Introduction to satellite constellations

orbital types, uses and related facts

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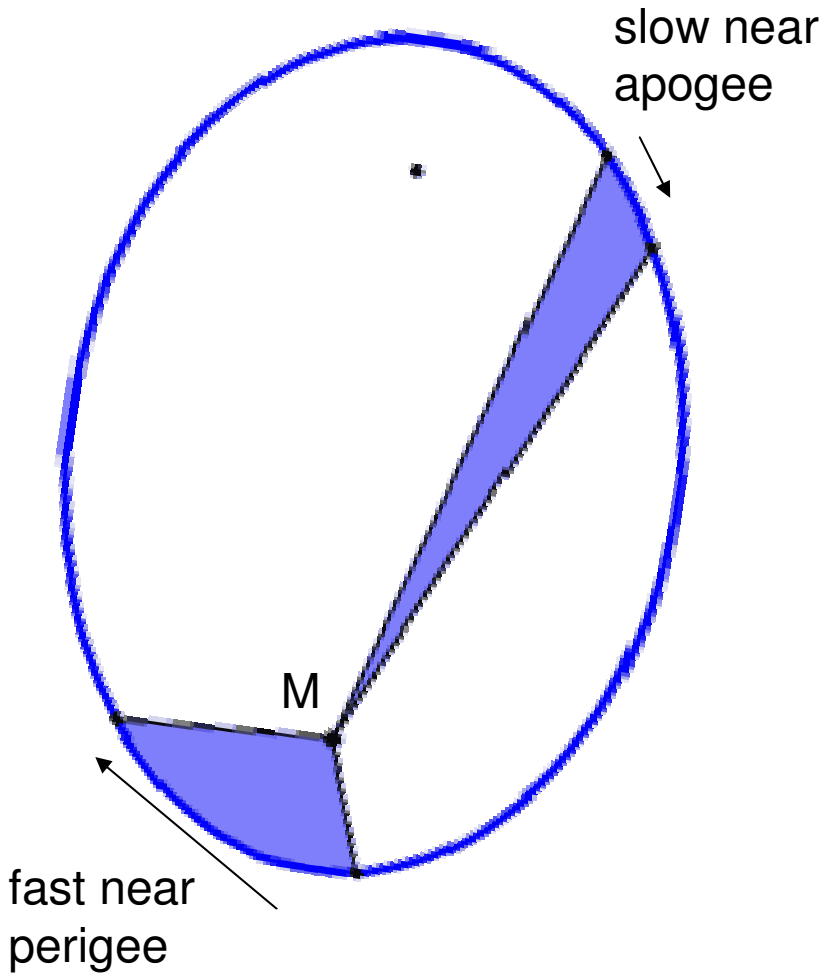
Guest lecture, ISU summer session
July 2006

created with SaVi
savi.sf.net

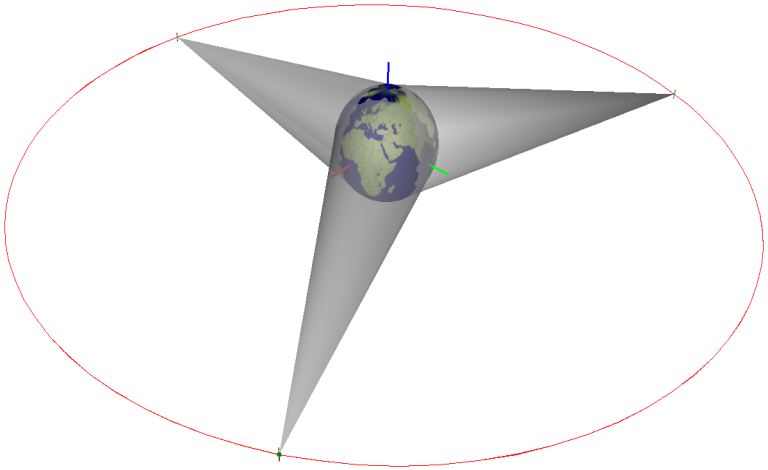
All orbits are ellipses

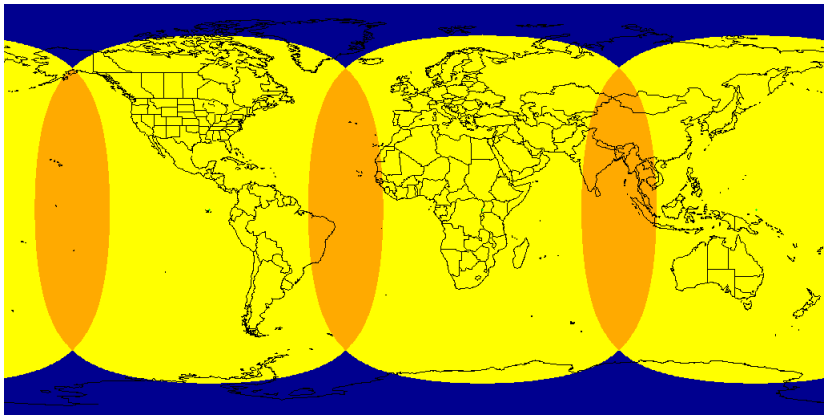
- **Kepler's first law**
  Earth mass M at focus of an ellipse. Circular orbit is just a 'special case' of the ellipse, where the two focii are positioned together to form one.
- **Kepler's second law**
  equal areas covered in equal times.



Most useful for communications – geostationary Earth orbit (GEO)

- Altitude (35786km) chosen so that satellite moves at same angular velocity as Earth's rotation, so appears still. (period: 1 *sidereal day*.)
- Three satellites spaced equally around the Equator cover most of Earth – but not the poles.
  (Arthur C. Clarke, 1945)
- Inmarsat's I-4 *BGAN* is nearest match to this.
  (2 of 3 satellites launched.)





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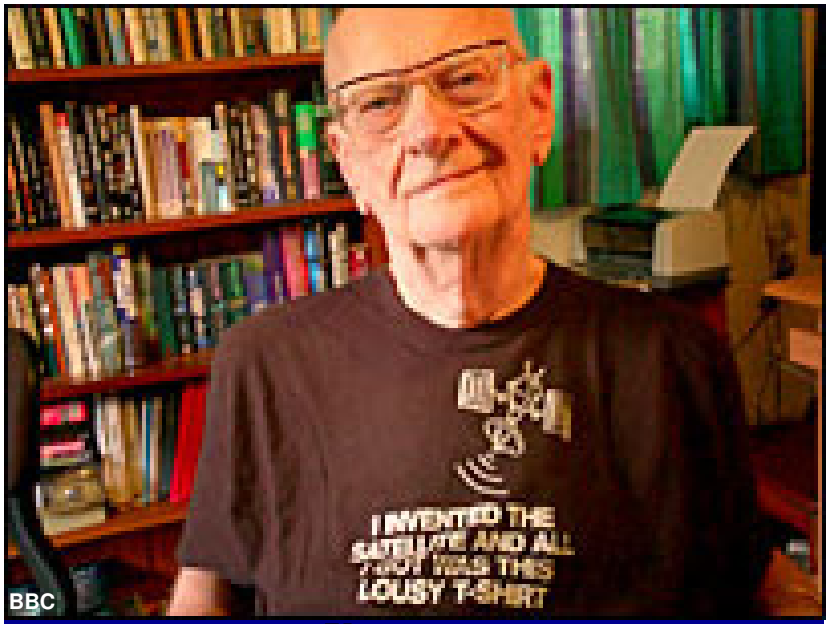
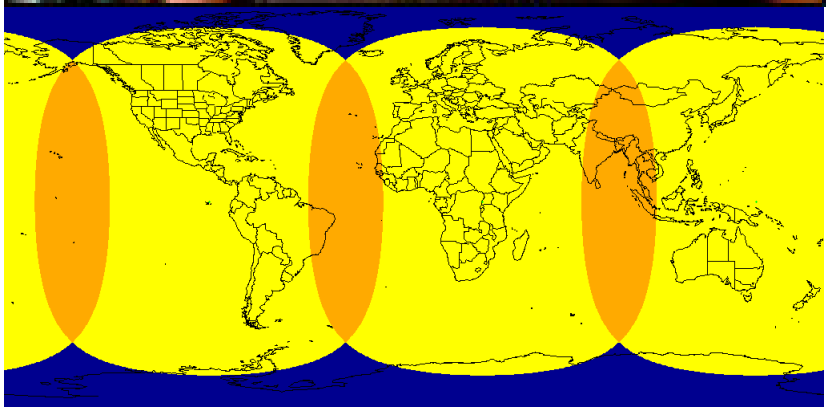
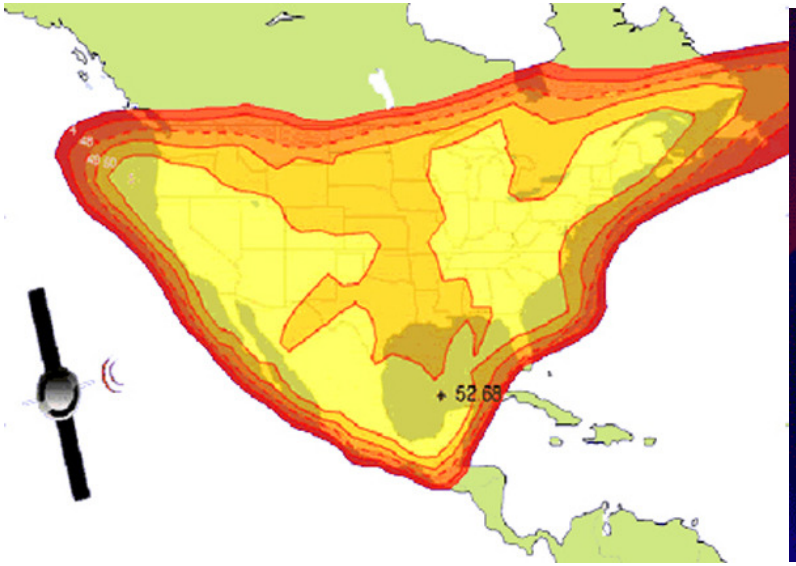
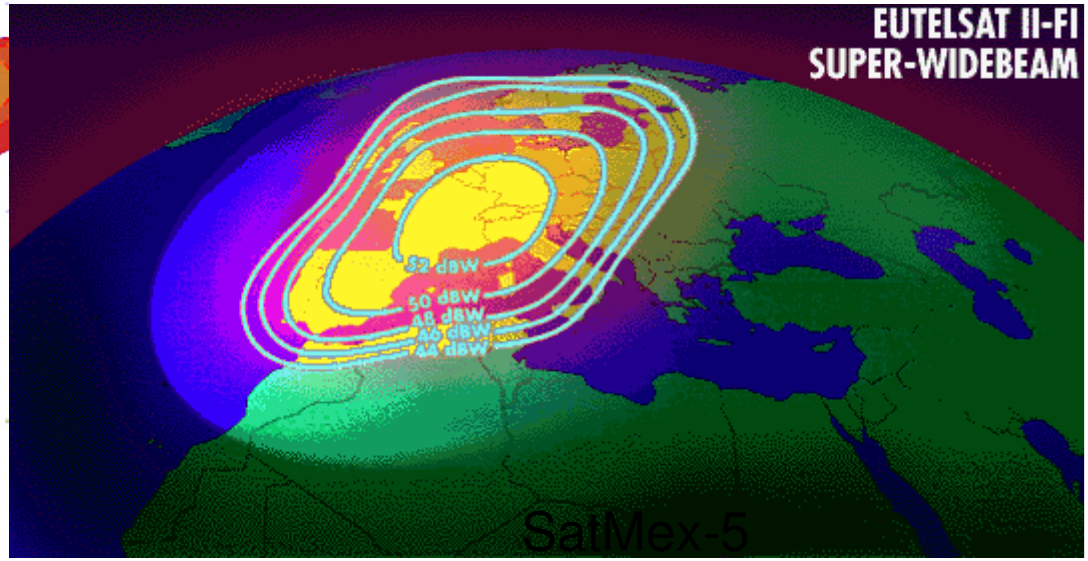




Satellite antennas tailor footprints

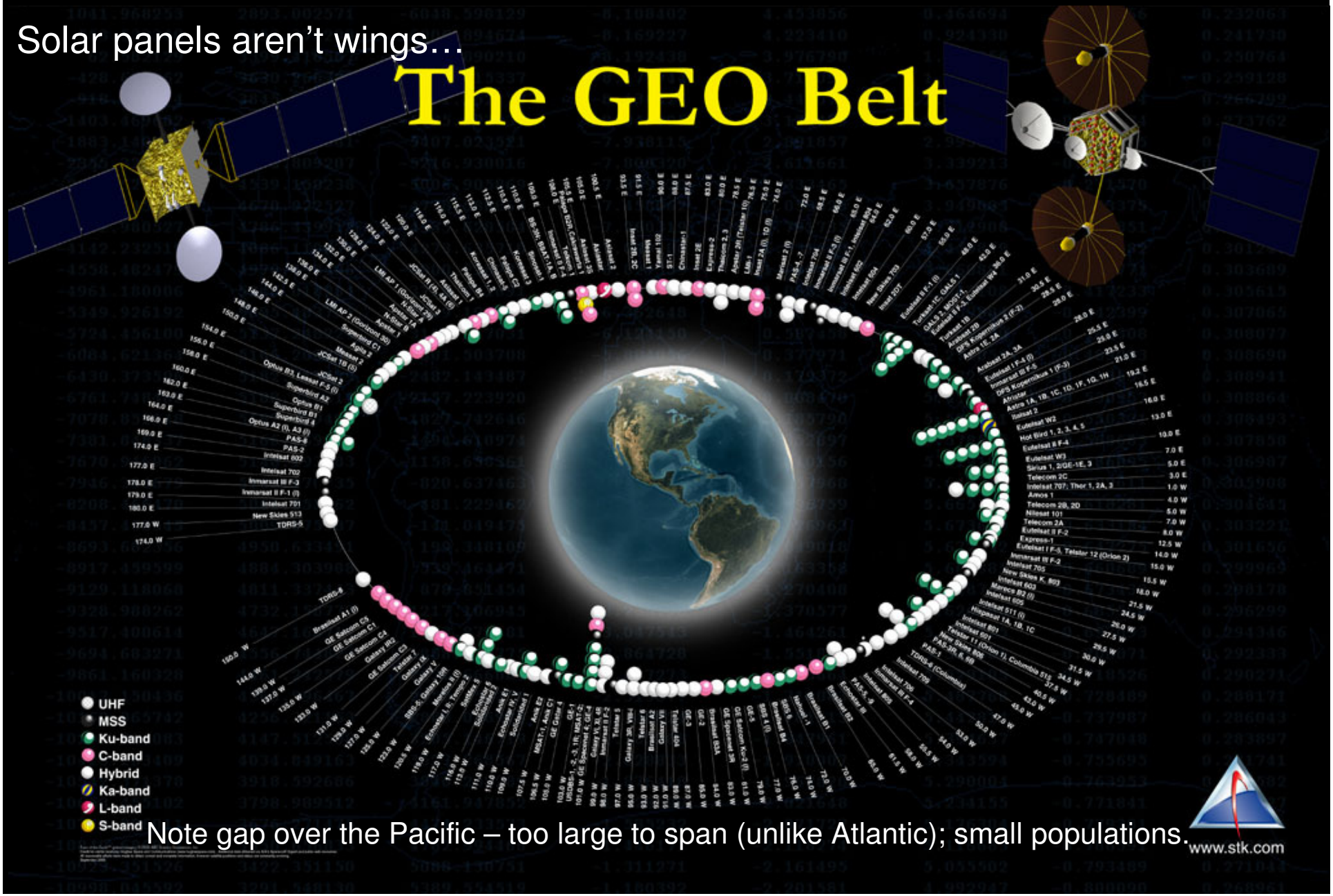
- Satellites don't always support perfectly spherical coverage areas.
- Shaped spotbeams let you concentrate coverage and power where you want it.
- Movable antennas let you provide more support (traffic) to a region on demand.





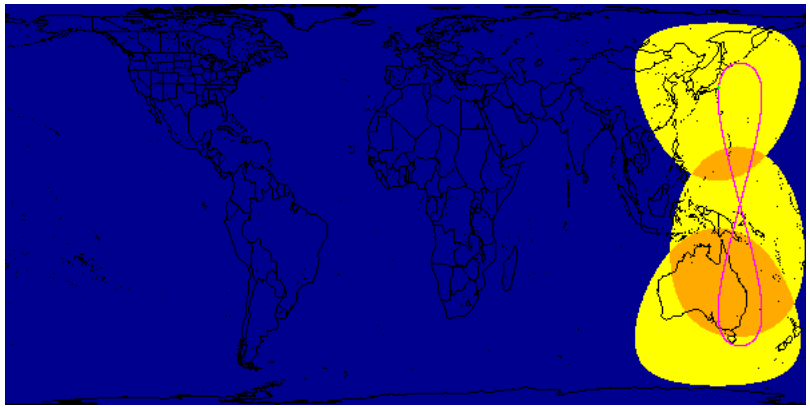
Actual geostationary orbit use (2001)

Solar panels aren't wings…



Note gap over the Pacific – too large to span (unlike Atlantic); small populations.

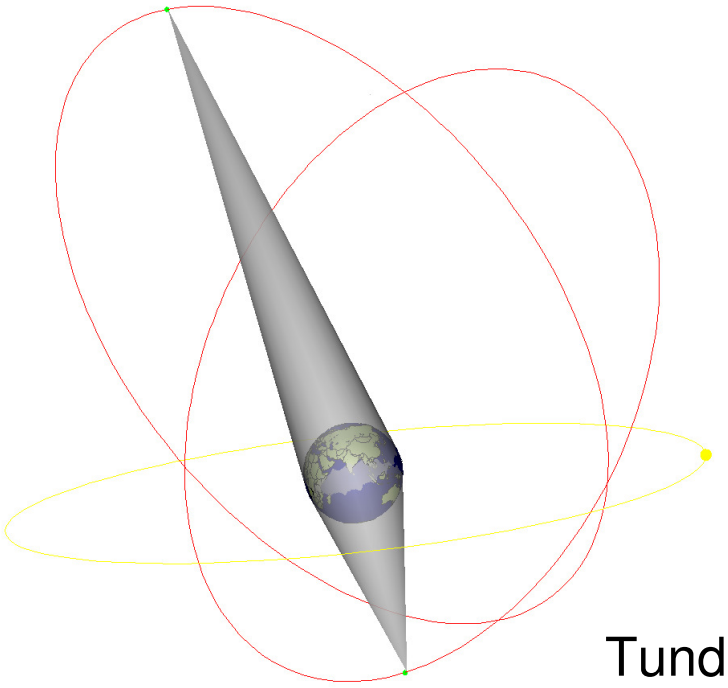
Inclined geosynchronous orbit



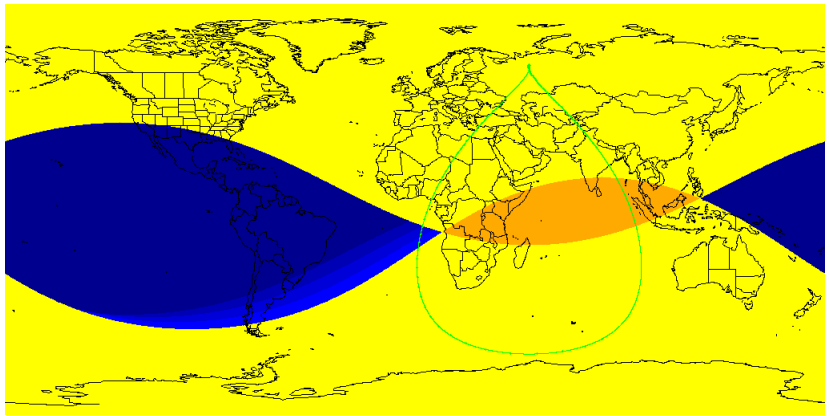
- Geostationary satellite reaches end of its planned life – stationkeeping fuel has run out, satellite moves in the sky south/north of the Equator. Can be used give a few hours' connectivity cheaply each day for polar research stations.
- Forms a figure-of-eight groundtrack throughout the day. Investigated for use for mid-latitude Japan to give high-bandwidth comms with smaller footprints.

Useful highly elliptical orbits (HEO)

- Molnya (0.5*sd* ~12hr) and Tundra (~24hr 1*sd* orbits) – cover high latitudes at apogee.
- Invented by Soviet military; then Russian satellite television in 1960s. 63.4º inclination.



Tundra



Yellow circular GEO orbit shown for scale

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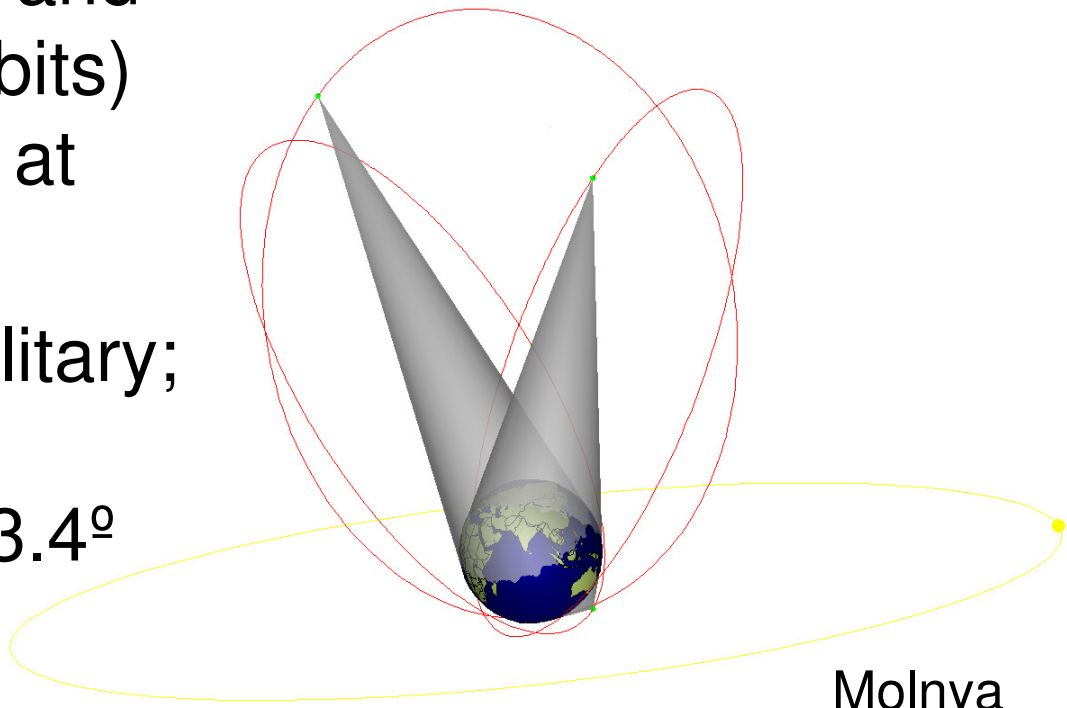
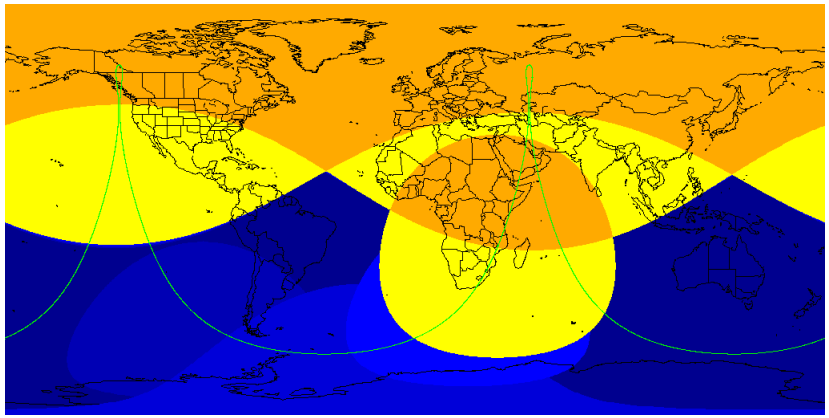


Molnya



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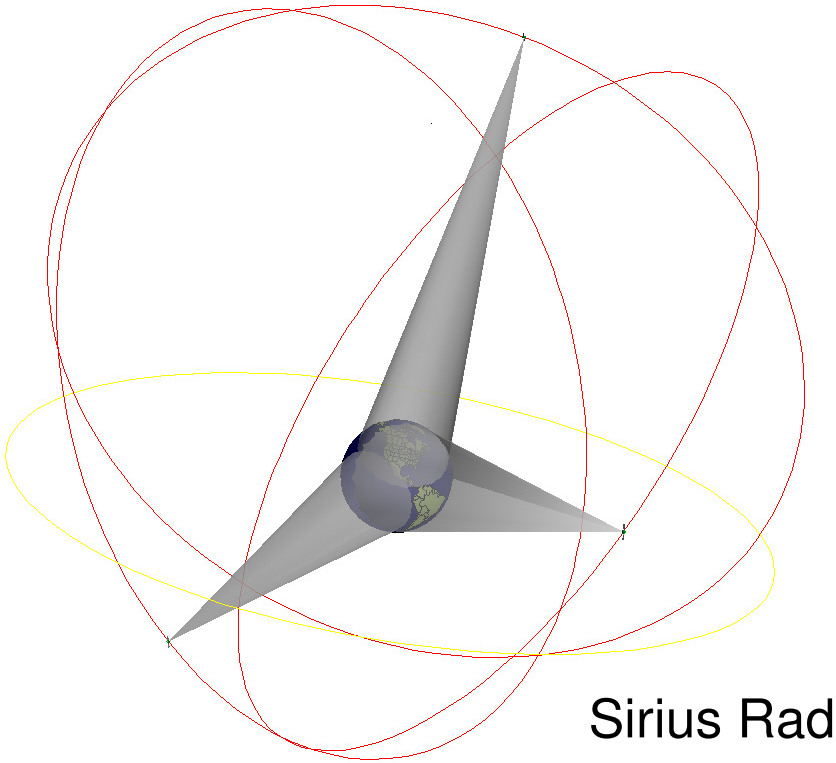
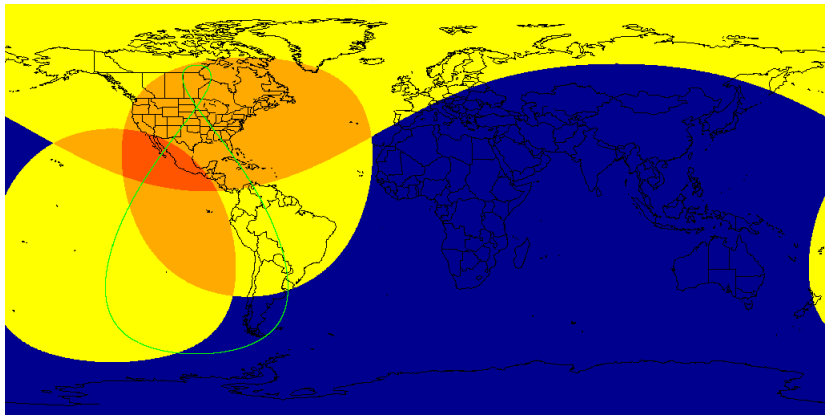
- *Sirius Radio* adopts this model over the continental US. (*XM Radio* has two GEO satellites, *Sirius* plans new GEO sat for diversity.)



Sirius Radio



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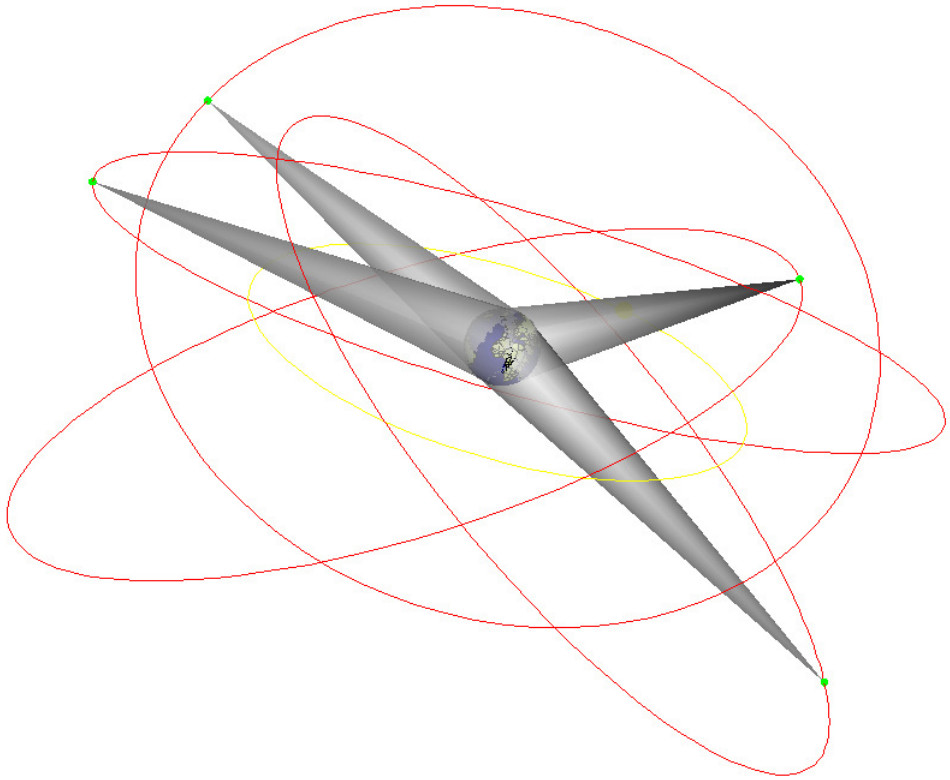
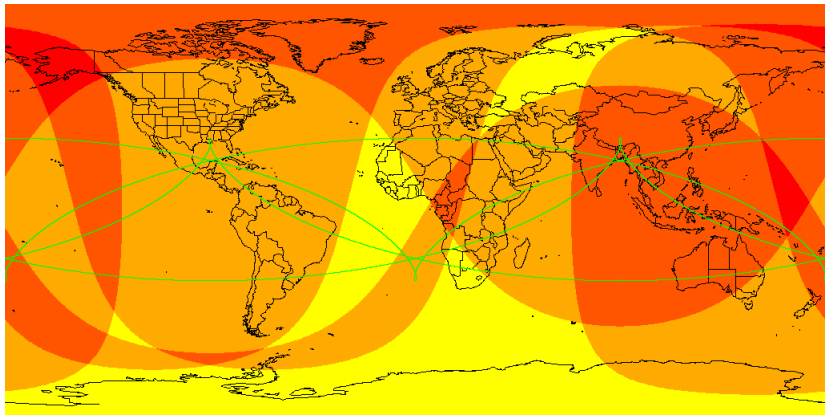
Optimal elliptical constellation

- Four satellites provide visibility to the entire Earth (Draim, 1987).
- Earth always inside a tetrahedron.
- Assumes Earth is flat – satellites often very low above horizon, easily obscured. **Not built.**
- Huge 2*sd* ~48-hr orbits with repeating groundtracks.





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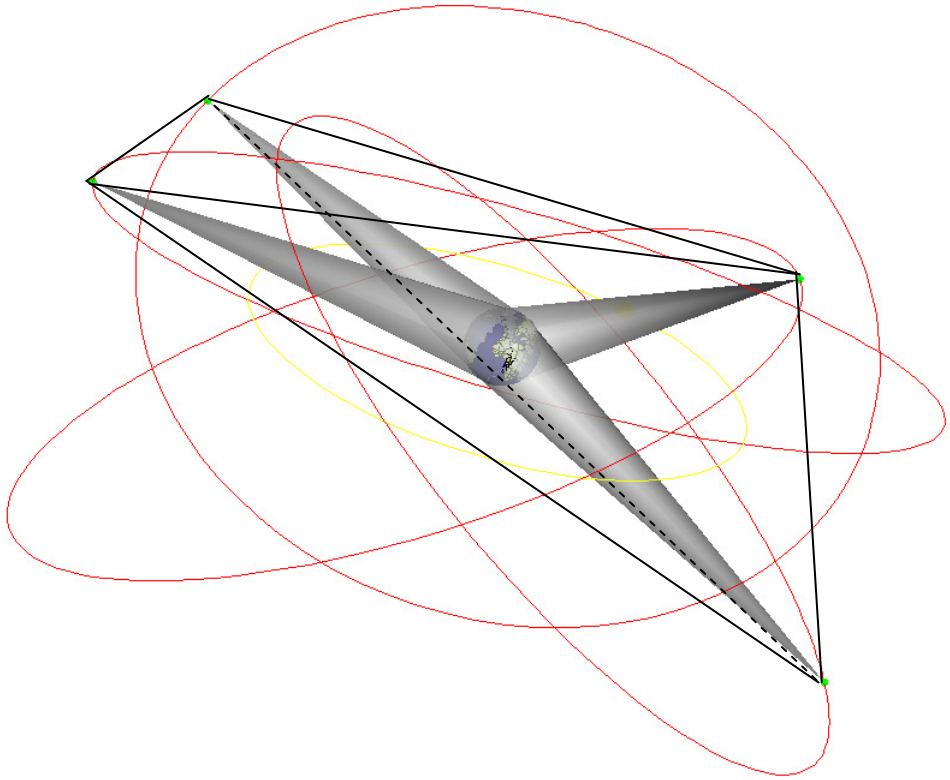

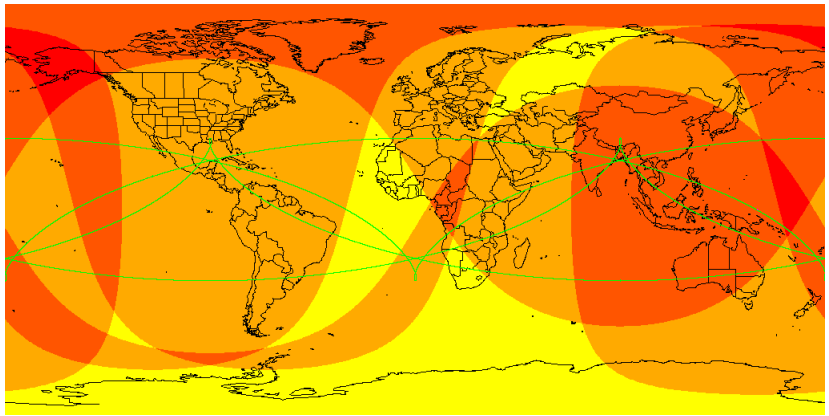

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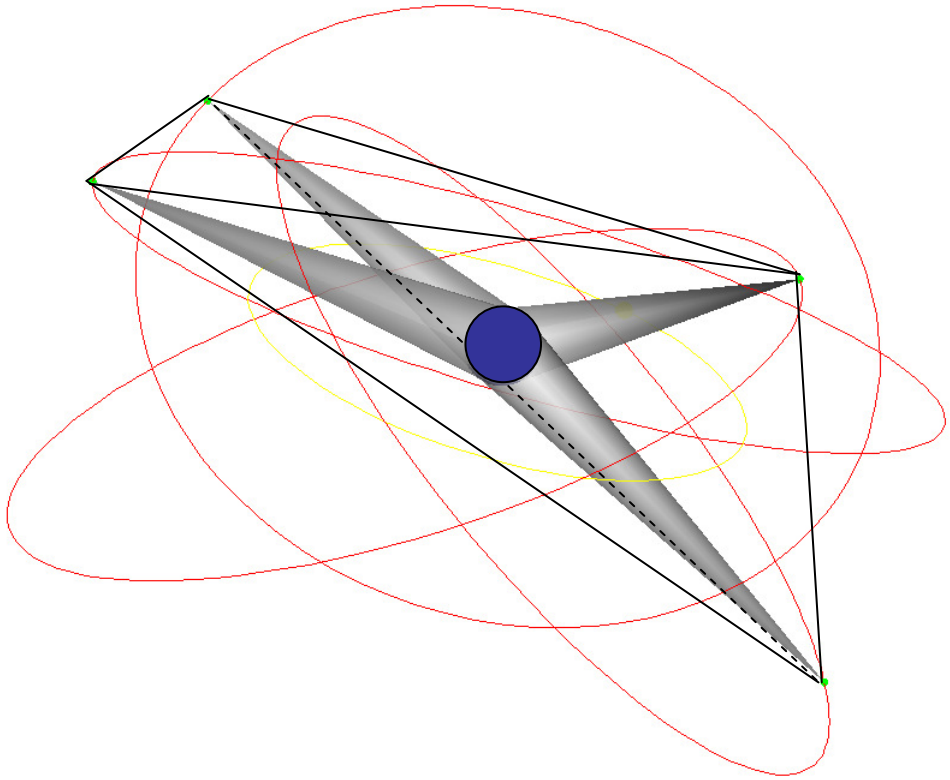
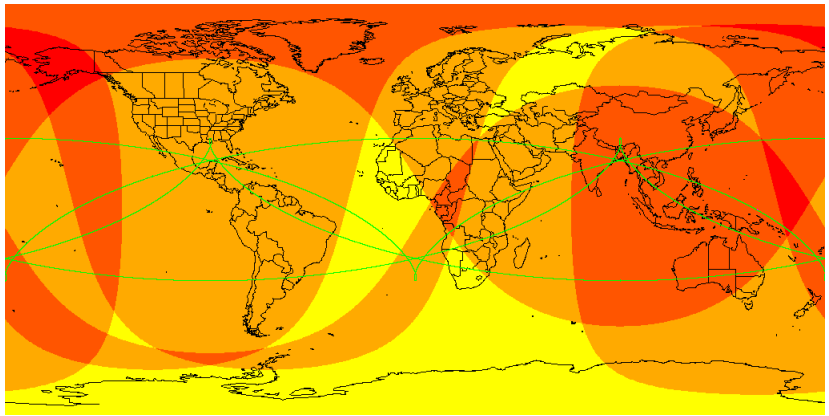
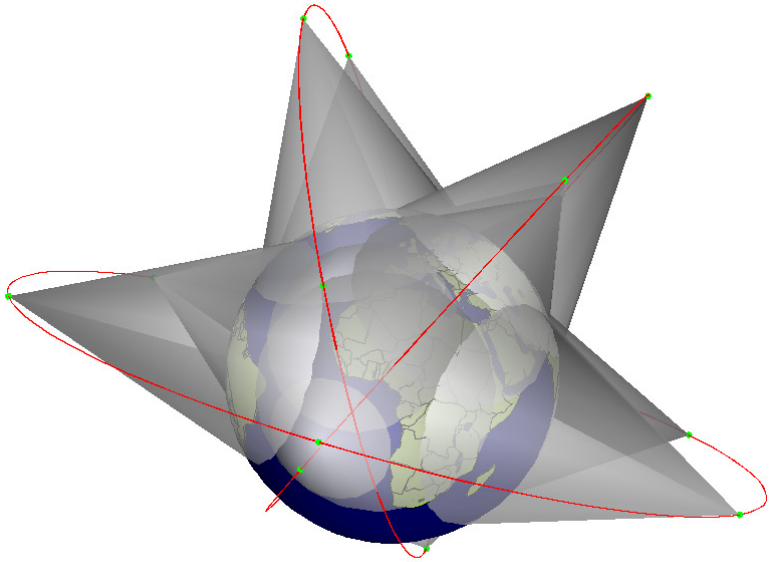
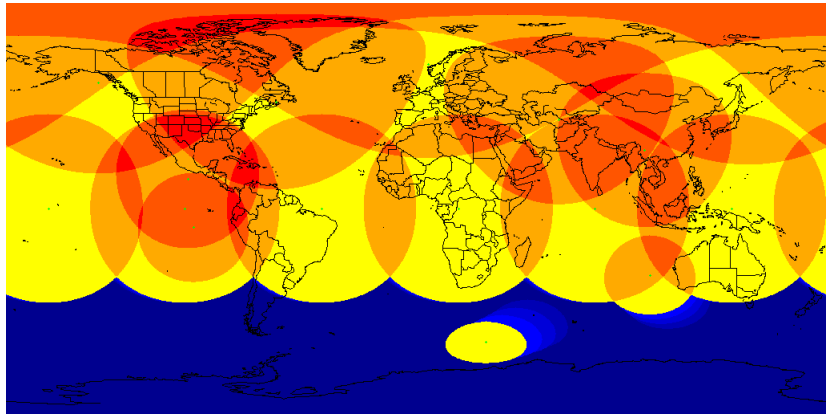




Ellipso – John E. Draim again

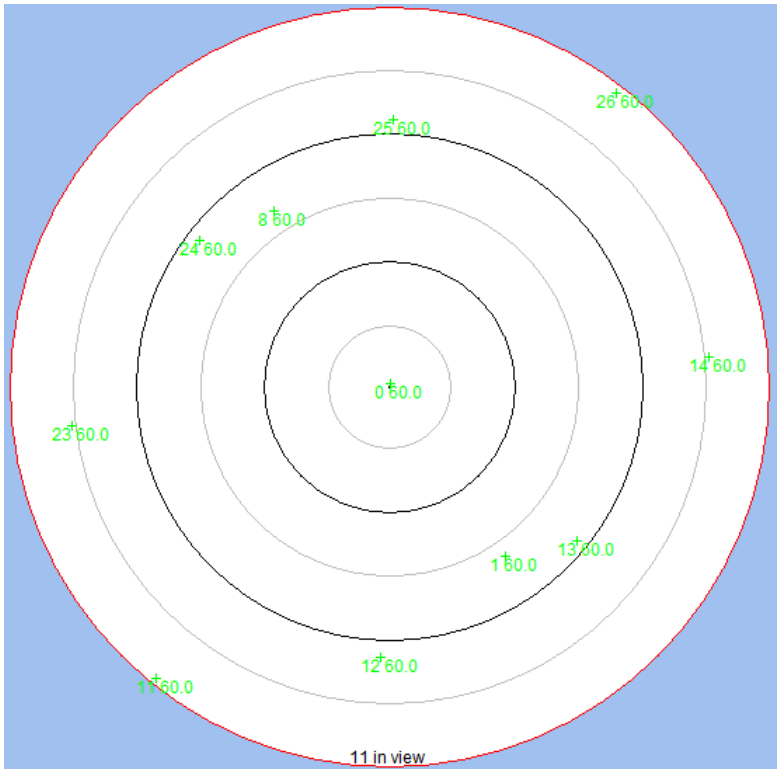
- Use of elliptical apogee to provide service at the northern high polar regions.
- Circular MEO orbit covers equatorial areas.
- Coverage of south poor: ‘my business plan can do without the people on Easter Island.’ – David Castiel, *Wired* 1.05
- Business plan to sell voice telephony. Oops. **Not built. Merged into *ICO*.**





Shadowing and urban canyons

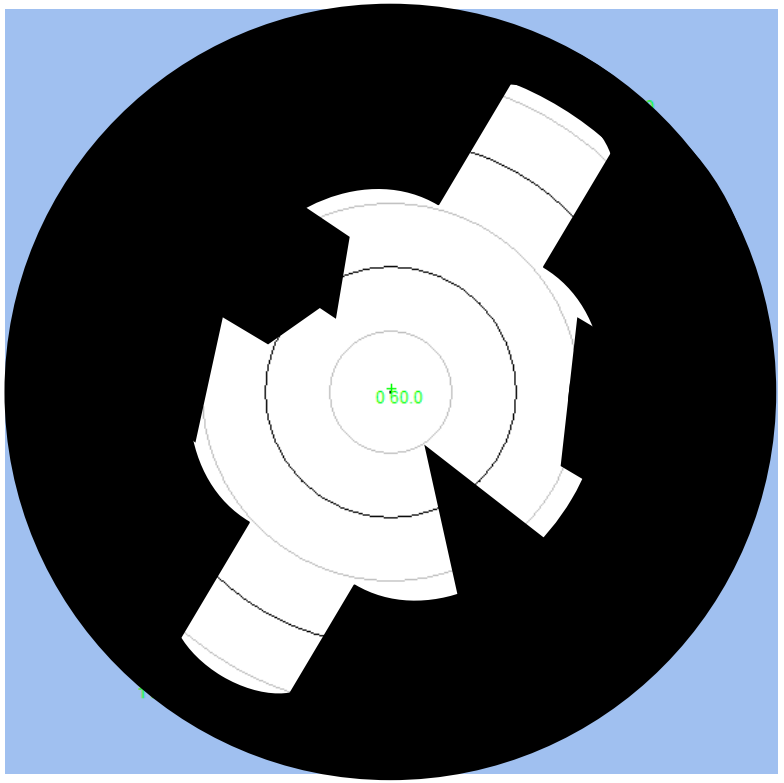
- No. of satellites you can see above horizon is *diversity*.



Galileo – lots of satellites in view.

Shadowing and urban canyons

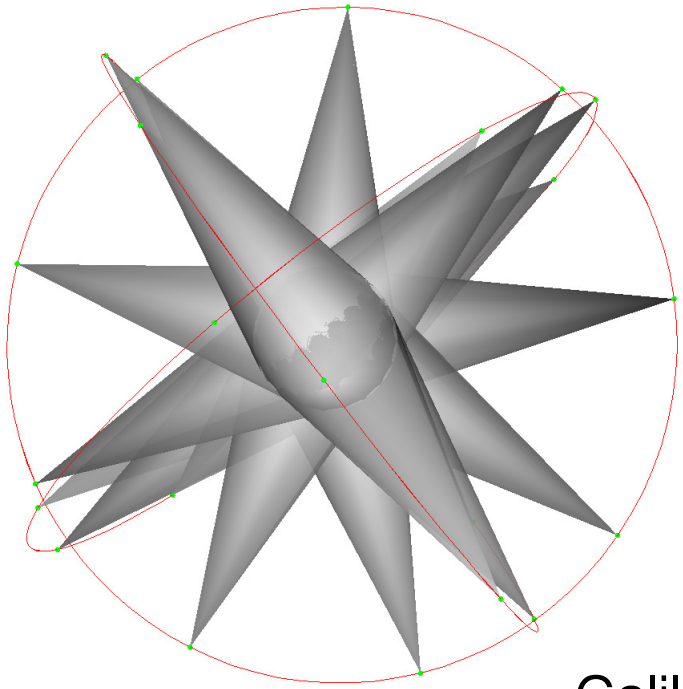
- No. of satellites you can see above horizon is *diversity*.
- But buildings/trees block your view of the horizon, limiting the number of satellites you can see.
- Skyscrapers and urban canyons mean no view of the sky (why *Sirius Radio* and *XM Radio* build city repeaters).



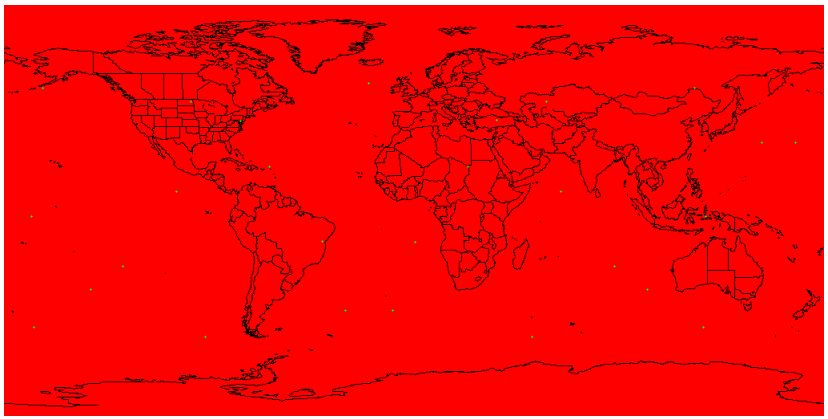
Galileo – lots of satellites in view.
…if you're not standing in a city street.

Navigation constellations

- *Galileo* and *GPS* (and *Glonass*) need to have high satellite diversity.
- You really need to see at least four satellites for a quick and accurate positioning fix (including height).

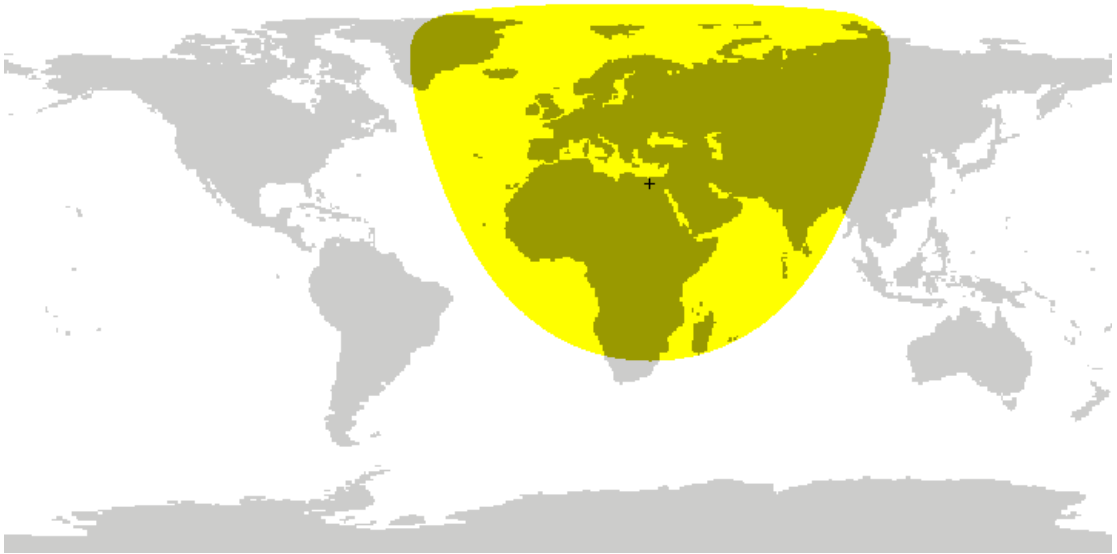


Galileo



It’s all about system capacity

- Multiple spotbeams let you reuse precious frequencies multiple times, increasing use.
- Reuse of frequencies by different spotbeams over multiple satellites increases overall system capacity.



ICO satellite footprint approximation

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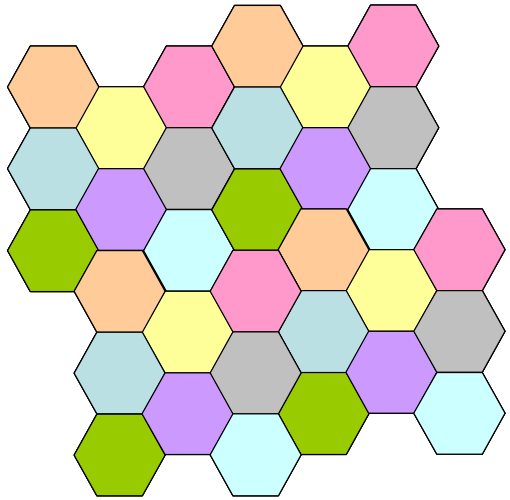
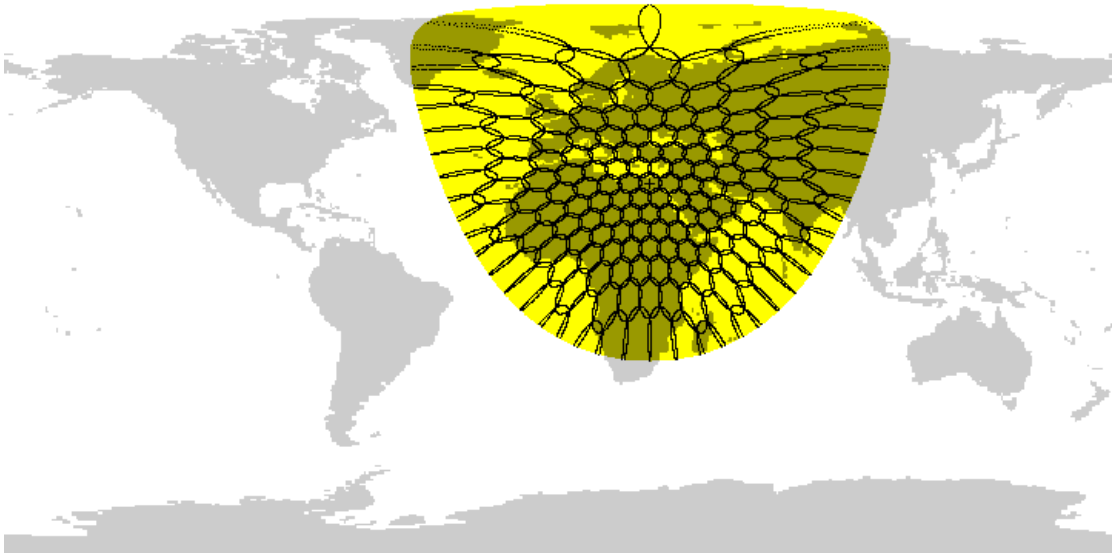


7-colour frequency reuse



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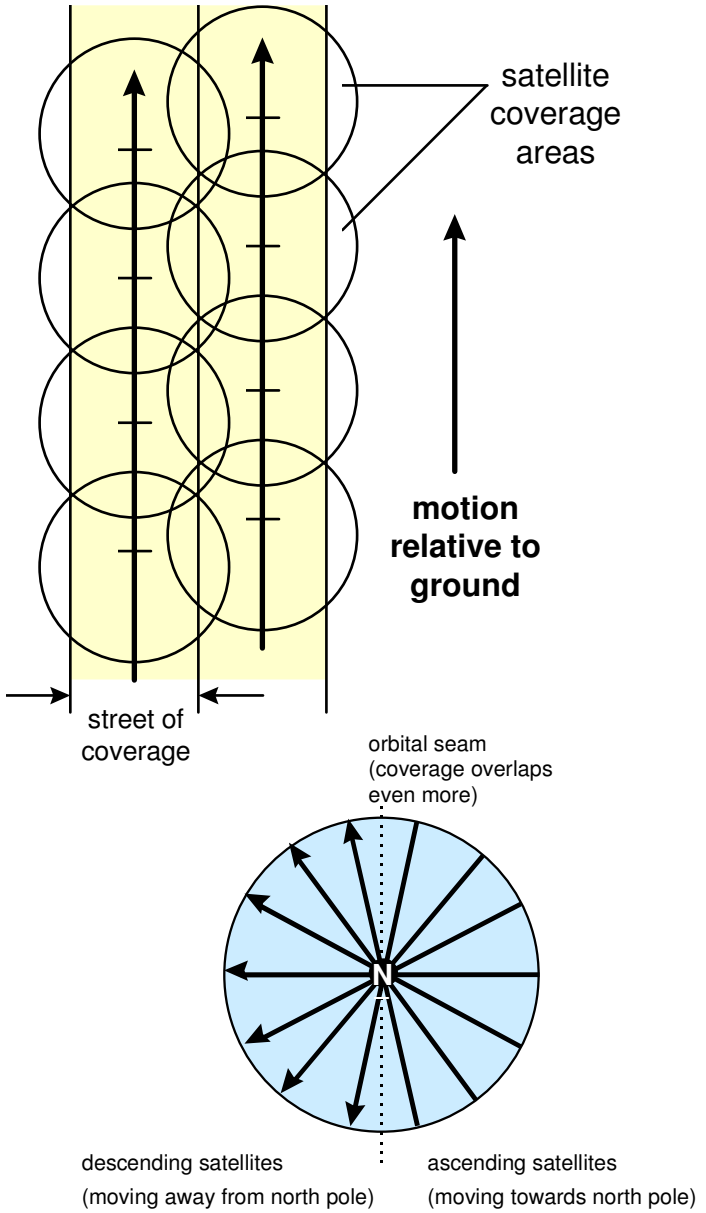
Walker star constellations

- Walker star geometry, based on Adams/Rider ‘streets of coverage’. Best diversity at poles, worst at Equator.
- Has orbital seam where ascending and descending planes pass each other and must overlap.



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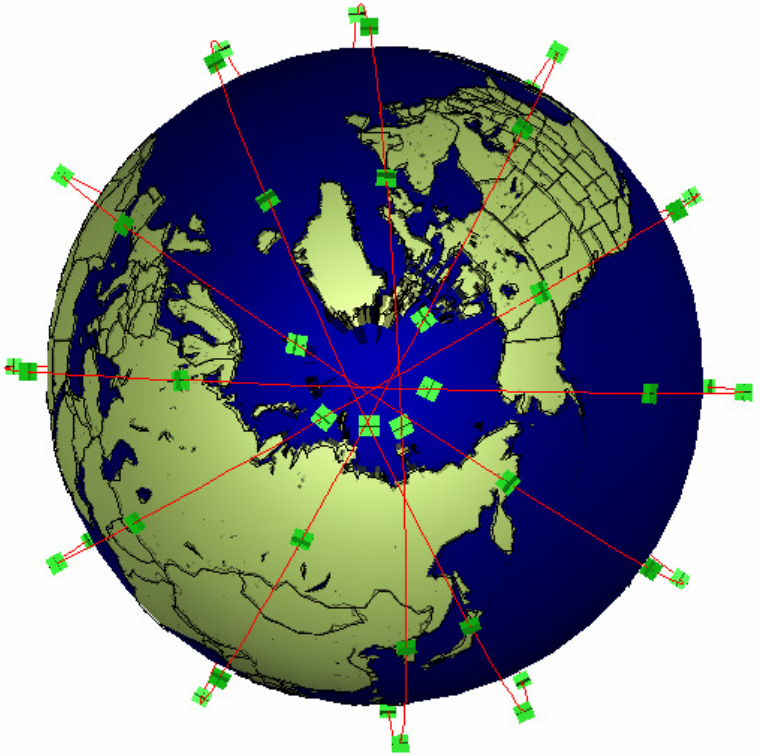

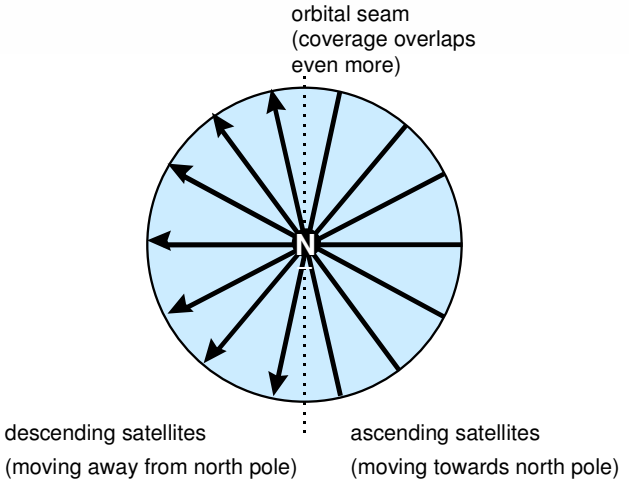

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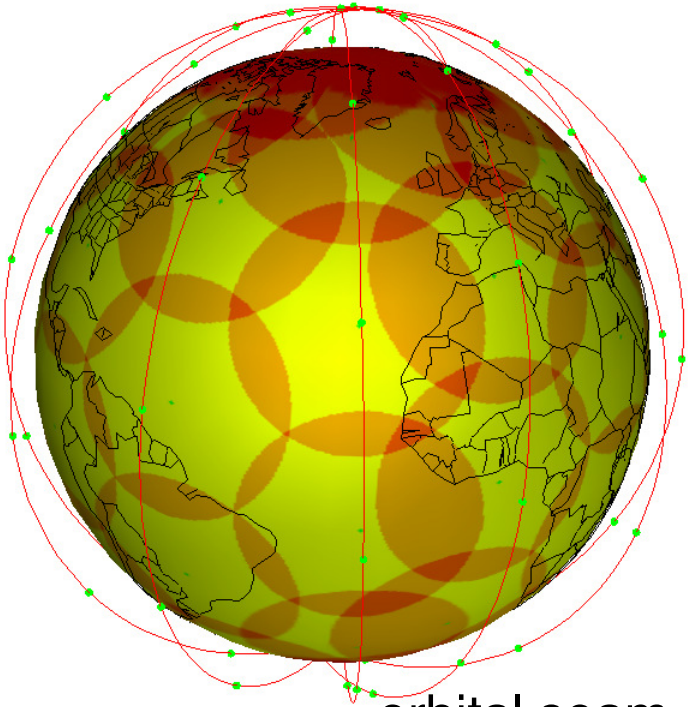

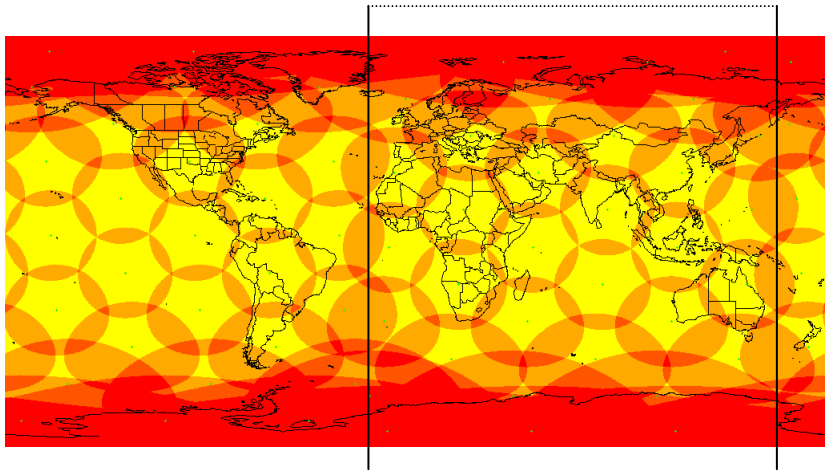

Ballard rosette (also Walker delta)

- Best diversity at mid-latitudes.
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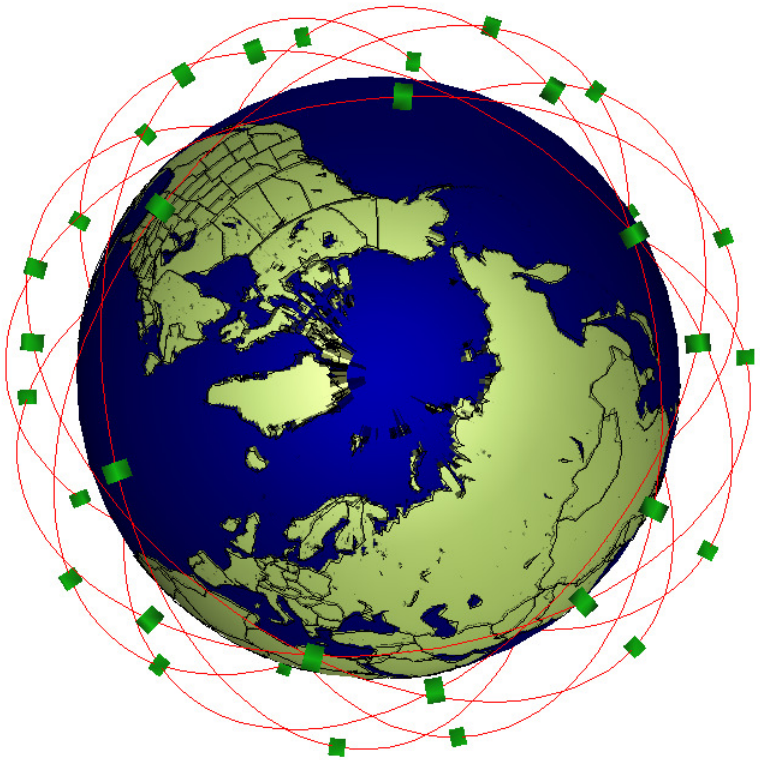

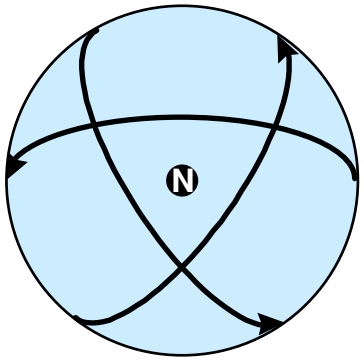

no orbital seam;
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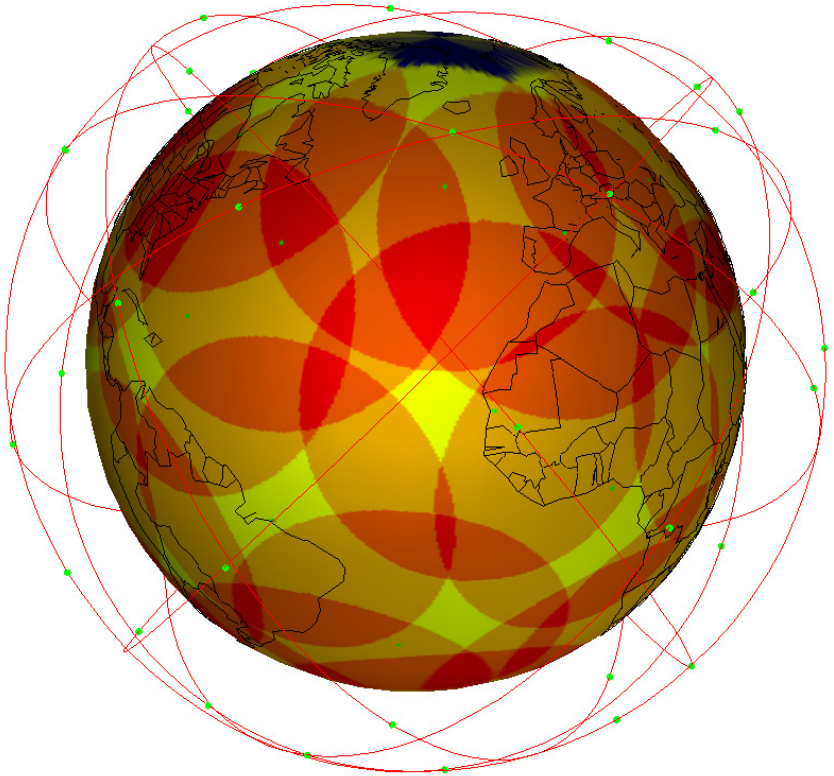
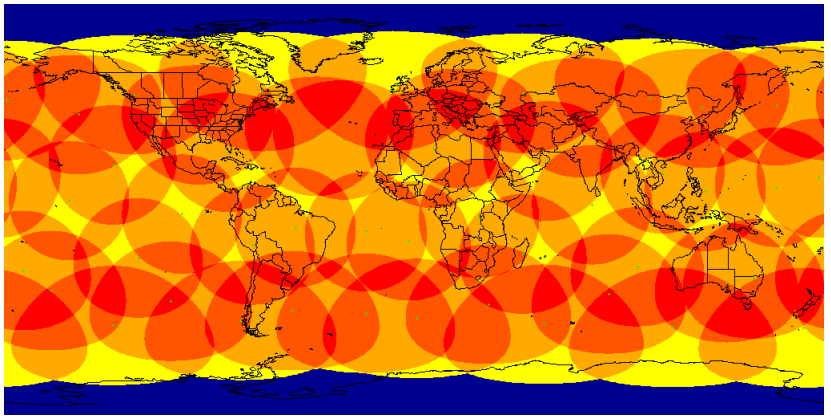
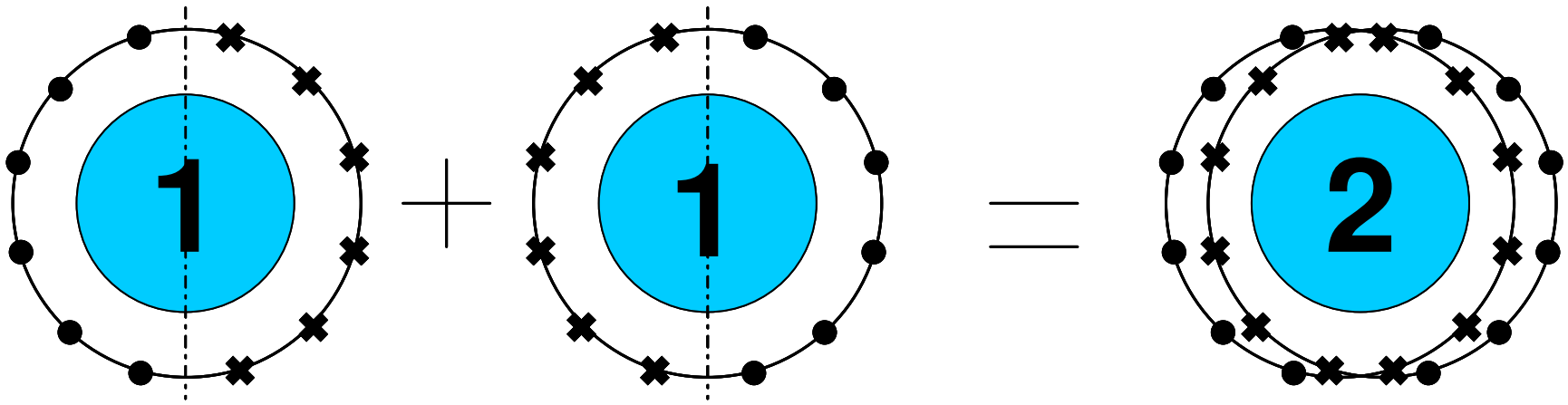




ascending and descending satellites overlap

A star is a rosette cut in half



✖ ascending satellites

● descending satellites

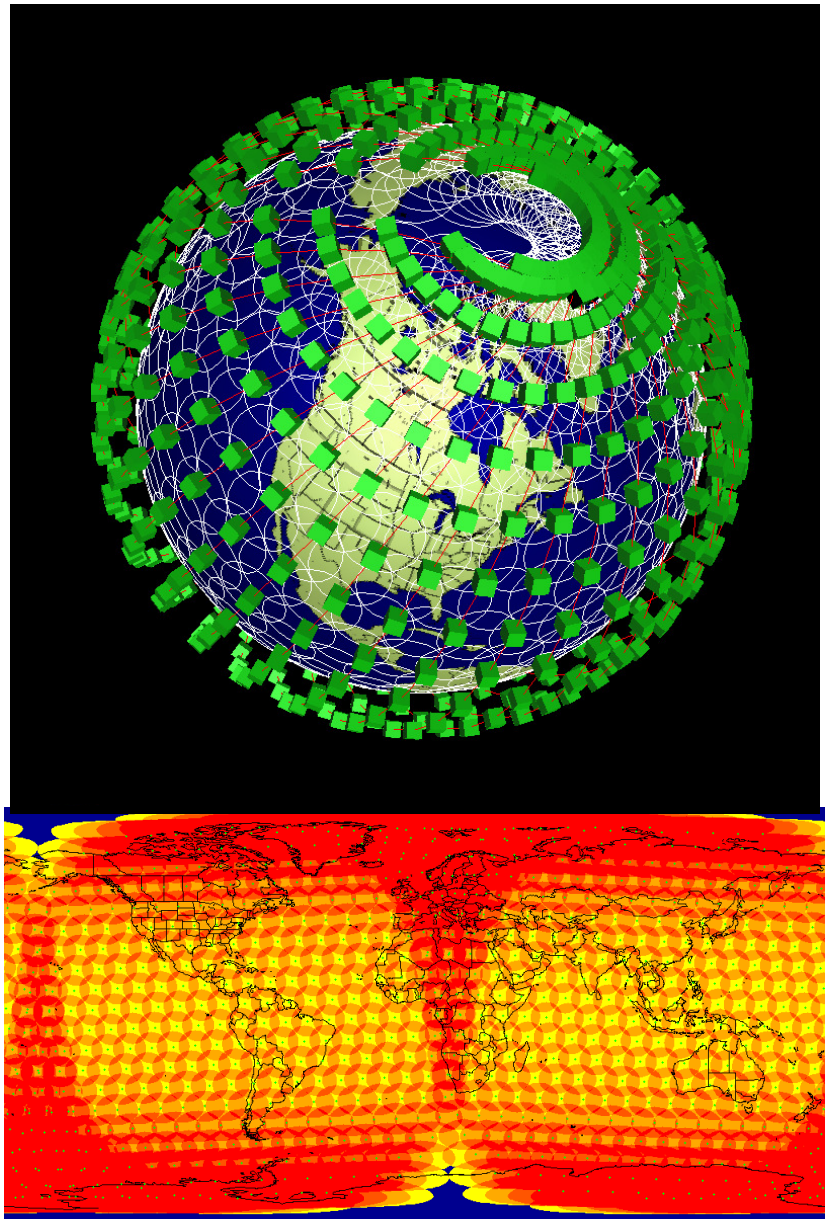
-·- orbital seam

constellations offset
slightly for clarity

Topologically speaking, a rosette is a torus mapped onto a sphere;
a Walker star is half a torus stitched onto a sphere.
A star has *one* surface of satellites over the Earth, a rosette, *two*.

The incredible shrinking *Teledesic*

- 1994: 840 satellites – announced the largest network system *ever*.



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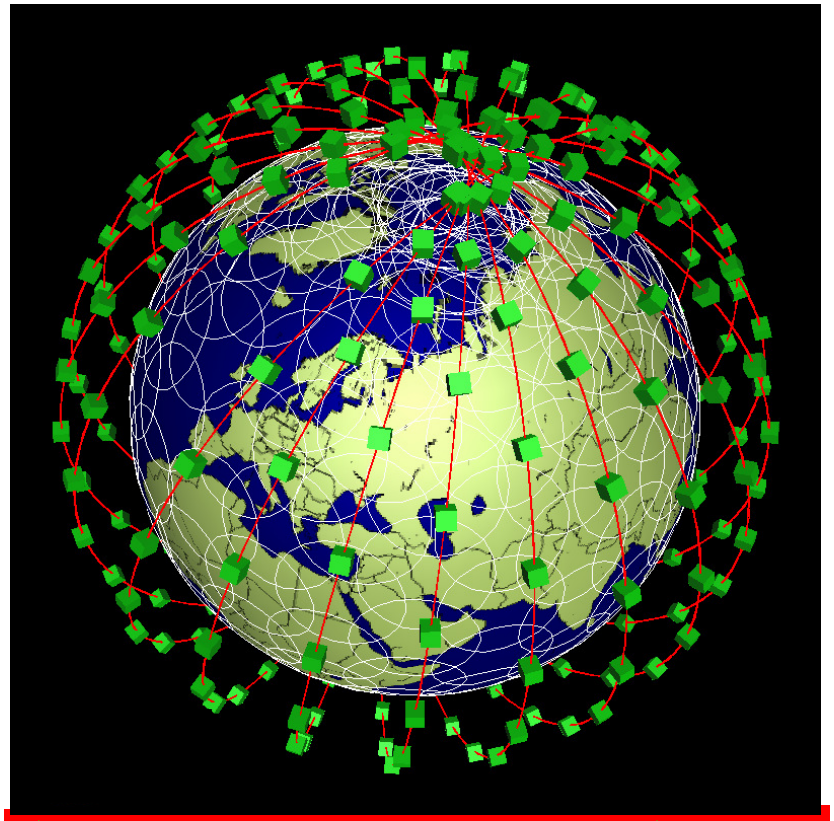

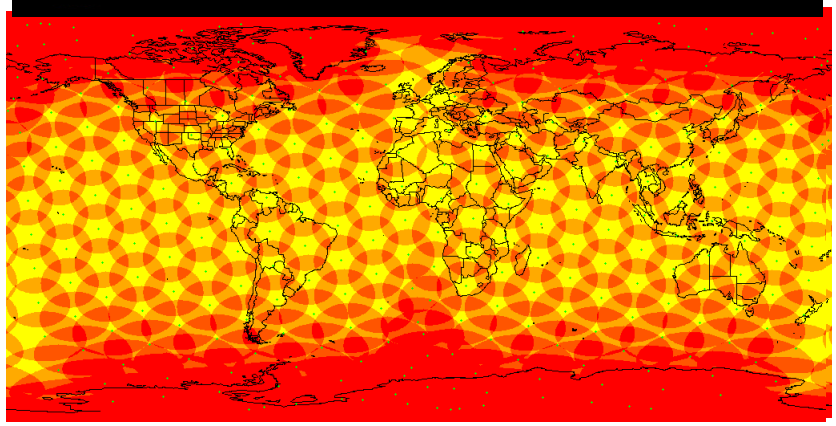

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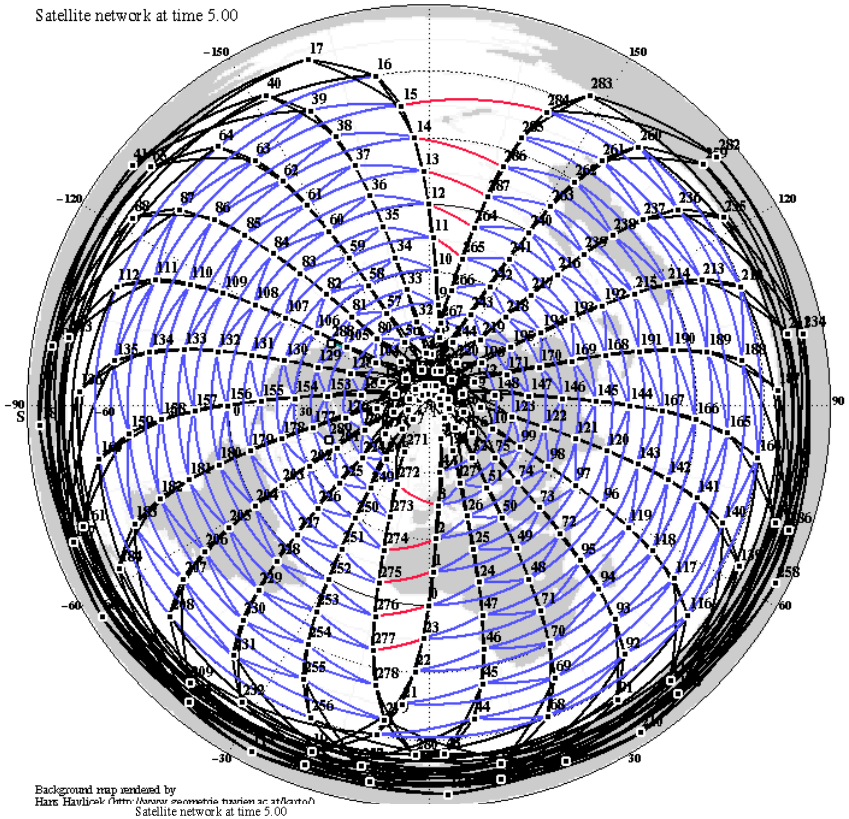

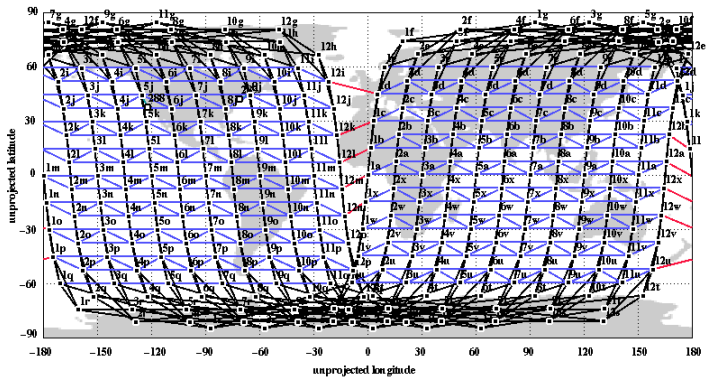

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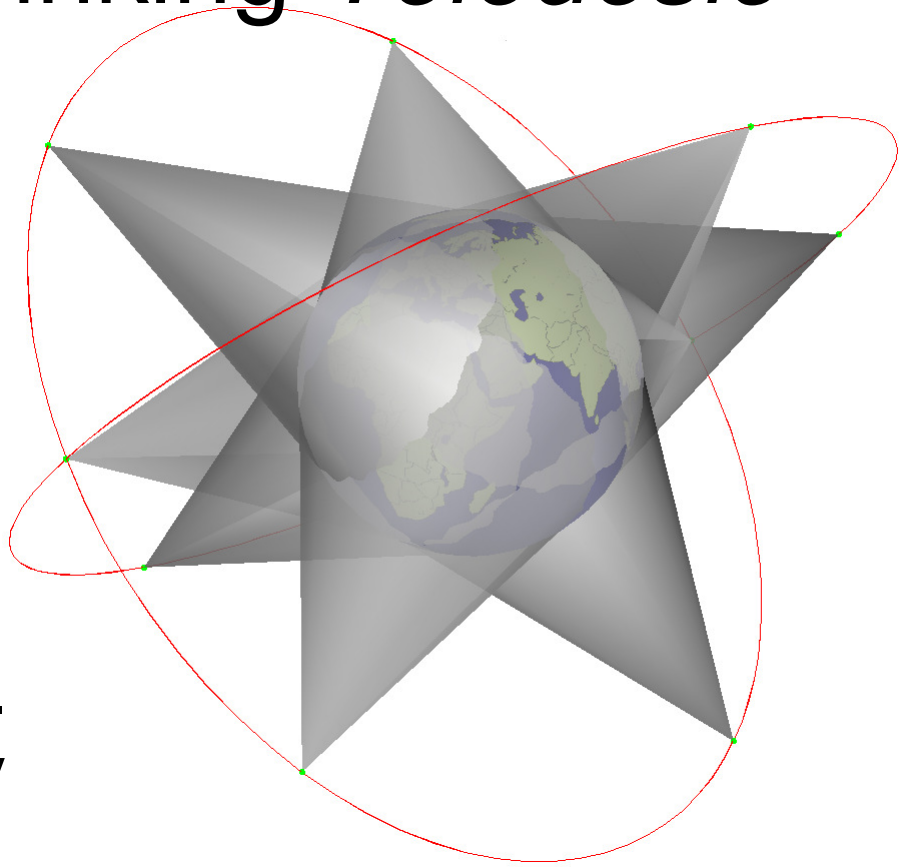
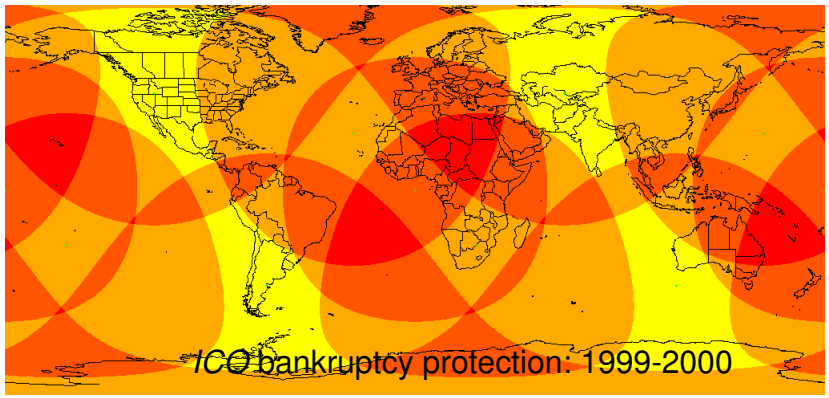
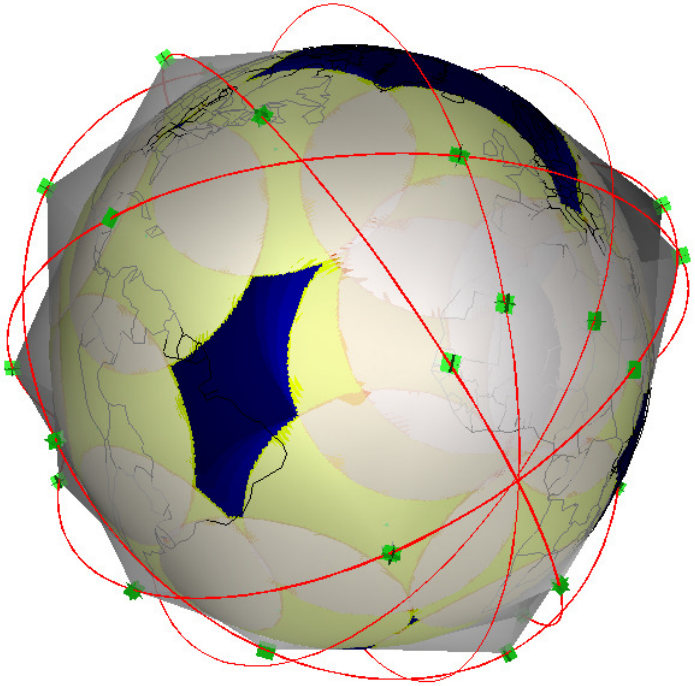
- Also most intersatellite links; redundant mesh even crossing the seam.
- Until 2002, down to thirty MEO satellites…
- Then bought *ICO Global* (which planned ten MEO sats for telephony; **only one in orbit.**)

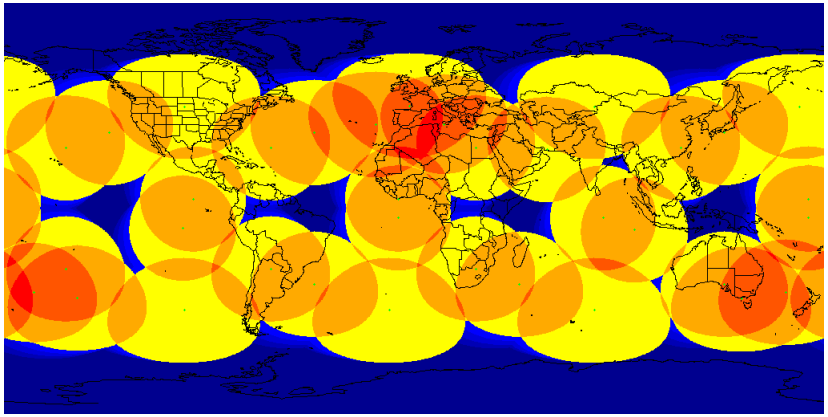




Continuous coverage only needed for continuous communication

- *Orbcomm* is a ‘little LEO’ constellation for simple messaging. Satellites are just simple VHF repeaters. Message delivered to ground station when satellite is in view.
- Store and forward – but here it’s at the sender, not on the satellite.
- …and US bankruptcy protection 2000-2001.



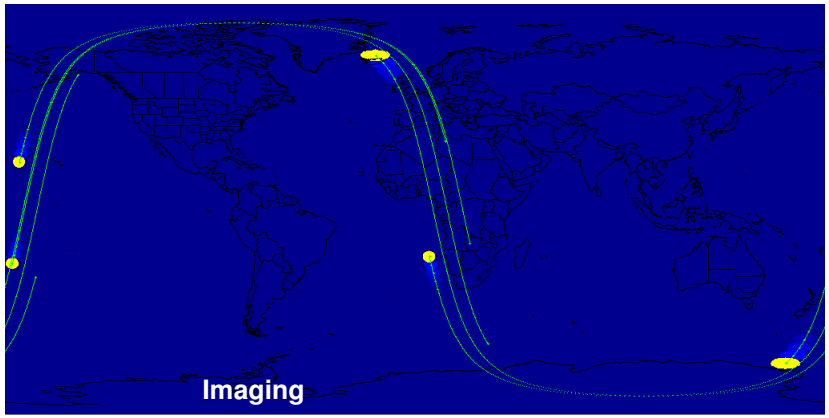


LEO remote sensing satellites

- LEO sun-synchronous orbits (inclination varies with altitude) are very useful; satellite ascends over the Equator at the same time every day everywhere on Earth. Makes it easier to calibrate, correct and compare your images. E.g Landsat, growing commercial imaging market.
- Also GEO imaging satellites for wide-area weather patterns, e.g. *Meteosat*.
- *Triana* – Al Gore proposed imaging from Earth-Sun Lagrange L1 point. He didn't win there, either.

Disaster Monitoring Constellation

- Single plane of four sun-synchronous imaging satellites, ascending at 10:15am over Equator. Fifth satellite at 10:30am.
- Gives overlapping daily coverage of any point on the Earth's surface.
- Coverage map shows 600km pushbroom imaging swath – large area by LEO imaging standards.



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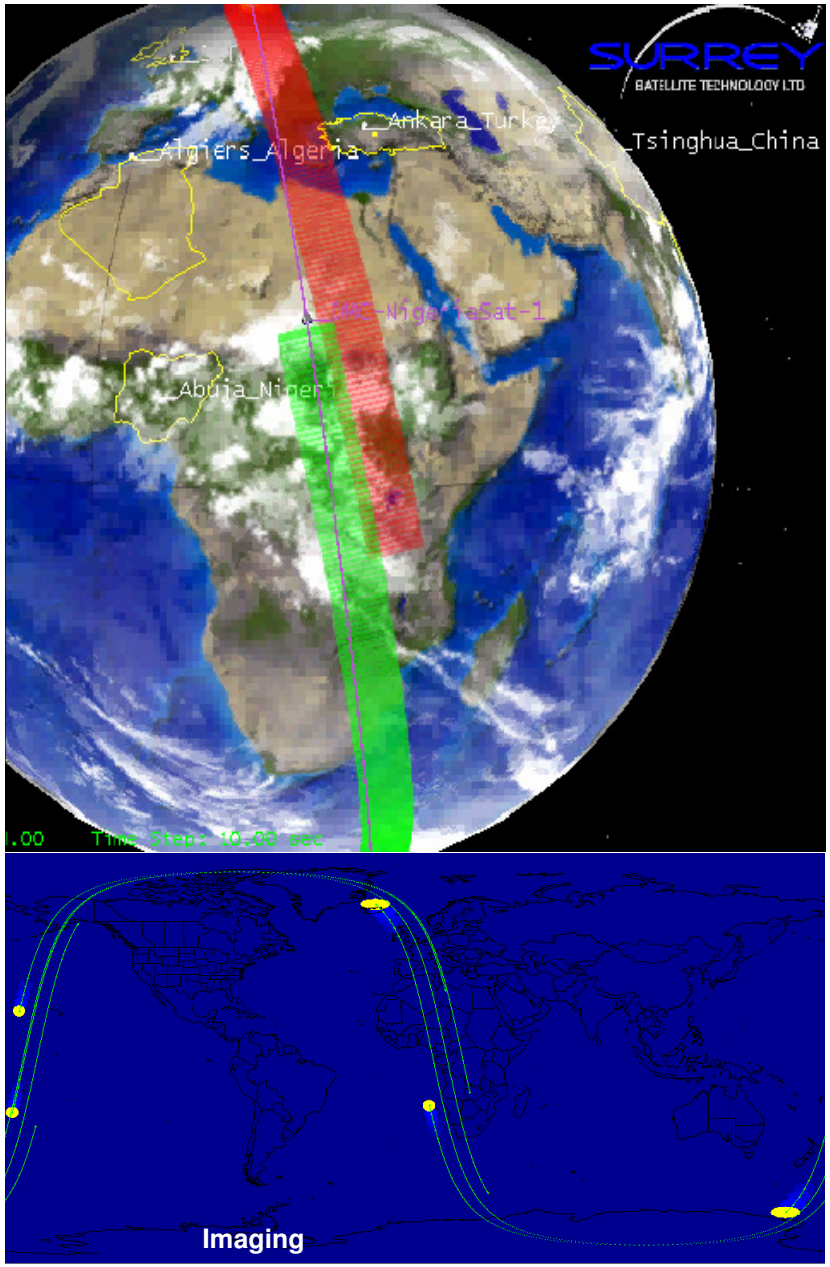
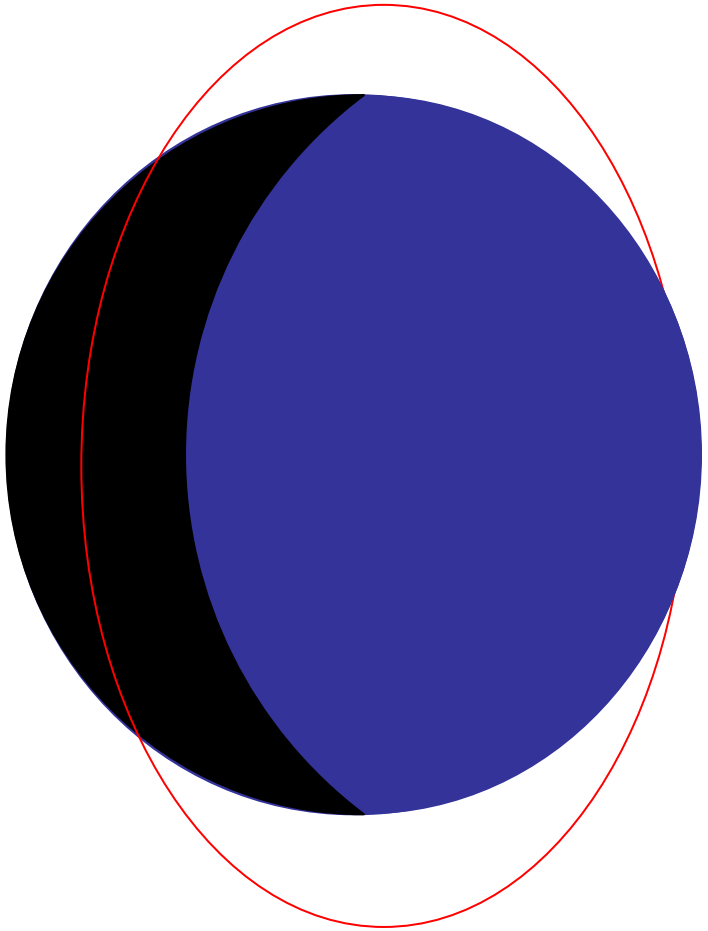


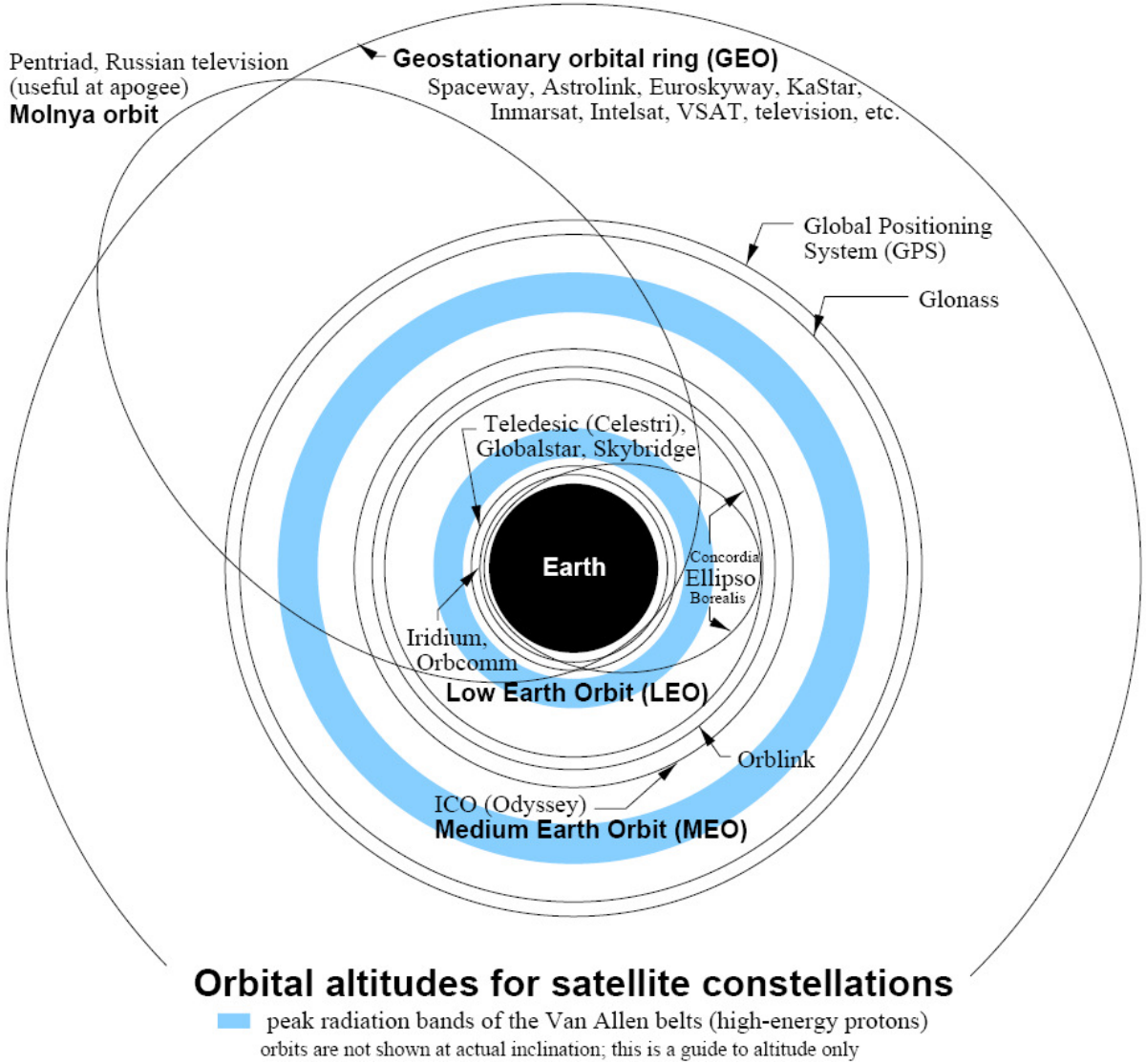
Other sensing satellites

- Radar imaging satellites don't have the daytime restrictions of imaging satellites – but night is still a strain on batteries.
- So these can be sun-synchronous at dawn and dusk – riding the day/night terminator, solar cells always in sunlight.



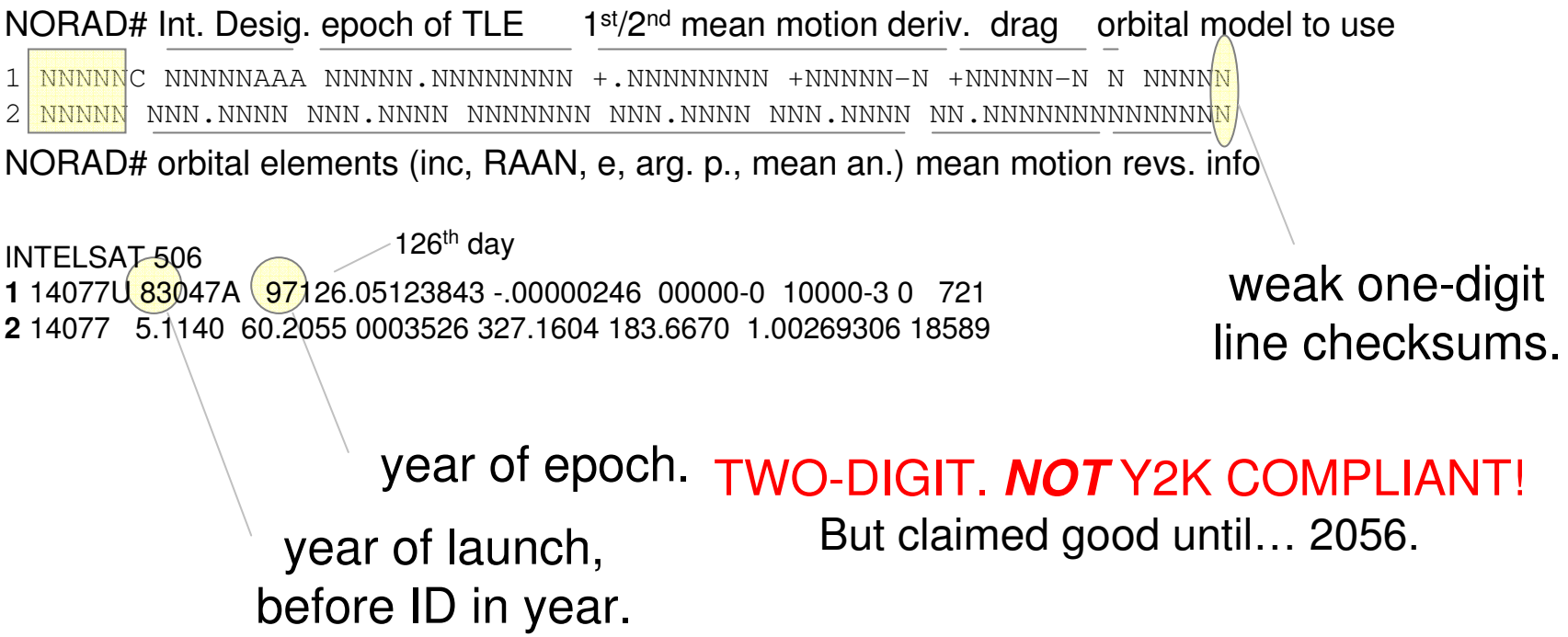
Quick overview of Earth orbits

- Polar view compares altitudes as if all orbits lie on Equator.
- Van Allen belts and radiation environment simplified – solar wind pushes them out of circular.



How to describe an orbit?

- Two-line element (TLE) format designed by NORAD, introduced November 1972.



Sample FORTRAN code can be found.

Summary

This talk has outlined:

- Overview of satellite orbits and coverage.
- Their advantages and uses.
- A number of unsuccessful business plans that were unable to make advantage of the advantages.

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Questions?

Thankyou

Lloyd Wood
http://www.ee.surrey.ac.uk/L.Wood/

oh, just google…

Exercises with SaVi