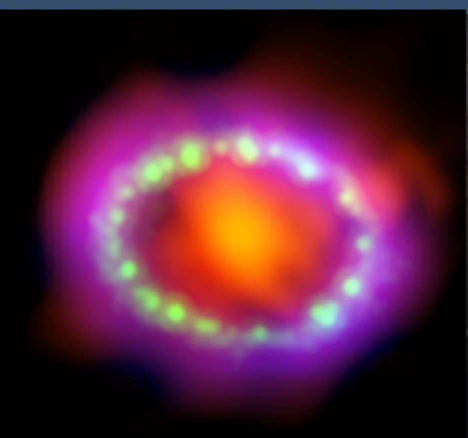
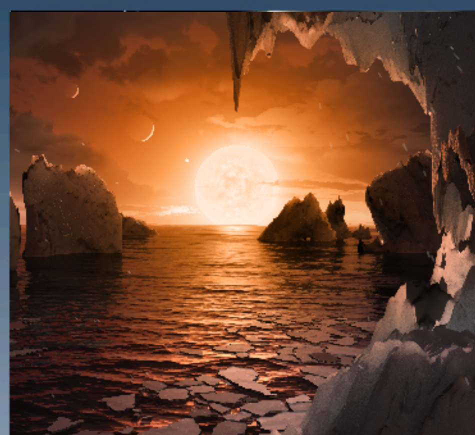
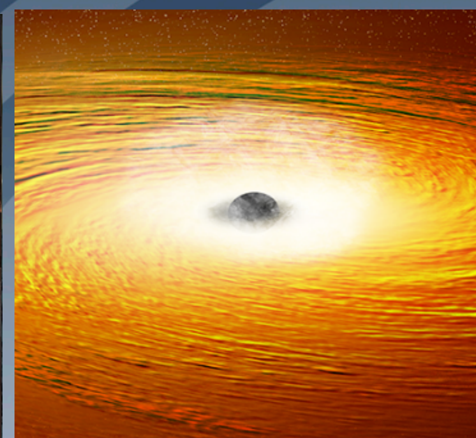
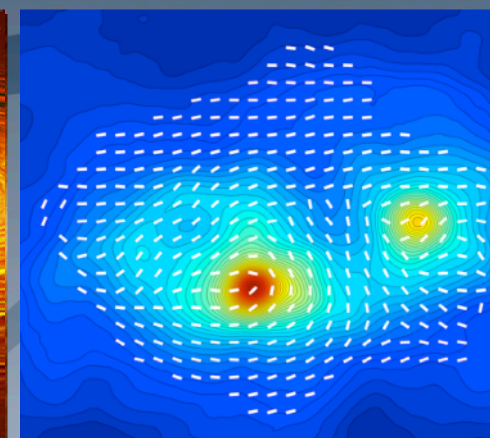
National Aeronautics and Space Administration

Astrophysics

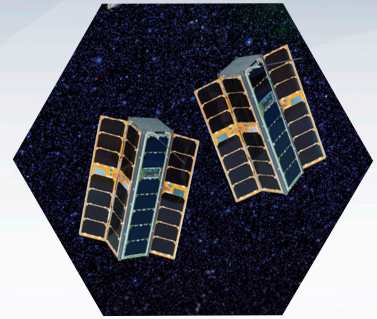





NASA Astrophysics CubeSats and SmallSats: Current and Future Prospects

Jan 6, 2020 AAS, Hawaii

Michael Garcia
NASA HQ
HST Program Scientist
Athena Deputy Program Scientist
APRA, LUVOIR Deputy PS
UV/Vis/ExoPlanets Program Scientist
Astrophysics CubeSats and SmallSats POC

Astrophysics CubeSats



- Astrophysics CubeSats are solicited annually via ROSES/APRA (D.3).
- CubeSats are reviewed along with other sub-orbital proposals; they compete with balloons and sounding rockets (and potentially ISS attached payloads).
- The largest CubeSats that are eligible via APRA are **12U.**
- Astrophysics CubeSats are funded via a $5M annual budget line that was originally appropriated by Congress, and is now part of Astrophysics planning.
- Over 2012-2018 we have received <6> CubeSat proposals/year; 6 have been selected, 14% selection rate (~1 per year). APRA average selection rate is ~30% for suborbital proposals.

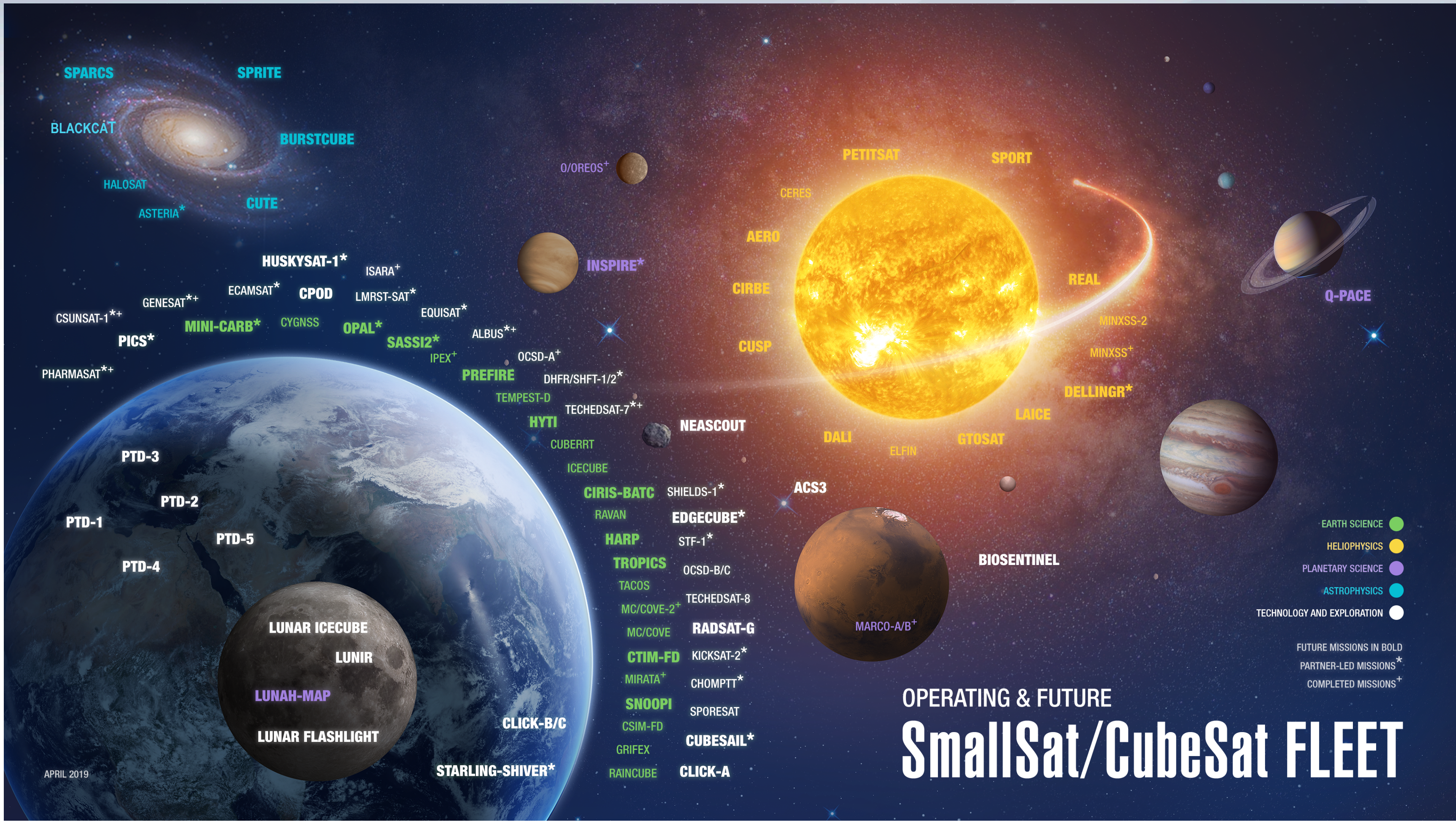
- Are CubeSats of limited use for flux-starved Astrophysics? (Sun, Earth, bright!)

Astrophysics CubeSats

- Over 2012-2018 we have received <6> CubeSat proposals/year; 6 have been selected, 14% selection rate. APRA average is ~30% for suborbital proposals
- Is the reason really that Astrophysics is flux starved?
- Learning Curve? Increased capabilities of CubeSat spacecraft/platforms?

Year	E	E/VG	VG	VG/G	G	F
2012				4	4	1
2013			1	3	2	1
2014			2	2	2	1
2015			3		1	
2016	1		1	1	1	
2017	1	2		1	1	

Lots of SMD CubeSats



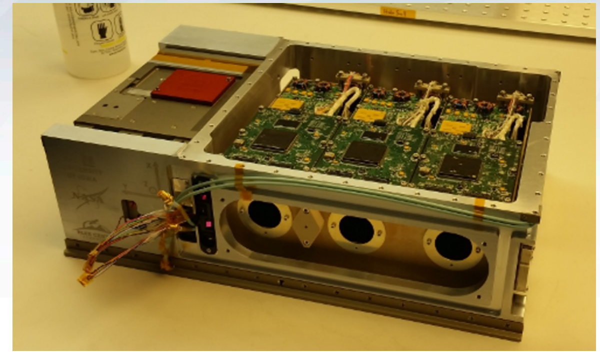
How Can Small Astrophysics CubeSats Compete with Big, Expensive Satellites already in Orbit?

The figure of merit for observing diffuse emission, survey grasp, is the product of effective area and solid angle of the field of view, AΩ. **HaloSat** has a small effective area, but a large field of view, giving it a grasp competitive with major missions.

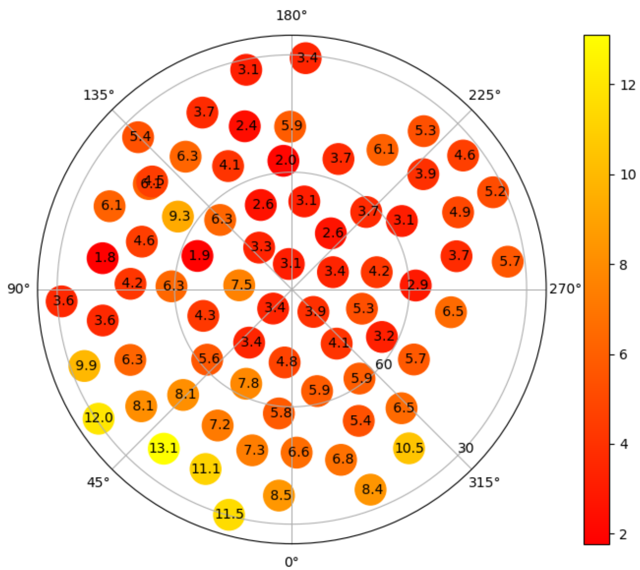
Instrument	Grasp (cm^2 deg^2)
HaloSat	26
Chandra	1.2
XMM-Newton	324

By Finding Unexploited Niches

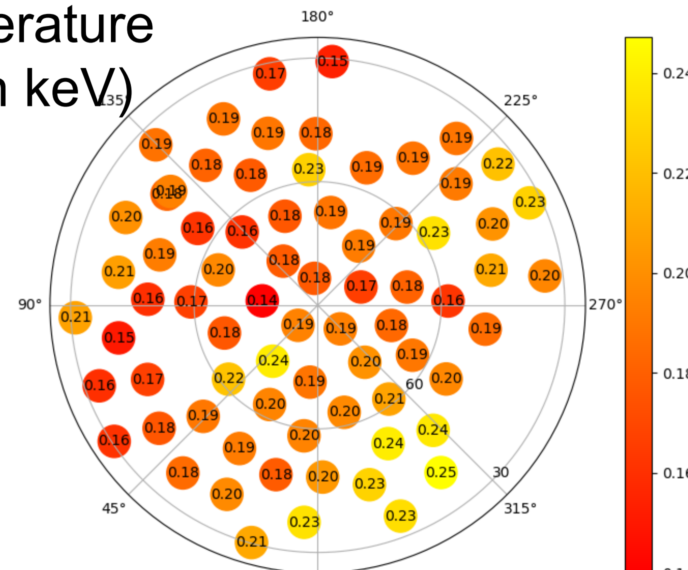
Science from APDs First CubeSat: HaloSat Results on Southern Galactic Halo



Emission Measure
(10^{-3} cm^{-6} pc)



Temperature
(kT in keV)

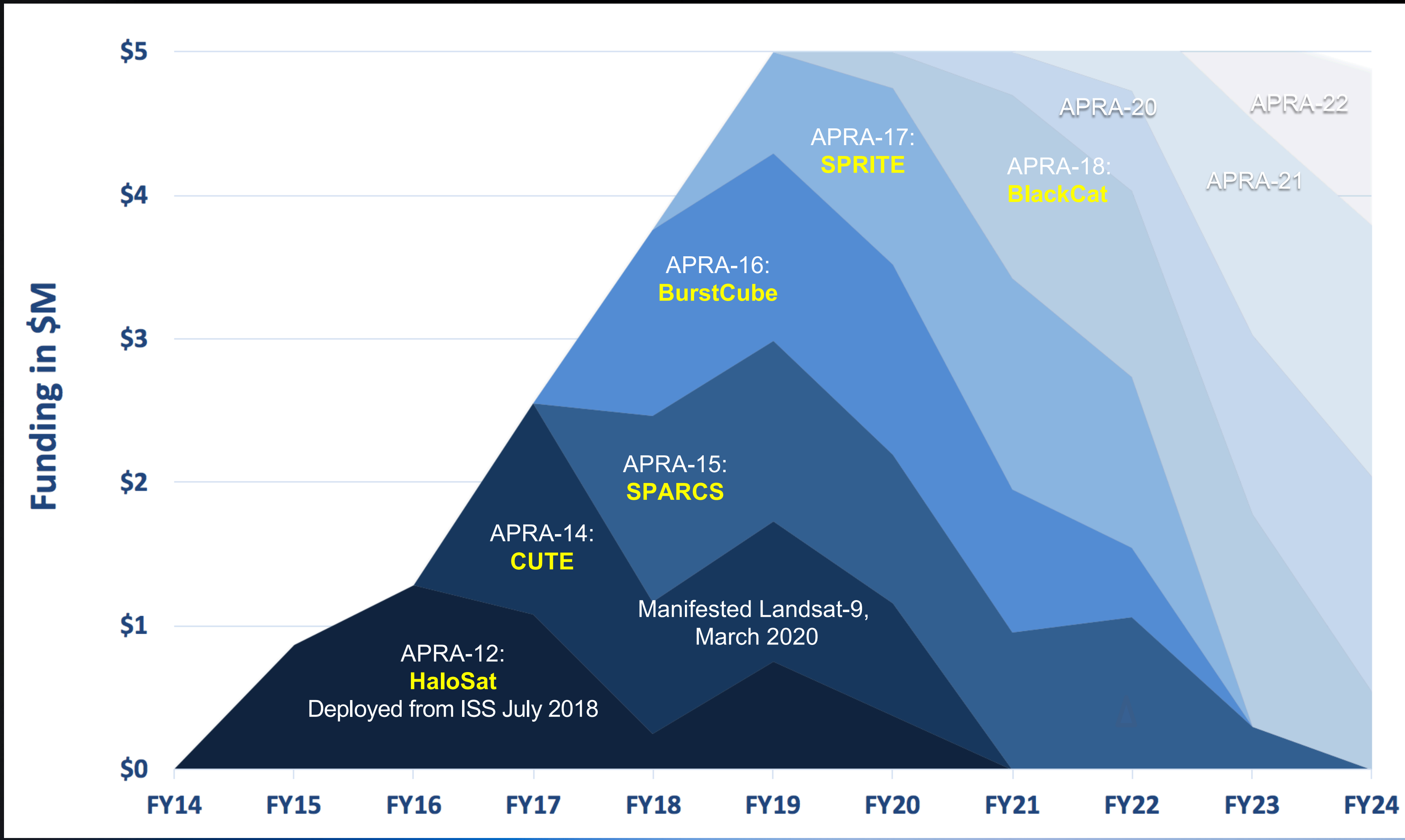


Large variation in EM – factors of 10x
New Finding: Halo is concentrated towards core, lumpy

HaloSat, APDs First CubeSat

The day before the launch, the Iowa HaloSat team met Astronaut Kay Hire.

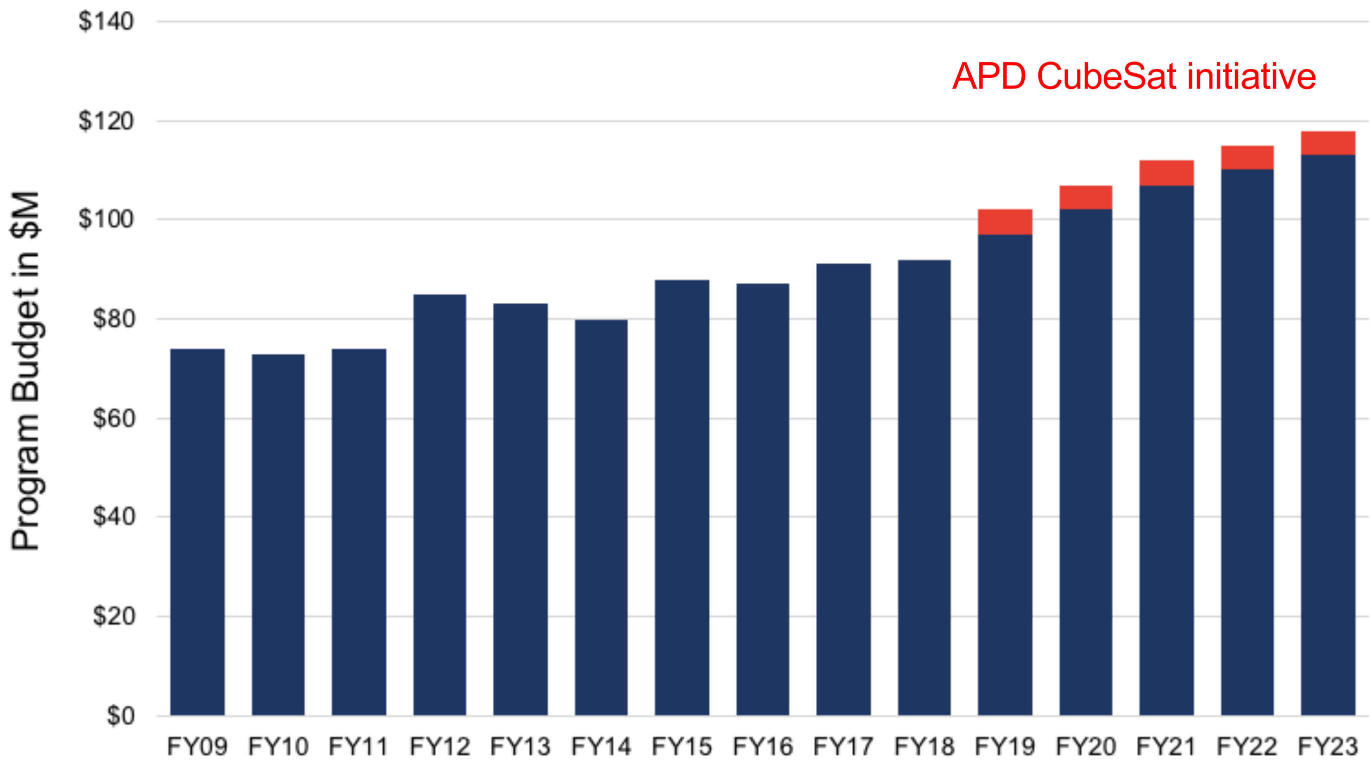
ASTROPHYSICS CUBESAT FUNDING



Launch
:

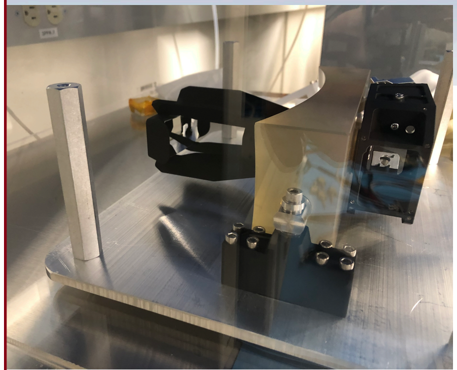
Astrophysics R&A and CubeSats Funding

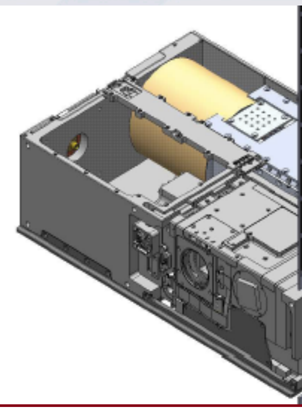
Program	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23
R&A	$74	$73	$74	$85	$83	$80	$88	$87	$91	$92	$97	$102	$107	$110	$113
CubeSat											$5	$5	$5	$5	$5
Total	$74	$73	$74	$85	$83	$80	$88	$87	$91	$92	$102	$107	$112	$115	$118



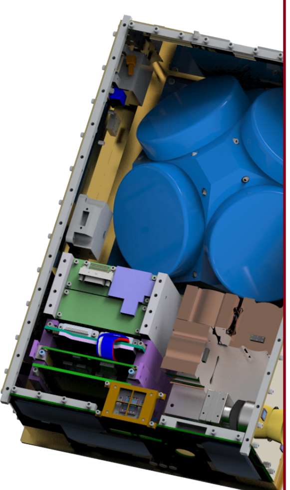
Five Astrophysics CubeSats in Development

- **CUTE, PI**: Kevin France, CU,
- **Science Objectives:** The Colorado Ultraviolet Transit Experiment (CUTE) will take medium resolution UV spectra of 14 hot Jupiters during transit, in order to measure atmosphere being ablated away. **Technologies:** BCT S/C, COTS telescope and camera.
- **Launch**: March 21 on LS-9

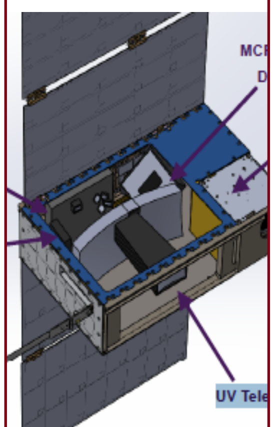




- **SPARCS, PI**: Eygenya Shkolnik, ASU
- **Science Objectives:** Determine rate, strength and 2-band color of bright UV flares from 25 M dwarfs, effect on habitability?
- **Technologies:** BCT S/C, d-doped CCD, UV dichroic.
- **Launch**: Fall 2021



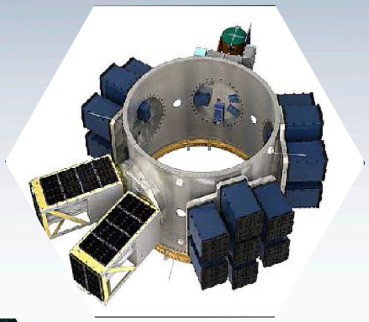
- **BurstCube, PI:** Jeremy Perkins (GSFC)
- **Science Objectives:** Rapid localizations for LIGO/Virgo detections with short GRBs; Search of g-ray transients.
- **Technologies:** Dillingr derived bus, Fermi-GBM like detectors.
- **Launch**: Fall 2021

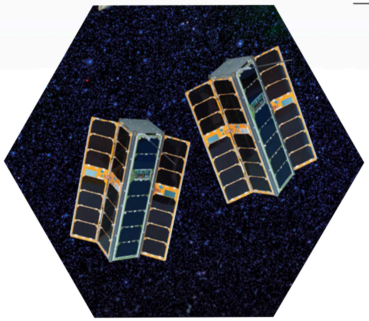


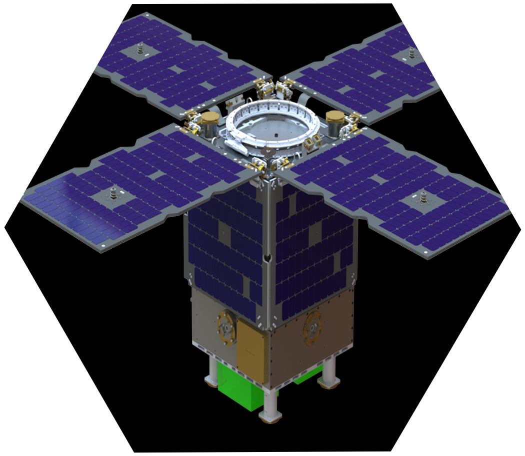
- **SPRITE, PI**: Brian Fleming, CU
- **Science Objectives:** Determine ionization rate of IGM from galaxies and AGN, trace feedback within galaxies driven by star-forming regions, using low-resolution imaging UV spectrograph.
- **Technologies:** in house S/C, UV coatings, next-gen MCP.
- **Launch**: Fall 2022

- **BlackCat, PI**: Abe Falcone, Penn St.
- **Science Objectives:** GRB/Transient detection in 0.2-20keV with coded mask.
- **Technologies:** CMOS x-ray CCD
- **Launch**: FY2024

2018, Nine Astrophysics Science SmallSat Studies







Waveband:

X-ray: 4, (XQSat, SEEJ, VTXO, HREXI)

UV: 2 (GUCI++, mDOT)

Vis: 1 (aMASS)

IR: 1 (ISCEA)

Radio: 1 (DAPPER)

Science Topics:

Cosmology/Clusters: 2 (DAPPER, ISCEA)

ExoPlanets: 3 (mDOT, MASS, SEEJ)

Transients/GW: 2 (GUCI++, HREXI)

X-treme Universe: 2 (XQSat, VTXO)

Technologies:

Formation Flying: 2 (VTXO, mDOT)

Results:

Lots of good concepts, 2019 AS^3, SmallSats in all future Explorer MO

Two Page Public Fact Sheets:

https://www.nasa.gov/feature/nasa-astrophysics-eyes-big-science-with-small-satellites

SmallSats Costing

- One Result from 2018 Astrophysics Science SmallSat Studies (AS^3)
- Grass Root Costs < Design Center Model costs.
- Why?

Mission Concept	PI Grass Roots Cost	Concept Study Cost	design center	factor increase
1	34.4	63	AMES	1.83
2	21 to 45	32	GSFC	1.00
3	26	37	GSFC	1.42
4	25.5	25.5	none	1.00
5	31	60	GSFC	1.94
6	35	50	AMES	1.43
7	23	52	JPL	2.26
8	33	91	JPL	2.76
9	33	35	MSFC	1.06
average				1.63

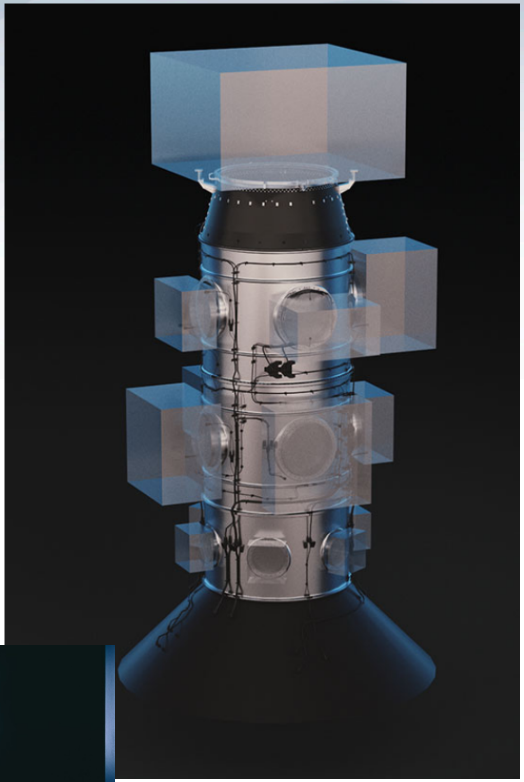
- One Example: BCT S5 bus quote \$2.7M, Design Center Model \$14M. Add 30% reserves and your \$25M program is >\$35M total. Have the vendors broken the cost curve, or are they overly optimistic?

Can we go bigger in R&A/APRA?

APRA/CSLI does allow up to 12U, but do date all Astrophyiscs CubeSats have been 6U and costs up to $5M total

Commercial Launchers and Buses?

SpaceX's SmallSat Rideshare Program
- Monthly rideshare missions **starting** 3/2020
- ESPA class payloads, 200 kg for "as low as $1M", to both LEO and SSO
- CSLI $0.9M for 12U CubeSat in last APRA
- APRA **does** allow 'bring your own ride'
- https://www.spacex.com/smallsat



York Space Systems S-class bus
- 85kg payload
- 3-axis stabilized (10", 1.5°/s)
- 100W orbit average power
- 22.5" × 22.5" × ≥18.9"
- $1.2M, comparable to CubeSat buses
- 12/year, growing to ~200/year
- https://www.yorkspacesystems.com/s-class/

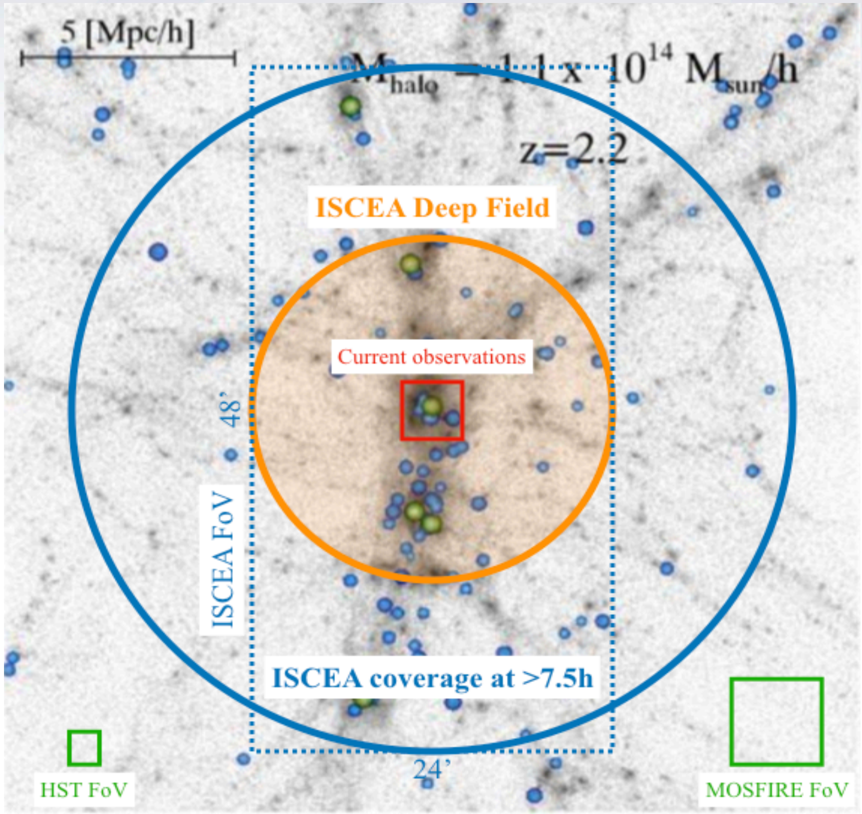
BACK UP

ISCEA: Infrared SmallSat for Cluster Evolution Astrophysics

PI: Yun Wang (Caltech/IPAC)

ISCEA pushes the envelope for “Big Science” at an extraordinary value from a SmallSat.

- Game-changing science of cosmic evolution at the peak of galaxy formation
- 25 cm aperture telescope with 0.32 deg^2 FoV, multi-object spectroscopy
- Demonstrating key innovative instrument technology that will be available to future satellite missions
- Valuable Guest Observatory beyond its prime mission



ISCEA FoV (large blue box) compared to current observations (small red square), for a simulated protocluster at z = 2.2. Background grayscale shows dark matter filaments. The blue and green filled circles highlight star-forming and passive galaxies in the protocluster, respectively.

DAPPER, Dark Ages Polarimeter PathfinER
PI: Jack Burns, UC Boulder

DAPPER Dark Ages Polarimeter PathfindER

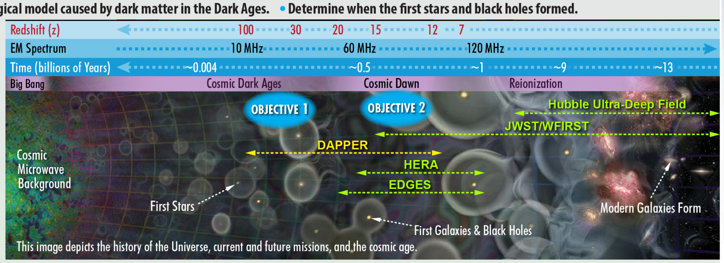
DARK COSMOLOGY: INVESTIGATING DARK MATTER IN THE DARK AGES

SCIENCE

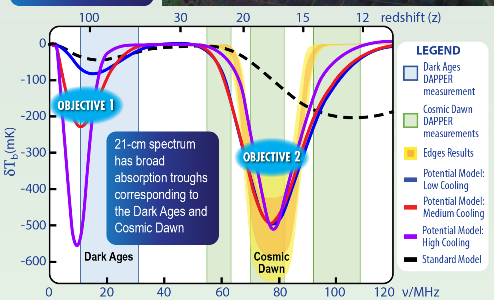
OBJECTIVE 1:
- Determine the level of divergence from the standard cosmological model caused by dark matter in the Dark Ages.

OBJECTIVE 2:
- Determine the level of excess cooling above the adiabatic limit for Cosmic Dawn.
- Determine when the first stars and black holes formed.

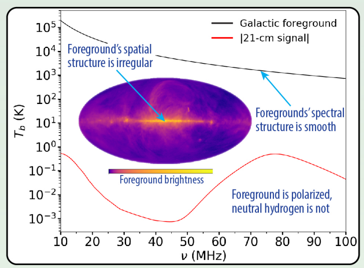
Will the observed behavior of redshifted neutral hydrogen redefine the standard cosmological model?



This image depicts the history of the Universe, current and future missions, and the cosmic age.



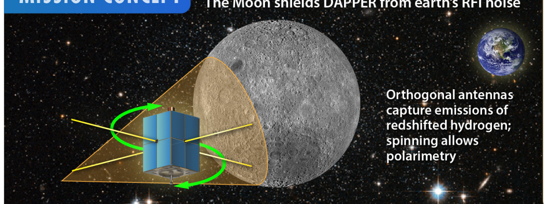
DAPPER uses the 21-cm all-sky signal to observe redshifts z = 83-12, associated with the Dark Ages and the Cosmic Dawn.

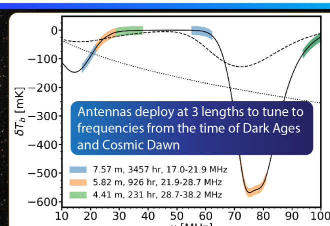


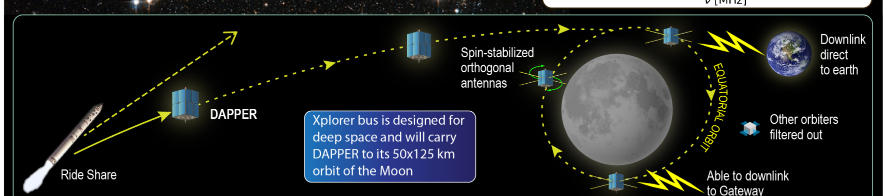
DAPPER separates Galaxy foreground from 21-cm signal using differences in spectral shapes, spatial structure, and polarization.

MISSION CONCEPT

The Moon shields DAPPER from earth's RFI noise





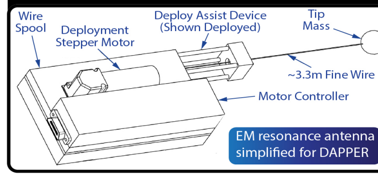


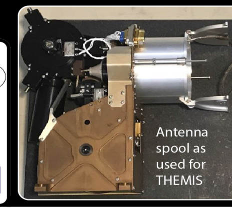
DAPPER Dark Ages Polarimeter PathfindER

DARK COSMOLOGY: INVESTIGATING DARK MATTER IN THE DARK AGES

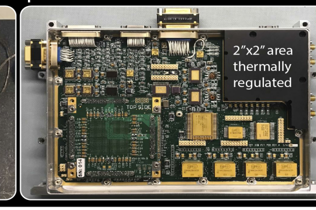
INSTRUMENT

Thermally robust antennas have been deployed in near-sun environment and in deep space.

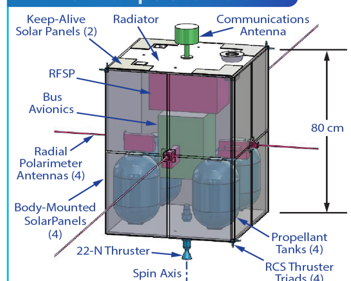




Spectrometer/Polarimeter used for Parker Solar Probe



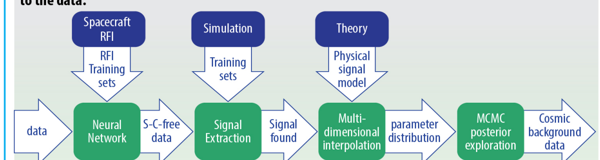
BRADFORD'S Xplorer SPACECRAFT



Spinning not only allows polarimetry but also stabilizes attitude and temperature.

DATA PROCESSING PIPELINE

Pipeline uses pattern recognition and training sets to separate signal from known S/C, foreground, and systemic effects, and then fits cosmological models to the data.

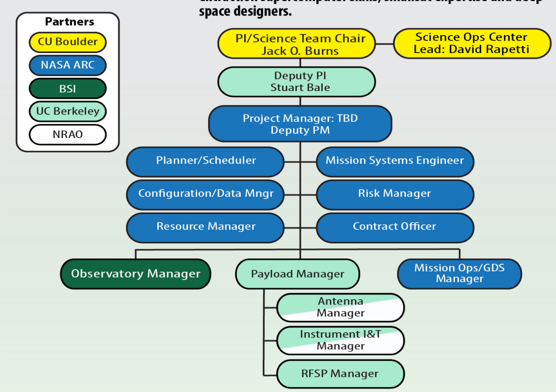


MANAGEMENT & ORGANIZATION

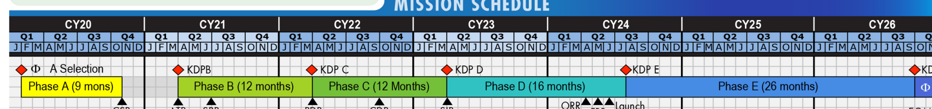
DAPPER SCIENCE TEAM		
Member	Role	Institution
J. Burns	PI	University of Colorado
S. Bale	Co-I	UC Berkley
R. Bradley	Co-I	NRAO
N. Bassett	Grad Student	University of Colorado
D. Bordenave	Grad Student	University of Virginia
J. Bowman	Collaborator	ASU
H. Falcke	Collaborator	Radbound University
S. Furlanetto	Collaborator	UCLA
M. Klein-Wolt	Collaborator	Radbound University
R. MacDowall	Collaborator	NASA GSFC
J. Mirocha	Collaborator	McGill
B. Nhan	Collaborator	University of Virginia
D. Rapetti	Postdoc	University of Colorado
K. Tauscher	Grad Student	University of Colorado

DAPPER ORGANIZATION

DAPPER's mission team combines polarimetry experience, signal extraction supercomputer skills, smallsat expertise and deep space designers.



MISSION SCHEDULE

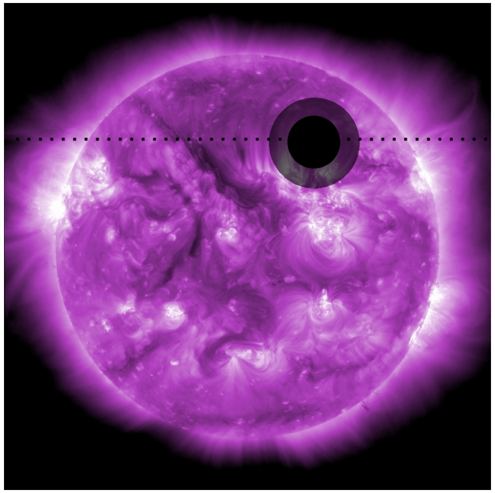


Mission schedule allows DAPPER to conduct observations during the construction of initial lunar infrastructure but before RFI grows too large.

SEEJ: Smallsat Exploration of the Exospheres of Nearby Hot Jupiters Orbiting X-ray Bright Stars

PI Scott Wolk, Smithsonian/CfA

- **The primary objective of SEEJ** (pronounced “siege”) **is to measure the depth of planetary transits of at least 10 Hot Jupiters from 0.5-2.0 keV to 2% percent accuracy**.
- This allows the measurement of the exosphere and mass loss of the planet which is often due to XUV flux.
- Using high cadence monitoring SEEJ will observe scores of transits of each TESS X-ray bright system detected.
- With a total of ~ 150 cm^2 EA SEEJ will achieve signal to noise similar to the published results of Chandra and XMM.
- Could launch by 2025

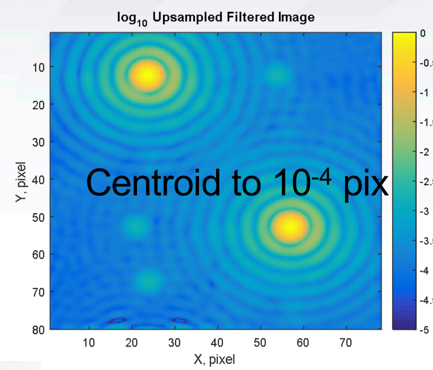


MASS (MicroArcsec Small Satellite) (M. Shao, JPL)

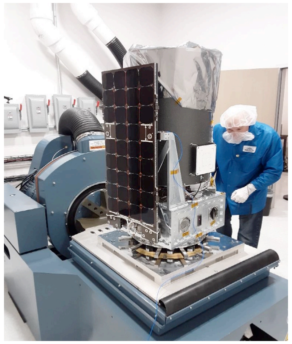
1st Exo-Earth in HZ around a G star.

Determine planetary masses via orbital astrometric wobble, for Earth mass planets around nearby stars

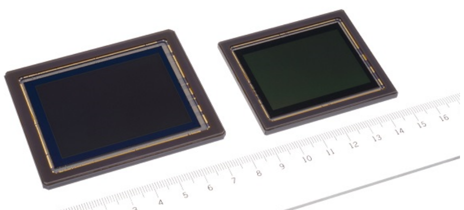
- 4~5 μas astrometry (1hr)
- 1 Mearth HZ (~6 nearby stars. & 2 Mearth ~14 stars in 3yr)
- 10^{-4} pix centroiding with laser sub-pixel characterization of detector (lab demo)
- New 100Mpix backside CMOS detectors now available (~1e read noise)
- Ultra-low cost ESPA S/C based on cubesat subsystems. $4M vs $35M for S/C bus. 2 in orbit.



HIP	Mass M_E	V mag	Dist., pc	Period, years	Signal, uas	time, hrs	Cumulative, hrs
71683	1	-0.01	1.35	1.21	4.79	100	100
71681	1	1.35	1.35	0.51	3.44	194	295
8102	1	3.49	3.65	0.56	1.32	1,325	1,619
2021	1	2.82	7.47	2.07	1.06	2,043	3,663
3821	1	3.46	5.95	1.10	1.05	2,102	5,765
99240	1	3.55	6.11	1.01	0.99	2,357	8,122
22449	2	3.19	8.03	1.91	0.96	625	8,747
108870	2	4.69	3.63	0.24	0.96	630	9,378
19849	2	4.43	5.04	0.47	0.89	725	10,102
15510	2	4.26	6.06	0.68	0.86	787	10,889
77952	2	2.83	12.31	4.05	0.83	827	11,716
27072	2	3.59	8.97	1.73	0.83	842	12,559
746	2	2.28	16.70	8.06	0.80	899	13,458
96100	2	4.67	5.77	0.49	0.79	913	14,371
57757	2	3.59	10.90	2.16	0.74	1,051	15,422
1599	2	4.23	8.59	1.11	0.73	1,084	16,506
105858	2	4.21	9.22	1.25	0.71	1,141	17,647
64394	2	4.23	9.15	1.19	0.70	1,169	18,816
78072	2	3.85	11.12	1.95	0.70	1,183	19,999
14632	2	4.05	10.53	1.57	0.68	1,250	21,249
12777	2	4.10	11.23	1.70	0.66	1,340	22,589
64924	2	4.74	8.53	0.79	0.64	1,389	23,978



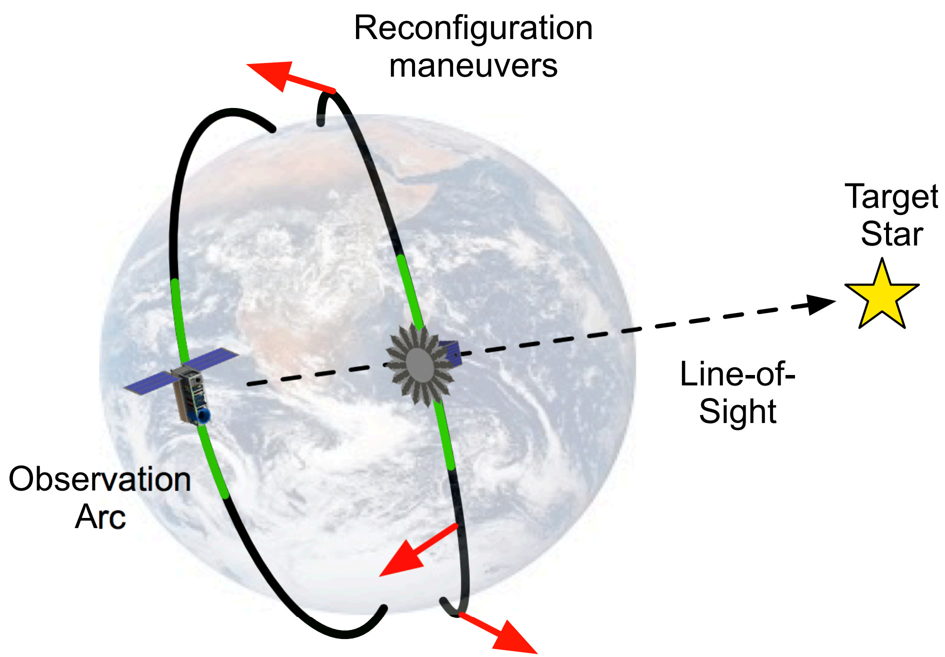
ARFL S5 Mission ESPA S/C
~35cm telescope
2/28/2019 launch
~$4M s/c bus



150&100Mpix CMOS backside sensor (1e read noise 3hz frame)

mDOT, minature Distributed Occulter Telescope
PI: Bruce MacIntosh (Stanford)

mDOT is a minuature starshade, occultor formation flying demonstrator

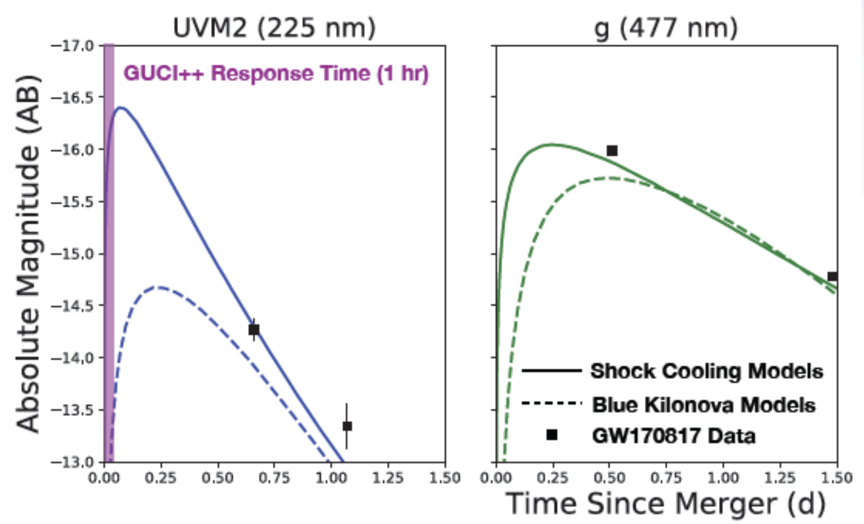


- Pair of cubesats (telescope = 6u, starshade = 180 kg) formation flying in LEO
- NUV bandpass, 10x more sensitive than LBTI HOST, exo-zodi light detection around 6-8 nearby bright stars
- 3m starshade, 10cm telescope
- Pathfinder for future larger star shades

GUCI++ Gravitational wave Ultraviolet Counterpart Imager, PI: Brad Cenko (NASA/GSFC)

GUCI++ is a network of 3-5 12U smallsats designed to characterize emission from NS-NS mergers

- Triggered by ground-based GW detectors
- 64 sq-degree, rapid UV multi-bandpass followup
- First All-sky UV synoptic survey when not doing GW followup
- Increased UV throughput of delta-doped detectors
- Expected rate 6/year



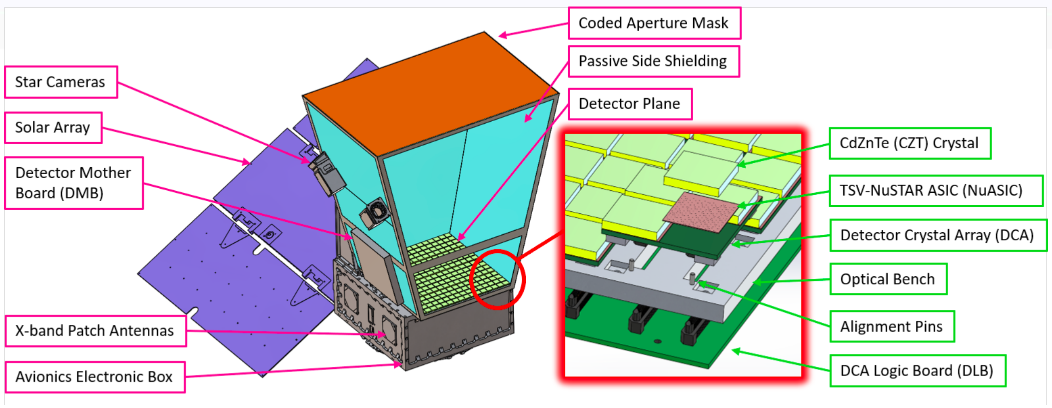
UV lightcurve is strong discriminator of models

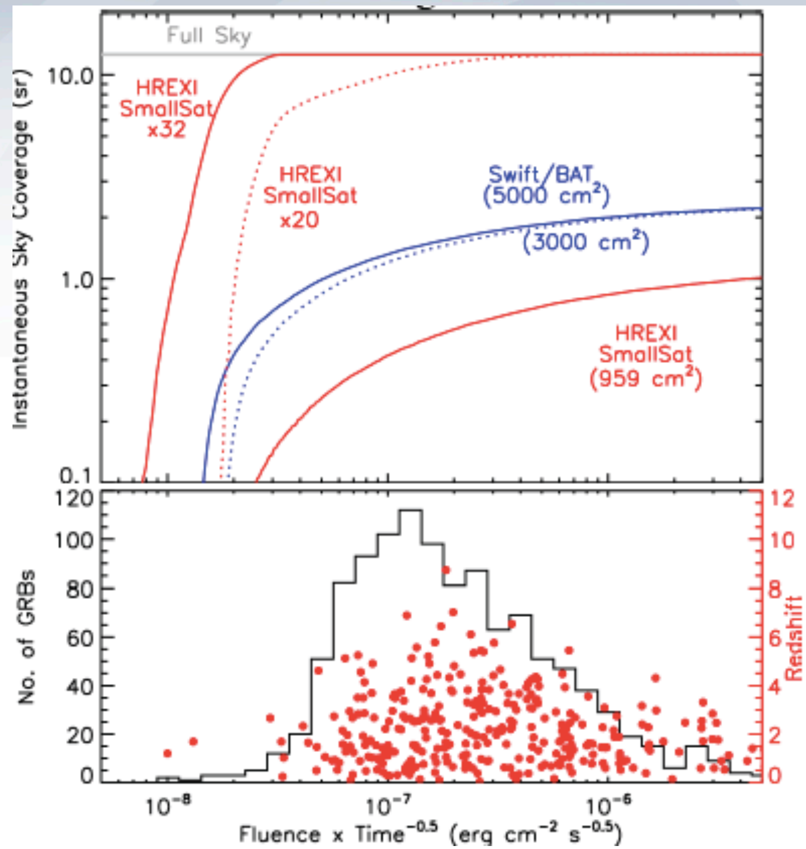
Table 4: – Wide-Field UV Survey Capabilities

Mission	Effective Area[a] (cm^2)	Field of View (deg^2)	Angular Resolution[b] (arcsec)	Bandpass (nm)	Étendue[c] (deg^2 cm^2)
Swift-UVOT	22.0	0.080	2.4	170-650	**1.8**
HST-WFC3/UVIS	4523	0.0020	0.08	200-1000	**9.0**
GALEX[d]	50.1	1.13	5.4	135–280	**56.6**
GUCI++[e]	71.2	64	30–40	180-230	**4556.8**

HREXI, High Resolution Energetic X-ray Imager
PI: Josh Grindlay (Harvard/CfA)

HREXI is network of 20-30 smallsats offering continuous all-sky 3-200 keV monitoring



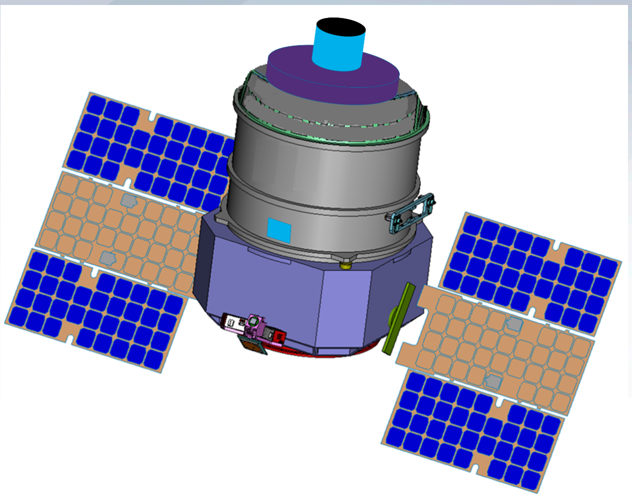


- Synoptic all-sky x-ray survey allows multiple science targets including GW followup, transients, and deep survey
- Coded aperature telescope, NuStar-like CZT detectors
- BCT uSat-S5 bus

A network of 32 would be more capable than current SoA (Swift/BAT), and would detect large numbers of high redshift GRBs

XQCSat, X-ray Quantum Calorimeter Satellite

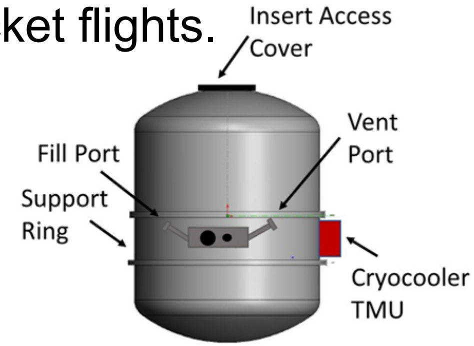
PI: Philip Kaaret,U. Iowa

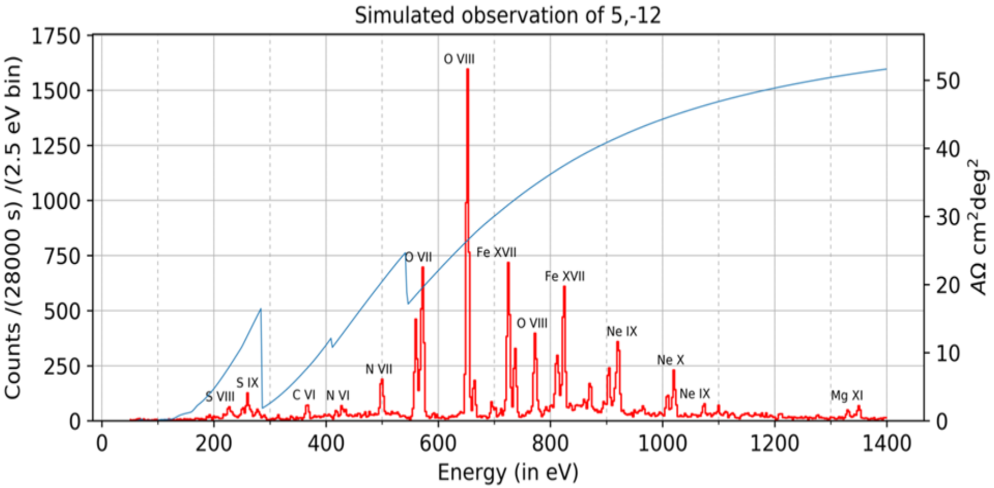


Feedback is an essential process in galaxy evolution. The Milky Way is a nearby laboratory to study feedback.

X-ray microcalorimeter with large field of view enables high resolution spectra of diffuse emission with 100× grasp of XRISM in ESPA-Grande envelope.

Based on technology demonstrated in Wisconsin rocket flights.





Simulated 28 ks spectrum has lines from all astrophysically important elements.

Challenge is to build a liquid helium-filled cryostat that will stay cold for mission duration of at least 30 days. We use technology developed for NASA/GSFC Superfluid Helium On Orbit Transfer (SHOOT) project.

VTXO, Virtual Telescope for X-ray Observations

PI: John Krizmanic (NASA/GSFC)

VTXO is a long focal length soft x-ray telescope that achieves 10mas spatial resolution, 50x beyond current capabilities

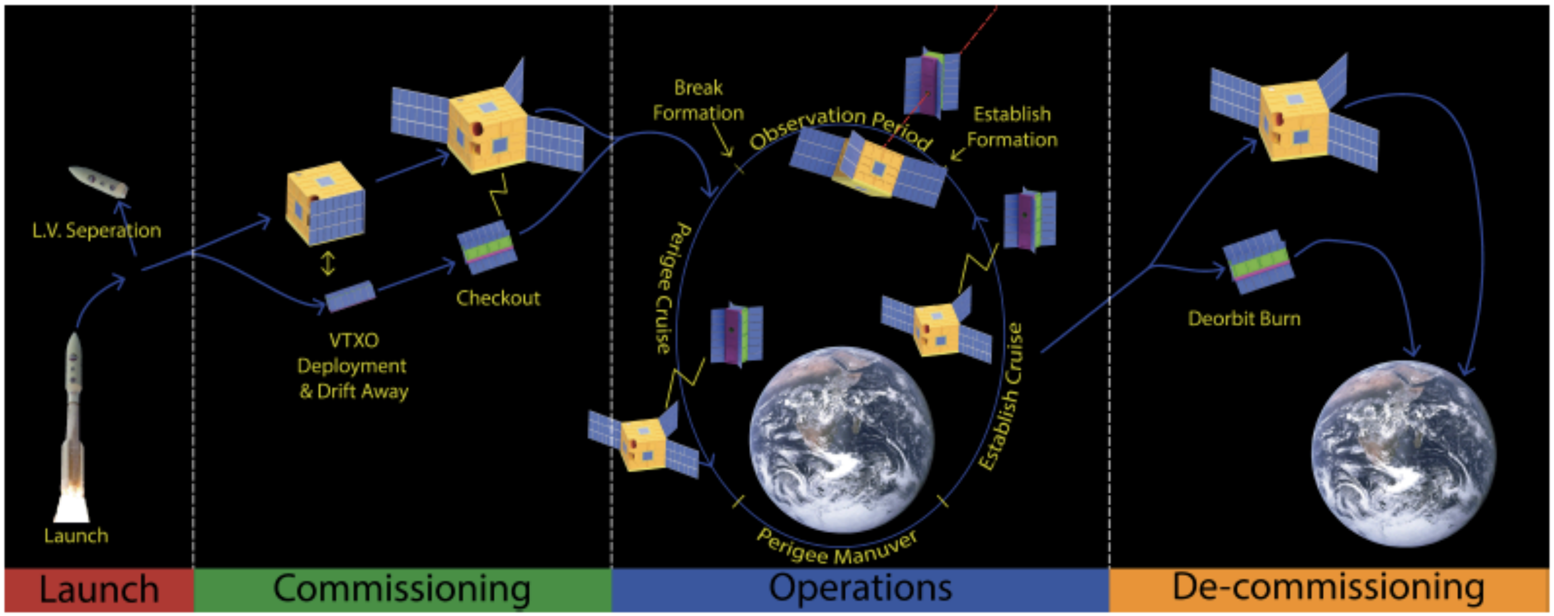


Figure 3: VTXO concept of operations.

- 6U Phase Fresnel Lenses operating in soft x-ray band, 27U detector sat
- 0.5 to 10 km focal length via formation flying
- Elliptical ~GTO like orbits allows hours long integration times with modest delta-V
- Probe closer to central engines in bright x-ray sources