ExoplanetSat:
A Nanosatellite Space Telescope for Detecting Transiting Exoplanets

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Outline

• Science

• Concept of operations

• Long term vision

• Spacecraft design
  – Ongoing trades
  – Payload
  – Attitude determination and control

• Hardware test results

• Future Work
- **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 ($7\sigma$ 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

Orbit Night:
Hold attitude
Observe target star

Orbit Day:
Hold attitude
Charge batteries

Slew:
Point solar arrays to sun

Slew:
Point optics to target star

Measurement:
Time series of stellar flux

Brown et al. 2001

2011 CubeSat Developers' Workshop
**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

Reaction wheels + Torque coils

Avionics

Solar array (35 W, peak BOL)

Payload

- MAI-200
- Flight processor
- CCD drive electronics
- Piezo stage controllers
- Comm. transceiver
- MEMS gyros
- Electrical power subsystem (EPS) + batteries

Not shown: patch antennas, wiring

Lens
Piezo stage
CCD
CMOS imagers
Baffle (not shown)
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
• 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
• 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)
• 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
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.
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Some Relevant Literature


