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

Ben Margalit NASA Einstein Fellow at UC Berkeley

<u>collaborators</u>: 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

FRBs as Flaring Magnetars and connections to SLSNe and LGRBs a brief FRBs – observational history:

- ms dureation ly flux x adid ibubstastistiv langle dispersion reference (Daw) re G (DM)
- first discovered only in Parkes archival data
- first discovered only in Parkes archival data 0 (Lorimer+07; Keane+11; Thornton+13; ...)
- they ARE astrophysical phenomena

(Petroff+15)

not microwave ovens, they ARE astrophysical phenomena [terrestrial atmospheric]

- o large all-sky rate ~ 10^3 sky⁻¹ d⁻¹ (e.g. Champion+16; Lawrence+17; ...)
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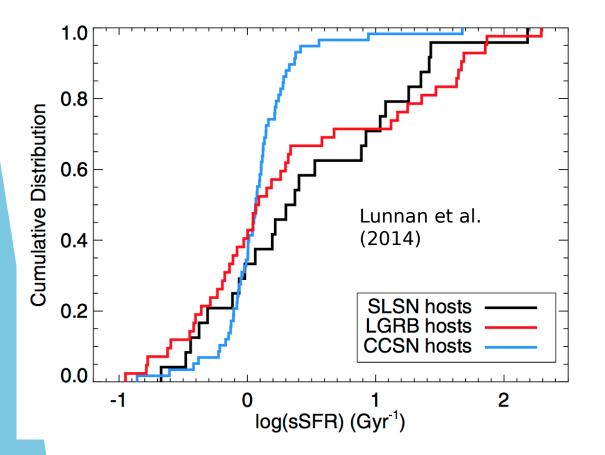
FRBs – observational history:

- 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)

where the observational clues

 $\frac{\text{point:}}{\text{lost gradaxy}} \Rightarrow retatted to SLSNee-I//LCRRB3?$

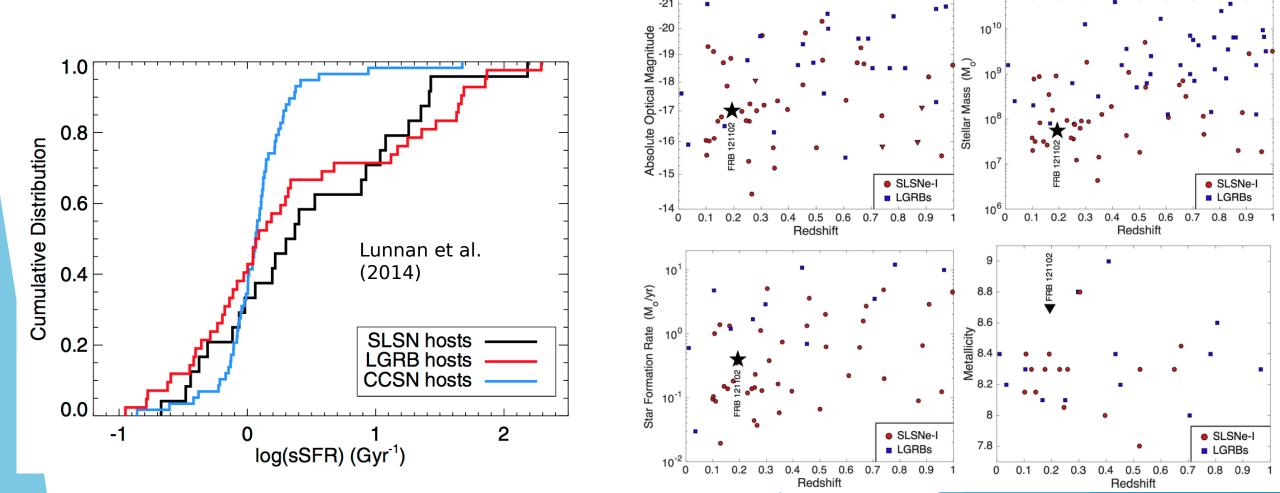
where the observational clues point: host gradaxy \Rightarrow retated to SLSNee-I//LCRRB3?



where the observational clues point: \circ host gradaxy \Rightarrow retated to SLSNee-I//LCCRRBS?

Metzger, Berger & BM (2017)

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where the observational clues

- $\frac{\text{point:}}{\text{lost gradaxy}} \Rightarrow \text{relatted to SLSSNed-l/LGBBsBs}?$
- S repetition ⇒ non-catealyachicseviene (also i (al

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- S repetition ⇒ non-catealysolycsevene (ad at (at source to the sourc

RM ⇒ magnetized electron-ion environment
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where the observational clues

- \bigcirc host gradaxy \Rightarrow related to SLSNed-1/LGBBBBs?
- S repetition ⇒ non-catealyadiyseviene (allophrate;17)
 Nicholl+17)

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- o ms timescales ⇒ NS origin ?
 o ms timescales → NS origin ?

where the observational clues

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 - ms timescales ⇒ NS origin ? ms timescales N∯ origin ? Smells like a

magnetar

where the observational clues

point:

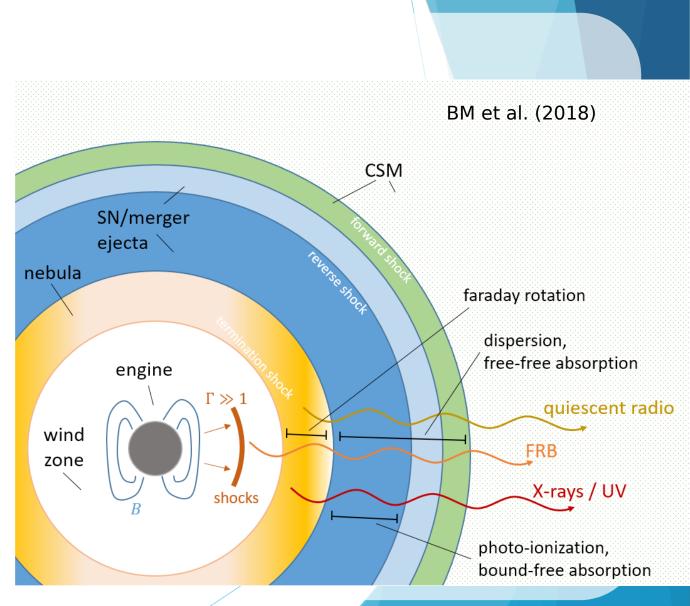
- host gradaxy \Rightarrow related to SLSSNed-V/LGGBRBB's ?
- repetition \Rightarrow non-catalysolysevente (at (at source to t)) Nicholl+17) also, FRB 121102's burst fluence distribution (e.g. Law+(17)) follows SGR/AXP burst fluence distributions (Gogus + 99,00; Gavriil+04; Scholz&Kaspill)
- \circ RM \Rightarrow magnetized electron-ion environment
- RM magnetized electron-ion environment
- \circ ms timescales \Rightarrow
- ms timescales

NS origin ? N¶ origin ? smells like a

a magnetar model:

schematic:

- magnetarflageeexexvatelteatter
 - injaced anaggretized electronion plasmainton ablate la

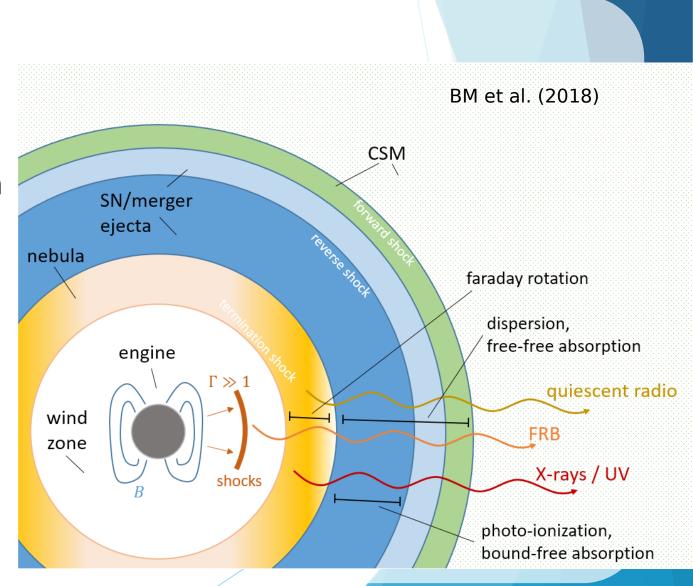


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<u>a magnetar model:</u>

schematic:

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- % in metabolappodduce 'quiiescentt'
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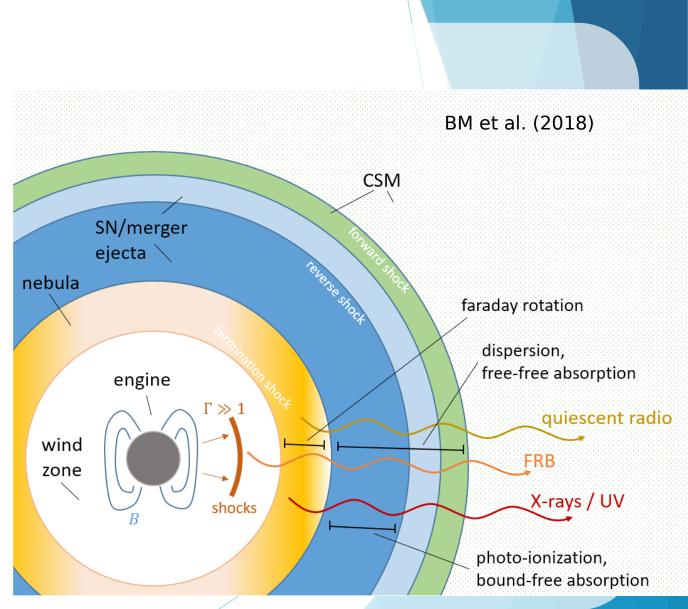


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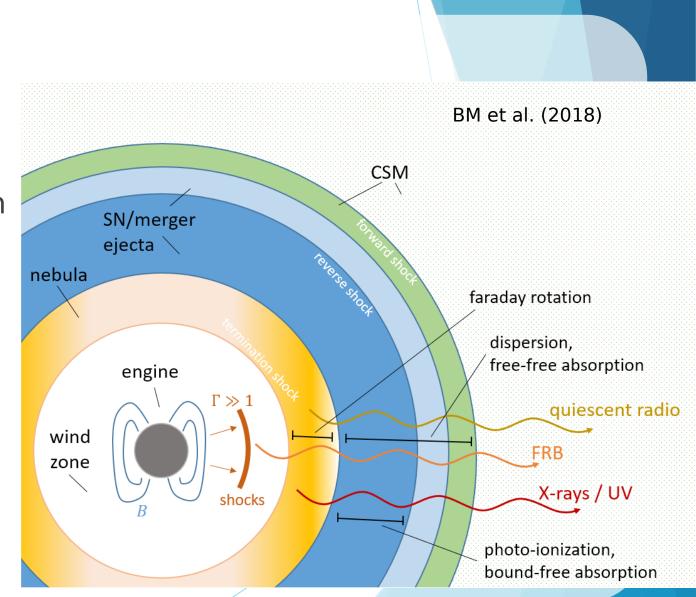


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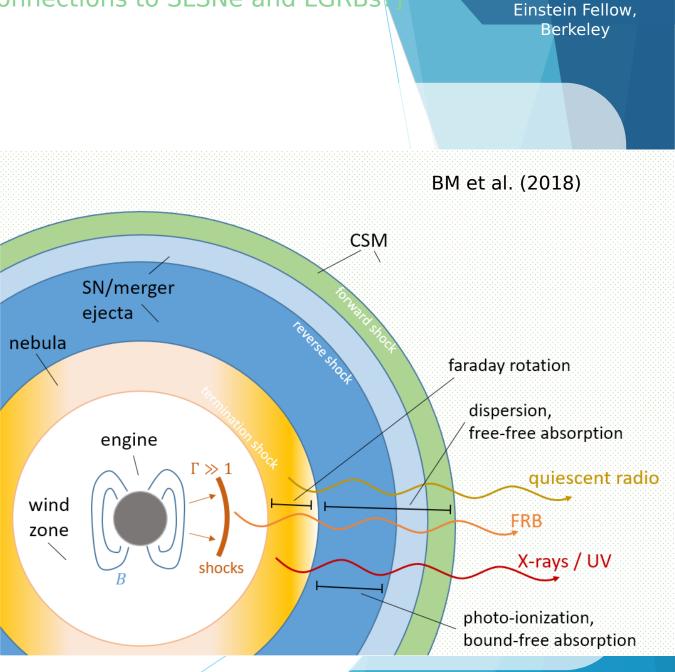
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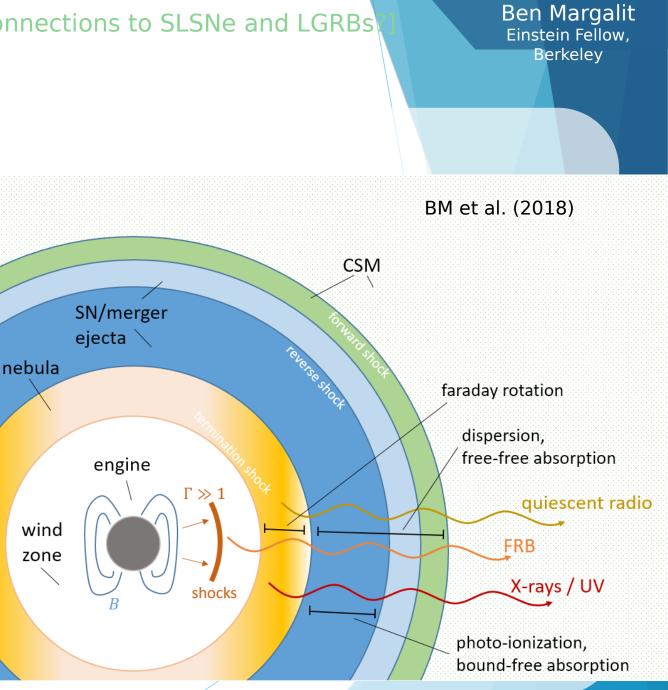
Beloborodov17)



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ejecta photo-ionization:

- FRB musetpprpagagetertuguguh SN ejecta
 - > free-free absorption todal and
- DM consonastreipeatee's eagter's age

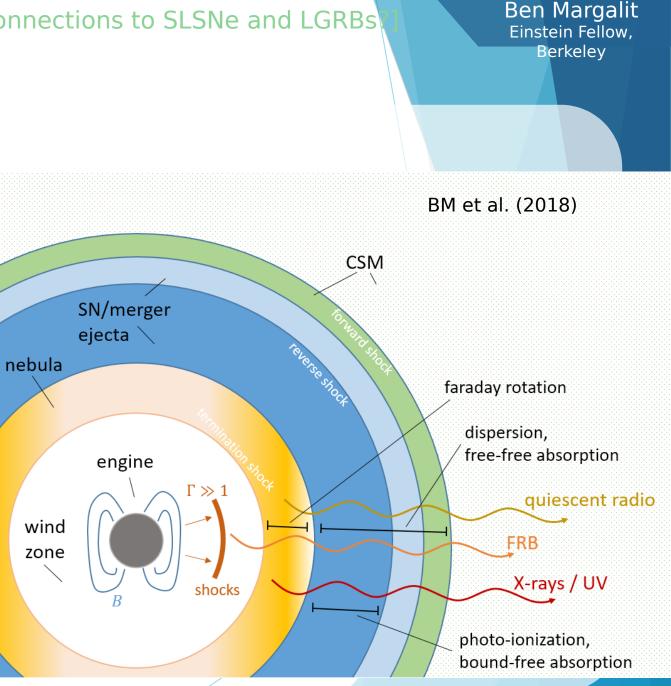


ejecta photo-ionization:

- FRB must propage tartheough SN ejecta
 - ⇒ free-free absorption local CaN
- constraint reipeater's eater's DM age
- only ionized ejecta contributes.
- owbyicontributes. 0 two ionizing sources:
 - shock heating
 - (Connor+16; Piro16; Piro&Gaensler18)
 Shock heating
 - (Connor+16; Piro16; Piro&Gaensler18) photo-ionization by engine
 - 0

(Metzger+14; Metzger, Berger&BM17; BM+18) photo-ionization by engine

(Metzger+14; Metzger, Berger&BM17; $PM \perp 10$



 cm^{-3})

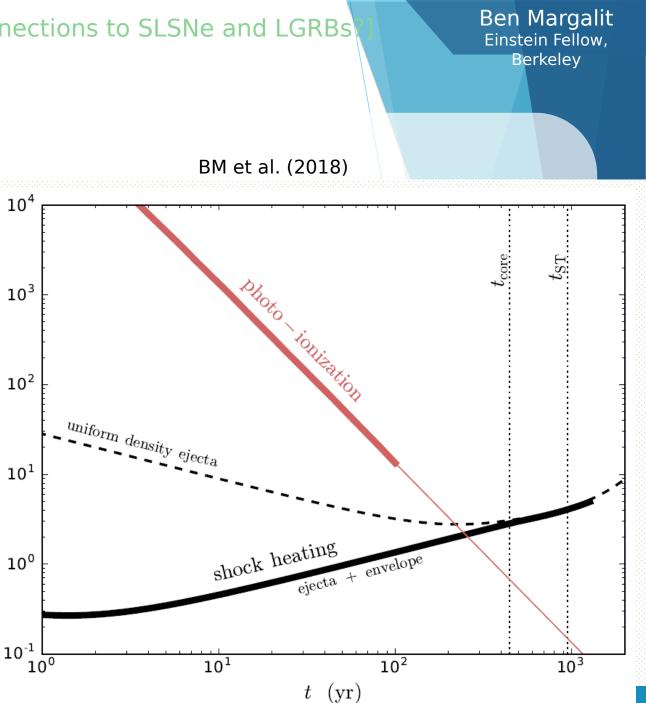
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DM

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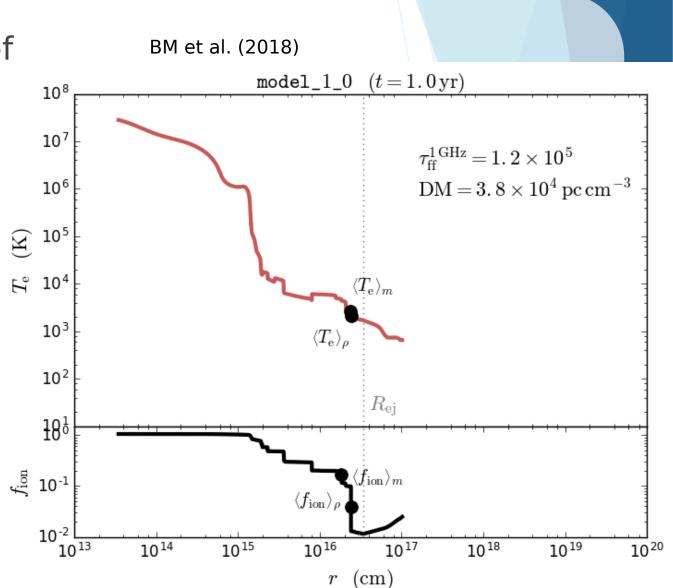
ejecta photo-ionization:

calculatephoetgoigizationateote of ejecta (w/ CLOUDY)

freefreetransparency timeaadd DM evodutition

6 find temporally coosts to intrization if a timp of if a ption, , implying:

• DM $\propto \langle f_{\text{ion}} \rangle_{\rho} \frac{M_{\text{ej}}}{(v_{\text{ej}}t)^2} \sim t^{-2}$ • $\tau_X \propto (1 - \langle f_{\text{ion}} \rangle_{\rho}) \frac{M_{\text{ej}}}{(v_{\text{ej}}t)^2} \sim t^{-2}$ • $\tau_{\text{ff}} \sim f_{\text{ion}}^2 \frac{M_{\text{ej}}^2}{(v_{\text{ei}}t)^5}$



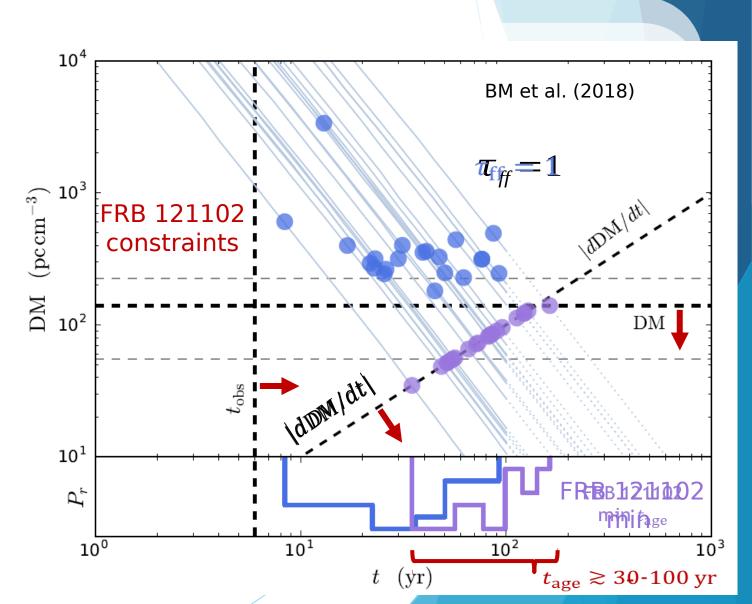
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ejecta photo-ionization:

if we assume ERBRABging impilar sinilateoy pe Sing net pes magnetars

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

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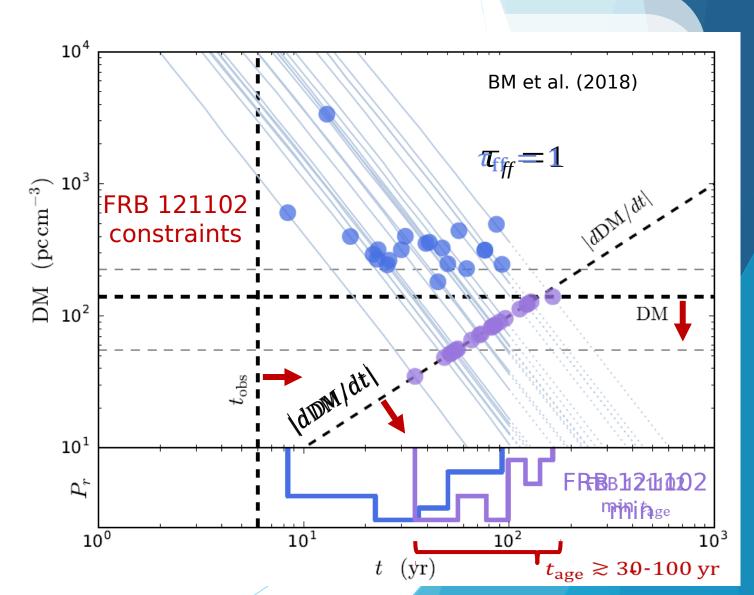
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⇒ repeater's $t_{age} \gtrsim 30-100$ yr repeater's 30-100 yr

- this assumption probabilistically
 consistent with DM, dDM/dt
 probabilistically consistent
 with DM dDM/dt
- buth age can be much younger if magnetar has high B-field (e.g. LGRB-type) but - age can be much

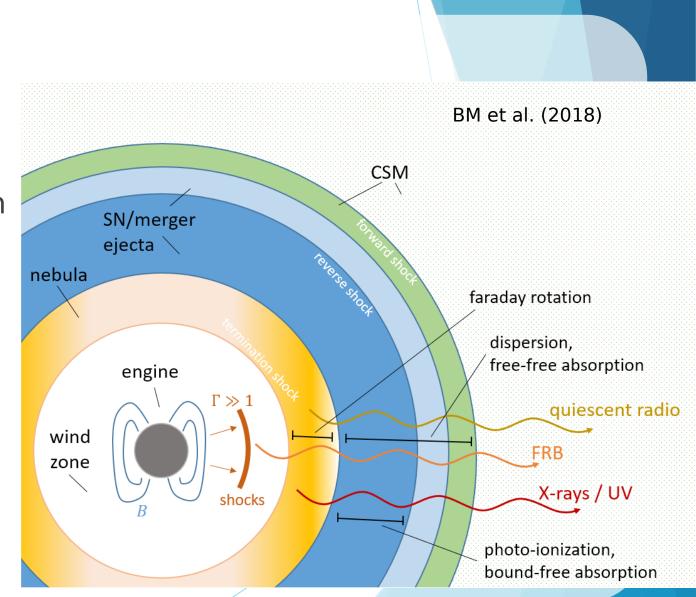
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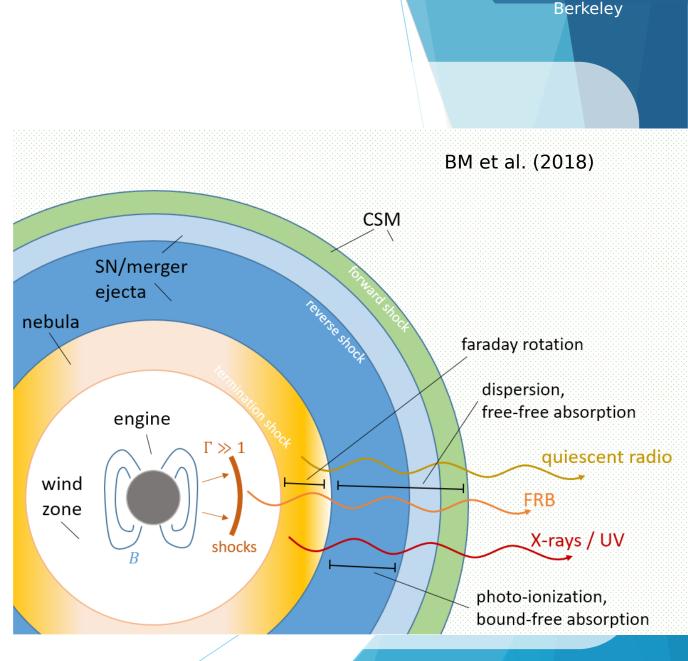
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magnetized nebula:

- one-zone-modelel:
 - 8 inject magnetic angry etector protorpt and sina $t^{-\alpha}$, $\dot{N}_e \propto \dot{E}$
 - 8 neubla'smaggenetinetinetine the parpiarte distribution versolved

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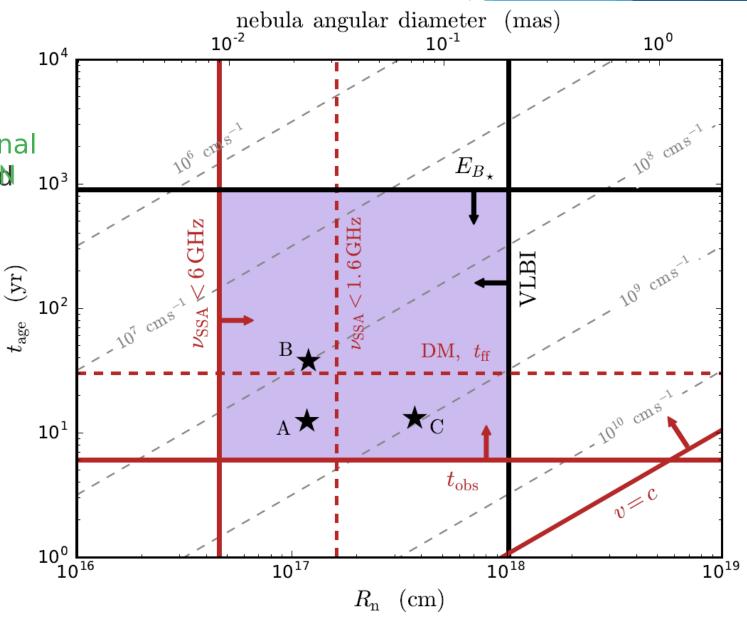
8 neubla'smaggenetirietie laha parpiartei aler distribution vevolved

$$\frac{dE_B}{dt} = -\frac{\dot{R}_n}{R_n} E_B + \frac{\sigma}{1+\sigma} \dot{E}, \qquad B_n \equiv \left(\underbrace{\underbrace{\Theta E_n B}}{R_n^3} \right)^{N/2}$$
$$\frac{\partial}{\partial t} N_{\gamma} + \frac{\partial}{\partial \gamma} \left(\dot{\gamma} N_{\gamma} \right) - 3 \frac{\dot{R}_n}{R_n} N_{\gamma} = \dot{N}_{\gamma}.$$
$$N_{\gamma} \equiv \left(\underbrace{\underbrace{dn_{ee}}}{d\gamma} \right) \qquad \text{cooling term includes adiabatic, synchrotron, bremsstrahlung, and inverse Compton losses}$$

goal – cate alter RMM synstyrothooteonis sionistion on the bula

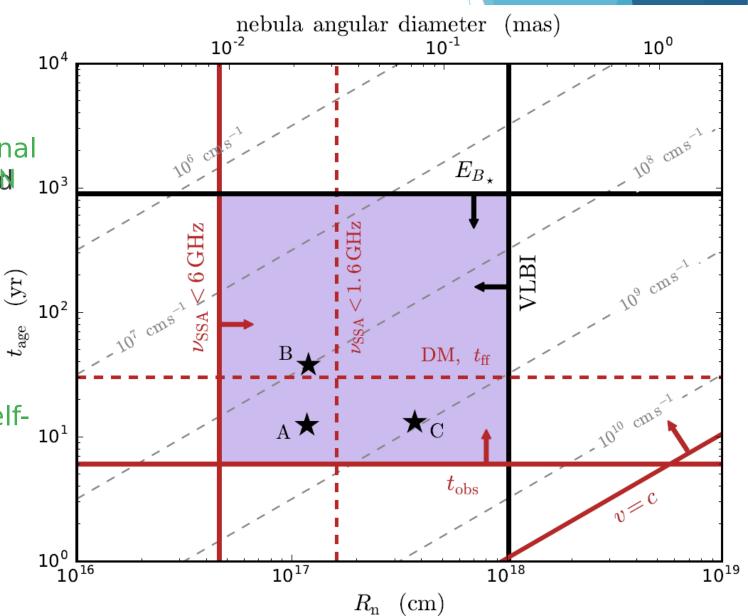
constraints:

- ♦ age:
 - lower limit from 6 yolsses entional baseline, affect to 6 plpottotionionid 6 dl 1
 Sheetjæcta
 - upper limit tf come eargediets, $t_{age} < E_{B_{\star}}/\nu L_{\nu}$



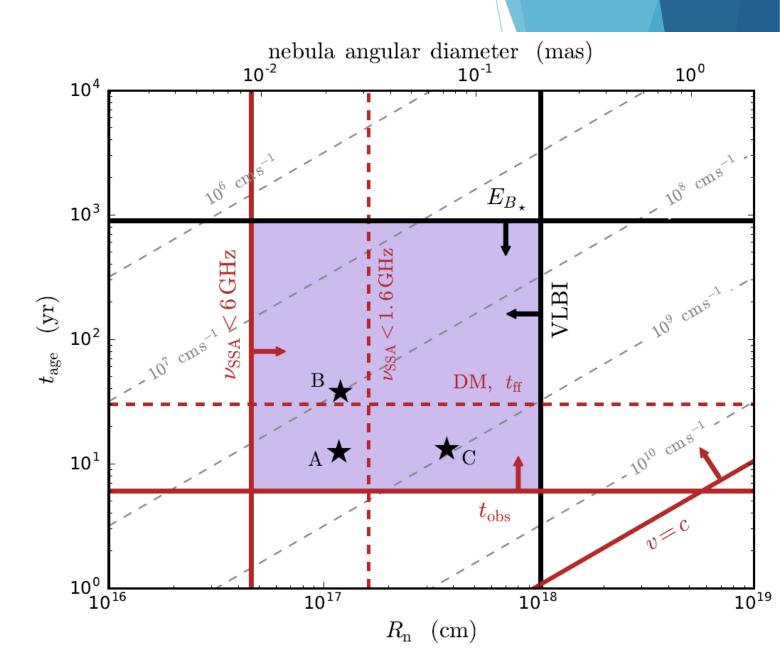
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- 8 nebulassize:
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 - & upper limit from / MBIB hiaganging



constraints:

- at a givenagege & h satisfying ditesementraints, constraping ditesementraints, constraping ditesements
 constraints, const
- ($E_{B_{\star}}, t_0, \alpha, v_n$) • only four free parameters ()



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results:

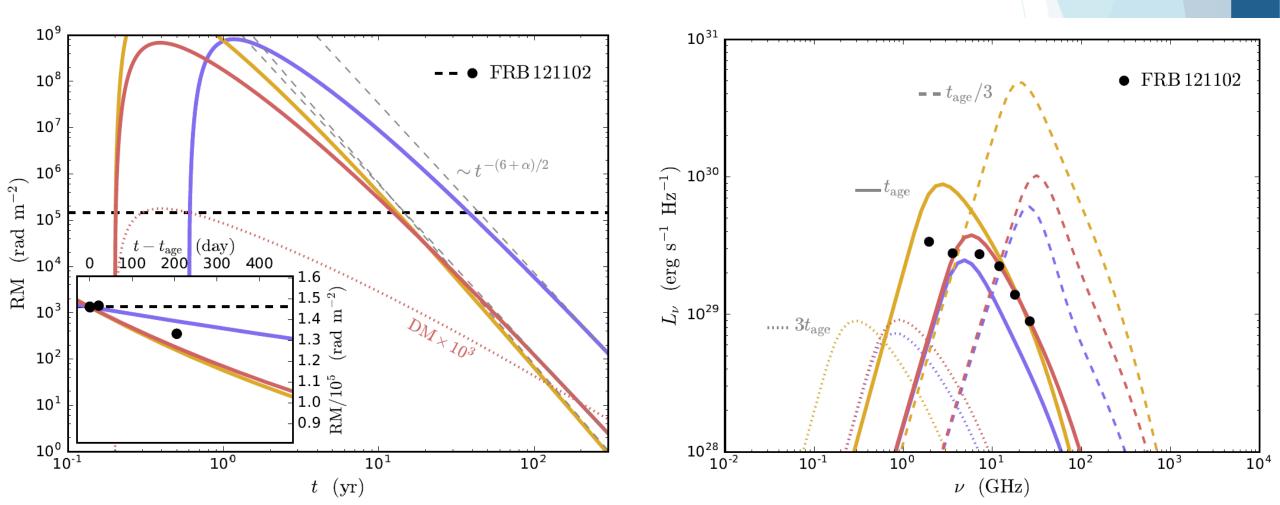
• problem highly constrained

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results:

problem highly constrained, but there are solutions

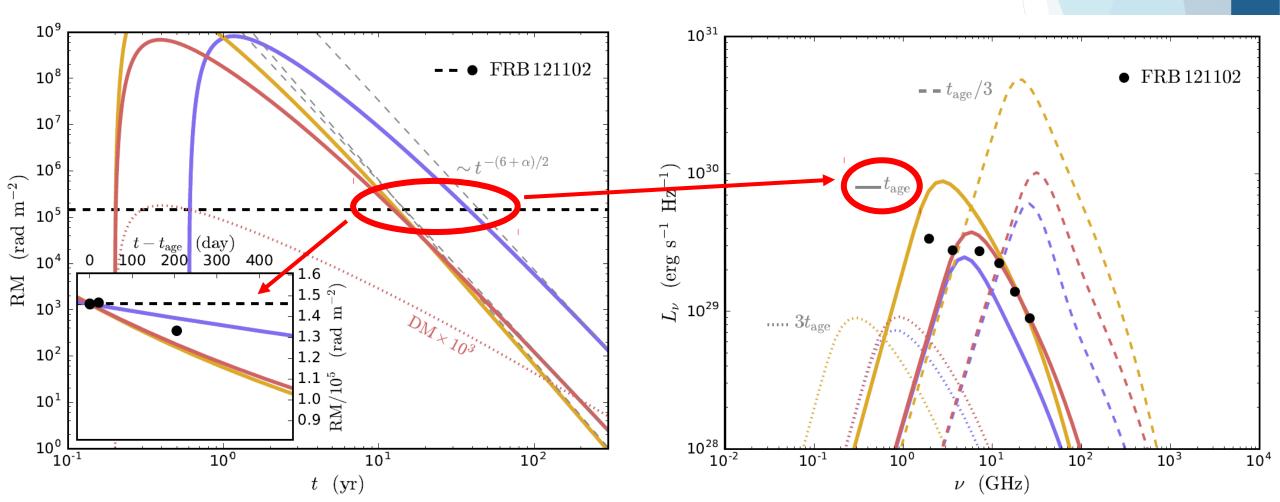


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results:

problem highly constrained, but there are solutions



<u>results:</u>

- model predicitions:
 - % secular decreases in RMRM $t^{-(6+\alpha)/2}$
 - $\frac{1}{2}$ decrease in queiner standard the site $t^{-(\alpha^2+7\alpha-2)/4}$

 - 8 self-absorption throws an ispectation with likely mater becowe law
 - % इष्ट्रह्यां सिंग्ल्यू : Jogarithmically तिव तर्राइक्रिफिफिलि हो दिन्द्र देख्त्र ये क्रि

 $\int_{\text{then}} \frac{1}{P} \left(< RM \right) \propto RM^{2} \left(\alpha = 1 \right) \left(\frac{1}{2} + \frac{1}{2} \right) \left(\frac{1}{2} + \frac{1}{2} + \frac{1}{2} \right) \left(\frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \right) \left(\frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \right) \left(\frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \right) \left(\frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \right) \left(\frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \right) \left(\frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \right) \left(\frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \right) \left(\frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \right) \left(\frac{1}{2} + \frac{1}{2} \right) \left(\frac{1}{2} + \frac{1}{$

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<u>summary / take-aways:</u>

- Stirst predictive model similateous bus kpleinping both laoge Rangen & lits (exodution) voldutiones cand radie scenter (and its speet (and) offs F&B elat 1002) of FRB 121102
- model is highly constrained by current observations
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- solutions for "reasonable" parameters are possible, but require:
- solutions for "reasonable" parameters are possible, but require:
 - large magnetic energy reservoir () more energy/particles njected at early times than at current epoch, but
 - modreneetherrogy eparatizeles injected at early times than at current epoch, but not much more! ()
- model makes many testable predictions
- model makes many testable predictions