The Seyfert II Nature of the IRAS Source FSC10214+4724

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ABSTRACT

We have observed the rest-frame optical and UV spectra of the luminous, high redshift IRAS source FSC10214+4724. We find the optical emission lines to be characterized by ratios similar to those found in Seyfert II galaxies. We support the conclusion of previous work that the UV emission lines are similar to those attributed to AGN rather than to star formation. The ratio $H\alpha/H\beta \geq 20$ (2σ lower limit) implies substantial reddening of the narrow line region with A_V >5.5, sufficient to hide a broad line region in our $H\alpha$ observations. Given this large inferred reddening and the strength of the UV continuum and emission lines, we conclude (as have others) that simple screen models of reddening are not appropriate for this object. These properties are very similar to those of the infrared luminous galaxies found at lower redshift, suggesting that FSC10214+4724 is the luminous extreme of the same population.

We also present H-band (1.6μm) imaging polarimetry observations and find that the rest-frame optical emission is unpolarized (P=3.2±2.0%). This deep image of the field shows FSC10214+4724 to possess an unresolved core, with several companions located within 10″ of the point source. We find it unlikely that this group of objects are physically associated with FSC10214+4724 at $z = 2.3$, we argue that their magnitudes and colors are more consistent with those expected for galaxies in a foreground group. While galaxy number counts would suggest that such a projection has a low probability of being observed randomly, a foreground group might gravitational lens the $z = 2.3$ source, making such random statistics inappropriate, and contribute to the large observed luminosity of FSC10214+4742. Comparison of H-band images taken on two occasions one year apart shows that FSC10214+4724 had varied by 0.16±0.03 magnitudes relative to a nearby star during that time.

The UV-optical emission line spectra, the bright dereddened continuum magnitude (K≤12) of the unresolved core, its extremely large bolometric luminosity, strong UV polarization and possible variability all suggest that FSC10214+4724 harbors an obscured AGN. Given that we observe no spectral features attributable to star formation, it appears that either star formation in FSC10214+4742 is more highly obscured at optical and UV wavelengths than the narrow line region of the AGN, or that the AGN (rather than star formation) dominates the large luminosity of this object.

keywords: Galaxies:formation – infrared : sources – infrared : spectra – Seyfert II.

1. INTRODUCTION

Rowan-Robinson *et al.* (1991) have identified the IRAS Faint Source Catalog (FSC) source 10214+4724 with a non-stellar object at a redshift of 2.286, making it one of the most bolometrically luminous objects known. The identification of the IRAS source with the $z = 2.286$ optical object is supported by its coincidence with a weak radio source (Rowan-Robinson *et al.* 1991), the detection of CO ($J = 3 - 2$) emission at $z = 2.286$ (Brown & Vanden Bout 1991), and the detection of a submillimeter continuum (Clements *et al.* 1992). In addition to its large bolometric luminosity, FSC10214+4724 has been observed to be highly polarized ($P \approx 16\%$) in the rest-frame UV (Lawrence *et al.* 1993). Soifer *et al.* (1991) reported a very large value for the equivalent width of Hα ($W = 700$Å in the rest frame – but see section 2.1) and a K magnitude roughly 2 magnitudes brighter than powerful radio galaxies at the same redshift (e.g. Lilly 1989, McCarthy 1993).

Much of the current interest in FSC10214+4724 concerns the origin of its extremely high luminosity. Rowan-Robinson *et al.* (1991) proposed that it could plausibly be explained as either a dust enshrouded QSO or as a galaxy undergoing a tremendous starburst.

Previously available data do not seem to conclusively rule out one model or the other. Here we present medium resolution spectroscopy of FSC10214+4724 from UV to red wavelengths in the rest frame, as well as rest frame optical imaging and polarimetry of FSC10214+4724. These data are used to show that FSC10214+4724 possesses a powerful active galactic nucleus (AGN) which could account for much of its bolometric luminosity.

2. OBSERVATIONS

2.1 *Near Infrared Spectroscopy*

Near infrared spectra were obtained with the Kitt Peak National Observatory (KPNO) Cryogenic Infrared Spectrometer (CRSP) mounted at the f/30 focus of the Mayall 4m telescope. The observations were obtained on several nights with cirrus clouds and poor seeing in February of 1992. A 300 l mm^{-1} grating was used in second order in the H and K bands giving a resolution of about 800 ($\sim$ 375 km sec^{-1}). The detector in CRSP was a 58×62 InSb array produced by Santa Barbara Research Corporation (SBRC). It was operated using multiple nondestructive read-out (Fowler & Gatley 1990) reducing the read noise to 80 electrons. An east-west slit with a 2″5 width was used for all observations. In the K band 150 minutes of data centered on Hα and [NII]6584,6548 were obtained through variable thin cirrus. In the H band, 60 minutes of integration covering [OIII]5007,4959 and Hβ were obtained under photometric conditions with poor seeing. To obtain a better limit on the Hβ flux we obtained an additional 5 hours of integration on the H band spectrum under good conditions using CRSP at the newly commissioned f/15 focus of the Mayall 4m in November of 1992.

The location of the object was alternated between two slit positions every 300 seconds. The first order sky subtraction and dark current removal was achieved by subtracting the average of bracketing exposures. The images were then flattened using a dome flat and residual sky emission was removed by fitting a third order polynomial perpendicular to the

dispersion axis along the portion of the slit not containing the object. To remove telluric absorption and instrumental throughput variations, observations of the F5 star BS4191 were interleaved with the object observations every hour. BS4191 was assumed to be a 6600K black body in the near-IR except in the region near Brγ, over which we interpolated. Wavelength calibration was obtained from a linear fit to night sky emission lines in the spectra. ¿From the residuals of the wavelengths of the night sky lines the absolute accuracy of the wavelength calibration is $3\pm10^{-4}\mu$m, or 40 km sec^{-1}.

Since our observations were not all obtained in photometric conditions, we derived our flux zero-points from the H and K band photometry presented in Soifer *et al.* (1991), who give H=17.15 and K=16.37 in a 3.″8 diameter aperture. From our H band image we estimate that our 2.″5 slit accepted 0.2 magnitudes less flux than the 3.″8 diameter aperture used by Soifer *et al.* We measure total emission line equivalent widths in the observed frame of 0.14μm and 0.06μm in the H and K bands. Thus, the line- corrected continuum magnitudes should be 17.77 (79μJy) and 16.66 (110μJy) in the H and K bands respectively. Given the quoted photometric errors in Soifer *et al.* and the uncertainly in aperture and emission line corrections we estimate an overall uncertainty of 30% in our near-IR emission line fluxes. We present the two-dimensional H and K band near-IR spectra in Figure 1. The one-dimensional flux calibrated near-IR spectra are presented in Figure 2b and the line strengths, observed wavelengths, widths, and equivalent widths are given in Table 1. Because Hα was not clearly resolved from NII we deconvolved the blended lines. The fit was constrained by fixing the relative wavelengths of the two [NII] lines and forcing all three lines to have the same FWHM. Figure 3 shows the result of the deconvolution. Our measured rest-frame equivalent width of 174±40Å for the Hα+[NII]6584,6548 blend is significantly smaller than the 700±200Å value reported by Soifer *et al.* (1991) for the unresolved blend in their lower resolution spectrum. A reanalysis of the Soifer *et al.* data now yields an equivalent width consistent with the values reported here (G. Neugebauer

1993, personal communication).

Recently, Clements *et al.* (1993) have presented Fabry-Perot observations of FSC10214+4724 at Hα. They report a flux, for what they argue is just the Hα line, of 1.3×10^{-14} erg cm^{-2} sec^{-1} which is nearly 5 times larger than our observed Hα flux. In conflict with the Soifer *et al.* (1992) imaging of the Hα emission, Clements *et al.* argue that the Hα emission is extended over a region of 1$''$.8. Our wide slit would have contained all of the flux even if the Hα were as extended as suggested by Clements, so the flux disagreement can not be explained by our observations missing flux that was in the Clements image. Also, while our long slit spectra do not offer very high spatial resolution, they would be able to differentiate a FWHM of 1$''$.8 for the Hα emission compared to the FWHM of the continuum source which we show in section 3.3 is nearly unresolved. The spatial profiles of the line (FWHM=2$''$.3$\pm$0$''$.1) and the continuum (FWHM=2$''$.1$\pm$0$''$.2) measured from our spectra are the same. If the FWHM of the Hα emission were actually 1$''$.8 as argued by Clements *et al.* , the FWHM of the Hα profile in our spectra after convolution with our continuum PSF would be 2$''$.8, inconsistent with the observed value. Thus our observations support the view of Soifer *et al.* (1992) that the Hα emission is predominantly compact.

2.2 *Optical Spectroscopy*

An optical spectrum of FSC10214+4724 was obtained on March 4, 1992 (UT) using the Kast spectrograph on the Shane 3m telescope at Lick Observatory. The spectrograph has two channels fed by a dichroic beam splitter. Both cameras use Reticon 1200 $\times$ 400 CCD arrays. The blue camera was used with a 600 l mm^{-1} grism giving 1.8Å pixel^{-1} covering 3200Å to 5200Å. The red channel was used with a 300 l mm^{-1} grating giving 4.5Å pixel^{-1} from 5200Å to beyond 9000Å. The object was observed for 3600 seconds with FWHM=2$''$ seeing and some cirrus. Flux calibration was made relative to observations of the spectrophotometric standard HZ15 (Stone 1977), whose published flux values were

extrapolated for wavelengths longward of 8370Å. A standard atmospheric extinction correction was applied, and telluric absorption bands in the red spectrum were removed using a fit to the continuum of the nearby 'star A' (in the notation of Rowan– Robinson *et al.* 1991) which was also on the slit during the observation. This recovers the CII]2326 emission line which is otherwise obscured by the atmospheric A-band. Because the optical spectrum was obtained in non-photometric conditions, we have rescaled its flux to match the magnitude measured in the Gunn r image presented in Rowan-Robinson *et al.* (1991). Wavelength calibration was achieved using spectra of Neon and HeHgAr calibration lamps, and verified by comparison with night sky emission features. We show our visible spectrum in Figure 2a. The fluxes, observed wavelengths, widths, and equivalent widths of the strongest lines are given in Table 1. We note that the redshift derived from the well-detected UV emission lines is $z = 2.283 \pm 0.0015$, in good agreement with the rest-frame optical emission line redshift (from Hα, [NII] and [OIII]) of $z = 2.284 \pm 0.0010$, but somewhat lower than the CO redshift of $z = 2.2856 \pm 0.0003$ (Solomon, Downes & Radford 1992). We return to this point in section 3.1 below.

2.3 *Infrared Imaging and Polarimetry*

Imaging and polarimetry in the H band (1.6μm) were obtained using the KPNO infrared imager (IRIM) at the f/8 focus of the Mayall 4m on the night of March 15, 1992 (UT). Once again the sky was covered with thin cirrus. The IRIM detector was a 58×62 InSb array manufactured by SBRC and the pixel size was 0″39. A rotating half wave plate followed by a fixed linear polarizer was placed in front of the dewar window to measure the linear polarization. With the half wave plate at position angles of 0, 22.5, 45 and 67.5 degrees, twelve images of 120 seconds each were taken at slightly different array positions, giving a total integration time of 96 minutes. First order sky subtraction and dark current removal were achieved by subtracting the average of the bracketing images. The images were then flattened using a median sky flat constructed from the data. Flattened images

were replicated into a 116×124 image with 0.″2 pixels. The replicated images were registered and averaged to produce the final image after applying a 3σ pixel rejection. The final image, with a PSF of FWHM=1.″0, is presented in Figure 4. The total polarization measured in a 1.″6 diameter aperture is 3.2±2.0% after correction for statistical bias. We take a conservative 2σ upper limit to be $P < 7\%$. The nearby bright star A was also measured in all images and found to be unpolarized ($P < 1\%$), implying that instrumental polarization is unimportant.

To test for variability, we again imaged FSC10214+4724 at H on March 3, 1993 (UT) with the newly recommissioned IRIM on the KPNO 4m. The new IRIM uses a 256×256 HgCdTe NICMOS array manufactured by Rockwell. Reimaging optics provide a cold Lyot stop and 0.″6 pixels. A total of 20 separate one minute exposures were taken with the telescope offset a short distance between exposures. The data was reduced as above. As there is diffuse emission near FSC10214+4724, great care must be taken in testing for variability since seeing differences will cause varying amounts of the diffuse light to be included within an aperture. We rebinned the H band image taken in March 1992 to the same pixel scale as the March 1993 data, then convolved it with a Gaussian to match the seeing of the 1993 image (FWHM=1.″4). We chose to make a differential measurement against star A to remove uncertainty in zero point determinations. FSC10214+4724 was 1.56±0.01 and 1.40±0.02 magnitudes fainter than star A in March 1992 and 1993 respectively, as measured in a 2.″4 diameter aperture.

3. DISCUSSION

3.1 *Emission Line Classification*

Our spectrum of the Hα emission has higher spectral resolution than that obtained by Soifer *et al.* 1991. We determine line widths of FWHM(Hα)=800±200 km sec^{-1} and FWHM(OIII[5007])=1200±200 km sec^{-1} after deconvolving the instrumental line profile.

The forbidden lines have roughly the same width as the hydrogen recombination lines. This would appear to rule out the specific "dusty" QSO model with $A_V \approx 1.5$ put forward by Soifer *et al.* (1991). Such a model remains possible if the broad line region is so heavily obscured that no broad lines are easily visible at Hα. However, such a model is not well constrained, simply requiring $A_V \geq 5$ for a broad Hα line similar to that in the luminous $z = 2.2$ quasar 1225+317 (Hill, Thompson & Elston 1993) to escape detection with the S/N ratio and resolution of our Hα spectra.

The ionization and excitation mechanisms in emission-line objects can be discerned from either detailed comparison with ionization computations or with two dimensional line ratio diagrams (e.g. Baldwin, Phillips & Terlevich 1981; Veilleux & Osterbrock 1987). Both approaches are useful, and the line ratio diagrams involving reddening insensitive pairs of lines are particularly valuable in this instance. The line ratios derived from our near IR spectra, [NII]6584/Hα = 1.05±0.20 and [OIII]5007/H$\beta \geq 20$ (3σ upper limit on Hβ) place FSC10214+4724 firmly within the locus defined by the Seyfert II galaxies in the diagram shown in Figure 1 of Veilleux & Osterbrock (1987). The rest-frame optical emission line spectrum of FSC10214+4724 appears to rule out classical HII regions as the origin of the observed narrow lines. In particular, the very strong emission of [OIII]5007 relative to Hβ is not seen in even the most metal poor star formation regions.

The rest-frame UV spectra presented here and in Rowan-Robinson *et al.* (1991, 1993) show features that are characteristic of gas photoionized by a fairly hard spectrum. The strong emission lines from highly ionized species (e.g. NV1240, CIV1548) are clear indicators of a non-stellar ionizing source (but see Terlevich *et al.* (1993) and references therein). As first noted by Rowan- Robinson *et al.* (1991) the UV spectrum (with the exception of the extremely weak Lyα line) is quite similar to those of powerful radio galaxies (e.g. Spinrad *et al.* 1985; McCarthy 1993) and to NGC 1068 (Snijders *et al.* 1986) and other Seyfert II galaxies (e.g. Kinney *et al.* 1993). The strength of [NeIV]2424 reveals

modest densities in the line emitting gas, since the critical density for this transition is $\sim 10^4$ cm^{-3}. The relative strengths of the UV lines, excluding Lyα, are well reproduced by photoionization of a low density gas by a $\nu^{-1.5}$ power-law with an ionization parameter of ~ 0.02 (Ferland & Netzer 1983). Star forming galaxies at the present epoch have distinctly different UV spectra. In general they do not have strong emission line spectra in the UV (Rosa *et al.* 1984; Hartmann *et al.* 1988; Kinney *et al.* 1993), but instead show CIV and SiIV absorption. Lines of CIV1548,1550, HeII1640 and CIII]1909 are seen in emission in only a very few star forming objects (e.g. NGC2366), but strong [NeIV]2424 and NV1240 emission is not observed. Overall, both the rest-frame visible and UV line spectra are clearly more similar to present day AGNs than to star forming objects. Finally, the permitted CIV1548,1550 and HeII1640 lines appear to be fairly broad, with FWHM of 1200±200 km sec^{-1} and 800±200 km sec^{-1} respectively after removing the instrumental line profiles. While not as broad as emission lines in quasars, they are similar to those seen in radio galaxies and Seyfert II galaxies, and are much broader than those expected for a star formation region where the line widths are set by the gravitational potential of the galaxy. It is also interesting to note that all of the well-detected visible and UV emission lines, observed with several different instruments and at different times, give significantly lower redshifts ($z = 2.283$) than the CO observations imply ($z = 2.286$; Brown & van den Bout 1991; Solomon *et al.* 1992; Radford 1993). We have no model for this effect, but we do make two suggestions. First, systematic shifts of emission lines are noted in other types of AGN and are usually associated with either bulk outflow or infall coupled with extinction (e.g. Espey *et al.* 1989). In this case, the CO line may give the true systemic velocity of FSC10214+4724 while the optical and UV emission lines are systematically shifted by bulk motion and obscuration. Alternatively, FSC10214+4724 could consist of two or more objects with non-zero relative velocities, one of which harbors the AGN while the other is associated with the observed molecular gas.

3.2 *Reddening*

The enormous far-infrared luminosity of FSC 10214+4724 implies a large amount of thermally emitting dust. Here we discuss our measurements of Hα, Hβ and Lyα to place limits on the reddening of the narrow line region in FSC10214+4724. For this discussion we will use an upper limit for the flux from Lyα at $z = 2.283$, although as we note below (and as seen in the spectrum of Rowan–Robinson *et al.* 1993) there is weak emission, at a discrepant redshift, which may be the red wing of Lyα.

If we assume low density case B recombination with $T_e = 10^4$ we expect Hα/Hβ=2.86 and Lyα/Hα=8.75 (Osterbrock 1974; Binette, Magris & Bruzual 1991). We measure Hα/H$\beta \geq 20$ and Lyα/H$\alpha \leq 0.1$ based on 2σ limits to Hβ and Lyα. For a simple screen model this Hα/Hβ ratio implies $A_V \geq 5.4$, using the visible-light galactic reddening curve of Whitford (1958) as parameterized by Miller and Mathews (1972). We emphasize that $A_V \geq 5.4$ *is truly a lower limit to the extinction* for several reasons. First, Hβ has not been convincingly detected and may be weaker than the quoted upper limit. Secondly, this amount of extinction implies that the source is optically thick at Hα and we may therefore only be seeing part of the narrow line region if the dust and gas are mixed in the narrow line region. Ingeneral, models where the extinction is not a simple screen (e.g. Witt *et al.* 1992), as we shall discuss is the case for FSC10214+4724, the differential extinction (the relative change in flux at different wavelengths) underestimates the actual extinction.

The upper limit on Lyα is consistent with this amount of reddening. With a galactic extinction curve (Seaton 1979), Lyα would be extincted by $\geq$17 magnitudes, and with an SMC extinction curve (Prévot *et al.* 1984) it would be extincted by $\geq$24 magnitudes. However from the extreme weakness of Lyα relative to NV1240 it seems clear that a simple screen model is inappropriate to describe the extinction from the UV to the optical. The Lyα/NV1240 ratio in Seyfert II and radio galaxies with UV spectra otherwise similar to

FSC10214+4724 is typically ~ 20 (e.g. Ferland and Osterbrock 1986; McCarthy 1993). The weakness of Lyα in FSC10214+4724 could be due either to resonant scattering-enhanced destruction (e.g. Binette, Magris & Bruzual 1991) or a Lyα absorption line at the redshift of FSC10214+4724 (e.g. similar to PKS0528-250, Foltz, Chaffee & Black 1988). Although our spectrum is noisy in this region, there appears to be an emission line at 4005Å which, if it were Lyα, would be at a redshift of 2.294. This is about 1000 km sec^{-1} to the red of the other UV and optical emission lines. This could be the red wing of a Lyα emission line that has either had its core destroyed by resonant scattering or absorbed by an intervening system. Given the large dust content and UV polarization, suggestive of scattering of the UV light in FSC10214+4724, resonant scattering destruction of Lyα seems likely.

The strength and relatively flat shape of the UV continuum and the UV line ratios also argue against a simple screen model with a large A_V. Application of a screen reddening correction to the continuum colors assuming $A_V = 5.4$ and a galactic extinction law (Seaton 1979) changes the r - K color from the observed 4.5 to an inferred intrinsic value ~ -4, leading to an overall spectral energy distribution that is strongly *rising* toward blue wavelengths in F_ν units. Nearly all AGN (i.e. QSOs, Seyfert I, Seyfert II and radio galaxies) and stellar populations have continua that are either falling from the optical to the UV or are roughly flat in F_ν units, although objects dominated by dust scattering can have spectra that are strongly rising in the near-UV (Tadhunter *et al.* 1987). Thus, no AGN or stellar population reddened by a simple screen model fits the spectral energy distribution of FSC10214+4724. Geometries that are more realistic and include intermixed dust and emission regions with scattering properly treated usually produce less reddening of the spectral energy distribution (Witt *et al.* 1992, Rowan-Robinson *et al.* 1993). There are several scenarios which can reconcile the large reddening indicated by the hydrogen lines with the blue color of the far-UV (FUV) continuum. The obscuring material may have a covering factor significantly less than unity. We are then seeing through regions of low

extinction in the FUV, but sample a wide range of optical depths at longer wavelengths. Alternatively, the continuum may come from several sources intermixed with dust. The strong polarization of the FUV continuum (Lawrence *et al.* 1993) and lack of detectable polarization in the rest-frame visible suggests a different transfer path for the UV and visible continua. We may be seeing the AGN directly in the rest-frame optical, but the UV is dominated by nuclear light scattered, and possibly reprocessed, by an anisotropic screen (Lawrence *et al.* 1993). The similarity between the FUV continuum shape, line ratios, and fractional polarization in FSC10214+4724 and powerful radio galaxies at similar redshifts strongly suggests that similar physical processes are at work (Cimatti *et al.* 1993).

If we apply the lower limit to the reddening derived from the Balmer decrement to the observed K-band and Hα fluxes we can derive lower limits to the unreddened K magnitude and the Hα flux. The fluxes increase by at least a factor of 75 so that the unreddened K magnitude of the point source is brighter than 12, comparable to the brightest quasars at $z > 2$ and 5 magnitudes brighter than the most luminous radio galaxies at the same redshift (McCarthy 1993). The corrected energy density at H ($\nu F_\nu \geq 3 \times 10^{-11}$ ergs cm^{-2}) is larger than the 60μm energy density ($\nu F_\nu = 10^{-11}$ ergs cm^{-2}). Thus, reprocessing of the rest-frame optical emission can provide the large observed far-IR bolometric luminosity of FSC10214+4724, implying there is no need for a large hidden power source. The Hα flux increases to greater than 2×10^{-13}erg cm^{-2} sec^{-1}, requiring 2×10^{57} h^{-2} (q_0=0.5) ionizing photons per second. The required ionizing photon flux could be provided either by 3×10^7 O5 stars or by a luminous quasar. If we take the bolometric luminosity of FSC10214+4724 to be $8 \times 10^{13} L_\odot h^{-2}$ ($q_0 = 0.5$) we find a ratio of the bolometric luminosity to the rate of photoionization of 100eV/ionizing photon ($4 \times 10^{-44} L_\odot$ sec). This value is consistent with those produced by model star bursts with ages of a few times 10^8 years if no stars less massive than 1 $M_\odot$ are formed and the upper mass cutoff of the initial mass function is $100 M_\odot$ (Maloney & Elston 1993, Scoville & Soifer 1991). Even with this lower mass cutoff

such models have star formation rates of about $10^4 M_\odot$ yr^{-1}, implying a gas depletion time of 10^7 years, assuming there is about $10^{11} M_\odot$ of H_2, and a 100% efficiency of converting gas to stars. Even with such an unphysically high efficiency of star formation, this gas depletion time scale is implausibly short as it is much less than the dynamical time scale of a large galaxy. In any case it is clear from the rest-frame optical and UV line ratios that star formation is not the primary source of ionizing photons in the observed narrow line region of FSC10214+4724.

3.3 *Morphology*

In the course of measuring the H band polarization of FSC10214+4724 we obtained a deep image of the source in seeing with FWHM=1.″0 (Figure 4). Soifer *et al.* (1992) and Lawrence *et al.* (1993) have also presented near-IR images of FSC10214+4724. We take a different approach to the analysis of our deep H band image. We have used the image of star A on the frame to subtract the bright point source component of FSC10214+4724. Figure 5a shows the PSF subtracted H band image of FSC10214+4724. In Figure 5b we show the result of a similar subtraction for the Gunn r band image taken by one of us (P.McC.) with the Palomar 5m in 1.″5 FWHM seeing, and shown in Rowan-Robinson *et al.* (1991). In Table 2 we present the H and r band photometry of sources near the point source component of FSC10214+4724 assuming the H and r band zero points given in Soifer *et al.* (1991) and Rowan-Robinson *et al.* (1991) respectively. The zero point uncertainties are about 0.1 mag for both bands. Photometry was obtained in 1.″5 diameter apertures centered on the same spatial positions in both the r and H band images and was corrected using the curve of growth of star A. The photometric error values given in Table 2 reflect only the errors in relative photometry, not the systematic zero point uncertainty. We note that the point source subtracts nearly perfectly in both the optical and near-IR images, implying that the dominant luminous component of FSC10214+4724 is truly unresolved (FWHM<0.″3 at H, <0.″5 at r). We are sensitive to 2σ surface brightness levels of <20.7

mag arcsec^{-2} at H and 25.2 mag arcsec^{-2} at r.

We see objects to the north and west of the nucleus, as previously noted by Soifer *et al.* (1992) and Lawrence *et al.* (1993). We also weakly detect several other nearby objects making it appear that FSC10214+4724 resides in a small group. Soifer *et al.* and Lawrence *et al.* suggest that this may be an interacting system of two or more highly luminous galaxies, analogous to nearby ultraluminous IRAS selected galaxies. Both assume that the nearby objects are physically associated with the bright point source. At the magnitude of the companions (K≈18 assuming H-K≈1.0, which is typical of galaxies with $z \geq 0.4$) deep field count surveys (e.g. Cowie & Songaila 1993) indicate a surface density of $\approx 10^4$ objects deg^{-2}. This would suggest that the chance of a random projection within 2″ is only about 10^{-2}. However, FSC10214+4724 was drawn from near the flux limit of the IRAS catalog. We suggest that the probability of projection may be enhanced by two mechanisms. First, the projected group of galaxies could contribute to the IRAS flux, thus requiring the projection for inclusion in the catalog. This seems unlikely, however, as the companion objects are not detected as radio sources in the deep VLA maps of Lawrence *et al.* (1993) and thus probably do not contribute significantly to the total 60μm flux of FSC10214+4724 if they obey the standard ratio of radio to IR flux (Helou, Soifer & Rowan-Robinson 1985). Alternatively, if the apparent companions are in the foreground, then they might gravitationally lens the $z = 2.3$ object associated with FSC10214+4724, amplifying its observed flux so that it is included in the Faint Source Catalog. Lensing could then provide a natural explanation why such a seemingly low probability projection would be found, since FSC10214+4727 is drawn from near the flux limit of the IRAS survey. A similar excess of galaxies near luminous QSOs has been reported (e.g. Stocke *et al.* 1987, Webster *et al.* 1988) and attributed to lensing.

The H magnitudes of the apparent companions (18.5, 19.3 and 19.5) are similar to those observed for $z \approx 2$ radio galaxies (Lilly 1989, McCarthy 1993), which are nearly

as luminous as brightest cluster galaxies at low redshift (Lebofsky & Eisenhardt 1986; $M_V = -23$ for $H_0 = 50$, Sandage 1972). It is unlikely that three high redshift companions would have such large luminosities unless they are undergoing a period of very rapid star formation. This appears implausible, since Soifer *et al.* (1992) find no strong Hα emission from these objects, and they are not detected as radio sources by Lawrence *et al.* (1993). The companions are also redder (R-H$\approx$4.4) than would be expected from simple models for an actively star-forming galaxy at $z = 2.3$, and are redder than the FSC10214+4724 point source despite the latter's large inferred reddening. The companions' magnitudes *are* appropriate, however, for those expected for $\sim L_*$ galaxies at $z \approx$0.6-1.0, depending on the assumed amount of luminosity evolution. Their colors are also consistent with those of early type galaxies in this redshift range. We therefore believe that these objects are more likely to be early type galaxies in a foreground group rather than actual companions to the $z = 2.3$ object.

3.4 *Variability and Polarization*

If FSC10214+4724 is a reddened quasar then it seems plausible that FSC10214+4724 should be a flux variable. The poor consistency of published photometry of FSC10214+4724 (Rowan-Robinson *et al.* 1991; Soifer *et al.* 1991; Lawrence *et al.* 1993) suggested the possibility of variability to us, although differing aperture sizes, seeing differences, and uncertainty in the zero points mean that no strong case can be made based on the previous data. As explained in section 2.3, we carefully matched the pixel scales and seeing in two H band images taken a year apart to make differential measurements of FSC10214+4724 against a nearby field star. It appears that FSC10214+4724 varied by 0.16$\pm$0.03 magnitudes during the year relative to star A. This amount of H band variability is not uncommon in optically selected quasars (Neugebauer *et al.* 1989). If variability is confirmed by further measurements, it could provide important constraints on the nature of FSC10214+4724.

The decline of the polarization of FSC10214+4724 from 16.4% in the FUV (Lawrence *et al.* 1993) to < 7% (2σ upper limit) at rest–frame optical wavelengths indicates that the optical and UV light originates either in distinct regions or take different paths between the source and the observer. The overall strength of the far UV polarization argues against transmission through aligned grains as the mechanism for the polarization. A similar trend of the continuum polarization increasing into the UV is observed in the Seyfert I galaxy Mkn 231 (Schmidt & Miller 1985) which is also an ultraluminous IRAS source. Based on spectropolarimetry, Schmidt and Miller concluded that the UV continuum of Mkn 231 is polarized by scattering from dust grains in the inner few hundred parsecs, while at longer wavelengths the continuum is less polarized since it is dominated by light viewed directly. The situation for FSC10214+4724 is probably very similar to that in Mkn 231, but more detailed spectropolarimetry is needed to evaluate this scenario.

4. ADDITIONAL DISCUSSION AND SPECULATION

The visible-to-UV emission line spectrum of FSC10214+4724 is similar to that of a Seyfert II or radio galaxy and quite unlike that of any star formation region. In objects similar to FSC10214+4724 with strong UV polarization, these types of spectra are often attributed to the presence of an active galactic nucleus which is obscured from the observer's line of sight by an asymmetric screen (Antonucci & Miller 1985; Scarrott, Rolph & Tadhunter 1990; Jannuzi & Elston 1991; di Serego Alighieri *et al.* 1989,1993). It would seem that given its large far–IR luminosity and low radio power, FSC10214+4724 is the radio quiet QSO analog of these types of sources. Indeed, the dereddened K magnitude of the unresolved component ($K \leq 12$) of FSC10214+4724 is as bright as the most luminous QSOs at the same redshift. As argued by Soifer *et al.* (1992), the spatially unresolved nature of the Hα emission is consistent with a narrow-line region of an AGN but not with a region of star formation. Also, both Rowan-Robinson *et al.* (1993) and Soifer *et al.* (1991, 1992) argue that the energetics of FSC10214+4724 can be explained by a quasar embedded

in a dust cloud with $A_V \geq 5$, consistent with our limit on the reddening. Thus, given the strong evidence that FSC10214+4724 contains an AGN which is obscured by an anisotropic screen and the lack of any direct evidence for star formation (i.e. stellar absorption lines associated with hot stars or emission lines associated with star formation regions), it seems inappropriate without more compelling observations to consider FSC10214+4724 to be a source dominated by star formation (e.g. a forming galaxy).

Undoubtedly FSC10214+4724 possesses a large amount of molecular gas, perhaps as much as $10^{11} h^{-2} M_\odot$ based on observations of multiple transitions of CO (Solomon, Downes and Radford 1992). The narrow width of the CO lines (240 km sec^{-1}) is not atypical of lower redshift ultra- luminous galaxies detected by IRAS (Sanders, Scoville & Soifer 1991), suggesting the gas resides in a cool disk configuration. Indeed, interferometer observations (Radford 1993) suggest that the CO emission is extended over a region of a few arcseconds, allowing molecular mass estimates to be consistent with (less than or equal to) the dynamical mass inferred from the linewidth. The ratio of bolometric to CO(1-0) luminosities in FSC10214+4724 is approximately 3000, assuming CO(3-2)/CO(1-0)≈1. Galaxies in the Sanders, Scoville and Soifer sample with bolometric luminosities less than $\sim 10^{11}\ L_\odot$ typically have values of this ratio of order 100. For galaxies with luminosities above $10^{12} L_\odot$ this ratio is usually three or four times larger. The most luminous galaxy in their sample, Mkn 231, also has the largest ratio of bolometric to CO luminosity (1000). Thus, while the value of this ratio in FSC 10214+4724 is much larger than is seen even for the highest luminosity galaxies in the Sanders *et al.* sample, it does seem to smoothly extend the trend of increasing L_{bol}/L_{CO} with bolometric luminosity. In particular, it is only three times larger than the ratio seen in Mkn 231, the highest luminosity galaxy in the Sanders *et al.* sample. The increasing ratio of bolometric to CO luminosity with larger bolometric luminosity can be straightforwardly interpreted as a shift of the dominant energy source from massive stars to an active galactic nucleus, as Sanders *et al.* suggest.

However, this conclusion must be tempered by our general lack of understanding of the interstellar medium at high redshifts (e.g., cloud properties and the degree of heavy element enrichment).

As in other "radio quiet" quasars, the extended radio emission may well be due to disk star formation (Condon, Gower and Hutchings 1987). Lawrence *et al.* (1993) and Rowan-Robinson *et al.* (1991,1993) suggest that the radio emission results from supernovae associated with a massive starburst. We can compute the ratio of far-IR luminosity to radio luminosity by taking the standard flux ratios in the proper rest-frame bands using data from Rowan-Robinson *et al.* (1993): $S(60\ \mu m)_{rest} = S(200\ \mu m)_{obs} = 230$ mJy; $S(100\ \mu m)_{rest} = S(330\ \mu m)_{obs} = 250$ mJy; $S(1.4\ GHz)_{rest} = S(0.4\ GHz)_{obs} = 3.52$ mJy. We compute $q=1.9\pm0.3$ which is the log of the ratio of bolometric to radio flux using the method of Helou *et al.* (1985). This is very nearly the same as the value found by Helou *et al.* for star forming disks and nuclear starbursts ($q=2.14\pm0.14$) or the large radio selected sample of Condon and Broderick (1986) ($q=2.35\pm0.30$). While this shows that FSC10214+4724 has a ratio of radio to IR flux similar to low redshift IRAS selected galaxies, the ratio of radio luminosity to bolometric far-IR luminosity is similar for both radio-quiet AGNs, star forming disks and nuclear starbursts (Rieke 1978; Sopp & Alexander 1991). Thus, the radio emission does not help to differentiate the contribution of the AGN and the star formation to the bolometric luminosity. Brown & Vanden Bout (1992) claim a tentative detection of emission from the fine structure cooling lines of carbon suggestive of photodissociation regions in dense molecular clouds exposed to the UV radiation field of a hot stellar population. If fine structure cooling lines are confirmed it would seem likely that part of the large bolometric luminosity of FSC10214+4724 is due to star formation.

Therefore, while FSC10214+4724 clearly harbors an AGN, and possibly actively star forming regions, the relative contributions of these components to its large bolometric flux is unclear. Its large far-IR flux and inclusion in the IRAS FSC could be due to the

presence of both an IR luminous AGN and rapid star formation. What *is* evident is that the rest-frame optical through UV emission of FSC10214+4724 is dominated by emission lines usually associated with AGN, and that star formation is not the dominant source of photoionization in this object. Given that we observe no spectral features attributed to star formation in the optical in UV, it appears that either star formation in FSC10214+4724 is highly obscured while the narrow line region of the AGN is not (a rather difficult geometry) or that the AGN (rather than star formation) dominates the large luminosity of this object. Many of the unanswered questions posed by this object also apply to the local far–IR luminous galaxies. In nearly all of its properties, FSC10214+4724 appears to be simply an extreme example of the far–IR luminous galaxy phenomena. If these local objects are dust enshrouded quasars (Sanders *et al.* 1988; Sanders, Scoville & Soifer 1991; Hines & Wills 1993), the greater luminosity of FSC10214+4724 may be due to the observed luminosity evolution of quasars between $z = 0$ and $z = 2$ (e.g. Boyle *et al.* 1991). Furthermore, the coincidence of a group of objects near FSC10214+4724 may enhance its apparent luminosity through gravitational lensing, reducing the required extrapolation from today's ultraluminous galaxies. While FSC10214+4724 is an unusual object by any standards, it is perhaps not as unique or unexpected as it seems at first glance and does not represent a new class of object but is very similar to known ultraluminous galaxies detected by IRAS.

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Figure 1. Two-dimensional near-IR spectra of FSC10214+4724. The H band spectrum which includes Hβ, and [OIII]5007,4949 is on the left. The K band spectrum which includes Hα blended with the [NII]6548 and 6584 lines is on the right. The pixels are 0.″9 by 17Å with longer wavelengths toward the right and east up. While continuum and the [OIII] lines are clearly detected in the H band, there is no convincing detection of Hβ, implying a large ratio of [OIII]/Hβ. In the K band the peak of the [NII]6563 line is nearly equal in brightness to that of Hα. These line ratios are similar to those seen in Seyfert II galaxies at low redshift and are very distinct from those of classical HII regions. None of the line emission appears to have greater extent along the slit than the does the continuum at this spatial resolution.

Figure 2. The UV to red spectrum (in the rest frame) of FSC10214+4724. The UV spectrum is dominated by high excitation emission lines (NV, CIV, HeII, CIII] and [NeIV]) characteristic of Seyfert II galaxies rather than star formation regions. The rest-frame optical region also shows a high excitation spectrum characteristic of Seyfert II galaxies with [OIII]/H$\beta \geq 20$. Such Seyfert II spectra are very common among ultraluminous IRAS selected galaxies at lower redshift. The high extinction inferred from a ratio of Hα/H$\beta \geq 20$ seems incompatible with a simple screen model of extinction given the strength of the UV emission lines and continuum.

Figure 3. The deconvolution of the blended Hα and [NII]6548 and 6584 emission lines. Given the signal to noise ratio of the spectra, we have required that all three lines have the same FWHM. The fluxes of the deconvolved emission lines are given in Table 1.

Figure 4. H band (1.6μm) image obtained of FSC10214+4724 with the KPNO 4m telescope in FWHM=1.″0 seeing. The pixels are 0.″2. North is up and east is to the left. Star A of Rowan-Robinson *et al.* (1991) is on the left and the identification of FSC10214+4724 is on

the right. A group of objects appears near the unresolved component of FSC10214+4724.

Figure 5. The H and r band images of FSC10214+4724 after subtraction of the scaled image of star A from the point source component. The pixels are 0.″2 in the H image and 0.″3 in the r image. North is up and east is to the left in both. The field of view is 12.″3 in the r image and 8.″2 in the H image. The point–source subtraction nearly perfectly removes the central component of FSC10214+4724, showing that it is unresolved. Three objects distinct from the point source are left in both the H band and r band image. The colors (r-H$\approx$4.4) and magnitudes (19.5<H<18.5) of these objects are more similar to those of a group of early-type galaxies at z=0.6-1 than those expected for z=2.3 galaxies associated with FSC10214+4724.

Table 1. Emission line data.

Line	λ (Å)	z	FWHM(km/s)	W_λ(Å)	f(10^{-16}ergs/cm^2/sec)
HI 1216	3993	2.284	-	-	< 5
NV 1240	4072	2.284	550	28	39
CIV 1549	5084	2.282	1040	73	44
HeII 1640	5381	2.281	1040	35	21
CIII] 1909	6265	2.282	1241	24	12
NeIV]2426	7959	2.280	400	11	5
HI 4861	15984	2.288	-	10	< 1.2
OIII]4959	16279	2.283	1200	120	25
OIII]5007	16437	2.283	1200	320	64
NII]6548	21504	2.284	800	34	13
HI 6563	21556	2.285	800	62	28
NII]6584	21623	2.284	800	78	29

Table 2. Photometic data.

Component	RA Offset arcseconds	Dec Offset arcseconds	r	H	r-H
Core	0.0 E	0.0 N	20.72±0.02	17.36±0.02	3.36±0.03
Comp 1	0.1 W	1.2 N	22.93±0.12	18.51±0.06	4.42±0.12
Comp 2	0.5 W	0.0 N	23.67±0.25	19.28±0.13	4.39±0.28
Comp 3	1.3 E	3.2 N	23.13±0.15	19.52±0.16	3.61±0.22

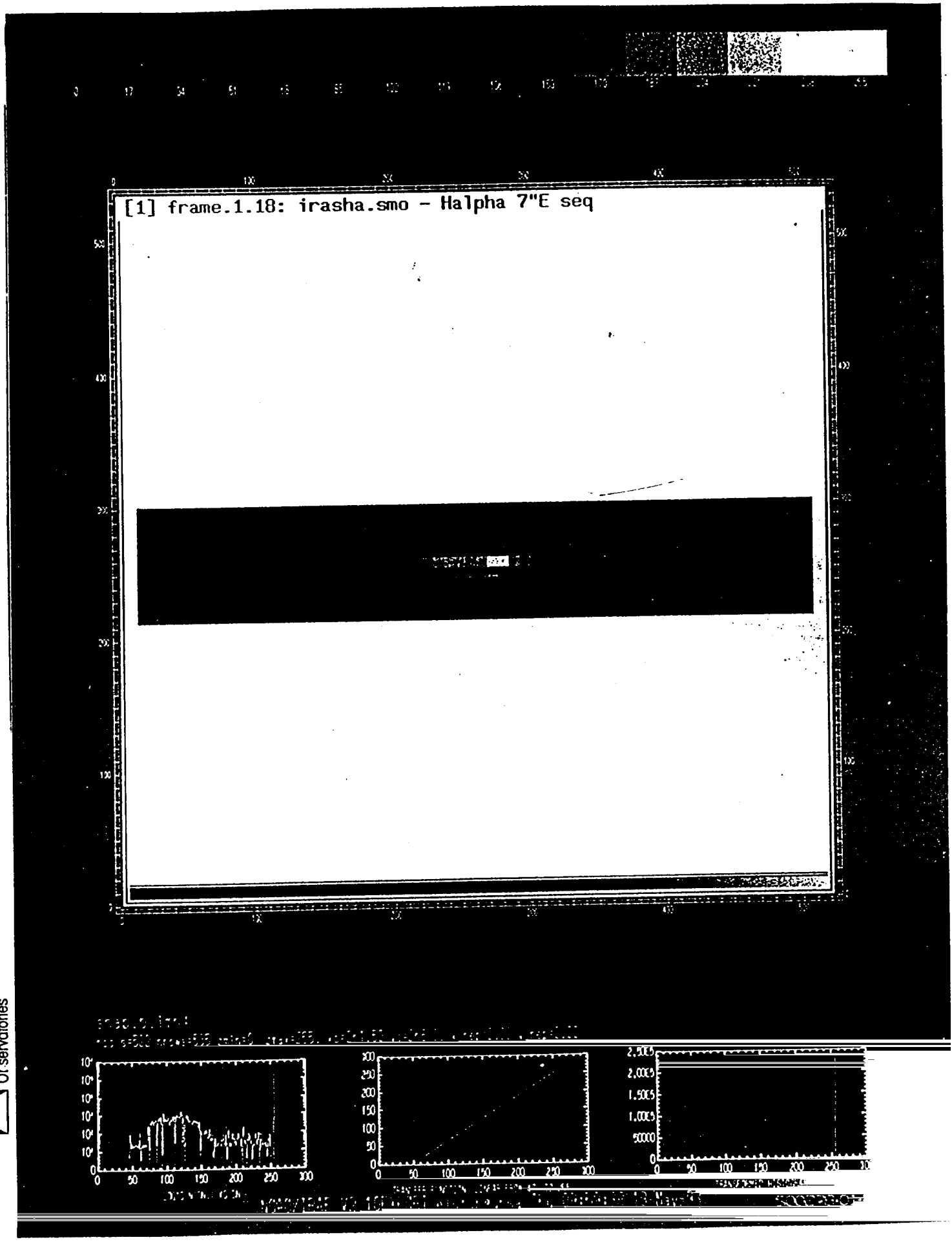

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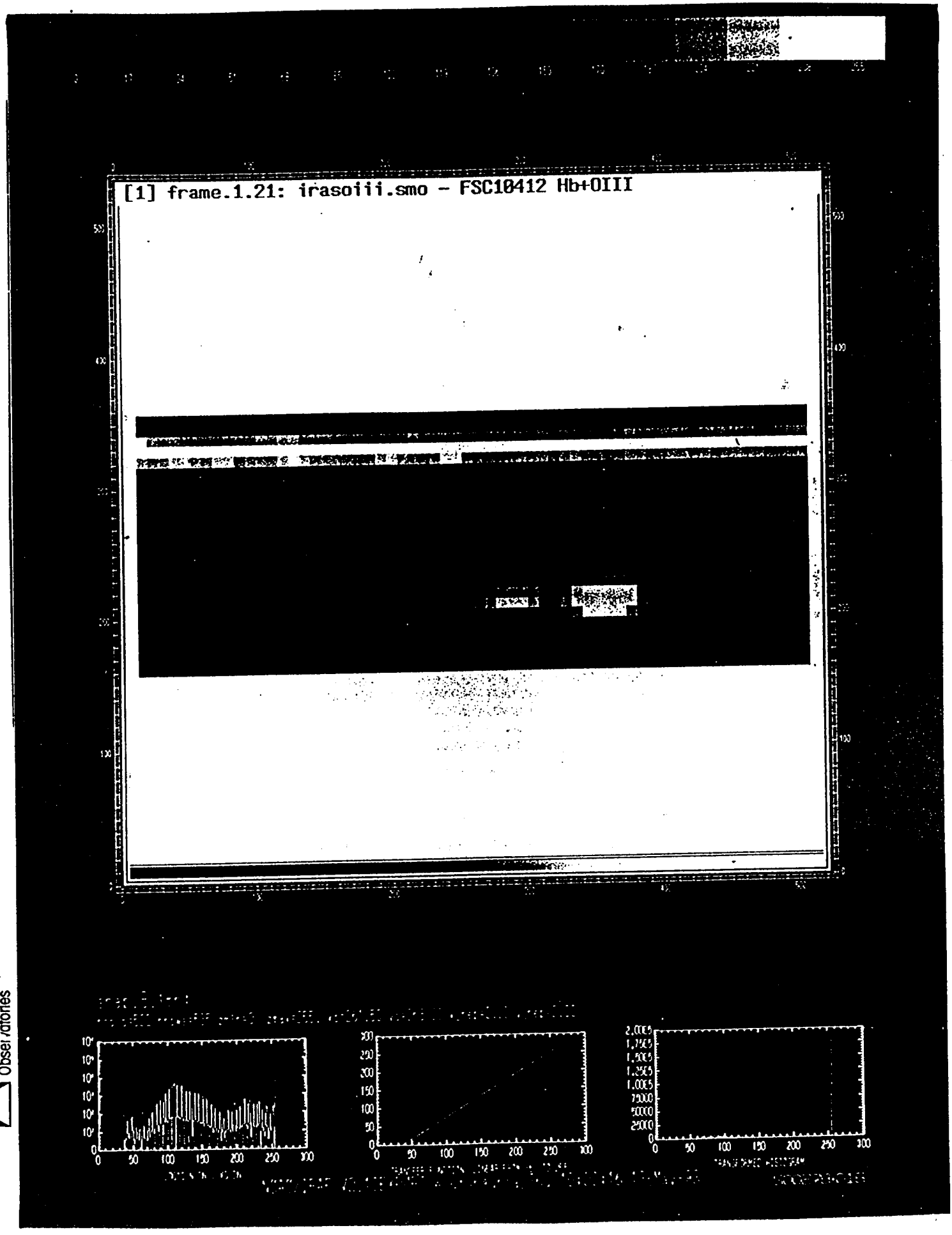
Figure 1b



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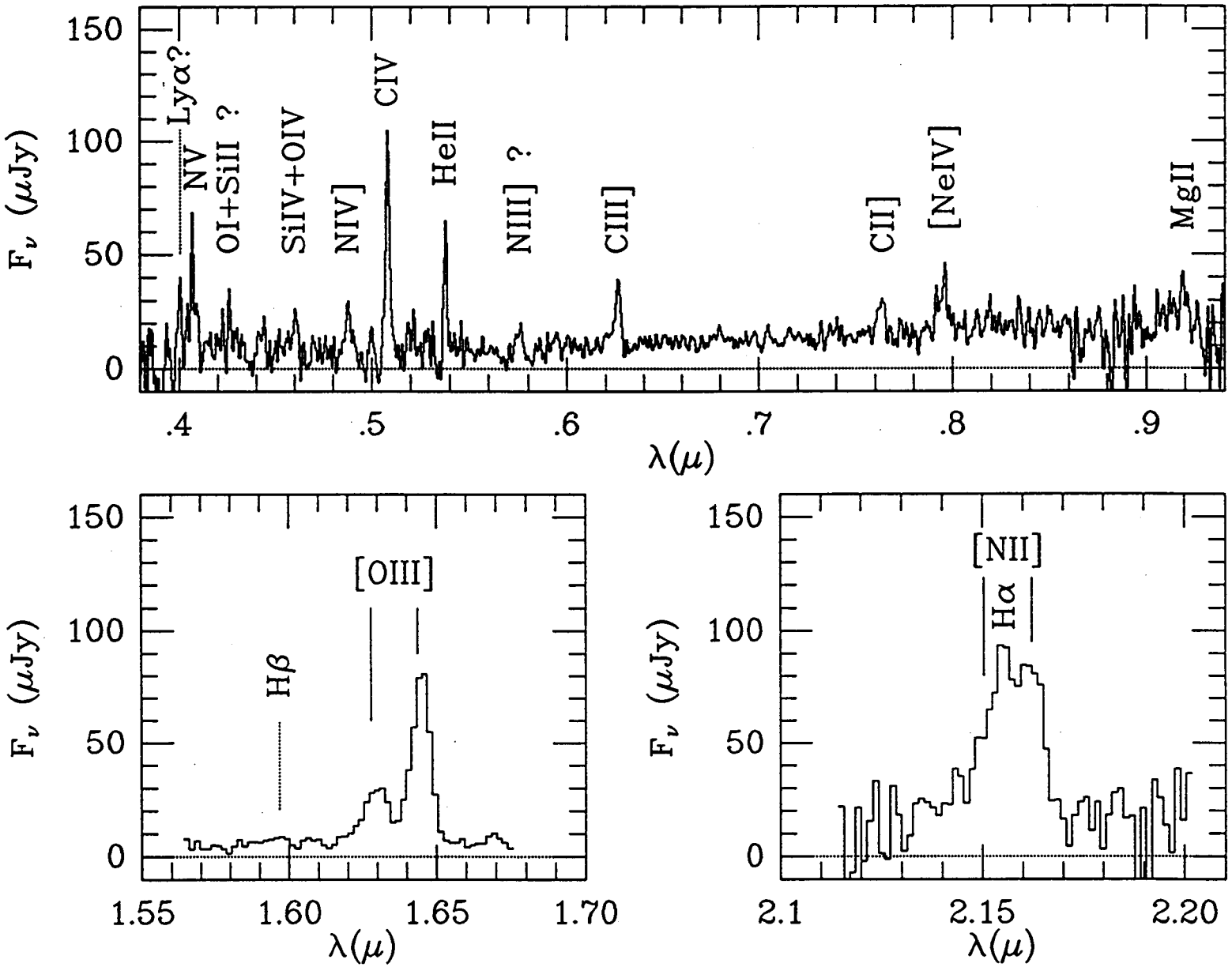
NV
CIV
HeII
CIII]
[NeIV]
Hβ
[OIII]
Hα
[NII]
F_ν (μJy)
$\lambda(\mu)$
0
50
100
150
.4
.5
.6
.7
.8
1.55
1.60
1.65
1.70
2.1
2.15
2.20


150
100
50
0
F_ν (μJy)
Lyα?
NV
OI+SiII ?
SiIV+OIV
NIV]
CIV
HeII
NIII] ?
CIII]
CII]
[NeIV]
MgII
.4
.5
.6
.7
.8
.9
$\lambda(\mu)$
Hβ
[OIII]
1.55
1.60
1.65
1.70
[NII]
Hα
2.1
2.15
2.20

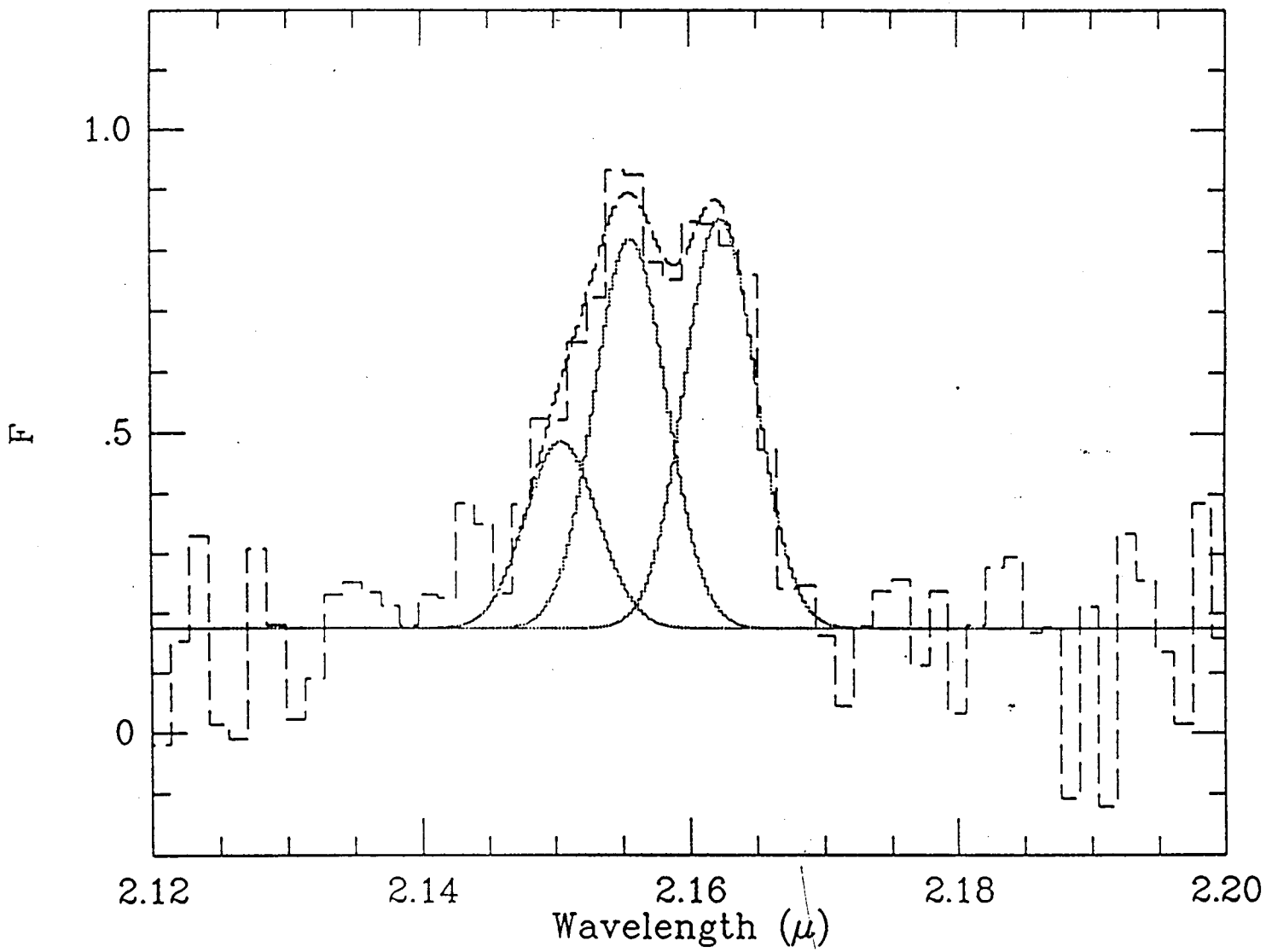
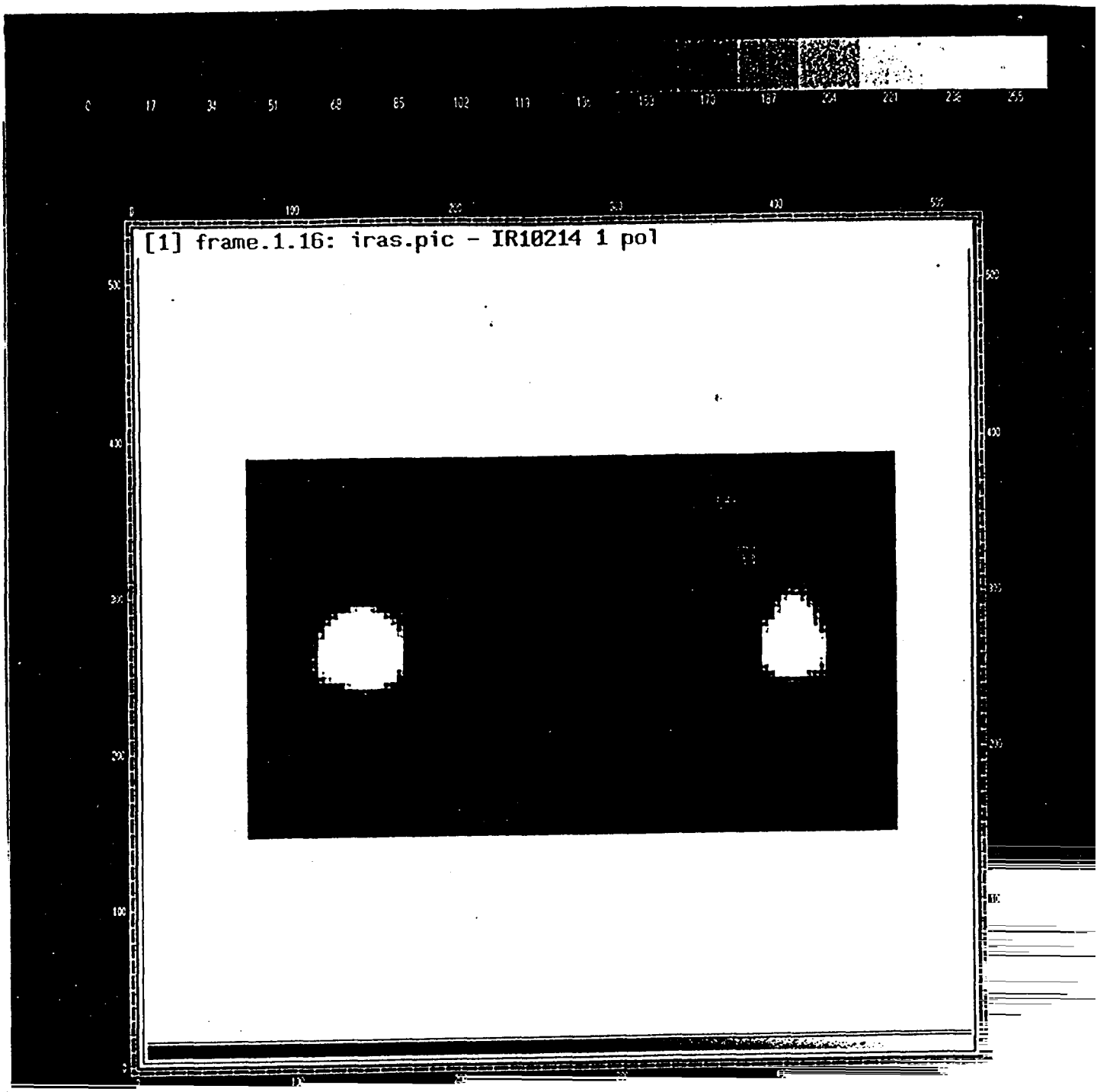

1.0
.5
0
F
2.12
2.14
2.16
2.18
2.20
Wavelength (μ)

Figure 4



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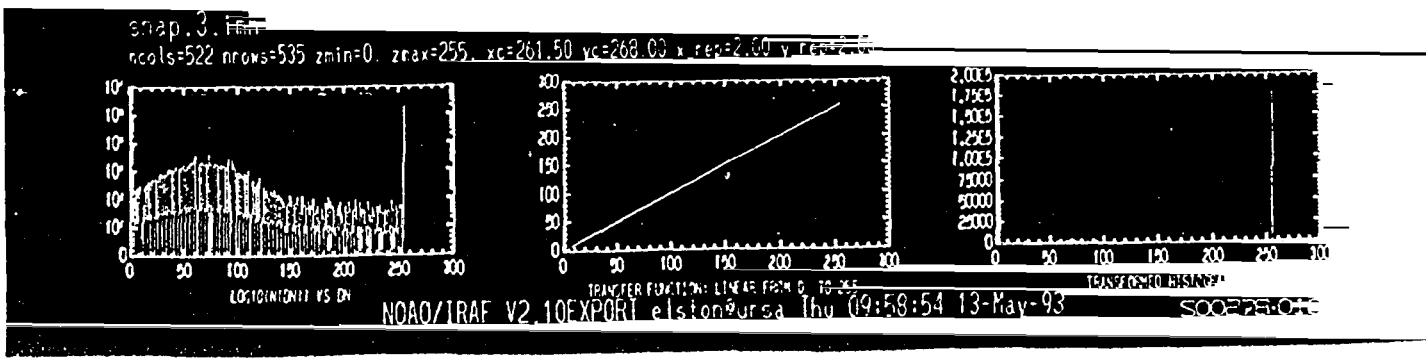
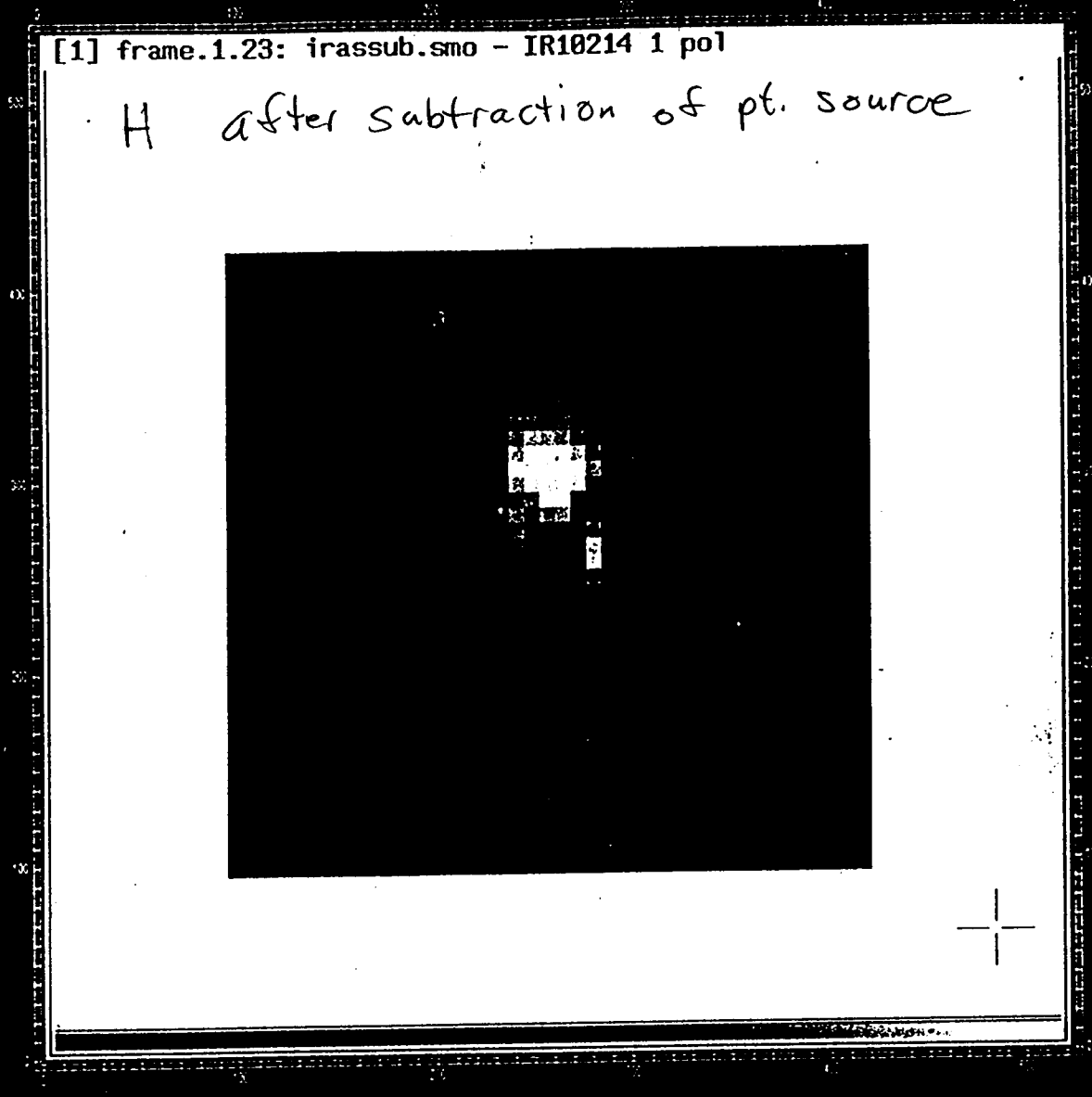
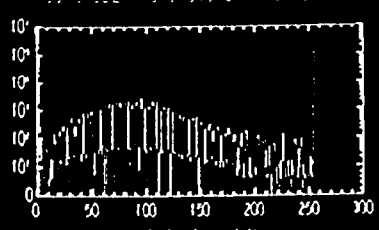
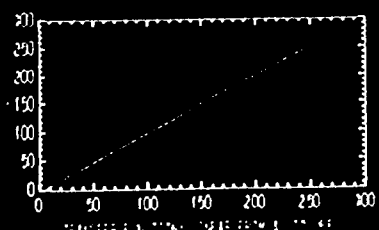


Figure 05a







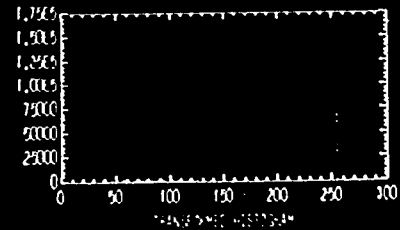


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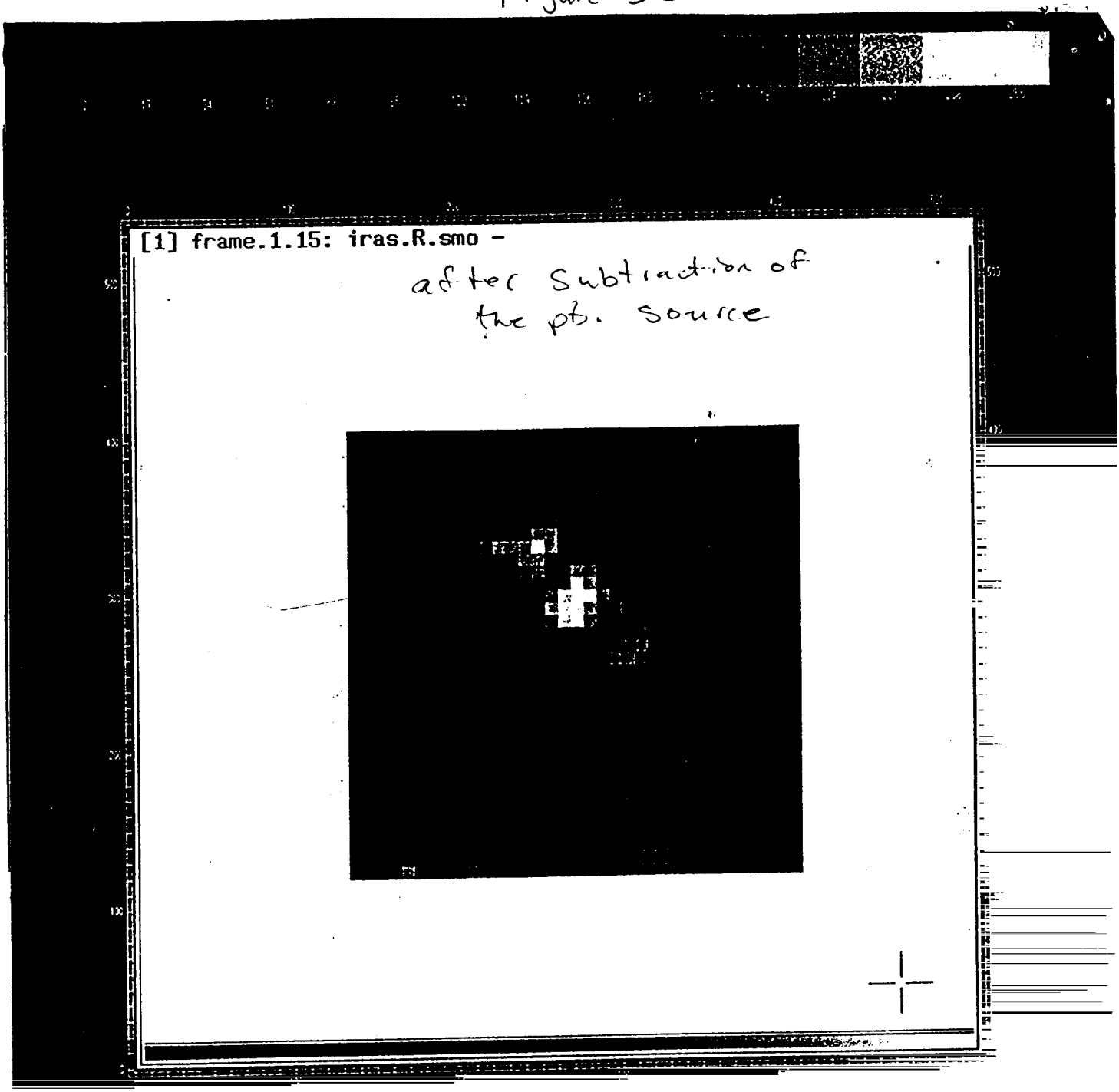
Figure 5b



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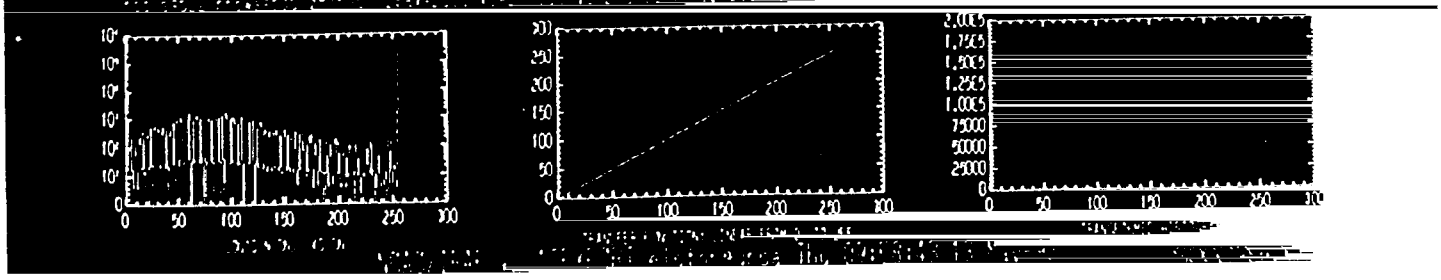
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