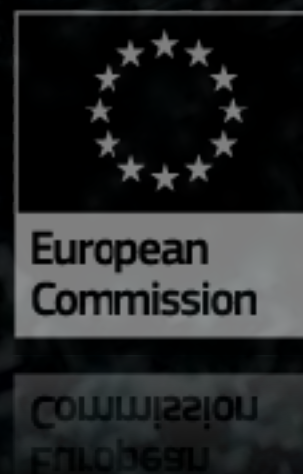


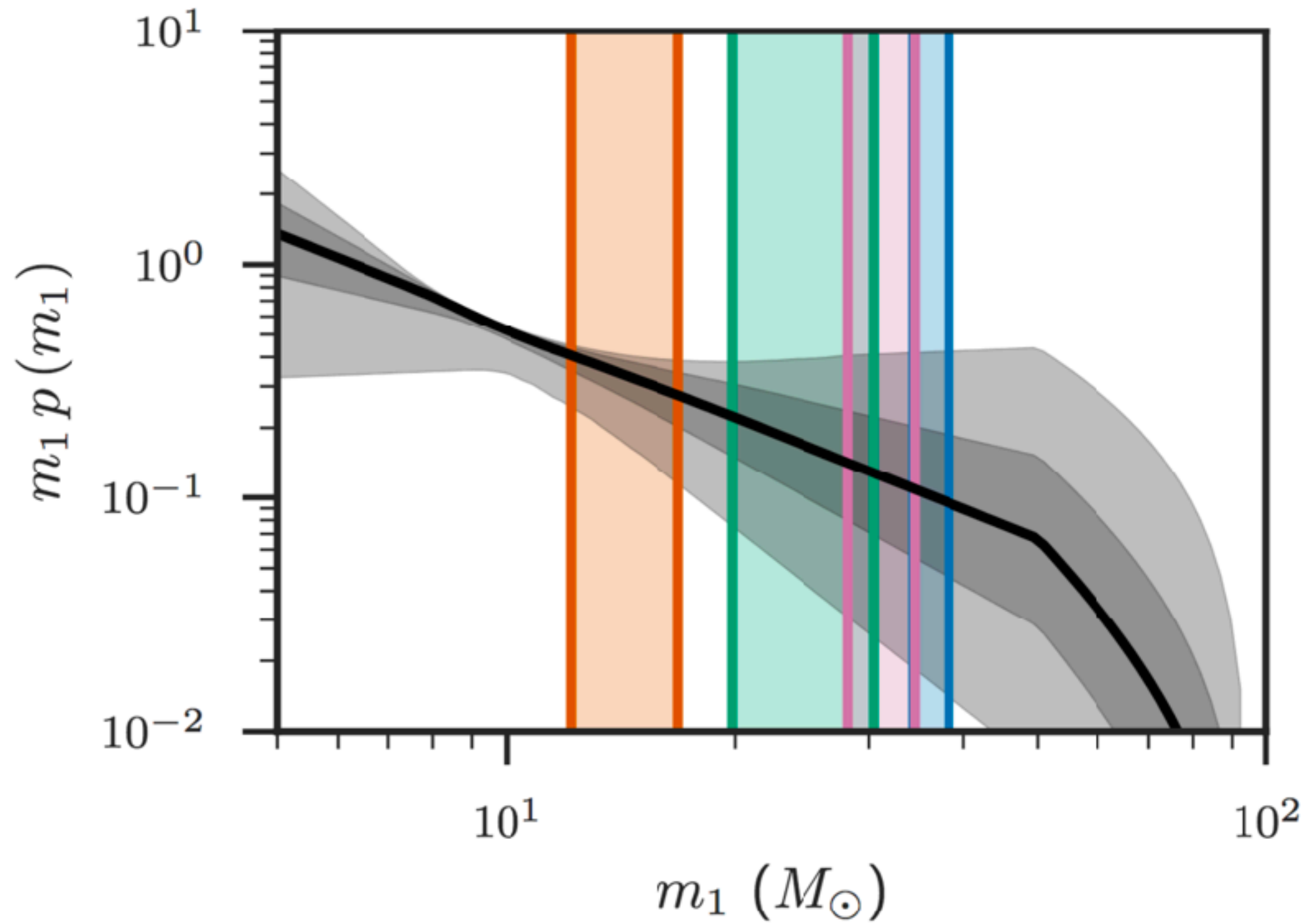
Cosmological tests with Multi-Messenger Astronomy

Alvise Raccanelli



H2020





Did LIGO detect DM?

Did LIGO detect dark matter?

Simeon Bird,* Ilias Cholis, Julian B. Muñoz, Yacine Ali-Haïmoud, Marc Kamionkowski, Ely D. Kovetz, Alvise Raccanelli, and Adam G. Riess¹

¹*Department of Physics and Astronomy, Johns Hopkins University,
3400 N. Charles St., Baltimore, MD 21218, USA*

We consider the possibility that the black-hole (BH) binary detected by LIGO may be a signature of dark matter. Interestingly enough, there remains a window for masses $10 M_{\odot} \lesssim M_{\text{bh}} \lesssim 100 M_{\odot}$ where primordial black holes (PBHs) may constitute the dark matter, if constraints from CMB spectral distortions can be avoided. If two BHs in a galactic halo pass sufficiently close, they radiate enough energy in gravitational waves to become gravitationally bound. The bound BHs will rapidly spiral inward due to emission of gravitational radiation and ultimately merge. Uncertainties in the rate for such events arise from our imprecise knowledge of the phase-space structure of galactic halos on the smallest scales. Still, reasonable estimates span a range that overlaps the $2 - 53 \text{ Gpc}^{-3} \text{ yr}^{-1}$ rate estimated from GW150914, thus raising the possibility that LIGO has detected PBH dark matter. PBH mergers are likely to be distributed spatially more like dark matter than luminous matter and have no optical nor neutrino counterparts. They may be distinguished from mergers of BHs from more traditional astrophysical sources through the observed mass spectrum, their high ellipticities, or their stochastic gravitational wave background. Next generation experiments will be invaluable in performing these tests.

Physical Review Letters, 116, 20

Progenitors ?

Determining the progenitors of merging black hole binaries

Alvise Raccanelli, Simeon Bird, Ilias Cholis, Ely D. Kovetz, and Julian B. Muñoz

*Department of Physics & Astronomy,
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Baltimore, MD 21218, USA*

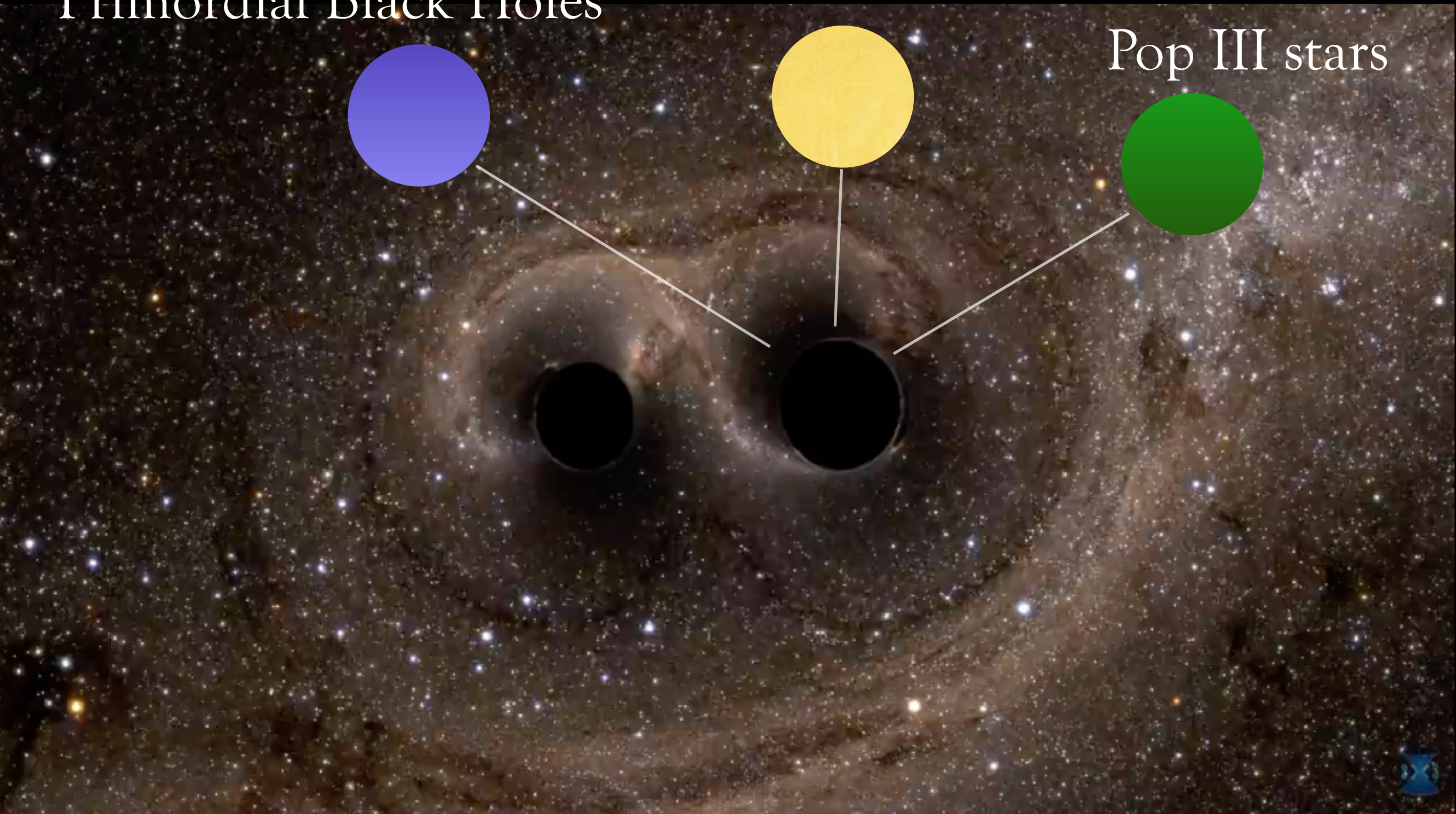
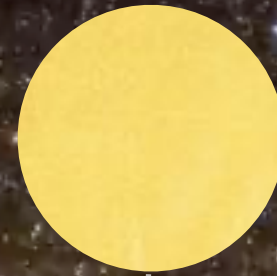
We propose a method for determining the progenitors of black hole (BH) mergers observed via their gravitational wave (GW) signal. We argue that measurements of the cross-correlation of the GW events with overlapping galaxy catalogs can determine if BH mergers trace the stellar mass of the Universe, as would be expected from mergers of the endpoints of stellar evolution. If on the other hand the BHs are of primordial origin, as has been recently suggested, their merging would be preferentially hosted by lower biased objects, and thus have a lower cross-correlation with star-forming galaxies. Here we forecast the expected precision of the cross-correlation measurement for current and future GW detectors such as LIGO and the Einstein Telescope. We then predict how well these instruments can distinguish the model that identifies high-mass BH-BH mergers as the merger of primordial black holes that constitute the dark matter in the Universe from more traditional astrophysical sources.

Progenitors ?

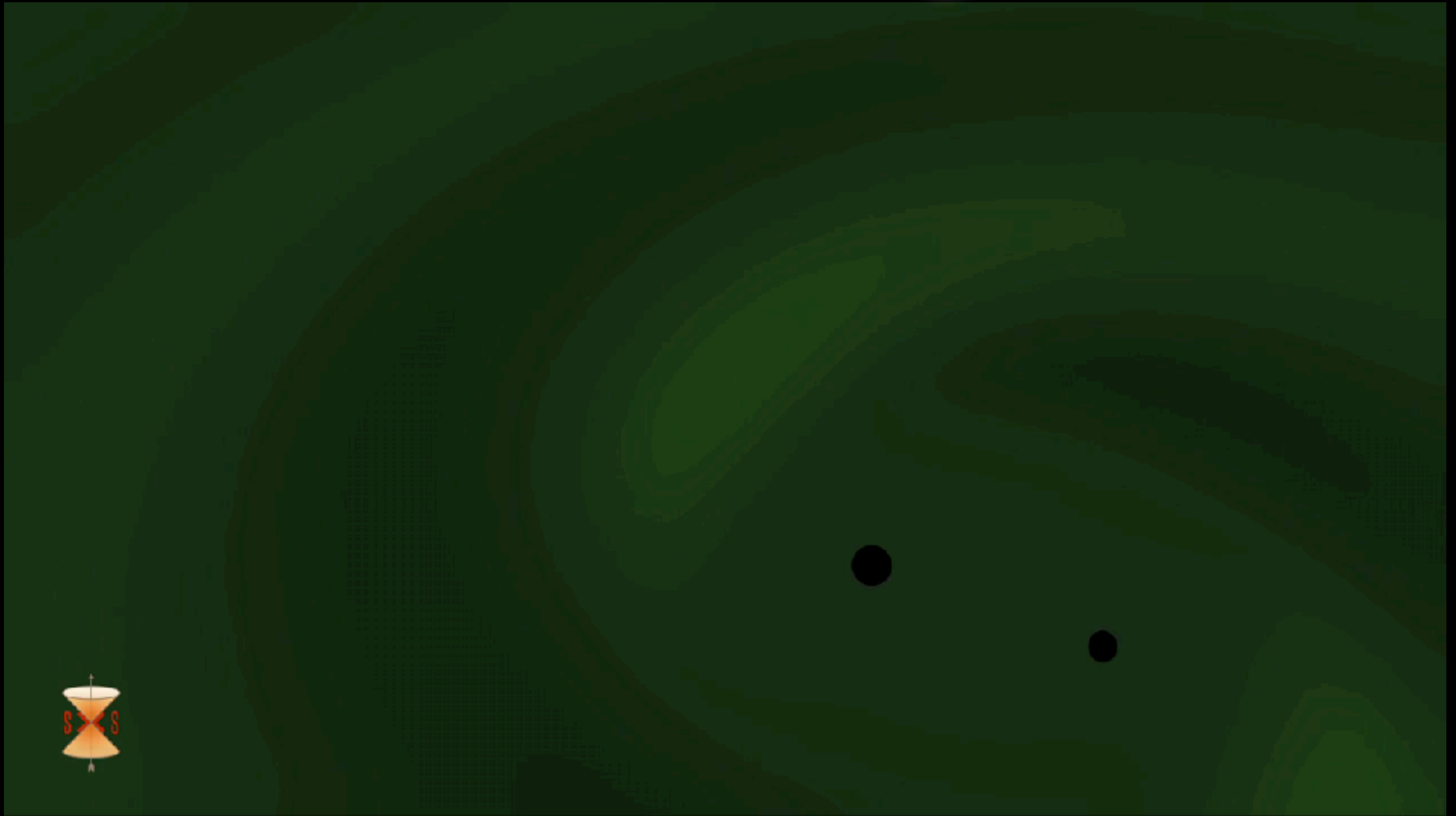
Primordial Black Holes

Stars

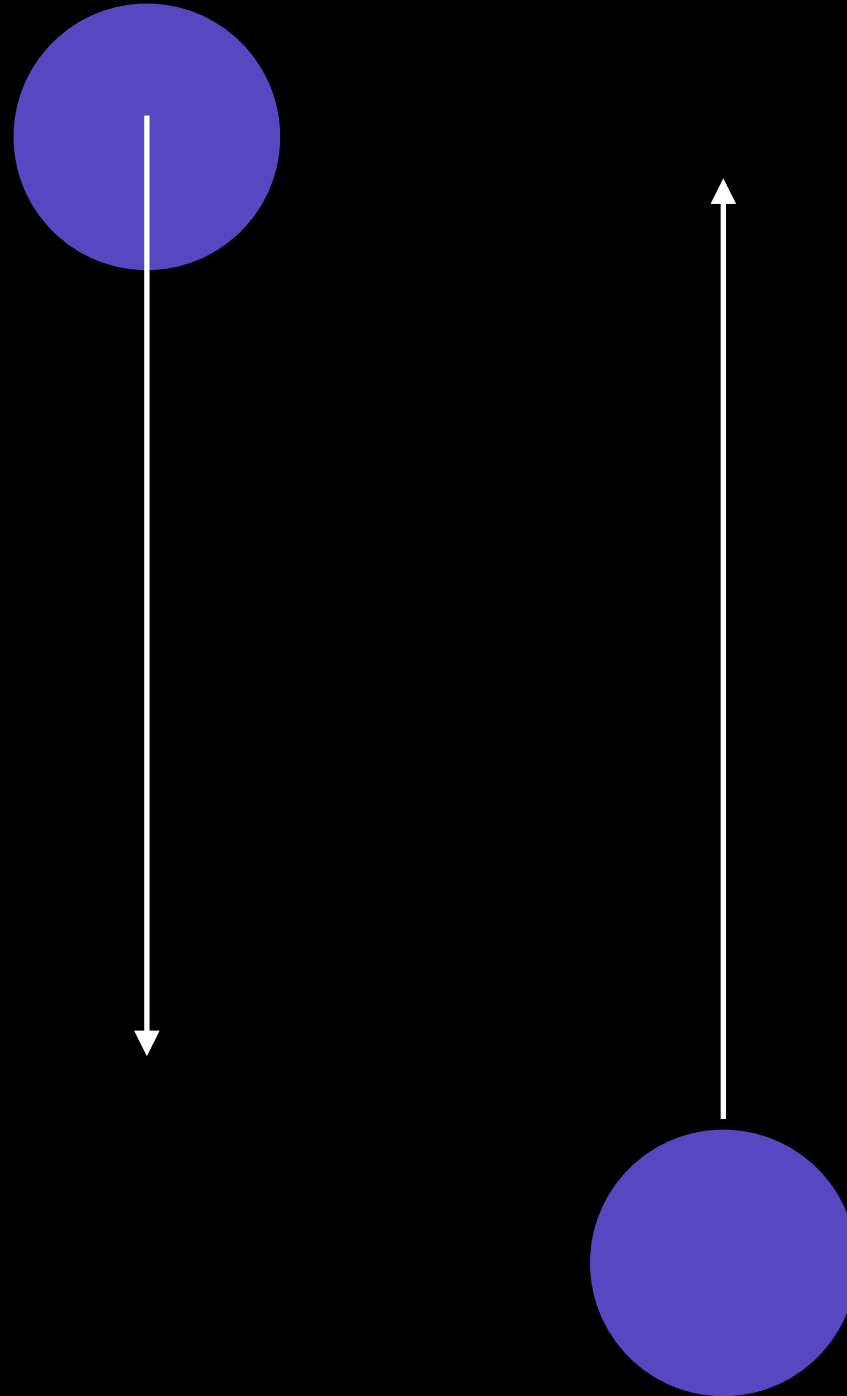
Pop III stars



BBH merger



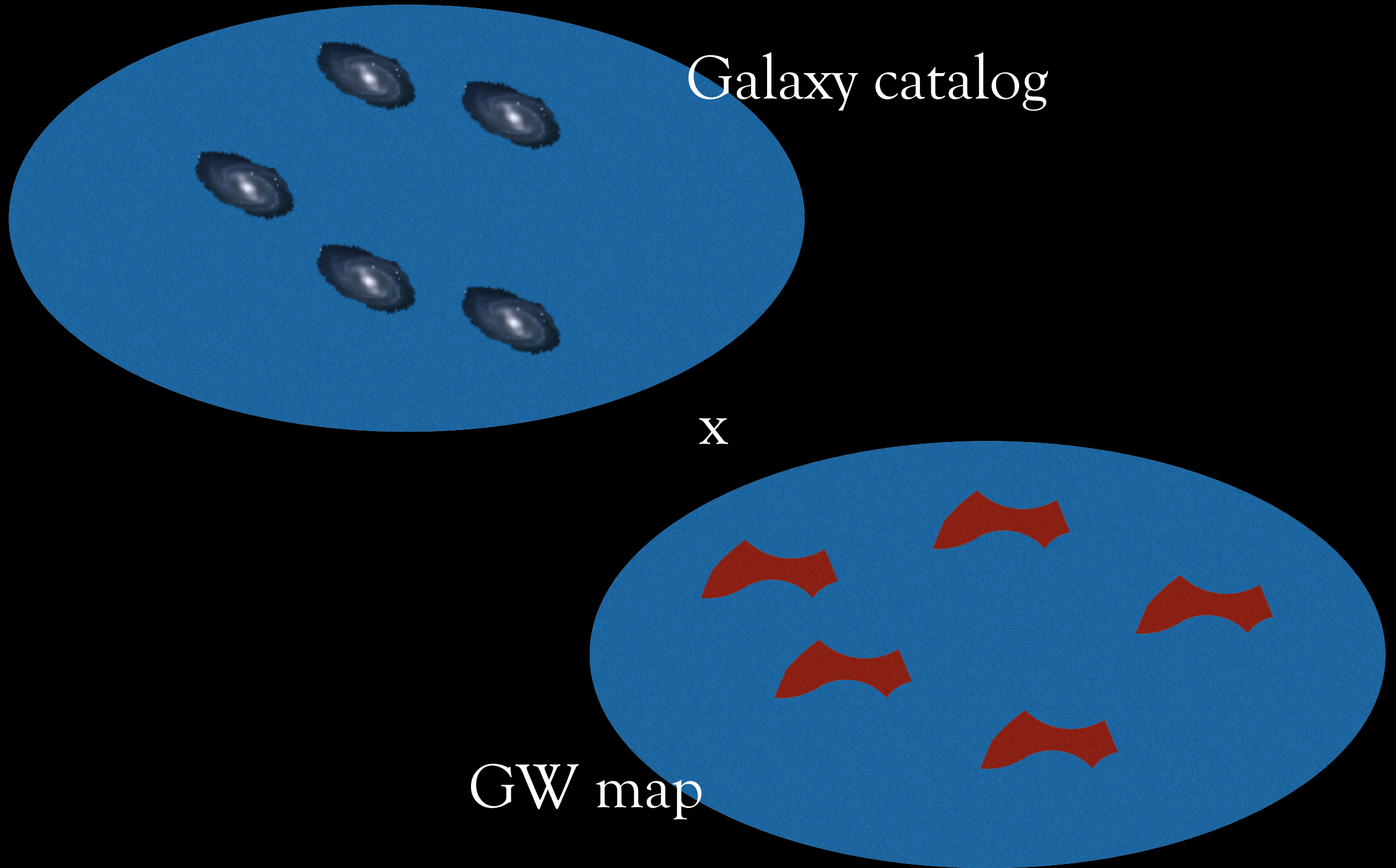
Big halos



Small halos

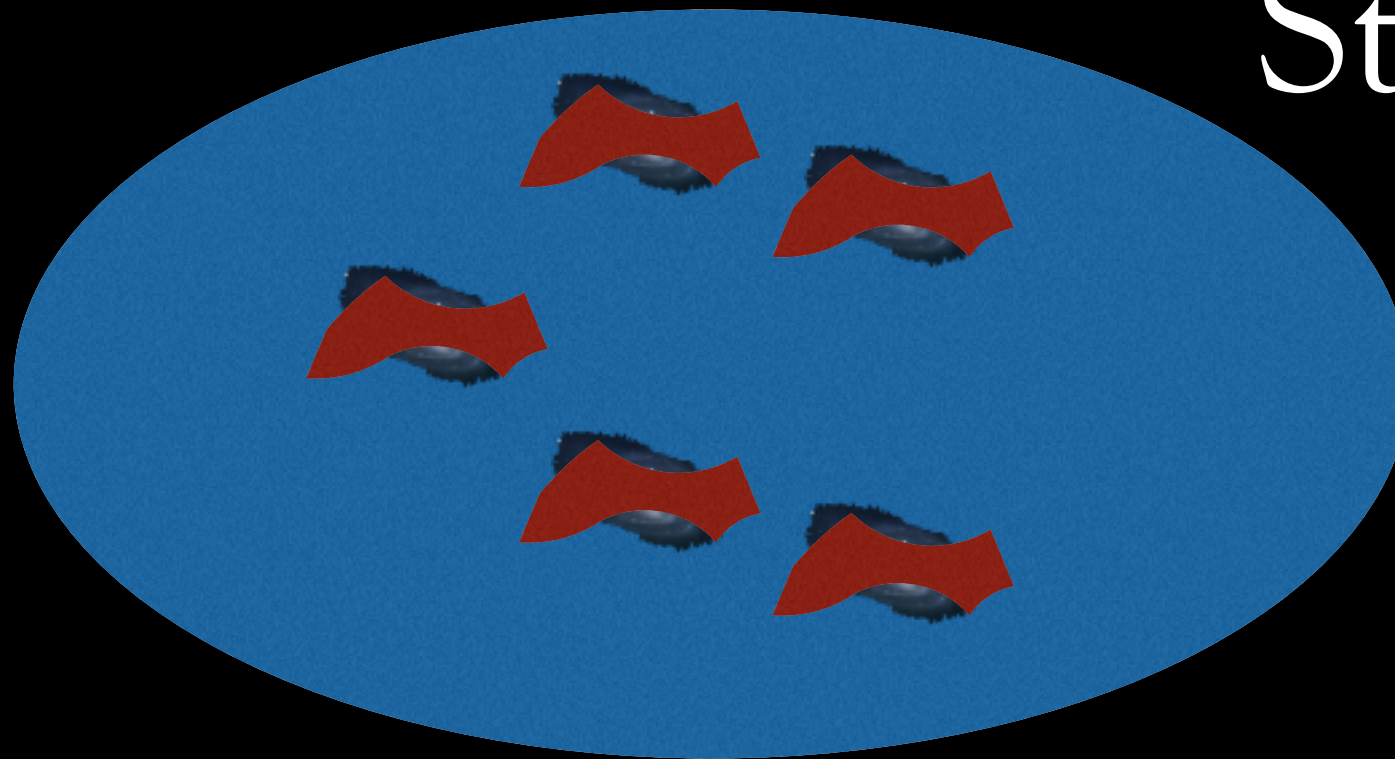
How small?
99% of events
in $M < 10^6 M_{\odot}$

Cross-correlations



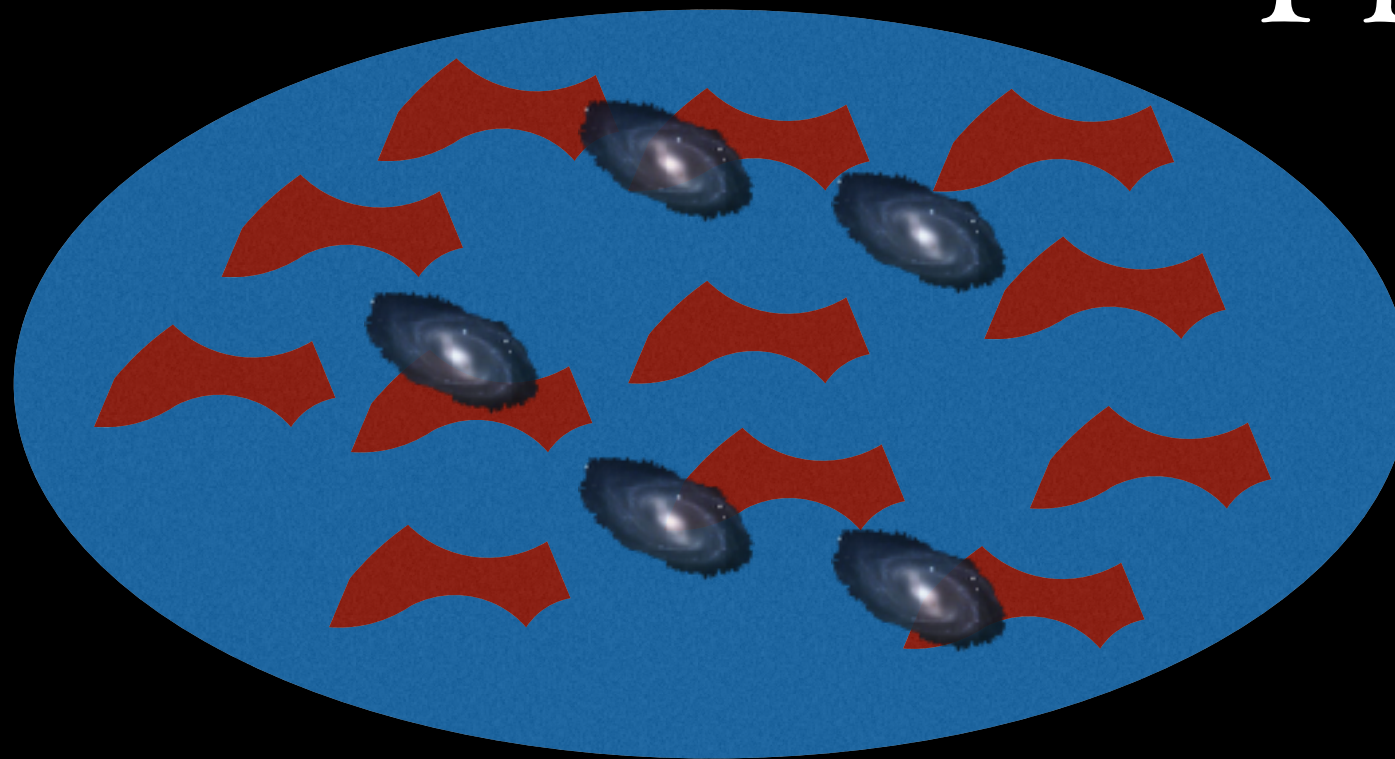
Cross-correlations

Stars

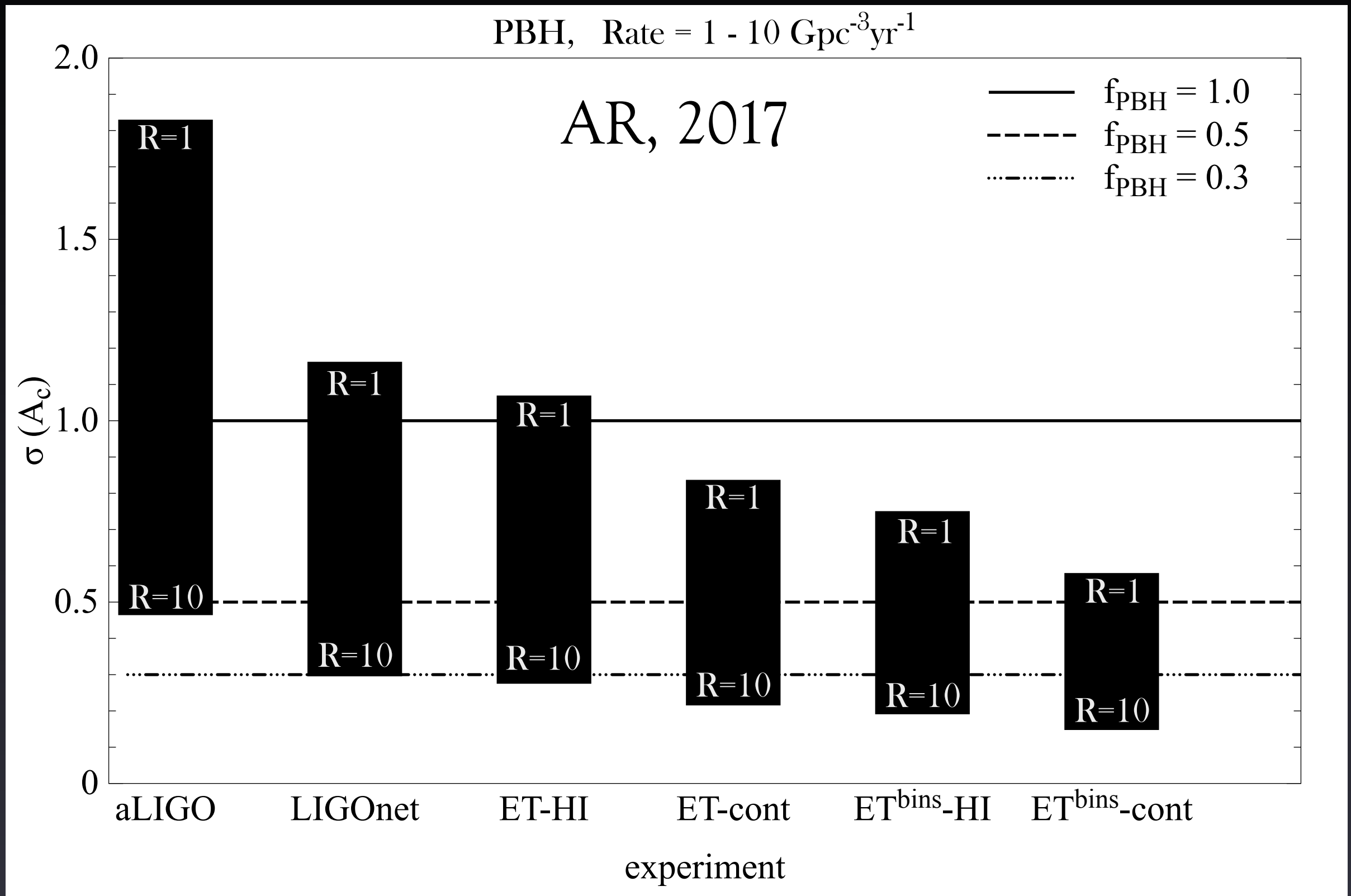


Cross-correlations

PBHs!



PBH-galaxy



PBH - Other probes

Eccentricity (Cholis et al., 2016)

FRB lensing (Munoz et al., 2016)

BHMF (Kovetz et al., 2016)

Conclusions

'At the moment our idea is just an idea,' Dr Bird told MailOnline. 'It's possible, but we don't know whether or not it is really true...it's an exciting possibility!'

'It's a plausibility argument which at the moment you cannot disprove,' Professor Peter Meszaros, an astronomer at Pennsylvania State University told **New Scientist**.

Conclusions

PBHs as DM are not ruled out

It is worth investigating more

In any case we will learn
interesting things

Black Holes in (Loop) Quantum Gravity

With

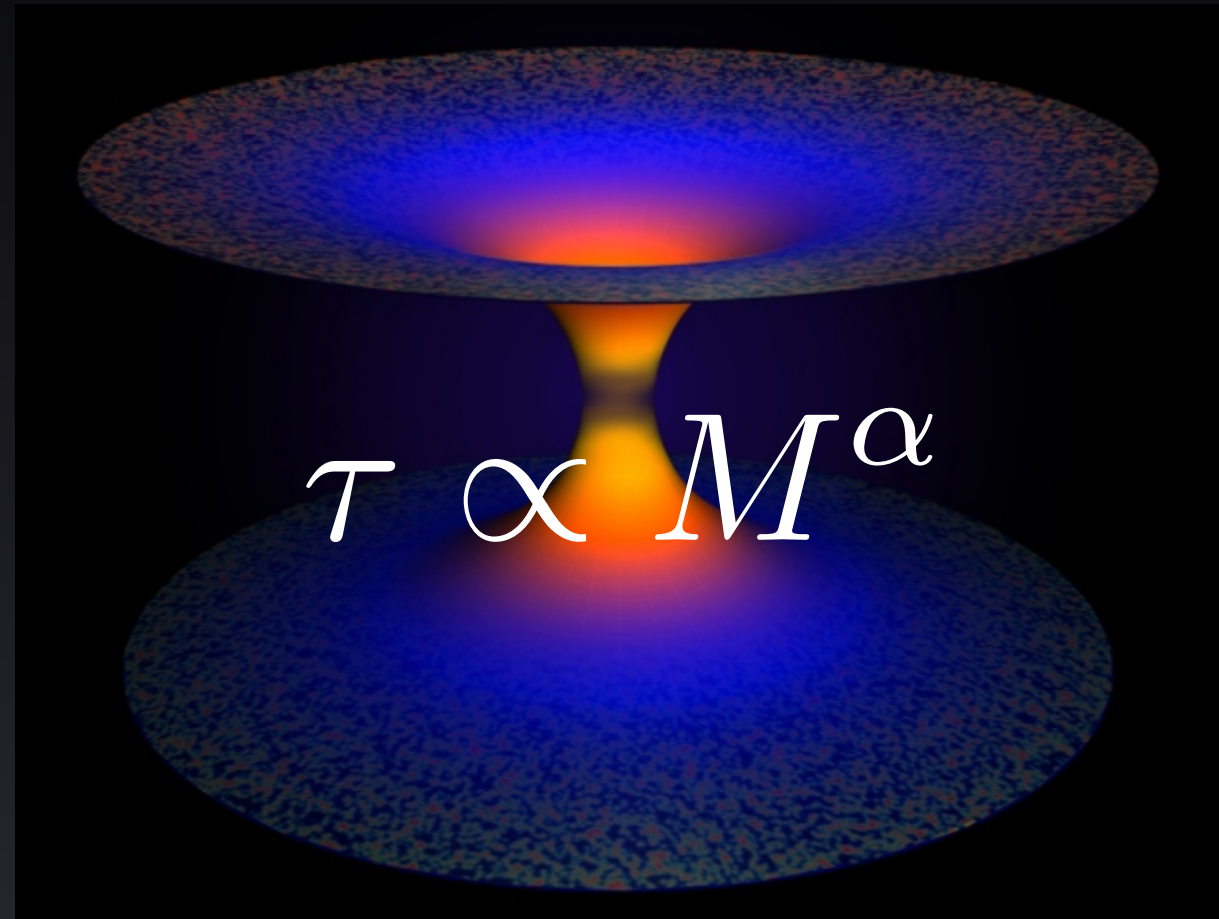
Francesca Vidotto

Licia Verde

Carlo Rovelli

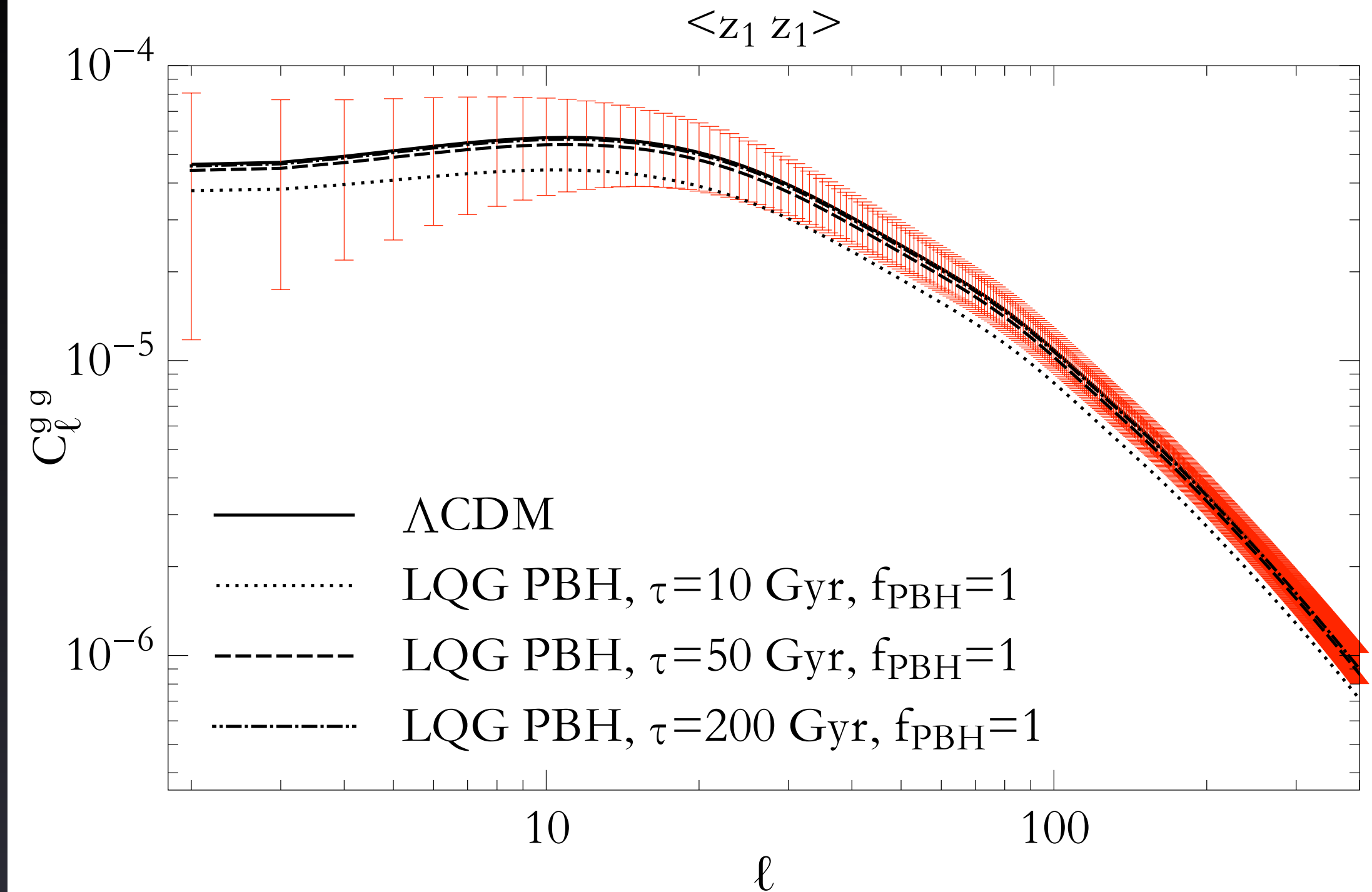
Quantum Gravity

Black Holes explode!

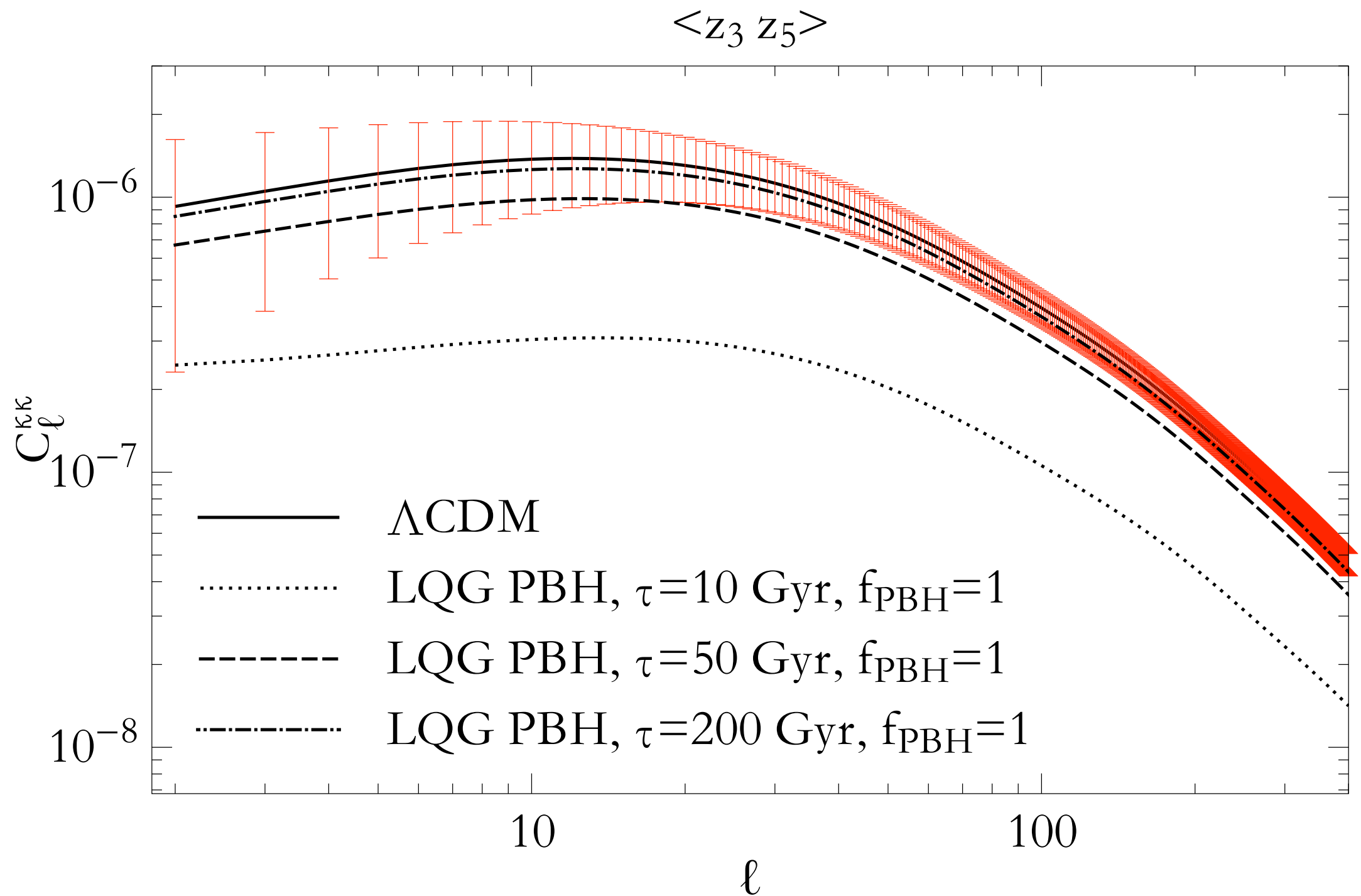


(tunneling to white holes - Rovelli)

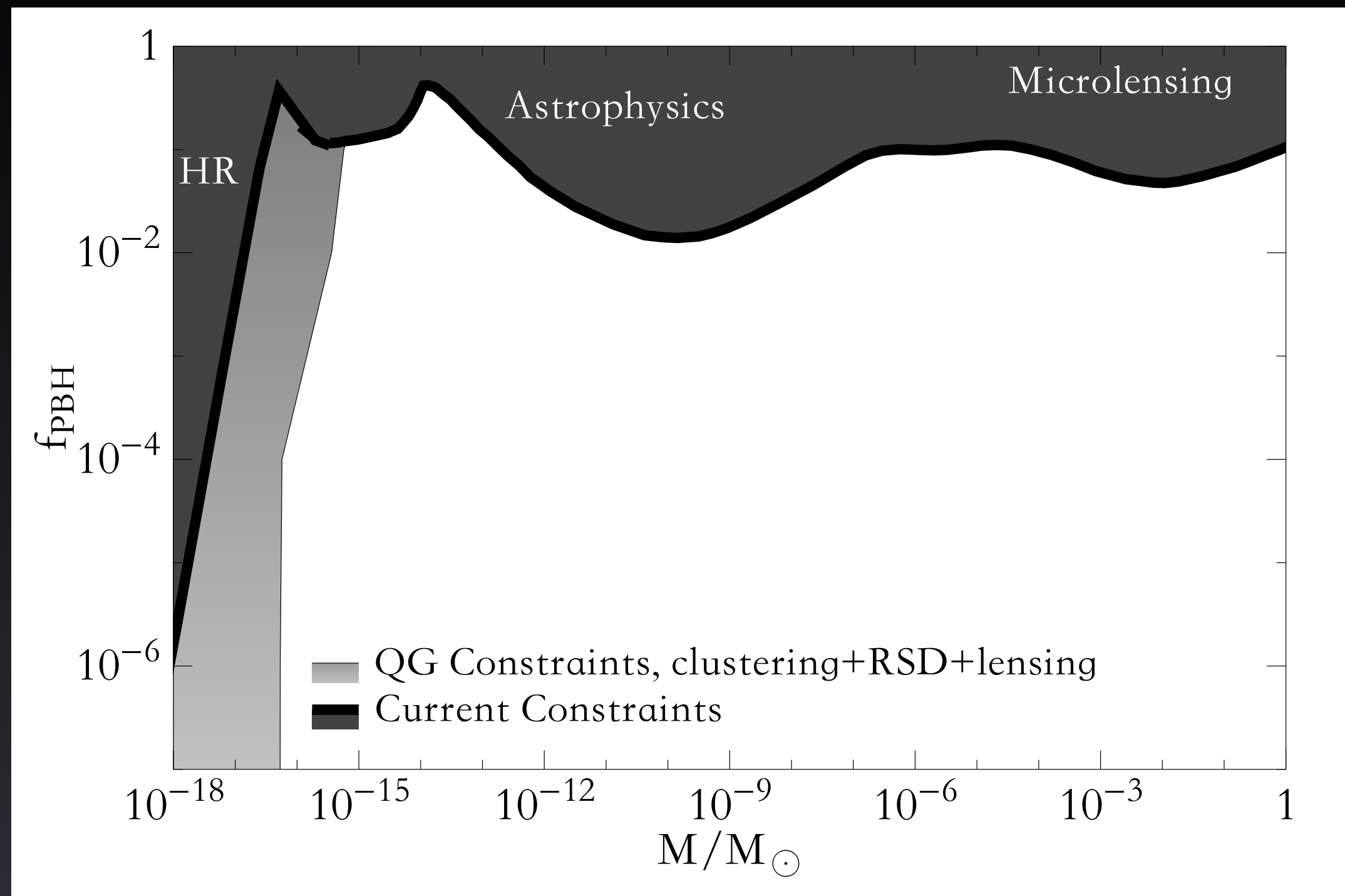
Quantum Gravity



Quantum Gravity



Quantum Gravity



Radio astronomy from the Moon



Radio astronomy from the Moon

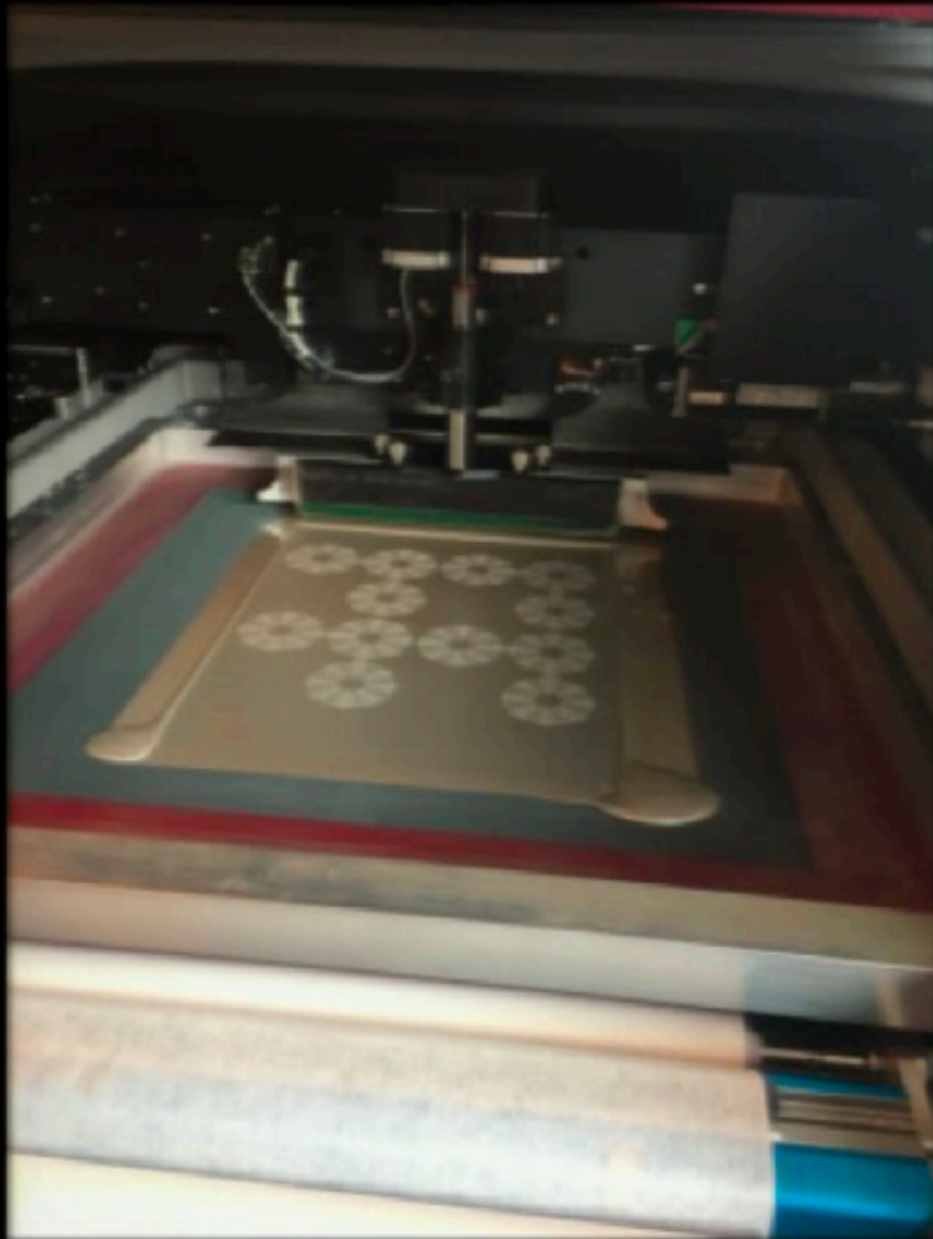


Radio astronomy from the Moon



Radio astronomy from the Moon

▶ ANTENNA PRINTING

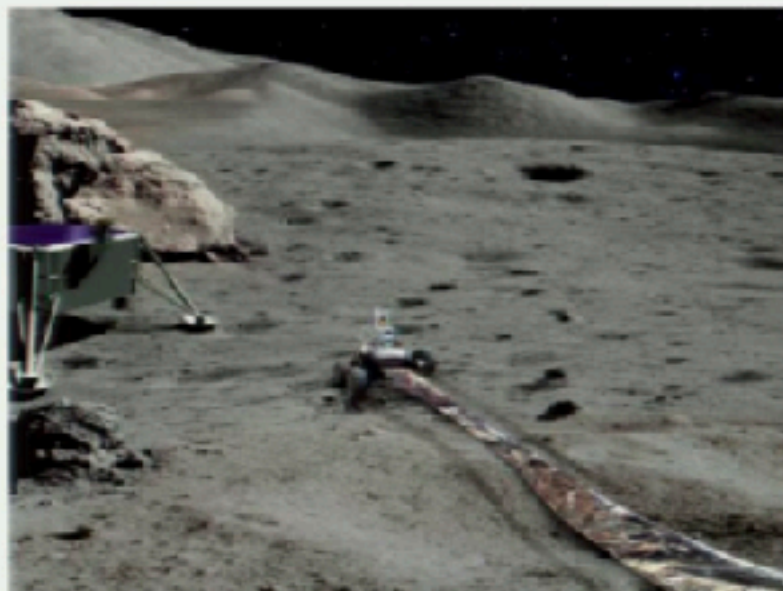


Radio astronomy from the Moon

Dark Ages Explorer needs km² collecting area: Deploy Kapton Film Antennas



Radboud University Nijmegen

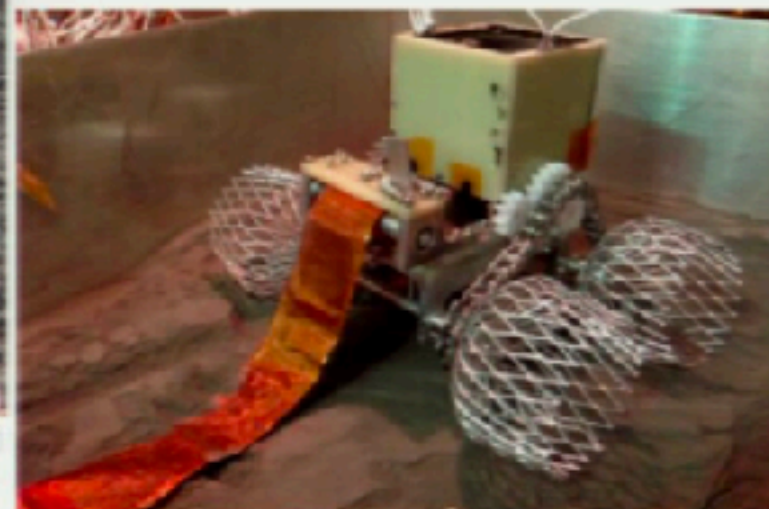


Artist's conception of roll-out Kapton film antenna on Moon's farside (South Pole Aitken Basin)



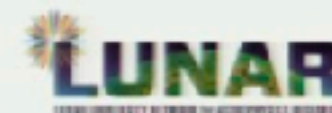
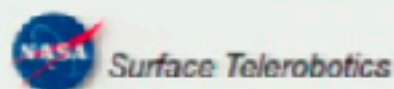
Kapton antenna test in New Mexico

- Metallic conductor deposited on surface of Kapton film.
- Unrolled, deployed by rover remotely operated from Orion on radio-quiet farside.
- Operate at $\nu < 100$ MHz.
- Film tested in vacuum chamber, with thermal cycling & UV exposure similar to lunar surface conditions, & in the field.



Rolling out Kapton film inside vacuum chamber with teleoperated mini-rover

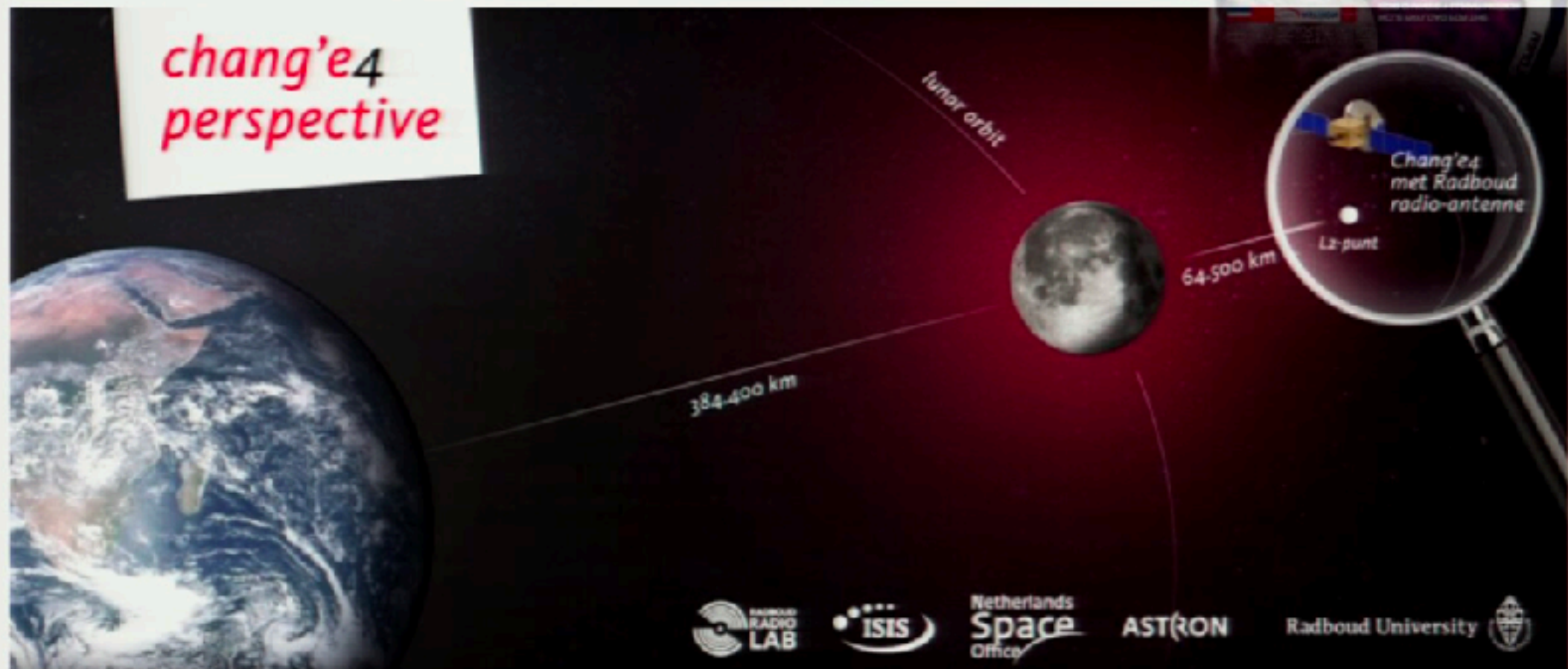
from Burns et al. (NASA, Lunar Science Institute)



Radio astronomy from the Moon

NCLE – NL/China Low-Frequency Explorer

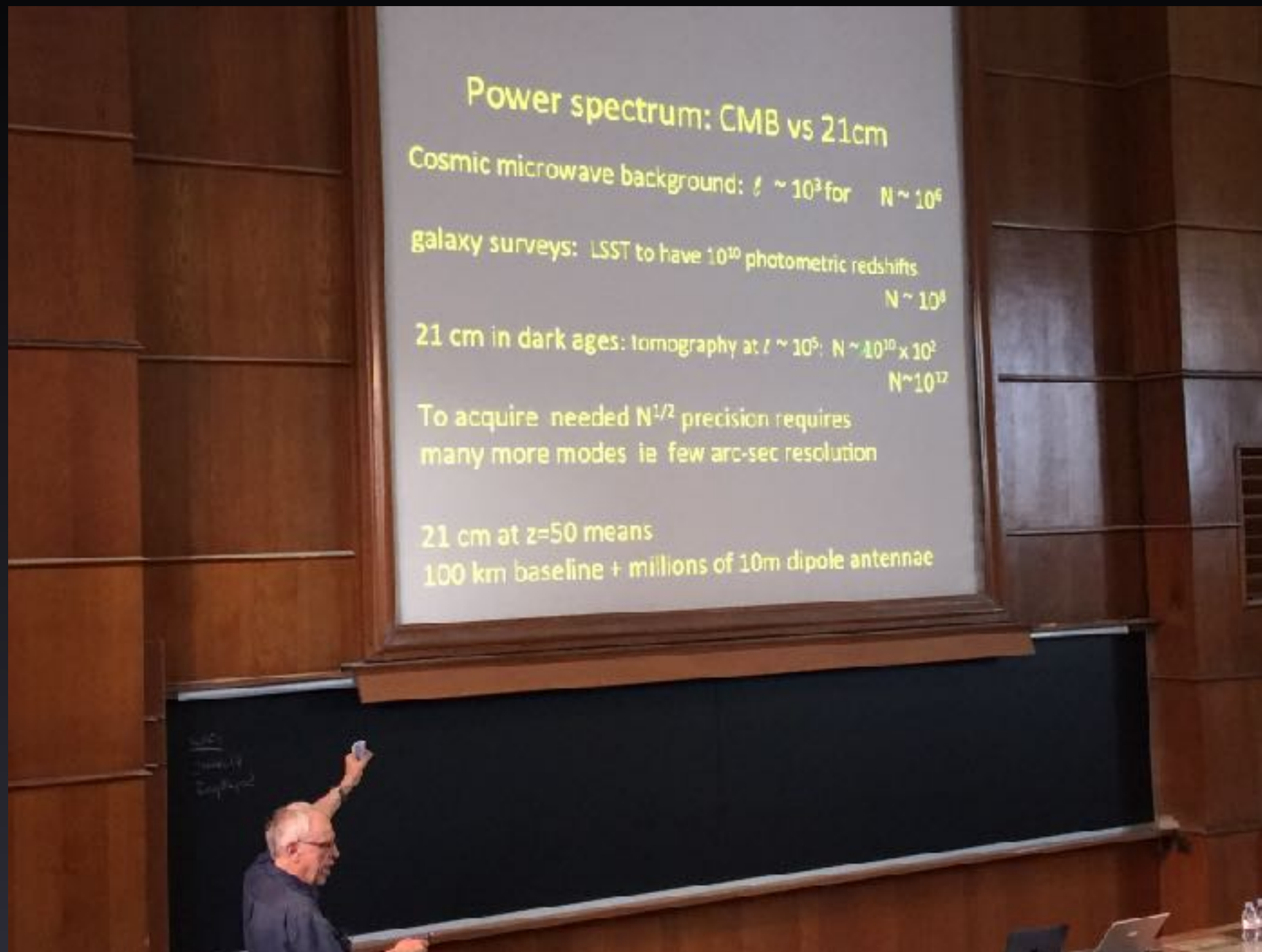
Onboard Chang'E4 relay satellite at Earth-Moon – L2
Launch 2018!



Radio astronomy from the Moon

Cosmology from the Moon

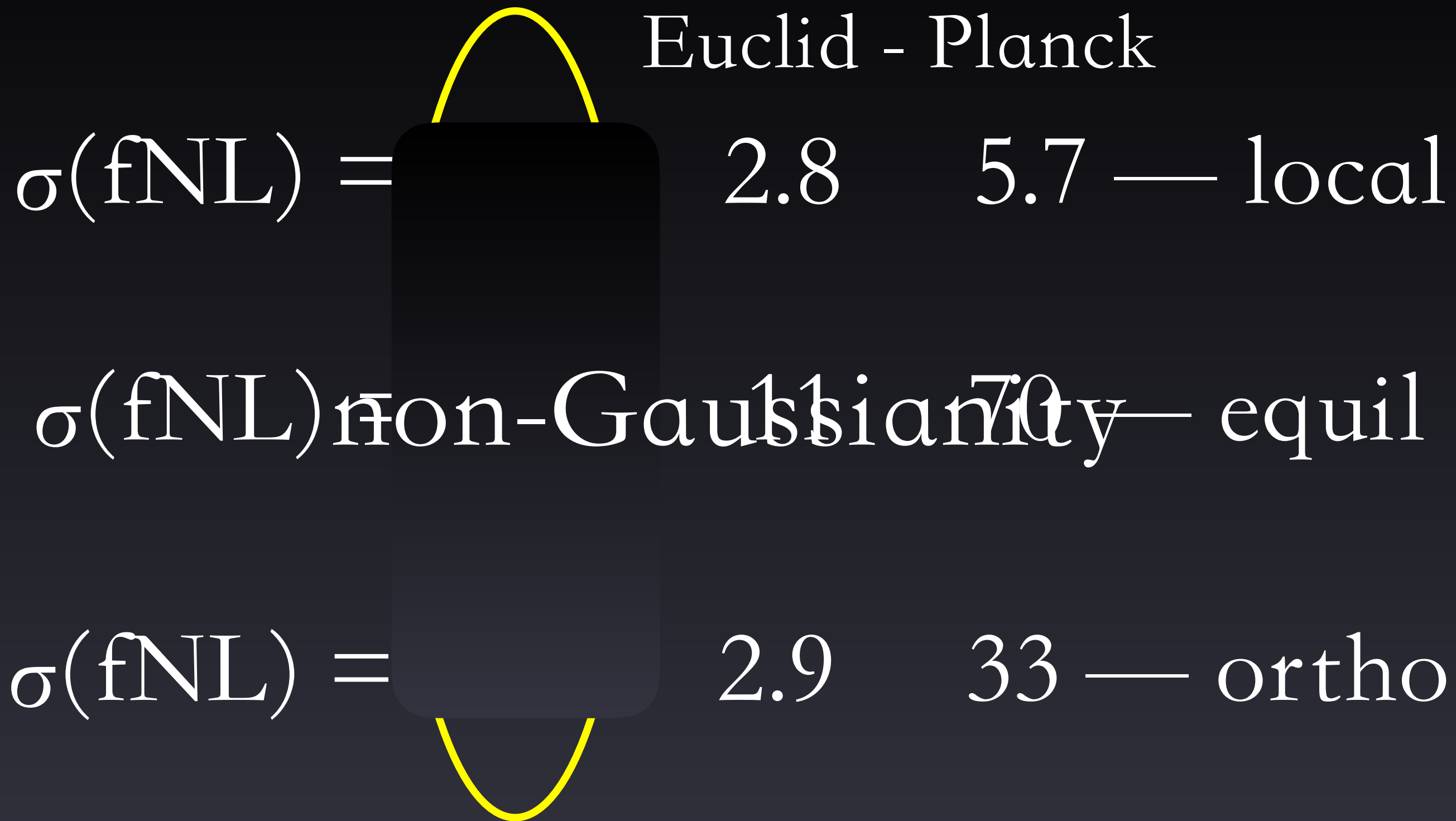
Radio astronomy from the Moon



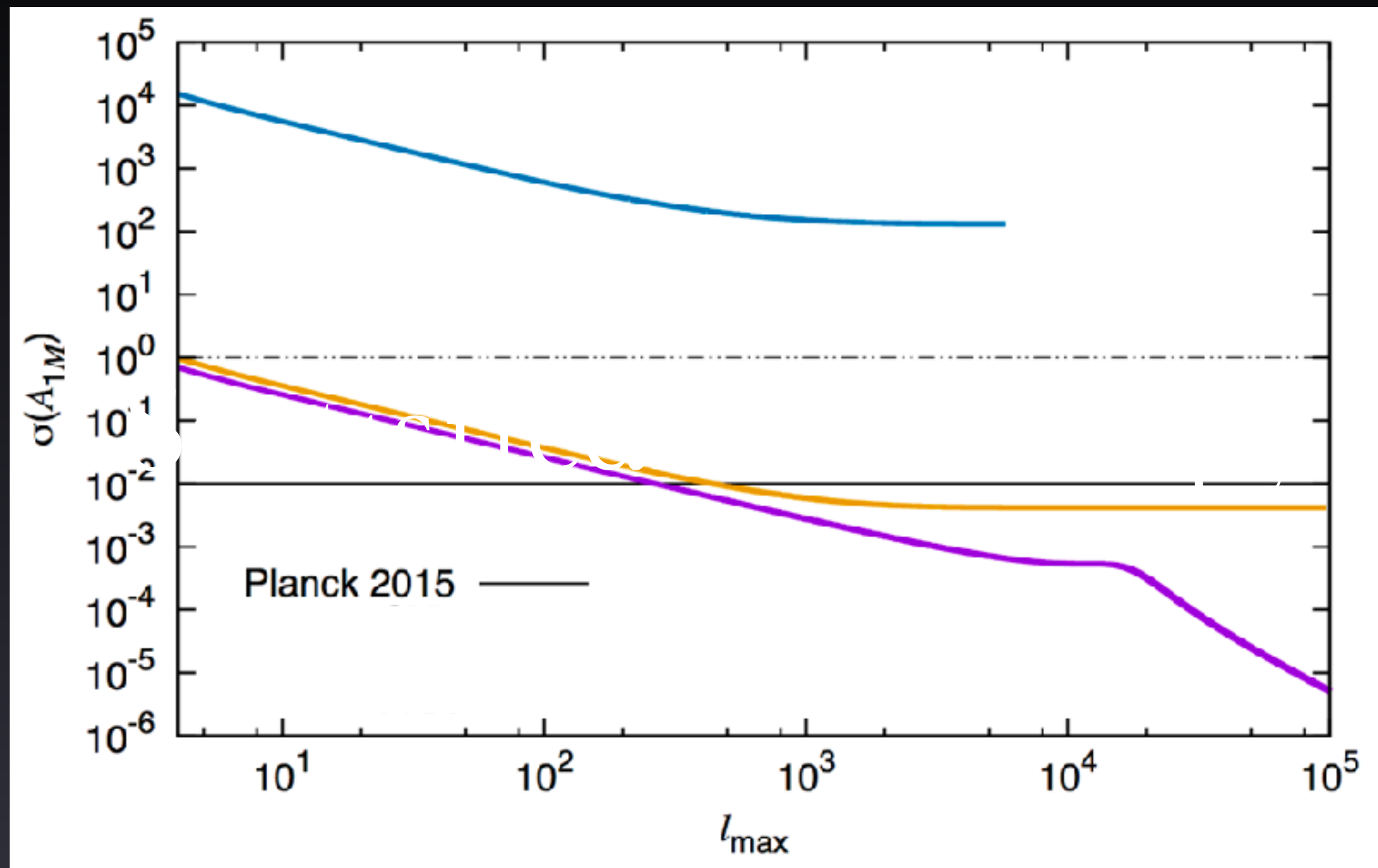
Radio astronomy from the Moon

	DESI	CMB S4
$\sigma(n_s) =$	$2.1e-3$	$2.7e-3$
Spectral index (n_s)	$4.9e-3$	$2.6e-3$
$\sigma(\beta_s) =$	$1.3e-2$	$4.5e-3$

Radio astronomy from the Moon



Radio astronomy from the Moon

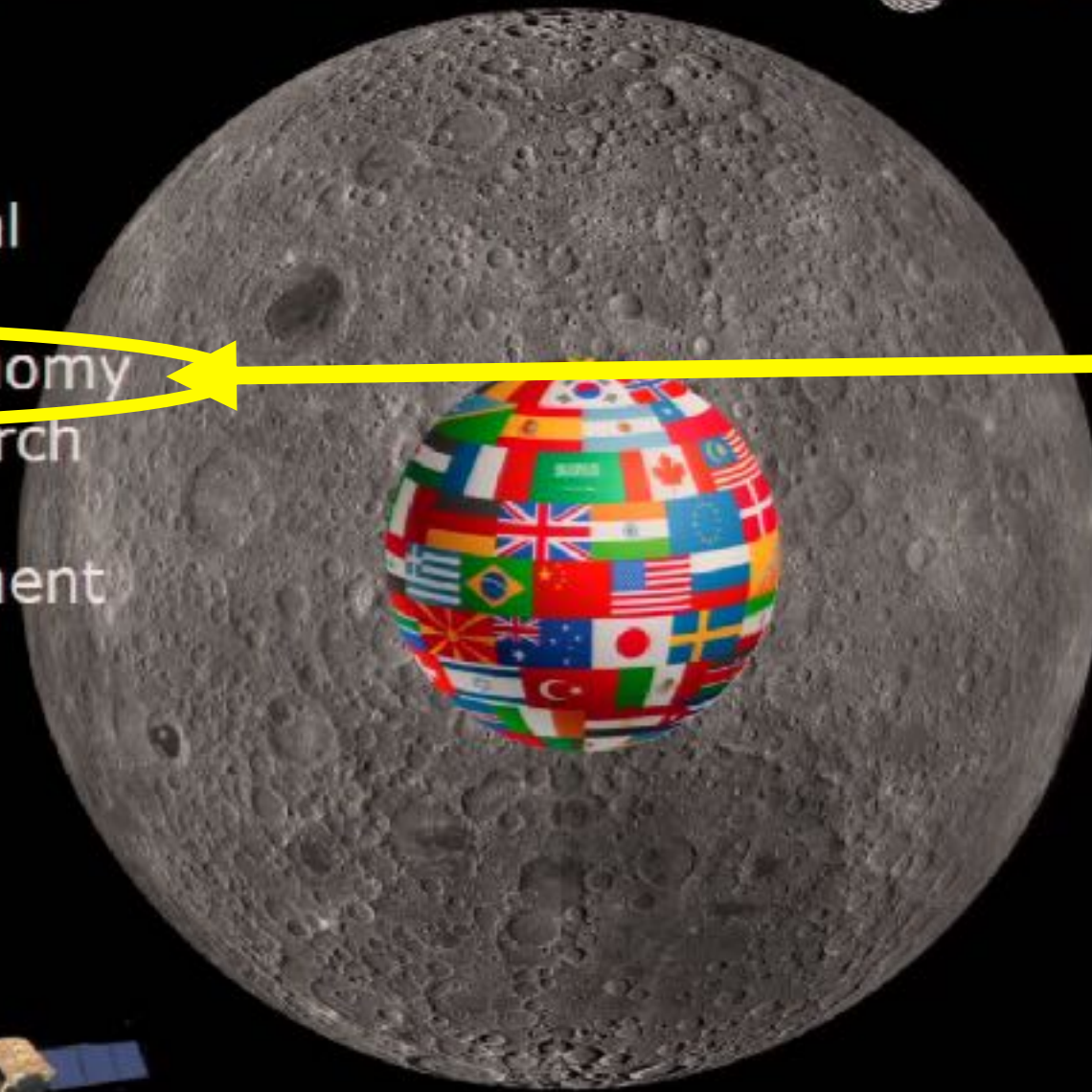


Conclusions

Proposal: sustainable moon surface operations



Exploration
Human & robotic
Public & commercial
Moon Science
Cosmology / astronomy
Fundamental research
Transportation
Resource management
Mining
Communication
Technology
Pioneering
Stepping stone...
Tourism
Outreach /STEAM



Conclusions



Thank

You