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Study of the QSO HE0354-5500 with combined *HST* imaging and VLT spectroscopy

An example of a deconvolution-based method for probing the QSOs host galaxies characteristics

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Abstract. The host galaxy of the QSO HE0354-5500 ($M_B = -24.7$, $z = 0.2674$) is studied on the basis of high resolution *HST* optical images and spatially resolved VLT slit spectra. The morphology and dynamics of the host are described. The gas ionization and velocity are mapped as a function of the distance to the central QSO. Reflection or scattering of the QSO Hα line from remote regions of the galaxy is detected. The line shifts show that the matter responsible for the light reflection moves away from the QSO, likely accelerated by its radiation pressure. Moreover, different resolved emission regions are found in the central kpc, both in the images and the spectra.

Key words. Quasars: host galaxies – deconvolution – individuals: HE0354–5500

1. Introduction

The study of the controversial bright QSO HE 0450–2958 (Magain et al. 2005) has revealed that combining *HST* imaging with slit spectroscopy is a fruitful tool in order to infer the host properties and to explore the triggering and fueling mechanisms of the QSO, though the true nature of this special case is still under debate (Merritt et al. 2006; Hoffmann & Loeb 2006; Feain et al. 2007; Papadopoulos et al. 2008).

We present another example of this kind of analysis applied to the Type 1 QSO HE 0354–5500 for which we have both high resolution images and slit spectra. This QSO is part of a 6 QSOs sample which are analysed with the same method in Letawe Y. et al. (2008).

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2. Observations and reduction

2.1. Images

The images have been obtained in October 2004 with the ACS/HRC onboard *HST* with the broad V-band filter F606W. Six exposures, taken during one *HST* orbit, are available: three short (40s) unsaturated ones, in order to be able to study the host properties very close to the central QSO, and three long ones (400s), saturated around the center, but providing a good S/N in the lower surface brightness regions. Moreover, a PSF star is observed during the same orbit. The data have been reduced (cosmic ray and bad, hot or warm pixels removal) with the Pyraf software.

2.2. Spectra

The spectra were obtained with the ESO VLT/UT1 in November 2000 with FORS1 in Multi Object Spectroscopy (MOS) mode, which consists in a set of 1″-slits with a fixed length of 19″. The QSO was observed with 3 different grisms, covering a total restframe wavelength band from 3500Å to 8500Å. One slit was centered on the QSO and the other ones on PSF stars and surrounding objects.

The reduction and deconvolution methods are presented in detail in Letawe et al. (2007), resulting in spatially deconvolved spectra with the QSO spectrum separated from the spectrum of its host galaxy.

3. Image processing

The *HST*/ACS images are processed with the MCS deconvolution algorithm (Magain et al. 1998), which is particularly well suited for separating point sources (the central nucleus) from diffuse ones (the host) and, as such, very well adapted to the study of QSO host galaxies (see Fig. 1). We simultaneously deconvolve the six individual images, in order to reach the best possible resolution and S/N ratio. It shows that the QSO host is involved in a collision with another galaxy.

4. Spatially resolved spectra

By superimposing the projection of the VLT slit onto the *HST* host galaxy images, we can identify which parts of the galaxy contribute to each part of the spatially resolved spectra. In our case, the slit is divided in regions A and B, accounting for spiral arms, C for the bulge, D for the intermediate region (containing disturbed spiral arms) between the two colliding galaxies, and E for the outer region next to the companion galaxy (see Fig. 1, upper frames).

5. Spectral analysis

After having corrected the spectra from reddening, we build diagnostic diagrams for each spatially resolved region, in order to disentangle between the different ionization sources (the AGN, stars, or composite regions) as suggested by Kewley et al. (2006). As far as we know, this is the first time that the hosts of Type 1 QSOs are analyzed with such diagnostic diagrams, except in Letawe et al. (2007) where the diagnostic diagrams are constructed from the integrated spectra.

Radial velocity curves are also built by comparing the wavelength shifts of some emission lines (Hα, [OIII] and [OII]) for every pixel along the slit, and then transforming the shifts in relative velocities with respect to the central QSO.

Lastly, some emission lines have been modelled by Gaussian shaped functions in order to extract the most accurate information.

6. Discussion

The *HST* image reveals a distorted host galaxy, with the probable presence of a few spiral arms, as well as an extended structure to the North, suggestive of a (nearly edge-on?) galaxy in violent interaction with the host.

The diagnostic diagrams (Fig. 1d) show that the source of ionization changes as one moves along the slit, from the S-E (region *A*) to the N-W (region *E*) with a more important contribution from stellar light on the S-E parts (opposite to the colliding galaxy), a mixture of sources in the central regions and ionization completely dominated by the AGN in the N-W region *E*.

Region *E*, because of the VLT seeing, may contain some contribution from the two colliding galaxies. However, its spectrum displays only emission lines, with no detectable continuum. Moreover, these emission lines extend to the outer regions, where no flux is measured on the *HST* image. We thus conclude that the spectrum is completely dominated by emission from AGN-ionized gas. The radial velocity curve (Fig. 1c) shows velocities increasing

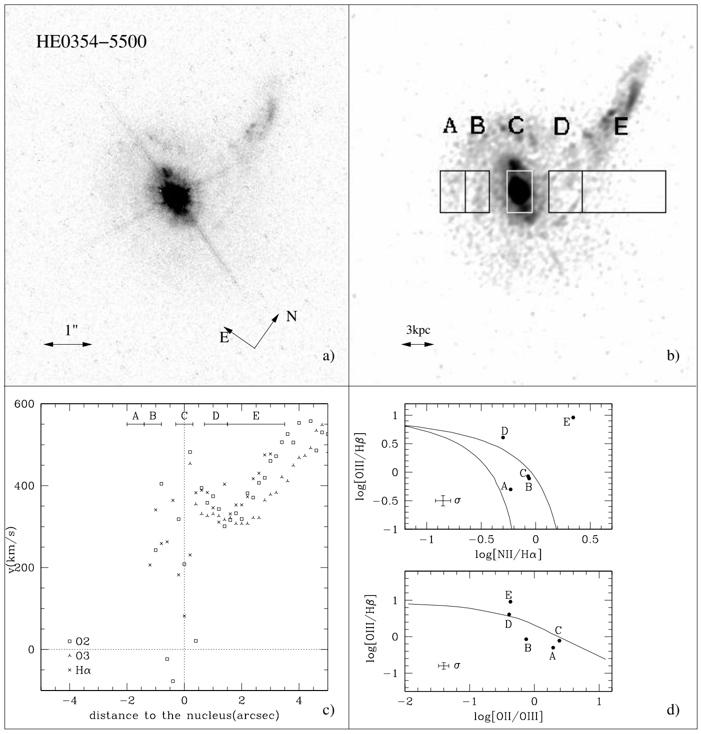

Fig. 1. HE0354–5500. a) Reduced image. b) Deconvolved image with the different parts of the slit in overlay (a zoom on the bulge is presented in Fig.3). The central QSO and the PSF spikes have been well removed. c) Radial velocity curve. d) Diagnostic ionization diagrams.

from +300 to +550 km s^{-1}, as one moves away from the center.

Moreover, in region *E*, the Hα-[NII] lines cannot be fit with a 3 Gaussians model, and an additional component is needed. This fourth component is much broader than the other ones and its width is similar to that of Hα in the QSO spectrum (Fig. 2). The similarity between the observed broad Hα line in region *E* and the corresponding QSO Hα line clearly suggests that reflection by dust or scattering by free electrons might explain this broad component. The relative velocity of the broad line with respect to the QSO is $v = +458 \pm 180\,\mathrm{km\,s^{-1}}$, which is close to the average radial velocity measured on the narrow emission lines. This near equality shows that the gas moves away from the central QSO, in a direction opposite to us, and at an angle $\sim 45°$ with respect to the line-of-sight. Determining the reflection process (dust or electrons) is hard to handle. On the one hand, the Balmer coefficient of 3.66 informs us of the presence of some dust. On the other hand, if the scattering is due to electrons, the reflected light must be broadened according to the random motion of the scattering electrons. In practice, we convolve the QSO Hα line by a Gaussian representing the electron velocity distribution (corresponding to a given temperature) and use this new profile instead of the QSO Hα line in the fit. The best fit gives an estimate of the electron temperature $T_{e^-} = 1.05 * 10^5$K. Increasing the electron temperature until the fit becomes unacceptable sets an upper limit $T_{max} = 4 * 10^5$K. Those temperatures are consistent with similar observations made by Dey & Spinrad (1996). We thus cannot draw firm conclusions about the reflection process, as both seem realistic.

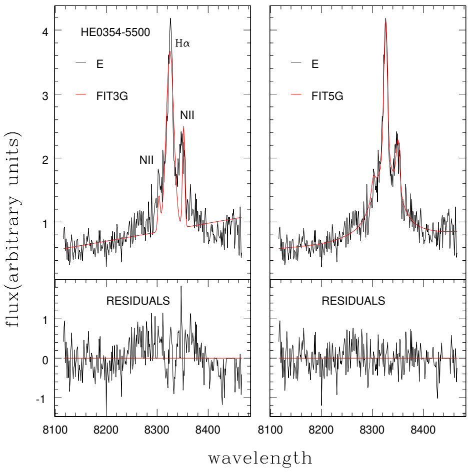

Fig. 2. Left: 3-gaussian fit of the region *E* around the Hα-[NII] lines, along with its residuals. Right: Including a broad line with the QSO characteristics considerably improves the total fit of the Hα–[NII] region.

Combining these two pieces of informations (reflected Hα line + diagnostic diagram) leads to the plausible interpretation that region *E* contains gas blown away by the AGN radiation. The radiation pressure, acting continuously as the gas moves away from the center, produces a continuous acceleration and a speed increasing from about 400 to 600 km s^{-1} in the region where we can measure it (i.e. outside the visible image of the host galaxy).

Other interesting features appear in the bulge region. The Hβ line displays a complex structure (Fig. 3, top right), which can be interpreted as the sum of several components moving at different speeds. Indeed, the deconvolved *HST* image (Fig. 3, left) shows, next to the bulge, three bright regions which, because of the spread of light due to the seeing, cannot be separated in the VLT spectra. Figure 3 shows that the Hβ line can be fitted by 4 gaussians, which is also the number of emission regions seen on the *HST* images. Such compact emission regions can be caused by starbursts.

Due to the presence of the [NII] lines, the Hα profile is not easy to interpret. However, Fig. 3 shows that a model with the same components as detected in Hβ can provide a satisfactory fit of the observations.

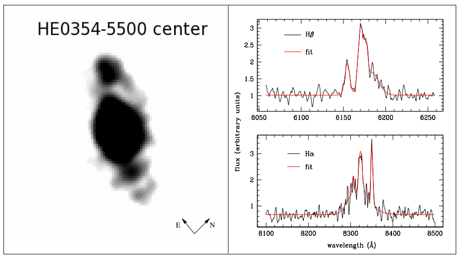

Fig. 3. Left: deconvolved central region of HE 0354-5500 revealing different bright areas. Right: fit of the spectrum of the central region *C* (see Fig.1) around Hβ (top panel) and Hα (bottom panel).

7. Conclusion

The present study has shown that a joint analysis of spatially resolved VLT spectra and high-resolution *HST* images, both carefully processed with the MCS method, is a powerful way to characterize the QSO host galaxies; it allows to discover phenomena which would not be accessible through imaging or spectroscopy alone. More specifically, HE 0354–5500 looks like a spiral galaxy undergoing a violent collision. It shows compact starburst regions close to the center and an extended gas component, reflecting the QSO Hα line, and most probably accelerated by the QSO radiation, up to distances as large as 8 kpc.

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