DETECTION OF OBJECTS NEAR A GEOSTATIONARY ARC BY WIDE-FIELD SURVEYS

A. Bijaoui, A. Maury, P. Oberti, Ch. Pollas

Observatoire de la Côte d'Azur, B.P. 4229, F-06304 Nice Cedex 4
France

F. Alby

CNES 18 Avenue Edouard Belin, F-31055 Toulouse Cedex
France
email = bijaoui@obs-nice.fr

ABSTRACT

A collaboration between the Observatoire de la Côte d'Azur (OCA) and the CNES started in 1996 for detecting and for identifying optical sources close to the geostationary ring, using the OCA Schmidt camera. The first observations on films were visually analyzed. An automated analysis method has also been developed. After removing the stellar trails by a specific transform, a multiscale analysis is performed in order to detect, measure and classify the sources. With this software we were able to find all the objects detected visually. A 2048 × 2048 CCD camera has now been installed at the focus of the Schmidt telescope. The field of view is reduced but the gain in sensitivity should allow us to detect small space debris down to $20cm$. We have planned to develop a specific software which will process the CCD observations.

1. INTRODUCTION.

The detection and the tracking of space bodies is often done by means of optical telescopes [Ref. 1, 2, 3]. The OCA Schmidt camera is located at "Plateau de Calern", near Grasse (France), at the longitude 6° 55′ 34″ E and at the latitude 43° 44′ 53″. Its aperture is $90cm$, and its field of view is 5°16′ × 5°16′ with photographic films [Ref. 4]. Its mechanical structure does not allow us to track fast moving objects, but its capability for detecting faint sources led us to observe and track the objects close to the geostationary ring.

In cooperation with CNES, this photographic camera has allowed us to examine the different software problems required to :

1. Extract automatically the candidate sources, as faint as possible;
2. Measure and to reduce the positions and the fluxes;
3. Get mean orbital elements, taking into account the standard perturbations;
4. Match the detected sources with published lists of objects using the mean orbital elements.

The analysis of films is done with a high-resolution scanner. The observation with CCD cameras has the advantage to put the digital image directly into the computer. These cameras have also an important sensitivity gain $(10-100)$ compared to the photography, and allows us a better exploitation of the telescope, even if the field of view is dramatically reduced. Therefore, we have carried on this project using a 2048 × 2048 CCD camera.

In this contribution, we will overview the different features of the observational methods. The reduction problems, with an emphasis on the detection, will be examined, and we will conclude on the perspectives opened by the use of the CCD camera.

2. PHOTOGRAPHIC OBSERVATIONS.

Unlike to the CCD camera, it is quite impossible with our film plate-holder to obtain one exposition every $2-3$ mn, and to analyze them separately. Therefore, on a same film we observed many short exposures taken every 30mn. By this way, about ten images of the same object can be recorded, on the same film. The telescope is obviously fixed for the observation of objects orbiting near the geostationary ring. We have used Technical pan Kodak emulsions, hypersensitized with forming gas. No optical filter was used.

The image texture is very typical, with long trails created by stars, and some very small spots due to geostationary sources (figure 1). Some artifacts due to the emulsion or to the photographic treatment can easily be recognized.

The films have been visually analyzed. A list of positions and estimated magnitudes are obtained for a set of exposures. For example, let us consider the film centered on the satellite TDF1 taken on May 16th 1996. Fifteen objects were detected, and classified in three categories:

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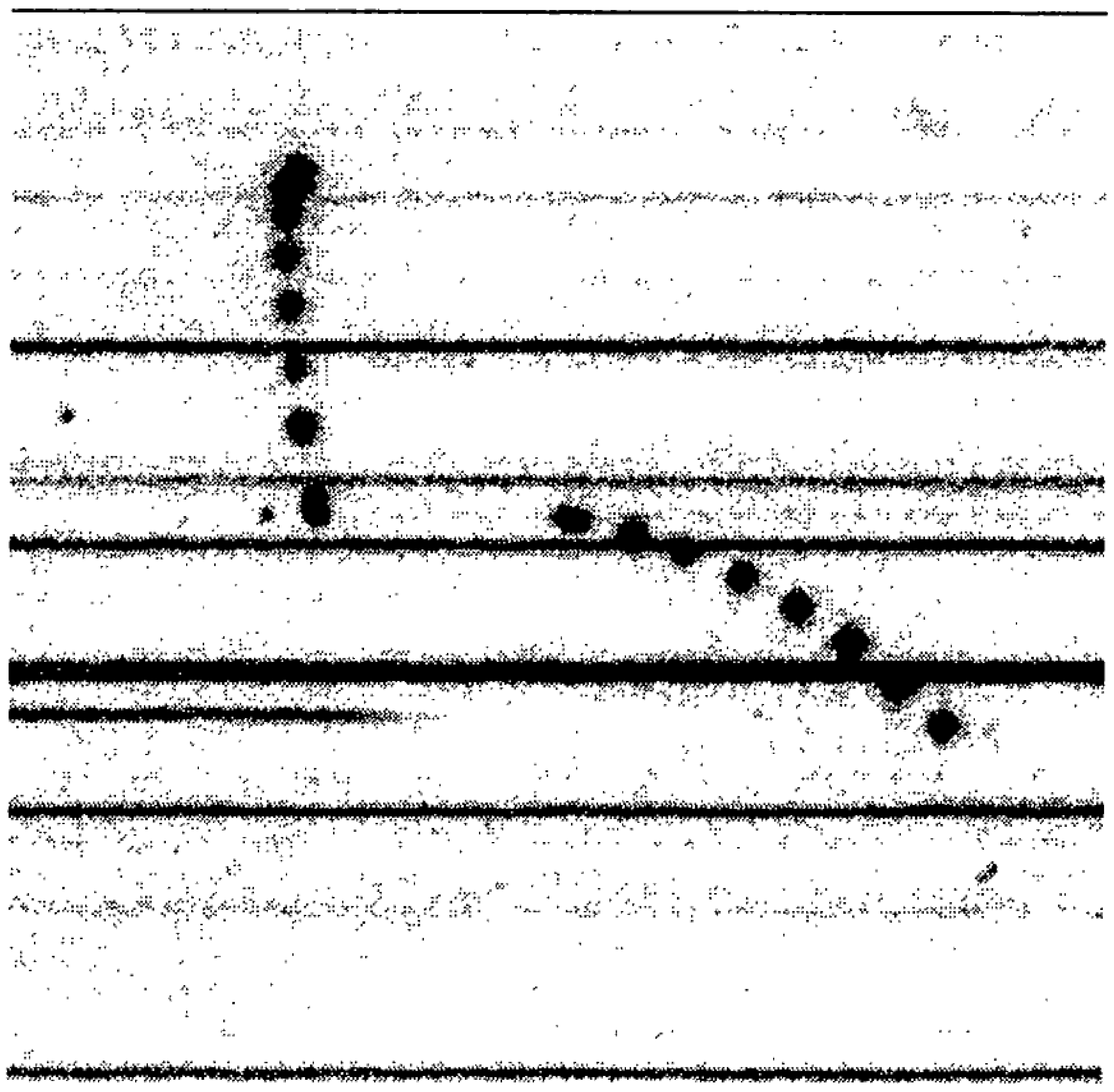

Figure 1: *The region corresponding to the satellites TDF1 and TDF2 on May 16th 1996. This image corresponds to* 512×512 *pixels, i.e.* 1/1600 *of the whole surface.*

1. Five slow moving objects. Four of them were bright (the visual magnitude is about 15) and very slow (the speed was less than 1′ per hour), while the fifth one was fainter by a factor 2 in luminosity and its speed was about 5′ per hour;
2. Four fast moving objects. Two had a speed around 20′ per hour, while the two other had a displacement around 1° per hour, from the North to the south. The fastest object was also the faintest with a visual magnitude approximatively 17;
3. Six objects with an atypical behaviour. One bright object was observed with a speed of about 8° per hour with only one trail. We have detected four other with also one trail. One of them had a speed correspondind to about 75° per hour. Two satellite trails have shown light flashes.

We have remarked that only objects with magnitude brighter than 17 have been detected while we would be able to detect objects ten times fainter with our technique.

The coordinates were reduced to a stellar reference frame, using the *Guide Star Catalog* from the *Space Telescope Science Institute* available on a CD-ROM. The position accuracy strongly depends on the exposure dating. The limit is directly related to the time needed to open and to close the large shutter in front of the telescope lens.

The object positions are first estimated into the equatorial frame at the epoch of the observations. A transformation is then done, allowing us to get the positions to the local reference frame. These positions are then processed in order to get the osculating orbital elements for further identifications. These parameters are determined using a local Keplerian orbit.

3. ANALYSIS OF THE PHOTOGRAPHIC FILMS.

The films were scanned with an AGFA Horizon Plus. This device is based on a 15000 pixels one dimensional CCD array. It allows one to scan films up to 24×36 cm^2 with a high resolution (up to 2540 ppi by interpolation) and an accuracy of 10 bits in transmission. We have chosen to register these images with a 1800×1800 ppi resolution, on 8 bits, which was more adapted to the characteristics of these films. With these parameters a film of 30×30 cm^2 is scanned in two parts and leads to about 500 Mb of data. The scanner is driven by a PC computer working with Windows95, but the data are thereafter processed on a DEC Alpha workstation working on OSF1.

The image texture is typical:

1. Each star creates on the film a trail long of many thousands of pixels;
2. The trails occupies a large part of the photographic images
3. The geostationary sources are detected as high contrasted and elongated sources.

A specific transform was designed for removing stellar trails. It consists of taking the minimum value of a set of running pixels, and to subtract the resulting image to the original one. On figures 2, 3, 4 we have successively displayed the results obtained on the TDF1 region after minimization, subtraction and a $4-\sigma$ thresholding. After these preliminary operations, it only remains :

- The satellites images;
- Small contributions corresponding to brightest stellar trails. Their intensity are less than the original trail, but they could be later on detected as real sources. They are essentially due to the noise along the trail, and it is quite impossible to remove them by a simple pattern analysis. Since they are aligned along the trails, it is easy to test aligned objects by a simple histogram of y coordinates in a zone, and to cancel the objects corresponding to a significant peak;
- Some stellar sources which corresponds to a short first exposure with sidereal tracking on.

These stars allow one to determine the coordinates in a stellar reference frame, and therefore to reduce the positions of the geostationary objects to this frame;

- Some few artifacts (only one is visible on figure 4).

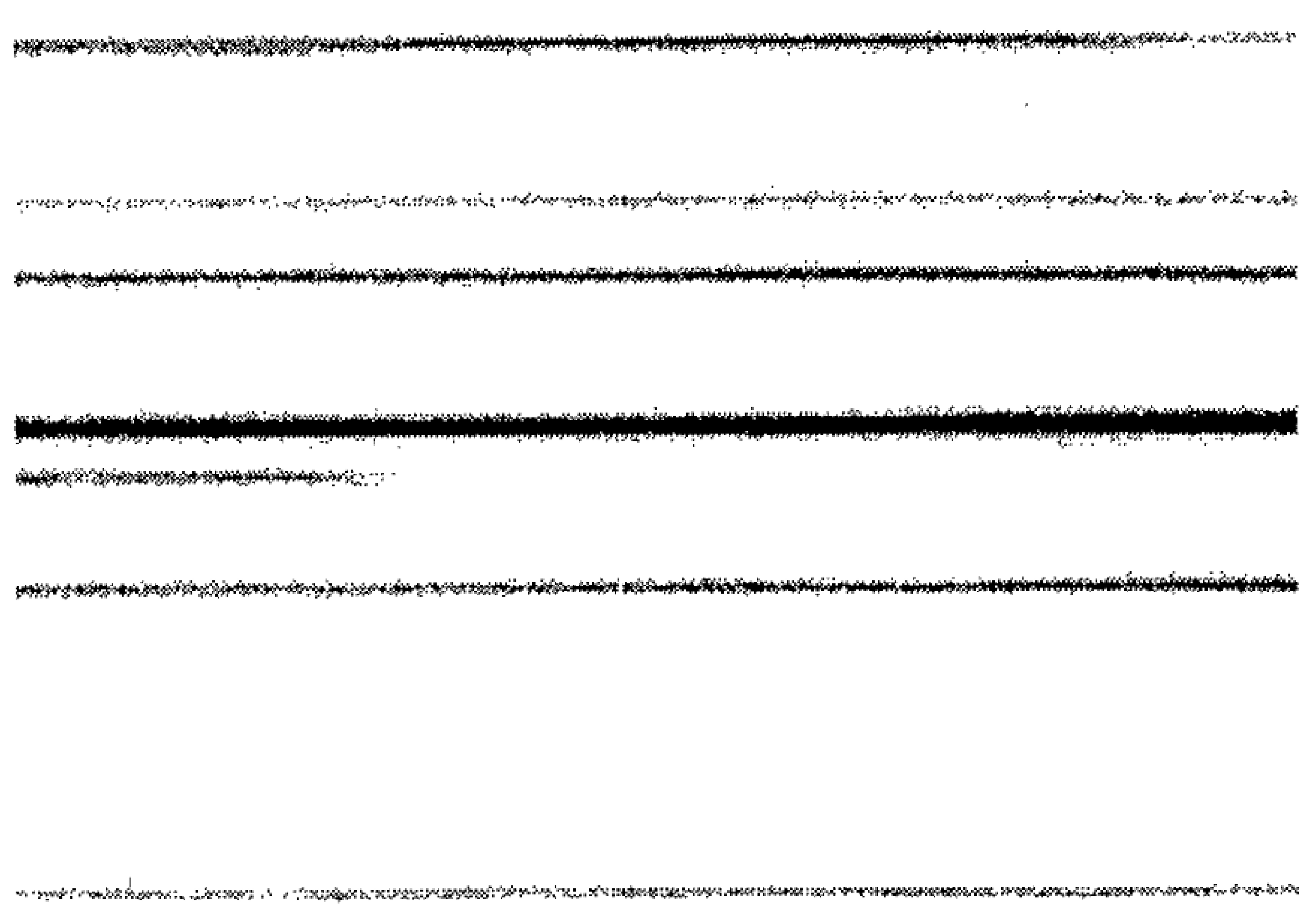

Figure 2: *The region corresponding to the satellites TDF1 and TDF2 after the specific transform.*

For detecting and measuring the sources we have applied a *Multiscale Vision Model* [Ref. 5]. This tool was developed for analyzing astronomical images, for which no contrasted contour exists. With this software we were able to find all the objects visually detected. This analysis provides a map of candidate sources, but our software does not contain a classification box which would allow us to select only the few sources corresponding to real objects. A visual control is necessary as of today.

4. THE CCD PROJECT.

With photographic films, the limiting magnitude is around 19, which is sufficient for detecting all the satellites, but insufficient for detecting small debris. A CCD camera was developed at the OCA and has been installed at the focus of the Schmidt telescope. The chip is a 2048×2048 from Loral Lockheed, cooled by Peltier modules at about $-40°$. This device allows us short exposures thanks to a fast transfer to the computer (45s).

This camera has many advantages:

- A ten-fold increase at least in sensitivity with respect to the photographic films;

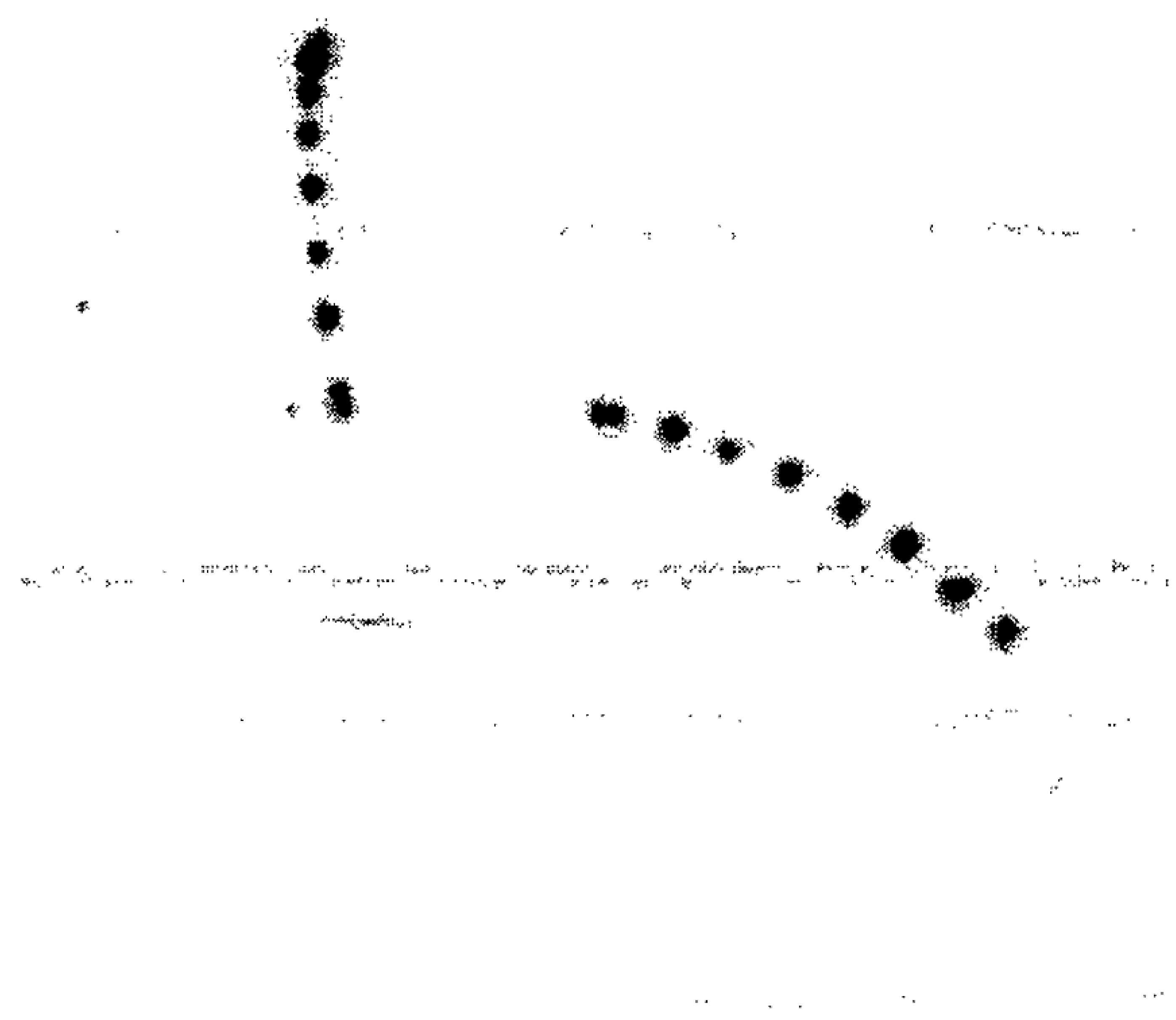

Figure 3: *The image after the subtraction of the specific transform. In the right bottom corner we can see a small artifact due to the photographic emulsion.*

- The ability to process the images in real time;
- A better exploitation of the telescope. The transfer time is quite equal to the exposure one, so half of the telescope time is used, while for photographic observations only 10% of this time was exploited;
- A reduction of the trail influence: their length are shorter and on one exposure we detect only the trails related to the stars passing in the field, while the trails are accumulated during the photographic exposures;
- The ability to obtain a better detection of geostationary sources : the resolution is better, each object looks like a point on a CCD frame, it is easy to confirm the detection by comparing many successive images.
- An improvement of the dating. Indeed, the film yields to an accuracy worse than 2s for the stellar right ascensions, which introduces an error of about 30" in position, corresponding to 4km on the geostationary orbit. Using the CCD camera, it is possible to reduce the error to 0.3", i.e. 40m on the orbit.

However, the field of view (FOV) is reduced to $35' \times 35'$, so the observed field is reduced by a factor about 100 compared to the photographic film. Using a reversed scan mode we should improve our efficiency by a factor of 2.5. We will install soon a 4096 × 4096 CCD camera, which will increase the

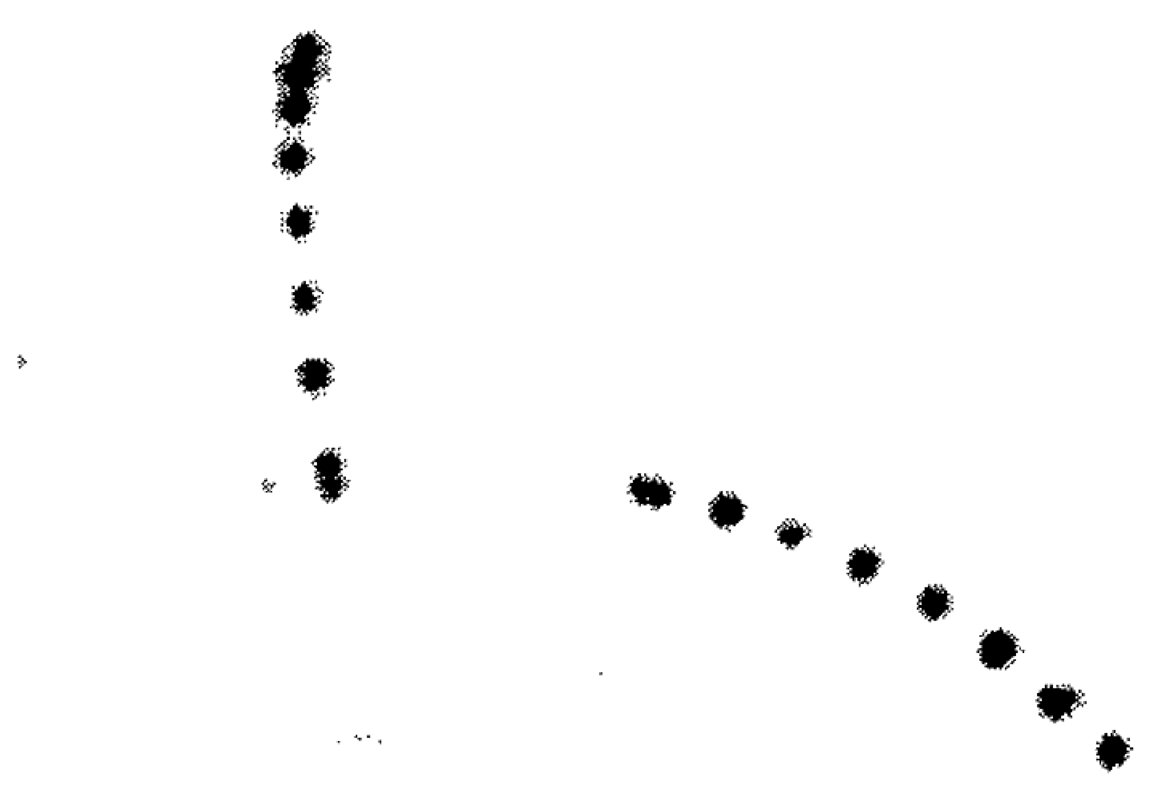

Figure 4: *The residual image after a $4-\sigma$ thresholding.*

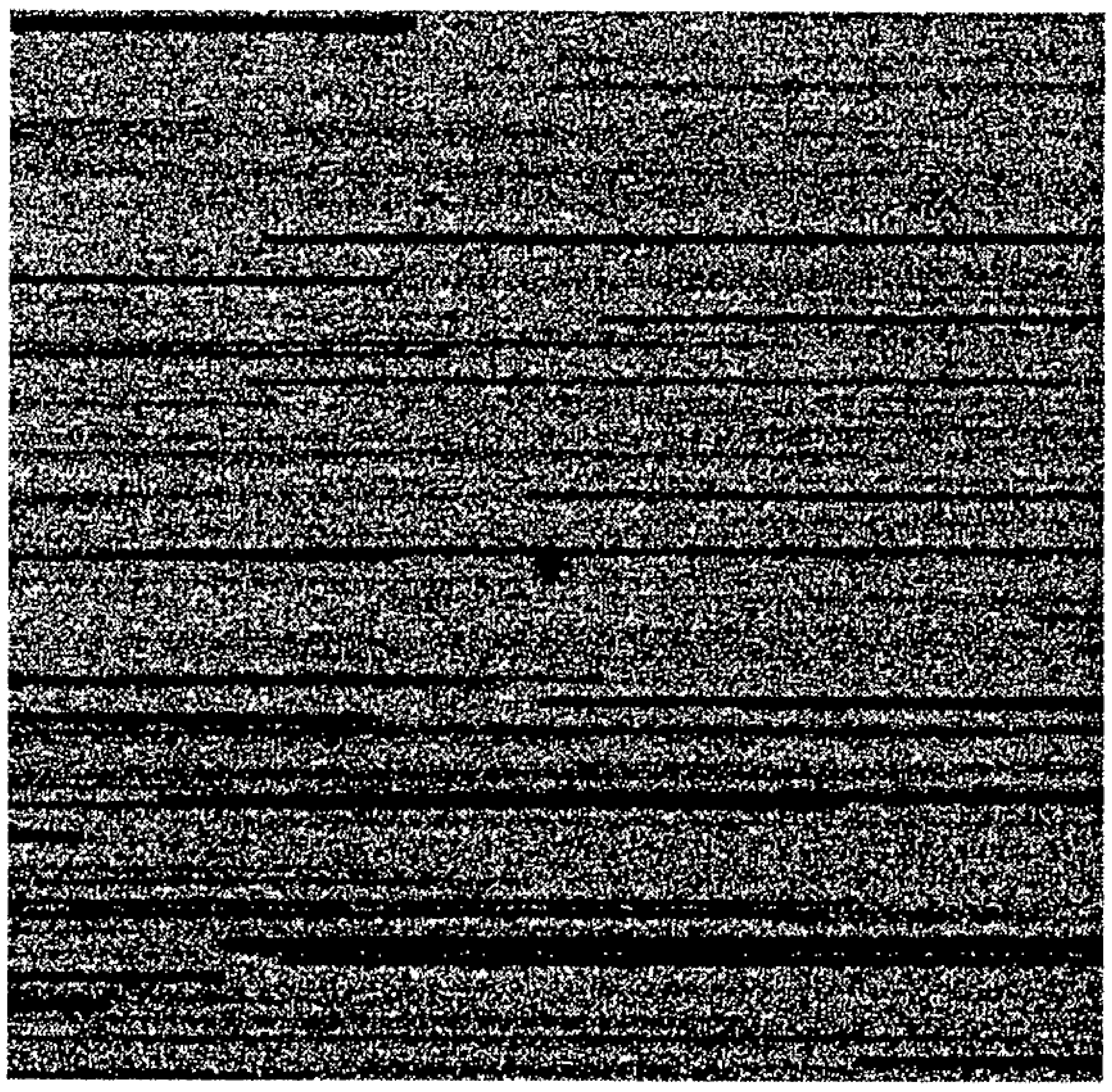

Figure 5: *The field around TDF2 on 23th September 1996.*

CCD FOV by a factor of 4. This camera is built in the framework of ODAS, which a near earth asteroid search program led by DLR-Berlin and OCA [Ref. 6]. Already, the CCD camera allows us now to study more carefully some selected fields.

5. FIRST CCD OBSERVATIONS.

We tested our CCD camera on the field near TDF2, on September 23th 1996. Six successive frames were taken, with an exposure time of 30s. On figure 5 we have plotted the image region around TDF2. During the exposure, the satellite was in the Milky way so many of stellar trails were recorded. On figure 6 the result after the trail removing, a small Gaussian smoothing and a $3-\sigma$ thresholding. We are able to detect objects fainter by a factor about 100 than TDF2. That could corresponds to a size smaller by a factor of 10.

The images contains many punctual events, only comparison the following images allows us to keep the real sources. This technique does not allow one to detect fast moving objects. We foresee to test different shifting to solve this problem.

Nevertheless, our preliminary tests have led to detect deeper objects than with photographic films, even with exposures shorter by an important factor.

6. PERSPECTIVES.

In a new collaboration with CNES, we have planned to develop a specific software which will process the CCD observations in order to:

1. Extract automatically the candidate sources, as faint as possible. We will take into account our preliminary work on the photographic films;
2. Get raw positions and fluxes;
3. Reduce these raw data in a stellar reference frame. An automated cross identification will be done with the *Guide Star Catalogue* and the positions will be reduced to the local stellar reference frame;
4. Reduce the coordinates in a local reference frame;
5. Get mean orbital elements, taking into account the standard perturbations;
6. Match the detected sources with published lists of objects using the mean orbital elements.

Observations are programmed in 1997 for a systematic surveillance near a few selected satellites.

7. CONCLUSION.

With this project, we have shown first, by photographic means, our capability to detect sources in a the geostationary ring. The step was essential for developing the tools adapted to the automated analysis. Thanks to the CCD properties we will carry out this project with an improved efficiency for the detection of faintest sources.

A whole analysis system is in preparation for a systematic detection, identification and follow up of the sources orbiting near some specific satellites.

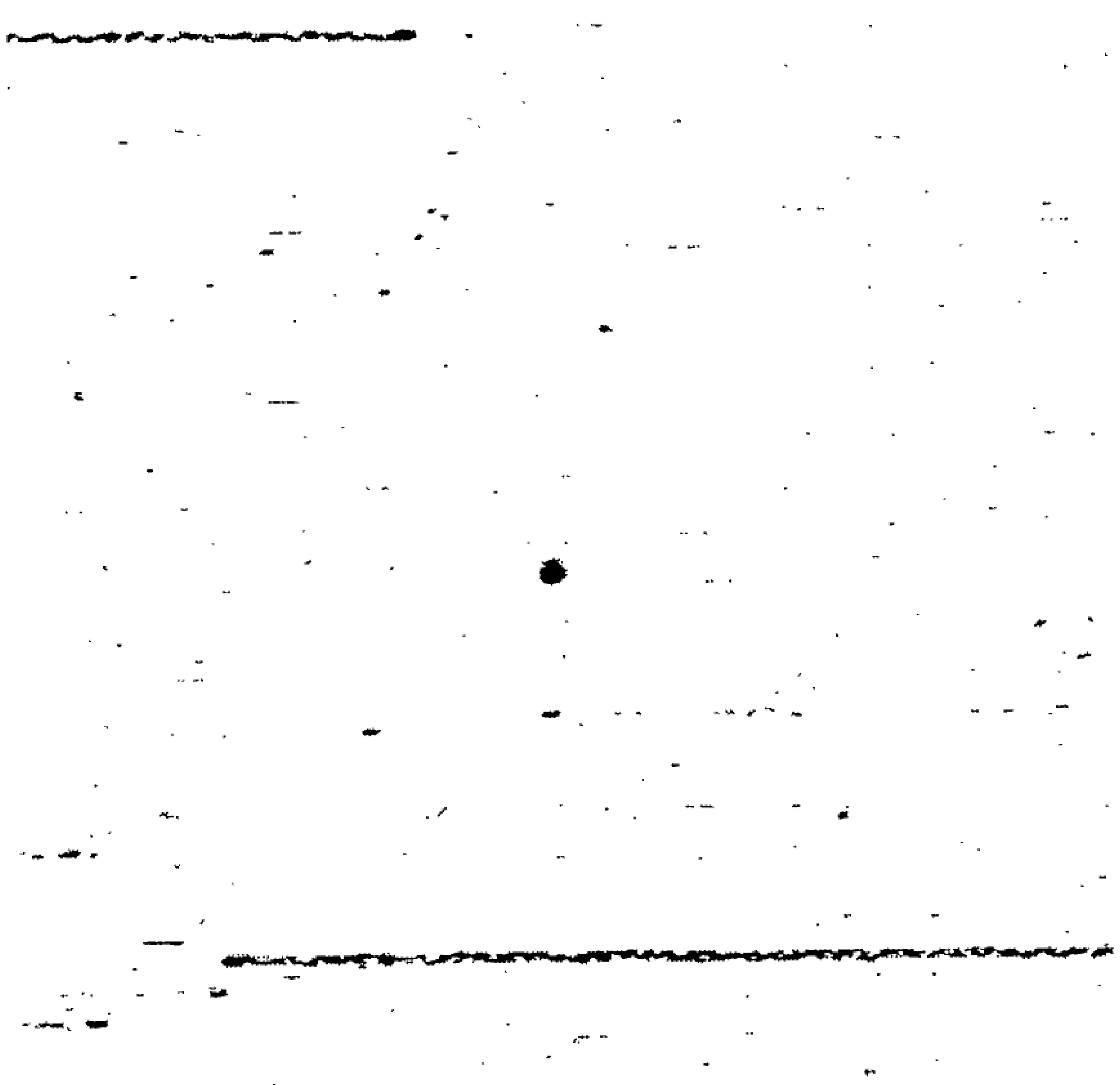

Figure 6: *The residual image after a thresholding.*

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