New Sensitivity to High Frequency Gravitational Waves from Radio Telescopes

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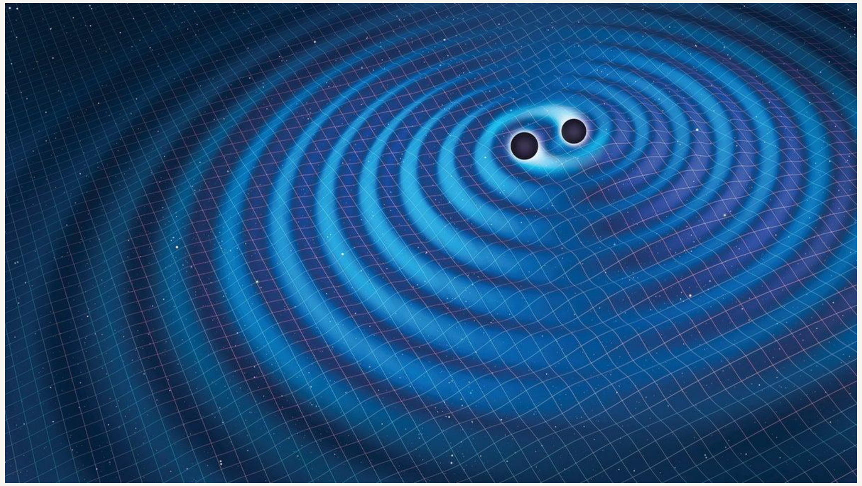
High Frequency Gravitational Waves

- Frequencies in MHz-GHz range
- No known Standard-Model sources(?)

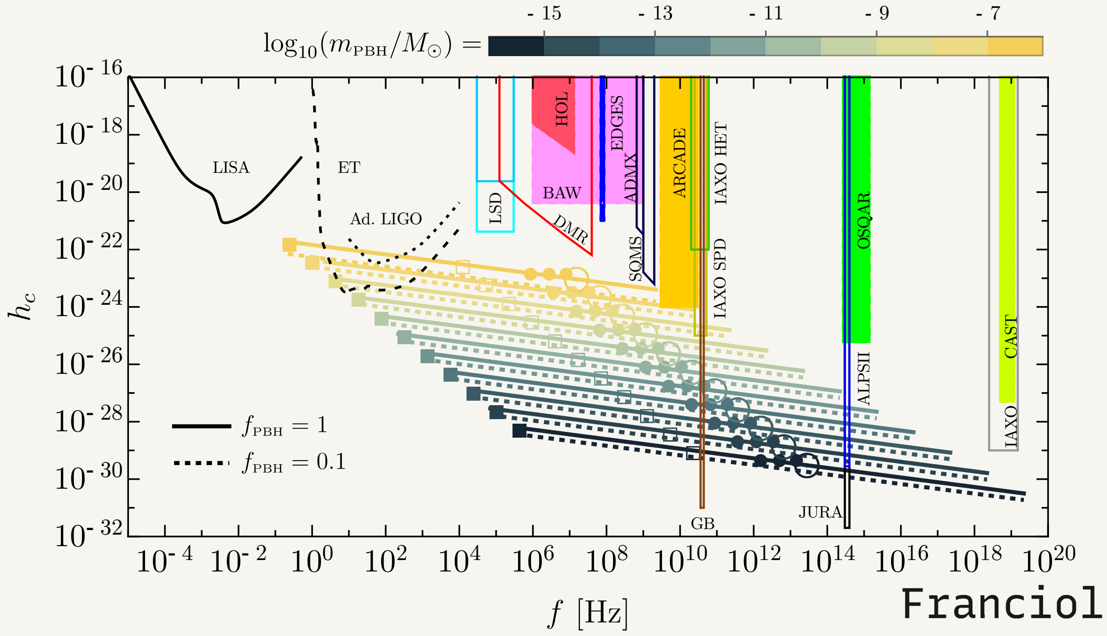
High Frequency Gravitational Waves

- Frequencies in MHz-GHz range
- No known Standard-Model sources(?)
- PBH Mergers
    - Most realistic source
    - Chirp behavior
    - Transient



Active Experimental Program

- Huge amount of experimental interest in high-frequency GWs!
- Significant challenges in searching for realistic sources



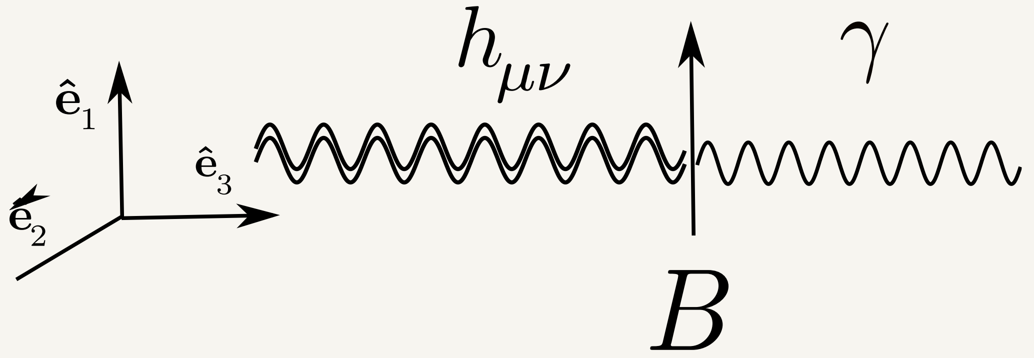
Franciolini et al., arXiv:2205.02153

Radio telescopes are uniquely powerful tools to search for high-frequency GWs.

Outline

- How are PBH mergers observable with radio telescopes?
- What is the nature of the signal?
- What telescopes can observe these?
- How good are they?

Gertsenshtein Effect



$\omega_{GW} = \omega_{EM}$

- SM process very similar to Primakoff effect for axions
- Probability of conversion:

$$P_{h\to\gamma} \propto G_N d B^2$$

- Small B field compensated by astronomical scales

Domcke & Garcia-Cely. arXiv:2006.01161

Gertsenshtein, Sov. Phys. JETP 14 (1962): 84.

PBH mergers appear as bright radio transients

PBH Merger Signal

- Radio flux = gravitational wave flux × $P_{h\to\gamma}$

$$S_{\text{obs}}(t) \propto h(t,d)^2 \int_0^d dr\, \frac{dP_{h\to\gamma}}{dr}$$

Strain from PBH Mergers

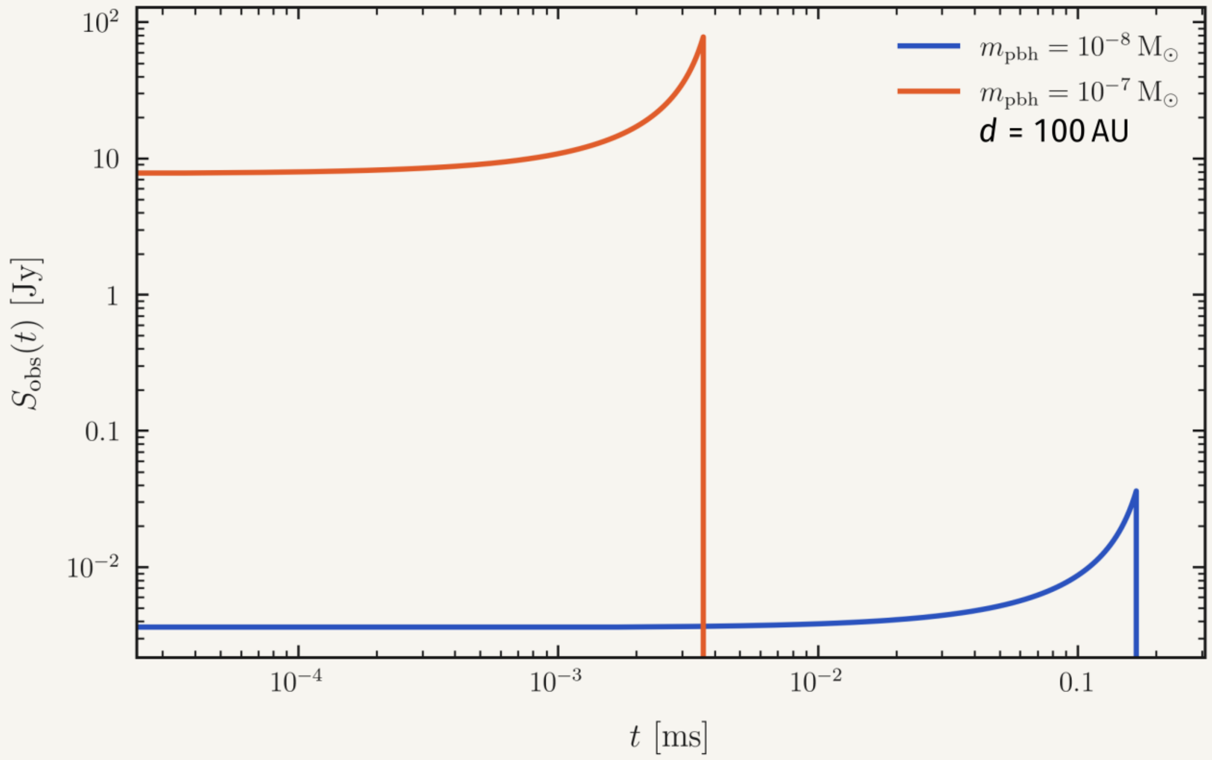
$$h(t) \approx 6 \times 10^{-16} \left(\frac{m}{10^{-6}\,\mathrm{M}_\odot}\right)^{5/3} \left(\frac{\omega_{\mathrm{GW}}(t)}{1\,\mathrm{GHz}}\right)^{2/3} \left(\frac{100\,\mathrm{AU}}{d}\right)$$

- Merger has characteristic timescale

$$t_0 \approx 10^{-6}\,\mathrm{sec} \left(\frac{m}{10^{-6}\,\mathrm{M}_\odot}\right)^{-5/3} \left(\frac{1\,\mathrm{GHz}}{\omega_{0,\mathrm{GW}}}\right)^{8/3}$$

PBH Merger Radio Flux Density

Central challenge: higher mass → higher strain & shorter signal length



PBH Merger Fluence

- Fluence found by integrating over time that the signal spends in telescope bandwidth

$$H_e = \int dt\, S_{\text{obs}}(t)$$

- Advantage of radio experiments: large bandwidths

What telescopes can detect these mergers?

Vast observational landscape!

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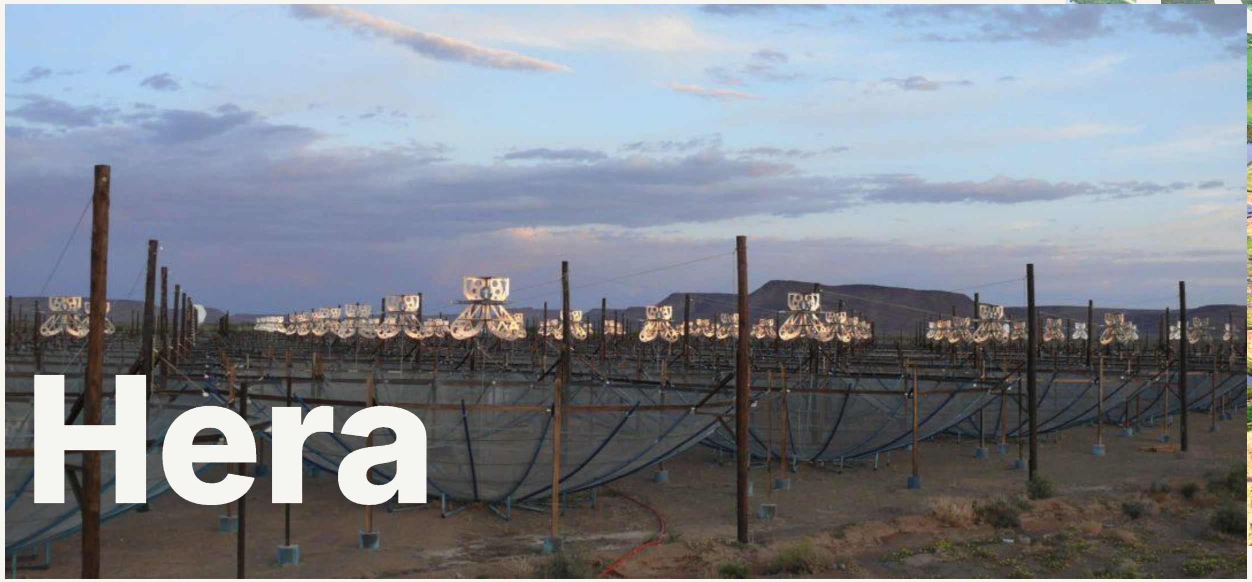

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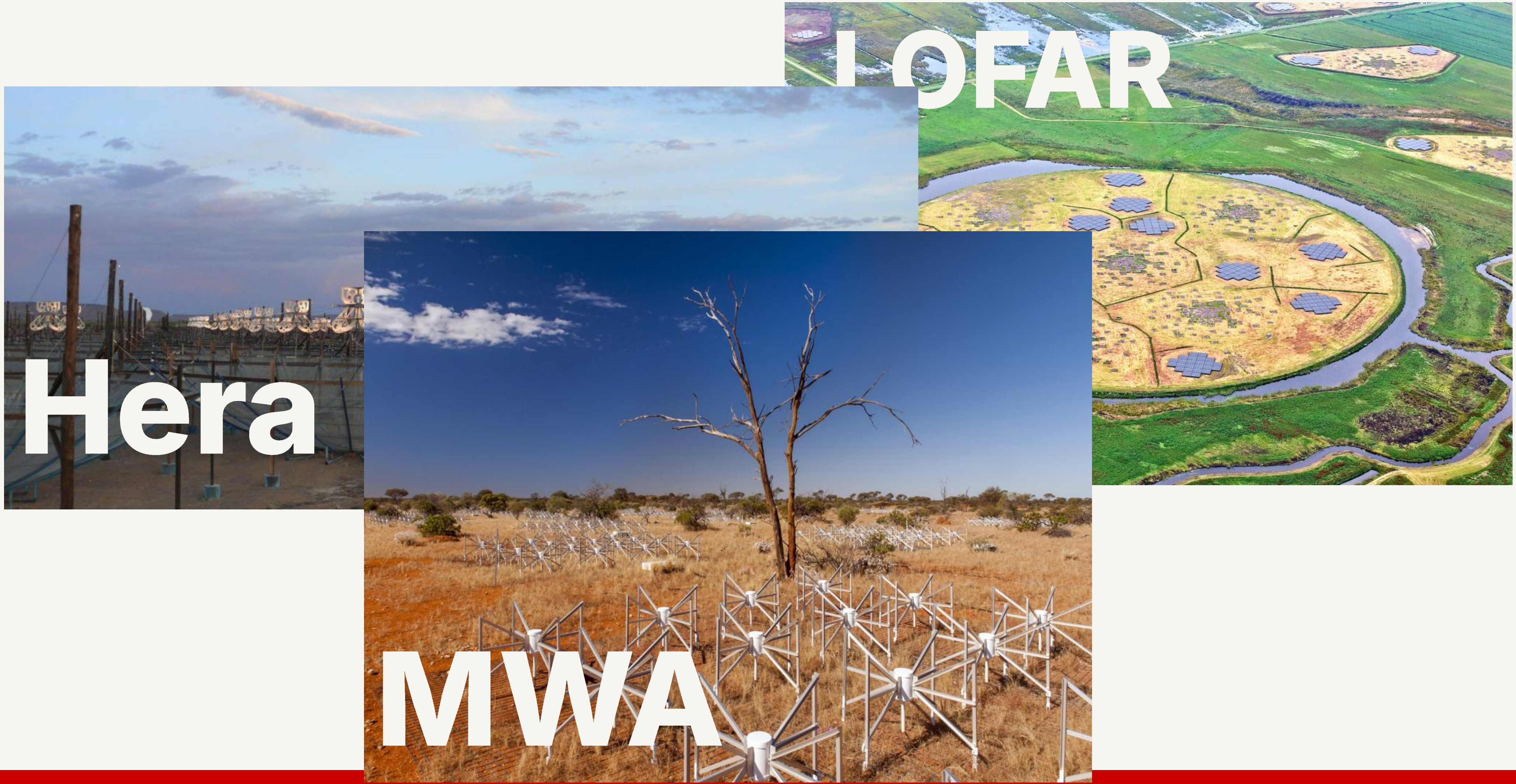

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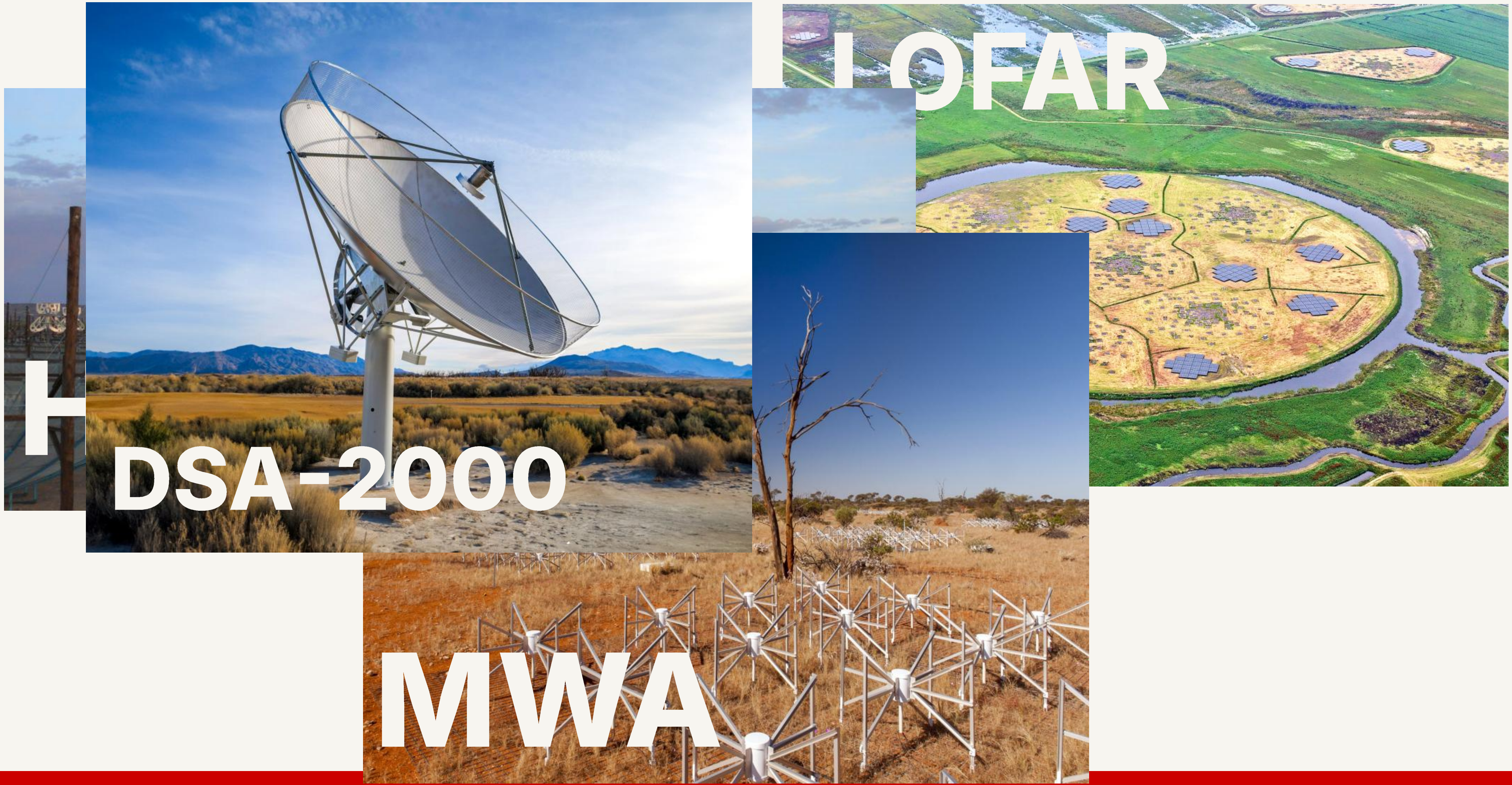

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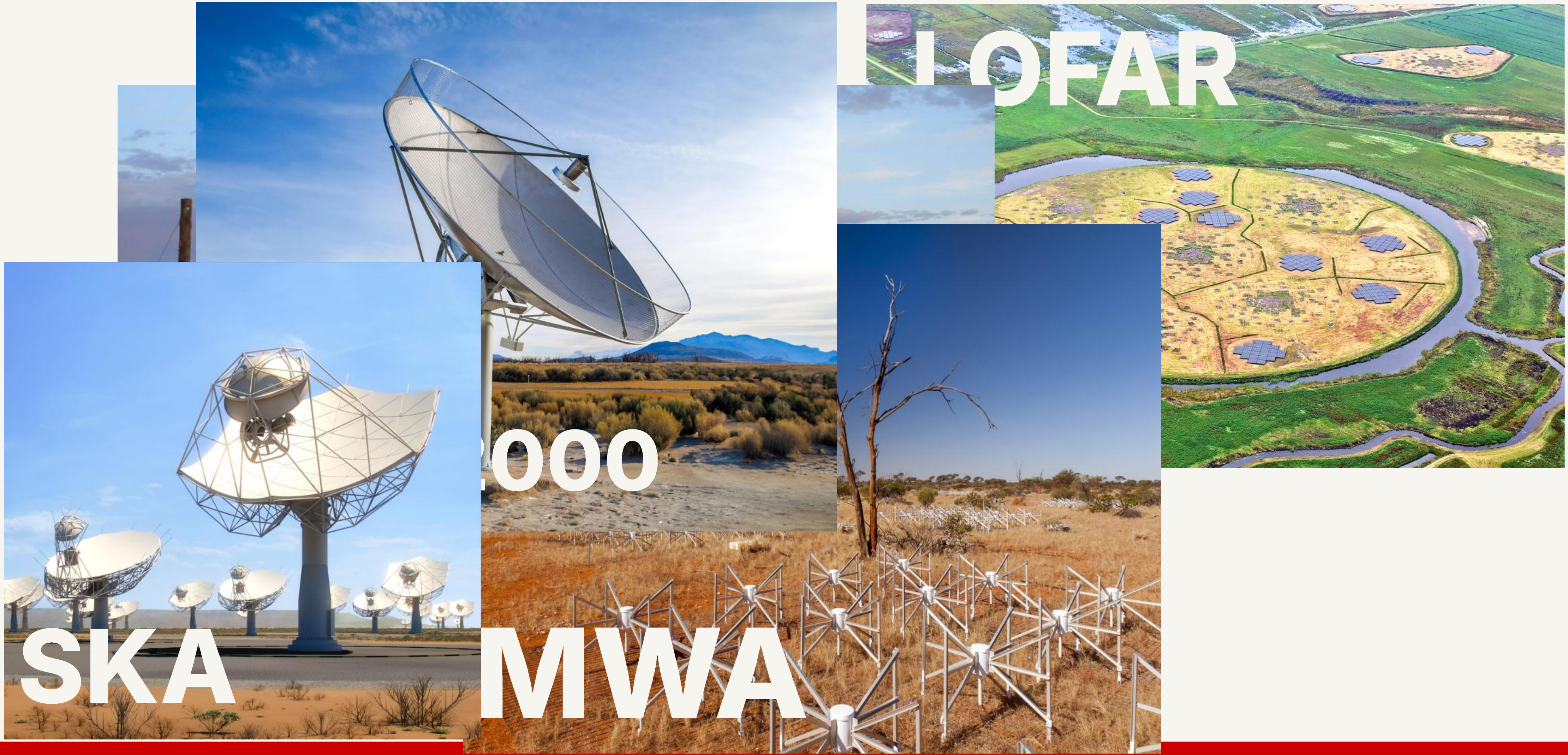

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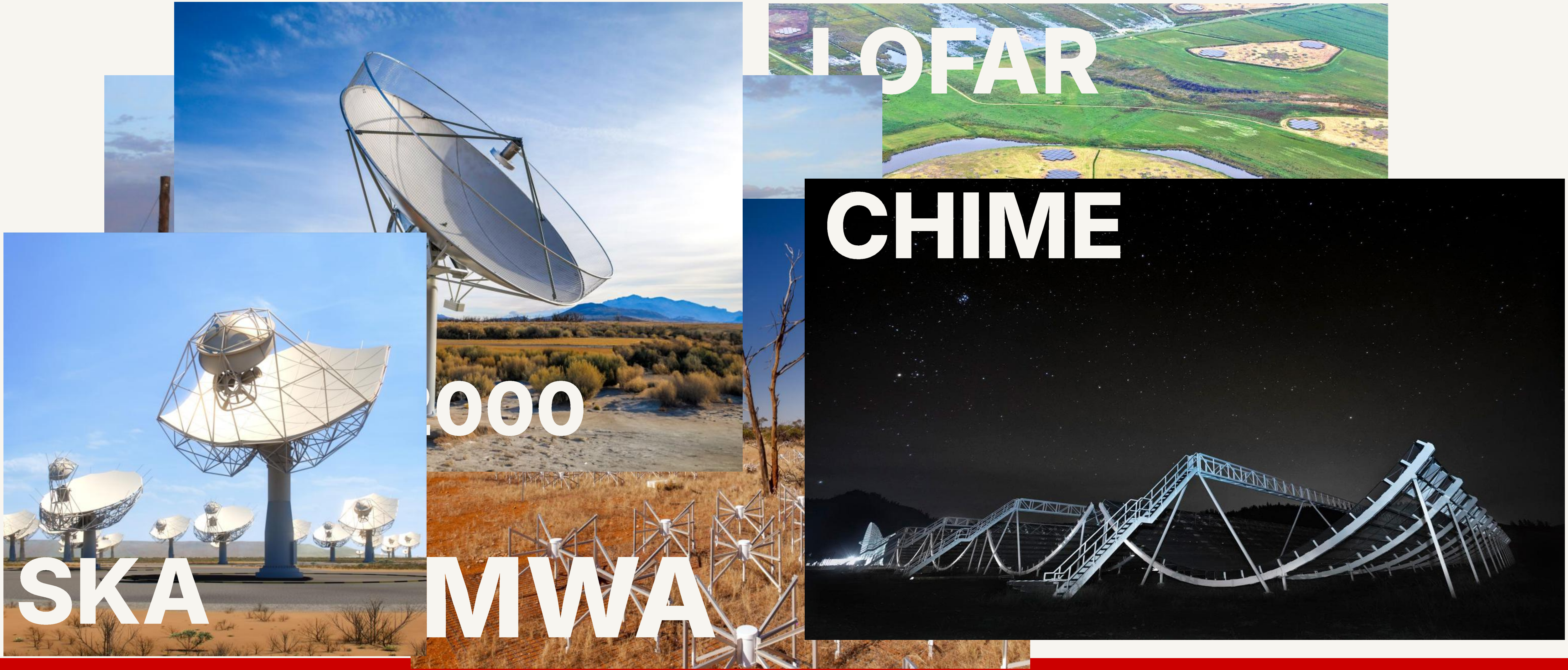

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FAST

- Five-hundred-meter Aperture Spherical Telescope
- 1.05 GHz – 1.45 GHz
- **Excellent at FRB detection**

CHIME

- Canadian Hydrogen Intensity Mapping Experiment
- 400 MHz – 800 MHz
- **Excellent at FRB detection**

Sensitivity to PBH Mergers

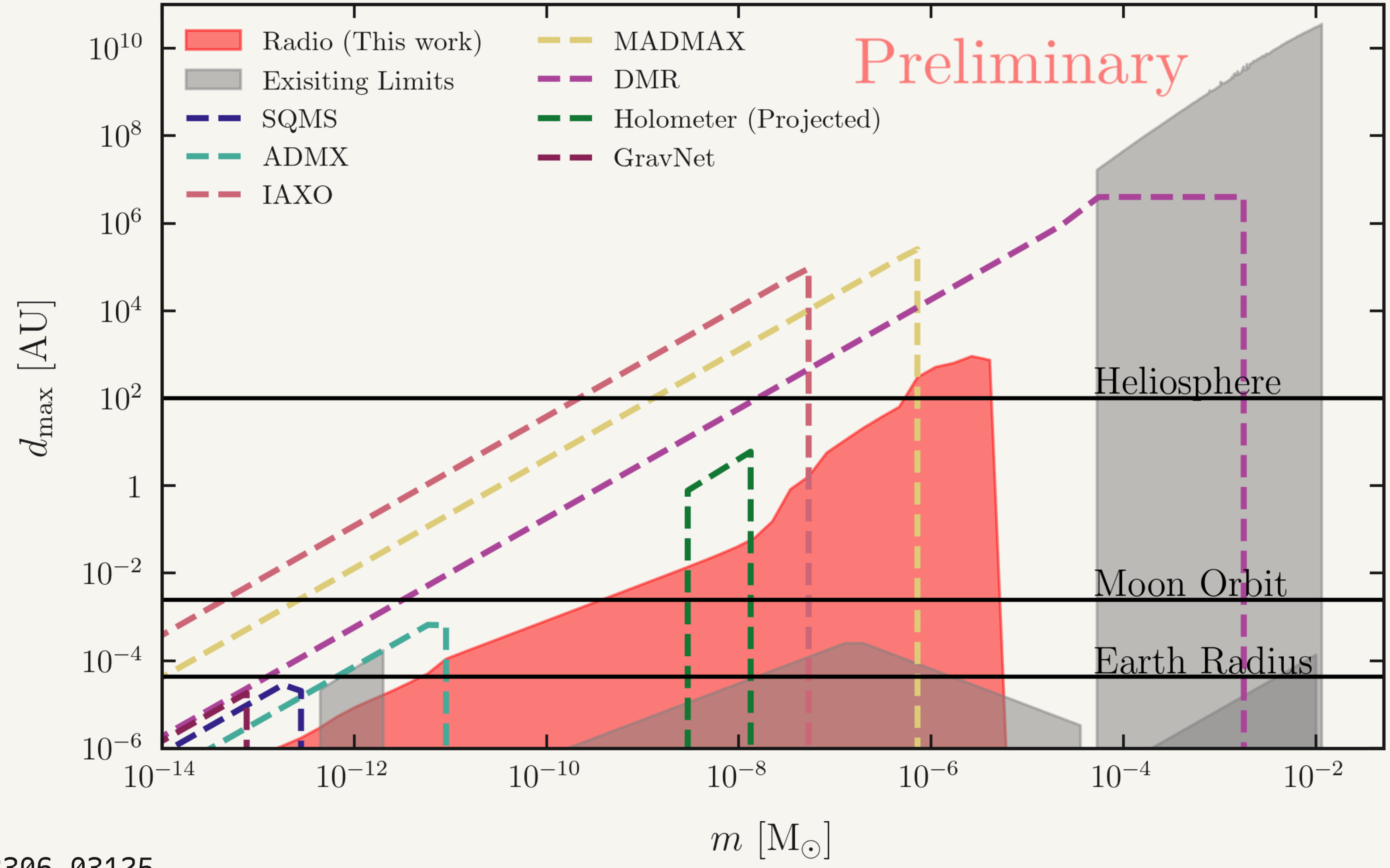
- PBH merger detectable if

$$H_e(m_{\mathrm{PBH}}, d) = \int_{t_0}^{t_{\max}} dt\, S_{\mathrm{obs}}(t; m_{\mathrm{PBH}}, d) > 0.5\ \mathrm{Jy\,ms}$$

- Solve for $d_{\max}$ such that $H_e(m_{\mathrm{PBH}}, d_{\max}) > 0.5\ \mathrm{Jy\,ms}$
- Chirp behavior is distinct among known radio sources!
  - Wouldn't be confused with FRB but may require new trigger system

Sensitivity to PBH Mergers

- What is the maximum distance at which we can detect a PBH merger?
- Require fluence > 0.5 Jy ms



Holometer: 1611.05560
LIGO: Miller et al., 2402.19468
ADMX SLIC: 1911.05772
Gravnet: 2308.11497
Other forecasts: Berlin et al., 2112.11465; Franciolini et al., 2205.02153; Domcke et al. 2306.03125

Summary

- PBH mergers are challenging to observe
- Radio telescopes have excellent sensitivity to these mergers
- Cosmological signatures of high-frequency gravitational waves are largely unexplored

We should be looking for new physics in the radio regime.

Questions?

Backup: Superradiance

- Requires existence of ultralight boson
- Appears as monochromatic, long-lived radio source
- Easier to detect for terrestrial experiments

$$m_b \sim 10^{-4}\ \text{eV}\left(\frac{m}{10^{-6}\ M_\odot}\right)^{-1}$$

$$\omega_{GW} = 4\pi \times 10^{2}\ \text{GHz}\left(\frac{m}{10^{-6}\ M_\odot}\right)^{-1}$$