# Recent Experience in Operating the First Quantum and Optical System of Satellite Laser Ranging Installed in Brazil

**Renato Alves Borges, Geovany Araújo Borges, Gennady Saenko, Andrey Pavlov**

raborges@aerospace.unb.br, gaborges@unb.br, g.saenko@mail.ru, pavlov_andrey@hotmail.com

Universidade de Brasília, Brasília - Brazil

OJC - RPC - PSI, Moscow - Russia


UN/Russian Federation Workshop on Applications of GNSS
IEBC, Krasnoyarsk, Russia
May $18^{th}$ – $22^{nd}$, 2015

## Timeline Overview

2006 Brazilian and Russian governments signed an agreement to install GLONASS reference and monitoring stations in Brazilian territory;

2012 Brazilian Space Agency elected University of Brasília to receive the first station;

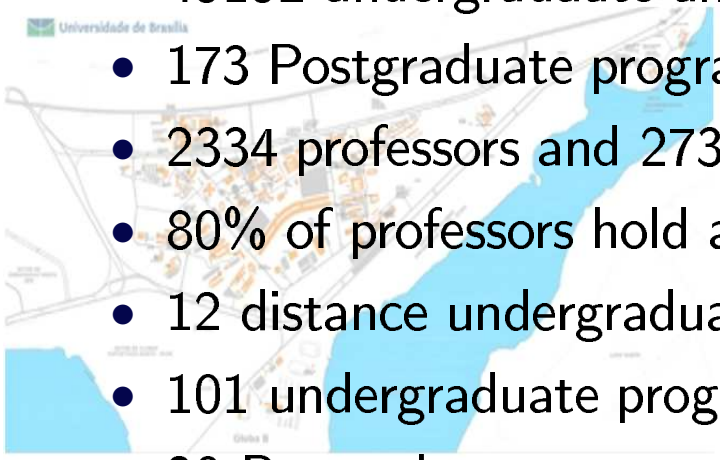
2013 GLONASS Differential Correction Station start operation;

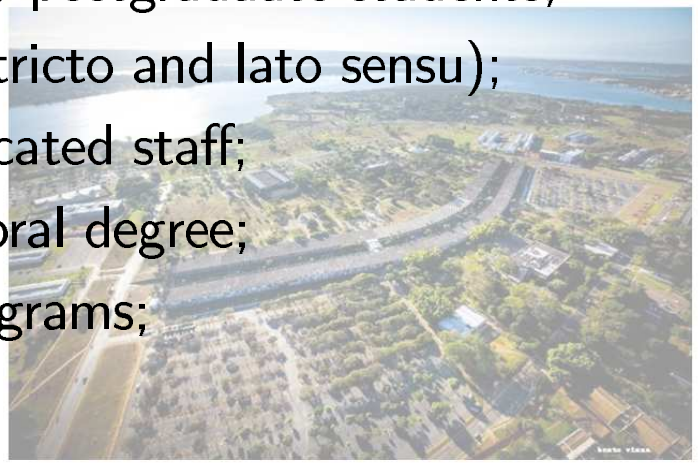
2014 GLONASS Quantum Optical Station start operation.

# Brasília city

# The University of Brasília

## UnB in numbers



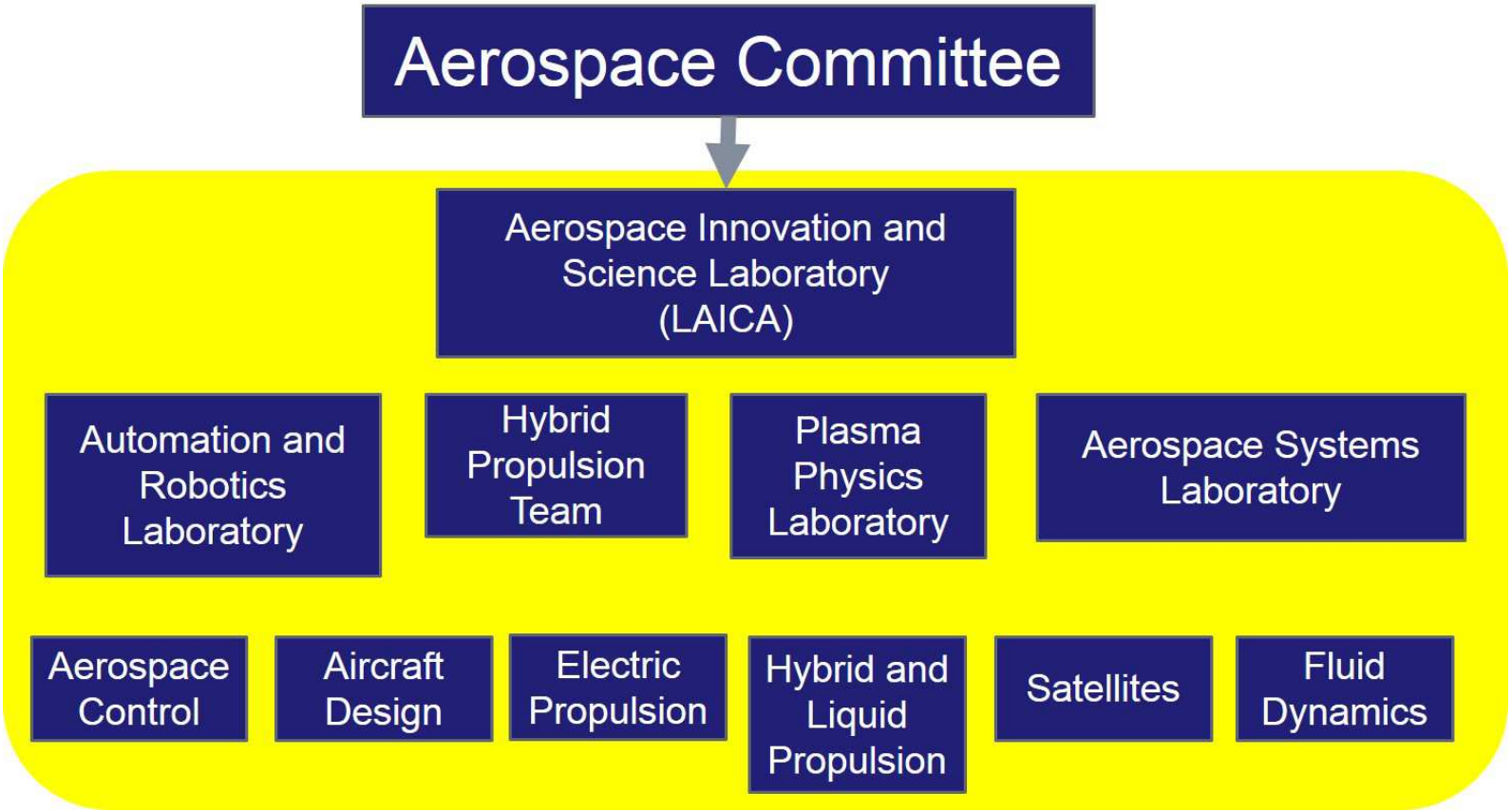



- 45152 undergraduate and 8019 postgraduate students;
- 173 Postgraduate programs (stricto and lato sensu);
- 2334 professors and 2738 dedicated staff;
- 80% of professors hold a doctoral degree;
- 12 distance undergraduate programs;
- 101 undergraduate programs;
- 20 Research centers;
- 26 Faculties;
- 4 Campuses;

$\Rightarrow$ 238 agreements with universities from 50 countries and International Organizations.

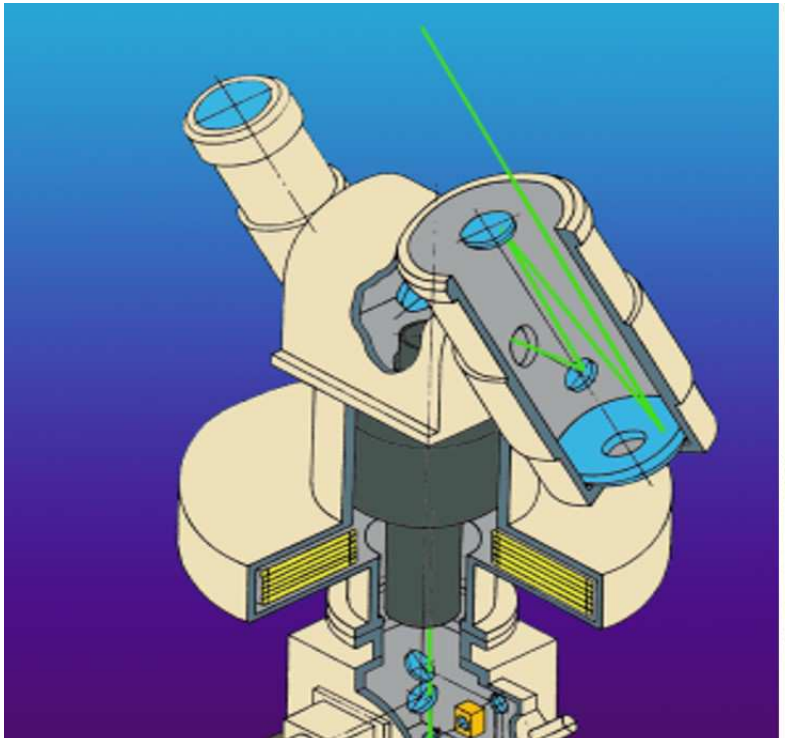
# Aerospace Infrastructure

## Aerospace Administrative Structure



# Compact Laser-Optical System for SLR, Angular Measurements and Photometry

| **Mount Parameters** |
|---|
| Mount type Az-El, with two flanges for equipment mounting |
| Digitally controlled torque motor drive |
| Equipment weight on each mount flange $\leq 20kg$ |
| Angular elevation rotation range from 0 to 90 deg |
| Angular azimuth rotation range from $-270$ to 270 deg |
| Maximum angular speed and acceleration are $30deg/s$ and $5deg/s^2$ |



# Compact Laser-Optical System Parameters

- **SLR of SC with retroreflectors:**

| Parameter Description | Feature |
|---|---|
| SC orbit height range | 400 to 36000 *km* |
| Orbit height for SC daytime measurements | 400 to 6000 *km* |
| NP RMS error (averaging interval 60s) | 0.5 to 2 *cm* |
| Elevation range | 20 to 85 *deg*. |

- **Angular measurements:**

| Parameter Description | Feature |
|---|---|
| Visual star magnitude | $\leq 14^m$ |
| RMS error for SC angular velocity up to 40 arcsec | $2''$ |

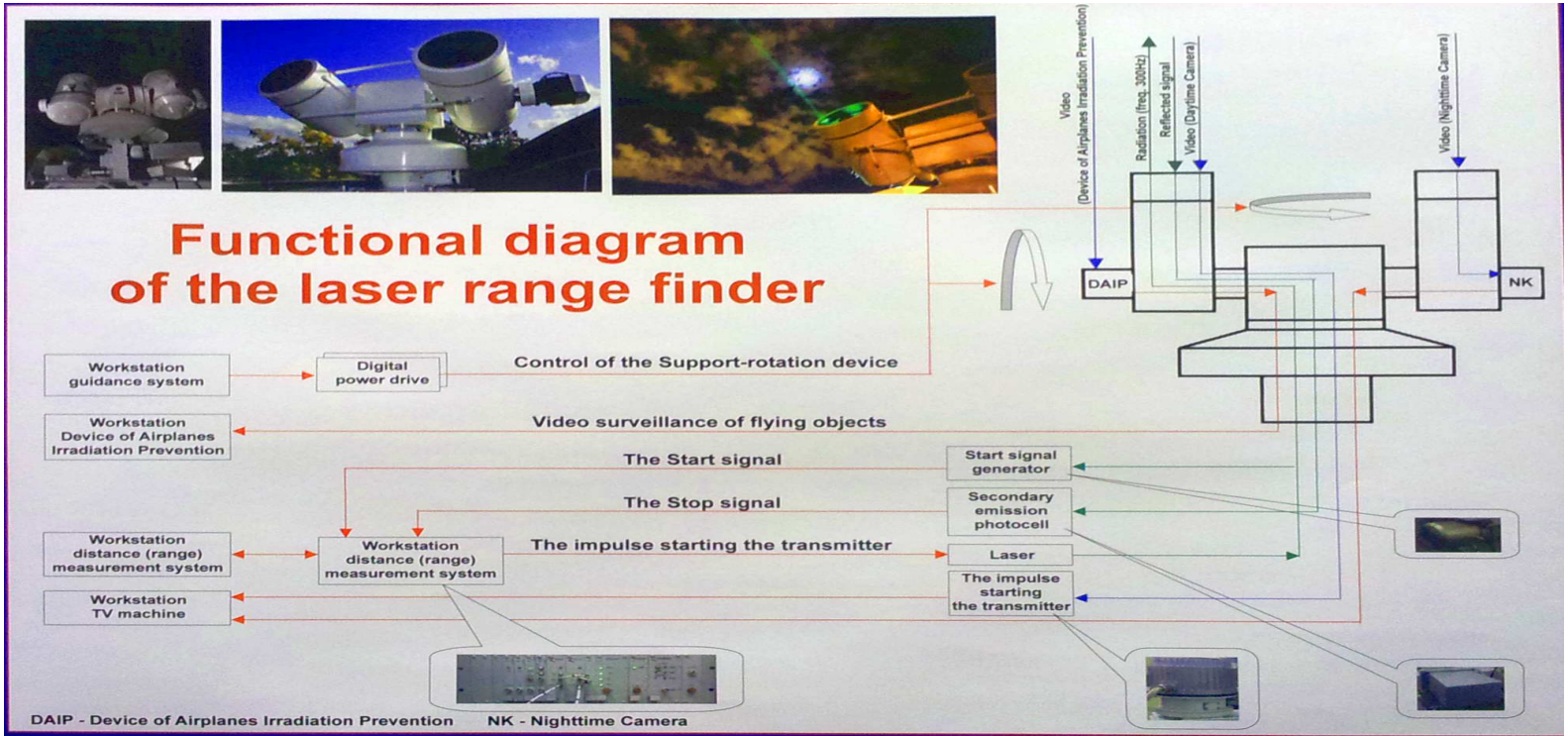
- **Photometry:**

| Parameter Description | Feature |
|---|---|
| Visual star magnitude | $\leq 12^m$ |
| Brightness determination error | $0.2^m$ |

# Compact Laser-Optical System Parameters

- **Laser ranging system parameters:**

| Parameter Description | Feature |
|---|---|
| Operation wavelength | $532nm$ |
| Pulse repetition rate | $300Hz$ |
| Laser pulse duration | $150ps$ |
| Minimum laser pulse energy | $2mJ$ |
| Output beam divergence | $5arcsec$ |
| Receive telescope diameter | $25cm$ |
| Laser fire epochs accuracy | $200ns$ |



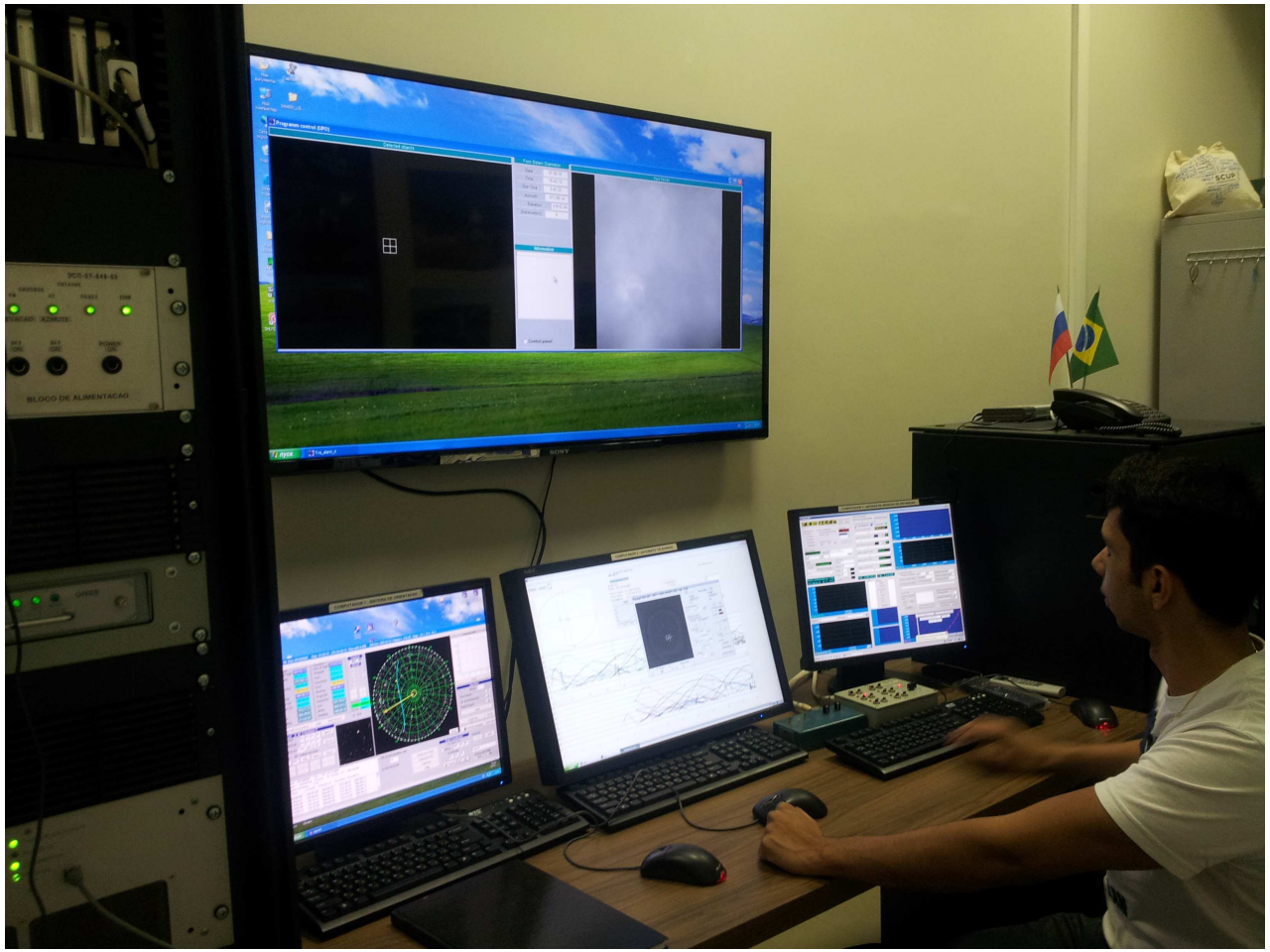
# One Way Station and ILRS

- **One Way Sation and IRLS:**
  - $\rightsquigarrow$ $L_1$ and $L_2$ radio signals receivers for GPS and GLONASS;
  - $\rightsquigarrow$ IRLS Site Code BRAL, Station #7407, DOMES# 48081S001, 15.7731 S, 132.1347 W.

# Operation of the QOS for SLR

## Activities in this first year:

- Technical team training;
- Software and hardware update.



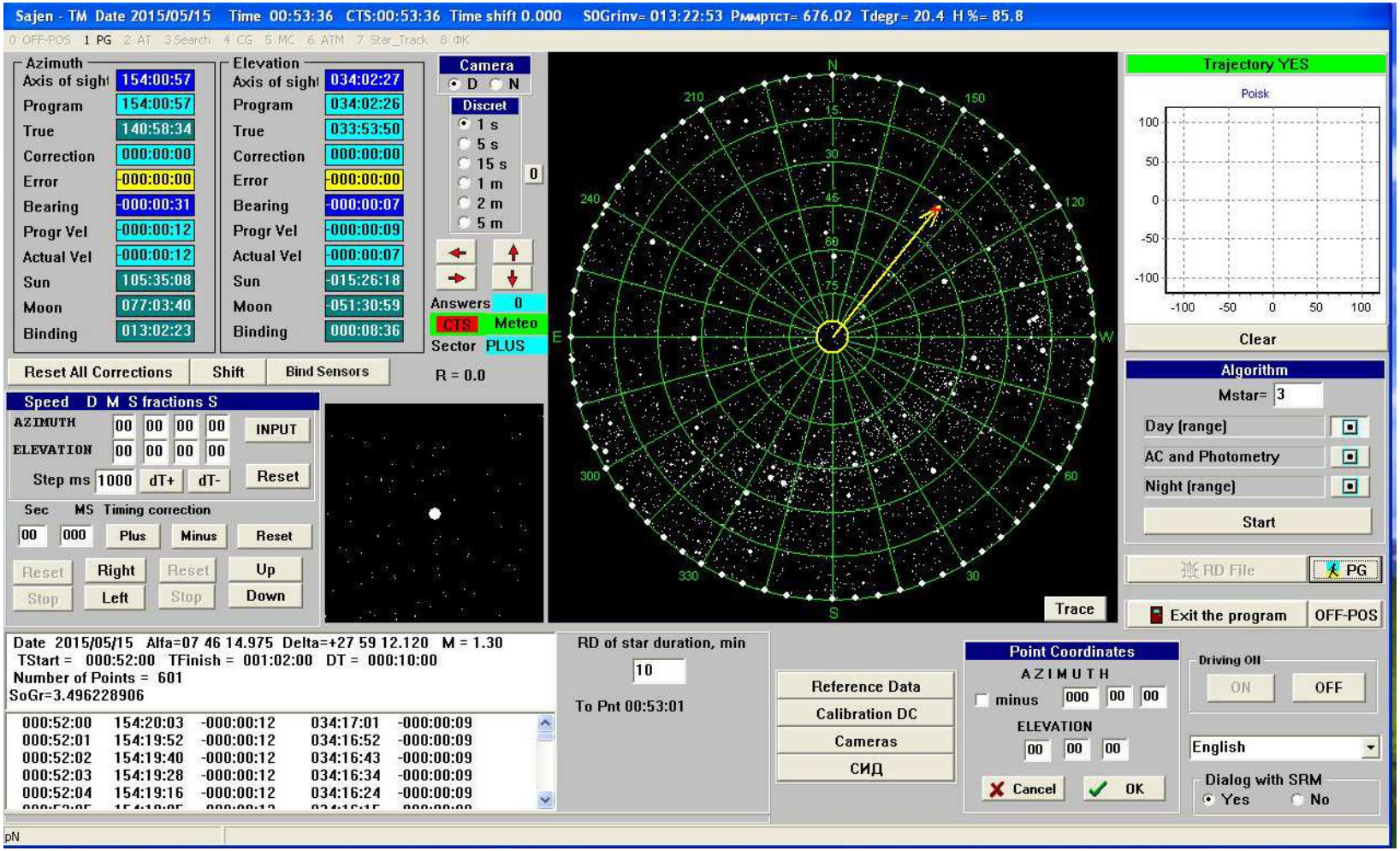
# Operation of the QOS for SLR

## Activities in this first year:

- GLONASS system and the UnB QOS presentations;
- Authorities visits.

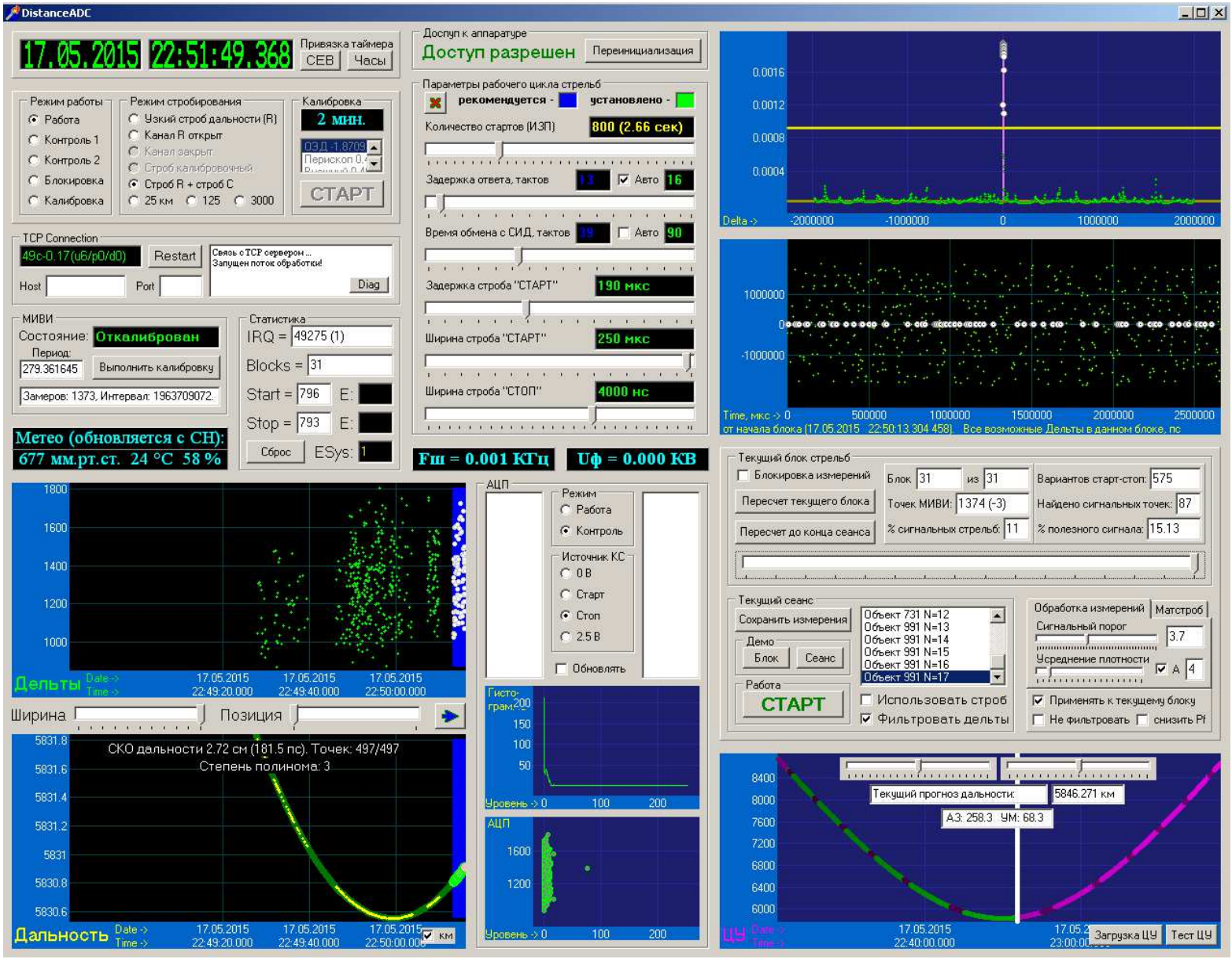
# Operation of the QOS for SLR

## Pointing/tracking control virtual panel.



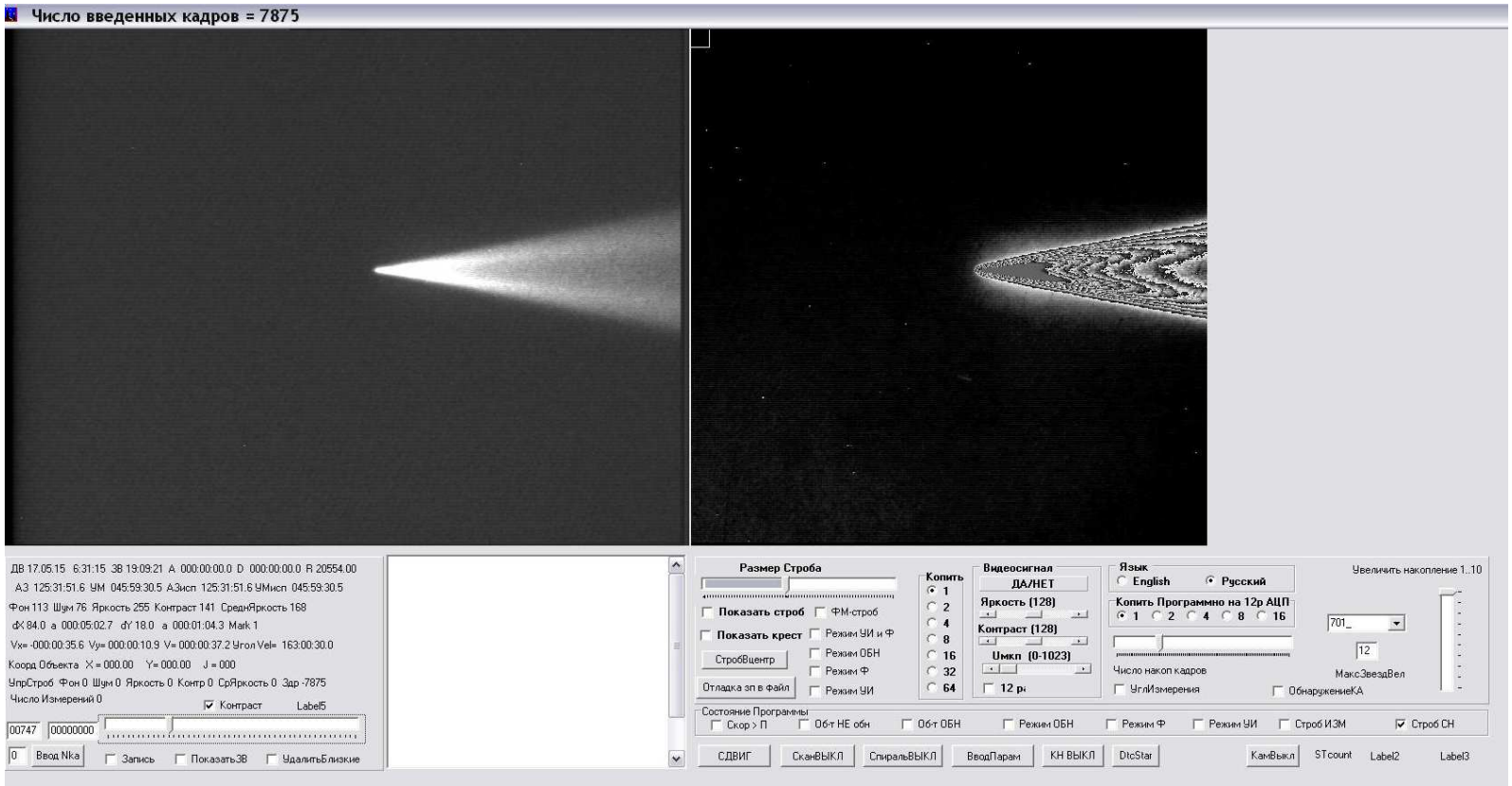
# Operation of the QOS for SLR

## Laser ranging control virtual panel (Lageos satellite 991).



# Operation of the QOS for SLR

Night camera virtual panel (Glonass satellite 747).



# Operation of the QOS for SLR

Some statistics.

| MONTH | WORKING DAYS | TOTAL MEASUREMENTS | SUCCESS | FAILURE | AVG. SUCCESS/DAY | % SUCCESS |
|---|---|---|---|---|---|---|
| Aug/2014 | 12 | 245 | 212 | 33 | 17.67 | 86.53 |
| Sep/2014 | 16 | 414 | 296 | 118 | 18.50 | 71.50 |
| Oct/2014 | 10 | 206 | 104 | 102 | 10.40 | 50.49 |
| Nov/2014 | 9 | 78 | 8 | 70 | 0.89 | 10.26 |
| Dec/2014 | 13 | 231 | 53 | 178 | 4.08 | 22.94 |
| **TOTAL** | **60** | **1174** | **673** | **501** | **11.22** | **57.33** |

Sample of the work done on 01/19/2015 - 27 success out of 53 tries.

| Satellite number | Start time | Stop time | Reflected signal | Amount reflected | RMS sm | Calibration (%) | Trajectory | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Rising | Zenith | Downward |
| 701 | 00:40 | 00:55 | | - | - | 13% | | | |
| 745 | 01:05 | 01:13 | | 691 | 3.77 | 13% | | | |
| 733 | 01:26 | 01:42 | | - | - | 13% | | | |
| 745 | 01:50 | 01:57 | | 1037 | 2.97 | 13% | | | |
| 701 | 02:12 | 02:19 | | 214 | 4.36 | 13% | | | |
| 733 | 02:26 | 02:40 | | - | - | 13% | | | |
| 755 | 02:46 | 02:51 | | 1359 | 2.86 | 14% | | | |
| 755 | 03:25 | 03:31 | | 900 | 2.9 | 14% | | | |
| 731 | 03:45 | 03:53 | | 443 | 2.91 | 14% | | | |

# Associated Research

## Current team at LAICA in the field of GNSS:

- 4 undergraduate students (more coming soon);
- 5 professors;
- 7 technical operators and support staff.

## Immediate applications:

- High-altitude balloons experiments;
- Advanced filtering solutions for GNSS/INS integration:
  - ⇝ Magnetometer sensitivity to local electromagnetic disturbances makes its use limited in GNSS/INS systems;
  - ⇝ Multi-model filtering can deal with such problem. MHF filters have been proposed and evaluated experimentally.
- UAV ground tracking using multi-GNSS solutions.

# Associated Research

## The LAICAnSat project:

- Development of a platform for aerospace systems testing and scientific experiments;
- Started in 2013 at LAICA;
- Divided in:
  - ⇝ Low Altitude Part (LAP): study of guidance of airdropped systems;
  - ⇝ High Altitude Part (HAP): high-altitude balloons experiments.

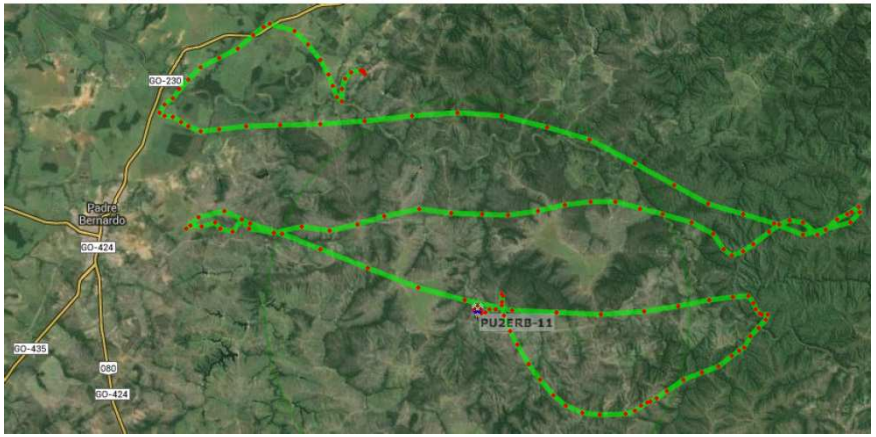
## Motivation:

- Study of airdropped systems for aerial delivery application;
- Cansats educational programs from Brazilian Space Agency (AEB);
- Platform for multidisciplinary experiments;
- Students training on aerospace systems;
- Low budget.

# LAICAnSat Launches


LAICAnSat-1, May 2, 2014.

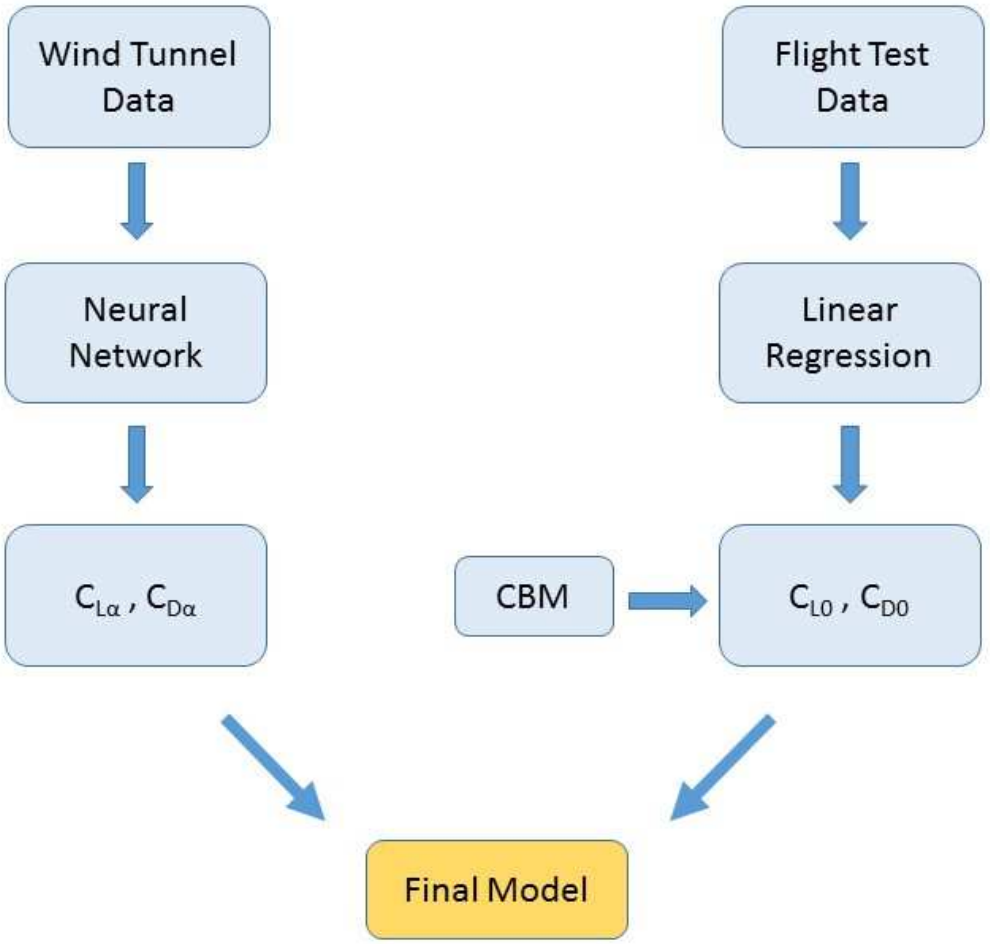

LAICAnSat-2, May 24, 2014.




LAICAnSat-1 trajectory.

# Aerodynamic Coefficients Estimation Using GNSS

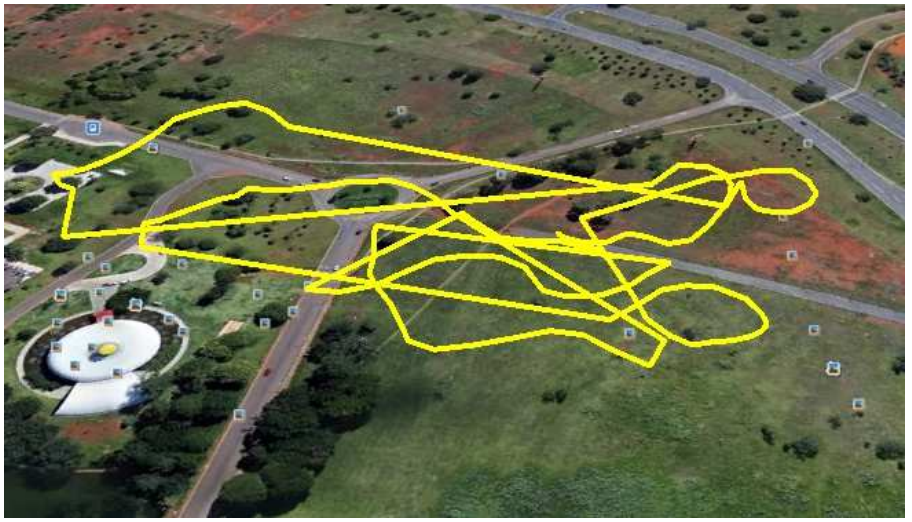
## Aerodynamic model identification procedure.[1]




[1] A. V. S. Silva et al. System identification of a square parachute and payload for the LAICAnSat. In Proc. of the 36th IEEE Aerospace Conference, Montana, USA, March 2015.

# Aerodynamic Coefficients Estimation Using GNSS

- Flight tests under different weather conditions (humidity, wind, temperature);
- Analysis of straight segments of trajectory;
- Constant control deflection;
- Constant forward airspeed $V_0$ and wind vector $\vec{V}_W$ assumption;
- $V_0$ and $\vec{V}_W$ to be estimated based on GPS positions;
- Aerodynamic and gravity are the only considered forces.



Complete test trajectory.

Selected data.

# Future LAICAnSat Perspectives

- **Standardization of LAICAnSat subsystems:**
  - ⇝ Payload structure (3U Cubesat);
  - ⇝ Electronics and avionics (microprocessor, radio with duplex communication system, APRS tracking system, actuators);
- **Boarding of scientific and technological payloads:**
  - ⇝ Fault-tolerant embedded systems with reconfigurable self-healing hardware (in collaboration with KTH, SAAB)
  - ⇝ Multi-GNSS solutions (GPS, GLONASS, Galileo and BeiDou);
  - ⇝ Differential GLONASS;
  - ⇝ PNT based on carrier phase and code measurements;
- **Unifying HAP and LAP experiments:**
  - ⇝ Guidance system implementation;
  - ⇝ Impact point prediction;
  - ⇝ Ground station design and construction.

# Conclusions and Future Works

- The GLONASS SLR and OW station represents an **excellent opportunity for the advancement of research on GNSS in Brazil**, especially at UnB, and also **improve the accuracy of PNT in the South America**;
- This first year operating the SLR station was important for **technical team training, adjustment of the station equipment, and providing a better understanding of the weather condition** in our region and its impact on the operation of the station;
- Future perspectives include:
  - ⇝ study and evaluation of atmospheric error models in our region;
  - ⇝ GLONASS precise position;
  - ⇝ study of SBAS typical architecture and implementations;
  - ⇝ **practical applications on HASP (LAICAnSat) and multipurpose autonomous rovers travelling (UE H2020)**.

# Thank You!

## Thank You For Your Attention!

UnB,
Brasília - Brazil

OJC - RPC - PSI,
Moscow - Russia


## Acknowledgements:

AEB
Brazilian Space Agency

ROSCOSMOS
Russian Space Agency