



SAPIENZA
UNIVERSITÀ DI ROMA

MEASUREMENT ACCURACY FOR ORBIT DETERMINATION OF GEO CLOSE APPROACHING OBJECTS

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DIMA

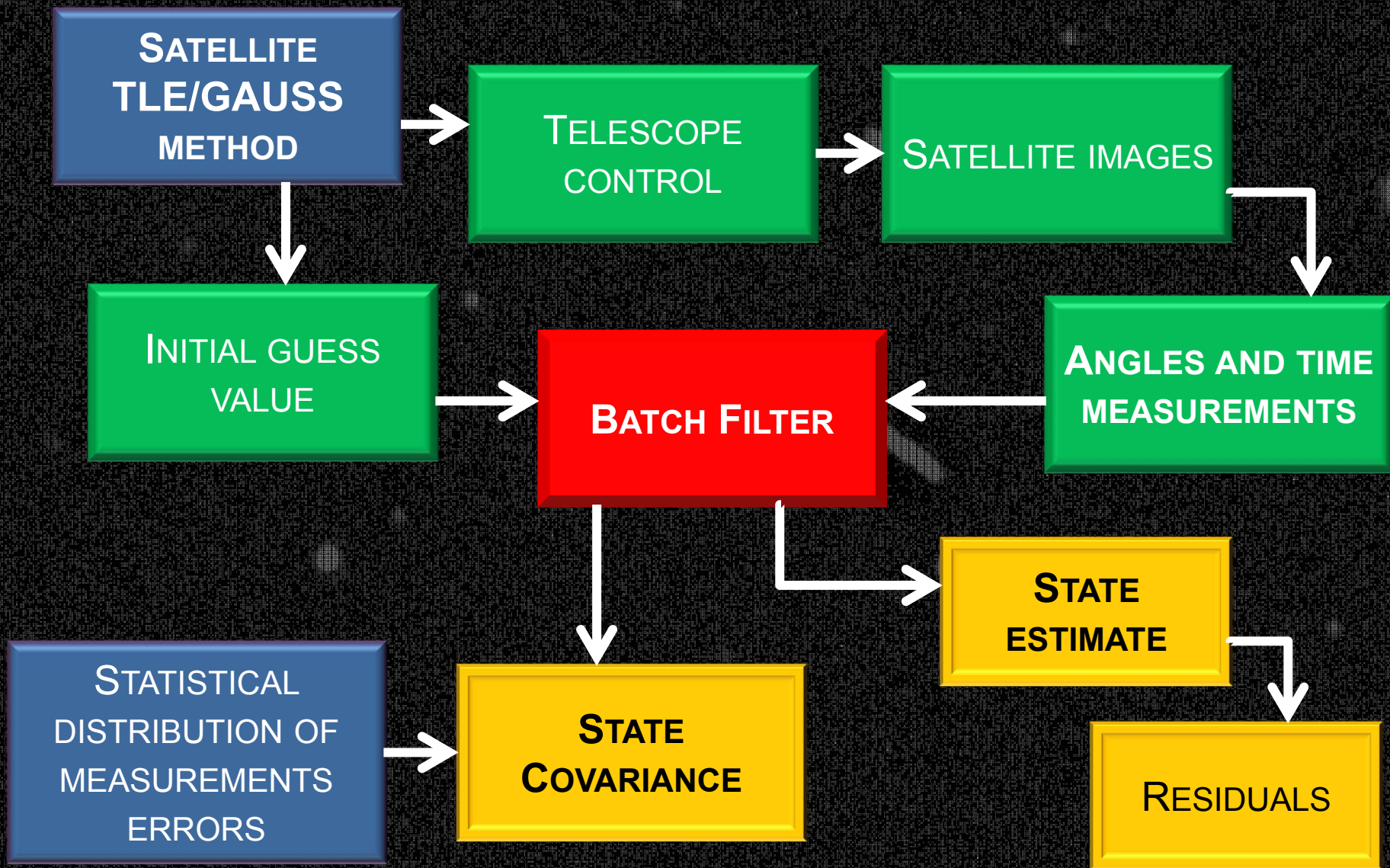
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ORBIT DETERMINATION FLOW



ALMASCOPE

- Telescope - 25 cm f/4 in newtonian configuration
- CCD Kaf1600E sensor , 1024x1536 pixels, each pixel is 9x9 micron (total chipsize 9.2x13.8 mm)
- Mount German equatorial

The field of view is of about 1 degree



ALMASCOPE - 2

- Telescope - 25 cm f/3 in modified cassegrain configuration
- CCD Kaf3200E sensor , 2184x1510 pixels, each pixel is 6.8x6.8 micron (total chipsize 14.85x10.26 mm)
- Mount German equatorial

The field of view is of about 1.4 degree

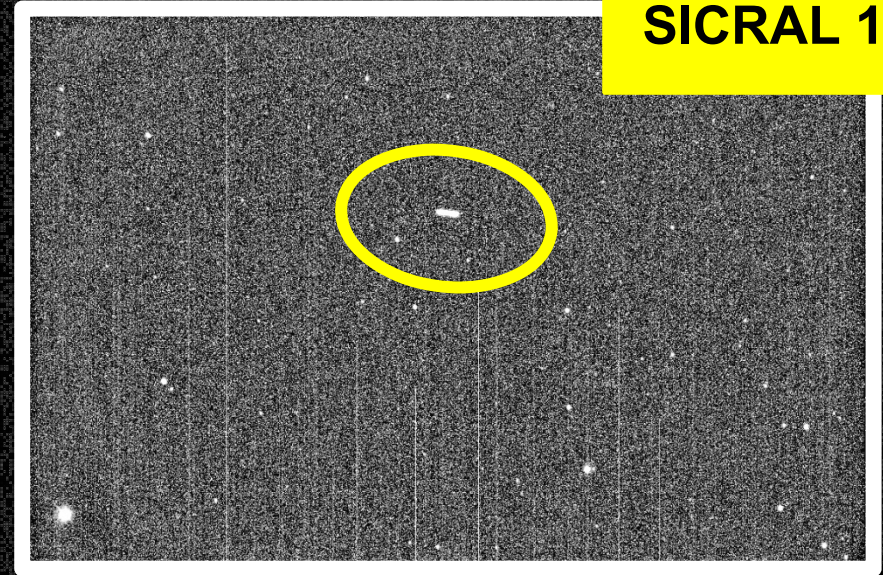


IMAGE ANALYSIS

Automatic image analysis

- Object detection
- Object identification

SICRAL 1



Image

**Star
catalogue**

Star field analysis

ESTIMATE ALGORITHM

STANDARD AMR OBJECTS

- Batch Filter, Non Linear least Square, Solution research with Levenberg-Marquardt method
- State parameters (X) \rightarrow Position and Velocity
- Minimization of functional (J) given by the residuals squared sum




$$\vec{X} = \begin{bmatrix} \tilde{r} \\ \tilde{v} \end{bmatrix}$$

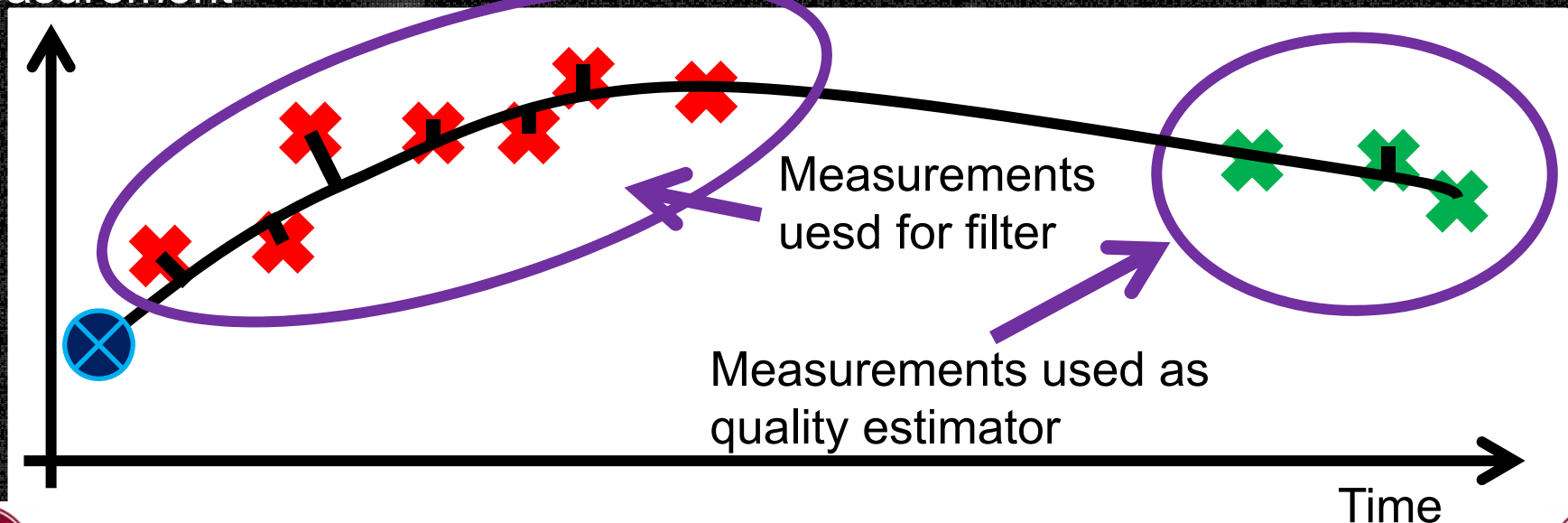
$$J = \sum_{i=1}^n \left([RA(X_i) - RA_{m_i}]^2 + [DEC(X_i) - DEC_{m_i}]^2 \right)$$

$$\begin{cases} RA(X_i) = \text{atan2}(y_i, x_i) \\ DEC(X_i) = \pi - \arccos\left(\frac{z_i}{\|\tilde{r}_i\|}\right) \end{cases}$$

RESIDUALS

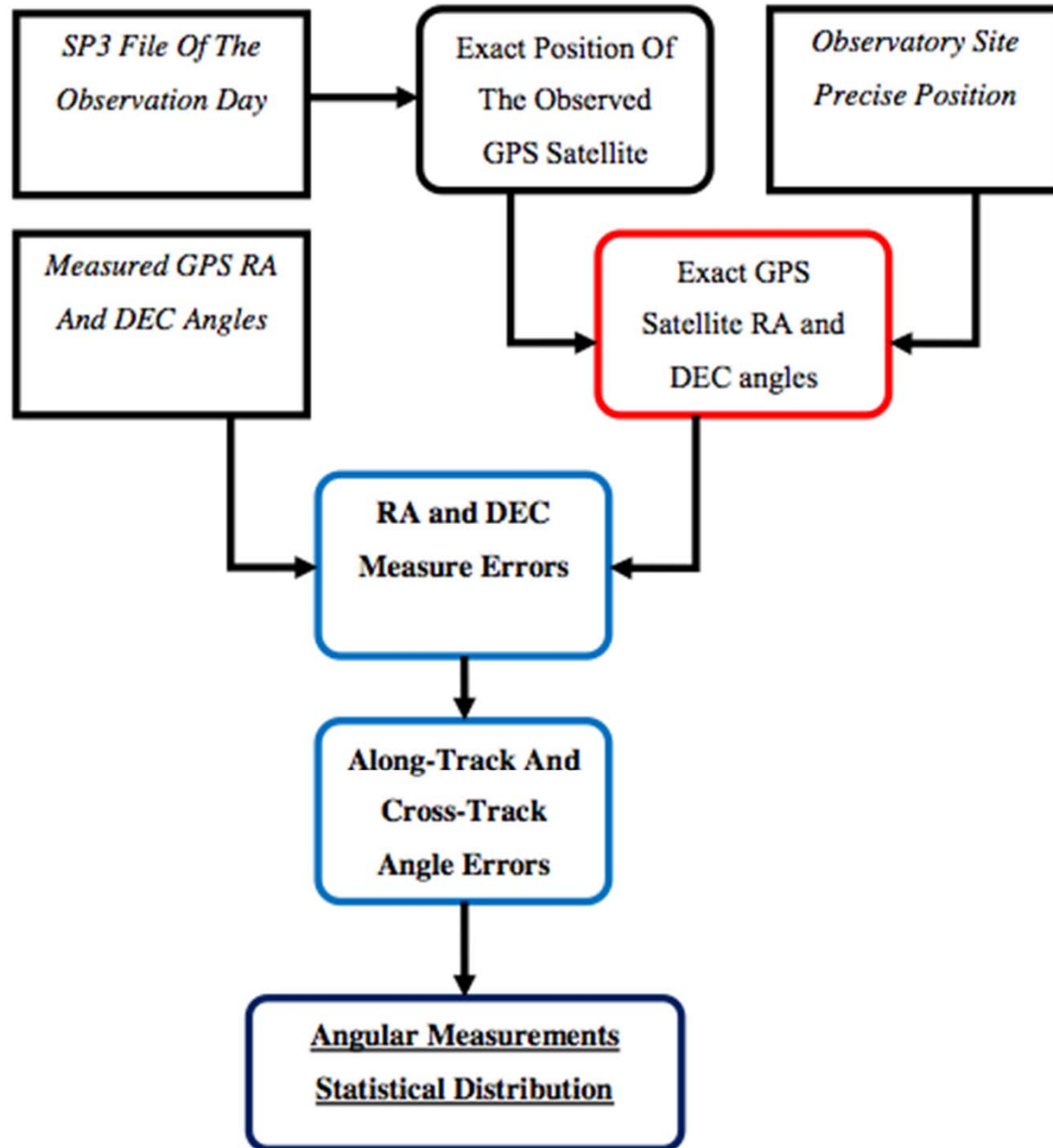
Estimate quality evaluation:

- Estimated Parameters at epoch 
- Residuals with respect to measurements used for estimate 
- Residuals with respect to measurements achieved 24/48 hours after the last measurement 



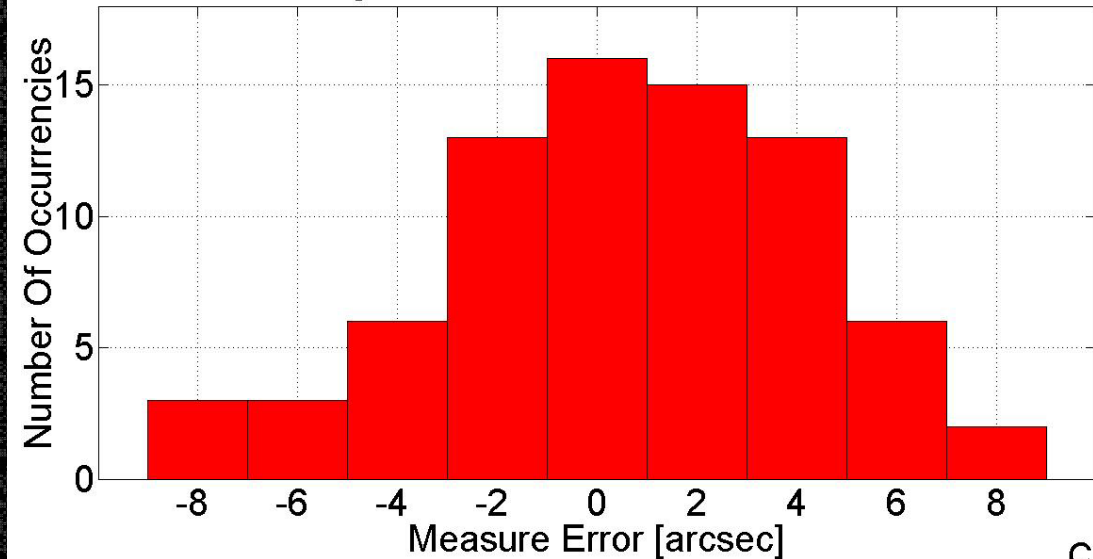
GPS CALIBRATION

GPS CALIBRATION FLOW



GPS MEASUREMENTS ACCURACY

Along-Track Measure Error Distribution

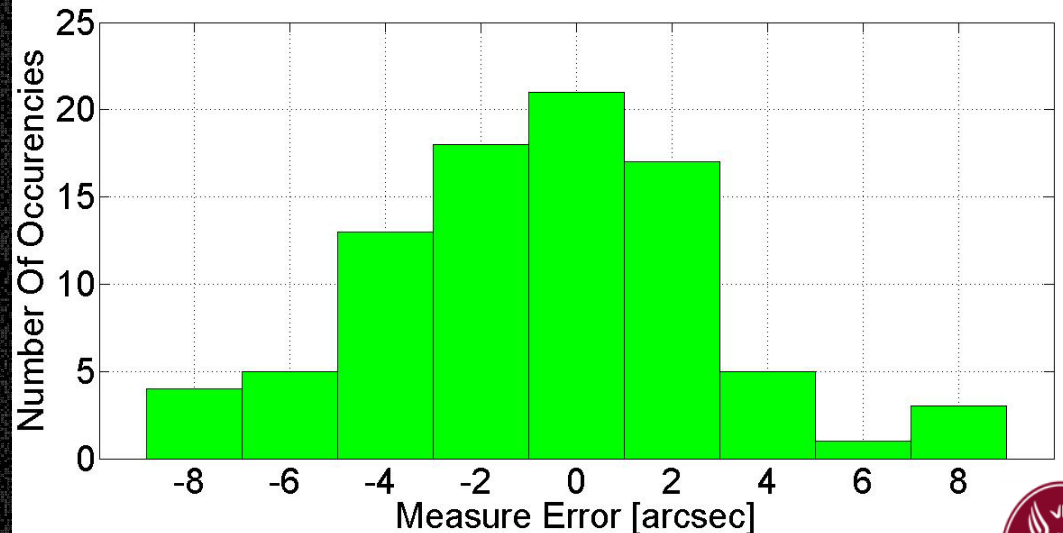


Along-Track standard

$$\sigma = 3.5 \text{ arcsec}$$

Cross-Track standard deviation:
 $\sigma = 3.3 \text{ arcsec}$

Cross-Track Measure Error Distribution



2.5 METER FOCAL LENGTH TELESCOPE



TELESCOPE “GRUPPO
ASTROFILI ANTARES”:

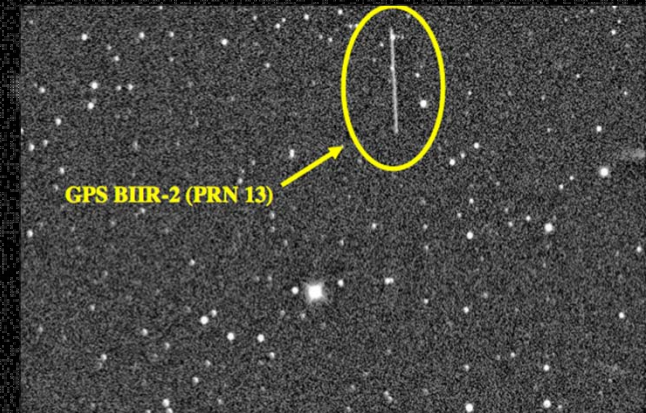
$\varnothing = 50 \text{ cm}$

FOCAL = 2.5 M

**GPS Along-Track and
Cross-Track standard
deviation:**

$\sigma = 1.5 \text{ arcsec (bin)}$

$\sigma = 0.8 \text{ arcsec (no bin)}$

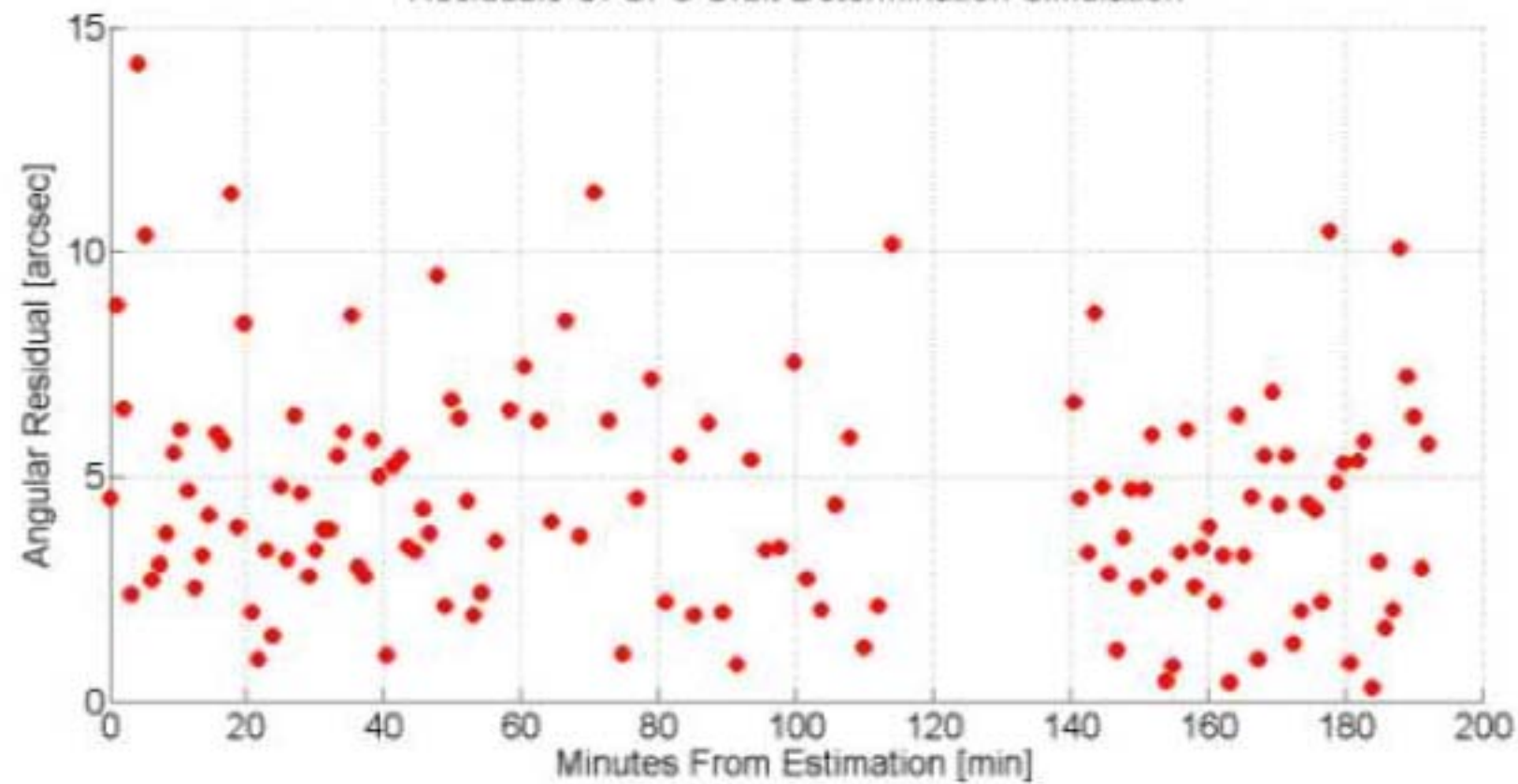


GPS POSITION ESTIMATE SIMULATION

- 3 hours of high precision angles (achieved from accurate ephemeris)
- Simulated measurements achieved using standard deviation analysis results ($\sigma=3.5''$)
- Obtained accurate angular position but error in range is about 650 meters (necessary a larger measurement arc of orbit)

	Exact position	TLE	estimated	error	$\ (r_{\text{esatto}} - r) \ $ [km]
X [km]	12107.415030	12100.853249	12107.872844	Estimate	0.648
Y [km]	-23168.672476	-23170.126766	-23169.070203	error	
Z [km]	-5679.794830	-5687.072855	-5679.566570	Tle error	9.906
$\ r\ $ [km]	26751.391596	26751.228408	26751.894798		

Residuals Of GPS Orbit Determination Simulation

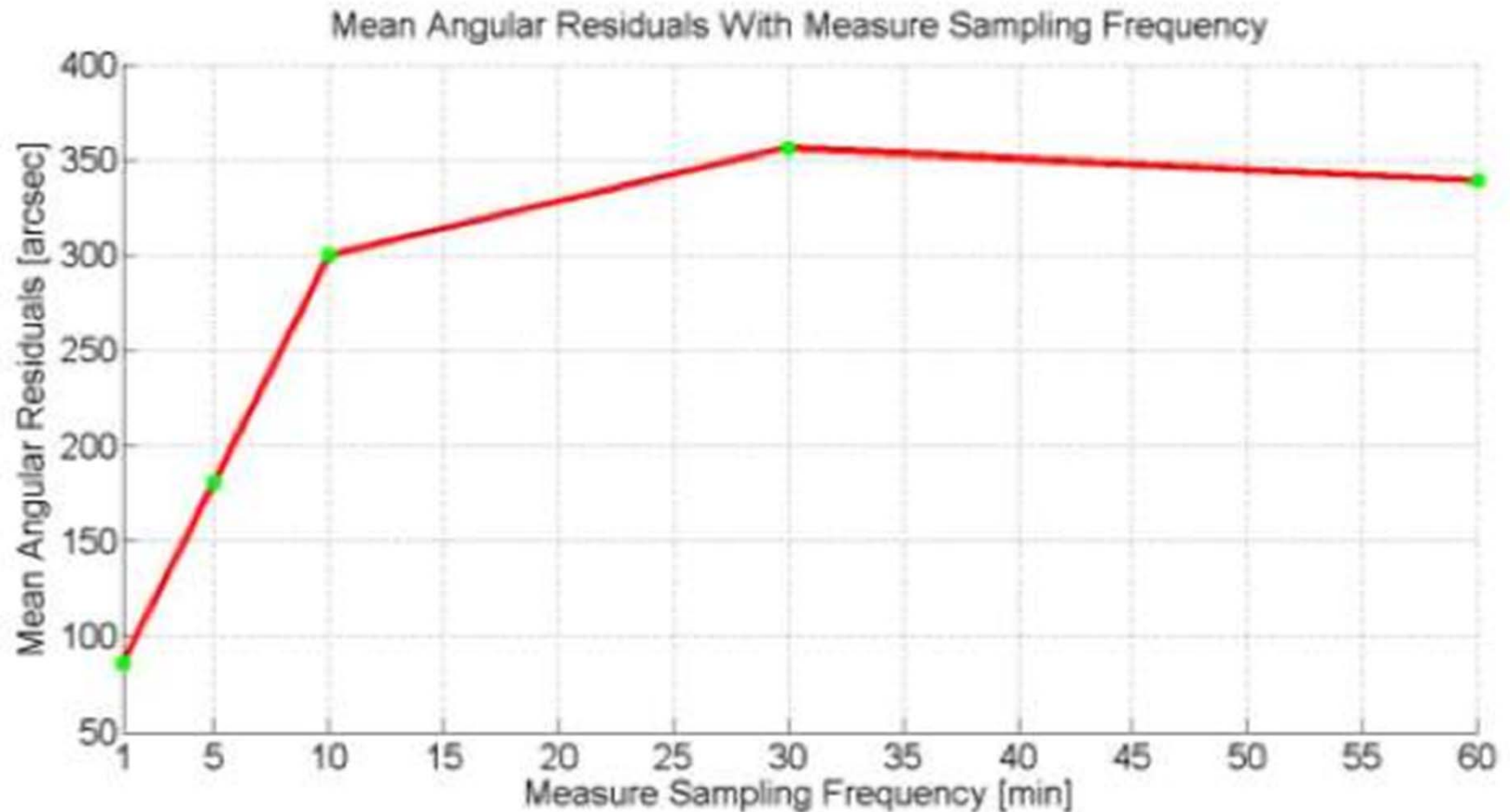


GEO CALIBRATION

GEO orbit determination simulation results

effect of measuring sampling frequency

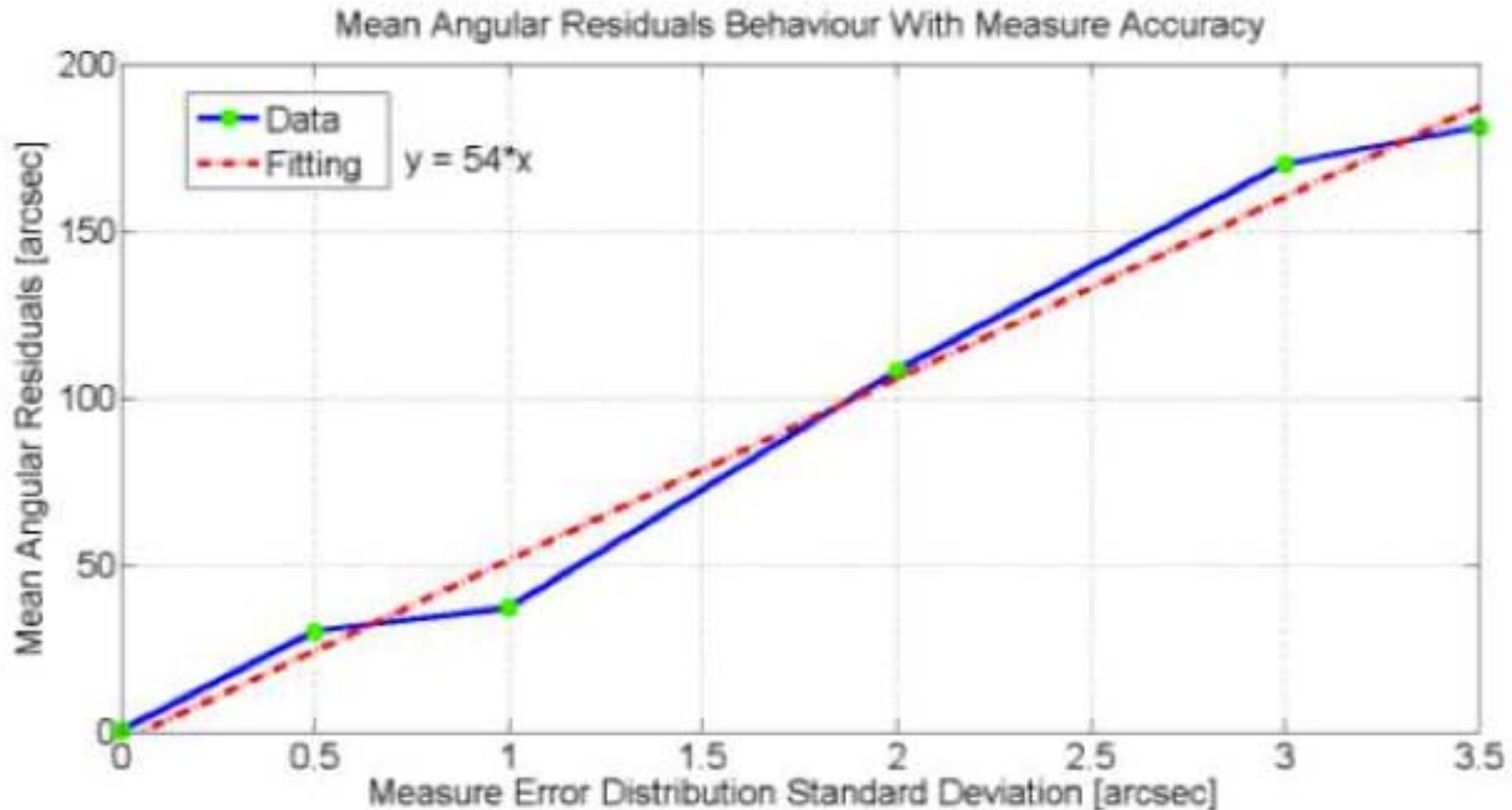
6 hours time span, $\sigma=3.5''$, residuals after 2 days propagation



GEO orbit determination simulation results

effect of measure accuracy

6 hours time span, 5 minutes sampling frequency, residuals after 2 days propagation



GEO orbit determination simulation results

effect of time span

5 minutes sampling frequency, $\sigma=3.5$ "

Measure Time Span [hr]	Along-Track Angular Drift [arcsec/day]	Along-Track Distance Drift [km/day]	Period Estimation Error [s]	Semimajor Axis Estimation Error [km]
6	100	20	6.7	2.80
9	30	6	2	0.80
12	15	3	1	0.42
24	1	0.17	0.07	0.03

Table 4. Measure Time Span Effects

INITIAL ORBIT DETERMINATION IN GEO 3 POINTS ONLY



Gauss method:
Analysis of time span between first and third measure
Based on a set of 8 hours measures taken every minute
Comparison between GAUSS method and accurate orbit estimation

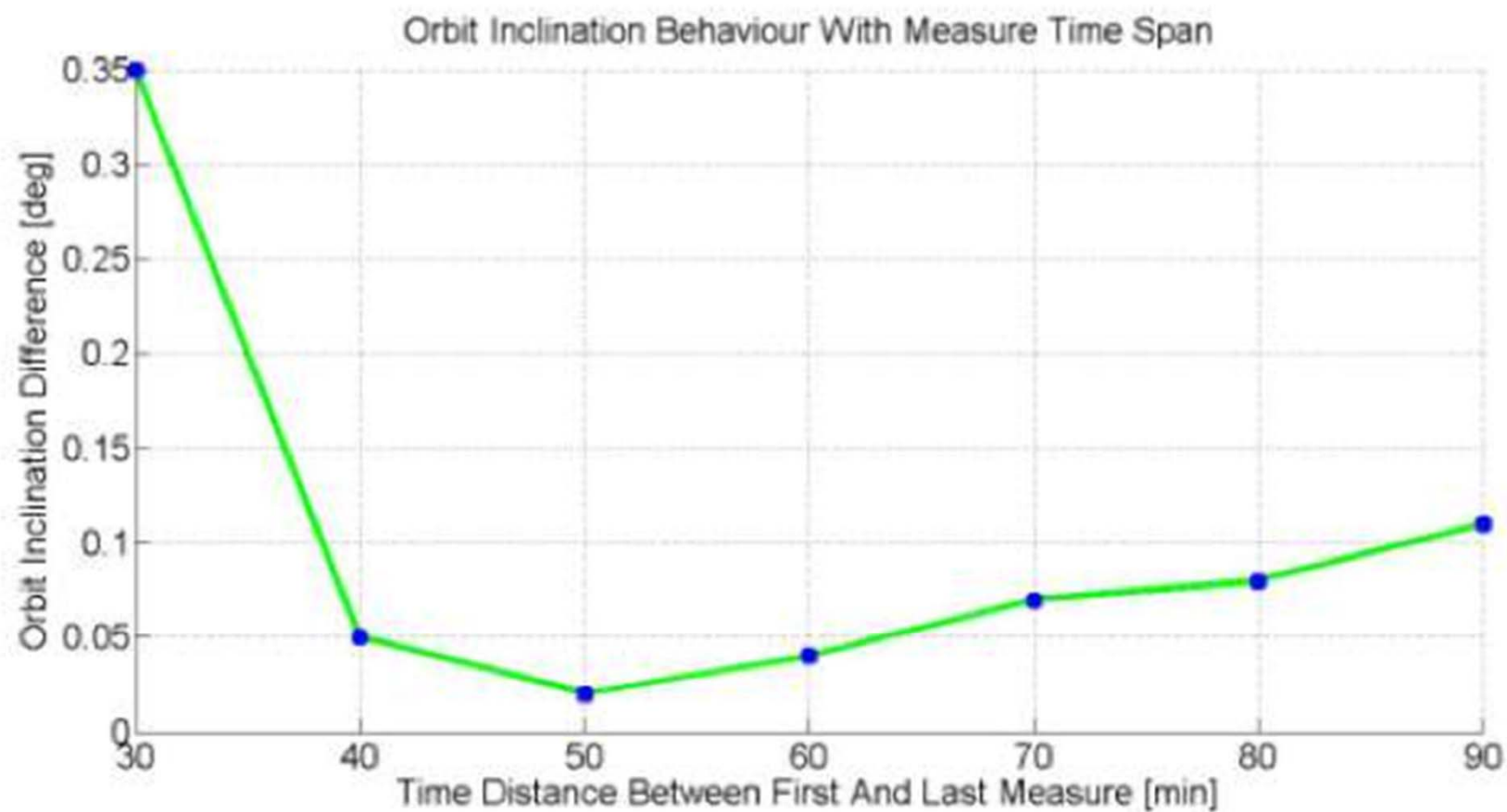
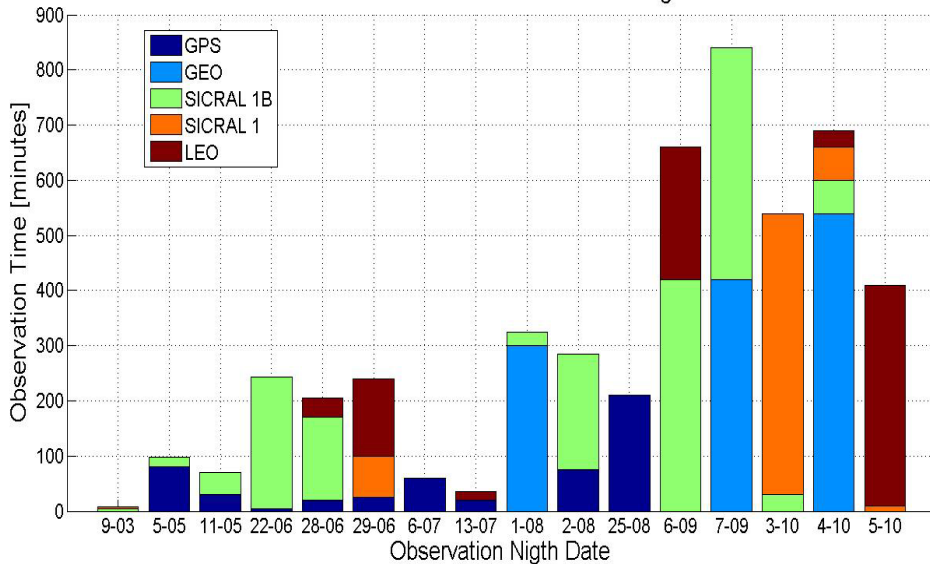


Figure 54. Gauss Method Orbit Determination: Inclination Behaviour With Measure Time Span

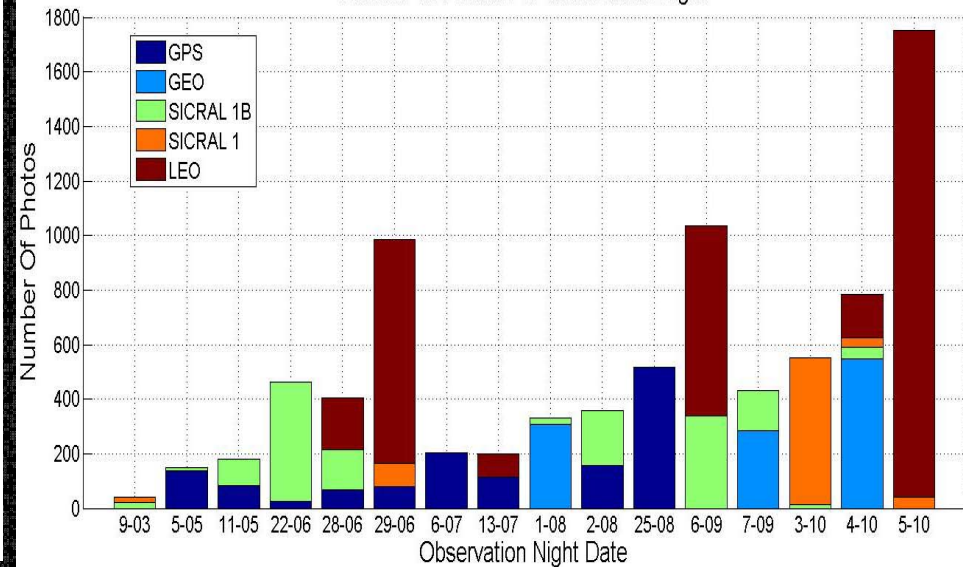
OBSERVATION CAMPAIGN

2011 OBSERVATION CAMPAIGN

Observation Time Per Observation Night

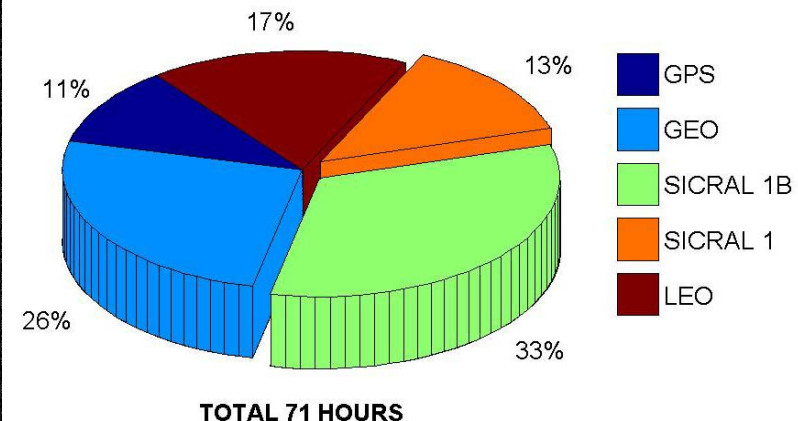


Number Of Photos Per Observation Night



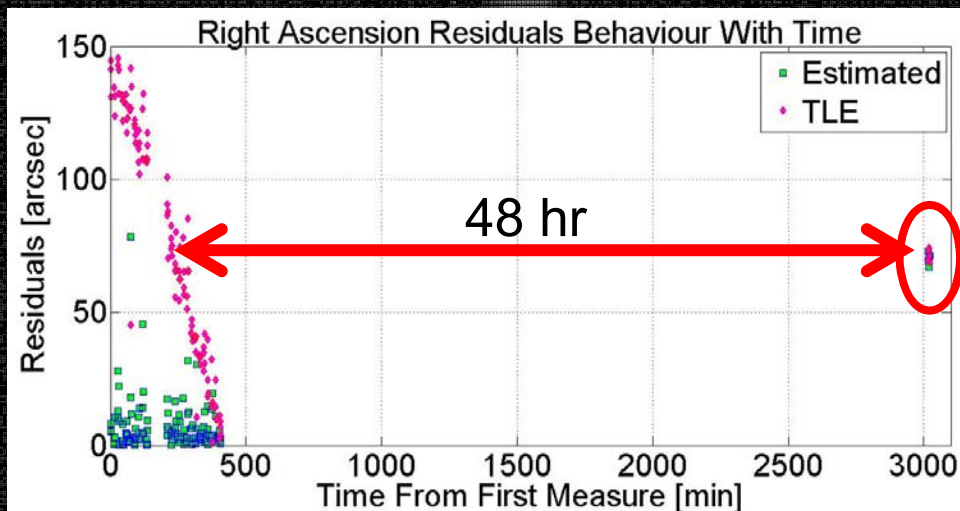
16 Notti	GPS	GEO	SICRAL 1B	SICRAL 1	LEO+GTO	TOTALE
Foto	1383	1139	1483	717	3660	8382
Minuti	524	1260	1617	658	860	4252

Total Observation Time And Percentage For Each Satellite Typology



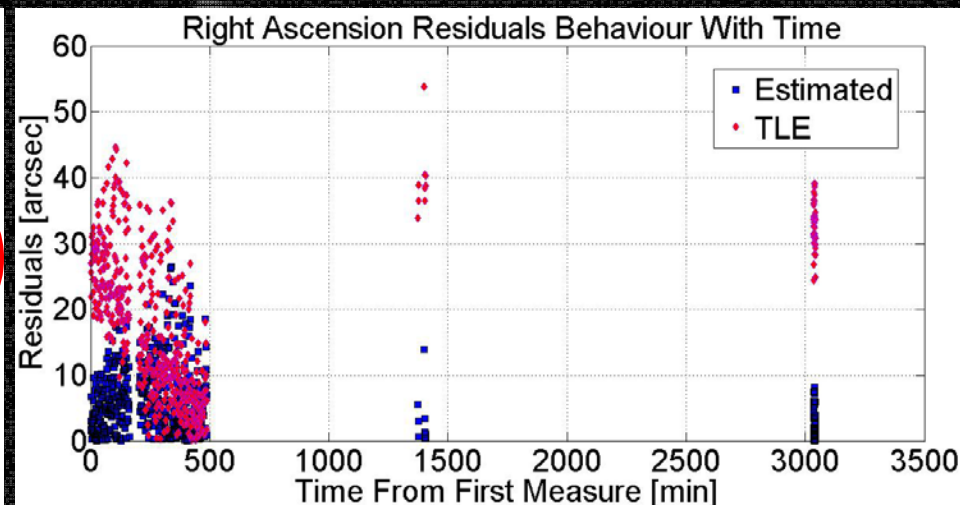
GEO ORBIT DETERMINATION RESULTS

❑ GEO estimate accuracy with one night measurements (similar or worst Than TLE)



1 night measurements

❑ GEO estimate accuracy with two night measurements (residuals always < 10 arcsec)

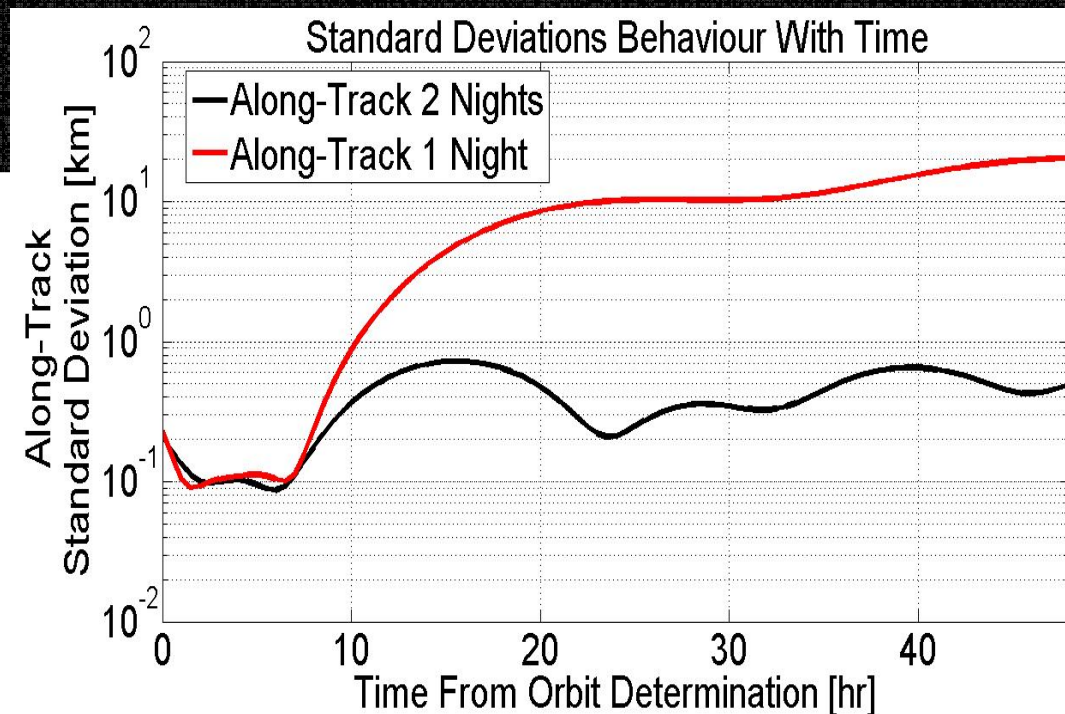


2 nights measurements

Covariance analysis

Along track covariance analysis

- Using 2 nights the along track components reduces over 2 order of magnitude



1 Nottata di Osservazioni

**2 Nottate
di Osservazioni**

Radial covariance analysis

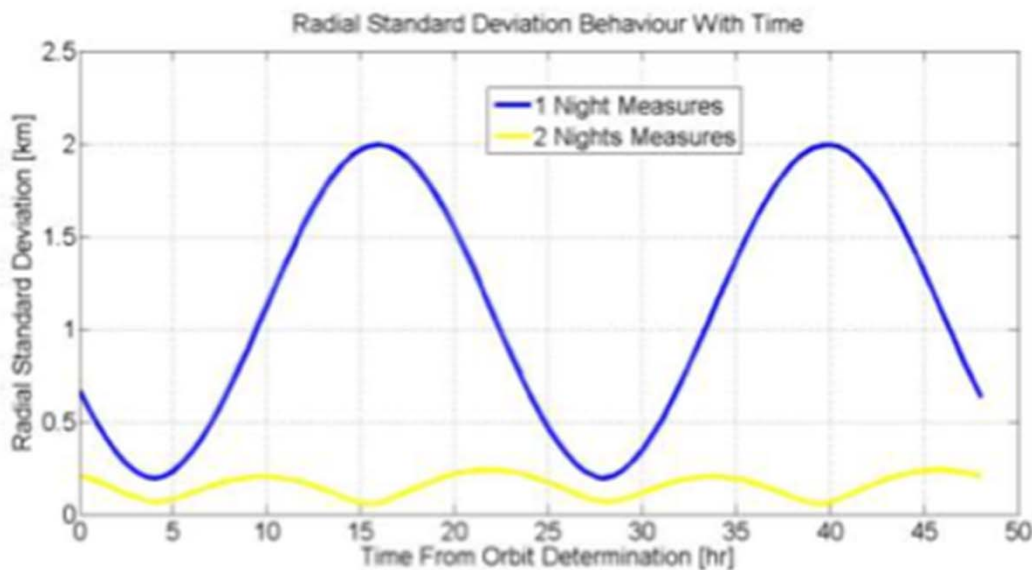
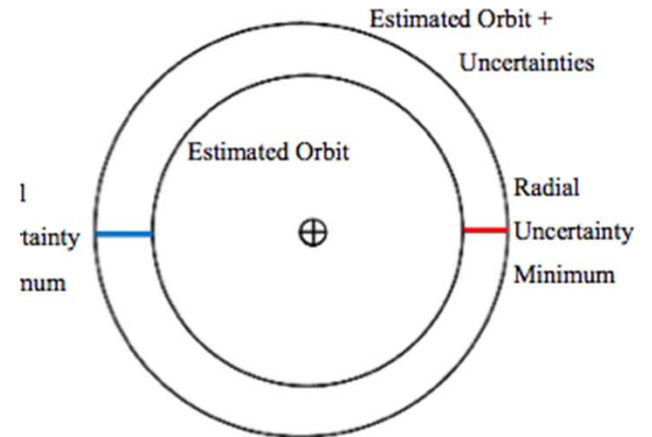


Figure 78. Estimated Covariance Standard Deviation Behaviours With Time. SICRAL 1 October 3rd And 4th. One Night And Two Night Comparison. Radial Component



Estimation Radial Uncertainties Behaviour Representation. One Night Measurement Case

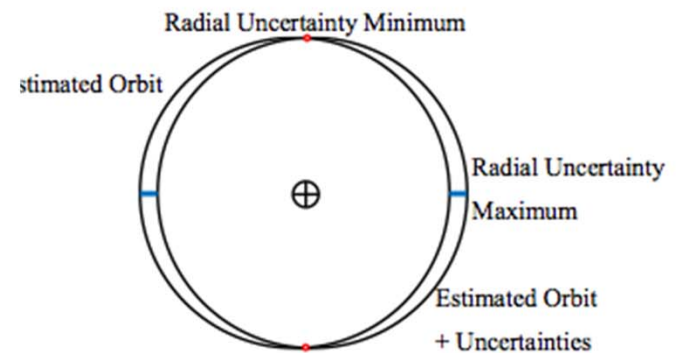


Figure 82. Estimation Radial Uncertainties Behaviour Representation. Two Nights Measurements Case

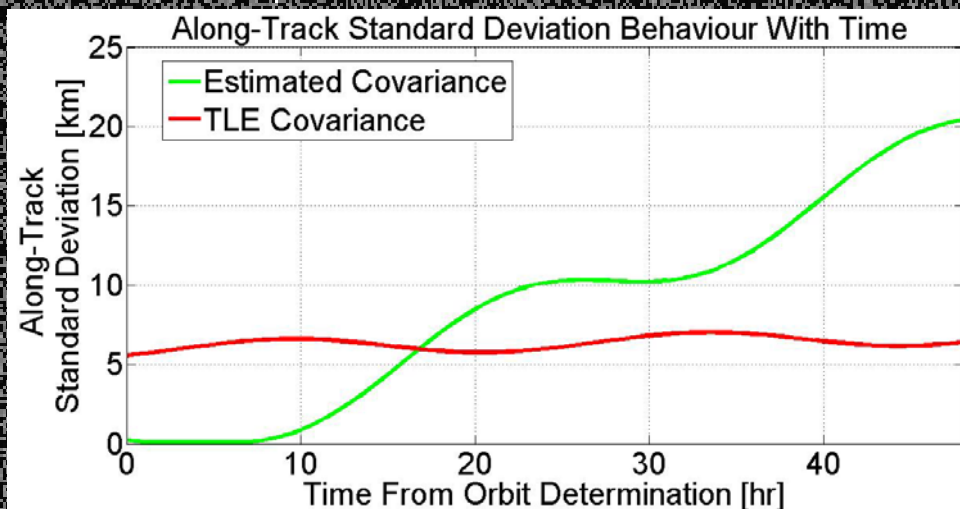
Covariance evolution: video

COVARIANCE ANALYSIS

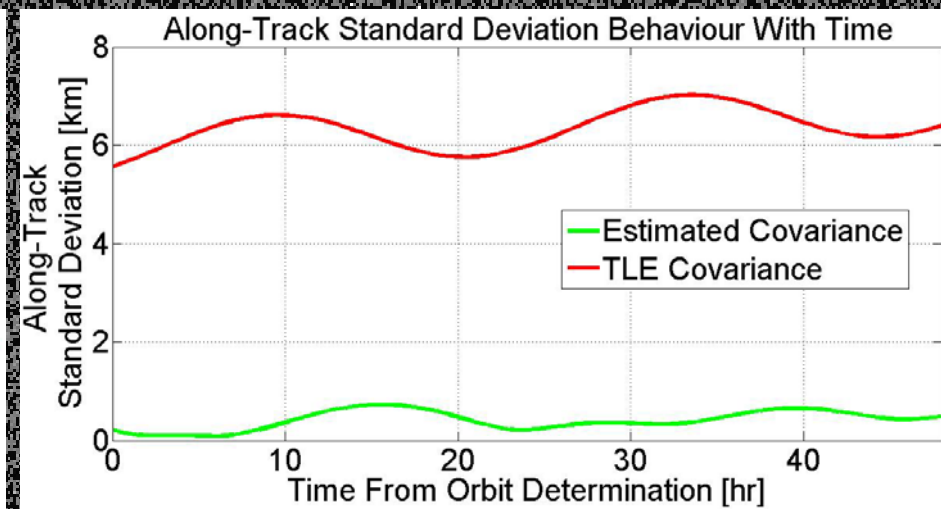
Comparison with TLE:

☐ Worst if considering one night.

☐ Better (1 order of magnitude) considering two nights



1 observation night



2 observation nights

Along-Track Error Standard Deviation				
	24 Hours Propagation	36 Hours Propagation	48 Hours Propagation	Maximum Value
One Night Measurements Covariance	10.14 km	12.24 km	20.42 km	20.42 km
Two Nights Measurements Covariance	0.21 km	0.52 km	0.49 km	0.72 km
TLE Covariance	5.99 km	6.92 km	6.40 km	7.02 km

Table 21. Along-Track Error Standard Deviation Comparison

Position Error Standard Deviation				
	24 Hours Propagation	36 Hours Propagation	48 Hours Propagation	Maximum Value
One Night Measurements Covariance	10.17 km	12.34 km	20.43 km	20.43 km
Two Nights Measurements Covariance	0.31 km	0.55 km	0.54 km	0.73 km
TLE Covariance	6.00 km	6.93 km	6.41 km	7.03 km

Table 22. Position Error Standard Deviation Comparison

Application: GEO manouver

Maneuvering GEO, SICRAL 1-B, 7 September

ORBIT DETERMINATION:

7 September 2011 00:00:00 UTC SICRAL 1-B SdR j2000

TLE:

X= 42112.408151 [km]

Y= -1941.8987 [km]

Z= -128.70509 [km]

VX= 0.142 [km/s]

VY= 3.0719 [km/s]

VZ= -0.0006052 [km/s]

e= 2.2e-4

i= 0.0937 deg

Ω = 83.8687 deg

Estimated state:

X= 42114.658384[km]

Y= -1935.48848 [km]

Z= -129.84135 [km]

VX= 0.1417 [km/s]

VY= 3.07179 [km/s]

VZ= -0.000512 [km/s]

e= 2.71e-4

i=0.176255 deg

Ω = 90.246 deg

Maneuvering GEO, SICRAL 1-B, 7 September

Orbit Determination:

7 Settembre 2011 20:18:08 UTC SICRAL 1-B SdR j2000

STATO TLE:

X= 22780.257873 [km]
Y= -35469.759219 [km]
Z= -68.180441 [km]
VX= 2.587590 [km/s]
VY= 1.662001 [km/s]
VZ= -0.008132 [km/s]

e= 2.1e-4
i= 0.0964 deg
 Ω = 83.67 deg

STATO STIMATO:

X= 22803.5361397 [km]
Y= -35459.318604 [km]
Z= -46.078166 [km]
VX= 2.5866662 [km/s]
VY= 1.6630929 [km/s]
VZ= -0.0053753 [km/s]

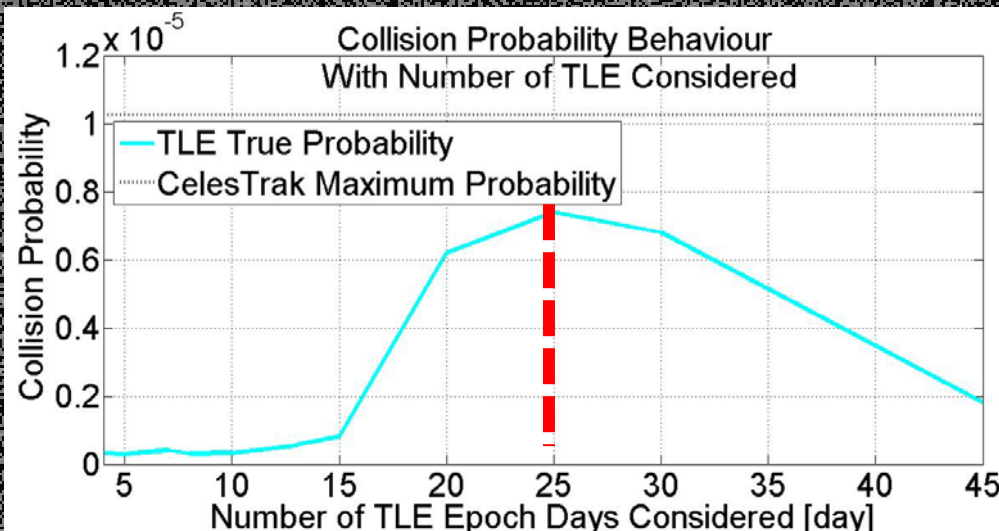
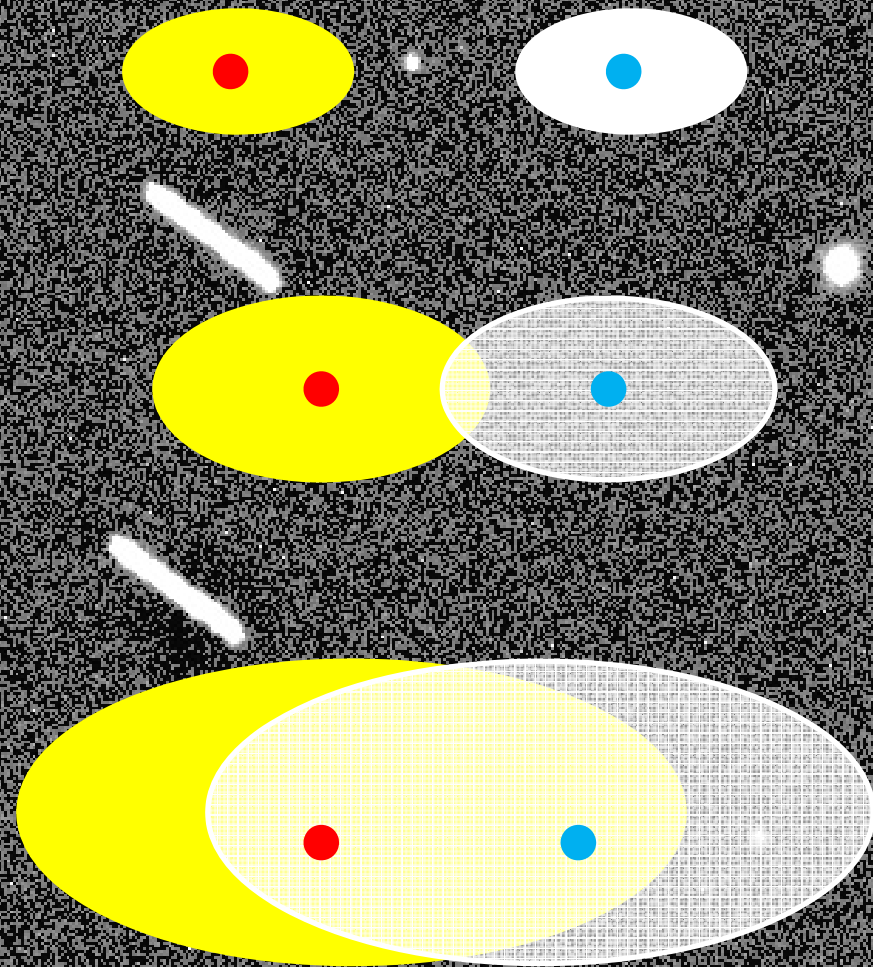
e= 2.36445e-4
i=0.118 deg
 Ω = 90.73 deg

Estimated manouver→ (Δi = 0.06 deg)

Application: Close Approach

CLOSE APPROACH

- Necessary to remain below the Dilution Threshold (about 1 km) for covariance
- CelesTrack/SOCRATES provide the maximum impact probability, Based on CA geometry

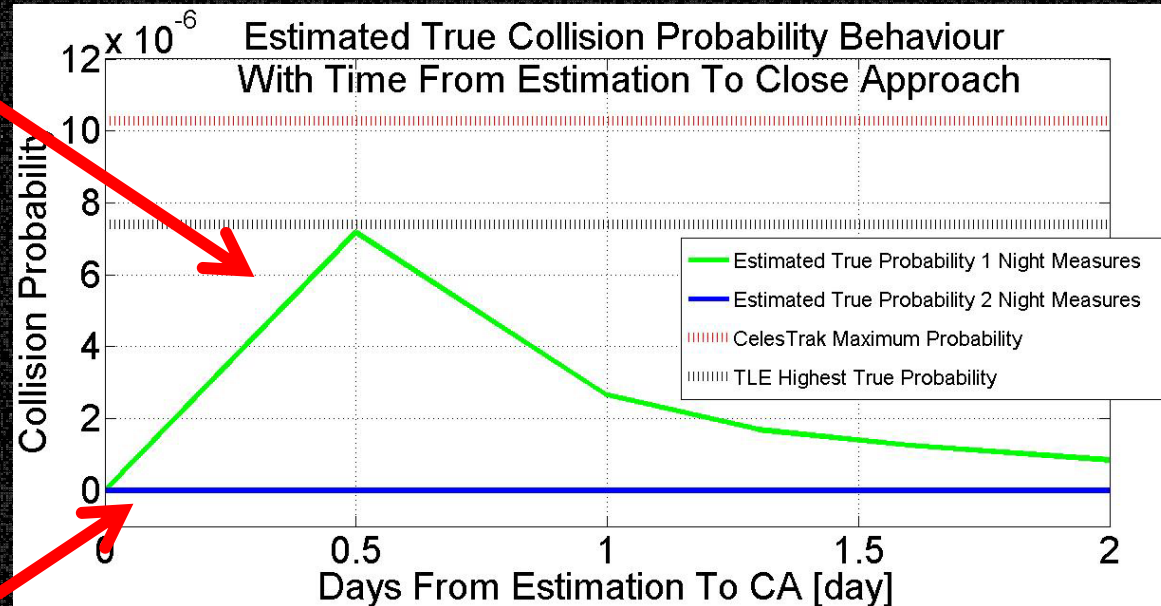


Dilution threshold

TLE True Collision Probability Behaviour With Number Of TLE Days Considered. EXPRESS 1 - GALAXY 4R Case

CLOSE APPROACH (II)

- 1 Night observation, threshold overcome



- Threshold not reached in the case of covariance achieved By 2 observations nights



- It is possible to calculate the real impact probability

CLOSE APPROACH: GORIZONT-

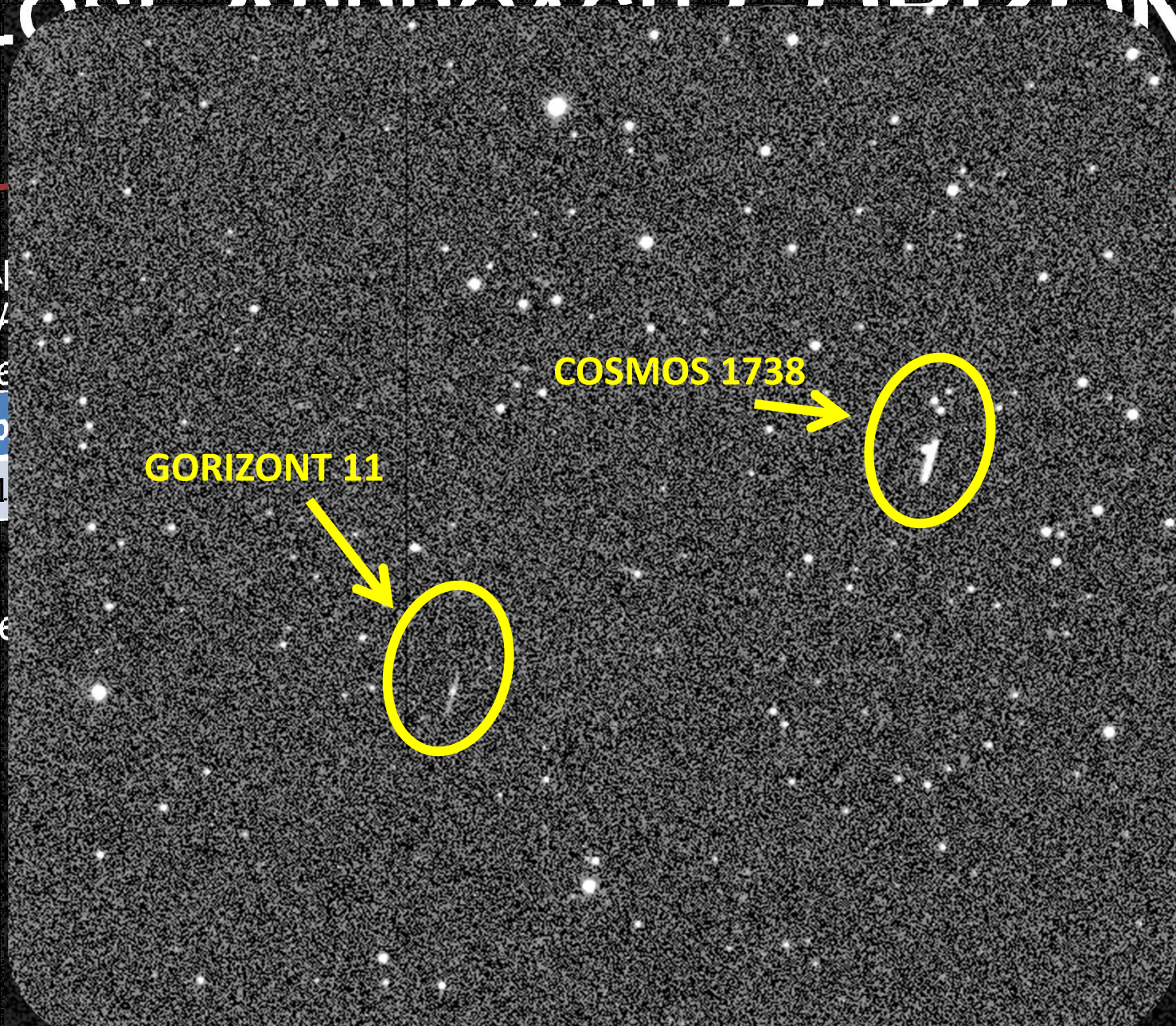
■ Close Approach
SOCR/...
December

Probab

3.543×10^{-4}

■ Estimate

by
d 16

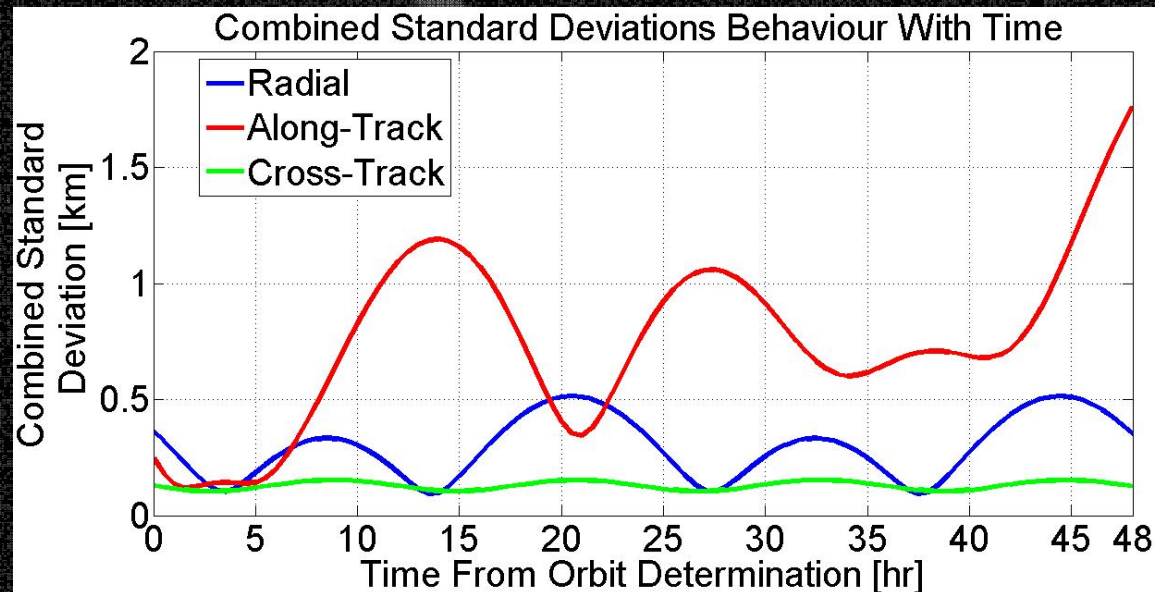


CLOSE APPROACH GORIZONT-COSMOS (II)

- Impact probability = 0

Probabilità	Istante CA	Distanza Minima
0	/	78 km

- real true distance > 70 km



CONCLUSIONS

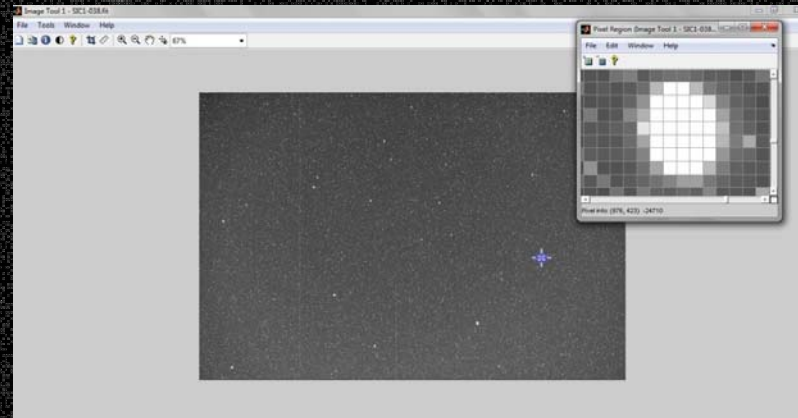
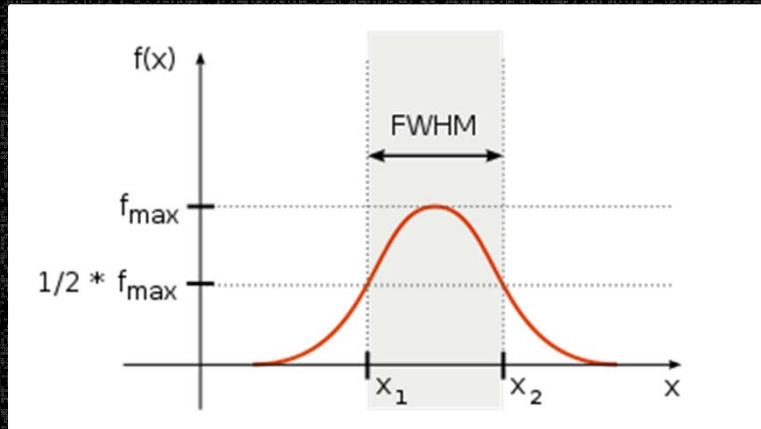
MEO orbit (GPS) accuracy of measurements estimated in about (3.5 arcsec) related to pixel angular measurement

"Close Approach Analysis accuracy for Geosynchronous satellite with optical measurements:

- ✓ residuals very accurate (< 10 arcsec) after 2 days from measurements, using two nights measures
- ✓ standard deviation lower than 1 km after 2 days
- ✓ True impact probability estimated

SITE VIGNA DI VALLE

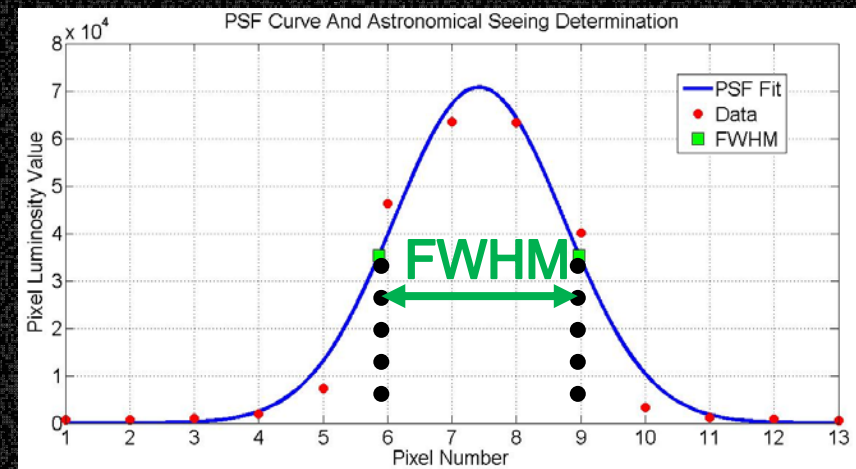
Seeing:



Sky brightness:

$$M_1 = M_2 - 2.5 \log_{10} (F_1/F_2)$$

Mean value= 17.8



mean value= 4.5 arcsec