MeV Gamma-ray Gravitational Wave (GW) Synergy

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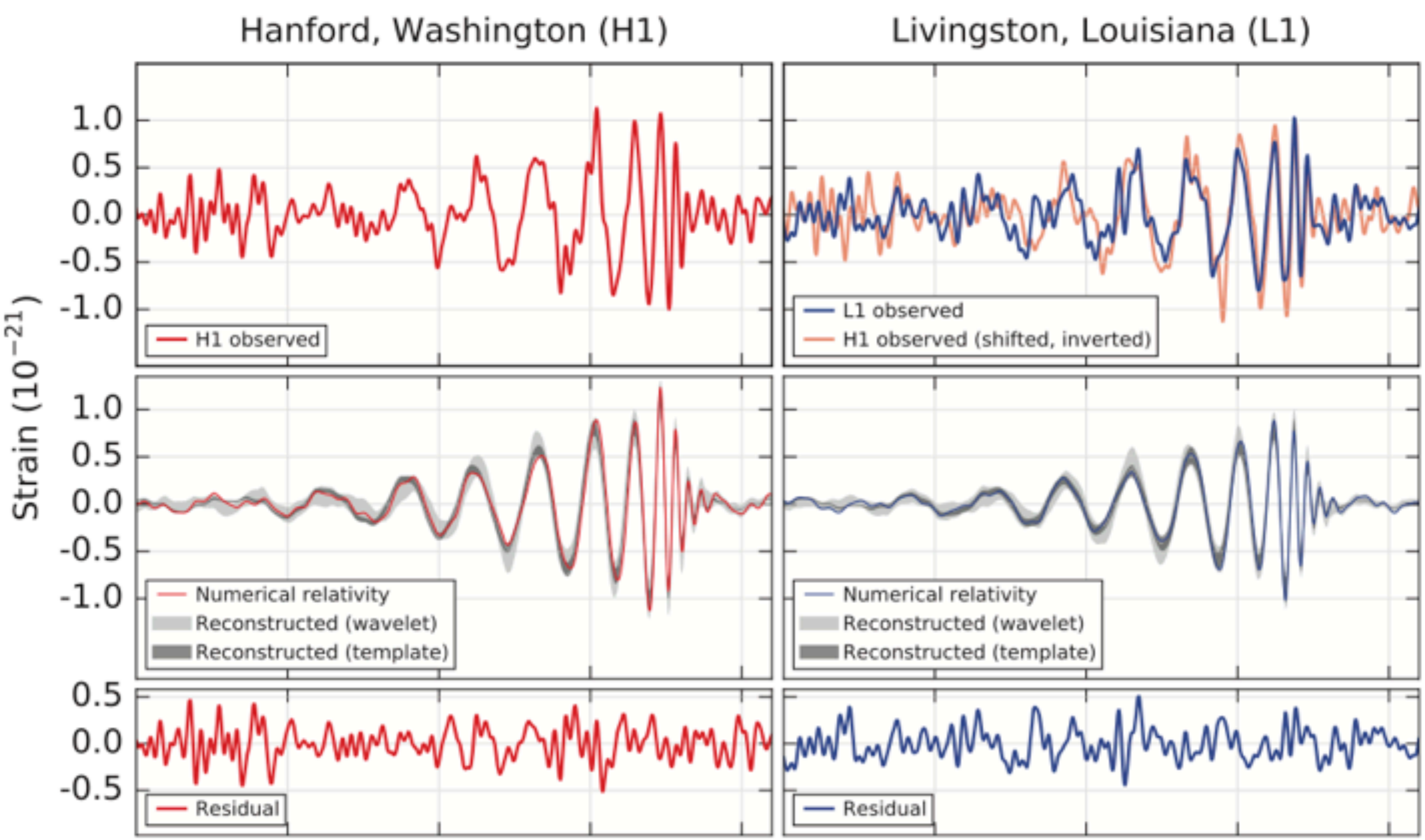
Gravitational wave astronomy is here: the most exotic compact mergers (BH-BH) may be the most commonly detected, at least for a while

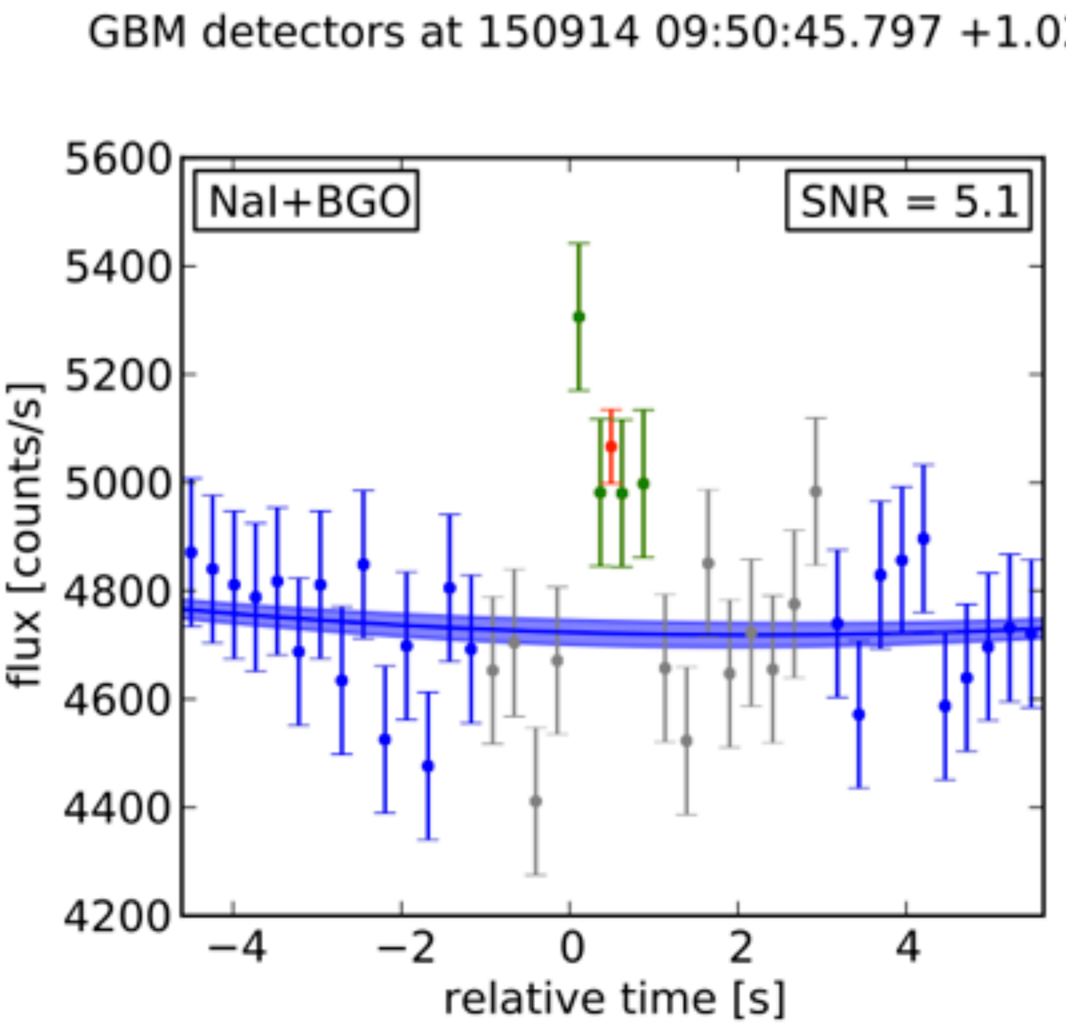


GW150914:
3 solar masses of
gravitational radiation!

Abbott et al. 2016

- O2 run later this year: more mergers, NS-NS horizon still unlikely

Can we expect high-energy electromagnetic counterparts? BH-BH mergers expected to be dark. GBM detected a weak event close in time to GW150914 with a 0.2% probability of occurring by chance.



- Duration, spectrum consistent with short GRB
- Localization very crude but consistent with GW150914
- Event looks unusual as arrival direction under spacecraft is not favorable.
- Need more LIGO - GRB-like-transient coincidences to be convinced this is the e-m counterpart of GW150914.

FAR = 27 hard events in 218821.1 s of GBM live time, factor of 3 for spectra searched, 90% confidence

$$P = 2 \times (4.79 \times 10^{-4}\ \text{Hz}) \times 0.4\ \text{s} \times (1 + \ln(30\ \text{s} / 0.256\ \text{s})) = 0.0022$$

Factor of 2 to account for offset in time in either direction

Offset between GW T0 and GBM event start

Effective trials factor for non-independent, variable time bins (30s is maximum offset set by the search window, 0.256 is the minimum set by native CTIME data)

VC+ 2016

High-energy counterparts are expected for NS-NS and NS-BH mergers: these mergers are the most popular model for short GRBs and, if they are mergers, GRBs are the only surefire e-m counterpart to mergers events.

Gamma ray radiation is seen in a jet as a short GRB that is detectable if the jet is pointed at us. GBM/BAT etc. can see very far.

Gravitational radiation is emitted in all directions and seen by LIGO/Virgo LIGO can't see NS-NS very far (70 Mpc in O1, ~200 Mpc at design).

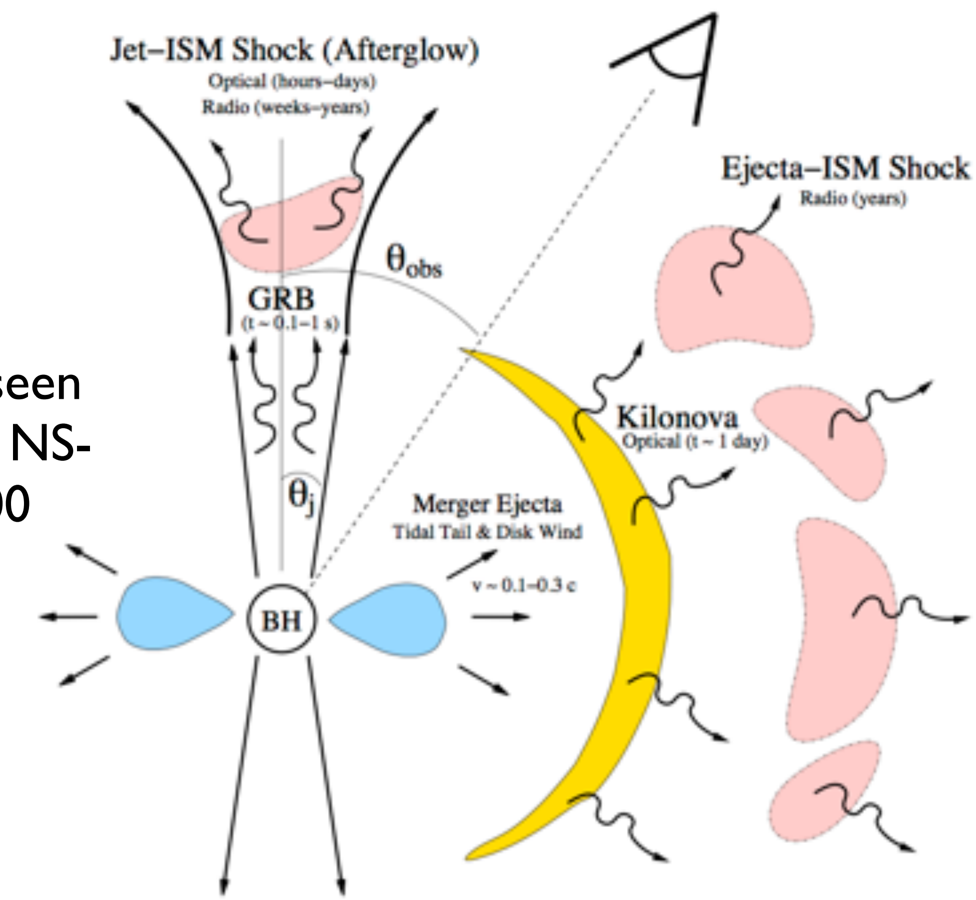
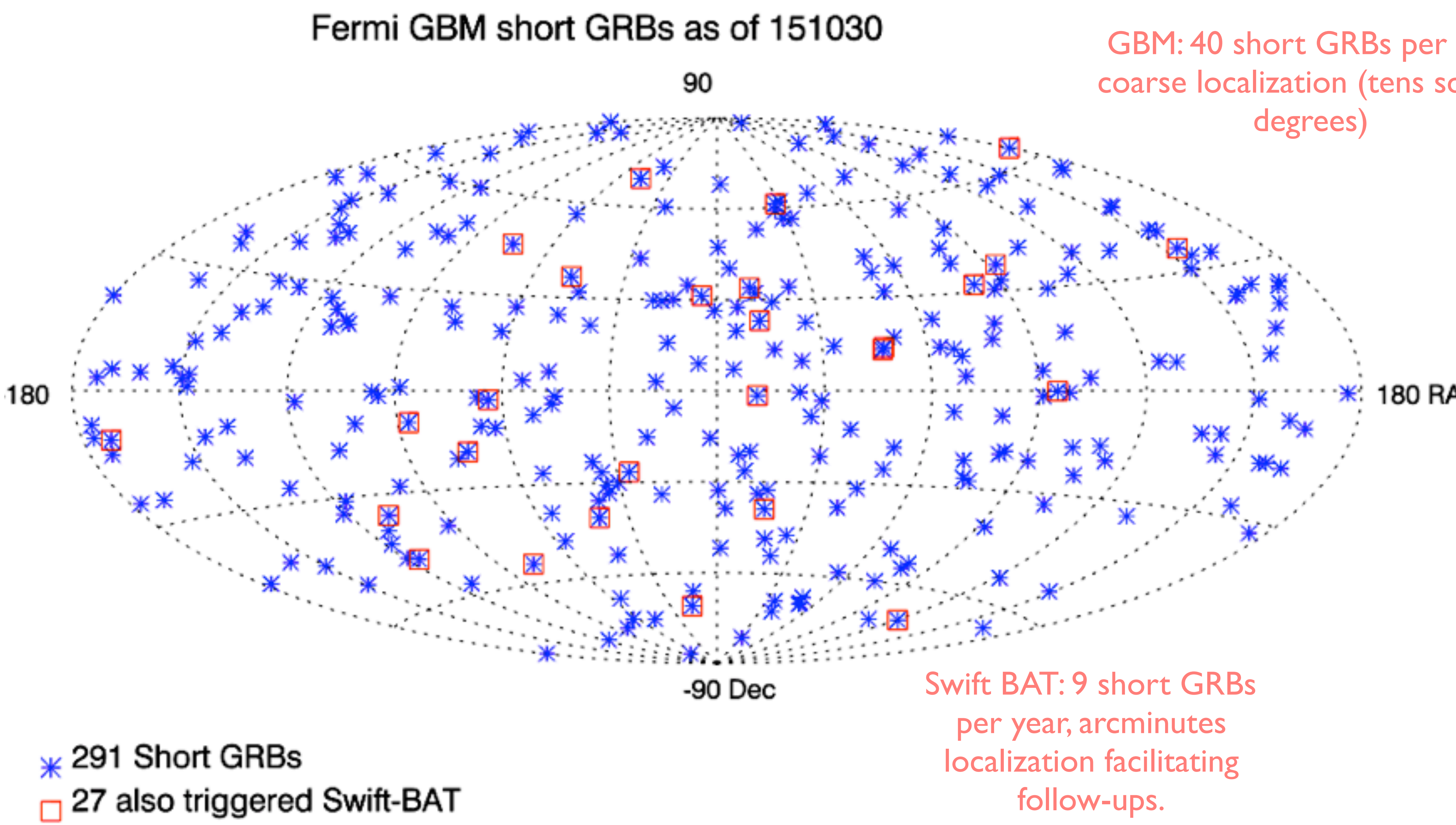


Figure 1 of Meztger & Berger 2012

Joint GRB LIGO/Virgo events happen when the jet is pointed towards us and the merger happens nearby i.e., quite rarely <1-- handful joint detections per year (model-dependent). It is very important to maximize the probability of joint GRB LIGO/Virgo detections and enable supporting observations that will provide the distance scale and energetics of the explosion.

Owing to all-sky coverage, Fermi GBM detects and localizes more short GRBs than other GRB detectors: numbers matter!

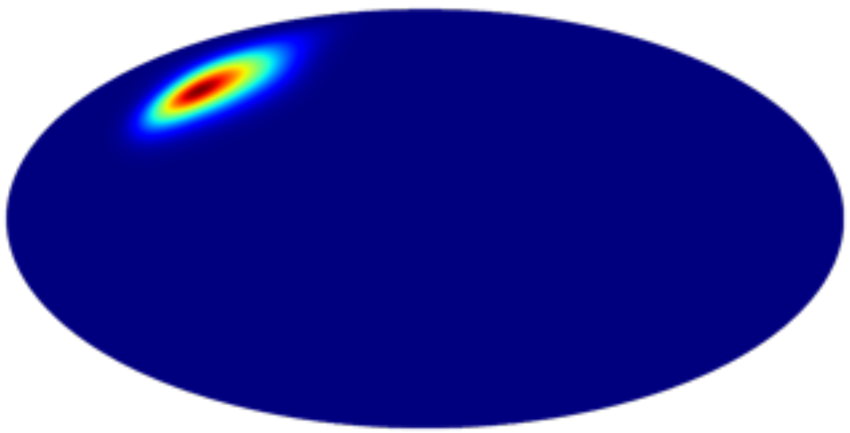


GBM: 40 short GRBs per year, coarse localization (tens square degrees)

Swift BAT: 9 short GRBs per year, arcminutes localization facilitating follow-ups.

Even a large banana and a large orange can help: using joint GBM-LIGO/Virgo detections and GBM non-detection to guide follow-up observers.

Typical GBM GRB localization region for weak GRB



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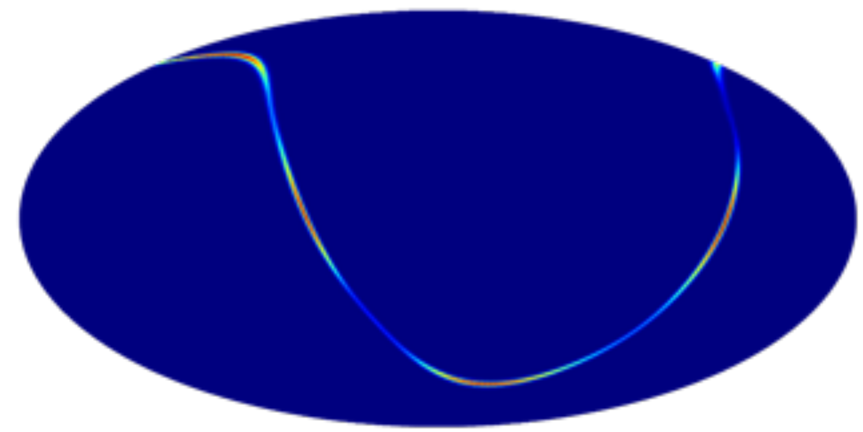
Typical LIGO localization region from http://www.ligo.org/scientists/first2years/: changes in 2016 with addition of Virgo



18 +/- 5 nearby galaxies (N. Gehrels et al. 2015, arXiv:1508.03608)

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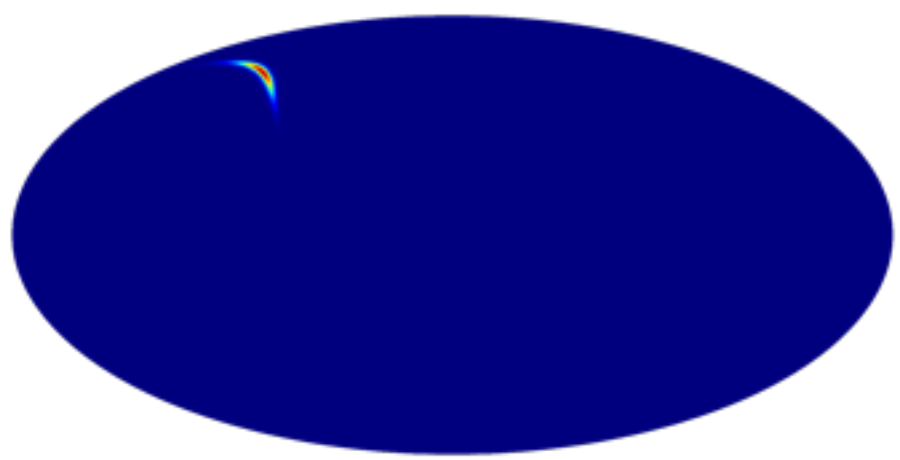
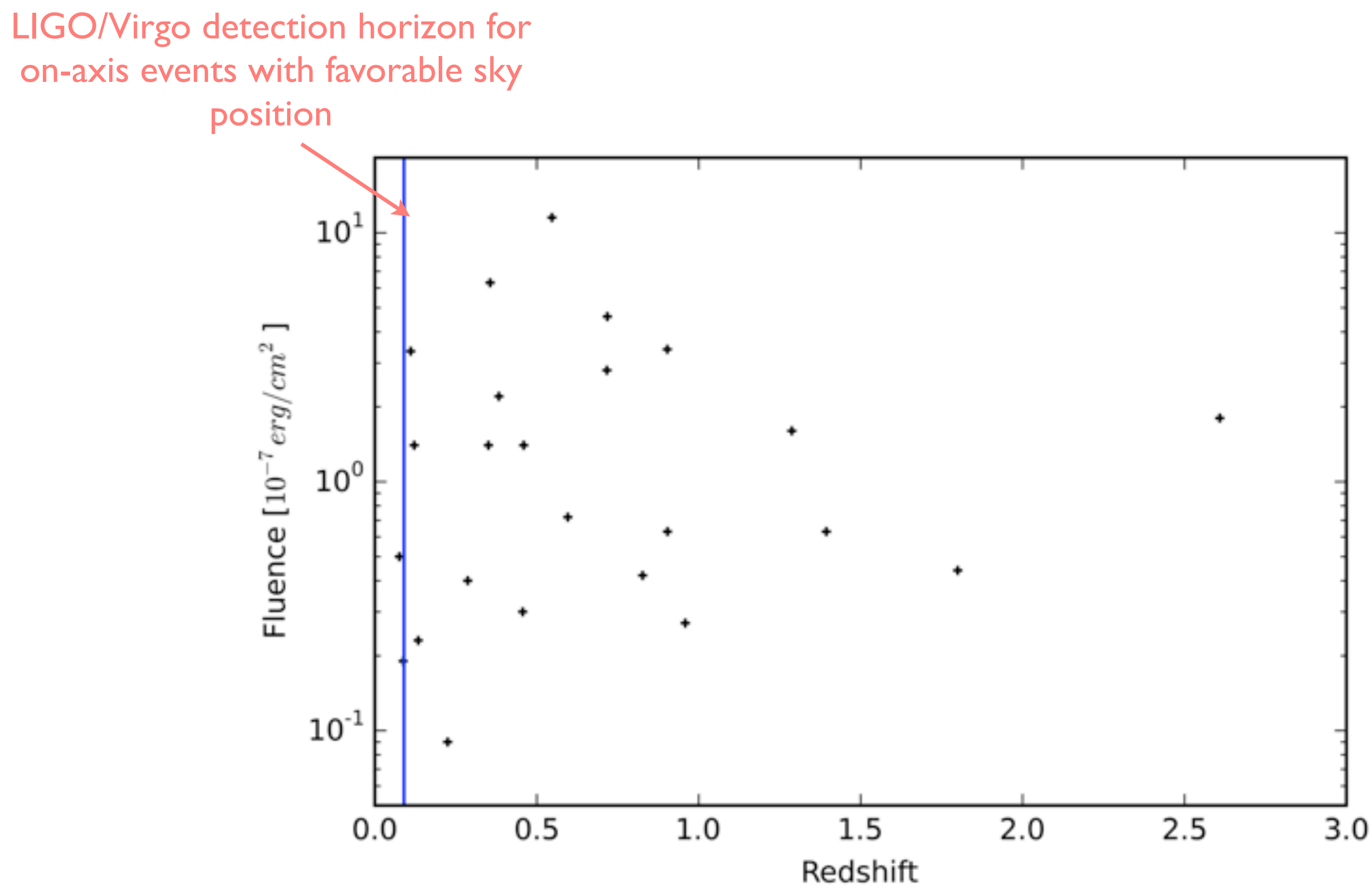


Typical reduction of 80% in sky region:

4 nearby galaxies: easier to follow up with XRT or optical telescopes.

- An MeV instrument with better localization capabilities would increase the probability of finding the afterglow and host -> redshift

Weak short GRBs are not necessarily more distant than bright short GRBs and may lie within the detection horizon of LIGO/Virgo: sensitivity is important even when only interested in nearby events.



- Extrapolating from sGRBs with known redshift gives <0.5 - 5 per year sGRB for GBM within LIGO/Virgo horizon (nearby z uncertain).
- This number is doubled with unseeded search for GRBs that do not trigger on-board.

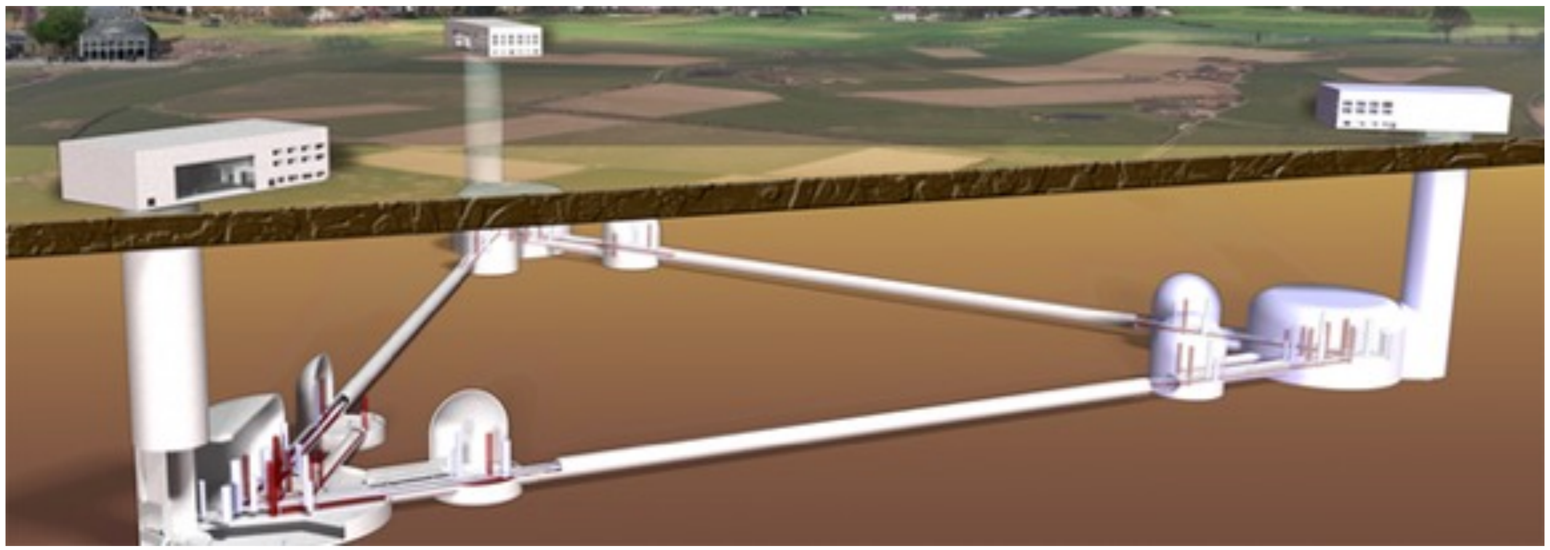
The significance of sub-threshold LIGO/Virgo candidates is strengthened with a coincident gamma-ray signal

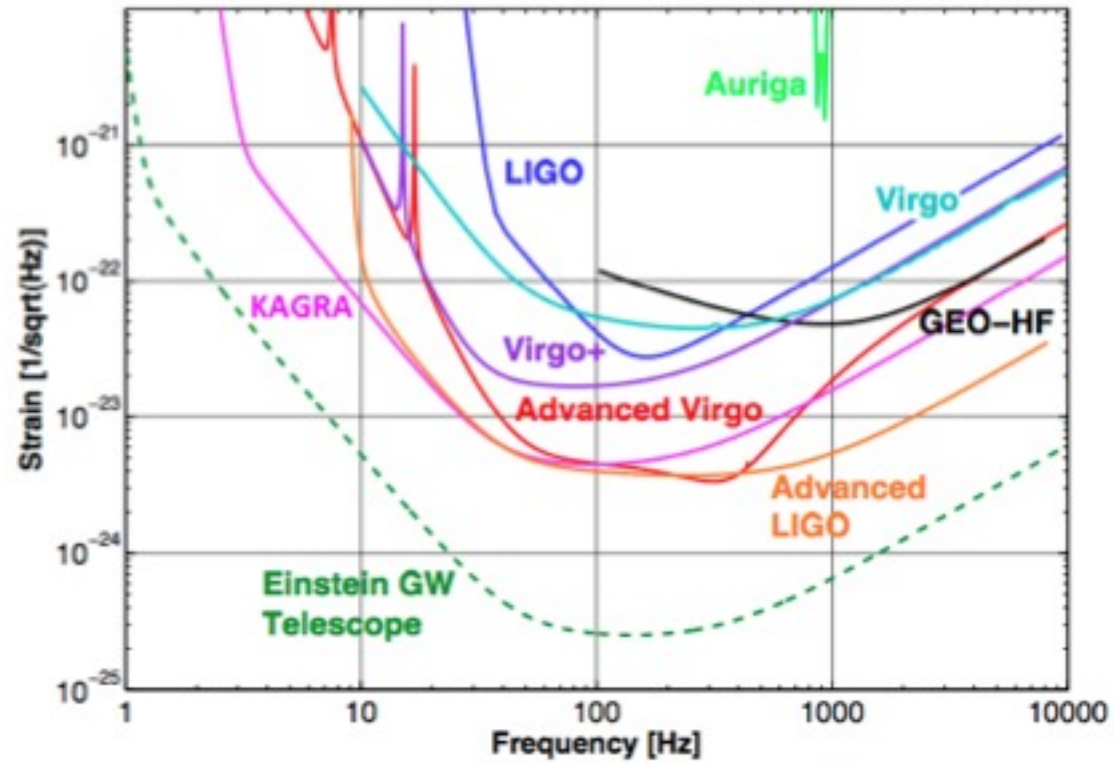
- Joint GBM-subthreshold search developed for LIGO/Virgo S6 science runs in 2009-2010 (L. Blackburn et al. ApJS 2015, 217, 8) - GBM background characterized and likelihood-based search finds known short GRBs in GBM data.
- In O1, the GW detection was bright but the GBM detection was sub-threshold!
- Sensitivity of LIGO/Virgo search can be improved by ~15 - 20 % relative to LIGO/Virgo alone (Blackburn et al. ibid; Kelley, Mandel & Ramirez-Ruiz 2013, PhRevD 87, 123004).

What can high-energy observations contribute besides helping with localization and follow-up?

- Establish mergers as progenitors of GRBs - joint detection rates will indicate collimation of GRB jet
- Identification of on-axis merger through the detection of GRB counterpart - removes degeneracy between inclination and distance
- Afterglow -> redshift unambiguously identifies host, providing another measure of distance.
- Can compare luminosity distance of GW and redshift of host to calibrate distance scale -> Hubble constant.
- Can compare e-m and GW energetics

Looking beyond LIGO/Virgo: next generation GW ground arrays?





Acernese et al 2015

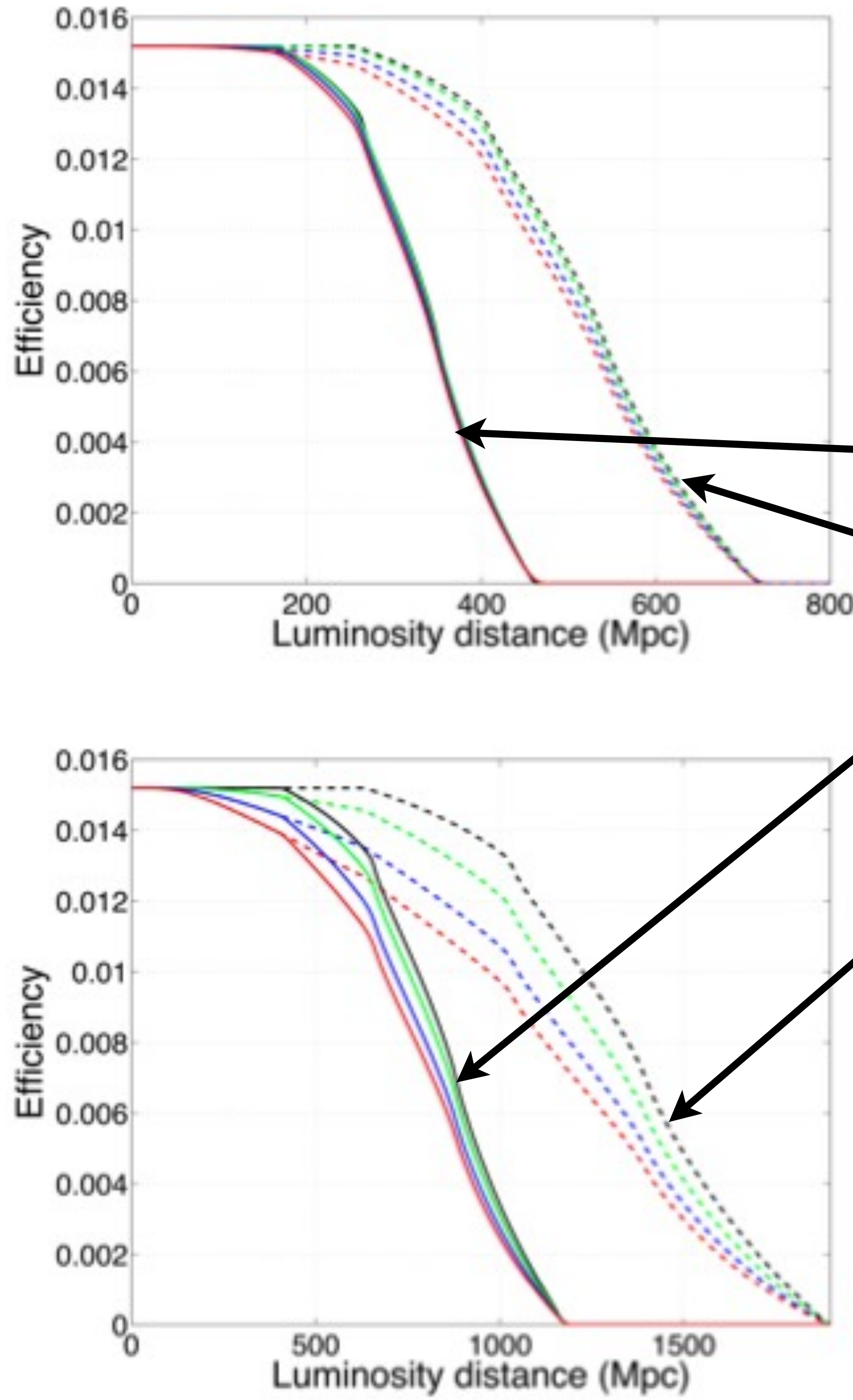
- Underground, 10 km arms! http://www.et-gw.eu/
- No localization capability: MeV counterpart v. important!
- Can see much farther than LIGO/Virgo: long GRBs (CC SN) likely sources

Looking beyond LIGO/Virgo: The MeV GRB instrument might have the limiting sensitivity!

a-LIGO/Virgo

Joint GW-GRB efficiency

Einstein telescope



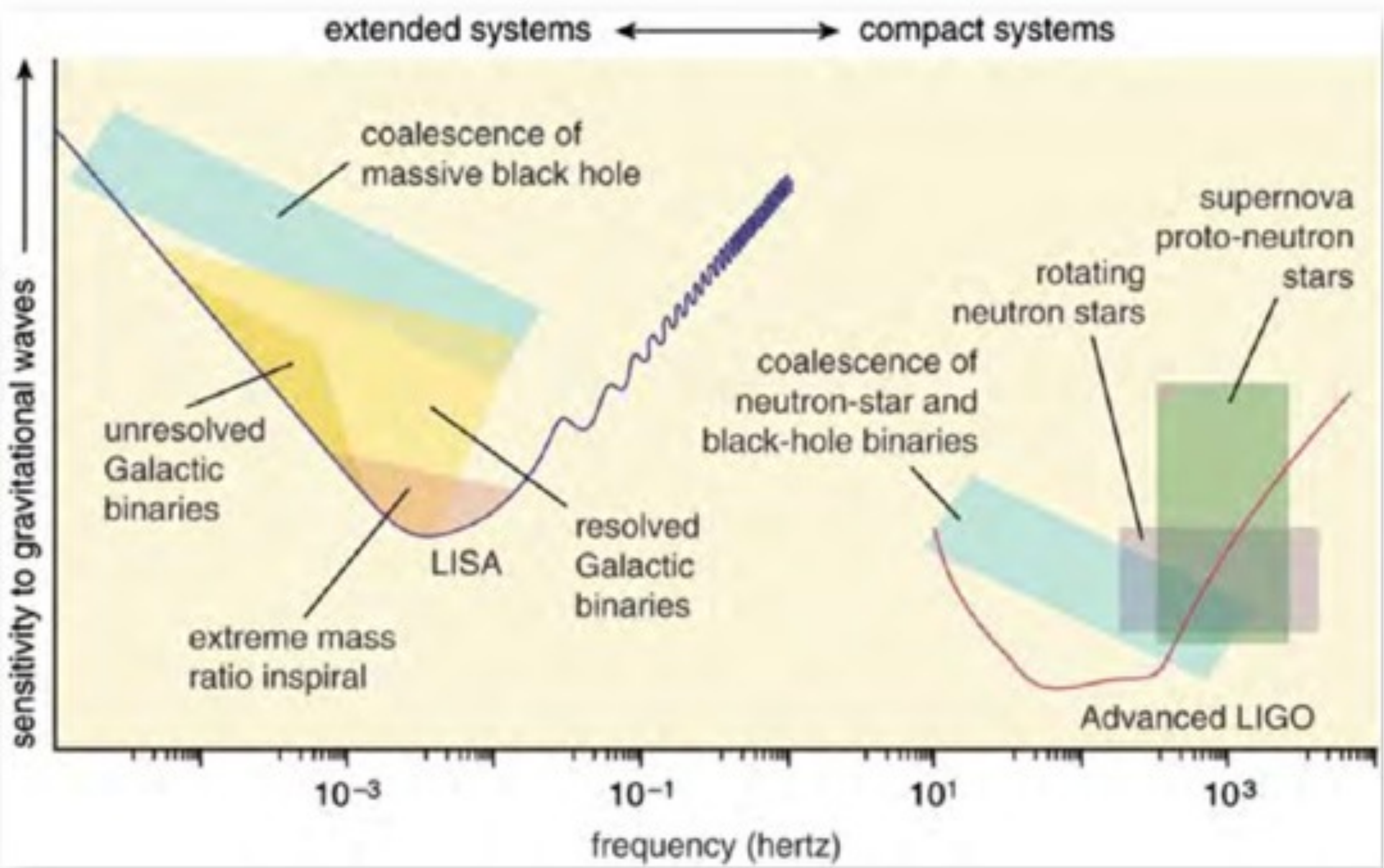
NS-NS

NS-BH

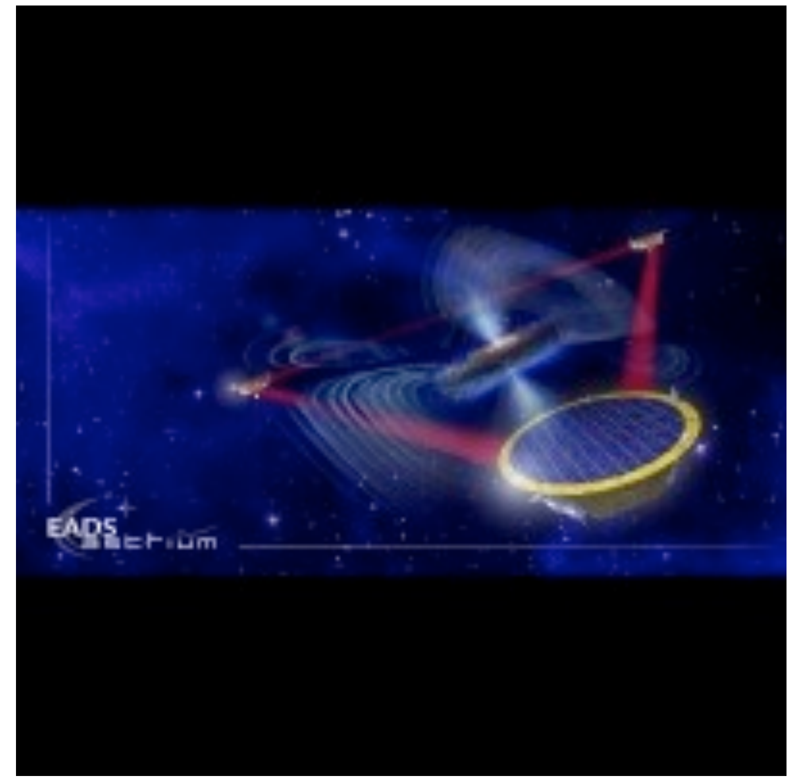
The colors reflect the efficiency of the MeV instrument - black is ideal detector

Régimbeau et al 2015

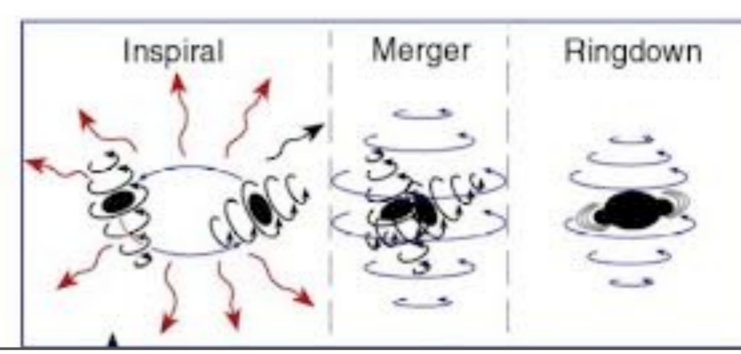
GW astronomy beyond mergers: LISA. 2035 is not that far in the future for planning space missions!



5 Mkm arms!
LISA pathfinder launched last Fall, test of technology to test control system for free masses (2 kg)



- Galactic binary systems (periodic), coalescence of MBH, Extreme Mass Ratio Inspirals, probing the geometry and dark energy content of the universe, seeing relics from inflation (?), new physics?
- Unclear what role MeV observations could play in LISA era. Inspiral time-scales = 1 year. Final merger = 10 minutes. Theorists?



Ideal MeV detector for GW astronomy

- Need a monitor of the transient high-energy (>50 keV) sky
- On-board trigger: identify on-axis mergers in real time to optimize follow-up
- Detects lots of GRBs - broad field-of-view, good sensitivity (nearby != bright; next-gen kHz GW detector may probe more distant universe)
- Localizes GRBs to sub-degree accuracy to facilitate follow-up observations for afterglow/hosts
- Has sub-MeV sensitivity to cover peak of GRB SED - energetics
- Are there signals from LISA sources we need to predict and design for?