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.
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
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.
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 $\sim 25R_E \rightarrow$ pre-breakup arc brightens at $\sim 10-12R_E$, where energy is converted

Fast flows impacting near-Earth drive inner magnetosphere space weather

Proton aurora (dusk)

Pulsating aurora (dawn)
Recent results: The critical role of Hall E-field in thin current sheets

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 Ez forms in the magnetotail thin current sheet. For more details of the simulation model, see Lin et al. (2014, 2017).
• 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 $\sim 15R_E$
FY19: also raised P4 apogee, to $\sim 14R_E$
FY20: THEMIS apogees all at \(~13.2R_E\); at ion kinetic scales; MMS at same flank m-pause
FY21/23: THEMIS apogees at \( \sim 13.2R_E \); Radially aligned w/ MMS and CL

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

THM, MMS, CL are all at Dayside
Study the kinetic/regional drivers of Rx at m’pause.

THM – MMS on resonant orbits (5:2):
P5:MMS = 5:2 \([P5 R_E = 13.2R_E]\)
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.
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)
THEMIS/ARTEMIS Publications per Year

- 2006: 68
- 2007: 67
- 2008: 78
- 2009: 98
- 2010: 139
- 2011: 138
- 2012: 155
- 2013: 151
- 2014: 137
- 2015: 143
- 2016: 140
- 2017: 104

2019 is partial
Publications, rel. to others of similar age

![Pubs per Year](chart.png)
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?

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>AIM</td>
<td>D. Janches/674</td>
<td>single sat</td>
<td>2007</td>
<td>Hampton U CU Boulder</td>
<td>$2,982</td>
<td>$2,982</td>
<td>$2,982</td>
<td>$2,982</td>
<td>$2,982</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geotail</td>
<td>G. Le/673</td>
<td>Japan msn</td>
<td>1992</td>
<td>n/a</td>
<td>n/a</td>
<td>$433</td>
<td>$433</td>
<td>$433</td>
<td>$433</td>
<td>$433</td>
<td>$433</td>
</tr>
<tr>
<td>GOLD</td>
<td>S. Jones/671</td>
<td>hosted instr</td>
<td>2018</td>
<td>CU Boulder</td>
<td>n/a</td>
<td>$5,500</td>
<td>$3,300</td>
<td>$3,300</td>
<td>$3,100</td>
<td>$3,100</td>
<td>$3,100</td>
</tr>
<tr>
<td>Hinode</td>
<td>S. Savage/2P13</td>
<td>JP mission</td>
<td>2006</td>
<td>n/a</td>
<td>n/a</td>
<td>$7,000</td>
<td>$7,000</td>
<td>$7,000</td>
<td>$6,500</td>
<td>$6,500</td>
<td>$6,500</td>
</tr>
<tr>
<td>IBEX</td>
<td>E. Christian/672</td>
<td>simple</td>
<td>2008</td>
<td>SwRI</td>
<td>APL</td>
<td>$3,400</td>
<td>$3,400</td>
<td>$3,400</td>
<td>$3,400</td>
<td>$3,400</td>
<td>$3,400</td>
</tr>
<tr>
<td>IRIS</td>
<td>A. Daw/671</td>
<td>simple</td>
<td>2013</td>
<td>LMSAL</td>
<td>NASA/Ames</td>
<td>$6,600</td>
<td>$6,500</td>
<td>$6,500</td>
<td>$6,500</td>
<td>$6,500</td>
<td>$6,500</td>
</tr>
<tr>
<td>MMS</td>
<td>T. Moore/672</td>
<td>4 sat's</td>
<td>2015</td>
<td>SwRI</td>
<td>GSFC</td>
<td>$20,700</td>
<td>$18,700</td>
<td>$16,800</td>
<td>$16,800</td>
<td>$16,800</td>
<td>$16,800</td>
</tr>
<tr>
<td>SDO</td>
<td>D. Pesnell/671</td>
<td>single sat</td>
<td>2010</td>
<td>GSFC</td>
<td>GSFC</td>
<td>$12,000</td>
<td>$12,000</td>
<td>$12,000</td>
<td>$12,000</td>
<td>$12,000</td>
<td>$12,000</td>
</tr>
<tr>
<td>STEREO</td>
<td>T. Kucero/671</td>
<td>single sat</td>
<td>2006</td>
<td>(GSFC/APL)</td>
<td>APL</td>
<td>$7,800</td>
<td>$7,800</td>
<td>$7,800</td>
<td>$7,800</td>
<td>$7,800</td>
<td>$7,800</td>
</tr>
<tr>
<td>THEMIS</td>
<td>D. Sibeck/674</td>
<td>5 sat's</td>
<td>2007</td>
<td>UCLA</td>
<td>APL</td>
<td>$5,000</td>
<td>$4,800</td>
<td>$4,800</td>
<td>$4,600</td>
<td>$4,600</td>
<td>$4,600</td>
</tr>
<tr>
<td>TIMED</td>
<td>D. Janches/674</td>
<td>single sat</td>
<td>2001</td>
<td>n/a</td>
<td>APL</td>
<td>$2,686</td>
<td>$2,610</td>
<td>$2,610</td>
<td>$2,610</td>
<td>$2,610</td>
<td>$2,610</td>
</tr>
<tr>
<td>Voyager</td>
<td>S. Dodd/JPL720</td>
<td>2 sat's</td>
<td>1977</td>
<td>n/a</td>
<td>JPL</td>
<td>$6,433</td>
<td>$5,500</td>
<td>$5,500</td>
<td>$5,000</td>
<td>$5,000</td>
<td>$5,000</td>
</tr>
<tr>
<td>Wind</td>
<td>L. Wilson/672</td>
<td>single sat</td>
<td>1994</td>
<td>n/a</td>
<td>GSFC</td>
<td>$2,200</td>
<td>$2,200</td>
<td>$2,200</td>
<td>$2,200</td>
<td>$2,200</td>
<td>$2,200</td>
</tr>
<tr>
<td>SDAC</td>
<td>J. Ireland/670</td>
<td>community service</td>
<td>GSFC operation</td>
<td>$2,984</td>
<td>$1,200</td>
<td>$1,200</td>
<td>$1,200</td>
<td>$1,200</td>
<td>$1,200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPDA</td>
<td>B. Cande/674</td>
<td>community service</td>
<td>GSFC operation</td>
<td>$2,450</td>
<td>$2,300</td>
<td>$2,300</td>
<td>$2,300</td>
<td>$2,300</td>
<td>$2,300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSMO</td>
<td>R. Burns/444</td>
<td>community service</td>
<td>GSFC operation</td>
<td>$11,939</td>
<td>$11,939</td>
<td>$11,939</td>
<td>$11,939</td>
<td>$11,939</td>
<td>$11,939</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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!**