International Worksop on Space Debris Re-entry

ESA/ESOC, Darmstadt/Germany
28th February – 1st March 2018

HOW CAN OPTICAL SYSTEMS SUPPORT IN RE-ENTRY EVENTS?

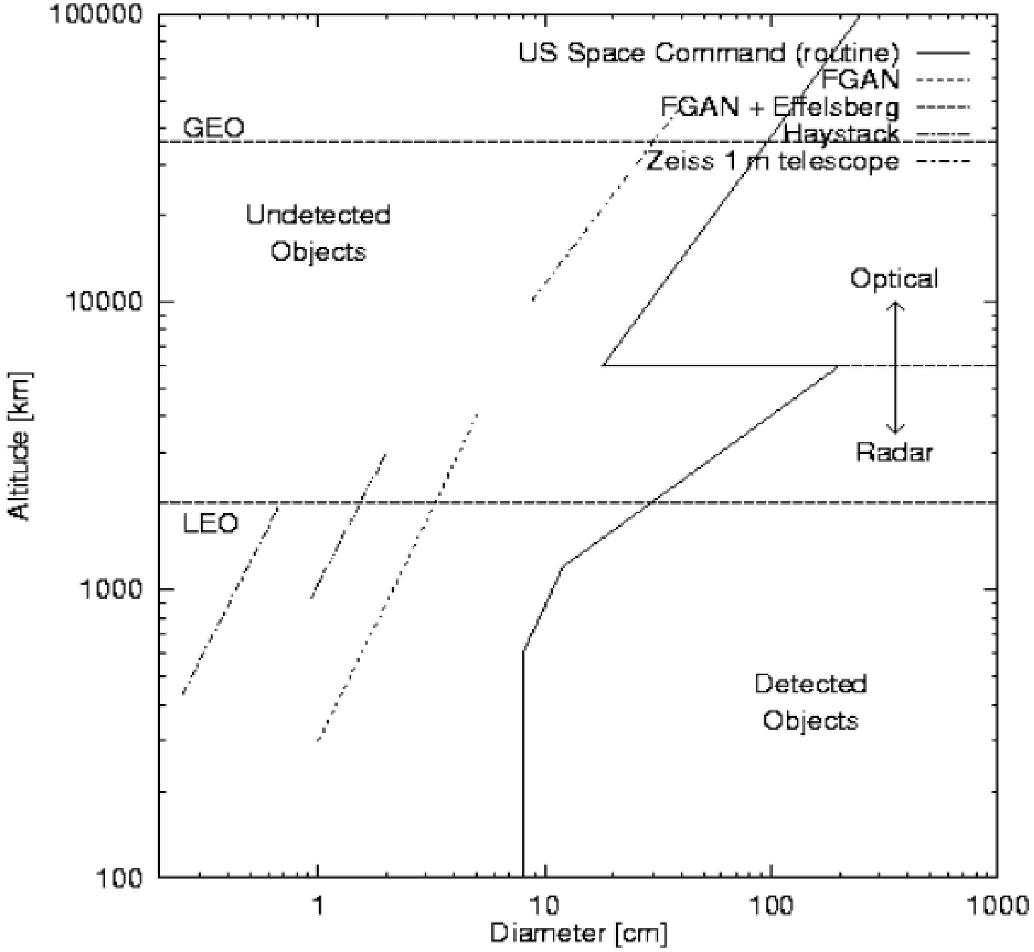
Noelia Sánchez-Ortiz
Jaime Nomen Torres
Nuria Guijarro López
Roxana Larisa Andrisan
Raul Domínguez González
Ramón Mañas Escudero

@ElecnorDeimos

OBSERVATIONS OF SPACE DEBRIS AND RE-ENTERING OBJECTS

Introduction

- **Satellite and Space Debris Sensors**
  - **Radars**
    - Normally used for observing objects in Earth Orbits (LEO) as their efficiency r largely with the distance between the and observed object
  - **Passive Optical Sensors (telescopes)**
    - They work well at large distances, but observation of objects at short altitud impacted by limitations due to relative velocity and observation geometry (illumination and weather conditions)
  - **Active Optical Sensors (SLR)**
    - SLR sensors required the observed obj have a retro-reflector system to allow detection, improved observation techn have lead to observe non 'collaborative objects.



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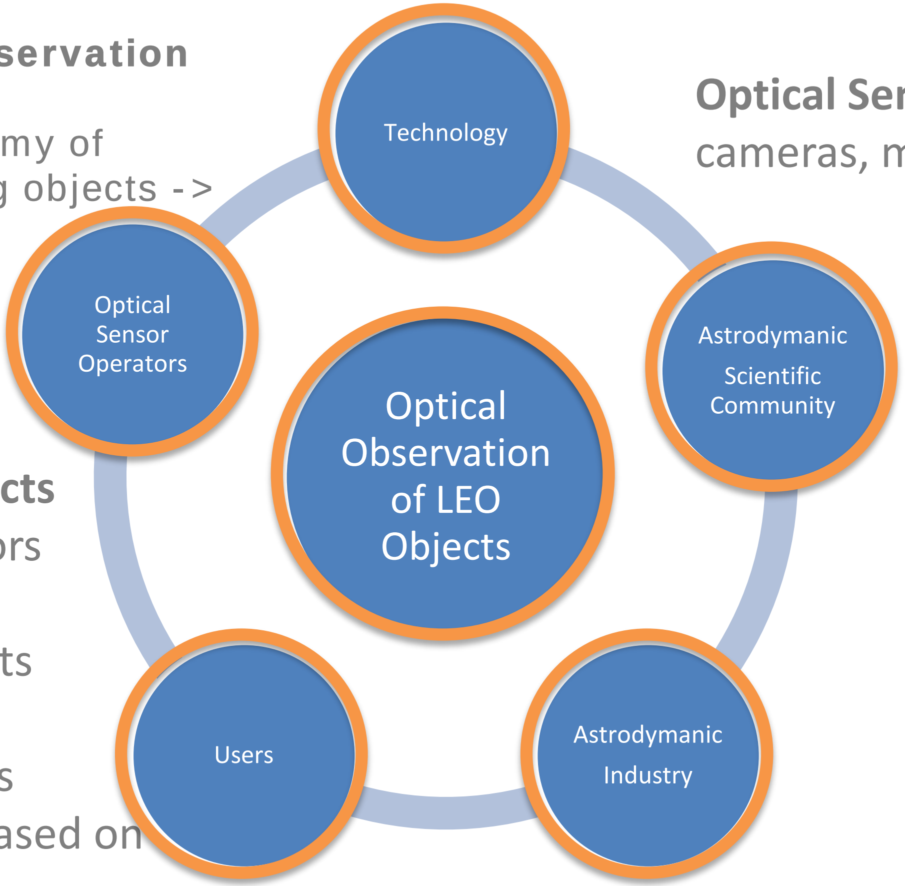
OBSERVATIONS OF SPACE DEBRIS AND RE-ENTERING OBJECTS

Motivation for LEO Optical Observation -> Opportunity for many actors

Motivation to improve observation methods/strategies
From the traditional Astronomy of distant & very slowly moving objects -> NEOs -> GEO/MEO -> LEO

Large population of LEO objects
Increasing number of operators
Future large constellations
More frequent Re-entry events

In GEO regime, now operators demand (efficient) services based on traditional SST observations



Optical Sensors evolution
cameras, mount, time tag ,…

Difficult access to Radar Data
Limited research or service provision development
For LEO regime SST services (Re-entry, Fragmentation, Conjunction analysis) and main activities like cataloguing, orbit computation,…

SLR observations limited up to recent days to collaborative objects; limitations now to non-operational objects

APPROACH TO OPTICAL OBSERVATIONS IN LEO REGIME

Main Limitations

- When **comparing with Radar or SLR sensors**:
  - Earth shadow impact
  - Meteorological and diurnal constraints
- When Comparing with **Optical observations of high altitude** objects
  - Earth Shadow impact is larger
  - High relative angular velocity between the observed object and sensor
  - Larger sky region
  - Much shorter observing windows (short arcs)

Main Aspects to be considered

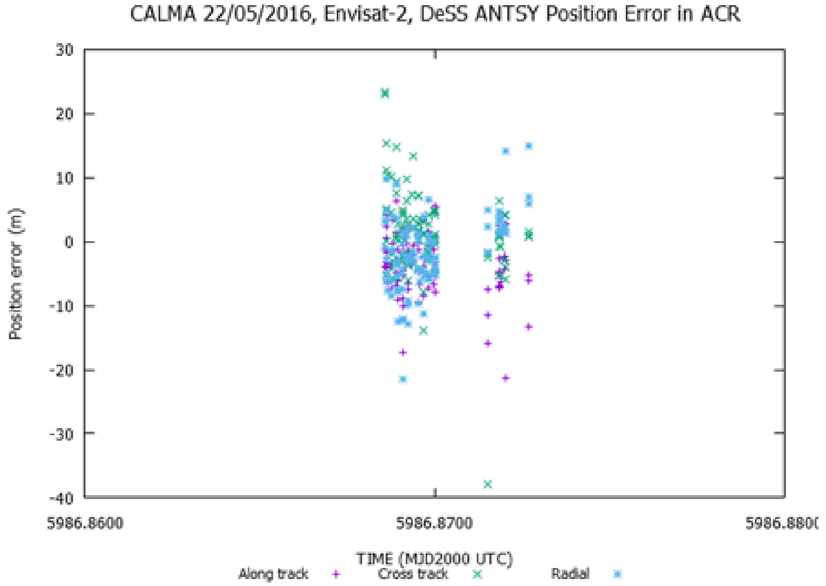
- Impact of **trailing loss** and trail detection mechanism (optimal exposure times, signal to noise ratio)
  - The SNR decreases linearly with the trail length (Trailing loss)
  - Exposure times must be as short as possible (no advantage of long exposures to find fainter objects in sidereal tracking)

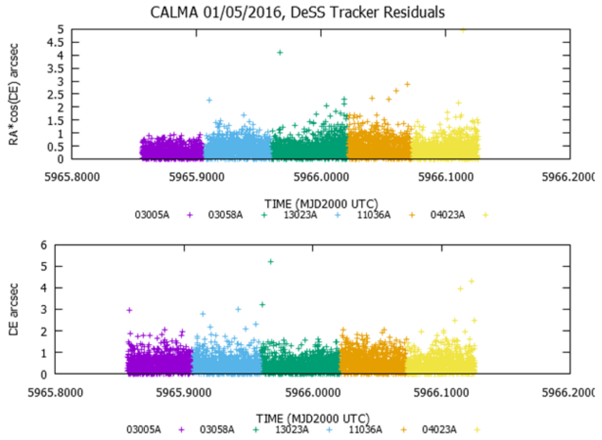
- **Image triggering** mechanism (accurate time tag of the observations)
  - Two kind of timing tag errors: Random & Systematic
  - LEO objects, with roughly 100 times faster angular speed than GEO objects

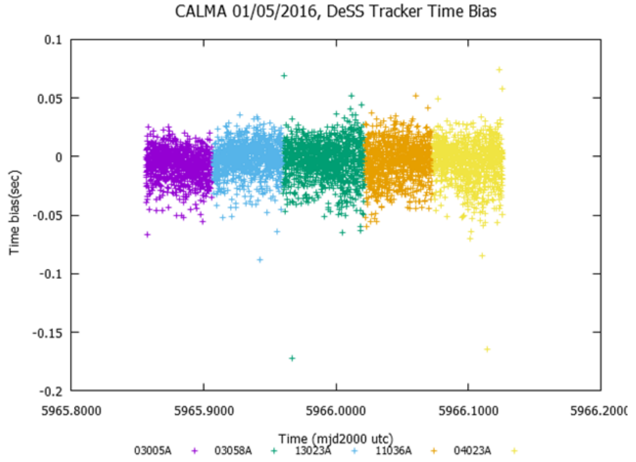
APPROACH TO OPTICAL OBSERVATIONS IN LEO REGIME

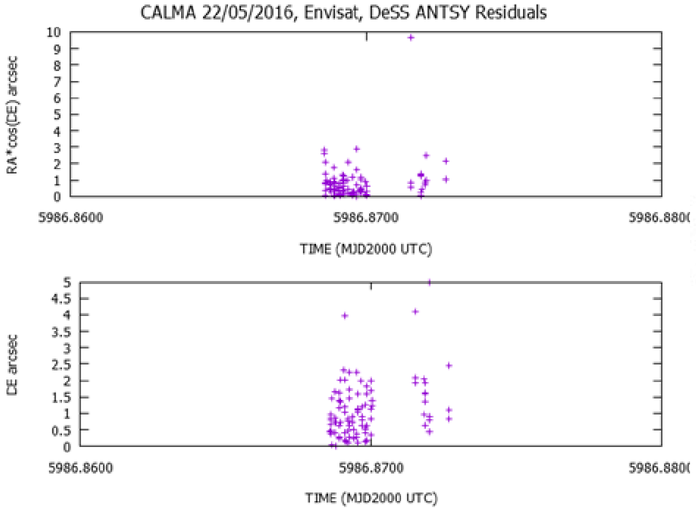
Calibration of Optical Sensors for Observations of LEO Objects

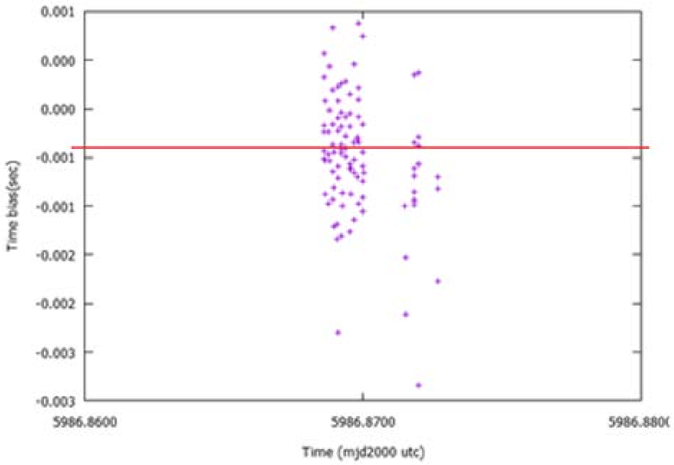
Observed Object	Time Tag Accuracy tolerance	Astrometric Accuracy
MEO GEO	±20 miliseconds	1 arcseconds
LEO	±1 milisecond	2 arcseconds







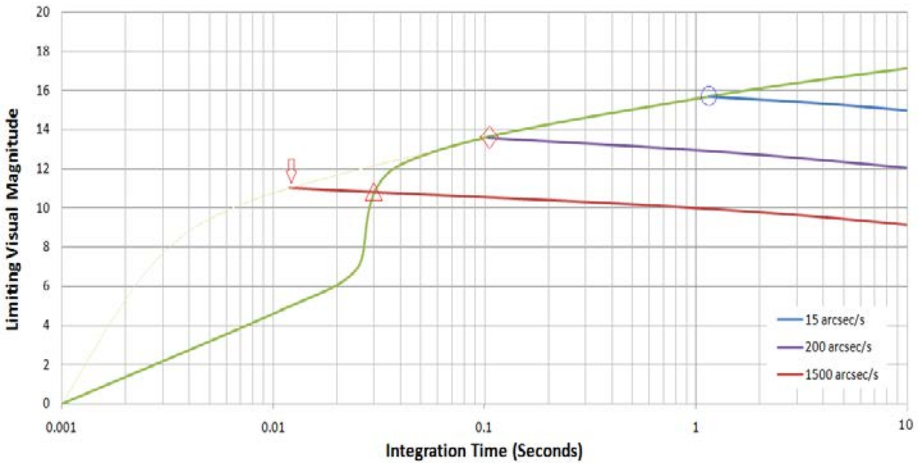




APPROACH FOR OPTICAL OBSERVATIONS IN LEO REGIME

Main Aspects to be considered (II)

- **Slowest and Fastest LEO angular speed** detection capabilities
  - Slowest detectable object: that one moving slow eough to produce all its signal inside one pixel (given exposure time, scale pixel resolution and FWMH)
  - Fastest detectable speed is defined as the shortest trail length to minimise trailing losses and inconvenience in detection process (accurate detection and measuring)
  - For fastest objects, SNR decreases (trailing loss) and the objecct can go out of the FoV
- **Short exposure times** are preferrred, two main problems:
  - CCD read noise dominance on shortest exposure times
  - Lack of background stars (allowing to solve images and measure)
- **Field of view** (traded-off with the read-out time)



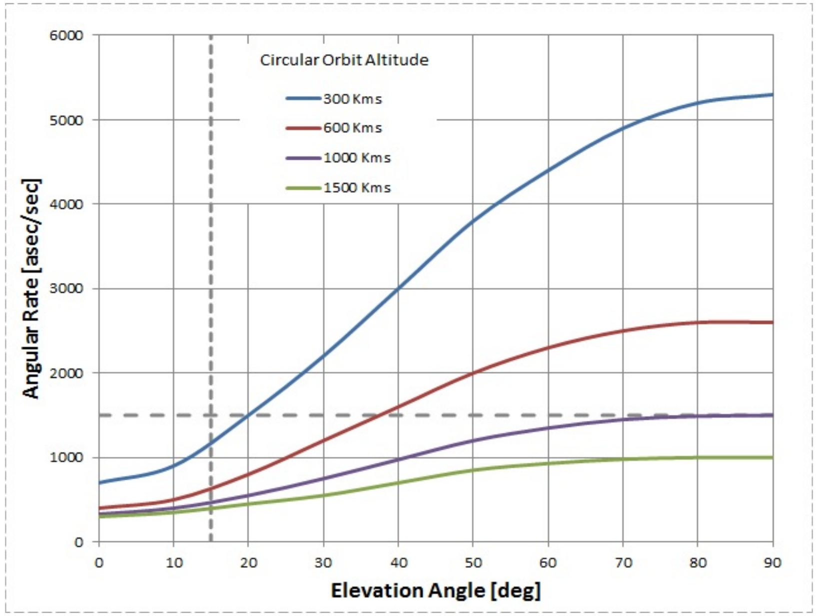
$$Exp.Time = \frac{Resolution \times Binning \times Trail\ Length}{Angular\ Speed}$$

magnitude	stars per degree2	stars per FoV
6.0	0.117	0.178
7.0	0.347	0.527
8.0	1.00	1.52
9.0	2.82	4.29
10.0	8.13	**12.36**
11.0	21.88	33.26
12.0	57.54	87.46

APPROACH FOR OPTICAL OBSERVATIONS IN LEO REGIME

Main Aspects to be considered (III)

- **Elevation and Angular speed**
  - Larger elevation speed at observer zenith
  - Reentering object > 2000 arcsec/sec
- **Tracking Schedule and Observation windows**:
  - Observation windows of LEO are few minutes short
  - Dynamic selection of target opportunities
    - Highest elevation
    - Closest to Earth Shadow
    - West or East preference
    - Last track angular distance
    - Closest to polar region
    - By predicted passes on good conditions
    - By Radar cross section catalogue



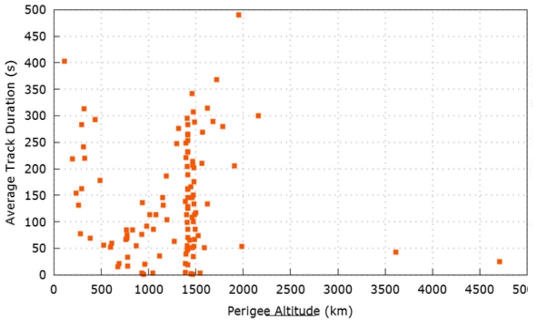
OPTICAL OBSERVATIONS IN LEO REGIME

Example of a LEO campaign

Night	Observed objects	Number of tracks	Average track length (sec)	Number of observations
11/08/2016	111	113	100.5	7350
12/08/2016	165	172	81	7311
13/08/2016	236	236	77	5463
14/08/2016	217	217	101	4188
22/08/2016	337	352	26.8	7149

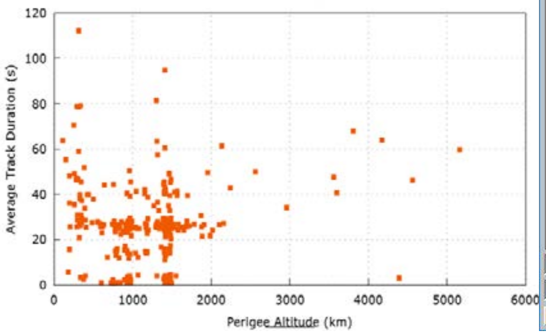
11/08/2016

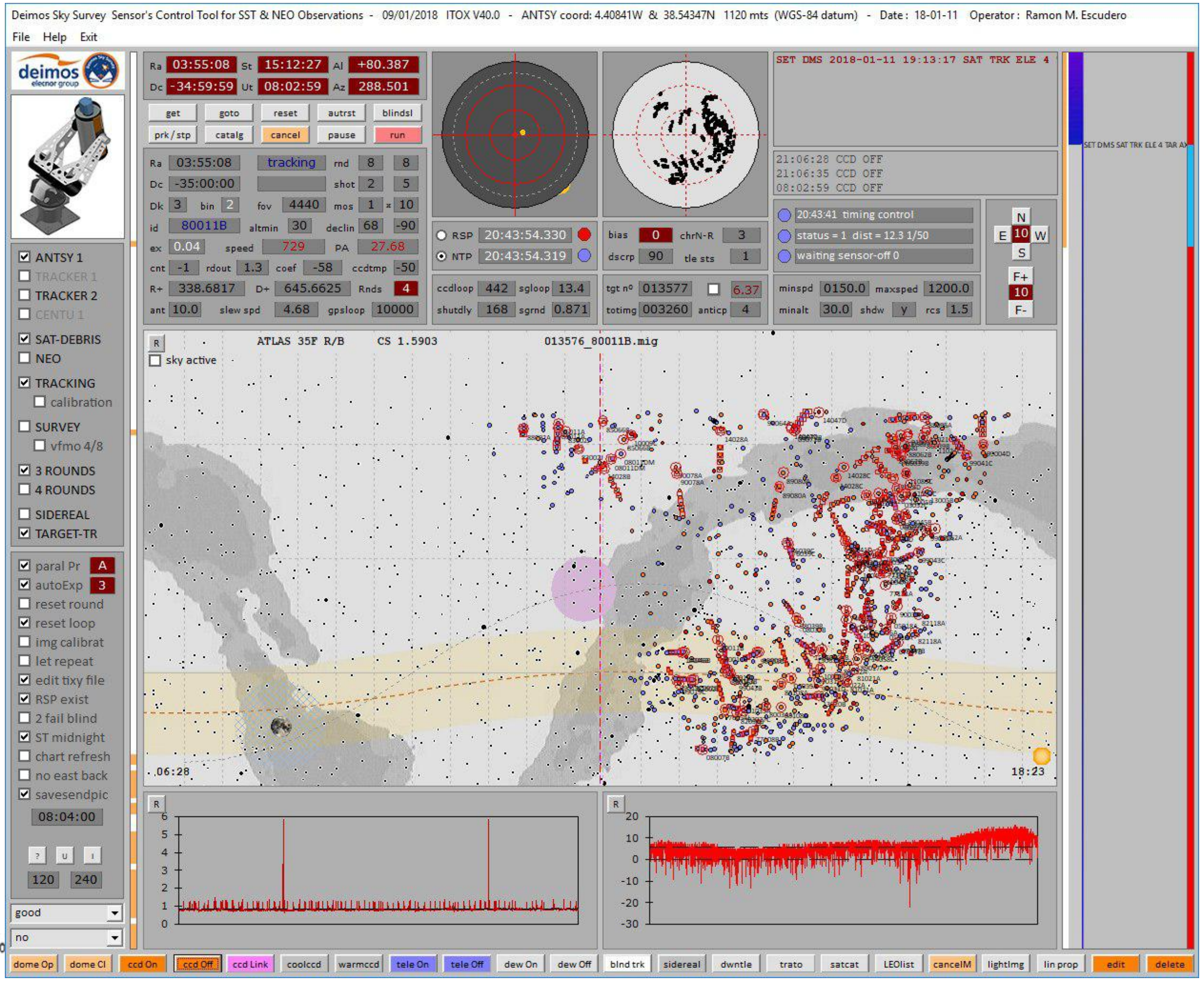
DeSS Antsy



22/08/2016

DeSS Antsy

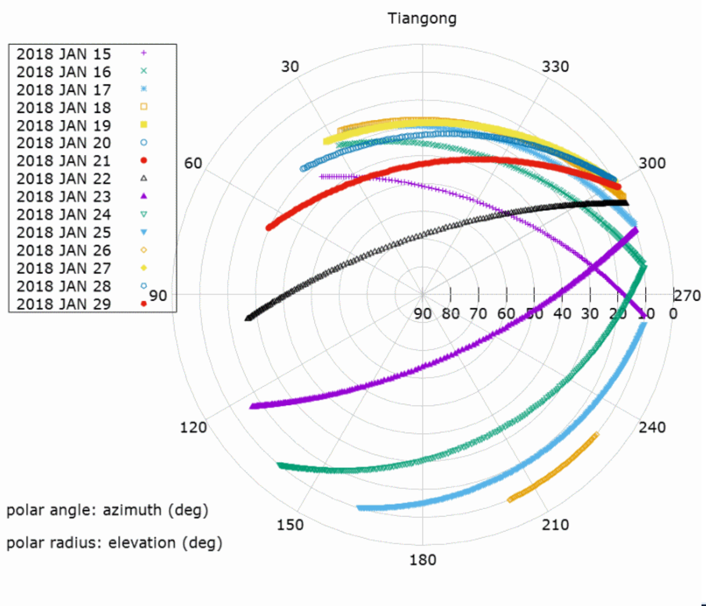


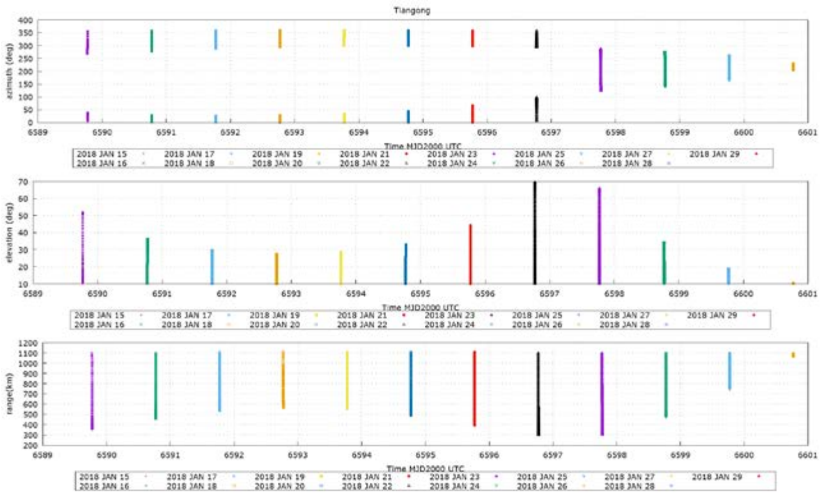


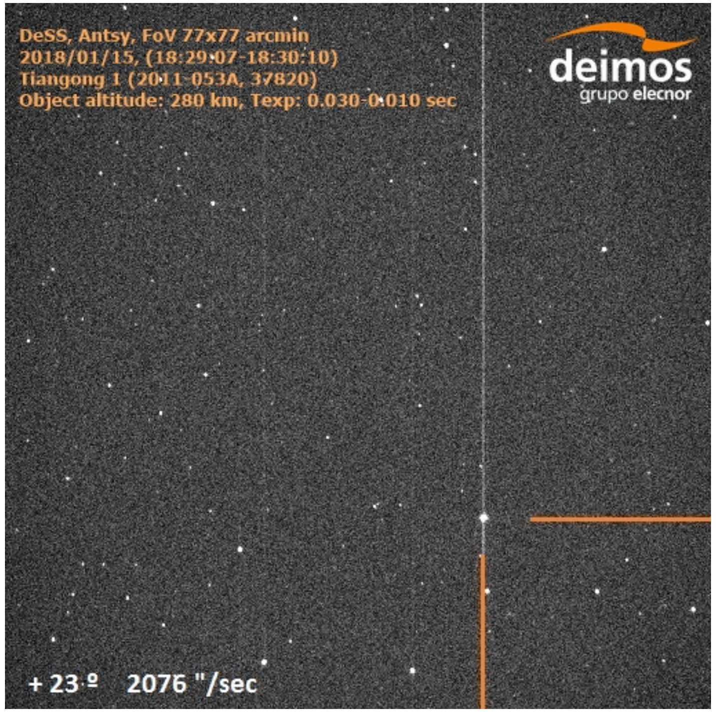
OBSERVATION OF TIANGONG-1

January Observation from DeSS / Spain (15-16 January 2018)

- Possible Passes
  - Almost every night
  - Sensor available along 4/5 nights
  - 2 succesful passes
  - Tiangong 1 altitude about 280 km



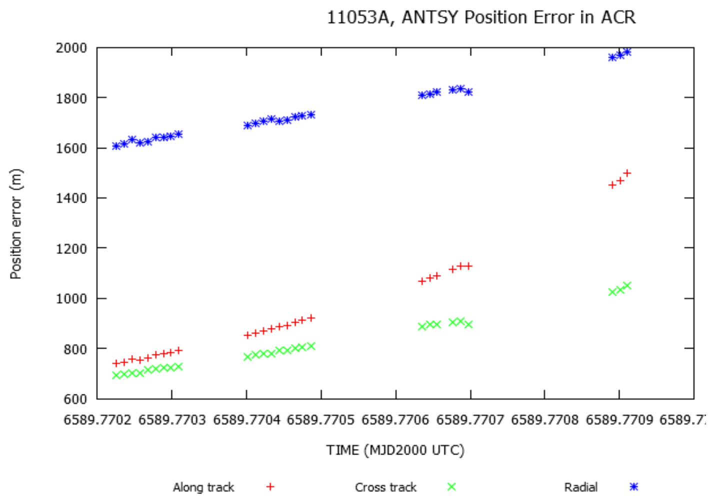


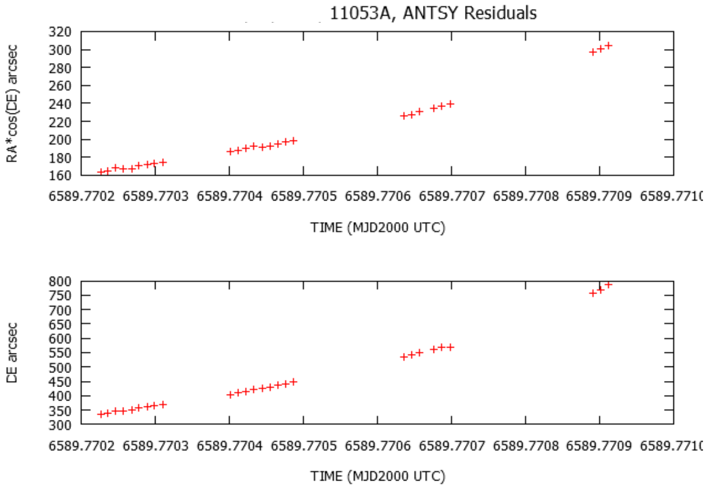


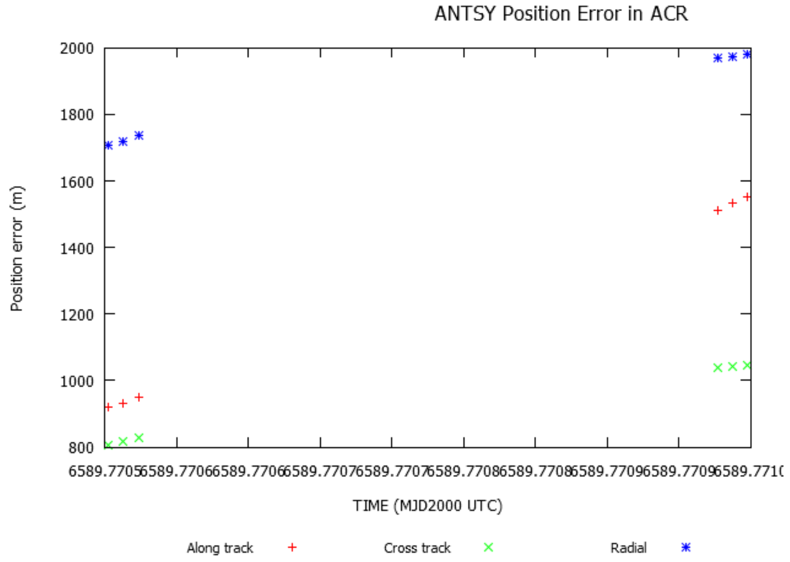
OBSERVATION OF TIANGONG-1

January Observation from DeSS / Spain (15-16 January 2018)

- Observations Comparison against TLE
  - CALMA comparison as per calibration analysis shown before
  - Lack of accurate orbit does not allow to evaluate observations quality
  - The analysis is driven by the poor TLE accuracy
  - 300 arcseconds off -> 5 minutes



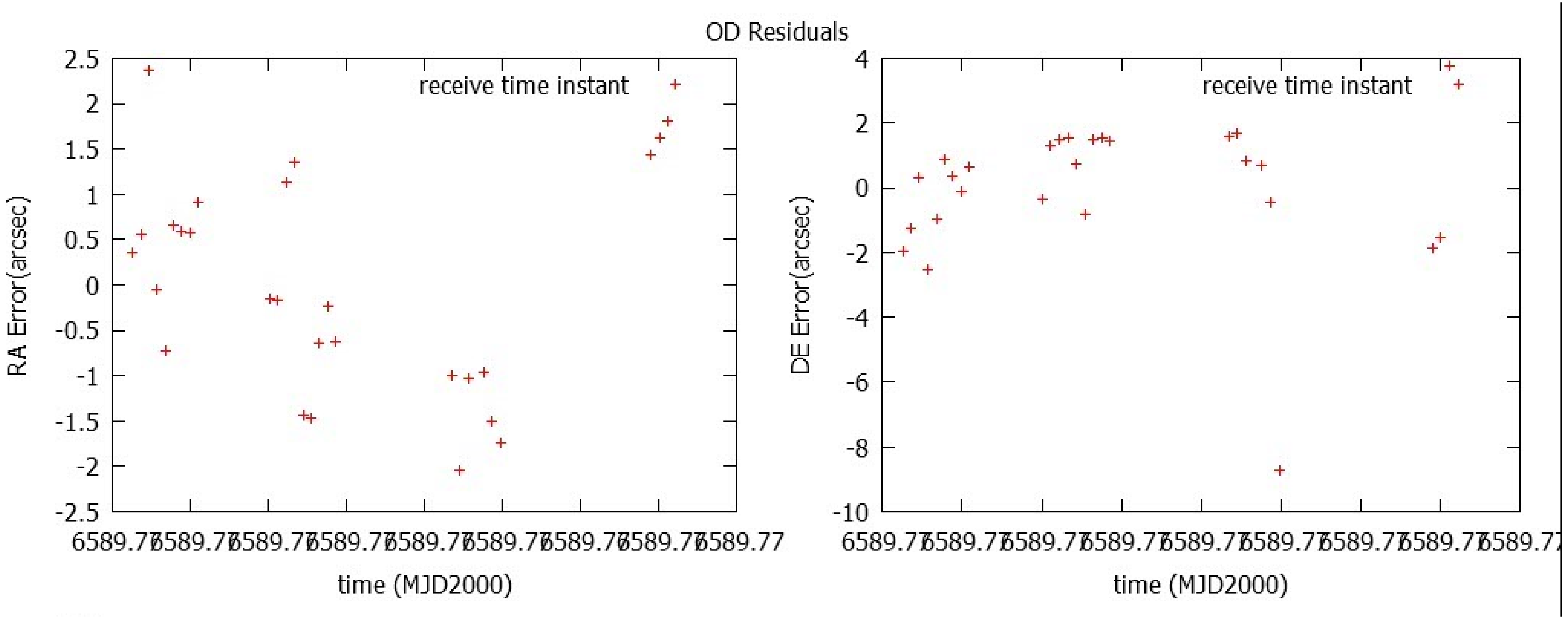




OBSERVATION OF TIANGONG-1

January Observation from DeSS / Spain (15-16 January 2018)

- Orbit Computation
  - Observations residuals



OBSERVATION OF TIANGONG-1

January Observation from DeSS / Spain

- Lessons learnt and Required upgrades for improving performances.
  - In spite not being a surveillance sensor, a bigger Field of View is required
    - to track and not miss fast angular speeds objects > 1º per seconds along their very short visibility windows
    - even more when expecting some fragmentations and TLEs uncertainty.
  - The increase of FoV can be achieved:
    - by reducing a bit the focal length of the system
    - rather than increase the size of the CCD camera, which usually introduces, with more pixels, slower imaging read-out and time.
  - As fastest as possible image cycle is mandatory
  - Processing of the images must deal correlating single detections on fully different FoVs, that not share same stars background, several degrees apart
  - Bright objects and saturation problems

OPTICAL OBSERVATION OF RE-ENTERING OBJECTS

Summary

- Approaches similar to traditional MEO/GEO optical observations can benefit the operational and accurate observation in LEO regime, when accounting for:
  - o Better time Tagging
  - o Trailing losses
  - o Optimum Exposure Times

- The design of a LEO sensor shall account for the observing strategy and the image processing mode
  - o The principle of trailing losses guides the full sensor concept related to resolution, FoV and exposure times definition and the way on how the processing of the images for auto-detection is implemented.

- The angular speed and the apparent brightness (phase angle) of the objects are the driving parameters concerning the ‘detectability’ capabilities more than the limiting orbital altitude ranges and object sizes.

- Below 2 arcseconds accuracy on single measurements corresponding to uncertainties of around 10 meters at 800 kms are possible with Antsy experimental low cost setup

- Re-entering objects can be observed, being the most demanding case, although feasible

EXPANDING FRONTIERS

Noelia Sánchez-Ortiz
noelia.sanchez@deimos-space.com

@ElecnorDeimos