FIFTEENTH MARCEL GROSSMANN MEETING
ROME, 1-7 JULY, 2018

Sketching **GRB 170817A / AT 2017 gfo** by **Data** *and* **Binary System**

Yu Wang

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Prompt5 (Valenti et al., 2017), MASTER (Lipunov et al., 2017), Swope (Drout et al., 2017; Villar et al., 2017), Magellan (Drout et al., 2017), VISTA (Tanvir et al., 2017), LCO (Arcavi et al., 2017), REM (Pian et al., 2017), Gemini-S (Kasliwal et al., 2017), Swift (Evans et al., 2017; Cowperthwaite et al., 2017), Subaru (Utsumi et al., 2017), PAN-STARRS (Smartt et al., 2017), skymapper (Andreoni et al., 2017), AST3-2 (Villar et al., 2017; Hu et al., 2017), IRSF(Utsumi et al., 2017), SAAO (Troja et al., 2017), NTT (Drout et al., 2017), T80S (D´ıaz et al., 2017), LaSilla (Smartt et al., 2017), VLT (Tanvir et al., 2017), CTIO (Troja et al., 2017; Kasliwal et al., 2017), PAN-STARRS (Smartt et al., 2017), B&C (Utsumi et al., 2017), SSO (Troja et al., 2017), zadko (Andreoni et al., 2017), Gemini (Troja et al., 2017; Kasliwal et al., 2017), du Pont (Drout et al., 2017), RC-1000 (Pozanenko et al., 2018), Keck (Drout et al., 2017), HST (Tanvir et al., 2017; Troja et al., 2017)

Data

Two Approaches

Black Hole - Black Hole
Neutron Star - White Dwarf
Black Hole - Neutron Star
Neutron Star - Neutron Star
White Dwarf - White Dwarf
Black Hole - White Dwarf

Binary Stars

Sketching **KILONOVA** *on* **WHITE PAPER**

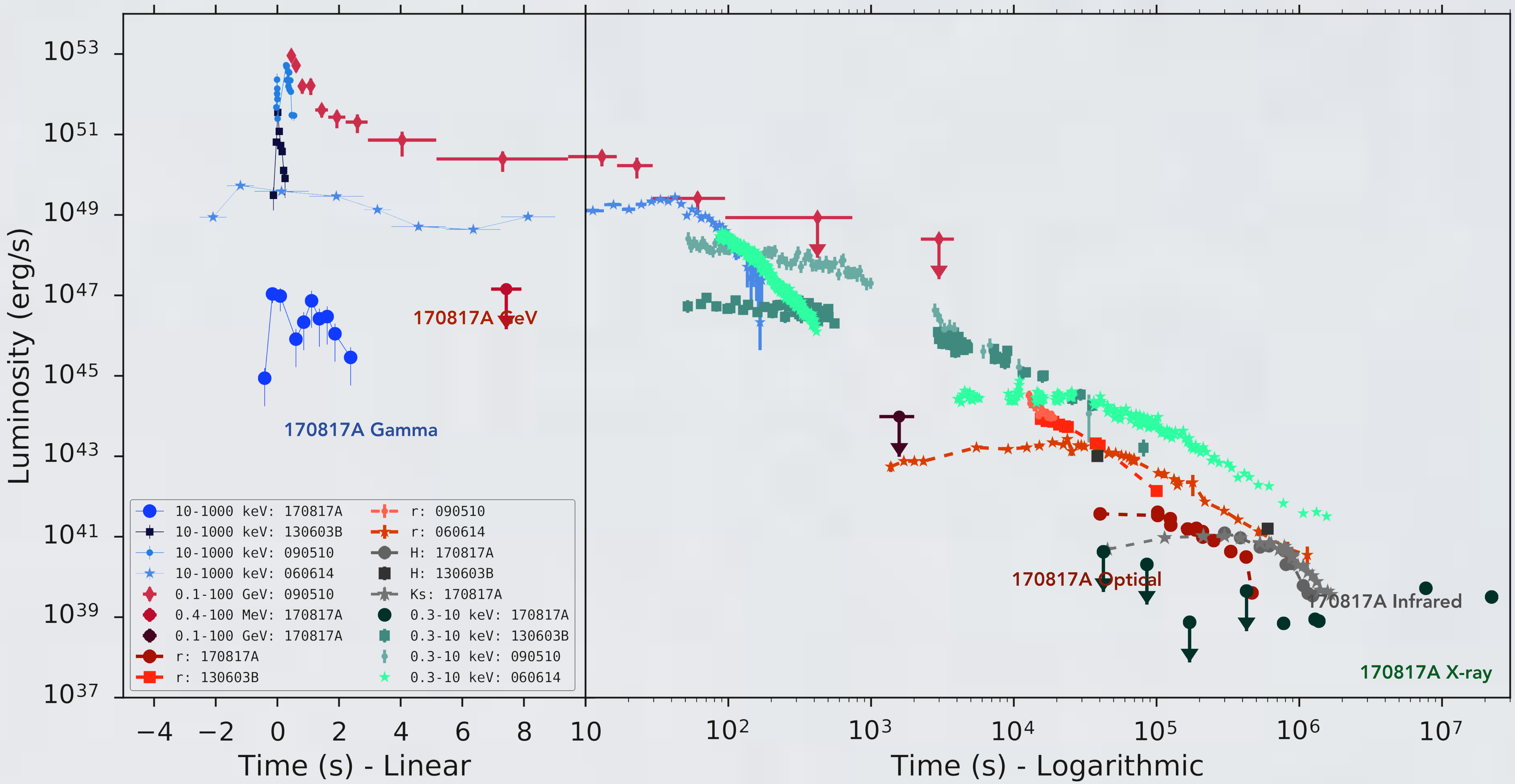
DATA

The detailed optical and infrared data gives us an opportunity to explore the kilonova in an observation-oriented way.

We start without employing any previously presumed astronomical models. We try to go as far as the data may guide, to obtain more information of the kilonova system.

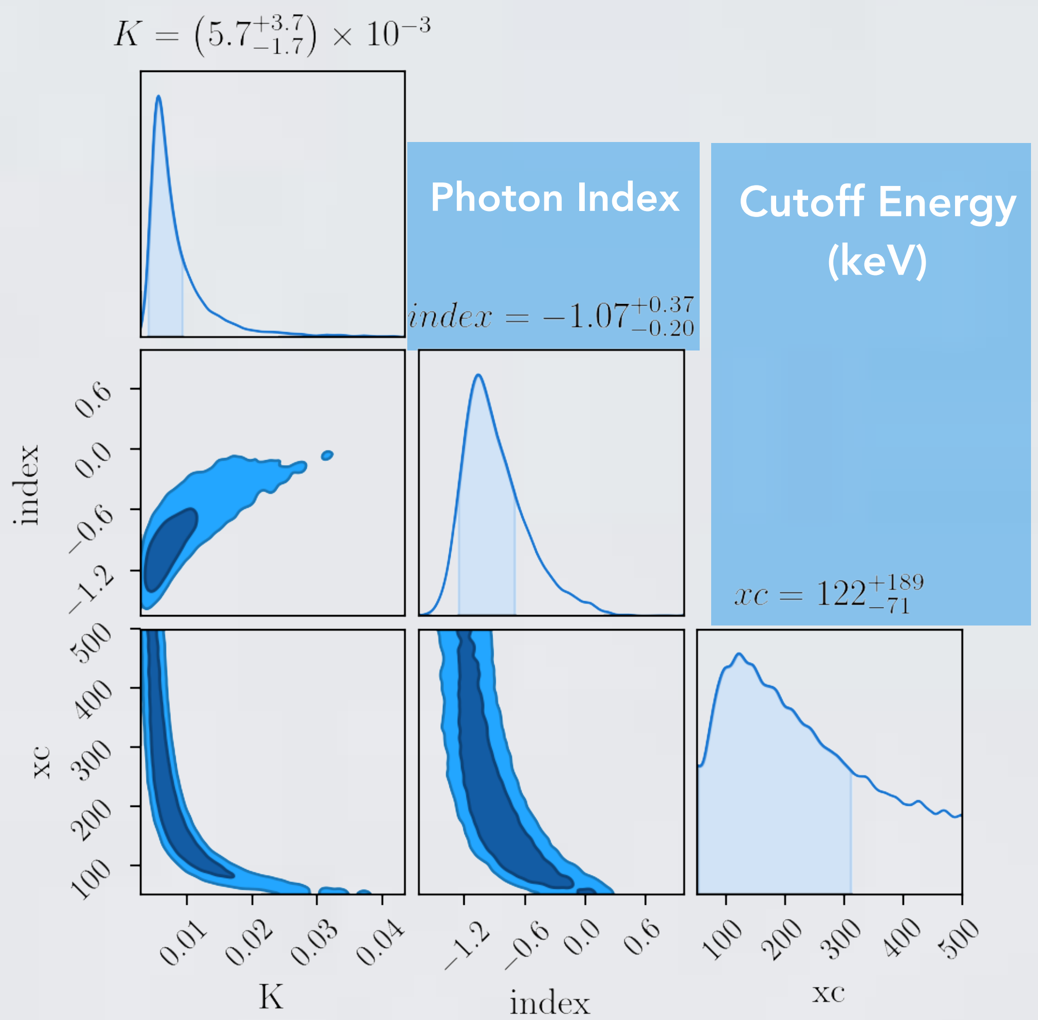
DATA

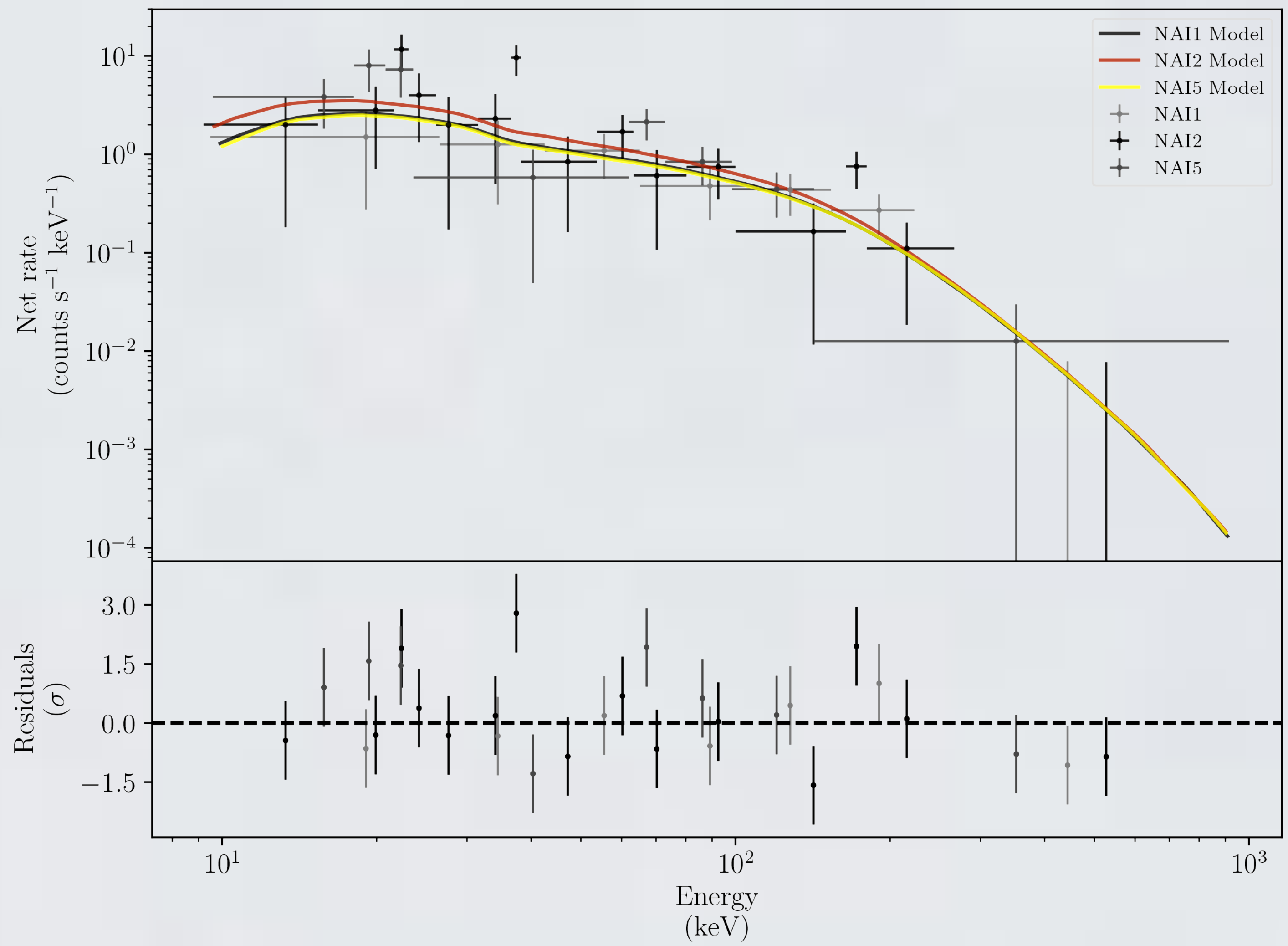
Light-Curve



The best observed short GRB 090510, the kilonova candidates GRB130603B and 060614: The infrared of 170817A indicates it has a kilonova counterpart similar to others. The GeV, gamma-ray, X-ray and optical differ from others.

Spectrum - Prompt 1/2 (-0.2 - 0.8 s)

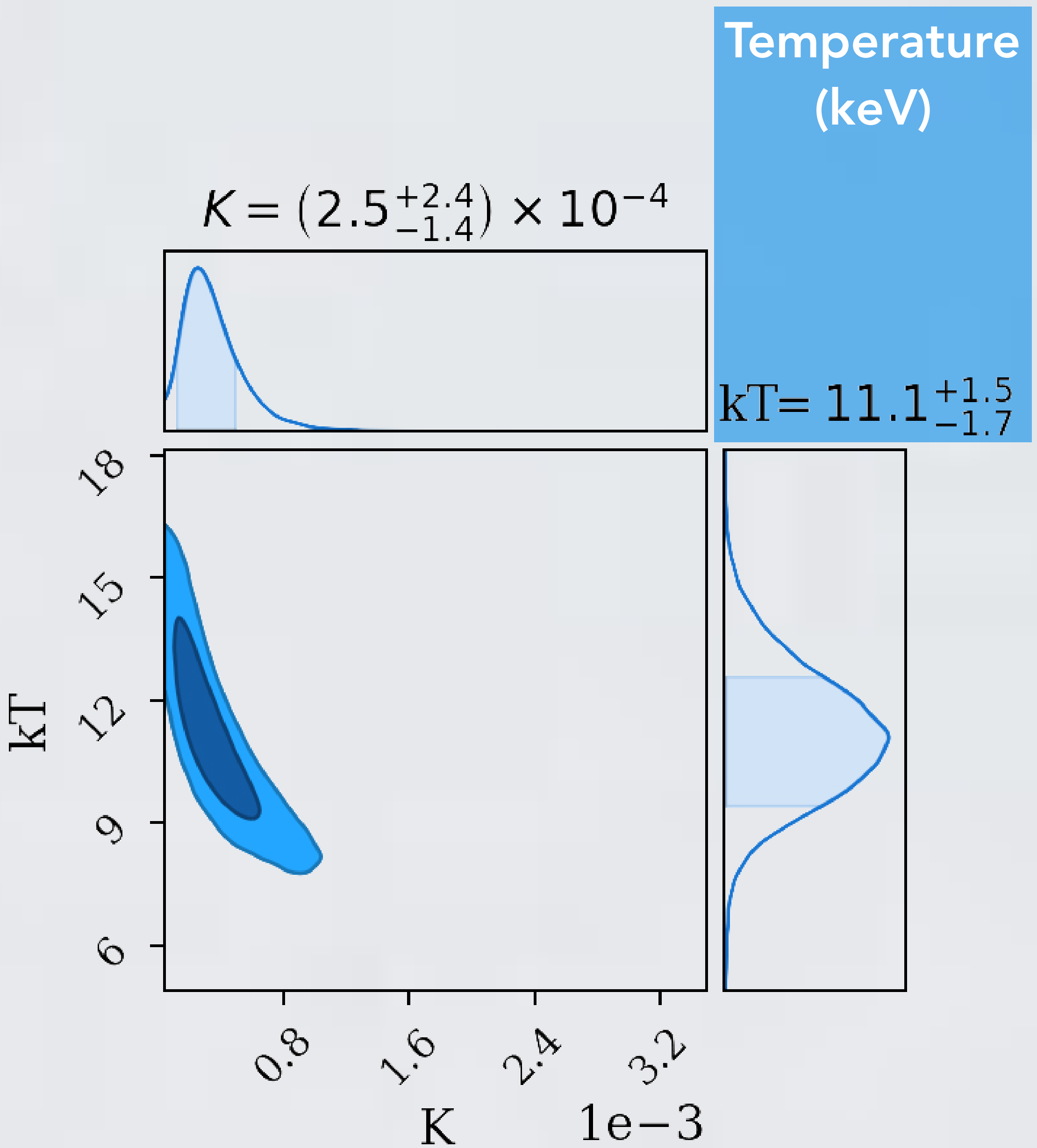


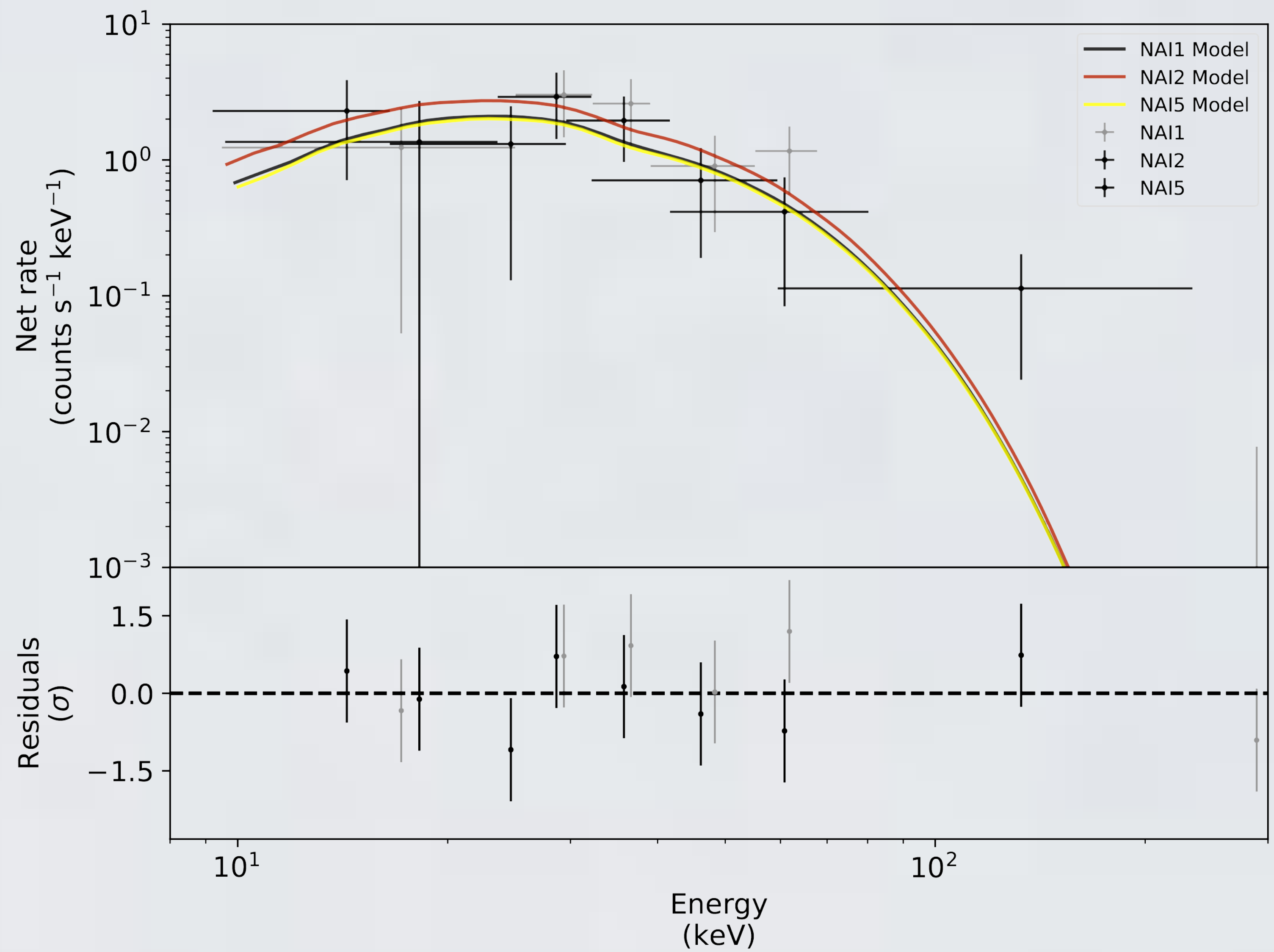


A cutoff power-law fitting of the first spike of the prompt emission, the cutoff energy ~ 200 keV.

DATA

Spectrum - Prompt 2/2 (0.8 - 1.8 s)



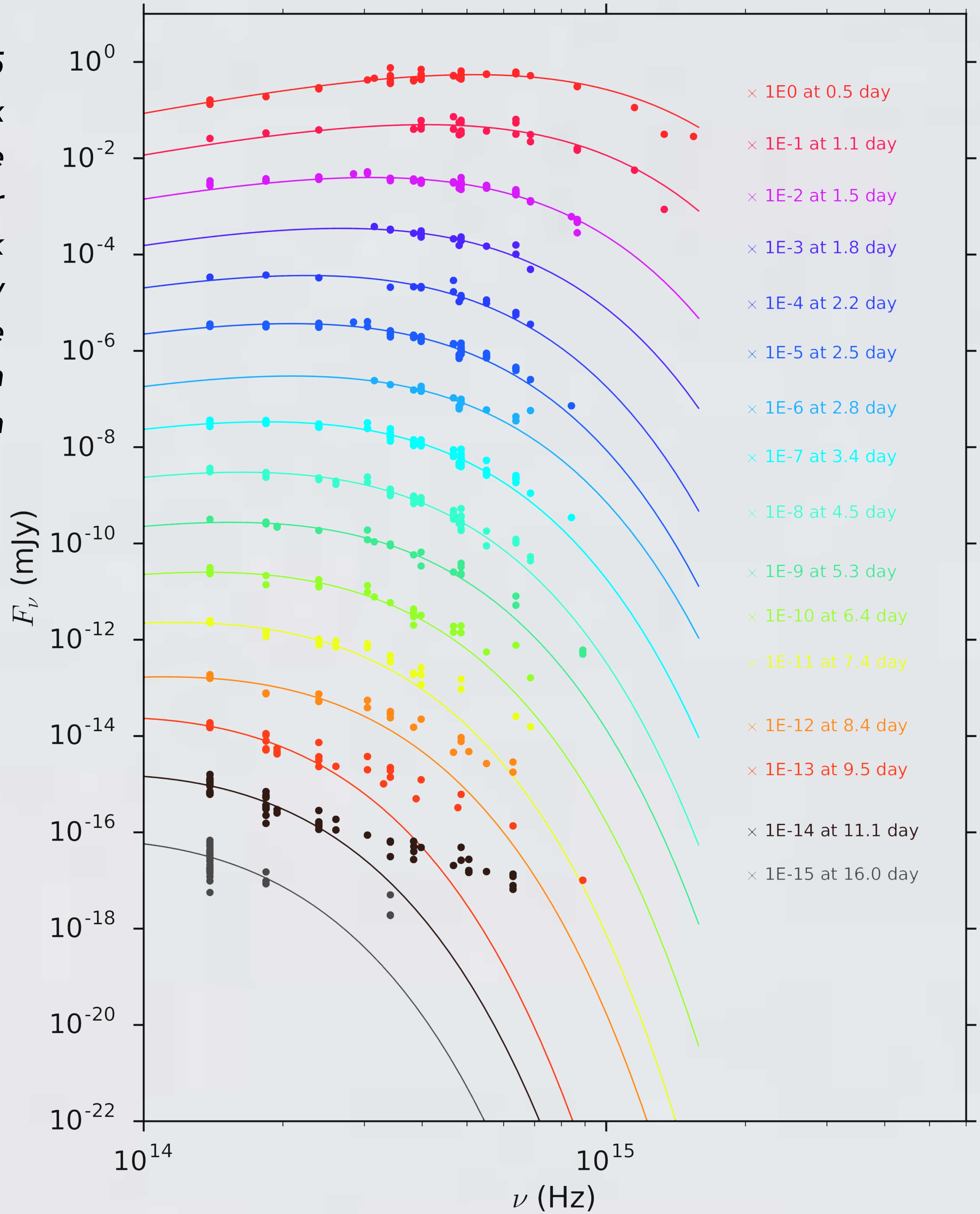


A blackbody fitting for the second spike of the prompt emission, the effective temperature is 11 keV.

DATA

Spectrum - Optical & Infrared (0.5 - 16 day)

Spectral evolution from ~ 0.5 day to ~ 16 day, the flux densities at different days are re-scaled to have a clear demonstration. The thick lines indicate the blackbody spectra, which well fit the data before ~ 7 days, then starts to deviate for the high frequency bands.

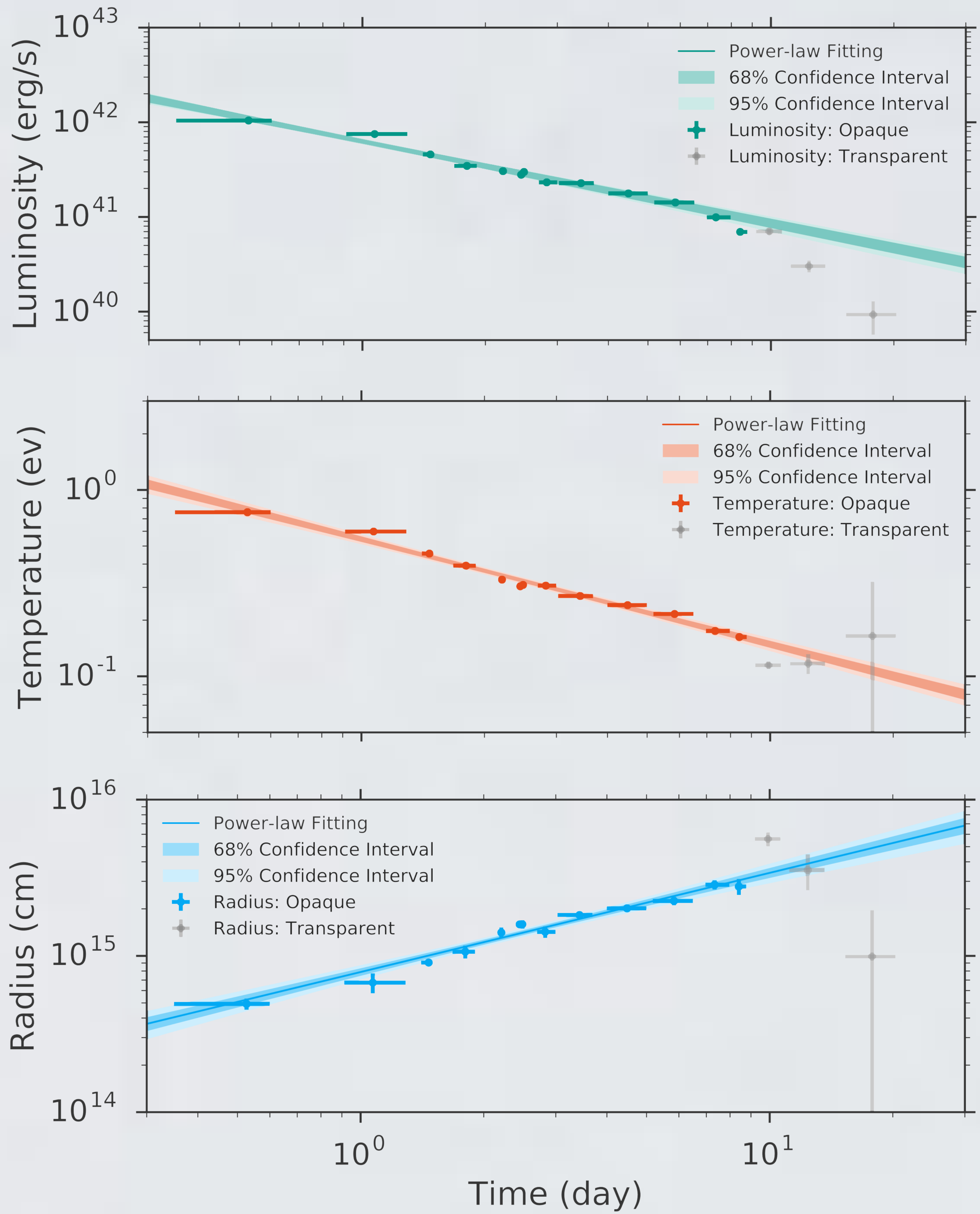


Credit: Data are retrieved from kilonova.space, maintained by James Guillochon. Thanks to the lessons from the GRAD MAP winter school.

DATA

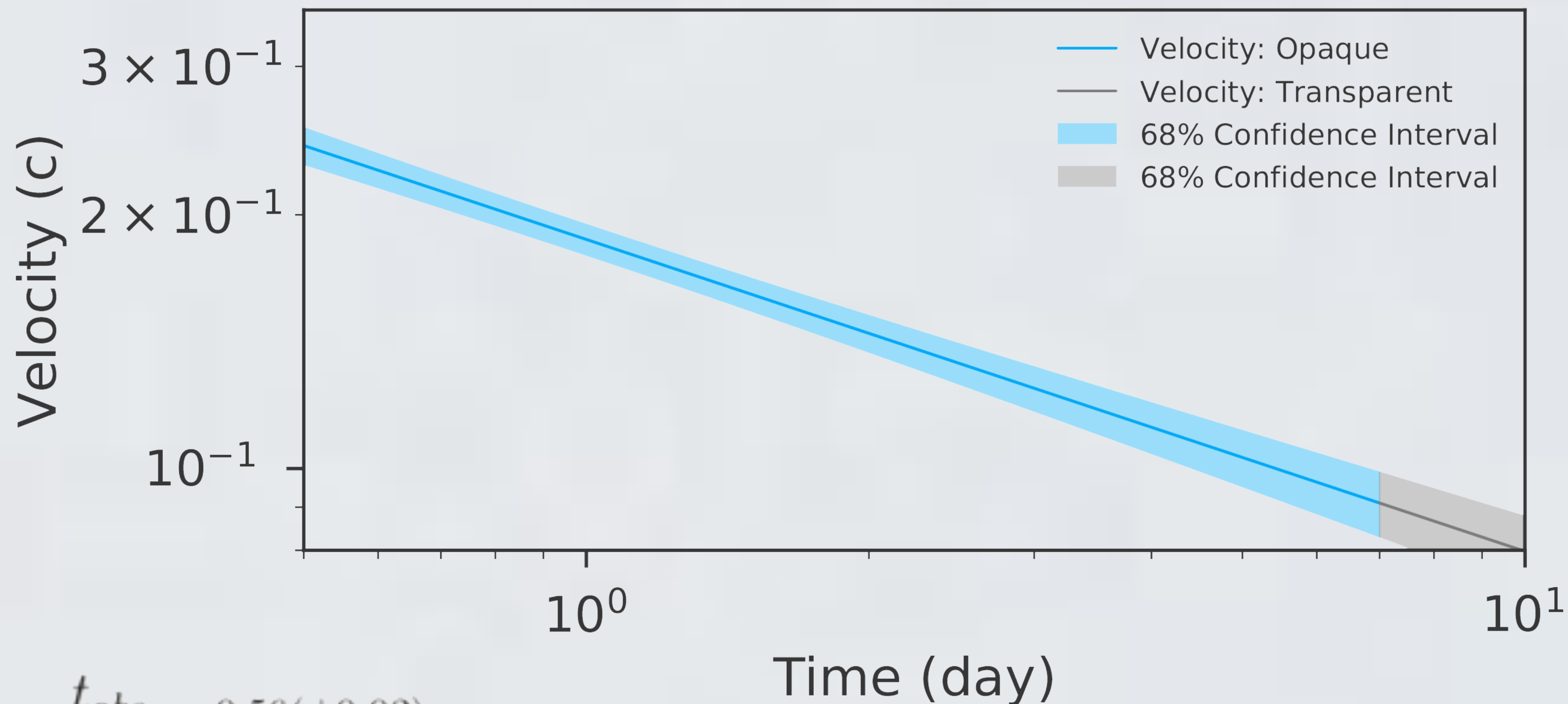
Spectrum - Optical & Infrared (0.5 - 16 day)

The evolution of the bolometric luminosity, temperature, and effective radius from the blackbody fitting. The deviation after ~ 7 days is a result of the system starting to deviate from the thermal equilibrium. During ~0.5 to ~7 days, the bolometric thermal luminosity decreases from 10^{42} erg s^{-1} to 10^{41} erg s^{-1}, the fitted temperatures drops from 1 eV to 0.1 eV. The effective radius inferred expands from 3×10^{14} cm to 3×10^{15} cm.



Velocity from dR/dt

For the data-covered time region (0.5 – 7 day), the observed velocity decreases from 0.24c to 0.09c, corresponding to the Lorentz factor 1.03 and 1.004.



$$T_{obs} = 6435(\pm123.58) \times (\frac{t_{obs}}{\mathrm{day}})^{-0.56(\pm0.02)}\ \mathrm{K}$$

$$L_{bol} = 6.60(\pm0.38) \times 10^{41} \times (\frac{t_{obs}}{\mathrm{day}})^{-0.95(\pm0.05)}\ \mathrm{erg/s}$$

$$R_{obs} = 0.77(\pm0.02) \times 10^{15} \times (\frac{t_{obs}}{\mathrm{day}})^{0.63(\pm0.04)}\ \mathrm{cm}$$

$$\beta_{obs} = \frac{dR_{obs}}{dt_{obs}} = 0.187(\pm0.008) \times (\frac{t_{obs}}{\mathrm{day}})^{-0.37(\pm0.04)}\ \mathrm{c}$$

Tracing Back to The First Second

The thermal spectrum of optical and infrared data tells that the photosphere is moving in a low-relativistic regime from 0.5 to 7 days. Therefore, the observed evolutionary properties of the temperature, the radius and the velocity can be treated the same as in the co-moving frame.

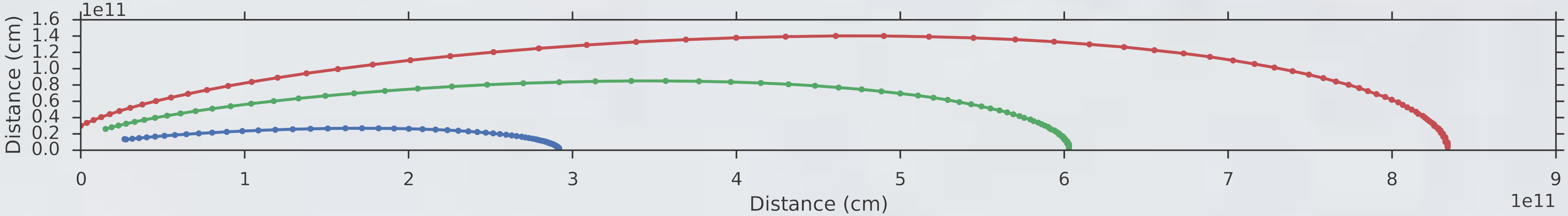
We are safe to assume the Lorentz factor and the co-moving temperature decrease as the laboratory radius expands,

$$\Gamma \propto R^{-1.17}$$

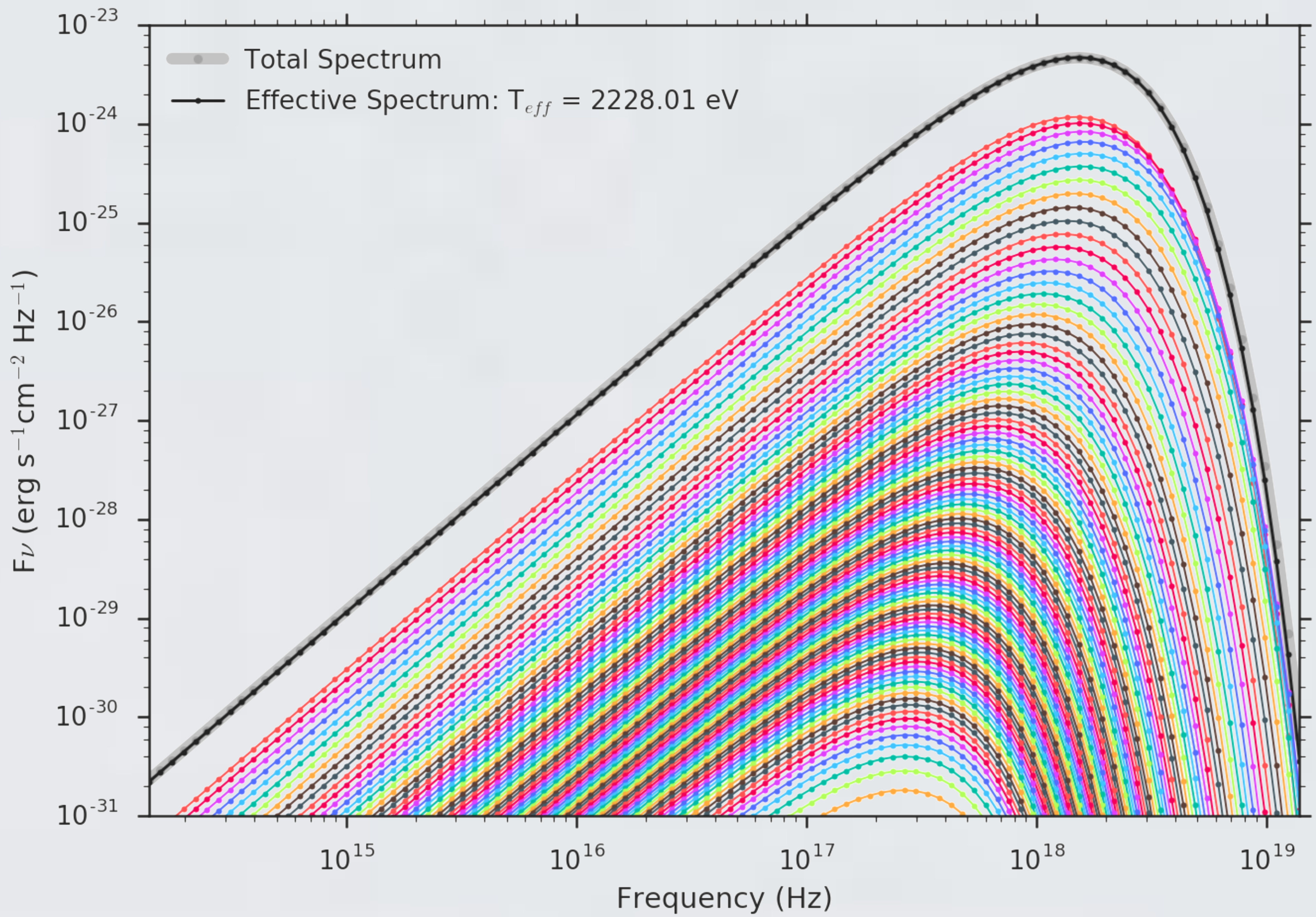
$$T' \propto R^{-0.90}$$

The power-law index of -0.9 for the co-moving temperature is close to an adiabatic system, of which the value is -1.0.

Photo-spherical Emission from Equal Arrival Time Surface

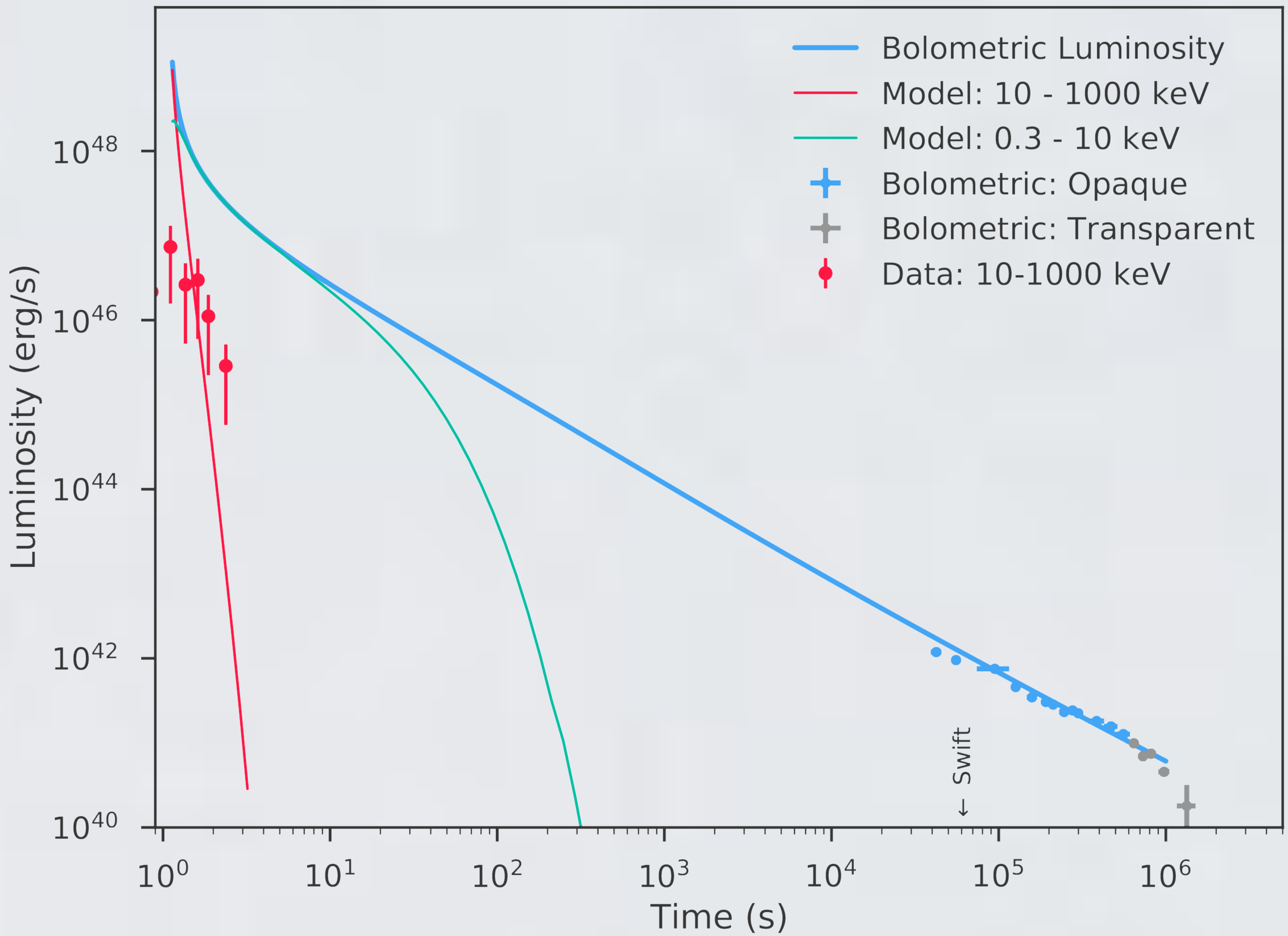


Photons arriving at a same observer's time are from a surface which has different radius, temperature, velocity for the surface elements at different angle. Emission treated with full relativistic equations numerically in order to accurate fit of the mild-relativistic expansion.



Gamma-ray and X-ray

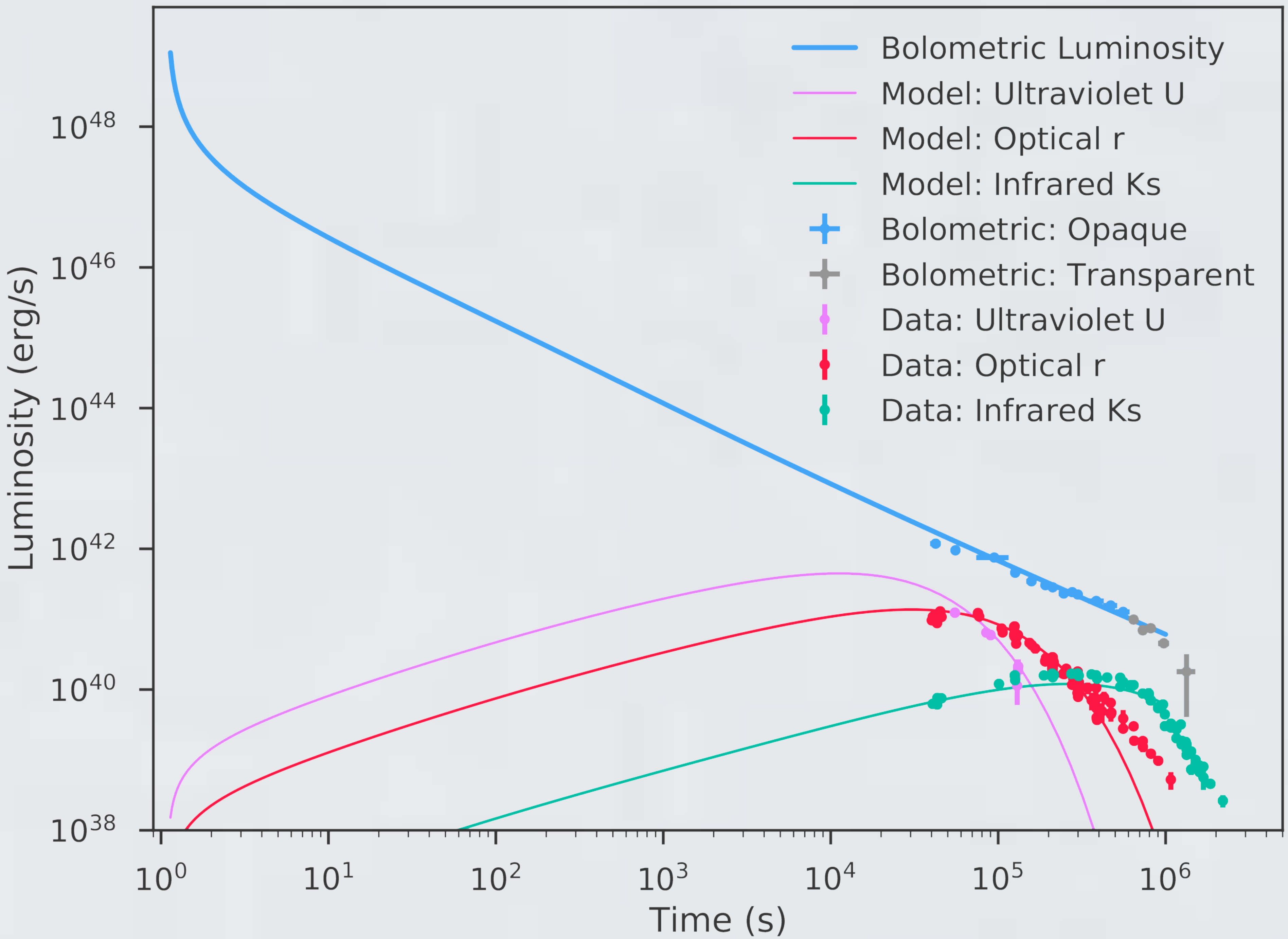
The gamma-ray emission from the tracing-back partially coincides the Fermi-GBM observation, but too high in the very beginning (1.0 - 1.15s) , the soft X-ray in Swift-XRT band drops before 100s, earlier than the starting time of the Swift-XRT observation.



Because the thermal prompt emission starts from ~1s, we are numerically tracing back to 1.1s.

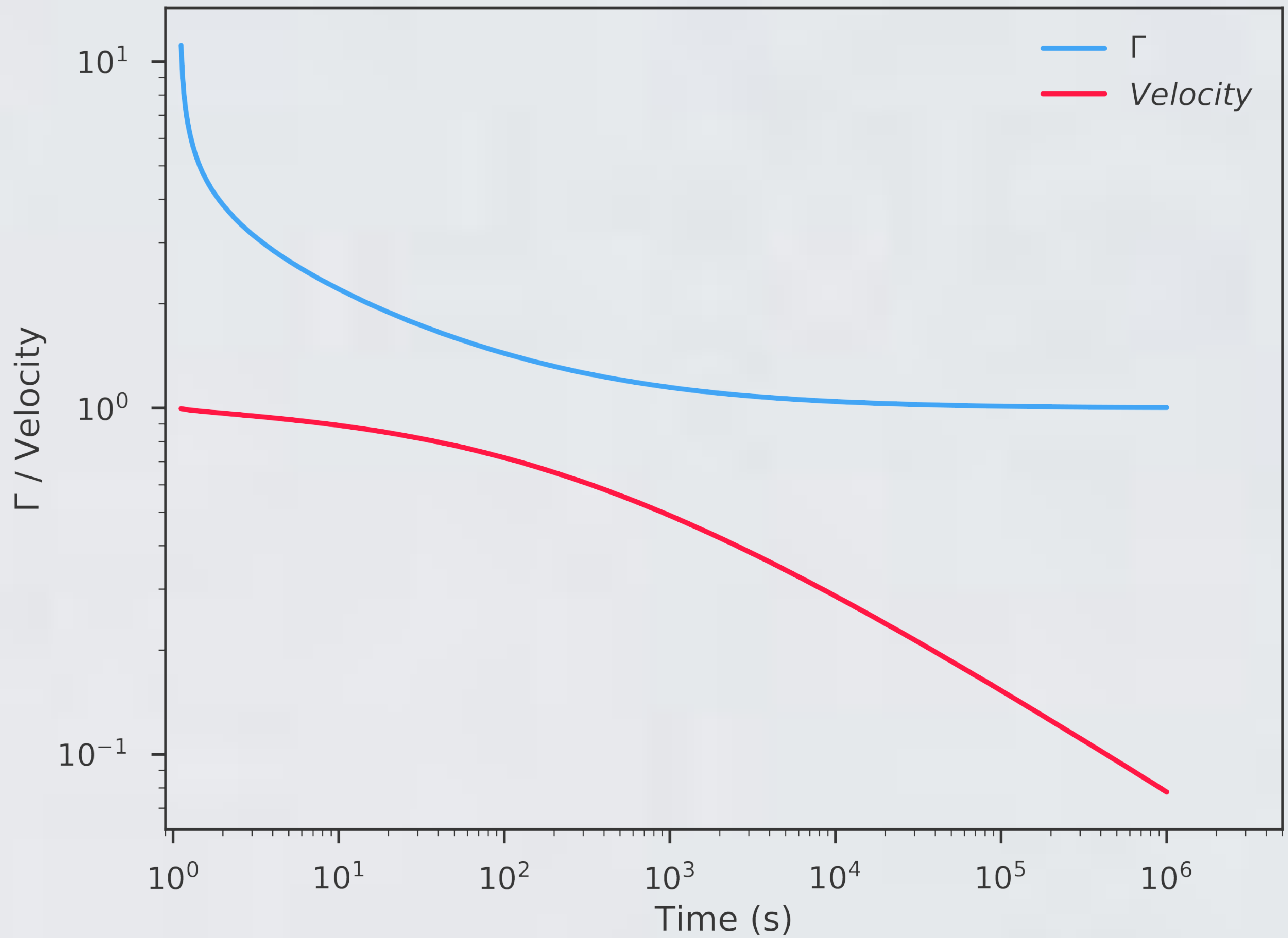
UV, Optical and Infrared

Example of UV, optical and infrared in U, r and Ks bands, there is no surprise of the good fitting and the deviation at time later than 7 days for optical frequency. These light-curve fittings must be consistent with the spectra fitting shown before.



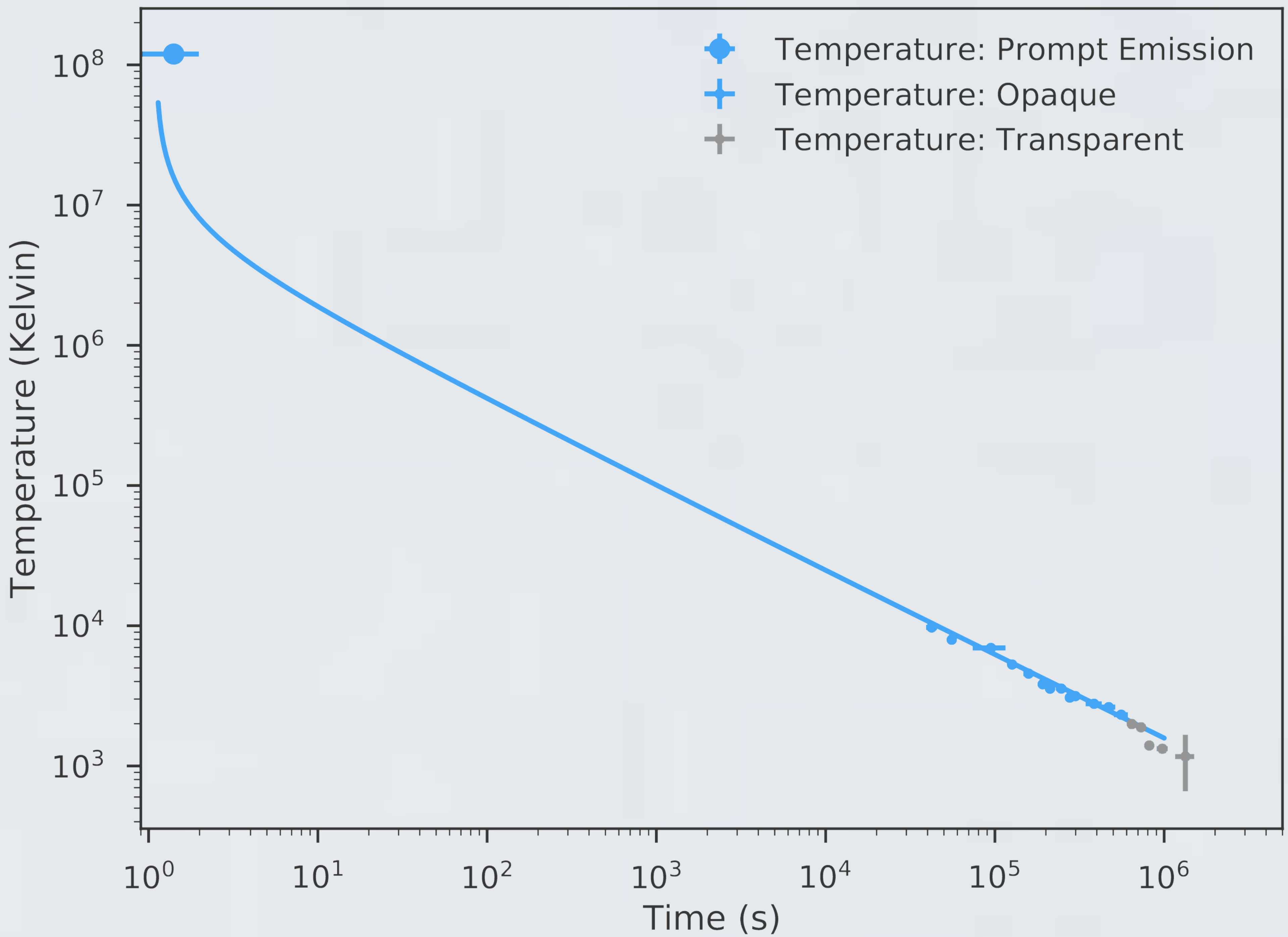
Velocity & Lorentz Factor

The tracing-back gives a mild-relativistic thermal expander with Lorentz factor ~ 10 from the first second (~ 1 s) and drops to the Lorentz factor ~ 1 in a few days.



Observed (Effective) Temperature

The tracing-back shows the observed temperature at a few keV, which is close to the observed temperature in the second spike of the prompt emission.



Can the fitting be better?

Current Result:

This simplest computation doesn't involve any free parameters. It is already capable to show the potential of fitting the Gamma-ray, UV, optical and infrared data, and to explain the missing of the X-ray afterglow.

But it has higher luminosity at the first 0.15s and a little lower temperature.

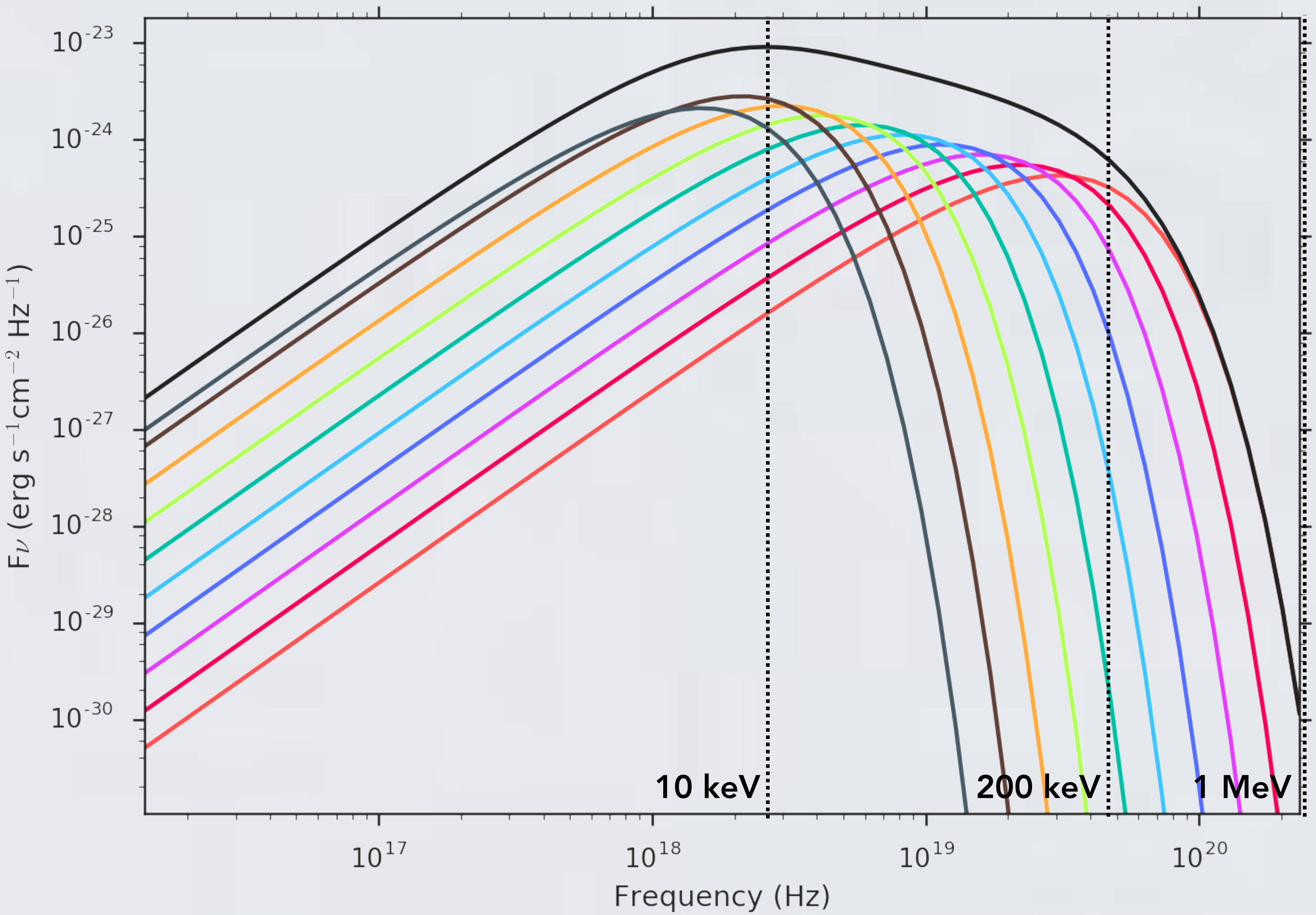
Better Result:

We only focused on the velocity decreasing part, the very beginning acceleration scenario is ignored.

If we involve an acceleration model, the velocity initially is slow, it will bring a smaller radius, and it may result in a higher temperature and a lower luminosity in the very beginning. The fitting can be improved.

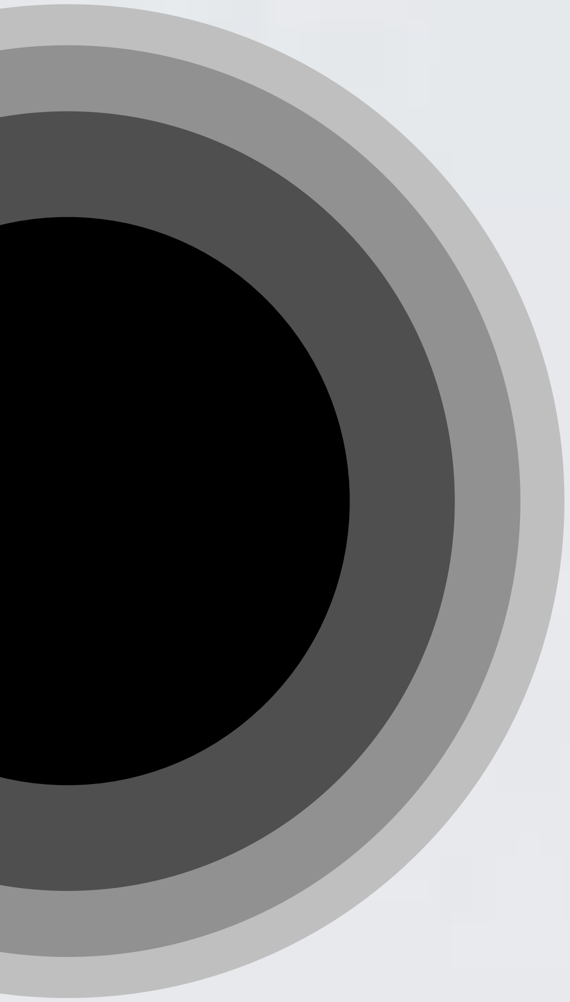
The Observed Thermal Spectrum in A Time Interval

If the data fitting takes a time interval in which the temperature evolves rapidly, the spectrum in the satellite energy range (eg. Fermi-GBM NaI 8 keV - 1 MeV) may show a cutoff power-law, the cutoff energy depends on the highest temperature, the power-law index depends on the temperature changing rate dT/dt.



Velocity of Layers

Considering the emission of each time bin corresponds to the mass layer with velocity more than v, assuming the velocity the each mass layer doesn't change much.



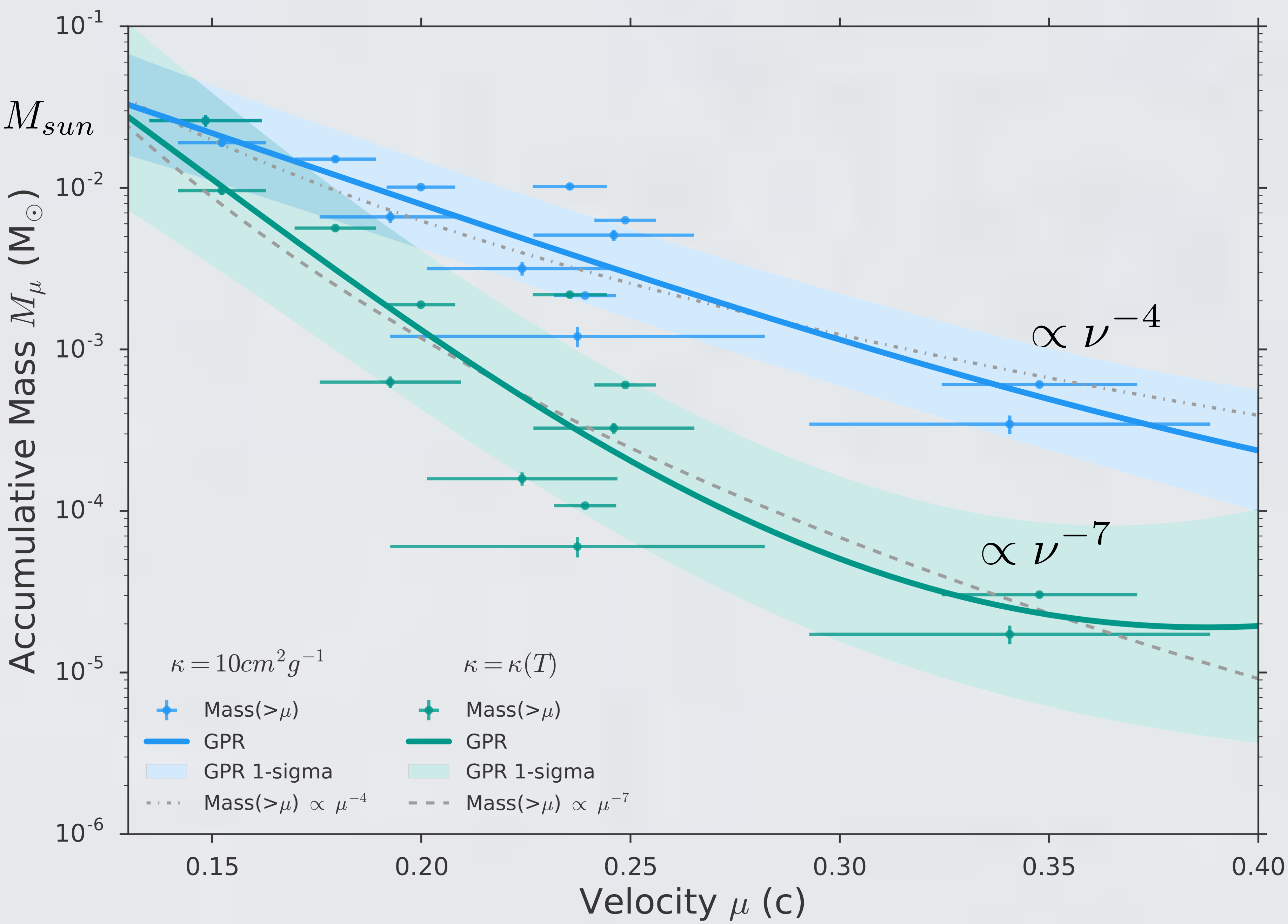
DATA

Mass Distribution

Considering the emission of each time bin corresponds to the mass layer with velocity more than v, the radiation escapes on a diffusion time scale.

$$t_\nu \simeq \frac{M_\mu \kappa_\nu}{4\pi R_\nu c}$$

$\sim 3 \times 10^{-2} M_{sun}$



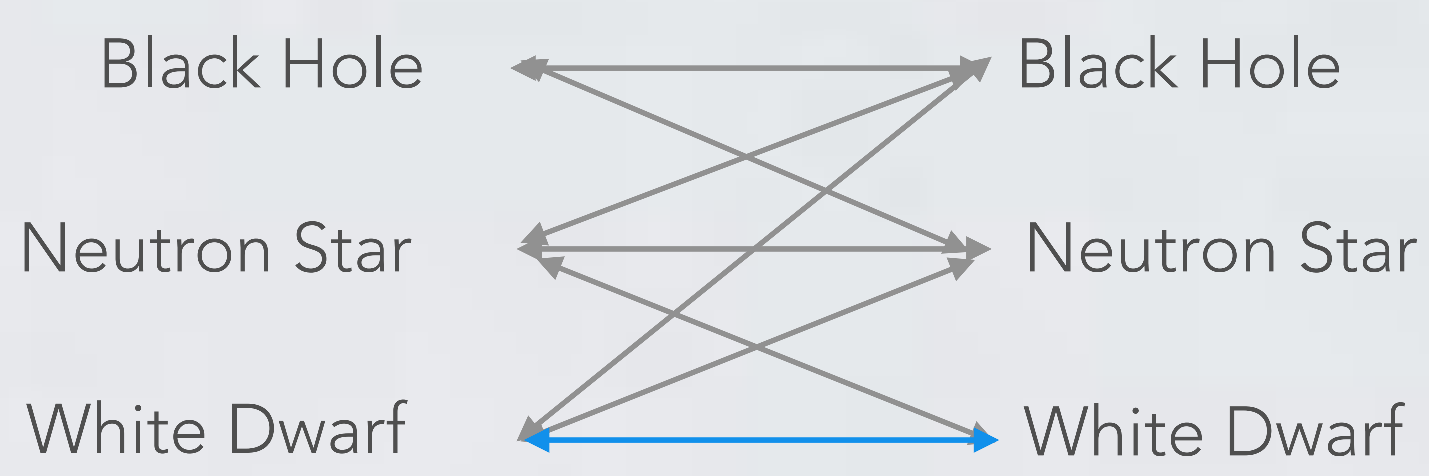
Sketching **KILONOVA**
on **WHITE PAPER**

BINARY SYSTEM

Different Binary Systems

Burst with low isotropic energy in the prompt emission is $< 10^{47}$ erg

1. Establishing fine structures of the radiation geometry
2. **A merger of the binary compact system releases low energy**



Only thinking on the EM radiation, without a presumed connection to GW.

For GRBs related to different binary systems, see details in Prof. Ruffini's talk on Thursday.

For the merger of binary systems, see details in Prof. Rueda's talk on Thursday.

White Dwarf Binary

Magnetic Field:

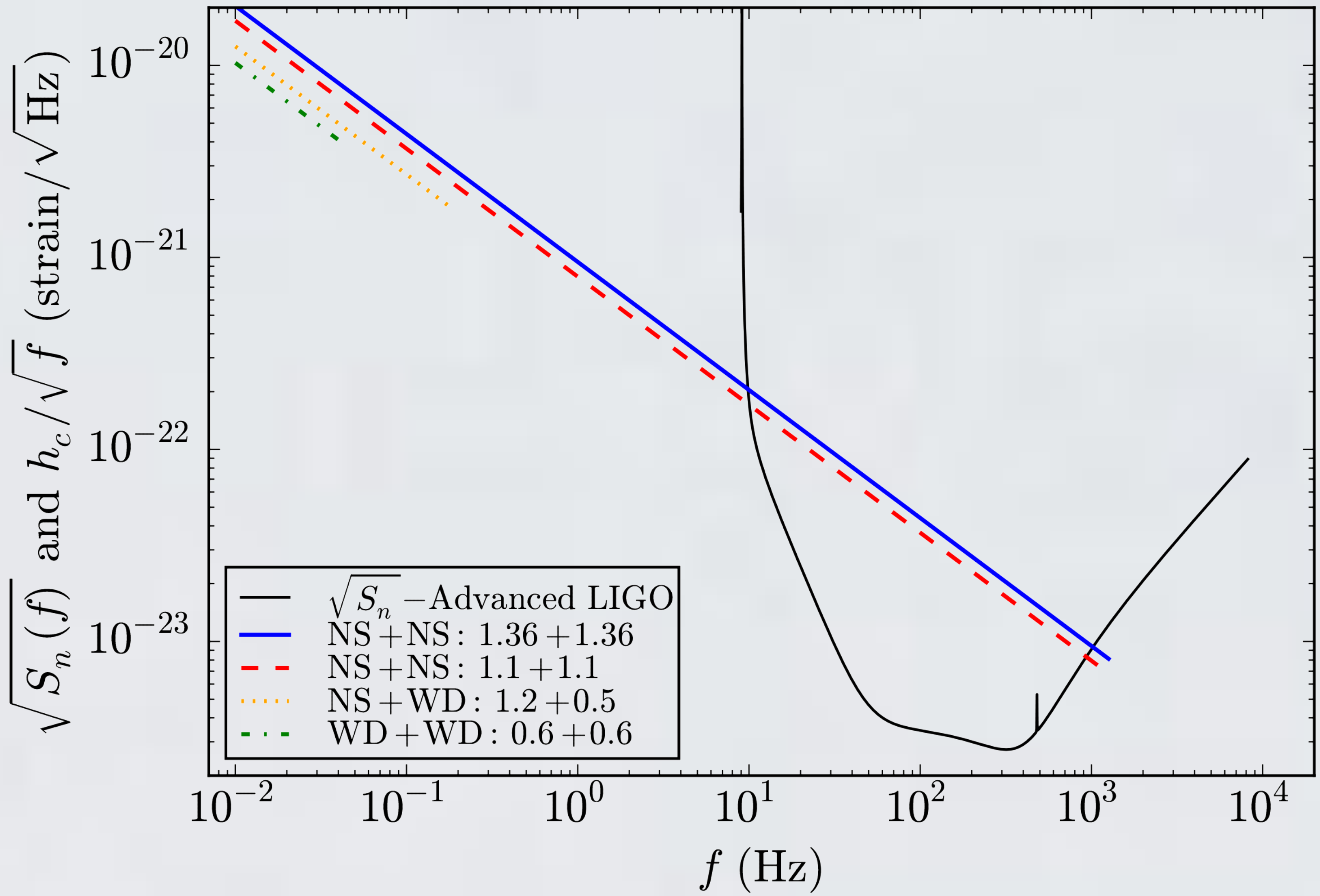
The hot, rapidly rotating, convective corona can produce, via an efficient $\alpha\omega$ dynamo, magnetic fields of up to $B \approx 10^{10}$ G .

Energy and Luminosity:

Magnetic energy of ~10^{46} erg is stored in a region of radius ~10^{9} cm and magnetic field of ~10^{10} G (Malheiro et al. 2012), which can be released from flares owing to the twist and stress of the magnetic field lines during the merger process

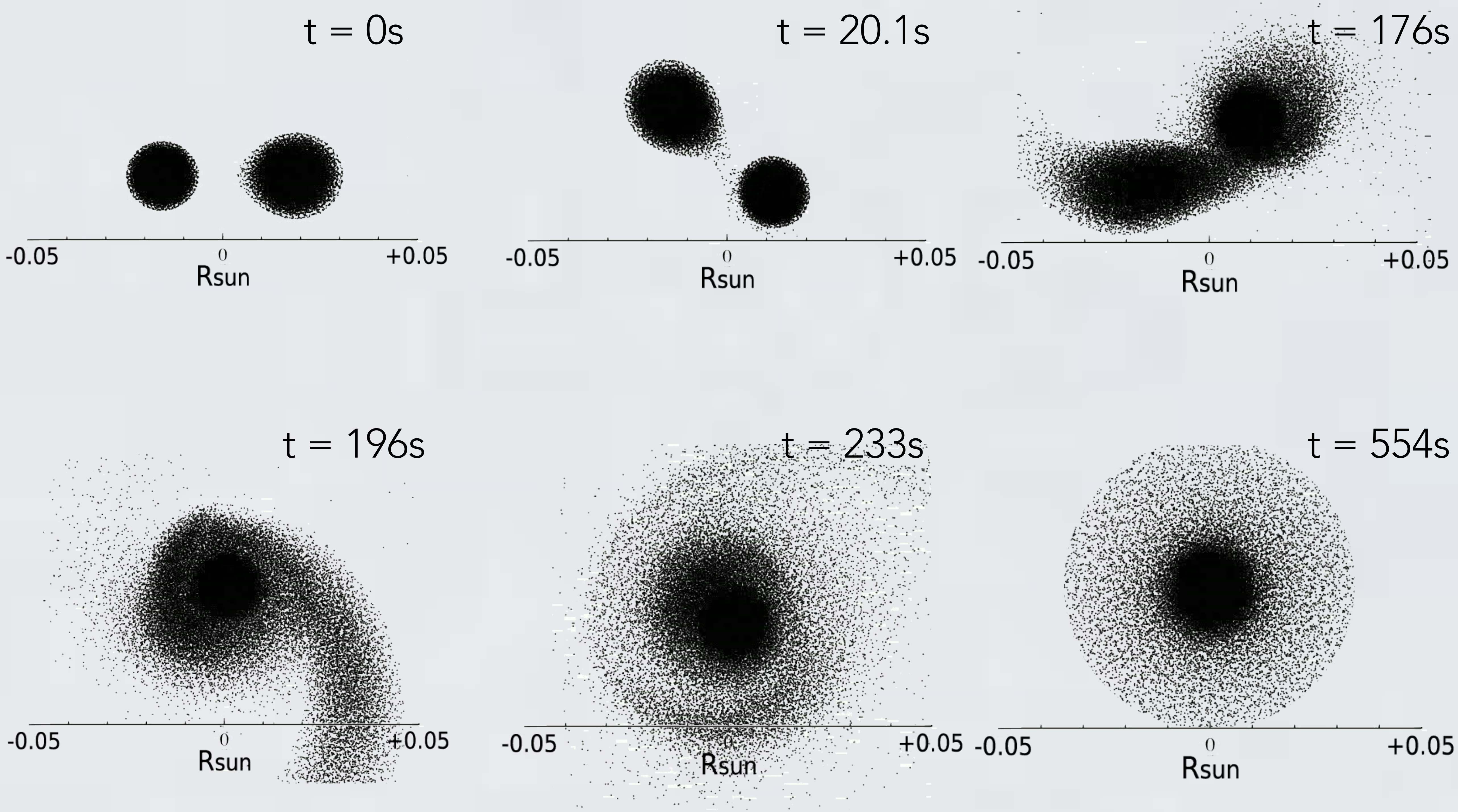
Such a radius would imply a photon travel time of the order of $r/c \sim 0.1$ s, so a peak luminosity of few ~10^{47} erg s^{-1} .

Gravitational Wave from WD-WD



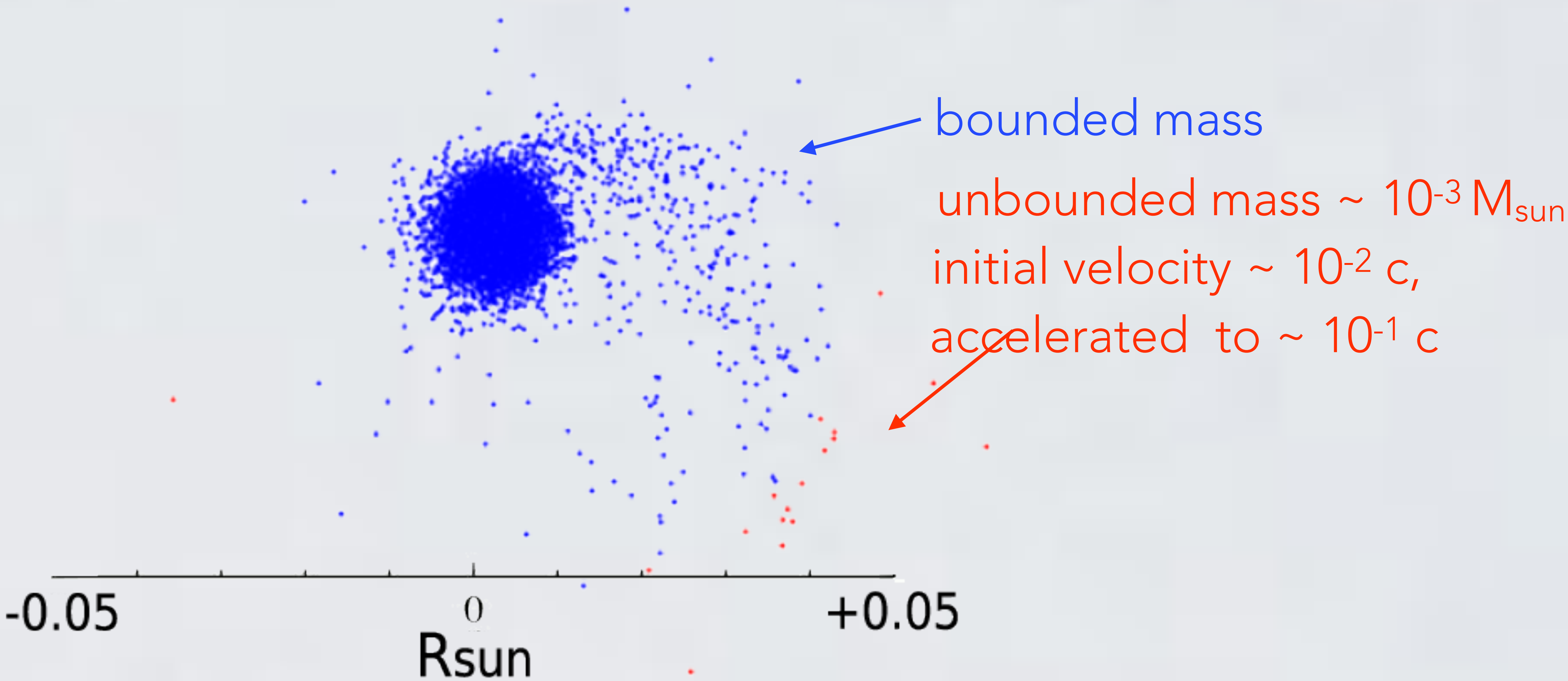
Frequency of GW from WD-WD merger is too low to be detected by Advanced LIGO

Simulation of White Dwarf Merger



SPH simulation with 7×10^4 particles

Simulation of White Dwarf Merger



Post Merger Configuration:

Three distinct regions: 1) a rigidly rotating, central WD, 2) on top there is a hot, differentially-rotating, convective corona, 3) surrounded by a rapidly rotating Keplerian disk .

Energy Injection from White Dwarf

1. No heavy element, **no radioactive energy**.

2. Rotational energy coming from the **spin-down** of the WD and the **fallback accretion** onto the WD.

Simple one layer model

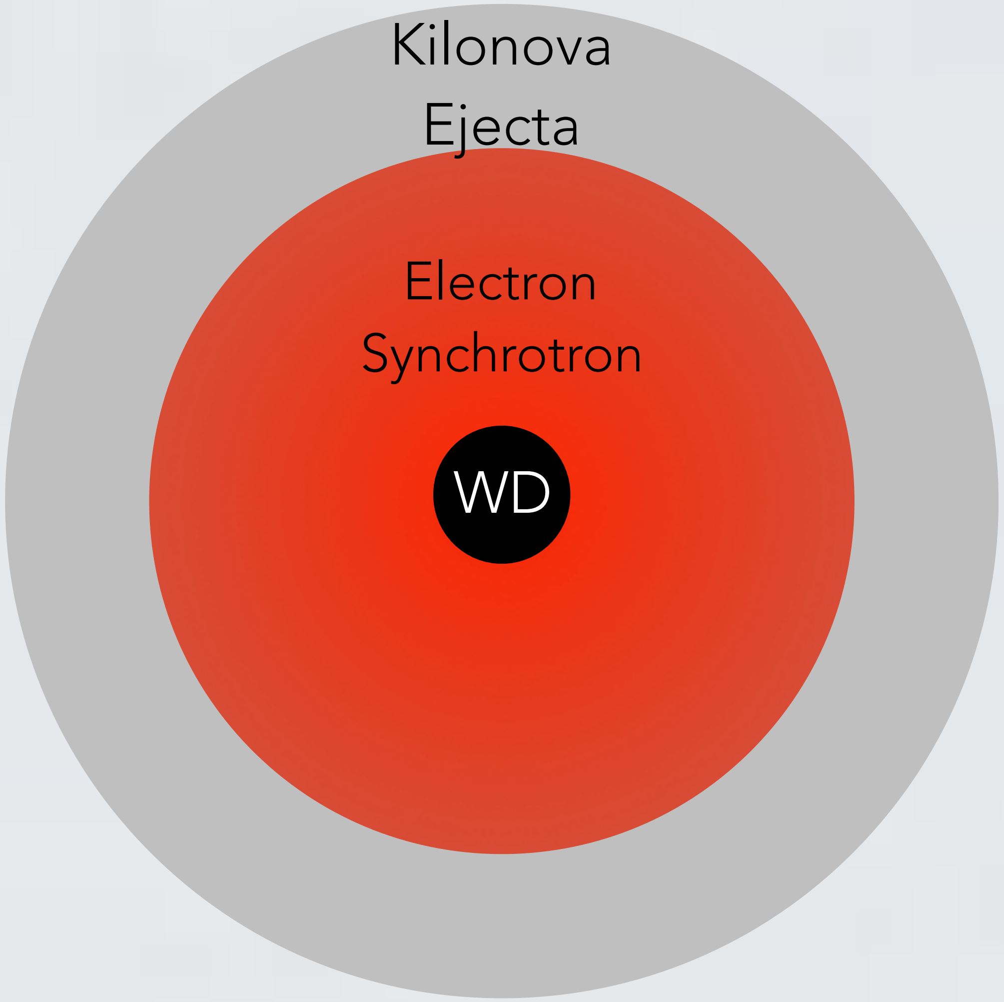
$$\frac{dE}{dt} = -P\frac{dV}{dt} - L_{\rm rad} + L_{\rm sd} + L_{\rm fb}$$

Spin-down by dipole emission

$$L_{\rm sd} = \frac{2}{3}\frac{B_d^2 R^6}{c^3}\omega^4$$

Fallback power. We have chosen fallback power parameters according to numerical simulations of WD-WD mergers (Loren-Aguilar et al. 2009): $L_{\rm fb,0}$ $=8.0\times10^{47}$ erg s^{-1} and $t_{\rm fb}$ =10s, and n=1.45.

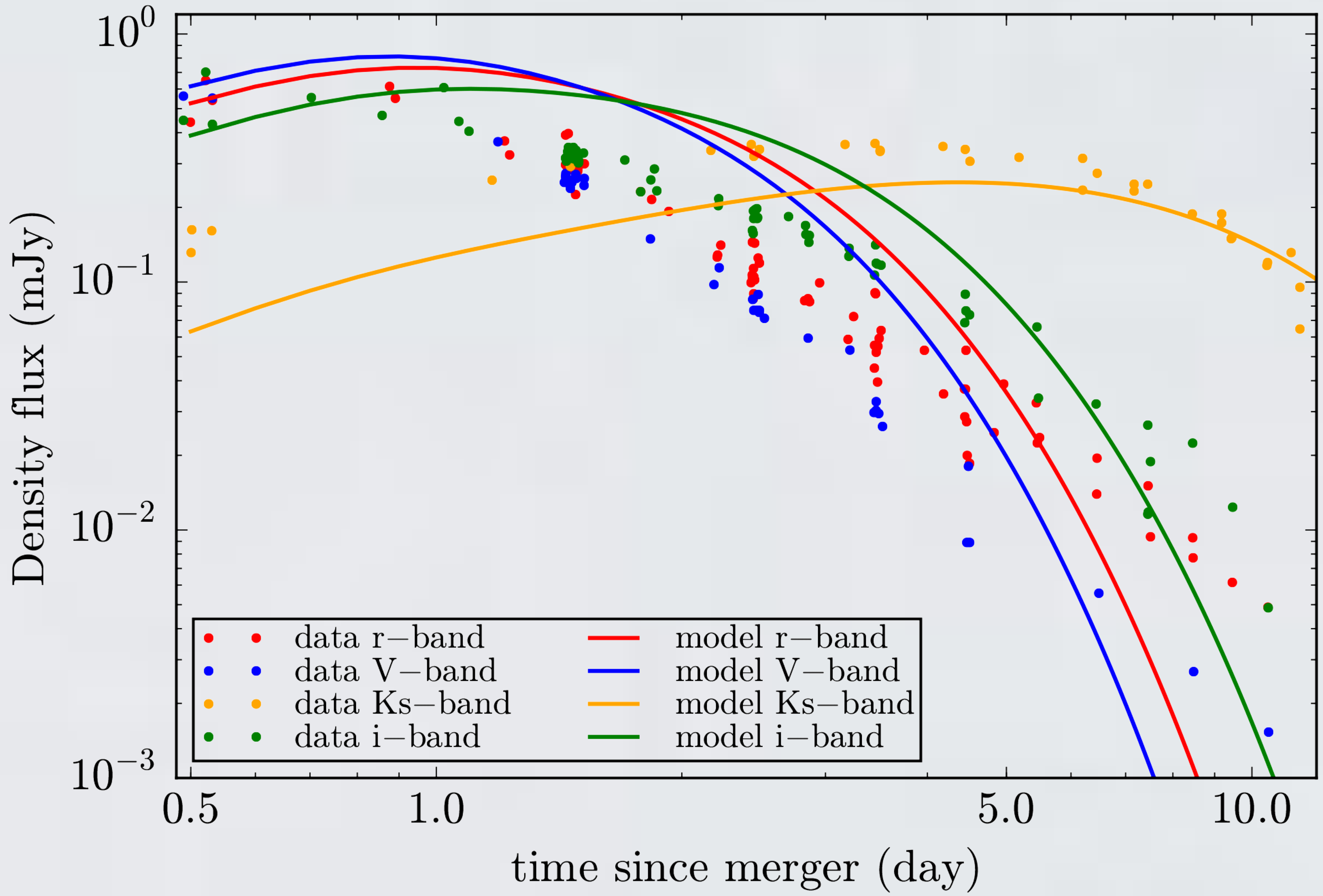
$$L_{\rm fb} = L_{\rm fb,0}\left(1+\frac{t}{t_{\rm fb}}\right)^n$$



Optical and Infrared

The ejecta are highly opaque at early times, the fallback accretion and the spindown power are transformed into the internal and kinetic energy of the ejecta. The expanding thermal emitter fits the optical and infrared emission.

Taking a low opacity $\kappa \sim 0.1$ cm^2 g^{-1} with respect to the heavy elements.



X-ray Re-rising

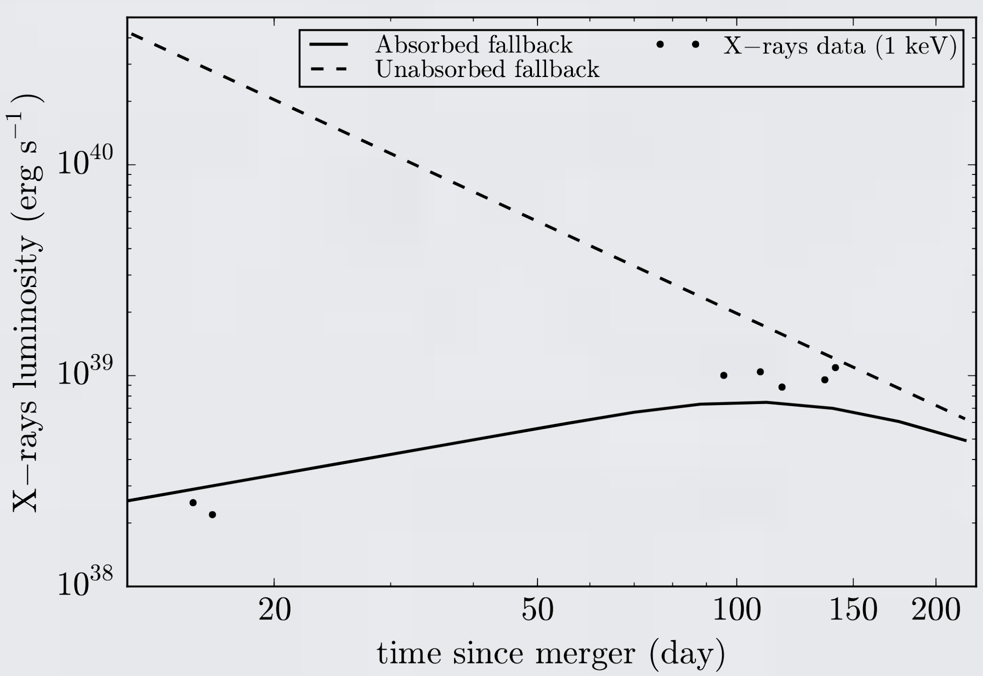
The X-ray luminosity taking into account the absorption from the ejecta can be calculated as

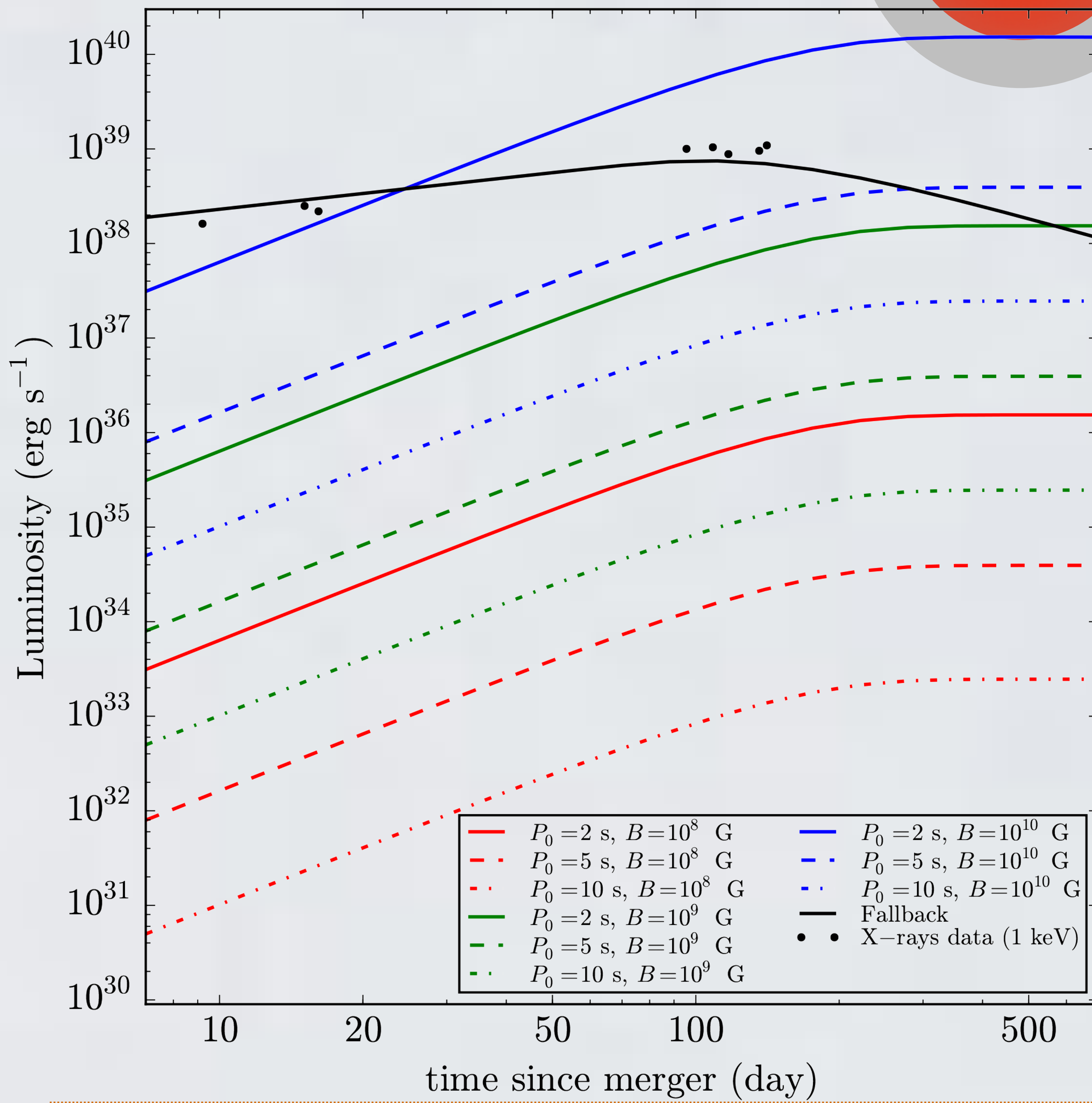
$$L_X \approx \frac{1-e^{-\tau_X}}{\tau_X}(L_{\rm fb}+L_{\rm sd}) \approx \frac{L_{\rm fb}+L_{\rm sd}}{1+\tau_X}$$

where τ_X is the optical depth of the X-rays through the ejecta

$$\tau_X = \kappa_X \rho_{\rm ej} r_{\rm ej}$$

$\boldsymbol{\kappa_X \approx 10^3\ \mathrm{cm^2\ g^{-1}}}$ is the bound-free opacity to the X-rays.





For synchrotron emission, see details in Dr. Karlica's talk on Tuesday.

CONCLUSION

DATA

- The decreasing of photo-spherical velocity is determined.
- Tracing back the temperature and the velocity found during 0.5 - 7 day gives potential to interpret the gamma-ray, X-ray, UV, optical and infrared are simply from a same thermal expander.
- The mass density profile is inferred by assuming thermal diffusion.

BINARY

- The WD-WD merger provides the energy which suits the total energy and the luminosity in the prompt emission.
- The optical and infrared emission come from the kilonova ejecta heated and accelerated by the fallback accretion.
- The synchrotron X-ray emission is suppressed by the bound-free absorption of the kilo nova ejecta before ~ 10 days, then it grows and peaks at ~ 100 days.

"Thank you"