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STUDY OF THE NUCLEAR ENVIRONMENT OF GALAXIES BY INTEGRAL FIELD SPECTROGRAPHY

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RESUMEN

Se muestran ejemplos de cubos de datos tridimensionales obtenidos en el medio ambiente del núcleo de galaxias activas y quietas. Esto permite una mucho mejor visión de la naturaleza compleja de los núcleos galácticos que las imágenes clásicas y la espectroscopía de rendija larga. Con el uso futuro de Optica Adaptiva y técnicas de deconvolución, se obtendrán datos de espectroscopía tridimensional con alta resolución espacial, similar a las imágenes del *Telescopio Espacial Hubble*.

ABSTRACT

Examples of three-dimensional data cubes obtained on the nuclear environment of both quiet and active galaxies are shown. They allow a much better view of the complex nature of galactic nuclei than classical imagery and long-slit spectroscopy. With the future use of adaptive optics and deconvolution techniques, three-dimensional spectrographic data with a spatial resolution approaching that of *HST* images will become available.

Key words: **GALAXIES: ISM — INSTRUMENTATION: SPECTROGRAPHS**

1. THE TECHNIQUE

Integral Field Spectrography, as coined by Courtès (1982), refers to any dispersing spectrograph which *simultaneously* covers a two-dimensional field on the sky and a number of wavelength bins. This is accomplished by using an optical converter that rearranges a quasi-square field on the sky into a suitable pattern on a classical long-slit or multi-slit spectrograph. This can be done with fibers (Vanderriest 1980), mini-lenses (Courtès 1982) or mirrors (Weitzel 1994). One common limitation of these techniques, which comes from the need for cramming a data cube onto an inherently two-dimensional detector, is the rather small field of view, usually around 5–10″ diameter on a 4-m class telescope.

Our group has developed the integral field spectrograph TIGER (Bacon et al. 1995), a mini-lens based system (see Figure 1) which has been used on a large variety of compact astrophysical objects, and especially on nuclei of galaxies, as shown below.

2. INTERSTELLAR MATTER IN SEYFERTS

The central region of the Seyfert galaxy NGC 1068 has been studied with TIGER at the Cassegrain focus of the 3.6-m CFH telescope in the blue and red regions of the spectrum. Figure 2 shows an [O III] λ5007 line image reconstructed from the 1100 individual spectra. A direct image, obtained with an interference filter

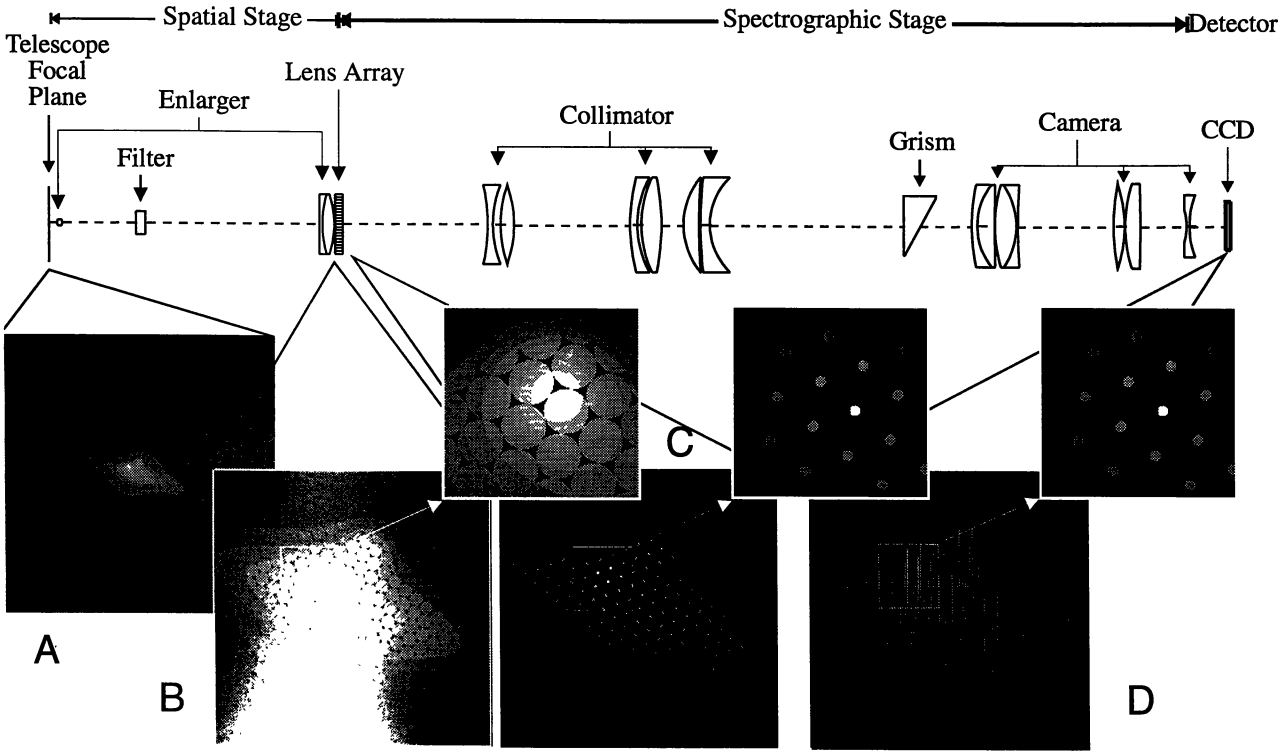

Fig. 1. Optical layout of the integral field spectrograph TIGER.

centered on the same line by the post-COSTAR *HST*, is shown for comparison. The huge difference in image quality is evident, with a FWHM around 0.1″ for the *HST* image versus 0.72″ for the TIGER reconstructed image. Note that the latter value has been measured through a non-linear least-squares fitting of the *HST* image, convolved to the TIGER image by an unknown Gaussian. In spite of this, kinematic evidence for the various compact components present in the central core and in the ionization cone bow front can be obtained from velocity slices of the TIGER data cube, as shown in Figure 3. Similarly, Figure 4, from the same data cube, shows reconstructed images in emission lines with different ionization levels. These also can be used to disentangle the various components and gain some physical insight.

3. INTERSTELLAR MATTER IN ELLIPTICALS

Figure 5 shows the radial velocity field in the [N II] λ6584 line of the central part of the prototypical "peanut-shaped" galaxy, NGC 128. The ionized gas distribution is tilted by about 45°, with a nearly cylindrical velocity field, equally tilted. This distribution strongly suggests a vertical resonance instability of counter-rotating gas, trapped by a triaxial object. This explanation will soon be tested, using the radial velocity field of the stellar component of the galaxy extracted from a similar data cube obtained at CFHT, but now in the 5200–5700 Å absorption line region.

4. CONCLUSIONS

Integral Field Spectroscopy is highly complementary to Scanning Fabry-Perot Spectroscopy in addressing a much smaller field, but a larger wavelength range and simultaneous (versus sequential) data collection. It offers

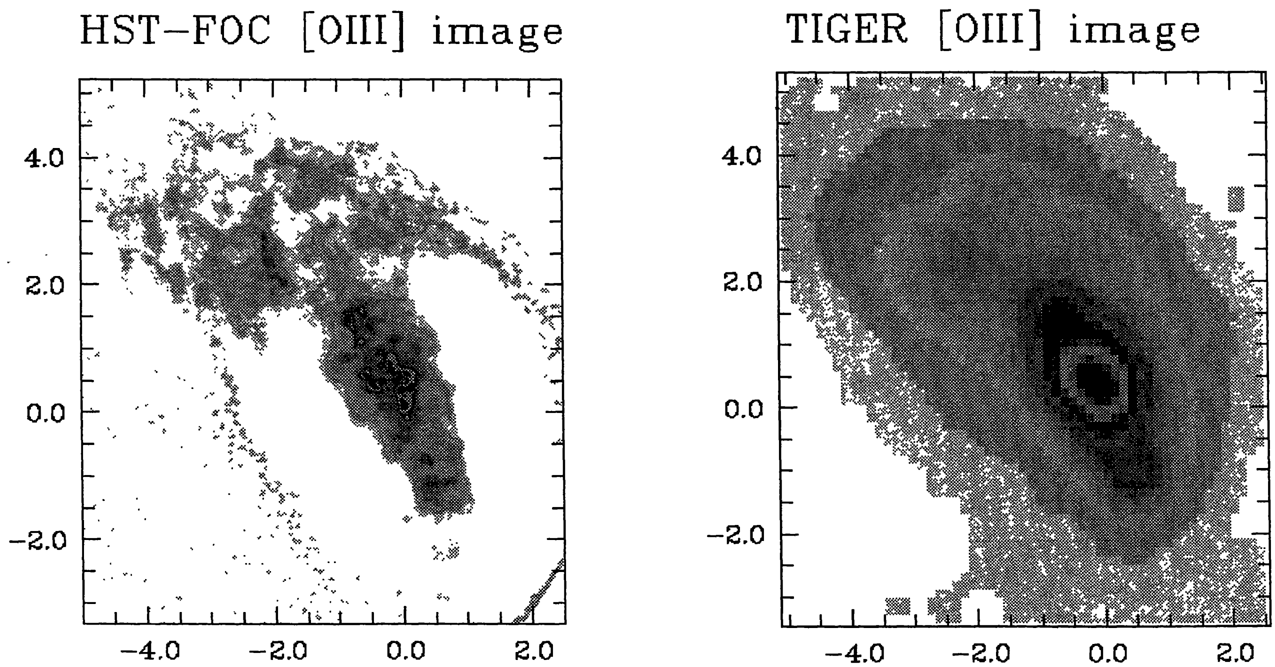

Fig. 2. Comparison of the *HST* [O III] image (left) with the reconstructed [O III] image (right) derived from a TIGER spectrographic data set.

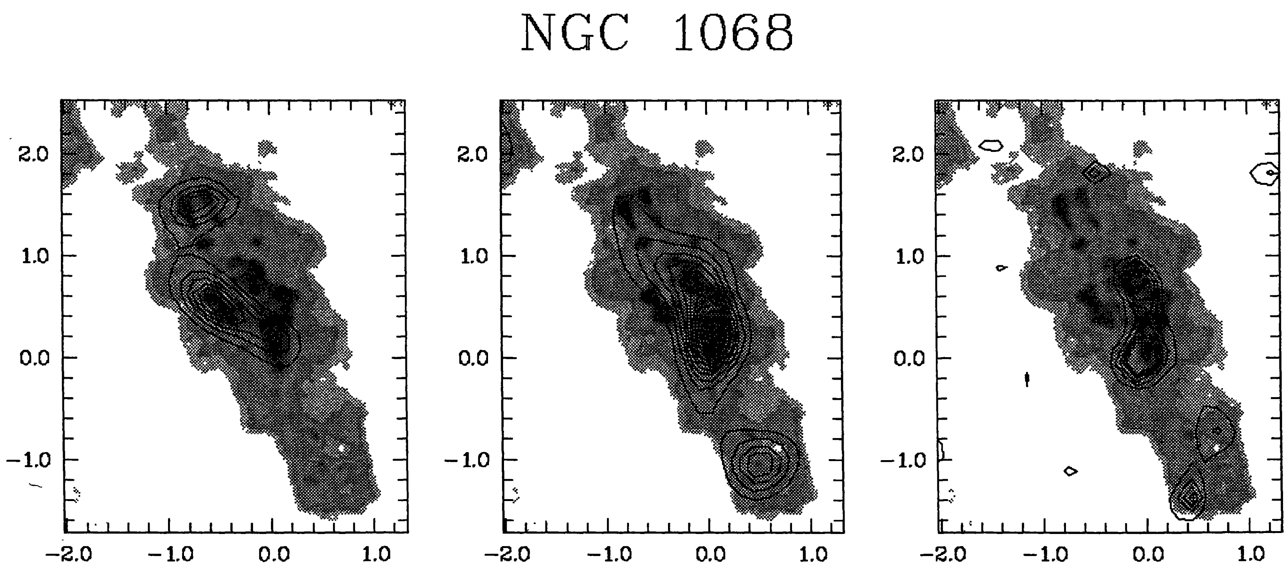

Fig. 3. Velocity slices through the [O III] line (TIGER spectrographic data) superimposed on the *HST* image. Left: V = −1 700 km s^{-1}. Center: V = +350 km s^{-1}. Right: V = +2 380 km s^{-1}, Velocity Width: 400 km s^{-1}.

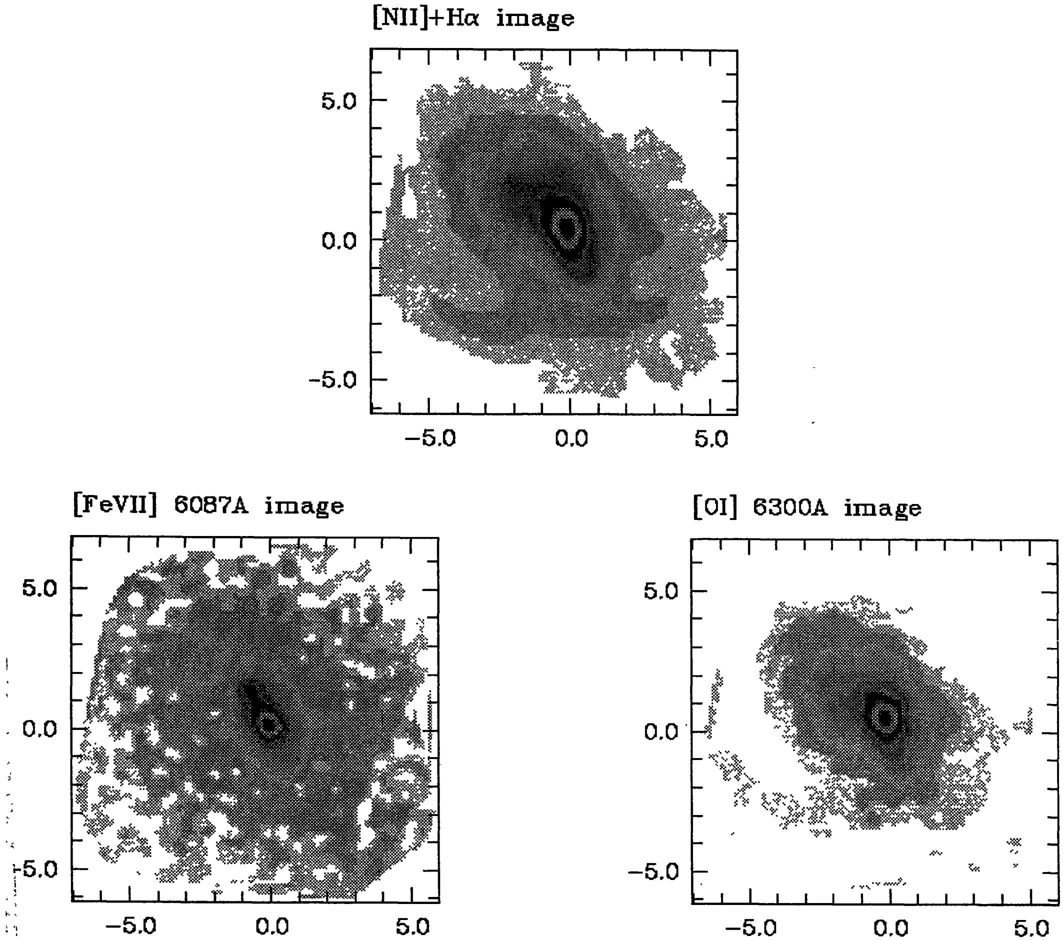

Fig. 4. TIGER reconstructed images in emission lines with different ionization levels.

spectrographic capability, ideally suited for the study of compact objects, e.g., those selected with the unique imaging capability of the *HST*.

Present instruments, however, give a direct spatial resolution at best slightly below 1″. Even with the help of the spectrographic information, this could severely limit the power of the technique. Figure 6 gives the result of a blind deconvolution of the reconstructed [O III] image of the center of NGC 1068 (see Fig. 1), again compared with the *HST* image. Note that our deconvolved image was obtained completely independently (in fact a month before) of the *HST* image. Obviously, the agreement is not perfect, mainly because of the poor spatial sampling (0.3″) of the TIGER data. It is clear nevertheless that most compact groups have been recovered, with only the *a priori* constraints of posititivity of the image and of the point spread function (PSF), plus an assumed circular symmetry of the PSF.

In the relatively near future, integral field spectrographs —coupled to adaptive optics facilities— will be available at large telescopes (e.g., the OASIS project at CFHT and the GMOS project at GEMINI). With the coming use of blind or myopic (e.g., using wavefront sensor residual measures) deconvolution techniques to improve the spatial resolution, spectrographic three-dimensional data cubes with nearly the image quality of the *HST* will become a reality.

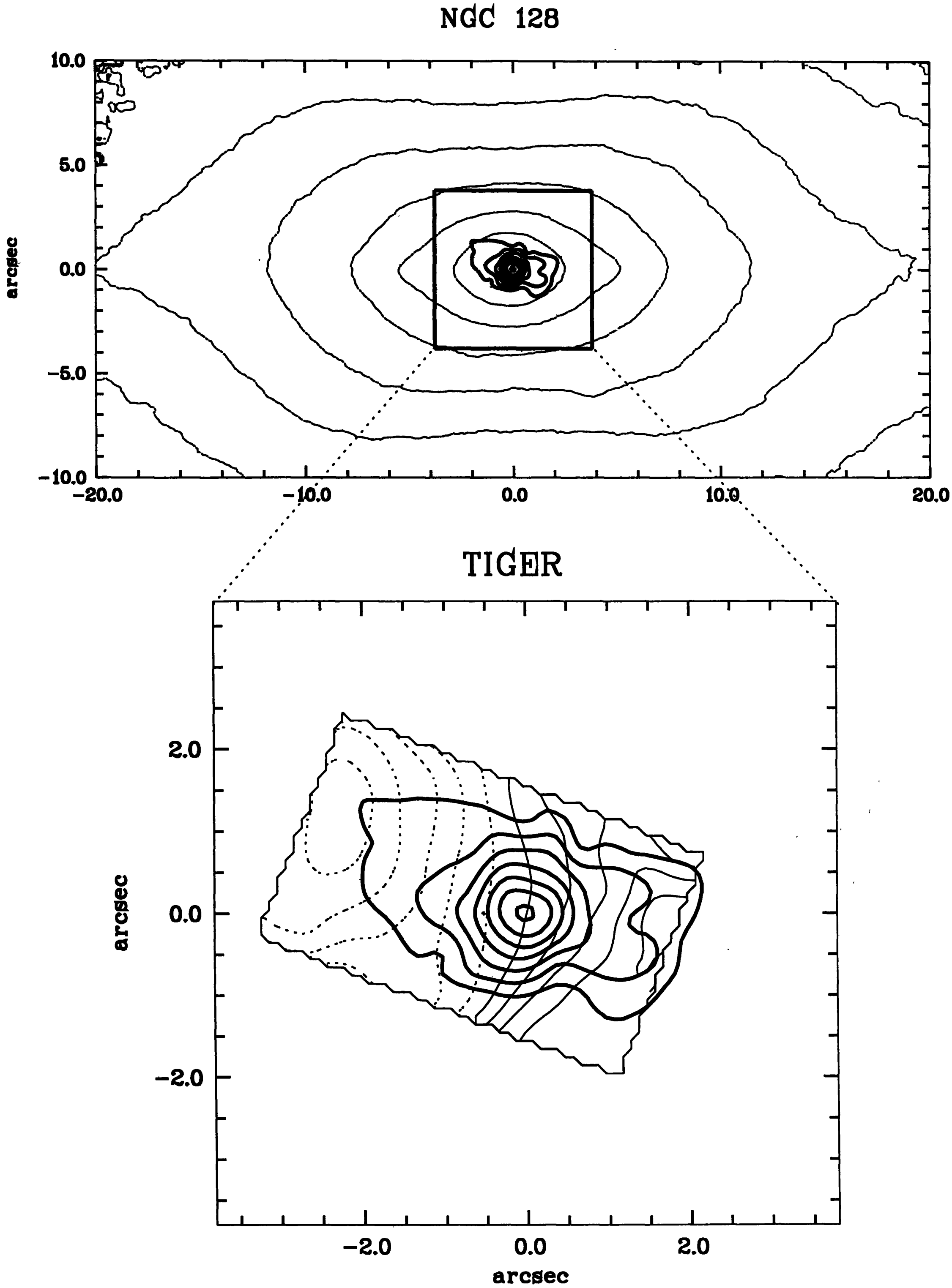

Fig. 5. Top: [N II] image of the central part of NGC 128. Bottom: Radial iso-velocity curves with the [N II] isophotes superimposed.

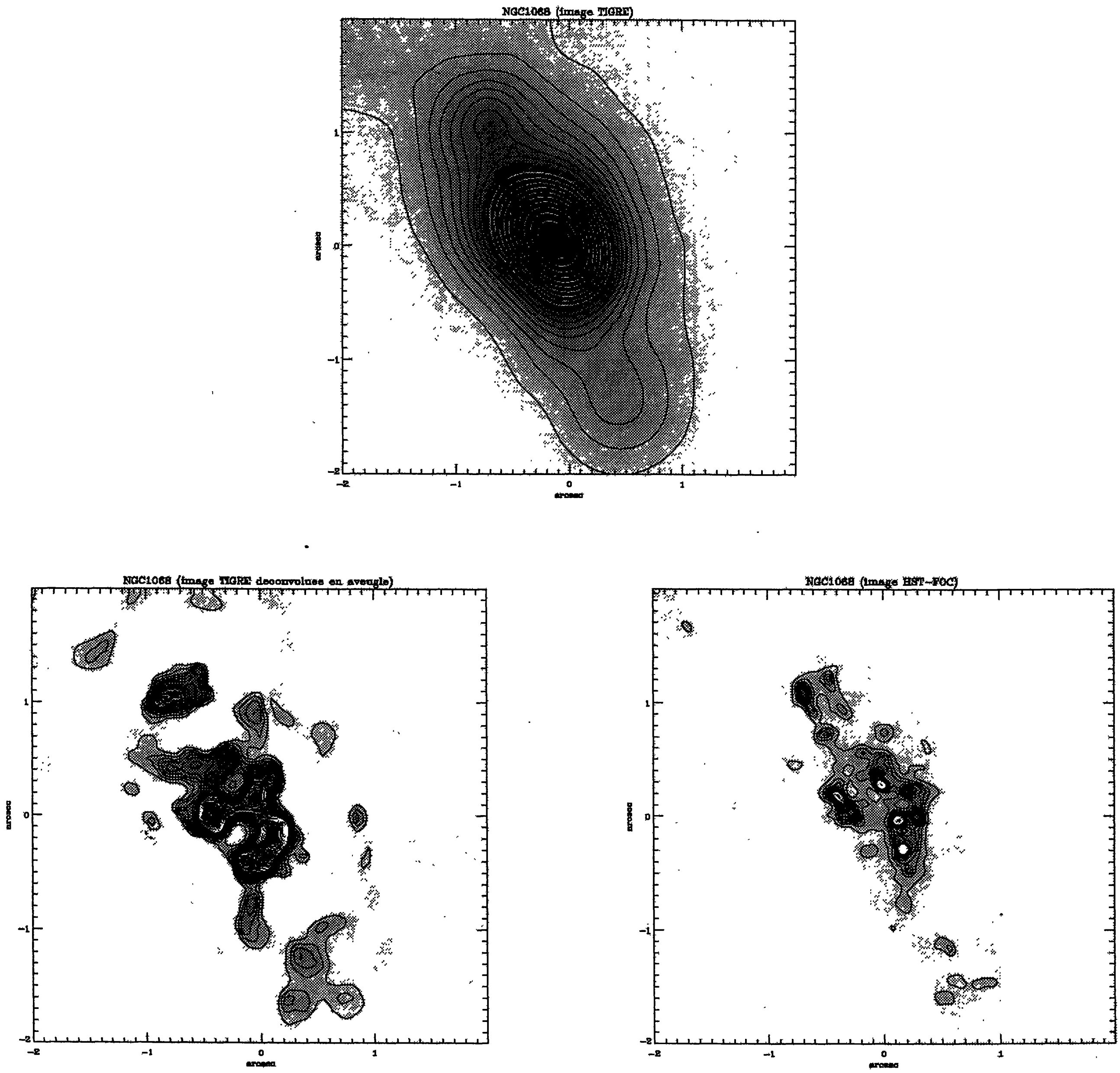

Fig. 6. Top: [O III] image of NGC 1068, reconstructed from the TIGER data cube. Bottom right: [O III] direct image from the *HST*. Bottom left: blind deconvolution of the TIGER image at top.

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