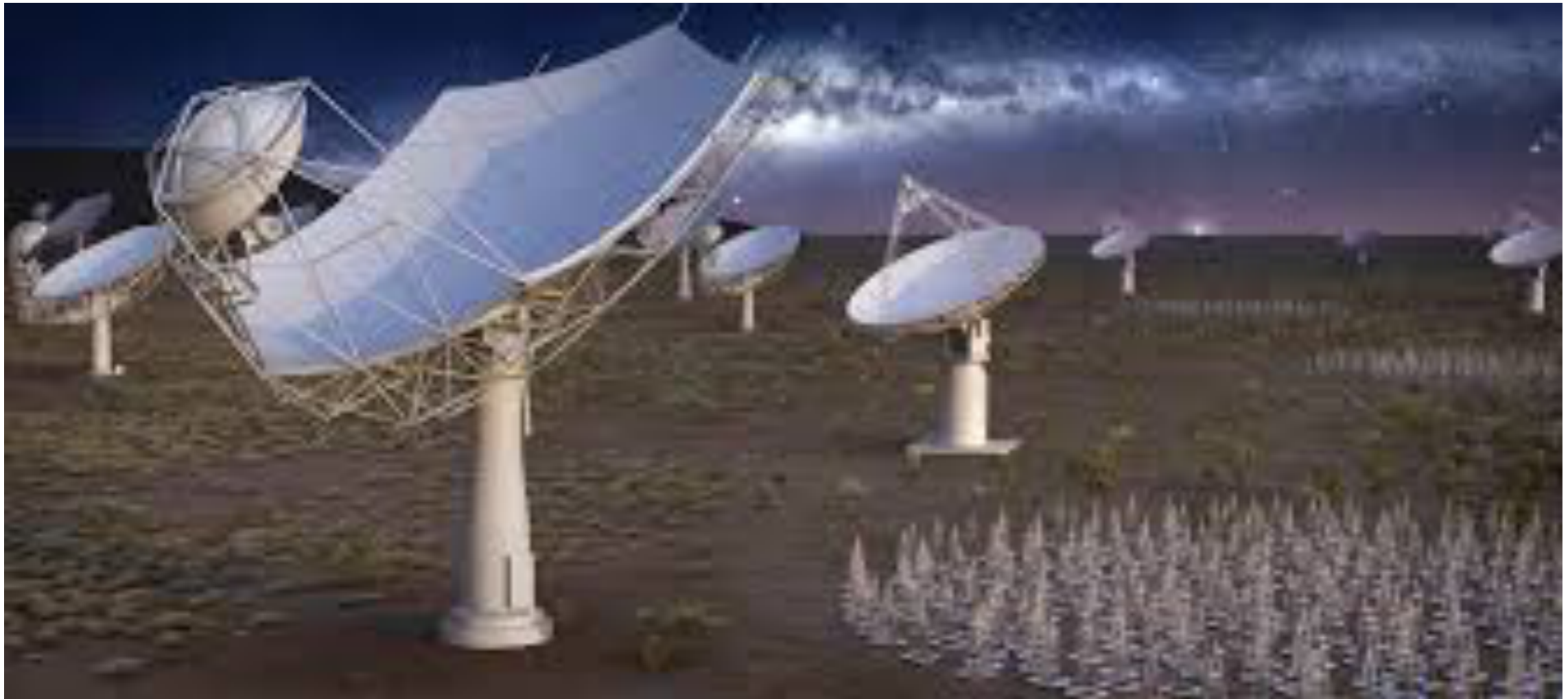
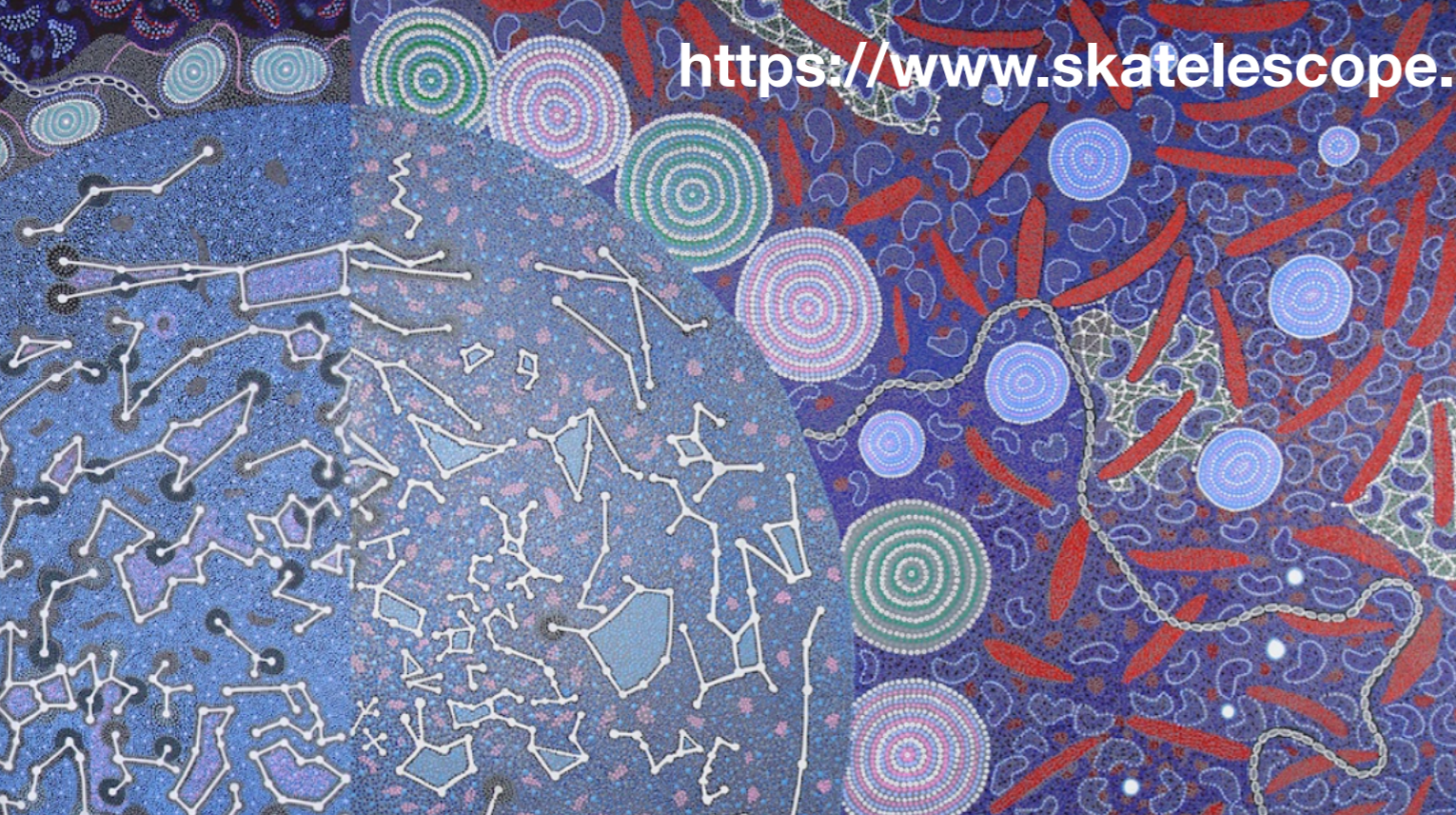


Fundamental Physics with SKA



Céline Boehm

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



A collaborative painting from Aboriginal Yamaji Artists from Western Australia and a collaborative quilt from South African indigenous artists, produced together for the [Shared Sky exhibition](#). Being located on similar latitudes on both continents, the two SKA sites in Australia and South Africa present essentially identical views of the night sky to the peoples that have lived there for tens of thousands of years, and to whom some of the oldest known artwork on earth can be attributed. Shared Sky reflects the SKA's One Sky concept: that no borders exist in the sky and that the night sky is an increasingly scarce natural resource that belongs to and is shared by all humanity.

PHOTO BY: Yamaji Art Centre, Western Australia / Bethesda Arts Centre, South Africa

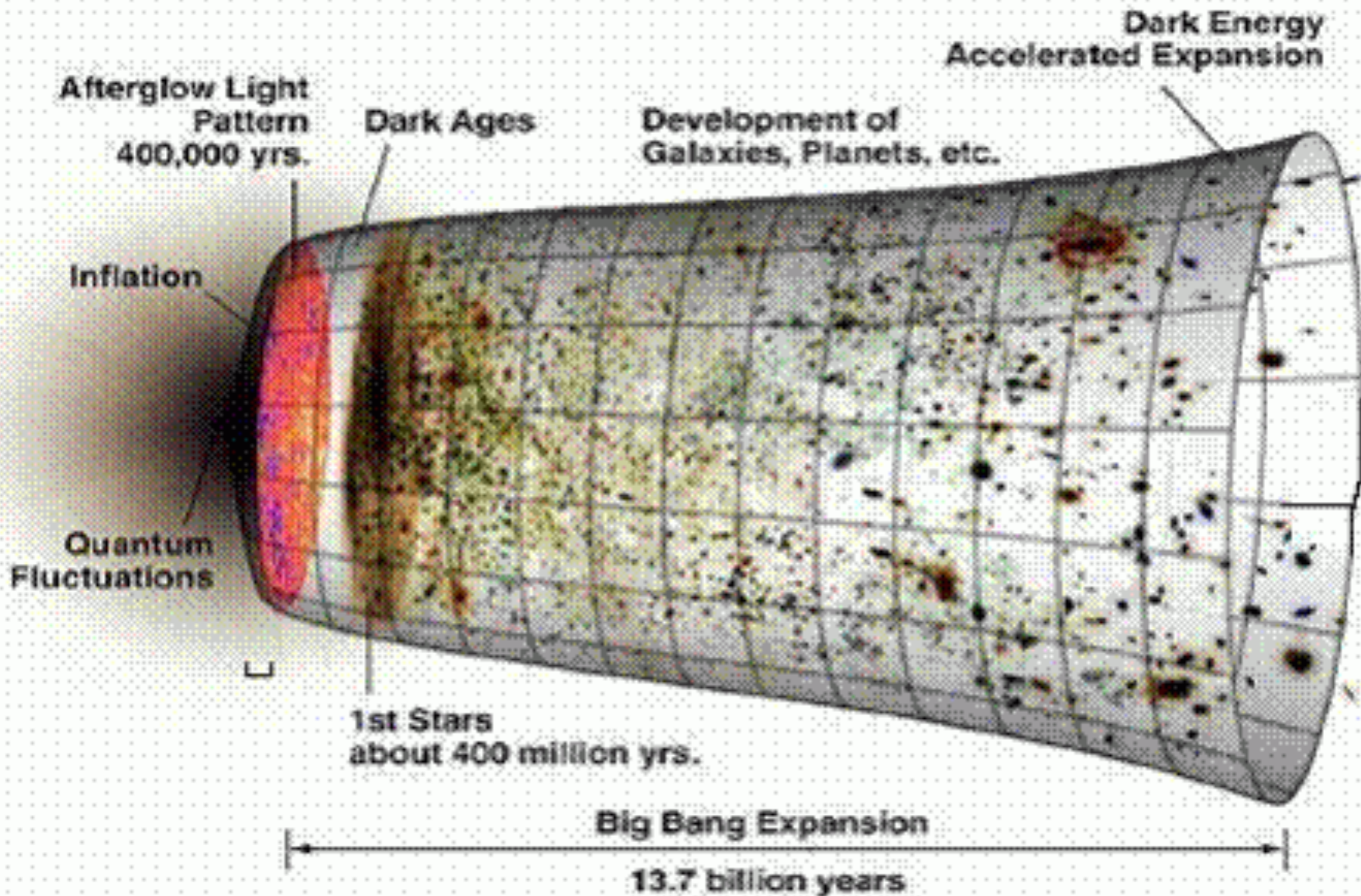
Fundamental Physics with SKA

Cosmic Dawn and Epoch of Reionization (First Stars and Galaxies)

Galaxy Evolution (HI, Continuum)

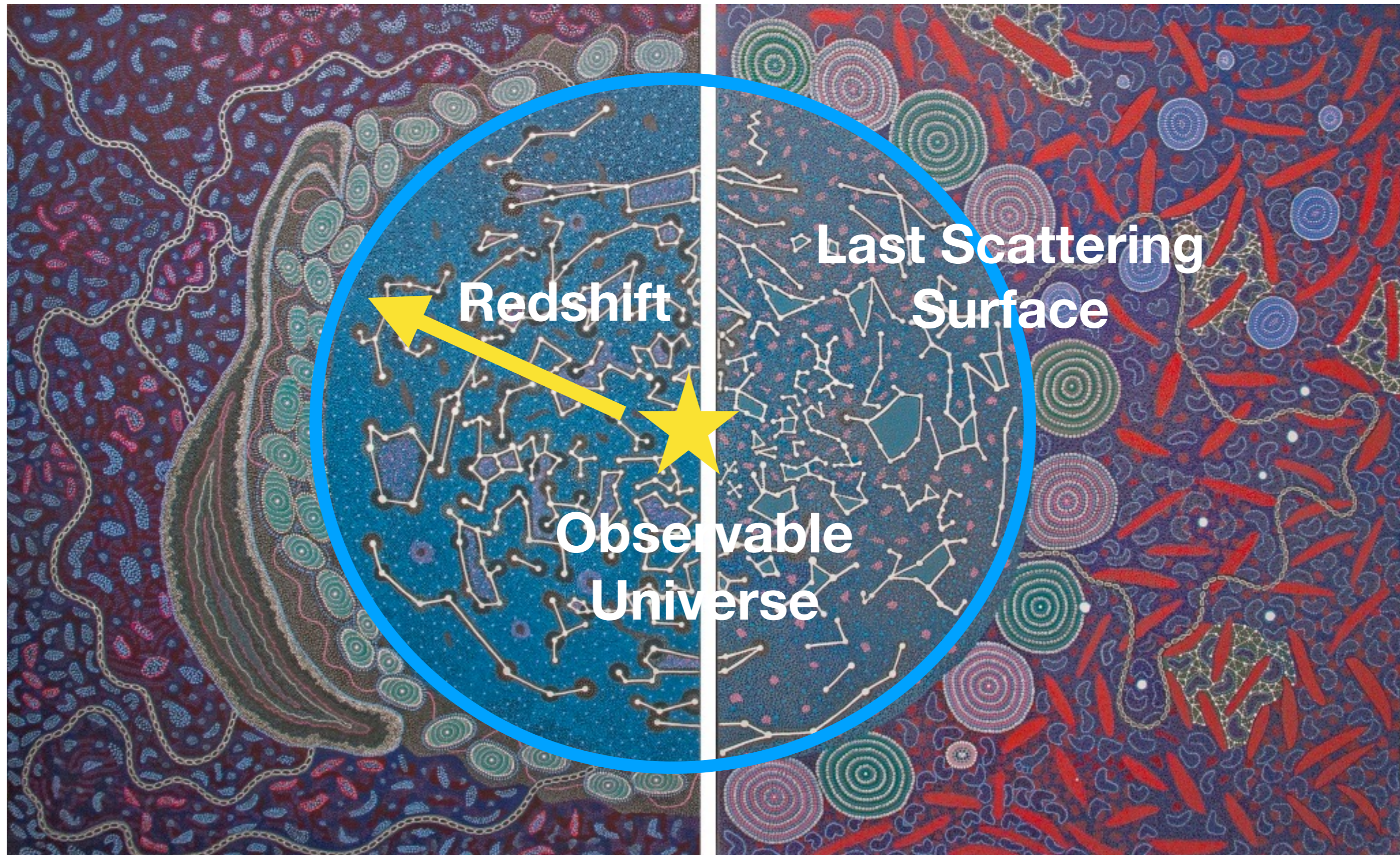
Cosmology (Dark Energy, **Dark Matter, Large-Scale-Structures)**

Testing General Relativity (Strong Regime, Gravitational Waves)



The observable Universe

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



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



elastic scattering
annihilations

...

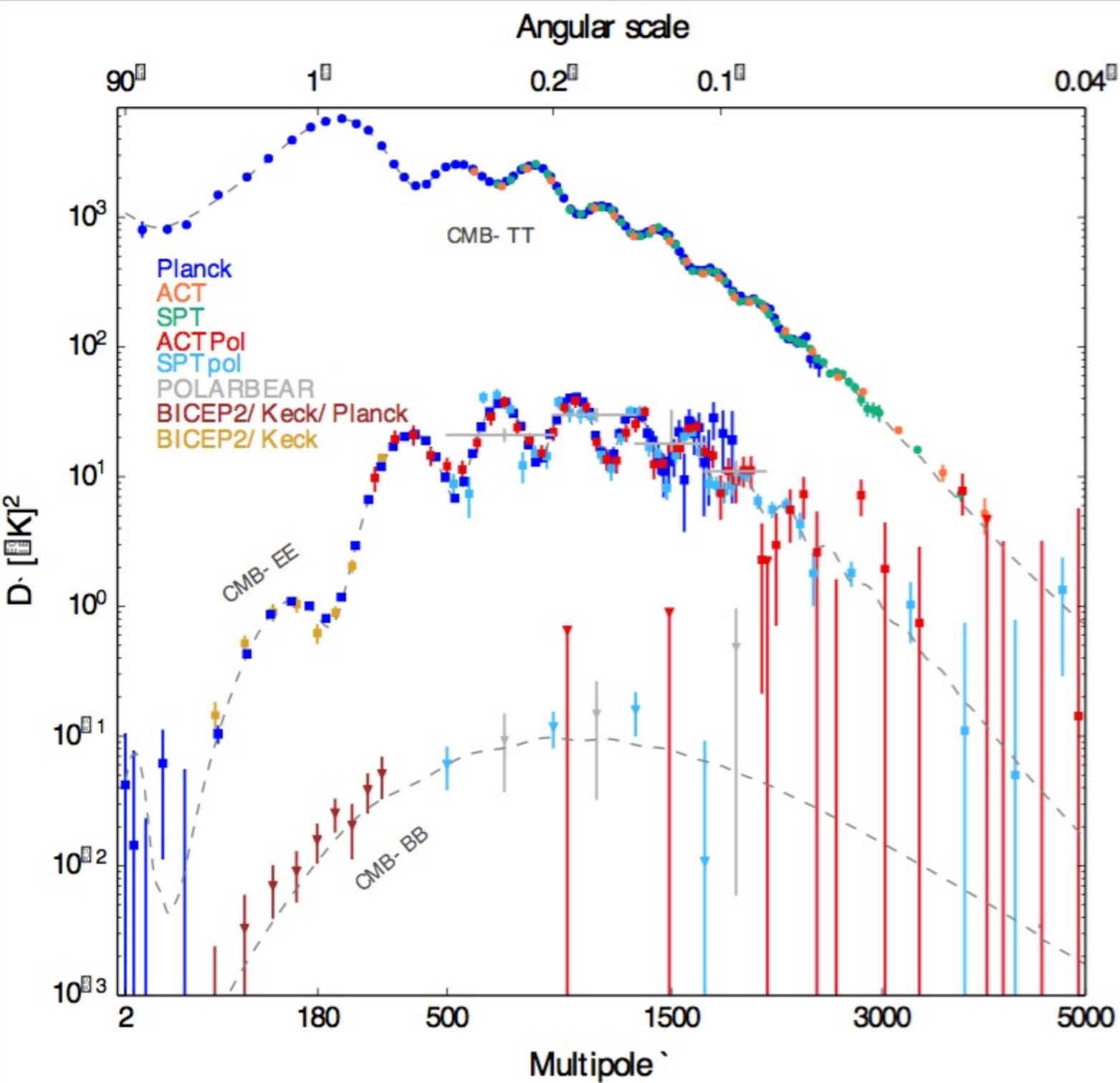
Standard Model of Elementary Particles

		three generations of matter (fermions)				
		I	II	III		
mass		$\approx 2.4 \text{ MeV}/c^2$	$\approx 1.275 \text{ GeV}/c^2$	$\approx 172.44 \text{ GeV}/c^2$	0	$\approx 125.09 \text{ GeV}/c^2$
charge		$2/3$	$2/3$	$2/3$	0	0
spin		$1/2$	$1/2$	$1/2$	1	0
	QUARKS	u up	c charm	t top	g gluon	H Higgs
		$\approx 4.8 \text{ MeV}/c^2$	$\approx 95 \text{ MeV}/c^2$	$\approx 4.18 \text{ GeV}/c^2$	0	
		$-1/3$	$-1/3$	$-1/3$	0	
		$1/2$	$1/2$	$1/2$	1	
		d down	s strange	b bottom	γ photon	
	LEPTONS	$\approx 0.511 \text{ MeV}/c^2$	$\approx 105.67 \text{ MeV}/c^2$	$\approx 1.7768 \text{ GeV}/c^2$	$\approx 91.19 \text{ GeV}/c^2$	
		-1	-1	-1	0	
		$1/2$	$1/2$	$1/2$	1	
		e electron	μ muon	τ tau	Z Z boson	
		$< 2.2 \text{ eV}/c^2$	$< 1.7 \text{ MeV}/c^2$	$< 15.5 \text{ MeV}/c^2$	$\approx 80.39 \text{ GeV}/c^2$	
		0	0	0	± 1	
		$1/2$	$1/2$	$1/2$	1	
		ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	
	GAUGE BOSONS					SCALAR BOSONS

Relevance for Dark Matter

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

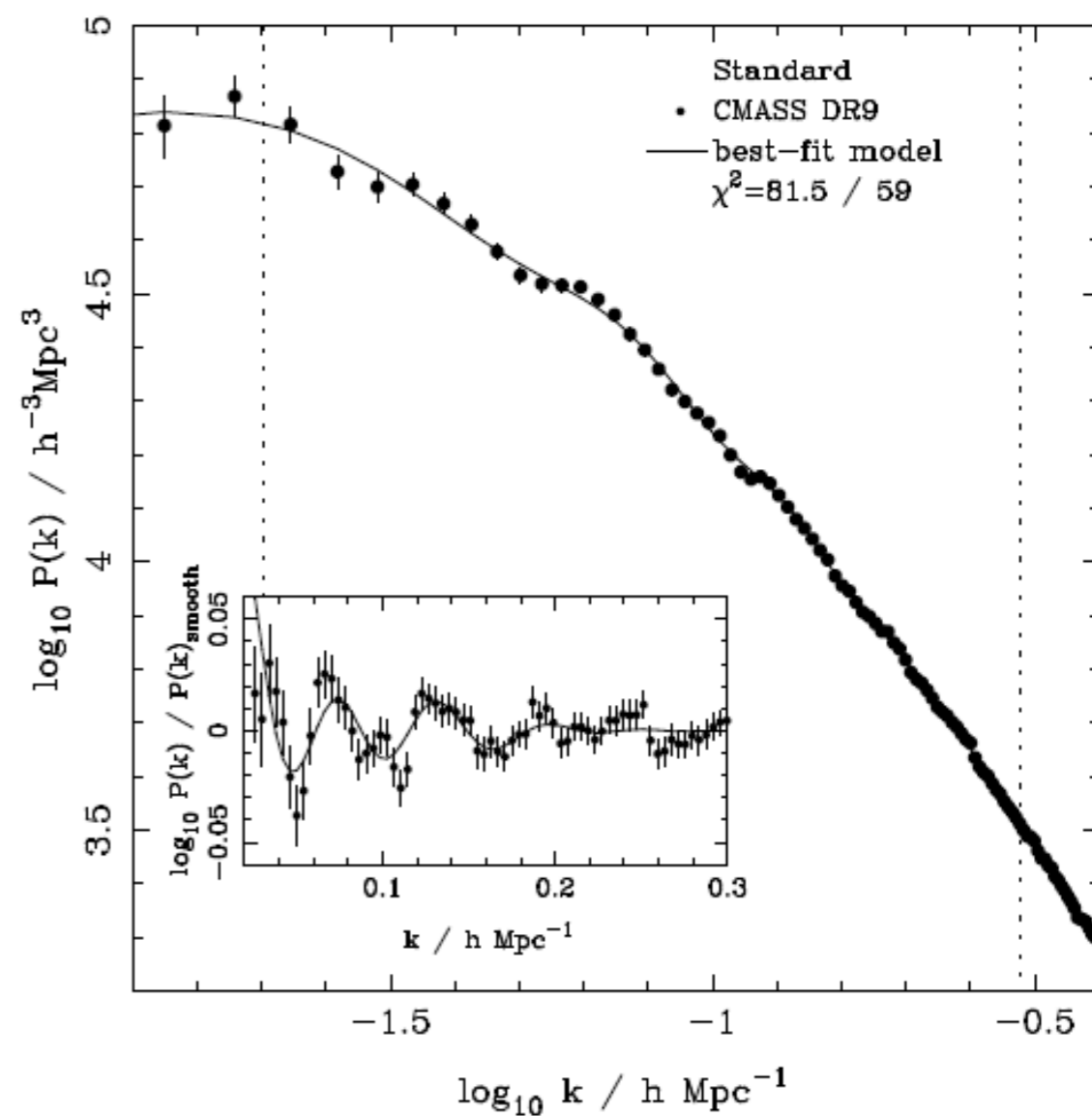
$$\begin{aligned}\dot{\theta}_b &= k^2 \psi - \mathcal{H} \theta_b + c_s^2 k^2 \delta_b - R^{-1} \dot{\kappa} (\theta_b - \theta_\gamma) \\ \dot{\theta}_\gamma &= k^2 \psi + k^2 \left(\frac{1}{4} \delta_\gamma - \sigma_\gamma \right) - \dot{\kappa} (\theta_\gamma - \theta_b) , \\ \dot{\theta}_{\text{DM}} &= k^2 \psi - \mathcal{H} \theta_{\text{DM}} ,\end{aligned}$$



Higher scales
Spherical harmonics



$P(k)$
Smaller scales
Fourier transforms



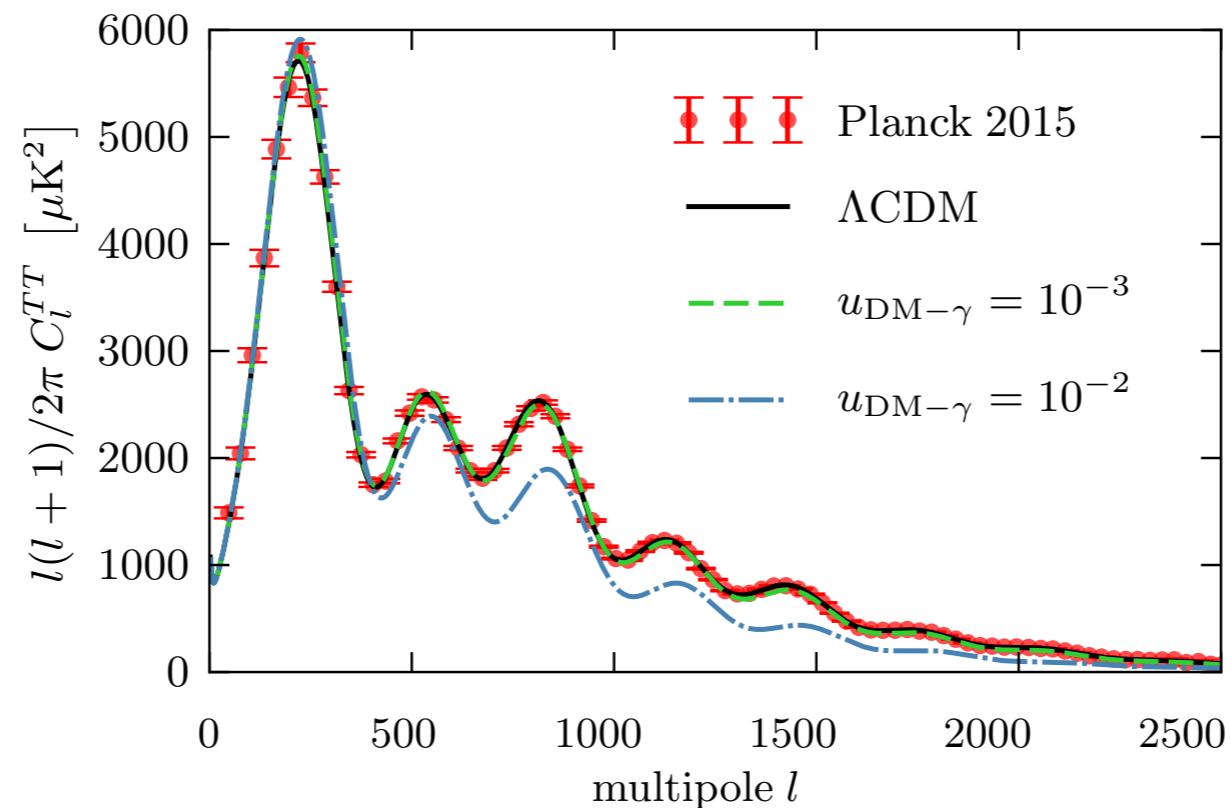
Testing the DM microphysics

without DM interactions

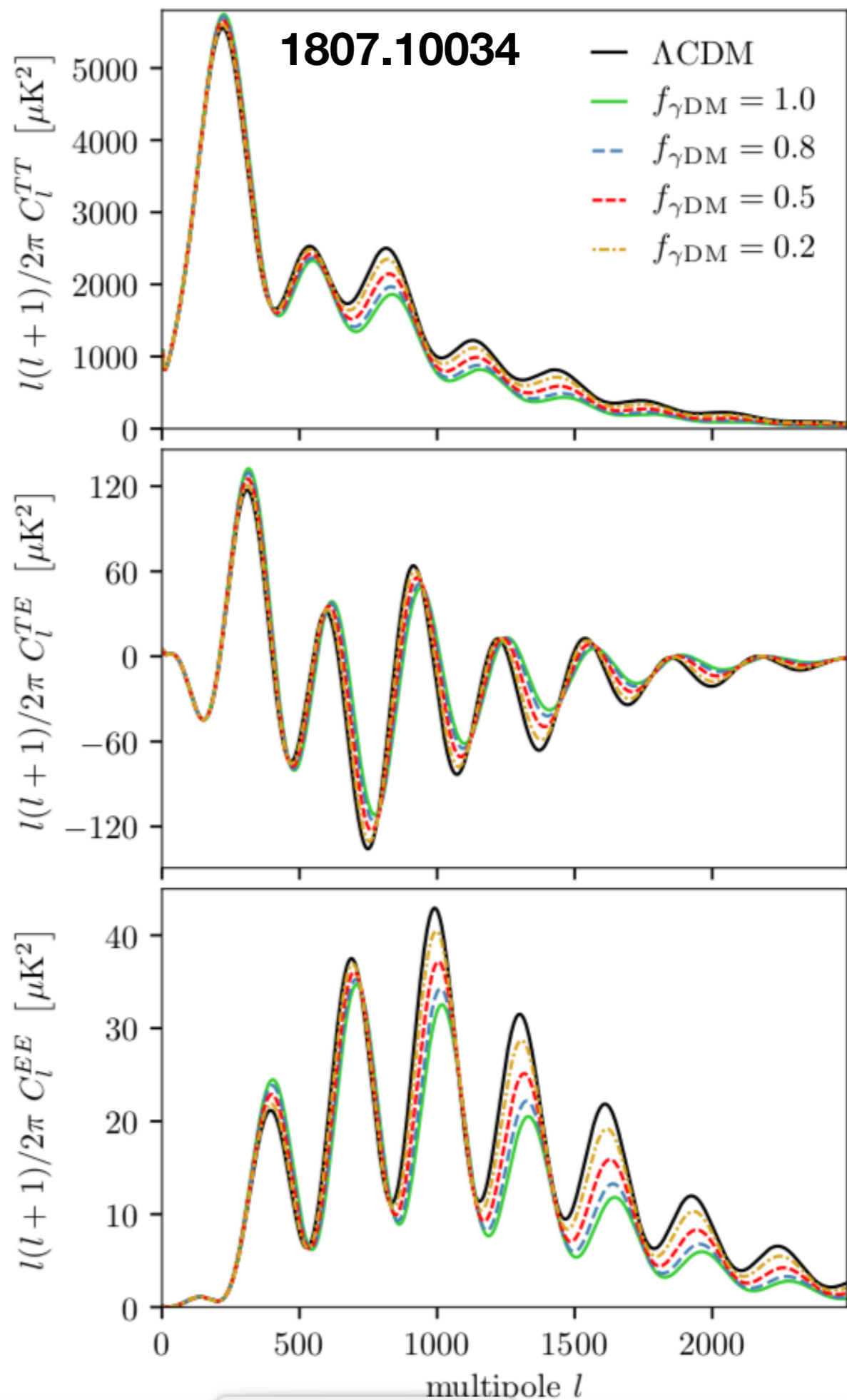
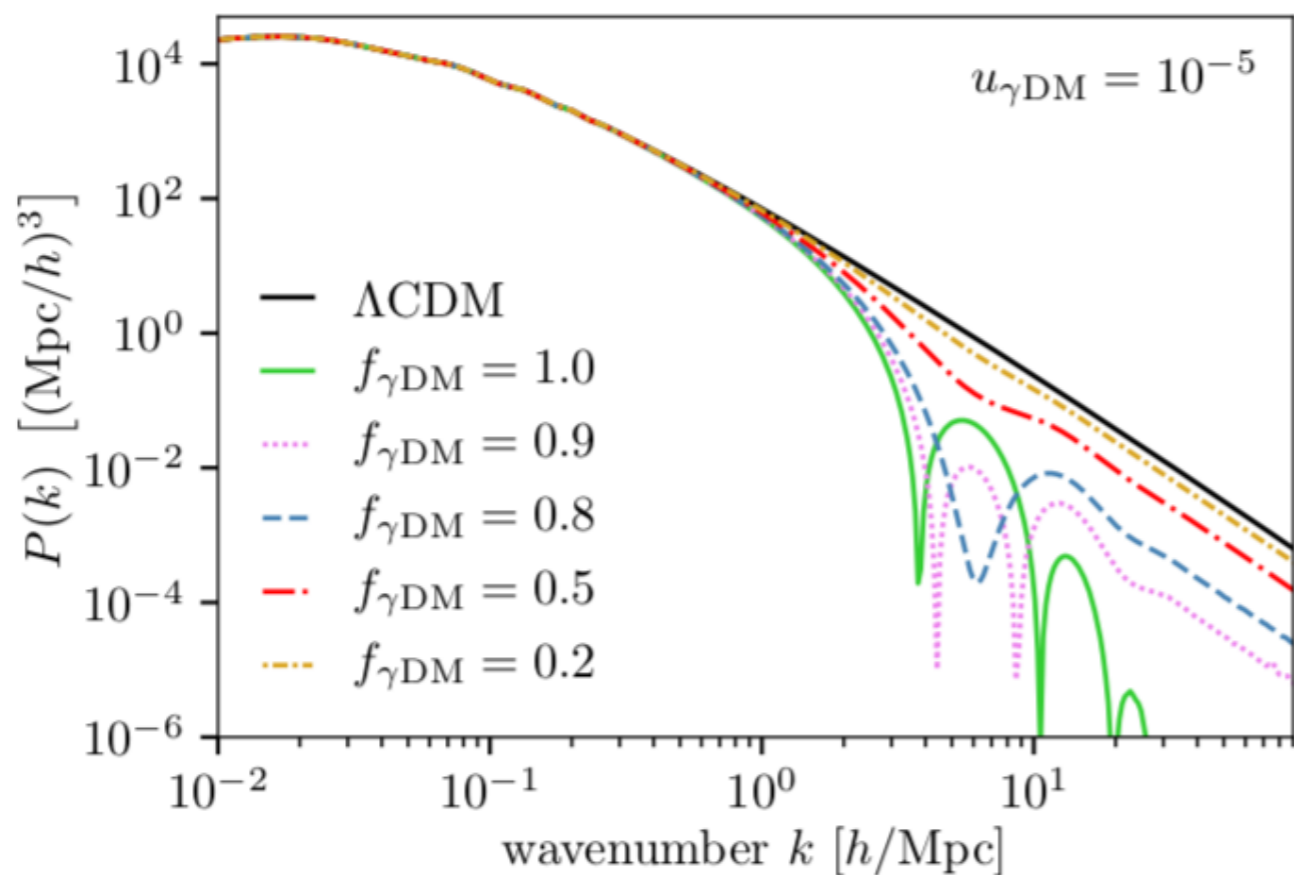
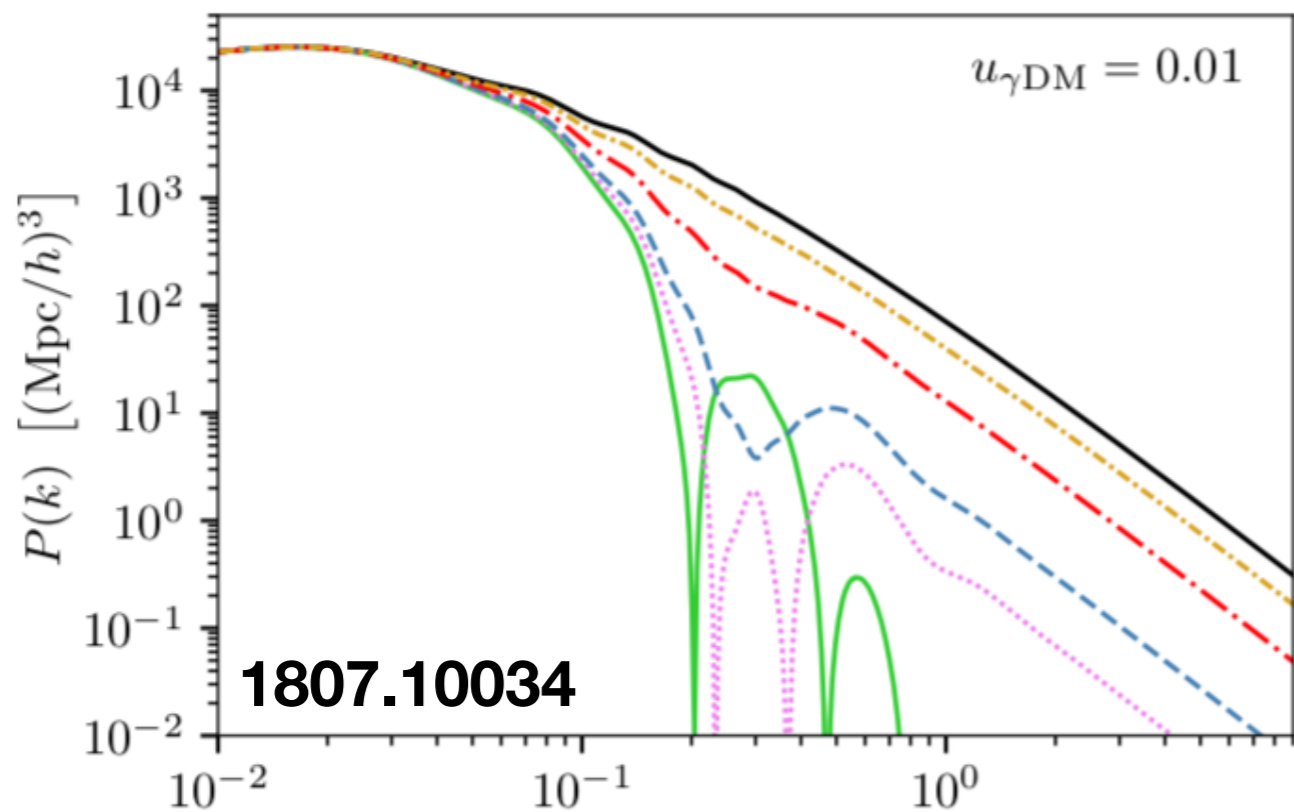
$$\begin{aligned}\dot{\theta}_b &= k^2\psi - \mathcal{H}\theta_b + c_s^2 k^2 \delta_b - R^{-1} \dot{\kappa}(\theta_b - \theta_\gamma) \\ \dot{\theta}_\gamma &= k^2\psi + k^2 \left(\frac{1}{4} \delta_\gamma - \sigma_\gamma \right) - \dot{\kappa}(\theta_\gamma - \theta_b), \\ \dot{\theta}_{\text{DM}} &= k^2\psi - \mathcal{H}\theta_{\text{DM}},\end{aligned}$$

with DM interactions

$$\begin{aligned}\dot{\theta}_b &= k^2\psi - \mathcal{H}\theta_b + c_s^2 k^2 \delta_b - R^{-1} \dot{\kappa}(\theta_b - \theta_\gamma) \\ \dot{\theta}_\gamma &= k^2\psi + k^2 \left(\frac{1}{4} \delta_\gamma - \sigma_\gamma \right) \\ &\quad - \dot{\kappa}(\theta_\gamma - \theta_b) - \dot{\mu}(\theta_\gamma - \theta_{\text{DM}}), \\ \dot{\theta}_{\text{DM}} &= k^2\psi - \mathcal{H}\theta_{\text{DM}} - S^{-1} \dot{\mu}(\theta_{\text{DM}} - \theta_\gamma).\end{aligned}$$



Interacting Scenarios



CDM

WDM

100 kpc

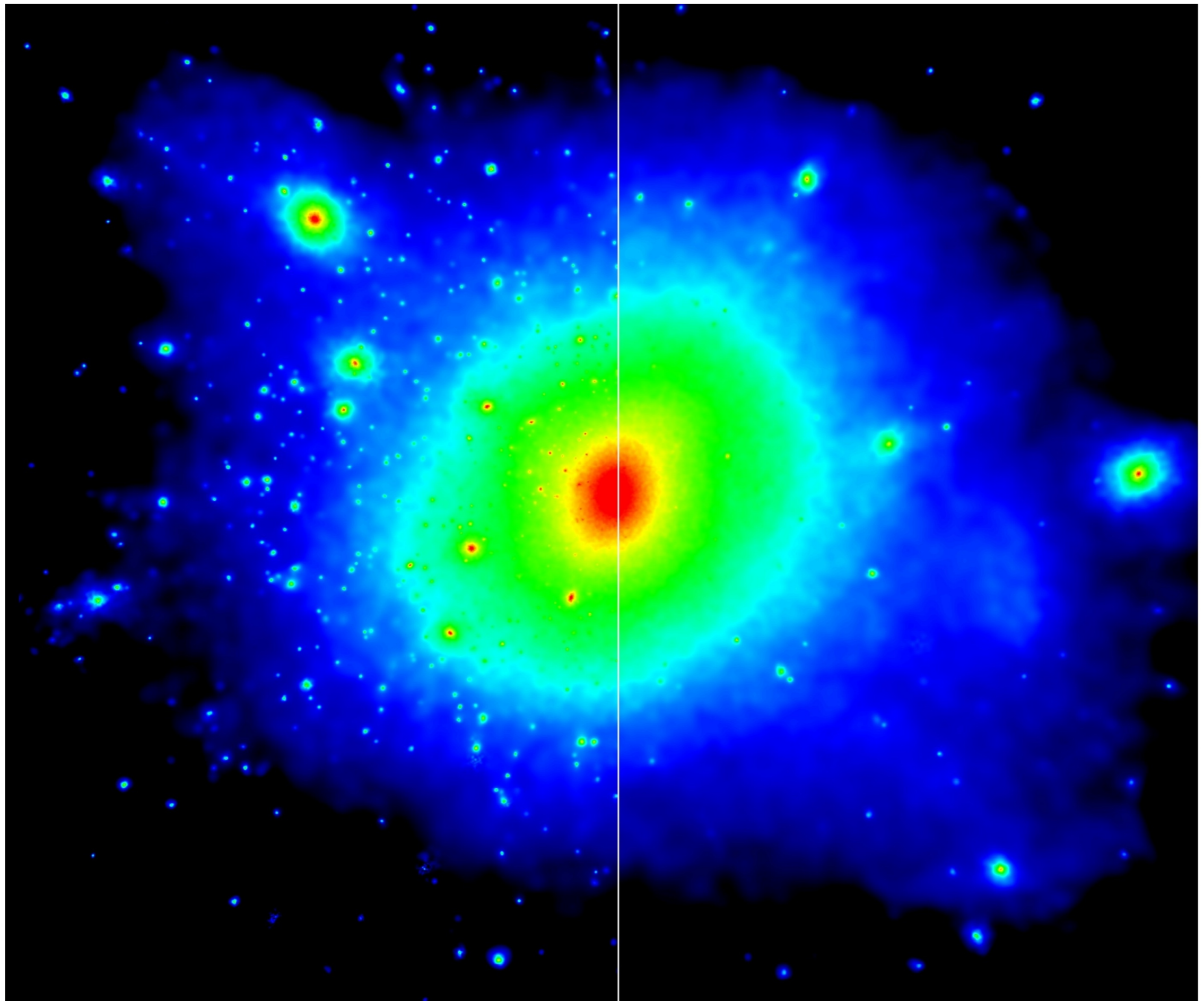
C.B., J. Schewtschenko et al

arXiv:1404.7012

γ CDM

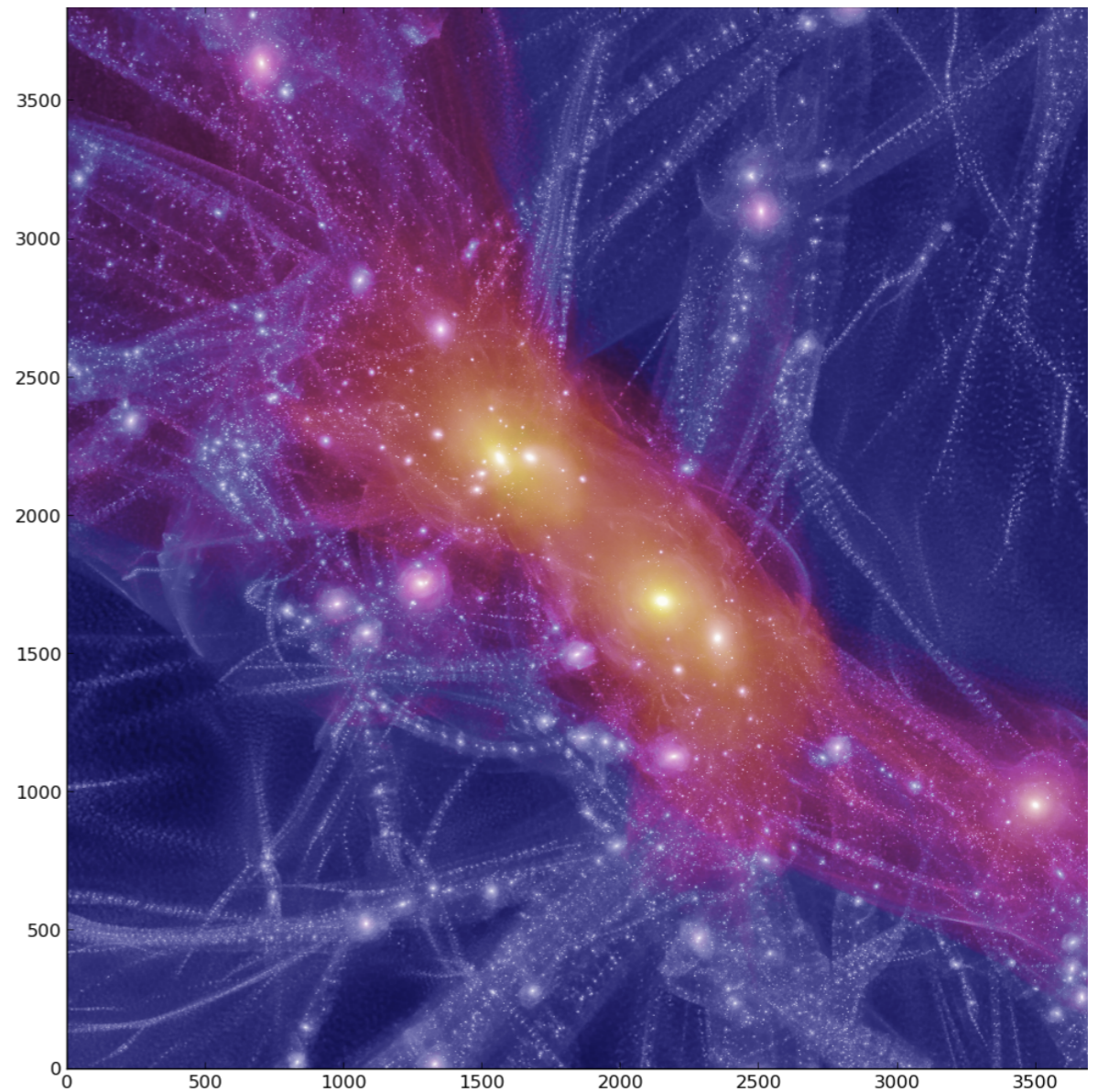
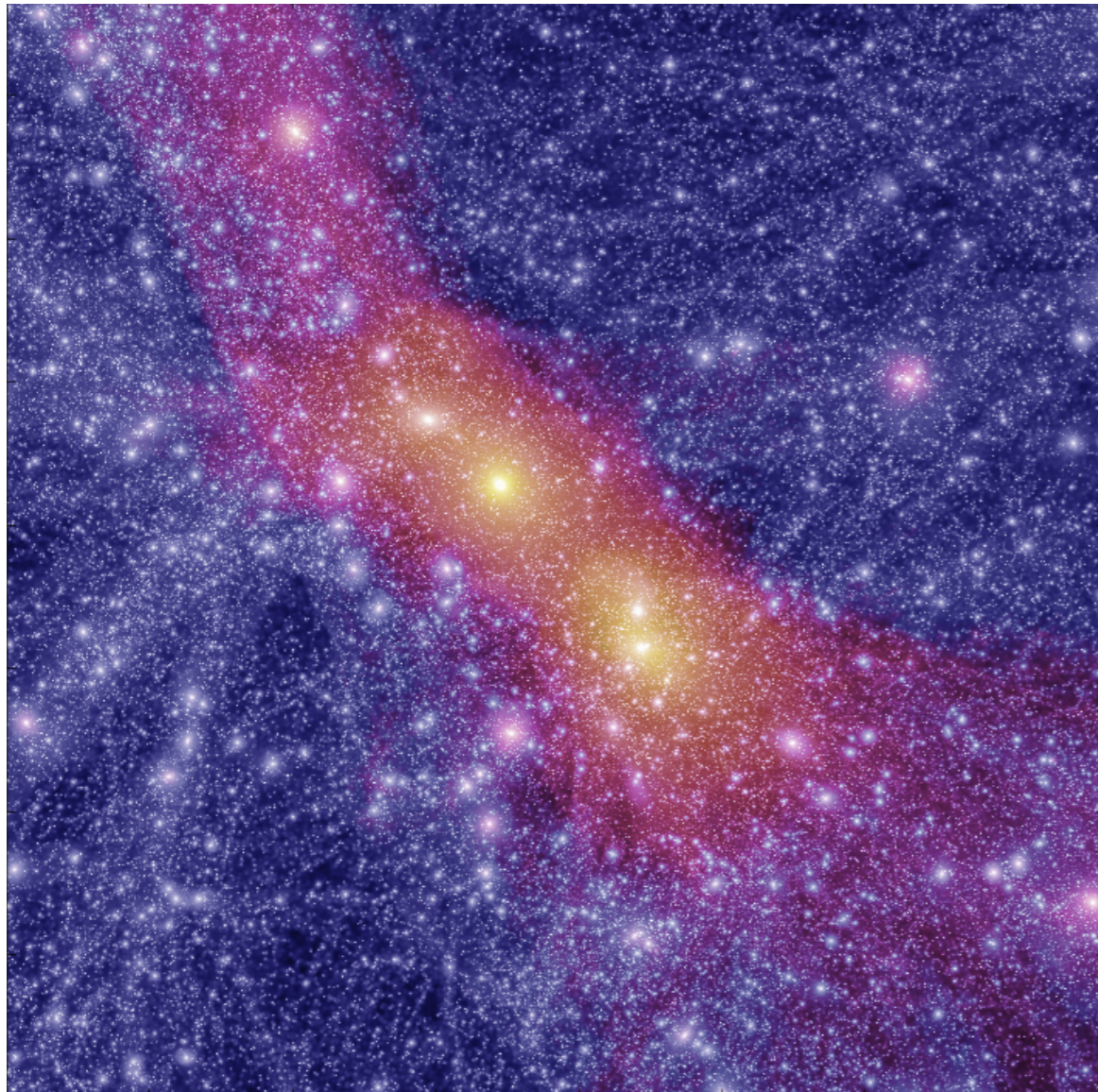
γ CDM'

$$\sigma_{\text{DM}-\gamma} \lesssim 10^{-33} \left(\frac{m_{\text{DM}}}{\text{GeV}} \right) \text{cm}^2$$



Distribution of matter in the Universe

Rather than



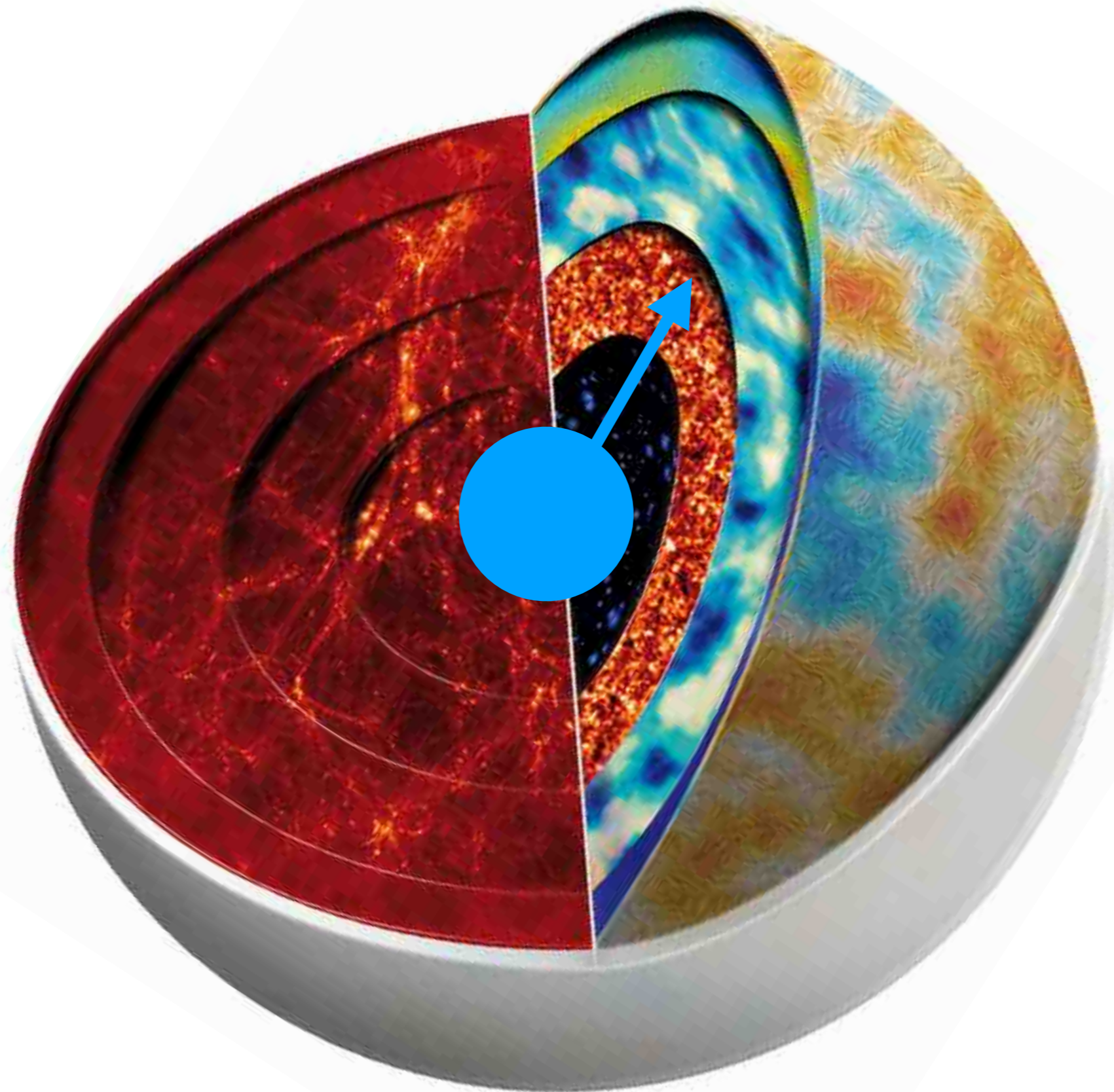
The picture we have in mind is correct

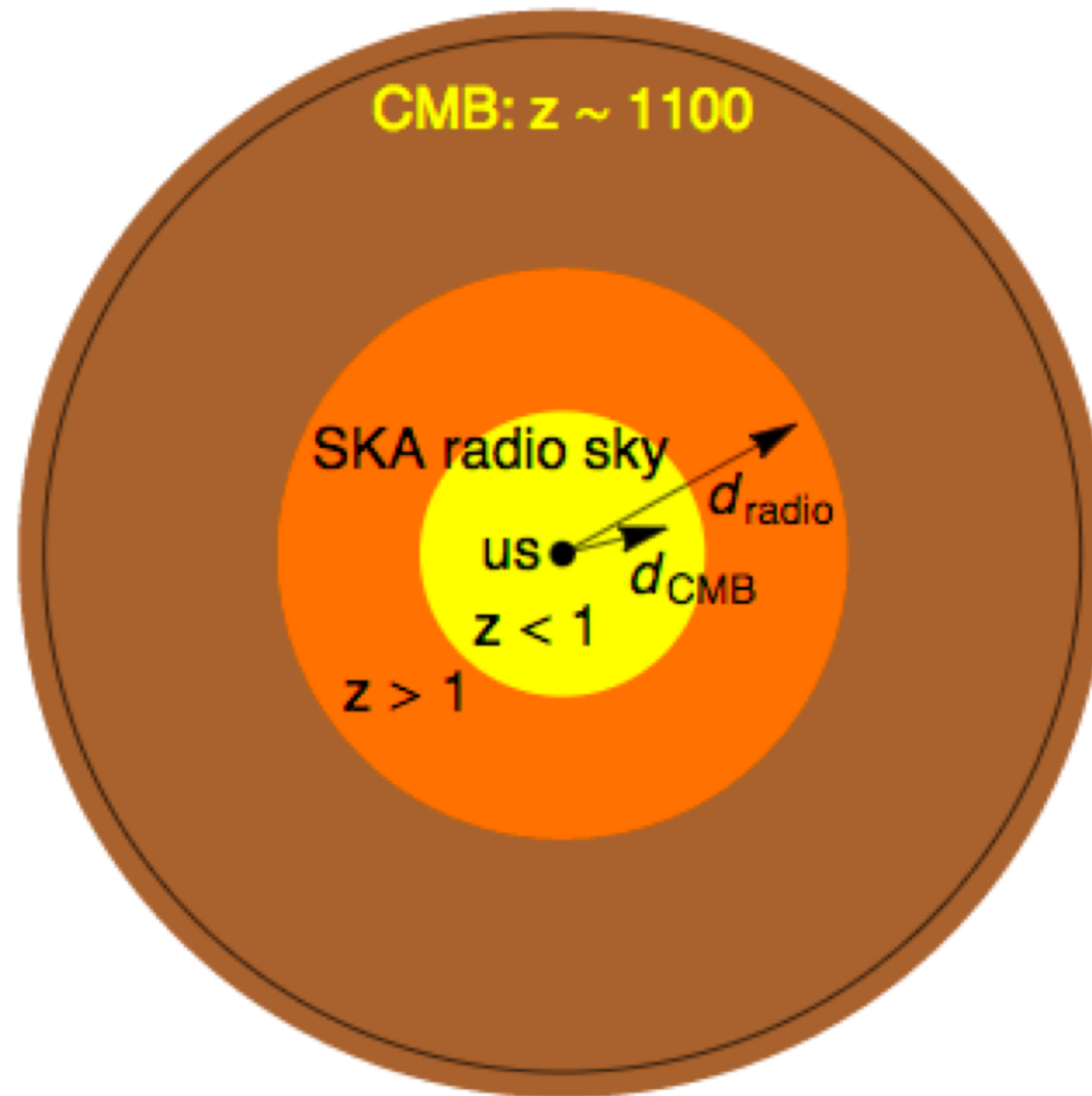
How could SKA help?

Any models

(dark energy, modified gravity etc)

SKA capability





AGNs
Radio galaxies

Schwarz et al. 2015

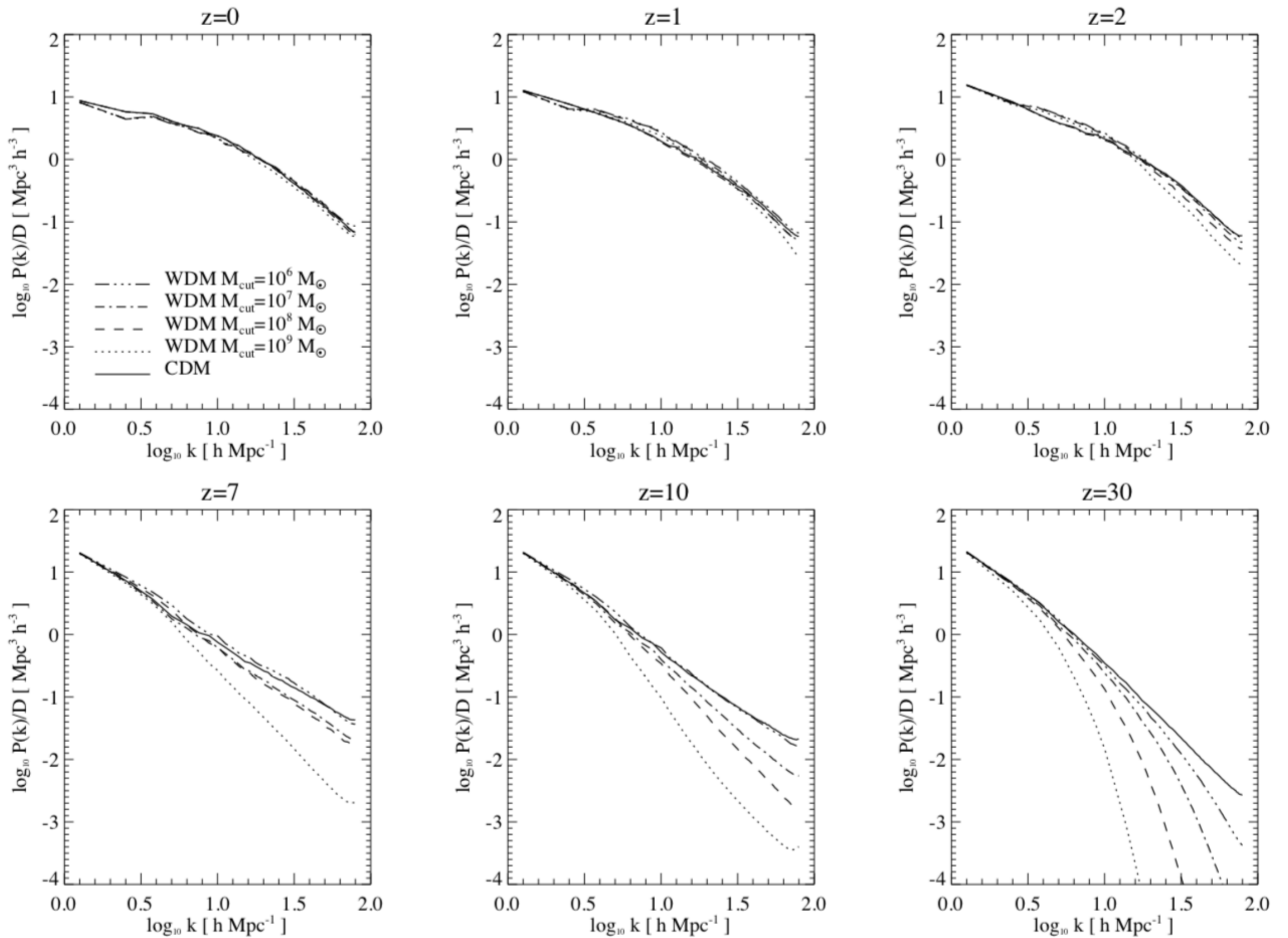
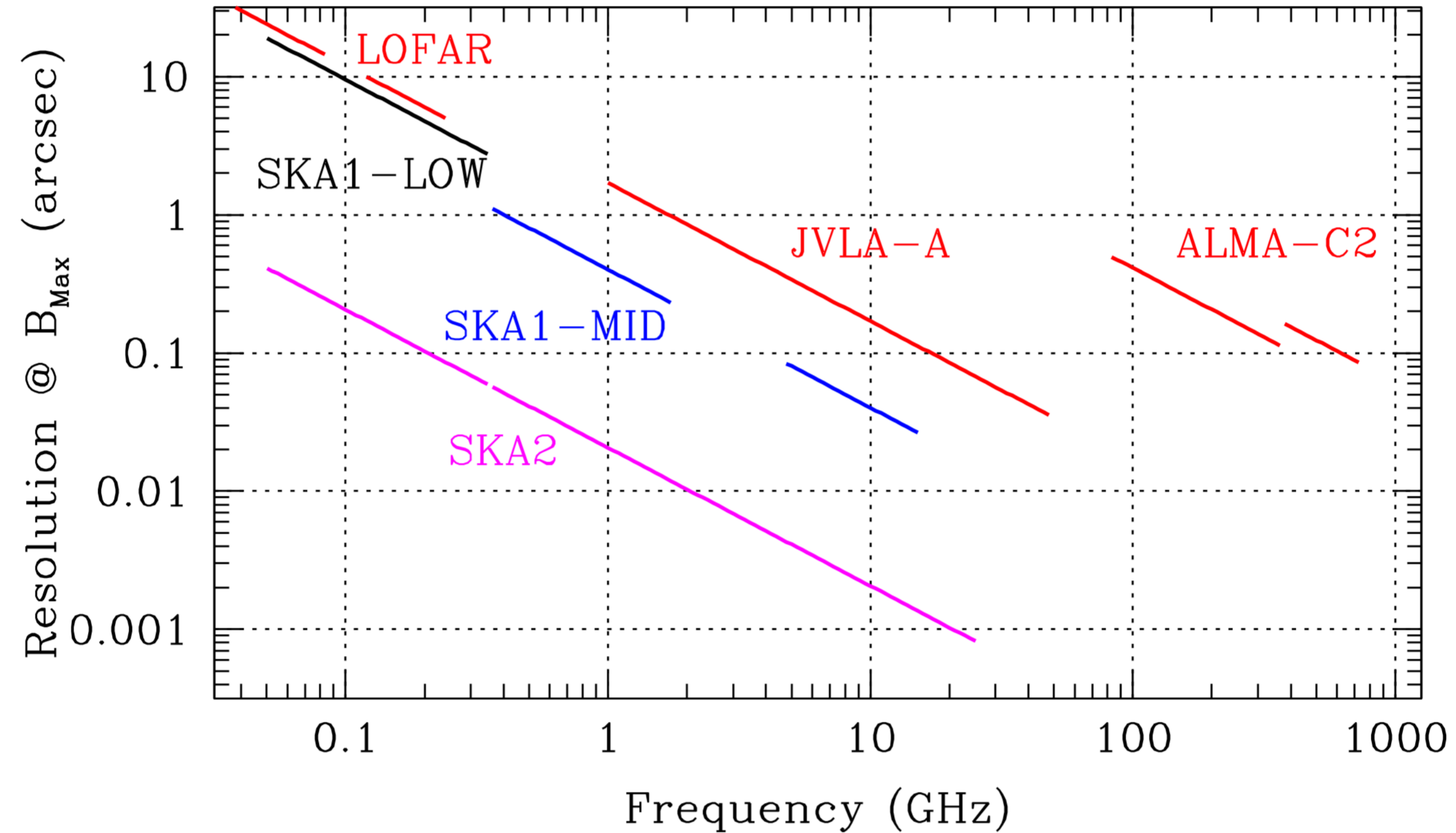


Figure 1. Snapshots of the dark matter power spectra measured in simulations of a series of DM models. CDM and 0.6, 1.1, 2 and 3.5 keV heavy warm WDM corresponding to respectively 10^9 , 10^8 , 10^7 and $10^6 h^{-1} M_{\odot}$ Lagrangian masses in the free-streaming length are shown. The power spectra 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 $z \leq 2$.

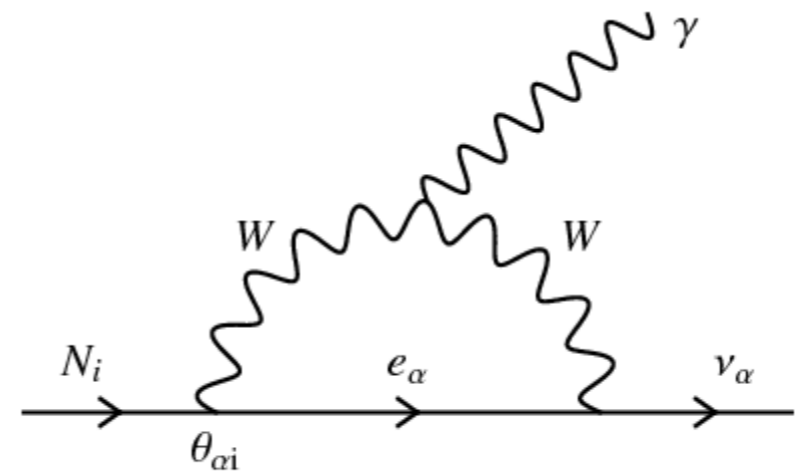
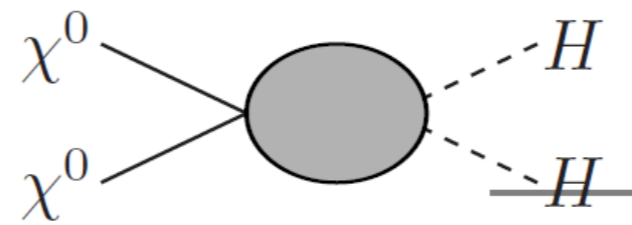
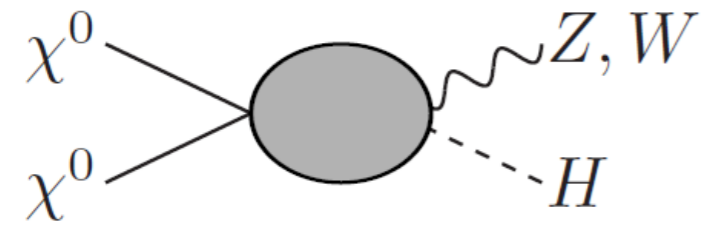
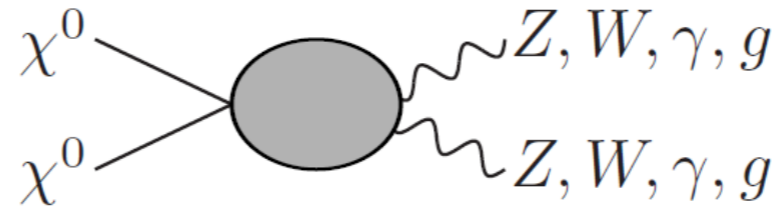
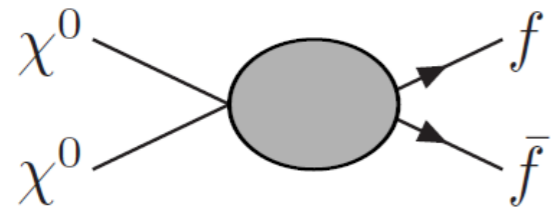
Dark Matter

Indirect detection



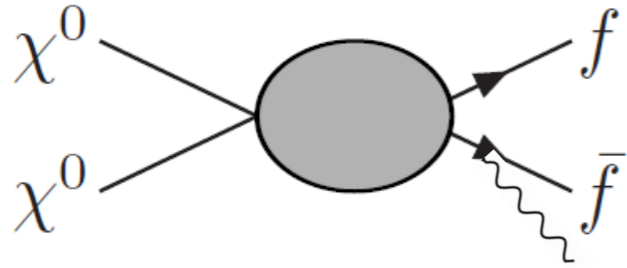
50 MHz to 14 GHz (eventually up to 30 GHz)

Dark Matter may annihilate/decay

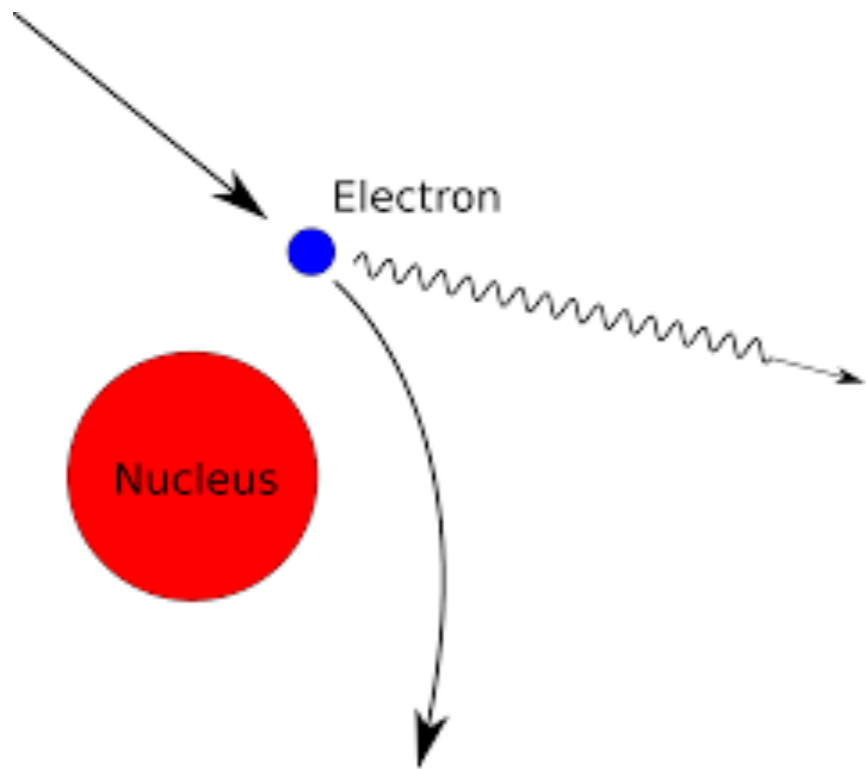


Emission from DM

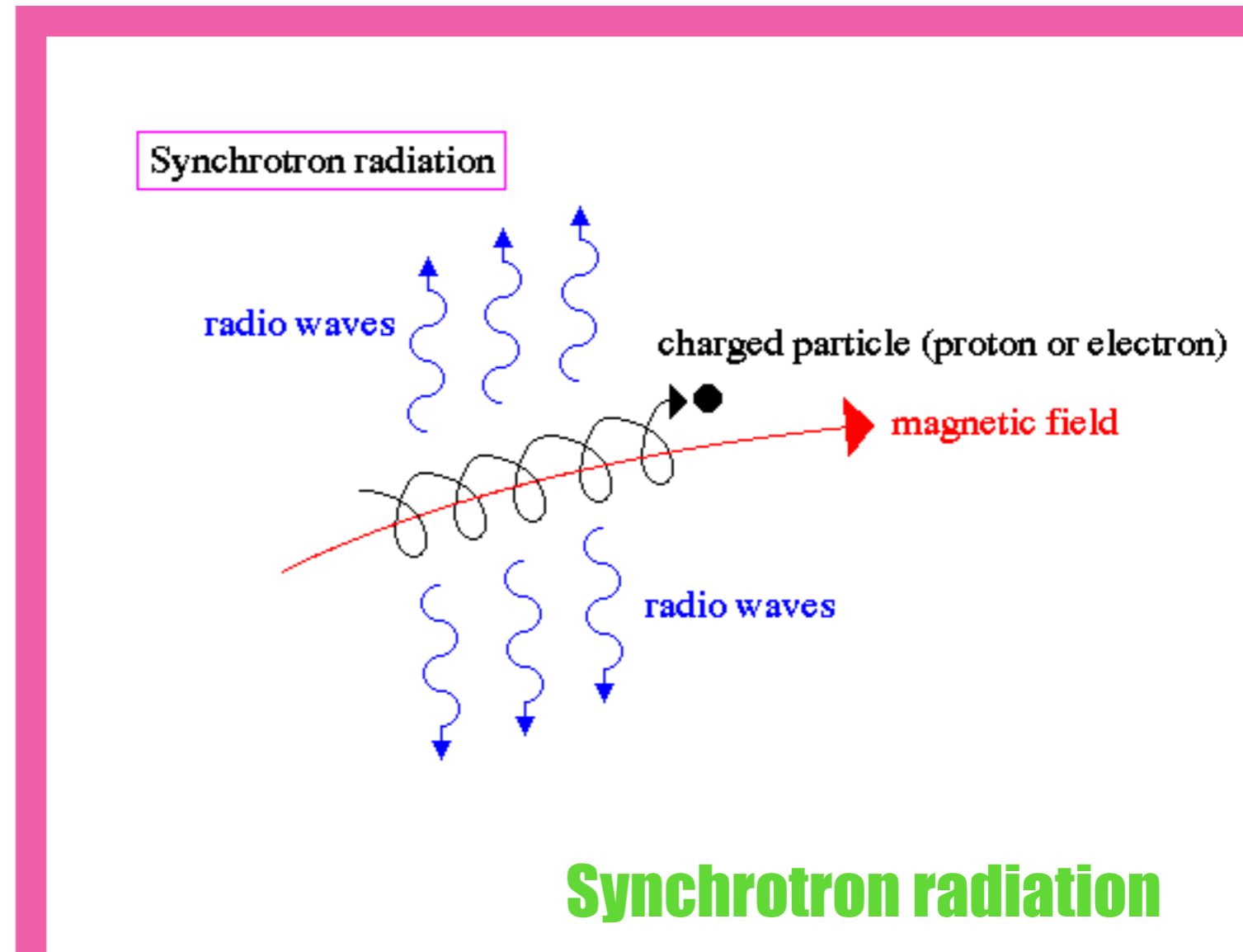
charged particles create photons



prompt emission (radiative correction)



Bremsstrahlung emission



Synchrotron radiation

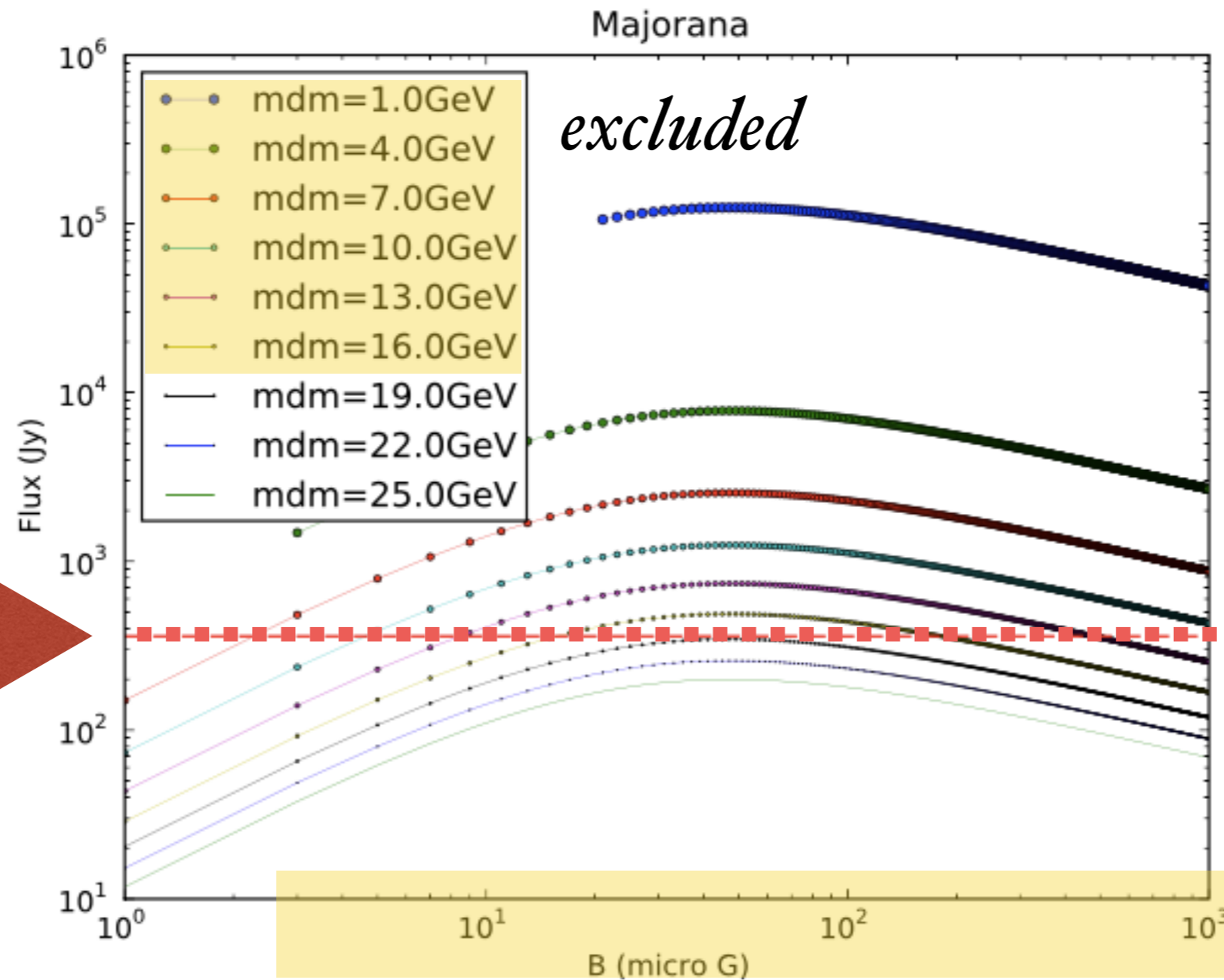
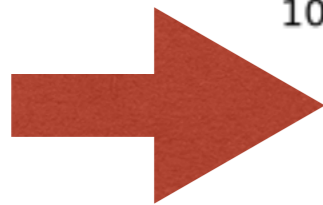
Radio constraints

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

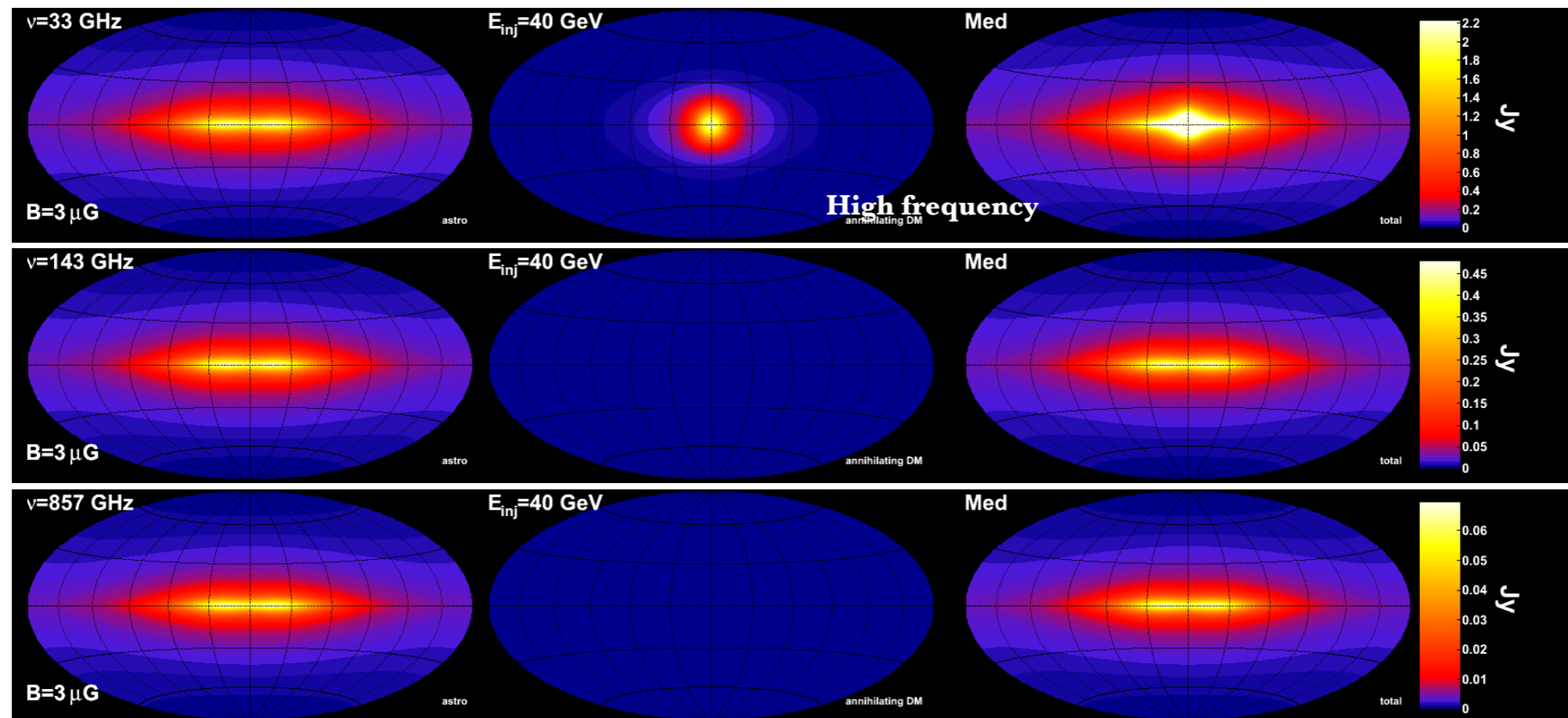
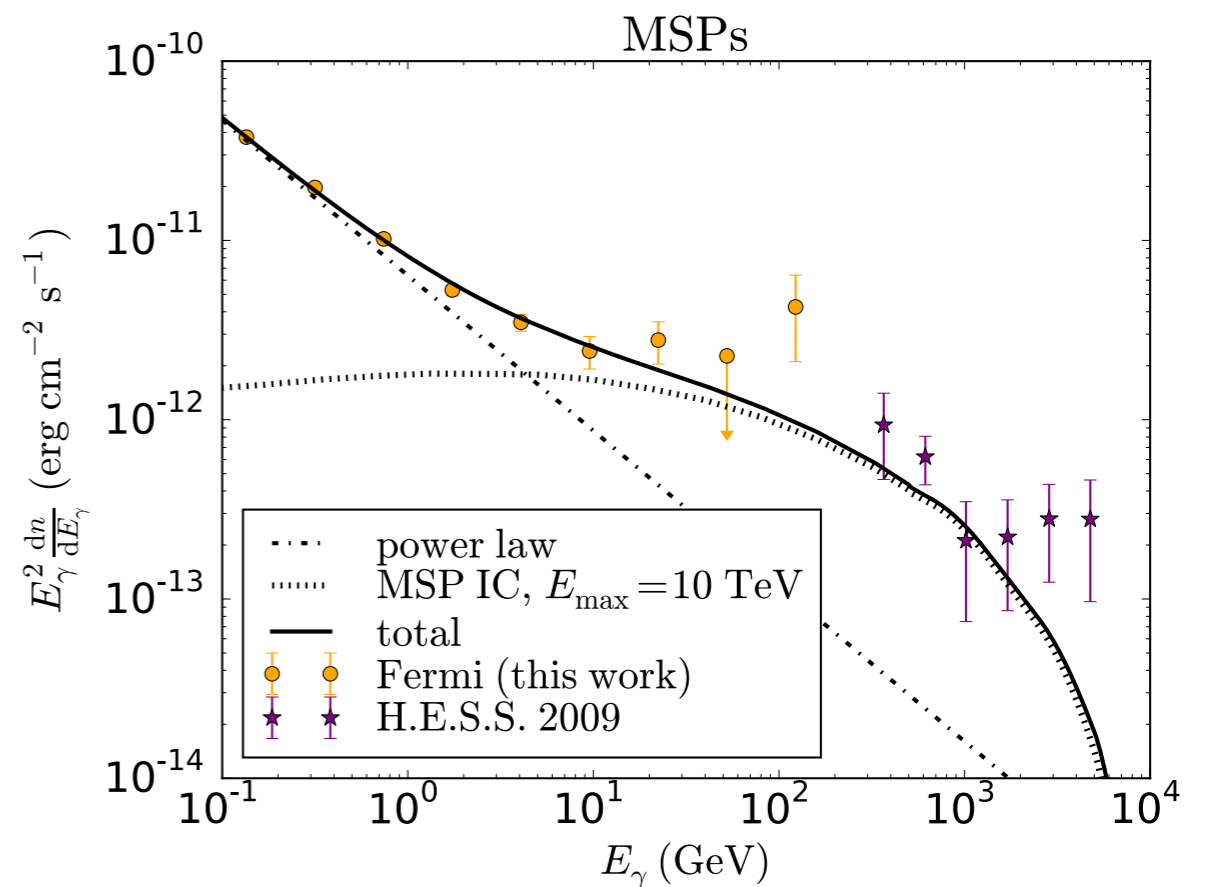
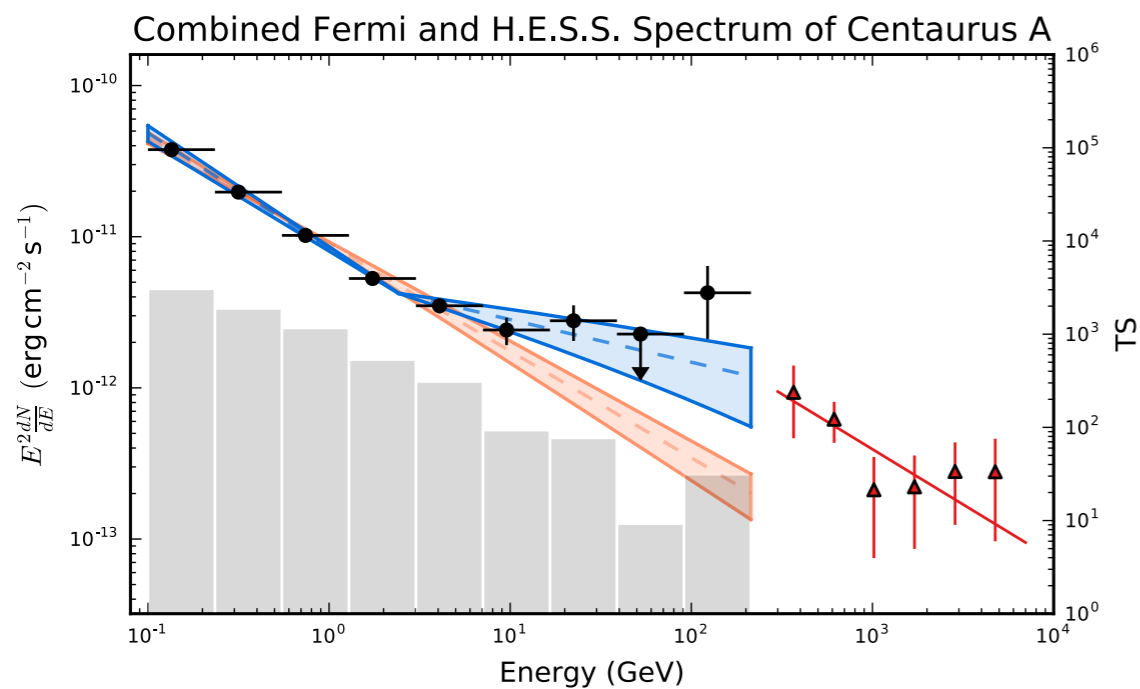
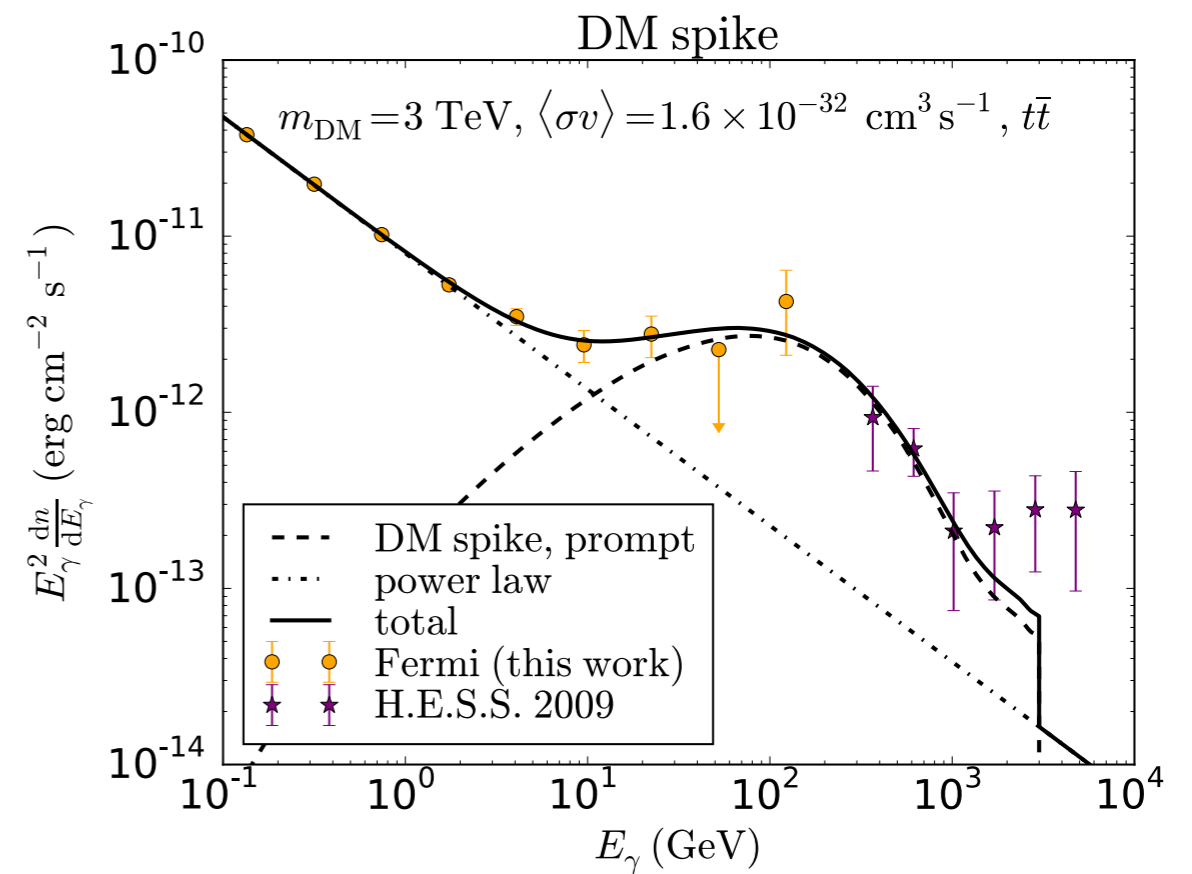
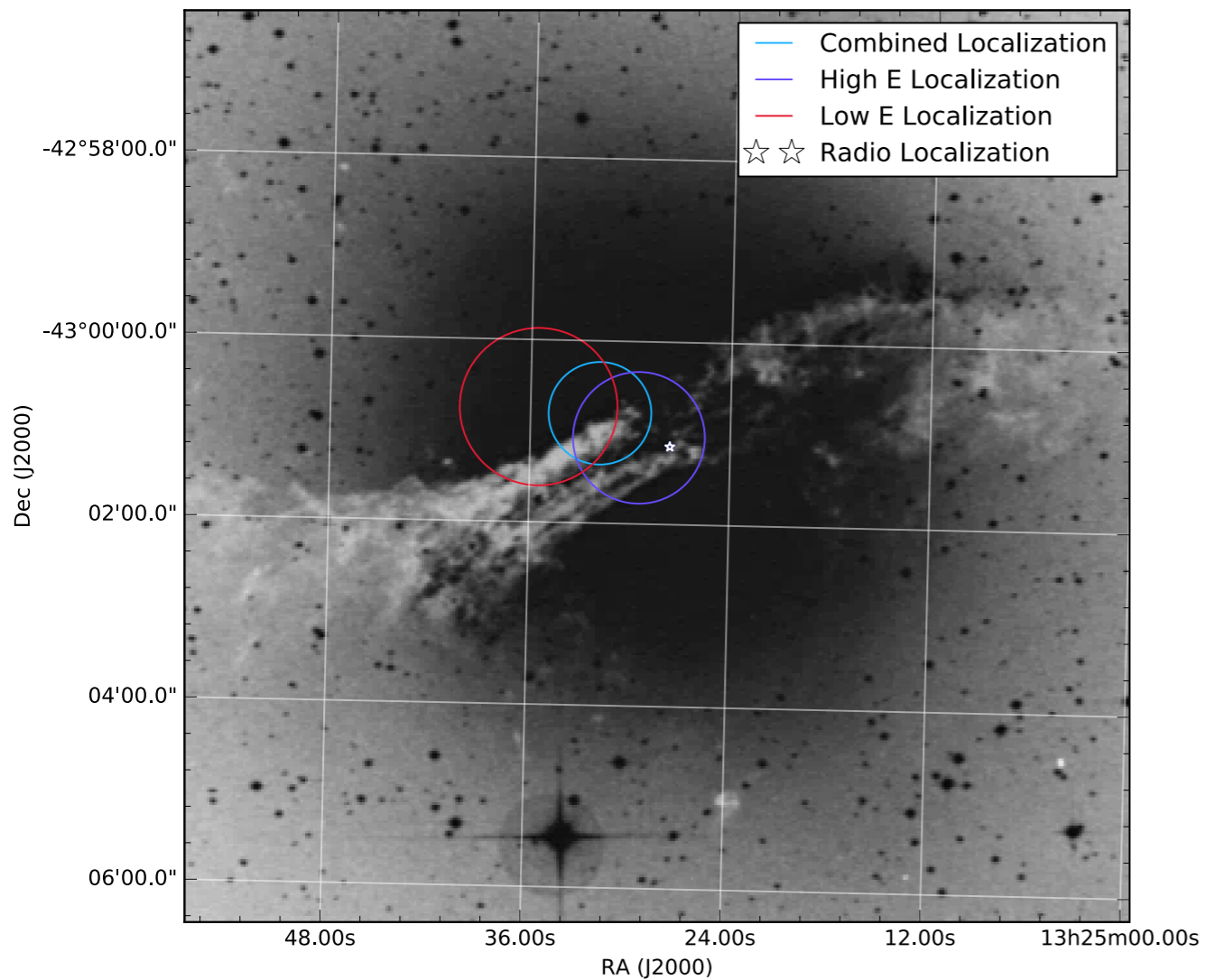


Figure 2. Synchrotron maps for 40 GeV dark matter particles $B = 3\mu\text{G}$. We use the MED parameter set and assume annihilating particles.

see prospects for SKA: arXiv:1502.03738

Centaurus A

arXiv:1603.05469

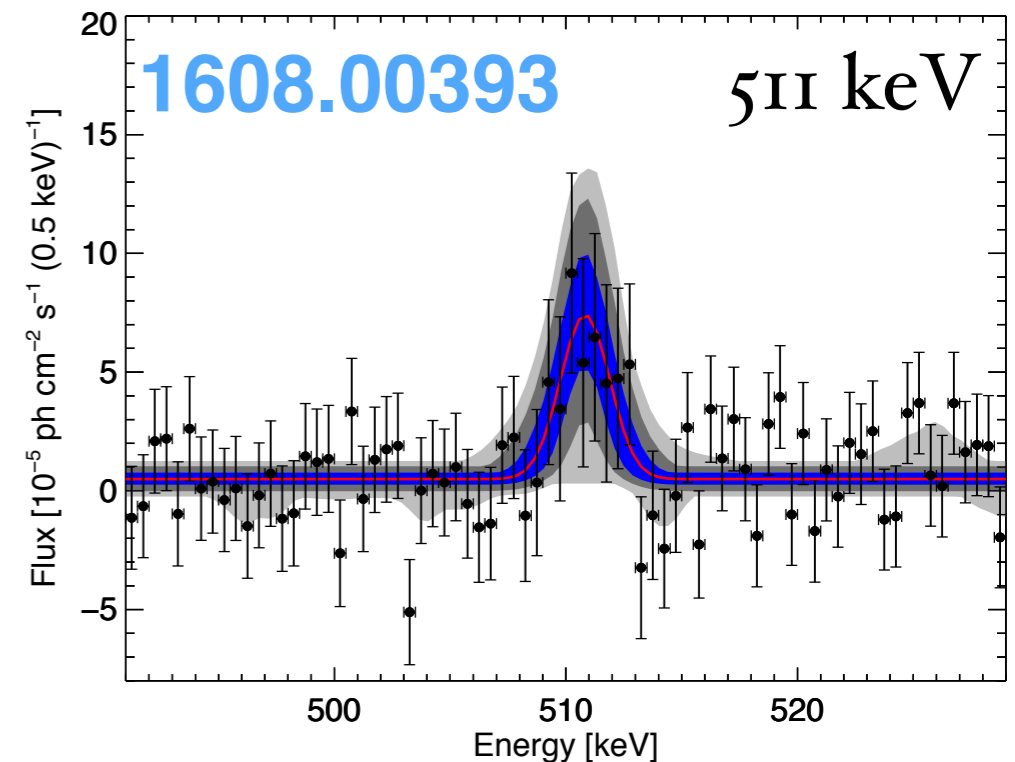
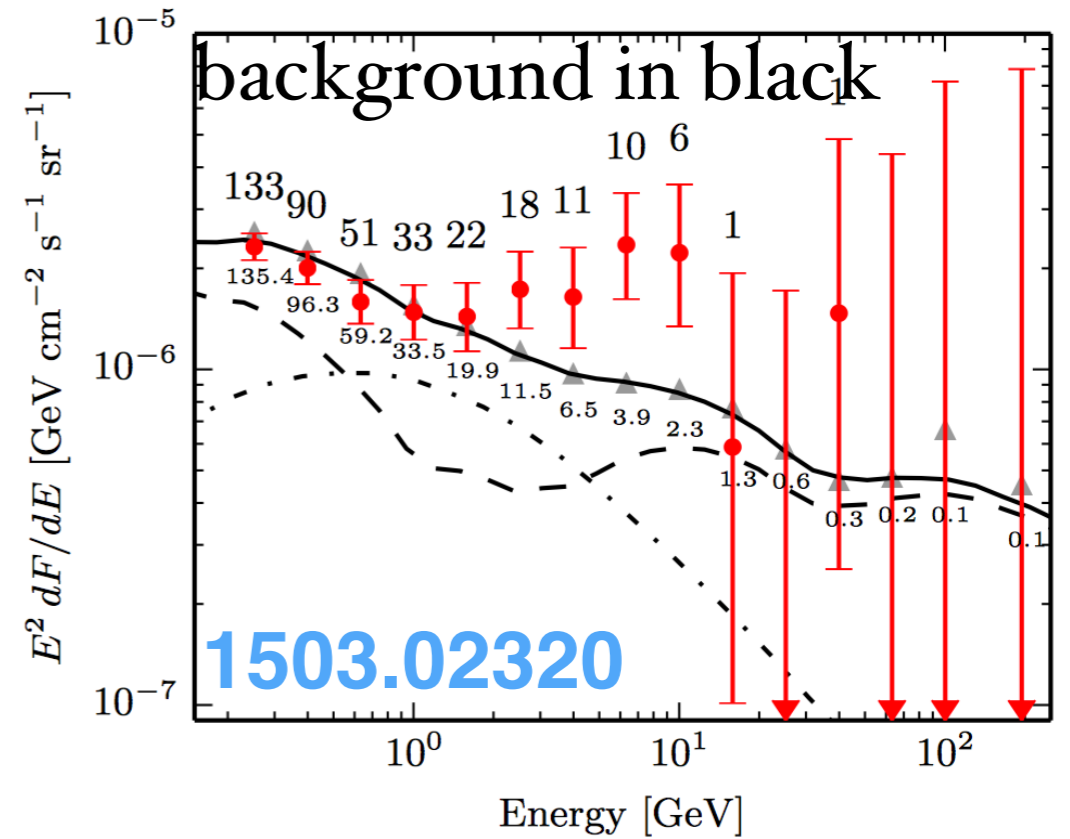
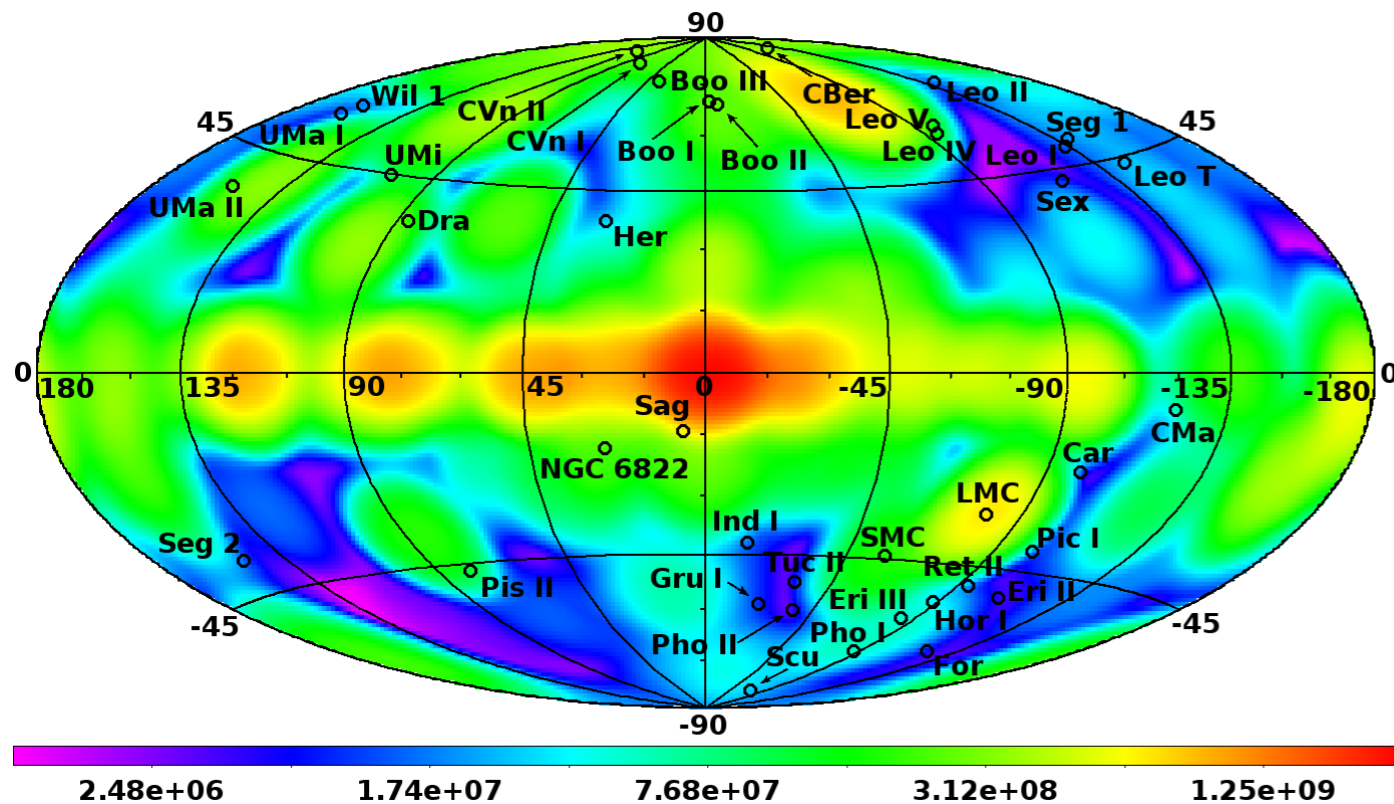


Reticulum II

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

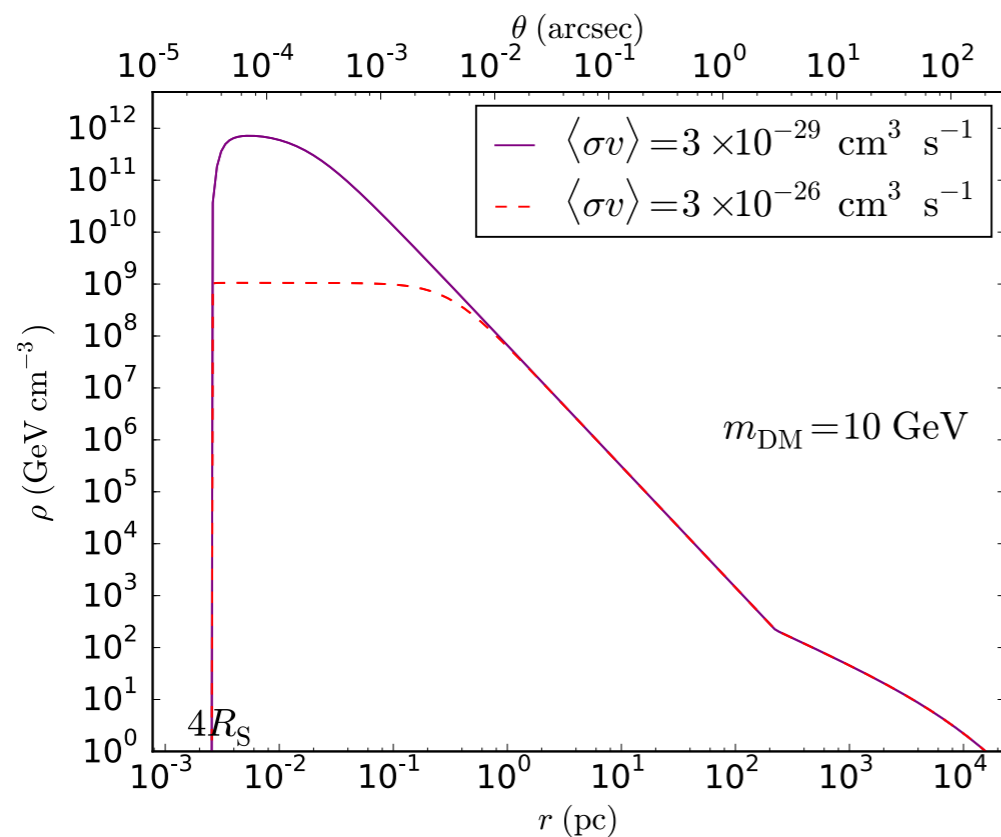
$$r v(r) = cst$$

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

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

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

NFW: $7/3$ inner slope



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

+ 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

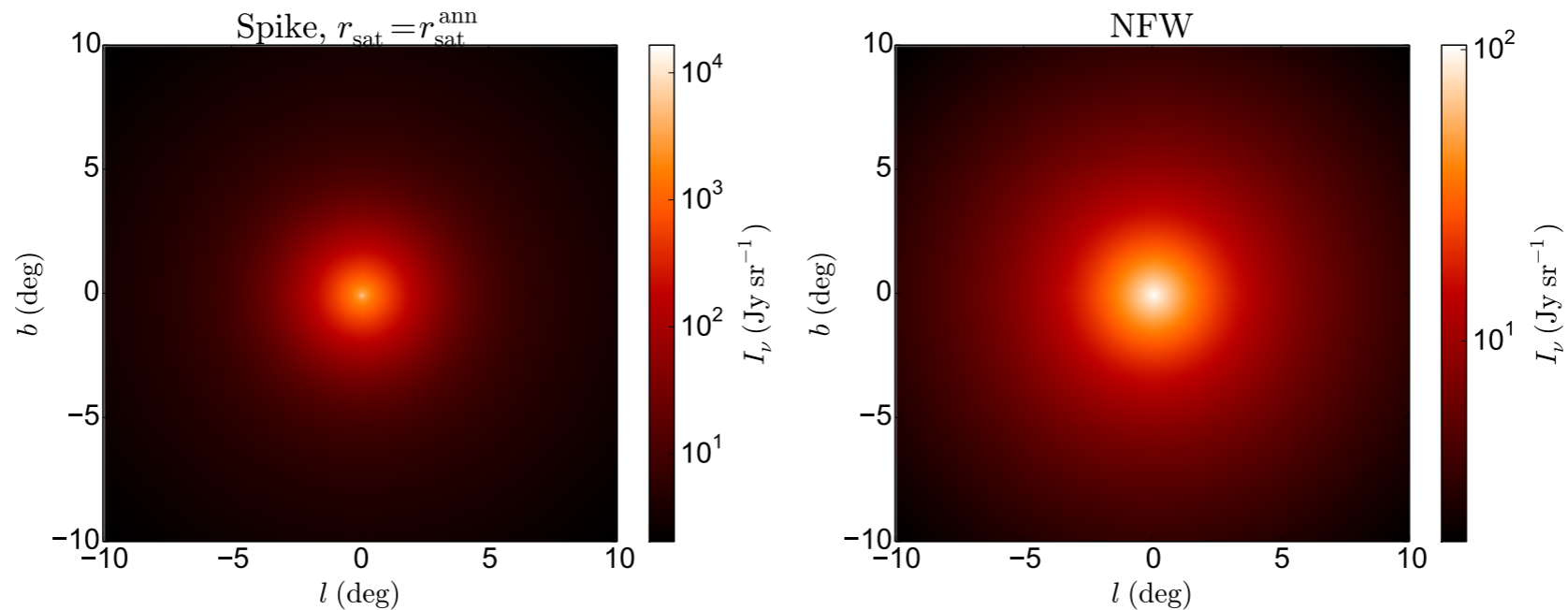
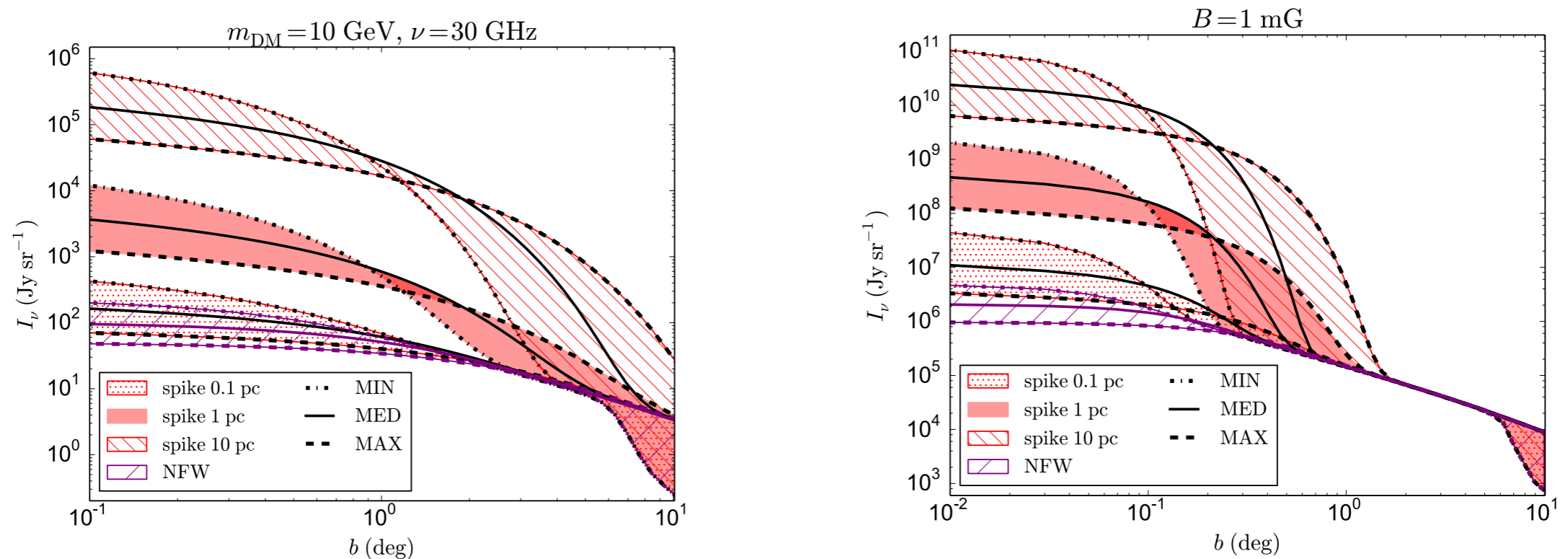
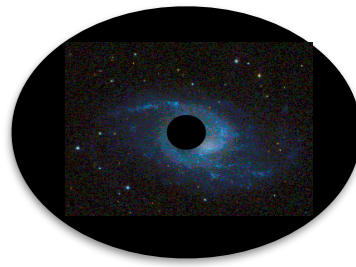


Figure 7.1: 30 GHz maps of the synchrotron intensity induced by 10 GeV DM particles, for $\langle\sigma v\rangle = 3 \times 10^{-26} \text{ cm}^3 \text{ s}^{-1}$, $B = 3 \mu\text{G}$, and the MED set of propagation parameters. The DM profiles used are a spiky profile with $\gamma_{\text{sp}} = 7/3$,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



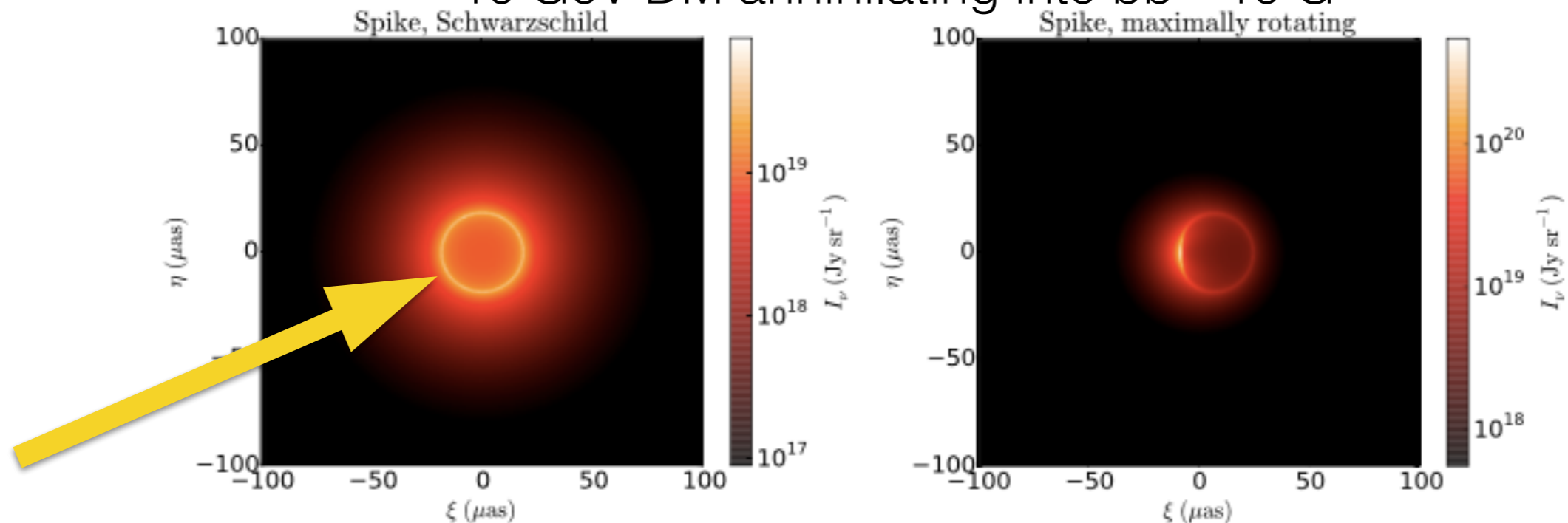
Black Hole shadow with EHT



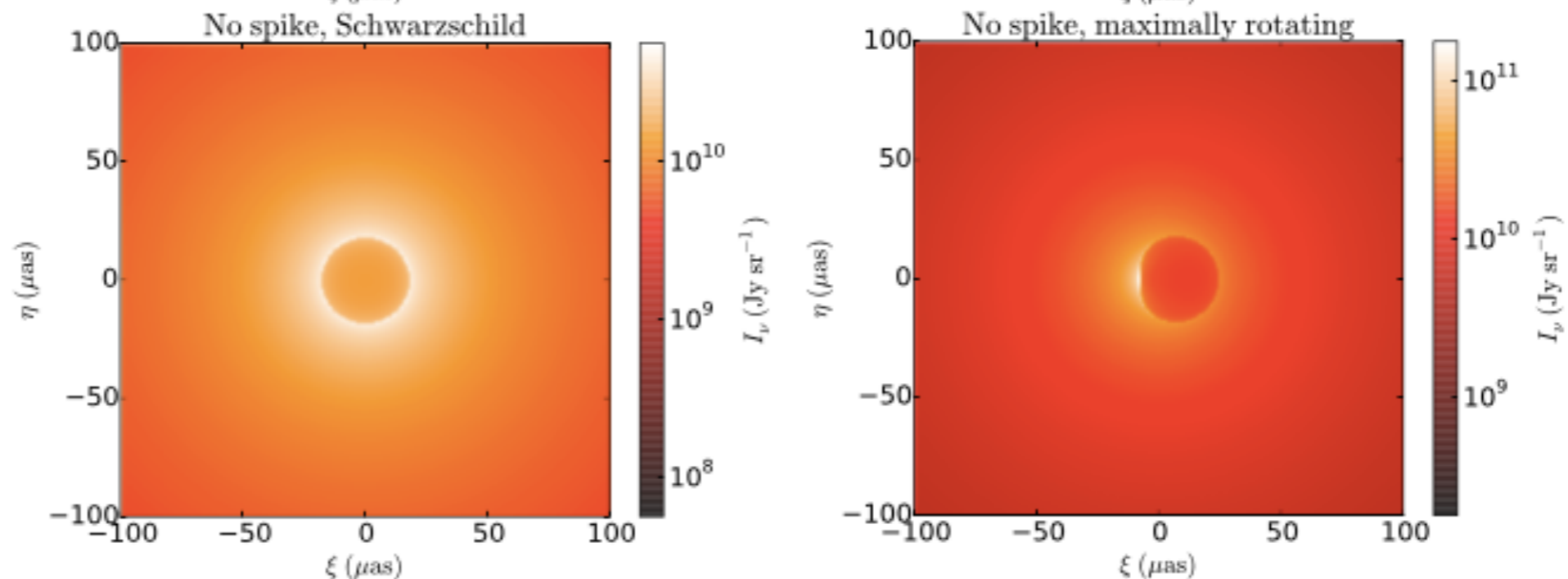
[arXiv:1611.01961](https://arxiv.org/abs/1611.01961)

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 $26 \mu\text{as}$ at 230 GHz and $17 \mu\text{as}$ 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 & H_0 (?)