw (NRAO)

Also thanks to:
- Eric Murphy (NRAO)
- Thomas Maccarone (TTU)

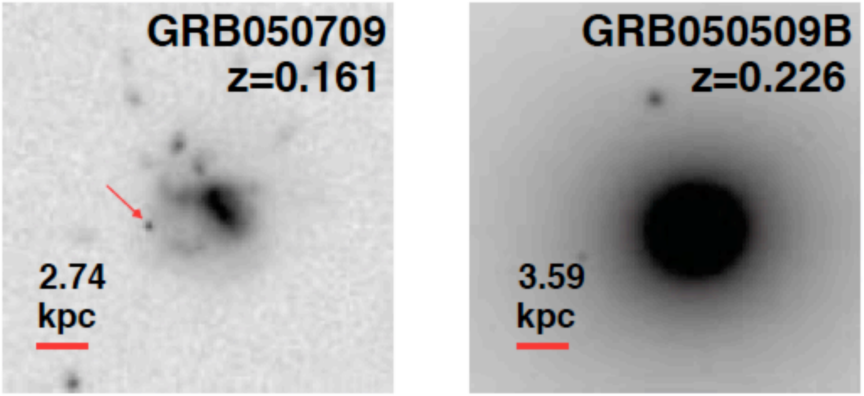
Goals of this community study

- **Relativistic ejecta** from nearby **compact binary mergers** (cosmic collisions) (and low-luminosity long GRB explosions) within Advanced LIGO reach (~150-200 Mpc): **can ngVLA enable direct size measurements**?



Granot et al. 2005

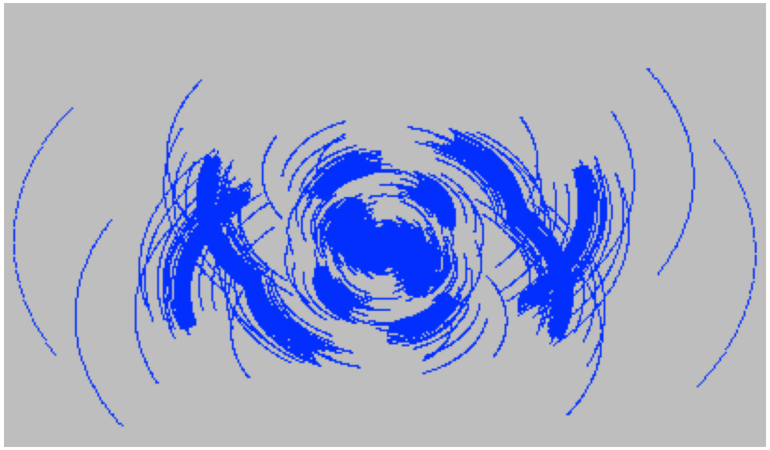
- **ngVLA role in host galaxy studies of compact binary mergers** within Advanced LIGO horizon (z<0.1): SFR, stellar age, mass, and/or Z could lead to **major insights on progenitors**.

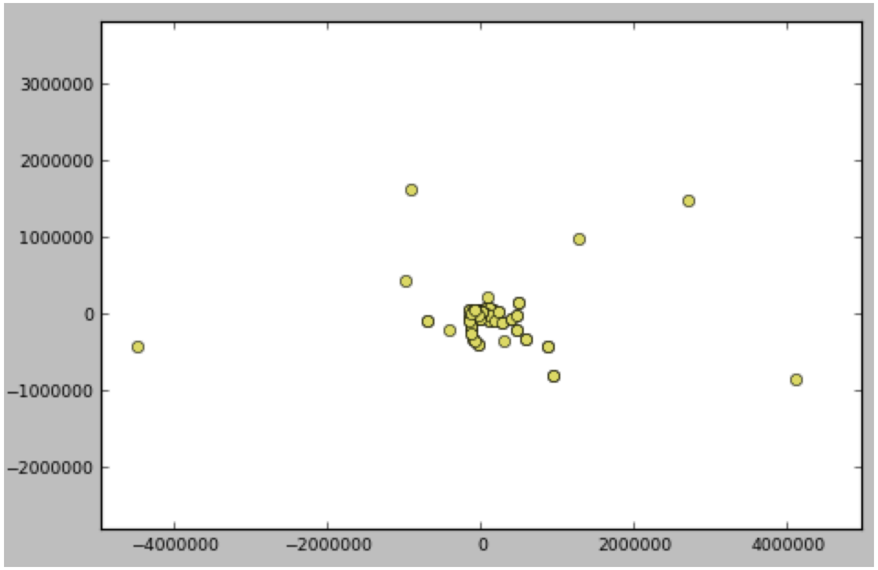


Gomboc 2012

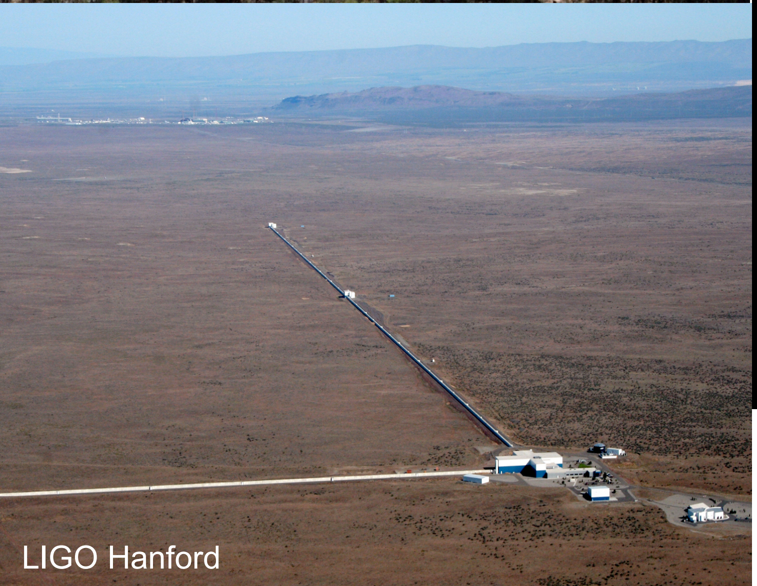
Assumed ngVLA configuration

- 300 18m-dishes extending through Texas, with VLBA stations available.
- Continuum sensitivity in 1hr @ 30 GHz →0.39 uJy/beam.
- Continuum sensitivity in 1hr @ 2 GHz →0.93 uJy/beam.

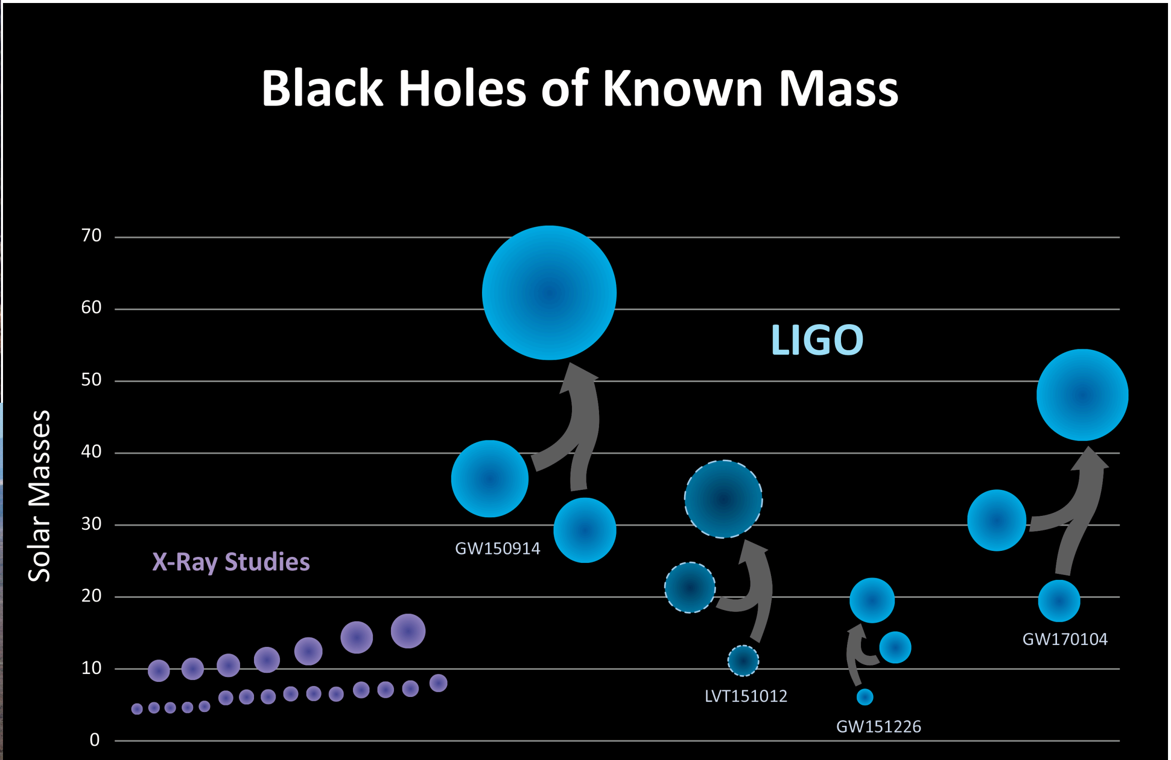




Welcome to the era of GW astrophysics!

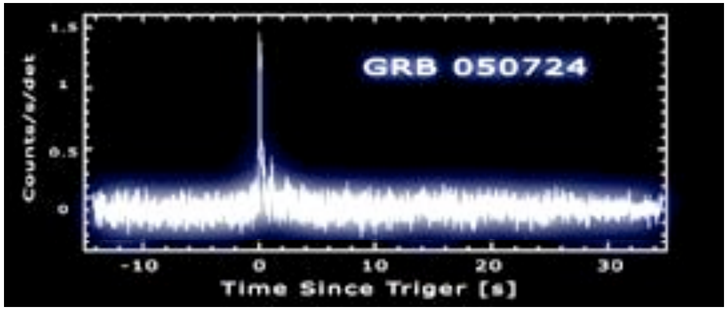


So far, **3 confirmed BBH mergers** in Advanced LIGO observing runs.

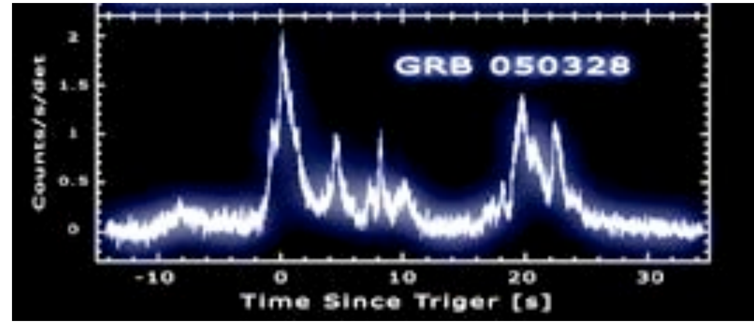


Credit: LSC/Sonoma State University/Aurore Simonnet

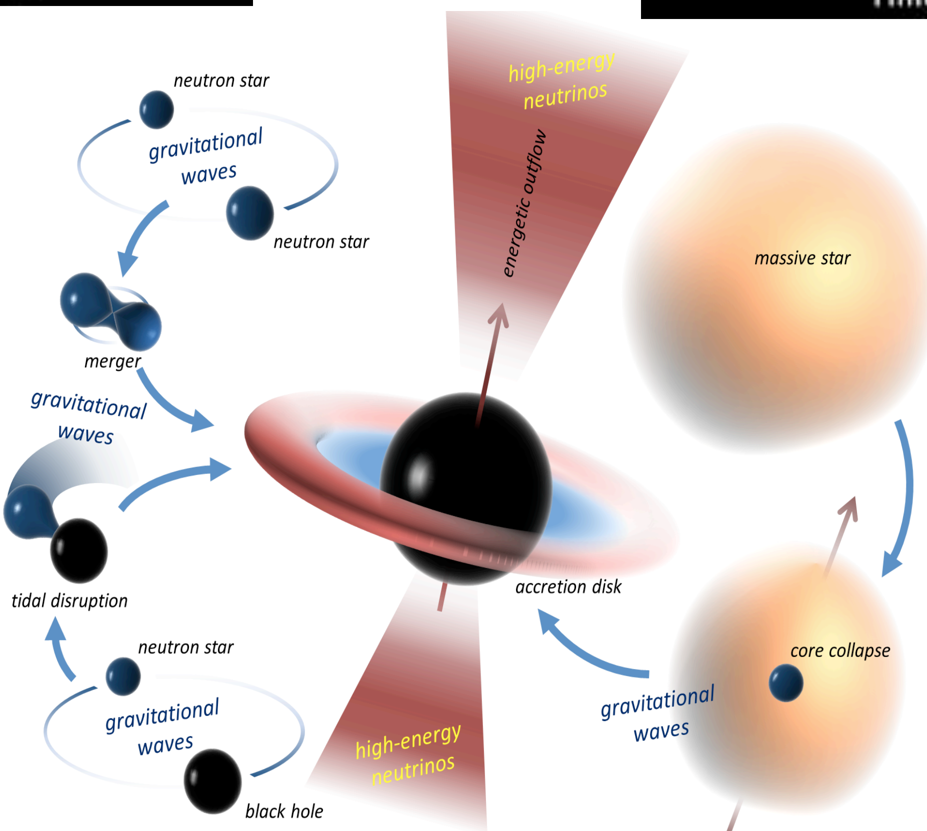
BHs are nice but NSs matter…



Credit: NASA

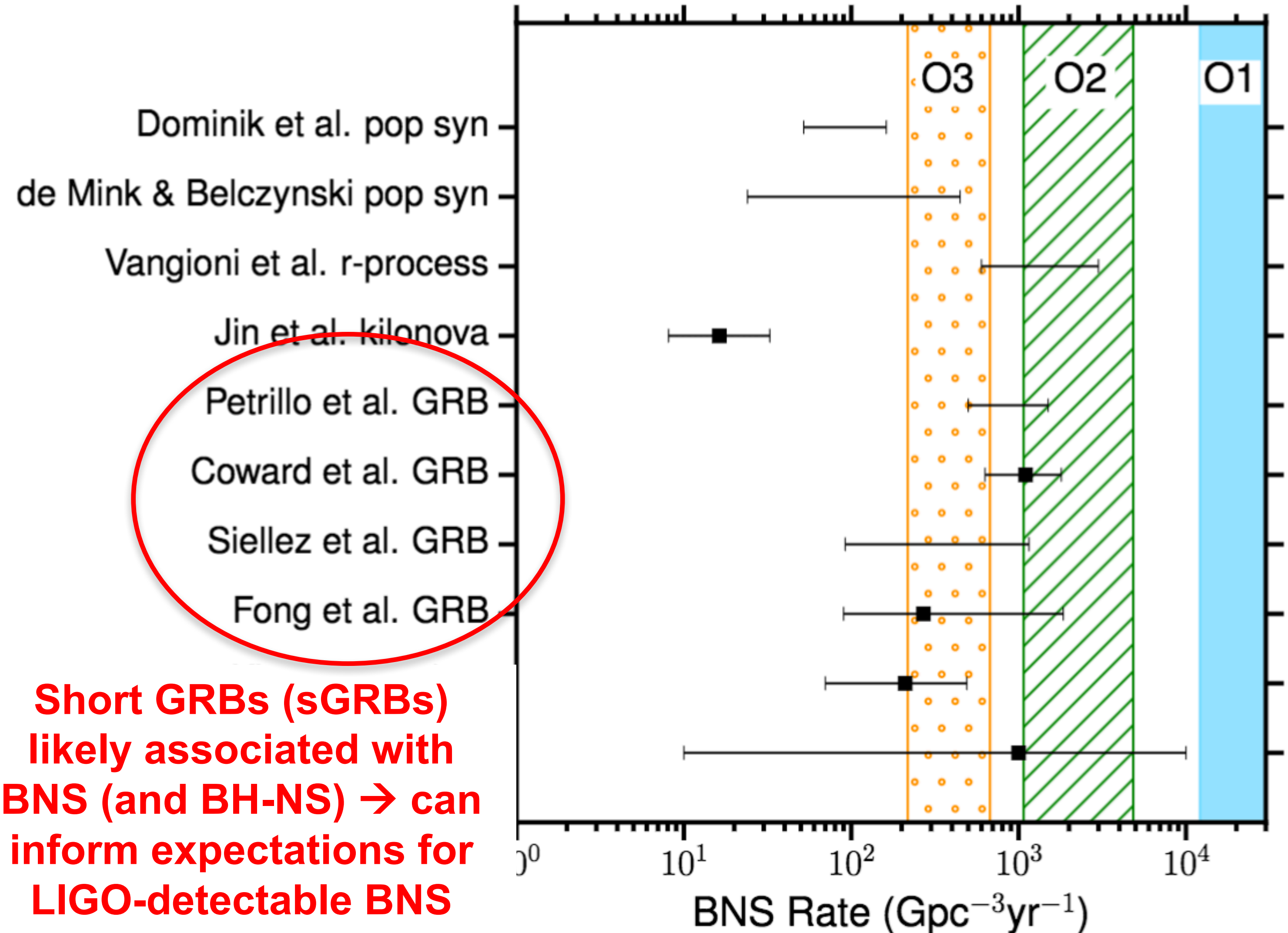


Credit: NASA



Credit: I. Bartos

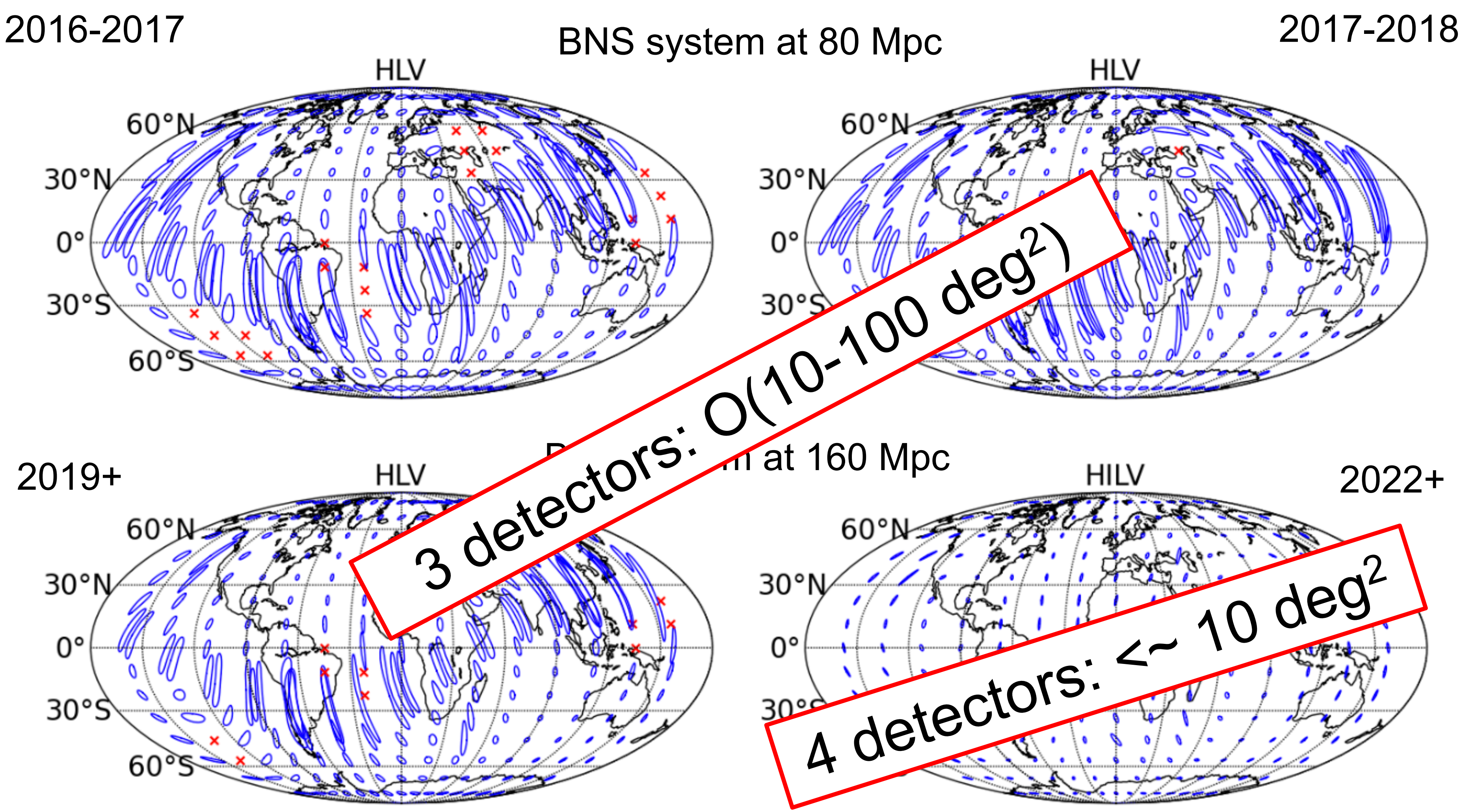
Constraints on BNS rates



Short GRBs (sGRBs) likely associated with BNS (and BH-NS) → can inform expectations for LIGO-detectable BNS population.

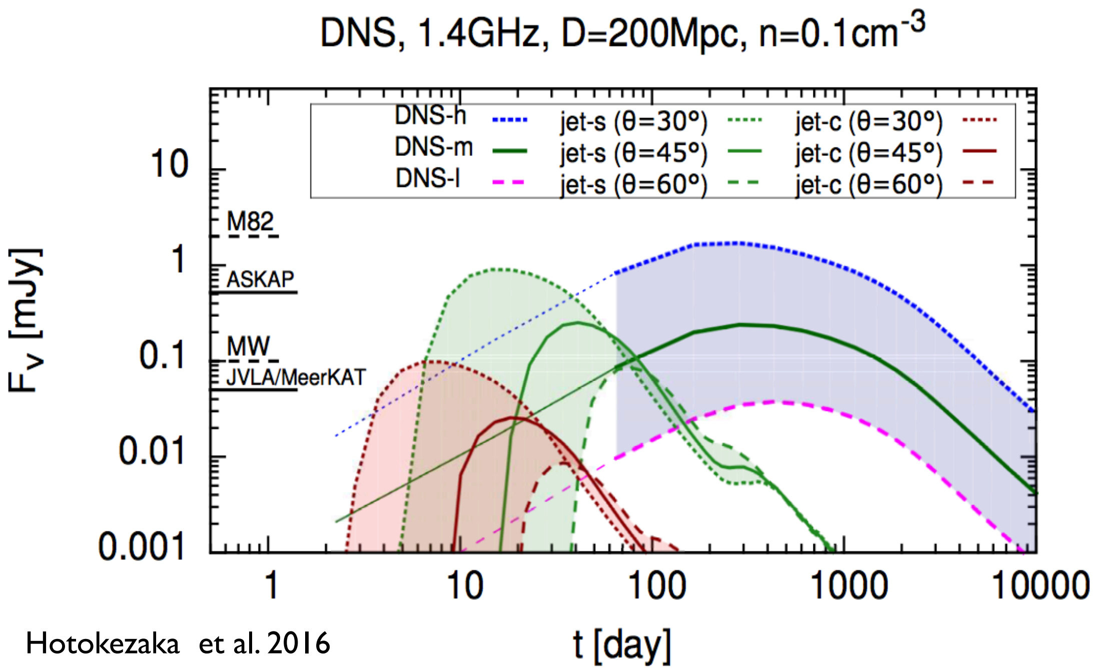
Abbott et al. 2016, ApJ, 832, L21

BNS: prospects for improved localizations



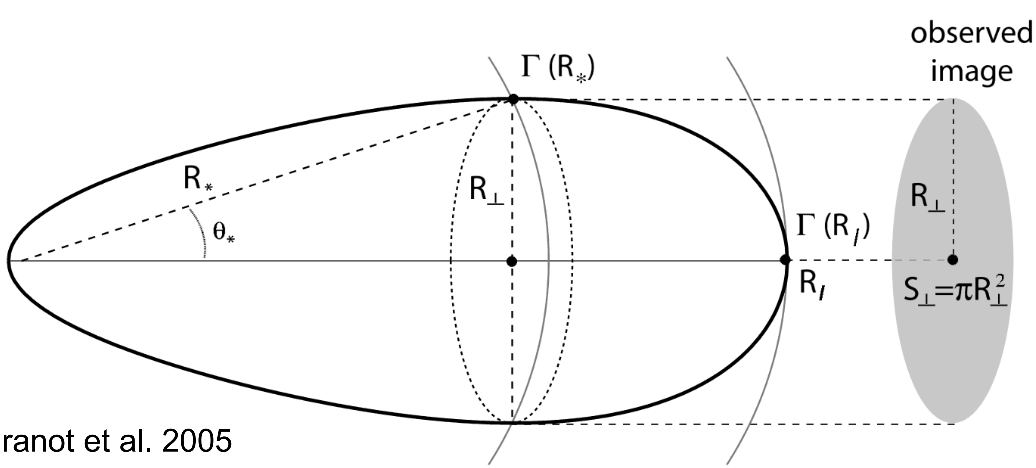
Abbott et al., Living Reviews in Relativity 19, 1 (2016)

Radio emission from BNS mergers



Hotokezaka et al. 2016

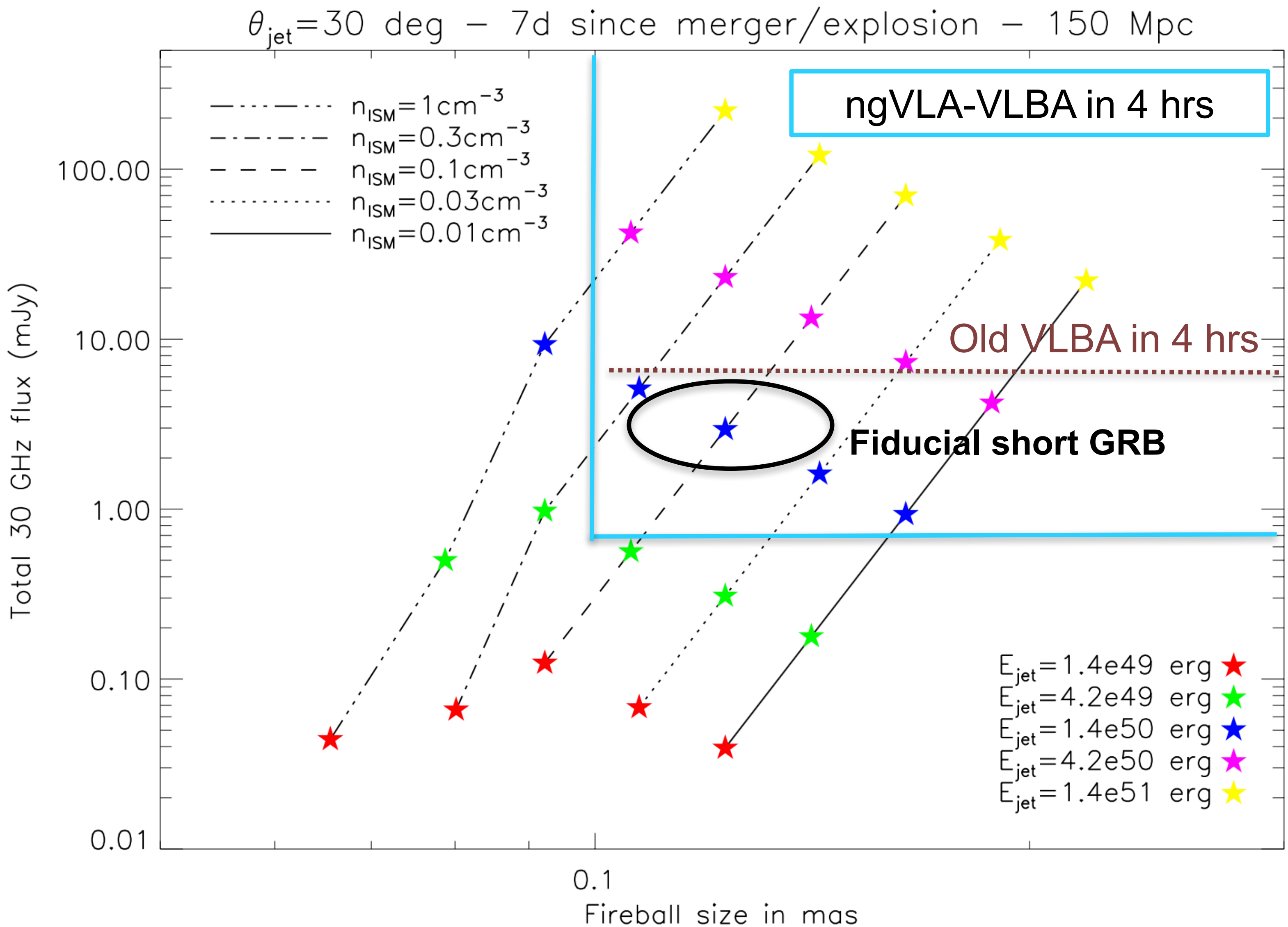
- Example of the zoo of model predictions for radio counterparts to BNS mergers.



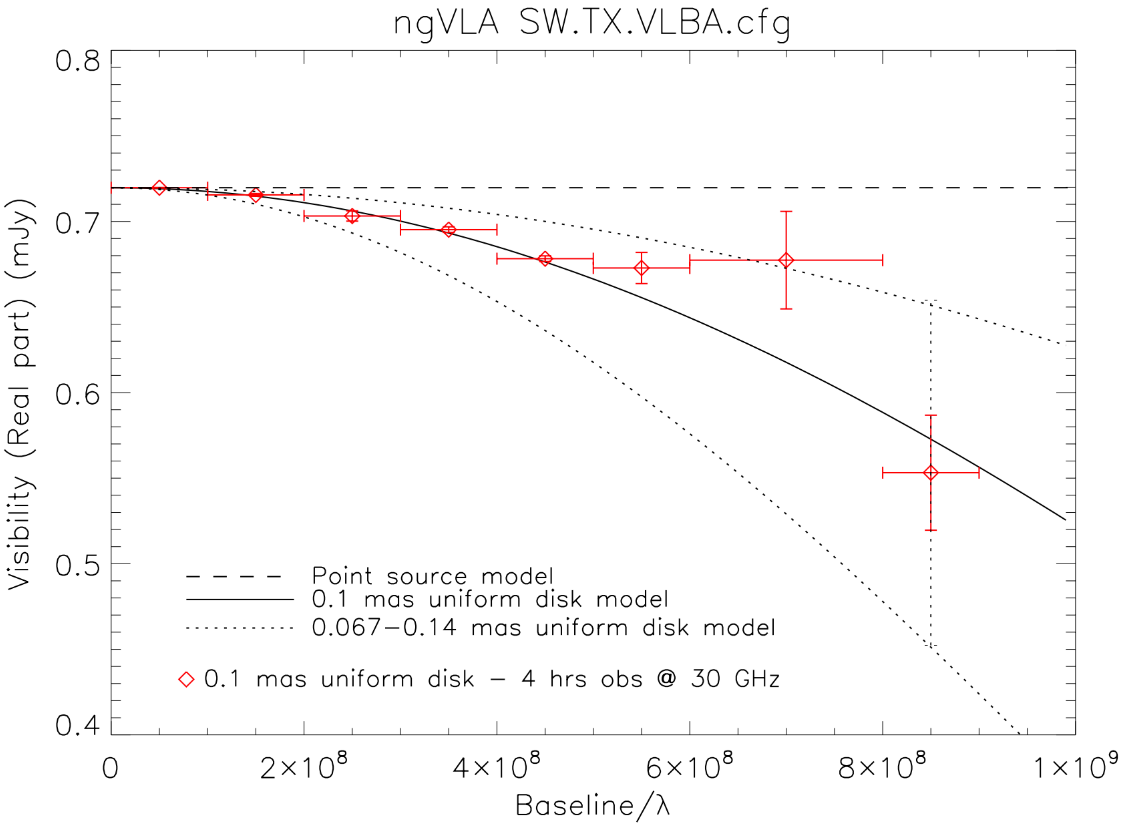
Granot et al. 2005

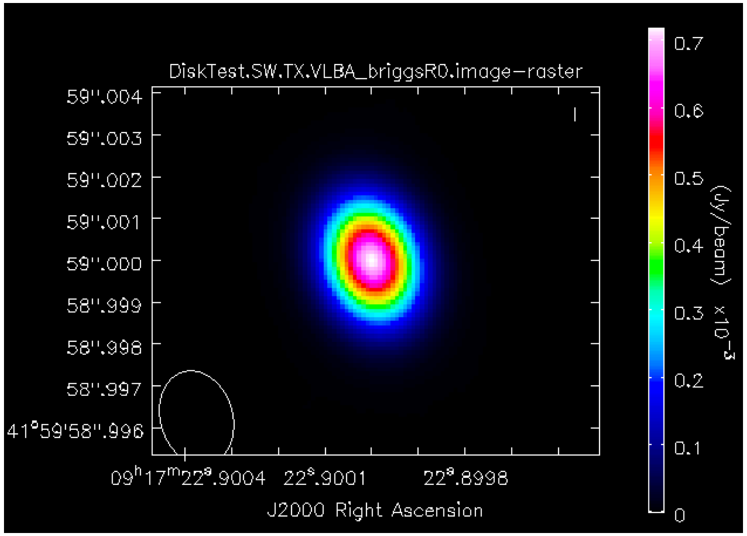
- Egg-shaped region from which photons emitted by relativistic ejecta reach an observer at a given time T.
- To reach the observer simultaneously, photons emitted at different locations are emitted at different times in the observer frame.

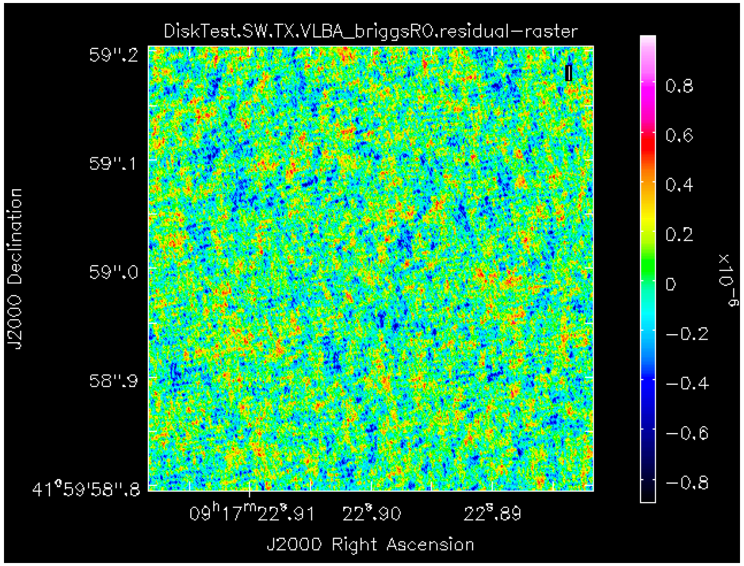
Relativistic ejecta from BNS @ 150 Mpc



ngVLA-VLBA: Resolving BNS ejecta



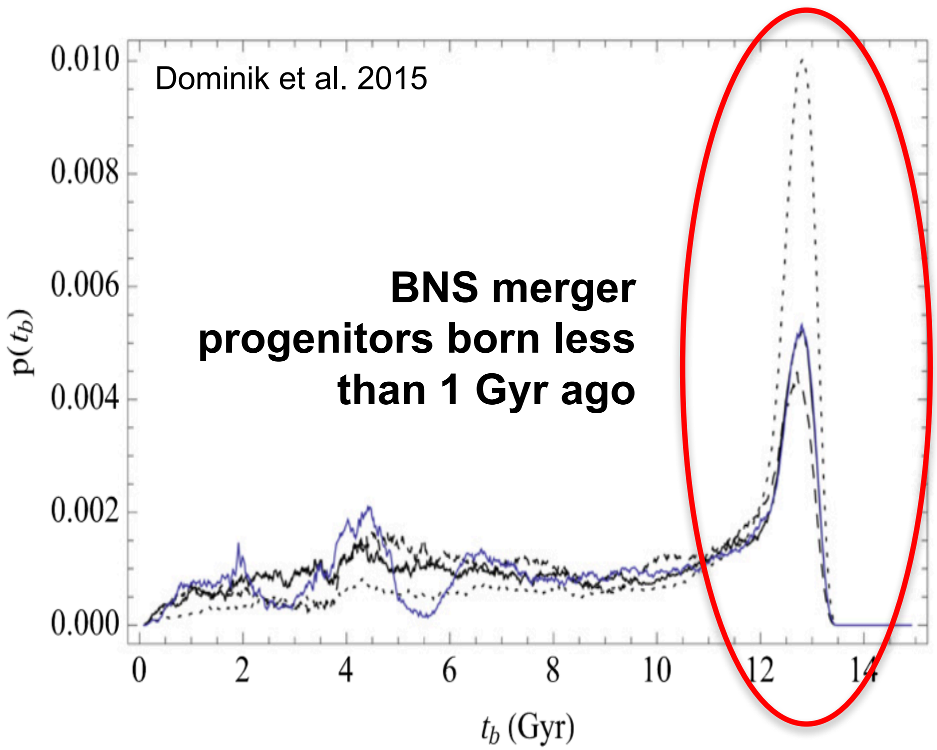


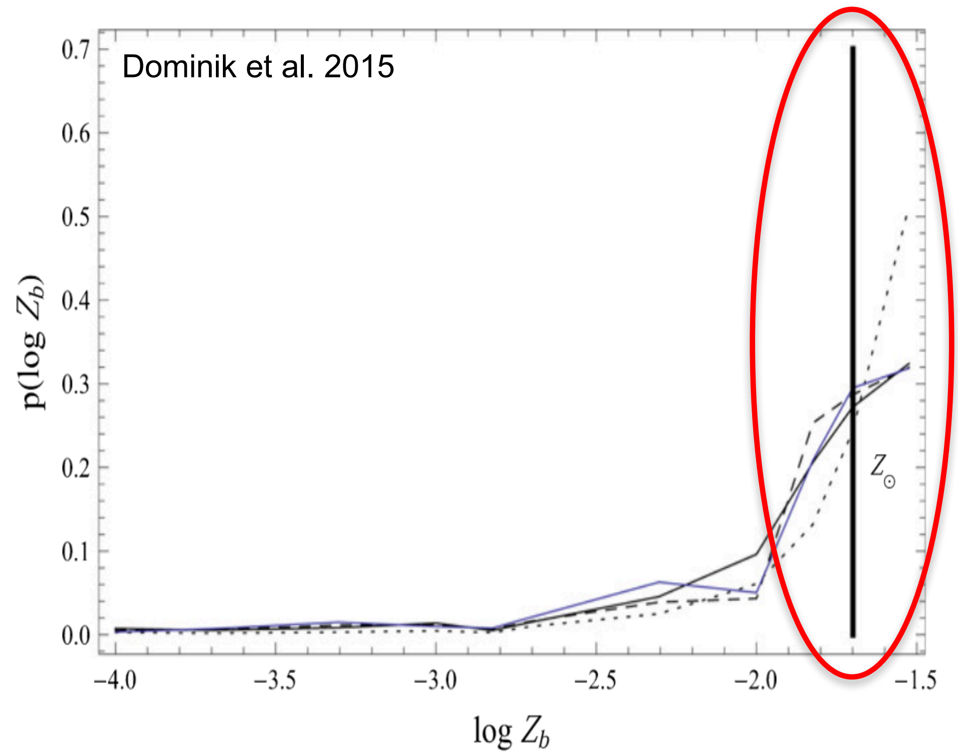


Noise normalized so the 1 hr sensitivity (Briggs weightening with R=0) equals the "nominal" ngVLA sensitivity (i.e. ~10x better than VLA).

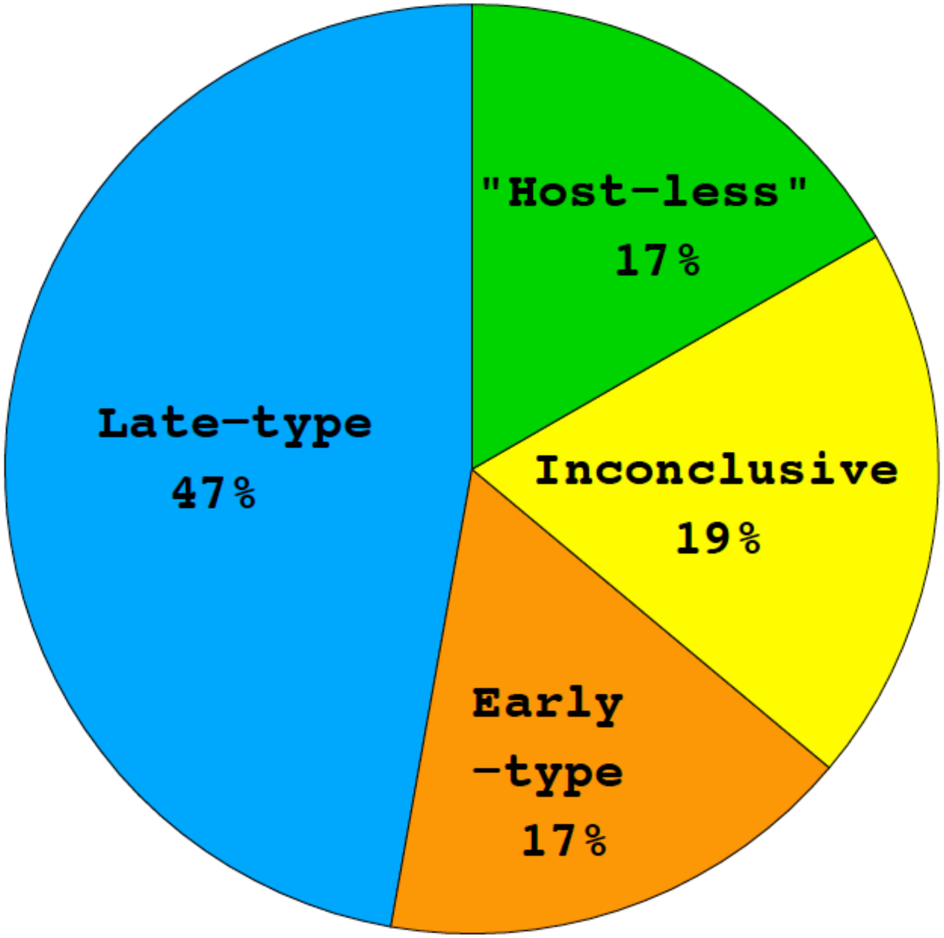
BNS: Progenitor ages and environmental Z

- Compact obj binaries merge shortly after formation, $N(t_{merge}) \sim t^{-1}_{merge}$. Average Z of universe increases with time, and BNS form efficiently in high-Z environments.
- **Birth rate of GW-detectable BNS peaks at 13 Gyrs after Big Bang;** 50% form in **$Z \geq 1\ Z_{\odot}$** or log(Z)≥-1.7.
- BNS merger GW horizon: **z~0.1** (~12.4 Gyr since Big Bang).





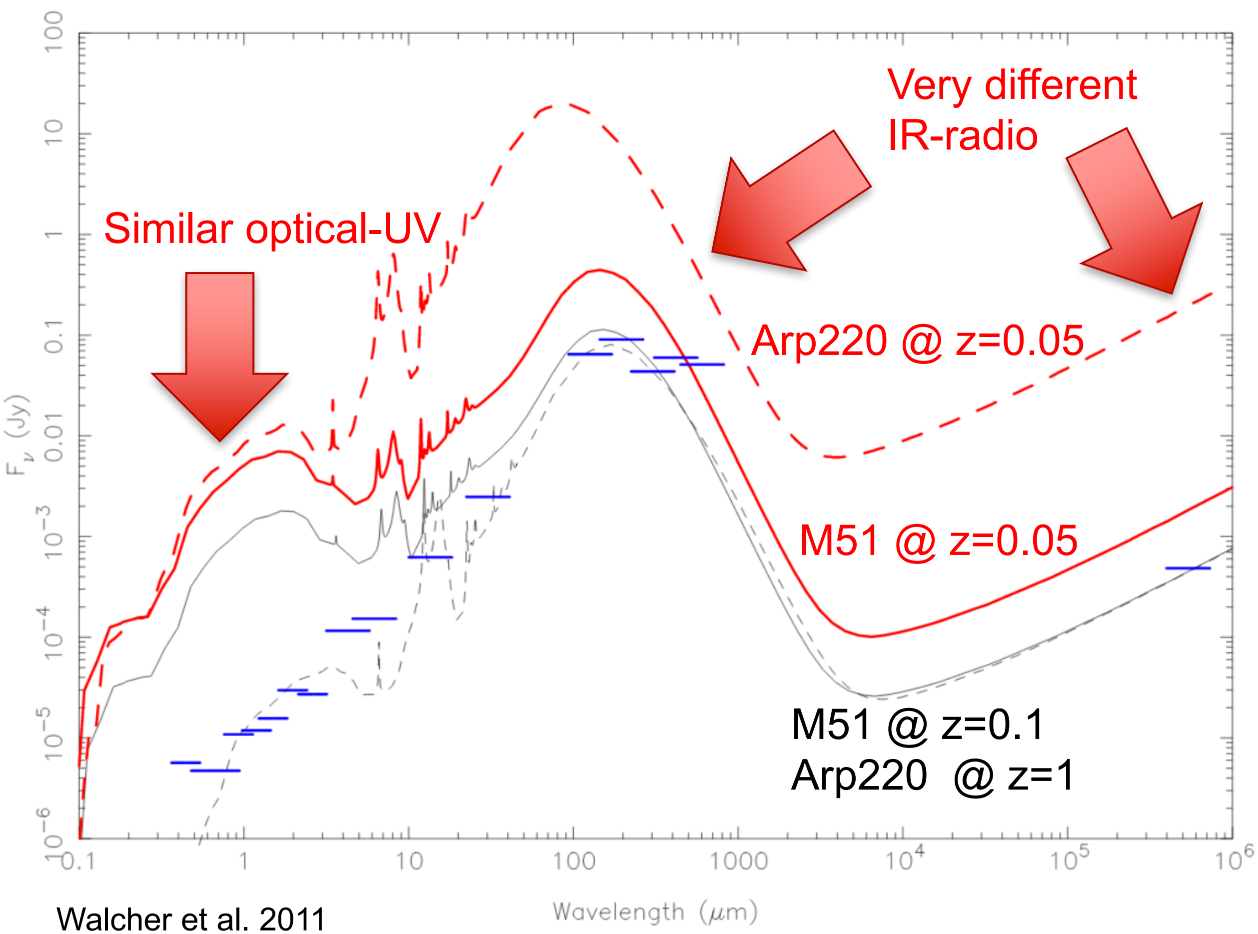
sGRB host galaxies: proxy for BNS hosts



Berger 2014

- Late-type galaxies seem to dominate the host sample.
- On average, stellar populations in **early-type galaxies are older than** those **in late-type galaxies**.
- **Star formation activity likely plays a role in the short GRB rate**, consistent with expectations from BNS mergers (progenitors less than 1 Gyr old).
- **Delay time between formation and merger** plays an important role in determining merger rates in early- and late-type galaxies (e.g., O'Shaughnessy et al. 2010).

Importance of broad-band SEDs



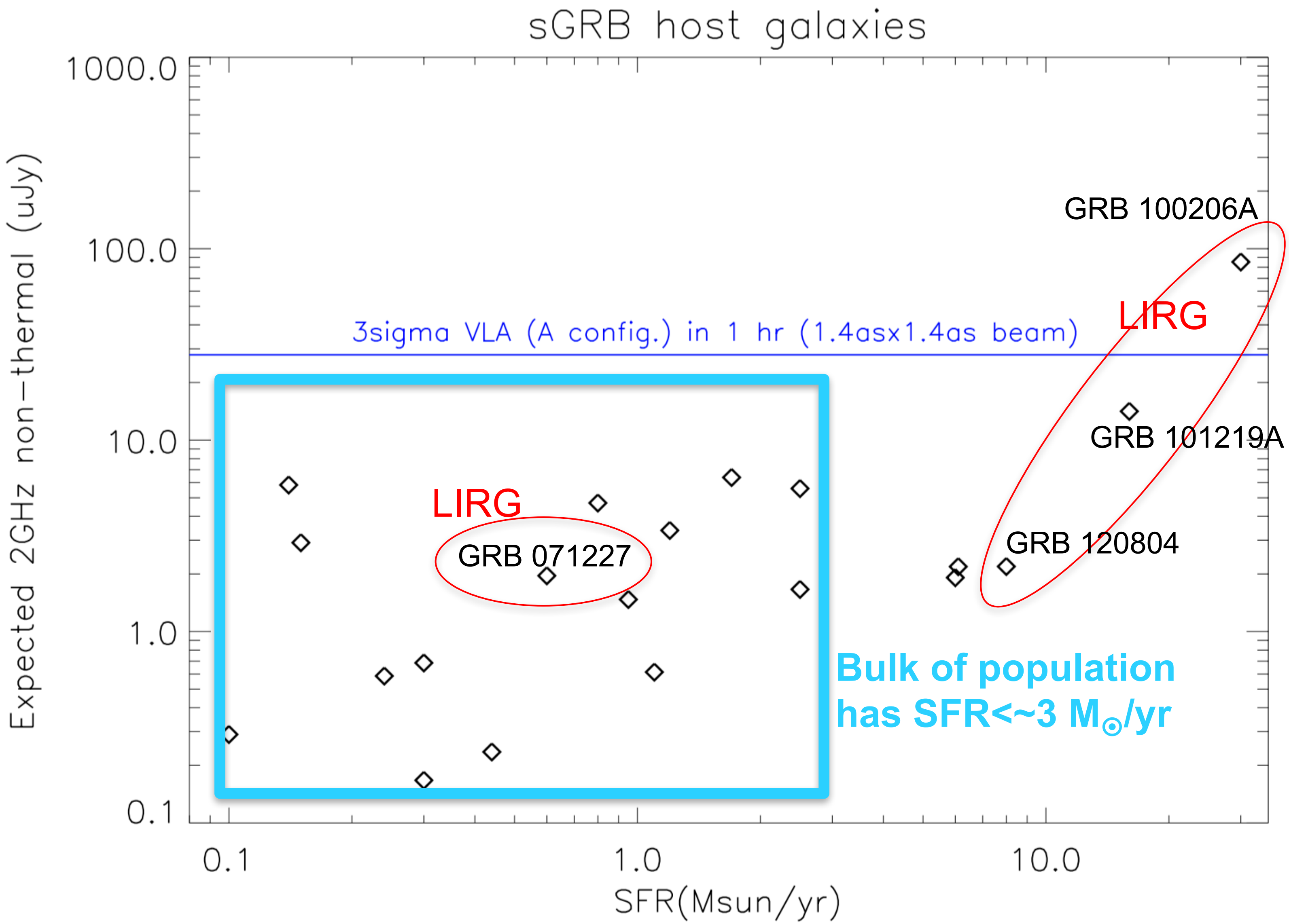
Walcher et al. 2011

Optical/UV only unreliable as measure of SFR in dusty galaxies!

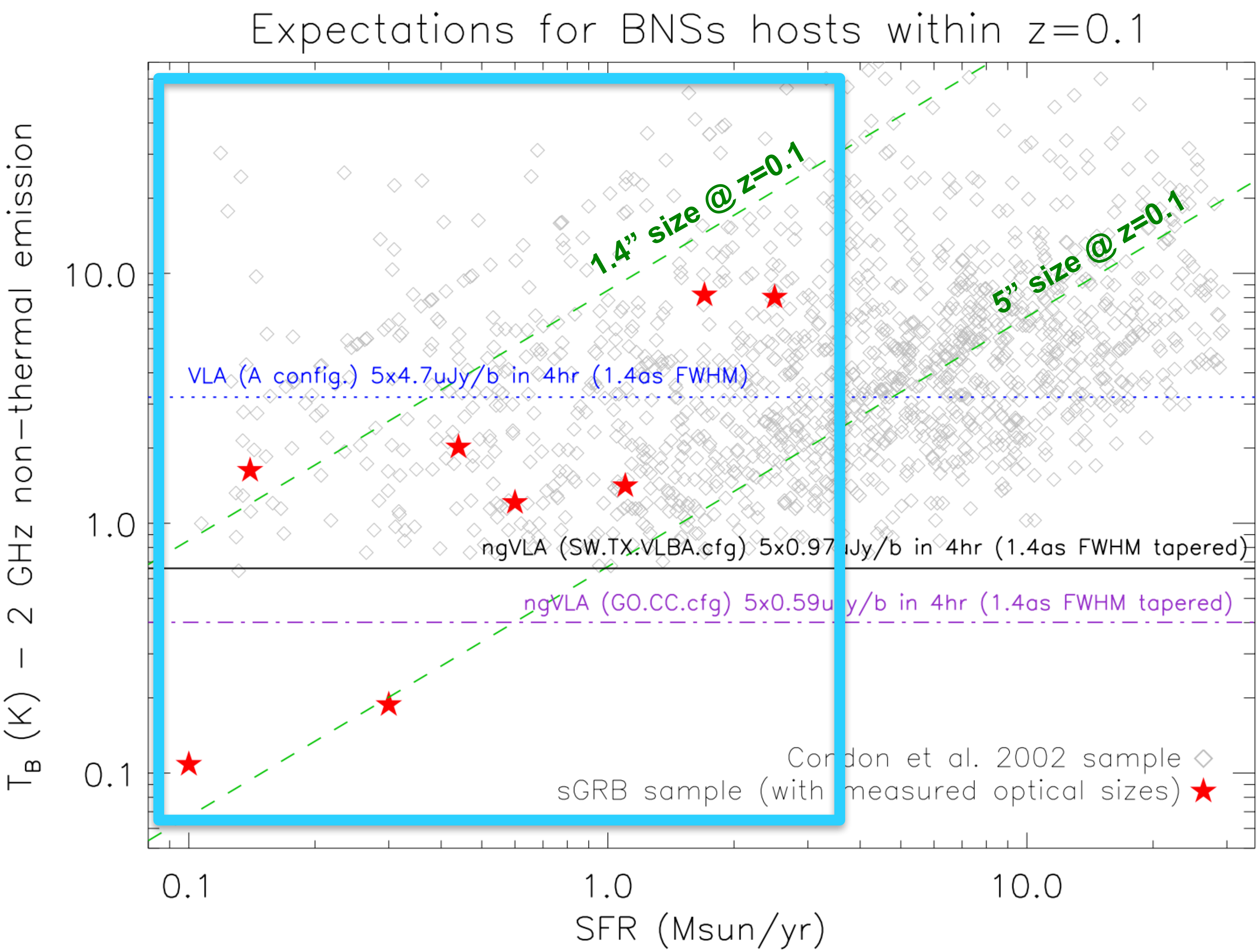
Radio helps break the age-dust-metallicity degeneracy.

Optical-radio SEDs from stellar population synthesis code GRASIL (Silva et al. 1998) for M51 (typical spiral with SFR~5 $M_\odot$/yr), and Arp220 (archetypal ULIRG → on average ~100 $M_\odot$/yr).

Expected non-thermal continuum @ 2 GHz



ngVLA: Detecting & resolving BNS hosts

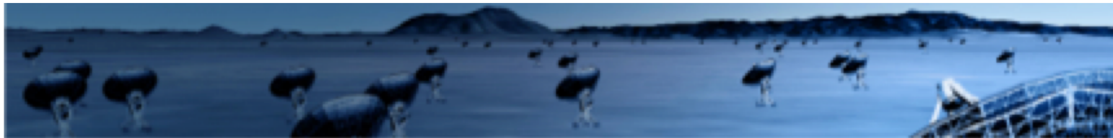


Conclusion

- ngVLA configuration with 300 18m-dishes extending through Texas (with VLBA stations) works for the goals of this project.

- To be done: Repeat estimates with 214 18m-dishes.

- Memo in preparation.



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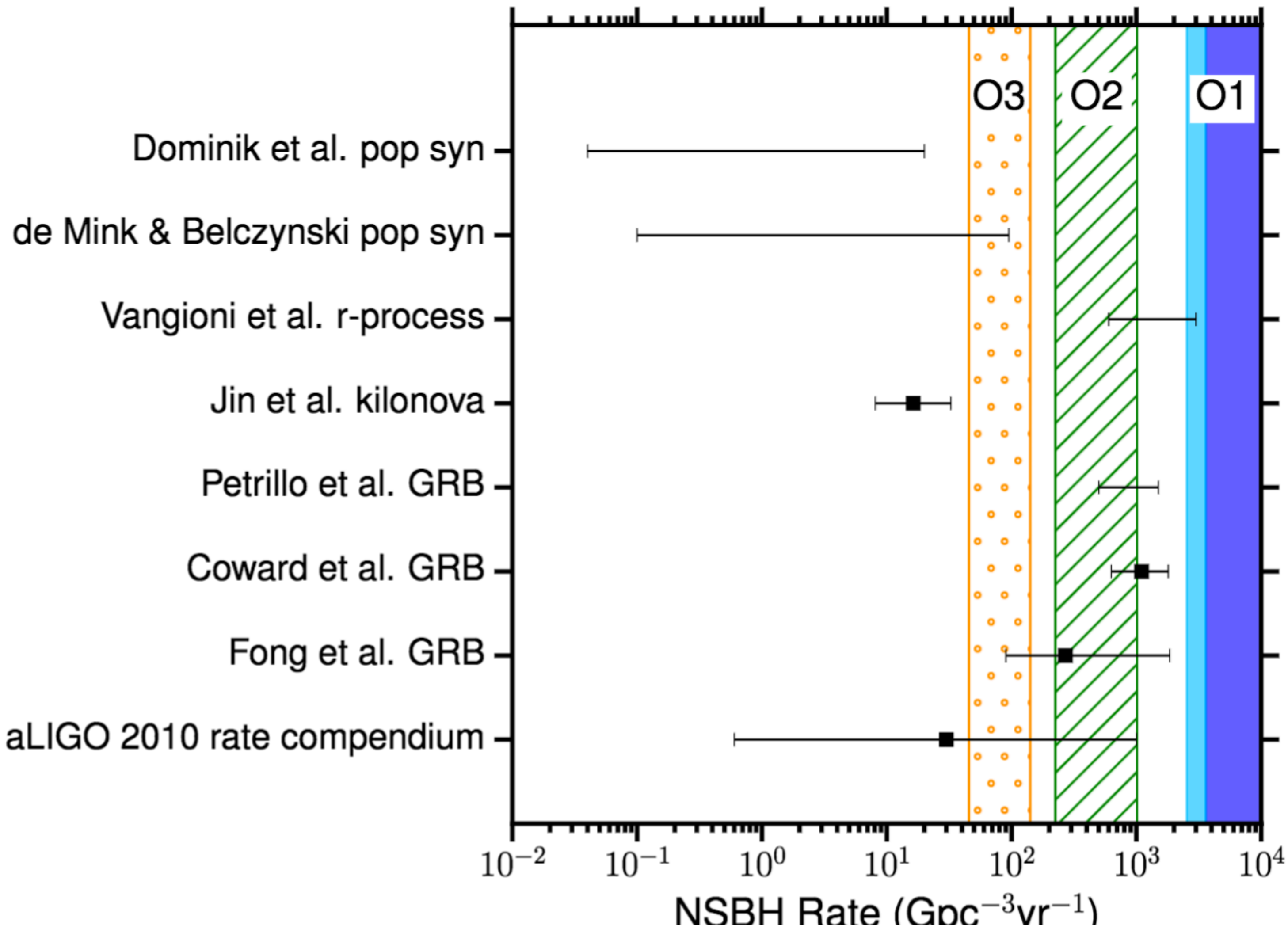
Current constraints on BH-NS rates



Dark blue: 5-1.4 $M_\odot$
Light blue:10-1.4 $M_\odot$

LVC, 2016, ApJ, 832L, 21

BBHs: Progenitor ages and environmental Z

- 50% of **detectable BBH** created within 2 Gyrs of Big Bang (longer delays to merger) and from **$Z<0.1Z_{\odot}$ (**or log(Z)<-2.7) environments.
- Farthest **detectable BBH** at **z=2** (or 3.3 Gyrs since the Big Bang).
- BH max mass depends on max ZAMS star mass in IMF (set to $M=150M_{\odot}$).