Particle Acceleration in Radio galaxies with flickering jets

GeV Electrons to UHECRs

Image: Meerkat observations of Fornax A (Maccagni+ 2020)

June 14-18, 2021

EXTRA-GALACTIC JETS AT ALL SCALES

LAUNCHING, PROPAGATION, TERMINATION

ioa

UNIVERSITY OF CAMBRIDGE

Herchel Smith Fund

James Matthews

Institute of Astronomy, University of Cambridge

Thanks to:
Andrew Taylor (DESY Zeuthen), Tony Bell, Katherine Blundell (Oxford), Anabella Araudo (Czech Academy of Sciences), Henry Whitehead, Chris Reynolds, Paul Hewett (Cambridge)

Take-home message

Accretion is *always* variable - jets should be too, and this is interesting for particle acceleration.

Powerful episodes can dominate observational appearance.

UHECRs can come from local, flickering sources.

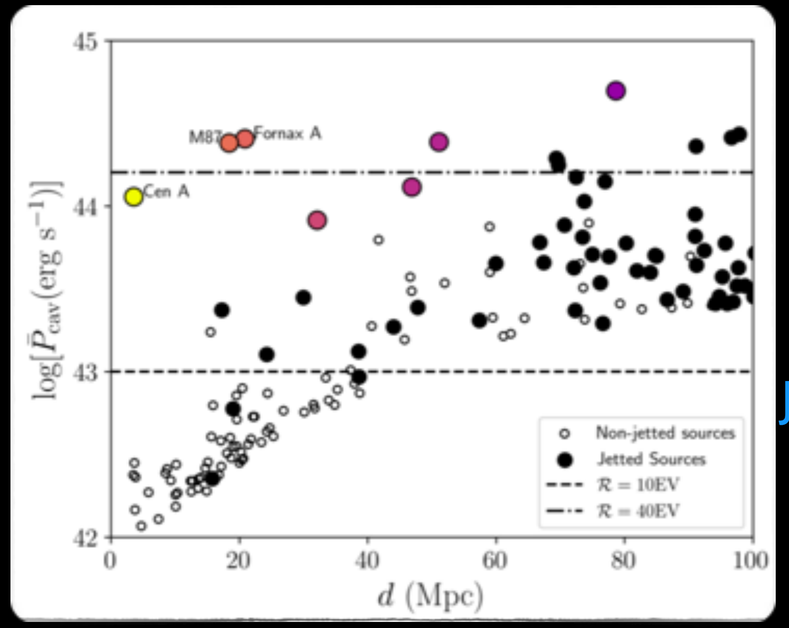
Motivation 1: UHECR sources must be local and powerful

- Origin of UHECRs an open question
- We need local UHECR sources within ~30 Mpc (Eichmann 2019, Guedes-Lang+ 2021)
  - Correlation with Cen A (e.g. PAO 2017, Bister 2021), possible association with Fornax A (JM+ 2018)
- Power requirement derived from Hillas (1984) energy:

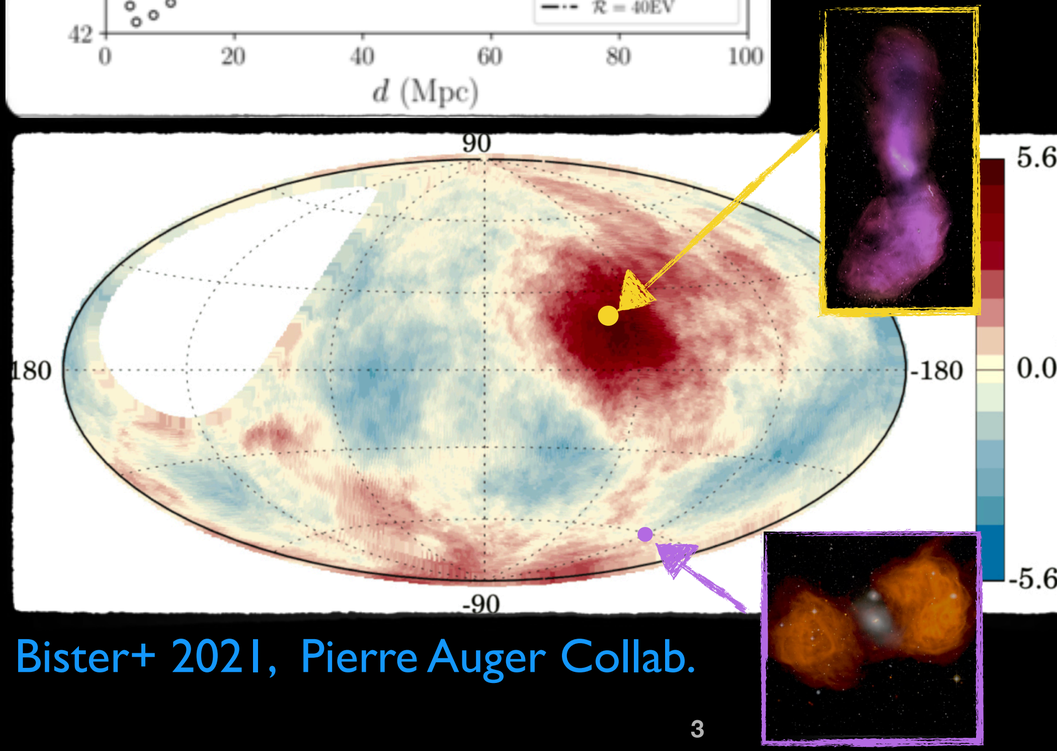
$$Q_k \gtrsim 10^{44} \left(\frac{E/Z}{10^{19}\mathrm{eV}}\right)^2 \left(\frac{\eta_B}{0.1}\right)^{-1} \beta^{-1} \ \mathrm{erg\ s^{-1}}$$

- Rules out puny FRIs - need local powerful radio galaxies
  - *but where are they??*

Aside: Starburst winds can be ruled out based on this.



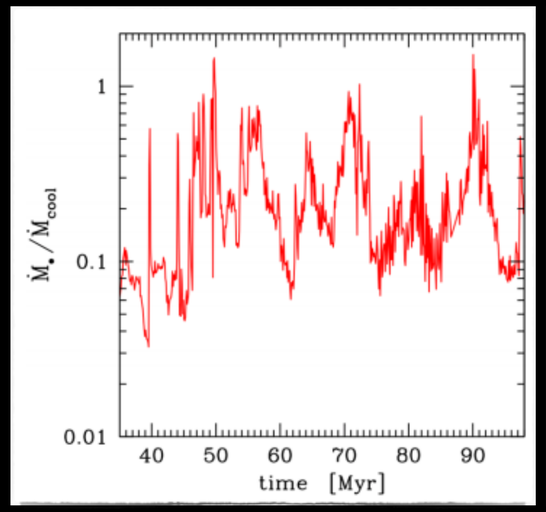
JM+ 2018)

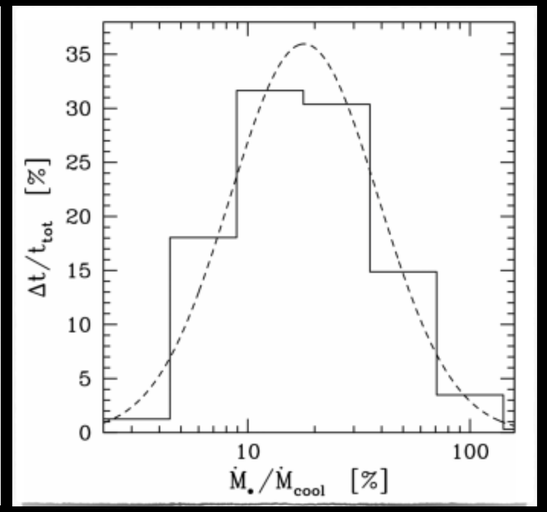


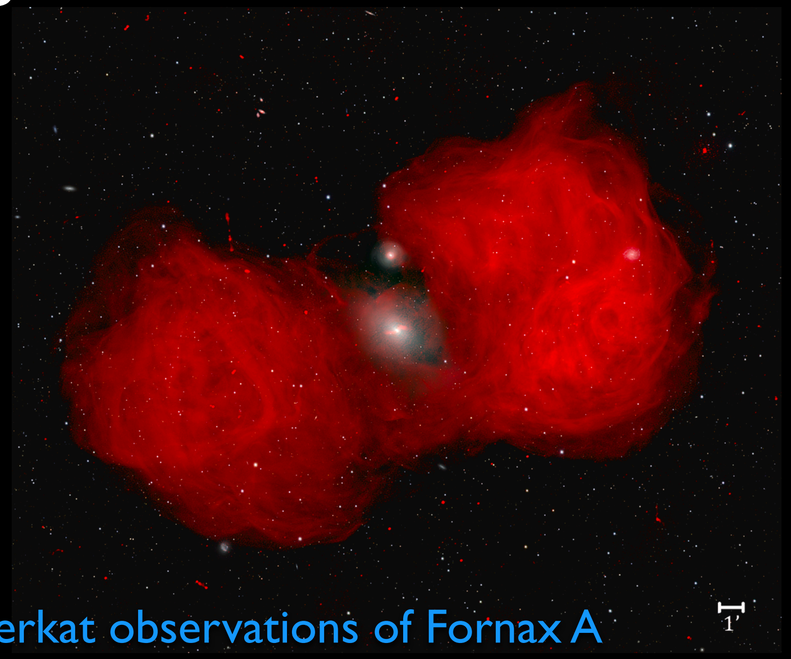
Bister+ 2021, Pierre Auger Collab.

Motivation II: Complex, variable activity in radio galaxies

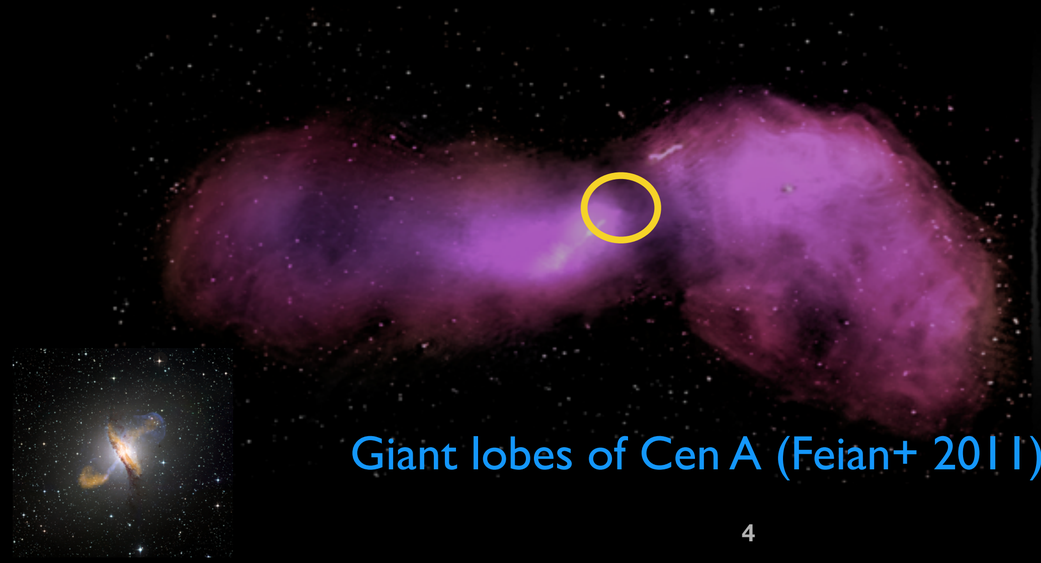
- Very same sources with UHECR associations
- Next generation radio telescopes reveal complex morphologies
- Flickering (pink noise) variability expected from fuelling simulations (e.g. Gaspari 2016, Yang & Reynolds 2016)







Meerkat observations of Fornax A (Maccagni+ 2020)

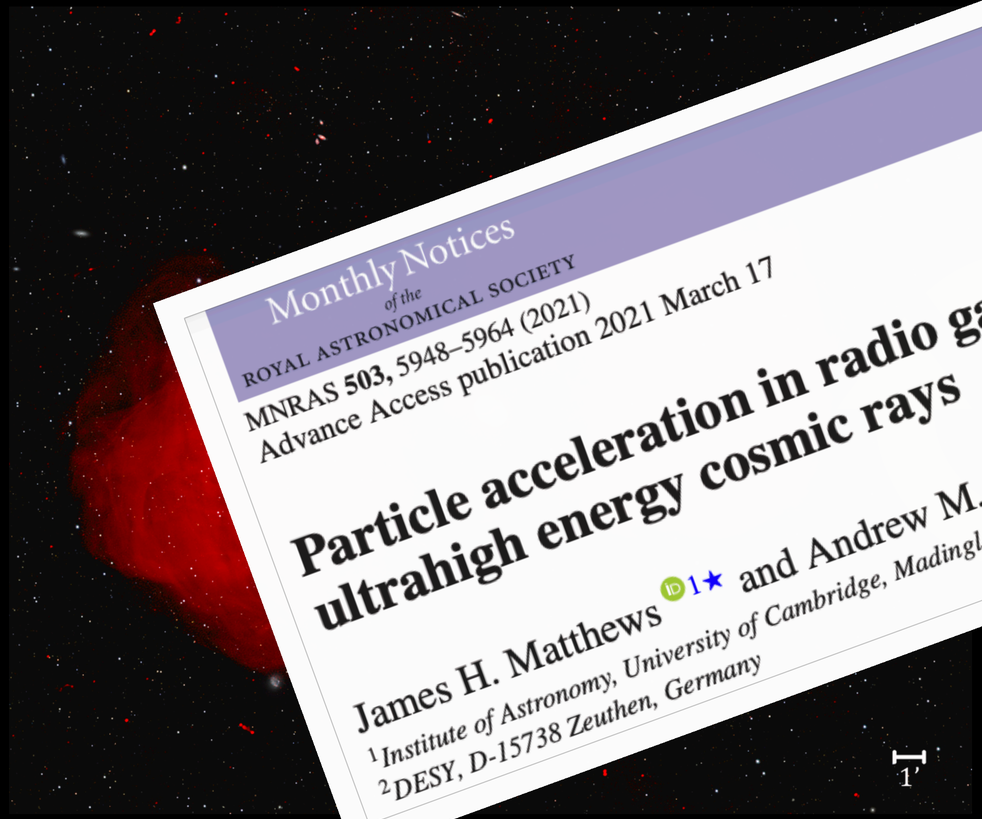


Giant lobes of Cen A (Feian+ 2011)

JM & Taylor 2021

This Work

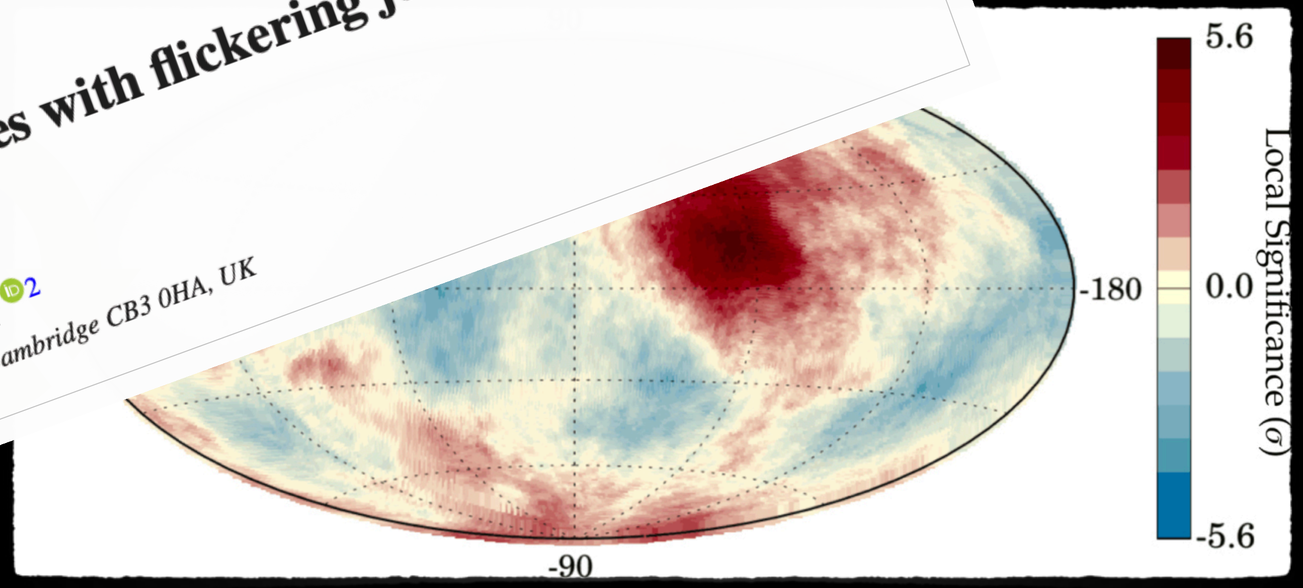
- Include time dependence, and link synchrotron electrons (GeV) to UHECR ion
- Key Q: How does jet variability affect the particle populations re galaxy lobes?



Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS 503, 5948–5964 (2021)
Advance Access publication 2021 March 17
doi:10.1093/mnras/stab758

Particle acceleration in radio galaxies with flickering jets: GeV electrons to ultrahigh energy cosmic rays

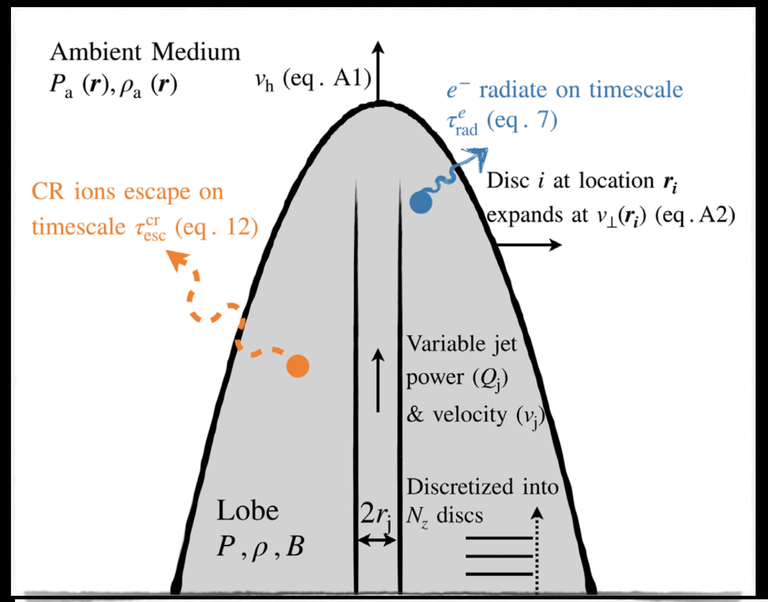
James H. Matthews [1]★ and Andrew M. Taylor [2]
[1]Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge CB3 0HA, UK
[2]DESY, D-15738 Zeuthen, Germany

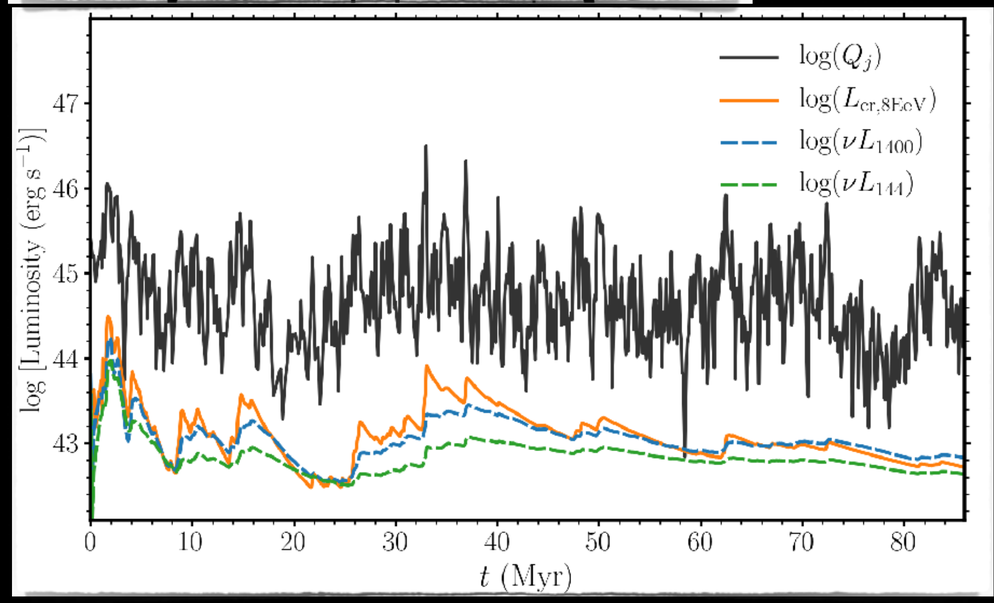


Particle Acceleration in Flickering Jets

- We developed a parameterised model of jet propagation for an input variable jet power
  - Coupled to simple particle module with source term and losses
- Can predict multi-messenger signatures over time for a "pink noise" jet
- Synchrotron and UHECR luminosities track jet power with a response set by cooling and escape time
  - …a low pass filter!
- Variation in power causes variation in both the normalisation and maximum energy of the particle distribution

$$Q_k \gtrsim 10^{44} \left(\frac{E/Z}{10^{19}\mathrm{eV}}\right)^{2} \left(\frac{\eta_B}{0.1}\right)^{-1} \beta^{-1} \ \mathrm{erg\ s^{-1}}$$

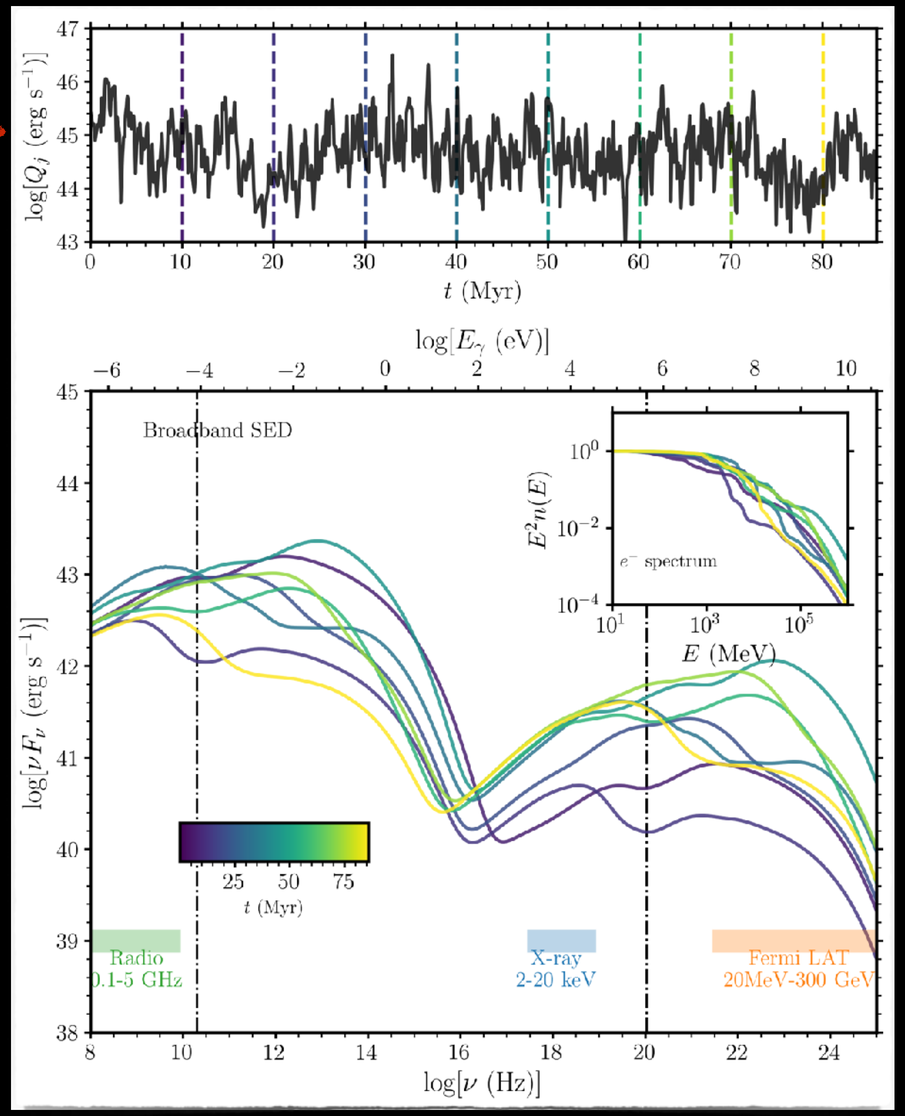


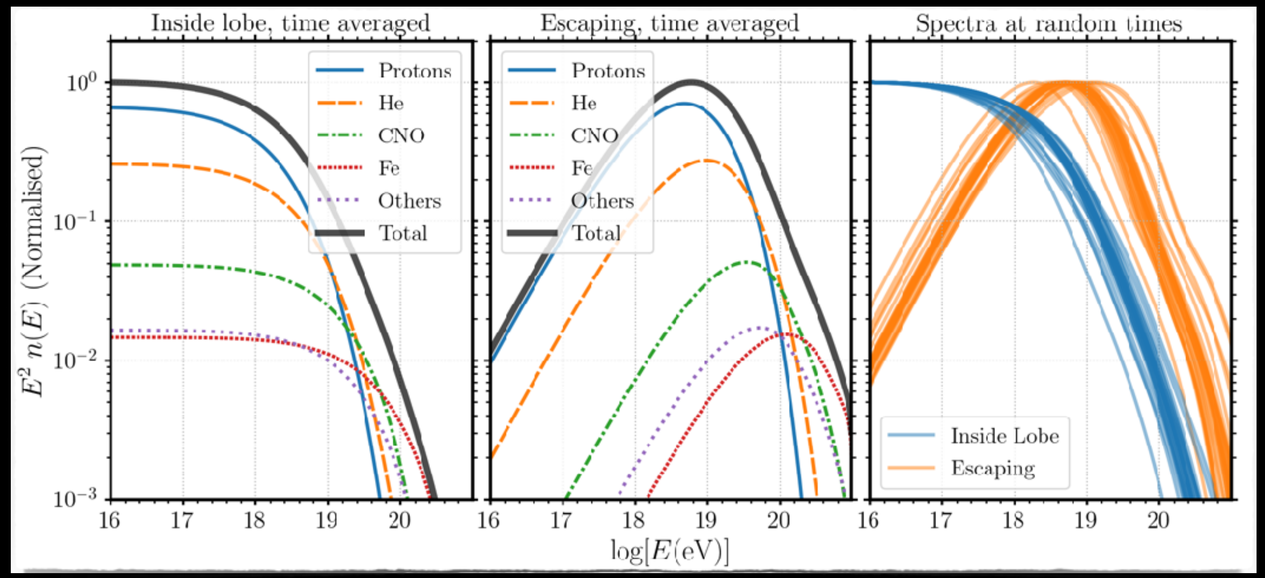


JM & Taylor 2021

CR and Radiation Spectra

- Curvature and bumps in the electron spectrum and broadband SED
- Cutoff in the CR spectrum is spread out according to the PDF of the jet powers
- Escaping CRs have different slope and composition to internal CRs -> stochasticity matters for UHECRs!

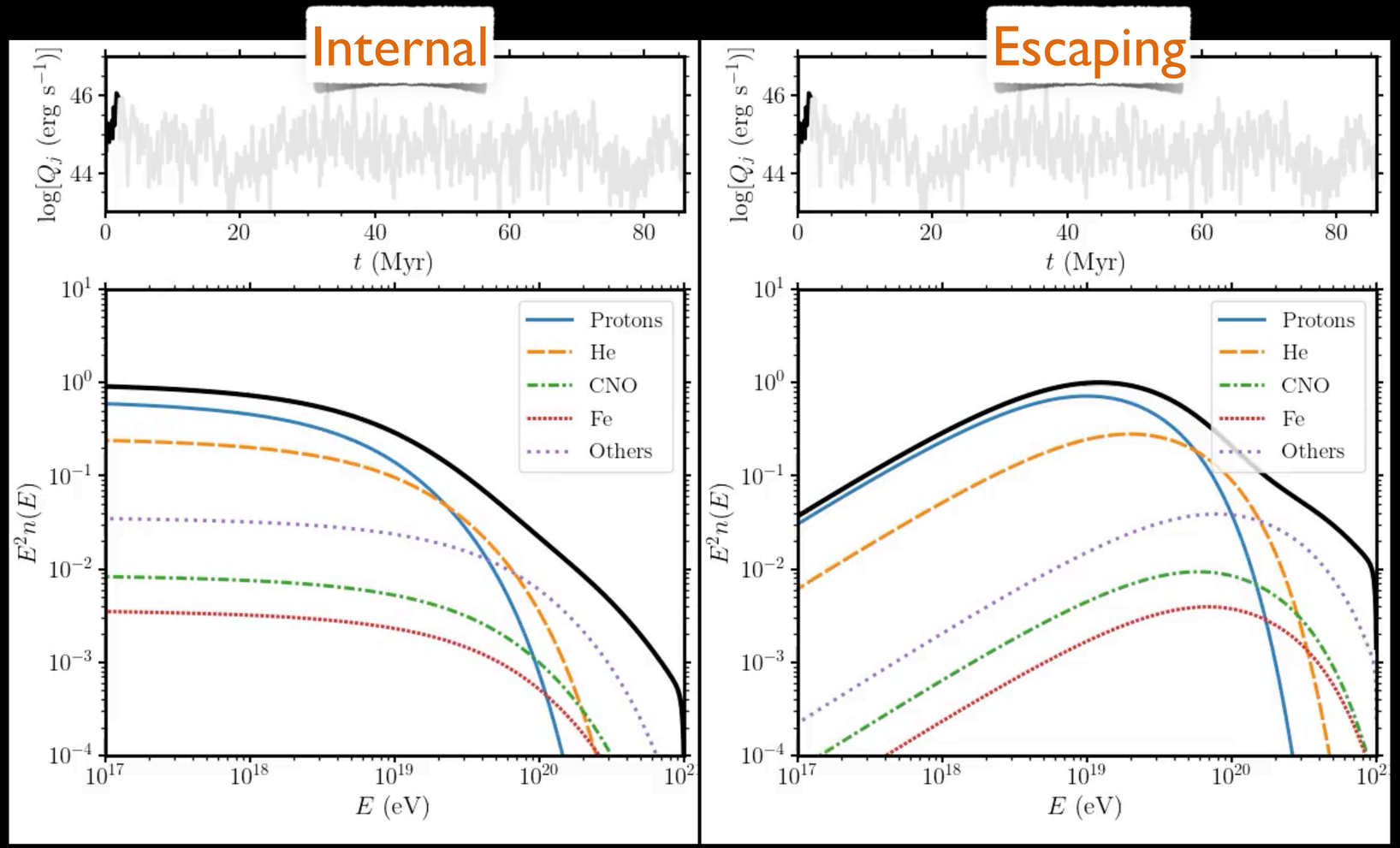




JM & Taylor 2021

Particle Acceleration in Flickering Jets

- Cutoff in the CR spectrum is spread out according to the PDF of the jet powers
- Escaping CRs have different slope and composition to internal CRs -> stochasticity matters for UHECRs!

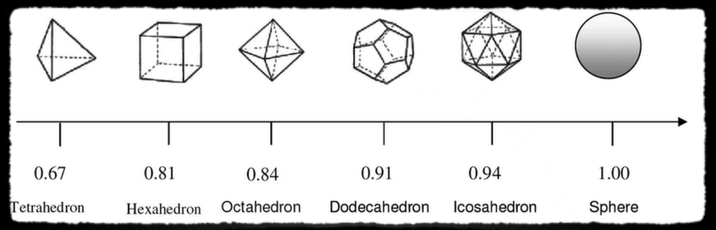


JM & Taylor 2021

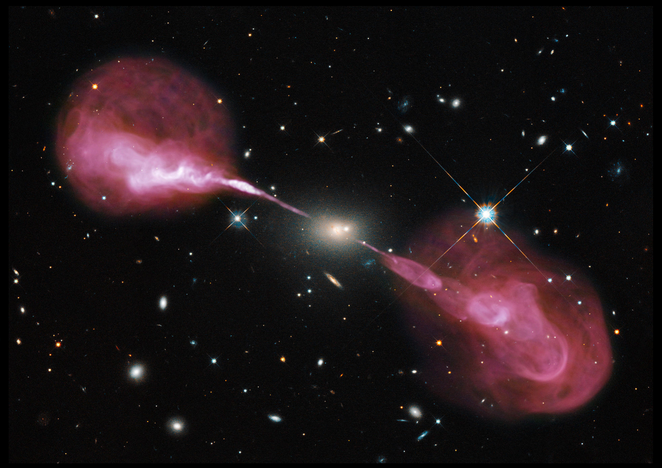
Morphology from Hydro sims

Henry Whitehead,
Cambridge Masters Student

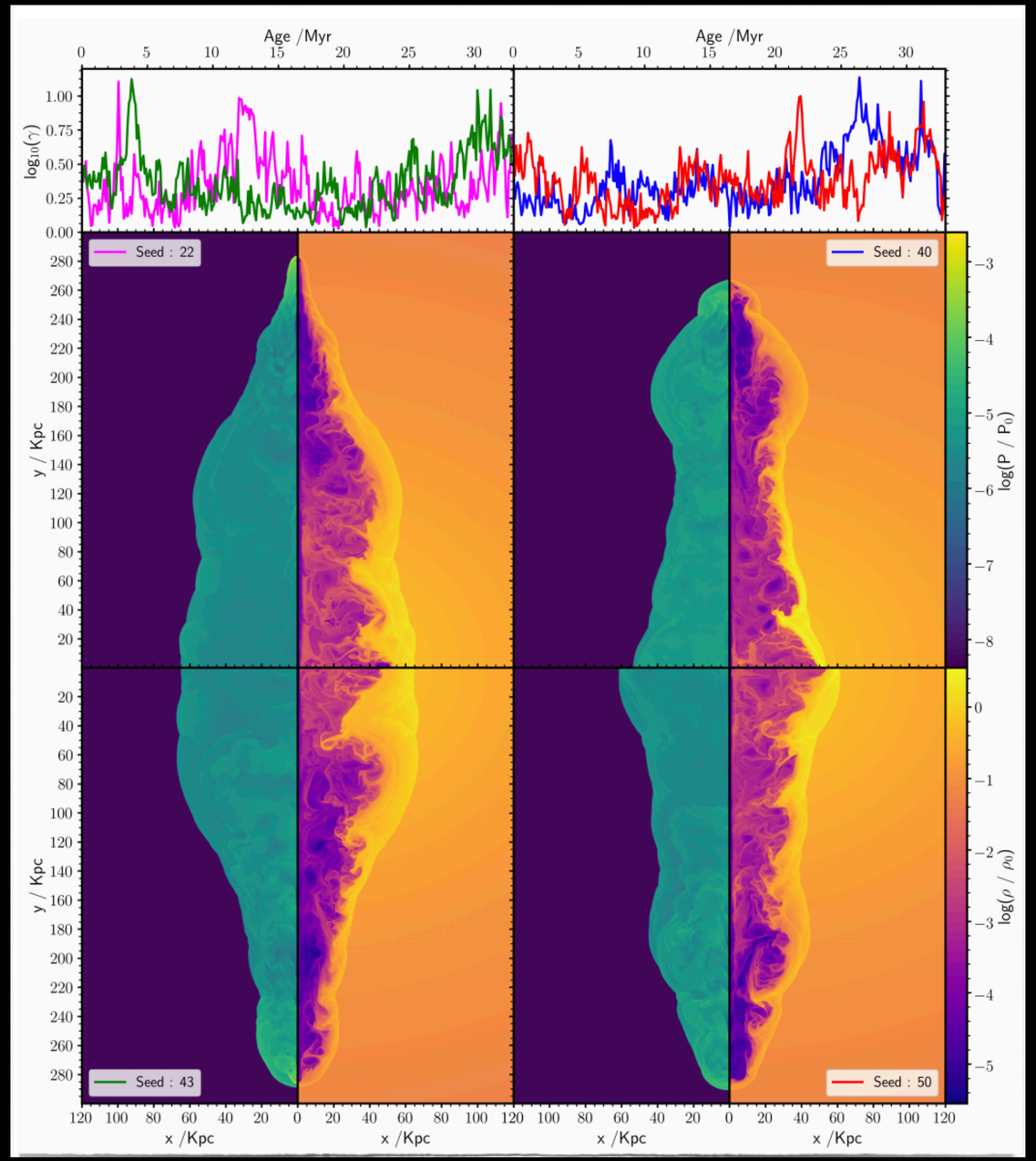
- We can run hydro simulations with a flickering jet power
- History of jet clearly encoded within morphology of source!
- Powerful episodes dominate propagation
- Henry's idea: use "sphericity" to measure the morphology of the lobe



Parallels with Hercules A?

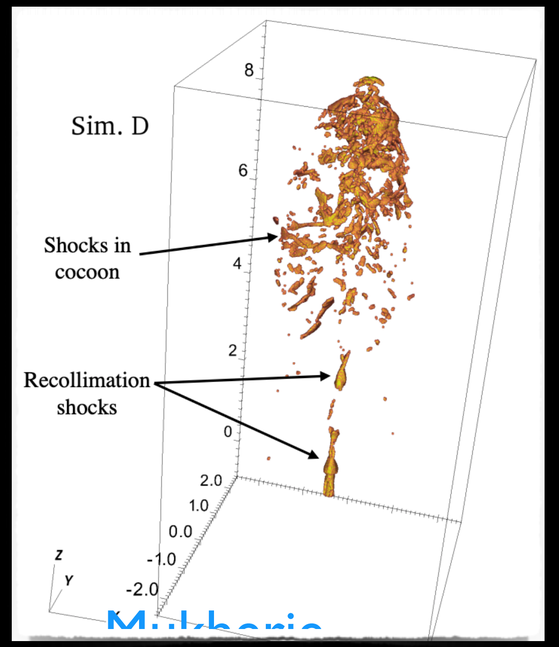


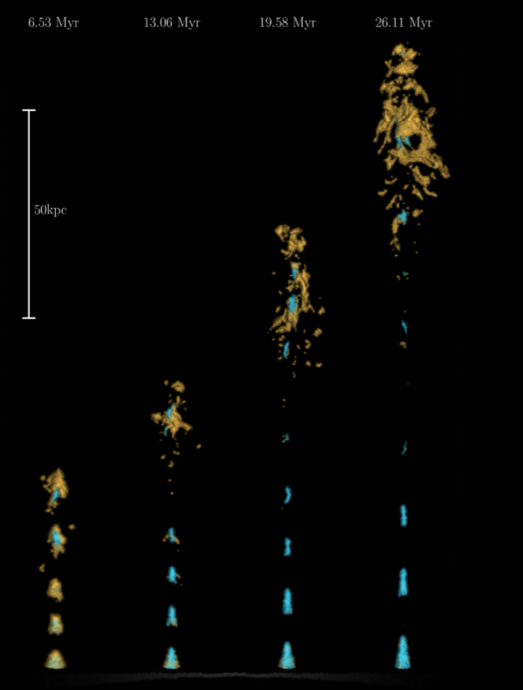
Credit: NASA, ESA, S. Baum and C. O'Dea (RIT), R. Perley and W. Cotton (NRAO/AUI/NSF), and the Hubble Heritage Team (STScI/AURA)

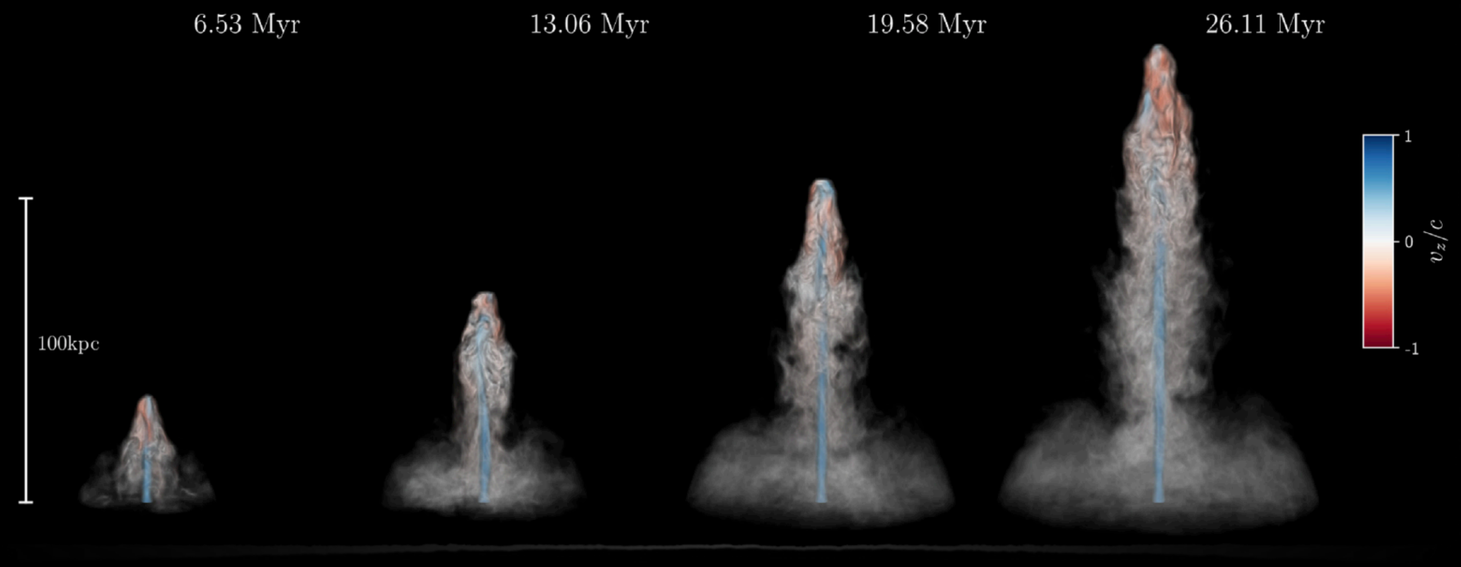


Backflow & Cocoon Shocks

- Jets produce strong backflow, which can be supersonic, v~0.1-0.5c
- Shocks produced in the cocoon from backflow
  - See also Reynolds+ 2003, Mignone+ 2007, Bell+ 20181
- Estimate of maximum proton energy: 5e19 eV -> UHECRs!
- How does variability affect the lobe shocks and turbulence?



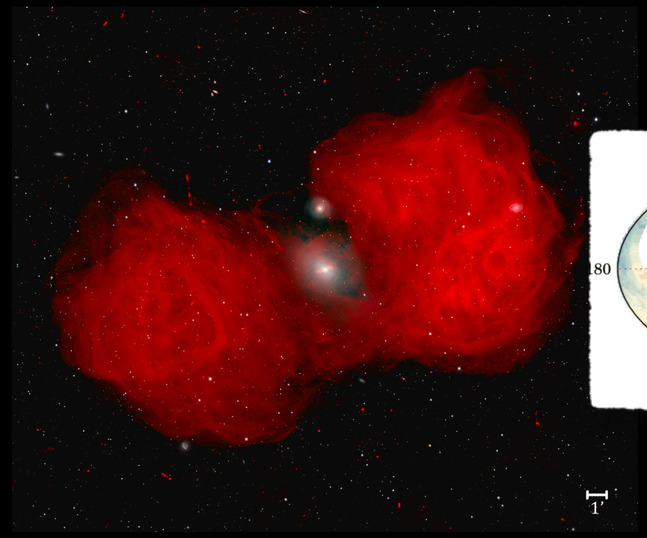


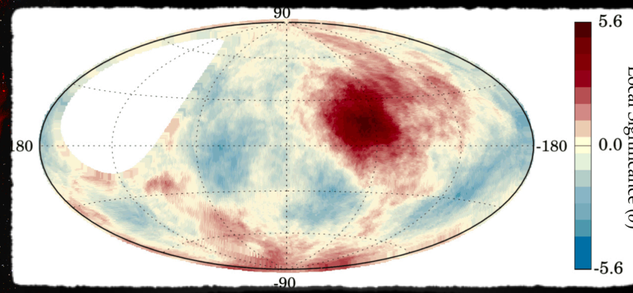


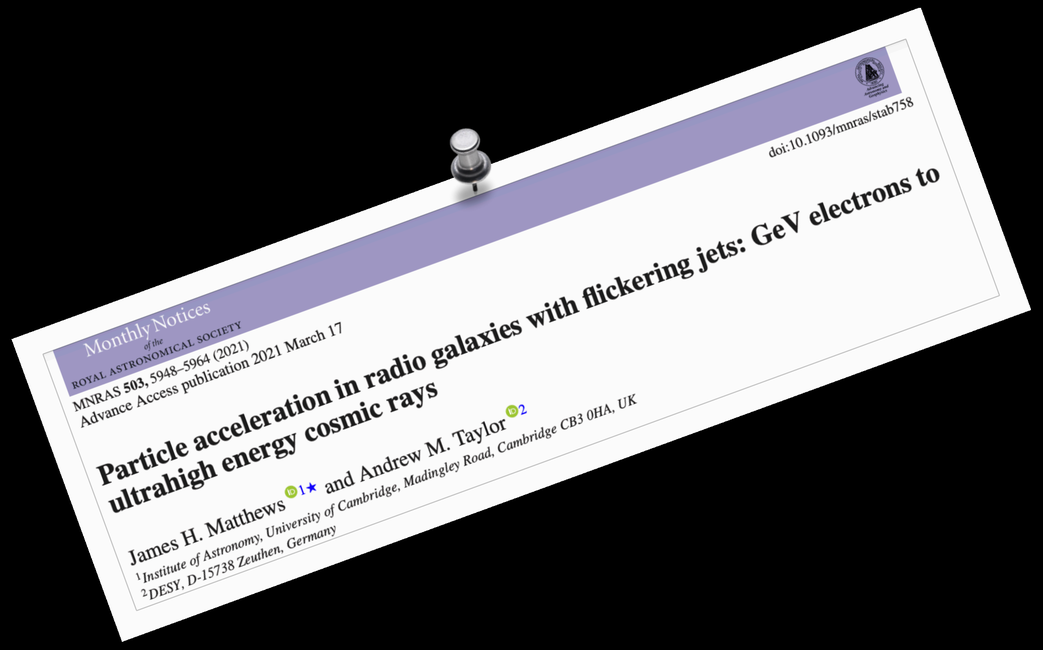
JM+ 2019
http://jhmatthews.github.io/uhecr-movies

Future Work

- Time-dependent UHECR propagation (w/ Tony Bell)
- Using more detailed particle treatments in PLUTO (e.g. Vaidya+ 18, Mukherjee+ 21)
- Impact on backflow structures? Shear acceleration? Kinks?Ideas welcome! (w/ You???)

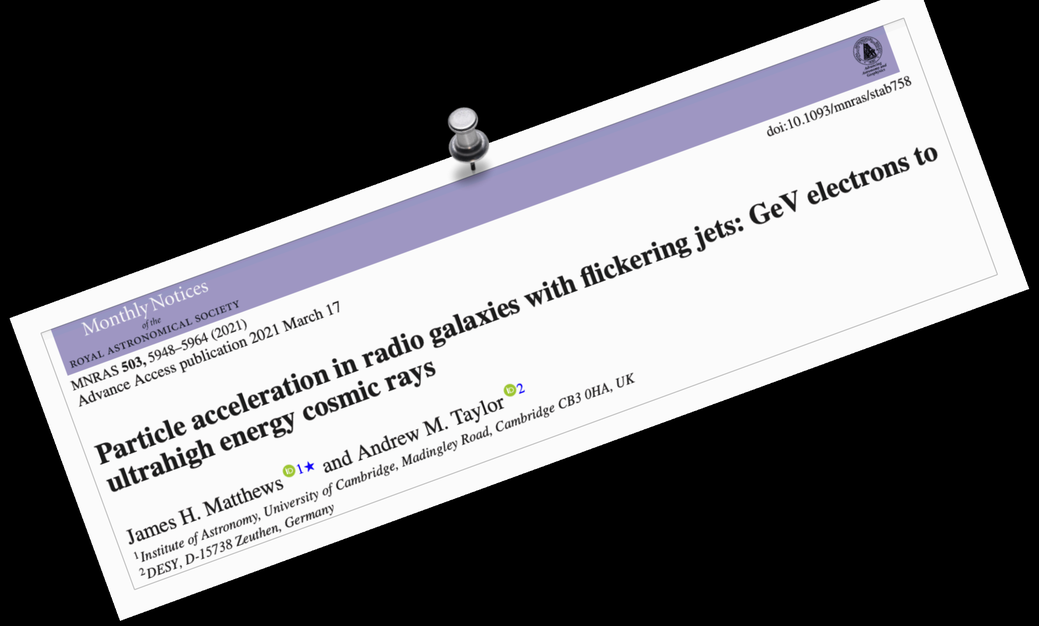


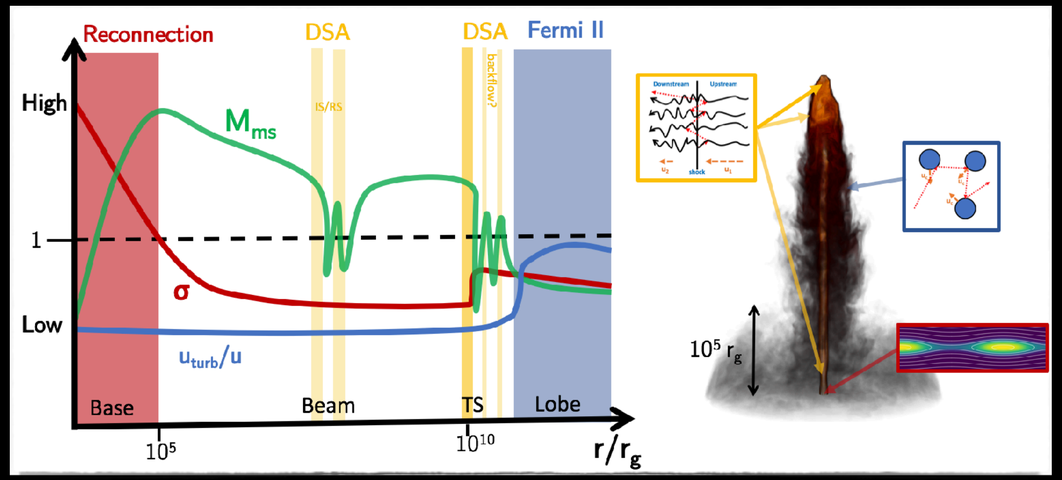




Conclusions

- Jet variability matters at all particle energies!
- Stochastic nature of accretion and jet launching critical for UHECR source studies
- Interesting effects on spectral curvature in broadband SED
- Potential to identify "proxy electrons" and link GeV to EeV energies





References:

- *Matthews & Taylor 2021, Matthews+ 2020, Review in "100 years of jets"(eds. Fender & Wijers), arXiv:2003.06587, Matthews+ 2018, MNLett, 479, 76 & 2019, MNRAS, 482, 4303*