



Science
GNSS-RO
Where We've Been, Where We're Going

Tom Yunck



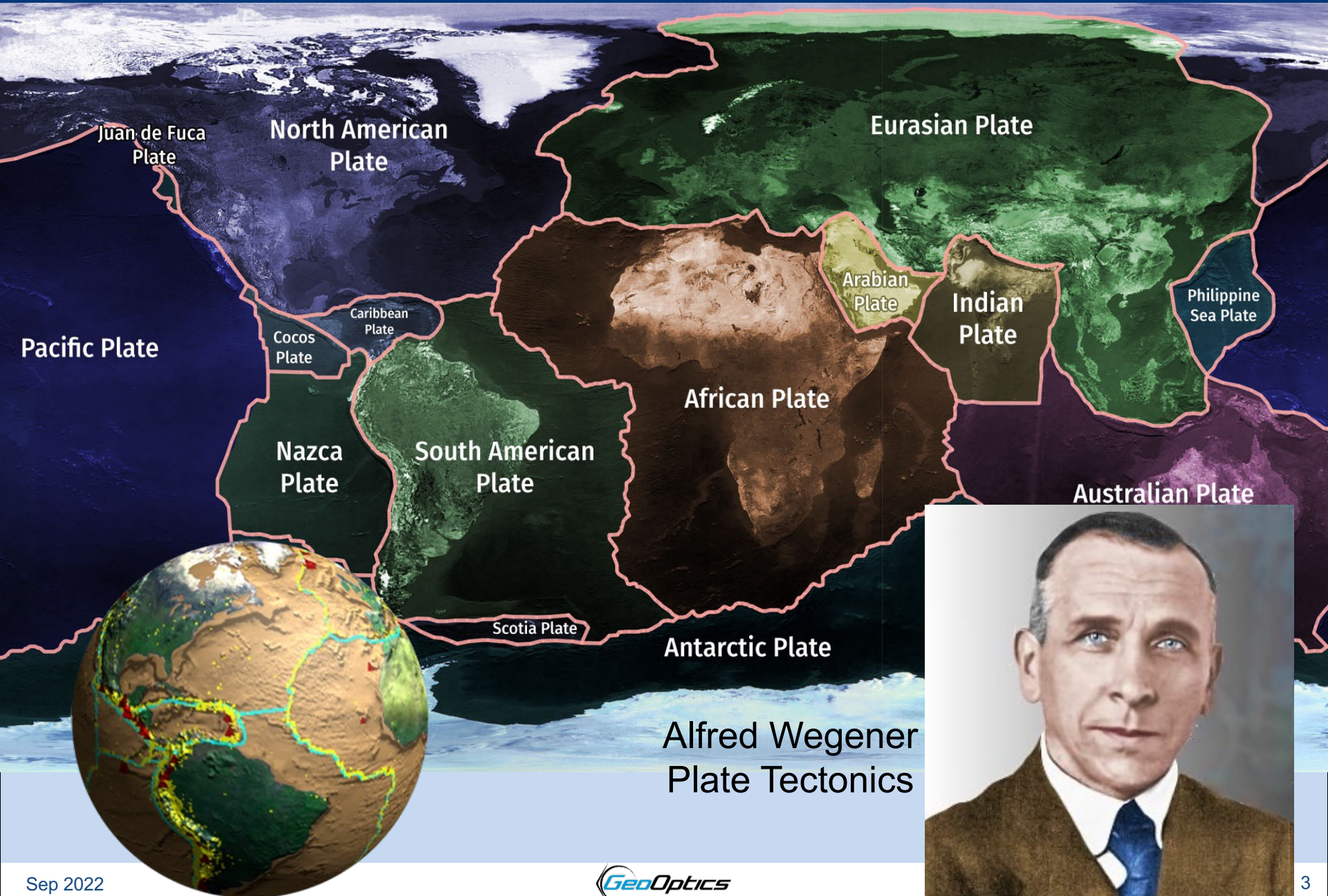
September 8, 2022



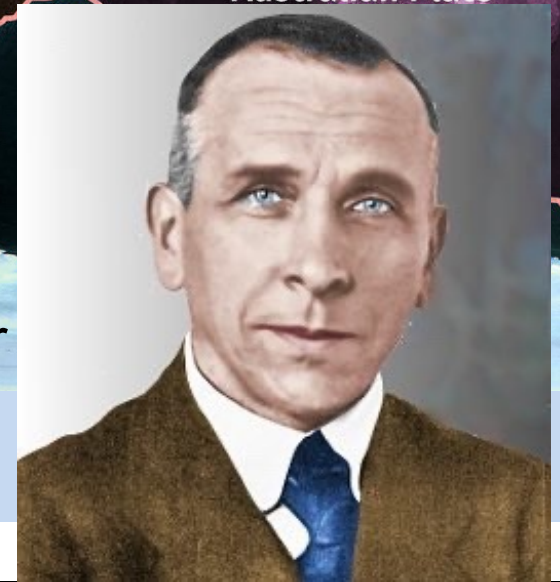
Origins



1915



Alfred Wegener
Plate Tectonics





1981



Early Mobile GPS Receiver



JPL' s SERIES Codeless Receiver
(Satellite Emission Radio Interferometric Earth Surveying)



First GPS Measurement of Plate Motion

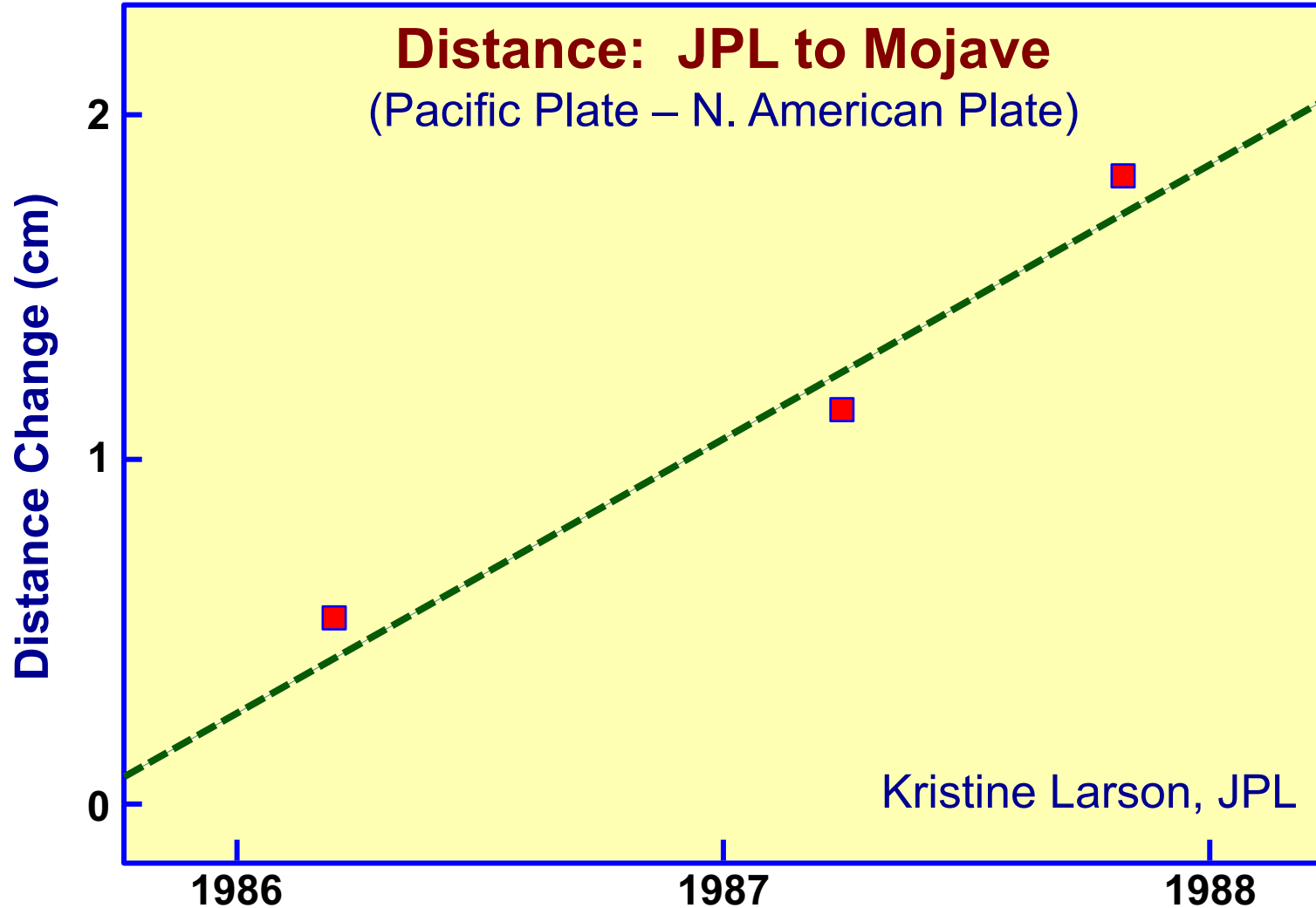
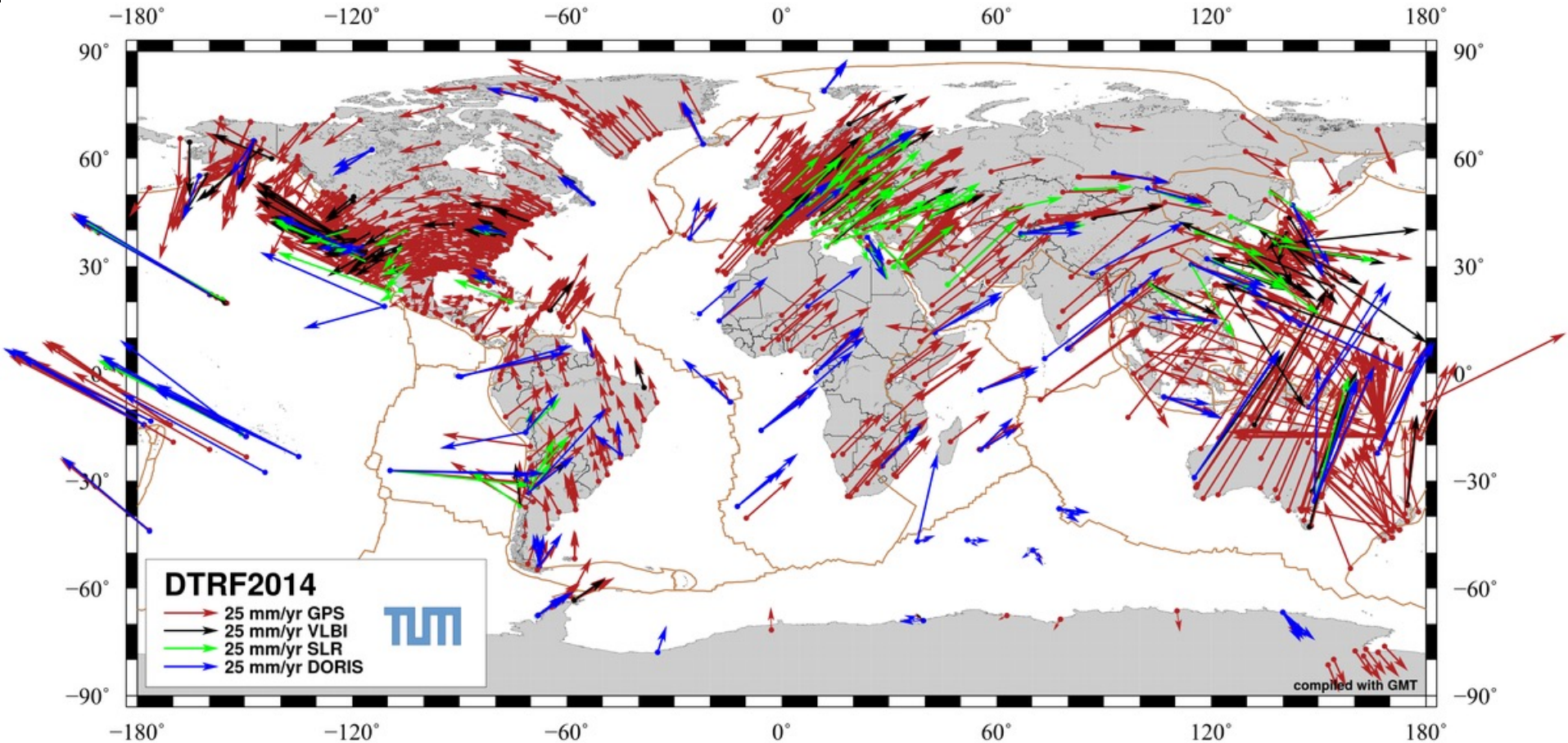




Plate Velocity Map





1981 To Space for POD



TOPEX/Poseidon POD (1981-95)

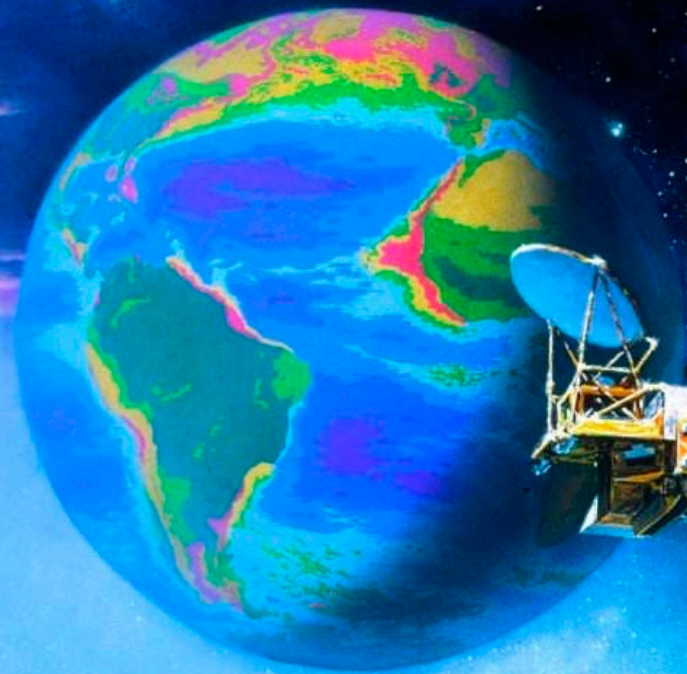


Goal: <10 cm
orbit accuracy

NORTHROP GRUMMAN

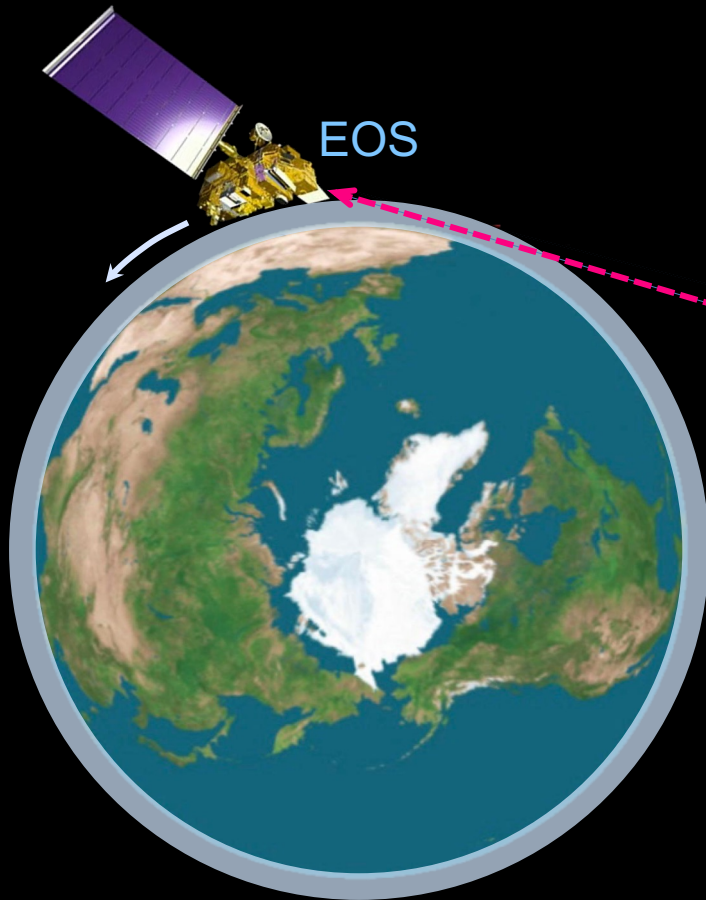
1987

NASA EOS Call



A Q U A

Earth Observing System



EOS

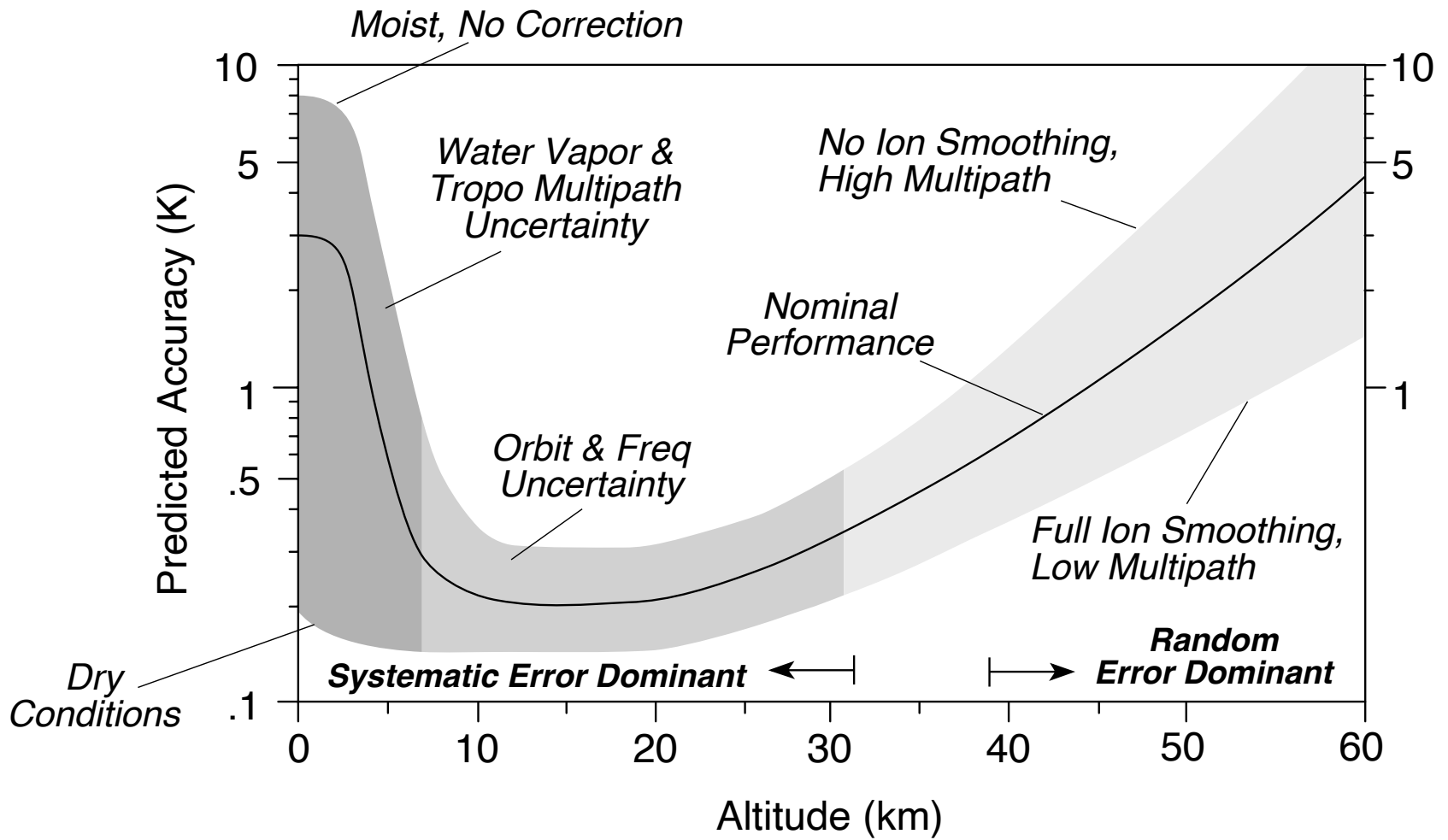


GPS

- Encrypted signal
- Suppressed carrier
- Destabilized clock (SA)
- One-way signal



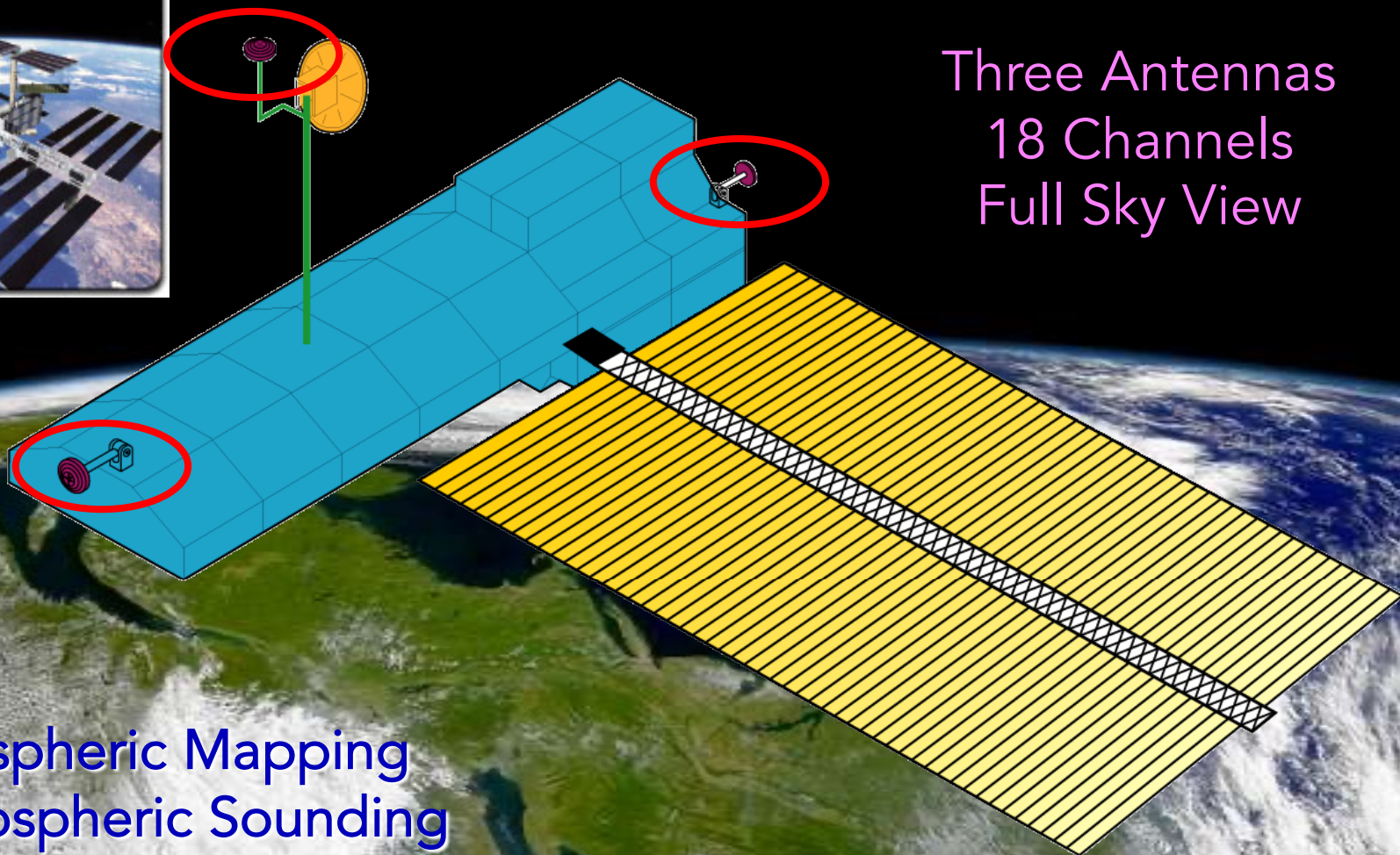
From GGI Proposal, 1988



GPS Geoscience Instrument

GPS Radio Occultation

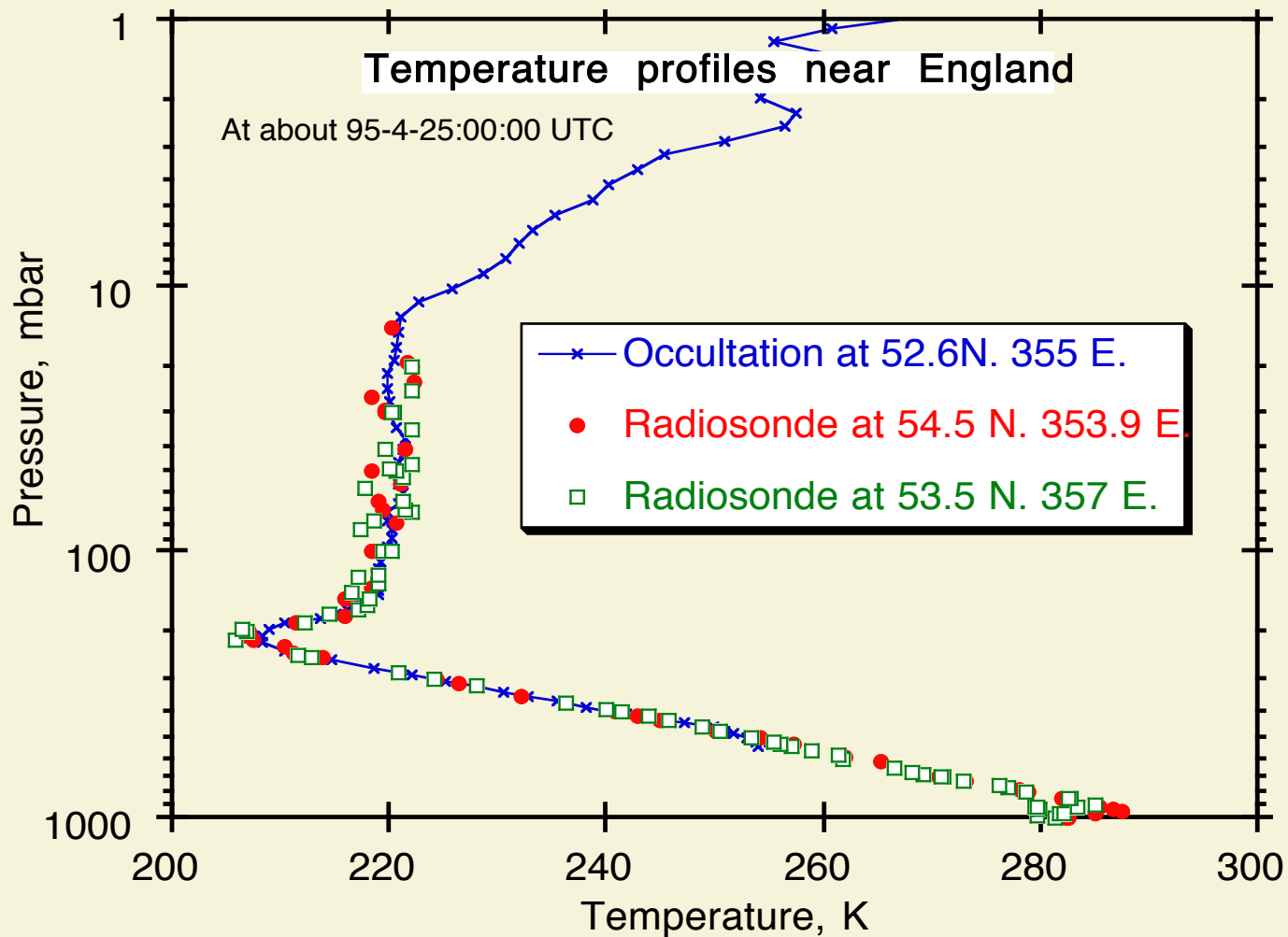
1988



Three Antennas
18 Channels
Full Sky View

Ionospheric Mapping
Atmospheric Sounding

Micro

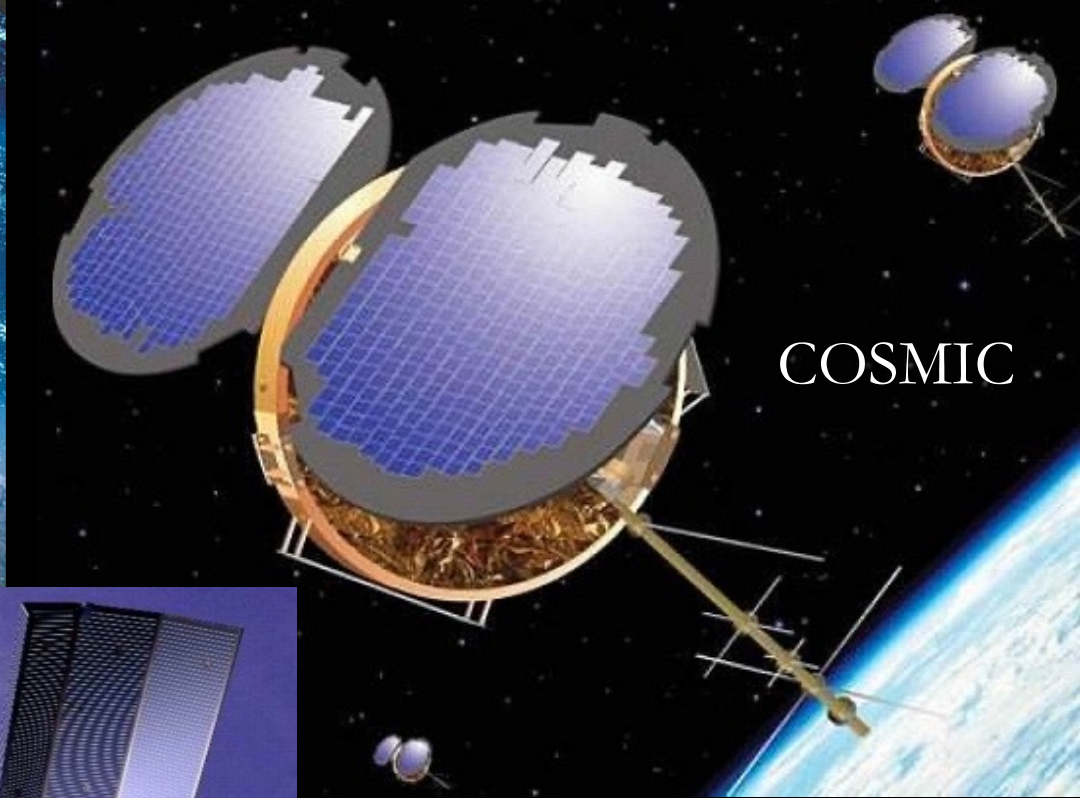


95

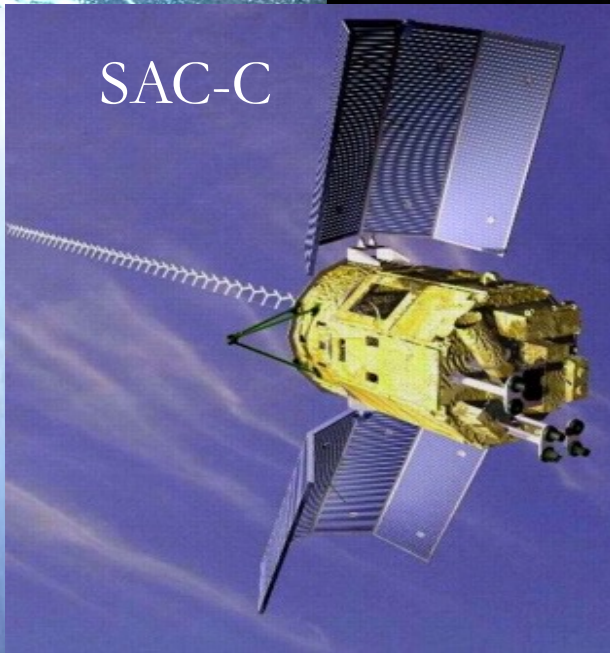
CHAMP



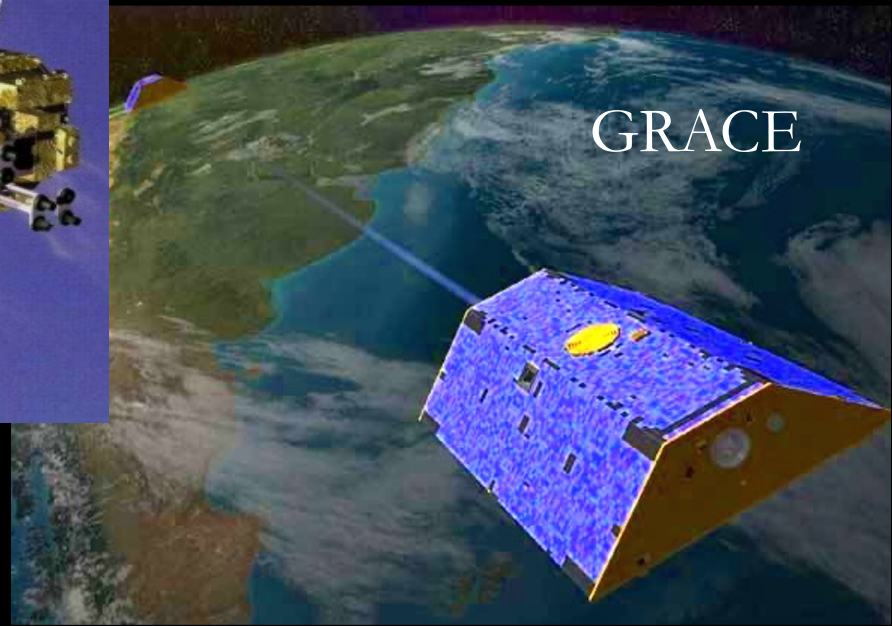
COSMIC



SAC-C



GRACE



COSMIC-2



GNSS RO
1995 - 2018



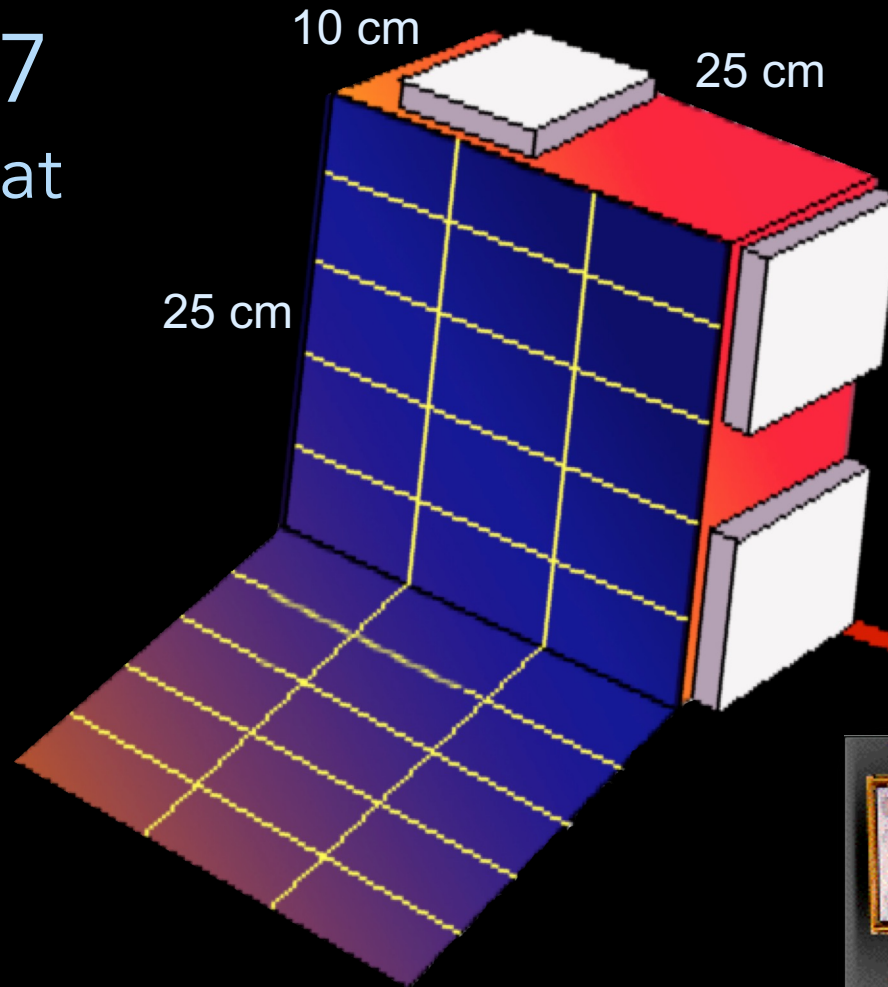


1996

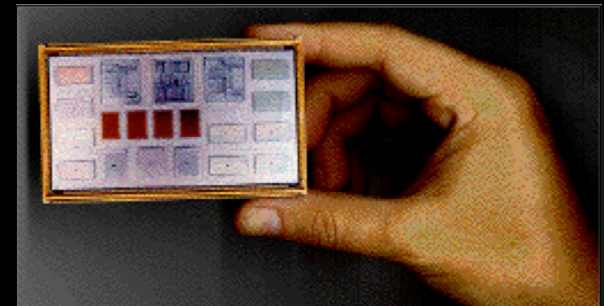
Let's Get Small



1997
RO-Sat



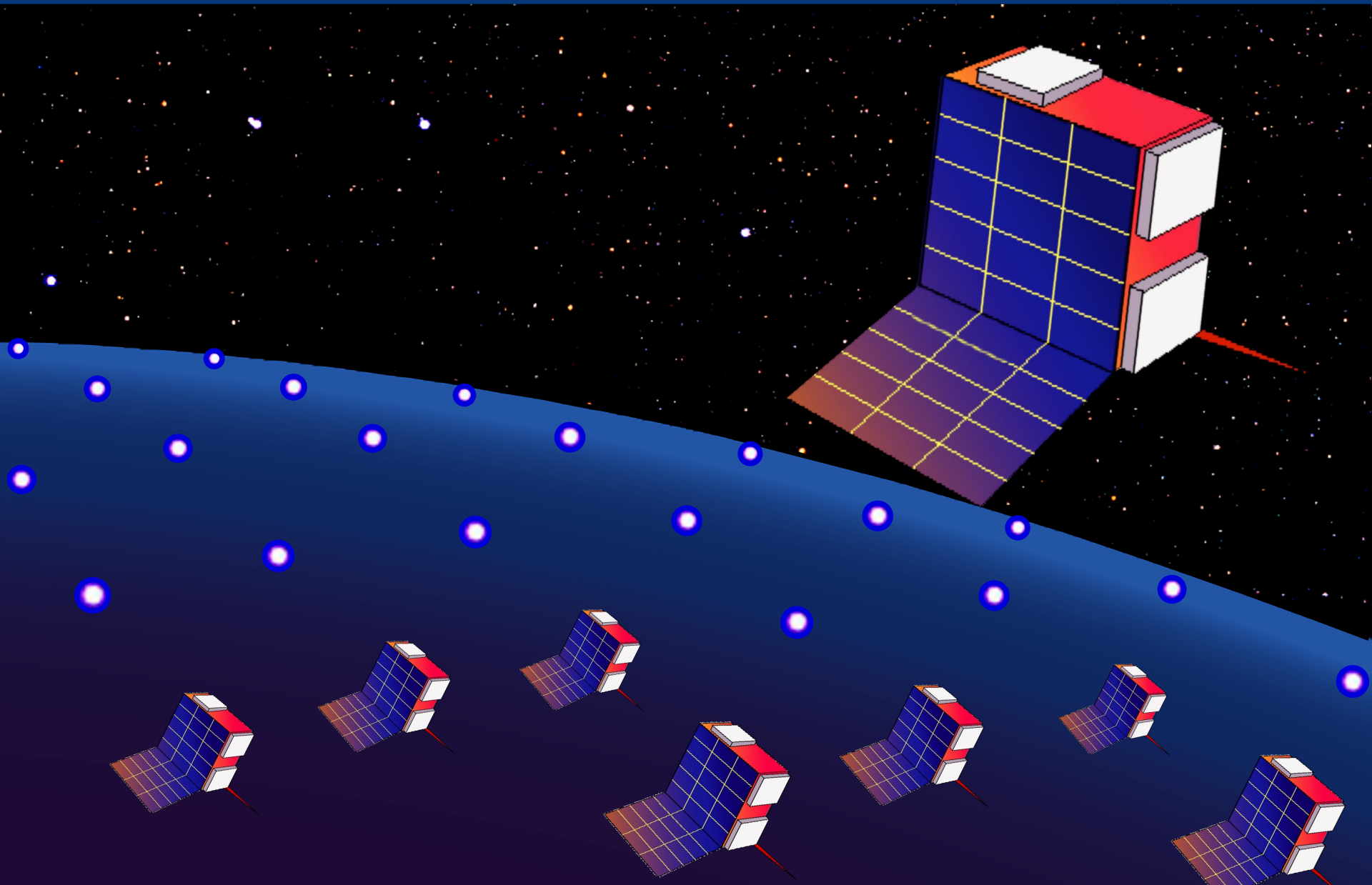
~6U



GPS-On-A-Chip

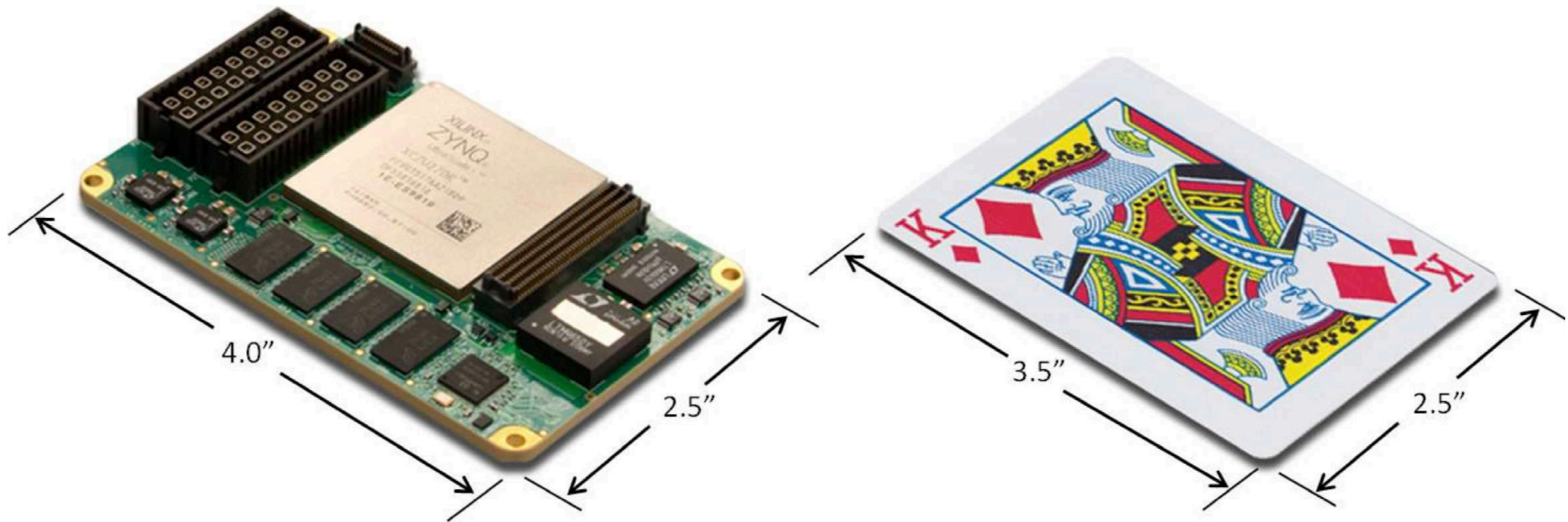


The Large GPS Space Array

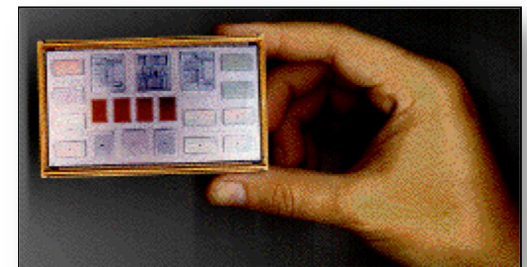




The Xilinx UltraScale+ RF System-on-a-Chip,
shown hosted on the Pentek 6001 module



Model 6001 QuartzXM eXpress Module

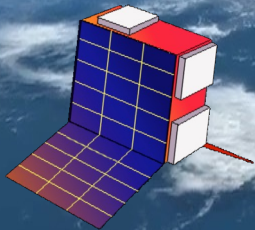
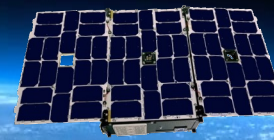
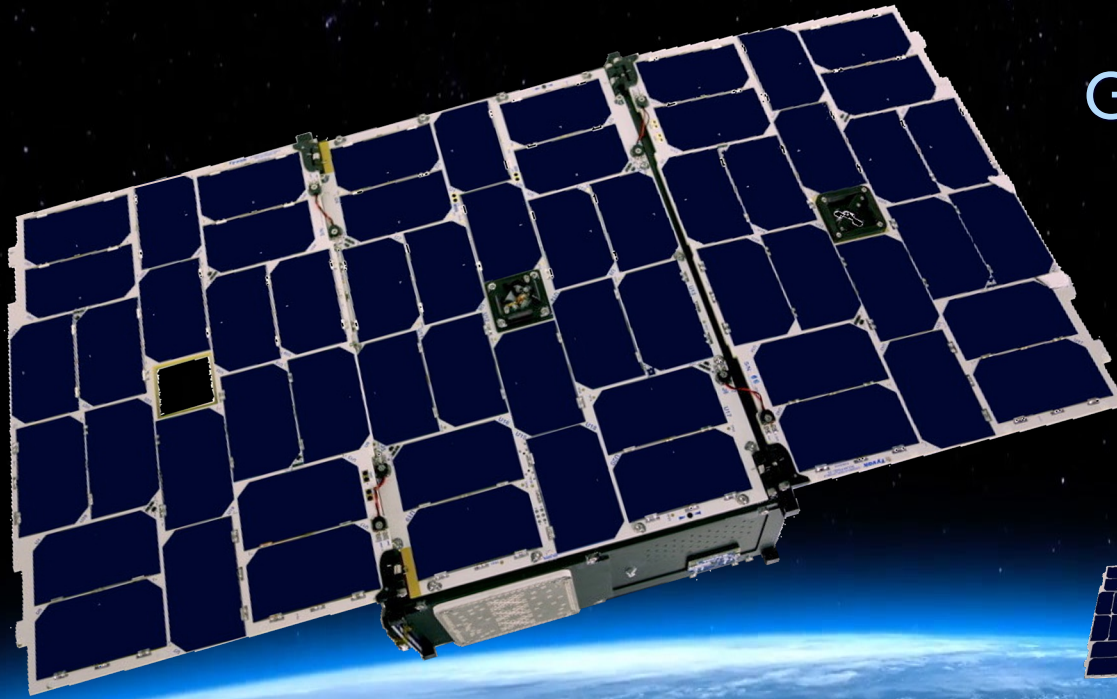




6U CICERO Satellites



GPS / Glonass / Galileo
Radio Occultation

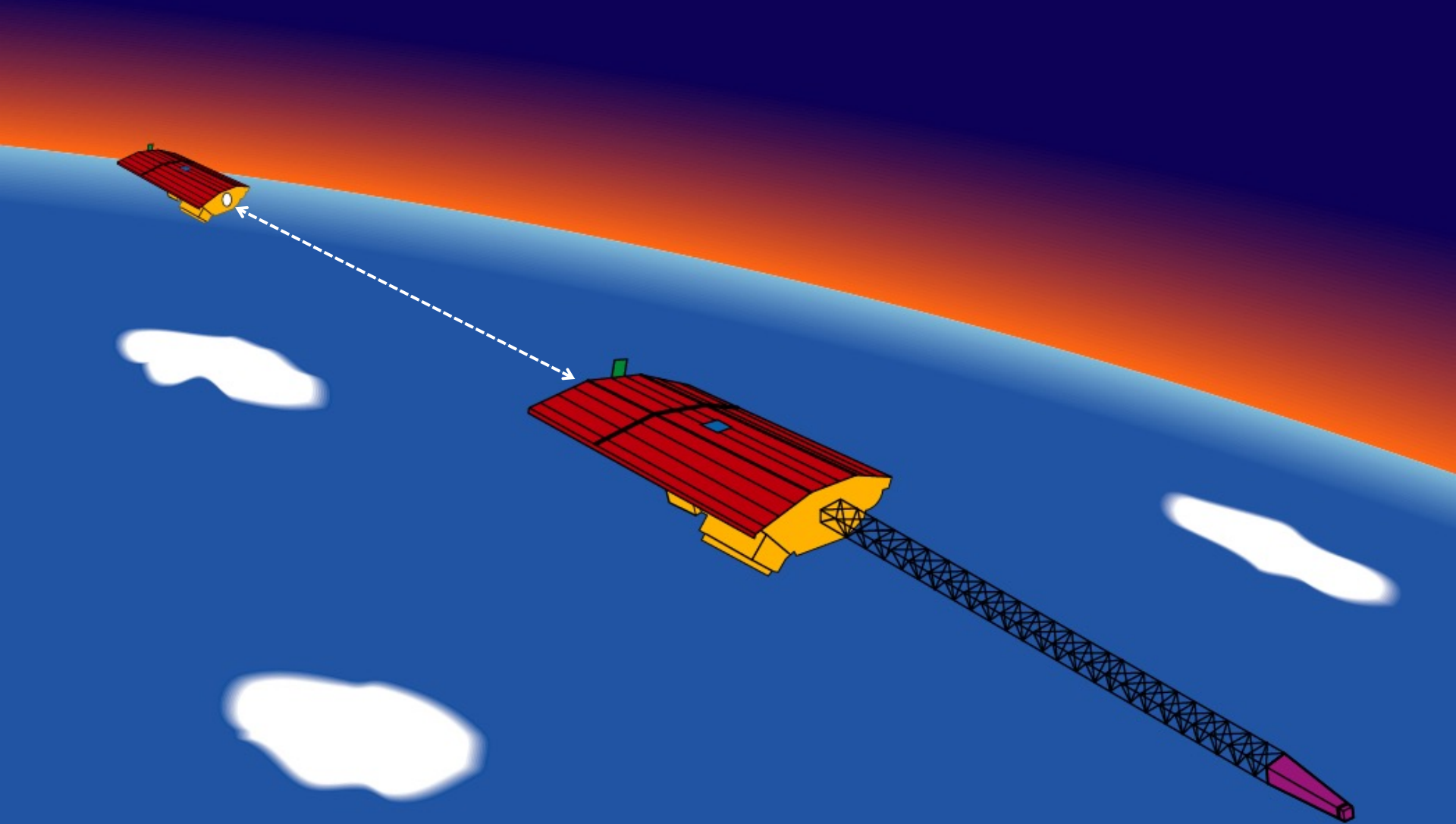




1992

The Pull of Gravity

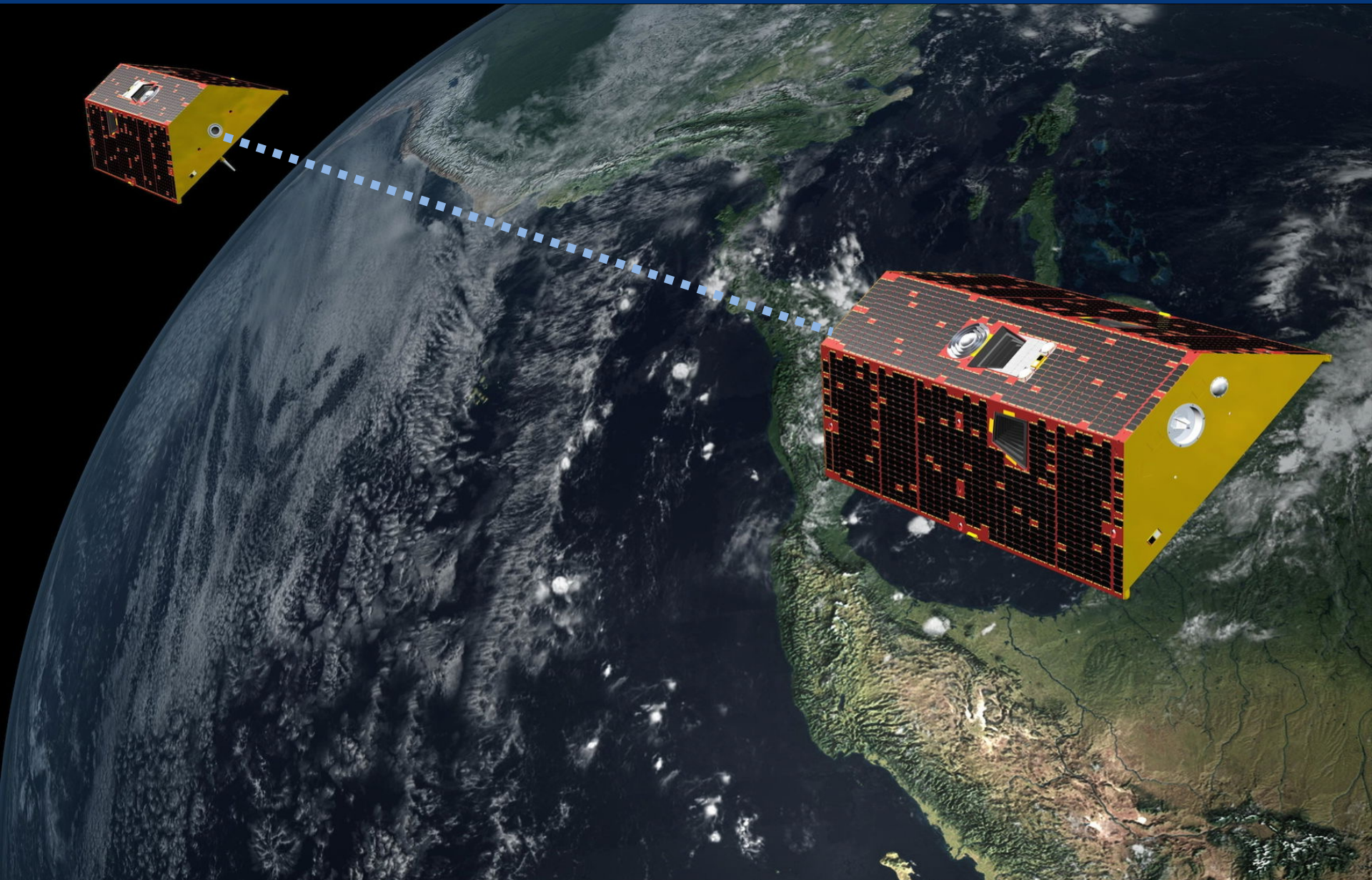
Geopotential Recovery & Atmospheric Change Experiment (GRACE)



T. Yunck, Aug 1993

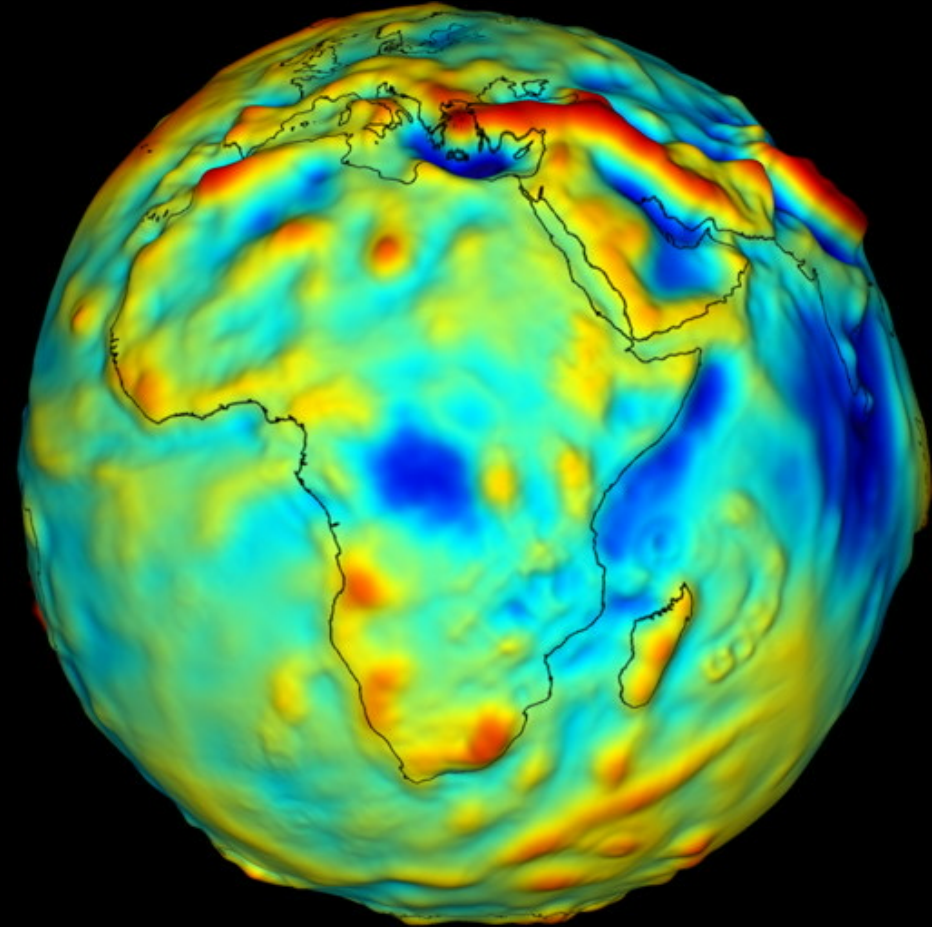
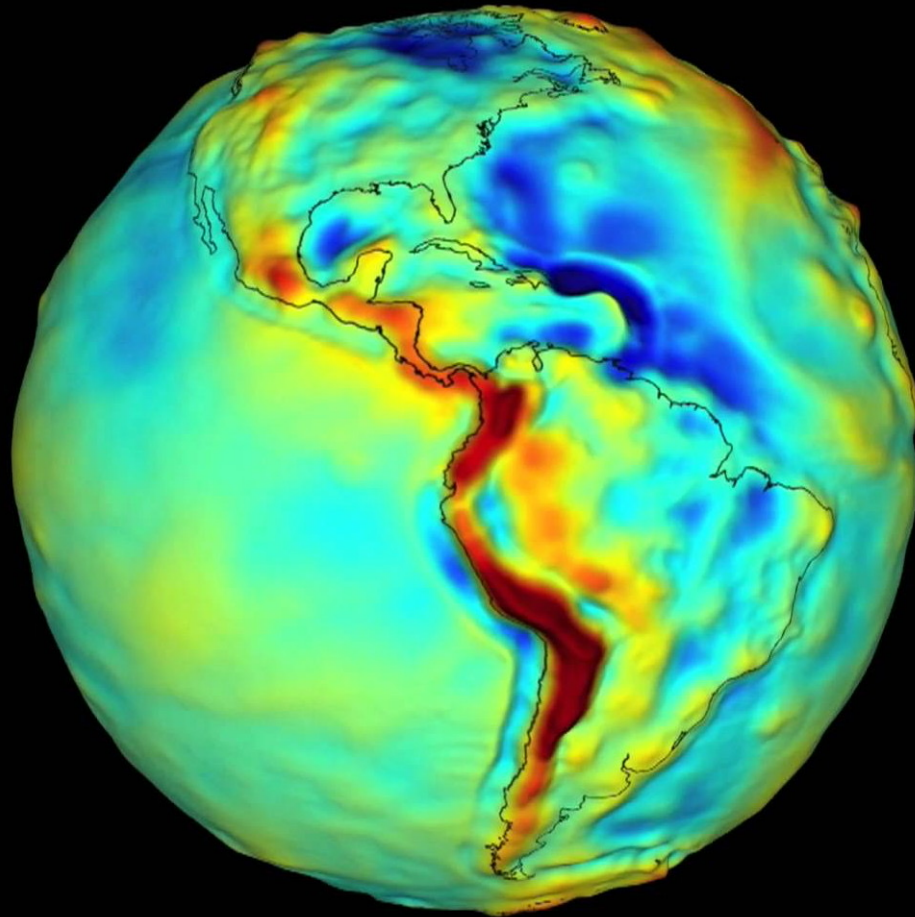


GRACE





A GRACE Gravity Solution





~2010
Generalized Gravity

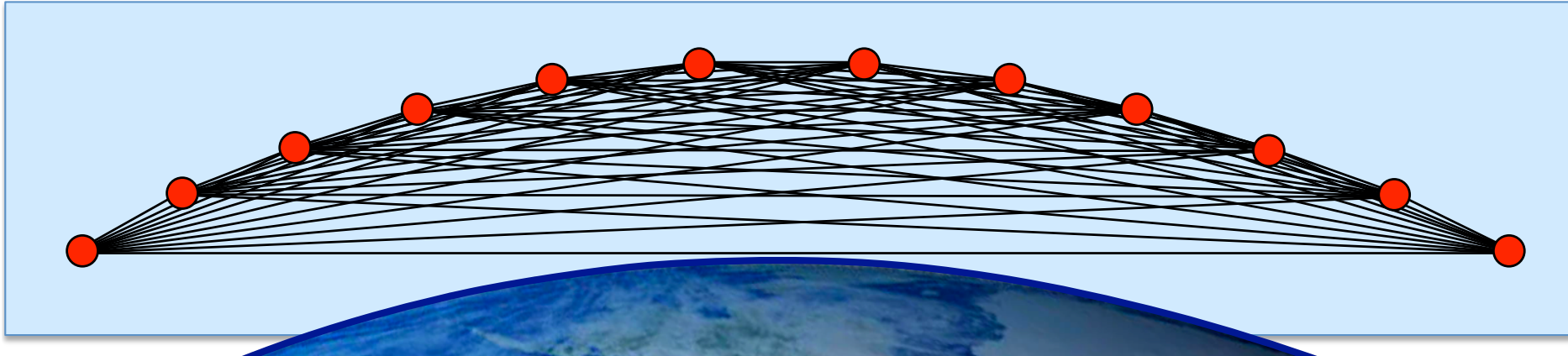


The EGO Concept



Multi-sat chain(s) exchanging mutual links

12 satellites \Rightarrow **66** dual-frequency links



Compare with GRACE-FO

- Improved single-link precision: **$\sim 4x$**
 - Many-link (root-n) noise averaging: **$3x-8x$**
 - Smaller attitude & thermal scale effects: **$> 3x$**
 - Physics-based isolation of the gravity signal
 - Broad gravity wavelength sensitivity, 2D obs
 - Potential for multiple orbit planes
 - Deep system redundancy
 - Permanent observatory
- } precision
- } systematics
- } observability
- } general

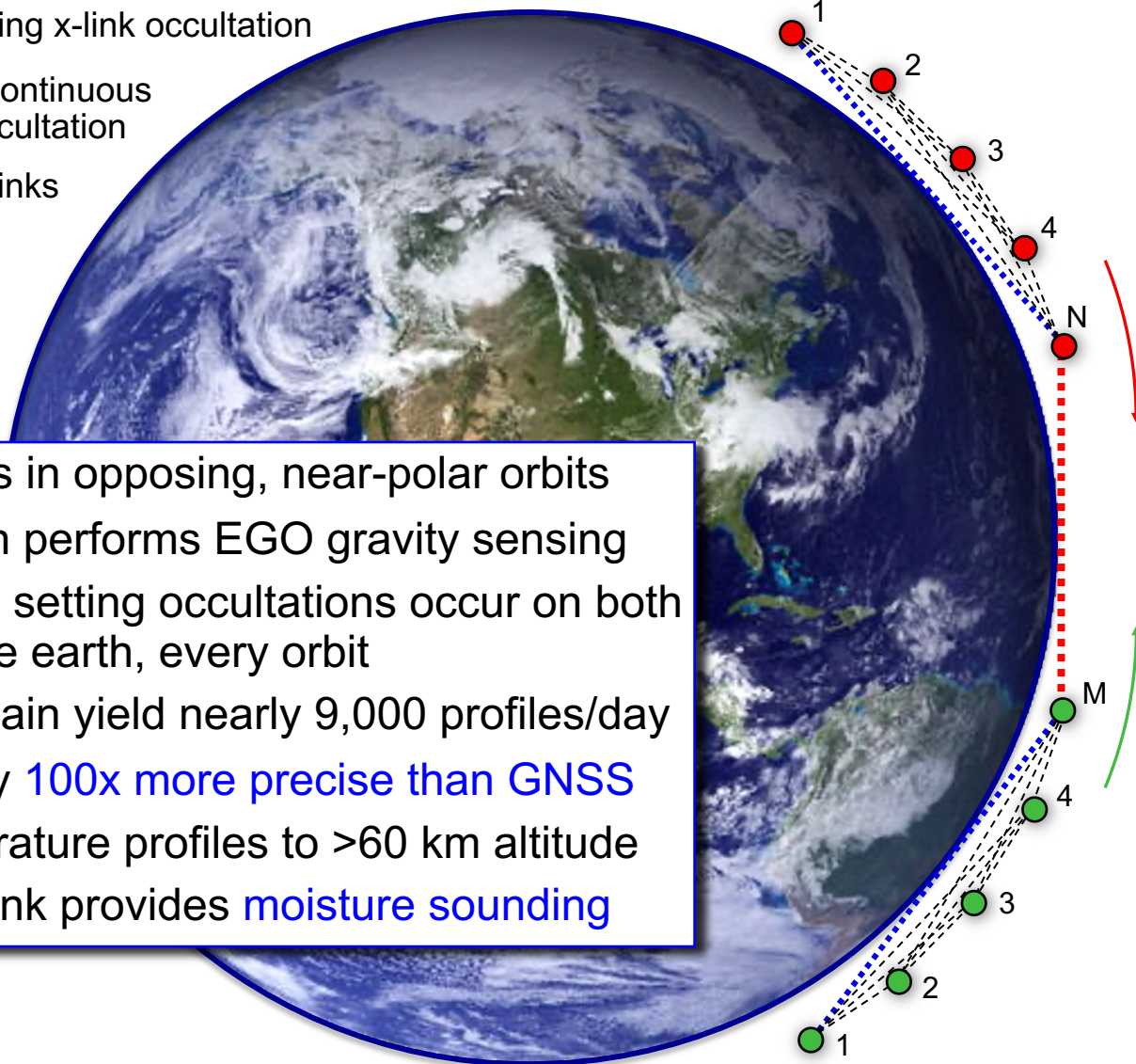


Twin-Arc Formation for XO



- Rising/setting x-link occultation
- Optional continuous x-link occultation
- Gravity x-links

- Two chains in opposing, near-polar orbits
- Each chain performs EGO gravity sensing
- Rising and setting occultations occur on both sides of the earth, every orbit
- 12 cells/chain yield nearly 9,000 profiles/day
- Refractivity **100x more precise than GNSS**
- RO temperature profiles to >60 km altitude
- ~22 GHz link provides **moisture sounding**





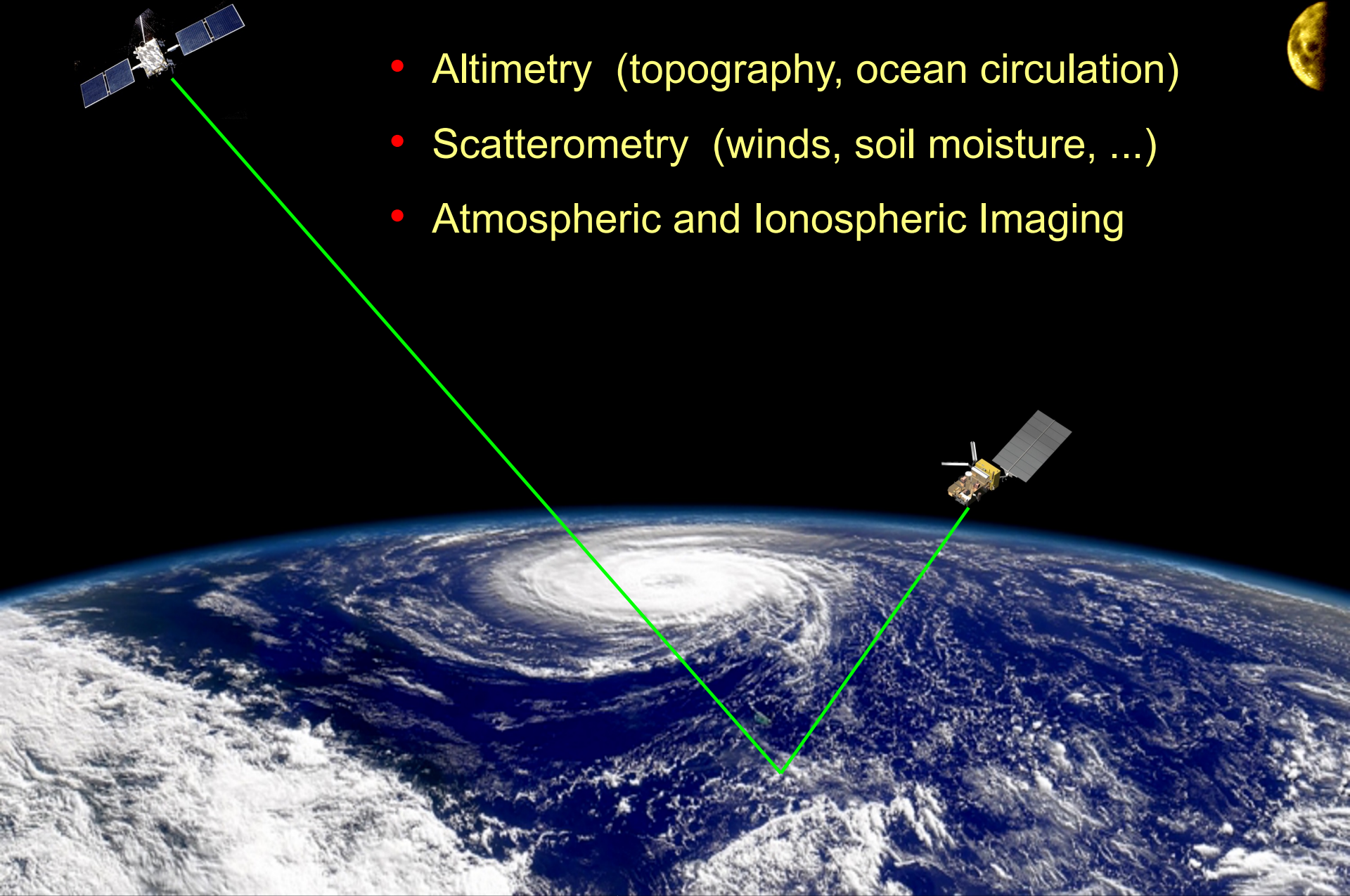
Add Reflections



GNSS Reflections



- Altimetry (topography, ocean circulation)
- Scatterometry (winds, soil moisture, ...)
- Atmospheric and Ionospheric Imaging





Add Radar

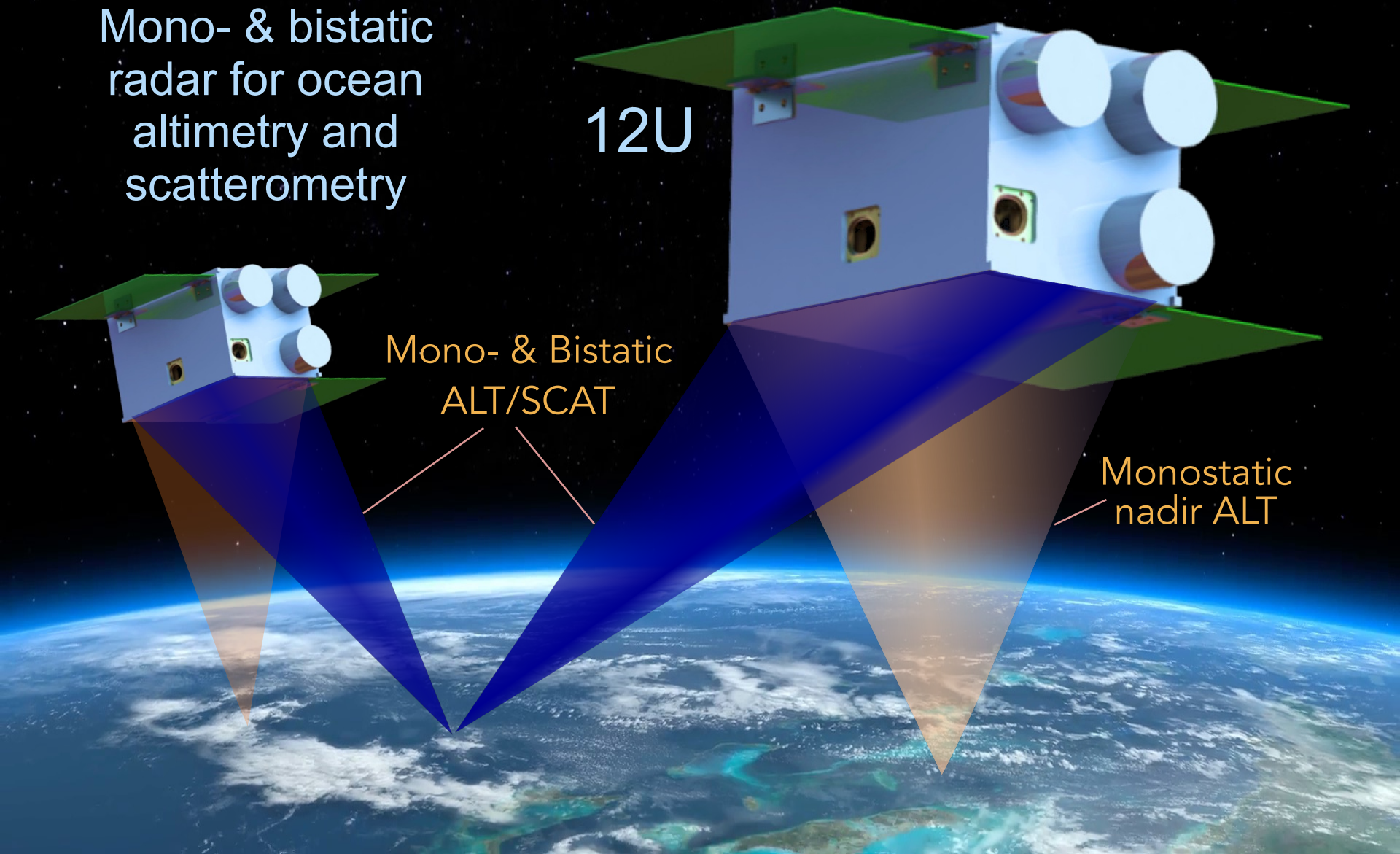


Mono- & bistatic
radar for ocean
altimetry and
scatterometry

12U

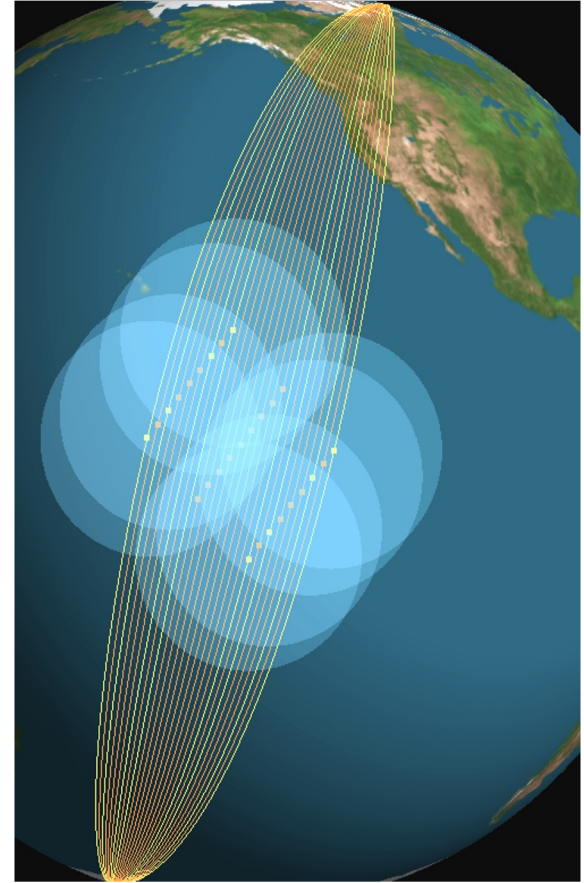
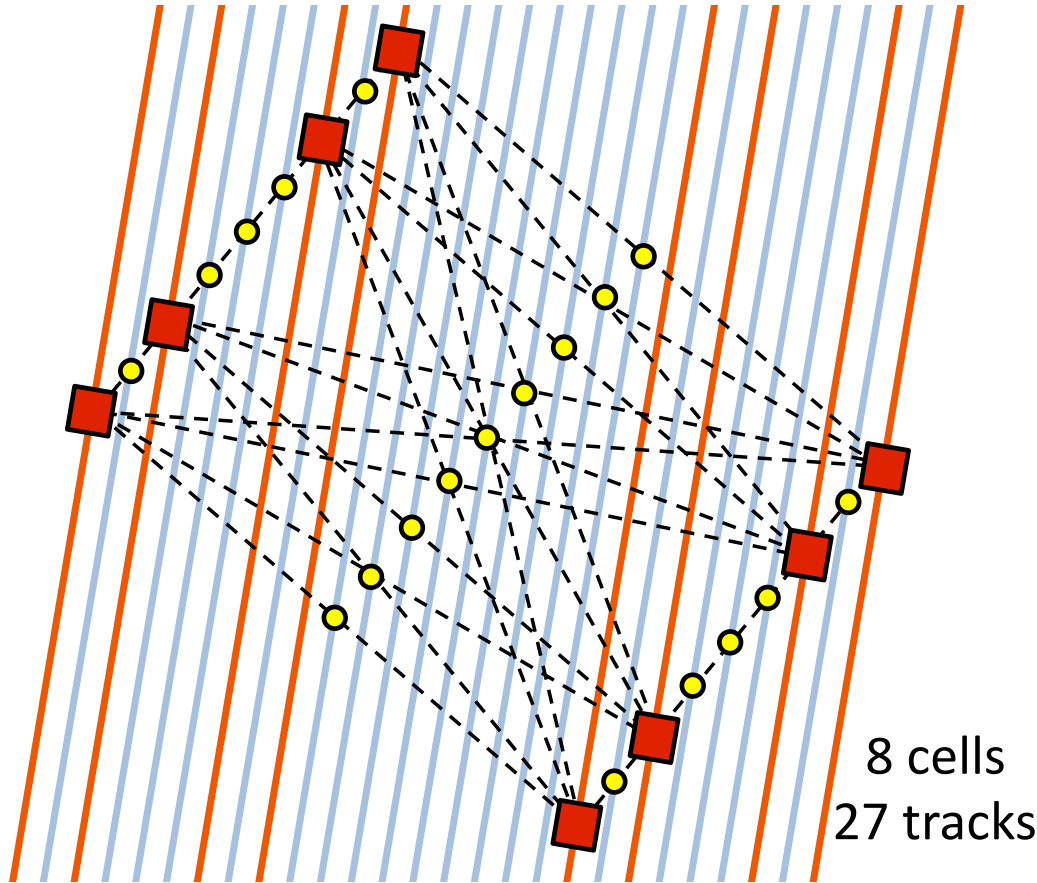
Mono- & Bistatic
ALT/SCAT

Monostatic
nadir ALT





Distributed Eight-Cell Array



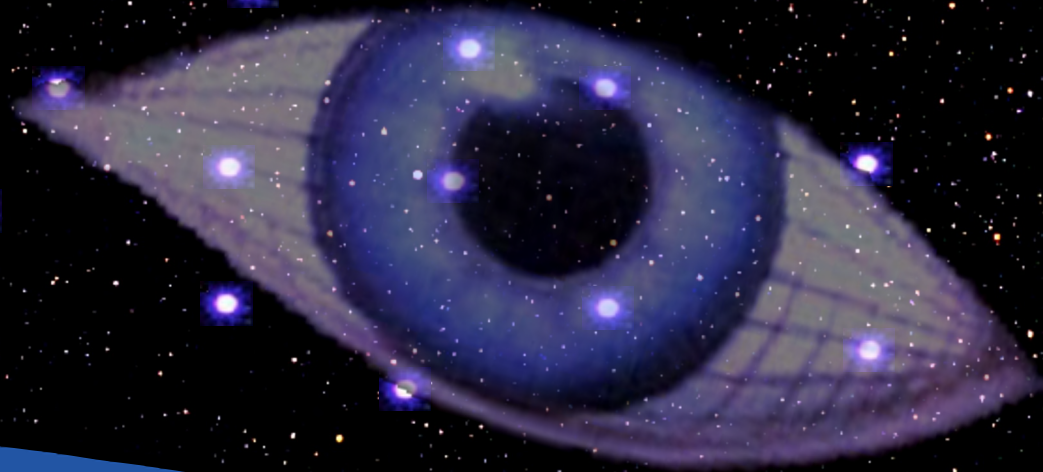
Super Altimetry • Super Scatterometry • Super Gravity



Imaging

Interferometry • Tomography • Holography

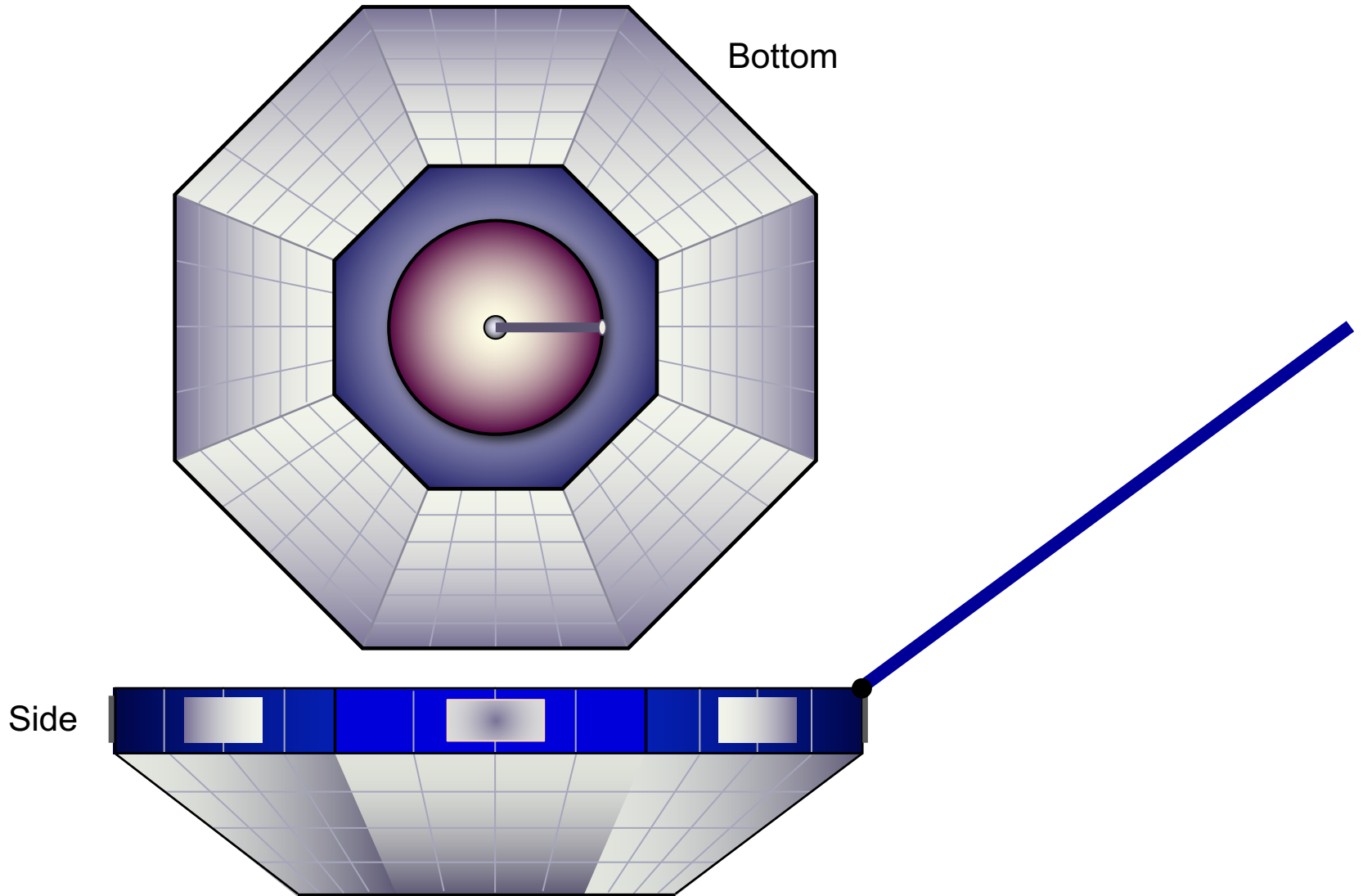
SAR & InSAR



POD Accuracy: ~1 cm
Wavelength: ~20 cm
Instantaneous phase alignment



Notional Spacecraft

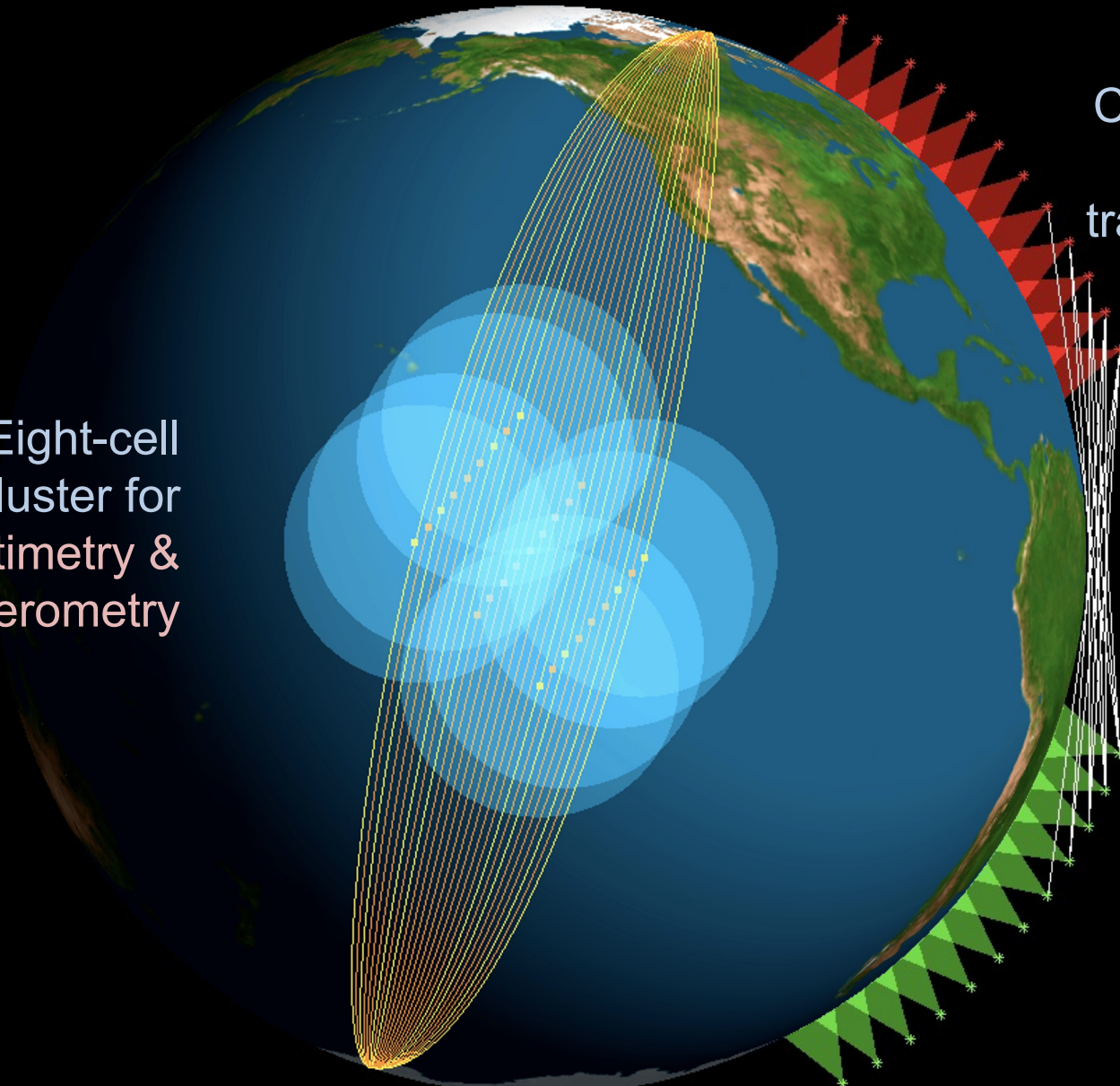




Broad Earth-Atmosphere Utility – *BEAUTY*



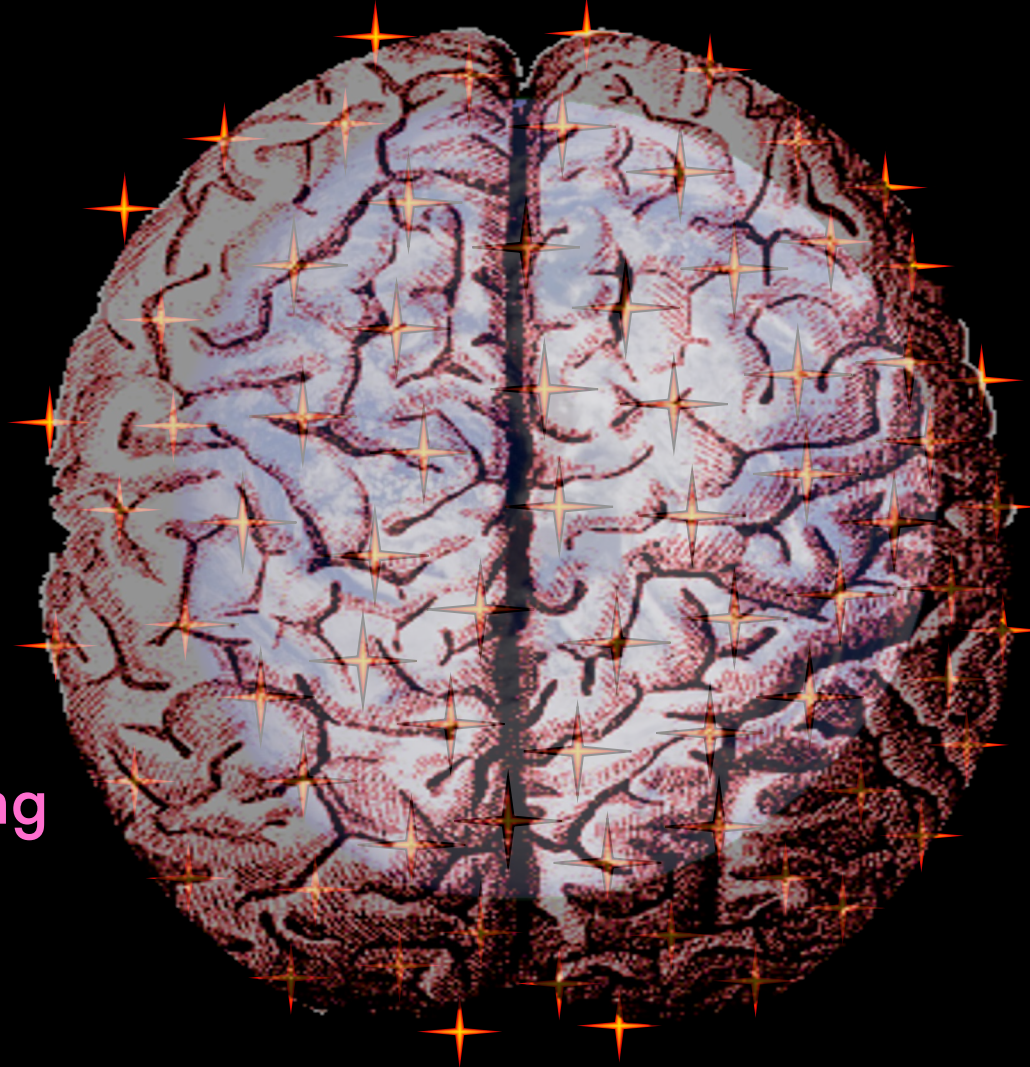
Eight-cell cluster for Altimetry & Scatterometry



Counter-orbiting crosslinking trains for Gravity Mapping & Crosslink Occultation



CORTEX



A Computing
Cloud