Indirect Dark Matter Searches with MeerKAT

Natasha Lavis, Michael Sarkis, Geoff Beck and Kenda Knowles

MGCLS
MeerKAT Galaxy Cluster Legacy Survey

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

NRF National Research Foundation

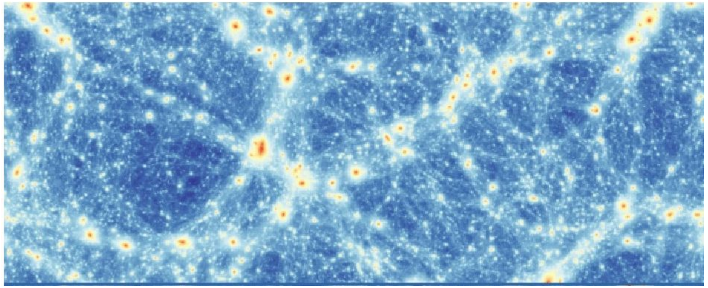
SARAO South African Radio Astronomy Observatory

Dark Matter

An essential component of our Standard Model of Cosmology

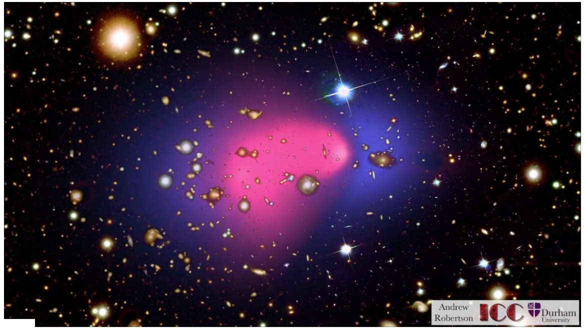
Large scale structure. Image Angulo et al 2022

100s Mpc



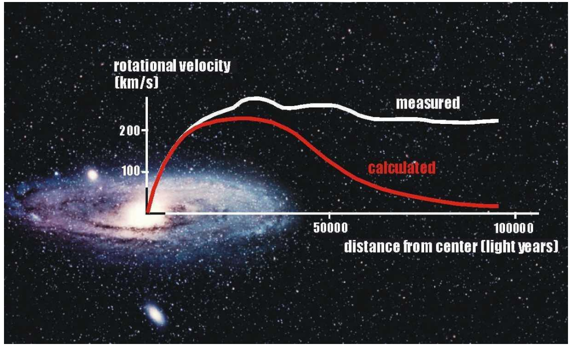
Galaxy clusters

Mpc



Galaxies

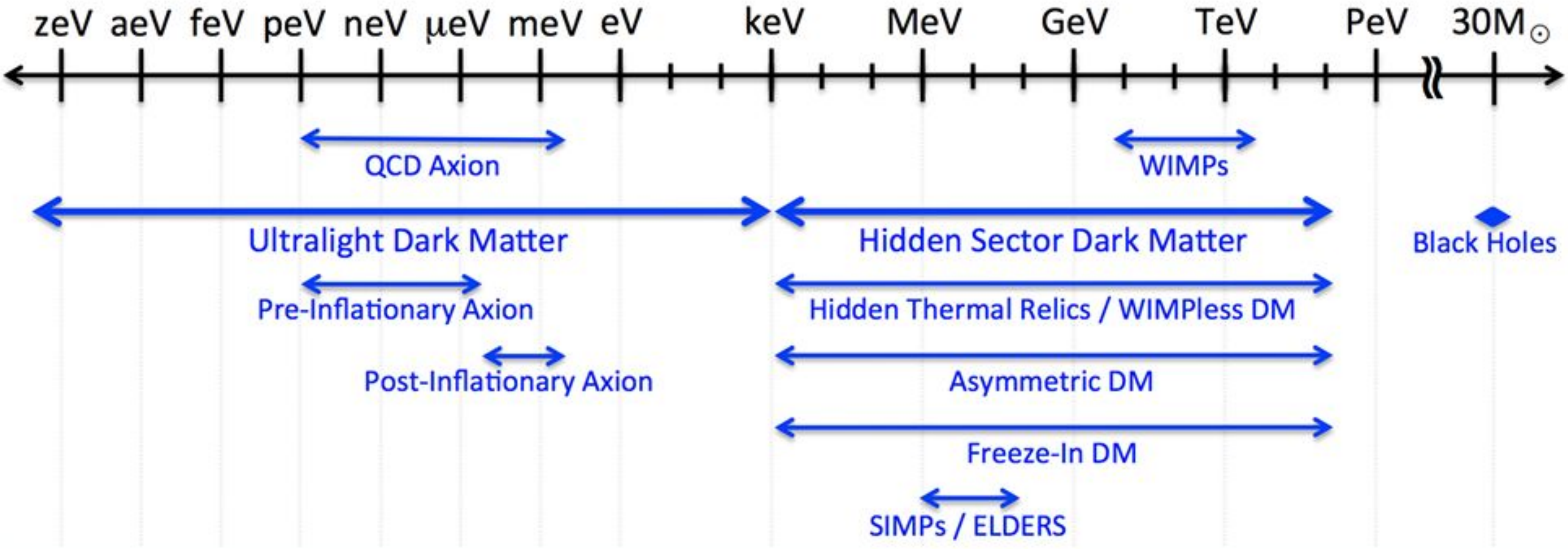
100s kpc



All of the evidence is only through gravitational probes, leaving the nature of DM an open question.

Dwarf galaxies

< kpc

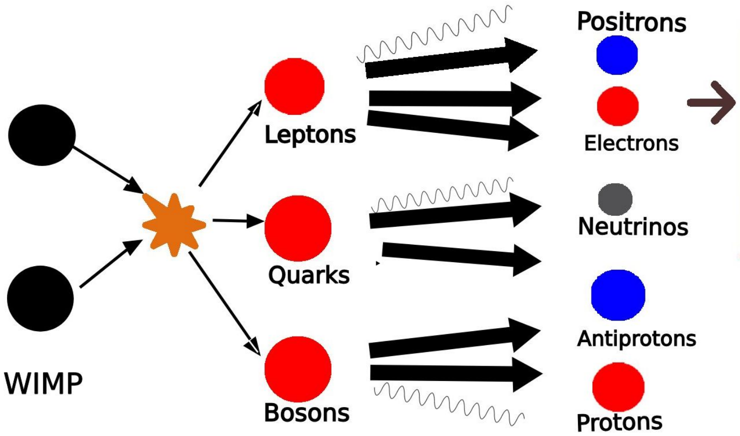


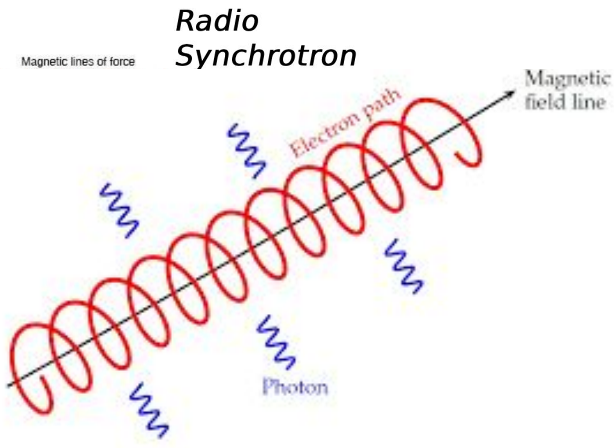
zeV aeV feV peV neV μeV meV eV keV MeV GeV TeV PeV 30M⊙
QCD Axion
WIMPs
Ultralight Dark Matter
Hidden Sector Dark Matter
Black Holes
Pre-Inflationary Axion
Hidden Thermal Relics / WIMPless DM
Post-Inflationary Axion
Asymmetric DM
Freeze-In DM
SIMPs / ELDERS

Indirect WIMP searches with radio

WIMPs can annihilate/ decay into standard model products. The resulting particles interact with the magnetic field of an astrophysical environment.

Resulting synchrotron emission is observable in the radio band.





Simplified recipe for radio signal.

1. Determine the source function of charged particles.

$$Q_e(r, E) = \langle \sigma v \rangle \sum_f \frac{dN^f}{dE} \mathcal{B}_f \frac{\rho_\chi^2}{2\mathrm{M}_\chi}$$

2. Solve the diffusion-loss equations to get φ.

- Green's functions.
- Operator splitting method.

$$\nabla \left(D(E, \mathbf{x}) \nabla \psi\right) + \frac{\partial}{\partial E} \left(b(E, \mathbf{x}) \psi\right) + Q_e(E, \mathbf{x}) = 0$$

3. Determine the synchrotron emission

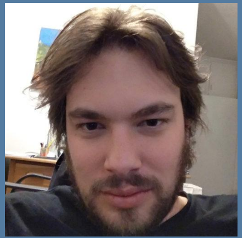
$$j_{\rm sync}(\nu, r, z) = 2 \int_{m_e}^{M_\chi} dE \; \psi(E, r) P_{\rm sync}(\nu, E, r, z)$$

4. Flux density

$$I_{\rm sync}(\nu, \Theta, \Delta\Omega, z) = \int_{\Delta\Omega} d\Omega \int_{\rm l.o.s} dl \; \frac{j_{\rm sync}(\nu, r, z)}{4\pi \Delta\Omega}$$

DarkMatters
Beck and Sarkis

Powerful in-house tool to model dark matter emissions given some standard parameters of target environment.



Dr G Beck

Dr M Sarkis

MeerKAT

Based in South Africa, in the Karoo desert.

SKA1-Mid precursor, and the best interferometer in the decimetre range.

Unique configuration of 64 dishes.

Incredible sensitivity, high angular resolution and large view of view.

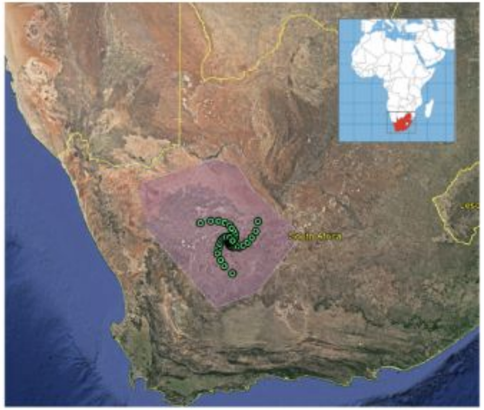
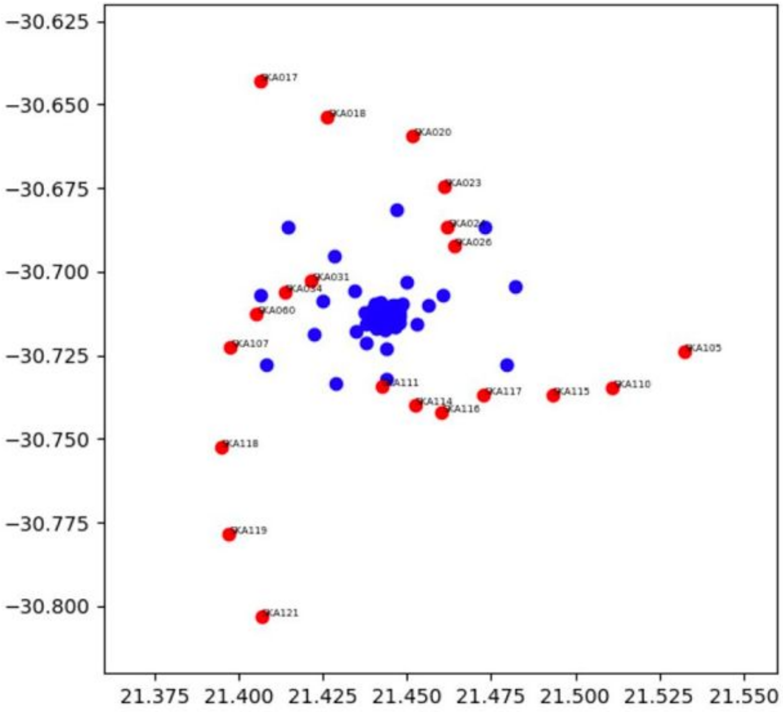


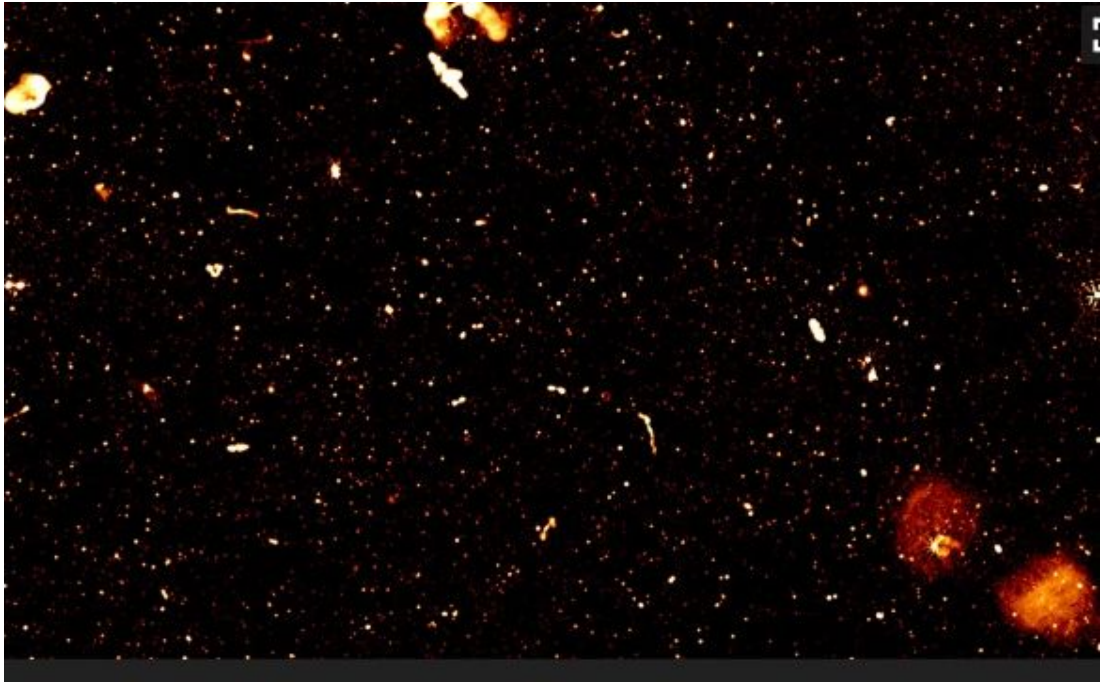
Image credit SKAO



Astrophysical targets

Aspects to take into account when choosing a target:

- Distance
- Dark Matter content
- Minimal uncertainties
- Presence of astrophysical signals



Wide field view of a cluster field released with MGCLS. (Image: SARAO)

MeerKAT Galaxy Cluster Legacy Survey

MGCLS
MeerKAT Galaxy Cluster Legacy Survey

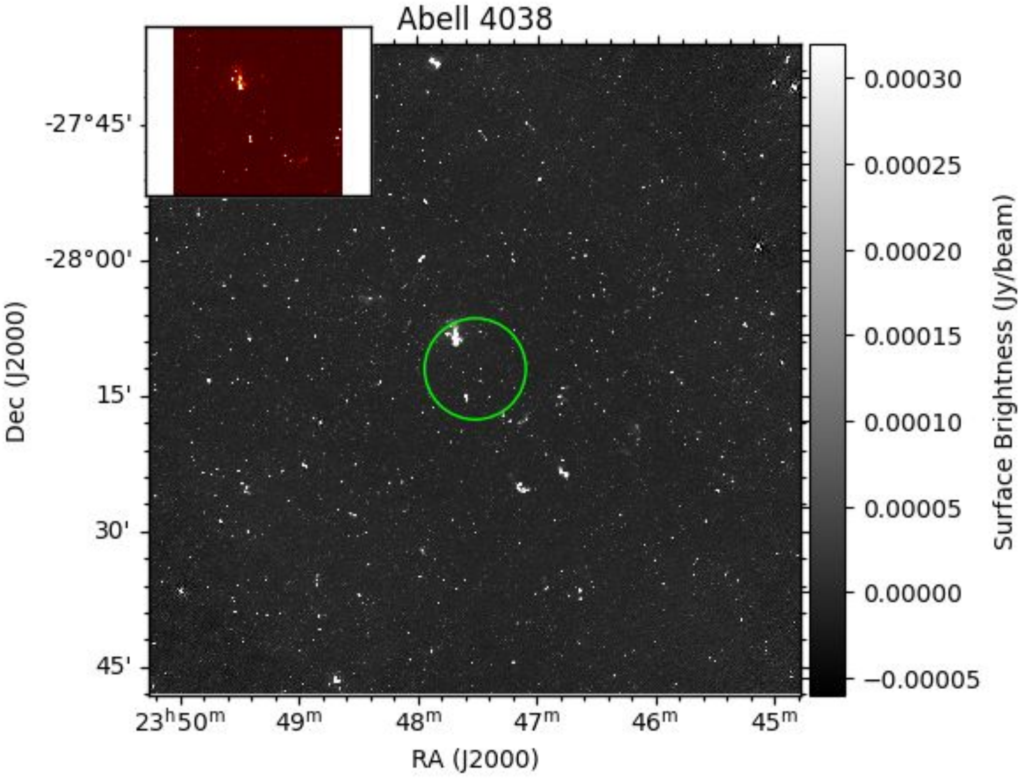
PI Kenda Knowles *Astronomy & Astrophysics* 657 (2022): A56.

115 galaxy clusters, 6-10 hours on source in full polarisation.

Data release 1 is publicly available

Includes enhanced spectral and polarisation image cubes 8 and 15 arcminute resolution

3- 5 µJy beam^{-1}



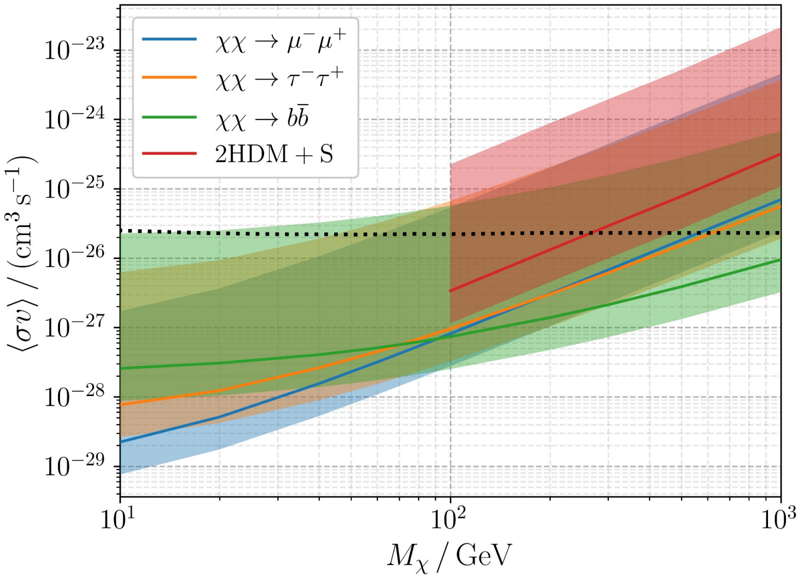
Abell 4038

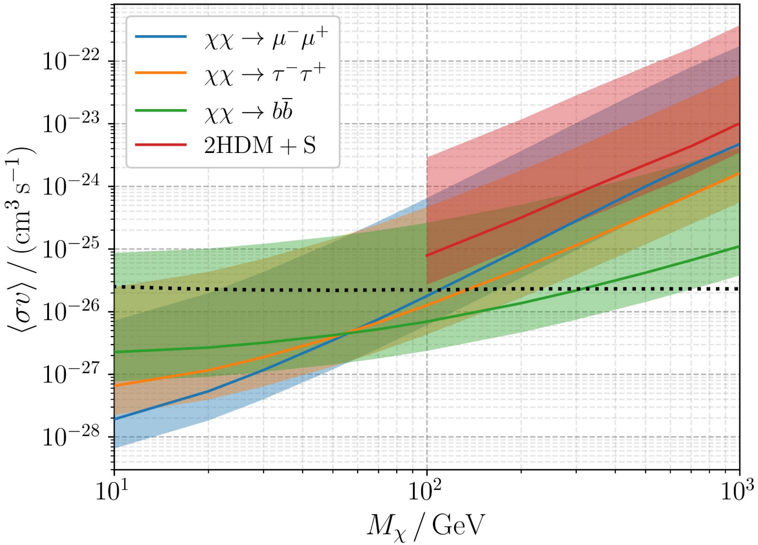
Lavis et al 2023 Physical Review D 108.12 (2023): 123536

Left integrated flux comparison

Right pixel by pixel

$$z = 0.028$$
$$B_0 = 8\,\mu\mathrm{G}$$
$$n_0 = 0.022\,\mathrm{cm}^{-3}$$
$$M_{\mathrm{virial}} = 6.66 \pm 1.4(10^{15} M_\odot)$$

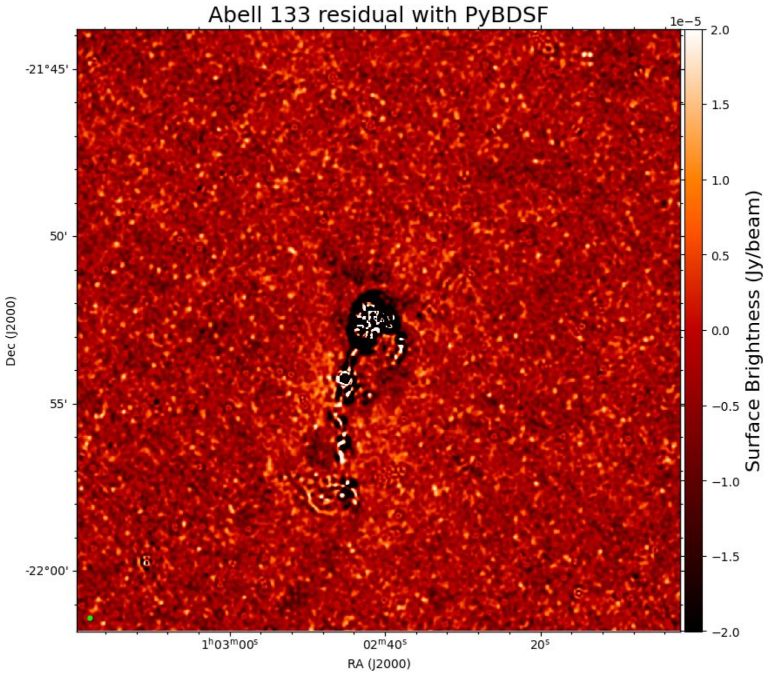


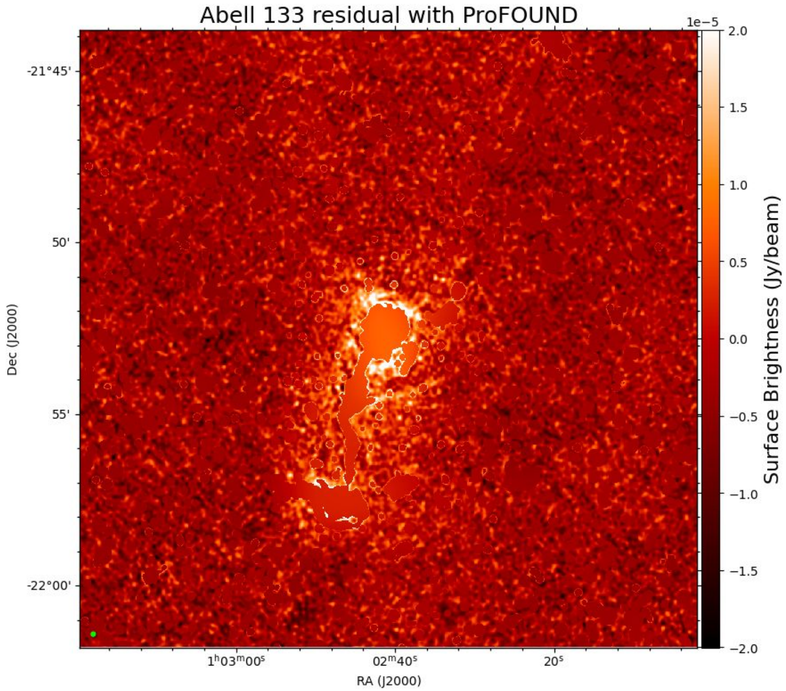


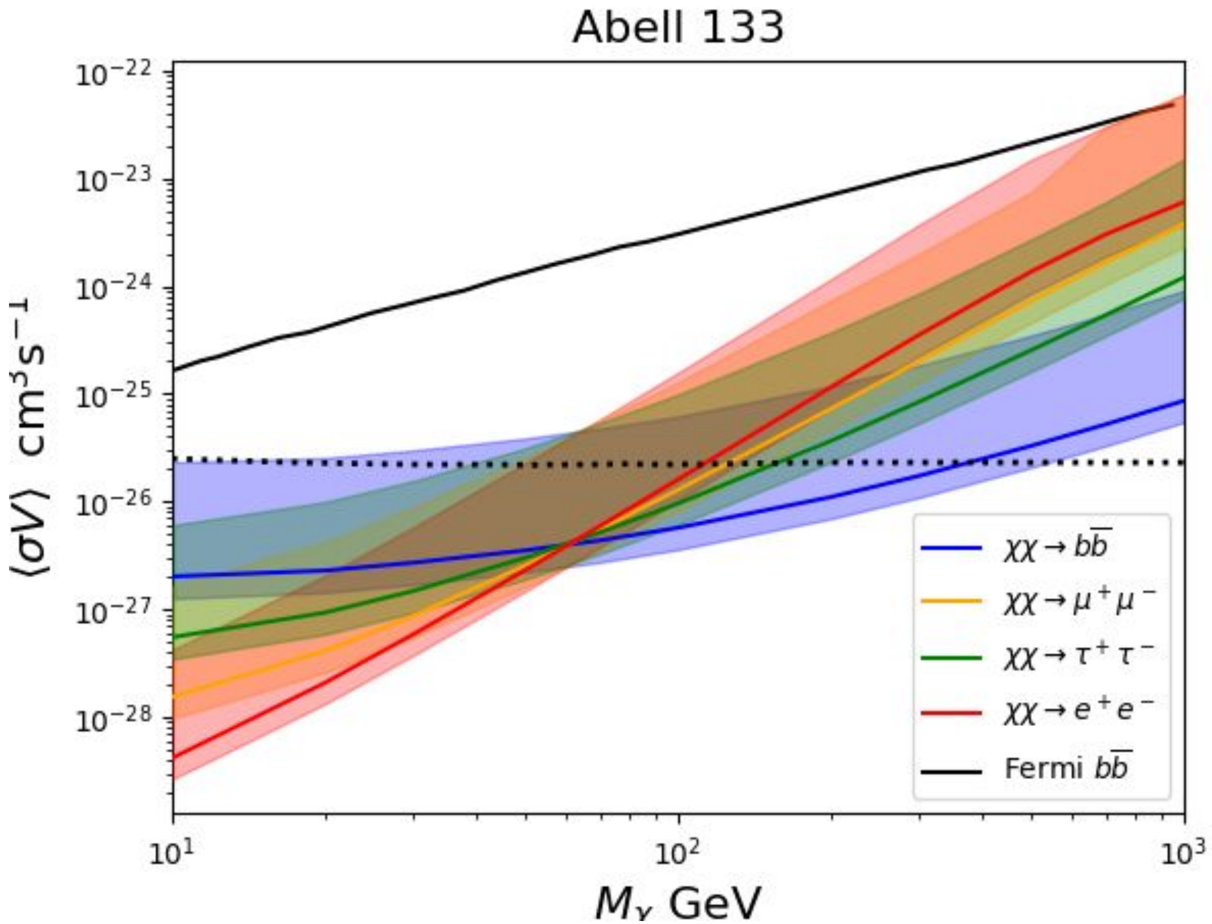
Removing contaminants

PyBDSF: radio source finder, fits Gaussians to islands of emission. Bad for extended emission.

ProFOUND: typically used for optical data, fits islands of emission pixel-wise to a given bound.





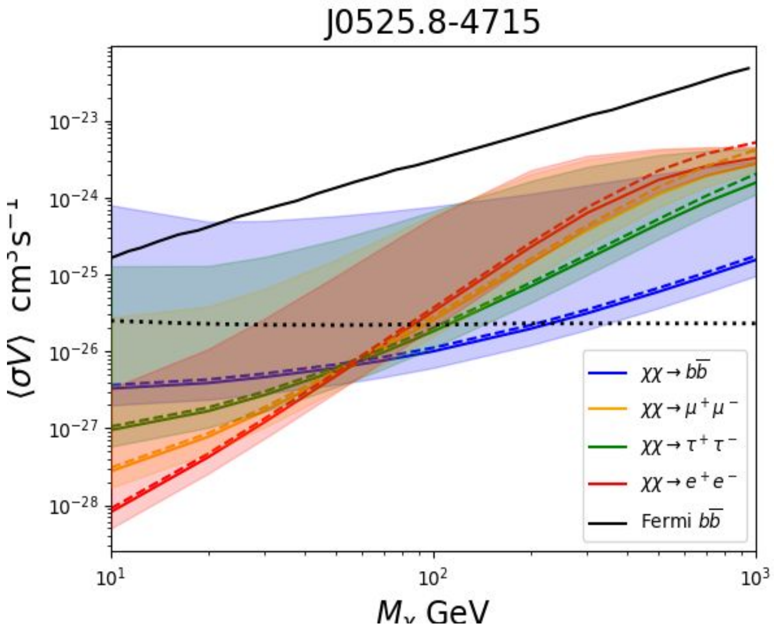


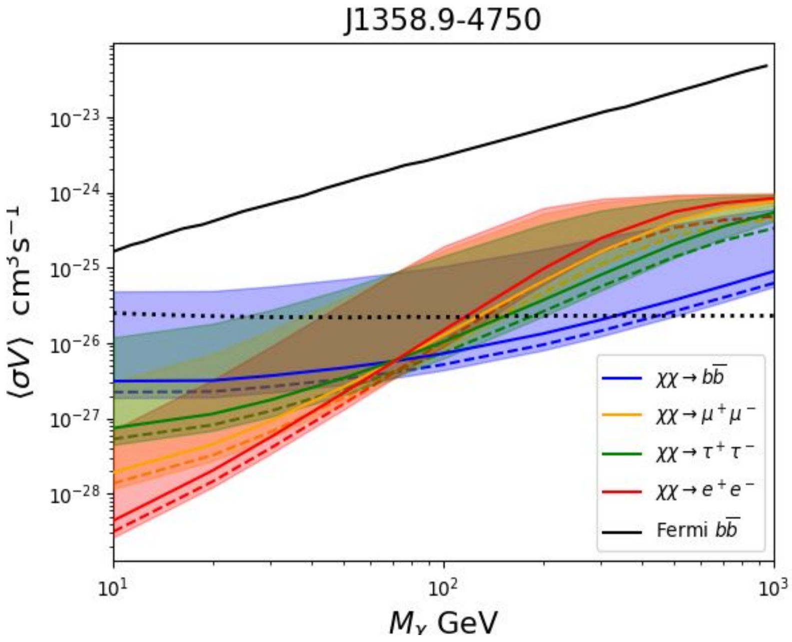
Abell 133
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-26}
10^{-27}
10^{-28}
$\langle \sigma V \rangle$ cm^{3}s^{-1}
10^1
10^2
10^3
M_χ GeV
$\chi\chi \to b\bar{b}$
$\chi\chi \to \mu^+\mu^-$
$\chi\chi \to \tau^+\tau^-$
$\chi\chi \to e^+e^-$
Fermi $b\bar{b}$

Additional targets

Two clusters without complex extended sources.

Subtraction comparable for the two packages.





Outlook

MeerKAT has allowed us to produce more stringent limits than gamma ray experiments.

Upcoming

Tool for determining WIMP upper limits given radio image planes.

Investigating axion signals with MeerKAT

natashalavis1@students.wits.ac.za