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ExoplanetSat:
A Nanosatellite Space Telescope for Detecting Transiting Exoplanets

Matthew W. Smith[1] (m_smith@mit.edu),
Sara Seager[1], Christopher M. Pong[1], Sungyung Lim[2],
Matthew W. Knutson[1], Timothy C. Henderson[2], Joel N. Villaseñor[1],
Nicholas K. Borer[2], David W. Miller[1], Shawn Murphy[2]

CubeSat Developers' Workshop
April 20-22, 2011
San Luis Obispo, CA

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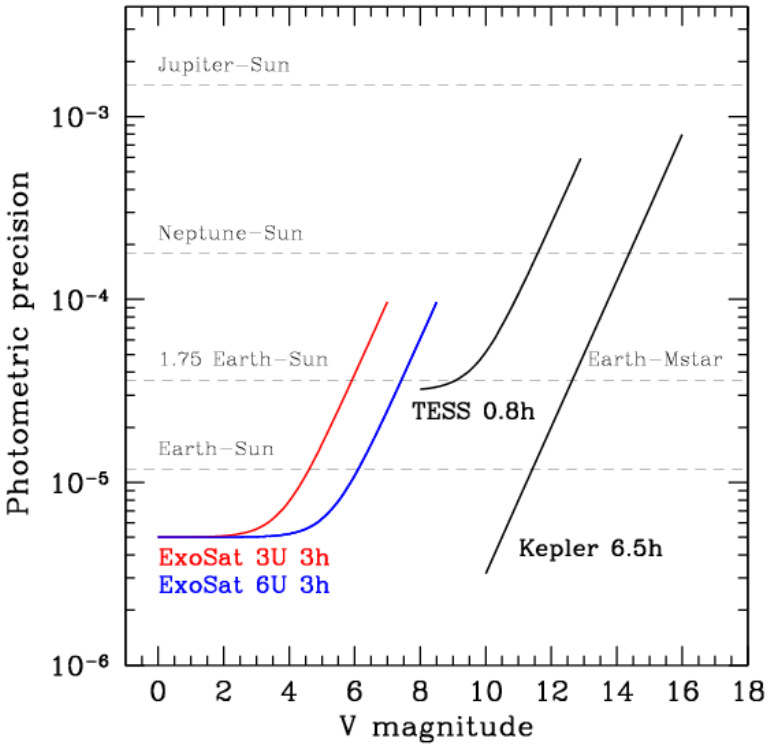
SPACE FLIGHT CENTER

Outline

- Science
- Concept of operations
- Long term vision
- Spacecraft design
  - Ongoing trades
  - Payload
  - Attitude determination and control
- Hardware test results
- Future Work

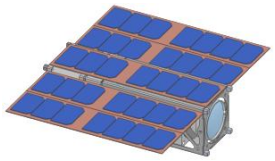
Exoplanet Science & Motivation

- **High-level goal:** Search the brightest Sun-like stars for transiting Earth-size planets
  - Constellation of satellites
  - Bright star search enables follow up characterization studies (vs. Kepler)
- **Prototype goal:** 3U CubeSat capable of 10 ppm photometry (7σ detection of Earth-sized planets) for bright ($0 \leq V \leq 6$) Sun-like stars



- Why CubeSat form factor for transit searches of bright stars?

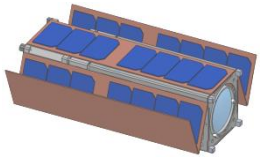
Bright stars are spread across the sky → Need many, dedicated telescopes → Low cost per spacecraft, frequent launches

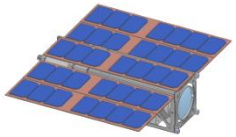


3U CubeSat form factor

Concept of Operation

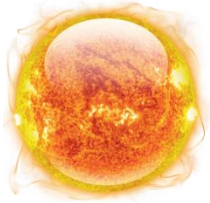
Orbit Insertion:
Deployment
from P-POD



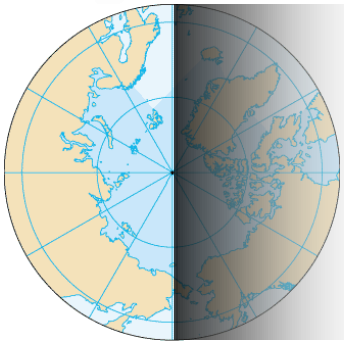


Acquisition:
Detumble satellite
Initialize attitude estimate

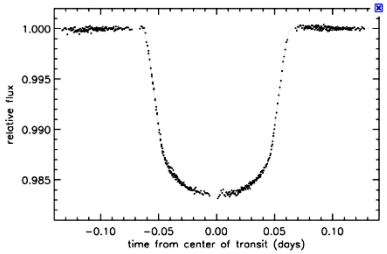
Slew:
Point solar arrays to sun



Orbit Day:
Hold attitude
Charge batteries



Orbit Night:
Hold attitude
Observe target star



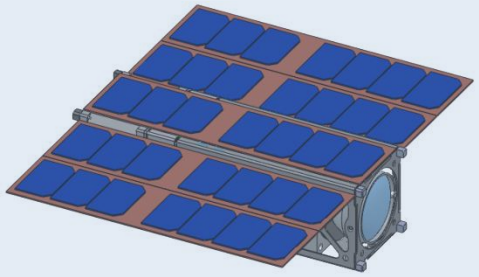
Brown et al. 2001

Slew:
Point optics to target star

Measurement:
Time series of stellar flux

Long-Term Vision

- Fleet of small satellites (3U CubeSats, 6U CubeSats, EPSA-class) in low-Earth orbit, collectively monitoring hundreds of Sun-like stars



Phase 1:

- Single prototype
- Tech demonstration (arsecond-level pointing)
- Observe alpha centauri (brightest Sun-like star)
- Search for transits of known super Earth exoplanets

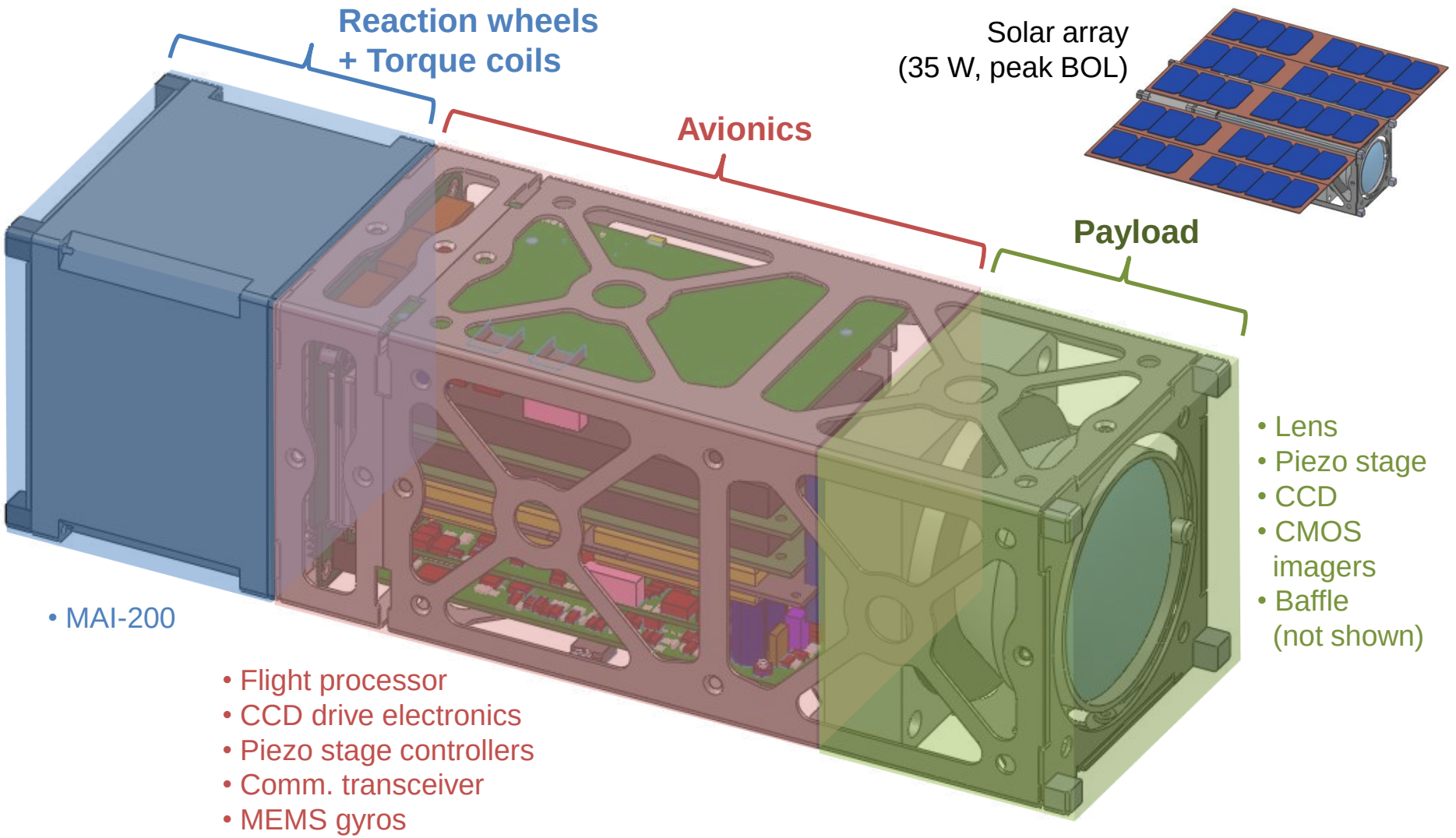
Phase 2:

- Add 3U models + 6U models with 120 mm apertures
- Observe 20 brightest stars for Earth-sized transits
- 10-15 spacecraft needed

Phase 3:

- Full planet detection survey
- Seek 95% confidence of 3+ planet detections
- Observe bright stars to V = 8
- Observe 250 stars
- Expanded fleet

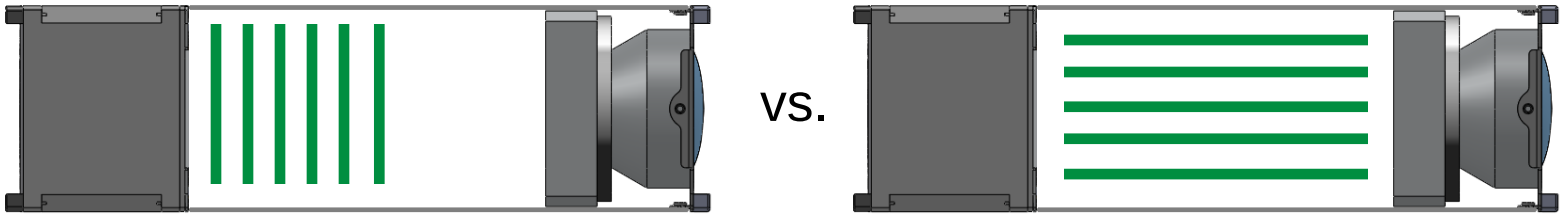
Spacecraft Design



Not shown: patch antennas, wiring

Ongoing Trades

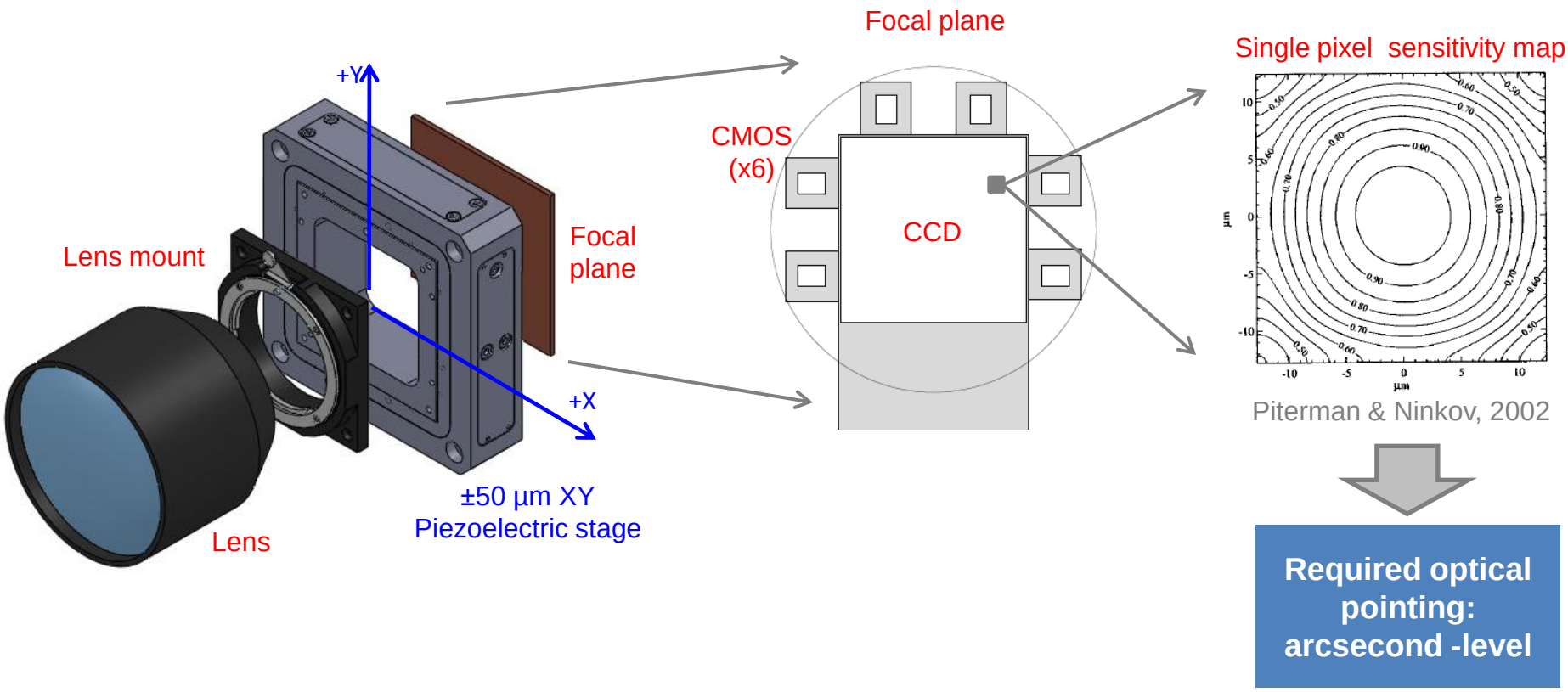
- Mass
  - Currently at approximately 5.5 kg
- Volume
  - Off-the-shelf vs. custom lens
  - Evaluating board layout (PC-104 cards vs. custom PCBs)



- Detector architecture
  - Number and placement of CMOS imagers for star tracking
  - Science detector selection

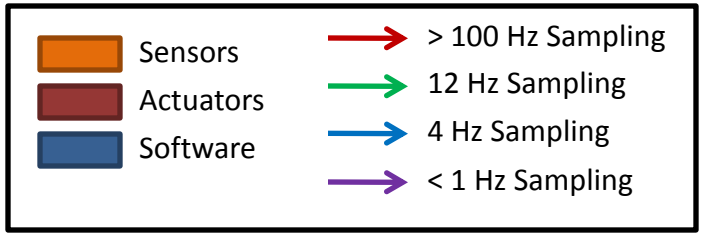
Payload

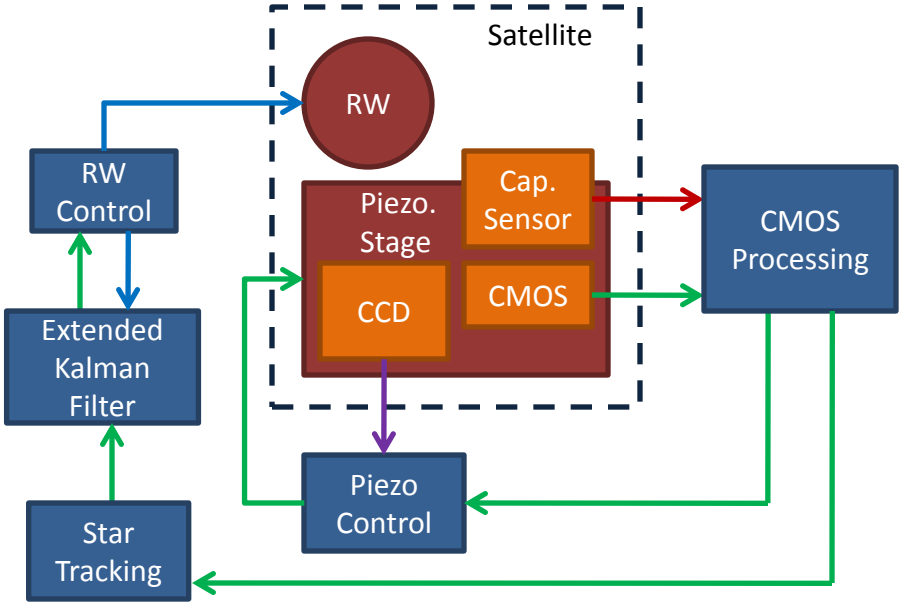
- Variation within CCD pixel requires arcsecond-level optical pointing
- Combined star tracker (CMOS imagers) and science telescope (CCD)
  - CCD: Defocused, ≥1 s integration time to collect many photons
  - CMOS: In focus, ≤100 ms integration time to provide frequent updates to estimator



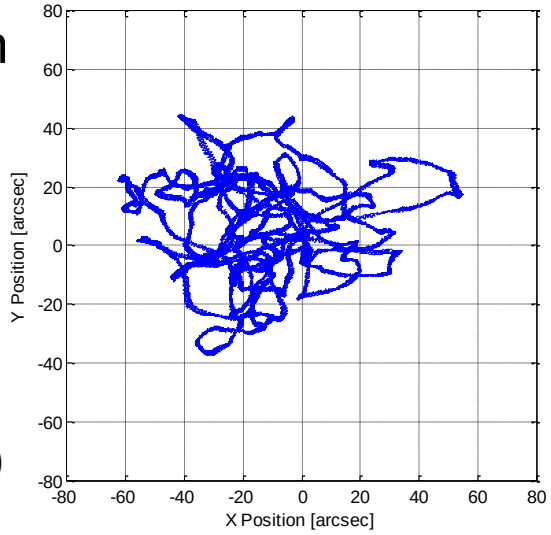
Attitude Determination & Control

- Two-stage pointing control
  1. Coarse pointing:
     Reaction wheels (< 120 arcsec 3σ)
  2. Fine pointing:
     Piezoelectric stage (5-10 arcsec 3σ)

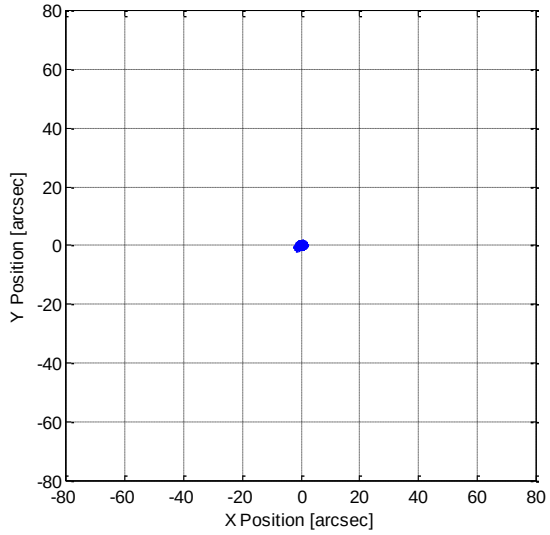




- Simulation results



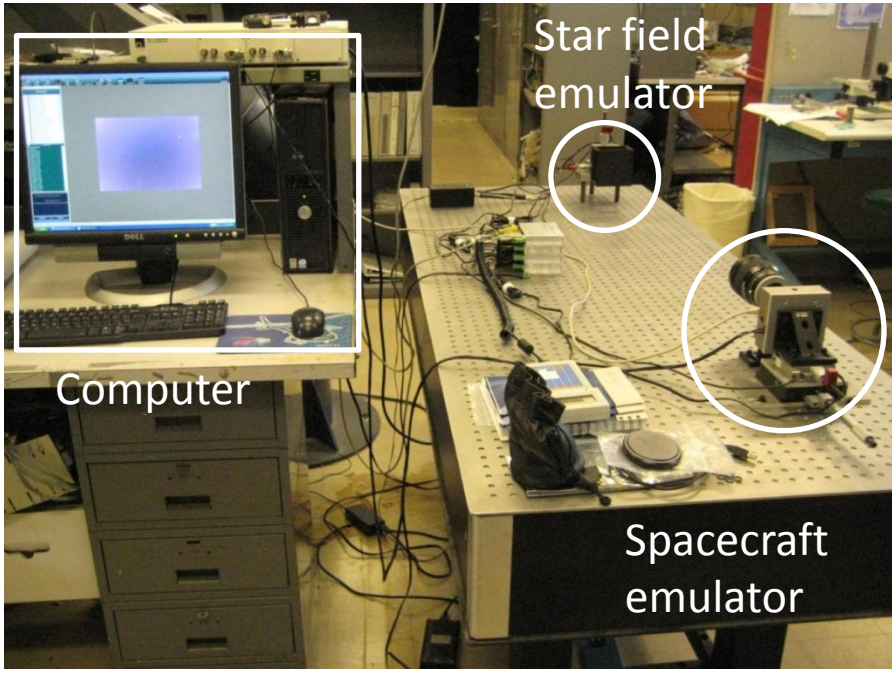
Coarse pointing (no stage)

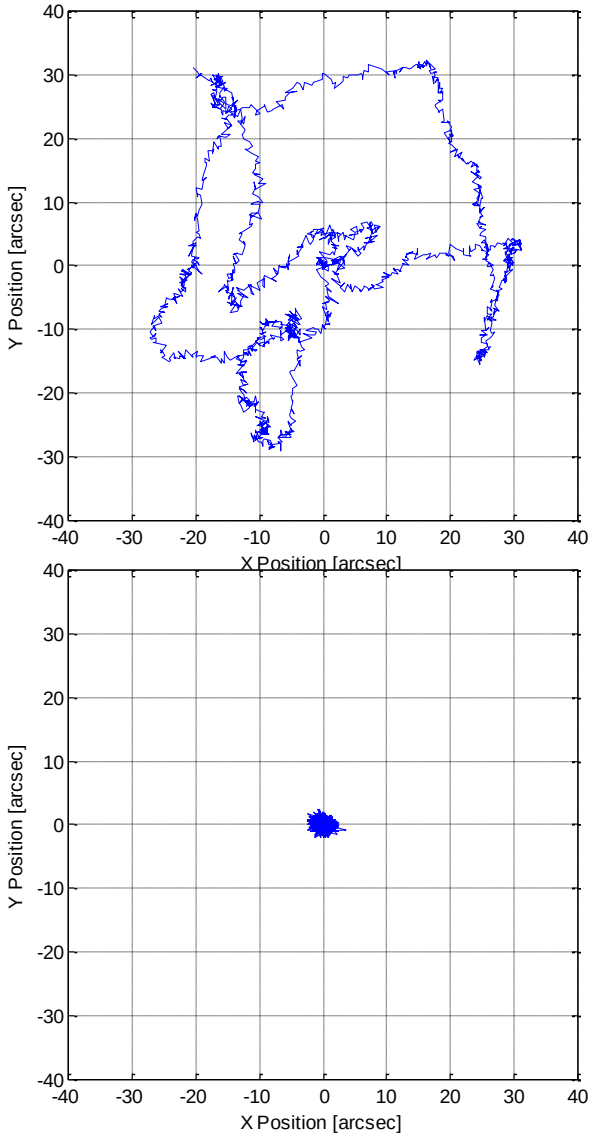


Fine pointing (with stage)

ADCS Testing

- Hardware in-the-loop test
  - Successful proof-of-concept demonstration of fine pointing stage: **2.3 arcseconds (3σ)**
  - Inject simulated residual pointing errors from reaction wheels using **star field emulator**
  - Correct for pointing errors on **spacecraft emulator** with lens, detector, piezoelectric stage





Future Path

- ADCS hardware-in-the-loop test bed
  - Spherical air bearing
  - Two-stage control functional demo (piezo stage + reaction wheels in the loop)
- Payload
  - Intrapixel sensitivity measurements
  - Mature science data processing pipeline
- Avionics development
  - FPGA + Microcontroller architecture
- "Bus" subsystems currently at varying levels of maturity
  - Power
  - Structure
  - Comm
  - Thermal
- Environmental testing at Draper, MIT, NASA GSFC
- Goal: launch in 2012-13 time frame
  - Selected under NASA CubeSat Launch Initiative in January, 2011

MIT 3DOF spherical air bearing test stand

Conclusion

- ExoplanetSat will combine the low-cost CubeSat platform with two-stage attitude control to detect Earth-sized planets around the brightest stars
- The 3U prototype is under development with a potential launch date through the NASA CubeSat Launch Initiative
- Key engineering breakthrough: very high precision pointing (arcsecond-level) in a CubeSat
- ExoplanetSat initiates the graduated growth of a modular, extensible constellation, with the final phase being many satellites surveying bright stars for other Earths

Acknowledgements

- NASA Jet Propulsion Laboratory
  - Dr. Wes Traub
  - Strategic University Research Partnerships Program (SURP)
- Lincoln Laboratory, Advanced Imaging Technology Group
  - Dr. Vyshi Suntharalingham
  - Dr. Barry Burke
- NASA Goddard Space Flight Center
  - Dr. Stephen Rinehart
- MIT
  - Students of 16.83x / 12.43x
  - Department of Aeronautics and Astronautics
  - Dr. George Ricker

Some Relevant Literature

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