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SPECTRAL IMAGERY: RECENT RESULTS WITH THE SPIFI AND THEIR IMPLICATIONS FOR COMETARY ATMOSPHERIC STUDIES*

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Abstract

Spectral polarimetric imaging of comets is proposed with state-of-the-art methods. Related observational data are shown and sensitivity levels are given which indicate the range of objects which may be studied. Some proposed observational goals are also indicated.

Comets are rapidly evolving objects temporally and spatially. Nearly all present knowledge of cometary morphological structure and evolution is deduced from reflected and resonantly scattered solar radiation. The portion of the emitted radiation due to primary photochemical processes has only recently become a subject of scrutiny in comets. All these aspects of comets require unusually sensitive, stable, and efficient observational methods in order that comets of a wide brightness range (or at various heliocentric distances) may be effectively studied.

The most useful information for a comet is likely to be a detailed determination of the spatial and temporal variations of the observed molecular and atomic emission features at a spectral resolution which resolves the line profiles and provides detailed velocity information. Since it is generally easier to obtain the above information by multiplexing spatially than by multiplexing spectrally for a number of readily evident reasons, I will discuss here a state-of-the-art spectral imaging device which I have constructed and used over the past several years.

The instrument is a servo-controlled polarimetric imaging Fabry-Perot interferometer, the SPIFI. The servo-control is accomplished via a capacitive method originally due to Hicks _et al._ (1974).[1] The etalon is blocked either with fixed interference filters or an acousto-optic tunable filter. Since the SPIFI is used at the Cassegrain focus and since all elements are illuminated close to normal incidence, very small instrumental-telescope polarization is present. Linear polarization measurements are accomplished with the introduction of polarizing beam splitters or a polarizing prism, the latter readily allowing both polarizations to be oserved simultaneously. The SPIFI can be used at resolving powers as low as 500 or as high as 150,000, in its present configuration. The spectral region in which the SPIFI can be used for spectral imagery is limited by atmospheric transmission at 3000Å and by available array detectors at about 11,000Å. The data shown here for spectral imaging were obtained with a SIT vidicon (in collaboration with T. McCord) and with a microchannel plate multianode detector with an S-11 photocathode (MAMA) which was provided by G. Timothy. Using an array detector such as the CCD's now becoming readily available, the SPIFI will have a maximum efficiency of better than 10 percent. The spatial resolution is at the disposal of the observer to a large extent when using the SPIFI with an array detector such a CCD. The main limitations are those related to proper imaging of a very large field of view. A field-of-view of over 1° is certainly possible for a wide range of spectral resolving powers. The spatial element will depend on the array detector format.

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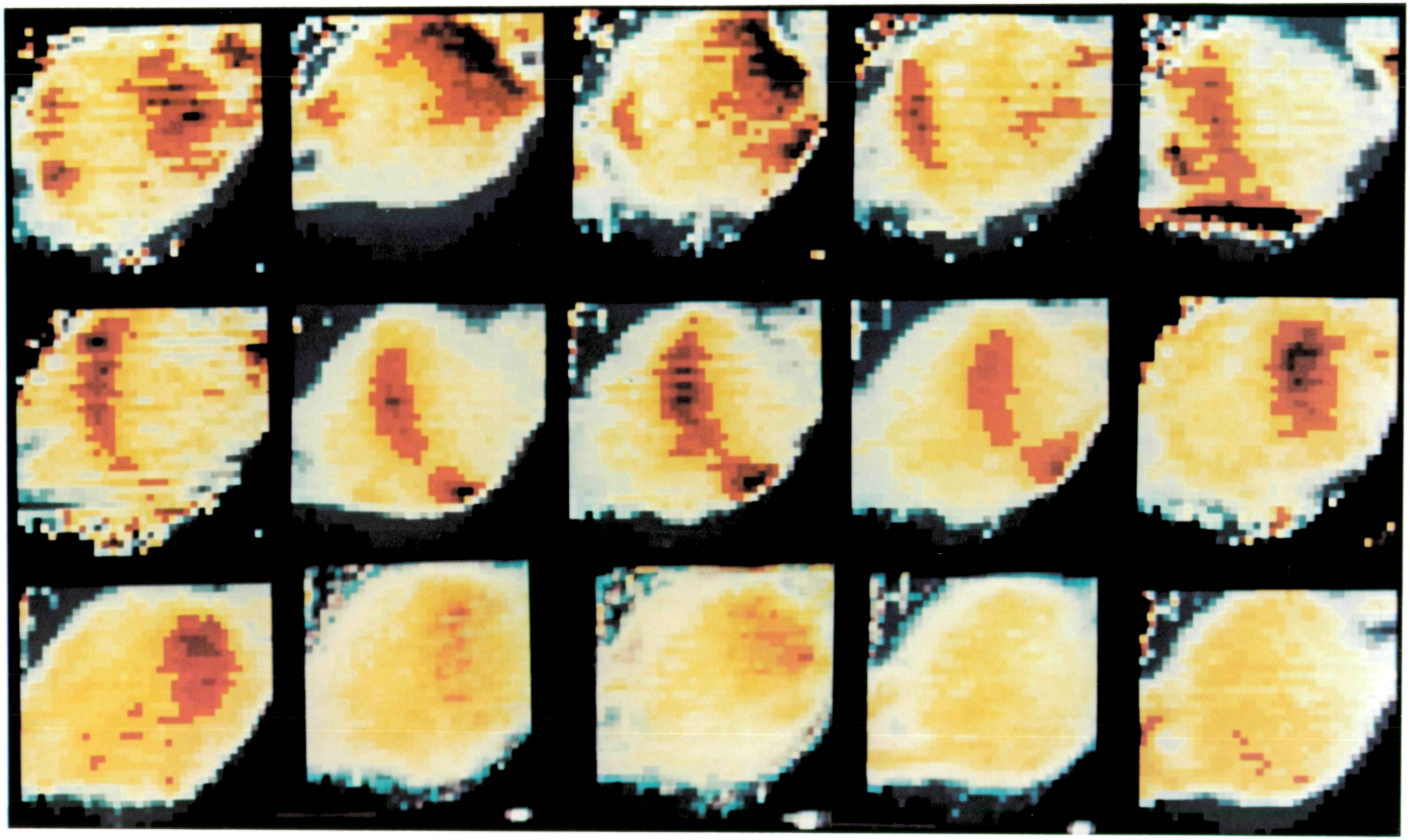

Figure 1. Spectral images of Saturn obtained with the SPIFI + SIT vidicon at a spatial resolution of better than 2". Here proper spatial sampling was observed, with each pixel corresponding to 0.65" in the original images. The grey scale indicates the presence of CH_4 absorption in the rotational feature of CH_4 at 6196.82Å, which we have studied extensively in the laboratory. The band which appears and moves across the image of the ball of Saturn (the rings are not plotted) reflects the Doppler shift of the absorption in the narrow pass band of the SPIFI. From this "cube" of images (there are a total of 27) we can construct more than 1000 spectral profiles on the disc of the planet, and many more for the rings.

With the SPIFI and a suitable array detector, we have obtained a number of spectral imaging results for absorption and emission line data. First, in Figure 1, an array of spectral images for Saturn demonstrates the application to an absorption line problem, related to the determination of the scattering properties and vertical structure of Saturn's atmosphere. The disc of Saturn is about 18" and we achieved better than 2" spatial resolution. The data band seen traversing the disc is the Doppler-shifted single rotational feature of CH_4 at 6196.8Å in resonance with the passband of the SPIFI as the images are incremented in wavelength by 40 mÅ. In Figure 2, an example profile selected from several positions on the planetary disk is shown. The detailed analysis of these data reveals that Saturn's atmosphere acts like a homogeneous scattering model (Smith, Macy, and McCord, 1980).

In Figure 3, a different type of object is imaged spectrally, the emission feature of [O III] near 5007Å was observed for the planetary nebula NGC-7662. The spatial resolution is about 3.1" while the object fills the 10x10 array detector nearly completely. Here the attainable spatial resolution was limited by the desire to image the entire object. The velocity resolution of several km/sec allows the profiles to be fully resolved, both in the expanding shell and in the intrinsic turbulent velocity of the shells. Spectral imaging observations of this and other planetary nebulae may be used to reveal morphological properties and excitation characteristics much like those of interest in cometary studies (Smith, W. H., Snow, T. P. and Timothy, G., 1979).

Since the spectral imaging observations are of high intrinsic value in cometary studies as described and since we have demonstrated that high quality spectral imagery at high spatial and spectral rsolution is now feasible, the next question that arises is to specify the range of brightness for which such data may be obtained. Our experience shows that at H_α a surface brightness of 21 m_v per arc second yeilds a signal-to-noise of 10 in an emission line observed at 100 mÅ resolution for a 30" area using a 2 meter telescope in a ten second integration. This corresponds to an integrated magnitude of about $m_v = 13.5$ over 30". Clearly many periodic comets reach this brightness so that observations may be programmed in the usual manner customary for large telescopes.

Even with this sensitivity, most interesting properties will require bright comets for their detailed investigation. For example, the suggestion has been made by Donn that molecular emissions can be examined as a function of position within the coma with the purpose of detecting rotational distributions arising from the formation process via photodissociation of a parent molecule. Carrying this suggestion one step further, certain species such as H_2O^+ will also preserve the formation temperature as well since the photoionization does not transfer angular momentum. The observation of either of these effects requires seeing-limited spatial resolution and consequently, bright comets to attain the required data in a reasonable time scale.

Spectral polarimetry in an imaging mode is also a important observable which now becomes available. Particularly near the nucleus, dust and gas together determine the nature of the emitted or scattered radiation. The separation of the two processes can be carried out only with polarization line profiles at adequate spatial resolution. Such observations at present are entirely lacking for comets so that the impact of such data can only be speculated upon now.

References

Hicks, T. R., May, B. H. and Reay, N. K. 1974, Mem. R. Astr. Soc. 166, 439.

Smith, W. H., Macy, W. and McCord, T. 1981, Icarus, in press.

Smith, W. H., Snow, T. P. and Timothy, G. 1979, BAAS 12, 203.

Note added in proof:
Subsequent to this workshop, we have had a successful observing session with the SPIFI in which we observed the resolved [OI] feature at 6300Å in Comet P/Stephan-Oterma. The results support the estimates of flux described in the text of this comet of a total magnitude of about 9 during the observations.

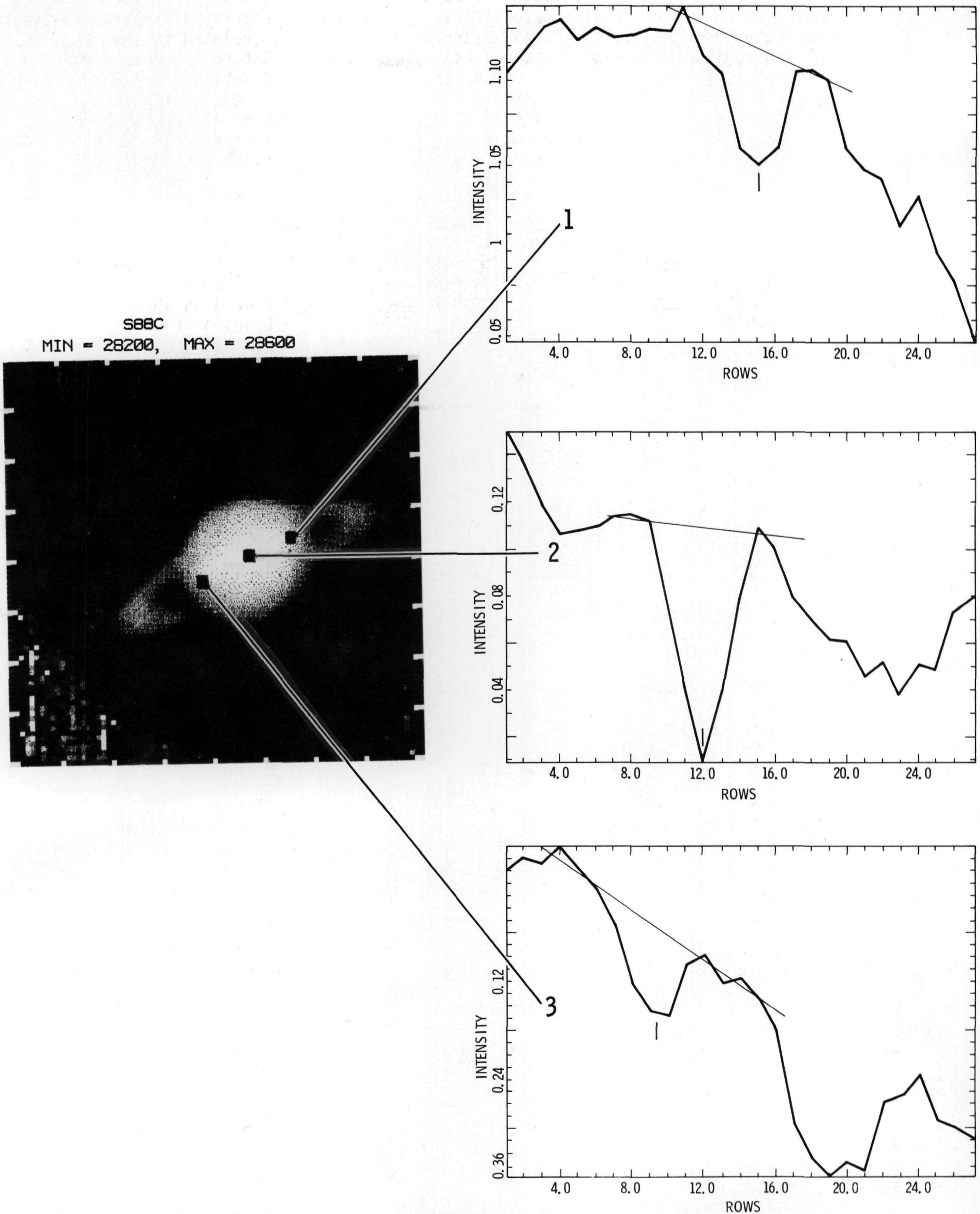

Figure 2. An example image and three spectral profiles extracted from an "image cube" at the indicated point on the disc. The decrease in the depth of the profiles is obvious. The variation detected for the feature across the planet in two directions is modelled, and found to be consistent with a rather simple homogeneous scattering model.

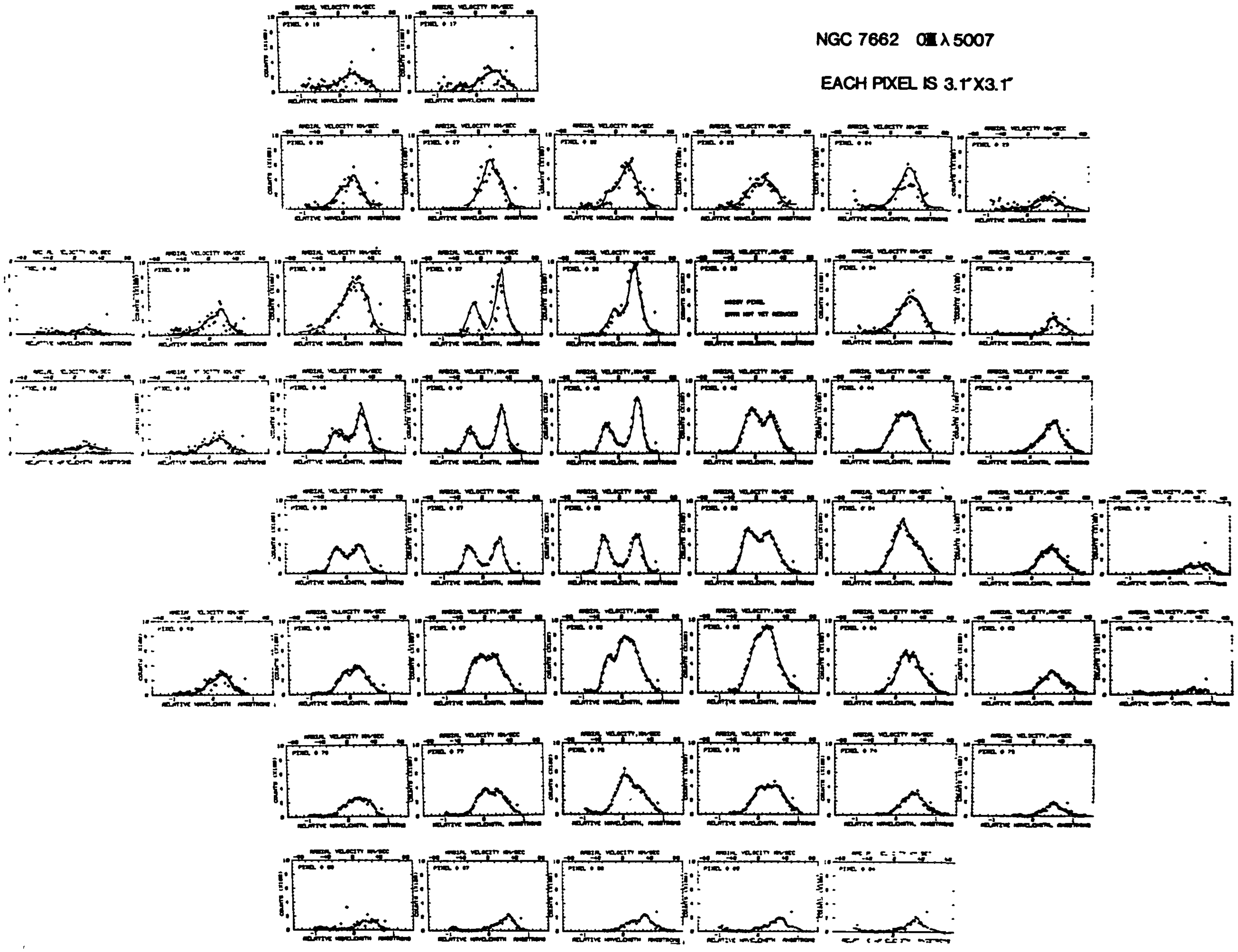

Figure 3. Spatially resolved line profiles for the [O III] transition at 5007Å in NGC 7662. The spatial resolution is 3" with seeing at 1", the limitation being due to the detector array (MAMA 10x10). The ability to multiplex spatially, however, demonstrates its value even for this number of elements. The data shown are presently being analyzed, and are corrected for response, but not yet fit with model profiles.