Gravitational Waves
and
the "Final Frontier" of Cosmology

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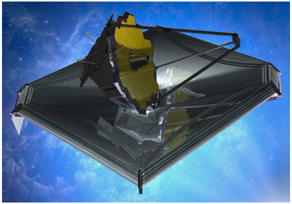
The Future of Gravitational-Wave Astronomy
ICTS-TIFR, Bengaluru
20 August 2019

Outline

- The “final frontier” of cosmology: detecting the first stars

JWST



TMT

SKA

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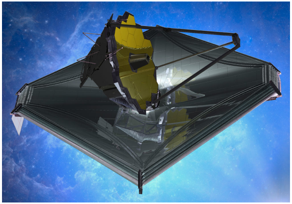

TMT

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- Gravitational wave detection requires knowledge of the first galaxies

  Reionization by first stars can potentially contaminate the *B*-mode CMB signal from primordial gravitational waves

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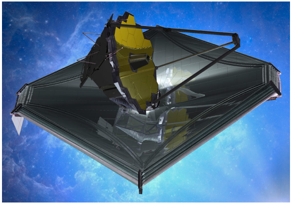

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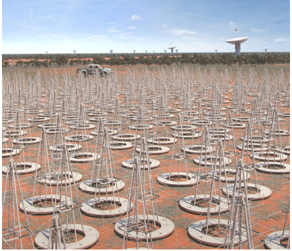


- Gravitational wave detection requires knowledge of the first galaxies

  Reionization by first stars can potentially contaminate the *B*-mode CMB signal from primordial gravitational waves

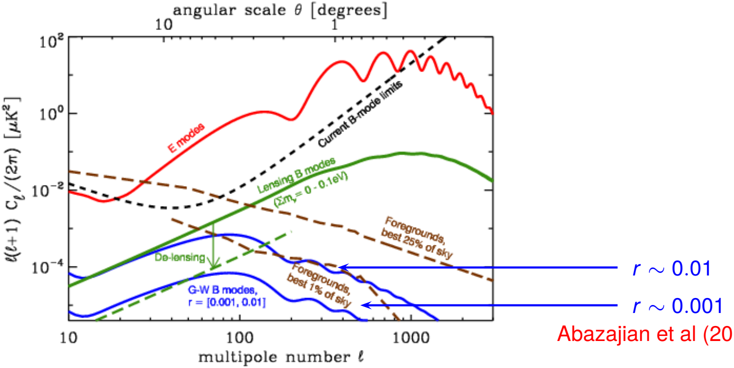
- Gravitational wave observations can shed light on the properties of the first galaxies

  Black hole mergers at high redshifts detectable by LISA

Gravitational wave detection requires knowledge of the first galaxies

B-mode polarization signal

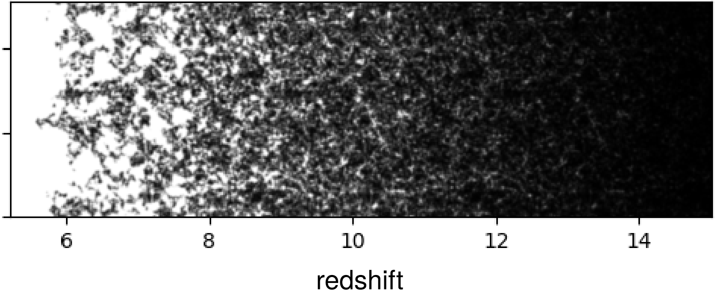
- Polarization signal much weaker than the temperature.



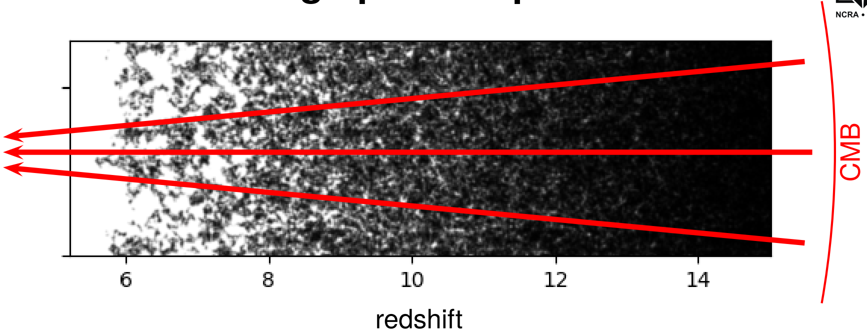
Abazajian et al (2015)

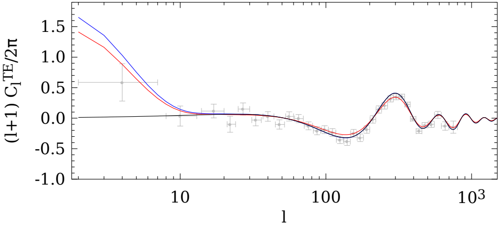
- Well-known that the signal contaminated by gravitational lensing, hence need to "de-lens" for detecting the primordial signal.
- Patchy reionization also generates *B*-mode

Thomson scattering optical depth



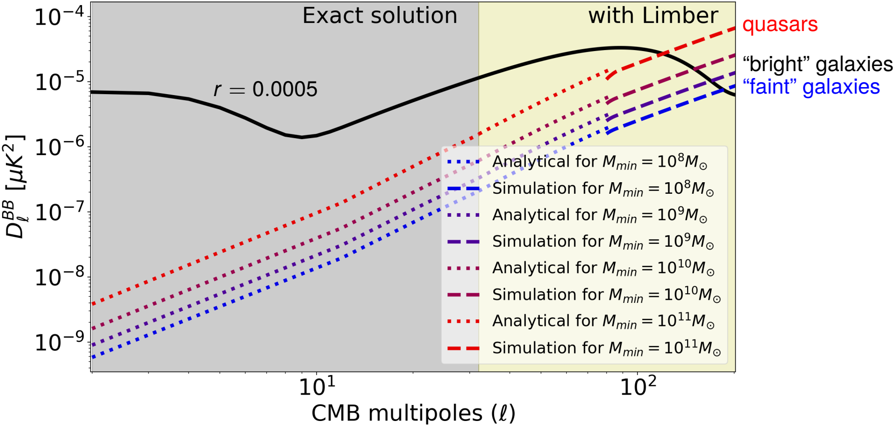
Thomson scattering optical depth





$$\tau_{\rm el}(\theta,\phi) = c\sigma_T \int_{t_{\rm LSS}}^{t_0} \mathrm{d}t \; n_e(t,\theta,\phi)$$

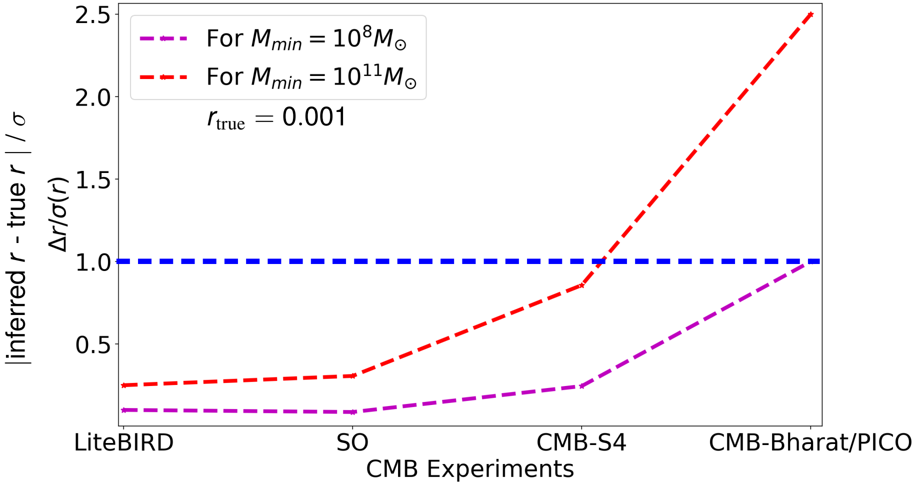
Patchy reionization vs gravitational waves



need to "de-τ" the CMB maps (along with de-lens)?

Mukherjee, Paul & **TRC** (2019)

Bias for future missions

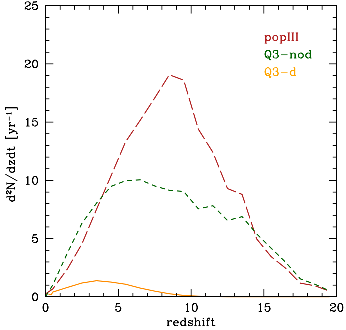


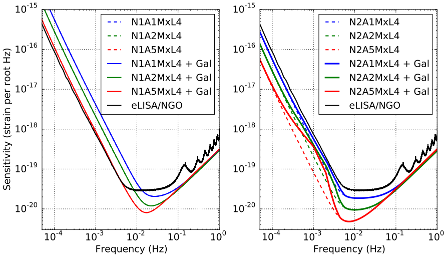
Need accurate information on reionization history for next-generation CMB experiments. Use 21 cm observations, kSZ signal, ...

Mukherjee, Paul & **TRC** (2019)

Gravitational wave observations can shed light on the properties of the first galaxies

Super-massive black hole mergers





Klein et al (2016)

Galaxy formation model

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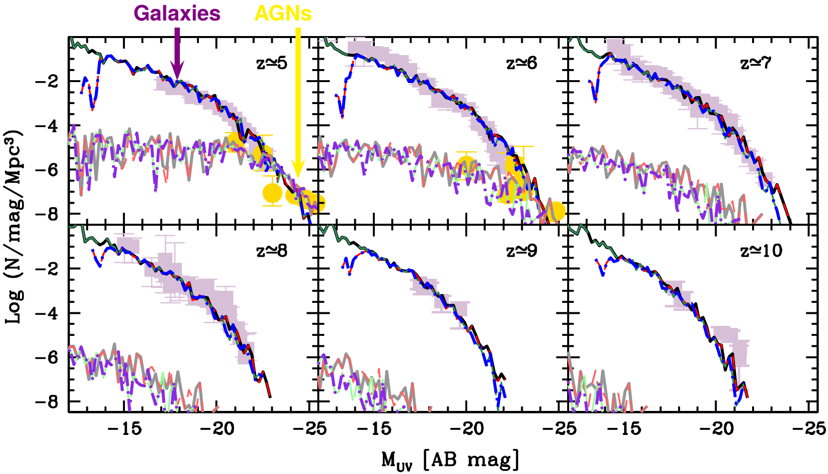
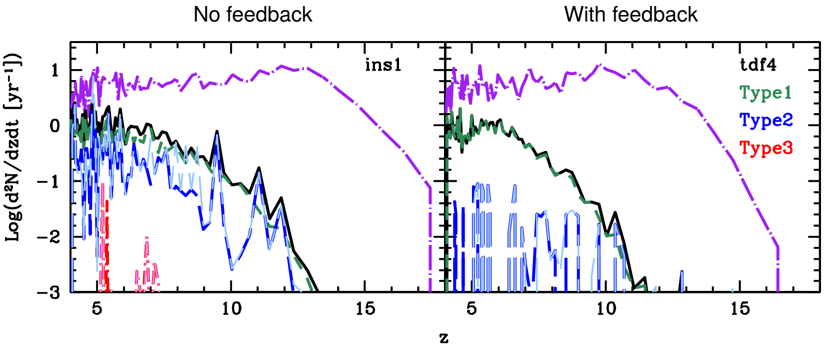
- Based on merger trees of dark matter haloes
- Accounts for various complex galaxy formation physics, e.g., star formation, supernova feedback, reionization feedback, . . .
  Dayal et al (2014), Dayal, **TRC** et al (2017)
- Also black hole seeding, growth, and feedback
  Dayal, Rossi, Shiralilou, Piana, **TRC** & Volonteri (2019)

Calibrated to (available) observations



Dayal, Rossi, Shiralilou, Piana, **TRC** & Volonteri (2019)

LISA event rates



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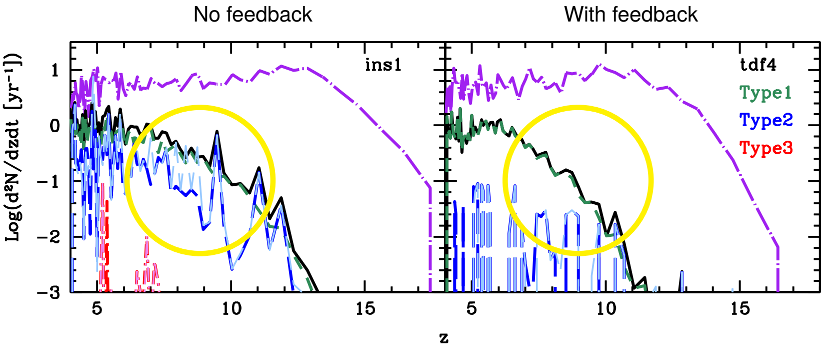

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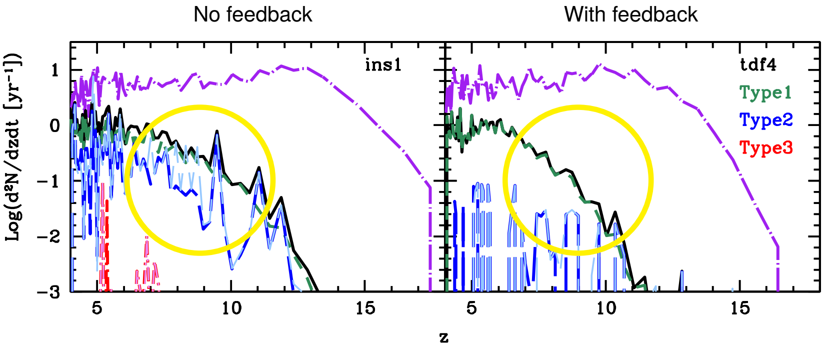

Future: implications for non-standard cosmology, e.g., Warm Dark Matter, also predictions for PTAs

Dayal, Rossi, Shiralilou, Piana, **TRC** & Volonteri (2019)

Summary

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- Gravitational wave astronomy in the future $\Longleftrightarrow$ "final frontier" of cosmology
- Gravitational wave detection requires knowledge of the first galaxies
- Gravitational wave observations can shed light on the properties of the first galaxies