arXiv:1805.07364v1 [astro-ph.GA] 18 May 2018

Characterizing Circumgalactic Gas around Massive Ellipticals at $z \sim 0.4$ I. Initial Results*

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22 May 2018

ABSTRACT

We present a new *Hubble Space Telescope* (*HST*) Cosmic Origins Spectrograph (COS) absorption-line survey to study halo gas around 16 luminous red galaxies (LRGs) at $z = 0.21 - 0.55$. The LRGs are selected uniformly with stellar mass $M_{\rm star} > 10^{11}\,{\rm M}_\odot$ and no prior knowledge of the presence/absence of any absorption features. Based on observations of the full Lyman series, we obtain accurate measurements of neutral hydrogen column density $N({\rm H\,I})$ and find that high-$N({\rm H\,I})$ gas is common in these massive quiescent halos with a median of $\langle \log N({\rm H\,I})\rangle = 16.6$ at projected distances $d \lesssim 160$ kpc. We measure a mean covering fraction of optically-thick gas with $\log N({\rm H\,I}) \gtrsim 17.2$ of $\langle\kappa\rangle_{\rm LLS} = 0.44^{+0.12}_{-0.11}$ at $d \lesssim 160$ kpc and $\langle\kappa\rangle_{\rm LLS} = 0.71^{+0.11}_{-0.20}$ at $d \lesssim 100$ kpc. The line-of-sight velocity separations between the H I absorbing gas and LRGs are characterized by a mean and dispersion of $\langle v_{\rm gas-gal}\rangle = 29$ km s^{-1} and $\sigma_{\langle v_{\rm gas-gal}\rangle} = 171$ km s^{-1}. Combining COS FUV and ground-based echelle spectra provides an expanded spectral coverage for multiple ionic transitions, from low-ionization Mg II and Si II, to intermediate ionization Si III and C III, and to high-ionization O VI absorption lines. We find that intermediate ions probed by C III and Si III are the most prominent UV metal lines in LRG halos with a mean covering fraction of $\langle\kappa({\rm C\,III})\rangle_{0.1} = 0.75^{+0.08}_{-0.13}$ for $W_r(977) \geqslant 0.1$ Å at $d < 160$ kpc, comparable to what is seen for C III in L_* and sub-L_* star-forming and red galaxies but exceeding Mg II or O VI in quiescent halos. The COS-LRG survey shows that massive quiescent halos contain widespread chemically-enriched cool gas and that little distinction between LRG and star-forming halos is found in their H I and C III content.

Предшествующая работа (группа J. Tumlinson)

arXiv:1702.02618v1 [astro-ph.GA] 8 Feb 2017

THE COS-HALOS SURVEY: METALLICITIES IN THE LOW-REDSHIFT CIRCUMGALACTIC MEDIUM [1]

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[1]Based on observations made with the NASA/ESA Hubble Space Telescope, obtained at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-26555. These observations are associated with programs 13033 and 11598.

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ABSTRACT

We analyze new far-ultraviolet spectra of 13 quasars from the $z \sim 0.2$ COS-Halos survey that cover the H I Lyman limit of 14 circumgalactic medium (CGM) systems. These data yield precise estimates or more constraining limits than previous COS-Halos measurements on the H I column densities $N_{\rm HI}$. We then apply a Monte-Carlo Markov Chain approach on 32 systems from COS-Halos to estimate the metallicity of the cool ($T \sim 10^4$ K) CGM gas that gives rise to low-ionization state metal lines, under the assumption of photoionization equilibrium with the extragalactic UV background. The principle results are: (1) the CGM of field L^* galaxies exhibits a declining H I surface density with impact parameter $R_\perp$ (at $> 99.5\%$ confidence), (2) the transmission of ionizing radiation through CGM gas alone is $70 \pm 7\%$; (3) the metallicity distribution function of the cool CGM is unimodal with a median of $10^{-0.51}\,Z_\odot$ and a 95% interval $\approx 1/50\,Z_\odot$ to $> 3\,Z_\odot$. The incidence of metal poor ($< 1/100\,Z_\odot$) gas is low, implying any such gas discovered along quasar sightlines is typically unrelated to L^* galaxies; (4) we find an unexpected increase in gas metallicity with declining $N_{\rm HI}$ (at $> 99.9\%$ confidence) and, therefore, also with increasing $R_\perp$. The high metallicity at large radii implies early enrichment. (5) A non-parametric estimate of the cool CGM gas mass is $M_{\rm CGM}^{\rm cool} = (9.2 \pm 4.3) \times 10^{10} M_\odot$, which together with new mass estimates for the hot CGM may resolve the galactic missing baryons prob-

Prochaska+,2017

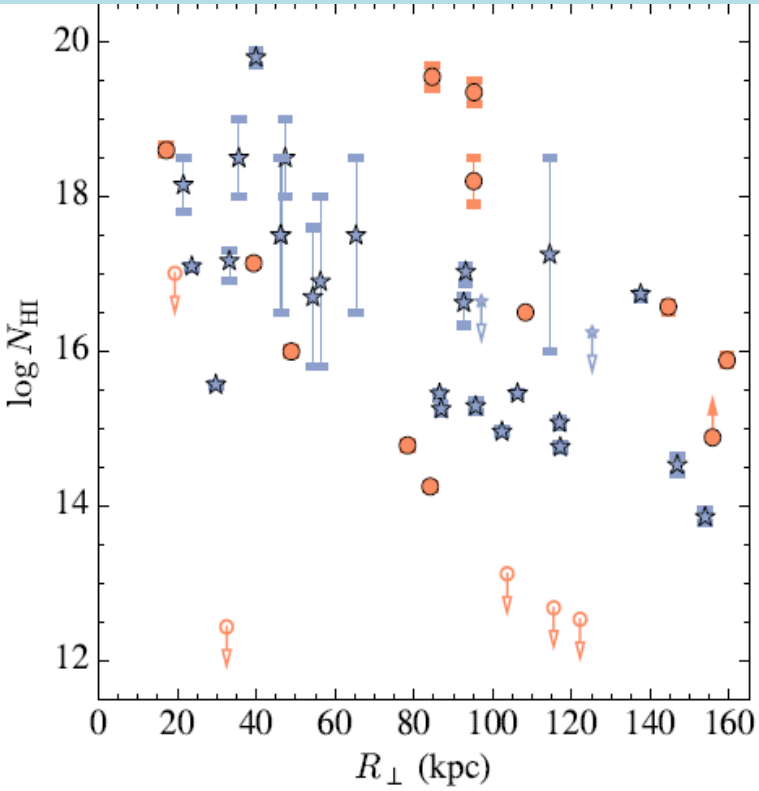
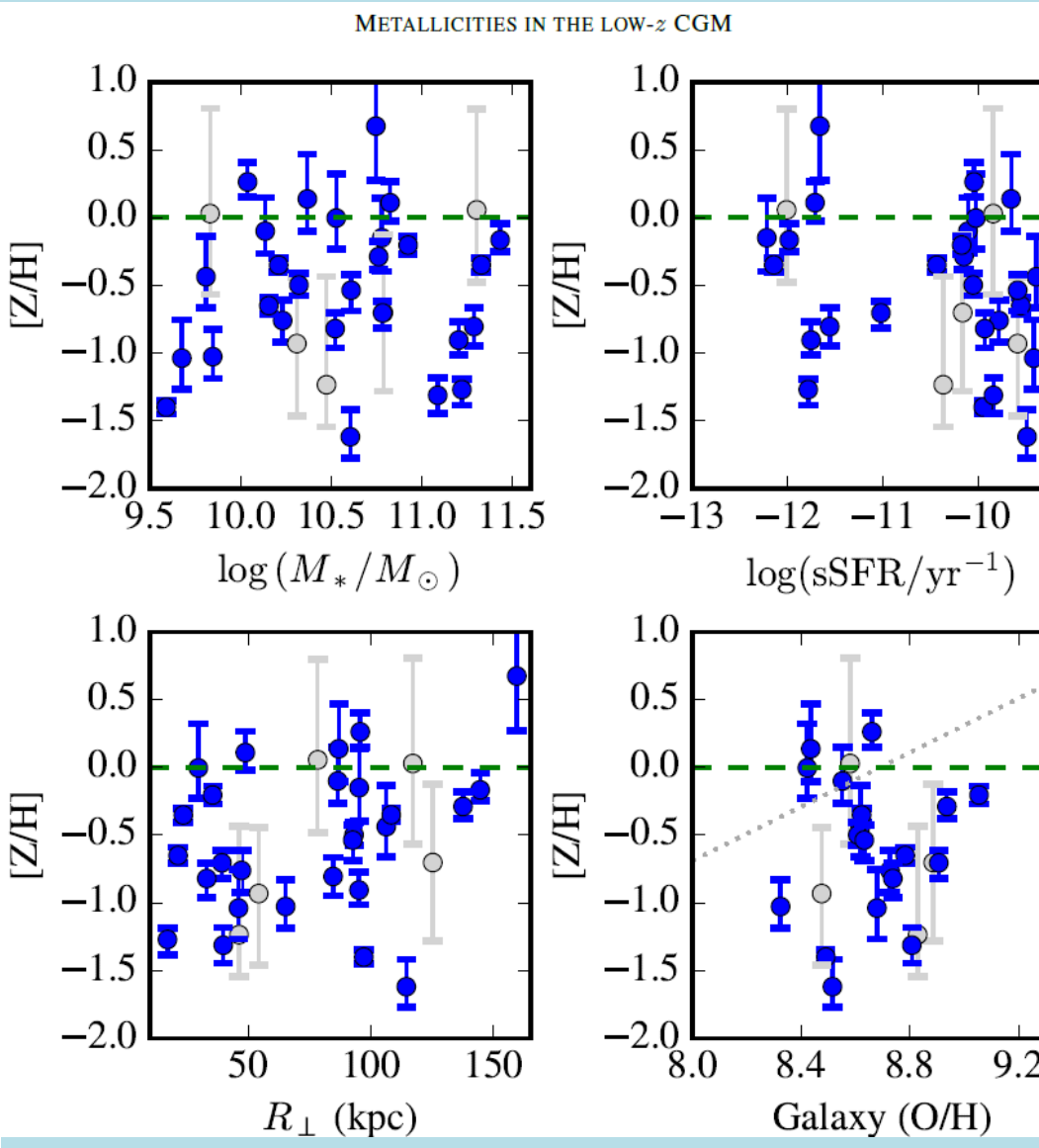


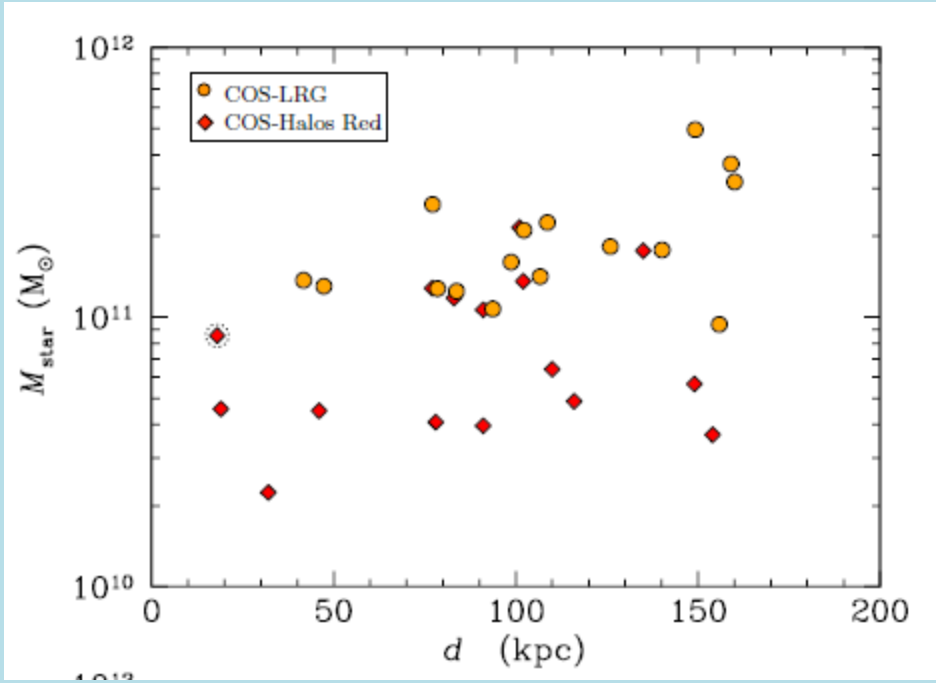
Figure 4. $N_{\rm HI}$ values for the COS-Halos survey versus the projected impact parameter $R_\perp$ to the target galaxy. The measurement of each CGM system is coded by the specific SFR (sSFR) such that red circles indicate a sSFR $< 10^{-11}$ $M_\odot$ yr^{-1}, while blue stars represent galaxies with sSFR higher than this limit. Open symbols indicate non-detections in H I and error bars (typically < 0.1 dex) are overplotted on detections. Note the high incidence of optically thick gas at $R_\perp < 60$ kpc and the overall trend to lower $N_{\rm HI}$ at higher $R_\perp$. The null hypothesis of no correlation is ruled out at $> 99.6\%$ confidence.



- Массивные галактики: сочетание горячего обеднённого газа короны с обогащённым горячим галактическим ветром. Присутствие холодного газа (~10^4К) в гало Е-галактик обнаружено, но происхождение – вопрос открытый.
- Local 21 cm and CO surveys of elliptical galaxies have also uncovered cold atomic and/or molecular gas in > 30% of nearby ellipticals (e.g., Oosterloo et al. 2010; Serra et al. 2012; Young et al. 2014). Together, these independent studies show that cool gas outlasts star formation in massive quiescent halos over an extended cosmic time period.
- No starbursts or AGNs!

- Cosmic Origins Spectrograph (COS) on board the Hubble Space Telescope (HST). The spectral coverage of COS enables observations of the full H I Lyman series transitions and metal absorption features that probe halo gas under different ionization conditions, including C III λ 977, O VI λλ 1031, 1037, Si III λ 1206, and Si II λ 1260.
- Выборка: 16 красных галактик с Mstar > 10^{11}Mc, z = 0.21 – 0.55 без признаков звездообразования. We search for corresponding absorption features in the spectrum of the background QSO over a line-of-sight velocity interval of ±500 km s−1 from the systemic redshift of the LRG
- The primary goals of the program are (1) to obtain accurate and precise measurements of neutral hydrogen column density N(H I) based on observations of the full hydrogen Lyman series and (2) to constrain the ionization state and chemical enrichment in massive quiescent halo.

В 13 из 16 галактик найдены Lyman absorption series.



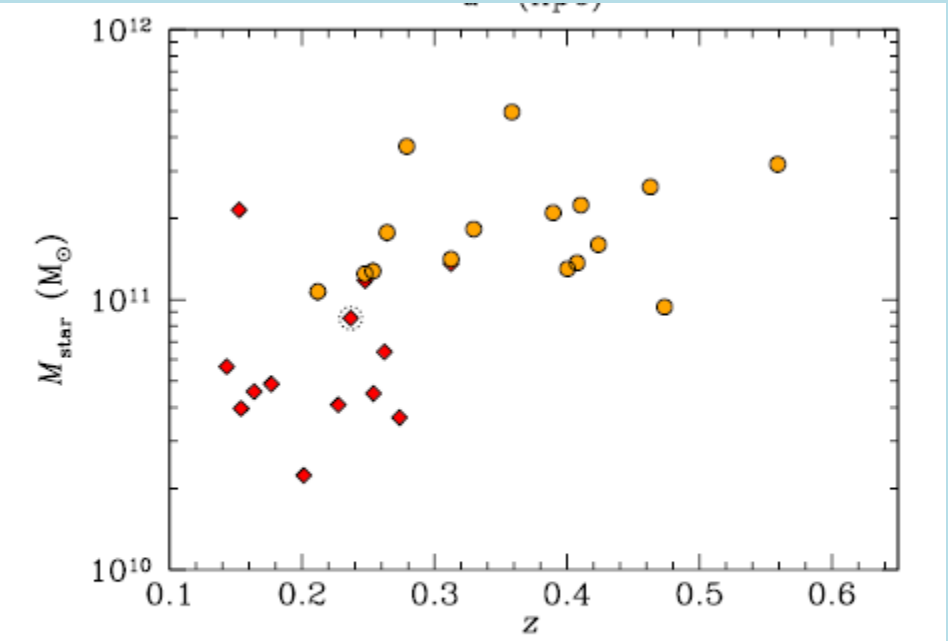


Figure 1. Comparisons of the LRGs in our studies (orange filled circles) and the red galaxies in the COS-Halos sample (red diamonds) considered by Thom et al. (2012). The LRGs form

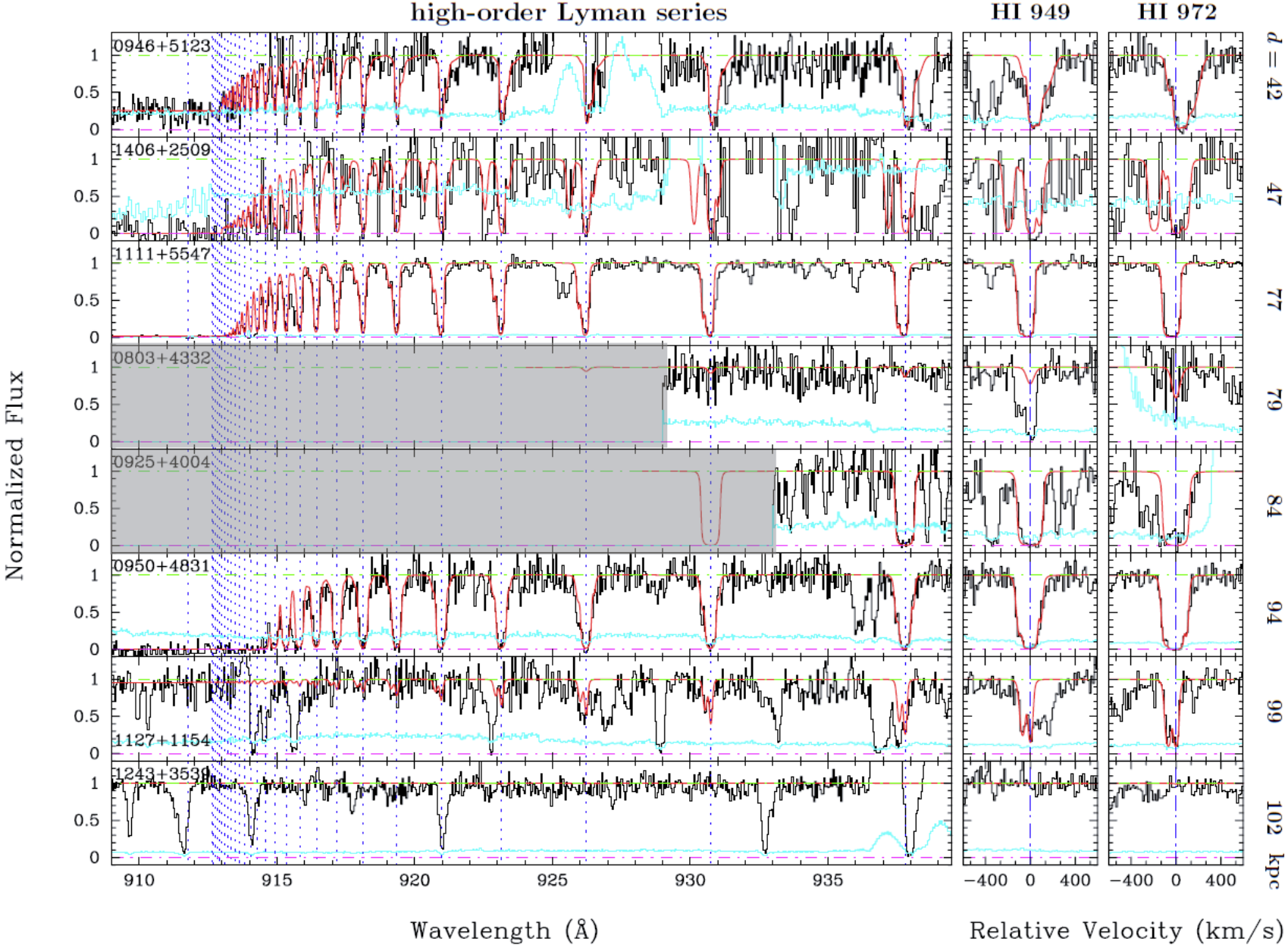


Figure 2a. The Lyman series absorption spectra observed at different projected distances from LRGs, from $d = 42$ kpc at the top and increasing to $d = 102$ kpc at the bottom. The continuum-normalized spectra are shown in black with the corresponding 1-σ error shown in cyan. The green and red dash-dotted lines mark the normalized continuum and zero flux levels for guidance. For each LRG halo, the velocity profiles of Lyγ, and Lyδ are presented in the two right panels with zero velocity corresponding to $z_{\rm abs}$ in Table 4, and the remaining higher-order Lyman series lines, along with the Lyman limit, are presented in the left panel with the blue dotted lines indicating the expected positions of the Lyman transitions. Spectral regions that are not covered by available COS spectra are greyed out. The best-fit Lyman series absorption spectra are shown in red

Результаты

- <log N(H I)> = 16.6 at d < ~ 160 kpc (~1/3Rvir).
- The line-of-sight velocity separations between the HI absorbing gas and LRGs are characterized by a mean and dispersion of $\langle v_{gas} - V_{gal} \rangle$ = 29 km s-1 and $\langle \sigma_{gas-gal} \rangle$ = 171 km s-1.
- Doppler bHI<20 km s-1, indicating a relatively cool gas temperature of T <3 10^4 K.
- A detailed ionization analysis is presented

in a subsequent paper (Zahedy et al. 2018, in preparation).