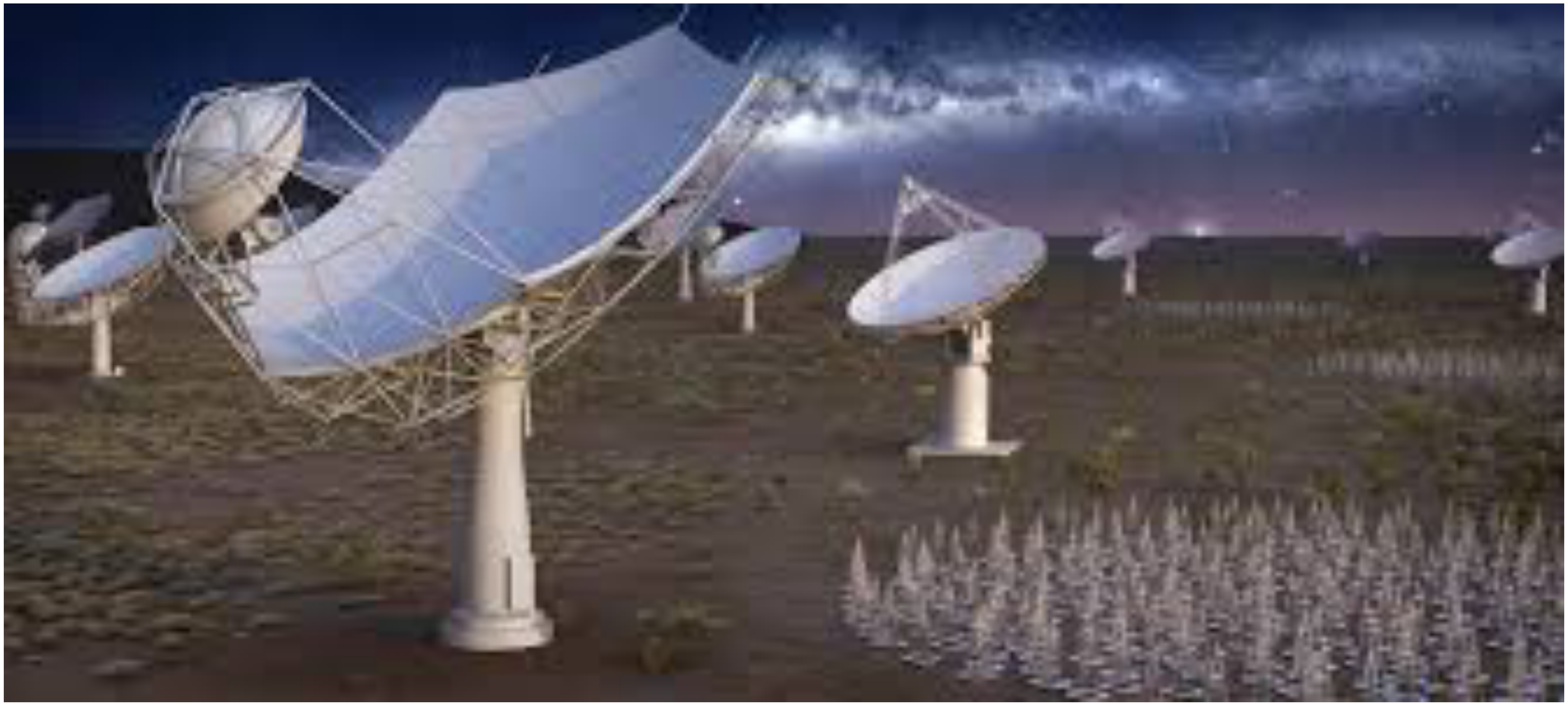
Fundamental Physics with SKA



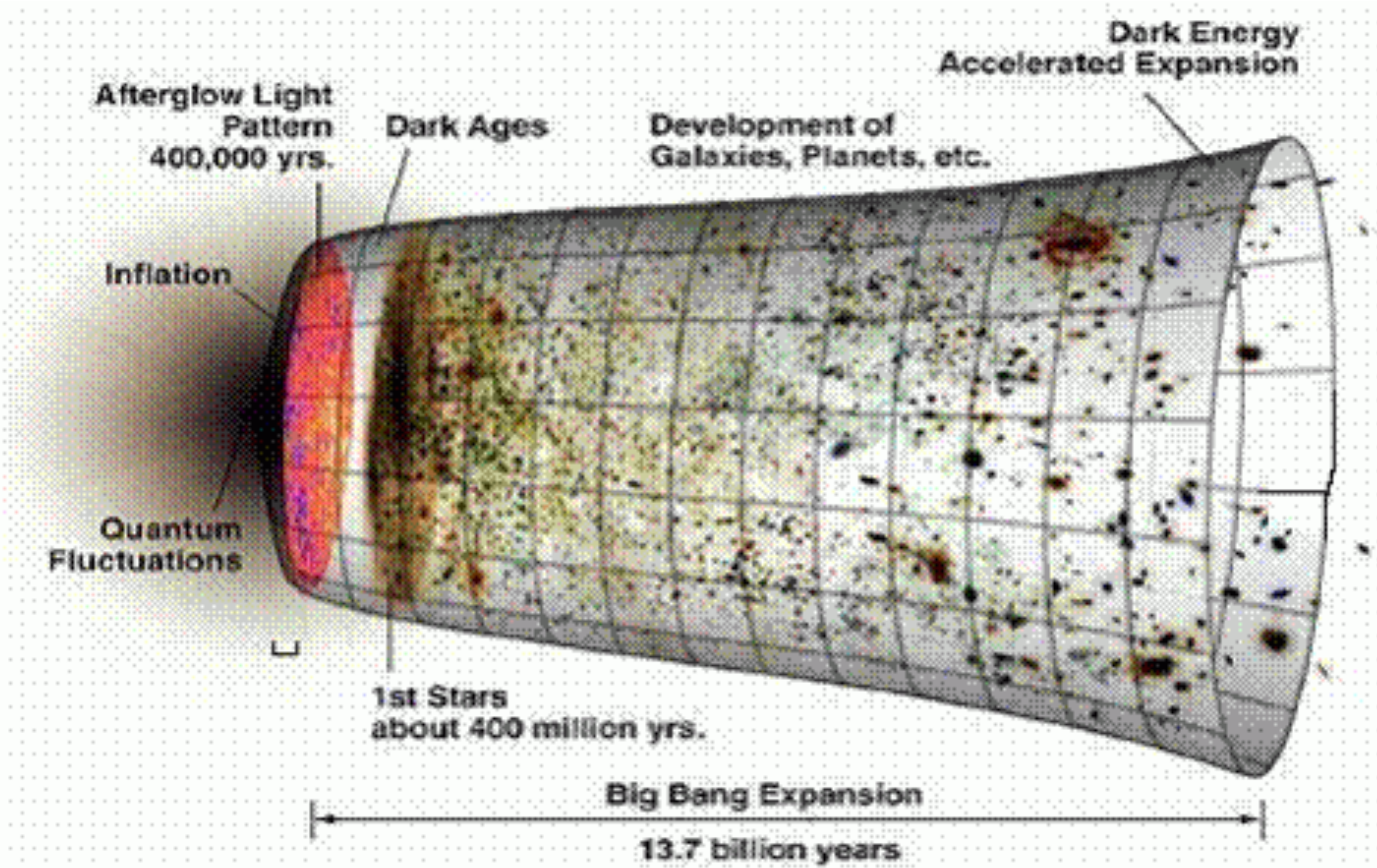
Céline Boehm

The University of Sydney THE UNIVERSITY OF SYDNEY

NZ SKA, Feb 2019

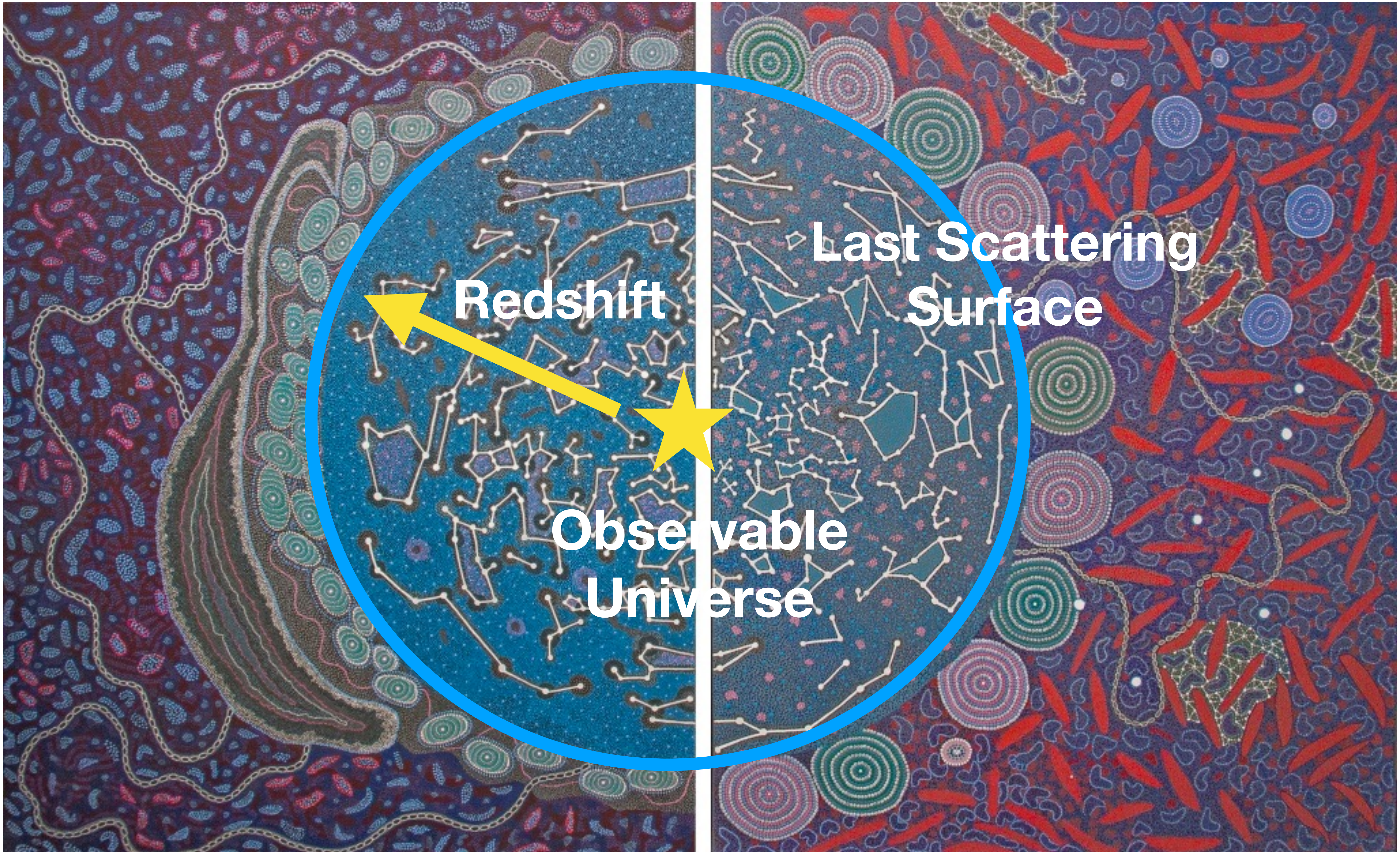
Fundamental Physics with SKA

Cosmic Dawn and Epoch of Reionization (First Stars and Galaxies)
Galaxy Evolution (HI, Continuum)
Cosmology (Dark Energy, Dark Matter, Large-Scale-Structures)
Testing General Relativity (Strong Regime, Gravitational Waves)

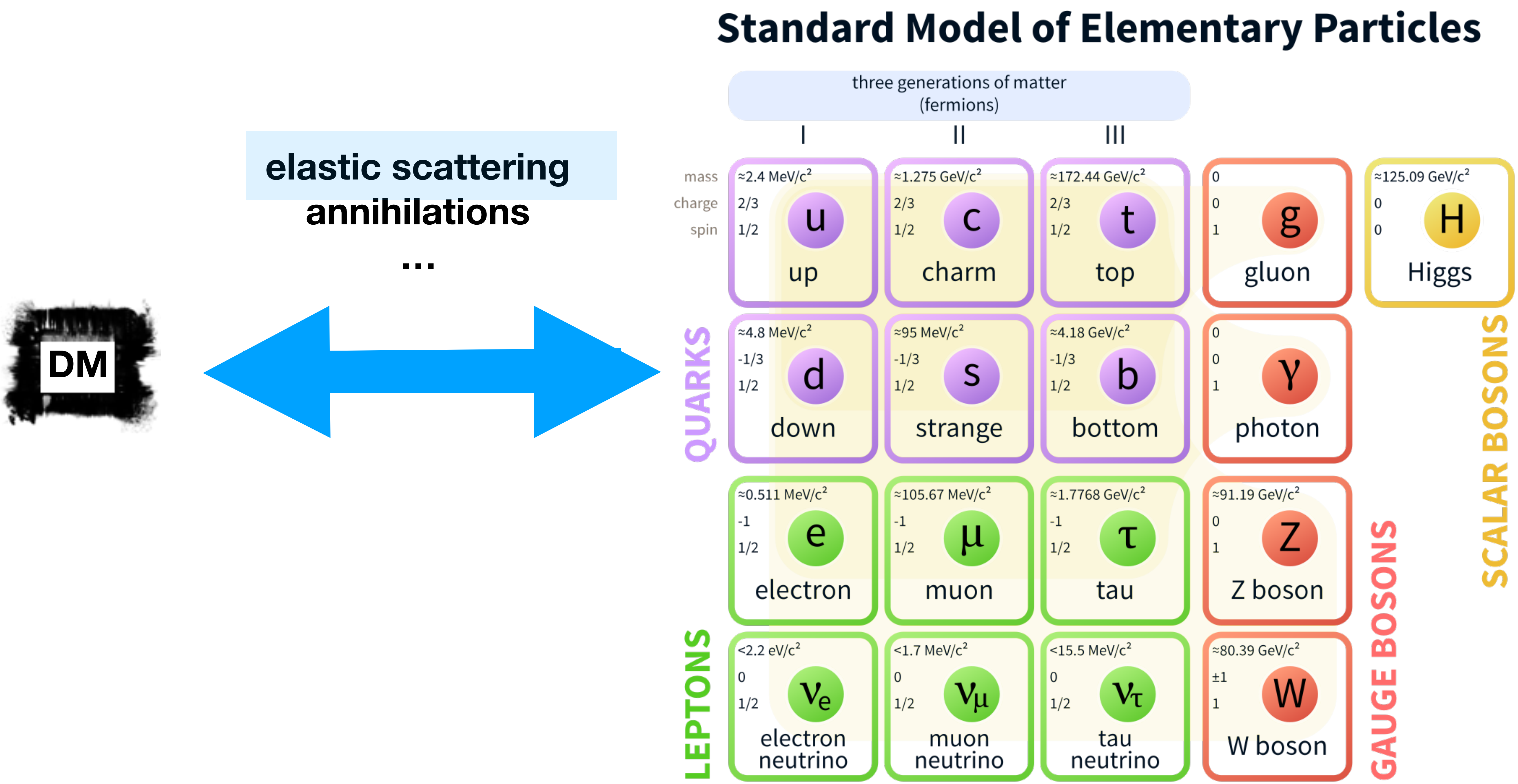

Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
400,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years

The observable Universe

https://www.skatelescope.org/shared-sky/



But (so far) the only way to reproduce observations is to add a new sector



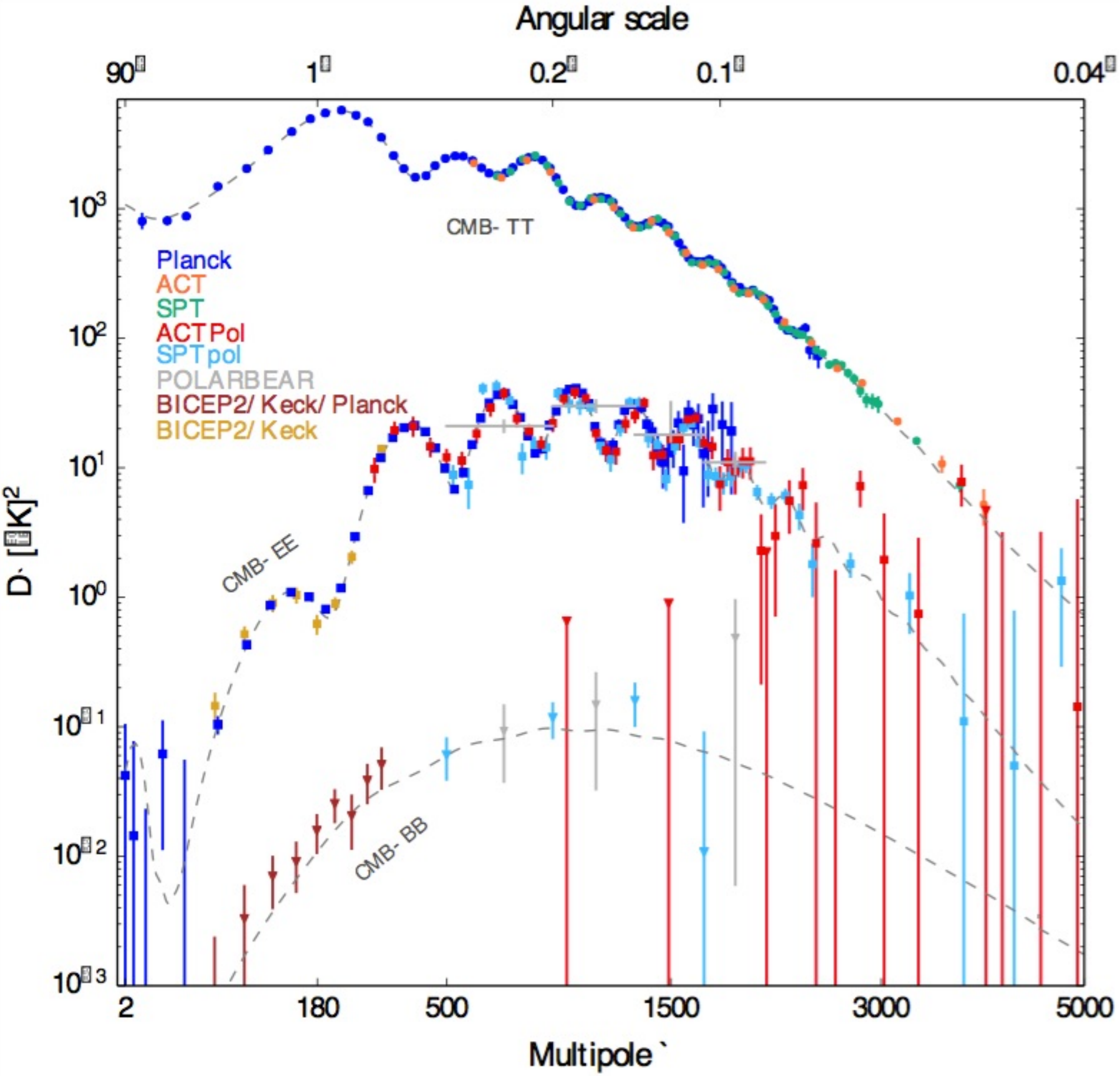
Relevance for Dark Matter

A simple set of equations to describe the evolution of the Universe

$$\dot{\theta}_{\mathrm{b}} = k^2\psi - \mathcal{H}\theta_{\mathrm{b}} + c_s^2 k^2 \delta_{\mathrm{b}} - R^{-1}\dot{\kappa}(\theta_{\mathrm{b}} - \theta_\gamma)$$

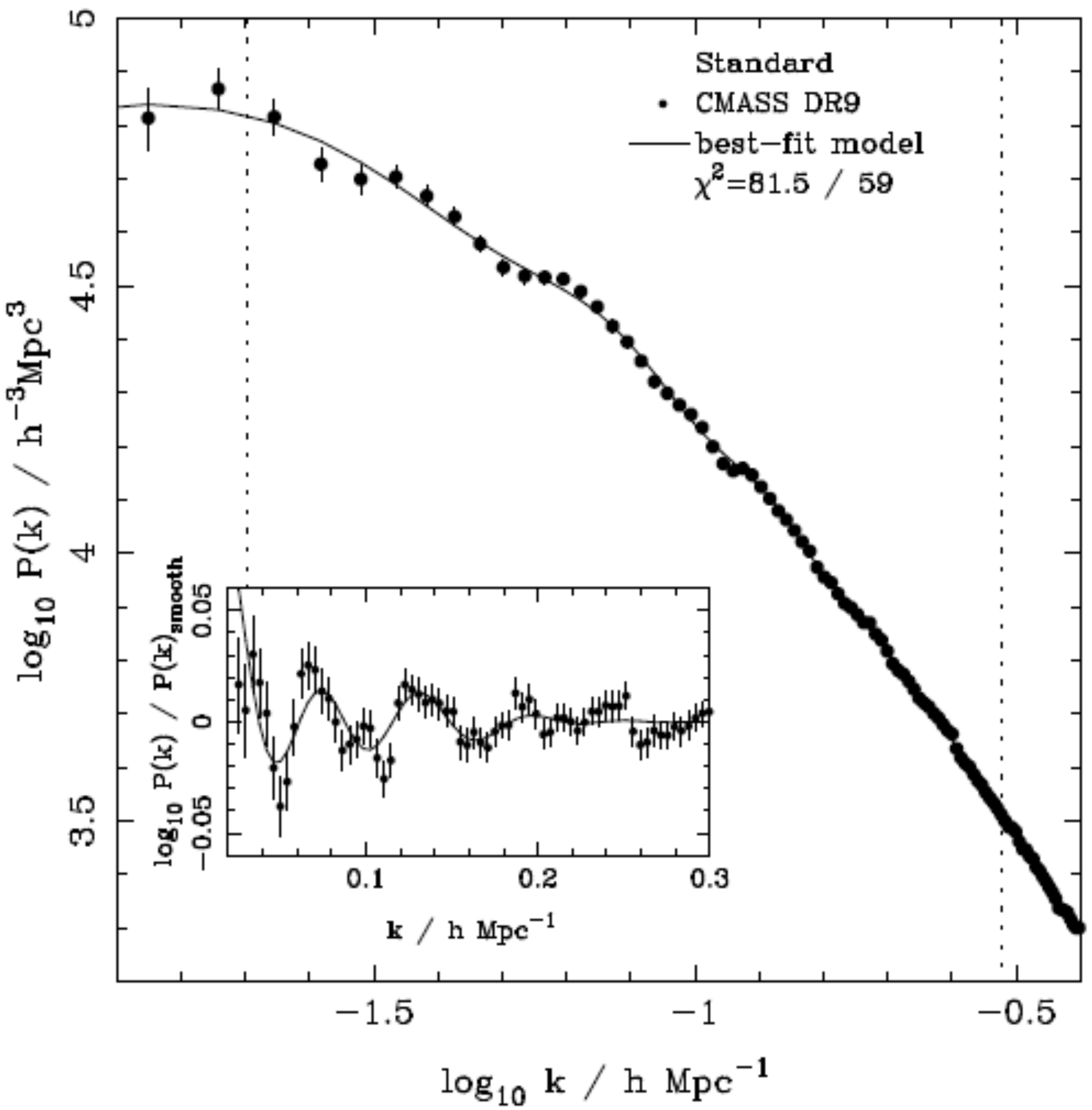
$$\dot{\theta}_\gamma = k^2\psi + k^2\left(\frac{1}{4}\delta_\gamma - \sigma_\gamma\right) - \dot{\kappa}(\theta_\gamma - \theta_{\mathrm{b}})\ ,$$

$$\dot{\theta}_{\mathrm{DM}} = k^2\psi - \mathcal{H}\theta_{\mathrm{DM}}\ ,$$



Higher scales
Spherical harmonics

P(k)
Smaller scales
Fourier transforms



Testing the DM microphysics

without DM interactions

$$\dot{\theta}_b = k^2\psi - \mathcal{H}\theta_b + c_s^2 k^2 \delta_b - R^{-1}\dot{\kappa}(\theta_b - \theta_\gamma)$$

$$\dot{\theta}_\gamma = k^2\psi + k^2\left(\frac{1}{4}\delta_\gamma - \sigma_\gamma\right) - \dot{\kappa}(\theta_\gamma - \theta_b) ,$$

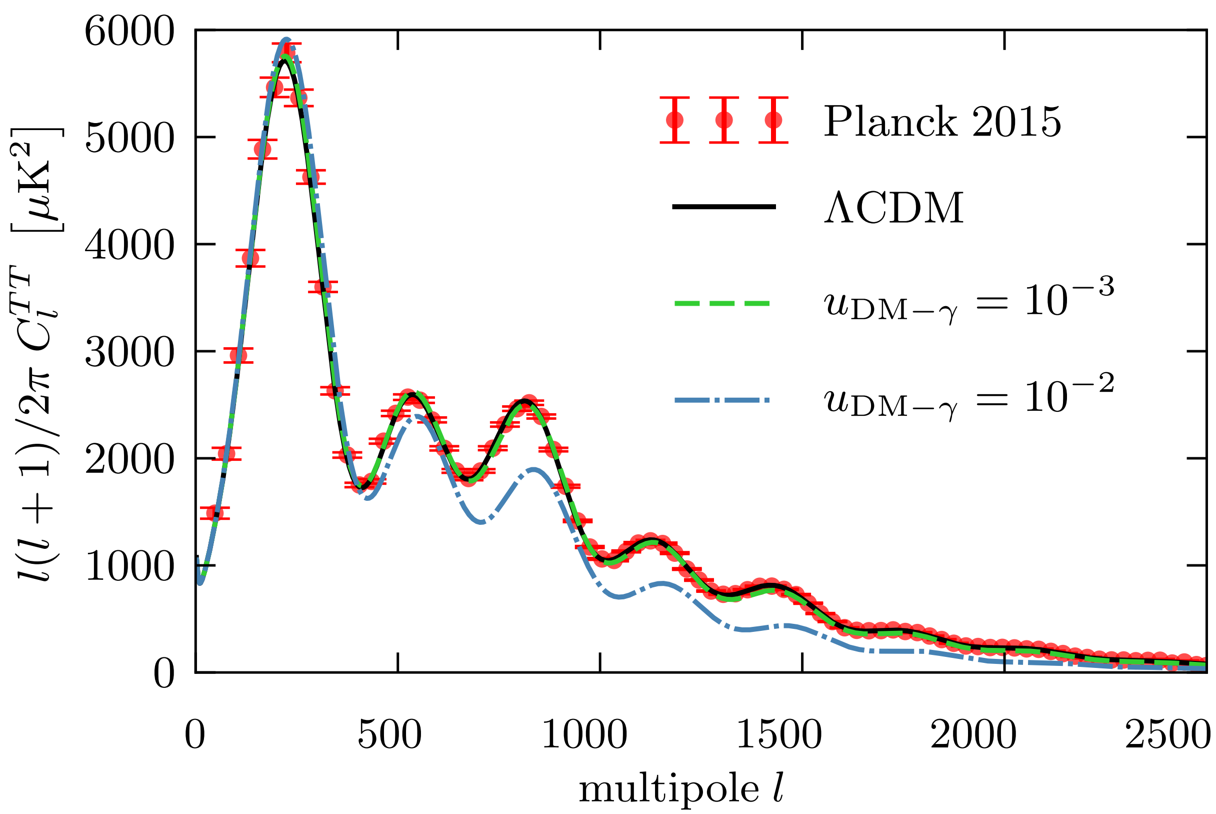
$$\dot{\theta}_{DM} = k^2\psi - \mathcal{H}\theta_{DM} ,$$

with DM interactions

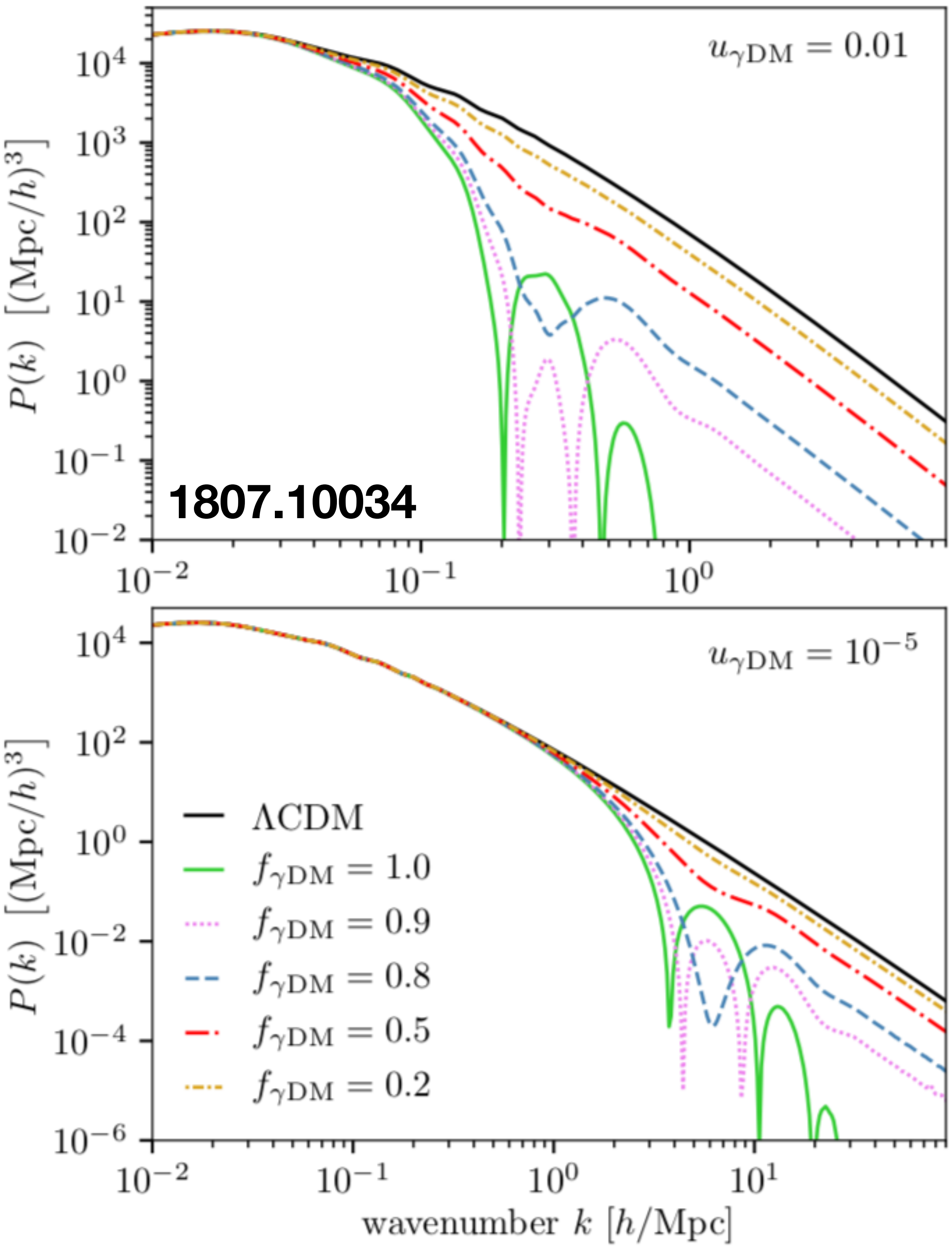
$$\dot{\theta}_b = k^2\psi - \mathcal{H}\theta_b + c_s^2 k^2 \delta_b - R^{-1}\dot{\kappa}(\theta_b - \theta_\gamma)$$

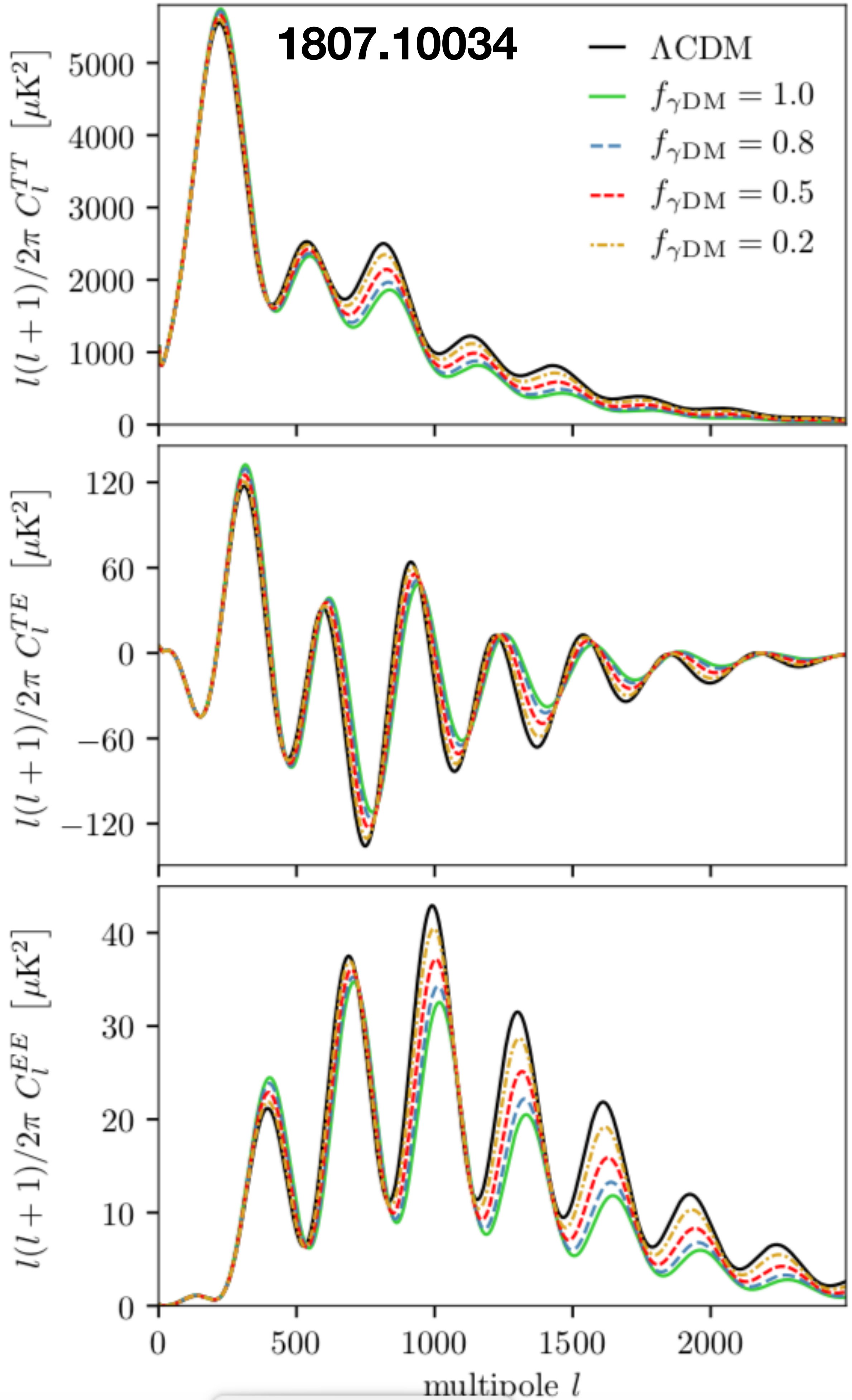
$$\dot{\theta}_\gamma = k^2\psi + k^2\left(\frac{1}{4}\delta_\gamma - \sigma_\gamma\right) - \dot{\kappa}(\theta_\gamma - \theta_b) - \dot{\mu}(\theta_\gamma - \theta_{DM}) ,$$

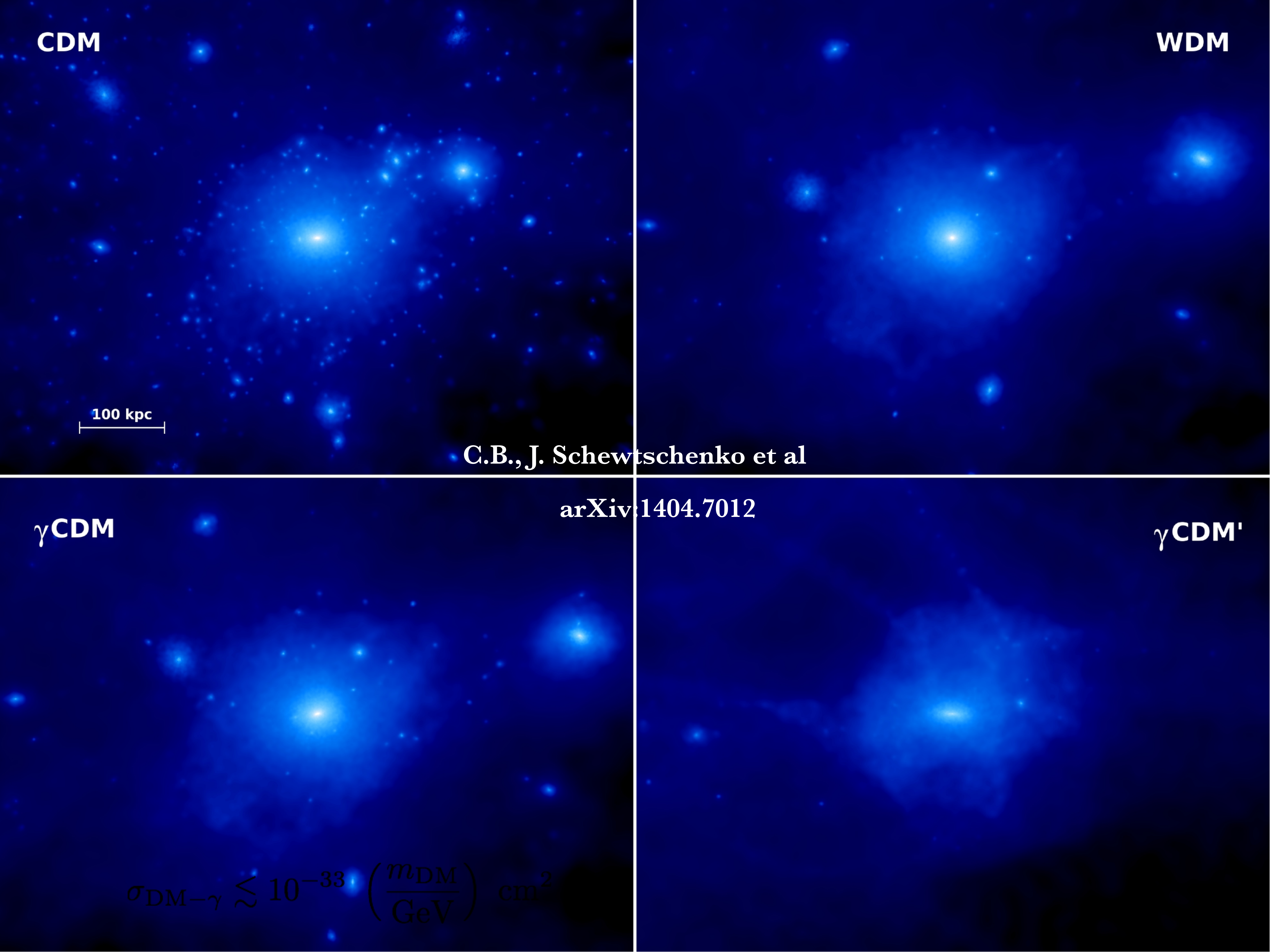
$$\dot{\theta}_{DM} = k^2\psi - \mathcal{H}\theta_{DM} - S^{-1}\dot{\mu}(\theta_{DM} - \theta_\gamma) .$$

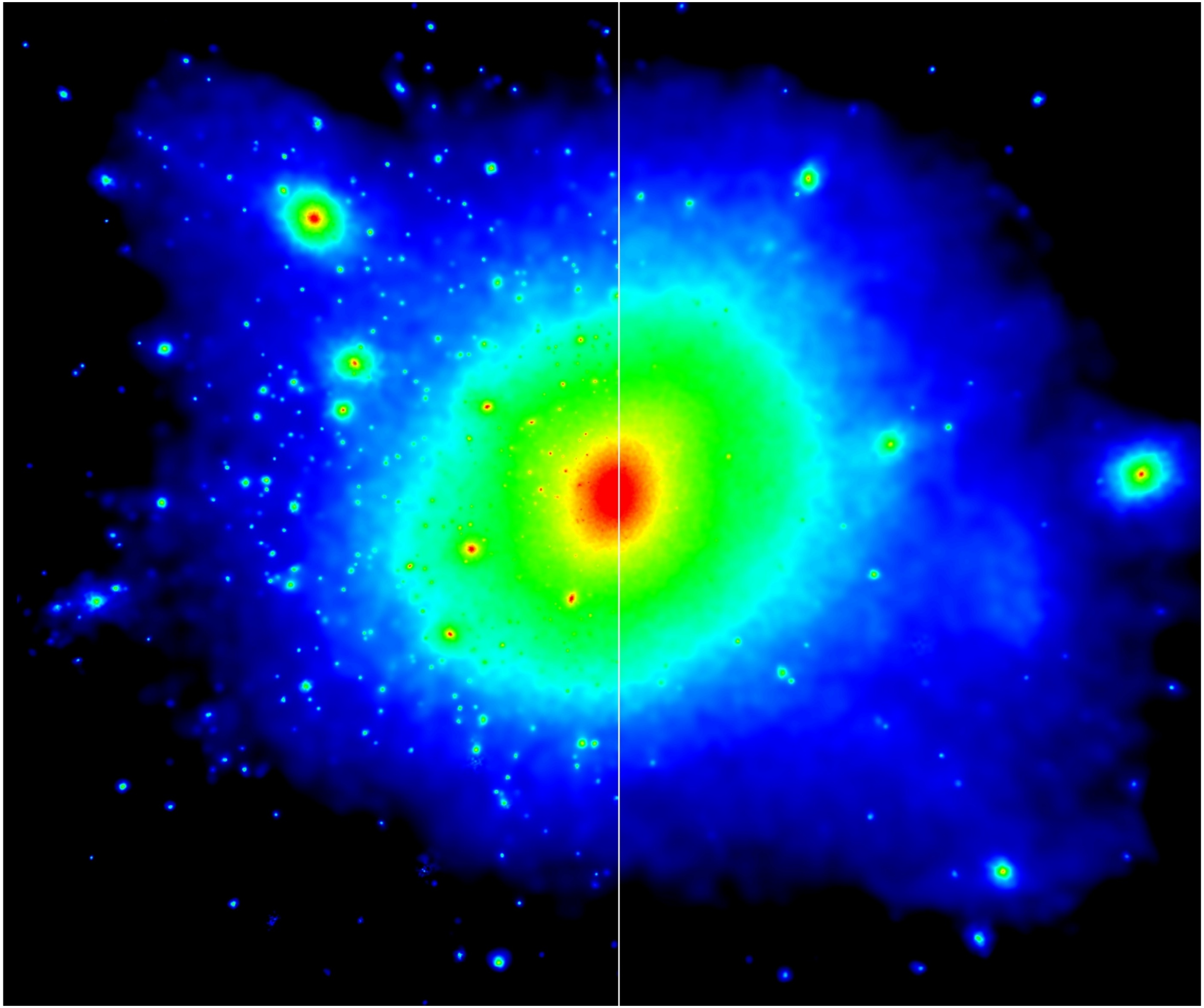


Interacting Scenarios



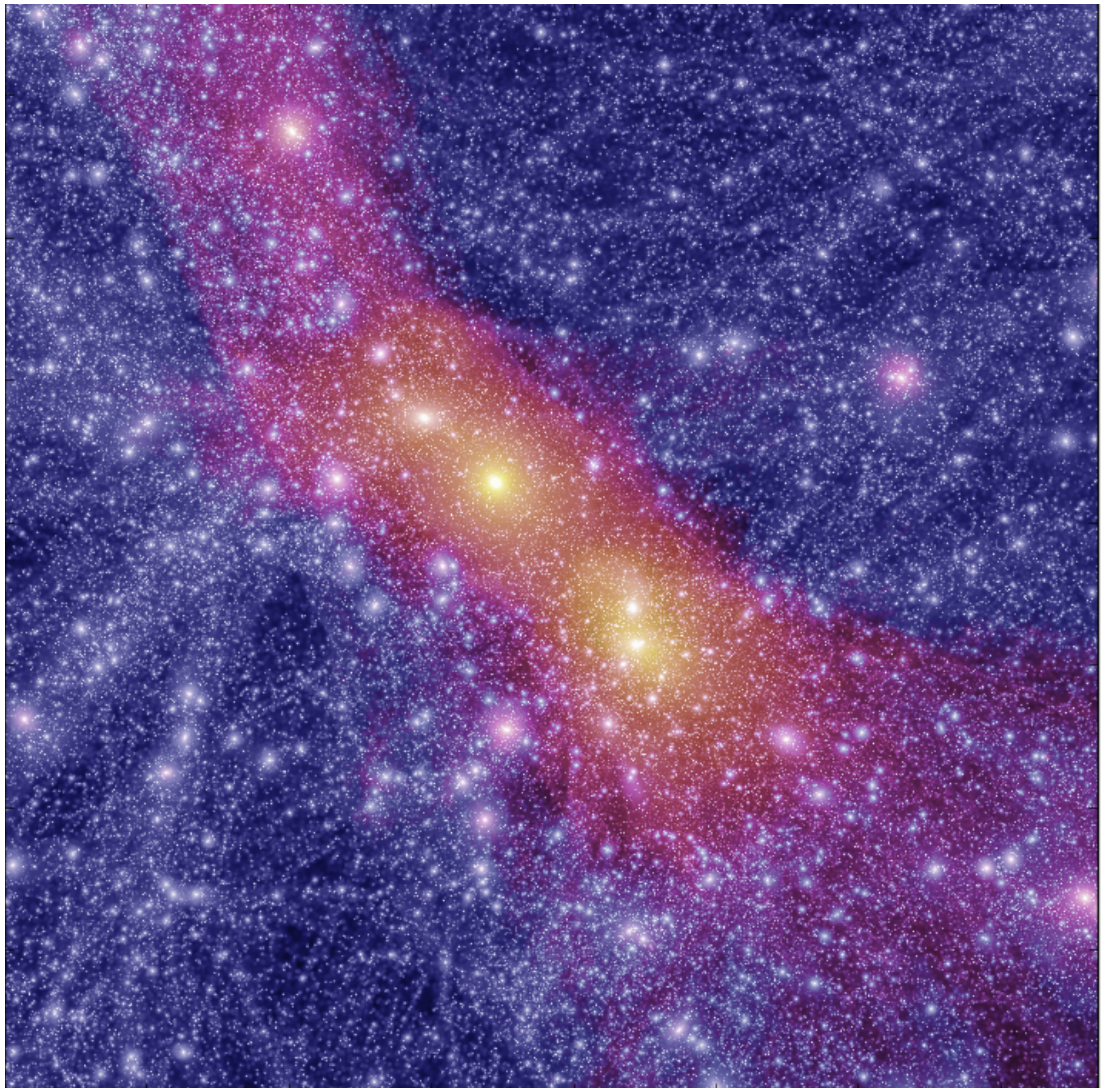


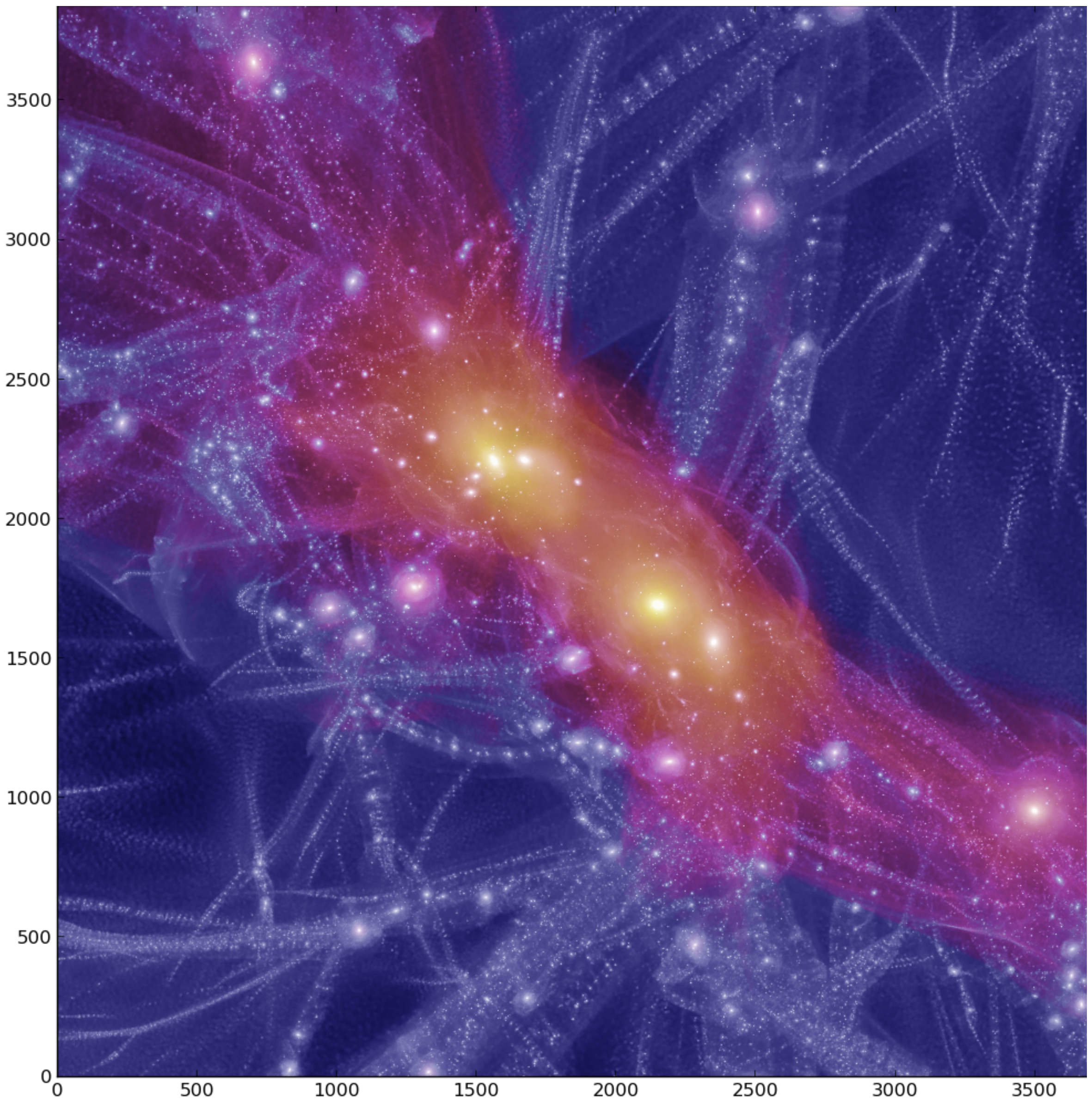

CDM
WDM
100 kpc
C.B., J. Schewtwschenko et al
arXiv:1404.7012
γCDM
γCDM'
$\sigma_{\mathrm{DM}-\gamma} \lesssim 10^{-33} \left(\frac{m_{\mathrm{DM}}}{\mathrm{GeV}}\right) \mathrm{cm}^2$



Distribution of matter in the Universe

Rather than



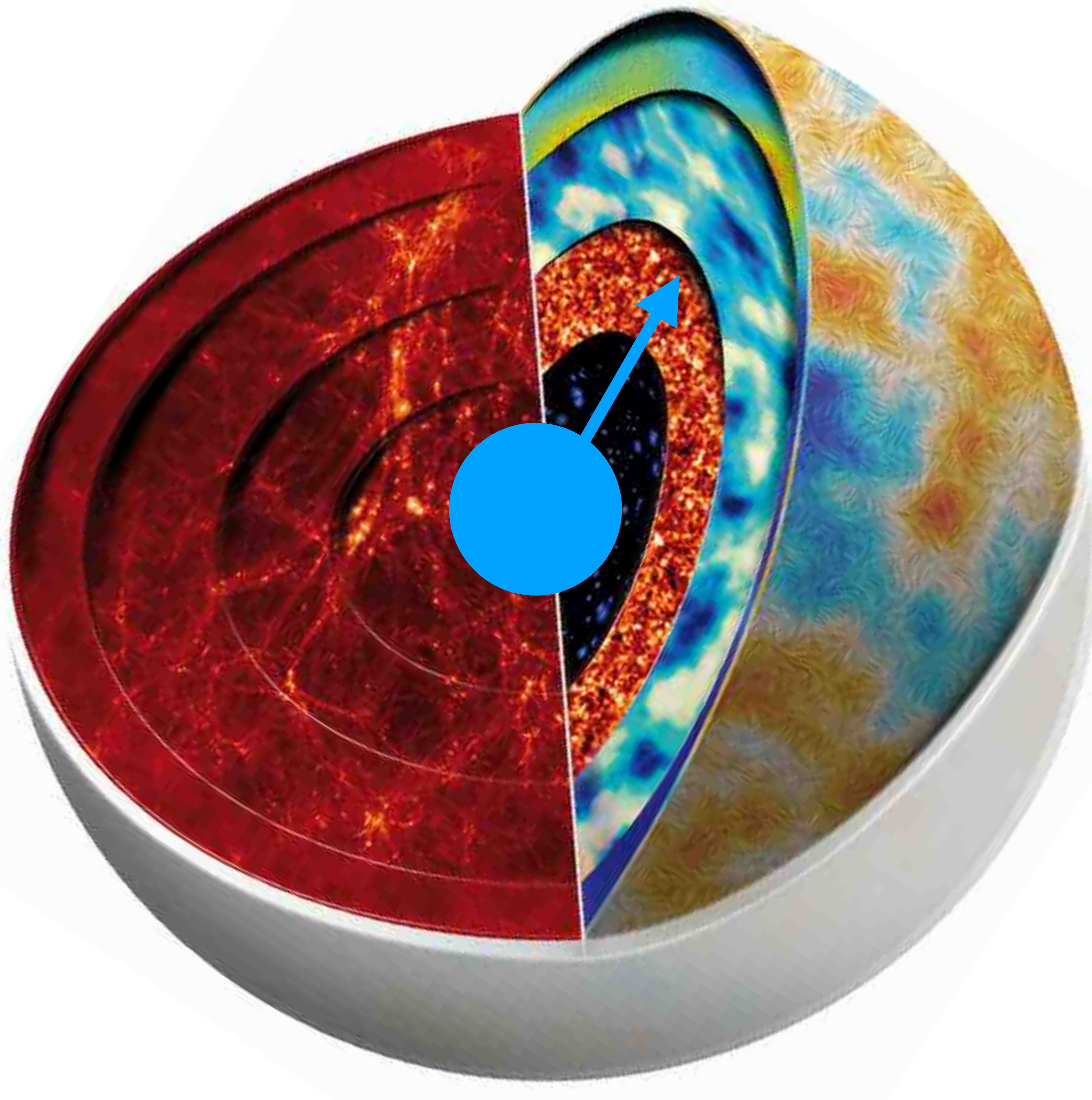


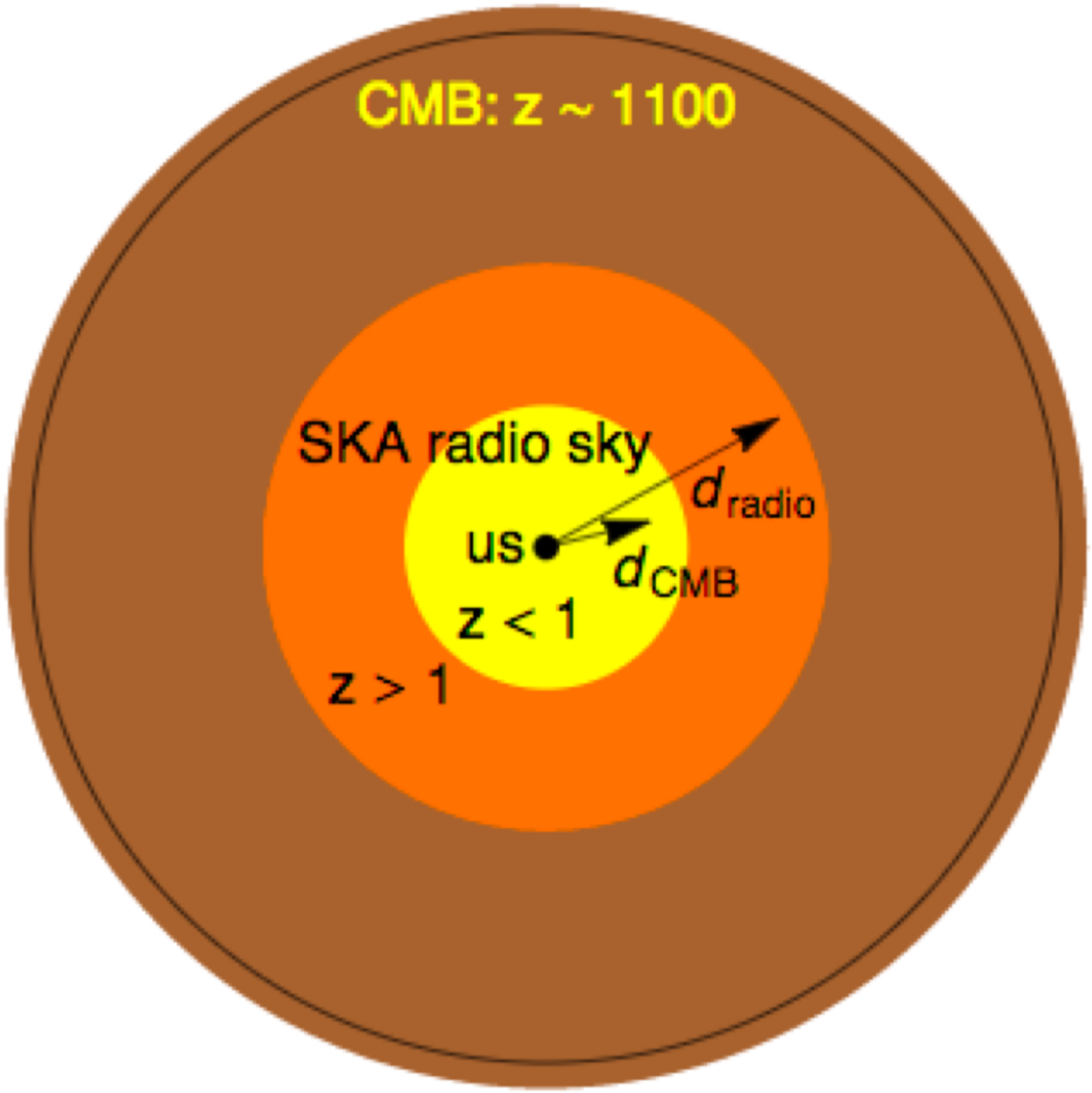
The picture we have in mind is correct

How could SKA help?

Any models
(dark energy, modified gravity etc)

SKA capability





AGNs

Radio galaxies

Schwarz et al. 2015

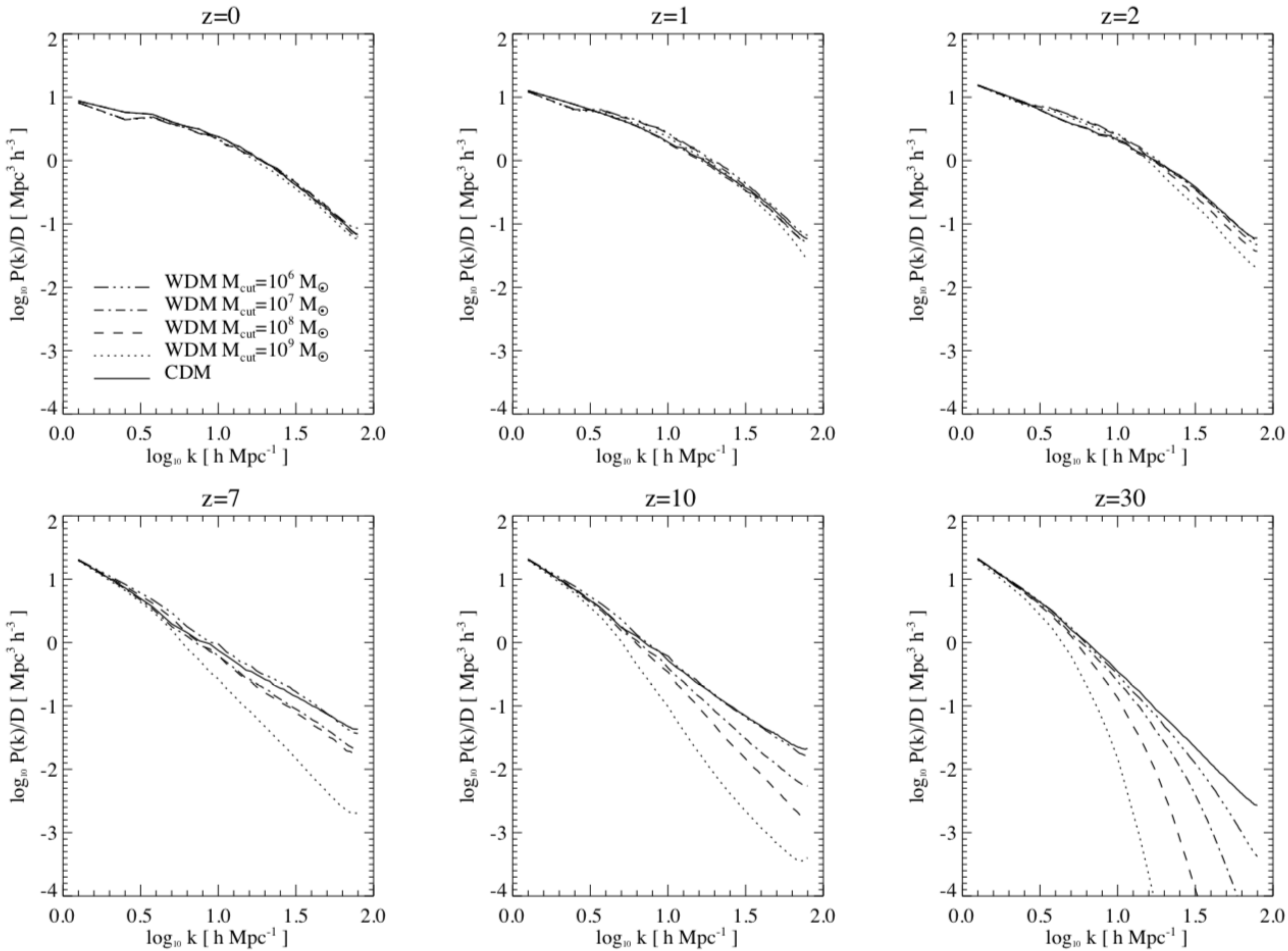
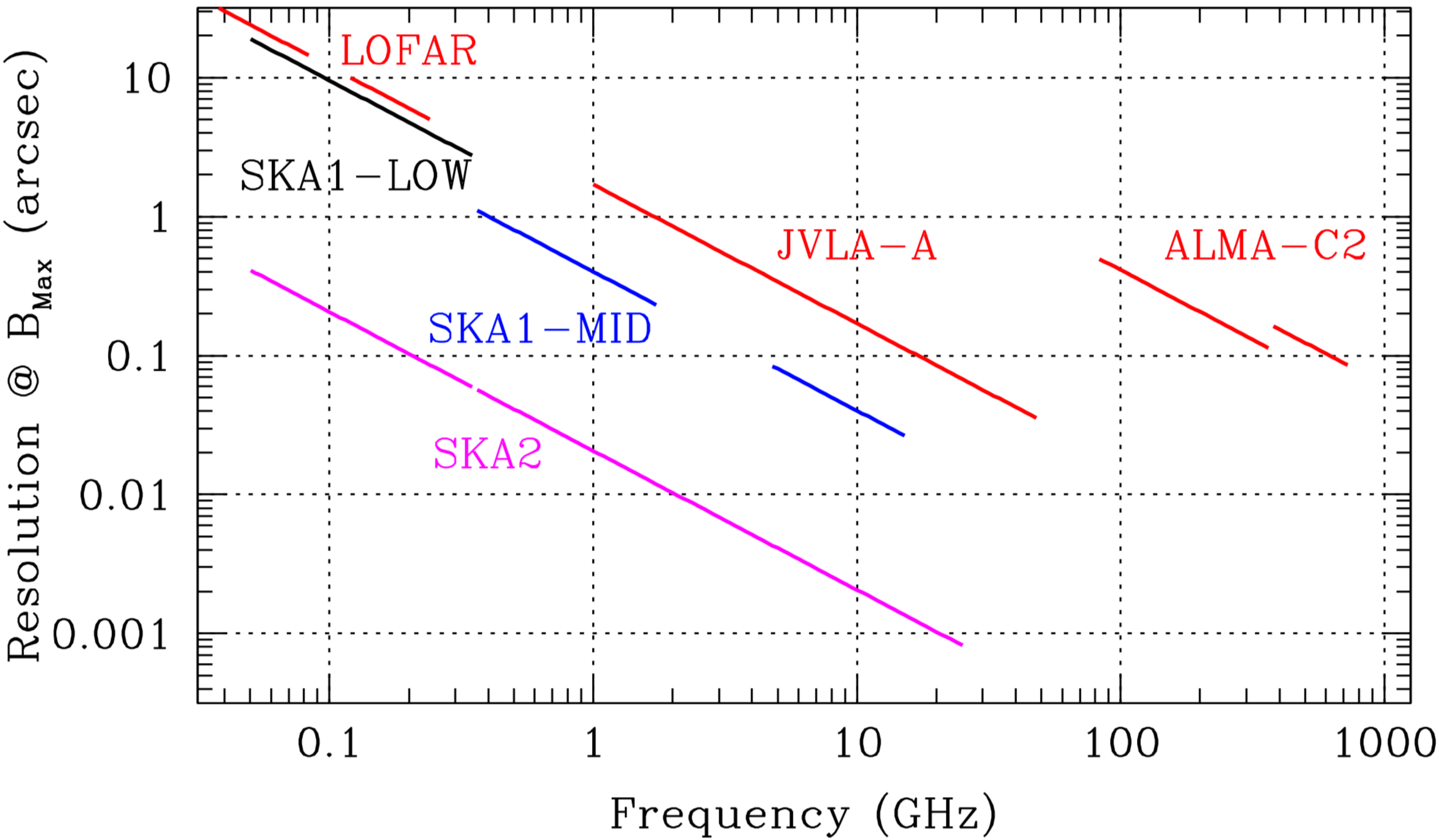


Figure 1. Snapshots of the dark matter power spectra measured in simulations of a series of DM models. CDM and 0.6, 1.1, 2 and 3.5 keV heavy warmon WDM corresponding to respectively 10^9, 10^8, 10^7 and 10^6 h^{-1} $M_\odot$ Lagrangian masses in the free-streaming length are shown. The power spectra have been divided by the linear growth factor to facilitate the comparison between redshifts. Note the exponential cut-off at z= 30 in the spectrum of WDM models and the similarity of the spectra of all five models over the simulated scales at z≤2.

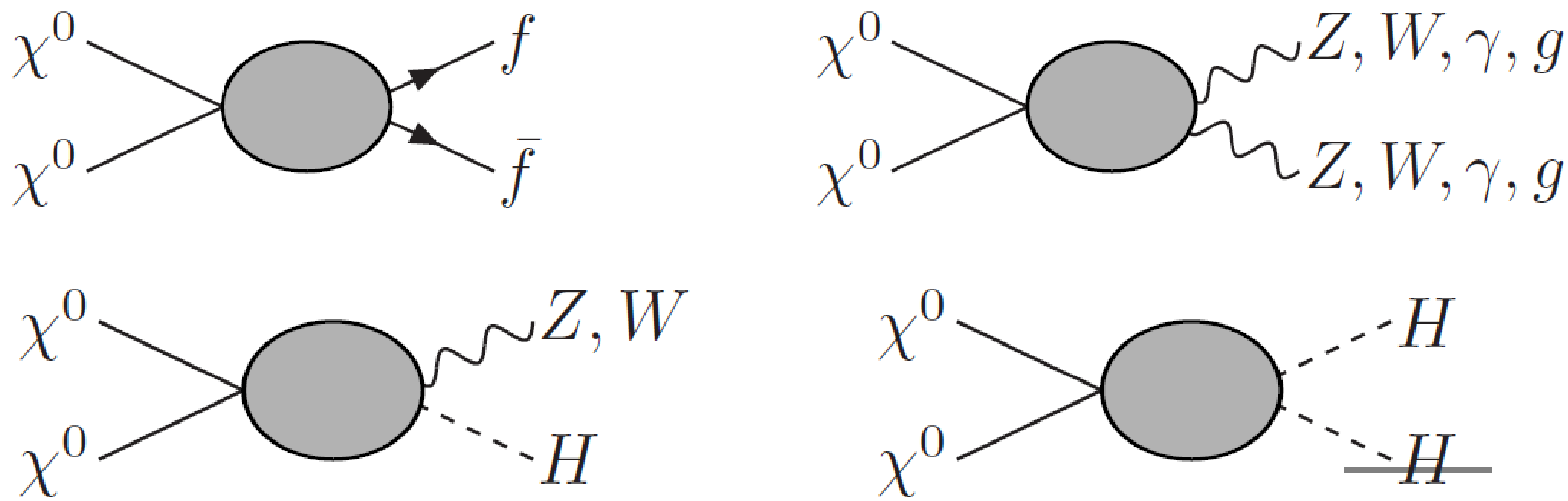
Dark Matter
Indirect detection

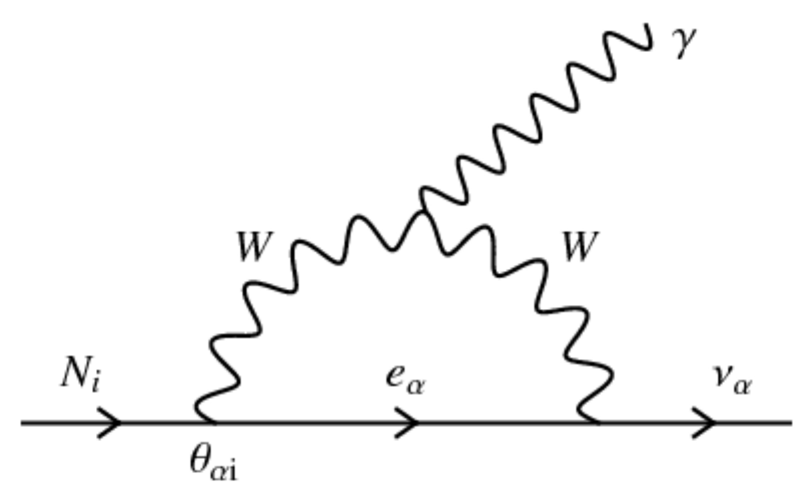
Courtesy slide Anna Bonaldi



50 MHz to 14 GHz (eventually up to 30 GHz)

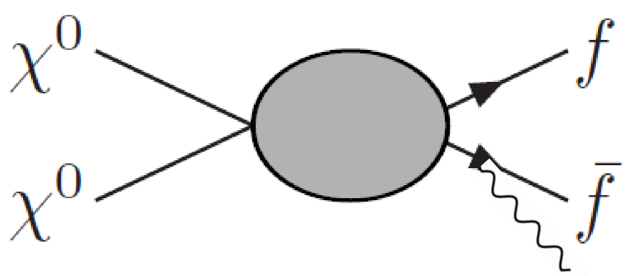
Dark Matter may annihilate/decay



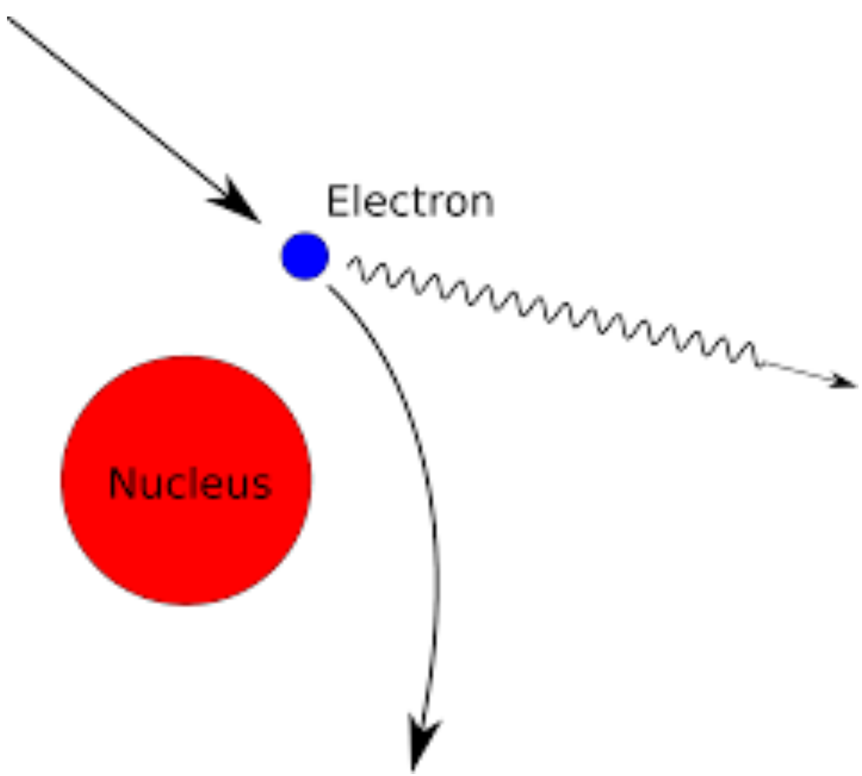


Emission from DM

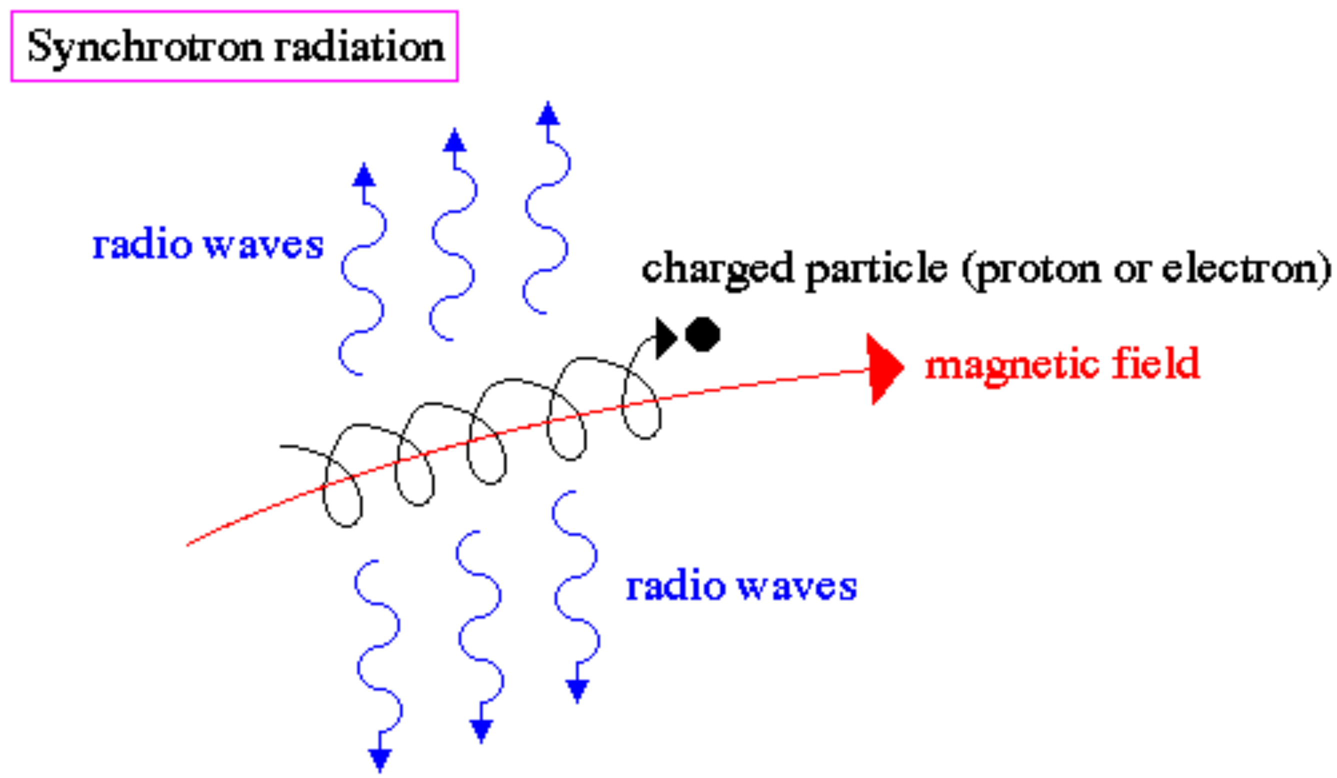
charged particles create photons



prompt emission (radiative correction)



Bremsstrahlung emission



Synchrotron radiation

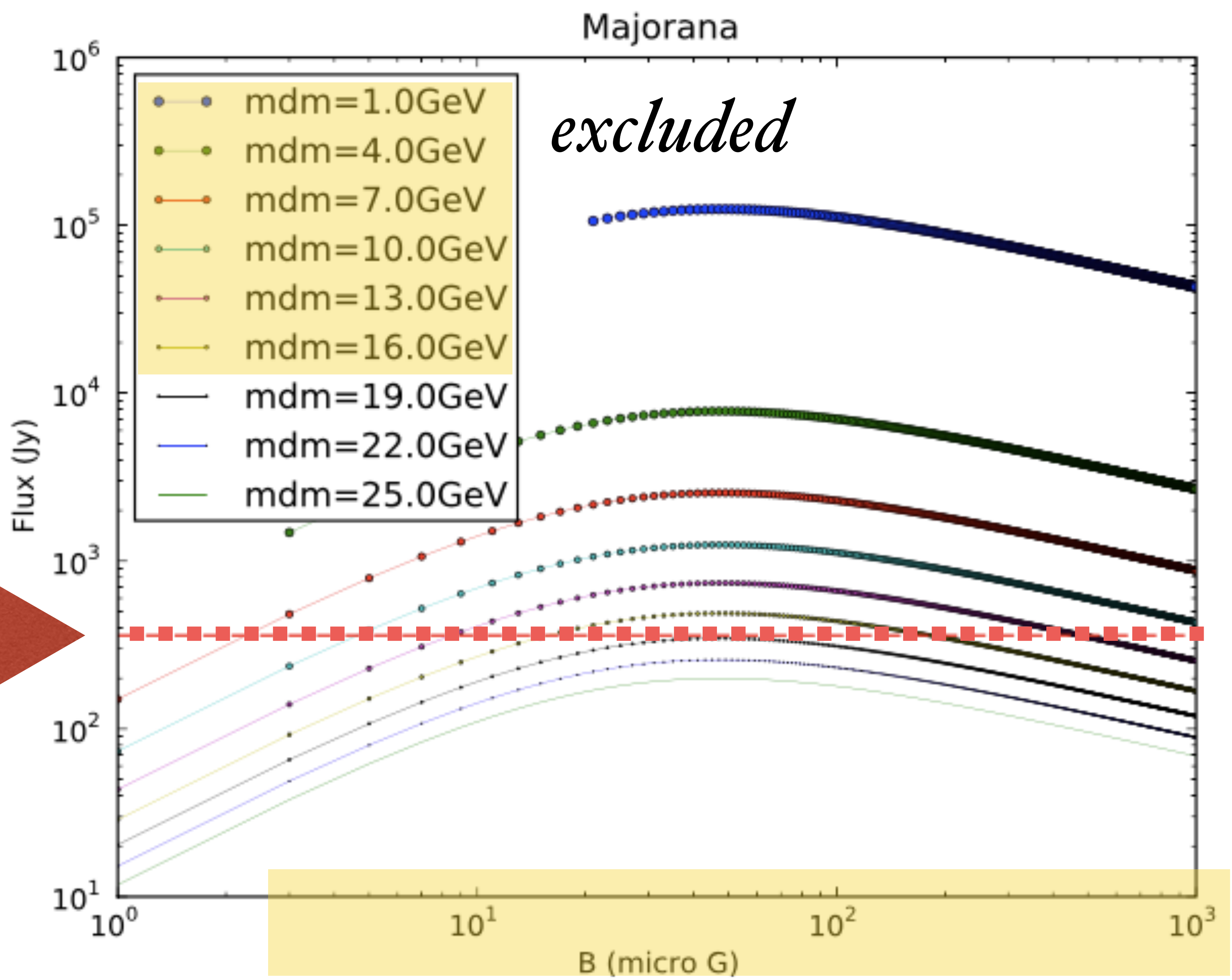
Radio constraints

from our Milky Way

astro-ph/0208458
arXiv:1008.5175

330 MHz

Sgr A*



Excludes up to 10 GeV particles for normal B field values

Microwave signals

arXiv:1105.4689

Astrophysical sources

DM

Sum of the contributions

40 GeV DM

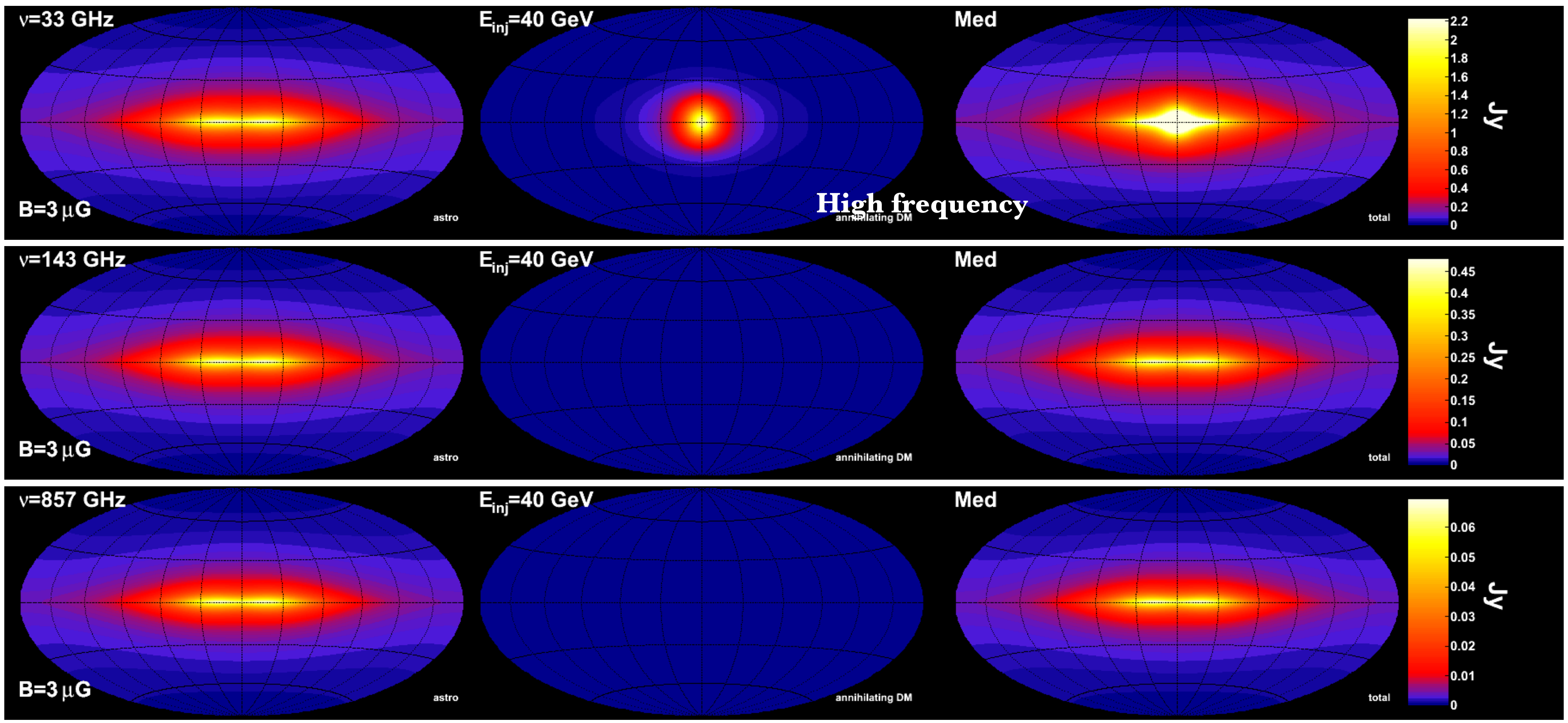
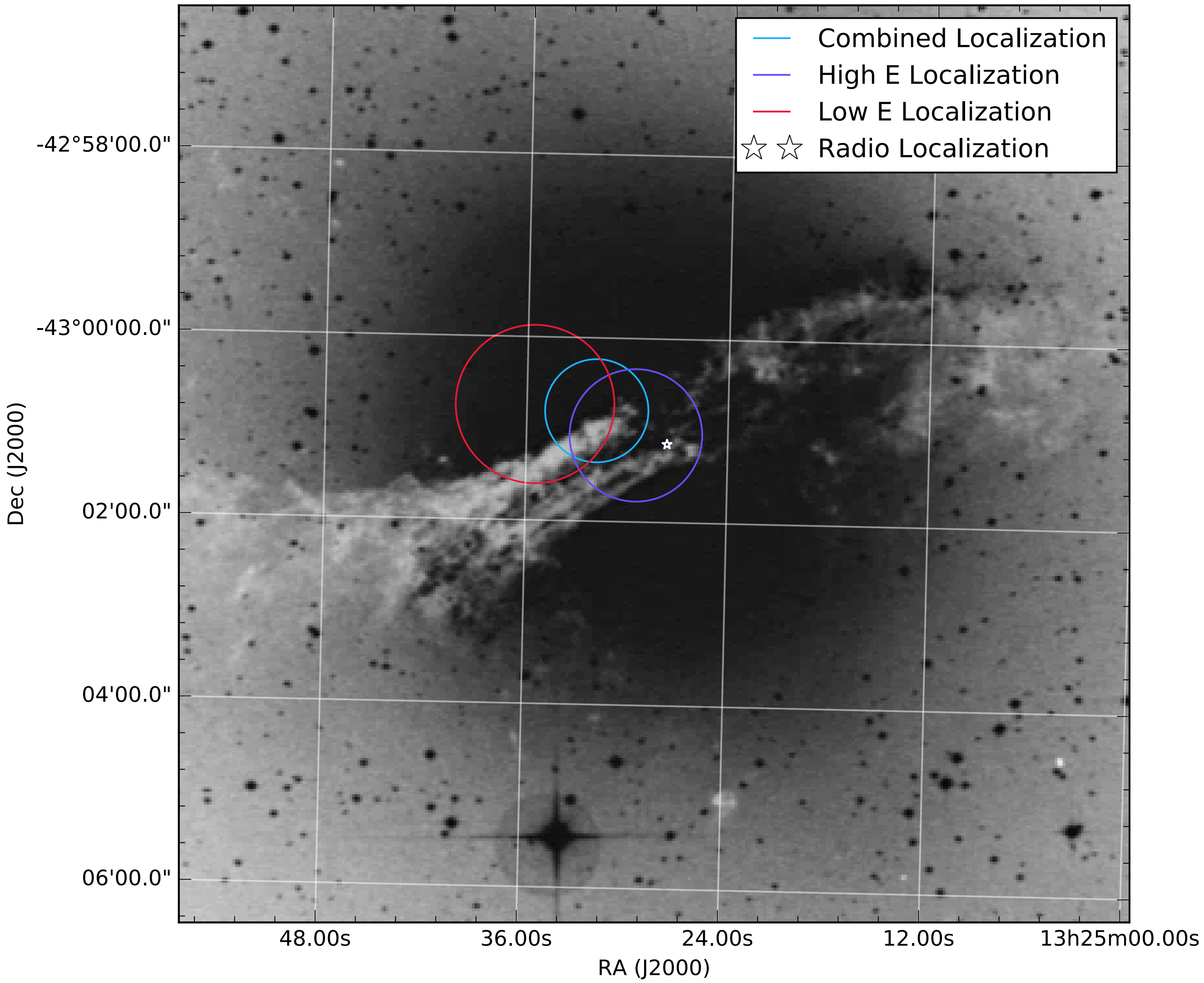


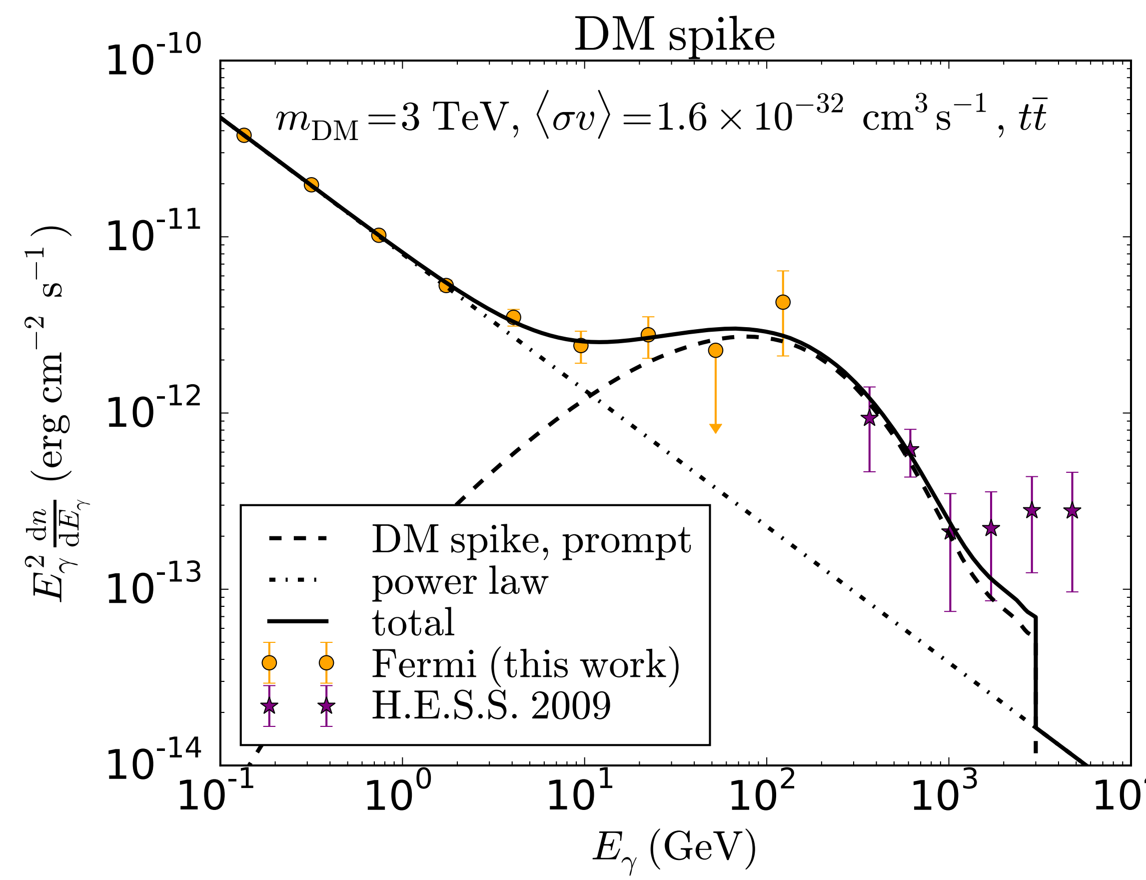
Figure 2. Synchrotron maps for 40 GeV dark matter particles $B = 3\mu$G. We use the MED parameter set and assume annihilating particles.

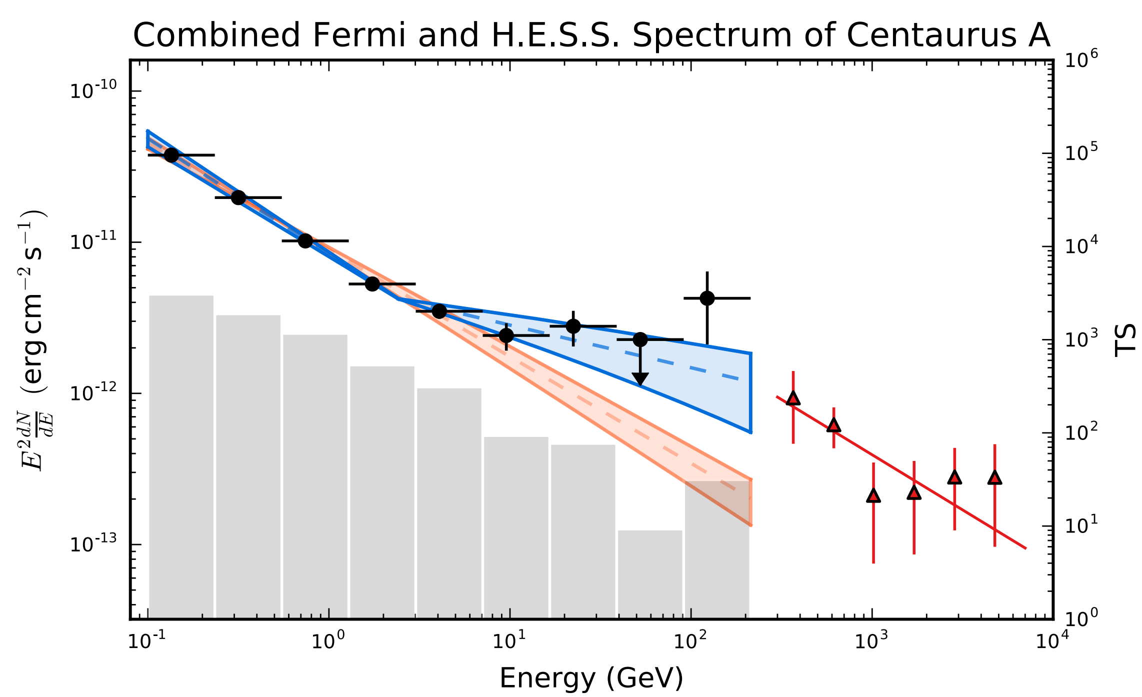
see prospects for SKA: arXiv:1502.03738

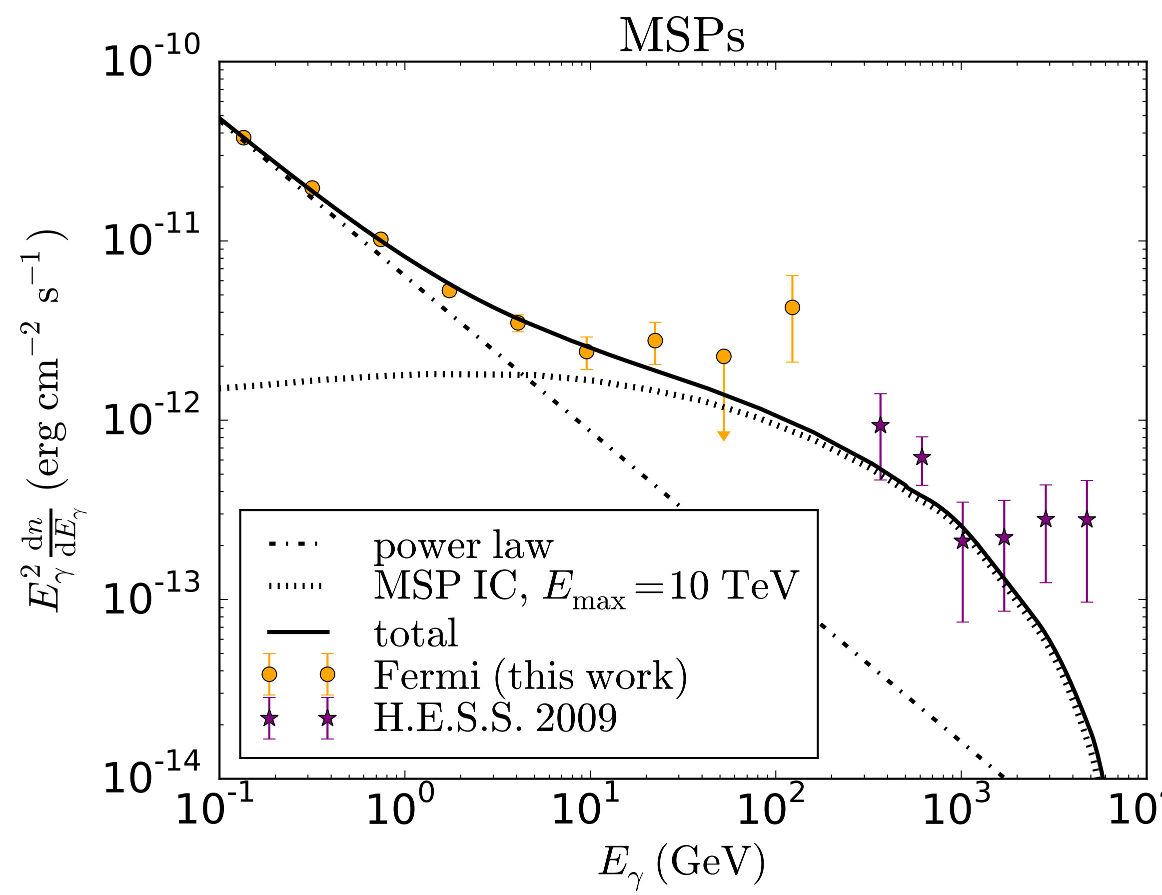
Centaurus A

arXiv:1603.05469







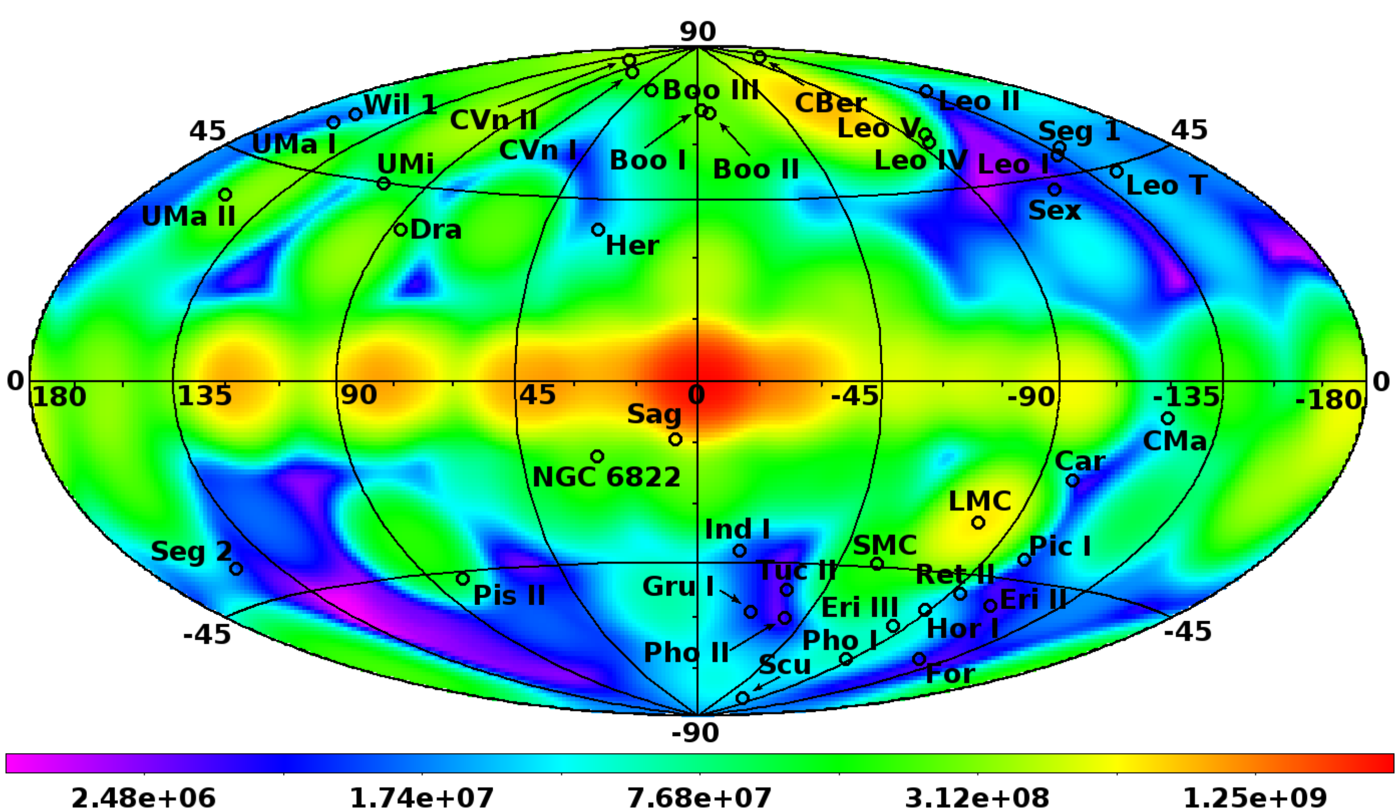


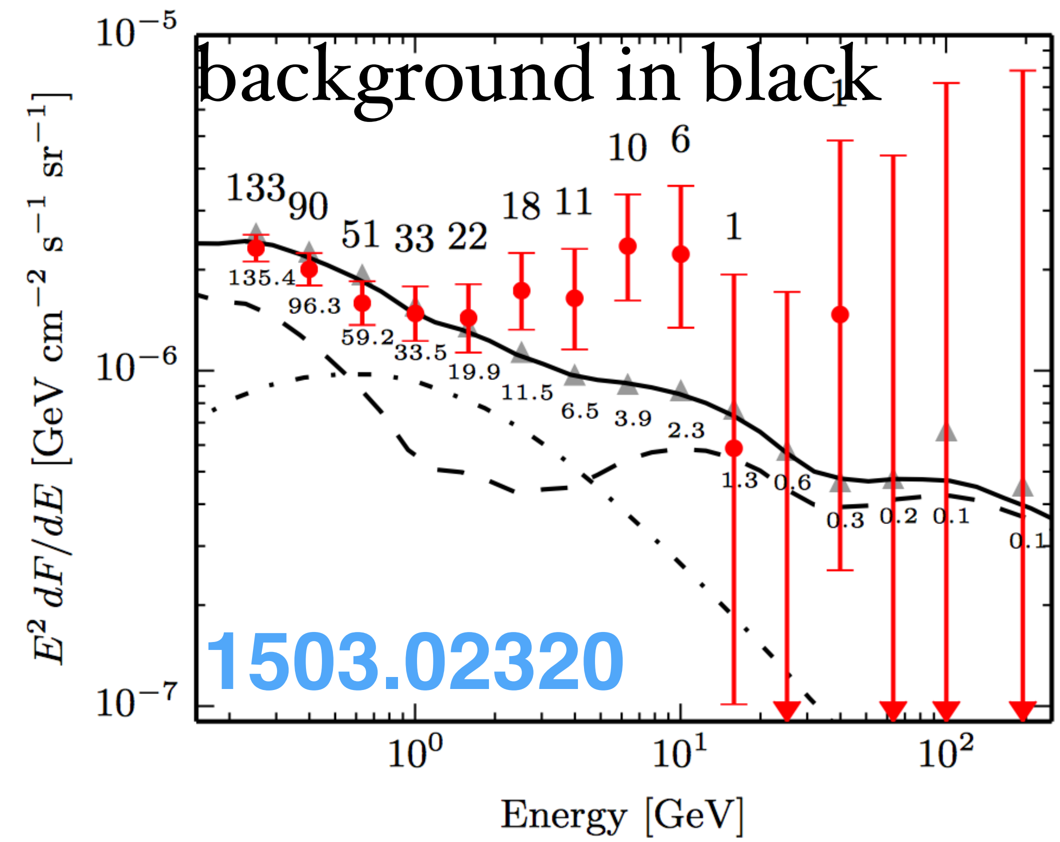
Reticulum II

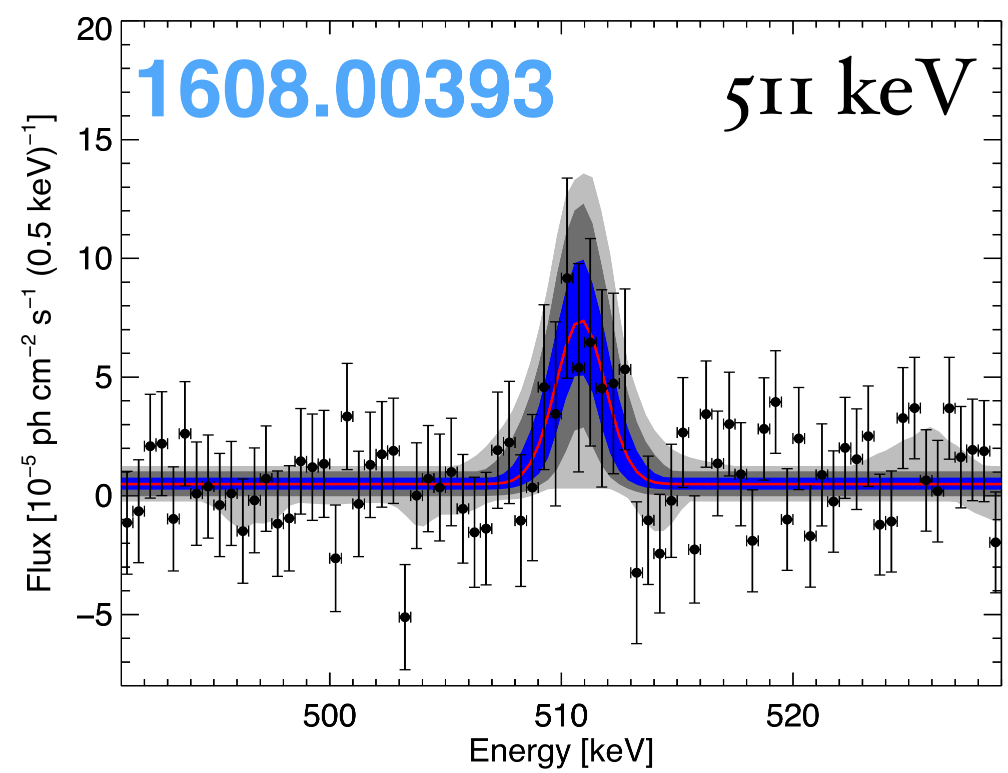
Excess of gamma-rays (GeV range)
but also 511 keV and radio

arXiv:1703.09921

Integral/SPI exposure map
Courtesy: T. Siegert







Spikes in the DM density distribution

Conservation of momentum in adiabatic growth from initial to final state

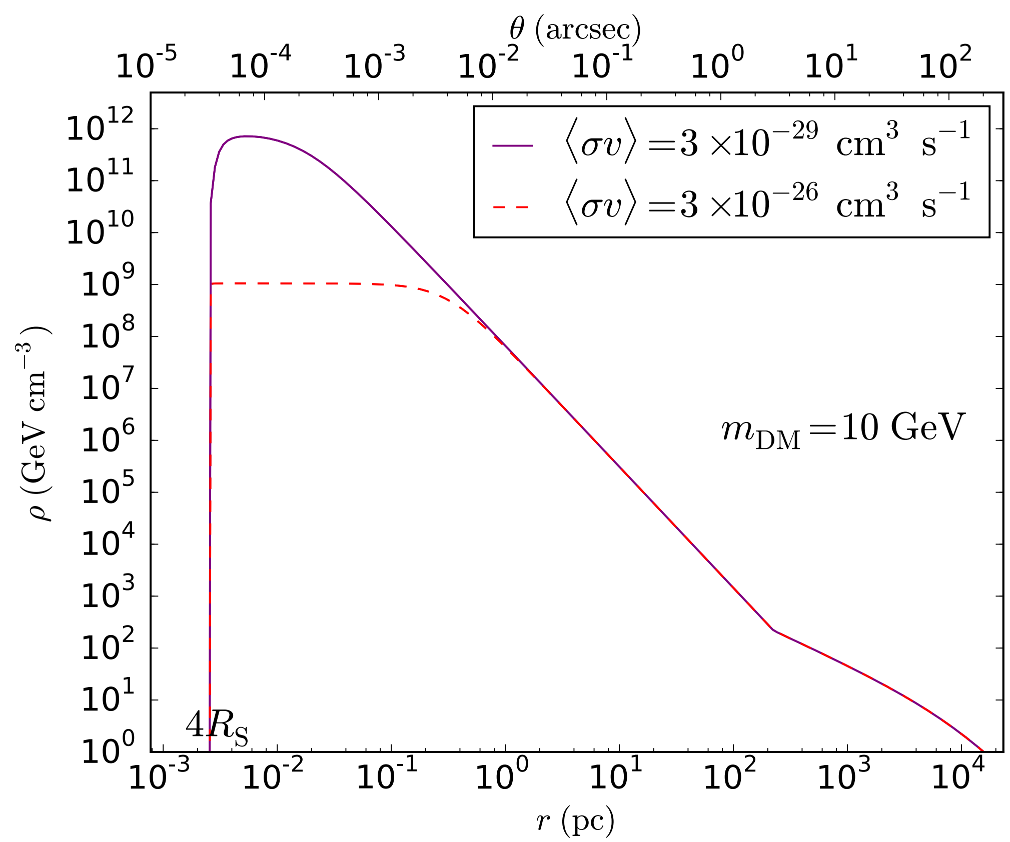
$$r\ v(r) = cst$$

$$v(r) = (GM(r)/r)^{1/2}$$

$$\int_0^{r_i} \rho_i(r) r^2\, dr = \int_0^{r_f} \rho_f(r) r^2\, dr$$

$$\boxed{\gamma_{sp} = \frac{9-2\gamma}{4-\gamma}.}$$

NFW: 7/3 inner slope



$$\rho_{sat} = \frac{m_{DM}}{\langle\sigma v\rangle\, t_{BH}}$$

+ spikes can be destroyed by galaxy dynamics.

stellar heating (+ mergers, non adiabatic contraction)

Implication of a DM spike for the MW

synchrotron emission of electrons and positrons **1311.0139**

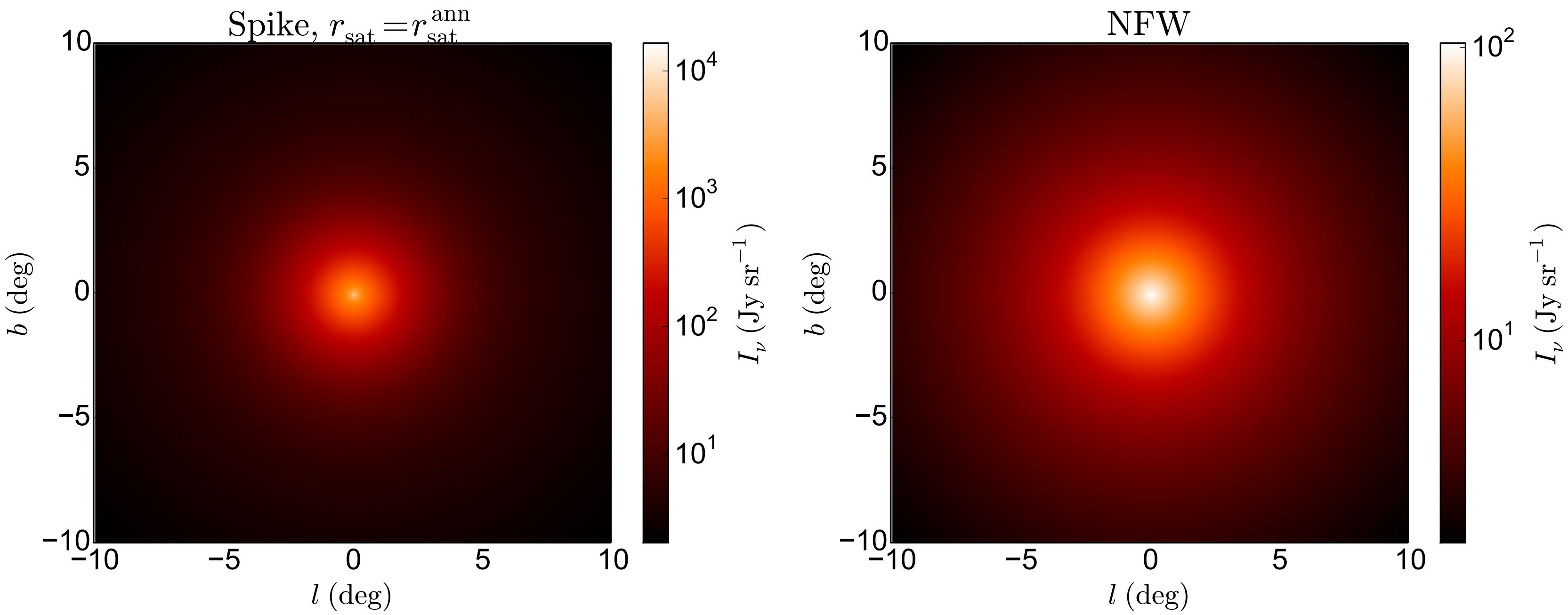
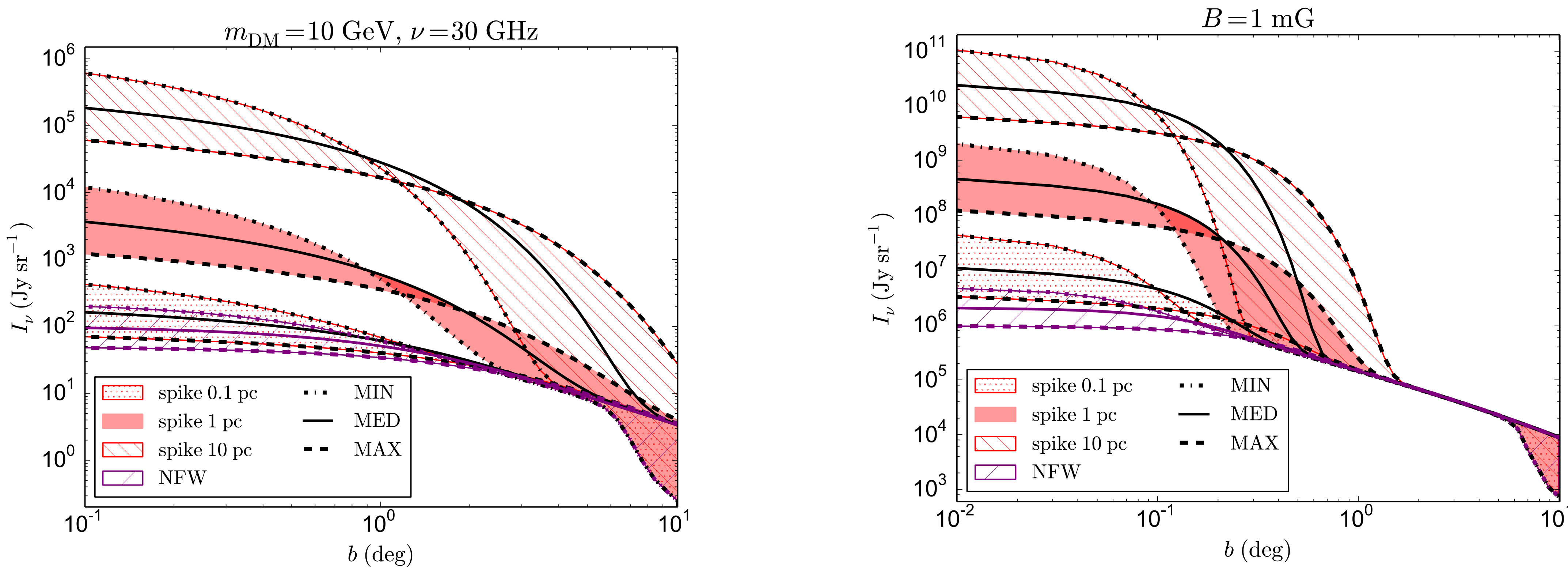
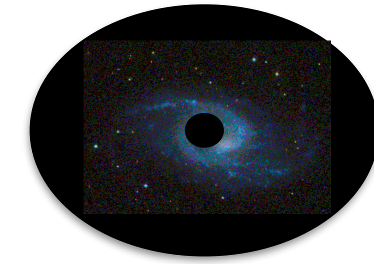


Figure 7.1: 30 GHz maps of the synchrotron intensity induced by 10 GeV DM particles, for $\langle \sigma v \rangle = 3 \times 10^{-26}$ cm^3 s^{-1}, $B = 3\ \mu$G, and the MED set of propagation parameters. The DM profiles used are a spiky profile with $\gamma_{sp} = 7/3$, $R_{sp} = 1$ pc, with $r_{sat} = r_{sat}^{ann}$ (**left panel**), and the NFW profile (**right panel**).



Black Hole shadow with EHT



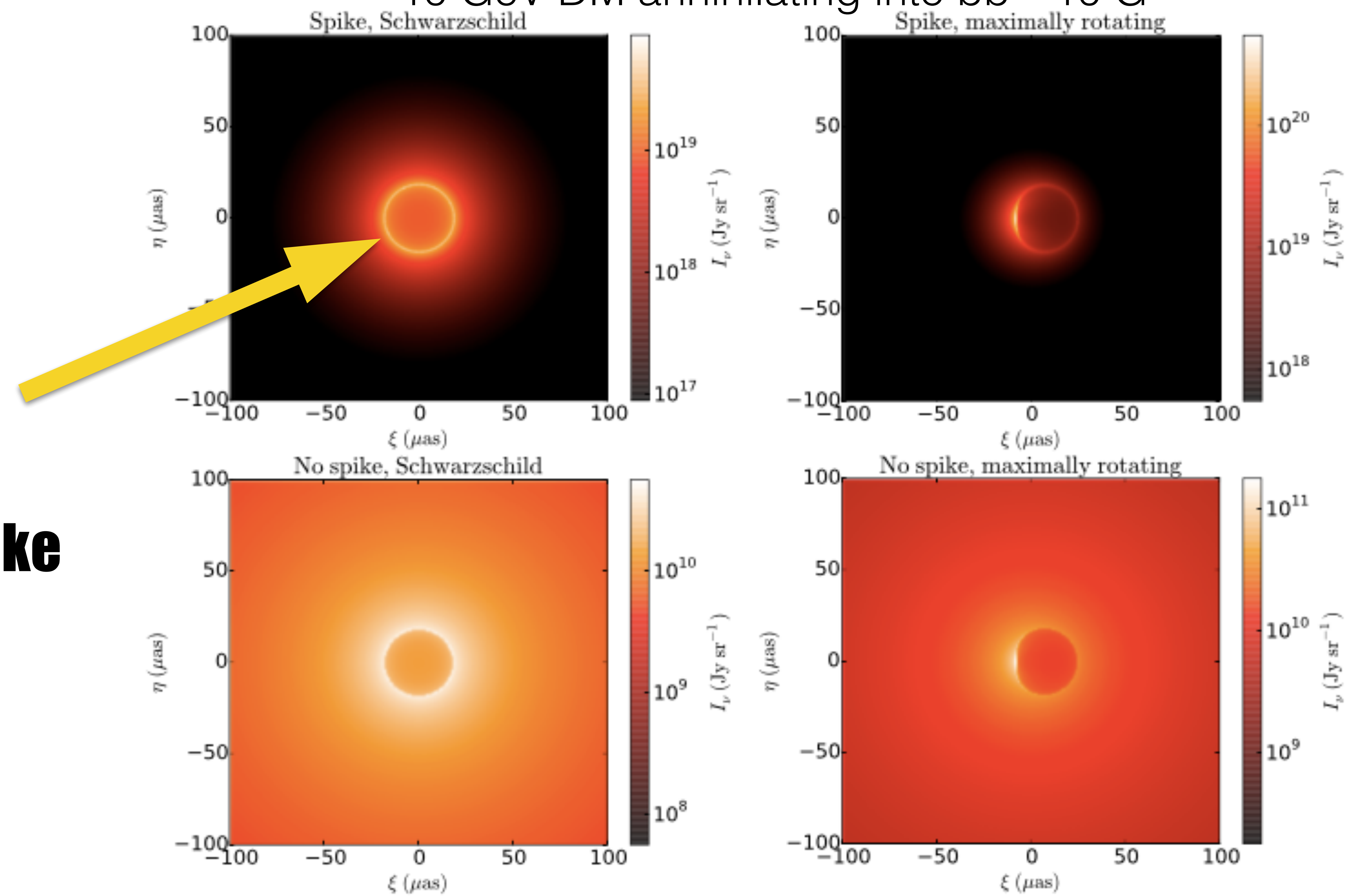
arXiv:1611.01961

synchrotron emission of electrons and positrons

10 GeV DM annihilating into $b\bar{b}$ 10 G

spike

no spike



EHT will access angular scales as small as 26 μas at 230 GHz and 17 μas at 345 GHz.

Conclusion

Radio astronomy can probe the parameter space

heading toward higher masses and/or weaker interactions
(unless the DM only interacts in the dark sector)

Still anomalies : will SKA help?

Cen A, Ret II

DM annihilations near BH

MW, M87, BH shadow

will SKA help?

Power Spectrum

new models & H0 (?)