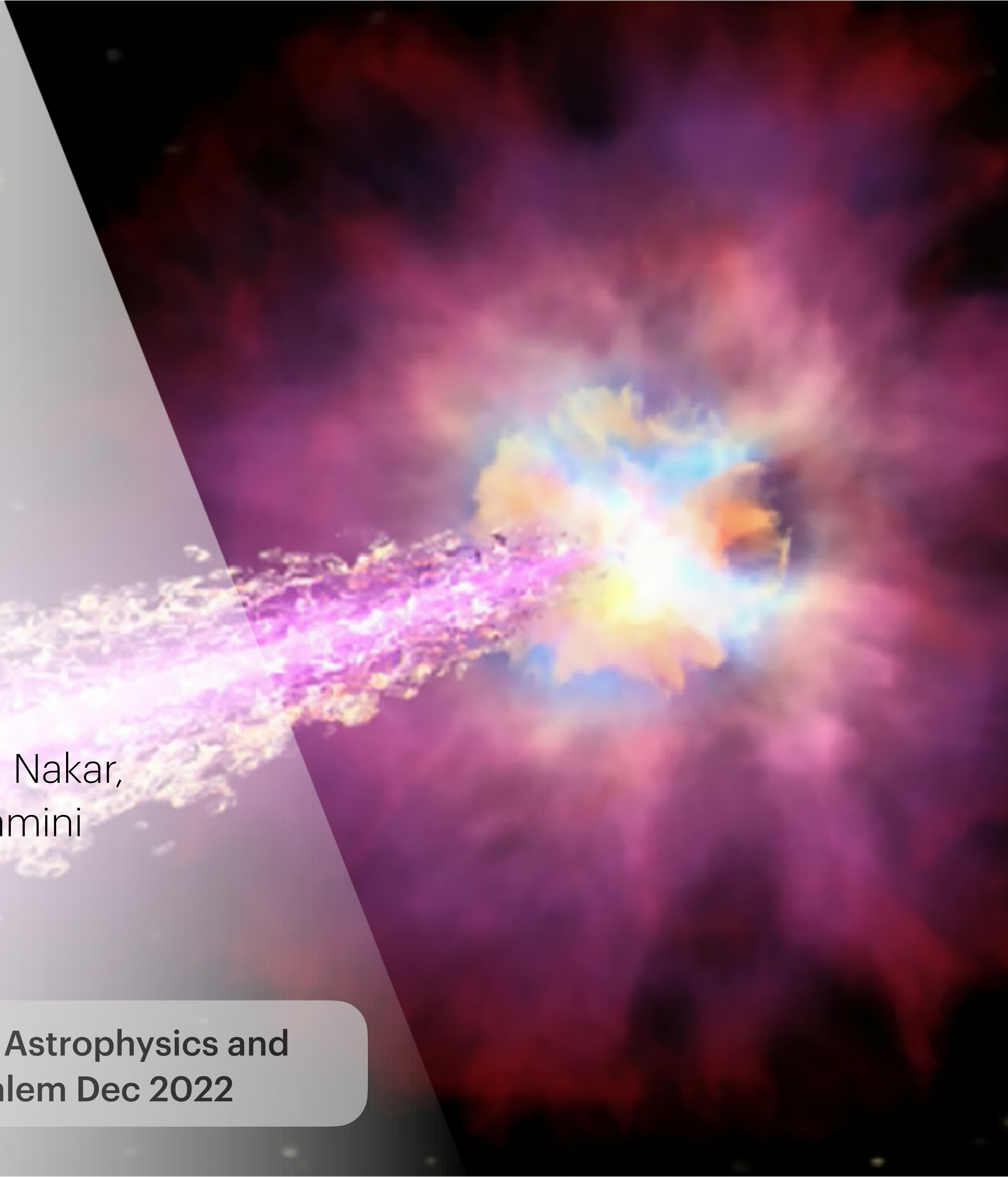
TDEs - some new ideas and some old ones



Tsvi Piran

Tatsuya Matsumoto, Rudolfo Barniol-Duran, Ehud Nakar, Glennys Farrar, Taeho Ryu, Julian Krolik, Paz Beniamini

erc
GRBs
TReX
MultiJets

Unsolved problems in Astrophysics and Cosmology; Jerusalem Dec 2022

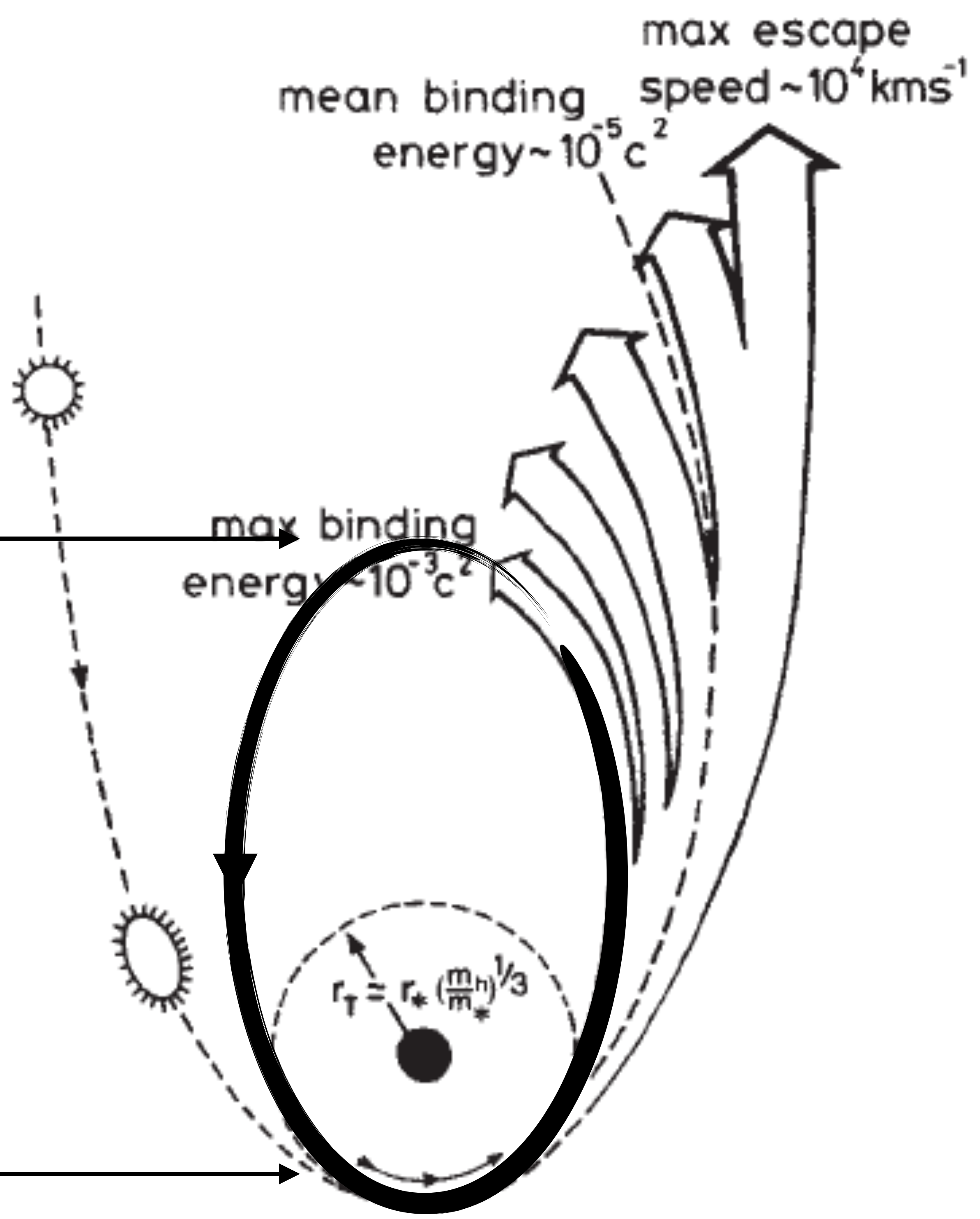
Outlook

- Prolog - what powers TDEs?
- Equipartition 101
- Relativistic Equipartition
- Off-Axis Equipartition
- TDEs' late radio flares
- Are TDE sources of UHECRs?

The “classical” picture

=> $R_0 \sim 1000\ r_g$
$t_0 \sim 1$ month

=> $R_t \sim 10\text{-}30\ r_g$

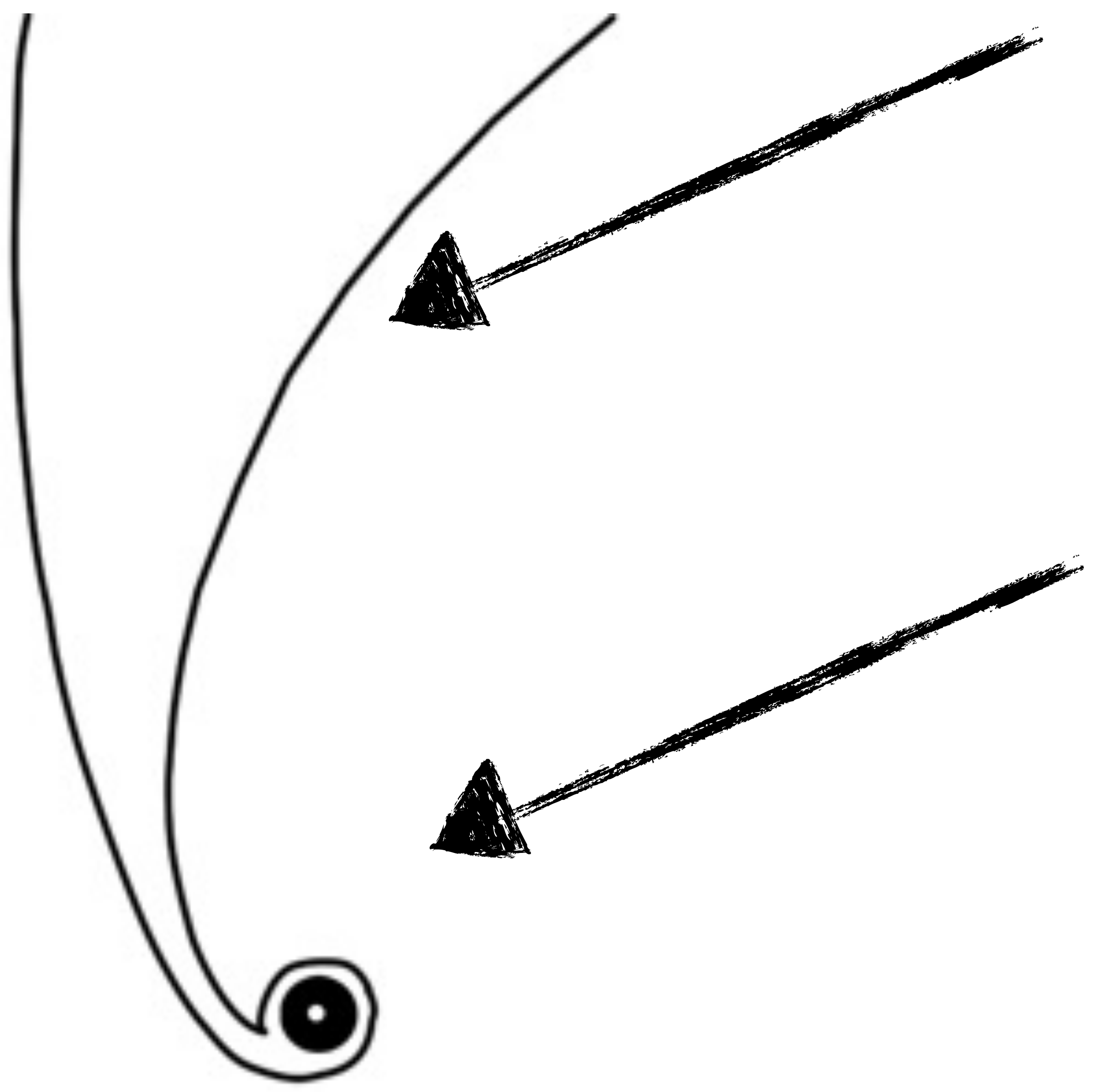


From: Rees 1988

What Powers TDEs?

A small disk forms around R_t

- Accretion of $\sim M_o$
  => $E \sim 10^{53}$ erg
- Disk at R_t ($\sim$10-30 r_g)
  => $T \sim 0.1$ keV
  => $v \sim> 50{,}000$ km/sec



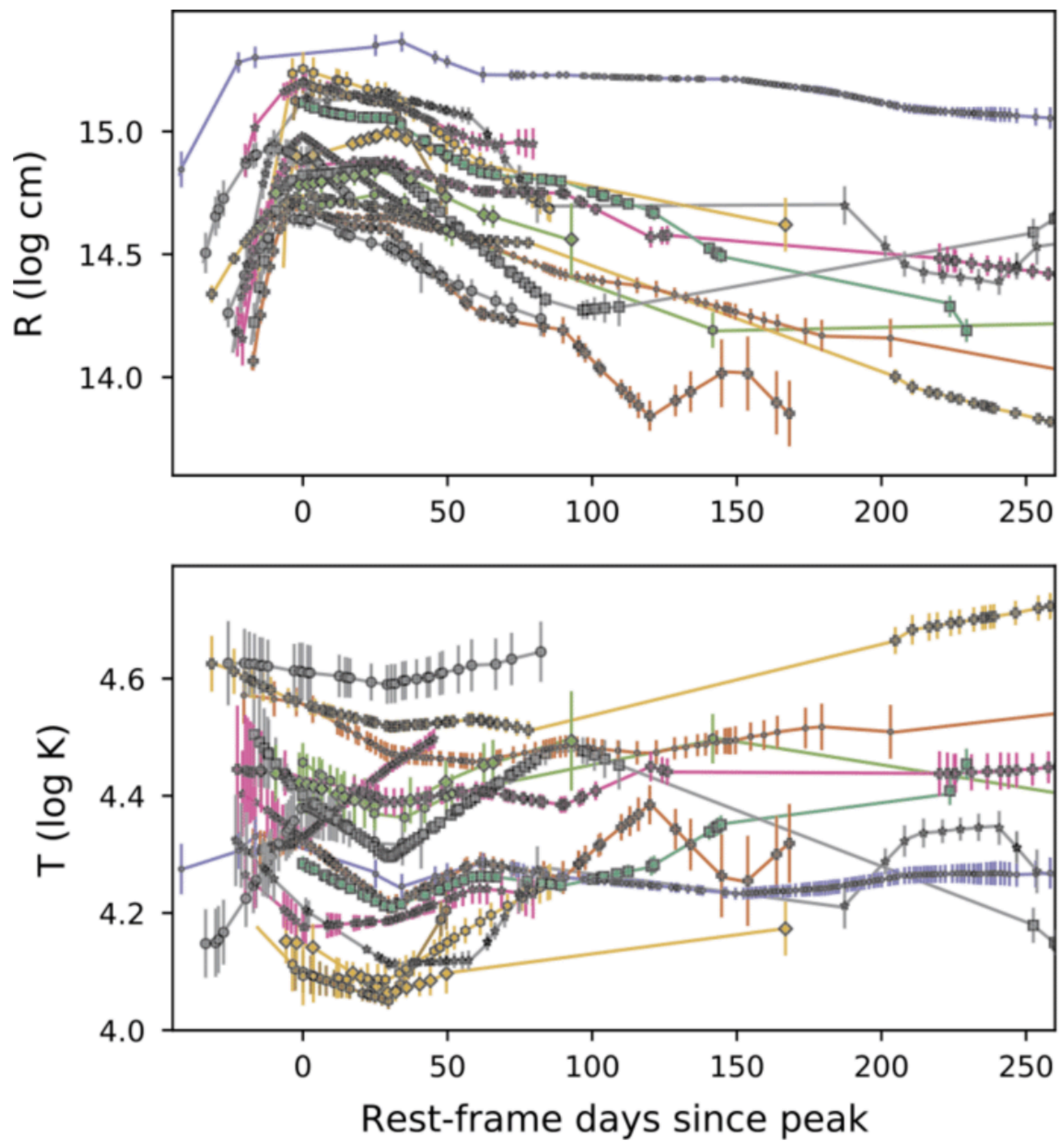
- The returning (bound) stream
- A compact disk of size ~ the tidal radius, $R_t \sim 25\ R_g$

The inverse energy crisis in optical TDEs

Expected	Observed
X-rays	**UV-optical**
T ~ 500,000 K	T ~ 50,000 K
R ~ 10 r_g	R ~ 500 r_g
v > 50000 km/sec	v ~ 5000 km/sec
E ~ 10^{53} erg	E ~ 10^{51} erg

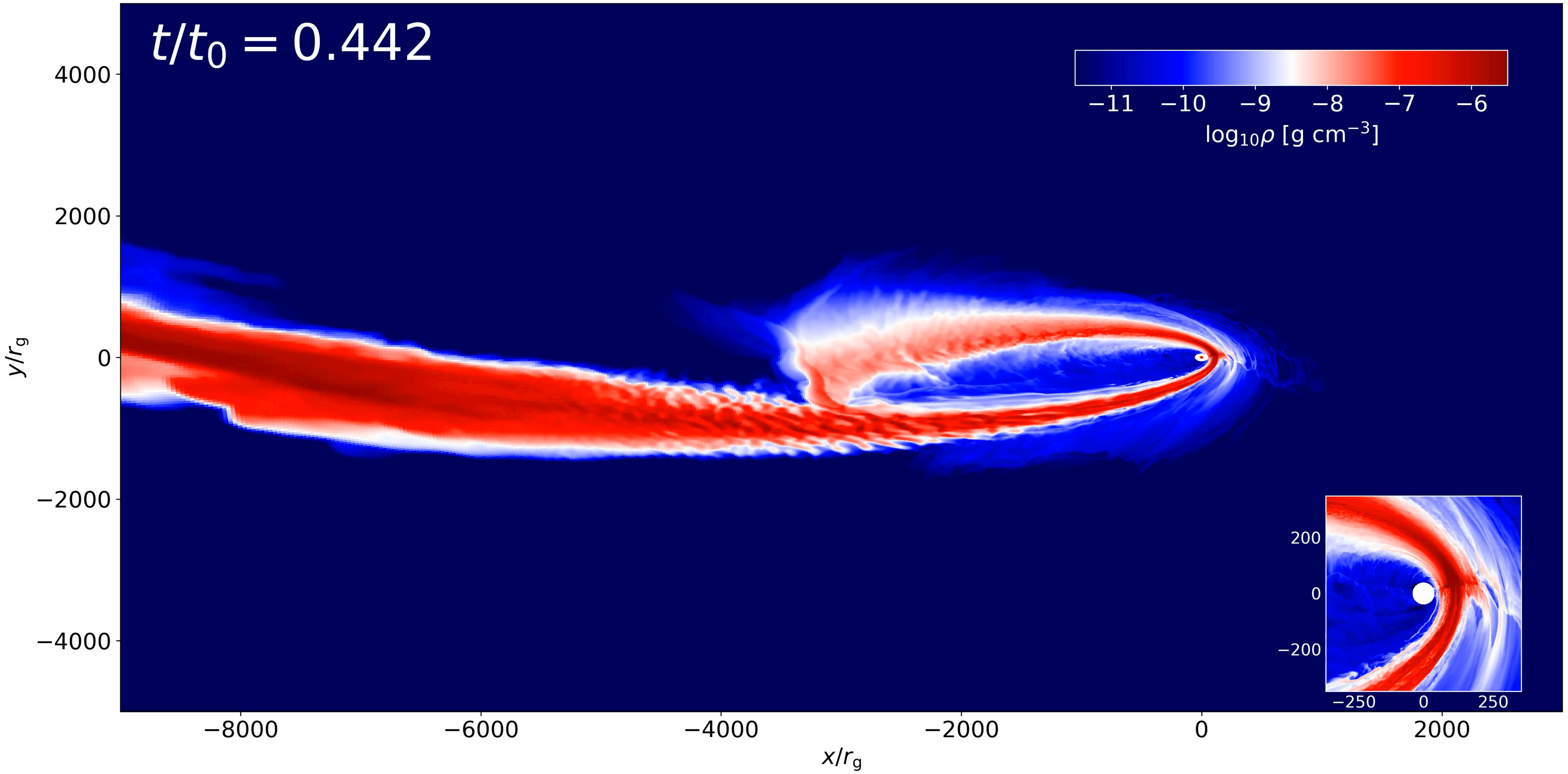
? (E ~ 10^{53} erg ⟷ E ~ 10^{51} erg)

From TP et al., 2015

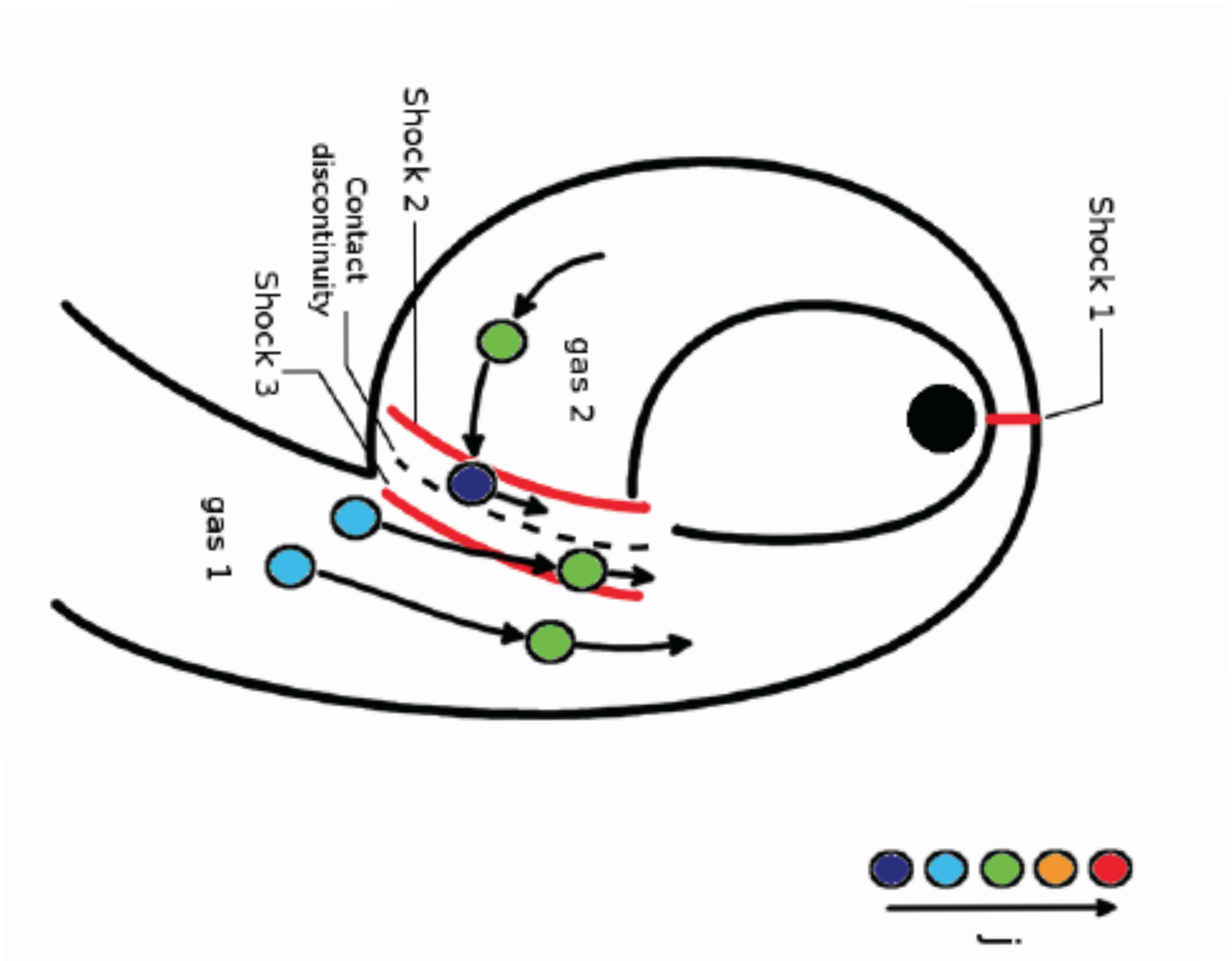


From Van Velzen et al, 2022

Energy Dissipation at outer shocks

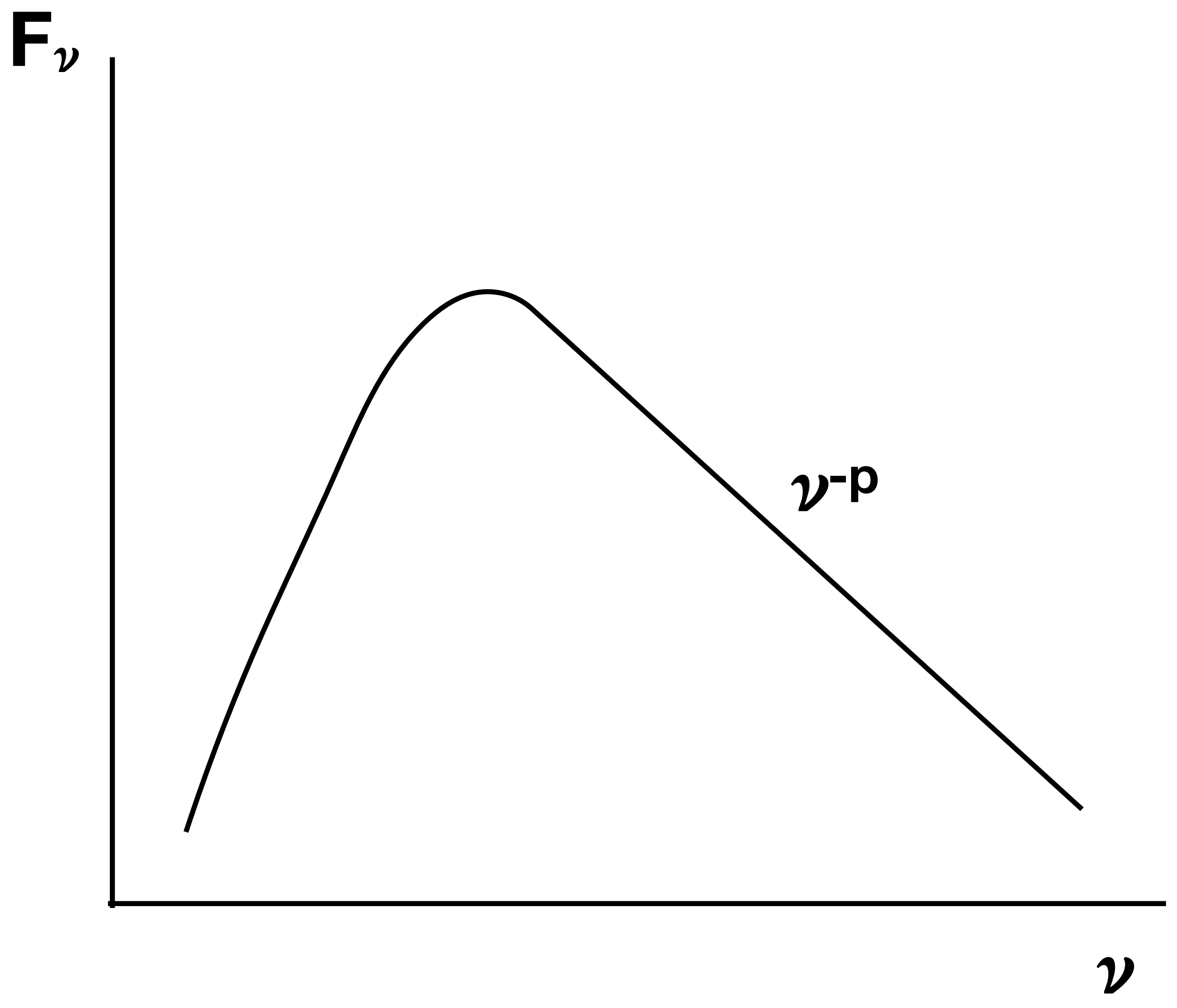


From Ryu et al., preliminary - 2022

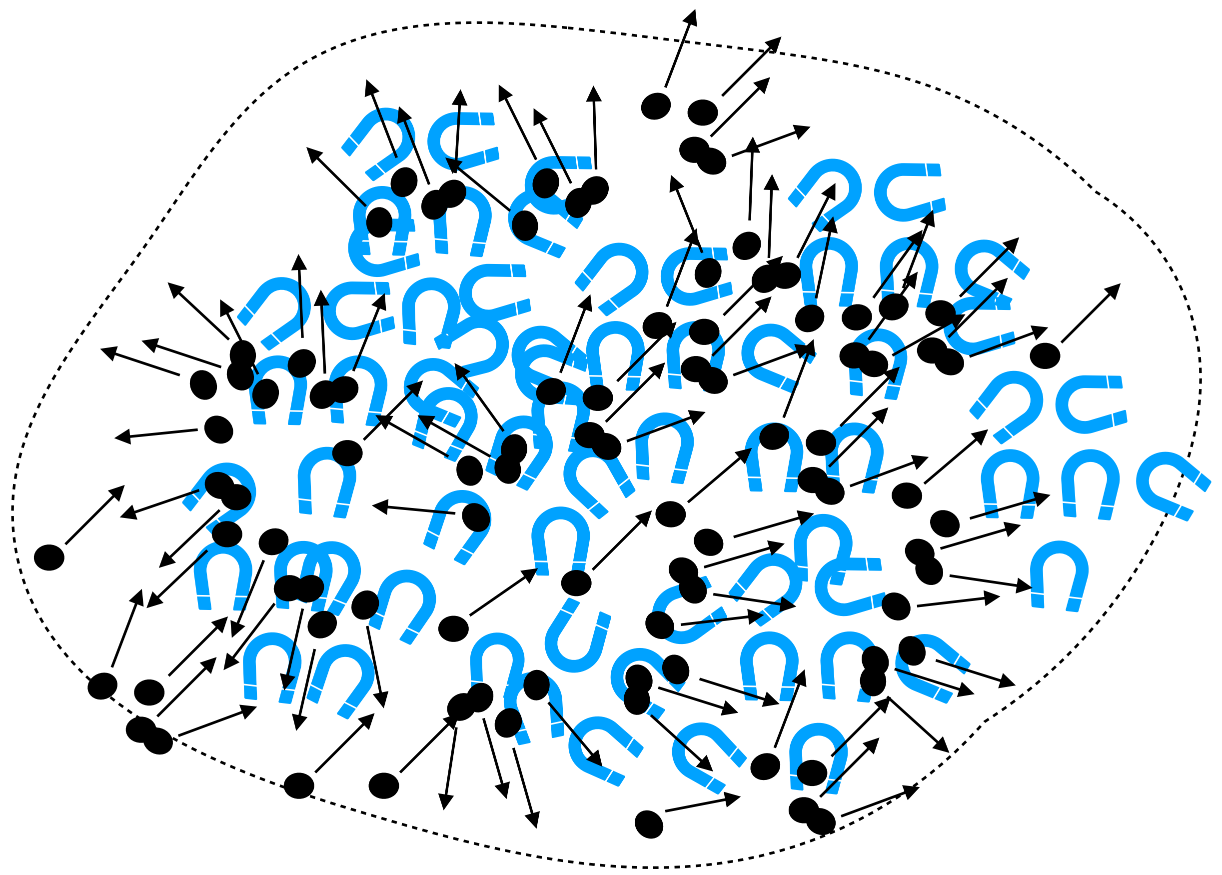


From Piran et al., 2015

Equipartition 101

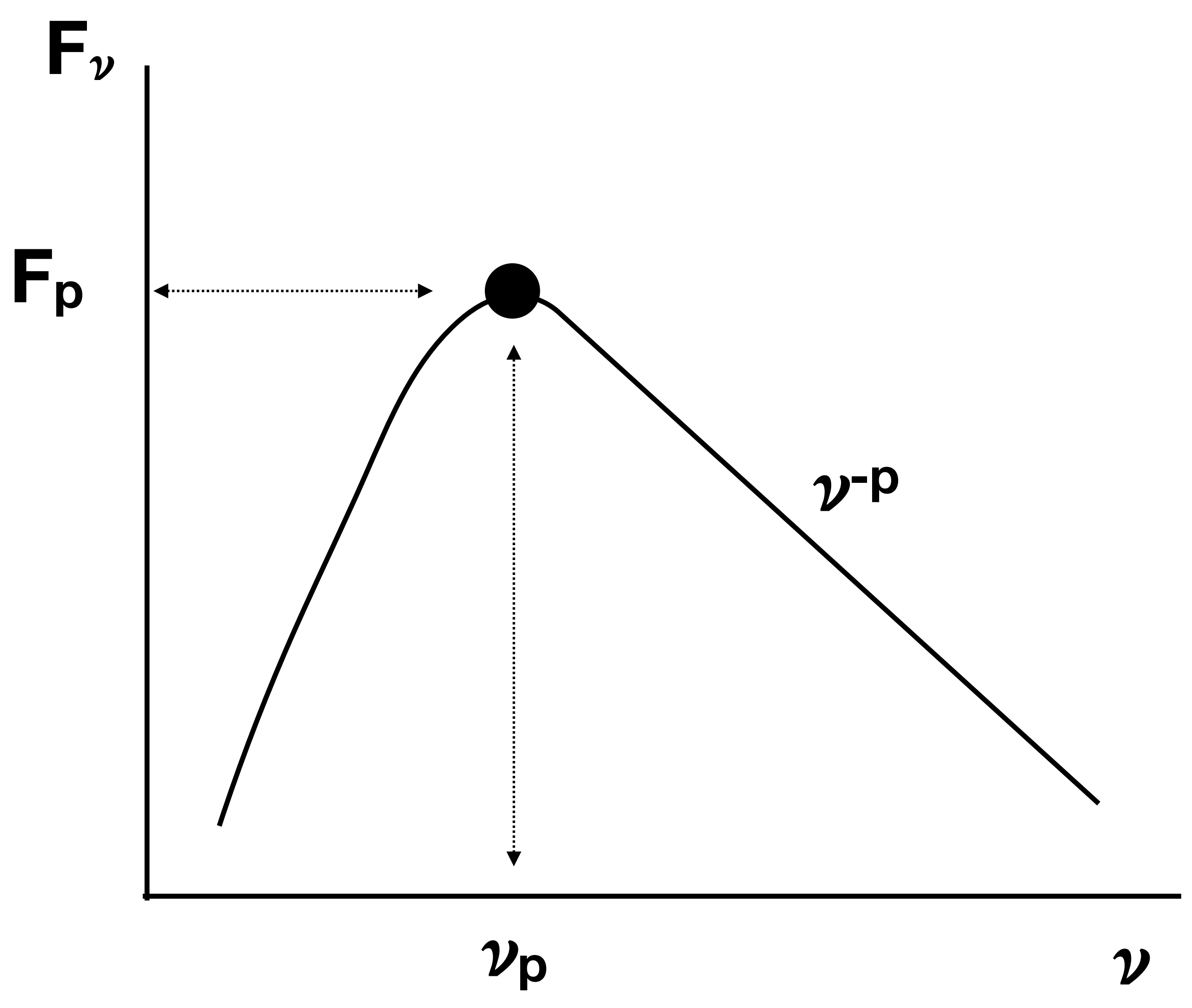


Self - Absorbed Synchrotron

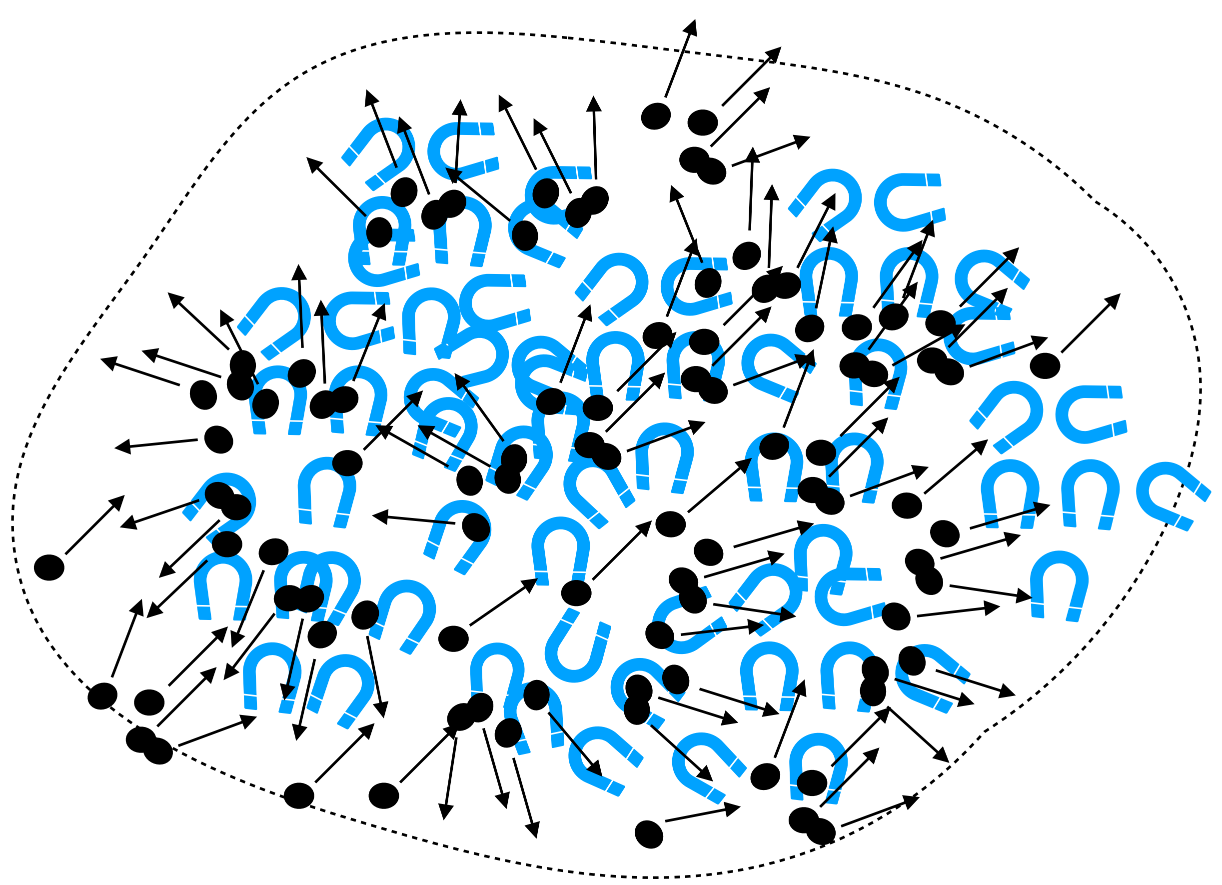


$$E = E_B + E_e = (B^2/8\pi)R^3 + N_e m_e c^2 \gamma$$

Equipartition 101



Self - Absorbed Synchrotron

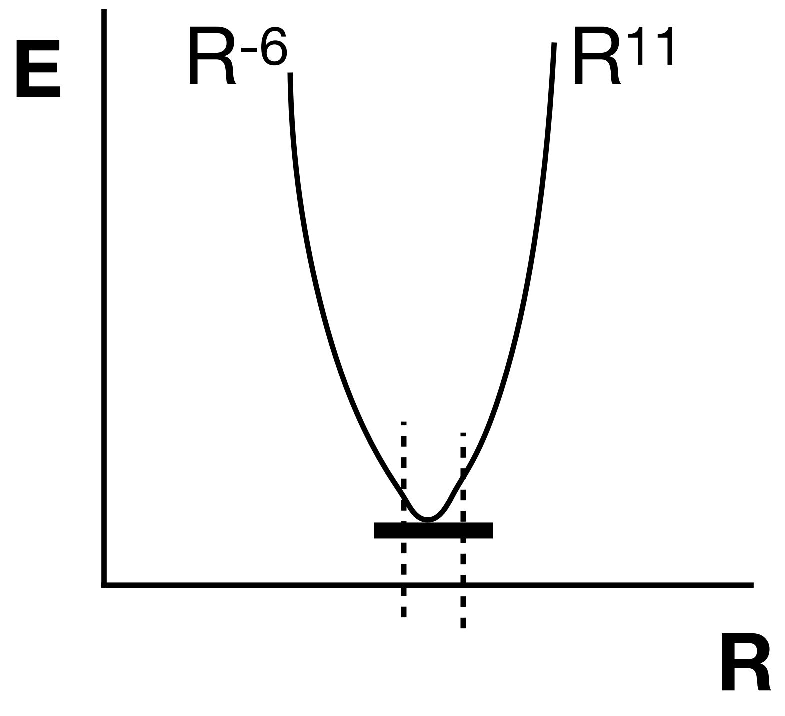


$$E = E_B + E_e = (B^2/8\pi)R^3 + N_e m_e c^2 \gamma$$

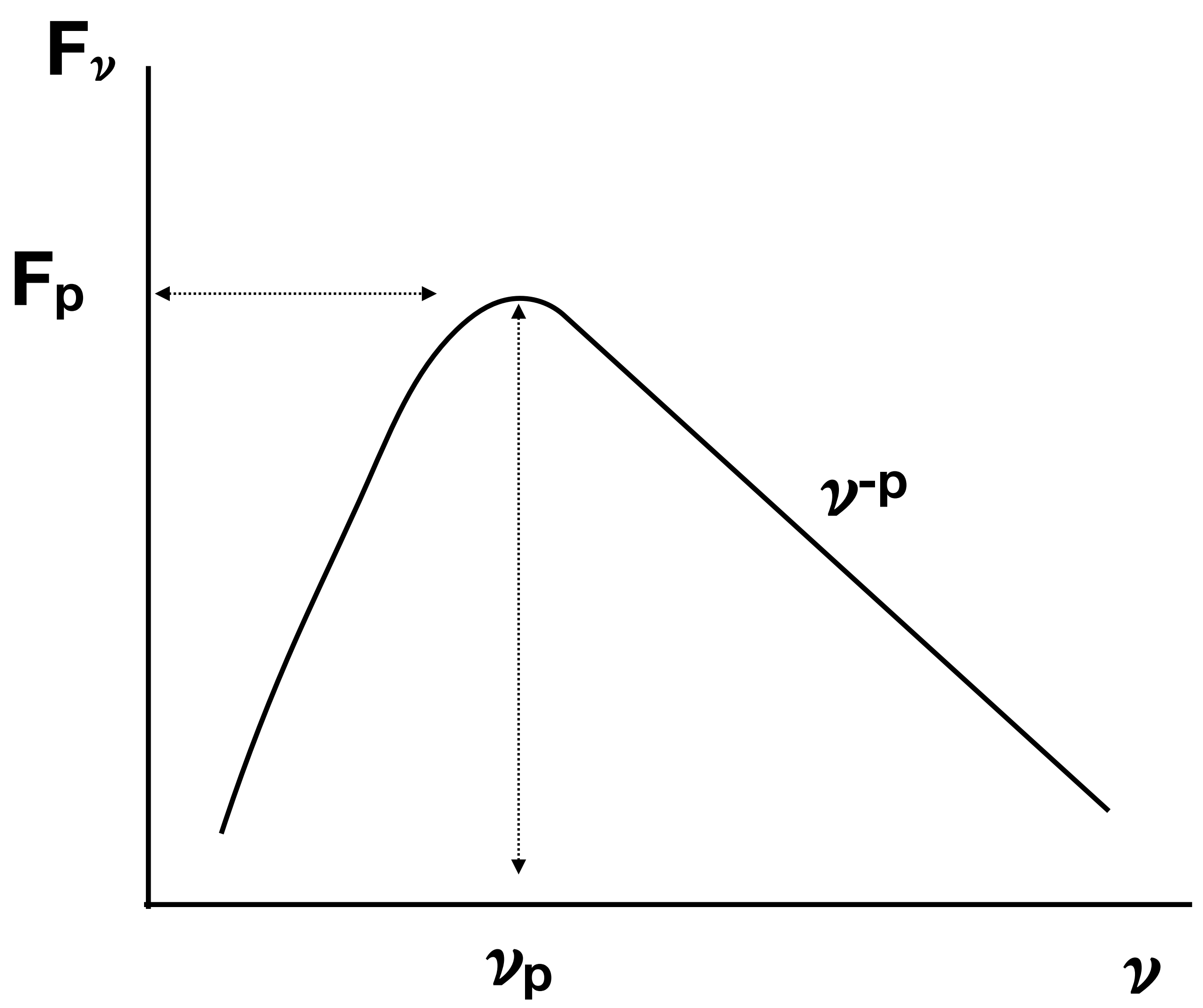
$$E = E_e + E_B = E_N \left[\frac{11}{17} \left(\frac{R}{R_{eq}} \right)^{-6} + \frac{6}{17} \left(\frac{R}{R_{eq}} \right)^{11} \right]$$

$$R_N \approx (1.7 \times 10^{17}\ \mathrm{cm}) \left[F_{p,\mathrm{mJy}}^{\frac{8}{17}}\ \nu_{p,10}^{-1}\ d_{L,28}^{\frac{16}{17}} \eta^{\frac{35}{51}} (1+z)^{-\frac{25}{17}} \right]$$

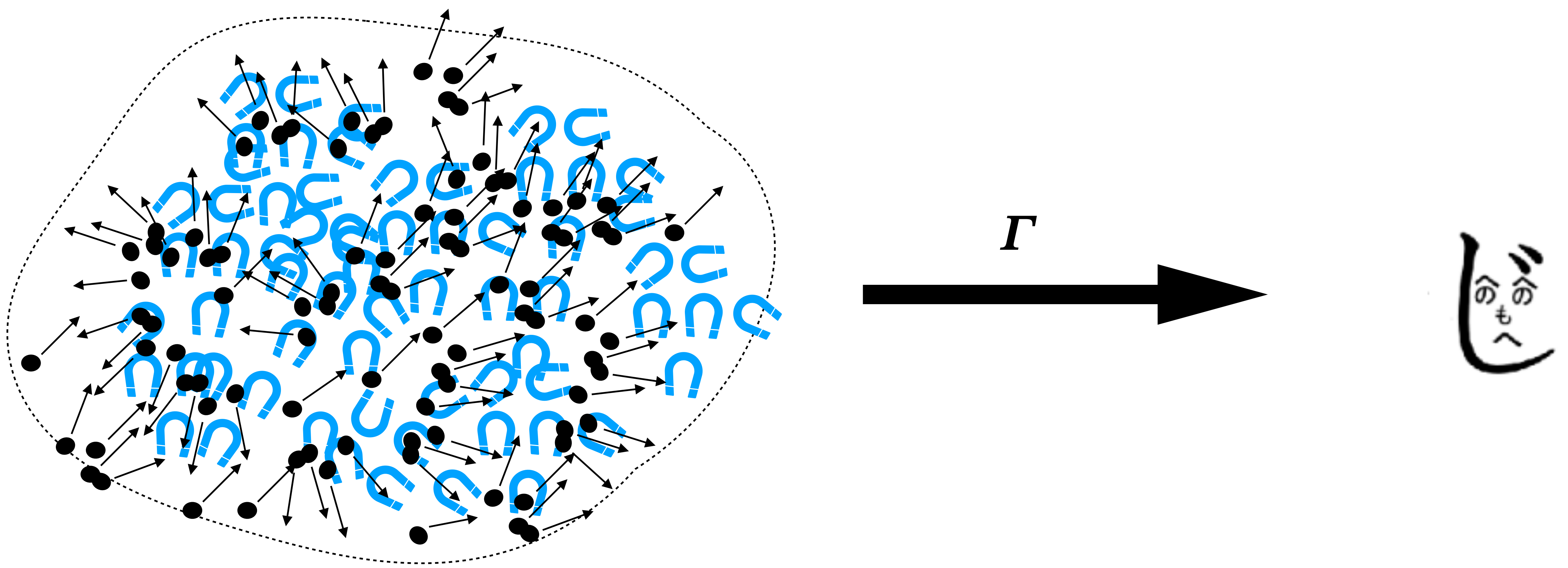
$$E_N \approx (2.5 \times 10^{49}\ \mathrm{erg}) \left[F_{p,\mathrm{mJy}}^{\frac{20}{17}}\ \nu_{p,10}^{-1}\ d_{L,28}^{\frac{40}{17}} \eta^{\frac{15}{17}} (1+z)^{-\frac{37}{17}} \right]$$



Relativistic Equipartition



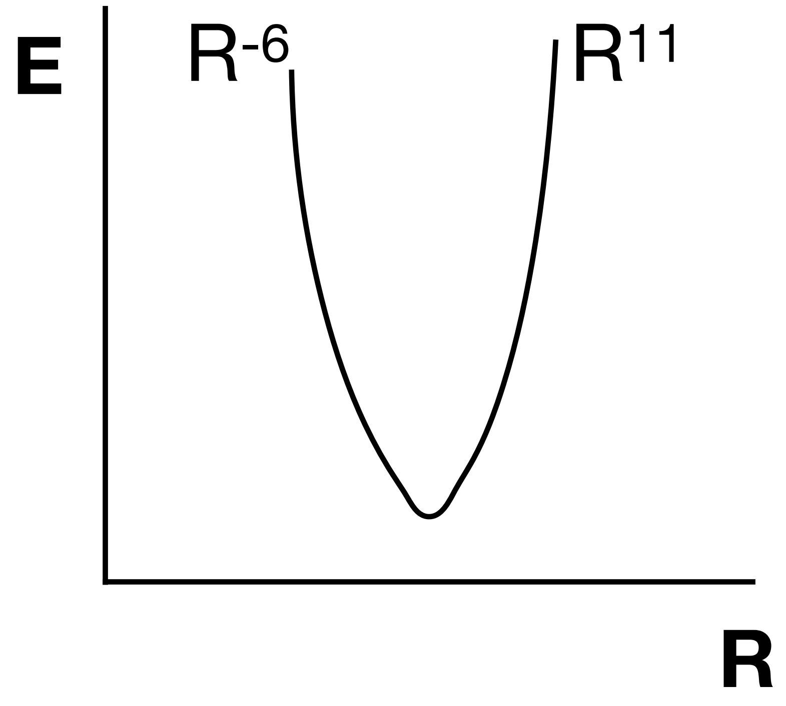
Self - Absorbed Synchrotron



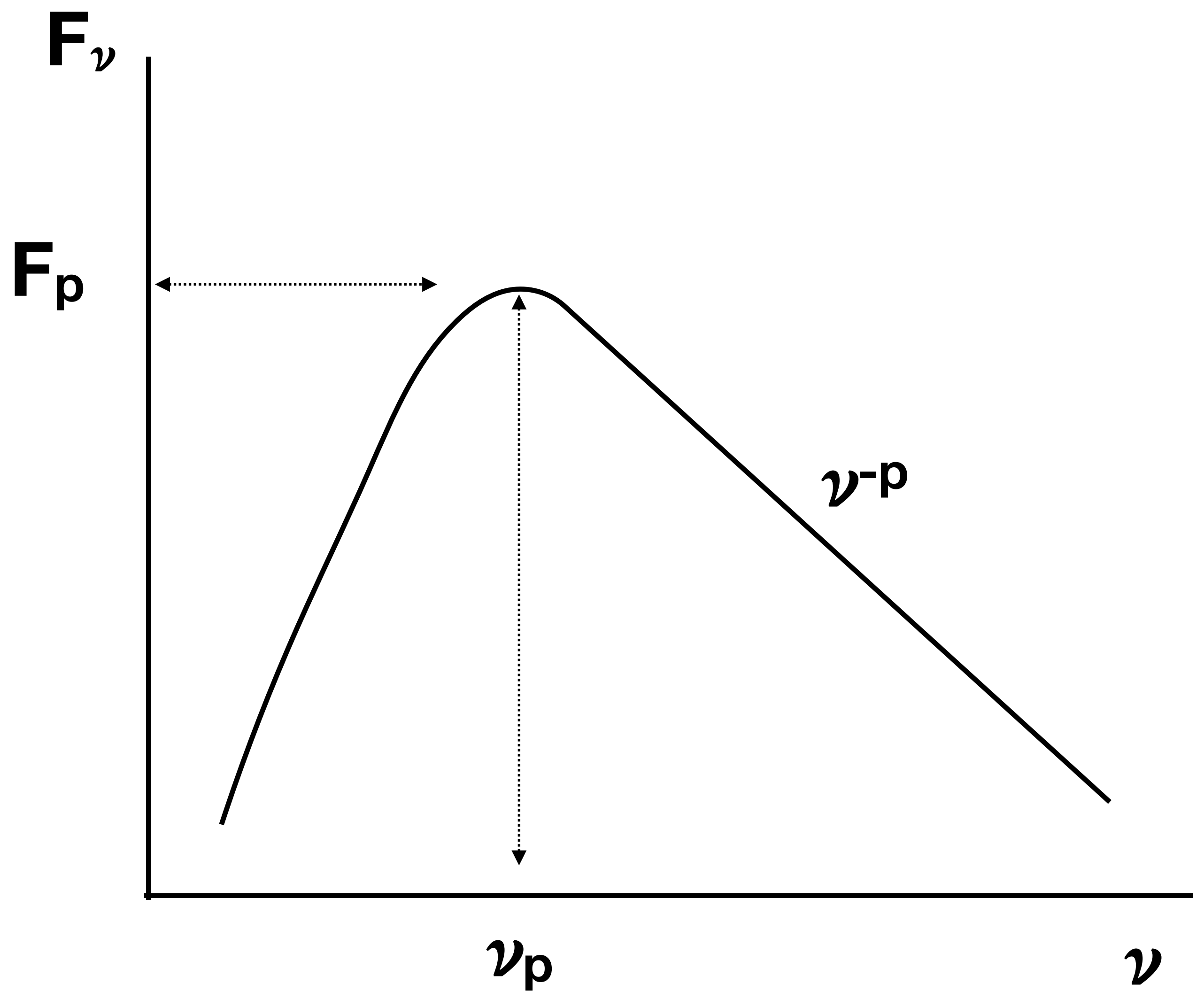
$$E = E_B + E_e = [(B\Gamma)^2/8\pi]R^3 + \Gamma N_e m_e c^2 \gamma$$

$$t = R/2c\Gamma^2$$

$$E = E_e + E_B = E_N \left(\frac{1}{\Gamma^{\frac{26}{17}}}\right)\left[\frac{11}{17}\left(\frac{R}{R_{\rm eq}}\right)^{-6} + \frac{6}{17}\left(\frac{R}{R_{\rm eq}}\right)^{11}\right]$$

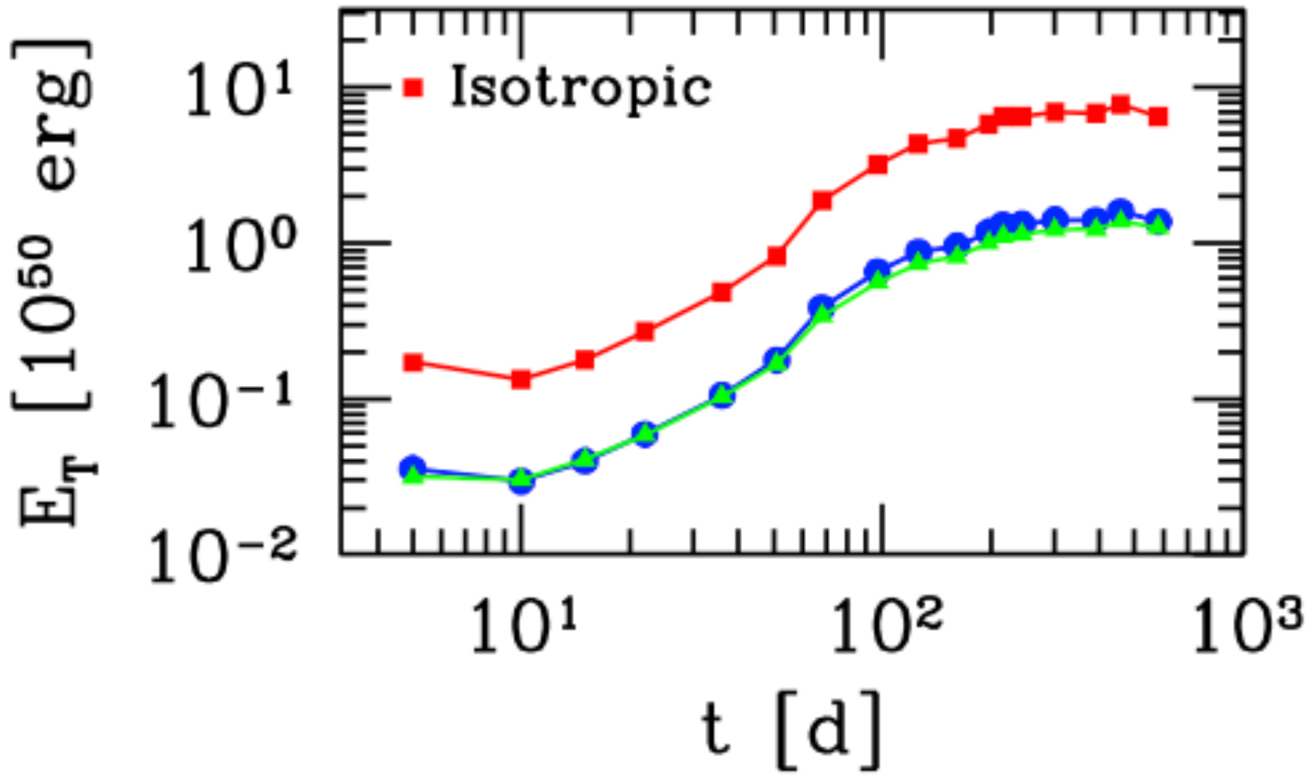


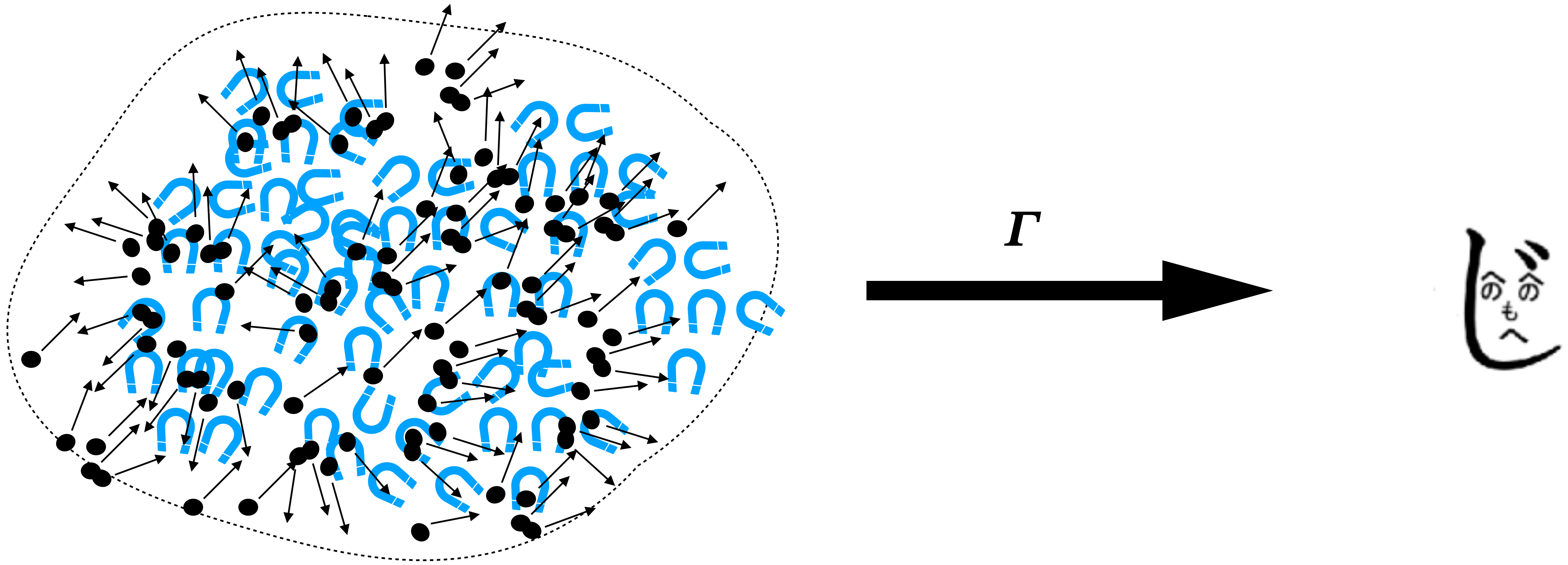
Relativistic Equipartition



Self - Absorbed Synchrotron

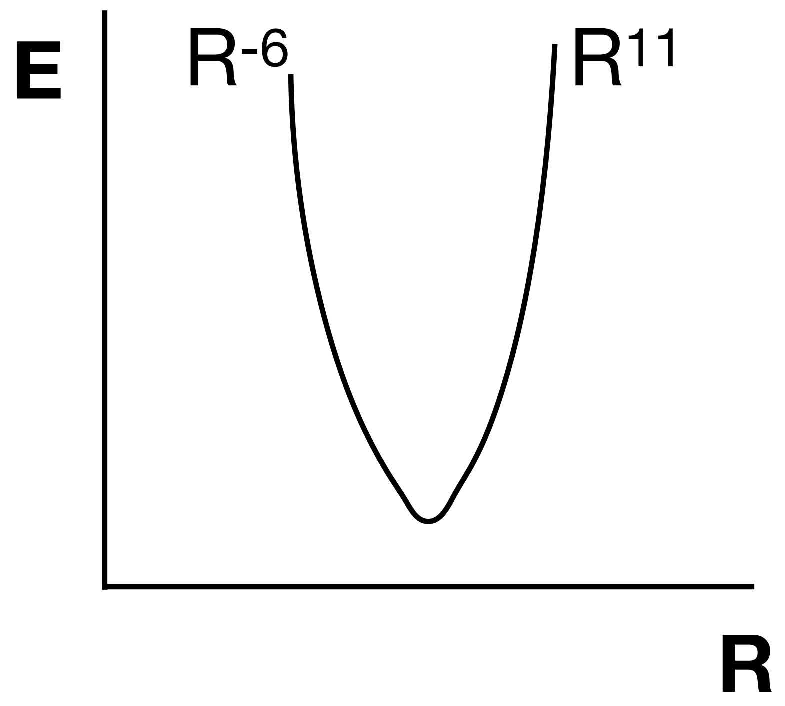
Energy implied by radio from Sw J1644



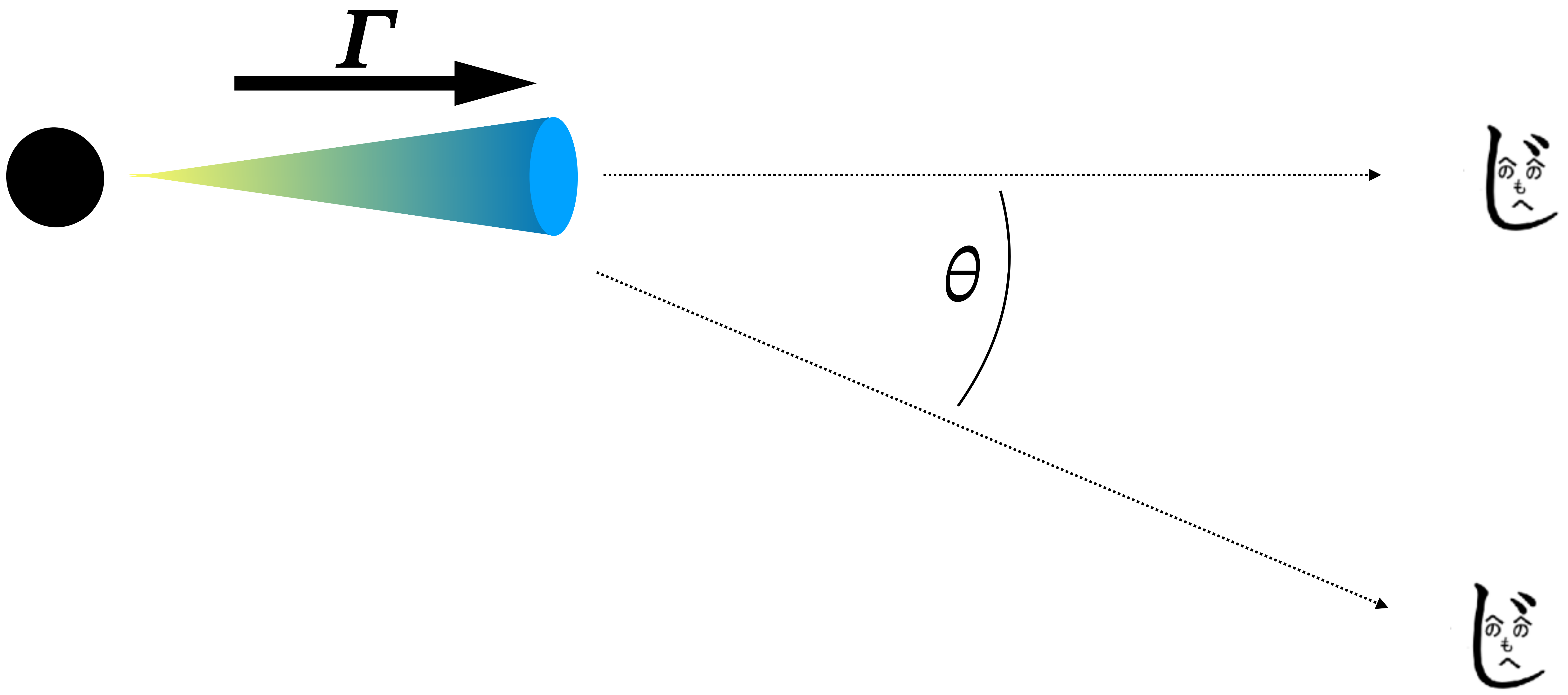


$$E = E_B + E_e = [(B\Gamma)^2/8\pi]R^3 + \Gamma N_e m_e c^2 \gamma$$

$$t = R/2c\Gamma^2$$



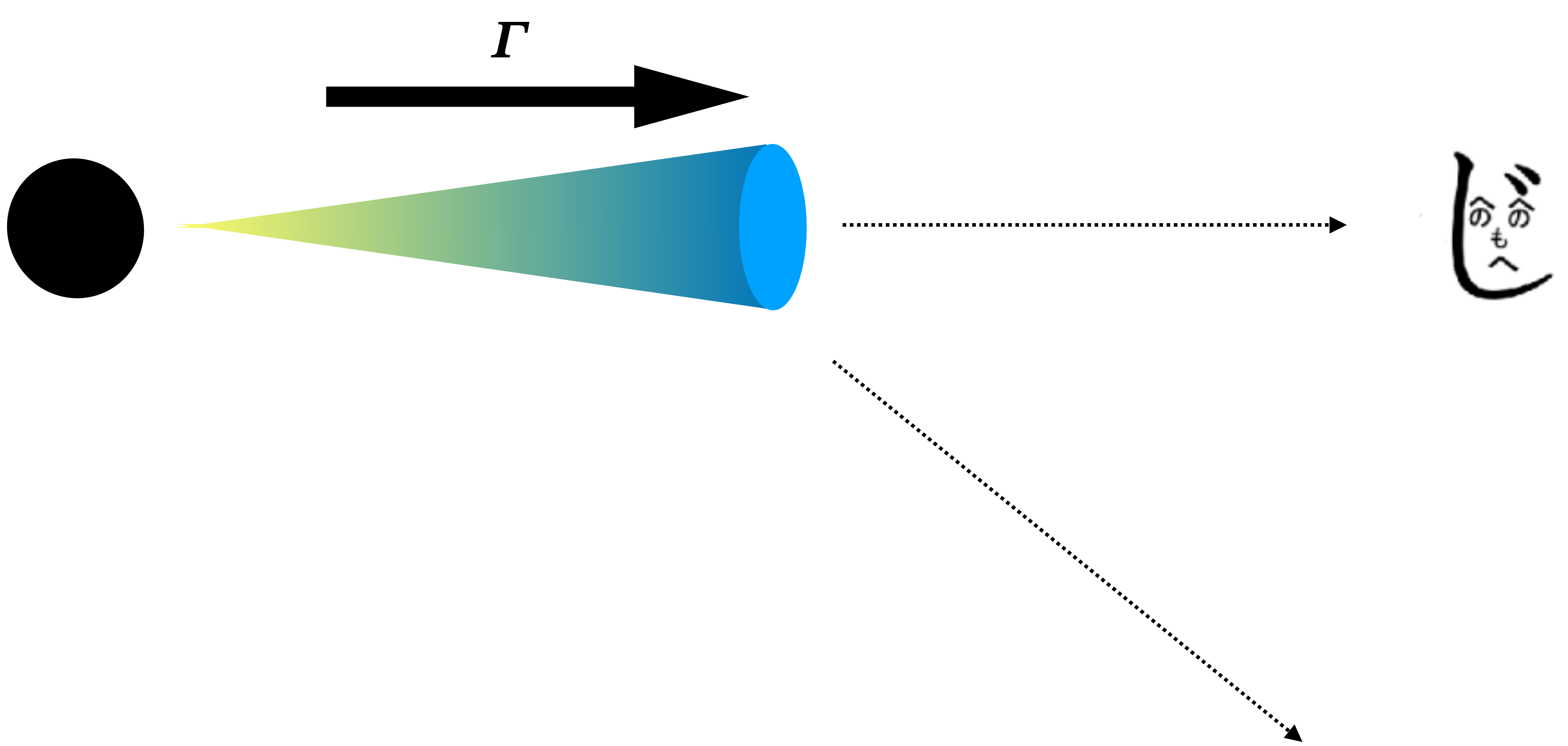
Off-Axis

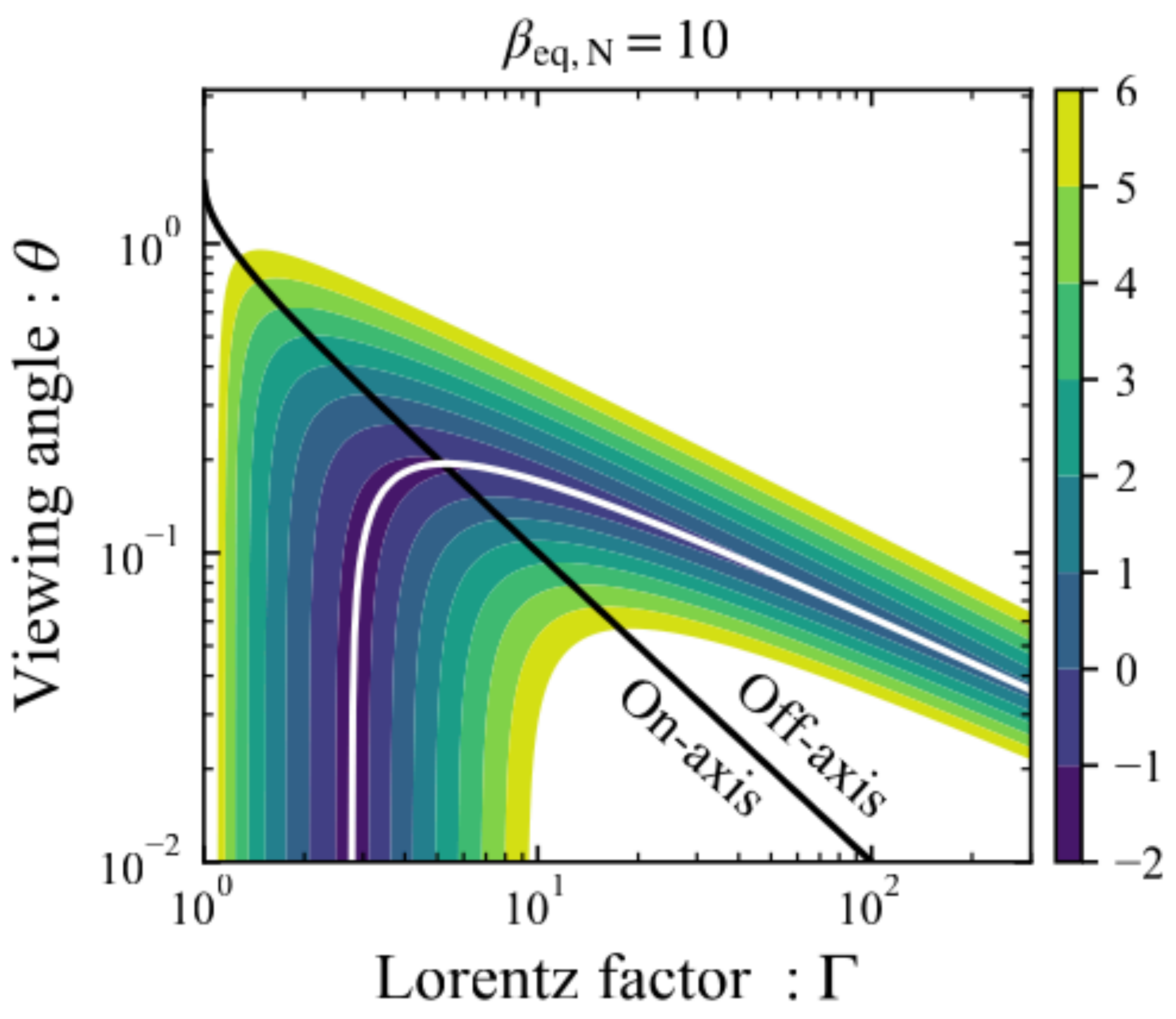


Which viewing angle is more likely?
Recall that the event is detected in optical!

Off-Axis Equipartition

$$\beta_{\mathrm{eq,N}} \equiv \frac{(1+z)R_{\mathrm{eq,N}}}{ct} \simeq 0.73 \left[\frac{F_{\mathrm{p,mJy}}^{\frac{8}{17}} d_{\mathrm{L},28}^{\frac{16}{17}} \eta^{\frac{35}{51}}}{\nu_{\mathrm{p},10}(1+z)^{\frac{8}{17}}} \left(\frac{t}{100\,\mathrm{day}}\right)^{-1}\right]$$





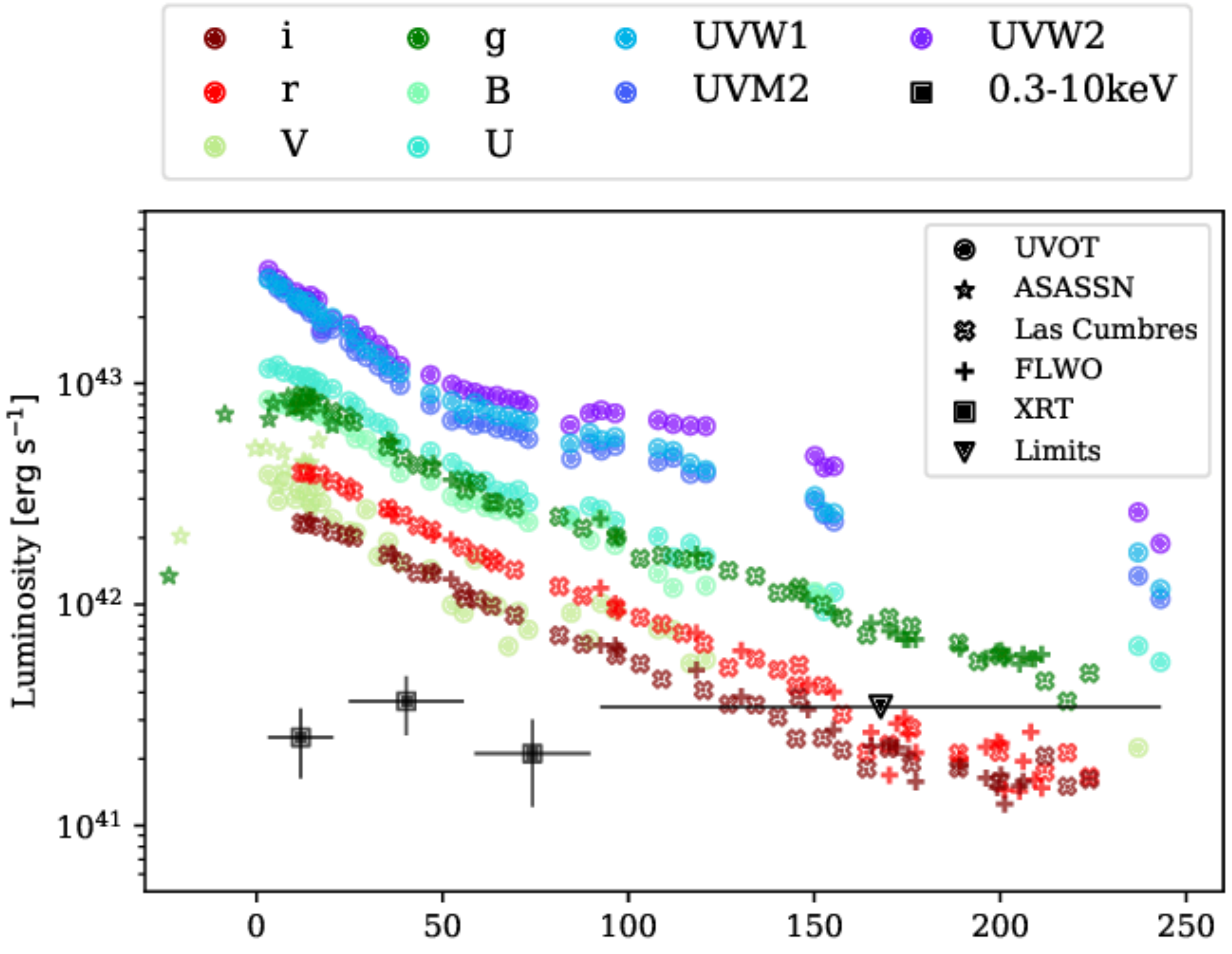
$$\delta_{\mathrm{D}} = \frac{1}{\Gamma\,(1-\beta\cos\theta)}$$

$$t = \frac{(1+z)R}{c\beta}(1-\beta\cos\theta)$$

TDEs' Delayed Radio Flare

TDE - AT 2018hyz

Optical

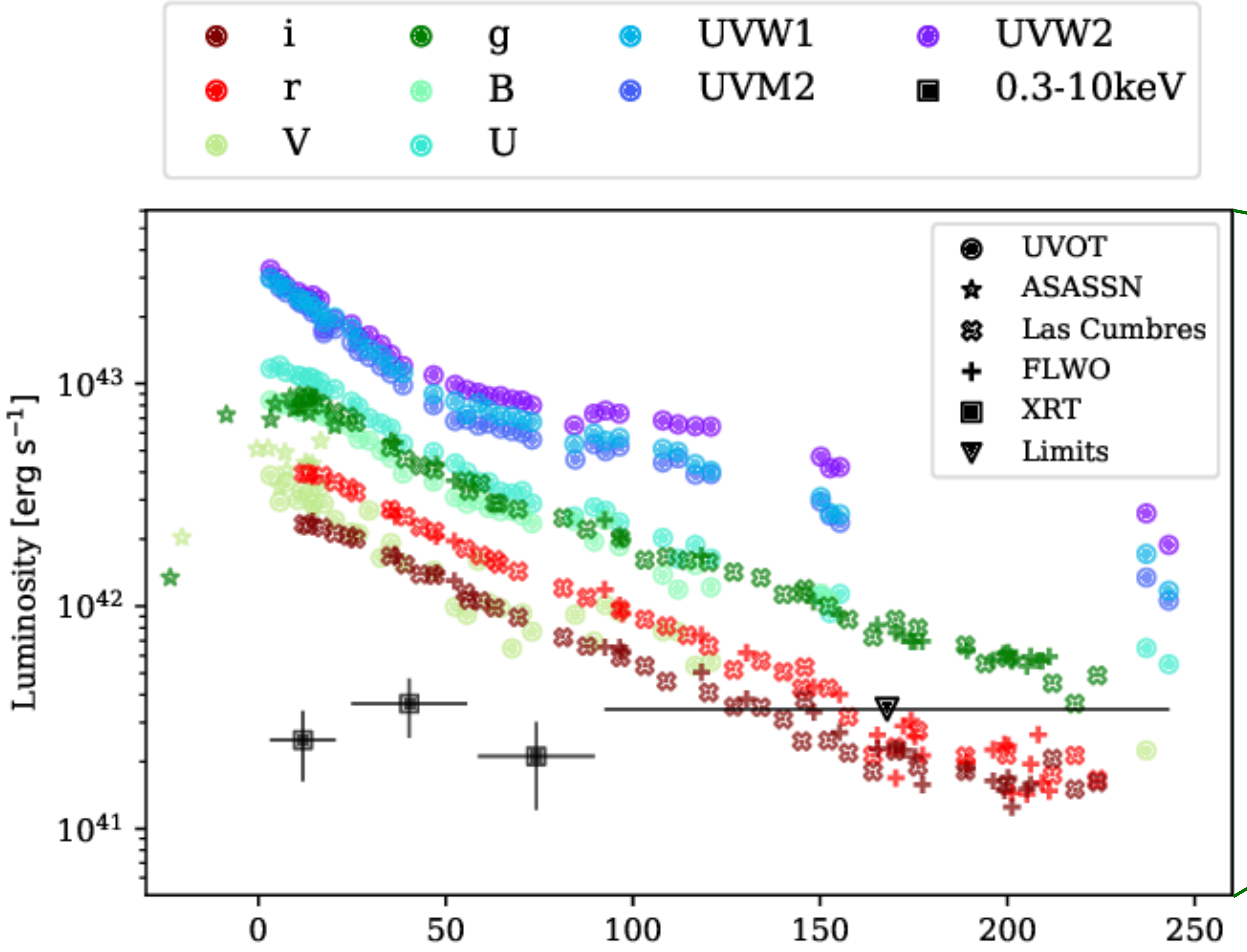


From Gomez et al., 2020

TDEs' Delayed Radio Flare

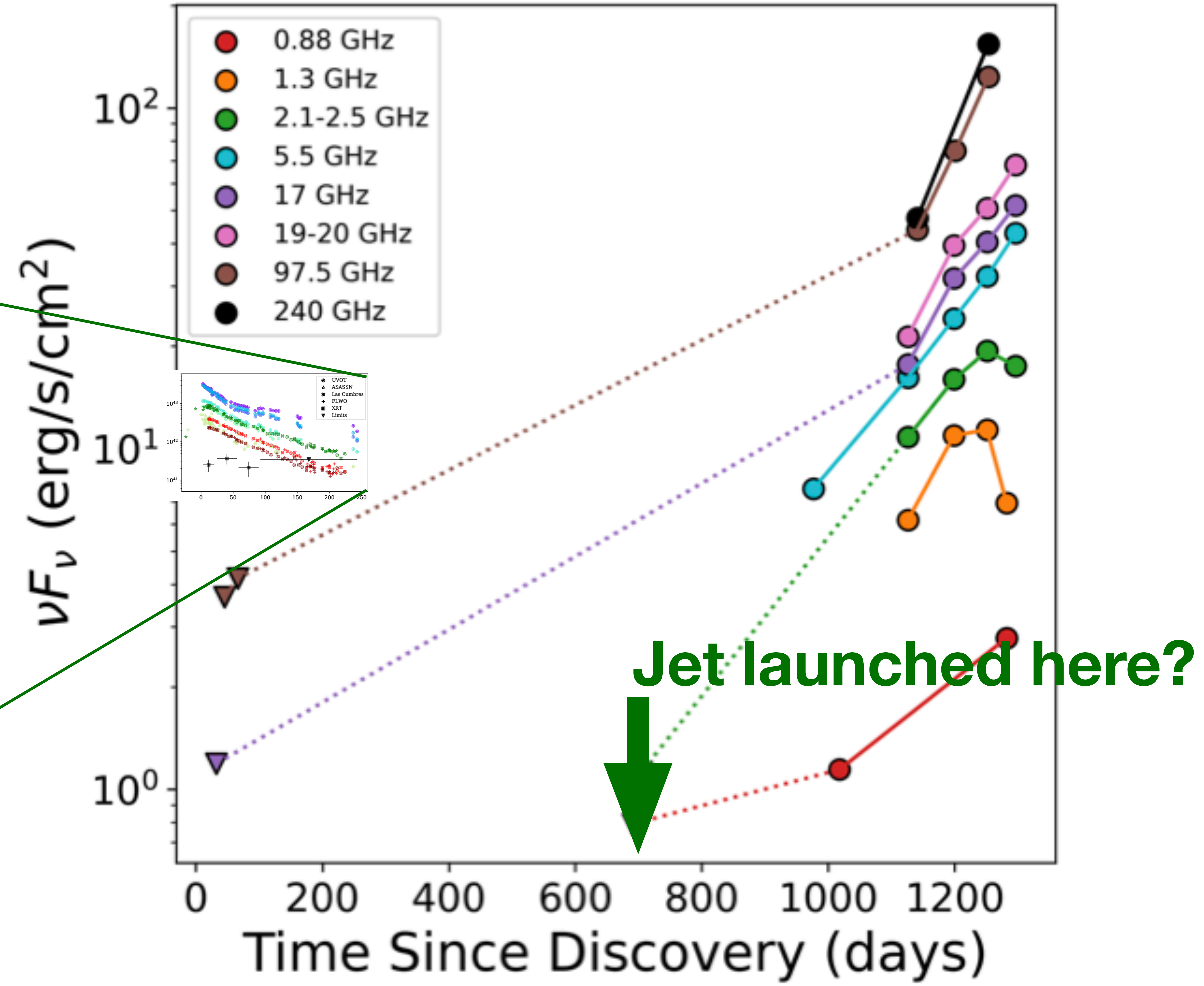
TDE - AT 2018hyz

Optical



From Gomez et al., 2020

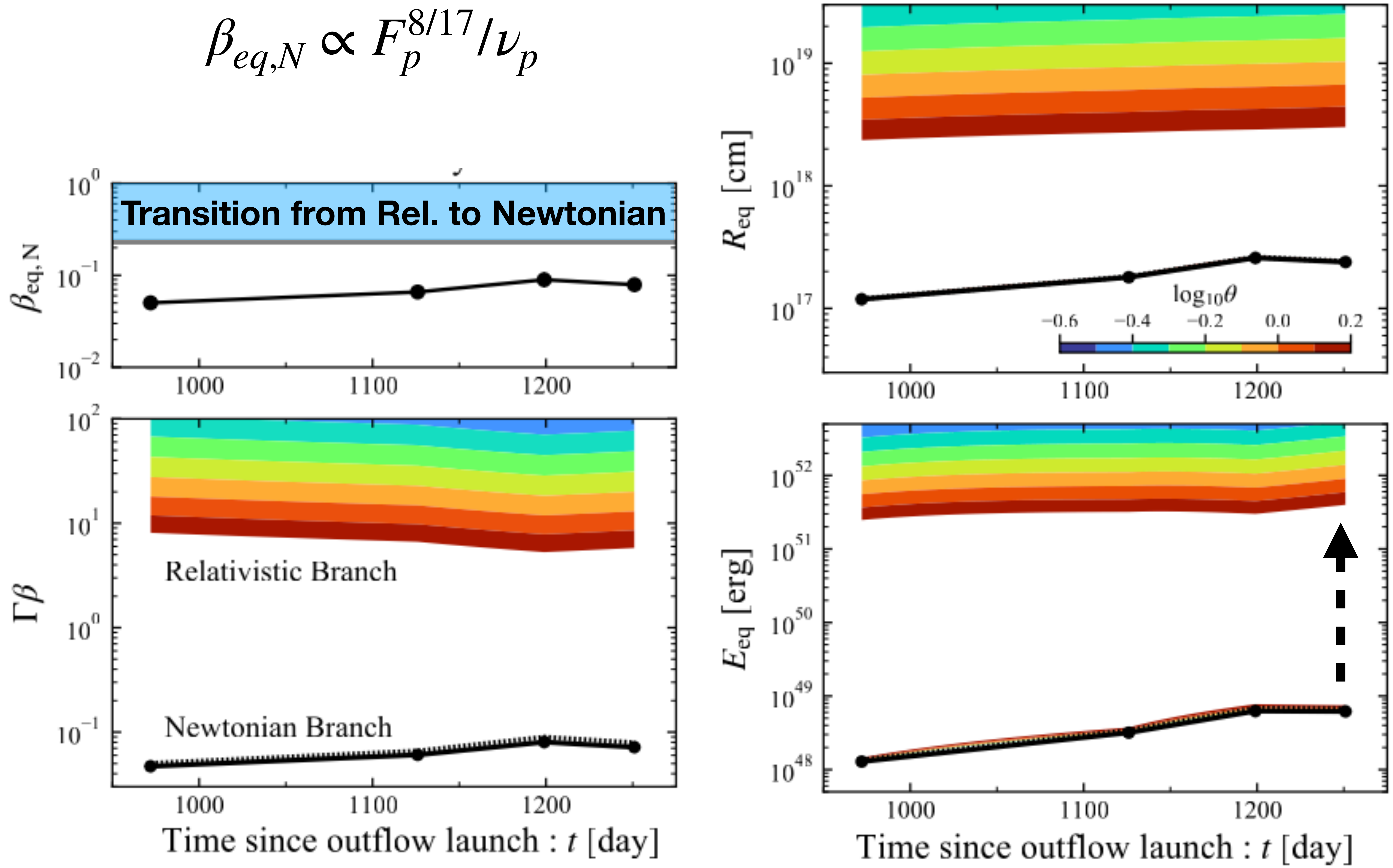
Radio



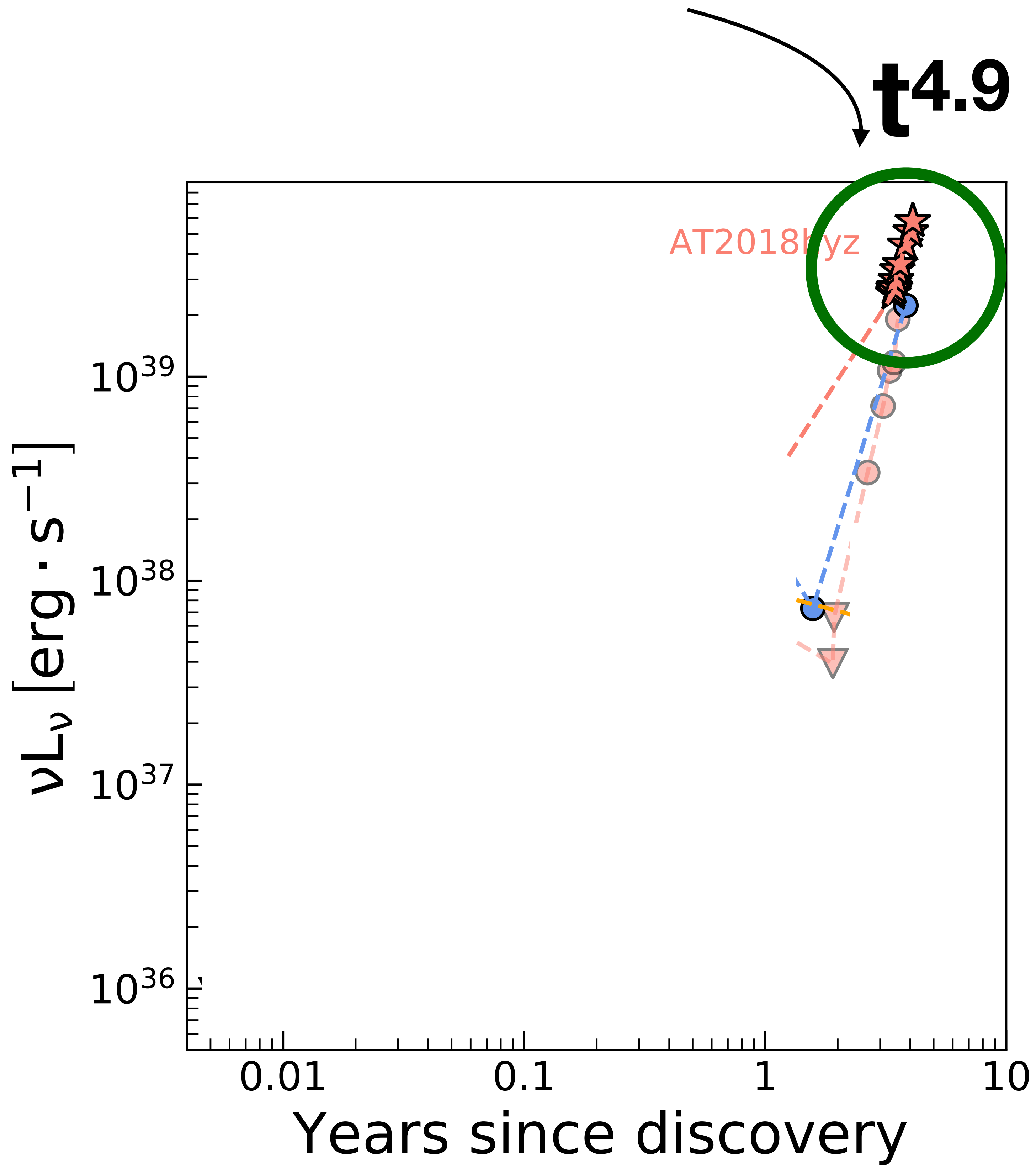
From Cendes et al., 2022

TDE AT2018hyz - an off-axis jet?

$$\beta_{eq,N} \propto F_p^{8/17}/\nu_p$$



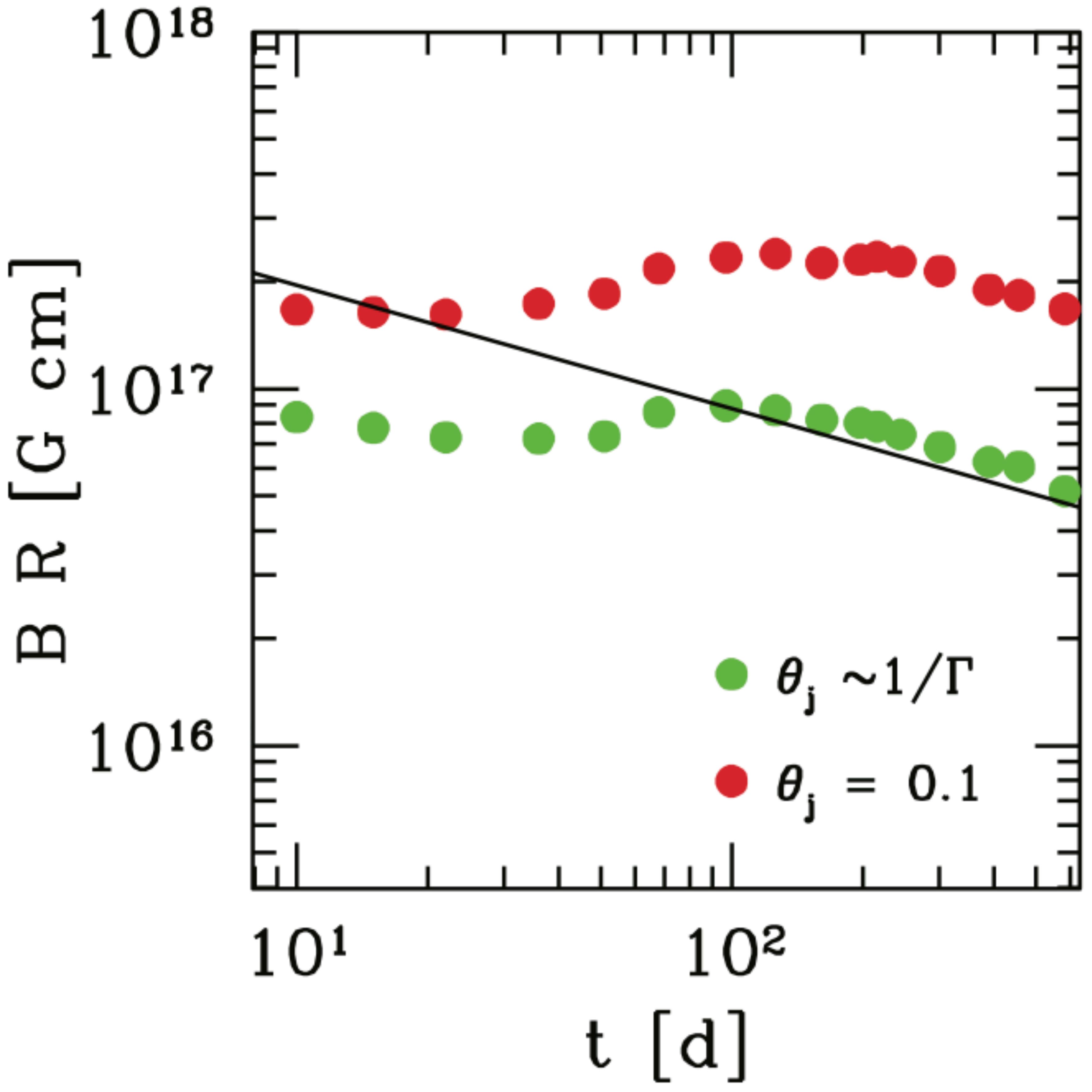
A prediction of the off-axis solution (much faster than ``regular" on-axis jet)



From Sfardi, Horesh et al., in preparation

UHECRs from TDEs?

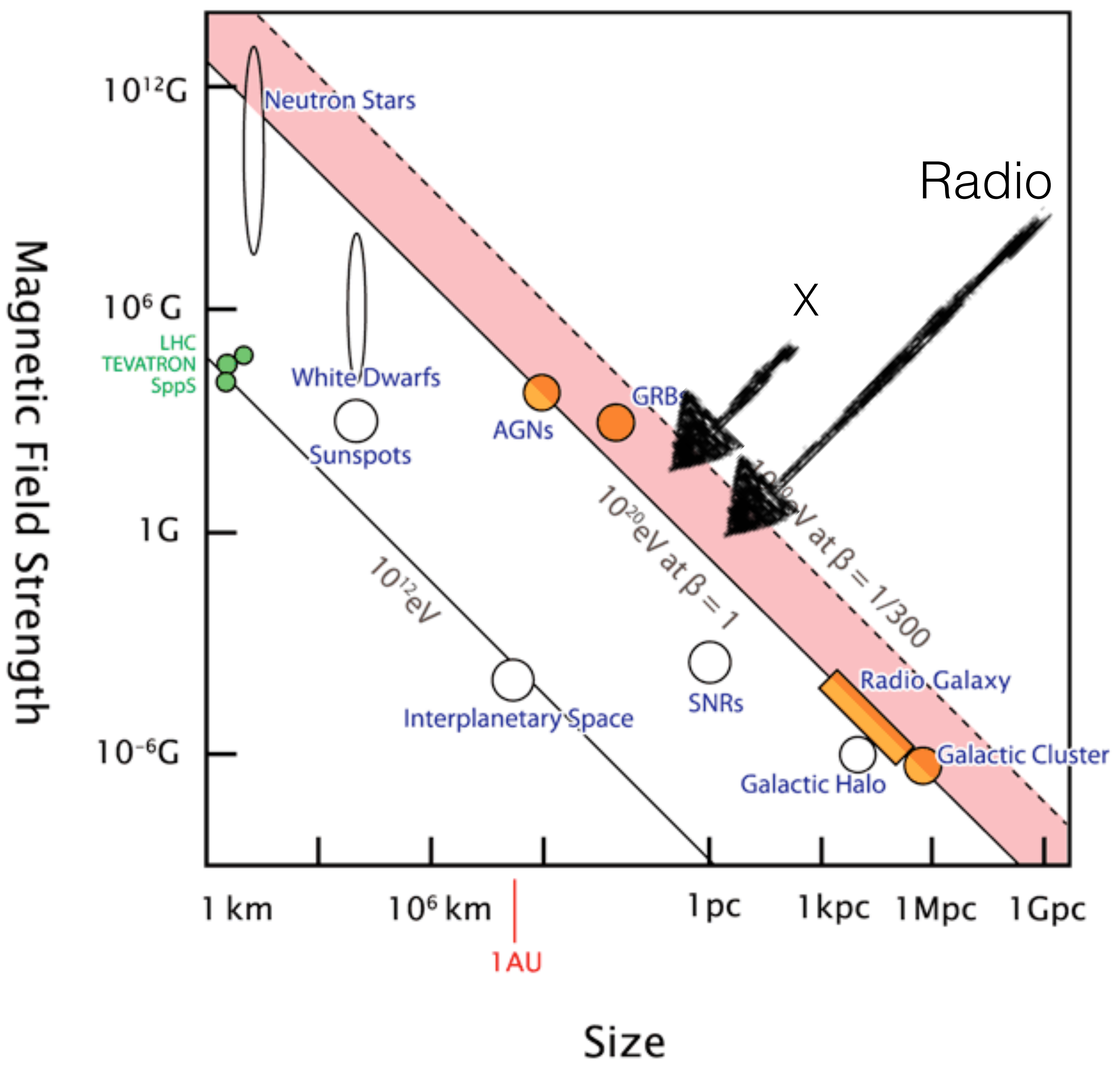
B*R in Sw J1644



From Farrar and Piran 2014

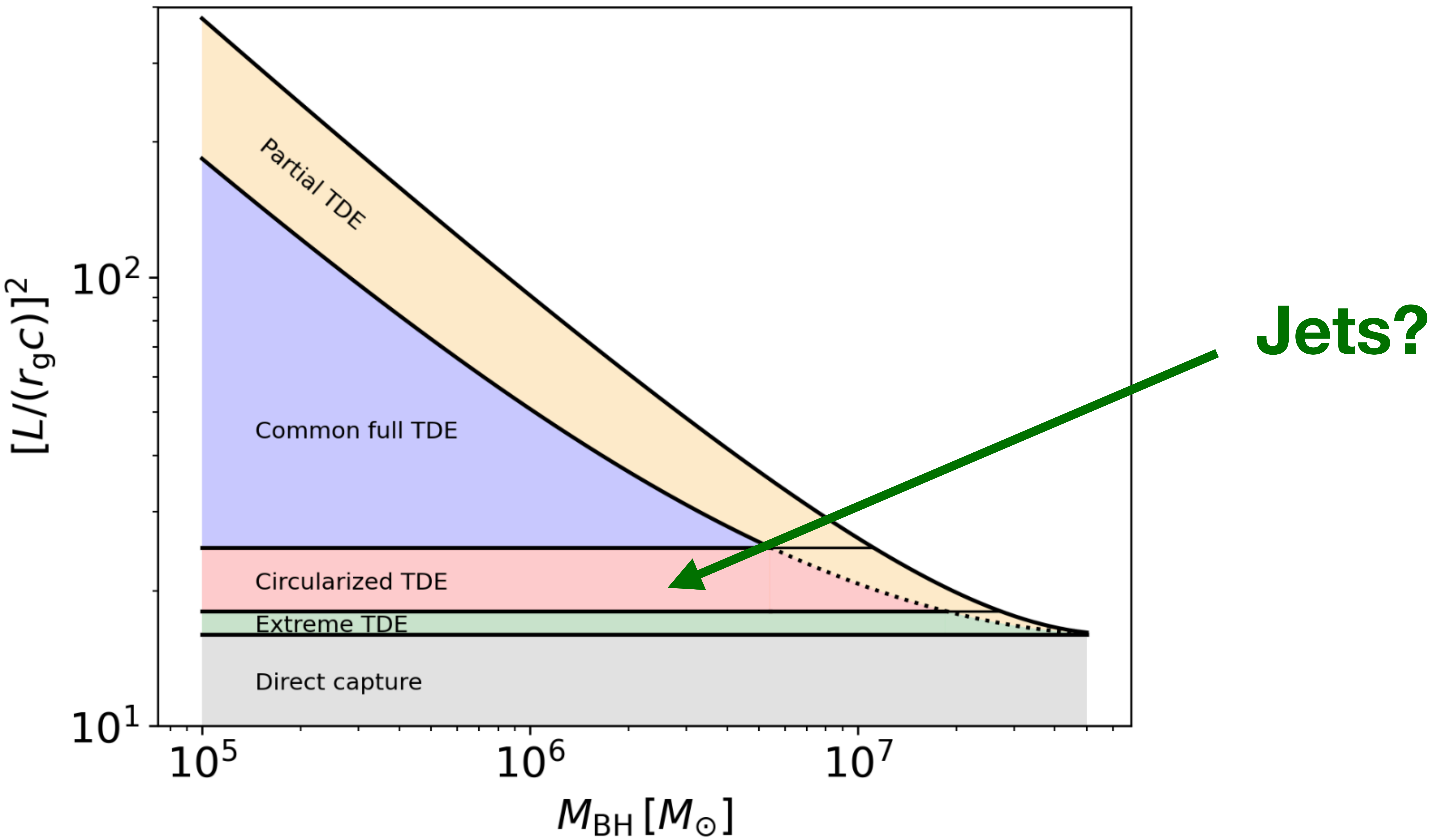
The Hillas criteria for acceleration of UHECRs to energy E

$$BR \gtrsim 3 \times 10^{17}\, \Gamma^{-1}\, Z^{-1}\, E_{20}\ \text{Gauss cm}$$



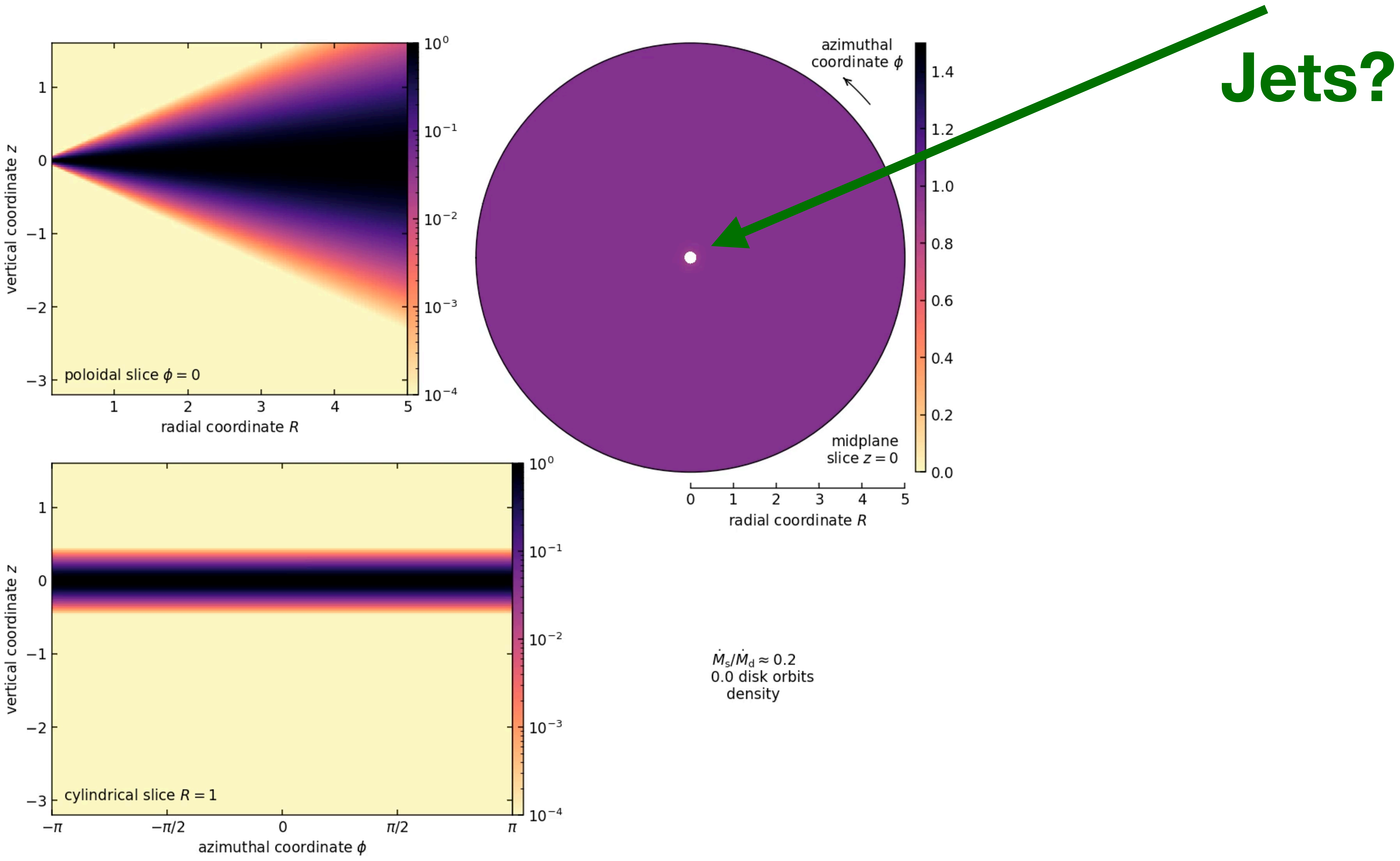
But - are there enough jetted TDEs?

Different TDEs



From Krolik, Ryu and Piran, 2020

TDEs in AGNs



Jets?
vertical coordinate z
radial coordinate R
poloidal slice ϕ = 0
cylindrical slice R = 1
azimuthal coordinate ϕ
azimuthal coordinate ϕ
midplane slice z = 0
$\dot{M}_s/\dot{M}_d \approx 0.2$
0.0 disk orbits
density

Some Conclusions and questions

- Off-axis relativistic equipartition analysis reveals a new phase space of solutions that were disregarded before.
- If Γ is not too large the off-axis solutions are energetically possible.
- $F_p^{8/17}/\nu$ determines whether the off-axis solutions are allowed.
- Late TDE radio flares may arise from off-axis jets when the jet come into sight.
- Off-axis jets must be more common.
- If TDE jets are common then TDEs could be the source of UHECRs
- **Open question**
  - **~~What powers optical TDEs~~?**
  - **Are jetted TDEs special? How and Why? A speculations - circularized TDEs or TDEs in AGNs**
  - **What is the source of B field needed for BZ of TDE jets?**
  - **How common are jetted TDEs?**
  - **Are TDEs a major source of UHECRs?**