The "Virtual" Space Telescope: A New Class of Science Missions

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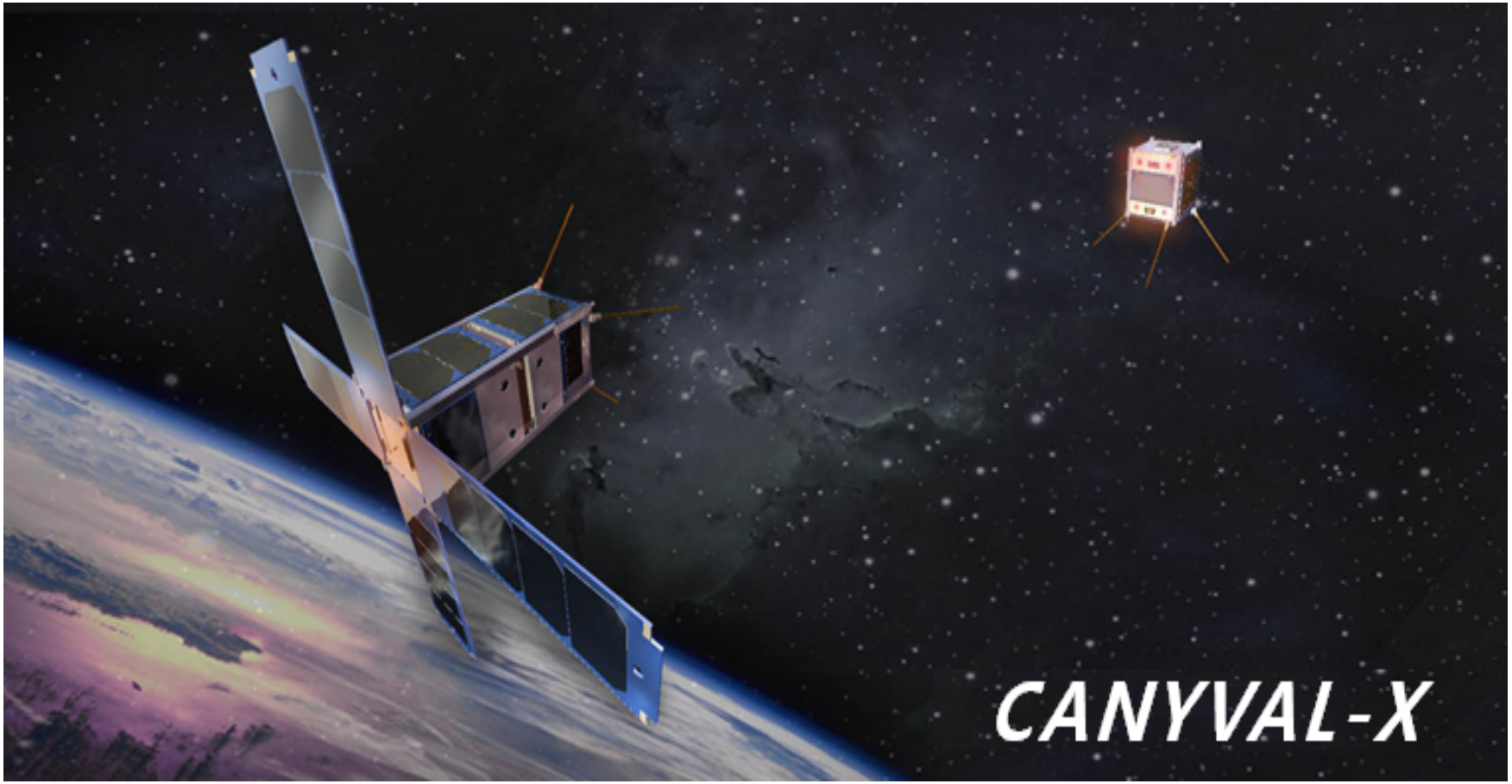


Neerav Shah and Philip Calhoun
NASA Goddard Space Flight Center
Presentation at SSWG
February 25, 2016

NASA Science Requires "Virtual" Telescope Capability

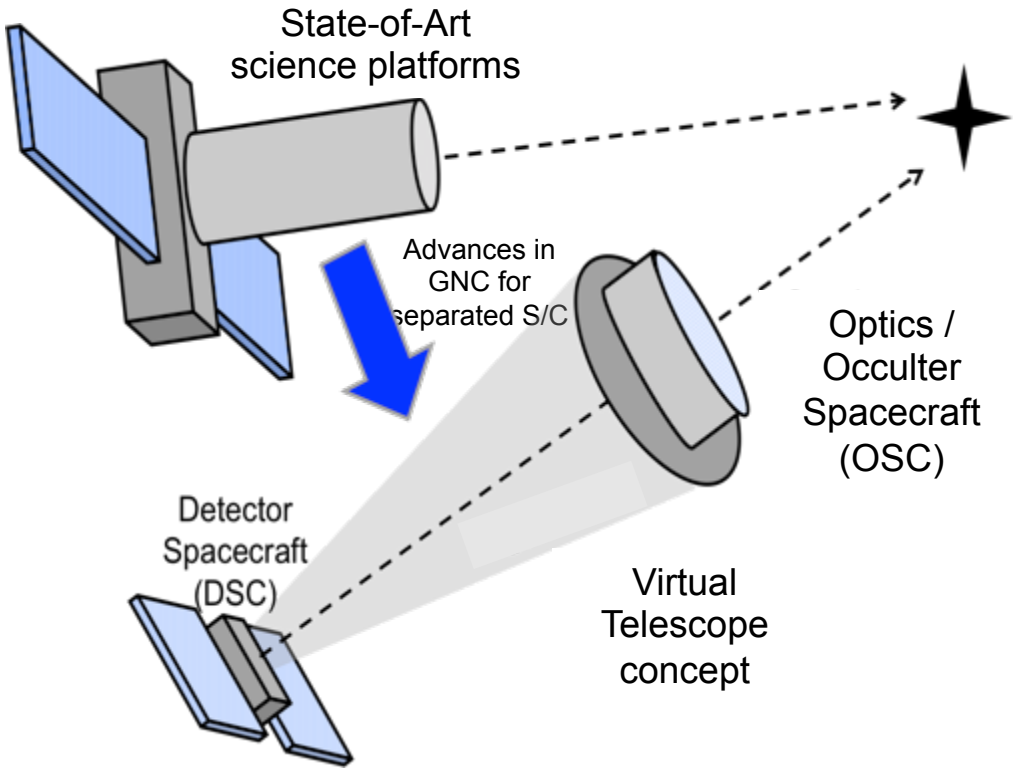
Goddard Space Flight Center

Many science investigations proposed by GSFC require two spacecraft alignment across a long distance to form a "virtual" space telescope.

Astrophysics:
- Milli Arc Second X-ray imaging
- Micro Arc Second X-ray imaging
- Calibration Telescope
- Starshade

Planetary:
- Exo-planet finder
- Near Earth Objects

Heliophysics:
- X-ray imaging of solar flares
- High-resolution UV/EUV imaging
- Next generation solar coronagraph



What's the Problem?

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To pass KDP-C, and for credible science proposals ➔ TRL 6

- **Perception:**

  Engineers and Technologists:

  Its been done already

  ➔ ***MMS, A-Train, GRAIL, PRISMA, CAN-X 4 5, EO-1, Hubble Servicing, etc.***

  Scientists and Program Managers:

  Precision formation alignment too risky

  ➔ ***Multiple launches, multiple spacecraft, never collected science***

- **Gap:**
  - Component technologies have been developed (some being developed) and tested (some still to be tested)
  - Relative spacecraft navigation and control demonstrated
  - Never formed a virtual science instrument
  - End-to-End System-level capability currently at TRL 4 → ***Need a system demo***

- **Approach:** *Min($) + CubeSats = Low-cost In-Space Demonstrations*

Roadmap to NASA Science using CubeSats

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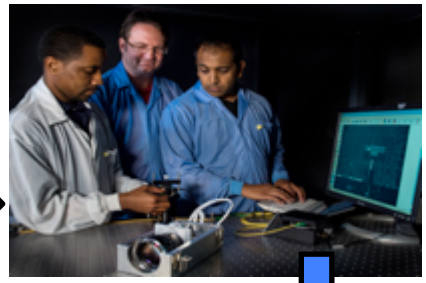

Ground/Lab Demo
- Component-level testing and development
- Goal: TRL 5

Current Status:
- Inertial Alignment System
- Lateral sensing
- Micro Propulsion
- Inertial Alignment Navigation Algorithms

In-Space Engineering Demonstration
- Integrated system level demonstration in space
- Goal: TRL 6/7

- CANYVAL-X (NASA + Yonsei + GWU) CubeSat Technology Demonstration Mission
- Build confidence and decrease risk for science-class missions

In-Space Science Demonstration
- Integrated system level demonstration including a science instrument
- Goal: TRL 8/9

- VTXO (2015 EpScore UNM + NMSU + GSFC)
- mDOT (Stanford, et.al.)

Science Missions

Relevant to StarShade Working Group

CANYVAL-X: The CubeSat Astronomy by NASA and Yonsei using Virtual Telescope Alignment experiment

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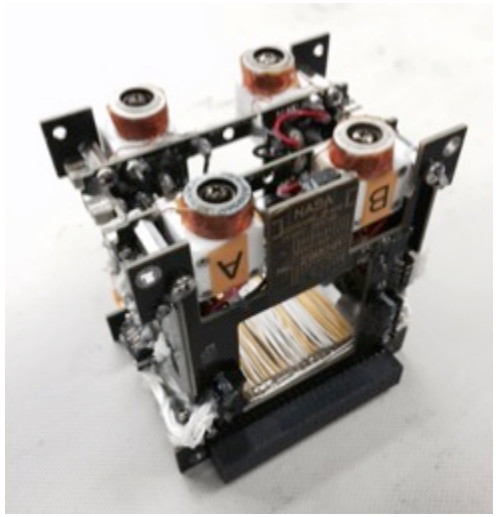
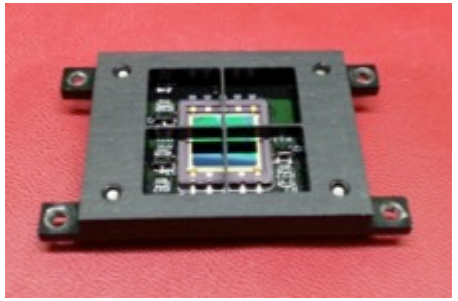
Mission Description

- CANYVAL-X: CubeSat mission as an Engineering Proof of Concept for the "Virtual" Telescope
- Validate GN&C architecture for precise dual-spacecraft inertial flight along a line-of-sight.
- **Goal: Solar Alignment < 1 arc-min (Accuracy & Stability (5 sec)) ➔ 0.3 cm**

Status

- GWU design and build mCAT
- GSFC delivered: Sun Sensor (May 2015), thrusters (mCAT) (Oct 2015)
- Yonsei Univ. building 2U and 1U spacecraft
- KARI completed Thermal Vacuum testing
- Launch on Falcon9 in mid-2016





Inertial Alignment

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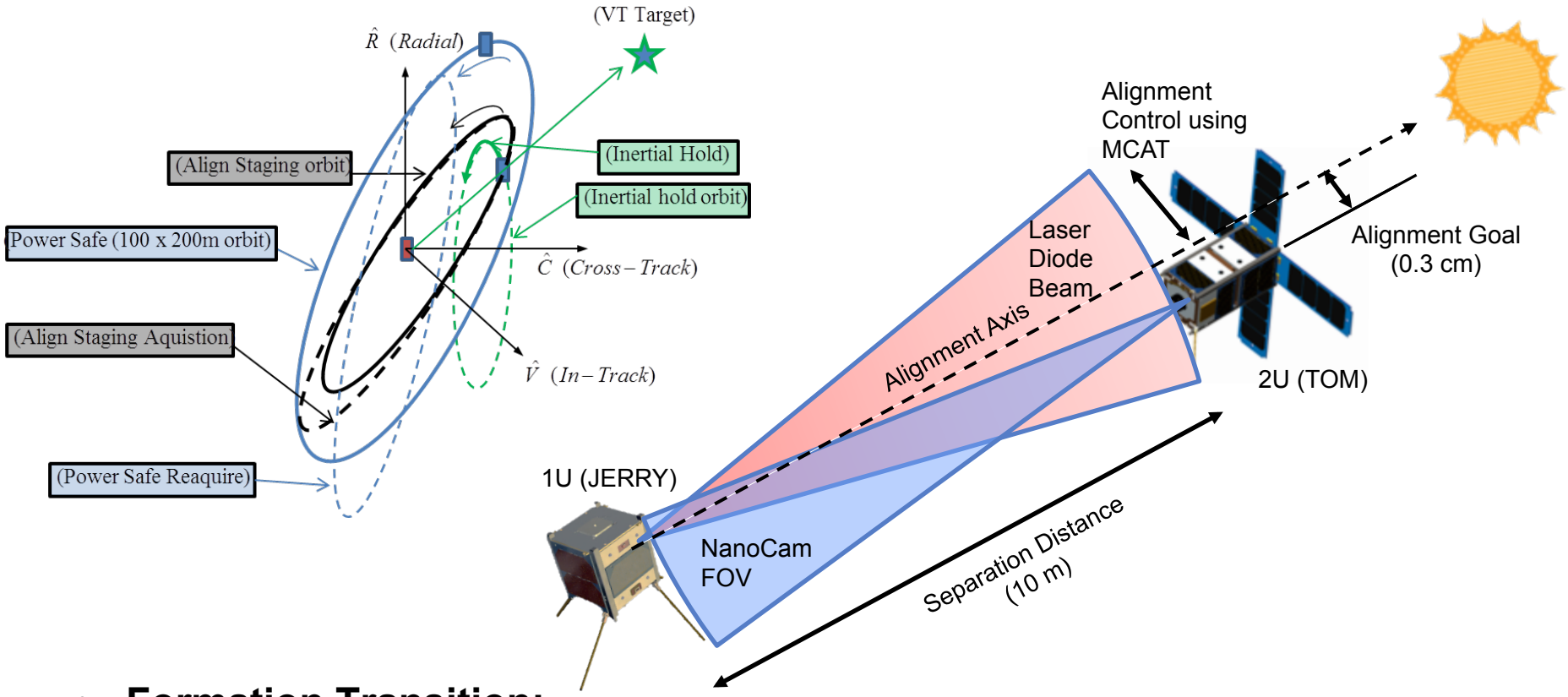

- **Formation Transition:**
  - Differential drag, GPS, and terminal point control to to get into string of pearls at 10 m range and 30 cm lateral
- **Formation Acquisition and "Science"**
  - Alignment system drives inertial alignment to 0.3cm → hold alignment for 10 minutes
- **~ 2 week inertial alignment experiment**

Mission-Requirement

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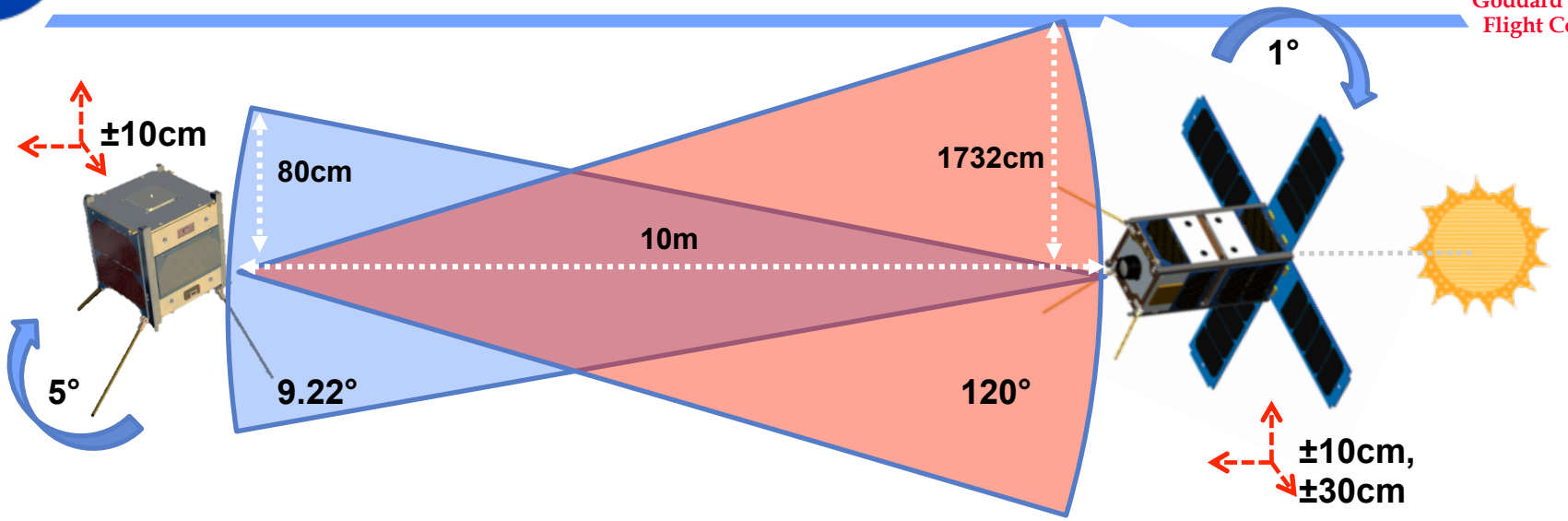

Parameter	JERRY (1U S/C)	TOM (2U+ S/C)
	Value	
Relative Distance	>= 10m	
Payload Angle	120°(±60°) (Half Intensity Beam Angle)	9.22° (NanoCam C1U Field of View)
Orbit Control	None	30cm (1 DOF µCAT x4+3axis Reaction Wheel)
Orbit Determination	Each Axis±10cm (GPS)	Each Axis±10cm (GPS)
Attitude Control	5 °(Magnetorquer) 10m x tan(5°)= 88cm	1° (Reaction Wheel) 10m x tan(1°)= 18cm
Attitude Determination	< 1 arcmin (GSFC Sun Sensor)	< 1 arcmin (GSFC Sun Sensor)

CANYVAL-X Relevance to Exo-S and SSWG

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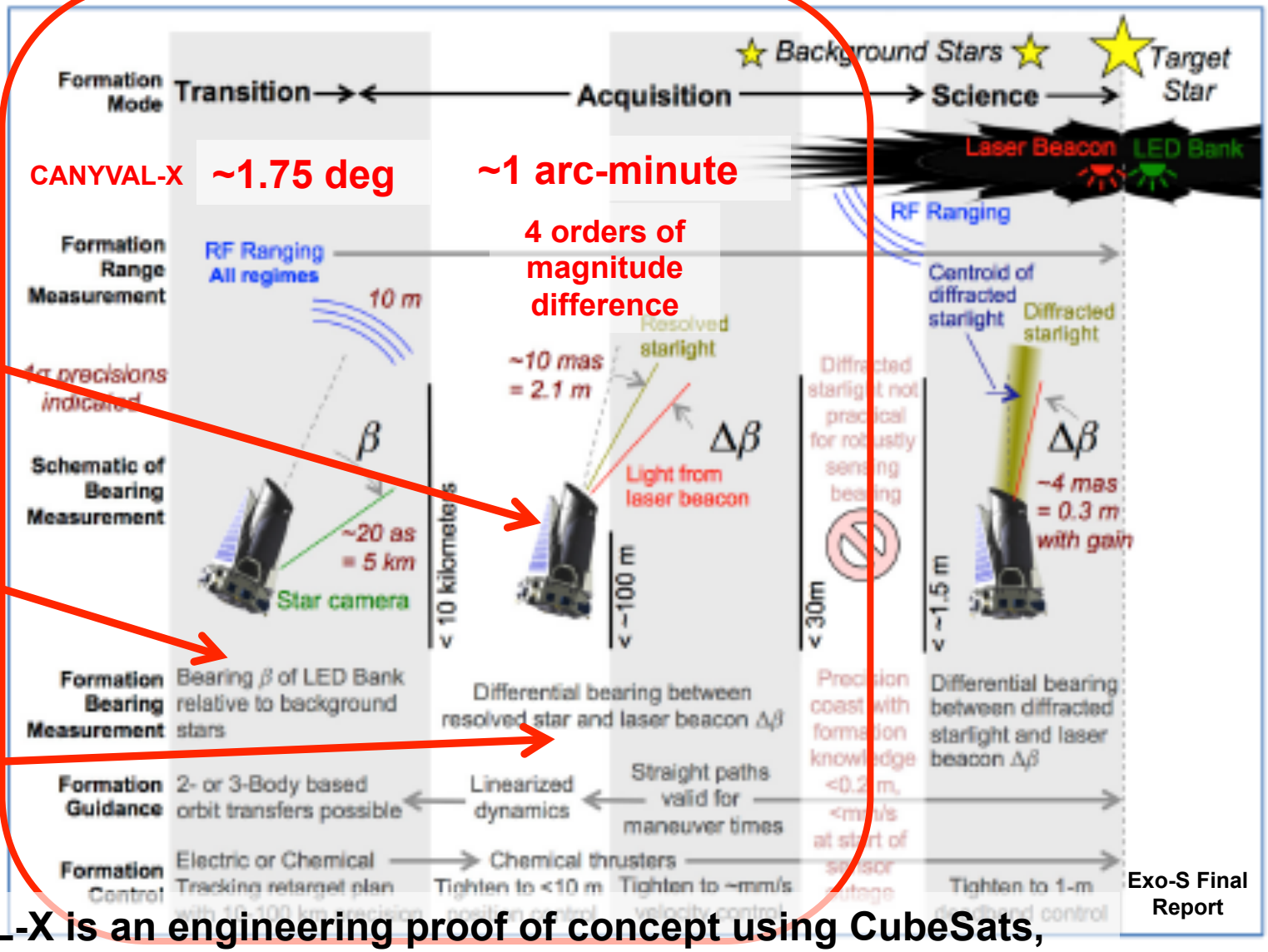
- CANYVAL-X demonstrates a similar formation architecture
- Optic replaced with Commercial Camera
- Inertial reference is sun instead of stars
- EKF to fuse sun and laser delta beta



Exo-S Final Report

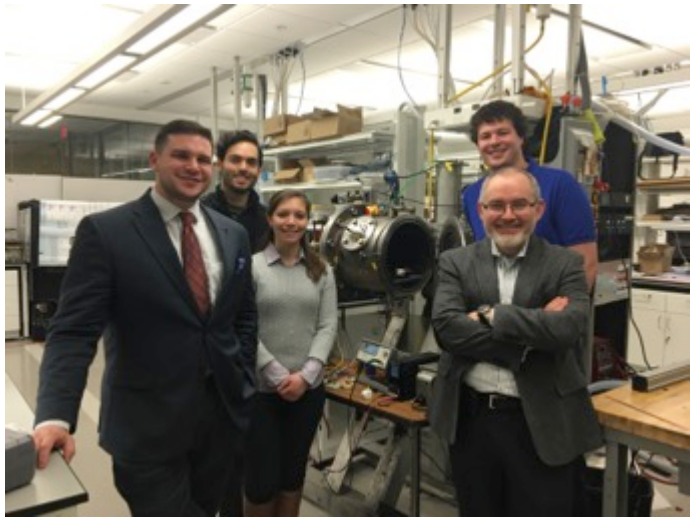
NOTE: CANYVAL-X is an engineering proof of concept using CubeSats, not designed to achieve the fine precision requried of a full-scale mission

Final Thoughts

- **Tech Demos that try to "do it all" get cancelled (paraphrase Chip Barnes presentation to SSWG on 2/11)**
- **Formation flying for over 50 years, but no one has ever built a formation flying science instrument**
  - ➔No mission has made a science measurement using a "virtual" space telescope
- **Seeking to reduce risk through system demonstrations on low-cost platforms. CubeSats are enabling.**
- **CANYVAL-X is an engineering proof of concept**

CANYVAL-X Team

Yonsei University



George Washington University

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Backup

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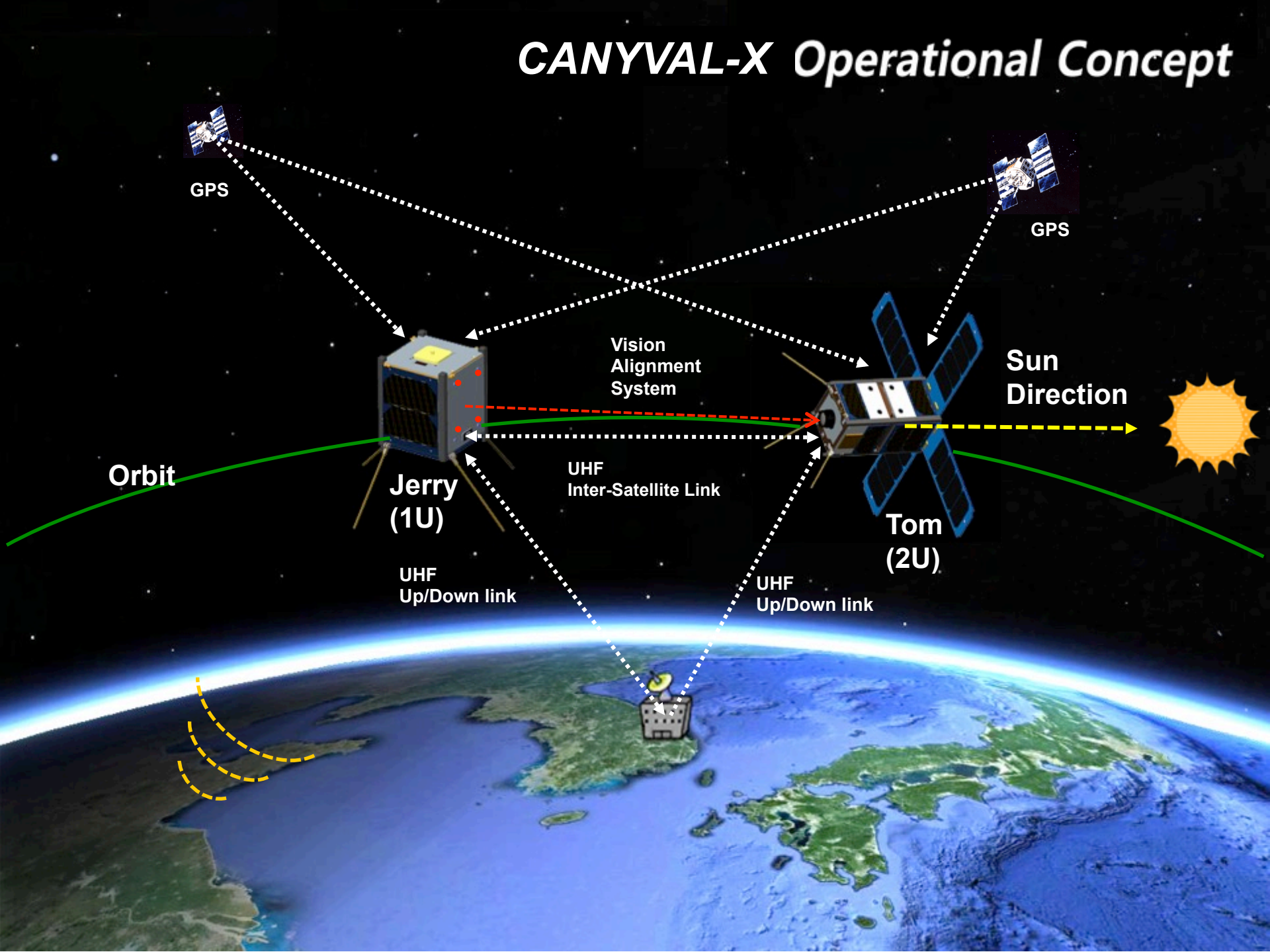
CANYVAL-X Operational Concept
GPS
GPS
Vision
Alignment
System
Sun
Direction
Orbit
Jerry
(1U)
UHF
Inter-Satellite Link
Tom
(2U)
UHF
Up/Down link
UHF
Up/Down link

CANYVAL-X CubeSat 2U (TOM)

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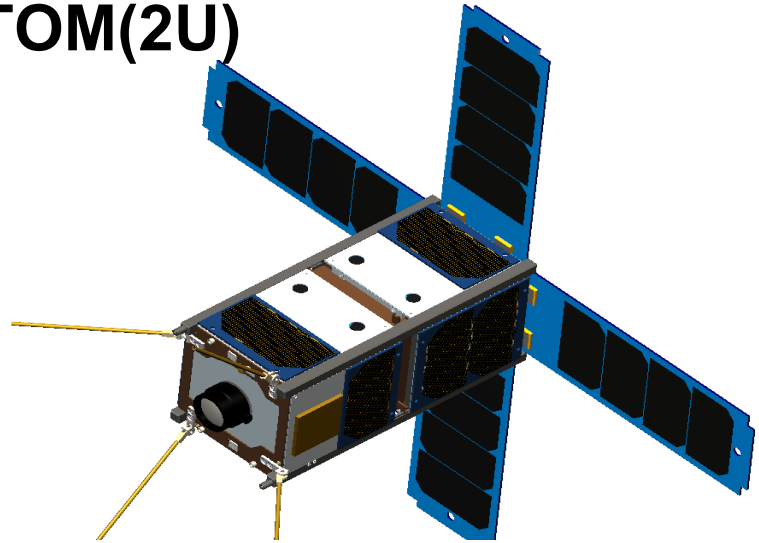
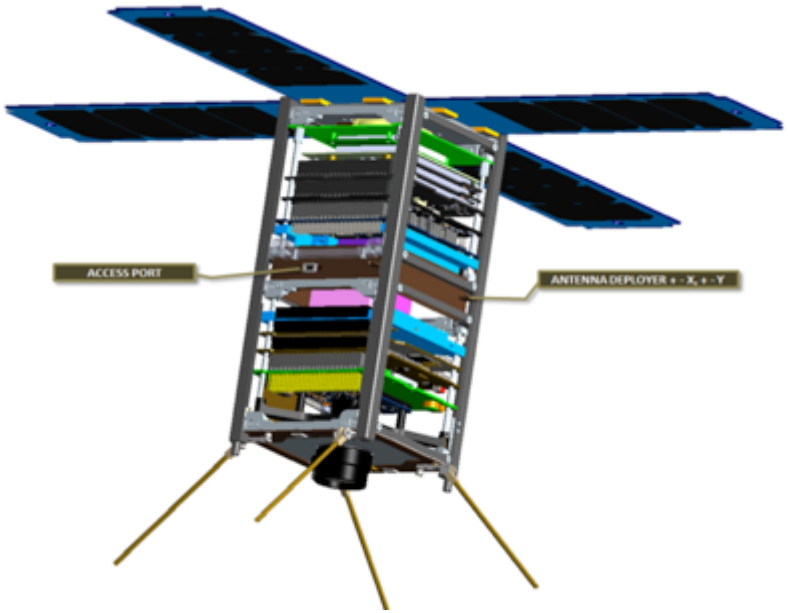
TOM(2U)





Properties	Value
Mission Life Time	3-6 Month
Payload	Visible Camera (NanoCam)
Payload Performance	2048 x 1536 pixels CMOS sensor 35mm lens / F1.9
GN&C	MCAT, Sun Sensor, NanoCam, Rea ction Wheels, Mag TorqRods)
Data Rate	Uplink : 4.8kbps(UHF) Downlink 100kbps(S-band)
Mass	2.7 kg

CANYVAL-X CubeSat 2U (JERRY)

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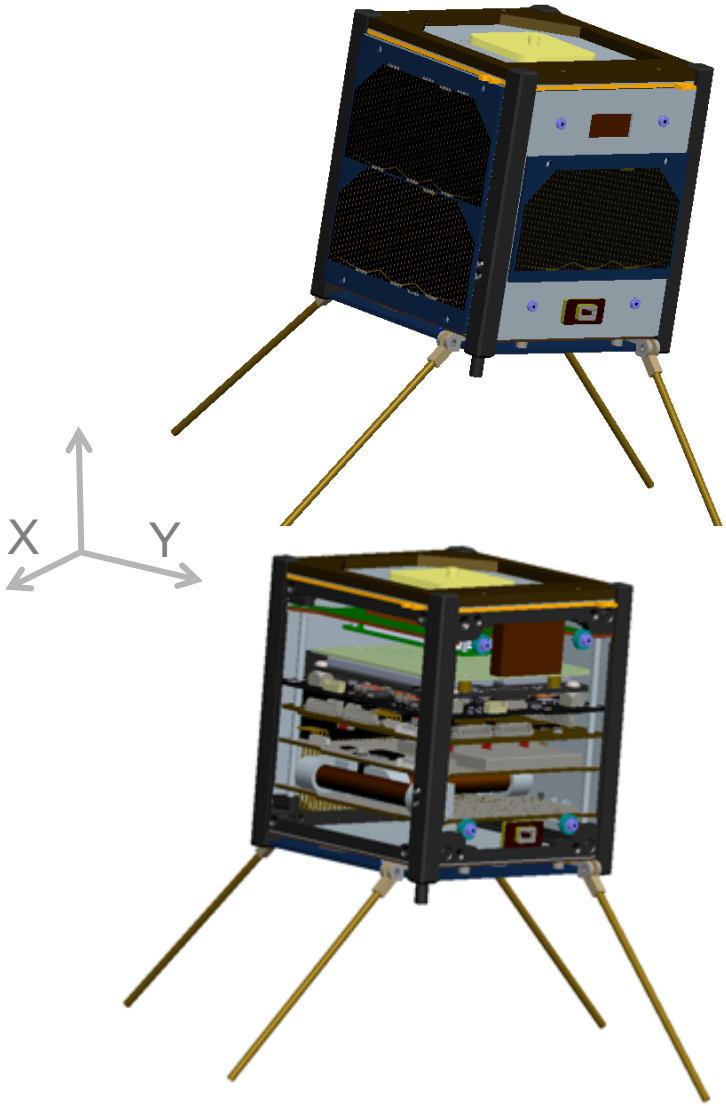
JERRY(1U)



Properties	Value
Mission Life Time	3-6 Month
Payload	4 Laser Diodes
Payload Performance	Half Intensity Beam Angle = ±60° Minimum angle(15.5°) intensity > 96%
ADCS Performance	(Magnetorquer, sun sensor)
Data Rate	Up/Downlink : 4.8kbps(UHF)
Mass	1.0 kg