Bologna, 2 November 2017

Kilonovae: A “Cosmic” Klondike
The Ultimate Gold Rush

Elena Pian

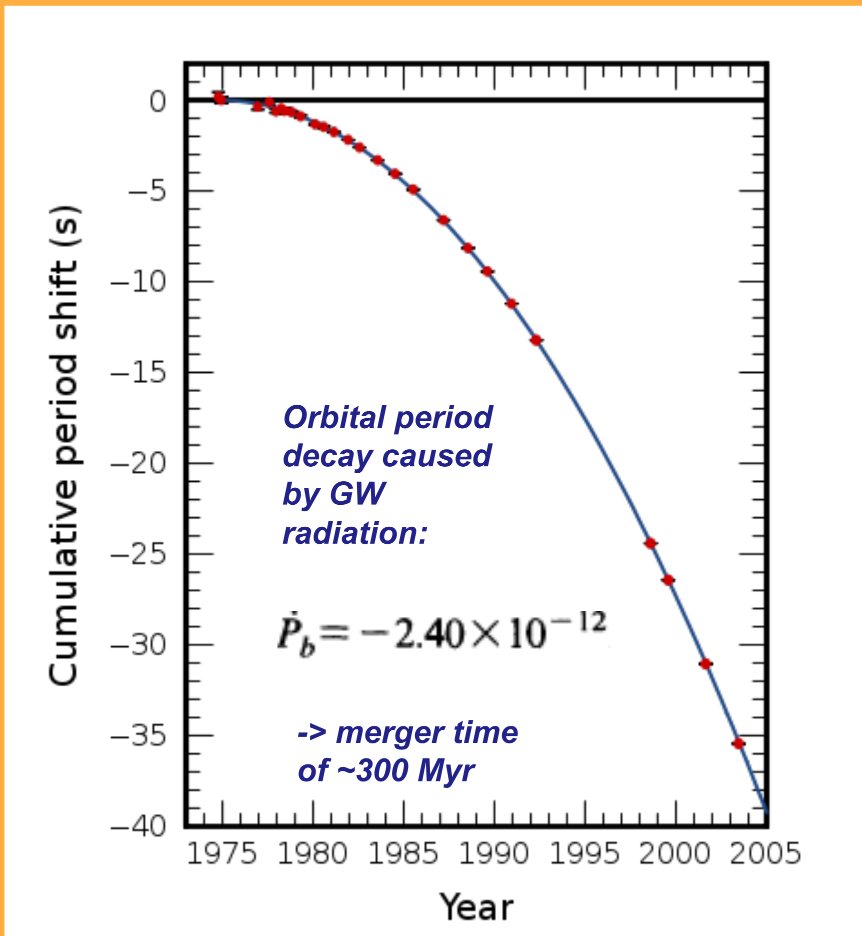
INAF - IASF Bologna, Italy

On behalf of a large collaboration

Binary compact star systems with merger times less than the age of the Universe

PSR1913+16

Orbital period = 7.75 hr



Orbital period decay caused by GW radiation:

$$\dot{P}_b = -2.40 \times 10^{-12}$$

-> merger time of ~300 Myr

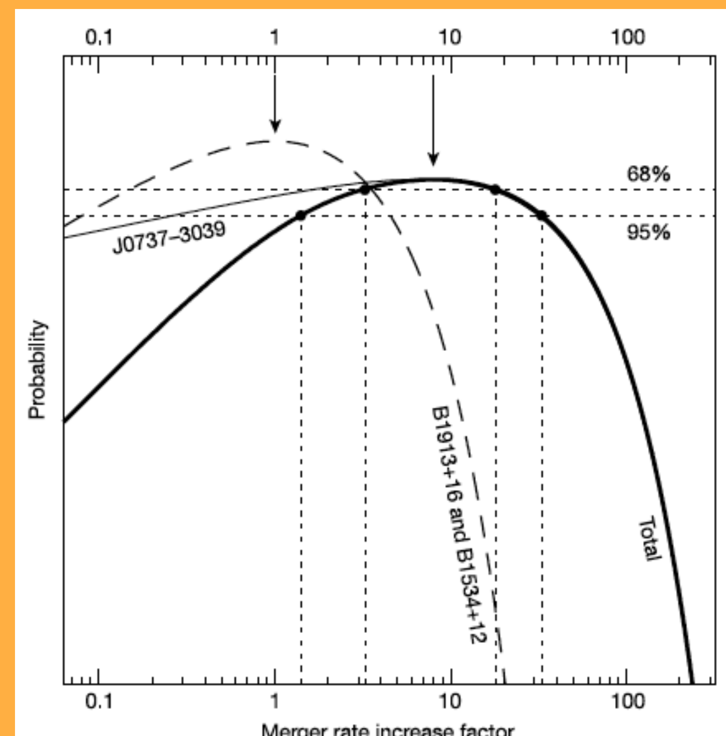
Hulse & Taylor 1975; Taylor & Weisberg 1982
NP 1993 to Hulse & Taylor

2003, Nat, 426, 531

An increased estimate of the merger rate of double neutron stars from observations of a highly relativistic system

M. Burgay[1], N. D'Amico[2,3], A. Possenti[3,4], R. N. Manchester[5], A. G. Lyne[6], B. C. Joshi[6,7], M. A. McLaughlin[6], M. Kramer[6], J. M. Sarkissian[5], F. Camilo[8], V. Kalogera[9], C. Kim[9] & D. R. Lorimer[6]

Binary PSR J0737-3039: merger time of ~85 Myr

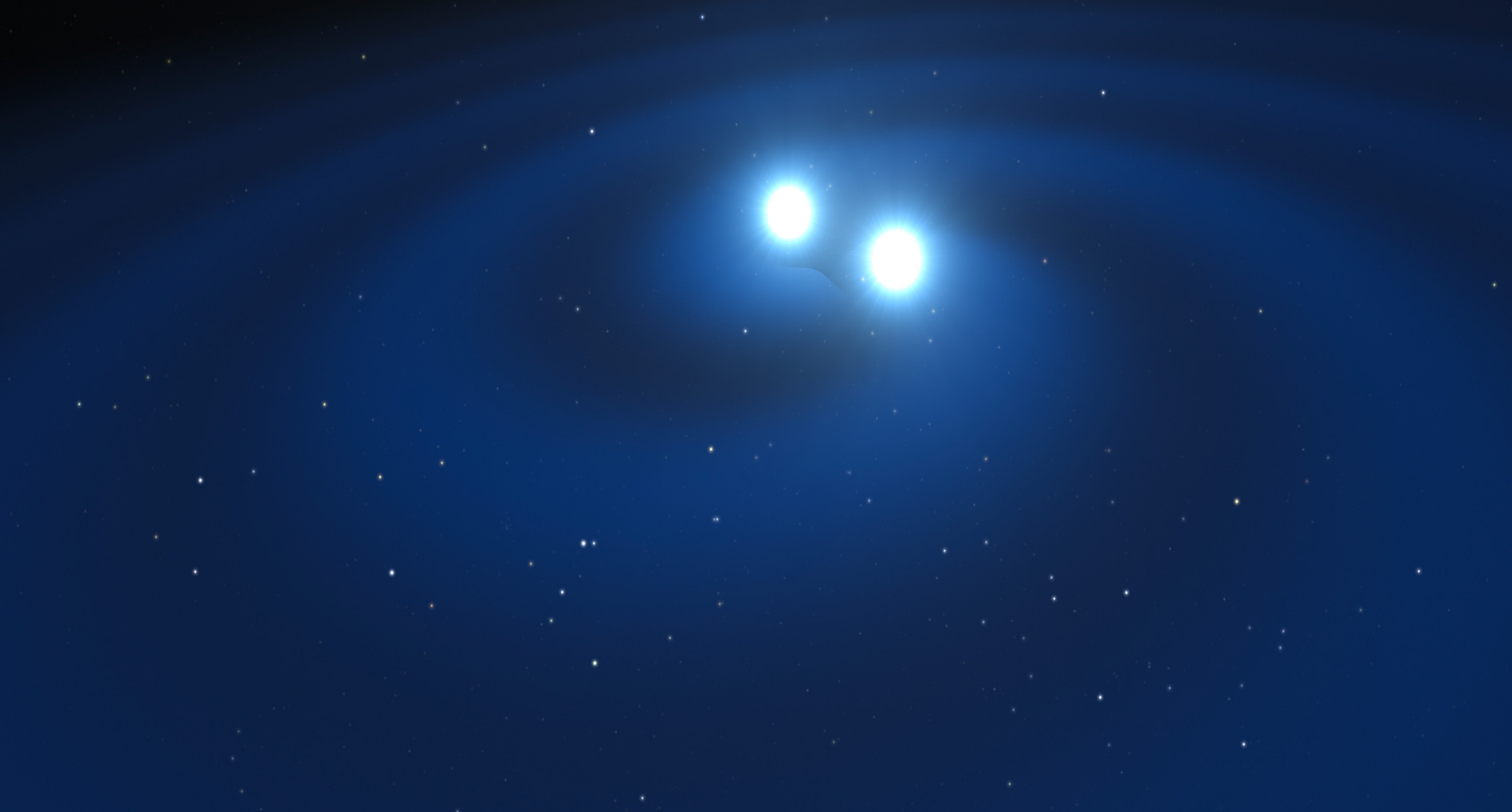


Double neutron star merger simulations by Computational relativistic astrophysics Groups (S. Rosswog, T. Janka, L. Rezzolla….)

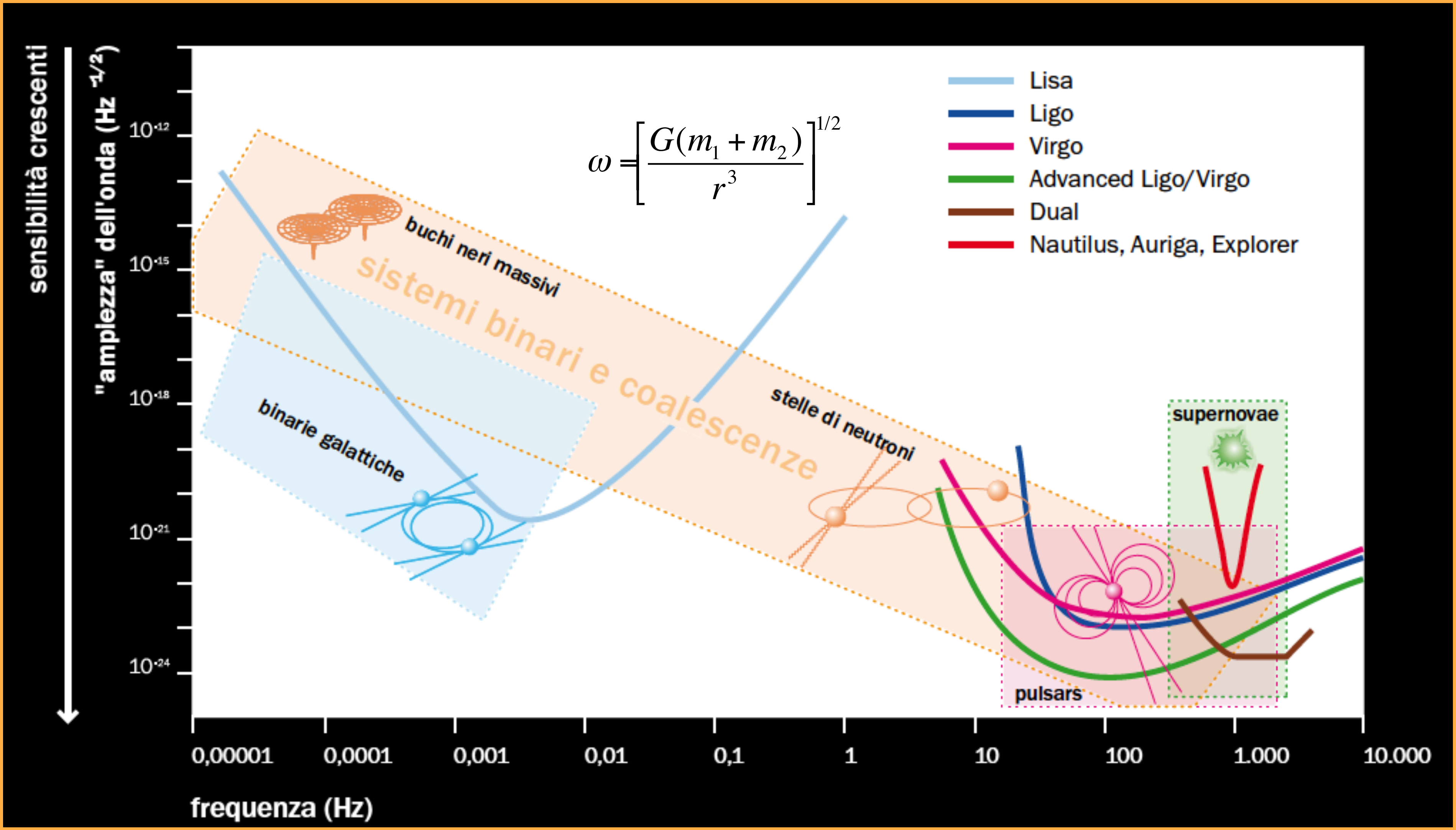
http://compact-merger.astro.su.se

A double neutron star merger is expected to produce:

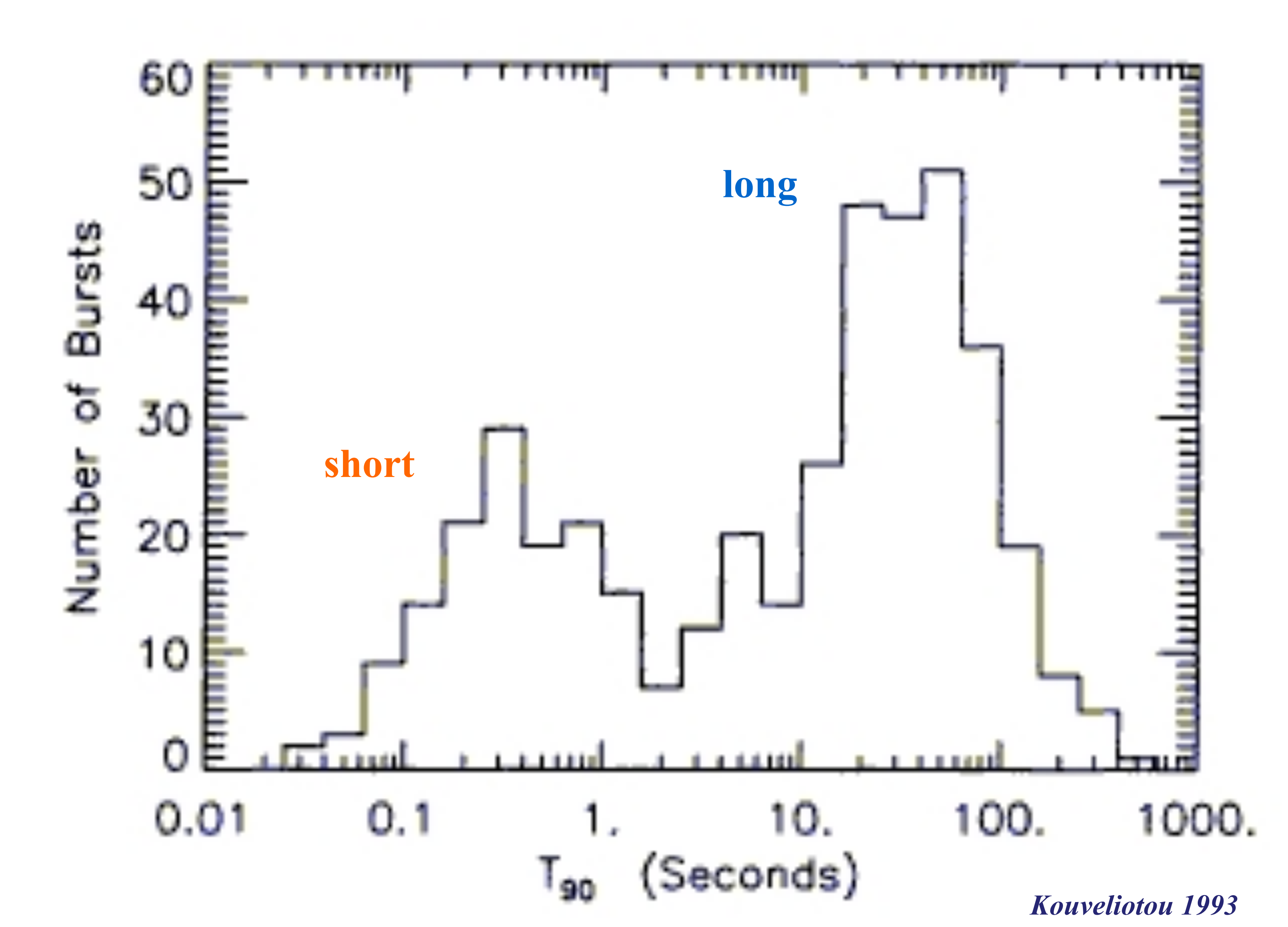
1) a GW signal at ~1-1000 Hz (nearly isotropic)
2) a short GRB (highly directional and anisotropic)
3) r-process nucleosynthesis (nearly isotropic)



GW amplitude-frequency diagram of known cosmic sources

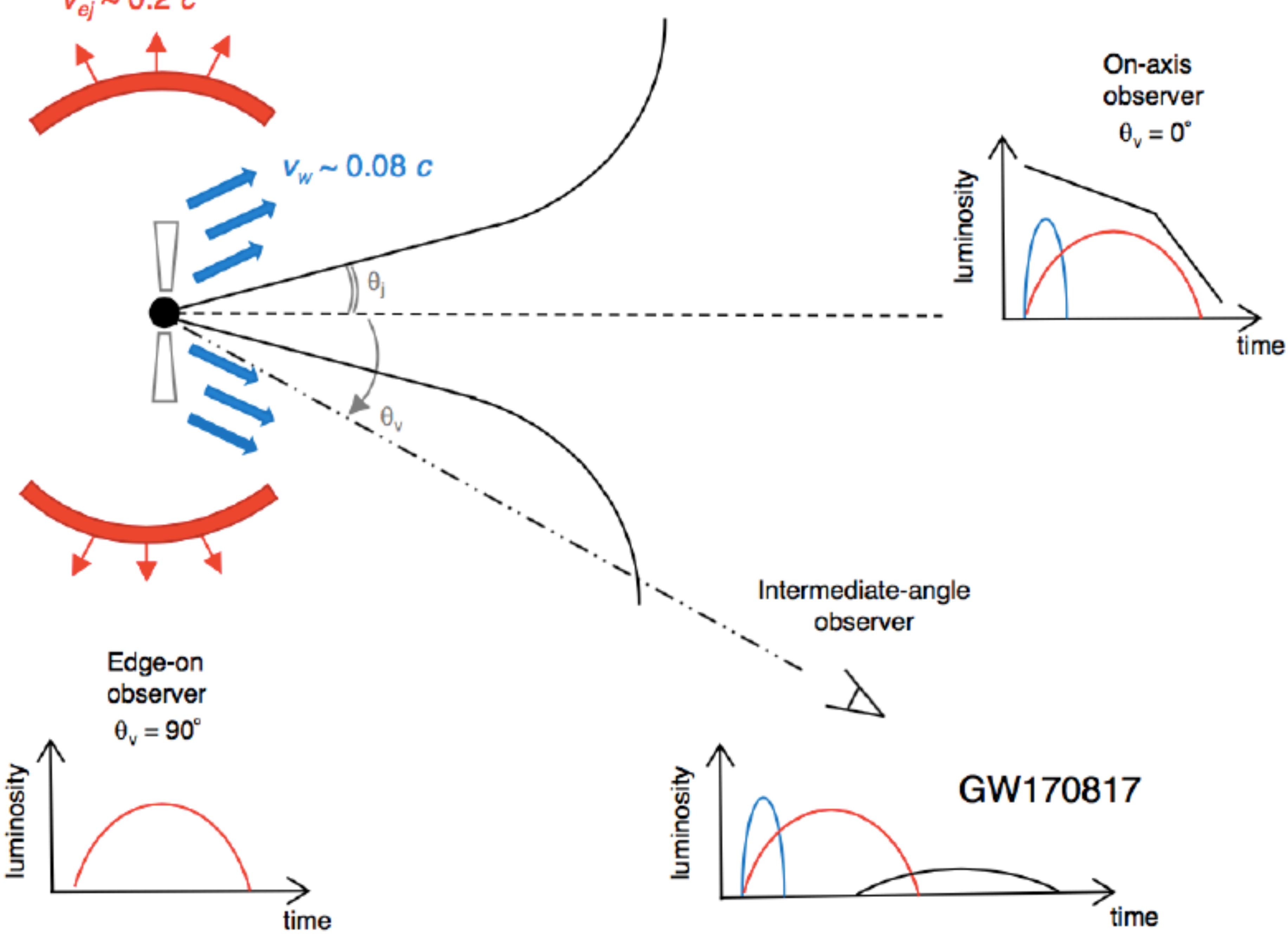


Bimodal distribution of GRB durations

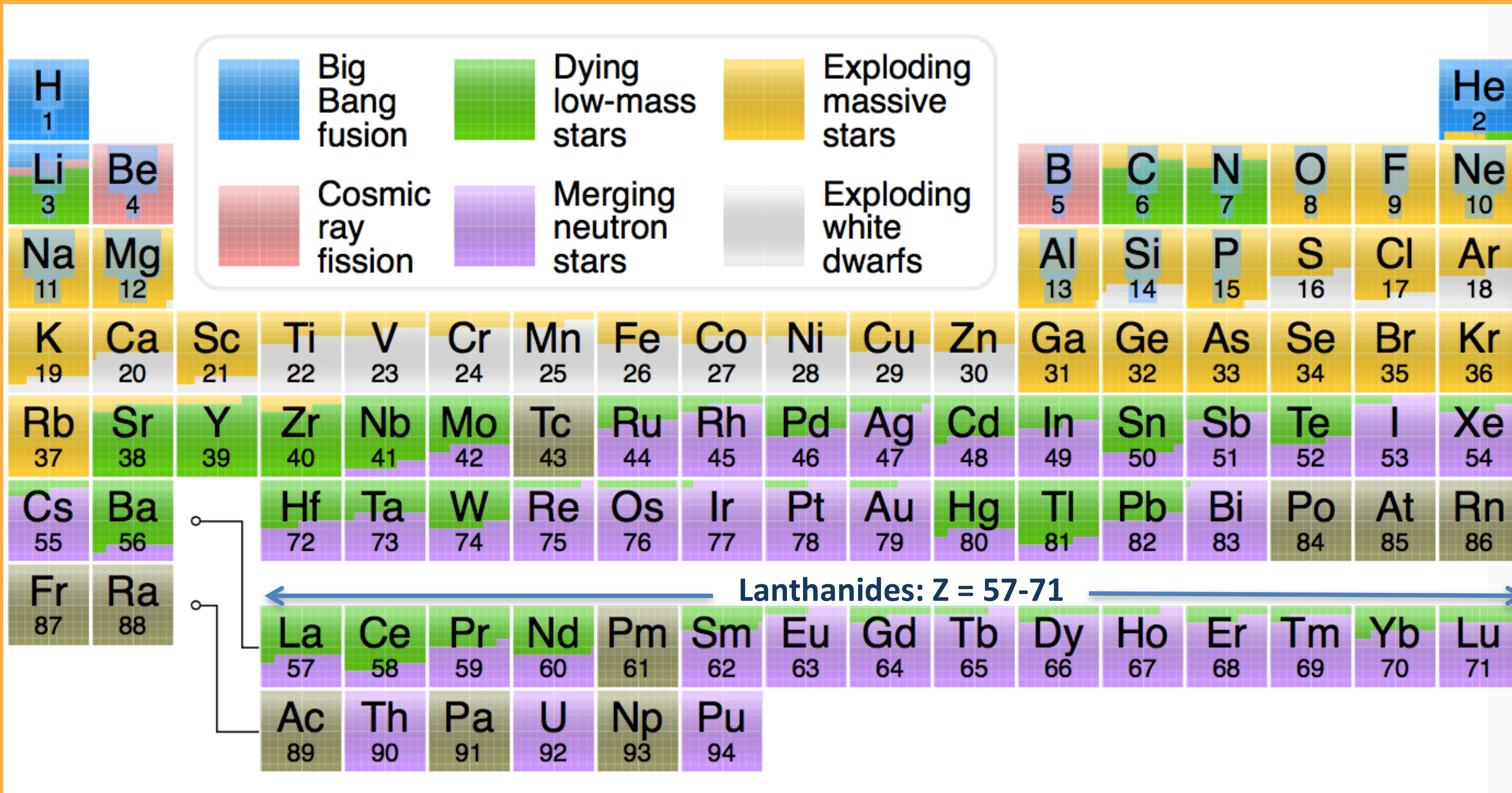


Geometry of GW/GRB/kilonova system

Troja et al. 2017



Periodic table of elements



https://en.wikipedia.org/wiki/R-process

Short GRB130603B
(z = 0.356)

<u>Kilonova</u>:

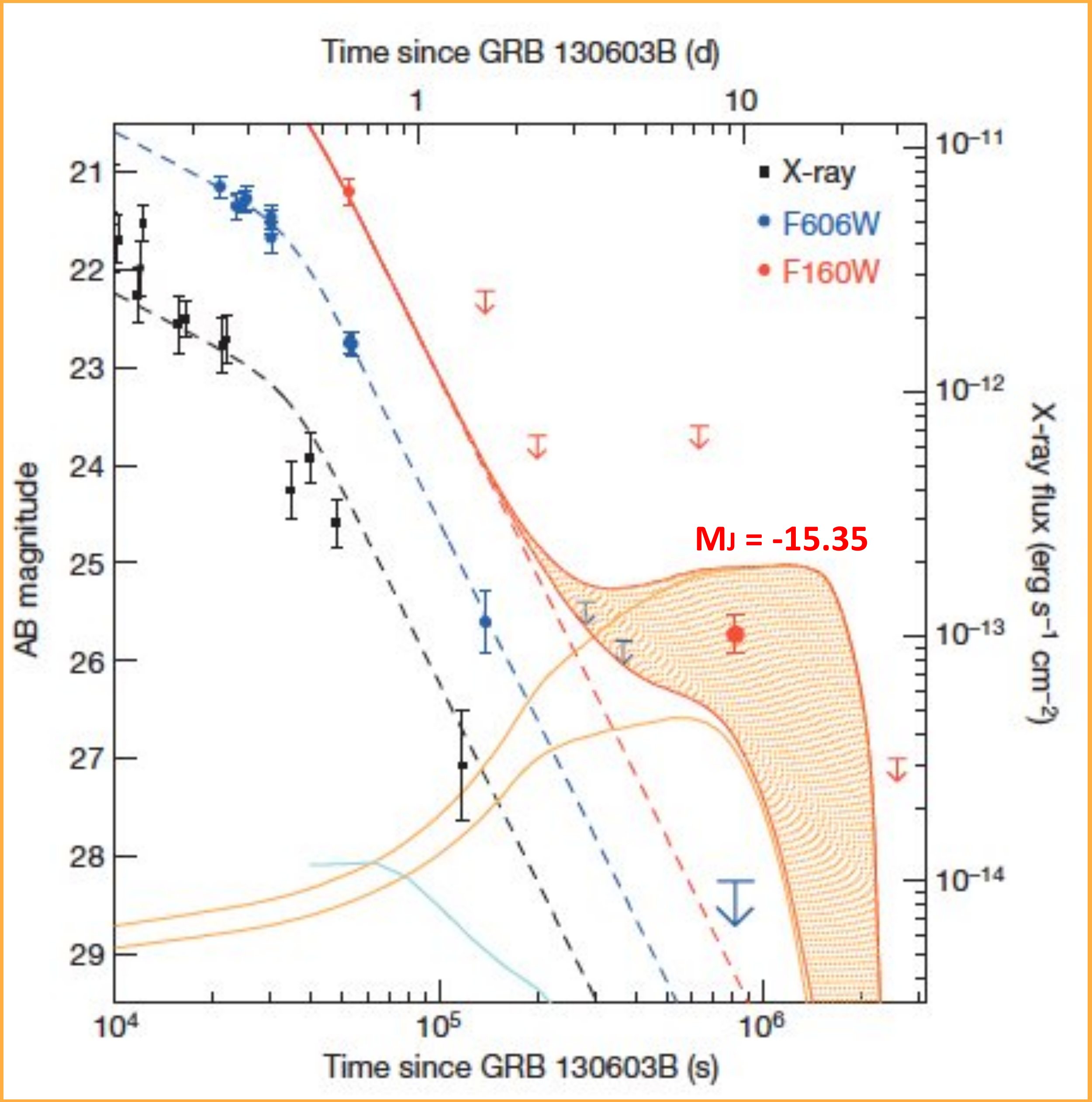
Ejection of r-process material from a NS merger (0.01-0.1 Mo) (Barnes & Kasen 2013)

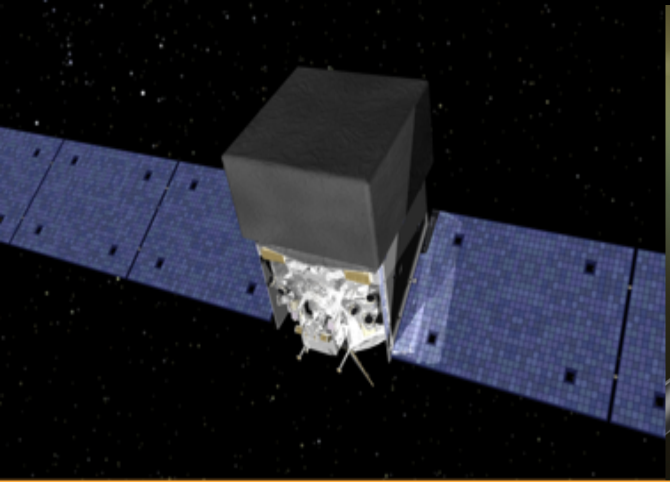
$M_H \approx -15$

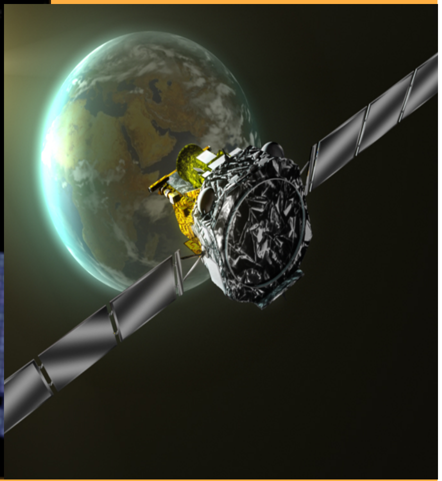
$M_R \approx -13$

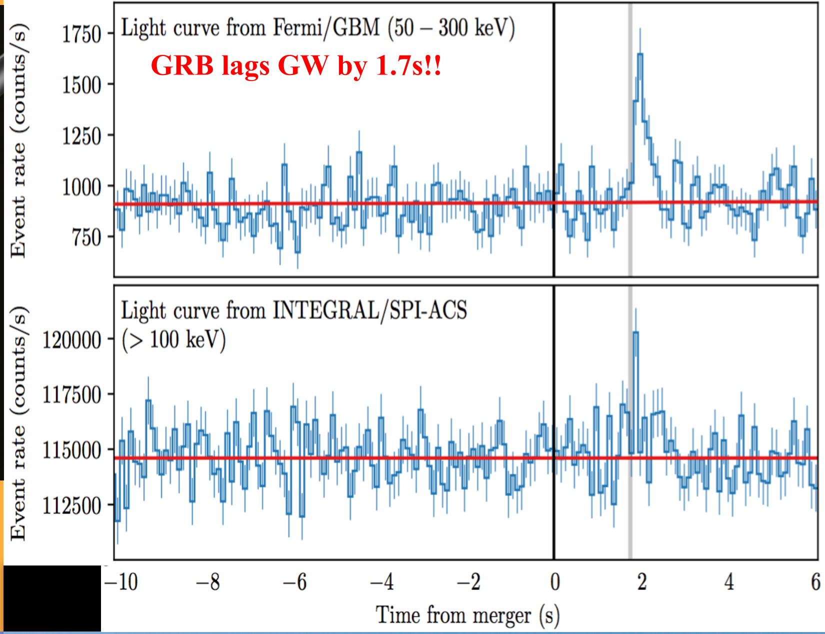
Tanvir et al. 2013;

Berger et al. 2013



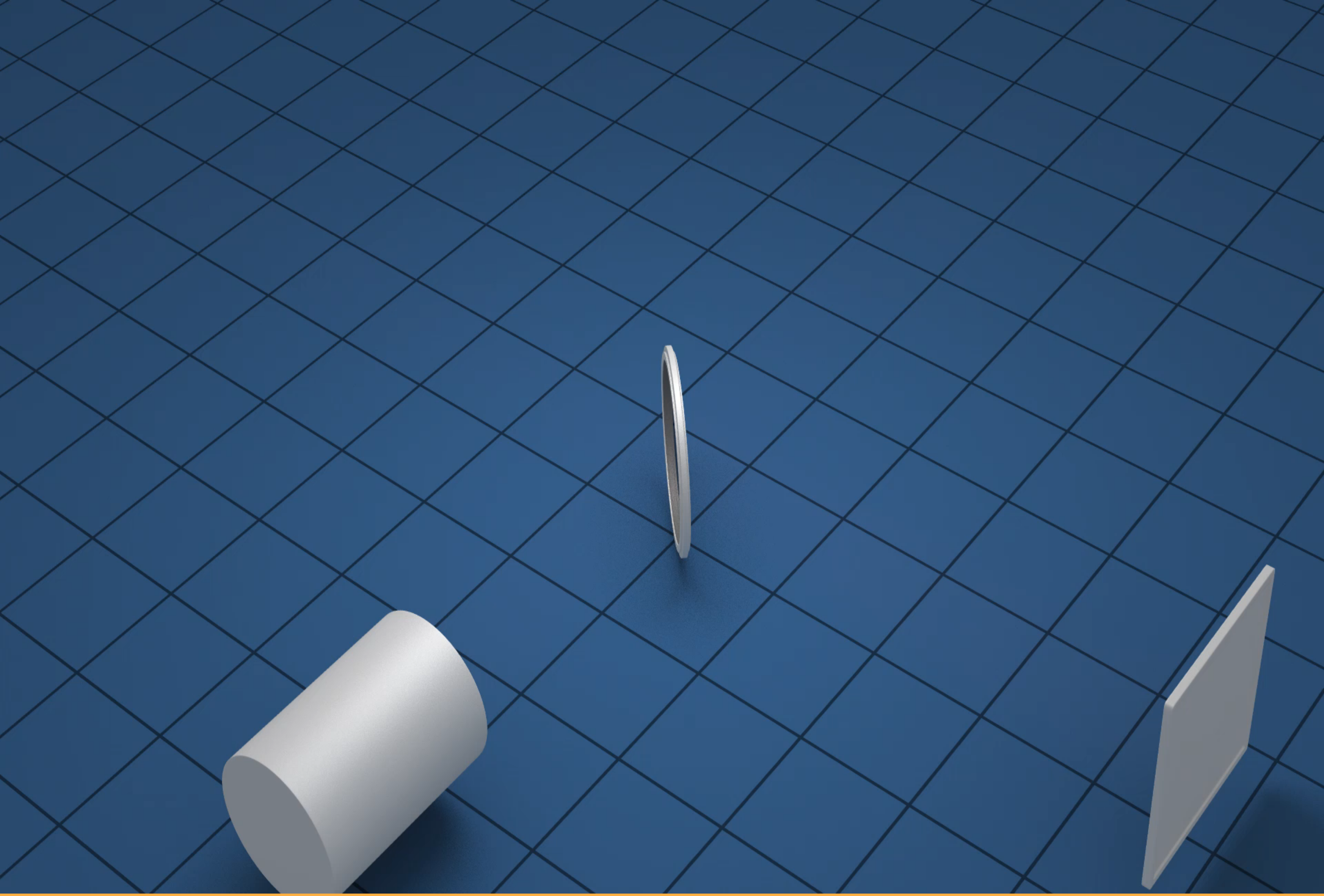


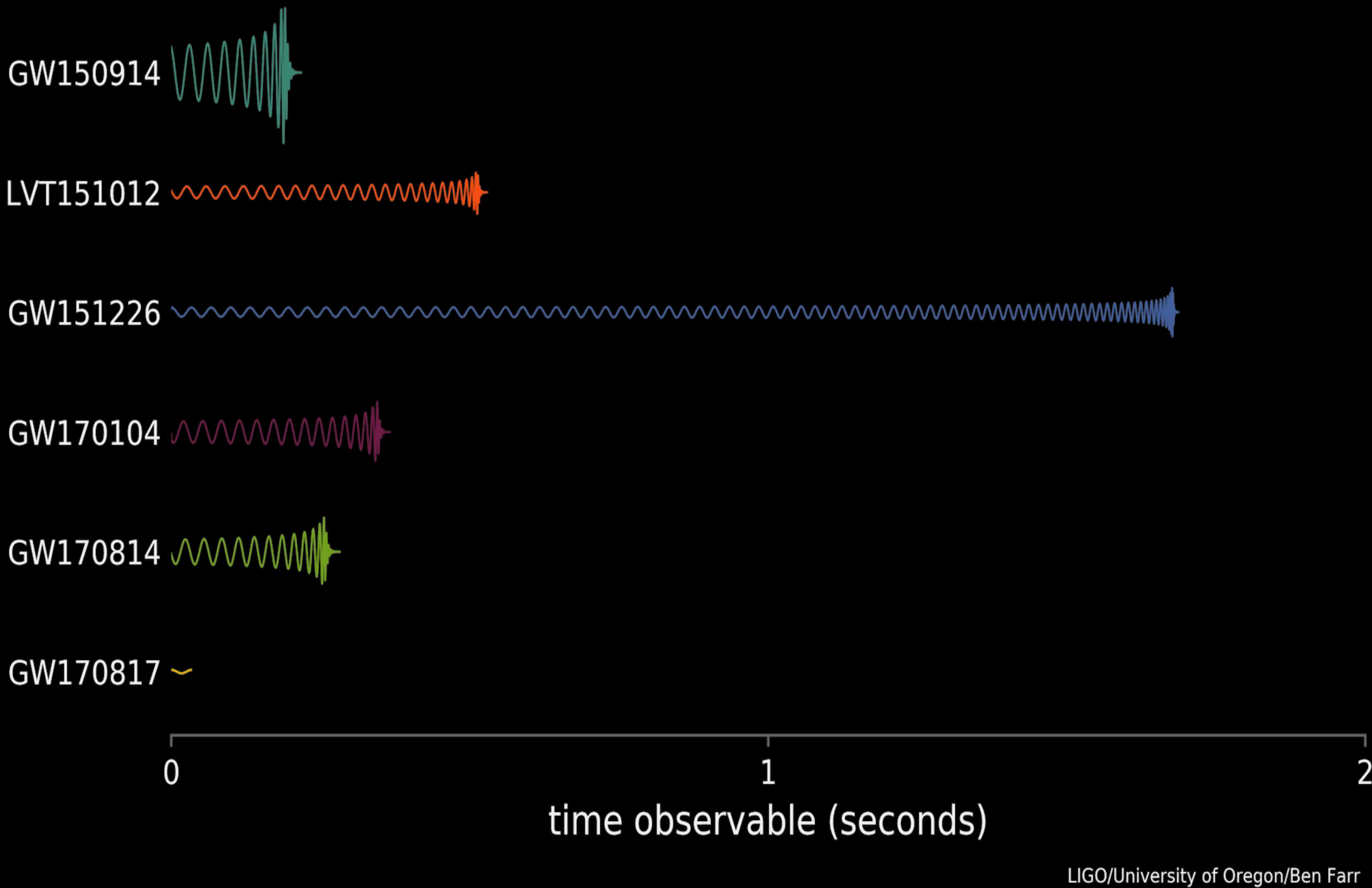




17 Aug 2017 12:41

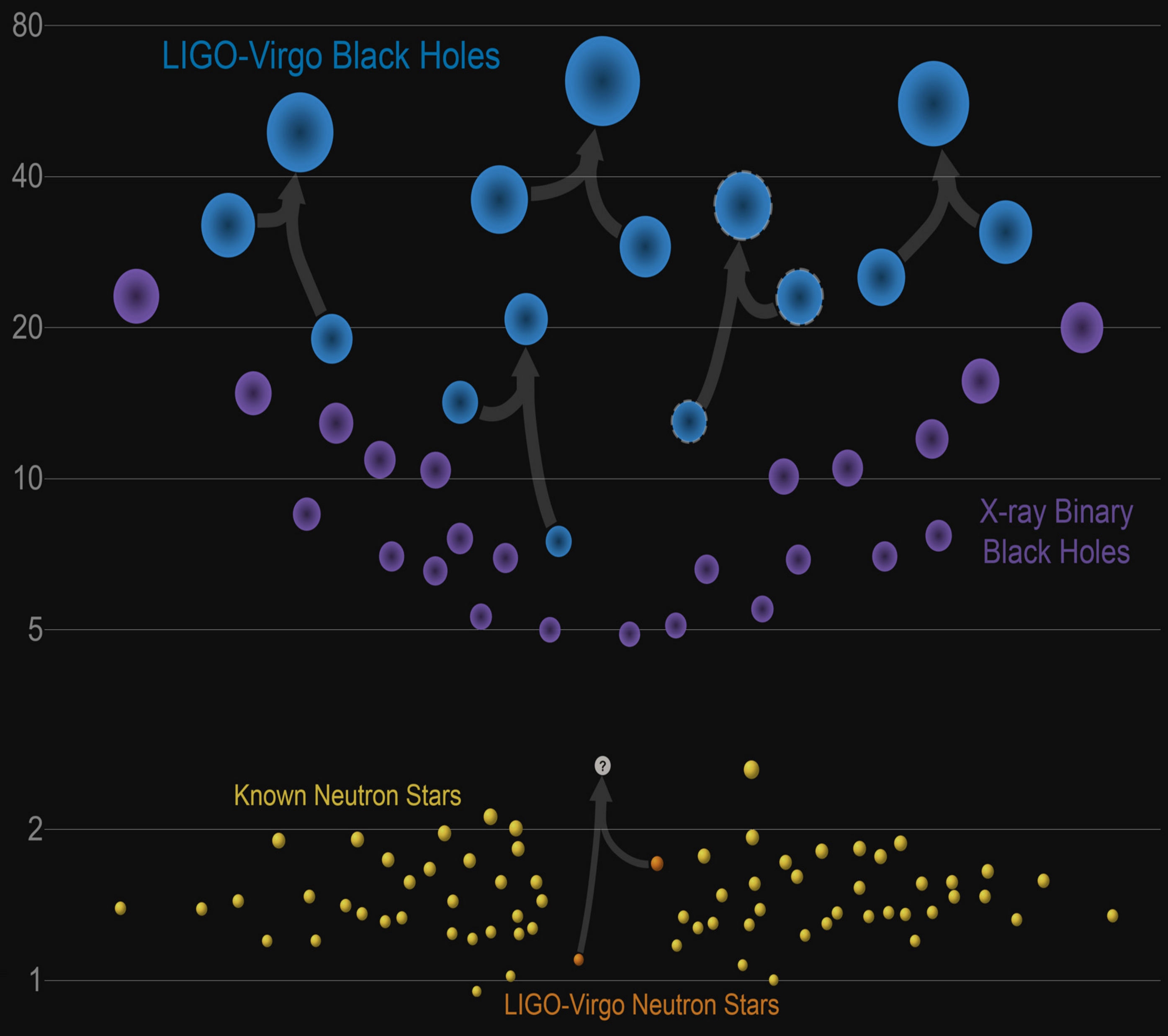
Credit: LIGO Scientific Collaboration, Virgo Collaboration, Fermi Collaboration, Integral collaboration

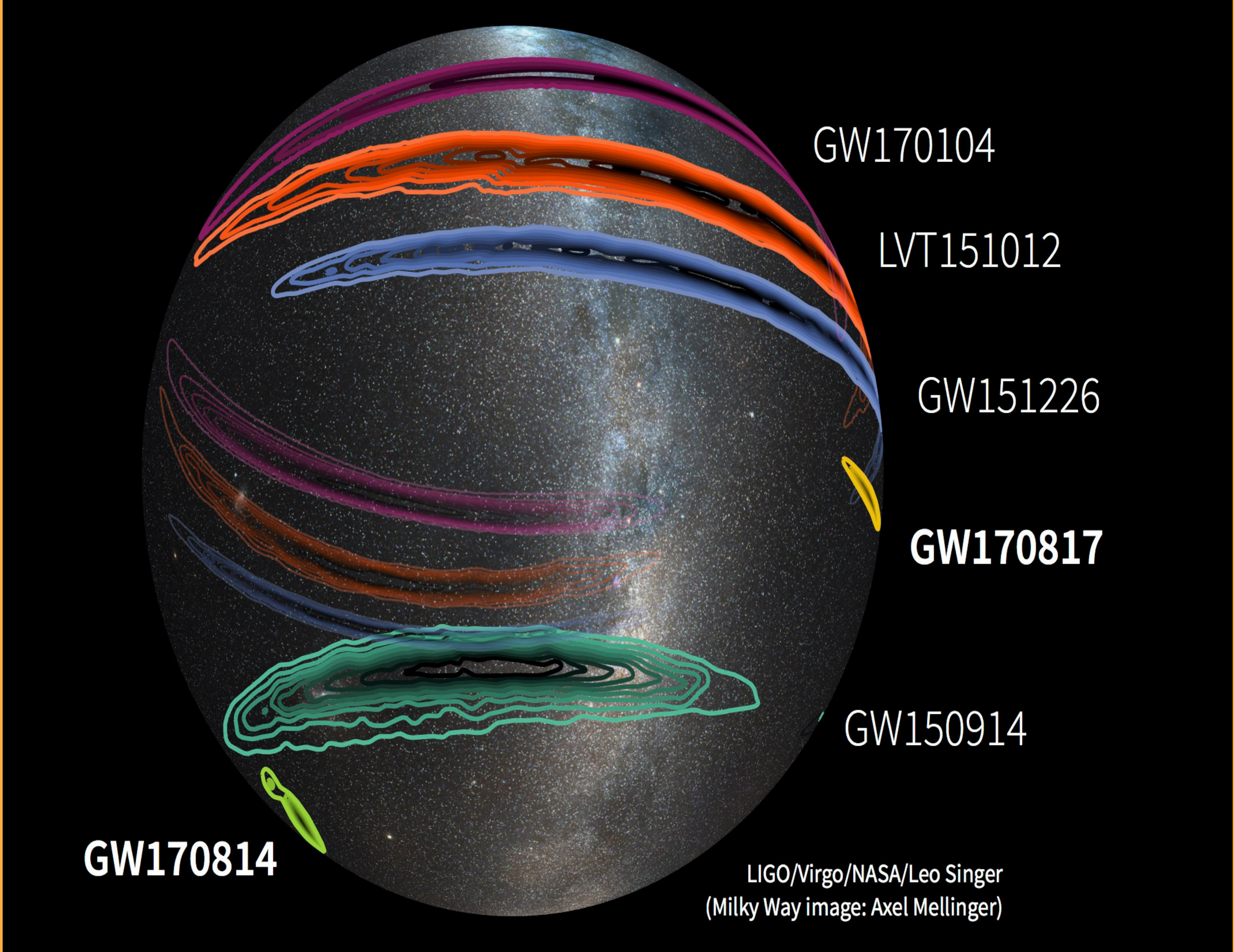



GW150914
LVT151012
GW151226
GW170104
GW170814
GW170817
0
1
2
time observable (seconds)
LIGO/University of Oregon/Ben Farr

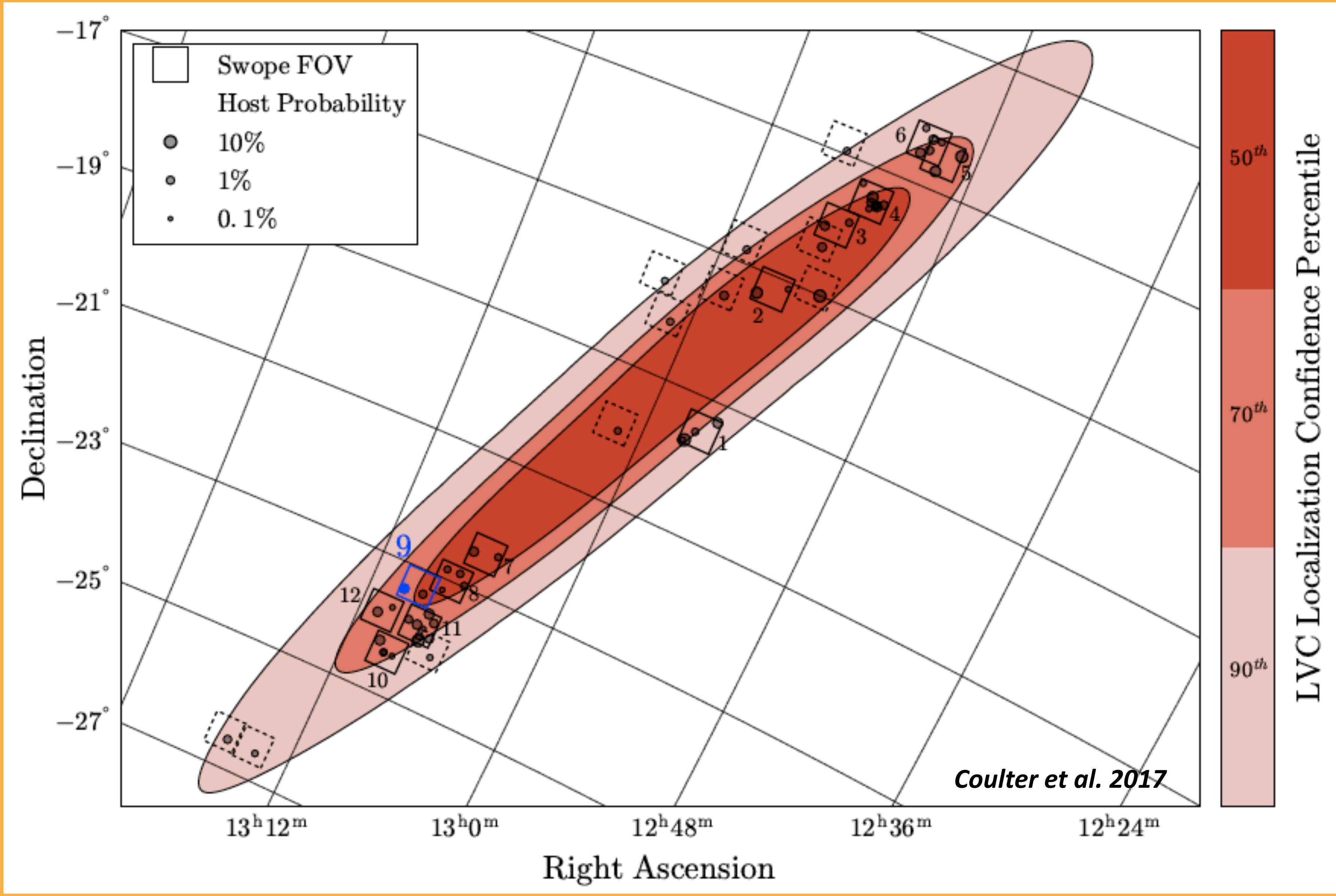
Masses in the Stellar Graveyard

in Solar Masses

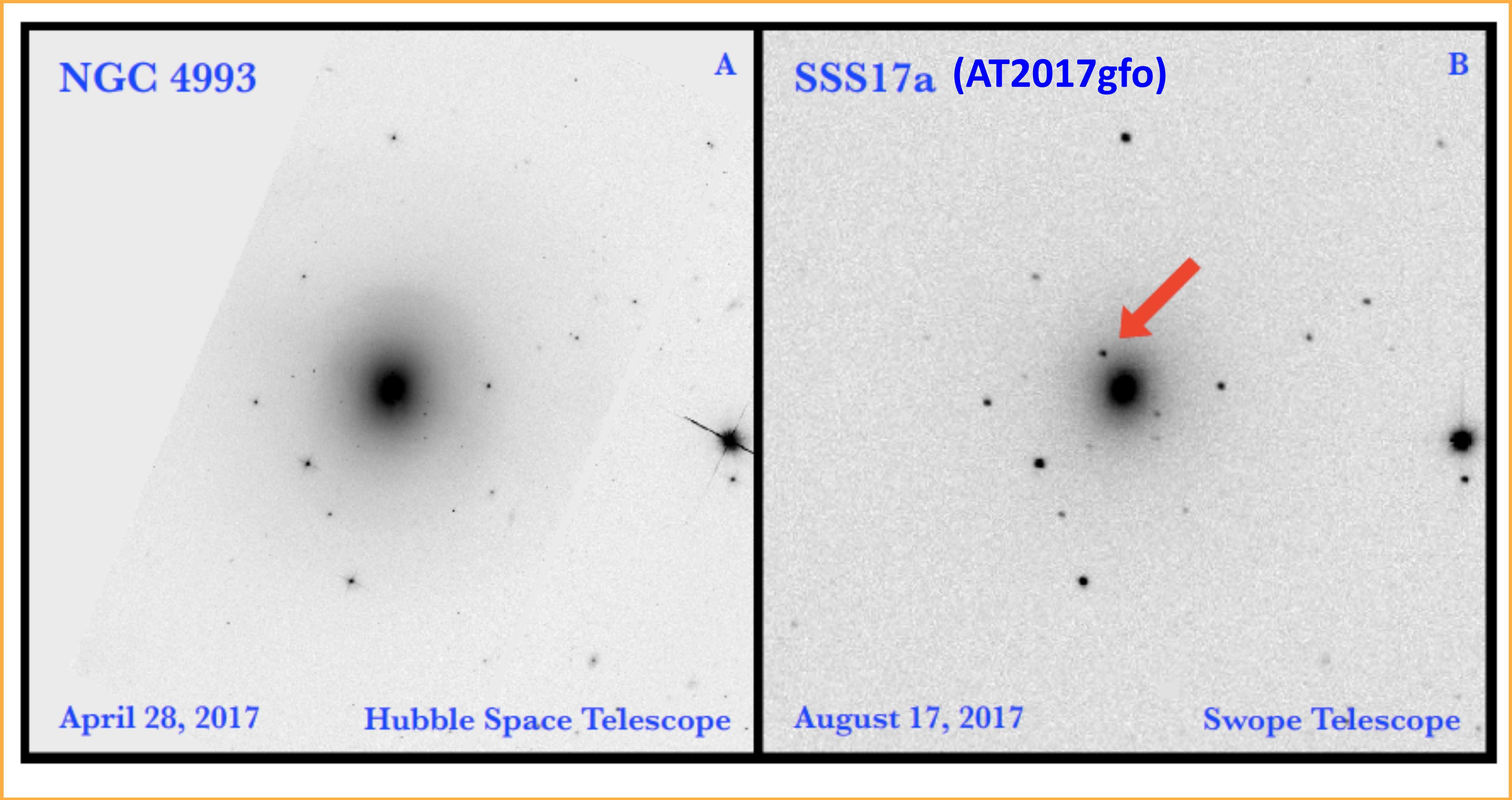



GW170104
LVT151012
GW151226
GW170817
GW150914
GW170814
LIGO/Virgo/NASA/Leo Singer
(Milky Way image: Axel Mellinger)

Search for GW170817 optical counterpart: GW error regions and Swope 1m pointings

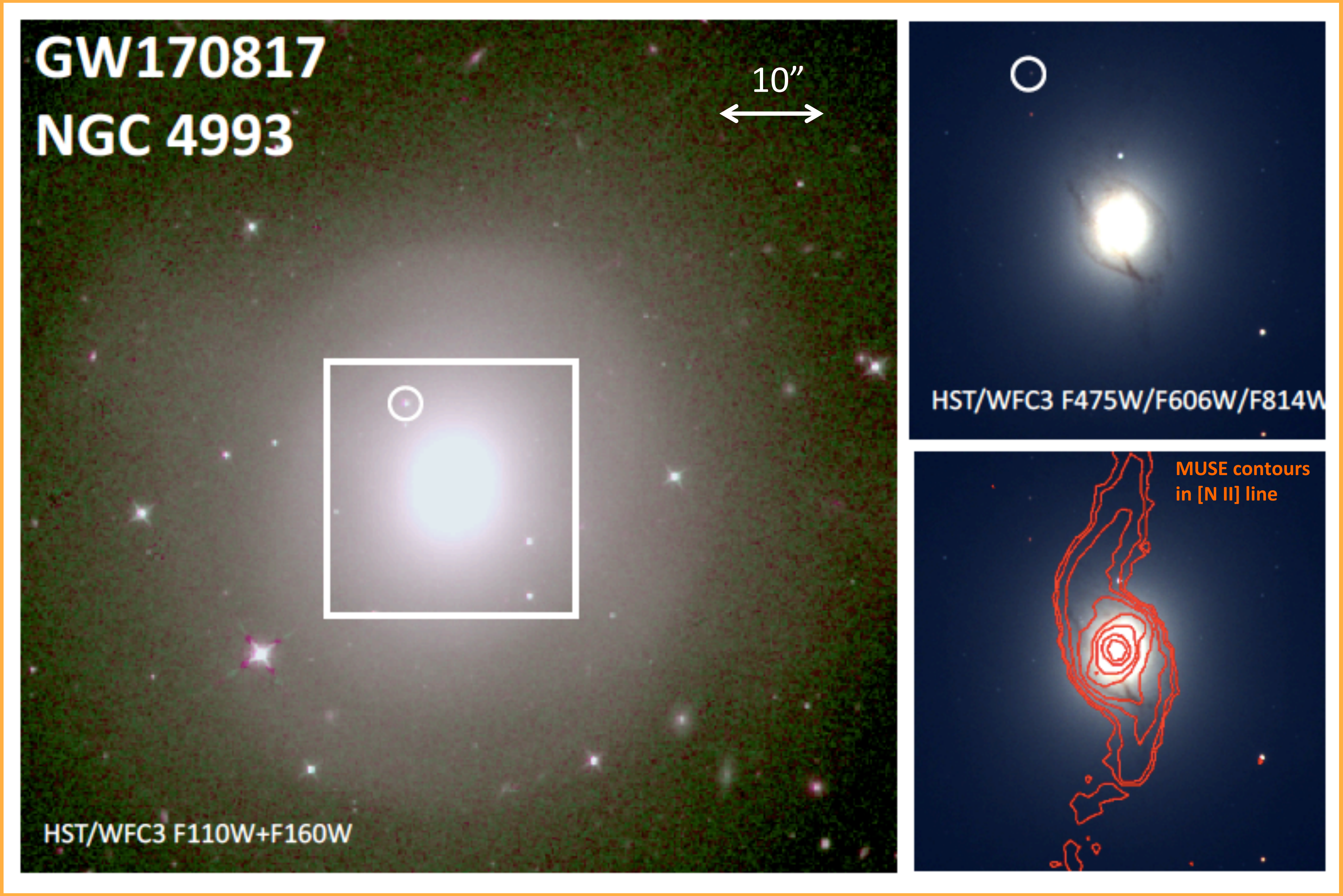


Comparison of Swope discovery image with archival HST image



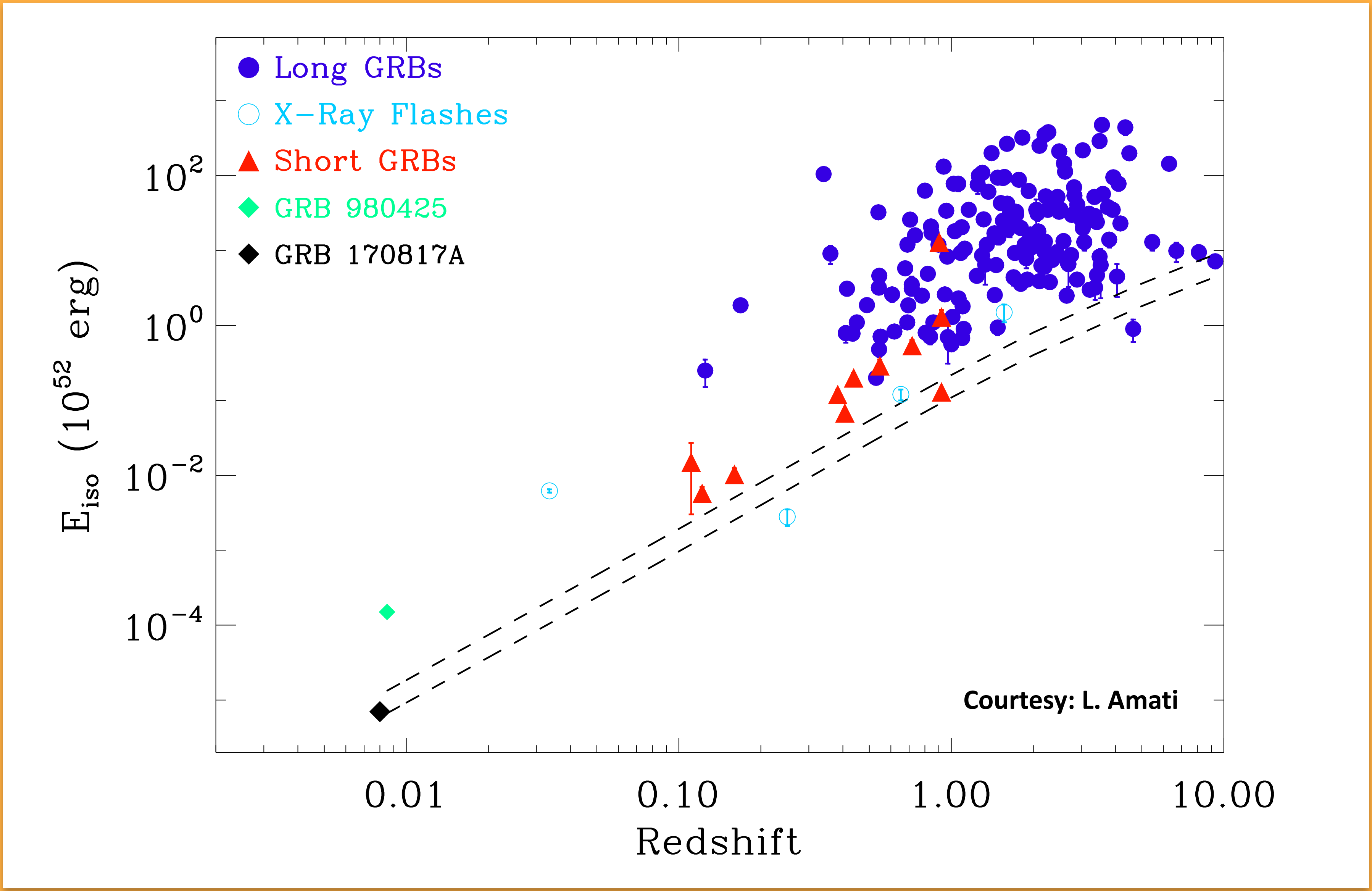
Coulter et al. 2017

Host of GW170817: Lenticular galaxy NGC 4993 (40 Mpc)

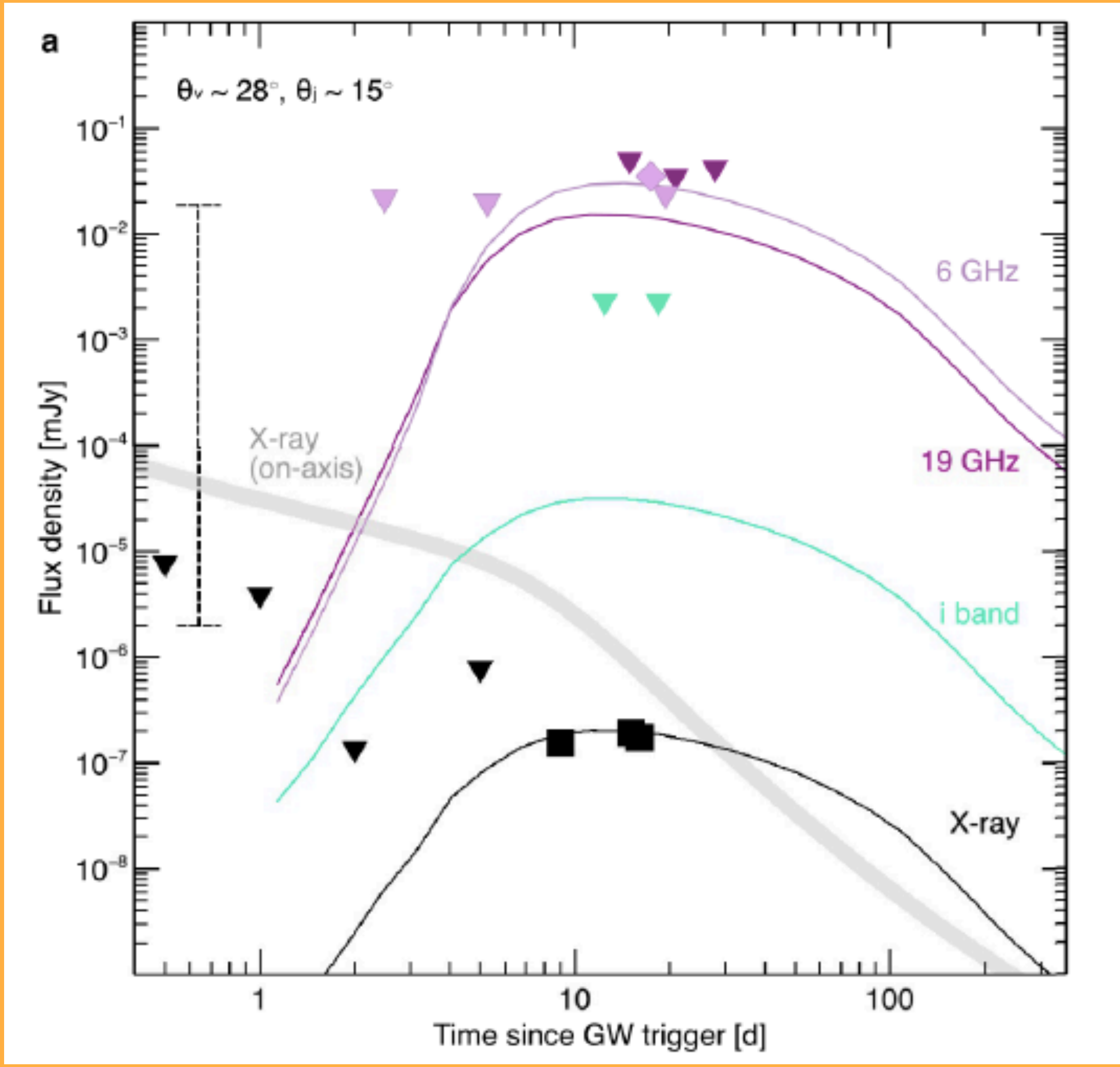


Levan et al. 2017

Energy output of GRBs



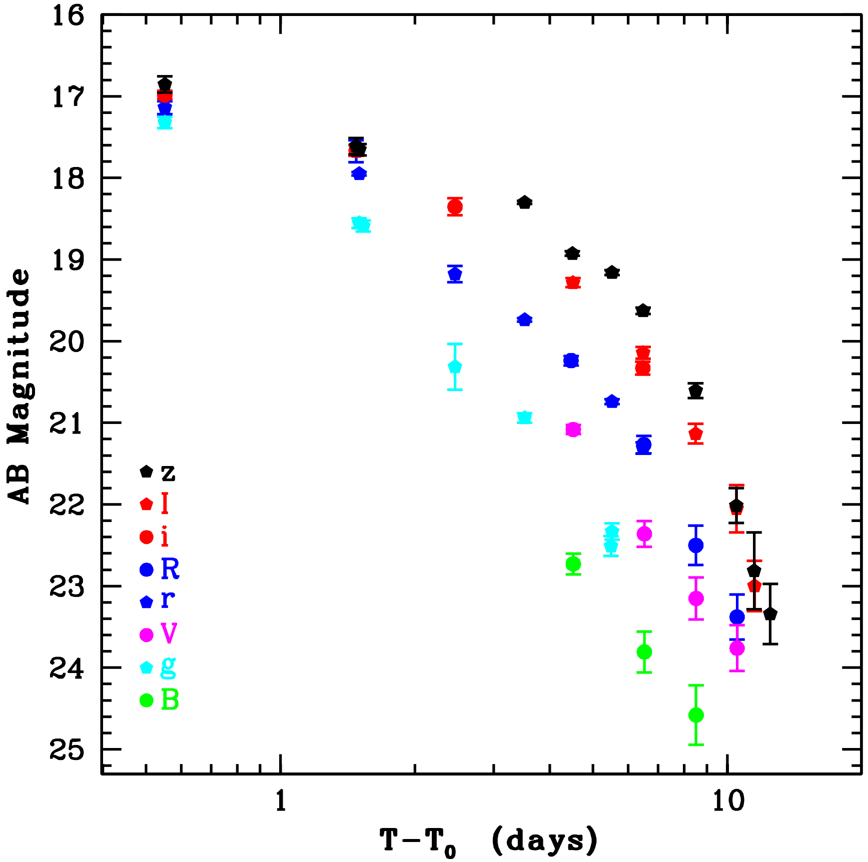
Multiwavelength light curves of AT2017gfo



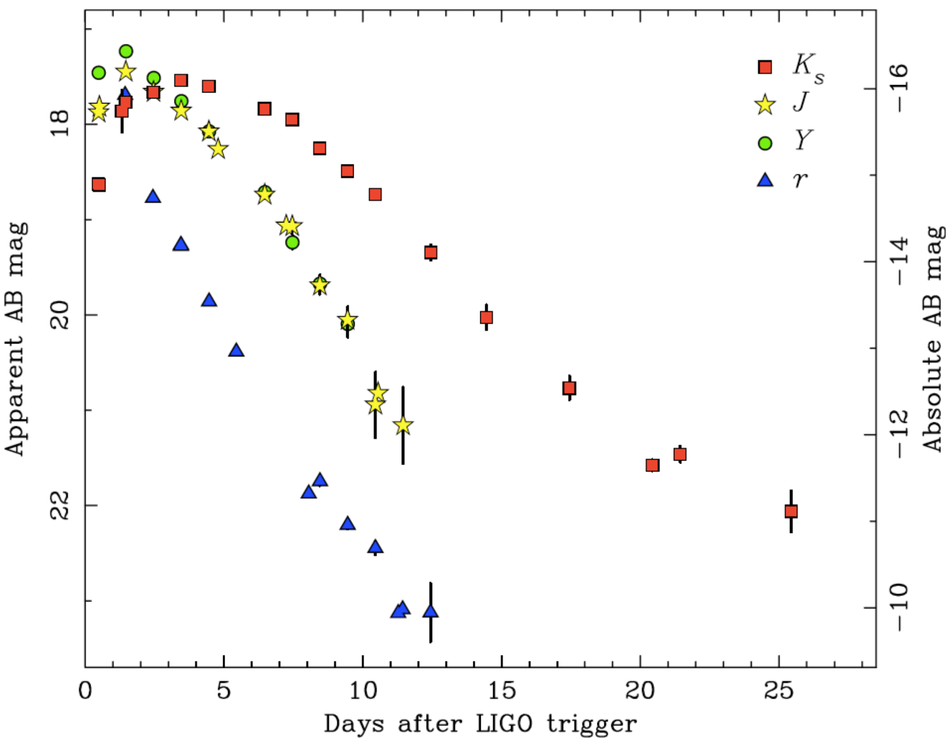
Troja et al. 2017

Optical and near-infrared light curves of GW170817 / AT2017gfo

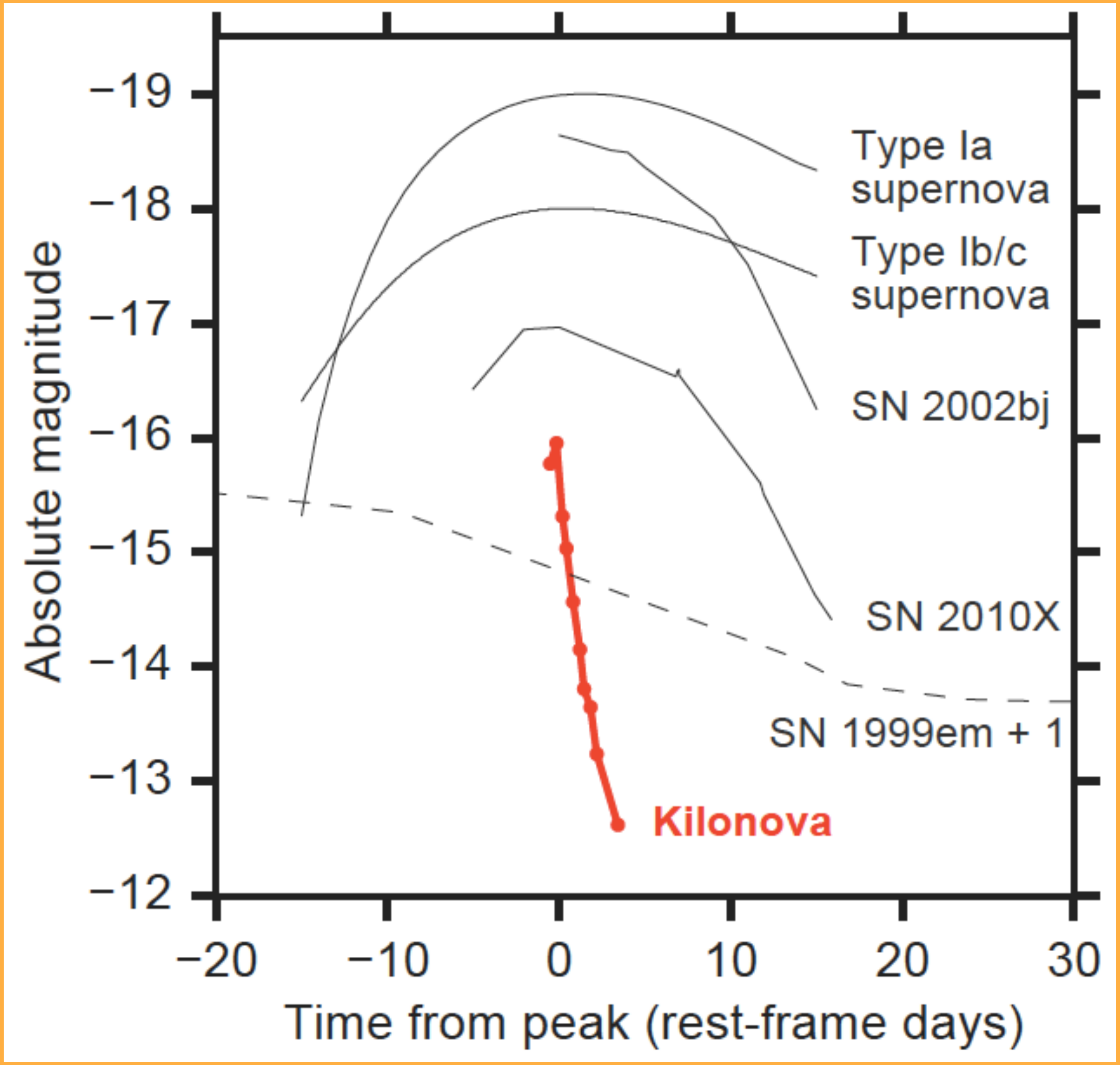
Pian et al. 2017



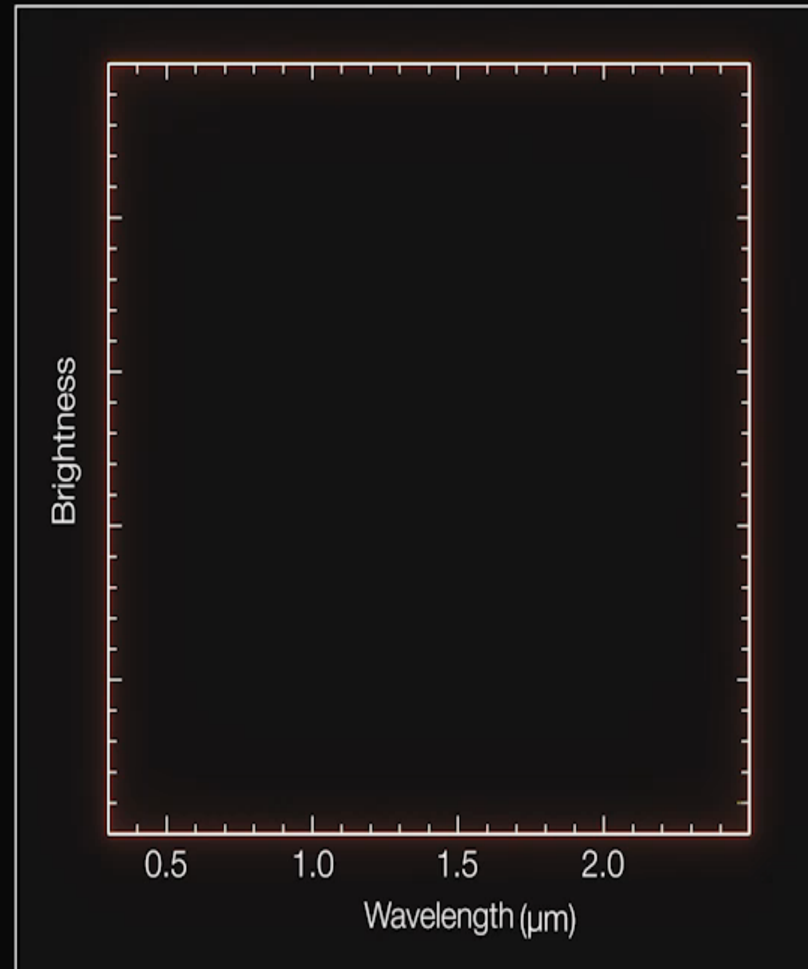
Tanvir et al. 2017



AT2017gfo evolves much more rapidly than any supernova

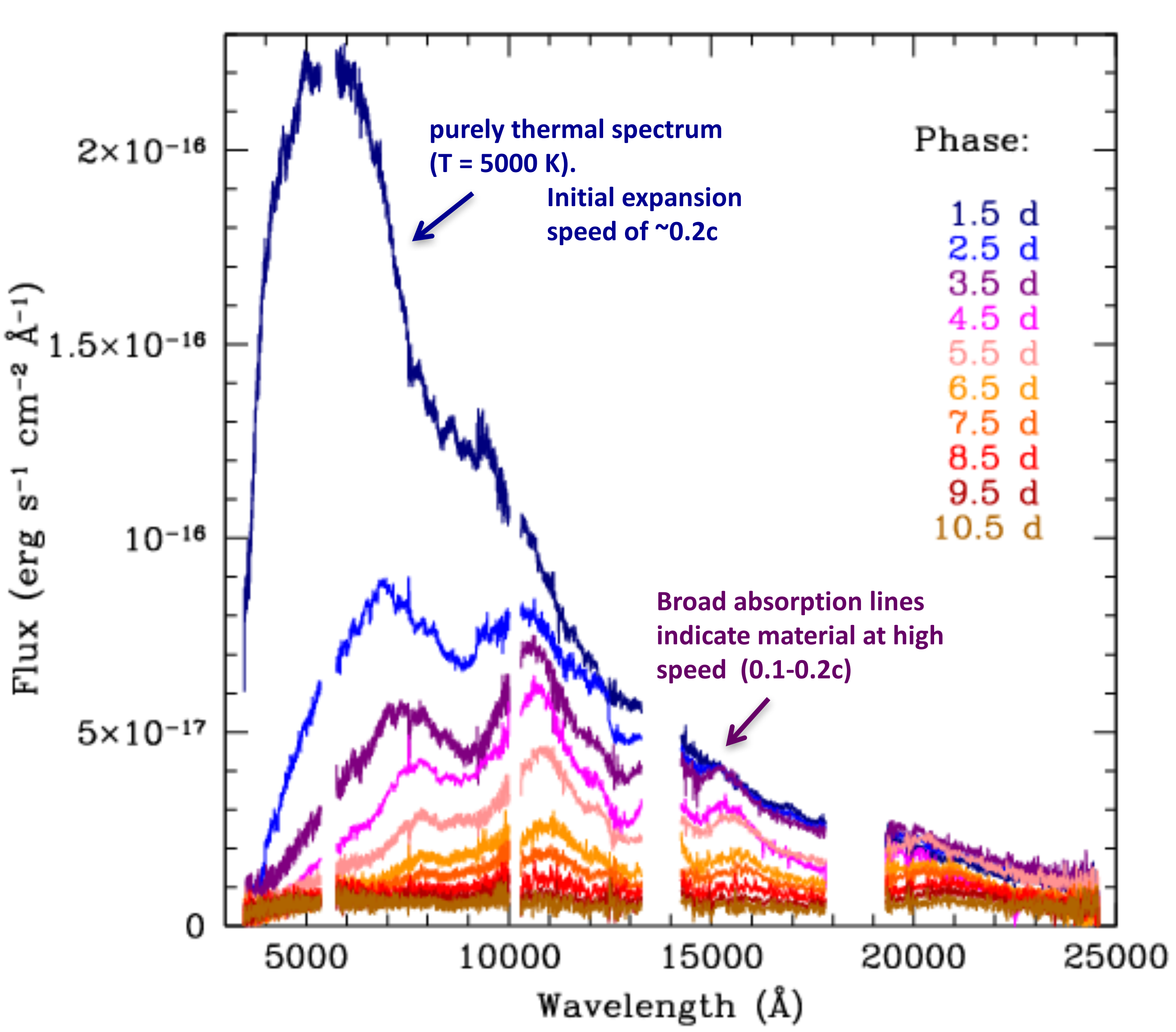


Arcavi et al. 2017



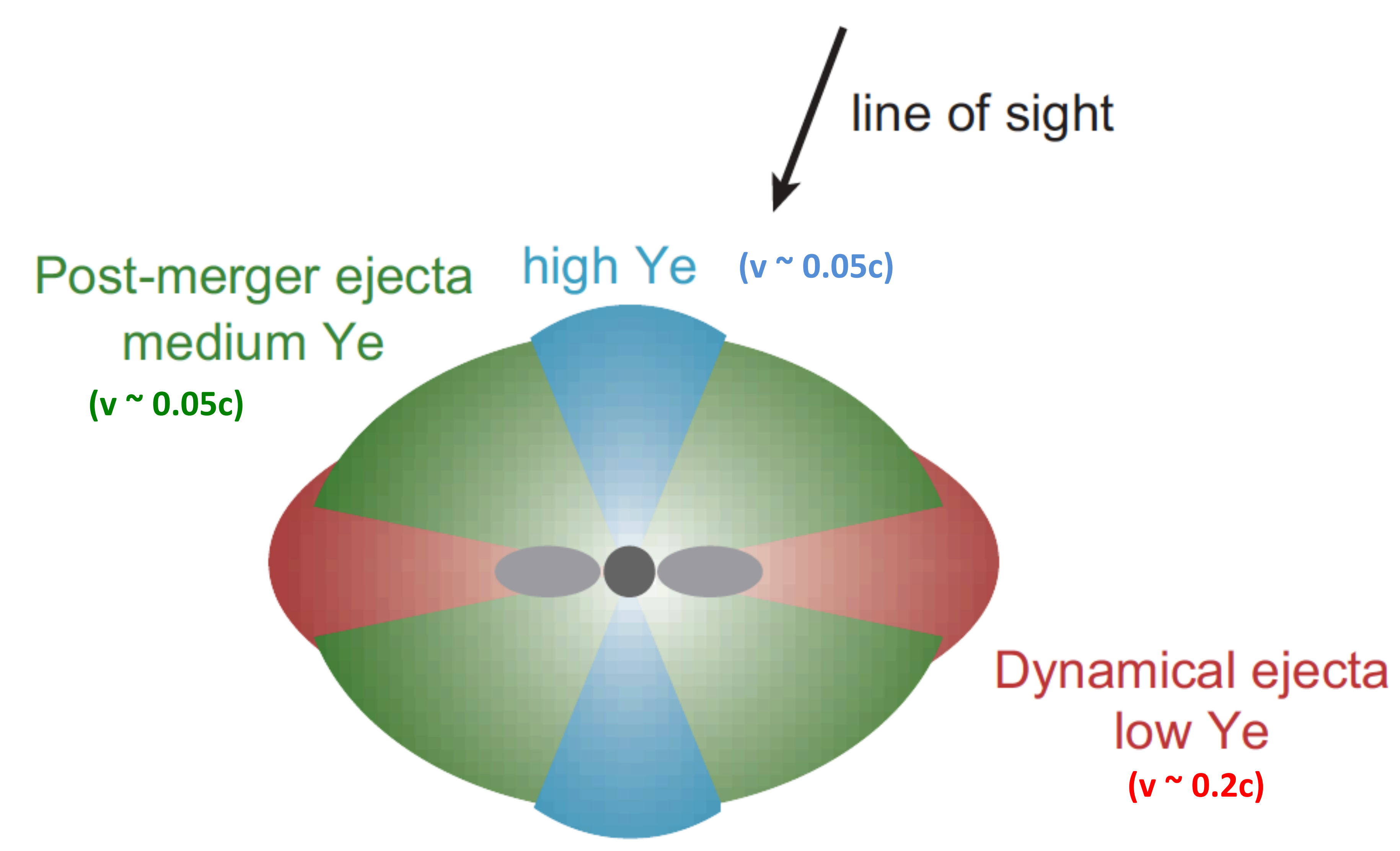
Time: -1225 days

ESO VLT X-Shooter spectral sequence of kilonova GW170817



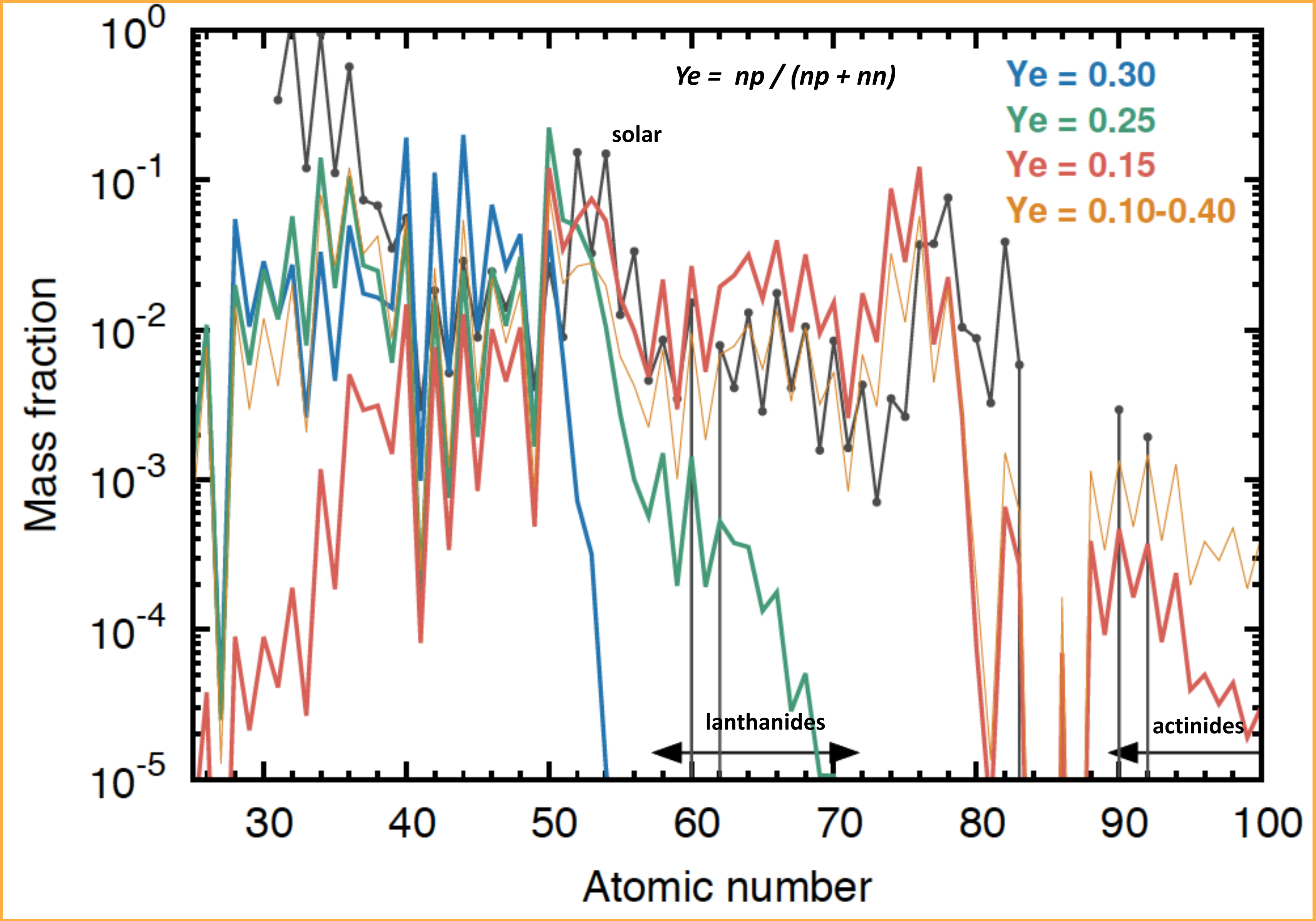
Pian et al. 2017; Smartt et al. 2017

Geometry of 3-component model for kilonova



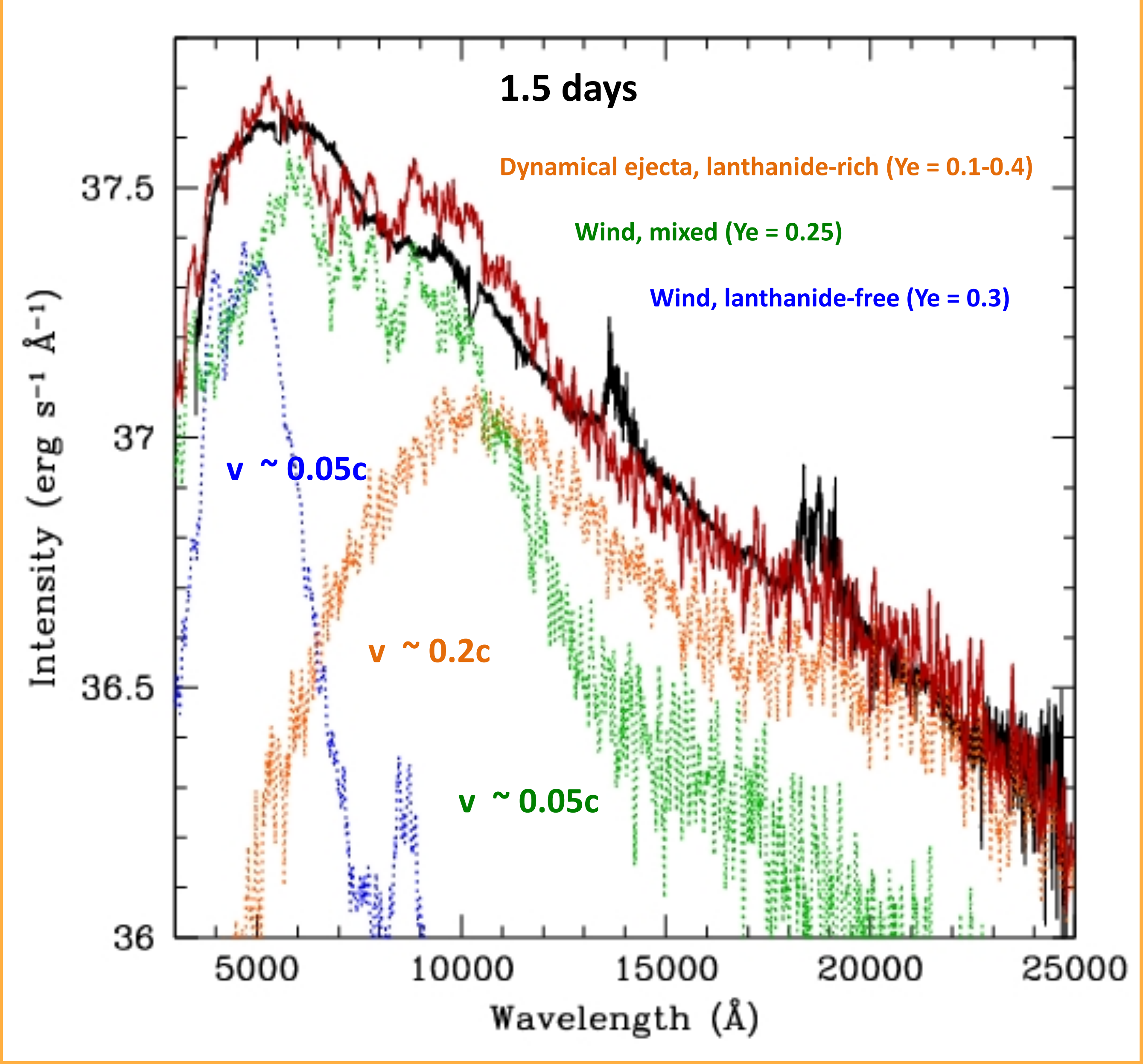
Tanaka et al. 2017, PASJ

Element abundances at 1 day after merger

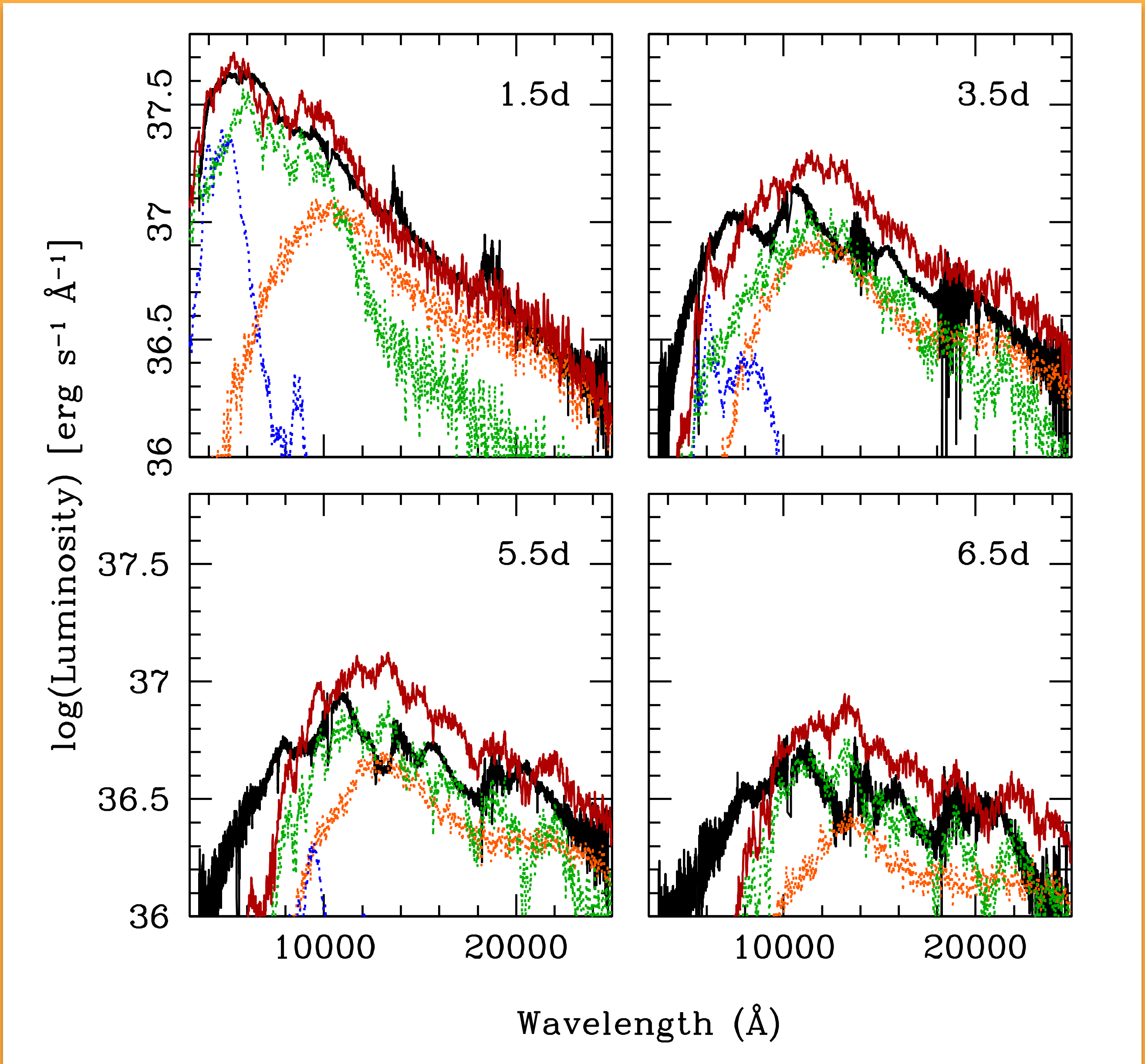


Tanaka et al. 2017, PASJ

Kilonova 3-component model for AT2017gfo



Kilonova 3-component model for AT2017gfo: ejecta mass is 0.03-0.05 solar masses



Conclusions and future work

GWs from double neutron star merger were directly detected.
The signature of r-process nucleosynthesis was unambiguously detected.
A unified scheme for short GRBs has been established.

The preliminary models require more than one component, with different Proportions of species (lanthanide-rich vs lanthanide-free). The ejecta are about 0.03-0.05 solar masses.

However we need more realistic atomic models and opacities to use with our radiative transport codes.

Future work must focus on identifying accurately the atomic species and measuring their abundances. We will thus trace heavy elements formation and evolution in the Universe.

Fundamental problem of NS Equation of State can also be addressed with joint gravitational and electromagnetic information (mass ejection should be larger for smaller radii of the NSs, i.e., for softer EoS).