Low Earth Orbit (LEO)

Any satellite in approximately circular orbit with semimajor axis less than, say, 1500 km is said to be in Low Earth Orbit. Sunsynchronous satellites are in low earth orbit, but many non-sunsynchronous satellites are also in orbit.

Perhaps the most important aspect of non-synchronous LEOs is that they sample all local times, which can be important for climate and other applications.

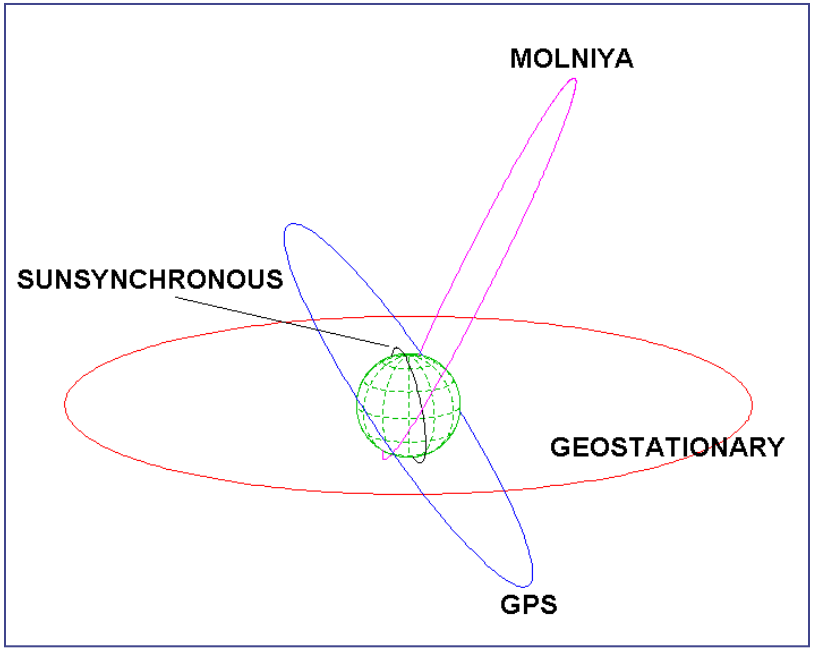
Mid-Earth Orbit (MEO)

1. Semimajor axis >LEO and <GEO
2. The Global Positioning System (GPS) is a good example

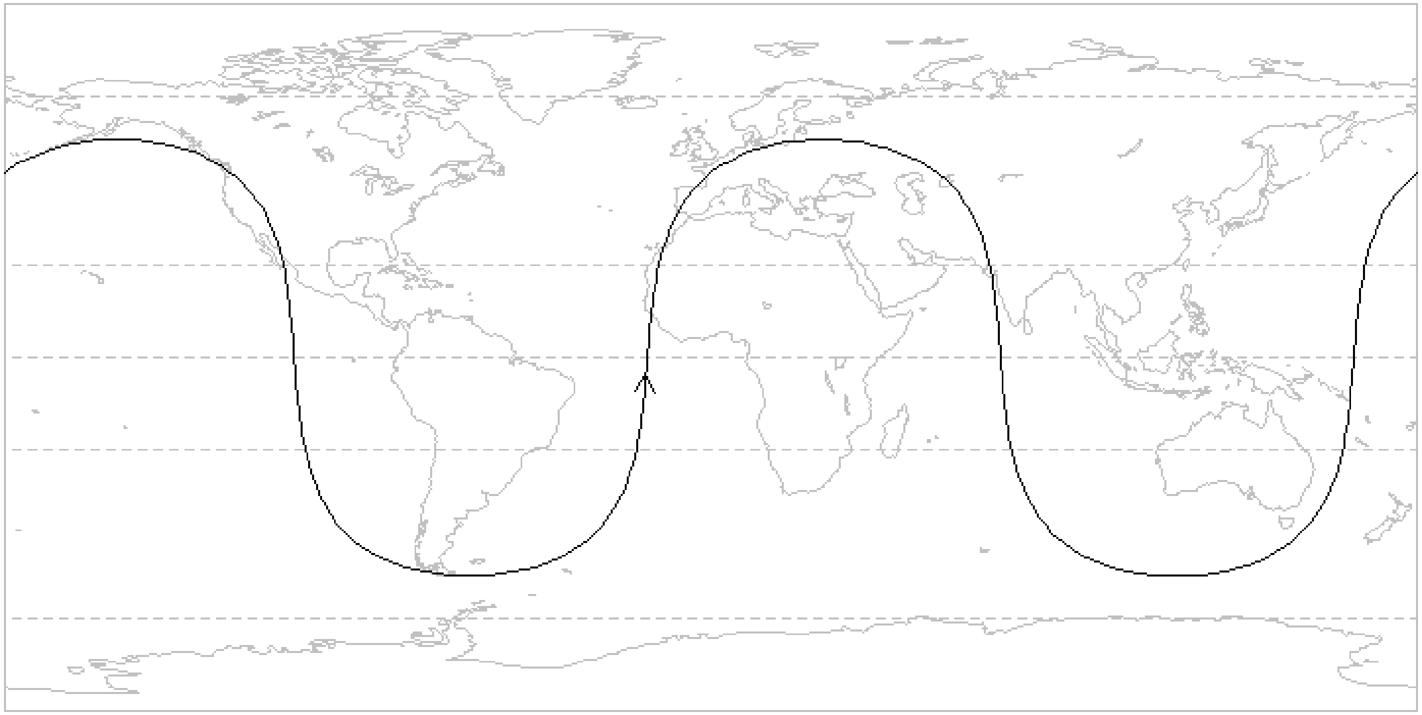
a = 26559 ± 5 km
(4.2 earth radii)

i = 55° ± 1°

ε = 0



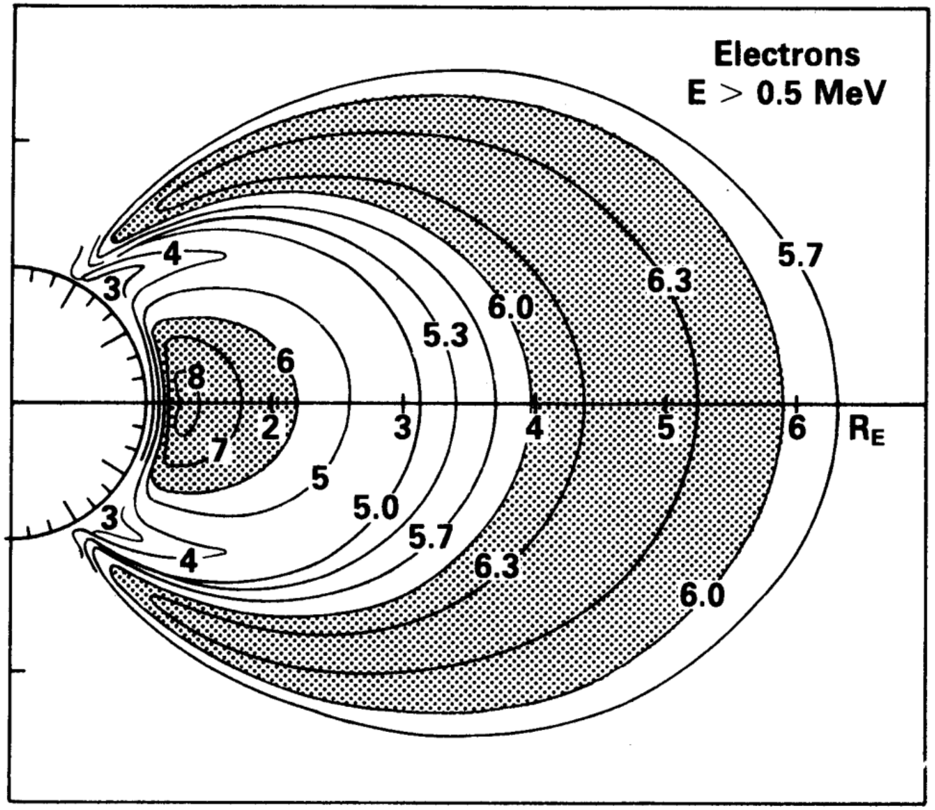
GPS Groundtrack



Synchronized with the earth:

- Makes two complete orbits while the earth turns once with respect to the plane of the orbit
- Groundtrack repeats

MEO continued

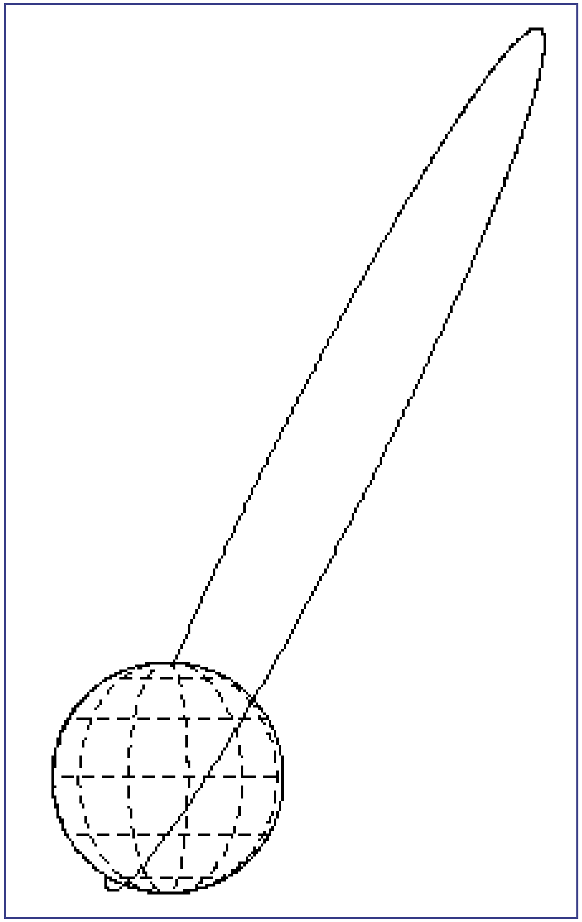


The Van Allen belts are a consideration for MEOs and other orbits.

Log_{10} of the omnidirectional flux in particles cm^{-2} sec^{-1}

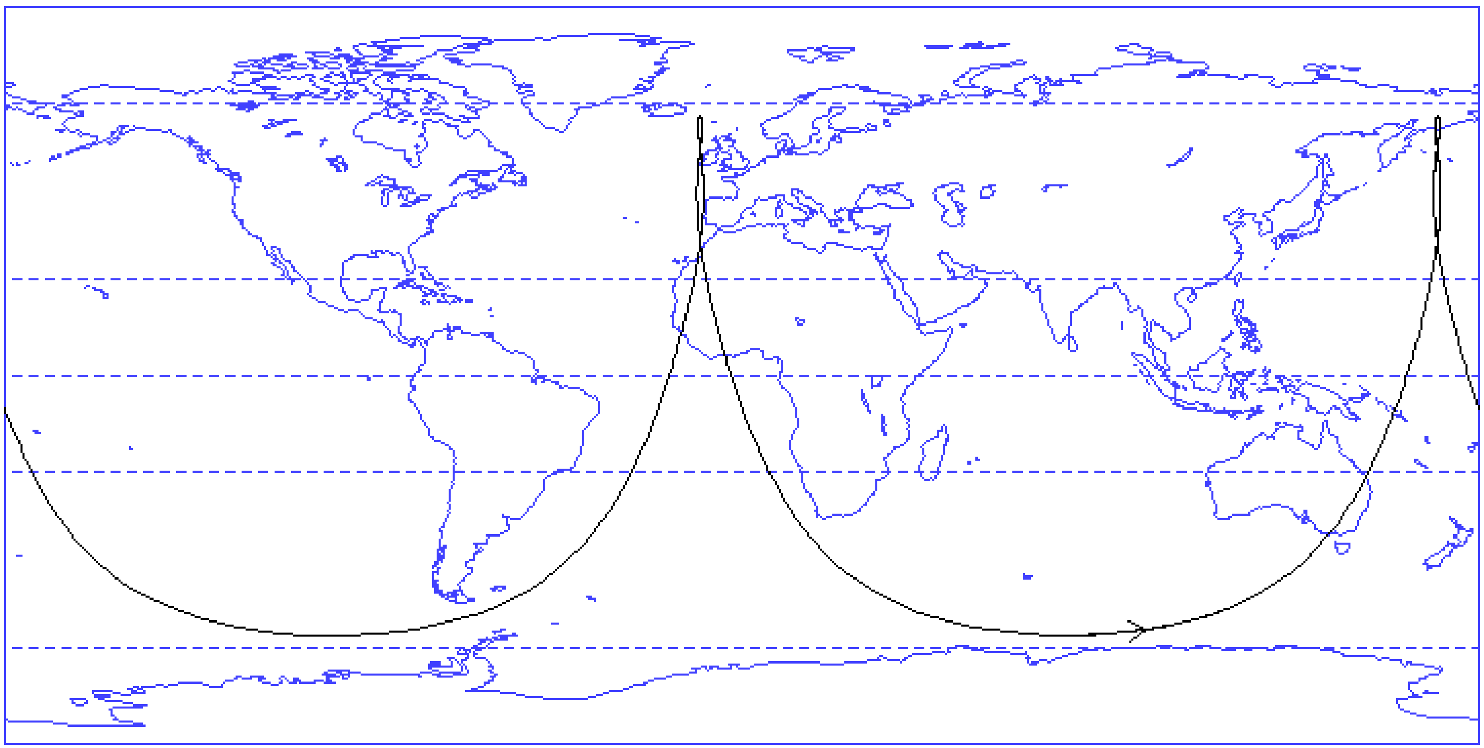
Molniya Orbit

- *Molniya* means *lightning* in Russian
- Used as communications satellites
- Highly elliptical orbit
  - eccentricity = 0.737
  - semi-major axis = 26,553 km
  - apogee = 46,127 km
    (3,960 km higher than GEO)
  - inclination = 63.4°
  - period = 717.7 min (≈12 hr)



$$\frac{d\omega}{dt} = \bar{n}\left[\frac{3}{2} J_2 \left(\frac{r_{ee}}{a}\right)^2 \left(1-\varepsilon^2\right)^{-2} \left(2 - \frac{5}{2}\sin^2 i\right)\right]$$

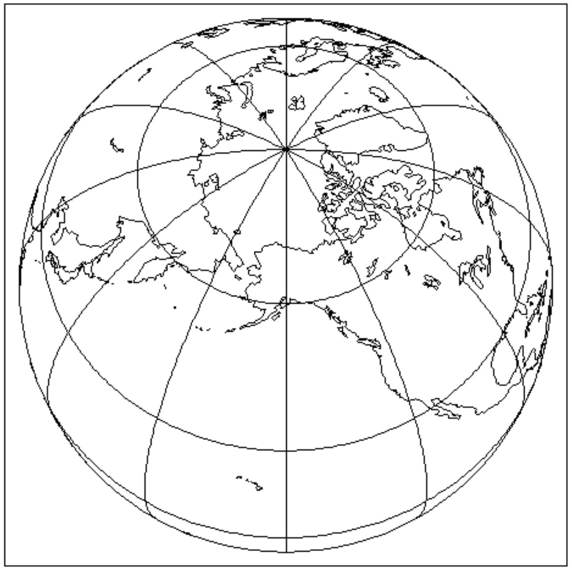
Molniya Groundtrack

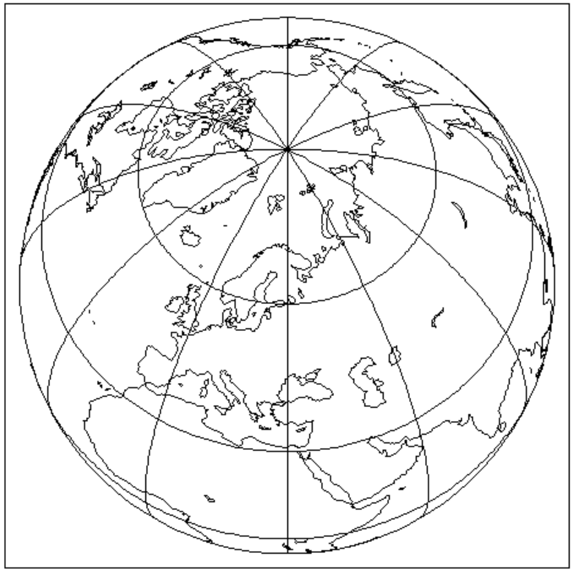


"Cusps" can be placed at any longitude.

Molniya Coverage

Sees this for 8 hr... …4 hr gap... ...then sees this for 8 hr.





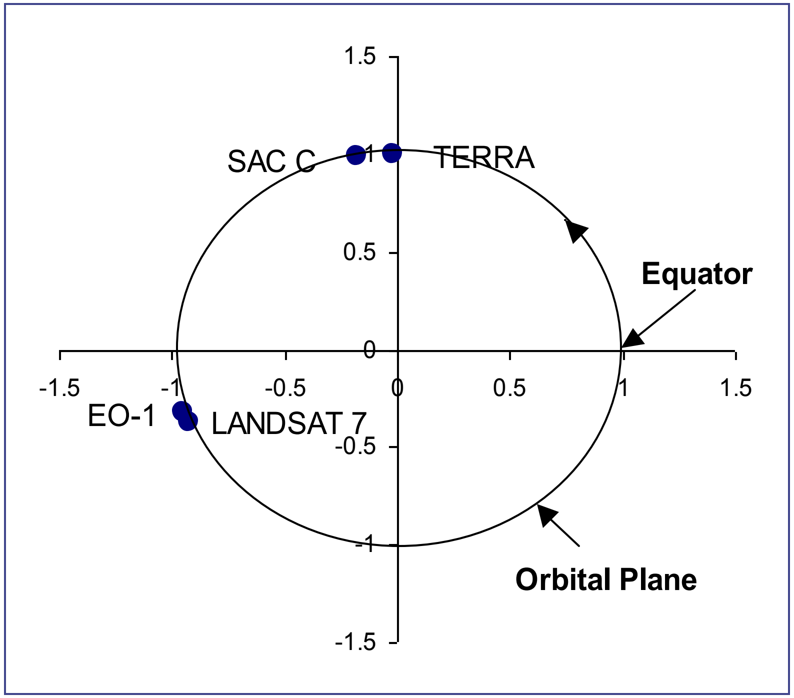
Three satellites provide 24-hr coverage

Kidder, S. Q., and T. H. Vonder Haar, 1990: On the use of satellites in Molniya orbits for meteorological observation of middle and high latitudes. *J. Atmos. Ocean. Tech.*, **7**, 517–522.

Formations

For two satellites to fly in formation, their orbital elements must be related.

- Their semimajor axes must be identical--else they would have different periods and would separate)
- Their inclination angles must be identical--else they would veer left and right)
- Their eccentricities must be identical (preferably zero)—else they would oscillate up and down
- And…



EO-1 flies 1 min behind Landsat 7

SAC-C flies 27 min behind EO-1

Terra flies 2.5 min behind SAC-C

Formations…

- Their mean anomalies and arguments of perigee must be related.

  Let Δt be the desired separation time. Then their angular separation must be:

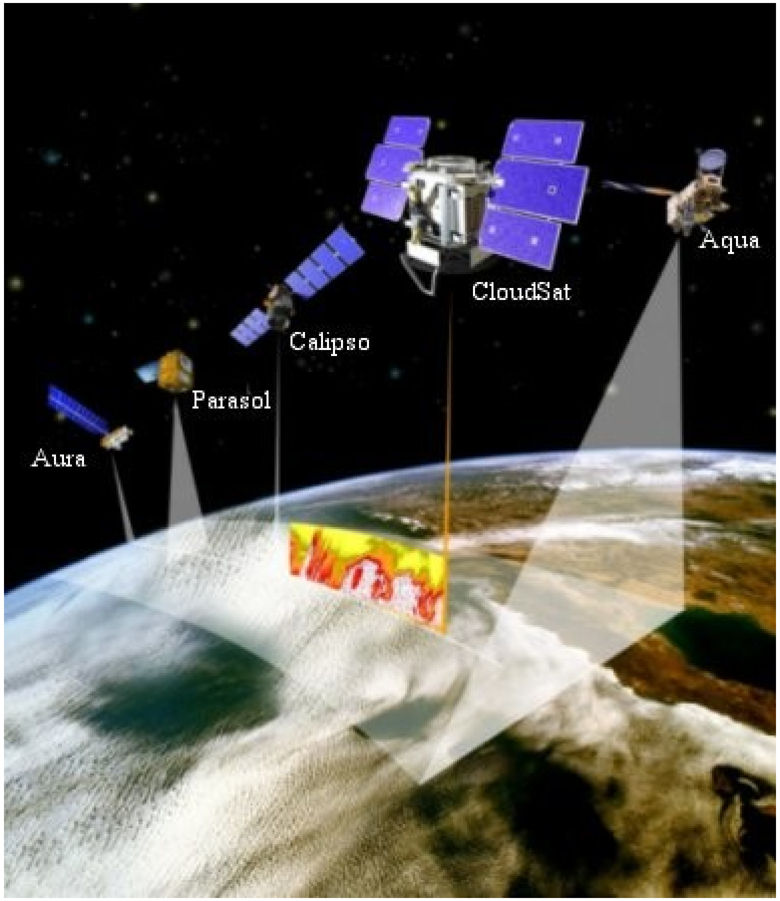
$$\Delta\Gamma = \Delta\left(M + \omega\right) = 360^\circ \frac{\Delta t}{\tilde{T}}$$

Assumes a circular orbit, for which $M = \theta$

- Their right ascensions of ascending node must be related so that they travel over the same ground track:

$$\Delta\Omega = \frac{d\Omega_{earth}}{dt}\Delta t$$

The A-Train



- CloudSat lags Aqua by a variable amount <120 s
- CALIPSO lags CloudSat by 15 ± 2.5 s
- CloudSat and CALIPSO fly about 220 km to the right of Aqua to avoid sun glint
- PARASOL lags Aqua by ~2 min
- Aura lags Aqua by ~15 min

Stephens et al., 2002: The CloudSat mission: A new dimension of space-based observations of clouds and precipitation. *BAMS*, **83**, 1771-1790.

A-Train Orbital Parameters

SATELLITE	ID	SEMI-MAJOR AXIS	NODAL PERIOD	INCLINA-TION	ECCEN-TRICITY	RIGHT ASCENSION	ARG. OF LATITUDE	LAG	
		km	min	deg		deg	deg	min	sec
AQUA	02022A	7077.775	98.89	98.22	8.29E-05	334.65	151.64	0.00	0
CLOUDSAT	06016A	7077.784	98.89	98.22	1.15E-04	336.83	148.61	0.83	50
CALIPSO	06016B	7077.782	98.89	98.22	1.01E-04	336.88	147.77	1.06	64
PARASOL	04049G	7077.756	98.89	98.22	1.04E-04	334.21	143.81	2.15	129
AURA	04026A	7077.808	98.89	98.22	8.37E-05	336.93	93.63	15.93	956
At 2007-02-01 0000 UTC									

- Aqua ECT = 13:35:19
- A-Train satellites make 233 orbits in 16 days and fly on the WRS-2 grid

Constellations

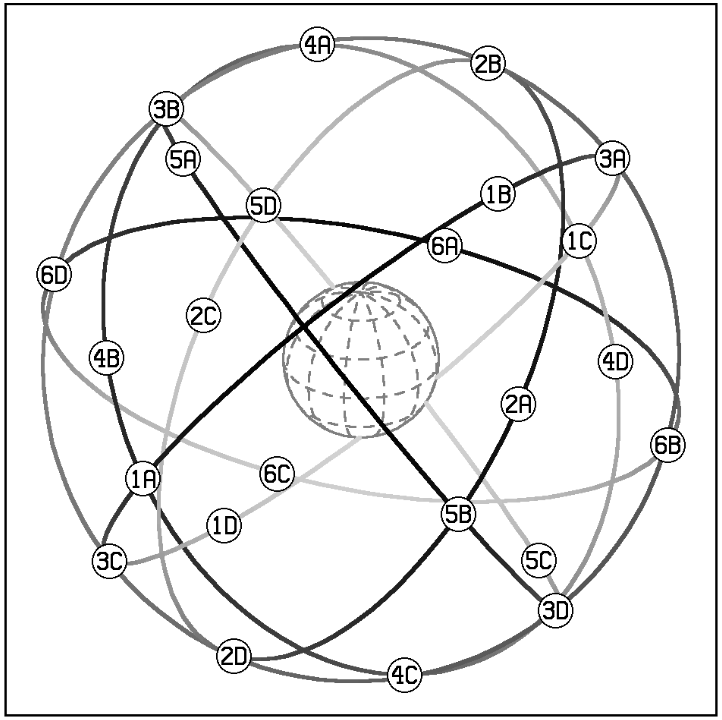
Several identical satellites in cooperative orbits

- Make possible new observing capabilities
- Take advantage of economies of scale
- Can reduce launch costs

The GPS Constellation

Parameter	*GPS*
Purpose	Navigation
Number of planes	6
Plane spacing (degrees)	60
Satellites per plane	4
Total satellites*	24
Orbital altitude (km)	20,181
Semi-major axis (km)	26,559
Inclination (degrees)	54.8
Nodal period (min)	717.9
Satellites per launch	1

*Not including on-orbit spares

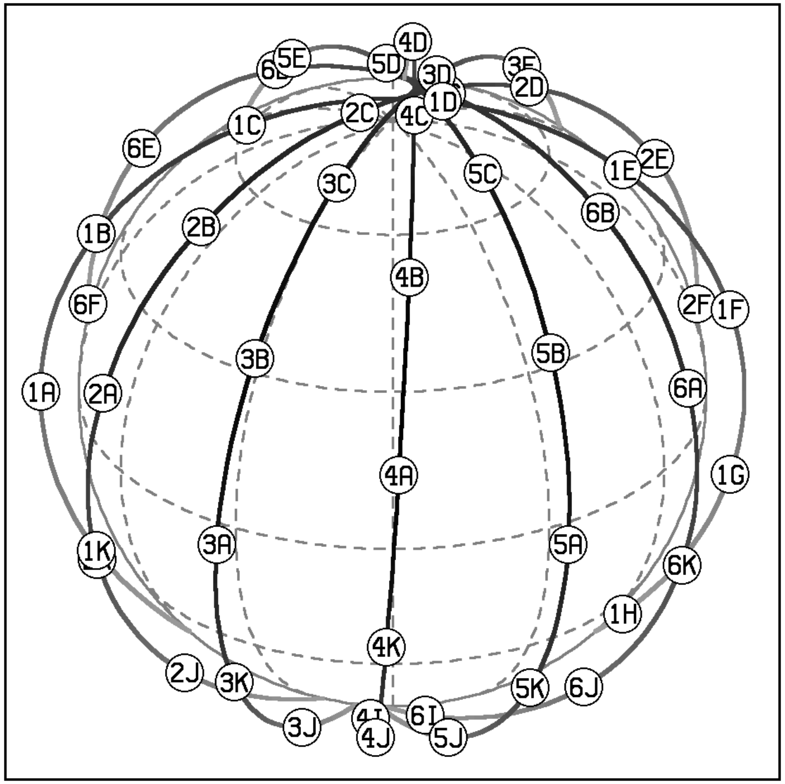


Designed so that at any point or time, several satellites are above the horizon.

The Iridium Constellation

Parameter	*Iridium*
Purpose	Telecom
Number of planes	6
Plane spacing (degrees)	30
Satellites per plane	11
Total satellites*	66
Orbital altitude (km)	775
Semi-major axis (km)	7,153
Inclination (degrees)	86.4
Nodal period (min)	100.5
Satellites per launch	2-7

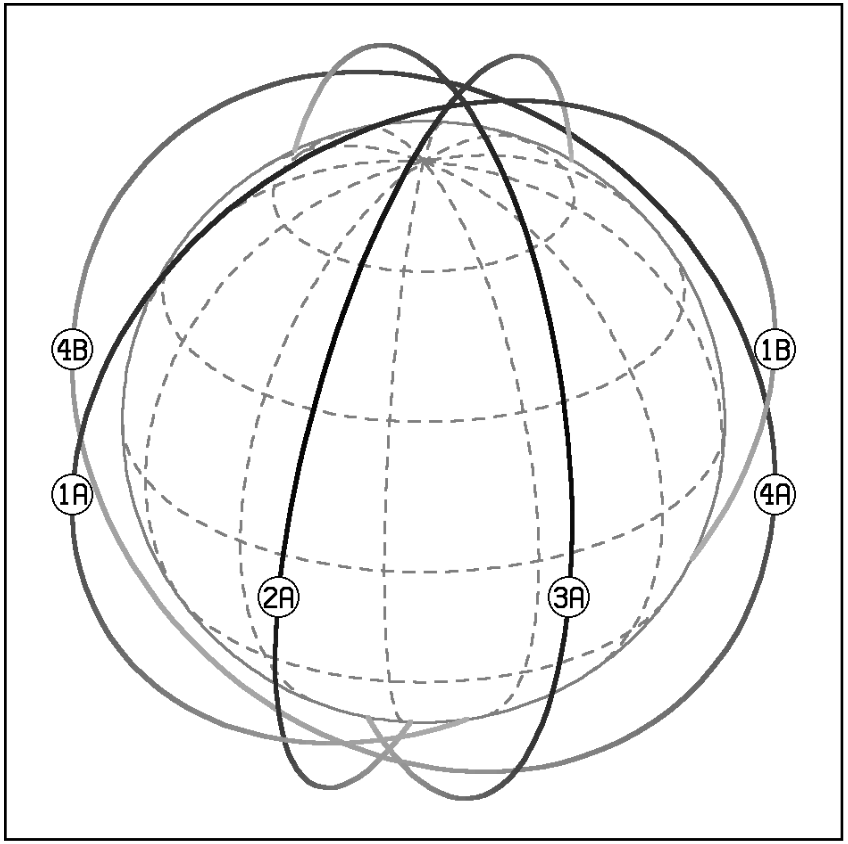
*Not including on-orbit spares



Note the “staggered” arrangement so the satellites can talk to each other.

A Meteorological Constellation

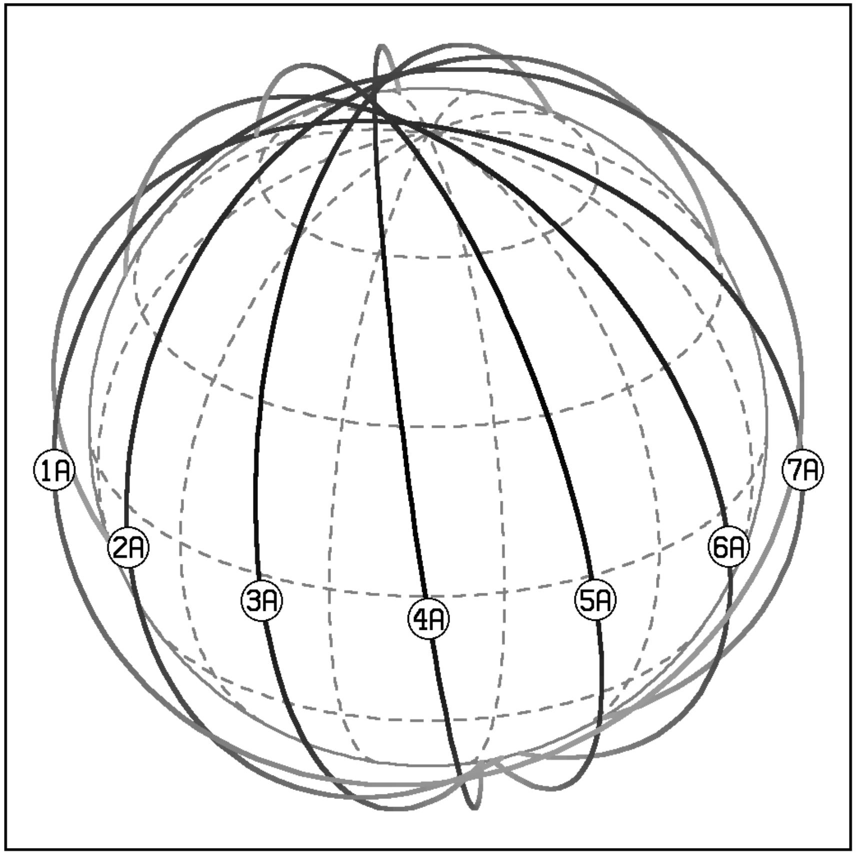
Parameter	*Value*
Purpose	Met. Obs.
Number of planes	4
Plane spacing (degrees)	45
Satellites per plane	2
Total satellites	8
Orbital altitude (km)	1,676
Semi-major axis (km)	8,054
Inclination (degrees)	85.2
Nodal period (min)	120
Satellites per launch	2



- 8 satellites
- Hourly observations everywhere on Earth

A Sunsynchronous Constellation

Parameter	*Value*
Purpose	Met. Obs
Number of planes	7
Plane spacing (degrees)	25.7
Satellites per plane	1
Total satellites	7
Orbital altitude (km)	850
Semi-major axis (km)	7,228
Inclination (degrees)	98.7
Nodal period (min)	101
Satellites per launch	1



- 7 satellites
- Observations each 101 minutes