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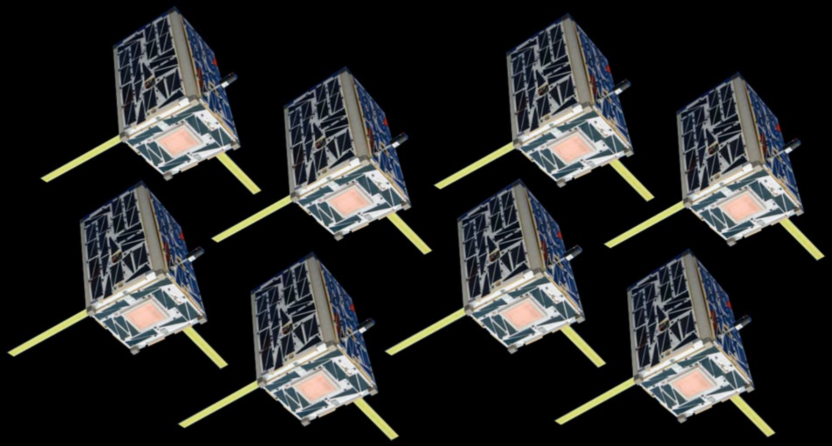

CubeSat Asteroid Impact Matrix Sample Return Mission Concept

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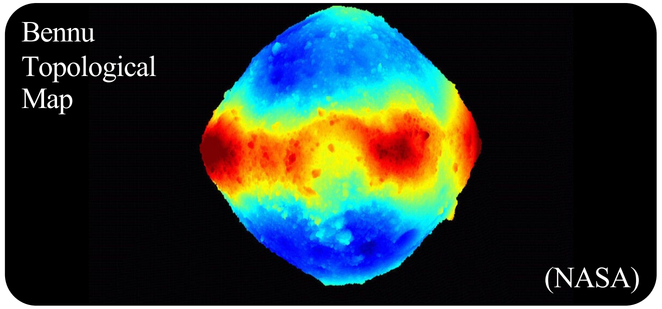
Outline

- Motivation
- Challenge
- Approach
  - Spacecraft design
  - Concept of Operation
  - Distributed satellite network
- Conclusion / Future Work

Motivation



Science Motivation

Planetary Defense

Technology Demonstration

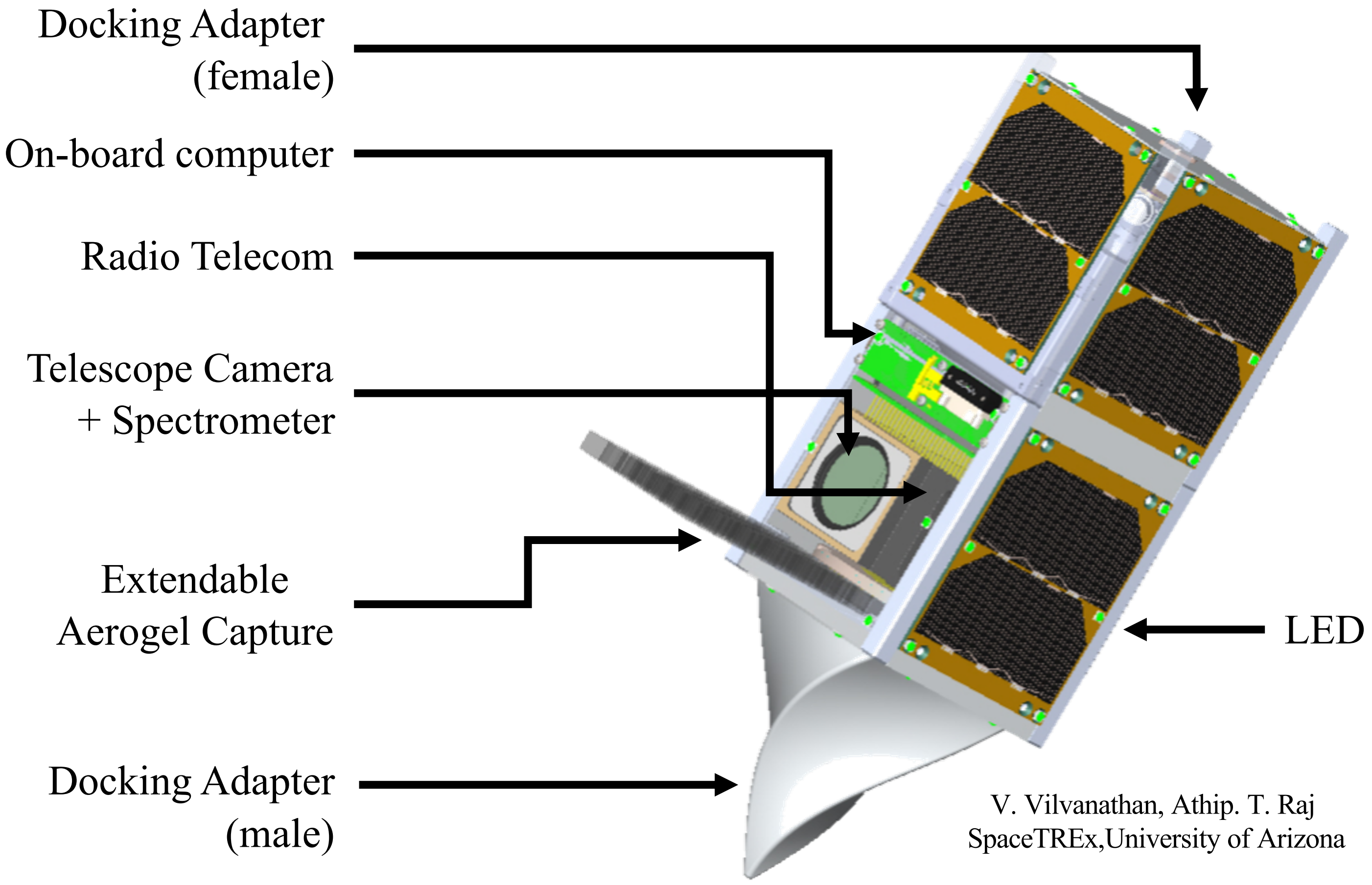
Challenges

Estimated target for this mission concept:

- USD$10M for spacecraft development
- 1 year development time
- 2-3 years mission duration
- Flyby return ΔV for near Earth asteroids

Mission	**DART**	**OSIRIS-REx**	**Hayabusa 2**
Development Budget (USD$M)	308	588.5	100 (estimated)
Development Time	3 years	5 years	4 years
Mission Duration	11 month	7 years	6 year
Target Body	Didymos	Bennu	Rygyu
Rendezvous return ΔV (km/s)	6.34	6.97	6.29
Flyby return ΔV (km/s)	3.40	3.73	3.36

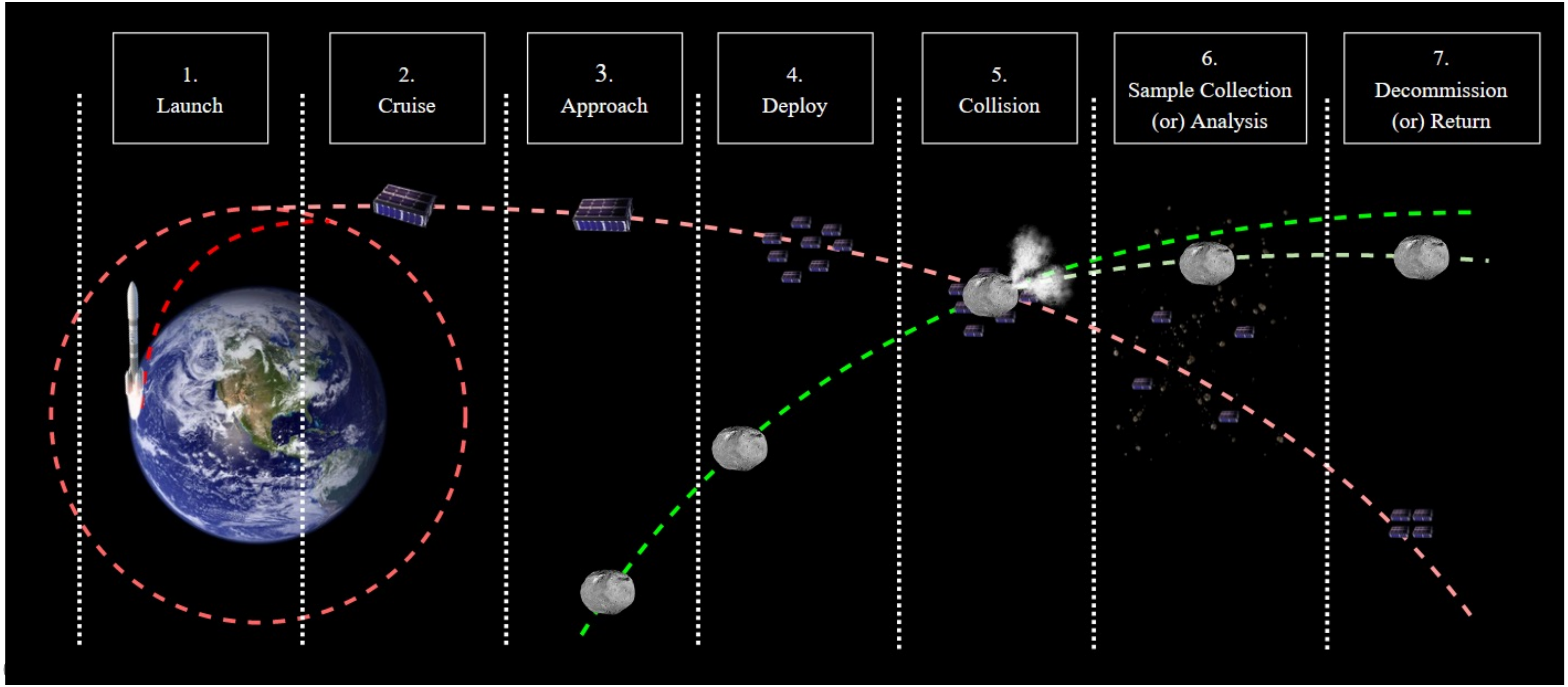
Preliminary Spacecraft Design



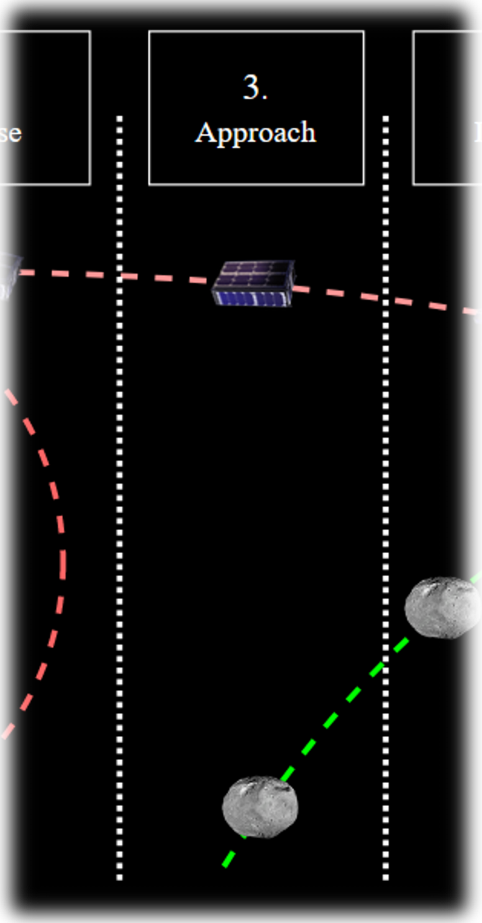
3D Rendering of Sacrificial CubeSat

	CubeSat Requirement
1	Volume at 3-4 U
2	Fully autonomous
3	COTS components if possible
4	Docking possible
5	Distributed command network
6	Communicate with nearby CubeSats
7	ADCS + monopropellant propulsion

Concept of Operation



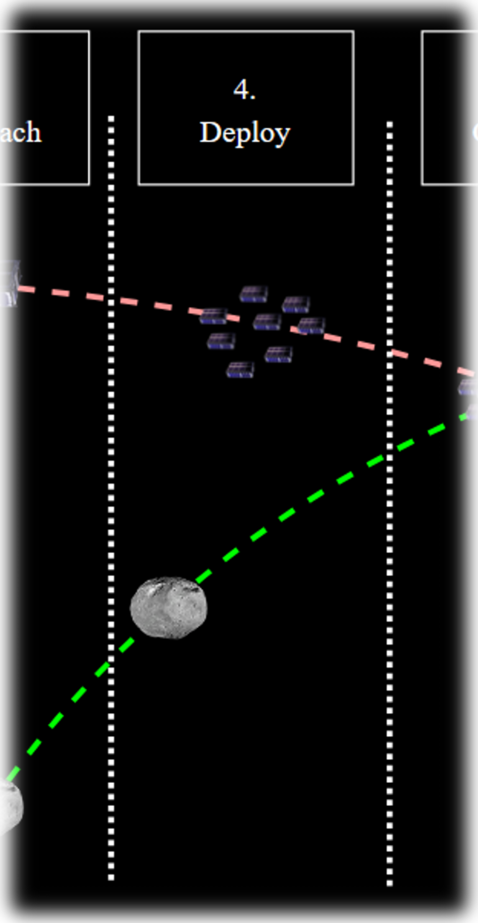
Phase 3: Approach



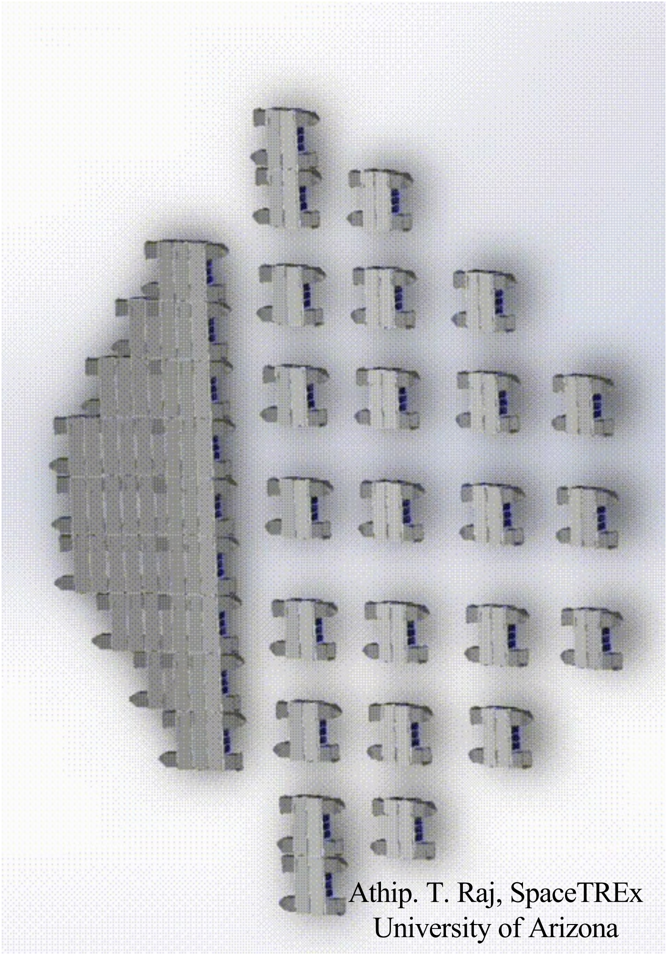
- Cameras track the asteroid position during approach and GNC subsystem operates
- Optional adjustments to trajectory in order to increase the probability of collision and sample collection

Images of comet captured by EPOXI mission during flyby in 2010 (NASA)

Phase 4: Deploy CubeSats

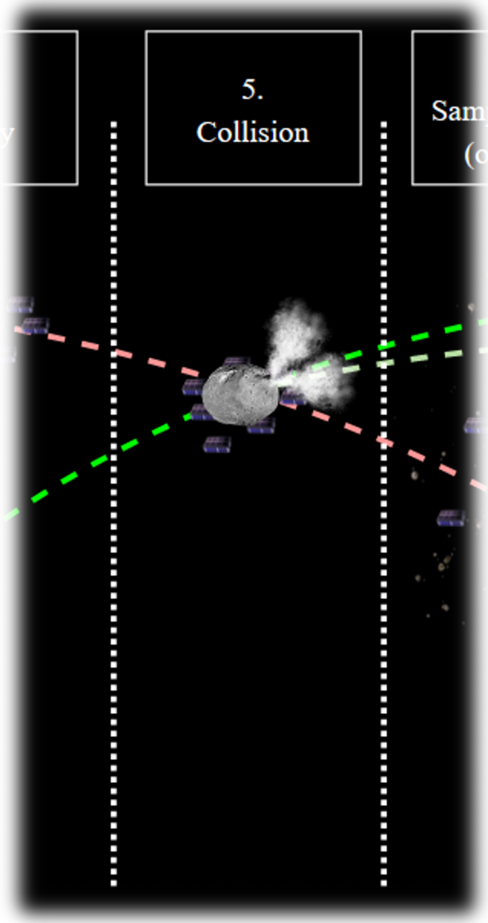


- CubeSats separate from the mothership/docked formation and form a 2D grid "fish-net" formation
  - "Fish-net" diameter 2x asteroid's
  - CubeSat separation less than asteroid diameter
- CubeSat swarm formation studied extensively in Earth's orbit
  - Further study required for deep space



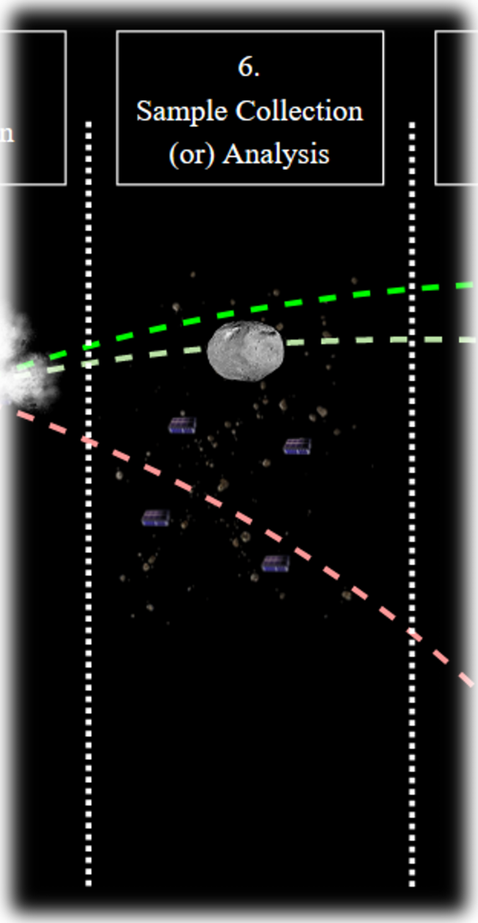
CubeSat Deploy Procedure

Phase 5: Collision



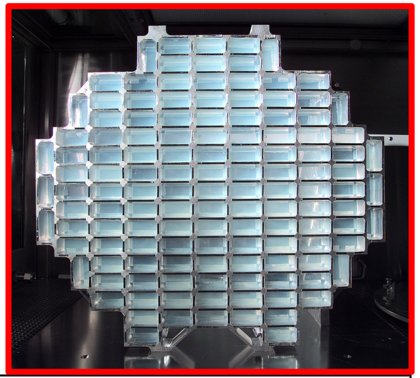
- A fraction of CubeSats are destroyed
- Surviving CubeSats use camera to monitor downrange debris, adjust position to avoid secondary collision in critical modules
- Further study into component robustness
- Further simulation required for ejecta modelling
  - Ensure good amount of downrange ejecta for collection
  - Realize specification for CubeSats (mass, size)

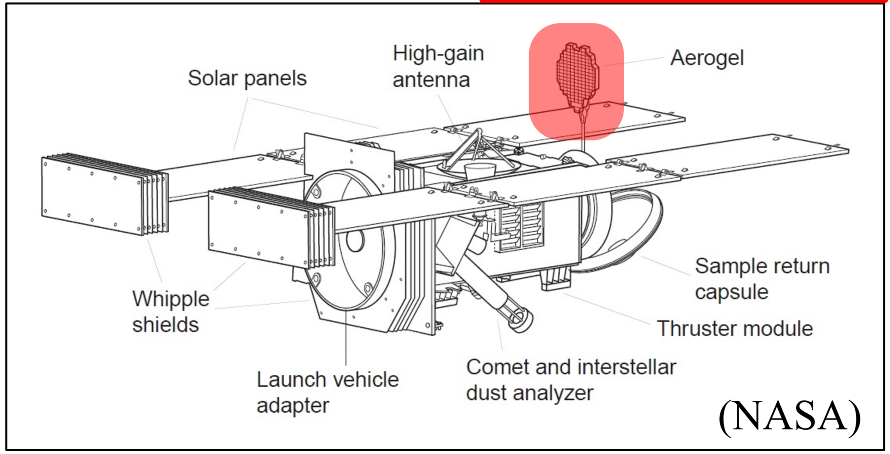
Phase 6: Collection/Analysis



- Surviving CubeSats attempt to use GNC to capture debris in aerogel collection module
- In-situ analysis
  - Composition
  - Regolith size distribution
  - Surface regolith cohesion
- Further ejecta simulations required to improve sample capture efficiency

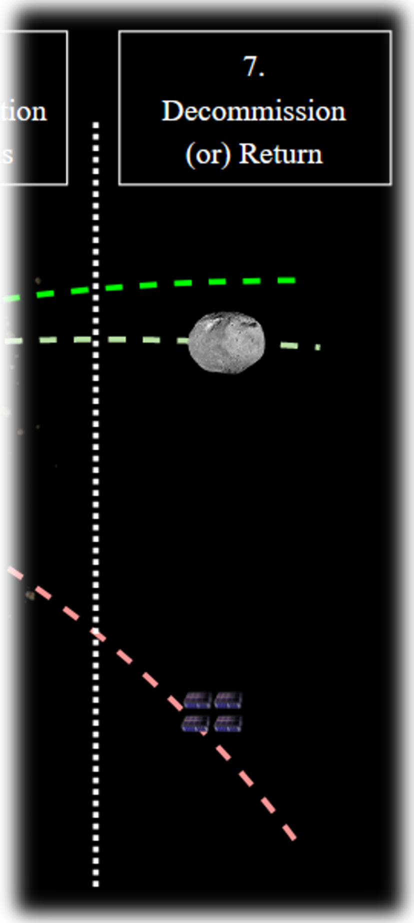
Stardust Sample Collection Module





Stardust Mission Spacecraft

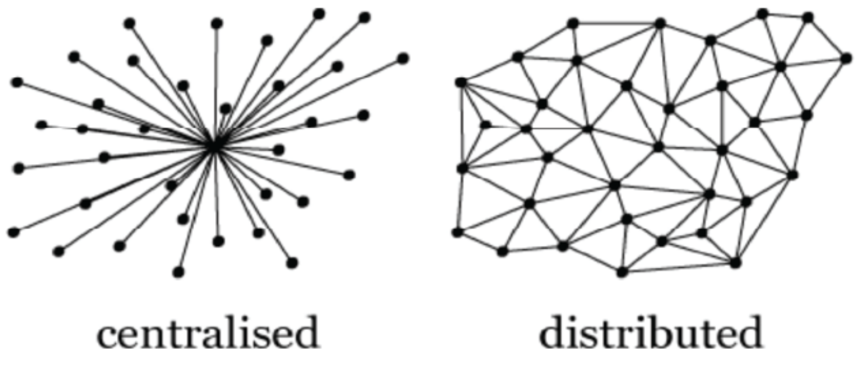
Phase 7: Return/Decommission



- The surviving CubeSats recombine and return to mothership
  - No re-entry heat shielding on CubeSats
  - Downlink primary scientific data
- Trajectory adjustment for Earth return trip
- If mission-critical failure occurs, adjust for decommission
  - No collision occurred
  - No sample collected
  - No CubeSats survived

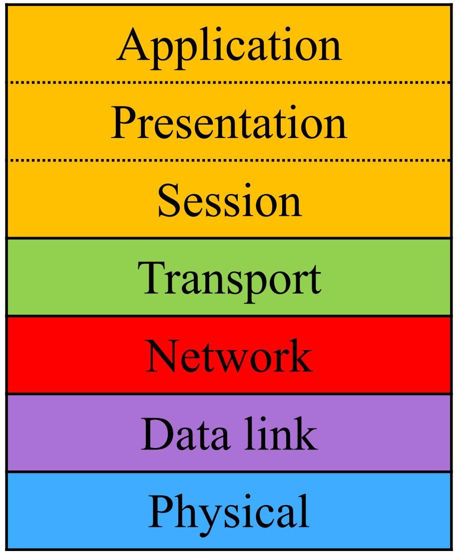
Distributed Processing Network

- Centralized command not possible in the “fish-net” CubeSat configuration
- Surviving CubeSats after the collision can reestablish another smaller functional network



Distributed Processing Network

- Physical: antenna design, specification, frequency band
  - …depend on "fish-net" specification
- Data link: scalability, bandwidth utilization, fairness
  - Require protocol to avoid collision
  - Contention-based (CSMA) vs. conflict-free (CDMA)
- Network: data packet routing
  - Proactive vs. reactive scheme
  - Multiple routing algorithm developed extensively
  - Consider switching scheme/algorithm at different phases



Framework for Inter-satellite communication (T. Vladimirova, 2010)

Conclusion / Future Work

- Enables a new age of asteroid exploration with low-budget, quick-turnaround, fast-result missions
- Standardizes asteroid exploration mission spacecraft development process with minor modifications for mission-specific objectives
- Demonstrates distributed network technology of CubeSats in deep space – requires further study to realize implementation
- Collision simulations and ejecta modelling required to evaluate the success rate of mission concept

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Adventure Awaits

Reference

1. Vladimirova, T., Bridges, C.P., Paul, J.R., Malik, S.A. and Sweeting, M.N., 2010, March. Space-based wireless sensor networks: Design issues. In *2010 IEEE aerospace conference* (pp. 1-14). IEEE.
2. Radhakrishnan, R., Edmonson, W.W., Afghah, F., Rodriguez-Osorio, R.M., Pinto, F. and Burleigh, S.C., 2016. Survey of inter-satellite communication for small satellite systems: Physical layer to network layer view. *IEEE Communications Surveys & Tutorials*, *18*(4), pp.2442-2473.