Prospects for multimessenger astrophysics with gravitational waves

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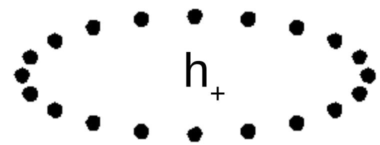
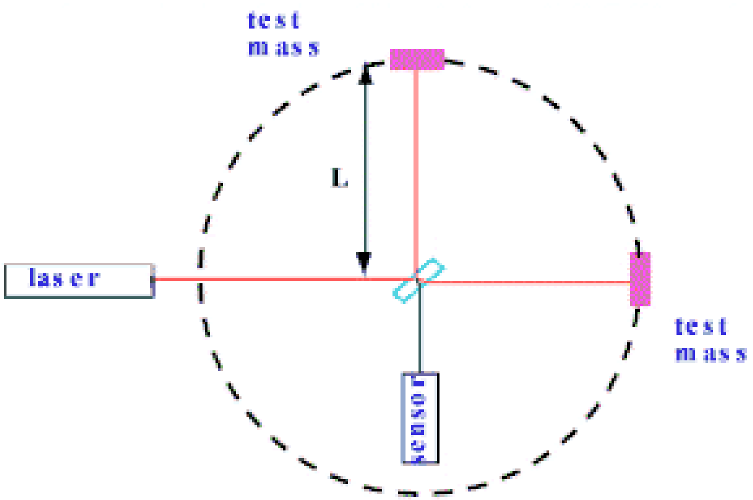
1-slide primer on Virgo

- Gravitational waves GW
  - Propagating space-time distorsion predicted by General Relativity
  - Goal: **measure GW directly (*in situ*)**

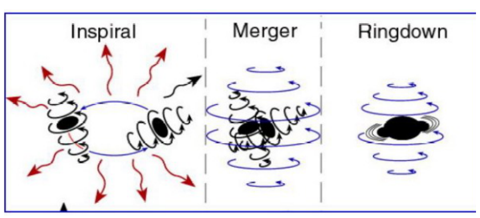


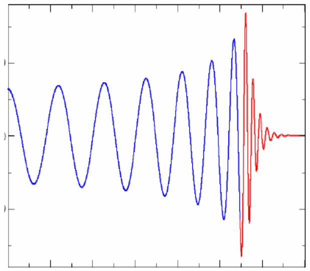
- Kilometric Michelson interferometer
  - Measure relative difference in optical path length to **10^{-21}, or 10^{-18} m** over km
  - Sensitive about few 100 Hz



- Target distant astrophysical sources
  - Typically: binaries of stellar mass compact objects (neutron star or black hole)

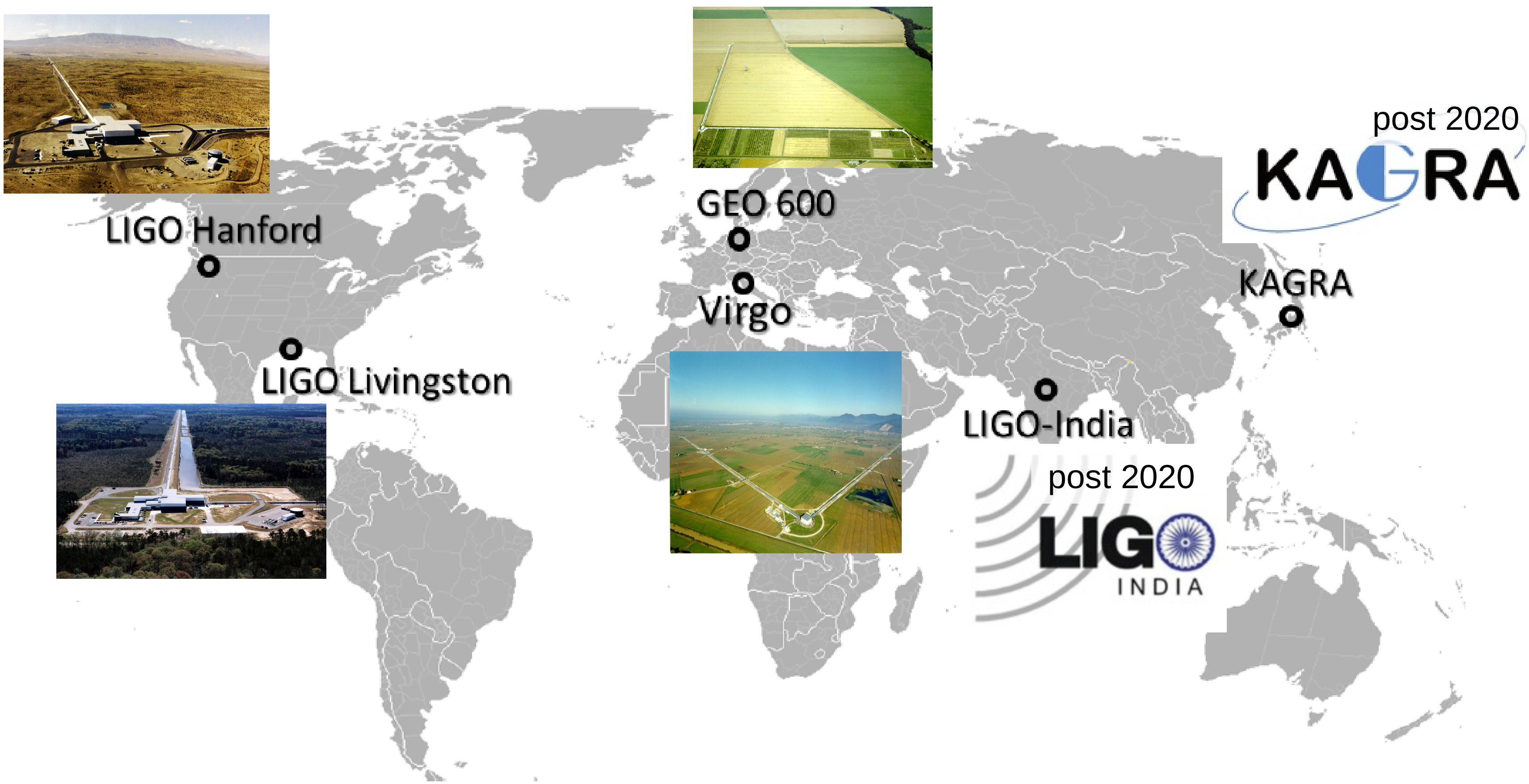
$h \sim 10^{-21}$ for NS binaries at 15 Mpc



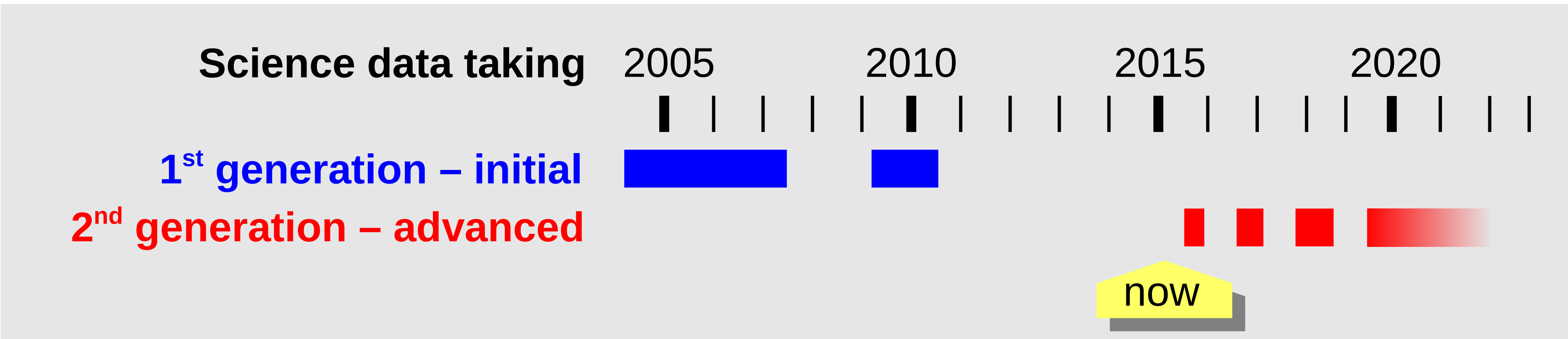


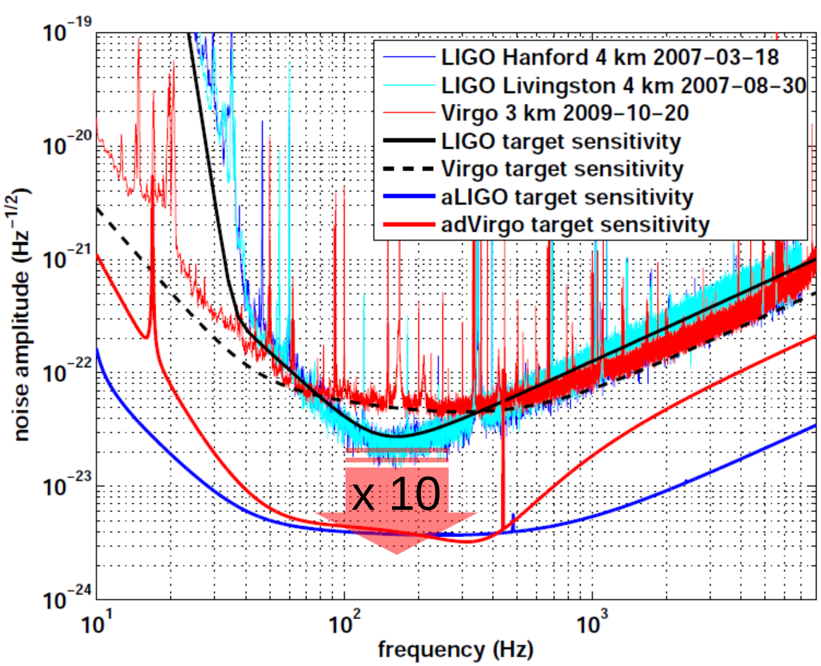
$$h(t) = \frac{\delta L(t)}{L} \propto \delta\Phi(t)$$

GW detectors in the world



GW detectors: status and timeline





1st generation – initial

3 joint LIGO – Virgo science runs
~2 yrs total, target sensitivity reached
40 papers on transient & continuous sources

horizon = detection range to coalescing binaries of neutron stars

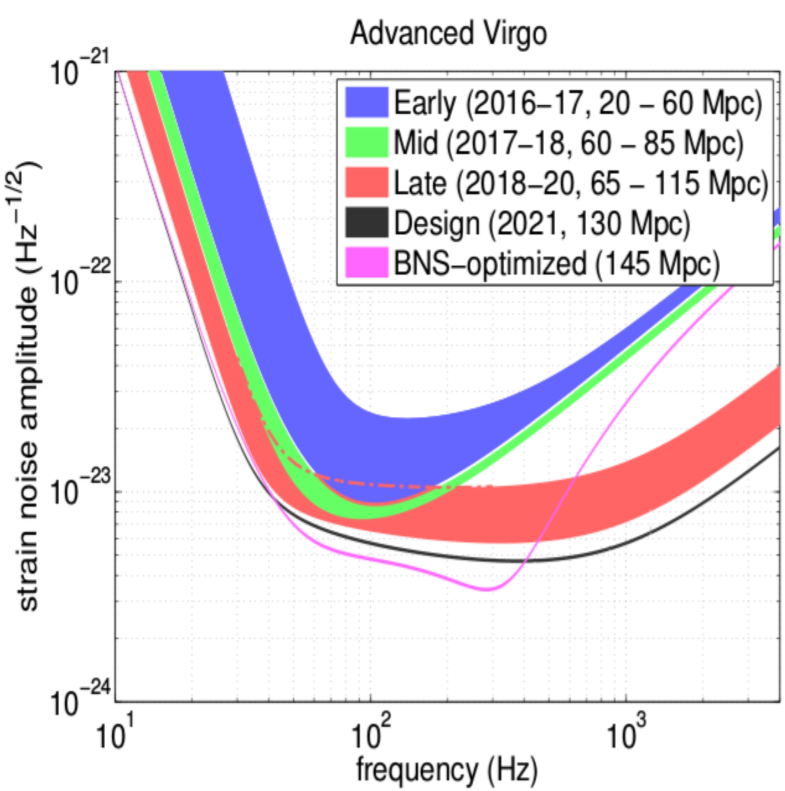
Initial: LIGO ~ 40 Mpc Virgo ~ 20 Mpc

2nd generation – advanced

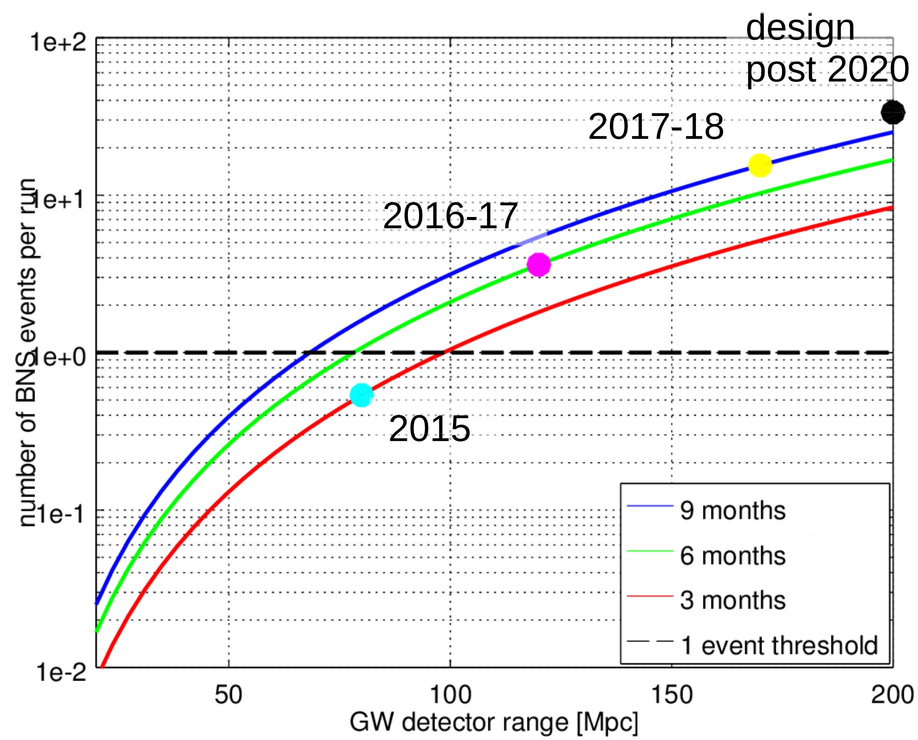
Improvement x 10 – # of events x 1000

Adv: LIGO ~ 450 Mpc Virgo ~ 320 Mpc

Science with 2nd generation 2015-2022+



estimate of event per run (optimistic, large error bars)



event $\propto$ (range)³ x obs. duration

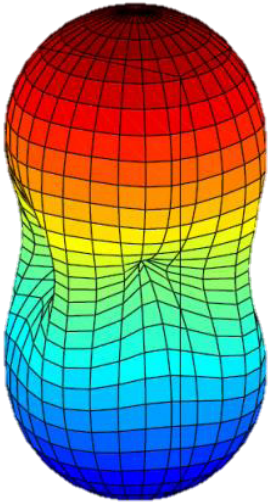
$$r_{\mathrm{BNS}} \approx 100/\mathrm{Myr}/\mathrm{MWEG}$$

next run

Epoch	Estimated Run Duration	$E_{\mathrm{GW}} = 10^{-2} M_{\odot} c^2$ Burst Range (Mpc) LIGO	Virgo	BNS Range (Mpc) LIGO	Virgo	Number of BNS Detections	% BNS Localized within 5 deg²	20 deg²
2015	3 months	40 – 60	–	40 – 80	–	0.0004 – 3	–	–
2016–17	6 months	60 – 75	20 – 40	80 – 120	20 – 60	0.006 – 20	2	5 – 12
2017–18	9 months	75 – 90	40 – 50	120 – 170	60 – 85	0.04 – 100	1 – 2	10 – 12
2019+	(per year)	105	40 – 80	200	65 – 130	0.2 – 200	3 – 8	8 – 28
2022+ (India)	(per year)	105	80	200	130	0.4 – 400	17	48

ArXiv:1304.0670

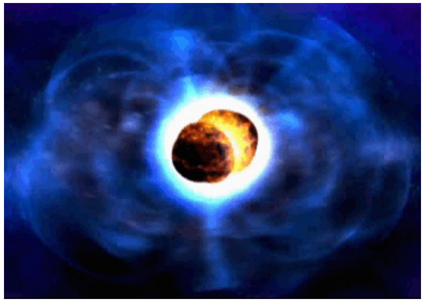
GW and multimessenger astrophysics



- **GW transient sources** are **highly energetic** astrophysical events and must be **relatively close** to be detected by LIGO and Virgo
  - GW emission is weakly beamed
- They will likely release **other types of radiations** (electromagnetic and neutrinos) too
  - e.g., **Gamma-ray bursts GRB**

    Long bursts associated to **core collapses of massive rapidly spinning stars** → *"burst"-like GW*

    Short bursts are believe to be from **coalescing compact binaries** (with one NS)→ *"chirp"-like GW*



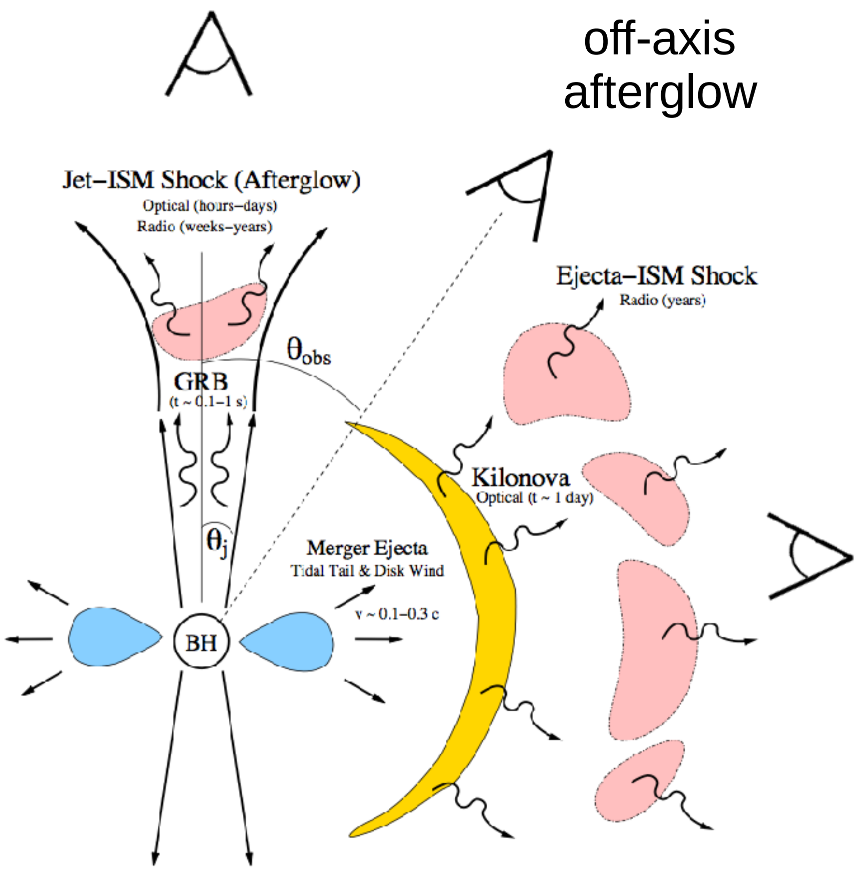
Credit: NASA/Swift

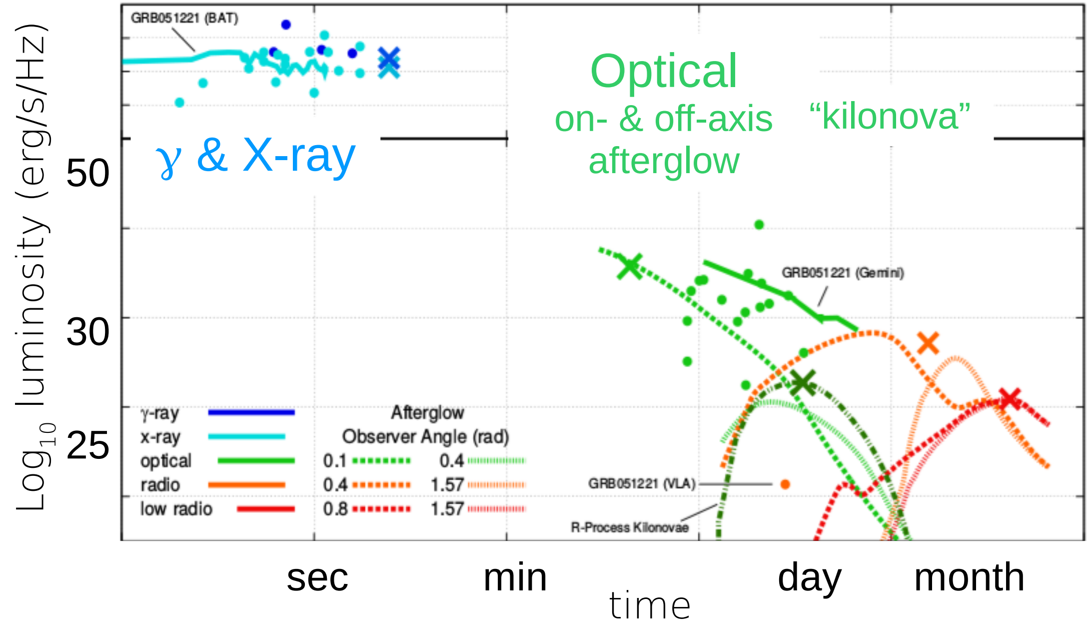
Potential EM counterparts to GW

Example of short hard burst

Prompt burst & on-axis afterglow
Bright but beamed

off-axis afterglow



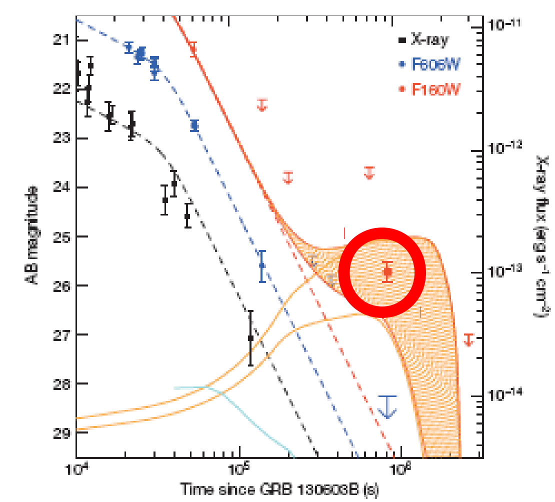


"kilonova"
Isotropic but dim

Optical transient due to decay of heavy elements in ejecta (r-process)

May be important sites for the production of heavy elements

1st candidate? GRB130603B

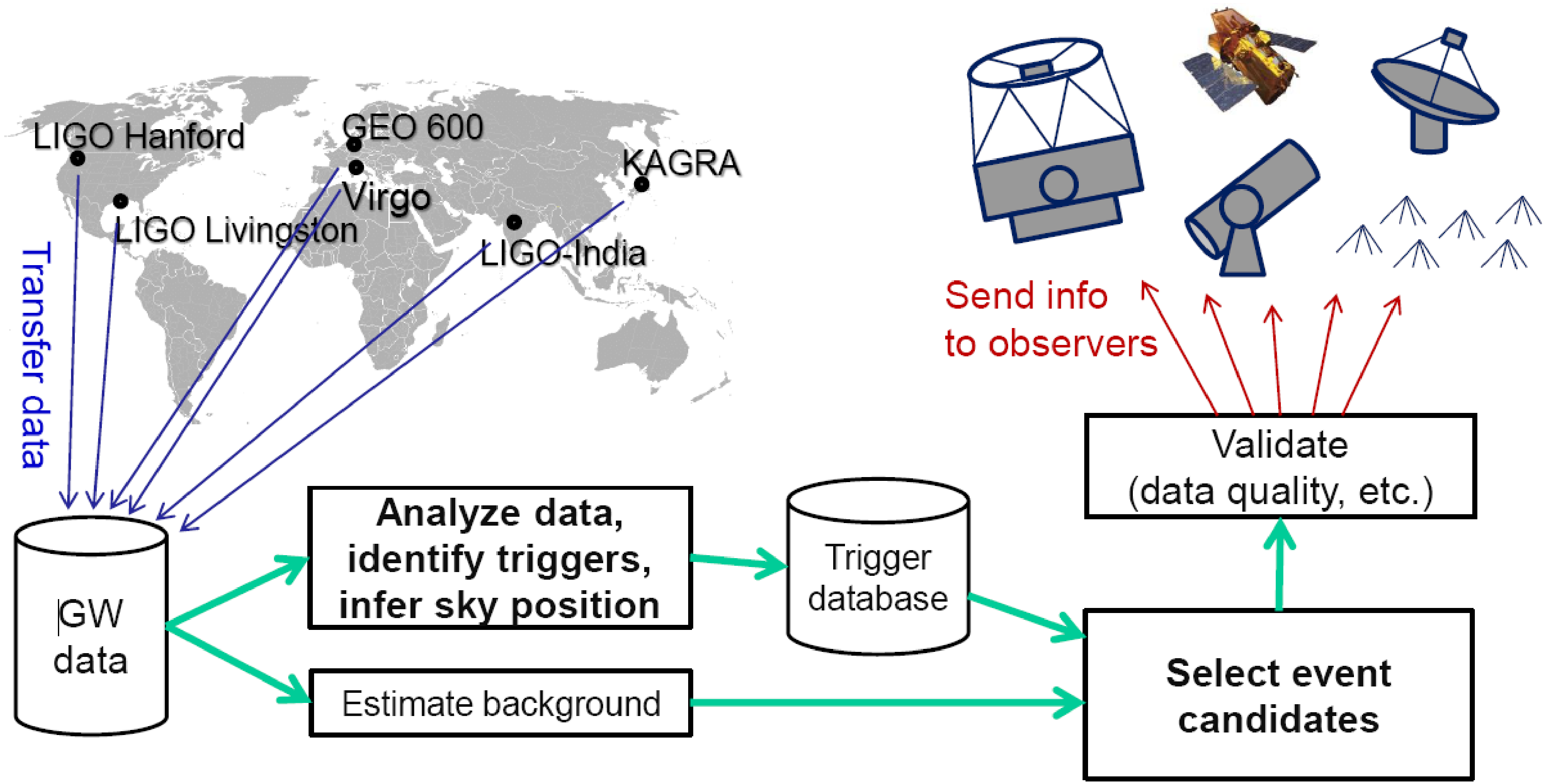


Courtesy of B. Metzger and Kelley et al, arXiv:1209.3027

Different strategies for joint observations

- Deep GW searches **triggered by astrophysical alerts**
  - e.g., process all GCN & SNEWS notices with few days latency
- **Electromagnetic follow-up** of GW alerts
  - e.g., seek a counterpart (GRB afterglow)
- Off-line joint **coincidence with other events** (possibly sub-threshold)
  - e.g., high-energy neutrinos

LIGO-Virgo GW alert system

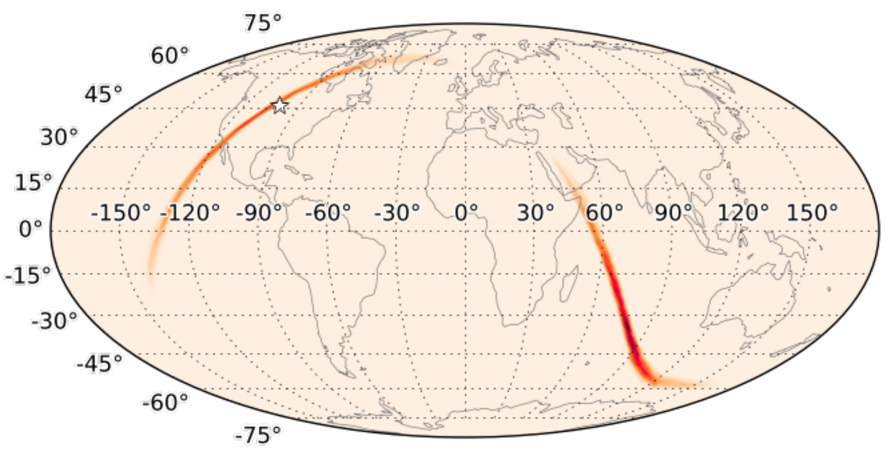


- Identify significant transients worth following up
- **Distribute alerts to observing partners within 5-10 mins**

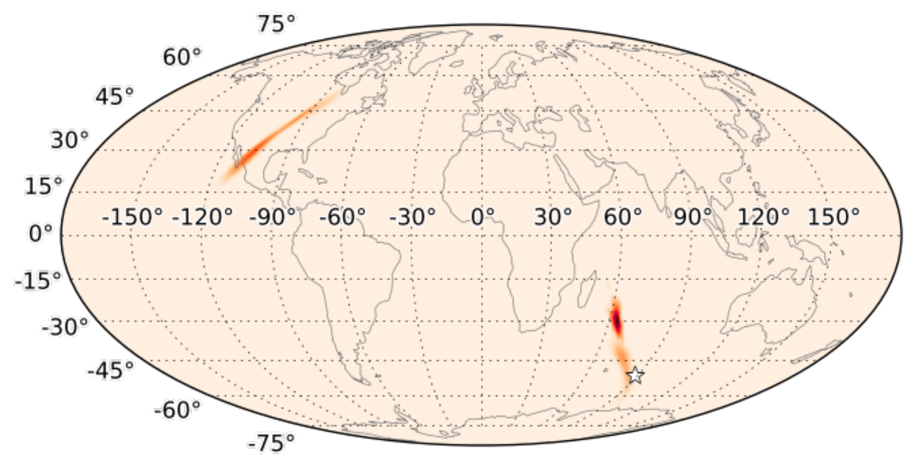
Error on sky localization

- **Reconstructed sky regions are large**!
  - Assuming pretty loud event with SNR = 12, FAR ~ 10^{-2} /yr
  - Credible region at 90 % level is **500 square degrees with 2 LIGO**
  - Reduces to **200 square degrees with Virgo**
  - Coverage of GW error box is **challenging**!

LIGO-only 2015

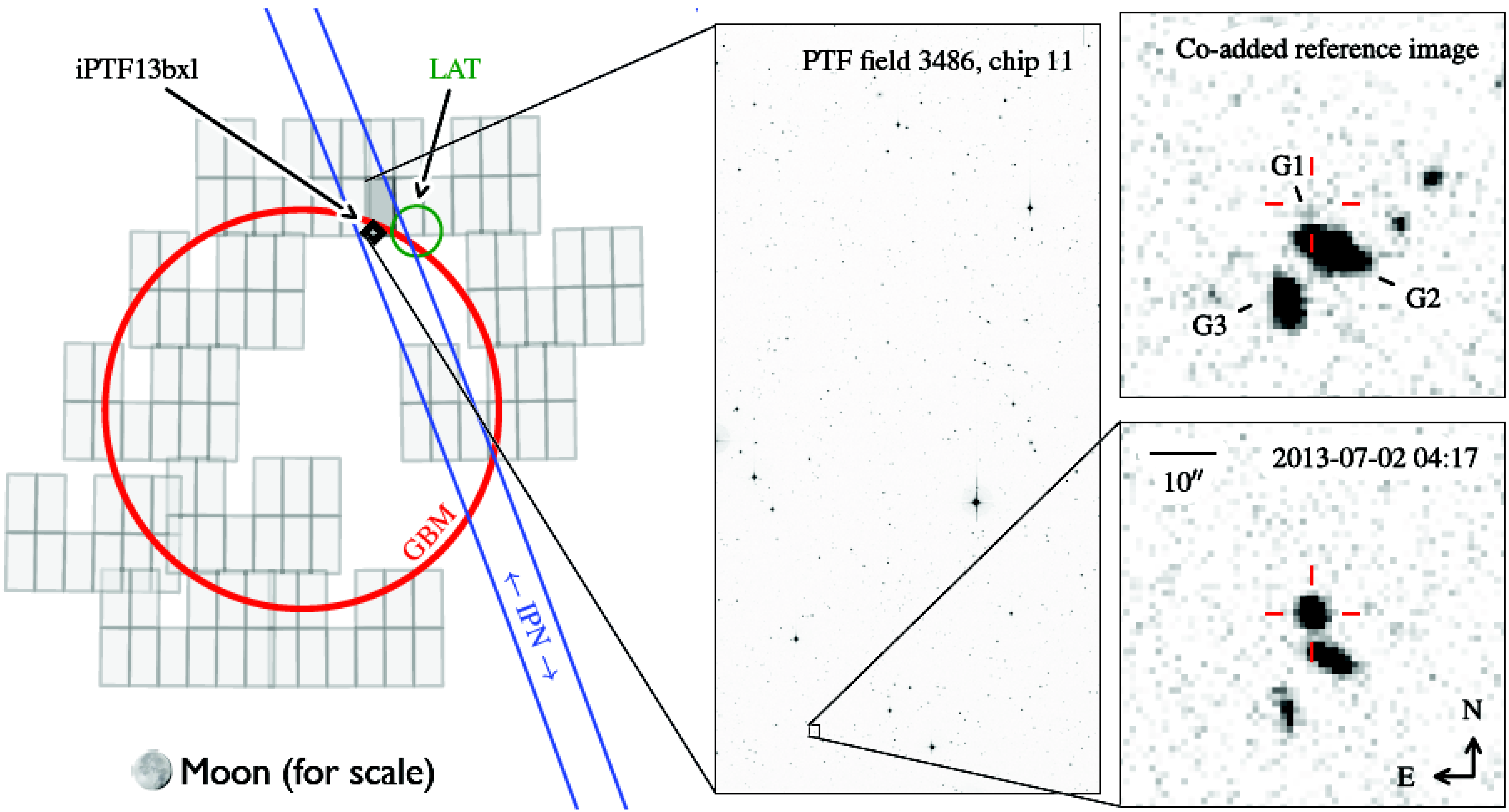


LIGO-Virgo 2016-17



Singer et al., ApJ795, 105 (2014) arXiv:1404.5623 http://www.ligo.org/scientists/first2years

Discovery & redshift of a GBM GRB in 71 deg^2



=SN2013dx

Singer et al.(2013, 2013, ApJL 776:34)

http://dx.doi.org/10.1088/2041-8205/776/2/L34

LIGO-Virgo EM follow-up program

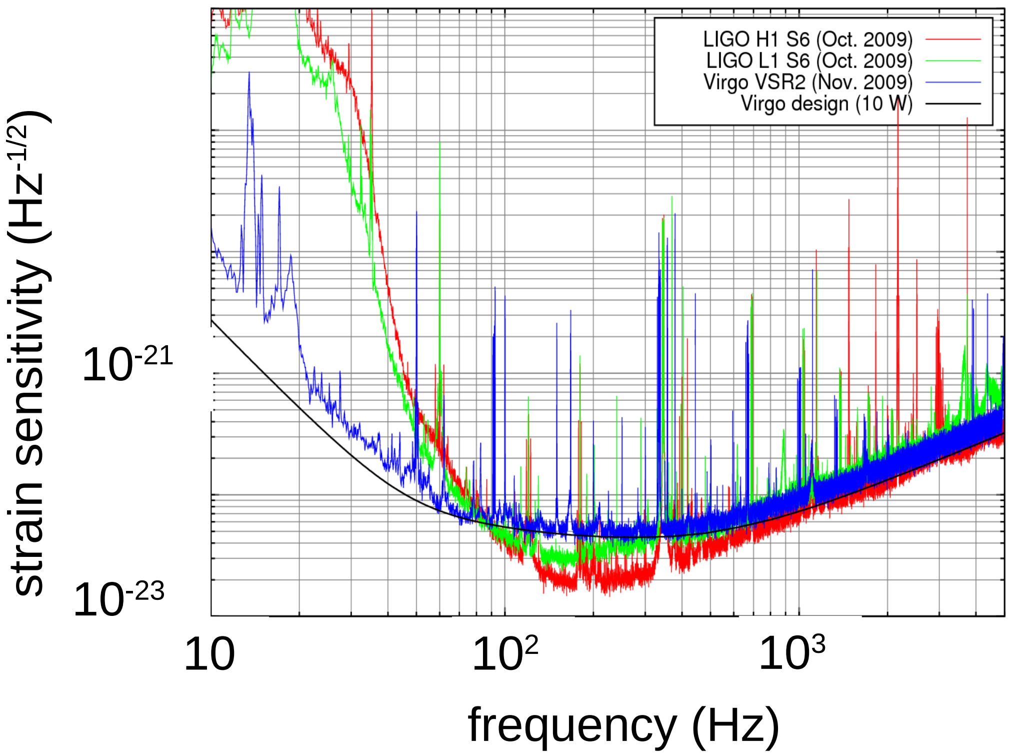
- Plan for public release **after first 4 detections**
- Two open calls for partnerships for early period
  - Signed agreements with **75 groups worldwide**
  - ~500 astronomers, 150 instruments, 10 space observatories
  - From radio to gamma-rays
- French involvement
  - TAROT et al. (Obs Nice), FIGARO, SVOM, nenuFAR
  - European coordination to access ESO instruments (VLT)

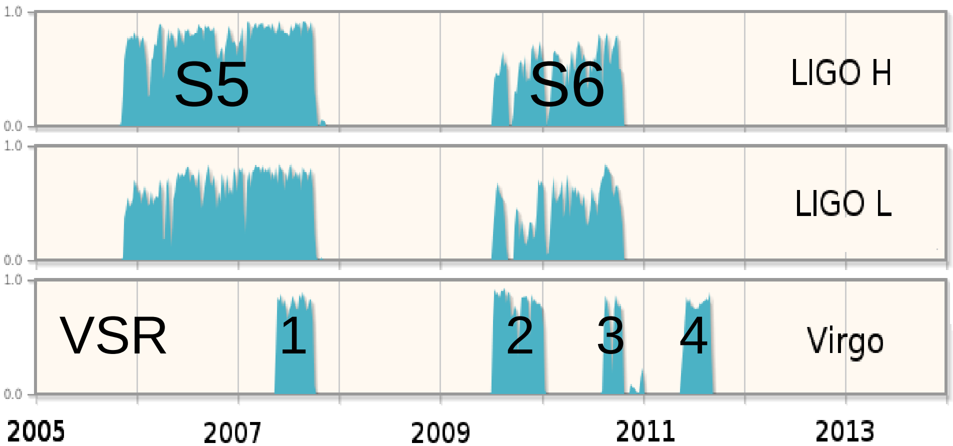
Science potential

- Clear **synergy with high-energy astrophysics**
- Potential impact on GRB physics
  - Demonstrate Short GRB vs BNS/BH-NS association
  - Beaming (ratio of GW events observed vs non-observed in γ-rays)
- Longer term: Cosmography with “standard sirens”?
  - Measure D_L with 1-10 % accuracy from GW – no cosmological ladder!
  - Get z from host identification or from γ-ray spectrum
  - Deduce H_0 to 10-30 % level with O(10) SHB

Science from 1st generation 2005-11

Reached design sensitivity!





3 joint LIGO – Virgo science runs

~2 yrs total

"horizon" = detection range of coalescing binaries of neutron stars (BNS)

LIGO ~ 40 Mpc and Virgo ~ 20 Mpc

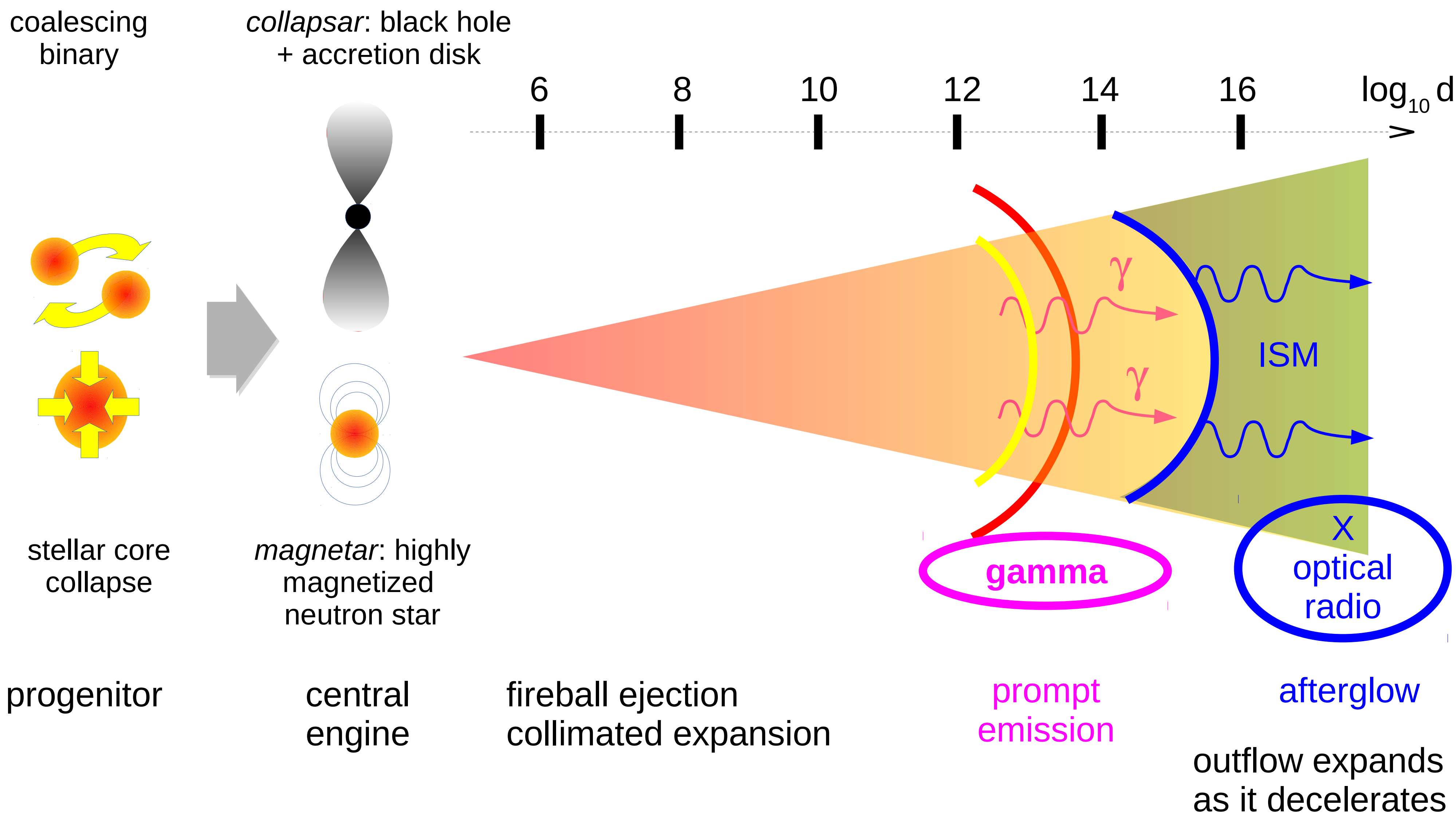
40 papers published and more to come

Transient sources (BNS, BBH and bursts; in connection with astrophysical triggers, e.g., GRB or neutrinos)

Continuous sources (pulsars)

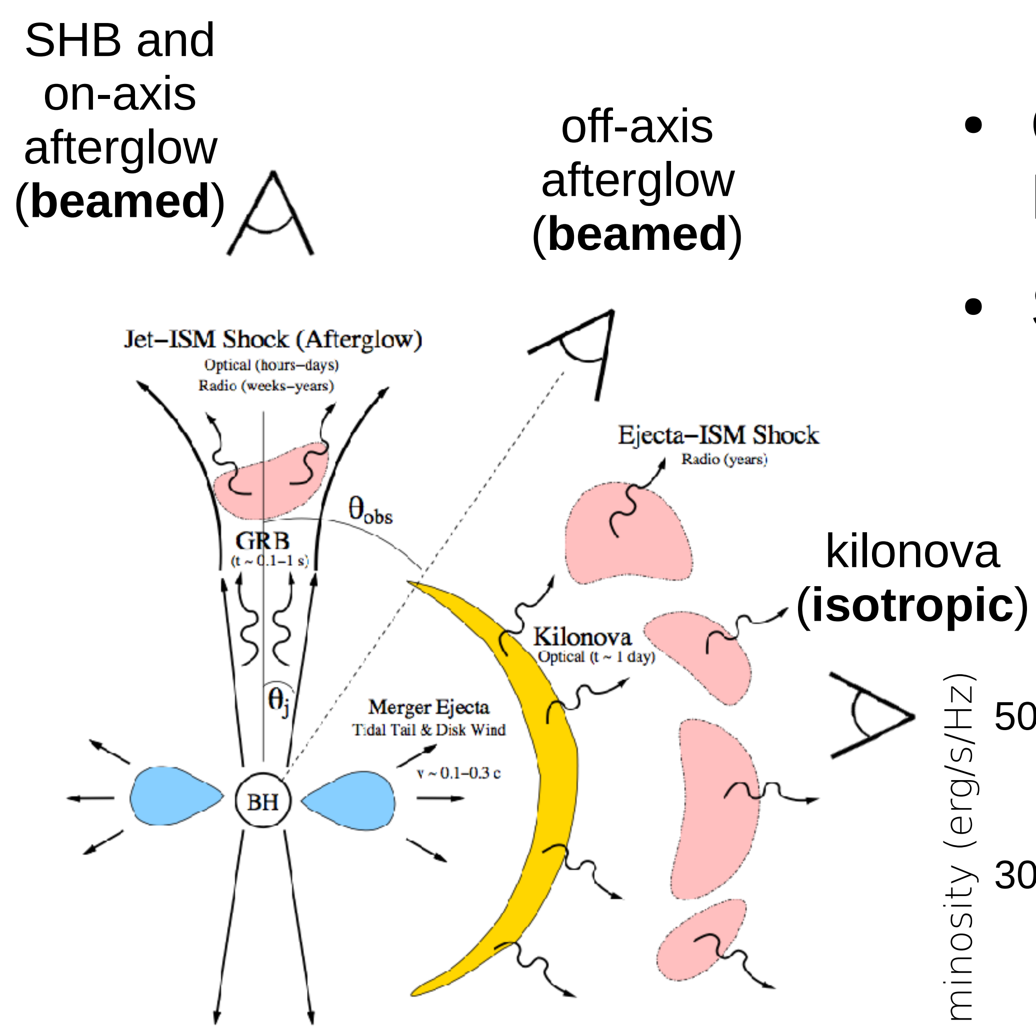
Stochastic background

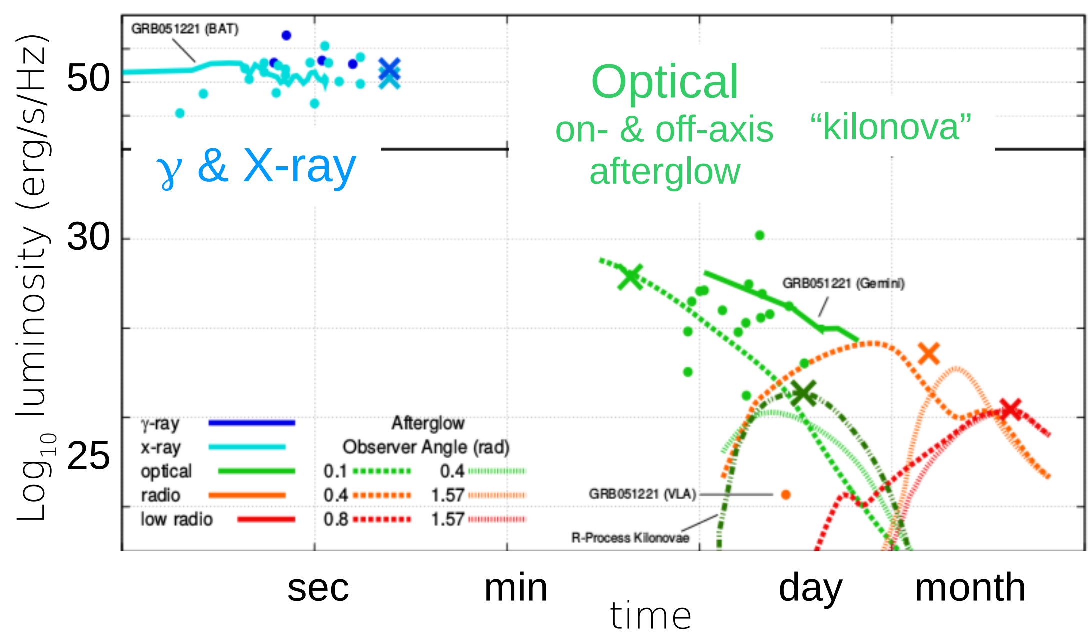
Gamma-ray bursts



EM counterparts to GW

- GW sources are likely sources of EM radiation as well
- Short gamma-ray bursts (SHB)
  - ✓ Potentially connected to BNS or BH-NS mergers





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