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Final Report on Reduction of EUVE Guest Observer Data

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Subject: Diffuse EUV Observations of Diffuse Filament LVC 88+36-2

Summary

We report on the observation of the HI filament LVC 88+36-2 with the Deep Survey/Spectrometers of EUVE. Detecting the shadow of this cloud in absorption might have proven the existence of a diffuse EUV background behind the cloud, and constrain the emission geometrys of the hot plasma in the Local Interstellar Medium (LISM). By detecting diffuse emission in the EUVE spectrometers, it would also be possible to constrain the temperature and pressure of the emitting regions as well as determine whether or not the hot phase of the LISM is in equilibrium with cosmic elemental abundances. Unfortunately, we did not detect a cloud shadow with this set of observations. This is due to a combination of circumstances, but mostly due to the fact that EUV diffuse emission is weak compared to the background levels of EUVE. If a shadow exists in the EUVE, then it is less than 1% of the EUVE detector background of 1e-3 cts arcmin^{-2} in the Deep Survey detector.

Introduction

LVC 88+36-2 was thought to be an excellent target for this probe of the hot LISM gas because:

1. It is a cold (T < 150K), dense (n_H ~ 75 cm-3), and nearby (d = 62pc +-20pc) cloud that is inside the Local Bubble of hot (T ~ 106) gas (Wennmacher, Lilienthal, and Herbstmeier, 1992)
2. It produces a shadow in the lowest energy (Ca and Cb) energy bands of the PSPC detector of ROSAT (Kerp, Herbstmeier and Mebold, 1993).
3. Its filamentary shape of ~ 20 arc minutes by 6 degrees is ideally suited to the field of view of the EUVE instruments.
4. This is an excellent candidate for detecting the emission from the conductive interface between a cold dense cloud and the hot ISM. The foreground column is low enough that many of the lines emitted by a plasma of log T ≈ 5 could be detected.

The first measurements of the diffuse soft x-ray (SXR) background were made from a sounding rocket more than 25 years ago (Bowyer, Field and Mack, 1968). Since then, a number of sky surveys have been done using broad band filters in the SXR regime (McCammon et al., 1983; Marshall and Clark, 1984; Garmire et al., 1992). These surveys confirmed the anti correlation of the diffuse SXR flux with galactic hydrogen column density and also measured a finite flux in the direction of the galactic plane, which implied a local origin to the flux, since radiation at these wavelengths is easily absorbed at typical galactic hydrogen column densities. It is widely accepted that the diffuse SXR background is due to thermal emission from a hot (T = 10^6K) coronal plasma component of the LISM and that most of it originates within a few hundred parsecs of the Sun (McCammon and Sanders 1990). The study of this emission is of considerable astrophysical interest in that the hottest phase of the ISM plays an important role in both supernova dominated theories of the ISM (McKee and Ostriker, 1977; Cox 1981).

However, models of the specific case of the ISM environment near the Sun differ widely on the geometry of the emitting and absorbing material (Kahn and Jakobsen, 1988; Snowden et. al., 1990). Also, the temperature and abundances of this hot plasma have not been determined accurately due to the observational limitations of broad band instrumentation and the very few pointings of spectroscopic instruments aboard sounding rockets (Bloch, 1988; Labov and Bowyer, 1991).

Spectrophotometry in the EUV band (70Å to 760Å) would greatly add to the understanding of the diffuse ISM emissions for three reasons. First, thermal radiation from optically thin plasmas at temperatures of 10^5 to 10^6K is emitted preferentially in narrow emission lines in the EUV (Raymond and Smith, 1977). The strength of EUV diffuse spectroscopy compared to broad band photometry is the unambiguous identification of this signature of a hot plasma. Second, due to the short attenuation length of EUV photons in neutral hydrogen and helium gas, there is an enhanced contrast between the emitting and absorbing gas compared to x-ray wavelengths. This helps in the detection of the spatial distribution of the very low density local gas. Third, spectroscopic observations of emission lines from the LISM allow for the subtraction of non-astronomical background sources. This is very important for orbiting satellite detectors because of background contributions from the time variable cosmic ray environment and the geocoronal EUV resonance lines.
The launching of a new generation of x-ray and EUV instrumentation into orbit over the last several years has expanded our knowledge of the spatial structure and spectrum of the diffuse background at these soft wavelengths. The position sensitive proportional counter (PSPC) on the ROSAT satellite is sensitive enough, due to its low background, to detect soft x-ray shadows of interstellar clouds. The Diffuse X-ray Spectrometer (DXS) instrument (Sanders and Edgar, 1992), flown as an attached payload aboard the shuttle in 1992, measured the spectrum of the diffuse emission over the energy range of 0.15 to 0.28 keV. Preliminary results show (Edgar et al. 1993) that many emission lines are detected, though the spectra were not consistent with the standard equilibrium plasma models with cosmic abundances. The first results from the EUVE diffuse spectroscopic survey along the ecliptic (Jelinsky, Vallerga and Edelstein, 1993) have placed stringent upper limits to the emission measure of the canonical 10^6K gas and require either depleted abundances or non-equilibrium conditions to be consistent with the standard LISM models and soft xray broad band results. As expected, with the newer, more sensitive observations, the "simple" models of the LISM must evolve into more complex models that explain these results.

Interstellar Cloud Shadows

The first ISM cloud detected by ROSAT was the Draco cloud, (Burrows and Mendenhall, 1992, Snowden et al 1991), a surprising result as the Draco cloud lies at a distance of 400pc and the emission it shadows must come from a hot component of the galactic halo. Not only does a shadow detection indicate a lower limit to the distance of the emitting plasma, it also allows a differential measurement of the flux shadowed. This is very important as most imaging instruments in orbit are dominated by a local, non astronomical background that precludes a measurement of an absolute diffuse flux. By using the limited spectral information given by the PSPC, Burrows and Mendenhall were able to fit an equilibrium single temperature model (Raymond and Smith, 1977) to the off-cloud minus on-cloud spectrum, resulting in a derived temperature of log T = 6.1 and an emission measure (EM) of 0.0063 cm-6 pc. The hot gas of the Local Bubble can be probed this way using known molecular clouds with distances closer than the edge of the Local Bubble. Snowden et. al (1993) observed one of the closest known molecular clouds, MBM 12 (Magnani, Blitz and Mundy, 1985) with the PSPC. Though the 3/4 keV shadow of this cloud was strong, indicating that most of the source of this flux was distant, the 1/4 keV shadow was weak and barely significant. Therefore, the foreground emission dominates the flux in this direction implying that this particular cloud is near the edge of the Local Bubble and that the source of the higher energy flux is not strongly mixed with the source of the lower energy flux. Since the distance to this cloud is well known (d=65pc; Hobbs, Blitz and Magnani, 1986), the extent of the hot component of the Local Bubble has a strong upper limit in this direction.

LVC 88+36-2 is a strikingly narrow and elongated filament with a very low velocity dispersion and located at $l = 88°$, $b = +36°$. It was first detected as very weak and diffuse filament on both plates (red and blue) of the Palomar sky survey and is seen in the 21 cm Berkeley survey (Heiles et al. 1974) as well as the IRAS 100 μm maps (Lillenthal and Wennmacher, 1990). Optical absorption measurements of the interstellar Na I D lines towards nearby stars in the same line of sight as the cloud give a distance upper limit of <60 pc +- 20 pc (Wennmacher, Lillenthal and Herbstmeier, 1992). This places LVC 88+36-2 well inside the Local Bubble boundary which in this direction towards the galactic pole ranges from d = 120 pc to 190 pc (Snowden et al .1990).

A pointed ROSAT PSPC observation of LVC 88+36-2 detected a shadowing of 40% of the diffuse background in the lowest energy band (Kerp, Herbstmeier and Mebold, 1993). A clear anti-correlation of the HI column density distribution and the soft x-ray counts exists. By assuming that all soft x-ray photons originate uniformly within the Local Bubble, Kerp et al derived a distance to the cloud of 40 pc and an upper limit to the foreground HI column of 7 x 1018 cm-2. If, however, the background flux originates in the more distant galactic halo and is attenuated by the total galactic HI in this direction, the distance to the cloud is increased to ≈ 60 pc. Corrections for local origins of detector background will only decrease these distances. This observation has clearly established the existence of a cold dense cloud inside the hot Local Bubble, though there is some doubt as to the source of the emission behind the cloud.

By extending the shadow observations of this cloud into the EUV wavelengths, a simple detection of a shadow would have indicated that the emission behind the cloud is from the extended Local Bubble rather than the galactic halo, as the optical depth at 100Å to the halo is $t \approx 6$ vs. $t \approx 2$ for the 1/4 keV band of ROSAT. If the cloud is not detected, a weaker conclusion can be reached that the EUV emission (if it exists) is all in the foreground and therefore the diffuse emission that causes the shadow observed by the PSPC observations originates in the halo.

The Observation and Analysis

The Lexan/Boron band of the Deep Survey imaging instrument is the most sensitive instrument aboard EUVE for detecting the existence of a shadow of hot gas at 106 K. It has the highest effective area ($A_{eff} \approx 25$ cm^2 at 100Å) and its bandpass extends out to beyond the strong complex of Fe lines near 175Å that dominate the emission from an equilibrium 106K gas.

The first data set was delivered on June 7th, 1994, which included the EUVE spectrometer data reduced with the standard EUVE package as if it were a point sources. However, LVC 88+36-2 is a diffuse object. It was requested that the Deep Survey data products be delivered so that a DS detection of the cloud be attempted before any spectral analysis be performed. The EGO center then delivered a tape which included DS lexan/boron data in QPOE format.

Using detector coordinates, a region of low background and minimal distortion and vignetting was defined. That region was then mapped to the sky given the 22 aspect pointing positions that occurred during this observation. At the time, it was thought that this technique would help us average out any non-uniformities in the response or the background of the detector. This technique is similar to the "dithering" technique being developed to smooth out the detector fixed pattern noise for bright sources. The resultant remapped count image had most of the counts at the center of the image. Along with this process, an exposure map as a function of sky coordinates was generated by individually selecting the good times of each pointing and then using the remapped count maps to define the region of the sky which was exposed. By convolving these low S/N maps with a 5x5 kernel allowed the derivation of a "map" of the exposure on the sky which peaked at the center of the cloud at 118,000 seconds. The reason the full 200,000 seconds originally requested was not reached was that the pointings were distributed with an RMS of 20 arcminutes resulting in larger solid angle at the expense of exposure. By dividing the count maps with the exposure maps resulted in a diffuse count rate map.

This count rate map (Fig. 1) shows the pattern of the rectangular Deep Survey filter mapped to the sky in overlapping regions with the most exposure, and therefore the highest signal to noise, in the central region. We observed the cloud on the sky with a DS role such that the axis of the cloud was almost perpendicular to the dispersion direction. By rotating the Fig. 1 image by 54 degrees clockwise puts the axis of the LVC cloud vertical on Fig. 2. Visual examination of this map does NOT show an obvious cloud shadow (though it does discover a new EUV source whose coordinates are close to the double HD 154712A+B which are both k stars.) The average count rate of the center 150 rows of Fig. 2 versus the horizontal position (across the narrow dimension of the cloud) is shown in Fig. 3. Also shown in fig. 3 is the width of the cloud in the xray shadows of 20 arc minutes. There again is no hint of a deficit in the background. A formal fit shows that it is less than 1% of the mean background for this region, which is about 10-3 cts arcmin^{-2} s^{-1}.

Discussion

This limit only applies to flux shadowed by a cloud at the distance of LVC 88. The observation gambled on the chance that the column might be low to this cloud and the diffuse background would be bright. There are many reasons why one would not expect to see such a cloud shadow. The first is lack of emission in the EUV behind the cloud. It is already known from the diffuse measurements in the EUV with the MW and LW spectrometers that the Fe lines that were thought to be bright in a hot thermal plasma are at least a factor of 6 dimmer than what you would expect from current coronal plasma models (Vallerga and Slavin 1997). Also, the foreground column density of hydrogen could easily be enough to erase any contrast. Since this document reports the lack of a detection, it was deemed fruitless to fit any spectral models to quantify the lack of detection, as there are no known spectral models that have been shown to work in this band, and any limits generated would not constrain the models of this system.

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Figure 1. Shown is the remapped count rate flux towards LVC 88+36-2 taken with multiple pointings (22) of the EUVE Deep Survey detector. The rectangular lines are due to imperfect exposure maps at the edges of the DS lexan band. The center of the image is RA: 17h 05 m 00s, Dec +59 17' 00'' with RA increasing to the right. The increase in signal to noise at the center is due to an increased exposure there (118,000s) versus the outer edges of the image.

Figure 2. Same as Fig. 1 but rotated 54 deg. clockwise to put LVC 88+36-2 vertical in the image to aide in the visual search for a shadow. No shadow is seen.

Figure 3. The average flux of the center 150 rows of fig. 2. The flux units are in Counts pxl^{-1} s^{-1}. There are 3.2 pixels per arc minute. If LVC 88+36-2 had an EUV shadow it would appear in the center of this plot with a width of 20'.

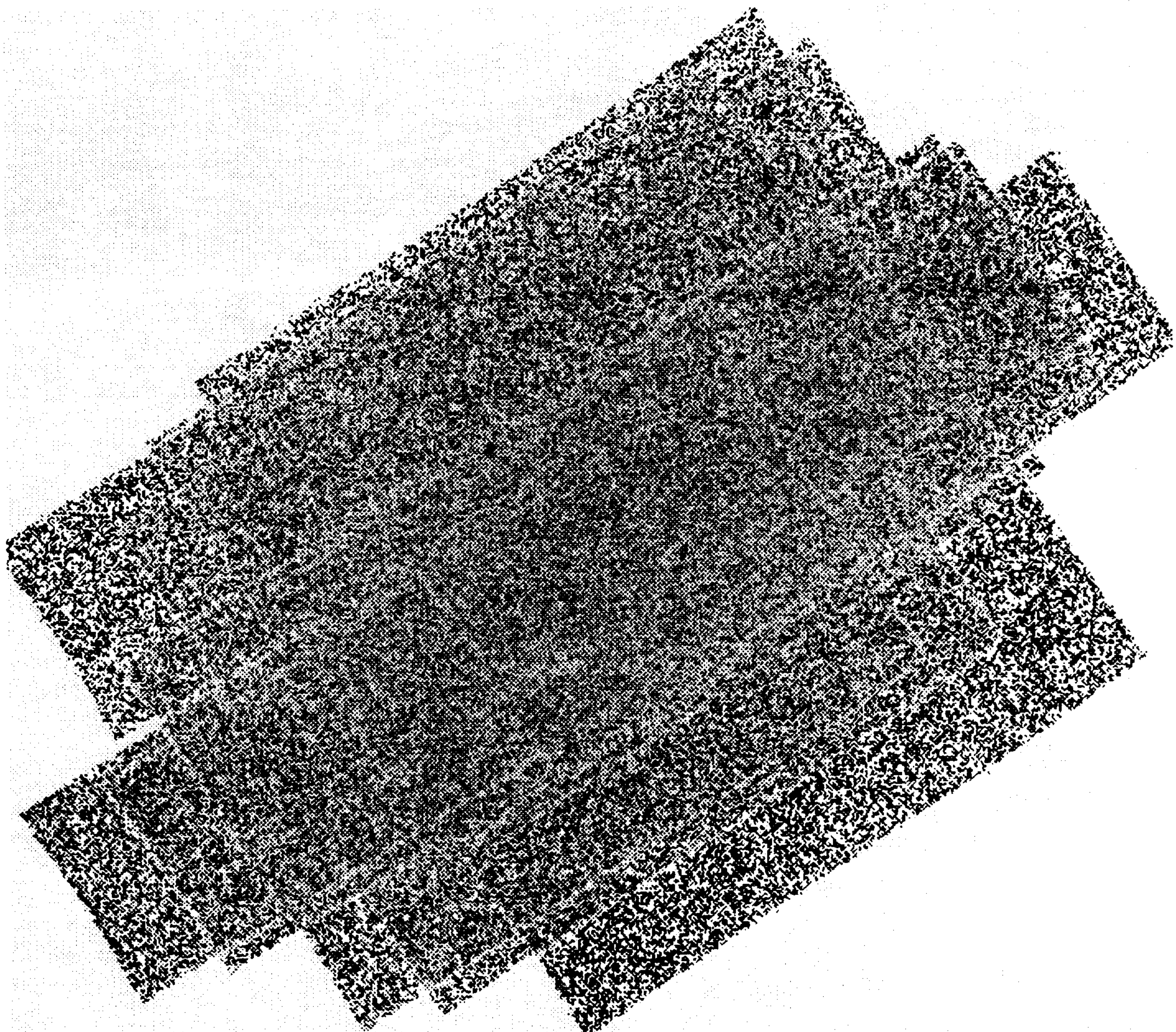


Fig 1

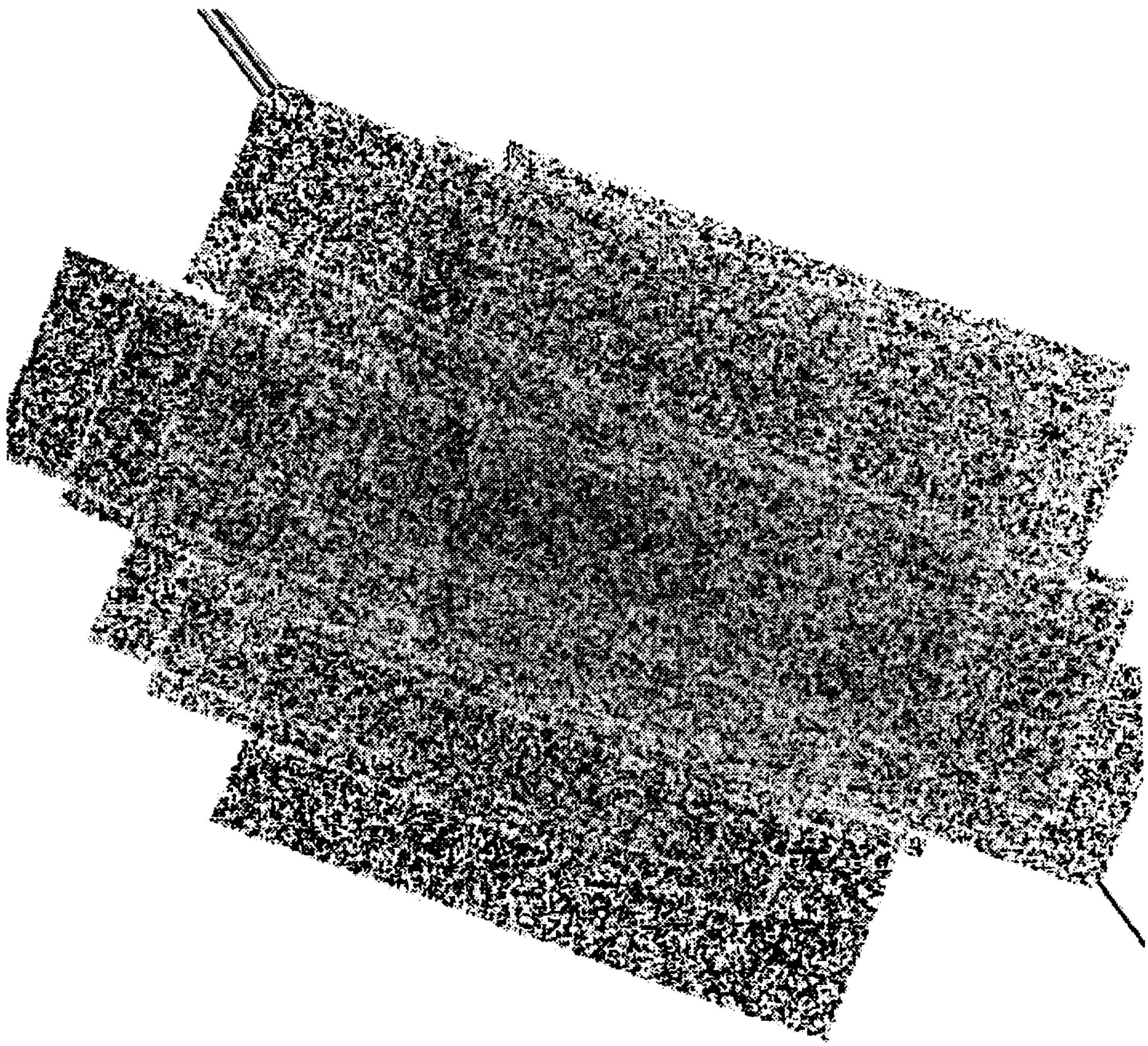
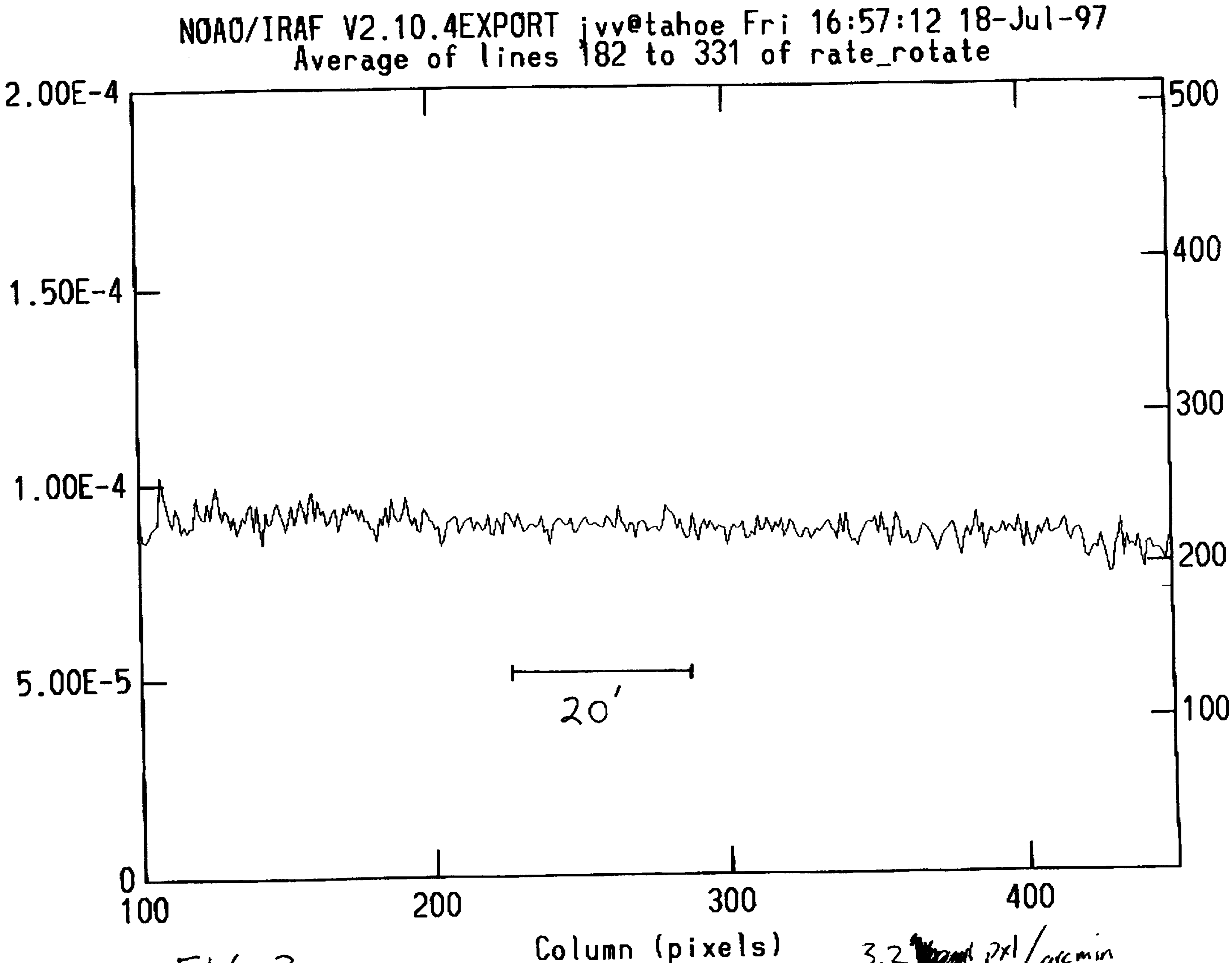


Fig 2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5.00E-5
0
500
400
300
200
100
200
300
400
20′
Column (pixels)
3.2 pxl/arcmin

FIG 3.