Beyond r-process:
The Cocoon emission in the early macronova in GW170817
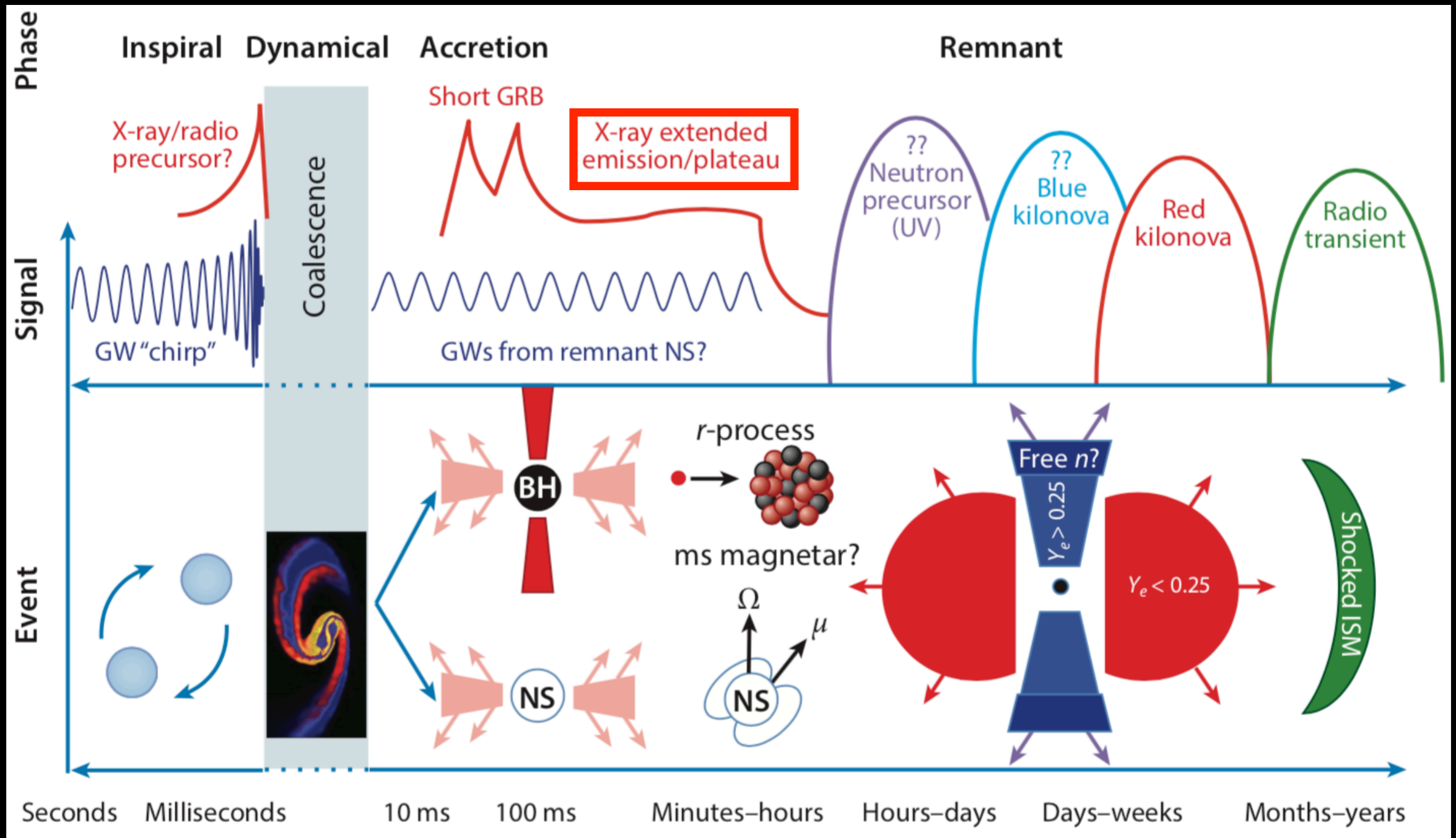
Hamid Hamidani, Kunihito Ioka, & Kenta Kiuchi

Review

Jet propagation in an expanding ejecta

(A) $t < t_m$: Inspiral

(B) $t = t_m$: Merger

(C) $t_m < t < t_0$: Mass ejection

(D) $t_0 < t < t_b$: Jet launch

(E)

sGRB
X-ray/γ-ray
(~sec)

Jet head
$r_h(t)$, $v_b(t)$

Macronova:
UV-Opt-IR
(~days–weeks)

Jet+Cocoon

Outer ejecta
$r_m(t)$, v_{ej}

$t \approx t_b$

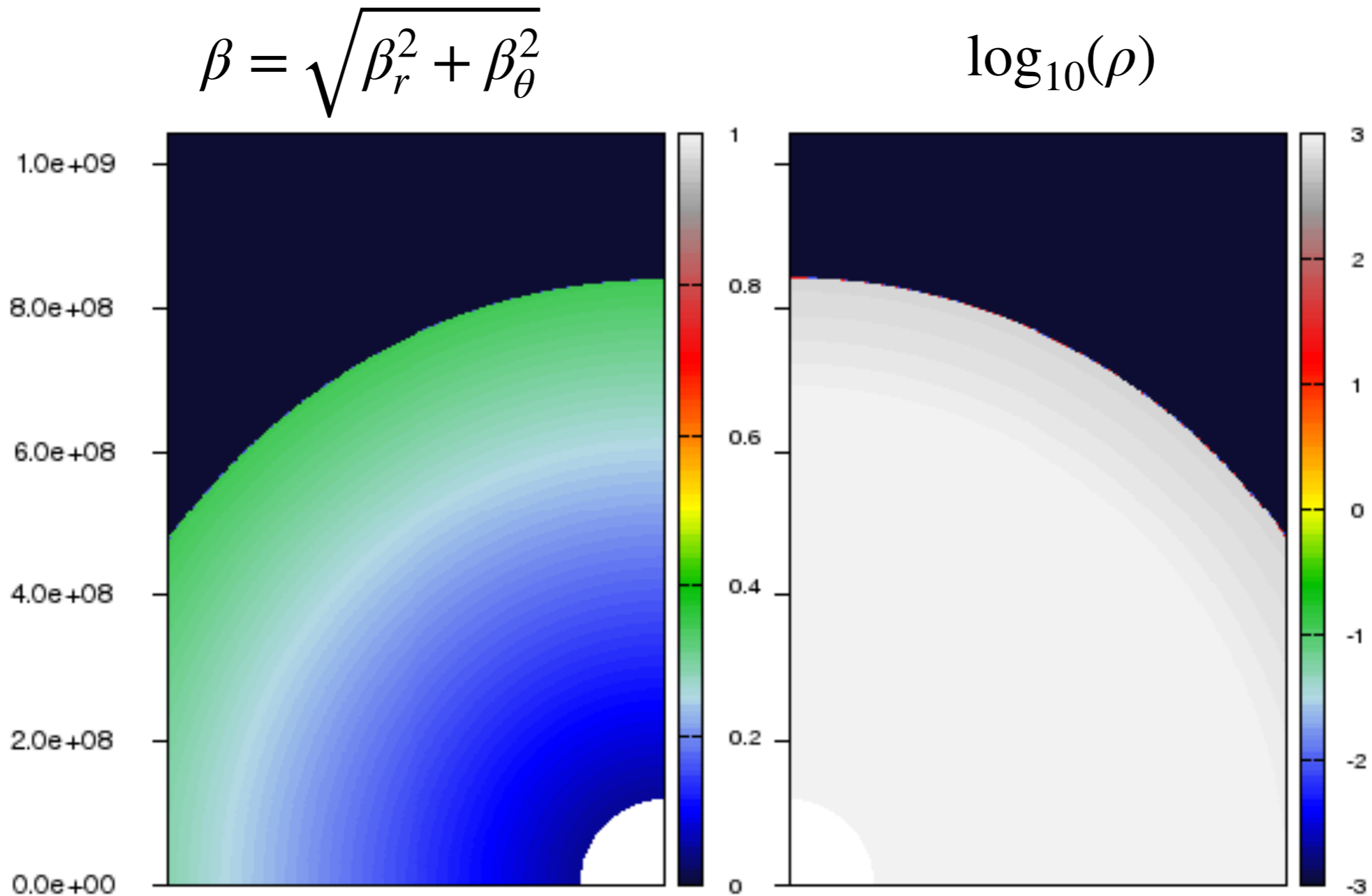**HH+19 in prep**
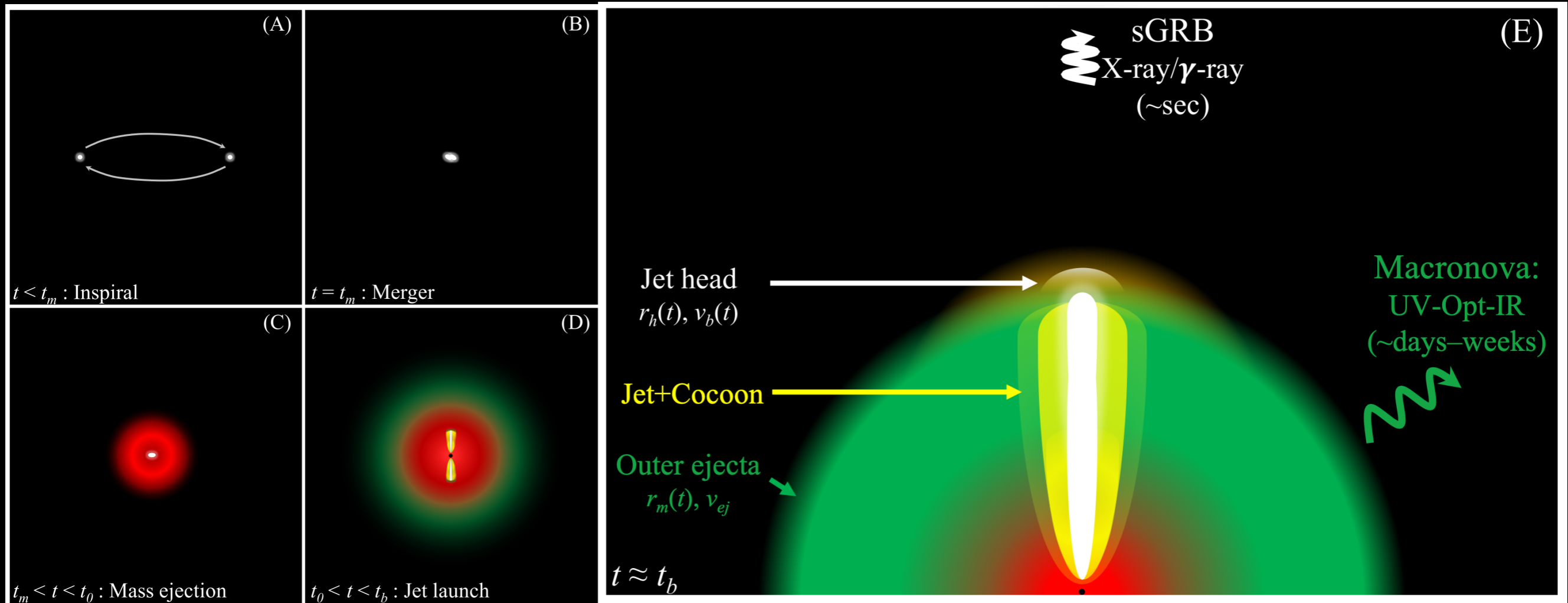
Motivation

- **Engine powered "Cocoon":**
  What EM counterparts/signature to be expected?
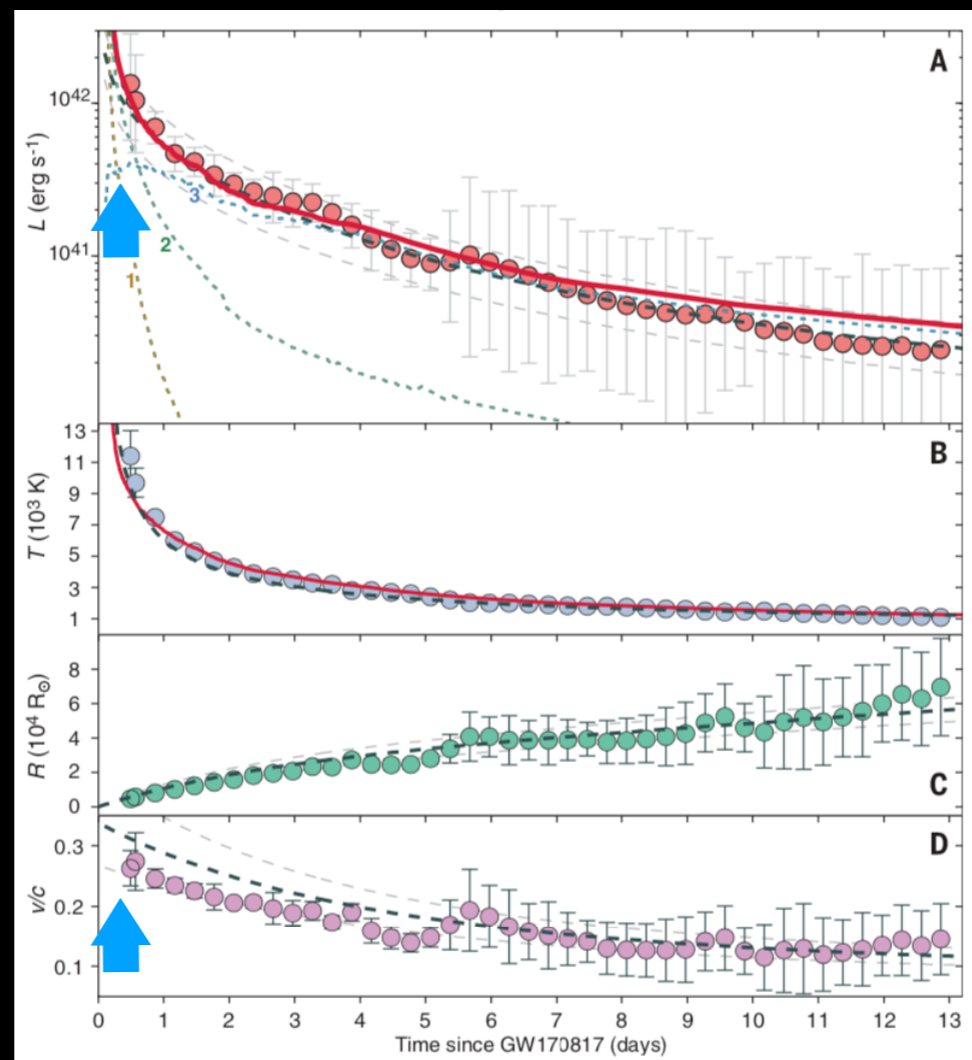
Credit: Kasliwal+17

Tool I. Numerical Simulations

$\beta = \sqrt{\beta_r^2 + \beta_\theta^2}$

$\log_{10}(\rho)$

Velocity   at t = 0.00 s   Density   at t = 0.00 s

Tool II. Analytic Modeling

Ram Pressure Balance

$$h_j \rho_j c^2 \Gamma_j^2 \beta_j^2 + P_j = h_e \rho_e c^2 \Gamma_e \beta_e^2 + P_e$$

Engine

Ejecta

Gives:
Jet head motion
Cocoon (*E*, *M*, <v>)
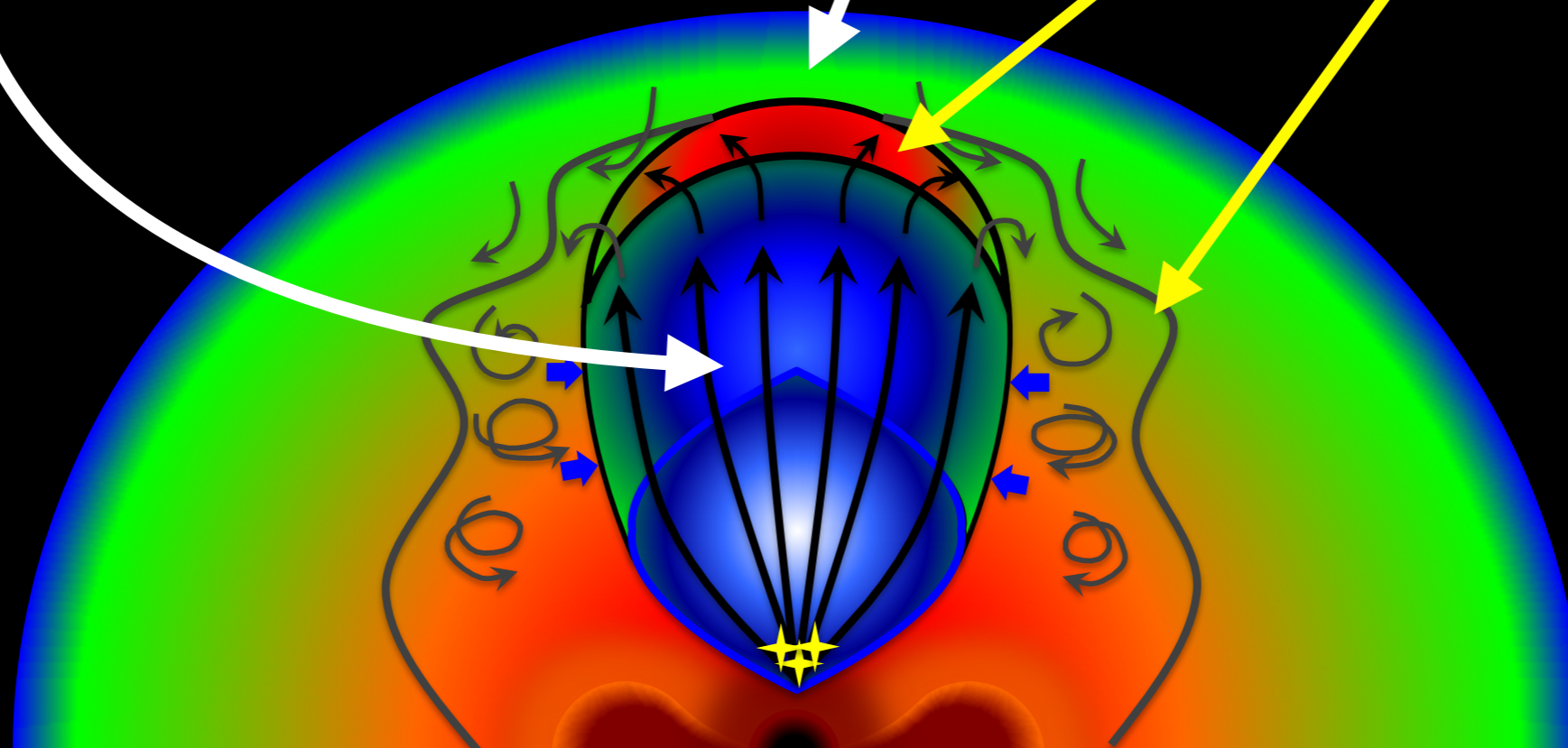
Tool II. Analytic Modeling

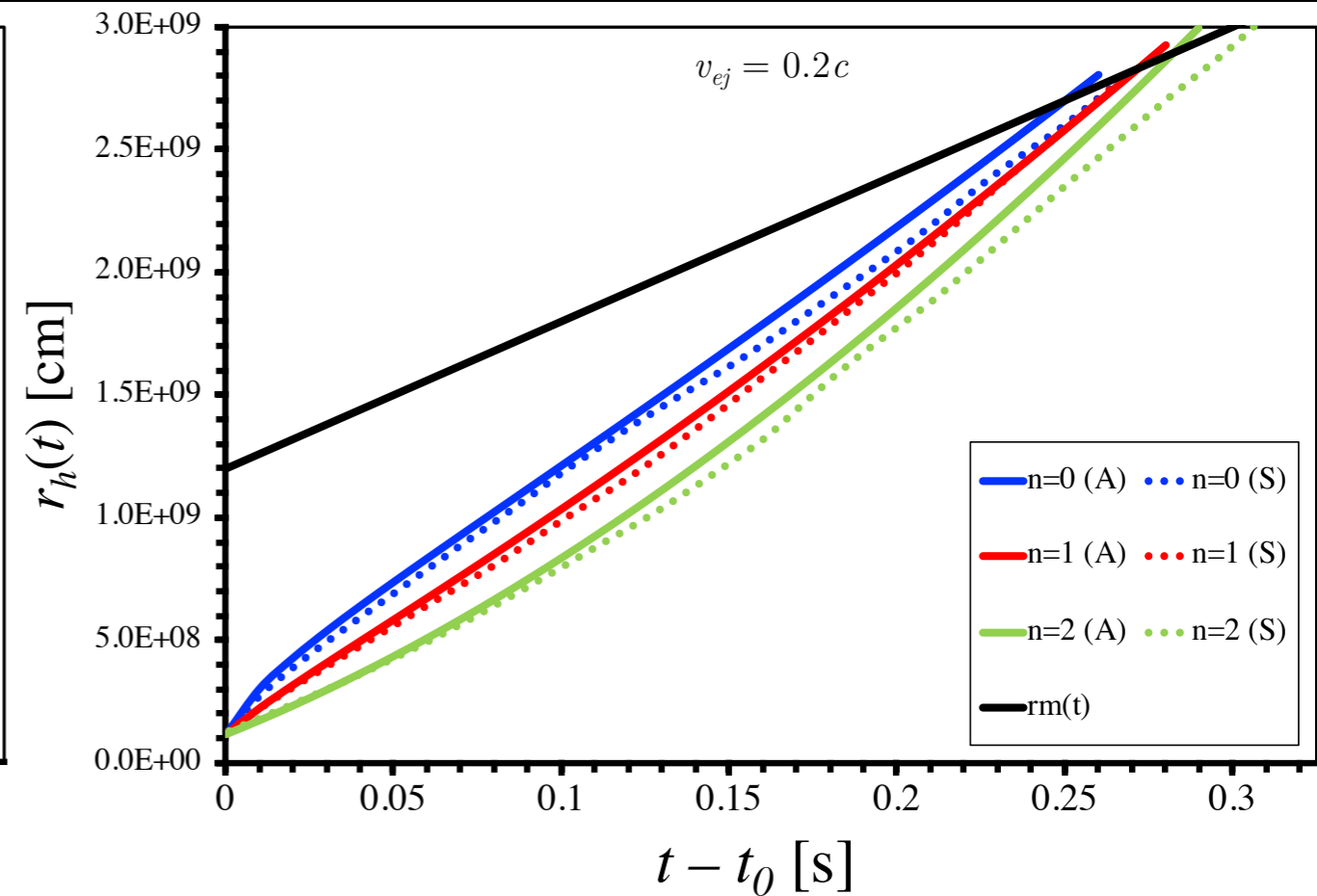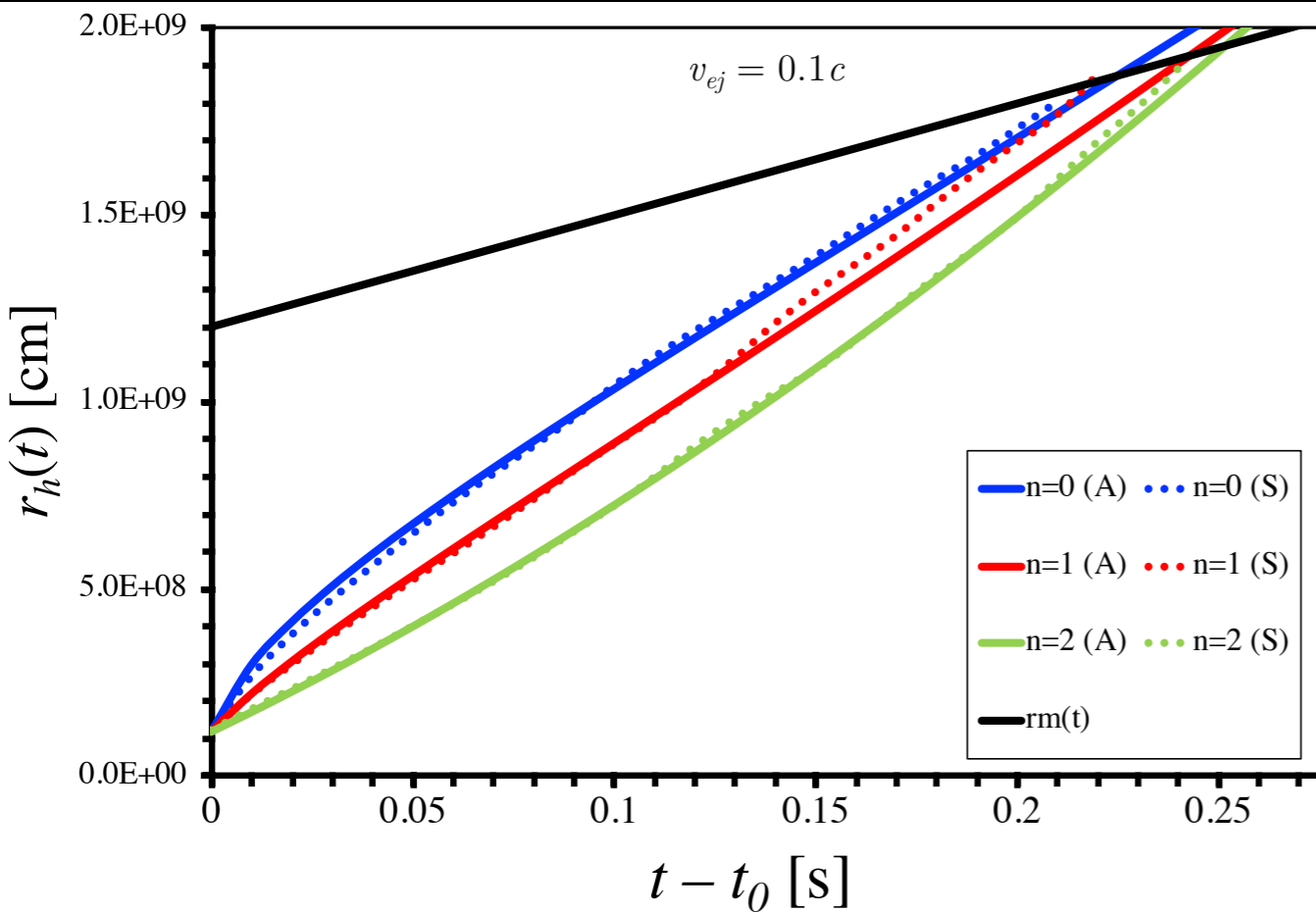$$\frac{dr_h(t)}{dt} = Ar_h(t)^{\frac{n-2}{2}}$$

Static medium

$$\frac{dr_h(t)}{dt} + \left(-\frac{v_{ej}}{r_m(t)}\right) r_h(t) = Ar_m(t)^{\frac{3-n}{2}} r_h(t)^{\frac{n-2}{2}}$$

Expanding medium

$$A = \sqrt{\left(\frac{r_{m,0}^{3-n} - r_0^{3-n}}{(3-n)r_{m,0}^{3-n}}\right)\left(\frac{4L_j}{\theta_j^2 M_{ej}c}\right)}$$

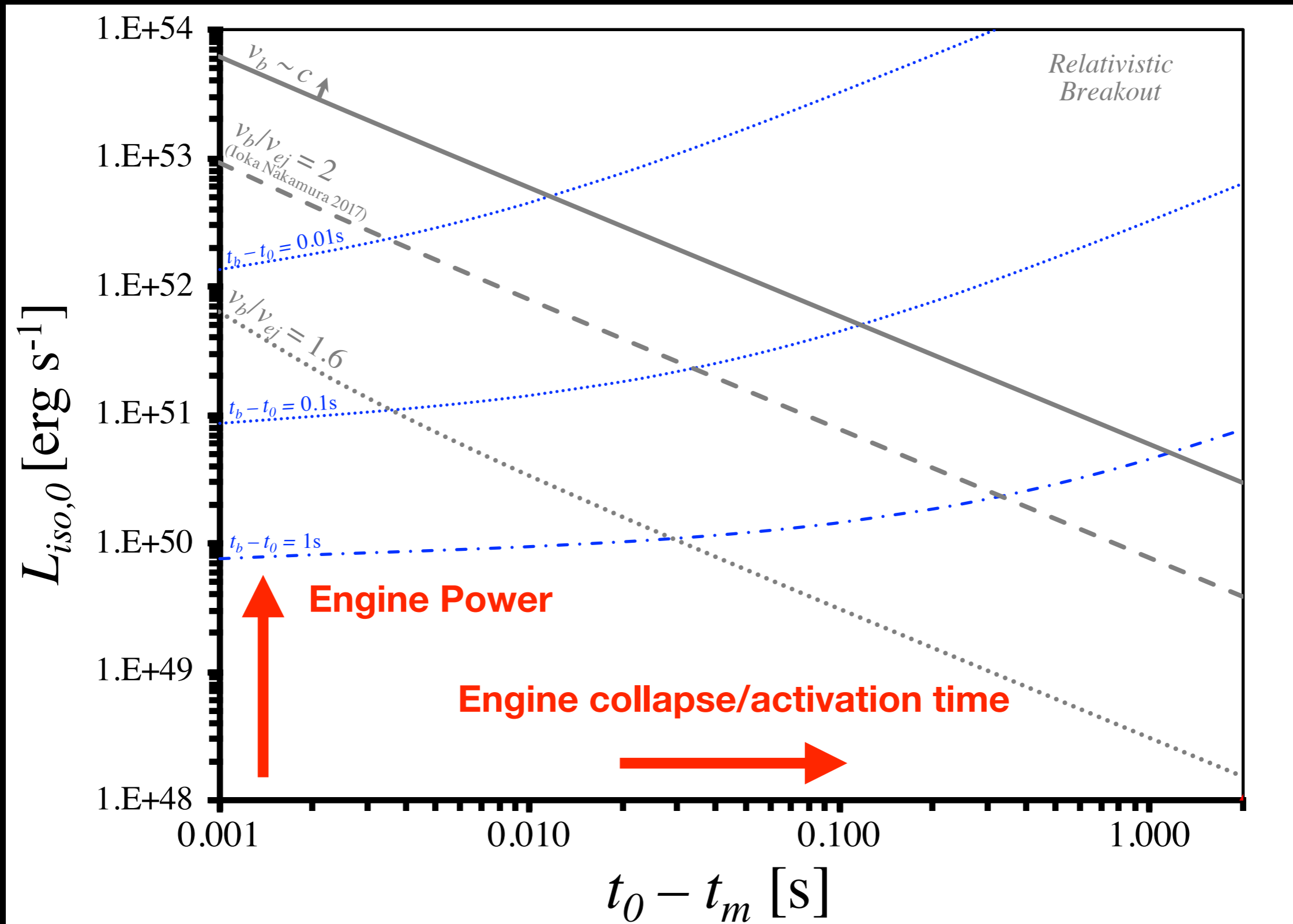# I. Analytic Vs. Numerical Breakouts

Results I:
Engine parameters and jet dynamics

$$t_b - t_0 = \left[\frac{r_{m,0}^{\frac{4-n}{2}} - r_0^{\frac{4-n}{2}}}{r_{m,0}^{\frac{4-n}{2}}} \frac{\sqrt{v_{ej}}}{(4-n)A} + \sqrt{\frac{r_{m,0}}{v_{ej}}} \right]^2 - \frac{r_{m,0}}{v_{ej}}$$

$$v_b = A\sqrt{r_b} + v_{ej}$$

$$A = \sqrt{\left(\frac{r_{m,0}^{3-n} - r_0^{3-n}}{(3-n)r_{m,0}^{3-n}} \right) \left(\frac{4L_{iso,0}}{M_{ej}c} \right)}$$

Results I:
Engine parameters and jet dynamics

II. Application for GW170817's Cocoon

Modeling The Cocoon

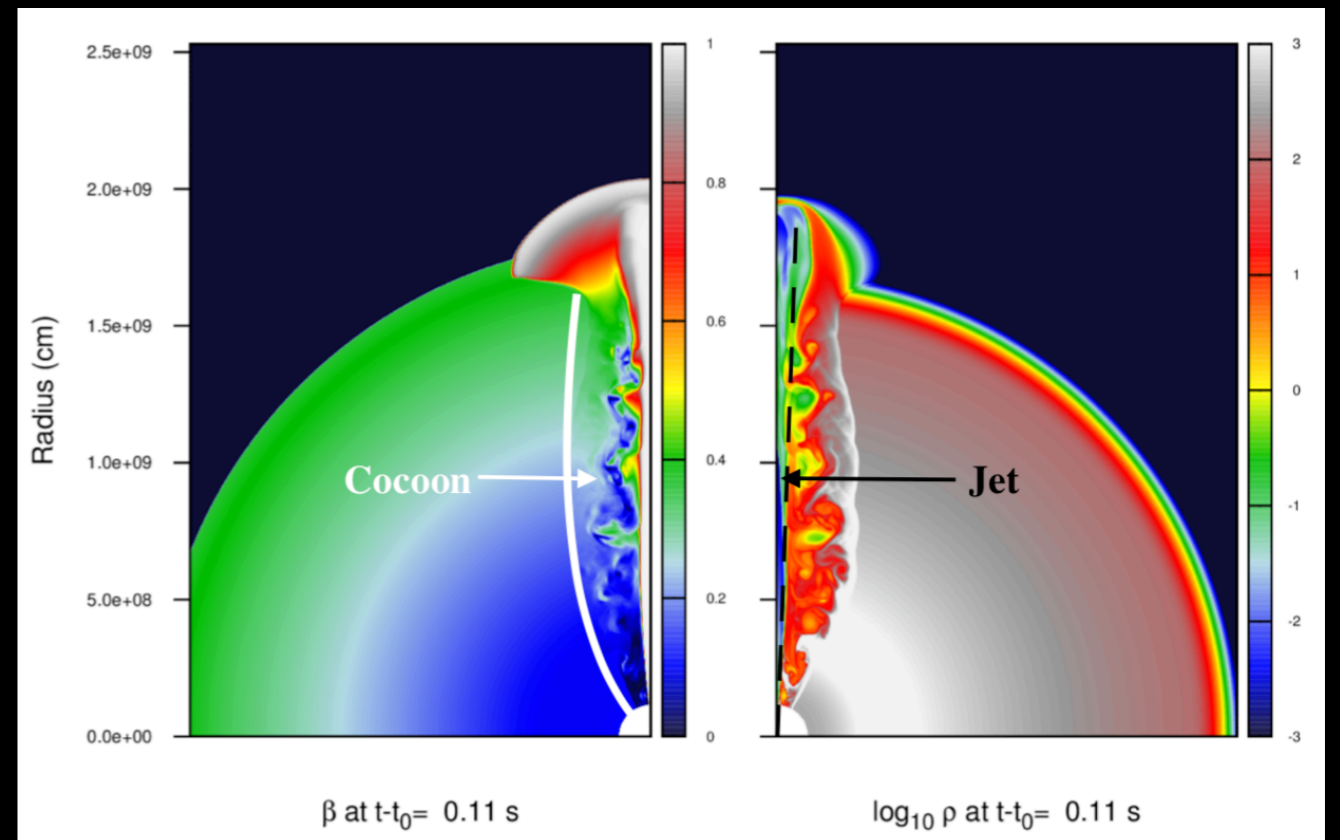**Approximations/Assumptions:**

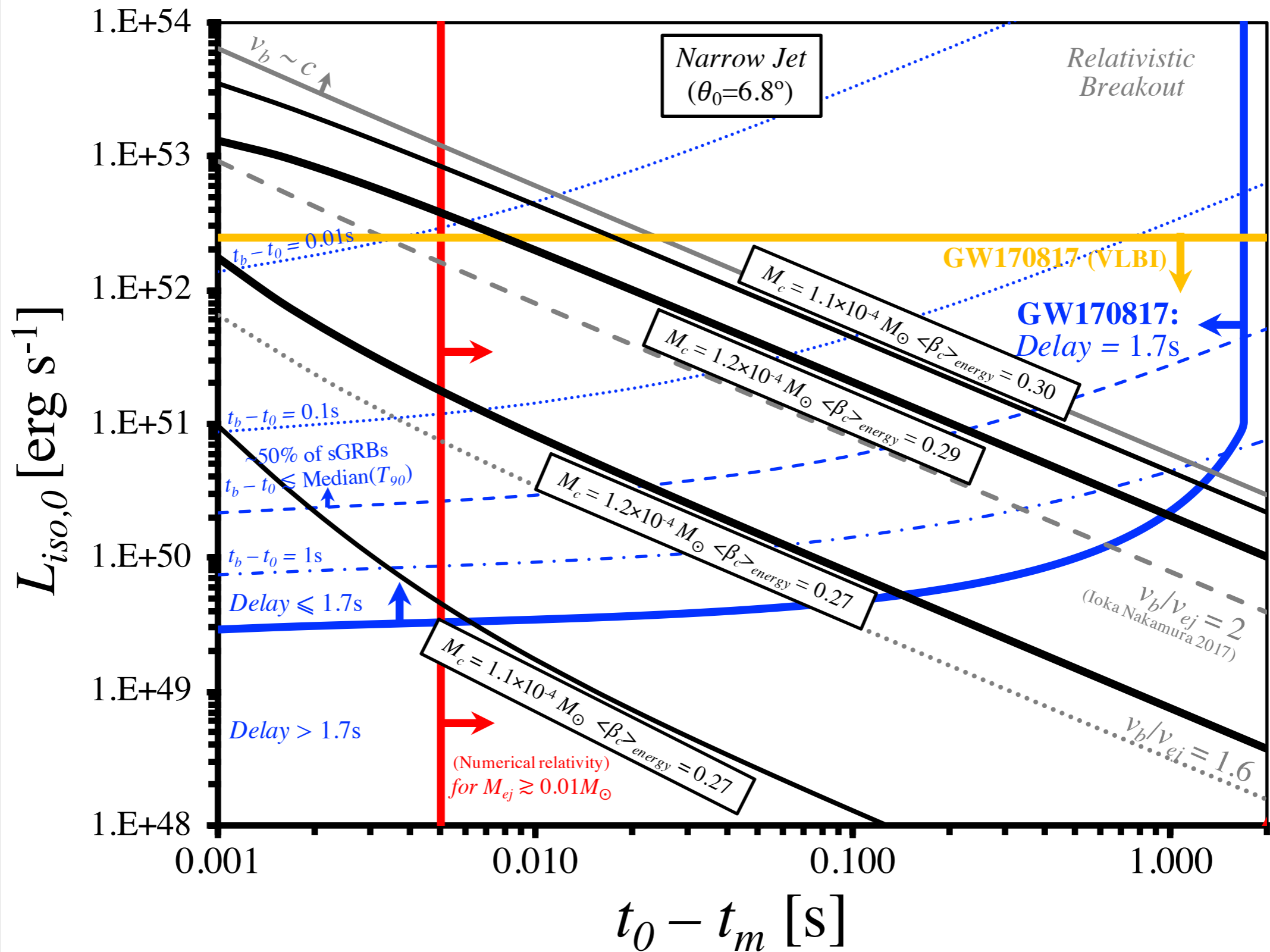$$E_{in} = L_j(t_b - t_0)(1 - 1/c \times R_b/(t_b - t_0))$$

$$E_{in} = 3P_cV_c$$

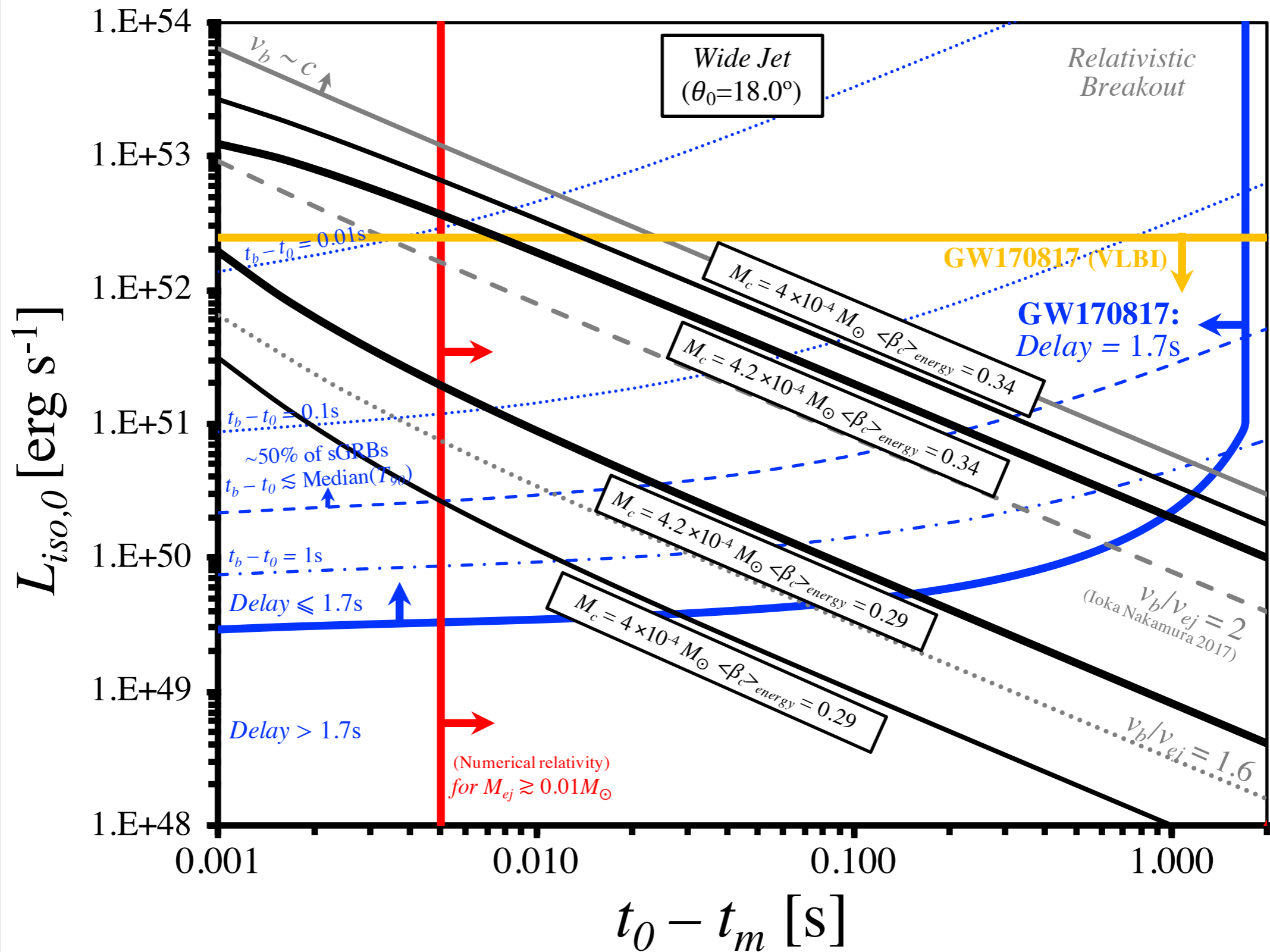$$\beta_\perp = \sqrt{\frac{P_c}{\bar{\rho}_a\left(r_h\right)c^2}}$$

$$E_c = E_{in} + E_{k,e}$$

Gives: $\quad E_c, M_c, \ \& \ \langle\beta_c\rangle$

β at t-t₀= 0.11 s   log₁₀ ρ at t-t₀= 0.11 s

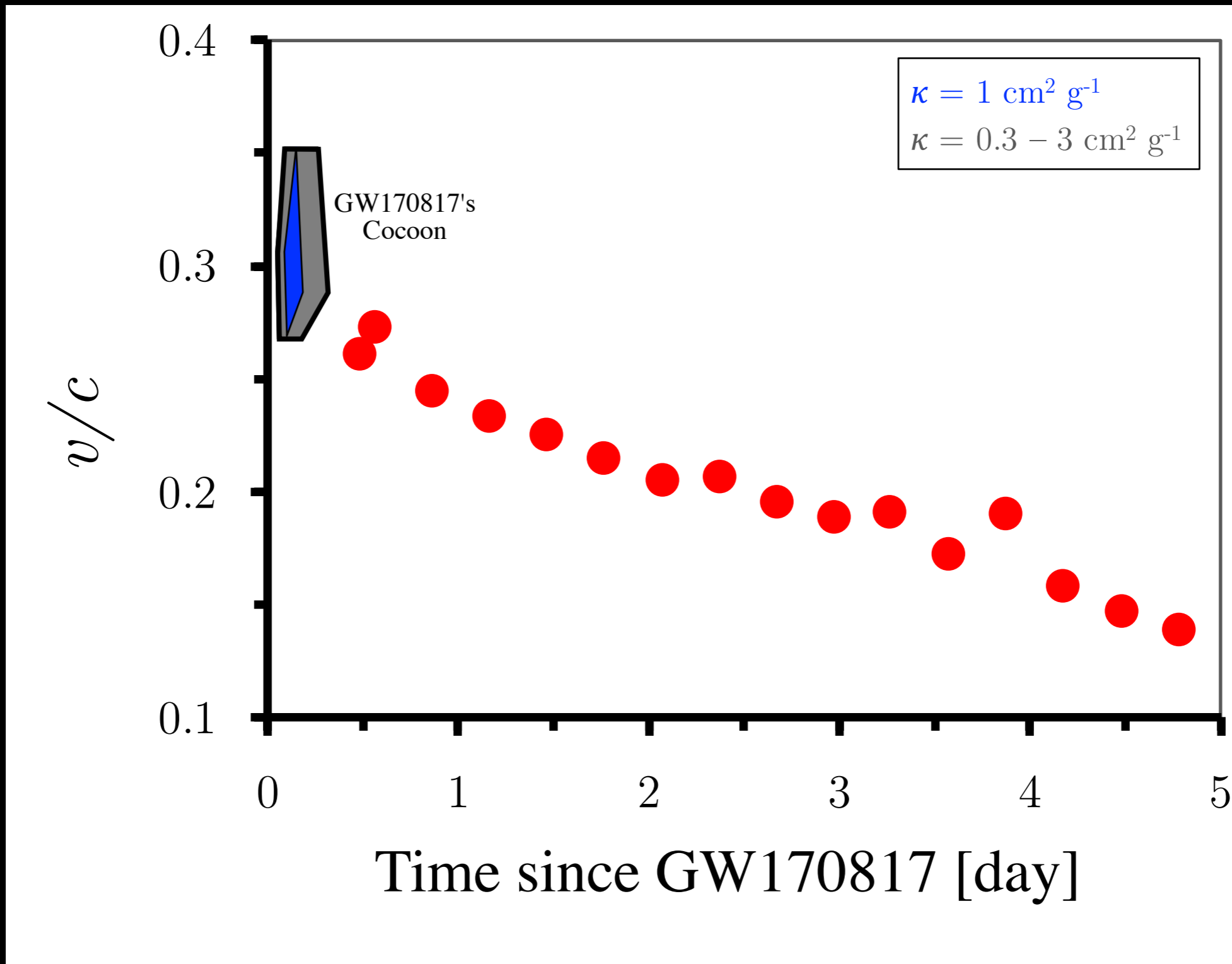# Results I:
GW170817's Cocoon (preliminary)

Results I:
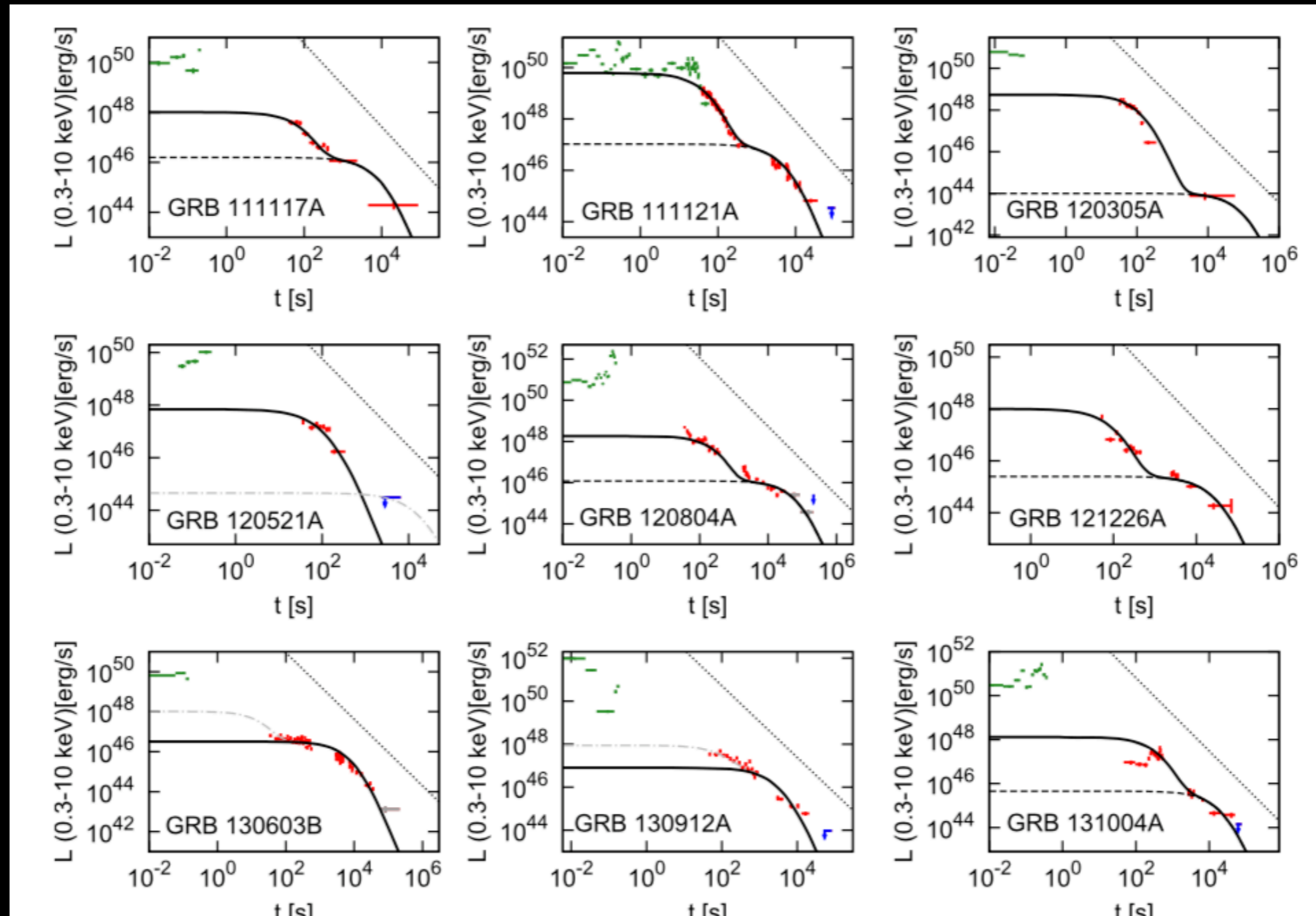## GW170817's Cocoon (preliminary)

The EM Counterparts
& The Cocoon

Photospheric Velocity (preliminary)

EE, and Plateau Emission
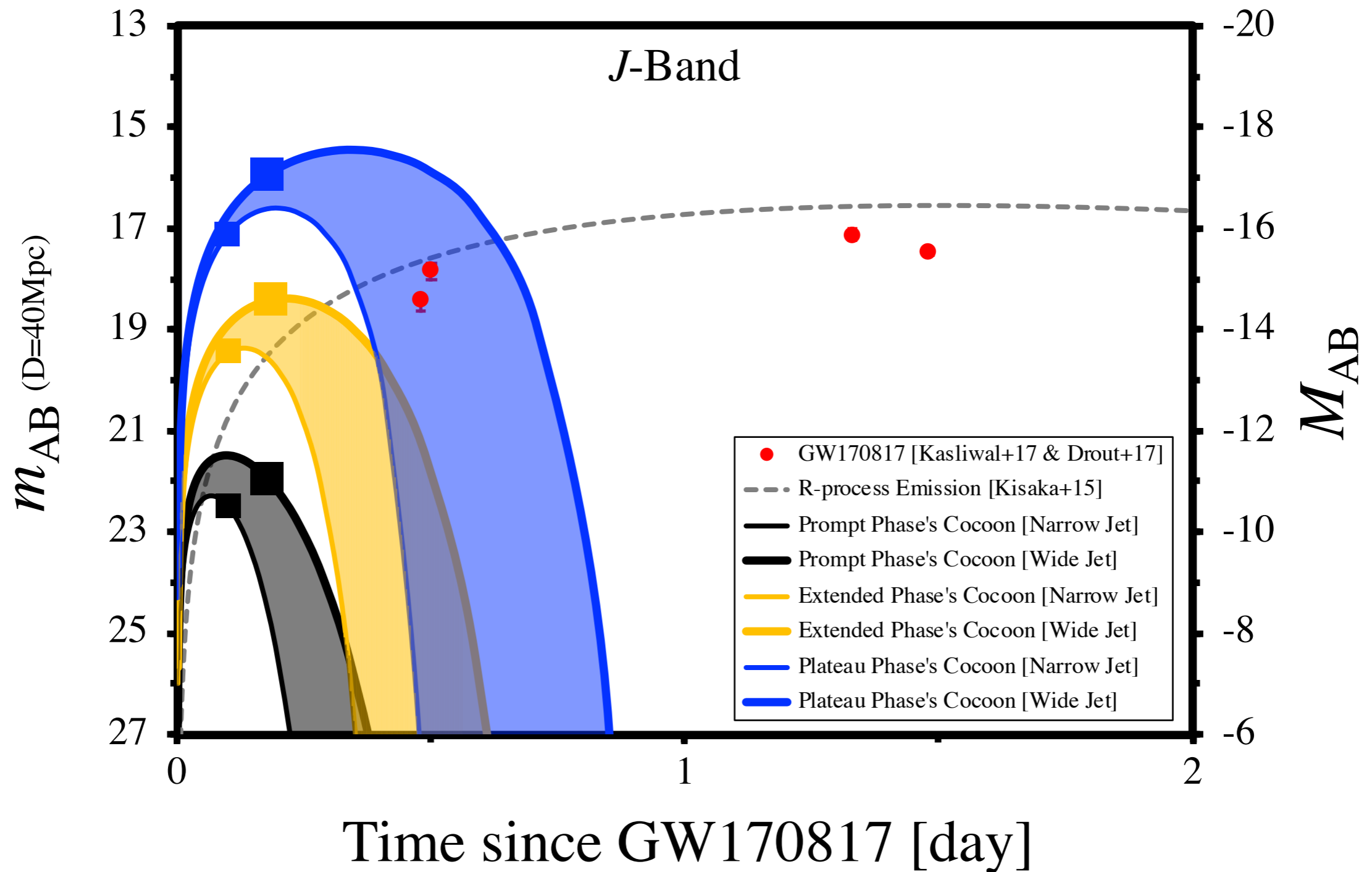

Kisaka+17

EE, and Plateau Emission

Kisaka+17
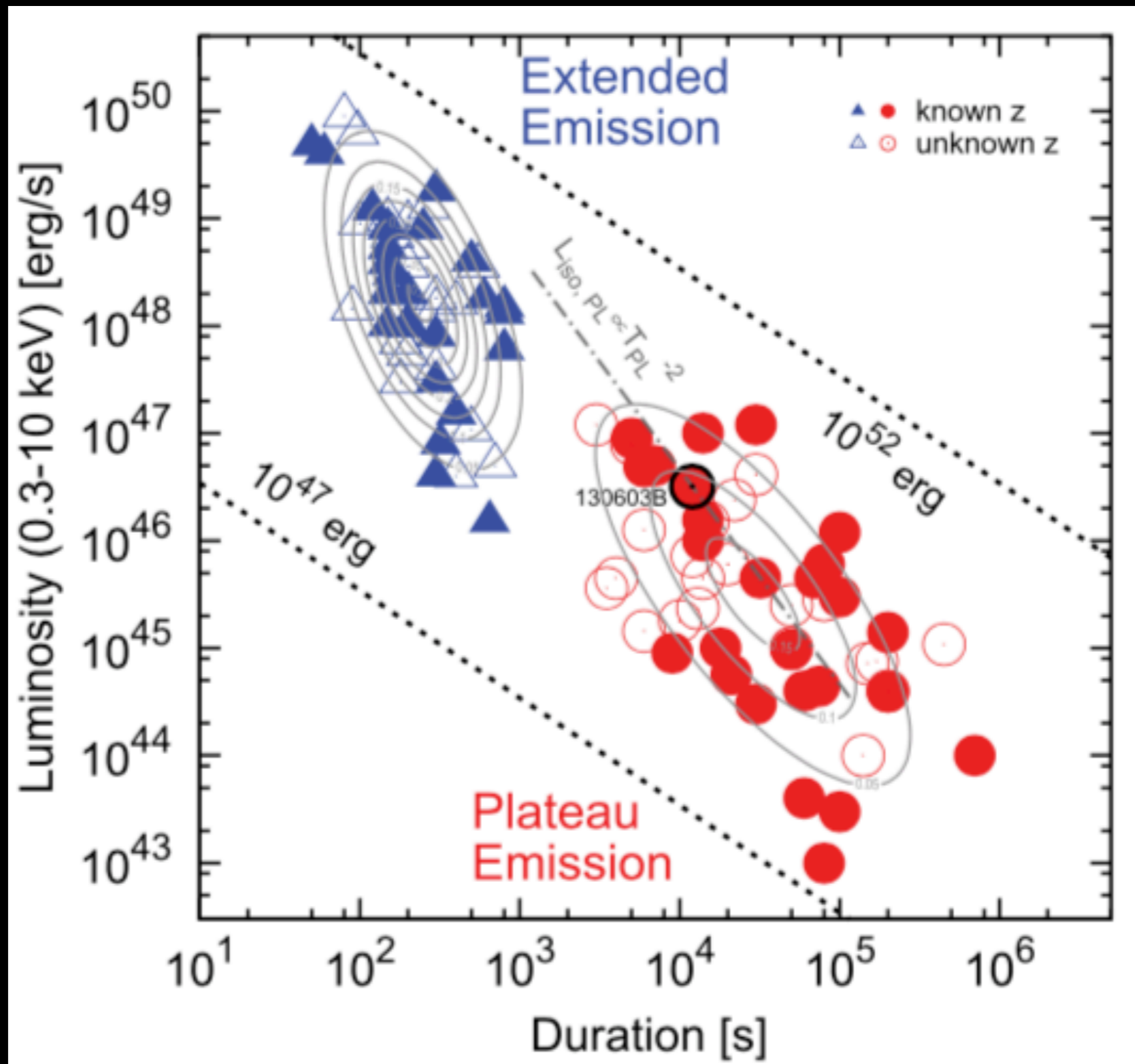
The Different Cocoons (preliminary)

The Cocoon outshining R-process (preliminary)

HH+19 in prep
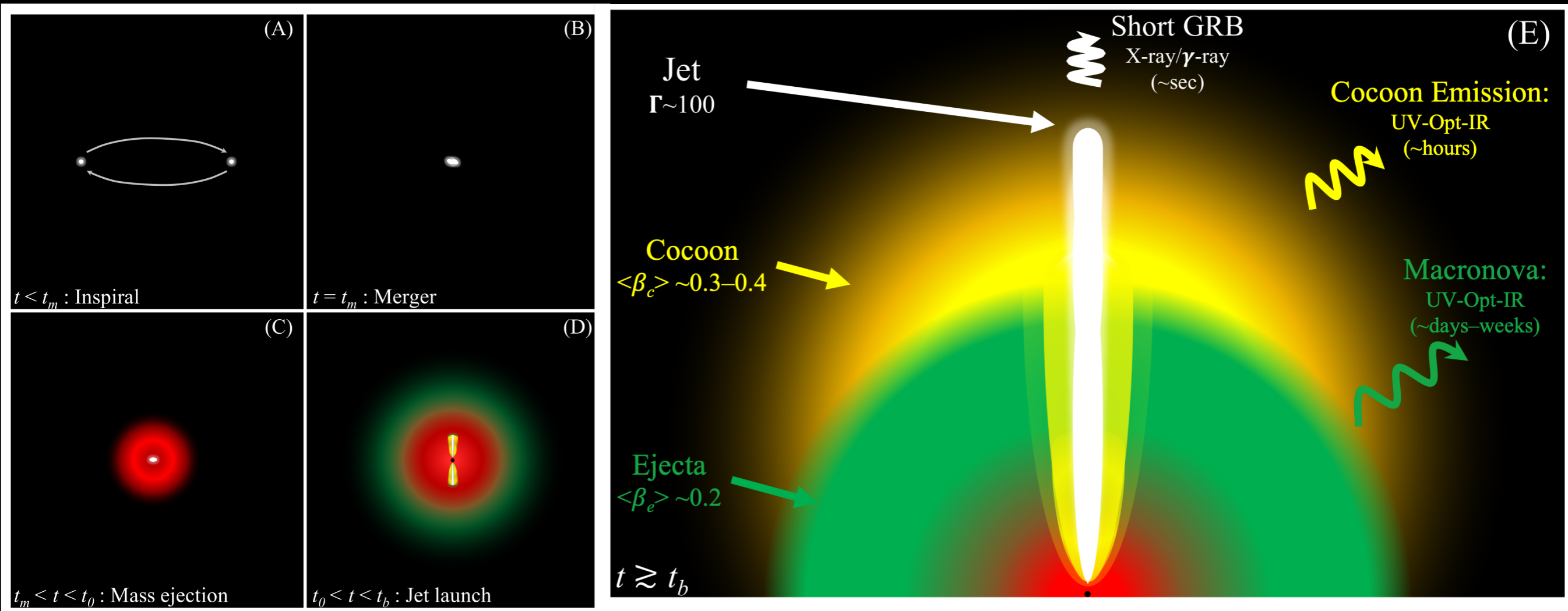
The Cocoon outshining R-process (preliminary)

HH+19 in prep

The Cocoon outshining R-process (preliminary)

HH+19 in prep
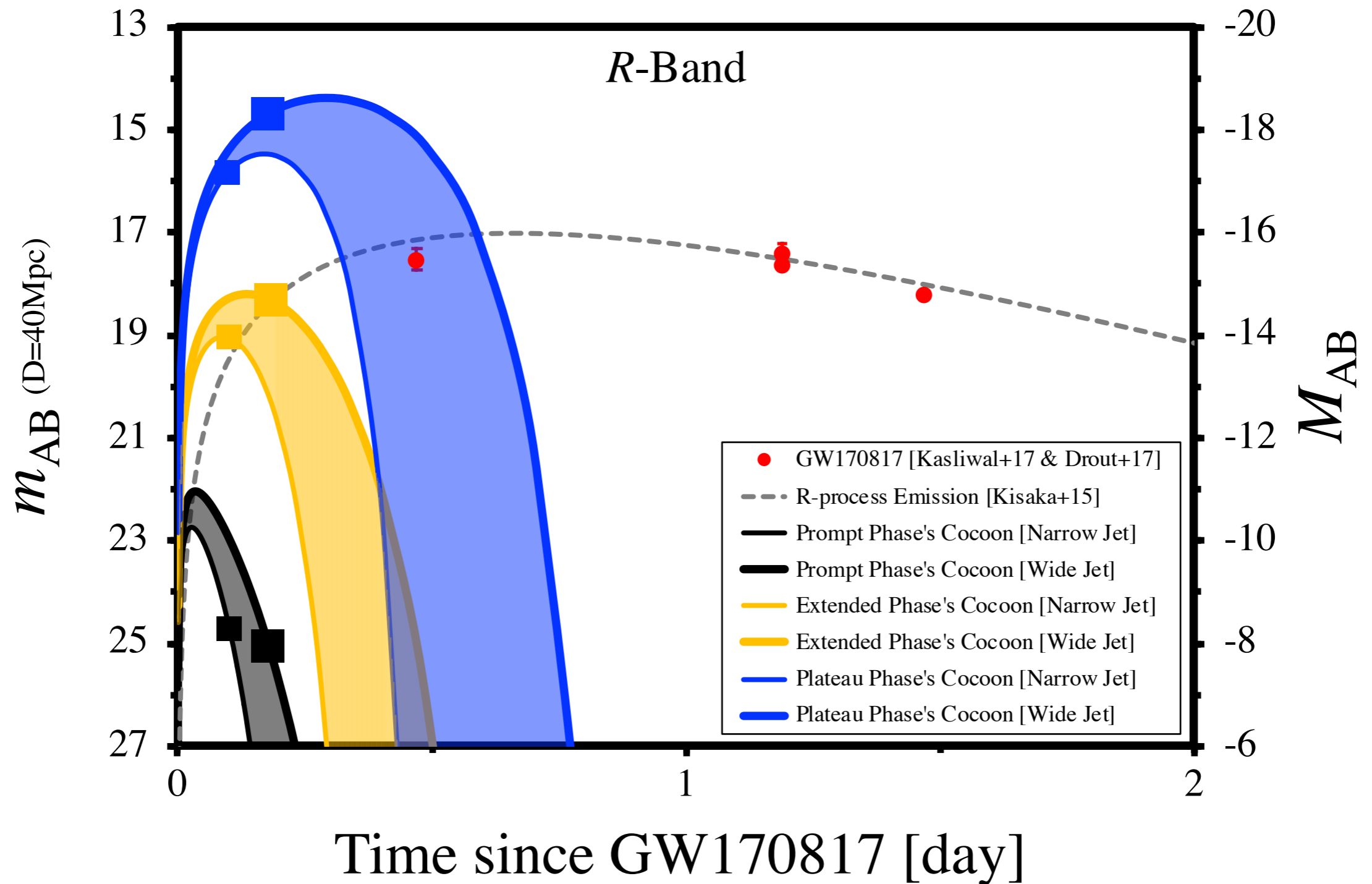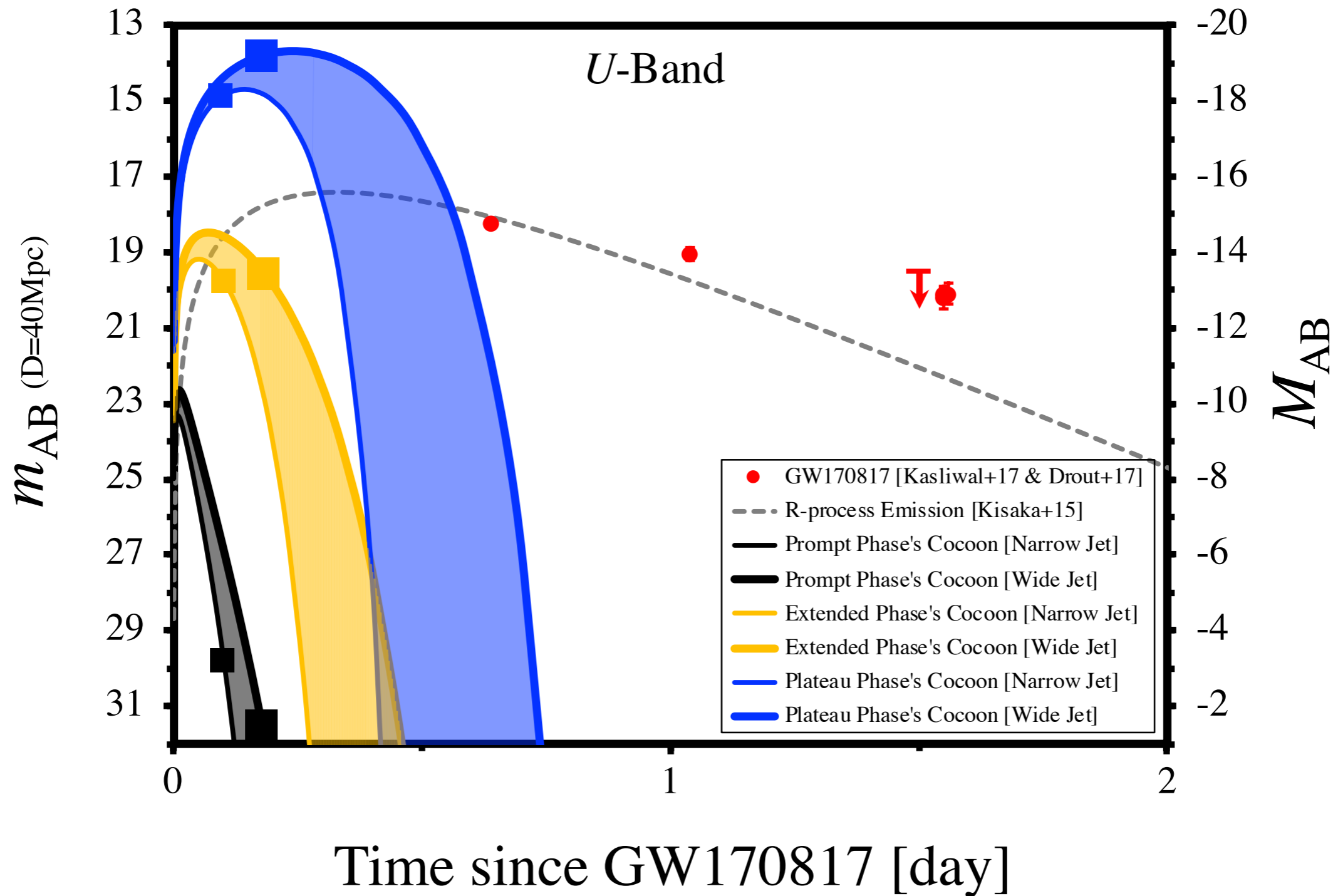
Temperature & Color (preliminary)

The Prediction

(A) $t < t_m$: Inspiral

(B) $t = t_m$: Merger

(C) $t_m < t < t_0$: Mass ejection

(D) $t_0 < t < t_b$: Jet launch

(E)

Short GRB
X-ray/$\boldsymbol{\gamma}$-ray
(~sec)

Jet
$\Gamma \sim 100$

Cocoon Emission:
UV-Opt-IR
(~hours)

Cocoon
$\langle\beta_c\rangle \sim 0.3\text{–}0.4$

Macronova:
UV-Opt-IR
(~days–weeks)

Ejecta
$\langle\beta_e\rangle \sim 0.2$

$t \gtrsim t_b$

HH+19 in prep
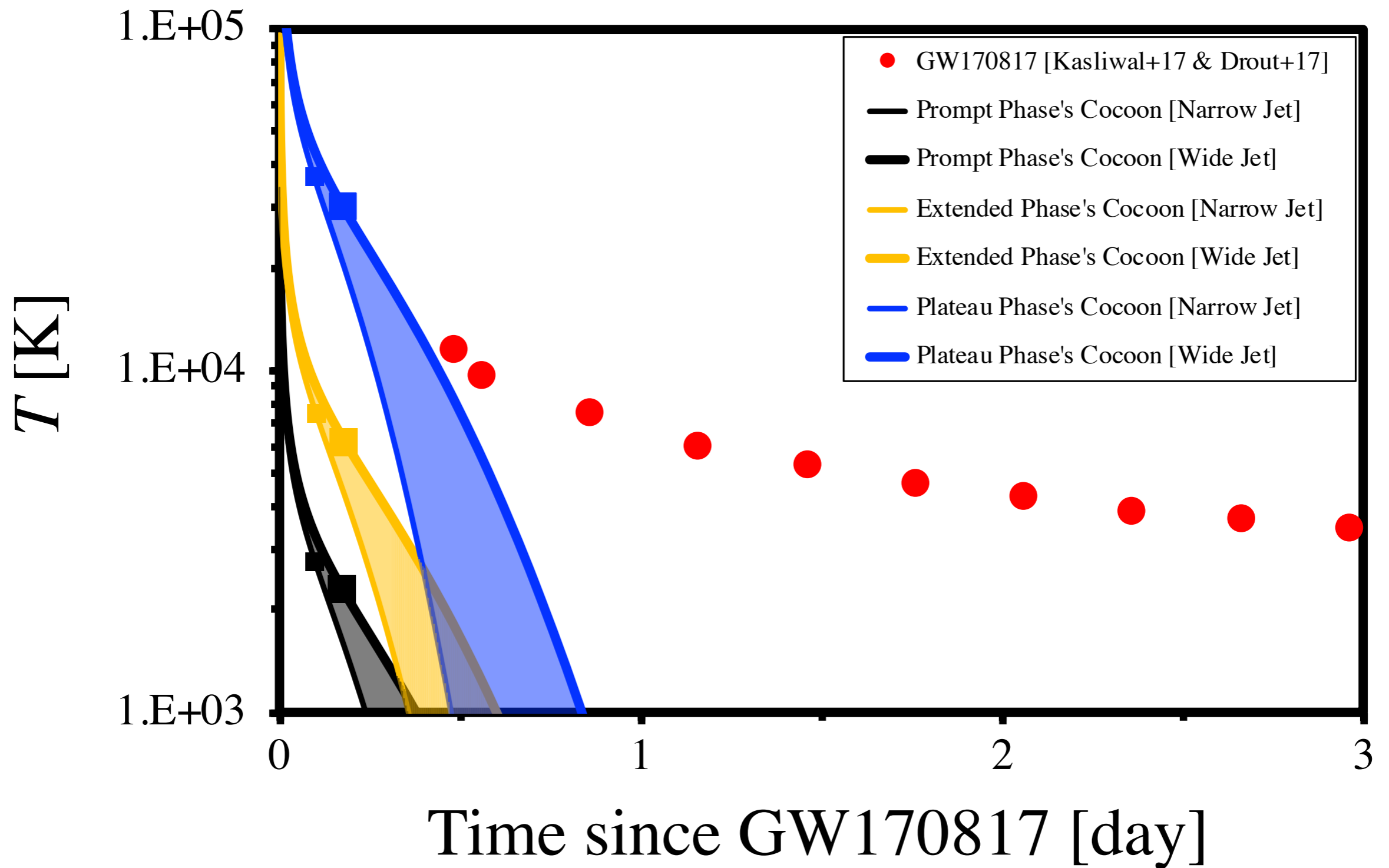
Summary

The Cocoon outshines r-process
likely to have contaminated the early macronova in GW170817

Large Opening Angles for the central engine
are excluded

Prediction of A Bright Early Counterparts
to peak and outshine r-process in the first a few hours
(if powered by the EE/PL emission of the engine)