LOOKING FOR THE FIRST GALAXIES WITH EMIR/GTC

R. Pello and D. Schaerer
Laboratoire d’Astrophysique de l’Observatoire Midi-Pyrénées, Toulouse, France

ABSTRACT

The new Pop III models by Schaerer (2002) have been used to derive the observed properties of the first galaxies in terms of the expected magnitudes and colors. The dependence of their properties on the IMF and upper mass limit for star formation are studied. The emerging synthetic spectra are used to discuss the implications on different observational features. Strong emission lines, such as Lyman-alpha and HeII \( \lambda 1640 \), could easily be detected with a good S/N with near-IR medium resolution spectrographs, such as EMIR at GTC. Our simulations aim at exploring possible observational constraints on the formation epoch of the first stars in galaxies.

Key Words: COSMOLOGY: EARLY UNIVERSE — GALAXIES: HIGH REDSHIFT — GALAXIES: EVOLUTION — INFRARED: GALAXIES

1. INTRODUCTION

In recent years, important advances have been made on the modeling of the first stars and galaxies forming out of primordial matter in the early Universe, the so-called Population III objects (cf. review of Loeb & Barkana 2001, proceedings of Weiss et al. 2000 and Umemura & Susa 2001). The detection of such sources, which constitute the first building blocks of galaxies, remains one of the major challenges of present day observational cosmology. Recent modelling efforts are motivated by the future space facilities such as NGST, which should be able to observe these objects at redshifts up to \( z \sim 30 \). Nevertheless, the detection and first studies on the physical properties of Population III objects could likely be started earlier using ground-based 10m class telescopes. Near-IR multi-object spectrographs, with intermediate resolution capabilities, such as EMIR at GTC (~2005) and the future KMOS at VLT (~2008), will allow observations of Population III objects up to redshifts of \( z \sim 18 \).

Among the expected direct observational signatures of Pop III stars or galaxies (i.e. ensembles/clusters of Pop III stars) we can mention:

- Strong UV emission and characteristic recombination lines of hydrogen and He II, especially Lyman \( \alpha \) and HeII (Tumlinson & Shull 2000, Bromm et al. 2001b, Schaerer 2002).
- Mid-IR molecular hydrogen lines at 2.12 \( \mu m \) and longer wavelengths formed in cooling shells (Ciardi & Ferrara 2001).
- Individual supernovae whose visibility in the rest-frame optical and near-IR could be enhanced due to time dilatation (Miralda-Escude & Rees 1997, Heger et al. 2001).
- High energy neutrinos from Pop III gamma-ray bursts eventually associated with fast X-ray transients (Schneider et al. 2002).

Rest-frame UV stellar and nebular continuous and recombination line emission represent the largest fraction of the energy emitted by Population III objects, which are generally thought to be predominantly massive or very massive stars (e.g. Abel et al. 1998, Bromm et al. 2001a, Nakamura & Umemura 2001).
2. SIMULATIONS OF POP III STELLAR SYSTEMS

Simulations have been done to support this scientific case, in view of the future near-IR facilities, such as EMIR at GTC and the future KMOS at VLT (preliminary version: Schaerer & Pelló 2001). A popular cosmology is adopted: Ω_m = 0.3, Ω_Λ = 0.7, Ω_b=0.05, H_0 = 75 km s^{-1}Mpc^{-1}). The reionization redshift is assumed to be \sim 6, but a small change in this value does not modify the conclusions of this paper. Lyman series troughs (Haiman & Loeb 1999), and Lyman forest following the prescription of Madau (1995) are included. We consider a fiducial stellar mass halo of 10^7 M_☉, corresponding to a collapsing DM halo of 2\times10^8 M_☉, thus typically to \sim 1.5 to 2 \sigma fluctuations between z=5 and 10 (e.g. Loeb & Barkana 2001). Magnitudes and S/N ratios are to be rescaled according to this value for other mass halos. The virial radius is of the order of a few kpc, and thus we consider that sources are unresolved on a 0.3" scale, with spherical symmetry. Simulations accounting for an extended Lyman α halo (cf. Loeb & Rybicki 1999) have also been performed (Pelló & Schaerer 2002).
We have considered different IMFs and ages for the stellar population, as well as two different star formation regimes (starburst and continuous star formation), following the prescriptions given by Schaerer (2002). Magnitudes and colors were derived for these sources in the visible and near-IR. A complete set of results will be presented in Pelló & Schaerer (2002). We have also computed the expected S/N ratios for the main emission lines. In this case, telescope parameters correspond to the GTC. The characteristics of the near-IR spectrograph are set similar to the expectations for EMIR (Balcells et al. 2000), with 0.2"/pixel, 1" slit-width, 0.8" seeing, and a mean total efficiency of 40%. All simulations shown subsequently were calculated for a young population, with a Salpeter IMF from 1 to 500 M⊙ (somewhat more “favourable” than a constant star formation case). Spectral resolutions from R=1000 to 5000 were considered.

3. SUMMARY OF RESULTS

3.1. Photometric properties

The importance of the nebular continuous emission, neglected in earlier studies (Tumlinson & Shull 2000, Bromm et al. 2001b), is shown in Figure 1. The predicted magnitude in the K' band is typically ∼ 24 to 25 for the reference halo mass. Similar effects are seen in J and H bands (see also Schaerer & Pello 2001). Examples of broad-band colors are given in Figure 2. Broad-band colors do not allow to constrain physical properties such as the IMF (i.e. the mass range of Pop III stars), ages, etc., but could be useful to identify the sources on ultra-deep photometric surveys (cf. below). Spectroscopy is needed to study the physics of these objects.

3.2. Spectroscopic properties

The expected S/N for the HeII λ1640 and Lyman α lines versus the redshift of the source (observed in the JHK bands), for a spectral resolution R=1000 and a nominal exposure time of 10⁵ sec, are shown in Figure 3. The simulations illustrate the following:

Lyman α can easily be detected with a good S/N over the redshift intervals z ∼ 8 to 18, with some gaps, depending on the spectral resolution (OH subtraction) and atmospheric transmission. A joint detection with HeII λ1640, the strongest HeII line, is possible for z ∼ 5.5-7.5 (Lyman α in optical domain), z ∼ 8-14 with both lines in the near-IR, again with some gaps. The typical line fluxes for the HeII λ1640 line range between 10⁻¹⁷ and a few 10⁻¹⁸ erg/s/cm².

The detection of both HeII λ1640 and Lyman α allows one e.g. to obtain a measure of the hardness of the ionising flux which constrains the upper end of the IMF and the age of Pop III systems. Measuring the continuum, when possible, will provide additional information on the stellar populations, extinction, etc.

Higher spectral resolution (R ∼ 5000) considerably increases the chances of detection between the sky lines. For unresolved lines (such as expected for HeII) the resulting decrease of S/N is modest. The medium spectral resolution is also favoured to attempt to measure the emission line profiles, in order to distinguish Pop III sources from potential very high-z AGN (cf. Tumlinson et al. 2001). Once this is obtained, the data can be rebinned to increase the S/N.
4. DISCUSSION AND FUTURE PROSPECTS

The expected number of Pop III objects and primordial QSOs has been derived by several authors. E.g. in a comprehensive study Ciardi et al. (2000) show that at z > 8 naked stellar clusters, i.e. objects which have completely blown out their ISM, and thus avoid local chemical enrichment, dominate the population of luminous objects. Although pilot studies have recently started to explore the possible formation of dust in Pop III objects (Todini & Ferrara 2001), the effect is generally neglected. Based on such assumptions, Oh et al. (2001) have calculated the predicted number of Pop III objects detectable in HeII lines with NGST for a one day integration time. Their estimate yields between 60 and 4500 sources in a 10′x10′ field of view, depending on the model parameters. The expected density of primordial quasars could be similar to that of PopIII galaxies (Oh et al. 2001). Thus, multiplexing is needed to allow highly efficient observations of relevant samples of Pop III objects.

An important issue for spectroscopic studies is the strategy for source selection. Given their peculiar SED (strong nebular continuous emission + lines) young Pop III bursts, or Pop III objects with ongoing massive star formation show distinct characteristics in their near-IR colors compared to “normal” galaxies at any redshift (Pelló & Schaerer 2002). Such objects could be detected from deep near-IR photometry based on a measurement of two colors with accuracies of the order of 0.2 mag. Ideal fields for the first studies are lensing galaxy clusters with areas of strong gravitational amplification, and other very deep fields with near-IR photometry. Also IFU near-IR observations could allow to detect the strong HeII emission lines. Because the observational signatures of primordial quasars are expected to be similar to those of genuine Pop III stars, a relatively high resolution is needed to obtain line profiles.

Thanks to its multiplexing, spectral resolution and wide field-of-view capabilities, EMIR at GTC is the suited instrument to start exploring the formation epoch of the first stars in galaxies.

This work has been done within the framework of the Cosmos/EMIR collaboration. We are grateful to A. Ferrara, J.P. Kneib and J. F. Le Borgne for interesting comments and discussion. Part of this work was supported by the French Centre National de la Recherche Scientifique, by the French Programme National de Cosmologie (PNC) and Programme National Galaxies.

REFERENCES

Abel, T., Anninos, P.A., Norman, M.L., Zhang, Y., 1998, ApJ 508, 518
Balcells, et al., 2000, SPIE 4008, 797
Bromm, V., Coppi, P.S., Larson, R.B., 2001a, ApJ 564, 23
Bromm, V., Kudritzki, R.P., Loeb, A., 2001b, ApJ 552, 464
Ciardi, B., Ferrara, A., Governato, F., Jenkins, A., 2000, MNRAS 314, 611
Ciardi, B., Ferrara, A., 2001, MNRAS 324, 648
Haiman, Z., Loeb, A., 1998, ApJ 503, 505
Heger, A., et al., 2001, astro-ph/0112059
Loeb, A., Barkana, R., 2001, ARAA 39, 19
Loeb, A., Rybicki, G.B., 1999, ApJ 524, 527
Madau, P. 1995, ApJ 441, 18
Miralda-Escude, J., Rees, M.J., 1997, ApJ 478, L57
Nakamura, F., Umemura, M., 2001, ApJ 548, 19
Oh, S.P., Haiman, Z., Rees, M.J., 2001, ApJ 553, 730
Pelló, R., Schaerer, D., 2002, A&A, in preparation
Schaerer, D., 2002, A&A 382, 28 (astro-ph/0110697)
Schaerer, D., Pelló, R., 2001, in “Scientific Drivers for ESO Future VLT/VLTI Instrumentation”, J. Bergeron and G. Monnet, Eds., Springer Verlag, in press astro-ph/0107274
Schneider, R., Guetta, D, Ferrara, A., 2002, ApJ, submitted astro-ph/0203432
Todini, P., Ferrara, A., 2001, MNRAS 325, 726
Tumlinson, J., Shull, J.M., 2000, ApJ 528, L65
Tumlinson, J., Giroux, M.L., Shull, J.M., 2001, ApJ 550, L1
Umemura, M., Susa, H., 2001, “Cosmic Reionization and Galaxy Formation”, Proceedings of the “The Physics of Galaxy Formation”, ASP Conf. Ser. 222, Eds. M. Umemura and H. Susa, p, 109 astro-ph/0108170
Weiss, A., Abel, T., Hill, V., Eds., 2000, “The First Stars”, Proceedings of the MPA/ESO Workshop 1999, Garching, Germany, Spring Verlag, Heidelberg

R. Pelló and D. Schaerer: Laboratoire d’Astrophysique de l’Observatoire de Toulouse, Edouard-Bélin, F-31400 Toulouse, France (roser.schaerer@ast.obs-mip.fr)