FRBs as Flaring Magnetars and their connection to SLSNe and LGRBs

[or, how a magnetar may create the environment of FRB121102]

Ben Margalit
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collaborators: Brian Metzger, Edo Berger, Matt Nicholl, Todd Thompson, Dan Kasen, Eliot Quataert, Raffaella Margutti, Tarraneh Eftekhari, Tuguldur Sukhbold

Einstein Symposium,

Harvard-Smithsonian CfA, Oct. 2nd 2018

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a brief

FRBs – observational history:

- ms duration Jy flux radio bursts with large dispersion measure (DM)
- first discovered only in Parkes archival data (Lorimer+07; Keane+11; Thornton+13; …)
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- they ARE astrophysical phenomena (Petroff+15)
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not microwave ovens, terrestrial atmospheric effects, …

- large all-sky rate $\sim 10^3\ \mathrm{sky}^{-1}\ \mathrm{d}^{-1}$ (e.g. Champion+16; Lawrence+17; …)
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FRBs – observational history:

- FRB 121102 [the 'repeater'] – a game changer:
  - discovered with Arecibo [also detected since by GBT, VLA, VLBI] (Spitler+14; Spitler+16; …)
  - repeats! [no periodicity] hundreds of observed over ~6yr baseline
  - DM has not changed noticeably
  - localized to metal-poor star-forming dwarf galaxy at z=0.2! (Chatterjee+17; Tendulkar+17)
  - co-located with extremely luminous 'quiescent radio source' (Marcote+17; see also Law+18)

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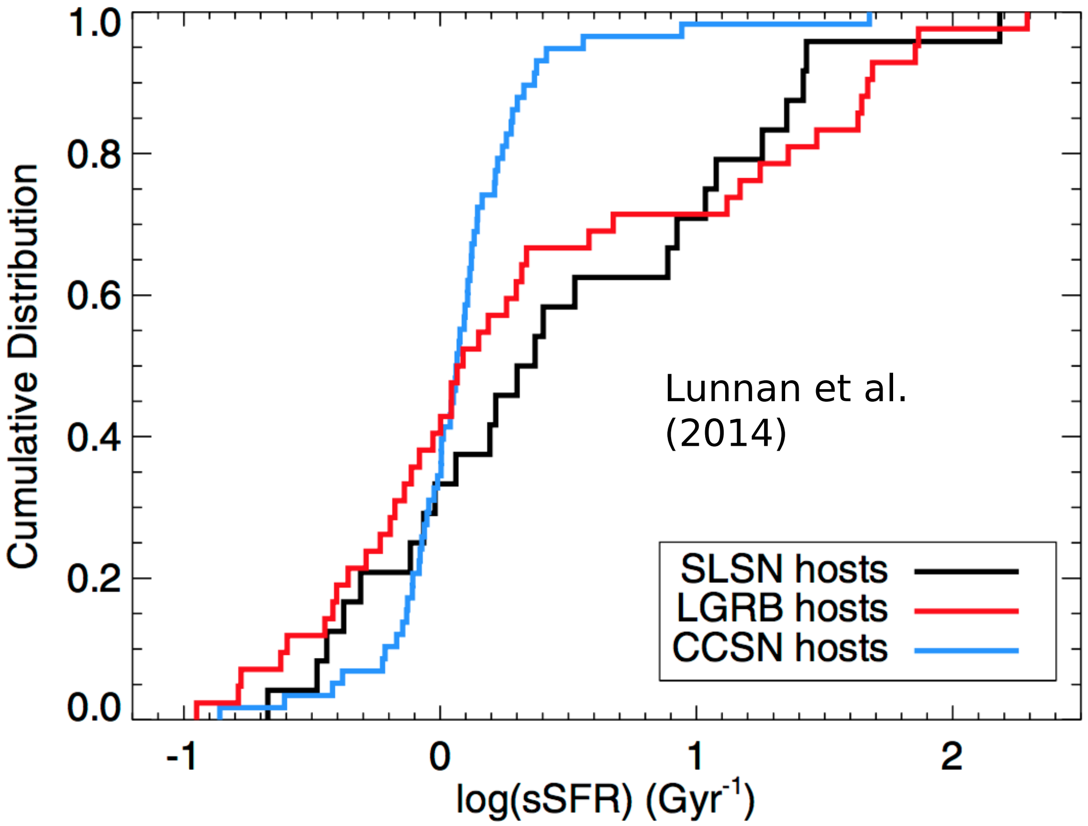

Lunnan et al. (2014)

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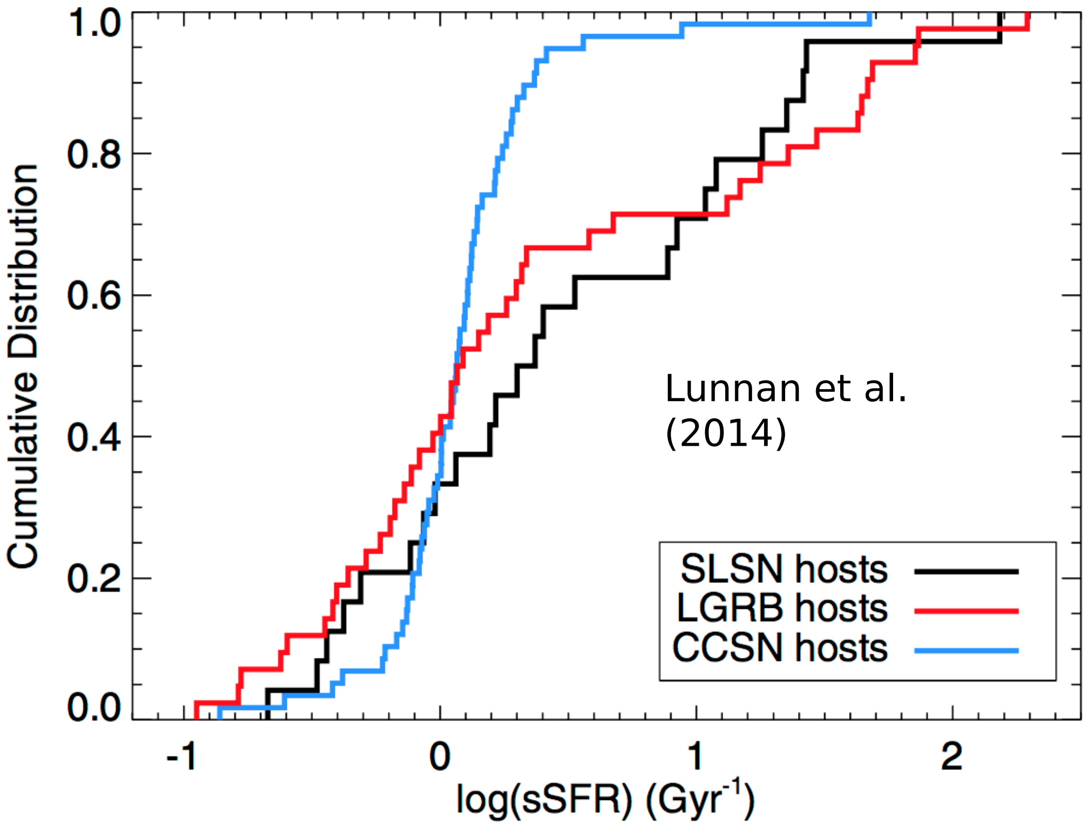
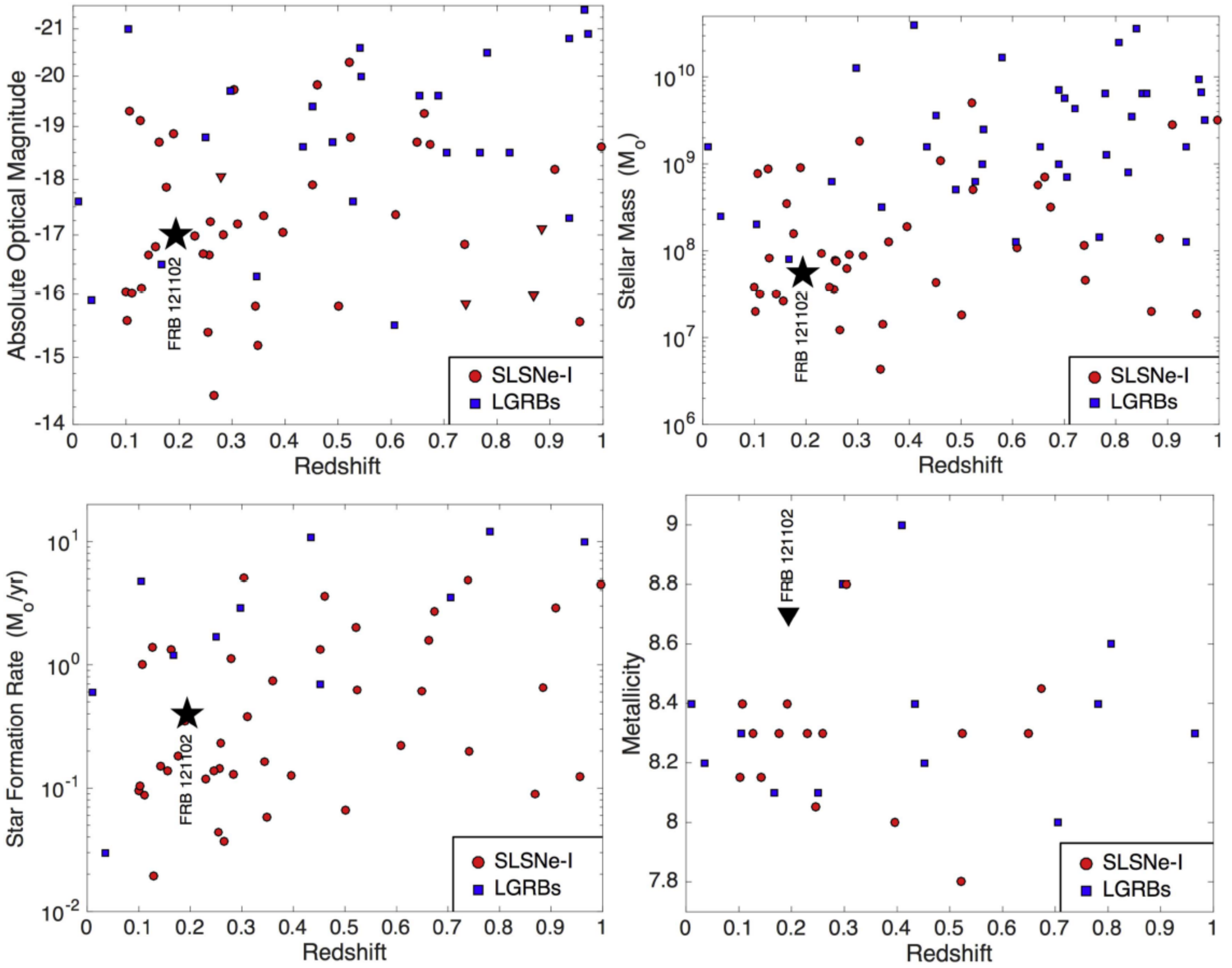
Metzger, Berger & BM (2017)





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smells like a magnetar

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- repetition ⇒ non-cataclysmic event (also rate; Nicholl+17)
  - also, FRB 121102's burst fluence distribution $dN/dE \sim E^{-1.7}$ (e.g. Law+17) follows SGR/AXP burst distributions (Gogus+99,00; Gavriil+04; Scholz&Kaspi11)
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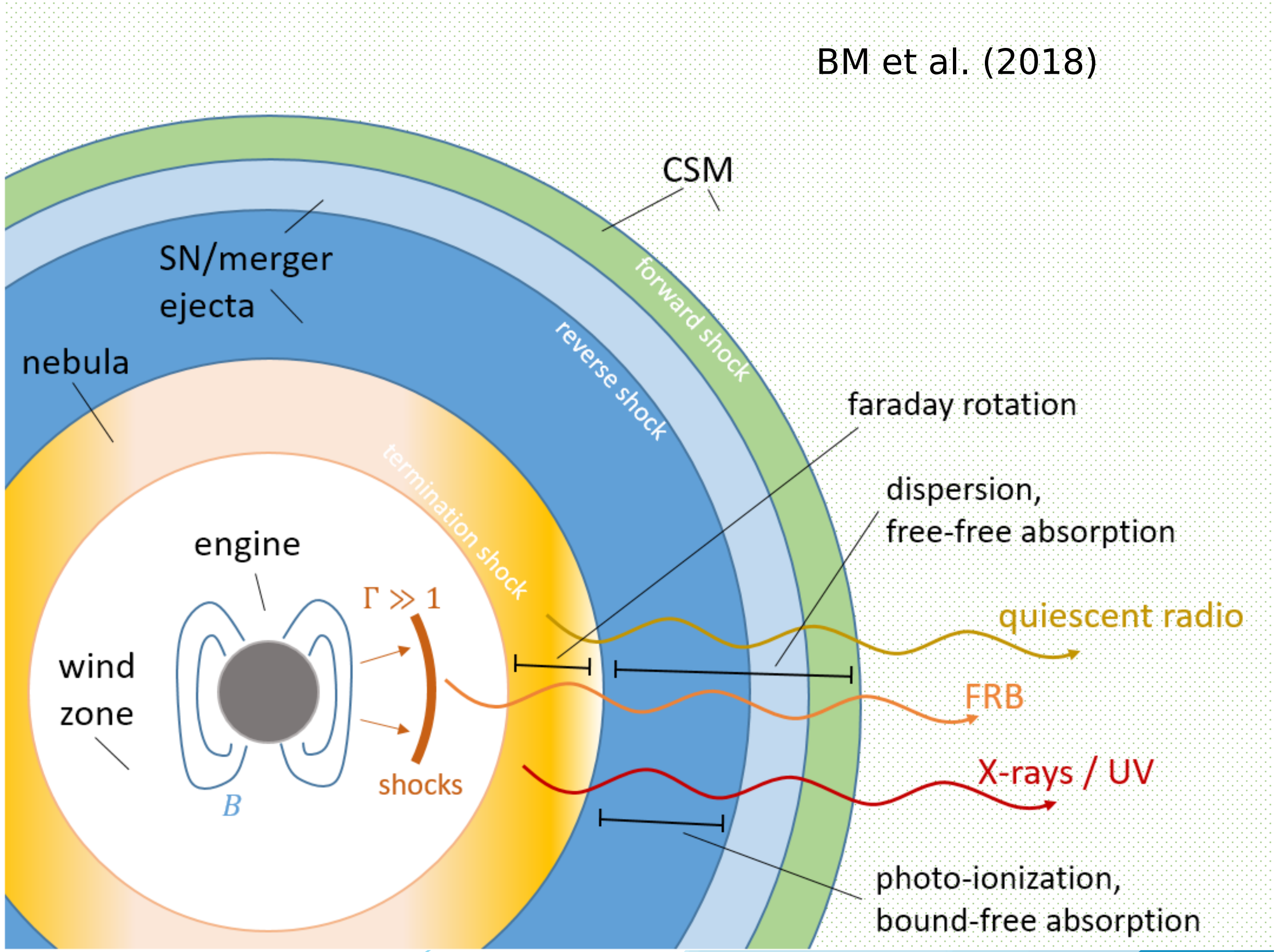

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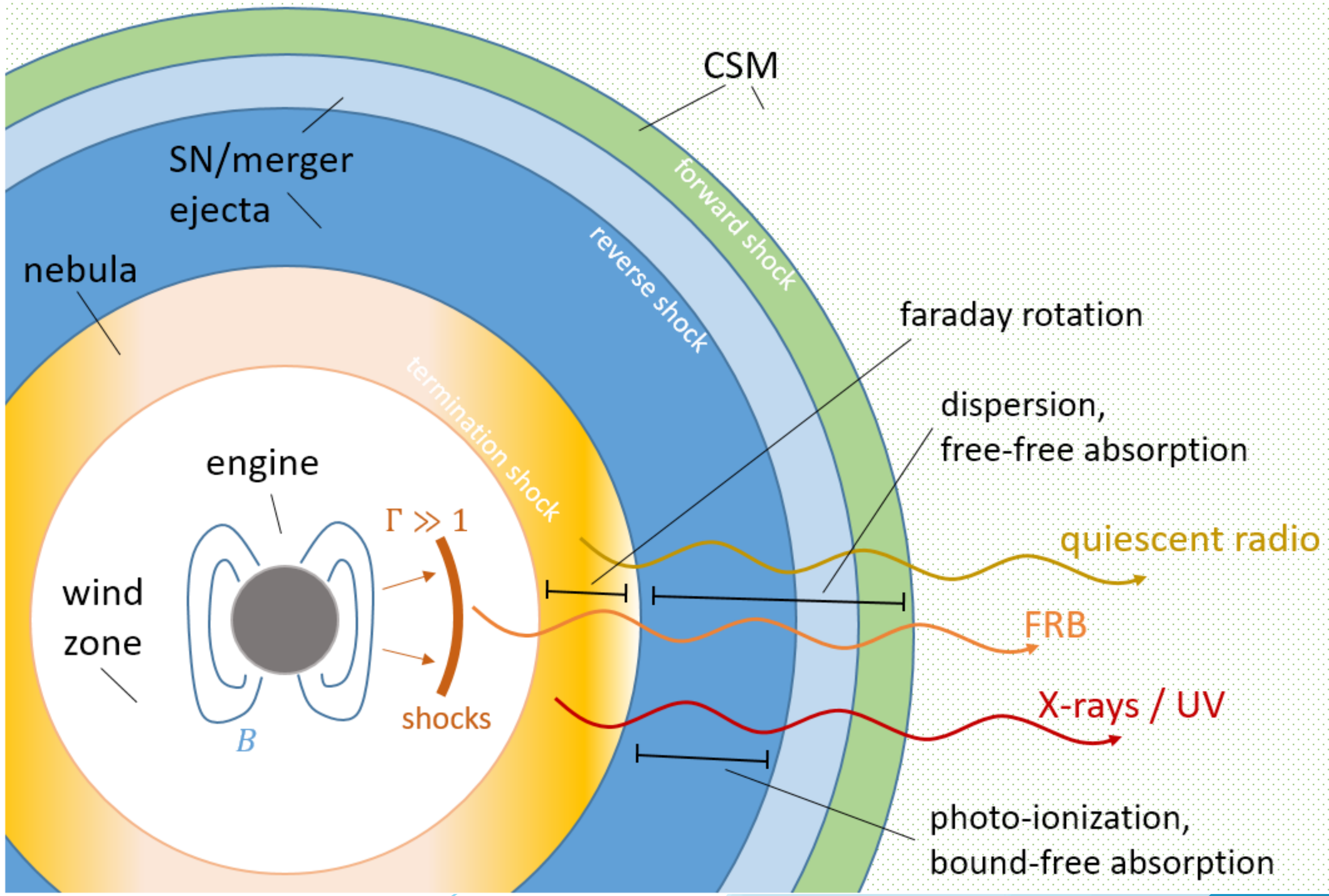

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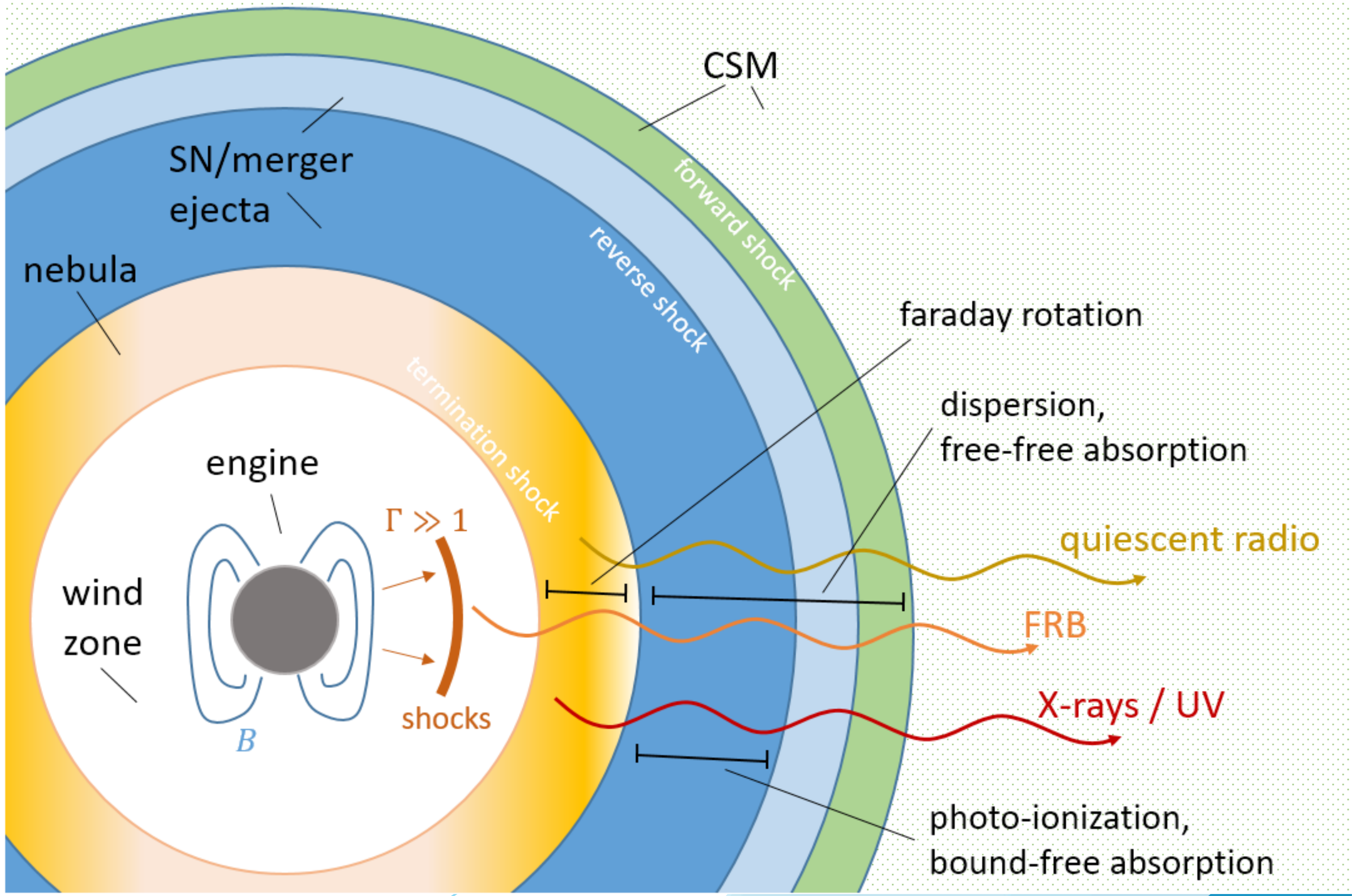

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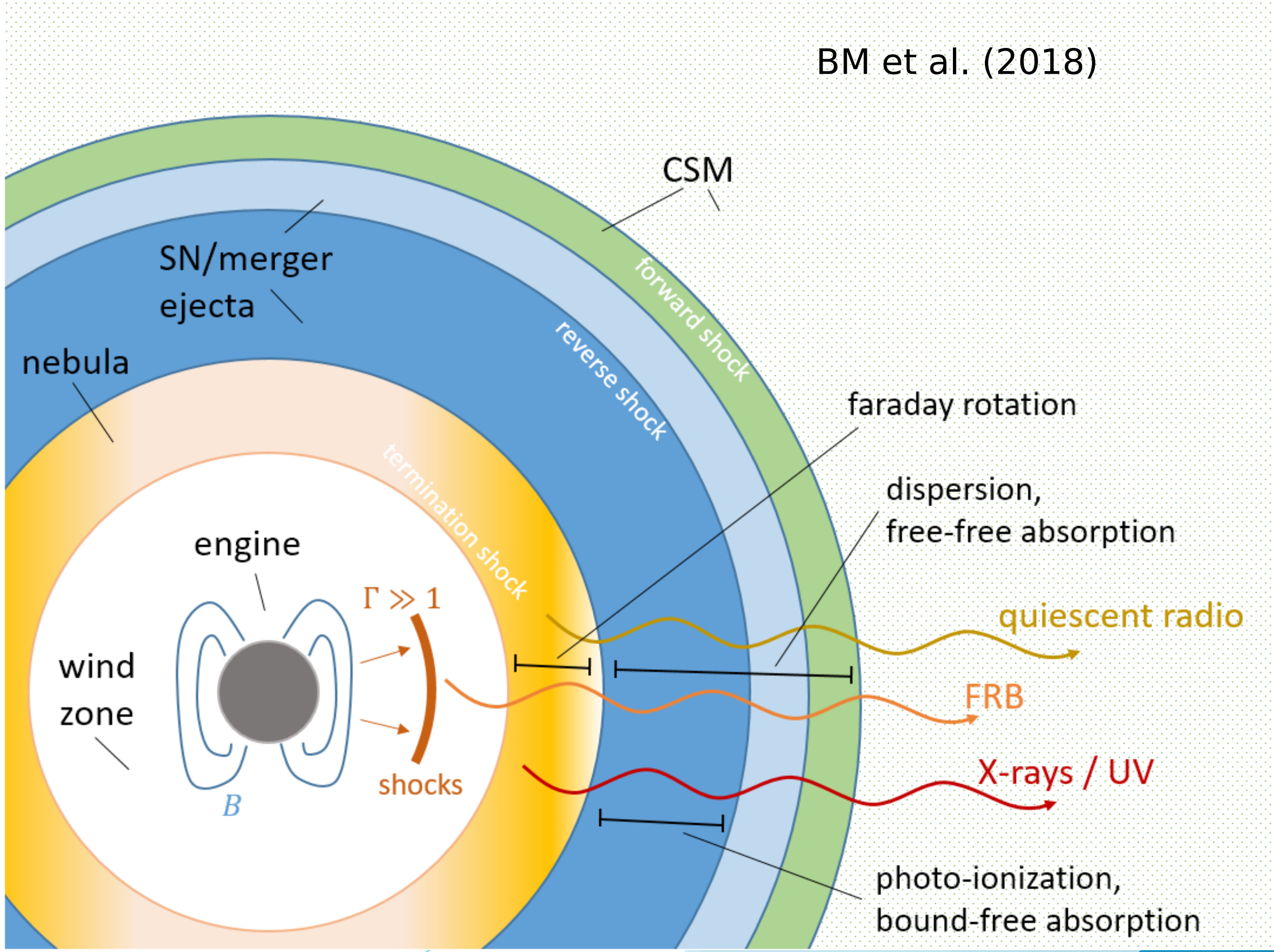

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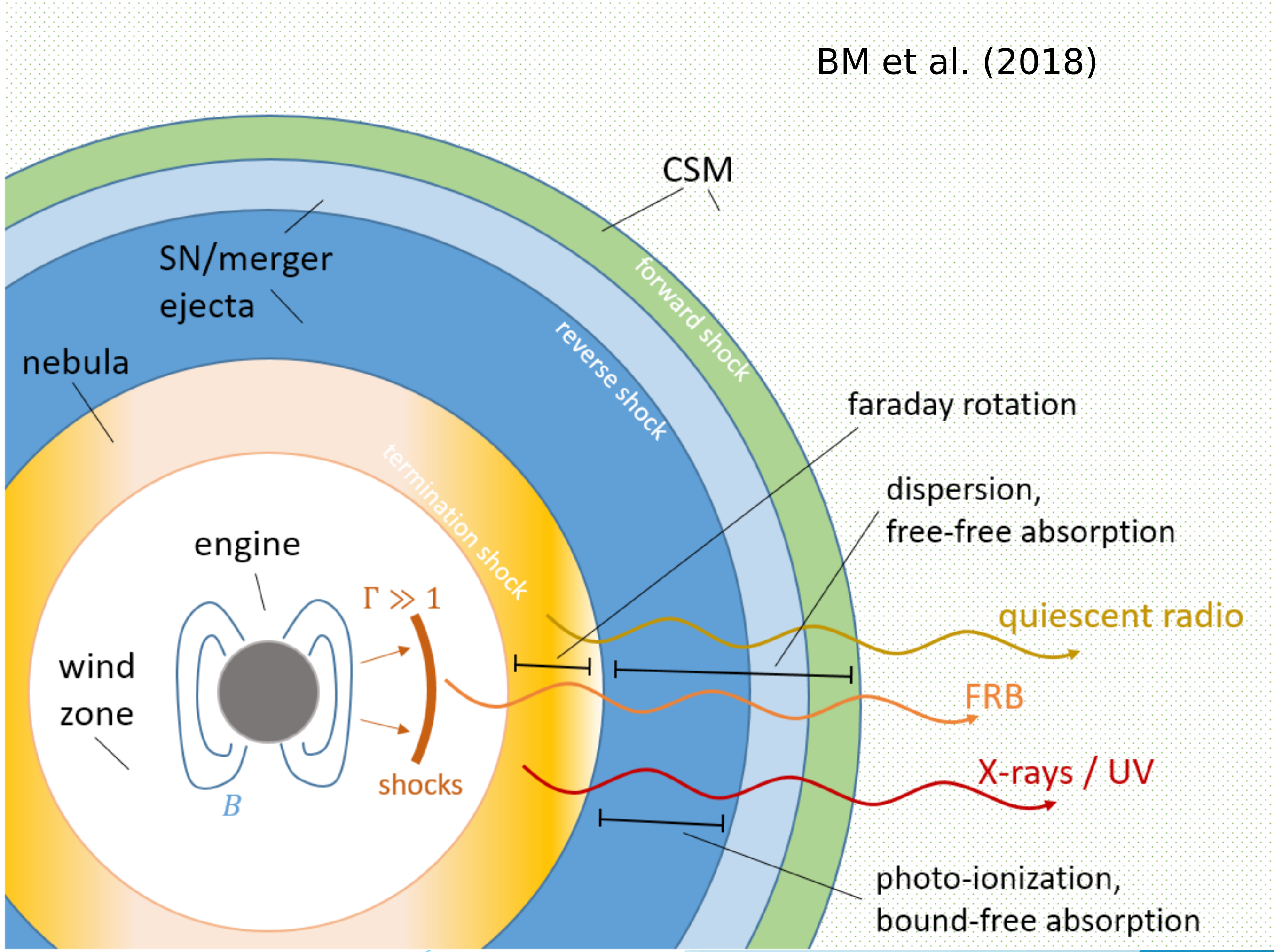

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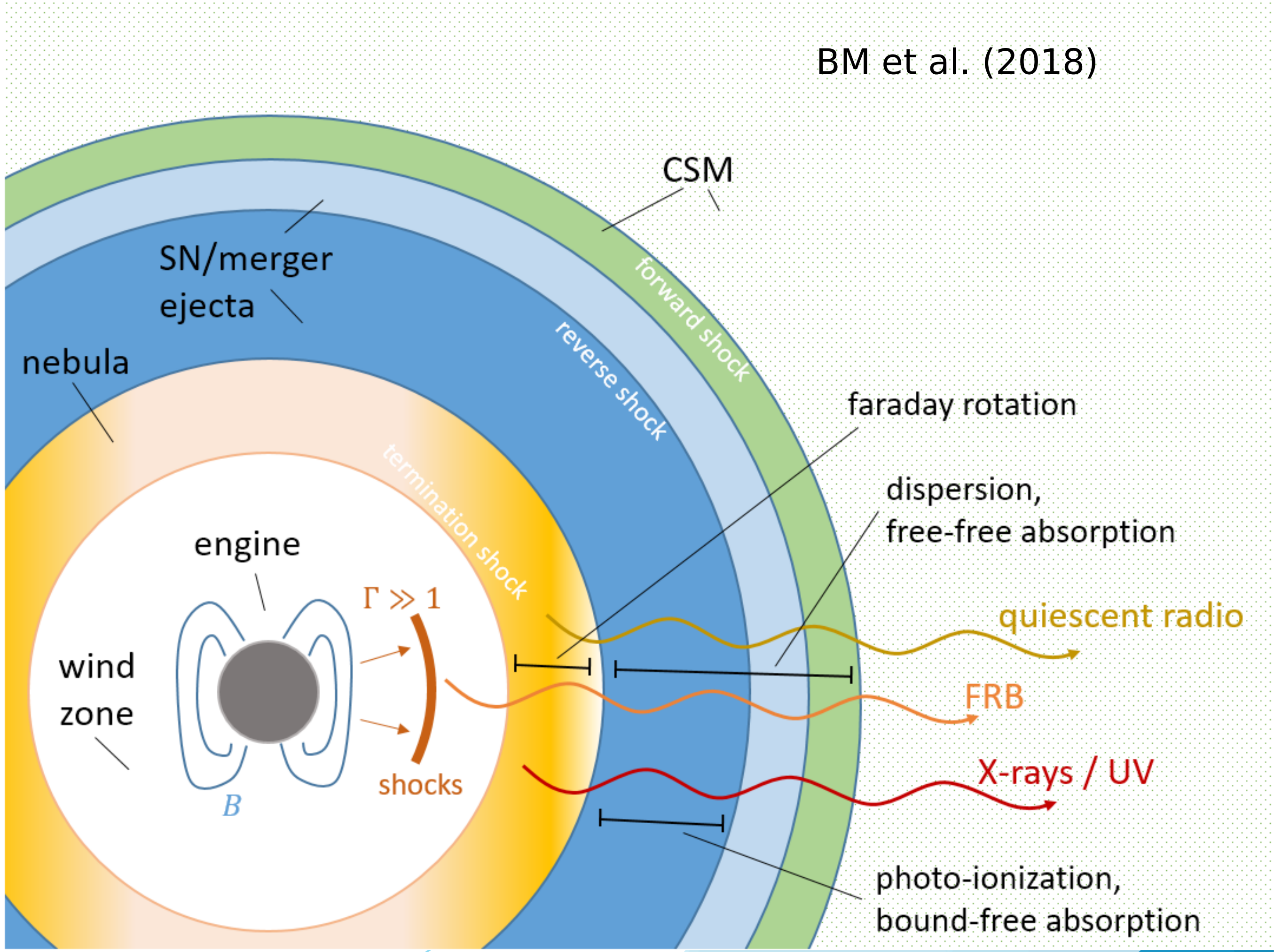

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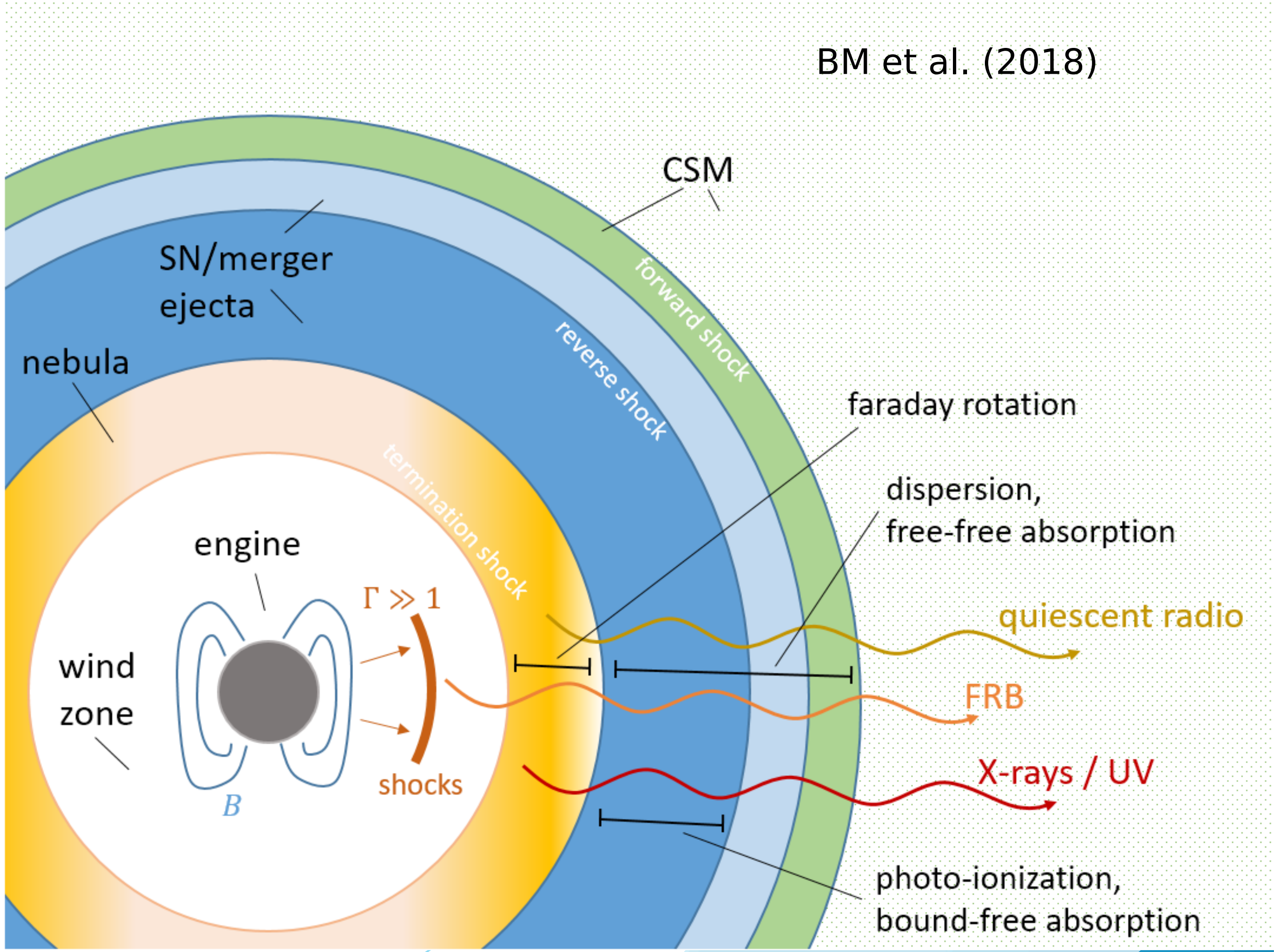

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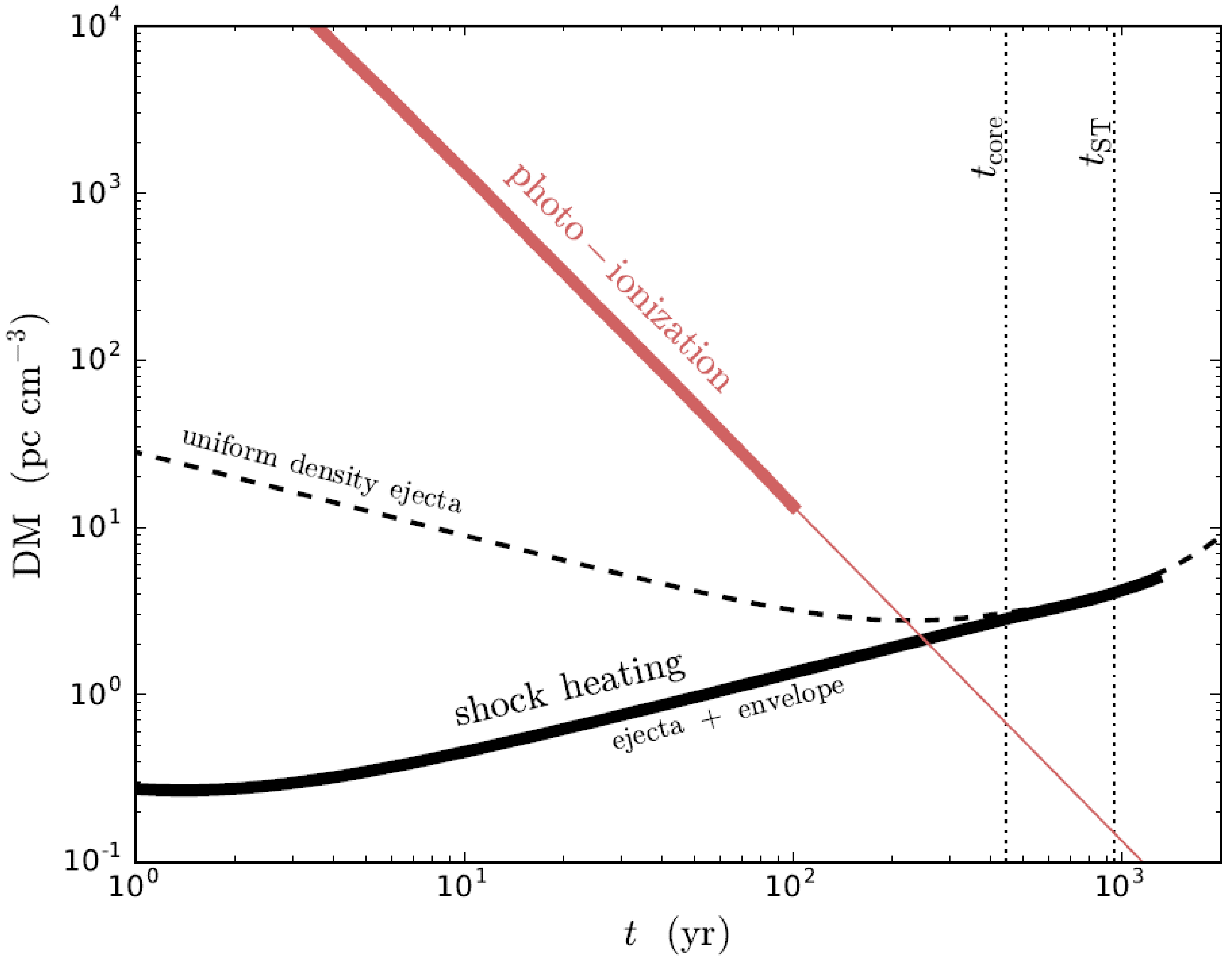

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ejecta photo-ionization:

- calculate photo-ionization state of ejecta (w/ CLOUDY)

  ⇒ free-free transparency time and DM evolution

- find temporally constant ionization fraction, $\langle f_{\rm ion} \rangle_\rho \sim t^0$, implying:
  - $\mathrm{DM} \propto \langle f_{\rm ion} \rangle_\rho \frac{M_{\rm ej}}{(v_{\rm ej} t)^2} \sim t^{-2}$
  - $\tau_X \propto (1 - \langle f_{\rm ion} \rangle_\rho) \frac{M_{\rm ej}}{(v_{\rm ej} t)^2} \sim t^{-2}$
  - $\tau_{\rm ff} \sim f_{\rm ion}^2 \frac{M_{\rm ej}^2}{(v_{\rm ej} t)^5}$

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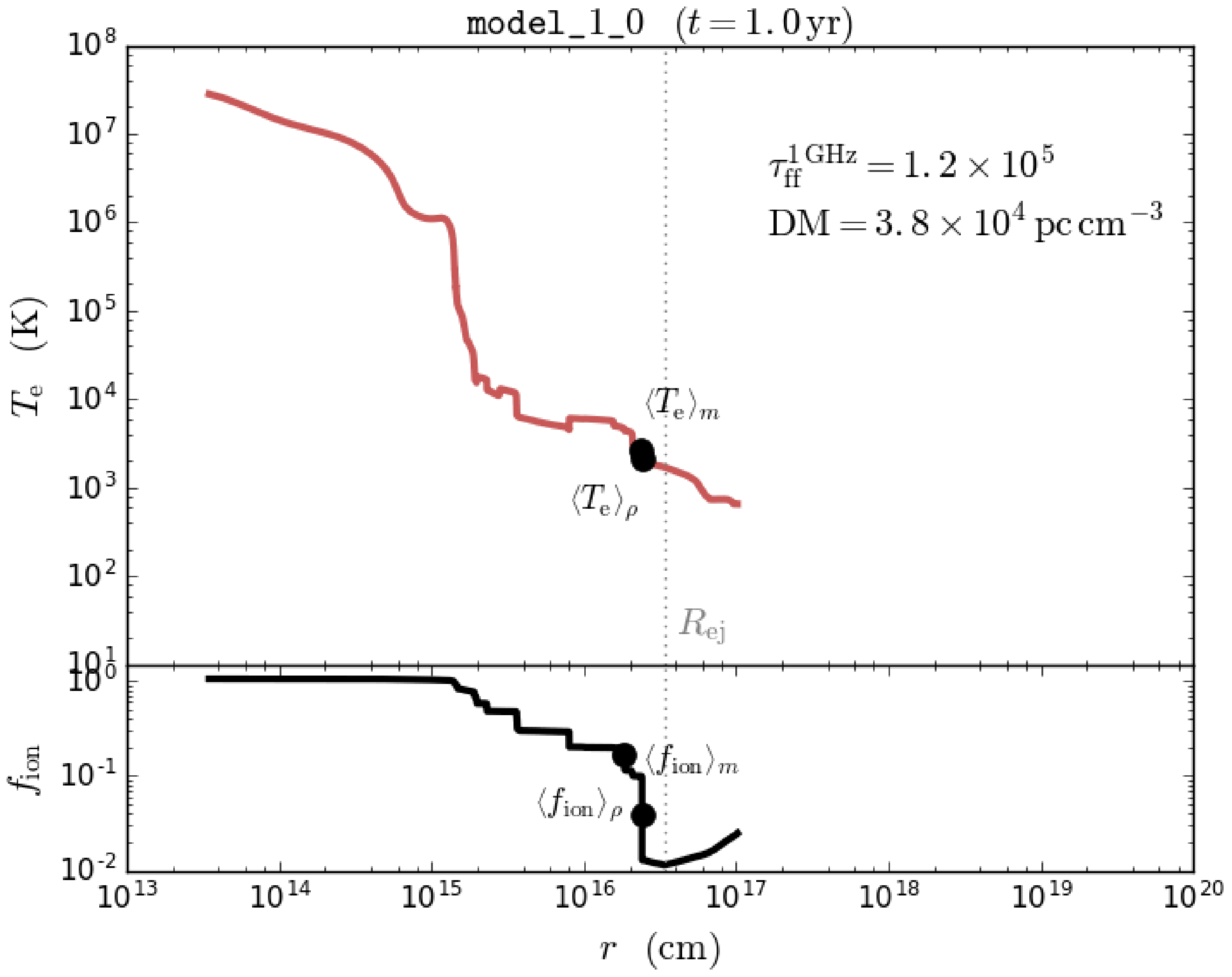

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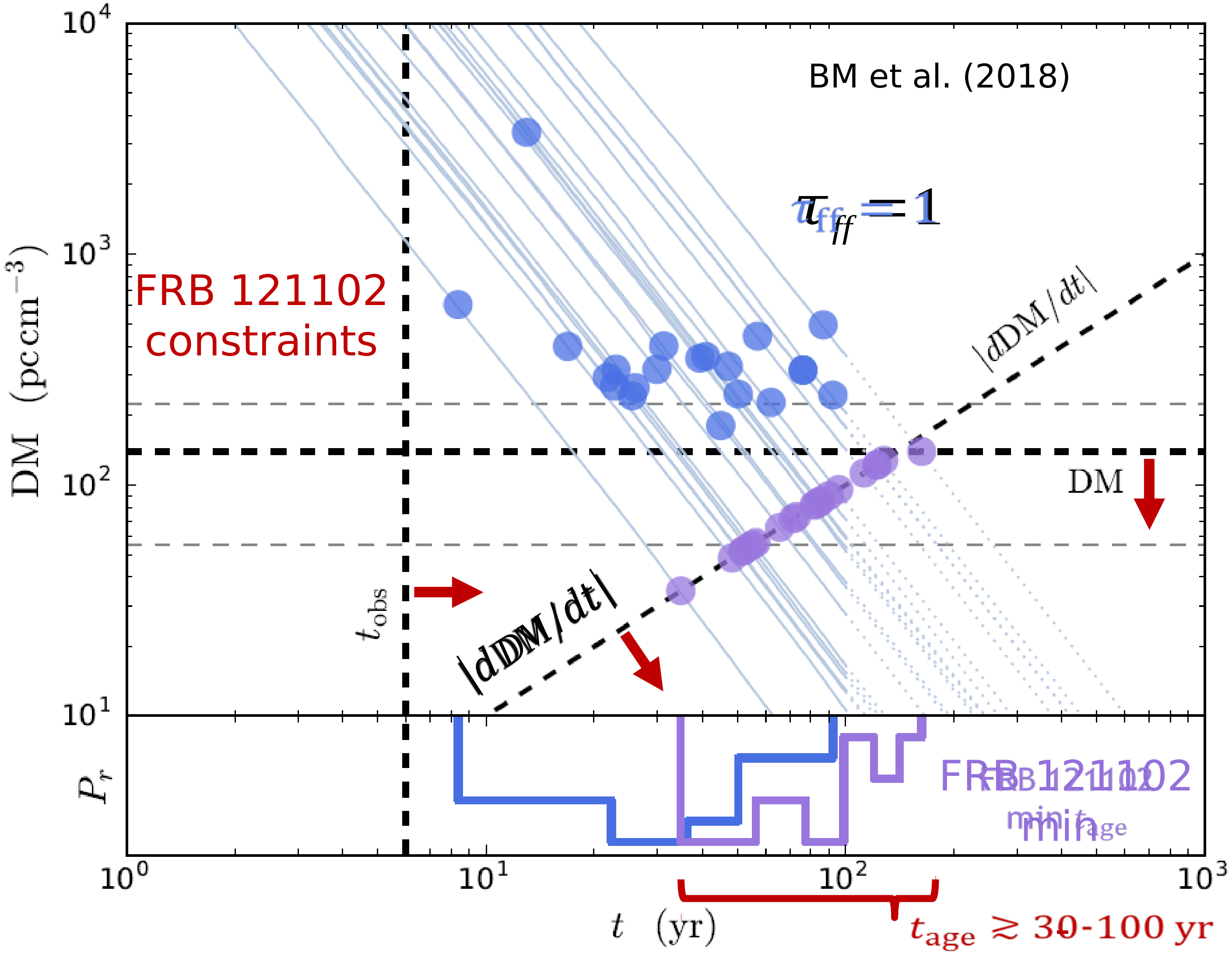
- if we assume FRB engine similar to SLSN-type magnetars

  ⇒ repeater's $t_{age} \gtrsim$ 30-100 yr

- this assumption probabilistically consistent with DM, dDM/dt



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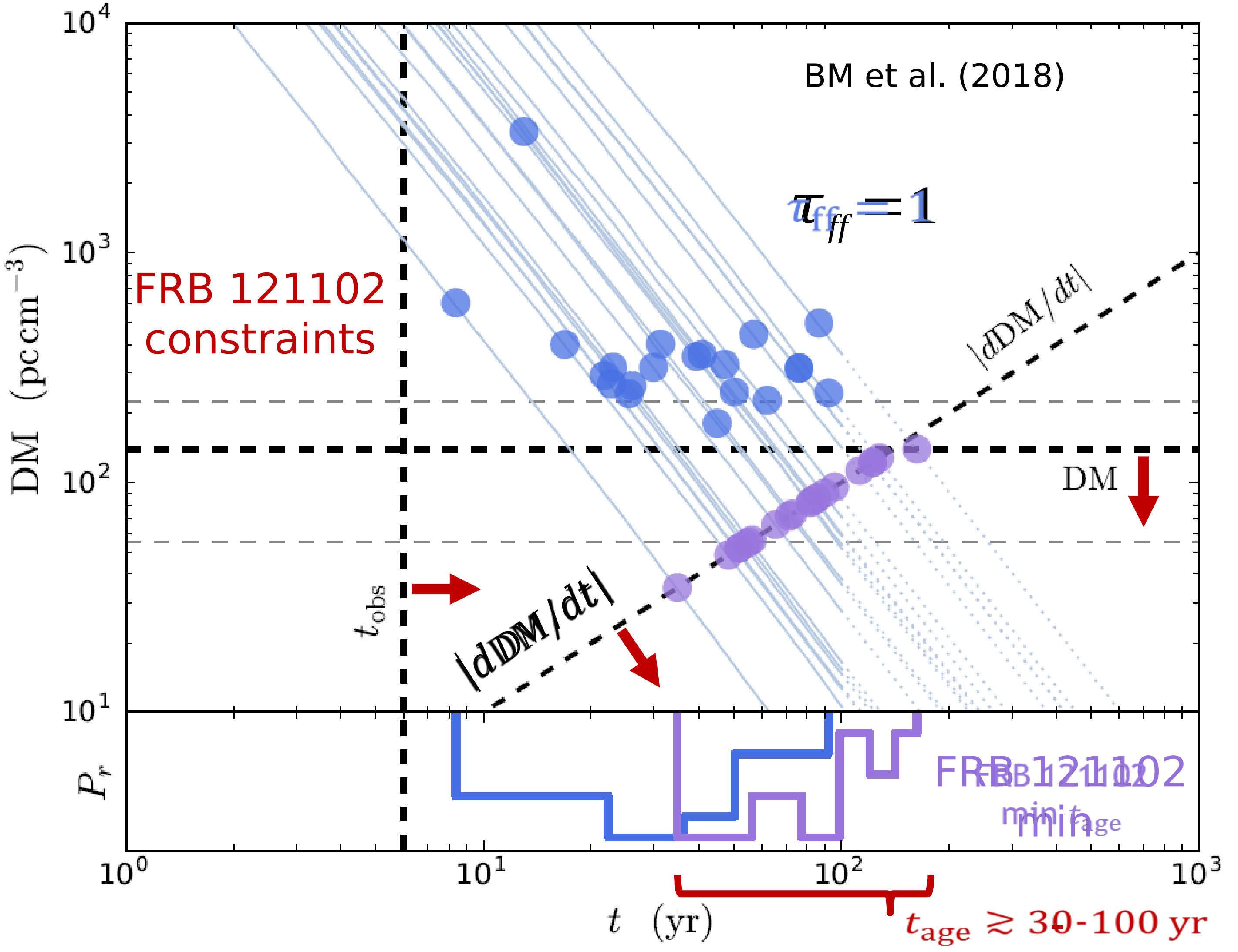

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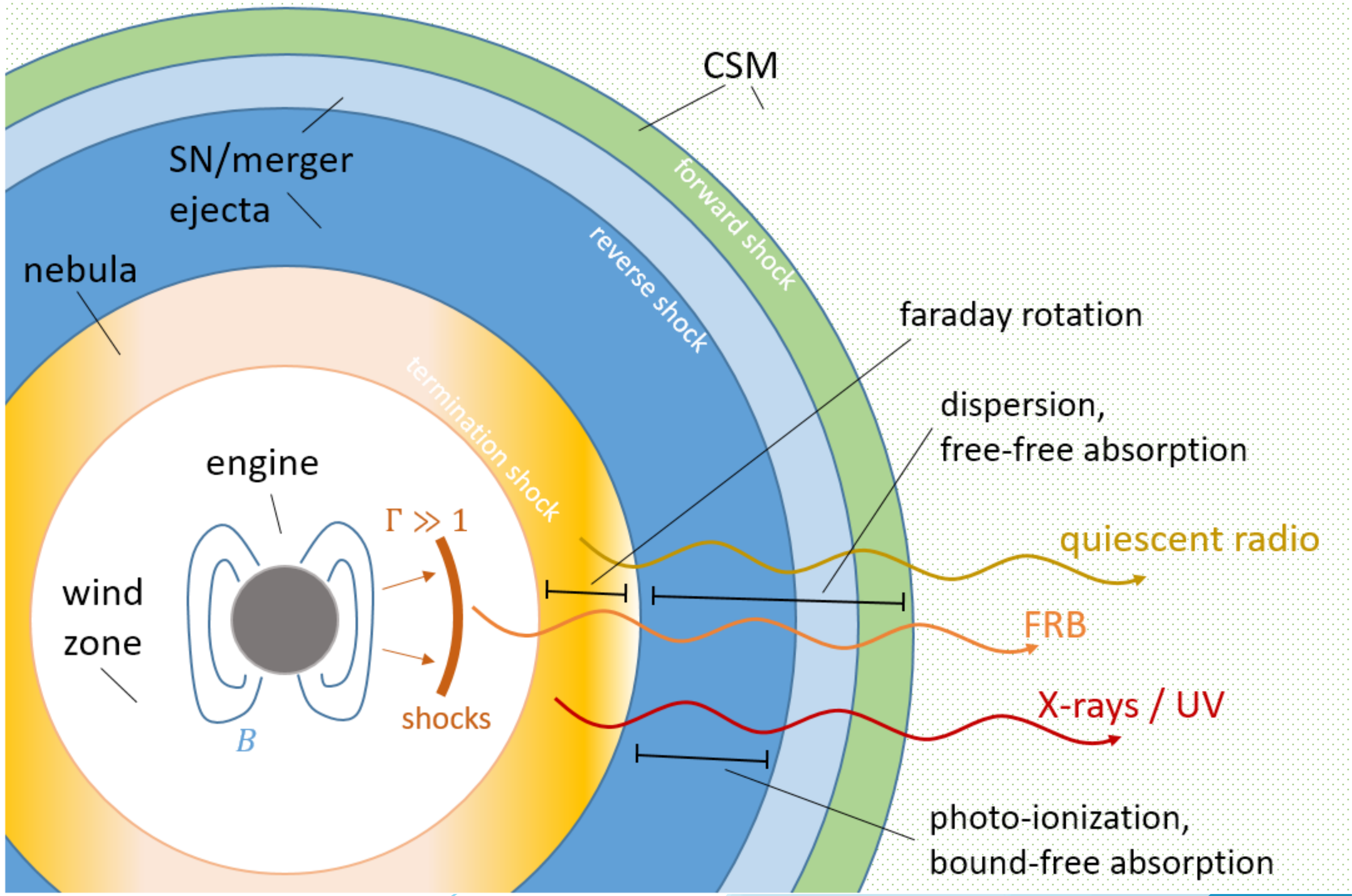

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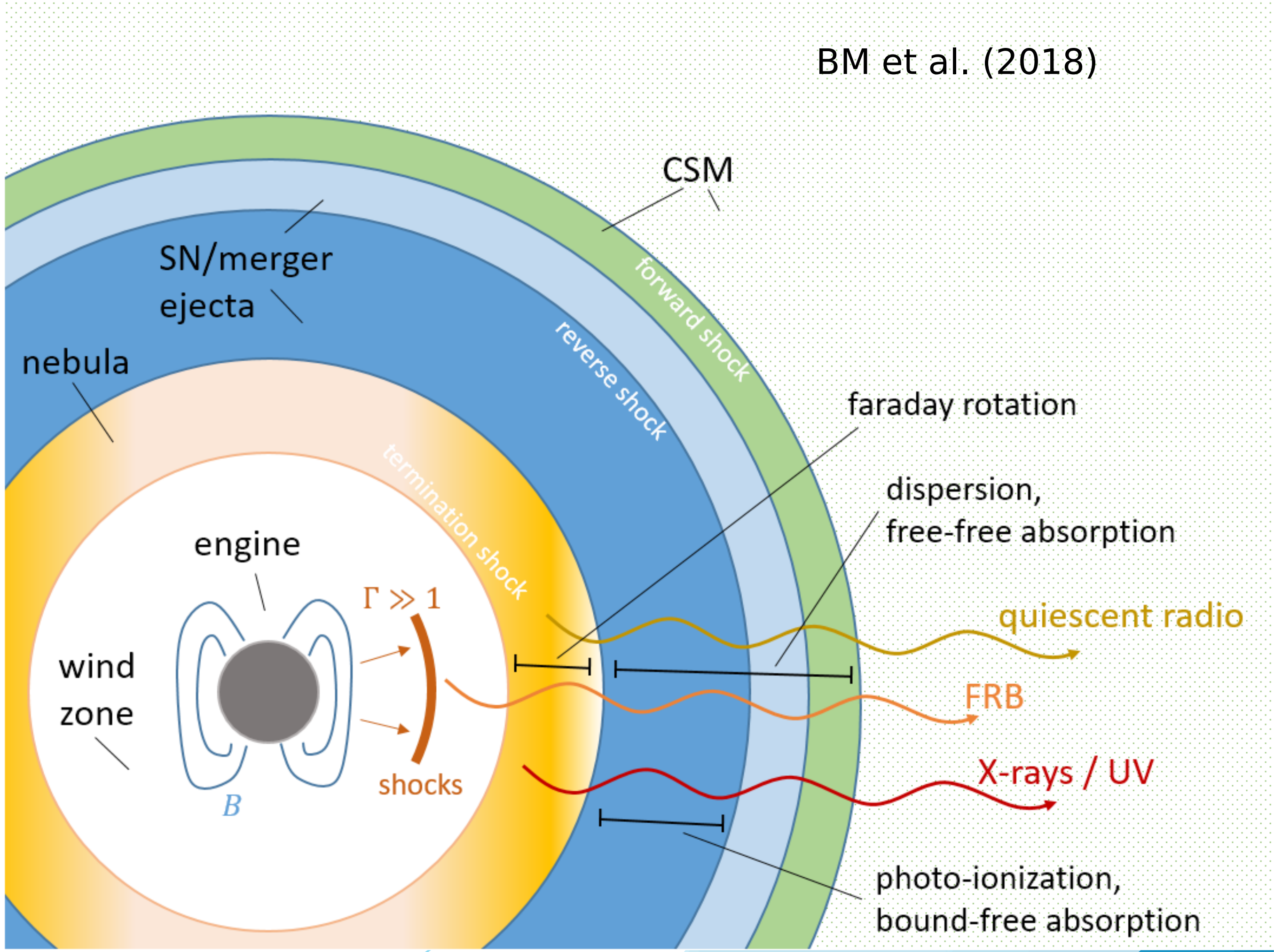

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magnetized nebula:

- one-zone model:
  - inject magnetic energy + electron-proton plasma; $\dot{E} \propto t^{-\alpha}$, $\dot{N}_e \propto \dot{E}$
  - neubla's magnetic field and particle distribution evolved

$$\frac{dE_B}{dt} = -\frac{\dot{R}_{\rm n}}{R_{\rm n}} E_B + \frac{\sigma}{1+\sigma}\dot{E},$$

$$B_n = \left(\frac{6E_B}{R_n^3}\right)^{1/2}$$

$$\frac{\partial}{\partial t} N_\gamma + \frac{\partial}{\partial \gamma}\left(\dot{\gamma} N_\gamma\right) - 3\frac{\dot{R}_{\rm n}}{R_{\rm n}} N_\gamma = \dot{N}_\gamma .$$

$$N_\gamma \equiv \left(\frac{dn_e}{d\gamma}\right)$$

cooling term includes adiabatic, synchrotron, bremsstrahlung, and inverse Compton losses

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- goal – calculate RM + synchrotron emission due to nebula

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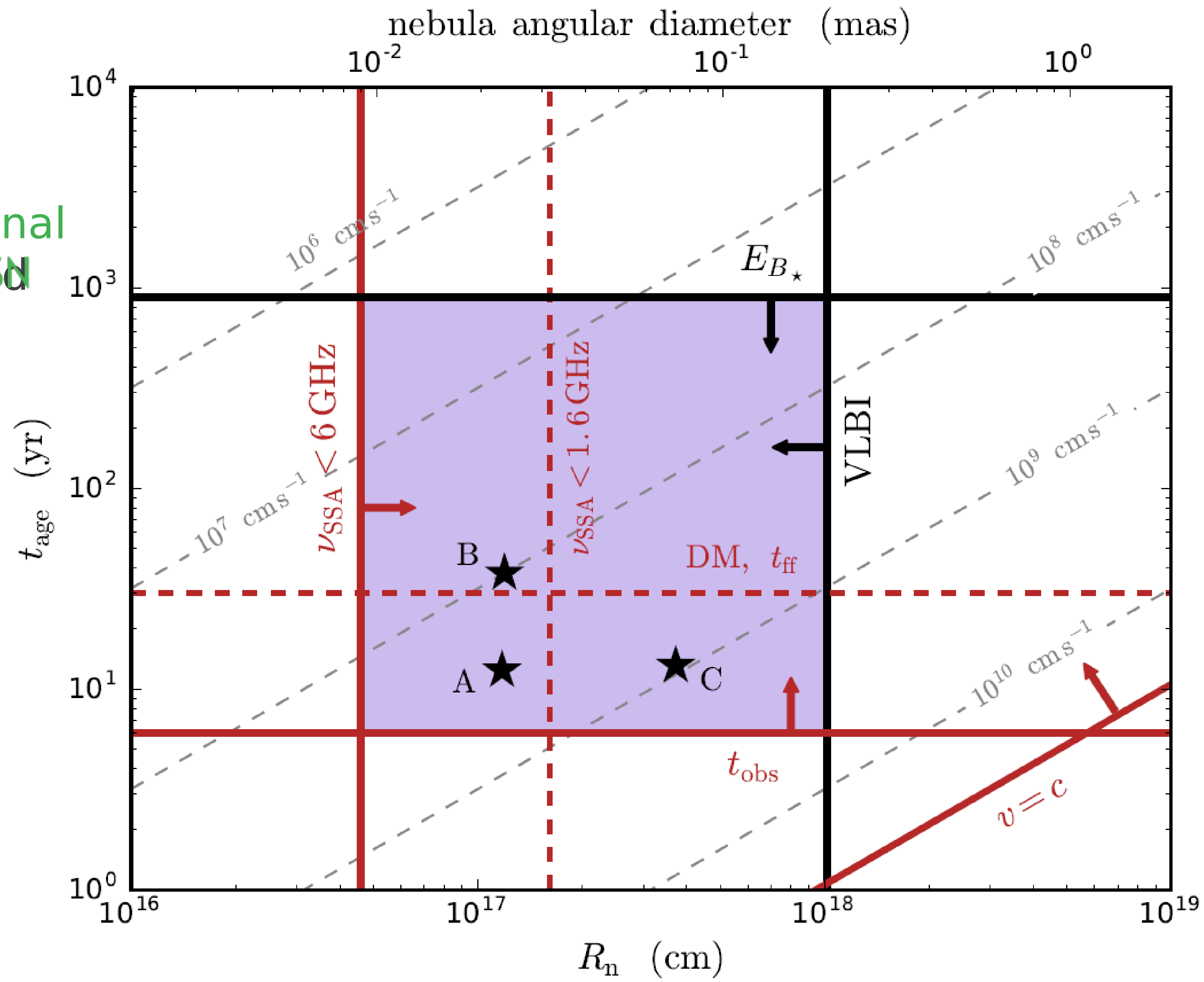
constraints:

- age:
  - lower limit from 6yr observational baseline, affect of photo-ionized SN ejecta
  - upper limit from energetics, $t_{age} < E_{B_\star}/\nu L_\nu$



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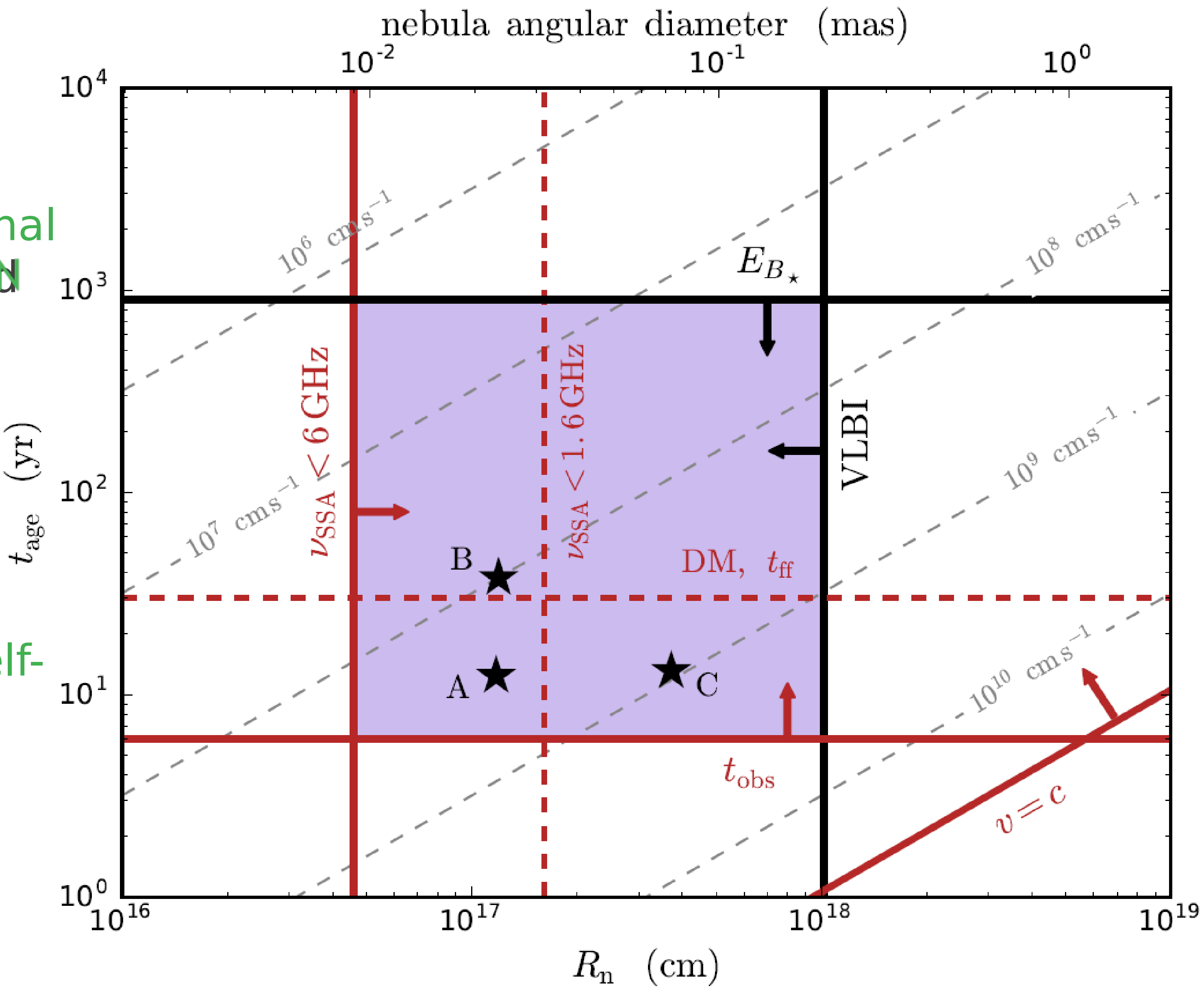
- nebula size:
  - lower limit from lack of clear self-absorption in quiescent source spectrum
  - upper limit from VLBI imaging



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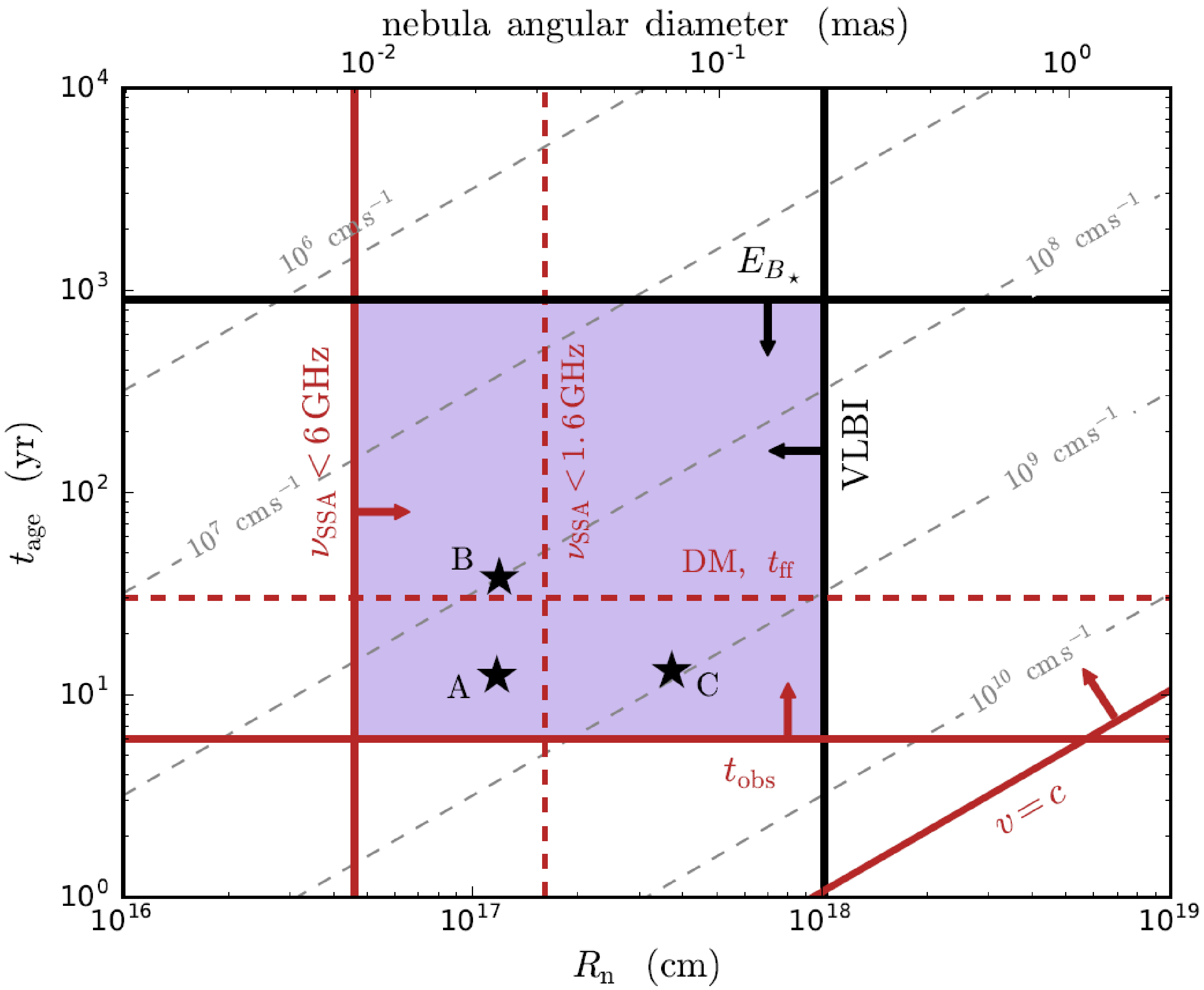
constraints:

- at a given age & R_n satisfying these constraints, must reproduce both RM, quiescent source luminosity and spectrum (!)
- only four free parameters $(E_{B_\star}, t_0, \alpha, v_n)$
- only four free parameters ()



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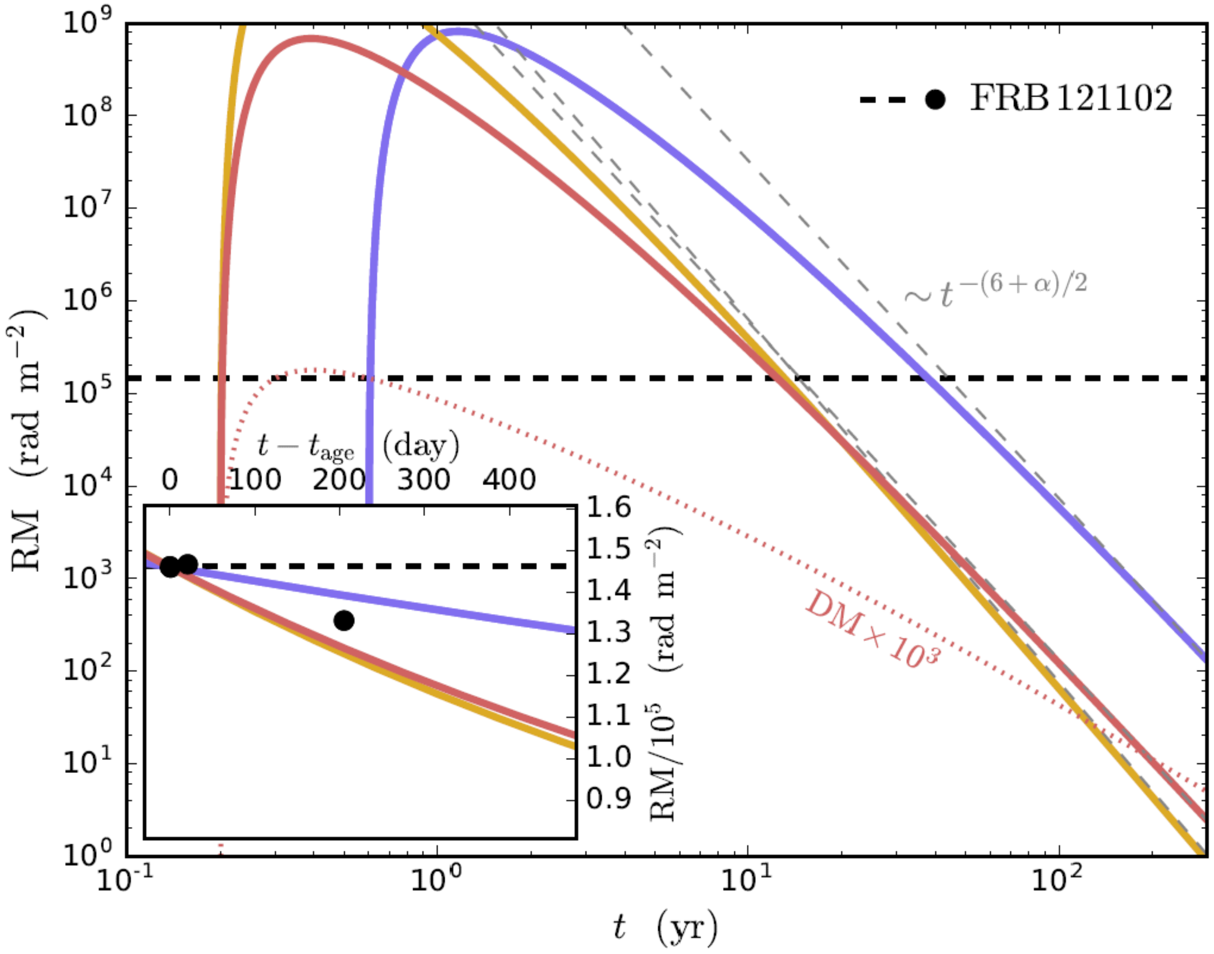

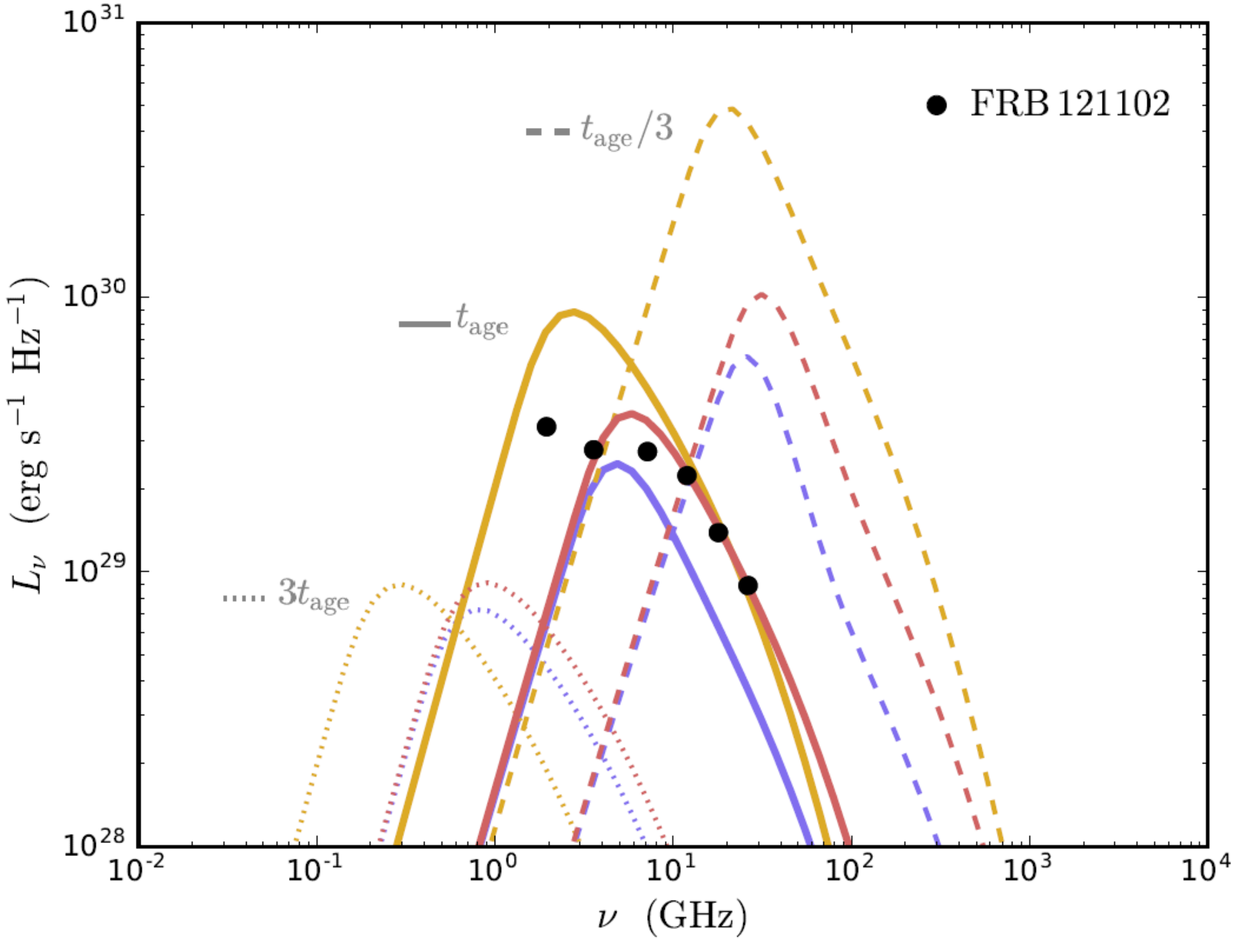

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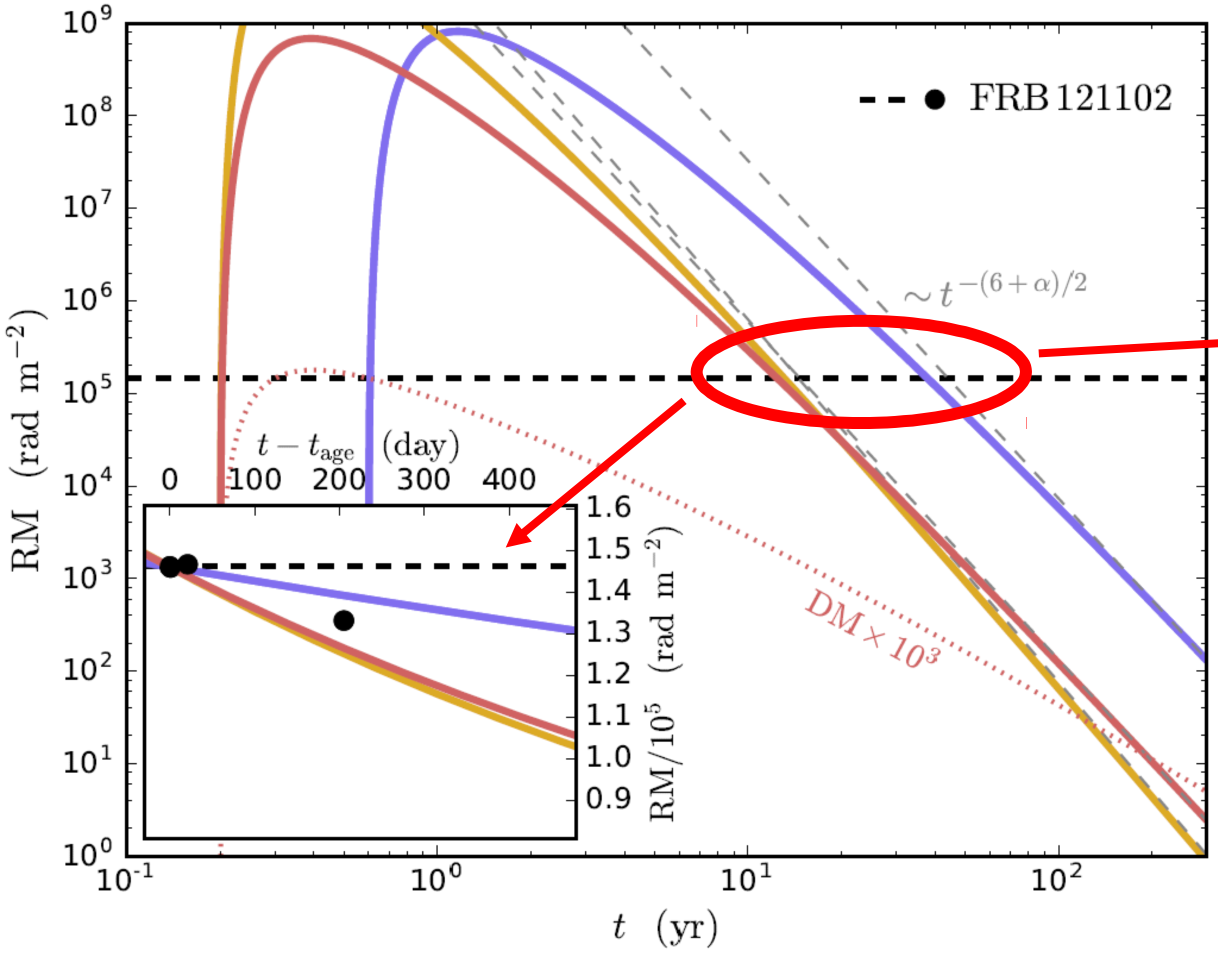

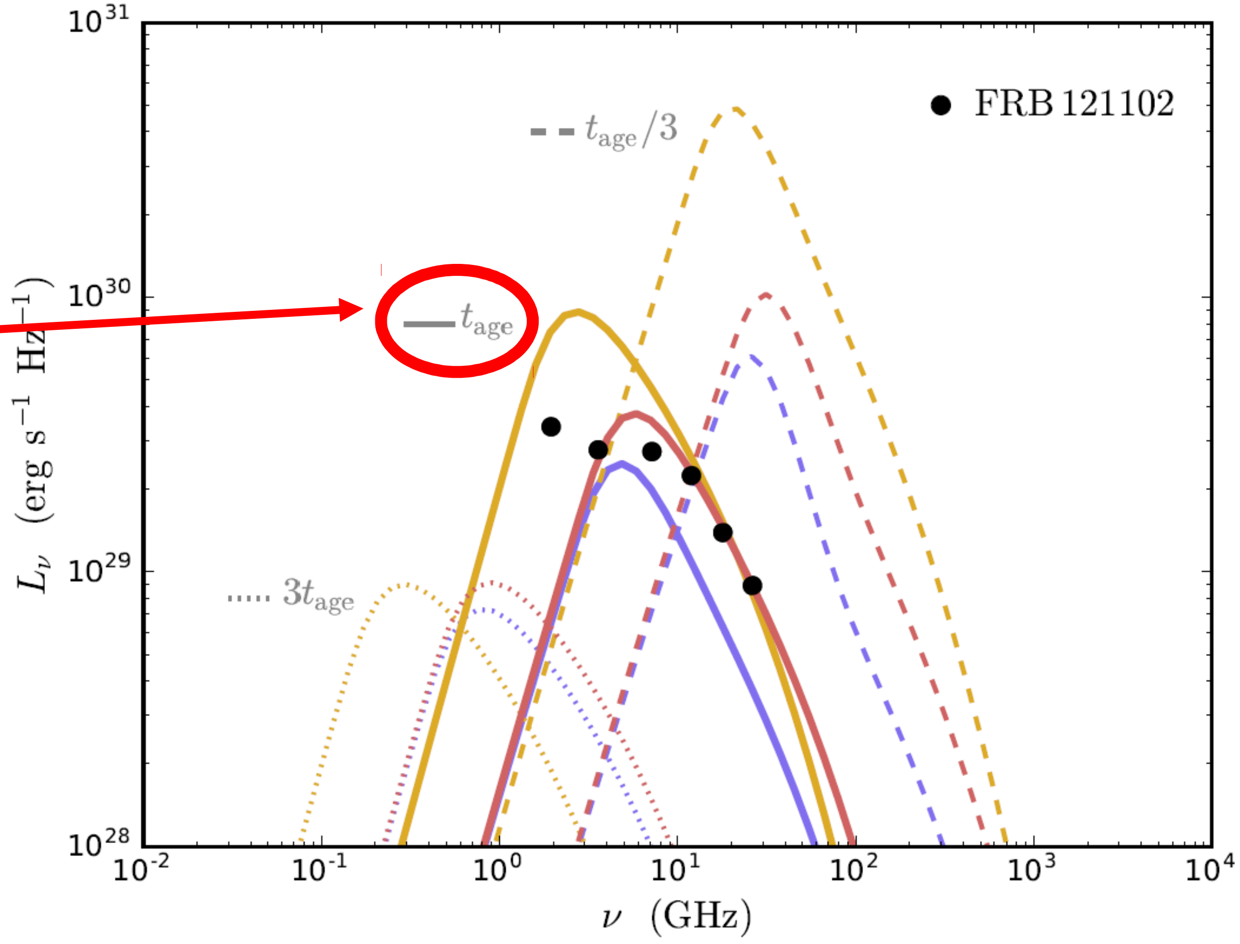

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results:

- model predictions:
  - secular decrease in RM $\sim t^{-(6+\alpha)/2}$
  - decrease in quiescent source luminosity, $L_\nu \sim t^{-(\alpha^2+7\alpha-2)/4}$
  - spectrum scales (roughly!) as $L_\nu \sim \nu^{-(\alpha-1)/2}$

    $\Rightarrow$ closure relationships!

  - self-absorption turnover in spectrum likely not much below 2 GHz
  - speculatively: ~logarithmically flat distribution of RM for discovered FRBs

(if detectability of FRB scales as engine activity $\dot{E} \propto t^{-\alpha}$, then $P(<\mathrm{RM}) \propto \mathrm{RM}^{2(\alpha-1)/(6+\alpha)} \sim \mathrm{RM}^{0.08}$)

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summary / take-aways:

- first predictive model simultaneously explaining both large RM (and its evolution) and quiescent radio source (and its spectrum) of FRB 121102
- model is highly constrained by current observations
- solutions for “reasonable” parameters are possible, but require:
  - large magnetic energy reservoir ($E_{B_\star} \gtrsim 10^{50}$ erg $\leftrightarrow$ $B_\star \gtrsim 2 \times 10^{16}$ G)
  - more energy/particles injected at early times than at current epoch, but not much more! ($\alpha \gtrsim 1$)
- model makes many testable predictions

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