Monitoring and tracking satellites and space debris using the electro-optical system

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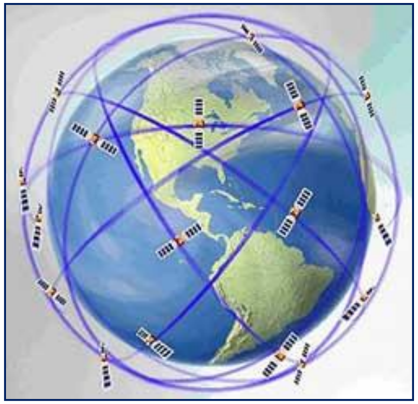
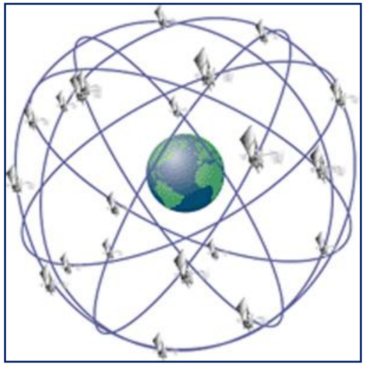
TYPES OF SATELLITE ORBITS

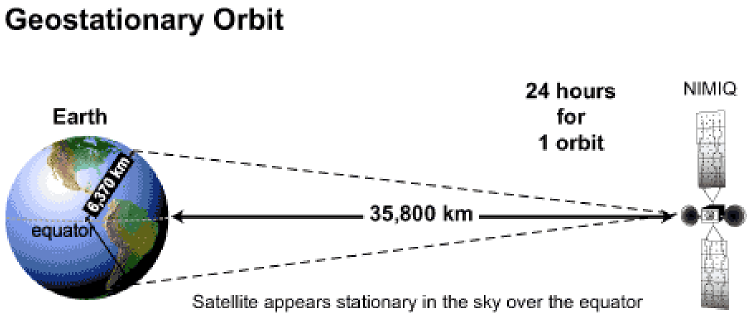
- Orbit height
  - Low Earth Orbit (LEO)
    - Attitude 360-2,000km
    - Satellite speed ~ 8km/sec
    - Orbital period ~ 90 min
    - Example: Globstar, 48 satellites in six planes, 1413km
  - Medium Earth Orbit (MEO)
    - Altitude 2,000km -35,786km
    - Satellite speed 8km/sec to 3 km/sec
    - Orbital period 2 to 24h
    - Example: GPS, 24 satellites in 6 planes, 20,200km
  - Geosynchronous orbit (GSO)
    - Altitude 35,768km
    - Satellite speed ~ 3km/sec
    - Non zero inclination
    - Orbital period 24 hours
  - Geostationary orbit (GEO)
    - GSO satellite in zero inclination orbit



Constellation of Globstar system

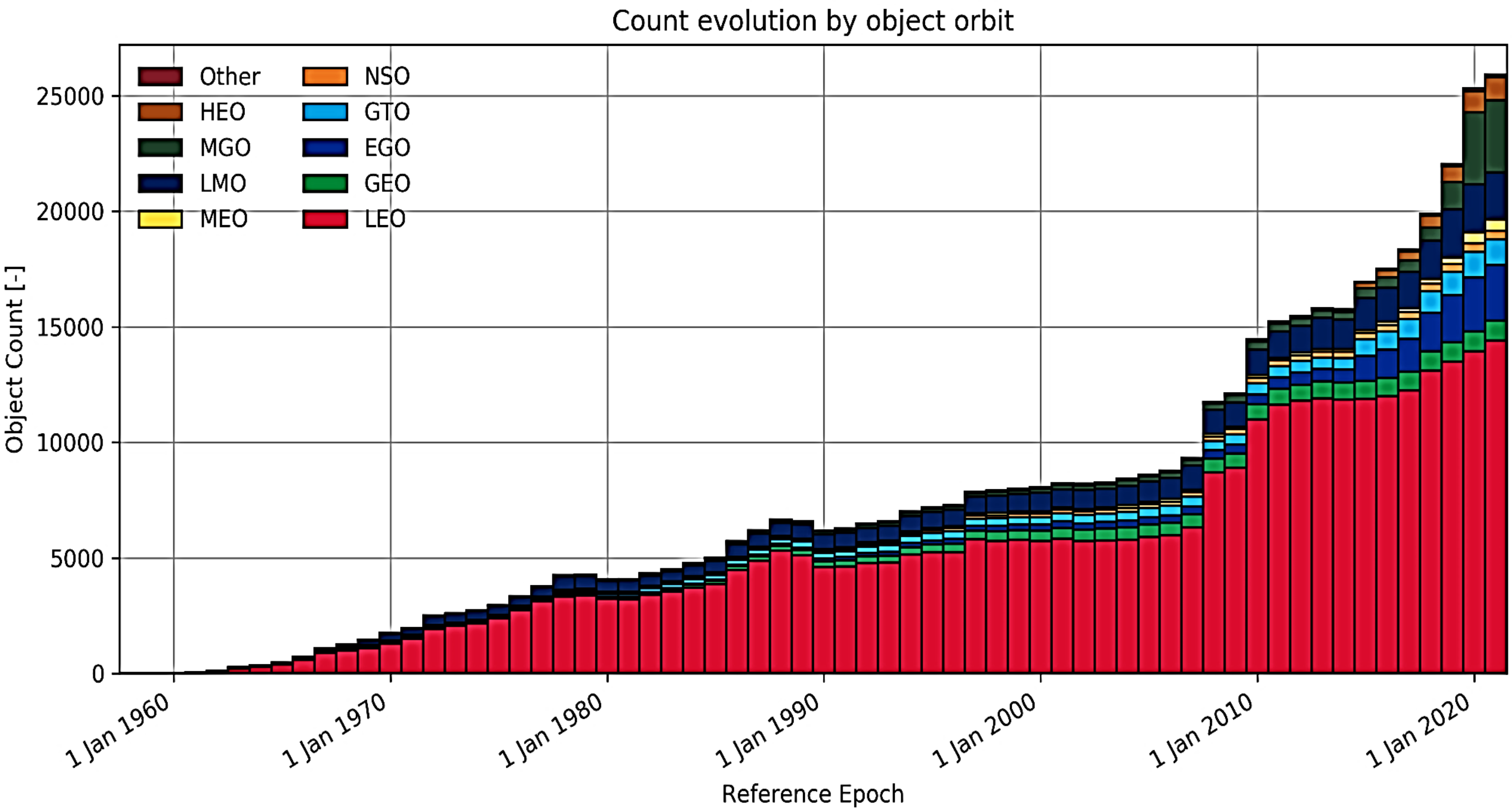


Constellation of GPS system



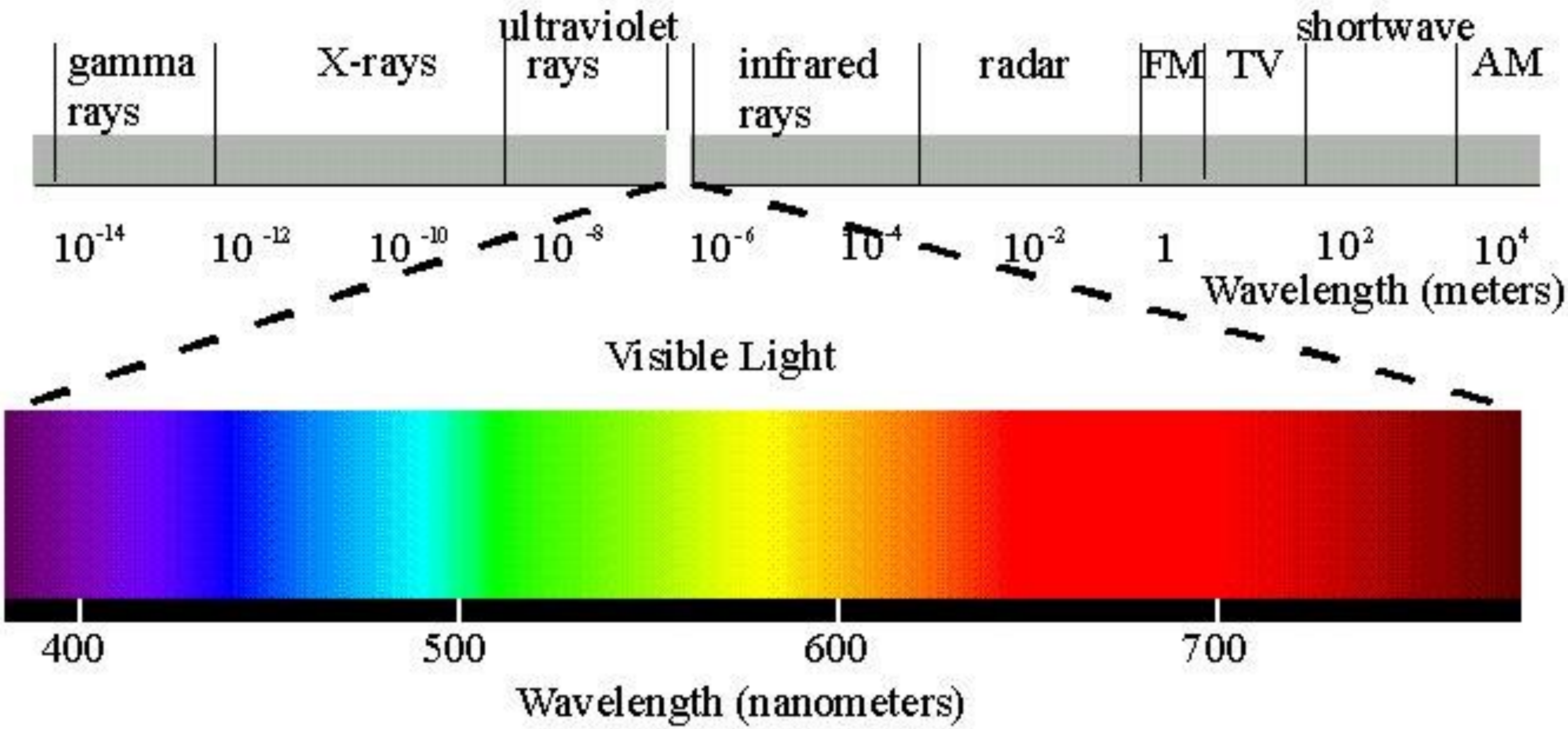

esa

Count Objects in Orbit



https://sdup.esoc.esa.int/discosweb/statistics/

Electromagnetic Spectrum



Ground based optical observations:

- **active systems (send – receive)**

  - Radar observation.
  - Laser observation.

Suitable for LEO Orbits

- **passive systems (receive)**

  - Photographic observation (electro-optics).

    1- Telescope

    2- CCD camera

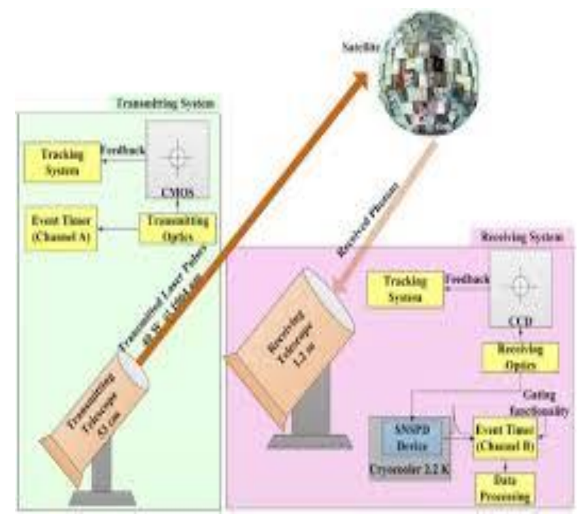
- Photographic observation generates respective (angle) information. Radar and laser observation generates information such as the distance (range), distance change (range rate), and angle with respect to the observer.

ACTIVE SYSTEMS

- Laser systems

– very small area on the sky.

- – Very sharp pulse
- Radar systems
- – Low resolving power.
- – Very high pulse power.

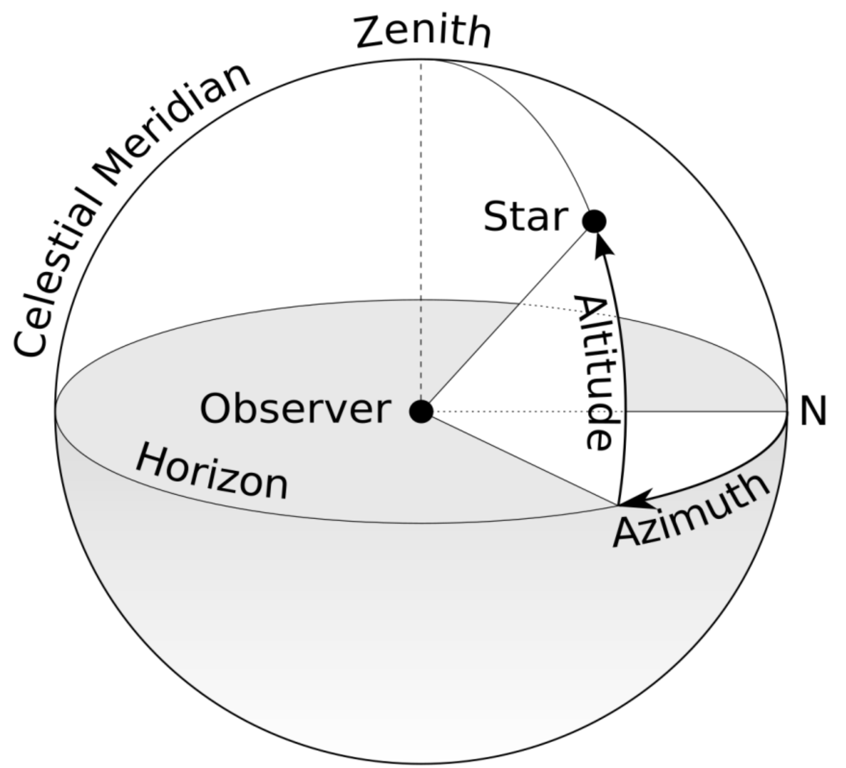


The horizontal coordinate (Alt-Az):

The **horizontal** coordinate system is based around an observers (or telescopes) 360° field of view, and the position of a target is given with respect to the observers local horizon. The system is fixed to the Earth and not the stars, with coordinates determined as follows:

•The **altitude** is the **angle** between the object and the closest point on the observer's local horizon (green curve in image). It can take any value between 0° and 90°.

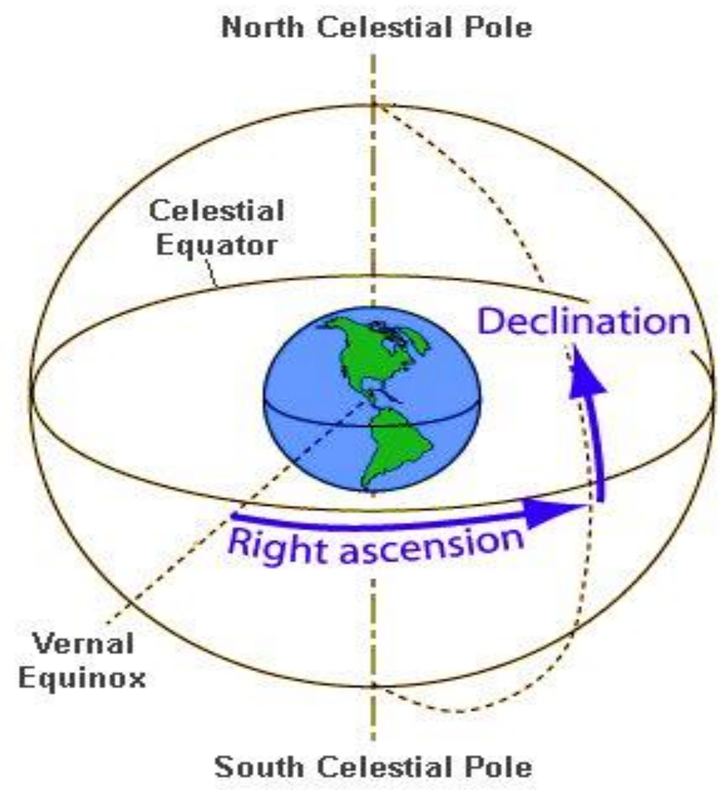
•The **azimuth** (Az) is the angle of the object around the horizon, running from the north point towards the east (red curve in image). It can take any value between 0° and 360°.

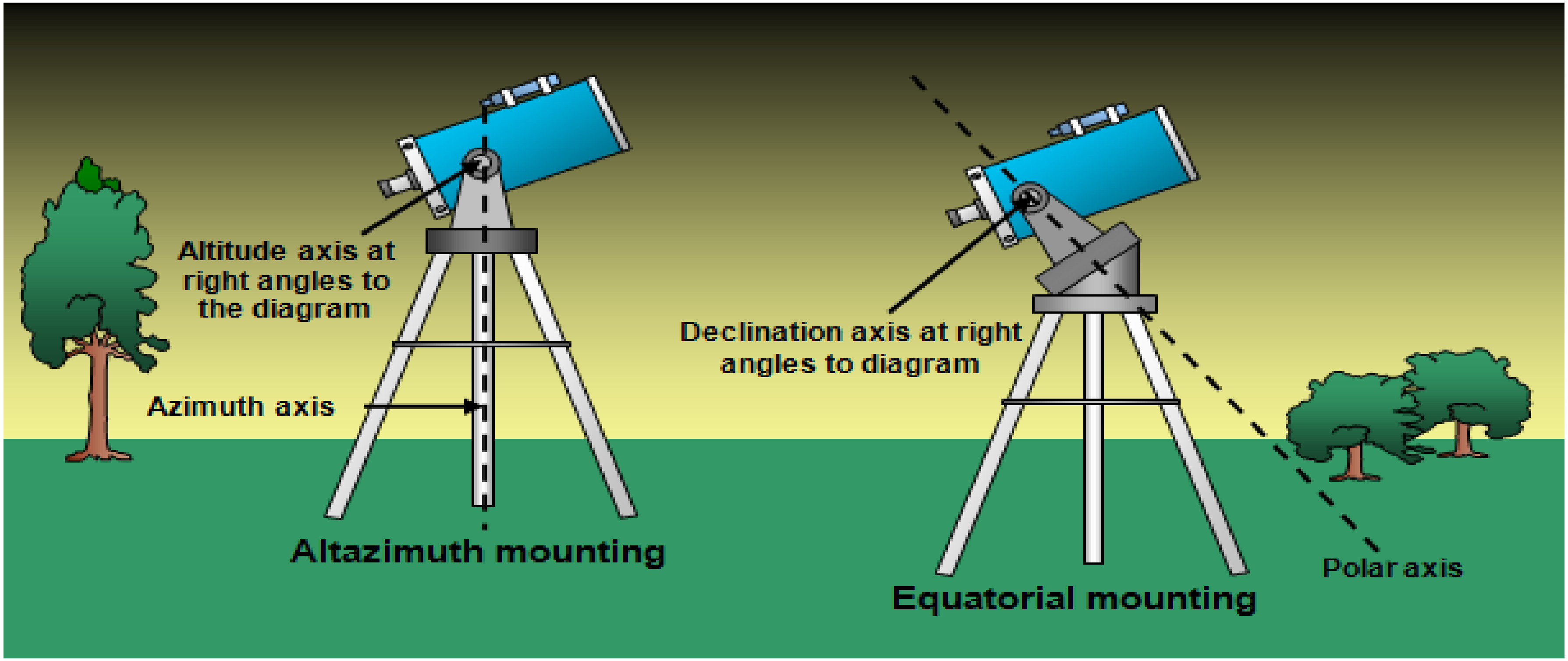


1- Equatorial Coordinate:

The **equatorial** coordinate system allows observers (or telescopes) to locate celestial objects using coordinates that are fixed in relation to the stars. The equatorial coordinates are then determined as follows:

- The **Declination** (Dec) measures the **angle** of an object above or below the celestial equator. It can take any value between -90° and 90°.
- The **Right Ascension** (RA) measures the angle of the arc that runs from the vernal equinox, along the celestial equator, to the closest point to the object. Unlike other systems, the RA is measured in hours instead of degrees, and can take any value between 0 and 24 hours. Note that there are (360/24) = 15° in one hour of right ascension.




Altitude axis at right angles to the diagram
Azimuth axis
Altazimuth mounting
Declination axis at right angles to diagram
Polar axis
Equatorial mounting


Altitude adjustment
Azimuth adjustment


Polar Axis
R A
a
a = Latitude
Declination Axis

Why photo-graphic?

	Electro-optics	Radar	Laser
Detection of satellites	Yes	Yes	No
Following the track of satellites	Yes	Yes	Yes
Photometric observations of satellites	Yes	No	No
Physical parameters of satellites	Yes	No	No
Type detection of satellites	Yes	No	No

Satellite visibility

In order to observe a satellite in visible light, three conditions must be fulfilled:

1. The satellite must be above the horizon.
2. The satellite must be illuminated by the Sun, i.e., it must not be in the Earth shadow.
3. The station must be in the Earth shadow (Sun below -12 elevation).

• LEO (Low Earth Orbit) satellites must with highest relative speed in the point of highest elevation. Usually they are also at brightest there. High speed leads to a long trail in the image, even the satellite is brighter. When the satellite becomes slower it usually becomes fainter also.

• Due to the condition of being illuminated by the Sun a LEO satellite is best visible in the evening and/or in the morning hours. The time interval depends on the satellite's altitude and on the geographical latitude of the observation site. For the Egyptian sites, the time interval in evening and morning is about 60 to 120 minutes (seasonal differences).

• The observation of MEO (Medium Earth Orbit, e.g., GPS satellite orbits) and GEO (Geostationary Earth Orbit) satellites are also possible to observe. Ideally, they are even illuminated most of the time.

How we can choose system ?

- GEO survey. telescopes having FOV from 3.5 – 8 degrees
- Local (deep) GEO survey. telescopes having FOV 2–2.2 degree
- Tracking of bright (brighter than apparent magnitude of 15.5) GEO and HEO objects. telescopes of 25 cm aperture.
- Tracking of the faint (fainter than apparent magnitude of 15.5) space debris at GEO and GTO with 40–80 cm aperture telescopes.
- Tracking observations of LEO objects with 12.5–25 cm aperture telescopes and survey of HEO objects with 18-cm telescope can be adjusted.

Field of view calculation

$$FOV[°] = 2 * arctan\left(\frac{p * I}{2 * F}\right) * \frac{180}{\pi} = 2 * arctan\left(\frac{S}{2 * F}\right) * \frac{180}{\pi}$$

$$FOV_{pixel}['']= 2 * arctan\left(\frac{p * I}{2 * F}\right) * \frac{180}{\pi} * \frac{3600}{I} \approx \frac{p}{F} * \frac{180}{\pi} * 3600$$

with: FOV_{pixel} = FOV of each pixel, given in arc-seconds

FOV = field of view in degree

p = pixel size, mm per pixel

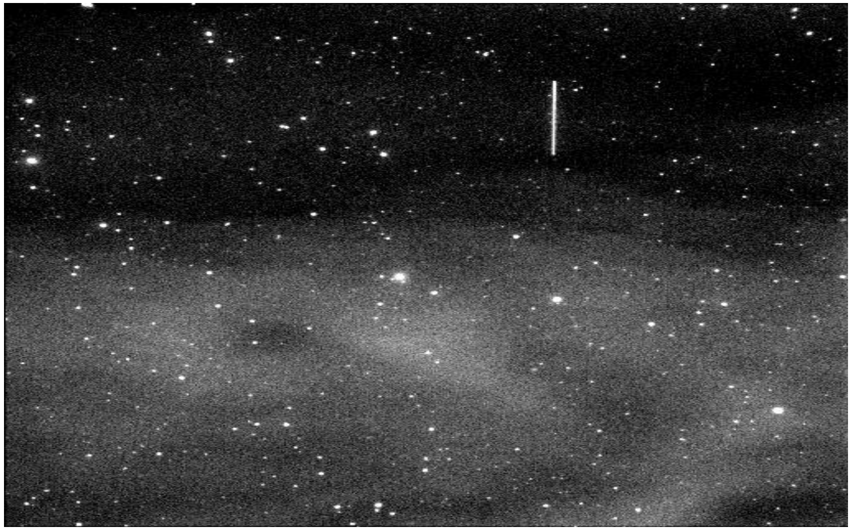
I = image size in pixels

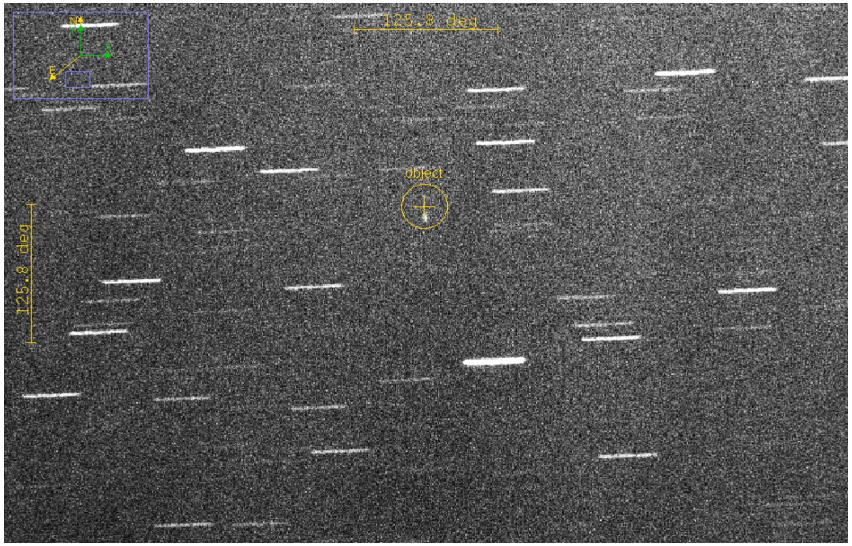
F = focal length in mm

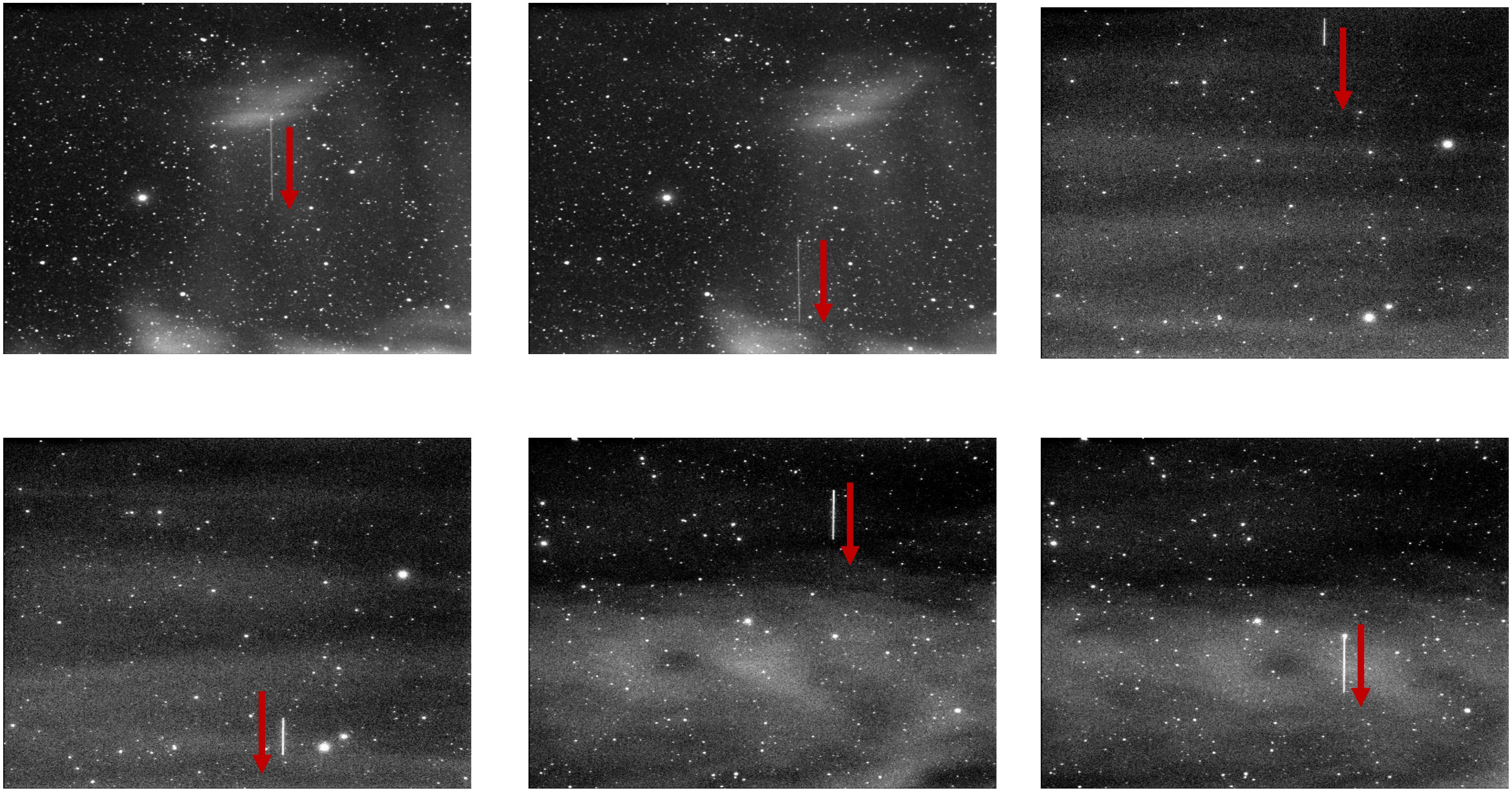
S = used sensor length in mm

Known objects tracking techniques

- Leap frog tracking: the stars appear as points while the tracked object produces an arc, whose length is determined by the angular velocity of the object and the exposure time
- Continuous Tracking: Images taken in this mode show the object as small point and the stars as arcs



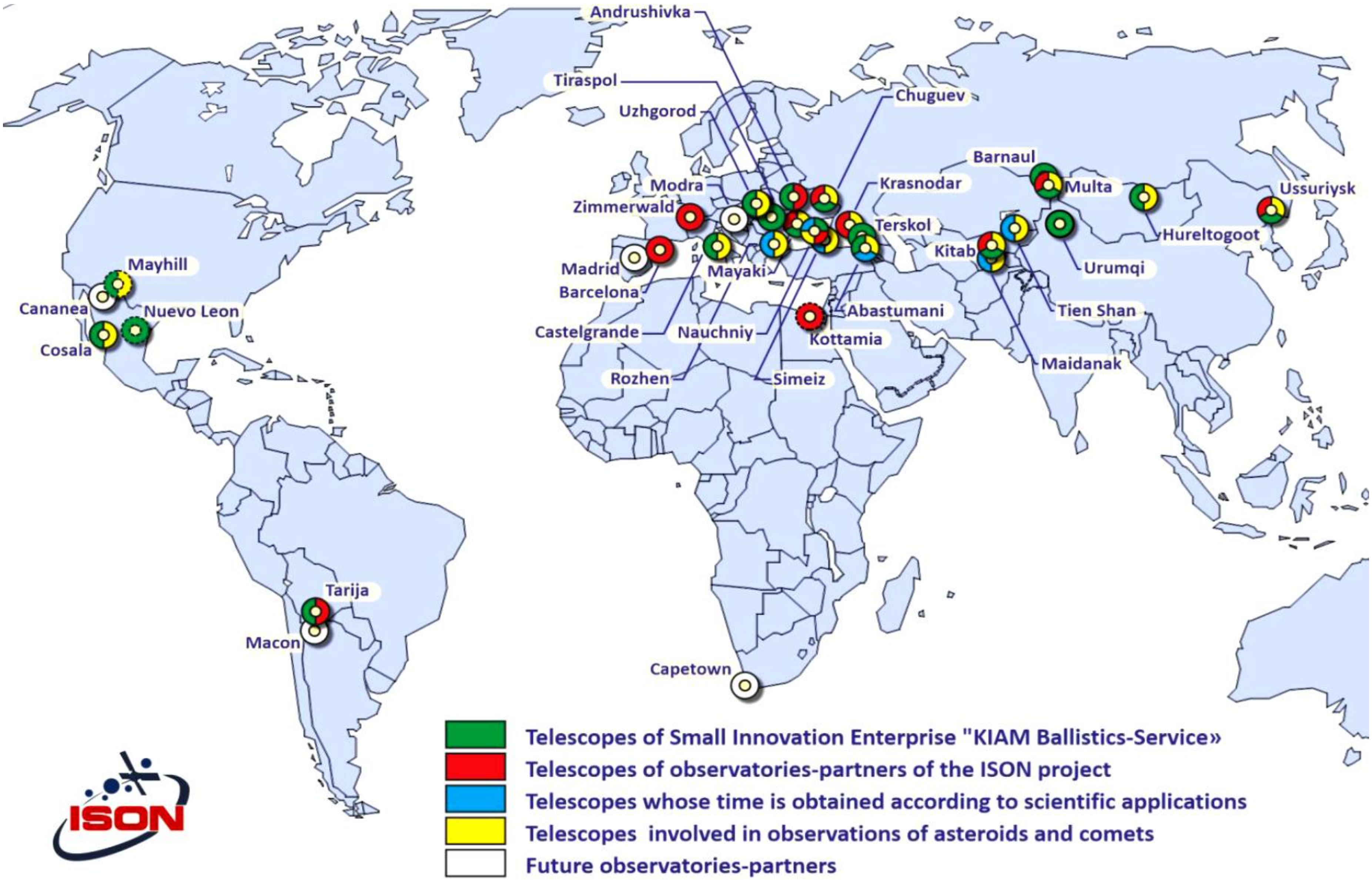




Unknown objects observations

1. Detection: Activities to detect incoming satellites and space debris, projectiles, space objects within the observed angles of the monitoring facilities.
2. Tracking: Activities to track the object within the initial orbit of ‘detection.
3. Calculation: Activities to determine orbits
4. Identification: Activities to identify the mission and nationality of the detected object with the precise orbit elements through ‘detection’ and ‘tracking’.
5. Cataloging: Activities to manage the database of collected data such as name, identification number, orbit elements, mission, etc.
6. Assessments: Activities to calculate the close approaches between two objects satellites and /or debris to analyze the conjunction and collision probability with dangers debris

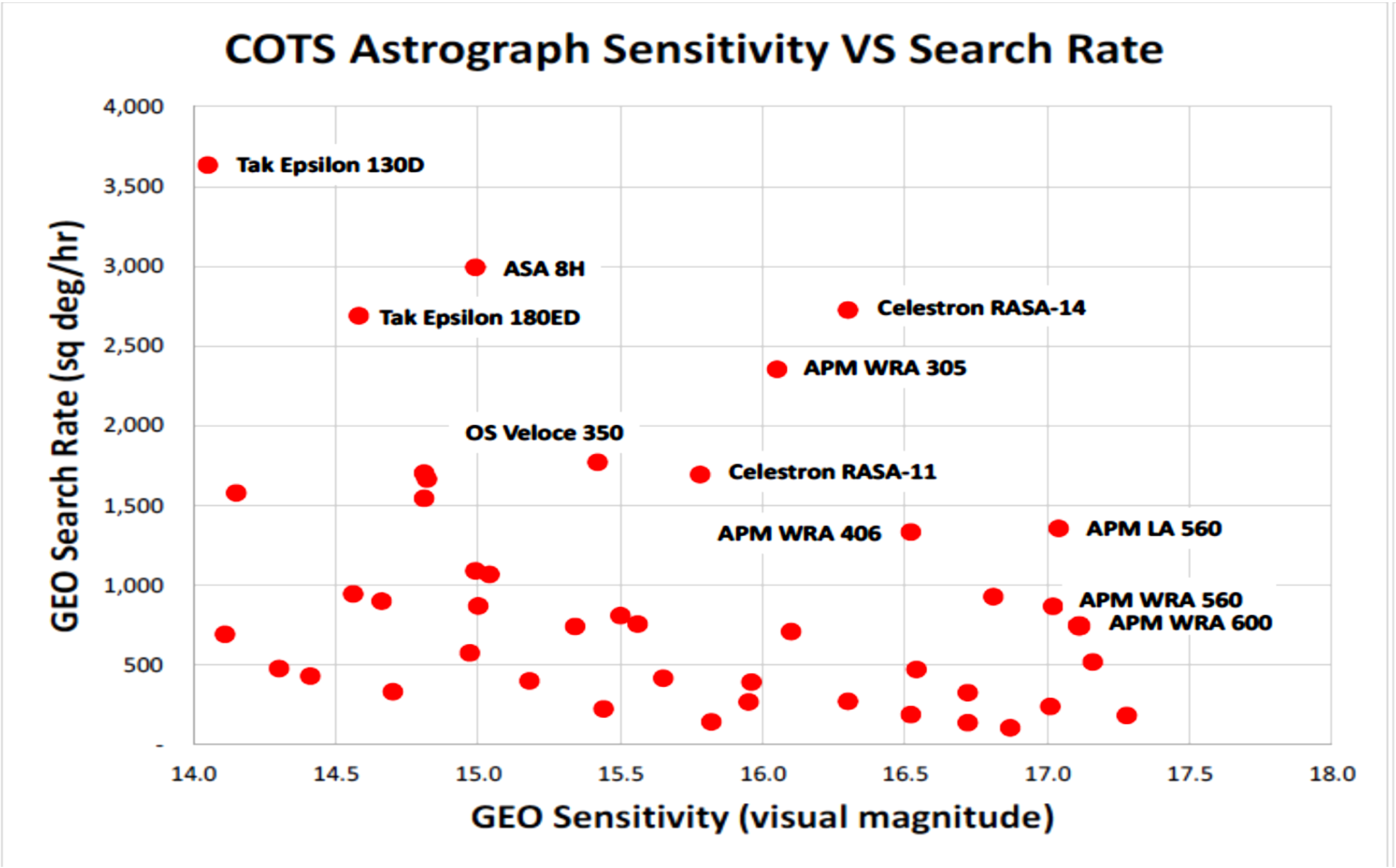
International Scientific Optical Network (ISON)



system structure

Hardware :
- Mount
- Tube
- CCD Camera
- GPS unit

Software :
- Mount control
- Camera control
- Image analysis
- orbit determination

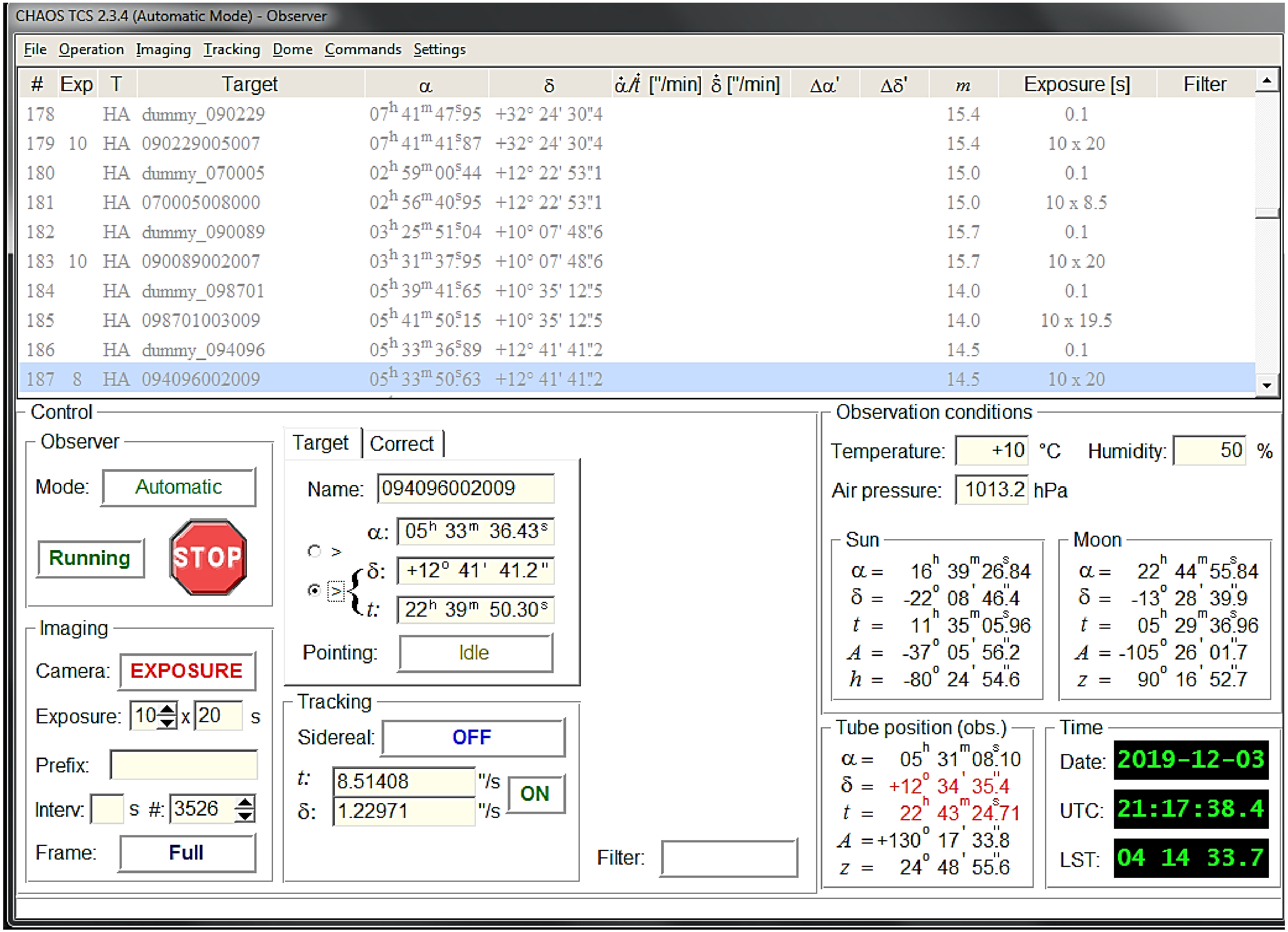


*Ackermann, M., Zimmer, P., McGraw, J., & Kopit, E. (2015). COTS Options for Low-Cost SSA. In Proceedings of the Advanced Maui Optical and Space Surveillance Technologies Conference. Maui, Hawaii.

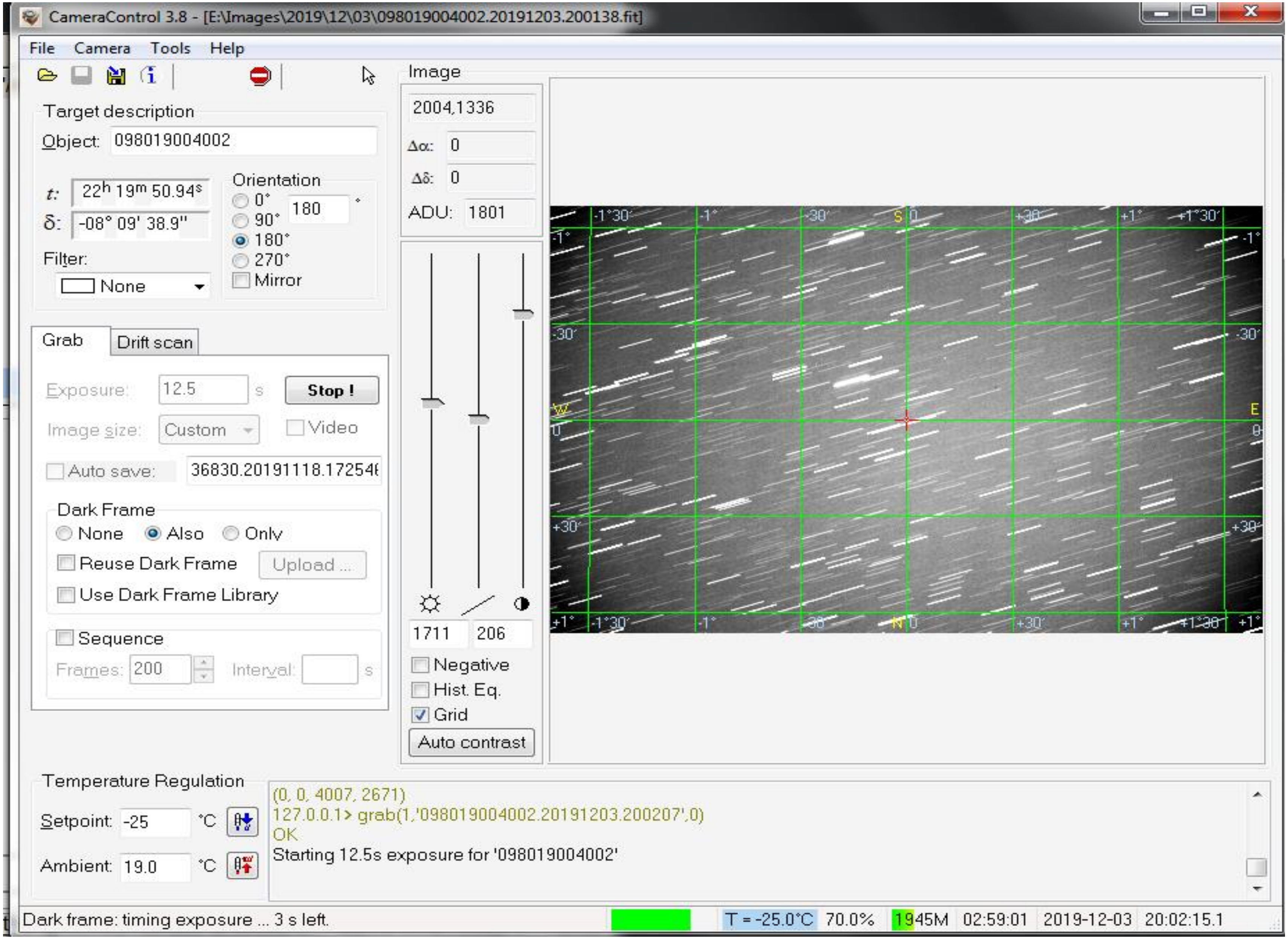
Optical Satellite Tracking Station (OSTS)-NRIAG

Items	Characteristics
Telescope Series	Celestron 11" Rowe-Ackermann Schmidt Astrograph with CGE Pro Mount
Telescope Aperture	11"
Telescope Focal Ratio	f/2.2
Telescope Focal Length	620 (mm)
Focuser Style	Internal Moving Primary
Focuser Speed	Dual Speed
Telescope Mount Type	Equatorial
CCD device	FLI MicroLine ML11002 Monochrome Camera Grade 2
Pixels	4072 x 2720 pixels
Pixel Size (µm)	9.0 x 9.0
Cooling	Peltier 55°C below ambient Temperature
Interface	USB 2.0
System (FOV)	3.4°×2.3°

Telescope control software

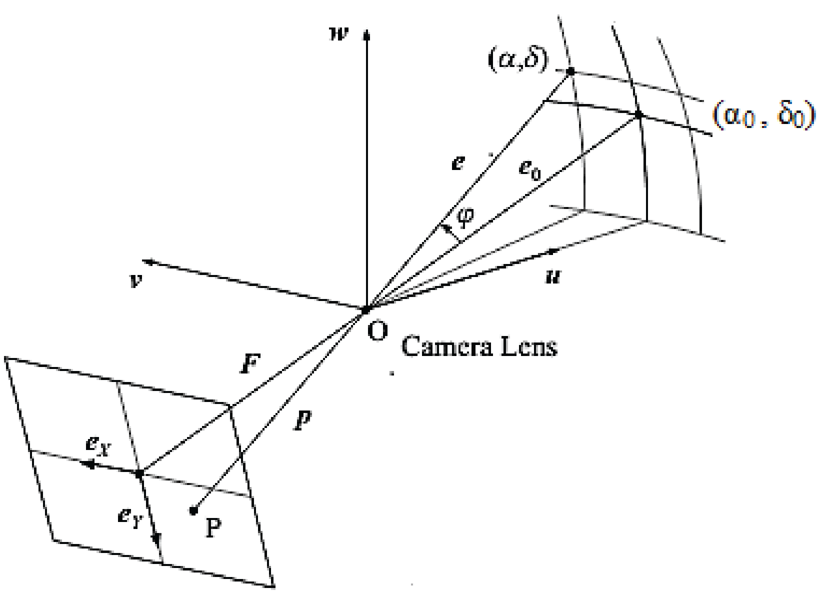


Camera control software



ASTROMETRY PROCESSING

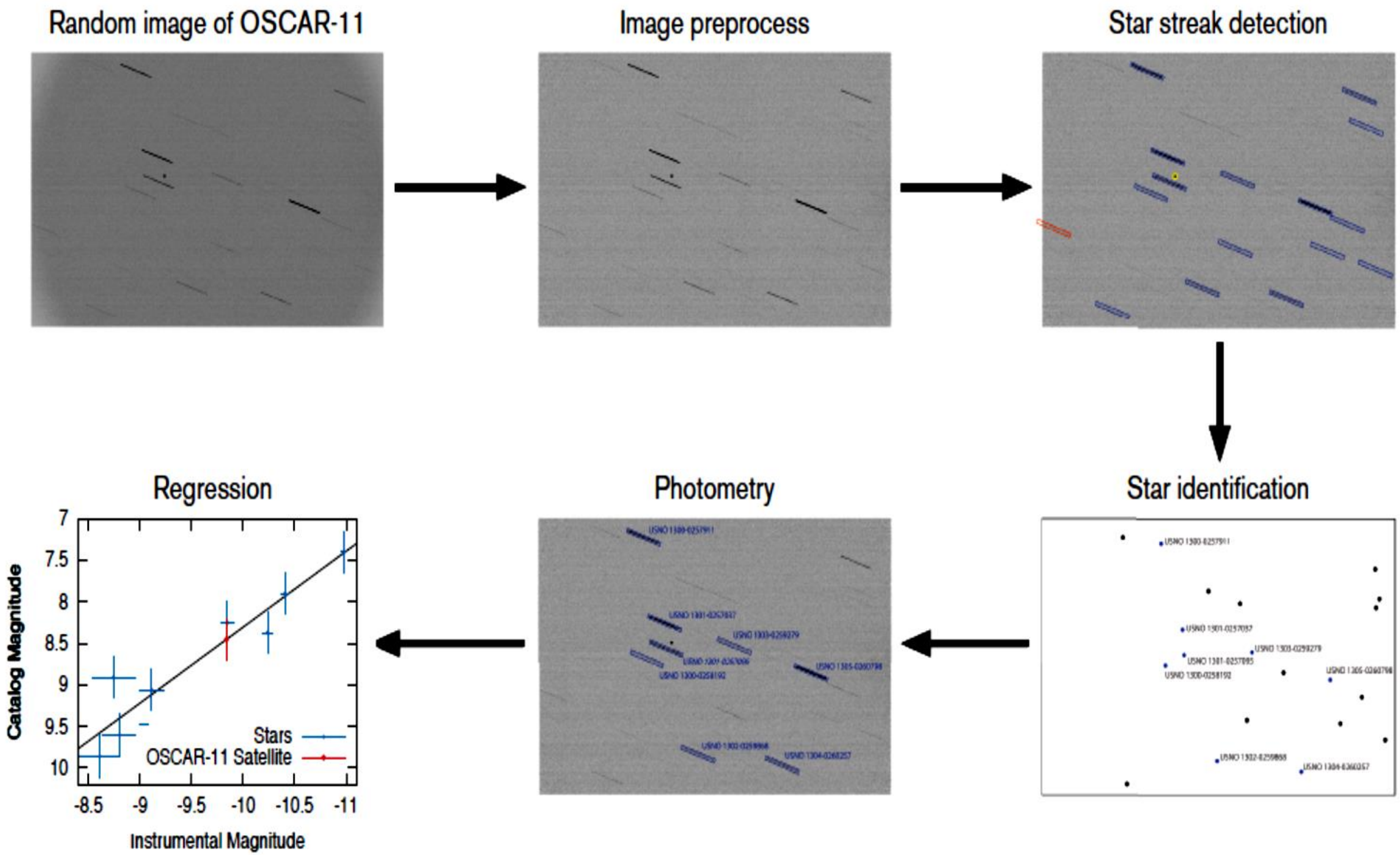
Astrometry is the science of measuring the positions of celestial objects. In CCD images, the first step is to determine the centroids of a set of stars (called reference stars) with known spherical coordinates, and also the centroids of the images of the objects whose position you wish to measure (that is, the target stars)

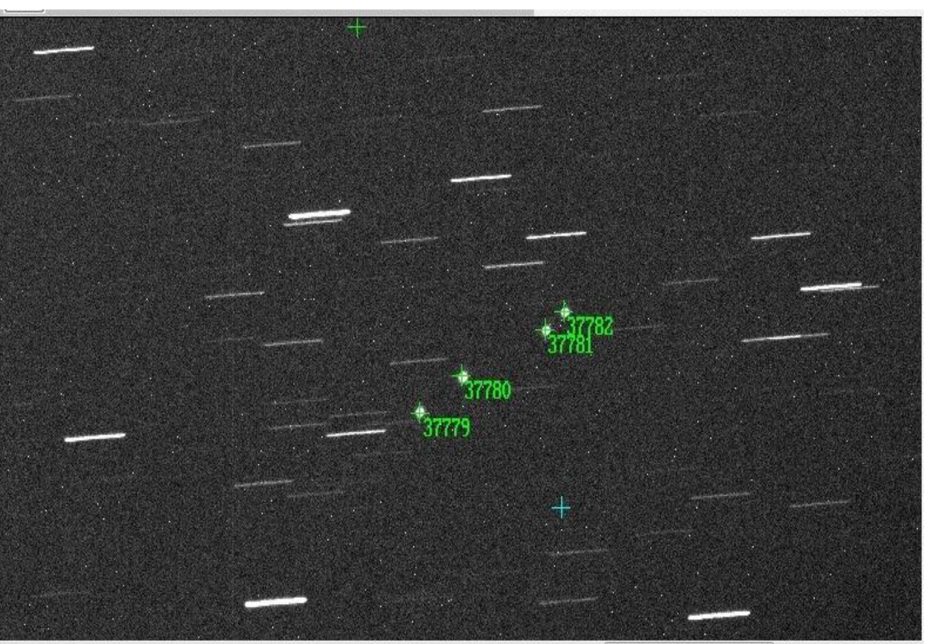


$$\alpha = \alpha_0 + \arctan\frac{-X}{\cos(\delta_0) - XY\sin(\delta_0)}$$

$$\delta = \arcsin\frac{\sin(\delta_0) - Y\cos(\delta_0)}{\sqrt{1 + X^2 + Y^2}}$$

Sample image processing using background field stars




Targets
37779
37779.20190314.215908.fit
37779.20190314.215932.fit
37779.20190314.215959.fit
37779.20190314.220023.fit
37779.20190314.220047.fit
37779.20190314.220111.fit
37780
37779.20190314.220047.fit
37781
37779.20190314.220047.fit
37782
37779.20190314.220047.fit
Frames
Name
Frames
26470.20190314.225359.fit 0
26470.20190314.225434.fit 0
26470.20190314.225508.fit 0
26470.20190314.225542.fit 0
26470.20190314.225616.fit 0
26470.20190314.225650.fit 0
26470.20190314.225723.fit 0
26470.20190314.225757.fit 0
26470.20190314.225831.fit 0
26470.20190314.225904.fit 0
Image
1:1
37782
37782
37781
37780
37779
Console
Vertex Shader: No errors.
Fragment Shader: No errors.
Vertex Shader: No errors.
Fragment Shader: No errors.
Visualization
Linear grayscale
Box
Stats
3219.4,2248.0
Obj:
ADU: 1917
FWHM:
SNR:
m:

37782
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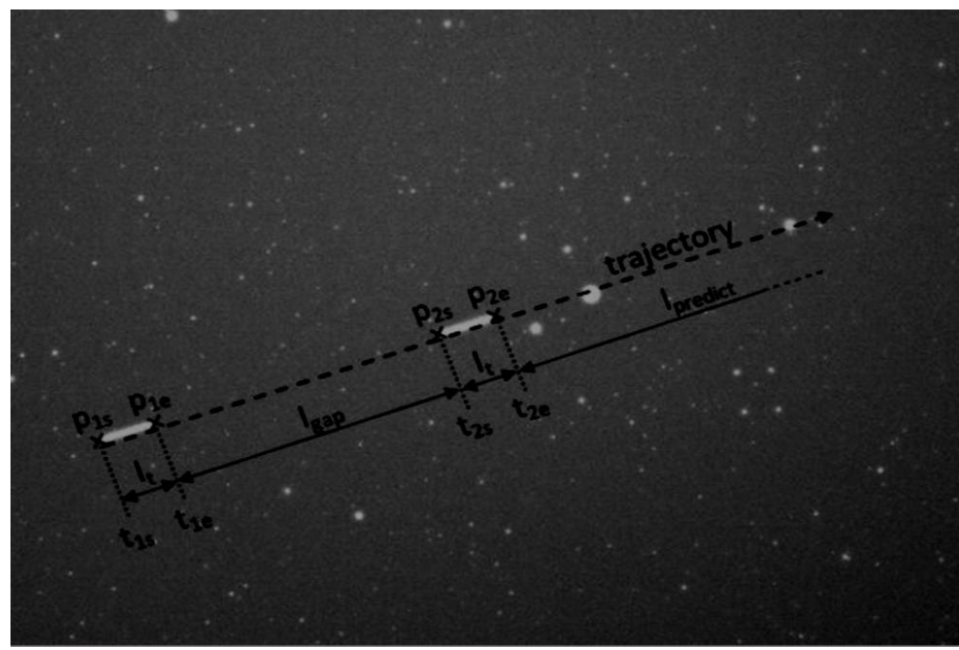

trajectory
$l_{predict}$
p_{2s}
p_{2e}
l_t
t_{2s}
t_{2e}
l_{gap}
p_{1s}
p_{1e}
l_t
t_{1s}
t_{1e}

SW of Orbit determination

Input data

- Measurements from optical system
- Current and forecasted geophysical data

Modules

- Initial orbit determination
- Analytical module for quick estimation of propagation
- Precise orbit determination

Subroutine required

- Coordinates transformation
- Earth gravitational potential
- Third body effect
- Atmospheric drag
- solar radiation pressure
- Least square technique and extended Kalman filter

output data

- orbital elements
- Observation plan for optical system

Orbit determination is a method of determining state of a satellite as a function of time using angles-only observations. The orbit determination problem consists of two basic parts: obtain an initial orbit and refine the orbit derived from the initial orbit determination (IOD) method. angles-only methods are used for initial orbit determination and least squares technique is used to refine orbit.

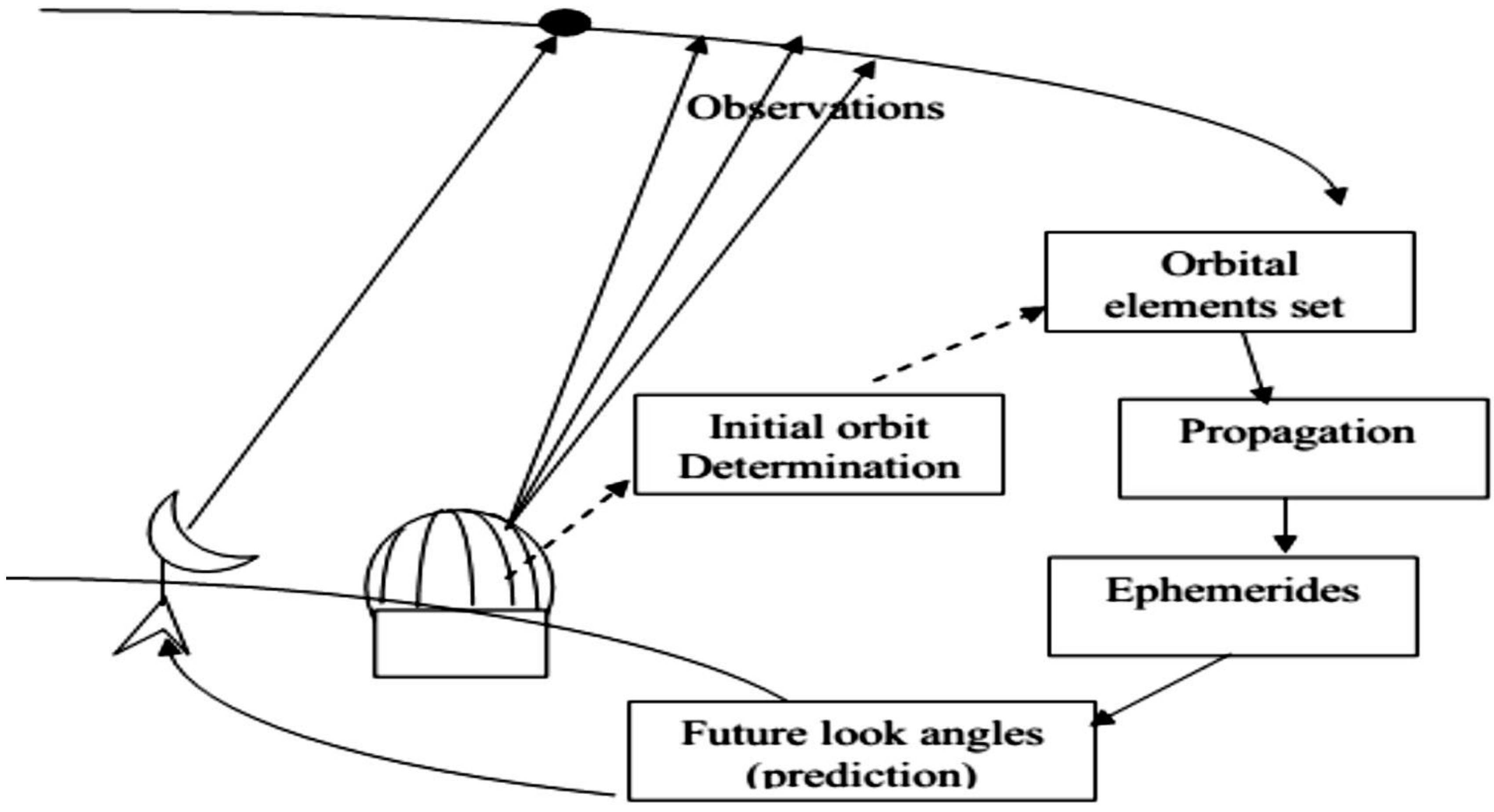
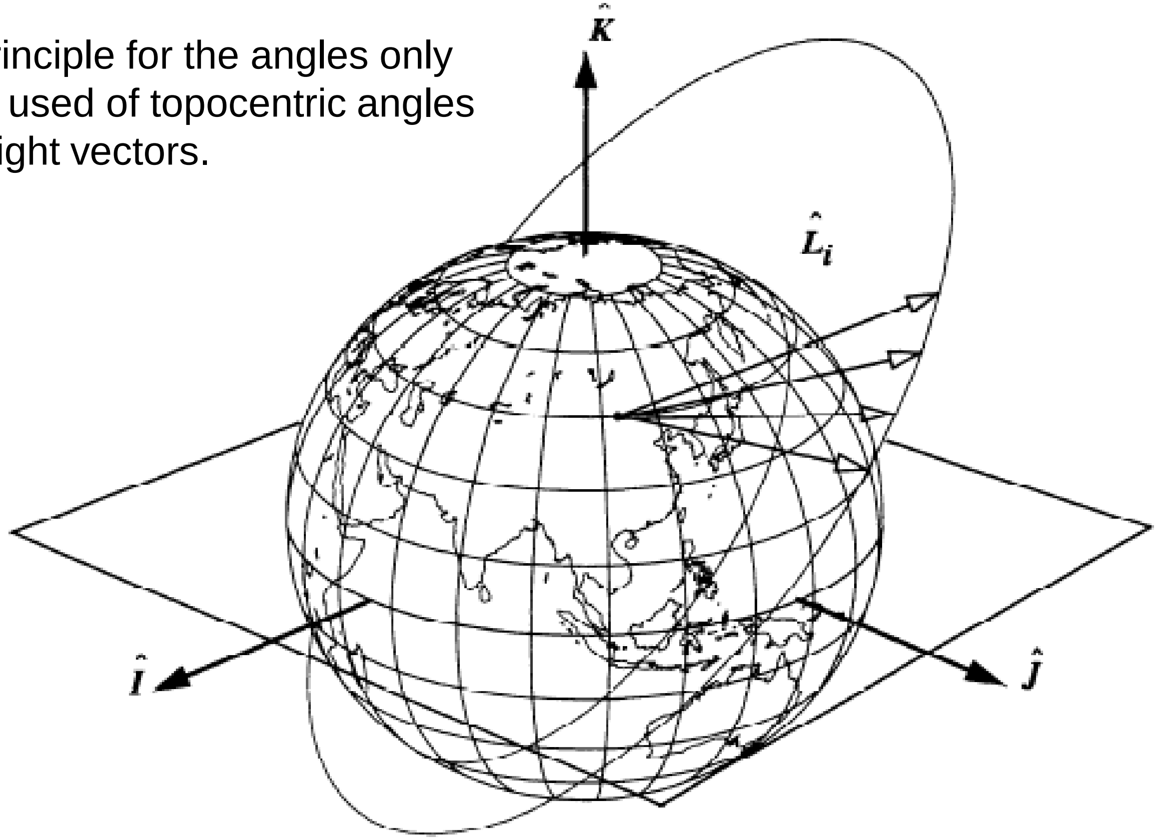


Figure shows principle for the angles only technique is the used of topocentric angles to form line-of-sight vectors.



Geometry of angels only observation

ANGELS ONLY ORBIT DETERMINATION

$$\vec{r}_{site} = \begin{pmatrix} C\ cos(\varphi_{gc})cos(\lambda_{gc}) \\ C\ cos(\varphi_{gc})sinA(\lambda_{gc}) \\ S\ sin(\varphi_{gc}) \end{pmatrix}$$

$$\mathrm{C} = \frac{\mathrm{R_E}}{\sqrt{1 - \mathrm{e_E}^2 \sin^2(\varphi_{\mathrm{gc}})}} + \mathrm{H} \quad , \qquad \mathrm{S} = \mathrm{C}\,(1 - \mathrm{e_E}^2) + \mathrm{H}$$

$$\hat{\mathrm{L}} = \begin{pmatrix} \cos(\delta_t)\cos(\alpha_t) \\ \cos(\delta_t)\sin(\alpha_t) \\ \sin(\delta_t) \end{pmatrix}$$

$$\vec{\mathrm{r}} = \rho\, \hat{\mathrm{q}} + \vec{\mathrm{r}}_{\mathrm{site}}$$

ANGELS ONLY ORBIT DETERMINATION METHODS

1. Gauss-Gibbs method.
2. Gauss H.Gibbs method.
3. Double R iteration.
4. Gooding method.

GAUSS METHOD

The Gauss method begins with the first assumption that all three position vectors lie in a plane. There for, the following equation is valid for some unknown particular values of c_1, c_2, and c_3.

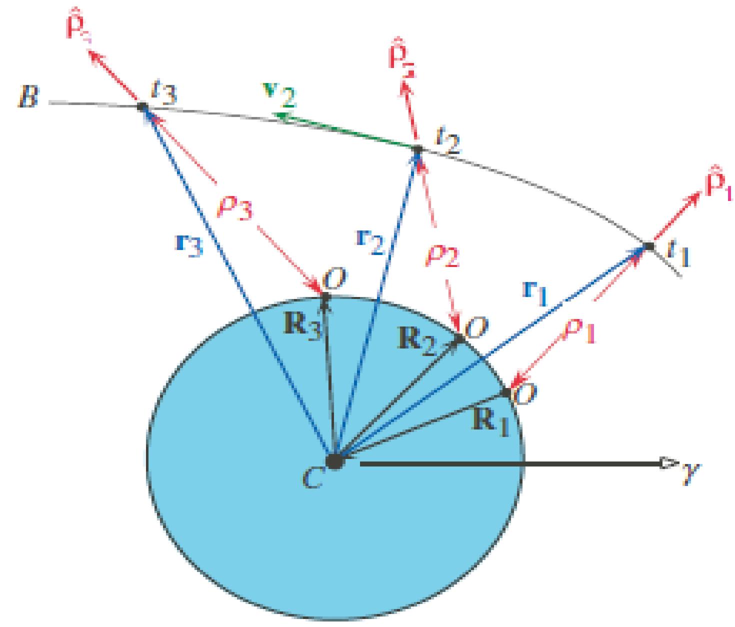
$$c_1\overrightarrow{r_1} + c_2\overrightarrow{r_2} + c_3\overrightarrow{r_3} = 0$$

$$\overrightarrow{r_1} \times \overrightarrow{r_3}(c_1) = \overrightarrow{r_2} \times \overrightarrow{r_3}(-c_2)$$

$$\overrightarrow{r_1} \times \overrightarrow{r_3}(c_3) = \overrightarrow{r_1} \times \overrightarrow{r_2}(-c_2)$$

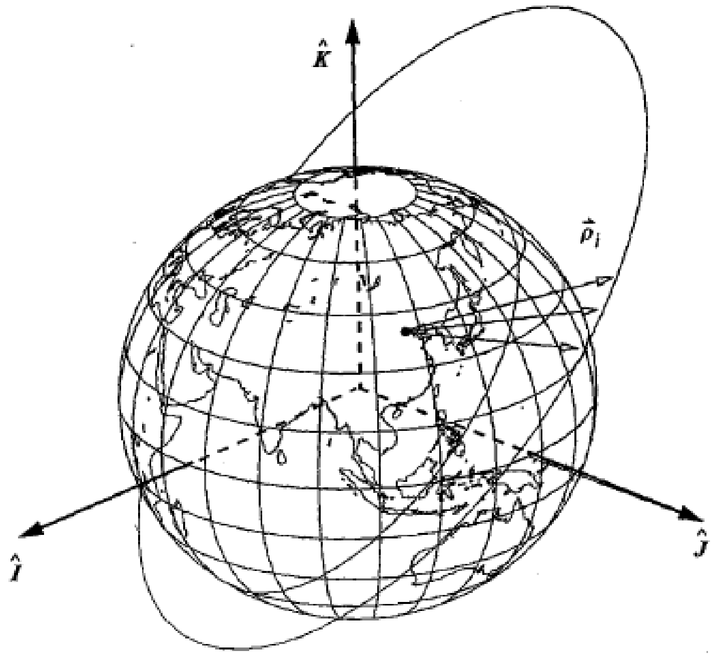
$$\overrightarrow{r_1} \times \overrightarrow{r_3}(c_1) = \overrightarrow{r_2} \times \overrightarrow{r_3}$$
$$\overrightarrow{r_1} \times \overrightarrow{r_3}(c_3) = \overrightarrow{r_1} \times \overrightarrow{r_2}$$

$$\vec{r}_i = f_i\vec{r}_2 + g_i\vec{V}_2 \qquad , i = 1,3$$



GIBBS METHOD

The Gibbs method uses three position vectors to determine the orbit. Solving Gibbs relies on knowing the Gauss formulation. The method works well for observations which have an angular separation greater than 1 degree.



$$\vec{D} = \vec{r_1} \times \vec{r_2} + \vec{r_2} \times \vec{r_3} + \vec{r_3} \times \vec{r_1}$$

$$\vec{N} = r_1(\overrightarrow{\vec{r_2} \times \vec{r_3}}) + r_2(\overrightarrow{\vec{r_3} \times \vec{r_1}}) + r_3(\overrightarrow{\vec{r_1} \times \vec{r_2}})$$

$$\vec{B} = (r_2 - r_3)\vec{r_1} + (r_3 - r_1)\vec{r_2} + (r_1 - r_2)\vec{r_3}$$

Then, we will obtain the middle velocity vector

$\overrightarrow{V_2} = \frac{L_g}{r_2}\,\vec{U} + L_g\,\vec{B}$ Where $L_g = \sqrt{\frac{\mu}{ND}}$ and $\vec{U} = \vec{D} \times \vec{r_2}$

HERRICK -GIBBS METHOD

$$t_{12} = t_2 - t_1, t_{23} = t_3 - t_2, t_{13} = t_3 - t_1$$

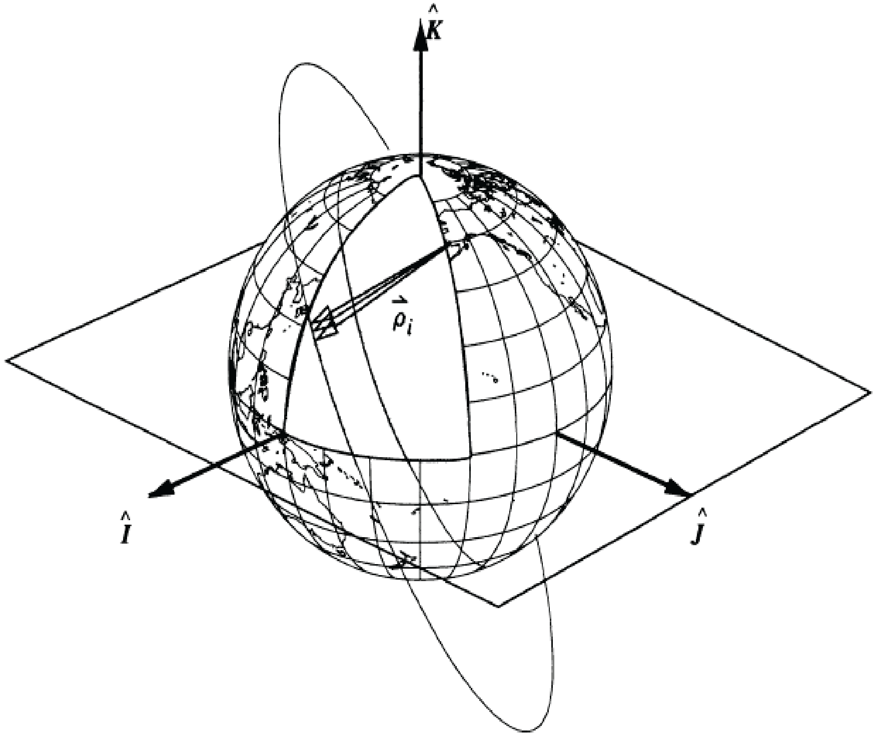
$$p_1 = \frac{t_{23}}{t_{12}\, t_{13}}, p_2 = \frac{t_{23} - t_{12}}{t_{12}\, t_{23}}, p_3 = \frac{t_{12}}{t_{23}\, t_{13}}$$

$$k_1 = \mu \frac{t_{23}}{12}, k_2 = \mu \frac{t_{23} - t_{12}}{12}, k_3 = \mu \frac{t_{12}}{12}$$

$$r_i = \sqrt{x_i^2}, \quad d_i = p_i + \frac{k_i}{r_i^3}, \quad i = 1,2,3$$

Finally, we will obtain the velocity vector

$$V_2 = -d_1 x_1 + d_2 x_2 + d_3 x_3$$



DOUBLE R-ITERATION

In Double r-iteration technique, there are four main steps to arrive at a solution.

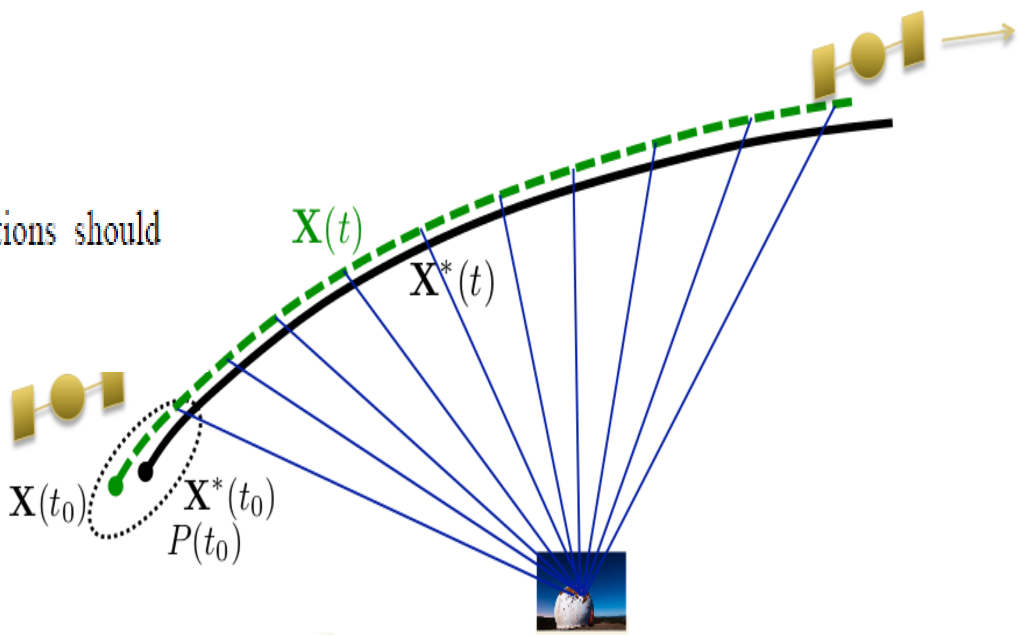
1) The first step bounds the guesses from the available information.
2) The second step, is the main idea of the technique Double r-iteration. The subsequent iterations use the second portion to determine intermediate guesses, so it is important to have a modular routine.
3) The third section begins the formal iterative process. It tries to align the times with the estimated values of the orbits.
4) Finally, a type of differential correction determines the answer.

GOODING METHOD

Given values are $\mathbf{R}_j$, t_j , and $\hat{\boldsymbol{\rho}}_j$, for $j = 1, 2, 3$
Assume a value for ρ_1 and ρ_3
while Not Maximum Iterations or Tolerance Reached *do*
Generate an estimated orbit by solving Lambert problem using $\mathbf{r}_1$, $\mathbf{r}_3$, and $t_3 - t_1$
Compute the error in the position measurement of the spacecraft at t_2
Iterate ρ_1 and ρ_3 using the Newton-Raphson procedure
end while

ORBIT DETERMINATION WITH DIFFERENTIAL CORRECTION

1- Pick an initial nominal state
2- Compute the values of the observed parameters Y_c at N times corresponding to the observations Y_o.
3- Compute the residuals or (O-C).
4- Calculate the partial derivatives.
5- Form the normal equations and solve it.
6- Update the elements
7- Lastly, apply the RMS test to determine if iterations should continue.



Thanks