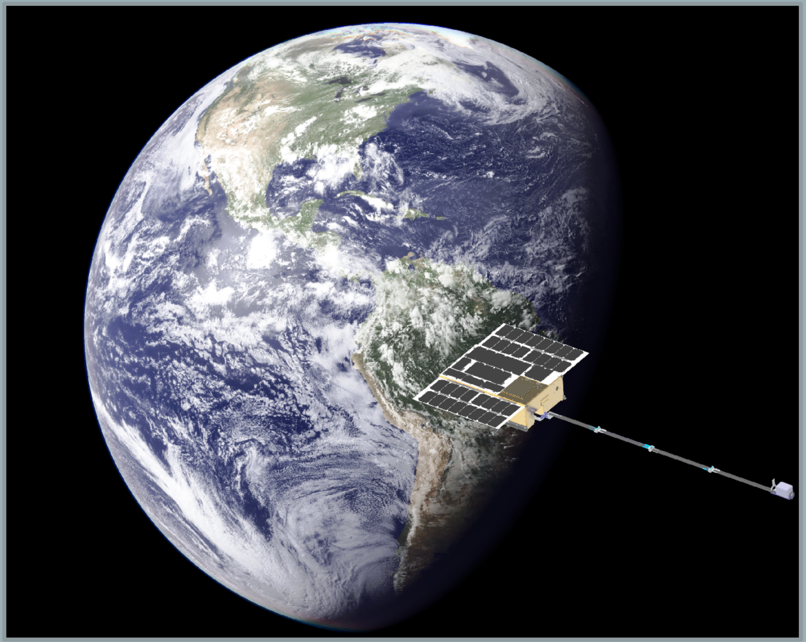
THE NEXT GENERATION OF HELIOPHYSICS CUBESAT EXPLORERS

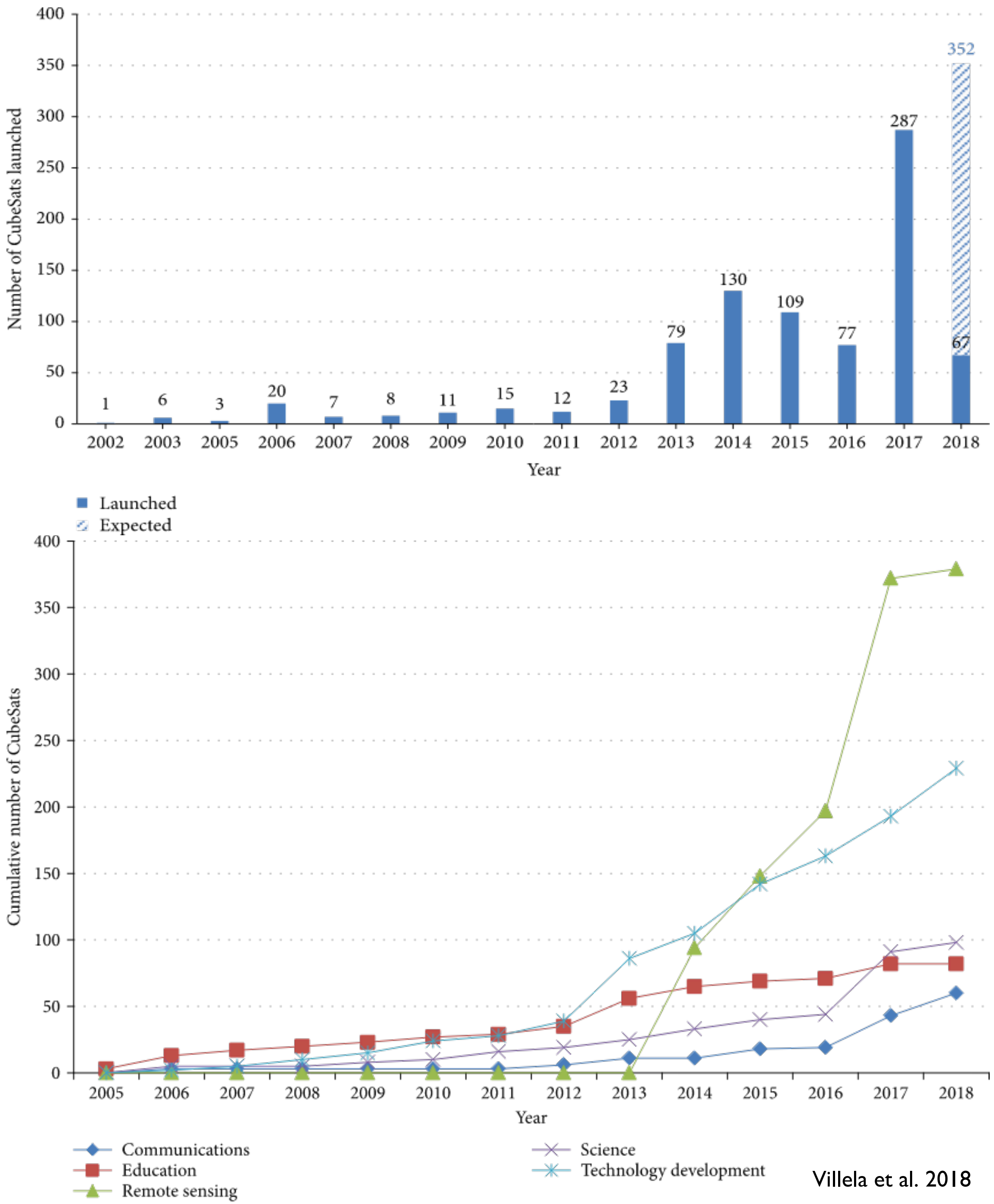


Lauren Blum

L. Kepko, D. Turner, C. Gabrielse, A. Jaynes, S. Kanekal, J. Lucas, R. Roder, L. Santos, GTOSat, CSSWE, CeREs, and Van Allen Probes teams

Discuss your work on CubeSat missions and how the field of spacecraft observation is being affected by these new instrument vehicles

CUBESAT COMMERCIALIZATION AND SCIENCE APPLICATIONS

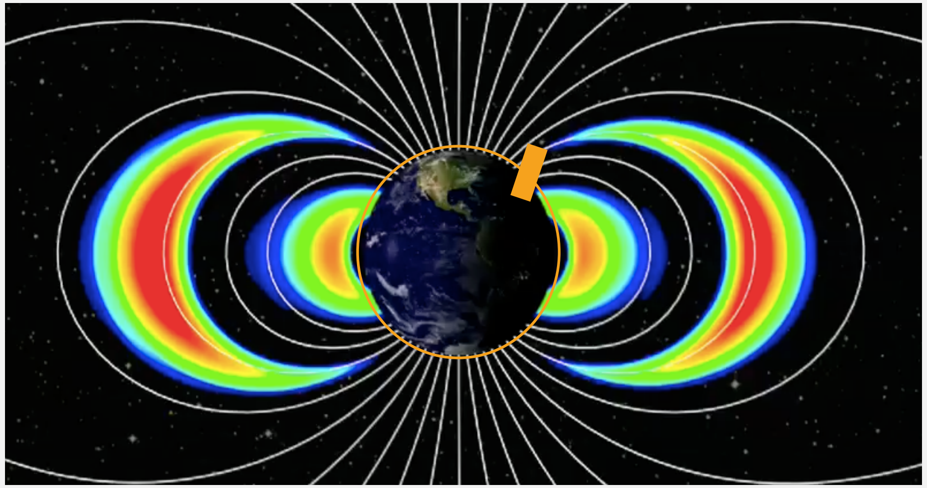


Villela et al. 2018

Planet Labs Inc. Dove Constellation: 189 in 14 "Flocks," Including single launch of 88 (Feb. 2017)

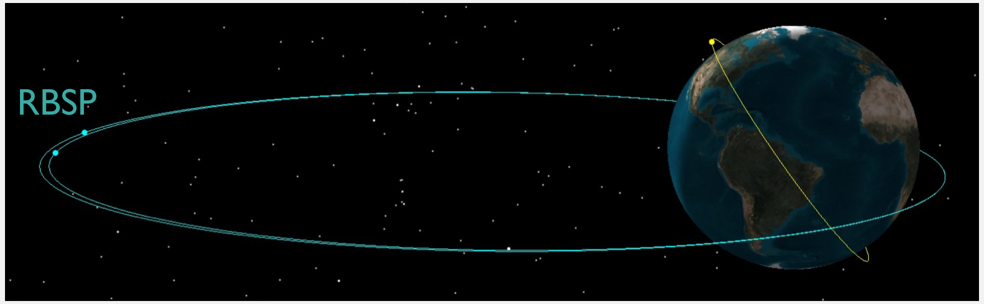
RADIATION BELT CUBESAT MISSIONS

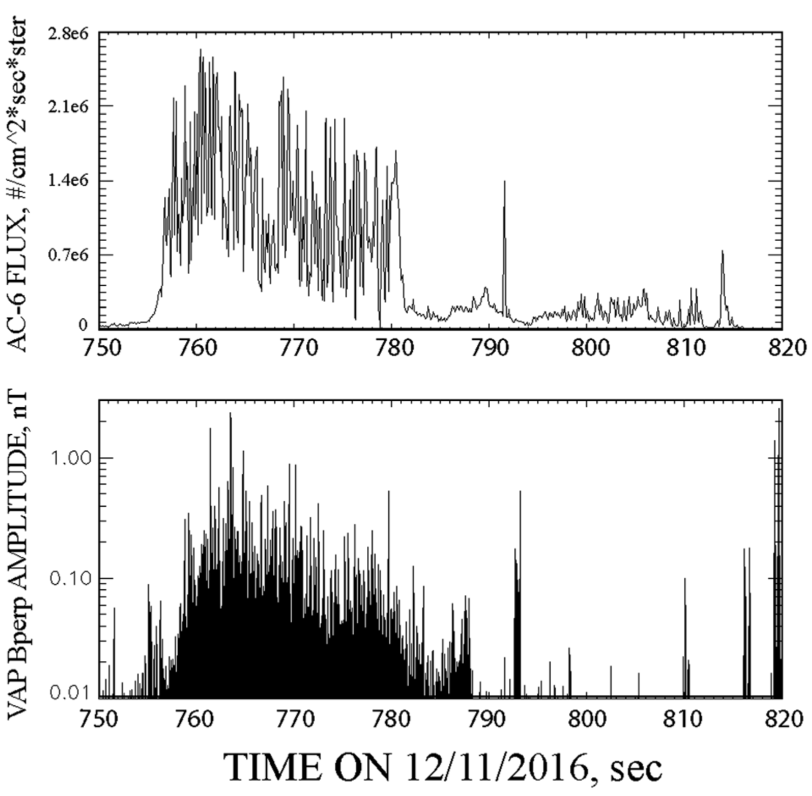
- Fantastic past/current/upcoming fleet of radiation belt CubeSat missions:
  - Past/Current: CSSWE (X. Li), FIREBIRD (H. Spence), AC6 (Aerospace), ELFIN (V. Angelopoulos), Aalto-1 (Finland)
  - Coming soon: CIRBE (X. Li), REAL (R. Millan), SNIPE (KASI), …



RADIATION BELT CUBESAT SCIENCE RESULTS

- Spatial, temporal scales of precipitation via multipoint measurements (e.g. Blum et al. 2013; Blake and O'Brien et al. 2016; Anderson et al. 2017; Shumko et al. 2018,2020)
  - CubeSat pairs (FIREBIRD, AC6, ELFIN), and CubeSats combined with balloons/other observatories
- Conjugate wave-precipitation observations (e.g. Blum et al. 2015; Breneman et al. 2017; Mozer et al. 2018; Capanollo et al. 2019)
- With RBSP decommissioned, what's next?





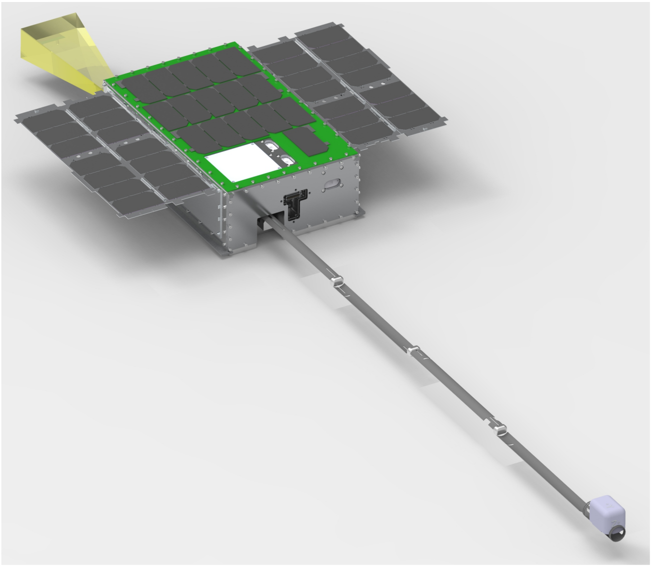
Mozer et al. (2018)

GTOSat

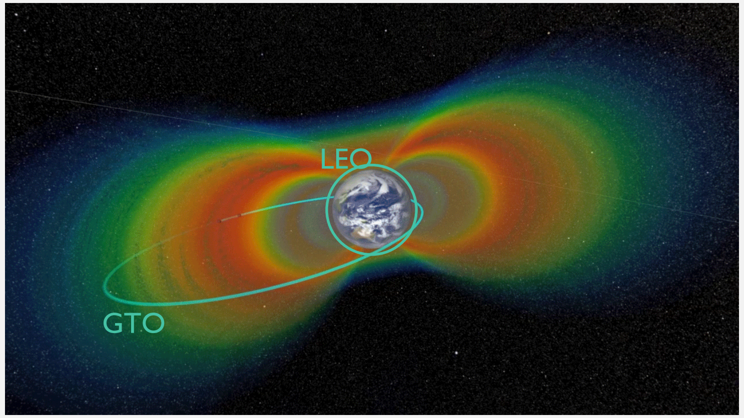
Aerospace • NASA GSFC • U of Iowa

GTOSAT

- ~$4.3M 6U CubeSat under development, targeting a launch ~late 2021 into geosynchronous transfer orbit (GTO)
- Team of engineers and scientists from NASA/Goddard, The Aerospace Corporation, University of Iowa, and JHU/APL
- 3 primary mission objectives:
  - Science - study energetic particle dynamics in Earth's outer radiation belt
  - Space weather - provide low-latency monitoring of the outer radiation belt
  - Technology advancement - demonstrate the ability and utility of smallsats beyond low Earth orbit (LEO)



Blum et al. (2020)



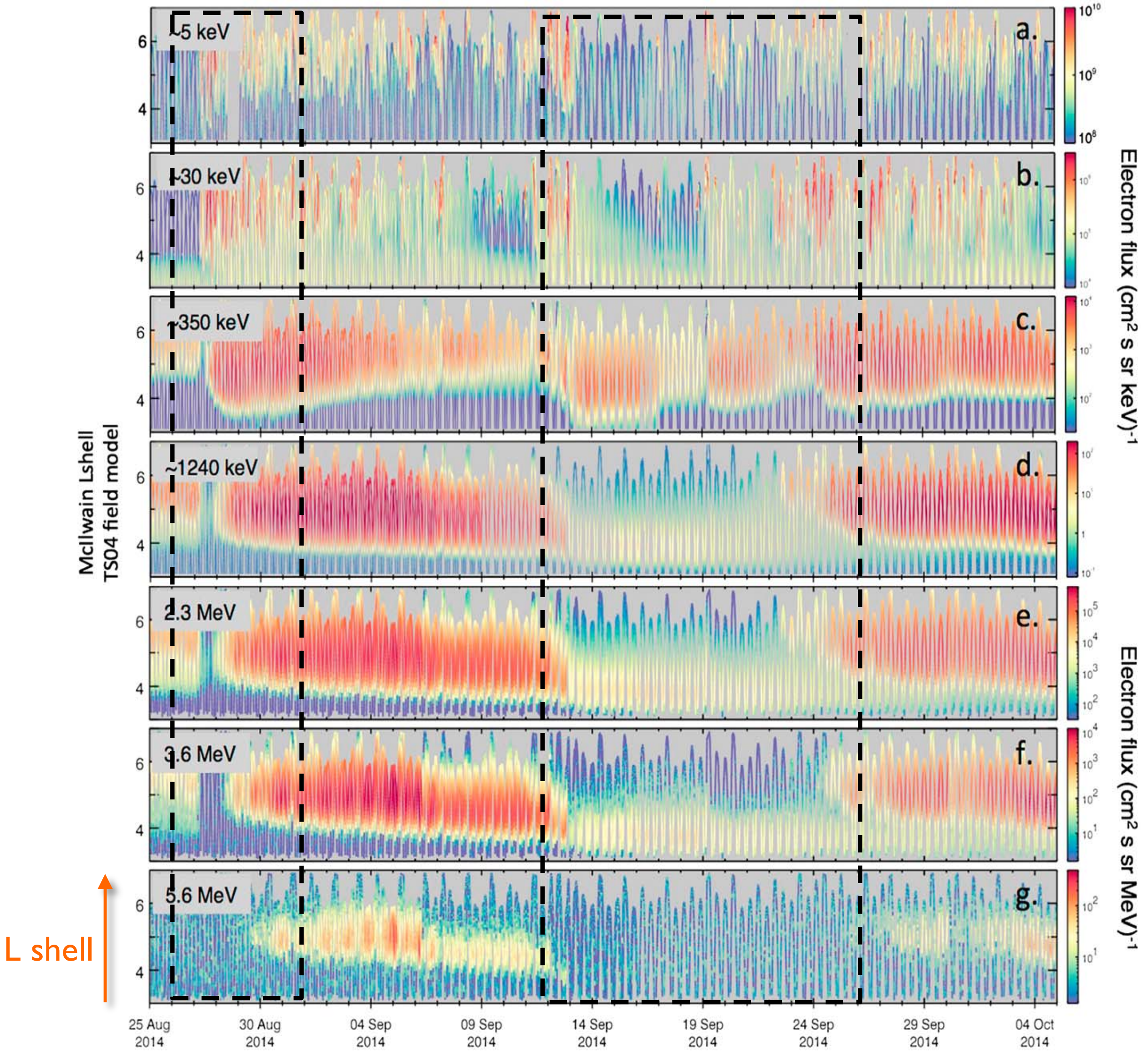
GTOSAT SCIENCE

Primary Science Objective:

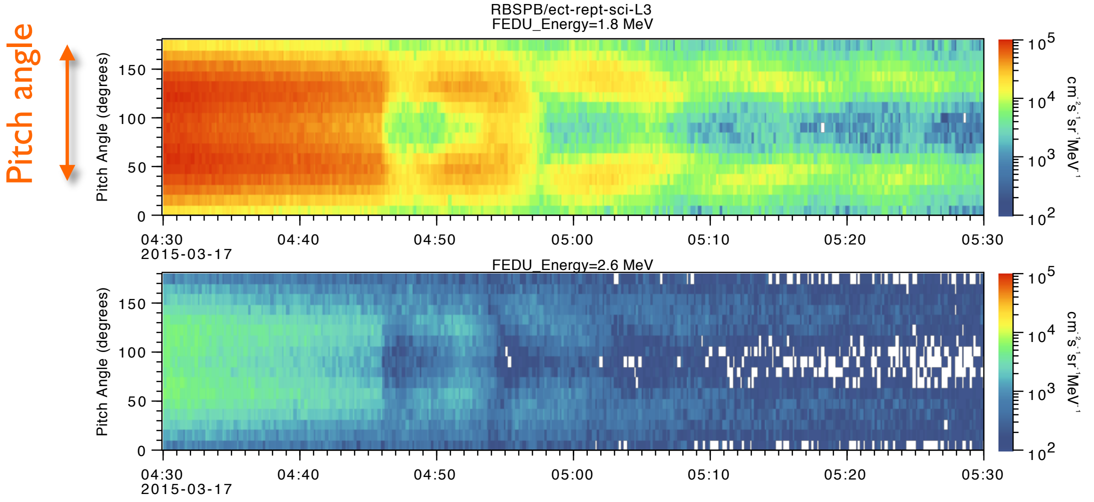
Quantitatively understand the energy and pitch angle dependent dynamics of electrons in the outer radiation belt

Observational Goals	
1.	Measure pitch angle distributions (PADs) in differential energies throughout the outer radiation belt
2.	Measure electron phase space density profiles through the outer radiation belt
3.	Measure energetic electron injections in to the inner magnetosphere (within GEO)

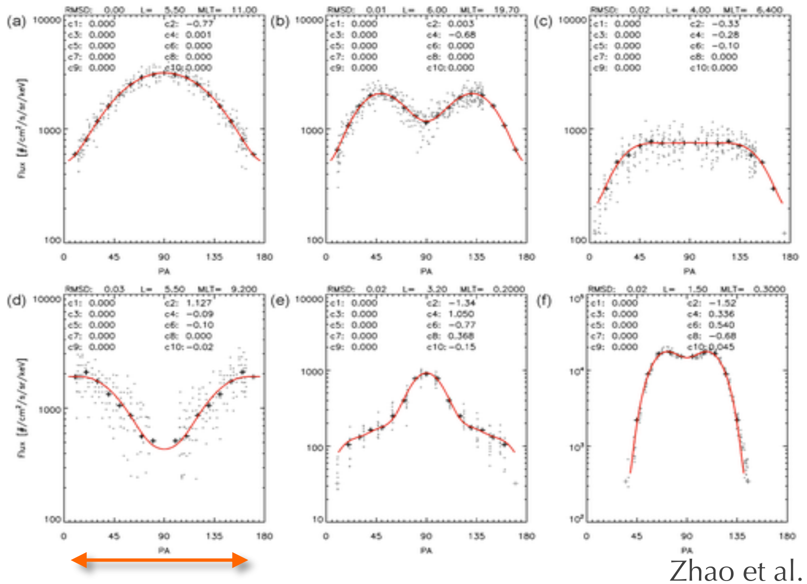
PITCH ANGLE AND ENERGY DEPENDENT DYNAMICS



Jaynes et al. (2015)

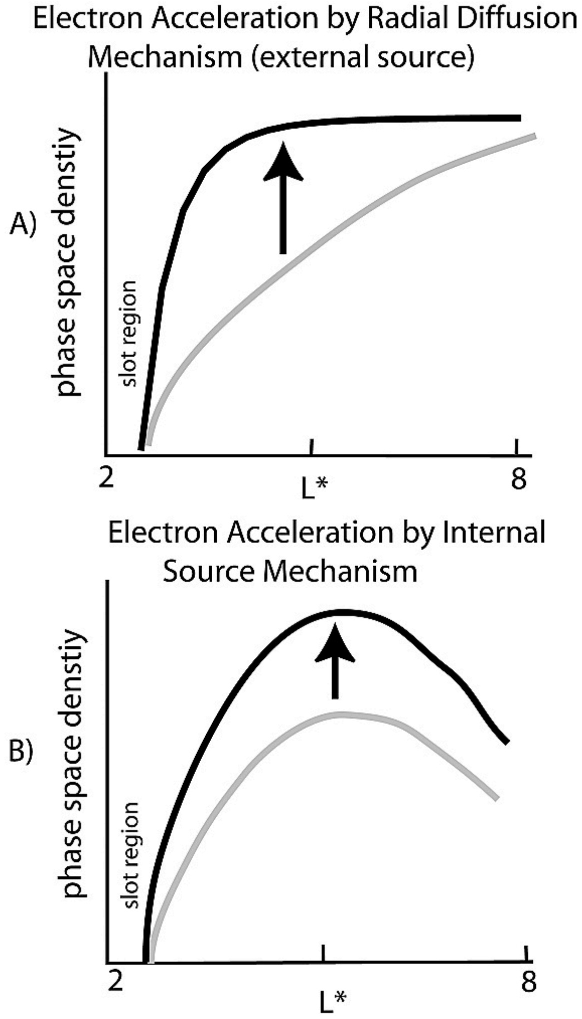


Adapted from Schiller et al. (2016)



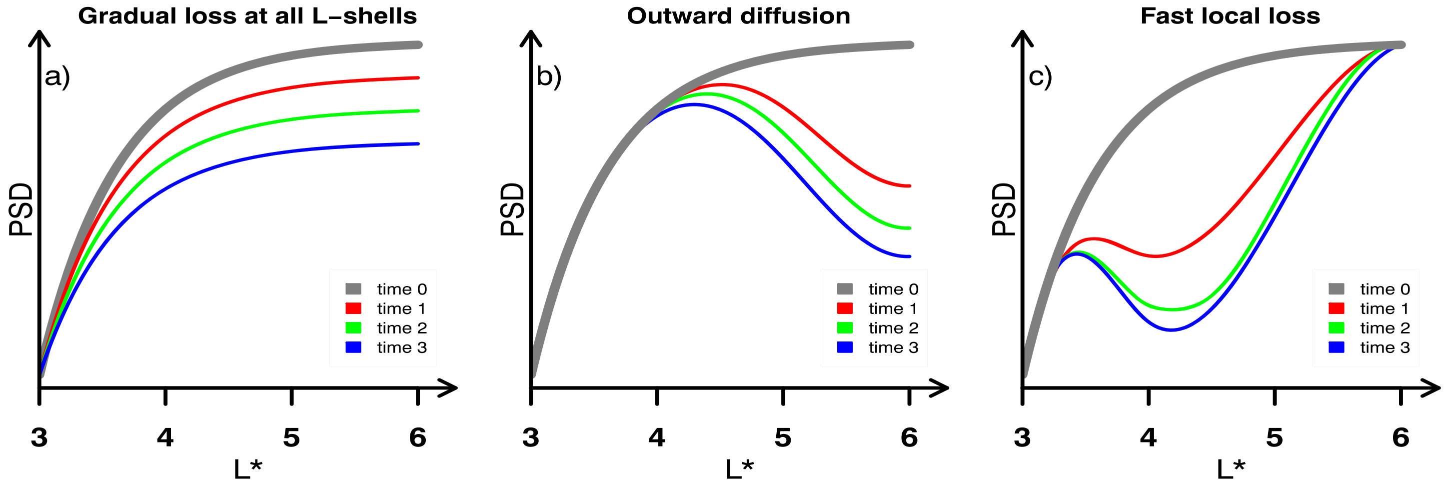
Zhao et al. (2018)

PHASE SPACE DENSITY PROFILES



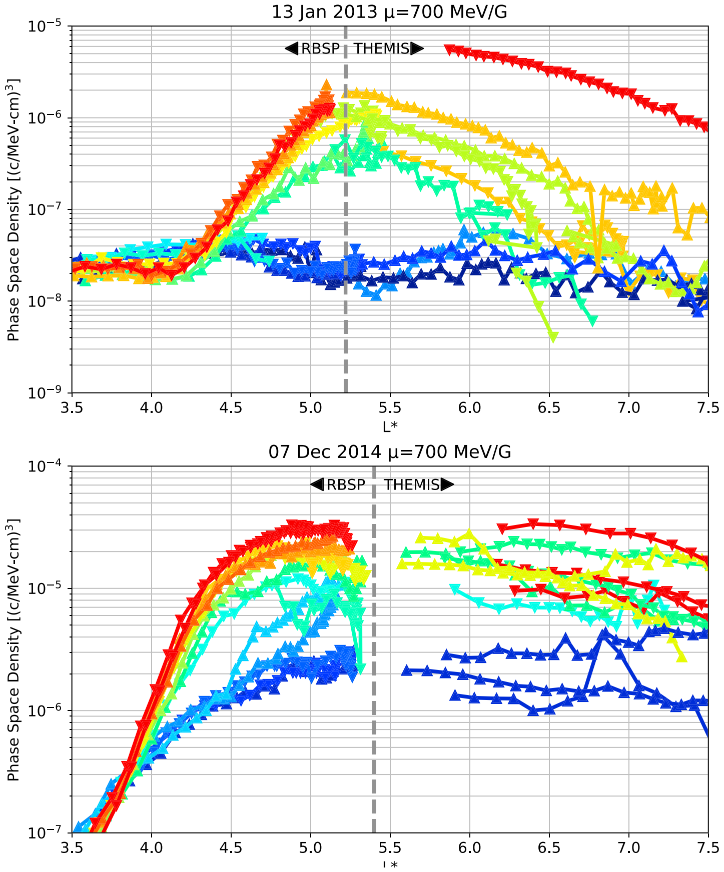
Green et al. (2004)

- Detailed phase space density profiles can give insight into both acceleration and loss mechanisms in the outer radiation belt

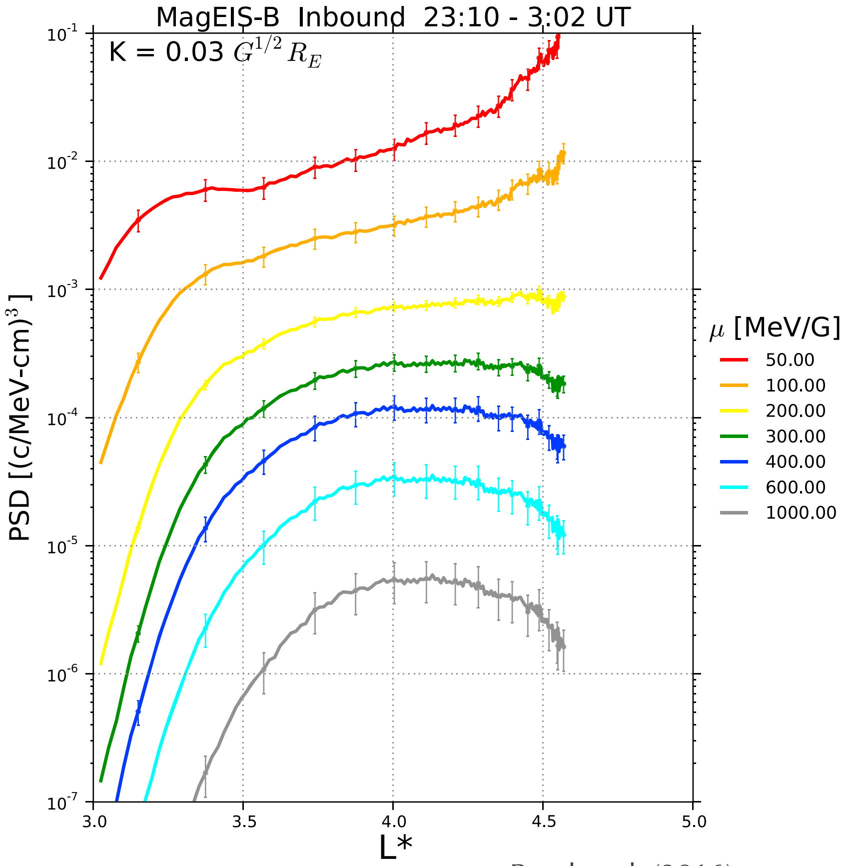


Shprits et al. (2017)

PHASE SPACE DENSITY PROFILES



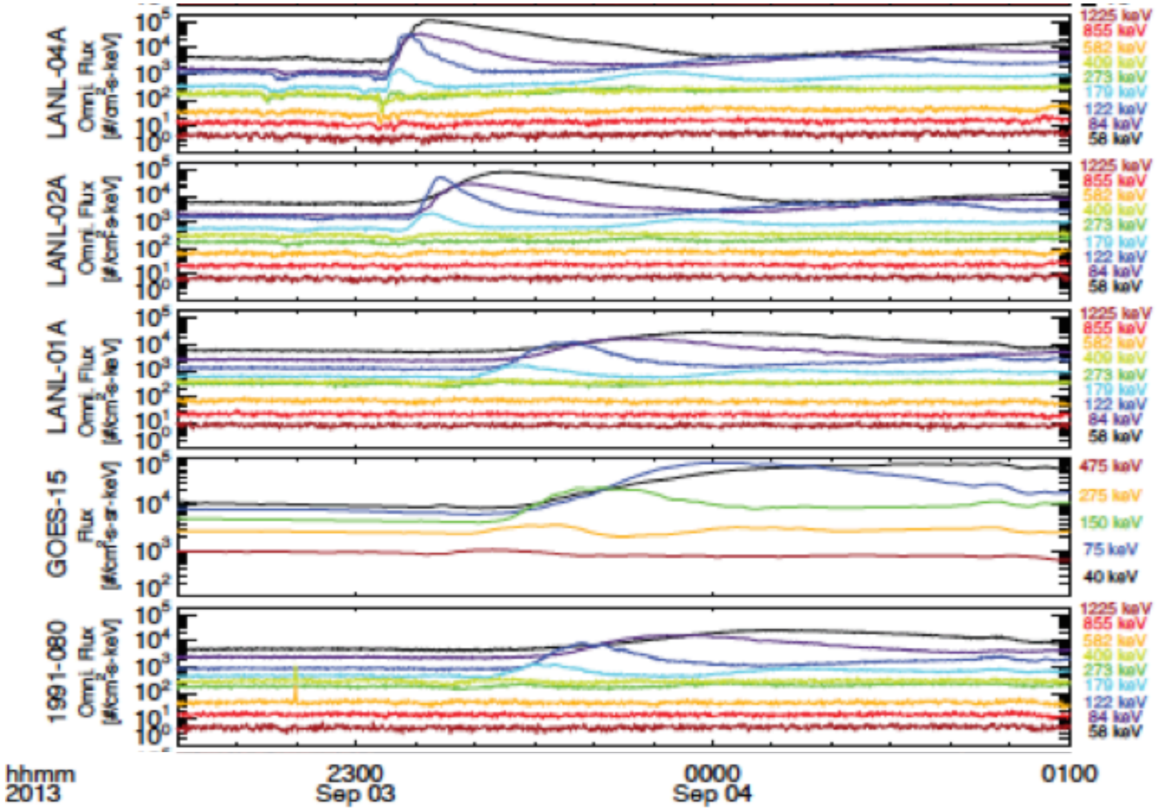
Boyd et al. (2018)



Boyd et al. (2016)

GTOSat will measure mu=~250-1000 MeV/G across L=4-7

ENERGETIC PARTICLE INJECTIONS



Courtesy of Drew Turner, Geoff Reeves

- Geosynchronous spacecraft constellations (i.e. LANL and GOES) can track the azimuthal drift of energetic electron injections
- A GTO-type orbit is needed to identify how deep radially the particles can reach
- GTOSat, in combination with the HSO, will answer questions regarding injection and transport of energetic electrons in the inner magnetosphere

GTOSAT SCIENCE

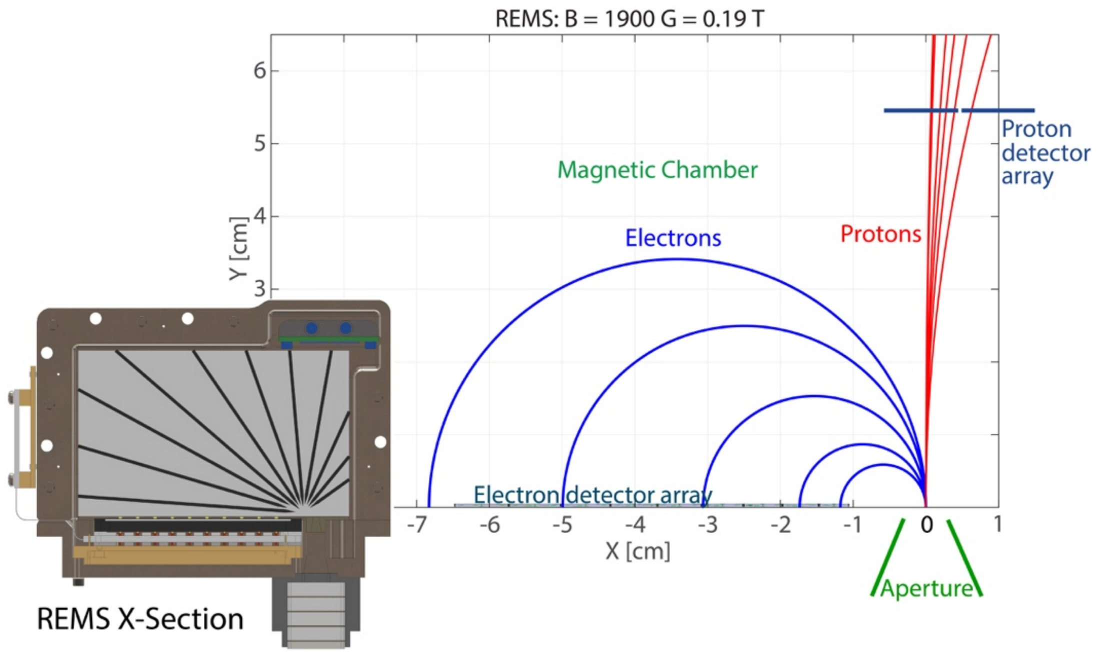
Primary Science Objective:

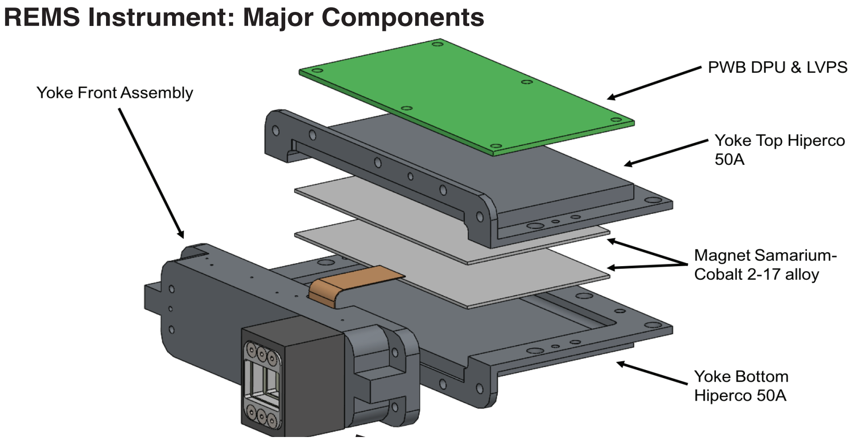
Quantitatively understand the energy and pitch angle dependent dynamics of electrons in the outer radiation belt

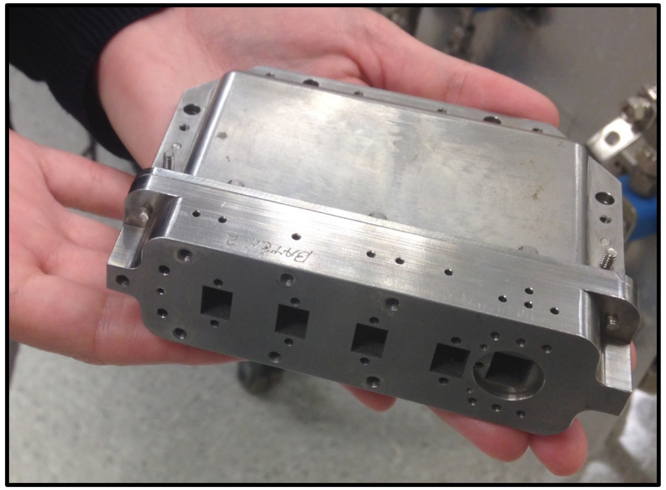
Observational Goals	
1.	Measure pitch angle distributions (PADs) in differential energies throughout the outer radiation belt
2.	Measure electron phase space density profiles through the outer radiation belt
3.	Measure energetic electron injections in to the inner magnetosphere (within GEO)

What key measurements (what subset of Van Allen Probes instrumentation) are needed to address these science goals?

REMS: RELATIVISTIC ELECTRON MAGNETIC SPECTROMETER

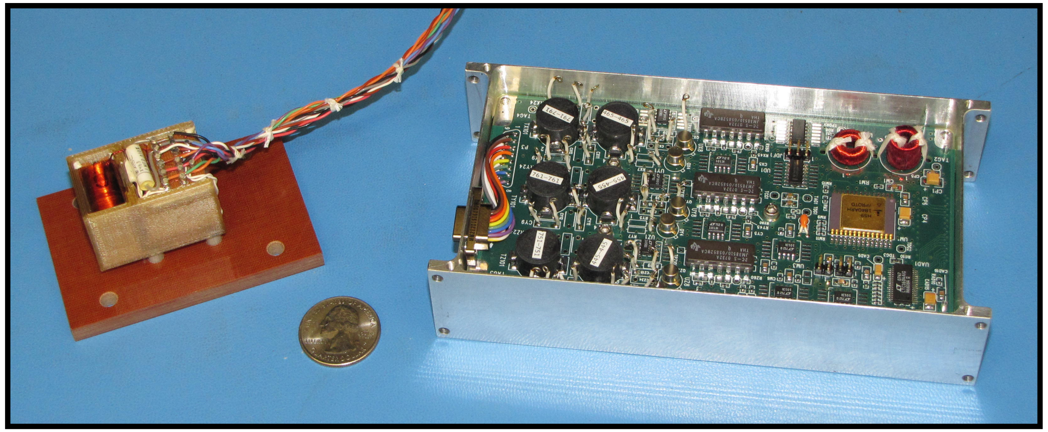


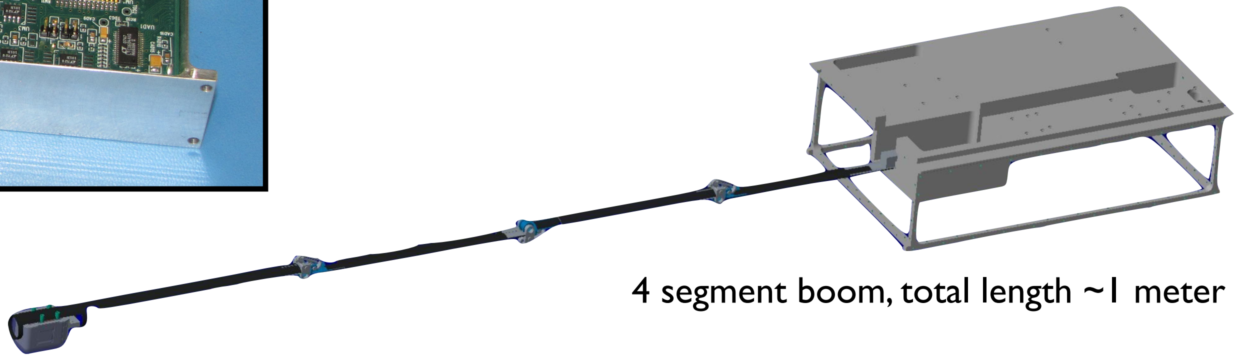




- Instrument Leads: Drew Turner, Christine Gabrielse; The Aerospace Corporation
- Modified version of the MagEIS instrument onboard Van Allen Probes
- Measuring <200keV to >1 MeV electrons,
  <200keV to > 8 MeV protons
- Volume: 12 x 11 x 5 cm, Mass: ~1 kg

MAGNETOMETER

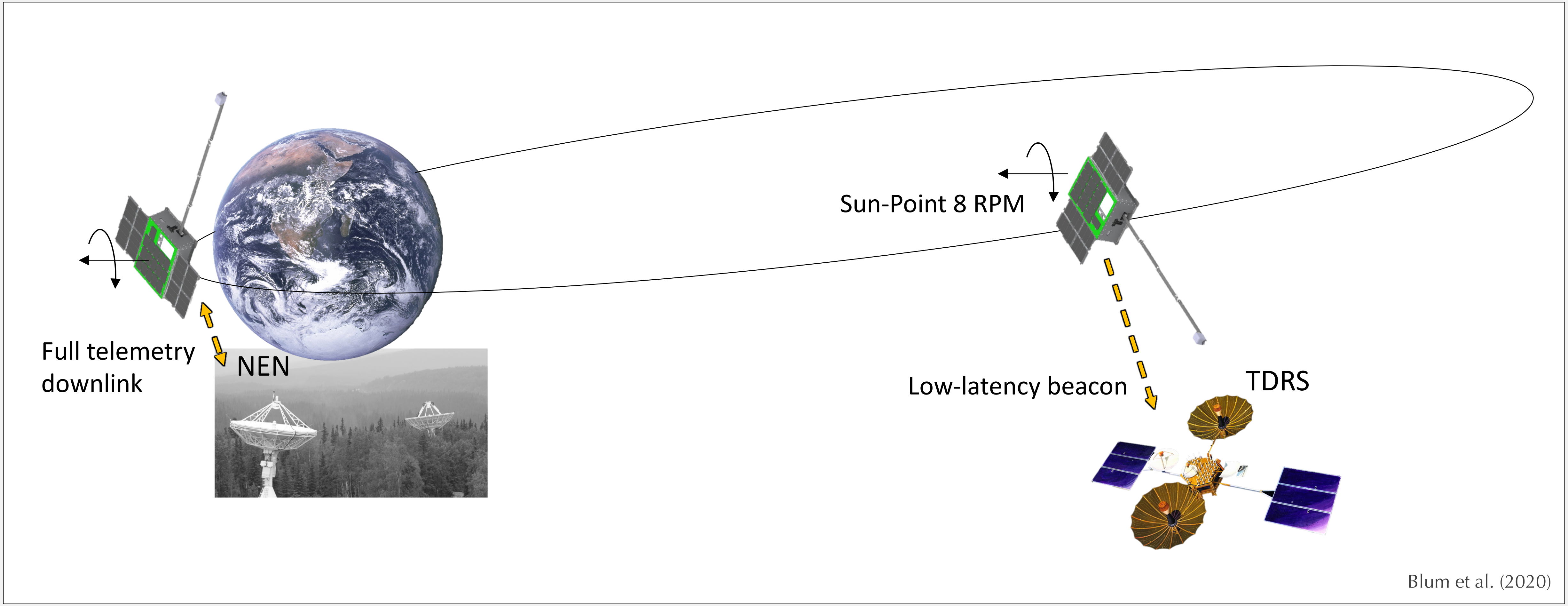




4 segment boom, total length ~1 meter

- Instrument Leads: Jared Espley, David Sheppard; NASA/GSFC
- Miniaturized version of the magnetometers on MAVEN, Juno, Parker Solar Probe
- 32Hz sampling in 2 dynamic ranges: +/- 4,096 nT at 0.125 nT resolution and +/- 65,536 nT at 2.0 nT

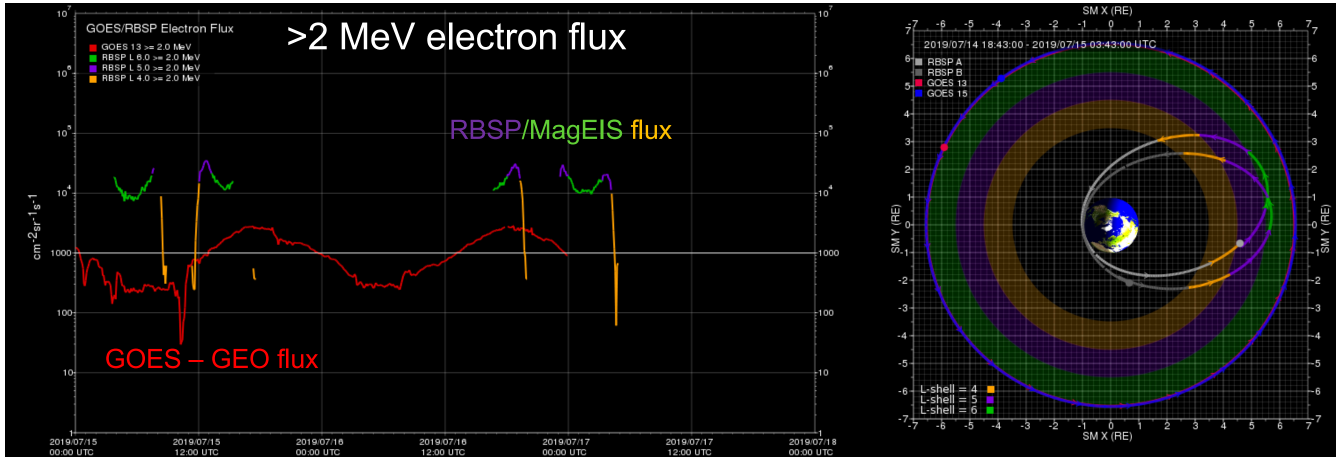
CONCEPT OF OPERATIONS



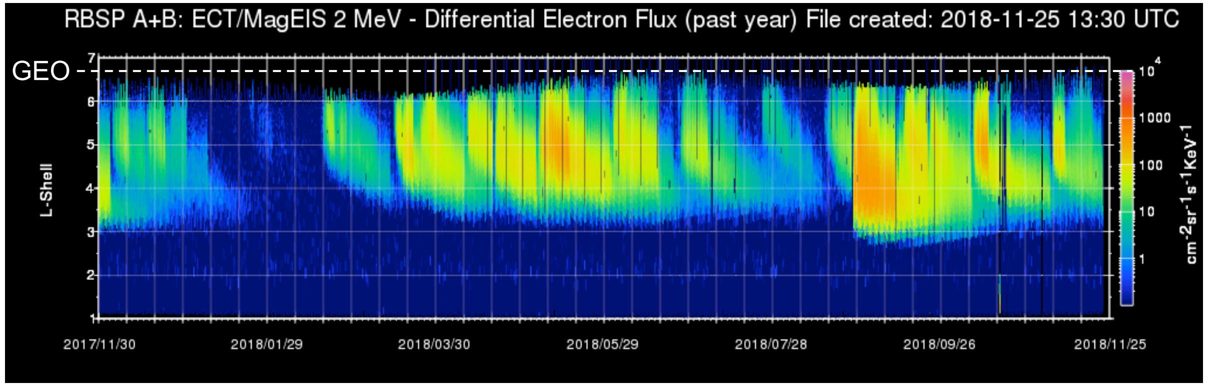
SPACE WEATHER MONITORING

- Replacement/supplement to Van Allen Probes's space weather beacon, to be used for radiation belt now-casting/forecasting and rapid spacecraft anomaly resolution
- Measurements from GTO provide critical information about the dynamic radiation environment below GEO, complementing GOES observations at GEO (Baker et al. 2019, Pinto et al. 2019)

NOAA/SWPC >2 MeV electron flux monitoring, using combined GOES and Van Allen Probe (RBSP) measurements:



https://www.swpc.noaa.gov/products/van-allen-probes-radiation-belt-plots



GTOSAT SPACECRAFT BUS

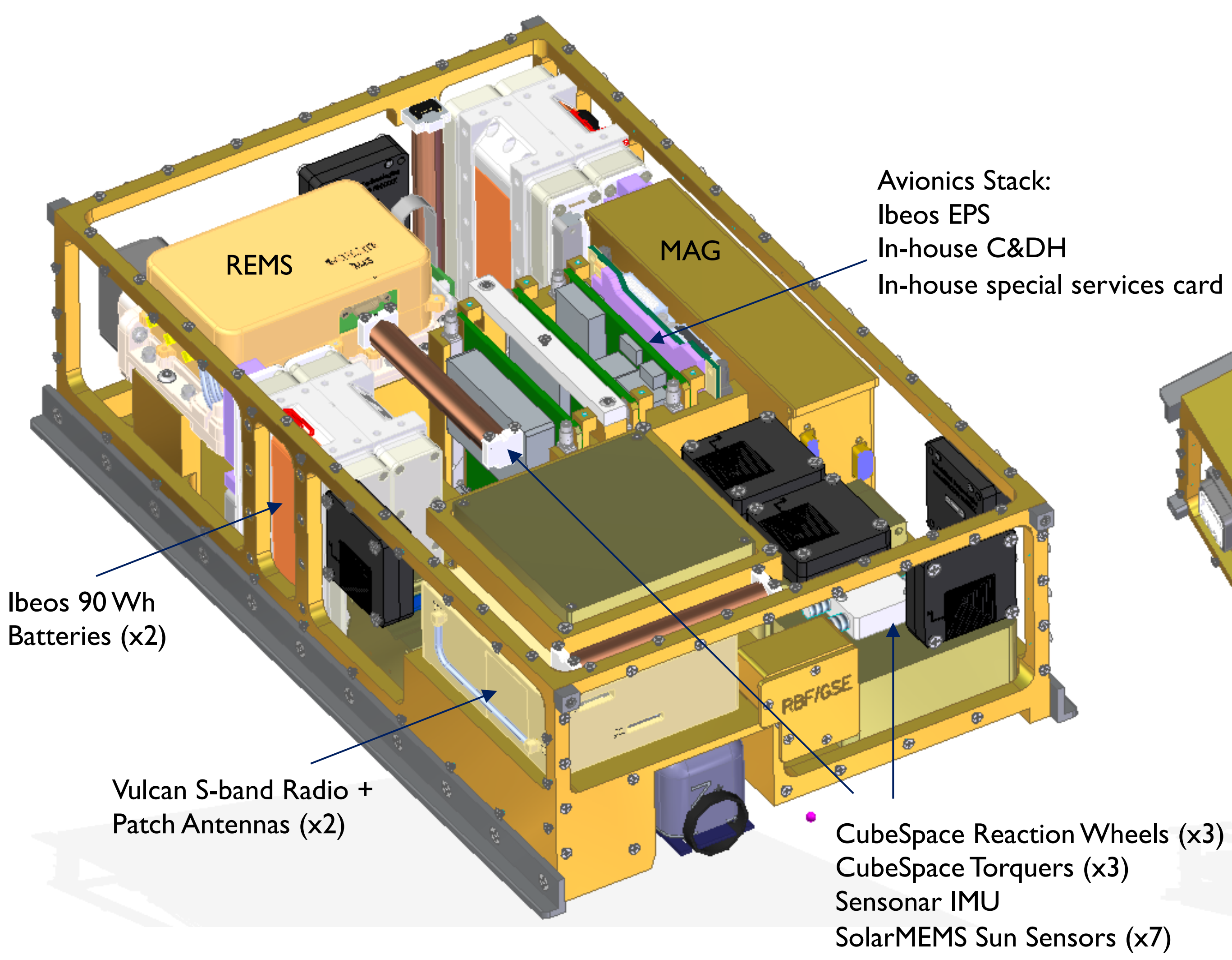
- A Dellingr follow-on to a high radiation environment

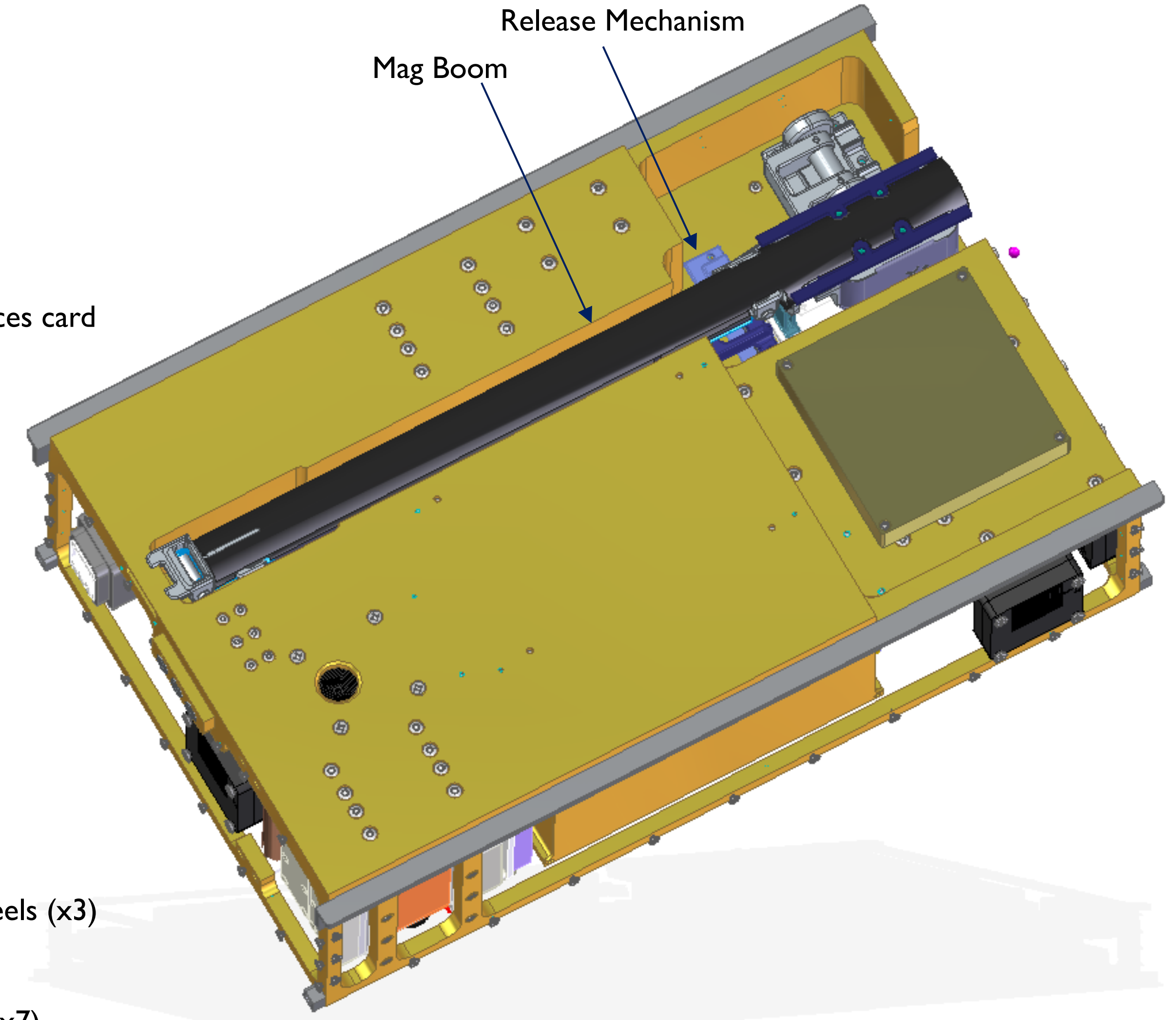
Dellingr 6U CubeSat (PI Larry Kepko) deployed from the ISS Fall 2017

CUBESAT BUSSES

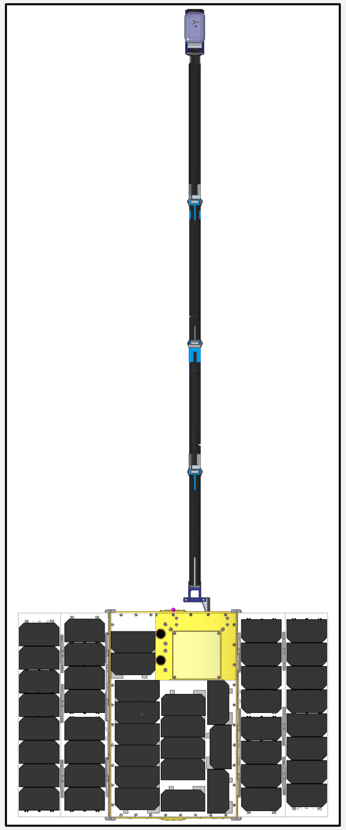
- Different approaches to building/buying CubeSats:
  - All in-house
  - Commercial components then assembled in-house
  - Commercial full busses (+ I&T, mission ops…)

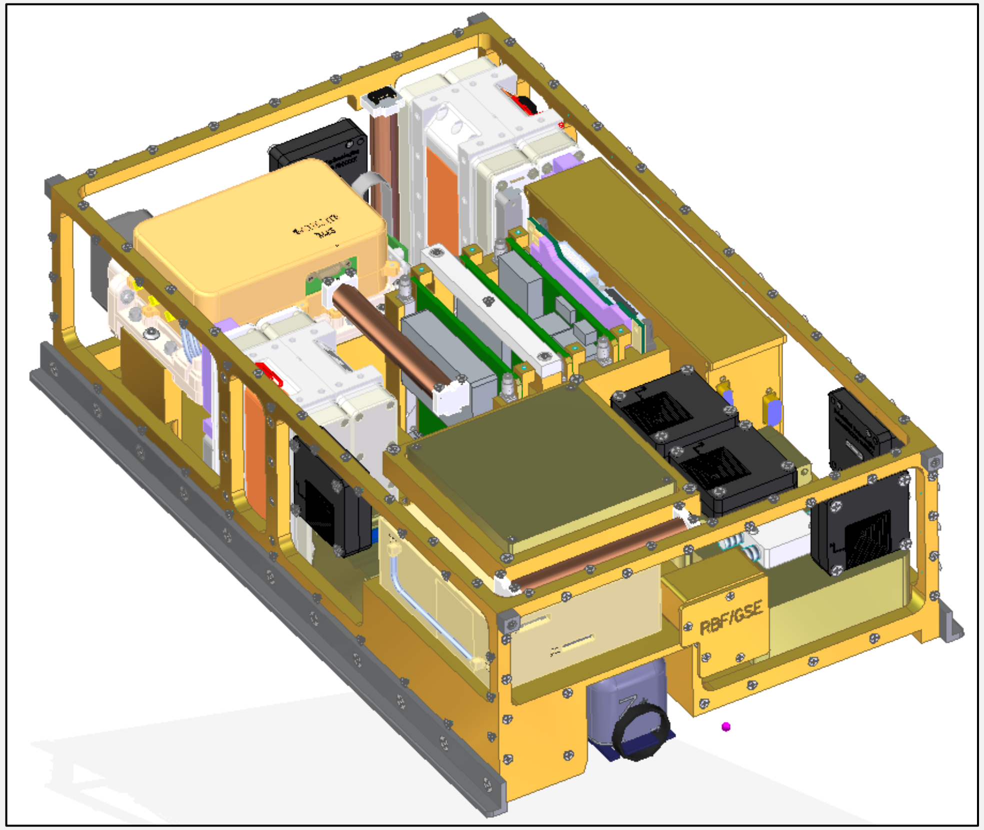
OBSERVATORY OVERVIEW





CUBESAT CHALLENGES:

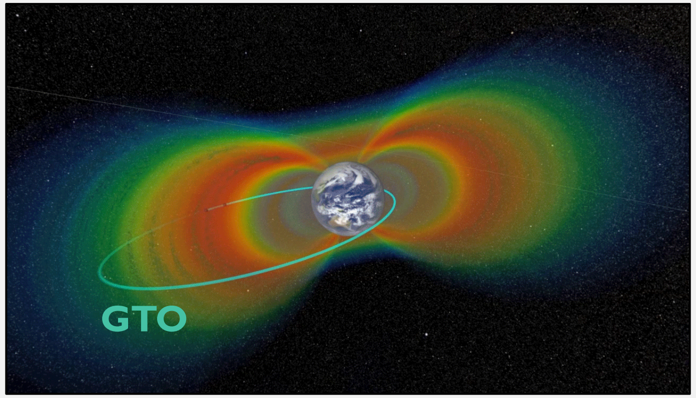


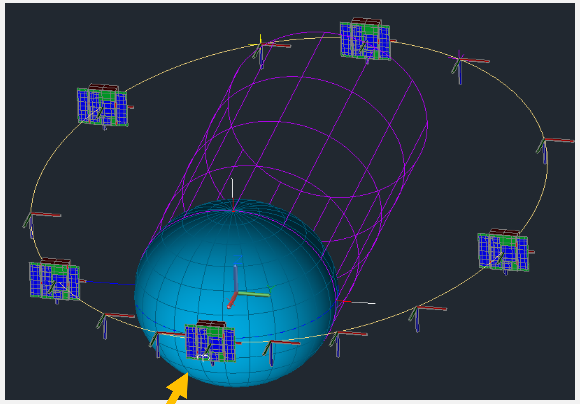


- Mass
- Volume
- Power

GTO CHALLENGES:

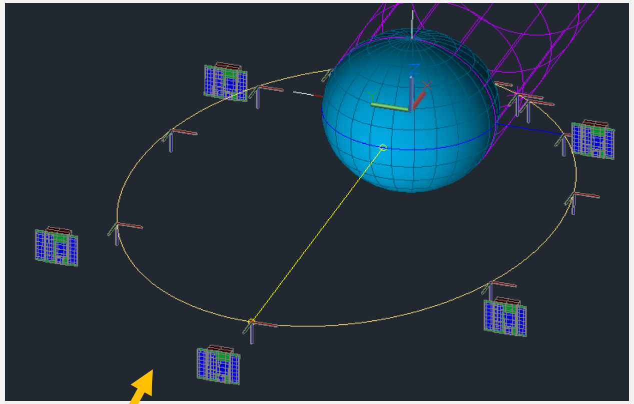
- Orbit!
  - Variable eclipse times – power and thermal design
  - Variable altitude – attitude control system design
  - Radiation environment – mechanical and electrical design





Sun

In shadow = 2hh-15mm



Sun

In shadow = 23mm

RADIATION CONCERNS

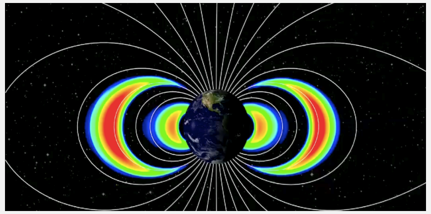
- Radiation environment
  - Total dose:
    - Current design reduces the total dose under 30 kRads assuming 0.150” aluminum shielding, NASA/LaRC z-shielding
  - Single events:
    - Critical system components (e.g. C&DH) are designed for harsh radiation environment, SEE tolerant
    - Watchdogs exist for critical components
      - EPS will reset entire spacecraft if watchdog is not petted by C&DH after a predetermined amount of time
      - C&DH will reset radio through a discrete line if radio is unresponsive
      - Radio can reset EPS (entire spacecraft) or C&DH from a ground command if radio is receiving power through discrete IO line
      - Periodic system (EPS) reset will occur to clear potential SEUs that are not easily detected
- Radiation on a budget
  - Attempt to meet requirements with least amount of components (no GPS, star tracker or propulsion)

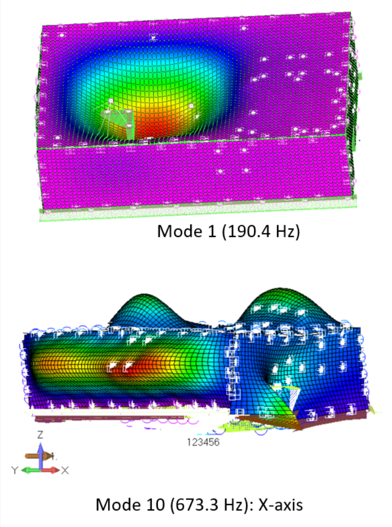
GTOSAT TIMELINE

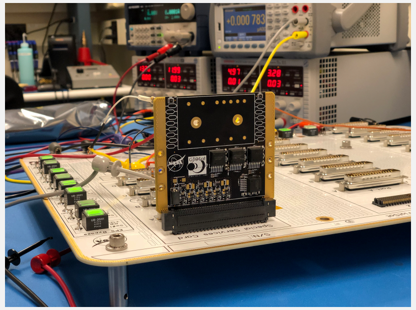
2018 | 2019 | 2020 | 2021 | 2022

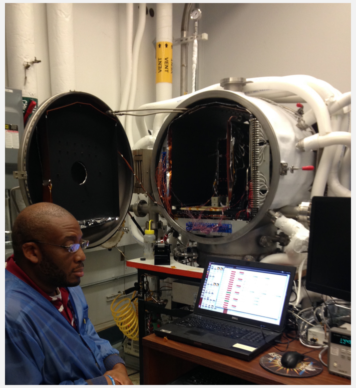
Today

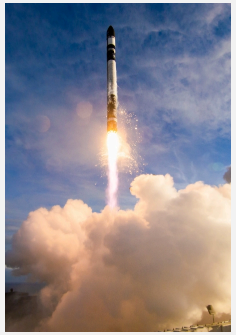
- Mission selected for funding!
- Mission Requirements Review
- Design Review
- Pre-Environmental Review
- Pre-Ship Review
- Nominal launch
- 1-year primary mission

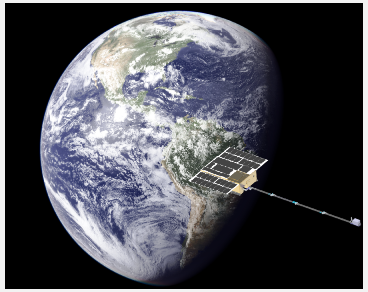








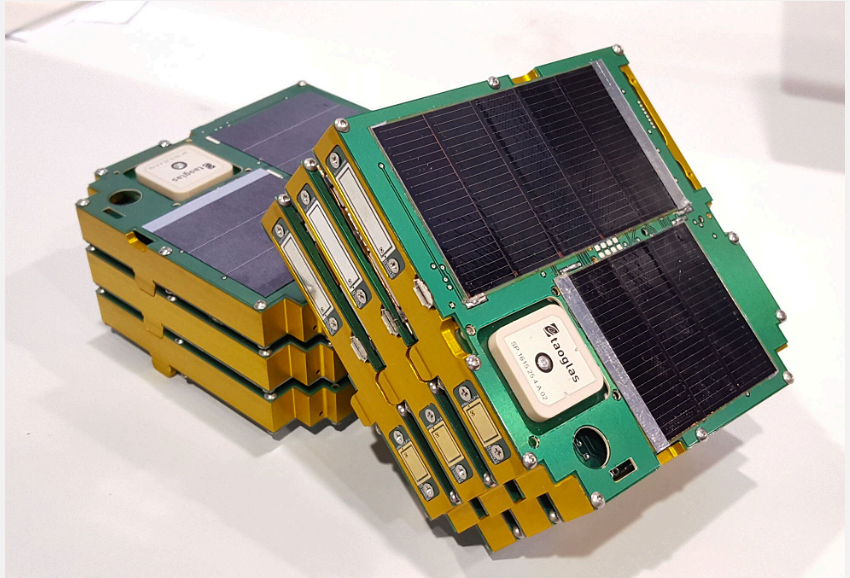




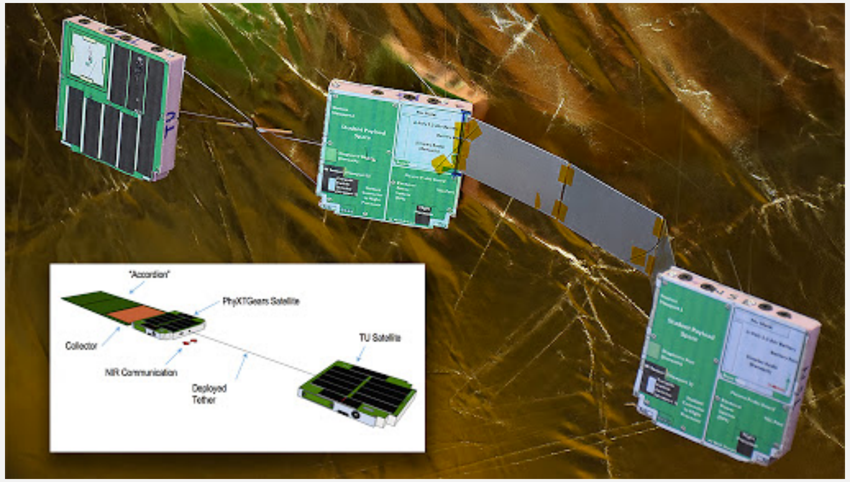
WHY DO YOU FEEL CUBESATS ARE IMPORTANT TO THE FUTURE OF OUR FIELD?

- Always looking for:
  - New things to measure
  - New ways of measuring
  - New places to measure from
- Higher risk, lower cost CubeSats can allow us to:
  - Probe regions we wouldn't normally
  - Utilize multipoint measurements we couldn't otherwise
  - Test out new technologies

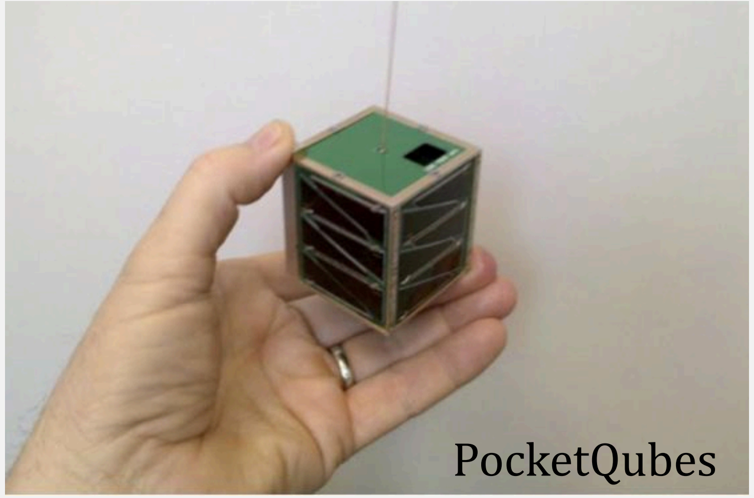
WHAT'S NEXT?



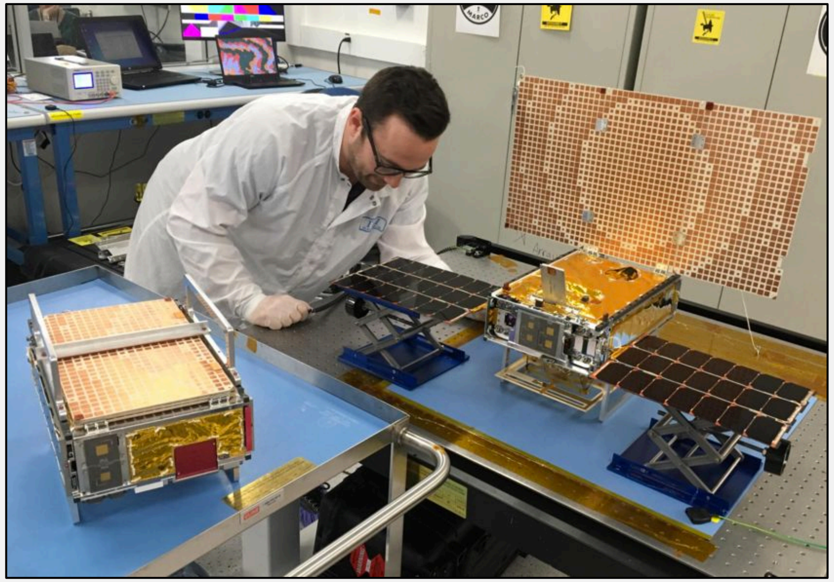
KickSats 1 + 2

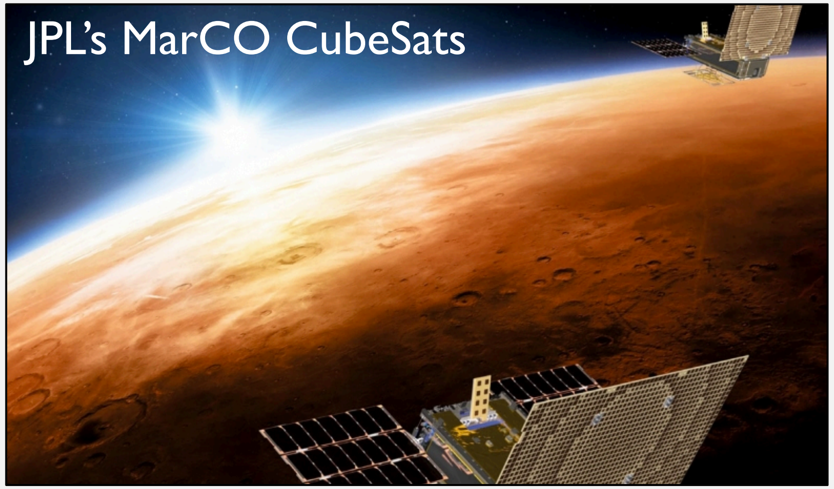


ThinSats


PocketQubes

WHAT'S NEXT?





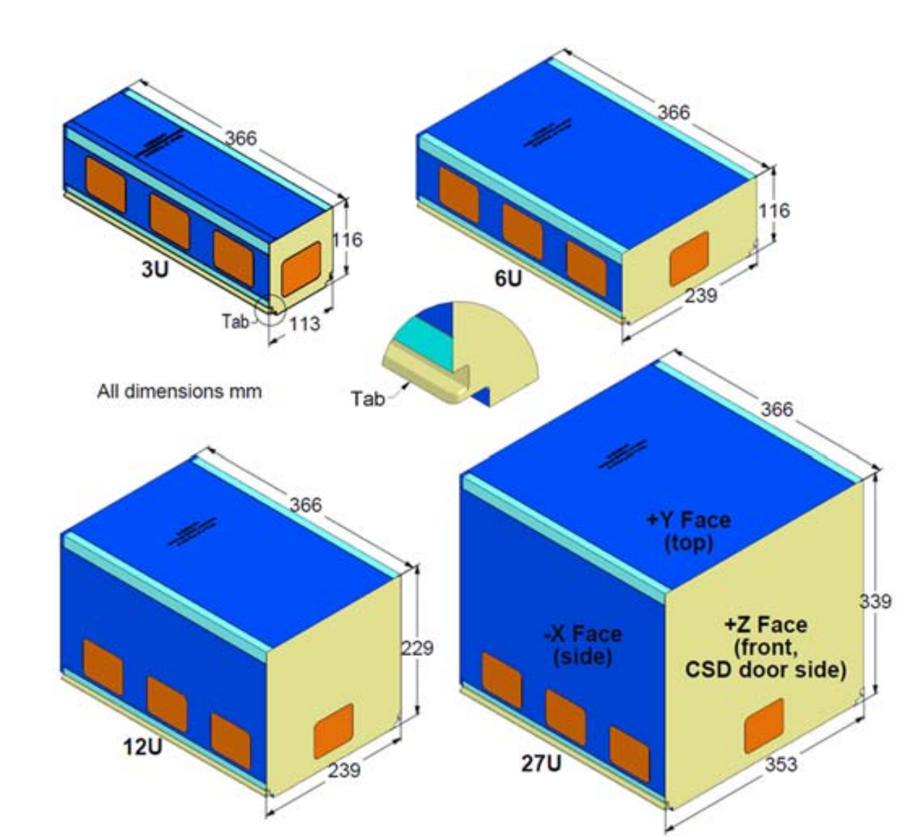
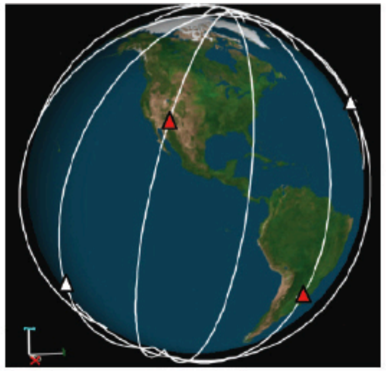
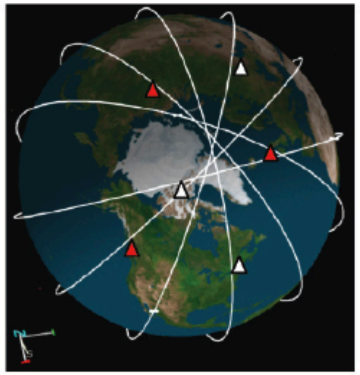


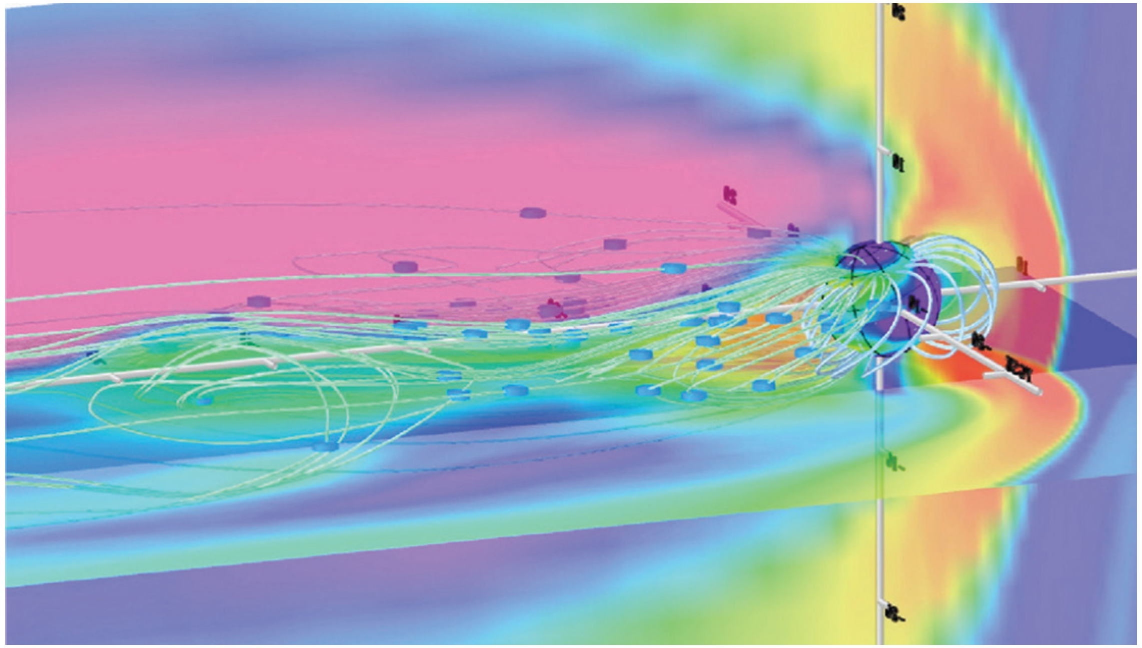
Figure 2-2: Payload sizes

WHAT'S NEXT?



Decadal Survey 2013

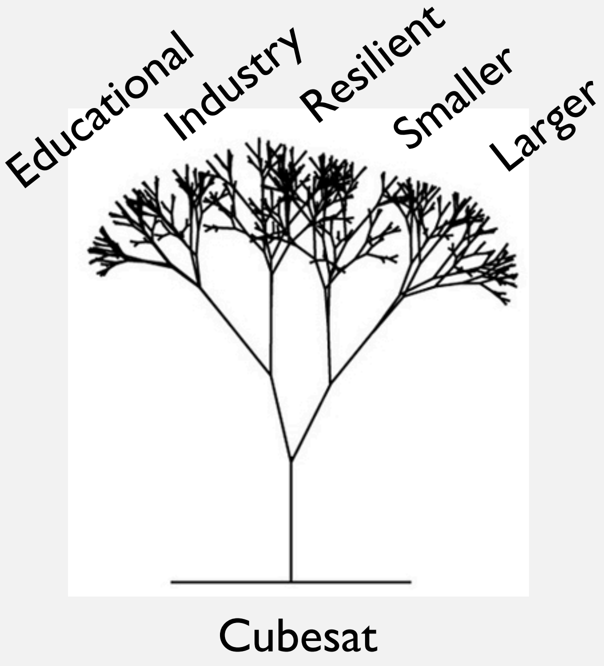




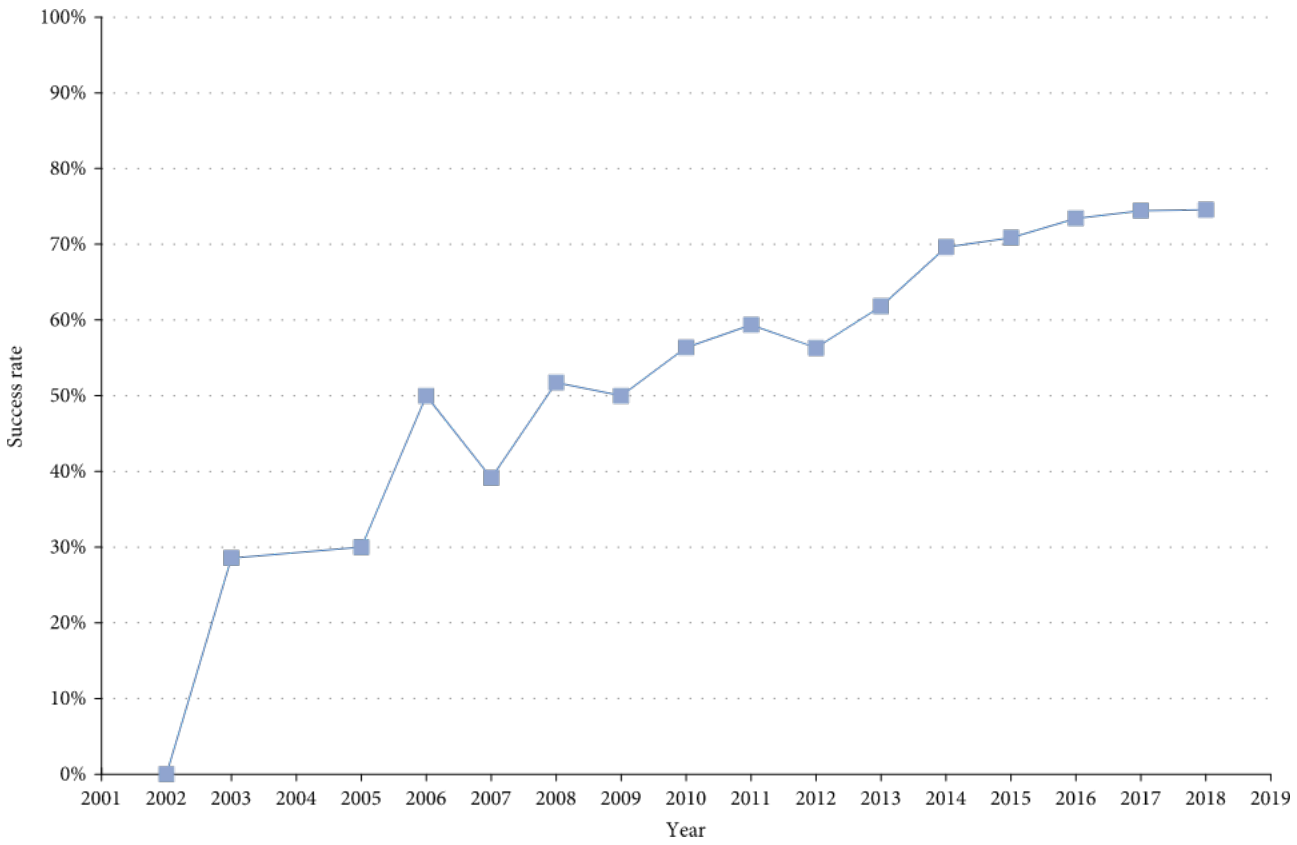
Spence et al. (2004)

WHAT'S NEXT?

- These paths not mutually exclusive
- Can continue to have CubeSats that are:
  - Fast, cheap
  - High risk, high reward
  - More reliable, capable
- Must then realize that these each mean different things in terms of cost, schedule, application



CUBESAT SUCCESS RATES



Villela et al. 2018