DARK MATTER AND BLACK HOLES

Neta Bahcall (Princeton U., USA):
Lighting Up The Dark: Where Is The Dark Matter?

How is Dark Matter distributed in the Universe? How does it relate to the observed distribution of light, stars, and baryons? These questions are examined using gravitational lensing and other observations that trace the distribution of mass in the Universe from small to large scales and reveal the connection between the dark and bright side of the Universe.
While the halos of dark matter around galaxies show an observed mass distribution that is considerably more extended than that of light, this trend changes on larger scales, where the mass, light, and stars trace each other remarkably well. This indicates the 'edge' of the dark matter distribution. The results further suggest that most of the dark matter in the Universe may be located in large halos (~300 Kpc) around galaxies, with no significant increase in the dark matter component on larger scales. The mass of groups, clusters, and large scale structure appear to be mostly made up by the total mass of the individual galaxy members, including their extended halos, plus gas. We find that the stellar mass fraction is constant on these large scales, with stars comprising only about one percent of the total mass.
How can stars follow the total mass so well? And where are the rest of the baryons? The connection between baryons, stars, and mass on these scales will be discussed, as well as the implications for cosmology, galaxy formation, and the mass-density of the universe.

Jerry Ostriker (Columbia U., USA):
Choosing the nature of dark matter to address small scale structure dramatically changes early galaxy formation

The standard LCDM paradigm has been phenomenally successful on many fronts. In particular, all predictions with respect to the overall cosmology and structure on large scales have proven accurate. But on small scales - kilo parsecs and less – the hierarchical model has been neither confirmed nor refuted. For example, dark matter cusps are predicted, but observations do not strongly confirm the predictions. With L, Hui, S. Tremaine, and E. Witten an exploration is under way concerning the possibility that very light axions provide the bulk of the dark matter. This choice would strongly smooth out small scale structure due to standard quantum effects and in addition would strongly suppress early formation of low mass halos and small galaxies. Thus predictions for “first light” provide strong tests of this cosmological model. In it the peak formation epoch of low mass halos (eg 10^8 Msolar) and the corresponding galaxies is later than in the standard LCDM model.

Zoltan Haiman (**Columbia U., USA**):
Forming massive seed black holes at high redshift

I will discuss a plausible scenario, in which a 10^5 Msun seed black hole can form at high redshift. This requires the synchronized formation of a pair of pristine atomic-cooling halos. The first halo to surpass the atomic cooling threshold forms stars. Soon after these stars are formed, the other halo reaches the cooling threshold – but due to its proximity to the first galaxy, it is exposed to the critical LW intensity required to prevent H2-formation and efficient fragmentation. We have found in N-body simulations that synchronized halo pairs are rare, but when subhalos are also included, they arise sufficiently frequently to account for the bright z=6 quasars. I will also show results from recent simulations to argue that the hyper-Eddington accretion flow in the nucleus of these proto-galaxies is not slowed down by radiative feedback, and can ultimately result in a 10^5 Msun seed BH remnant. I will argue that fragmentation is also not an obstacle to this scenario.

Tal Alexander (**Weizmann Institute, Israel**):
Supra - exponential growth of seed black holes in the early universe

I describe how the dynamics of a O(10 Mo) black hole in a compact stellar cluster embedded in a dense cold flow at z > 15 can launch a phase of supra-exponential growth that produces a >>10 Mo BH seed in O(10^7 yr).

Tom Broadhurst (**Ikerbasque, Spain**):
Comparison of the latest Hubble Data with the First Simulations of Bosonic Dark Matter for the "No - WIMP Era"

Our new cosmological simulations of light bosons in the ground state reveal an unknown world of standing waves that distinguish this cold, wave-like form of CDM from standard particle CDM. Key predictions are verified with the Hubble Frontier Fields, and with local dwarf galaxy cores and QSO flux anomalies. This exploration is timely because of the continued laboratory absence of WIMPs, and may establish light bosons, like axions, as the most viable interpretation of dark matter.

HIGH-REDSHIFT GALAXIES

George Becker (**University of California, Riverside**):
Reionization: What We Know From Quasar Absorption Lines

In the past few years, the favored picture of hydrogen reionization has become one in which reionization ended fairly late (z=6-7) and was primarily driven by star-forming galaxies. The field is far from a consensus, however, and a broad range of models are still plausible. I will review what quasar absorption lines tell us about the intergalactic medium (IGM) long after, just before, and potentially during the reionization epoch. Improved measurements of the ionization and thermal state of the IGM over a wide range in redshift promise to place strong constraints on when reionization occurred and the nature of the sources responsible.

Mia Bovill (**STScI, USA**) [**replacing Massimo Stiavelli**]:
Detecting First Light with the JWST

Detecting First Light with the JWST Abstract: We will present an overview of the JWST and its capabilities for direct observations of the epoch of the first galaxies. We will present an overview of predictions for the observed distribution and number density of directly observable Pop III and Pop II star clusters and black holes. Finally we will discuss candidates for the z=0 counterparts of these high redshift systems.

Jaiyul Yoo (**U. of Zurich, Switzerland**):
Relativistic Effect in Galaxy Clustering as A Novel Probe of Cosmology

Precision measurements in current and future galaxy surveys bring in new challenges, demanding substantial advances in theoretical modeling. I will discuss the recent theoretical advances in formulating galaxy clustering in a general relativistic context. The relativistic effect in galaxy clustering or the deviation from the standard Newtonian description becomes substantial on large scales, in which modified gravity theories deviate from general relativity and the fingerprint of the inflationary epoch remains in its pristine form. At higher redshifts probed by 21cm observations, the relativistic effect is more important as the scales probed is larger and the horizon size is smaller. I will discuss how the subtle relativistic effect in galaxy clustering can be used to test general relativity and probe signatures of the early Universe. Finally, I will present future applications to 21cm cosmology.

Tommaso Treu (**UCLA, USA**):
The first galaxies through a magnifying GLASS

Ly alpha emission is a powerful probe of the physics of galaxies and the intergalactic medium at the epoch of reionization. I will present results from an unprecedented study of Lyman alpha emitters at z>~7 based on slitless grism spectroscopy obtained with the Hubble Space Telescope as part of the Grism Lens-Amplified Survey from Space (GLASS). By virtue of the gravitational lensing magnification produced by foreground clusters of galaxies, GLASS can efficiently look for Lyman alpha emission in hundreds of galaxies at z>7 (detecting Lyman alpha in 20-30), as well as provide the first measurements of its spatial extent.

Rogier Windhorst (**Arizona State, USA**):
HST Observations of Escaping Lyman Continuum Radiation from Galaxies and Weak AGN at 2.3 < z < 5: (How) Did they Reionize the Universe, and what JWST must do next

Co-I's: Brent Smith, Seth H. Cohen, Rolf A. Jansen, Linhua Jiang, Mark Dijkstra, Akio Inoue, Anton M. Koekemoer, Richard, Bielby, John W. MacKenty, Robert W. O'Connell, Joseph I. Silk

We present observations of the Lyman Continuum (LyC) radiation that may be escaping from galaxies and weak AGN with reliably measured spectroscopic redshifts at z=~2.3-5. For this, we analyzed reprocessed Hubble Space Telescope (HST) Wide Field Camera 3 (WFC3) and Advanced Camera for Surveys (ACS) mosaics of the Early Release Science (ERS) field in four filters that sample LyC over this redshift range. With our best current assessment of the WFC3 and ACS systematics, we find that the LyC emission of faint galaxies at < z > ~= 2.37, 2.68, 3.47, and ~5.0 is generally detected at the >3--4-sigma level, in typical image stacks of 10-37 objects in the WFC3/UVIS F225W, F275W, F336W, and ACS/WFC F435W filters, respectively. Their measured signal corresponds to total LyC fluxes of AB~29.5-30.7 mag. The LyC flux of weak AGN is typically ~1 mag brighter levels at z~=2.3-4.8, but averaged over 4--10x fewer objects per stack. The stacked galaxy LyC light-profiles are much flatter than their UV-continuum profiles at radii r ≤ 0.7". Their weighted-average LyC light-profile is significantly non-centrally concentrated over this redshift range, which may be explained by a radial dependence in the ISM porosity at 2.3 < z < 5.

With SED-fitting of the UV-continuum longwards of Lya, the observed LyC flux corresponds to an average LyC escape fraction of f_{esc}=0.1-18% at z=2.3-3.5, while increasing to possibly ~100% at z > 4.35. The available data for galaxies are bounded by a trend with z of f_{esc} = (0.006+/-0.002) x $(1+z)^{\{1.5+/-0.7\}}$. However, a better description seems to be a more sudden, larger increase inf_{esc} with redshift that occurred around z = 3, which we suggest is due to dust accumulating in (massive) galaxies as they grow with cosmic time. Our best fits of f_{esc} (z) suggest that galaxies collectively may have measurably contributed to maintaining cosmic reionization at redshifts z>3--5, while (weak) AGN likely produced a significant fraction of the ionizing LyC flux at z ~< 2.5. Complete reionization at z < 6--7 may be further enabled by a steep faint-end of the galaxy luminosity function at higher redshifts, integration to very faint luminosities (M_{AB} = -14 mag), and possibly also that f_{esc} increases at fainter luminosities and lower metallicities at higher redshifts than can be sampled with the current data. Last, we address how JWST NIRSpec and FGS+NIRCam grism spectroscopy will be critical to significantly expand on this work.

http://www.jwst.nasa.gov/ or http://www.asu.edu/clas/hst/www/jwst/

Paul Shapiro (U. of Texas at Austin, USA):
Simulating Reionization and Its Observable Consequences

I will summarize recent progress in modelling the epoch of reionization by large-scale simulations of cosmic structure formation, radiative transfer and their interplay, which trace the ionization fronts that swept across the IGM and ionized it, to predict observable signatures of this process. Reionization feedback affected the evolution of galactic sources, thereby impacting reionization, itself. Star formation suppression, for example, may explain the observed underabundance of Local Group dwarfs relative to N-body predictions for Cold Dark Matter. With this in mind, I will describe the first fully-coupled radiation-hydrodynamical simulation of the reionization of the Local Universe, in a volume large enough to model the global history of cosmic reionization and with enough resolving power to follow the formation and evolution of all the atomic-coolinggalactic halos in that volume. A representative box of size 90 Mpc on a side is filled with atomic gas and dark matter with initial conditions derived from a constrained realization of the Gaussian-random primordial density and velocity fluctuations chosen to reproduce the observed features of the Local Group, including the Milky Way and M31, and the local universe beyond, including the Virgo and Coma clusters. The RAMSES-CUDATON hybrid CPU-GPU code was used to perform this simulation on the Titan supercomputer at Oak Ridge National Laboratory, with 4096-cubed N-body particles for the dark matter and 4096-cubed cells for the atomic gas and ionizing radiation. The simulation is called CoDa, for "Cosmic Dawn".

Dominique Aubert (Observatoire Astronomique de Strasbourg, France):
« Looking at » galaxy populations during the reionization using cosmological simulations

Using the newly developed cosmological code EMMA, we produced several large simulations of the reionization that satisfy simultaneously constraints on the cosmic SFR, ionization history and luminosity functions at $z > 6$. We will present the properties of the atomic cooling galaxies produced in such models (UV Magnitude, Stellar and baryonic content, escape fraction). We will also discuss the sensitivity of these results on the assumptions made on e.g. the stellar populations properties.

RADIATIVE EMISSION OR ABSORPTION

Marc Kamionkowski (Johns Hopkins U., USA):
Intensity mapping with CO (and other) lines

Martin Haehnelt (U. of Cambridge, UK):
Probing the end of hydrogen reionization with Lyman-alpha absorption

Lyman-alpha absorption in high-redshift QSO spectra is a key diagnostic for how hydrogen reionization proceeded. I will discuss implications of the rather large scales (>= 50cMpc) of observed large opacity fluctuations at $z > 5.5$ for the nature of the sources of ionising radiation.

Tzu-Ching Chang (ASIAA, Taiwan):
21cm Intensity Mapping

The redshifted 21-cm emission from neutral hydrogen has emerged as a powerful probe for large-scale structure; a significant fraction of the observable universe can be mapped in the Intensity Mapping regime out to high redshifts. At redshifts around unity, the 21-cm emission traces the matter distribution and can be used to measure the Baryon Acoustic Oscillation (BAO) signature and constrain dark energy properties. I will describe our HI Intensity Mapping program at the Green Bank Telescope (GBT), aiming at measuring the 21cm power spectrum at z=0.8. A 800-MHz multi-beam focal-plane array for the GBT is currently under construction in order to facilitate a large-scale survey for BAO and the redshift-space distortion measurements for cosmological constraints.

Asantha Cooray (**UC Irvine, USA**):
Near-Infrared Background and Anisotropies as a Probe of Reionization

I will discuss the use of optical/near-IR extragalactic background light and its spatial fluctuations as a probe of first light galaxies. I will summarize our existing program CIBER and results from Hubble, Spitzer and other datasets to measure IR fluctuations including first detection of a Lyman drop-out component with Hubble/ACS and WFC3. I will end the talk with a summary of capabilities on fluctuation measurements with SPHEREx, a small explorer that was selected for a Phase A by NASA recently.

Nathalie Mashian (**Harvard U., USA**):
Predicting the intensity mapping signal for multi-J CO lines in the early universe

We present a novel approach to estimating the intensity mapping signal of any CO rotational line emitted during the Epoch of Reionization (EoR). Our approach is based on large velocity gradient (LVG) modeling, a radiative transfer modeling technique that generates the full CO spectral line energy distribution (SLED) for a specified gas kinetic temperature, volume density, velocity gradient, molecular abundance, and column density. These parameters, which drive the physics of CO transitions and ultimately dictate the shape and amplitude of the CO SLED, can be linked to the global properties of the host galaxy, mainly the star formation rate (SFR) and the SFR surface density. By further employing an empirically derived *SFR-M* relation for high redshift galaxies, we can express the LVG parameters, and thus the specific intensity of any CO rotational transition, as functions of the host halo mass M and redshift z. Integrating over the range of halo masses expected to host CO-luminous galaxies, i.e. $M \geq 10^8 M_\odot$, we predict a mean CO(1-0) brightness temperature ranging from ~ 1 μK at z = 6 to ~ 0.2 μK at z = 10 in the case where the duty cycles of star formation and CO luminous activity are assumed to be 0.1 ($f_{UV} = f_{duty} = 0.1$). In this model, the CO emission signal remains strong for higher rotational levels, with ~ 0.3 and 0.1 μK for the CO J = 10->9 transition at z = 6 and 10 respectively. If instead we adopt duty cycles of unity, the estimated CO(1-0) brightness temperature declines to $< T_{CO} > \sim 0.6$ μK at z = 6 and ~ 0.03 μK at z =10 respectively; the correspondingly reduced signal strengths of the higher J lines make detection of these transitions at high significance less likely in the $f_{UV} = f_{duty} = 1$ model.

Andrei Mesinger (**Scuola Normale Superiore, Italy**):
Lyman alpha emitters as a probe of reionization

The large cross-section of the Lyman alpha line makes it a sensitive probe of the ionization state of the intergalactic medium (IGM). Hence, the observability of Lya emission from galaxies is one of the most promising near-term probes of the as-yet uncharted Epoch of Reionization (EoR). Unfortunately, its utility is hampered by a lack of understanding of the intrinsic emission, as well as our inability to accurately model the IGM on the required range of scales. I will discuss how recent advances in multi-tiered EoR modeling and Bayesian EoR parameter estimation can be applied to interpreting observations of: (i) the drop in the fraction of color-selected galaxies with strong Lya emission; (ii) the clustering of high-z Lyman alpha emitters (LAEs); and (iii) the correlation of LAEs with the cosmic 21cm field.

Richard Ellis (**Caltech, USA**):
Spectroscopic Studies of Galaxies in the Reionization Era

Spectroscopy is a highly valuable tool for addressing outstanding questions in understanding the role that galaxies play in driving cosmic reionization. I will review recent progress in the use of Lyman alpha emission as a probe of the neutrality of the intergalactic medium, rest-frame UV metal lines as indicators of the ionizing spectrum and weak absorption lines as a proxy to the escape fraction of ionizing photons. With the approaching launch of JWST, these diagnostics collectively offer an important route to progress.

SIMULATIONS

Volker Bromm (U. of Texas at Austin, USA):
The Formation of the First Stars and Galaxies

I will review the emerging theoretical framework for the formation of the first stars and galaxies, discuss key open questions, and suggest strategies to test these ideas with upcoming observational facilities.

Gen Chiaki (U. of Tokyo, Japan):
Numerical simulations of low-metallicity collapsing gas clouds

The star formation in the low-metallicity gas clouds is investigated. The first (Pop III) stars formed in the cosmological minihalos without metal and dust are considered to be massive (10--1000 Msun). On the other hand, the present-day (Pop III) stars are relatively low-mass (1 Msun). It is considered that the typical mass scale of the stellar mass is reduced in the course of the metal and dust pollution of the gas in the early Universe. In order to define the critical metallicity and dust amount above which the first low-mass (Pop II) stars are formed, we estimate the mass of the stars formed in the clouds with various metallicities, employing the three-dimensional simulations. We set the realistic component of the heavy elements and size distribution of dust grains, which are taken from self-consistent calculations of a Pop III supernova. We also consider accretion of the gas-phase metal onto grains (grain growth) during cloud collapse. We employ a uniform cloud and three cosmological minihalos taken from Hirano et al.(2014) as initial conditions, enhancing metallicity up to 10^{-6} -- 10^{-3} Zsun, and follow their evolutions. As a result, the gas does not fragment in most cases with metallicities 10^{-3}--10^{-4} Zsun because the rapid gas heating owing to the formation of hydrogen molecules halts the gas elongation. We can observe that the gas fragments due to rapid dust cooling for one of four minihales for 10^{-5} Zsun.

Ilian Iliev (U. of Sussex, UK):
Radiative Feedback of the First Objects and its Effects on Galaxy Formation and the Detectability of the Epoch of Reionization

Simulations of the early structure formation and the Epoch of Reionization have now reached sufficient volume, dynamic range and resolution to make reliable predictions of the fundamental features and observable signatures of these epochs at the full range of relevant scales. I will summarise important recent progress we have made in this area, including performing a series of simulations of early structure formation on all scales from the tiny cosmological minihaloes hosting the very first stars up to very large volumes of hundreds of Mpc, with up 6912^3=330 billion particles, largest by far simulations of this epoch. We have derived a precise high-z halo mass function and scale-dependent halo clustering, directly useful for modelling the LOFAR and SKA sky. These structure formation simulations were used as basis for performing state-of-the-art radiative transfer simulations in volumes of up to $(714\ \mathrm{Mpc})^3$, comparable to the full volume of the LOFAR EoR experiment, but including all atomically-cooling ionizing sources. I will present simulations of the effects of small-scale structures (minihaloes and low-mass haloes, Lyman-Limit systems, local gas clumping) on the progress, properties and duration of reionization. I will discuss the best observational signatures, from point of view of the simulations, for using EoR radio observations to understand the nature of the ionizing sources.

I will also present the first results from the Cosmic Dawn simulation, the largest radiative hydrodynamics cosmological simulation to date with grid of 4096^3, ran on 8,192 GPUs+CPUs, combined with a suite of Adaptive Mesh Refinement, massively parallel radiative hydrodynamics simulations of reionization. Our simulations resolve and follow in detail the feedback effects of all star forming objects from the minihaloes hosting the first stars onward, including the effects from baryon-dark matter differential velocities. This allows us to address questions like what was the nature of the first sources, what is the post-reionization abundance and spatial distribution of satellite galaxies and globular clusters, how much such objects contributed to reionization and how radiative feedback influenced later galaxy formation and the intergalactic medium?

John Wise (Georgia Institute of Technology, USA):
Synthetic Observations of the First Galaxies

The HST campaign Frontier Fields will discover an even larger sample of galaxies at redshifts greater than 6. We present observational predictions for this high-redshift population, using the Renaissance Simulations, a suite of high-resolution cosmological simulations, that enables the correlation between key observables and the physical properties of the first galaxies in the universe. We utilize stellar population synthesis models, dust extinction using Monte Carlo methods, and photo-ionization modeling, all sourced from the simulation data, to obtain synthetic observations of the first galaxies. Using these results, we will be able to constrain the following properties of the first galaxies: (1) star formation histories and stellar populations, (2) nebular emission and dust extinction, and (3) the faint end of the luminosity function.

Garrelt Mellema (Stockholm U., Sweden):
The three-dimensional view of the redshifted 21cm signal from reionization

The redshifted 21cm signal from the cosmic dawn and epoch of reionization is a three-dimensional dataset which makes it extremely rich in properties but also challenging to analyse. In this talk I will present recent results on the use of redshift space distortions in the 3D 21cm signal for constraining the source properties of reionization and the reionization history, as well as a first exploration of how telescope noise affects our ability to determine the topology of ionized regions from 3D tomographic 21cm data.

Bradley Greig (Scuola Normale Superiore, Italy):
21CMMC: an MCMC framework for the astrophysics of reionisation

Currently, the astrophysics of the reionisation epoch is poorly understood. In order to quantify what we can learn about the reionisation astrophysics from current and future 21 cm experiments, we developed 21CMMC. This is a public, parallelised, MCMC analysis tool incorporating the EoR semi-numerical simulation code 21CMFAST. It can recover constraints on astrophysical parameters from current or future 21 cm EoR experiments, accommodating a variety of EoR models, as well as priors on individual model parameters and the reionisation history. By studying the resulting impact on the EoR astrophysical constraints, 21CMMC can be used to optimise: (i) interferometer designs; (ii) foreground cleaning algorithms; (iii) observing strategies; (iv) alternate statistics characterising the 21cm signal; and (v) synergies with other observational programs.

Stuart Wyithe (U. of Melbourne, Australia):
Modelling galaxy formation and reionization with DRAGONS

This talk will describe the Dark-ages Reionization And Galaxy-formation Observables from Numerical Simulations (DRAGONS) project which combines N-body and hydrodynamic simulations with semi-analytic and semi-numerical methods to produce a spatially dependent reionization model that is self-consistently coupled to the evolution of a realistic galaxy population. I will present results from this model calibrated to the stellar mass function of galaxies and the Thompson scattering optical depth, including galaxy luminosity functions at z~5-10, and discuss the fraction of ionising radiation from stars that has been observed at high redshift. I will then discuss how different scenarios for the galaxy formation physics alter the build up of stellar mass at z>5, and are manifested in the statics of the redshifted 21cm signal.

Kyungjin Ahn (Chosun U., Korea):
Role of First Galaxies in Cosmic Reionization and Their Impact on the Intergalactic Medium

Cosmic reionization is believed to produce a set of patchy H II regions which are typically of a few 10s of Mpc but with a large variance in their size. We present a suite of numerical simulations of cosmic reionization not only in boxes which are large enough for statistical reliability, but also with implementation of sub-grid physics to span the full dynamic range of radiation sources. Smallest halos hosting the first galaxies, or minihalos, may yield as much as 25% of ionization of the Universe, before the process is taken over by more massive halos. We discuss this result in relation to the recent compilation of CMB polarization anisotropy by the Planck mission. We also present a scenario for clustered high-redshift star and X-ray source formation in and around high-density peaks, and show that their impact on the intergalactic medium can be probed by the Square Kilometre Array with high spatial event rates. Finally, we discuss the impact of relative velocity between baryon and dark matter on the formation of the first objects around Jeans filtering scale.

COSMIC DAWN AND BEYOND

Andrea Ferrara (Scuola Normale Superiore, Italy):
First stars, First Black Holes

The appearance of the first stars about 100 million years after the Big Bang marked the beginning of the Reionization Epoch, an extended process in which the cosmic gas was ionized by the UV photons from the existing luminous sources. Most likely, in addition to stars, black holes also formed during the same epoch as end-products of massive star evolution, from direct collapse of gas clouds, or by stellar merging in dense stellar clusters. These black holes represent the "seeds" out of which observed super-massive black holes powering the most distant quasars were built. I will review the properties of first stars and black holes, their role for reionization, and the tight physical relationships between these two types of sources. I will put particular emphasis on the critical current and future experiments, like the Near Infrared Background fluctuation power spectrum and its cross-correlations, that could allow us to understand in detail these initial phases of cosmic structure formation.

Rennan Barkana (Tel Aviv U., IAP Paris, U. of Oxford):
Cosmic Dawn: From Theoretical Ideas to the SKA

The "cosmic dawn" era was rich with astrophysics, and should have left a number of distinct 21-cm signatures. This was all considered speculative when I helped lay out the theoretical predictions a decade ago, but there is now an enormous observational effort (including within the Square Kilometre Array) that promises to finally confront theory with data and begin the exploration of a new cosmic era.

Matt Jarvis (U. of Oxford, UK):
Searching for high-redshift radio sources in the EoR: Problems and solutions

I will give an overview of the current status for searching for radio sources in the EoR that could be used as beacons for 21-cm absorption experiment, highlighting some of the issues that we face. However, some future facilities will be ideal for finding such sources, paving the way for 21cm absorption studies.

Leon Koopmans (Kapteyn Astro. Institute, Netherlands):
Route 21: A bumpy road towards the Cosmic Dawn

Were it not for the bright Galactic and extra-Galactic foregrounds, the 21-cm emission of neutral hydrogen from the Epoch of Reionization and Cosmic Dawn could have been detected several decades ago. But as of yet it has not been detected. I will review the daunting list of challenging facing the first detection of this emission, ranging from mode mixing to the ionosphere, illustrated by the results from current experiments (e.g. LOFAR, MWA, PAPER and GMRT) as well as improved theoretical analyses. I will discuss how these challenges are, or can be, addressed and the lessons that are being learned for the design of future arrays such as the SKA and HERA, which aim not only to detect the 21-cm emission statistically, but also image it directly, and in the case of SKA expand the redshift regime to the Cosmic Dawn. Whereas major progress is being made, Route 21 remains a bumpy ride.

Olivier Dore (JPL/Caltech, USA):
The SPHEREx mission

Jorryt Matthee (**Leiden Observatory, The Netherlands**):
Discovery of the brightest Lyman-alpha emitters in the epoch of re-ionisation

I will present recent results from our wide-field narrow-band survey to search for z=6.6 galaxies through their Lyman-alpha emission line. We have found that luminous Lya emitters are much more common than previously thought, with possible implications for re-ionisation. Because of their brightness, these sources can be studied in great detail, and allowing us to prepare for what we can expect for fainter sources with the next generation of telescopes. Using Keck, the VLT and HST we find that our brightest galaxy, "COSMOS REDSHIFT 7" (CR7), has a very surprising nature, with spectroscopic evidence for a very hard, PopIII-like, ionising source.

Uros Seljak (**UC Berkeley**):
Nonlinear clustering of large scale structure: from first light until today

I will review perturbative and non-perturbative approaches to the nonlinear clustering of cosmological structures, including dark matter, galaxies, and other tracers. Some of the second order bias terms I will discuss are the second order density bias, tidal tensor bias, peak bias, and the relative baryon-CDM velocity bias. I will present applications of these perturbative approaches to the lowest order statistics, including power spectrum, bispectrum and trispectrum.

REIONIZATION AND FIRST GALAXIES

Benedetta Ciardi (**MPA, Germany**):
Prospects for LOFAR detections

In this talk I'll discuss what LOFAR can do in terms of detection of HII regions produced by high-z QSOs, 21cm forest and cross-correlation with galaxy surveys.

Josh Dillon (**UC Berkeley, USA**):
21 cm Power Spectrum Estimation in Theory and in Practice: Statistical Techniques and Early Results from First Generation Interferometers

Realizing the promise of 21 cm cosmology to provide an exquisite probe of astrophysics and cosmology during the cosmic dark ages and the epoch of reionization has proven extremely challenging. We're looking for a small signal buried under foregrounds orders of magnitude stronger. We need large interferometers producing mountains of data to even have a chance of seeing the signal. To confront the twin challenges of foregrounds and sensitivity, we need both fast and rigorous statistical techniques to turn our data into cosmologically interesting results. In this talk, I will present the steps my colleagues and I have taken to rigorously and optimally estimate the 21 cm power spectrum, both in theory and with data from PAPER and the MWA, including recent limits. I will also discuss the need for precisely understood maps and foreground models for estimating power spectra, especially if we want to enlarge the "EoR window" by subtracting foregrounds. Finally, I will examine the lessons we have learned for future 21 cm interferometers designed for probing the « Cosmic Dawn » like HERA.

Charlotte Mason (**UCSB/UCLA, USA**):
The Galaxy UV Luminosity Function Before the Epoch of Reionization

The rest-frame UV galaxy luminosity function (LF) and its evolution with redshift are crucial tracers of galaxy properties over cosmic time. In addition, integrating the UV LF provides the number of ionizing photons available for reionization. I will present a model for the evolution of the galaxy UV LF where star formation is driven by the assembly of dark matter halos under the assumption of a halo mass dependent, but redshift independent, star formation efficiency. I will introduce a new self-consistent treatment of the halo star formation history, which allows us to make predictions at redshift z > 10, when growth is rapid. Our simple model is remarkably successful at capturing the evolution of the UV LF over all the available observations ($0 < z < \sim 10$), and I will discuss the implications of our predictions at higher redshifts, including the contribution of galaxies to reionization, and prospects for "First Light" surveys with JWST and WFIRST.

Anastasia Fialkov (ENS Paris, ITC Harvard):
The effect of first X-ray sources on cosmic observables

COSMOLOGY

Masahiro Takada (IPMU, Japan):
Halo bias

Halo bias is one of the most important ingredients when using biased tracers such as galaxies and clusters for cosmology. In this talk I first present the first significant evidence of assembly bias for cluster-scale halos which we found from a combination of clustering and weak lensing signals for SDSS redMaPPer cluster sample. Then, if time allows, I also propose a novel way of calibrating halo bias using separate universe simulation technique.

Irina Dvorkin (IAP, France):
The origin of dispersion in DLA metallicities

Damped Lyman-alpha absorbers (DLAs) dominate the neutral gas content of the Universe in the redshift range z=0-5 and are likely the progenitors of low redshift galaxies. The chemical properties of DLAs can be determined with great precision, and provide a unique probe of the properties of cold neutral gas out of which stars form at high redshifts. Recent chemical abundance measurements of DLAs revealed a large intrinsic scatter in their metallicities. In this talk I will discuss a semi-analytic model specifically designed to study this scatter. This model accurately traces the chemical evolution of the interstellar matter in small regions of the Universe with different mean density, from over- to underdense regions. I will show that the different histories of structure formation in these regions, namely halo abundance, mass and stellar content are reflected in the chemical properties of the proto-galaxies, and that the dispersion arising from this environmental effect is an important contribution to the overall intrinsic scatter.

Mario Livio:
Type Ia Supernovae and Cosmology

I will review recent observational and theoretical developments in the study of Type Ia supernovae (SN Ia), and their use in determining the characteristics of dark energy. In particular, I will examine the question of the progenitors of SN Ia, given new observational constraints and detailed theoretical simulations.

COSMOLOGY AND ENERGETIC PARTICLES

Ofer Lahav (UCL, UK):
Galaxy Surveys: More Than Dark Energy

Raul Jimenez (iCrea, Spain):
Do we Understand the Universe?

Yoel Rephaeli (Tel Aviv U., Israel):
Galactic Energetic Particles and Their Radiative Yields in Clusters

Lorenzo Amati (INAF - IASF Bologna, Italy):
Shedding light on the dark Universe with Gamma-Ray Bursts

Gamma-Ray Bursts (GRB) are the most luminous and remote phenomena in the Universe, with isotropic-equivalent radiated energies up to more than 10^{54} erg and a redshift distribution extending to at least z = 9-10. Thus, they are in principle very powerful tools for cosmology. I summarize the status and perspectives of the research activities aimed at using GRB to explore the early Universe at the end of the "dark ages". In particular, thanks to present and perspective multi-wavelength observational efforts, GRB can provide unique information on star formation rate and metallicity evolution of the ISM and IGM up to redshift ~10, the first generation of stars (pop III), the sources and physics of re-ionization, the faint end of galaxies luminosity function.

Sergey Sazonov (Space Research Institute, Moscow, Russia):
Preheating of the Universe by cosmic rays from primordial supernovae at the beginning of cosmic reionization

It is widely believed that X-rays from the first accreting black holes could significantly heat the primordial IGM. We propose another IGM heating mechanism associated with the first stars. As known from previous work, the remnants of powerful supernovae ending the lives of massive Pop III stars could readily expand out of their host minihalos into the surrounding IGM. We argue that during the evolution of such a remnant a significant fraction of the SN kinetic energy can be put into low-energy cosmic rays that will eventually escape into the IGM. These subrelativistic cosmic rays could propagate through the Universe and heat the IGM to $\sim 10^2$-10^3 K already by z~20-12, before more powerful reionization/heating mechanisms came into play. Future 21-cm observations can constrain the energetics of the first supernovae and provide information on the magnetic fields in the primordial IGM.

Anna Schauer (ITA / Heidelberg U., Germany):
Lyman-Werner UV Escape Fractions from Primordial Halos

Population III stars can regulate star formation in the primordial Universe in several ways. They can ionize nearby halos, and even if their ionizing photons are trapped by their own halos, their Lyman-Werner (LW) photons can still escape and destroy H_2 in other halos, preventing them from cooling and forming stars. LW escape fractions are thus a key parameter in cosmological simulations of early reionization and star formation but have not yet been parametrized for realistic halos by halo or stellar mass. To do so, we perform radiation hydrodynamical simulations of LW UV escape from 9--120 $M_\odot$ Pop III stars in 10^5 to 10^7 $M_\odot$ halos with ZEUS-MP. We find that photons in the LW lines (i.e. those responsible for destroying H_2 in nearby systems) have escape fractions ranging from 0% to 85%. No LW photons escape the most massive halo in our sample, even from the most massive star. Escape fractions for photons elsewhere in the 11.18--13.6~eV energy range, which can be redshifted into the LW lines at cosmological distances, are generally much higher, being above 60% for all but the least massive stars in the most massive halos. We find that shielding of H_2 by neutral hydrogen, which has been neglected in most studies to date, produces escape fractions that are up to a factor of three smaller than those predicted by H_2 self-shielding alone.

Ben Wandelt (IAP Paris):
Analysis challenges for cosmological data sets

REIONIZATION AND COSMIC DAWN

Jonathan Pritchard (Imperial College London, UK):
Linking 21cm statistics and astrophysics

Felix Mirabel (CEA-Saclay, France):
High Energy Sources in the Reionization Epoch

Lincoln Greenhill (Harvard U., USA), for the LEDA and LWA-OV collaborations:
The Large Aperture Experiment to Detect the Dark Age (LEDA): Results and Prospects

The Large Aperture Experiment to Detect the Dark Age (LEDA) seeks to measure the sky-averaged absorption spectrum of the HI 21cm transition at z~20, and from this, to derive direct constraint on the thermal state of the IGM and on Lya and X-ray fluxes from pockets of star formation at the close of the Dark Age. The primary LEDA deployment is at the Long Wavelength Array station in the California Owens Valley, where LEDA systems provide the digital signal processing backbone. LEDA methodology includes joint application of single-antenna radiometry and interferometric calibration of antenna gain patterns, ionospheric seeing, and the sky brightness distribution. I will introduce the instrument, present the current level of residuals, discuss recent upgrades intended to mitigate systematics, and conclude with comments about making power spectrum measurements with LEDA systems and successors. LEDA has demonstrated architectural and design principles that scale by two orders of magnitude with current technology, sufficiently so as to support sizable advances in sensitivity to the 21-cm power spectrum for $16 < z < 22$.

Daniel Whalen (ITA / Heidelberg U., Germany):
Finding the First Cosmic Explosions

Primordial stars formed about 200 Myr after the big bang, ending the cosmic dark ages. They were the first great nucleosynthetic engines of the universe and may be the origins of the supermassive black holes found in most massive galaxies today. In spite of their importance to the evolution of the early universe not much is known for certain about the properties of Pop III stars. But with the advent of JWST, WFIRST and the 30 m telescopes it may soon be possible to directly observe the explosions themselves in the NIR and thus unambiguously constrain the properties of the first stars. I will present radiation hydrodynamical calculations of the light curves of the first SNe in the universe and discuss strategies for their detection. I will also describe how some may already have been captured in surveys of galaxy cluster lenses such as CLASH, Frontier Fields and GLASS.

Benoit Semelin (LERMA, Observatoire de Paris):
How much physics do you need to model the 21 cm forest?

Pierre Ocvirk (Observatoire Astronomique de Strasbourg, France):
Cosmic Dawn (CoDa): the First Radiation-Hydrodynamics Simulation of Reionization and Galaxy Formation in the Local Universe

Saleem Zaroubi (Kapteyn Astro. Institute, Netherlands):
Upper limits on the EoR from LOFAR