

Cosmological Reionization Summary Talk, HRI 2010

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for Andrea who is now too senior to still be around at the conclusion of the conference

Image: Paul Geil

Things We (think we) Know About Hydrogen Reionization

- ΛCDM cosmology plus hierarchical structure formation
- Photo-ionization provided the ionization mechanism, as evidenced by the Ly α forest
- Stars rather than quasars provided the ionizing photons, at 6<z<20



Recurring themes (this week & last)

- Reionization history. Using observations to tie down ionized frac.
 - constraints from the Ly-alpha forest and CMB
- The photon crisis. Are there enough photons to reionize the Universe at a redshift > 6?
 - photon starved reionization
 - halo mass of detected LBGs at z>6 and faint end slope
 - escape fraction
- Role of feedback. What is the "self regulation" of reionization?
 - chemical
 - mechanical
 - radiative

- Progress in simulation
 - Large boxes, many particles
 - The rise of realistic galaxy models
 - enrichment
 - Ly-alpha galaxy models

Nearly Absent themes (this week & last)

• Models of 21cm fluctuations

- Exotic processes in the early Dark Ages effect the 21cm statistics and spectrum. Decaying Black-holes, cosmology and Dark-Matter
- However: Attempts and techniques for detecting fluctuations over cosmic time, and for identifying individual features in 21cm intensity cubes





Ionizing Background Sources

- Given priors on the evolution of the QLF and SFH, and spectra, fit for the superposition quasars+stars that satisfies the IGM constraints
- Quasars:
 - Hopkins et al. (2007) luminosity function
 - $\Rightarrow \alpha_{QSO} = 1.6$ (Telfer et al. 2003)
- Stars:
 - star formation tracing Hernquist & Springel (2003) model
 - α_{*}=1 at 1-4 Ryd, no emission beyond
 4 Ryd (Kewley et al. 2001)





Reionization History



Throw all observations at detailed model and make predictions

Choudhury & Ferrara 2008

Reionization History: new constraint I

Recent z~6 C IV results

Number density and mass density of C IV both decline sharply at z > 5.4



Reionization History: new constraint II

Reionisation around J0818+1722



Reionization History: new constraint III?



Reionization History: Future constraints?

Principle components of the reionization history with precise CMB maps from Planck

 Hyperfine ³HeII is complementary to HI during reionization. In particular the HeIII fraction will provide information on the spectrum of the sources responsible

• Tomography at higher radio frequencies with lines of CO will trace the star formation during reionization and afterwards

• Metalicity distribution for metal poor stars (probe 1st generation?)

Photon Crisis

Implications for ionising sources

Constraints range from ~6 - 30% of required emissivity at z>6



Photon Crisis

- Semi-analytic models tuned to follow the Pop-III to Pop-II transition produce a steep faint end slope (Ferrara)
- Combination of galform with Simplex also produces a very steep faint end slope



- Analytic model histories require low mass halos and feedback to extend reionization -> most photons come from low mass galaxies
- F_{esc} remains very hard to model and could be between zero and one for these small galaxies (Paardekooper, Fernandes, others)
- Importance of galaxy structure during starburst.
- Dust IMF etc must change faster than density for escape at high z

Photon Starved?



Feedback

- Feedback not as strong as expected from energetic considerations
- The range of masses generally effected 10^5 10^8 solar masses
- Negative feedback in the same object as star formation as well as in neighbouring objects
- SN can provide positive feedback where star formation is not central in the halo
- Metals from the first stars responsible for chemical feedback



 Galaxy formation in GIMIC appears more sensitive to feedback physics than SF prescription

Large-Scale Simulations of Reionization

[Iliev et al. 2006a, 2007a; Mellema, Iliev, et al. 2006; and in prep.]

N-body: CubeP³M 1728³-3072³ part. (5.2 to 29 billion) or more -4000³-5488³ (64-165 billion) density slices velocity slices halo catalogues-sources Scales well at least up to 21,952 cores

35-114/h Mpc (CubeP³M) resolving 10⁸ M_{str} halos up to 21 x 10⁶ sources 50-100 dens. snapshots simple source models sub-grid clumping no hydro – large scales. -C²-Ray code (Mellema, Iliev, et al. 2006) radiative transfer • noneq. chemistry • precise • highly efficient • coupled to gasdynamics • massively parallel (scales well up to 10,240 cores).

Coupled to hydro

Contrast with Large-Scale Structure



http://www.mpa-garching.mpg.de



http://www.cfa.harvard.edu/

- N-body simulations provide a solution to a well posed problem. The source of the structure is gravitation
- Simulations of reionization are less well posed. We do not understand the sources of the structure
- It was asked "if we had a 21cm PS, would the reionization history be understood?" I would say the answer is no.

Modeling of Reionization

- With respect to ionized structure, reionization modelling has yielded the following "solid" results
 - HII regions form preferentially in overdense regions
 - HII regions form around clustered sources
 - The HII region volume function
 - The relation between HII region size and neutral fraction
 - The generic shape of the 21cm power spectrum
 - The PDF of 21cm intensity fluctuations is non-gaussian
 - Ly-alpha forrest plus CMB data calls for some combination of radiative feedback or evolution in IMF/escape fraction
- Detailed numerical simulation are needed to make quantitative predictions and to interpret precise observational data, but each of these was found from analytic models

New Progress in Numerical Simulations I

Six orders of magnitude in length scale



- The frontier is to use what is known about galaxies where there are observations to model the sources of structure in the reionization era
- Also heard about SimpleX2 program to couple radiation transport in a gas medium with dust and cooling, soon to be coupled with hydrodynamical evolution

New Progress in Numerical Simulations II

Encode information about high-z galaxies Metals and galaxy/IGM interactions star formation, winds, stellar Metal Density populations... Absorption lines can be markers for galaxies too faint to image Reionization probe (Oh 2002) * OI, CII, Si II C II Column Density C IV Column Density $0 \leftrightarrow H$ charge exchange: $\Delta E(OI) \approx \Delta E(HI) \longrightarrow f_{OI} \approx f_{HI}$ Joint constraint on enrichment & Oppenheimer+ 09 ionization MUST MEASURE HIGH AND LOW-IONIZATION SPECIES

 Simulations start to probe the importance of winds on galaxy formation, particularly with respect to feedback on star formation via ejection and enrichment

George Becker -- KICC

New Progress in Numerical Simulations III



- Gadget plus pop-synthesis and RT to look at Ly-alpha LF
- Also: Ly-alpha studies beyond case-B and observed large EW

Conclusion

• This has been a very enjoyable meeting where I learned a lot

Thanks to Jasjeet, Tirth and HRI from all of us