Observing the Cosmic Dawn and Epoch of Reionization with the 21-cm line

Gianni Bernardi

What physics?

credit: Greig & Mesinger, see also Mesinger’s talk
21-cm cosmology observational requirements/challenges

1) Low frequency (< 200 MHz) interferometers with large collecting area $\rightarrow$ high brightness sensitivity, a lot of collecting area within a few km. SKA-low is tailored to measure the CD/EoR signal;
21-cm cosmology observational requirements/challenges

1) Low frequency (< 200 MHz) interferometers with large collecting area → high brightness sensitivity, a lot of collecting area within a few km. SKA-low is tailored to measure the CD/EoR signal;

2) Foreground separation/isolation;
Foreground separation/isolation

coldest regions are $\sim 100-200 \text{ K}$
Foreground separation/isolation

GB et al. (2009)
Foreground separation/isolation

$\delta T$ (mK) at $z=7.02$ (117 MHz) with [5',0.8 MHz]

Mellema et al. (2015)
A tale of 20 years…

LOFAR

MWA

PAPER
So far only upper limits... still some ground to cover...
... but with a recent, unexpected upturn!

Bowman et al. (2018), see also Braun’s talk
... but with a recent, unexpected upturn!

if the origin is cosmological (also see Spinelli’s talk) it needs a complete re-thinking of current models

Bowman et al. (2018)
Large-aperture Experiment to detect the Dark Ages (LEDA) or chasing the sky-averaged 21-cm signal from the Cosmic Dawn

- four V-inverted dipoles sensitive to the 21-cm emission in the $15 < z < 35$ range;
- custom built front-end for calibration;
- site: Owens Valley (CA);

GB, Greenhill & McQuinn (2015);
Price, Greenhill, Fialkov, GB et al. (2018)
LED A early results

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- custom built front-end for calibration;
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Price, Greenhill, Fialkov, GB et al. (2018)
LEDA current status
12-day averaged spectrum ($11 \text{ h} < \text{LST} < 12 \text{ h}$, effectively 4 hours on the sky):

$\sim$1.1 K residual rms

Room for improvement: add 10 more days (with broader LST range), improve the RFI rejection, + …
The Hydrogen Epoch of Reionization Array (HERA) or the next 21-cm cosmology interferometer

**Location:** S30° 34’, E21° 25’ E (South Africa)

**Configuration:** 331 hex-pack, 21 outriggers
- **Min baseline:** 14.6m (7.8° scale)
- **Max baseline:** 1066m (9’ beam)

**Array core:** 310m diameter

**Element:** 14m diameter (9° fov @150 MHz)

**Frequency**
- **Digitized:** 50 - 250 MHz
- **EOR band:** 100 - 200 MHz
- **Channel:** 97.7 kHz

\[ T_{sys} = 100 + T_{sky} \]
### HERA collaboration

<table>
<thead>
<tr>
<th>Aaron Parsons (PI)</th>
<th>Jonathan Pober</th>
<th>Steven Murray</th>
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<td>Zuhra Abdurashidova</td>
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<td>Gianni Bernardi</td>
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<td>Judd Bowman</td>
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<td>Rich Bradley</td>
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<td>Bryna Hazelton</td>
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<td>Jacqueline Hewitt</td>
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<td>Jack Hickish</td>
<td>Saul Kohn</td>
<td>Zak Martinot</td>
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<td>Abraham Neben</td>
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<td>Adrian Liu</td>
<td>Matt Kolopanis</td>
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<td>Paul La Plante</td>
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<td>Andrei Mesinger</td>
<td>Juan Mena Parra</td>
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<td>Miguel Morales</td>
<td>Jordan Mirocha</td>
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### HERA specs

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<th>Instrument Design Specification</th>
<th>Observational Performance</th>
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<tr>
<td>Element Diameter: 14 m</td>
<td>Field of View: 9°</td>
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<tr>
<td>Minimum Baseline: 14.6 m</td>
<td>Largest Scale: 73.8</td>
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<td>Maximum Core Baseline: 292 m</td>
<td>Core Synthesized Beam: 25′</td>
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<tr>
<td>Maximum Outrigger Baseline: 876 m</td>
<td>Outrigger Synthesized Beam: 11′</td>
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<td>EOR Frequency Band: 100–200 MHz</td>
<td>Redshift Range: 6.1 &lt; z &lt; 13.2</td>
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<tr>
<td>Extended Frequency Range: 50–250 MHz</td>
<td>Redshift Range: 4.7 &lt; z &lt; 27.4</td>
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<td>Frequency Resolution: 97.8 kHz</td>
<td>LoS Comoving Resolution:</td>
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<td>Survey Area: (\sim 1440 \text{ deg}^2)</td>
<td>1.7 Mpc (at (z = 8.5))</td>
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<tr>
<td>(T_{\text{sys}} = 100 + 120(\nu/150\text{MHz})^{-2.55}) K</td>
<td>Comoving Survey Volume: (\sim 150 \text{ Gpc}^3)</td>
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<td>Sensitivity after 100 hr:</td>
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<td>50 (\mu\text{Jy beam}^{-1})</td>
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**Note.** Angular scales computed at 150 MHz.
HERA at the SKA SA site
HERA at the SKA SA site
Highly redundant configuration to boost sensitivity on selected 21-cm modes,
A number of outriggers to aid foreground modelling and calibration
HERA constraints on CD/EoR

Greig & Mesinger (2016)
'Gold Sample' constraints
HERA + Planck priors
With 25% modeling error on $P_{21}(k)$
Lyman-$\alpha$ emission fraction
Quasar near zone
Lyman-$\alpha$ galaxy clustering
Dark Lyman-$\alpha$ forest pixels

Observed Frequency (MHz)

$\Delta^2$ (mK^2)

Redshift $z$

Fiducial Model
CDM Annihilation
Large Halos
HERA-350

deBoer et al. (2017)
Early science has started...
... including foreground separation/isolation

Foreground dominated modes (coherent emission on tens of MHz scales $\rightarrow$ small k modes along the line of sight)

“Foreground free” (EoR) region
and modelling systematic effects
Conclusions

1) We are actively pursuing a confirmation (or lack) of the anomalous global 21-cm signal claimed by EDGES: hopefully an answer in the next few months;

2) HERA (the most sensitive 21-cm SKA precursor) is coming online: upper limits appearing in 2019 (?);

3) The Italian CD/EoR community is still small but very active;

4) The measurement of the 21-cm signal from the CD/EoR is where SKA-low will really be transformational, probing a redshift range inaccessible to any other probe;