Hunting dark matter with a MeerKAT

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DARK MATTER

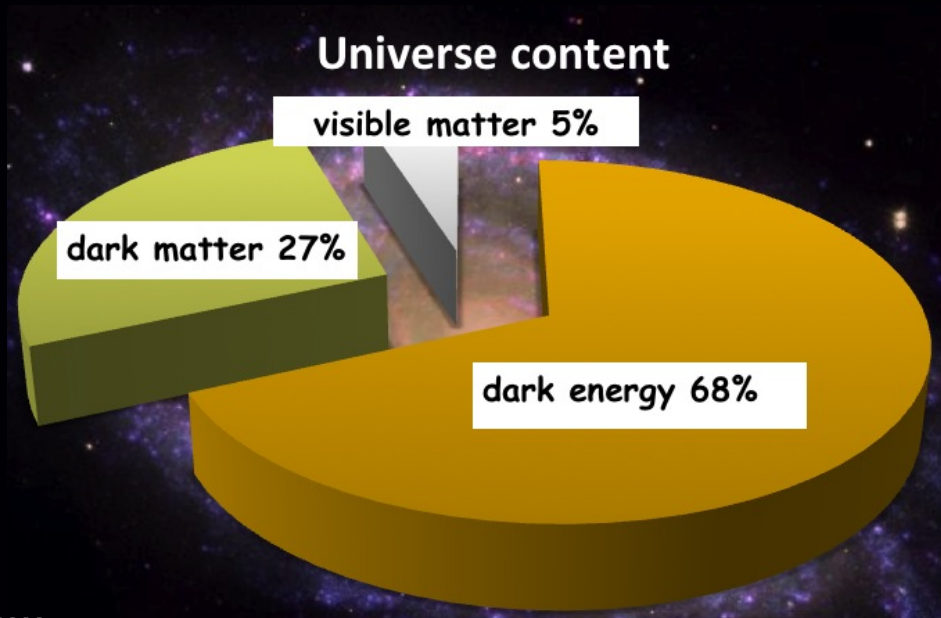
UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Talk outline

- What do we know about dark matter?
- How do you search for the invisible?
- Previous searches with radio telescopes
- MeerKAT and the MGCLS
- Results with galaxy clusters
- Conclusion

What do we know about dark matter?

- It’s important
- It’s massive
- It’s probably a particle
- Electrically neutral

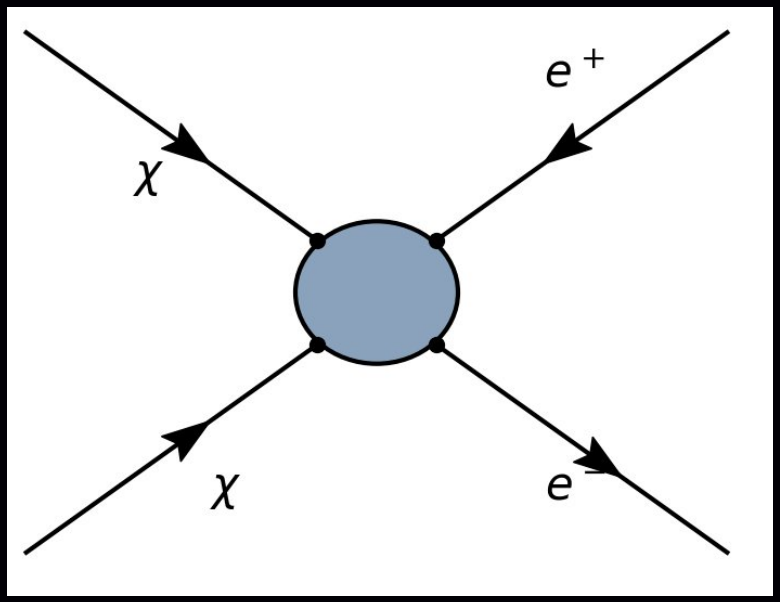


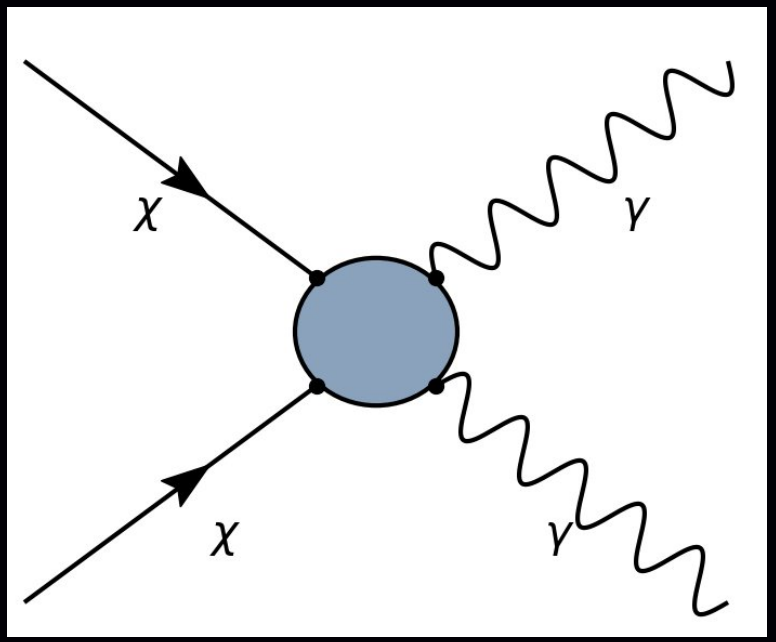
That’s not much to go on....

So how do we search for it?

WIMPs (Weakly Interacting Massive Particles)

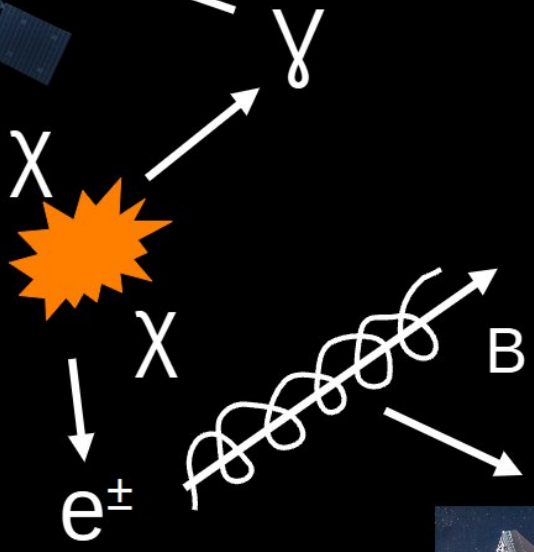
- Very “generic” type of dark matter (lots of possible models!)
- Massive, neutral particle with weak interactions
- Could decay or self-annihilate





The standard model products are visible!

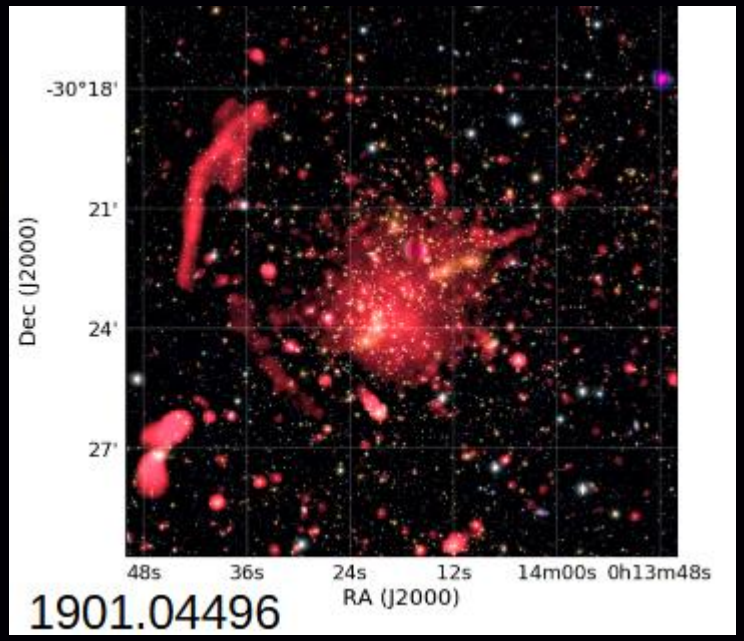
What to look for?



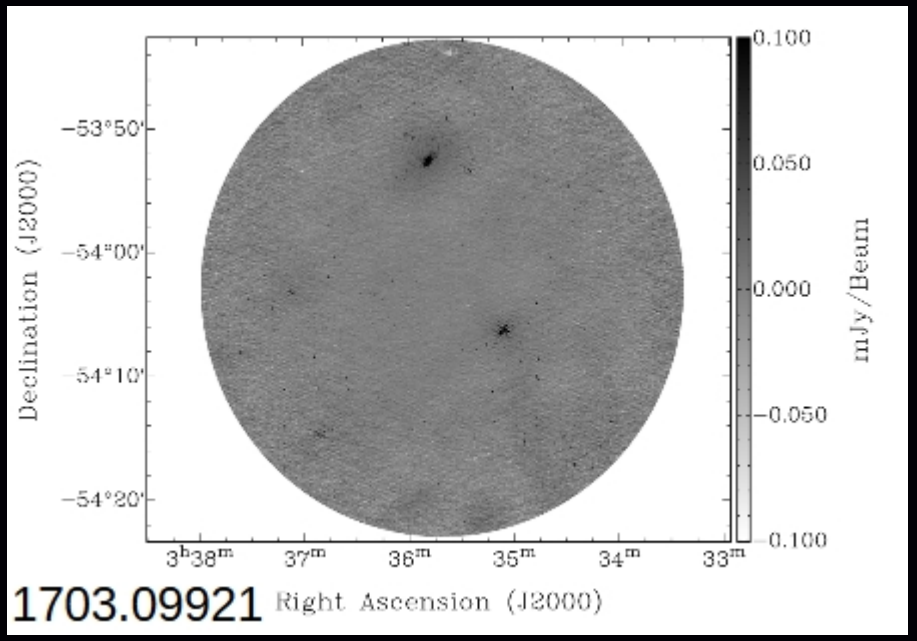
For large DM masses
(> 5 GeV)

Signatures in radio

- Diffuse emission: no clear point source
- Dark matter exists in a halo
- Strong central emission from high density



Diffuse



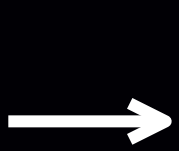
Point sources

Solving diffusion equations

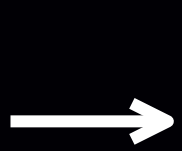
$$\frac{d\,\psi}{d\,t} = \nabla(\mathrm{D(E,r)}\nabla\psi) + \frac{d}{dE}(\mathrm{b(E,r)}\psi) \; + \; \mathrm{Q(E,r)}$$

- Our own code: DarkMatters (will be public soon)
- Crank-Nicolson discretisation
- Accelerated ADI solver like Galprop
- Matrix equations solved with sparse solver
- Fast and accurate

Particle physics
+
Dark matter halo
+
Magnetic field
+
Diffusion environment



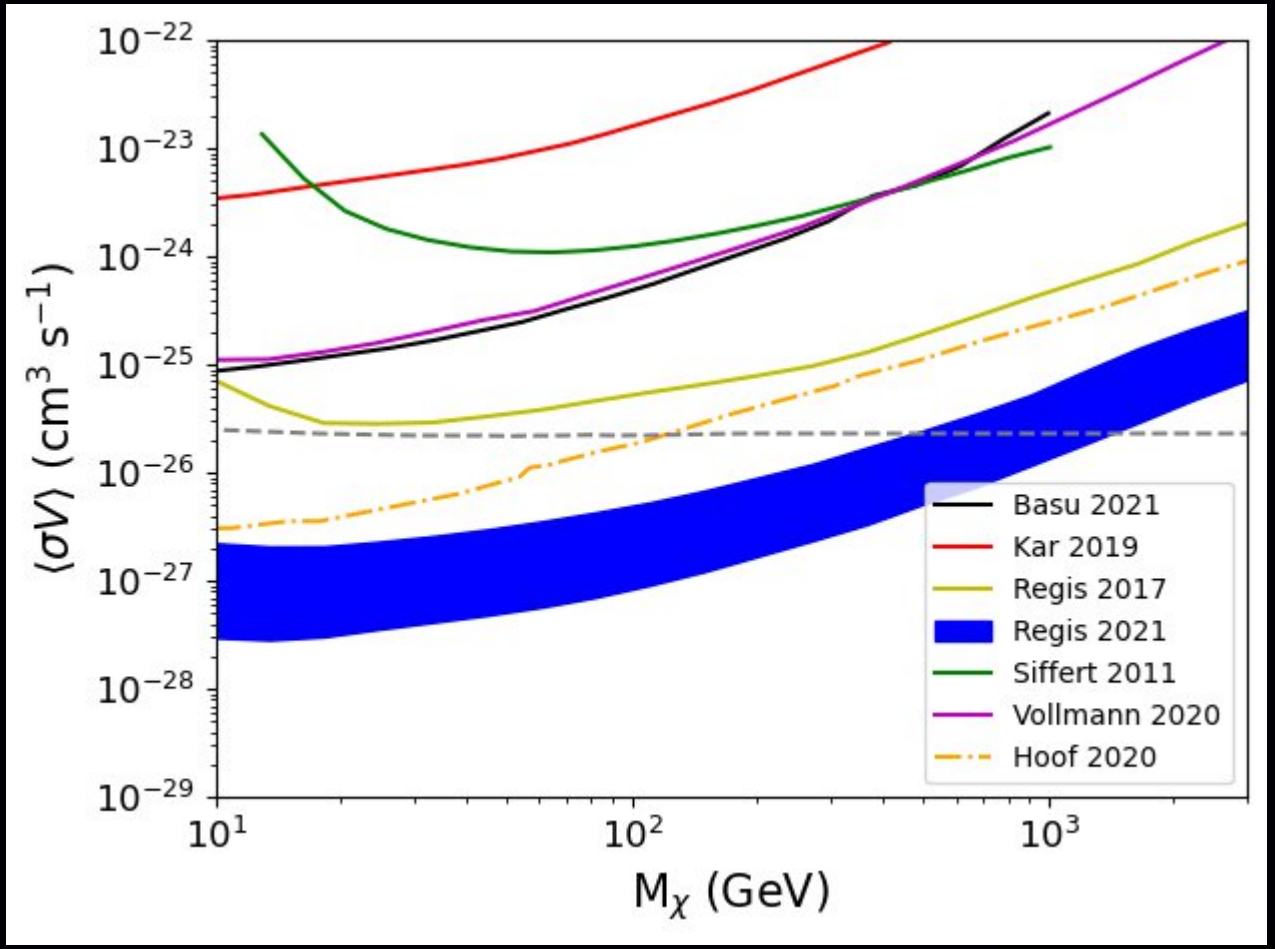
DarkMatters



Radio predictions

Searches for WIMPs

- Haven't found DM
- Placed limits on annihilation rate



Galaxy clusters vs dwarfs

Galaxy clusters:

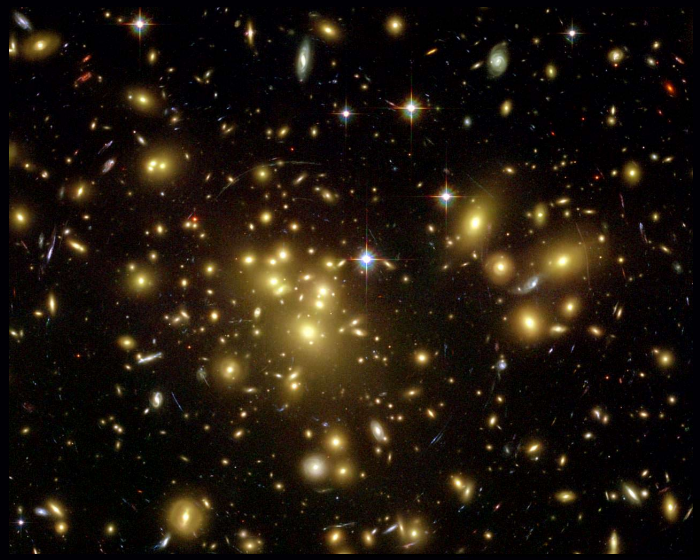
Pros:
Highly DM dominated
Magnetic field information
Diffusion information
Halo information

Cons:
Baryonic backgrounds

Dwarf galaxies:

Pros:
Highly DM dominated
Low baryonic backgrounds

Cons:
Magnetic field unknown
Diffusion environment unknown
Halo uncertainties



Why MeerKAT?

- High angular resolution (resolve small sources)
  Need to subtract point sources to see diffuse
- High sensitivity (faint DM emissions)
- Wide frequency bands
- Many frequency channels (line searches)

The MGCLS

MeerKAT Galaxy Cluster Legacy Survey, arXiv: 2111.05673

- 115 Galaxy clusters at L-band (900 - 1670 MHz)
- 6-10 hrs observation on each cluster
- 8 arcsecond resolution
- 3-5 μJy/beam sensitivity

- 62 with diffuse emission (56 of which are new)
- We want those without diffuse and at low z
- We need to pick those with halo information though!

The MeerKAT Galaxy Cluster Legacy Survey

I. Survey Overview and Highlights

K. Knowles[1,2,3,⋆], W. D. Cotton[4,3], L. Rudnick[5], F. Camilo[3], S. Goedhart[3], R. Deane[6,7], M. Ramatsoku[2,8], M. F. Bietenholz[9,10], M. Brüggen[11], C. Button[7], H. Chen[12], J. O. Chibueze[13,14], T. E. Clarke[15], F. de Gasperin[11,16], R. Ianjamasimanana[2,3], G. I. G. Józsa[3,2,17], M. Hilton[1,18],

The MGCLS: our targets

So far we have found 3 good targets

A4038

Virial mass 4.6 x 10^{14} M_{sun} (Wojtak and Lokas 2007)
z ~ 0.028
Cool-core B ~ 8 μG

RXCJ0225.1-2928

M_{500} ~ 0.96 x 10^{14} M_{sun} (Shakouri et al 2016)
z ~ 0.06
Not cool-core B ~ 5 μG

A133

R_{vir} ~ 1.44 Mpc (Zhu et al 2021)
c_{vir} ~ 6.28
Cool-core B ~ 8 μG

The MeerKAT Galaxy Cluster Legacy Survey

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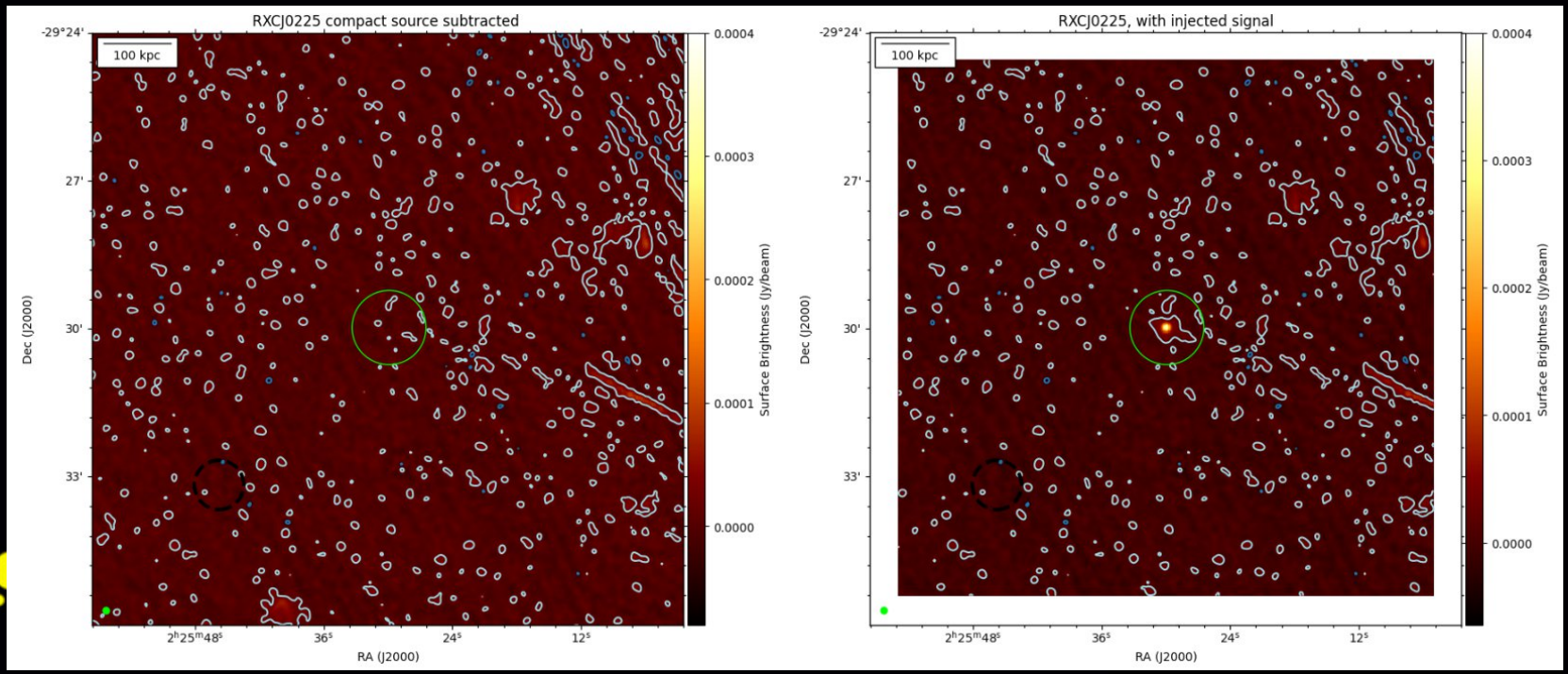
The MGCLS: our method

For each target we do the following:

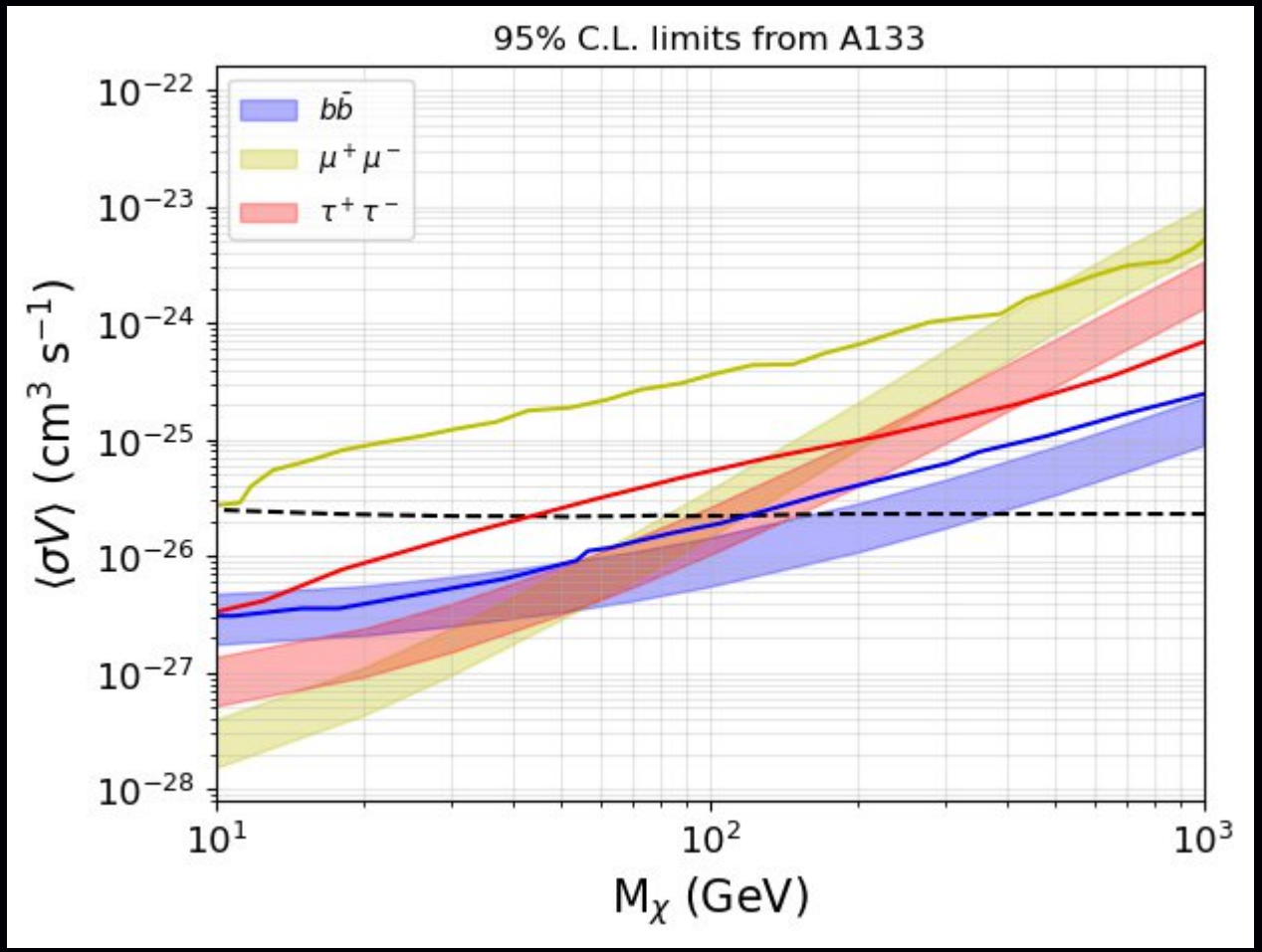
- Subtract point sources (image plane only - PYBDSF)
- Compare residual map and DarkMatters map
- Perform χ^2 test to find 95% confidence exclusion
- Consider both NFW and shallow cusp halos



Results: A133

Lavis, Sarkis, Beck, & Knowles in prep

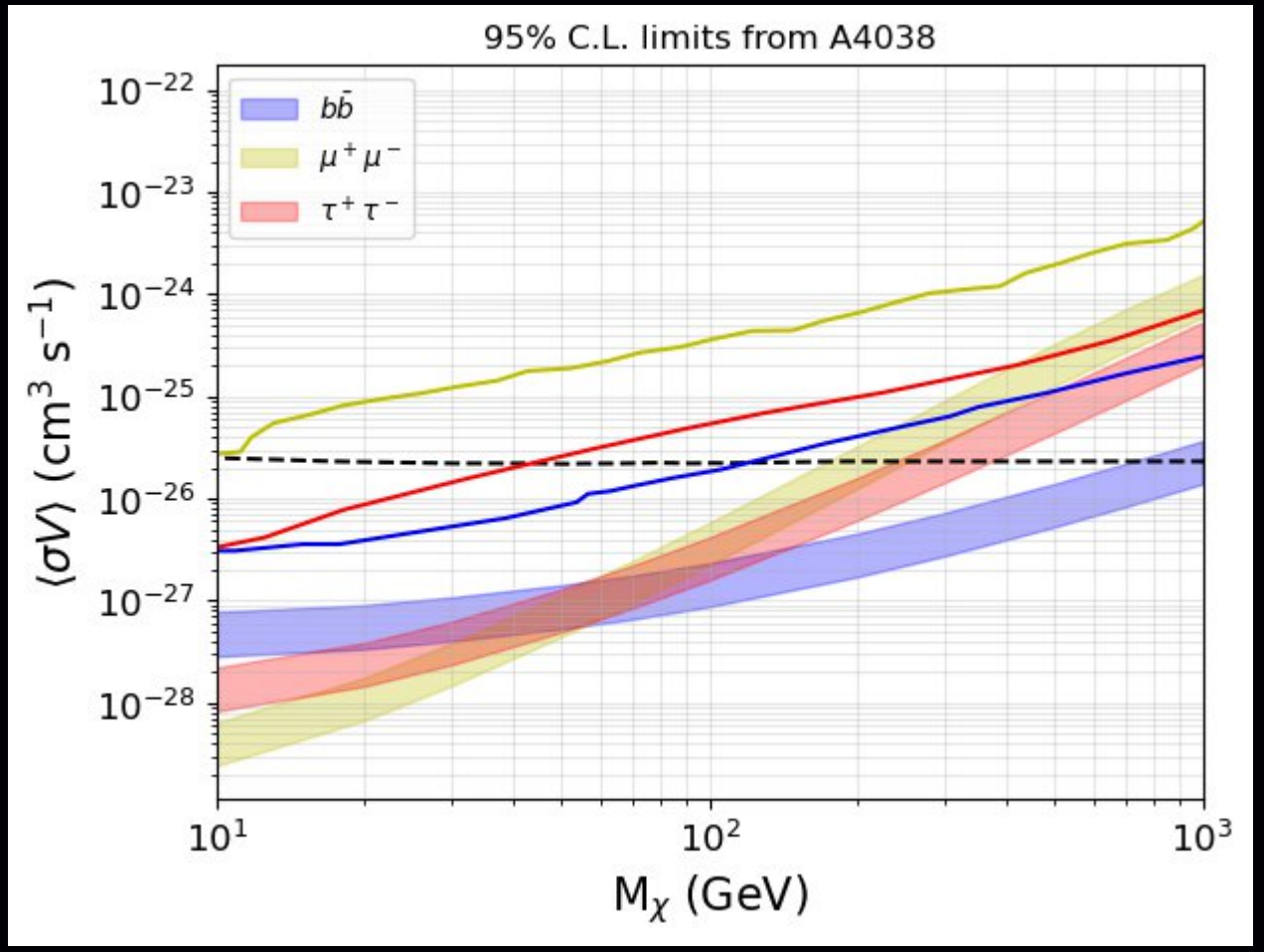
Solid lines: Fermi-LAT (gamma-rays)



We exceed Fermi-LAT within halo uncertainties

Results: A4038

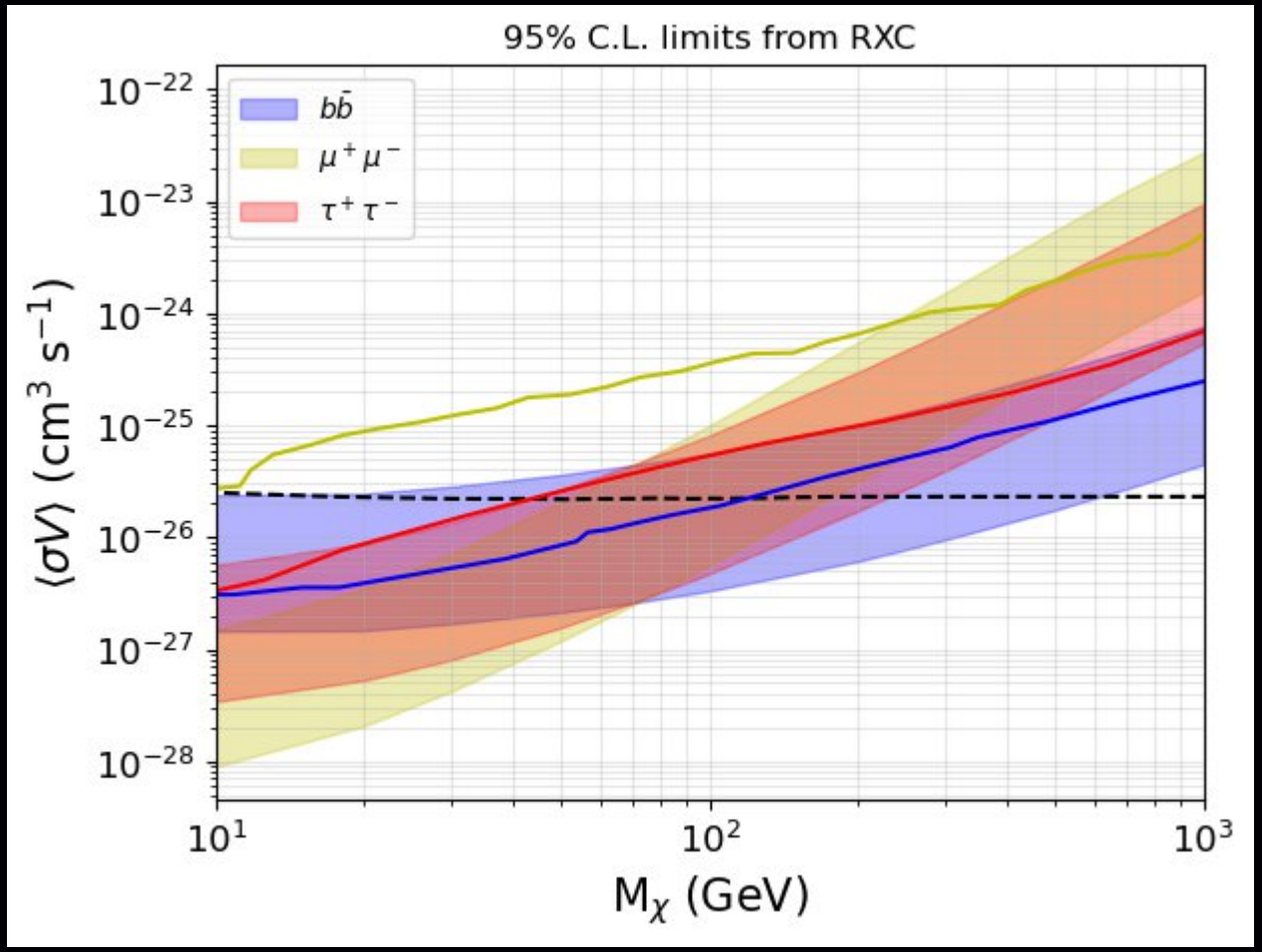
Lavis, Sarkis, Beck, & Knowles in prep



Way better than Fermi! Competes with Regis 2021

Lavis, Sarkis, Beck, & Knowles in prep

Results: RXCJ0225.1-2928



Very sensitive to halo profile, but very strong for NFW

Conclusions and the future

- Powerful limits from MGCLS, competitive with best in literature
- This will improve with more advanced analysis
- Source subtraction from visibilities needed
- Dwarf galaxy analysis currently underway
- Discovery potential (not just constraints)?

MeerKAT and South Africa are on the cutting edge of DM searches