Multimessenger observations outlook

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The messengers

- Electromagnetic waves- photons
- Gravitational waves
- Cosmic rays
  - Neutrinos
  - Protons, nuclei
  - Electrons, positrons

The Sun

The first multimessenger source:

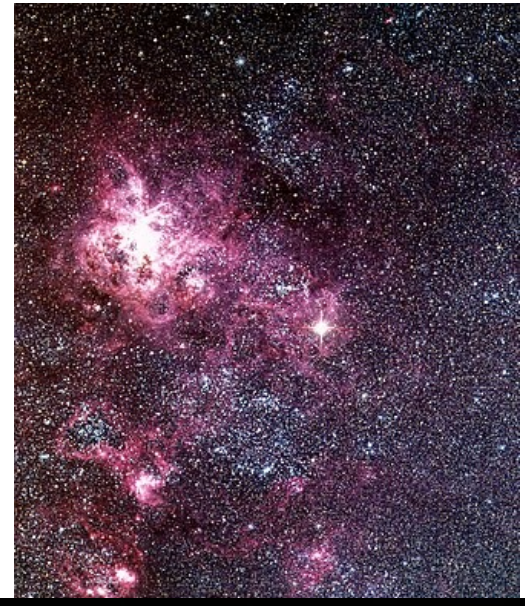
- light

- neutrinos

- solar wind

Other stars?

Supernovae



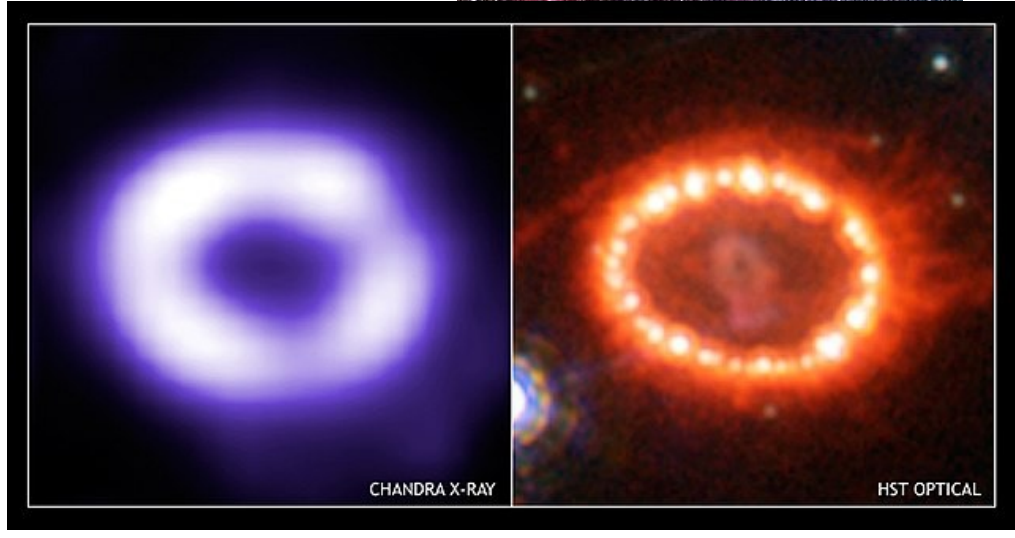
SN1987A
- light
- neutrinos

Search for GWs from nearby supernovae - LVK triggered search

So far only upper limits

Low rates within sensitivity radius

See talks by di Palma and by Szczepanczyk.

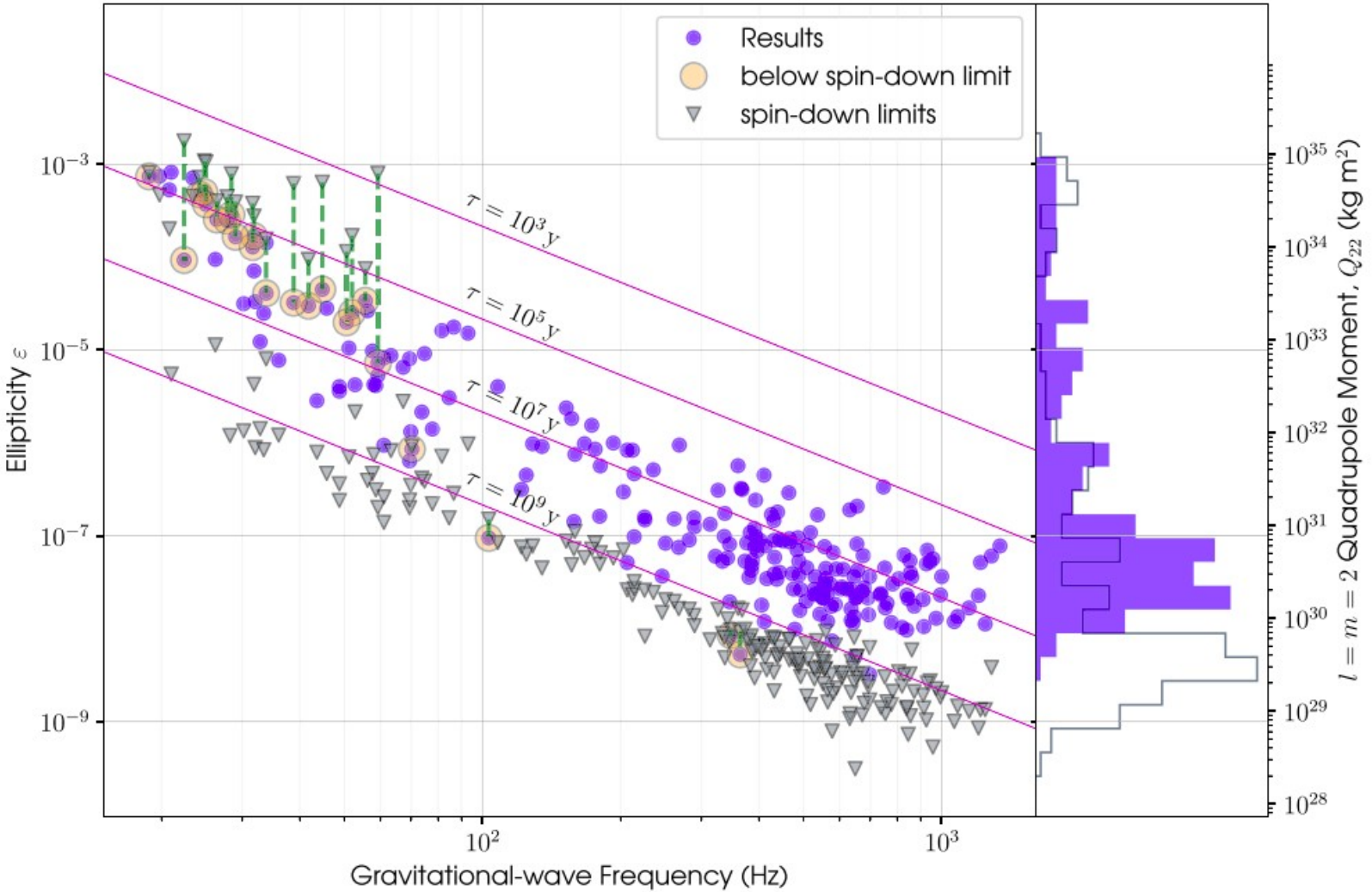


Pulsars

- EM sources - from radio to HE

- known particle acceleration sources but no direct detection of high energy particles

- GW searches, limits on eccentricity

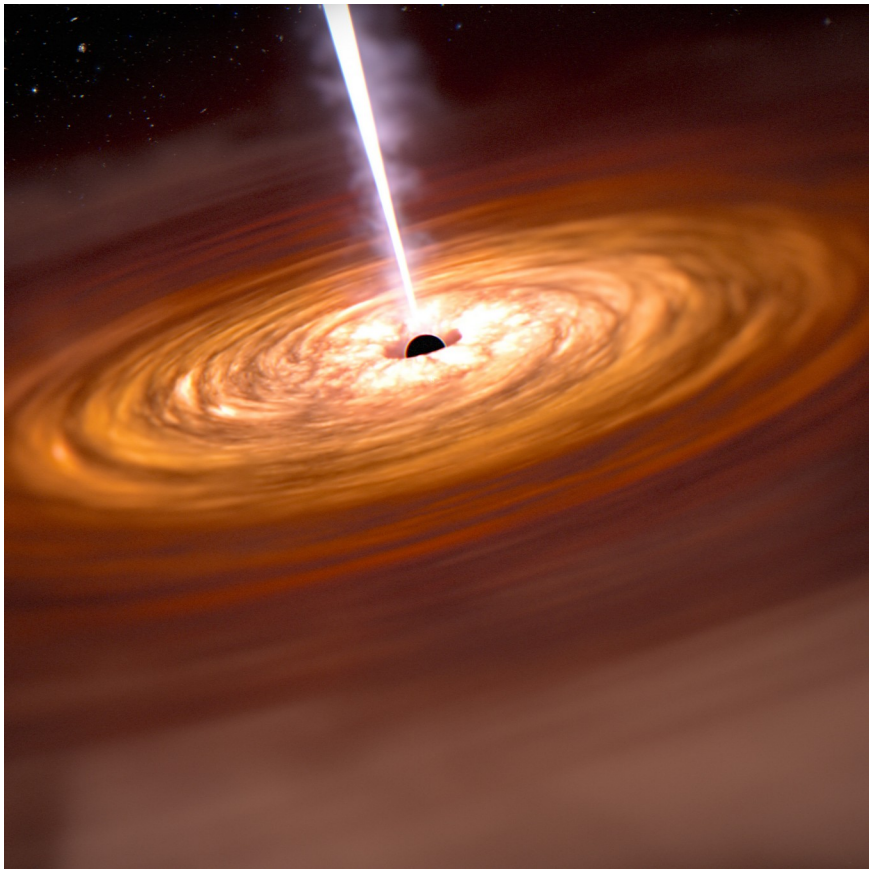

Results
below spin-down limit
spin-down limits
$\tau = 10^3$ y
$\tau = 10^5$ y
$\tau = 10^7$ y
$\tau = 10^9$ y
Ellipticity ε
10^{-3}
10^{-5}
10^{-7}
10^{-9}
10^2
10^3
Gravitational-wave Frequency (Hz)
$l = m = 2$ Quadrupole Moment, Q_{22} (kg m^2)
10^{35}
10^{34}
10^{33}
10^{32}
10^{31}
10^{30}
10^{29}
10^{28}

AGNs, massive BH

- very intense EM radiation

- evidence for neutrinos (talk by Bellenghi)

- GWs ? Possible from catching other objects, stars, BH:
    Extreme mass ratio inspirals, (LISA)
    Mergers (LISA, PTA)



BNS mergers

GW170817

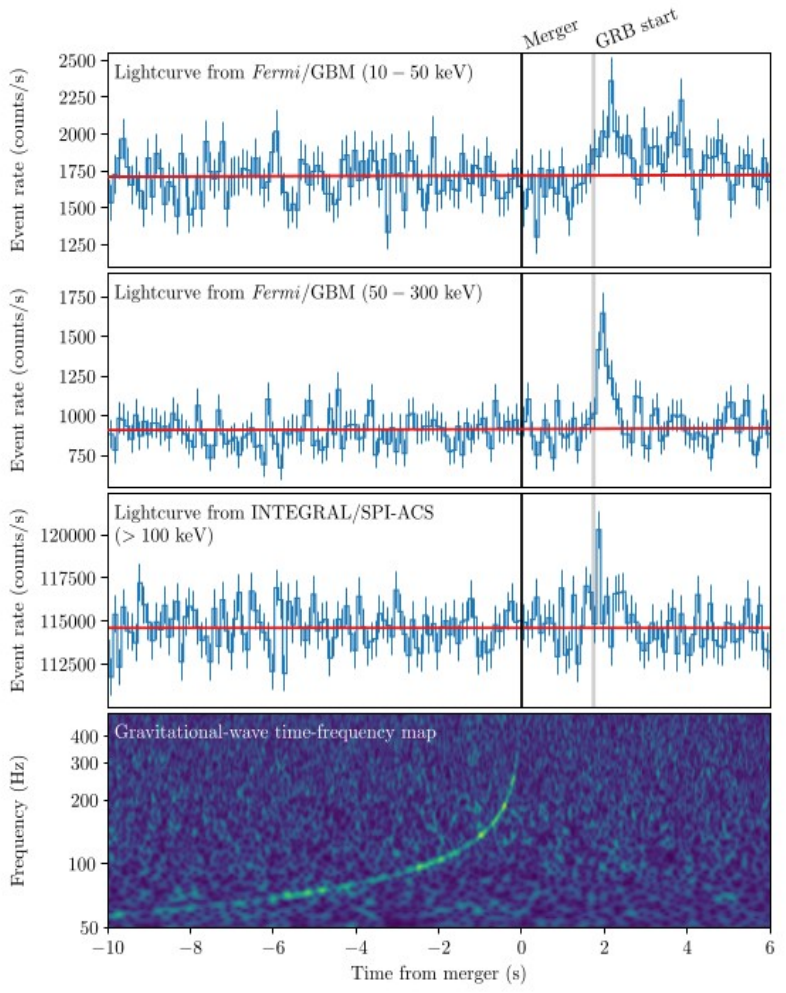
GW trigger

- Gamma ray burst

- optical counterpart, afterglow, kilonova

Search continues….

A case for CRs and neutrinos



UHECRs – the evidence

- Spectrum must extend to 100s EeV
- Composition – no protons, heavy nuclei
- Luminosity- ~6×10^{44} erg/Mpc^3/yr
- Anisotropy - dipole
- Small scale anisotropy – sources? Centaurus cluster?

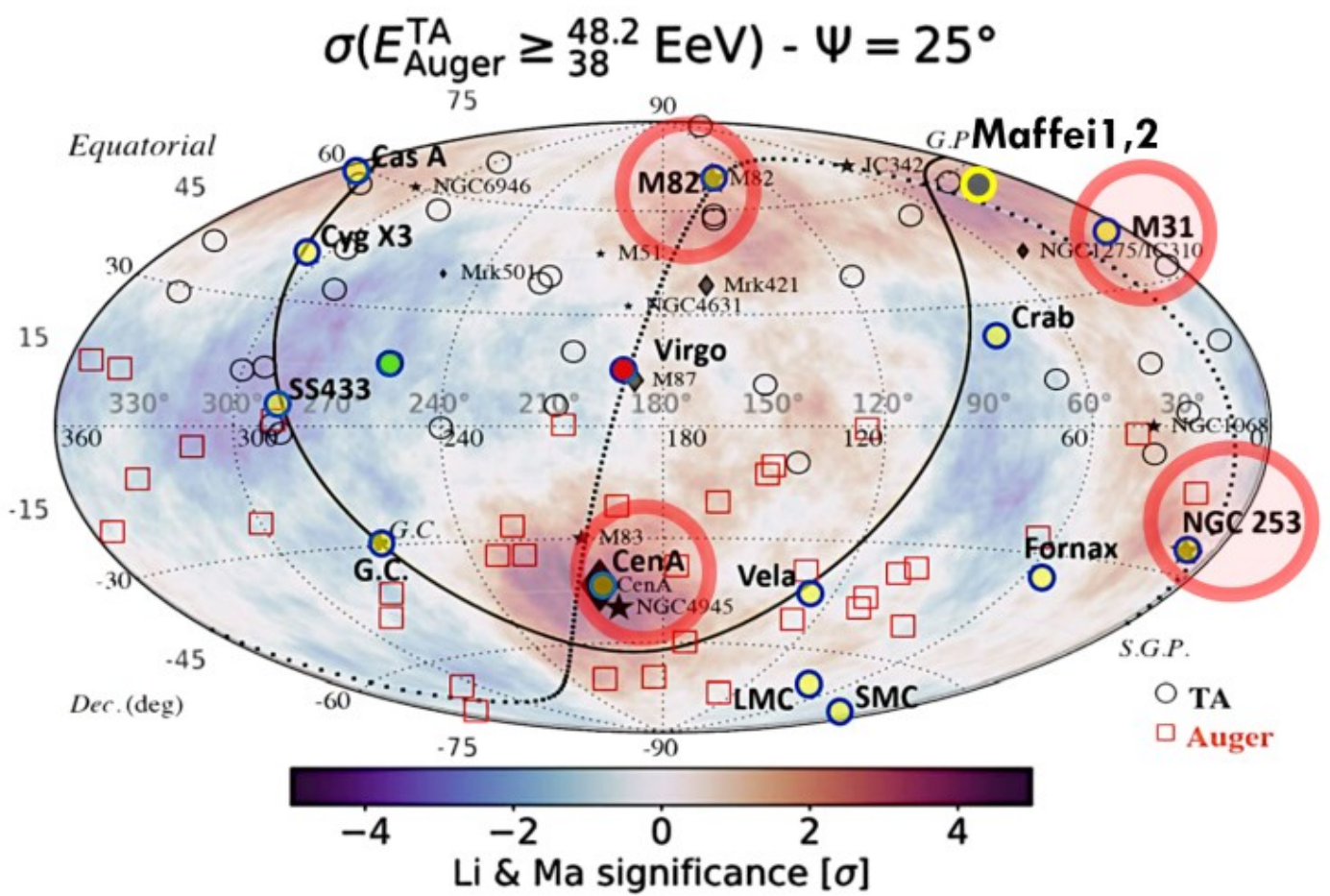


Figure 6. The arrival directions of the most recently reported UHECR above 100 EeV measured by Auger and TA, together with nearby astronomical source candidates in Hammer Celestial coordinates.

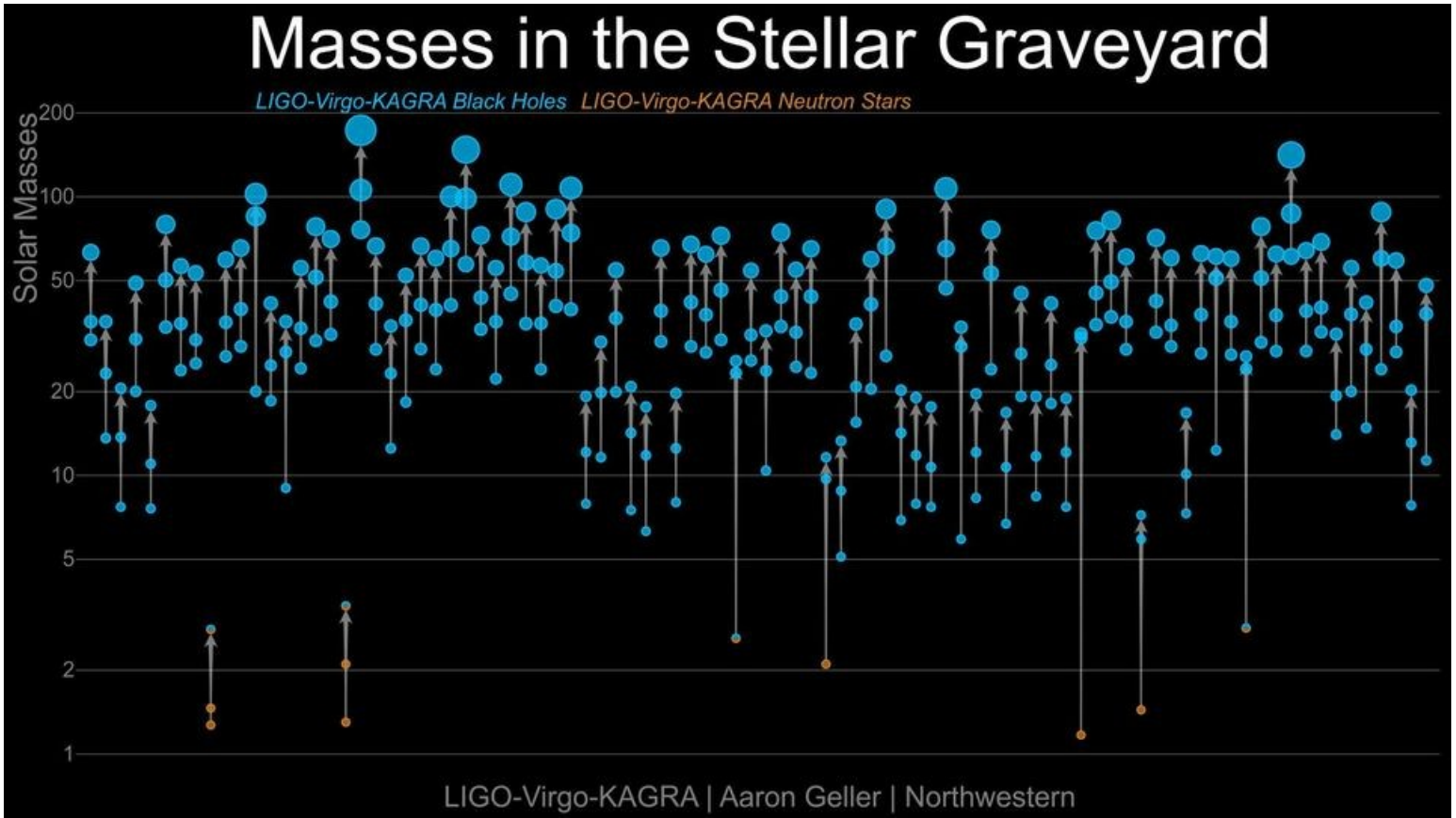
Fargione et al 2024

Possible origin – the guilty

- Black holes
  - Big – accretion in all flavors
  - Small – Long GRBs, hypernovae
- Neutron stars:
  - Single - magnetars
  - **Binary – mergers, short GRBs**
- Shocks in large outflows

GW sources – a suspect?

- What do we know?
  - BBH
  - BHNS
  - BNS



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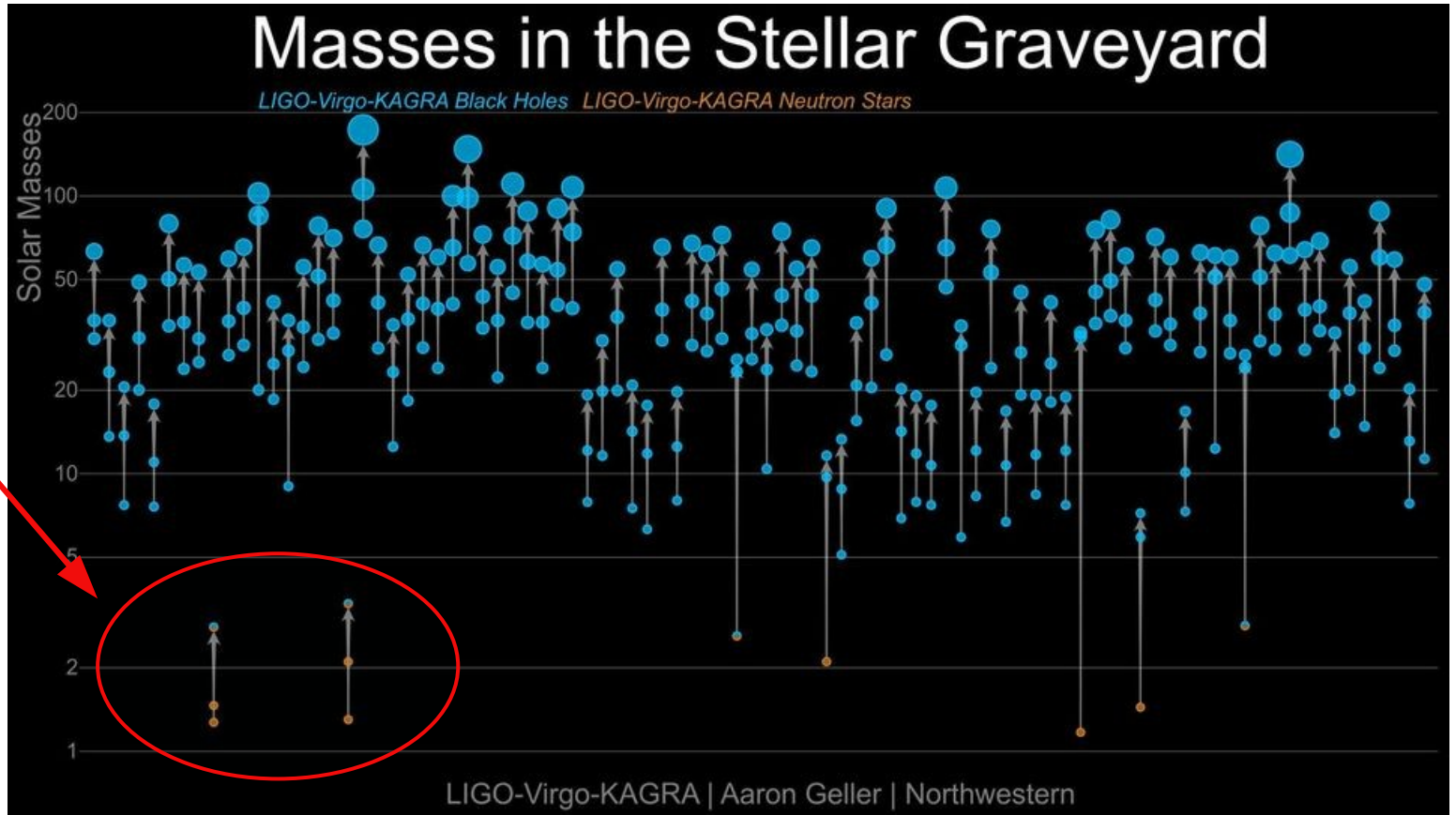


The merger rate densities

- BBH estimate $R = 17.9 - 44 \mathrm{Gpc}^{-3}\mathrm{yr}^{-1}$
- BNS estimate $R = 10 - 1700 \mathrm{Gpc}^{-3}\mathrm{yr}^{-1}$
- BHNS estimate $R = 7.8 - 140 \mathrm{Gpc}^{-3}\mathrm{yr}^{-1}$
- The local supernova rate ~ $10^5 \mathrm{Gpc}^{-3}\mathrm{yr}^{-1}$
- The BH formation rate is ~ $10^4 \mathrm{Gpc}^{-3}\mathrm{yr}^{-1}$

Energetics of BNS GW sources

Luminosities:

- GW: Each BNS merger emits $0.1Mc^2 \approx 2 \times 10^{54}\mathrm{erg}$

$$Q_{inj}^{GW} \approx 2 \times 10^{45} - 4 \times 10^{47}\mathrm{erg\ yr^{-1}Mpc^{-3}}$$

- Kinetic energy only $10^{51-52}\mathrm{erg}$

$$Q_{inj}^{kinetic} \approx 2 \times 10^{43} - 4 \times 10^{45}\mathrm{erg\ yr^{-1}Mpc^{-3}}$$

BNS - energetics

- Energy injection in CRs from BNS mergers – 10% of jet energy

$$Q_{inj}^{kinetic} \approx 2 \times 10^{42} - 4 \times 10^{44} \mathrm{erg\ yr^{-1} Mpc^{-3}}$$

  or more if more kinetic energy…

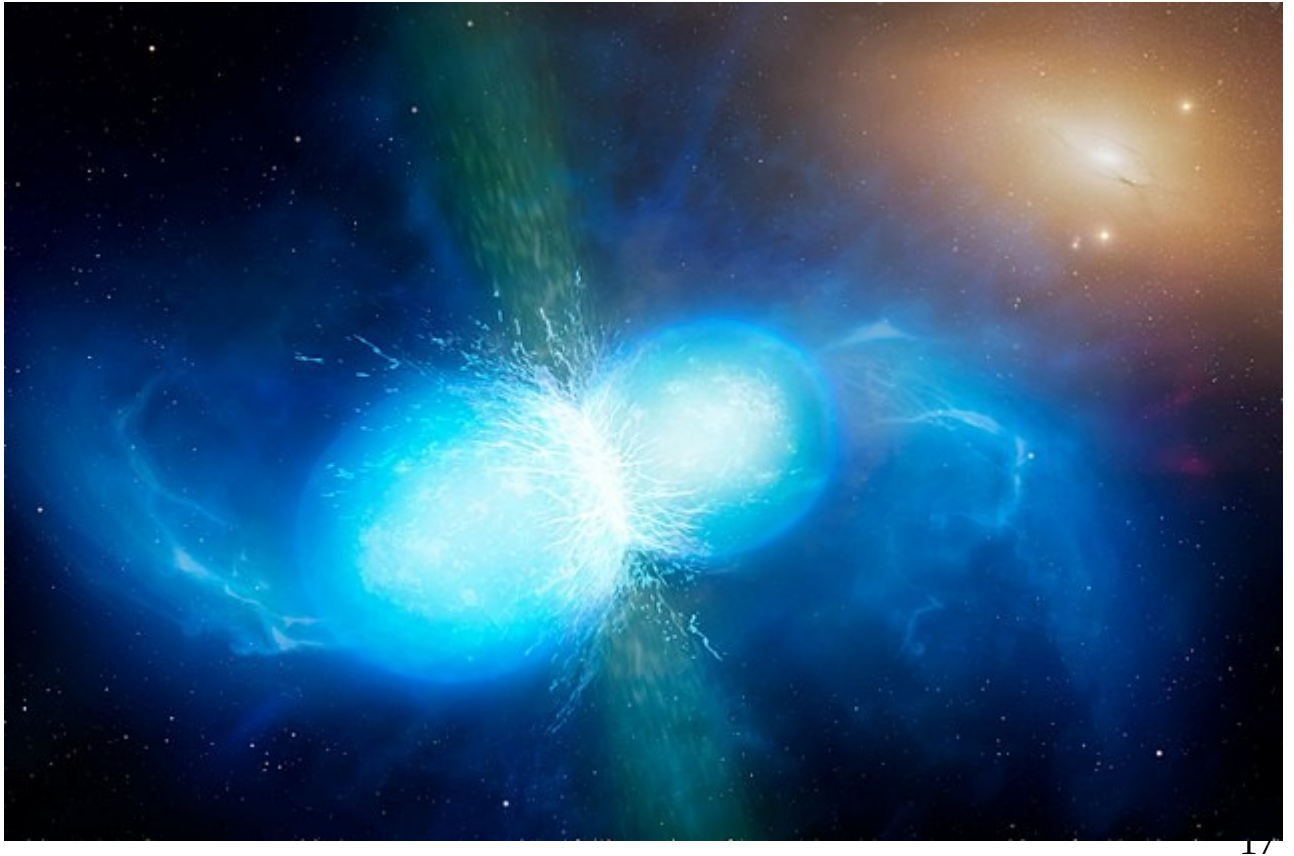
- Compatible with UHECR needs energetic requirement

BNS – kilonovae

Lots of heavy material

Ample source of heavy nuclei

Likely little or no hydrogen



BNS mergers

- Known to make GRBs
- Relativistic outflows

  Many models of particle acceleration in jets
- Collision of magnetospheres

Merging BNS – how to make them?

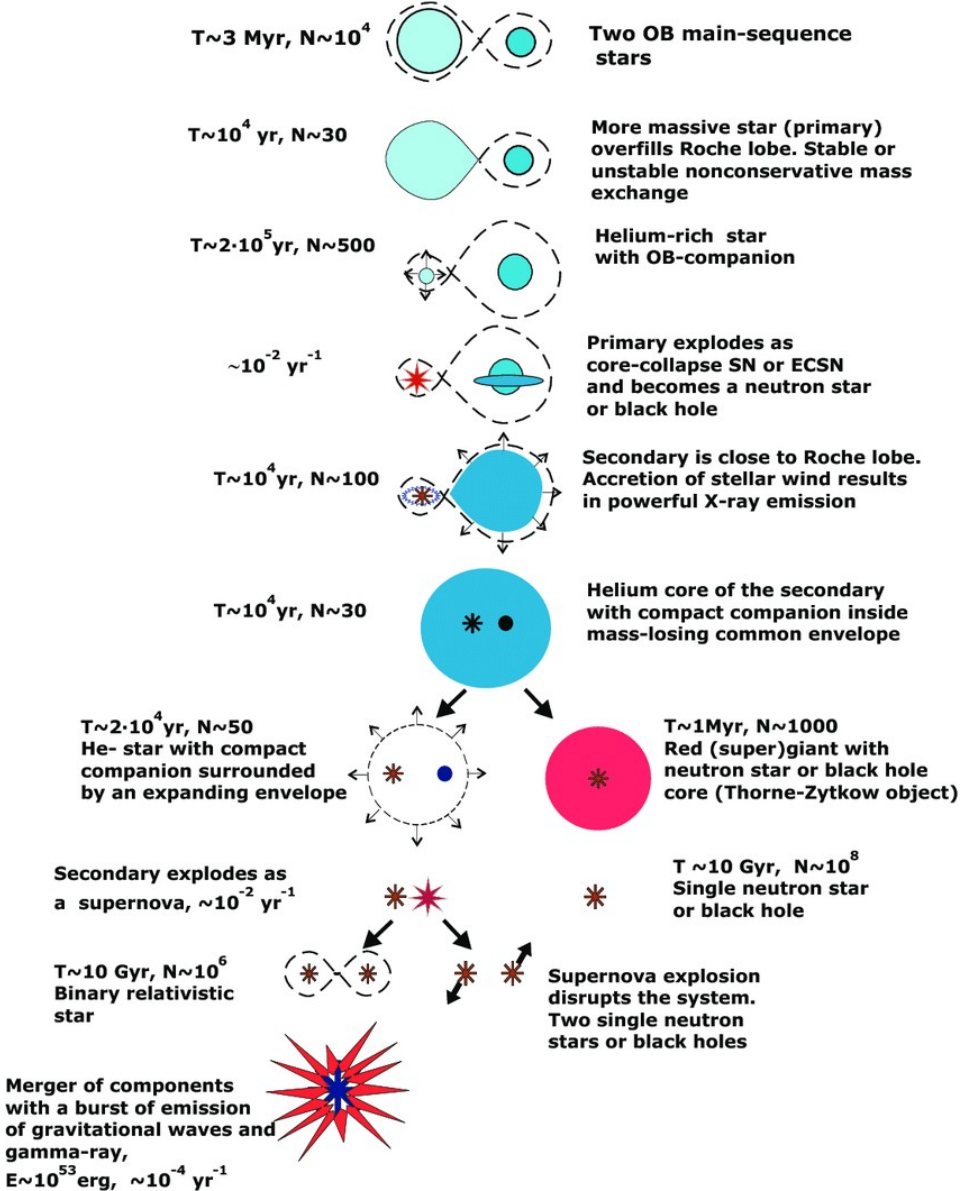
Binary evolution in field

- population compatible with Galactic binary pulsars

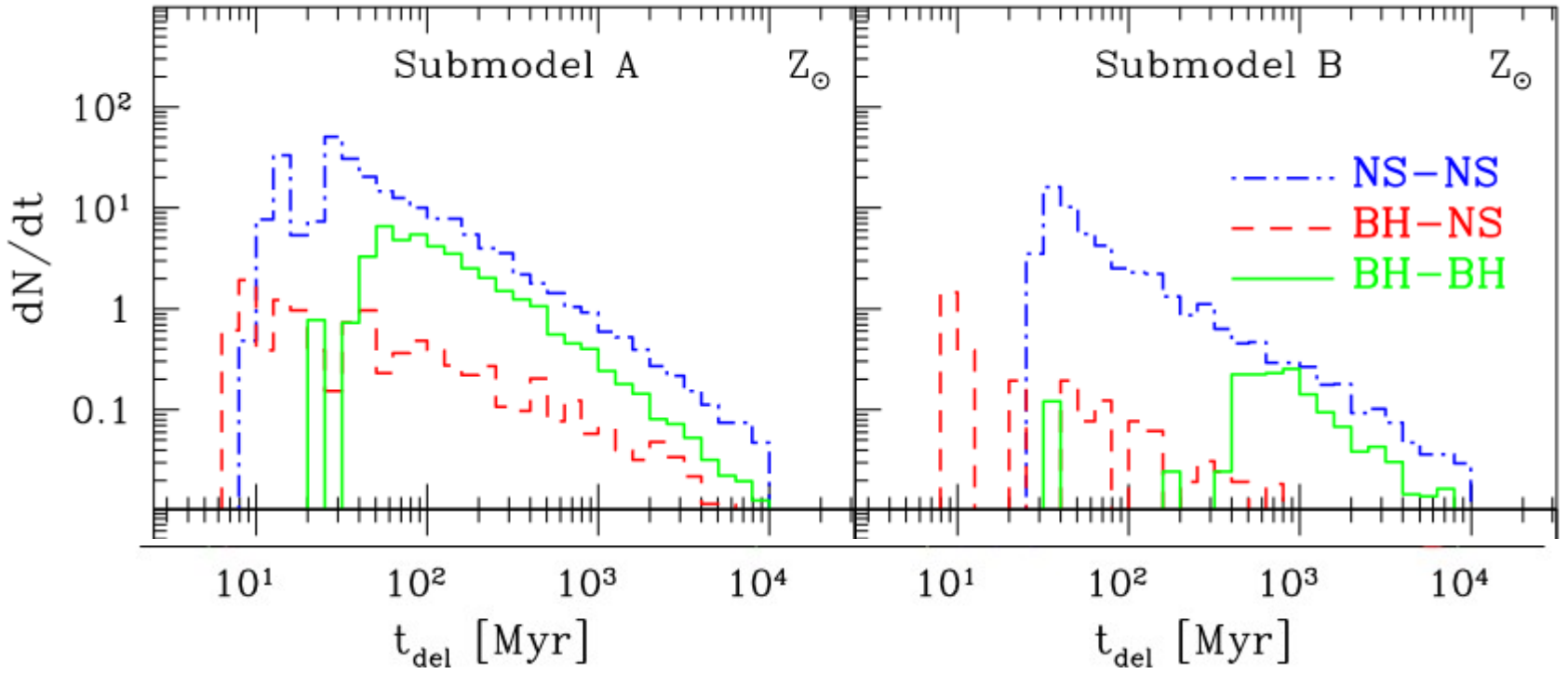
Globular clusters

- more freedom
- less mass higher efficiency
- simiar propoerties

See talk by Askar.

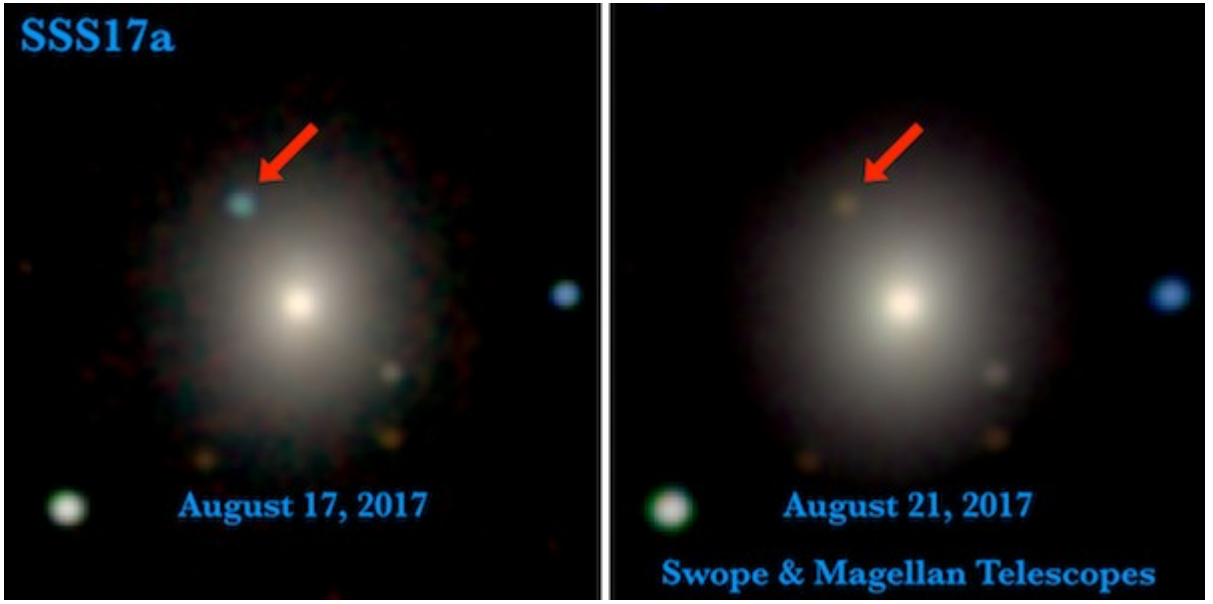


BNS delay to merger



Merger time peak 10-30Myrs after star formation – connection with starburst galaxies

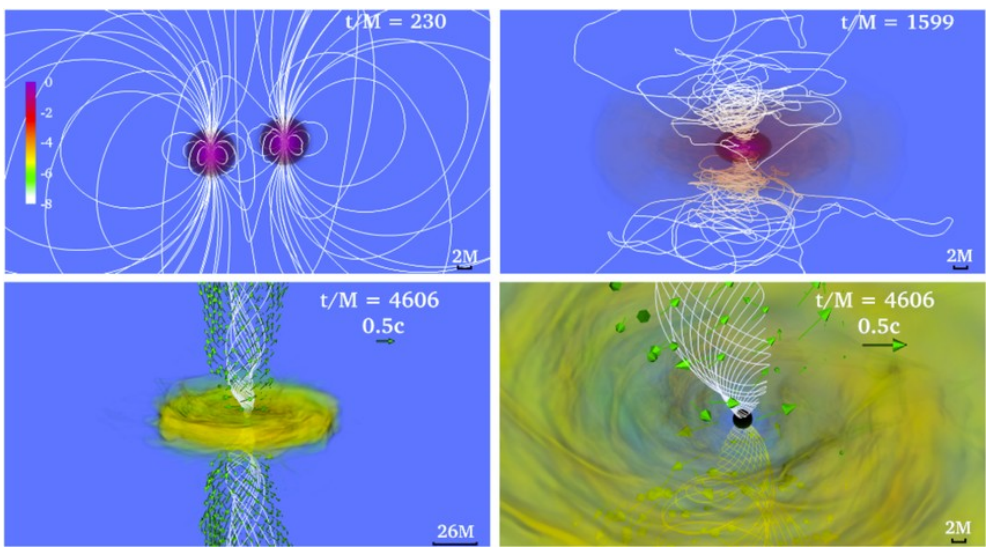
However, GW170817...



Host is an old elliptical galaxy with almost no star formation….a trace of a merger recently

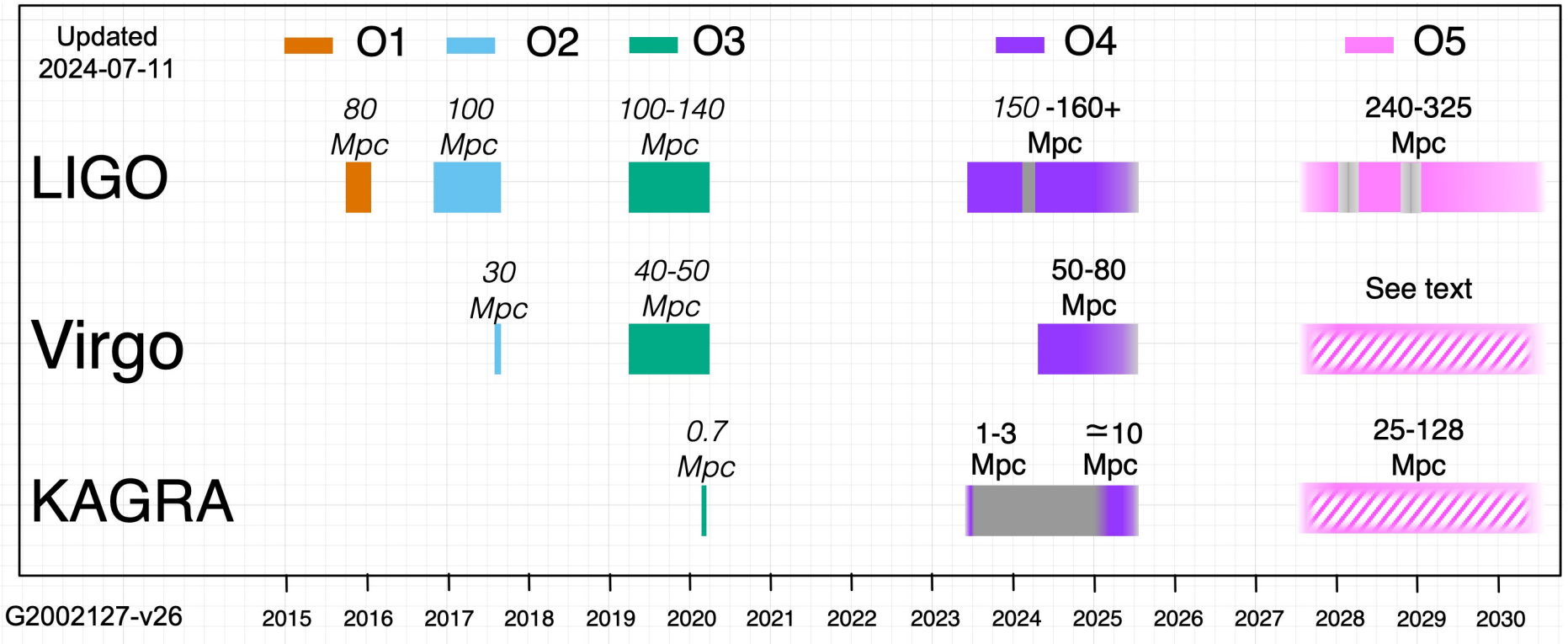
Short GRBs – in and out of galaxies – because of the delay tails

Some circumstantial evidence points towards the suspect



Ciolfi 2020

GW observations past and future



Expect more than 4 years of data taking with BNS range ~200Mpc

Number of BNS expected

Time Volume to be probed: 0.4-0.5 Gpc^3

Number of sources: 4 – 680 given the rate uncertainty in the rate

Typical distance: 140 Mpc, but if rate is large one may expect a close BNS down to 20Mpc

Still too far for UHECR! Delay too long…

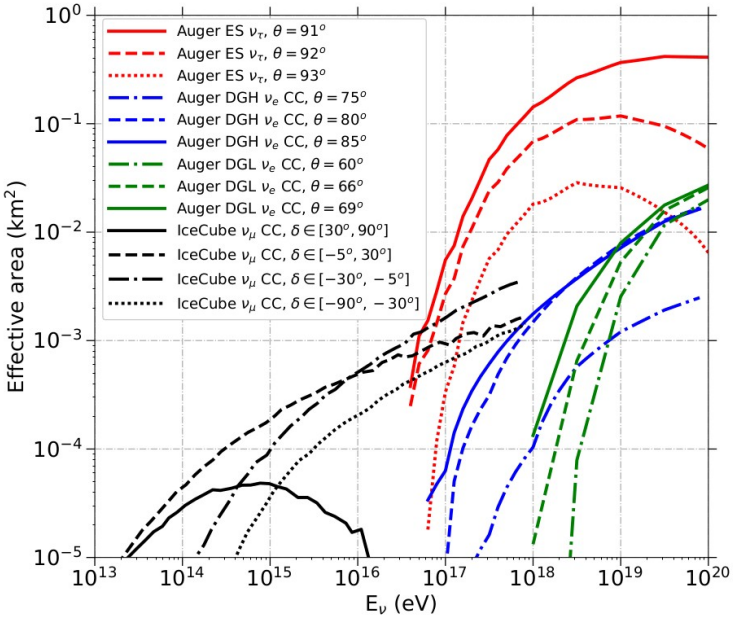
BUT…...

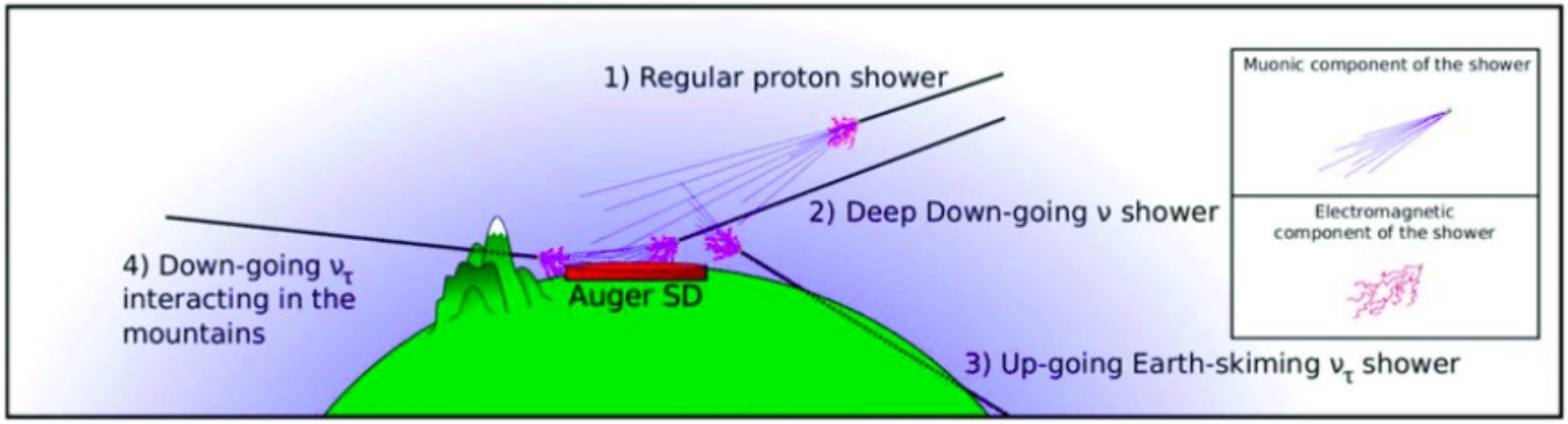
Another possibility - neutrinos

- Acceleration of cosmic rays in jets should be accompanied by neutrino production
- Neutrinos will move like photons, and exchange flavors
- UH neutrinos can be observed
  - Pierre Auger Observatory
  - GRANDE (talk by He)
  - Ice Cube (talk by Berwick)

PAO

PAO: FOV~ 0.6 sr
Expected # BNS mergers in the FOV: 0.2 -34 over O4 and O5.





Required neutrino luminosity

- Assume optimistically 20 Mpc
- Energy in neutrinos to detect one neutrino in PAO

$$E^{\nu} \approx 10^{47}\mathrm{erg}$$

- Efficiency of conversion to neutrinos needed

$$\frac{E^{\nu}}{E^{\mathrm{jet}}} > 10^{-4}$$

Can neutrinos be detected from BNS mergers?

- Arguments for BNS origin of UHECR:
  - Energetics, star forming galaxies, composition, physical mechanism
- Observational verification
  - Direct CR impossible
  - Neutrinos coincident with BHS mergers- viable in the next 10 years, if neutrinos produced effectively
- Require converting more than 10^{-4} of jet energy to neutrinos, and some luck.

Summary

- Multimessenger astronomy is on the rise – lots of questions:
- Will pulsars be seen in GWs?
- GWs from nearby supernovae?
- BNS mergers as sources UHECR and neutrinos?