History and outlook of further development of satellite navigation systems

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Navigation

- Is the overall name for procedures, which can be used for determination of current location of objects (either on the ground, in the sea or in the air).
- Navigation also enables to find the shortest or the most appropriate way to the destination.

Different options for navigation:

- Personal communication (a person who knows the place – tour guide).
- Based on signage (traffic signs, tourist signs, building signs).
- Comparative navigation – comparison of current terrain and map.
- Terrestrial navigation based on compass (either magnetic or gyroscopic), line of possition, etc.
- Inertial navigation.
- Astronomical navigation based on location of the Sun, Moon and stars - (sextant, compass a chronometer).
- Radio navigational aids – based on radio beacons (NDB – radio compass, VOR).
- Ground hyperbolical navigational systems – i.e. (LORAN, OMEGA).
- Satellite navigational systems – GPS, GLONASS, Galileo, Compass.

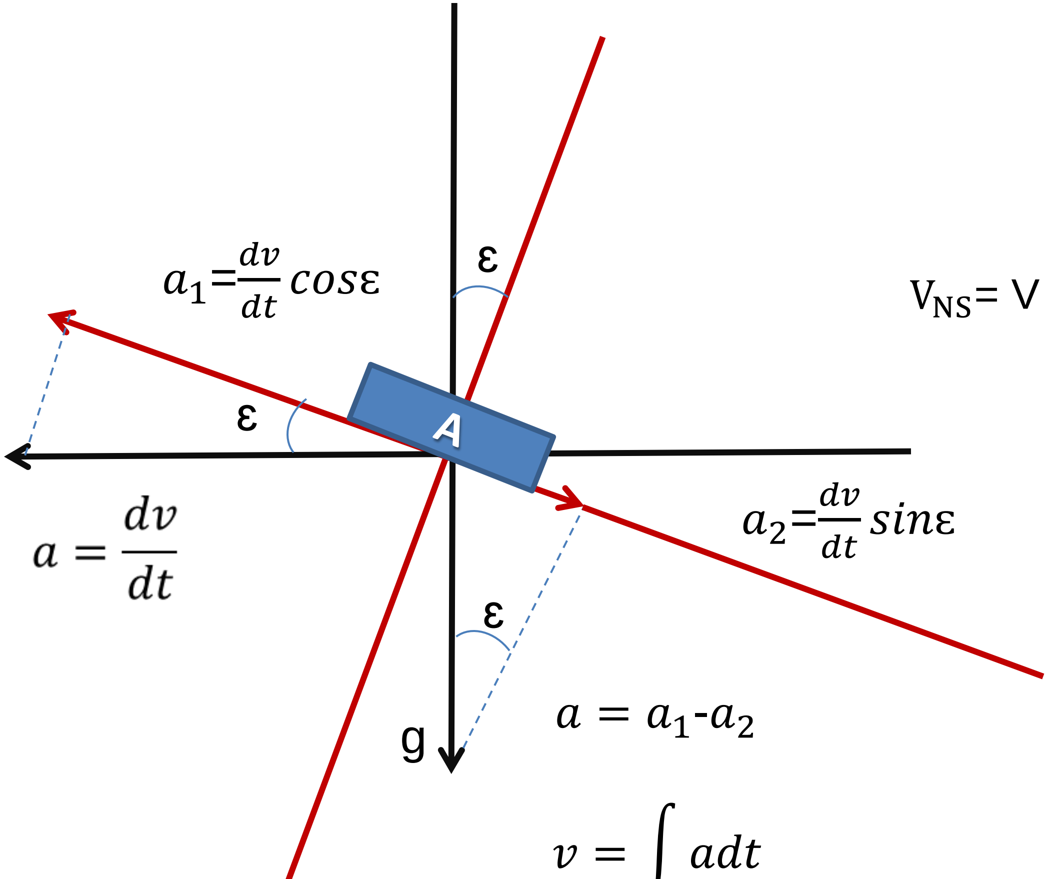
Inertial navigation systems

- The principle of INS is based on the second Newton´s law, which describes force as a function of mass of a current object anh its acceleration with respect to inertial space

$$F = m.a$$

- First, for each of the six degrees of freedom (x,y,z and θ_x, θ_y and θ_z), it integrates over time the sensed acceleration, together with an estimate of gravity, to calculate the current velocity. Then it integrates the velocity to calculate the current position.
- Accelerometer - very sensitive part of INS. It is mounted on a platform that is horizontally stabilised by gyroscopes. Accelerometers are oriented N-S and E-W. It is very important for a platform to be horizontally stabilised so the sensed acceleration is not affected by a standard gravity.

Errors due to shift of a platform

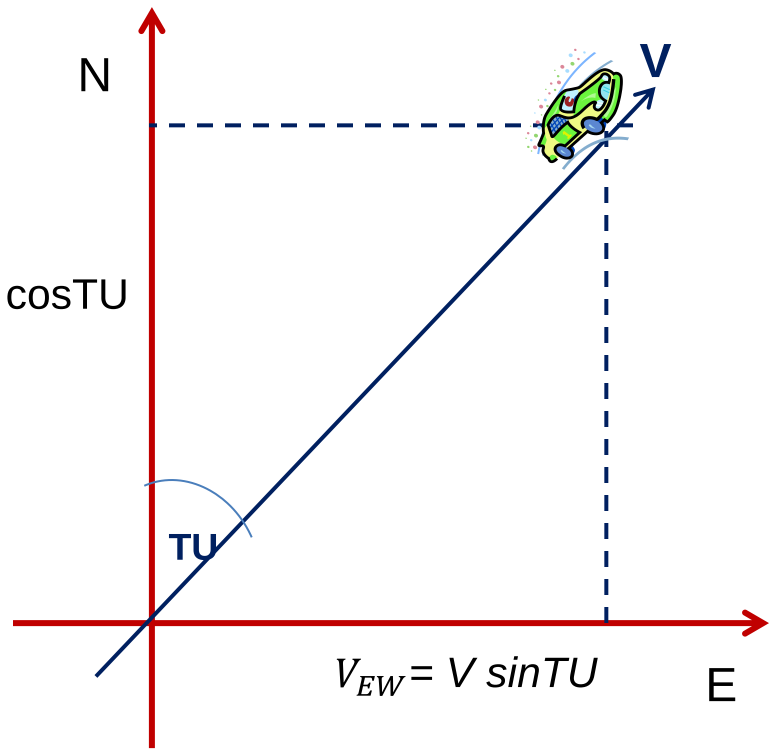


$$a = a_1 - a_2$$

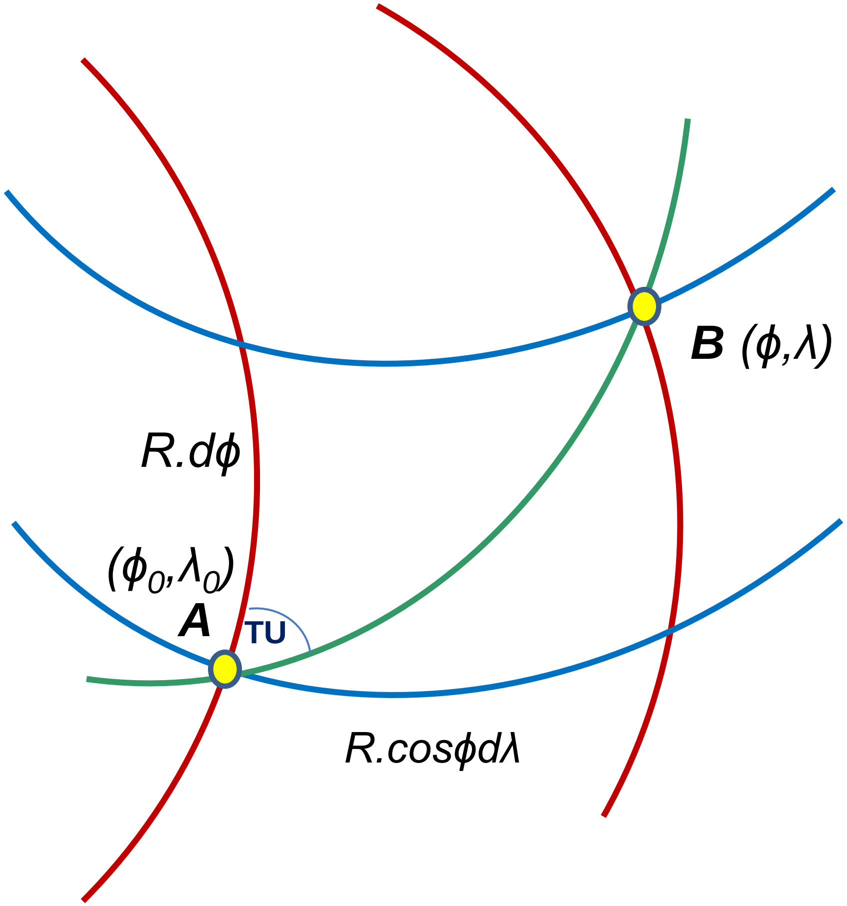
$$v = \int a dt$$

$$s = \int v dt$$

Projection of vector of velocity in coordinate system



Projection of vector of velocity in spherical coordinate system



$$\Delta\phi = \int \frac{V_{NS}.\cos TU}{R} dt$$

$$\Delta\lambda = \int \frac{V_{EW}.\sin TU}{R.\cos\phi} dt$$

$$\phi = \phi_0 + \Delta\phi$$

$$\lambda = \lambda_0 + \Delta\lambda$$

Celestial navigation

- Aviation has been using it since 60-ties in the last century.
- Current location was determined by sextant, chronometer a Astronomical navigational tables (ANT).
- The actual angle between celestial body and the horizontal plane of the observer was measured and also the time of measurement was recorded. Then azimuth and intercept were found in the ANT and then astronomical line of position(LOP) was recognised.
- Two angles of celestial bodies measured – two LOPs.
- Then the LOPs were plotted in a map. Their intersection defined actual possition of an airplane.
- Experienced navigator was able to plot one LOP in about three minutes two LOPs in six minutes).
- The problem was that aircraft were fast and they rapidly changed their position in six minutes.

Navigational systems

- ground systems
  - **autonomous systems** do not need additional beacons besides airborne equipment,
    - dead reckoning navigation
    - dead reckoning combined with predefined map situation
    - inertial systems
  - **nonautonomous systems** need external devices (radio beacons etc.),
- satellite systems

Satellite navigation systems

Doppler systems

TRANSIT – USA (1964)

PARUS/CIKADA (1974)

Distance measuring systems

NAVSTAR / GPS (1973)

(NAVigation System using Time And Range /Global Positioning System)

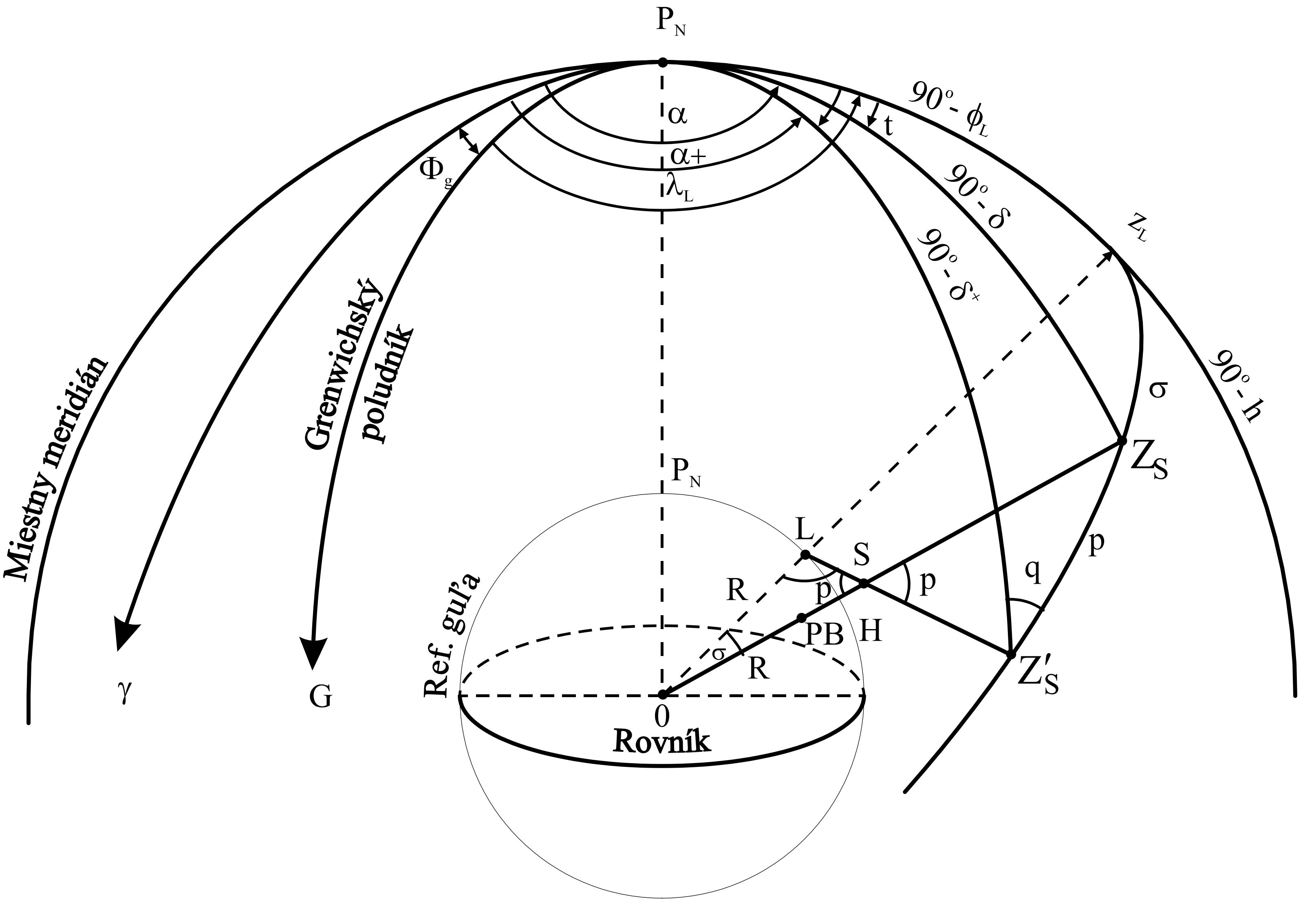
GLONASS (približne 1980)

(GLObalnaja NAvigacionnaja Sputnikovaja Sistema

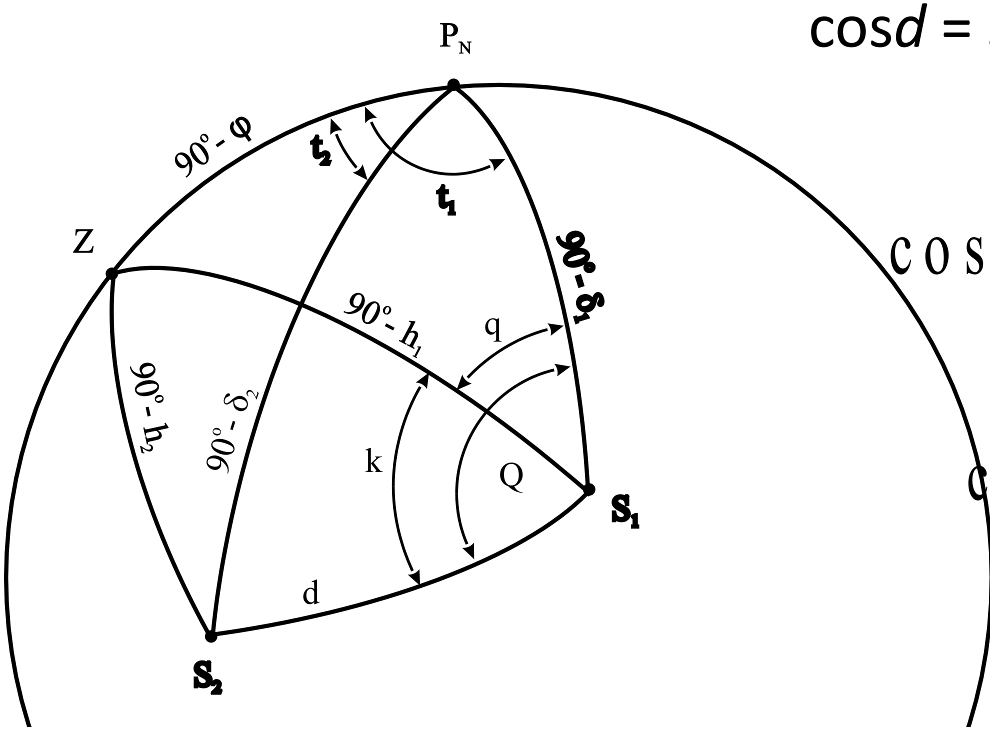
Determination of location using satellites

- Fotogrametrical method
- Determination of location by measuring of elevation angles
- Determination of location by measuring of azimuths
- Determination of location by measuring of zenith distances
- Doppler´s method (aviation navigation only)
- Determination of location using GEO satellites
- Determination of location by measuring of distances
  - On the inside surface of the celestial sphere
  - In the orthogonal coordinate system

Fotogrametrical method



Determination of location by measuring of elevation angles



$$\cos d = \sin\delta \sin\delta_2 + \cos\delta_1 \cos\delta_2 \cos(t_{G1} - t_{G2})$$

$$\cos Q = \frac{\sin\delta_2 - \sin\delta_1 \cos d}{\cos\delta_1 \sin d}$$

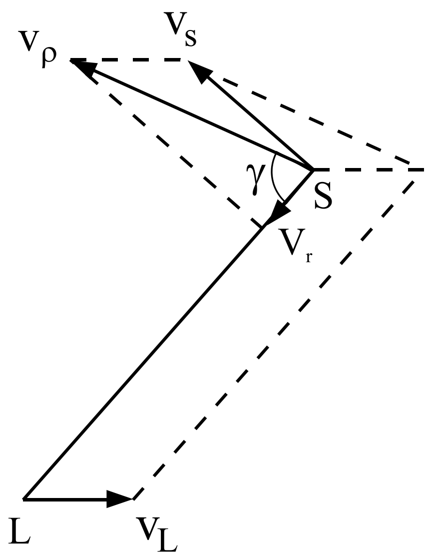
$$\cos k = \frac{\sin h_2 - \sin h_1 \cos d}{\cos h_1 \sin d}$$

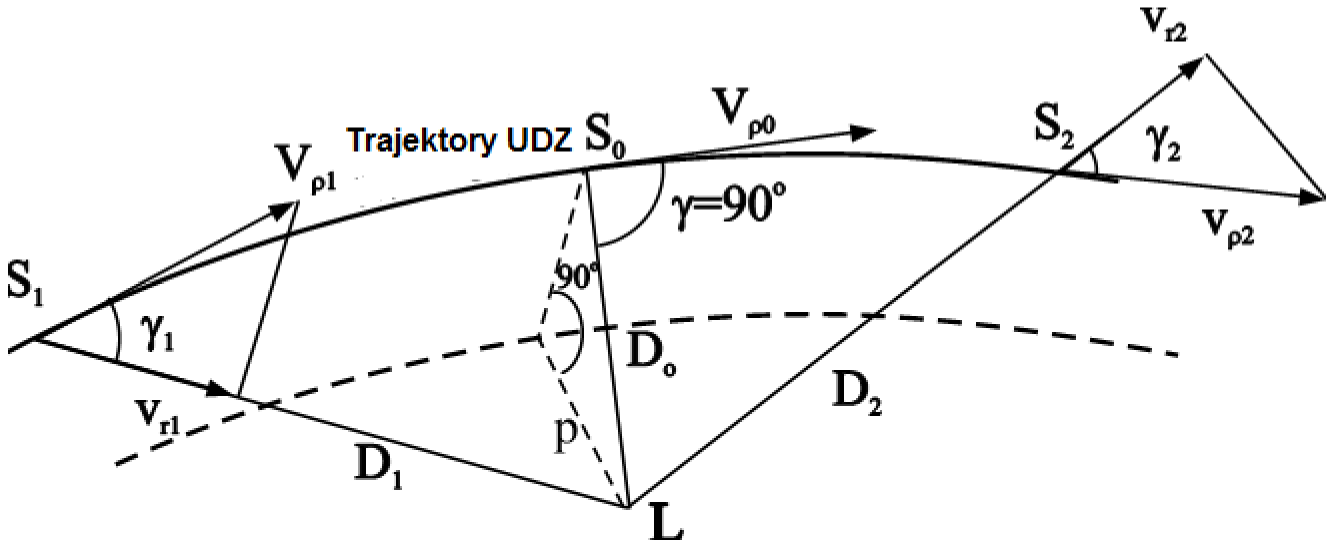
$$\cos t_1 = \frac{\sin h_2 - \sin\delta_1 \sin\varphi}{\cos\delta_1 \cos\varphi}$$

$$\sin\varphi = \sin\delta 1 \ \sin h1 + \cos\delta 1 \ \cos h1 \ \cos q$$

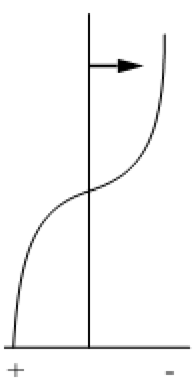
$$\lambda = t_1 - t_{G1}$$

Doppler´s method



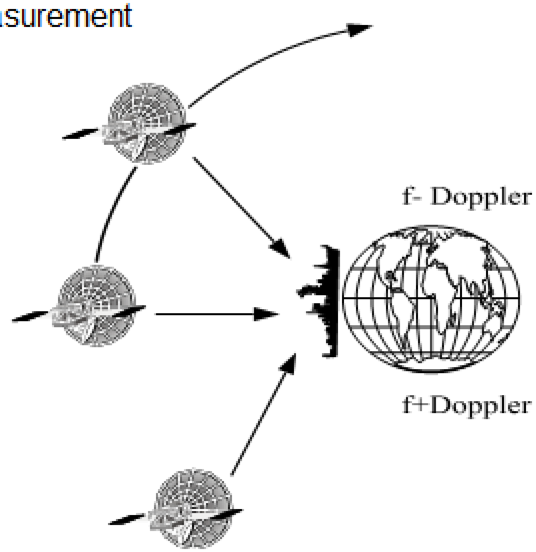


Doppler shift

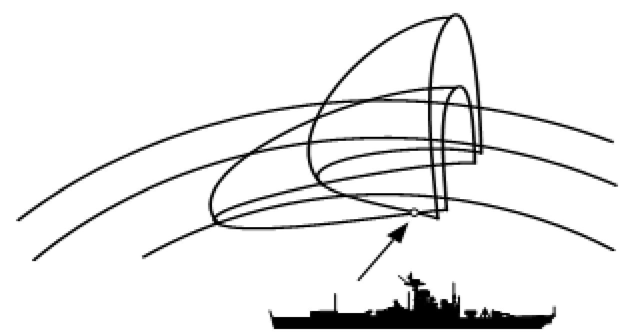


frequency

Principle of measurement

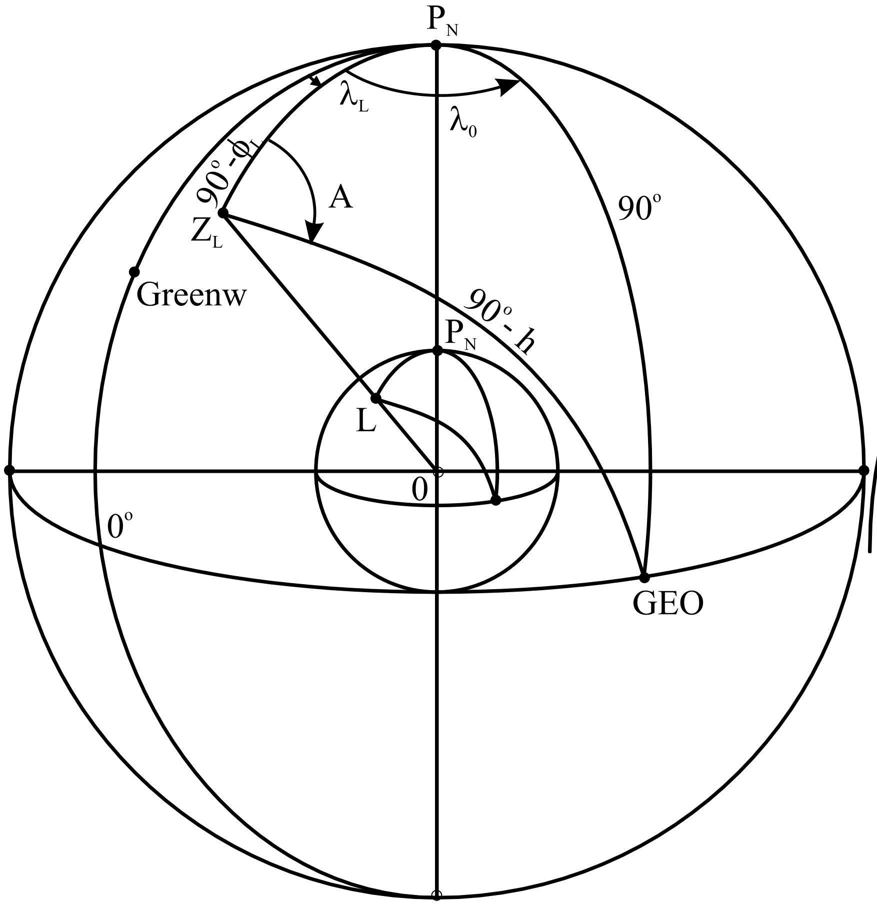


Determination of Doppler location according to

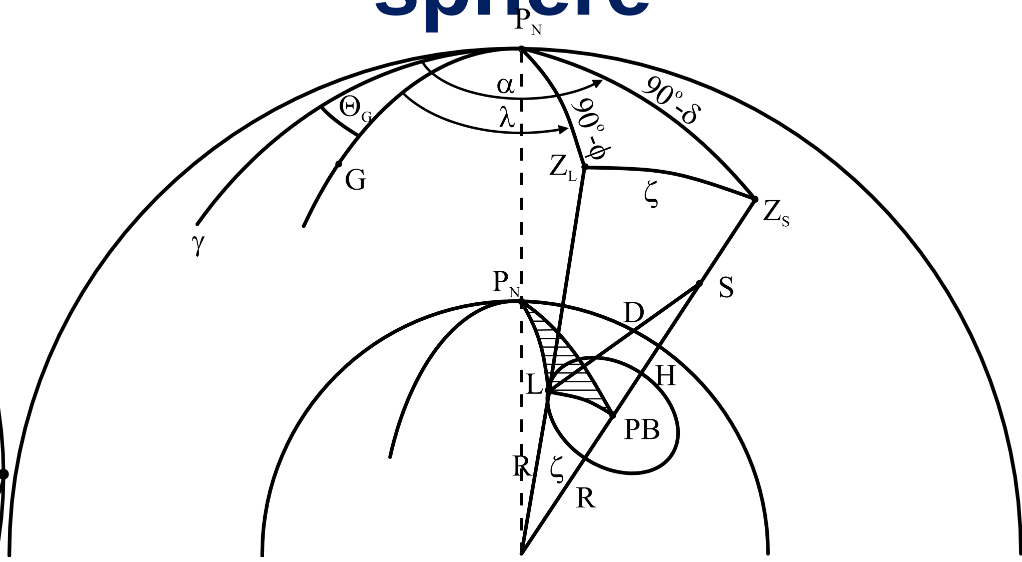


Internection of two hyperboloids with sufrace of the Earth

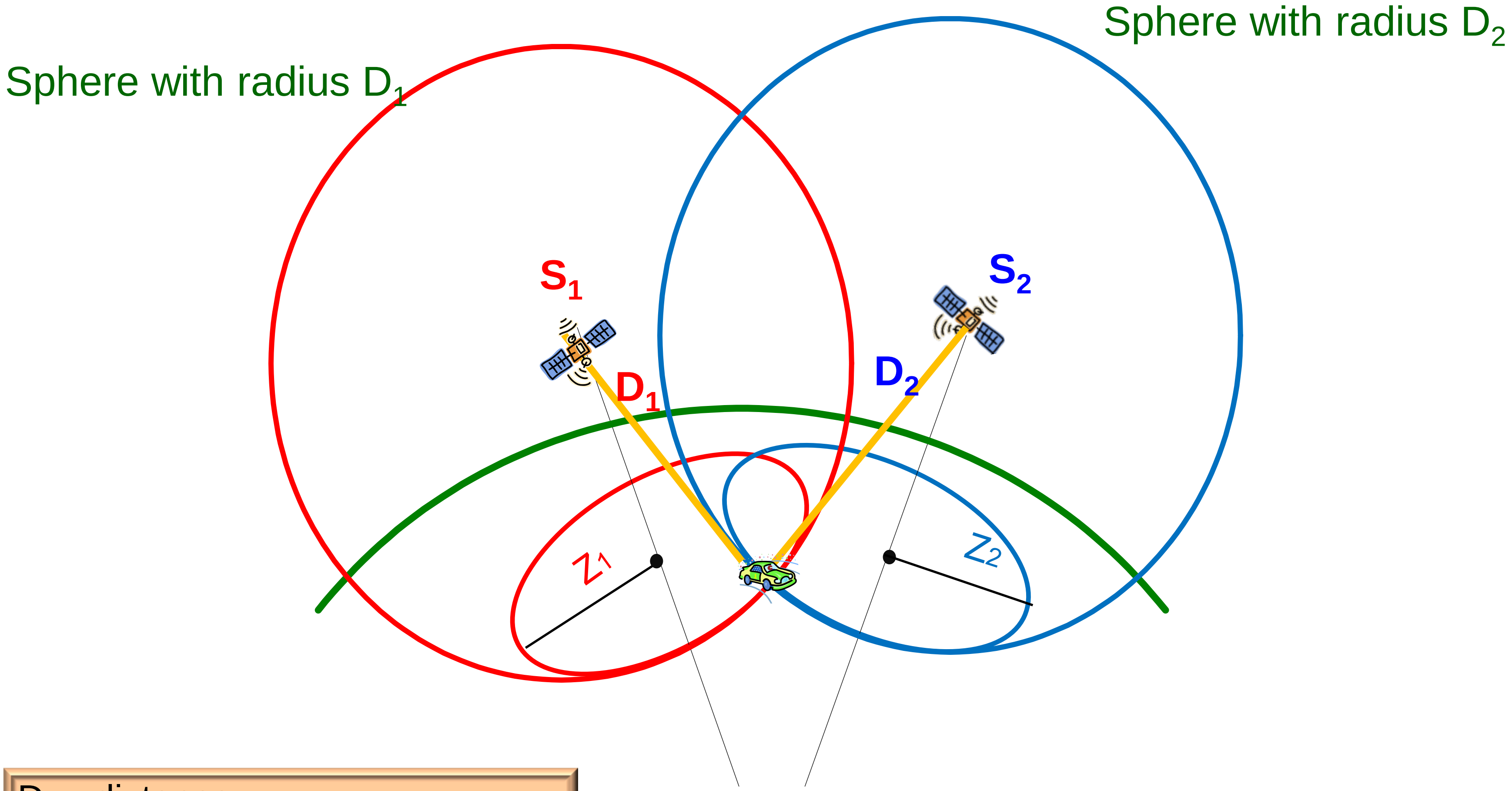
Determination of location using GEO satellites



Determination of location by measuring of distances on surface of celestial sphere



Geometry of distance measuring satellite systems



D_i - distance
S_1 ,S_2 – location of satellites
Z_i – zenith distance of satellites

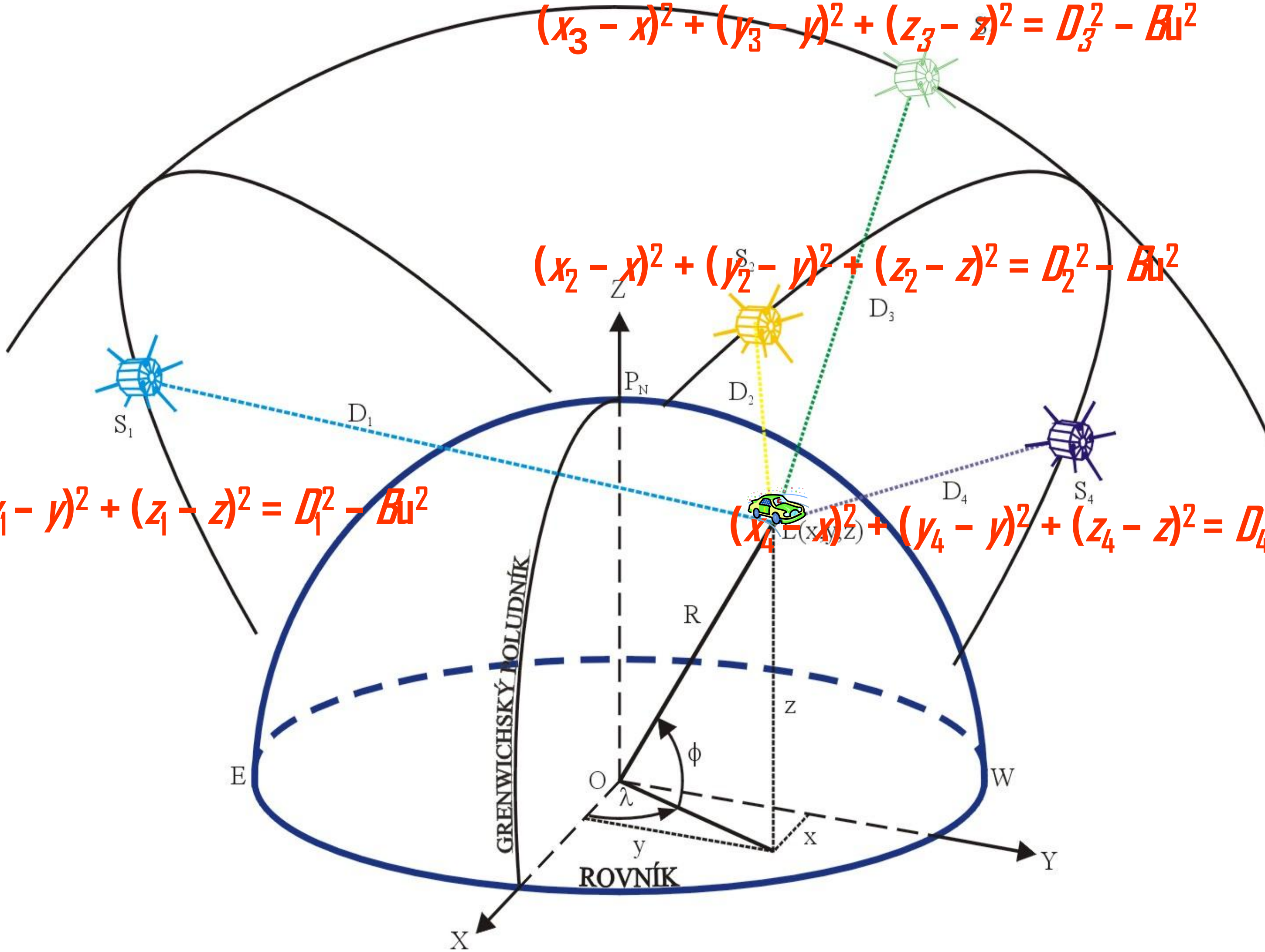
Determination of location by measuring of distances in the orthogonal coordinate system

$$(x_3 - x)^2 + (y_3 - y)^2 + (z_3 - z)^2 = D_3^2 - Bu^2$$

$$(x_2 - x)^2 + (y_2 - y)^2 + (z_2 - z)^2 = D_2^2 - Bu^2$$

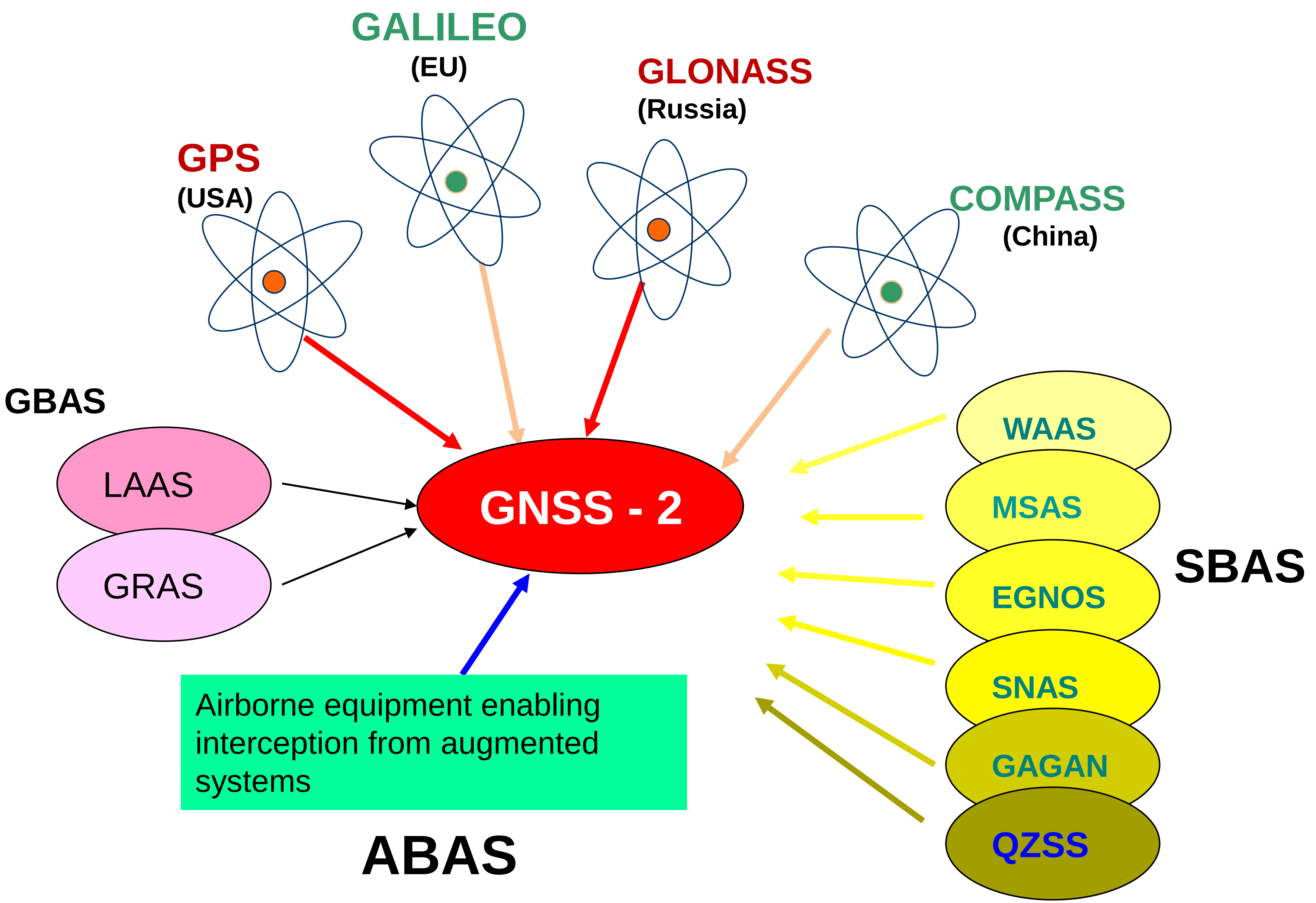
$$(x_1 - x)^2 + (y_1 - y)^2 + (z_1 - z)^2 = D_1^2 - Bu^2$$

$$(x_4 - x)^2 + (y_4 - y)^2 + (z_4 - z)^2 = D_4^2 - Bu^2$$

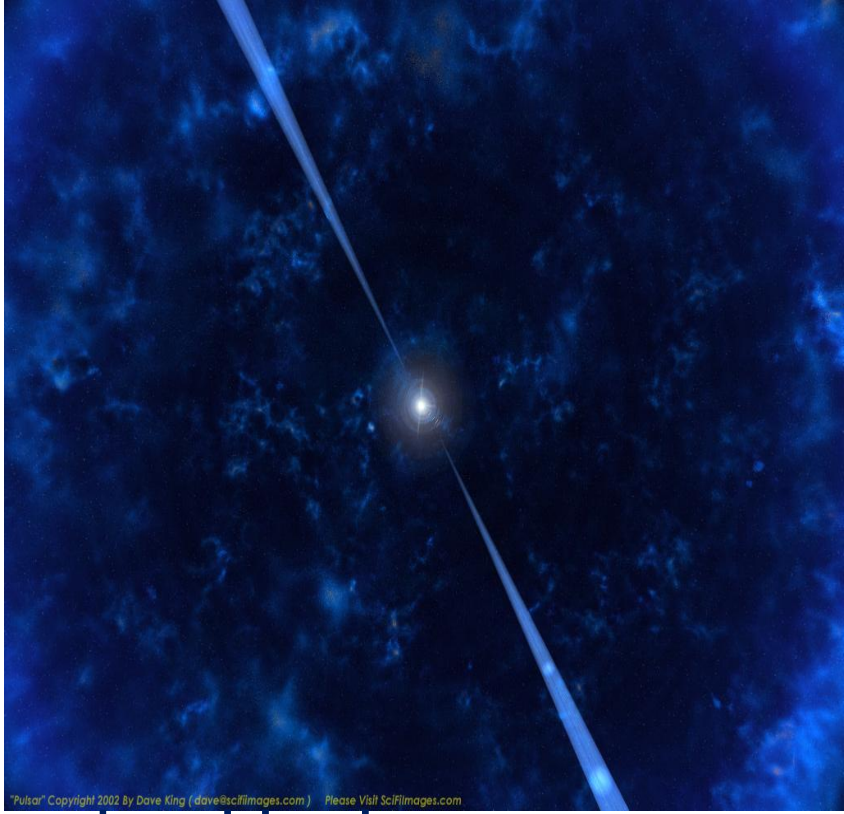


Bu = c Δ*T* – *equivalent of shift of user´s clock*

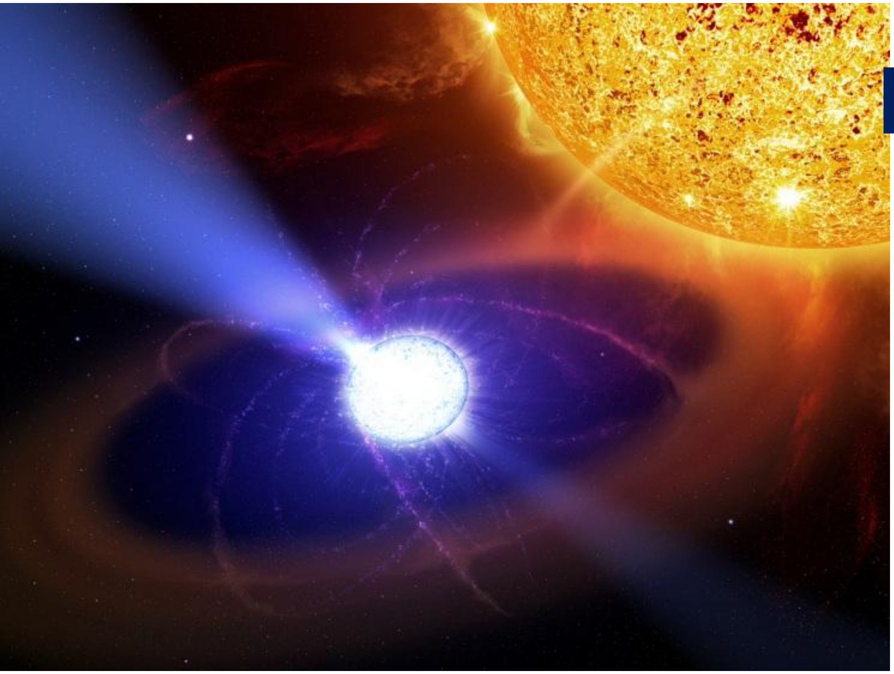
Development of GNSS



Radio pulzars



- highly magnetized, rotating neutron stars that emit a beam of electromagnetic radiation – the first pulsar observed by Jocelyn Bell Burnell in 1967.
- Electromagnetic radiation is emitted in the direction of magnetic axes. Most commonly, magnetic axes are shifted 10° from rotational axes.
- In case magnetic axe goes through ecliptic plane an observer sees blinking, the same effect as it is created by a lighthouse.



Navigation according to pulsars

- Pulsars are marked as PSR [number] ± [coordinates]
- PSR stands for „Pulsating Source of Radio“.
- Number determines location of pulsar in the sky (according to equatorial coordinates II. type. (declination δ, right ascension α and PSR).
- Pulsar could not however be recognised as really pulsing.
- Currently there is a lot of effort in place to use pulsars for spatial navigation and also for GNSS based navigation.

"... the ways by which men arrive at knowledge of the celestial things are hardly less wonderful than the nature of these things themselves"

Johannes KEPLER

Thank you for your attention