A lanthanide-rich kilonova in the aftermath of a long gamma-ray burst

Yu-Han Yang et al. Nature

Reporter: Yehao Cheng

12/04/2024 @SWIFAR, YNU

Outline

1. Background introduction
2. Observation properties
3. Theoretical analysis
4. Summary

1.1 Gamma-ray burst & afterglow

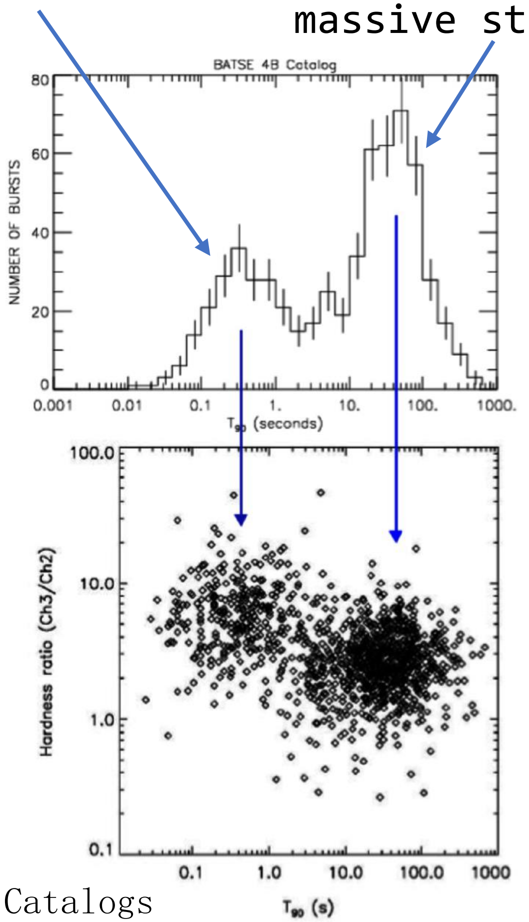
- Gamma-ray bursts are the most violent explosion in the universe , E=10^{48}–10^{52} erg.

Short duration GRB from BNS merger

Long duration GRB from massive star core collapse

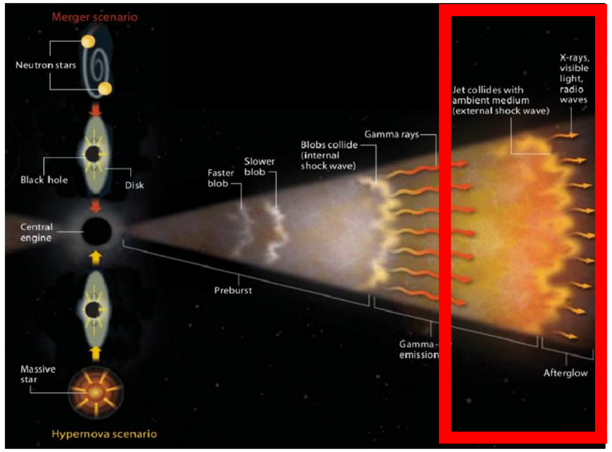
$T_{90} < 2s$

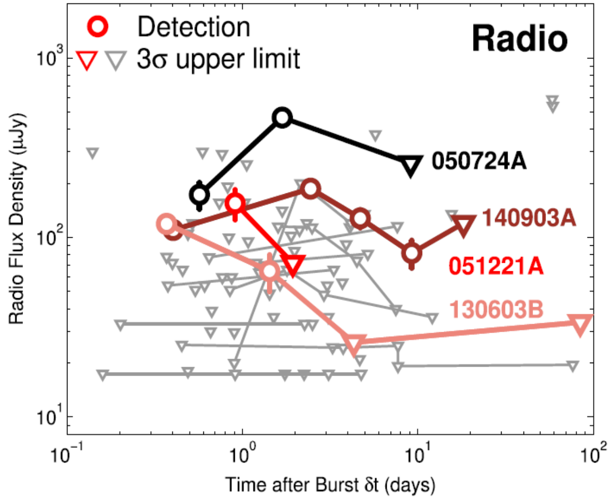
$T_{90} > 2s$

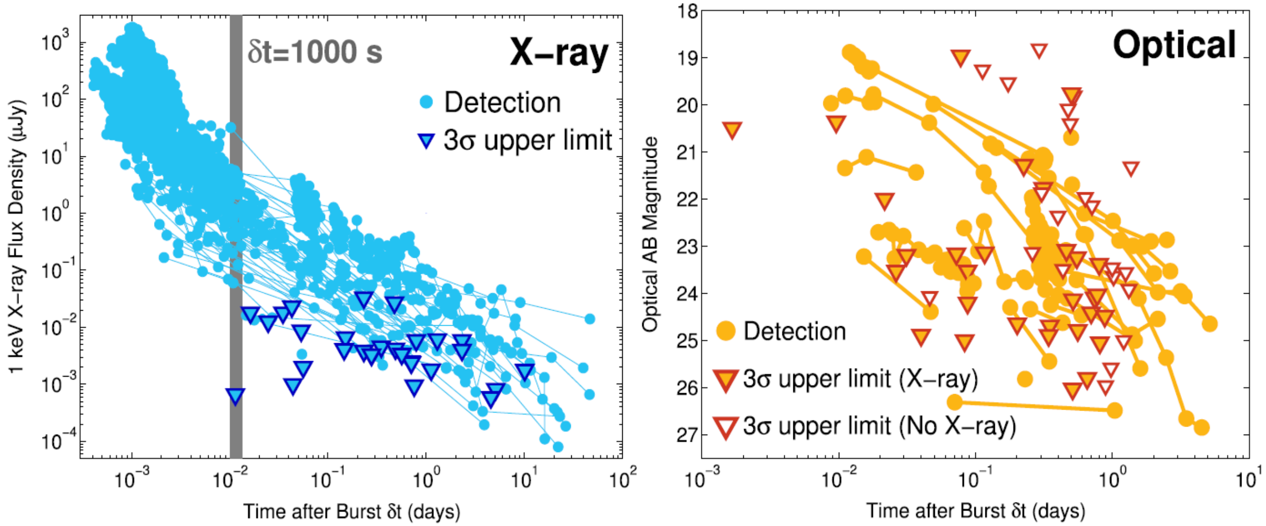


BATSE GRB Catalogs (http://gammaray.msfc.nasa.gov/batse/grb/catalog/).

Afterglow







Fong et al, 2015

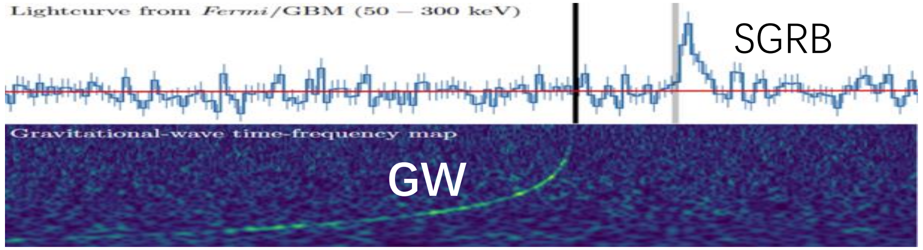
1.2 Kilonova

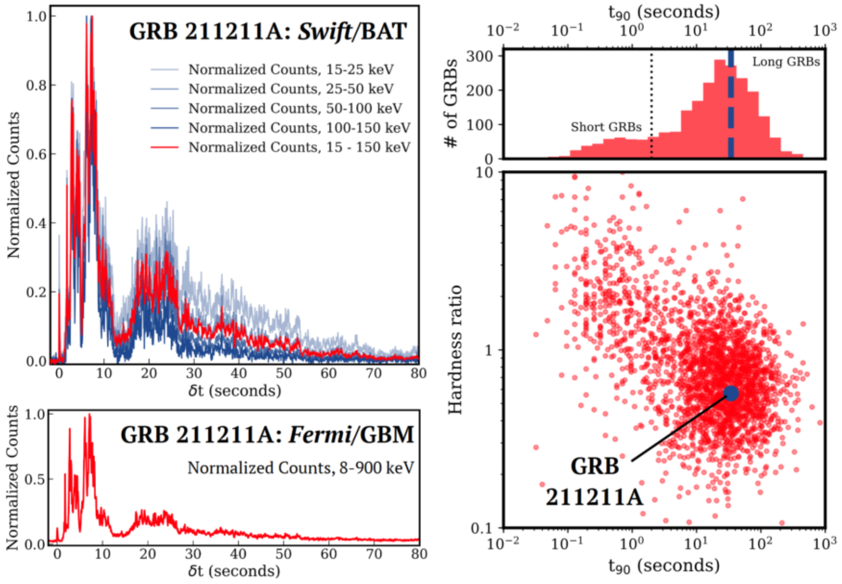
TRANSIENT EVENTS FROM NEUTRON STAR MERGERS

Li-Xin Li and Bohdan Paczyński
Princeton University Observatory, Princeton, NJ 08544-1001; lxl@astro.princeton.edu, bp@astro.princeton.edu
Received 1998 July 27; accepted 1998 August 26; published 1998 September 21

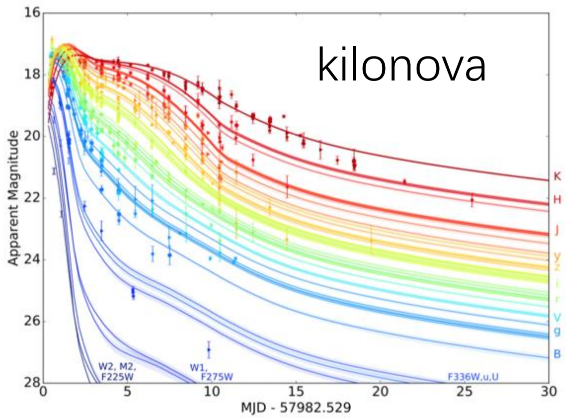
- Li & Paczyński proposed a model for transient sources produced by the merger of BNS or BHNS. (1998)

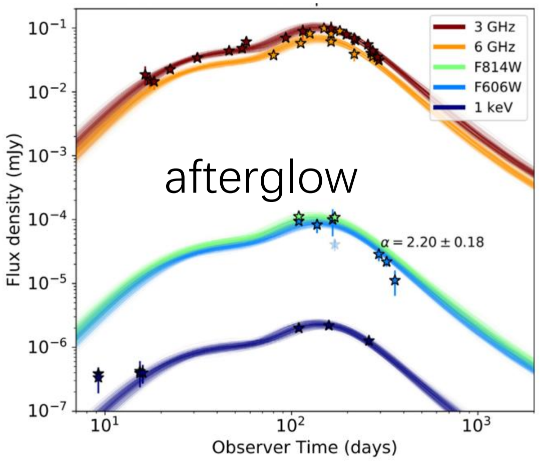
GW 170817, GRB 170817A , AT 2017gfo

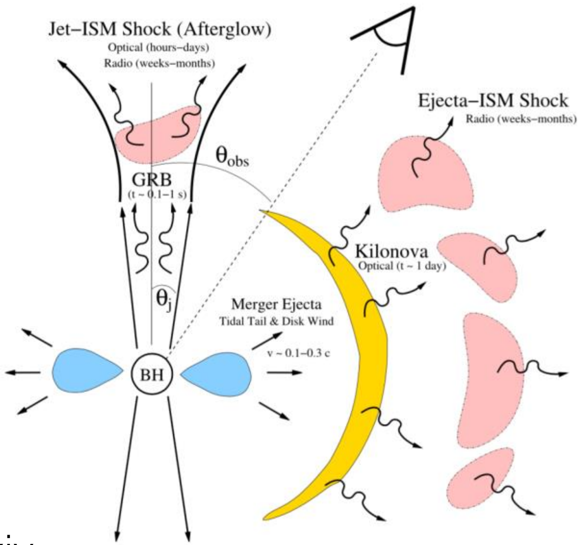


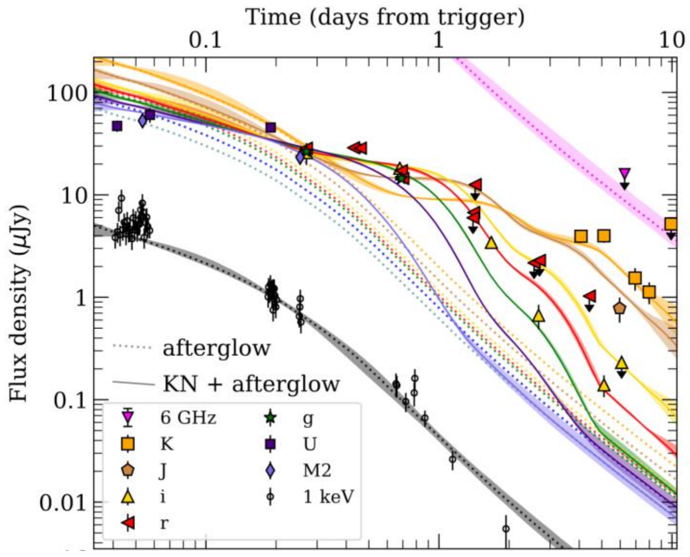


- Distance: 350 Mpc
- Minute-duration
- Spectral hardness lie close to the mean of the long-GRB population.









Villar +, 2017, ApJ; Lamb +, 2019, ApJ; Metzger 2019, Arxiv

Rastinejad et al., 2022 Nature

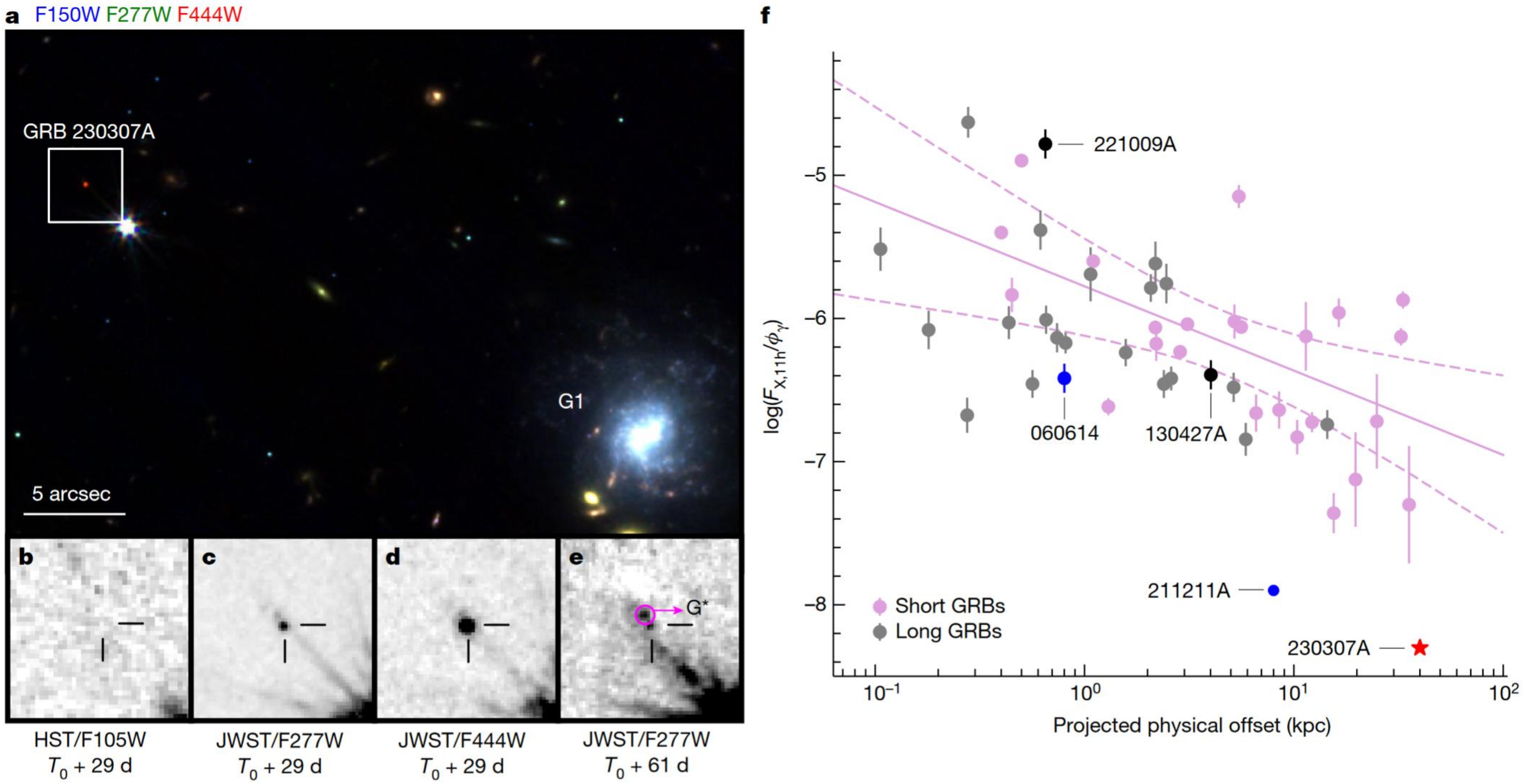
2.1 Host galaxy

GRB 230307A stands out from the general population of LGRBs for three properties:

(1) a record-setting gamma-ray fluence;

(2) a weak X-ray counterpart ;

(3) a strong blue-to-red colour evolution.



Host galaxy candidates

(1) A distant (z ≳ 3.9) star-forming galaxy (G⋆ in Fig. 1e)

(2) A local origin in the Magellanic Clouds

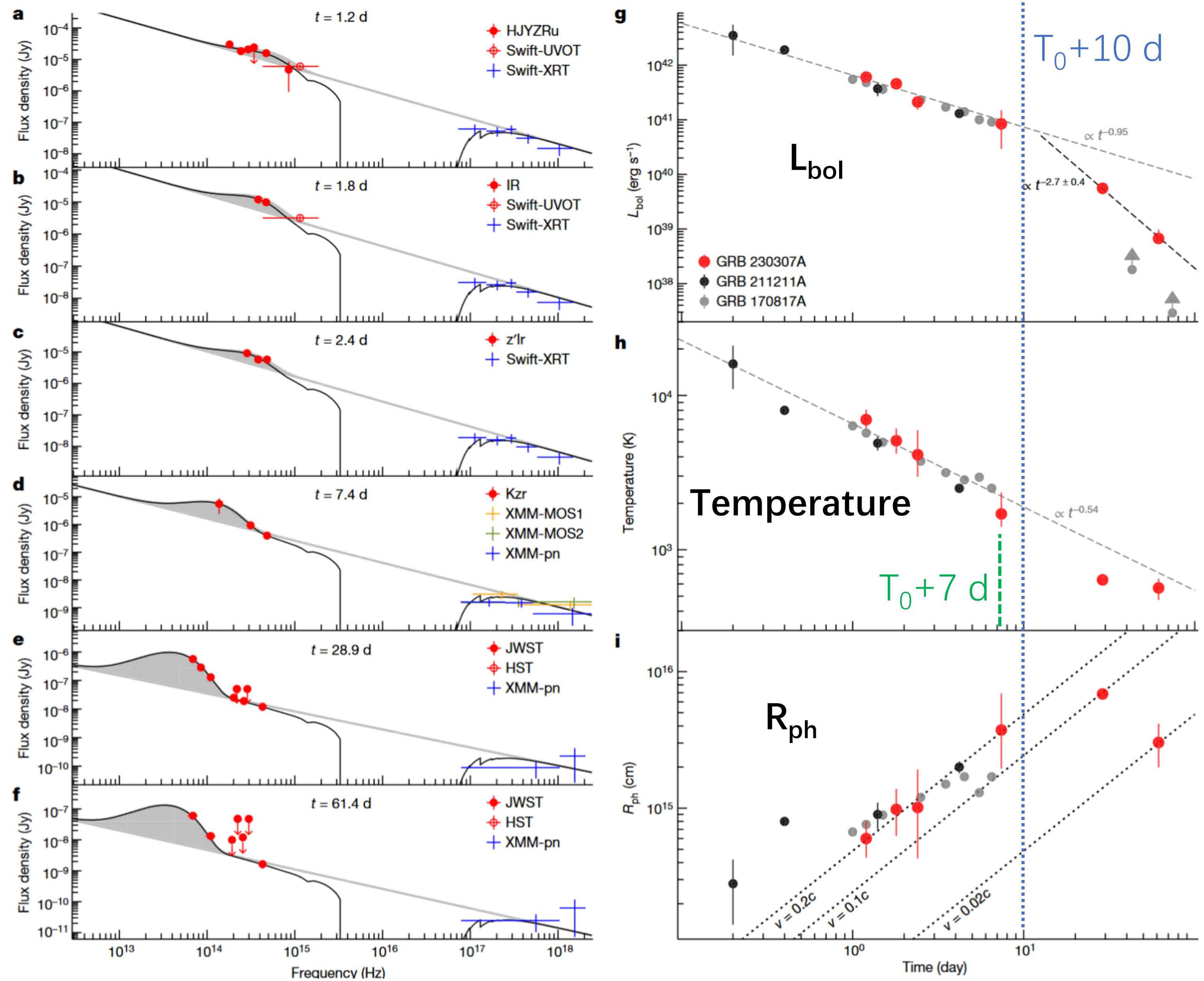
(3) A nearby (z ≈ 0.0647, 291 Mpc) face-on spiral galaxy (G1 in Fig. 1a)

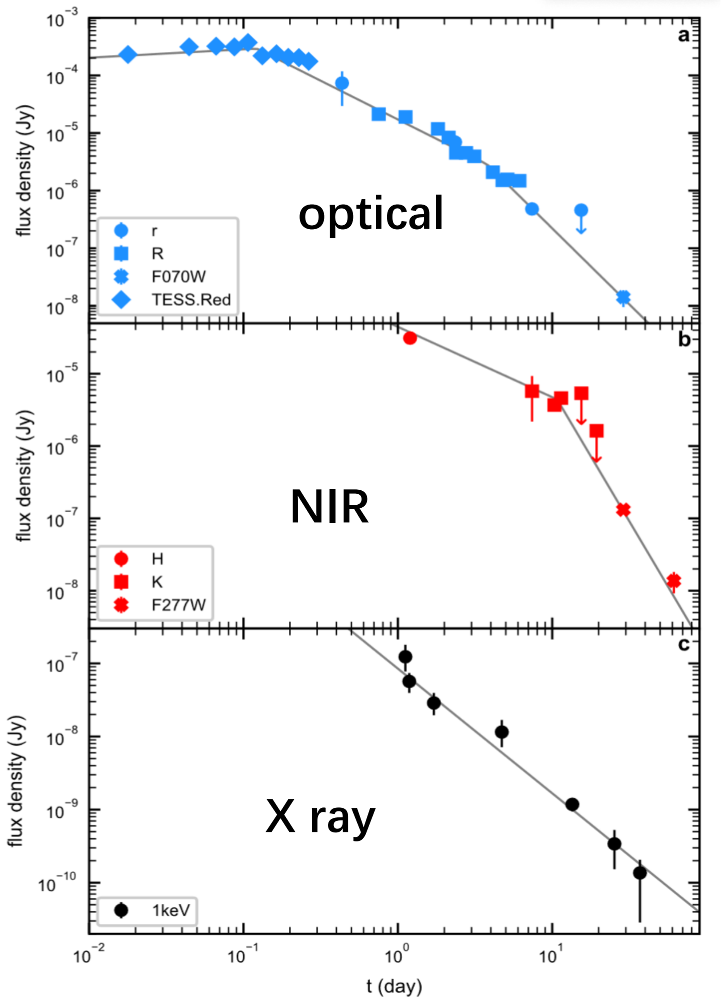
Velocity of fireball $v \approx \frac{(1+z)R_{ph}}{t} < c$

→ $z < 0.43$

2.2 SED and light curve

Blackbody component + power law





The data show that the ejecta is only partially optically thin and its late-time NIR luminosity is still dominated by photospheric emission of the inner layers.

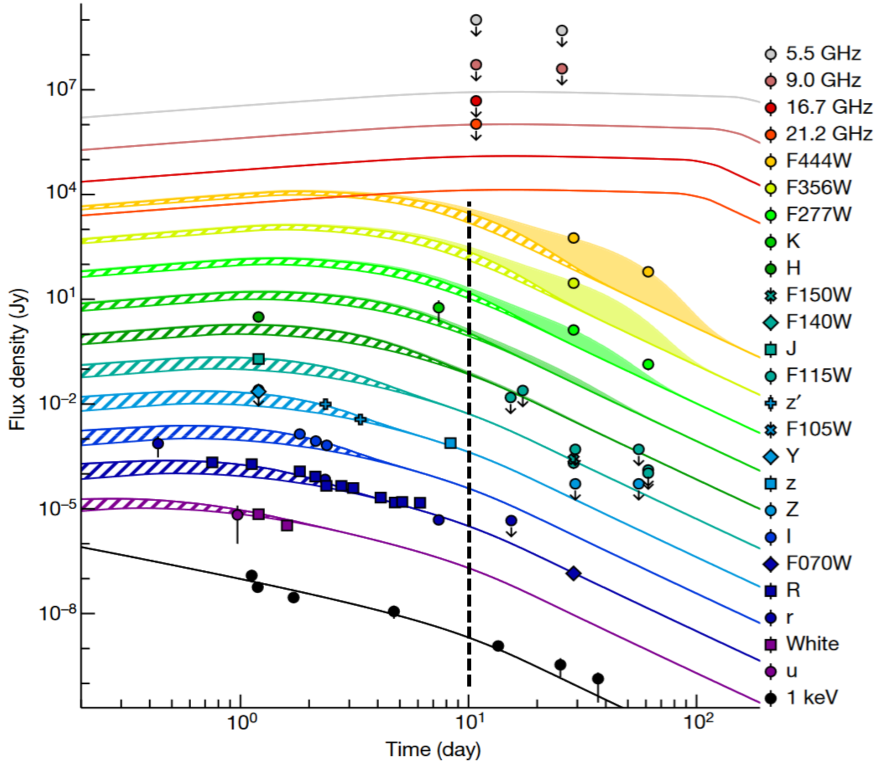
3.Theoretical analysis

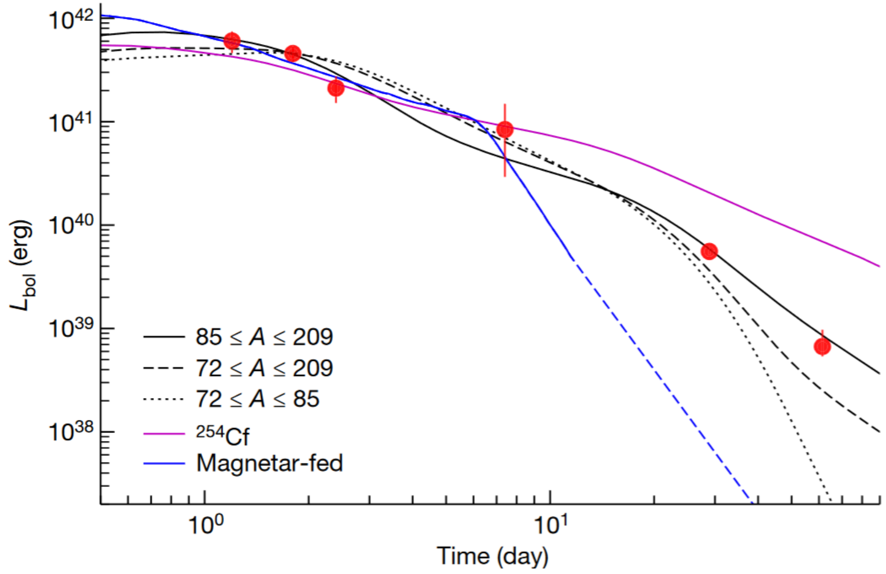
- Model : afterglow + two kilonova
- Inclusion kilonova component : Bayesian information criterion ($\Delta BIC > 140$)
- Two kilonova components : $\Delta BIC = 19$

Two kilonova components:

(1). Fast moving ejecta ($v \approx 0.2c$) with mass $M_{ej} \approx 0.03 M_{\odot}$ and opacity $\kappa \lesssim 3\ cm^2 g^{-1}$.

(2). Slower ejecta ($v \approx 0.03c$) with slightly more massive $M_{ej} \approx 0.05 M_{\odot}$ and opacity $\kappa \gtrsim 13\ cm^2 g^{-1}$





A radioactive-powered kilonova containing r-process elements beyond the first peak (atomic mass number A ≳ 85) shows a better agreement with the data.

- Bolometric luminosity
- Evolution of the photospheric radius
- The inferred high opacity

Points to lanthanide production in the merger ejecta, and confirms kilonovae are a cosmic site of heavy r-process elements

4. Summary

1. The afterglow is produced from the relativistic shock and their interaction with the ambient medium.

2. The kilonovae are powered by the radioactive decay of nuclei heavier than iron, thought to be synthesized in the merger of two compact objects.

3. An extremely bright burst, GRB 230307A occurred at a nearby (291Mpc) face-on spiral galaxy.

4. The counterpart of GRB 230307A can be described by afterglow plus two kilonova components.

(1)The first component mostly contributes to the optical and NIR emission over the first few days, then quickly fades away.

(2) This component becomes visible after about T_0 + 10 d and dominates the late-time emission

5. The bolometric lightcurve, coupled with the observed evolution of the photospheric radius and the inferred high opacity, points to lanthanide production in the merger ejecta.

Thanks!