IWSSC 2008 Tutorial
Satellite Networks I: constellations
orbital types, uses and advantages

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created with SaVi

savi.sf.net

**International Workshop on Satellite and Space Communications 2008, IWSSC 2008,
1 October 2008, Toulouse, France**

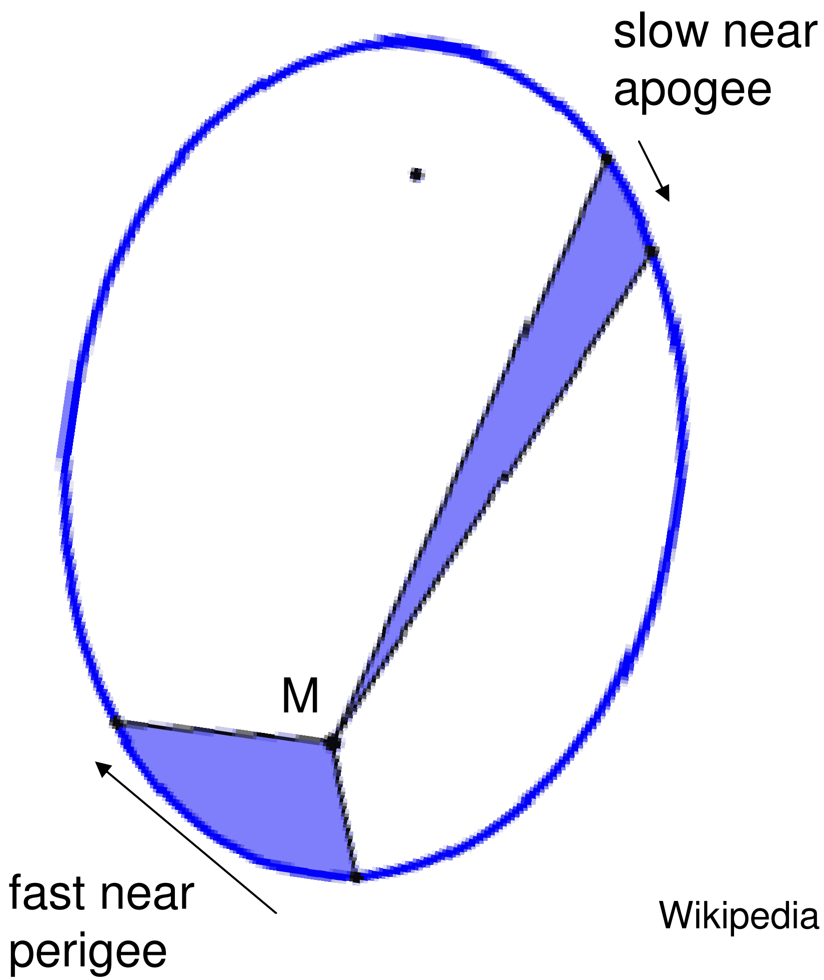
Who am I? What's my perspective?

- Did masters project on satellite constellations with intersatellite links, at ENST Toulouse.
- Did PhD on same at University of Surrey.
- Went to program router code for Cisco Systems.
- Later moved into their new space team.
- Tested Cisco mobile Internet router in space on UK-DMC satellite, working with Surrey Satellite Technology Ltd and NASA Glenn.
  - My team was first to test IPv6 in space…
  - and first to use the 'bundle protocol' in space.
- I'm **networking-oriented**. Not a channel guy!

One reason my PhD took so long…

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.
- **Kepler's third law**
  circular orbits ($T^2 \propto r^3$) are the most useful for us.



Wikipedia

Images from other organisations are used with attribution and thanks

How to describe an orbit?

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

NORAD# Int. Desig. epoch of TLE 1st/2nd mean motion deriv. drag orbital model to use

```
1 NNNNNC NNNNNAAA NNNNN.NNNNNNNN +.NNNNNNNN +NNNNN-N +NNNNN-N N NNNNN
2 NNNNN NNN.NNNN NNN.NNNN NNNNNNN NNN.NNNN NNN.NNNN NN.NNNNNNNNNNNNNN
```

NORAD# orbital elements (inc, RAAN, e, arg. p., mean an.) mean motion revs. info

126th day

```
INTELSAT 506
1 14077U 83047A   97126.05123843 -.00000246  00000-0  10000-3 0   721
2 14077   5.1140  60.2055 0003526 327.1604 183.6670  1.00269306 18589
```

weak one-digit line checksums.

year of epoch.

TWO-DIGIT. *NOT* Y2K COMPLIANT!

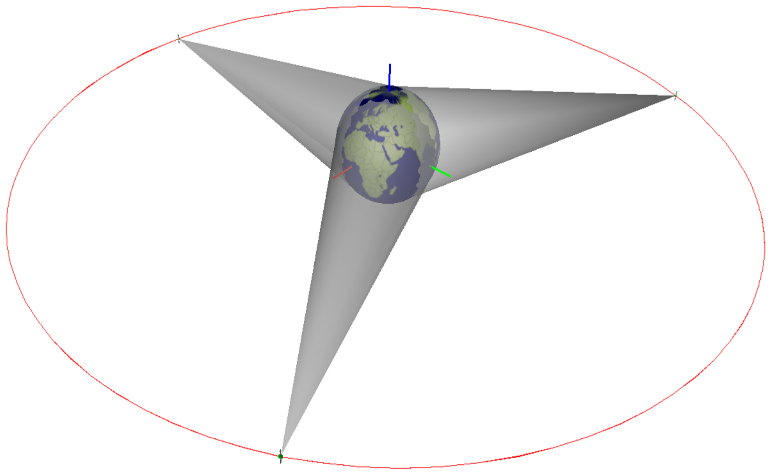
But claimed good until… 2056.

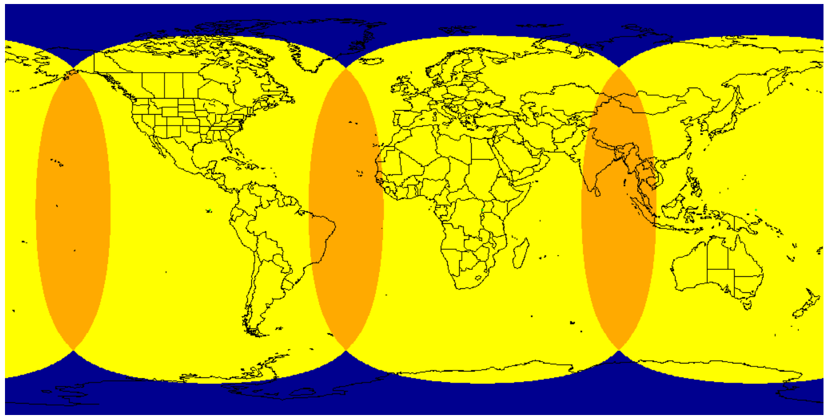
year of launch, before ID in year.

Sample FORTRAN code can be found.

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 can see most of the Earth – but not the poles.
(Arthur C. Clarke, 1945)





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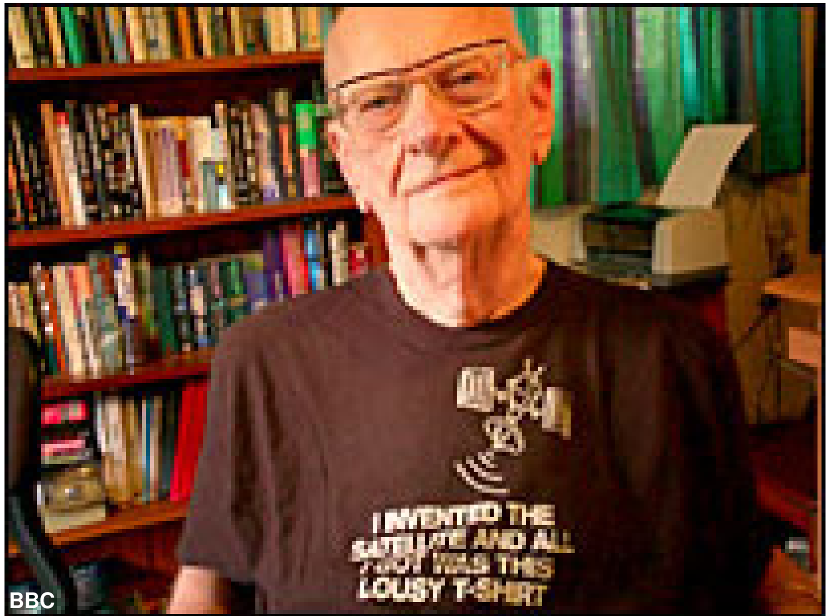
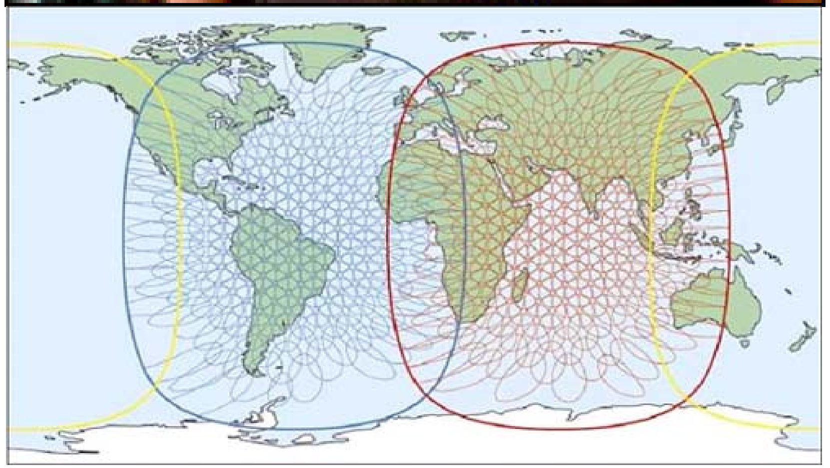
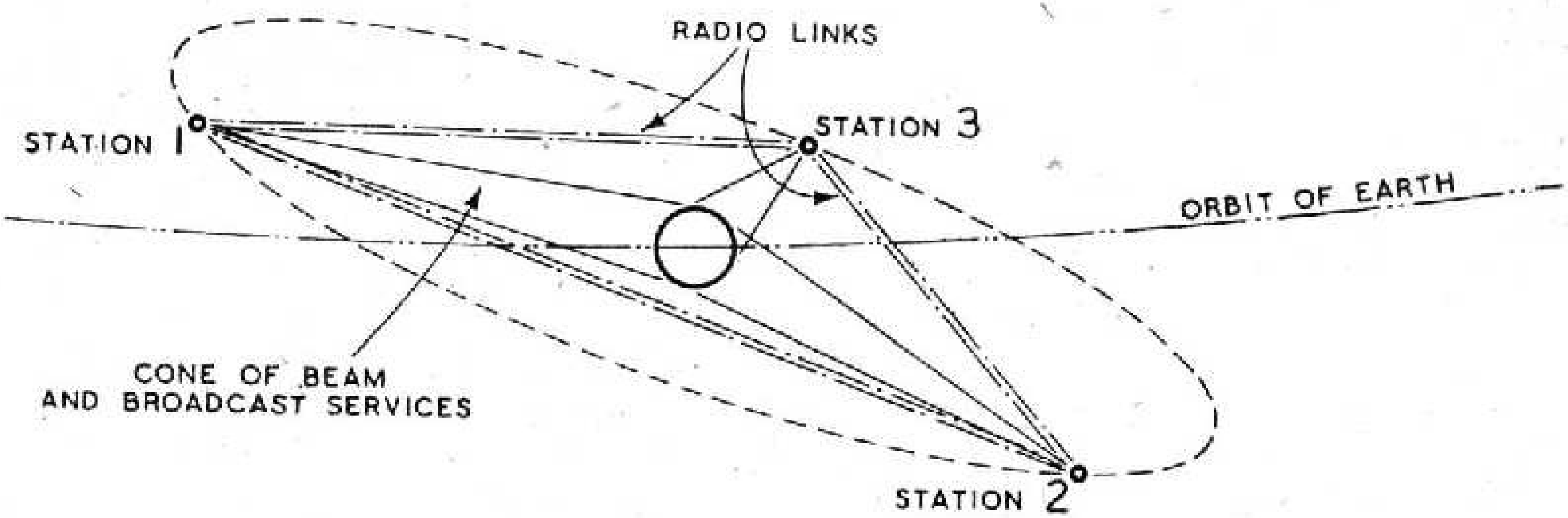
  (Arthur C. Clarke, 1945)
- Inmarsat's I-4 *BGAN* is nearest match to this. Third sat launched 18 Aug 2008.





Intersatellite links are an old idea…

commonly written as ISLs

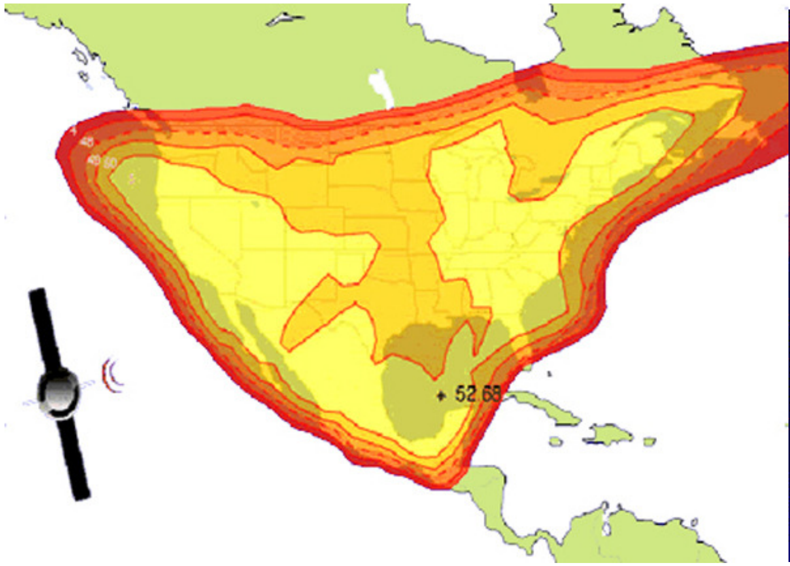


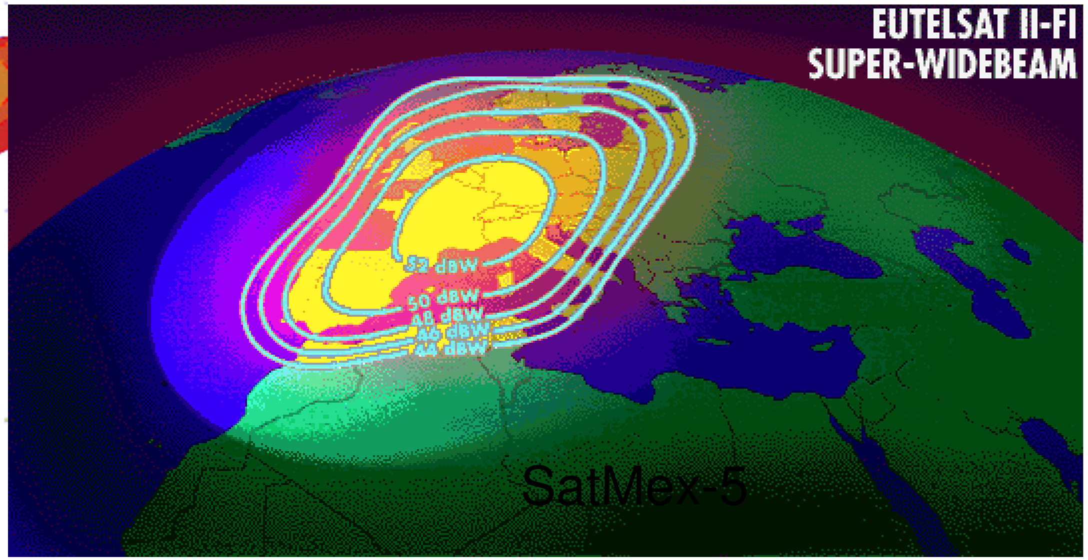
…but interconnecting geostationary satellites is *still* cutting-edge stuff.

Fig 3 from **Extra-Terrestrial Relays**, Arthur C. Clarke, *Wireless World*, 1945.

Satellite antennas tailor footprints

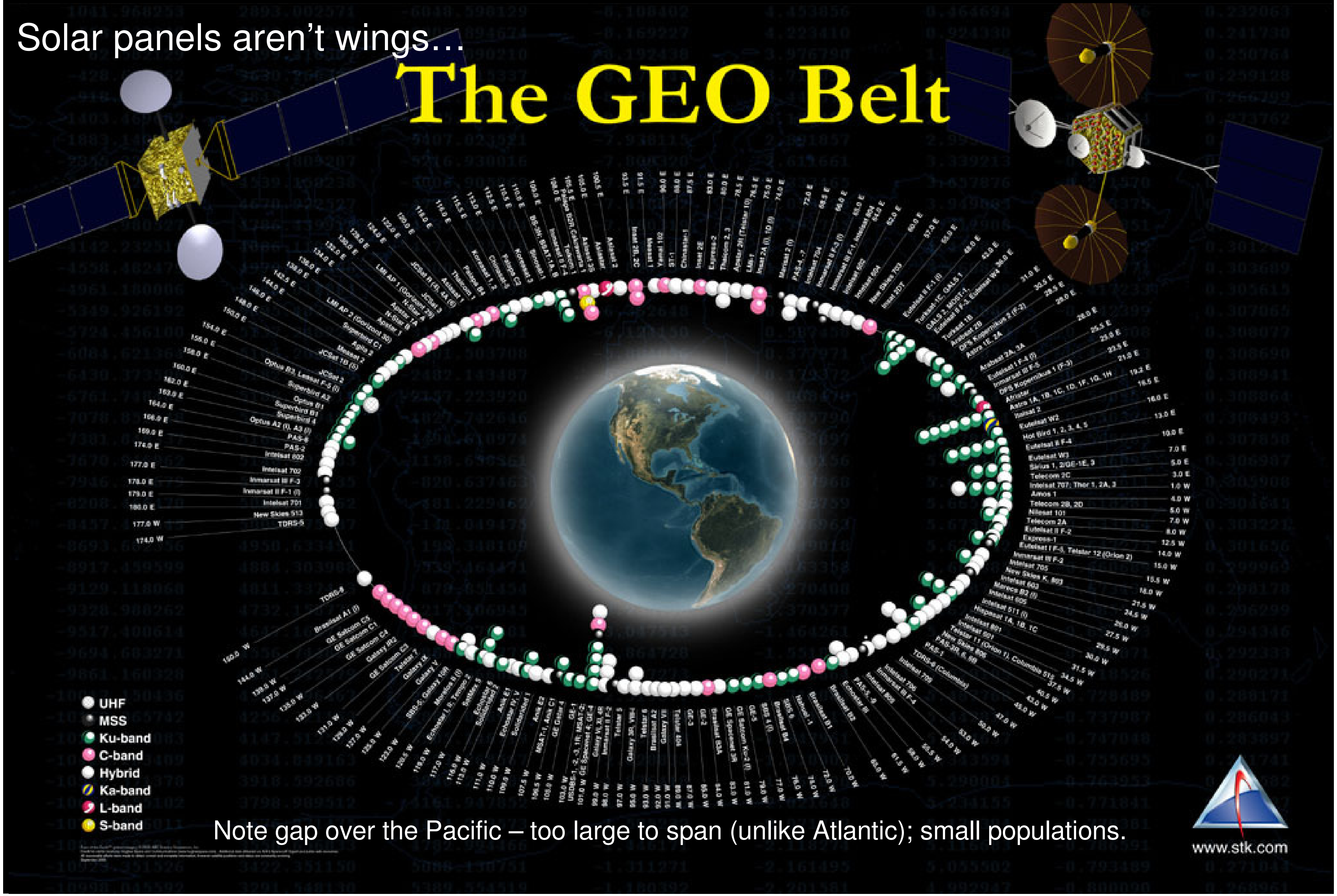
- Satellites don’t always support perfectly spherical coverage areas.
- Shaped spotbeams let you concentrate coverage and power where you want it.
- Movable antennas let you provide more support (traffic) to a region on demand.





Actual geostationary orbit use (2001)

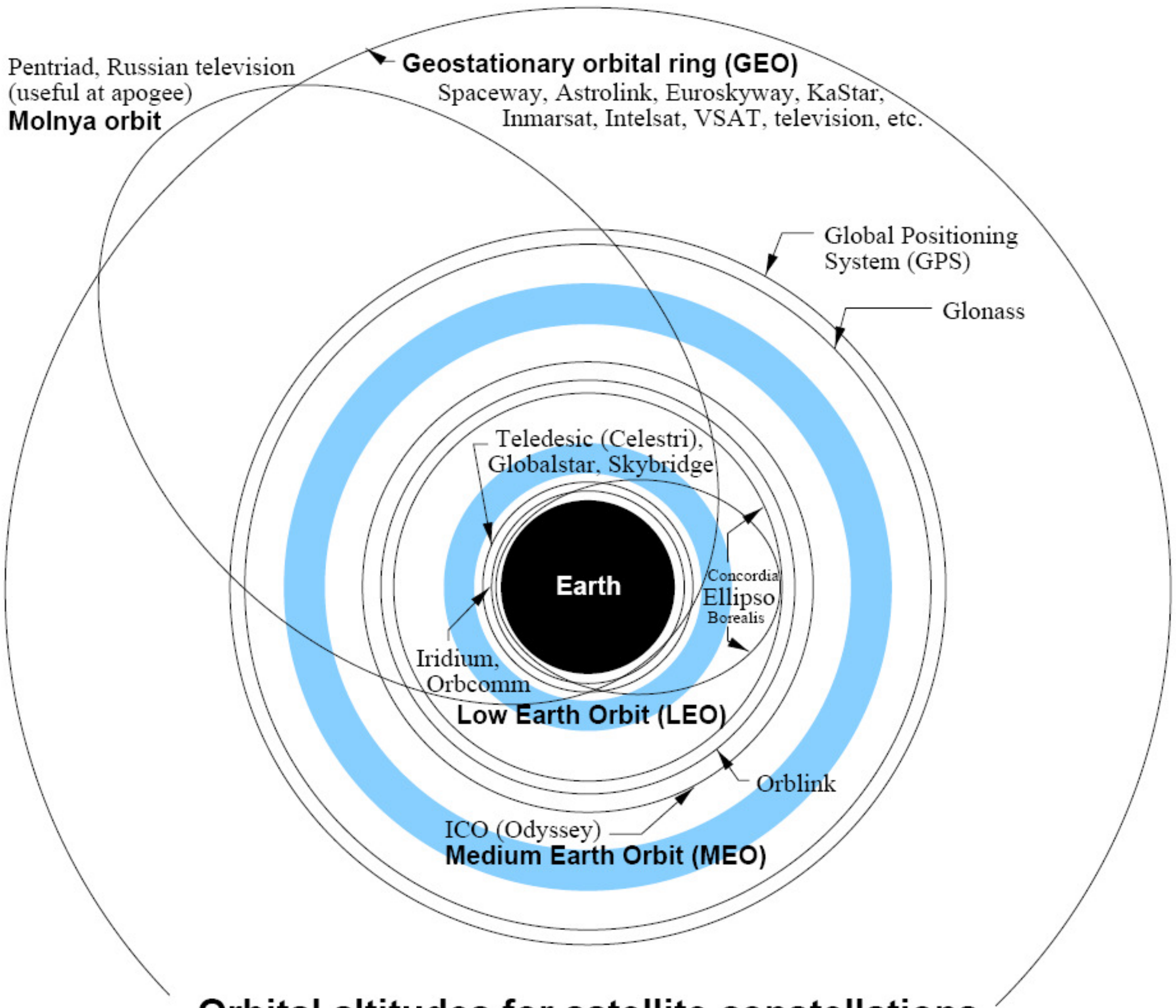
Solar panels aren't wings…



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

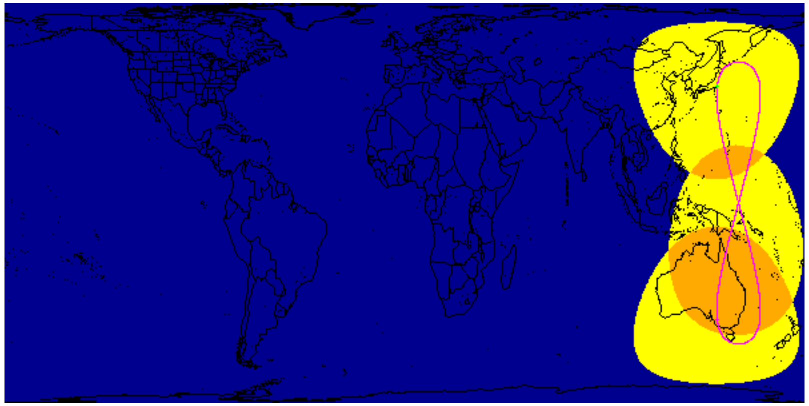
Quick overview of Earth orbits

- 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.



Orbital altitudes for satellite constellations
peak radiation bands of the Van Allen belts (high-energy protons)
orbits are not shown at actual inclination; this is a guide to altitude only

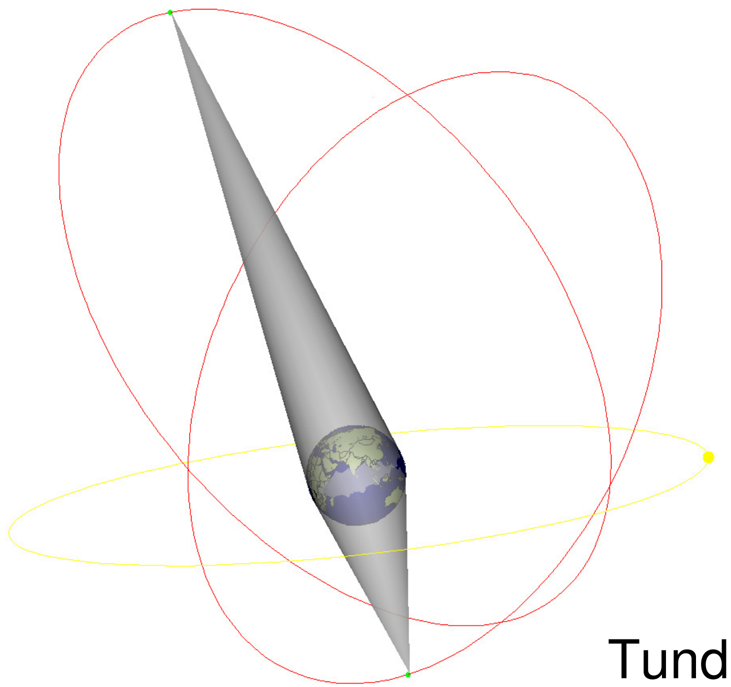
Inclined geosynchronous orbit



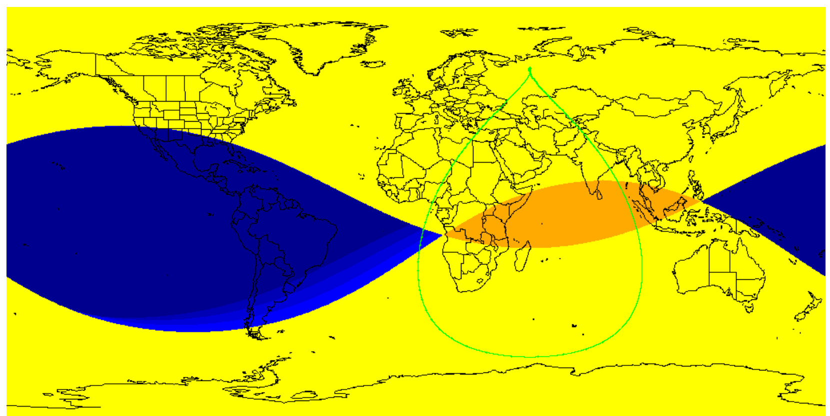
- Geostationary satellite reaches end of its planned life – stationkeeping fuel has run out, satellite moves in the sky south/north of the Equator. Can be used give a few hours’ connectivity cheaply each day for polar research stations.
- Forms a figure-of-eight groundtrack throughout the day. Investigated 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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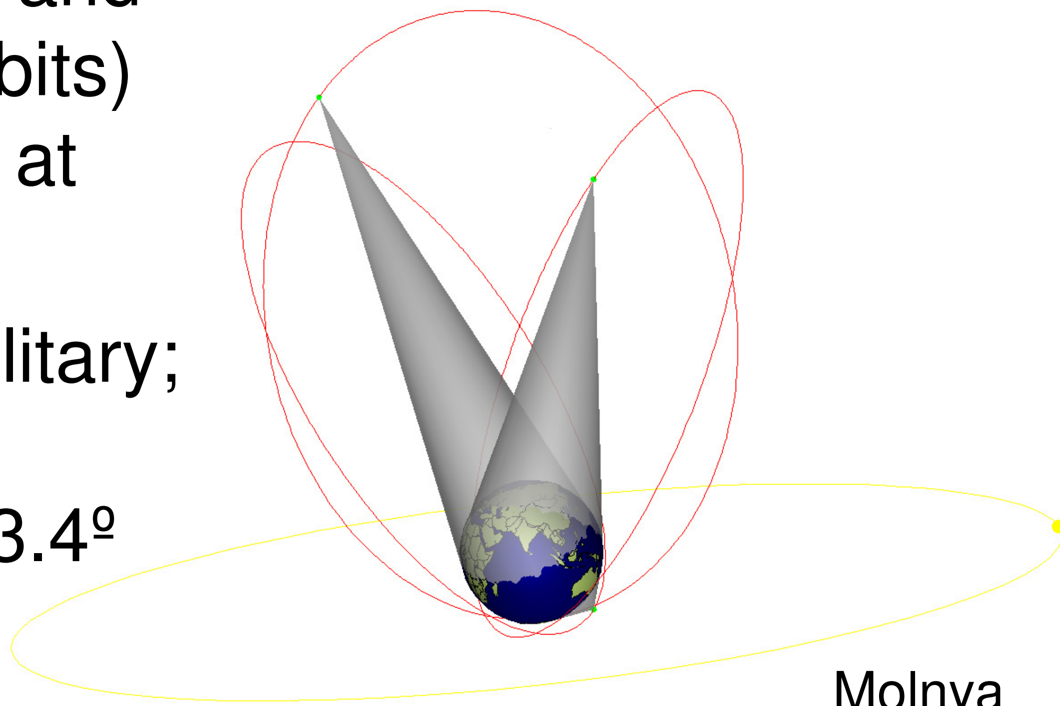
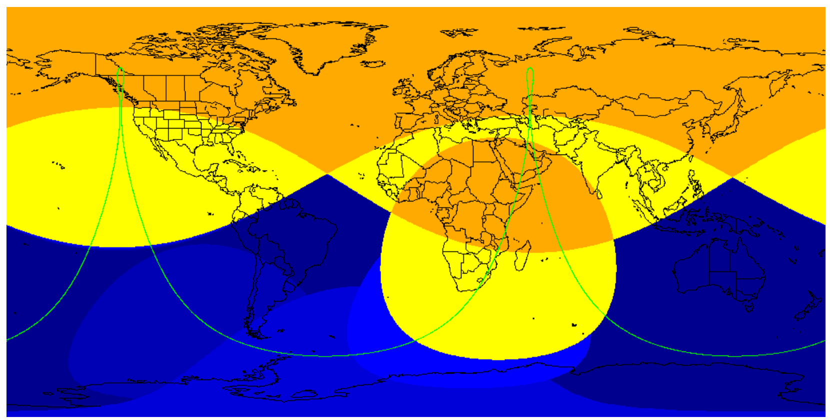


Molnya



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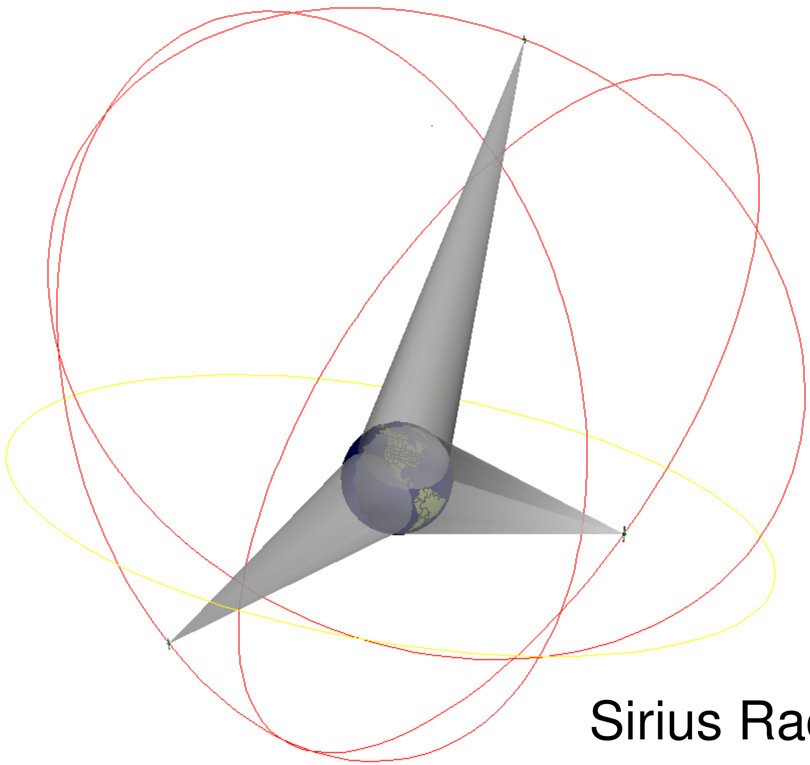
- *Sirius Radio* adopted this model over the continental US, before merging with *XM Radio*, which had two geostationary satellites.



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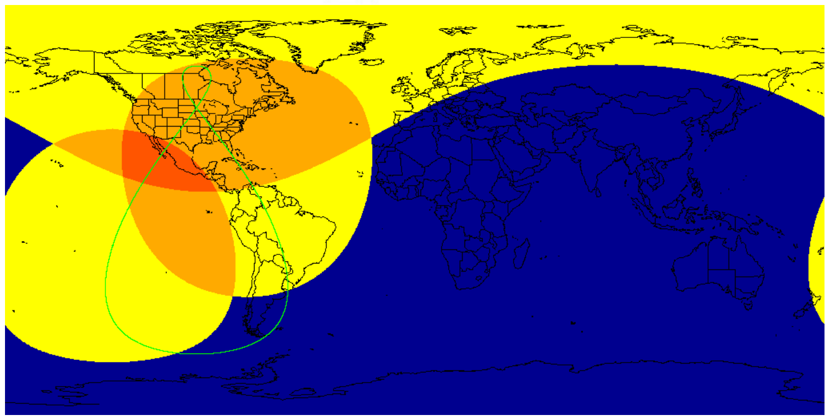
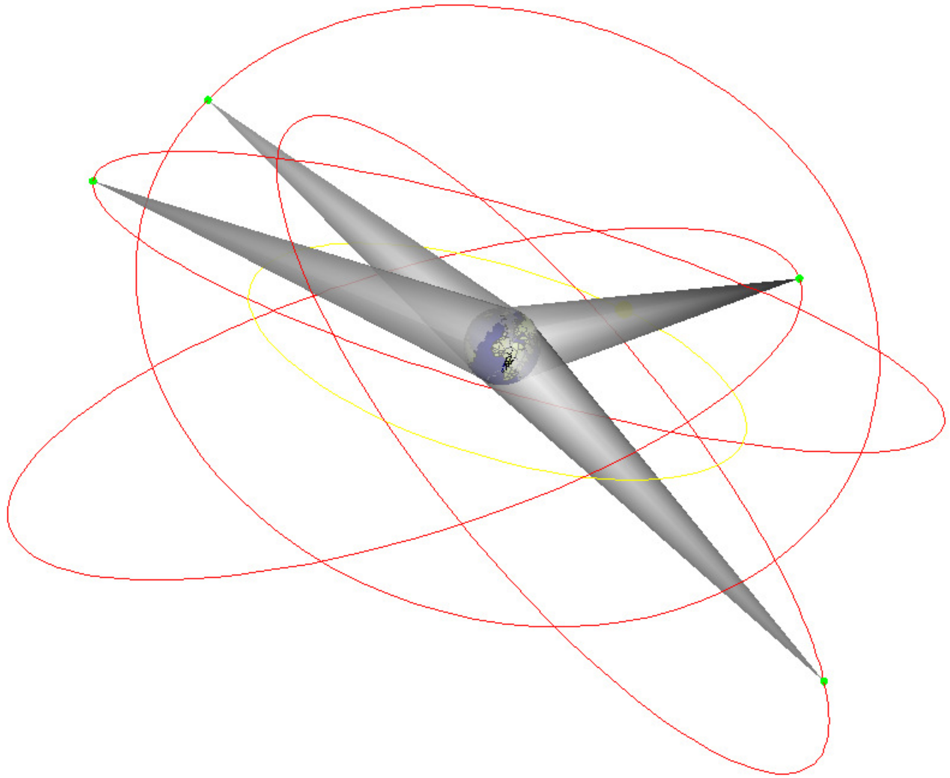
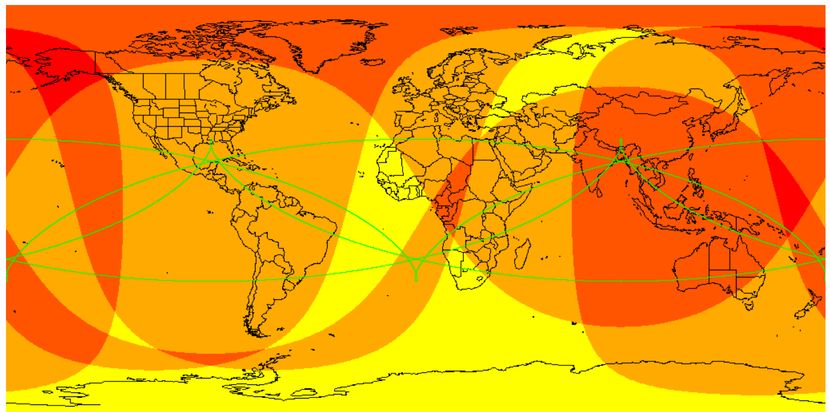
Sirius Radio



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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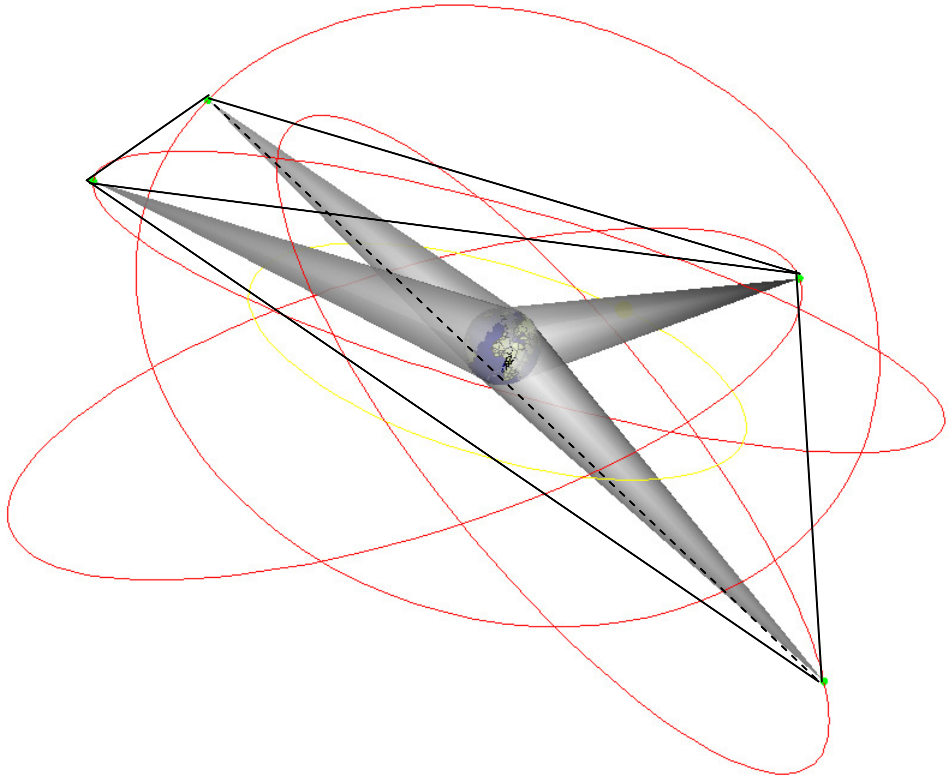

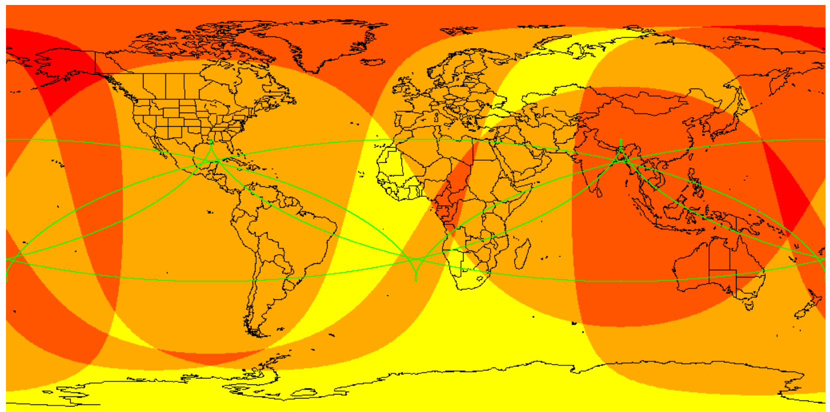

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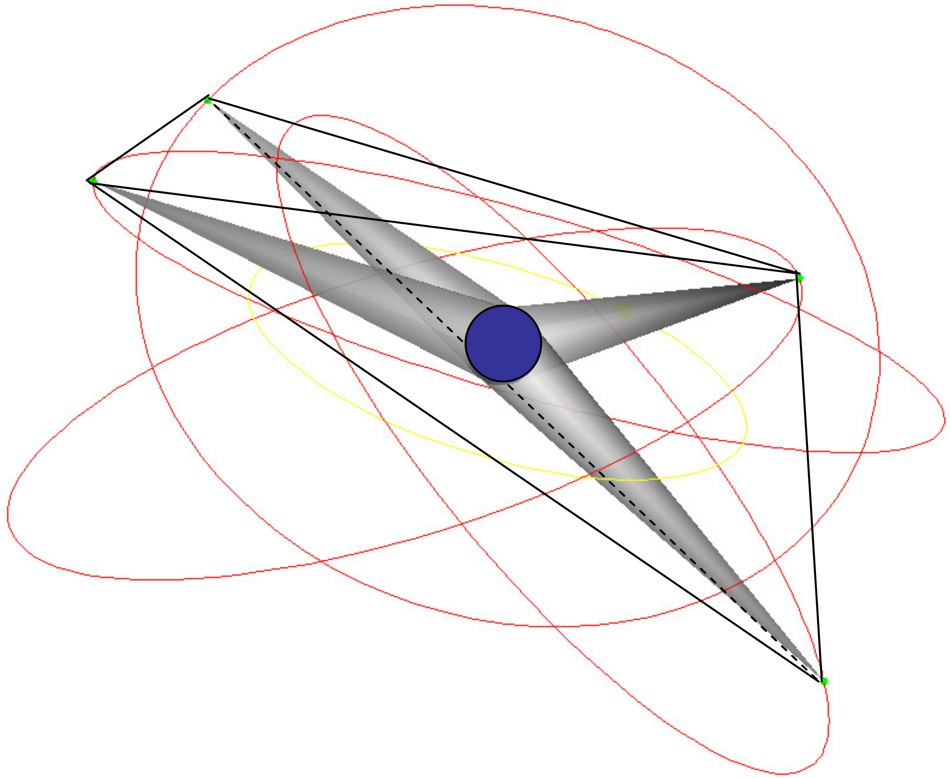

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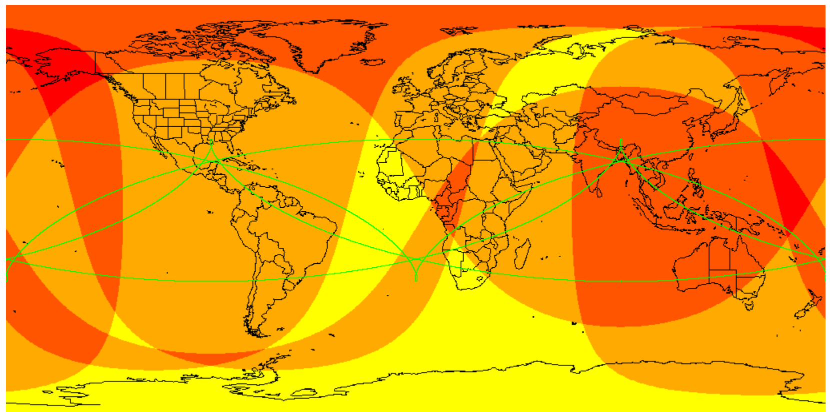
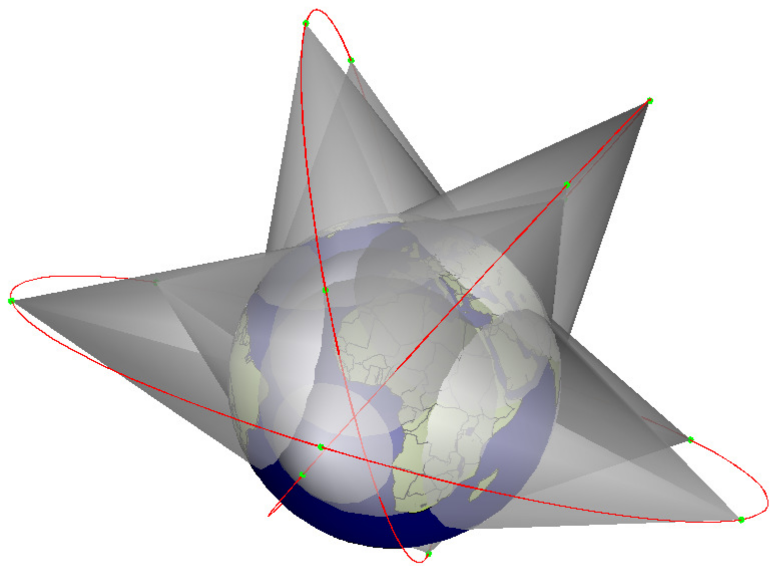
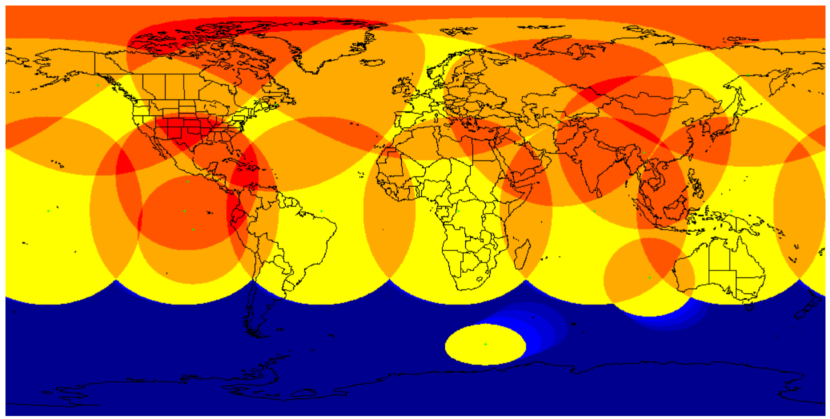


Ellipso – John E. Draim again

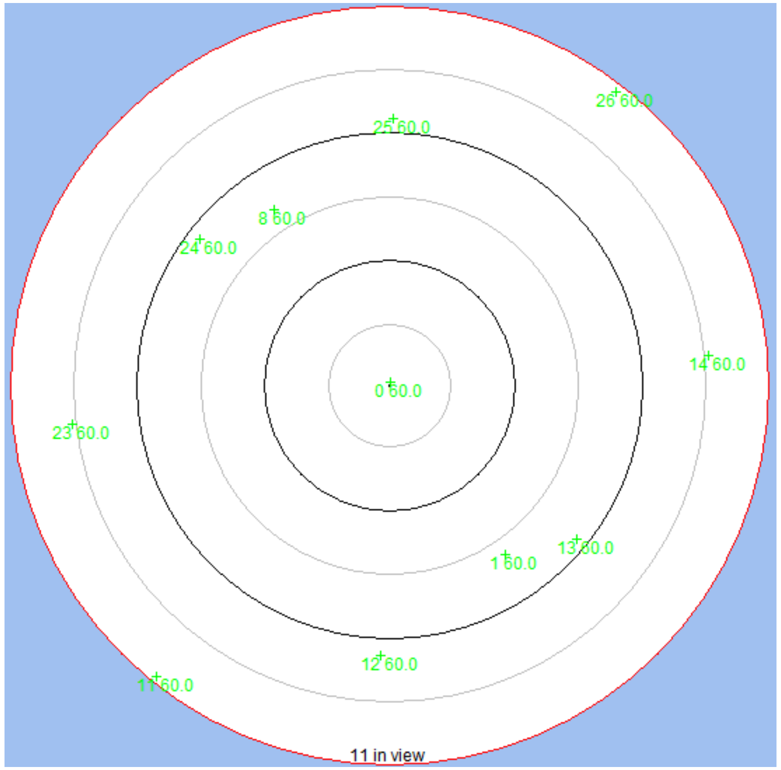
- Use of elliptical apogee to provide service at the northern high polar regions.
- Circular MEO orbit covers equatorial areas.
- Coverage of south poor: ‘my business plan can do without the people on Easter Island.’ – David Castiel, *Wired* 1.05
- Business plan to sell voice telephony. Oops. **Not built.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





Shadowing and urban canyons

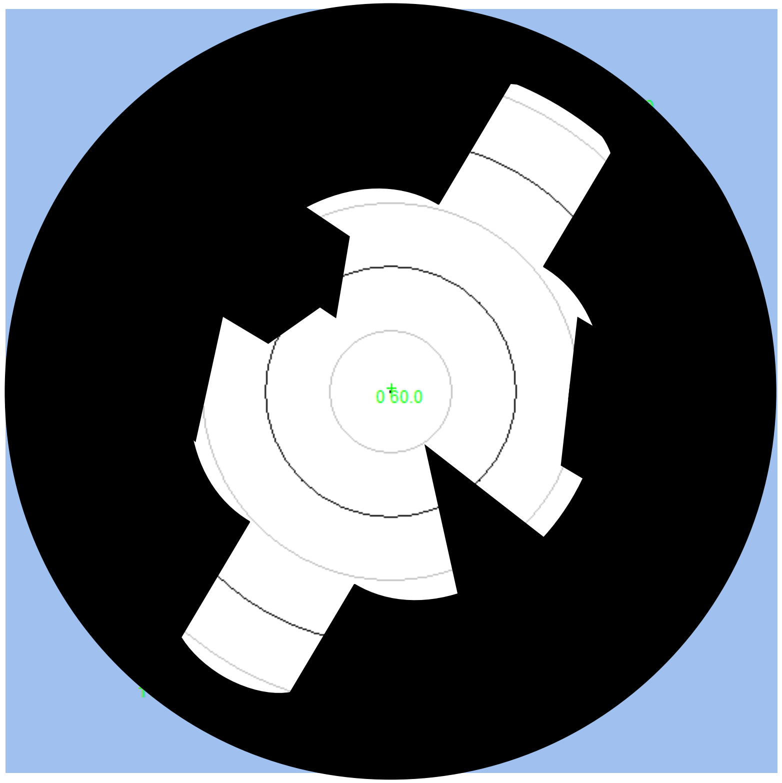
- No. of satellites you can see above horizon is *diversity*.



Galileo – lots of satellites in view.

Shadowing and urban canyons

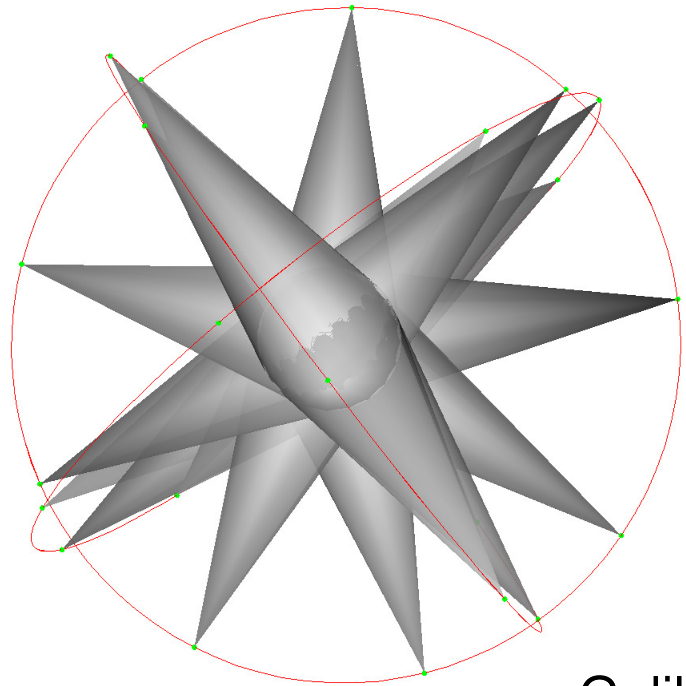
- No. of satellites you can see above horizon is *diversity*.
- But buildings/trees block your view of the horizon, limiting the number of satellites you can see.
- Skyscrapers and urban canyons mean no view of the sky (why *Sirius Radio* and *XM Radio* build city repeaters).



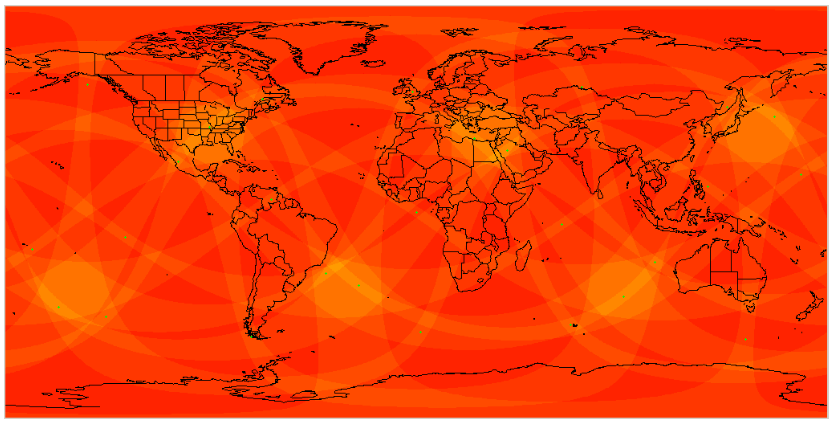
Galileo – lots of satellites in view.
…if you're not standing in a city street.

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).

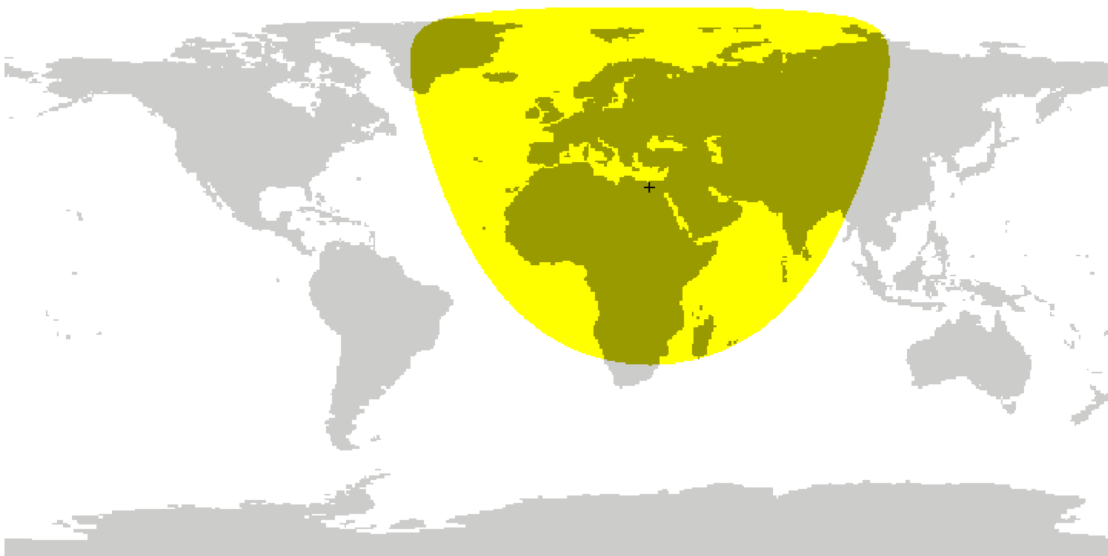


Galileo



Communication 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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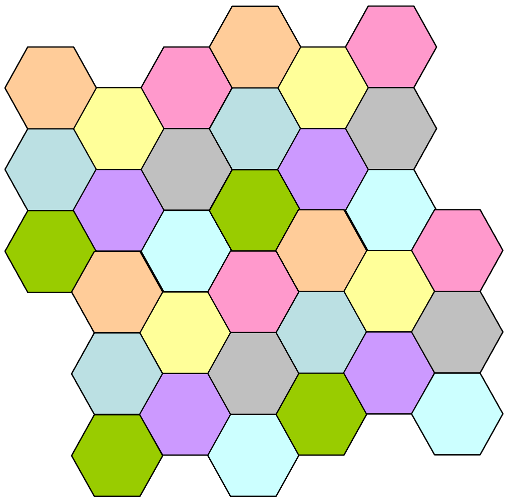
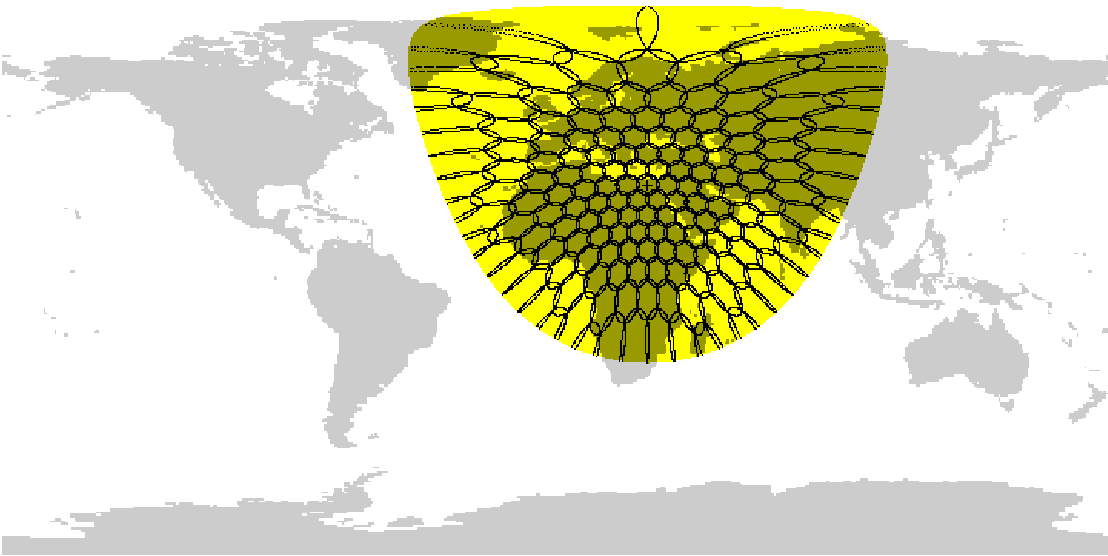

7-colour frequency reuse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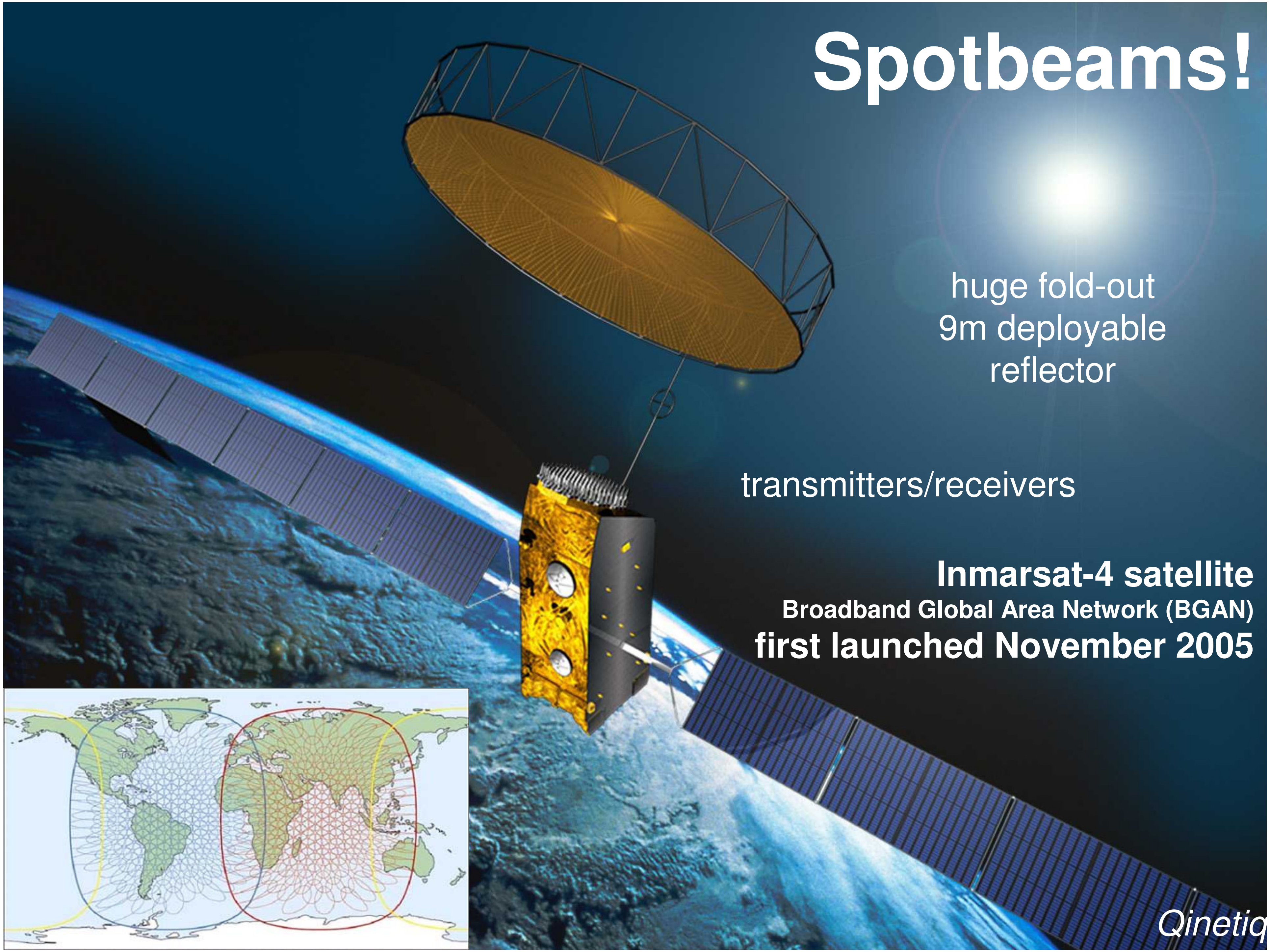
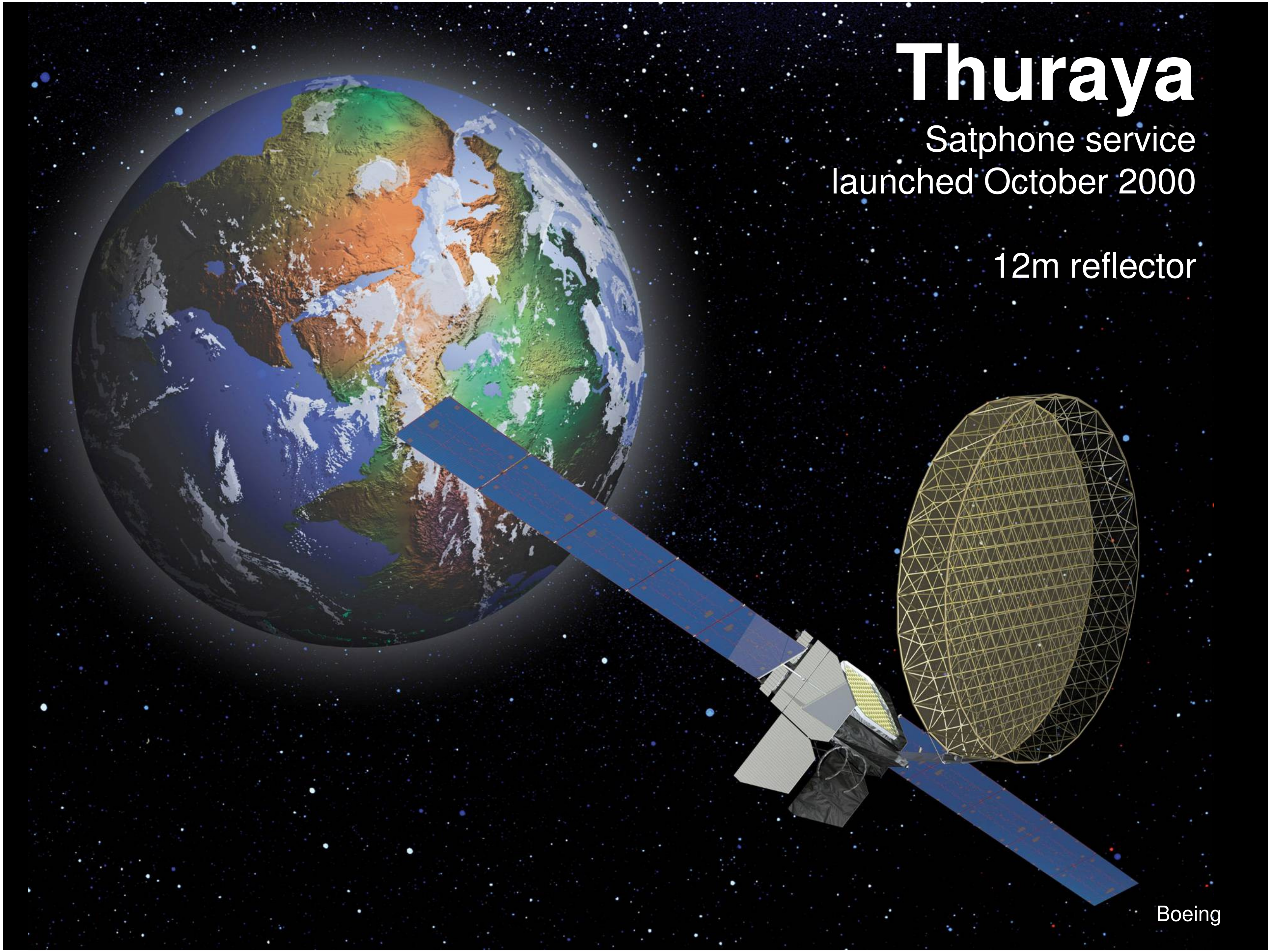
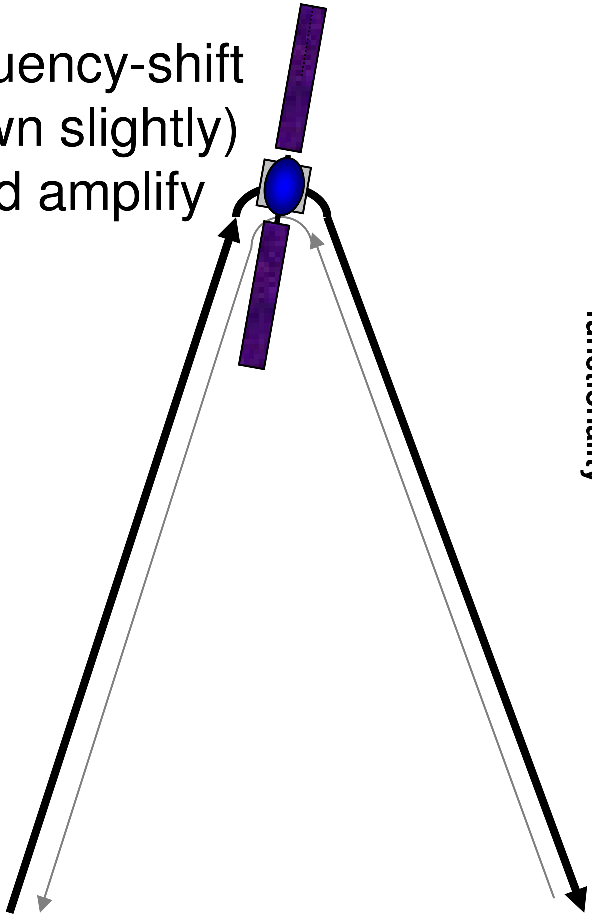

Spotbeams!
huge fold-out
9m deployable
reflector
transmitters/receivers
Inmarsat-4 satellite
Broadband Global Area Network (BGAN)
first launched November 2005
Qinetiq


Thuraya
Satphone service
launched October 2000
12m reflector
Boeing

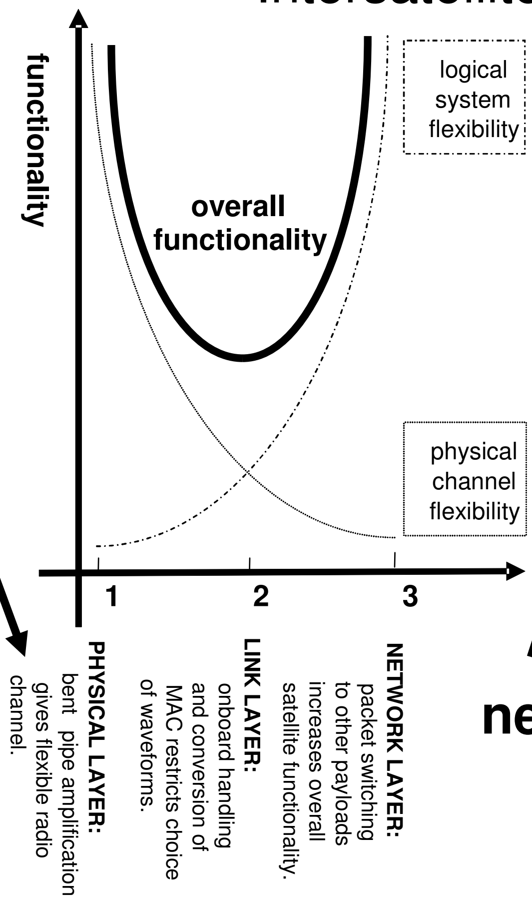
Uplink and downlink choices

frequency-shift
(down slightly)
and amplify



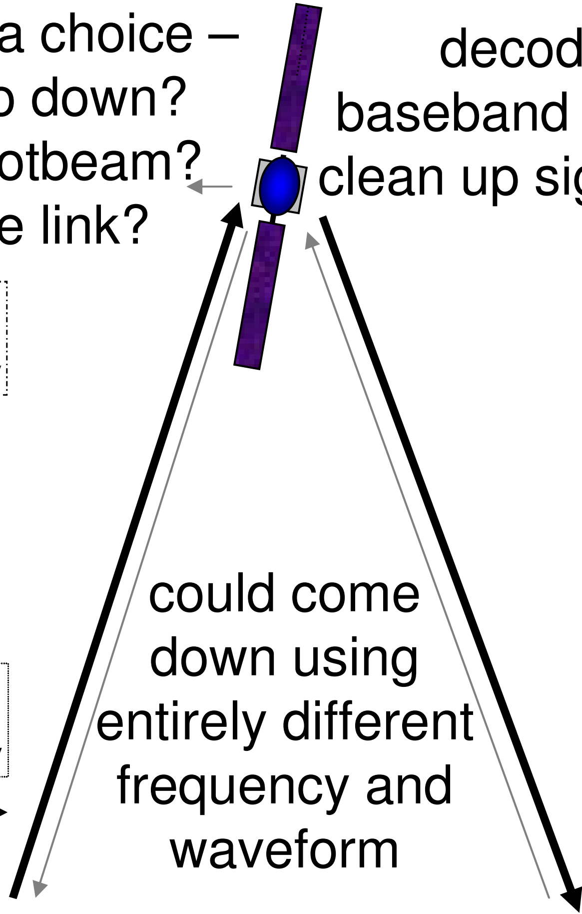
traditional 'bent-pipe'

switching on ground
can lead to 'double hops'



Can make a choice –
where to go down?
Another spotbeam?
Intersatellite link?

decode to
baseband and
clean up signal

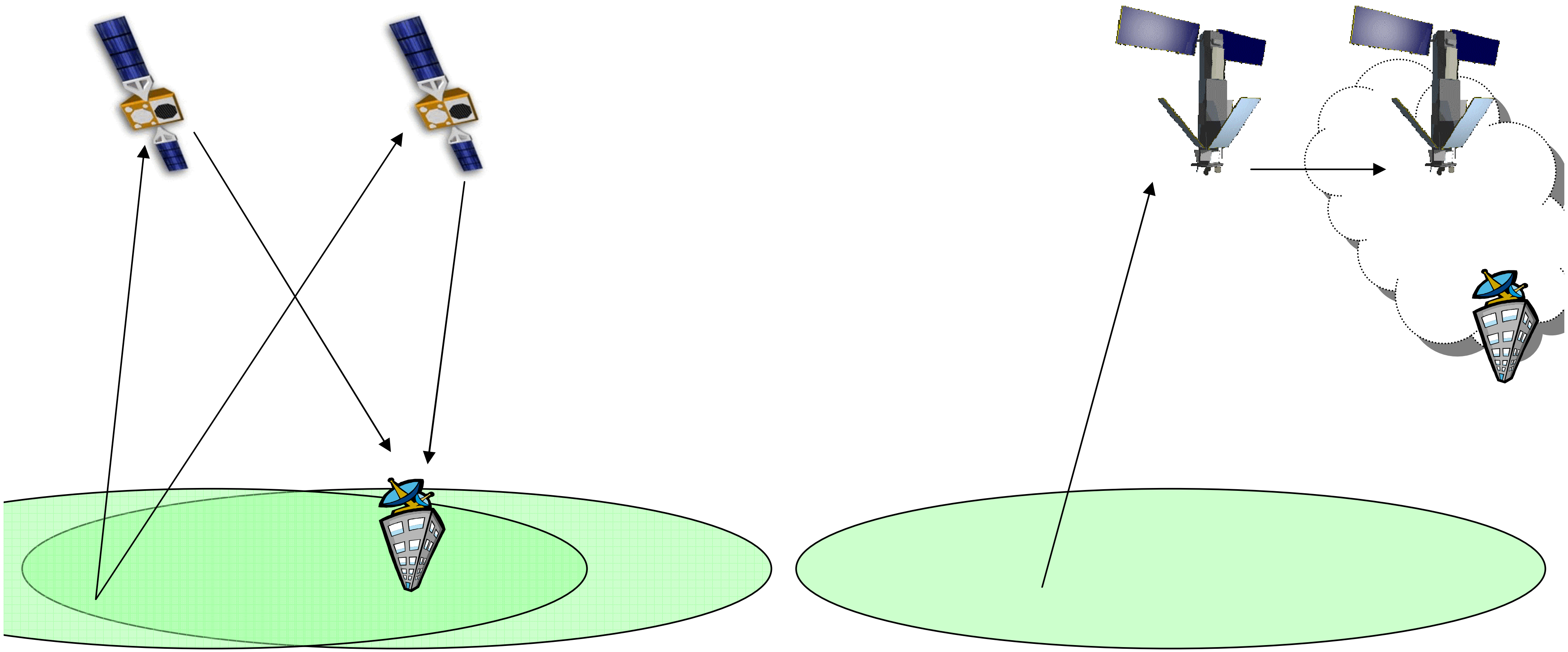


newer 'onboard processing'

gaining some acceptance
with different tradeoffs.

Globalstar vs *Iridium*

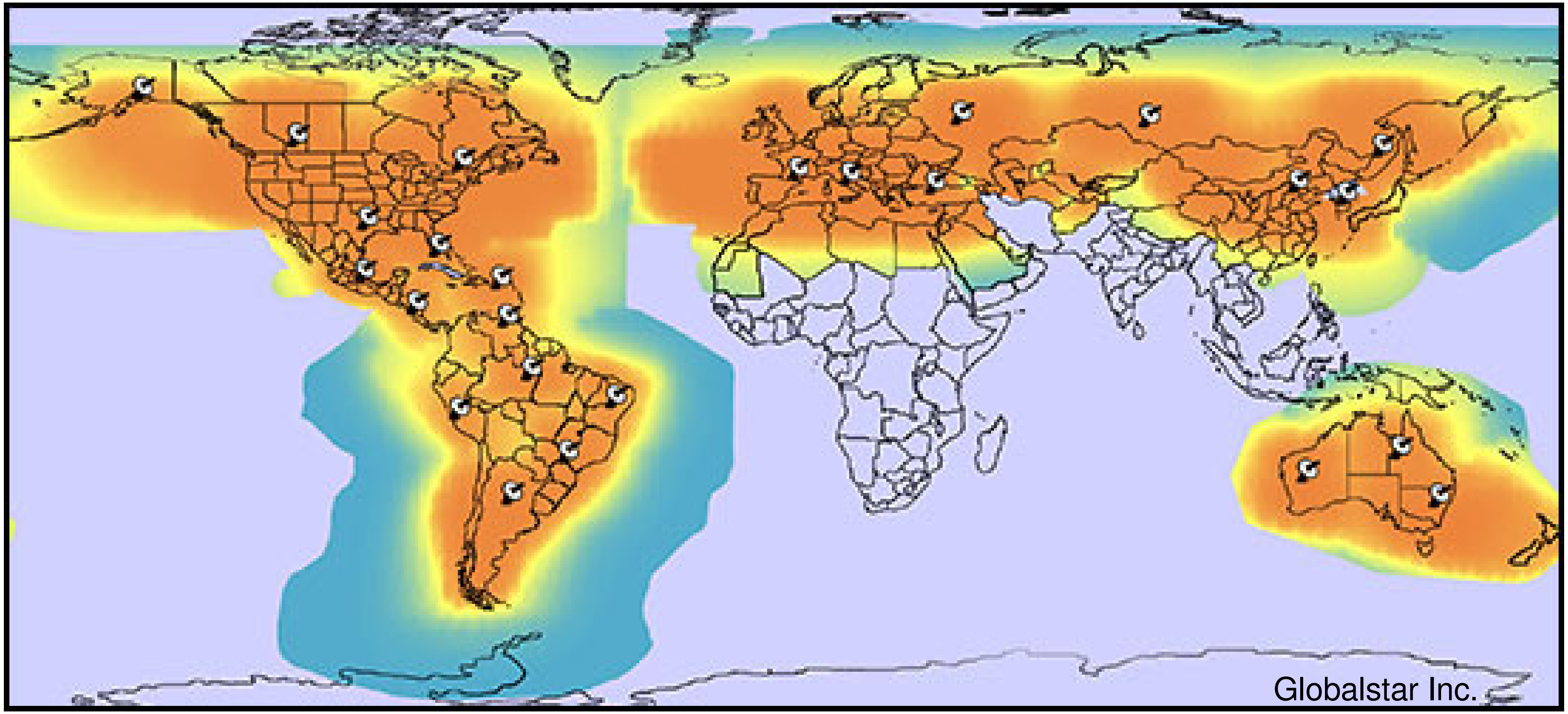
across intersatellite links to satellite
that sees ground station



bent-pipe
CDMA recombination.
Uses diversity, but must complete link
in nearby ground station

onboard processing
Doesn't use CDMA or diversity.
But doesn't need a nearby ground
station; less ground infrastructure.

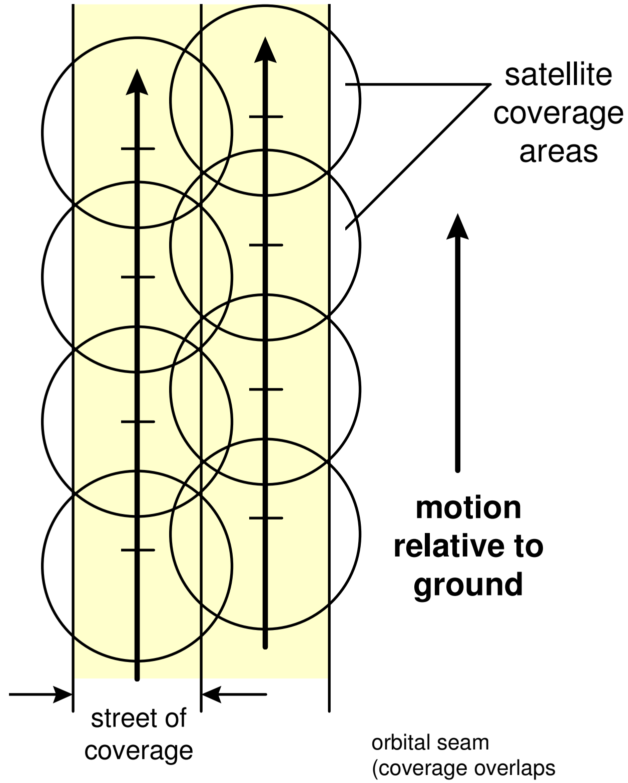
Globalstar coverage

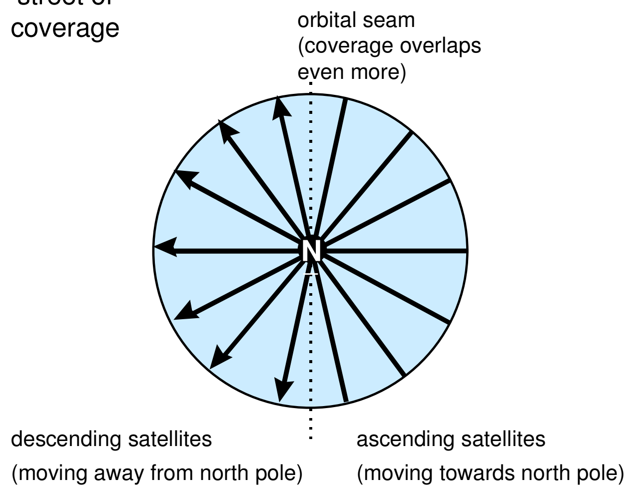


where its satellites can connect you to a local ground station
notice Cuba – interdicted.

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.
- Circular orbits are most useful throughout the orbital period – signal strength remains consistent.





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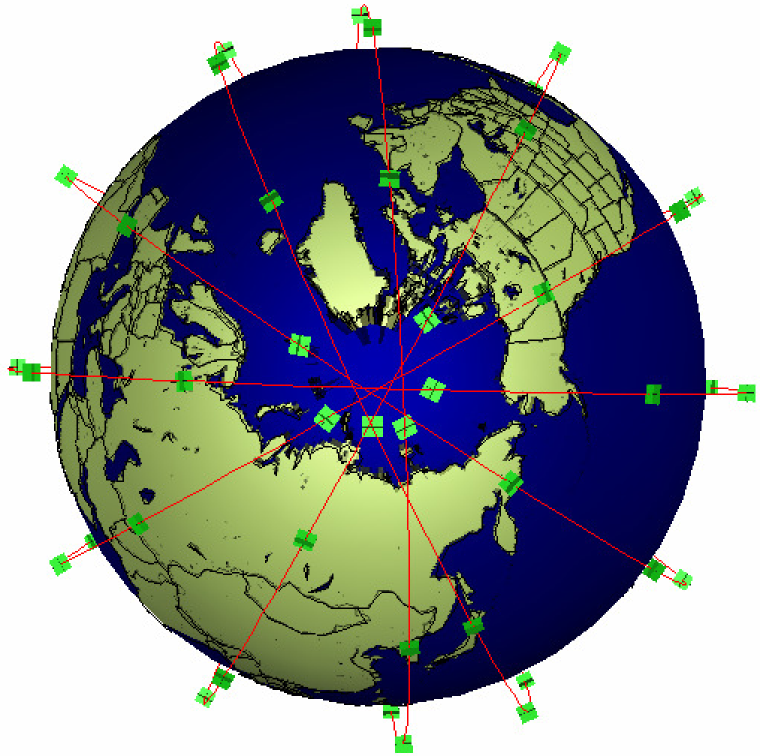

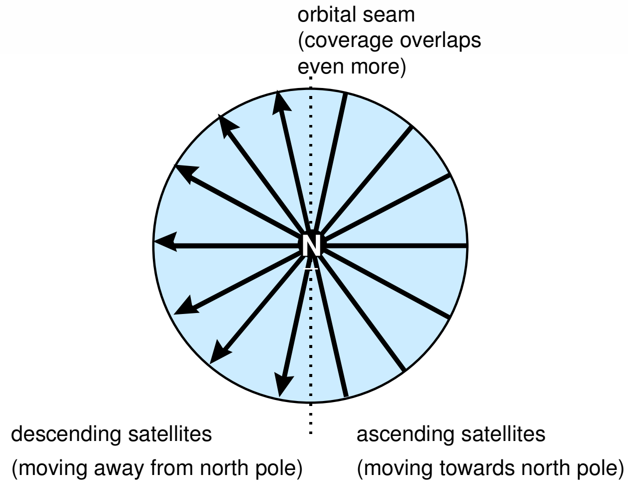

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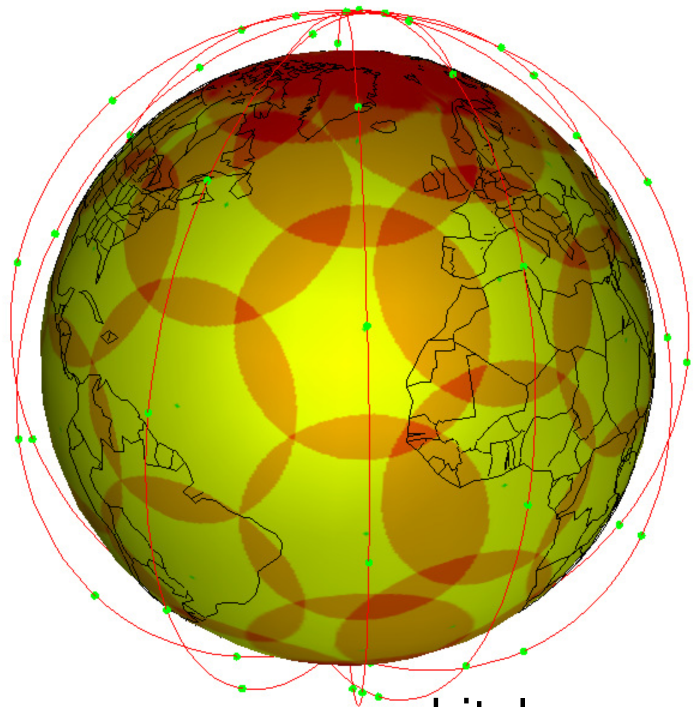
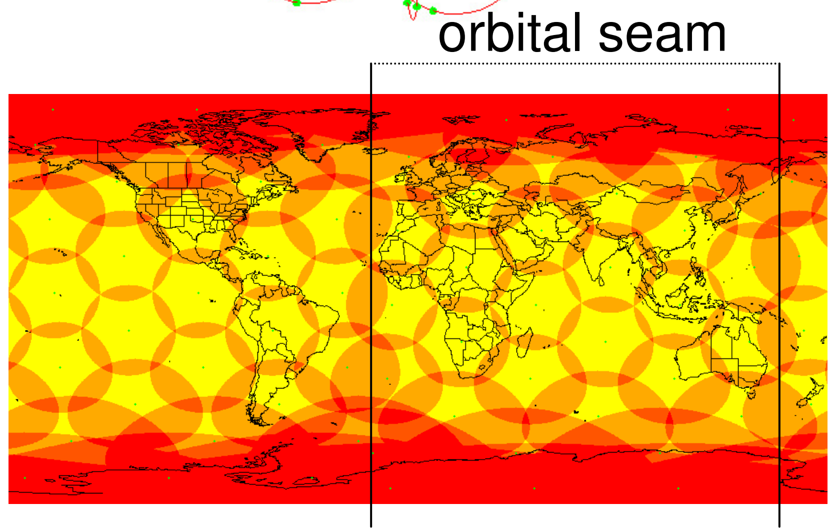
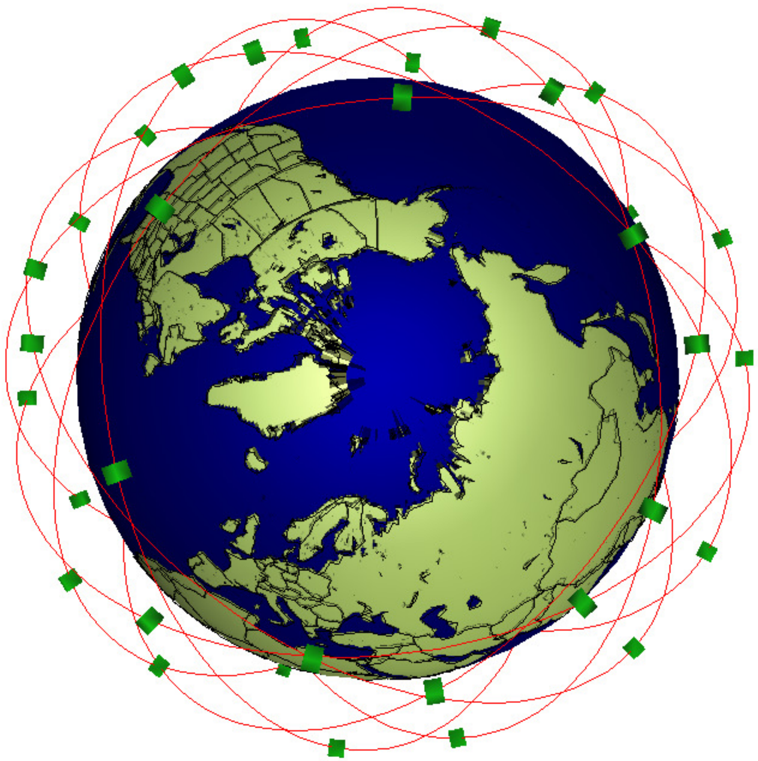
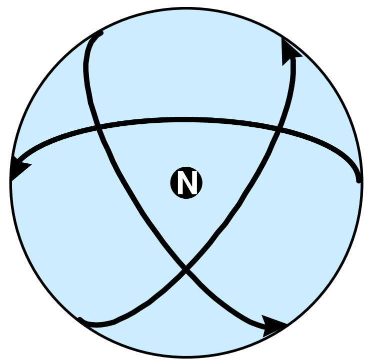




Ballard rosette (also Walker delta)

- Best diversity at mid-latitudes.
- Usually no coverage at poles; not global.
- Only operating LEO example: *Globalstar* (Voice telephony. Also went through US bankruptcy protection after *Iridium* did, 2002-2004.)





no orbital seam;
ascending and descending satellites overlap

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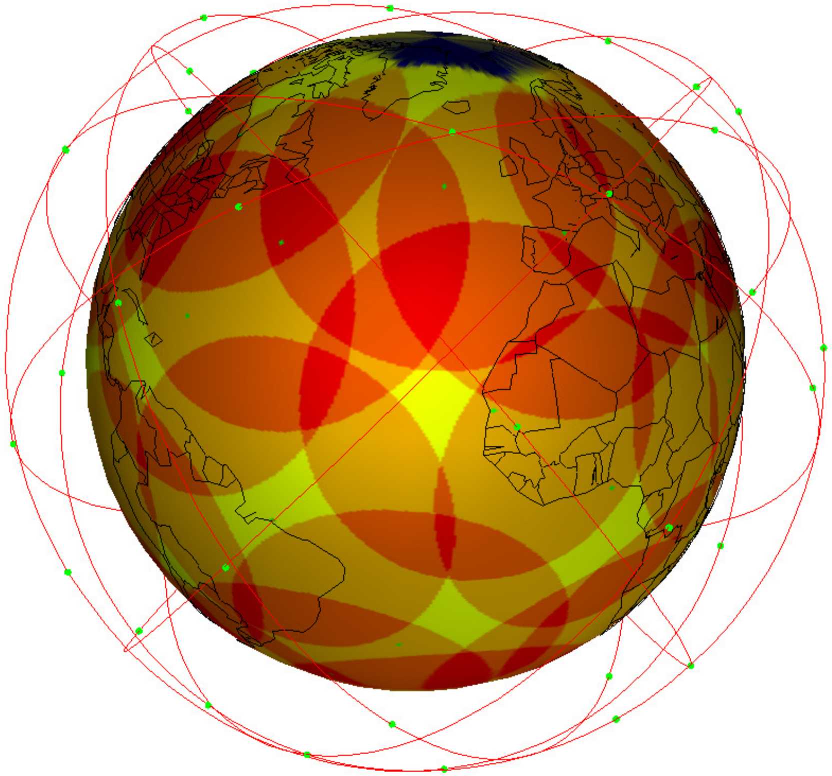
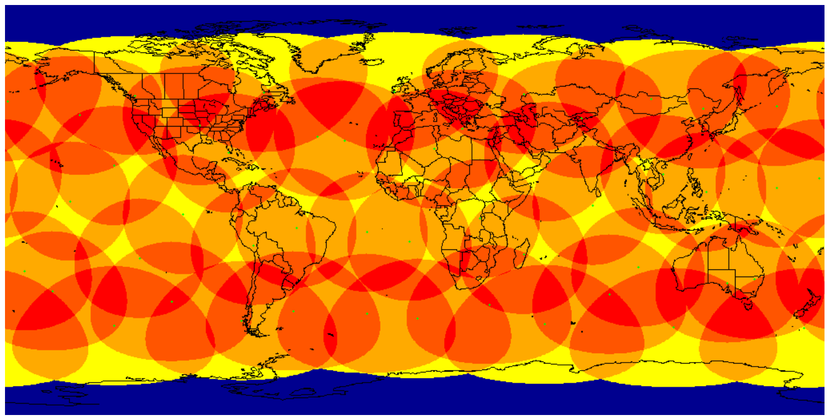
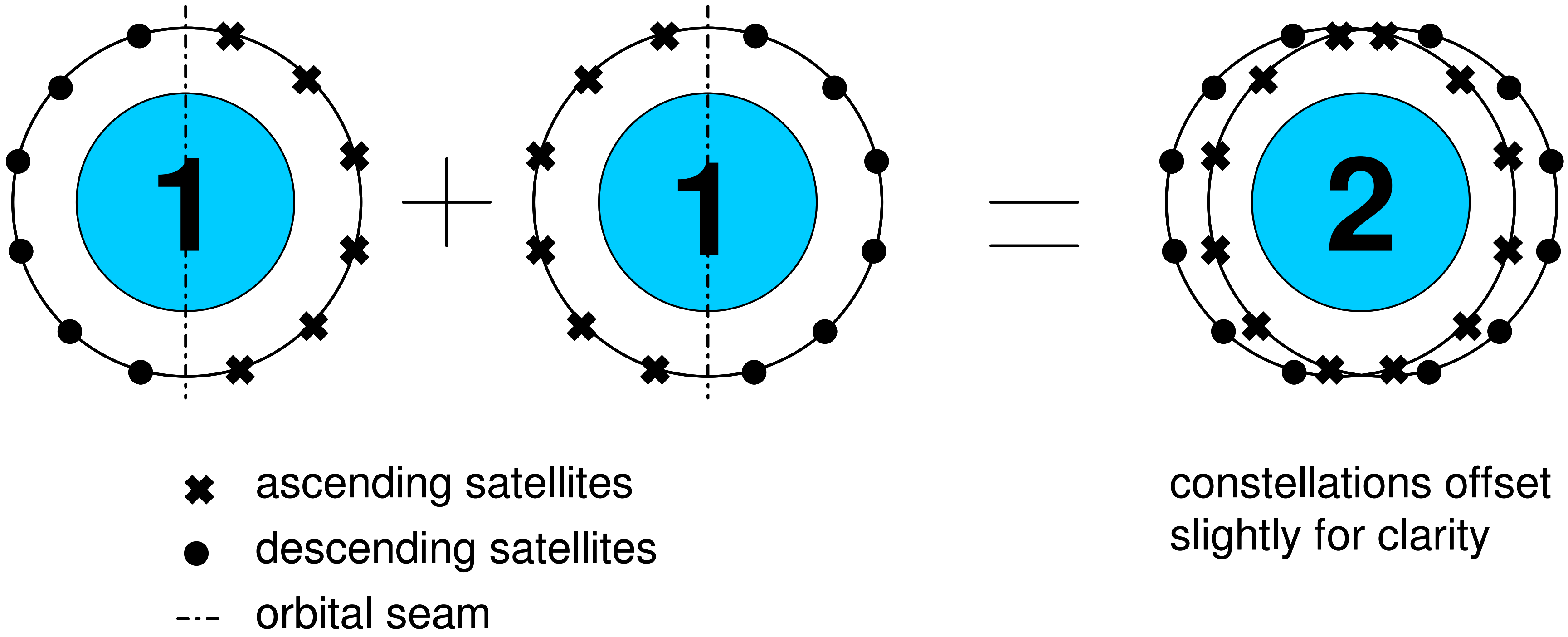




ascending and descending satellites overlap

A star is a rosette cut in half



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*.

Globalstar Inc. *vs* Iridium Satellite

Compare Q2 2008 results for three months ending 30 June.

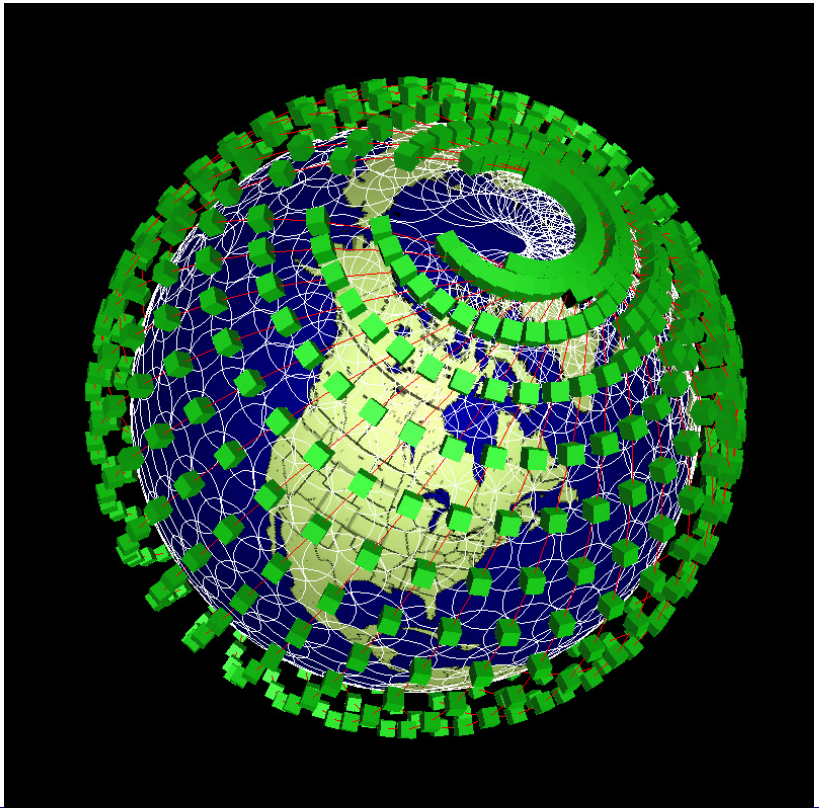
	Globalstar Inc.	Iridium Satellite
subscribers	316,000	280,000
revenue	$16.7 million	$82 million
EBITDA	($2 million) *loss*	$26 million
new satellites	currently being integrated and tested by Thales Alenia Space.	Iridium NEXT downselected to: Thales Alenia Space, Lockheed Martin.

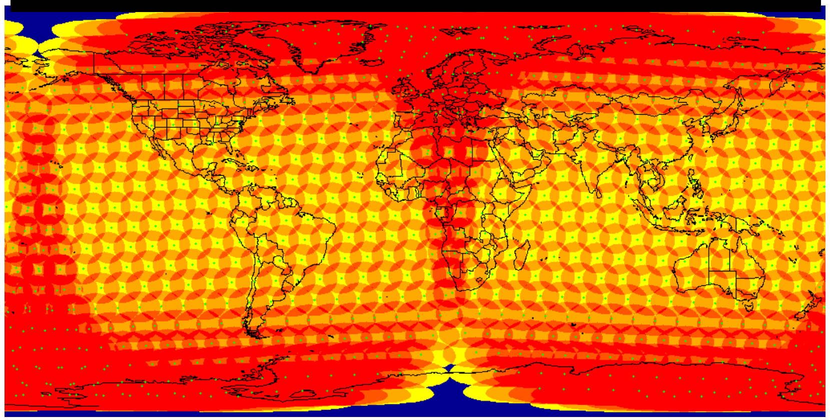
Both are planning replacement constellations as existing satellites near end of life.

>20% of Iridium Satellite's profits is from polar regions.
Globalstar Inc. spent $1.1 million buying Brazilian gateway operator.

The incredible shrinking *Teledesic*

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





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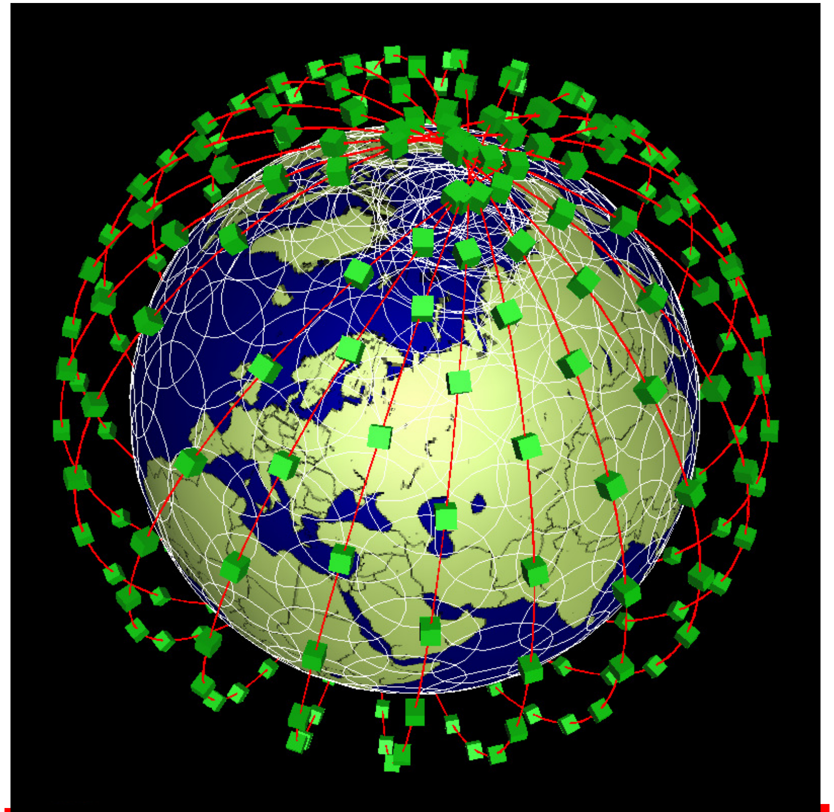

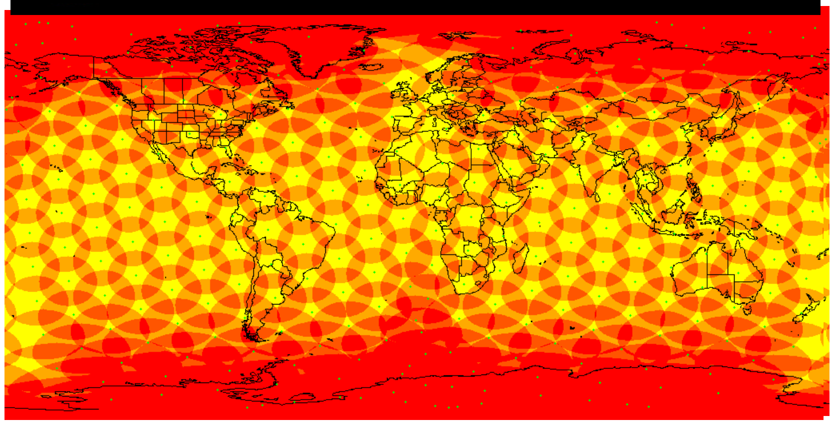

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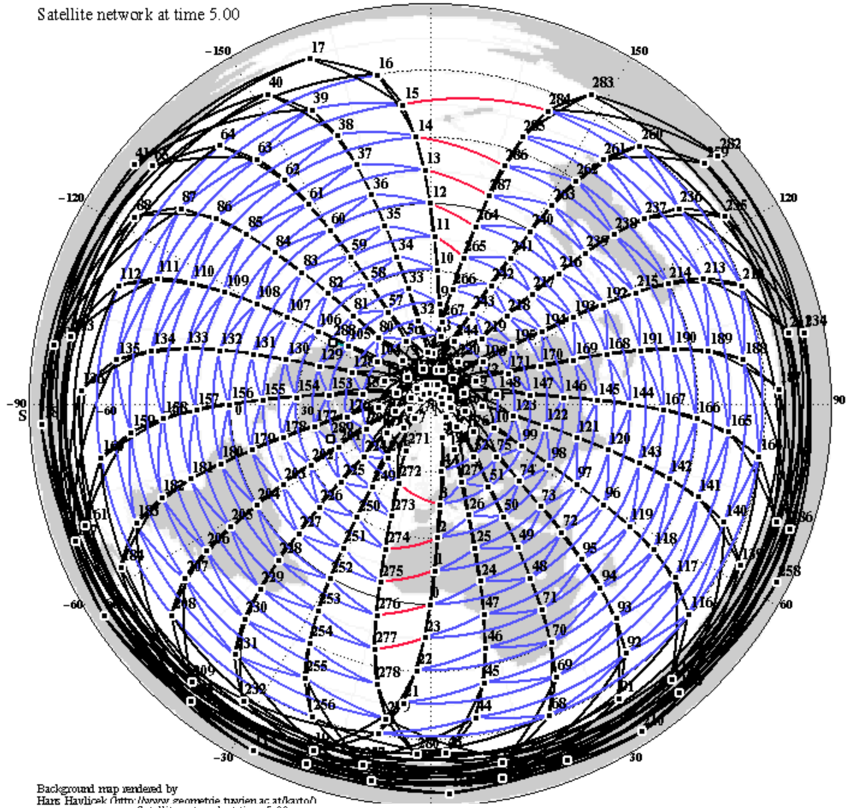
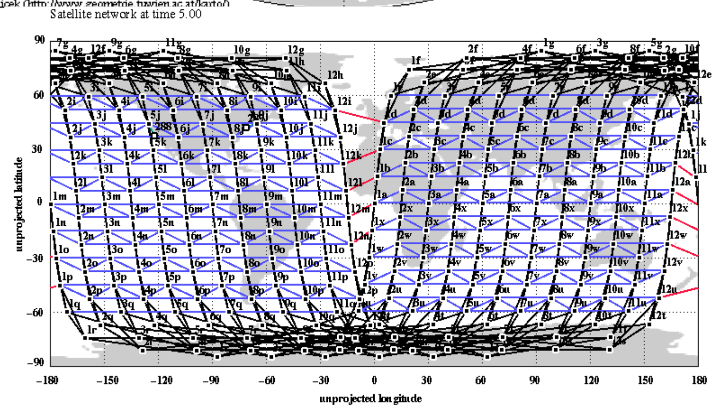
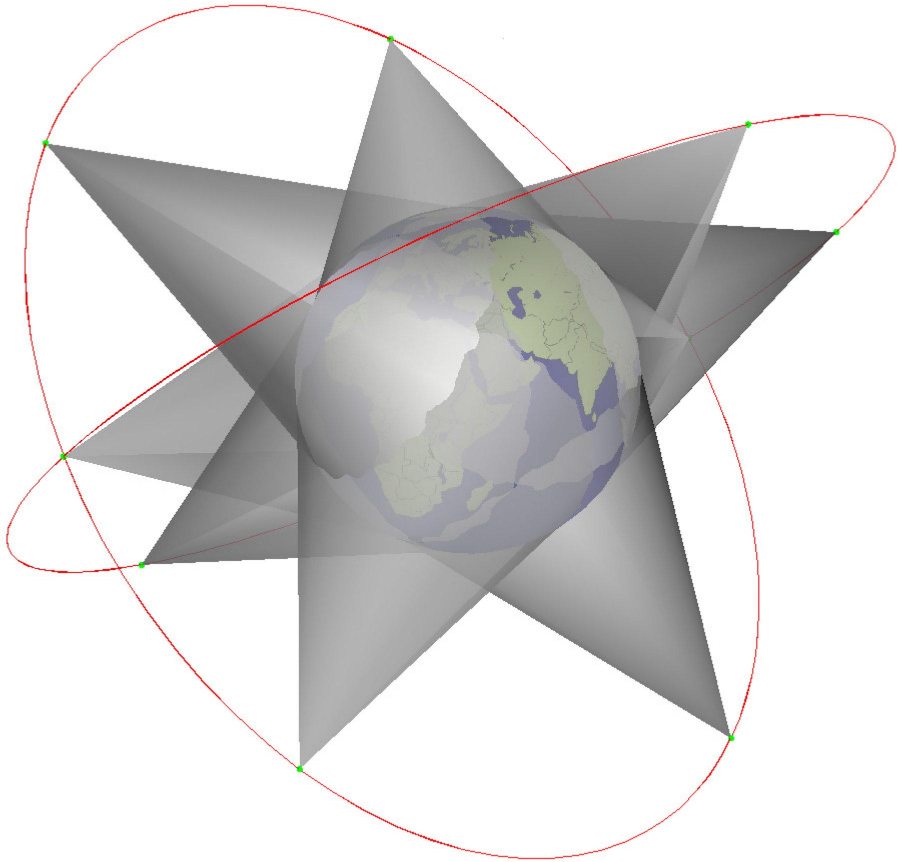
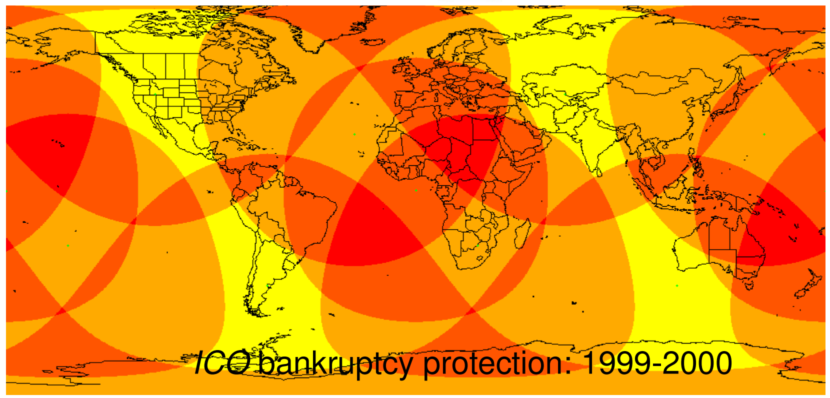




The incredible shrinking *Teledesic*

- 1994: 840 satellites – announced the largest network system *ever*.
- Until 1997: planned 288 satellites. Still biggest!
- 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; no ISLs and **only one in orbit.**)

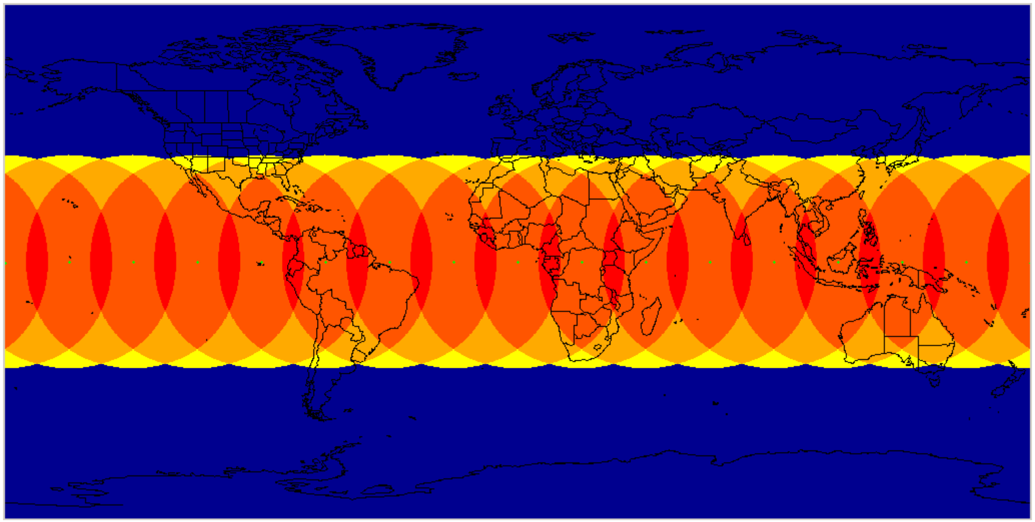




ICO bankruptcy protection: 1999-2000

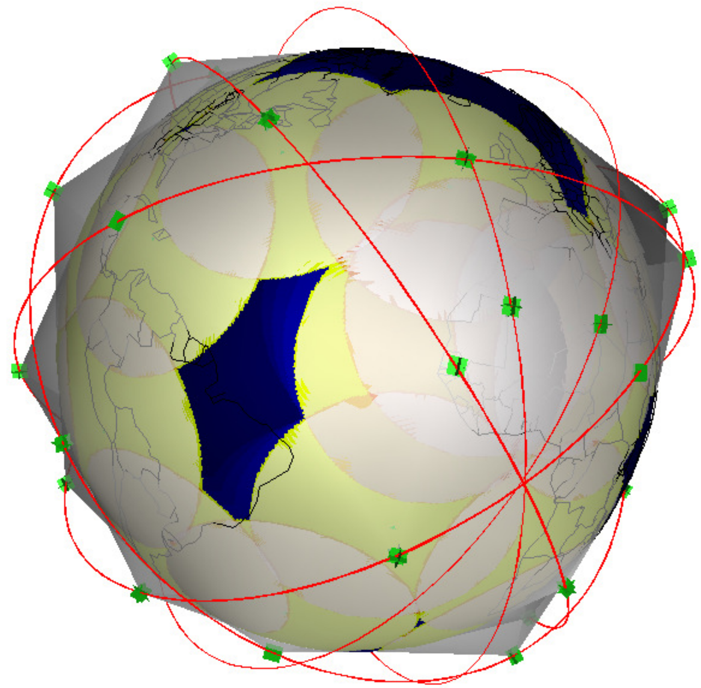
New kid on the block: *Google.*

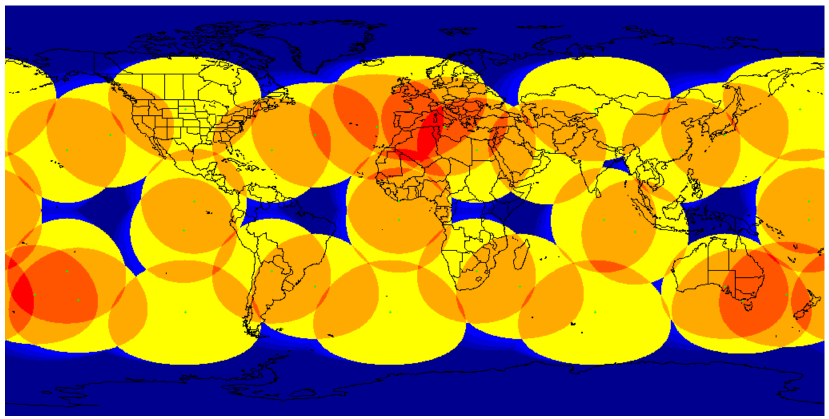
Needs satellite imagery for Google Maps and Google Earth. Gets ~4m resolution imagery from GeoEye-1 (launched 6 Sep 2008).
<0.5m imagery is restricted.
Funding **O3b Networks**, along with HSBC, others. O3b aims to backhaul African cellular networks via MEO ring of satellites covering 45^o-45^o latitude.



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.





Some views of intersatellite links

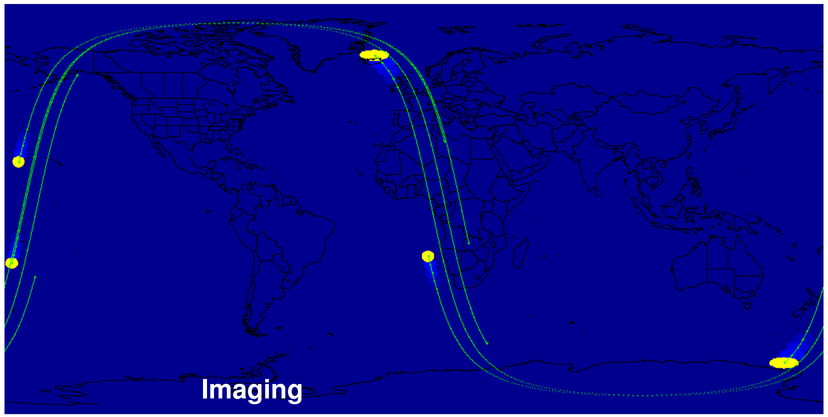
- **Iridium** has 10Mbps Ka-band radio crosslinks.
- **ESA** plans backhauling LEO remote sensing satellites. Demonstrated with *SILEX* laser long-distance crosslink and Artemis Ka-band.
- **US DoD** wants reachback to CONUS from theatre. Building *TSAT Transformational Satellites* – five geostationary satellites with long-distance laser crosslinks.
- **Clustering and slot clouds** short-distance wireless connecting stationkeeping satellites.

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* and the 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.

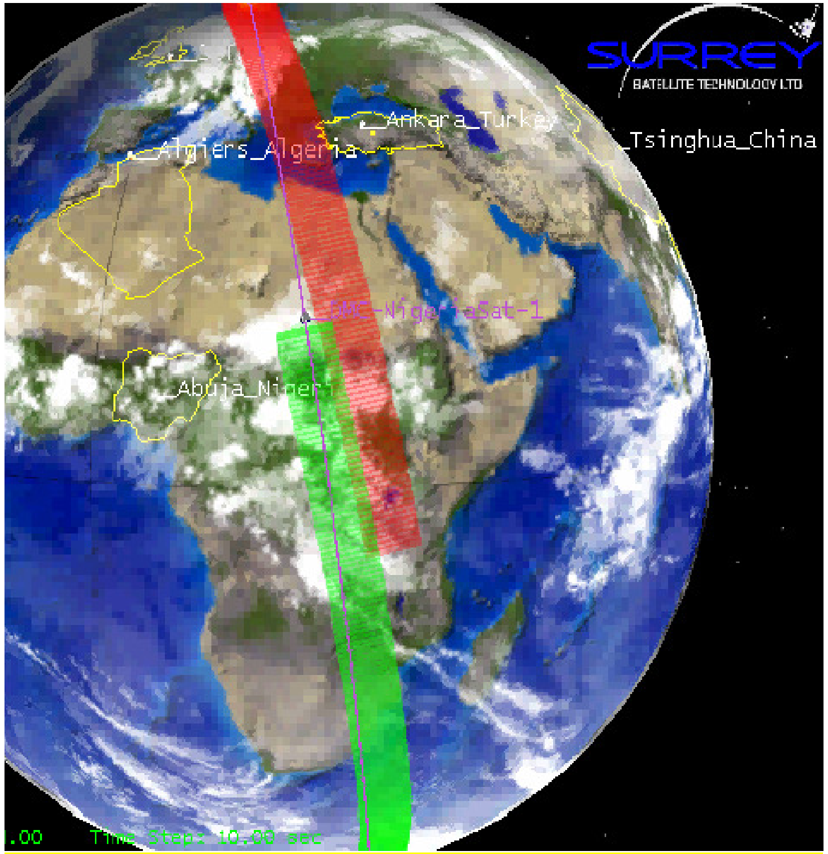
Disaster Monitoring Constellation

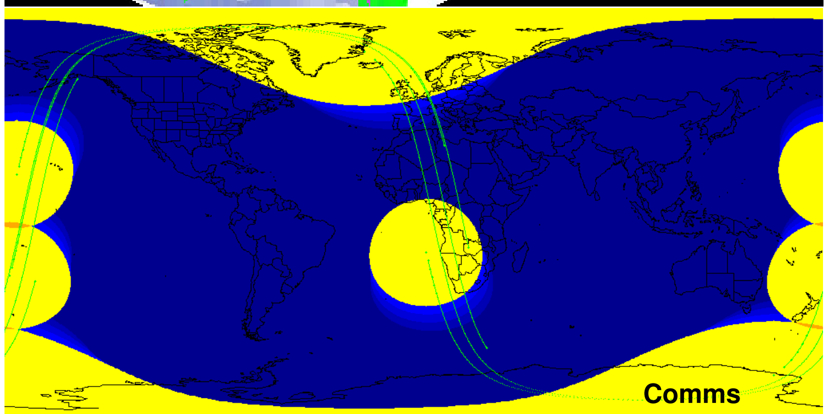
- Single plane of four active sun-synchronous imaging satellites, ascending at 10:15am over Equator. Fifth satellite at 10:30am.
- Gives overlapping daily coverage of any point on the Earth’s surface.
- Coverage map shows 600km pushbroom imaging swath – large by LEO imaging standards. More to be launched

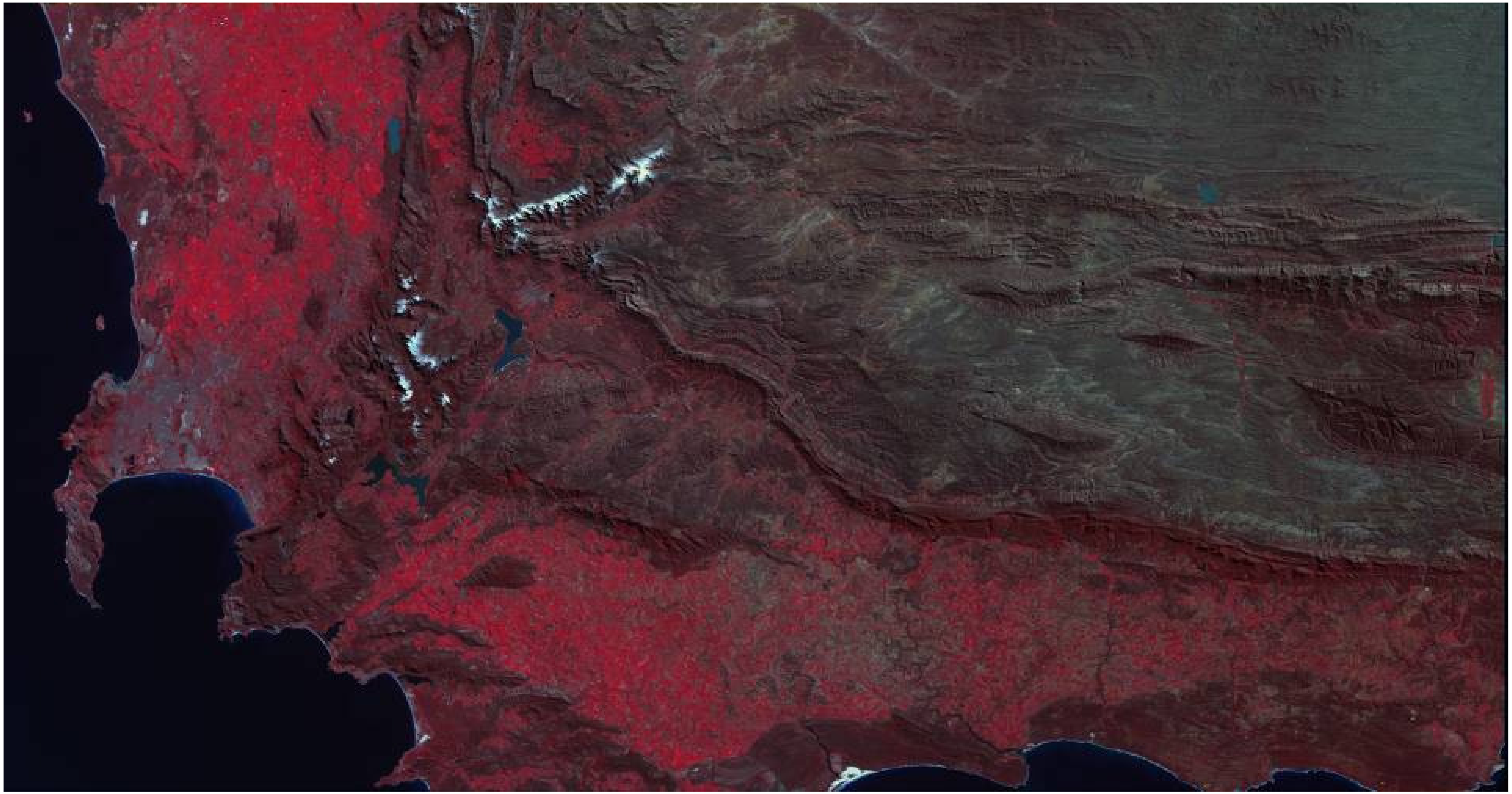


Disaster Monitoring Constellation

- Single plane of four active 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.
- Communications access a little larger – passes over ground stations <14 min.
- *RapidEye* (5 sats launched 29 August 2008) similar.







www.dmcii.com

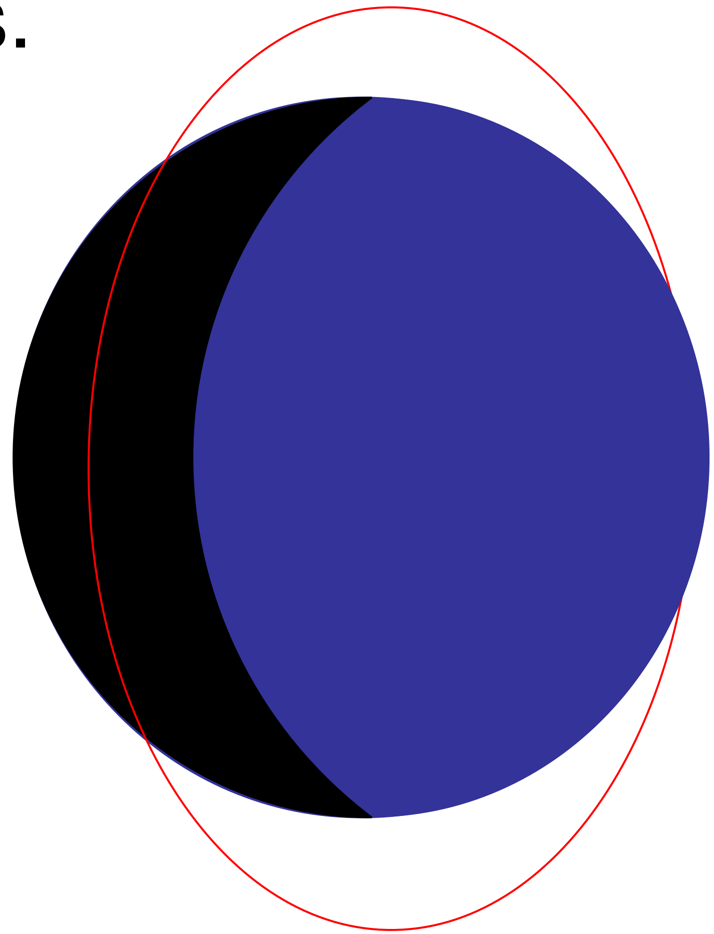
Sample Disaster Monitoring Constellation (DMC) image

The Cape of Good Hope and False Bay. False colours – red is vegetation.
Taken by UK-DMC satellite on the morning of Wednesday, 27 August 2008.

First sensor imagery delivered by bundles from space.

Other sensing satellites

- Radar imaging satellites are *active*, not *passive* sensors.
- They 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.



Sensing benefits from ISLs

- **backhauling through GEO** to give longer periods of connectivity to download data, e.g. half an hour instead of ten minutes.
- **Synchronising payloads on different sensor satellites**, so that measurements taken at the same time can be combined.
  - 3D stereoscopic imaging
  - Wide-aperture phased-array sensing
  - combined hyperspectral imaging,
    - e.g. combining the capabilities of the climate-sensing ‘A-train’.
  - scientific measurements otherwise not possible,
    - e.g. GRACE gravity measurement (launched March 2002).

Summary

This talk has outlined:

- An overview of satellite orbits and coverage.
- A number of satellite constellation designs
- Their varied advantages, uses, and tradeoffs.
- Intersatellite links and design choices.
- Business plans using constellations – the successful and unsuccessful ones.
- A boom-and-bust cyclical industry.

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Questions?

Thankyou

Lloyd Wood

http://info.ee.surrey.ac.uk/L.Wood/

oh, just google…