Detection and dynamics analysis of Space Debris in the GEO Ring

E. Lacruz[1], C. Abad[1], J.J. Downes[1] D. Casanova[2], & E. Tresaco[2]

[1]Centro de Investigaciones de Astronomía (CIDA) Venezuela
[2]Centro Universitario de la Defensa (CUD) de Zaragoza, España

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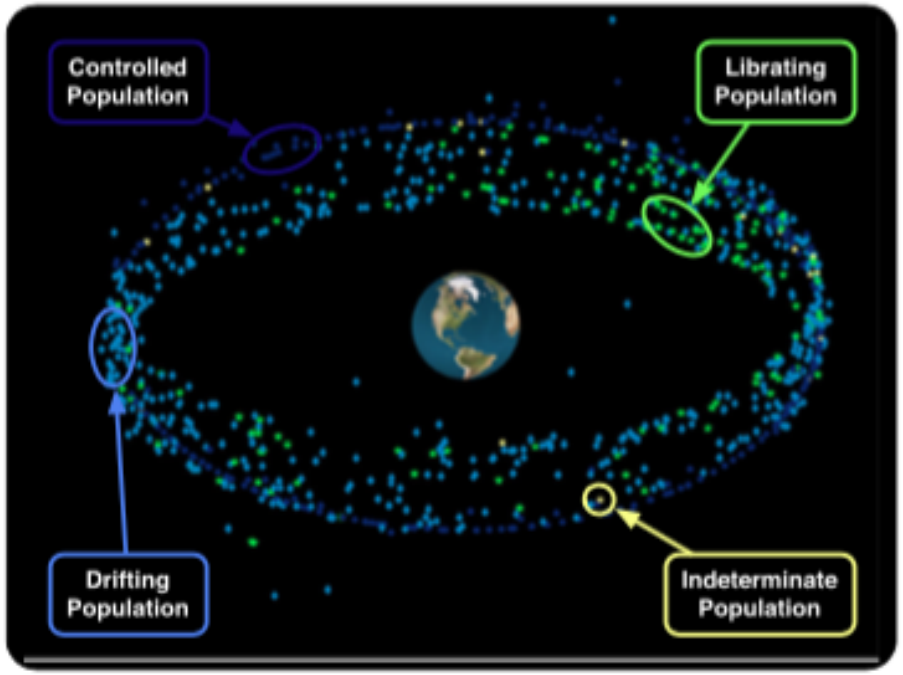
Stationary Orbit

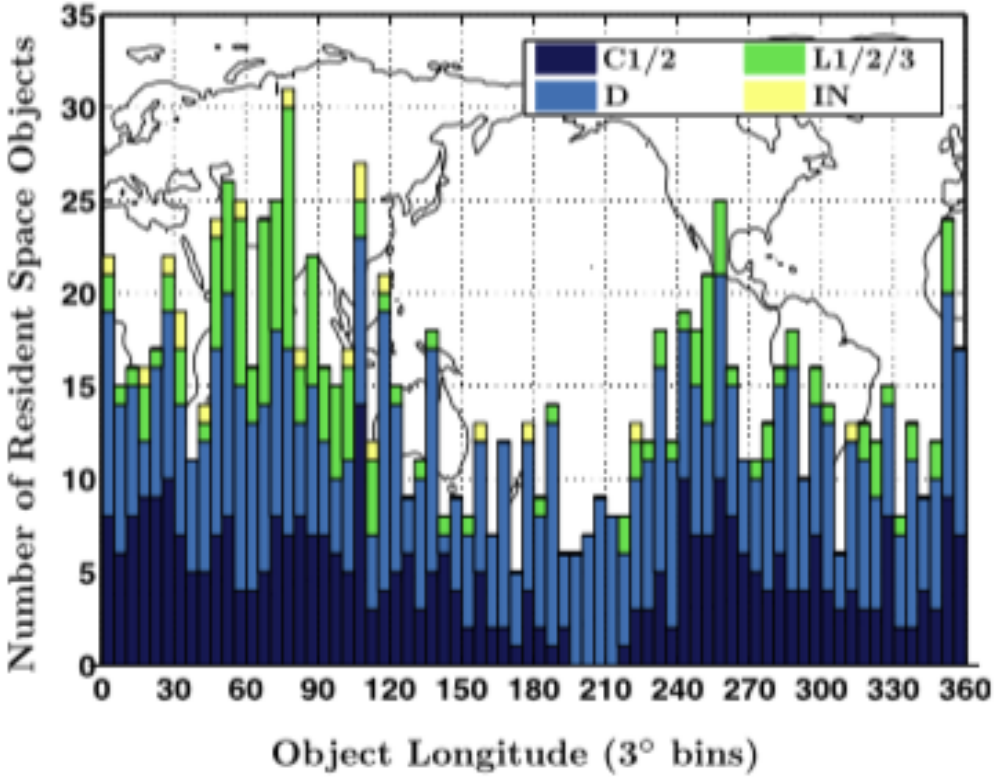
- $P =$ sideral day, $i = 0 \quad \Rightarrow \quad$ stationary satellites.
- Fixed point (little window due to perturbations) on the equatorial plane of the planet.



(Anderson, et. al., 2013)

Stationary Orbit

- $P =$ sideral day, $i = 0 \quad \Rightarrow \quad$ stationary satellites.
- Fixed point (little window due to perturbations) on the equatorial plane of the planet.
- Distribution of satellites GEO ring (Anderson, et. al., 2013).



Goals

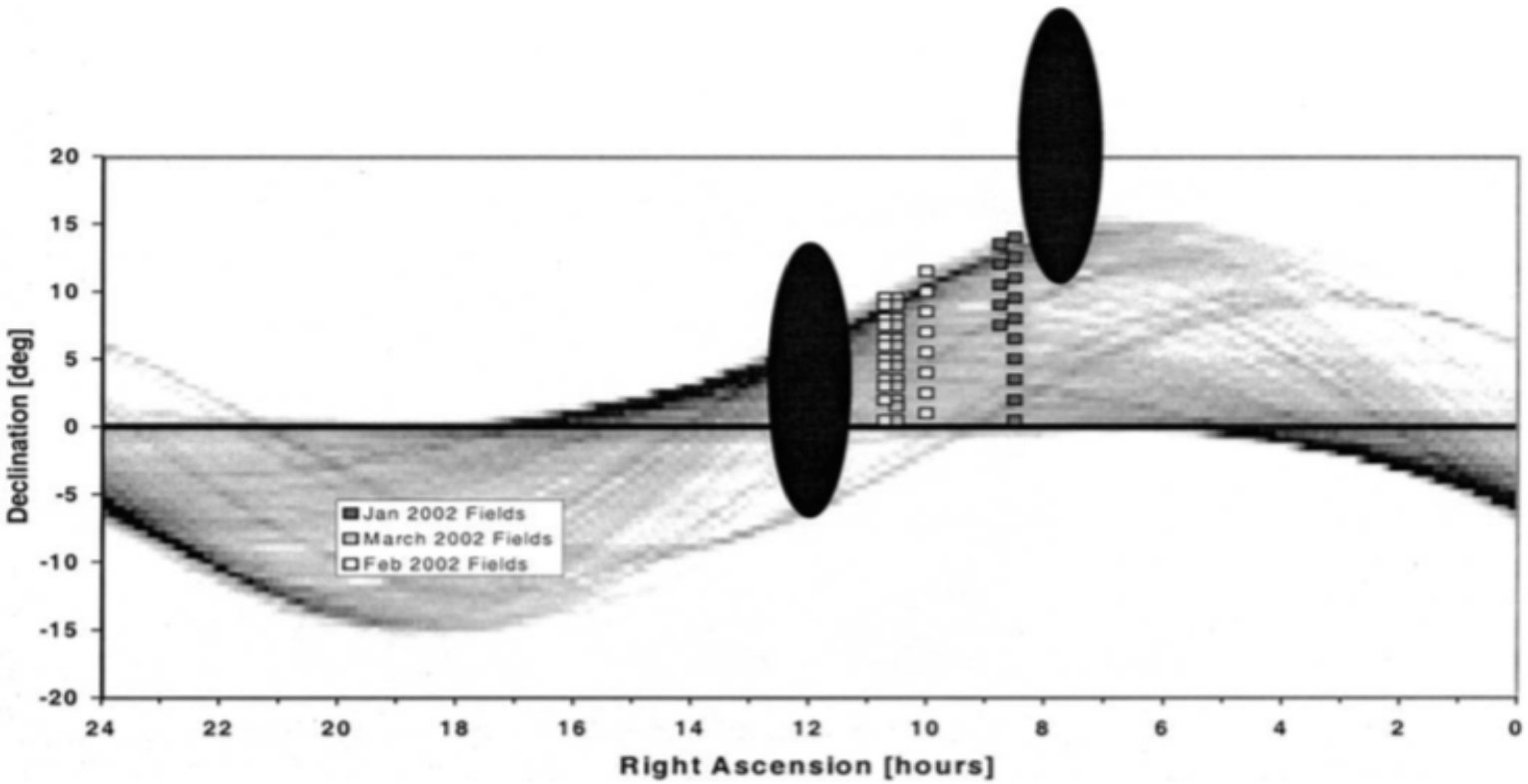
Detect and track orbiters in the GEO ring with low Signal to Noise Ratio, which allow to calculate preliminary orbits (Initial condition for ephemeris determinations).

1. Detect orbiters in the GEO ring through of optical tracking.
2. Determinate the relative motion of orbiters in the GEO ring.
3. Calculate geocentric coordinates on the order of $1''$ and determinate preliminary orbits.
4. Predict the area to mass ratio and the orbital dynamics.

Optical Tracking

- Field observation.

Apparent density catalogued orbiter in the GEO ring (Schildknecht et al. 2004).



ESA's 1-meter telescope at the Teide Observatory in Tenerife.

Optical Tracking

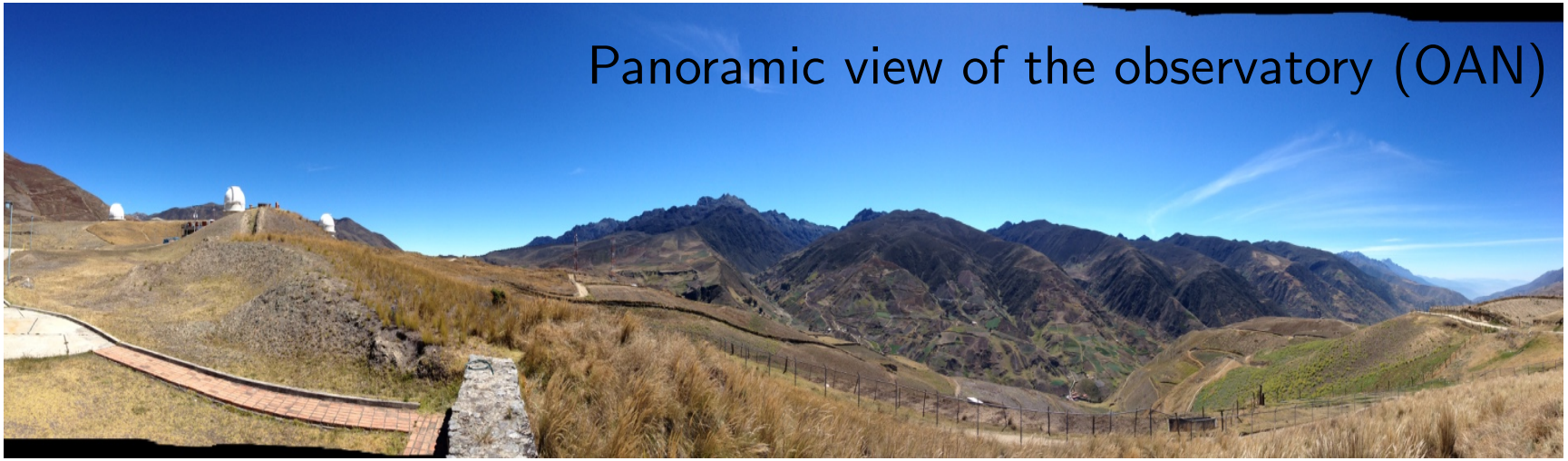
- Field observation.

Apparent density catalogued orbiter in the GEO ring (Schildknecht et al. 2004).

- Field observation from OAN:

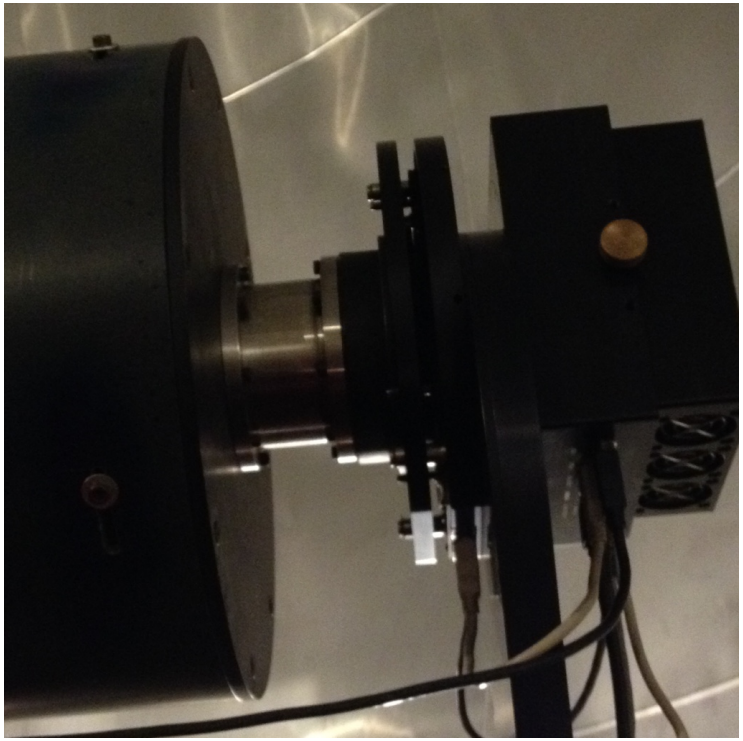
$\alpha \in [8^\circ, 117^\circ] \quad \Leftrightarrow \quad [0^h53, 7^h8]$ (right ascension).
$\delta \in [-2^\circ, +2^\circ]$ (declination).

Observational Tools



Observational Tools

1-meter Reflector Zeiss telescope in mode f/5.



CCD PROLine 9000 2kx2k.

Ground Tracking and Data Acquired

- Optical tracking method.

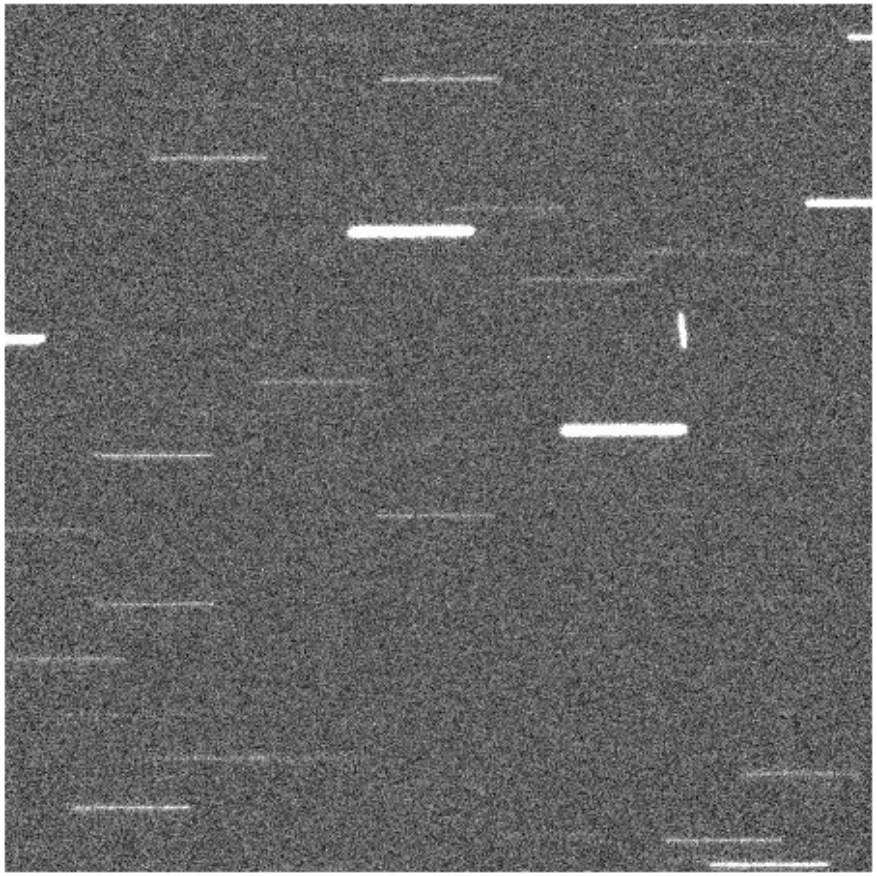
The telescope is fixed with the sideral motor off.
Exposure time 10 second.
Clear filter.
Mode F/5.

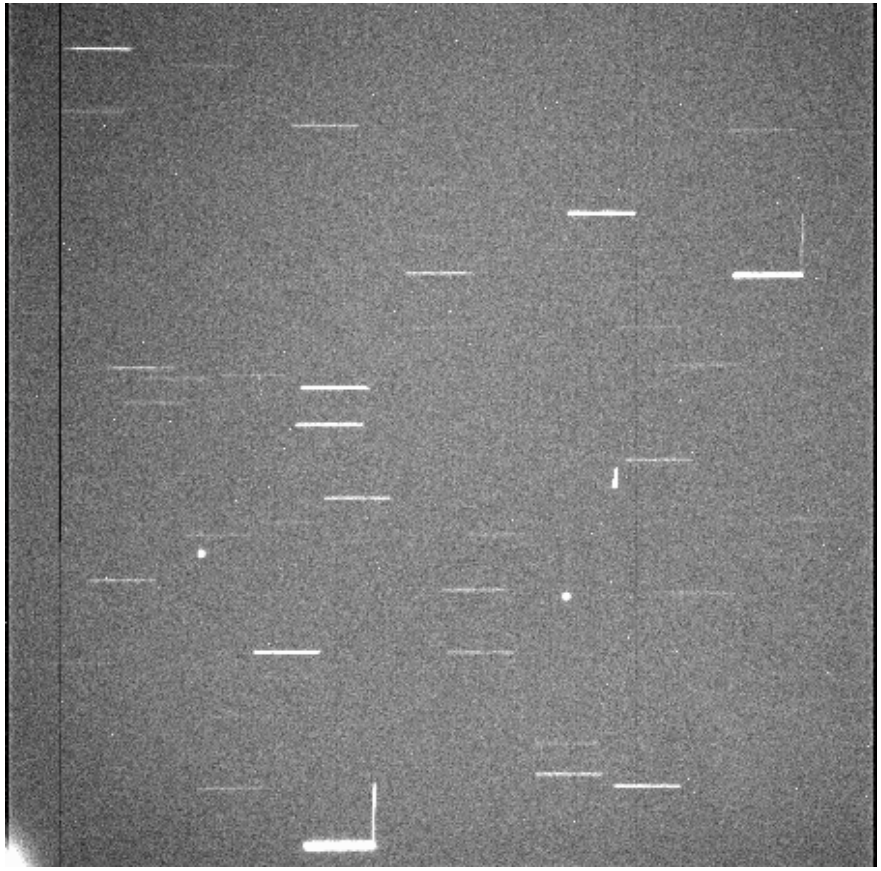
- Two years of data.
  - 200 Gbs $\approx$ 20000 observations.
  - Most of the observations contain GEO satellites.

$\alpha \in [8^\circ, 92^\circ]$ (right ascension) scattered observations.
$\delta \in [-9''5, -9''5]$ (declination).

Ground Tracking and Data Acquired

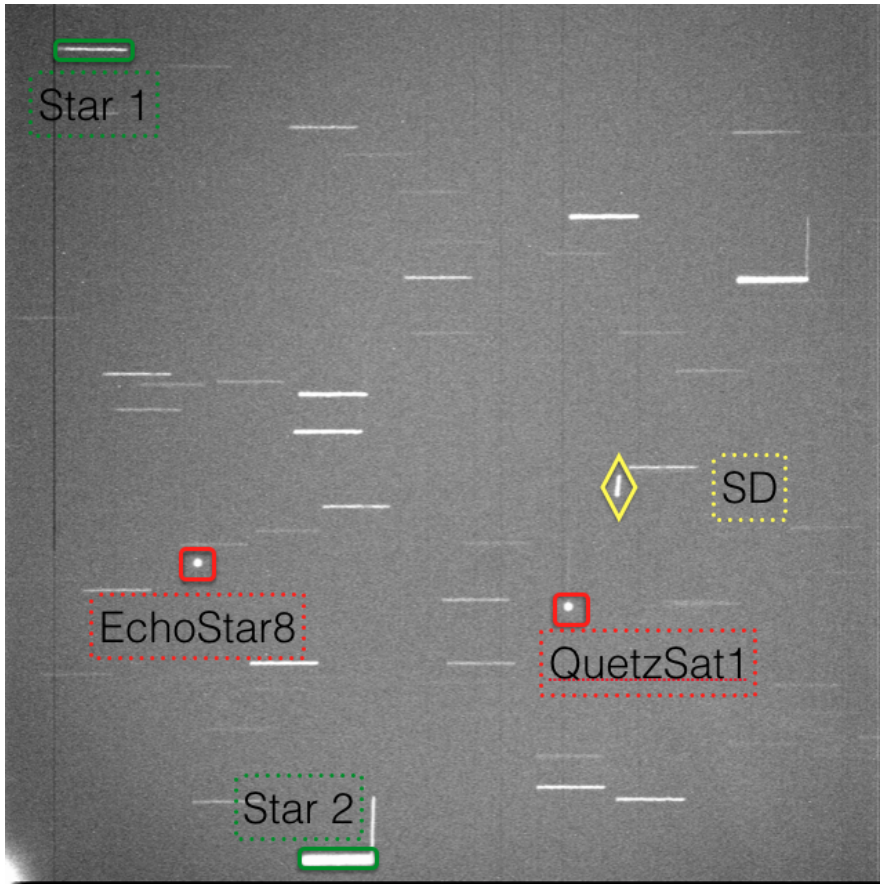
- Observations: March 03, 2016.





Ground Tracking and Data Acquired

- Point-like (EchoStar8 and QuetzSat1) and streak-like (field stars) images.



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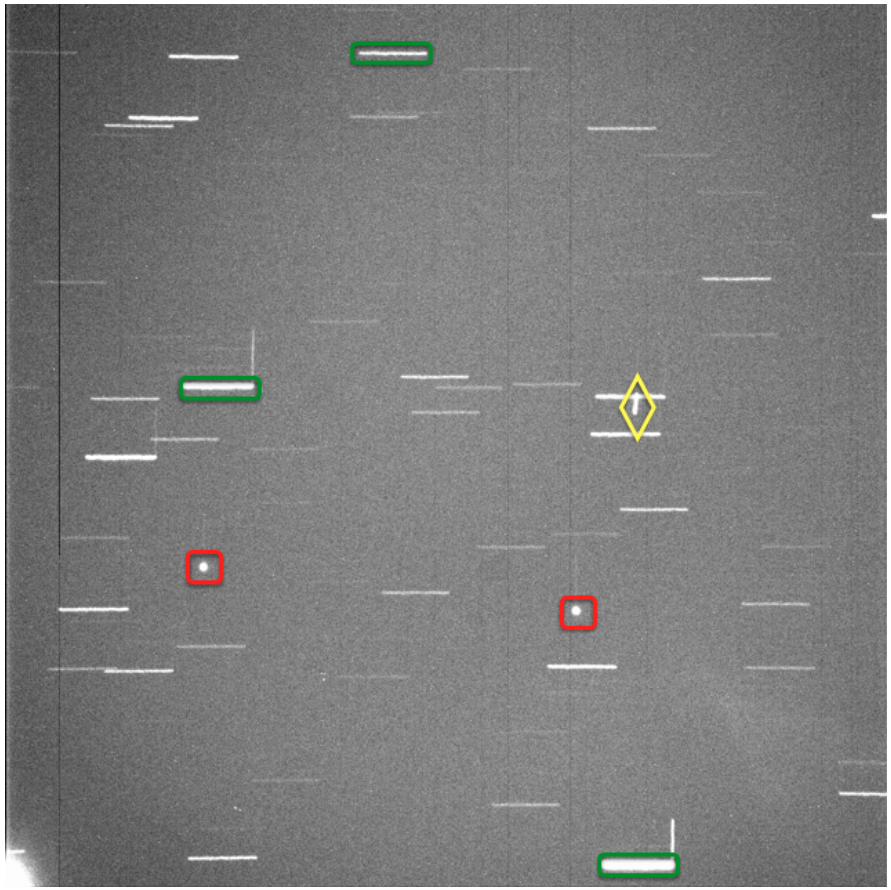

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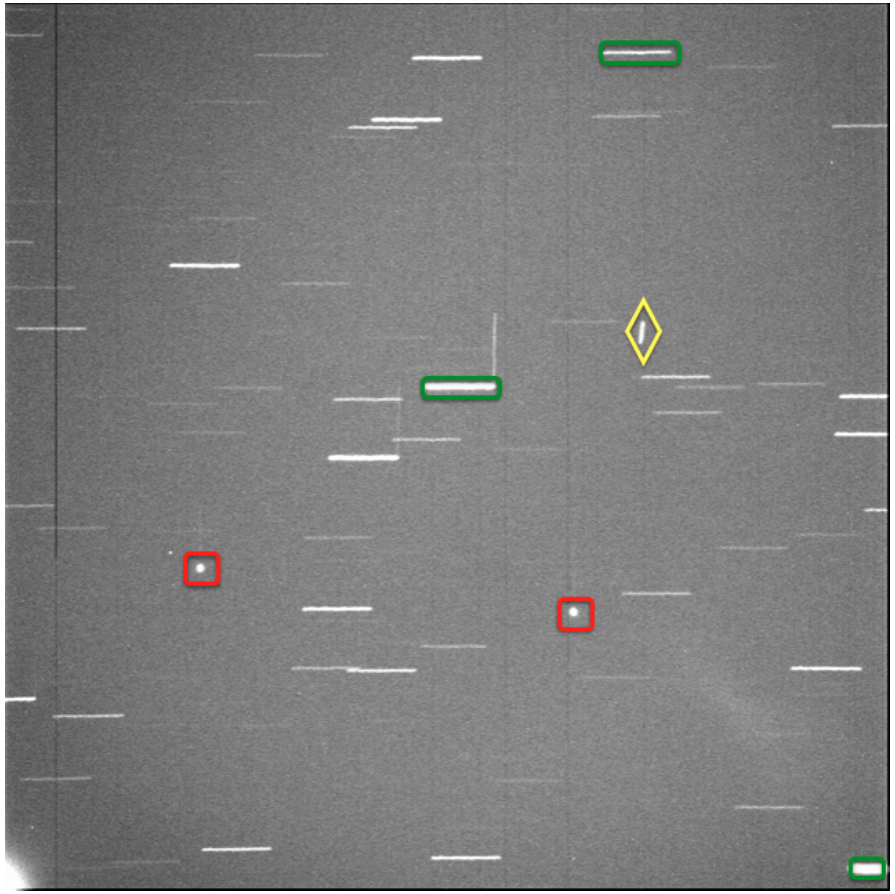

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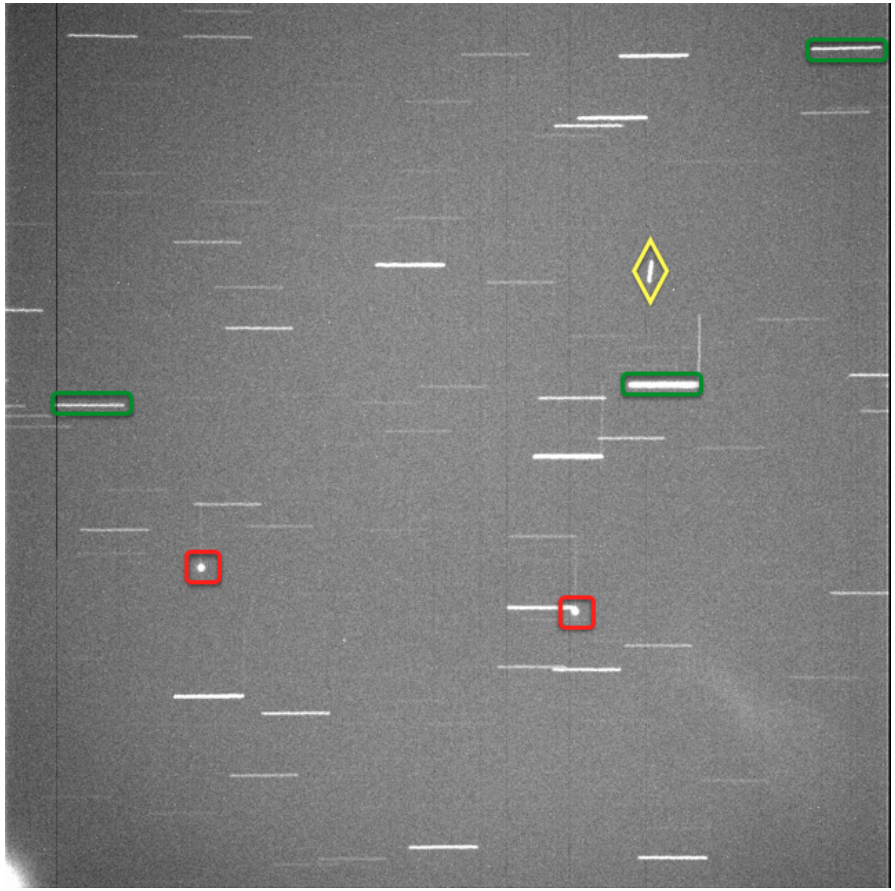

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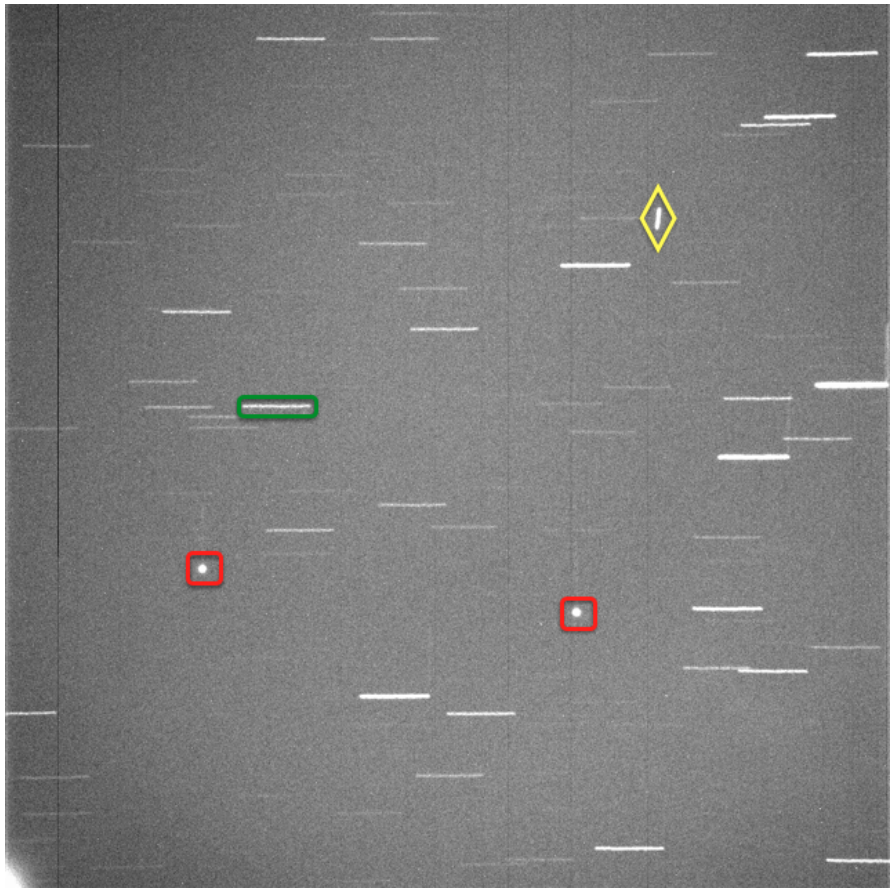

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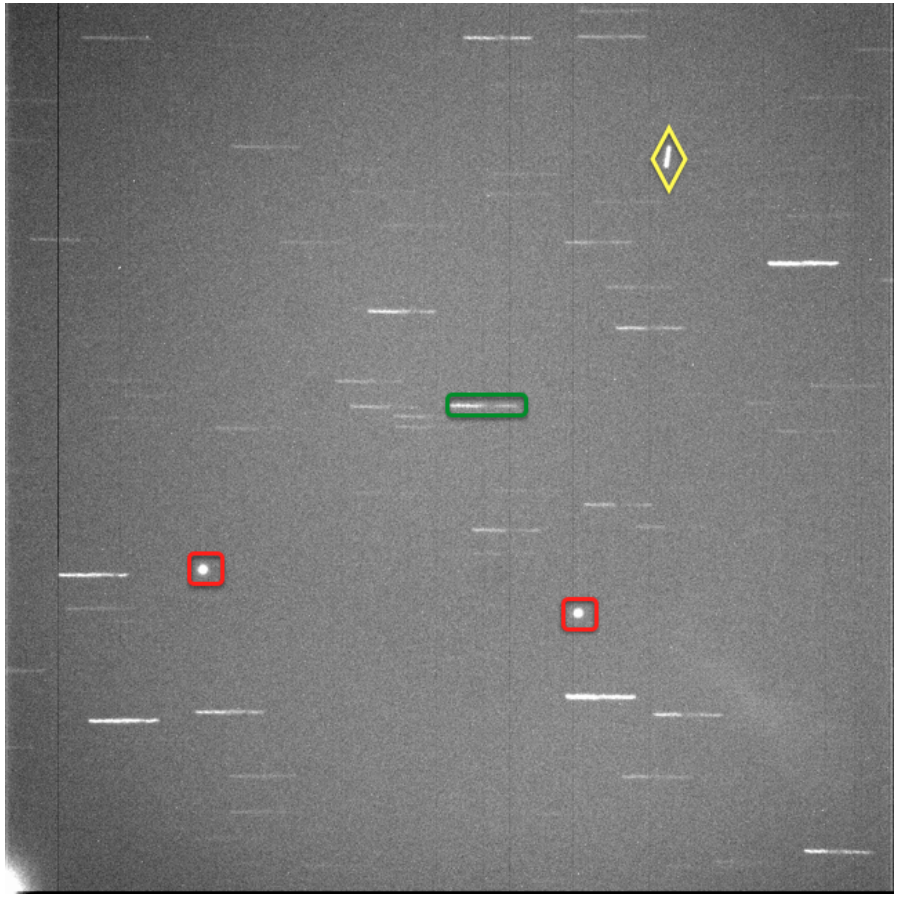

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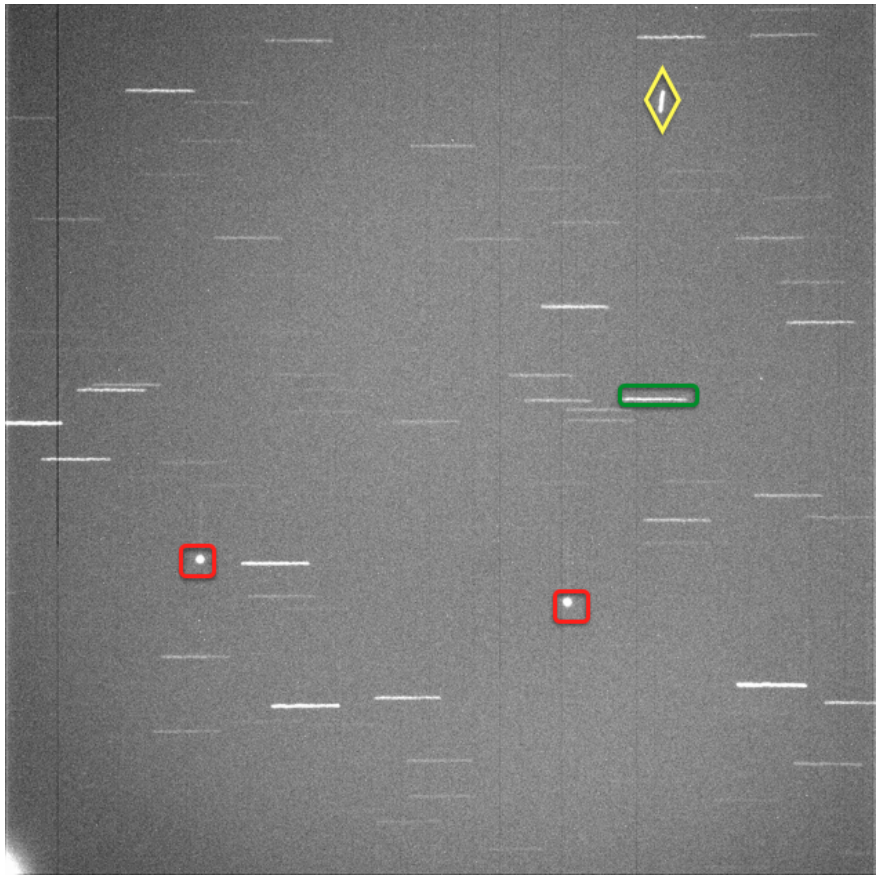
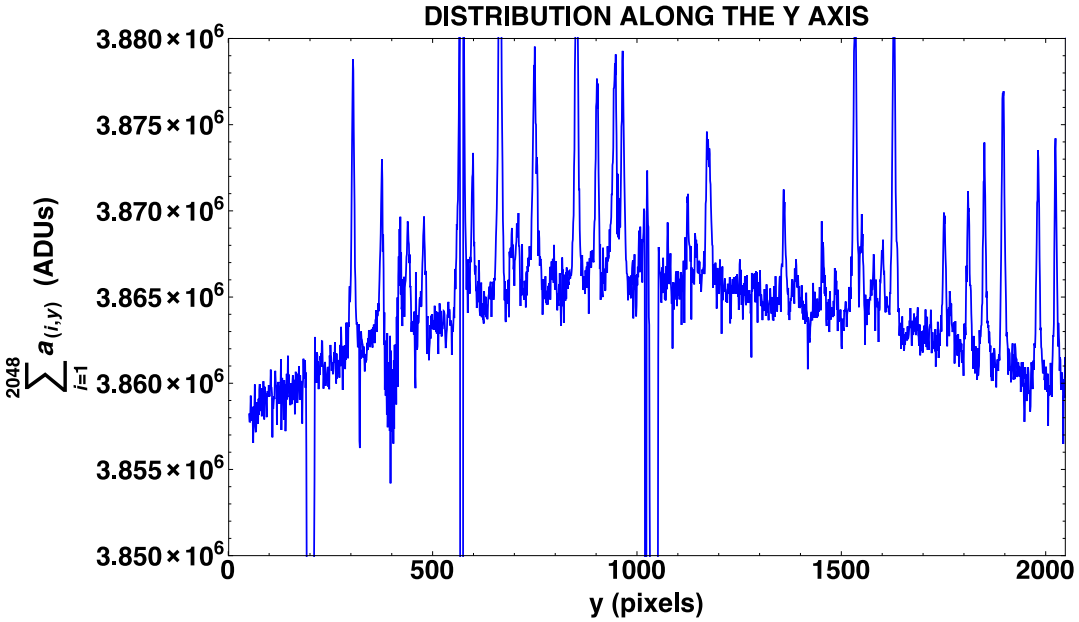


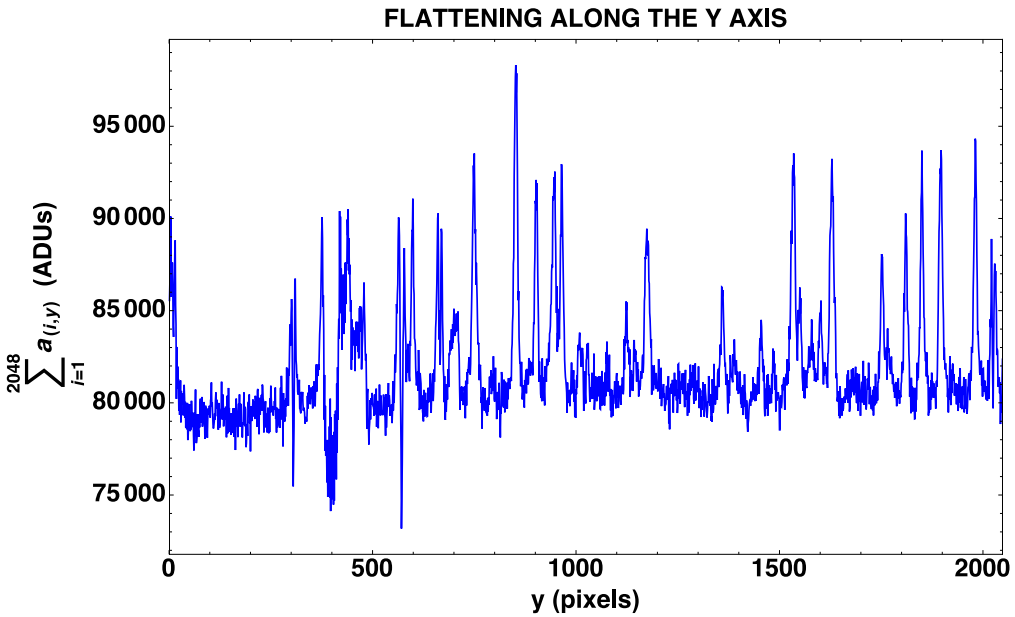
Calibration

Automatic calibration process.
This is a standard step before the reduction process.

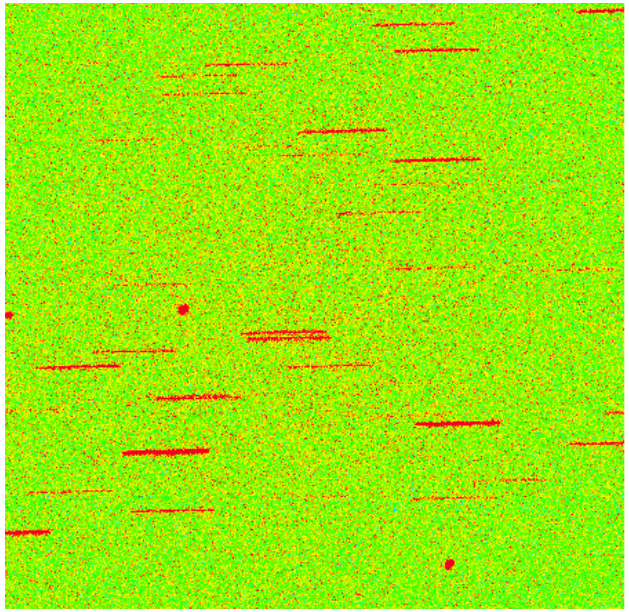
- Loading all image calibrations (Bias, Dark, Flat, and all observations).
- Trimming and overscan (all observations).
- Determination of Signal to Noise Ratio (SNR) (MasterBias).
- Determination of Termal Noise (MasterDark).
- CDD sensitivity (MasterFlat and Normalized Flat).
- Image calibrations.

Checking the Calibration Process





Distribution functions along the right ascension, α.



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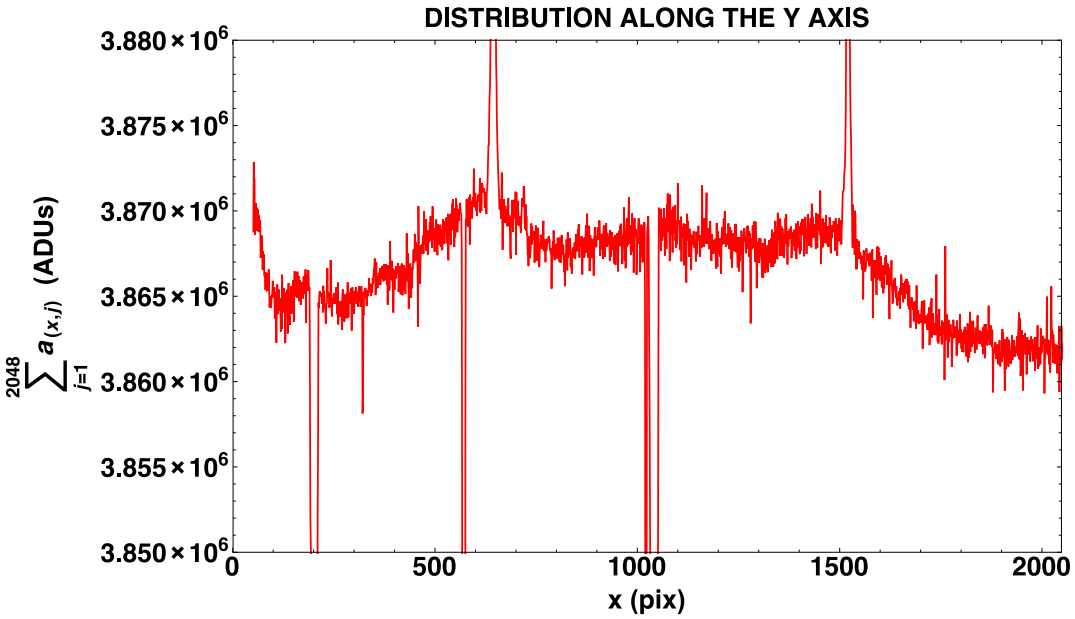
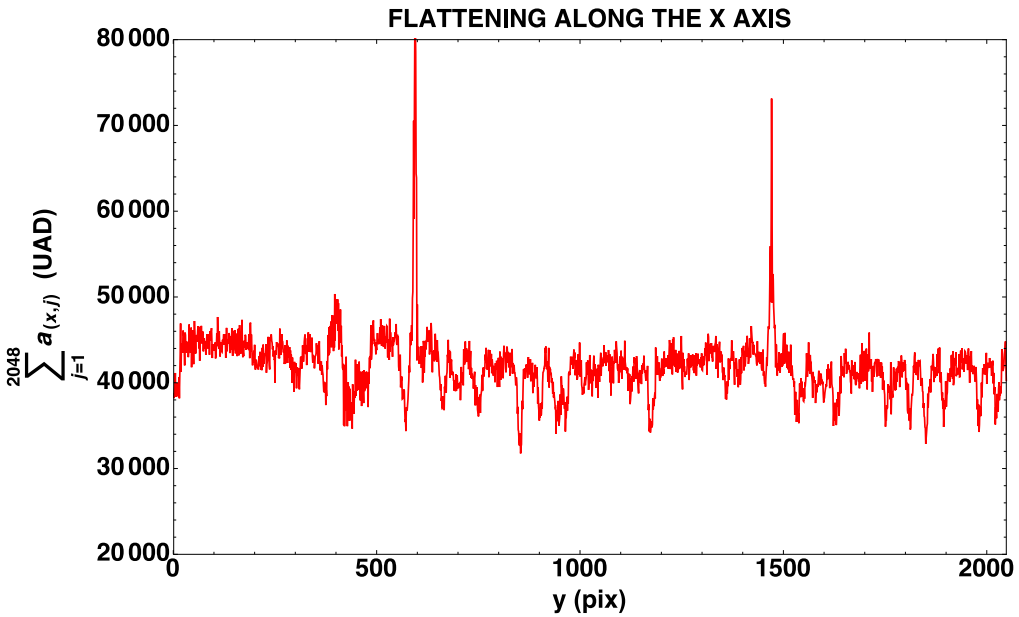
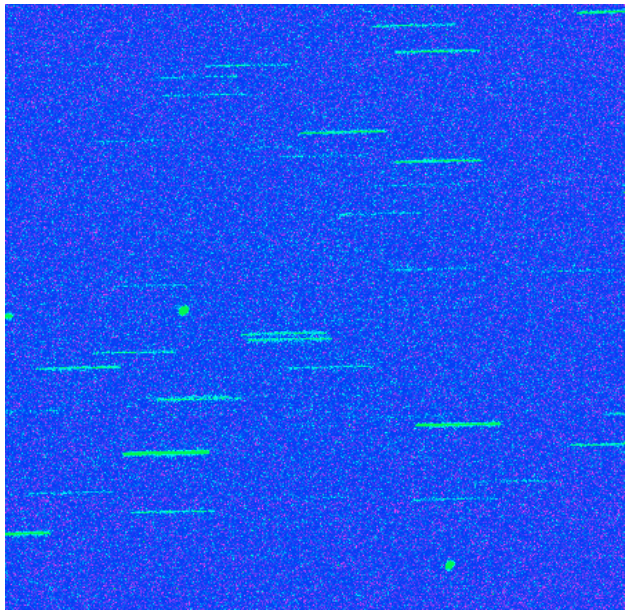
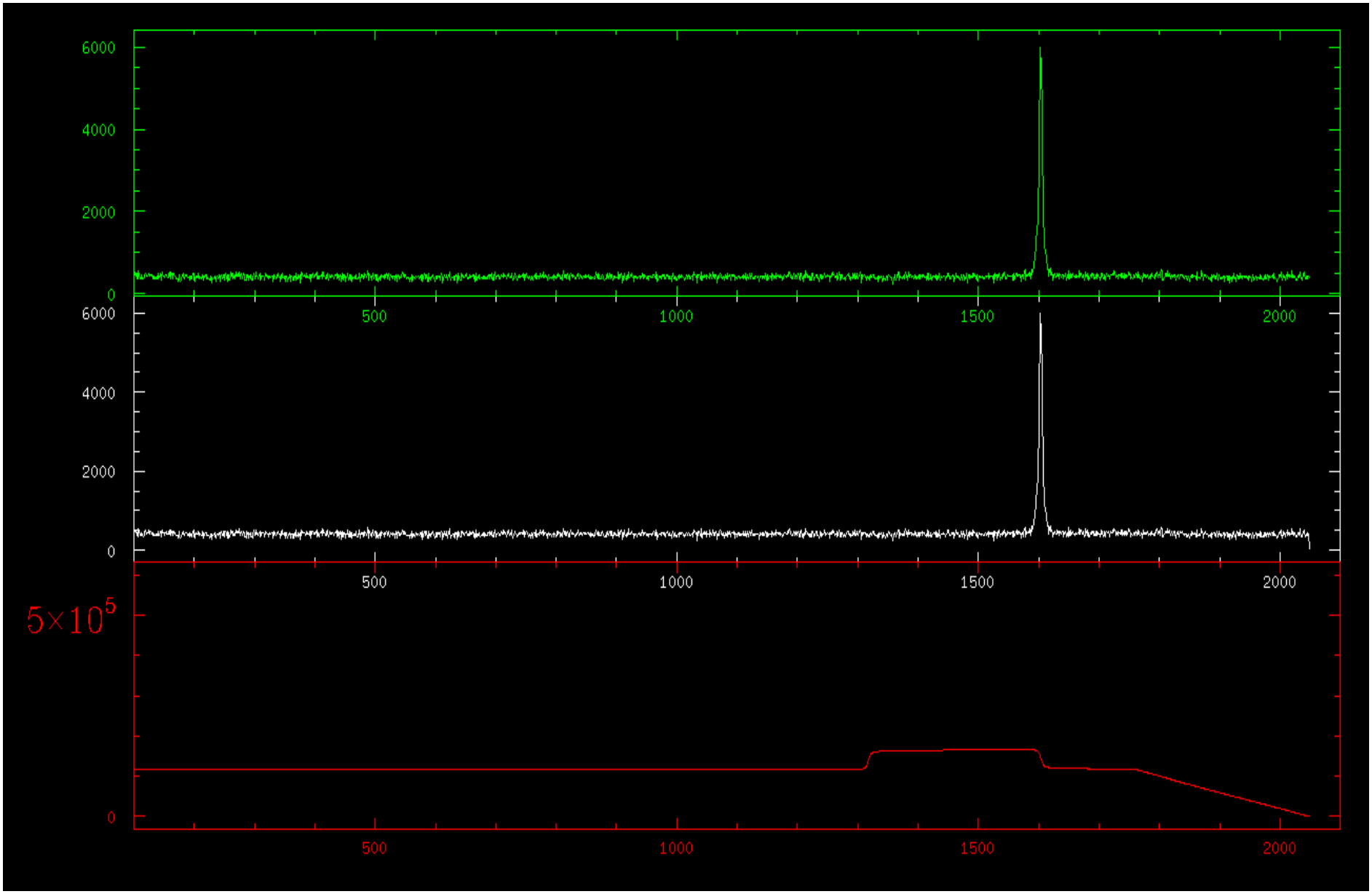




Distribution functions along the declination, δ.



Detecting Objects



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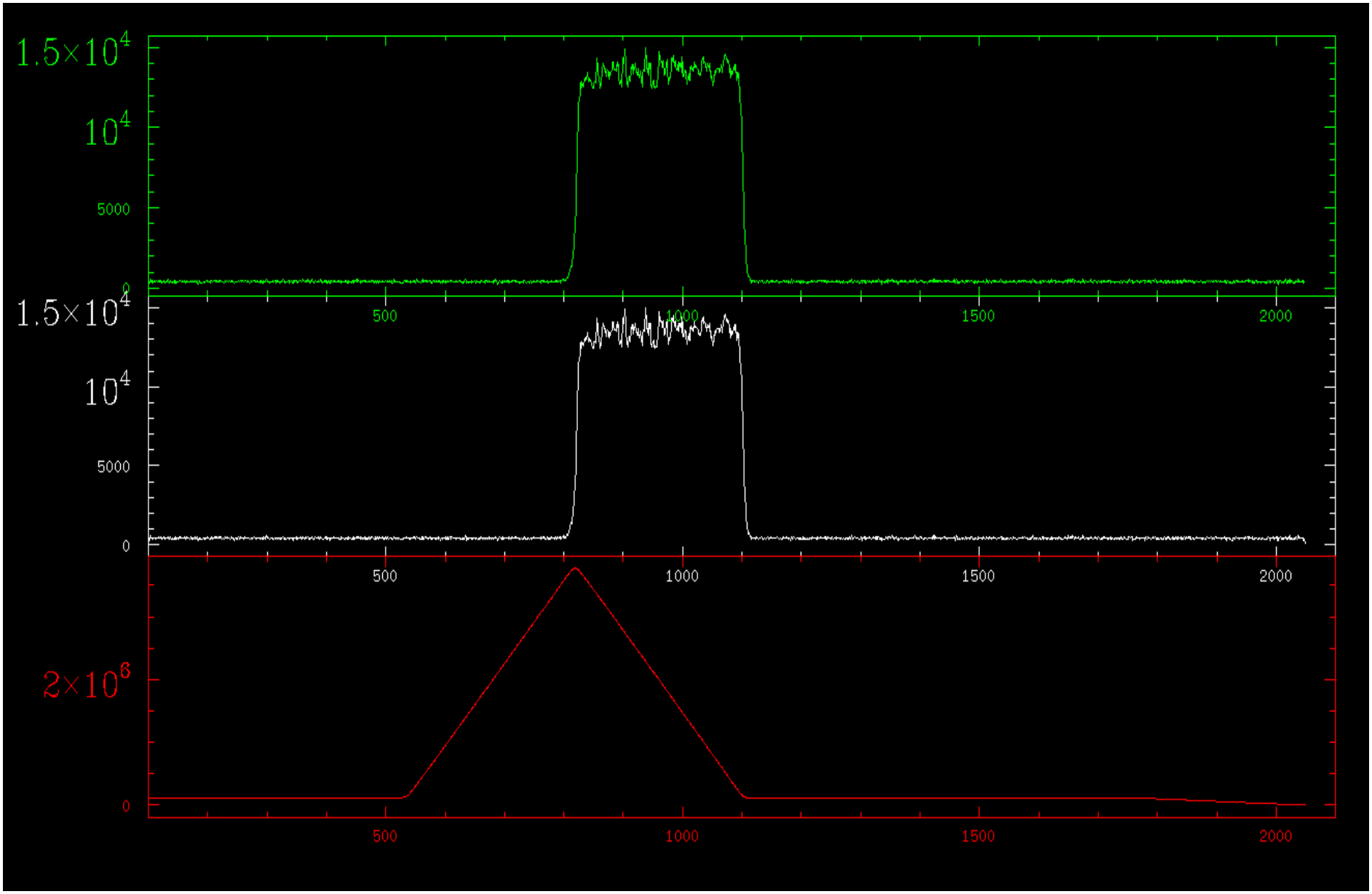

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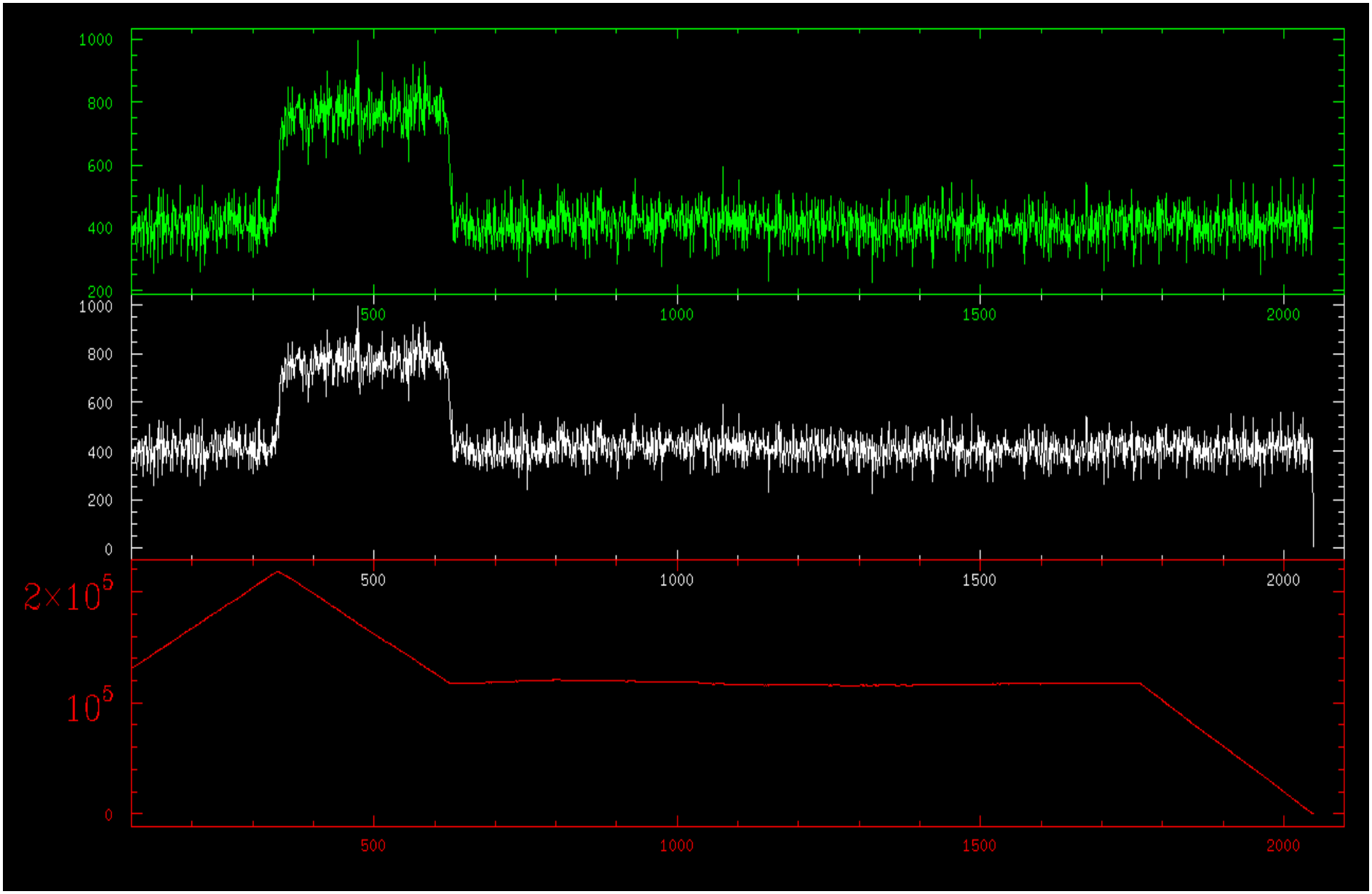
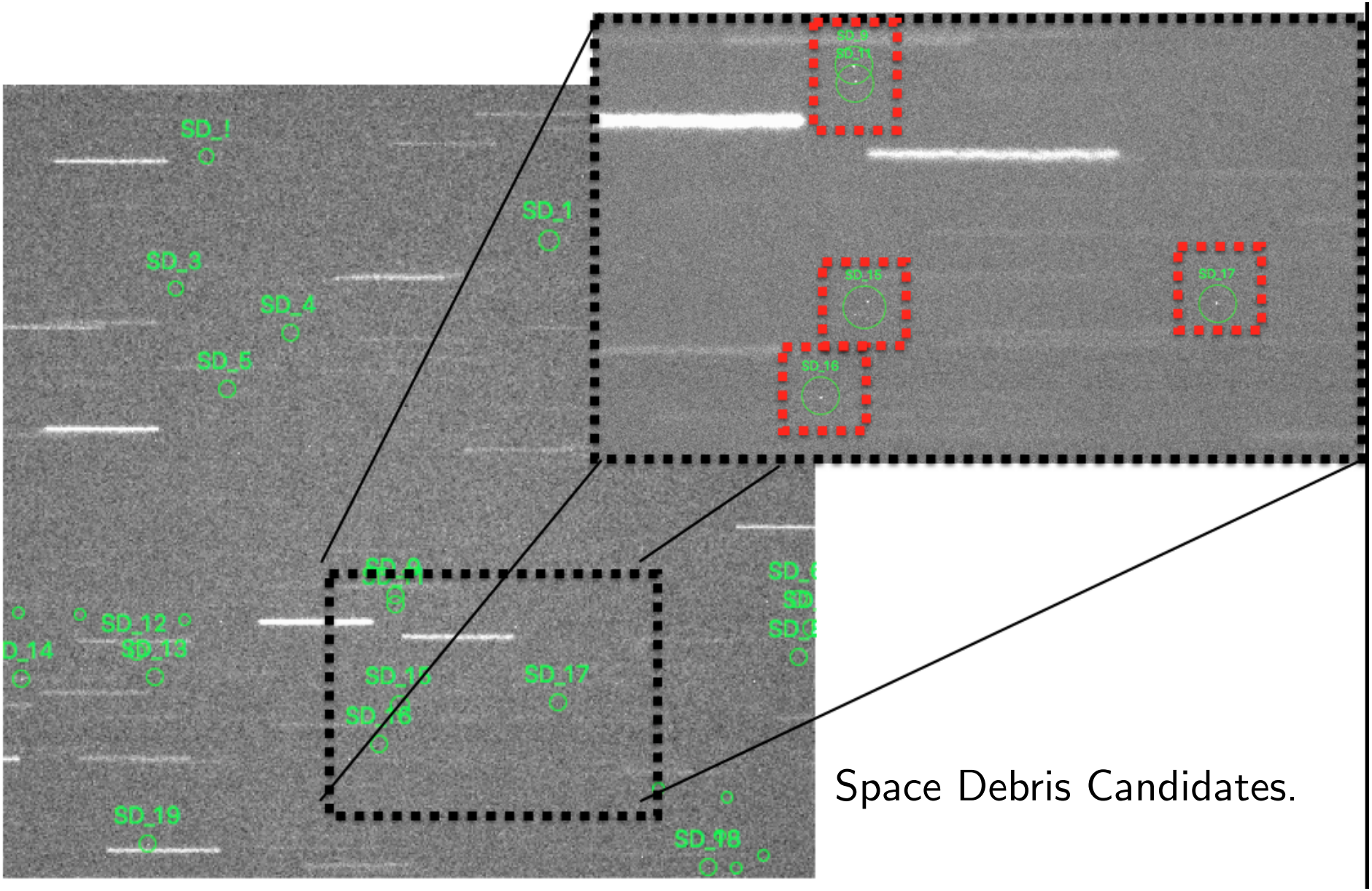


Detecting Orbiters

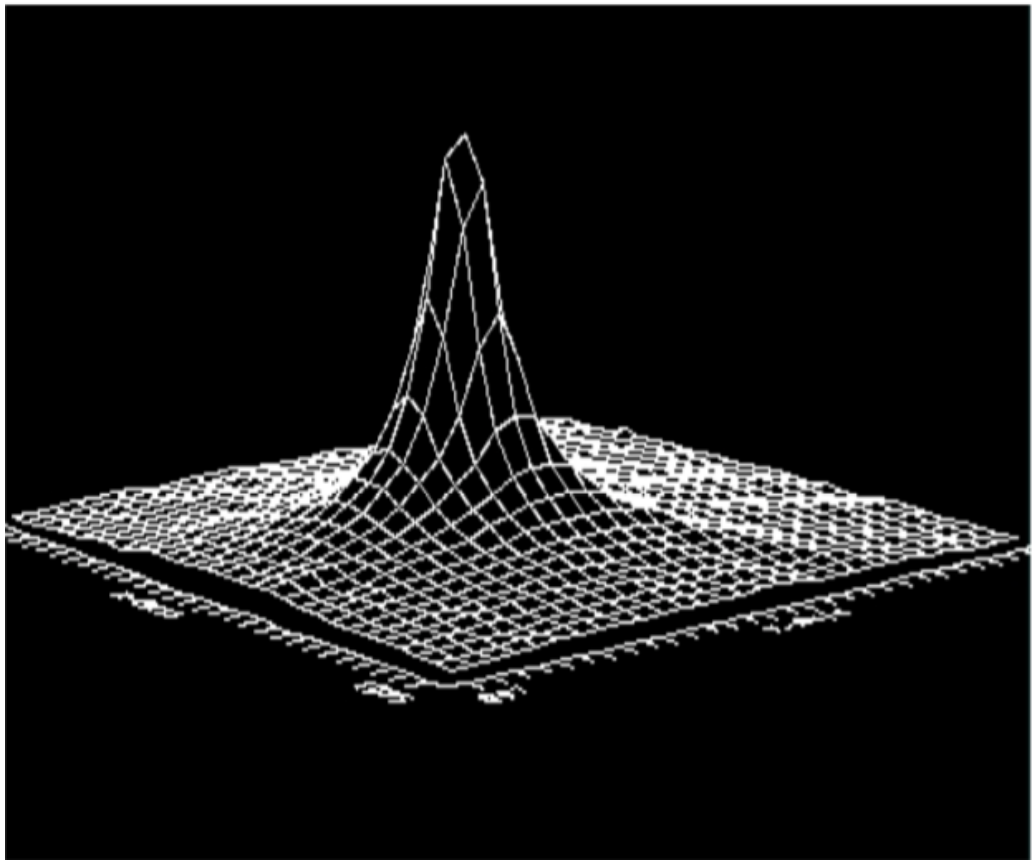


Space Debris Candidates.

Measurement of coordinates (x, y)

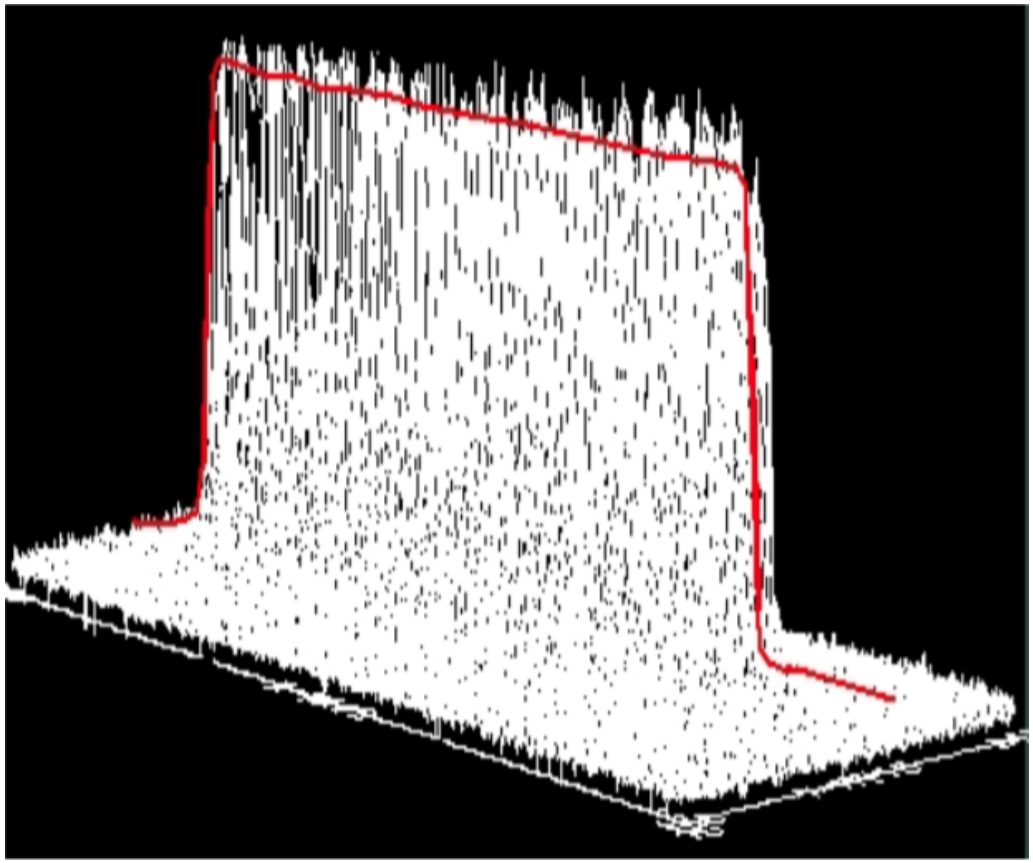
- Point source images: to fit a Gaussian PSF.

$$f(x, y) = A\, e^{-\left(\frac{(\mu_x - x)^2}{2\,\sigma_x^2} + \frac{(\mu_y - y)^2}{2\,\sigma_y^2}\right)}.$$



Measurement of coordinates (x, y)

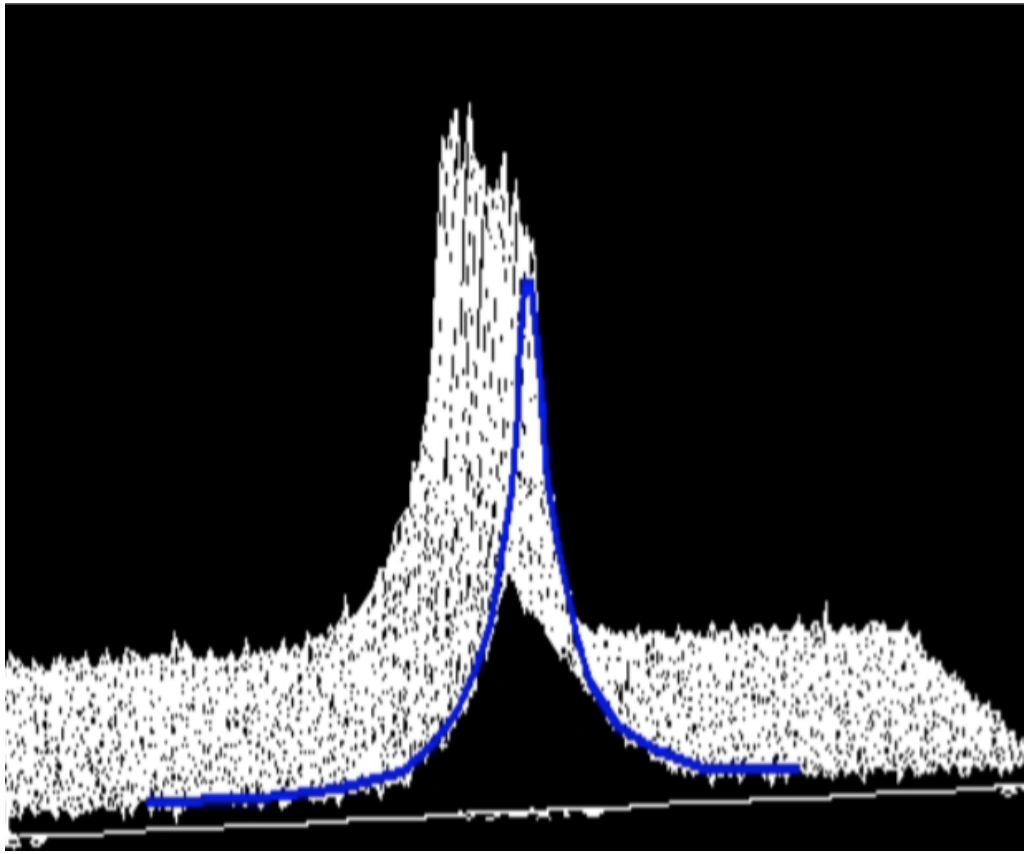
- Trail images (right ascension axis) to fit a Tepuy PSF.
  $g(u) = \frac{A}{2\tan^{-1}(b\,c)}\left[\tan^{-1}(b\,(u-c)) - \tan^{-1}(b\,(u+c))\right]$,
  $u = x - x_0$.



Measurement of coordinates (x, y)

- Trail images (declination axis) to fit a Gaussian PSF.

$$h(y) = A\, e^{-\left(\frac{(\mu_y - y)^2}{2\,\sigma_y^2}\right)}.$$



Identification and Transformation

- Identification:
  - We use the gnomonic projection to transform the CCD to the celestial sphere, i.e. transforming maximum circles into straight lines on the plane focal telescope.
  - $(x_\star,\ y_\star)_m \quad \rightarrow \quad (u,\ v,\ w)$.
  - We use the UCAC4 stars catalogue to identify $(\alpha_\star,\ \delta_\star)_{cat} \quad \rightarrow \quad (\xi,\ \eta,\ \zeta)$.
- Transformation:
  - We calculate the transformation (R) between coordinate systems.
  - $(u,\ v,\ w) \quad \leftrightarrow \quad (\alpha_\star,\ \delta_\star)_{cat}$.
  - R depends on the orientation of CCD respect to the celestial sphere and telescope position.

$$\boxed{(x_\star,\ y_\star)_m \quad \rightarrow \quad (u,\ v,\ w) \quad \leftrightarrow \quad (\xi,\ \eta,\ \zeta) \quad \leftarrow \quad (\alpha_\star,\ \delta_\star)_{cat}.}$$

Matrix Solution

Three stars are needed to find out the matrix solution. If we use n stars for the solution we obtain $3n$ condition equations (Stock's Method, (Stock,1981).

$$\begin{aligned}
\xi_1 &= a_{11}u_1 + a_{12}v_1 + a_{13}w_1 \\
\eta_1 &= a_{21}u_1 + a_{22}v_1 + a_{23}w_1 \\
\zeta_1 &= a_{31}u_1 + a_{32}v_1 + a_{33}w_1 \\
&\vdots \\
\xi_n &= a_{11}u_n + a_{12}v_n + a_{13}w_n \\
\eta_n &= a_{21}u_n + a_{22}v_n + a_{23}w_n \\
\zeta_n &= a_{31}u_n + a_{32}v_n + a_{33}w_n
\end{aligned}$$

$$\begin{aligned}
\sum_{i=1}^{n} \xi_i u_i &= \sum_{i=1}^{n} a_{11}u_i^{2^2} + \sum_{i=1}^{n} a_{12}v_i u_i + \sum_{i=1}^{n} a_{13}w_i u_i, \\
\sum_{i=1}^{n} \xi_i v_i &= \sum_{i=1}^{n} a_{11}u_i v_i + \sum_{i=1}^{n} a_{12}v_i^2 + \sum_{i=1}^{n} a_{13}w_i v_i, \\
\sum_{i=1}^{n} \xi_i w_i &= \sum_{i=1}^{n} a_{11}u_i w_i + \sum_{i=1}^{n} a_{12}v_i w_i + \sum_{i=1}^{n} a_{13}w_i^2,
\end{aligned}$$

$$\begin{aligned}
\sum_{i=1}^{n} \eta_i u_i &= \sum_{i=1}^{n} a_{21}u_i^2 + \sum_{i=1}^{n} a_{22}v_i u_i + \sum_{i=1}^{n} a_{23}w_i u_i, \\
\sum_{i=1}^{n} \eta_i v_i &= \sum_{i=1}^{n} a_{21}u_i v_i + \sum_{i=1}^{n} a_{22}v_i^2 + \sum_{i=1}^{n} a_{23}w_i v_i, \\
\sum_{i=1}^{n} \eta_i w_i &= \sum_{i=1}^{n} a_{21}u_i w_i + \sum_{i=1}^{n} a_{22}v_i w_i + \sum_{i=1}^{n} a_{23}w_i^2,
\end{aligned}$$

$$\begin{aligned}
\sum_{i=1}^{n} \zeta_i u_i &= \sum_{i=1}^{n} a_{31}u_i^2 + \sum_{i=1}^{n} a_{32}v_i u_i + \sum_{i=1}^{n} a_{33}w_i u_i, \\
\sum_{i=1}^{n} \zeta_i v_i &= \sum_{i=1}^{n} a_{31}u_i v_i + \sum_{i=1}^{n} a_{32}v_i^2 + \sum_{i=1}^{n} a_{33}w_i v_i, \\
\sum_{i=1}^{n} \zeta_i w_i &= \sum_{i=1}^{n} a_{31}u_i w_i + \sum_{i=1}^{n} a_{32}v_i w_i + \sum_{i=1}^{n} a_{33}w_i^2,
\end{aligned}$$

The orthogonality of the matrix tells about how good is the transformation matrix between coordinates.

Off-axis Aberrations

The *oaa* are the off-axis aberrations, which is given by:
$oaa = a_3 \frac{y^3}{R^3} + a_2 \frac{y^2\,\theta}{R^2} + a_1 \frac{y\,\theta^3}{R} + a_0\,\theta^3$, where, y and θ are the field angle and aperture radius.

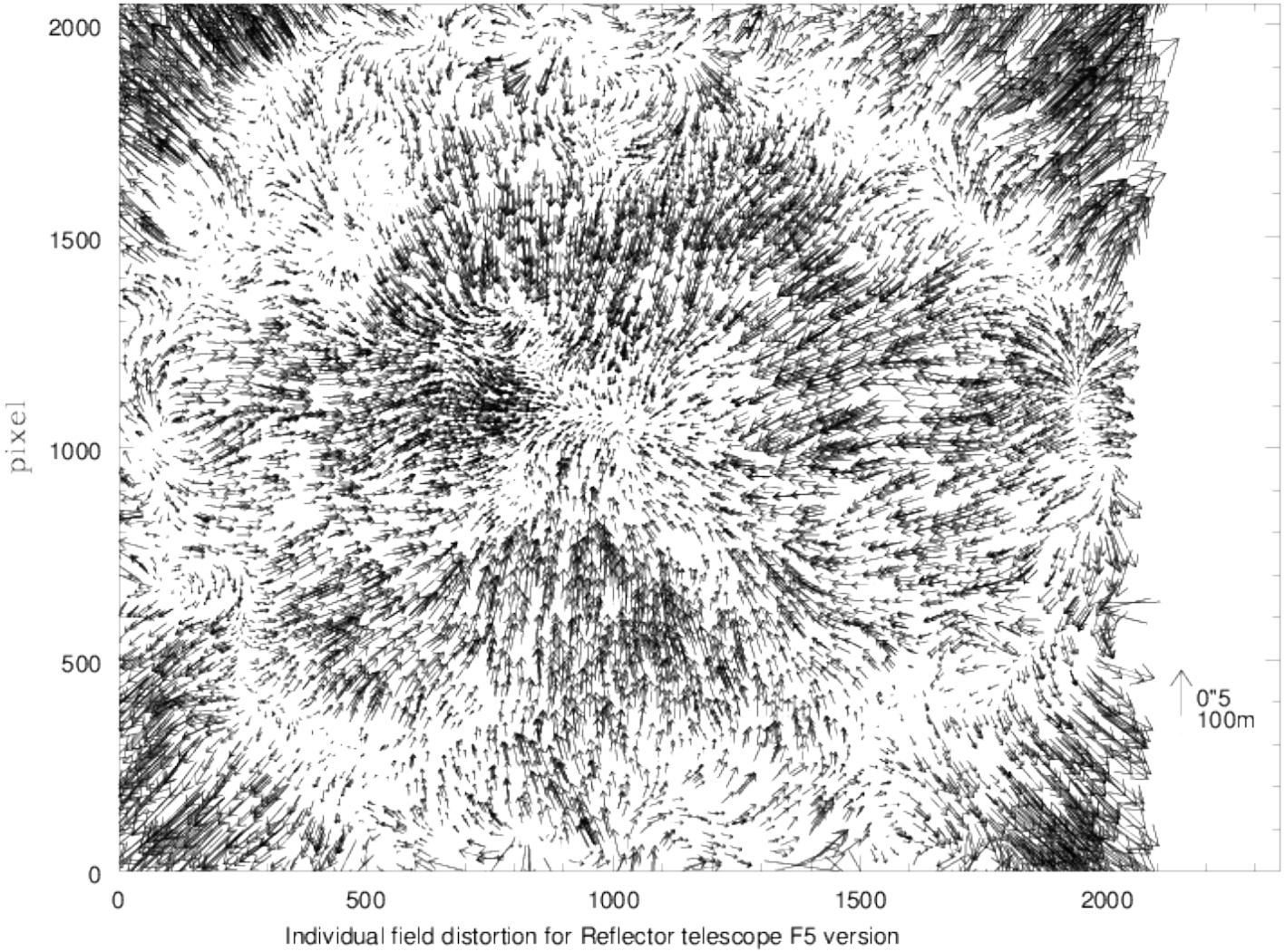
- Spherical aberrations.
- Coma.
- Astigmatism.
- Distortion and field of curvature.

- We need to determinate the telescope field distortion.

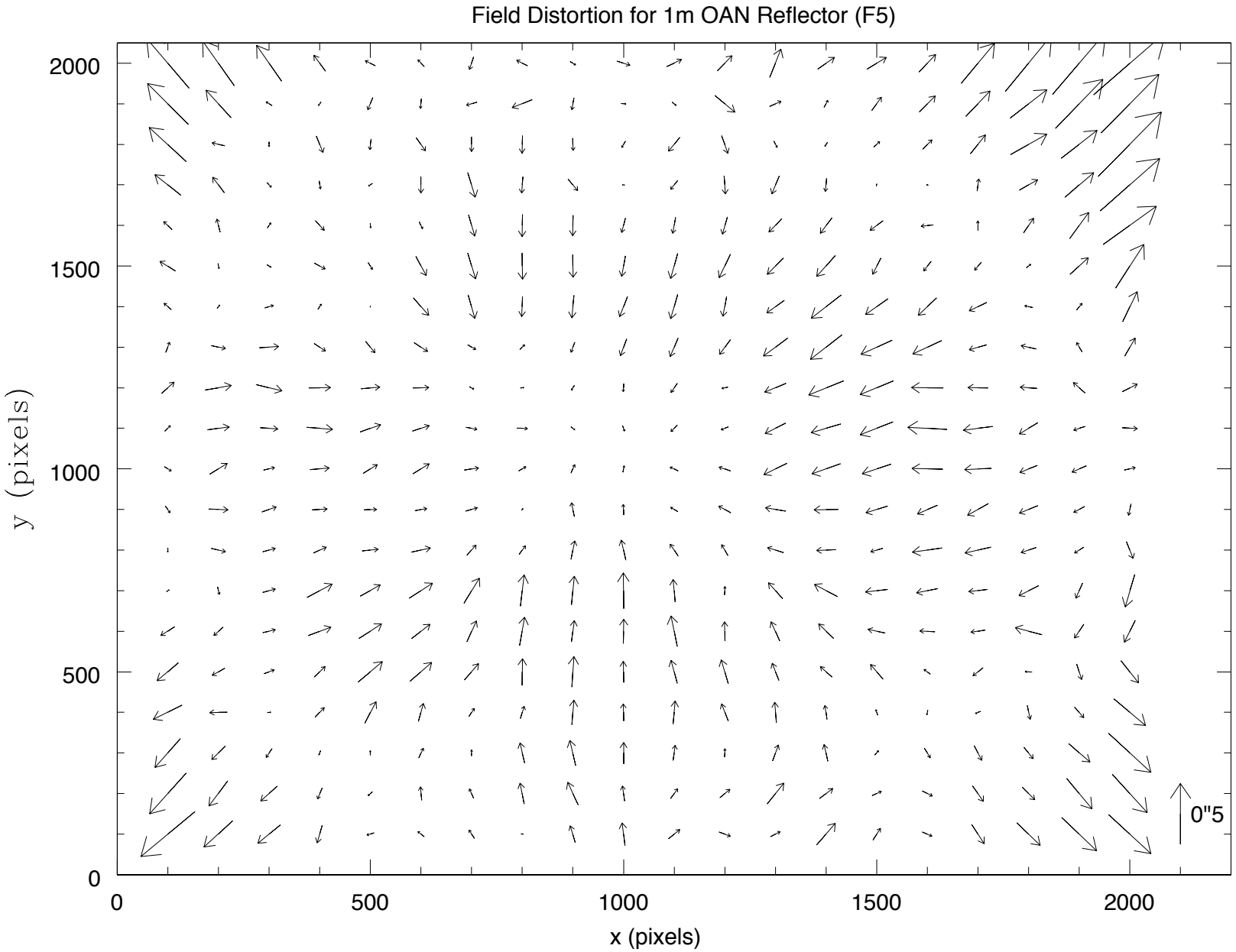
- An error of 1" is equivalent to an error of 200 m (at 42164 km).

Field distortion

Sliding Weighted Polynomial (Polinomio Deslizante). (Stock & Abad, 1988).

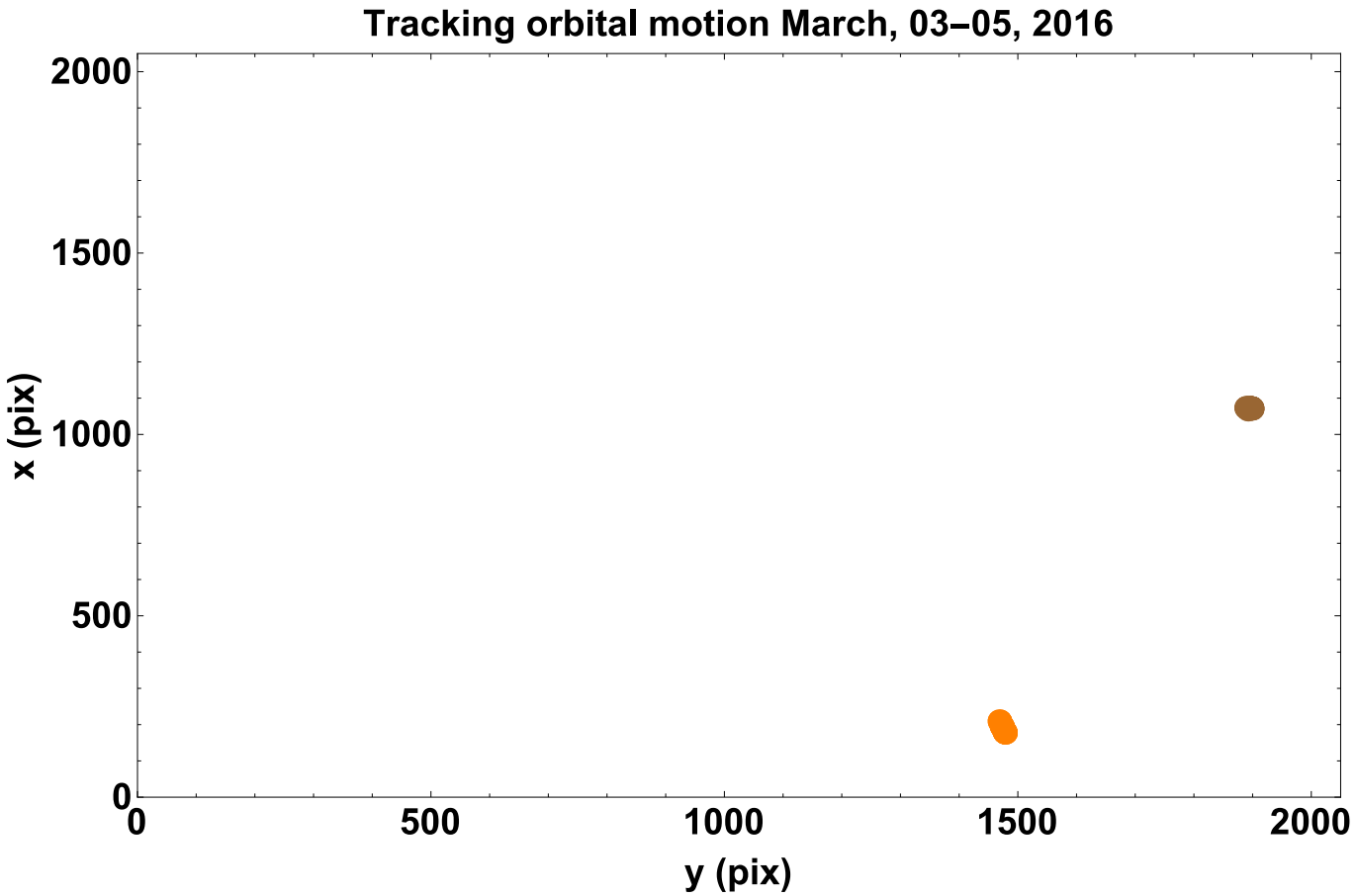


Field distortion



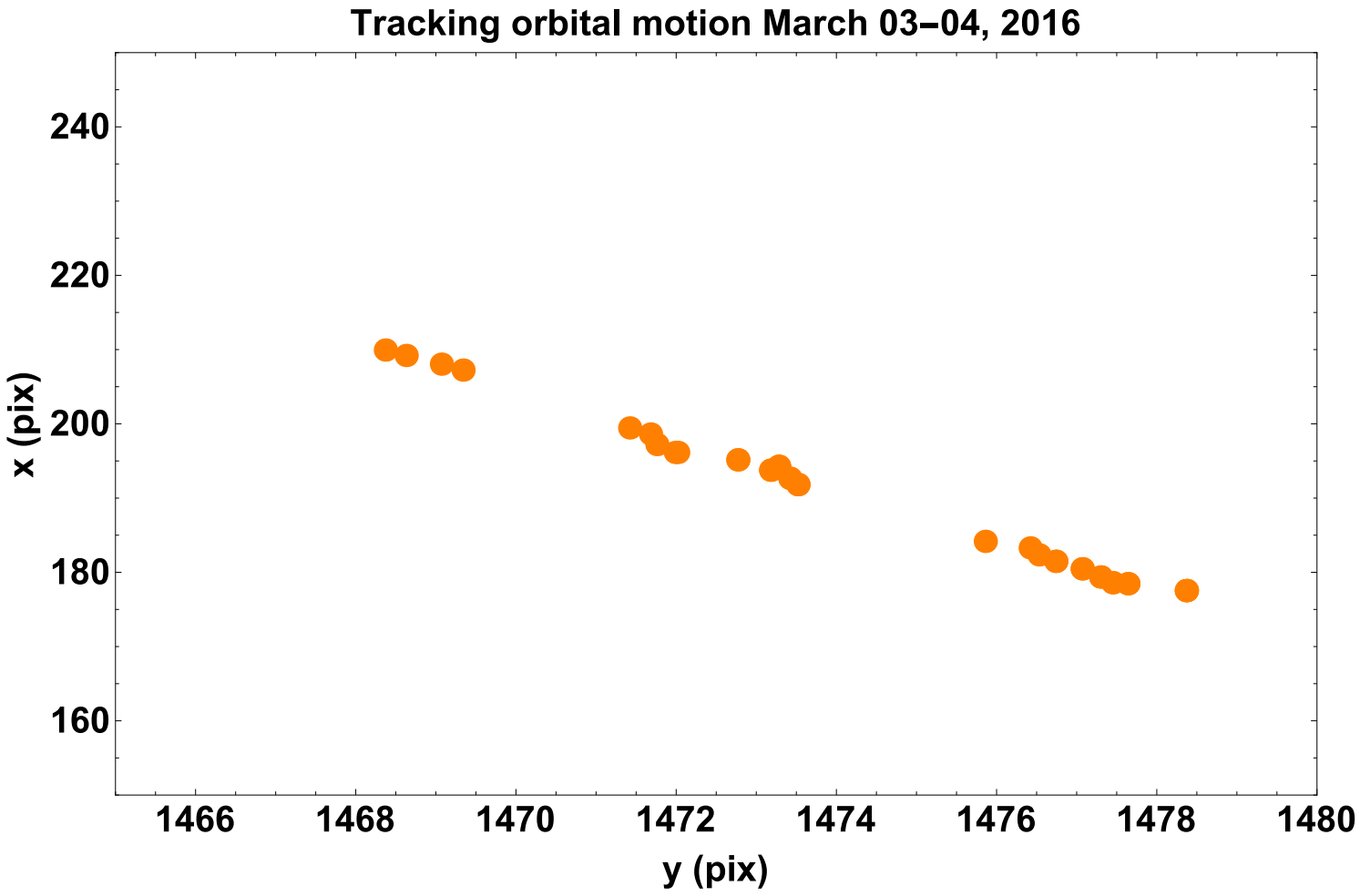
Relative Motion

Relative Motion of a GEO satellite in the operations window 43° W, nearby equilibrium unstable point 11.5 W. March 03-04, 2016 (34 measurement orange point) and March 04-05, 2016. (21 measurement brown point).



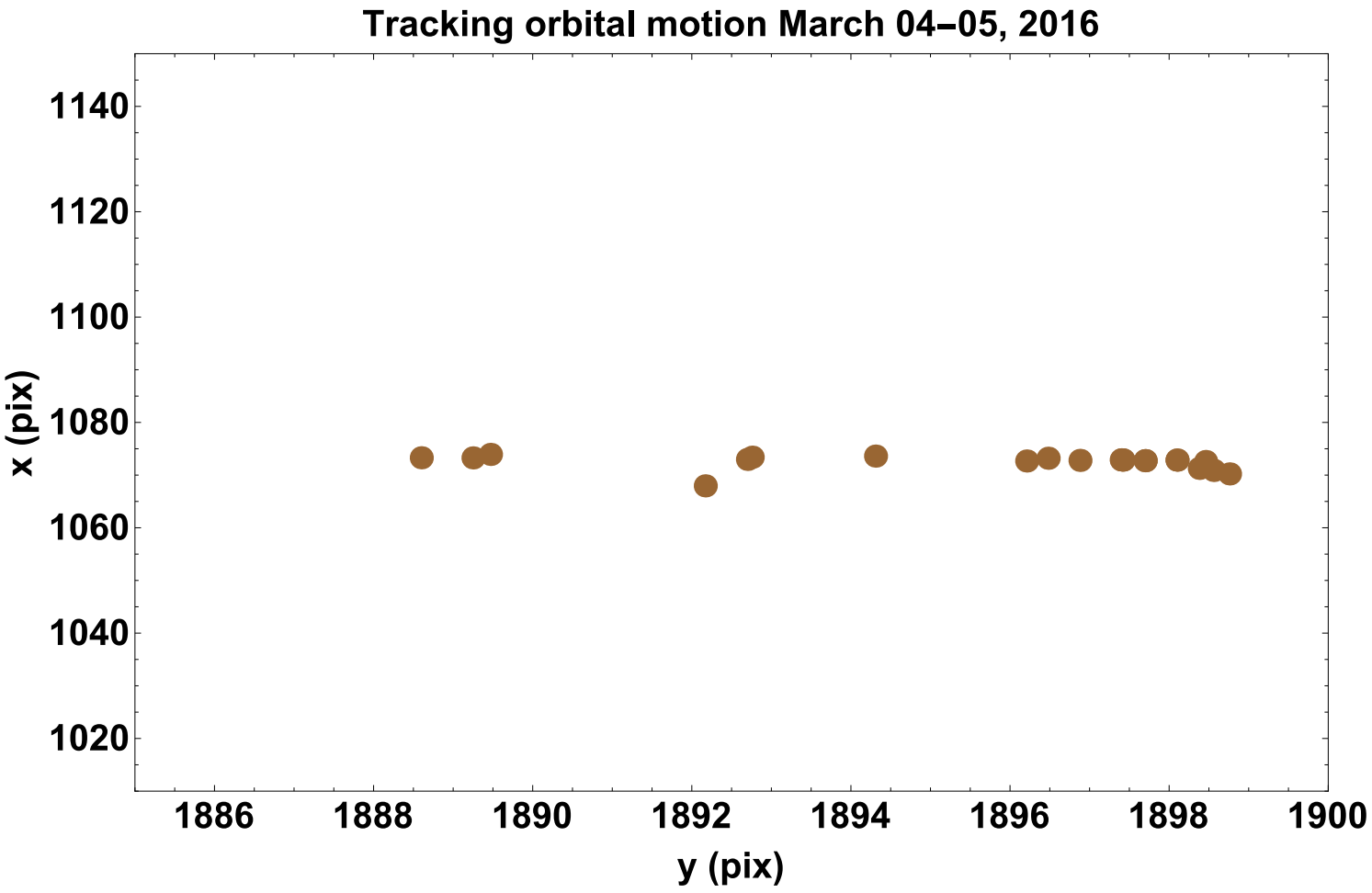
Relative Motion

Relative Motion of a GEO satellite in 43° W. Movement $20.1776'' \leftrightarrow 7.51625^m$.



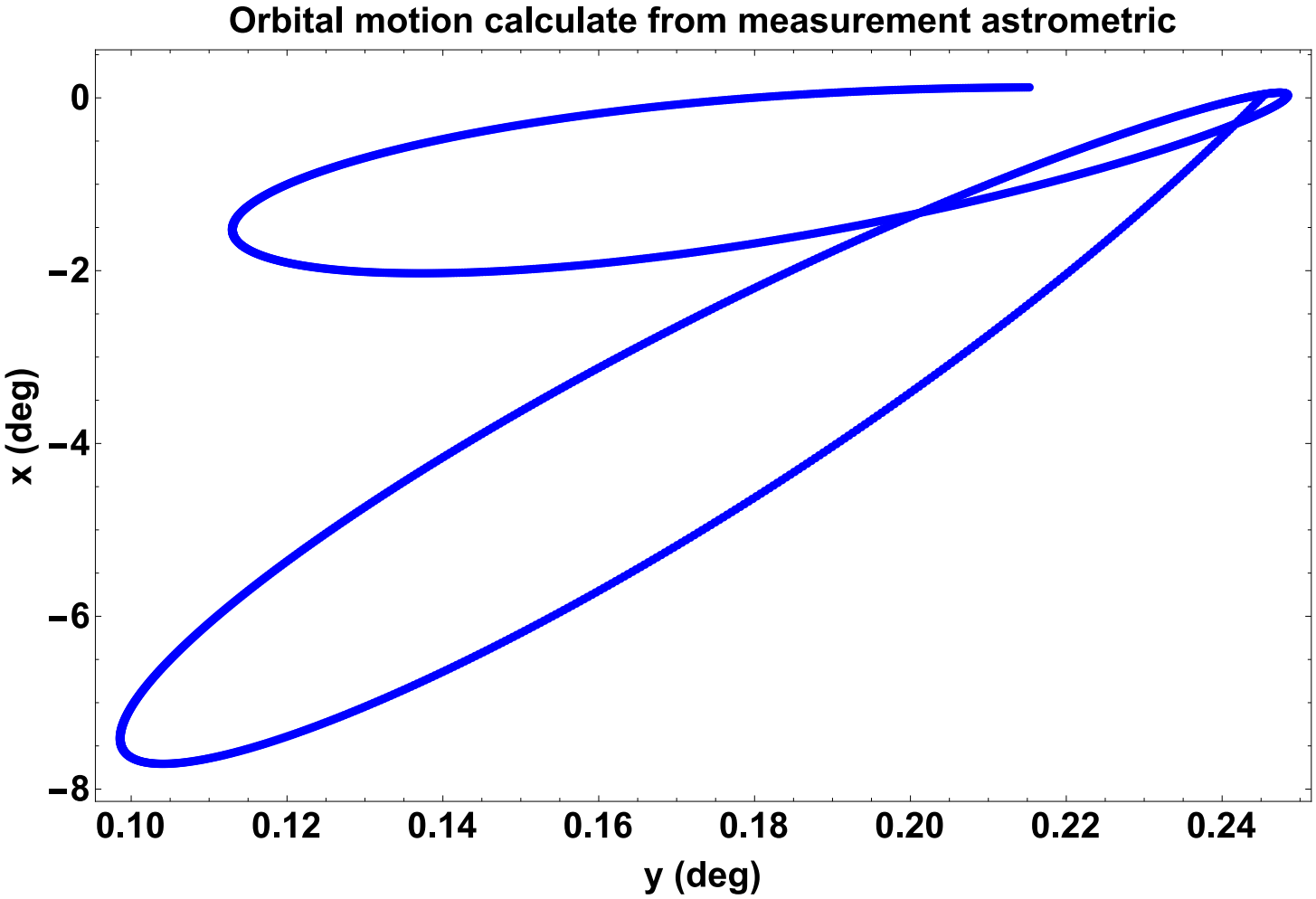
Relative Motion

Relative Motion of a GEO satellite in 43° W. Movement $5.33397'' \quad \leftrightarrow \quad 11.333'^{m}$.



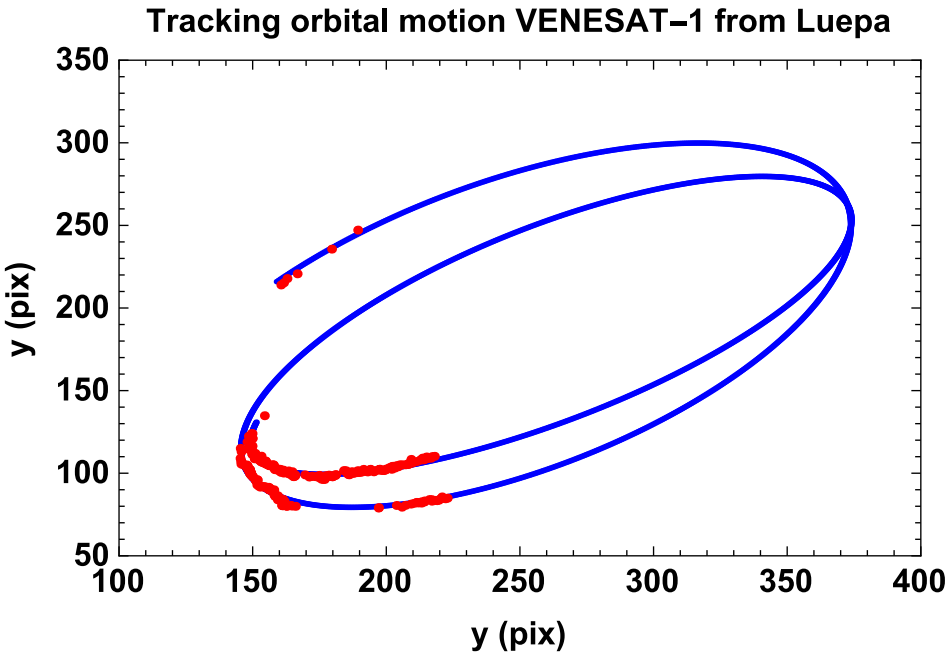
Relative Motion

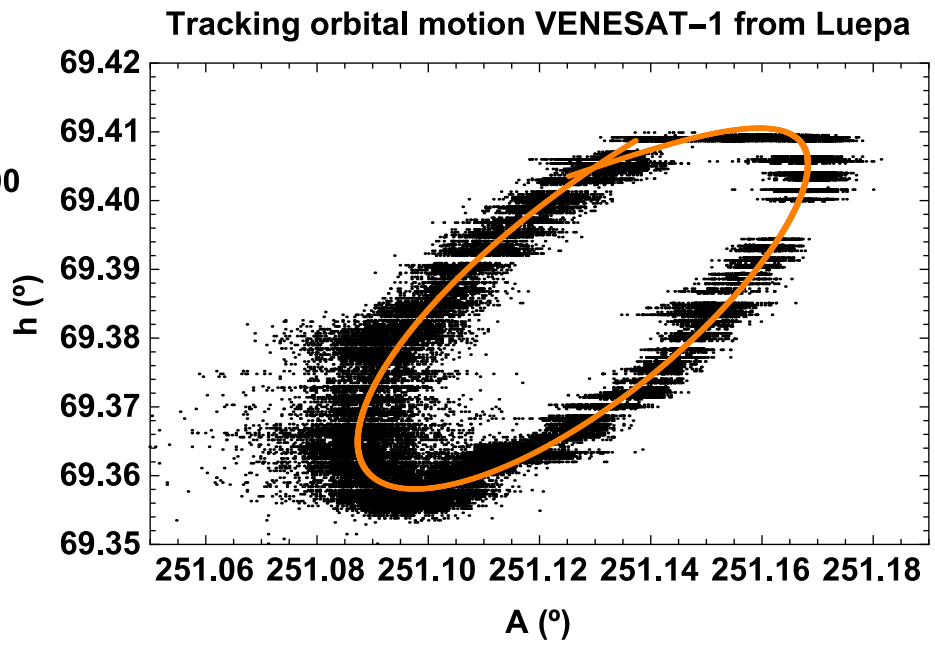
Relative Motion of a GEO satellite in 43°. Adjustment by least square at coordinates (x, y) are through of the circular functions.



Relative Motion

Relative Motion satellite in window 78°. Telemetric and optical tracking nearby equilibrium stable point (105.3°) W.





Conclusions

- Optical Tracking and acquired many astrometric observations.
- We determinate de field distortion and correct the coordinates.
- We calculate the relative motion of the satellites in the GEO ring nearby the equilibrium stable and unstable point.
- Opening to study perturbations.

Future work

- Orbit Determinations (ephemeris).
- Study the behavior the relative motion in all GEO ring and the possibility determinate the effect make of perturbations, gravitational potential and Solar Radiation Pressure.
- Calculation of the parallax, for determinate the distance, r.

Thanks for your attention!!!

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