Dark Photons in the Radio Sky

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SKA is more sensitive to dark photons — a highly motivated Standard Model extension — than highly precise CMB measurements

What Are Dark Photons?

The **dark photon** (A') is one of the simplest and most **well-motivated extensions of the Standard Model** — a new U(1) gauge boson. It is a compelling **dark matter candidate** and also arises in a **wide variety of hidden-sector models**.

Dark photons have a mass $m_{A'}$ and couple to the ordinary photon through **kinetic mixing** ϵ:

kinetic mixing portal

where the plasma frequency ($\propto n_e$) matches $m_{A'}$, photons **resonantly convert** and **disappear** from radio maps.

What is the Signal?

- Converted photons leave a **temperature deficit** in radio sky maps

$$T(\omega, \hat{n}) = (1 - P_{\gamma\to A'}(\omega, \hat{n}))T_{\rm CMB}(\omega)$$

- $P_{\gamma\to A'}$ traces gas overdensities and is spatially correlated with **galaxy positions**.

Why SKA?

30×
stronger signal
at GHz vs. *Planck*

arcsec
resolution
vs. arcmin from *Planck*

Learn More

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2511.09630 2511.09637

Questions? Comments?

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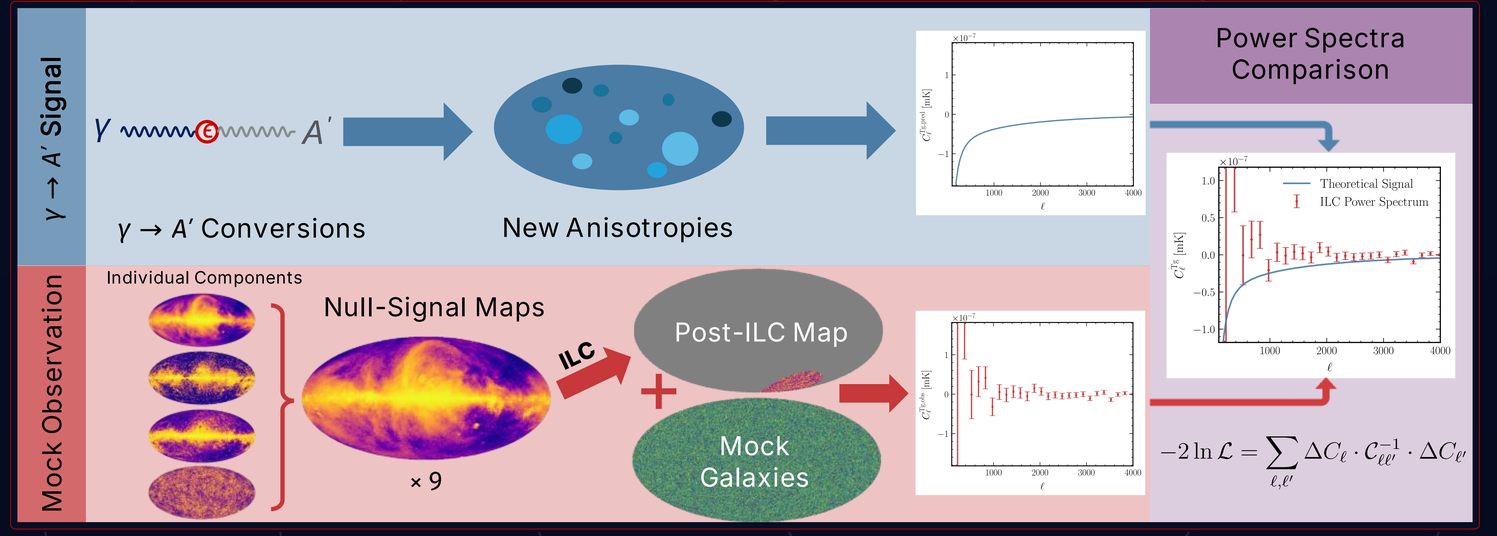
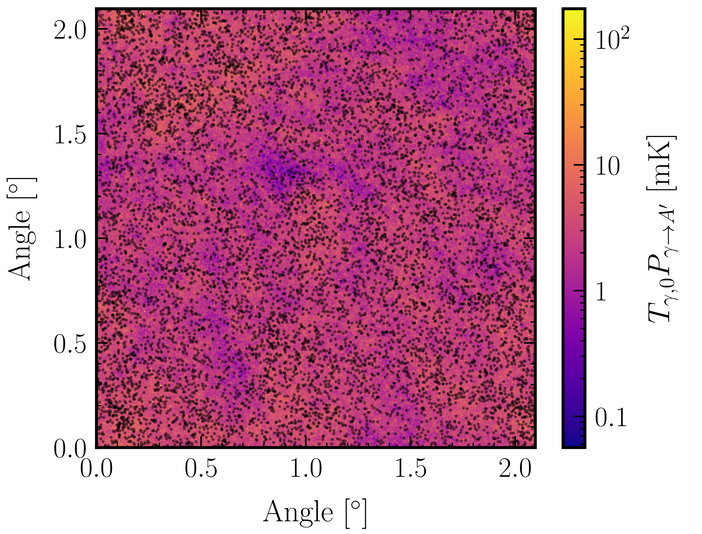
bakerem/dark_photons_radio_sky

Analysis Pipeline

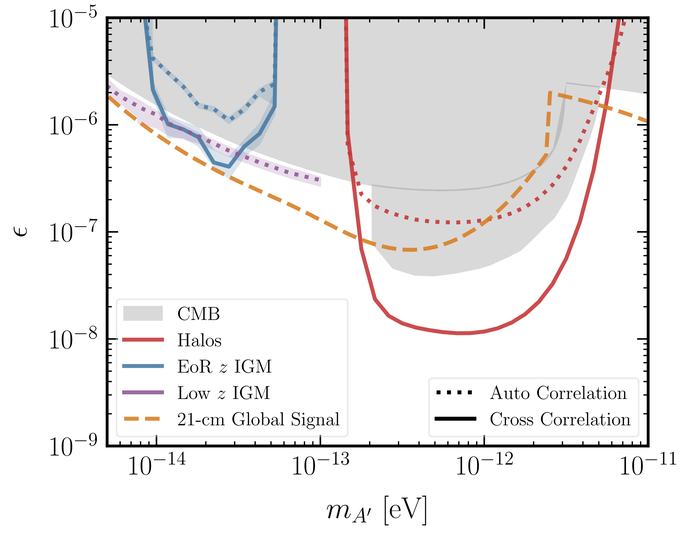


Simulated Signal



Mock high-redshift galaxy catalog overlaid on temperature deficit from $\gamma \to A'$ conversions. Galaxy overdense regions are correlated with larger temperature deficits.

Forecast Sensitivity



Forecasted SKA sensitivity to dark photons from considering auto-correlations (dotted lines) and cross-correlations with the relevant galaxy survey (dashed lines). Also shown is the expected sensitivity of a 21-cm global signal experiment to $\gamma \to A'$ conversions.

4× better than *Planck*

Three Environments

$\gamma \to A'$ conversions occur in different cosmological environments → gives sensitivity to different $m_{A'}$

DM Halos — dense ionized gas in galaxy halos at $z \leq 4$, probing $m_{A'} \sim 10^{-13}$ eV–10^{-11} eV.

EoR IGM — reionization-era gas at $z \sim 5 - 35$, probing $10^{-14}\,\text{eV} \lesssim m_{A'} \lesssim 5 \times 10^{-14}\,\text{eV}$.

Late IGM — diffuse post-reionization gas, probing $m_{A'} \sim 10^{-14}$ eV.

Modeling Approach

Signal: Resonant conversion probability computed from 21cmFAST electron-density lightcones spanning $z = 5 - 35$ and from analytic halo modeling.

Foreground Removal: Constrained optimization (Needlet ILC) combines info from simulated multi-frequency SKA images (0.41 GHz to 12.53 GHz), maximizing the dark photon signature relative to foregrounds.

Mock Galaxies: Use 21cmFAST to simulate high z galaxy survey and analytic model for low-redshift galaxies

21-cm Power Spectrum

- $\gamma \to A'$ conversions leave strong signal in 21-cm PS, but there are experimental challenges
- Signal scales as $1/\omega \Rightarrow$ power confined to **smallest $k_\parallel$ modes**
- Dark photon signal lives inside the wedge and is removed with the foregrounds
- Requires creative ideas to extract signal!

⇒ SKA **imaging** + cross-correlation is a simpler strategy.

What's Next

- **Real Data:** Could get pathfinder constraints with real radio data
- **Extending Modeling:** Using radio galaxies as a backlight could drastically improve SKA's sensitivity
- **High-freq. GW:** Radio telescopes can also function as high frequency GW detectors, exceeding sensitivity of terrestrial experiments

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