Future searches for GW counterparts with new astronomical facilities

Lord Rosse "not so easy to use" 48 inch telescope, Ireland

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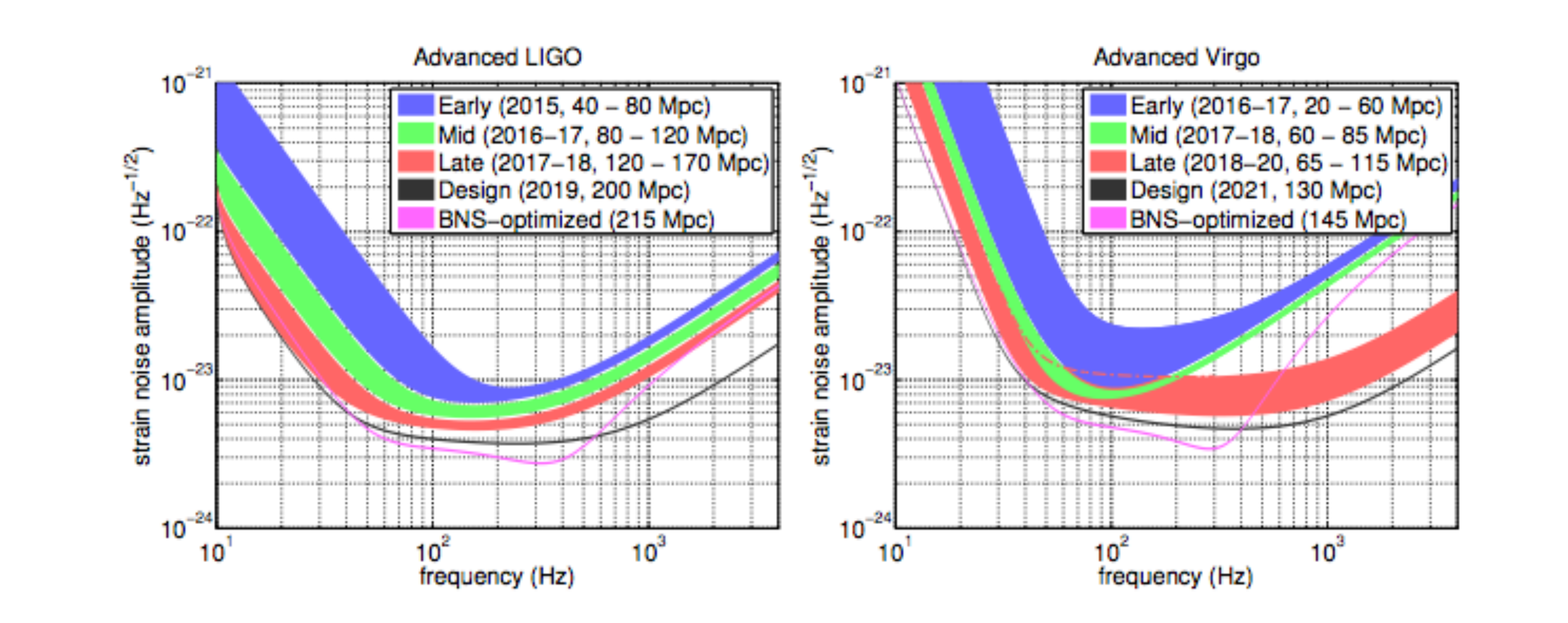
Input data:

- Advanced LIGO and Advanced VIRGO (aLIGO & AdV) localisation capabilities.

Goal:

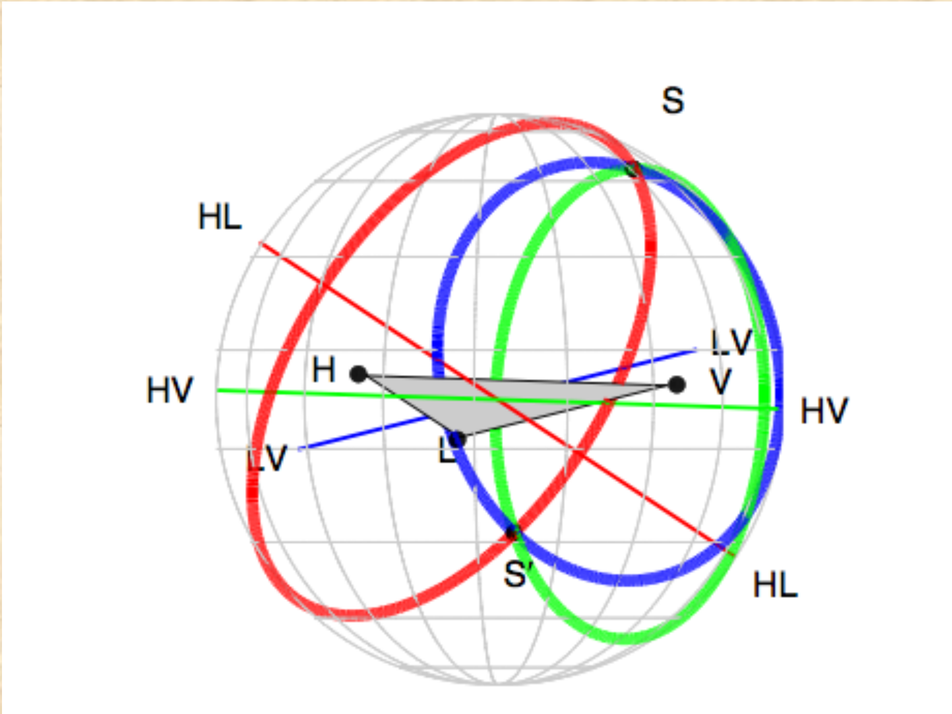
- Provide hints for an efficient management of follow-up activities (mainly electromagnetic).



From Aasi et al. (2013, arXiv: 1304.0607)

“Late” and “early” performances are very different (of course…). Yet the true schedule for reaching the goal is foreseen many delicate steps.

No specific astrophysical source will be considered, i.e. a generic recipe is discussed. Clearly the follow-up strategy does depend on the specific object to be searched.



From Aasi et al. (2013, arXiv: 1304.0607)

Localisation accuracy is a strong function of the number of operational sites.

No need to discuss (you know better than me) the “principia” behind GW sources localization. We assume localization is possible, independently of the specific recipe (four or more detectors with timing information only, or other parameters included in the analysis.

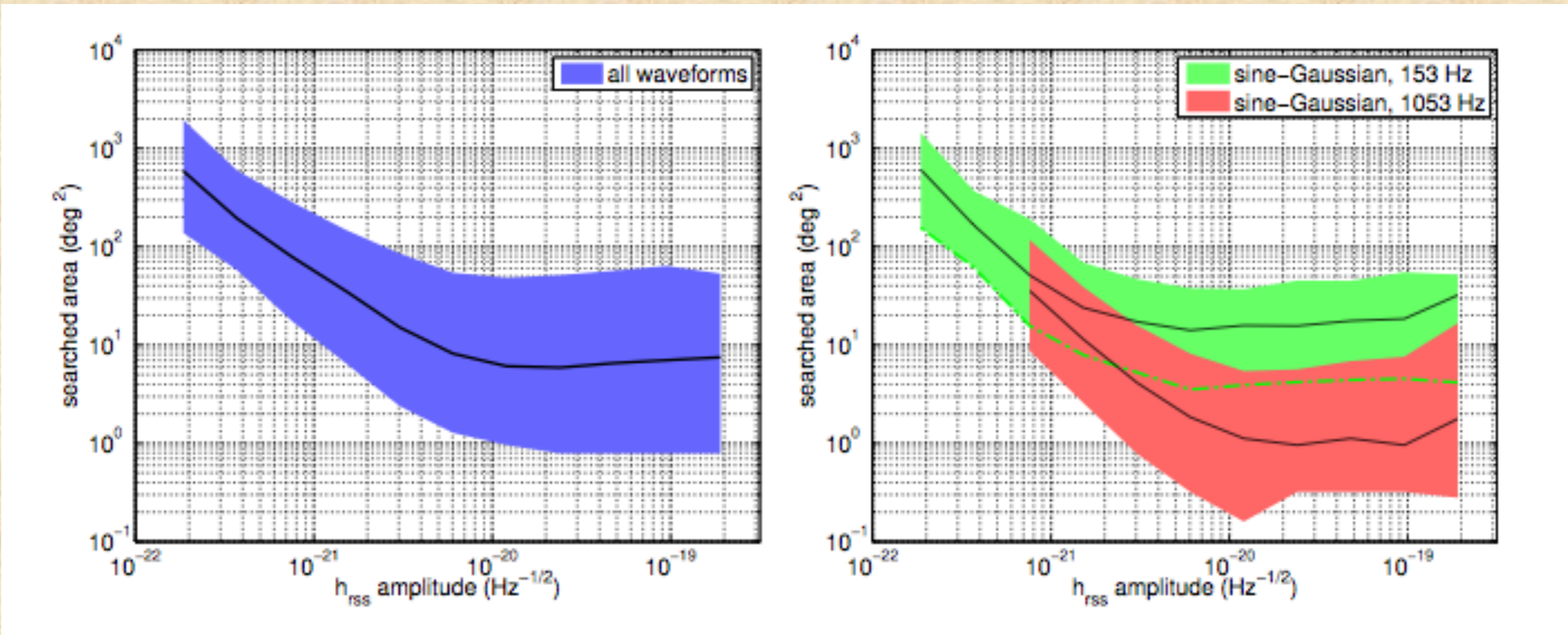
An important factor to know, even from the "psychological" point of view, is the rate of false alerts.

Typical rates for Binary Neutron Star (BNS) coalescences are among 0.4 – 400 alerts/year (depends on many factors of course).

Similar rates for NS-BH and BBHs. Other sources are supposed to give less alerts or we simply do not know.

I copy from Aasi et al. a false alert rate for aLIGO and AdV of at most 10^{-2}/year for coalescence of compact binaries.

Yet, at lower frequencies, i.e. bursts, the situation if far more difficult and a false alert/year is possible.

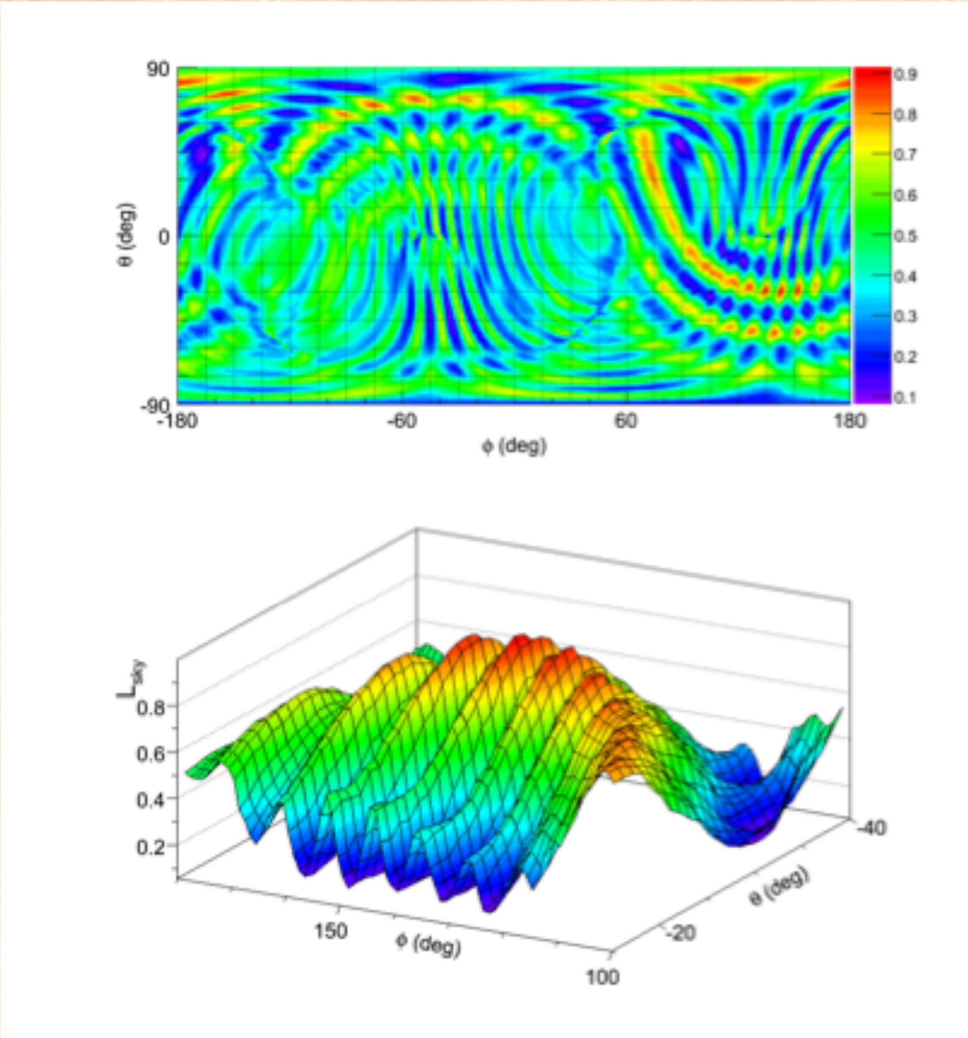


From Aasi et al. (2013, arXiv: 1304.0607)

Localization of course depends on the SNR of the detected signal, its waveform, etc.

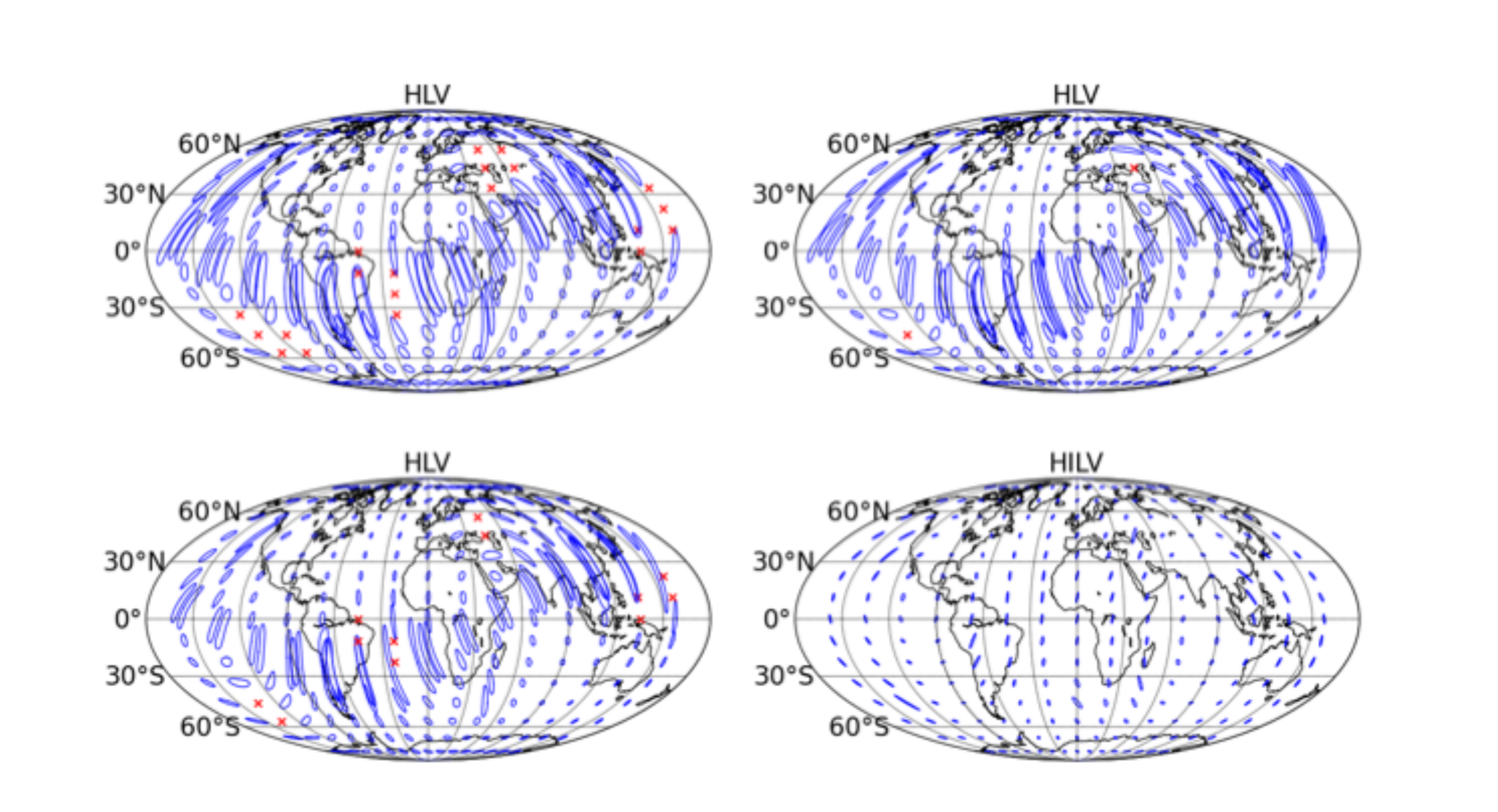
Areas to be searched 30 and 200 deg^2 are typically required.

And the shape of the "higher probability" source location is often somehow puzzling.



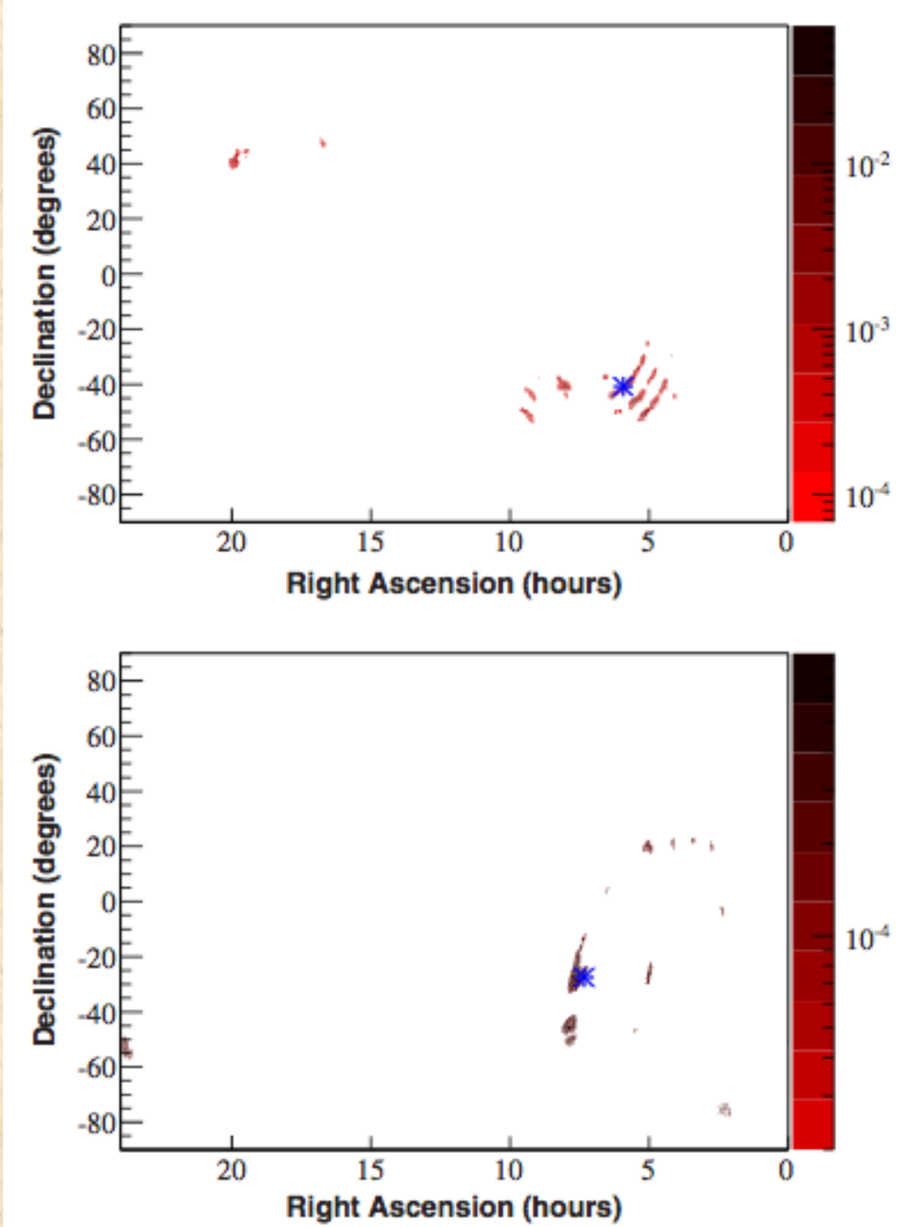
Simulation from Klimenko et al. (2011, Phys. Rev. D., 83, 2001)

Simulation for a face-on BNS system at 80 Mpc (top) and 160 Mpc (bottom). Left to right: system improvements results.



Simulation from Aasi et al. (2013, arXiv:1304.0607)

There are also "real" cases to study with the present LIGO-Virgo:



These two events turned out to be false alerts, yet the follow-up procedure was activated with several ground based telescopes and *Swift*.

Likely, no plausible electromagnetic counterpart was found...

From Evans et al. (2012, ApJS 203, 28)

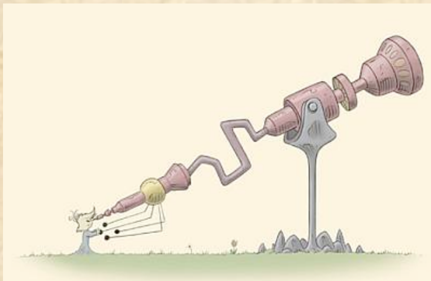
So, summing up, and simplifying:

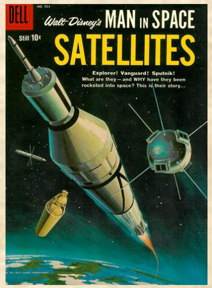
- On a long term, real a few degree error circles, possibly connected, will be provided.

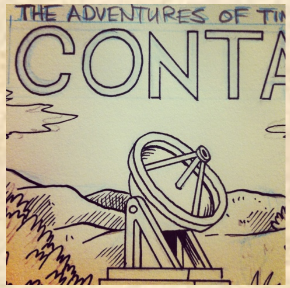
- On a shorter term we have to develop a procedure for hundreds of degrees error boxes, often disconnected.

- Follow-up should be multi-wavelength, rapid, and deep. Requirements often in contradiction.

- A synergy of ground-based (multiple sites) and space-borne facilities is necessary.







How can we manage this (demanding) observational task?

A few figures, just to handle the problem:

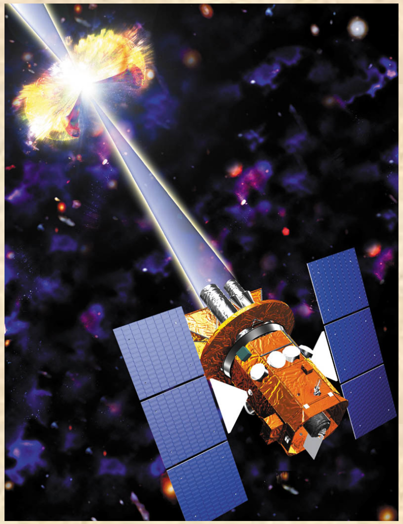
- X-rays
  - *Swift*-XRT FoV is ≈ 24x24 arcmin^2 (≈ 0.16 deg^2).
  - XMM-Newton FoV is ≈ 30x30 arcmin^2 (≈ 0.25 deg^2).
  - Chandra FoV is is ≈ 30x30 arcmin^2 (≈ 0.25 deg^2).

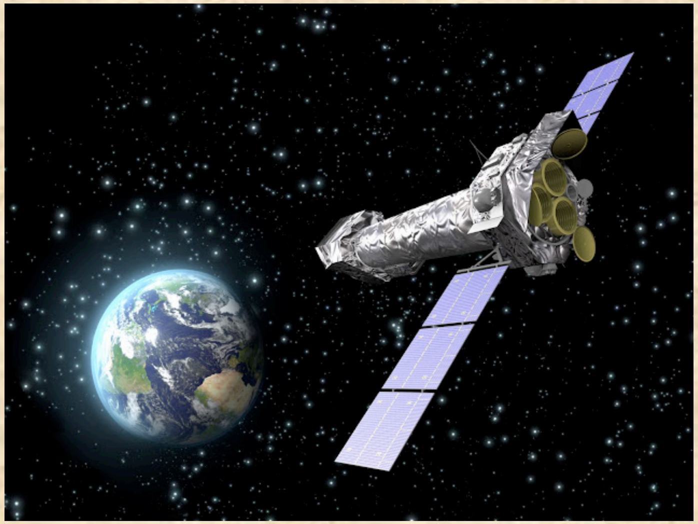
These are all "present" facilities. No way to predict which of them, if any, will still be operational on a 10-year timescale.
Only *Swift*, however, offers the required flexibility for rapid reaction.

Is rapidity in reacting important?

- *Swift*-XRT can point in a few tens of seconds if the alert is coming from BAT. ToO pointings in a few hours are routinely carried out. Definitely feasible a more rapid reaction time for GW alerts.

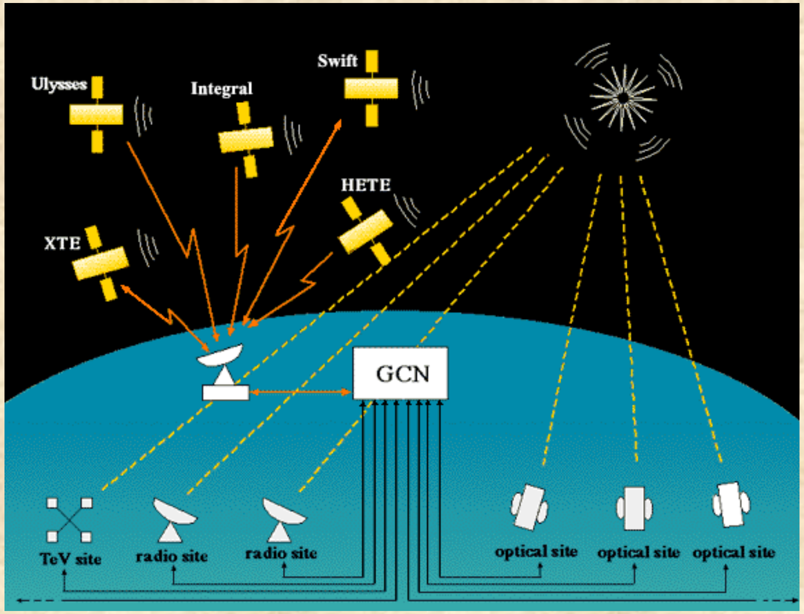
- XMM-Newton and Chandra host ToO observations, but their reaction time is considerably longer. Probably too long (days).





An important topic often not fully appreciated

- *Swift* is financed till 2014, and there are reasonable hopes it can get two more years of supported activity.
- The problem is that there are no alternatives, now, and likely in the future, to *Swift*.
- So, without *Swift*, no more high-energy well-localized alerts.



- Optical-NIR

  - Existing wide-sky optical monitors (TORTORA, PiSky, etc.) have a field of view (FoV) of, typically, 10x10 deg^2. Unfortunately, they have modest sensitivities (R mag ≈10-12). Too modest for GW counterpart searches.

  - Typical FoV for large optical facilities (Dolores@TNG, FORS@VLT, etc.) is 10x10 $arcmin^2$ (≈ 3×10^{-2} deg^2), although wider FoVs, 15-20x15-20 $arcmin^2$, are also common (0.06 – 0.10 deg^2).

  - Optical facilities with 1-2x1-2 deg^2 FoV (MEGACAM@CFHT, VST, VISTA, etc.) are also available, and in the (near) future likely more and more common.

  - A large set of modest-size robotic telescopes are available (REM, LT, PROMPT, etc.), high flexibility but usually small FoV.

- Reaction time

  - Small-size robotic telescope can react in a few tens of seconds, in a fully-automatic way.

  - Among the big telescopes, only the VLT is equipped with a rapid response mode, It can point in 7min after the alerts.

  - The other telescopes can usually react in several tens of minutes to hours.

  - Survey telescopes, as far as I know, do not even accept ToOs.

- Radio (from mm to m)

  - Many available instrument, however in most cases far too narrow Field of View (≈arcmin). Some of them are designed for high spatial resolution (i.e. ALMA).

  - Some SKA pathfinders are very interesting, as ASKAP, with ≈30 deg^2 at 1.4 GHz. Sensitivity might be an issue, but it allows a very efficient scanning of the GW error boxes.

  - Low-frequency facilities, as LOFAR (15-75 MHz), can "see" a large fraction of the sky (≈ 10 – 1000 deg^2), depending on the specific configuration and frequency.

  - Present facilities, as the EVLA (Lazio et al., IAU Symp. 285, 2011), offers a FoV comparable to typical optical-NIR facilities, 7x7 arcmin at 1-50 GHz.

- High-energies (100 KeV – TeV)

  - *Swift*-BAT (coded-mask, 1.4 sr, 10% of the full-sky), *Fermi*-GBM (20% of the full-sky) are well suited instruments.

  - Swift can re-point rapidly, although sensitivity can be an issue after the "main event".

  - Cherenkov facilities (MAGIC, VERITAS, HESS) have a few deg FoV and can point rapidly.

  - All-sky Cherenkov facilities have a very high duty-cycle, although sensitivity is an issue.

  - VHE observations are very exciting from the scientific point of view, probably not very useful for a follow-up. Satellite gamma-ray monitor are on the contrary perfect mates for GW follow-ups.

Example:

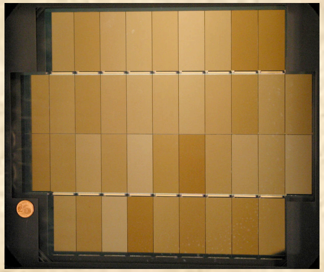
- Let's assume to have a 100 deg^2 FoV

- With a 10x10 $arcmin^2$ FoV you need a few x 1000 pointings to cover the whole error box.
- 5min/pointing means roughly a full week! Unfeasible.

- FoV of ≈ deg is, essentially, mandatory. About 100 pointings to cover the whole box would mean several hours of observations. Feasible for an important scientific goal.

- As a matter of fact multiple facilities well distributed in lat/long are necessary.

Deg FoV optical/NIR facilities



- As mentioned, good telescopes are available (MEGACAM@CFHT, VST, VISTA, etc.) and more are coming soon.
- In most cases these are PI- or project-driven instruments. Yet, it should be possible to negotiate an agreement. For open-time facilities a well designed follow-up program should be proposed.

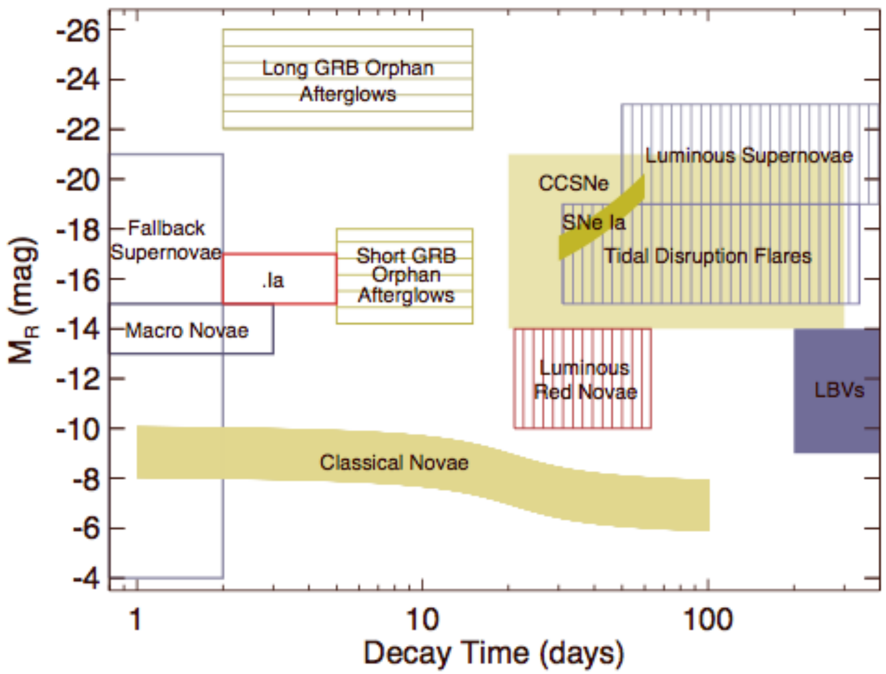
- In a few years, 2015, the LSST will be operational. 8m-class telescope with about 10 deg^2 FoV.

- Pan-STARRS (a few 1.8m telescope with about 3 deg^2 FoV each) is a more manageable alternative.

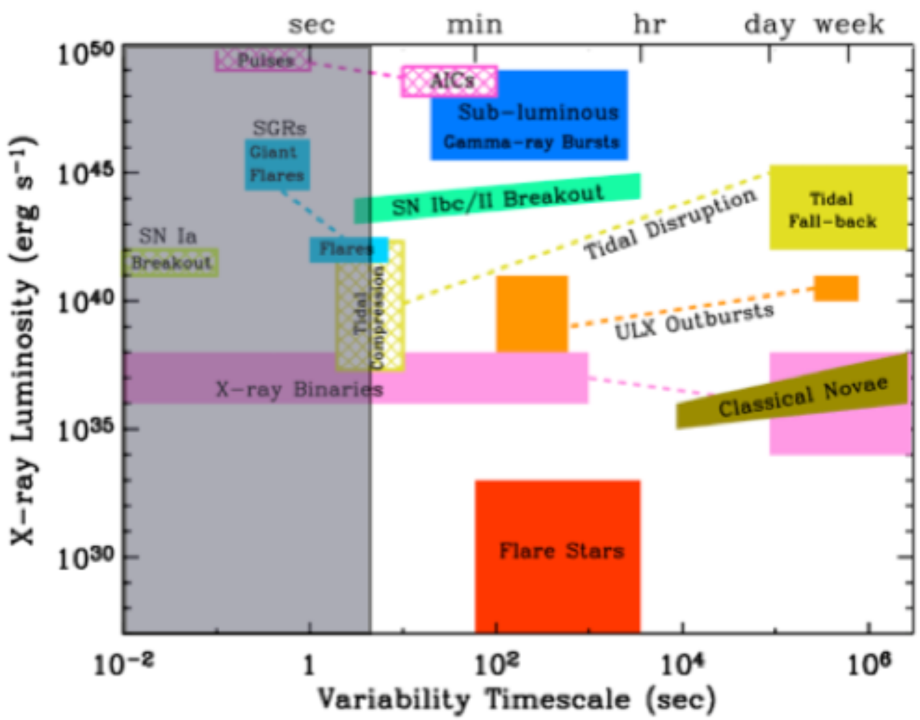
Best solution?

- LIGO-VIRGO and evolutions are very demanding enterprises.
- As it happens for other facilities, with just an affordable (?) increase in complexity and cost, a set of “private” fully-robotic optical(/NIR) telescopes could be a rewarding choice.
- 1m, 3 deg^2 FoV, fully robotic, optical multi-band, could cost about 1-2 M€
- 3 of these instruments could be built and managed with 5 M € or so.

An impressive output in the field of time domain astronomy:



Rau et al. 2009



Soderberg et al. 2009

These devoted facilities could in turn be the sources of transient alerts of interest for GW observations.

Thanks for your attention!