NAVIGATION OF THE RADIOASTRON MISSION

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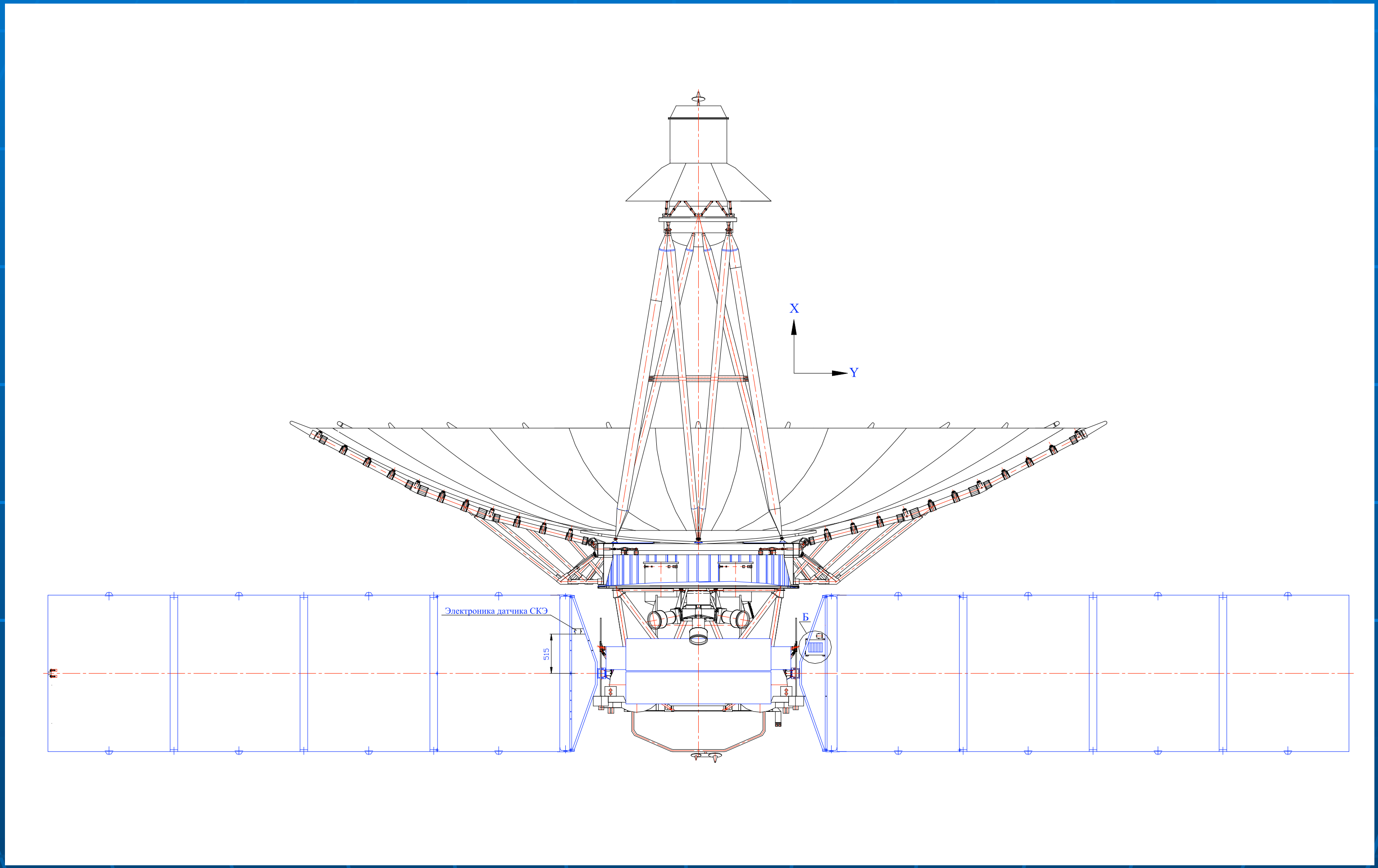
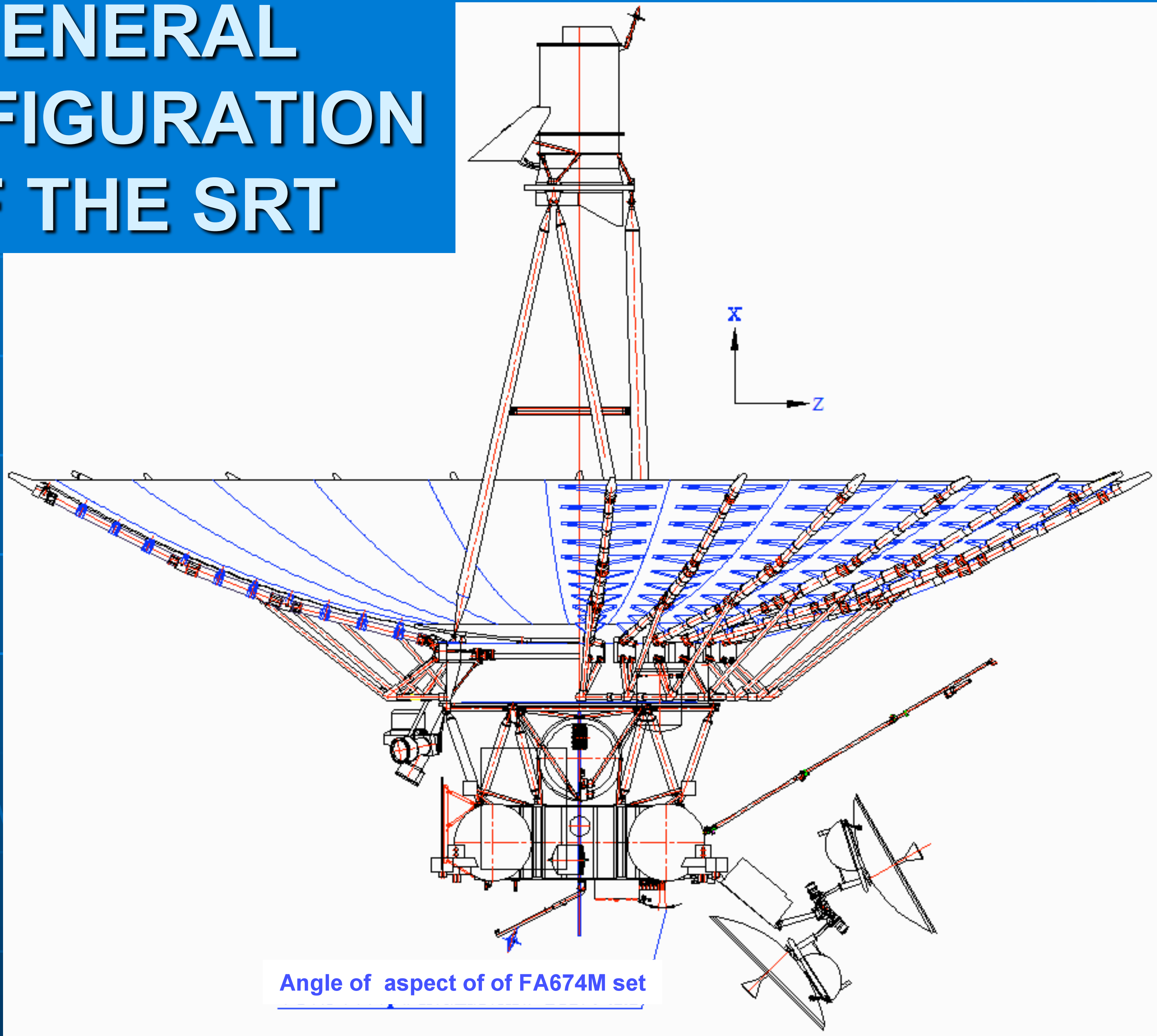
SC CONSTRUCTION / GENERAL VIEW

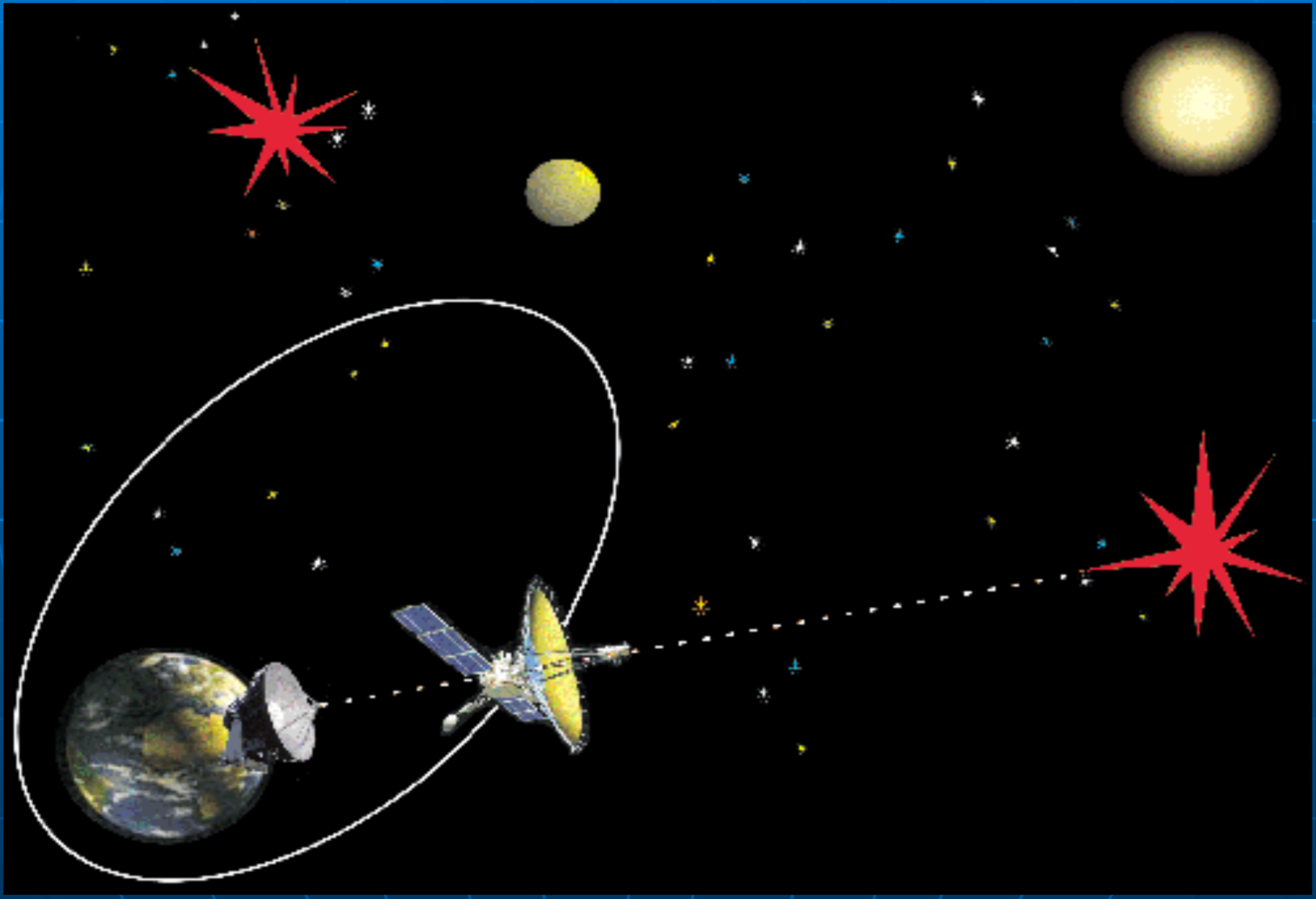


- $S_m = 93.000 m^2$ – profile area,
- $S_l = 17.000 m$ – typical size.

GENERAL CONFIGURATION OF THE SRT



THE GROUND-SPACE RADIO INTERFEROMETER (ARTIST'S VIEW)



GENERAL OUTLINE

RadioAstron project is an international collaborative mission to launch a free flying satellite carrying a 10-meter radio telescope in high apogee (~350,000 km) orbit around the Earth. The aim of the mission is to use the space telescope to conduct interferometer observations in conjunction with the global ground radio telescope network in order to obtain images, coordinates, motions and evolution of angular structure of different radio emitting objects in the Universe with the extraordinary high angular resolution.

BASIC PARAMETERS OF THE SPACE RADIO TELESCOPE

Band	P	L	C	K
Frequencies (MHz) of observations	327	1665	4830	18392-25112
Bandwidth (MHz) for each polarization	4	32	32	32
Fringe size (μas) [base line 350 000 km]	540	106	37	7,1 -10

GROUND RADIO TELESCOPES

		Spectral bands				
Radio Telecope	Diameter (m)	P	L	C	K	Supposed observing time in % *)
Arecibo	305	+	+	+	-	5
ATCA	50	-	+	+	+	10
Bear Lakes	64	+	+	+	-	40
Bonn	100	-	+	+	+	20
Evpatoria	70	+	+	+	-	95
GBT	100	-	-	+	+	15
GMRT	240	+	-	-	-	5
Goldstone	70	-	+	+	+	15
Jodrell Bank	76	+	+	-	-	15
Kalyazin	64	+	+	+	-	50
Madrid	70	-	+	+	+	15
Parkes	64	+	+	+	+	10
Tidbinbilla	70	-	+	+	+	15
VLA	130	+	+	+	+	15
VLBA	80	+	+	+	+	20
WSRT	90	+	+	+	-	20

SCIENTIFIC PROGRAM

The main scientific goal of the mission is to investigate a variety of astronomical objects with an unprecedented angular resolution up to several millionth of arcsec.

The resolution achievable by RadioAstron would permit an investigation of the following targets of great interest of modern astrophysics:

- A study of the central engine of Active Galactic Nuclei (AGN) close to the events' horizon of the supermassive black hole, via their structure and emitting nuclear regions dynamics, and, also, their spectra, polarization and variability.
- Parameters of the cosmological model, dark matter and dark energy in the Universe determined by means of the redshift dependence of the AGN para-meters, and, also, by effects of gravitational lensing.
- Structure and dynamics of the star formation regions by the maser and megamaser spectral line emission.

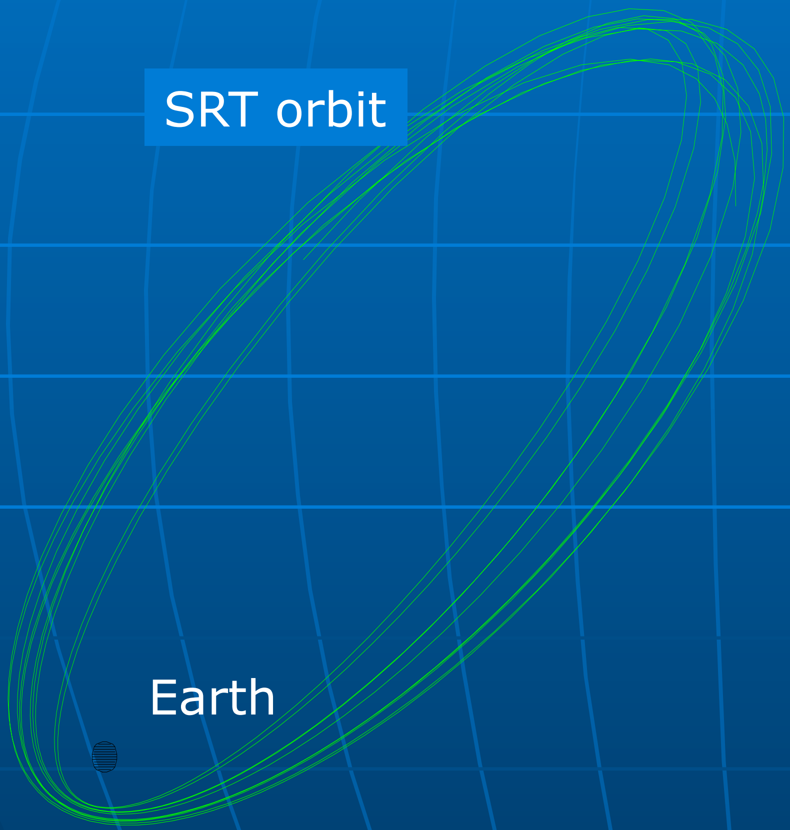
SCIENTIFIC PROGRAM

Continuation...

- A structure of the star mass black holes, neutron and possible quark stars in our Galaxy (particularly, by the “interstellar interferometer” method), and determination of their proper motions and parallaxes.
- Structure and distribution of the interplanetary and interstellar matter by the investigation of fluctuations of the visibility function scintillation of pulsars.
- Construction of a high precision celestial coordinate frame.
- Development of a high precision model of the Earth gravitation field, and

  General Relativity tests by means of the precision redshift measurements.

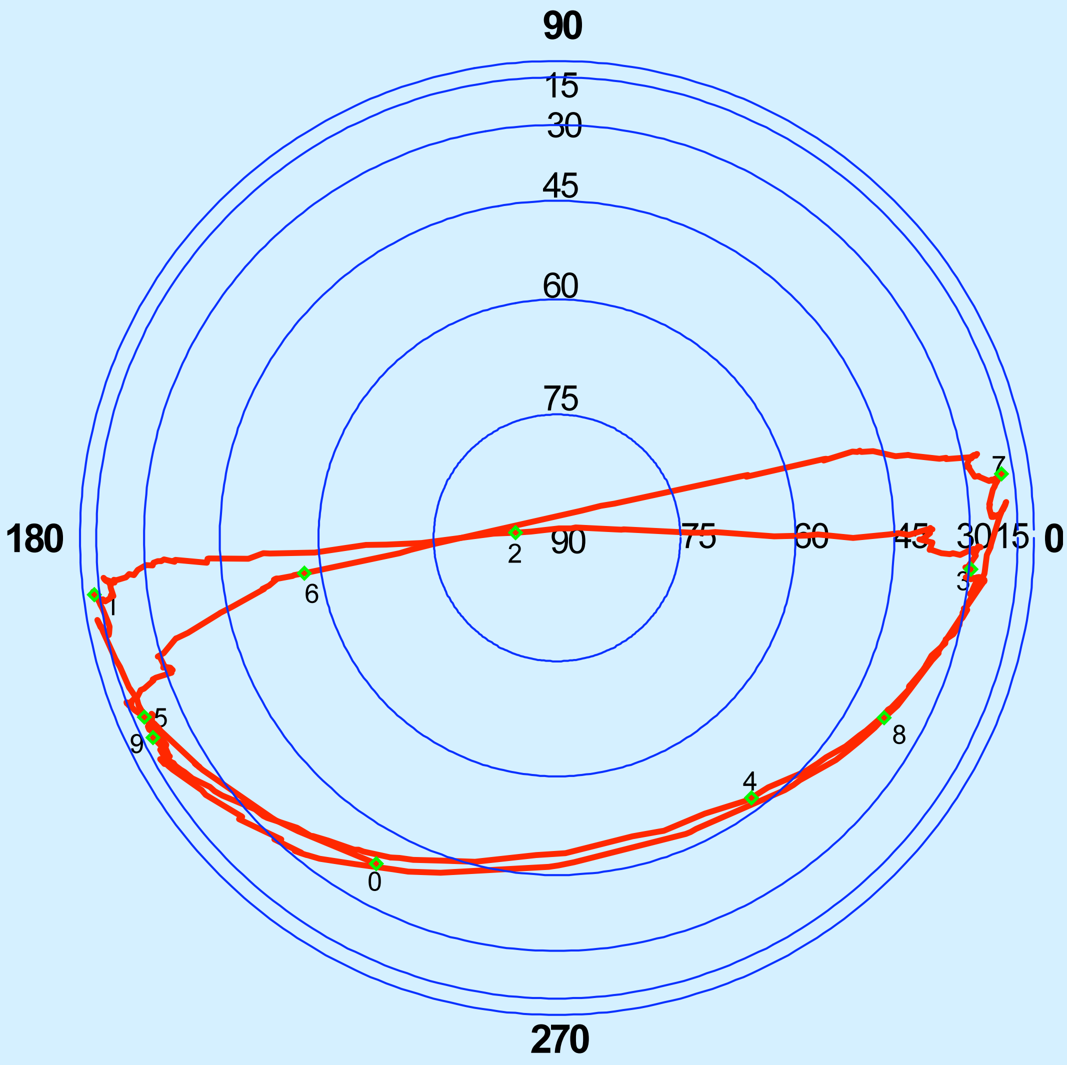
SEGMENT OF ORBIT OF SRT



Initial orbital parameters

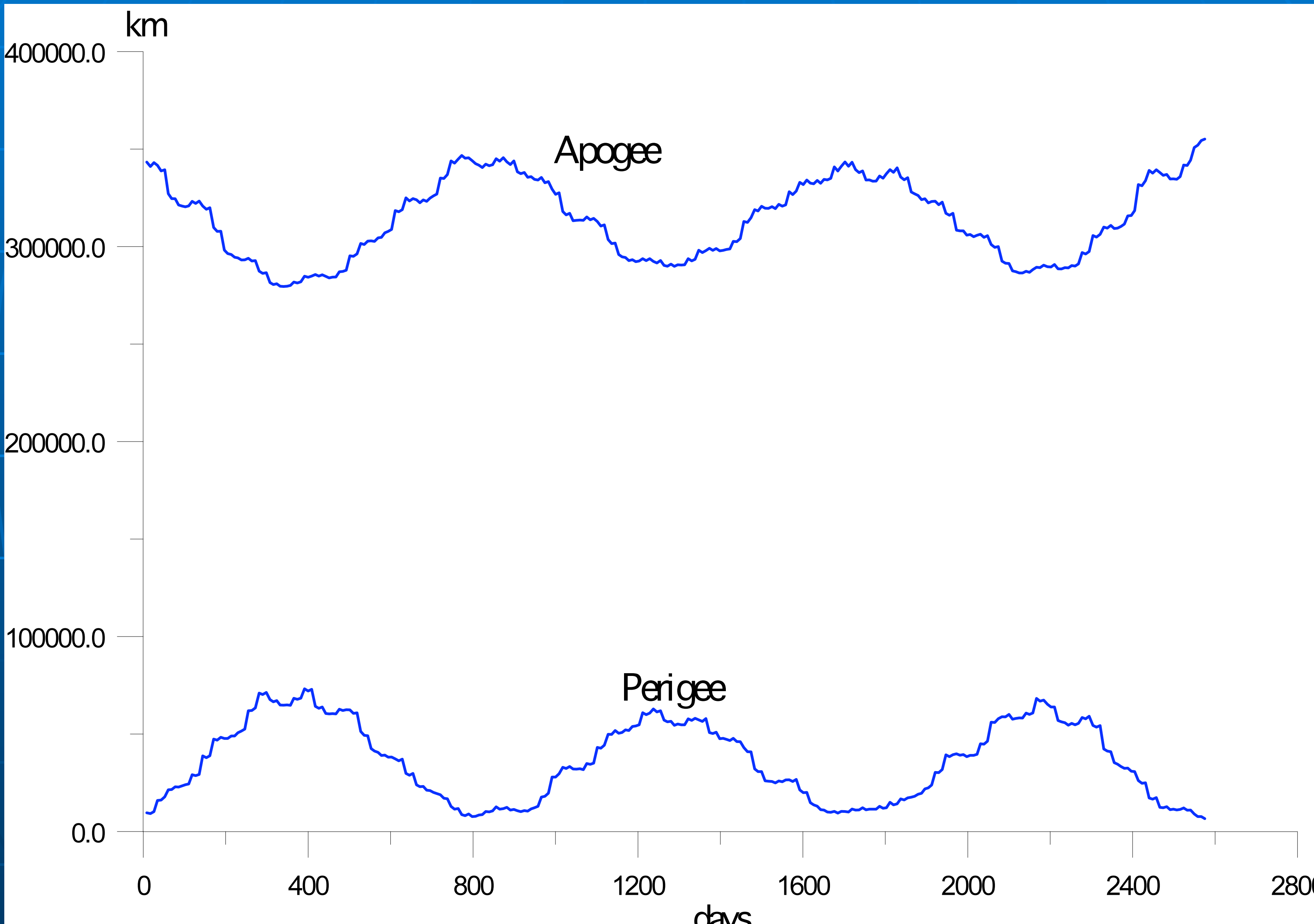
- Apogee Height: 330,000 km
- Perigee Height: 400 км
- Period: ~ 8 days
- Inclination i : ~ 51.4°
- Argument of perigee ω: 292°
- Longitude of ascending node Ω: 331°

EVOLUTION OF NORMAL VECTOR TO ORBITAL PLANE FOR 9 YEARS



Significant evolution of normal to orbital plane vector makes it possible to observe radio sources in very different parts of northern celestial hemisphere thus allowing to us to state and proceed various astrometrical problems

APOGEE AND PERIGEE EVOLUTION FOR 7 YEARS



THE ACCURACY REQUESTS

Forecast errors of the spacecraft motion parameters should not exceed

Position	±600 m
Velocity	±20 mm/s
Acceleration	±10-8 m/s2

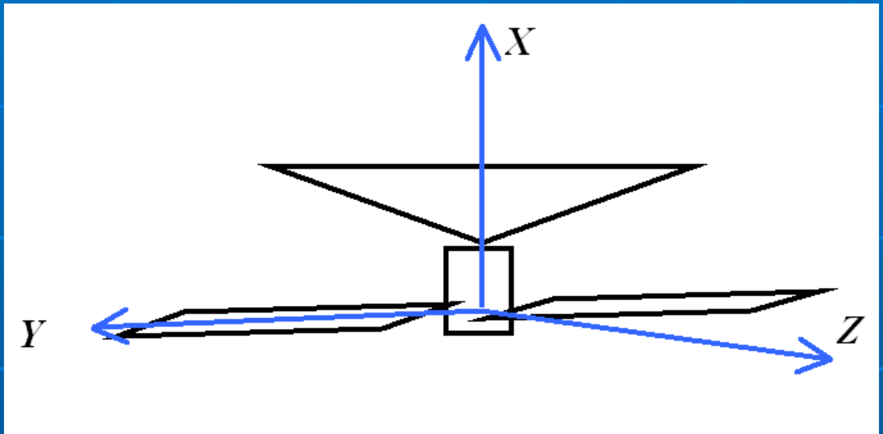
This accuracy is necessary for radio-maps construction.

But for solving astrometrical problems this accuracy <u>is not sufficient</u>!

THE DIFFICULTIES OF THE NAVIGATION

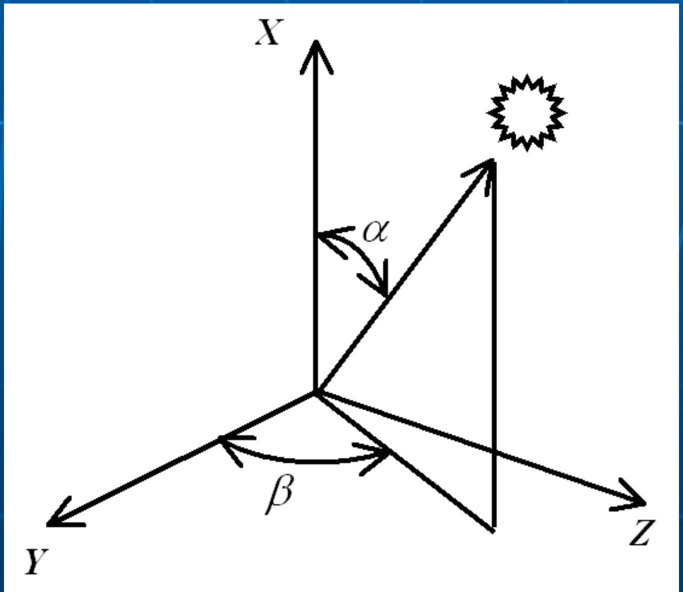
- Great distance from the Earth
- Uncertainty of the gravitational field at large distances from Earth
- The uncertainty of the Sun radiation model
- The uncertainty of earth magnetic field
- The pressure of solar radiation has an effect on the different elements of spacecraft surface thus creating force-moments around the spacecraft center of masses
- Non gravitation perturbation due to the absence of the orientation moments scheme in wheels desaturation procedure
- Location of the laser retro reflector array (LRA) limiting time of using SLR only to some special technological hours

SC ORIENTATION RELATIVELY TO THE SUN

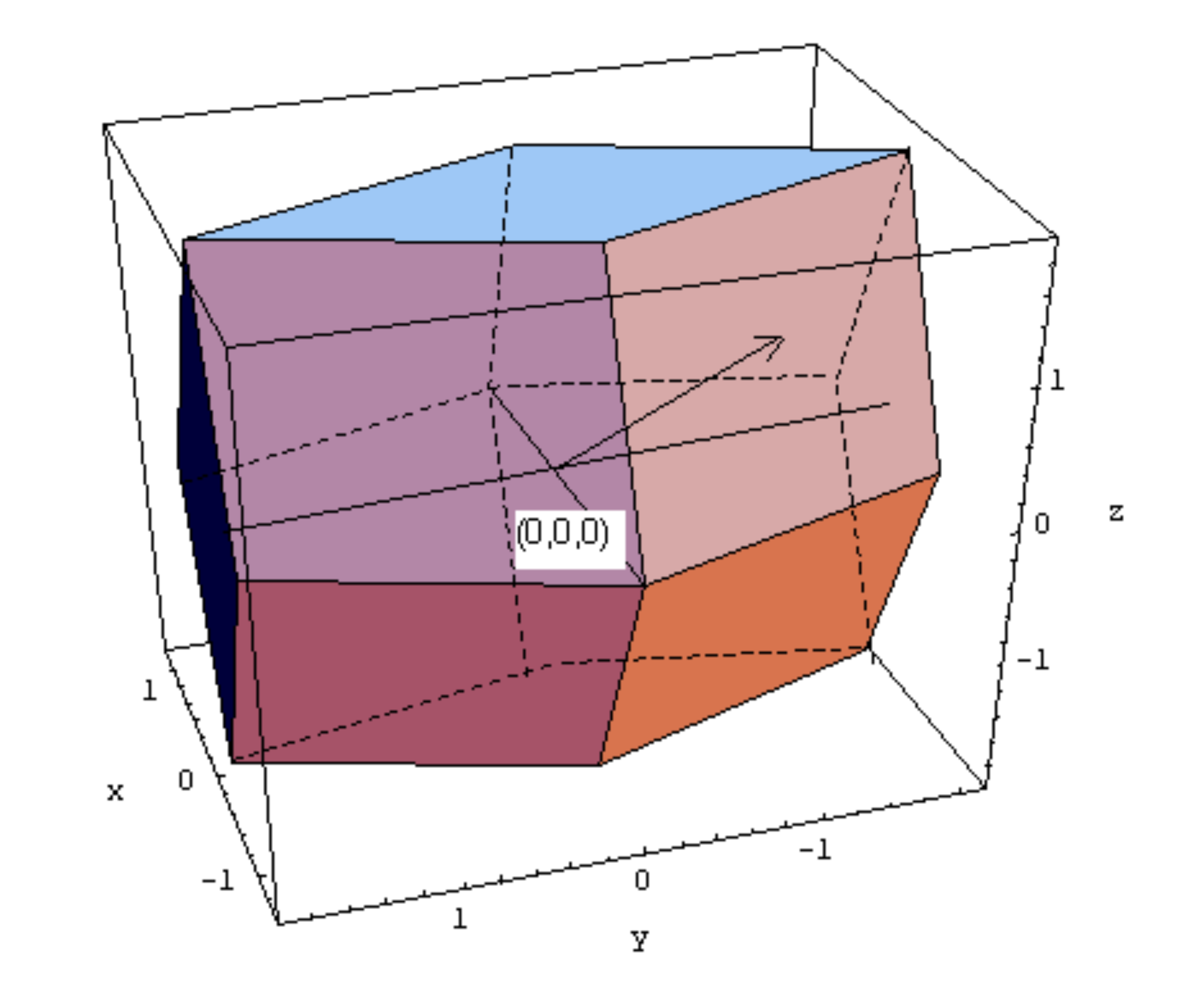


SC orientation relatively to the Sun is defined by two angles α and β in the structural coordinate system (OXYZ)

Structural Coordinate System (OXYZ)



POSSIBILITIES OF MOMENTUM'S SATURATION



Possibilities of acccumulated momentum's saturation are exhausted when the momentum vector goes out of the figure of disposable kinetic momentum.
At this time there must be procedure of desaturation of reaction-wheel system

Accumulated kinetic momentum arisen from forces of solar radiation pressure (vector) and the figure of disposable kinetic momentum

DURATION OF THE FLIGHT WITHOUT RWS DESATURATION

For mostly practically interesting angles α and β

Days		α								
		90 °	100 °	110 °	120 °	130 °	140 °	150 °	160 °	170 °
β	80°	2.02	2.24	3.35	8.28	5.08	3.06	2.80	3.53	6.91
	90 °	1.97	2.16	3.24	8.46	11.9	3.06	2.76	3.46	6.79
	100 °	2.02	2.24	3.35	8.05	4.91	3.06	2.80	3.53	6.91

FEATURES OF THE RWS DESATURATION PROCEDURE

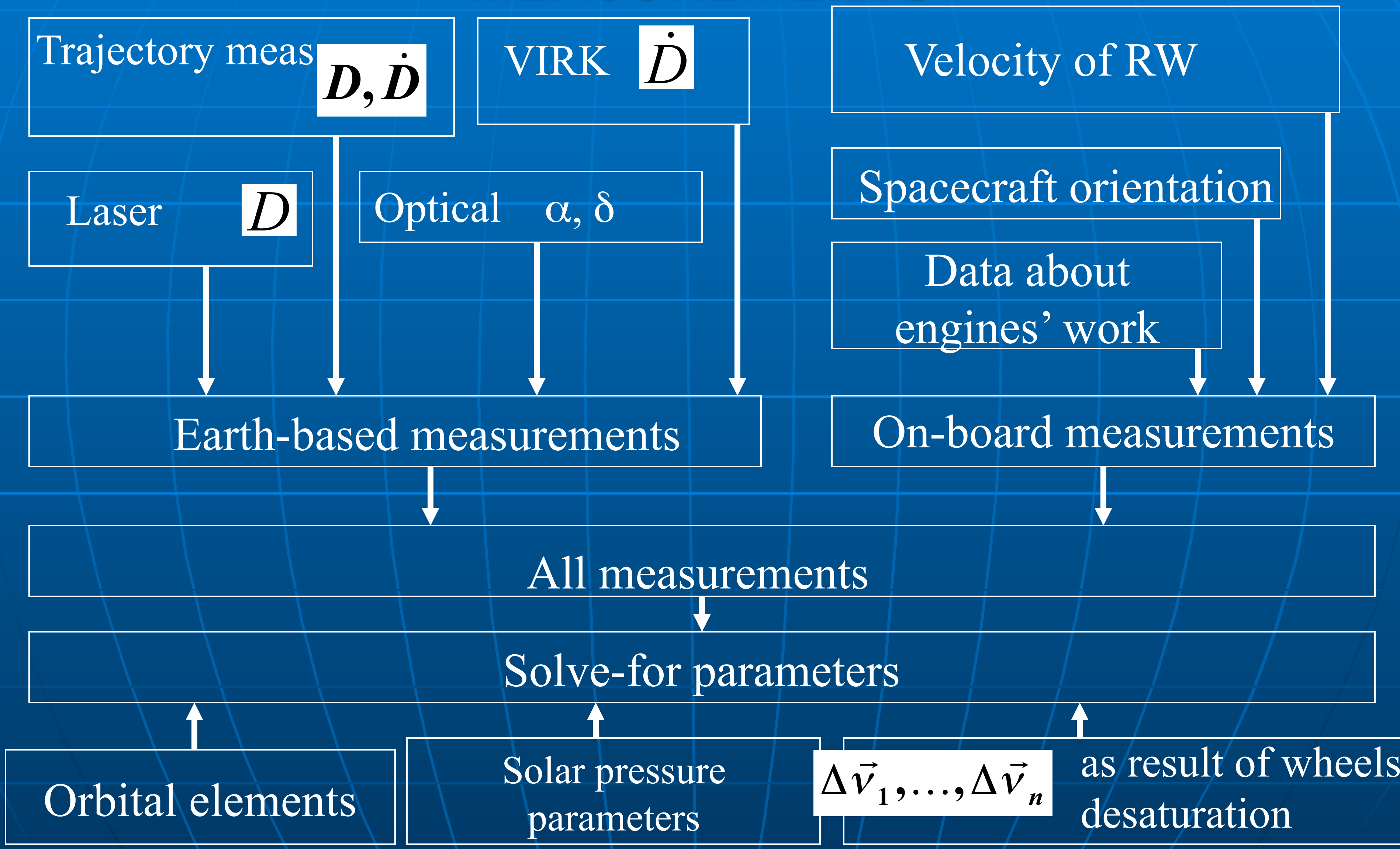
- Desaturation is done by the stabilization engines
- Desaturation of momentum along axis Oy and Oz of Structural Coordinate System leads to turning-on of engines creating acceleration of center of mass of SC during engines' thrusting
- Force applied to center of mass of SC is pointed along positive values of Ox axe
- As a result center of mass of SC inherits additional ("parasitic") impulse
- Additional impulse coordinates y and z are equal to zero, while x-component is non-zero and positive

So the flight can not be considered as passive motion it is an active one!

ACQUIRED VELOCITY IMPULSE (DESATURATION OF MOMENTUM ALONG OY AXE)

Velocity (mm/s)		α									
		90º	100º	110º	120º	130º	140º	150º	160º	170º	180º
β	80º	7,8	7,8	7,8	7,4	3,8	7,8	7,8	7,8	7,8	7,8
	90º	7,8	7,8	7,8	7,8	7,8	7,8	7,8	7,8	7,8	7,8
	100º	7,8	7,8	7,8	7,2	3,7	7,8	7,8	7,8	7,8	7,8

FITTING PARAMETERS ESTIMATION FROM EARTH-BASED AND ON-BOARD MEASUREMENTS



RADIO MEASUREMENTS

On Control Stations (CS, Ussuryisk, Bear Lakes) there will be measurements of distance to the SC *D* and radial velocity *D'*, with accuracies

$$\sigma_D = 20\ m$$
$$\sigma_{D'} = 0.2\ mm/sec$$

On Tracking Stations (TS, Pushino, Green Bank, Titbinbilla and others) there will be measurements of radial velocity *D'*, with accuracy

$$\sigma_{D'} = 0.1\ mm/sec$$

On the Laser Ranging Stations there will be measurements of distance to the SC with accuracy

$$\sigma_D = 10\ cm$$

After correlation data processing there will be the group time delay τ and the frequency of interference f received

ESTIMATION OF THE SPACECRAFT MOTION PARAMETERS AS WELL AS SOLAR PRESSURE AND VELOCITY IMPULSES

Estimated parameters:

$\vec{X}_0$ – state-vector of the SC at the t_0

$\Delta\vec{v}_1,\ldots,\Delta\vec{v}_n$ – velocity impulses at $t_1,\ldots,t_n$

κ – solar pressure coefficient

$\psi^C = \psi\left(\vec{X}\left(t, \vec{X}_0, \kappa, \Delta v_1, \ldots, \Delta v_n\right)\right)$ – calculated values of tracking measurements

$\vec{X}\left(t, \vec{X}^+\left(t_k, \vec{X}^+\left(t_{k-1}, \ldots, \vec{X}^+\left(t_1, \vec{X}_0\right)\right)\right)\right)$ – calculated state-vector at the measurement time

$\vec{X}_i^+\left\{\vec{r}_i, \vec{v}_i^+\right\} = \left\{\vec{r}_i, \vec{v}_i + \Delta\vec{v}_i\right\}$ – state-vector after velocity impulse

$\Delta\vec{v}_1^{app}, \Delta\vec{v}_2^{app}, \ldots, \Delta\vec{v}_n^{app}$ – velocity impulses obtained from on-board measurements

THE FUNCTIONAL FOR MINIMIZATION

$$\Phi\left(\vec{Q}\right) = \sum_{k=1}^{N} p_k \left[\psi_k^O - \psi_k^C\left(t_k, \vec{X}_0, \vec{q}, \Delta\vec{v}_1, \ldots, \Delta\vec{v}_M\right)\right]^2 +$$

$$+ \sum_{j=1}^{N} \left[\Delta\vec{v}_j^{app} - \Delta\vec{v}_j\right] K_j^{-1} \left[\Delta\vec{v}_j^{app} - \Delta\vec{v}_j\right]^T$$

DETERMINATION OF ΔV FROM ON-BOARD MEASUREMENTS

From data about engines' work:

$$\Delta \vec{v}_k = \frac{\sum \vec{f}_i \Delta t_i}{m}$$

From velocity of reaction wheels:

$$\Delta \vec{v} = -\frac{\vec{K}}{d\, m}$$

$\vec{f}_i$ – thrust of engine , Δt_i – duration of engine's work, d – baseline, m – SC mass

SOME SCIENTITIC TASKS WHICH SOLVING NEEDS SLR

HIGHLY ACCURATE DEFINITION OF GRAVITATIONAL FIELDS

- SC motion will be influenced for the most part by gravitational fields of the Earth and the Moon
- Due to the highly elliptical orbit of the SC in the apogee its motion will be influenced mainly by lower (J_2, J_3) harmonics of the Earth gravitational field

Thus SLR will make it possible to improve parameters of gravitational fields of the Earth and the Moon

SHARP RESONANCE MOTION

- SC will be moving in the presence of two sharp resonances with own motion of the Moon (1:3)

$T_{SC} \approx 9$ days ≈ 27 days/3 $\approx$ $T_{☾}/3$

SLR will make it possible to test the models of the motion of space object in the presence of sharp resonances and to build subsequent analytical models of such a motion

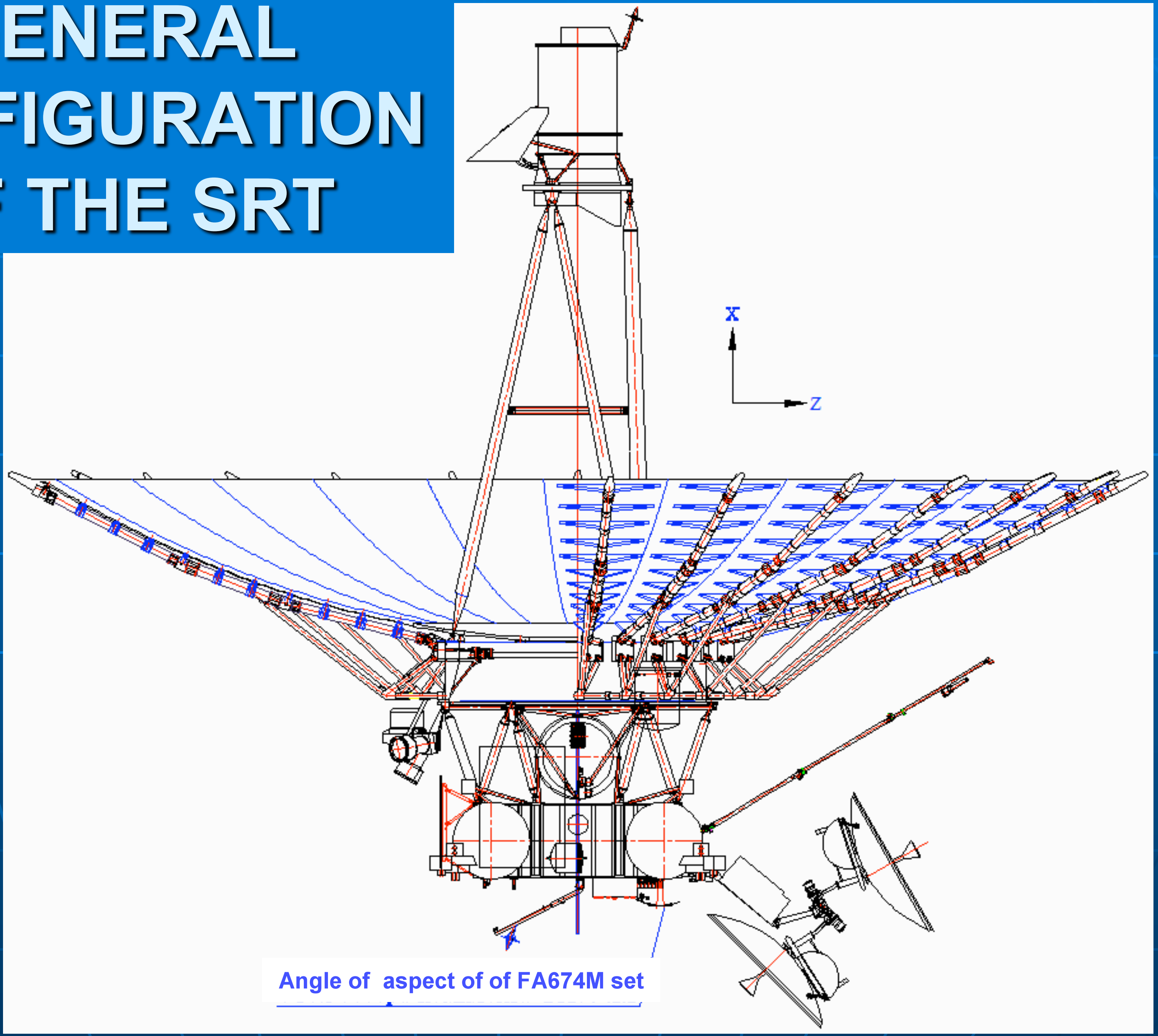
A TEST OF THE GRAVITATIONAL REDSHIFT WITH RADIOASTRON

General relativity and quantum theory are the two pillars of modern physics. However, they are incompatible and may show inconsistencies with observations. While quantum theory has been verified at a level of 0.7 parts in a billion, general relativity has only been tested at a level orders of magnitude lower. One of the most accurate tests of general relativity was provided by the gravitational redshift experiment of Gravity Probe A. It verified the equivalence principle, part of general relativity, with an accuracy of 70 parts in a million. RadioAstron with its highly eccentric orbit and large apogee, hydrogen maser on board the spacecraft, and three-way Doppler system should allow a gravitational redshift test with an accuracy one to two orders of magnitude higher than that of Gravity probe A. It would therefore be the most accurate test of general relativity by far.

(From the Norbert Bartlet’s report presented at Moscow Workshop devoted to RadioAstron mission, 2008)

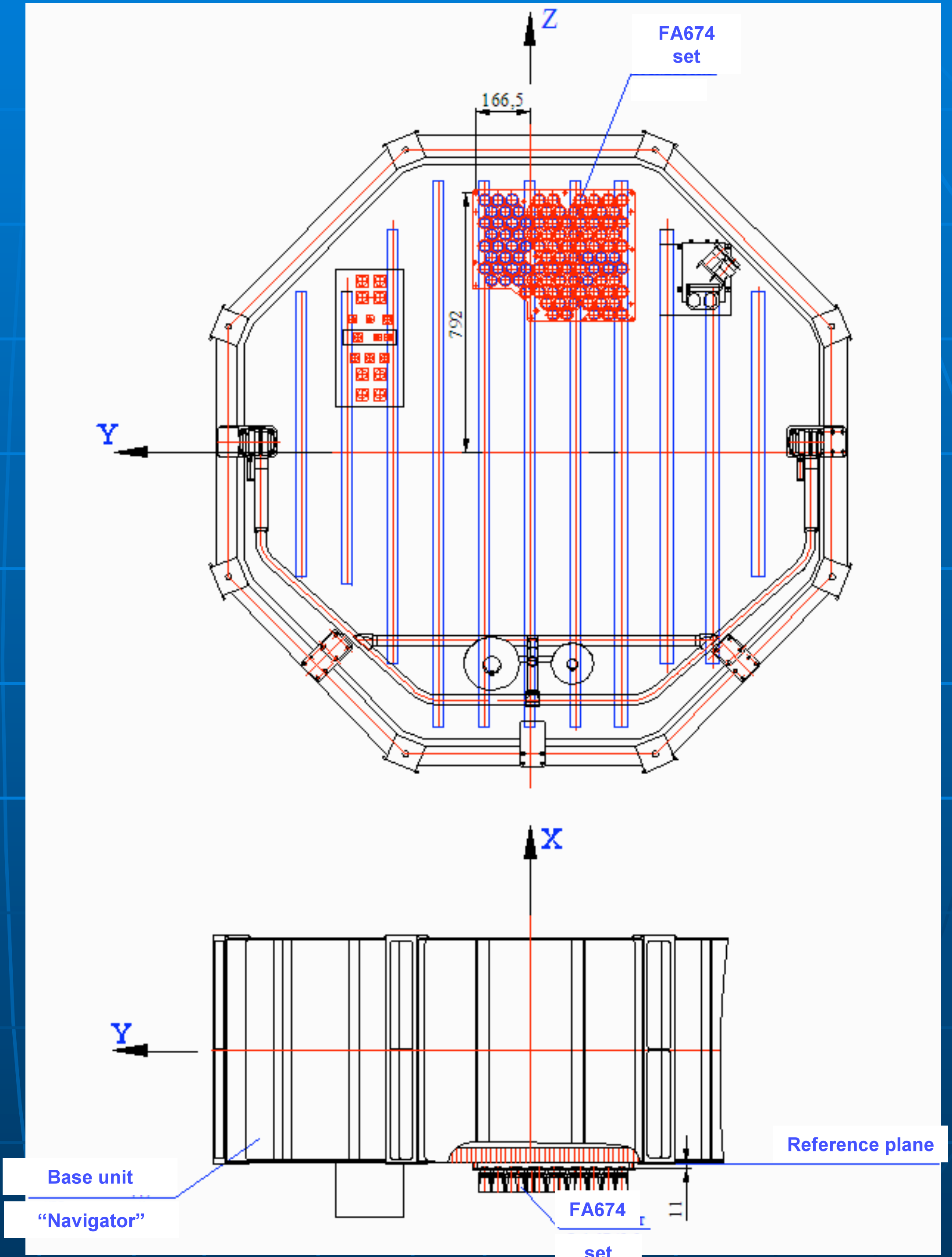
POSSIBILITIES TO USE SLR FOR RADIOASTRON MISSIOIN

GENERAL CONFIGURATION OF THE SRT



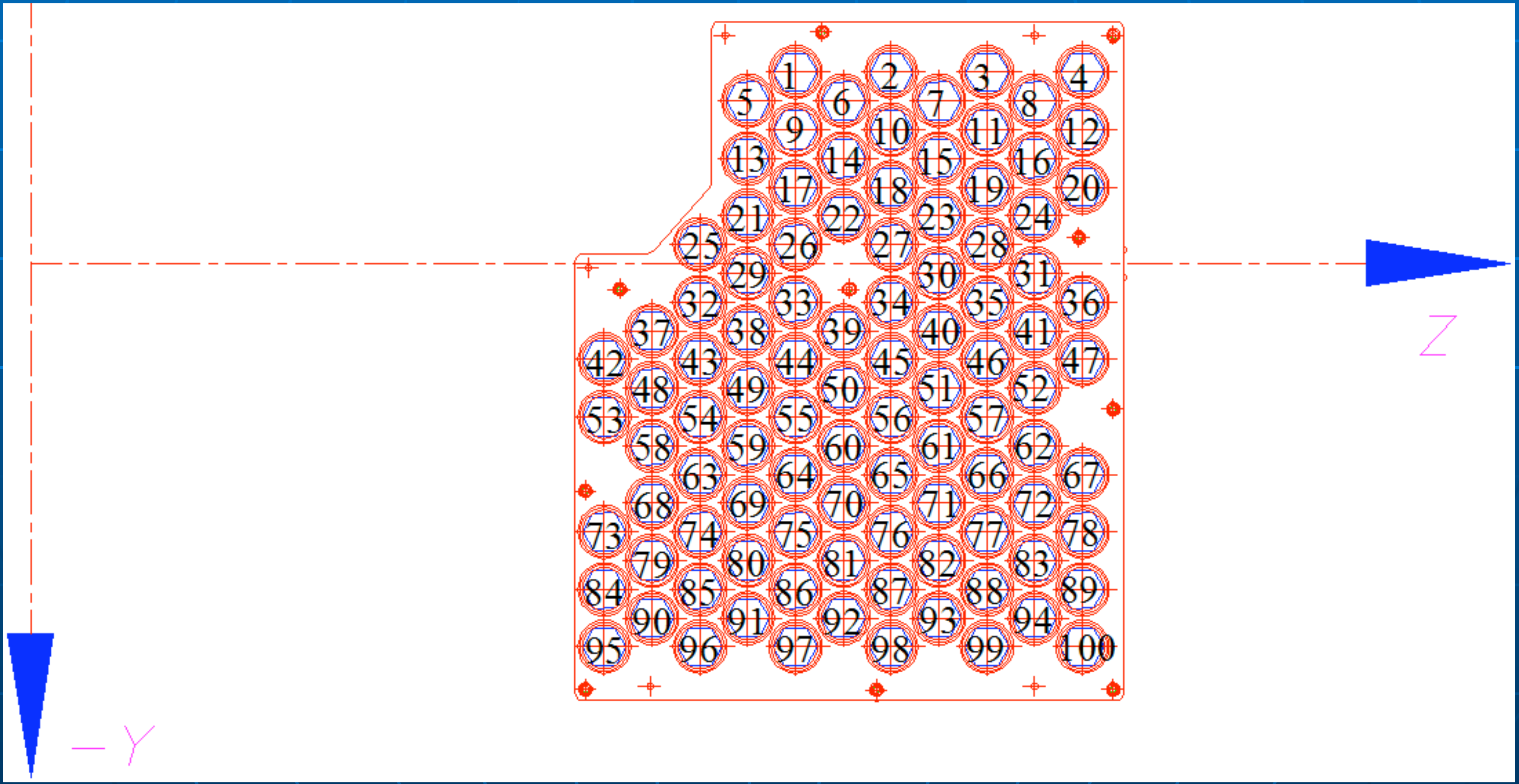
ON-BOARD LASER RANGING EQUIPMENT

Laser Ranging Array (LRA) is situated on the back panel of the SC.



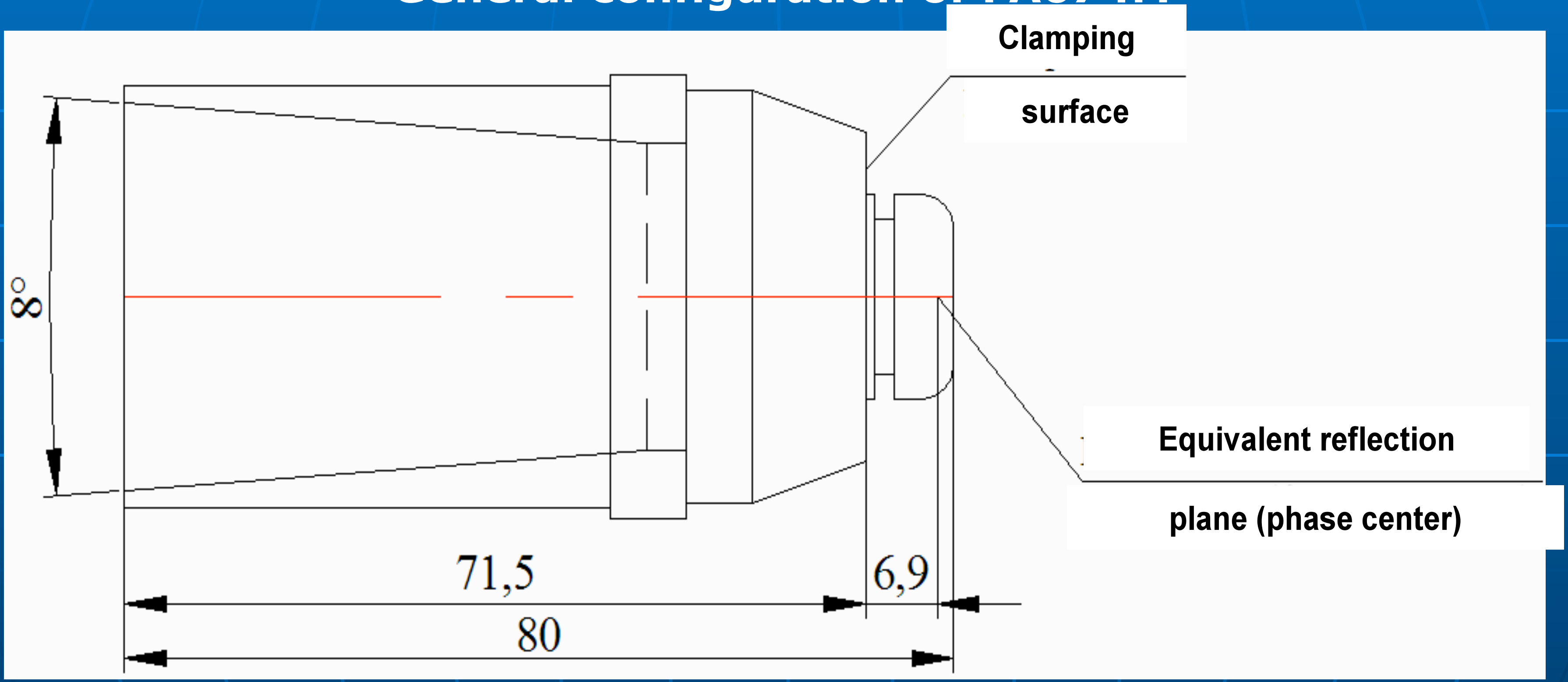
ON-BOARD LASER RANGING EQUIPMENT

Numeration of FA674M



ON-BOARD LASER RANGING EQUIPMENT

General configuration of FA674M



The retro-reflectors are silver-coated and have blinds

THE STATIONS PERSPECTIVE FOR RA LASER LOCATION

Presumably these stations have potential to range the Moon

Name	Latitude	Longitude
Apache Point (USA)	31,2° N	103,6° W
Grasse (France)	43,8° N	6,9° E
MacDonald (USA)	30,7° N	104,0° W
Matera (Italy)	40,6° N	16,7° E
Wrightwood (USA)	34,4° N	117,7° W

CONCLUSION

Using all the measurements mentioned above like radio measurements, satellite laser ranging, on-board telemetry will make us to solve the stated scientific tasks