HI intensity mapping

David Alonso – Oxford Astrophysics

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The 21cm signal

- Hyperfine transition
- Strongly forbidden
  \[ t_{1/2} \approx A_{01}^{-1} = 1.11 \times 10^7 \, \text{y} \]
- A 3D tracer of neutral hydrogen
  \[ \nu = \frac{\nu_{21}}{1 + z} \]
  \[ dL = \frac{3}{4} A_{10} h \nu_{21} n_{\text{HI}} \phi(\nu) \, d\nu \, dA \, dr \]

\[ T_{21}(z, \hat{n}) = (0.19055 \, \text{K}) \frac{\Omega_b \, h (1 + z)^2 \, x_{\text{HI}}(z)}{\sqrt{\Omega_M (1 + z)^3 + \Omega_\Lambda}} \frac{1 + \delta_{\text{HI}}}{\sqrt{\Omega_M (1 + z)^3 + \Omega_\Lambda}} \]


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Neutral hydrogen in the Universe

- 21cm is ideal to study the physics of the EoR and the Dark Ages.
- At late times the Universe is ionized. HI inside galaxies (DLAs).

✔ Spectrally isolated
✔ Small obscuration
✔ Signal grows with $z$

✗ Difficult to observe many individual objects
→ Intensity mapping

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Intensity mapping

- Large pixels: joint emission from multiple galaxies instead of resolving them.
- We only care about large scales
- “Cheap” way to observe large volumes
Cosmology with intensity mapping

- Forecasts: constraining power competitive with largest redshift surveys.
Cosmology with intensity mapping

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Bull et al. 1405.1452

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Ultra-large scales

Ultra-large scale cosmology

- Primordial non-Gaussianity

\[
\Delta b_M(k, f_{NL}) = f_{NL} [b_M(k, 0) - 1] \frac{3\delta_L \Omega_m H_0^2}{c^2 k^2 T(k) D(z)}
\]

Camera et al. ArXiv:1305.6928

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Ultra-large scales

Ultra-large scale cosmology

- GR effects in LSS

\[ \Delta_N = \delta_n - \frac{1}{\mathcal{H}} \frac{\partial v_r}{\partial \chi} + (5s - 2) \left[ \kappa - \frac{1}{\chi} \int (\phi + \psi) d\eta \right] + \]
\[ \left[ \frac{2 - 5s}{\mathcal{H} \chi} + 5s - \frac{\partial \ln(a^3 \bar{n})}{\mathcal{H} \partial \eta} + \frac{\mathcal{H}'}{\mathcal{H}^2} \right] \left[ \psi + \int (\dot{\phi} + \dot{\psi}) d\eta - v_r \right] + \]

Bonvin & Durrer, arXiv:1105.5280
Challinor & Lewis, arXiv:1105.5292
Hall, Bonvin & Challinor, arXiv:1212.0728

PRELIMINARY!
Radio foregrounds

Extragalactic foregrounds:
- Point sources
- E.G. free-free

Galactic foregrounds:
- Synchrotron (I,Q,U)
- Free-free
- Dust

Earth:
- Atmosphere: clouds, H2O, ionosphere
- RFI

Instrument:
- Spillover
- Gain fluctuations
- Beam fluctuations
- Polarization leakage
Radio foregrounds

Galactic synchrotron

Haslam 1982
408 MHz map

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Radio foregrounds

Instrumental effects:
- Beam convolution
- Polarization leakage
- Noise


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Intensity mapping simulations

Foregrounds will have an important effect on the recovered IM signal.

- The foreground-cleaned measurements will probably be biased → transfer function must be accurately characterized.
- Foreground subtraction will induce extra variance in the power spectrum.
- It could also affect the correlation structure of the measurements.
- The performance of different cleaning methods must be studied.
Blind foreground subtraction

- Blind methods: minimize assumptions about foregrounds $\rightarrow$ foregrounds are $\nu$-smooth

- Blind source equation

$$T(\nu, \theta) = \sum_{k=1}^{N_{fg}} f_k(\nu) S_k(\theta) + T_{\text{cosmo}}(\nu, \theta) + T_{\text{noise}}(\nu, \theta)$$

$$x_i = T(\nu_i, \theta), \quad A_{ik} = f_k(\nu_i), \quad s_k = S_k(\theta)$$

- Methods: LOS fitting, PCA, ICA

Blind foreground subtraction

Signal+FG

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Signal only

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Cleaned map

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 Blind foreground subtraction

Most important features still observable! (BAO, shape...)

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Blind foreground subtraction

Bias and variance of the recovered power spectrum

- Radial scales:
  - Significantly larger contamination on large scales (dominated by foregrounds)
  - Larger variance on large scales

- Angular scales:
  - Bias ~ 20% of errors
  - Uncertainties increased by ~20%
  - Similar bias across all scales

Overall: equivalent results found for all methods
Conclusions

• Intensity mapping is a potentially powerful cosmological probe.

• Forecasts show it to be competitive with next-generation redshift surveys.

• IM gives us access to extremely large volumes, and allows us to study cosmology on ultra-large scales.

• Relativistic contributions could be difficult to detect.

• Observational challenges: huge (10^5) galactic and extragalactic foregrounds.

• Computational challenges: fast simulations to study errors, systematics, model independence...

• Blind foreground subtraction: simplest but efficient methods.

• For smooth foregrounds, main cosmological observables are preserved.

• Instrumental effects (beam, polarization leakage) may be a lot more important.
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Obrigado! ¡Gracias!