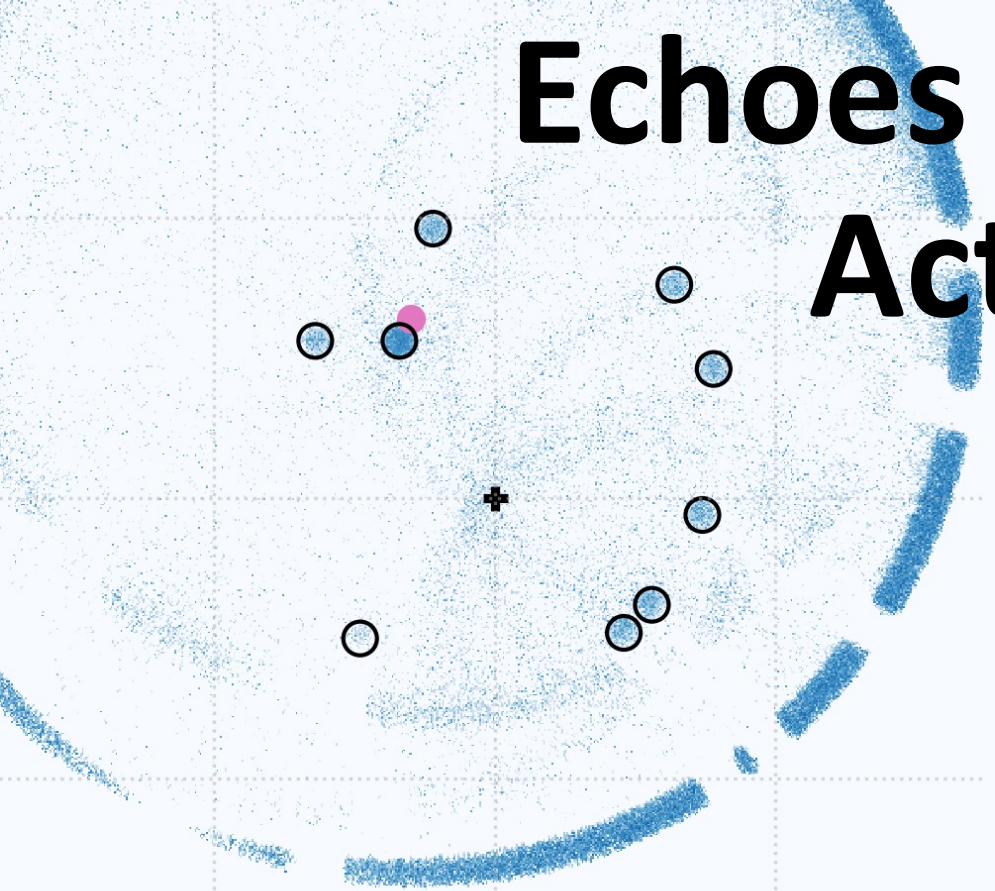
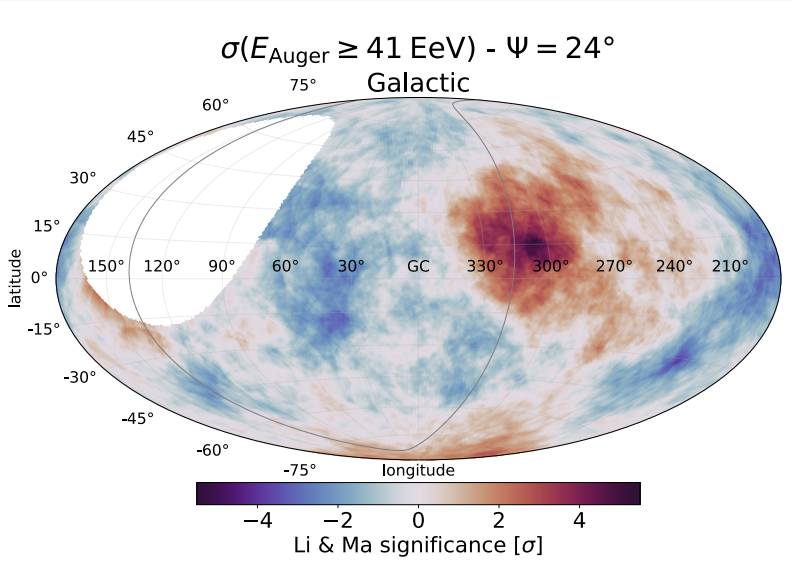
Echoes from Cen A's Active Past





Work done in collaboration with:

James Matthews (University of Cambridge/Oxford)

and

Tony Bell (University of Oxford)

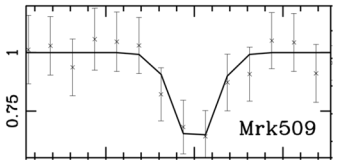
DESY.

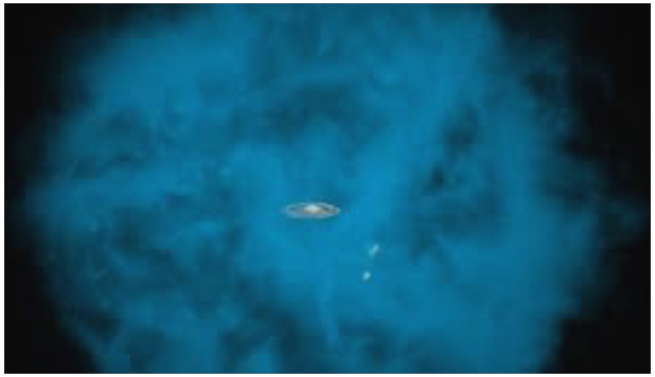
Building on the results of Bell et al. MNRAS 448 (2022)

The Large Thermal Pressure in the Halo

X-ray observations of bright AGN indicate the presence of a hot local absorber.

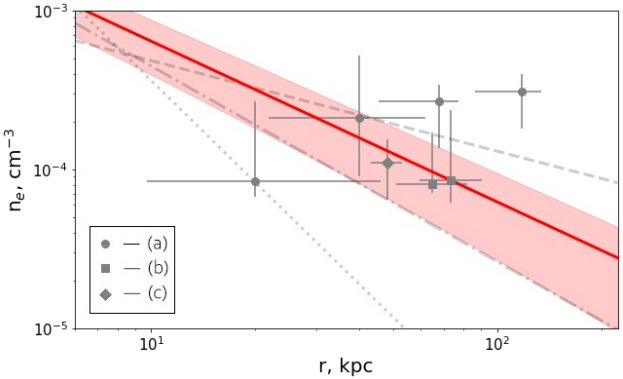
Gupta ApJ, 756 (2012)





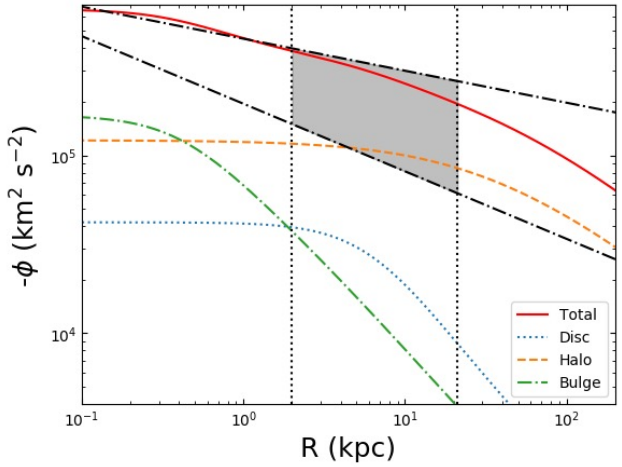
More recently, the ram pressure stripping of satellite galaxies + emission from the hot absorber have been collectively used to probe the halo gas.

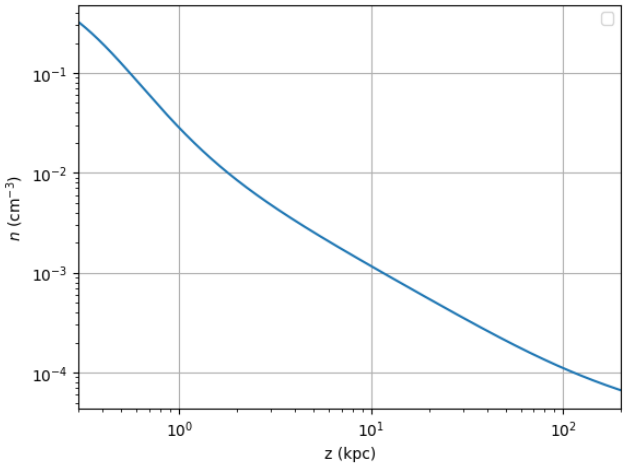
Faerman ApJ 835 (2017), Martynenko MNRAS, 511 (2022)



These results are consistent with expectations if the halo gas is in hydrostatic equilibrium

Faerman ApJ 835 (2017), Tourmente 2207.09189, (2022)





Faerman ApJ, 893 (2020)

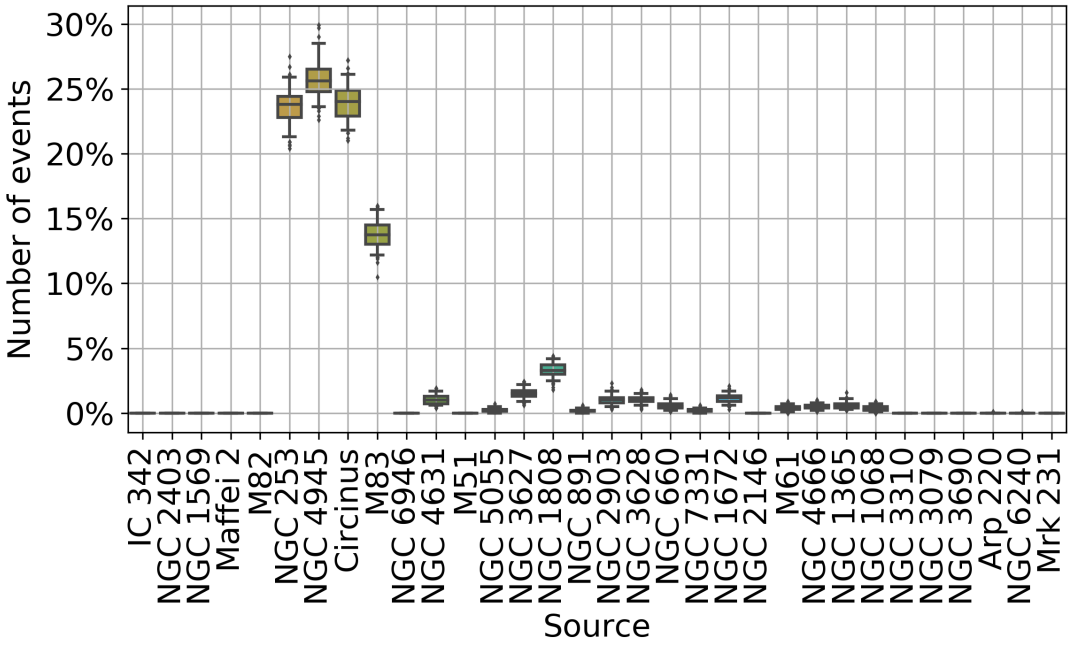
$$\mathbf{B(100\ kpc) \approx 0.2\ \mu G}$$

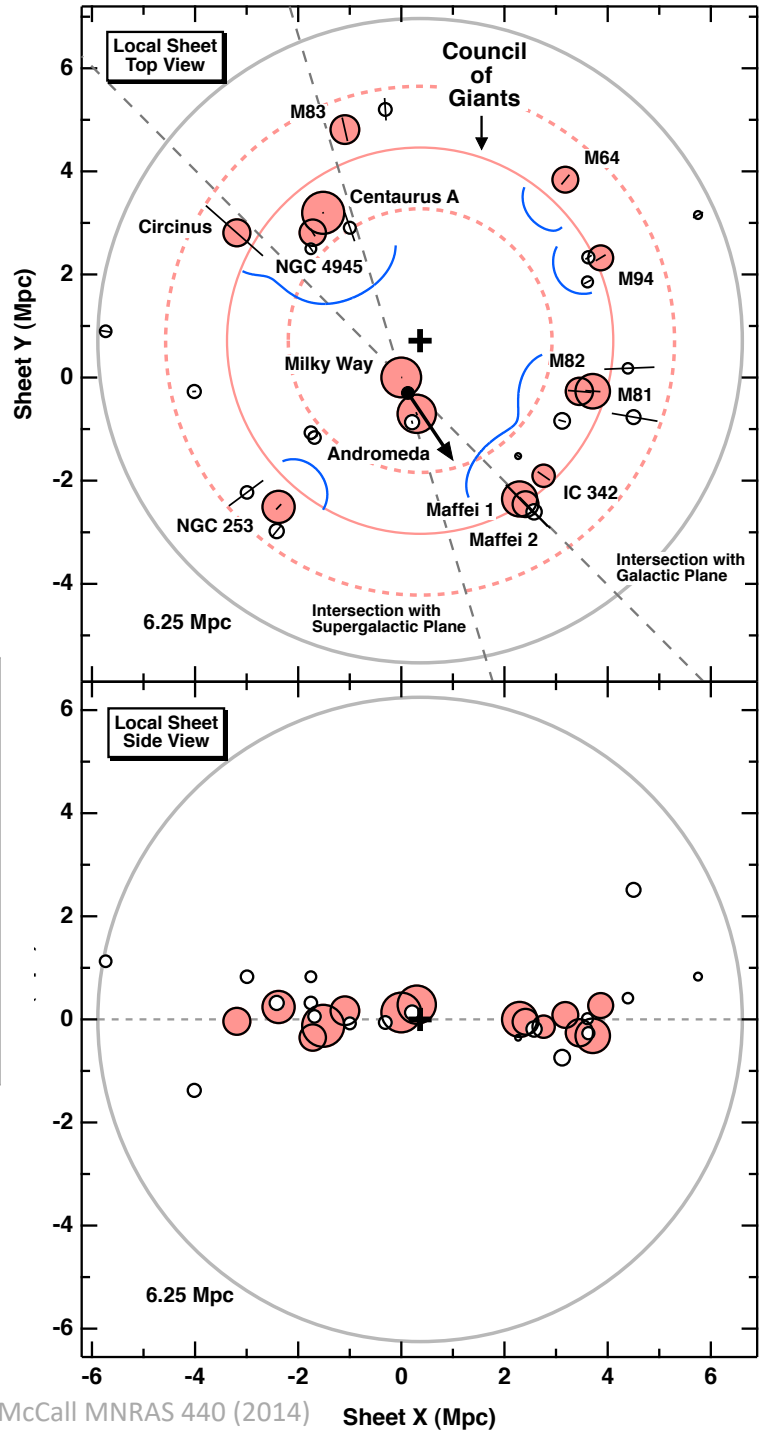
$$\mathbf{r_L(10\ EV) = 50\ kpc}$$

Our Local Extragalactic Neighbourhood

The local (<10 Mpc) extragalactic objects are structured, sitting in a roughly circular disk shape

van Vliet MNRAS 510 (2021)

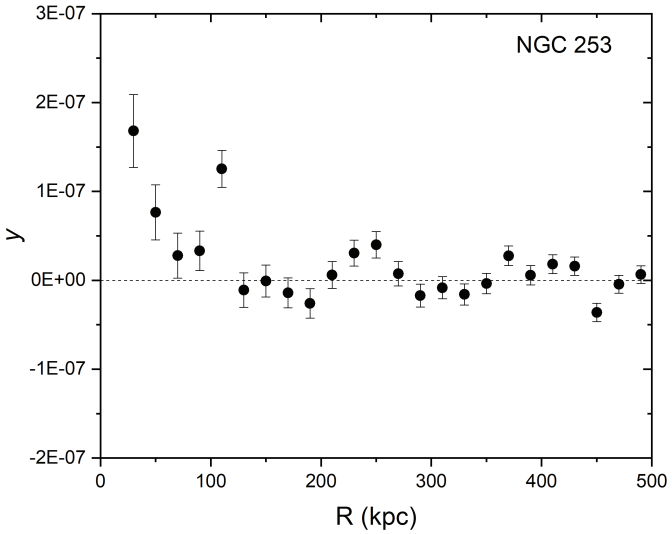


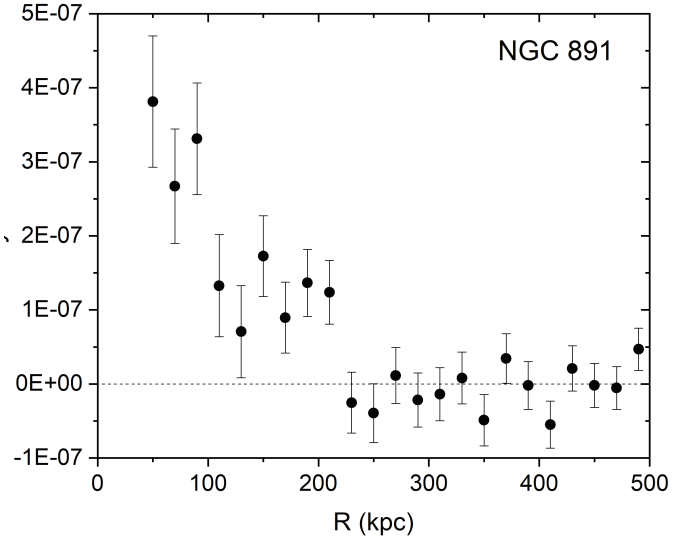


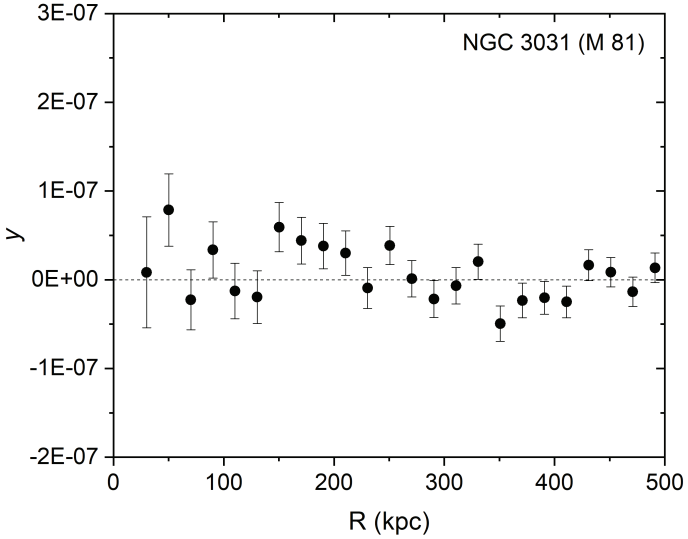
McCall MNRAS 440 (2014)

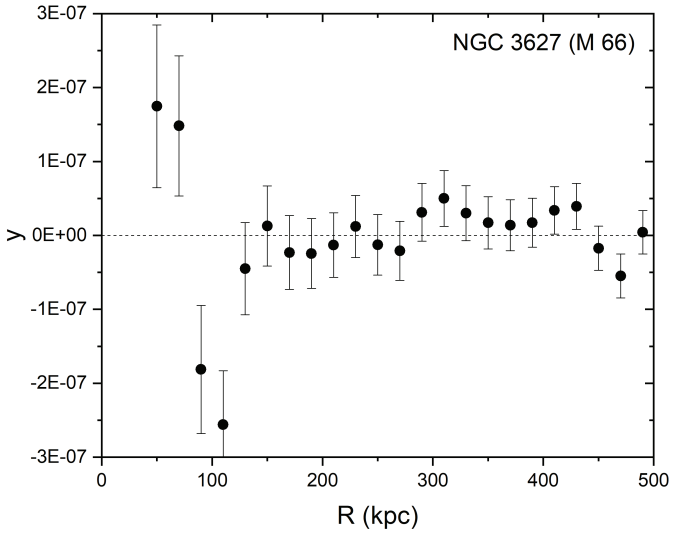
Extended Hot Gas Around CoG Members?

Bregman et al. ApJ 928 (2022)







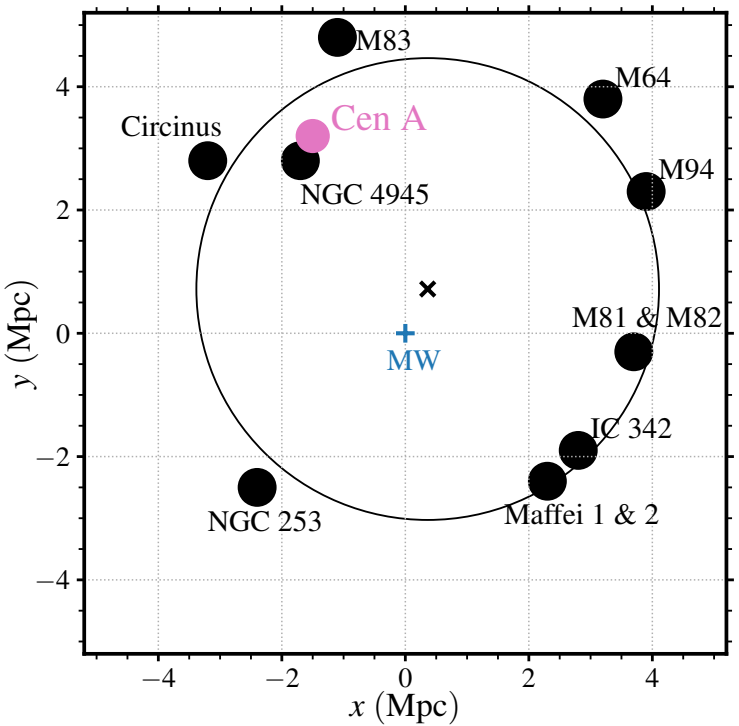


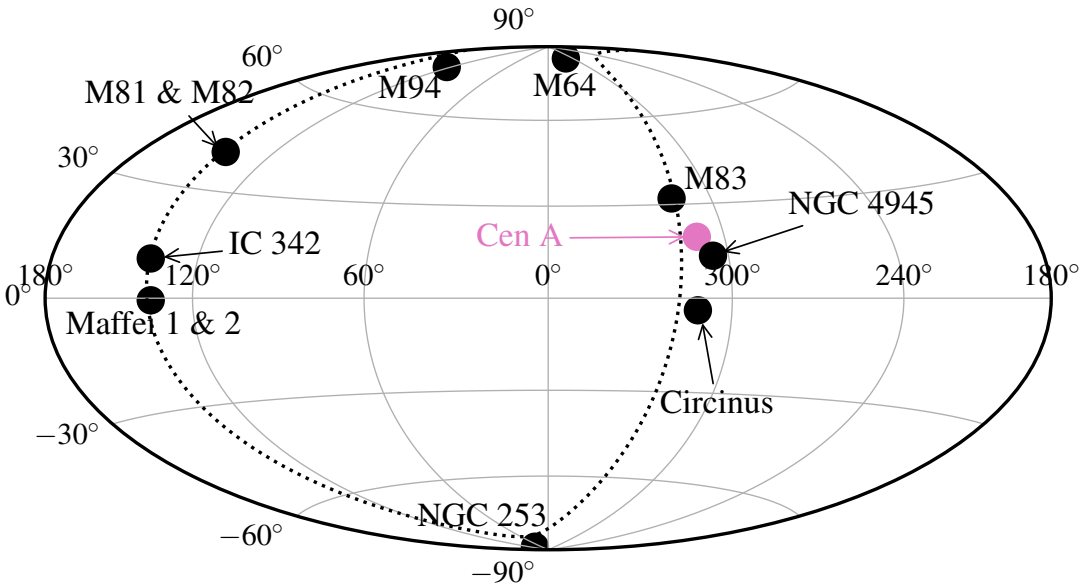
Local Extragalactic Structure
The Council of Giants

Cen A is unique within the council of giant structure are being the only object proving a kinetic luminosity capable of giving rise to multi EeV acceleration

Lovelace et al. (1976)

$$\mathbf{E_{max}} \lesssim \frac{\mathbf{Z}}{\eta}\left(\beta \mathbf{L_{KE}} \alpha \hbar\right)^{\mathbf{1/2}} \approx \mathbf{10}\,\frac{\mathbf{Z}}{\eta}\left(\frac{\beta \mathbf{L_{KE}}}{\mathbf{3\times 10^{43}\ erg\ s^{-1}}}\right)^{\mathbf{1/2}}\ \mathbf{EeV}$$



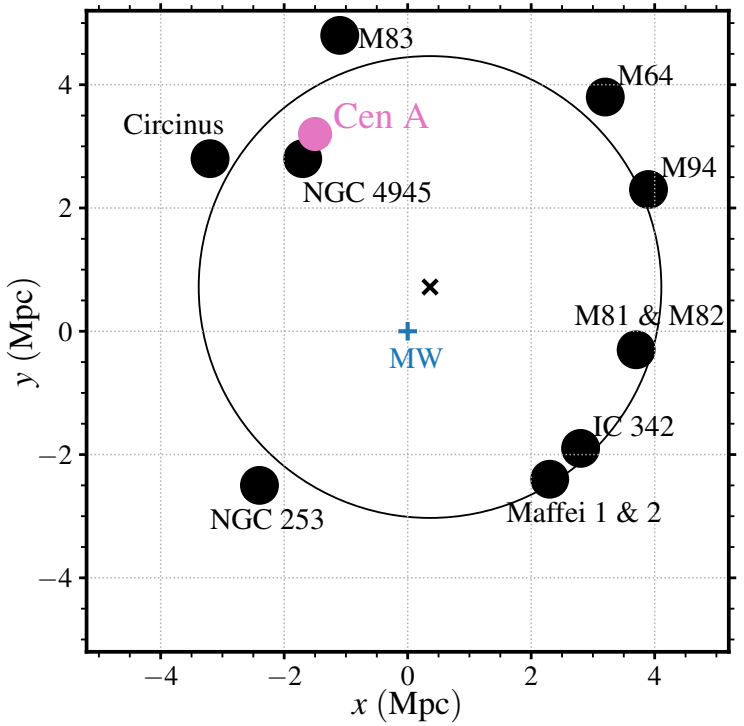


Simulation Setup

- Particles initially fill 300 kpc region surrounding Cen A (isotropic momentum distribution)
- Large angle particle scattering occurs within the virial region (< 300 kpc) of all members of the council of giant system
- Outside the virial radii of these galaxies the particle propagation is treated as ballistic
- Fundamental parameter of problem- optical depth of scattering regions

$$\tau = \frac{\mathbf{r_{vir}}}{\mathbf{l_{sc}}}$$

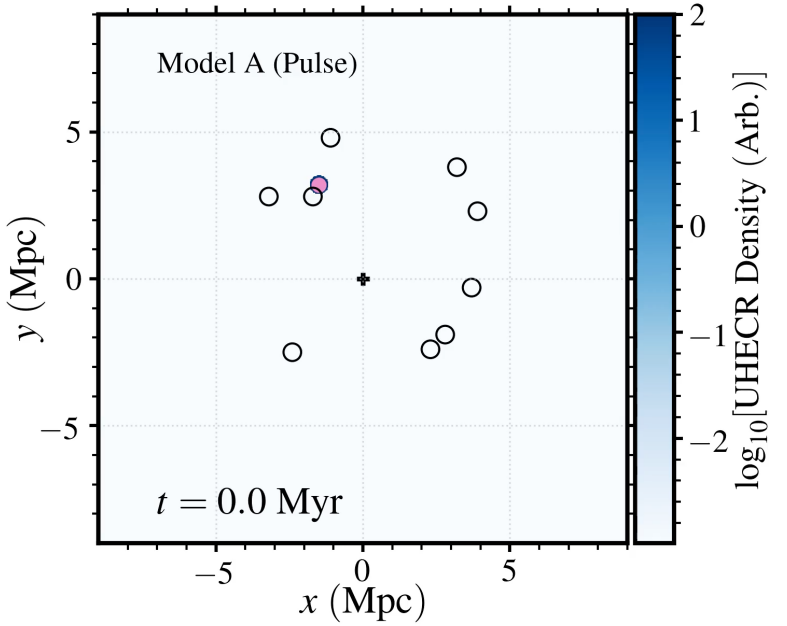
- Echo signals results are rather insensitive to optical depth of scattering regions, provided $\tau > 1$

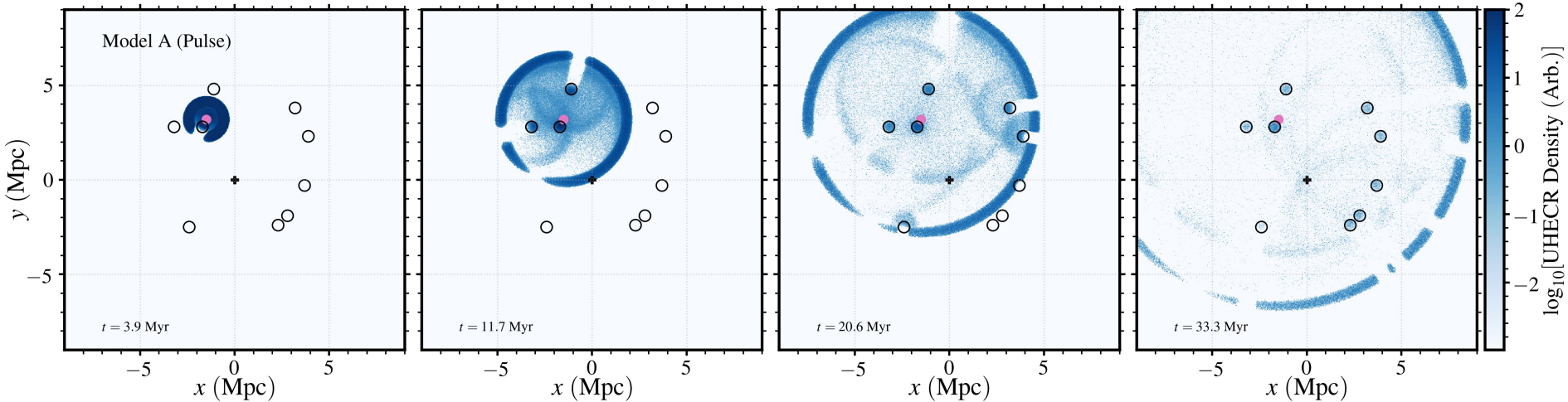


- Only He and Fe injected into the system (fragile and robust species compared to crossing time of system)
- Particles photo-disintegrate en-route in extragalactic radiation fields
- 30 EeV particles being focused on
- Deflections from MW magnetized halo intentionally left out

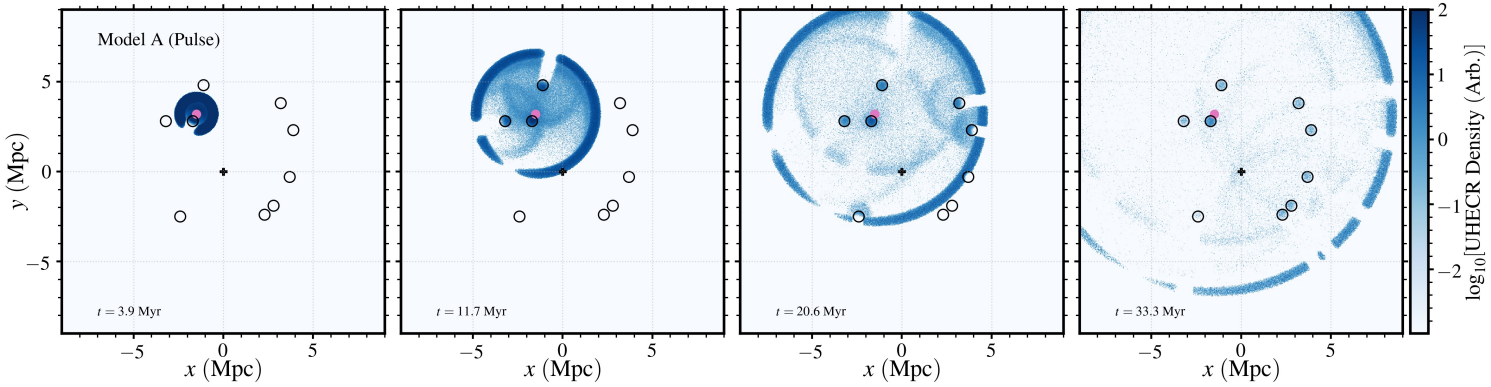
Simulations of UHECR Propagation Through the CoG Structure

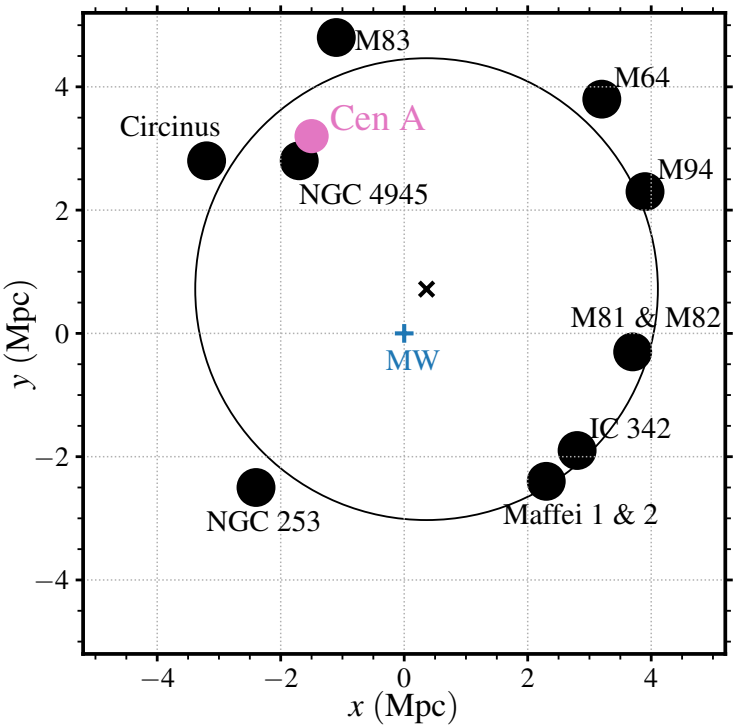
Pulse release of particles from Cen A and propagation of these particles through the CoG structure

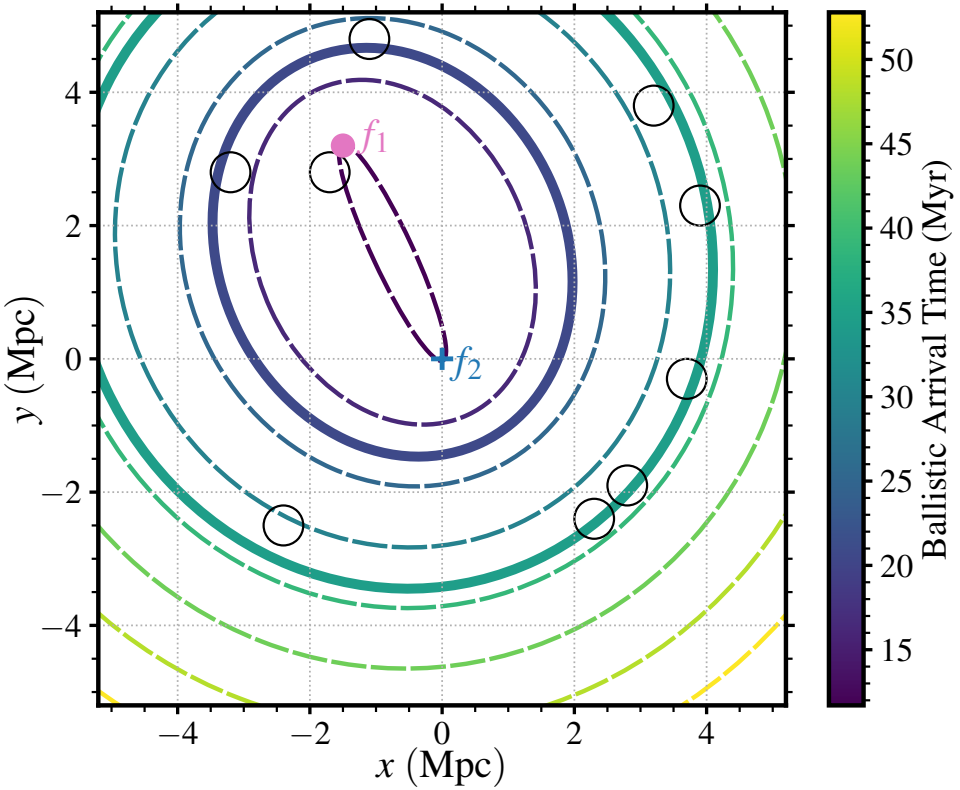




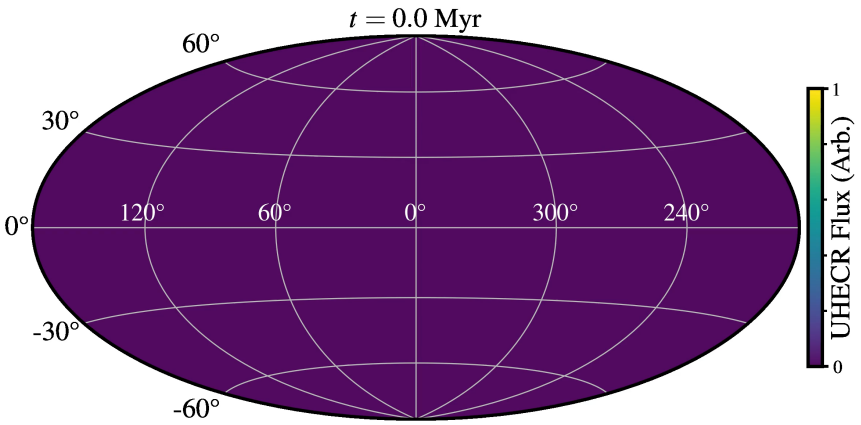
The Focusing of the Echo Waves

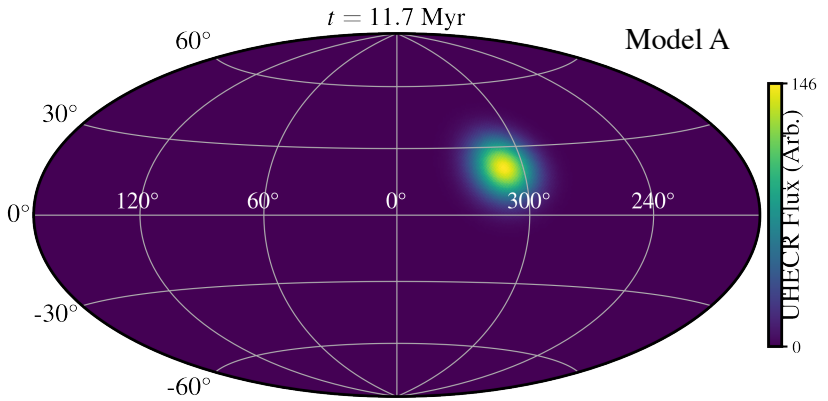


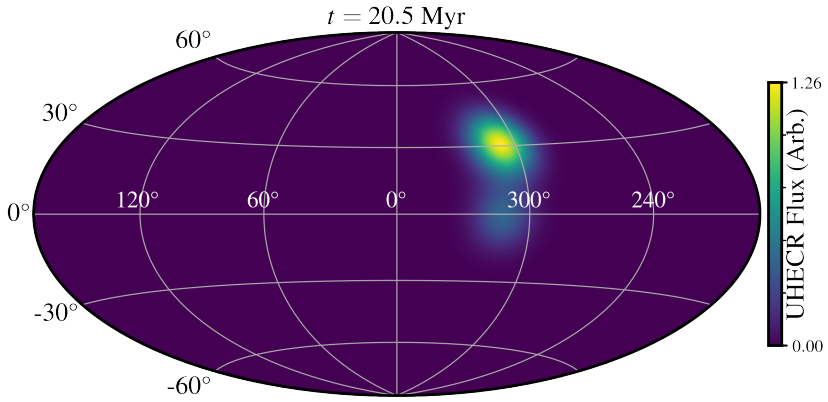


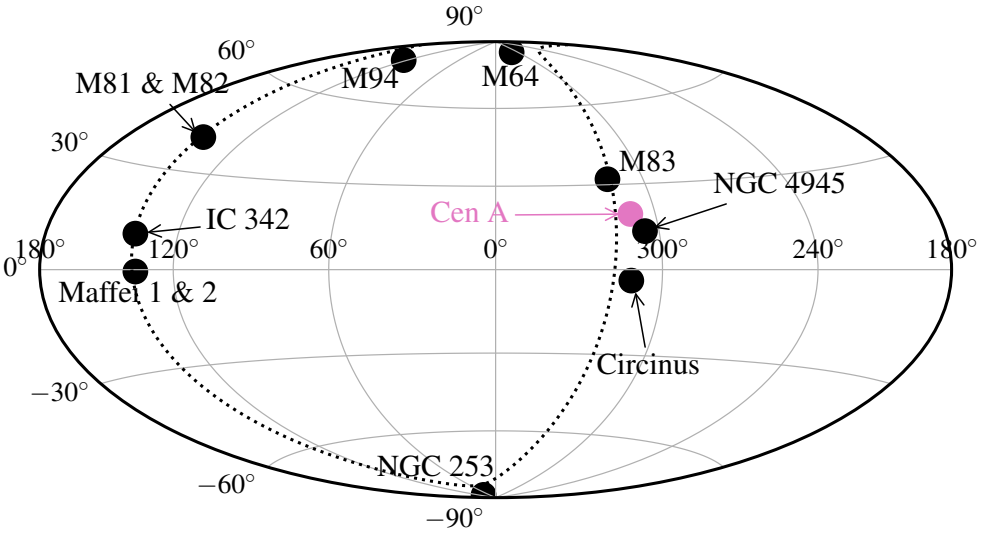


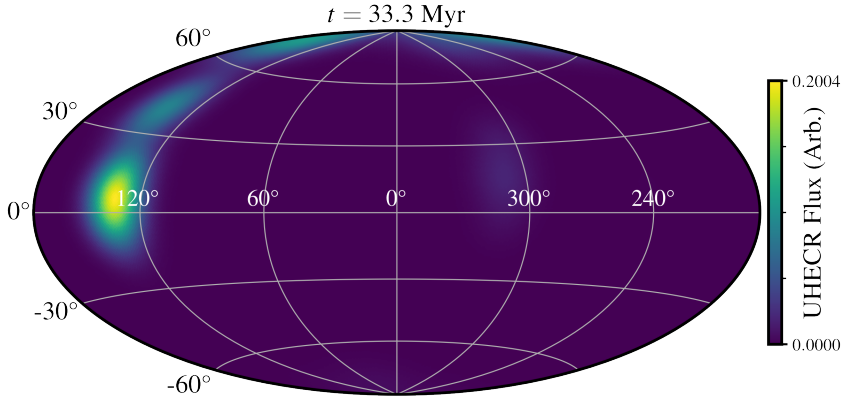
Milky Way Based Observers











Particle Acceleration/Release Scenarios

Model B:
The UHECR output of Cen A is described by:

$$\mathbf{L = L_0 e^{-t/\tau_{dec}}}$$

$$\tau_{\mathbf{dec}} = \mathbf{3\ Myr}$$

The UHECR output of Cen A exponentially decays after the initial burst

Model C:
The UHECR leakage out of Cen A is rigidity dependent

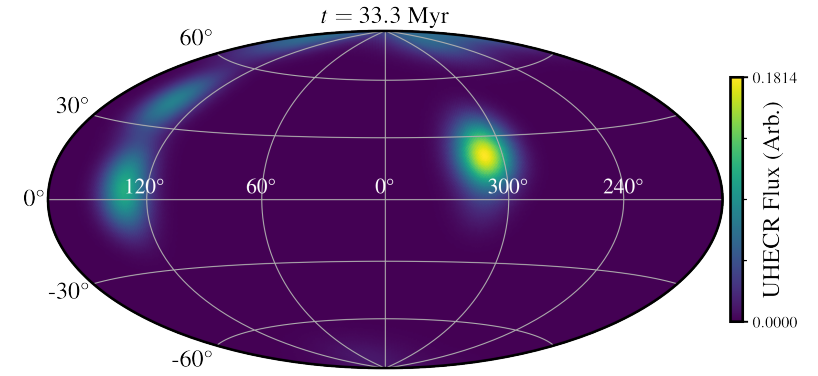
$$\tau_{\mathbf{esc}} = \tau_{10} \left(\frac{\mathbf{(E/Z)}}{\mathbf{10\ EV}} \right)$$

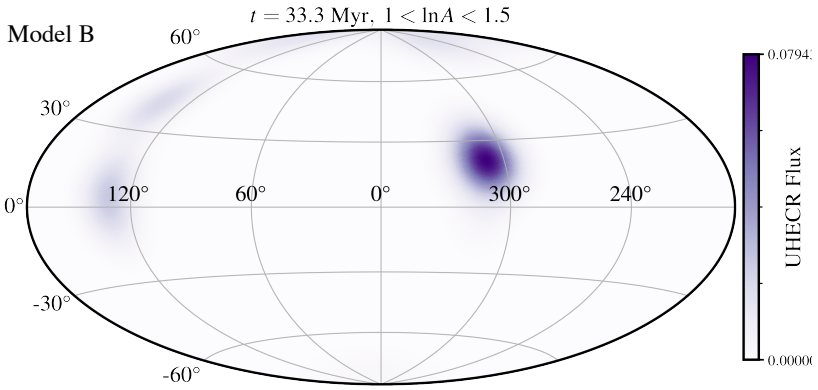
$$\tau_{10} = \mathbf{1.5\ Myr}$$

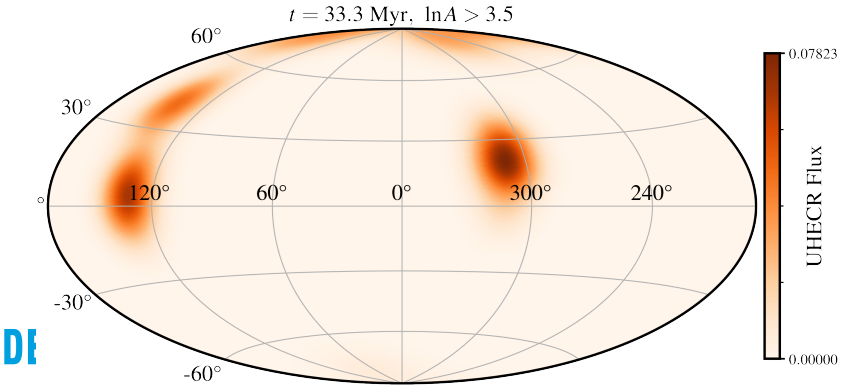
The UHECR escape from the source region in a rigidity dependent manner

Distinguishing Between Model B and Model C Results

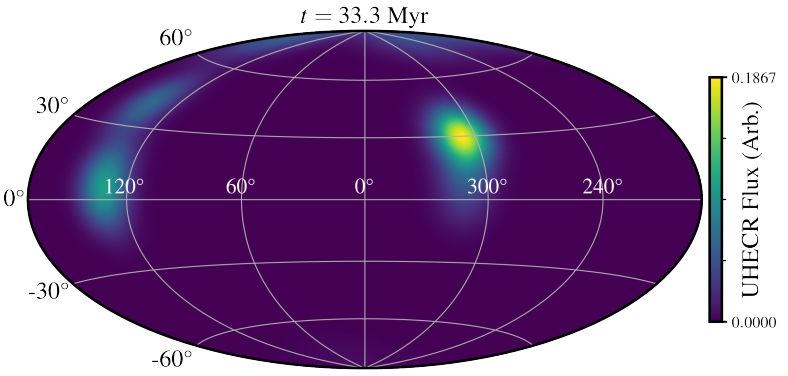
Model B

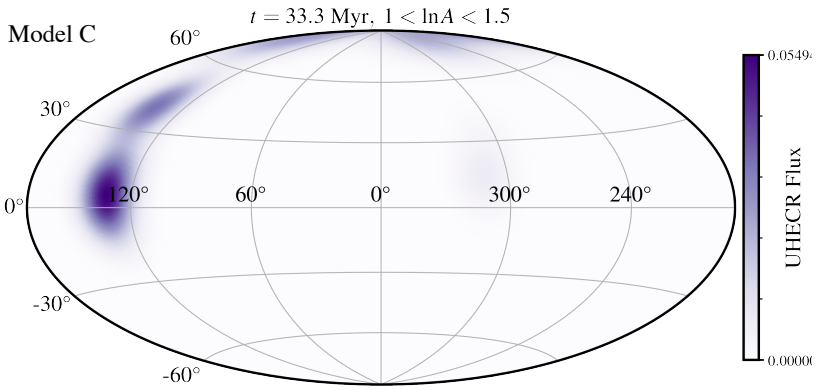


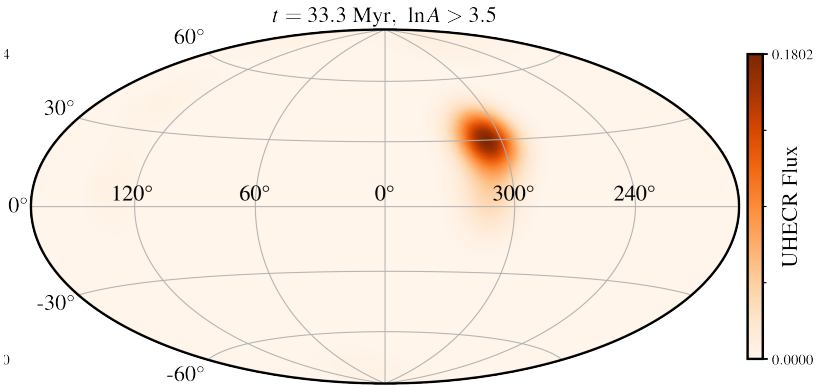




Model C

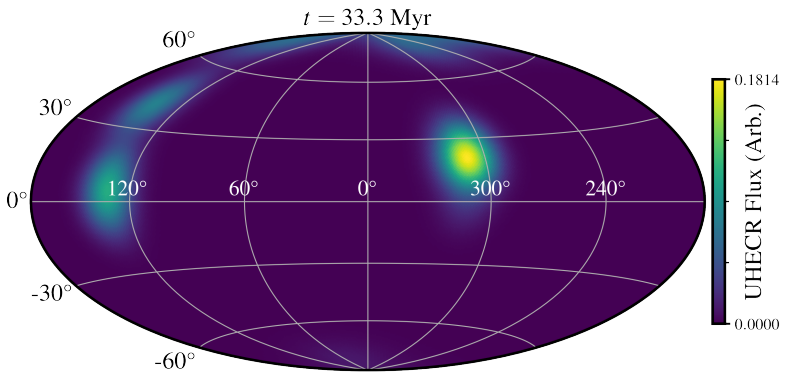


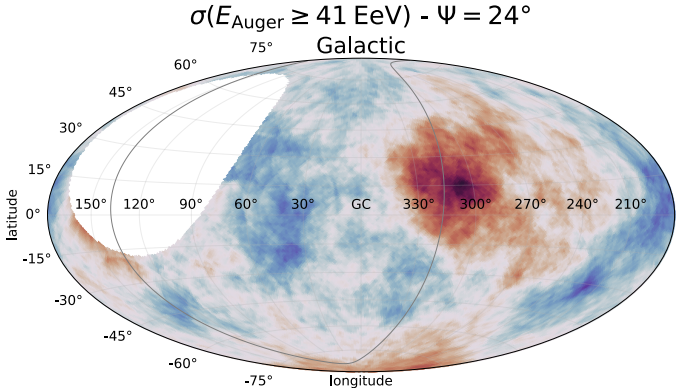




Conclusions

- Observational evidence over the last 10 years has mounted suggesting that galaxies are significantly thermally pressured (suggesting magnetically pressured) out to their virial radius
- UHECR propagating within the magnetic halos around local galaxies (in the Council of Giants structure) may be strongly deflected
- If strong deflection in magnetic halos are at play, the presence of the Council of Giant structure, within which Cen A and the Milky Way reside, can imprint itself on the arriving UHECR skymap
- Such an imprint may explain the correlation that PAO and TA have reported with local structure
- A key diagnostic of this imprint comes from the composition skymaps, expected to He rich in the echo and source regions

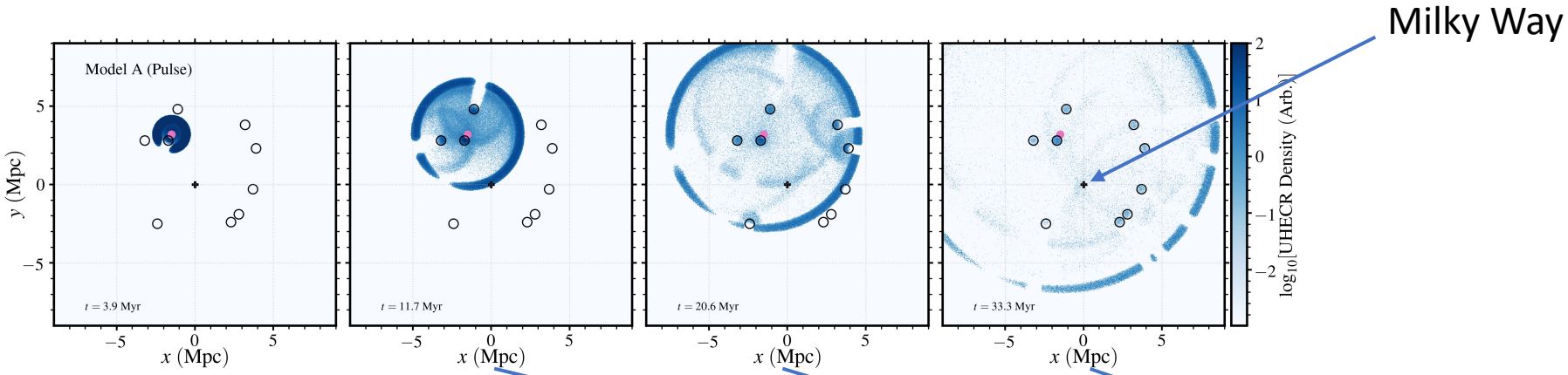


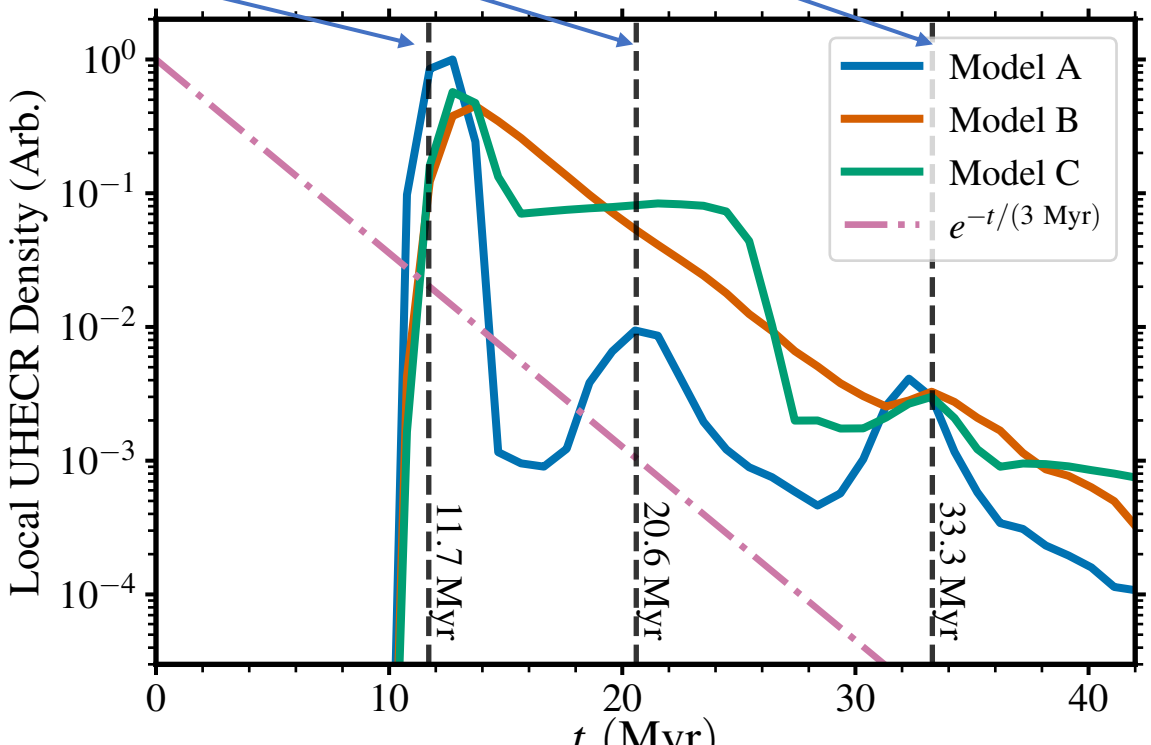


DESY.

Extra Slides

Echo Waves





DESY.

The Uniqueness of Cen A within the Council of Giants

$$t_{acc} = \eta \frac{R_{lar}}{c\beta^2}$$

$$t_{esc.} = \frac{R}{c\beta}$$

[AM Hillas (1984)]

$$E_{max} = \beta e B R$$

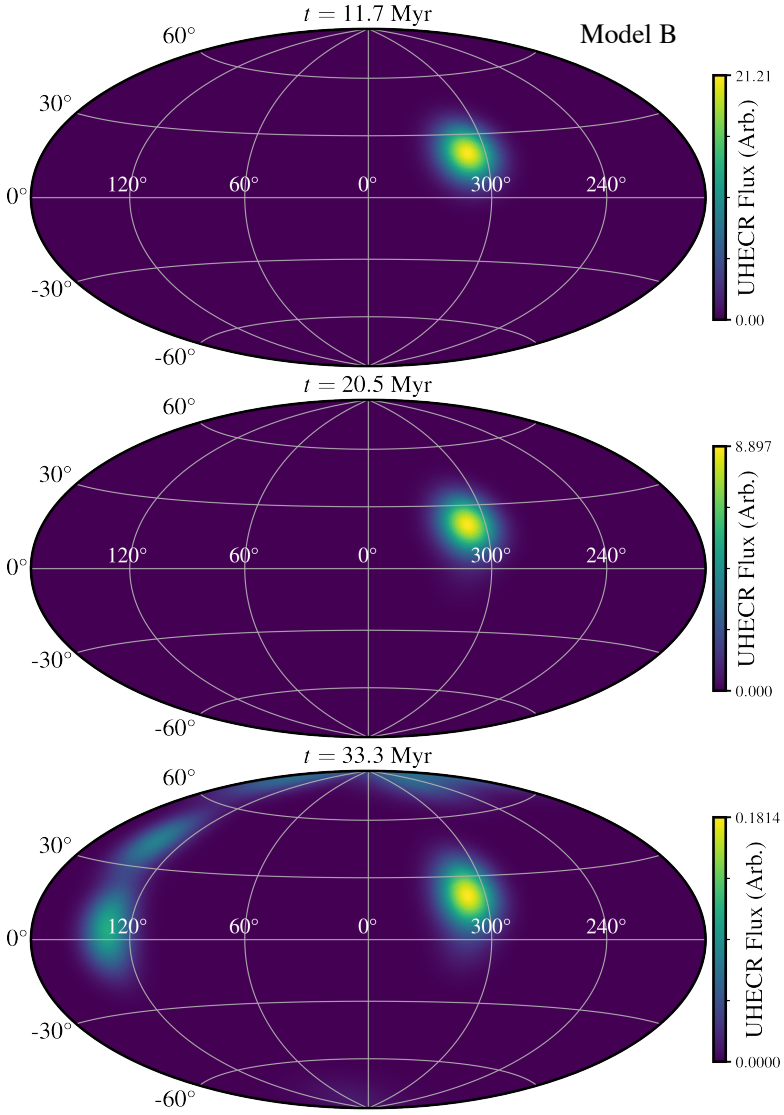
$$L_B = U_B 4\pi R^2 \beta c$$

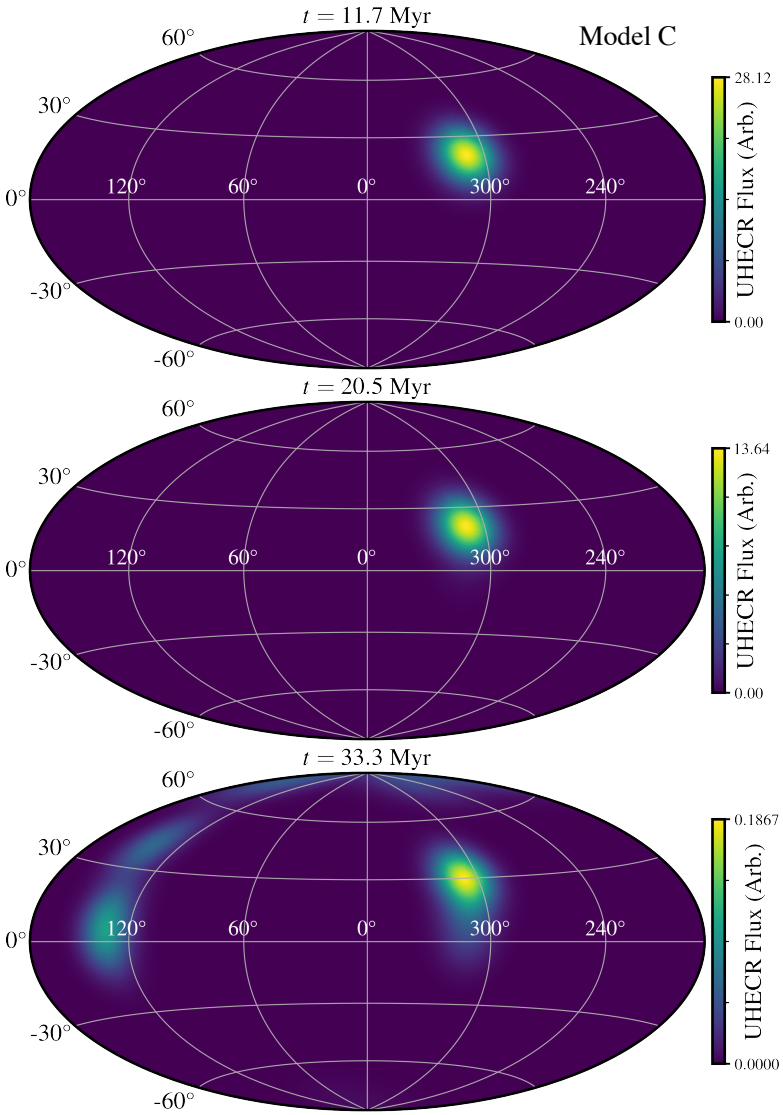
Under the assumption of equipartition of energy between kinetic energy and magnetic field:

[Lovelace et al. (1976)]

$$E_{max} \lesssim \frac{Z}{\eta} (\beta L_{KE} \alpha \hbar)^{1/2} \approx 10 \frac{Z}{\eta} \left(\frac{\beta L_{KE}}{3 \times 10^{43}\ erg\ s^{-1}} \right)^{1/2} EeV$$

Particle Acceleration/Release Scenarios





Extragalactic Magnetic Field is Hugely Uncertain