Ballistic vs Diffusive Propagation in AGN jets

SFB kickoff meeting 2022

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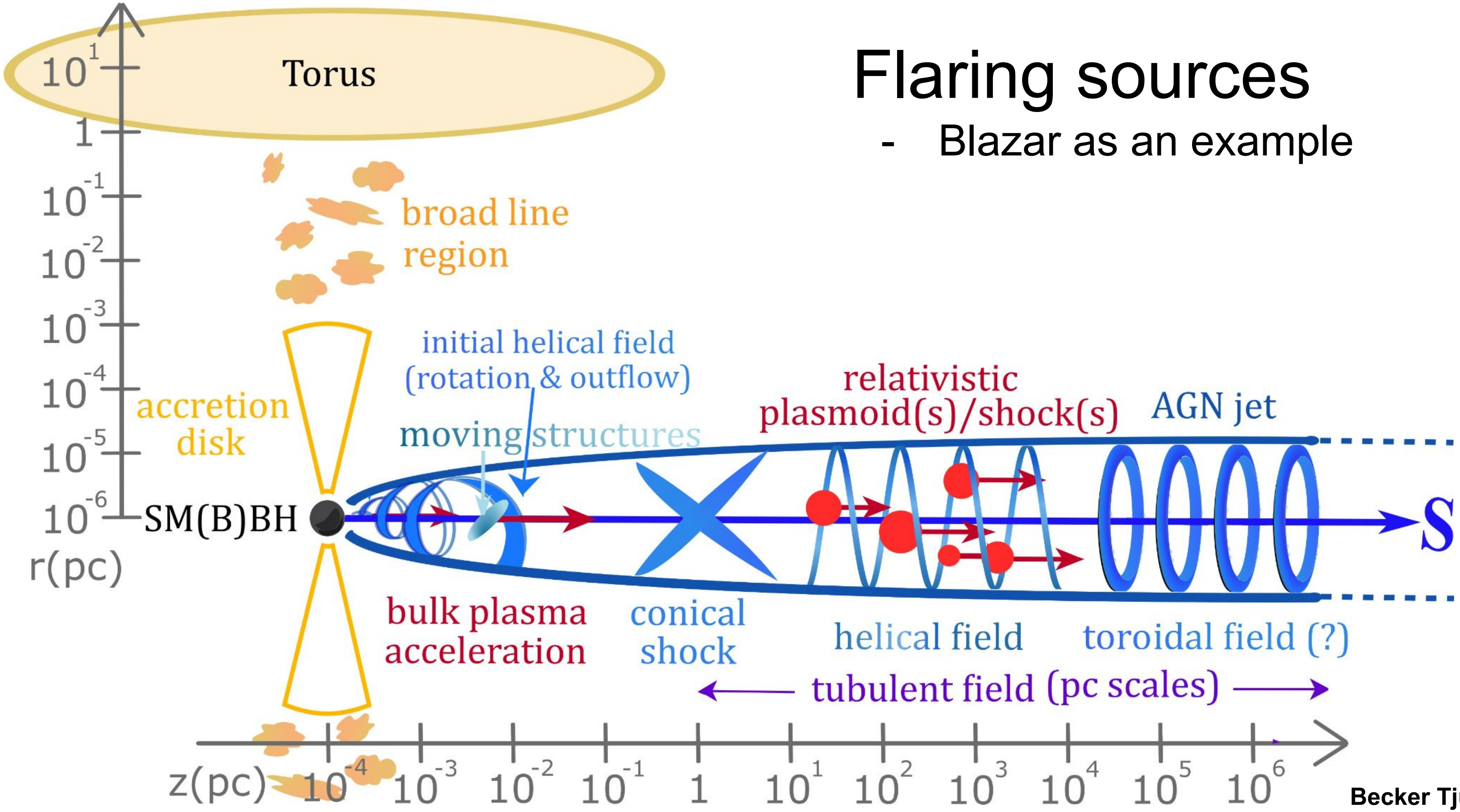
DFG Deutsche Forschungsgemeinschaft
RUB
SFB 1491

Flaring sources

- Blazar as an example



Becker Tjus+ (2022)

Ballistic vs diffusive transport

$$\frac{\partial n}{\partial t} = \underbrace{\nabla \cdot (\hat{\kappa} \nabla n)}_{\text{Spatial diffusion}} - \underbrace{\vec{u} \cdot \nabla n}_{\text{Advection}} + \underbrace{\frac{1}{p^2} \frac{\partial}{\partial p} \left(p^2 \kappa_{pp} \frac{\partial n}{\partial p} \right)}_{\text{Momentum diffusion}} + \underbrace{\frac{p}{3} (\nabla \cdot \vec{u}) \frac{\partial n}{\partial p}}_{\text{Ad. energy changes}} + \underbrace{S}_{\text{Source}}$$

Leaky-Box Model

neglect:

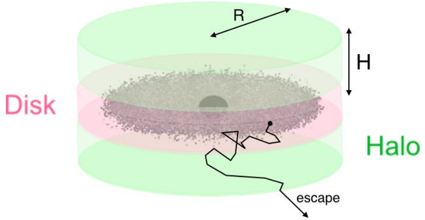
- Advection
- Mom. diff.
- Ad. *E* changes

& **steady-state:**

$$\frac{\partial n}{\partial t} = 0$$

escape term:

$$\nabla \cdot (\hat{\kappa} \nabla n) = -\frac{n}{\tau_{\text{esc}}}$$



https://w3.iihe.ac.be/~aguilar/PHYS-467/PA3.html

$$n(E) = \tau_{\text{esc}}(E) \cdot S(E)$$

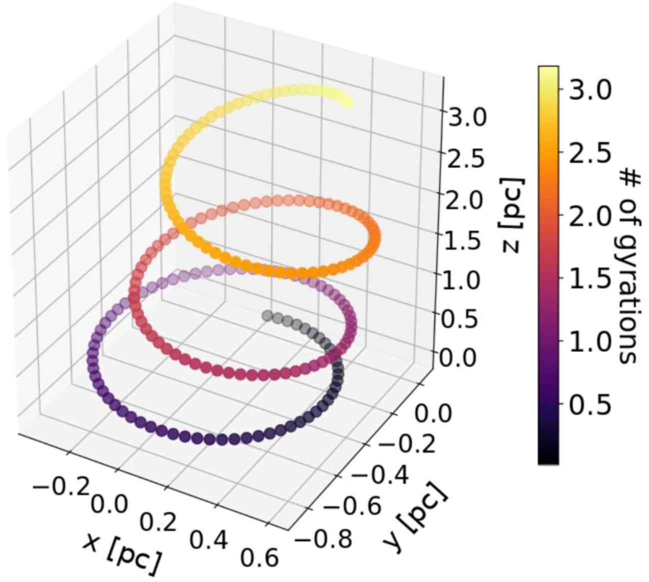
$\tau_{\text{esc, diff}} \lesssim \frac{d_{\text{esc}}^2}{2\kappa}$

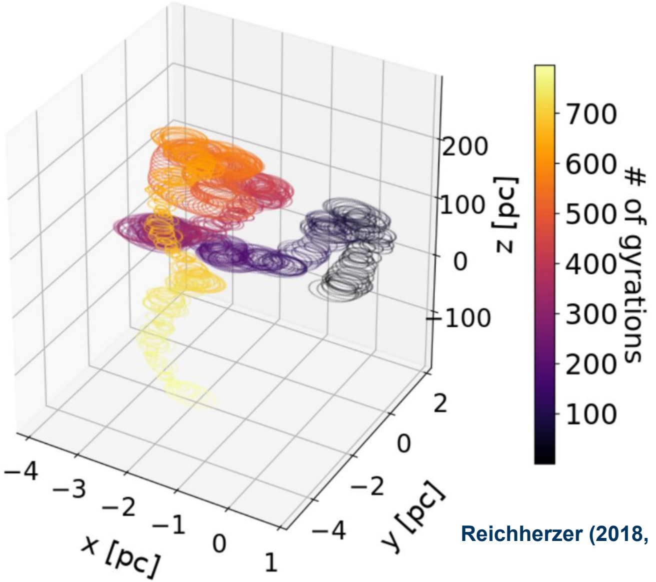
diffusive → $\propto E^{-\delta-\alpha}$

ballistic → $\propto E^{-\alpha}$

$\tau_{\text{esc, ball}} = \frac{d_{\text{esc}}}{c}$

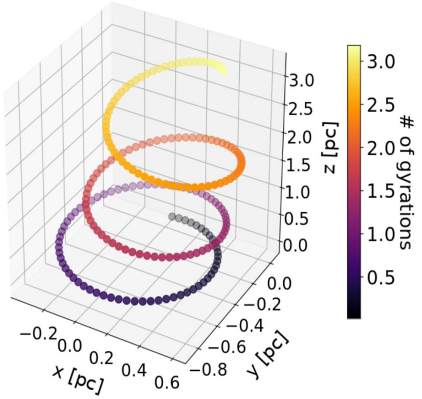
Diffusive vs. ballistic transport

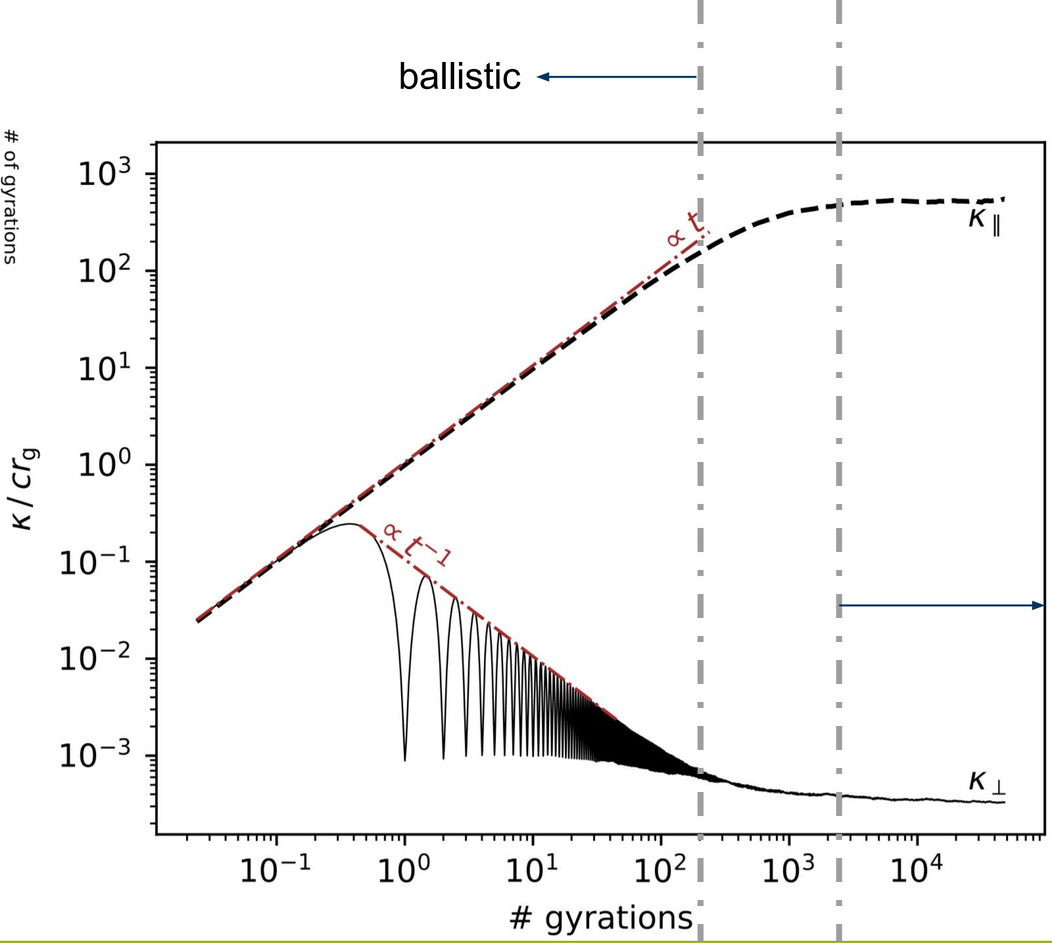


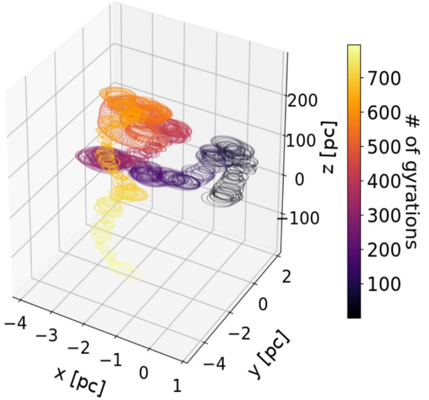


Reichherzer (2018, Master thesis)

→ transport equation describes diffusive transport at **large time scales**: $$\frac{\partial f}{\partial t} = \sum_i \kappa_i \frac{\partial^2 f}{\partial x_i^2}$$



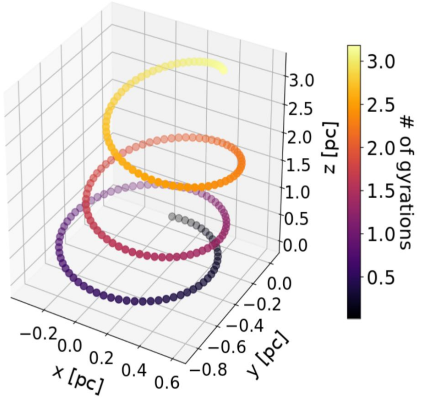




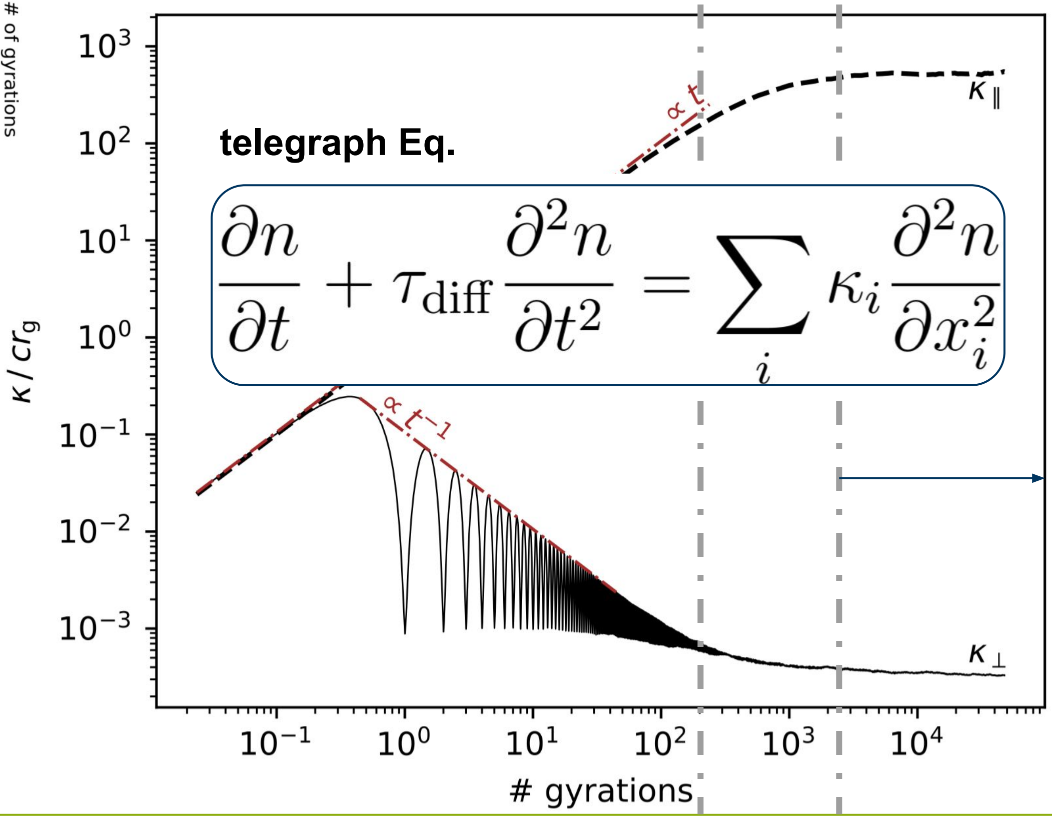
$$\kappa = \frac{\langle (\Delta x)^2 \rangle}{2t}$$

$$\frac{\partial n}{\partial t} = \sum_i \kappa_i \frac{\partial^2 n}{\partial x_i^2}$$

diffusion Eq.



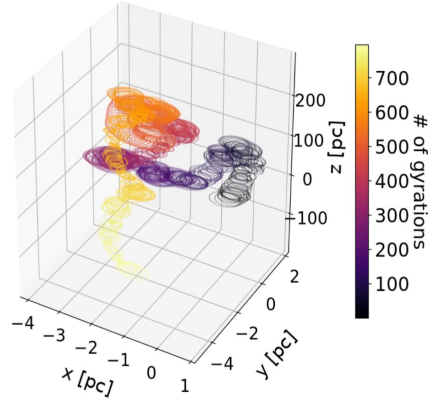
ballistic



telegraph Eq.

$$\frac{\partial n}{\partial t} + \tau_{\mathrm{diff}} \frac{\partial^2 n}{\partial t^2} = \sum_i \kappa_i \frac{\partial^2 n}{\partial x_i^2}$$

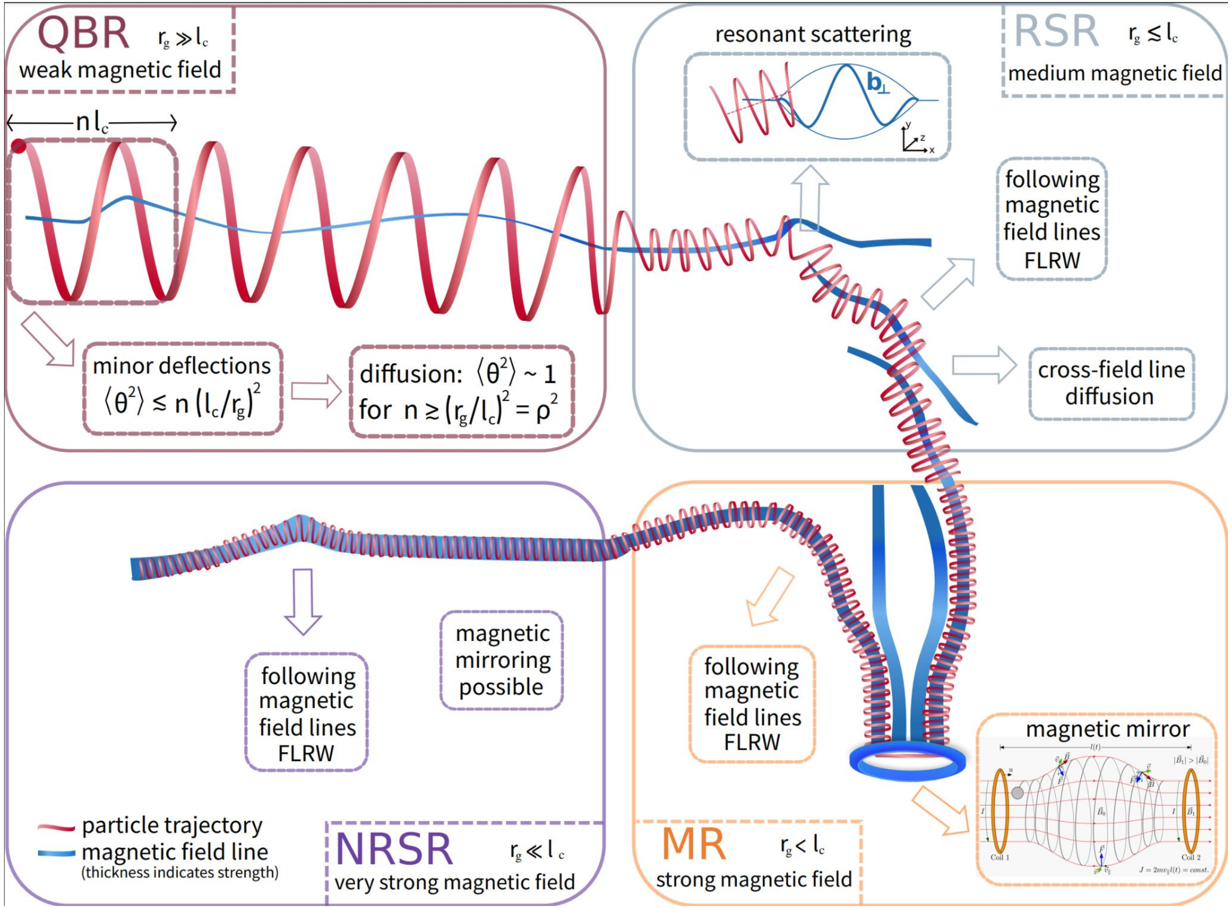
diffusive



$$\frac{\partial n}{\partial t} = \sum_i \kappa_i \frac{\partial^2 n}{\partial x_i^2}$$

diffusion Eq.

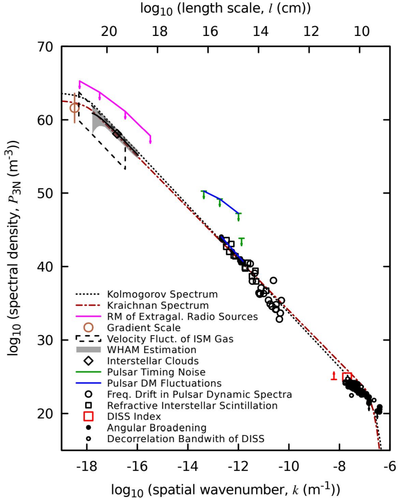
Energy transport regimes

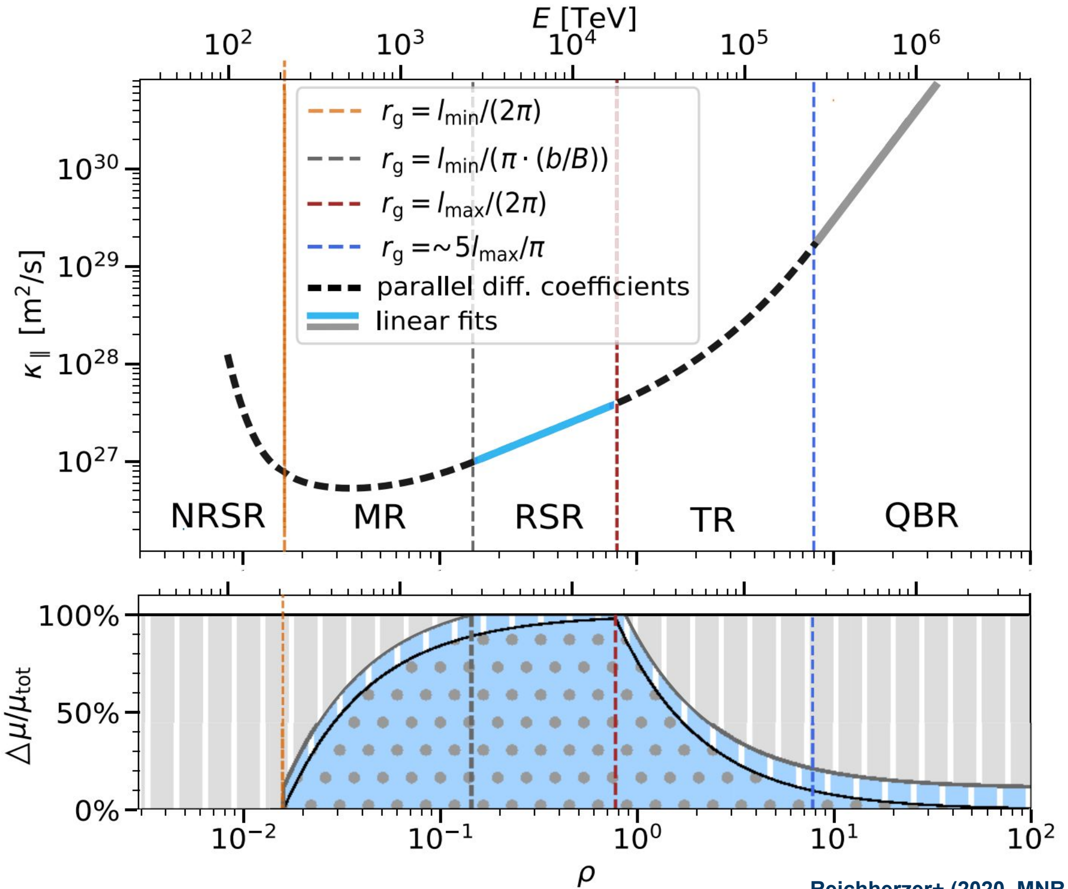


Reichherzer+ (2021, SN Applied Sciences)

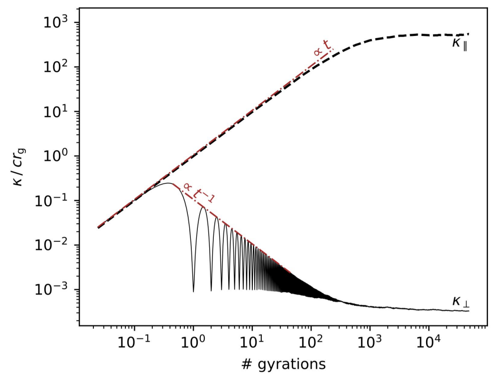
Energy transport regimes

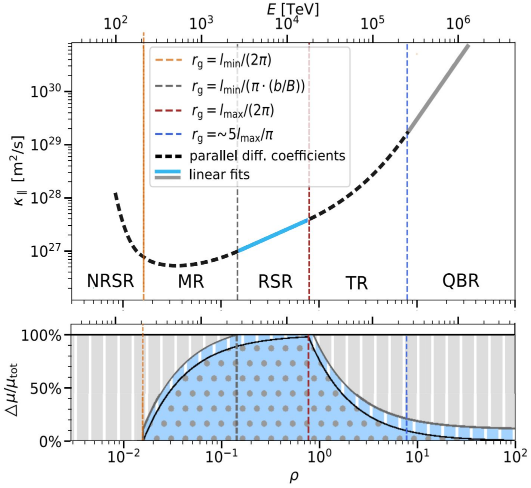
gyro-resonance criterium: $|\mu| = \dfrac{l}{2\pi r_g}$





Reichherzer+ (2020, MNRAS)

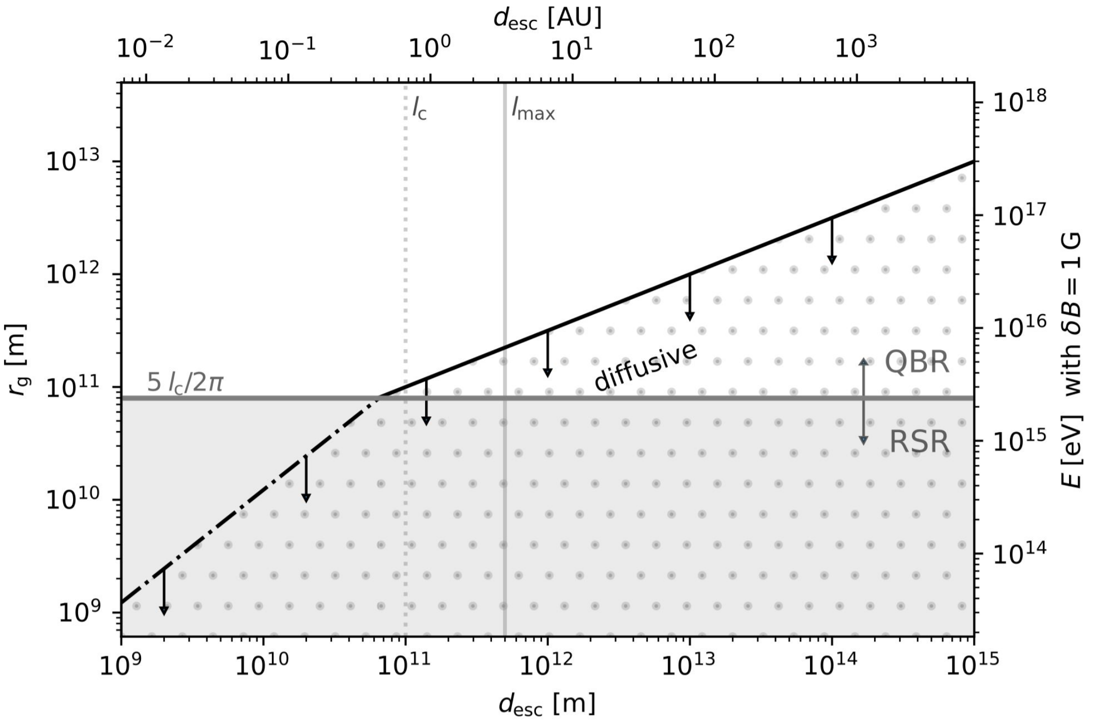




$$r_g \lesssim \begin{cases} \sqrt{3}\, d_{esc}/\sqrt{2} \\ \sqrt{d_{esc}\, l_c} \end{cases}$$

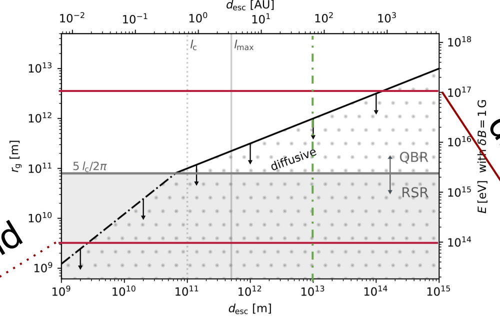
$$\text{RSR} : r_g \lesssim 5 l_c / 2\pi$$

$$\text{QBR} : r_g \gg 5 l_c / 2\pi$$



Reichherzer (2022, PhD)

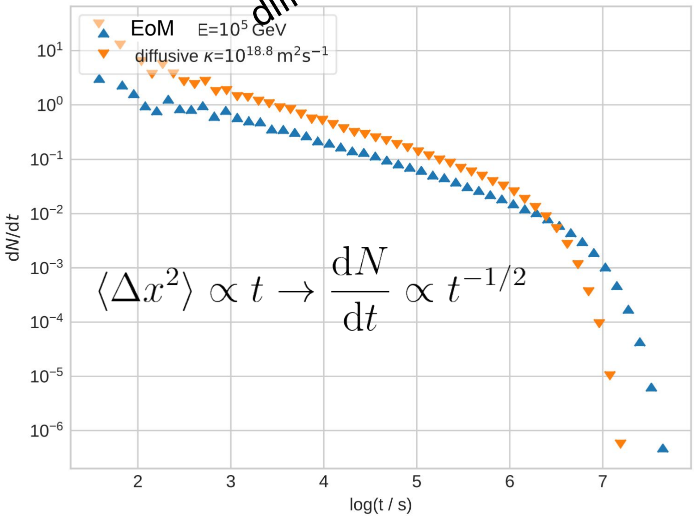
Influence on CR escape flux

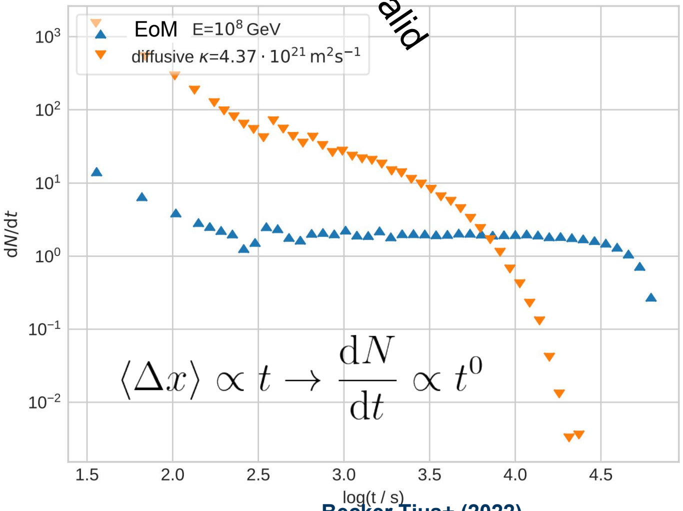


PR (2022, PhD)

diffusive approach valid

diffusive approach invalid

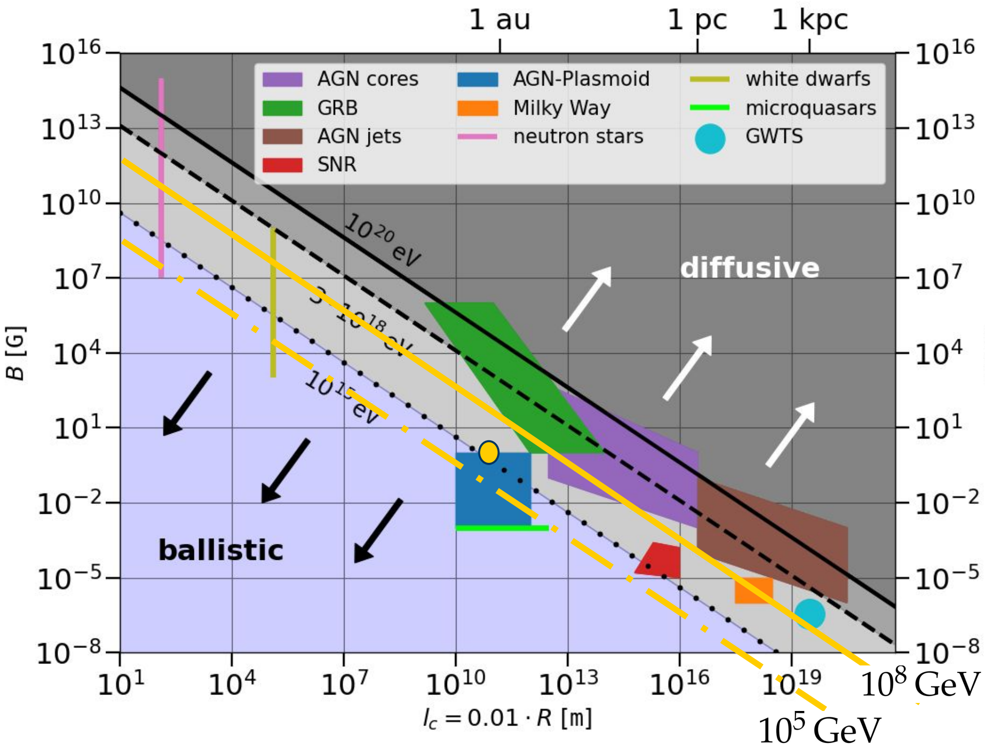




Becker Tjus+ (2022)

Marcel Schroller

Hillas-Like Overview Plot



Ilja Jaroschewski

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Escape times

$$\frac{\partial n}{\partial t} = \underbrace{\nabla \cdot (\hat{\kappa} \nabla n)}_{\text{Spatial diffusion}} - \underbrace{\vec{u} \cdot \nabla n}_{\text{Advection}} + \underbrace{\frac{1}{p^2}\frac{\partial}{\partial p}\left(p^2 \kappa_{pp} \frac{\partial n}{\partial p}\right)}_{\text{Momentum diffusion}} + \underbrace{\frac{p}{3}(\nabla \cdot \vec{u})\frac{\partial n}{\partial p}}_{\text{Ad. energy changes}} + \underbrace{S}_{\text{Source}}$$

escape term:

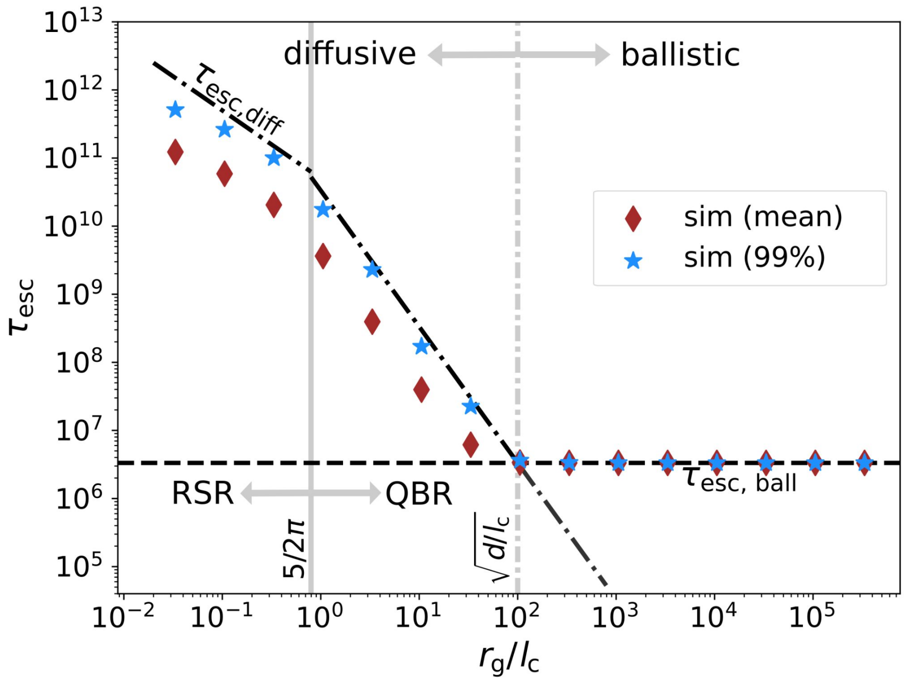
$$\nabla \cdot (\hat{\kappa} \nabla n) = -\frac{n}{\tau_{\rm esc}}$$

$$\text{diffusive(RSR, Bohm)}: r_{\rm g} \lesssim \sqrt{d_{\rm esc}\, l_{\rm c}}$$

$$\text{diffusive(QBR)}: r_{\rm g} \lesssim \sqrt{d_{\rm esc}\, l_{\rm c}}$$

$$\text{ballistic}: r_{\rm g} \gtrsim \sqrt{d_{\rm esc}\, l_{\rm c}}$$

$$\tau_{\rm esc} \approx \begin{cases} 3\, d_{\rm esc}^2 / (2\, c\, r_{\rm g}) \\ d_{\rm esc}^2\, l_{\rm c} / (2\, c\, r_{\rm g}^2) \\ d_{\rm esc}/c \end{cases}$$



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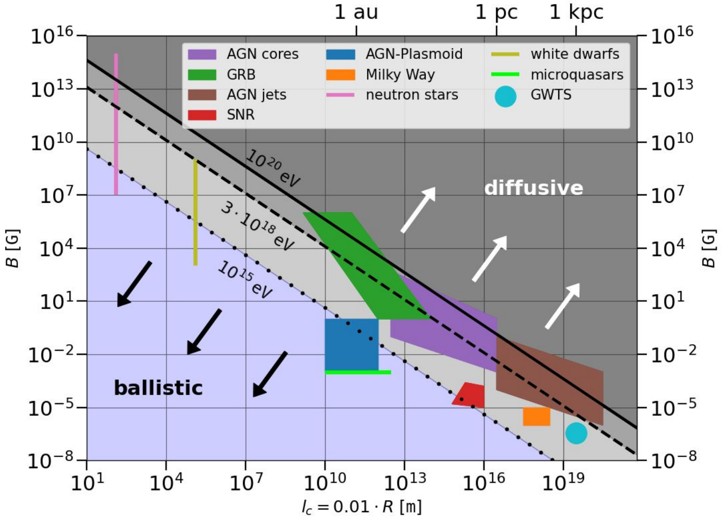
Ballistic vs Diffusive Propagation in AGN jets

- **Diffusion influences**
  - Time characteristics & escape times from sources (→ lightcurves)
  - CR and secondary spectra
- **When is CR-transport diffusive?**
  - ~ Mean free path
  - Particles need time to become diffusive
  - Hillas-like overview plot
- **Steady-state diffusion**
  - Energy scaling influences MM spectra
- **Contribute to understanding of**
  - Multimessenger signatures of flaring (extragalactic) sources



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