Emission line measurements in the magnified z = 3.357 HII region behind the cluster RX J0848+4456

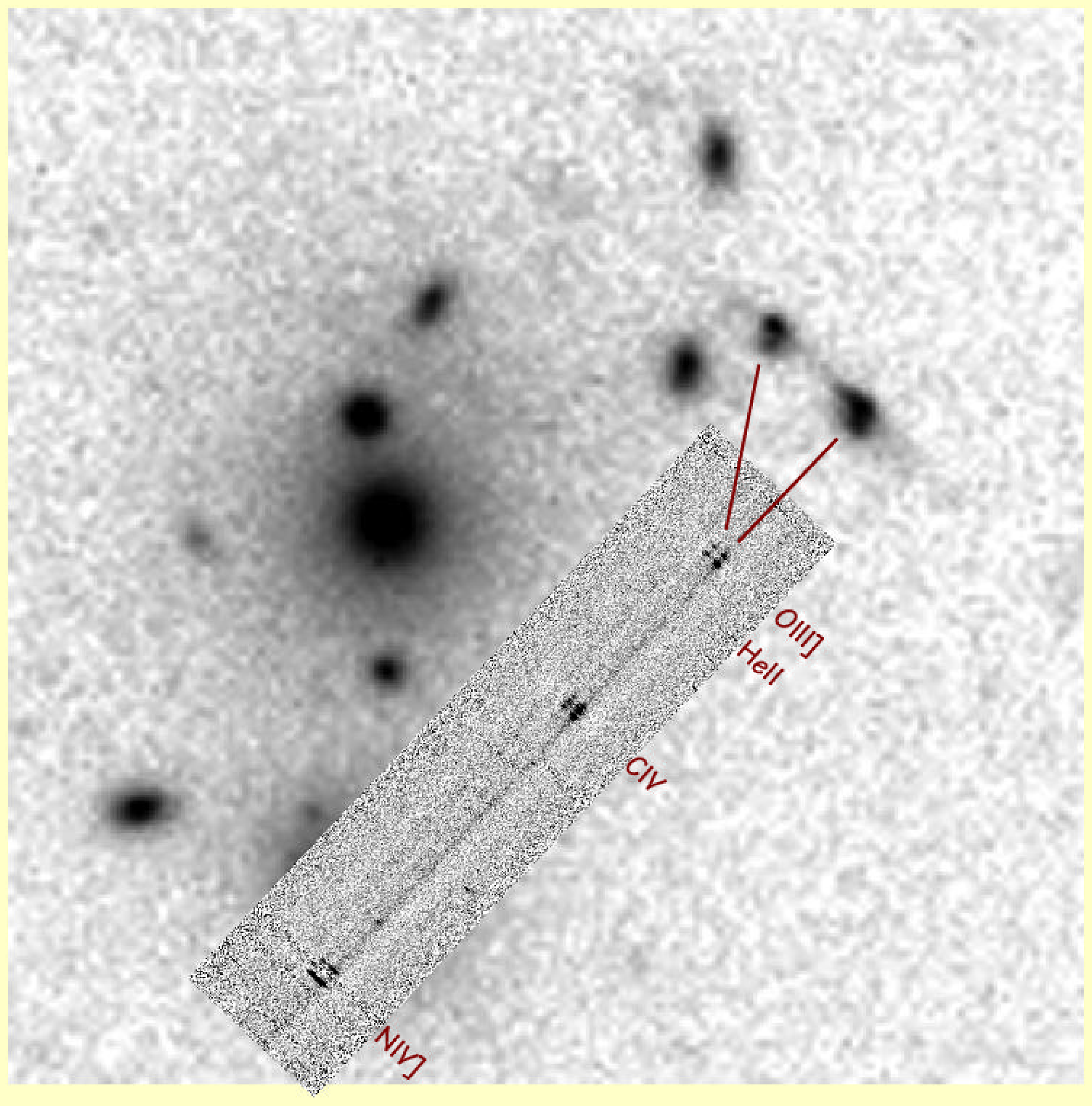
R A E Fosbury (ST-ECF)
A Humphrey & M Villar-Martín
(University of Hertfordshire)
P Rosati (ESO)
G Squires (Caltech)
S A Stanford & B P Holden
(University of California, Davis)
M Rauch (Carnegie Observatories)

Introduction

Emission line spectroscopy of stellar-photoionized nebulæ (HII regions/galaxies) at high redshift is crucial for tracking the chemical evolution of galaxies at early epochs. The recognition of 'primordial' HII regions will be based on both the gas-phase element abundances — measured from emission line ratios — and on the effective temperature of the ionizing stellar radiation field which is dependent on the upper end of the stellar mass function. The desire to find and analyse such objects is one of the primary scientific drivers for the NGST NIR spectroscopy (Kennicutt, R. 1998, ESA SP-429, p81) that will allow measurements to be made of the restframe optical spectrum.

In addition to their obvious importance for element abundance studies, such objects offer the intriguing possibility of studying the size and mass of objects that are seeing perhaps their first burst of star formation. While the calibration of the relationship between HII region/galaxy emission line velocity dispersions and $H\beta$ luminosity has been carried out in the local Universe (Melnick, Terlevich & Terlevich, 1999, MNRAS, 311, 629, MTT, and references therein), the extension of this technique to high redshifts (and hence, presumably, low metallicities) can be of real value as a cosmological tool. This poster reports measurements of restframe UV emission line strengths and widths in an HII region at z = 3.357, lensed by a cluster at z = 0.543.

Emission line objects with weak continua are difficult to find using broad-band imaging techniques. This has stimulated spectroscopic searches from the ground, notably ones using clusters as magnifying lenses (Ellis et al. 2001, ApJ, 560, L119).



An HST WFPC2 image of the the region of the arc (upper right). This is a combination of 10 x 1200s exposures in F702W. The two bright condensations in the arc have identical spectra. They are clearly resolved radially as well as tangentially. The overlay shows part of the LRIS spectrum from Holden et al. (2001) with the slit aligned along the arc.

Holden et al. (2001, AJ, 122, 629) have reported the serendipitous discovery of a bright emission line arc in the cluster RX J0848+4456 which shows narrow emission lines of NIV] 1486; CIV 1550; HeII 1640 and OIII] 1664 at a redshift of 3.36.

The two components of the arc and the extended morphology imply that the source object lies along a fold caustic. Our first approximation to a strong lensing model (with z_{lens} = 0.543, z_{source} = 3.357) predicts a velocity dispersion of the lens of 480 km/s, in good agreement with the measurment of the velocity dispersion of the lensing cluster, and a magnification of ~ 1.3 mag.

New data

We have obtained a moderately high (R ~ 4,000) resolution optical spectrum with the Keck ESI spectrograph — a one hour exposure of the brighter of the two arc components (Fosbury et al. in prep.) — and are able to measure additional emission lines, notably Ly_α and CIII] 1909.

This allows us to derive accurate line widths for all lines and to study the prominent absorption components in Ly_α and CIV.

Discussion

From photoionization modelling, the nebula is ionized by stars with an effective temperature of at least 75,000K. The gas metallicity is a few percent of Solar. The ionization parameter is quite high, U ~ 0.1. Such stellar temperatures and low gas metallicities are approaching the extreme values expected for a primordial HII region ionized by first generation stars (see eg. Bromm, Kudritzki & Loeb, 2001, ApJ, 552, 464).

From the CIII] doublet ratio, the elecron density is near the low density limit, ie. $n_e \leq 10^{3.5}$ cm^{-3}

The velocity dispersions measured for the doubly ionized lines OIII] and CIII] are around 37 km/s while the values for the triply ionized NIV and CIV are larger, ~ 90 km/s.

The absorptions in Ly_α and CIV indicate an outflowing wind in a high state of ionization.

Using the width of the OIII] lines in the MTT calibration

$\log L(H_\beta) = 5 \log \sigma - \log O/H + 29.5$

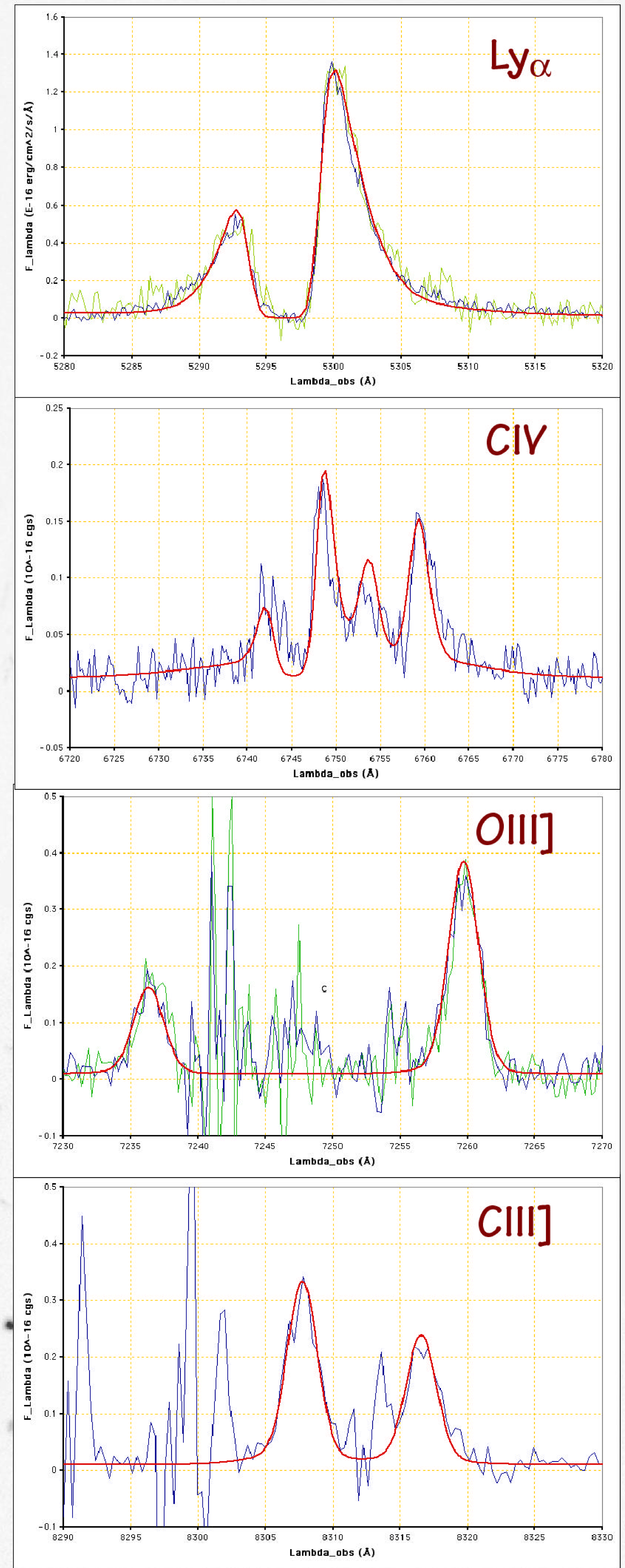
allows us to estimate the intrinsic H_β luminosity assuming [O/H] = -1.3. The resulting value, $\log L(H_\beta)$ = 41.7 (cgs), can be used as a 'standard candle' to investigate the combination of the cosmology and the lensing model.

Inferring the H_β flux from the UV line spectrum and our photoionization model (which gives OIII]/H_β = 0.7) , using a cosmology with H_0 = 65, Ω_M = 0.3 and Ω_Λ = 0.7 and using our initial magnification estimate of 1.3 mag, this translates to an observed, lensing corrected value of $\log L(H_\beta)$ = 42.9. This difference of just over a dex could be ascribed to the magnification estimate (which we are refining), the calibration of the MTT σ-L relationship at low metallicity or the cosmological model.

The refining of this technique should offer access to a powerful probe of both astrophysics at high z and of cosmological parameters.

Å		E-16 erg/cm^2/s			km/s
Line	Lambda_rest	Flux	error	Unabsorbed_flux	Sigma_corr
Ly-a	1215	7.52	0.60	23.5	190
NIV]	1486	1.05	0.16		98
CIV	1550	1.76	0.32	10	80
HeII	1640	0.33	0.11		
OIII]	1664	1.43	0.09		36
CIII]	1909	1.84	0.18		39

Measurements of velocity dispersion (of the dominant narrow component corrected for instrumental resolution) and total flux for the strong emission lines in the arc. These are measured from the 1 hour exposure Keck ESI spectrum.



Sections of the Keck ESI spectrum of the brighter arc component plotted as observed flux per unit wavelength vs. observed wavelength. Regions which appear in two orders appear as overplotted spectra. The red lines show gaussian fits from which the velocity dispersions and line strengths are derived. Both Ly_α and CIV include absorption components with pure gaussian absorption coefficients.

Based on observations from the W M Keck Observatory and the NASA/ESA Hubble Space Telescope.