What Next Gravitational Waves

Sottotitolo: «Che ci si fa col multimessenger?*»

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*Antonio Masiero, GdL coordination meeting, 21/01/16

Avvertenze:

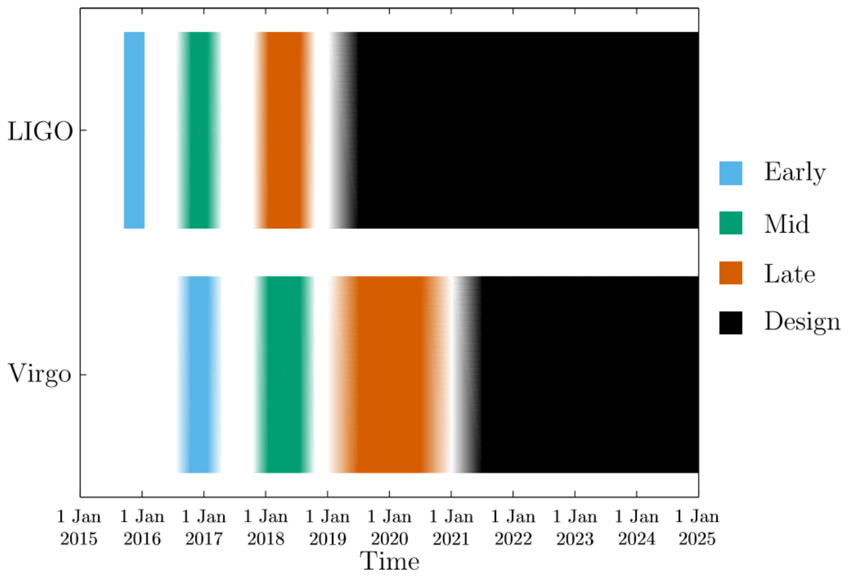
- Per "ovvie" ragioni di tempo e di tempi il talk è principalmente incentrato su detectors interferometri terrestri
- Il "fil rouge" del talk è indagare le future potenzialità dell'approccio multimessenger

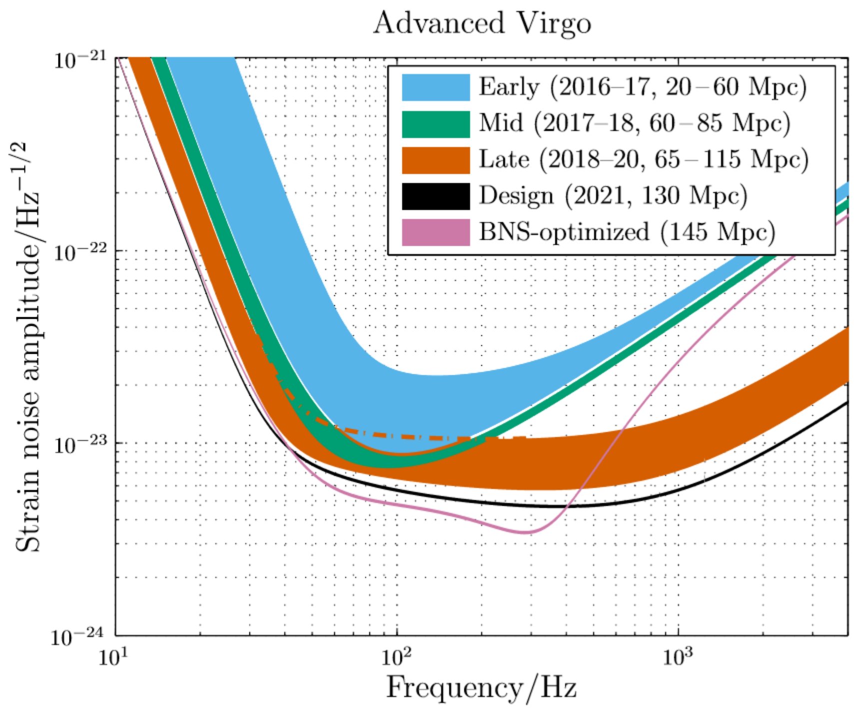
Credits:

- M. Branchesi, INFN-Fi/Univ Urbino
- V. Mandic, University of Minnesota
- M. Razzano, INFN/Univ Pisa
- B. Sathyaprakash, Cardiff University
- 7^{th} ET symposium, 2-3 Feb 2016
- **GW150914**

What Next? Let start from «What now»!

- First target: have AdV operative and achieve the target sensitivity

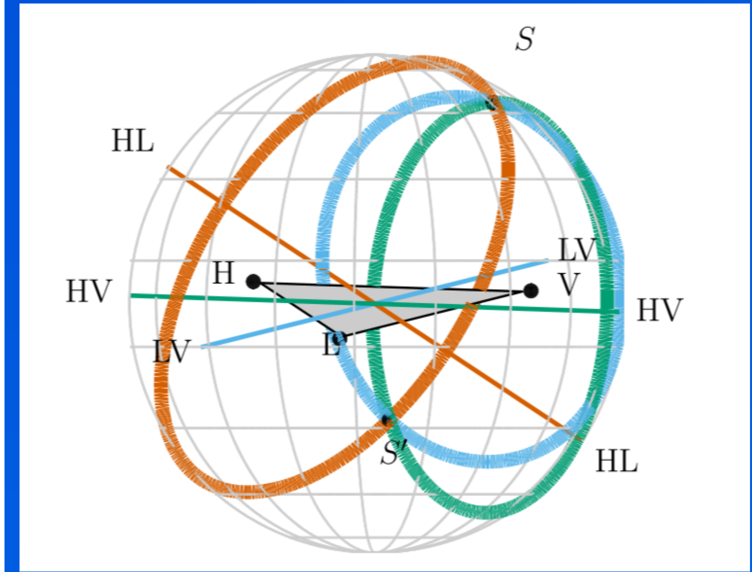




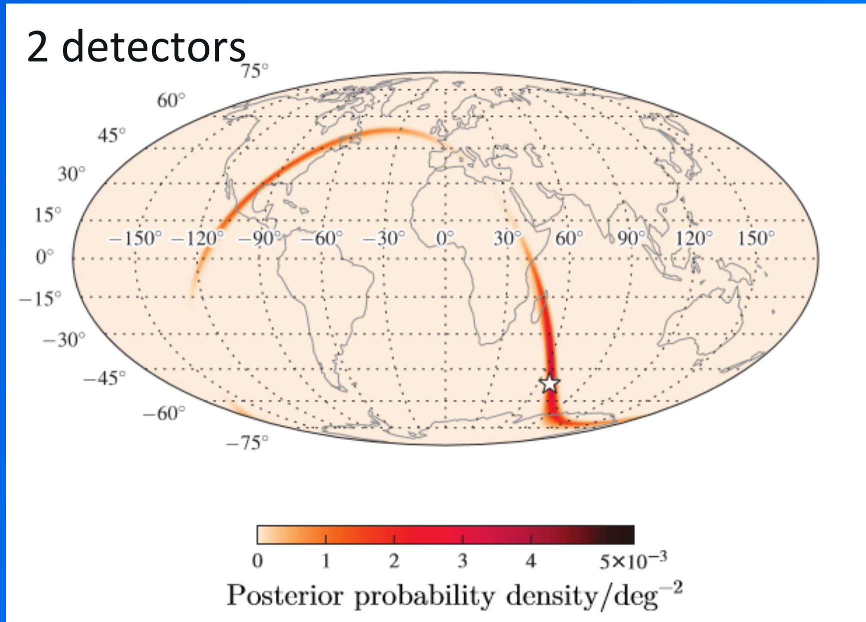
B.P.Abbott et al., Living Reviews in Relativity 19, 1 (2016)

Sky localization

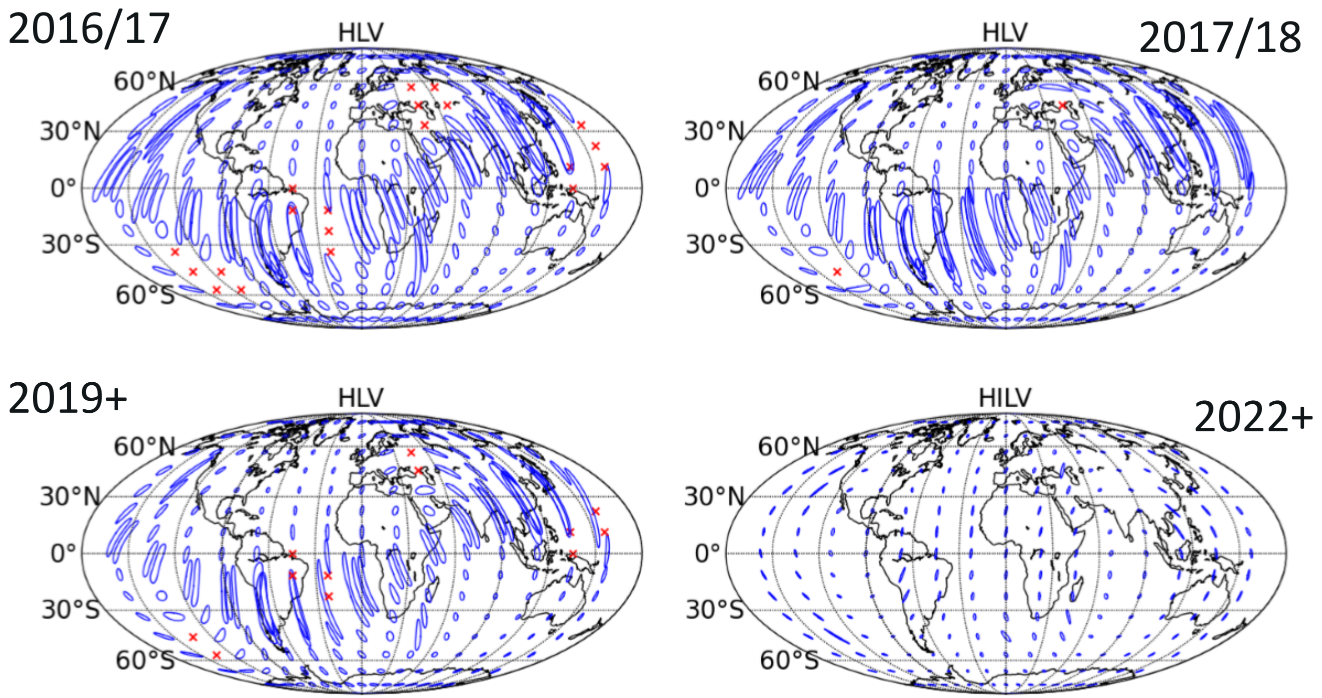
- To localise the GW source we need a network (≥3) of detectors (5 parameters→2Δt, 3 Amplitudes) and a good SNR:



- 2 detectors: a circles
    - Improvement by phase relationship
- 3 detectors: 2 points



Sky localization evolution



Epoch			2015 – 2016	2016 – 2017	2017 – 2018	2019+	2022+ (India)
Estimated run duration			4 months	6 months	9 months	(per year)	(per year)
Burst range/Mpc		LIGO	40 – 60	60 – 75	75 – 90	105	105
		Virgo	—	20 – 40	40 – 50	40 – 80	80
BNS range/Mpc		LIGO	40 – 80	80 – 120	120 – 170	200	200
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Estimated BNS detections			0.0005 – 4	0.006 – 20	0.04 – 100	0.2 – 200	0.4 – 400
90% CR	% within	5 deg^2	< 1	2	> *1 – 2*	> *3 – 8*	> *20*
		20 deg^2	< 1	14	> *10*	> *8 – 30*	> *50*
	median/deg^2		480	230	—	—	—
searched area	% within	5 deg^2	6	20	—	—	—
		20 deg^2	16	44	—	—	—
	median/deg^2		88	29	—	—	—

Why this attention to the pointing capabilities?

- The detection of GW opens a revolutionary paradigm in the observation of the universe:
  - GW detectors listen the universe, localising the source, giving information on the mass and dimension of the source, identifying the processes that involve large amount of asymmetric and accelerated matter
  - “Telescopes” follows the indication on the localisation and see the electromagnetic and astroparticle messages, describing what is occurring in the “external” shells and in the neighbouring of the catastrophic event

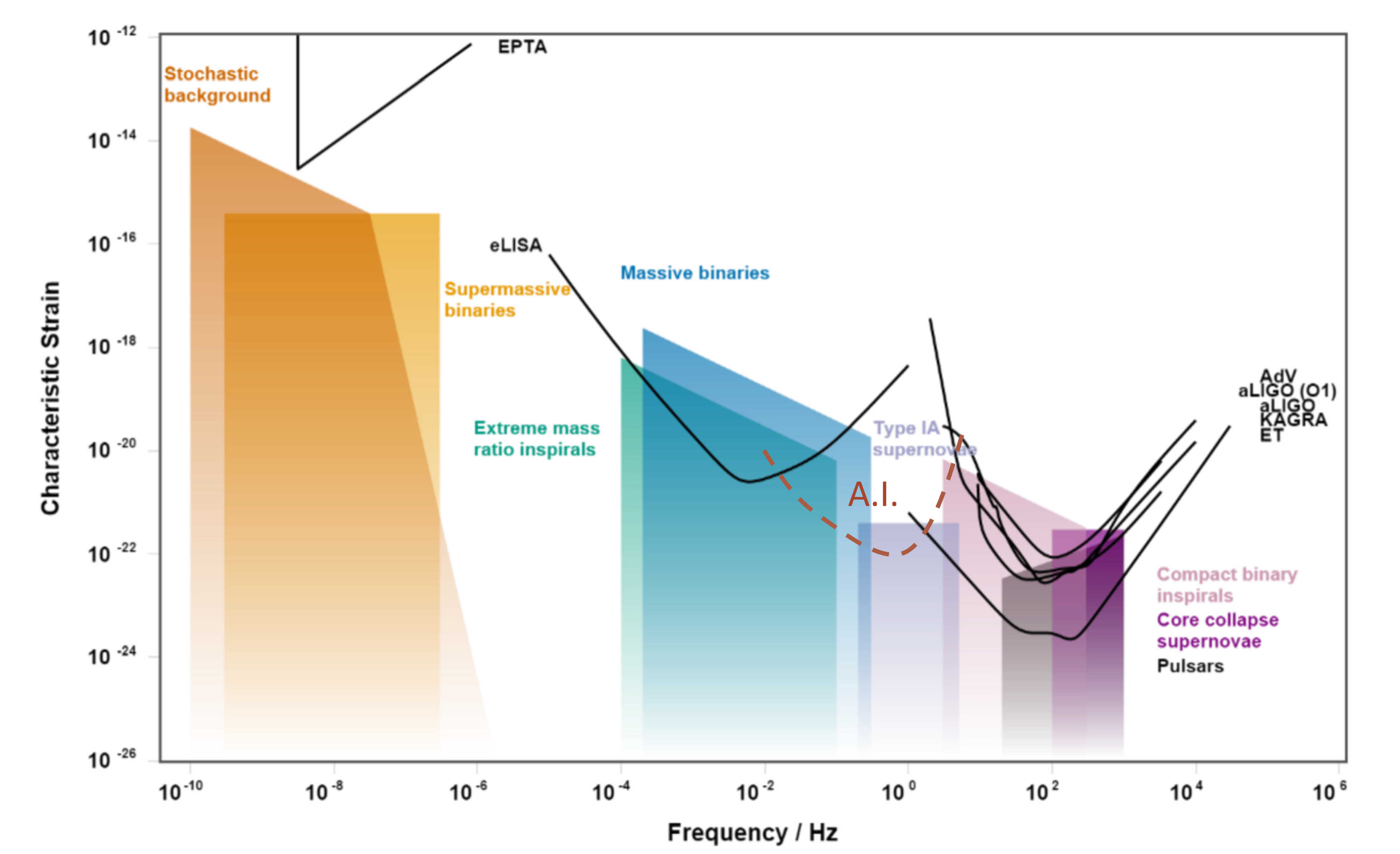
- Multi-messenger observation of the Universe

OK, what we will do together?

… and sometimes alone

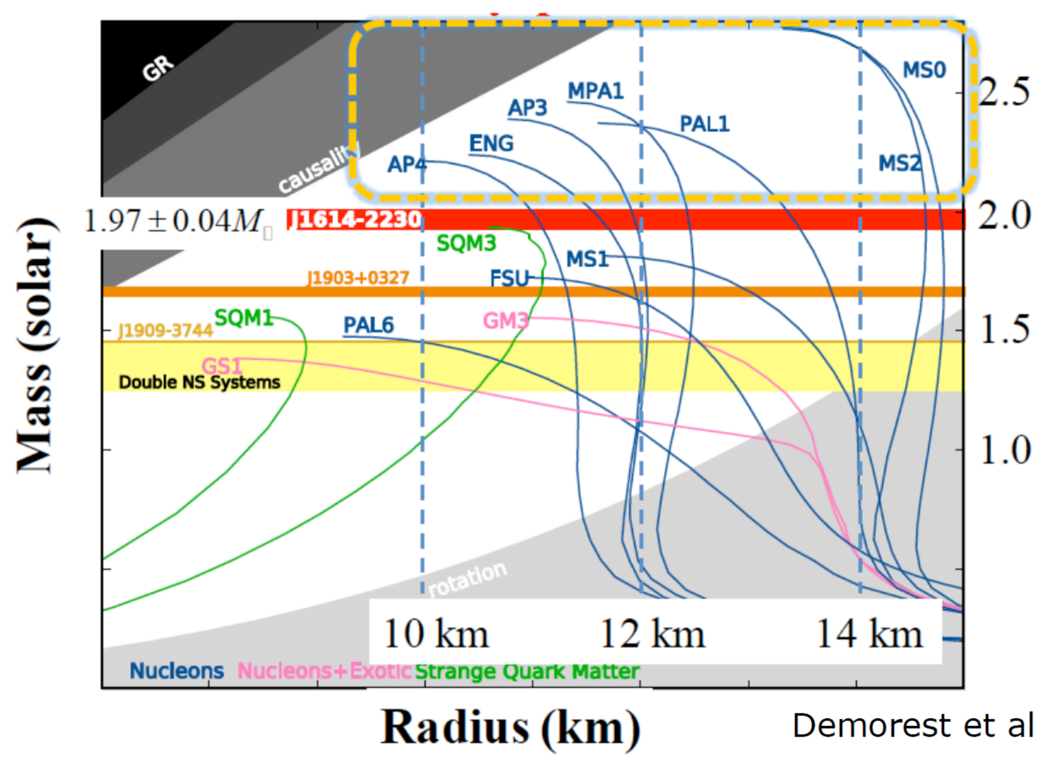
74 MOUs with collaborations managing telescopes, neutrino observatories, satellites , …

Frequency/Sources Scenario



Fundamental Physics

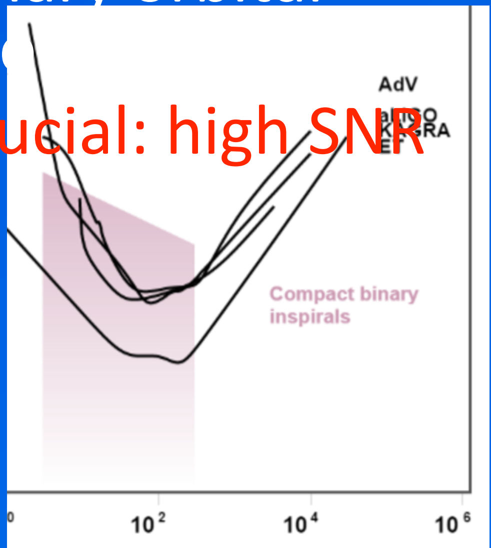
- What is the matter in the extreme conditions of a NS? ($\rho > \rho_c \sim 10^{15}\ g/cm^3$)
  - Nucleons (n,p,e,μ)?
  - Hyperon rich matter?
  - Quark Matter? Deconfined quarks?
- Plethora of possible EOS of a NS:

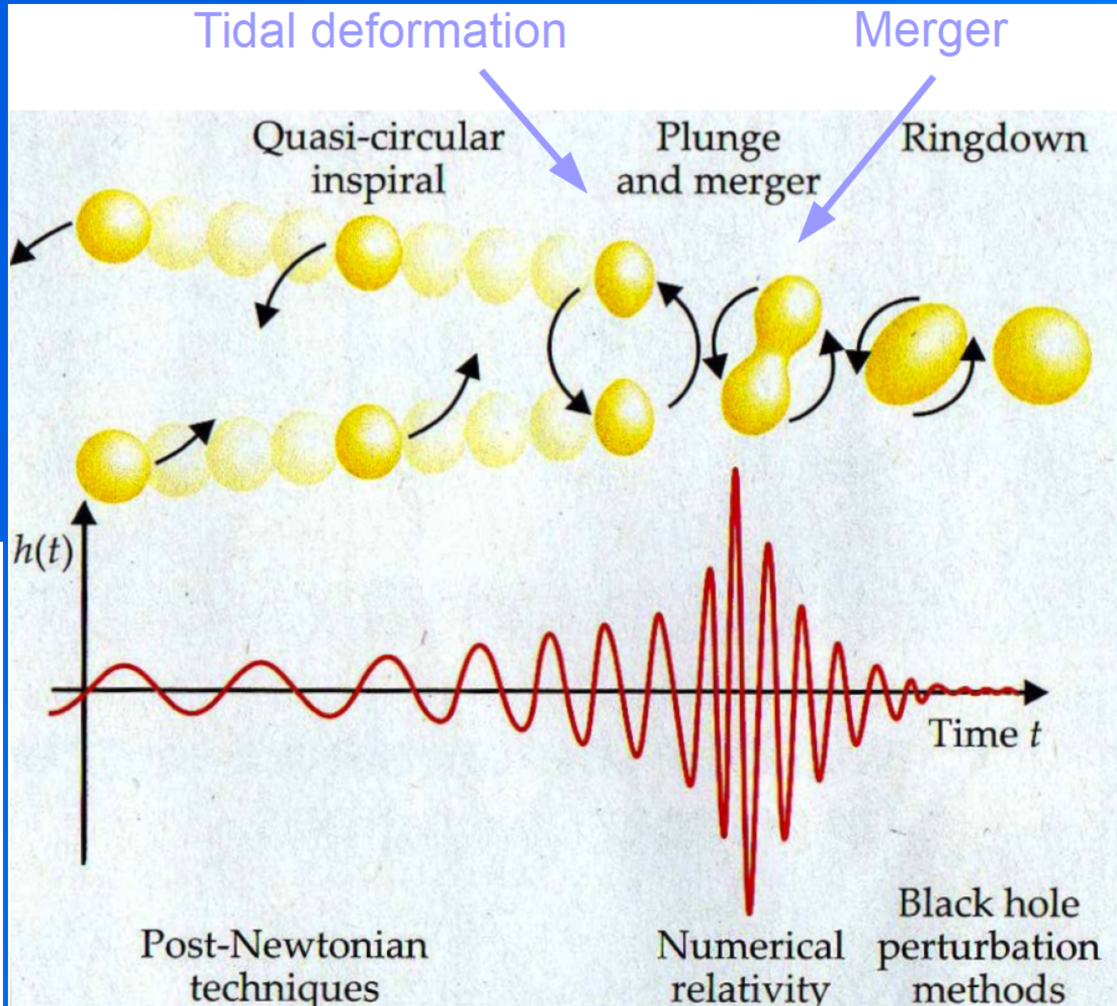


Demorest et al (2010)

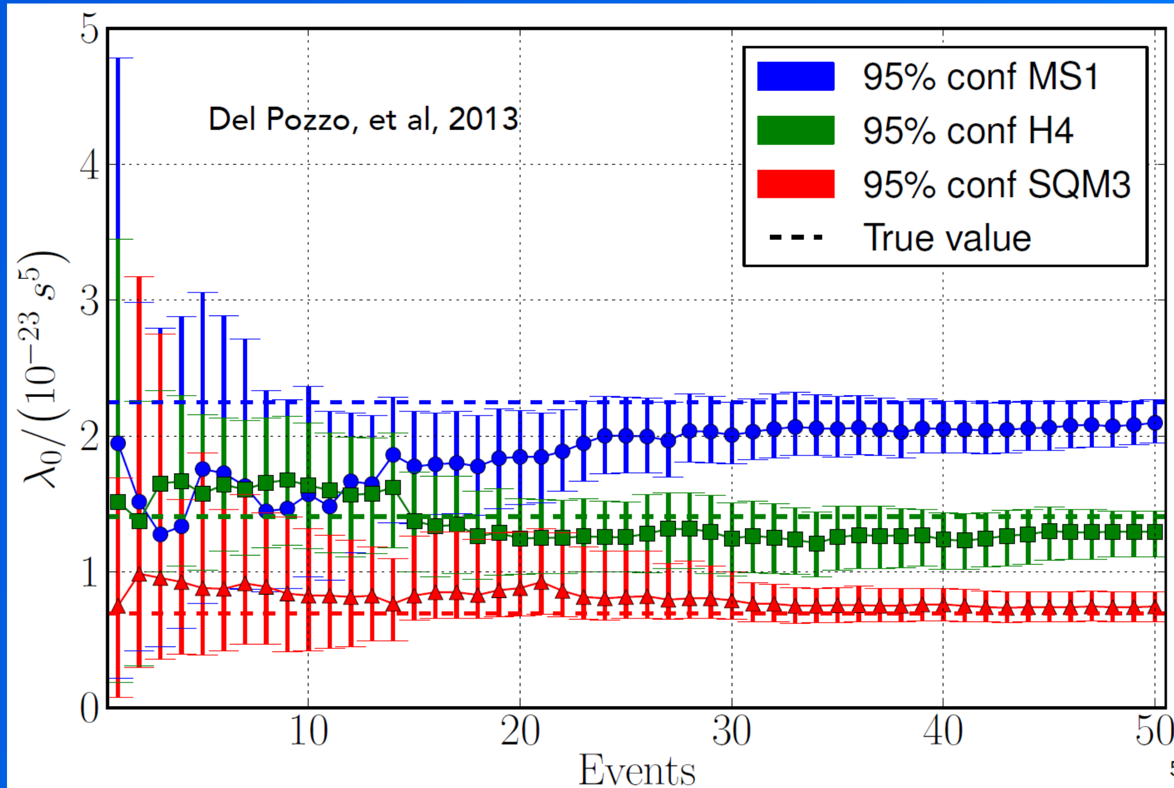
Observing BNS deformation

- GW observation from NS coalescing binaries could constrain the EOS:
  - Tidal deformation λ of the NS under external field is related to its EOS and it affects the binary orbital ev
  - Crucial: high SNR





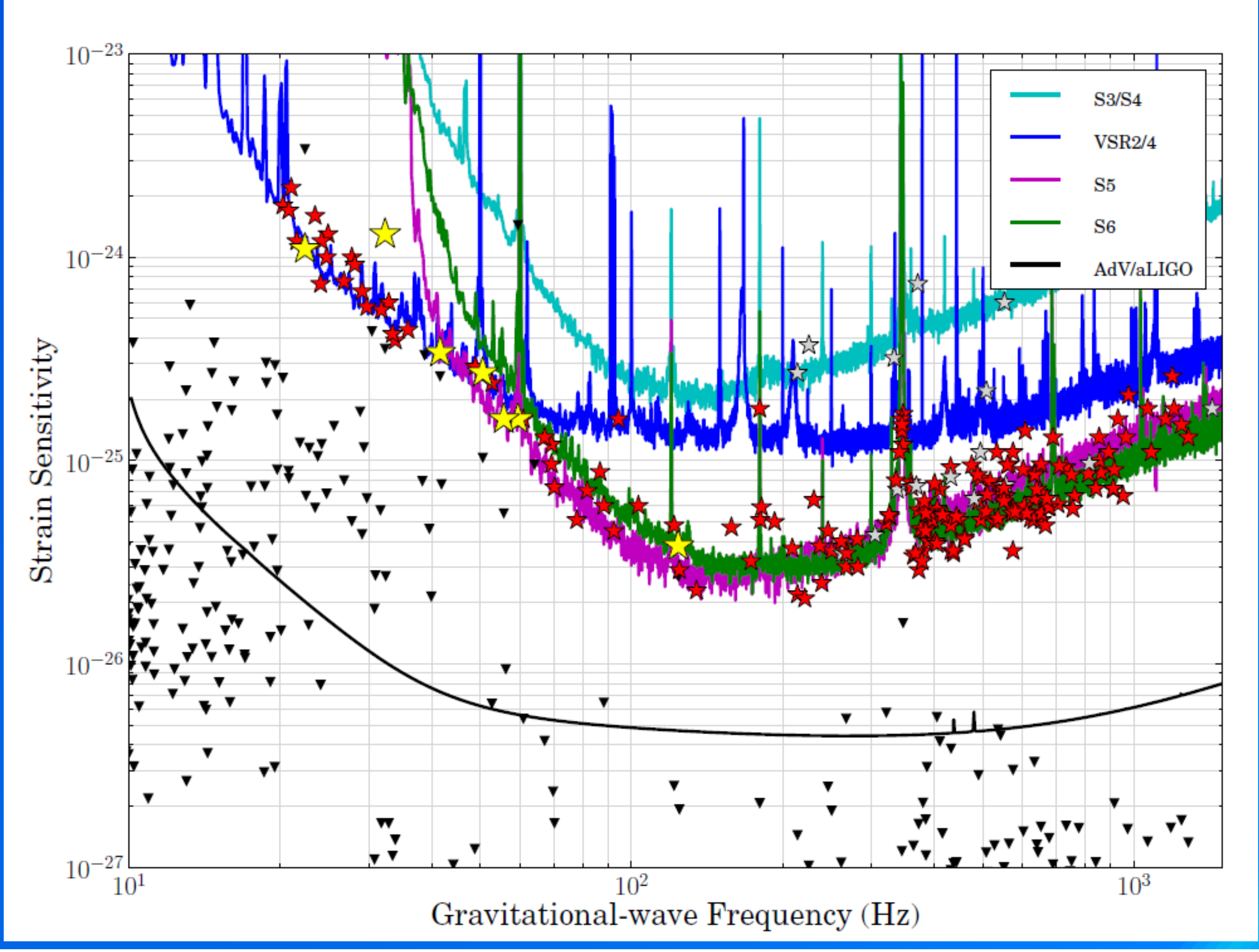
Discriminating NS EOS



- Possible in 2G – 2G+ - 3G
- EM counterpart:
  - GRB emission:
    - Confinement of some of the parameters (BH-NS coalescence)
    - Info on the external crust
  - High energy Neutrino emission:
    - Info on the nuclear processes in the Hyper-massive NS
    - Info on the shockwave

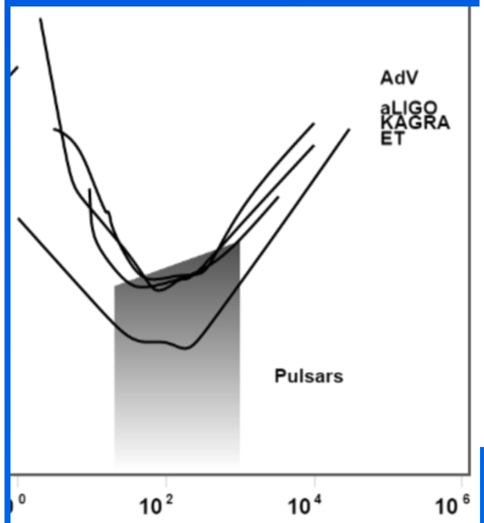
Isolated NS

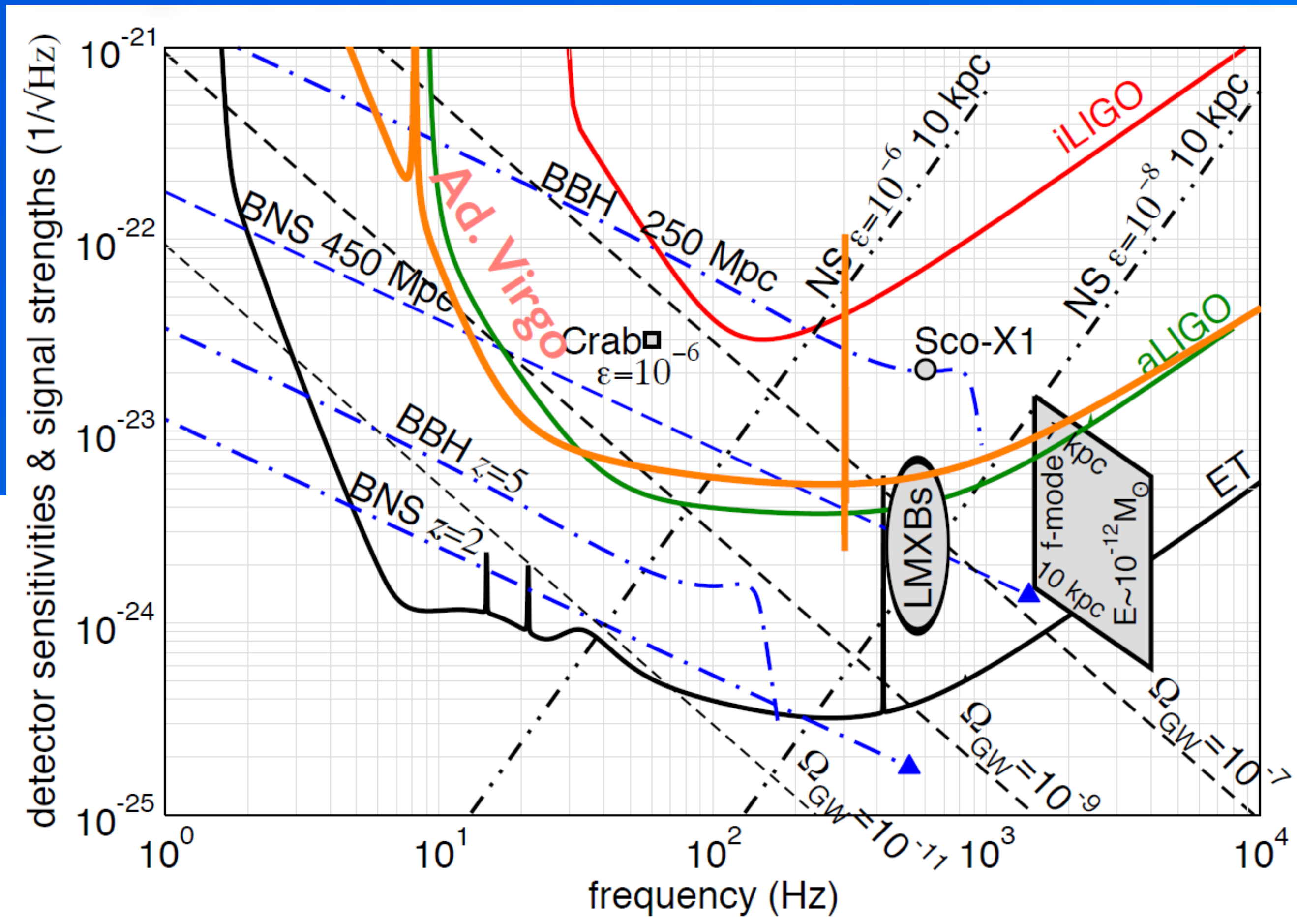
- NS EOS can be constrained by observing GW emission by isolated NS
  - E.M. counterpart: radiotelescopes



Isolated NS

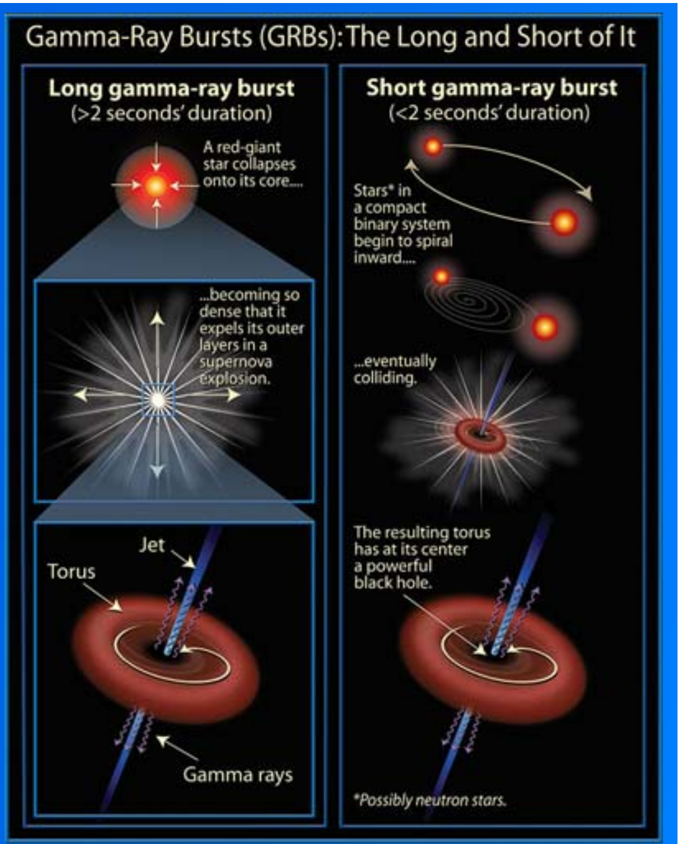
- NS EOS constrains, NS crust studies, glitches, but:
  - NS with plausible eccentricity have a faint signal





GRB progenitors

- The simultaneous detection of GW and sGRB from a coalescing BNS could confirm the nature of the progenitors of the GRB
- But it is possible to obtain also a measure of the cosmological model of the Universe



$$D_L(z) = \frac{c(1+z)}{H_0}\int_0^z \frac{dz}{[\Omega_M(1+z)^3 + \Omega_\Lambda(1+z)^{3(1+w)}]^{1/2}}$$

GW

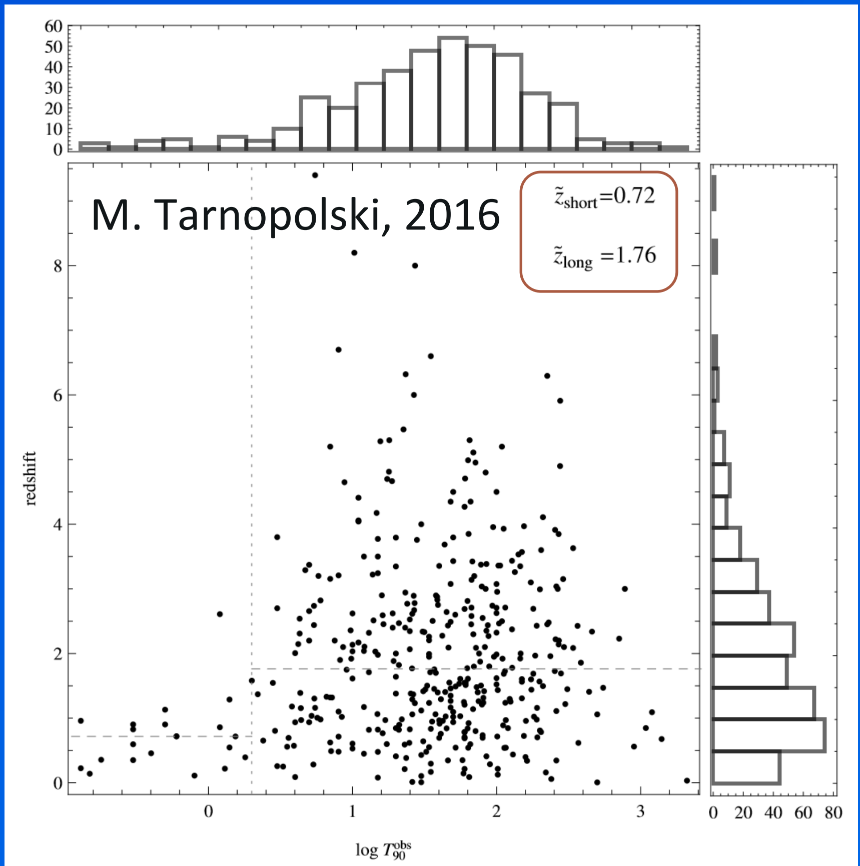
GRB

Affected by the Mass ambiguity due to the red-shift of the frequencies (in effect considering the merging phase it is possible to resolve the ambiguity)

Ω_M: total mass density
Ω_Λ: Dark energy density
H_0: Hubble parameter
w: Dark energy equation of state parameter

Cosmography

- But, how far GWDs need to observe GW from BNS to have the coincidence?



- We need 10^5 of coincidences at high z and high SNR
  - Future detectors (ET)

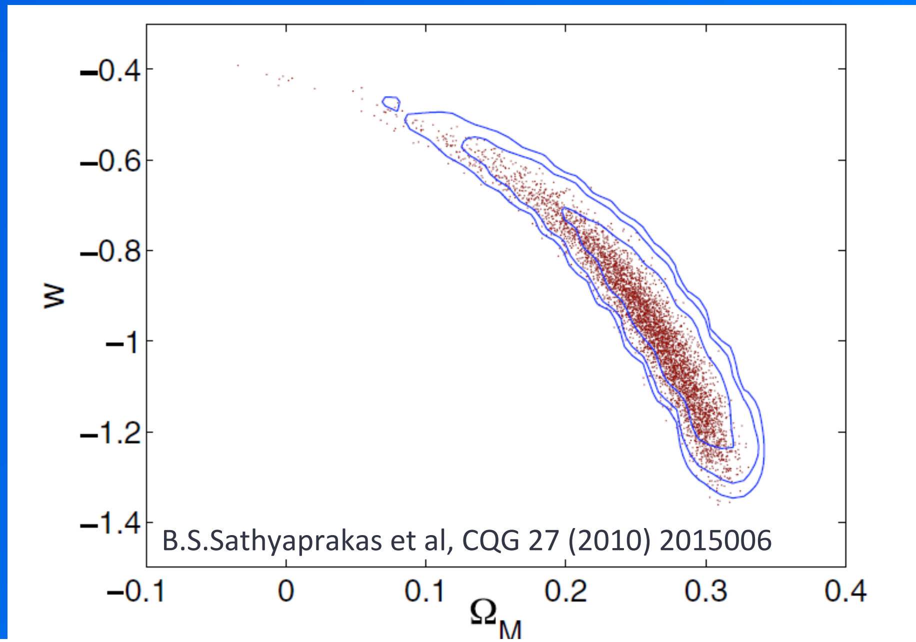
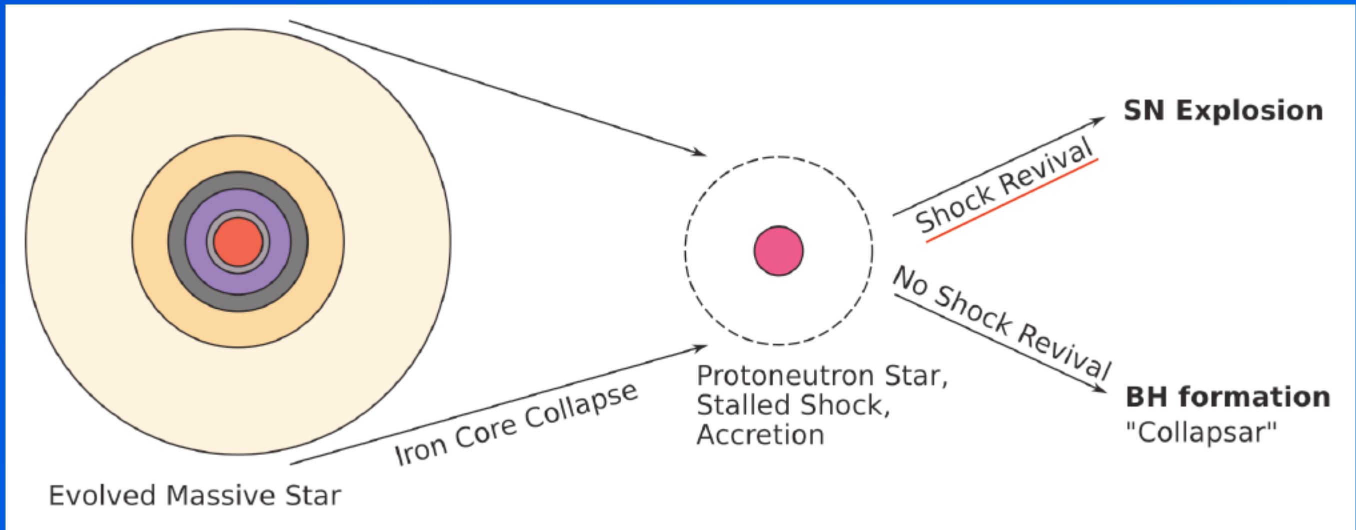


Figure 3. Scatter plot of the retrieved values for (Ω_Λ, w), with 1-σ, 2-σ and 3-σ contours, in the case where weak lensing is not corrected.

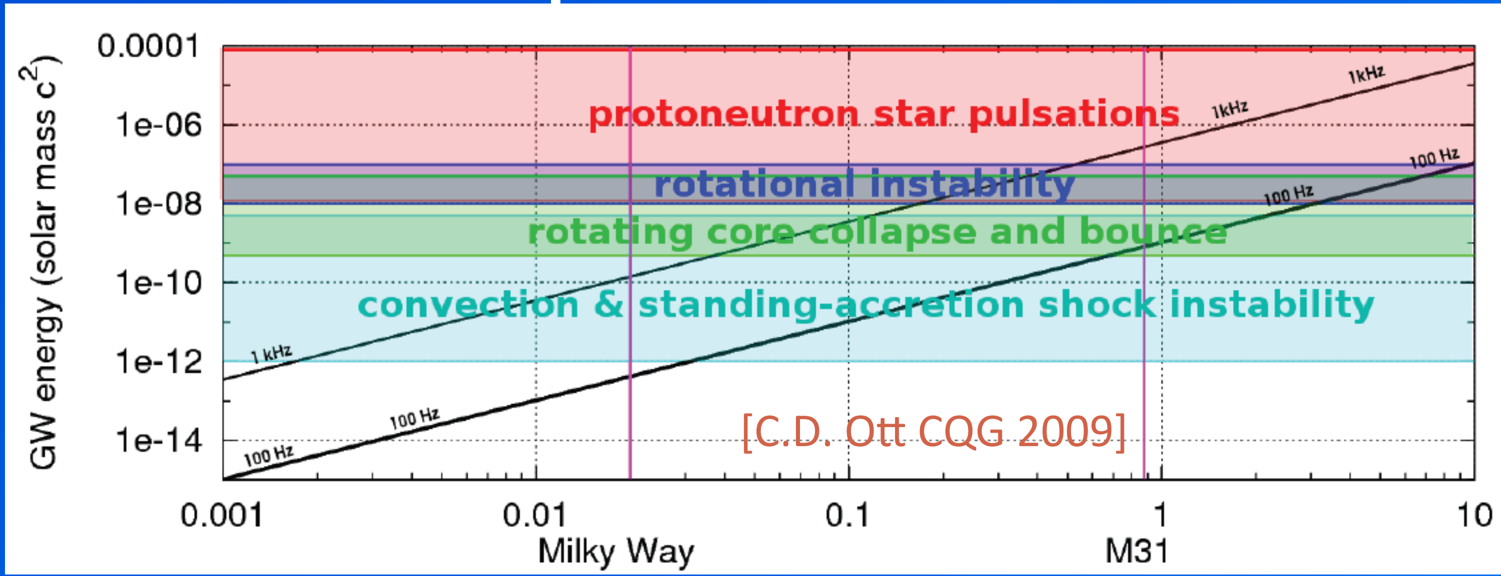
Supernova Explosions

- Mechanism of the core-collapse SNe still unclear
  - Shock Revival mechanism(s) after the core bounce TBC



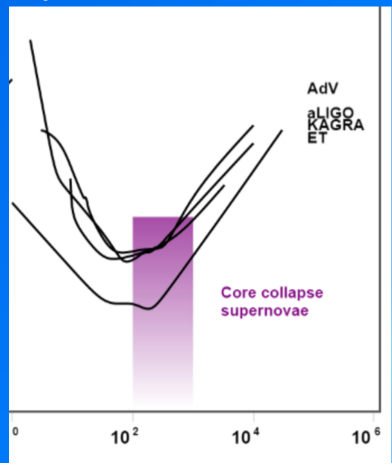
- GWs generated by a SNe should bring information from the inner massive part of the process and could constrains on the core-collapse mechanisms
- But, quantity of energy emitted in GW quite unpredicted and small
  - Advanced detectors expected to be sensible within the galaxy (few events per century)
    - 3G (ET)

Stellar explosions - SNe

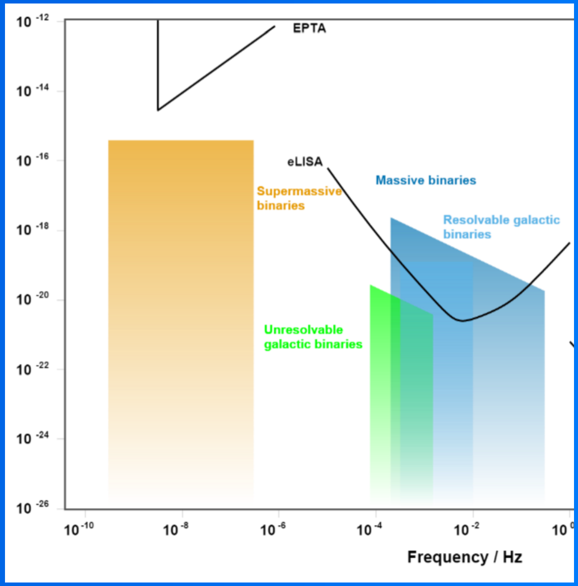


ET scenario

- Low energy neutrino detection can contribute to the determination of the explosion mechanism, but is there overlap in the detection range?
  - Mton neutrino detectors?
- Coincident/afterglow E.M. observations



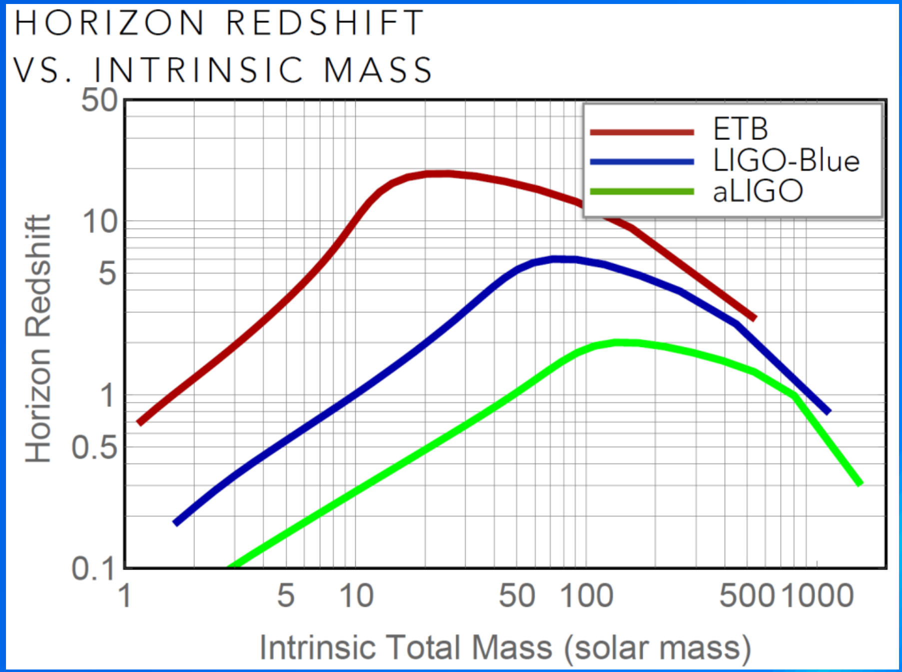
SMBH and Galaxies



- Supermassive black holes formation
  - Observe merging history up to z ~ 5-15
  - Compare with EM observation of distant galaxies
  - Are IMBH the seeds for SMBHs?
- SMBHs evolution with time
  - Case of Dual AGN
    - What are typical frequency ranges?
    - In the EPTA and eLISA frequency range
  - Probe EM in strong regime (physics of accretion disks and jets)
  - High energy Neutrino emission

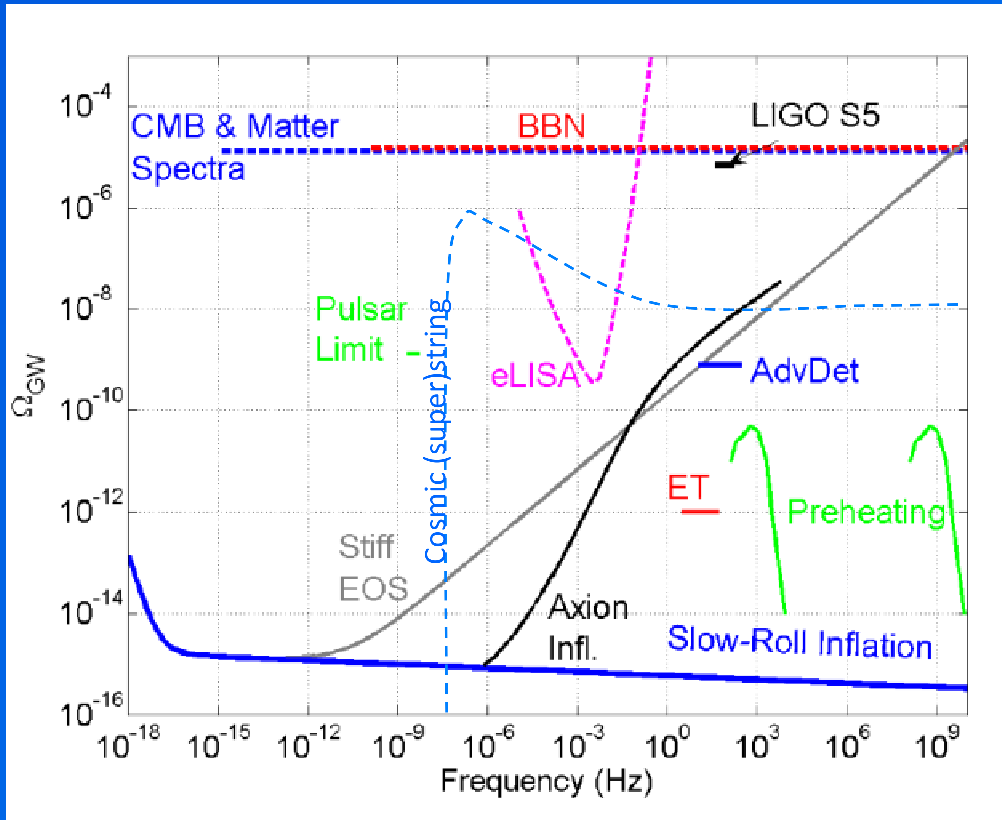
Intermediate mass Black Holes & A.I.

- GW150914 demonstrated the existence of stellar mass black-holes: what about IMBH?
- IMBH could range from 10^3 to 10^5 Ms
- A.I. aim to detect IMBH:
  - Technology to be demonstrated (Magia Adv in CSN2)
  - Realistic noise models to be developed
  - Newtonian Noise immunity to be demonstrated
  - Possible synergies with underground detectors
  - What about multi-messenger?

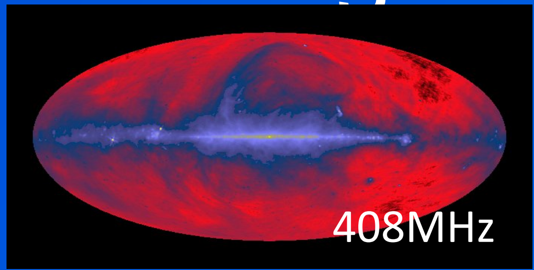


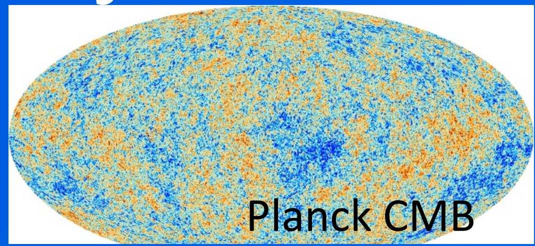
Stochastic Background

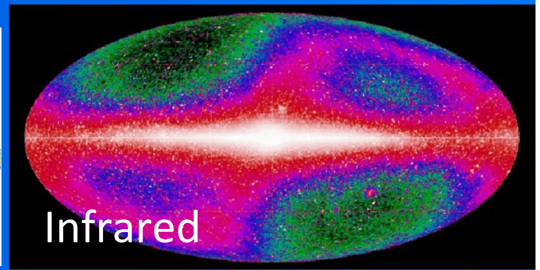
- Similarly to the CMB we have a stochastic GW background of cosmological origin:
- Its Energy density (Ω) depends on the inflation model:

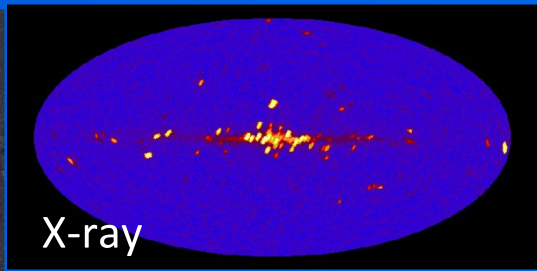


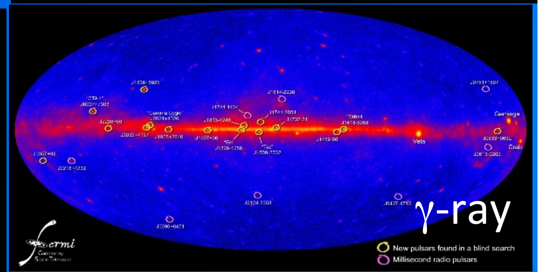
Multimessenger sky

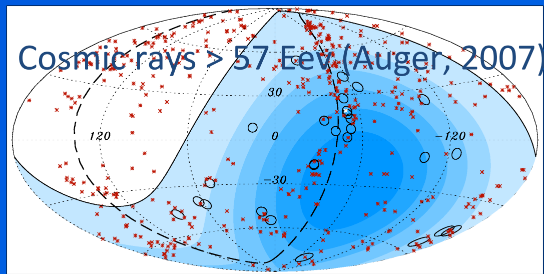


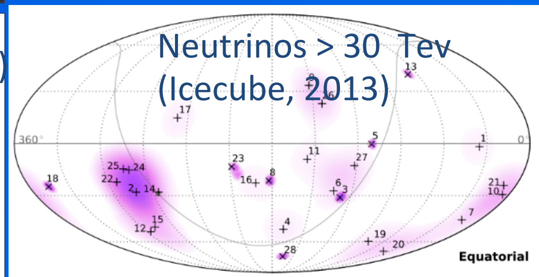




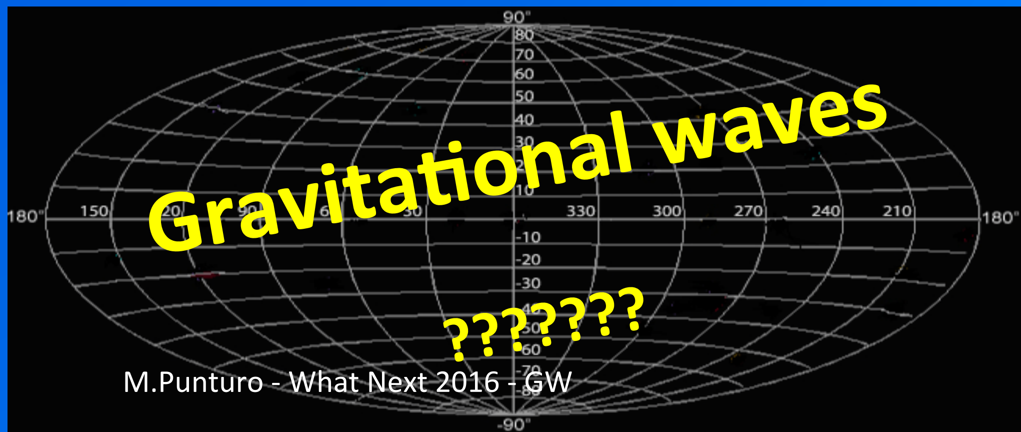






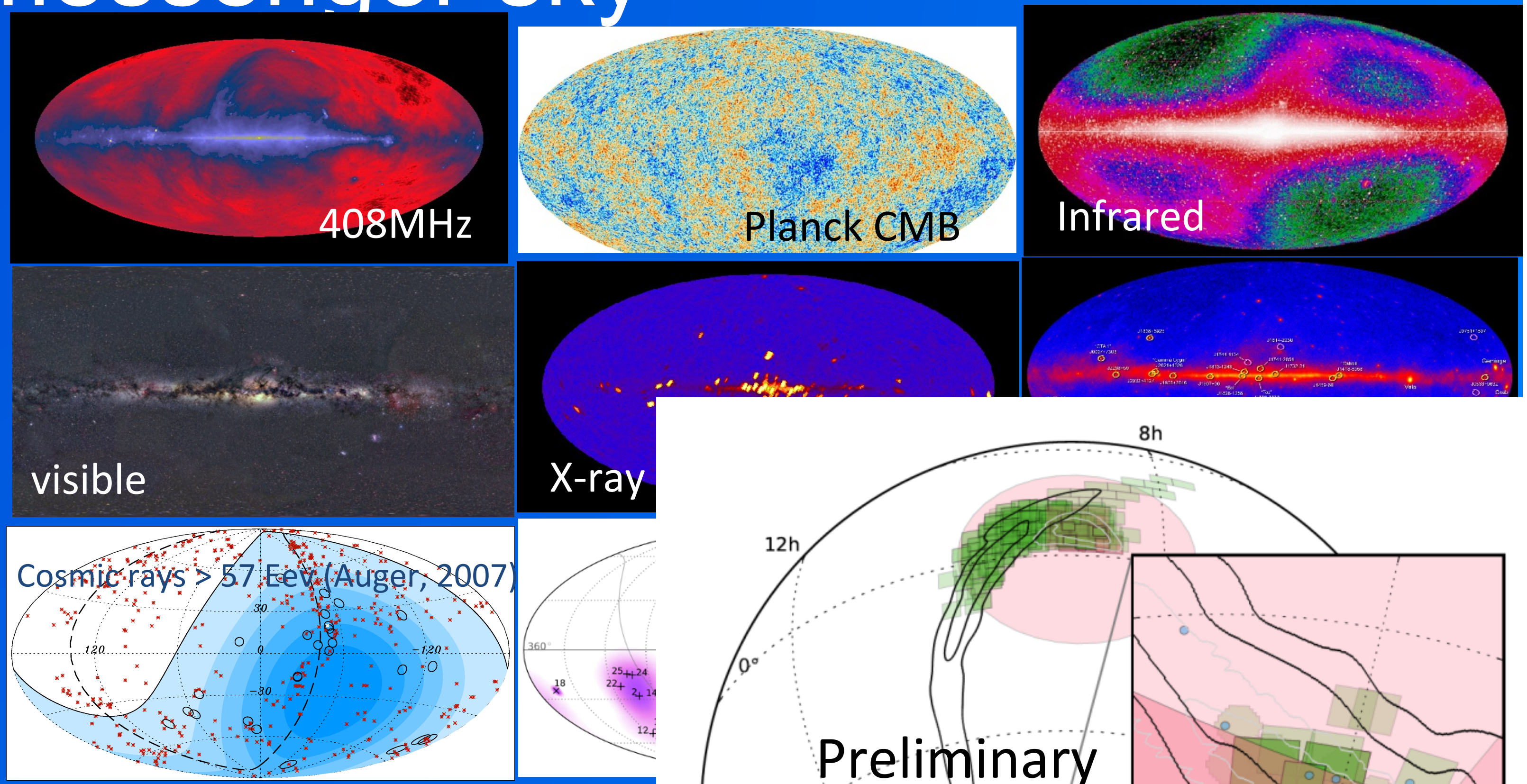


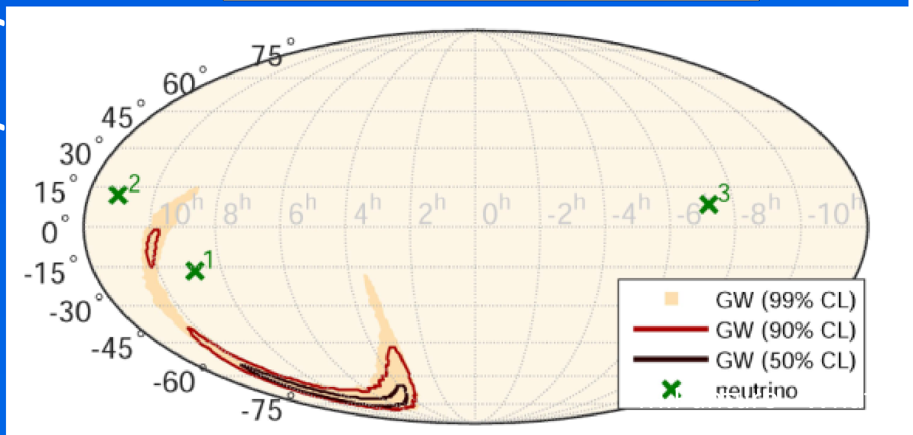
- Before 11/02/2016

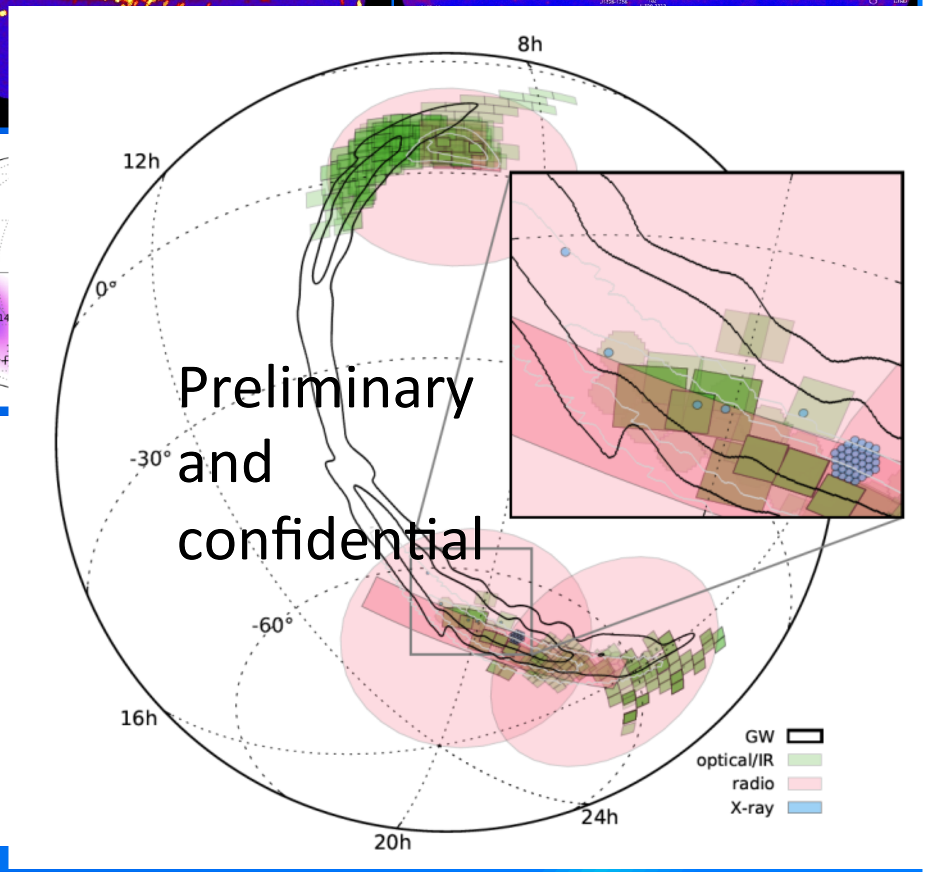


Multimessenger sky

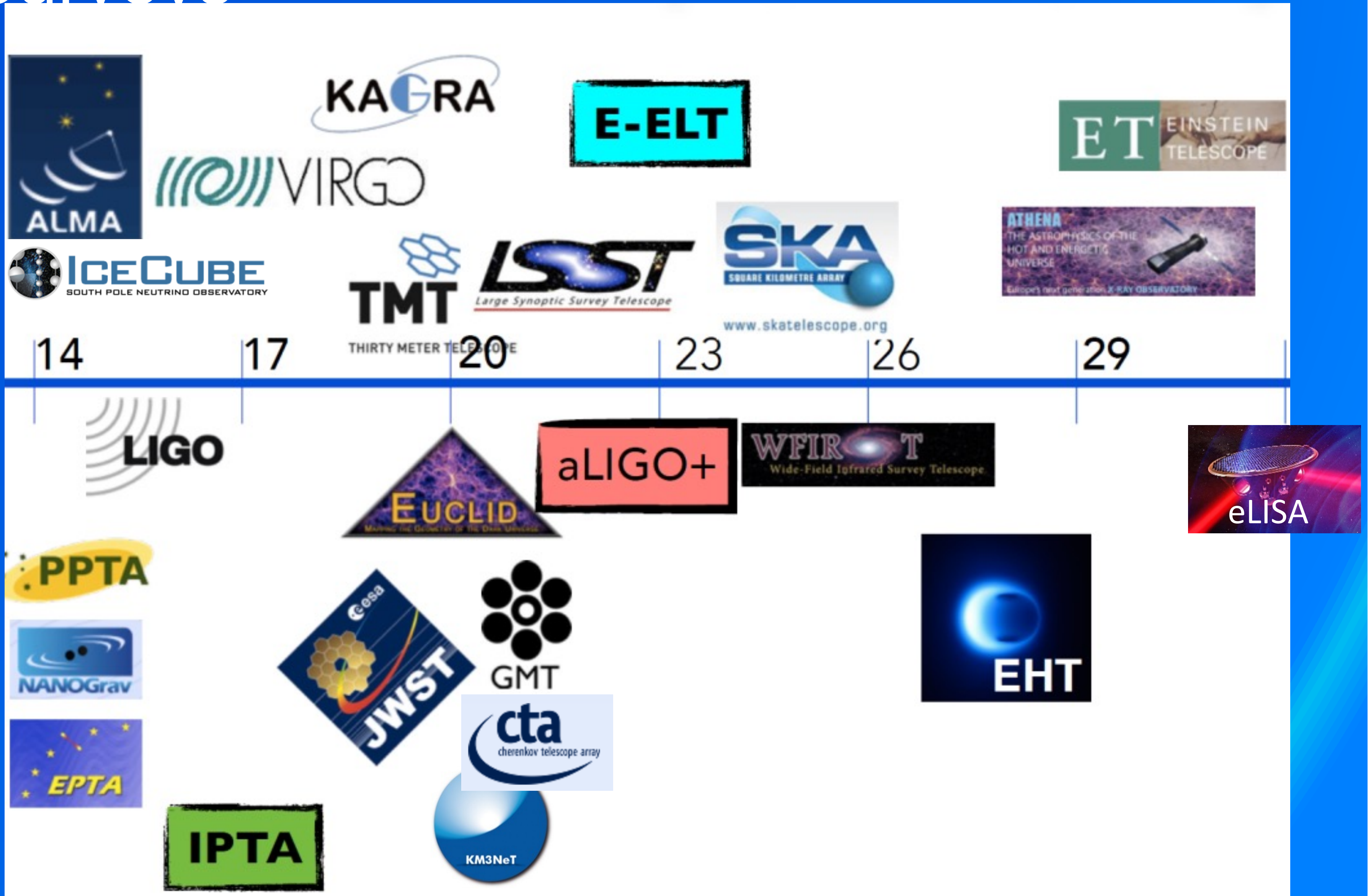
- After 11/02/2016







Timescale of Telescopes, Missions, Surveys



End

Extra Slides

7th Einstein Telescope Symposium: 'the first joint ET-LIGO 3G meeting'

ET EINSTEIN TELESCOPE

2-3 February 2016 *Florence*
Europe/Rome timezone

- Overview
- **Scientific Programme**
- Call for Abstracts
  - View my abstracts
  - Submit a new abstract
- Timetable
- Contribution List
- Book of abstracts
- Registration
  - Registration Form
- List of registrants
- Travel and living information

Support

The annual ET symposium is organised the next 2-3 February, in Florence, Italy. You can find all the logistic information in the web site of the event: https://events.ego-gw.it/indico/conferenceDisplay.py?confId=34
That event will be the **first joint ET-LIGO 3G meeting**, focusing on possible future scenarios, the scientific targets and strategies, the enabling technologies needed to realise the 3rd generation GW observatories.
The meeting will be organised around few selected talks allowing long discussions and a poster session is expected.
The structure of workshop is the following:

- Tuesday 2nd, Morning: Global scenario
- Tuesday 2nd, Afternoon: Technologies
- Wednesday 3rd, morning: Global scenario and roadmapping

The workshop is preceded by a meeting focused on the next H2020 call on integration of research infrastructures to be held in the afternoon on February 1st.

Global Scenario

Analysis of the science targets of a 3G observatory and/or network. Definition of the requirements for a 3G observatory. Costs of the future infrastructures

Roadmapping

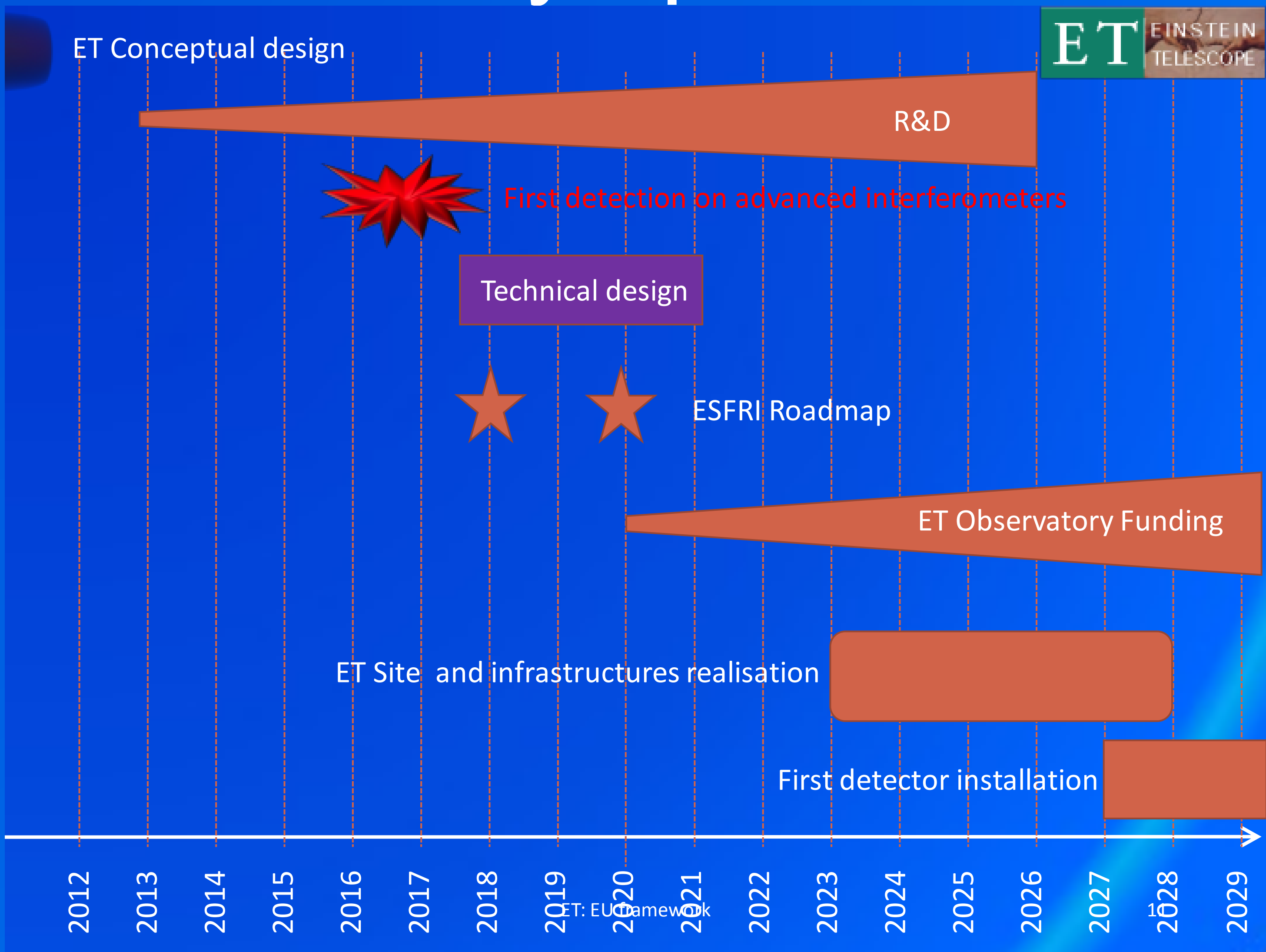
How to arrive to a network of 3G observatories? What is the correct timing? What will be our financial strategy? Do we need a global R&D strategy? How to collaborate in order to achieve our targets?

Technologies

Questions:

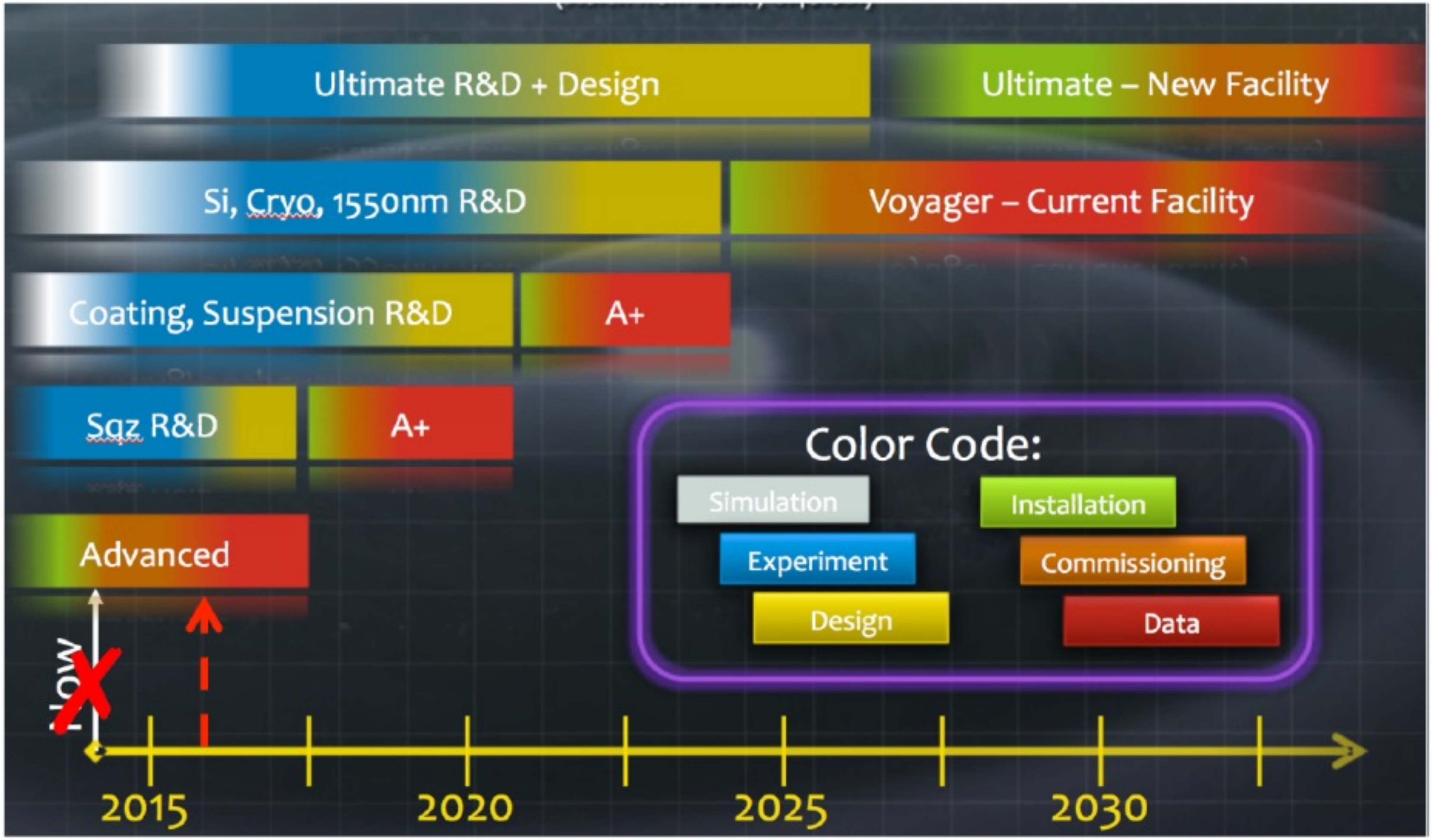
- What about the papers under publication by Fermi-GBM and Fermi-LAT?
- What is the most promising frequency range?
- Timelines?

Timeline discussed at the 7th ET symposium



Recycling (of slides, that is): A rough timeline to critique

(stolen from Evans, G1401081)



GW150914 – Fermi-GBM

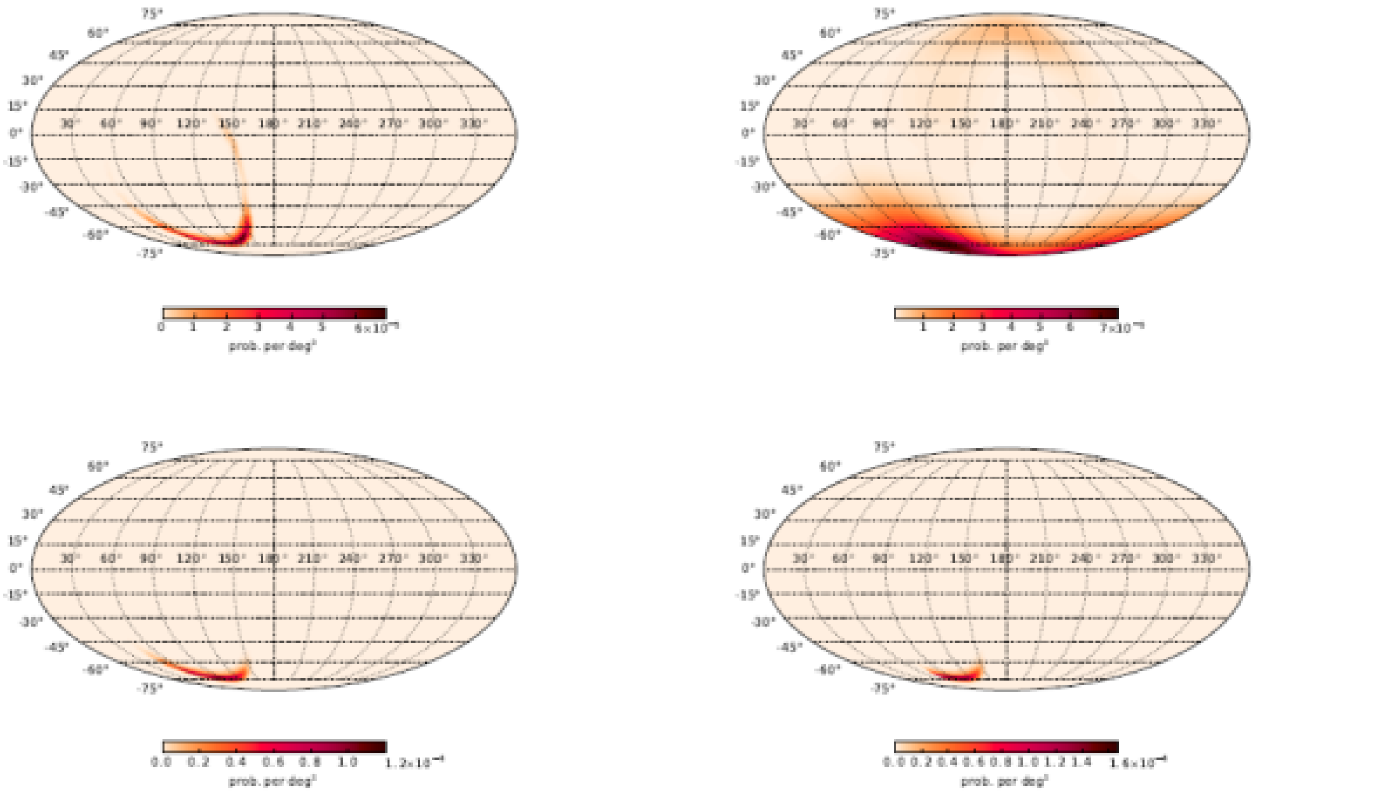
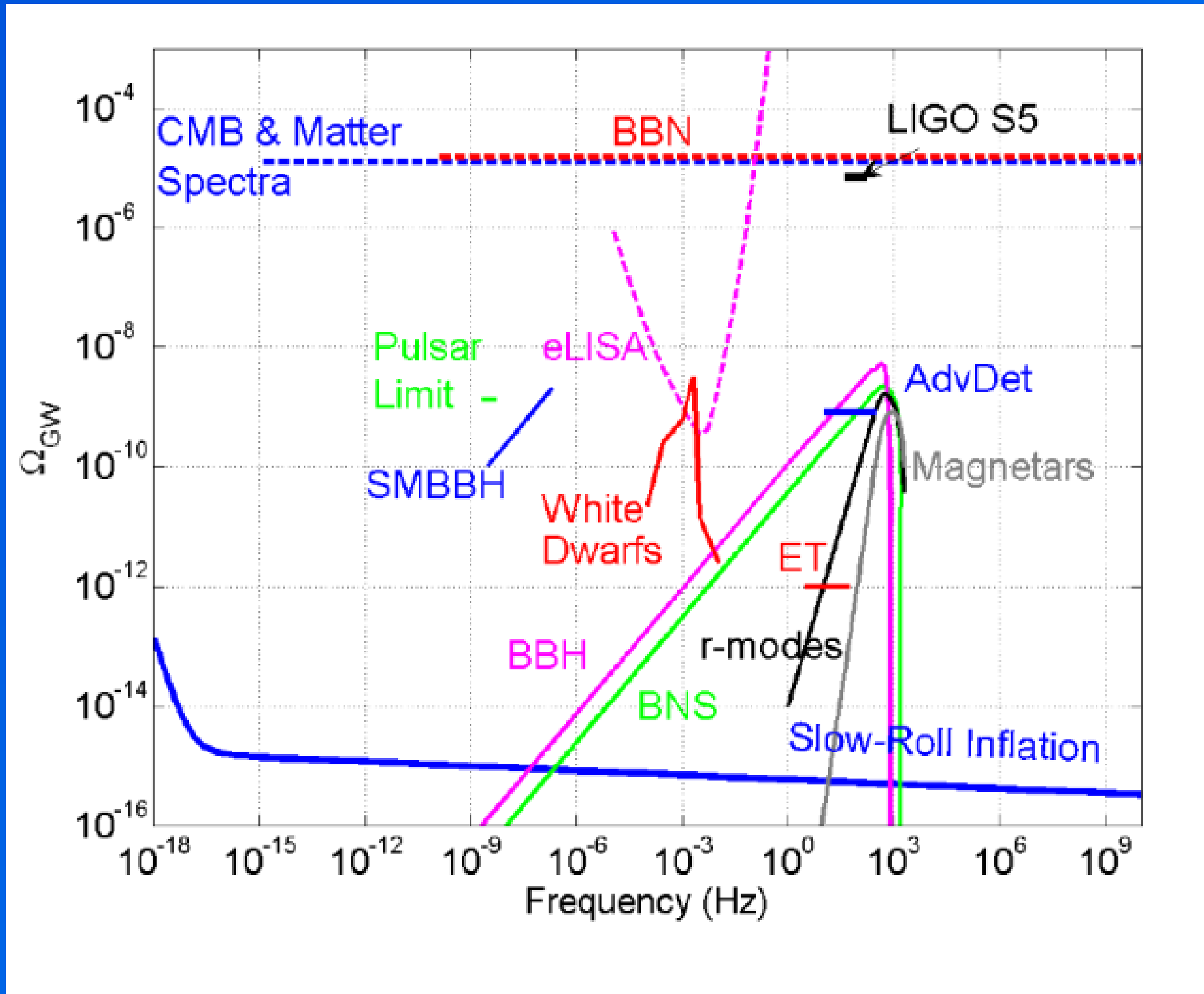


Fig. 8.— The LIGO localization map (top left) can be combined with the GBM localization map for GW150914-GBM (top right) assuming GW150914-GBM is associated with GW event GW150914. The combined map is shown (bottom left) with the sky region that is occulted to *Fermi* removed in the bottom right plot. The constraint from *Fermi* shrinks the 90% confidence region for the LIGO localization from 601 to 199 square degrees.

Stochastic Foregrounds GW



ET infrastructure

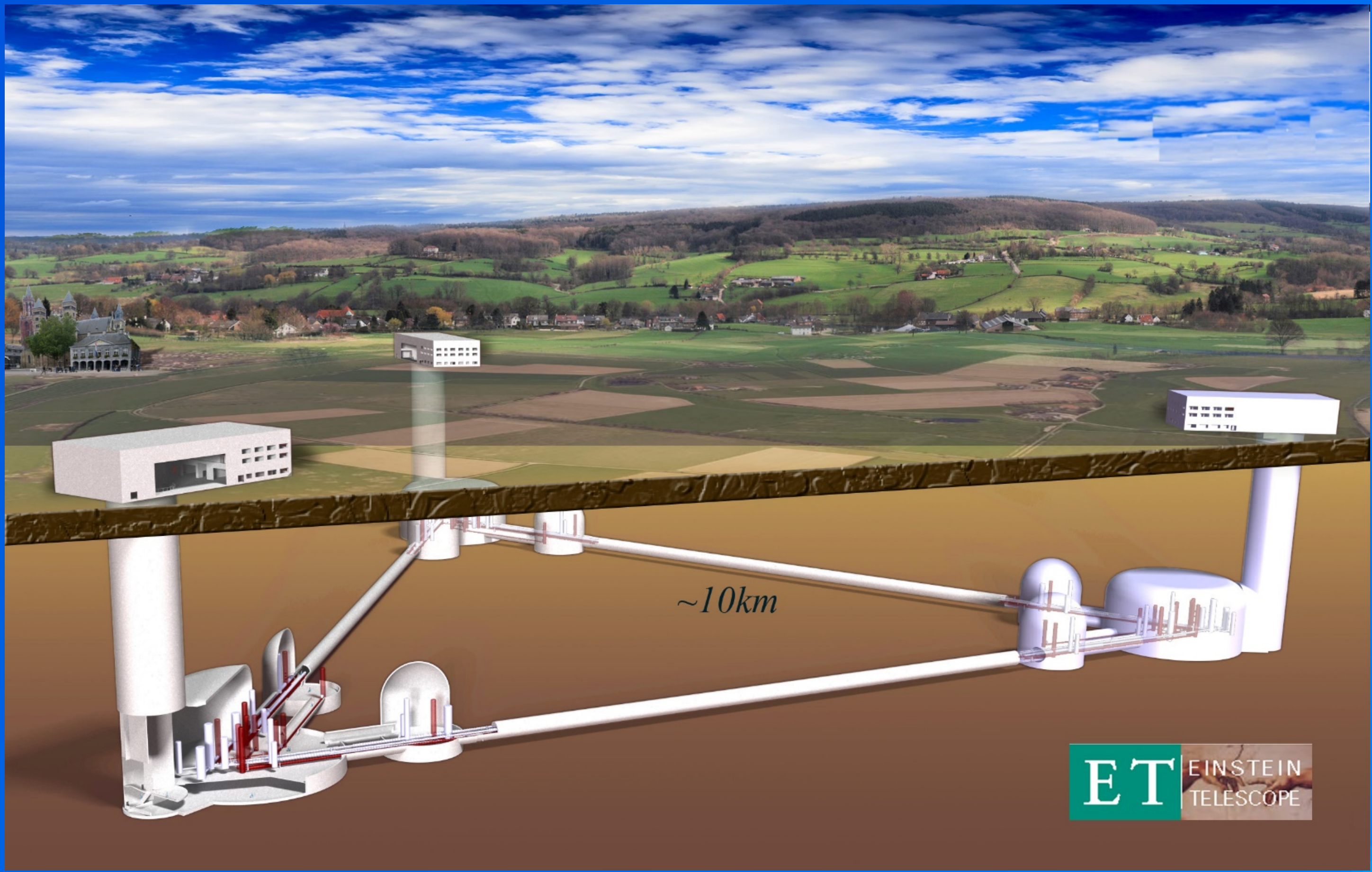


Table 1: Summary of a plausible observing schedule, expected sensitivities, and source localization with the advanced LIGO and Virgo detectors, which will be strongly dependent on the detectors' commissioning progress. The burst ranges assume standard-candle emission of $10^{-2} M_{\odot}c^2$ in gravitational waves at 150 Hz and scale as $E_{\mathrm{GW}}^{1/2}$, so it is greater for more energetic sources (such as binary black holes). The binary neutron-star (BNS) localization is characterized by the size of the 90% credible region (CR) and the searched area. For 2015 – 2016 and 2016 – 2017, these have been calculated from parameter-estimation studies (neglecting detector calibration uncertainty) [31, 99] using LALInference [110]. The CRs for subsequent periods are estimated from timing triangulation (highlighted by italics), which is known to provide estimates on average a factor of ~ 4 too large for a three-detector network [60, 31], hence these serve as a conservative bound. Both ranges as well as the BNS timing-triangulation localizations reflect the uncertainty in the detector noise spectra shown in Figure 1. Differences in the shape of the detector noise curves and also relative sensitivities between detectors have an effect on the localization areas. The BNS detection numbers also account for the uncertainty in the BNS source rate density [14]. BNS detection numbers and localization estimates are computed assuming a signal-to-noise ratio greater than 12. Burst localizations are expected to be broadly similar to those derived from timing triangulation, but vary depending on the signal bandwidth; the median burst searched area (with a false alarm rate of $\sim 1\ \mathrm{yr}^{-1}$) may be a factor of $\sim 2 – 3$ larger than the values quoted for BNS signals [51]. No burst detection numbers are given, since the source rates are currently unknown. Localization and detection numbers assume an 80% duty cycle for each instrument.

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