CubeSats in Astronomy and Astrophysics

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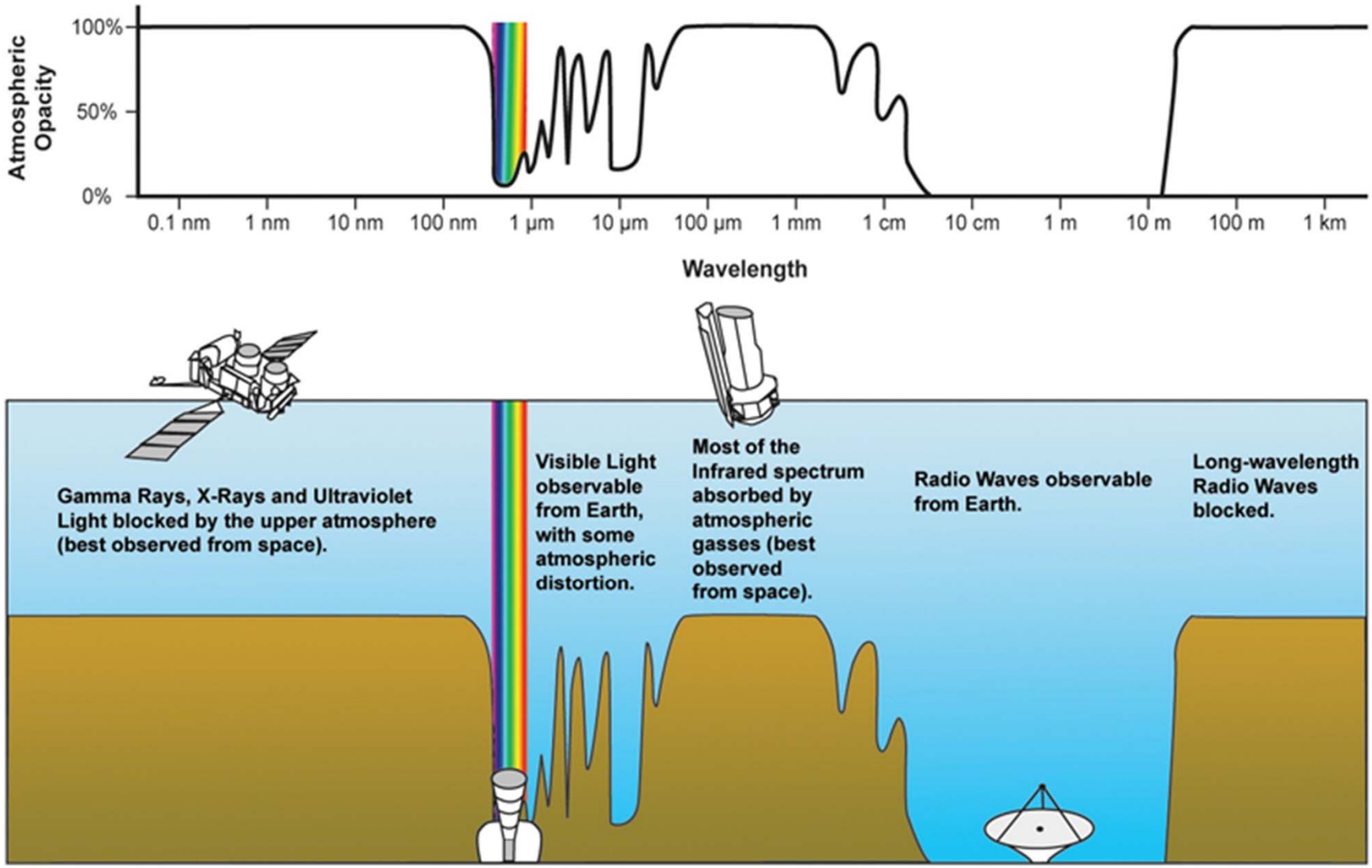
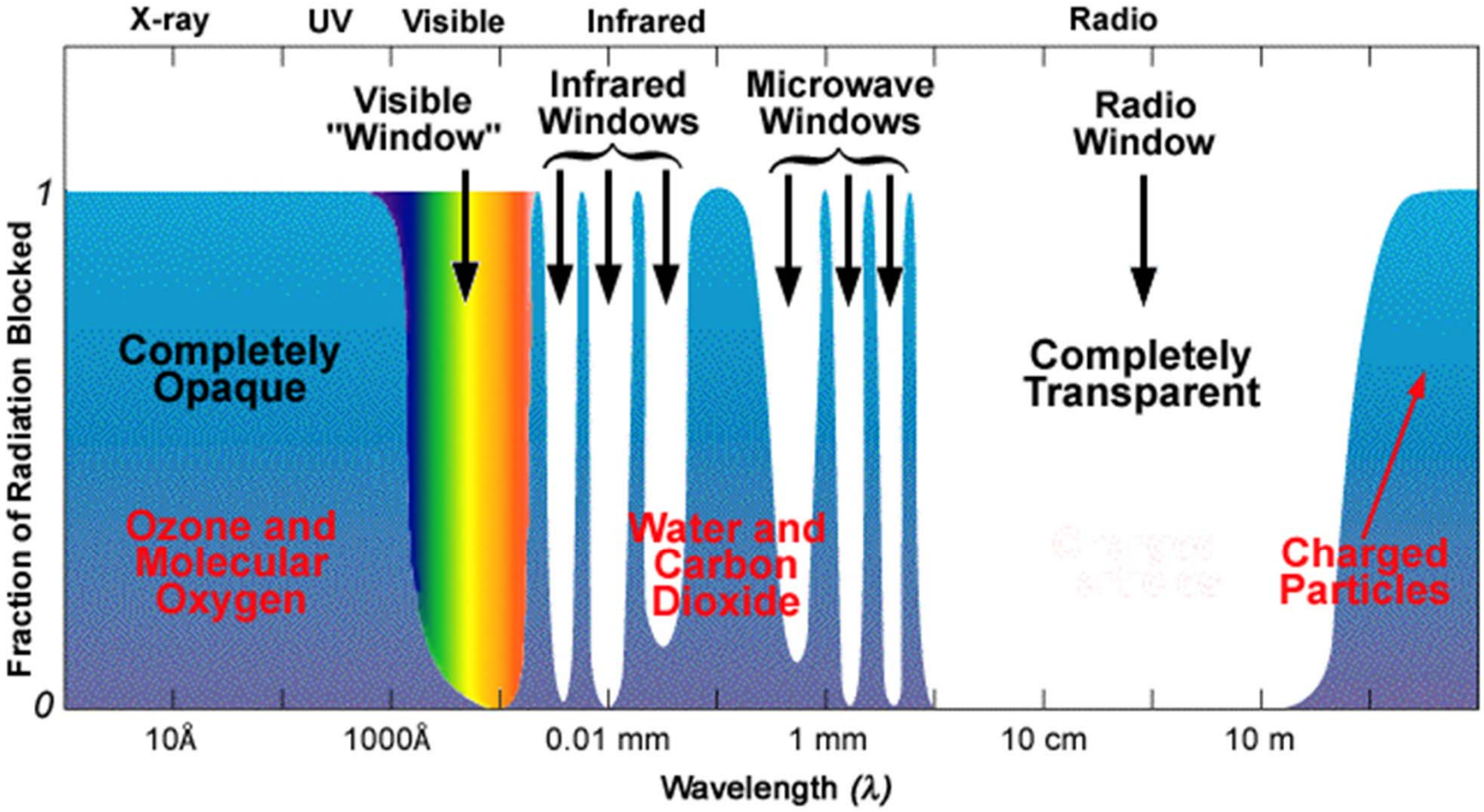
Sept. 2, 2015

Above the Atmosphere



[http://www.ipac.caltech.edu/outreach/Edu/Windows/irwindows.html]

Above the Atmosphere



[http://www22.homepage.villanova.edu/rex.saffer/SESAME/radiation_files/transatmos.jpg]

Astronomy and Astrophysics

- **CubeSat Opportunities and Limitations**
  - *Some* Limitations → Technology Development
- Cosmic dawn
- Galactic evolution
- Stellar evolution
- Extrasolar planets
- To Infinity and Beyond!
- Technology Development

CubeSat Opportunities and Limitations

- **Opportunities**
  - Above the atmosphere
  - Can sit and stare at targets (assuming pointing is good enough)
  - More launch opportunities
  - Lower cost*
- **Limitations**
  - Aperture
    - Deployables
    - Distributed apertures
  - Pointing
  - Navigation
  - Limited downlink data rates
  - Limited power
  - Orbits determined by host

**hardware costs may be lower, however, still have personnel, and carry higher risk*

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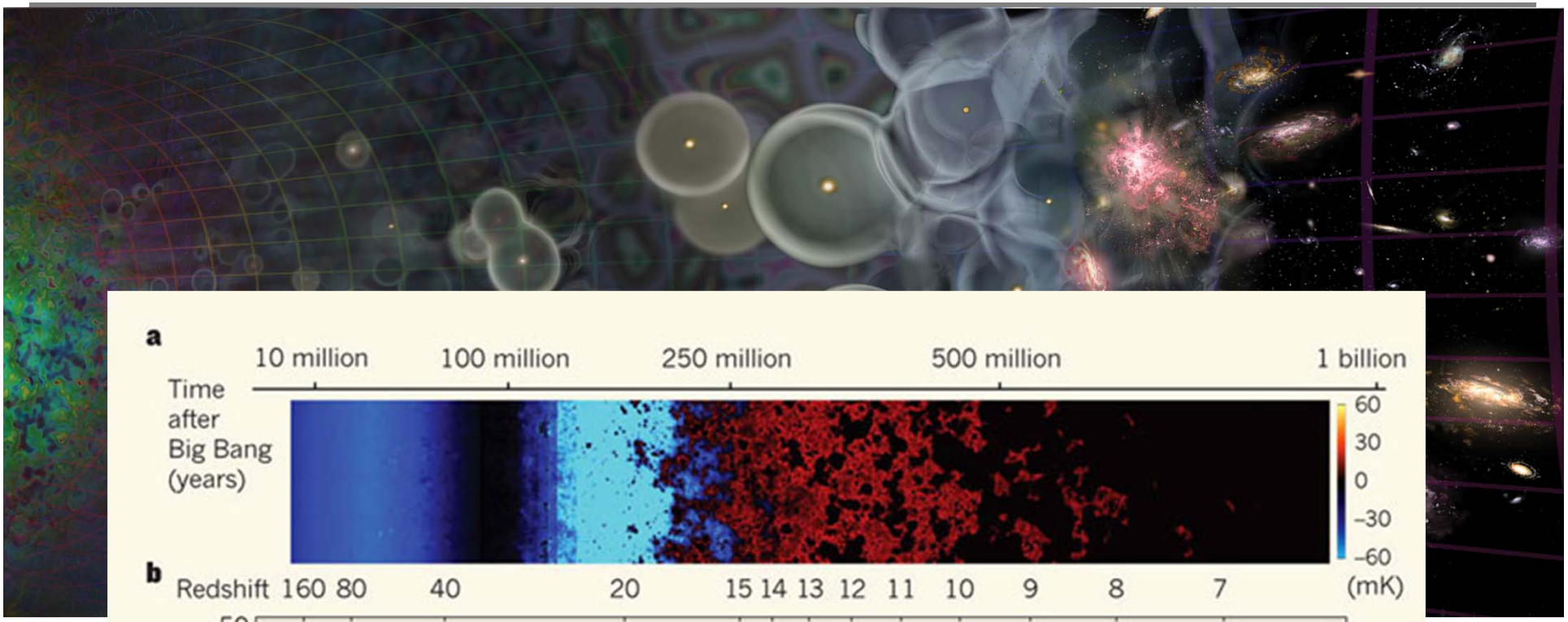
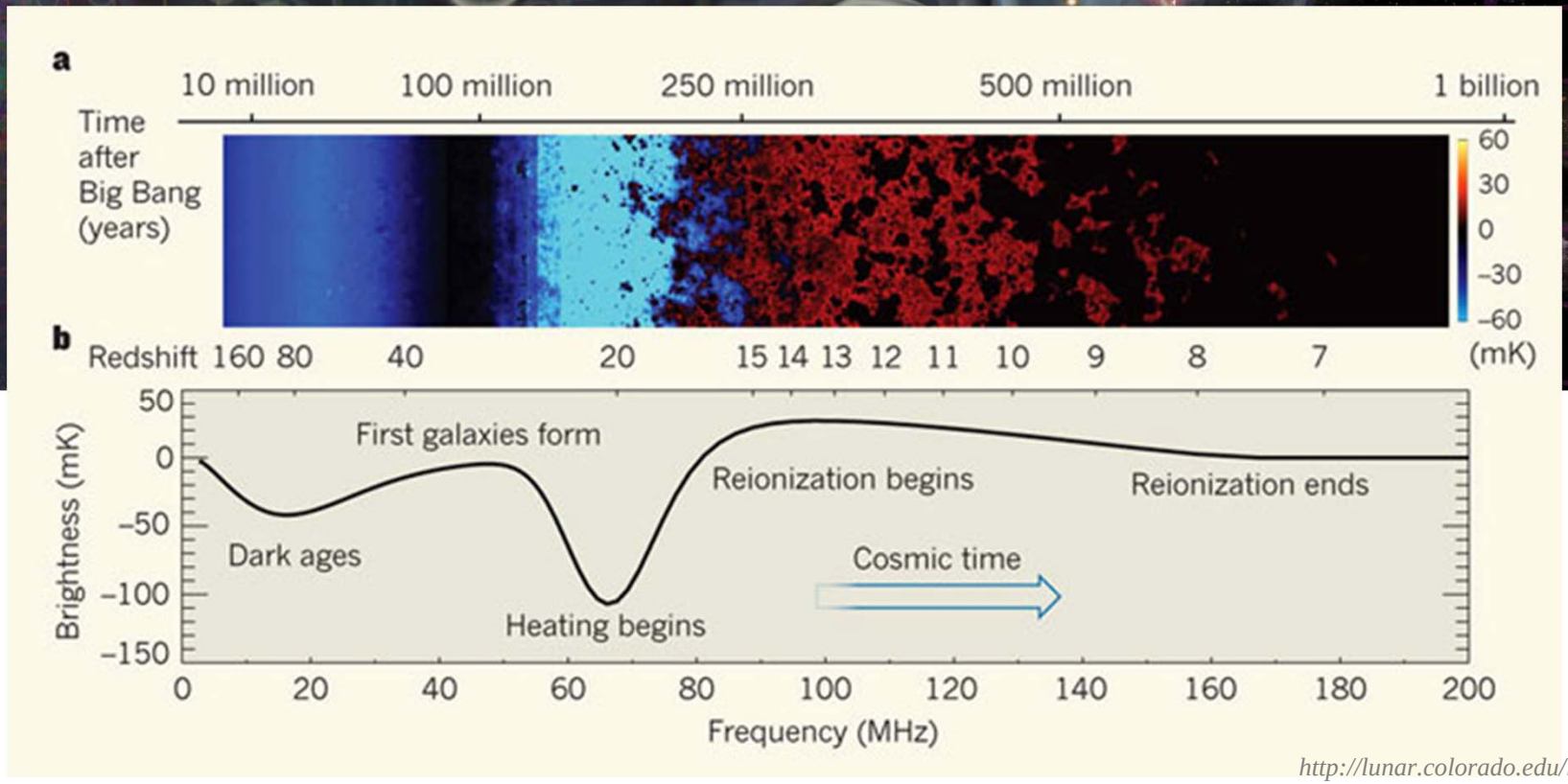
Cosmic Dawn: Neutral Hydrogen



http://lunar.colorado.edu/lowfreq/

Cosmic Dawn: Neutral Hydrogen

- Fly distributed CubeSat HF and VHF receivers



http://lunar.colorado.edu/lowfreq/

Cosmic Dawn: Missing baryons

- Observations fail to locate about half of the baryons required in cosmology.
  - Maybe they are in hot galactic halos?
  - *Absorption* spectra suggest this, but limited directionality of observations
- **HaloSat** will map O VII and O VIII line *emission* to look at Milky Way to see if we have a massive, extended, hot halo.

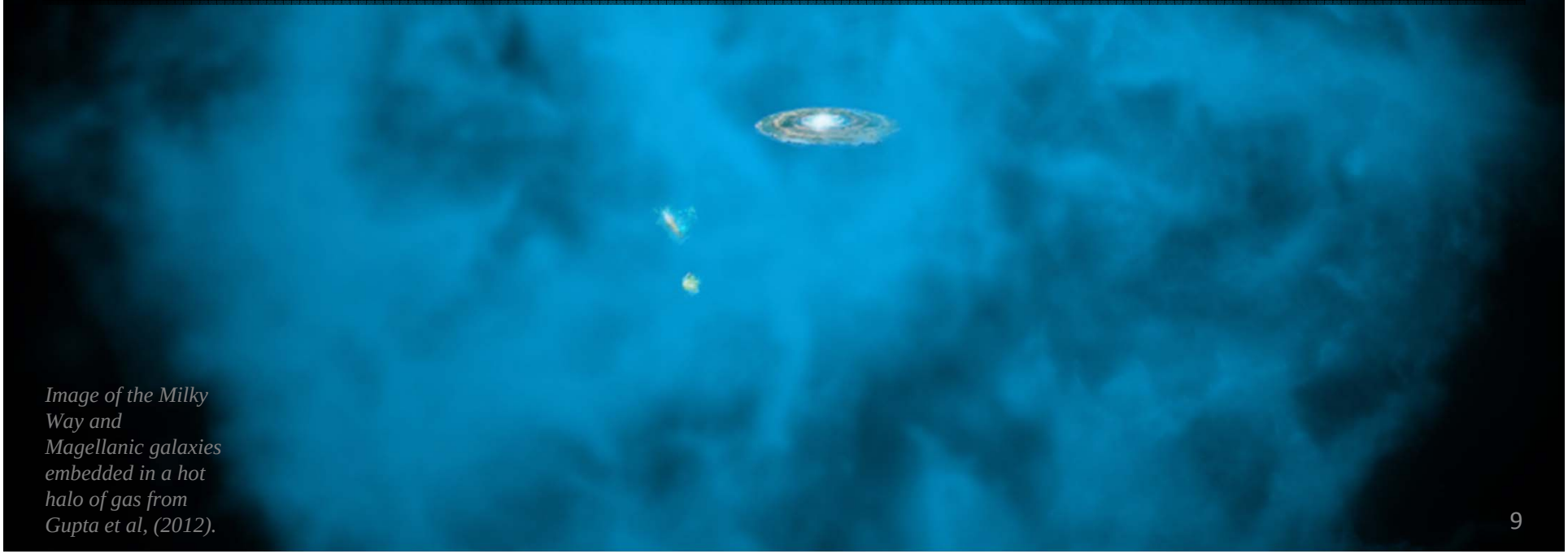
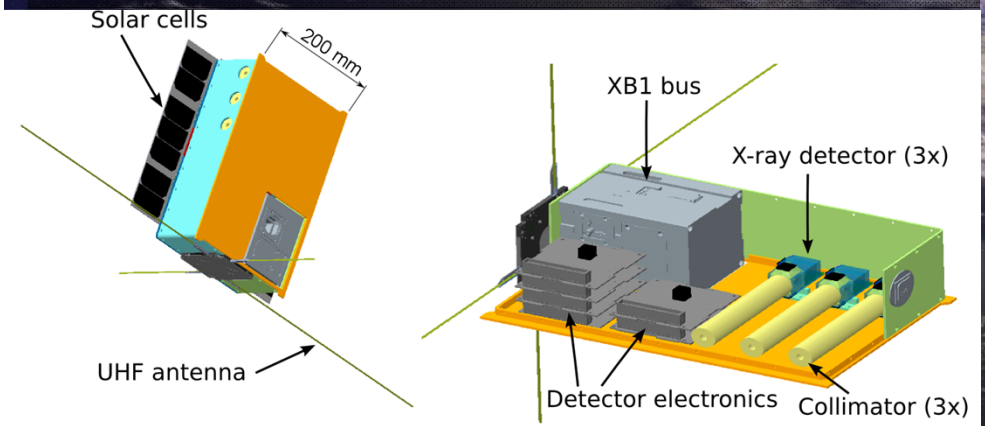


Image of the Milky Way and Magellanic galaxies embedded in a hot halo of gas from Gupta et al, (2012).

Cosmic Dawn: Missing baryons

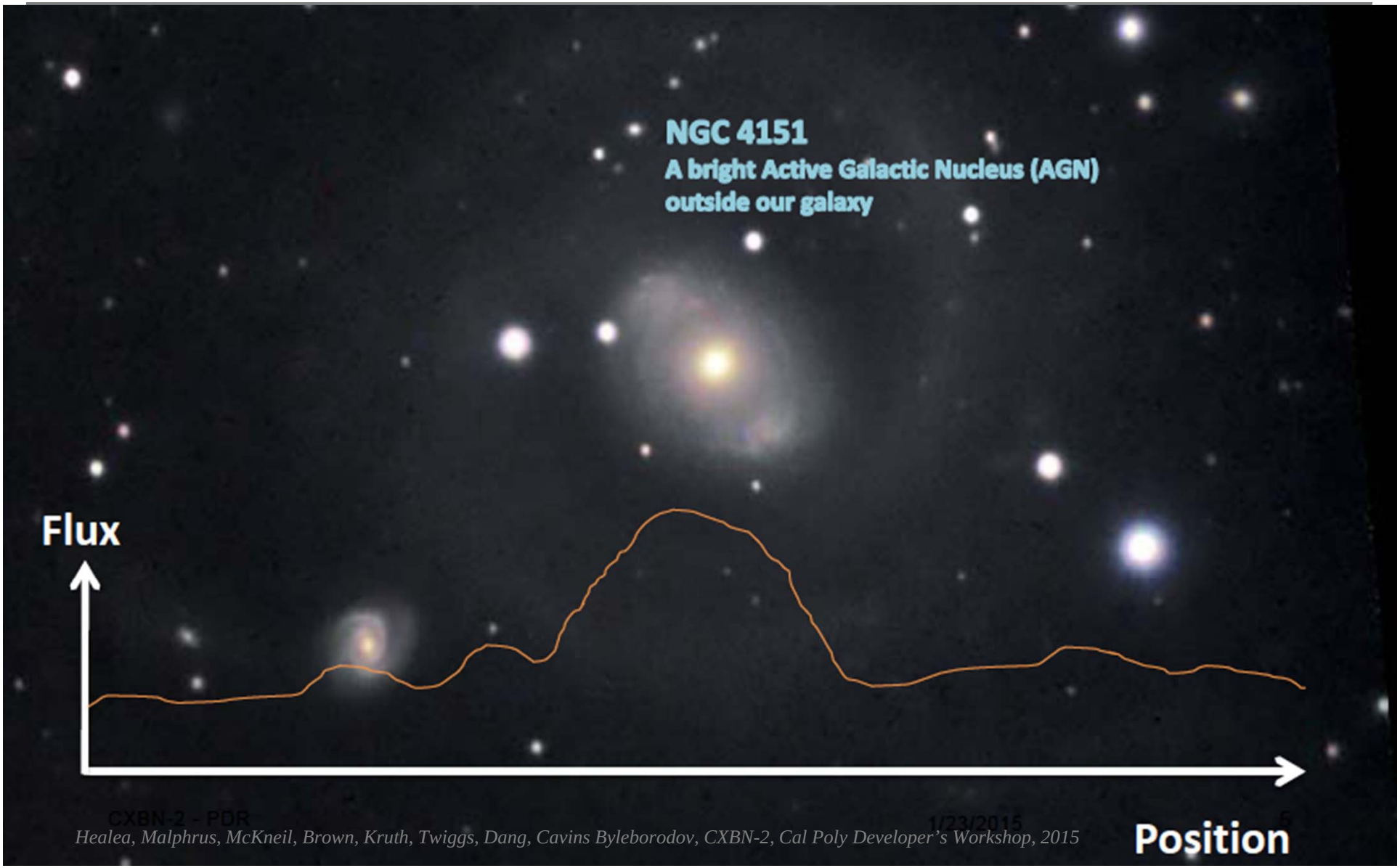
- HaloSat:
  6U with Amptek X-ray detectors
- Measure the oxygen emission in 400 fields over 90% of the sky.
- Study solar wind charge exchange emission to remove uncertainty on the oxygen line emission measurements.



Poster 27

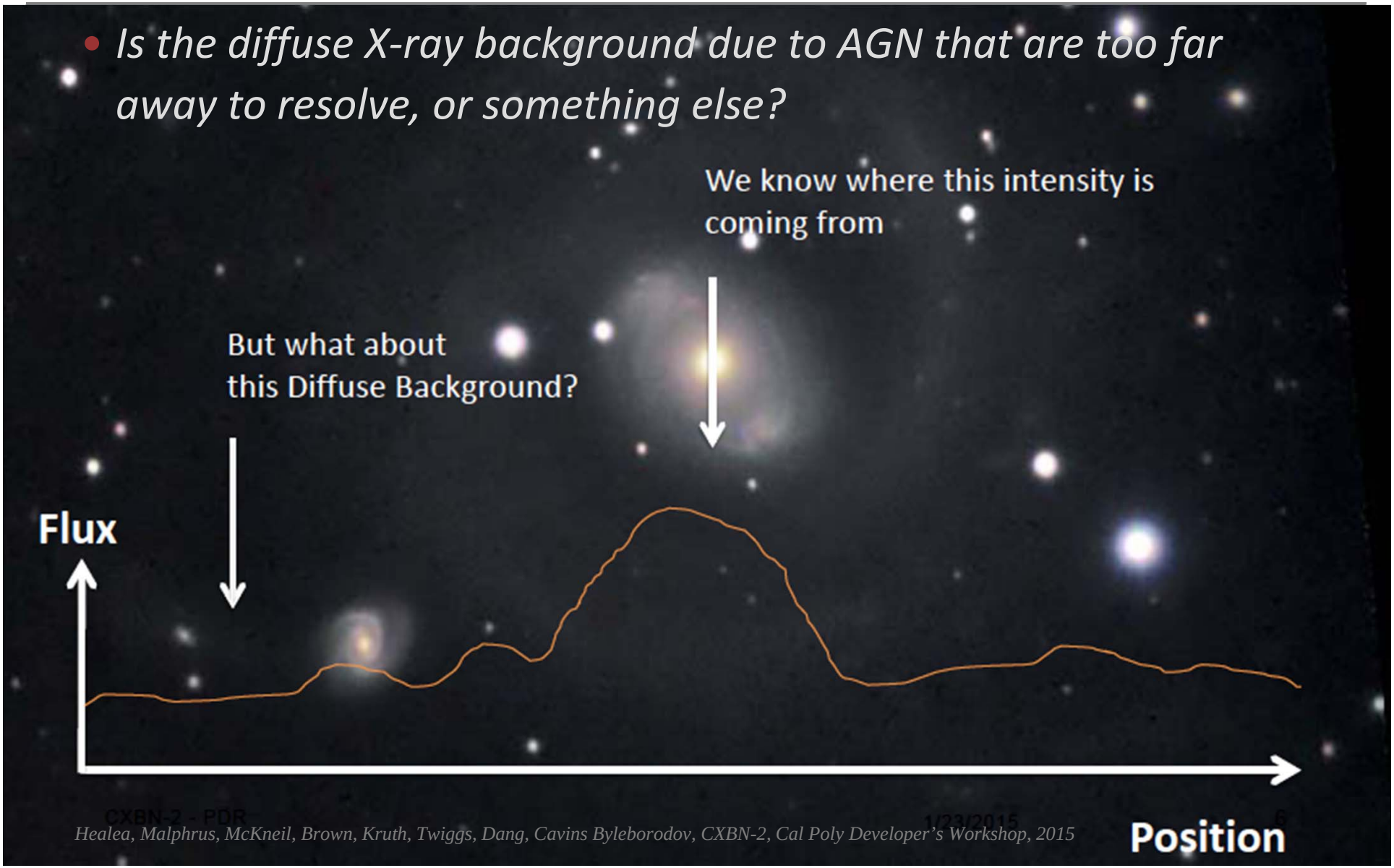
Kaaret et al., American Astronomical Society, HEAD meeting #14, #116.21 (2014)

Cosmic Dawn: Diffuse X-ray Background



Cosmic Dawn: Diffuse X-ray Background

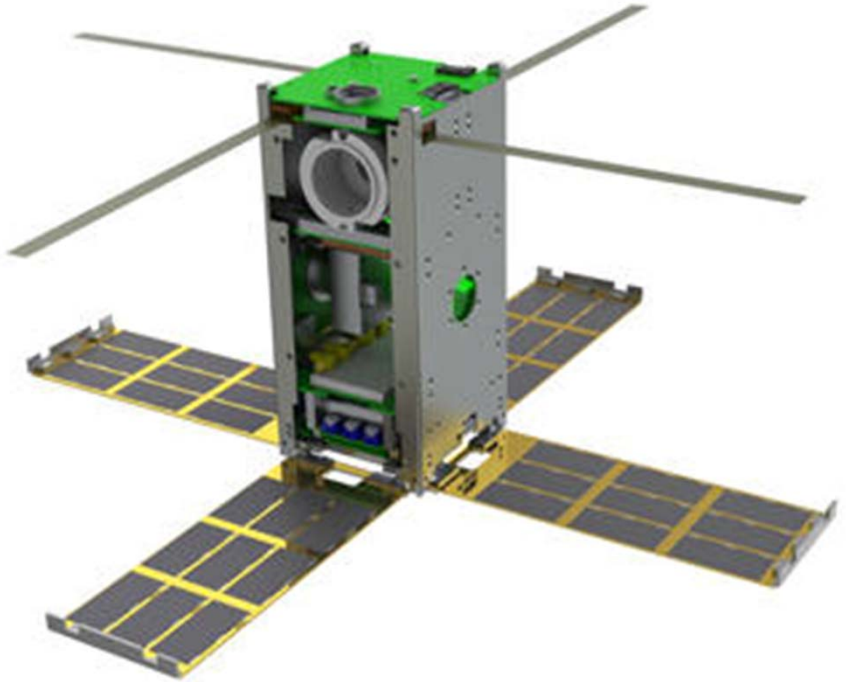
- *Is the diffuse X-ray background due to AGN that are too far away to resolve, or something else?*



Healea, Malphrus, McKneil, Brown, Kruth, Twiggs, Dang, Cavins Byleborodov, CXBN-2, Cal Poly Developer's Workshop, 2015

Cosmic Dawn: Diffuse X-ray Background

- Cosmic X-Ray Background Nanosatellite-2 (CXBN-2)
  - CXBN-2 a follow-on to CXBN-1 launched by NASA ELaNa in 2012
  - CXBN-1 S/C Bus operated successfully but the Experimental Detector Array did not achieve nominal operation
- CXBN-2 NASA ELaNa selected mission for launch in 2016



- Goal is to make a precise measurement of the cosmic (diffuse) X-ray background in the 20 – 50 KeV range using a 2U CubeSat platform

Healea, Malphrus, McKneil, Brown, Kruth, Twiggs, Dang, Cavins Byleborodov, CXBN-2, Cal Poly Developer's Workshop, 2015

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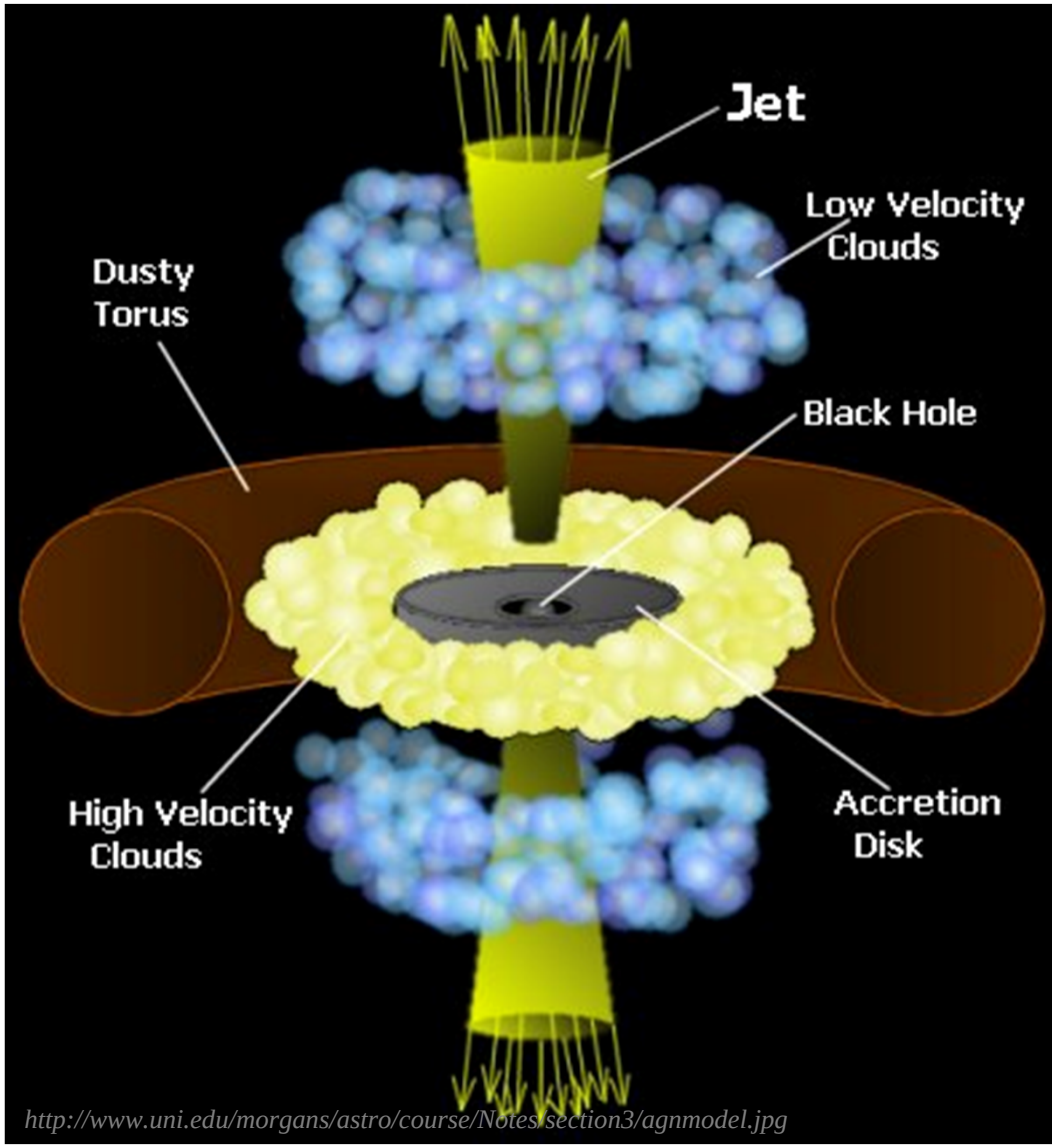
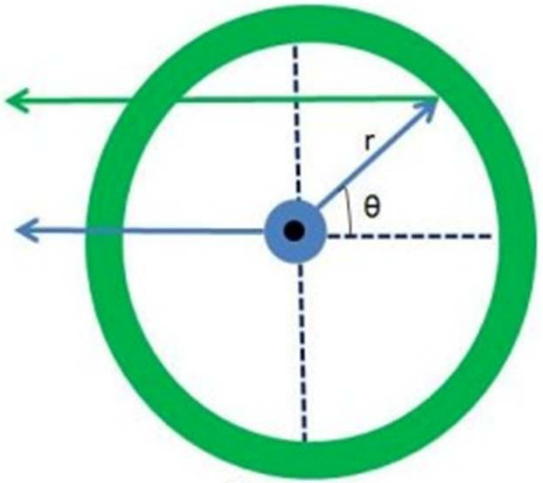
Galactic Evolution: Black Hole mass

- Active Galactic Nuclei
  - Supermassive black hole with accretion disk
- Black Hole mass?
  - If it's nearby, measure Doppler shift of material orbiting black hole
  - But most aren't nearby
- Reverberation Mapping:
  - Region of gas called the Broad Line Region that gets photoionized by accretion disk and emits light at characteristic wavelengths.

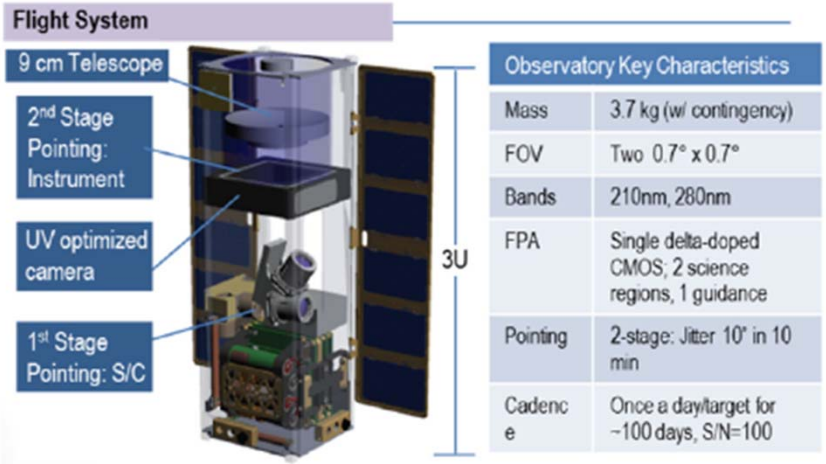


Galactic Evolution: Black Hole mass

- Broad Line Region emissions are "reprocessed" from central continuum source
- Need to stare at AGN continuum source and record variability and events
- Radius of BLR ~few light days
  - Continuously observe to correlate source events with BLR emission
- Can put UV detector on CubeSats to do this
  - E.g., Space Explorer for Accretion and Reverberation (SpEAR)



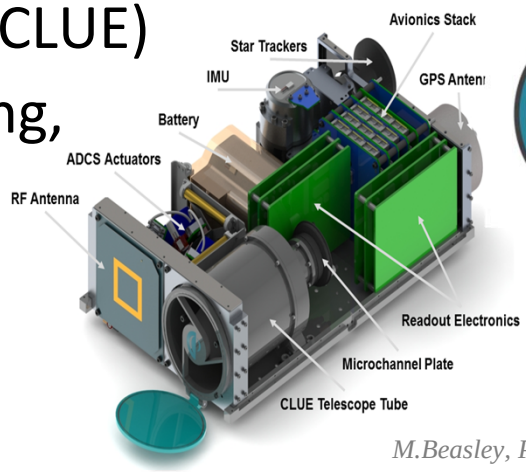
http://astrobites.org/2012/03/14/measuring-the-black-hole-mass-in-markarian-6-using-reverberation-mapping/



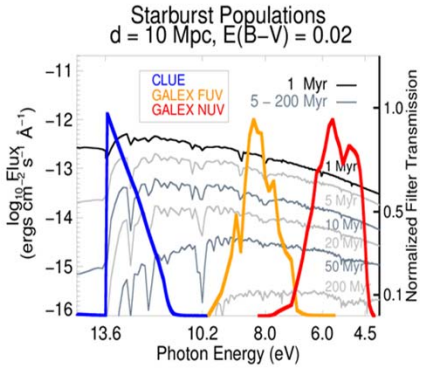
http://asd.gsfc.nasa.gov/conferences/uvvis/missions/UVVis_Missions_Ardila.pdf

Galactic Evolution: Stellar Populations

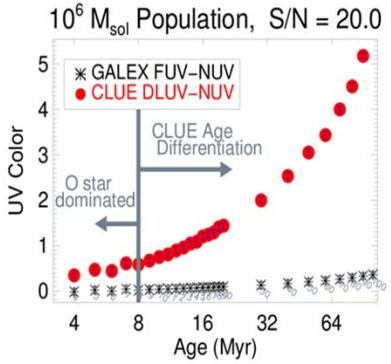
- Compact Lyman Ultraviolet Explorer (CLUE)
- UV observations help distinguish young, massive stellar populations in star-forming galaxies.
  - Lyman alpha, 912-1100 angstroms
- Also energetic radiation from the hot upper atmospheres of low-mass exoplanet host stars.
- And also supernova remnants
- Modest pointing requirements
  - 15 arcsecond resolution
  - 2.66 degree field of view
- Long integration times help counter small aperture



M.Beasley, Planetary Resources



Leitherer et al. 1999; 2010; age in Myr shown



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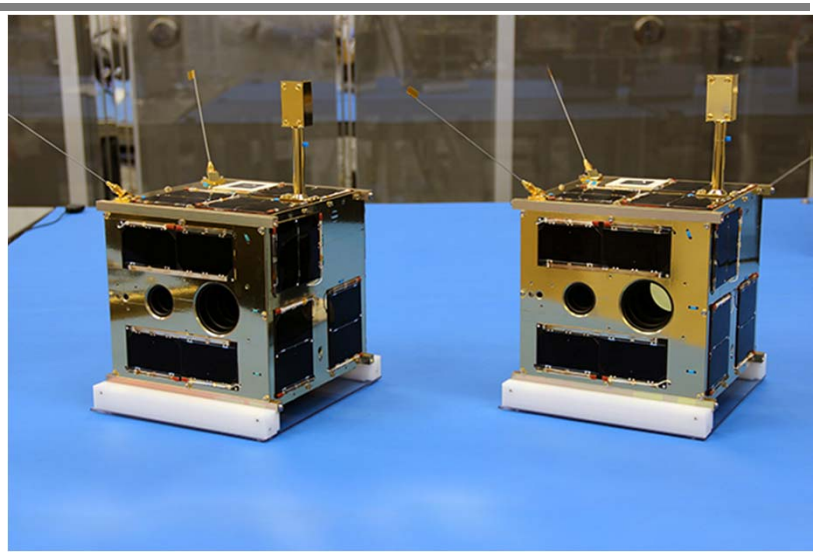
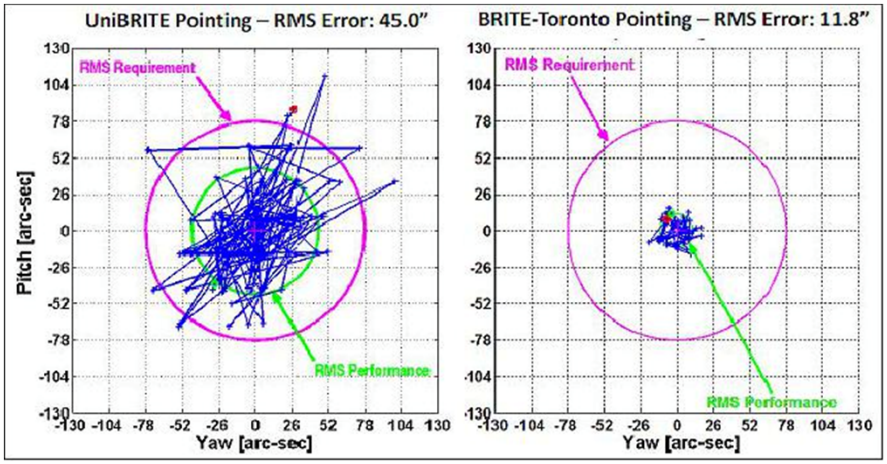
Stellar Evolution: Variability

- Study variability of massive, luminous stars and supernova
- BRITE (BRIght Target Explorer) Constellation
  - 7 kg, 20 cm cube nanosatellites
  - Space Flight Laboratory at UTIAS
  - Req. was 60 arcsec (0.0167 deg)
- Multiple satellites help with continuous viewing
- Different filters on satellites
- Demonstrated up to 12 arcsec RMS pointing over 15 min



http://utias-sfl.net/?page_id=407

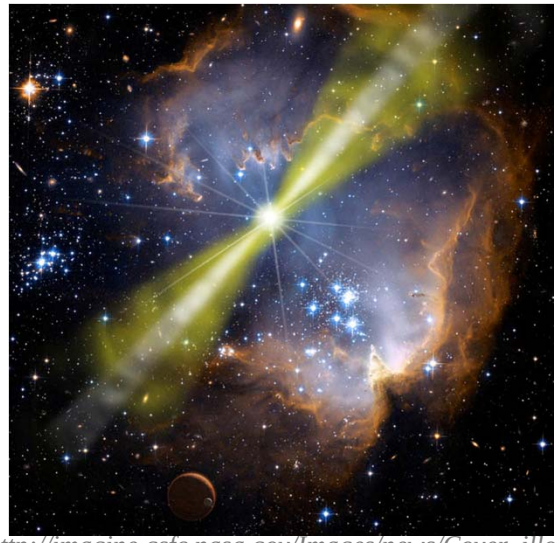


Stellar Evolution: X-ray polarimetry

- Neutron stars have the highest magnetic fields known in the universe
  - Quantum electrodynamics predicts they should be highly polarized
  - Use X-ray detectors and reflective multilayer optic
- Gamma ray bursts are one of the most powerful explosions, but understanding the nature of their central engine is uncertain
  - Measure X-ray polarization
  - Gas chamber detector

Posters 24, 28, and 59

http://www.nasa.gov/wise/pia18848



http://imagine.gsfc.nasa.gov/Images/news/Cover_illo.jpg

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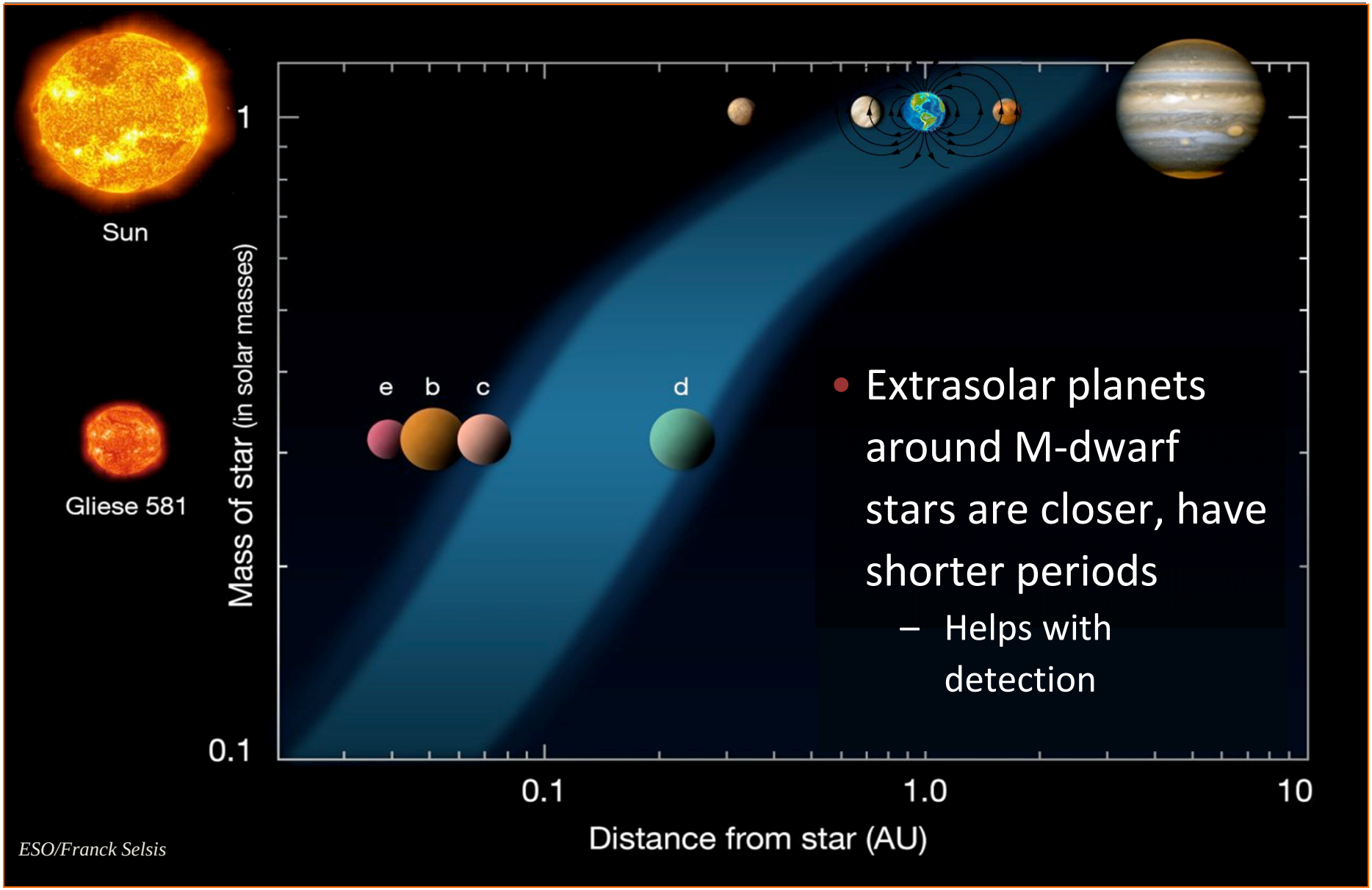
Extrasolar Planets: Technology

- ASTERIA: Arcsecond Space Telescope Enabling Research in Astrophysics (JPL Phaeton project)
  - Arcsecond-level line of sight pointing error (piezo stage)
  - Highly stable focal plane temperature control
- Enables precision photometry to study stellar activity and transiting exoplanets…
  - E.g., stare at targets as long as needed to capture transit events

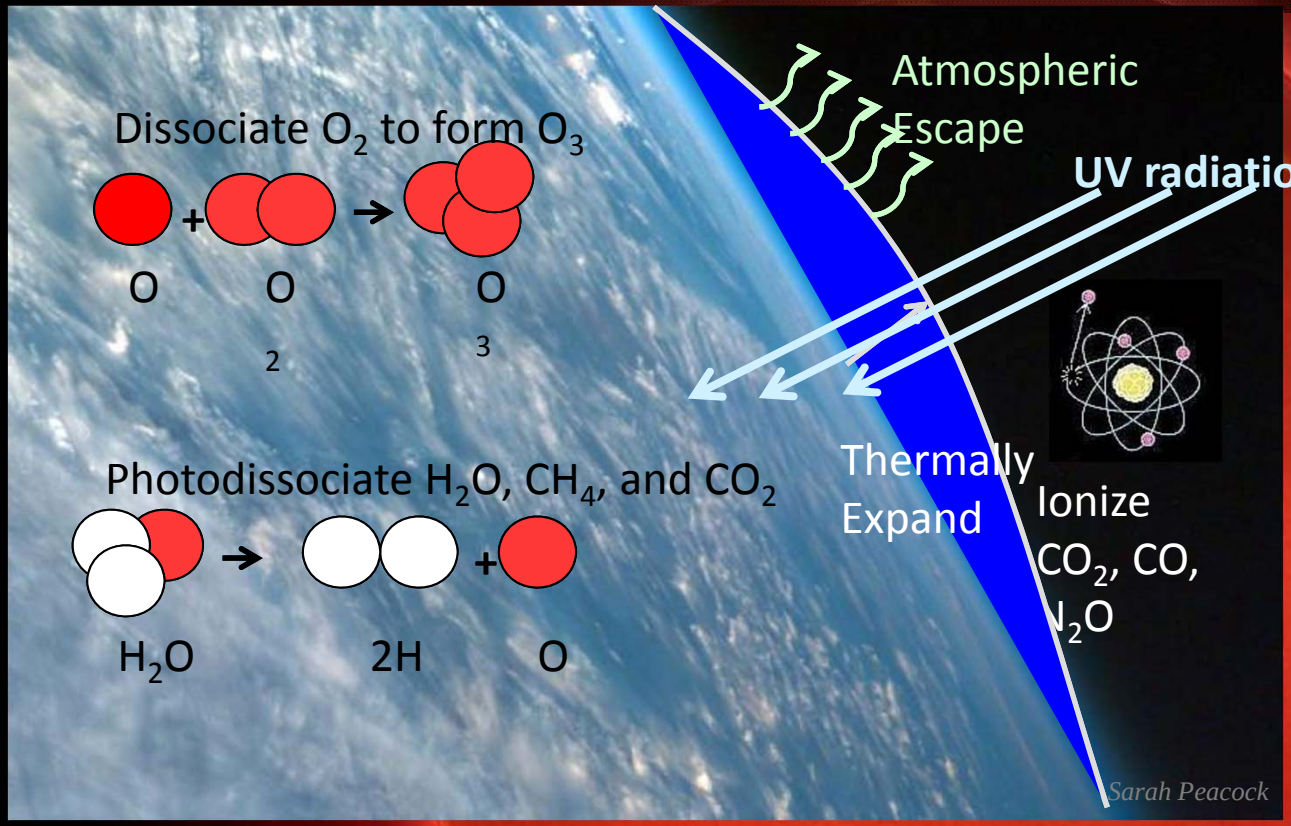
Extrasolar Planets: Habitable zone



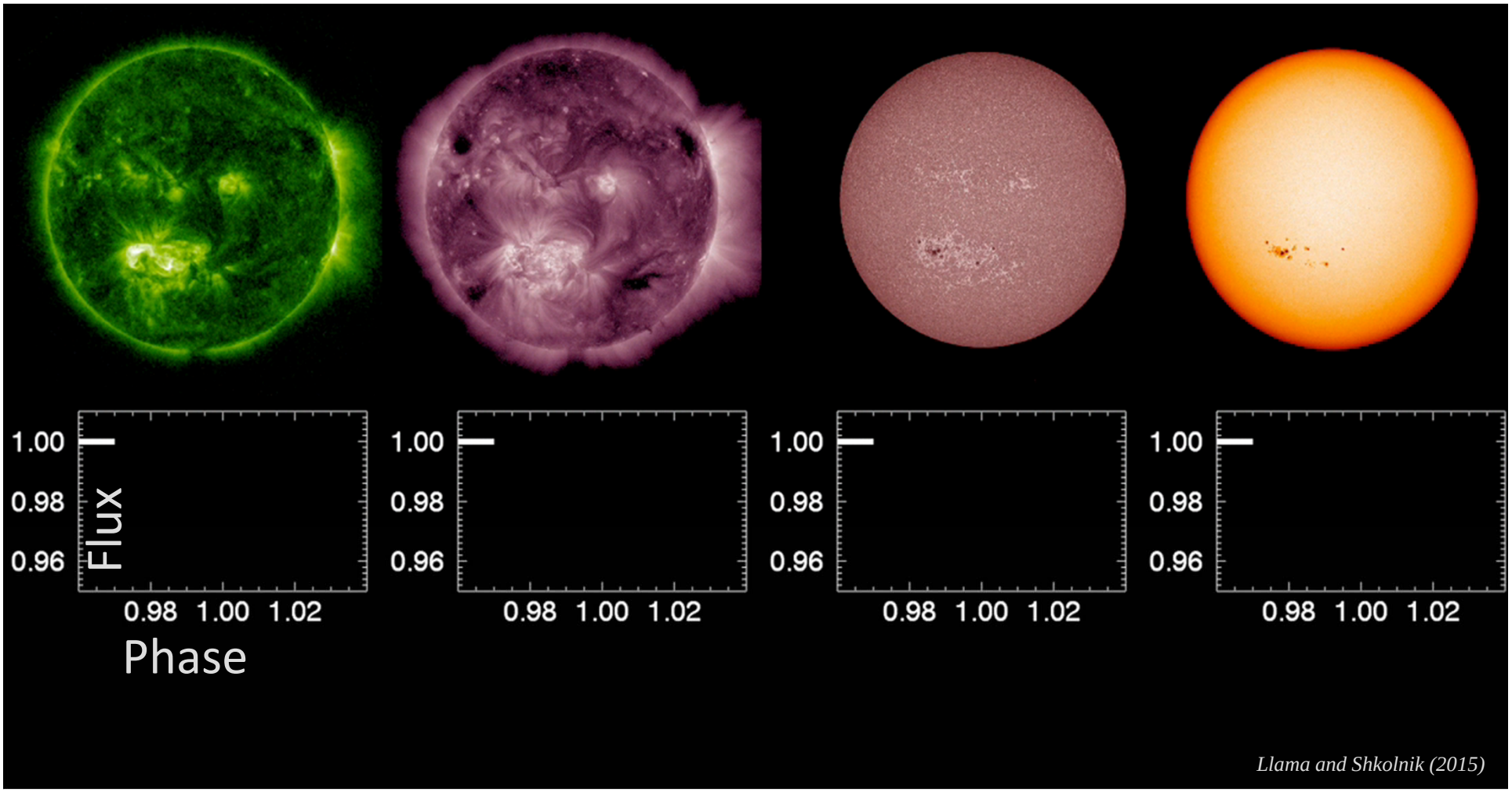
- Extrasolar planets around M-dwarf stars are closer, have shorter periods
  - Helps with detection

Extrasolar Planets: Radiation

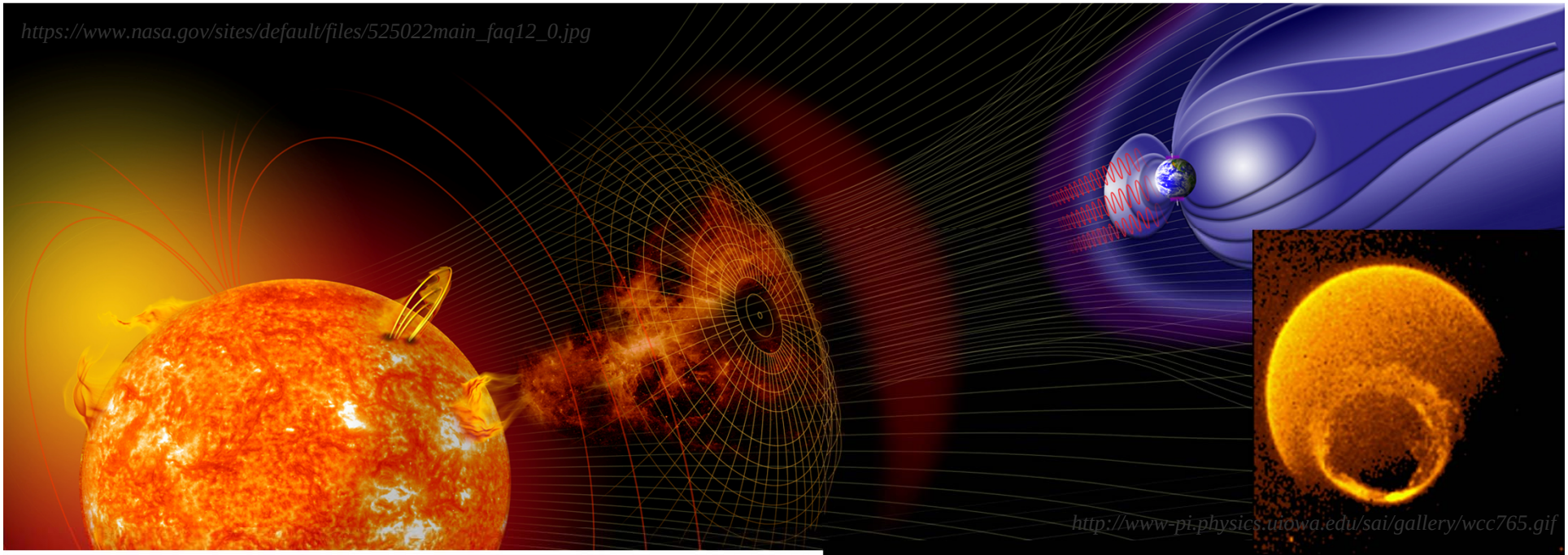
- Measure M-dwarf activity and exoplanet radiation environment
  - Habitable?



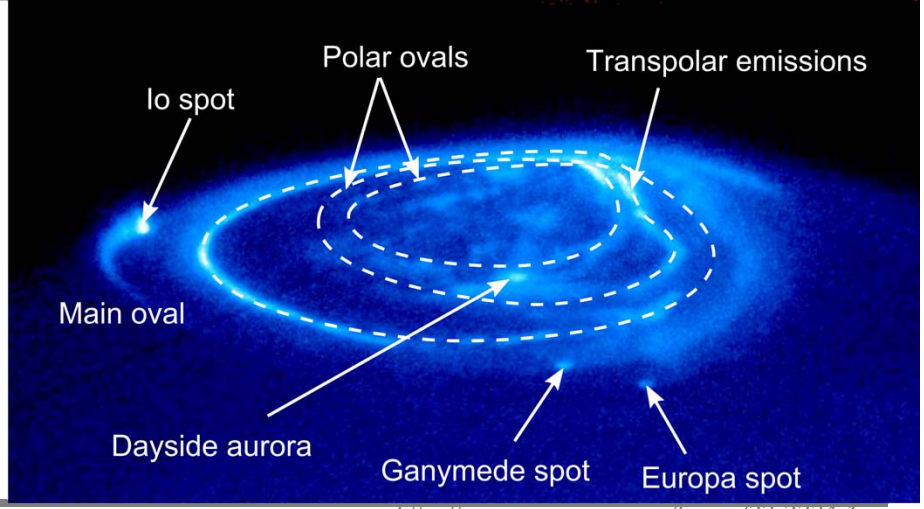
Extrasolar planets: Multi-wavelength



Extrasolar Planets: Magnetic fields



- ~ 1% of input energy to auroral region emitted in UV
- ~ 1% of auroral input energy into electron cyclotron maser radio emission

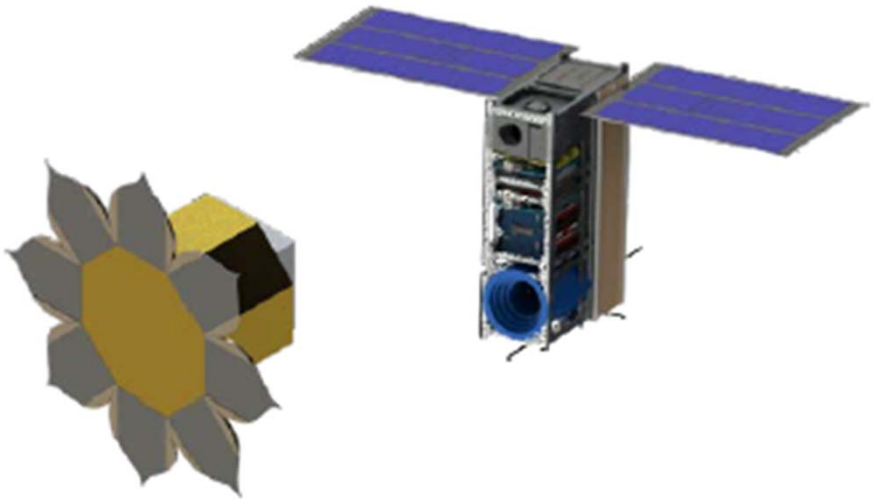


http://en.spaceengine.org/forum/22-3224-1

Extrasolar Planets: Technology

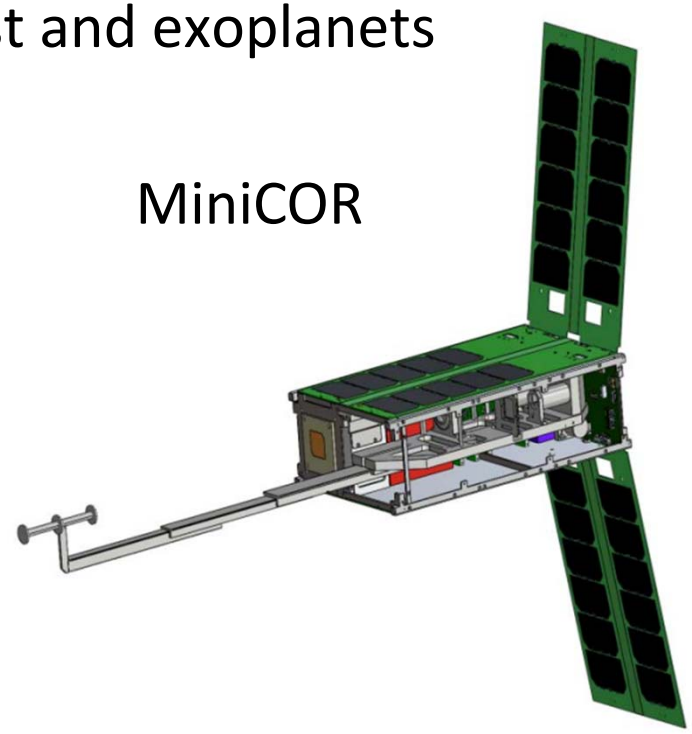
- Miniature “Exo-S” and “Exo-C”
  Exoplanet-Starshade and Exoplanet-Coronagraph
- Direct imaging of exozodiacal dust and exoplanets

Miniaturized Distributed Occulter/Telescope (mDOT)



Koenig, D’Amico, Macintosh, Titus SPIE 2015

MiniCOR

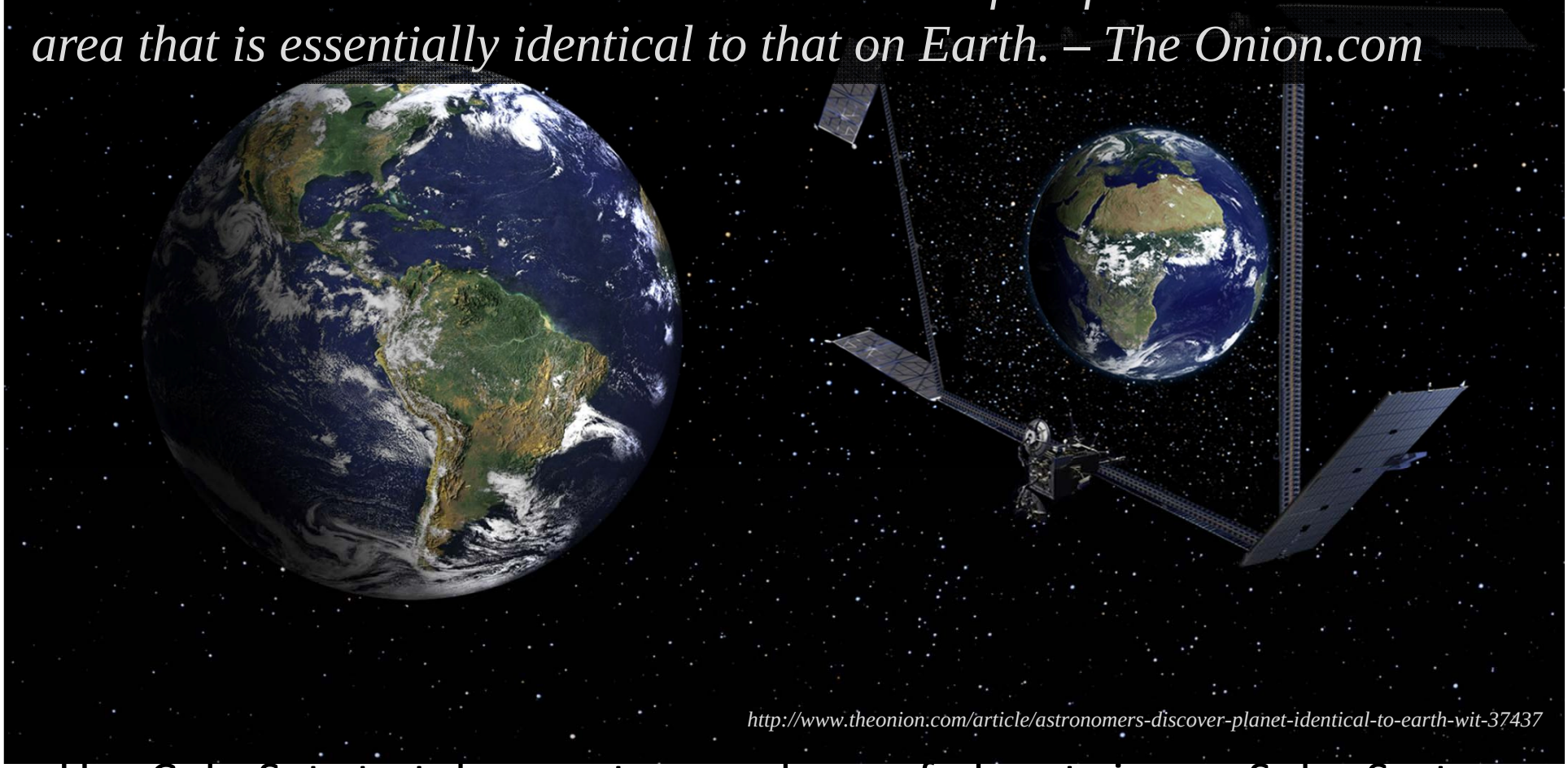


Korendyke et al., SmallSat 2015

Poster 30

Extrasolar Planets: Solar System Analogues

The newly discovered planet reportedly possesses an atmosphere of similar thickness to our own and has a ratio of surface water to land area that is essentially identical to that on Earth. – The Onion.com



http://www.theonion.com/article/astronomers-discover-planet-identical-to-earth-wit-37437

- Use CubeSats to take spectra vs. phase of planets in our Solar System

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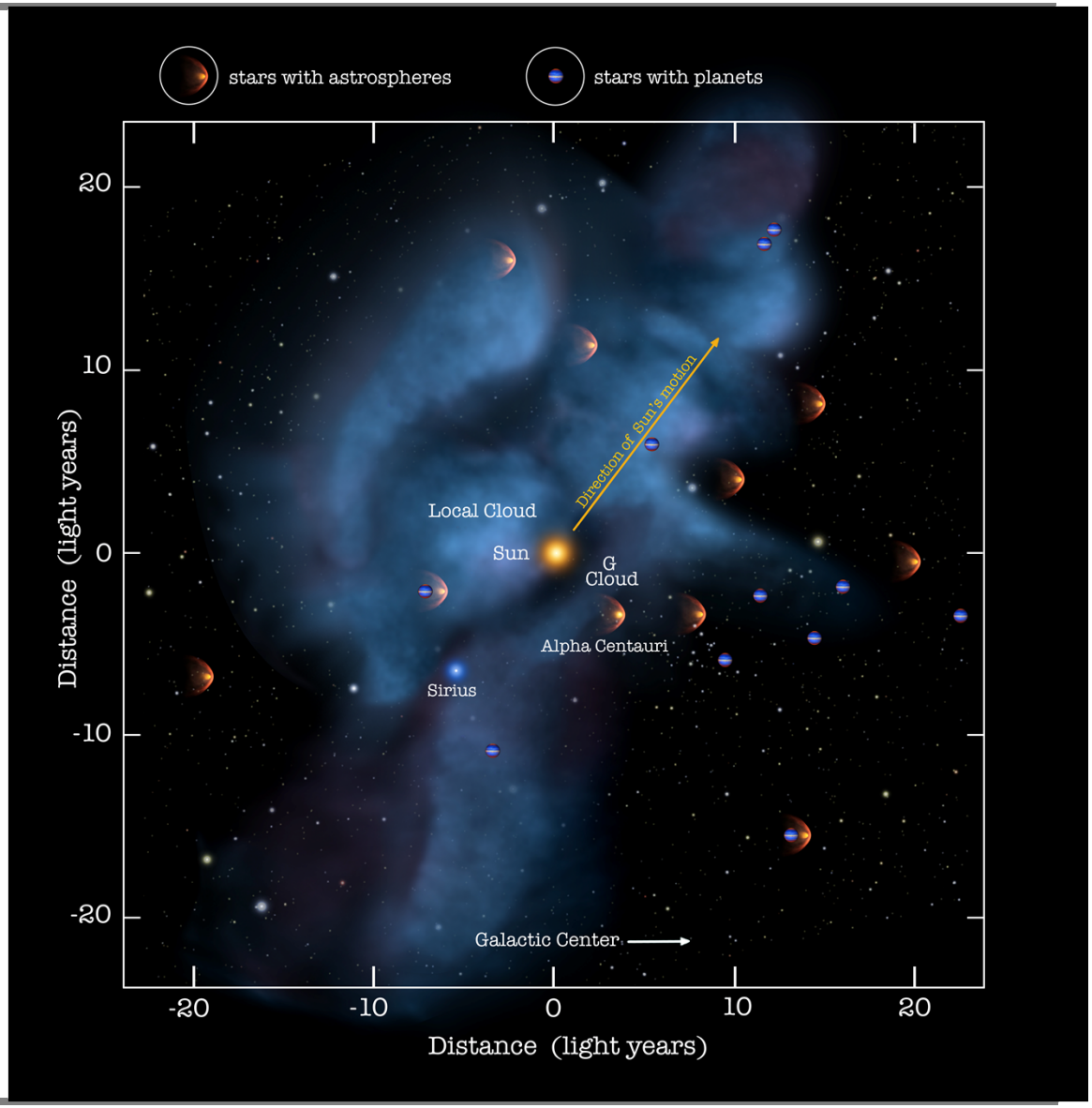
To Infinity and Beyond!

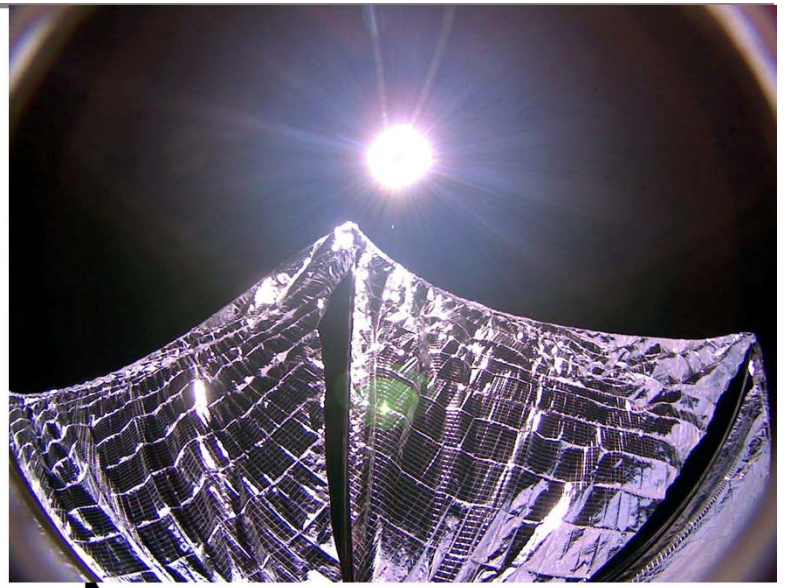
- Stars with astrospheres and planets nearby
- Can technology development with CubeSats get us there?



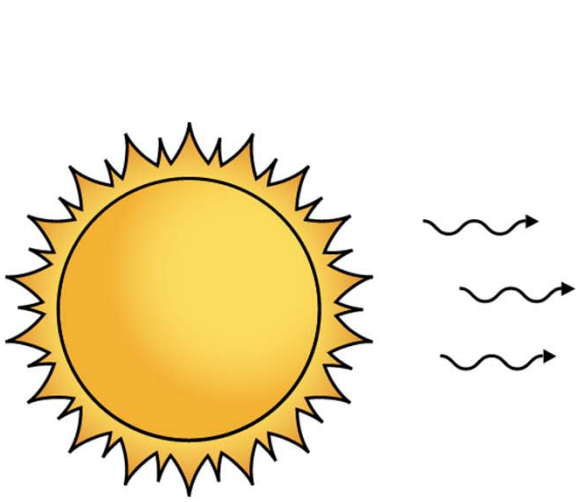
Fritsch, 2015

To Infinity and Beyond! Lightsail

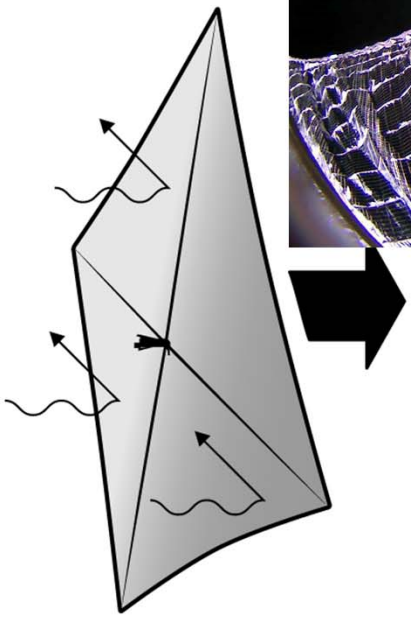
- Lightsail is a citizen-funded project by The Planetary Society



http://sail.planetary.org/index.html

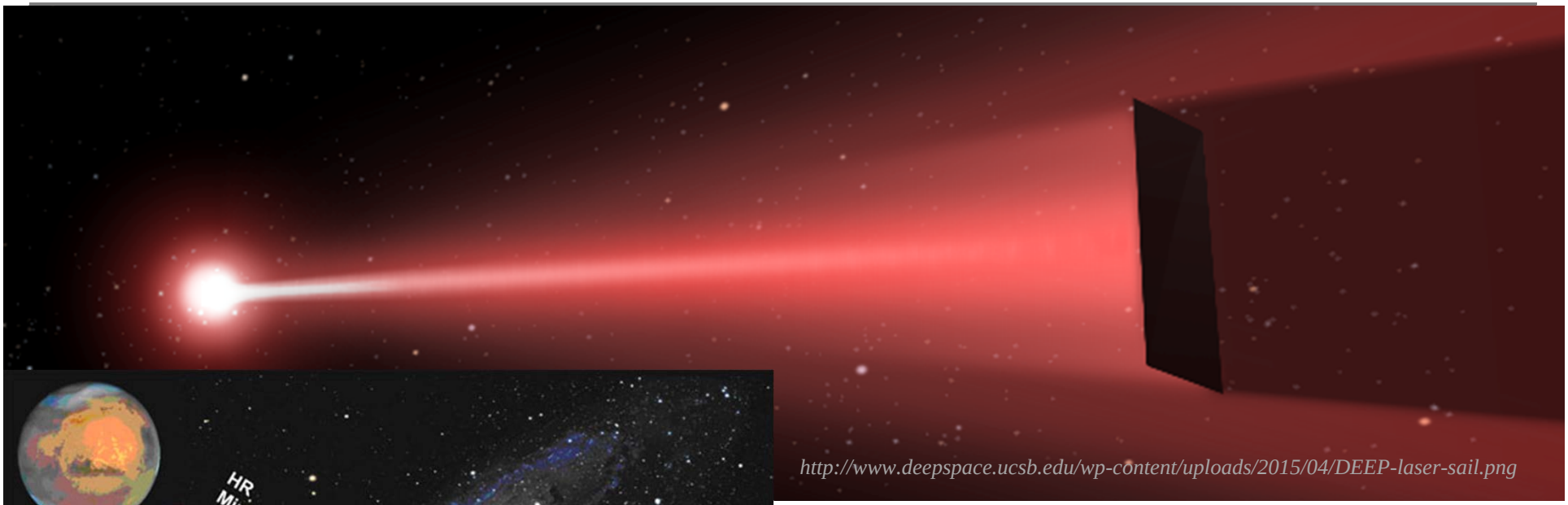


PHOTONS HAVE ENERGY AND MOMENTUM

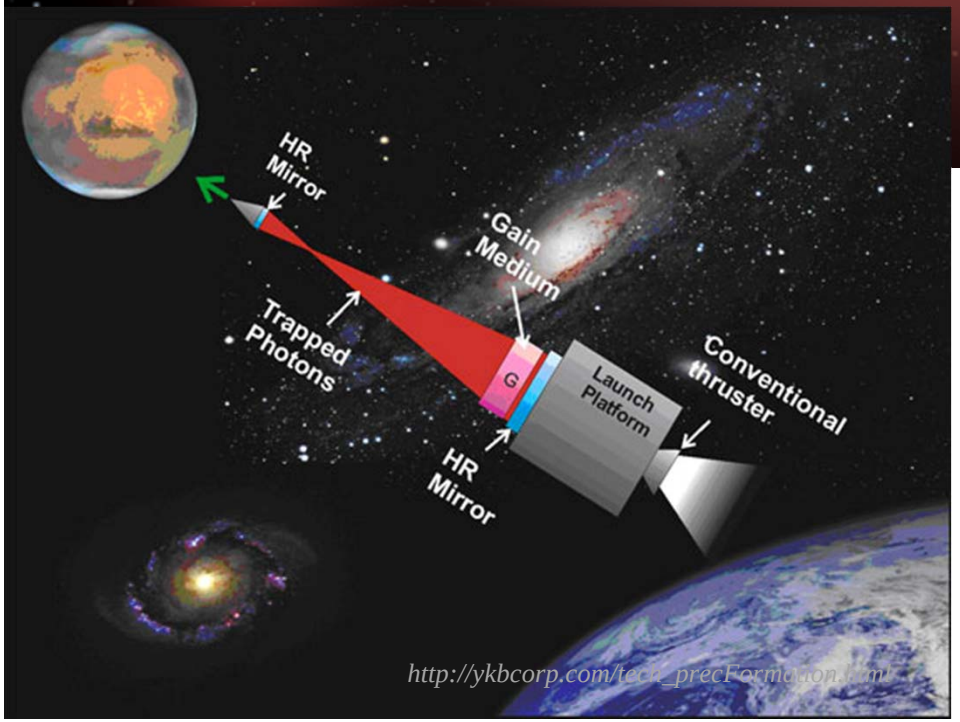


THE PHOTONS REFLECT OFF THE SAIL, TRANSFERRING MOMENTUM

To Infinity and Beyond! Laser sails



http://www.deepspace.ucsb.edu/wp-content/uploads/2015/04/DEEP-laser-sail.png



http://ykbcorp.com/tech_precFormation.html

- Photonic Laser Thrusters amplify photon thrust with an active resonant optical cavity formed between two mirrors on paired spacecraft.

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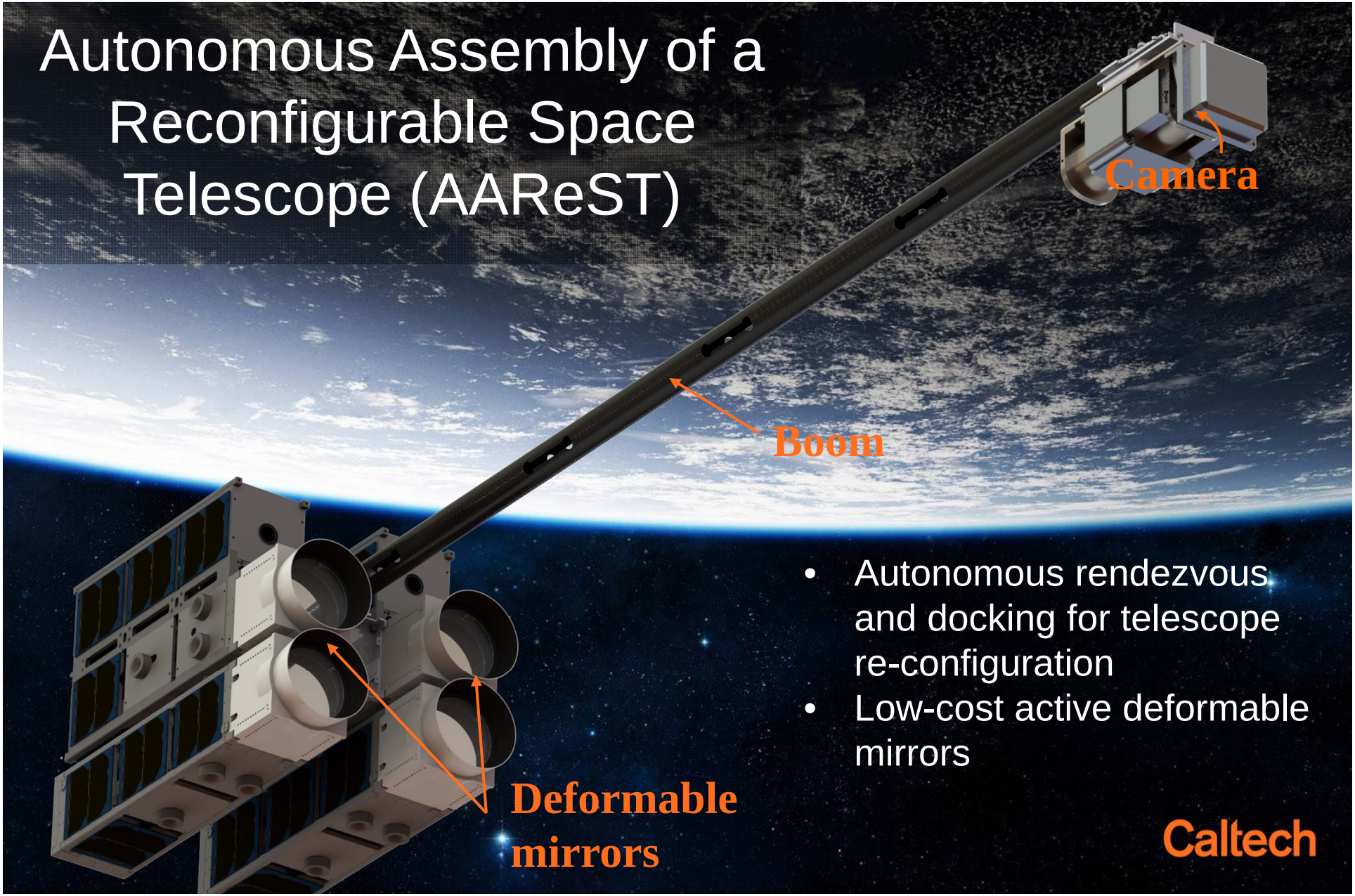
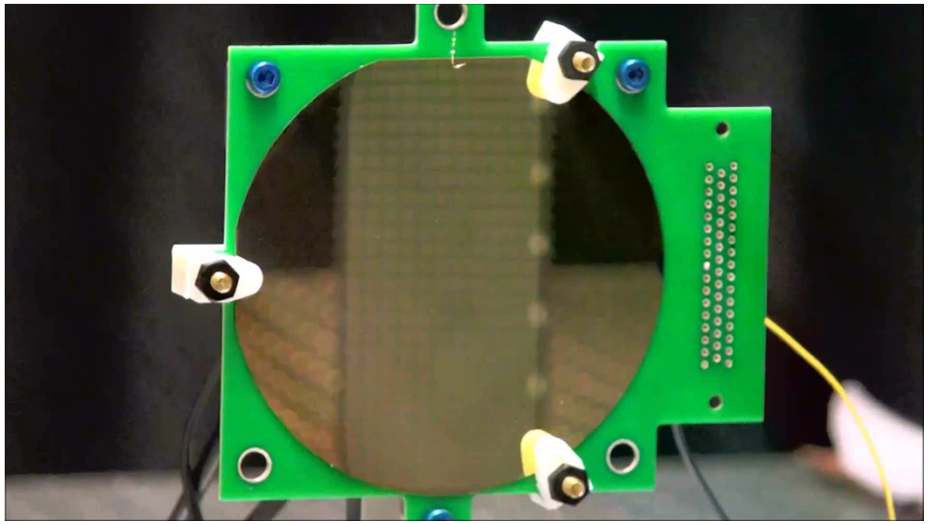
Technology Development: Aperture



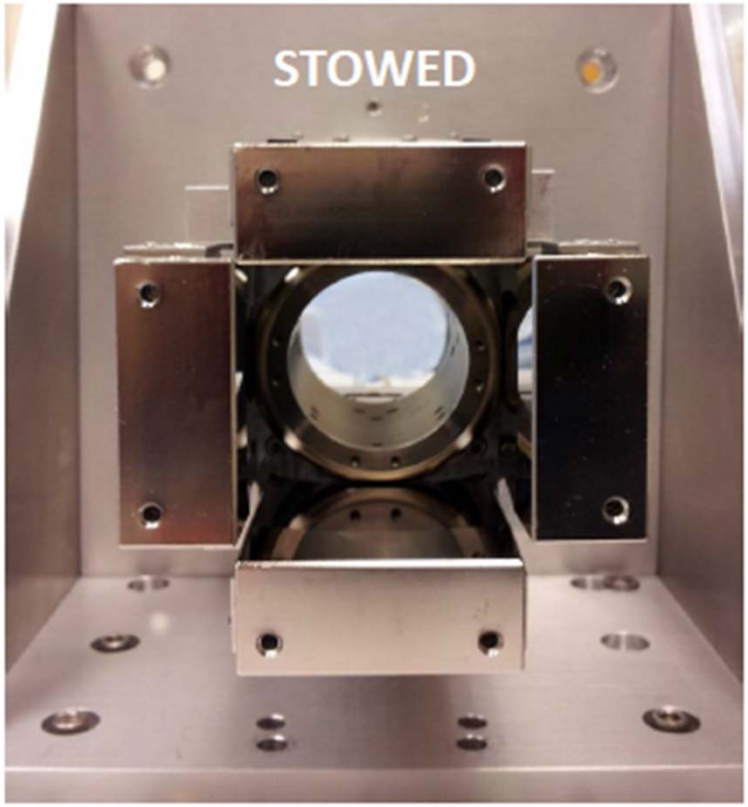
Technology Development: Wavefront

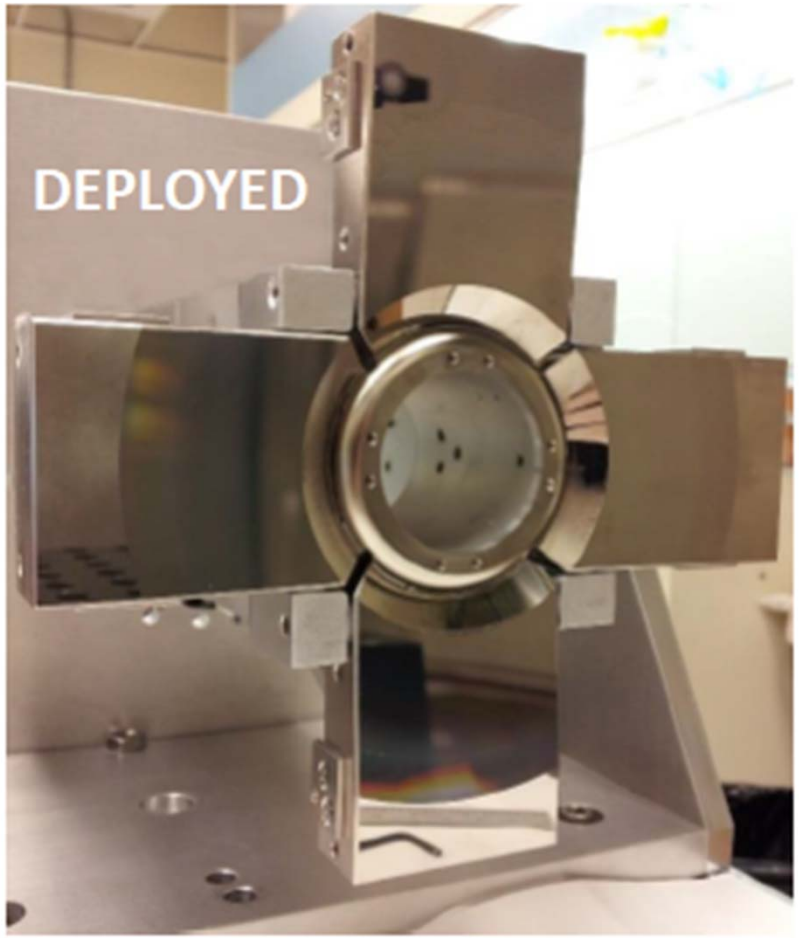
- AAReST deformable mirrors for on deployables



Technology Development: Aperture

- Utah State University Space Dynamics Laboratory “Petal”
  - Deployable Petal Telescope

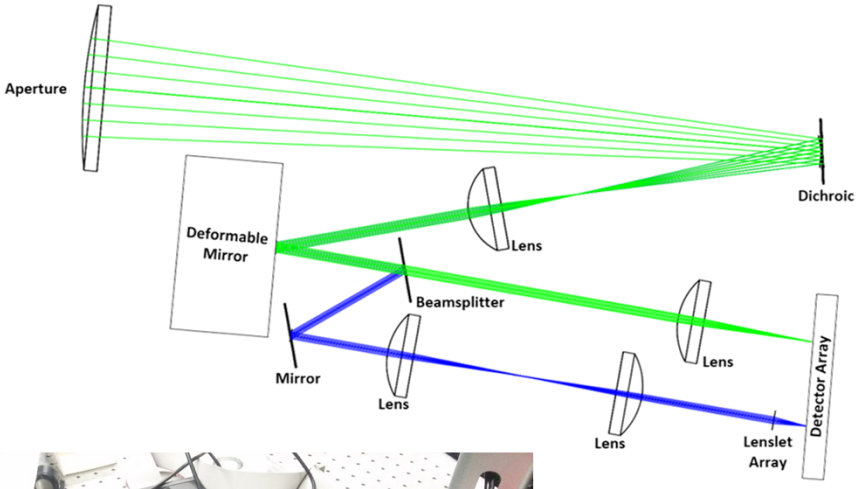


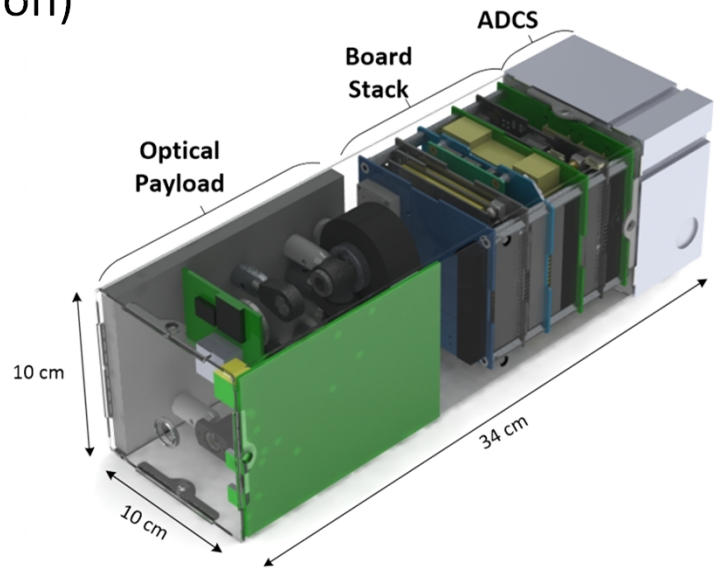


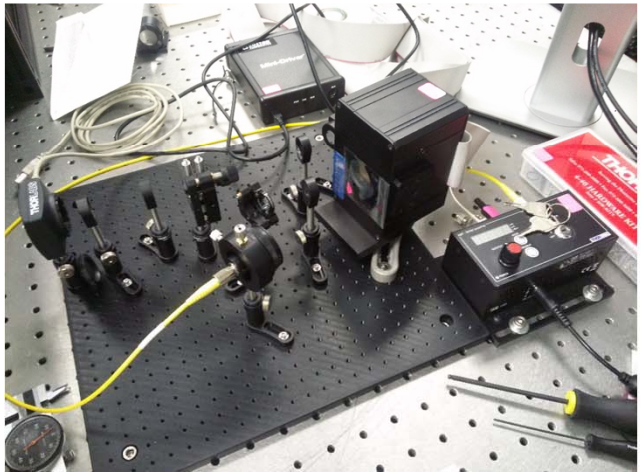
http://www.sdl.usu.edu/downloads/petal-telescope.pdf

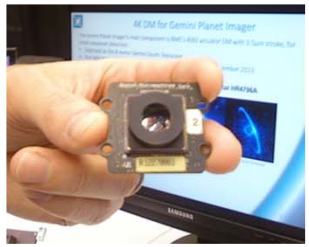
Technology Development: Wavefront

- MIT high-actuator count DM test platform
  - DeMi (deformable mirror demonstration)









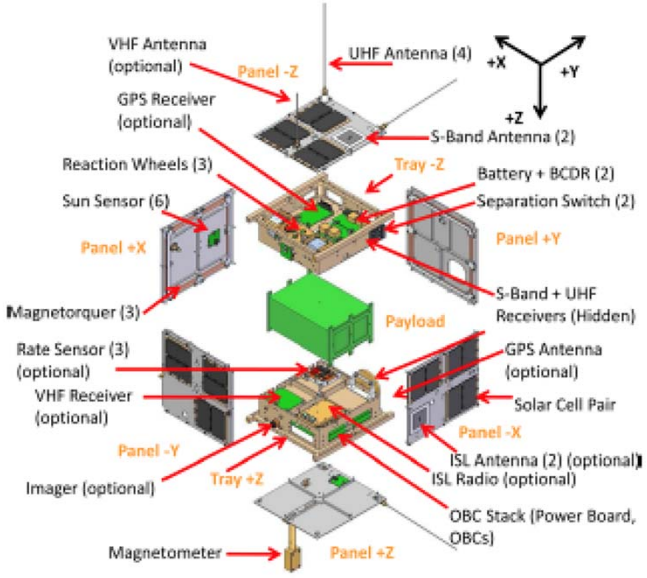
BMC Mini Mirror

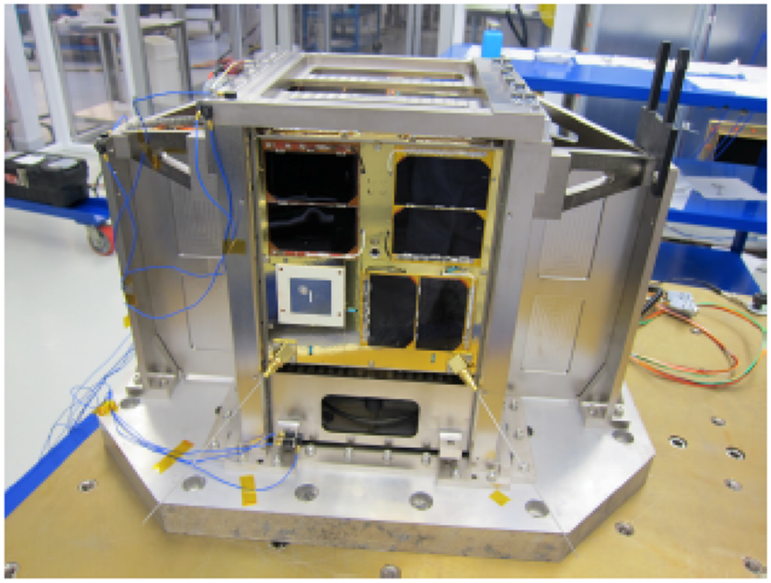
Technology Development: Formation

- CanX-4 and CanX-5 have demonstrated relative navigation using carrier phase differential GPS
  - Space Flight Laboratory at UTIAS
  - *Newman et al., SmallSat 2015*
  - Separations from 1 km to 50 m
  - ATO: along track orbit
  - PCO: projected circular orbit

Table 5: Summary of formation control results

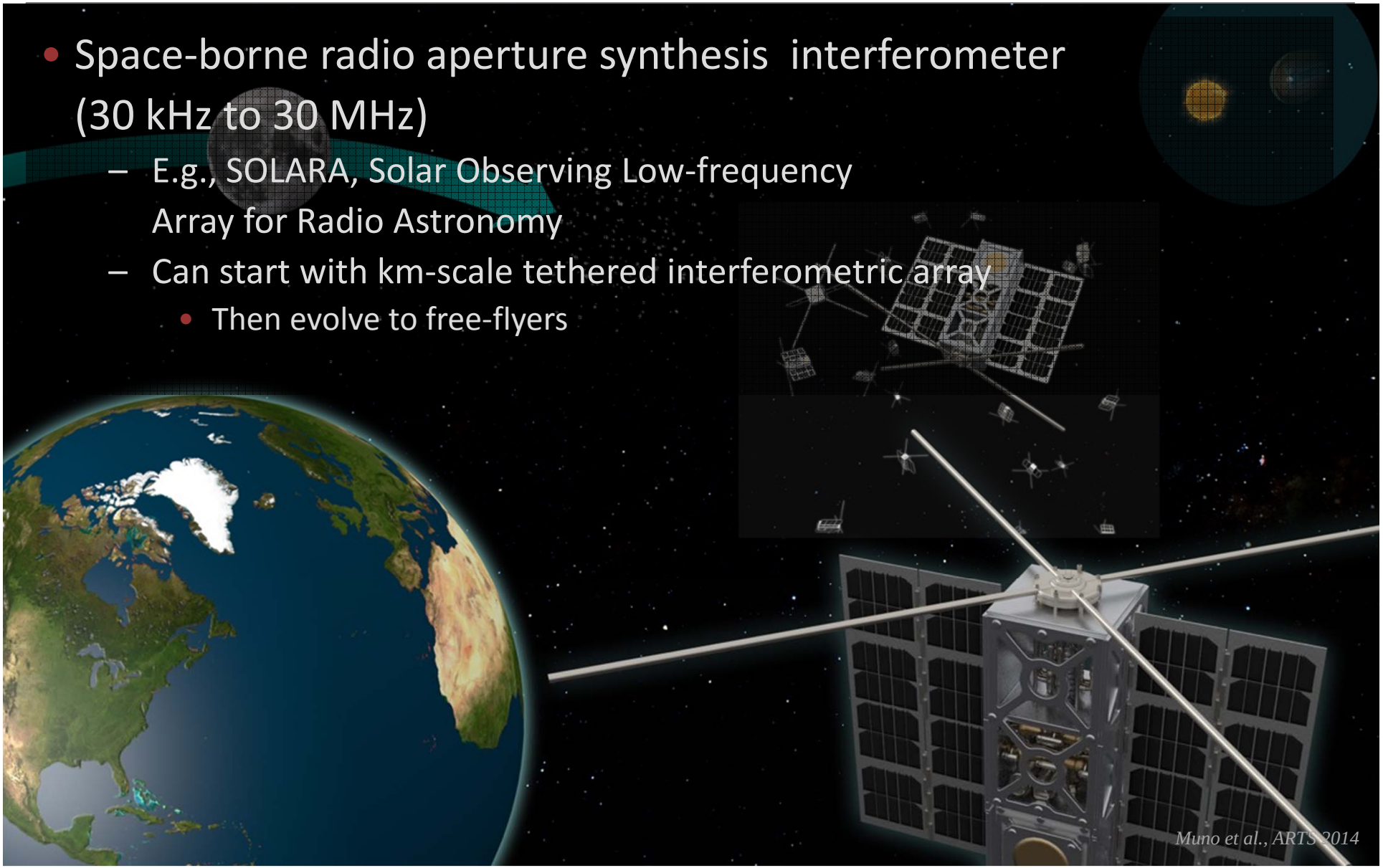
Formation	$\Delta v_{expected}$ [cm/s/orbit]	Δv_{actual} [cm/s/orbit]	Δr_{actual} 3D-RMS [m]	Δr_{actual} 3D-RMS [m]
ATO 1000	3.65	5.55	0.590	0.453
ATO 500	1.71	1.62	0.345	0.513
PCO 100	0.99	1.63	0.517	0.602
PCO 50	3.07	1.27	0.554	0.594





Technology Development: Interferometry

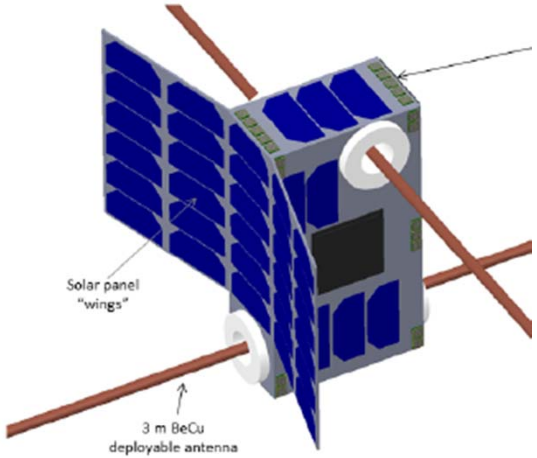
- Space-borne radio aperture synthesis interferometer (30 kHz to 30 MHz)
  - E.g., SOLARA, Solar Observing Low-frequency Array for Radio Astronomy
  - Can start with km-scale tethered interferometric array
    - Then evolve to free-flyers



Muno et al., ARTS 2014

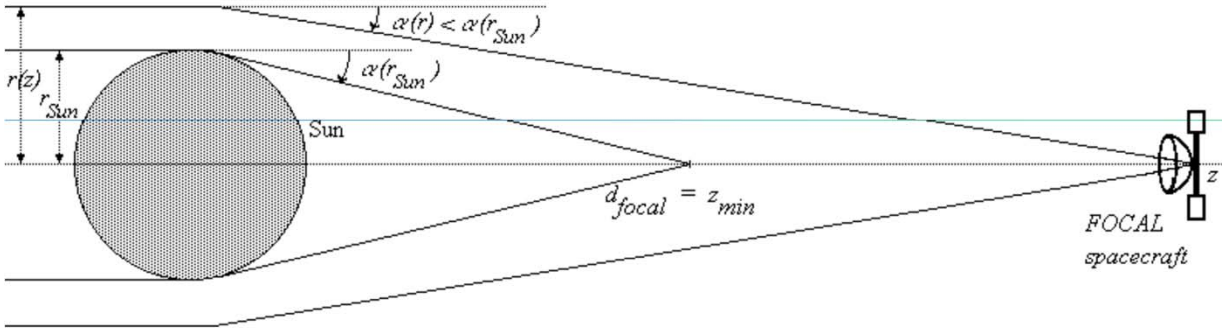
Technology Development: Other

- Use CubeSats as calibration sources for low frequency ground based radio arrays
  - Currently use Orbcomm 137 MHz, but would like frequency comb



http://kiss.caltech.edu/workshops/magnetic2013/presentations/knapp.pdf

- Solar gravity lens at 750 AU from the Sun
  - Collecting area ~80 km telescope
  - Fly CubeSats (with coronagraphs) through the Einstein ring



http://www.spaceroutes.com/astrocon/AstroconVTalks/Maccone-AstroconV.pdf and input from L. Friedman

Summary

- **CubeSats can obtain important scientific measurements toward answering important astronomy and astrophysics research questions**
  - They have time available on orbit to look around, to stop and stare
  - Distributed measurements for improved temporal and spatial characterization
  - Can complement larger missions
- Technology development areas:
  - X-ray, UV, IR detectors and low frequency radio receivers; thermal control
  - Deployable apertures
    - Wavefront correction
  - Deployables for power, communications
  - Deployable sails for propulsion
  - Distributed constellations and formation flying
    - Interferometry
    - Gravimetry (planetary science)
  - Detector development and thermal control
  - Navigation and attitude control
  - Propulsion systems

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