# The DiskSat: A Two-Dimensional Containerized Satellite

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# *CubeSats and the Small-Satellite Revolution*

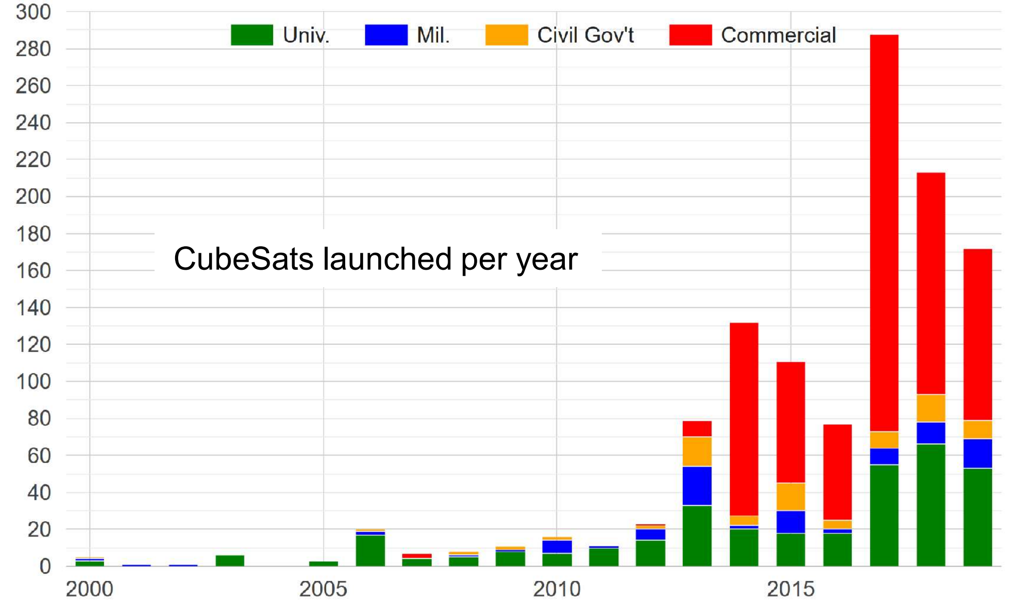
*The power of "containerization"*

Containerization of terrestrial shipping

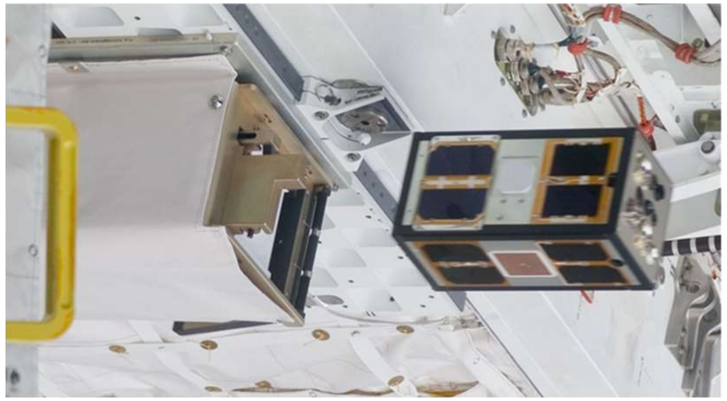
Images courtesy U.S. DOT

- CubeSats revolutionized the small satellite industry through containerization, just as containerization revolutionized terrestrial shipping
  - *Containerization simplifies the interface and protects the host, enabling inexpensive rideshare*
  - *In 20 years, over 1100 CubeSats have been launched worldwide*
  - *CubeSats have flown on at least 20 different launch vehicle types*
- CubeSats are rigidly constrained by the volume of the container
  - Limits on power and aperture, even with complex deployables

Containerization → Reduced launch risk and simplified interface → Inexpensive rideshare → Frequent and flexible launch → Commercial expansion → Mass production




Data from M. Swartwout



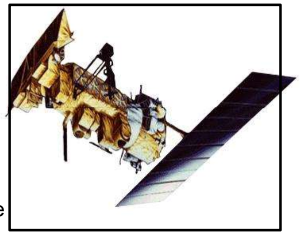
PSSCT-2 leaving dispenser on STS-135

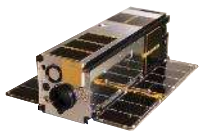
Image courtesy NASA

***How to get the benefits of containerization without the limitations of CubeSats?***

# *Need to Think Beyond Scaling Satellite Size to Realize Future Space Enterprise*

NOAA Image





?

| Tech Features for Future Space | Traditional HVA | Micro-/Nano-satellites | ? |
|---|---|---|---|
| Lots of aperture | Large apertures → high gain → high throughput | Small size limits aperture, deployable apertures have limited history of success | ***We need an architecture that has large aperture and high power but that can be mass manufactured at low cost and packaged for mass deployment*** |
| Frequency agility | Multiple frequencies, phenomenologies possible on large platform | Power-limited, cannot easily carry articulating apertures (e.g., optical comm nodes) | |
| Orbital versatility | Bus designed to operate in one orbital environment | Bus designed to operate in one orbital environment | |
| Maneuverability | Higher thrust being introduced | Few COTS options, low ΔV | |
| Mass production | Bespoke manufacture | Mass manufacture demonstrated by industry | |
| Efficient LV packing | High mass, volume → ~1 per launch | Can deploy tens at a time from one launch vehicle | |
| Low cost per unit | *O*($1B) per unit | *O*($1M) per unit | |

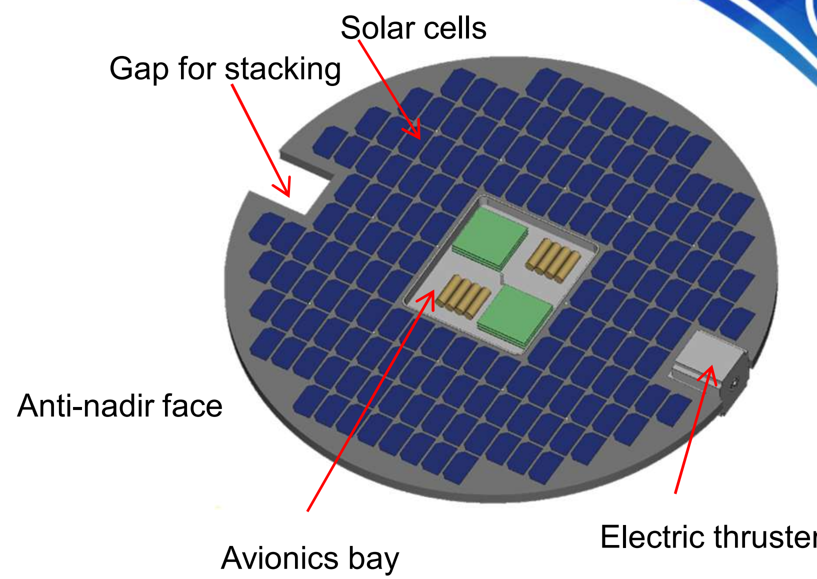
By just scaling traditional bus (rectangular prism), aperture goes as $r^2$ and mass (cost!) goes as $r^3$

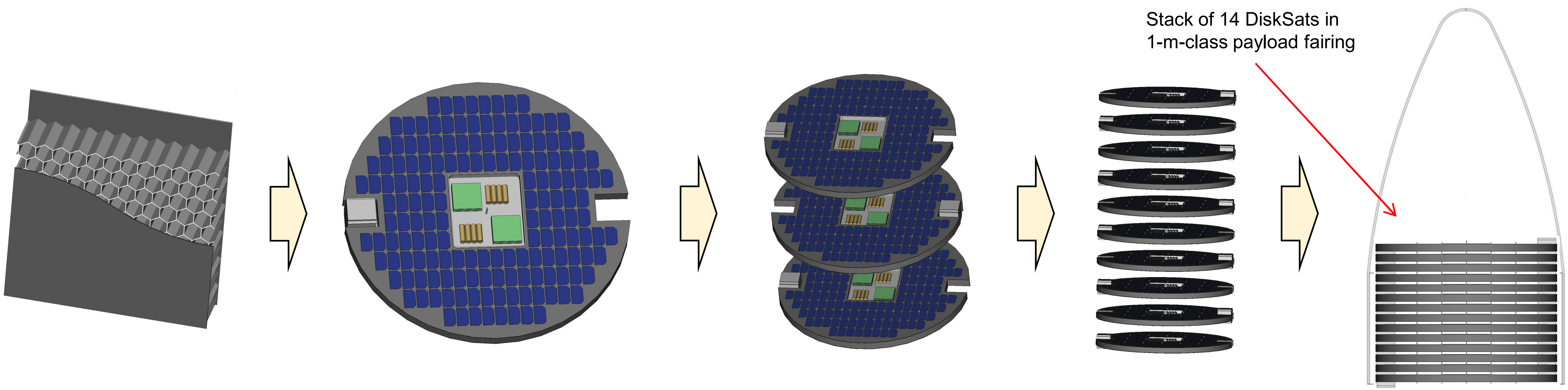
**New paradigm: think two-dimensional → aperture goes as $r^2$ and mass (cost) goes as $r^2$**

# *Out-of-the-(CubeSat)-Box*

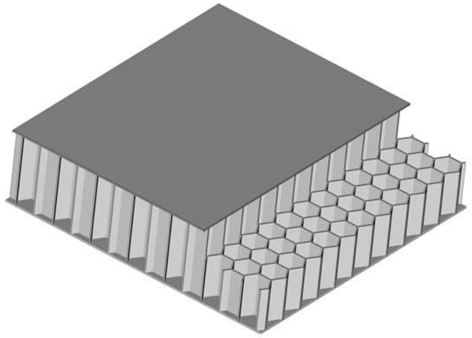
## *DiskSat – Containerization in an Alternate Form*

- Efficient shape: thin disk 1 meter diameter, 2.5 cm thick
  - *Large surface area for power and aperture* ***without deployables***
  - ***Volume equal to ~20U CubeSat***
- Stackable for containerization
  - *Sized to stack in 1-m-class payload fairing*
- Simple construction
  - *Structure based on composite sandwich*
  - *Satellite components distributed throughout internal volume, or in a central avionics bay*

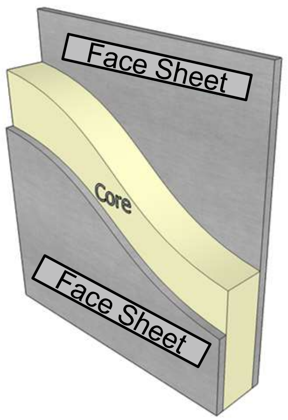


# *DiskSat Mass Budget*



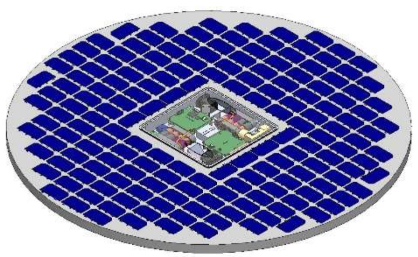
Aluminum honeycomb core



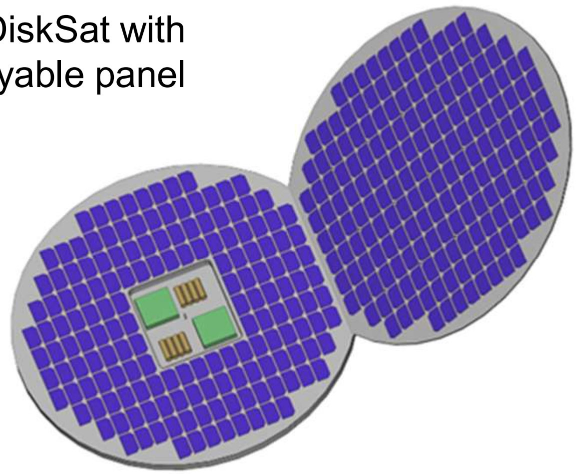

Foam core

- Disk structure - honeycomb-core graphite-epoxy sandwich
  - Choose thickness per mission need
  - Structural mass of 1-m-diameter DiskSat: 2.2 kg for 2.5 cm thickness, 3.2 kg for 5 cm thickness
  - Increasing diameter increases mass in proportion to area
  - Foam core may provide lower mass, but may lead to high thermal gradients across thickness
- Satellite bus
  - *Avionics mass ~1 kg (based on AeroCube)*
  - *Solar cell and battery mass depends on power requirements; ~2-3 kg*
  - *Optional deployable panel (for extra power) adds ~2 kg*

DiskSat without deployable panel

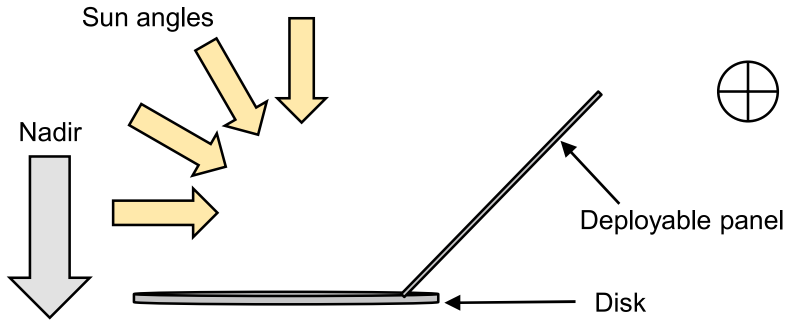


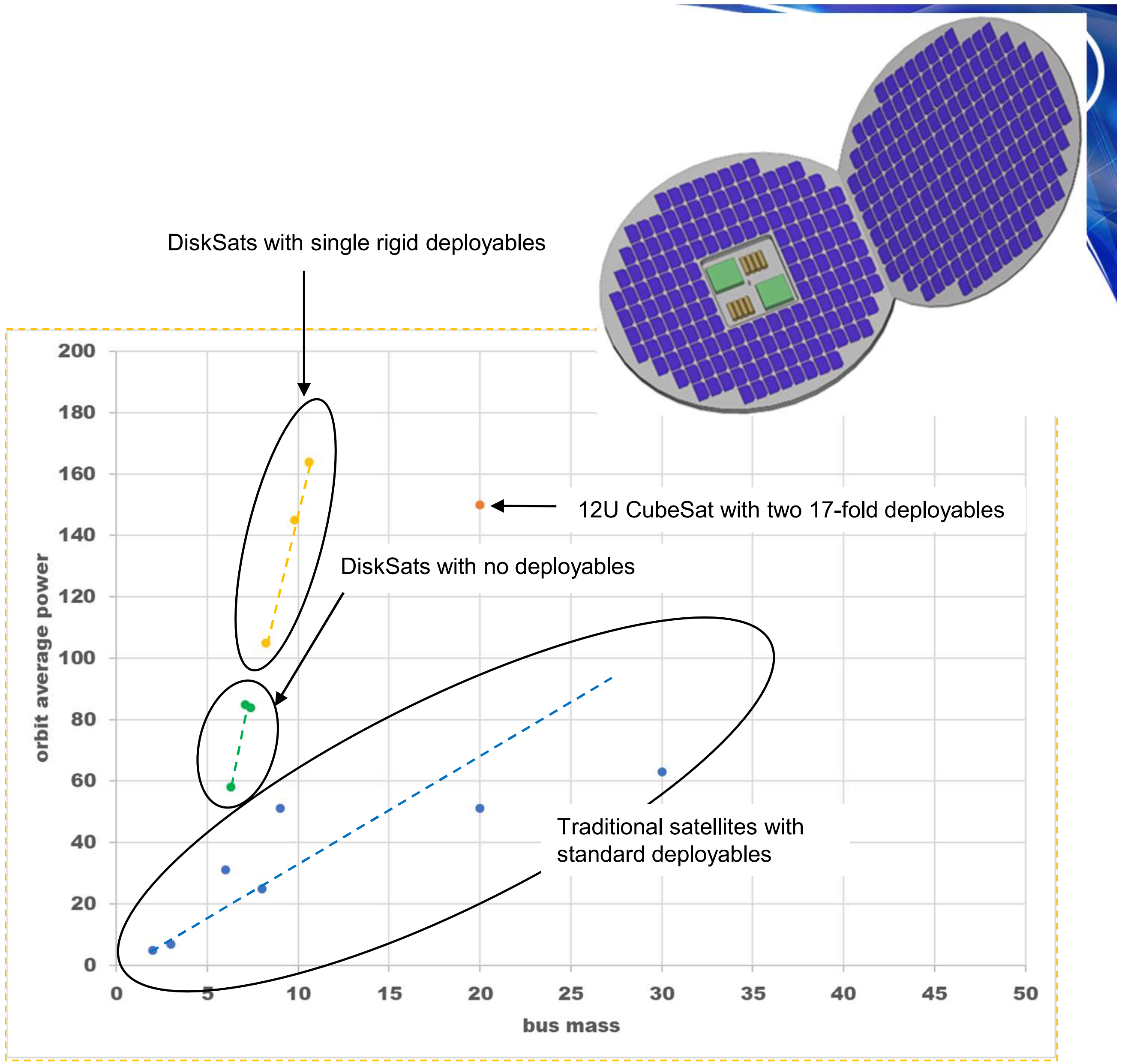
DiskSat with deployable panel



# DiskSat Power Budget

- DiskSat achieves high power-to-mass ratio without complex deployable solar panels
  - *1 m diameter has surface area of 0.79 m$^2$ and can hold 200 W of solar cells*
  - *1.2 m diameter increases surface area and peak input power to 290 W*
- Optional deployed panel
  - *A simple rigid solar panel deployed on a single-hinge doubles surface area for little mass penalty*
  - *At ~30 degrees, the deployed panel ensures steady orbit average power independent of solar beta angle*
  - *A 1.2 m DiskSat with a single deployable panel can produce over 160 W orbit average power with a bus mass ~10 kg*
- Traditional satellite buses below 50 kg cannot produce 150 W orbit average without complex multi-fold deployables and mass at least 20 kg



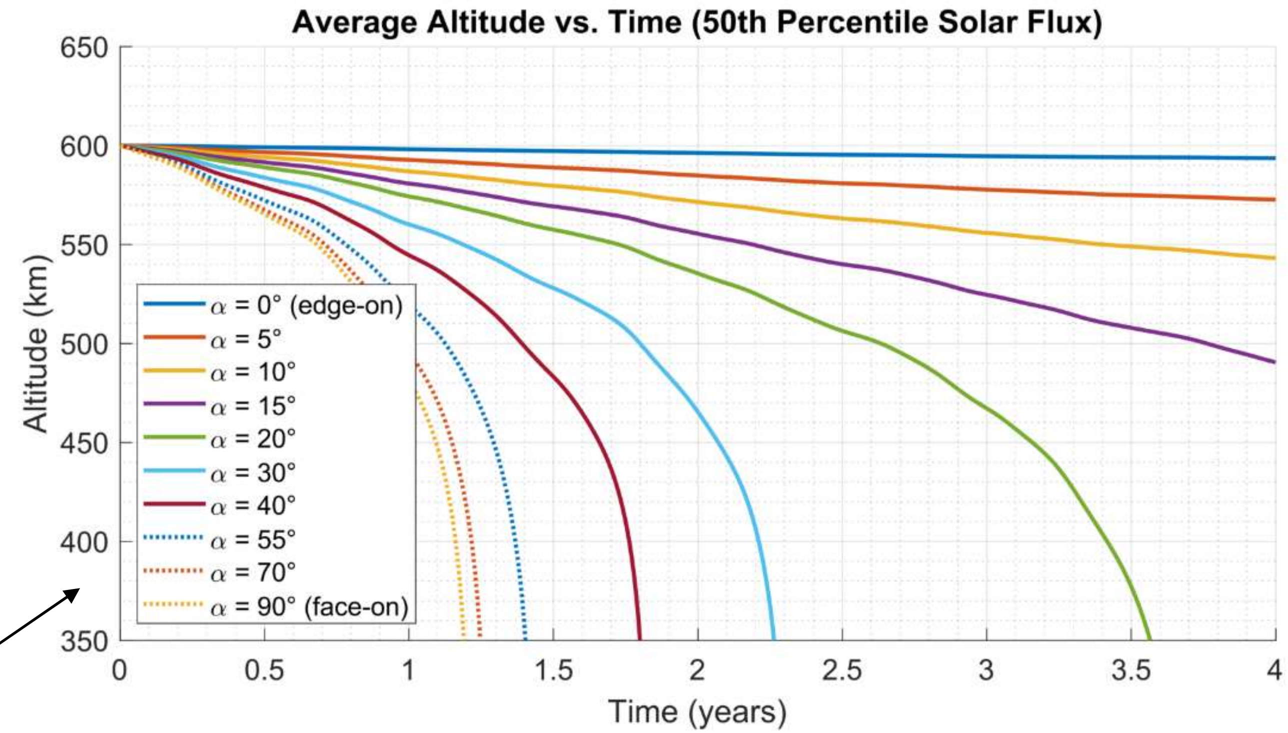

Typical orbit-average power available from various satellite bus designs assuming comparable LEO orbits

# *Orbit Raising, Orbit Maintenance, Maneuverability*

*DiskSat has unparalleled "orbit agility" when coupled with electric propulsion*

- Commercially-available flight-proven EP systems can provide as much as 5000 m/s delta-v for a 10-kg DiskSat
- DiskSat has a uniquely advantageous power/mass ratio without the complexity of deployables

- Applications
  - *Orbit raising*
    - Initial deployment at lower altitude increases launch payload mass
  - *Orbit maintenance*
    - Less than 10 m/s/year delta-v at 600 km orbit altitude
    - 800 m/s/year delta-v enables sustained flight at 200 km orbit altitude
  - *Rapid rephasing of constellations*
  - *De-orbit at end of life*
  - *Cis-Lunar space*
    - <4000 m/s delta-v required for transfer from GEO to lunar orbit
    - Other orbits in cis-Lunar space reachable with comparable delta-v

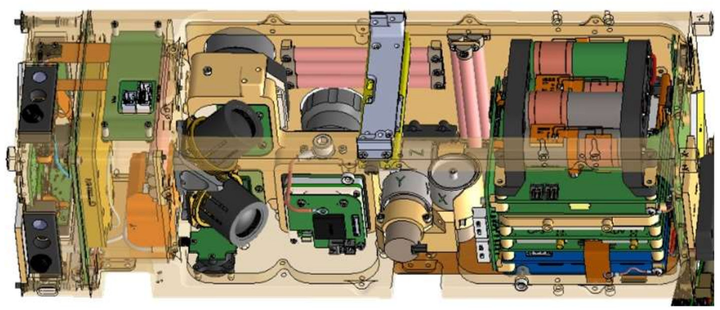



Deorbit with propulsion or enhanced drag

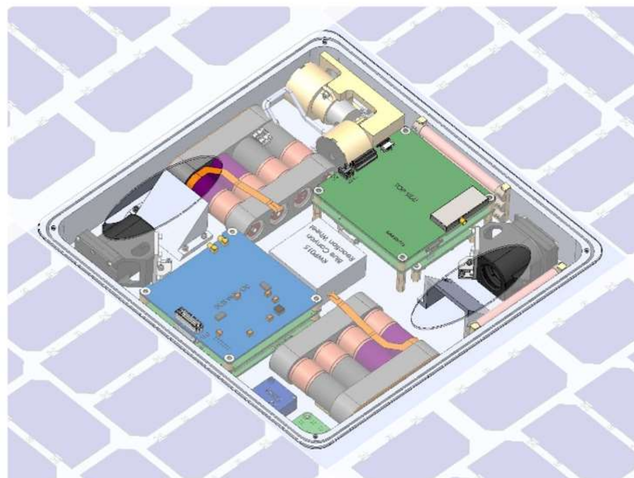
# *Volume Budget and Manufacturability*

*DiskSat Compared to a CubeSat*

- DiskSats are mass limited, but have large volumes
  - a 5 cm thick x 1-m diameter DiskSat has a volume 13x that of 3U CubeSat
- Extended layout and increased volume lower unit cost compared to a CubeSat
  - *Simplifies mechanical structures*
  - *Eliminates complex harness routing*
  - *Simplifies post-assembly functional testing and component R&R*
  - *Increased surface area simplifies thermal management*

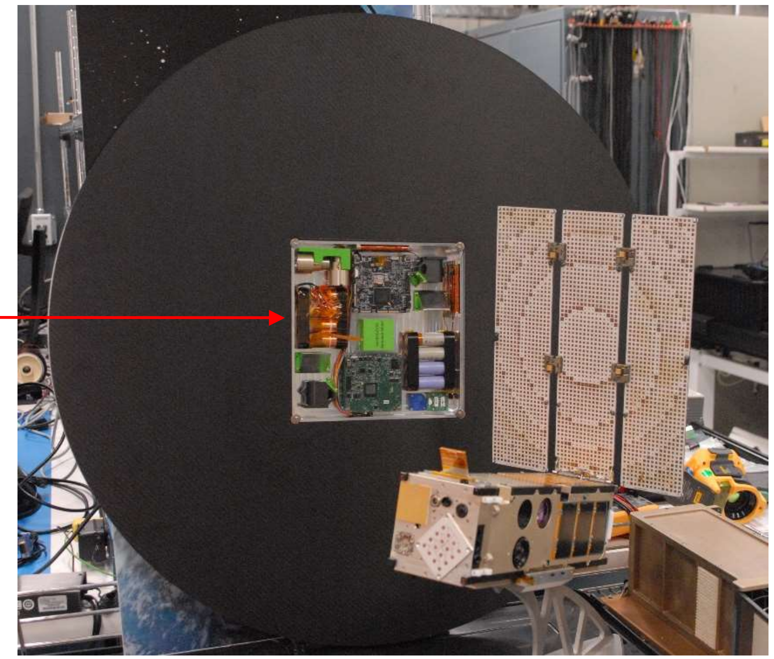


**Interior layout of ISARA 3U CubeSat (2017)**



**ISARA avionics notionally reconfigured into a DiskSat "chassis box"**

**The ISARA 3U CubeSat (with deployed antenna) next to a notional 3U-equivalent DiskSat**

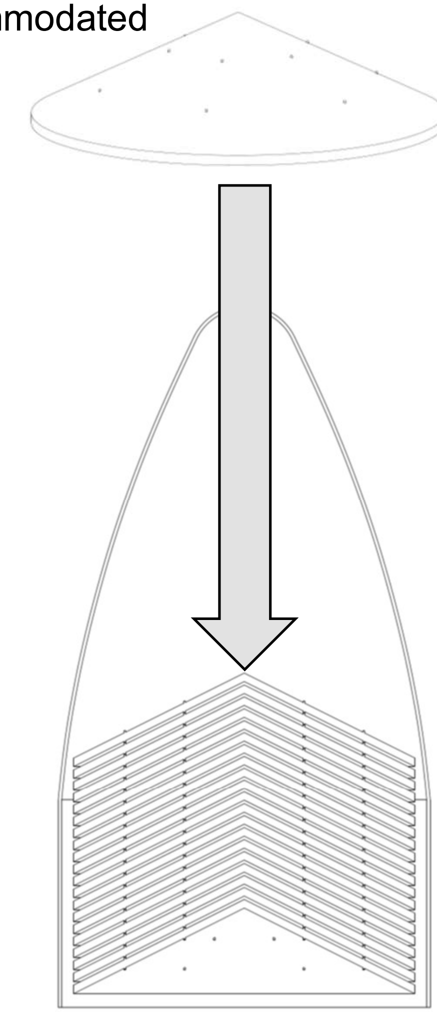


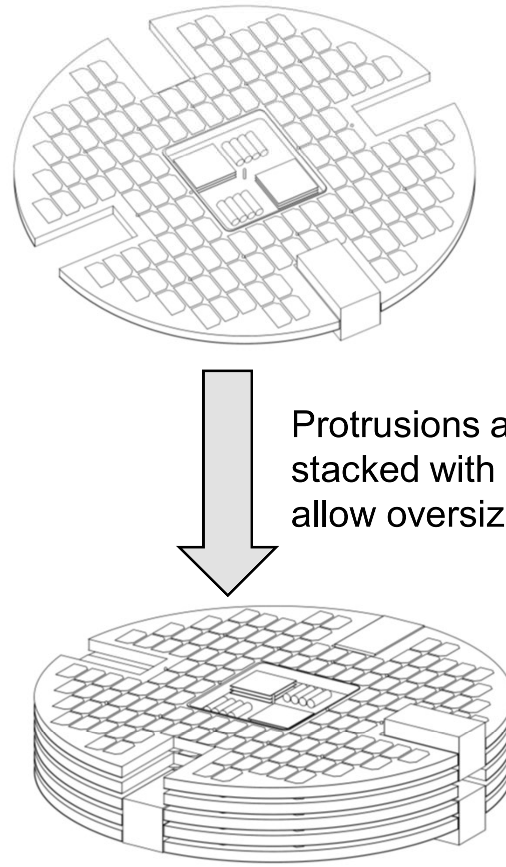
***The DiskSat is an efficient approach to building and deploying constellations of very small satellites***

# *Stackability*

- Stacking satellite-to-satellite is an efficient use of launch volume
- Non-circular and non-flat shapes can also be stacked
- Components thicker than the nominal DiskSat thickness can protrude
- Corresponding cutouts in adjacent DiskSats accommodate any protrusions
- Disk thickness not strictly limited

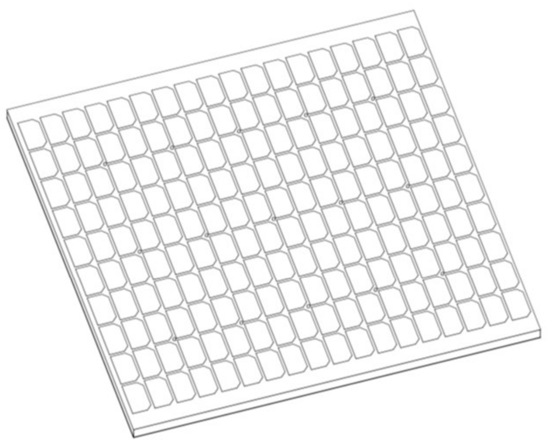
Non-flat stackable shapes can be accommodated





Protrusions and cutouts, stacked with clocking, to allow oversize components

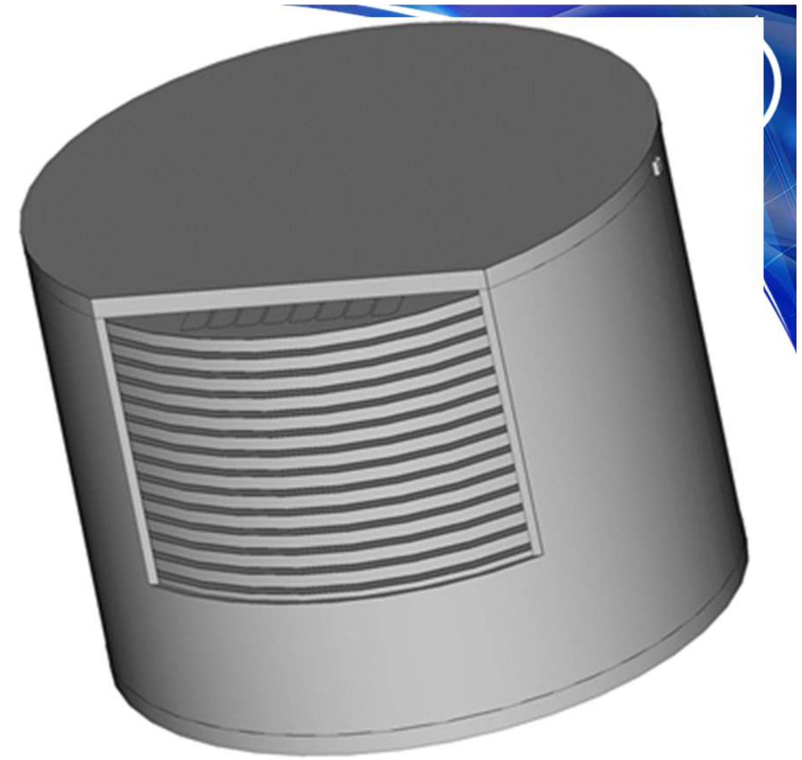
Non-circular shapes (ESPA port envelope)



# ***DiskSat Dispenser***

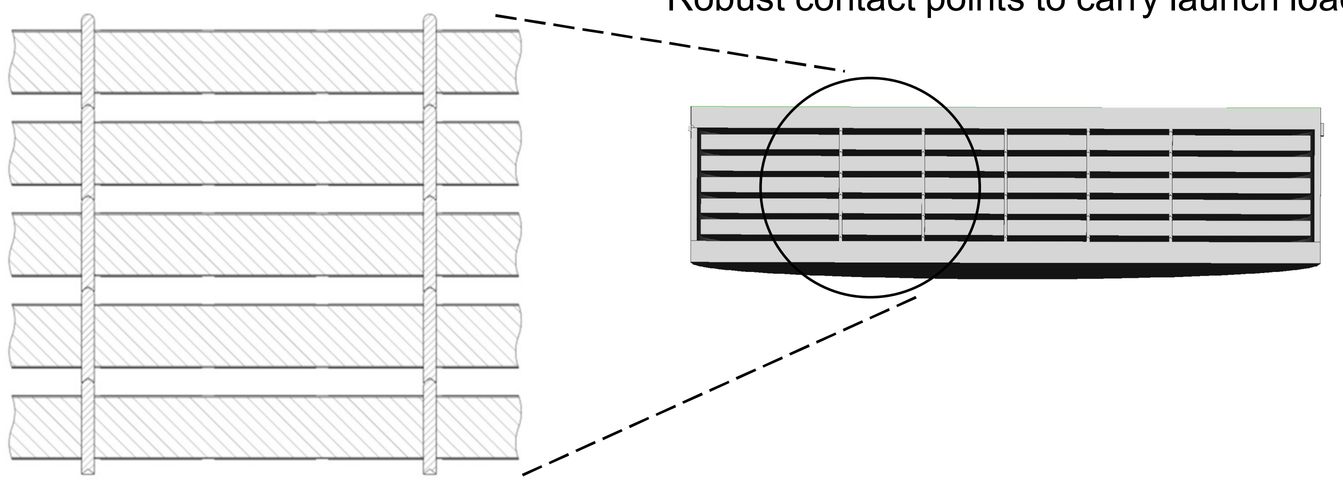
*Launch loads and satellite ejector*

- Requirements
  - *Support satellites against launch loads*
  - *Containment to protect primary*
  - *Eject satellites one at a time after launch*
    - Simultaneous release as used in CubeSats could be problematic with large stacks of disks
- Approach
  - *Separate launch loads from the ejection process*
  - *Transfer launch loads through disk stack directly to cannister*
  - *Dispenser mechanism is loosely coupled to disks during launch and does not carry launch loads*
  - *Single mechanism to lift stack and deploy top disk one at a time*

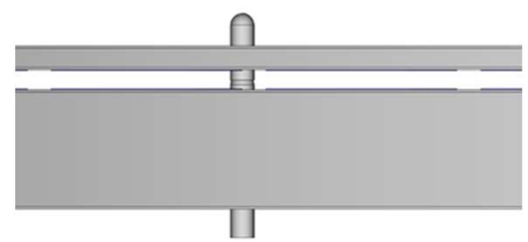


Launch container (cutaway)

Robust contact points to carry launch loads



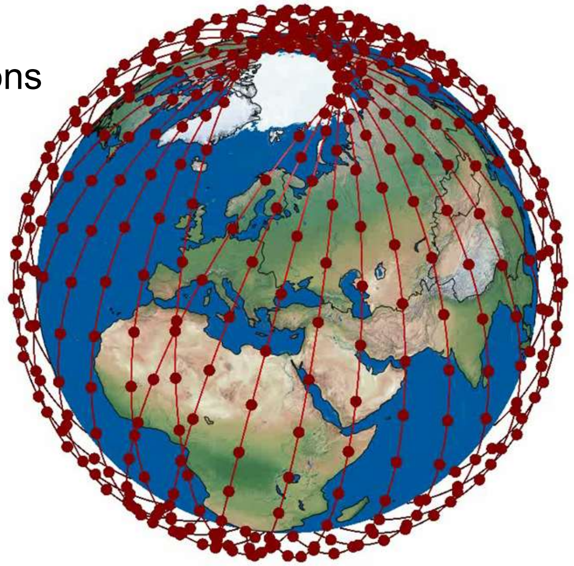
Secondary load pins in deployable panels

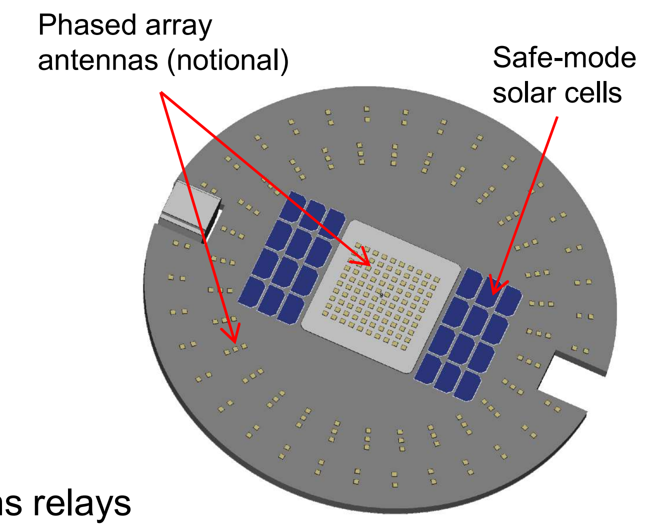


# *Mission Applications*

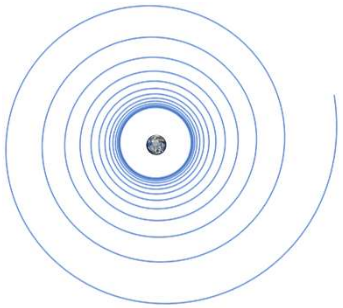
- Constellations
  - *Ideally suited to populating well-structured constellations of large-aperture, low-mass satellites*
  - *Efficient small-launch-vehicle packing*
  - *One orbital plane per launch*
  - *Or two or three planes per launch with low-altitude dispensing and differential precession*
- Missions requiring large apertures
  - *Communications, radar, etc.*
- Missions requiring high power
  - *Radar, high-power EP, etc.*
- Missions requiring large delta-v or continuous thrusting
  - *Low-altitude thermosphere ("Ignorosphere") characterization (160-300 km)*
  - *Low-altitude (high-resolution) imaging*
  - *Orbit raising and orbital agility*
  - *Cis-lunar space – self-propelled from GEO to lunar orbit*
- Low-budget missions with components too large for a CubeSat
  - *In rideshare, a 1-m-class DiskSat should have launch costs comparable to a 3U CubeSat*

Well-structured constellations





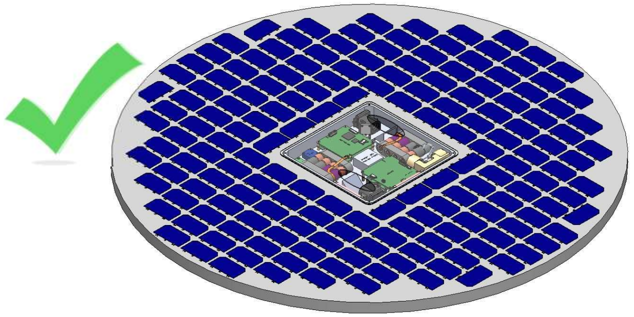

Communications relays



Earth-escape trajectories

# Summary

- Key enablers for future space enterprise have been identified: just going smaller (micro/nano-satellites) doesn't get you there
  - *Need to think outside of the (CubeSat) box*
- Aerospace is developing a new paradigm for satellite form factor: **DiskSat**
  - ***"Two-dimensional" bus architecture is low SWaP and has large aperture <u>(no deployables!)</u>***
- Form factor offers unique capabilities in a 10–20 kg package:
  - *Large surface area for high power and RF apertures*
  - *Large ΔV via electric propulsion for maneuvering, altitude changes, or even cis-lunar missions*
  - *Large total volume for accommodating payloads*
  - ***Very-low-altitude operations (<250 km) via low-drag edge-on flight***
- Diverse mission applications:
  - *Large constellations*
  - *RF receivers and transmitters*
  - *Radar*
  - *High power*



100 cm dia (166 W installed)

***Aerospace is developing a DiskSat risk-reduction and proof-of-concept demonstration mission***