The 21 cm Frontier

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Outline

- What do bigger 21 cm instruments buy us?
  - Imaging
  - Statistical studies
  - Higher redshifts
  - Angular coverage
  - The 21 cm forest
- What other probes will we have?
  - Competition
  - Synergy

The 21 cm Signal

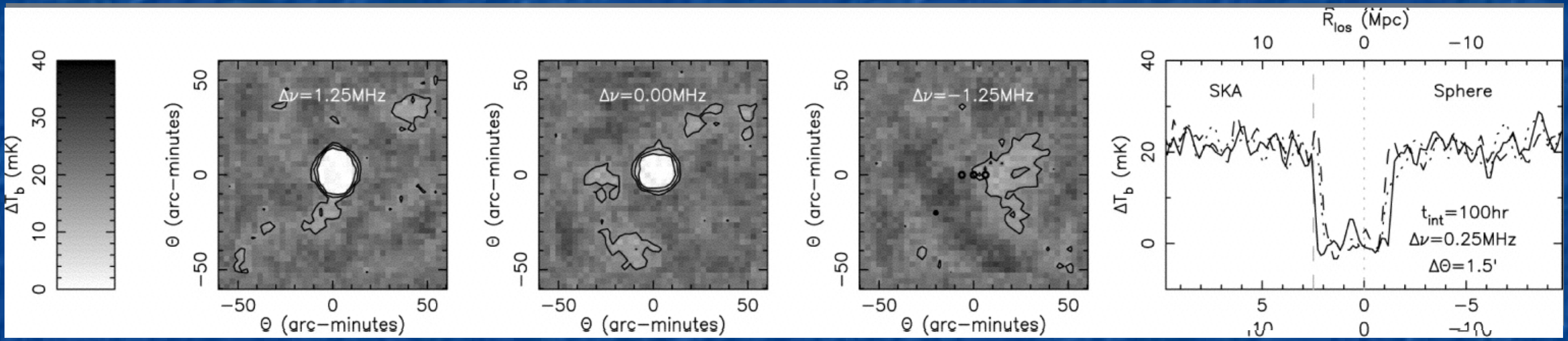
For movie, see

http://pantheon.yale.edu/~am834/

QuickTime™ and a
mpeg4 decompressor
are needed to see this picture.

Mesinger & Furlanetto (2007)

21 cm Imaging: Quasar HII Regions



Wyithe et al. (2005)

- First generation can (barely) detect structures with modest resolution
- SKA or SKA pathfinder can securely detect quickly

Future Directions I

- Better imaging
  - Quasars should become easy
  - Some imaging of “normal” reionization
  - More collecting area!
  - Longer baselines for higher angular resolution (1 arcmin = 2 Mpc)

Reionization from 21 cm Surveys

For movie, see
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mpeg4 decompressor
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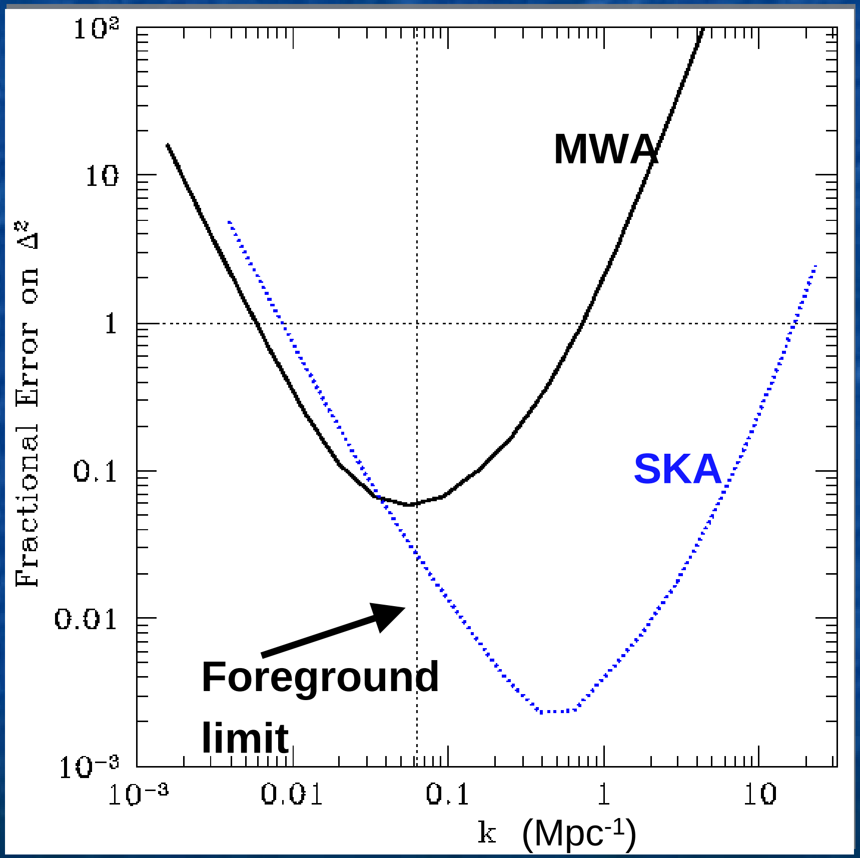
Mesinger & Furlanetto (2007)

Error Estimates: z=8



- Survey parameters
  - z=8
  - T_{sys}=440 K
  - t_{int}=1000 hr
  - B=6 MHz
  - No systematics!
- MWA (solid black)
  - A_{eff}=7000 m^2
  - 1.5 km core
- SKA (dotted blue)
  - A_{eff}=1 km^2
  - 5 km core
- LOFAR very close to MWA

Pushing to Smaller Scales

MWA

SKA

MWA

For movie, see

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QuickTime™ and a
mpeg4 decompressor
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SKA

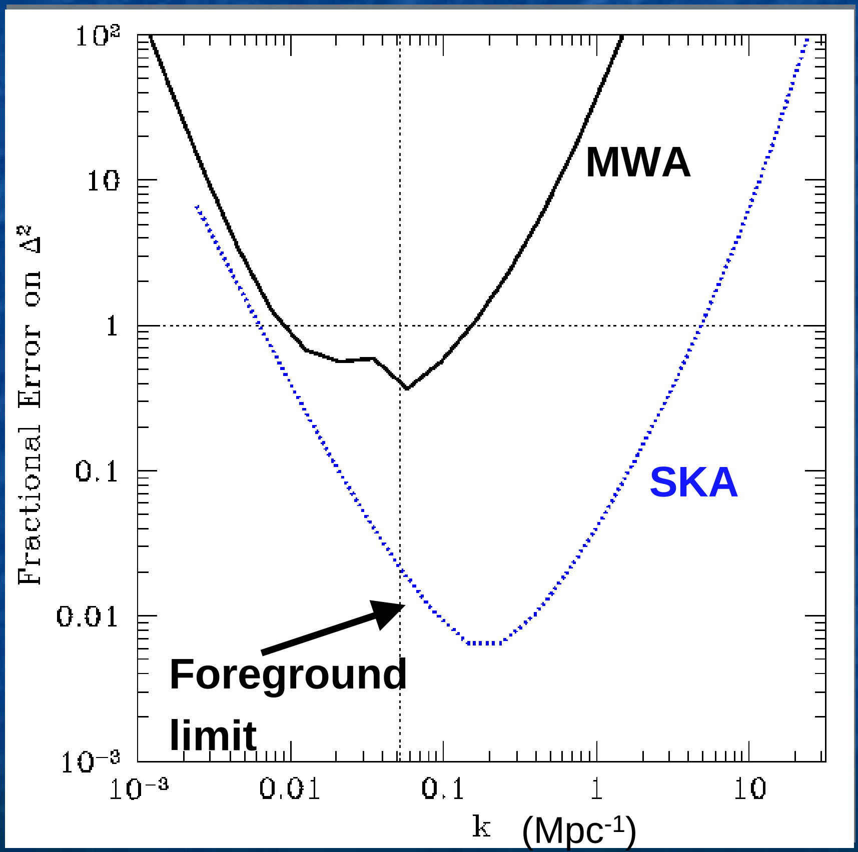
(Mpc^{-1})

Mesinger & Furlanetto (2007)

Future Directions II

- Better imaging
- Smaller scales
  - More detailed statistics
  - Dynamic range could be key for interpreting observations
  - More collecting area!
  - Longer baselines help (few km)

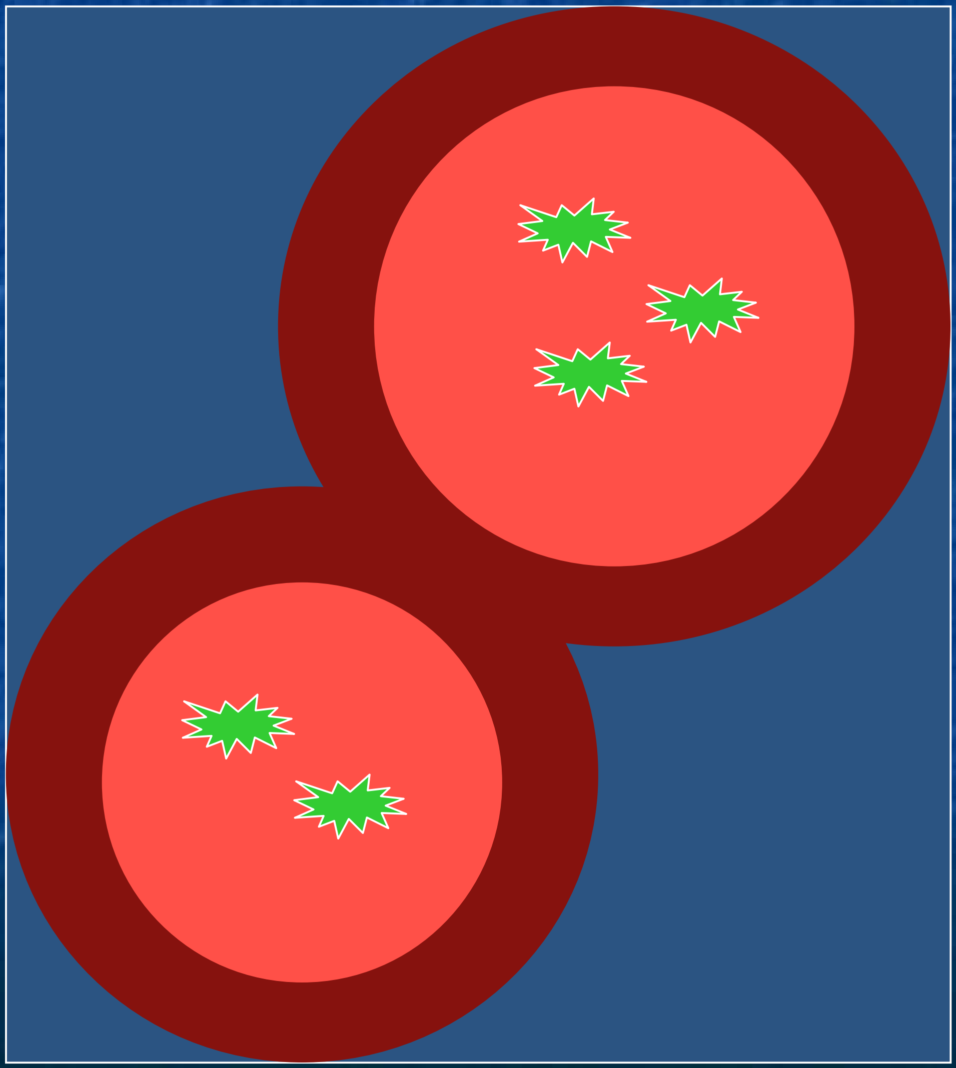
Error Estimates: z=12



- Survey parameters
  - z=12
  - T_{sys}=1000 K
  - t_{int}=1000 hr
  - B=6 MHz
  - No systematics!
- MWA (solid black)
  - A_{eff}=9000 m^2
  - 1.5 km core
- SKA (dotted blue)
  - A_{eff}=1 km^2
  - 5 km core

The First X-rays

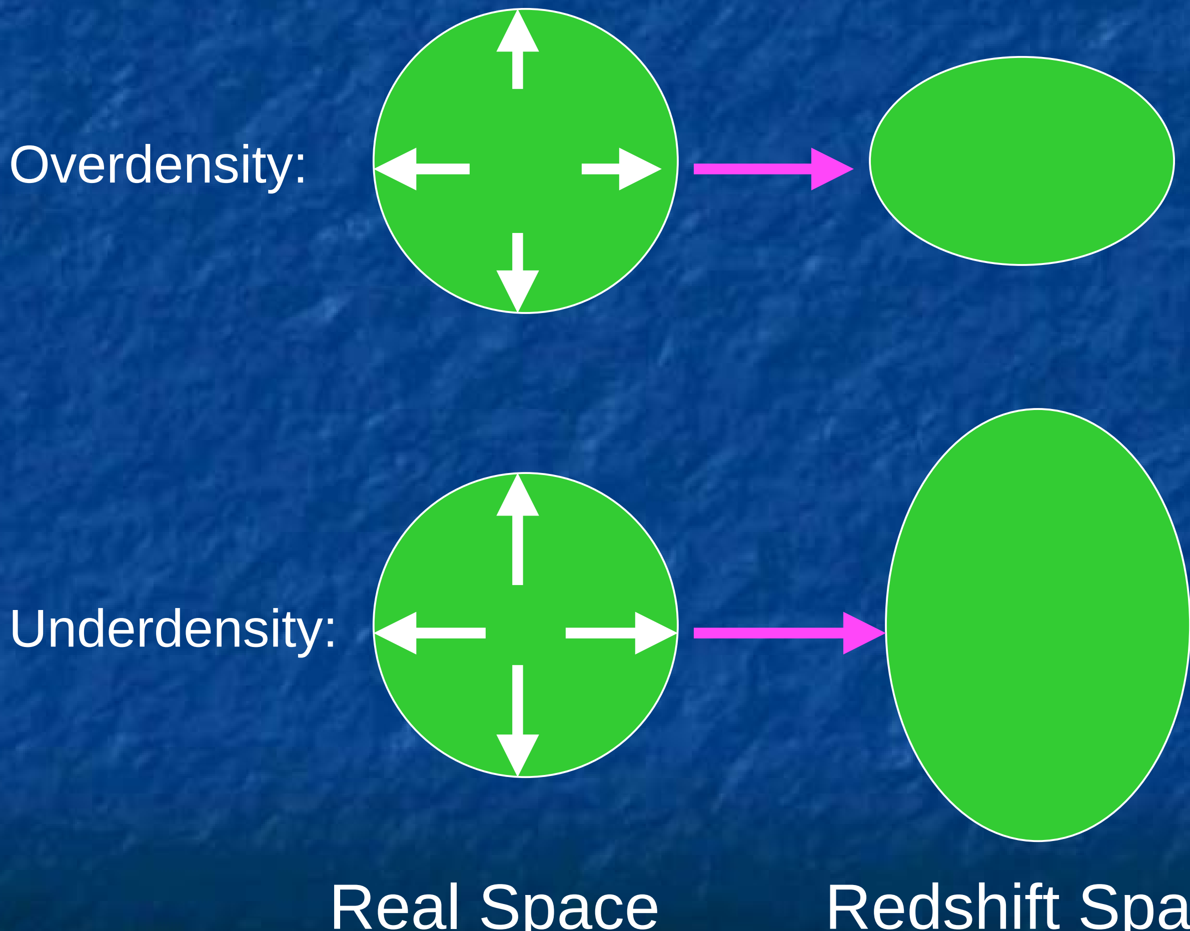
- X-ray photons heat gas near sources
- Hot IGM near dense gas, cool IGM near voids
- High contrast fluctuations!
- Map era of first quasars, stellar remnants, Pop III stars (?)



Future Directions III

- Better imaging
- Smaller scales
- Higher redshifts
  - Farther back in reionization, and first sources
  - More collecting area in compact core
  - Optimize design for lower frequencies

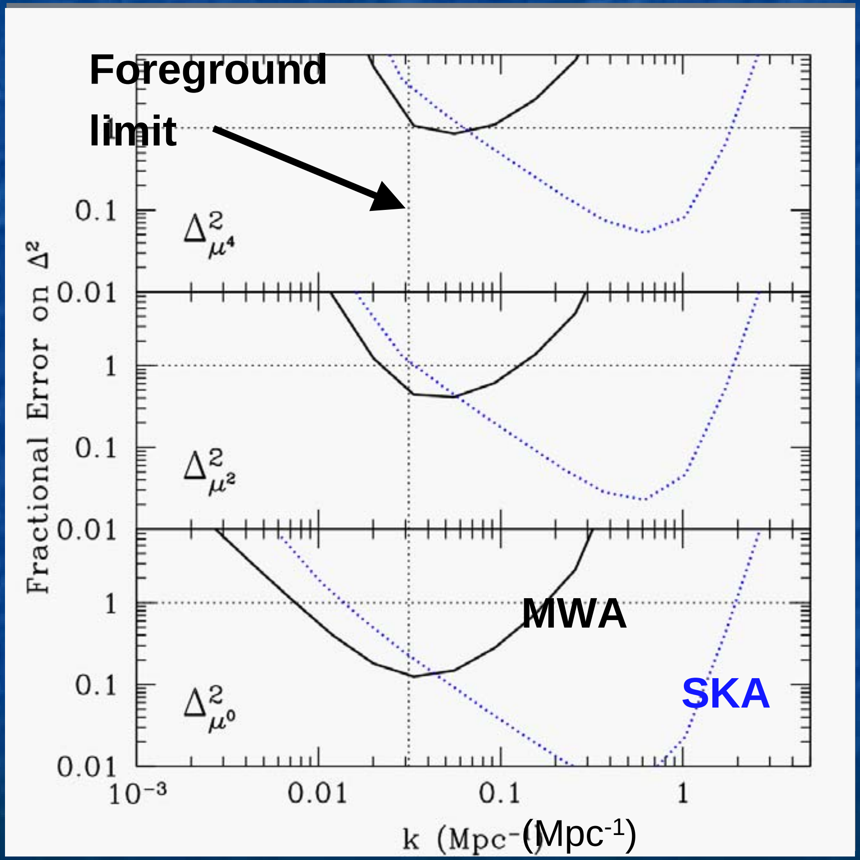
Redshift Space Distortions



Overdensities and underdensities are AMPLIFIED along line of sight.

Amplification depends on velocity (dark matter) and measures cosmology.

Anisotropies in the Signal



- Survey parameters
  - z=8
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- MWA (solid black)
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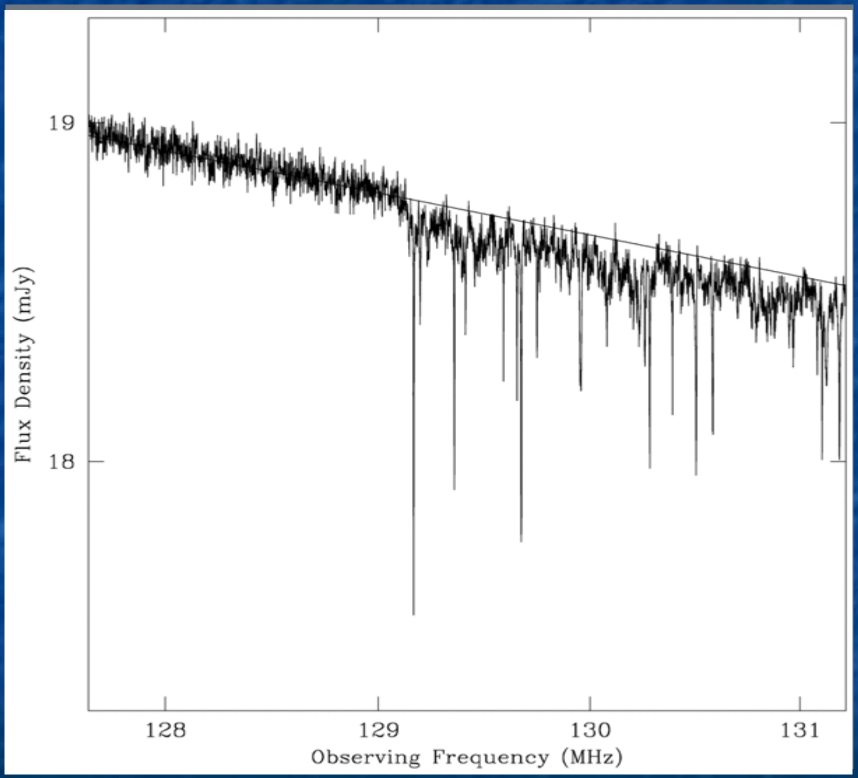
- LOFAR very close to MWA

Future Directions IV

- Better imaging
- Smaller scales
- Higher redshifts
- Redshift space distortions
  - More information, especially on “fundamental” cosmology
  - Requires long baselines

The 21 cm Forest

- Advantages
  - Probes individual features and objects
  - Can see the smallest-scale structure allowed to exist
  - No foregrounds
- Disadvantages
  - Requires high-z quasars!
  - Isolated lines of sight
  - Large collecting area



Carilli et al. (2002)

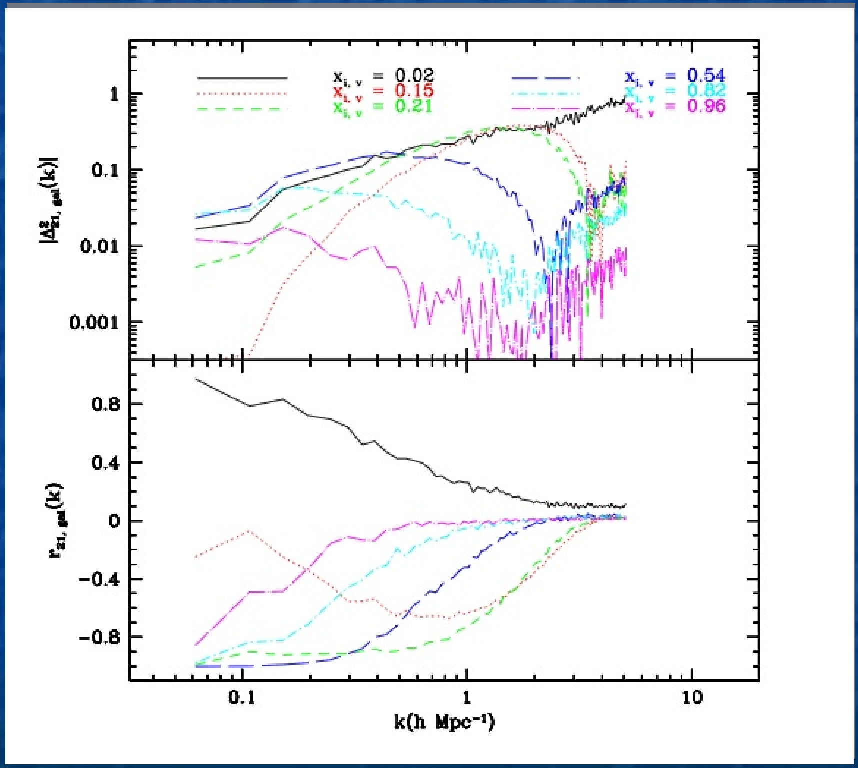
Future Directions V

- Better imaging
- Smaller scales
- Higher redshifts
- Redshift space distortions
- The 21 cm Forest
  - Unique small-scale information
  - Requires sources!
  - More collecting area

The Competition

- CMB: integrated measurements of reionization (ACT, SPT, Planck)
  - Will help pin down reionization redshift
- Quasar and GRB spectra
  - Best method so far, but potential may be limited
- Galaxy surveys: study sources, not IGM
  - Near-term: LAEs from ground-based cameras
  - Longer term: JWST, JDEM, TMT

The 21 cm-Galaxy Cross-Correlation



Lidz, Zahn, & Furlanetto (in prep)

- Can be done with LAEs or LBGs
- Significant advantages in 21 cm data analysis (SF & AL 2007)
- Challenge: wide-field near-IR surveys
  - JWST?
  - JDEM?
  - Ground-based cameras?

Conclusions

- MWA, LOFAR, PAPER are only the first steps. Improvements help with…
  - True imaging
  - Better statistics and dynamic range
  - Higher redshifts
  - Redshift space distortions
  - 21 cm forest?
- Most robust information may come from cross-correlation with other data sets (galaxies)
- Key questions:
  - Frequency coverage
  - Weighting small vs. large scales
  - Candidates for cross-correlation/21 cm forest
  - …and can we even do it?!?