A Geosynchronous Synthetic Aperture Radar

for Tectonic Mapping, Disaster Management, Measurements of Vegetation and Soil Moisture

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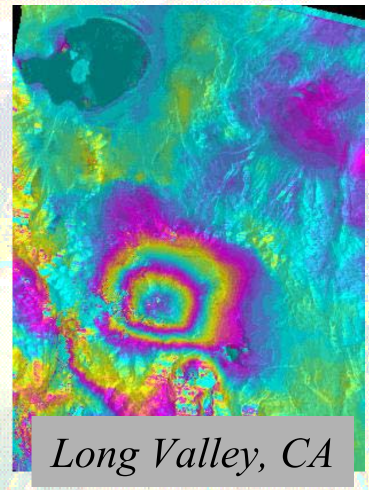
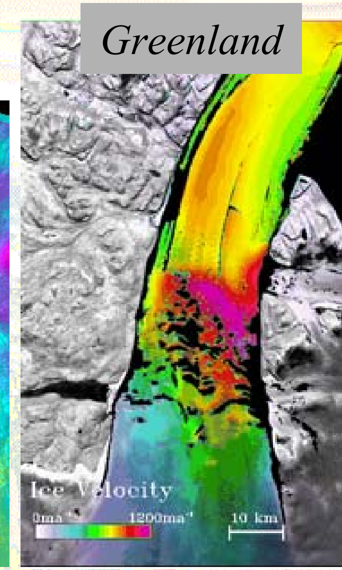
A Geosynchronous SAR Concept

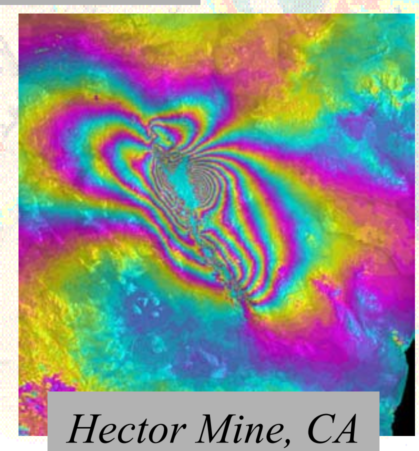
SAR Science & Applications

- Earth Dynamics
  - Interferometric SAR (InSAR) has demonstrated its ability to map displacements at the centimeter and sub-centimeter level.
  - InSAR has mapped co-, inter-, and post-seismic motion

- Key Future Requirements:
  - Fine temporal resolution, would allow dense spatial observations of transient phenomena with spatial density several orders of magnitude finer than complementary GPS time-series analysis
  - Improved accessibility, need to be able to get to any area where and when earthquakes happen to allow an unprecedented view of Earth dynamics
  - Future goals include mapping strain accumulation on pre-seismic stress, which will involve atmosphere (troposphere/ionosphere) mitigation and correction techniques





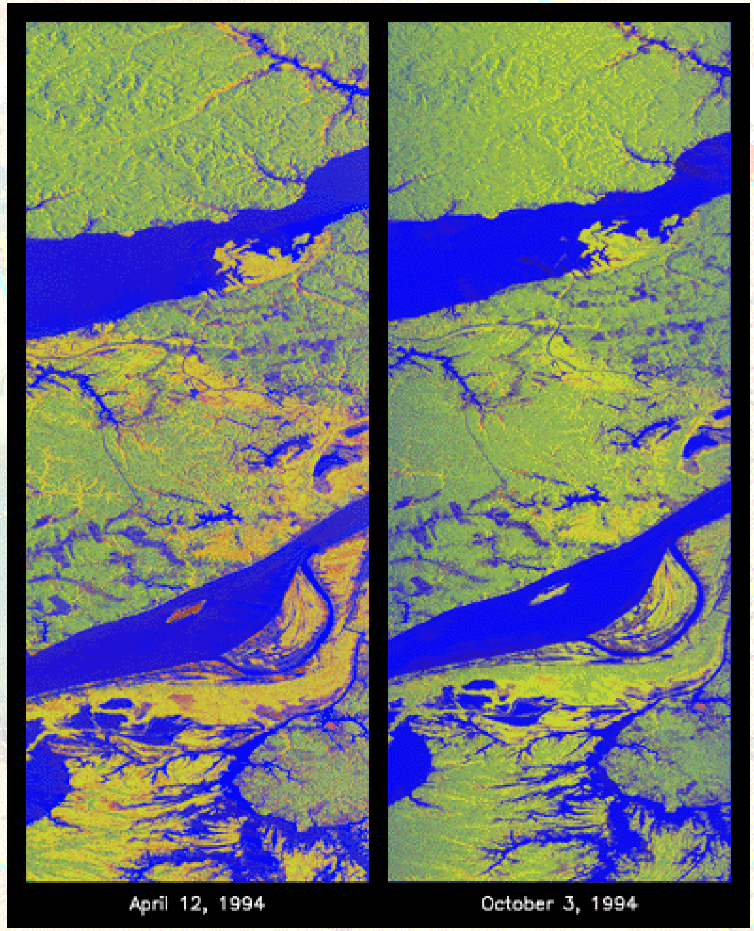


Raw ERS–1/2 data courtesy ESA

Disaster Management

- Imaging radar has mapped Earthquakes, volcanoes, mud slides, forest fires, and flooding
  - InSAR is particularly sensitive to land surface changes, generally detectable in interferometric correlation images
  - Operates even if continuous cloud cover hinders the observation with optical sensors
  - SAR is sensitive to standing water under dense vegetation
  - Pre- and post-disaster data can provide the extend and intensity of small and large scale surface changes.

- Key Future Requirements:
  - Timely data from extended target areas, allowing disasters to be observed as they develop



SIR–C data NASA/JPL

Vegetation Mapping & Soil Moisture

- Vegetation
  - Monitoring the conversion of vegetation cover due to human or natural disturbances and the dynamics of its recovery is one of the keys to understanding the global carbon cycle.
  - NRC report (1997) suggest L-band cross-pol. channel is most effective for measuring vegetation biomass regeneration or recovery
  - Crop classification using SAR polarimetry
- Soil Moisture
  - Active microwave sensors are considered the most promising sensors for estimating soil moisture on a global scale
- Key Future Requirements:
  - Vegetation: Frequent data acquisitions required over growing season
  - Soil moisture: Requires measurement very frequently, e.g. every 1-2 days.

Polarimetric C-band SAR image
Danish Center for Remote Sensing

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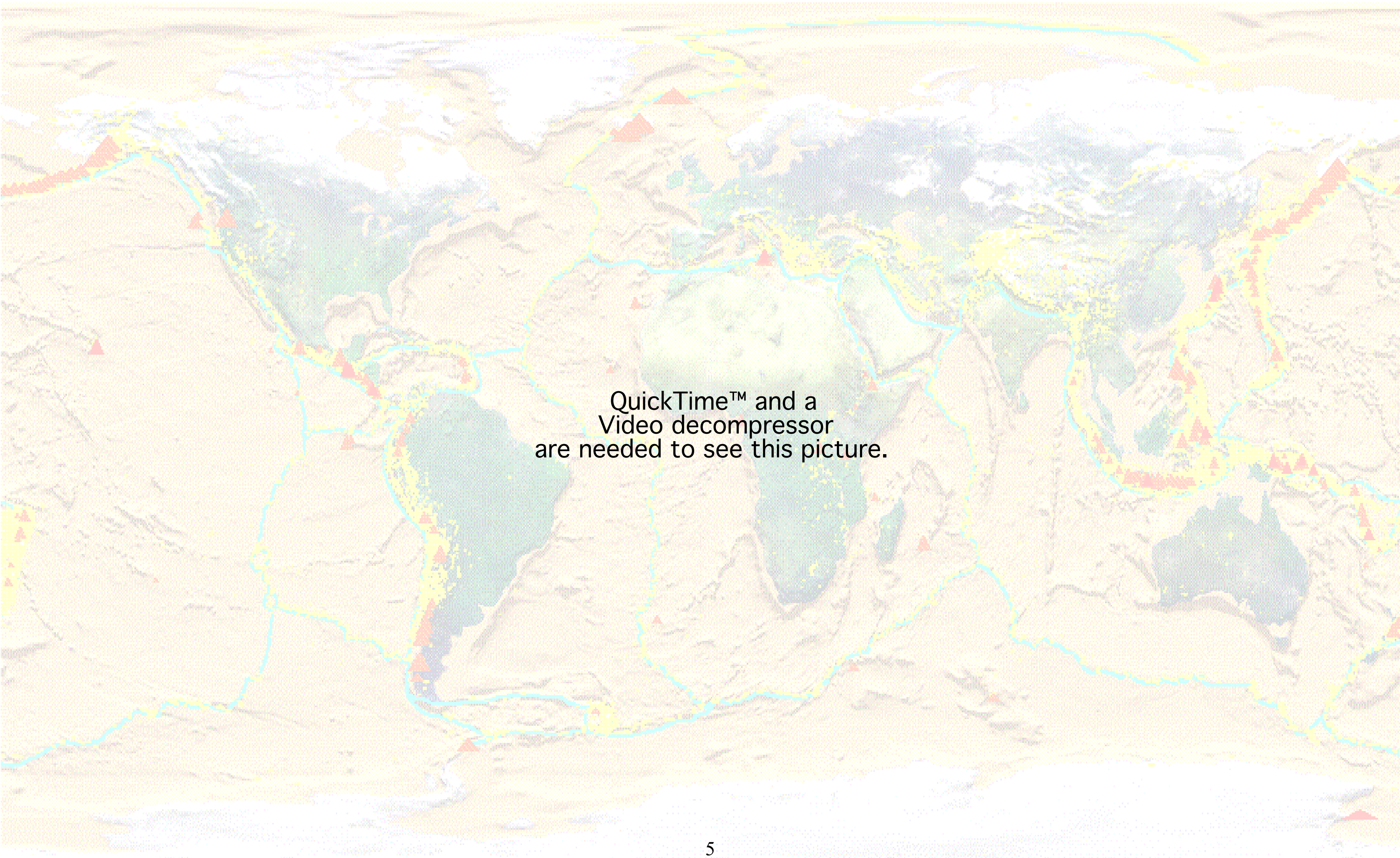
The Geosynchronous Viewpoint



Why a GeoSynchronous SAR?

- Accessibility
  - One geosynchronous SAR can provide daily coverage for approximately 1/3 of the globe
  - Most areas within the coverage region can be mapped from different view directions. A geosynchronous SAR can provide 3-dimensional displacement data on a daily basis
- Revisit Time
  - Disaster areas can be monitored for between 1 1/2 hours per day to 2 times 2 1/2 hours per day
  - Antenna beam can dwell on a selected area for extended periods of time
- Flexibility
  - A geosynchronous SAR can provide very high resolution for selected areas or it can provide daily moderate resolution data at multiple aspect angles covering its entire accessible area

Previous Work

- Tomiyasu K.:

  "Synthetic Aperture Radar in Geosynchronous Orbit," Dig. Int. IEEE Antennas and Propagation Symp., U. Maryland, 42–45, May 1978

  "Synthetic Aperture Radar Imaging from an Inclined Geosynchronous Orbit," IEEE Trans. Geosci. Remote Sens. GE-21(3), 324–328 (1983)

- Holt, B. & Hilland, J.

  "Rapid-Repeat SAR Imaging of the Ocean Surface: Are Daily Observations Possible?" Johns Hopkins APL Technical Dig., 21(1), 162–169, 2000

Orbit Stuff

- Simple geosynchronous orbit (e=0):

$$\vec{r}_{sat} = r_G \begin{pmatrix} 1+(\cos i - 1)\,\sin^2 \omega_G t \\ (\cos i - 1)\cos\omega_G t\,\sin\omega_G t \\ \sin i\,\sin\omega_G t \end{pmatrix}$$

$$\omega_G = 2\pi / T_s = 72.92 \cdot 10^{-6} \qquad r_G = \sqrt[3]{GM_E / \omega_G^2} = 42164\ \text{km}$$

Velocity:

$$\vec{v}_{sat} = \omega_G\, r_G \begin{pmatrix} (\cos i - 1)\,2\sin\omega_G t \\ (\cos i - 1)\,2\cos\omega_G t \\ \sin i\,\cos\omega_G t \end{pmatrix}$$

At an inclination of 50° the velocity varies from 2600 m/sec at the Equator to 1100 m/sec at the most northern point. The nadir point velocity correspondingly varies between 393 m/sec and 166 m/sec

GeoSync SAR Overview (1)

- Antenna Size?
  - Ambiguity limit

    Doppler sampling:

$$f_{\mathrm{PRF}} \geq 2\frac{v}{L} \quad \Leftrightarrow \quad T_{\mathrm{PRF}} \leq \frac{L}{2v}$$

    Range ambiguities:

$$\frac{cT_{\mathrm{PRF}}}{2} \geq \rho \frac{\lambda}{H} \tan\theta$$

  - Antenna size:

$$A_{\mathrm{ant}} \geq 4\rho\lambda \tan\theta \frac{v}{c}$$

    Geostationary orbit, v=2600 m/sec, mapping out to 50° incidence angle (with 2x margin):

    A=720 m^2 => D=30 m

GeoSync SAR Overview (2)

- How much power does it take?

$$P_r = \frac{P_t G_{\text{ant}}}{4\pi\rho^2}\sigma^0 \frac{cT_p}{2\sin\theta}\frac{\lambda\rho}{D_{\text{ant}}}\frac{1}{4\pi\rho^2}A_{\text{ant}}\frac{1}{L_{\text{loss}}} = \frac{P_t A_{\text{ant}}^2}{8\pi\rho^3}\frac{cT_p}{\sin\theta}\frac{1}{\lambda D_{\text{ant}}}\frac{1}{L_{\text{loss}}}\sigma^0$$

$$P_n = kTB$$

  - Assume: 20 kW DC-power, 15kW of L-band RF-power @ 20% duty cycle, 200 Hz design PRF => transmitted pulse-length 1 msec, NF=3 dB, loss 3 dB, range to 50° incidence angle, σ^0 =–20 dB(m^2/m^2), SNR=10dB

$$P_r = \frac{15kW\left(\frac{\pi}{4}30m^2\right)^2}{8\pi(37785\text{ km})^3}\frac{3\cdot10^8 m/\sec 10^{-3}\sec}{\sin 50°}\frac{1}{0.24m\ 30m}\frac{1}{2}0.01m^2 = 1.5\cdot10^{-12}W = -118dBW$$

$$P_n = kTB = kNTB = 1.38\cdot10^{-23}W\sec/K\cdot2\cdot290K\cdot B = 0.1\cdot1.5\cdot10^{-12}W$$

$$\Leftrightarrow$$

$$B = 18.8\ MHz$$

$$\Leftrightarrow$$

$$\Delta g = \frac{c}{2B\sin\theta} = 10m$$

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Resolution

- Range resolution:

$$\Delta g(\theta = 50°, B = 20MHz) = \frac{c}{2B\sin\theta} = 10m$$

$$\Delta g(\theta = 10°, B = 80MHz) = \frac{c}{2B\sin\theta} = 11m$$

- Azimuth resolution?

$$\Delta x = \frac{L}{2}\frac{R_e}{R_e + h} = \frac{30}{2}\frac{6.4}{42} = 2.3\text{m}$$

- Observation time?

$$L_s = \frac{\lambda\rho}{L}\frac{R_e + h}{R_e} = \frac{0.25\cdot 38\cdot 10^6\cdot 42\cdot 10^6}{30\cdot 6.4\cdot 10^6} = 2\cdot 10^6 m$$

$$T_s = \frac{L_s}{v} = \frac{2\cdot 10^6\text{m}}{1100\text{m}/\text{sec}} = 1800\,\text{sec} = 30\,\text{min}$$

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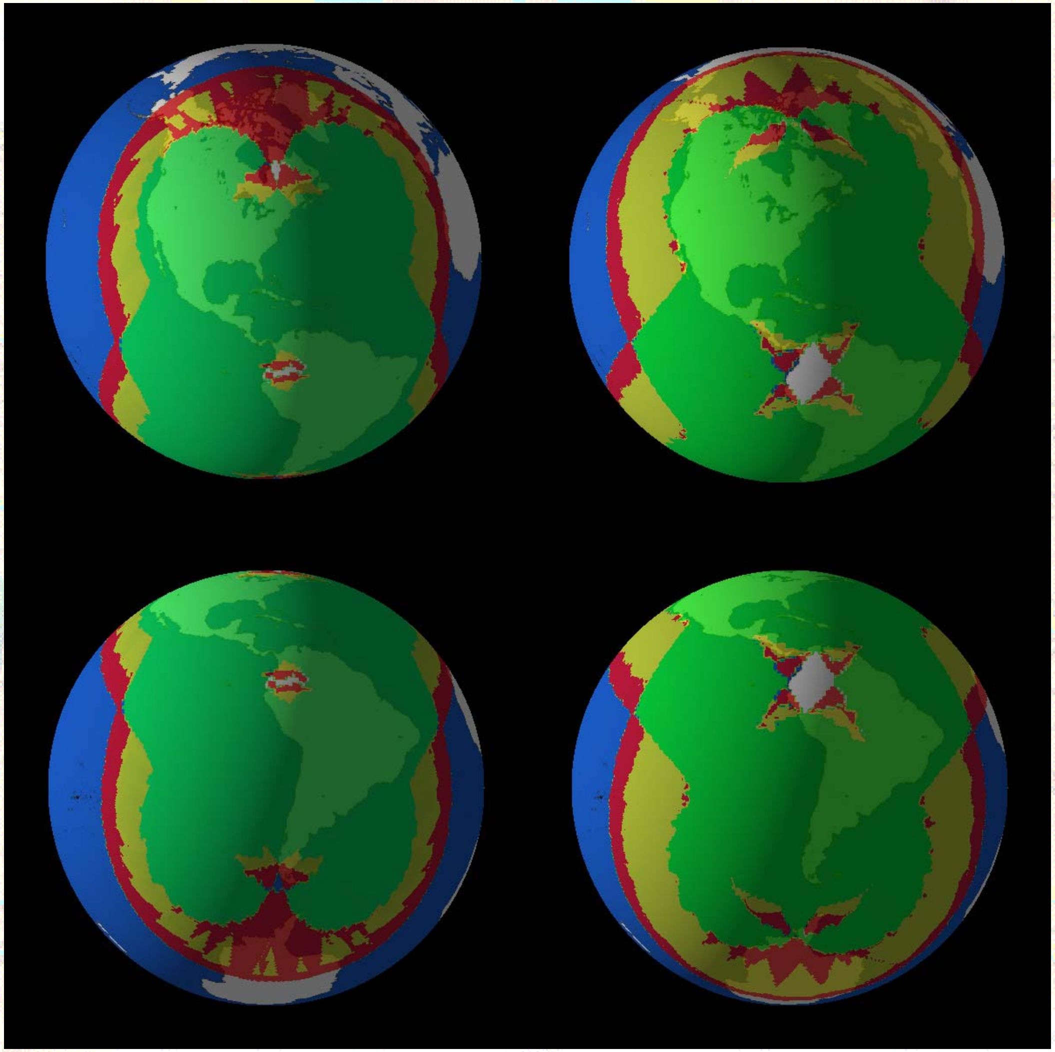
Coverage

- Range 1000–5000 km
  (requires ±7° of beam steering, basically cross-track)

- Squint ±60°
  (requires ±7° of beam steering, basically along-track)



Coverage map for geosynchronous satellite, 50° inclination. Green indicates dayly 3-d mapping, yellow 2-d, red 1-d mapping

Modes

- **Modes:**
  - Standard resolution 600 km strip mapping mode providing one swath per day. This mode would support a 10 m resolution with multiple looks (4–5), and suited for high resolution mapping
  - Scan-SAR mode supporting coverage of 4000 km swaths on either side of the nadir track, at 50 m resolution (4–5 looks). This mode would provide daily continental coverage
  - A scan-SAR mode which would support three aspect angles (45° forward, broadside, 45° backwards) of 2800/4000/2800 km swaths on both sides of the nadir track to provide 3–d displacement mapping of extended areas in a single day. This mode would be very useful for tectonic studies
  - Spotlight SAR mode where the beam is locked on a single target area for extended periods of time. This mode would be suitable for disaster management
  - High resolution stepped frequency mode. Step the instantaneous bandwidth (e.g. limited to 18 MHz because of SNR limitations and data rate) from day to day within an 80 MHz band. Stagger such sub-bands coherently. In the far range an 80 MHz bandwidth provides single look imagery with 2.5 m ground range resolution and 2 m azimuth resolution. In the very near range the ground range resolution would be 3–4 times worse
- **Data rates and volumes:**
  - Data rate 150 Mbits per 20 MHz channel (oversampled 25%)

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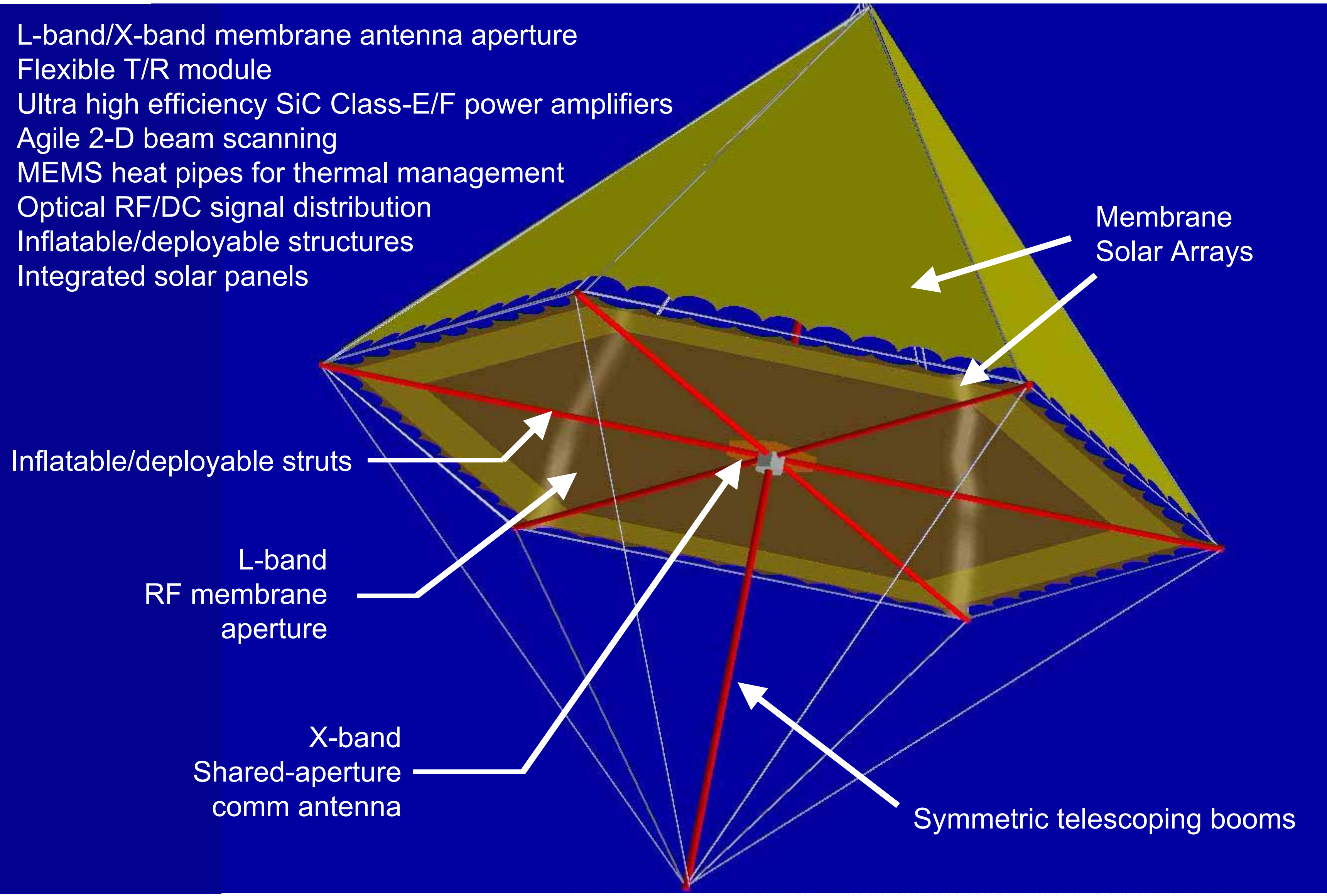
Flexible Hexagonal Antenna

- L-band/X-band membrane antenna aperture
- Flexible T/R module
- Ultra high efficiency SiC Class-E/F power amplifiers
- Agile 2-D beam scanning
- MEMS heat pipes for thermal management
- Optical RF/DC signal distribution
- Inflatable/deployable structures
- Integrated solar panels



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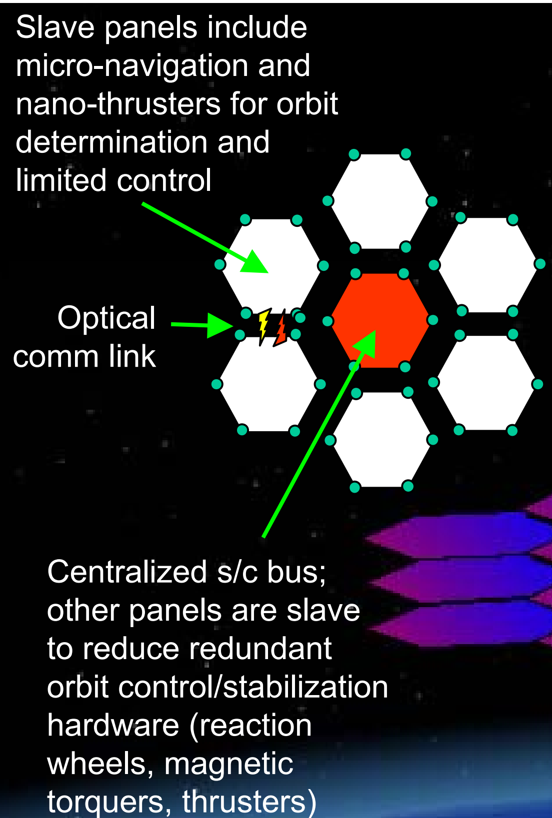
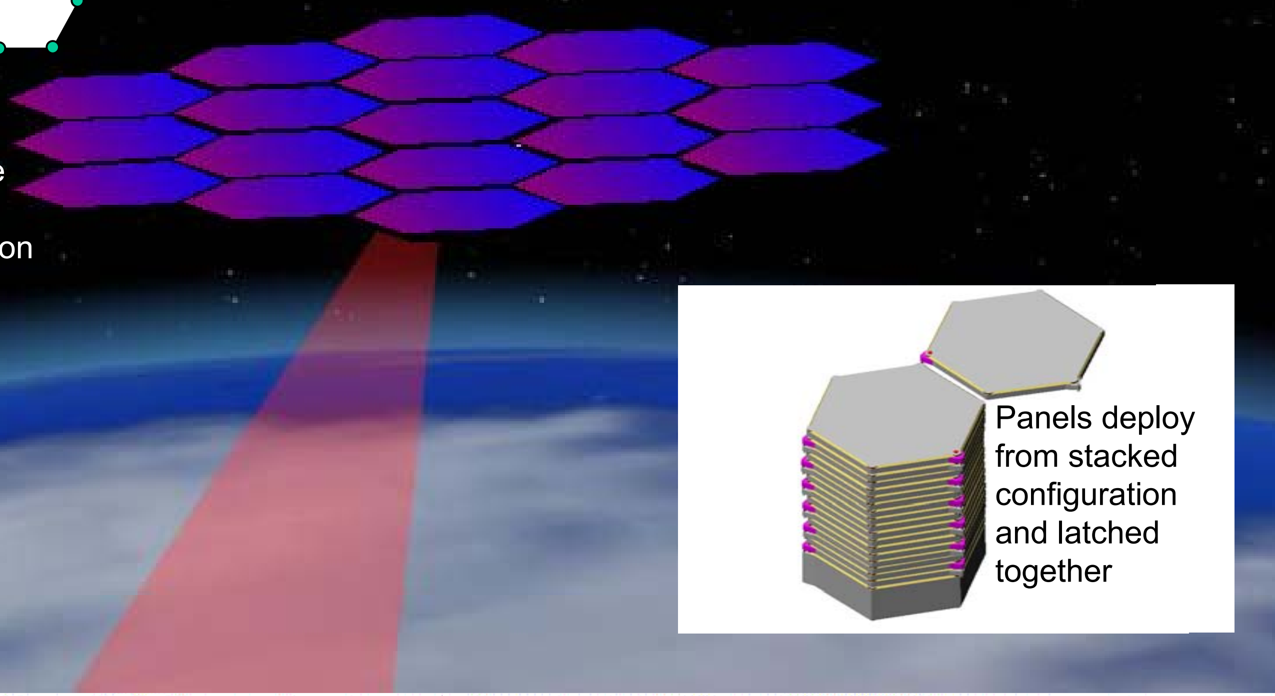
Autonomous Reconfigurable Antenna

- Autonomous panels operate as stand-alone radar and spacecraft
- Reconfigurable panels for in-space assembly of very large aperture antennas
- Enables a variety of array configurations; panels can be added using multiple launches
- Thin hexagonal panels have high packaging efficiency





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System Design

- Hardware evolution:

Mass Estimate	5 years	10 years	20 years
Antenna	2700 kg (3 kg/m^2)	1800 kg (2 kg/m^2)	900 kg (1 kg/m^2)
Support electronics	200 kg	50 kg	25 kg
Solar panels	200 kg	Shared with antenna	Shared with antenna
Platform (30% of PL)	870 kg	560 kg	230 kg
Total Mass	**3970 kg**	**2410 kg**	**1155 kg**

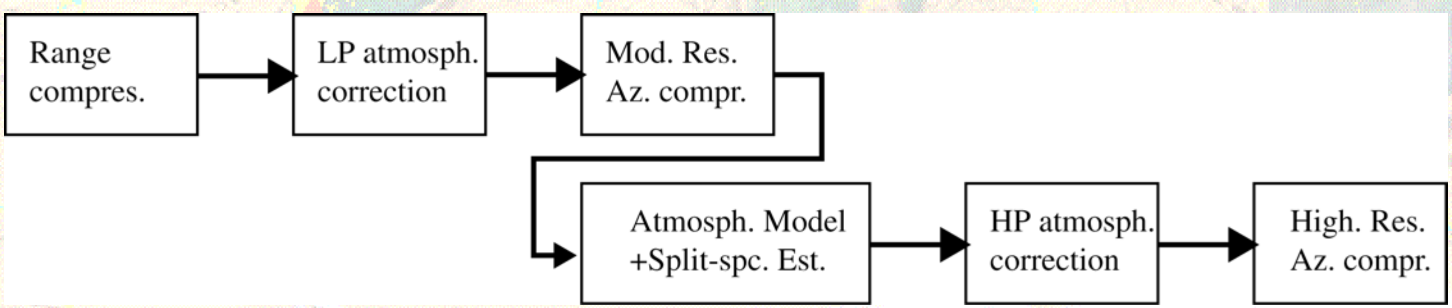
Power Estimate	5 years	10 years	20 years
RF Power (peak/avg)	**15 KW / 3 KW**	**35 KW / 7 KW**	**65 KW / 13 KW**
Radar Overall Power Efficiency	20%	40%	70%
Radar DC Power	15 KW	17 KW	19 KW
Spacecraft DC Power	5 KW	2 KW	1 KW
Total Power	20 KW	19 KW	20 KW

Technology	5 years	10 years	20 years
	Flexible Hexagon Antenna	Flexible Hexagon Antenna	Reconfigurable Antenna
	Mechanically deployable structure	Inflatable/ridigizable structure	Inflatable/ridigizable structure
	Rigid Si Class-C T/R	Flex Si Class-E T/R	Flex SiC Class-E/F T/R
	Conventional RF/DC manifold	Optical RF/DC manifold	Optical RF/DC manifold
		Integrated solar array and X-band comm	Integrated solar array and optical comm
			Nano-spacecraft & micro-thrusters for autonomous control

Data Processing

- Extremely long processing apertures and aperture times
- Horizontal antenna curvature is varying rapidly mandating frequent reference function updates invalidating standard batch processing techniques
- Atmospheric corrections/mitigation is required to accommodate temporal and spatial perturbations over long aperture
- Multistage processing concept likely required

QuickTime™ and a
Video decompressor
are needed to see this picture.



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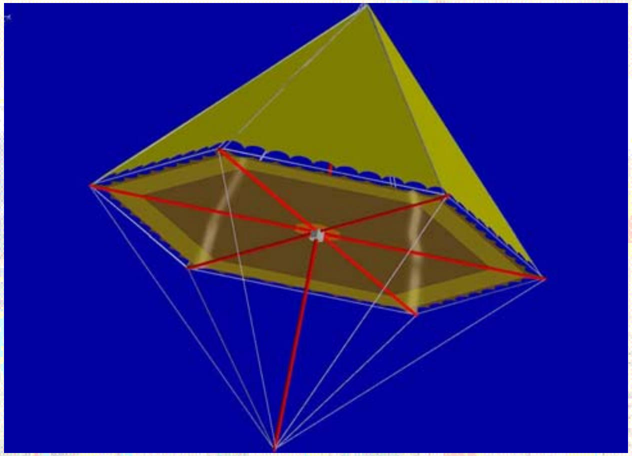
Outlook



- Technically feasible within 10 years
- Significant challenges
  - Antenna design & technology
  - Data processing scheme
  - Correcting for atmospheric perturbations
  - Reduce cost!!!
- Scientific benefits
  - Unique coverage, including 3-D displacement measurements
  - Daily acquisitions, will support time critical applications
  - Very large flexibility from very large coverage moderate resolution, to high resolution imaging with moderate coverage
- Disaster management
  - Unique capabilities when timeliness, robustness to weather, and accessibility are critical!