Phoenix:
Initial Technical Elements and Interfaces (Satlet/PODs)

Mr. David Barnhart, TTO Program Manager

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Mr. Dave Neyland
Director, TTO
Dave.Neyland@darpa.mil

Mr. Barry Ives
Deputy Director, TTO
Barry.Ives@darpa.mil

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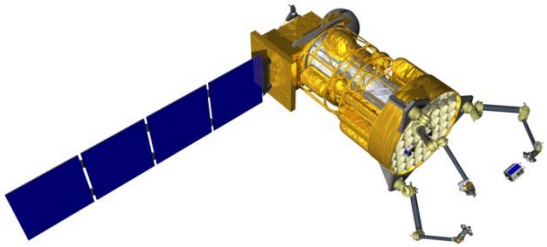
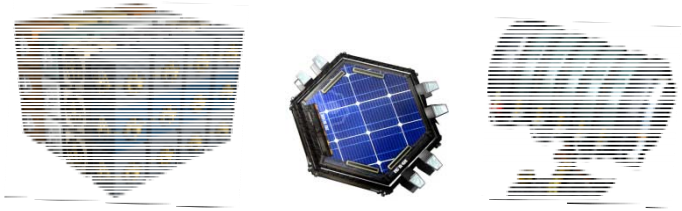
Three basic concepts combine to create the Phoenix architecture

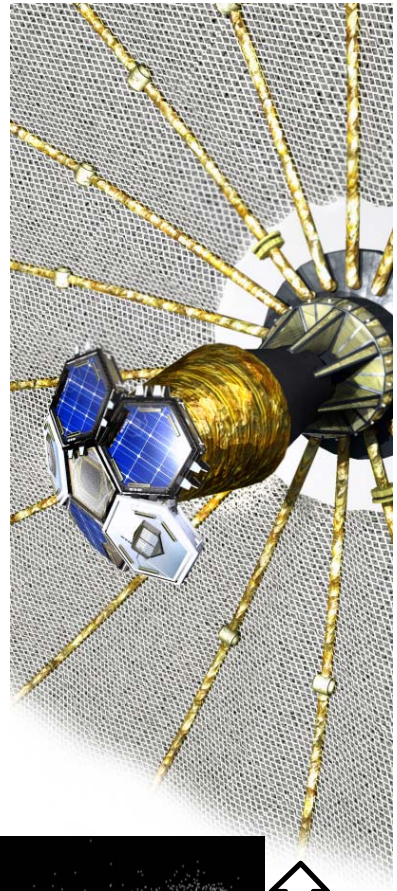
Tele-presence control of Robotic Servicer/Tender



Aggregation of "Satlet's"



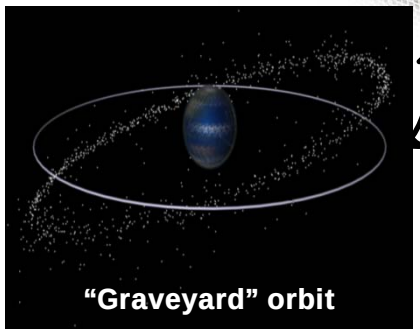
Repurposing retired components into value added systems or services



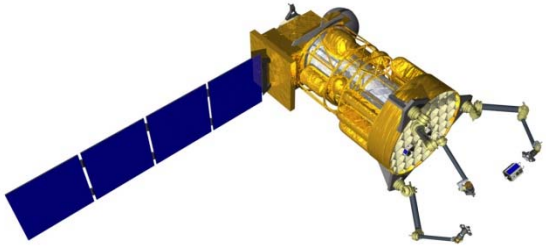
Dispensing payloads via existing Commercial Hosted Payloads service

SES-2, host to CHIRP

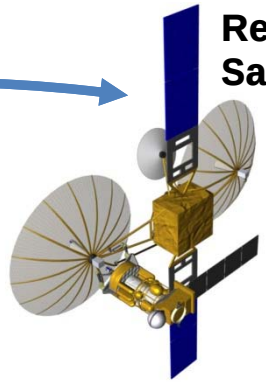
Intelsat 14, host to the IP Router In Space (IRIS) Joint Capability Technology Demonstration



The concepts are then broken into individual technical elements

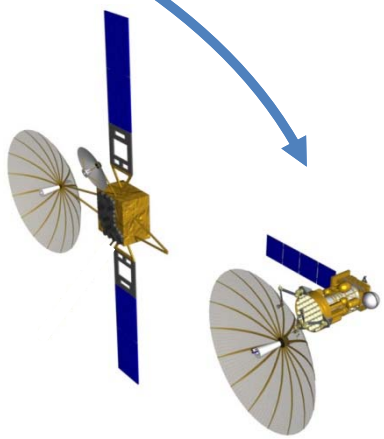


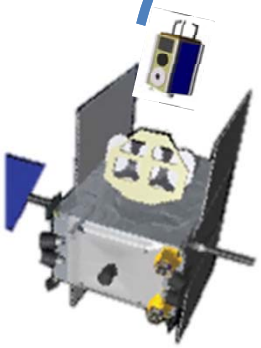
Retired Communications Satellite



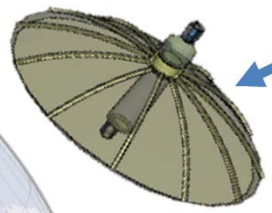
Tender/Servicer Spacecraft

- Spacecraft Bus.
- RPO Sensors.
- Primary Robotics (FREND Arms).
- Tools/end effectors and Tool Changers.
- Next generation hyper-dexterous manipulators
- Toolbelt and/or Toolcaddy.
- High performance Ground-Servicer/Tender Comms.
- Tele-presence algorithms and S/W.





Commercial Communications Satellite to host Ridealong PODs



New Technologies

- PODs (Payload Orbital Delivery system).
- Satlets (contained within PODs containers).

On Earth

- Ground Communication Facility for Service/Tender.
- Ground Operations Facility for Robotics Payload Suite.
- N-DOF Test Facility for Robotic and Ops Validation.

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Notional breakdown of technical elements/components for the Phoenix Program

Major Interface Elements		Gov't Supported	Bids or Partners
Tender/Servicer Integration		✓	
- Spacecraft bus modifications and completion		✓	
- Rendezvous sensor suite			✓
- Robotics Payload Integration		✓	
	Primary Robotic Arm (FREND)	✓	
	- Tools (i.e. secondary end effectors, saws, grips, changers etc.)		✓
	- High performance Ground-to-Servicer/Tender communications		✓
	- Tele-presence algorithms and S/W (Training and validation)		✓
	- Next generation hyper-dexterous manipulators		✓
Toolbelt and/or Toolcaddy			✓
Satlets (Multiple variants)			✓
PODs			✓
Commercial bus ridealong slot (to host PODs)			✓
Retired Communications Satellite		✓	
	- Retired aperture	✓	
N-DOF Test Facility for Robotic and Ops Validation			✓
Ground Communication Facility for Servicer/Tender			✓
Ground Operations facility for Robotics Payload			✓

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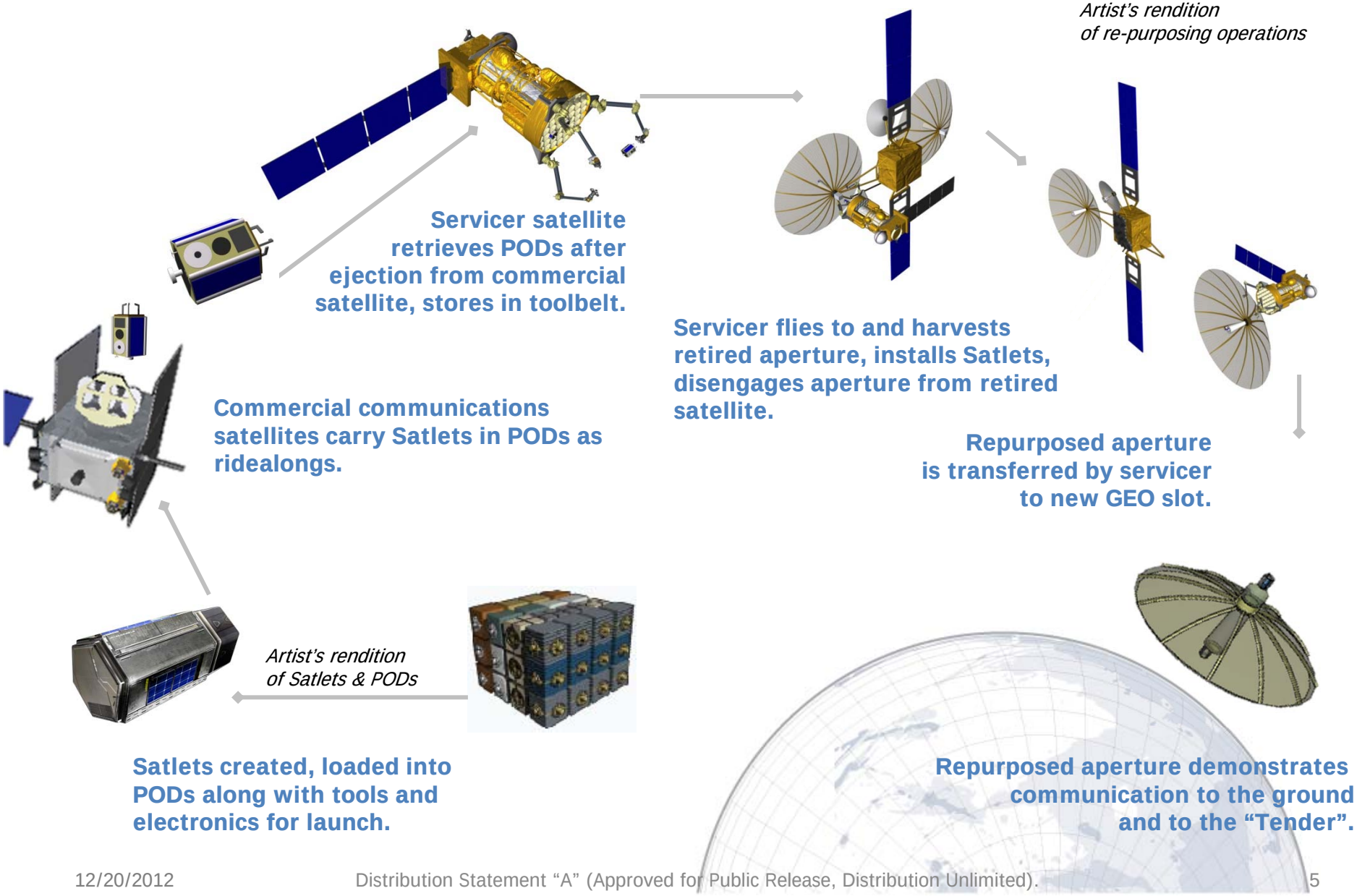
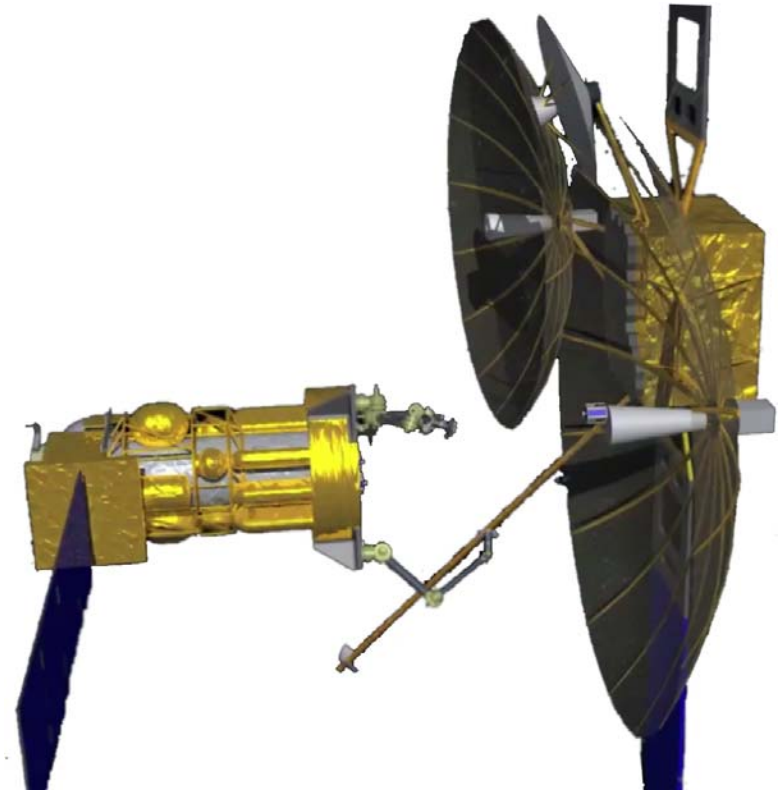
Phoenix demonstration notional concept of operations

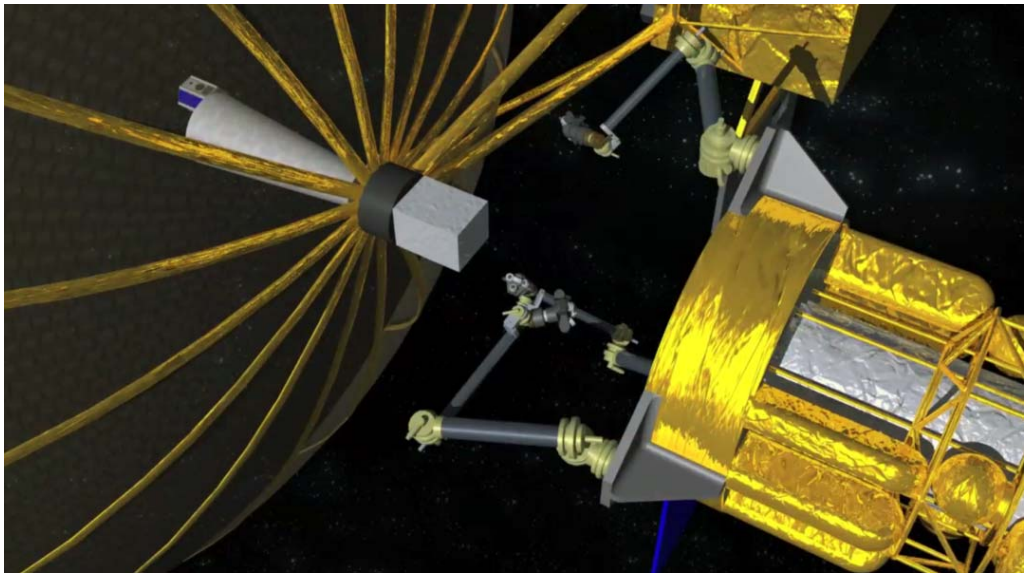


Example of detailed considerations in proximity operations

Considerations in Servicer/Tender proximity operations:

- Local obstacle avoidance inputs for tele-presence operators.
- Variety of structural attach points.
- Optimal location to dis-engage aperture from satellite.
- Multi-arm grappling requirements and/or scenarios.





Simple concepts with many un-explored technical challenges

Environment

- Unknown static discharge state of the retired satellite and/or aperture.
- Very high radiation doseage on electronics.

Retired Satellite

- Unknown tumble rate(s).
- Unknown dynamics for extended structure(s).
- Unknown condition of metal or structures to be used for grappling.
- Unknown propellant load and associated dynamics.

Retired Aperture

- Non-consistent supports (e.g. material and different construction frames, i.e. tubular, square, I-Beam etc).
- Varying Feed collectors (center, offset, on satellite etc).
- Unknown state of the antenna collection mesh/substrate.

Operations in Space

- Delay time for Robotic tele-presence control.
- Local tele-operator situational awareness limitations.
- Limitations in degrees-of-freedom vs. manipulation needs.
- Mitigation of multiple RF emissions between different elements, simultaneously.

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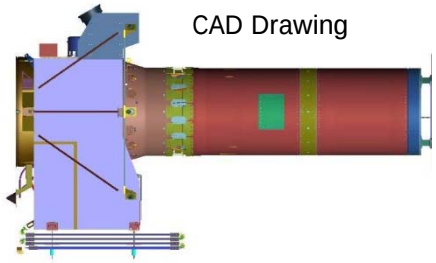
Representations of major elements that flow from Phoenix concepts

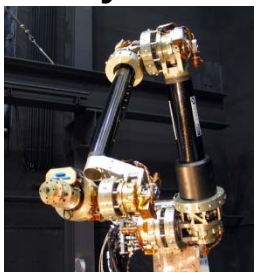
Servicer / Tender



CAD Drawing

Example retired satellite with aperture

Primary Robotics

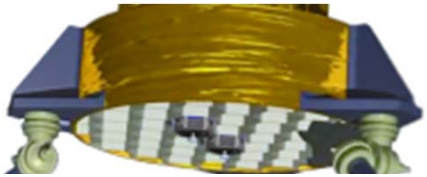


Naval Research Lab

Tools

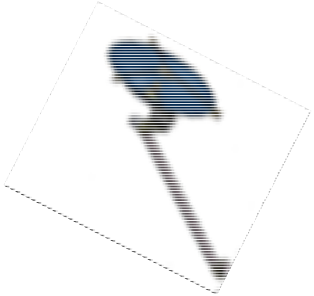
ESA

Toolbelt / Toolcaddy

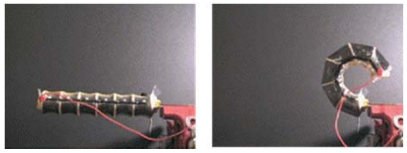


Artist's Concept

High performance communications



Next generation hyper-dexterous manipulators

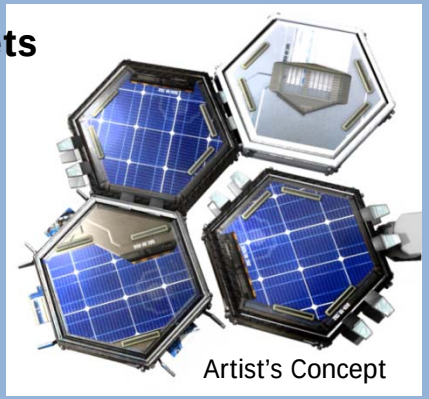


DARPA INSPACE 2006 AFRL Contract

PODs

Artist's Concept

Satlets

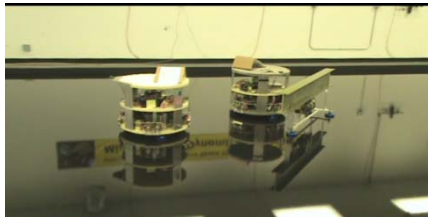


Artist's Concept

Tele-presence Control

Da Vinci medical robot control device

N-DOF Testbeds



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Servicer/Tender: Functions and nomenclature

"Servicer" refers to functions that the GEO spacecraft does to affect actions to another object. These include:

- Rendezvous and proximity operations.
- Transfer from GEO to Graveyard orbit.
- Robotic operations.
- Storing PODs and Satlets and Tools.

"Tender" refers to functions that the GEO spacecraft does after or beyond "servicing." These include:

- Stable standoff up to 1 km from the repurposed aperture.
- RF collection and re-transmission from the repurposed aperture.
- Inspection of the re-purposed aperture after release.

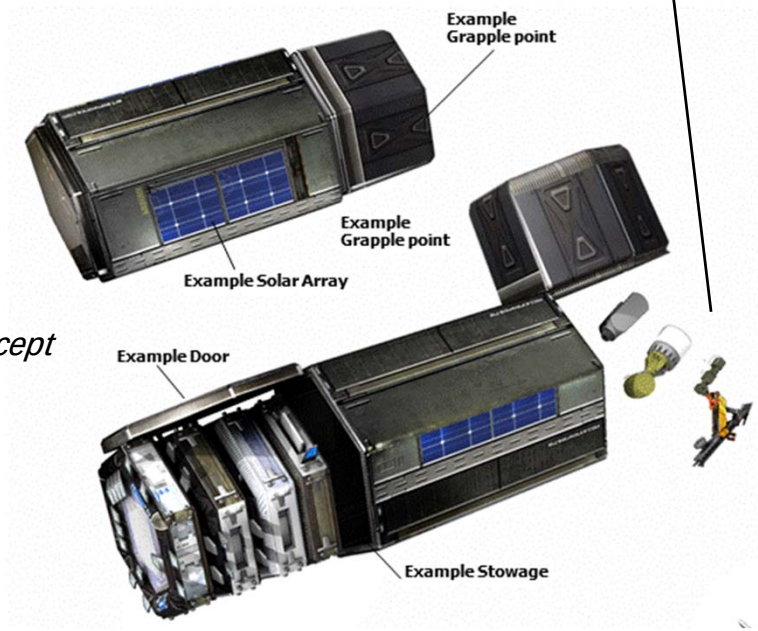
PODs: Nomenclature

PODs (Payload Orbital Delivery System)

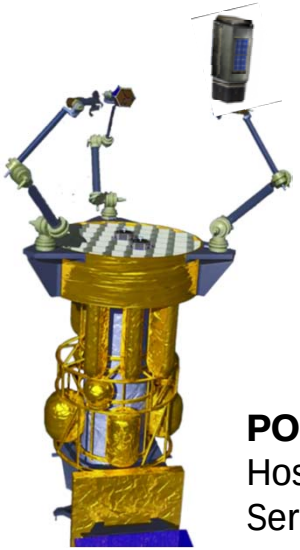
- Structural container that supports Satlets, tools, electronics, etc. during launch on a hose communications satellite.
- Can be dispensed into space to be picked by the Servicer/Tender.

PODs are meant to contain multiple Satlets, tools, electronic boxes all of varying sizes and shapes.

Multiple tools for Servicer/Tender stored in the PODs.



Notional artist concept



DARPA is looking for non-traditional methods for internal structural support for various items, and for methods of power/control to maximize size/weight/power .

PODs have multiple interfaces to contend with: Host communications satellite, grapple tools on Servicer/Tender, toolbelt on Servicer/Tender.

Satlet: Concept and nomenclature

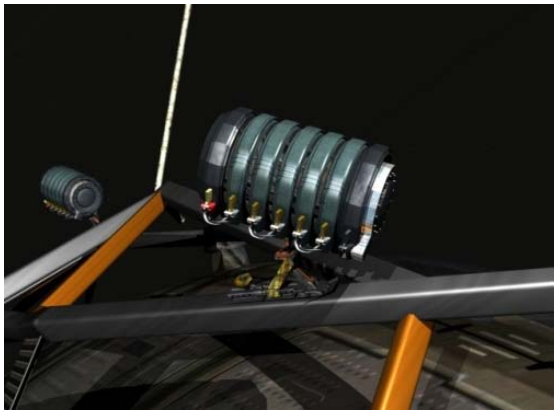
"Satlet"

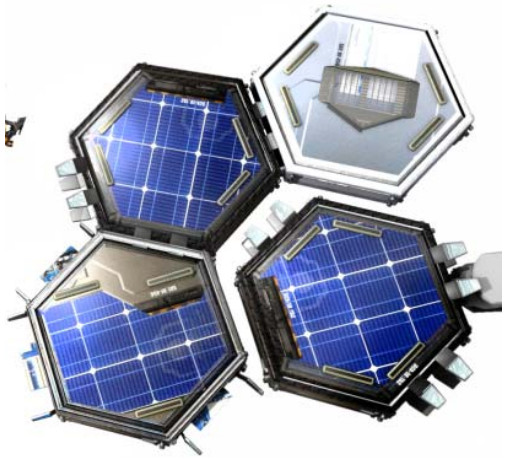
- Individual "cell" used to provide a specific function, either singularly or aggregated with others.

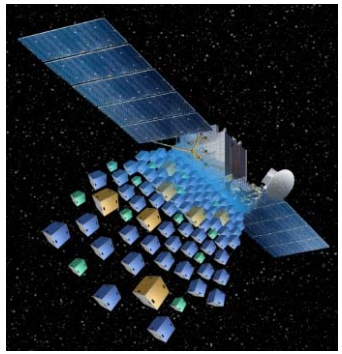
Notional Satlet functional variants for Phoenix:

- RF energy collector at feedhorn of existing aperture.
- Attitude control stabilization of aperture.
- Momentum management of aperture.
- Power generation and/or transfer.

Satlet examples



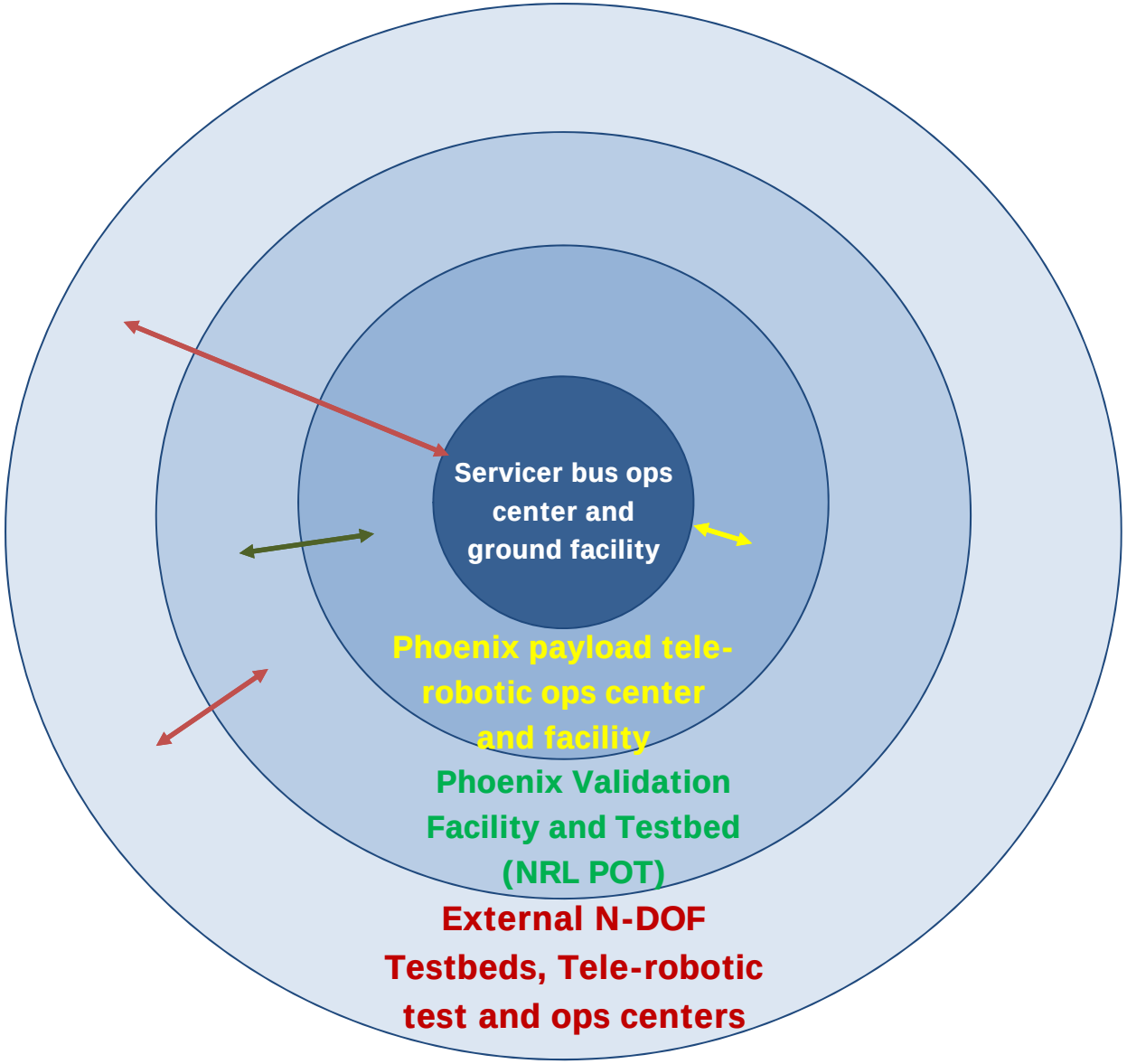




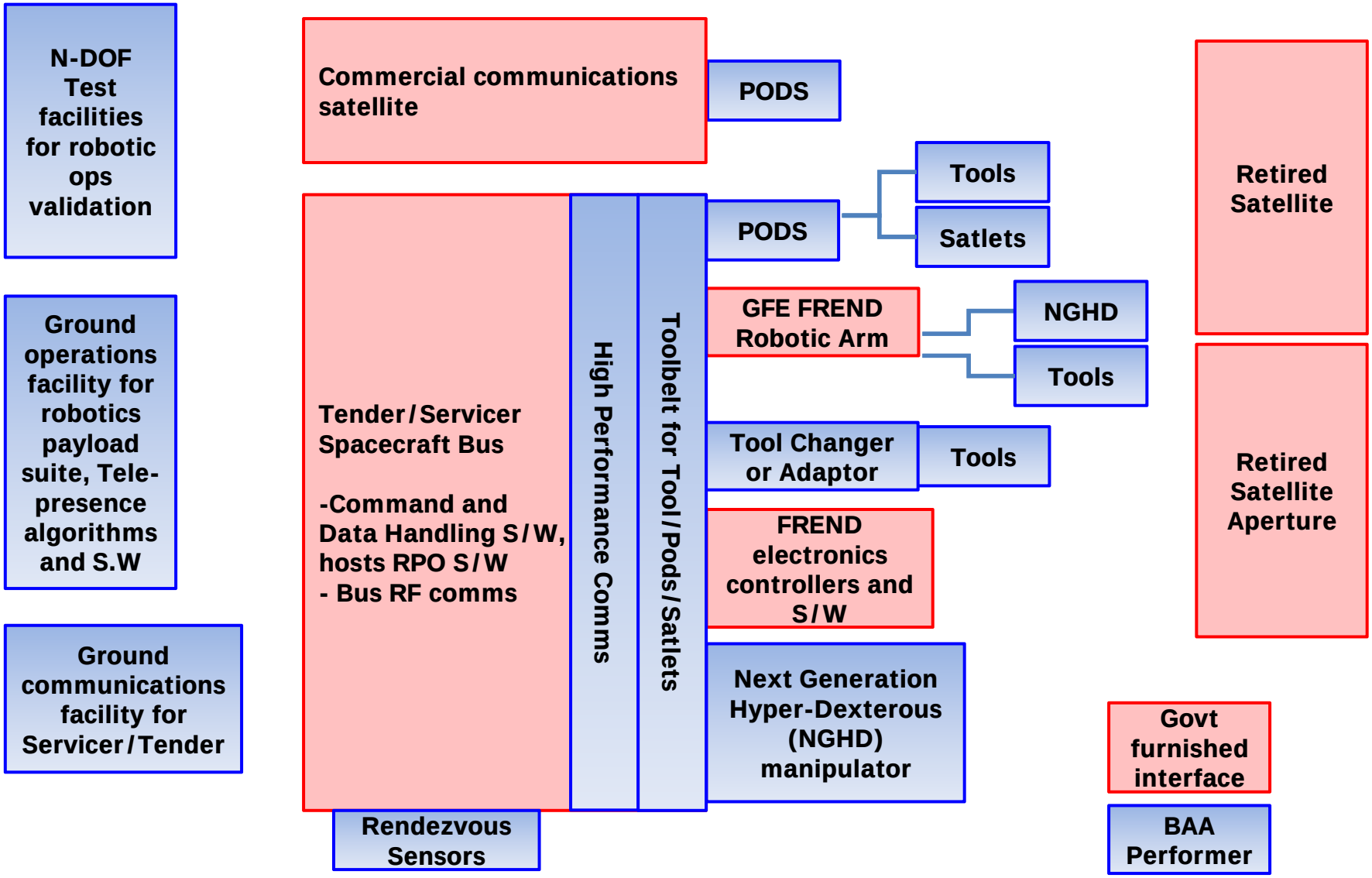
Artist's Concepts

Interaction between test, training and on-orbit operations

- Goal is to develop a suitable control interface between the Phoenix robotic systems onboard and various testbeds and operations centers, worldwide.
- A classic "front room/backroom" style is considered to facilitate both the ground test and validation requirements, along with actual on-orbit operations.
  - Allows a single operations center (ie "front room) to command/control the "bus."
  - Allows separate payload/telerobotic locations (i.e. "backrooms") to interface with the bus ops center and/or ground test facilities Storing PODs and Satlets and Tools.



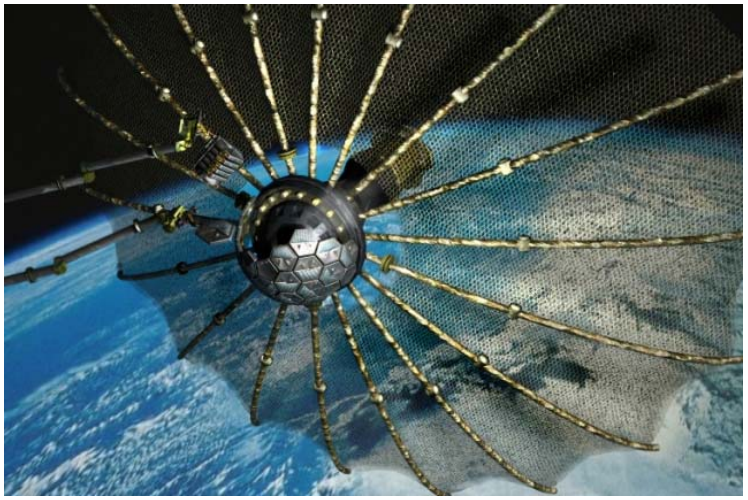
Notional functional interface diagram



Element: Satlets

- Definition: Individual elements that provide limited satellite subsystem functionality to transform a harvested antenna into a working satellite.

- Considerations: Multiple variants are envisioned depending upon the functions required. For Phoenix only a limited set are envisioned; Satlets that replace the collectors or feedhorn of the harvested antenna; Satlets that aggregate together to provide attitude control of the harvested antenna; Satlet or Satlets that provide momentum dumping capability.



Artists conception of Satlets installed at the back of an aperture for attitude control. Hexagonally "plated" satlets are shown but but are notional only (shape and number TBD).

Notional Attributes
Geometric shape
Aggregation efficiency loss(es)
Aggregated reliability
Attitude Control Capability
Aggregation Interface
Inter-Satlet communications
RF collection Capability
Collector to feedhorn Interface
Satlet to Tender/Relay comms
Etc

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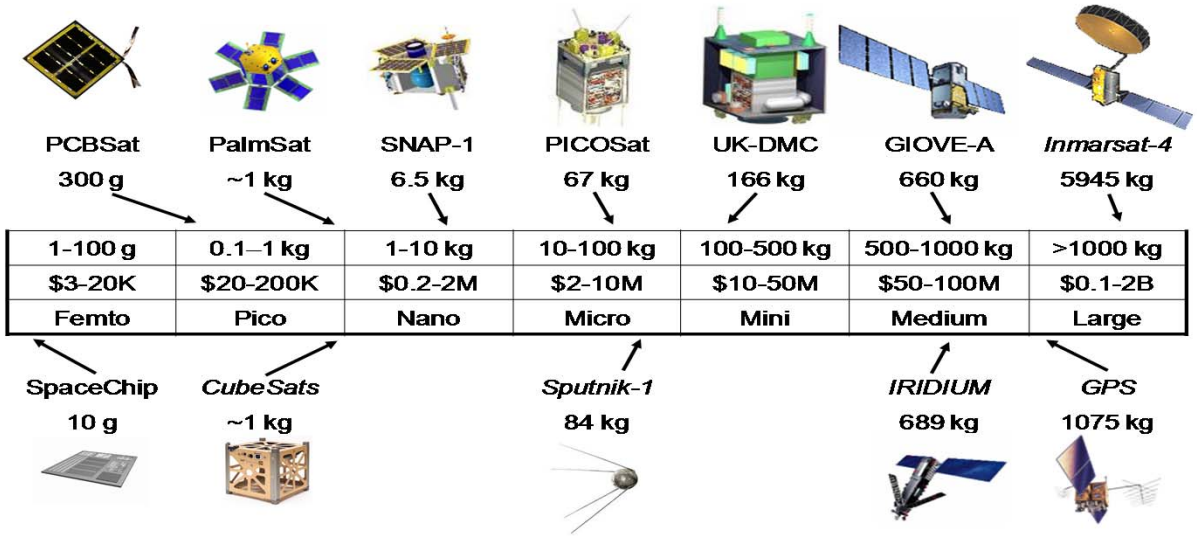
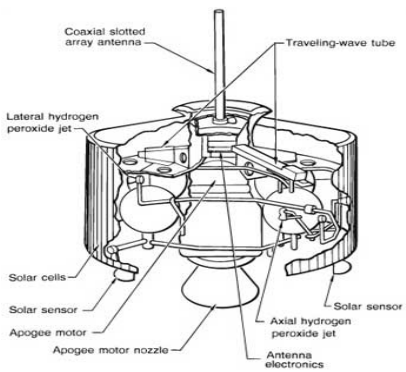
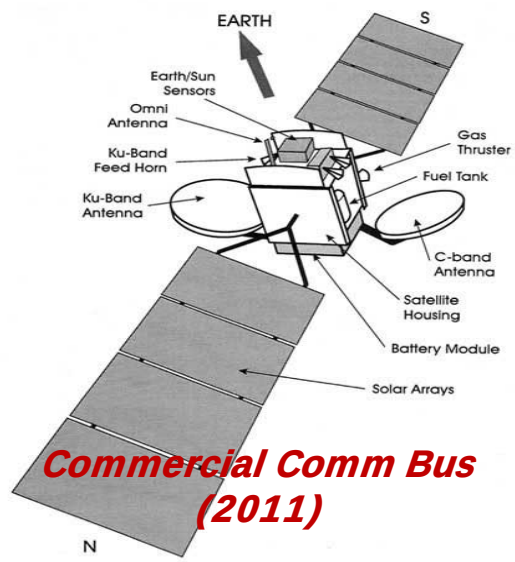
Where does notion of Satlet come from…



Static morphology over all sizes and history



Syncom 2 (1963)



Commercial Comm Bus (2011)

Satellite internal makeup (ie morphology or composition) has remained consistent for 50 years and drives the relationship between cost, mass, and performance

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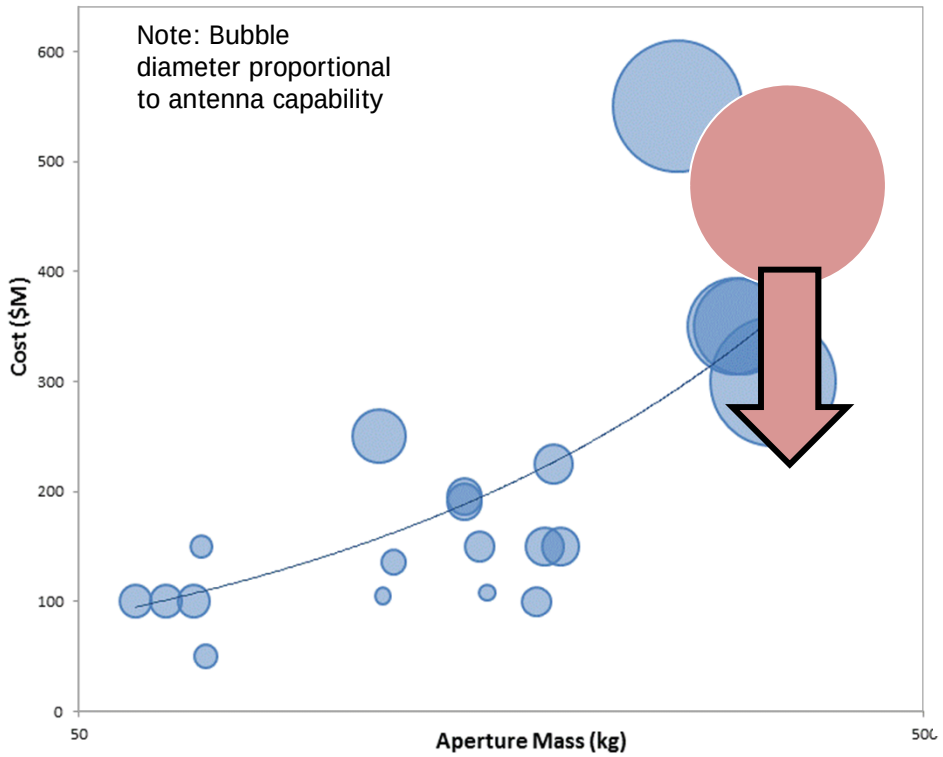
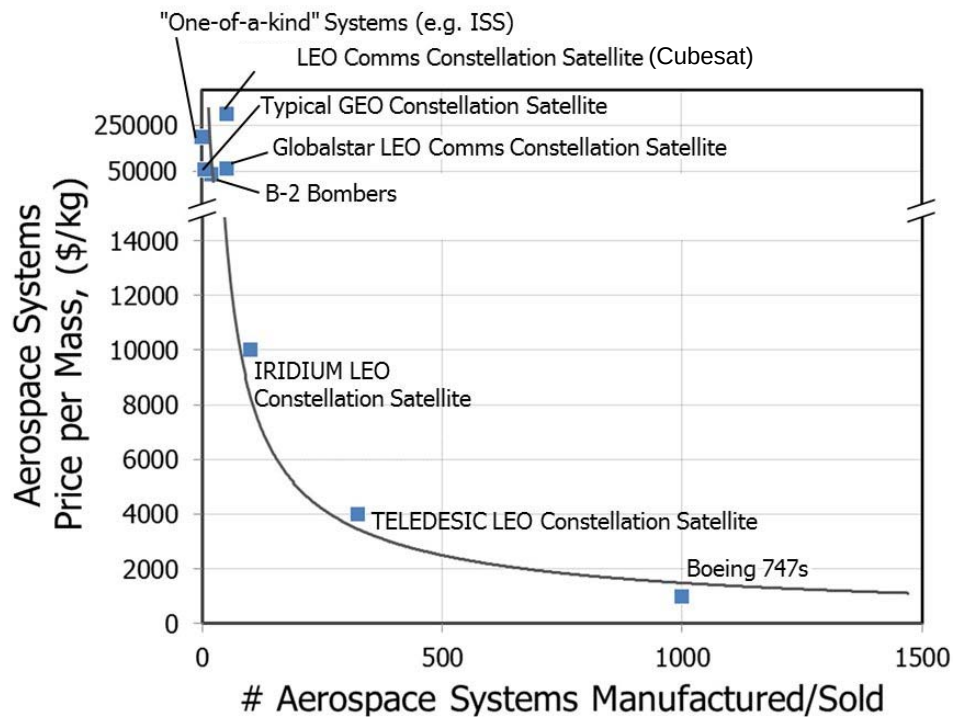
Recall, Phoenix supposition is to lower cost yet keeping aperture mass (and by extension capability) the same

Traditional satellite architecture and tempo have spawned a simple cost calculus based on mass

Yet most cost efficiency is typically through higher number of units sold/delivered per unit time…



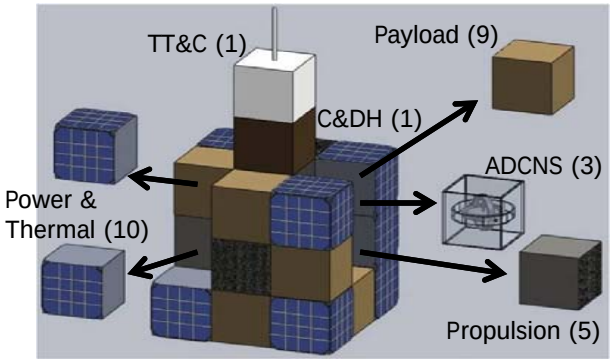


It is possible to change the cost vs mass ratio at the same performance point for space systems by combining high volume low cost manufacturing production with re-use of existing apertures…

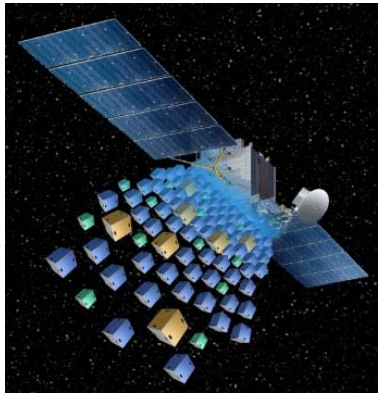
Satellite morphological reconstruction: Leveraging cellular architecture to increase volume production of satellite functions at lower cost

Morphological reconstruction for satellites:

- **Cellular morphology** is a proposed alternative satellite architecture which would **leverage high-volume, low-cost manufacturing technologies** to mass-produce small, standardized units, each with the scaled-down function of a traditional satellite subsystem or component.
- The **"cells"** would then be **assembled** in arbitrary numbers and geometries into a satellite with the aggregate function of the assembled cells, a satellite customized to a particular mission without the need for customized design and build.



Artist's Concepts



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Analogous architectural approach via cells found in biology

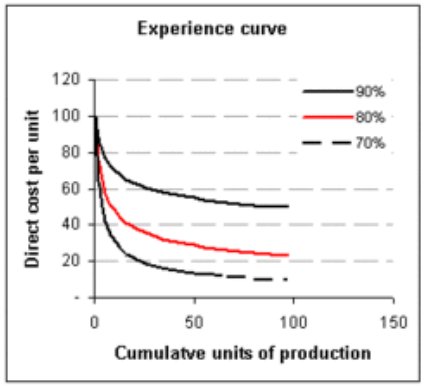
Biology aggregates specialty cells for performance at various scales.

	# of Specialty Cell Types	Typical Cell Total
Placozoa	4	Few thousand
Hydra	15	50-70,000
Jellyfish	22	Several Million
Satellite	~8*	~8-25*

Satellite subsystems that could be "cellularized", e.g.

Power subsystem
Attitude control, secondary structure
Attitude determination
Telemetry, tracking and control
Command and data handling
Thermal subsystem
Primary structure
Propulsion

By disaggregation of each subsystem and component to its lowest "specialization" cell, **high volume manufacturing learning curves from non-traditional aerospace industries can be applied to satellites.**



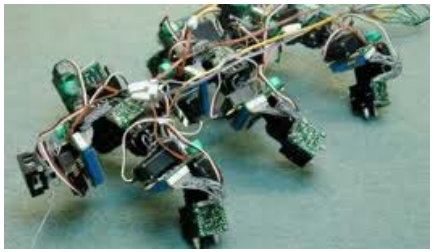
Hydra	Satellite
Hydrostatic skeleton	Primary structure
Muscles	Attitude control
Sensory	Attitude determination
Nettles	TT&C
Nerves	C&DH
Interstitial	Thermal subsystem
Glands	Power subsystem
Cilia	Propulsion

Cubelets (US)

Distribution authorized to the Department of Defense and U.S. DoD contractors only.

Examples of ground robotics systems addressing morphology by “cell” like single unit addition

Ground robotics shows examples of both specialty and reconfigurable morphological “cells” which assemble into unique arrangements to change topology and thus functionality.



Will (US)

Cubelets (US)

Shen (US)

ATRON (Denmark)

GZ (Germany)

Murata (Japan)

Festo Molecubes (Germany)

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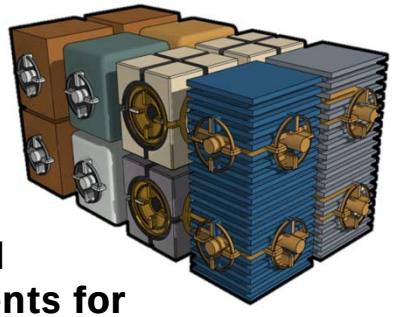
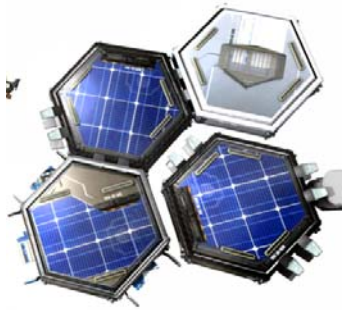
Phoenix intends to apply the "system cell" morphological concept using independent subsystem "Satlet" aggregation

Artist's Concept of "Satlet" aggregation





Satlet aggregation matches only what is functionally required

Telemetry, tracking and control x2

Attitude determination x1

Power subsystem x2

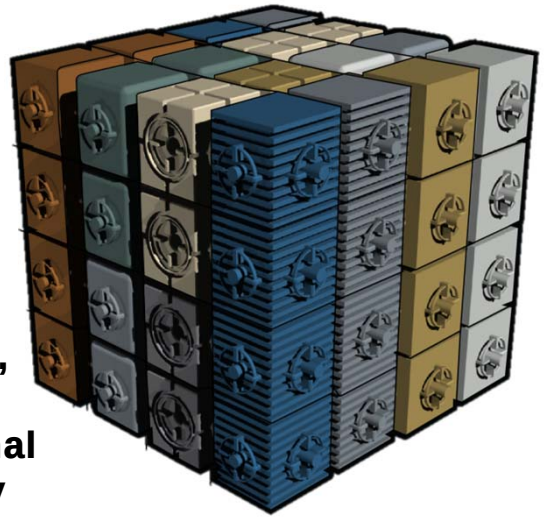
Command and data handling x2

Payload x2

Propulsion x4

Thermal subsystem x2

Functional requirements for payload aggregates to ~ 8 kg "bus" mass



Telemetry, tracking and control x8

Attitude determination x8

Power subsystem x14

Command and data handling x4

Payload x8

Propulsion x8

Thermal subsystem x14

By increasing aggregated "Satlets", the functional performance of normal satellite functionality goes up (~ 32kg bus mass)

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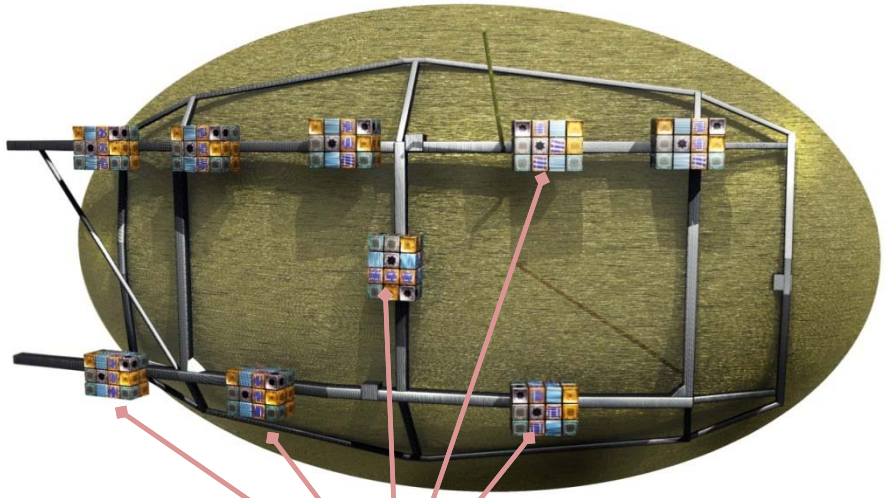
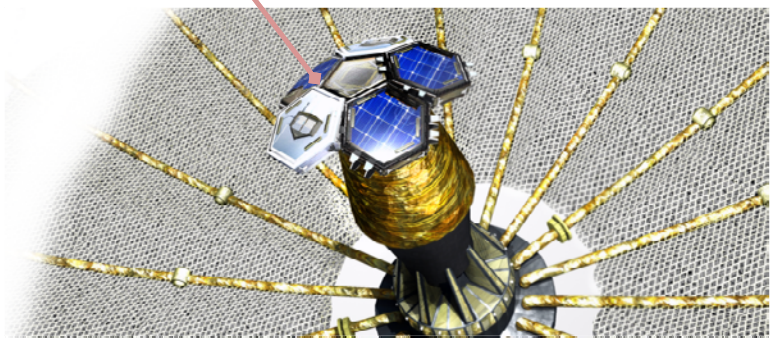
Example of Satlet “aggregation” for Phoenix

Example aggregation of Satlets for repurposed antenna:

- Maintain attitude control of TBD kg aperture using N Satlets, each with TBD Nm-s momentum control, aggregated together
  - Control to +/- 10 degrees pointing at Earth
- Provide RF collection point
- Provide means to control momentum buildup



Example of n-Satlets placed on antenna structure and at RF collector feed



Derived Requirements (eg):

- Cross-Satlet communications to coordinate aggregated control
- Ability to accept external communications as to the vector by which the Satlets collectively must point to.
- Appropriate processing to coordinate attitude control and cross Satlet communications
- Power to support the aggregated Satlet functions
- Ability to grasp/grapple antenna, and aggregate with each other

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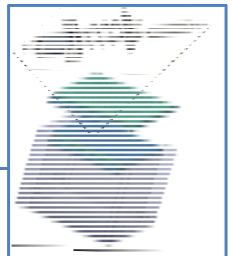
While there is a range of cellularization options and tradespace, Phoenix intends to concentrate on functions required for aperture repurpose demo

Range of cellularization options

Pure cellularization at subsystem and component level.

Typical satellite components
Primary structure
Propulsion
Telemetry, tracking and control
Attitude control, secondary structure
Thermal subsystem
Command and data handling
Power subsystem

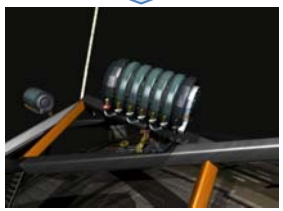


miniature electric thrusters

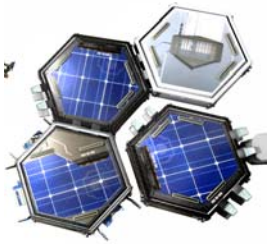
cellularized microelectronics

Hybrid approach:

- Some celluralized subsystems.
- Some custom components/systems.



System level satellite "cells."



Notional Satlet variants for initial evaluation on Phoenix:

- Attitude control Satlet
- Momentum control &/or dumping Satlet
- RF collector Satlet

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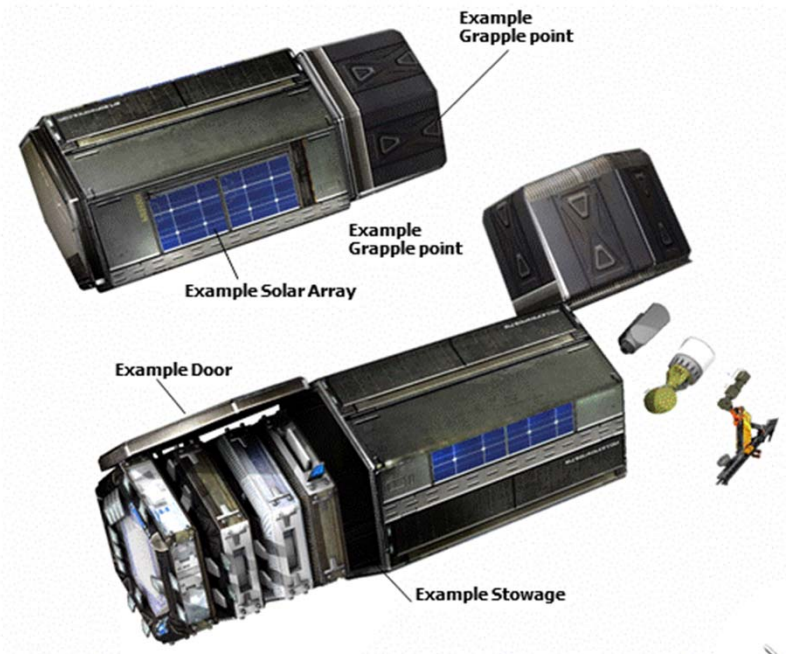
NEED

Element: PODs

- **Description:** A payload orbital delivery system (or PODs) is meant to provide the structural housing for multiple tools, Satlets and other electronics boxes to be carried in a variety of volumes as hosted commercial ridealong payloads.
- **Considerations:**
  - PODs (and contents) must survive launch forces.
  - Active or passive power onboard (ie internal hdwe provides power until it is used elsewhere)
  - Active or passive navigation aides for Servicer/Tender capture
  - Life internal to commercial hosted payload bay, and external to free space in GEO.
  - Variable internal configurations of PODs contents
  - Storeability onboard the Servicer/Tender

Notional artist concept



Notional Attributes
Ejection method
Ejection velocity and attitude
Ability to fit within variable forms
Active Radio Beacon
Power Required
Thermal Required
Shock and Vibration
PODs-to-launcher interface
Internal hdwe to PODs interface
Grapple capability
Housing (single unit or assembleable)
Etc

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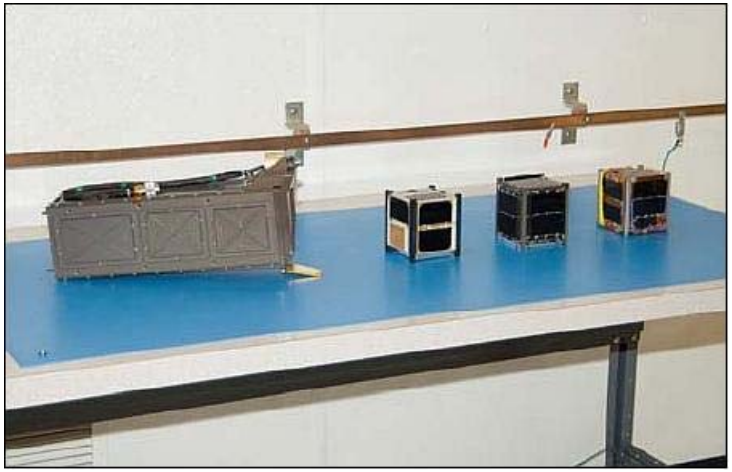
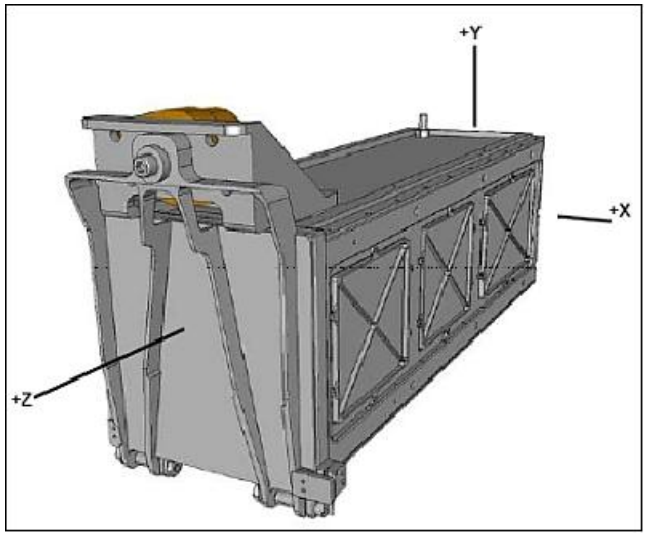
Current State of the art

NEED

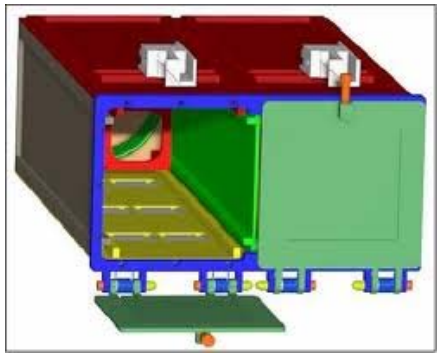


P-POD and (3) 1U Cubesats (NASA Image)



Poly Picosat Orbital Deployer MkIII model (CalPoly)

- http://events.eoportal.org/presentations/570/10001824.html



Double P-POD design (CalPoly)

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Variable 3-D packaging challenges for both PODs and internal content geometries

- The PODs must interface to a range of volumetric sizes/shapes to the number of satellite hosted ridealong manufacturers
  - The PODs geometric shape itself has to be flexible

- The PODs internal components may have multiple shapes/sizes
  - Satlet & tool geometries are unknown

- Non-traditional packaging methodologies and materials are of interest
  - Non-metallic non-contiguous packing materials
  - Conformable at the time of packing
  - Packaging that “breaks down” on orbit (ie UV)
  - Non-volatile outgassing, or condensation of outgassed products
  - PODs structure that “assembles” based on geometry of internal parts and host volume etc

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Combining “volume” production with increased delivery to GEO

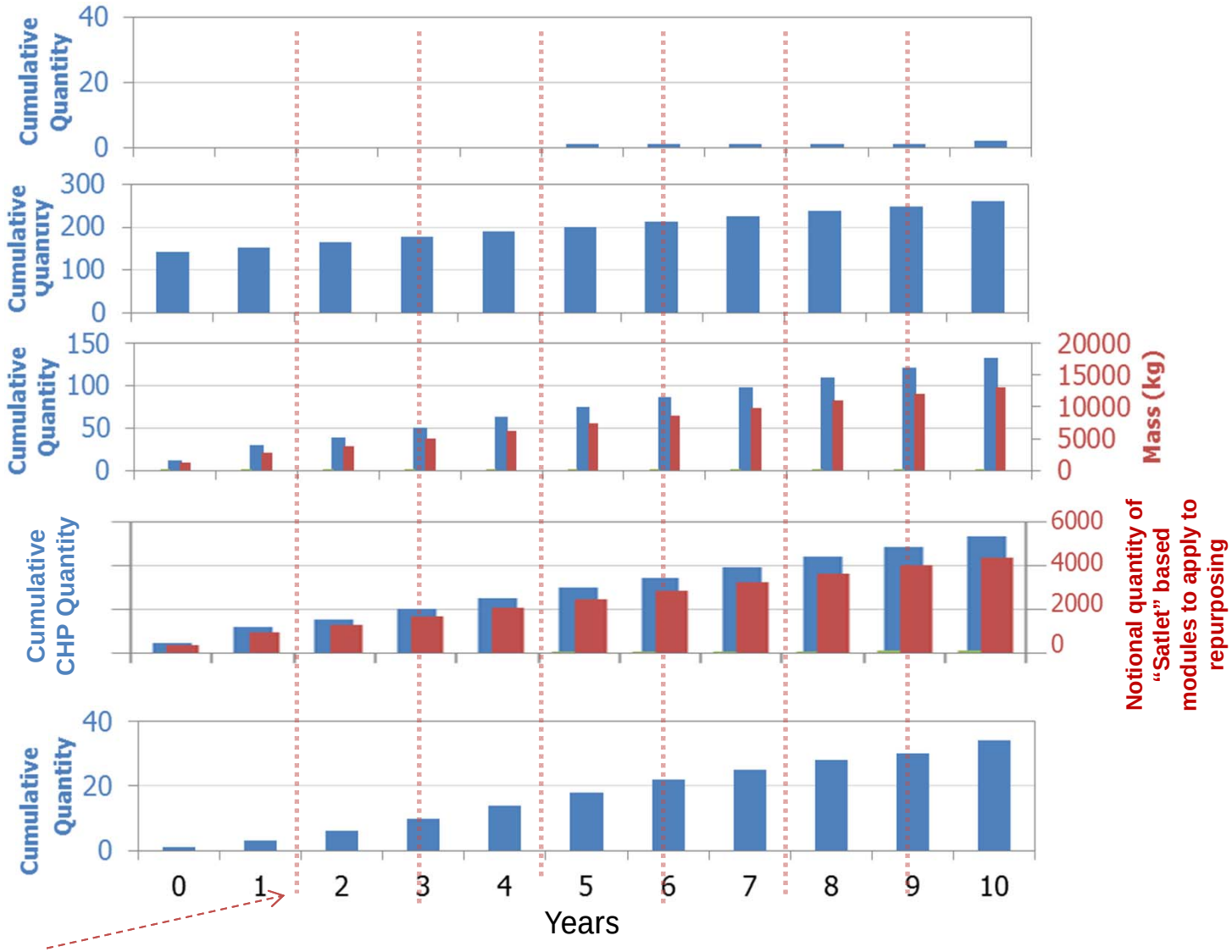
Current DoD GEO satellite development and launch tempo (between 5-9 years between deployments)

Decommissioned useable apertures are increasing each year

Commercial Hosted Payload (CHP) mass is ~1000kg/year, into foreseeable future

Possible to use CHP opportunities to increase volume and tempo of Satlet aggregation

Possible to leverage CHP and volume Satlet production to repurpose apertures/components to support DoD efforts



“Moore’s law”

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