



# 21-CM THEORY UPDATE

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June 8, 2018

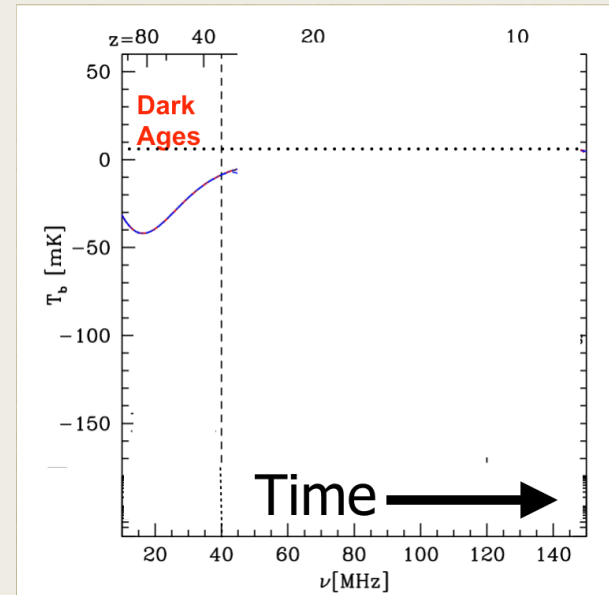


# High-Level Goals

- Provide theoretical motivation for lunar 21-cm arrays
  - *Study of first generations of luminous objects*
- Provide a suite of **astrophysics** models that can be constrained with such telescopes
  - *“Best guess” models and parameterizations of distant sources*
- Interpret existing measurements of the Cosmic Dawn
  - *What does the EDGES trough mean?*

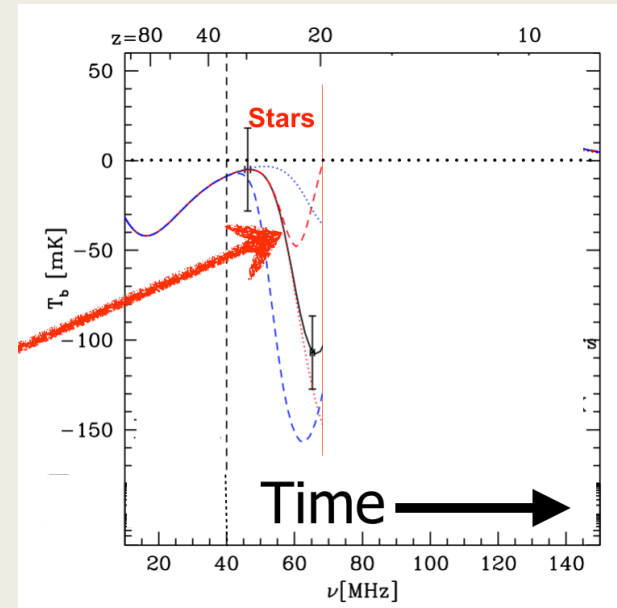
# The Global 21-cm Signal

- Observed frequency maps to redshift, so spectrum provides time evolution of radiation backgrounds in the Universe
- Phase 1: pre-astrophysics, so provides cosmological info
  - *Could be probed with DAPPER*



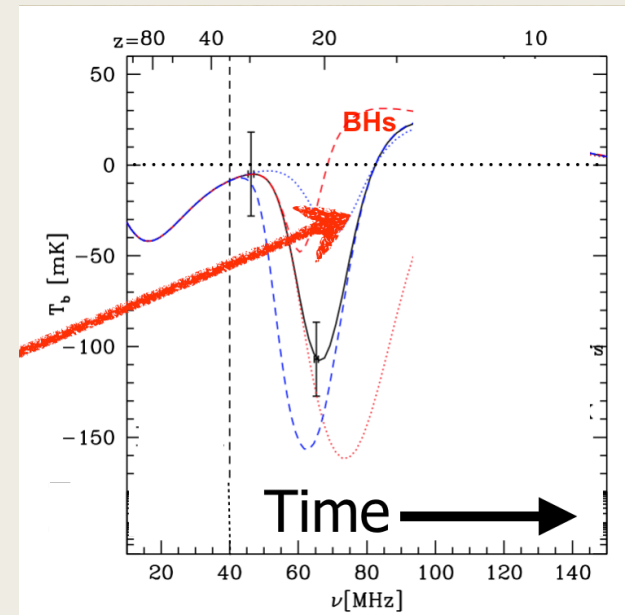
# The Global 21-cm Signal

- Phase 2: first stars flood the Universe with UV photons
  - *Could be probed with EDGES, DARE, others?*



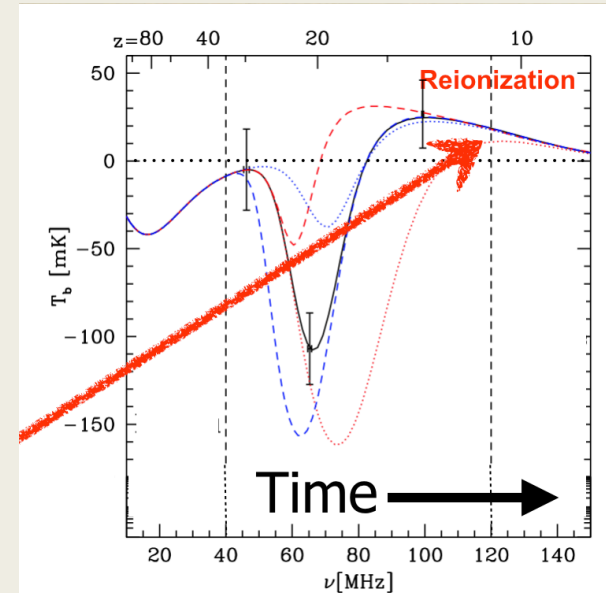
# The Global 21-cm Signal

- Phase 3: black holes flood universe with X-ray photons, heating the gas
  - *Could be probed with EDGES, DARE, others?*

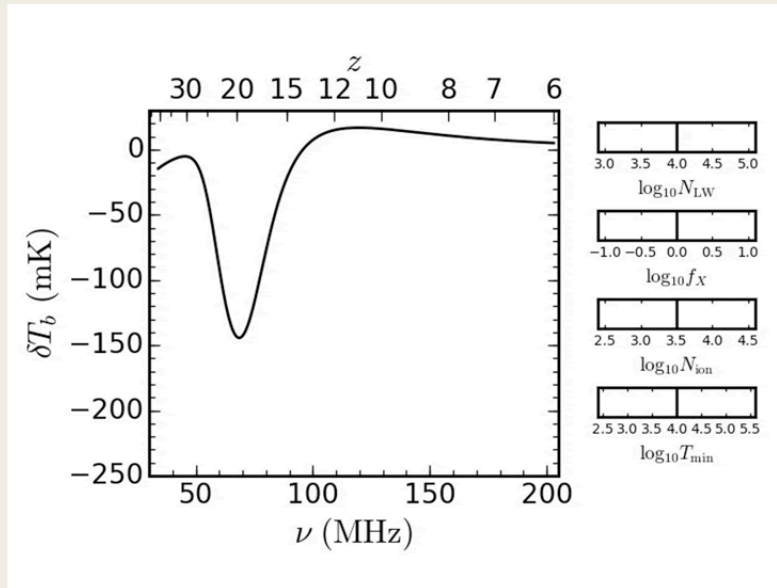


# The Global 21-cm Signal

- Phase 4: reionization
  - *Could be probed with EDGES, many other ground-based*
- NOTE: all of these eras also have fluctuations that could be constrained with existing instruments + lunar arrays



# The Global 21-cm Signal: Models



# Goals in Year 1

- Develop semi-analytic models of Pop III star formation
- Identify unique signatures of Pop III star formation in the 21-cm global signal
- Combine galaxy, global signal, interferometer, and CMB constraints into one framework

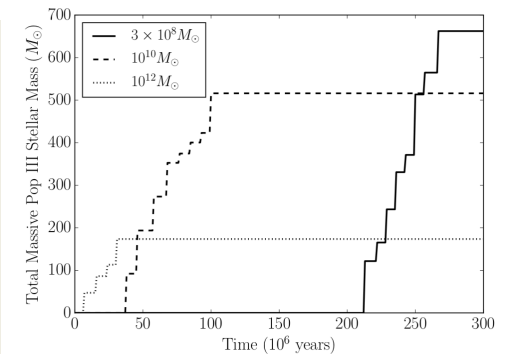
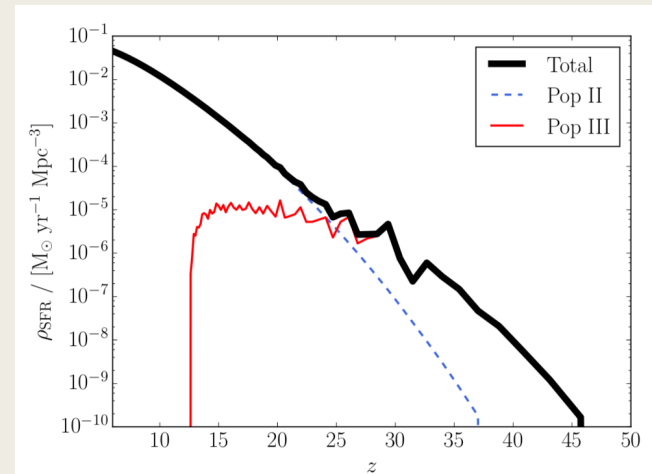


# Progress in Year 1

- Develop semi-analytic models of Pop III star formation
- Identify unique signatures of Pop III star formation in the 21-cm global signal
- ~~Combine galaxy, global signal, interferometer, and CMB constraints into one framework~~
- Interpret EDGES signal for astrophysicists

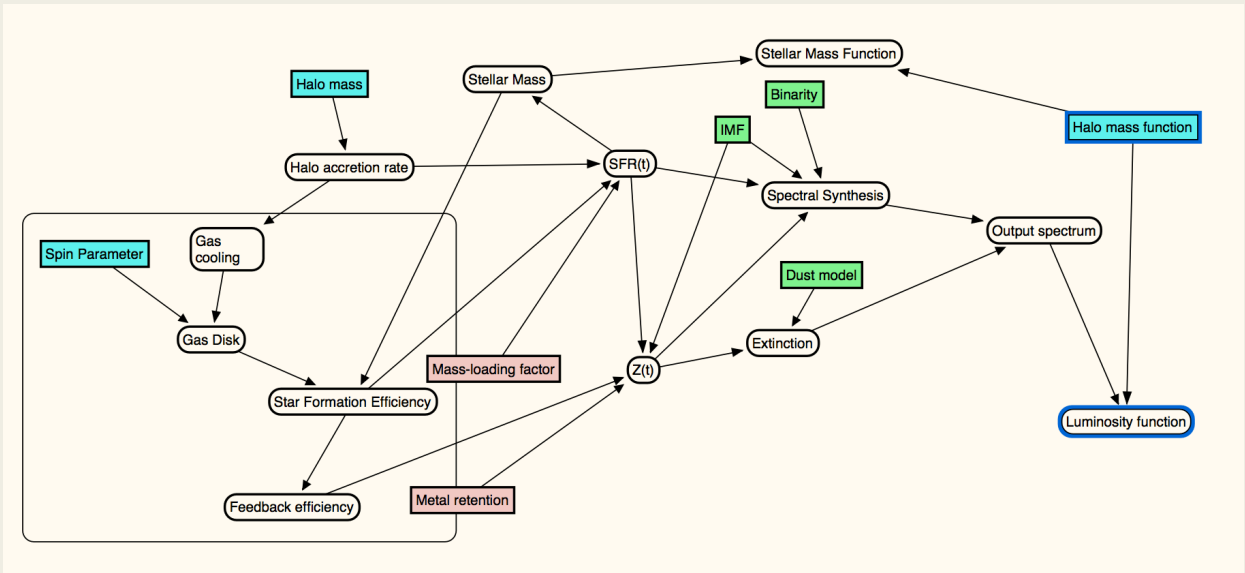
# Models of the First Luminous Sources: Pop III Stars

- Mebane et al. (2018) developed a semi-analytic model of Pop III star formation, focusing on the transition to “normal” galaxies
  - *Normal galaxies essential for understanding end of Pop III*
  - *Wide range of input assumptions lets us search for key observables*
- Current goals: integrate source model into 21cmFAST to map fluctuations (and improve physics of model)



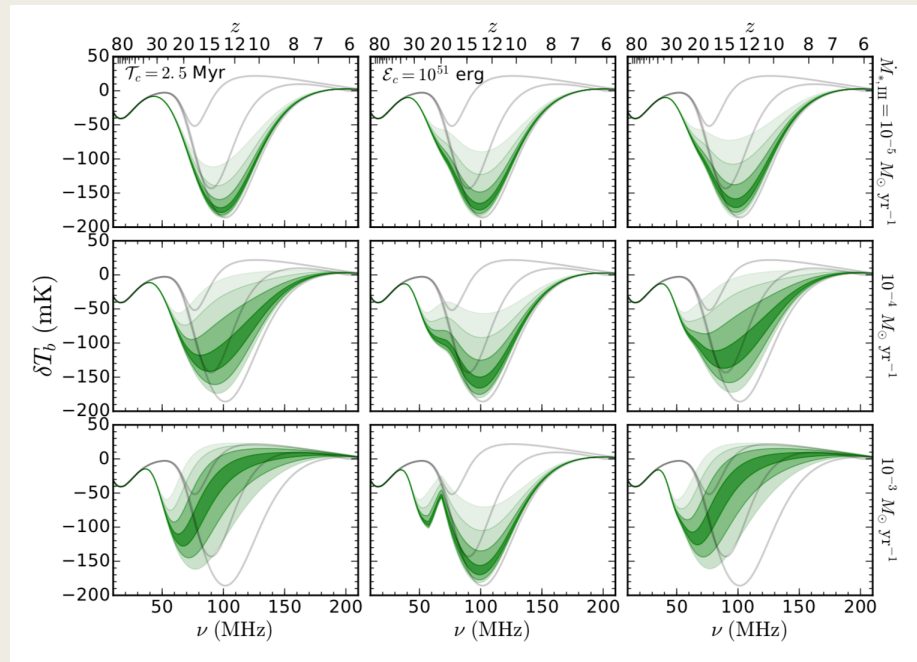
# Models of the First Second Luminous Sources: Pop II Stars

- Ongoing work to develop flexible semi-analytic model of Pop II star formation: crucial context for Pop III
- Much more difficult proposition! No models exist relevant to this era that are simple enough to span uncertainties!



# Studying the Pop III Era with the 21-cm Line

- Mirocha et al. (2018) studied the effects of “realistic” Pop III models on the 21-cm background



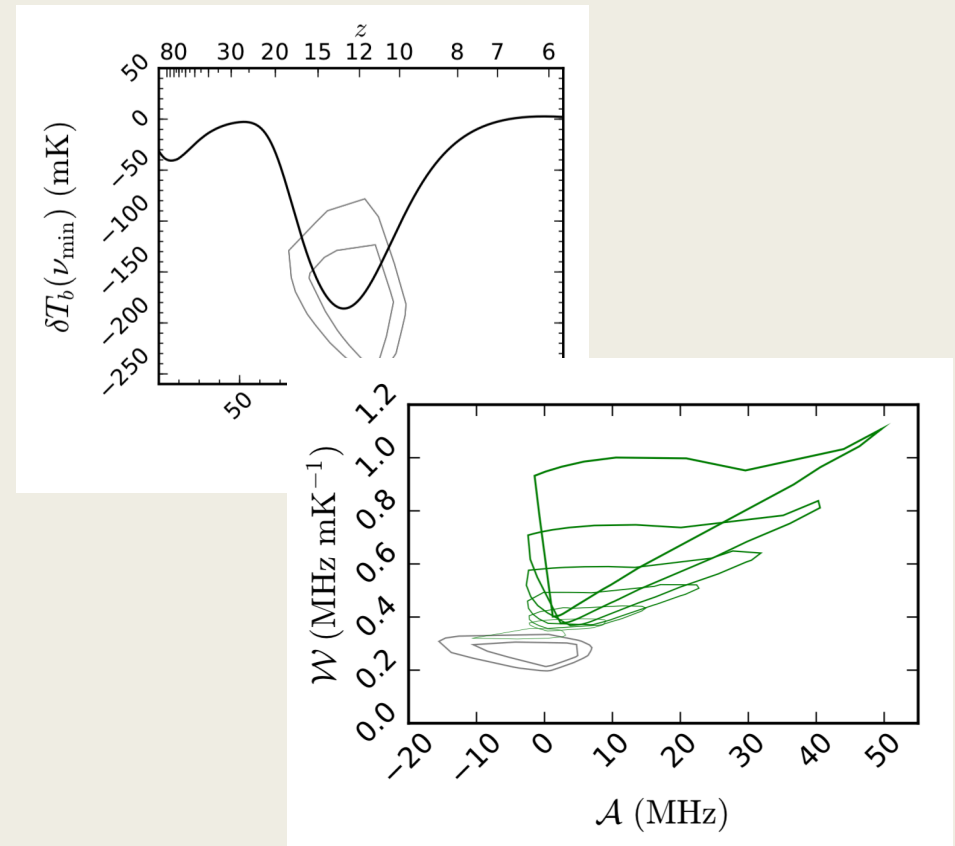
# Studying the Pop III Era with the 21-cm Line

- Mirocha et al. (2018) studied the effects of “realistic” Pop III models on the 21-cm background
- Identified a space in which SOME Pop III models can be cleanly distinguished from Pop II models, ASSUMING the latter are measured independently reasonably well

$$\mathcal{A} = |\nu^+ - \nu_{\min}| - |\nu^- - \nu_{\min}|$$

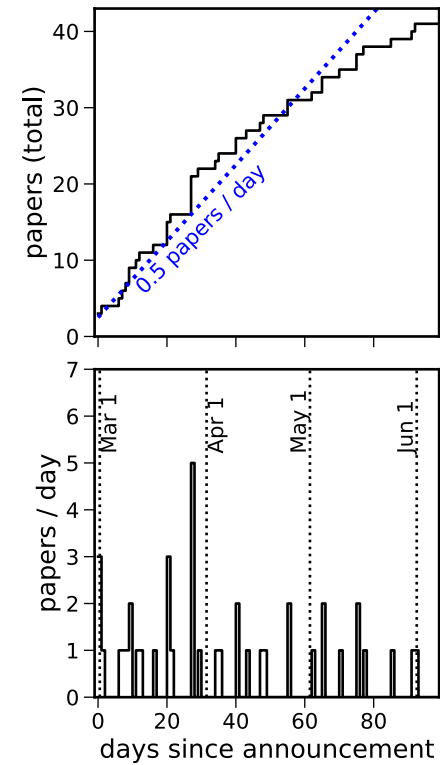
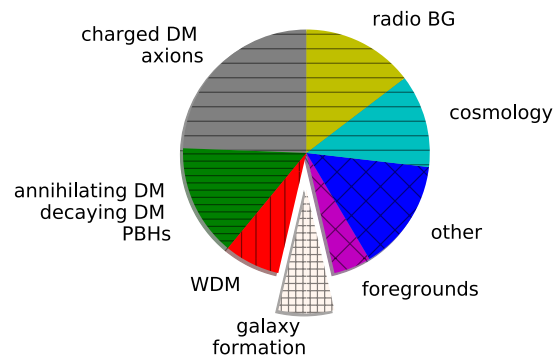
$$\mathcal{W} = \frac{\text{FWHM}}{\delta T_b(\nu_{\min})}$$

- Proof-of-concept for indirect detection of Pop III stellar populations!



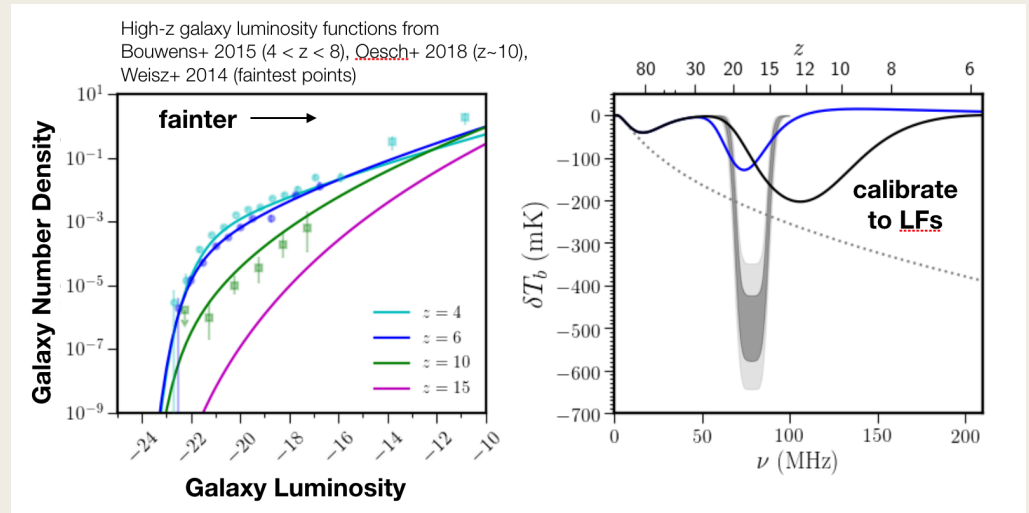
# Interpreting the EDGES signal

- This has made a splash!
- MANY potential explanations



# The Astrophysical Implications of EDGES

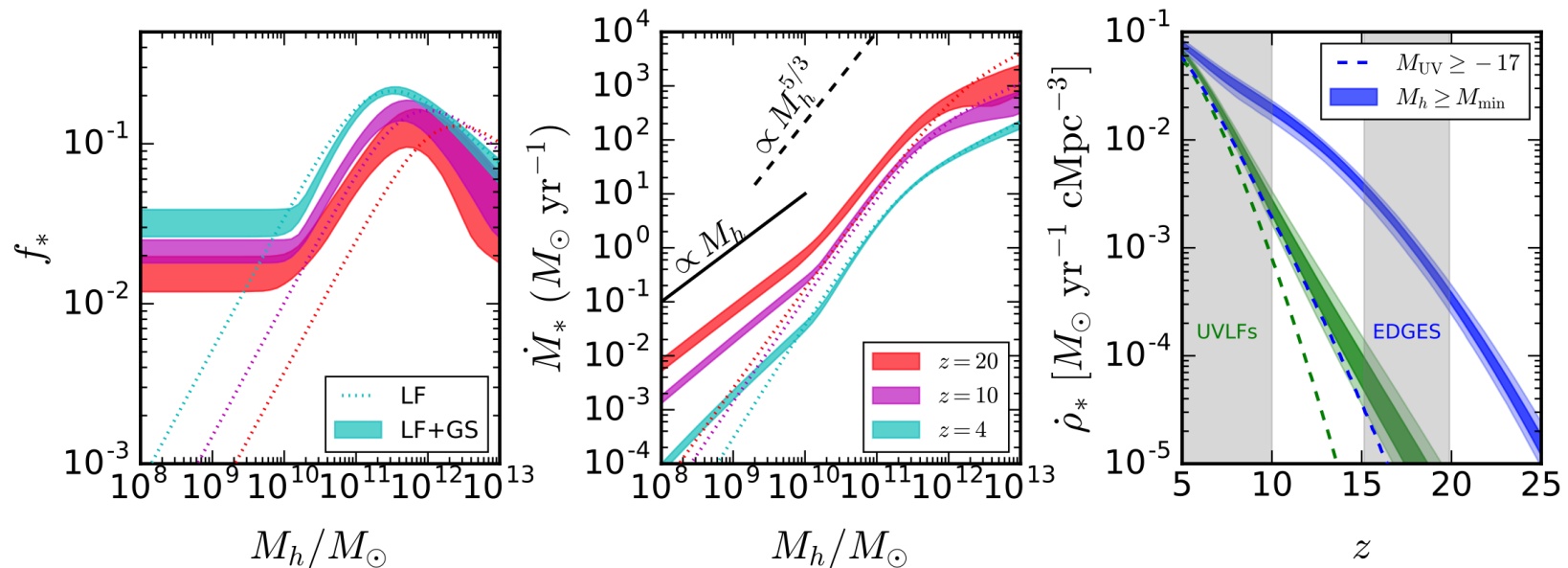
- Mirocha & Furlanetto (2018) applied our galaxy + 21-cm framework to the EDGES detection
- The least-noticed aspect of the EDGES signal is its timing:  $z \sim 17$  is significantly EARLIER than we'd expect from a “vanilla” galaxy model



Mirocha, Furlanetto, & Sun (2017)

# The Astrophysical Implications of EDGES

**Q. What must SFE be to fit EDGES signal?**

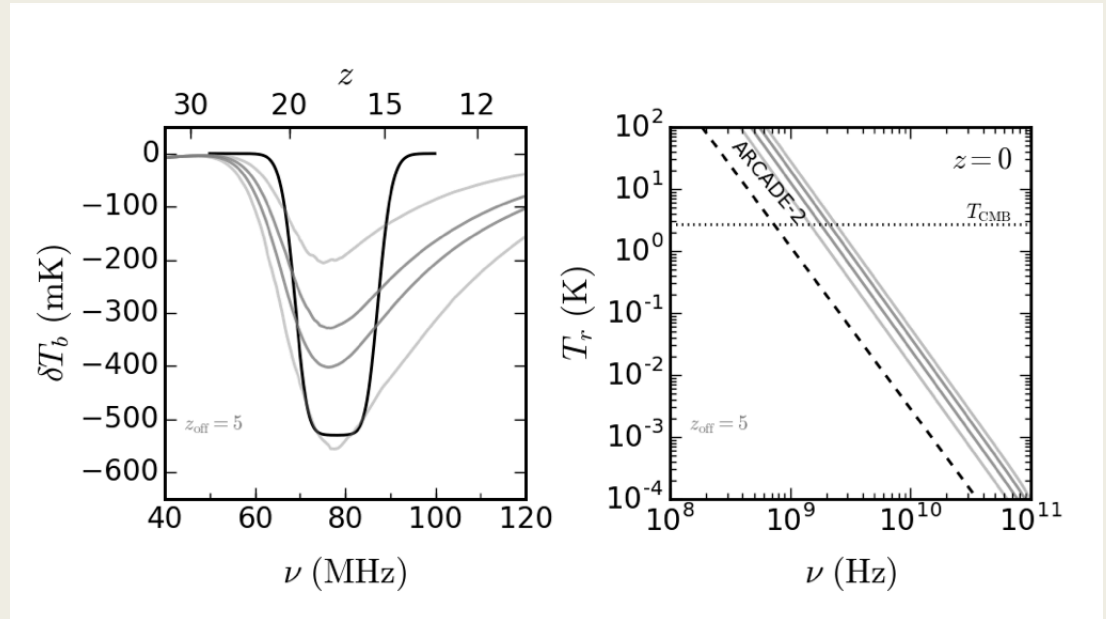


Mirocha & Furlanetto (2018)



# The Astrophysical Implications of EDGES

- Can we solve the amplitude problem as well with a self-generated radio background?
- NO, unless:
  - *Early stars produce radio ~1000x more efficiently than local stars (to get the amplitude)*
  - *The enhancement shuts off at  $z \sim 15$  (to get the shape)*



Mirocha & Furlanetto (2018)

# Goals for Year 2

- Test implications of EDGES for other source models
  - *Pop III, globular clusters, AGN*
- Complete integration of a new source model framework into 21cmFAST
  - *Will enable realistic Pop III AND Pop II models, plus combinations*
  - *Test effects of spatial variations (metallicity, ionization) on global Pop III evolution*
  - *Estimate the effects of Pop III on the 21-cm power spectrum*
  - *Provide targets for lunar radio observatories*
- Build analytic description of 21-cm power spectrum
  - *Enable combined constraints from 21-cm interferometers + other observables*
  - *Seek intuitive description of “Cosmic Dawn” signals*
- Build semi-analytic model of “normal” galaxies
  - *Incorporate realistic star formation, metallicity evolution, burstiness*
  - *Enable combined constraints of galaxy observables and 21-cm*