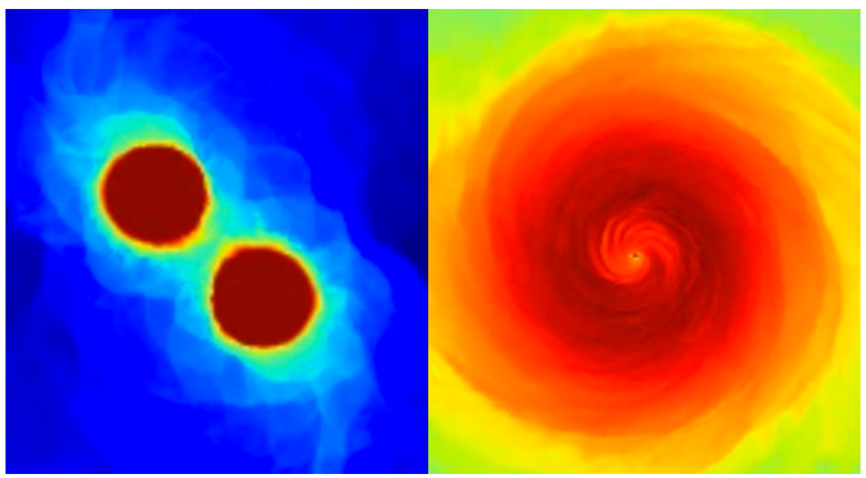
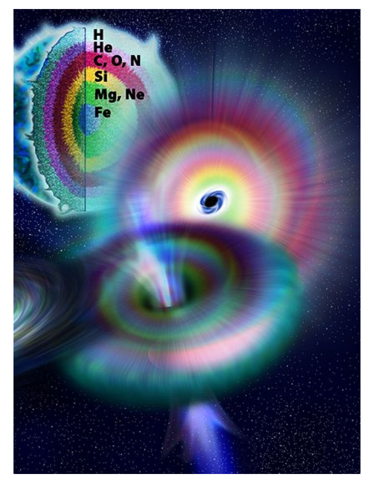
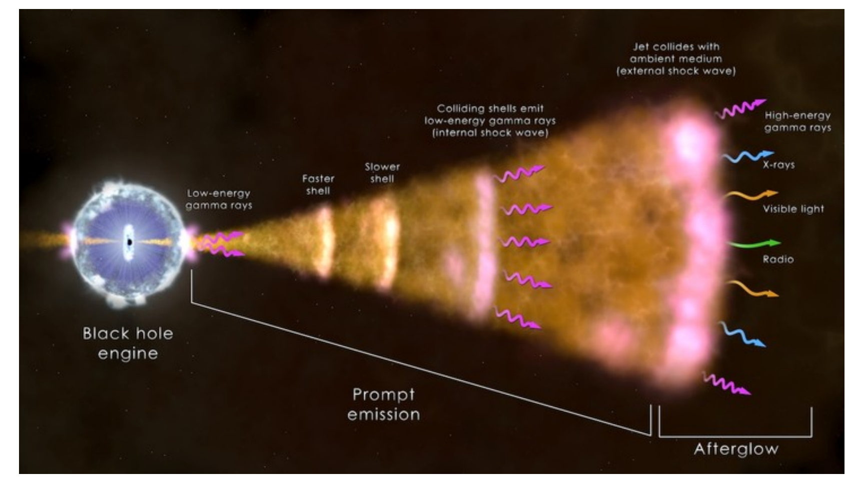
ICTP school: GRB afterglows slides







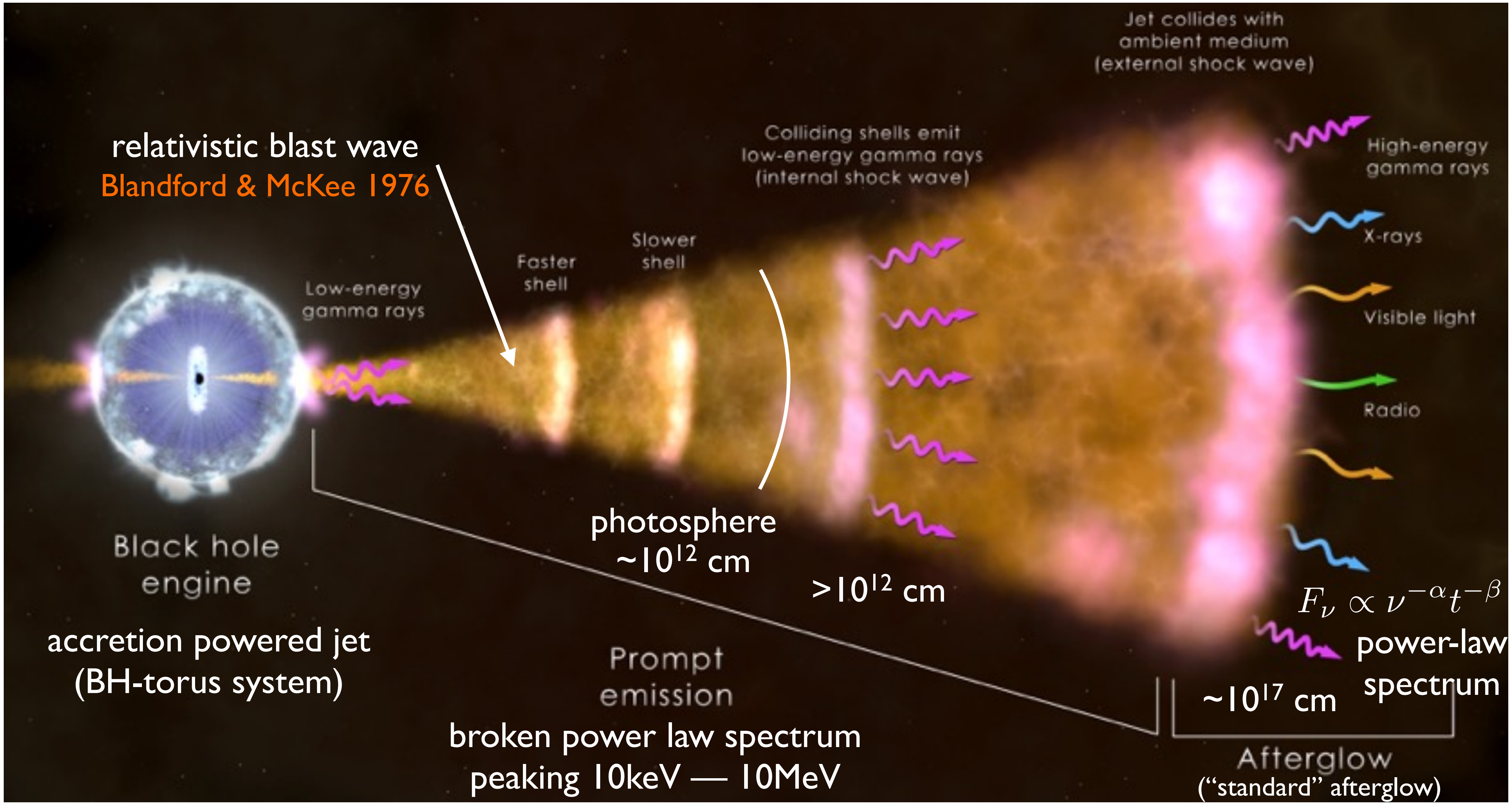
Daniel M. Siegel

Center for Theoretical Physics & Columbia Astrophysics Laboratory

Columbia University

ICTP school *The Sound of Space-time: The Dawn of Gravitational Wave Science*,
Sao Paulo, Dec 10-14, 2018

The canonical GRB picture



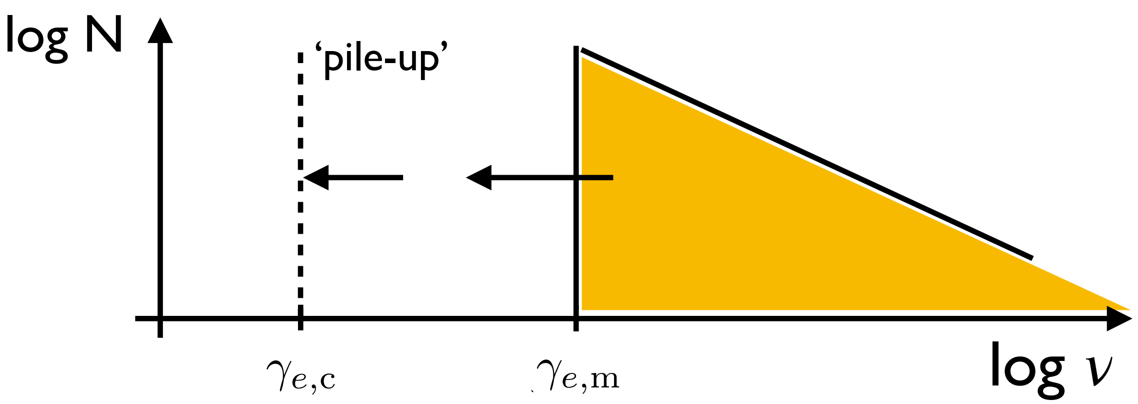
How does the relativistic blast wave give rise to observable emission?

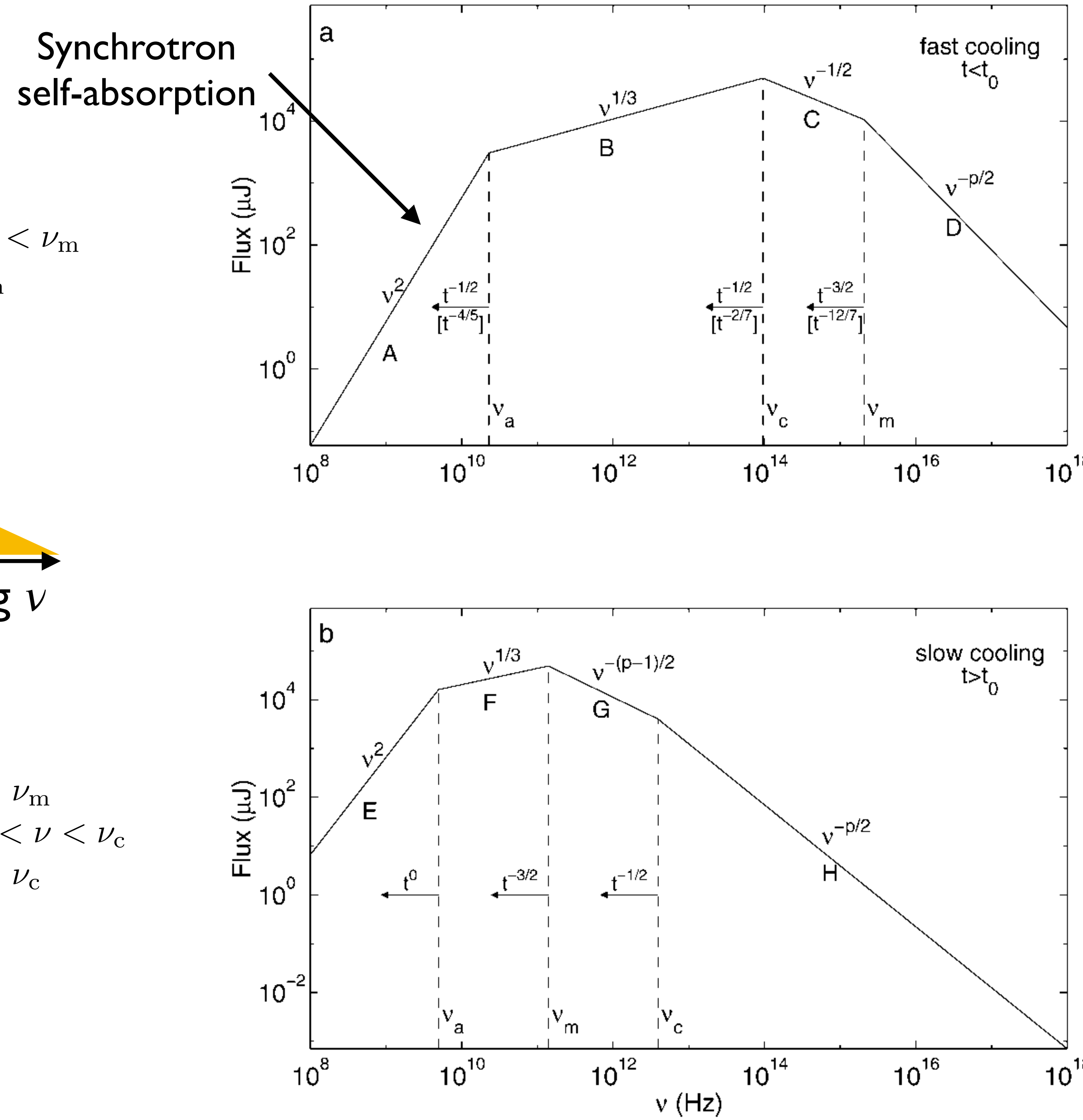
Synchrotron afterglow spectrum

Two regimes:

fast cooling $(\gamma_{e,\mathrm{m}} > \gamma_{e,\mathrm{c}})$

$$F_{\nu,\mathrm{tot}} = \begin{cases} (\nu/\nu_\mathrm{c})^{1/3} F_{\nu,\mathrm{max}}, & \nu < \nu_\mathrm{c} \\ (\nu/\nu_\mathrm{c})^{-1/2} F_{\nu,\mathrm{max}}, & \nu_\mathrm{c} < \nu < \nu_\mathrm{m} \\ (\nu/\nu_\mathrm{m})^{-p/2} (\nu_\mathrm{m}/\nu_\mathrm{c})^{-1/2} F_{\nu,\mathrm{max}}, & \nu > \nu_\mathrm{m} \end{cases}$$

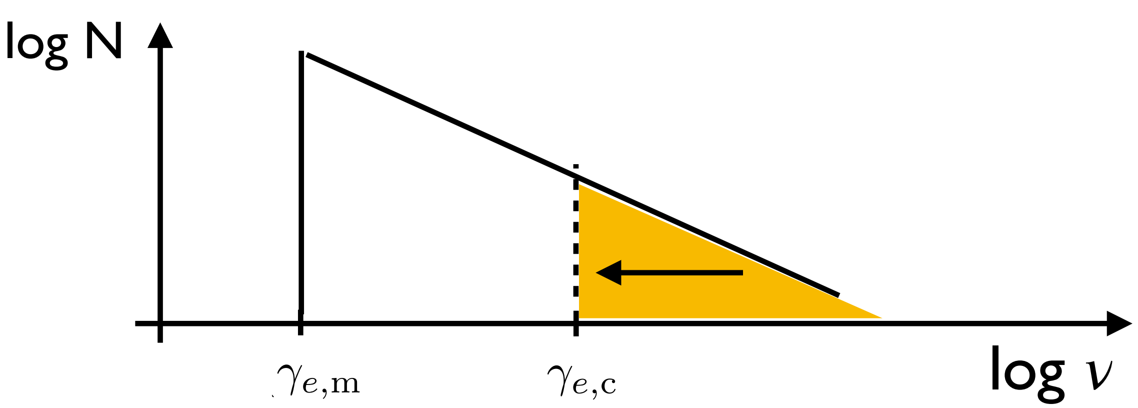




Sari+ 1998

slow cooling $(\gamma_{e,\mathrm{m}} < \gamma_{e,\mathrm{c}})$

$$F_{\nu,\mathrm{tot}} = \begin{cases} (\nu/\nu_\mathrm{m})^{1/3} F_{\nu,\mathrm{max}}, & \nu < \nu_\mathrm{m} \\ (\nu/\nu_\mathrm{m})^{-(p-1)/2} F_{\nu,\mathrm{max}}, & \nu_\mathrm{m} < \nu < \nu_\mathrm{c} \\ (\nu/\nu_\mathrm{c})^{-p/2} (\nu_\mathrm{c}/\nu_\mathrm{m})^{-(p-1)/2} F_{\nu,\mathrm{max}}, & \nu > \nu_\mathrm{c} \end{cases}$$



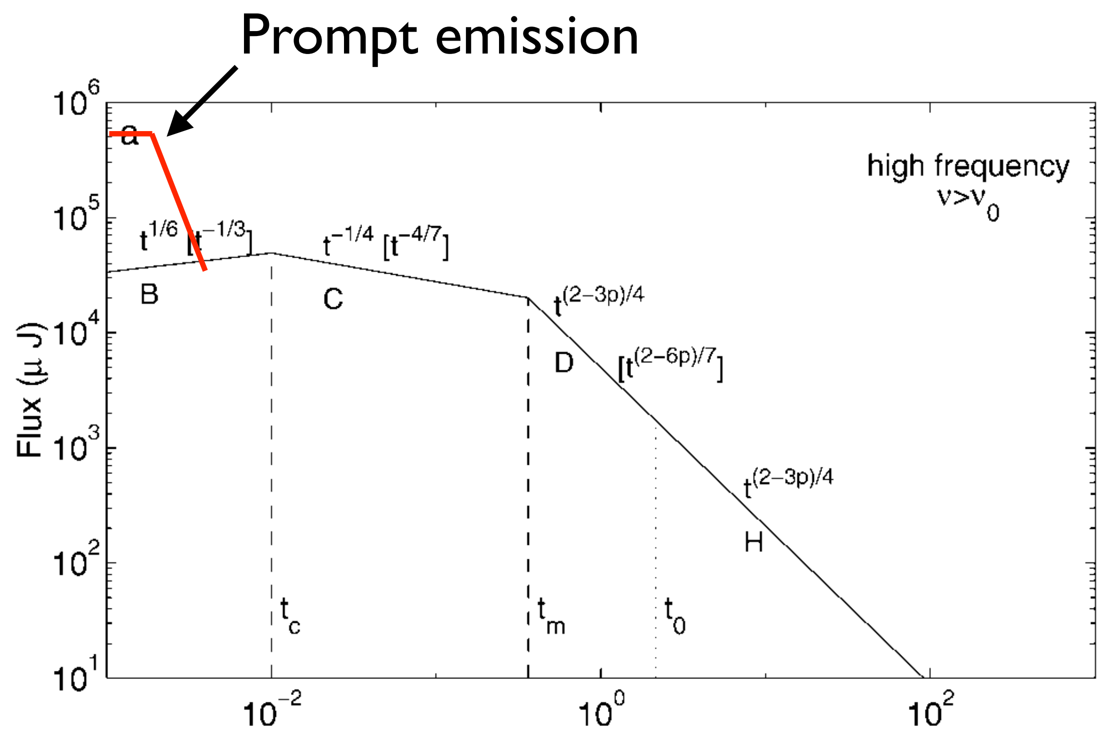
$$F_{\nu,\mathrm{max}} = \frac{1}{4\pi D^2} N_e P_{\nu,\mathrm{max}} = \frac{m_e c^3 \sigma_\mathrm{T}}{9e} (32\pi m_\mathrm{p})^{1/2} \epsilon_B^{1/2} n^{3/2} \gamma^2 R^3 D^{-2}$$

Synchrotron afterglow lightcurves

Two scenarios:

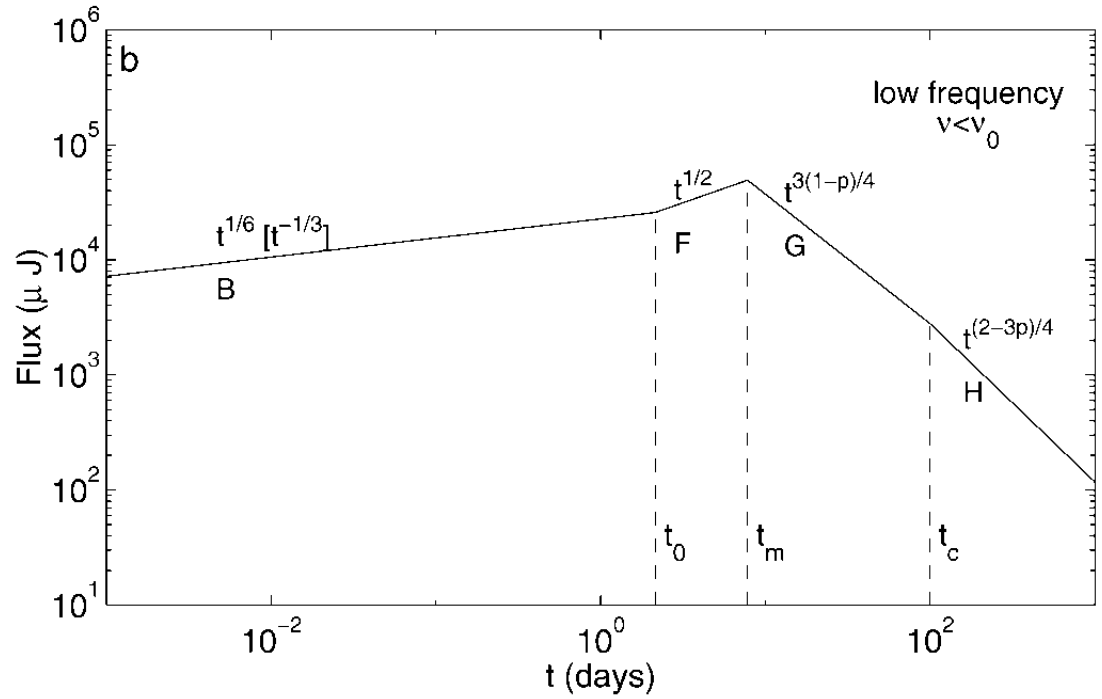
High-frequency lightcurve: $\nu_{\rm obs} > \nu_0$

$$L \simeq \nu_{\rm obs} F_{\nu,{\rm tot}}(\nu_{\rm obs}) \propto \begin{cases} \nu_{\rm c}^{-1/3}, & \propto t^{1/6}, & t < t_{\rm c} \\ \nu_{\rm c}^{1/2}, & \propto t^{-1/4}, & t_{\rm c} < t < t_{\rm m} \\ \nu_{\rm c}^{1/2}\nu_{\rm m}^{(p-1)/2}, & \propto t^{-(3p-2)/4}, & t > t_{\rm m} \end{cases}$$



Low-frequency lightcurve: $\nu_{\rm obs} < \nu_0$

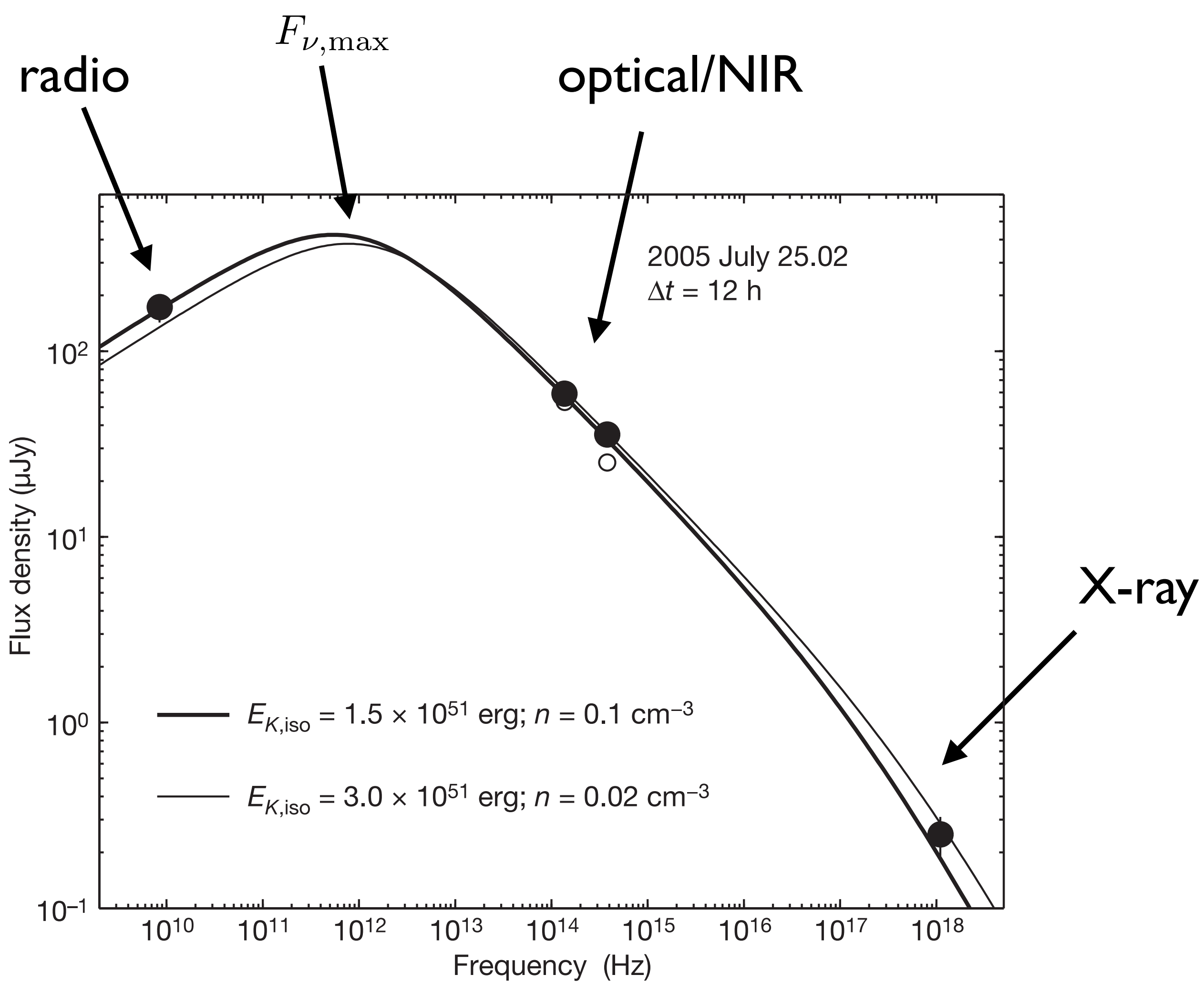
$$L \simeq \nu_{\rm obs} F_{\nu,{\rm tot}}(\nu_{\rm obs}) \propto \begin{cases} \nu_{\rm c}^{-1/3}, & \propto t^{1/6}, & t < t_0 \\ \nu_{\rm m}^{-1/3}, & \propto t^{1/2}, & t_0 < t < t_{\rm m} \\ \nu_{\rm m}^{(p-1)/2}, & \propto t^{-3(p-1)/4}, & t_{\rm m} < t < t_{\rm c} \\ \nu_{\rm m}^{(p-1)/2}\nu_{\rm c}^{1/2}, & \propto t^{-(3p-2)/4}, & t > t_{\rm c} \end{cases}$$



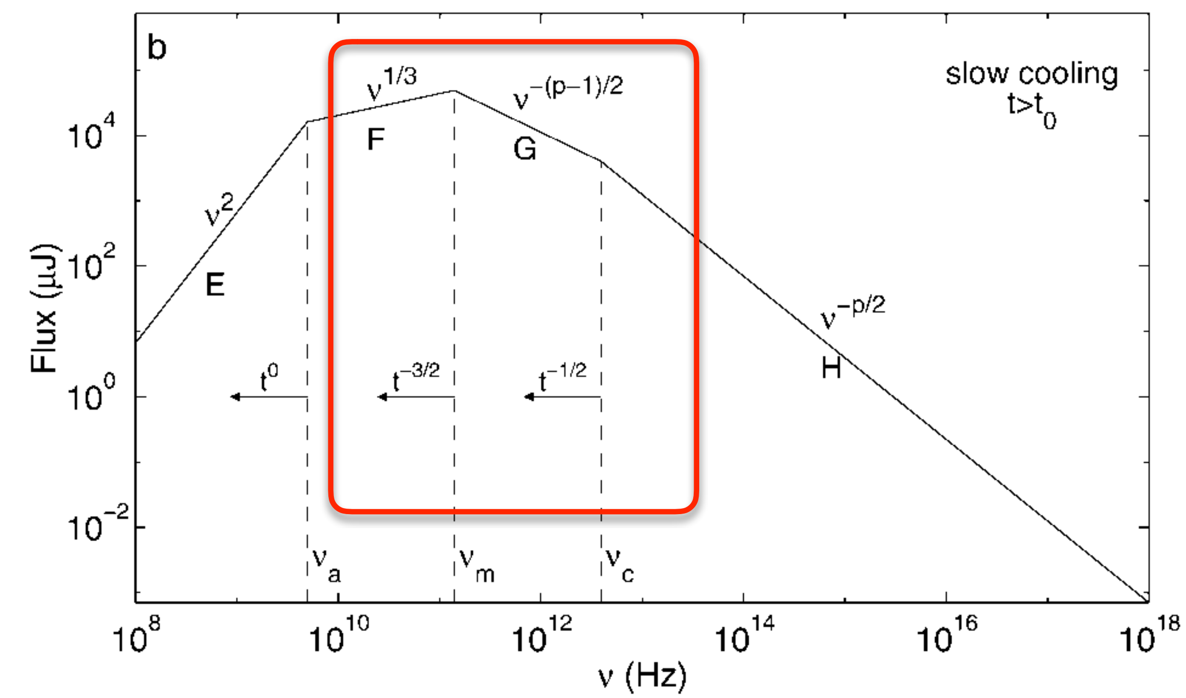
Sari+ 1998

Afterglow spectrum of GRB 050724

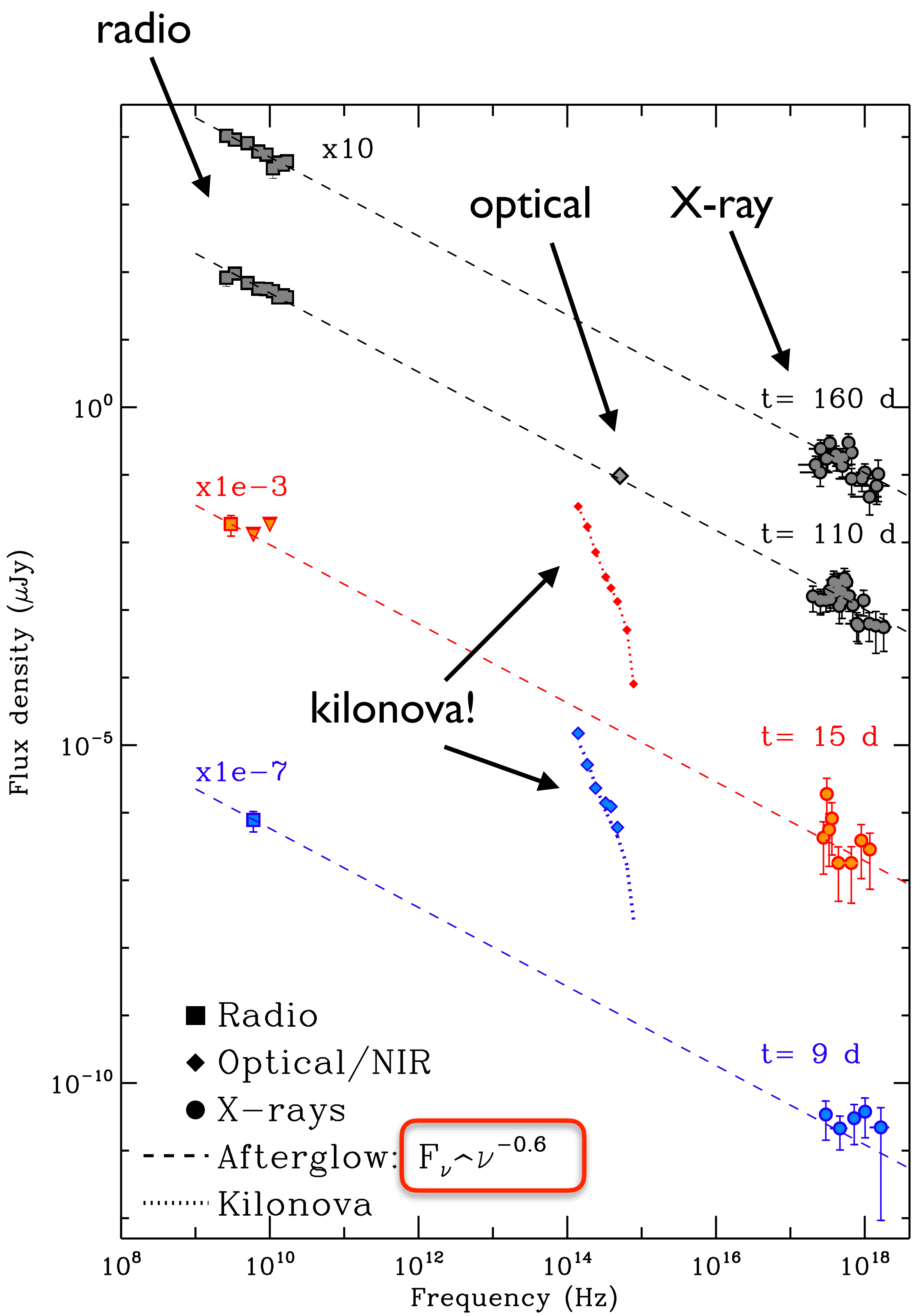
First observed short GRB with detected radio+optical/NIR+X-ray afterglow



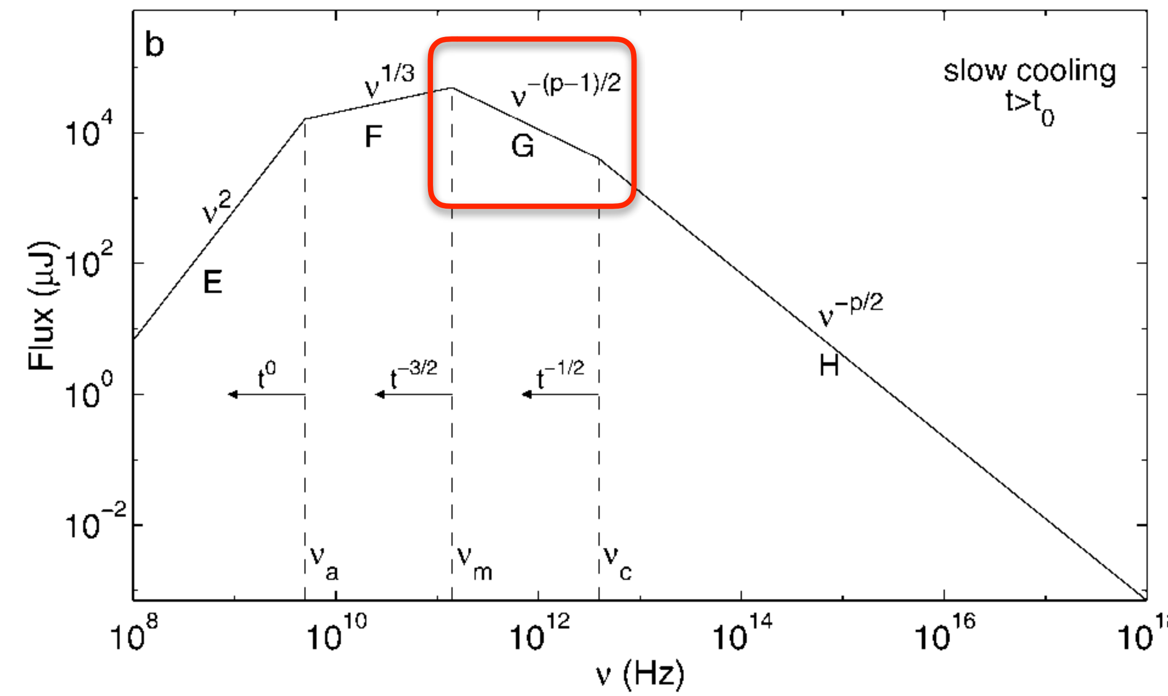
Berger+ 2005, Nature



Afterglow spectrum of GW170817



Margutti+ 2018



- perfect power-law over 9 orders of magnitude in frequency!

  $\nu_{\rm c}$ above X-rays

  $\nu_{\rm m}$ below radio

  $\longrightarrow$ slow-cooling regime

$$(p-1)/2 = 0.6 \quad \Rightarrow \quad \boxed{p = 2.2}$$

- other inferred parameters:

$$E \sim 5 \times 10^{50}\,\mathrm{erg}, \quad n \sim 10^{-4}\,\mathrm{cm}^{-3}, \quad \epsilon_e = 0.02, \quad \epsilon_B = 0.001$$