Fukuoka, 25 April 2019

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OSSERVATORIO DI ASTROFISICA E SCIENZA DELLO SPAZIO DI BOLOGNA
Plesso Area della Ricerca CNR

Long and short GRB progenitors

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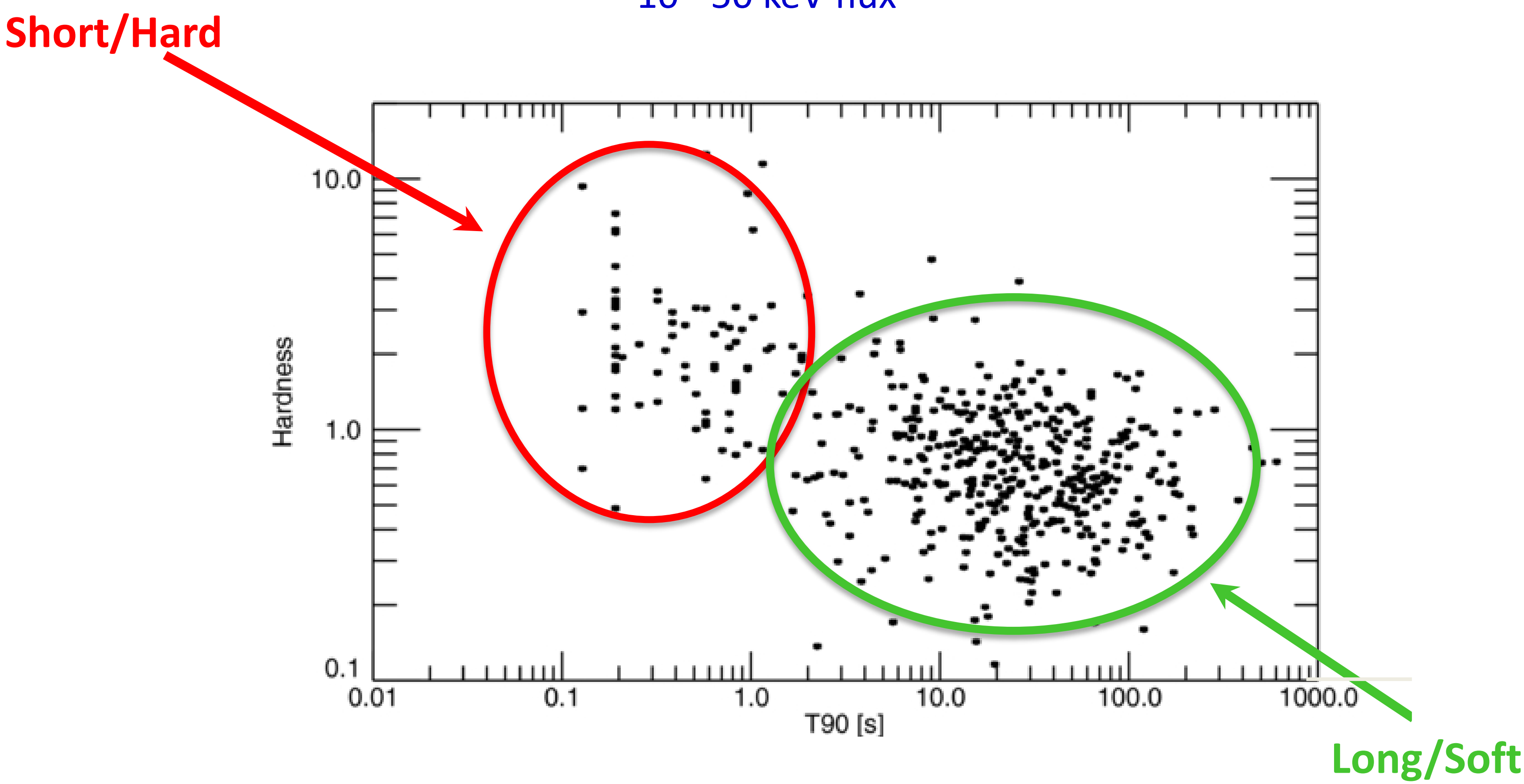
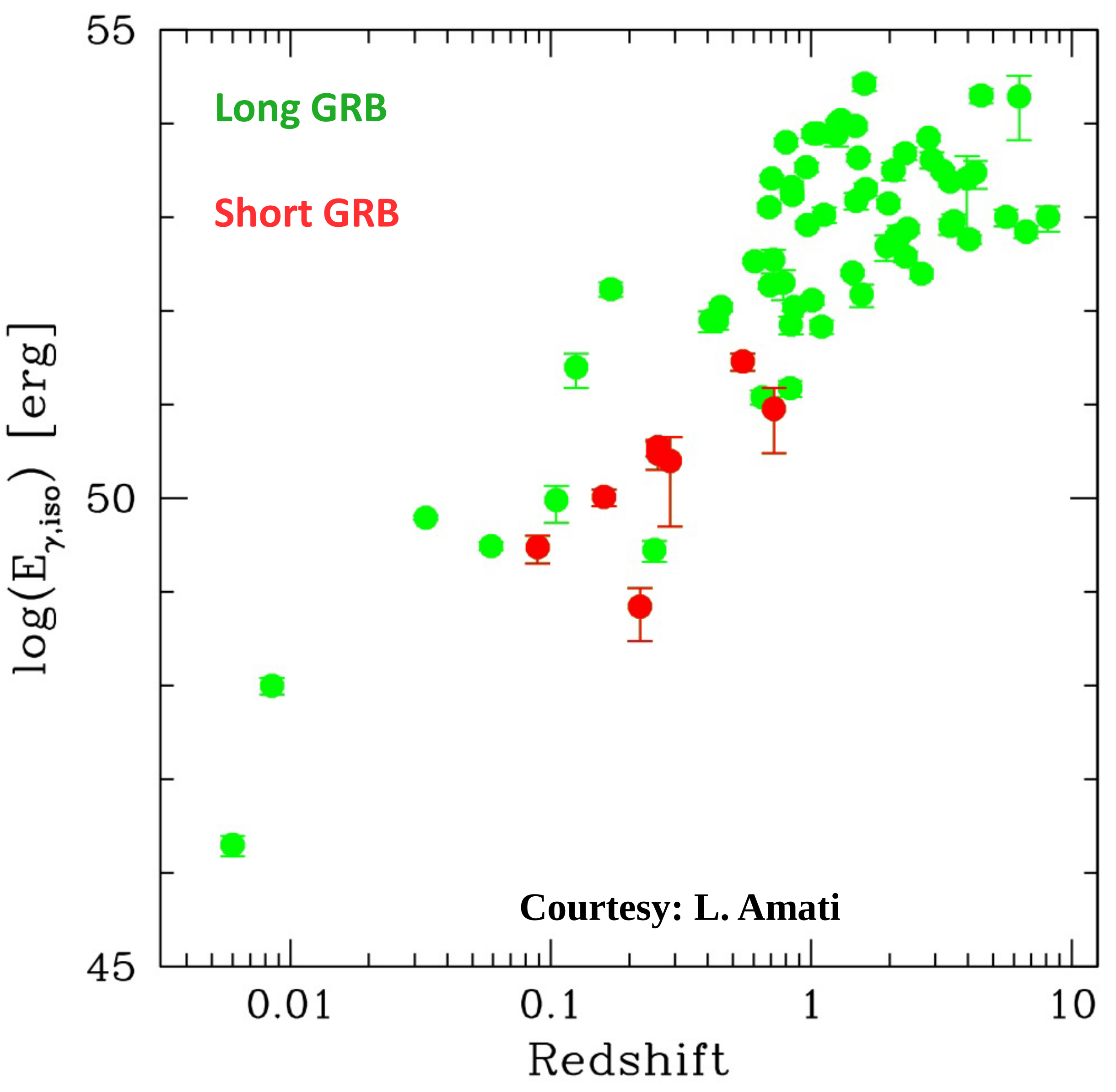
Hardness-Duration Classification of GRBs

$$H = \frac{\text{50 - 300 keV flux}}{\text{10 - 50 keV flux}}$$



Kouveliotou+1993; von Kienlin+2014

Isotropic irradiated gamma–ray energy vs redshift

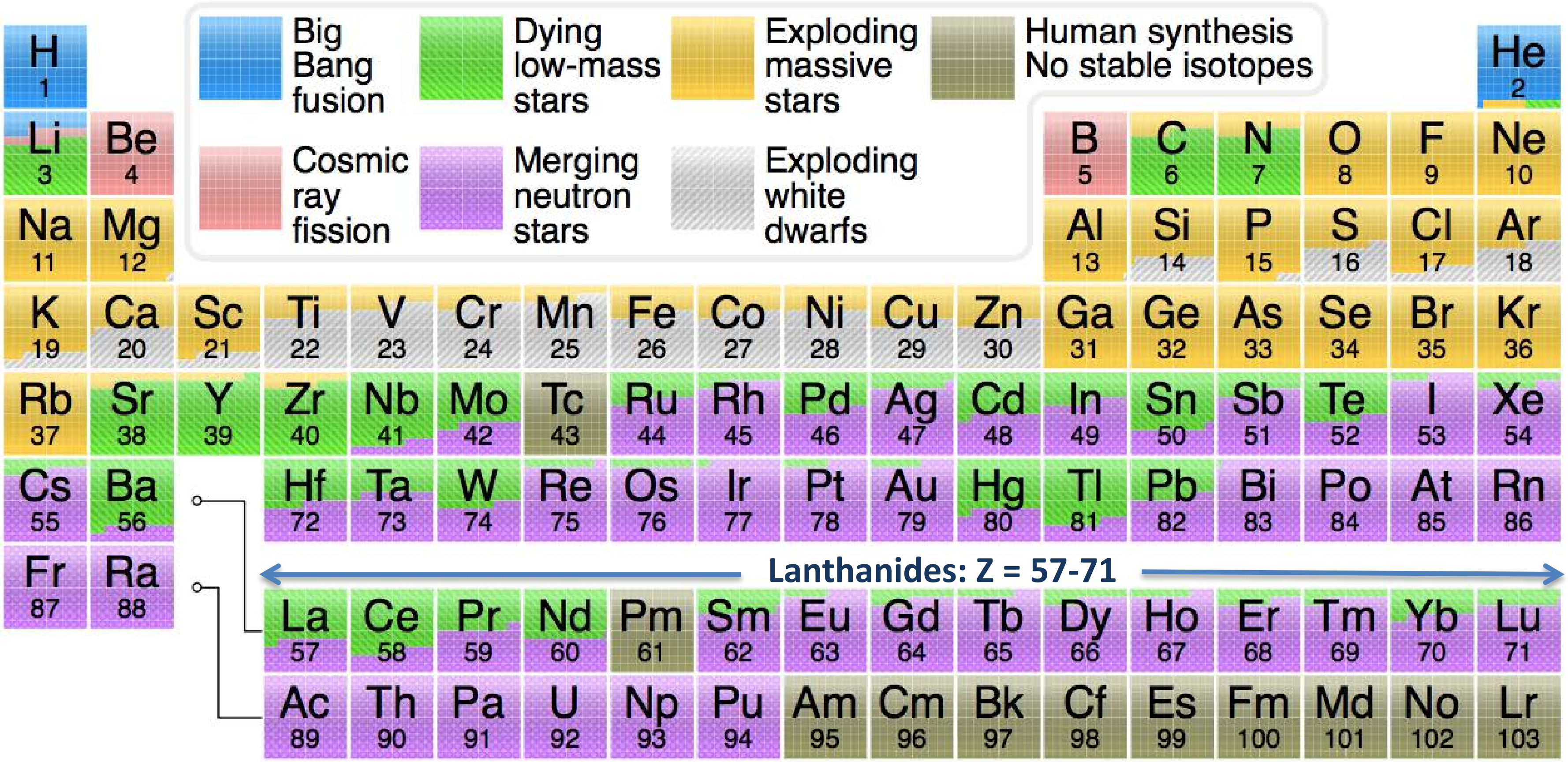


A double neutron star merger is expected to produce:

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

Lattimer & Schramm 1974; Eichler et al. 1989; Li & Paczynski 1998

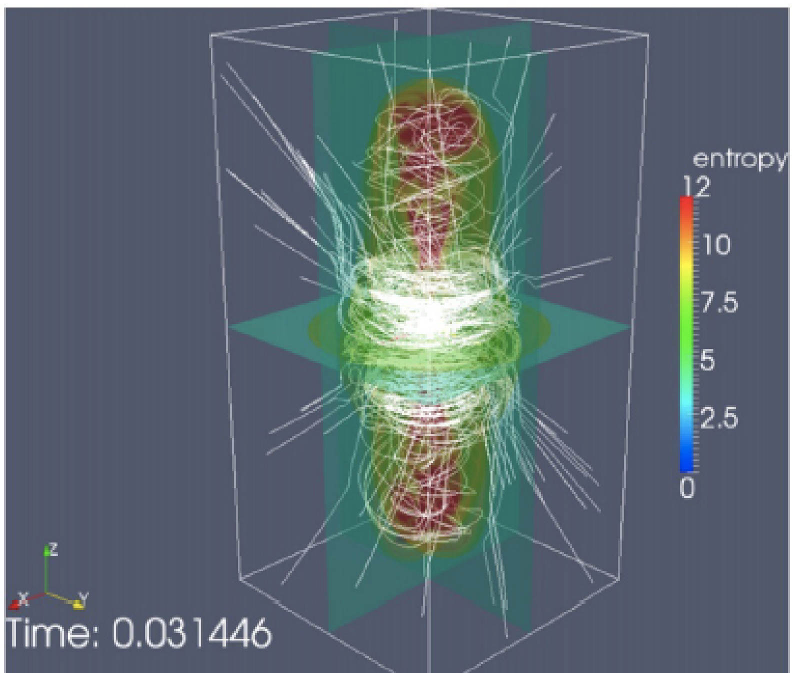
Periodic table of elements



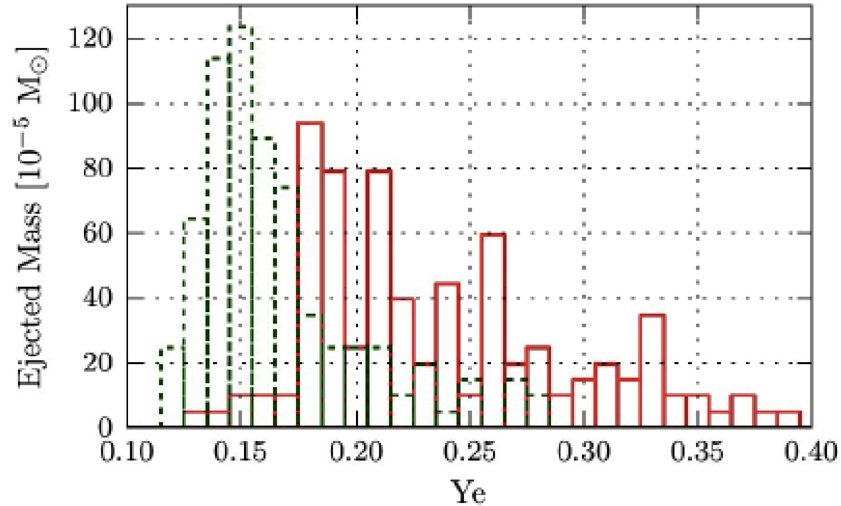
https://en.wikipedia.org/wiki/R-process

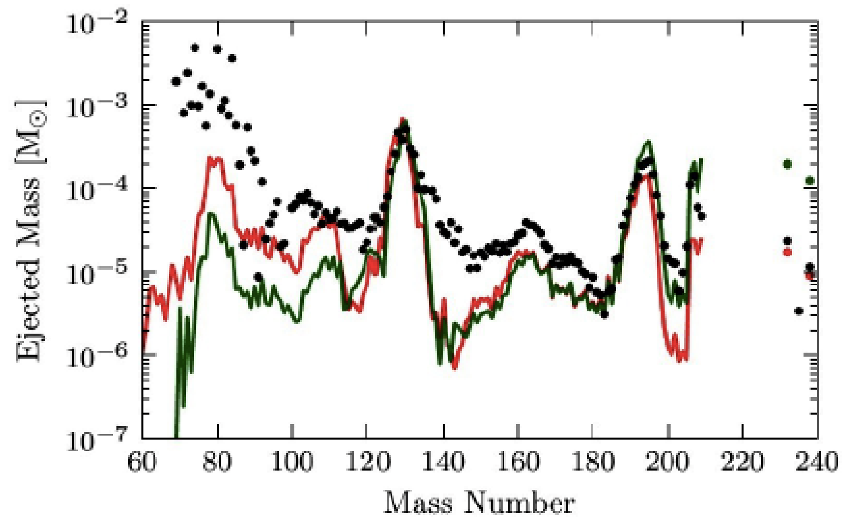
Jet-Supernova Models as r-process Sites?

- MHD-driven polar "jets" could sweep out n-rich matter.
- Requires extremely fast matter ejection, extremely rapid rotation and extremely strong magnetic fields in pre-collapse stellar cores.
- Should be very rare event; maybe 1 of 1000 stellar core collapses?



Winteler et al., ApJL 750 (2012) L22





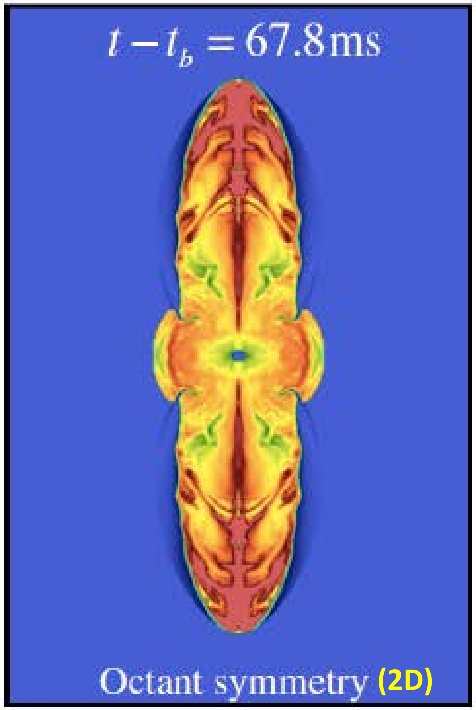
Courtesy: Th. Janka, 2016

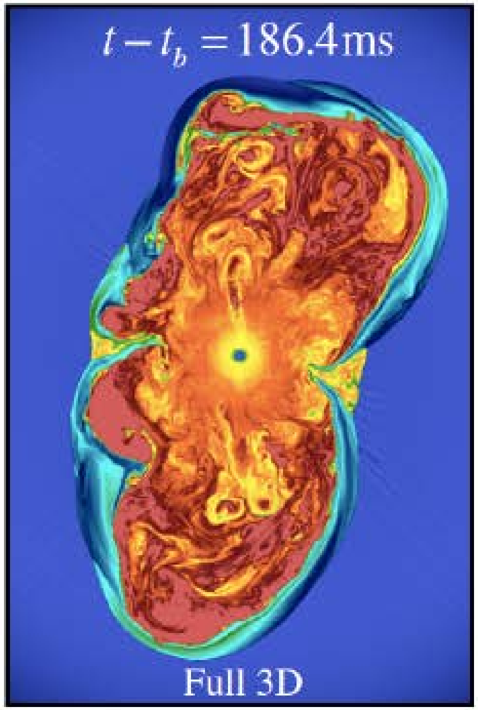
Jet-Supernova Models as r-process Sites?

BUT:

- MHD-driven polar 'jets" in 3D develop kink instability.
- Assumed initial conditions not supported by stellar pre-collapse models.
- Dynamical scenario does not provide environment for robust r-process.

From Th. Janka, 2016





Mösta et al., ApJL 785 (2014) L29

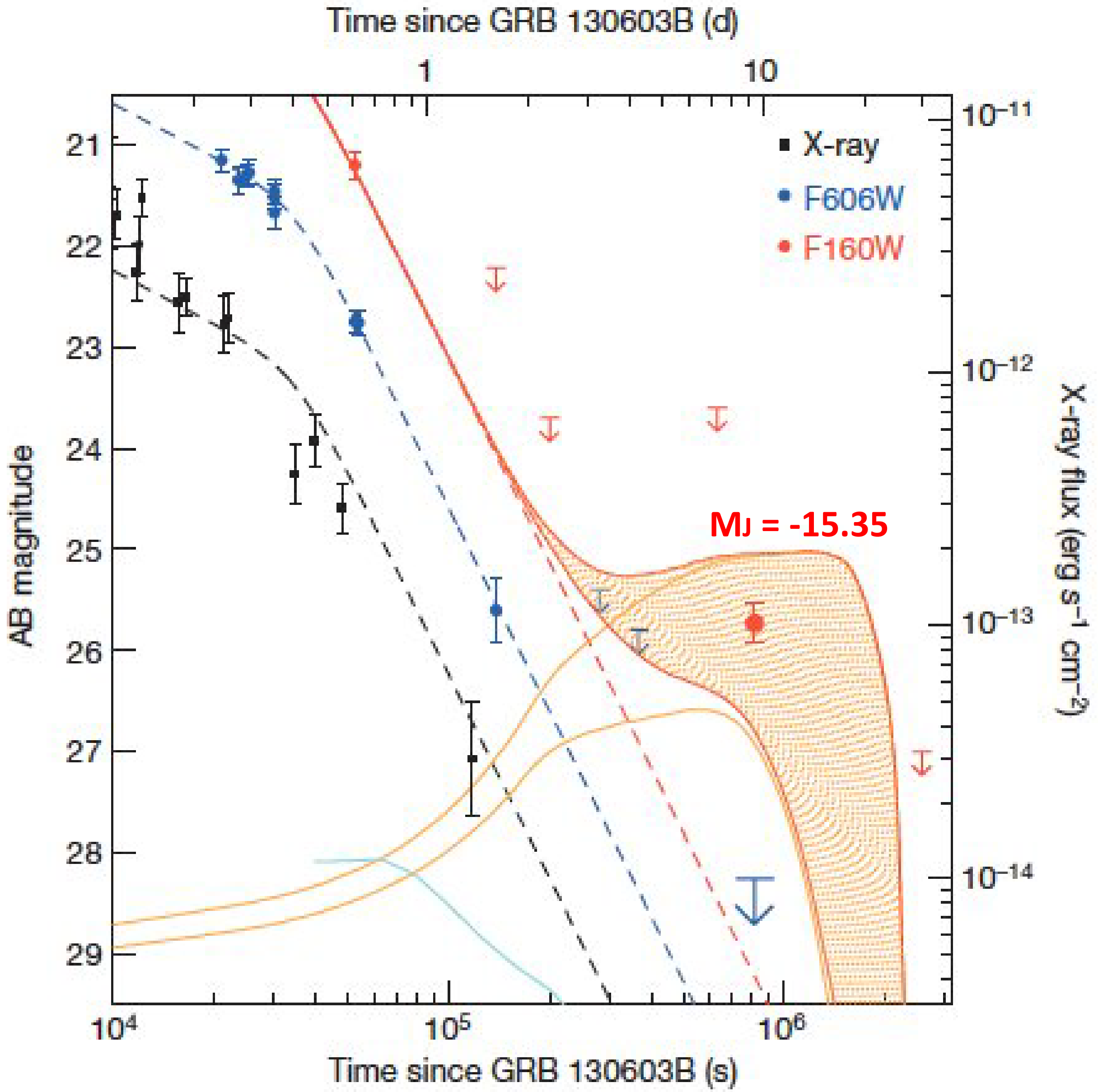
Short GRB130603B
(z = 0.356)

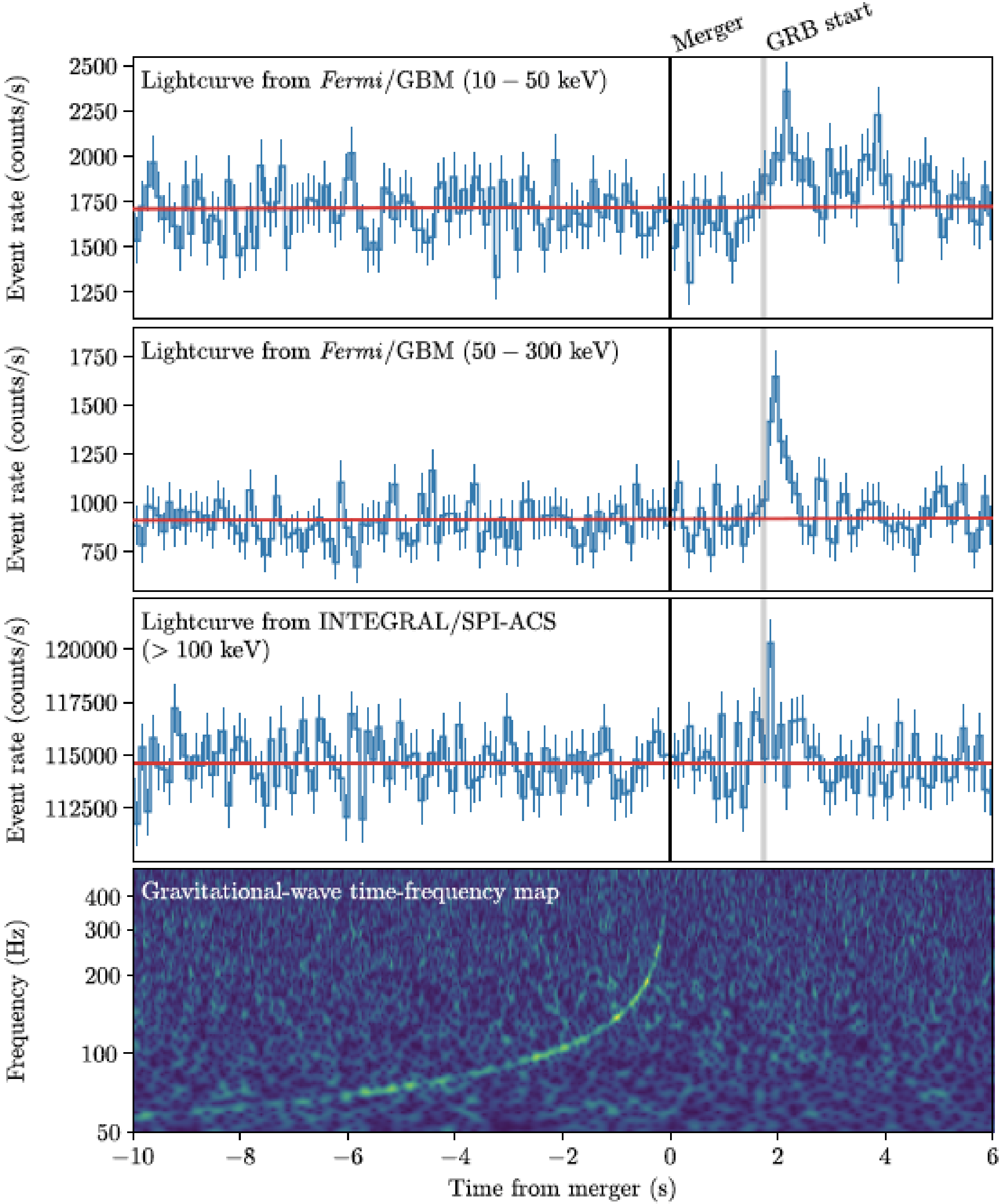
Kilonova:
Ejection of r-process material from a NS merger (0.01-0.1 Mo) (Barnes & Kasen 2013)

$M_H \approx -15$

$M_R \approx -13$

Tanvir et al. 2013;
Berger et al. 2013



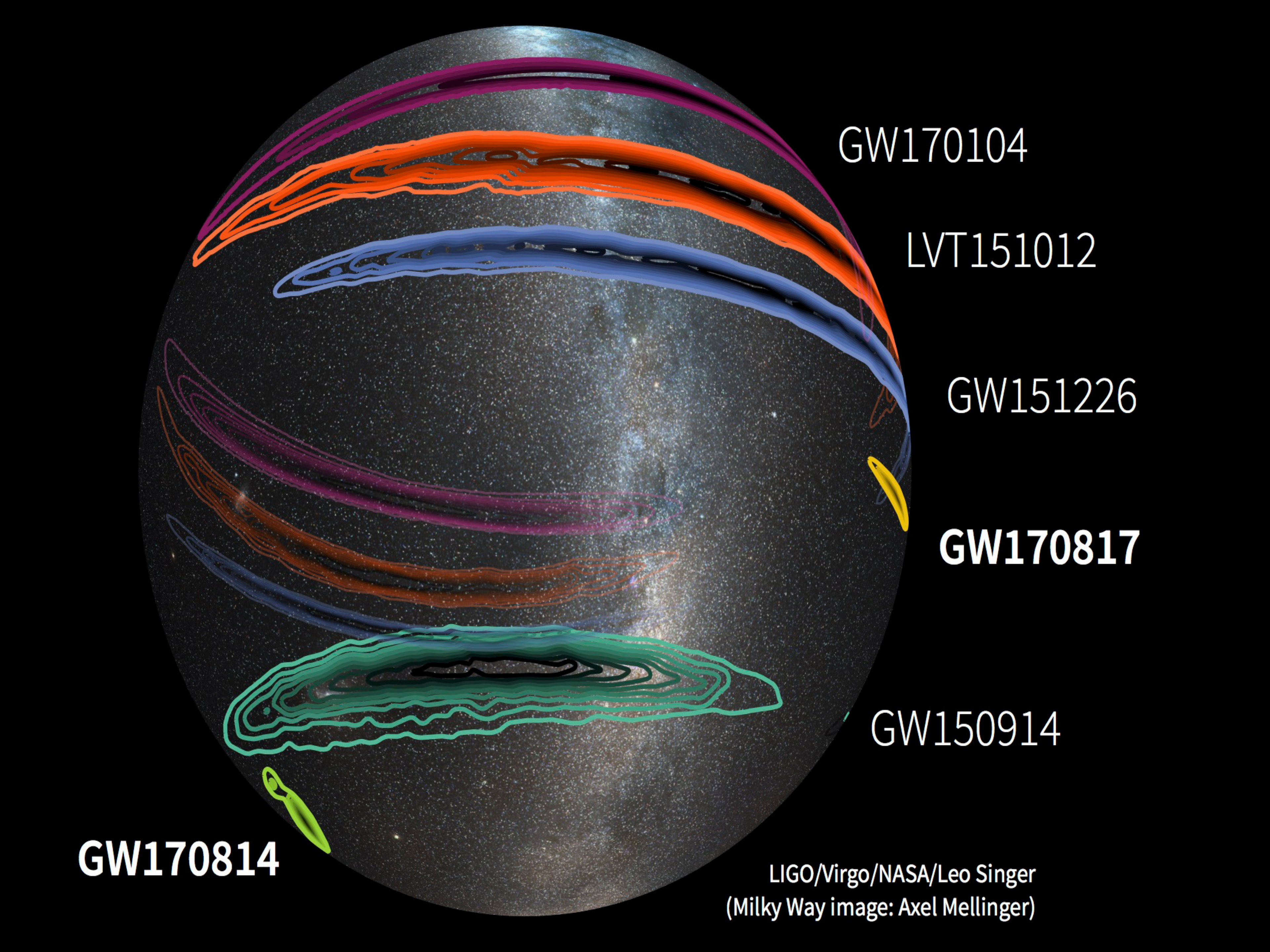


GW170817 and GRB170817A

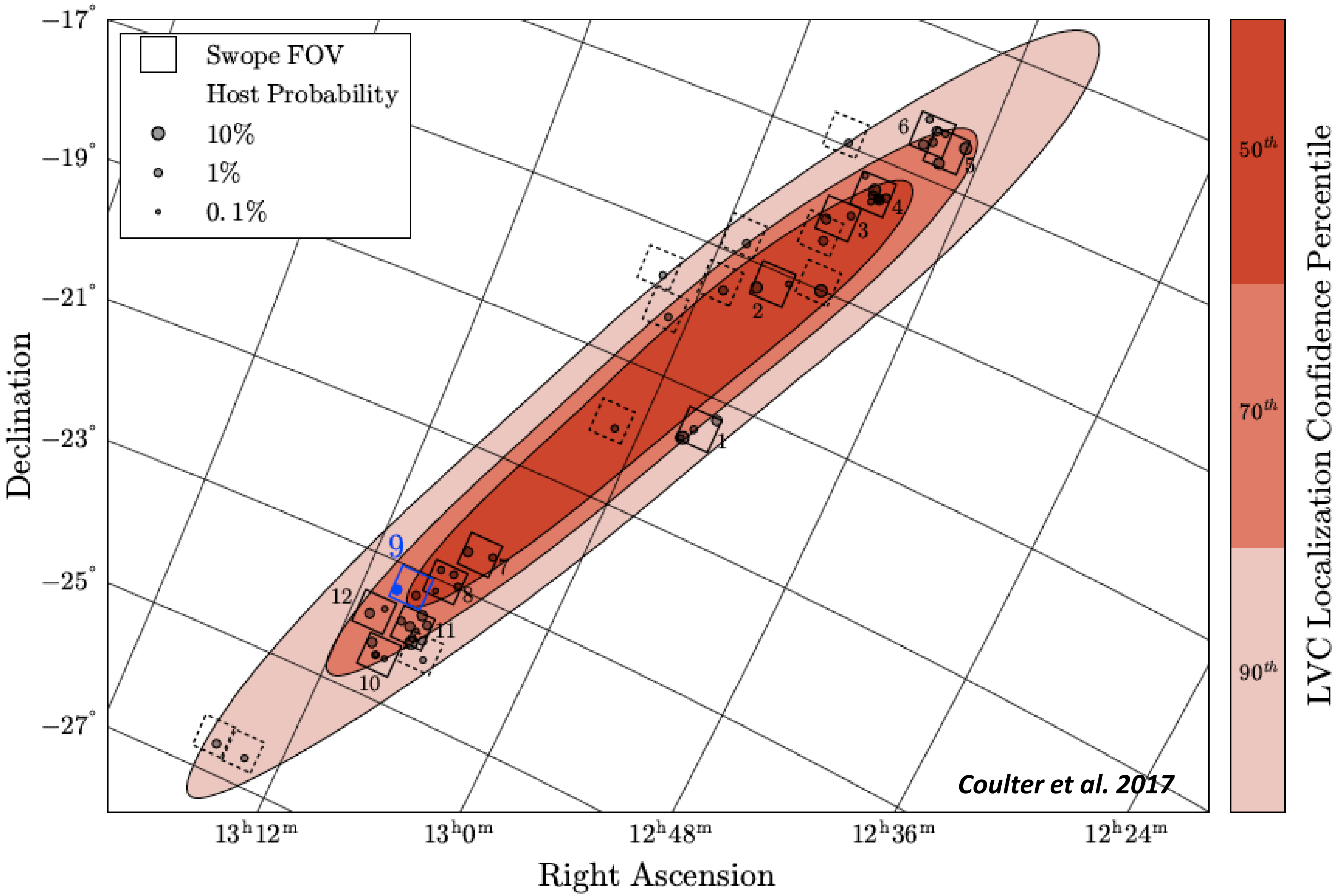
Epeak ~ 200keV
Egamma ~ 1.e46 erg

The short GRB170817A lags GW signal by 1.7s: is this timescale related to the engine or to the plasma outflow?

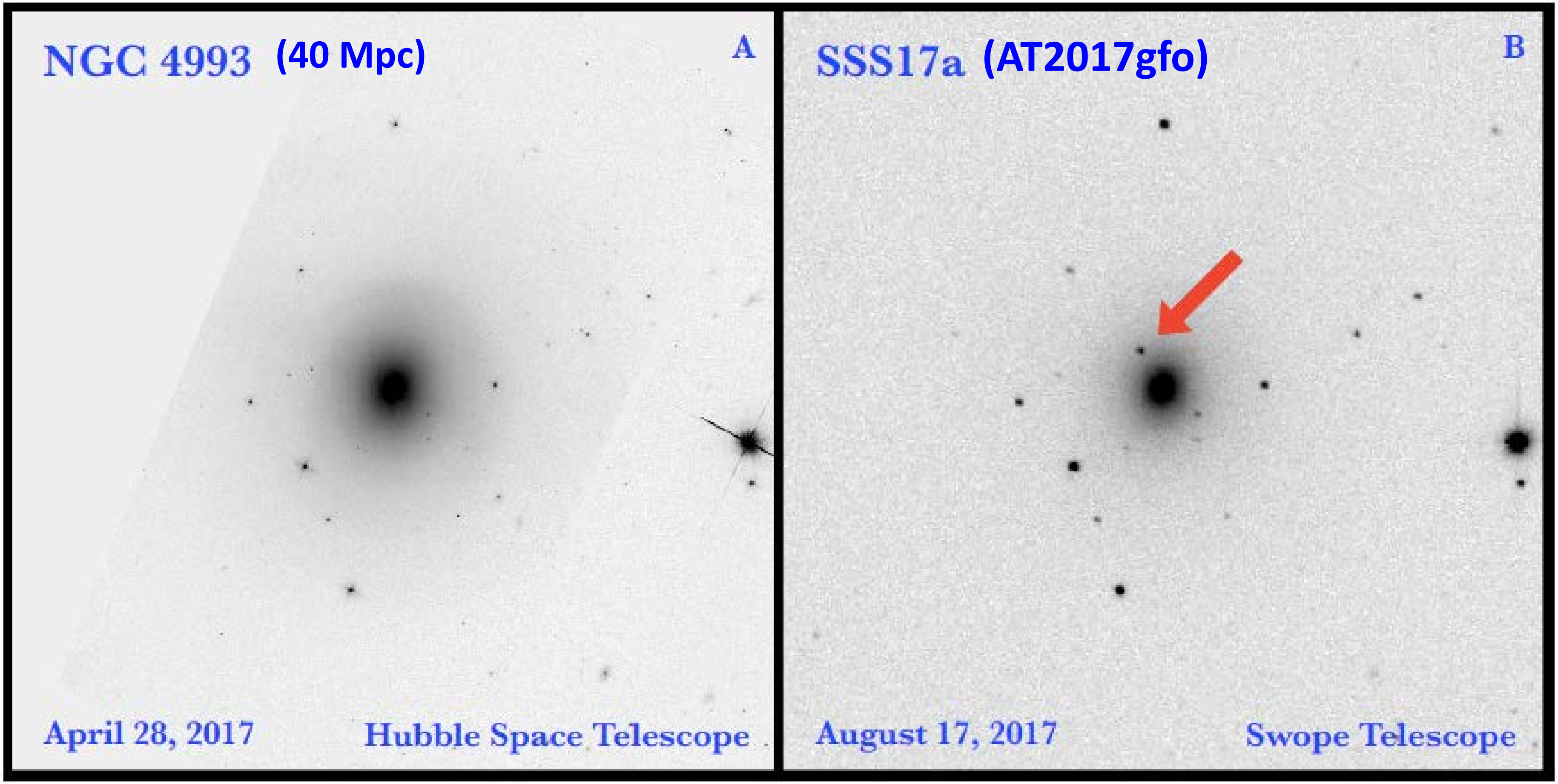
Abbott et al. 2017;
Savchenko et al. 2017;
Fermi Collaboration 2017


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



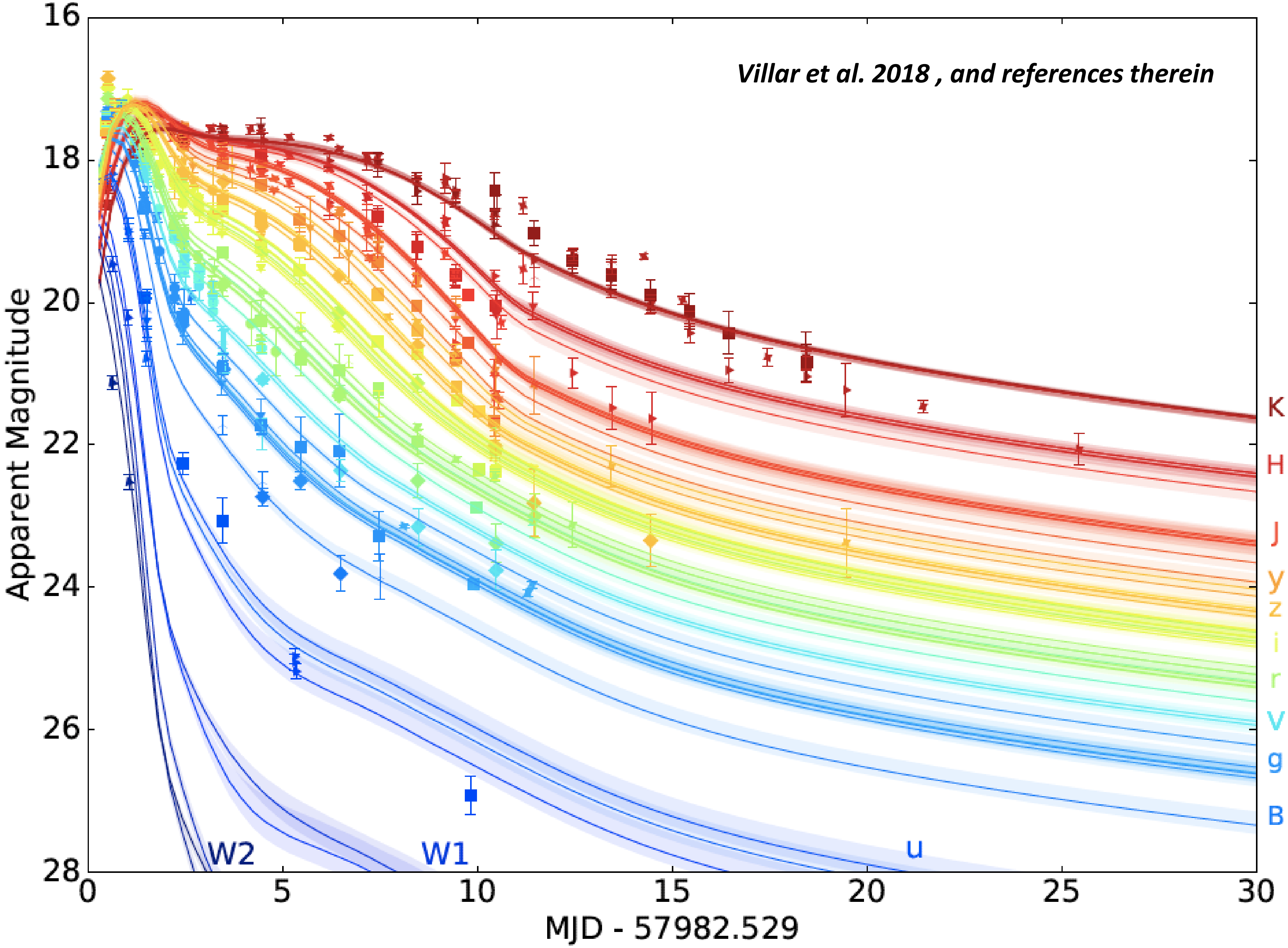
Comparison of Swope discovery image with archival HST image



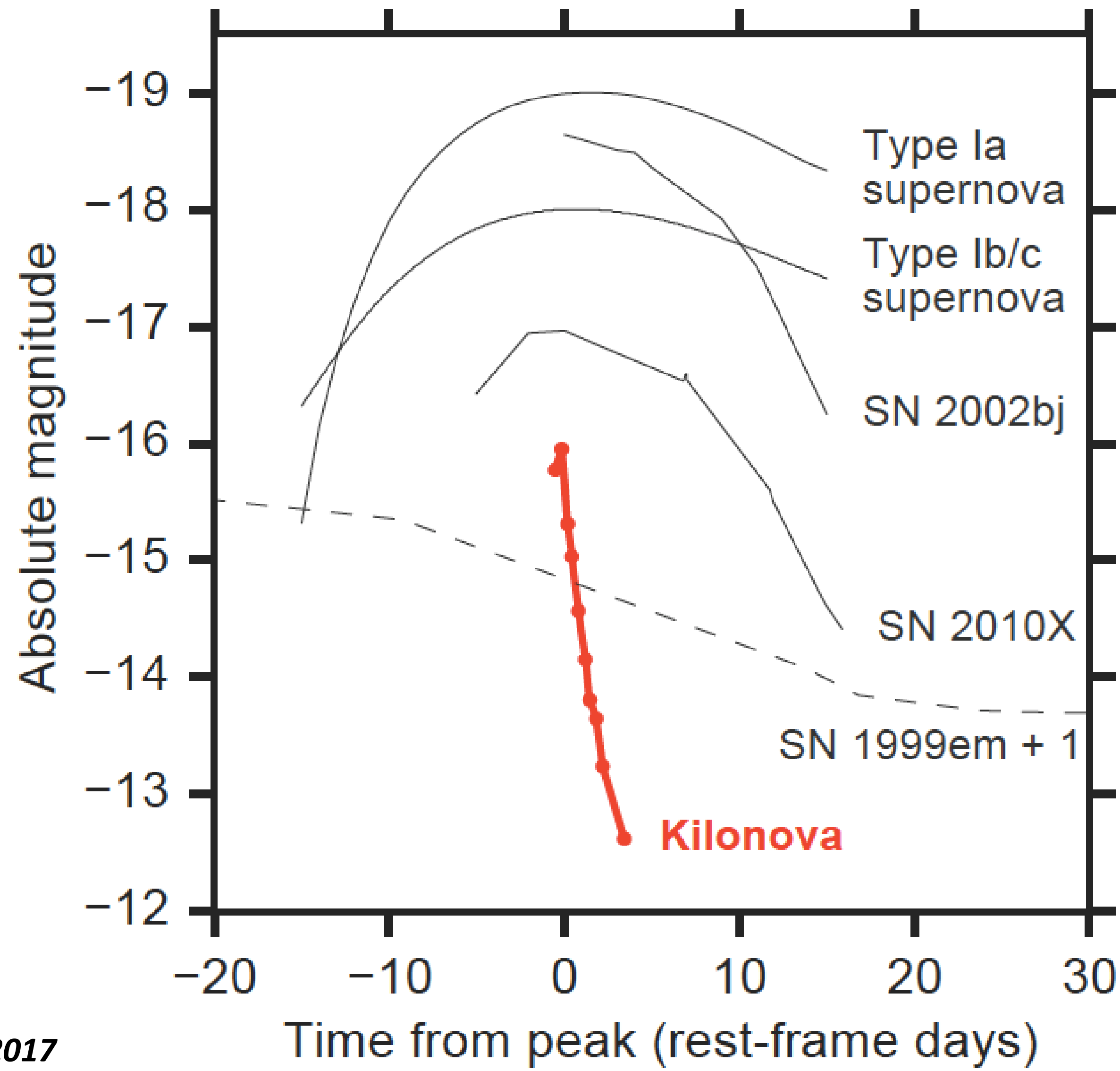
3′

Coulter et al. 2017

Optical and near-infrared light curves of GW170817 / AT2017gfo

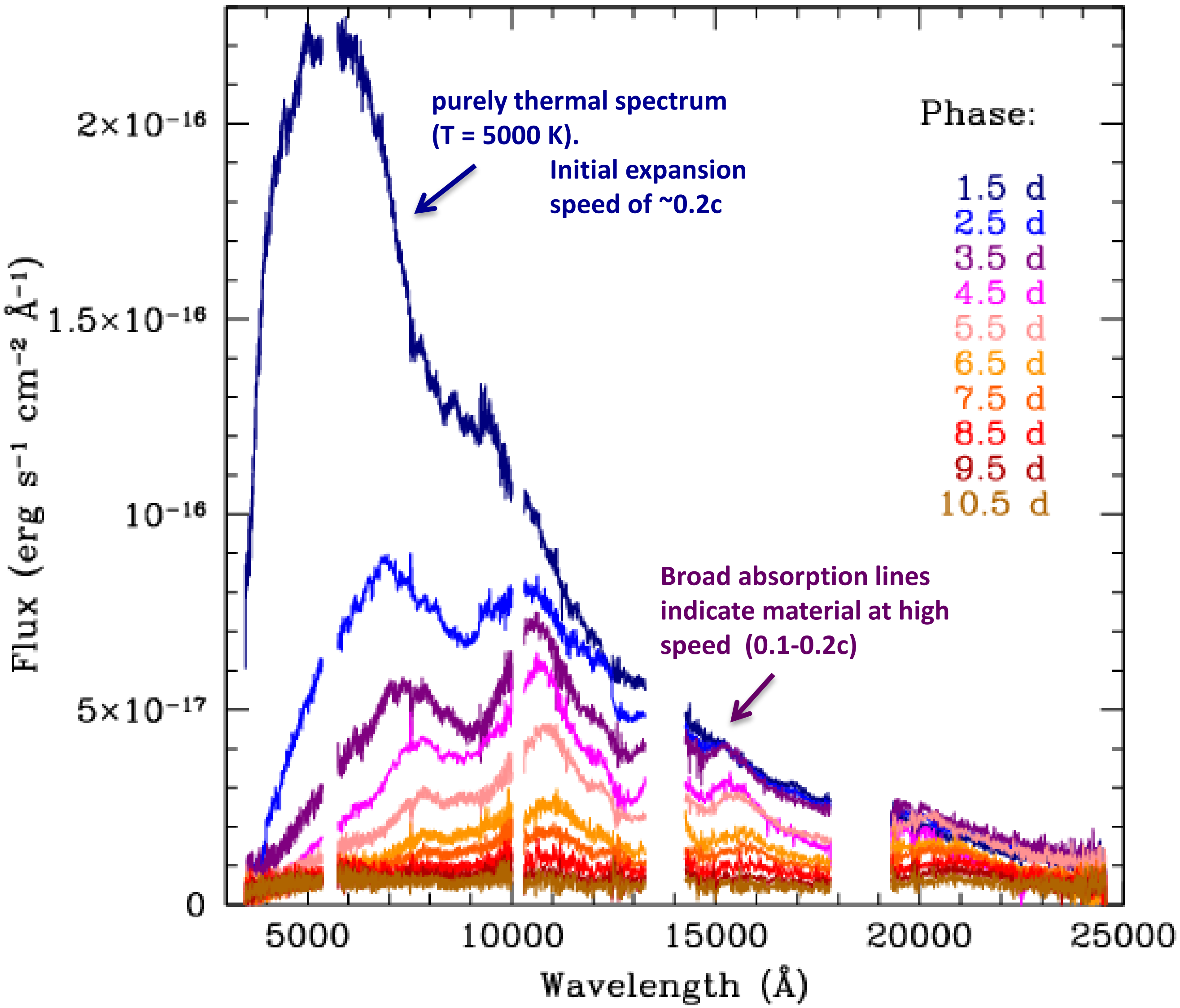


AT2017gfo evolves much more rapidly than any supernova



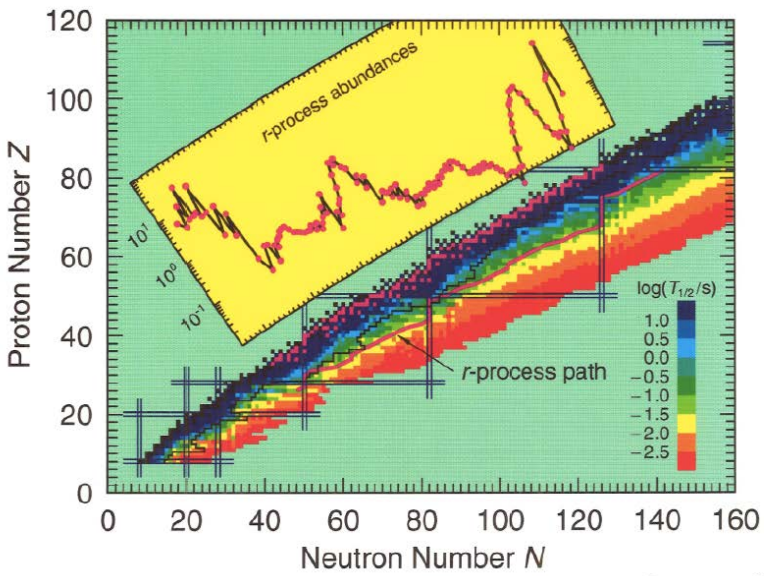
Arcavi et al. 2017

ESO VLT X-Shooter spectral sequence of kilonova GW170817

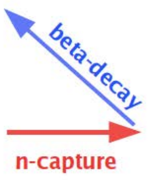


Pian et al. 2017; Smartt et al. 2017

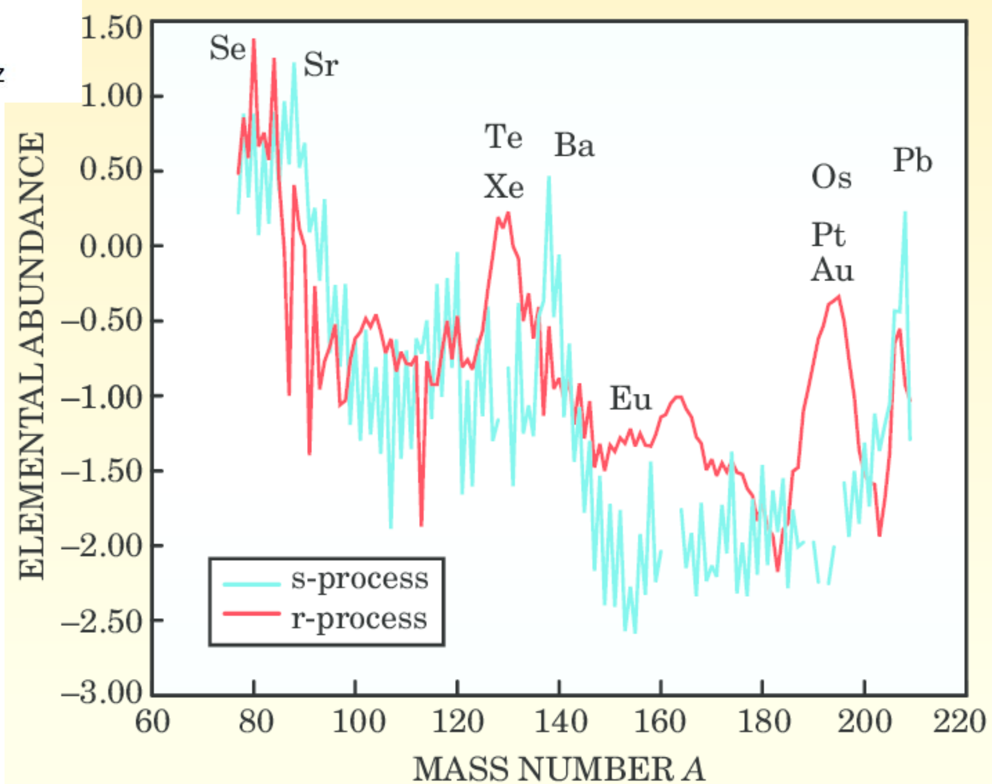
s- and r-Process Nucleosynthesis



Courtesy: K.-L. Kratz

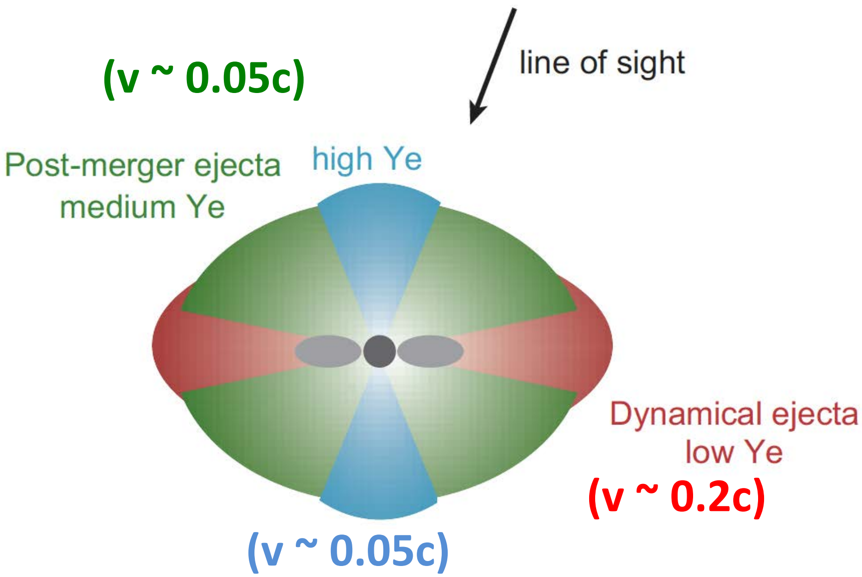


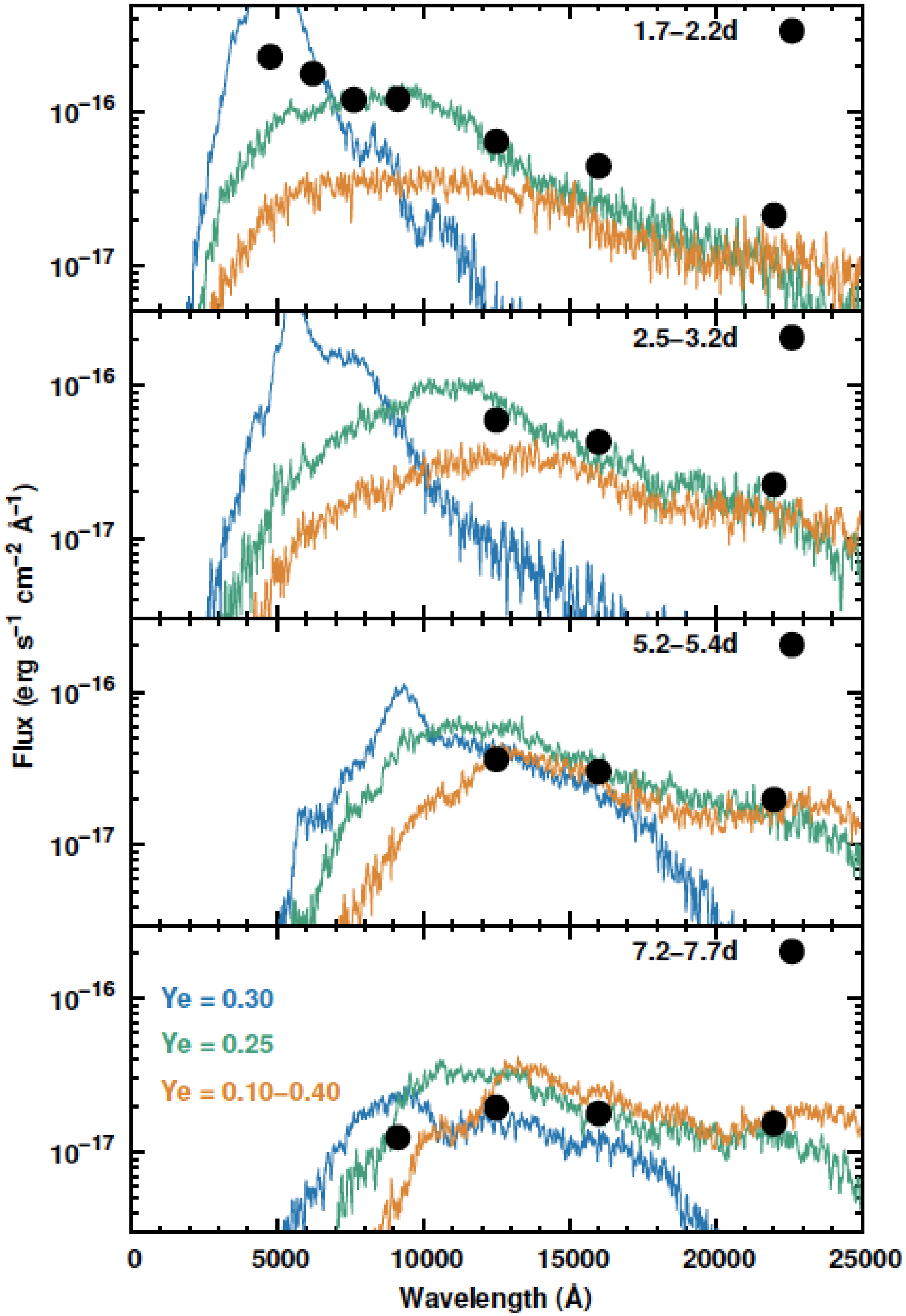
Solar system abundances of heavy elements produced by r-process and s-process neutron capture.



Geometry of 3-component model for kilonova and resulting spectra

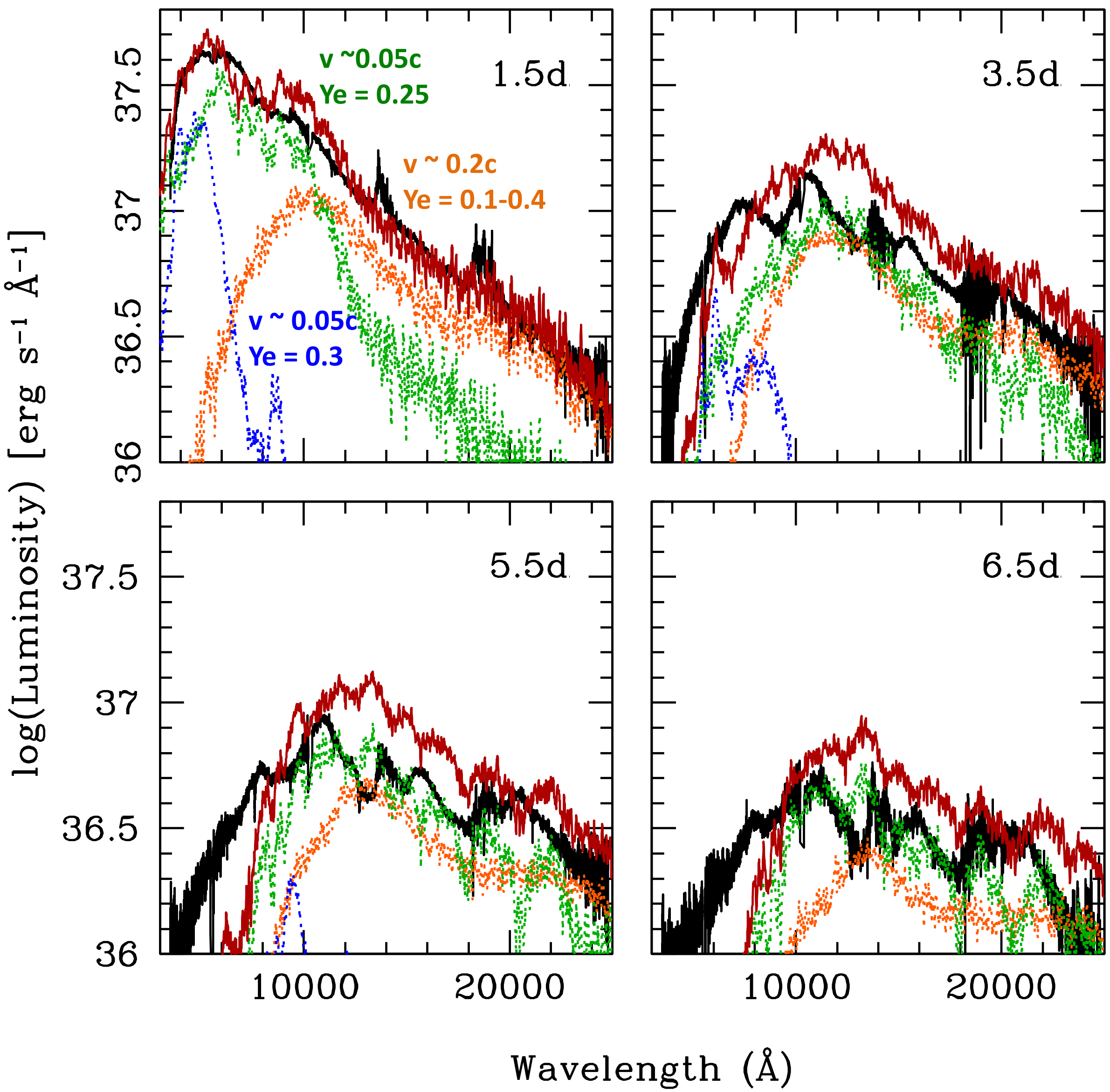
M_{ej} ~ 0.03

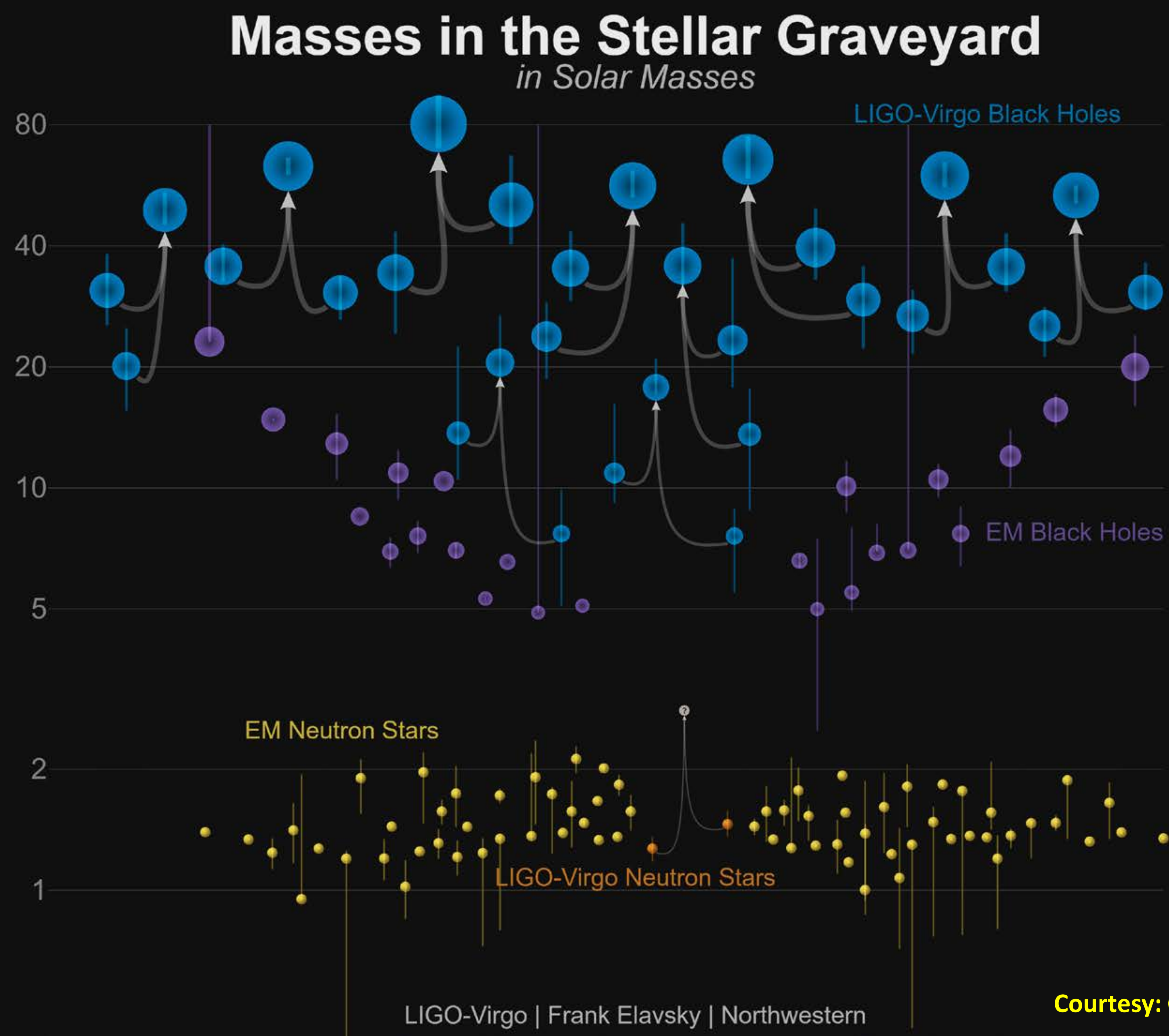




Tanaka et al. 2017, Utsumi et al. 2017

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





Courtesy: O. Birnholtz

Conclusions

Long GRBs are accompanied by energetic Ic supernovae. The supernova kinetic energy (~e52 erg) dominates the event.

Short GRBs are produced by binary neutron star mergers. They are accompanied by kilonovae with ejecta masses of 0.03-0.05 Msun.

Note that the kinetic energy of the kilonova is also orders of magnitude larger than the short GRB energy (e50 vs e46 erg in the case of GW170817).

More than one kilonova component seems to be necessary to account for the spectrum, with different proportions of species (lanthanide-rich vs lanthanide-free).

More realistic atomic models and opacities are necessary, to be used with density structure profiles, nuclear reaction networks and radiative transport codes.

Kilonova remnant still uncertain -> O3?