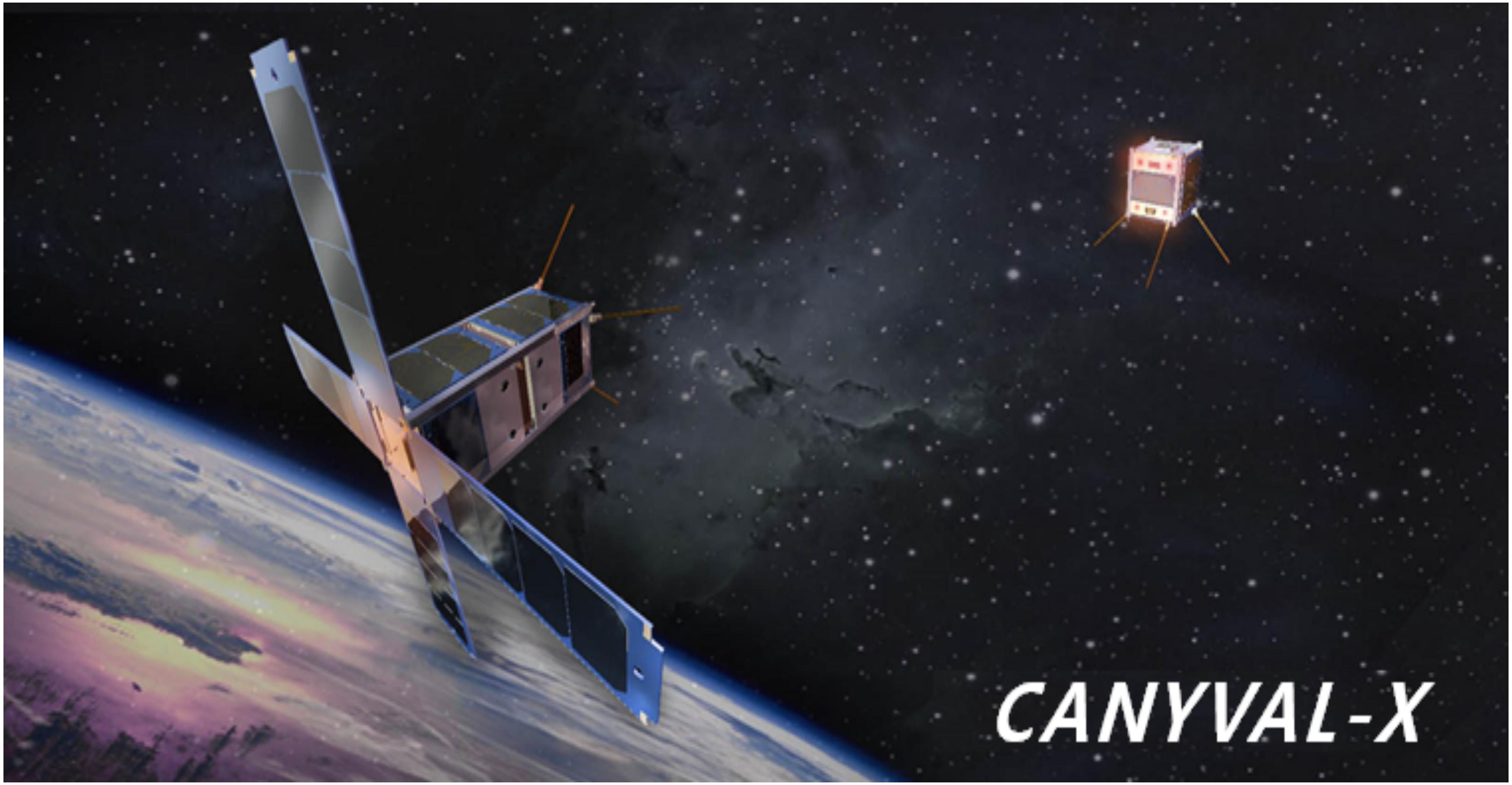
# The "Virtual" Space Telescope: A New Class of Science Missions

Goddard Space Flight Center




**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:**

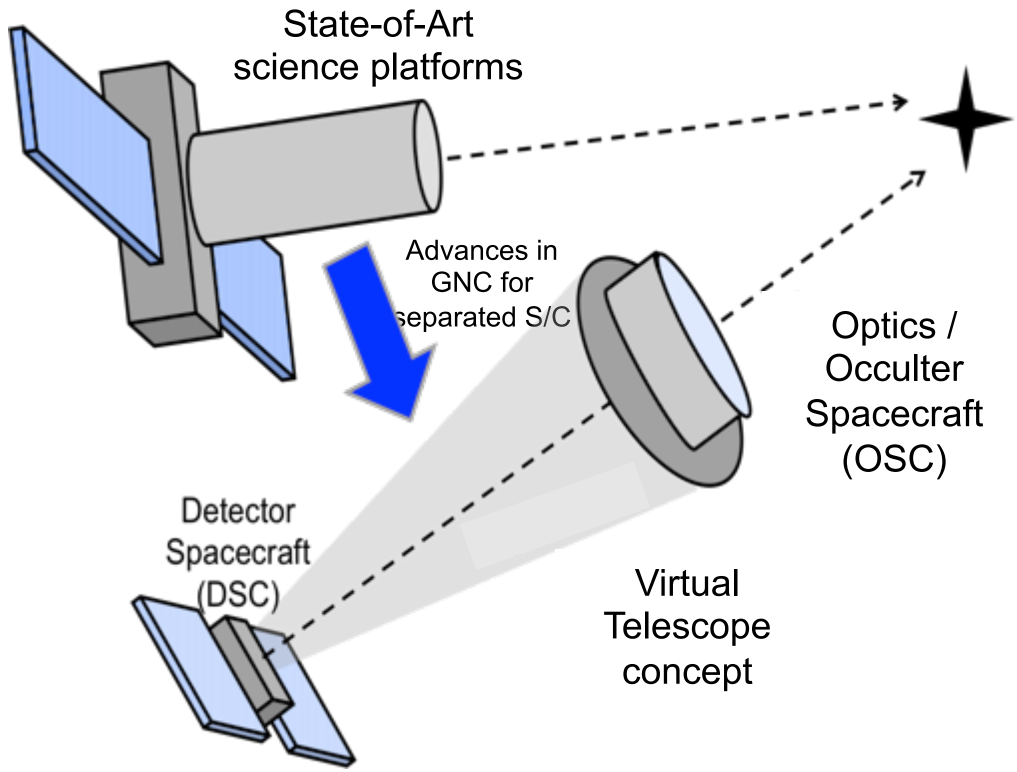
- Milli Arc Second X-ray imaging
- Micro Arc Second X-ray imaging
- Calibration Telescope
- Starshade

**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?



**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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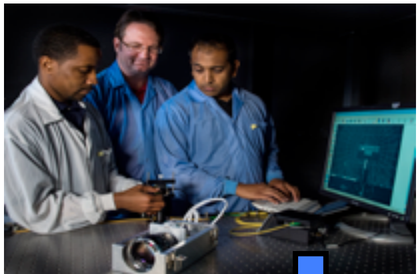


**Ground/Lab Demo**

- Component-level testing and development
- Goal: TRL 5

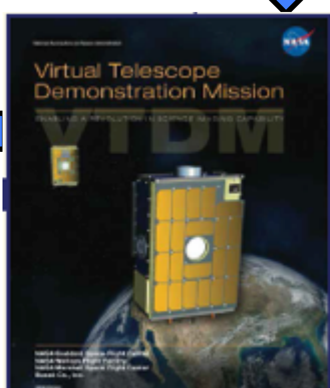
## Current Status:

- 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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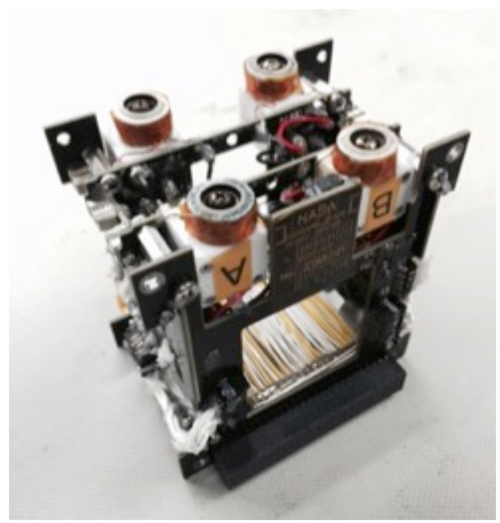
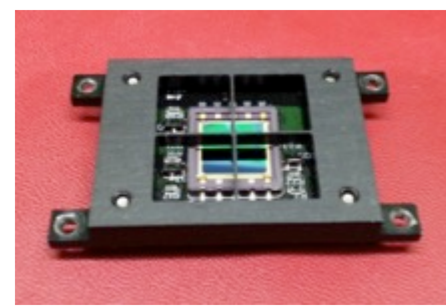
## Mission Description

- 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**

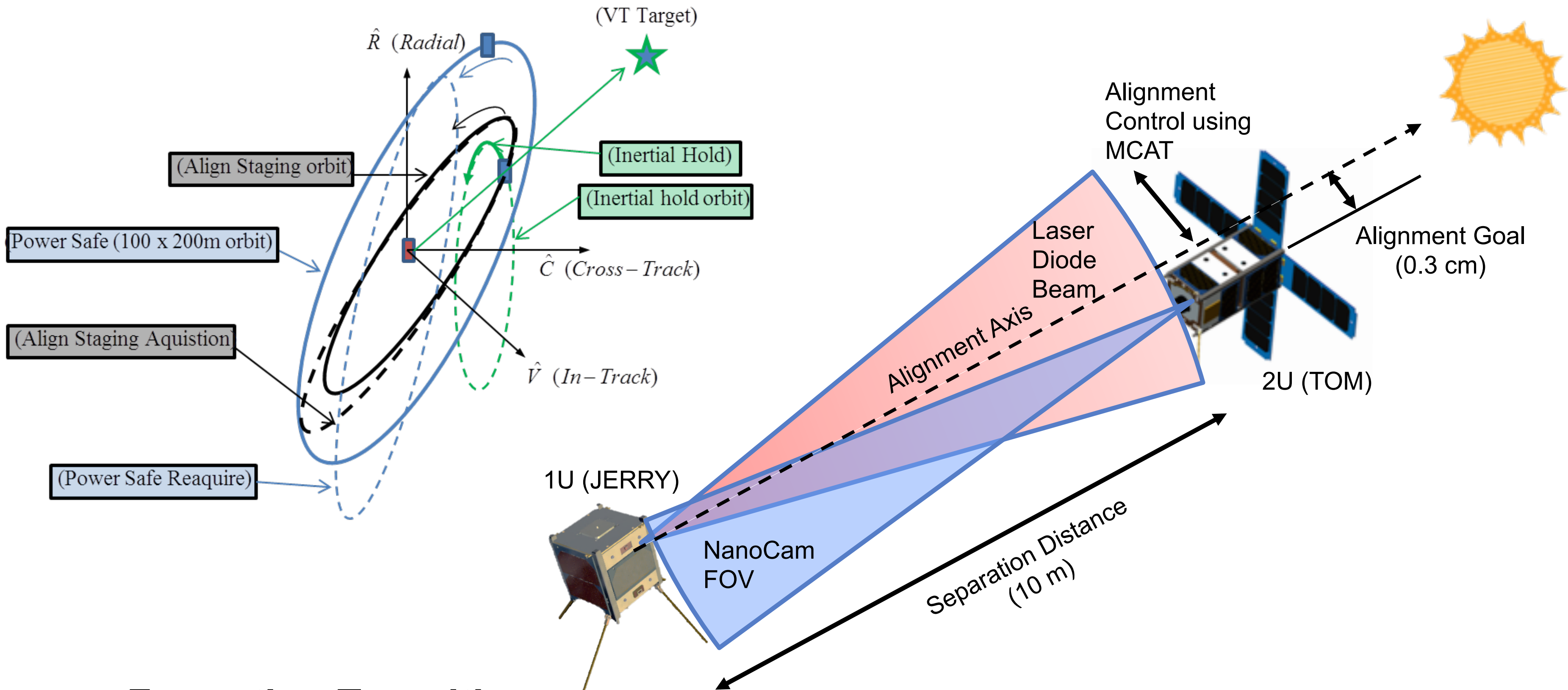
## Status

- 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





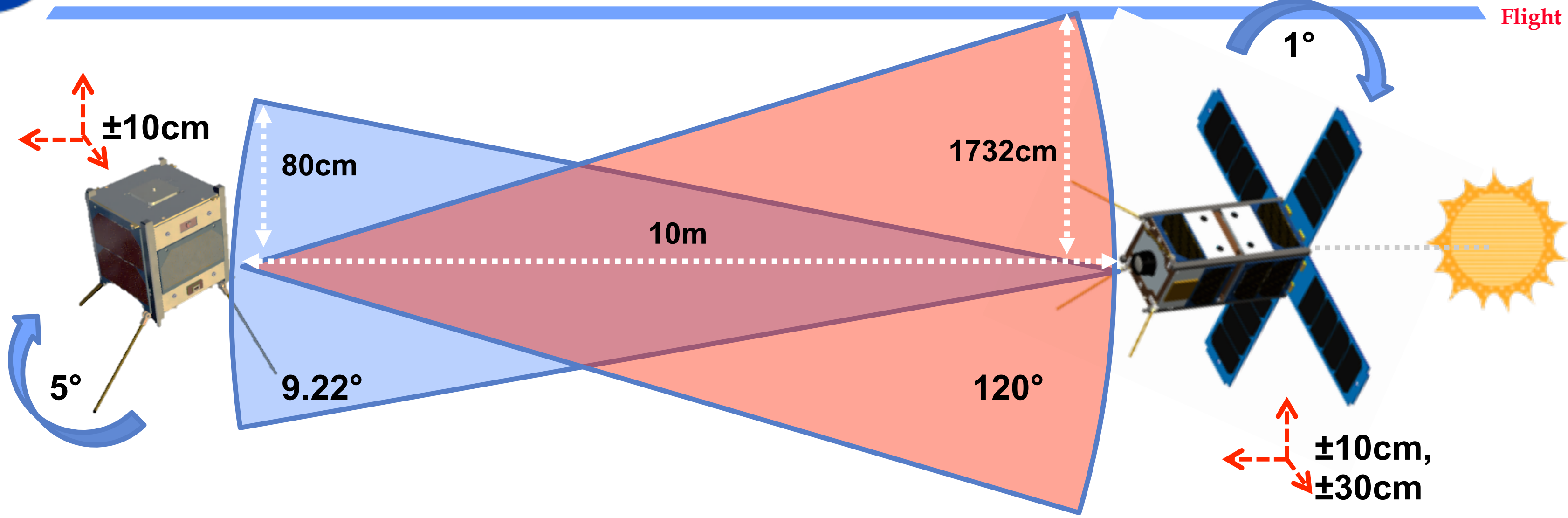
# Inertial Alignment




- **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






| Parameter | JERRY (1U S/C) | TOM (2U+ S/C) |
|---|---|---|
| | Value | |
| Relative Distance | >= 10m | |
| Payload Angle | 120°(±60°)<br>(Half Intensity Beam Angle) | 9.22°<br>(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)<br>10m x tan(5°)= 88cm | 1° (Reaction Wheel)<br>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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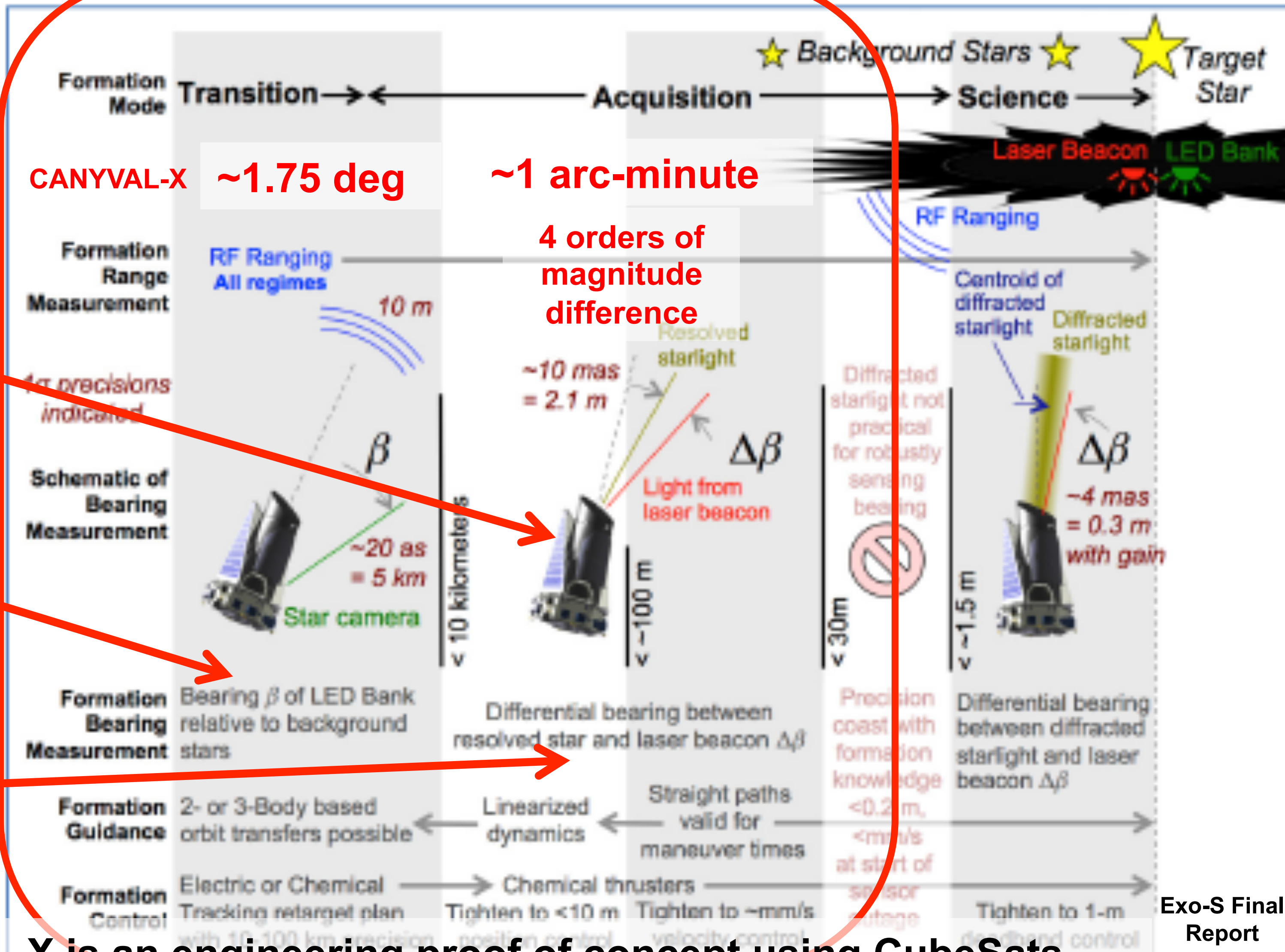
- CANYVAL-X demonstrates a similar formation architecture
- Optic replaced with Commercial Camera
- Inertial reference is sun instead of stars
- EKF to fuse sun and laser delta beta




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

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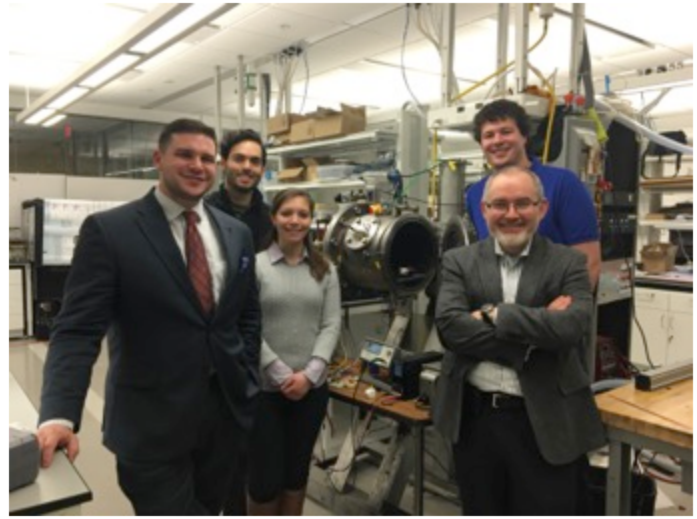
- **Tech Demos that try to "do it all" get cancelled (paraphrase Chip Barnes presentation to SSWG on 2/11)**
- **Formation flying for over 50 years, but no one has ever built a formation flying science instrument**
  - ➔No mission has made a science measurement using a "virtual" space telescope
- **Seeking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

# CANYVAL-X Team

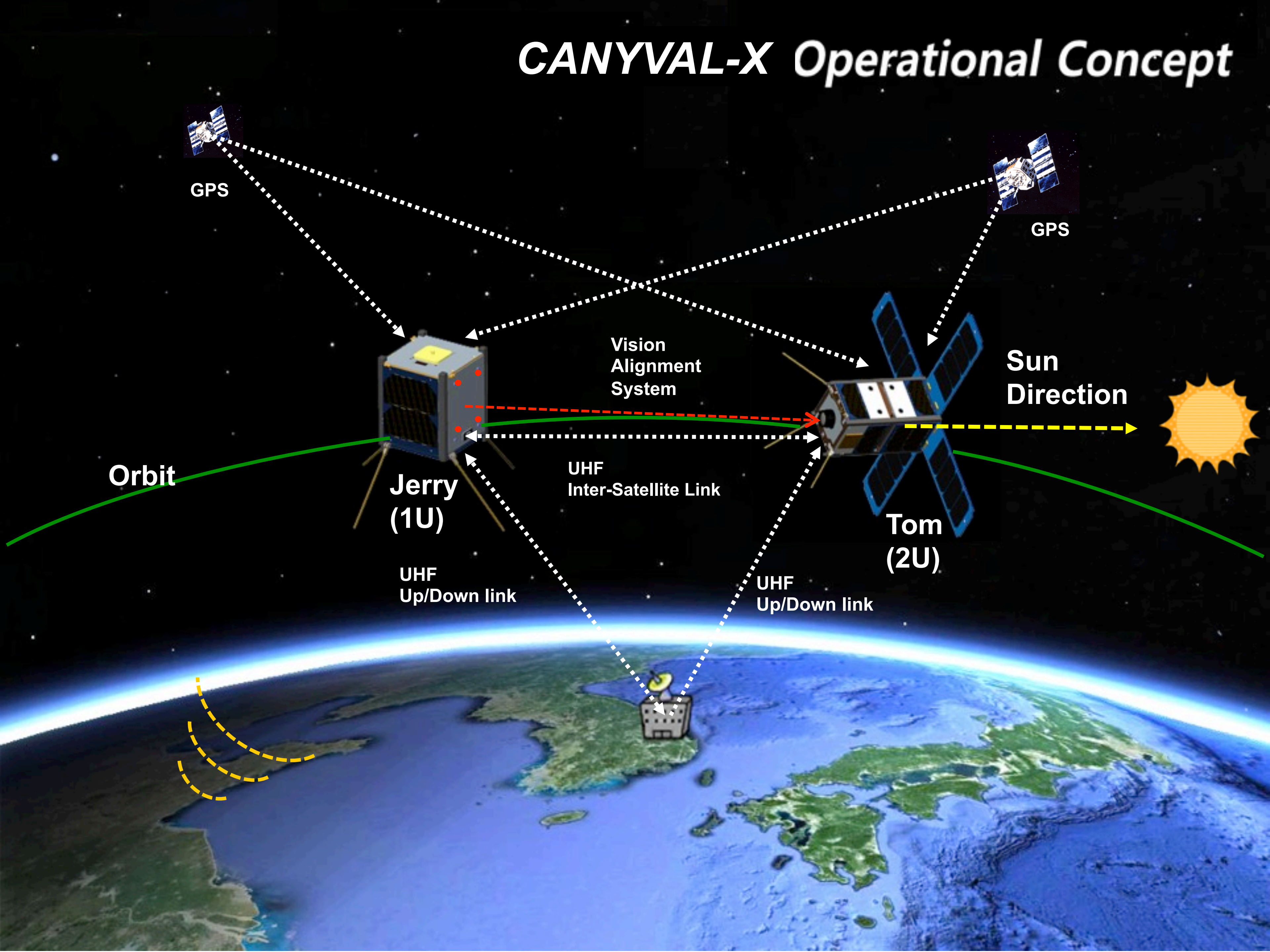
Yonsei University



George Washington University

NASA Goddard Space Flight Center

# Backup


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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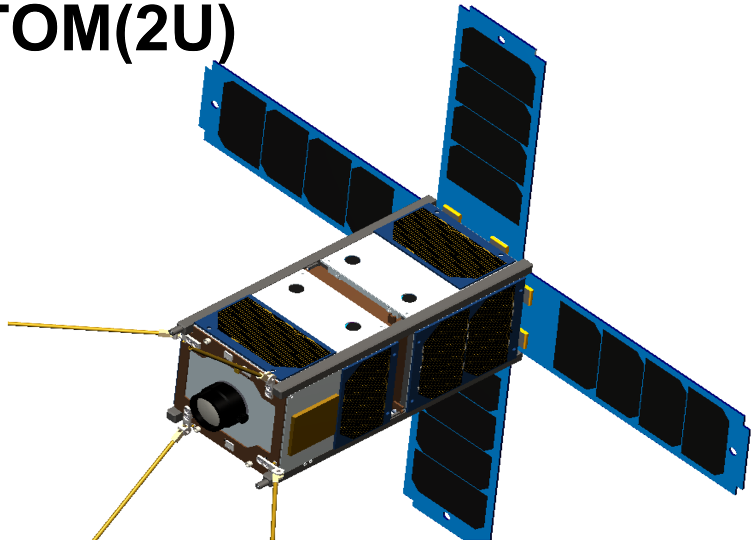
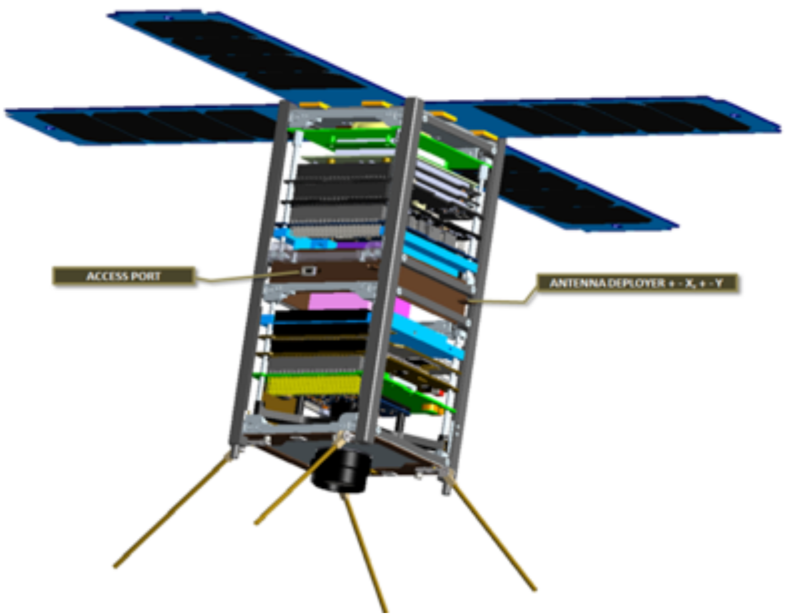
## TOM(2U)






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

# CANYVAL-X CubeSat 2U (JERRY)

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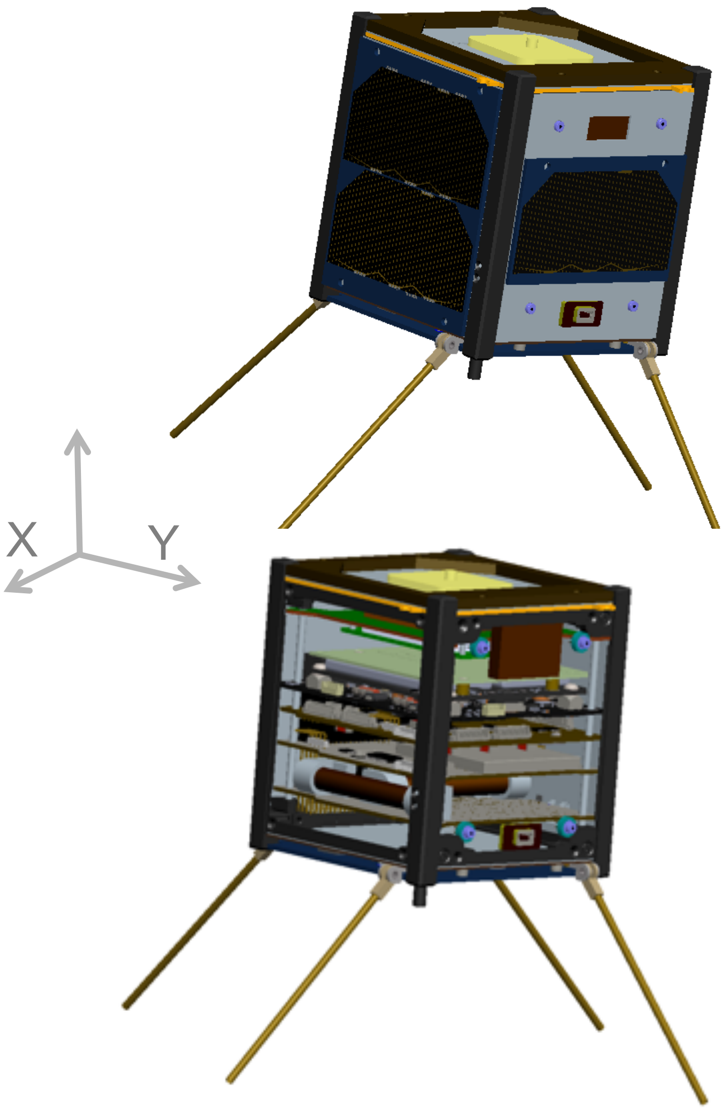
## JERRY(1U)




| 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 |