# Towards a Unified Model for GRB 060218

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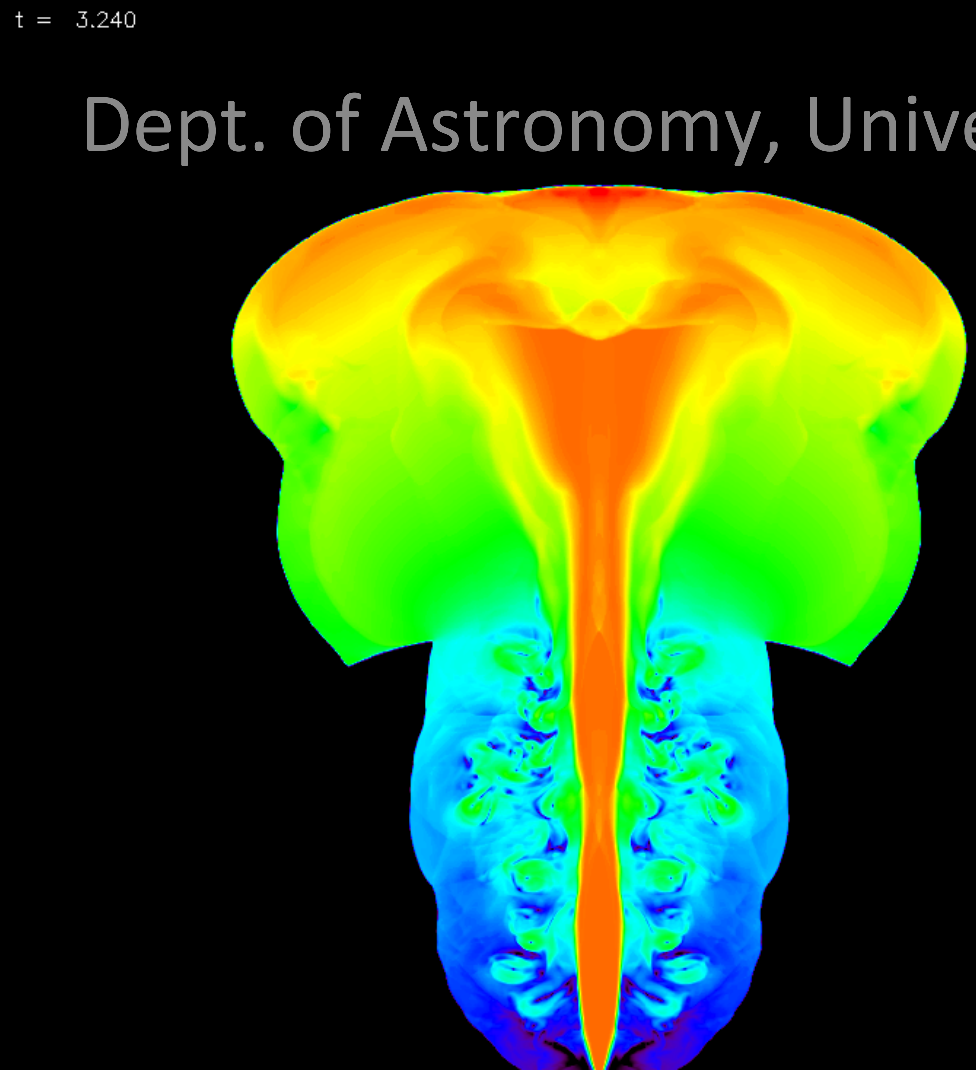


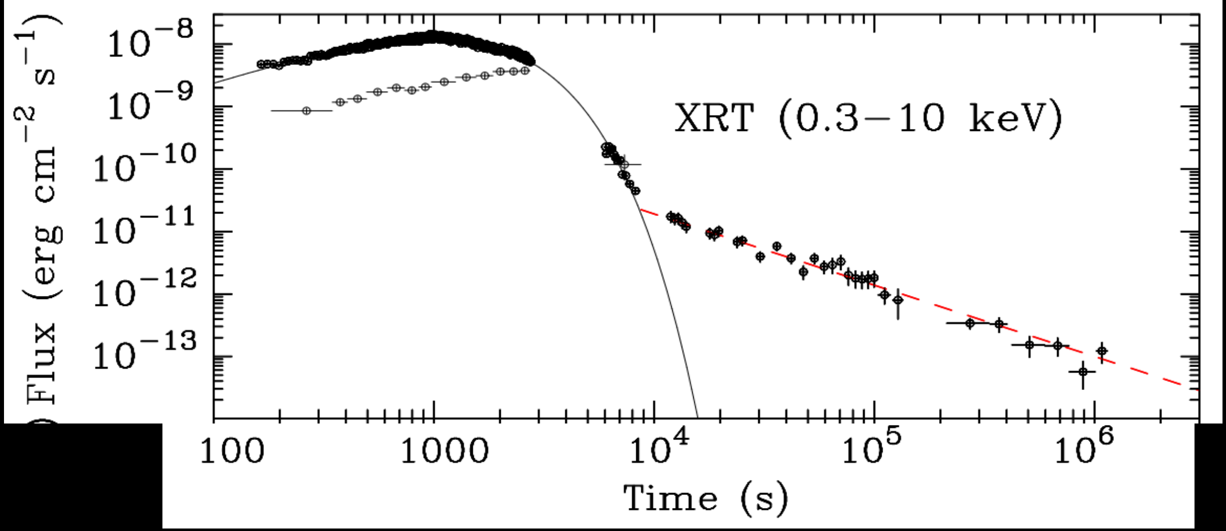
1819

1882

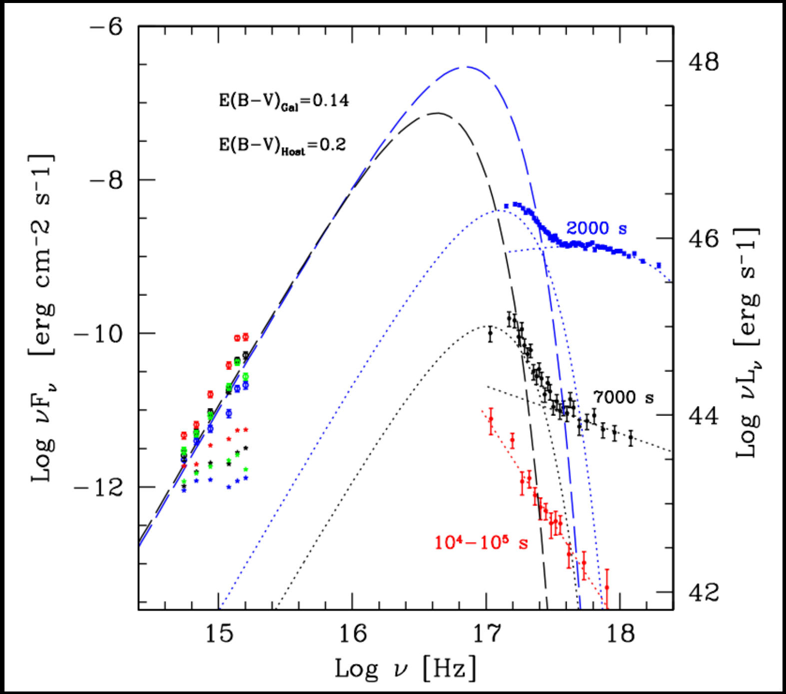
# GRB 060218: Observations

- Prompt X-rays/γ-rays (< 2000 s)
- Early optical emission (0.1 – 1 days)
- X-ray afterglow (0.1 – 10 days)
- Radio afterglow (2 – 20 days)

Campana et al. 2006



Ghisellini et al. 2006



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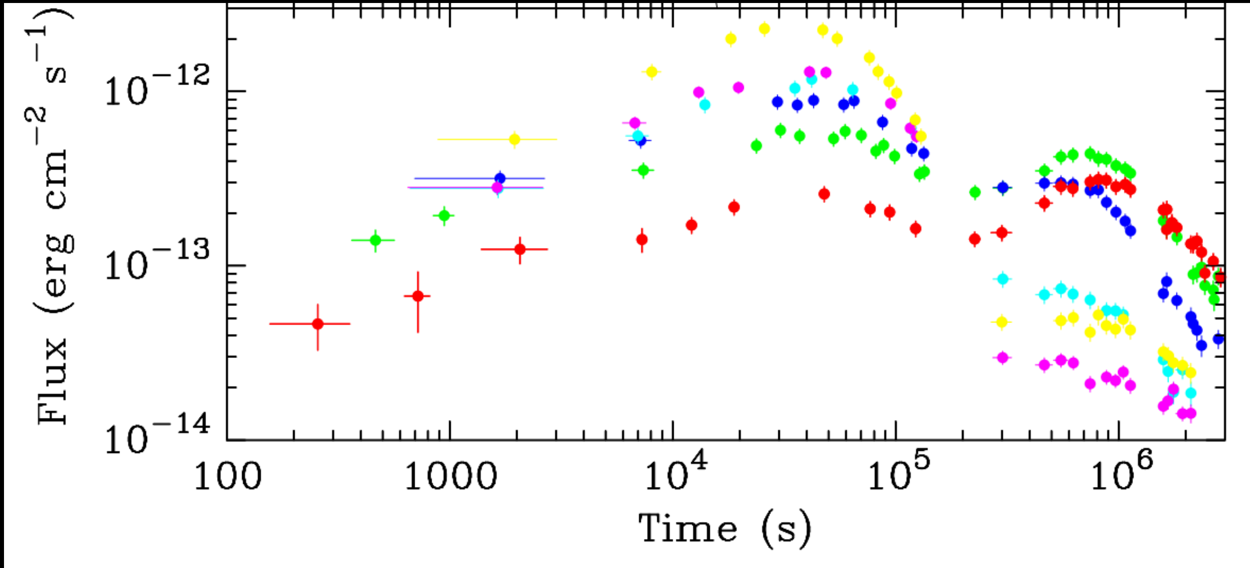

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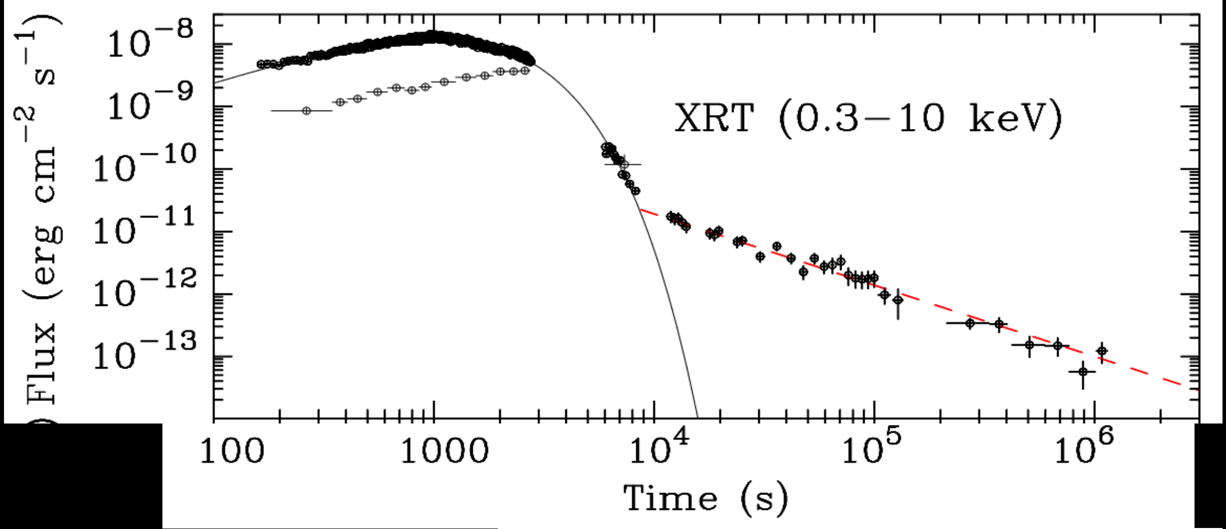
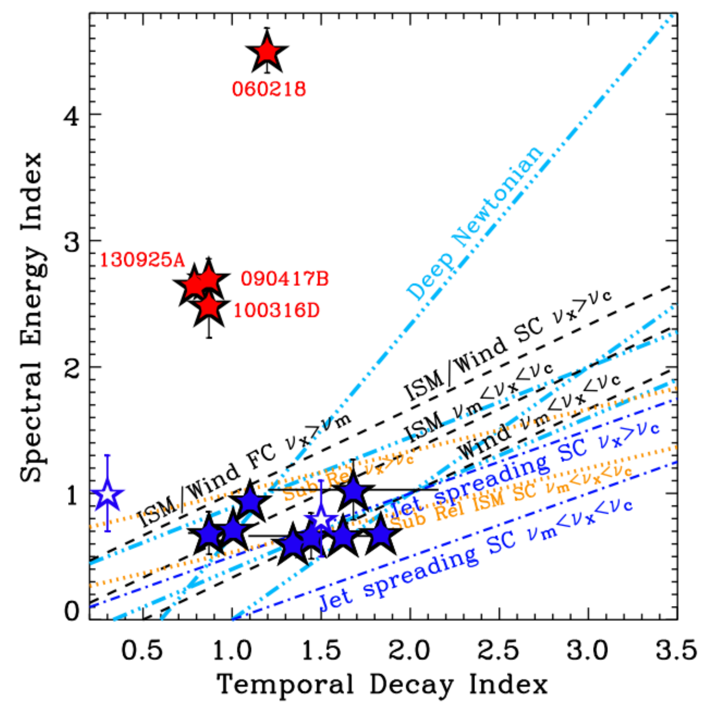


Margutti et al. 2014



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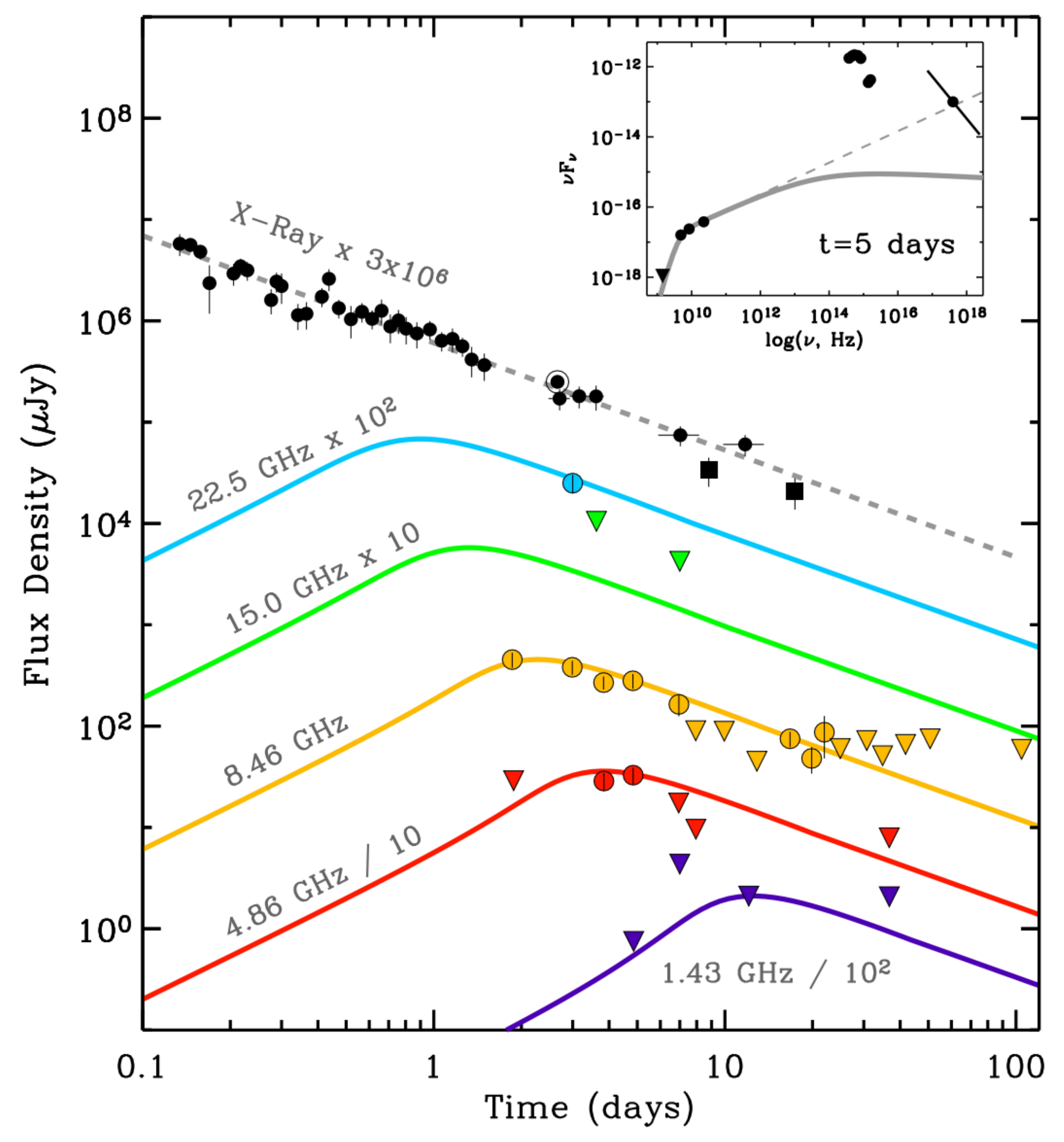

Soderberg et al. 2006

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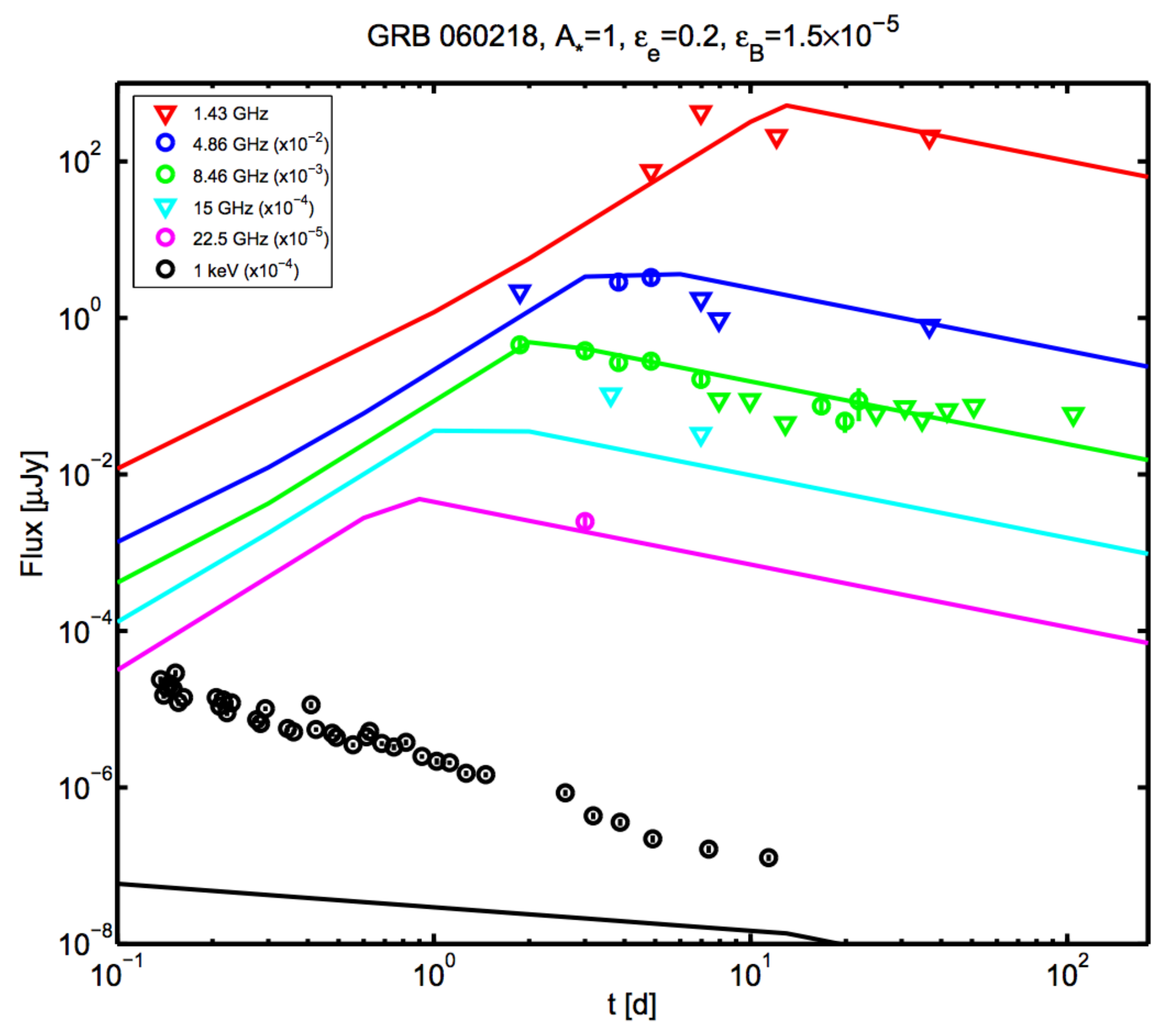
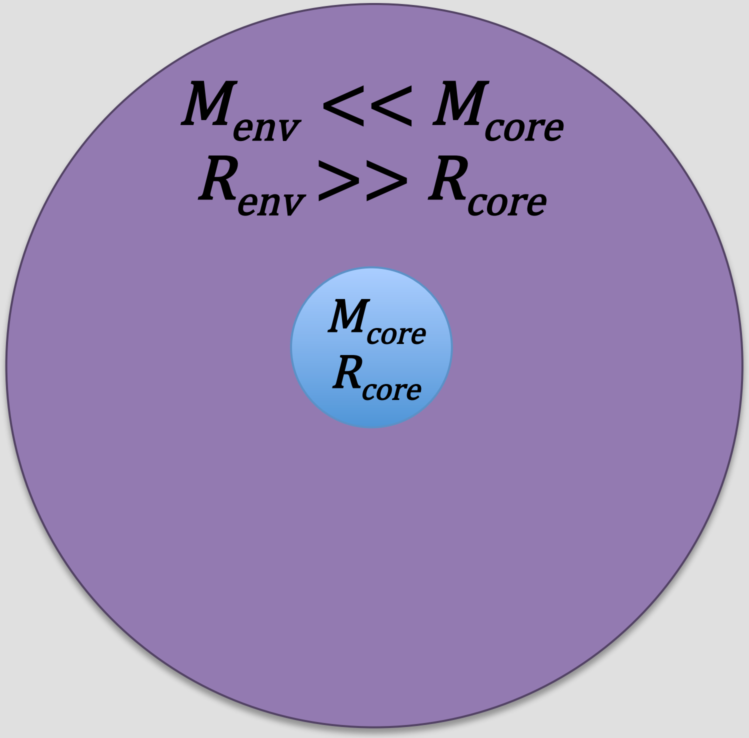


Barniol Duran et al. 2014

# Model Walkthrough

$t = 0$ s $\quad R_{jet} = 0$ cm $\quad R_{SN} = 0$ cm

$n << M_{env}/R_{core}^3$



$M_{env} << M_{core}$

$R_{env} >> R_{core}$

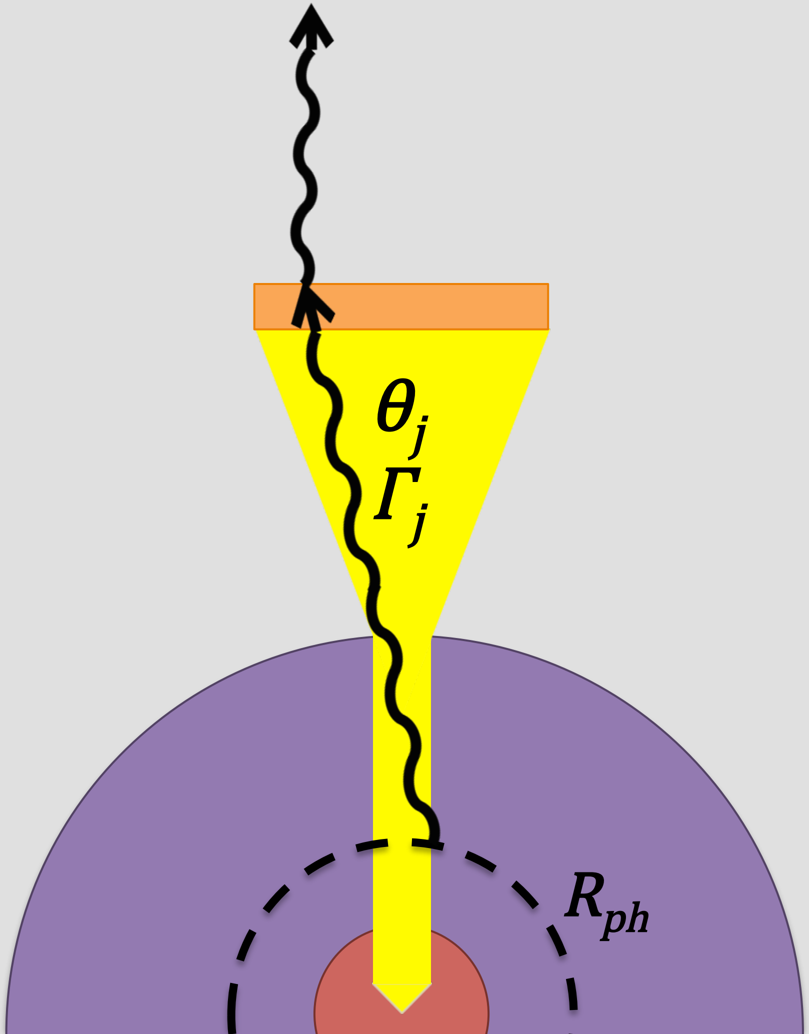
$M_{core}$

$R_{core}$

- The progenitor is a ~2 $M_{sun}$ star with a dense circumstellar wind
- Some process creates an optically thick, low-mass envelope around the star
  - Pre-explosion mass loss?
  - Stripped circumbinary envelope as in SN IIb?
- Collapse to a compact object launches the supernova ($E_{SN} = 2 \times 10^{51}$ ergs) and a low-luminosity jet ($L_j \sim 10^{45}$ ergs/s)

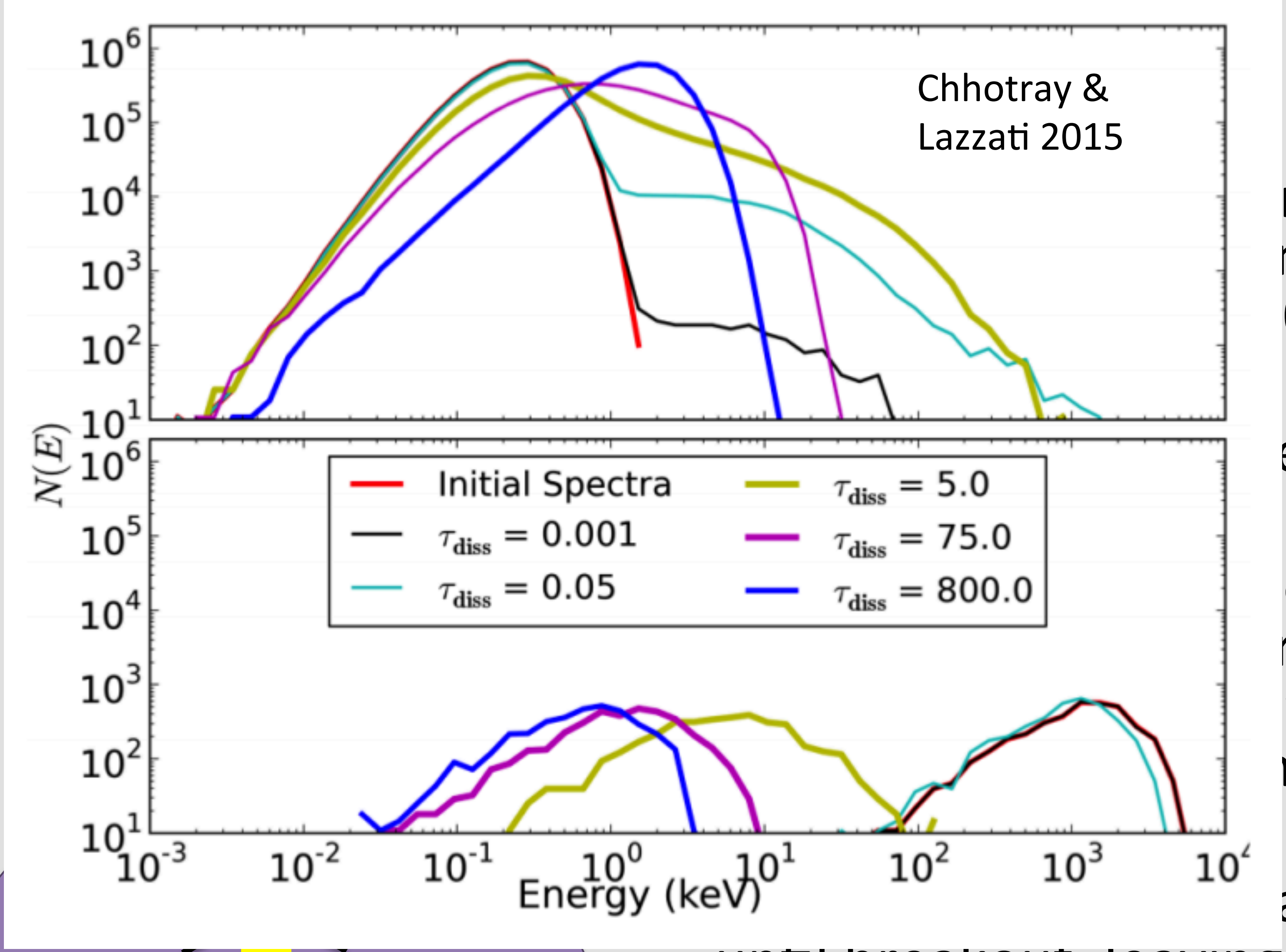
# Model Walkthrough

t = 1600 s $R_{jet}$ ~ $10^{13}$ cm $R_{SN}$ ~ $10^{12}$ cm



- After ~1600 s the jet breaks out of the envelope, and lasts an additional ~3000 s
- The jet remains collimated until breakout, leaving the envelope mostly intact
- Thermal X-rays are emitted from the jet photosphere at ~$10^{12}$ cm.
- Thermal photons scatter from electrons in external shocks or the jet itself to produce the nonthermal component

# Model Walkthrough


Chhotray & Lazzati 2015

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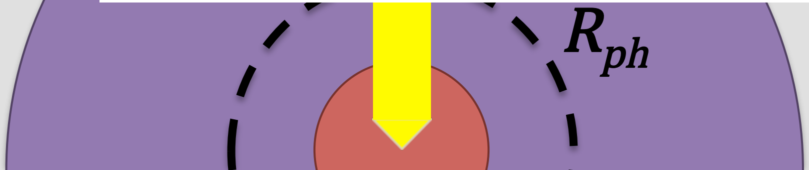
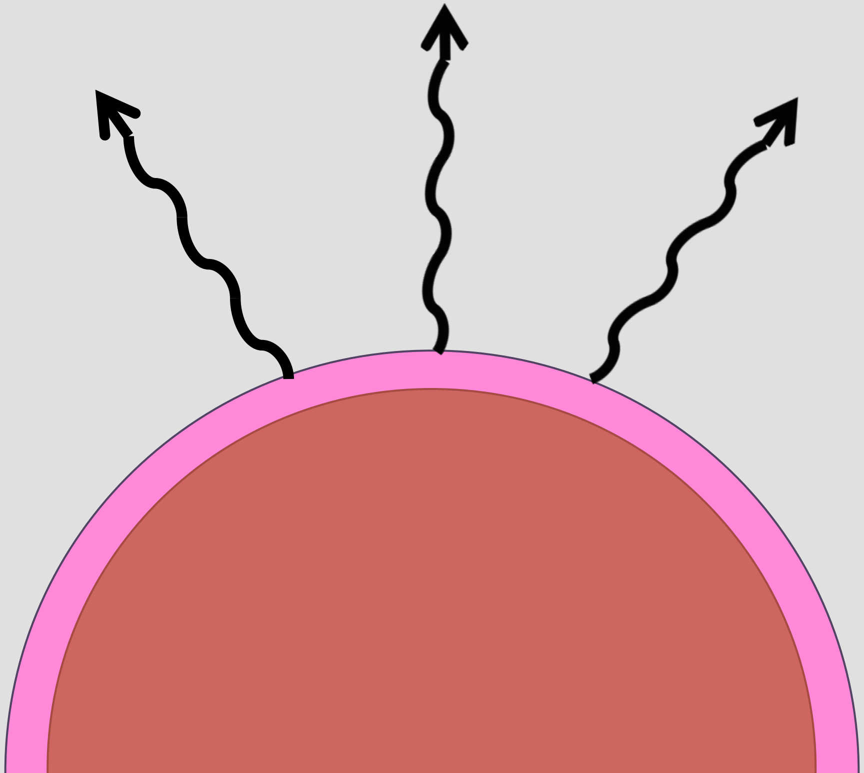


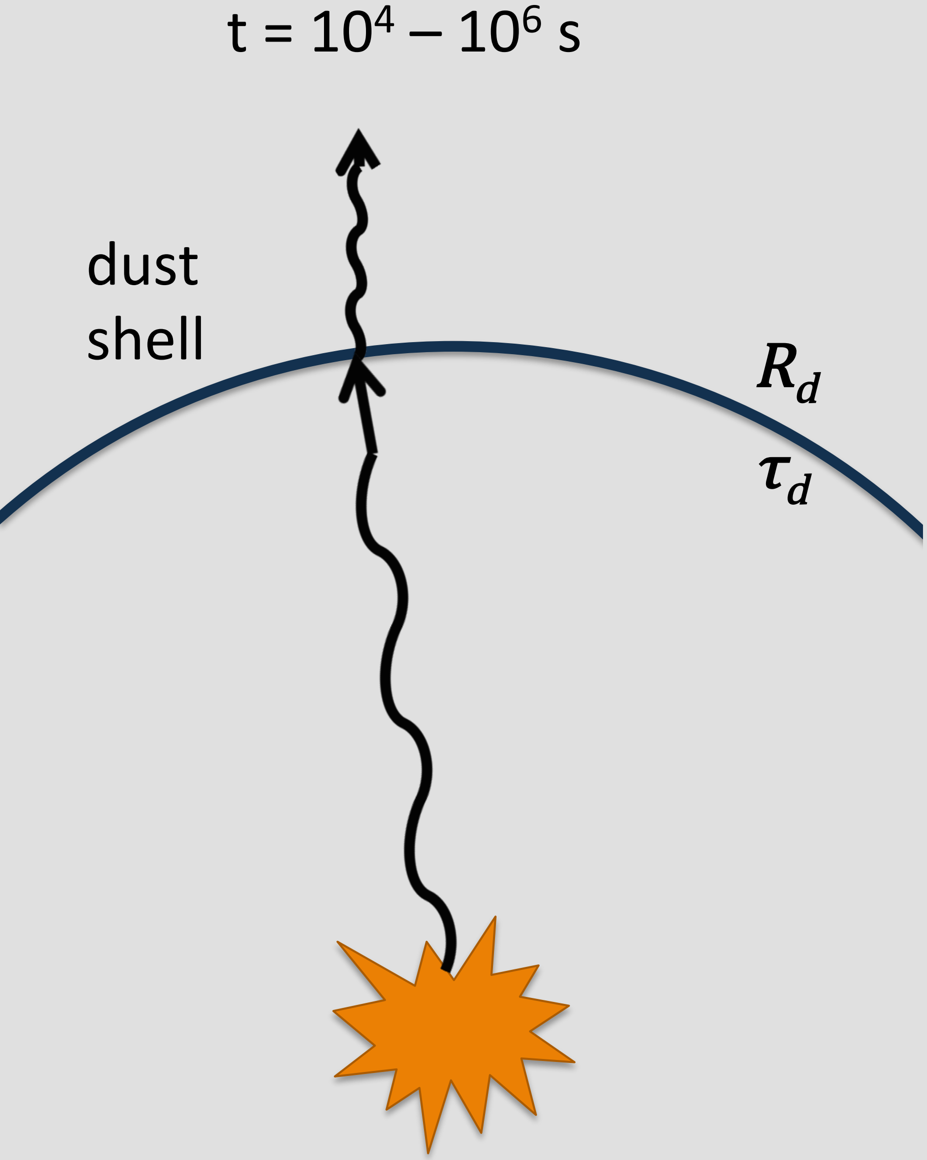
# Model Walkthrough

t = 0.4 days $R_{jet} \sim 4 \times 10^{16} (\Gamma/3)^2$ cm $R_{SN} \sim 10^{14}$ cm



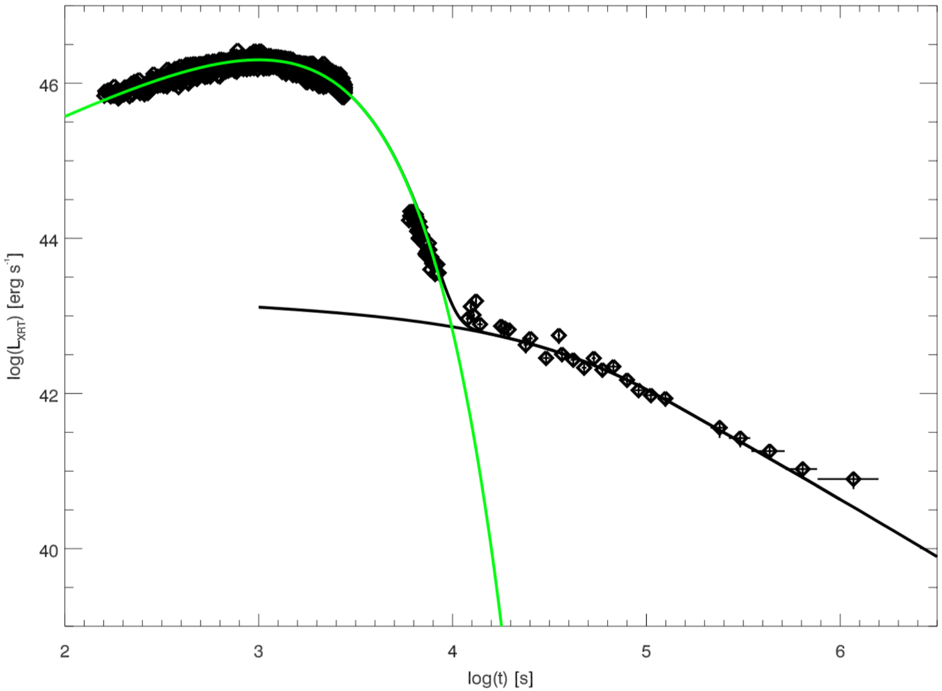
- The jet continues to expand into the CSM, gradually decelerating
- The SN ejecta shocks the low-mass envelope and pushes it out like a piston
- A burst of optical emission escapes when radiation can diffuse out of the cooling envelope (Nakar & Piro 2014)
- We derive $M_{ext} = 4 \times 10^{-3} M_{sun}$ and $R_{ext} = 9 \times 10^{12}$ cm

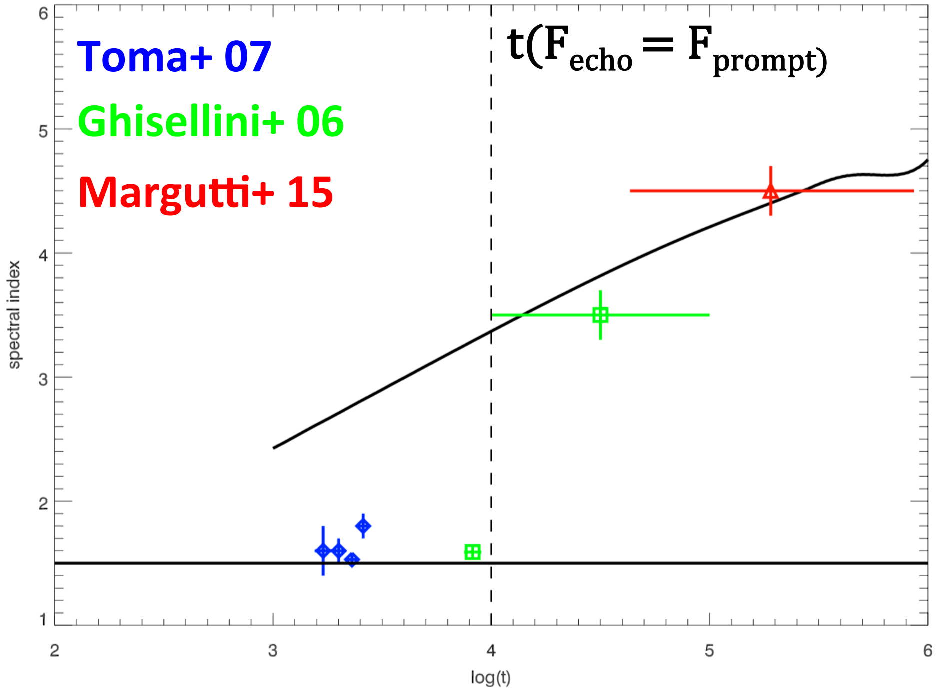
# Model Walkthrough



- Meanwhile, the prompt X-rays are scattered by dust grains at $R_d$
- The resulting dust echo can reproduce the afterglow light curve and steep spectrum
- We find $R_d = 35$ pc, $\tau_d(1 \text{ keV}) = 0.006$ based on modeling the echo
- Optical extinction is $A_V \sim 0.1$, consistent with host galaxy extinction measured from Na I D observations

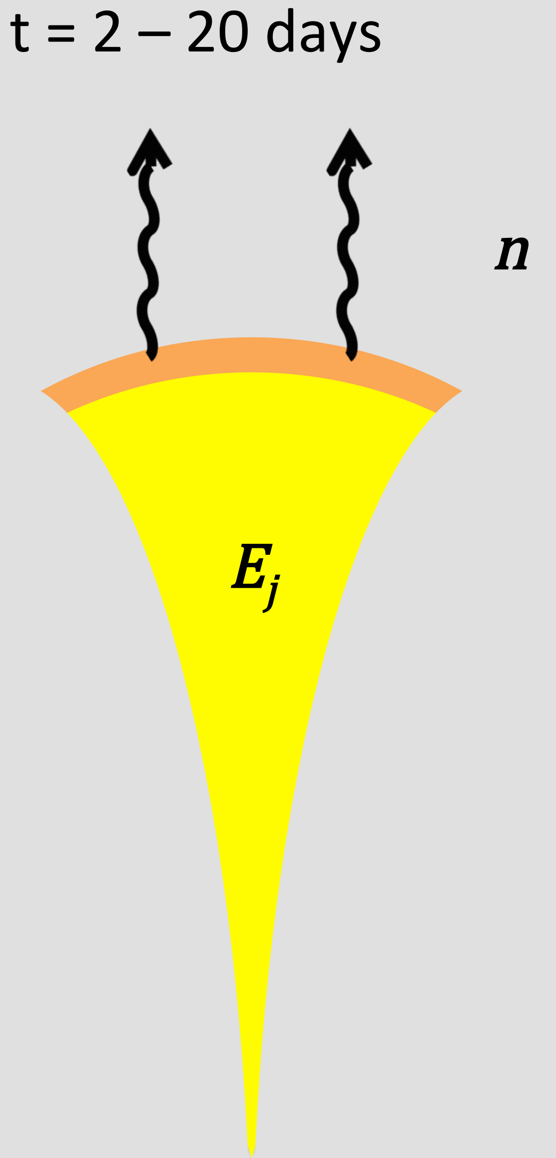
# Dust Echo Emission





- Modified version of Shao et al. (2008) model specific to GRB 060218
- Optical depth per unit grain size $\tau_a \propto \tau_d E^{-s} a^{4-q}$
- Prompt spectrum is fit with an empirical blackbody + Band function model
- Best-fit parameters: $R_d$ = 35 pc, $\tau_d$(1 keV) = 0.006, $a_+$ = 0.25 µm, s = 2, q = 4
- $\tau_d$ is well determined because the total flux is well constrained;
  $R_d$ is somewhat uncertain because the time when the light curve turns over is not well constrained

# Model Walkthrough



- The radio can be explained as external shock synchrotron from the nonrelativistic phase of the jet outflow
- The flow may or may not be spherical during this time
- Parameters: $n \sim 100$ cm$^{-3}$ , $\Gamma_j \sim 2.4$, $\theta_j \sim 0.4$, and $E_j \sim 2 \times 10^{48}$ ergs for $\varepsilon_e = 0.1$, $\varepsilon_B = 0.1$
- The same jet parameters can explain BOTH the prompt thermal X-rays and the radio

# Takeaway Points

- ***Decoupling*** of the optical emission, prompt X-rays + radio, and X-ray afterglow is needed to fit the data
- The X-ray afterglow's unusually steep spectrum and high flux (compared to the radio) can be attributed to a dust echo of the prompt emission.  Only a moderate amount of dust ($A_V \sim 0.1$) is necessary.
- The double-peaked optical emission is compelling evidence for an extended low-mass envelope surrounding the progenitor—perhaps the best case yet of this mechanism in action.
- A low-luminosity, intrinsically long-lived jet can explain both the prompt X-rays and the radio at later epochs.
- Comptonization of thermal seed photons by mildly relativistic electrons in the jet or reverse shock is the best explanation for the prompt nonthermal X-rays.