Overview

✓Despite their age, the THEMIS/ARTEMIS spacecraft and instruments function like new, providing a unique resource to explore the equatorial magnetosphere.

✓Mission is very cost effective (< \$1.2M/spacecraft) – a “steal” for the novel, high-quality observations from these orbits.

✓THEMIS re-invents itself every few years to address cutting edge science - next 4 years can be as productive as prime mission thanks to unique alignments with MMS. Additionally, ARTEMIS can be a key solar wind radiation monitor for the Lunar Gateway and contributes to coordinated space observations from the moon.

✓Planning the orbits and operations for this exciting new period has started, and is proceeding well.

✓Working with HQ to improve Senior Review 2020 (SR20) in-guide budget.

Outline

Mission history highlights: see FY17 Senior Review presentation

- FY07-09: THEMIS prime mission; established Rx triggers substorms.
- FY09-11: Spawned ARTEMIS, studied kinetic scales at $R<12R_E$, revealed importance of regional activations at dayside and nightside.
- FY12-13: Revealed MI coupling & mapping processes (arcs); global connections of elemental activations and substorm energy conversion.
- FY15-17: Established day-night links of regional activations, particle acceleration in transients and energy conversion during storms.

✓Recent findings and future plans.

- FY18-20: Solar wind/tail global circulation and energy conversion view from regional/MHD scales across H/GSO platforms, and MI coupling – (pubs, in progress, reinforce plans)
- FY 19-20 Progressively moving THEMIS from MHD to ion kinetic scales
- FY 21-24 MMS + THEMIS study ion kinetics at the same meridian

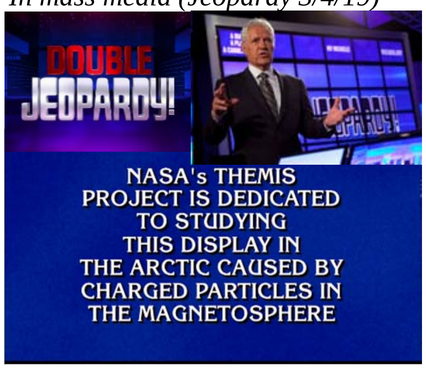
✓Senior Review 2020 In-guide Budget Inconsistent with Potential

- THEMIS science & leadership (at GEM, AGU and other forums) will be decimated. Synergies with other missions under H/GSO will be curtailed.

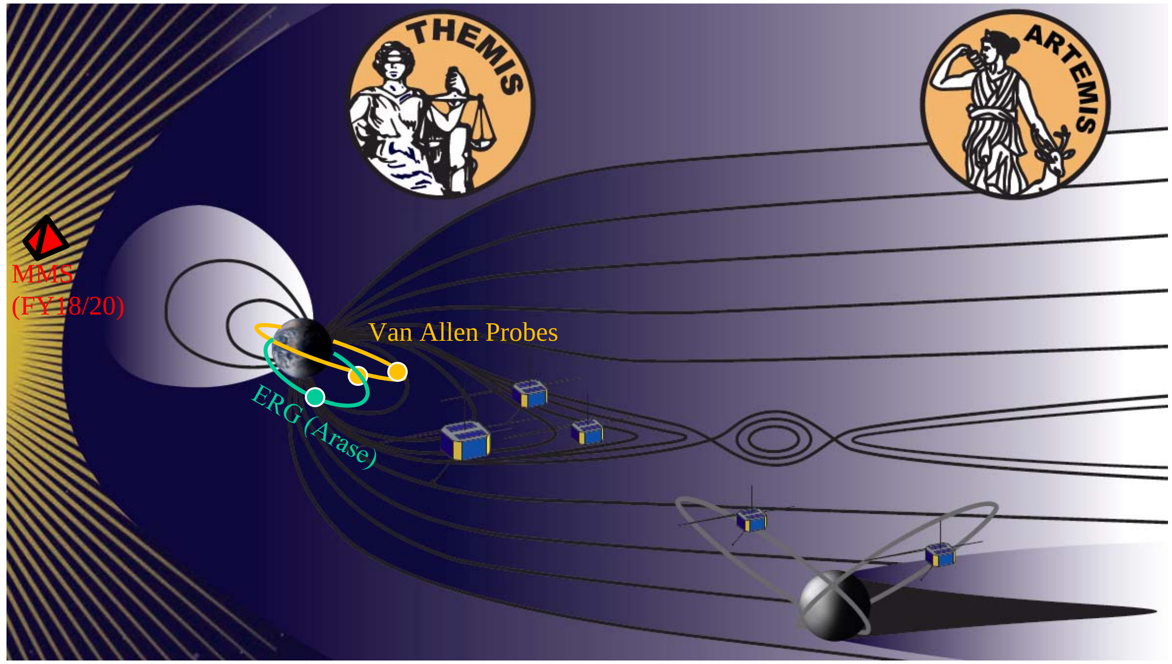
THEMIS is a cornerstone in HPS's new era of exploration w/ coordinated assets

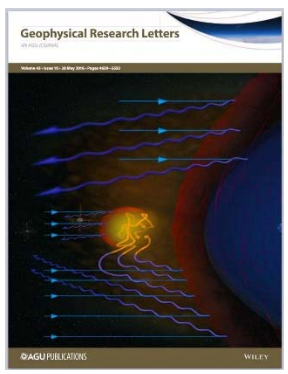
THEMIS in the press

In mass media (Jeopardy 3/4/19)

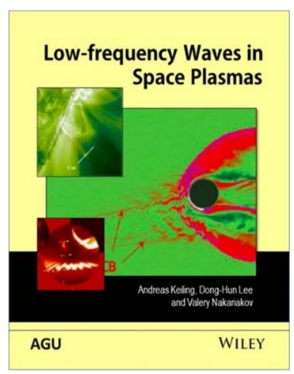


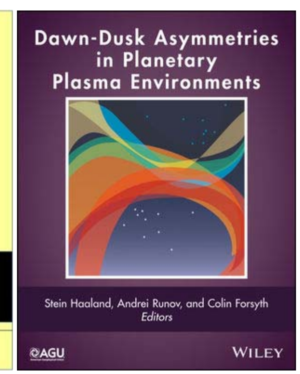
In popular magazines (Nat. Geo. 2019)

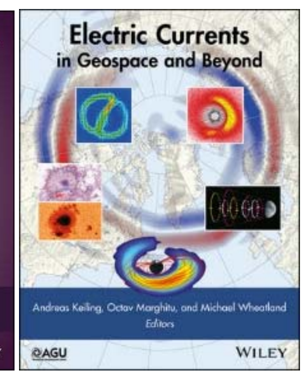




7 Covers + 14 Highlights



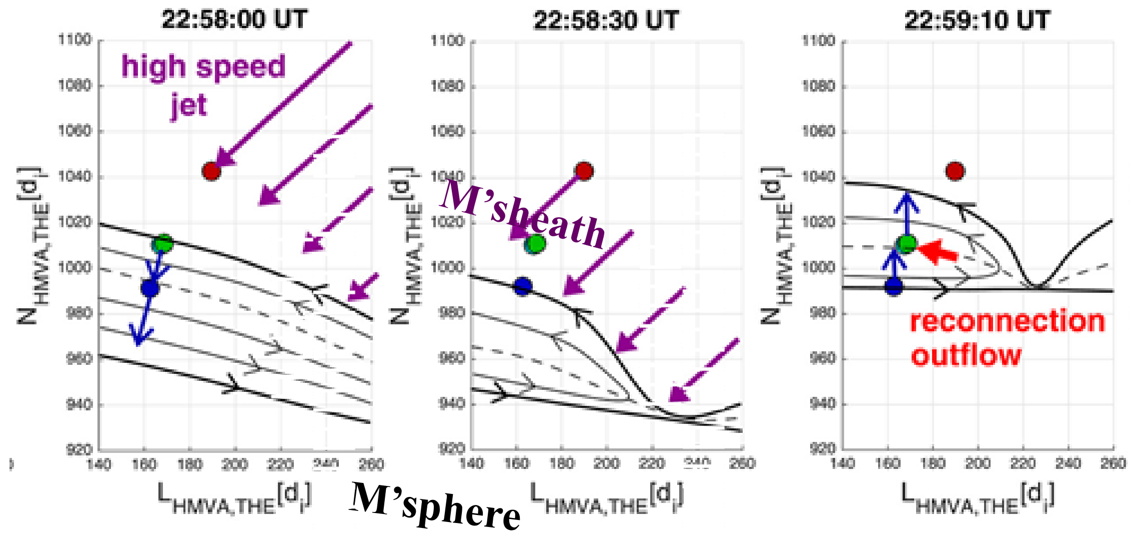




4 Monographs on Magnetospheric Waves, Asymmetries and Currents,…

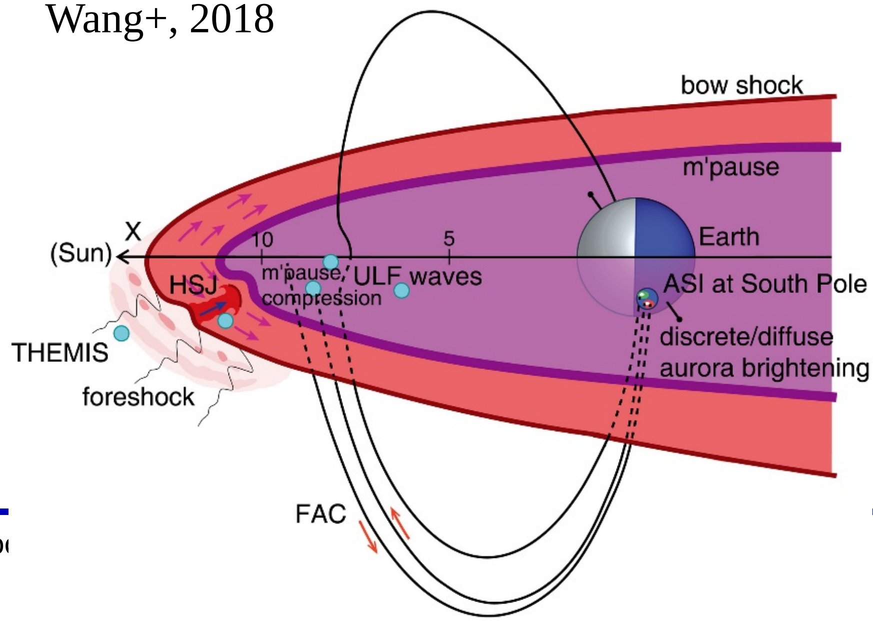
Dayside Rx, variable and localized → polar cap patches tracking Rx bundles

Hietala+, 2018



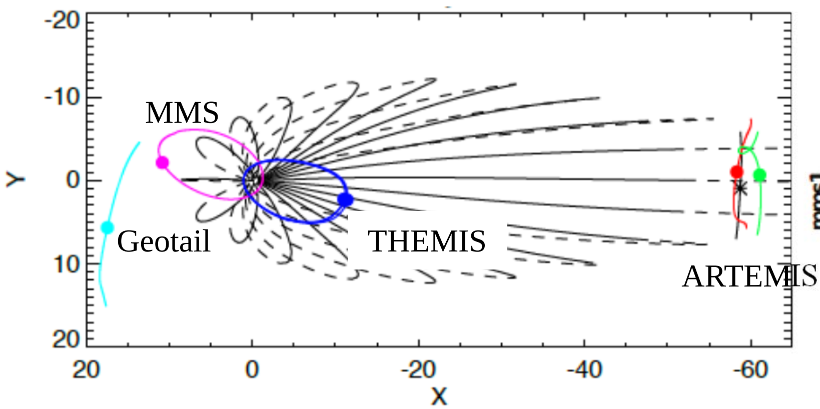
Dayside RX controlled by: magnetosheath jets

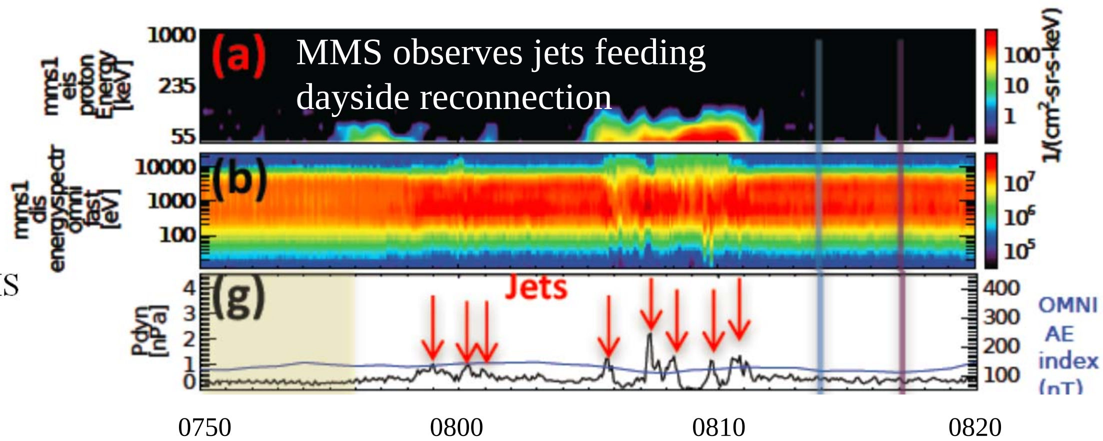
Wang+, 2018

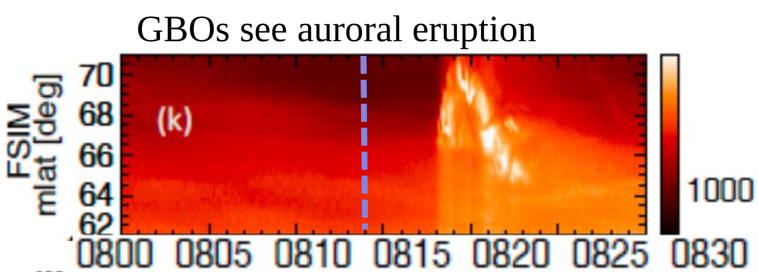


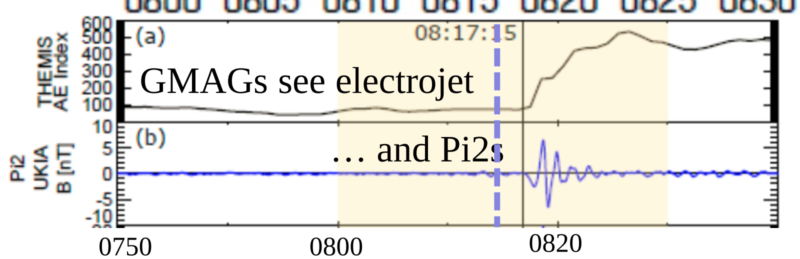
Dayside transients have global impact

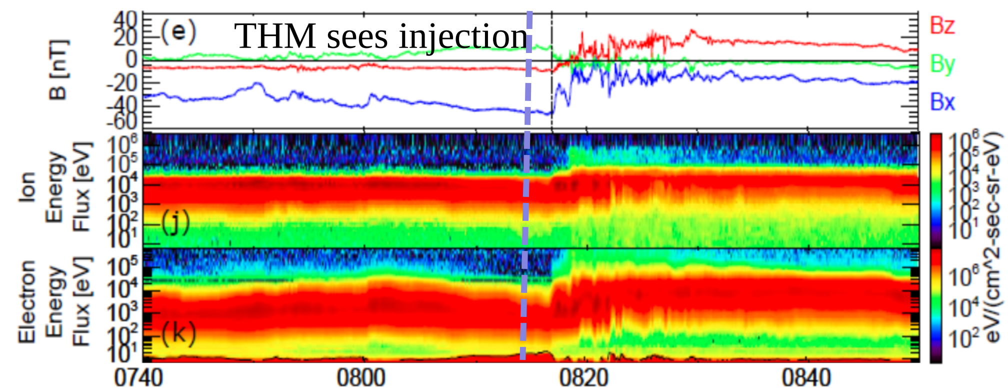
Recent results: H/GSO observations, Nykyri+, JGR, 2019 (GEM campaign event)

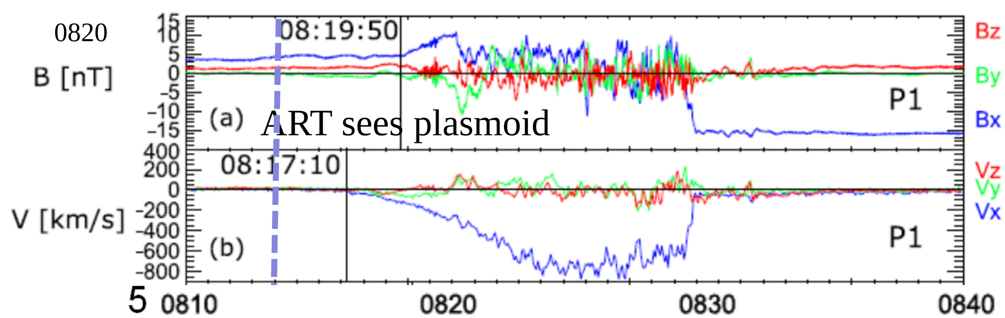






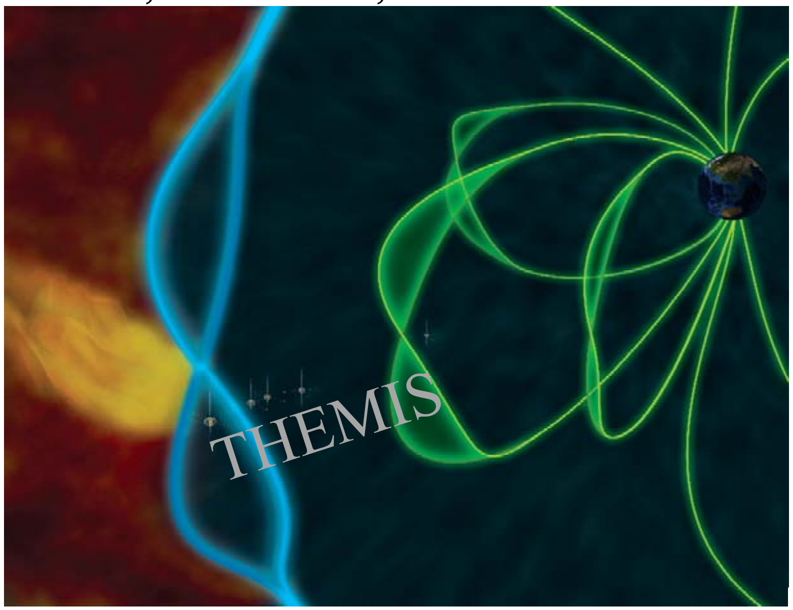






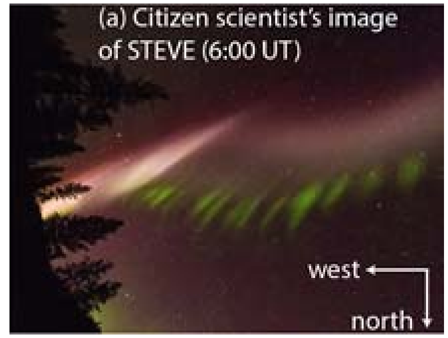
Recent results: a very old and a very new scientific puzzle resolved

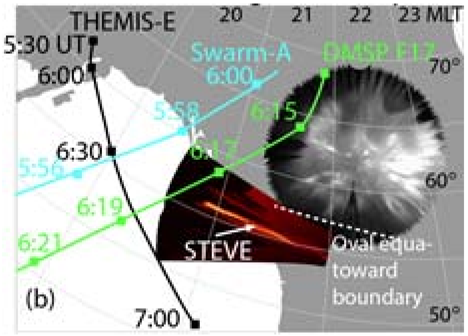
Archer+, Nat. Comm., 2019

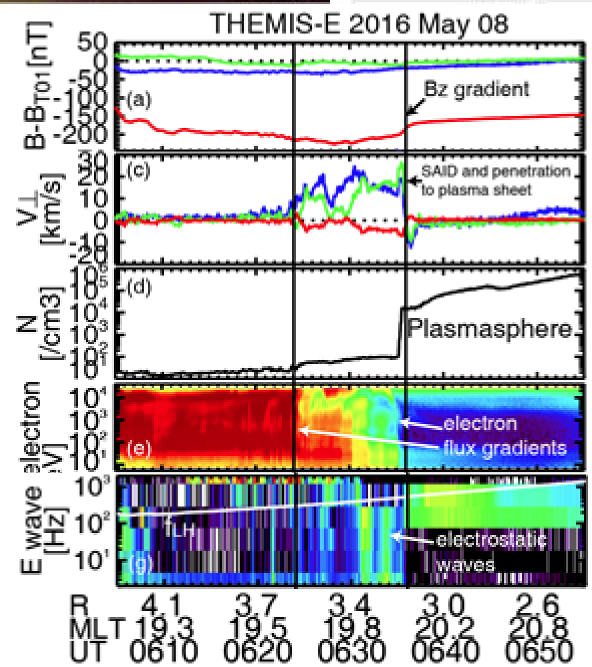


THEMIS discovered the elusive origin of "magic" frequencies on ground magnetometers, solving a 45 year old mystery. They are now identified as magnetopause "vibrations" excited by solar wind pressure variations. In this paper, a high-speed jet (a localized impulse) was used to clearly identify the magnetopause response.

Nishimura+ 2019 (Chu+, Gallardo+, Sivadas+ all in 2019)





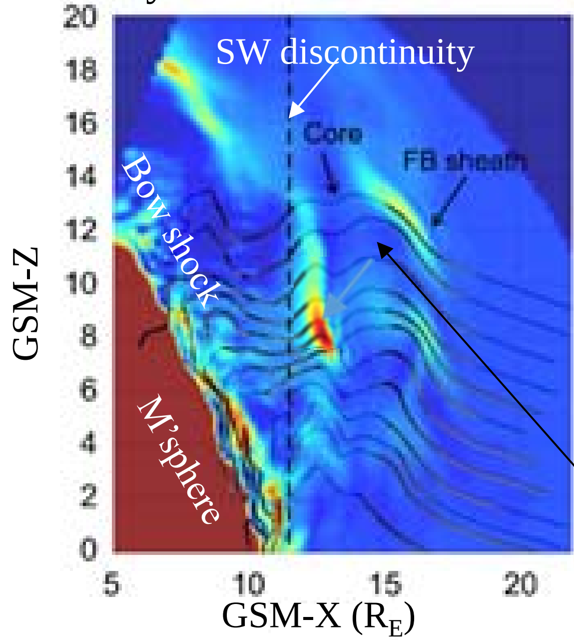


THEMIS discovered the magnetospheric origin of STEVE, a new type of emission identified by citizen scientists in 2018.

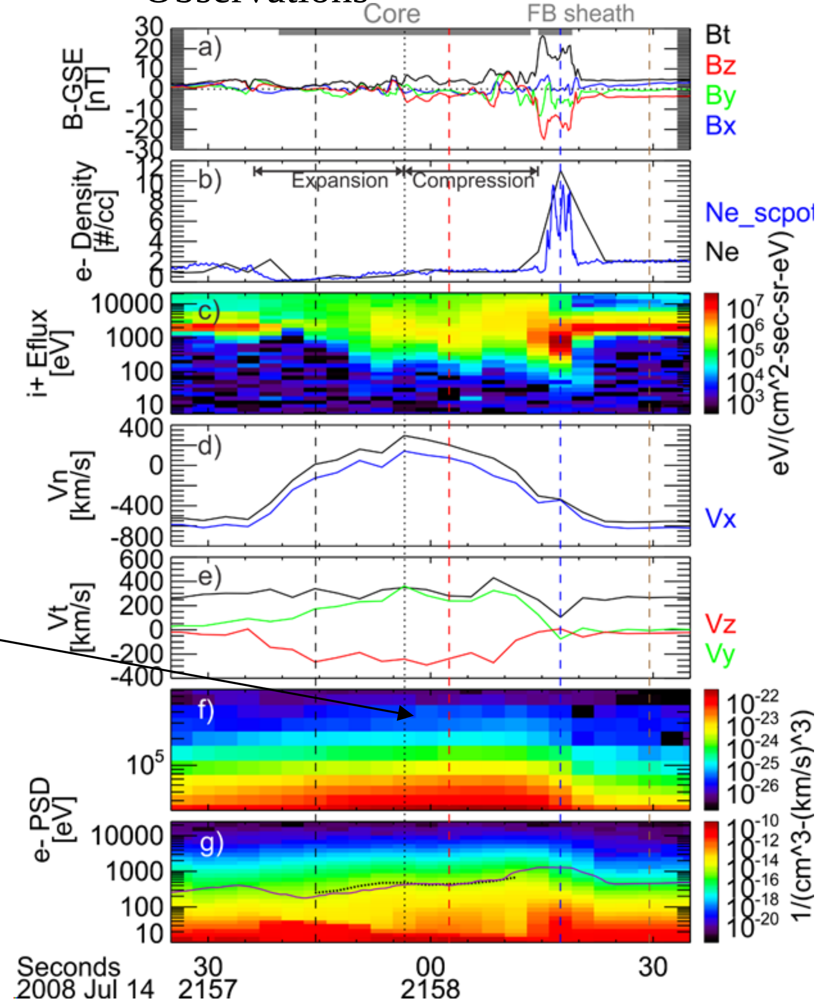
Recent results: production of relativistic electrons at foreshock bubbles

Liu+, Science Adv., 2019

Hybrid simulation



Observations

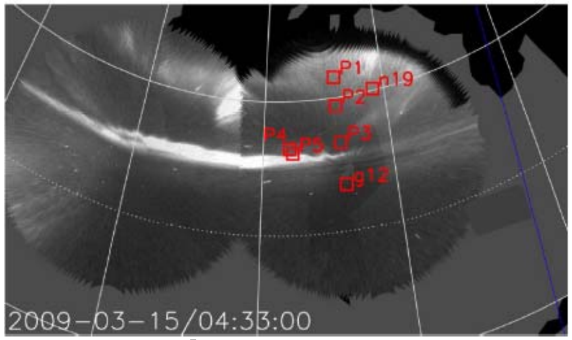


Relativistic electrons

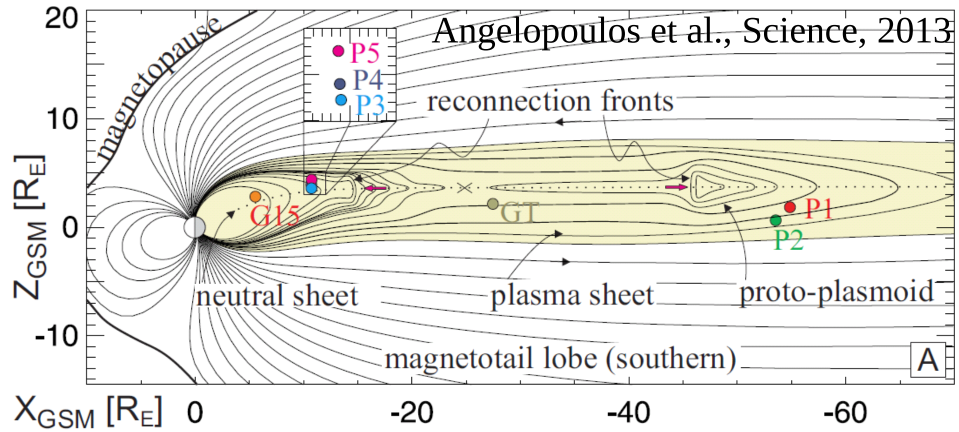
In 2016 THEMIS found that relativistic electrons are produced at **foreshock bubbles** (**FBs**). Now THEMIS has found the mechanism that accelerates those electrons to such energies: betatron acceleration at the strong field of the FB and Fermi acceleration between the FB sheath and the bow shock. The combined effect causes a >10x increase in foreshock electron energy, sufficient to explain the observed FB energy and pitch-angle spectra.

Building on past results that global connections produce regional activations

Nightside Rx at ~25R_E → pre-breakup arc brightens at ~10-12R_E, where energy is converted

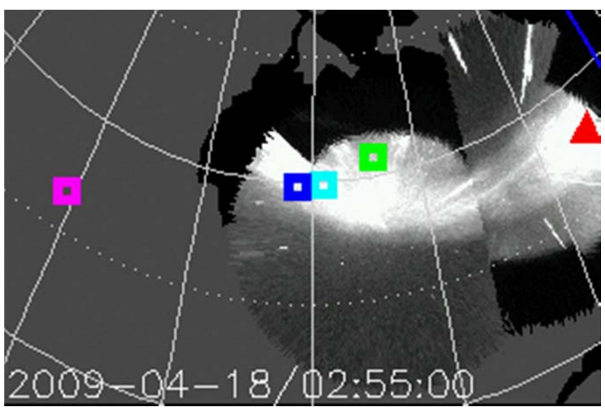


Sergeev et al., T2012
Jiang et al., T2012



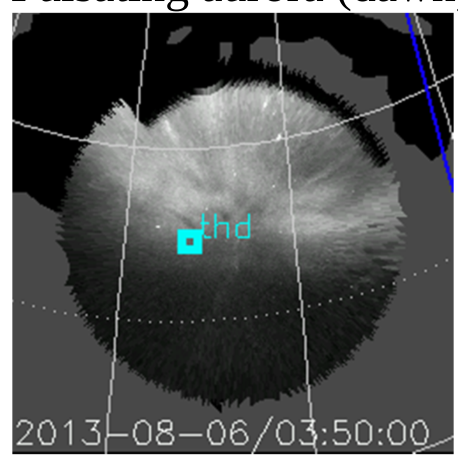
Fast flows impacting near-Earth drive inner magnetosphere space weather

Proton aurora (dusk)



Nishimura et al., JGR, 2015

Pulsating aurora (dawn)



THEMIS
ARTEMIS

Recent results: The critical role of Hall E-field in thin current sheets

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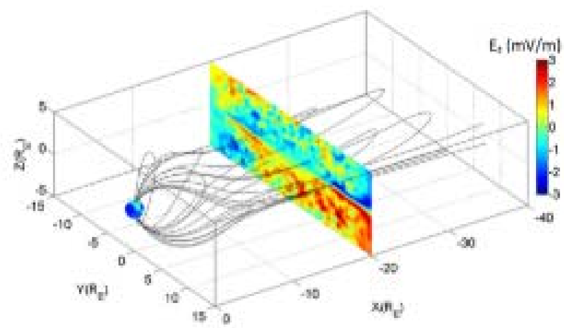


THE HALL ELECTRIC FIELD IN EARTH'S MAGNETOTAIL THIN CURRENT SHEET

Global hybrid simulation result of AuburN Global hybrId CodE in 3-D showing the configuration of magnetic field lines and the contour of Hall electric field Ez at x = − 20 RE at t = 1, 144 s. The simulation uses a pure southward interplanetary magnetic field, −10 nT, and a steady solar wind speed in the x direction, −700 km/s. The structure of the magnetotail (characterized by stretched field lines) forms self-consistently via interaction between the interplanetary magnetic field/solar wind and the geomagnetic field. The Hall electric field Ezforms in the magnetotail thin current sheet. For more details of the simulation model, see Lin et al. (2014, 2017).

THEMIS ARTEMIS

Optimized H/GSO is needed to understand global connections

- To understand global connections requires coordinated assets in space and the ground – this is far cheaper and more effective than launching a new mission. This is an unprecedented opportunity to conduct new science with the current Heliophysics Fleet.

- By adjusting the THEMIS orbits to ensure its positions and data-taking are optimal when MMS is crossing key regions of space, and by coordinating with ground assets the THEMIS team is optimizing the global observations of the magnetosphere, in conjunction with VAP, ERG and other missions.

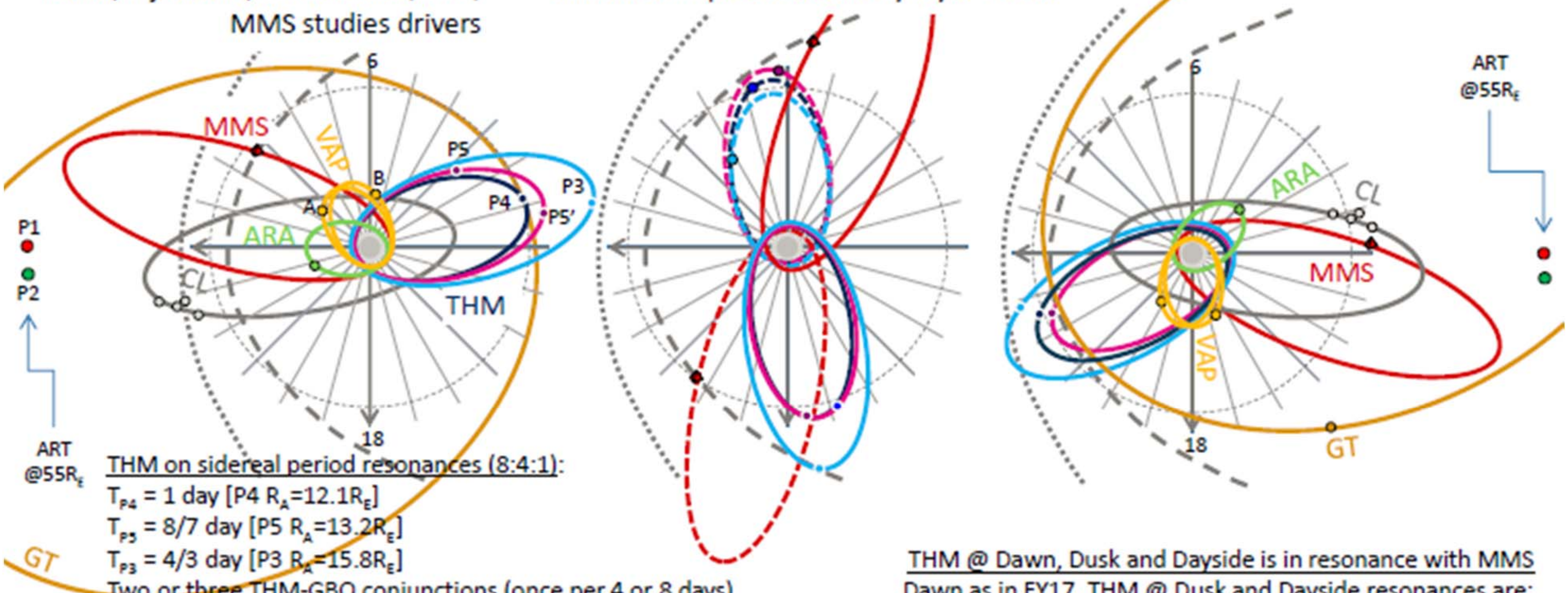
FY18: THEMIS raised P3 apogee to ~15R_E

THM/ART-MMS-VAP in FY18. P3,4,5 at resonant orbits w/GBOs or w/MMS.

MMS Dayside #3 (THM in Tail) (Feb. 12, 2018)
THM on sidereal period resonances, together with GBOs studies Rx fronts, injections, links to ARA, VAP; MMS studies drivers

MMS, THM at Dawn or Dusk respectively (dashed: Dec. 2017; solid: May 2018). In both, THM is on MMS-resonant orbits. THM-MMS explore asymmetries of Rx, and drivers of m'pause boundary layer flows.

MMS Tail #3 (THM at dayside) (MMS "1st extended-tail", 8/29/2018) THM-MMS on resonant orbits, study dayside-nightside Rx simultaneously.



THM on sidereal period resonances (8:4:1):
T_{P4} = 1 day [P4 R_A=12.1R_E]
T_{P5} = 8/7 day [P5 R_A=13.2R_E]
T_{P3} = 4/3 day [P3 R_A=15.8R_E]
Two or three THM-GBO conjunctions (once per 4 or 8 days) explore the dominant energy conversion in the tail and the drivers of nightside reconnection, while MMS captures the global drivers of these phenomena at the dayside.
VAP-THM jointly study effects in inner magnetosphere.

THM @ Dawn, Dusk and Dayside is in resonance with MMS Dawn as in FY17. THM @ Dusk and Dayside resonances are:
P4,5:MMS = 5:2 [P4,5 R_A=13.2R_E]
P3:MMS = 2:1 [P3 R_A=15.5R_E]
Every time MMS is inbound, P3 is at apogee.
Every 2 MMS P4,5 are also at apogee.

THEMIS ARTEMIS

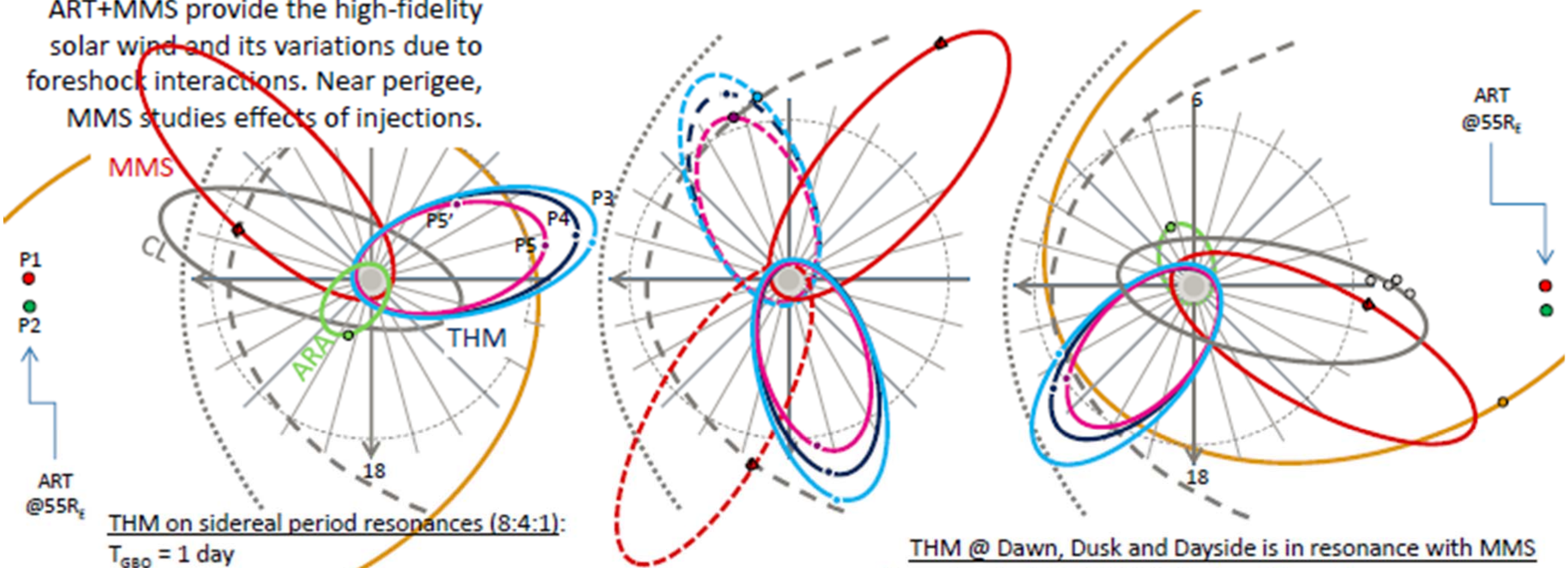
FY19: also raised P4 apogee, to ~14R_E

… in FY19: THM at resonant orbits w/ GBOs or MMS.

MMS Dayside #4 (THM in Tail) (Mar. 30, 2019)
THM studies dominant energy conversion further out in m'tail, as ART+MMS provide the high-fidelity solar wind and its variations due to foreshock interactions. Near perigee, MMS studies effects of injections.

MMS, THM at Dawn or Dusk respectively (dashed: Jan. 2019; solid: Jul. 2019).
As in FY18, but explore asymmetries over a wider swath of m'pause.

MMS Tail #4 (THM at dayside) (MMS "2nd extended-tail", 9/21/2019).
THM-MMS on resonant orbits, study dayside-nightside Rx simultaneously.



THM on sidereal period resonances (8:4:1):
T_{GBO} = 1 day
T_{P5} = 8/7 day [P5 R_A=13.2R_E]
$T_{P3,4}$ = 4/3 day [P3,4 R_A=15.8R_E]
Two or three THM-GBO conjunctions (once per 4 or 8 days) explore the dominant energy conversion in the tail and the drivers of nightside reconnection, while MMS captures the global drivers of these phenomena at the dayside.

THM @ Dawn, Dusk and Dayside is in resonance with MMS
Dawn is as in FY17. THM @ Dusk and Dayside resonances are:
P5:MMS = 5:2 [P5 R_A=13.2R_E]
P3:MMS = 2:1 [P3 R_A=15.5R_E]
Every time MMS is near apogee P3 is too.
Every 2 MMS periods P5 is also at apogee.
P4 is on same period as P3 at night & dusk but as P5 elsewhere.

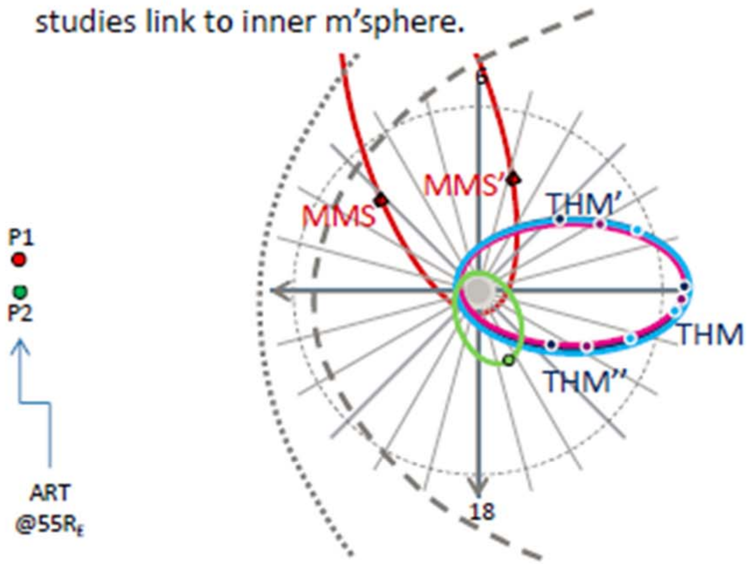
FY20: THEMIS apogees all at ~13.2R_E; at ion kinetic scales; MMS at same flank m-pause

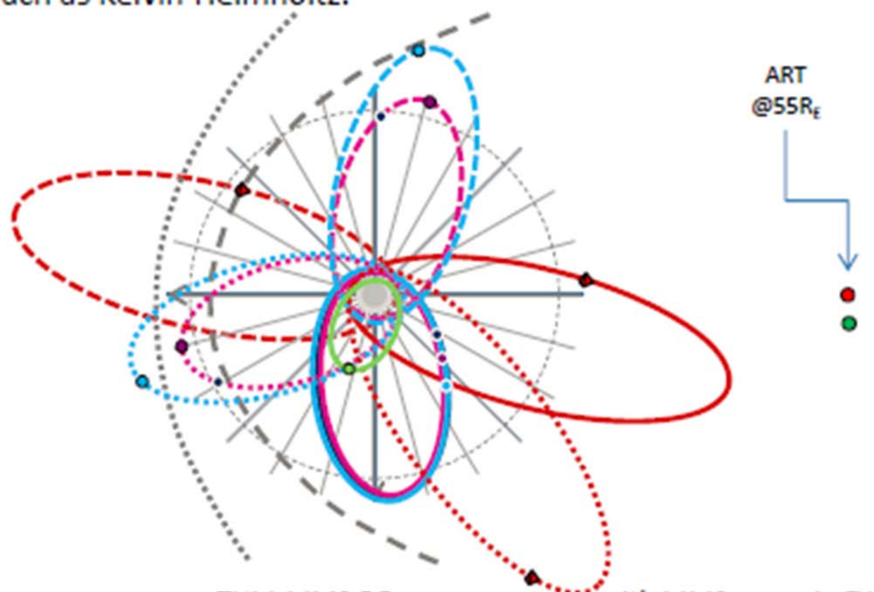
…FY20: THM at resonant orbits w/MMS or GBOs → All THM at 13.2R_E (from Feb. 2020).

THM @ Tail (MMS at Dawn) (May. 9, 2020)
THM-MMS study the dominant energy conversion in the tail from kinetic scale separations while MMS studies link to inner m'sphere.

THM, MMS both at dusk (dotted: Oct. 2019)
MMS, THM both at dawn (dashed: Jan. 2020)
Evolution of Rx and its relationship to growth of low-latitude boundary layer instabilities, such as Kelvin-Helmholtz.

MMS @ Tail (solid: Sep. 8, 2020).
THM is an MMS-resonant string-of-pearls, studying connections to both m'pause and inner m'sphere.



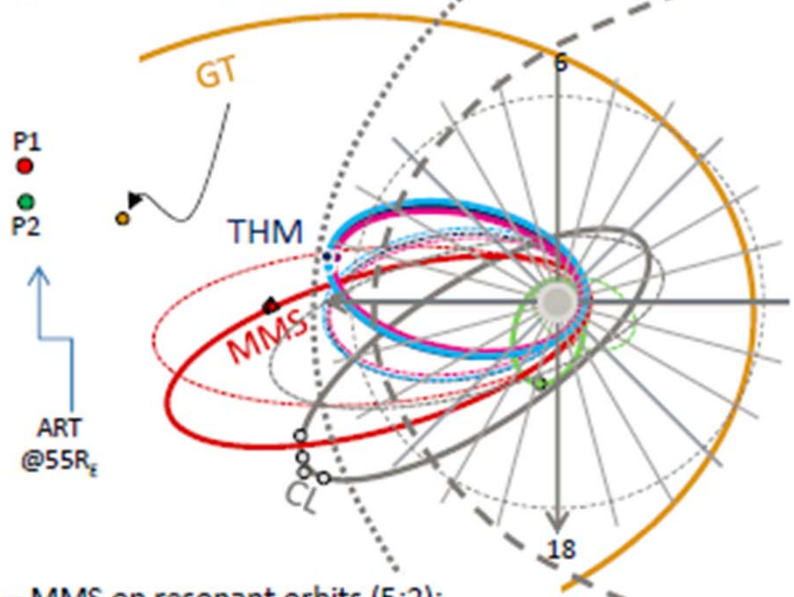


<u>THM – MMS on resonant orbits (5:2):</u>
P5:MMS = 5:2 [P5 R_A=13.2R_E]
Every 2 MMS periods, when MMS passes through its in- or out-bound leg, THM is near apogee or inbound leg.
From its kinetic-scale separations THM explores the dissipation of flow and magnetic energy in the tail while MMS captures their effects in the inner magnetosphere.

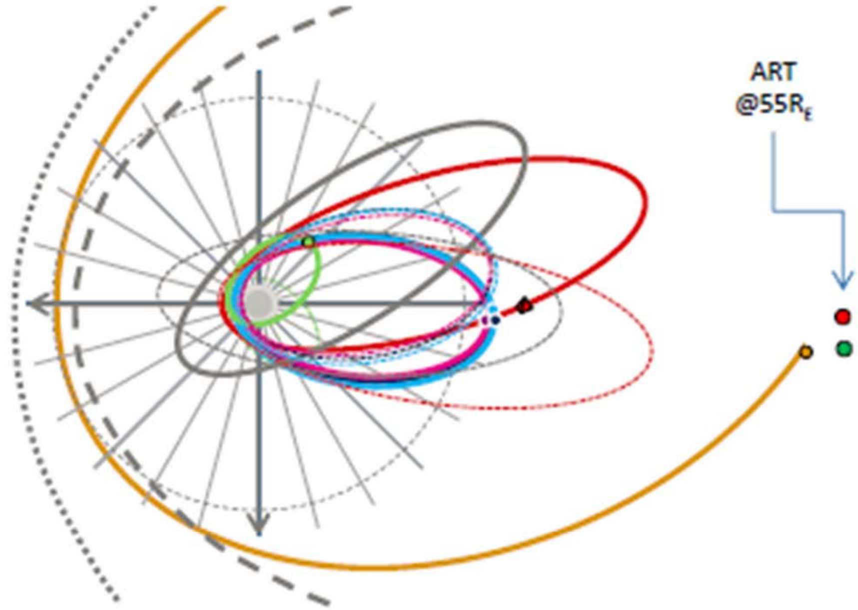
<u>THM-MMS@Dawn resonances with MMS are as in FY19</u>
(5:2 for P4,5 and 2:1 for P3).
<u>MMS @ Tail resonances are as in FY20 THM@tail</u>
(5:2 for all P3,4,5). Once every other MMS orbit, MMS is at Rx point and THM is at m'pause to capture day/night connections. The other MMS orbit THM is at in-bound leg (string of pearls) studying link of Rx/injections to inner magnetosphere over a wide range of L-shells

...FY21/22: THM Clustered, in conjunction with CL, MMS; resonant w/MMS

THM, MMS, CL are all at Dayside
(solid: Jan. 10, 2021; dashed: Feb. 2, 2022)
Study the kinetic/regional drivers of Rx at m'pause.



THM, MMS, CL all in Tail
(solid: Aug. 8, 2021; dashed: Aug 31, 2022).
Study the drivers and consequences of tail Rx.

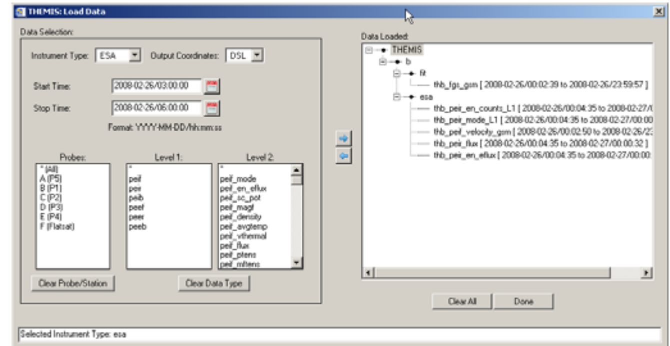


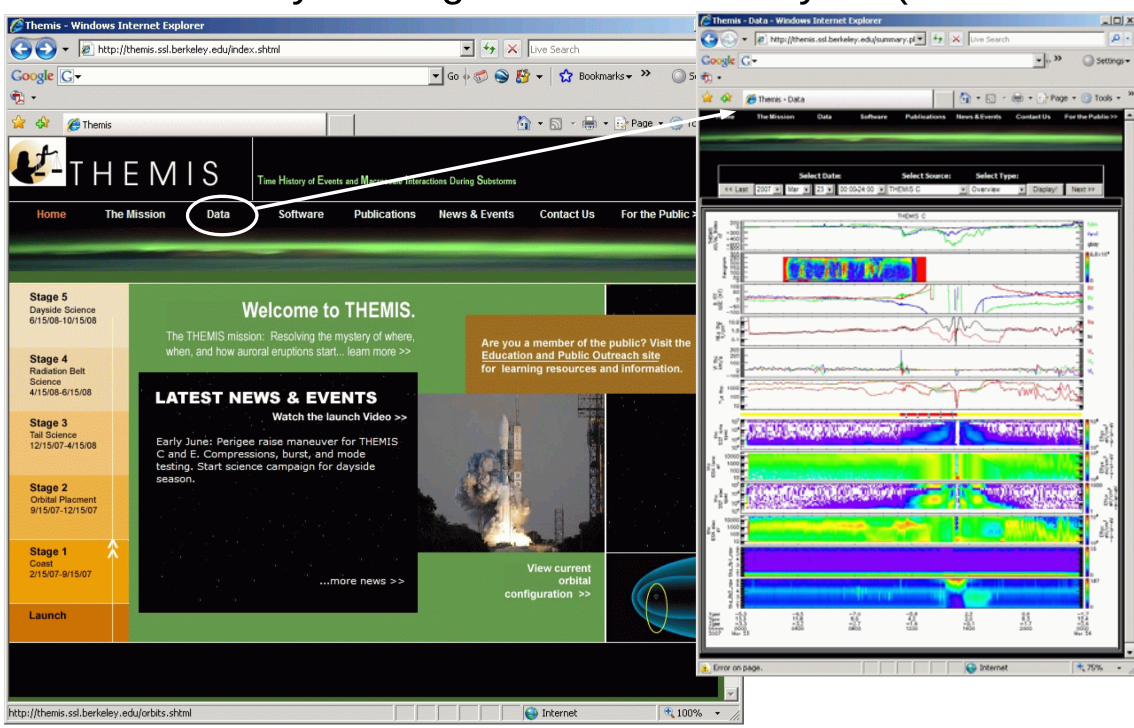
THM – MMS on resonant orbits (5:2):
P5:MMS = 5:2 [P5 R_A=13.2R_E]
Every 2 MMS periods, when MMS passes through its in- or out-bound leg, THM is near apogee or inbound leg. From its kinetic-scale separations THM explores magnetopause reconnection in response to drivers from foreshock transients (which can be studied kinetically with MMS and regionally with Cluster), whereas Arase studies the inner magnetosphere consequences.

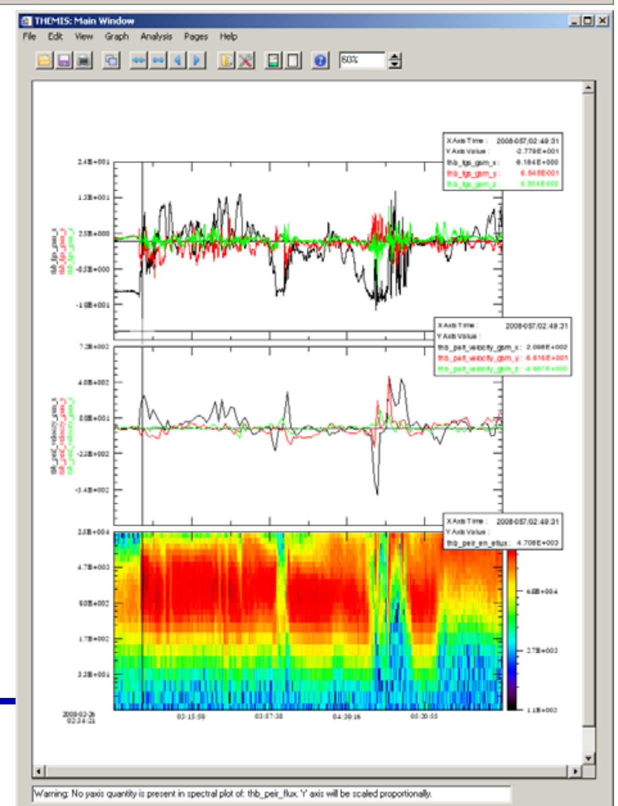
THM – MMS on resonant orbits (5:2) in tail:
P5:MMS = 5:2 [P5 R_A=13.2R_E]
Same as in Dayside (left). When MMS passes through its outbound leg it crosses the plasma sheet radially from ~7R_E to ~20R_E, when the THM cluster on ion-scale separations is near the neutral sheet. The inner magnetosphere effects of injections are measured by Arase.

Data Processing and Community Support

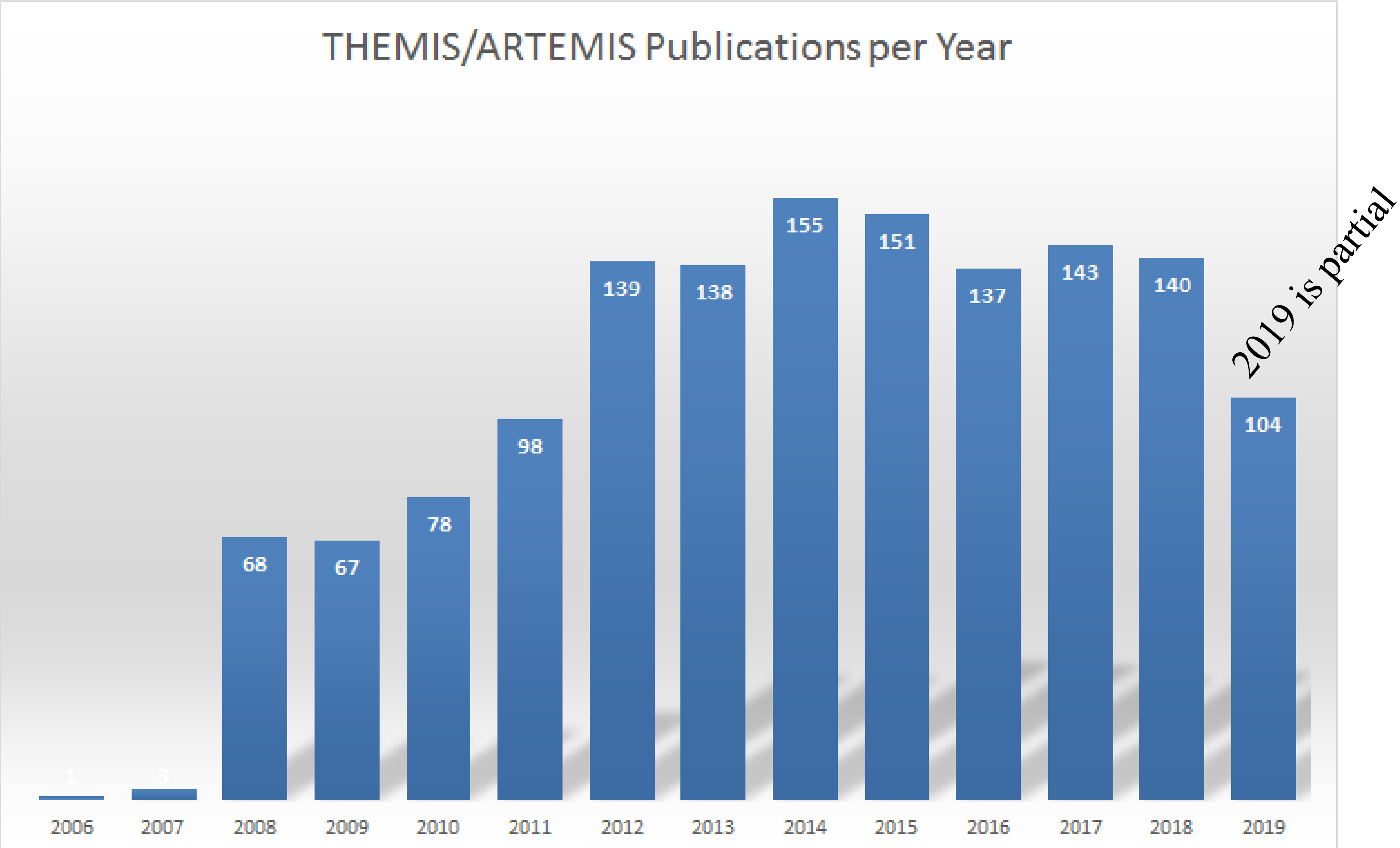
- All data/plots available, calibrated 1 day after downlink (http://sprg.ssl.berkeley.edu)
- Routine data distribution in 4 ways
  - CDF downloads from SPDF, UCB, 4 mirror sites
  - HTTP and FTP socket connection through software (seemless)
  - Bundled downloads via UCB site (per instrument, spacecraft, product)
  - On-line at VMOs, and PDS (data is SPASE compatible).
- Free, powerful software distribution, on-line docs, tutorials
  - IDL-based, platform independent
  - Community demos biannually at GEM meetings + trainings on demand
- On-line Support (THEMIS_Science_Support@ssl.berkeley.edu)
- SVN configuration-controlled: distributed, grass-roots effort
- Community training sessions twice a year (GEM and AGU)



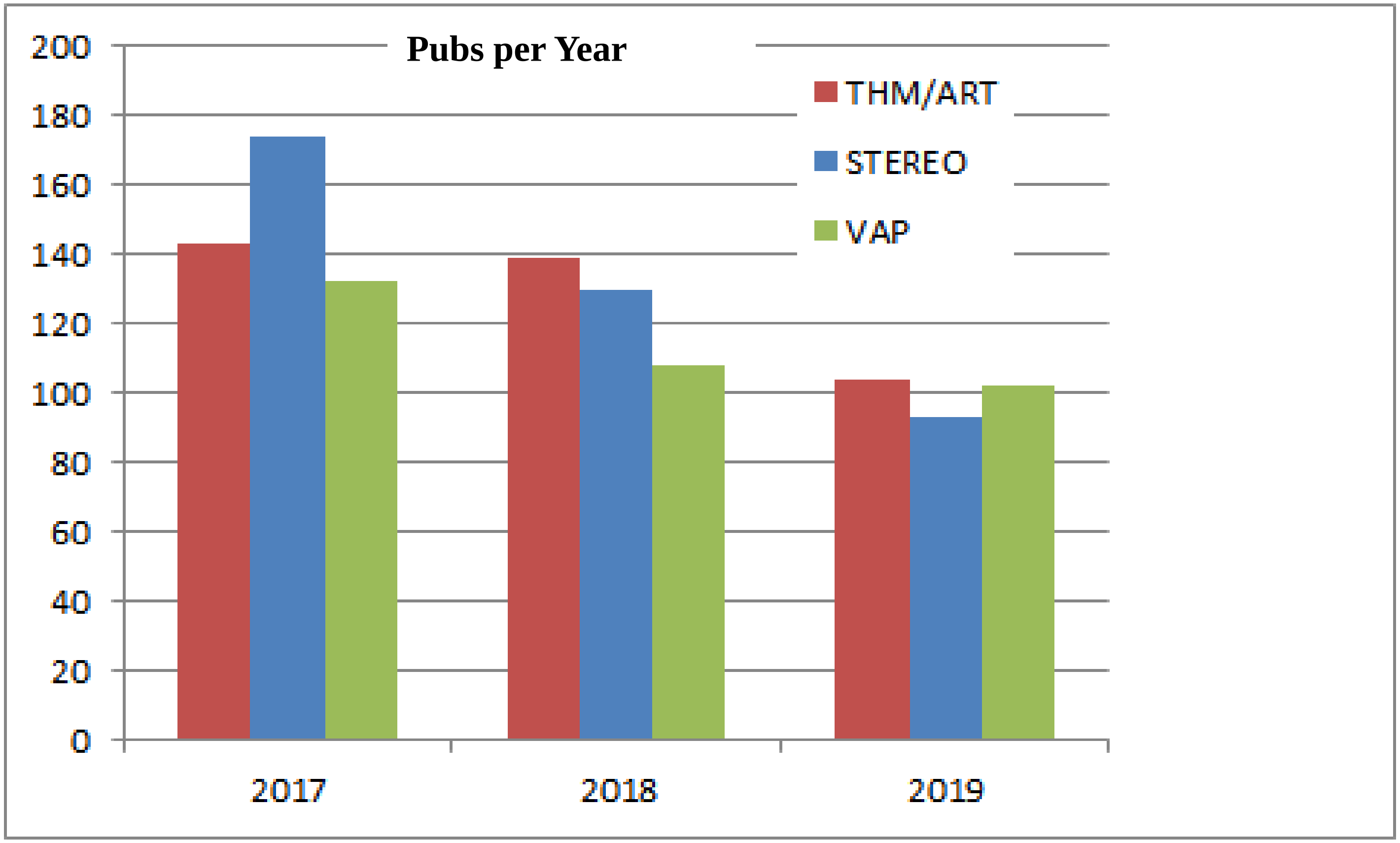




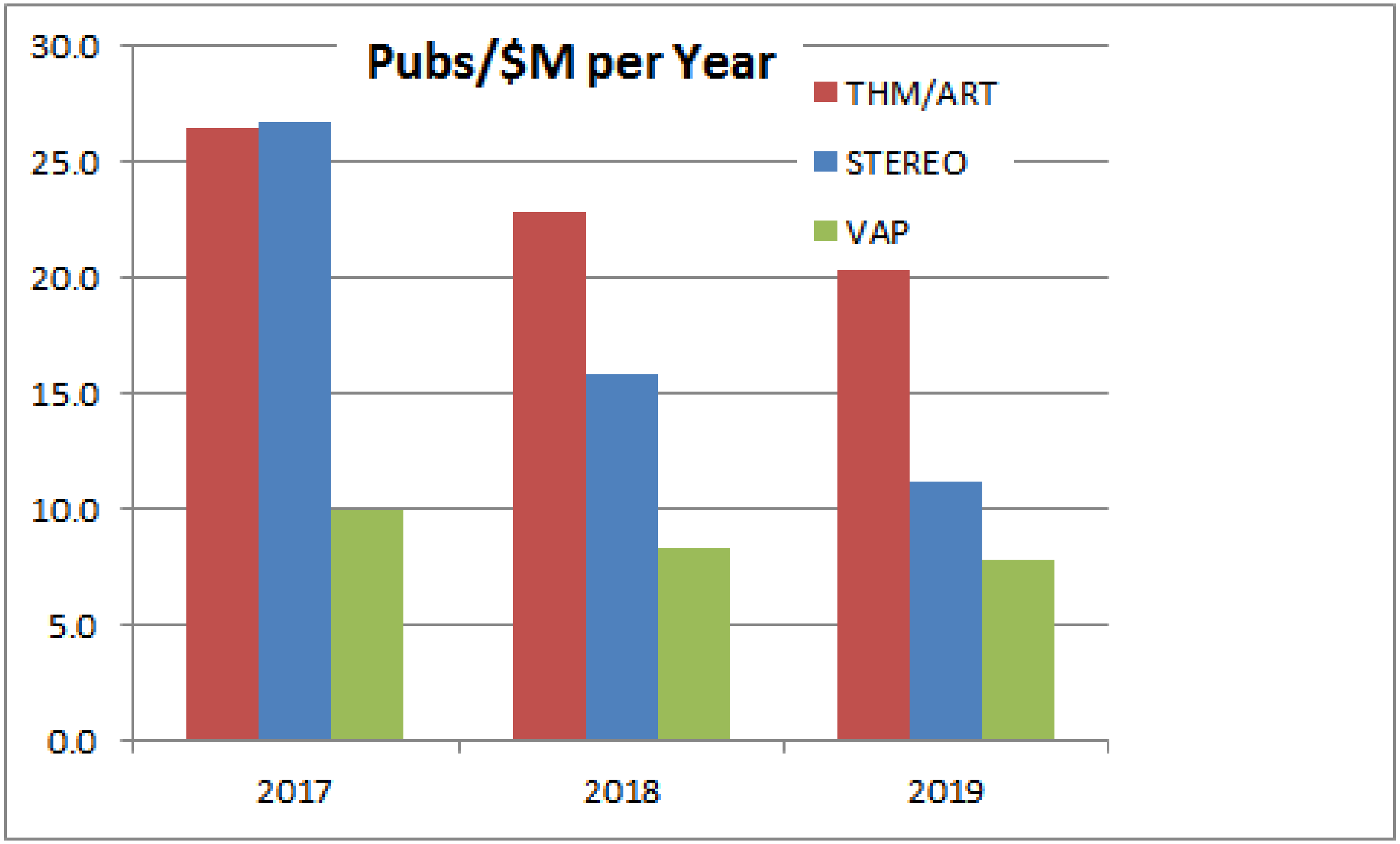
Publications



Publications, rel. to others of similar age



Pubs/$M, rel. to others of similar age



Current projections

Current guide (below) does not allow science plans to materialize. HQ informed, but so far unresponsive. Red are University PI-ed or operated missions. What action to take?

Mission	MS/PI	Comments	Launched	Lead Org.	Msn Ops	FY2020	FY2021	FY2022	FY2023	FY2024	FY2025
AIM	D. Janches/674	single sat	2007	Hampton U	CU Boulder	**$2,982**	*$2,982*	*$2,982*	*$2,982*	*$2,982*	*$2,982*
Geotail	G. Le/673	Japan msn	1992	n/a	n/a	**$433**	*$433*	*$433*	*$433*	*$433*	*$433*
GOLD	S. Jones/671	hosted instr	2018	CU Boulder	n/a	**$5,500**	*$3,300*	*$3,300*	*$3,100*	*$3,100*	*$3,100*
Hinode	S. Savage/ZP13	JP mission	2006	n/a	n/a	**$7,000**	*$7,000*	*$7,000*	*$6,500*	*$6,500*	*$6,500*
IBEX	E. Christian/672	simple	2008	SwRI	APL	**$3,400**	*$3,400*	*$3,400*	*$3,400*	*$3,400*	*$3,400*
IRIS	A. Daw/671	simple	2013	LMSAL	NASA/Ames	**$6,600**	*$6,500*	*$6,500*	*$6,500*	*$6,500*	*$6,500*
MMS	T. Moore/672	4 sat's	2015	SwRI	GSFC	**$20,700**	*$18,700*	*$16,800*	*$16,800*	*$16,800*	*$16,800*
SDO	D. Pesnell/671	single sat	2010	GSFC	GSFC	**$12,000**	*$12,000*	*$12,000*	*$12,000*	*$12,000*	*$12,000*
STEREO	T. Kucero/671	single sat	2006	(GSFC/APL)	APL	**$7,800**	*$7,800*	*$7,800*	*$7,800*	*$7,800*	*$7,800*
THEMIS	D. Sibeck/674	5 sat's	2007	UCLA	UCB	**$5,000**	*$4,800*	*$4,800*	*$4,600*	*$4,600*	*$4,600*
TIMED	D. Janches/674	single sat	2001	n/a	APL	**$2,686**	*$2,610*	*$2,610*	*$2,610*	*$2,610*	*$2,610*
Voyager	S. Dodd/JPL72	2 sats	1977	n/a	JPL	**$6,433**	*$5,500*	*$5,500*	*$5,000*	*$5,000*	*$5,000*
Wind	L. Wilson/672	single sat	1994	n/a	GSFC	**$2,200**	*$2,200*	*$2,200*	*$2,200*	*$2,200*	*$2,200*
SDAC	J. Ireland/670	community service		GSFC operation		**$2,984**	*$1,200*	*$1,200*	*$1,200*	*$1,200*	*$1,200*
SPDA	B. Candey/B. Mc	community service		GSFC operation		**$2,450**	*$2,300*	*$2,300*	*$2,300*	*$2,300*	*$2,300*
SSMO	R. Burns/444	community service		GSFC operation		**$11,939**	*$11,939*	*$11,939*	*$11,939*	*$11,939*	*$11,939*

Summary

- ❑ Heliophysics is at a cross-roads
  - ✓ Understanding how kinetic phenomena drive global processes is a “must”.
  - ✓ THEMIS/ARTEMIS have the fuel, science and skills to provide the needed observations, coordination and cross-platform software for the field
  - ✓ The proposed plan is an ideal response to the Decadal Survey charge to HPS
  - ✓ The alignments of the next few years will not arise again in our careers.

- ❑ Current budget only permits data acquisition but analysis will not match the potential of the mission for discovery.

- ❑ Given plans to conduct science of and from the moon ARTEMIS’ potential is also to remain untapped unless budget projections change.

- ❑ Time-scale for SR proposal (now delayed to April 2020) suggests that HQ will not have the ability to modify the guide in response the SR results.

- ❑ Advice on how to proceed is welcome!