

# DETECTING DARK MATTER SIGNALS BY RADIO DATA OF GALAXY CLUSTERS

CHAN, Man-Ho

# DARK MATTER

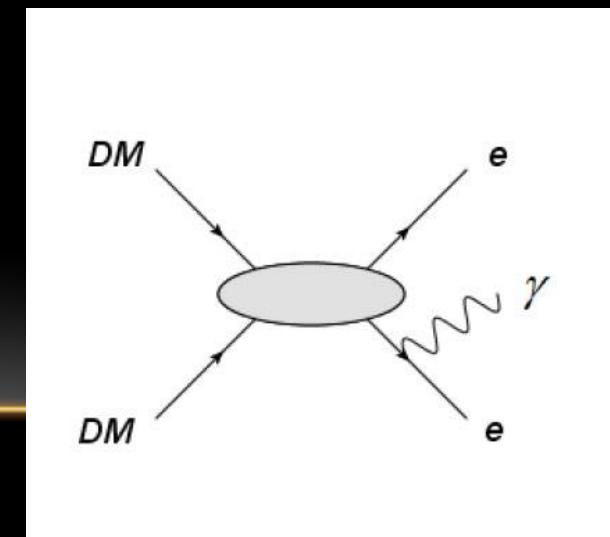
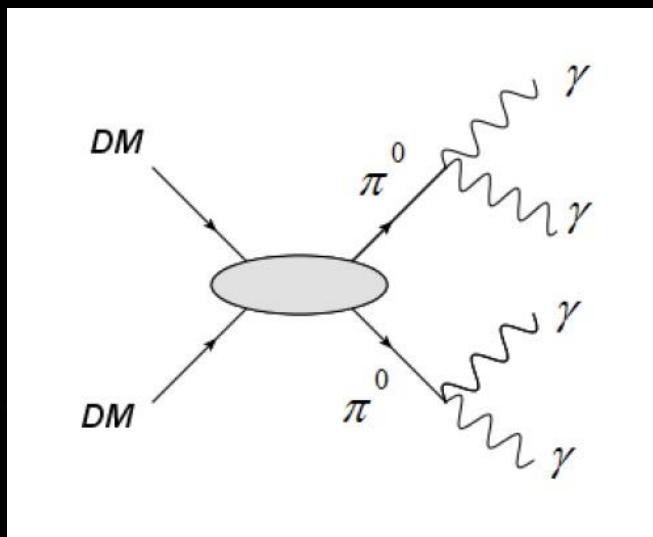
- Ordinary matter: reflect/emit electromagnetic waves → can be observed!
- Some objects do not reflect/emit any electromagnetic waves → cannot be observed!
- We call them “Dark Matter”

## DARK MATTER CONTENT

- 90% of total mass is dark matter in normal galaxies
- More than 99% of total mass is dark matter in M87
- 95% of total mass is dark matter in our galaxy
- Nearly 90% of total mass is dark matter in galaxy clusters

# DARK MATTER ANNIHILATION

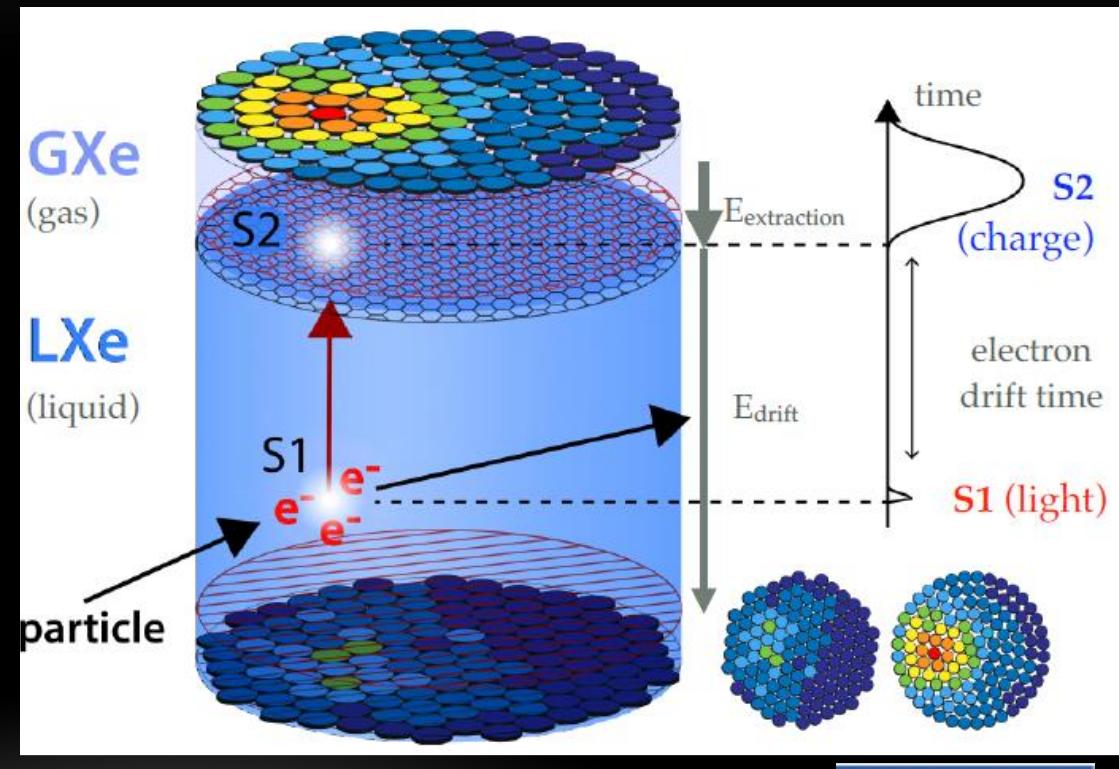
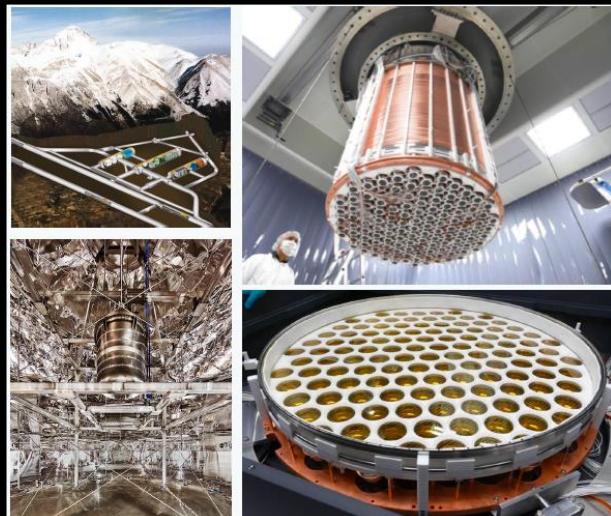
- Particle + Anti-particle  $\rightarrow$  annihilation (give photons, electrons, positrons, etc.)
- If dark matter particle = dark matter anti-particle, then  $\chi + \chi \rightarrow$  photons, electrons, etc.



# WAYS TO DETECT/CONSTRAIN DARK MATTER

- Direct-detection experiments
- Indirect-detection experiments
  - Gamma-ray detection
  - Positron detection
  - Radio detection

# DIRECT-DETECTION EXPERIMENT

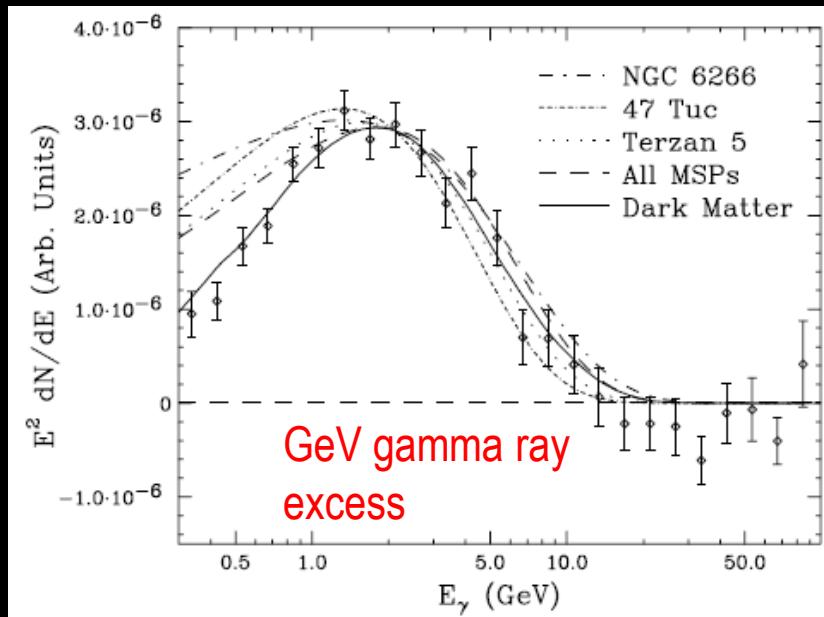


XENON1T experiment

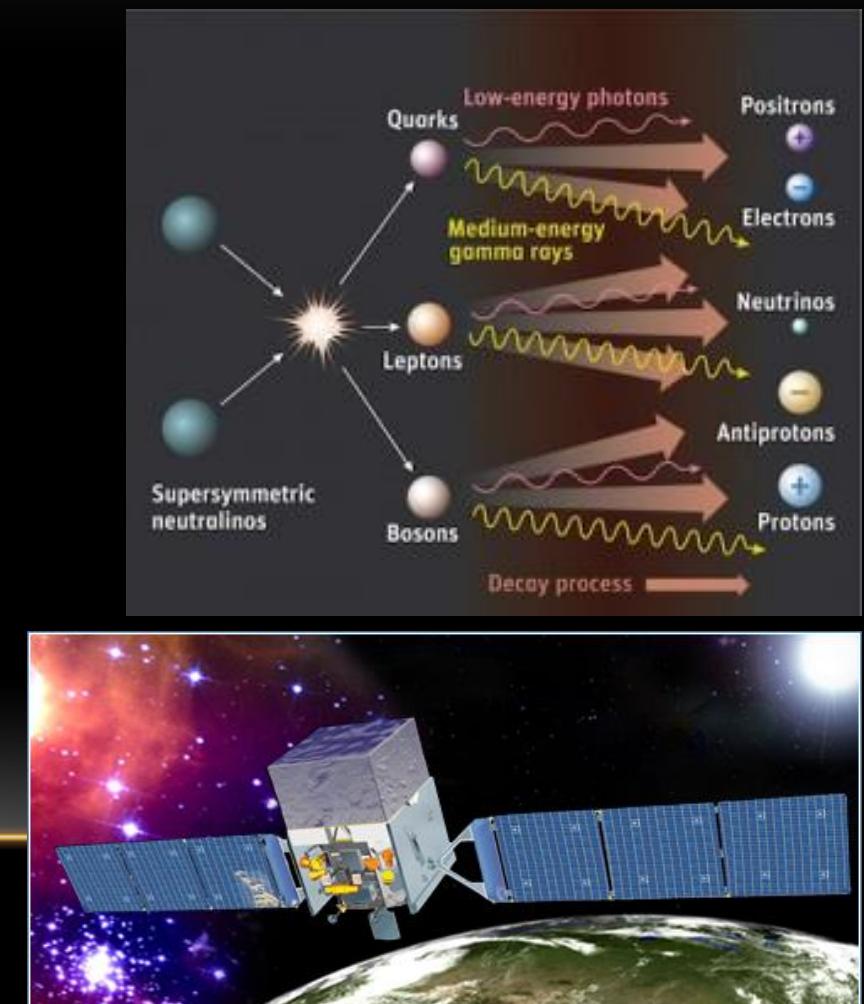


# INDIRECT-DETECTION EXPERIMENT

- Gamma-ray detection
- Detect gamma-ray signal from dark matter annihilation / decay

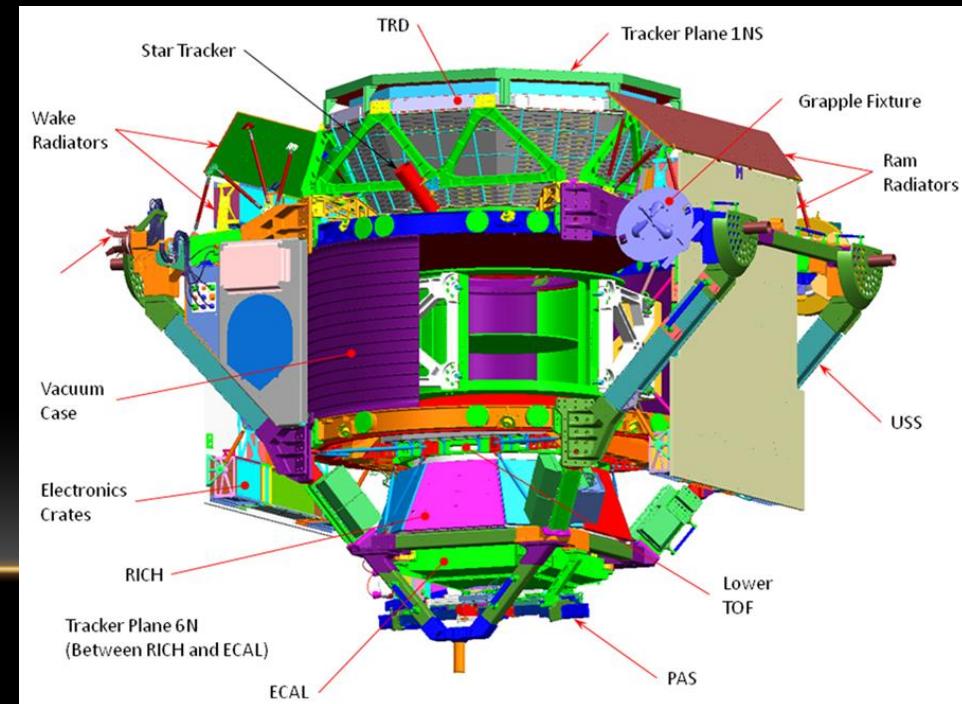
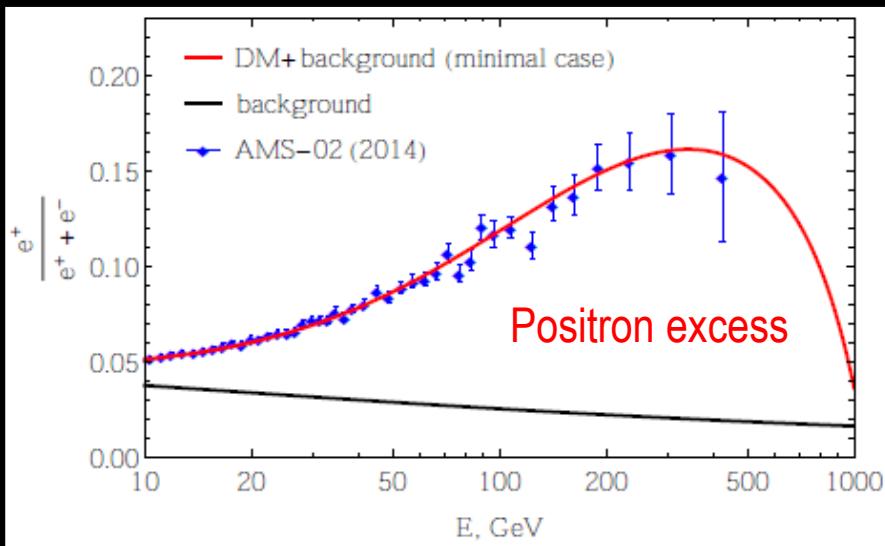


Fermi-LAT Gamma ray detection  
DM mass  $\sim 10 - 100$  GeV



# INDIRECT-DETECTION EXPERIMENT

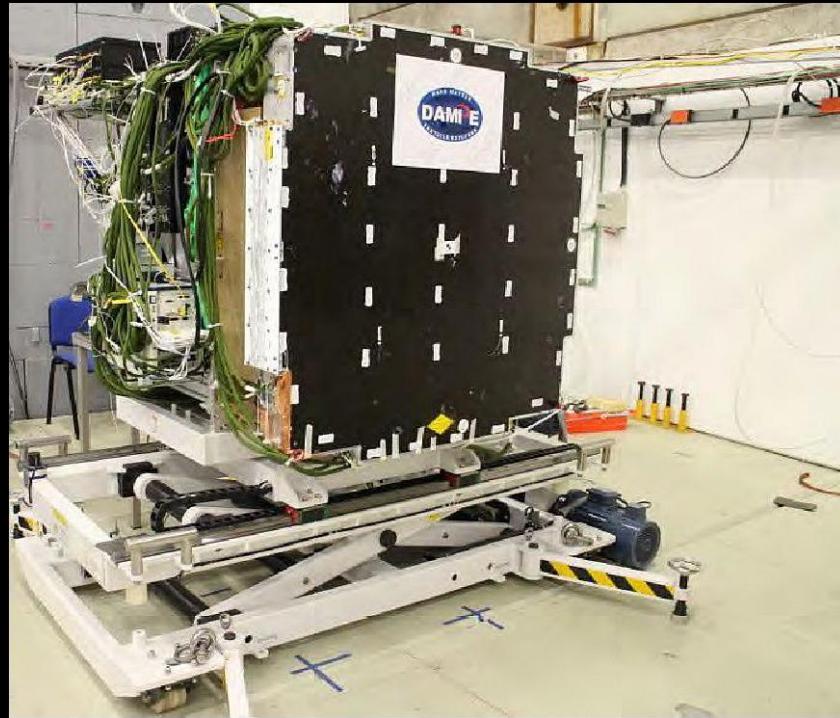
- Alpha-Magnetic-Spectrometer (AMS) detection (led by Nobel Laureate Prof. Samuel Ting)
- Detect positron and anti-proton signals



Dark matter mass  $\sim 50 - 600$  GeV

# INDIRECT-DETECTION EXPERIMENT

- Dark Matter Particle Explorer (DAMPE)
- Detect gamma-ray and positron/electron signals

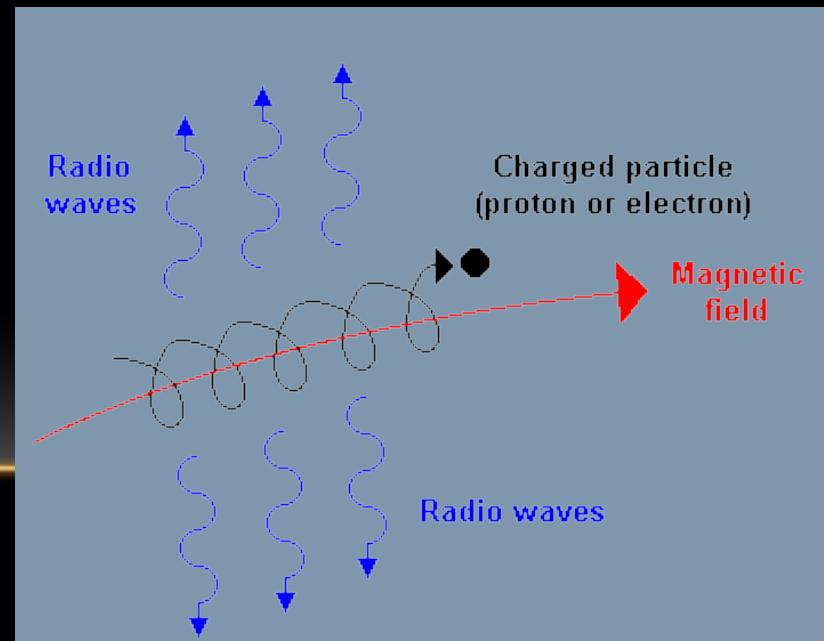
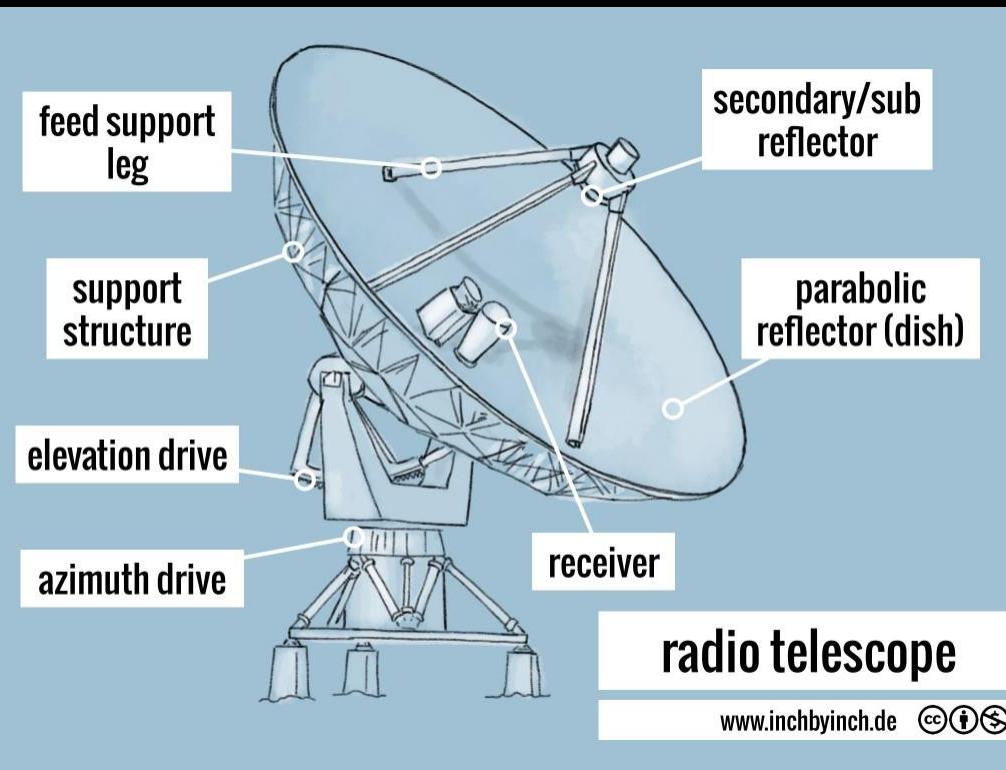
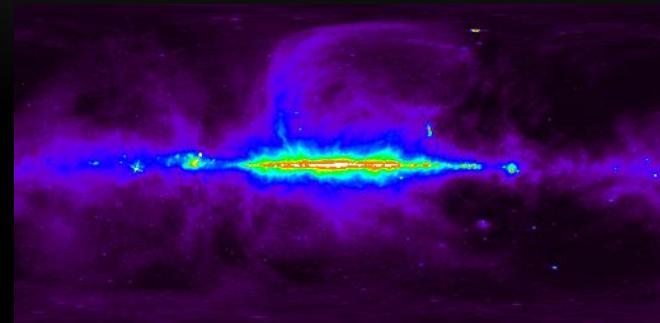


Launched in 2015

Credit: CAS

# INDIRECT-DETECTION EXPERIMENT

- Radio detection (synchrotron radiation)



# RADIO CONSTRAINTS OF DARK MATTER

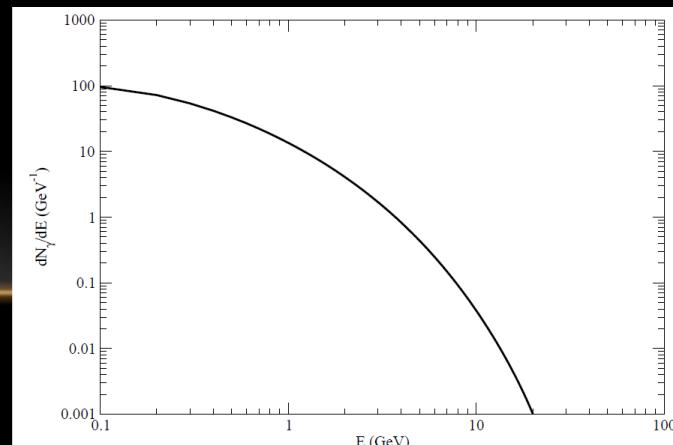
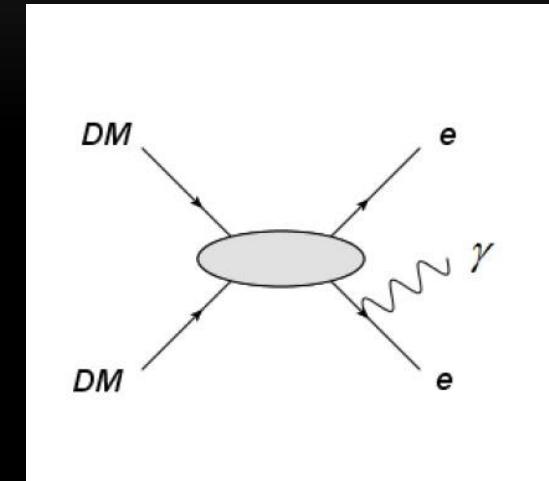
1. Radio signals can be detected easily
2. Synchrotron radiation is well-understood
3. We analyze **galaxy clusters'** radio spectra

Possible systematic uncertainties:

- Magnetic field profile
- Dark matter density profile (Burkert / NFW / Einasto)

# CONSTRAINING ANNIHILATING DARK MATTER

- Dark matter + Dark matter → photons, electrons, positrons, neutrinos, etc.
- Possible annihilation channels: ee,  $\mu\mu$ , bb, hh, WW, etc.
- Annihilation rate =  $\dot{N} = \left(\frac{1}{m^2}\right) \int \rho^2 (\sigma v) dV$
- If dark matter particles are **thermal relic** (the simplest model), the annihilation cross section is  $\sigma v \approx 3 \times 10^{-26} \text{ cm}^3 \text{ s}^{-1}$
- The energy spectrum of each annihilation channel can be predicted

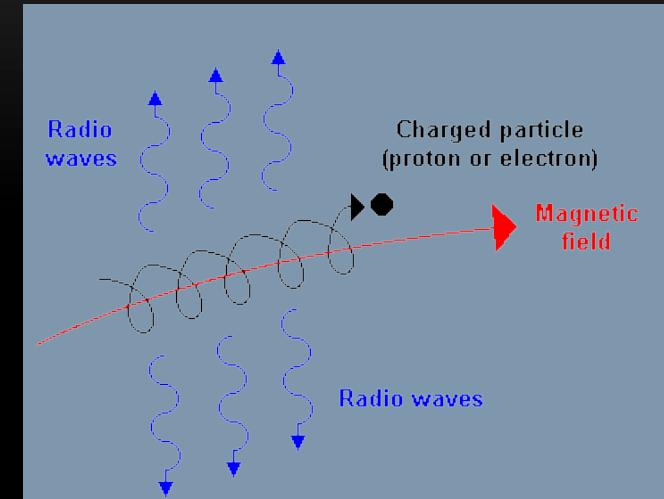


Gamma-ray spectrum of bb channel ( $m = 40 \text{ GeV}$ )

# SECONDARY EMISSION

- Synchrotron radiation

electrons/positrons produced from DM annihilation interact with magnetic field to produce radio waves



- Cooling
- Synchrotron
- Inverse Compton Scattering
- Coulomb Scattering
- Bremsstrahlung

# THE TWO-COMPONENT MODEL

1. Two-component model: DM contribution + CR contribution
2. Predict radio flux emitted due to dark matter annihilation as a function of parameters (dark matter mass  $m$ ):  $S_{DM}(\nu)$
3. Including the cosmic-ray emission spectrum (primary emission, secondary emission, in-situ emission, etc.):  $S_{CR}(\nu)$
4. Compare the predicted value  $S_{DM} + S_{CR}$  with the observed spectrum  $S_{obs}(\nu)$
5. Calculate and maximize the likelihoods
6. We can obtain the best-fit ranges of  $m$

# DIFFUSION EFFECT

- For secondary emission, electrons/positrons would cool down during diffusion

$$\frac{\partial}{\partial t} \frac{dn_e}{dE} = \nabla \left[ D \nabla \frac{dn_e}{dE} \right] + \frac{\partial}{\partial E} \left[ b \frac{dn_e}{dE} \right] + Q \quad \text{Diffusion equation}$$

- The cooling time scale  $\tau_c$  in a galaxy cluster is much smaller than the diffusion time scale  $\tau_d$ , there exists an equilibrium state such that

$$\frac{dn_e}{dE} = \frac{1}{b} \int_E^m Q dE' = \frac{\sigma v \rho^2}{2m^2 b} \int_E^m \frac{dN'}{dE} dE'$$

- The cooling time scale is characterized by  $\tau_c = \frac{1}{b}$
- The diffusion time scale is characterized by  $\tau_d = \frac{R^2}{D_0}$

# SYNCHROTRON PREDICTION

The synchrotron  
kernel function

- Synchrotron power:  $P(\nu, E) = \frac{1}{2} \int \sin^2 \theta d\theta F\left(\frac{x}{\sin \theta}\right) \left(\frac{\sqrt{3}e^3 B}{m_e c^2}\right)$

- $S_{DM}(\nu) = \frac{1}{4\pi D_L^2} \int_0^R \int_{m_e}^m 2 \frac{dn_e}{dE} P dE (4\pi r^2) dr$

- DM distribution: assumed hydrostatic equilibrium

$$\rho_{DM}(r) = \frac{1}{4\pi r^2} \frac{d}{dr} \left[ -\frac{kTr}{\mu m_p G} \left( \frac{d \ln n(r)}{d \ln r} + \frac{d \ln T}{d \ln r} \right) \right]$$

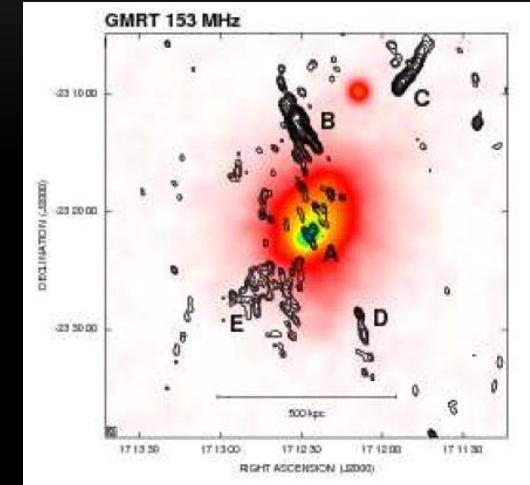
- Magnetic field profile:

$$B(r) = B_0 \left[ \left( 1 + \frac{r^2}{r_c^2} \right)^{-\frac{3\beta}{2}} \right]^\eta$$

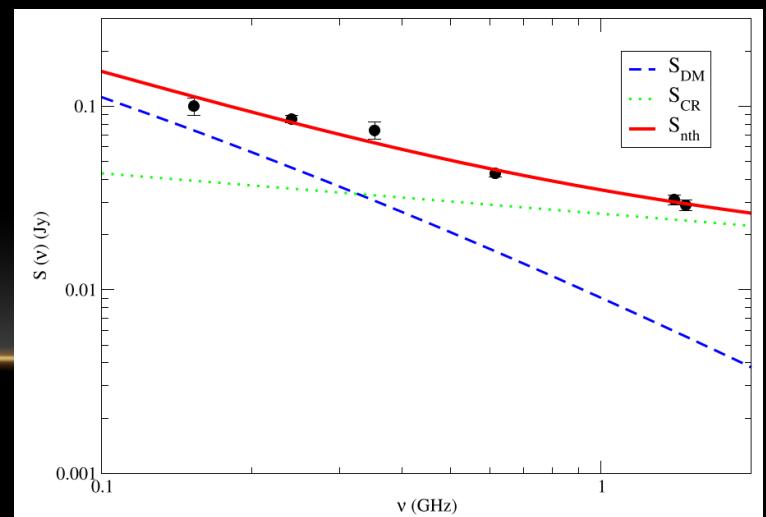
$$B_0 \propto \epsilon^{-0.5} n_0^{0.5} T^{3/4}$$

# LATEST WORK: USING CONTINUUM SPECTRUM

- Our study: central radio halo of the Ophiuchus cluster
- Best-fit: 40 – 50 GeV (b quark channel)
- But the signal is only “marginally positive” ( $< 2\sigma$ )
- CR model: constant spectral index model

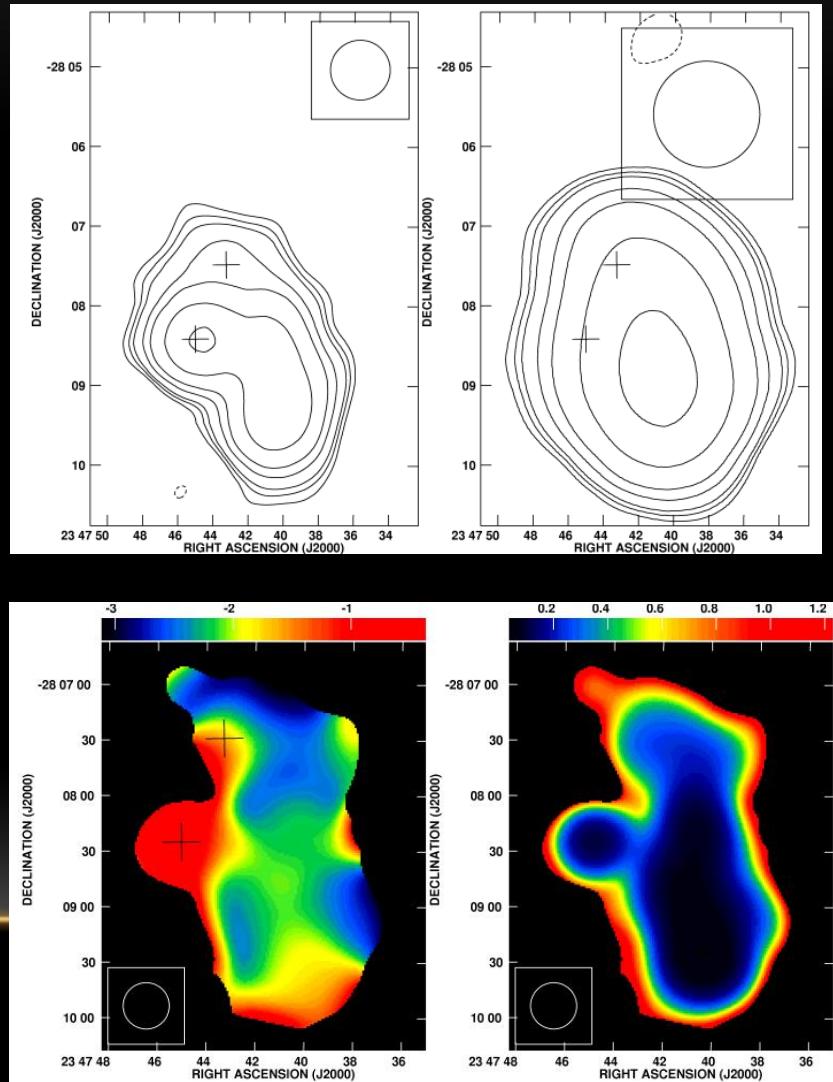
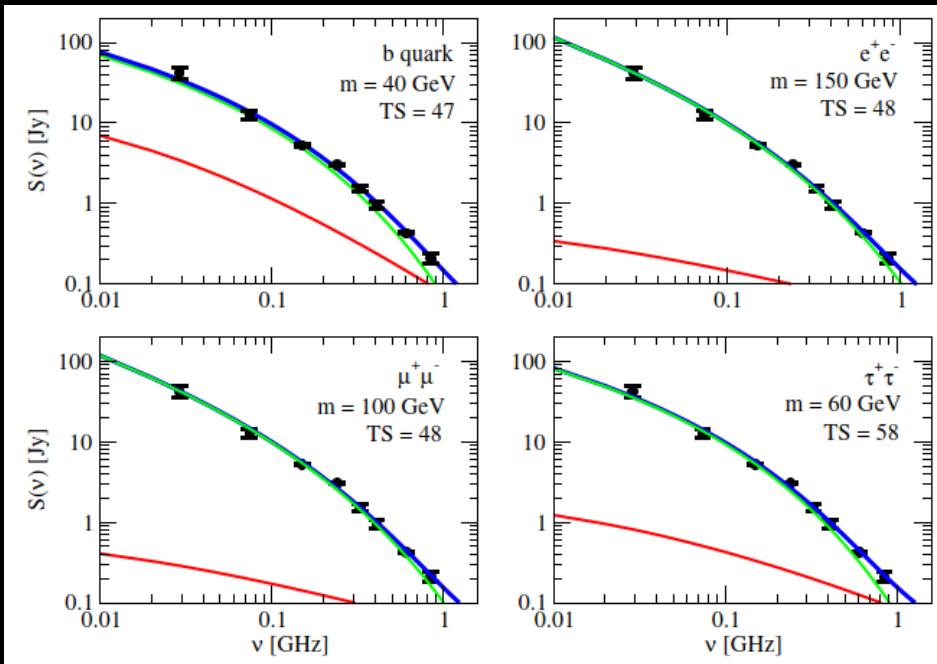


Murgia et al. (2010), A&A, 514, A76.



# ANOTHER STUDY: A4038 CLUSTER

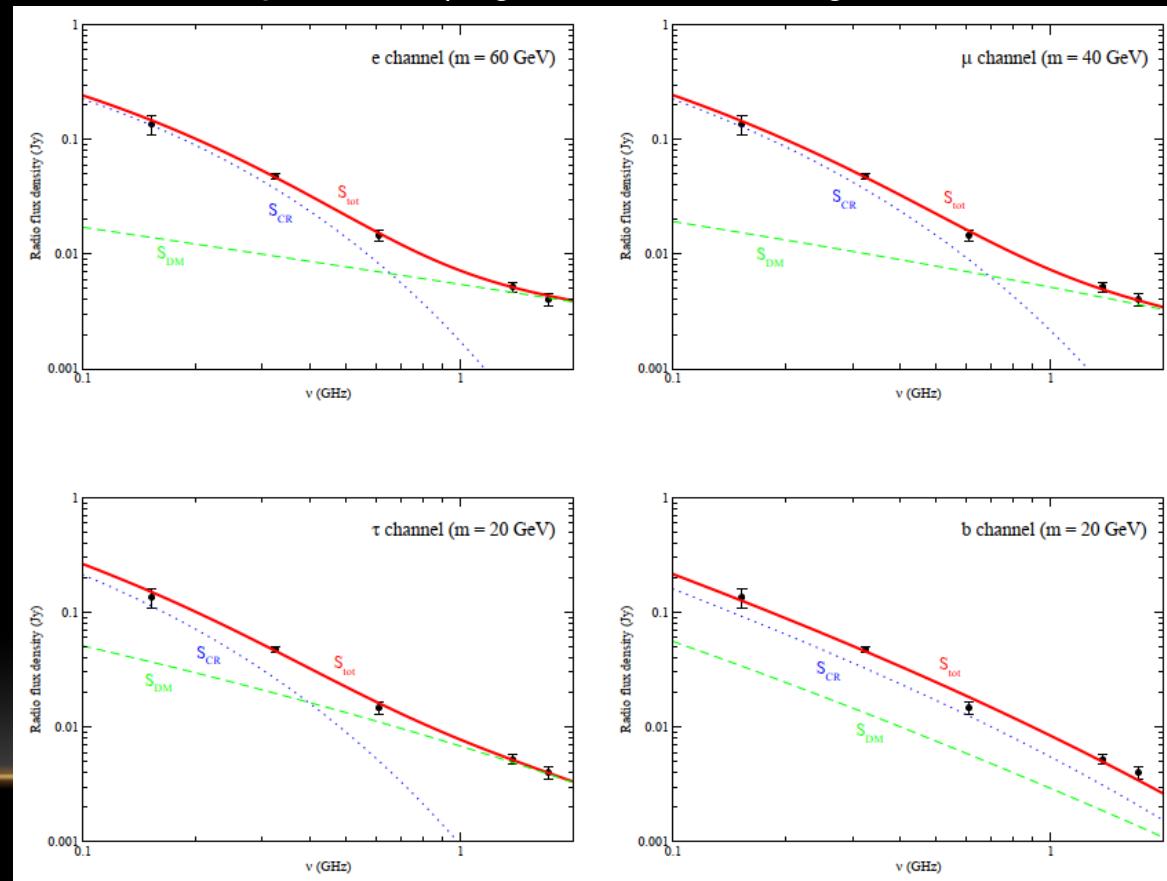
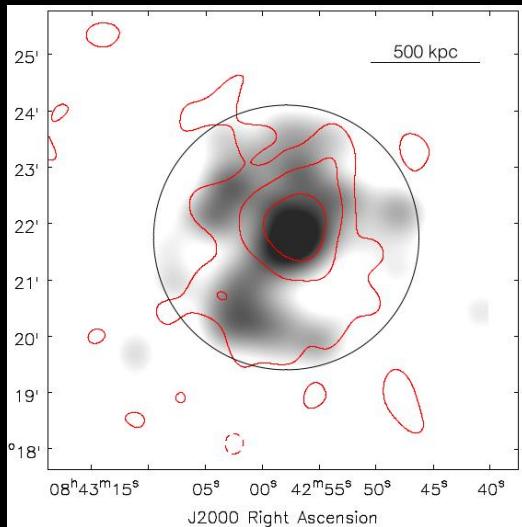
- We study another cluster: A4038 cluster
- Similar best-fit: 40-50 GeV for b quark channel ( $6.9\sigma$  statistical significance)



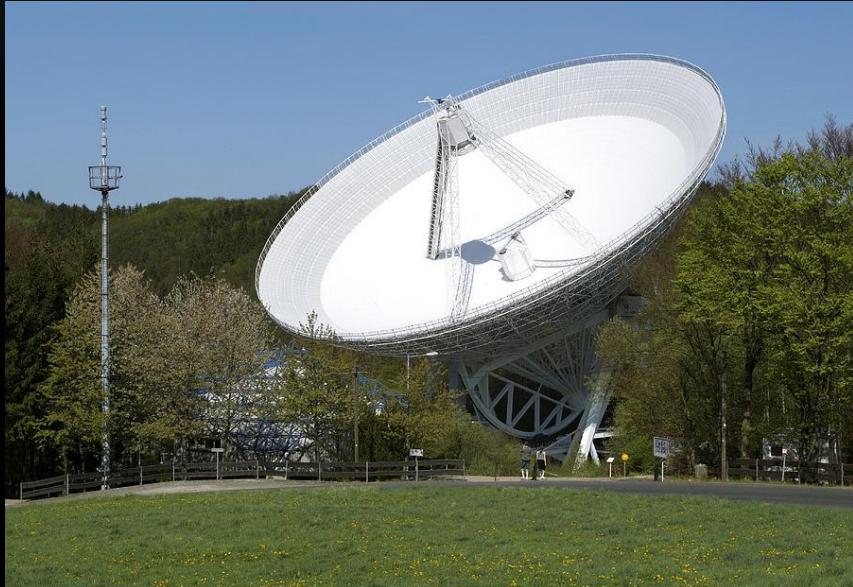
# STUDY OF A HIGH-REDSHIFT GALAXY CLUSTER – ABELL 697 CLUSTER

- Abell 697 cluster: redshift = 0.282 (distance = 911 Mpc)
- The synchrotron radio flux is redshift dependent (e.g. the ICS cooling is proportional to  $(1+z)^4$ )

Best-fit annihilation channel is  $e^+e^-$   
channel with mass = 60 GeV  
Generally speaking,  $m = 30-150$   
GeV is still allowed



# FURTHER STUDIES



100-m Effelsberg radio telescope



MeerKAT



FAST (500 m)

# OUR COLLABORATION TEAM

- Leader: Chan, Man Ho (The Education University of HK)
- Co-leader: Leung, Chun Sing (Hong Kong Polytechnic University); Stephen Ng (University of Hong Kong)
- Collaborators: Geoff Beck (University of the Witwatersrand), Lang Cui (XAO), Z. C. Pan (NAO), Lei Qian (FAST), Jackie Ma (Max Planck)
- Research team member: Lee, Chak Man

## REFERENCES

- Chan M. H. & Lee C. M. (2019), *Phys. Dark Univ.*, 26, 100355.
- Chan M. H. & Lee C. M. (2020), *Mon. Not. R. Astron. Soc.*, in press (arXiv:1912.03640).
- Chan M. H., Lee, C. M., Ng, C.-Y. & C. S. Leung (2020). *Astrophys J.*, 900, 126.

# Q&A!

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Thanks!