JD 07: The Universe at z>6

Home
Program
SOC
Venue
Registration
Participants
Proceedings
GA Website
IAU

Proceedings

The contributions to this Joint Discussion, whose editors are Daniel Schaerer and Andrea Ferrara, will be published in a special series of IAU publications, Highlights of Astronomy Vol. 14., editor-in-chief: Karel A. van der Hucht, publisher: Cambridge University Press (CUP, UK).

The pdf file with all contributions is available here.

Table of Contents

Preface

The exploration of the earliest phase of star and galaxy formation after the Big Bang remains an important challenge of contemporary astrophysics and represents a key science driver for numerous future facilities. During this phase the first stars and galaxies appear and start to light up and ionize the then neutral Universe ending thereby the so called cosmic dark ages and leading progressively to the complete reionization we observe now at redshift $z \sim 6$ or earlier.

Important theoretical and numerical advances have been made in the modeling of the early Universe. Also, it has recently become possible to obtain direct observations of galaxies, quasars, and the intergalactic medium (IGM) out to redshift $z \sim 7$. Furthermore new optical to near-IR observations using ground-based and space-borne telescopes are now opening up the view to even higher redshift, directly probing for the first time galaxies during the first billion years after the Big Bang.

Motivated by these facts Joint Discussion 07 on "The Universe at $z > 6$" was organised during the General Assembly as a forum to present and discuss the latest results both from numerical modeling and from observations in this rapidly advancing field. The Scientific Organising Committee (SOC) was composed of Andrea Ferrara (Italy), Esther Hu (USA), Matthew Lehnert (Germany), Roser Pelló (France), Daniel Schaerer (Switzerland), and Yoshiaki Taniguchi (Japan).

Judging at least from the attendance — a very full room with up to $\sim$ 150 persons! — this Joint Discussion was a success. We hope that all participants, speakers, poster presenters, and the "audience" felt the same. In any case we thank all the persons who have contributed to this Joint Discussion, the SOC members, all the local organisers, and the participants.

Daniel Schaerer and Andrea Ferrara, co-chairs SOC and editors
Geneva and Trieste, 22 november 2006

Highlights of Astronomy, Volume 14
XXVIth IAU General Assembly, August 2006
K.A. van der Hucht, ed.

DOI: 00.0000/X000000000000000X

Lyman Break Galaxies at $z > 6$

Rychard J. Bouwens[1], Garth D. Illingworth[1]

[1]UCO/Lick Observatory and Department of Astronomy, University of California Santa Cruz, Santa Cruz, California 95064, USA
email: bouwens@ucolick.org, gdi@ucolick.org

Abstract. Extending the study of star-forming galaxies to $z > 6$ is extremely difficult due to the faintness of the sources and the challenging nature of deep near-infrared observations. Nevertheless, current observations are now just good enough that we can begin drawing some conclusions about the nature of galaxies at $z \gtrsim 7$. At present, deep near-infrared observations with NICMOS (reaching $\gtrsim 27$ AB mag at 5σ) cover more than 20 arcmin^2 of area with deep optical coverage and allow us to identify 4 strong $z \sim 7-8$ candidates. Comparing this sample with dropout samples at later times ($z \sim 4-6$), we are able to study evolution in the rest-frame *UV* LF over the range $z \sim 8$ to $z \sim 4$. We find strong evidence for significant evolution in the characteristic luminosity with time (brightening by ~ 2 mag from $z \sim 8$ to $z \sim 4$). The observed evolution appears to be the direct result of hierarchical growth in the galaxy population.

Keywords. galaxies: evolution, galaxies: formation, galaxies: high-redshift

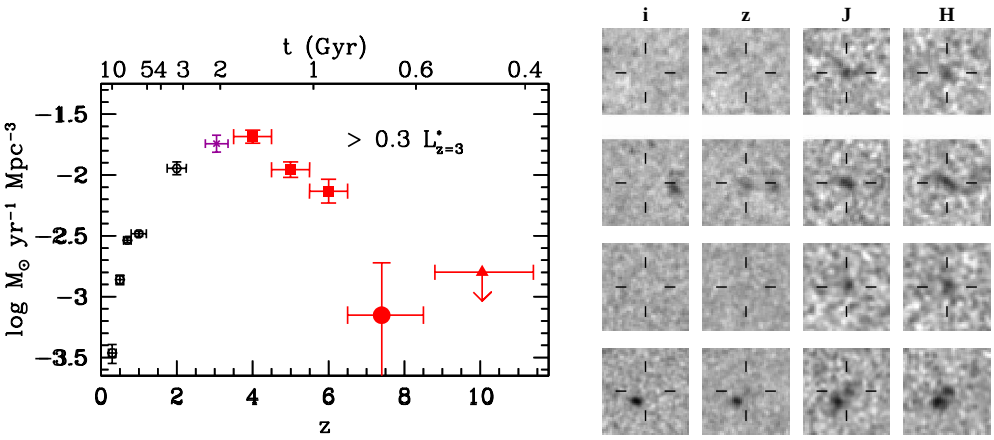

Figure 1. *(left)* Star Formation History of the Universe (uncorrected for extinction and integrated down to $0.3L^*_{z=3}$). Shown are our determinations at $z \sim 4-6$ (large red squares: Bouwens et al. 2006 and Bouwens et al. 2006, in preparation), our recent determination at $z \sim 7.4$ (large red circle: Bouwens & Illingworth 2006), and upper limits at $z \sim 10$ (red triangle: Bouwens et al. 2005). Included are also determinations at $z \sim 0-2$ (Schiminovich et al. 2005) and $z \sim 3$ (Steidel et al. 1999). The star formation rate density is observed to increase rather dramatically from $z \sim 8$ to $z \sim 4$. *(right)* Optical and near-infrared images of four candidate star-forming galaxies at $z \sim 7-8$. These galaxies were found in deep NICMOS imaging available over the Ultra Deep Field and GOODS fields (Bouwens & Illingworth 2006).

References

Bouwens, R.J. & Illingworth, G.D. 2006, *Nature* 443, 189-192
Bouwens, R.J., Illingworth, G.D., Blakeslee, J.P., & Franx, M. 2006, *Astrophys. J.*, in press.
Bouwens, R.J., et al. 2005, *Astrophys. J. Lett.*, 624, 5-8.
Steidel, C.C., et al. 2006, *Astrophys. J.*, 519, 1-17.
Schiminovich, D., et al. 2005, *Astrophys. J. Lett.*, 619, 47-50.

Highlights of Astronomy, Volume 14
XXVIth IAU General Assembly, August 2006
K.A. van der Hucht, ed.

DOI: 00.0000/X000000000000000X

Subaru surveys for the high-redshift universe

Y. Taniguchi[1]

[1]Department of Physics and Engineering, Graduate School of Science, Ehime University.
Bunkyo-cho 2-5, Matsuyama 790-8577, JAPAN

Abstract. We present a brief summary of Subaru observations of high-z galaxies. We discuss our future plan to porbe galaxies beyond $z = 10$.

Among the most pressing issues in modern observational cosmology is the question of finding and studying the first generation of galaxies- their formation epoch, their early evolution and their contribution to cosmic reionization. This provides clues towards early star formation activity in the Universe and mass assembly in galaxies as well as the long standing problem of understanding the physical processes responsible for cosmic reionization of intergalactic medium. Furthermore, this provides an independent test for WMAP results which identifies the reionization epoch to be at $z \sim 11$. This is the only direct observation currently available constraining the epoch of reionization.

The Subaru Telescope has been used to search for very high-z galaxies for these several years. The very wide field of view of Suprime-Cam aloows us to identify more than 100 galaxies beyond $z = 5$; $z \sim 5.7$ (e.g., Shimasaku et al. 2006, PASJ, 58, 313), $z \sim 6.6$ (e.g., Taniguchi et al. 2005, PASJ, 57, 165; Kashikawa et al. 2006, ApJ, 648, 7), and $z \sim 7$ (Iye et al. 2006, Nature, 443, 186; Hu et al. 2006, IAU, JD7, in press). In order to extend the search for galaxies at $z > 10$. we are promoting to use our custom made near-infrared narrow-band filter (NB2296) on MOIRCS- Subaru to carry out an ultra-deep survey to search for Lyα emitting galaxies at $z \sim 18$. The central wavelength of this filter is 2296 nm, with a bandwidth corresponding to 23 nm. Therefore, this filter can detect Lyα emission from galaxies at $z \approx 17.9$; $z_{\rm min} = 17.8$ and $z_{\rm max} = 18.0$. The relatively large field of view of MOIRCS ($4' \times 7'$) allows a wide-area and ultra-deep survey, rather unprecedented at near-IR wavelengths. Although a reionization redshift of $z \sim 9$ is found by WMAP, it is expected that there are Population III sources out to $z \sim 30$.

Highlights of Astronomy, Volume 14
XXVIth IAU General Assembly, August 2006
K.A. van der Hucht, ed.

DOI: 00.0000/X000000000000000X

Galaxies in the First Billion Years: Implications for Reionization and the Star Formation History at $z > 6$

A. J. Bunker[1]E. R. Stanway[2], L. P., Eyles[1], R. S. Ellis[3], R. G. McMahon[4], M. Lacy[5] and D. P. Stark[3]

[1] University of Exeter, School of Physics, Stocker Road, Exeter, EX4 4QL, U.K.
email: bunker@astro.ex.ac.uk

[2] Astronomy Dept., University of Wisconsin, 475 N. Charter Street, Madison, WI 53706, U.S.A.

[3] California Institute of Technology, Mail Stop 169-327, Pasadena, CA 91109, U.S.A.

[4] Institute of Astronomy, Madingley Road, Cambridge, CB3 0HA, U.K.

[5] Spitzer Science Center, 1200 E. California Blvd., Pasadena, CA 91125, U.S.A.

Abstract. We discuss the selection of star-forming galaxies at $z \sim 6$ through the Lyman-break technique. *Spitzer* imaging implies many of these contain older stellar populations (> 200 Myr) which produce detectable Balmer breaks. The ages and stellar masses ($\sim 10^{10}\,M_{\odot}$) imply that the star formation rate density at earlier epochs may have been significantly higher than at $z \sim 6$, and might have played a key role in reionizing the Universe.

Keywords. galaxies: high-redshift; evolution; formation; stellar content

---

We have discovered a population of star-forming galaxies at $z \sim 6$ and beyond (within the first billion years) through the i'-drop technique. The first application of this to *HST*/ACS imaging was presented in Stanway, Bunker & McMahon (2003), using the public GOODS survey. We were able to prove this technique through Keck/DEIMOS spectroscopy (Bunker et al. 2003). Using the same i'-drop selection, our first analysis of the Hubble Deep Field revealed 50 star forming galaxies at redshifts around 6 with magnitudes $z_{AB} > 28.5$ (Bunker et al. 2004). *Spitzer* observations with IRAC enable us to estimate the stellar masses and luminosity-weighted ages for this population; we find in some cases that there are Balmer breaks, indicating ages of > 200 Myr and formation redshifts of $z \sim 10$ (Eyles et al. 2005). From the whole sample of v-drops and i'-drops we estimate the stellar mass density at $z \approx 5$ (Stark et al. 2006) and at $z \approx 6$ (Eyles et al. 2006). The implications of this work are that the previous star formation history was higher prior to $z \sim 6$, and might have played a key role in generating the UV photons necessary to reionize the Universe at $z \sim 8 - 10$. Our work is the strongest constraint to date on the star formation history at $z > 6$.

References

Bunker, A., Stanway, E., Ellis, R., McMahon, R., McCarthy, P.J. 2003, MNRAS, 342, L47
Bunker, A.J., Stanway, E.R., Ellis, R.S., McMahon, R.G. 2004, MNRAS, 355, 374
Eyles, L., Bunker, A., Stanway, E., Lacy, M., Ellis, R., Doherty, M. 2005, MNRAS, 364, 443
Eyles, L., Bunker, A., Ellis, R., Lacy, M., Stanway, E., Stark, D., Chiu, K. 2006, `astro-ph/0607306`
Stanway, E.R., Bunker, A.J., McMahon, R.G. 2003, MNRAS, 342, 439
Stark, D.P., Bunker, A.J., Ellis, R.S., Eyles, L.P., Lacy, M. 2006, `astro-ph/0604250`

Highlights of Astronomy, Volume 14
XXVIth IAU General Assembly, August 2006
K.A. van der Hucht, ed.

DOI: 00.0000/X000000000000000X

New Constraints on the Comoving Star Formation Rate in the Redshift Interval $6 < z < 10$

R. S. Ellis[1], D.P. Stark[1], J. Richard[1], A. Bunker[2], E. Egami[3], J.-P. Kneib[4]

[1] California Institute of Technology, Mail Stop 169-327, Pasadena, CA 91109, U.S.A.
[2] University of Exeter, School of Physics, Stocker Road, Exeter, EX4 4QL, U.K.
[3] University of Arizona, Tucson, United States
[4] Laboratoire D'Astrophysique, Marseille, France

Abstract. Recent progress in measuring the optical depth of neutral hydrogen in distant quasars and that of electron scattering of microwave background photons suggests that most of the sources responsible for cosmic reionisation probably lie in the redshift interval 6 to 10. We present two new observational results which, together, provide valuable constraints on the contribution from star-forming sources in this redshift interval. First, using a large sample of v-band dropouts with unconfused Spitzer IRAC detections, we determine the integrated stellar mass density at $z = 5$. This provides a valuable "integral constraint" on past star formation. It seems difficult to reconcile the observed stellar mass at $z = 5$ with the low abundance of luminous i, z and J-band dropouts in deep Hubble Space Telescope data. Accordingly, we explore whether less luminous star-forming sources in the redshift interval 6 to 10 might be the dominant cause of cosmic reionization. In the second component of our research, we report on the results of two surveys for weak Lyman alpha emitters and z and J-band dropouts highly-magnified by foreground lensing clusters. Although some promising $z = 8 - 9$ candidates are found, it seems unlikely that low luminosity sources in this redshift interval can dominate cosmic reionization. If our work is substantiated by more extensive and precise surveys, the bulk of the reionizing photons may come from yet earlier sources lying at redshifts $z > 10$.

Keywords. galaxies:high-redshift, infrared: galaxies, early universe

Highlights of Astronomy, Volume 14
XXVIth IAU General Assembly, August 2006
K.A. van der Hucht, ed.

DOI: 00.0000/X000000000000000X

Observations of Galaxies at $z > 6$ The Properties of Large, Spectroscopic Samples

E.M. Hu[1], L.L. Cowie[1], Y. Kakazu

[1]Institute for Astronomy, Honolulu, United States

Abstract. Observed properties of spectroscopically confirmed galaxies at $z \gg 5$ and $z \gg 6$ based on selection from deep, multi-wavelength wide-field samples provide a picture of the current status of the properties of high-redshift galaxies and their evolution to yet higher redshifts.

In the current presentation, we use results of deep, wide-field spectroscopy with the multi-object DEIMOS spectrograph on Keck in combination with deep, wide-field multi-color imaging studies using the SuprimeCam CCD camera of Subaru for a number of fields, to evaluate the luminosity function of high-redshift galaxies and its evolution at $z > 6$. High-redshift candidates are selected using both narrow-band Lyman alpha emission and broad-band colors with a high success-rate from a number of SuprimeCam (0.5 degree FOV) fields.

Luminosity functions and Lyman alpha emission line profiles and equivalent widths appear similar between samples at $z \sim 5.7$ and $z \sim 6.5$, and the galaxy distribution is structured both spatially and in redshift. A large amount of cosmic variance is seen in the distribution of $z \gg 6$ galaxies from field to field.

The observed properties are discussed in relationship to their impact on strategies for complementary optical surveys of high-redshift galaxies, and in relationship to surveys at very different wavelengths (X-ray, far-infrared, and submillimeter) that cover the same regions.

Keywords. galaxies:high-redshift, infrared: galaxies, early universe

Highlights of Astronomy, Volume 14
XXVIth IAU General Assembly, August 2006
K.A. van der Hucht, ed.

DOI: 00.0000/X000000000000000X

Properties of Lyα Emitters at Redshift ~ 6

Crystal L. Martin[1]†, Marcin Sawicki[1], Alan Dressler[2] and Patrick J. McCarthy[2]

[1]Department of Physics, UCSB, Santa Barbara, CA 93106, USA
[2]OCIW, 813 Santa Barbara Street, Pasadena, CA 91101-1292, USA

Abstract. We confirm the redshift of several $z \sim 6$ objects discovered by our IMACS multislit emission-line survey. Their Lyα luminosities are lower than those of galaxies previously discovered using narrow-band imaging, as expected due to the excellent sky-supression inherent to this technique. Based on the line profiles of these objects, we argue that they are extremely young starbursts and find strong evidence for prominent galactic winds. This population of young galaxies is largely beyond the reach of current large surveys that use continuum selection.

Keywords. galaxies:high-redshift, line: identification, techniques:miscellaneous

1. Overview of the IMACS Multislit Survey

Using the Inamori Magellan Areal Camera and Spectrograph (IMACS) on the Baade Telescope, we carried out a spectroscopic, emission-line survey through the OH-free atmospheric window at 8200 Å. A custom blocking filter and multislit mask allowed us to search 50 square arcminutes of *blank sky* per pointing. The total survey area to date is 200 square arcminutes, a significantly larger area than that covered by previous multislit surveys (Martin & Sawicki 2004, *ApJ* 603, 414; Tran et al. 2004, *ApJ* 612, 89).

We discovered nearly 300 emission-line galaxies and identified $\sim 90\%$ of them as foreground objects in our follow-up observations. From the spectra of the confirmed Lyα emitters, we derive physical properties of galaxies at redshift 5.7. For example, we detect N V $\lambda\lambda 1239, 43$ in the spectrum of MSDM 29.5+5.1 in addition to a 280 km s^{-1} wide Lyα line. We argue that this object is either a very young starburst (light dominated by O and WR stars) or a Type II AGN. Higher resolution spectra of this object and that of MSDM 80.0+3 reveal structure in the Lyα line profiles characteristic of radiative transfer effects in galactic winds (Hansen & Oh 2006, *MNRAS* 367, 979; Verhamme et al. *astro-ph/0608075*).

These Lyα emitters are the first discovered using the multislit search technique. They are drawn from a much larger volume than lensed searches. Typical line fluxes, $F \approx 6 \times 10^{-18}$ ergs s^{-1} cm^{-2} or $\log L \approx 42.32$ erg s^{-1}, are fainter than those from narrow-band imaging surveys. Addition of our results to those from these techniques – see Malhotra & Rhoads 2004 (*ApJ* 617, 5); Hu et al. 2004 (*AJ* 127, 563); Shimasaku et al. 2006 (*PASJ* 58, 313); and Santos et al. 2004 (*ApJ* 606, 683) – will better determine the luminosity of the knee in the Lyα luminosity distribution near redshift 6. Measurement of the Lyα luminosity function will impact the outstanding question of whether the objects that ionize the intergalactic medium have been identified and make it possible to trace the progression of Reionization via evolution in the luminosity function.

† Work supported by the David and Lucile Packard Foundation.

Highlights of Astronomy, Volume 14
XXVIth IAU General Assembly, August 2006
K.A. van der Hucht, ed.

DOI: 00.0000/X000000000000000X

Observations of Galaxies at $z > 6$ The Properties of Large, Spectroscopic Samples

S. Malhotra[1], J. Rhoads[1]

[1]Arizona State University, Tempe, United States

Abstract. A strong Lyman-alpha line enables relatively easy detection of high redshift galaxies. Lyman-alpha galaxies are now known from $z = 3$ to 6.6. No evolution is discerned in the Lyman-alpha line luminosity function in this redshift range. This implies that the intergalactic medium at $z = 6$ is at least 50% ionized over more than 50% of the volume. Recent continuum detections of these galaxies from HST, MMT and Spitzer are now allowing us to address questions about the nature of these Lyman-alpha emitters, their stellar populations and ages. We find that by and large the Lyman-alpha galaxies are young galaxies dominated by stellar populations that are less than 25 Million years old.

Keywords. galaxies:high-redshift

Highlights of Astronomy, Volume 14
XXVIth IAU General Assembly, August 2006
K.A. van der Hucht, ed.

DOI: 00.0000/X000000000000000X

An observational pursuit for PopIII stars in a Lyα emitter at $z>6$ through He II emission

Tohru Nagao[1]

[1]National Astronomical Observatory of Japan, Mitaka, Tokyo 181-8588, Japan
email: tohru@optik.mtk.nao.ac.jp

Abstract. We report our on-going observational project to search for population III (PopIII) stars in high-z galaxies. We searched Lyα emitters (LAEs) with a large equivalent width (EW), by our new selection technique "NB921-depressed i'-dropout selection". We found 8 photometric candidates and spectroscopically identified 5 LAEs with EW_0(Lyα) $>$ 100Å. We then carried out a very deep near-infrared spectroscopy for a LAE among the above five, to search for the redshifted He IIλ1640 emission from PopIII stars in the galaxy, but obtained only an upper limit.

Keywords. Early Universe, Galaxies: Evolution, Galaxies: Starburst, Stars: Early

---

The detection and investigation of the first-generation stars, Population III (PopIII) stars, will be one of the main goals of astronomy in the next decade. Since galaxies with massive PopIII stars are expected to show a very strong Lyα emission and a detectable He II emission in their spectra (e.g., Schaerer 2002, 2003), we are promoting a project to search for such spectroscopic signatures of PopIII stars.

We developed a new method to select Lyα emitters (LAEs) with a large equivalent width (EW) at a wide redshift range, $6.0 < z < 6.5$, by focusing "NB921-depressed i'-dropout" objects (Nagao et al. 2004). Through the follow-up spectroscopic observations with Subaru and Keck telescopes, we identified 5 strong LAEs with EW_0(Lyα) $>$ 100Å, among 8 photometric candidates (Nagao et al. 2005a, 2006).

Among the identified NB921-depressed i'-dropout galaxies, we focused on a LAE at $z = 6.33$ and with EW_0(Lyα) = 130Å and carried out a very deep J-band spectroscopic observation to search for the redshifted He IIλ1640 emission from PopIII stars in this LAE. Even after 42 ksec of integration with the Subaru/OHS spectrograph, no emission-line features are detected in the J band. We obtained a 2σ upper limit of 9.06×10^{-18} ergs s^{-1} cm^{-2} on the He IIλ1640 flux, which corresponds to a luminosity of 4.11×10^{42} ergs s^{-1}. This upper limit implies that the upper limit on the PopIII star formation rate is in the range 4.9–41.2 $M_\odot$ yr^{-1} if PopIII stars suffer no mass loss and in the range 1.8–13.2 $M_\odot$ yr^{-1} if strong mass loss is present. The non-detection of He II in the target LAE may thus disfavor weak feedback models for PopIII stars.

Acknowledgements

This study was done under a large collaboration and the names of collaborators cannot be given in the author list due to the limited space. TN is financially supported by JSPS.

References

Nagao, T., Taniguchi, Y., Kashikawa, N., et al. 2004, *ApJ* 613, L9
Nagao, T., Kashikawa, N., Malkan, M. A., et al. 2005a, *ApJ* 634, 142
Nagao, T., Motohara, K., Maiolino, R., et al. 2005b, *ApJ* 631, L5
Nagao, T., Murayama, T., Maiolino, R., et al. 2006, *A&A* submitted
Schaerer, D. 2002, *A&A* 382, 28
Schaerer, D. 2003, *A&A* 397, 527

Highlights of Astronomy, Volume 14
XXVIth IAU General Assembly, August 2006
K.A. van der Hucht, ed.

DOI: 00.0000/X000000000000000X

The end of the reionization epoch probed by Lyα emitters at $z = 6.5$

Nobunari Kashikawa[1]et al.

[1]National Astrronomical Observatory of Japan, Mitaka, Tokto, 181-8588, Japan

Abstract. We report an extensive search for Lyα emitters (LAEs) at $z = 6.5$ in the Subaru Deep Field (SDF). We carried out spectroscopic observations with Subaru/Keck to identify LAEs at $z = 6.5$ that were selected by narrow-band excess at 920nm. We have identified eight new LAEs based on their significantly asymmetric Lyα emission profiles. This increases the sample of spectroscopically confirmed $z = 6.5$ LAEs in the SDF to 17. Based on this spectroscopic sample of 17, complemented by a photometric sample of 58 LAEs, we have derived a more accurate Lyα luminosity function (LF) of LAEs at $z = 6.5$, which reveals an apparent deficit at the bright end, of ~ 0.75 mag fainter $L*$, compared with that observed at $z = 5.7$. The difference has 3σ significance, which is reduced to 2σ when cosmic variance is taken into account. Several LAEs with high Lyα luminosity have been actually identified by spectroscopy at $z < 5.7$, while our LAE sample at $z = 6.5$ has no confirmed object having such a high Lyα luminosity. The LF of the rest UV continuum, which is not sensitive to neutral IGM, of our LAE sample has almost the same as those of LAEs at $z = 5.7$ and i-dropouts at $z \sim 6$, even at their bright ends. This result may imply that the reionization of the universe has not been completed at $z = 6.5$. The decline of the Lyα LF implies the cosmic neutral fraction $x_{HI} = 0.45$ based on a theoretical IGM model, although this predicted value is strongly model dependent. The spatial distribution of our LAE sample was found to be homogeneous over the field, based on three independent methods to quantify the clustering strength. The composite spectrum of our LAE sample clearly reveals an asymmetric Lyα profile with an extended red wing, which can be explained by either a galactic wind model composed of double Gaussian profiles, or by a reionization model expected from the damping wing profile. Although our result has uncertainties in LAE evolution and large cosmic variance, it can be interpreted that LAEs at $z = 6.5$ are at the end of the reionization epoch.

Keywords. cosmology: observations, early universe

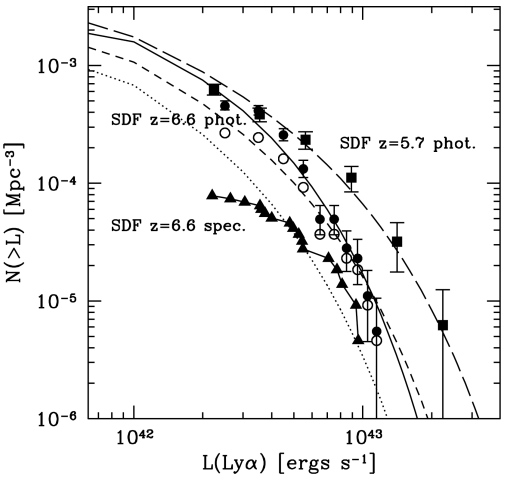

Figure 1: Cumulative Lyα LF of our LAE sample at $z = 6.5$. The open circles denote the raw counts of our spectroscopic sample + additional photometric sample, and the filled circles are corrected for detection completeness. The triangles denote the raw counts of the pure spectroscopic sample. The squares indicate the LF of LAEs at $z = 5.7$ evaluated from the SDF. The short-dashed and dotted lines show the Schechter LFs, in which the Lyα luminosities are reduced by a factor of 0.6 ($L^* \times 0.6$) and 0.4 from the $z = 5.7$ LF, respectively.

References

Kashikawa, N. et al. 2006, *ApJ* 648, 7

Highlights of Astronomy, Volume 14
XXVIth IAU General Assembly, August 2006
K.A. van der Hucht, ed.

DOI: 00.0000/X000000000000000X

Metallicity and Black Hole Masses of $z \sim 6$ Quasars

J.D. Kurk[1], F. Walter[1], D. Riechers[1], H.-W. Rix[1], S. Wagner[2], L. Pentericci[3] and X. Fan[4]

[1]Max-Planck-Institut für Astronomie, Königstuhl 17, D-69117, Heidelberg, Germany
[2]Landessternwarte Heidelberg, Königstuhl 12, D-69117, Heidelberg, Germany
[3]Osservatorio Astronomico di Roma, Via di Frascati 33, I-00040, Monte Porzio Catone, Italy
[4]Steward Observatory, The University of Arizona, 933 N. Cherry Av., Tucson, AZ 85721, USA

Abstract. We present NIR spectroscopy of emission lines of a sample of five $z \sim 6$ quasars, including fainter objects than observed before. The measured FeII / MgII ratios are around solar and consistent with a lack of evolution of the metallicity of quasar BLRs up to $z \sim 6$, suggesting that stars in their hosts formed at $z \gg 6$. The BH masses, measured from both MgII and CIV line widths are within the range $2 - 16 \times 10^8$ $M_\odot$, the smallest found in such distant objects.

Keywords. Galaxies: high-redshift – Galaxies: fundamental parameters – Galaxies: abundances

---

Quasars at $z \sim 6$ provide direct probes of galaxy hosts and the IGM close to the epoch of reionization. In the last few years, more than twenty such objects at $z > 5.7$ have been discovered. We have selected five of these for follow-up NIR spectroscopy. The sample† contains all published quasars observable by the VLT with $z > 5.8$ and includes quasars with magnitudes in the range $18.7 < i^* < 20.5$ at $5.8 < z < 6.3$, extending this kind of research by about a factor two down the luminosity function (e.g., Maiolino et al. 2004).

Observations were carried out with ISAAC in low resolution mode in the SZ, J and K bands with exposure times of one to three hours per spectrum. The emission lines were fitted by a Gaussian curve (MgII), Lorentzian curve (CIV) or iron template (FeII, from Vestergaard & Wilkes 2001), while the underlying continuum was fitted by a power law. In the region around 3000 Å, the Balmer pseudo-continuum was modeled. The measured FeII / MgII ratios are in the range 2.2 – 4.7, consistent with those found in lower redshift quasars. Applying the relations found by McLure & Jarvis (2002) and Vestergaard (2002) to the width of the MgII and CIV lines and the continuum fluxes at $\lambda_0 = 3000$ Å and 1350 Å, respectively, we find black hole (BH) masses of 2, 3, 12, 13 and 16 $\times 10^8$ $M_\odot$.

These results imply that the metallicity of BLRs in quasars does not evolve up to $z \sim 6$, suggesting a period of intense star formation at $z > 10$ in the host galaxy. We also find that quasars at $z \sim 6$ do no only contain BHs more massive than 10^9 $M_\odot$.

JK is supported by the DFG under grant SFB/439. Based on observations carried out at ESO, Paranal, Chile (267.A-5689, 069.B-0289, 071.B-0525, 074.A-0477, 076.A-0304).

References

Fan, X. et al. 2001, *AJ* 122, 2833
Fan, X. et al. 2004, *AJ* 128, 515
Maiolino, R. et al. 2004, *A&A* 420, 889
McLure, R. J. & Jarvis, M. J. 2002, *MNRAS* 337, 109
Vestergaard, M. & Wilkes, B. J. 2001, *ApJS* 134, 1
Vestergaard, M. 2002, *ApJ* 571, 733

† J0836+0054, J1030+0524, J1306+0356, J0005−0006, J1411+1217 (Fan et al. 2001, 2004).

Highlights of Astronomy, Volume 14
XXVIth IAU General Assembly, August 2006
K.A. van der Hucht, ed.

DOI: 00.0000/X000000000000000X

Populations of Candidate Black Holes at Redshift 7 or Above

A.M. Koekemoer

[1]Space Telescope Science Institute, Baltimore, United States

Abstract. I will describe recent results on constructing samples of candidate active galactic nuclei (AGN) at or beyond redshift 7, probing several orders of magnitude fainter than the top end of the quasar luminosity function at redshift 6. These advances have been made possible by the advent of deep, wide multi-waveband surveys that enable the selection of samples of sources that are detected at radio or X-ray wavelengths but completely undetected at optical wavelengths to very deep limits. A variety of multi-band selection criteria are used to identify the high-redshift candidates and eliminate lower-redshift interlopers by means of extensive spectral energy distribution modelling. The resulting constraints on the numbers of high-redshift AGN at or above redshift 7 are used to examine the evolution of the AGN luminosity function at high redshift, and help understand the properties of the first supermassive black holes in the universe.

Keywords. galaxies: active, quasars: general

Highlights of Astronomy, Volume 14
XXVIth IAU General Assembly, August 2006
K.A. van der Hucht, ed.

DOI: 00.0000/X000000000000000X

Reionization imprints in high-z QSO spectra

S. Gallerani,T. Roy Choudhury, A. Ferrara

SISSA/ISAS, via Beirut 2-4, 34014 Trieste, Italy.
email: galleran@sissa.it, chou@sissa.it, ferrara@sissa.it

Abstract. We use a semi-analytical approach to simulate absorption spectra of QSOs at high redshifts with the aim of constraining the cosmic reionization history. More details are given in Gallerani et al. (2006) and the references therein.

Keywords. intergalactic medium quasars: absorption lines - cosmology: theory large-scale structure of Universe.

We consider two physically motivated and detailed reionization histories: (i) an Early Reionization Model (ERM) in which the intergalactic medium is reionized by PopIII stars at $z > 10$ (Choudhury & Ferrara 2005), and (ii) a more standard Late Reionization Model (LRM) in which overlapping, induced by QSOs and normal galaxies, occurs at $z \sim 6$. From the analysis of current Lyα forest data at $z < 6$, we conclude that it is impossible to disentangle the two scenarios, which fit equally well the observed Gunn-Peterson optical depth, flux probability distribution function and dark gap width distribution. At $z > 6$, however, clear differences start to emerge which are best quantified by the dark gap width distribution, as can be seen from Figure 1.

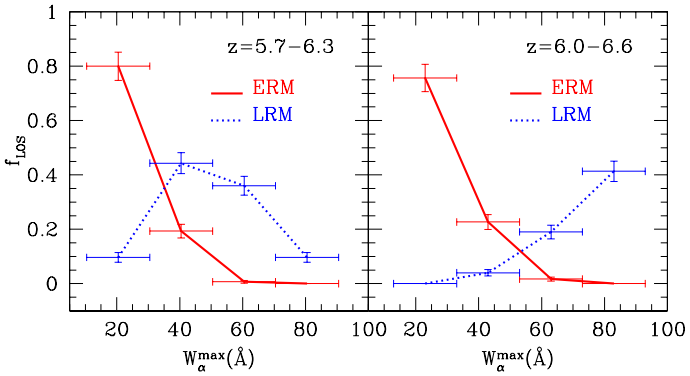

Figure 1. Distribution of the largest dark gap widths $W_\alpha^{\max}$ for 300 lines of sight in the redshift range 5.7 - 6.3 (left panel) and 6.0 - 6.6 (right panel) for ERM (solid red line) and LRM (dotted blue line). The vertical error bars denote the cosmic variance; the horizontal error bars show the bin size.

We find that 35 (zero) per cent of the lines of sight within $5.7 < z < 6.3$ show dark gaps widths > 50 Å in the rest frame of the QSO if reionization is not (is) complete at $z \gtrsim 6$. We conclude that the dark gap width statistics represent a superb probe of cosmic reionization if about ten QSOs can be found at $z > 6$.

References

Gallerani S., Choudhury, T. R., Ferrara A., 2006, MNRAS, 370, 3
Choudhury T. R., Ferrara A., 2005, MNRAS, 361, 577

Highlights of Astronomy, Volume 14
XXVIth IAU General Assembly, August 2006
K.A. van der Hucht, ed.

DOI: 00.0000/X000000000000000X

On the Size of H_{II} Regions around High Redshift Quasars

A. Maselli[1] †, S. Gallerani[2], A. Ferrara[2], T.Roy Choudhury[3]

[1] Max-Planck-Institut für Astrophysik, Karl-Schwarzschild-Strasse1, 85748 Garching, Germany
[2] SISSA/International School for Advanced Studies, via Beirut 2-4, 34014 Trieste, Italy
[3] Centre for Theoretical Studies, Indian Institute of Technology, Kharagpur 721302, India

Abstract. We investigate the possibility of constraining the ionization state of the Intergalactic Medium (IGM) close to the end of reionization ($z \approx 6$) by measuring the size of the H_{II} regions in high-z quasars spectra, via a combination of SPH and 3D radiative transfer (RT) simulations and a statistical analysis of mock quasar spectra through the simulated cosmological volume.

Keywords. cosmology: theory - radiative transfer - methods: numerical - intergalactic medium-cosmology: large scale structure of Universe

---

The size of H_{II} regions around high-z luminous quasars prior to complete reionization is strongly dependent on the mean neutral hydrogen fraction of the IGM, x_{HI}. Previous studies (e.g. Wyithe & Loeb 2004) have tried to constraints x_{HI} using the size of high-z QSOs H_{II}, measurable in their own spectra as the extent of the transmitting region between the quasar emission redshift and the onset of the Gunn-Peterson trough.
The aim of our work is to assess the robustness of the above method. We have performed a combination of state-of-art multiphase SPH and 3D radiative transfer (RT) simulations to accurately predict the properties of a typical high-z quasars H_{II} region (eg. extent, geometrical shape, inner opacity), assuming an initial $x_{HI} = 0.1$.
The simulation results show that RT effects do not induce strong deviations from spherical symmetry; we find a mean dispersion in the H_{II} region size along different LOS of the order of roughly 6 % of the mean radius.
By deriving and analyzing mock spectra through the simulated quasar environment we have found that the H_{II} region size deduced from quasar spectra typically underestimates the physical one by 30%. This effect, to which we refer as *apparent shrinking*, results to be almost completely due to resonant absorption of residual H_I inside the ionized bubble. Additional maximum likelihood analysis shows that this offset induces an overestimate of the neutral hydrogen fraction, x_{HI}, by a factor ≈ 3. By applying the same statistical method to a sample of 6 observed QSOs spectra analyzed by Fan et al. (2006), our study favors a mostly ionized ($x_{HI} < 0.06$) universe at $z = 6.1$.
All together the results of our work suggest that measurements of the H_{II} size in quasar spectra can only provide rough constraints on x_{HI}, as far as the knowledge of intrinsic properties of observed QSOs remains incomplete.
More details are given in Maselli et al. (2006) and references therein.

References

Fan, X., Carilli, C. L., & Keating, B., 2006, astro-ph/0602375
Maselli, A.; Gallerani, S.; Ferrara, A.; Choudhury, T. R. 2006, astro-ph/0608209
Wyithe, J.S.B. & Loeb, A., 2004, Nature, 427, 815

† Part of this work was supported by the DFG Priority Program 1177

Highlights of Astronomy, Volume 14
XXVIth IAU General Assembly, August 2006
K.A. van der Hucht, ed.

DOI: 00.0000/X000000000000000X

Constraints on Very Faint High-z Quasars

Mark Dijkstra[1]

[1] The School of Physics, The University of Melbourne, Parkville, VIC 3066, Australia
email: dijkstra@physics.unimelb.edu.au

Abstract. I discuss the constraints that can be derived on the abundance of high redshift ($z > 6$) (mini)quasars from the unresolved Soft X-Ray Background. Furthermore, I will show how existing Lyα surveys can be used to probe the very faint $M_B \gtrsim -21$ ($\gtrsim 7-8$ magnitudes fainter than the SDSS quasars) end of the $z \geqslant 4.5$ quasar luminosity function.

Keywords. galaxies: high-redshift, X-rays: diffuse background, cosmology: theory, quasars: emission lines.

1. Constraints from the Soft X-ray Background

A population of black holes (BHs) at high redshifts ($z > 6$) that contributes significantly to the ionization of the intergalactic medium would be accompanied by copious production of hard (>10 keV) X-ray photons. The resulting hard X-ray background would redshift and be observed as a present-day soft X-ray background (SXB). In Dijkstra et al.(2004) we show how existing models, in which BHs are the main producers of reionizing photons in the high-redshift universe, contribute more to the present-day SXB, than its unresolved component. This suggests that accreting BHs (be it luminous quasars or their lower-mass "miniquasar" counterparts) did not dominate reionization. These results depend most sensitively on the exact spectrum emitted by these accreting BHs.

2. Constraints from Lyα Surveys

There is good evidence that low numbers of Active Galactic Nuclei (AGN, or quasars) are among observed faint Lyα emitters at $z = 4.5 - 6.5$. Combining this observations with an empirical relation between the intrinsic Lyα and B-band luminosities of AGN, we obtain an upper limit on the number density of AGN with absolute magnitudes $M_B \in [-16, -19]$ at $z = 4.5 - 6.5$ (Dijkstra & Wyithe, 2006). These AGN are up to two orders of magnitude fainter than those discovered in the Chandra Deep Field, resulting in the faintest observational constraints on the quasar luminosity function at these redshifts to date. We believe that existing and future Lyα surveys could make a significant contribution to our understanding of the formation and evolution of high redshift BHs and AGN.

Acknowledgements

MD is supported by the Australian Research Counsil. I thank my collaborators Zoltan Haiman, Abraham Loeb and Stuart Wyithe for many useful discussions and the organisers of Joint Discussion 7, particularly Daniel Schaerer, for the opportunity to present this work.

References

Dijkstra, M., Haiman, Z., & Loeb, A. 2004, ApJ, 613, 646
Dijkstra, M., Wyithe, J.S.B., 2006, accepted for MNRAS, astroph/0606334

Highlights of Astronomy, Volume 14
XXVIth IAU General Assembly, August 2006
K.A. van der Hucht, ed.

DOI: 00.0000/X000000000000000X

Dust at z>6: observations and theory

R. Maiolino[1]

[1]INAF - Osservatorio Astronomico di Roma, Monte Porzio Catone, 00142, Italy
email: maiolino@oa-roma.inaf.it

Abstract. I shortly review the investigation of dust in the early universe. I discuss the possible evolution of the dust properties, as well as the possible dust production mechanisms at z>6.

Keywords. Dust, galaxies: ISM, galaxies: active, early universe

---

Dust plays a crucial role in the early universe. It affects the formation of high mass stars, it allows the formation of low mass stars in low metallicity environments (Schenider et al. 2006), and it also greatly enhances the formation of molecules. However, according to the standard scenarios we expect little or no dust at z>6. Indeed, in the local universe dust is mostly produced in the envelopes of evolved, low mass stars (mostly AGB stars) and, as a consequence, most of the dust is produced with a delay of about 1 Gyr with respect to the onset of star formation. At z>6 the age of the universe is less than 1 Gyr, thus falling short of time to produce dust through AGBs. Therefore, although other production mechanisms have been proposed, a strong decrease of the average dust mass in galaxies is expected at z>6, just because the main dust contributor is missing. Currently there are only hints of this effect, observed in the IR data of high-z QSOs (e.g. Jiang et al. 2006) and in the optical-UV SEDs of star forming galaxies (e.g. Eyles et al. 2006). The most sensitive tracer of the dust mass is its far-IR emission, which at z>6 is observed in the submm-mm range. However, currently there are only a few submm-mm detections, of hyperluminous QSOs, at z>6, preventing any meaningful investigation on the evolution of the dust mass at high-z. However, these observations reveal that in these few objects huge masses of dust ($\sim 10^8 M_\odot$) have already formed by z=6 (Beelen et al. 2006). Such large masses cannot be accounted for by AGB stars at such early times in the universe. An alternative, rapid channel of dust production are the ejecta of type II SNe (Todini & Ferrara 2001). The dust properties inferred from the extinction curve in QSOs at z>6 are consistent with the presence of SN dust (Maiolino et al. 2004). Whether dust production in SNe can be efficient enough to account for the whole dust mass observed in bright QSOs at z>6 is still under debate. The constraints on the SN dust yield inferred from Galactic SNRs are not conclusive (Spitzer mid-IR observation only probe the warm component of dust, while submm observations provide only loose upper limits). However, the recent Spitzer detection of dust forming in SN2003gd (Sugerman et al. (2006)) indicate a dust production efficiency which could account for the dust masses observed at z>6.

References

Beelen, A., et al. 2006, *ApJ* 642, 694
Eyles, L., et al. 2006, *MNRAS* submitt., astro-ph/0607306
Jiang, R., et al. 2006, *AJ* in press, astro-ph/0608006
Maiolino, R., et al. 2004, *Nature* 431, 533
Schneider et al. 2006, *MNRAS* 369, 1437
Sugerman et al. 2006, *Science* 313, 196
Todini, P. & Ferrara, A. 2001, *MNRAS* 325, 726

Highlights of Astronomy, Volume 14
XXVIth IAU General Assembly, August 2006
K.A. van der Hucht, ed.

DOI: 00.0000/X000000000000000X

Studying the first galaxies at centimeter and millimeter wavelengths

F. Walter[1], C. Carilli[2], F. Bertoldi[3], P. Cox[4] and K. Menten[5]

[1]Max Planck Insitut für Astronomie Heidelberg, Germany
[2]National Radio Astronomy Observatory, USA
[3]Bonn University, Germany
[4]IRAM, France
[5]Max Planck Insitut für Radioastronomie Bonn, Germany

Abstract.
Observations of the most distant (z∼6) QSOs in the centimetre and millimetre regime currently serve as the only direct probe of the host galaxies of these extreme systems in the Epoch of Reionization. Such observations reveal that about 1/3 of the hosts contain massive reservoirs of dust (>10^8 $M_\odot$) and molecular gas (> 10^10 $M_\odot$) – the fuel for galaxy formation, and also indicate coeval starbursts at a rate >10^3 $M_\odot$ yr^{-1}, adequate to form a large elliptical galaxy in a dynamical timescale. These data imply that a highly metal enriched, molecular ISM, can be generated in galaxies within 870 Myr of the big bang. High resolution imaging of the gas also provide an estimate of the host galaxy dynamical mass. However, current observations are restricted to rare, hyper-luminous IR galaxies. I will close by considering the prospects of observing the gas, dust, and star formation in the first 'normal' galaxies (eg. the Ly-α galaxies) into cosmic reionization (z>6), using ALMA and the EVLA.

Keywords. radio lines: ISM,radio lines: galaxies, quasars: general

---

We present some new results of our ongoing efforts to study the properties of the molecular gas and dust in high–redshift quasars. Our ongoing survey using MAMBO at the IRAM 30 m to detect dust emission in z∼6 QSOs has resulted in a number of new detections (Wang, Carilli et al. 2007, in prep.). As the detected objects are dust–rich they represent good targets to perform follow–up observations of the molecular gas phase. We also report on observations of the (rest–frame) FIR continuum of the GRB 050904 at z=6.29 with MAMBO which have resulted in a non–detection of the GRB host galaxy (Walter et al. 2006). Sensitive radio continuum observations of the quasars using the VLA have resulted in a number of new detections which reveal that at least some of the objects appear to be radio loud (Wang, Carilli, et al. 2007, in prep.). These observations provide a glimpse of what will be possible with the expanded (E)VLA, which will improve the continuum sensitivity of similar observations by an order of magnitude. Observations of the molecular gas phase in z∼6 objects are still limited by A) redshift uncertainties and B) the sensitivity of current instruments. This is the main reason why to date there is only one z>6 CO detection (the z=6.42 QSO J1148+5251, Walter et al. 2003, 2004). This situation will improve dramtically with the advent of new telescopes with larger bandwidths and collecting area (most notably ALMA) which will also enable us to map the CO emission in the host galaxies at these extreme redshifts. Of additional interest are detection and mapping experinents of the emission from ionized carbon which appears to be bright in the z=6.42 QSO (Maiolino et al. 2005)

Highlights of Astronomy, Volume 14
XXVIth IAU General Assembly, August 2006
K.A. van der Hucht, ed.

DOI: 00.0000/X000000000000000X

Spectroscopy of the near infrared afterglow of GRB 050904 at $z = 6.3$

N. Kawai[1]

[1]Department of Physics, Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro-ku, Tokyo 152-8551, Japan

Abstract. We present the optical/NIR spectrum of the afterglow of GRB 050904 obtained with the Faint Object Camera And Spectrograph on the Subaru 8.2m telescope taken 3.4 days after the burst. It is, as of June 2006, the only GRB with a known redshift larger than 6. The spectrum shows a clear continuum at the long wavelength end of the spectrum with a sharp cutoff at around 900 nm due to Ly alpha absorption at a redshift of 6.3 with a damping wing. Little flux is present in the waveband shortward of the Ly alpha break. A system of absorption lines of heavy elements at redshift $z = 6.295 \pm 0.002$ were also detected, yielding a precise measurement of the largest known redshift of a GRB. Analysis of the silicon and sulphur absorption lines suggests a dense environment around the GRB with the metallicity larger than 0.1 solar, providing unique information on the galaxy and star forming region at $z > 6$. This observation has shown that GRB is a powerful probe of the early Universe.

Keywords. galaxies:high-redshift, gamma rays: bursts

Highlights of Astronomy, Volume 14
XXVIth IAU General Assembly, August 2006
K.A. van der Hucht, ed.

DOI: 00.0000/X000000000000000X

Implications for the Cosmic Reionization from the Optical Afterglow Spectrum of the Gamma-Ray Burst 050904 at z = 6.3

Tomonori Totani[1], Nobuyuki Kawai[2], George Kosugi[3], Kentaro Aoki[4], Toru Yamada[3], Masanori Iye[3], Kouji Ohta[1] and Takashi Hattori[4]

[1]Department of Astronomy, Kyoto University, Sakyo-ku, Kyoto 606-8502, Japan
[2]Department of Physics, Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro-ku, Tokyo 152-8551, Japan
[3]National Astronomical Observatory of Japan, 2-21-1 Osawa, Mitaka, Tokyo 181-8588, Japan
[4]Subaru Telescope, National Astronomical Observatory of Japan, Hilo, HI 96720, USA

Abstract. The gamma-ray burst (GRB) 050904 at $z = 6.3$ provides the first opportunity of probing the intergalactic medium (IGM) by GRBs at the epoch of the reionization. Here we present a spectral modeling analysis of the optical afterglow spectrum taken by the Subaru Telescope, aiming to constrain the reionization history. The spectrum shows a clear damping wing at wavelengths redward of the Lyman break, and the wing shape can be fit either by a damped Lyα system with a column density of $\log(N_{\rm HI}/{\rm cm}^{-2}) \sim 21.6$ at a redshift close to the detected metal absorption lines ($z_{\rm metal} = 6.295$), or by almost neutral IGM extending to a slightly higher redshift of $z_{\rm IGM,u} \sim 6.36$. In the latter case, the difference from $z_{\rm metal}$ may be explained by acceleration of metal absorbing shells by the activities of the GRB or its progenitor. However, we exclude this possibility by using the light transmission feature around the Lyβ resonance, leading to a firm upper limit of $z_{\rm IGM,u} \leqslant 6.314$. We then show an evidence that the IGM was largely ionized already at $z = 6.3$, with the best-fit neutral fraction of IGM, $x_{\rm HI} = 0.00$, and upper limits of $x_{\rm HI} < 0.17$ and 0.60 at 68 and 95% C.L., respectively. This is the first direct and quantitative upper limit on $x_{\rm HI}$ at $z > 6$. Various systematic uncertainties are examined, but none of them appears large enough to change this conclusion. To get further information on the reionization, it is important to increase the sample size of $z \gtrsim 6$ GRBs, in order to find GRBs with low column densities ($\log N_{\rm HI} \lesssim 20$) within their host galaxies, and for statistical studies of Lyα line emission from host galaxies.

Keywords. cosmology: observations, cosmology: theory, early universe

1. Introduction

See Kawai et al. (2006) and Totani et al. (2006) for details of our work.

References

Kawai, N., et al. 2006, Nature, 440, 184
Totani, T., Kawai, N., Kosugi, G., Aoki, K., Yamada, T., Iye, M., Ohta, K., & Hattori, T. 2006, PASJ, 58, 485

Highlights of Astronomy, Volume 14
XXVIth IAU General Assembly, August 2006
K.A. van der Hucht, ed.

DOI: 00.0000/X000000000000000X

Cosmic Microwave Background: Probing the Universe from $z = 6$ to 1100

D.N. Spergel [1]

[1]Princeton University, Princeton, NJ, United States

Abstract. Observations of cosmic microwave background temperature and polarization fluctuations are sensitive to both physical conditions at recombination ($z = 1100$) and physical process along the line of sight. I will discuss recent results from the Wilkinson Microwave Anisotropy Probe and planned ground and space-based observations. The talk will emphasize the role of CMB observations in determining the initial conditions for the growth of structure and as a probe of the physics of reionization.

Keywords. galaxies:high-redshift, gamma rays: bursts

Highlights of Astronomy, Volume 14
XXVIth IAU General Assembly, August 2006
K.A. van der Hucht, ed.

DOI: 00.0000/X000000000000000X

Anisotropies of the IR Background and primordial Galaxies

Asantha R. Cooray

Center for Cosmology, Department of Physics and Astronomy, University of California, Irvine, CA 92697, USA

Abstract. We discuss anisotropies in the near-IR background between 1 to a few microns. This background is expected to contain a signature of primordial galaxies. We have measured fluctuations of resolved galaxies with Spitzer imaging data and we are developing a rocket-borne instrument (the Cosmic Infrared Background ExpeRiment, or CIBER) to search for signatures of primordial galaxy formation in the cosmic near-infrared extra-galactic background.

Keywords. large scale structure of universe — diffuse radiation — infrared: galaxies

---

The intensity of the cosmic near-infrared background (IRB) is a measure of the total light emitted by stars and galaxies in the Universe. While the absolute background has been estimated by space-based experiments, such as the Diffuse Infrared Background Experiment (DIRBE), the total IRB intensity measured still remains fully unaccounted for by sources. Primordial galaxies at redshifts 8 and higher, especially those involving Population III stars, are generally invoked to explain the missing IR flux between 1 μm and 2 μm, with most of the intensity associated with redshifted Lyman-α emission during reionization, though there are difficulties with such an assumption. As pointed out in Cooray et al. (2004), if a high-redshift population contributes significantly to the IRB, then these sources are expected to leave a distinct signal in the anisotropy fluctuations of the near-IR intensity, when compared to the anisotropy spectrum associated with low-redshift sources. In Sullivan et al. (2006), we presented clustering measurements at 3.6 μm in several fields of Spitzer IRAC data and we refer the reader to this work for more details and implications.

We are also developing a rocket-borne instrument (the Cosmic Infrared Background ExpeRiment, or CIBER) to search for signatures of primordial galaxy formation in the cosmic near-infrared extra-galactic background. CIBER consists of a wide-field two-color camera, a low-resolution absolute spectrometer, and a high-resolution narrow-band imaging spectrometer. The cameras will search for spatial fluctuations in the background on angular scales from 7 arcseconds to 2 degrees. In a short rocket flight CIBER has sensitivity to probe fluctuations 100 times fainter than DIRBE. By jointly observing regions of the sky studied by Spitzer and Akari, CIBER will build a multi-color view of the near-infrared background, allowing a deep and comprehensive survey for first-light galaxy background fluctuations. The low-resolution spectrometer will search for a redshifted Lyman cutoff feature between 0.8 - 2.0 microns. The high-resolution spectrometer will trace zodiacal light using the intensity of scattered Fraunhofer lines, providing an independent measurement of the zodiacal emission.

References

Cooray et al. 2004, ApJ, 606, 611
Sullivan et al. 2006, astro-ph/0609451

Highlights of Astronomy, Volume 14
XXVIth IAU General Assembly, August 2006
K.A. van der Hucht, ed.

DOI: 00.0000/X000000000000000X

Additional sources of ionization in early universe and 21 cm line

Evgenii O. Vasiliev[1,2] and Yuri A. Shchekinov[3]

[1]Tartu Observatory, 61602 Tõravere, Estonia [2]Institute of Physics, University of Rostov, Stachki Ave. 194, Rostov-on-Don, 344090 Russia
email: eugstar@mail.ru
[3]Department of Physics, University of Rostov, Sorge St. 5, Rostov-on-Don, 344090 Russia
email: yus@phys.rsu.ru

Abstract. We consider the influence of decaying dark matter particles and ultra-high energy cosmic rays (UHECRs) on the ability of neutral gas at redshifts $z = 10-50$ to emit and absorb in the 21 cm line . We show that the signal in 21 cm is sensitive to properties of decaying particles and UHECRs, and conclude that future radio telescopes (LOFAR, LWA and SKA) are able not only to detect 21 cm signal originated from decaying particles and UHECRs, but discriminate between them as well.

Keywords. early universe, dark matter, diffuse radiation

Decaying dark matter particles can strongly affect the reionization of the universe (e.g. Chen & Kamionkowski (2004)). Additional ionization and heating from such particles before the reionization affects also the ability of neutral gas to absorb or emit in 21 cm line. Thus the decaying dark matter can influence the cosmological 21 cm background. We consider three sorts of decaying dark matter particles: long- and short-living particles, as well as ultra-high energy cosmic rays (UHECRs), if they form from decaying superheavy dark matter particles (e.g. Berezinsky et al (1997)). The long-living particles provide permanent heating, so the gas kinetic temperature grows towards lower redshifts. Contrary, in case of the short-living particles the injection rate of heat decreases fastly, when the lifetime of particles becomes comparable with the comoving age of the universe, which manifests in a relatively fast decrease of the kinetic temperature at low redshfts. The UHECRs produce only Ly-c and Ly-α photons, which give negligible heating, and the major influence on the 21 cm brightness temperature history is through the Wouthuysen-Field effect. We show that long-living and short-living unstable dark matter particles and UHECRs produce fairly distinct dependences of brightness temperature on redshift $T_b(z)$ – the first and the third give negative and positive second derivatives of the curves $T_b(z)$, while the second has $T_b(z)$ with an inflection point. This circumstance may have a principal significance for choosing a strategy for observational discrimination between these sources of ionization. In the presence of UHECRs 21 cm can be seen in absorption with the brightness temperature $T_b = -(5-10)$ mK in the range $z = 10-30$. Decayng particles can stimulate a 21 cm signal in emission with $T_b \sim 50-60$ mK at $z = 50$, and $T_b \simeq 10$ mK at $z \sim 20$. Future radio telescopes (such as LOFAR, LWA and SKA) seem to have sufficient flux sensitivity for detection the signal in 21 cm influenced by decaying particles and UHECRs.

References

Berezinsky, V.S., Kachelrieß, M. & Vilenkin, A., 1997, *Phys. Rev. Lett.* 79, 4302
Chen, X. & Kamionkowski, M., 2004, *Phys. Rev. D* 70, 043502

Highlights of Astronomy, Volume 14
XXVIth IAU General Assembly, August 2006
K.A. van der Hucht, ed.

DOI: 00.0000/X000000000000000X

Assessing the influence of metallicity on fragmentation of protogalactic gas

A.-K. Jappsen[1,2], S.C.O. Glover[2], R.S. Klessen[3] and M.-M. Mac Low[4]

[1] Canadian Institute for Theoretical Astrophysics, University of Toronto, Toronto, ON M5S 3H8, Canada; email: jappsen@cita.utoronto.ca

[2]Astrophysikalisches Institut Potsdam, An der Sternwarte 16, 14482 Potsdam, Germany; email: sglover@aip.de

[3] Insitut für Theoretische Astrophysik / Zentrum für Astronomie der Universität Heidelberg, Albert-Überle-Str. 2, 69120, Germany; email: rklessen@ita.uni-heidelberg.de

[4]Department of Astrophysics, American Museum of Natural History, 79th Street at Central Park West, New York, NY 10024-5192, USA; email: mordecai@amnh.org

Abstract. In cold dark matter cosmological models, the first stars to form are believed to do so within small protogalaxies. We study the influence of low levels of metal enrichment on the cooling and collapse of ionized gas in these protogalactic halos using three-dimensional, smoothed particle hydrodynamics simulations.

Keywords. stars: formation, methods: numerical, hydrodynamics, early universe

---

We wish to understand how the evolution of early protogalaxies changes once the gas forming them has been enriched with small quantities of heavy elements, which are produced and dispersed into the intergalactic medium by the first supernovae. Adding heavy elements to the gas increases its ability to radiate heat and to control its temperature. It has been argued that enrichment beyond a certain "critical metallicity" allows the first solar-mass stars to form, while protogalaxies with fewer metals form only massive stars, with masses greater than a hundred times solar. This idea has been accepted as a working hypothesis by many cosmologists, but it has yet to be rigorously tested. Although observational tests will not be feasible until the next generation of telescopes become available, we can begin to test this idea numerically, using high-resolution hydrodynamic simulations that incorporate the effects of the appropriate chemical and thermal processes. Our initial conditions represent protogalaxies forming within a fossil HII region – a previously ionized region that has not yet had time to cool and recombine. We vary the initial redshift between $z = 15$ and $z = 30$ and the dark matter halo masses between 5×10^4 and 10^7 $M_\odot$. The gas mass resolution lies between 20 and 400 $\mathrm{M}_\odot$ (Jappsen et al. 2006). Our simulations demonstrate that for metallicities $\mathrm{Z} \leqslant 10^{-3}$ $\mathrm{Z}_\odot$, metal line cooling alters the density and temperature evolution of the gas by less than 1% compared to the metal-free case at low densities ($n < 1\,\mathrm{cm}^{-3}$) and high temperatures ($T > 2000\,\mathrm{K}$). We also present the results of high-resolution simulations using particle splitting (Kitsionas & Whitworth 2002) to improve resolution in regions of interest. These high-resolution simulations allow us to address the question of whether or not there is a critical metallicity above which fine structure cooling from metals allows efficient fragmentation to occur, producing a modern IMF rather than only high-mass stars.

References

Kitsionas, S. & Whitworth, A.P. 2002, *MNRAS* 330, 129
Jappsen, A.-K., Glover, S.C.O., Klessen, R.S. & Mac Low, M.-M. 2006, *astro-ph/0511400*

Highlights of Astronomy, Volume 14
XXVIth IAU General Assembly, August 2006
K.A. van der Hucht, ed.

DOI: 00.0000/X000000000000000X

UV Radiative Feedback on High–Redshift Proto–Galaxies

Andrei Mesinger, Greg L. Haiman, and Zoltán Haiman
Department of Astronomy, Columbia University, 550 West 120th Street, New York, NY 10027

Abstract. We use three-dimensional hydrodynamic simulations to investigate the effects of a transient photoionizing ultraviolet (UV) flux on the collapse and cooling of pregalactic clouds. These clouds have masses in the range 10^5 – 10^7 $M_\odot$, form at high redshifts ($z \gtrsim 18$), and are assumed to lie within the short–lived cosmological HII regions around the first generation of stars. In addition, we study the combined effects of this transient UV flux and a persistent Lyman–Werner (LW) background (at photon energies below 13.6eV) from distant sources. In the absence of a LW background, we find that a critical specific intensity of $J_{\rm UV} \sim 0.1 \times 10^{-21}$ergs s^{-1} cm^{-2} Hz^{-1} sr^{-1} demarcates a transition from net negative to positive feedback for the halo population. A weaker UV flux stimulates subsequent star formation inside the fossil HII regions, by enhancing the H_2 molecule abundance. A stronger UV flux significantly delays star–formation by reducing the gas density, and increasing the cooling time, at the centers of collapsing halos. At a fixed $J_{\rm UV}$, the sign of the feedback also depends strongly on the density of the gas at the time of UV illumination. Regardless of whether the feedback is positive or negative, we find that once the UV flux is turned off, its impact starts to diminish after $\sim 30\%$ of the Hubble time. In the more realistic case when a LW background is present, with $J_{\rm LW} \gtrsim 0.01 \times 10^{-21}$ergs s^{-1} cm^{-2} Hz^{-1} sr^{-1}, strong suppression persists down to the lowest redshift ($z = 18$) in our simulations. Finally, we find evidence that heating and photoevaporation by the transient UV flux renders the $\sim 10^6$ M$_\odot$ halos inside fossil HII regions more vulnerable to subsequent H_2 photo–dissociation by a LW background.

Keywords. cosmology: theory – early Universe – galaxies: high-redshift – evolution

1. Introduction

See Mesinger et al. (2006) for details of our work.

References

Mesinger, A., Bryan, G.L., & Haiman, Z. 2006, ApJ, 648, 835

Highlights of Astronomy, Volume 14
XXVIth IAU General Assembly, August 2006
K.A. van der Hucht, ed.

DOI: 00.0000/X000000000000000X

Part 5. Poster papers of parts 1 to 4

1. A high-accuracy method for the removal of point sources from maps of the cosmic microwave background.

Authors: *A.T. Bajkova*

2. A universe with both decelaration and acceleration.

Authors: *L.N. de Silva*

3. CMB quadrupole induced polarisation from large scale structure.

Authors: *G. Liu, A. da Silva, N. Aghanim*

4. Modeling $z \sim 3$ Lyman-alpha spectra to gain insight into high redshift Lyman-alpha emitters.

Authors: *A. Verhamme, D. Schaerer*

5. News from $z \sim$ 6–10 galaxy candidates found behind gravitational lensing clusters.

Authors: *A. Hempel, D. Schaerer, R. Pelló, E. Egami, J. Richard, J.-P. Kneib, M. Wise*

6. Nucleosynthesis without a beginning.

Authors: *G.R. Burbidge*

7. Observational test on a generalized theory of gravity.

Authors: *S. Rahvar, M.M. Sheikh Jabbari, S. Baghram, F. Habibi*

8. Probing weakest extragalactic magnetic fields with gamma-ray bursts.

Authors: *K. Ichiki, K. Takahashi, S. Inoue*]

9. SDSS J0836+0054: a radio quasar at $z \sim 6$ with a resolution of 40 pc.

Authors: *S. Frey, Z. Paragi, L. Mosoni, L.I. Gurvits*

10. Space/time, supernovae, and the faint young sun.
Authors: *L.M. Riofrio*

11. Stability and formation of cluster of galaxies, galaxies, clusters of stars and stars in some cosmological models.
Authors: *M.I. Wanas, A.B. Morcos, M.A. Bakry*

12. Subaru deep imaging of the field of QSO 1508+5714 at $z = 4.28$.
Authors: *Y.P. Wang, Y.P. Wang, T. Yamada, I. Tanaka, M.Iye*

13. The 21-cm signature of the early radiation sources.
Authors: *L. Chuzhoy, M.A., Alvarez, P.R. Shapiro*

14. The mass loss from hot Pop III star.
Authors: *J. Krticka, J. Kubat*

15. The spectrum of primordial gravitational waves.
Authors: *M. Soares-Santos, E. M. de Gouveia Dal Pino*

Subject Index

Object Index

Author Index