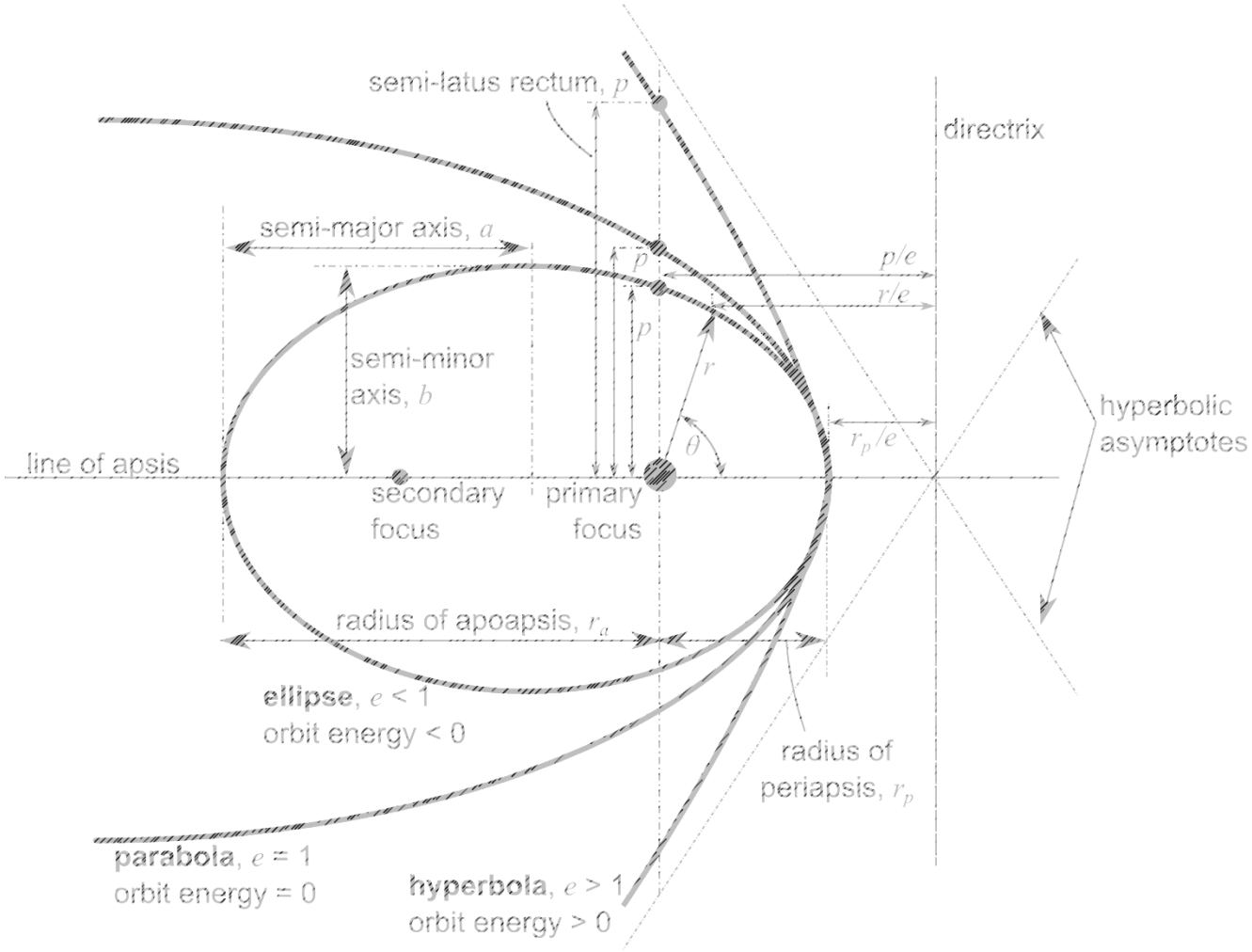
Orbits for Polar Applications

Malcolm Macdonald



malcolm.macdonald.102@strath.ac.uk

University of Strathclyde Engineering

Overview

Where do we currently put spacecraft?

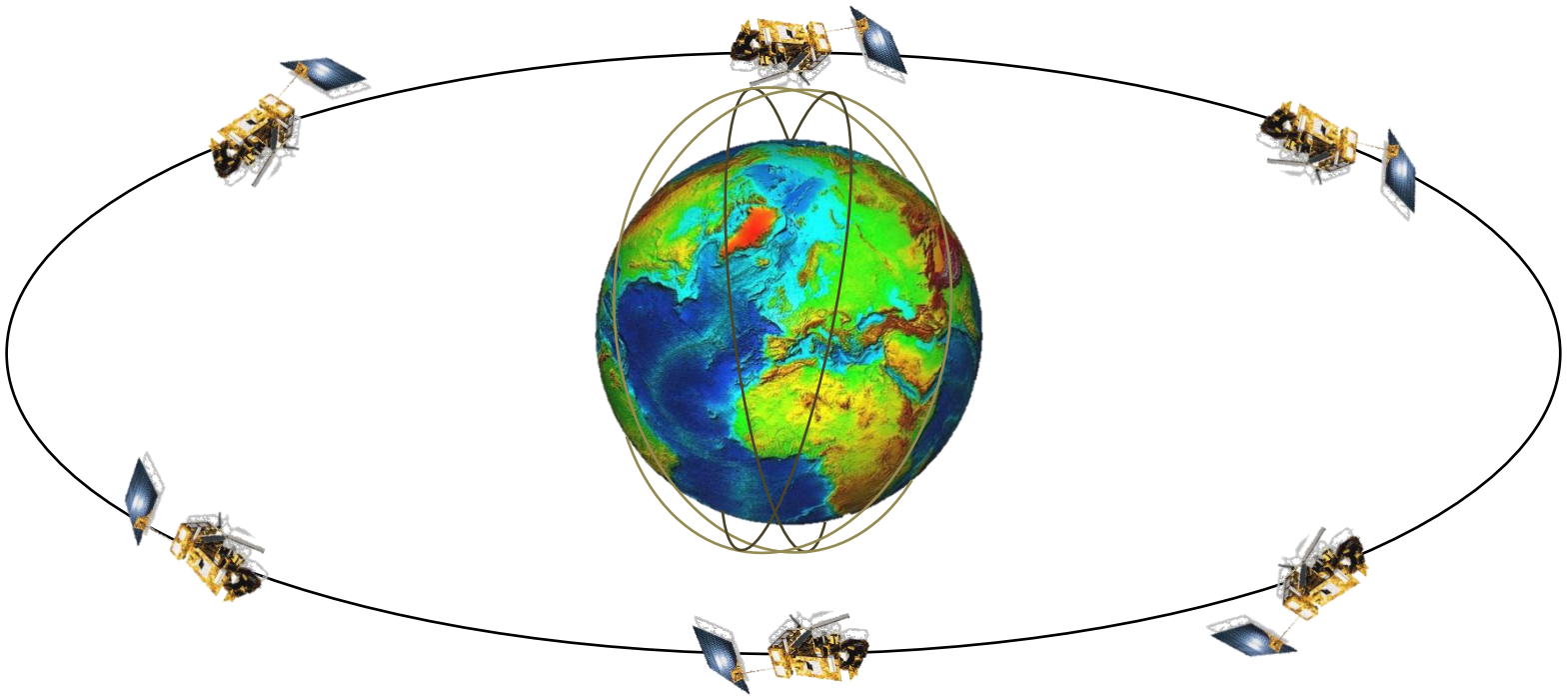
Where else can we put spacecraft?

Image Credit: ESA

Where do we currently put spacecraft?

Spacecraft monitor Earth from 2 basic orbital positions,

- near-polar LEOs at 600 – 800 km altitude
- Geostationary platforms at ~36 000 km altitude



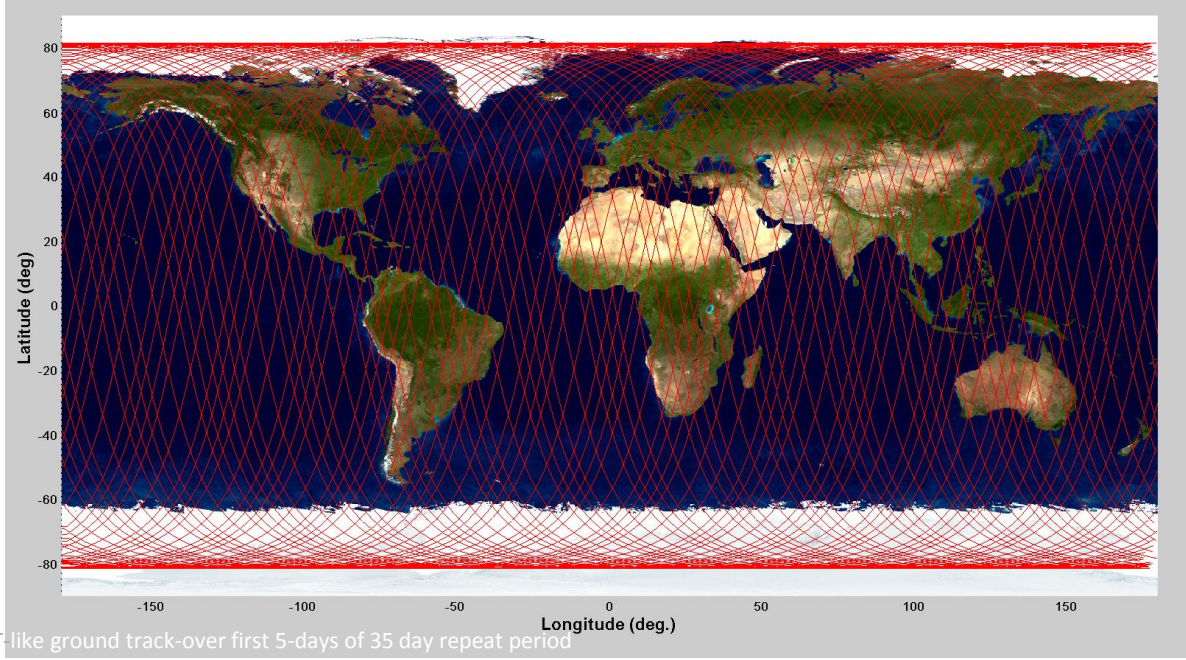
University of Strathclyde Engineering

DEPARTMENT OF MECHANICAL & AEROSPACE ENGINEERING
ADVANCED SPACE CONCEPTS LABORATORY

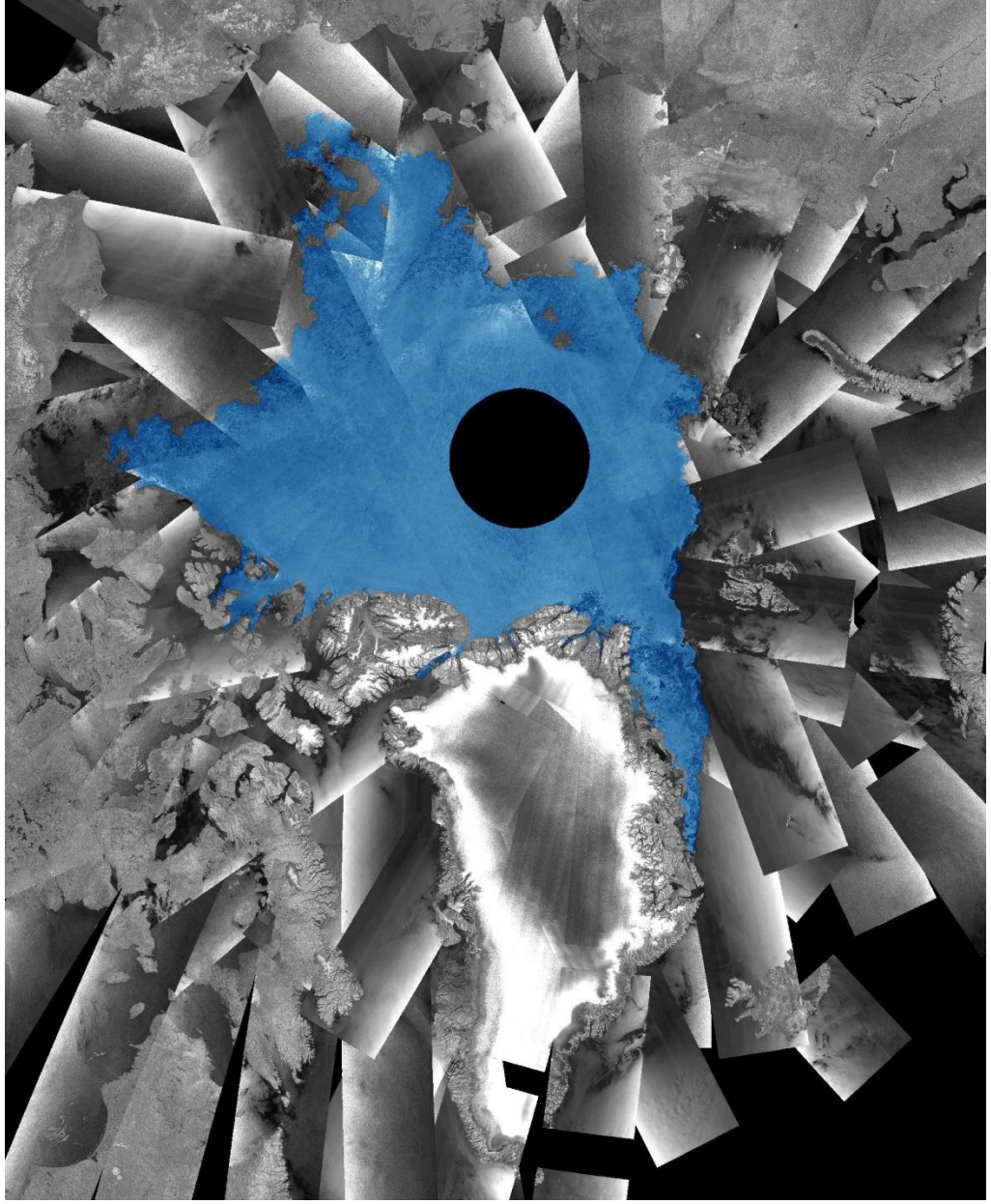
Global coverage & polar applications tend to use Sun-Synchronous orbits

- Repeat ground-track over N days
- Instrument FoV & coverage requirements drive repeat period

- Orbit does not pass over poles
- From ground-track: polar coverage better than equatorial

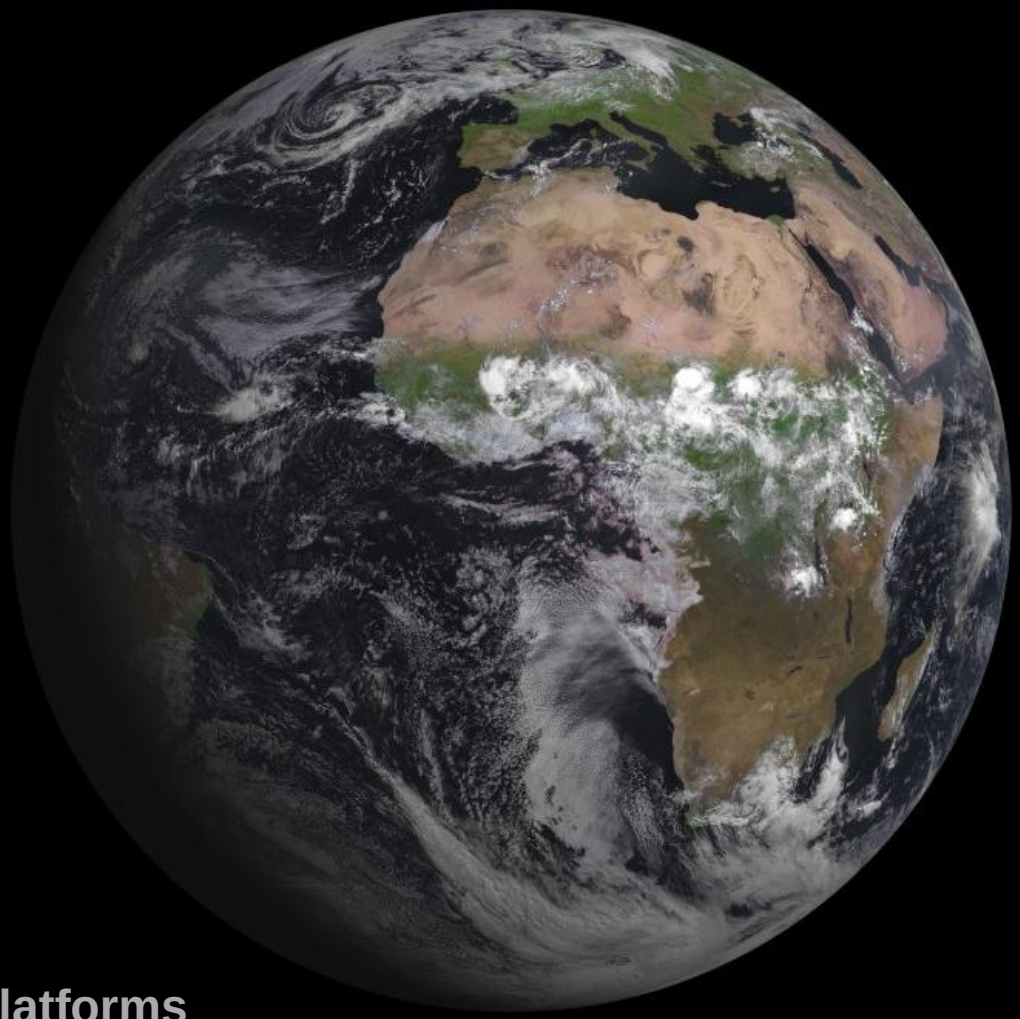


Images show ENVISAT-like ground track-over first 5-days of 35 day repeat period



ENVISAT Mosaic Image of the Arctic Ocean

Mosaic of radar images acquired between 9 and 11 September 2011 over the Arctic Ocean



Geostationary platforms

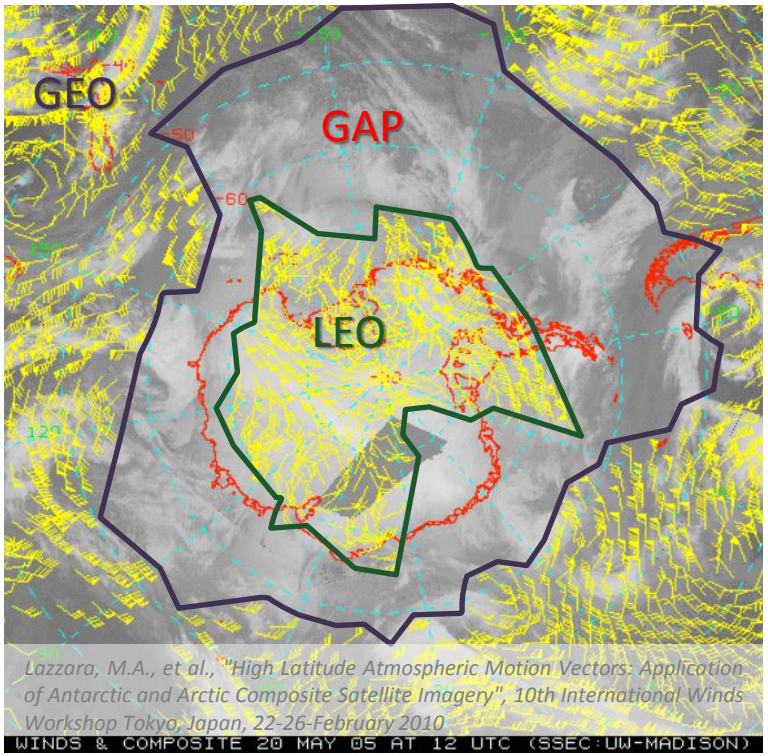
Suffer rapidly decreasing horizontal resolution with increasing latitude; many products not available beyond central belt

Image Credit: EUMETSAT

Composite Images

Hourly AMVs from composite images

- A ‘ring’ of missing observations exists
  - from <50° to >70°



Lazzara, M.A., et al., "High Latitude Atmospheric Motion Vectors: Application of Antarctic and Arctic Composite Satellite Imagery", 10th International Winds Workshop Tokyo, Japan, 22-26-February 2010

Image Credit: Malcolm Macdonald

What's wrong with where we currently put spacecraft?

Lack of high-temporal resolution at high latitudes for EO applications, and lack of visibility for communication applications

Non-spherical Earth enables sun-synchronous orbits

- Also causes rotation of orbit perigee
- Zero secular variation at $(3 + 5\cos(2i)) = 0$
  - i = (90 ± 26.6) degrees

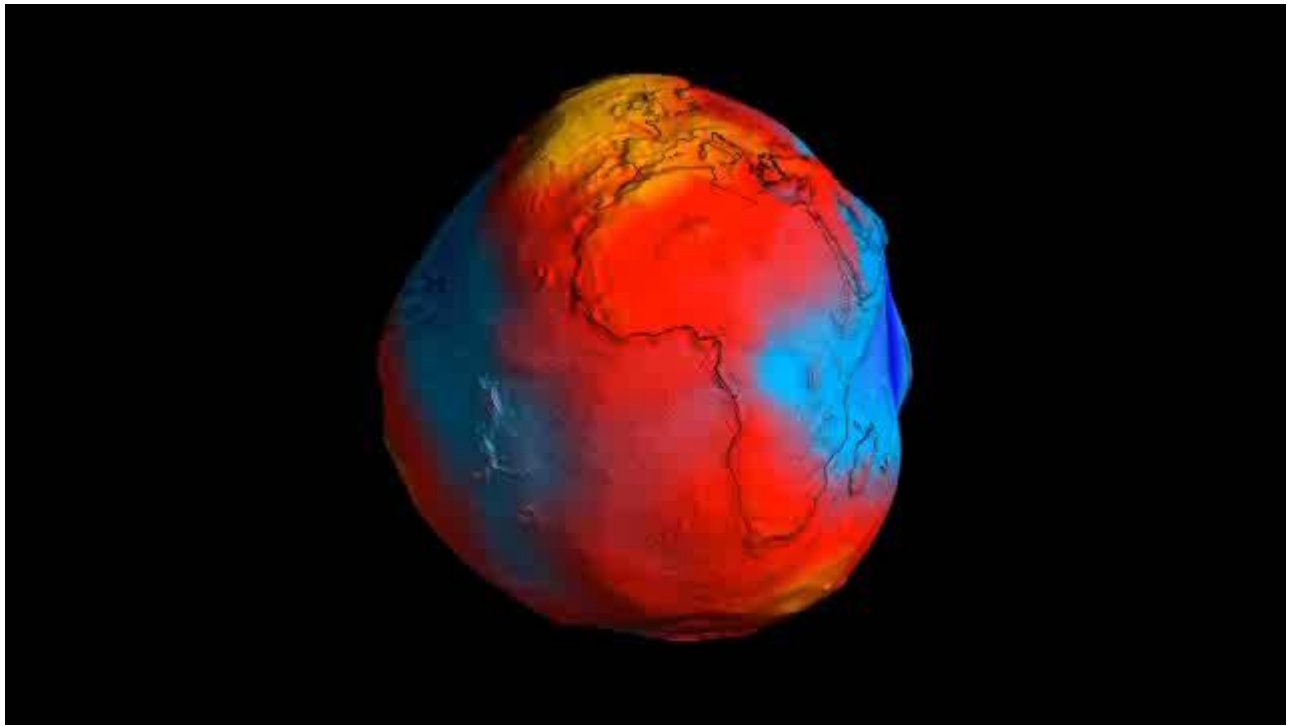
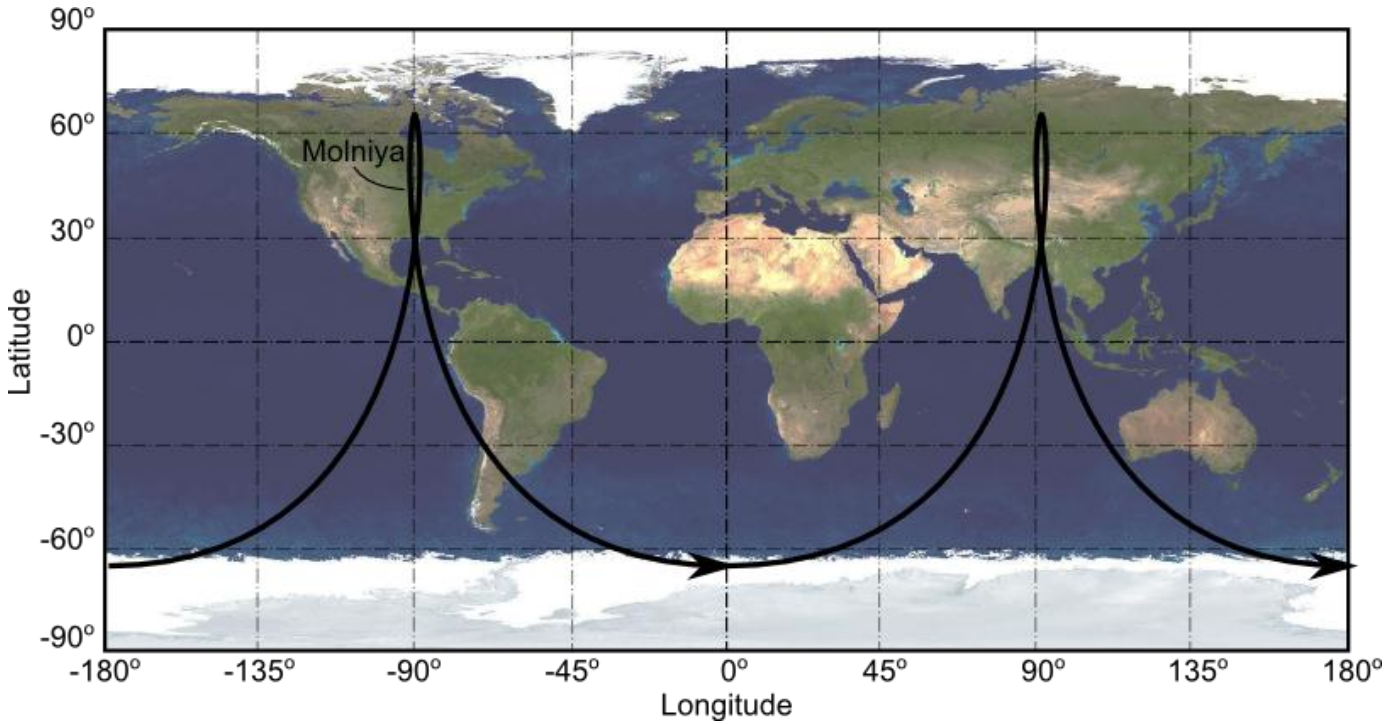


Image Credit: ESA

Molniya orbit has a period ½ of a sidereal day

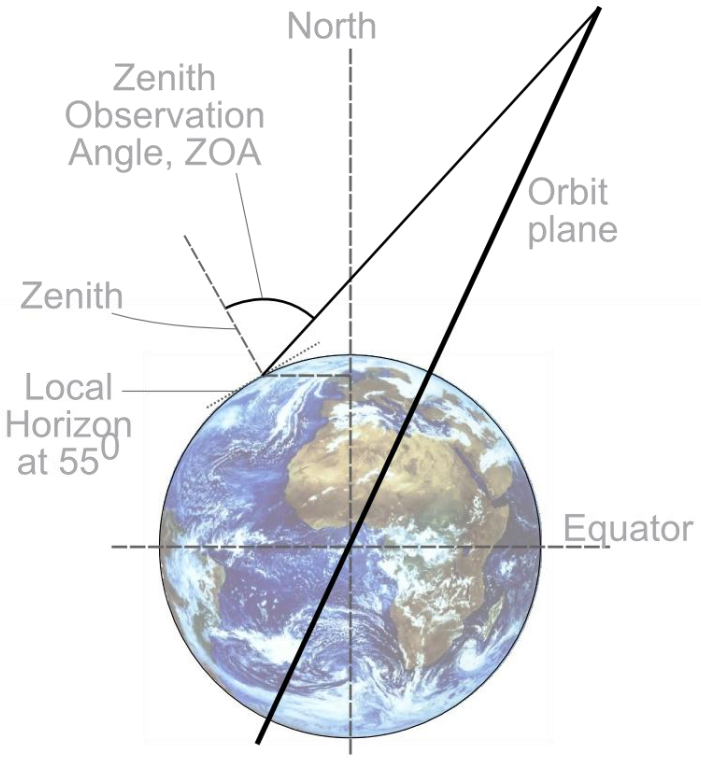
- Other orbit periods are available



Молния

From GEO the ZOA at 55° latitude is 63°

- On Molniya orbit, minimum ZOA to all longitudes is 69°
  - i.e. a single platform cannot provide hemispheric-like observations
  - Polar observations would remain dependent on composite images
- Three spacecraft required to provide continuous observation to all longitudes at latitudes 55 – 90°, with OZA <60° with composite images



Critical inclination results from the shape of the Earth

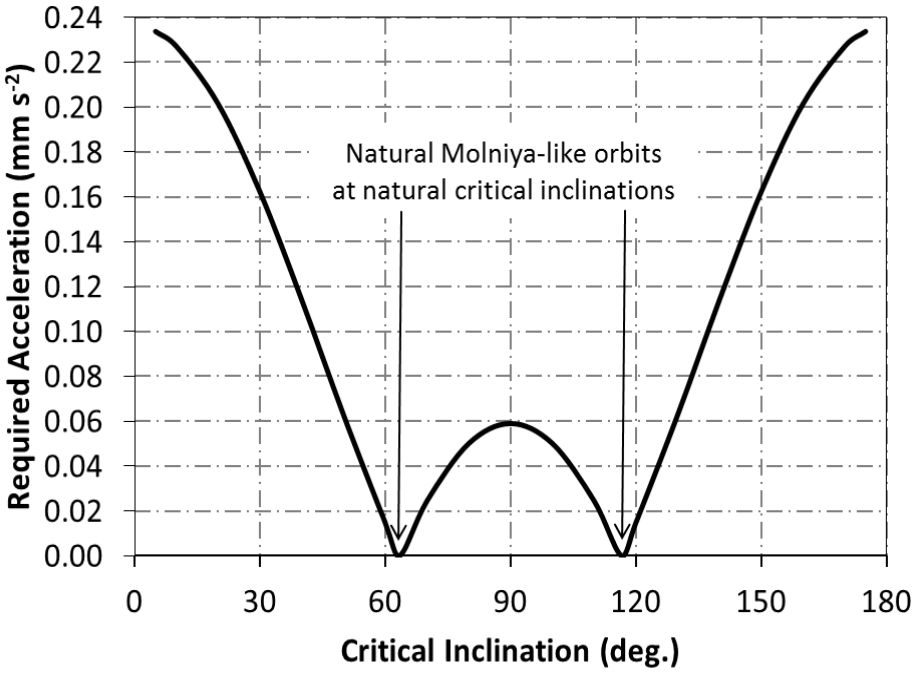
- If Earth were a different shape the critical inclination would be different…
  - So, lets change the shape of the Earth!

Taranis Orbit

Use low-thrust propulsion to modify the geopotential perturbations

- how spacecraft 'feels' the gravity of Earth

- Redefining the critical inclination as a function of the thrust magnitude

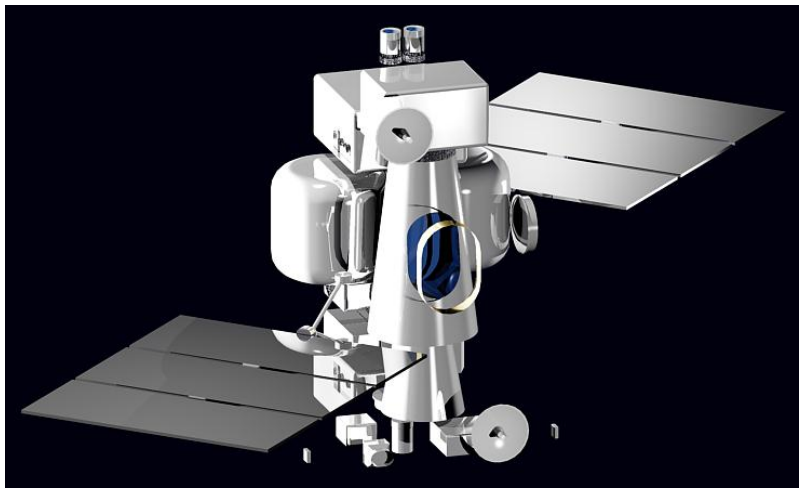


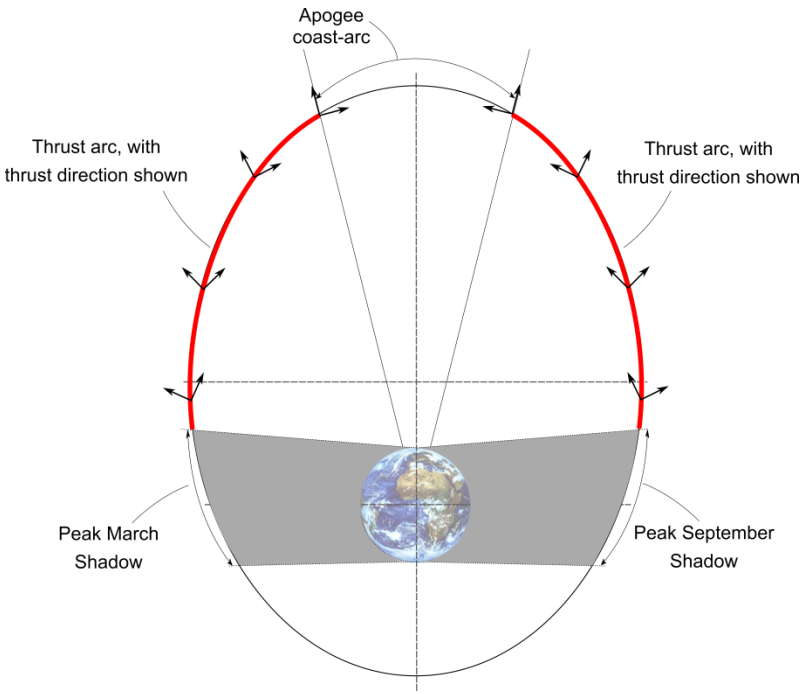
Acceleration required assuming continuous acceleration on a 12-hr orbit

Taranis Orbit

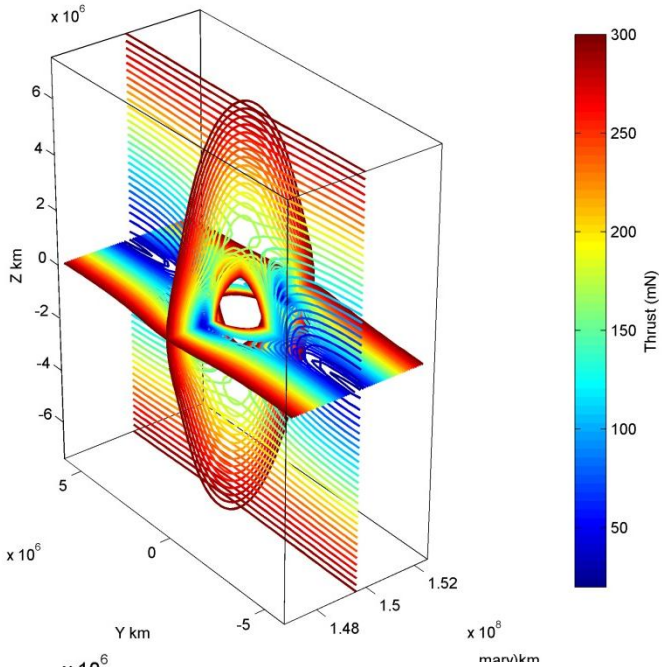
16-hr orbit, 10000 x 42000 km @90°

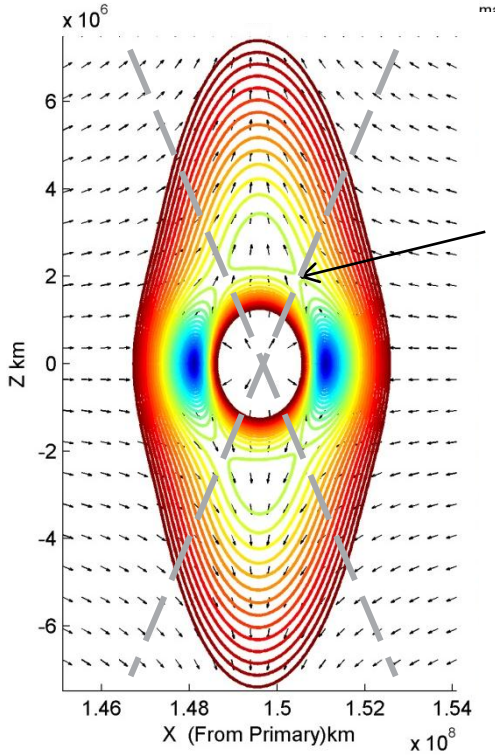
- Observation of all longitudes at latitudes 55 – 90°, with OZA <60°
  - 4 spacecraft for continuous coverage
  - 2 spacecraft for composite coverage
- Altitude change <2500 km
  - Apparent diameter variation of 0.5º
- 2 tonne spacecraft
  - 20mN thrust
- 10+ year mission
  - Based on SEVIRI-like payload
- 3.3kW total power
  - 12 – 15 m^2 solar array
  - 1.6kW available for instruments





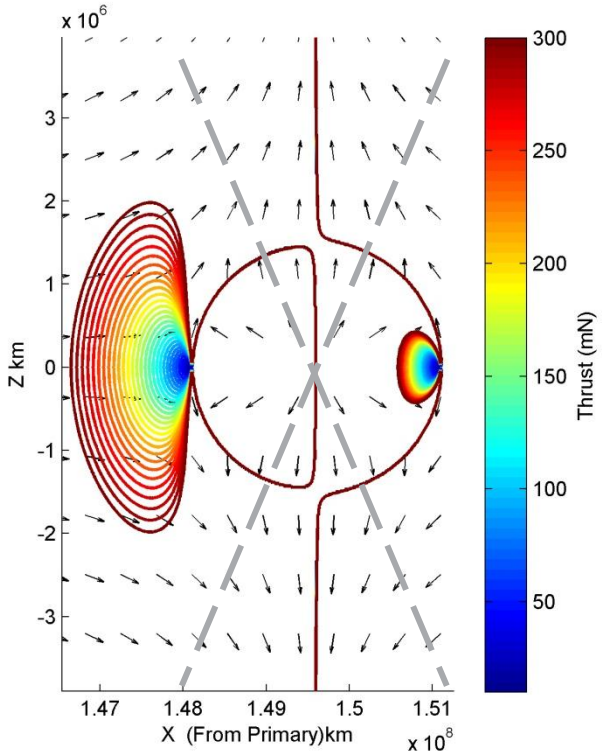
1000 kg spacecraft





Minimum SEP thrust a
around 2.5 million
kilometre altitude

Solar sail propulsion cannot access same volume of space, and cannot get to polar axis

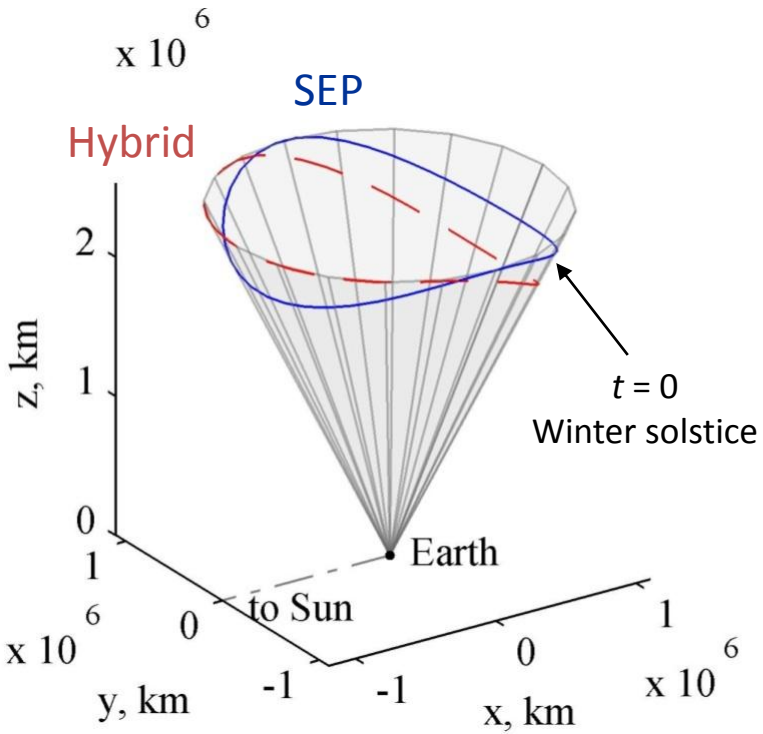


University of Strathclyde Engineering

Advanced Concepts – Polesitter

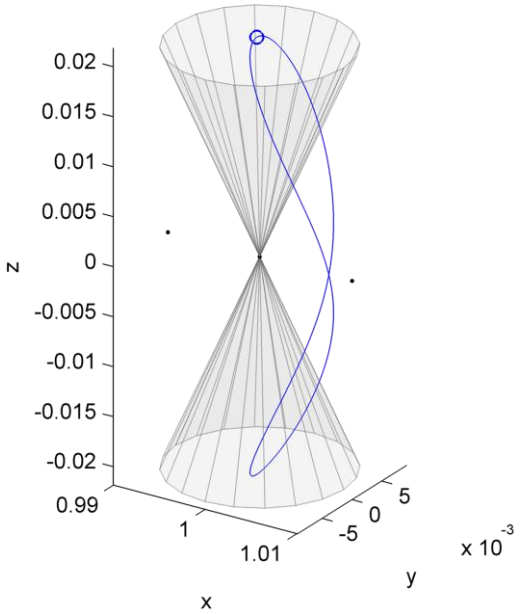
Hybridisation of these propulsion technologies is a popular concept

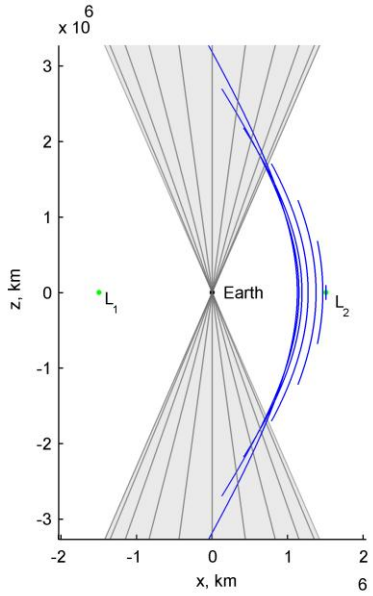
- Increases SEP mission lifetime
- Maintains access to polar axis
- Altitude varied to minimise propellant consumption
  - Can fix altitude at cost of propellant

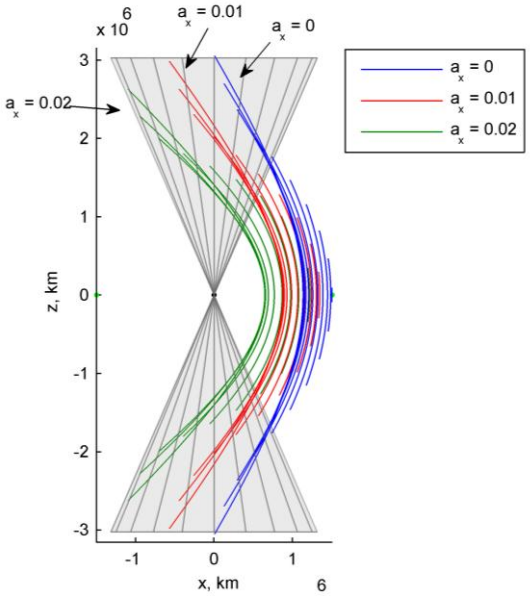


Families of periodic, non-Keplerian orbits

- Exploit attraction of Earth and Sun
  - Completely natural; no propulsion system needed
- Can displace towards Earth using a solar sail







University of Strathclyde Engineering

DEPARTMENT OF MECHANICAL & AEROSPACE ENGINEERING

ADVANCED SPACE CONCEPTS LABORATORY

Image Credit: SeeGlasgow

University of Strathclyde Glasgow

www.strath.ac.uk/mae

Polar Telecommunications

For areas within geostationary coverage,

- Total capacity will exceed total demand in the Arctic for all regions.
  - But, assuming 10-15% of the total GEO capacity is consumed by Arctic users, gaps between demand and offers may occur in 2015-2020.

For areas outside geostationary coverage,

- PCW plans to provide broadband coverage over Canadian Arctic from 2017
- In Russia, PolarStar & Arktika planned to provide broadband coverage from about same time
- No system planned to provide broadband coverage over the European part of the Arctic.

Main challenge for future satellite communication in Arctic is to avoid the lack of broadband coverage over the European part of the Arctic that is outside coverage of geostationary satellites.