# Mission design and analysis and the birth of a new mission: ARTEMIS

MISSION DESIGN AND ANALYSIS

- Driver: Compelling Science
- Funding: Match Agency Goals, Opportunities
- Can I Measure It? Instruments
- Can I Accommodate Instruments? Bus
- Can I Get There? Orbit, Launch
- Can I Get Data Back? Ground/Space Link
- Can Demonstrate Closure? Iterative process
- What Can I Throw Off? Descopes
- What Did I Miss? Review Team
- Optimize: Science per $$ reducing risk

EXAMPLE: ARTEMIS

- What's in a name?
- Science Packaging
- Orbit Optimization
- Data Relay and Descopes

Book: Mission Design and Analysis: Wertz and Larson
THEMIS/ARTEMIS proposal: http://themis.ssl.berkeley.edu/news
http://www.igpp.ucla.edu/public/vassilis/ESS265/20080602

# Mission Driver: Compelling Science

IS PEOPLE'S TIME, NATION'S $$ WORTH IT IN YOUR MIND?

For Science:
- Does it resolve an outstanding, key science question in the field?
- Will it result in changing textbooks and hundreds of papers?

For Team and Public:
- Can you explain science simply, provide compelling reasoning?
- Why should the people's families and the public care?

CAN GOALS CONVINCE THE SCIENCE TEAM
- Is it worth spending nights and weekends in the lab?
  - Will it result in name recognition (papers) for the science team?
  - Is the instrument team vested already in this type of science?
- Possible reasons:
  - Evolutionary step in instrument for a revolutionary step in science
    (Examples: FAST: Rocket-quality data throughput 10 times a day, resolve auroral acceleration
    THEMIS: Unprecedented magnetotail alignments 30 times a year, resolve substorm mystery)
  - First in instrument capability, for a great potential in science
    (Examples: IMAGE: First Energetic Neutral Atom instruments, resolve ring current structure, dynamics)

CAN GOALS GALVANIZE ENGINEERING TEAM
- Can they talk about the project to their families ?
- Are the tall poles challenging (interesting) but not overwhelming (futile) ?

# Matching Agency Goals, Opportunities

DOES MISSION SCIENCE ADDRESS AGENCY PROGRAMMATIC NEEDS

IS SCIENCE RECOGNIZED IN:

NASA DECADAL SURVEYS
NASA ADVISORY COUNCIL AND NATIONAL ACADEMY PUBLICATIONS
NATIONAL SCIENCE FOUNDATION VISION STATEMENTS
DEPARTMENT OF ENERGY

- Goals must match the intent of NASA vision statements
- Goals must letter
- Possible reasons:

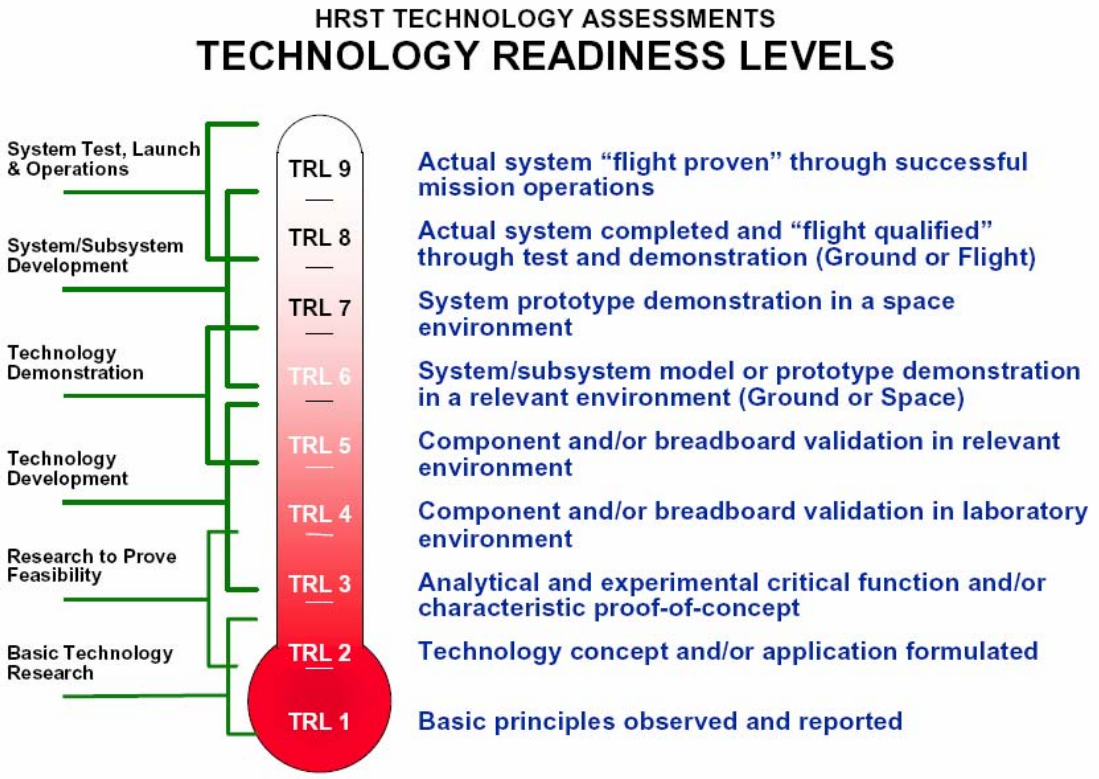
WHAT ARE THE FUNDING OPPORTUNITIES?

- NASA Assigned Missions: Living with a Star (Heliophysics), Solar-Terrestrial Probe Line (Heliophysics), New Frontiers (Planetary), Mars Exploration (Planetary), Outer Planets Flagship (Planetary), Physics of the Cosmos (Astrophysics)
- NASA Competed missions: Explorers (Heliophysics, Astrophysics), Earth System Science Pathfinders (Earth), Discovery (Planetary)
- Missions of Opportunity: Instruments on non-NASA satellites, Satellites on non-NASA launches
  - One call per year
- NSF (new program): Micro/Nano-satellites as clusters or secondary payloads
  - One call per 6 months

# Can I measure it: Instruments

INSTRUMENT SELECTION, CONSIDERATIONS

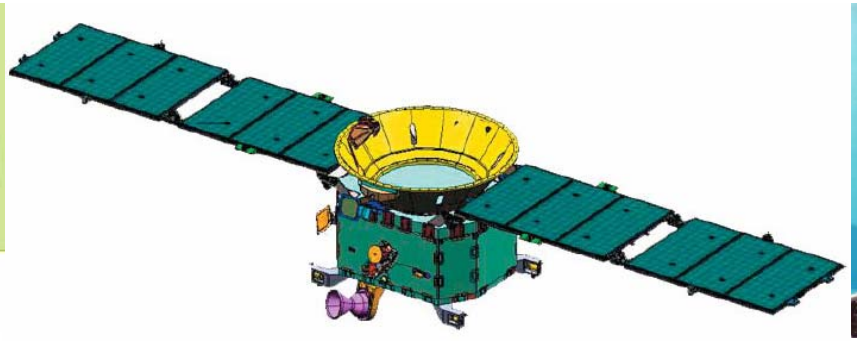
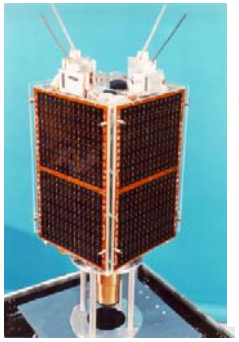
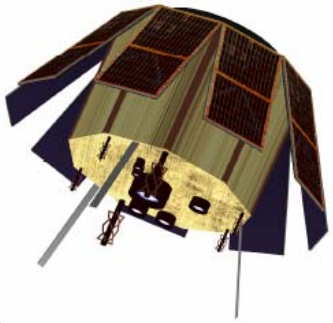
- Minimum number of instruments that meet or exceed science goals (lean and focused)
- Heritage: Must have been demonstrated to perform in a similar environment (low risk)
  Technology Readiness Levels (TRL) [NASA Code-Q Web Site]
- Case #1: Previously flown instruments with parts upgrades and science improvement (low risk)
  Usually considered TRL#7, 8 or 9
  - Upgrade electronics parts with other flight-qualified parts (e.g., FPGAs vs discrete)
  - Upgrade mechanical design for better science yield, parts (e.g., ESA serrated spheres, and SMA actuator)
- Case #2: New flight instrument, previously flown on balloons, rockets or test flight
  - Upgrading TRL level gradually under low risk to agency
- Select team heritage: core team with institutional heritage – high chance for success



# Can I Accommodate Instruments? Bus

CONSIDERATIONS

- Can it match pre-qualified bus design from NASA catalog? (http://rsdo.gsfc.nasa.gov) FLEXBUS, ROADRUNNER, MINISTAR, MINIBUS…

- Power:
  - Size total instrument power, including 20-30% conversion efficiency
  - Account for orbit shadow time, estimate Transmitter ON power, obtain orbit average and peak power
  - Find appropriate spacecraft match (to guess, compute solar array size assuming 28% array efficiency)
    - Note Solar Constant is 1.4 kW/m$^2$ with a small (7%) yearly fluctuation due to Earth's rotation (scale by distance to Sun for other planets)
    - Efficiencies result from common power distribution design, common data processing, storage and relay to ground
- Mass:
  - Size total instrument mass, including 15-30% margin (depending on maturity) and 15% for harness
  - If it does not fit in standard spacecraft capability, design your own from scratch:
    - A good rule of thumb is 10-30% of the total (dry) spacecraft mass is in the instruments
    - Depends on whether propulsion, torque rods, thermal pipes, and other complexities are needed
    - Efficiencies result from instrument-spacecraft mechanical team integration from the beginning

# Instrument accommodation. Bus – in practice

Approach #1 (typical for PI led, Helio-physics missions)

- Academia conducts preliminary bus design
- Issues a Request For Proposals from industry
- Work with multiple industry partners (fire-walled) to scope interest and capability
- Determine one partner to go to proposal with, based on:
  - Experience, Working relationship, Importance of mission to company
- Determine system design and performance based on:
  - Known components from recent flights, major subsystem RFPs
- Identify development areas, explore solutions, work on reducing risk
- Answer question: what if I get into trouble?
  - Identify instruments for descope: science impact, cost/schedule benefit
- Iterate, to solidify solution meets requirements and develop confidence
- Science is key to requirements definition, science closure and system optimization
- Major cost driver is how (unavoidable) technical surprises are handled by the team

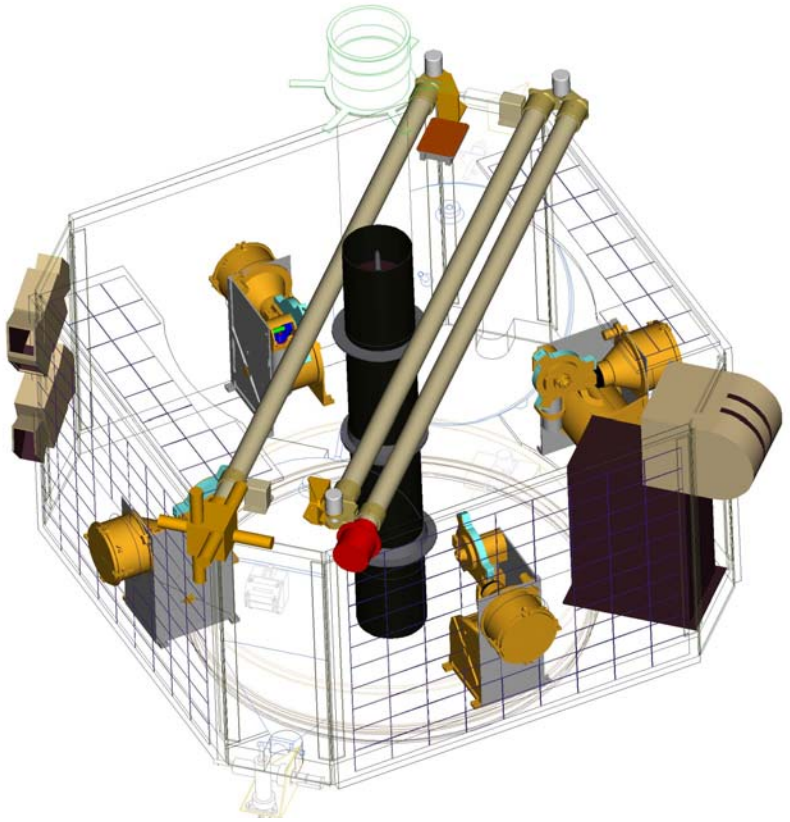
Approach #2 (typical for non-PI led, or for Astrophysics missions)

- Industry or NASA Center leads bus design in response to:
  - Management Organization's separate calls for instruments and spacecraft, or
  - Direct affiliation with instrument teams by virtue of development of one instrument (e.g., optical)
- Team frozen early, iteration is difficult, changes can be costly
- Primary role of scientists is to define requirements and their flow-down early, accurately
- Scientists support the proposal organization by:
  - Providing advice on impact of instrument component and bus design/component trades on science
- Additional cost drivers are requirements creep: science / programmatic

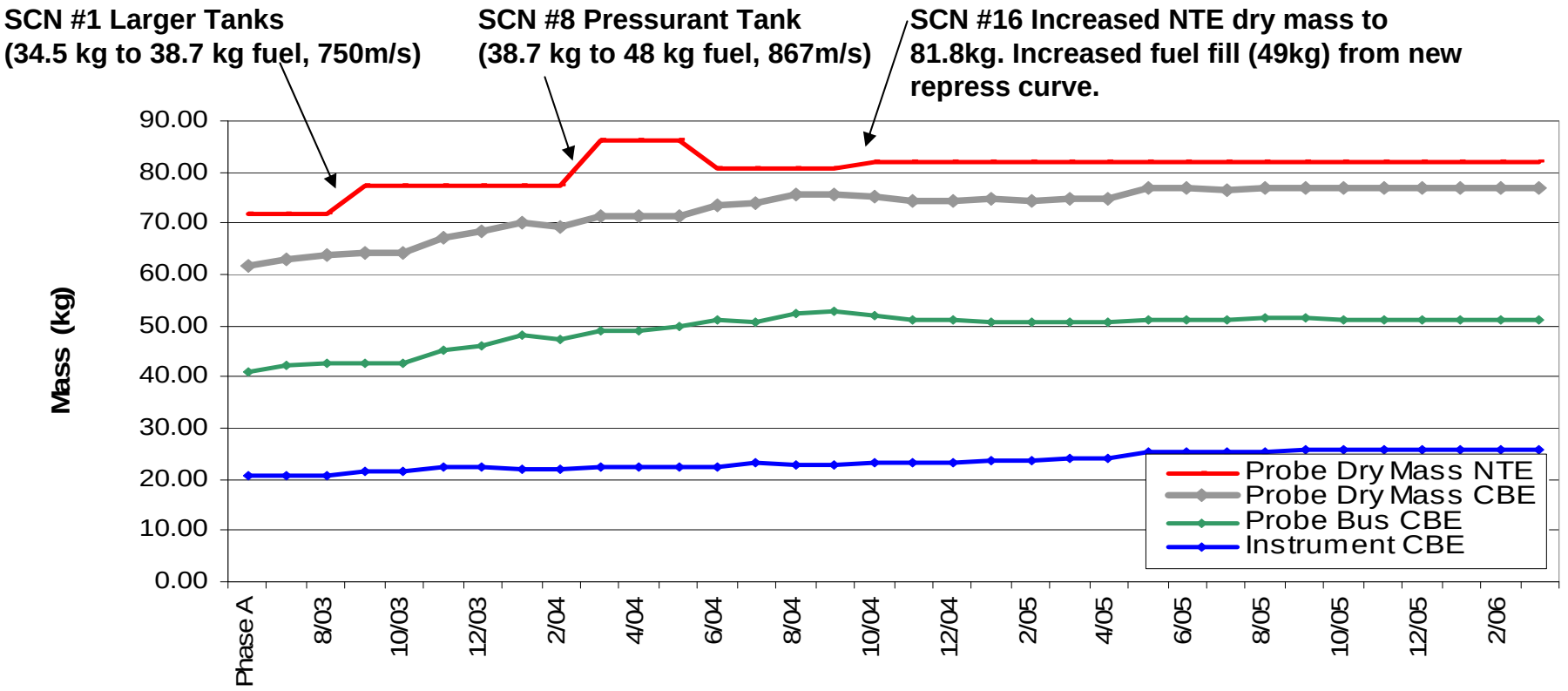
# Instrument accommodation. Bus – examples

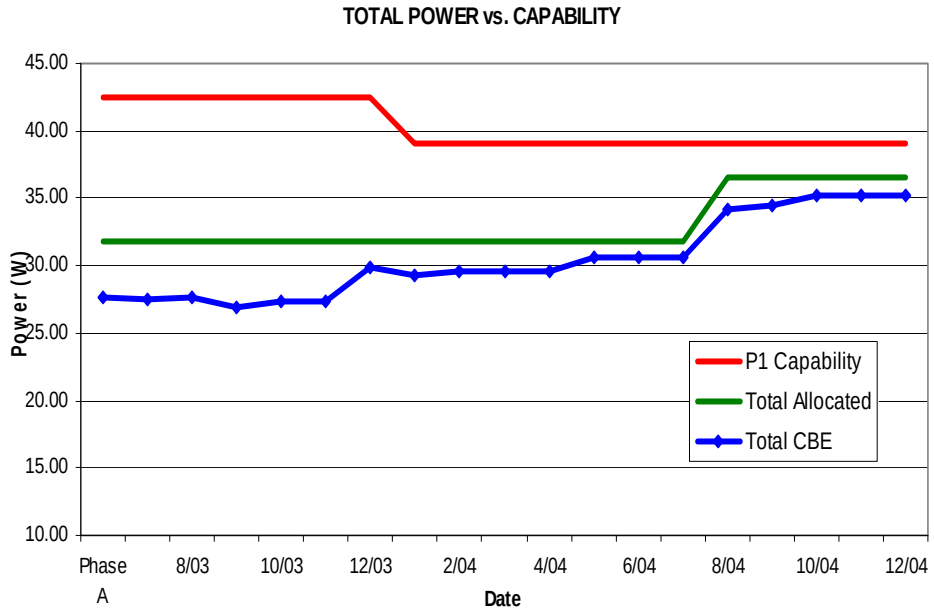
| Instrument | Mass (kg) | Power (W) | Recent Flight | Insti-tute |
|---|---|---|---|---|
| FGM @ sensor | 0.1 | Equator-S | | TUBS |
| FGM boom | 1.2 | Fast, Lunar Prospector | | UCB |
| FGM @ DPU | 0.3 | 0.8 | MIR | IWF |
| ESA @ sensor | 2.1 | 1.9 | FAST | UCB |
| ESA @ DPU | 0.3 | 0.6 | FAST | UCB |
| SST @ sensor | 1.3 | 0.9 | WIND | UCB, ESTEC |
| SST @ DPU | 0.1 | 0.2 | WIND | UCB |
| SCM @ sensor | 0.7 | | Cluster | CETP |
| SCM boom | 0.5 | Lunar Prospector | | UCB |
| SCM pre-amps | 0.3 | 0.1 | Cluster | CETP |
| EFI (4) @ spin-plane | 7.2 | 0.3 | Cluster | UCB |
| EFI (2) @ axials | 4.1 | 0.2 | POLAR | UCB |
| EFI/SCM @ DPU | 1.7 | 2.8 | FAST | UCB |
| DPU process, compress & store | 1.2 | 4.5 | FAST, Lunar Prospector | UCB |
| Total | 21.0 | 12.1 | | |
| Maximum expected | 23.6 | 14.8 | | |
| Average reserve | 13% | 22% | | |

***Table E-5.*** *Summary of each probe's instrument characteristics. Sensors include harness and MLI. Power includes power conversion and conditioning. Maximum expected values derived from grass-roots, based on maturity level of each subsystem.*



Reserve = Uncertainty [%] Based on Maturity
Maximum expected = Total + Reserve
Margin = Reserve
Contingency = (Available – Max )/Max [%]


SCN #1 Larger Tanks
(34.5 kg to 38.7 kg fuel, 750m/s)
SCN #8 Pressurant Tank
(38.7 kg to 48 kg fuel, 867m/s)
SCN #16 Increased NTE dry mass to
81.8kg. Increased fuel fill (49kg) from new
repress curve.
Mass (kg)
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Phase A
8/03
10/03
12/03
2/04
4/04
6/04
8/04
10/04
12/04
2/05
4/05
6/05
8/05
10/05
12/05
2/06
Probe Dry Mass NTE
Probe Dry Mass CBE
Probe Bus CBE
Instrument CBE


TOTAL POWER vs. CAPABILITY
Power (W)
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
Phase A
8/03
10/03
12/03
2/04
4/04
6/04
8/04
10/04
12/04
Date
P1 Capability
Total Allocated
Total CBE

# Can I Get There? Orbit Design, Launch

## ORBIT DESIGN CONSIDERATIONS

- Which orbit is needed to do the science?
- Can I get to it using direct injection?
- Can I maintain orbit without any maneuvers?
- Can I avoid propellant using magnetic torquers?
- If the answer is NO a propulsion system is needed
  - Cold gas (best for infrequent attitude changes but not orbit changes)
  - Solid motor (best for single orbit change to attain orbit efficiently)
  - Hydrazine $N_2H_4$ (both for attitude and orbit changes, requires plumbing)
    - Blowdown or with pressurant
- Orbit maintenance for science purposes can be significant
  - Science needs to have direct involvement
  - Either scientist performs task (FAST, THEMIS) or direct communication designers (ARTEMIS)

## LAUNCH CONSIDERATIONS

- Launch vehicle selection can make or break project
  - Often, a larger launch vehicle is more cost effective than beating mass of subsystems
- Launch elements can play significant role in mission design
  - Direct communication with launch provider is critical to mission success
- Launch vehicle can provide additional services
  - Often less expensive and more efficient to ask for mission-unique services than complicate bus

# Orbit design – example of science involvement

THEMIS MISSION DESIGN: Angelopoulos, Frey

Maneuver Calculator:

- •Excel spreadsheet that performs mission design using impulsive orbit changes
- • Models orbit changes, bus re-orientations, side thrusts, beta thrusts etc
- • Optimizes launch elements as function of launch date

GTDS: Goddard Trajectory Determination System

- • Integrates orbit in gravity field of Earth, Moon etc.
- • Actual force fields, but discontinuous at thrust times

GMAN: Generalized MANeuver tool

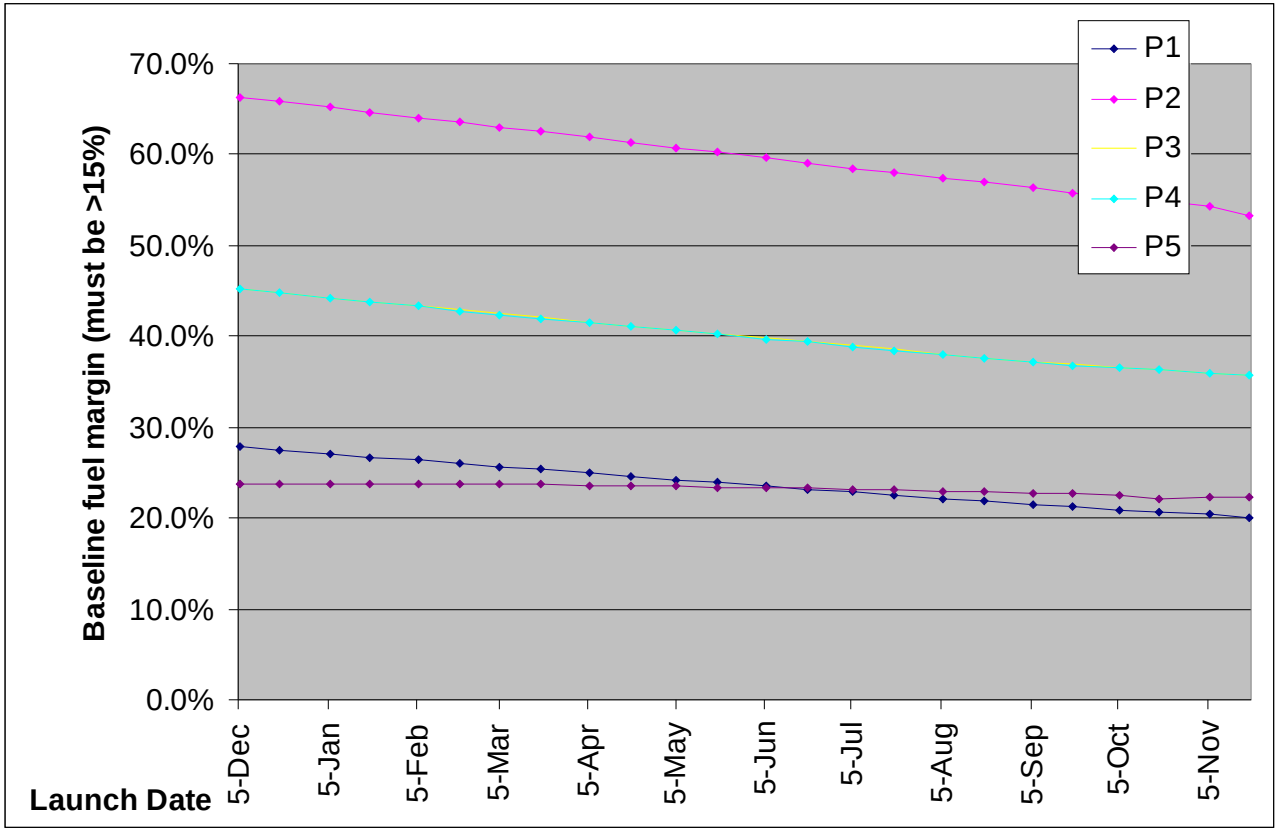
- • Simulates thruster location, pulsed or continuous thrusting
- • Used to validate orbit, and generate commands to spacecraft

| PROBE4 | PROBE4 | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Maneuver # | Maneuver Title | Ra [Re] | preburn Rp [Re] | postburn Rp [Re] | preburn Va [km/s] | preburn Vp [km/s] | postburn Va [km/s] | postburn Vp [km/s] | preburn Inc [deg] | postburn Inc [deg] | dV(km/s), nominal | dV(km/s), cumulat. | #thrust | +/- angle rear | BURN: beta | BRN? sideBRN | preBRN? | Nburns | Nominal Burn (min) | postburn Mass (base loading; no inefficiencies) |
| PC-1 | Launch Vehicle Target Orbit | 14.200 | n/a | 1.048 | n/a | n/a | 0.777 | 10.533 | n/a | 17.0 | | 0.000 | 2 | 180 | | | | | 1 | | 125.746 |
| PC-2 | Probe Actual Injection Orbit (here reor to ecliptic normal) | 15.032 | n/a | 1.047 | n/a | n/a | 0.735 | 10.557 | n/a | 17.2 | | 0.000 | 2 | 180 | 90 | | | | 1 | | 125.746 |
| Px-1 (new) | Perigee raise to stable orbit for checkout | 15.032 | 1.048 | 1.150 | 0.736 | 10.553 | 0.768 | 10.041 | 17.1 | 17.1 | 0.033 | 0.033 | 2 | 180 | 90 | 0 | 0 | 0 | 1 | 10.7 | 123.849 |
| P4-2, M2I | Perigee raise to reduce APER drifts and dif.precess. | 15.032 | 1.175 | 1.440 | 0.776 | 9.928 | 0.852 | 8.894 | 15.3 | 8.3 | 0.125 | 0.158 | 2 | 180 | 90 | 0 | 0 | 0 | 1 | 78.3 | 116.514 |
| P4-3, M1A | Apogee trim and ma placement with Canada | 11.779 | 1.444 | 1.444 | 0.853 | 8.881 | 1.076 | 8.776 | 8.0 | 8.0 | 0.106 | 0.263 | 2 | 180 | 90 | 0 | 0 | 1 | 1 | 130.8 | 110.267 |
| P4-4, M2A | Prg raise (minimize diff. Rap); Inc adjust; ma Target T1 | 11.779 | 1.444 | 1.440 | 1.076 | 8.775 | 1.074 | 8.789 | 8.0 | 7.6 | 0.006 | 0.269 | 2 | 30 | 0 | 28 | 1 | 0 | 1 | 12.3 | 109.937 |
| P4-5, M2A | PRG raise post-T1 (minimize diff. Rap) | 11.779 | 1.460 | 1.620 | 1.081 | 8.723 | 1.132 | 8.230 | 6.6 | 6.6 | 0.051 | 0.320 | 2 | 30 | 0 | 28 | 1 | 0 | 1 | 109.5 | 107.319 |
| P4-5, (apglock) | APG adjust (to match new prg); ma Target D1 | 11.599 | 1.620 | 1.620 | 1.132 | 8.230 | 1.148 | 8.222 | 6.6 | 6.6 | 0.008 | 0.328 | 2 | 30 | 0 | 28 | 1 | 1 | 1 | 17.7 | 106.927 |
| P4-6, M2A | PRG adjust, ma placement and Target T2 | 11.599 | 1.641 | 1.643 | 1.155 | 8.164 | 1.155 | 8.158 | 5.6 | 5.6 | 0.001 | 0.329 | 2 | 30 | 0 | 28 | 1 | 0 | 1 | 1.5 | 106.895 |
| P4-7, M2A | PRG adjust, ma placement and Target D2 | 11.599 | 1.663 | 1.664 | 1.162 | 8.103 | 1.162 | 8.099 | 4.6 | 4.6 | 0.000 | 0.329 | 2 | 30 | 0 | 28 | 1 | 0 | 1 | 1.0 | 106.872 |
| P4-8 | Re-entry maneuver (prg change) | 11.599 | 1.665 | 1.048 | 1.162 | 8.096 | 0.944 | 10.452 | 4.5 | 4.5 | 0.218 | 0.547 | 2 | 30 | 28 | 0 | 1 | 0 | 3 | 540.0 | 96.268 |
| P4-9 | Re-entry maneuver (apg change) | 11.599 | 1.049 | 1.049 | 0.945 | 10.447 | 0.945 | 10.447 | 4.5 | 4.5 | 0.000 | 0.547 | 2 | 30 | 0 | 28 | 1 | 1 | 1 | 0.0 | 96.268 |
| | | | | | | | | | | dVtotal= | 0.547 | | | | | | | | Final mass= | | 96.268 |

# Launch – example of science involvement

THEMIS δV margin as function of (delayed) launch date, Past Jan 20, 2006

- Launch Elements: APG=14.2Re, INC=17deg, APER=-50deg
  - Optimized fuel for Nov 19 + 3 months and a Feb 2008 T1 (tail #1) season
  - Requires coast phase in near-identical orbits for ~10 months
    - Robust orbit design (immune to further delay)
    - Drawback is getting prime science 11 months later, and additional ops costs
    - Benefit is the additional (clustered) coast phase science and calibration



# Can I get the data back? Ground-Space Link

PERFORM ROUGH LINK MARGIN ANALYSIS

- What is a reasonable antenna (size, efficiency)
- What is a reasonable contact time
  - Based on view factor, contact frequency and cost/contact
- Downlink margin (dB) must be significant (>6dB at proposal stage, >3dB at launch)
- Uplink margin less critical (>3dB at proposal stage, can be improved by larger transmitter power)
- Absolute analysis of the coupling (see below, for THEMIS) => How much data per contact
- Relative analysis: scale using known spacecraft (next page) => How much data per contact

| THEMIS - BGS Ground Station Downlink | |
|---|---|
| Frequency | 2282.5 MHz |
| Modulation | BPSK |
| Probe Antenna Gain | -3.0 dBic |
| Probe EIRP | 3.7 dBW |
| Range | 30,000 km |
| Path Loss | 189.2 dB |
| Polarization and Pointing Losses | 1.0 dB |
| Ground Station G/T (11-m Antenna) | 24.0 dB/K |
| Data Rate | 524.288 kbps |
| Bandwidth | 1048.576 kHz |
| Coding Gain RS + Rate-1/2 Conv. | 8.0 dB |
| BER | $10^{-6}$ |
| Required Eb/No | 2.5 dB |
| Predicted Eb/No | 8.9 dB |
| Implementation Loss | 2.3 dB |
| **Link Margin** | **4.1 dB** |

| THEMIS - BGS Ground Station Uplink | |
|---|---|
| Frequency | 2101.8 MHz |
| Modulation (Mod. Index: 1.0 rad) | PCM/PSK/PM |
| Grnd Station Antenna Gain | 45.7 dB |
| Grnd Station EIRP (11-m Antenna) | 66.8 dBW |
| Range | 197,000 km |
| Path Loss | 204.8 dB |
| Polarization and Pointing Losses | 1.0 dB |
| Probe G/T | -31.6 dB/K |
| Data Rate | 1.0 kbps |
| Bandwidth | 2.0 kHz |
| Coding Gain | 0.0 dB |
| BER | $10^{-6}$ |
| Required Eb/No | 10.5 dB |
| Predicted Eb/No | 20.8 dB |
| Implementation Loss | 2.5 dB |
| **Link Margin** | **7.8 dB** |

# Ground-Space Link: relative analysis

- Relative analysis: scale using known link margin

$$\text{Rate} \propto ( D_G^2 \text{ Power} ) / r^2,$$

Where $D_G$ is Ground Antenna Diameter, Power is the radiated power from the spacecraft and r is the distance between spacecraft and ground.

- Knowing THEMIS link margin to the Berkeley Ground Station, an 11m diameter dish what is the downlink rate using the DSN 26m diameter dish from the moon (400000km)?

*Answer*: THEMIS achieves comfortably a 500kbps downlink rate at 30,000km distance from the 11m dish, therefore it can achieve $500 * (26/11)^2 * (30/400)^2 = 15.7$kbps ~ 16kbps

- The entire memory is 2Gbits. Cost effective use of DSN necessitates no longer than 3 hrs of contact once per day. Factor of 2 compression has been demonstrated already. What fraction of its uncompressed (total) memory size is it reasonable for ARTEMIS to transmit?

*Answer*: 3*3600*16kbps = 173Mbits compressed or 345Mbits decompressed data. This is 1/6 of the total memory. It is also about ½ of the original THEMIS requirement.

# Can I demostrate closure? An iterative process

SHOW ORBIT, INSTRUMENTS, DATA OBTAINED CAN ANSWER QUESTIONS.

By analysis, testing and simulation

- Analyze orbits to show satellite(s) will be in the right position
  - Satellites at the right location, often enough to provide needed observations/statistics
- Show test or flight data that instrument will perform as designed
  - Noise level below expected signal
  - Geometric factor sufficient to measure expected flux
  - Time resolution of measurements sufficient to resolve phenomena
- Show data obtained are sufficient to answer key mission questions
  - Perform data analysis using simulated data
  - Introduce noise and signal comparable to what is expected from observations
- Is performance robust to nature's surprises?
  - Overlap in frequency/energy between sensors allows critical measurements by both?
  - Are more resources needed to solidify/convince skeptics?

# What can I throw off? Descopes

DESCOPES ARE KEY TO MISSION SELECTION AND SUCCESS:
THEY PROVIDE CONFIDENCE, BEYOND PROJECT CONTINGENCY

Design a mission that is robust to technical, schedule/cost risk but:

Plan science reduction options which still achieve key mission goals.

- Descopes are reductions in science capability which still leave much of the baseline mission intact
  - Examples:
    - A non-critical instrument or part of an instrument (e.g., THEMIS EFI axials and SCM)
    - A reduction in total flight time or mission targets (e.g., DAWN only at Vesta)

- Minimum performance floor is the minimum number of instruments, data volume, that still make the critical observations and render mission worth flying. Descopes should never result in a minimum mission.

- Descopes must be assigned an implementation schedule
  - At which time are only partial benefits to schedule/cost expected?

# What did I miss? Review Team

REVIEW TEAM IS A KEY ELEMENT OF SUCCESS.

TWO KINDS: PEER AND FORMAL
IN PROPOSAL PERIOD CALLED: RED TEAM AND SELECTION PANEL

- Peer reviews are informal, designed as additional pairs of expert eyes
  - Table – top, science or technical discussions
  - Very detailed, benefit both sides
  - Low profile, chaired by sub-system lead
  - Open report, issues closed or argued, dispositioned by chair.

- Formal reviews are called by the selection or funding agency, the project, or the funding organization
  - Formal presentations but discussions are deep and technical
    - Reviewers compelled to discover things and be useful
    - Developers compelled to answer truthfully and show best effort
  - Increased stakes result in significant amount of preparation and requests for action (RFAs)
  - Reports, additional work, engineer-to-engineer discussions are very costly to development
  - A necessary evil, they increase project costs and result often in flight delays

- Streamlining the Review process benefits project and taxpayer

- Scientist's role: explain requirements, excite panels, make them stakeholders

# Optimize: Science per $$

OBJECTIVE OF SCIENTIST IS TO OPTIMIZE MISSION SCIENCE PER DOLLAR

- Winning against fierce competition already results in elevated promises, and
- Peer pressure on missions to include another or better instrument is tough, but
- The best science optimization is done by an efficient, integrated team of scientists and engineers who understand the importance of measurements

OBJECTIVE OF FUNDING AGENCY IS TO REDUCE RISK, INCREASE PUBLICITY

- The higher the project cost, the higher the profile and the stakes
  - Generates a lot of reviews, and busy work
  - Project gets scrutinized costs grow even higher – a vicious cycle
  - At launch minor old details assume renewed importance

- Project-generated review teams are often very risk-adverse
  - The lowest risk flight-project is one that never flies !

- Compelling science is often the decisive factor in moving forward
  - RHESSI: Need to make observations at Solar Max, must launch ASAP !

# The birth of a new mission: ARTEMIS

COMPELLING SCIENCE:

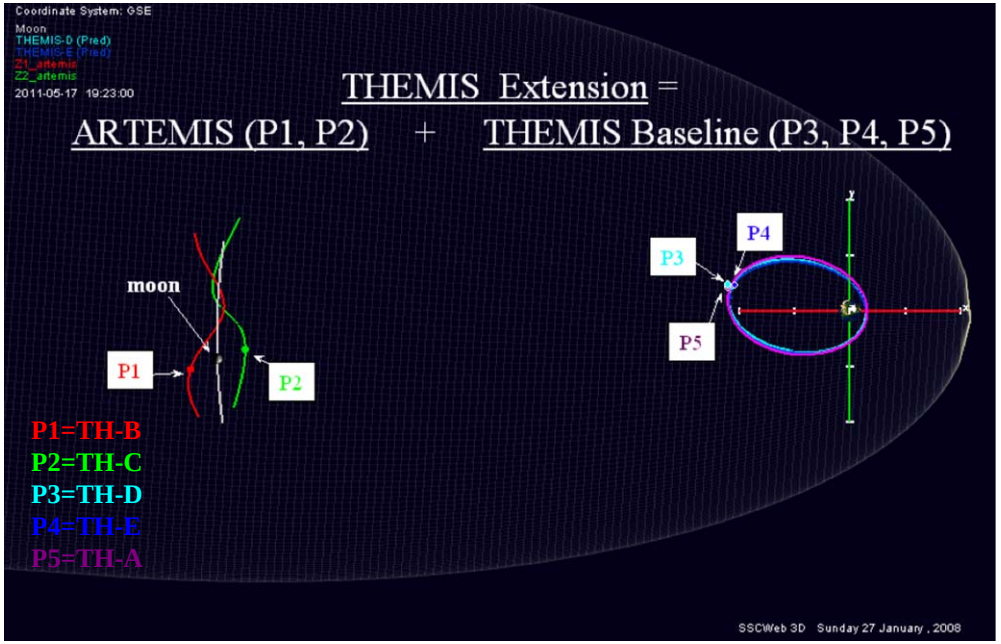
- *First* two-point measurements of the distant tail reconnection, solar wind shock acceleration, turbulence and the lunar wake.

COMPELLING PUBLIC RELATIONS REASON:

- If P1 is not redirected to the moon after the end of its prime mission its fuel will freeze and it will *die*.

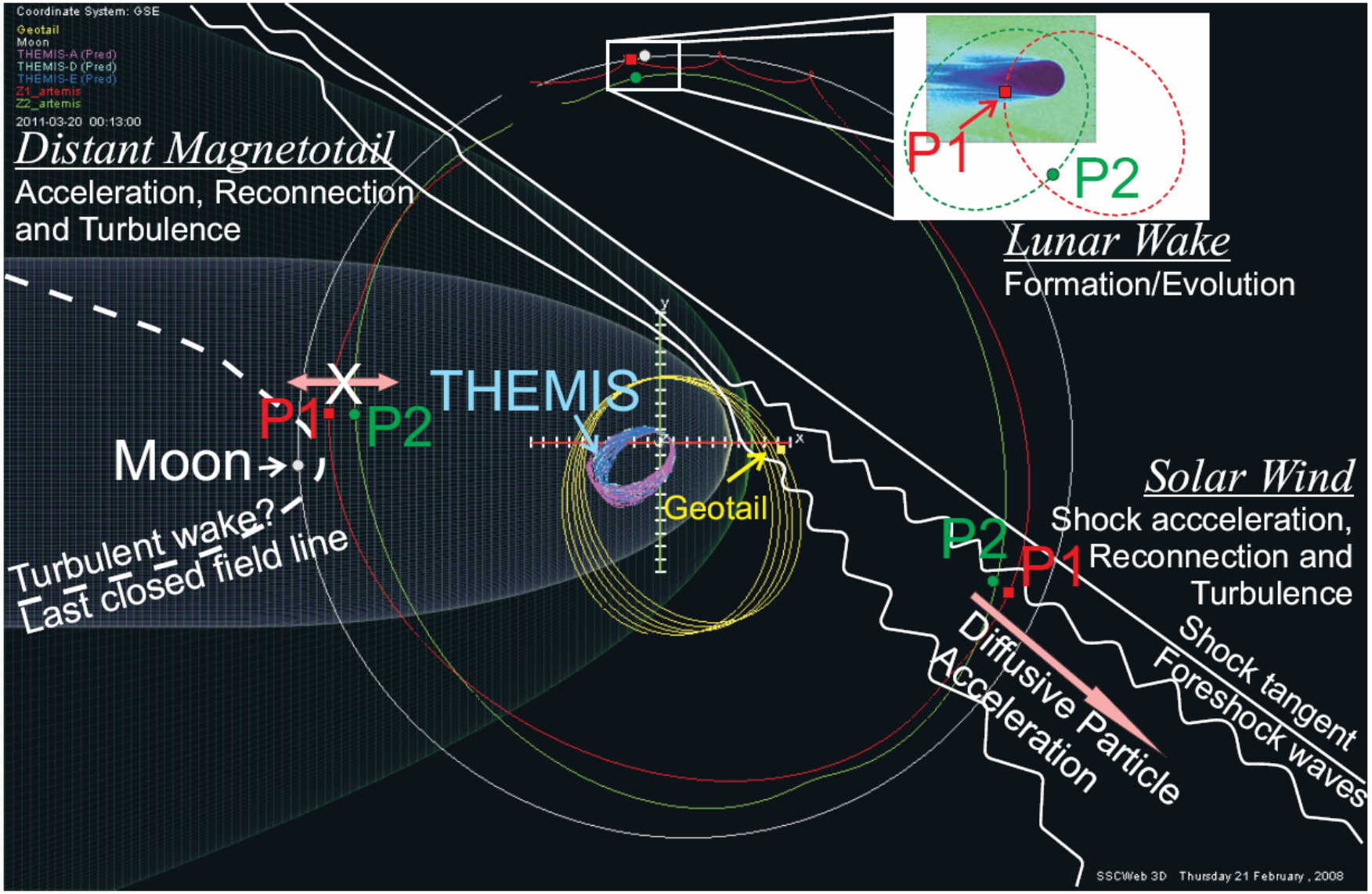
WHAT'S IN A NAME?

- Acceleration, Reconnection Turbulence and Electrodynamics of Moon's Interaction with the Sun (ARTEMIS) was also the goddess of the moon. Easy to remember and relate to.



# ARTEMIS: Science Packaging

WHEN? Ascend starts in October 2009. Arrive in October 2010.
HOW LONG? Mission duration = 2 years (2010 – 2012)



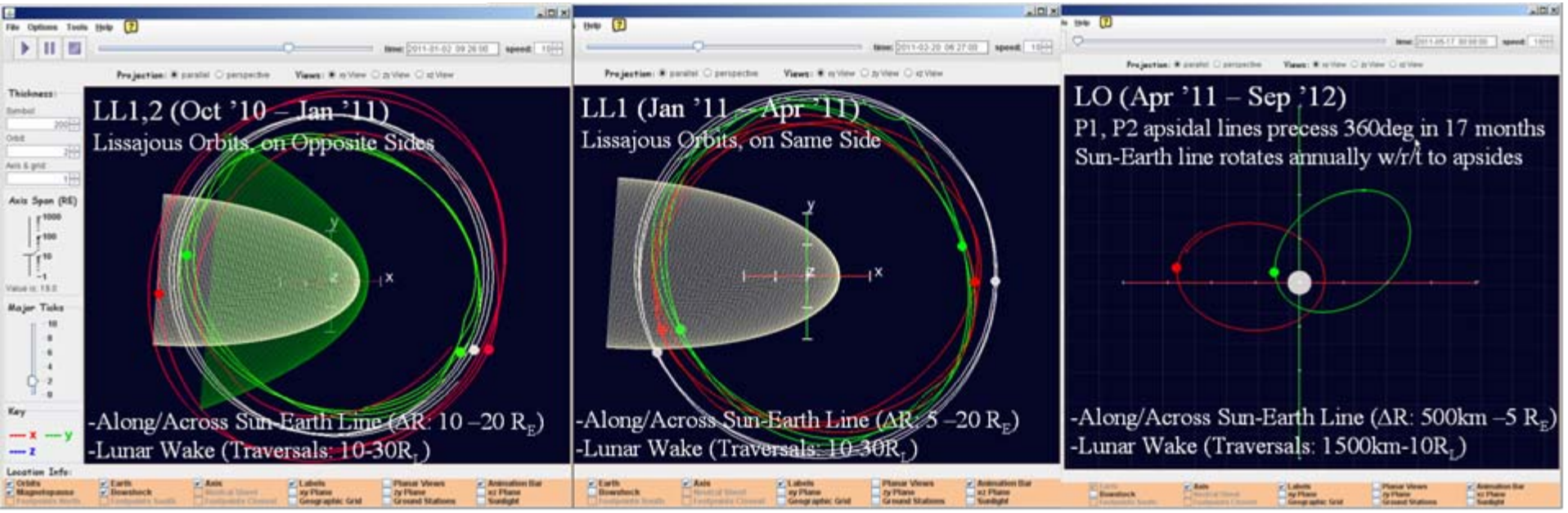
# ARTEMIS: Orbit Optimization

Lissajous Orbits (meta-stable orbits):

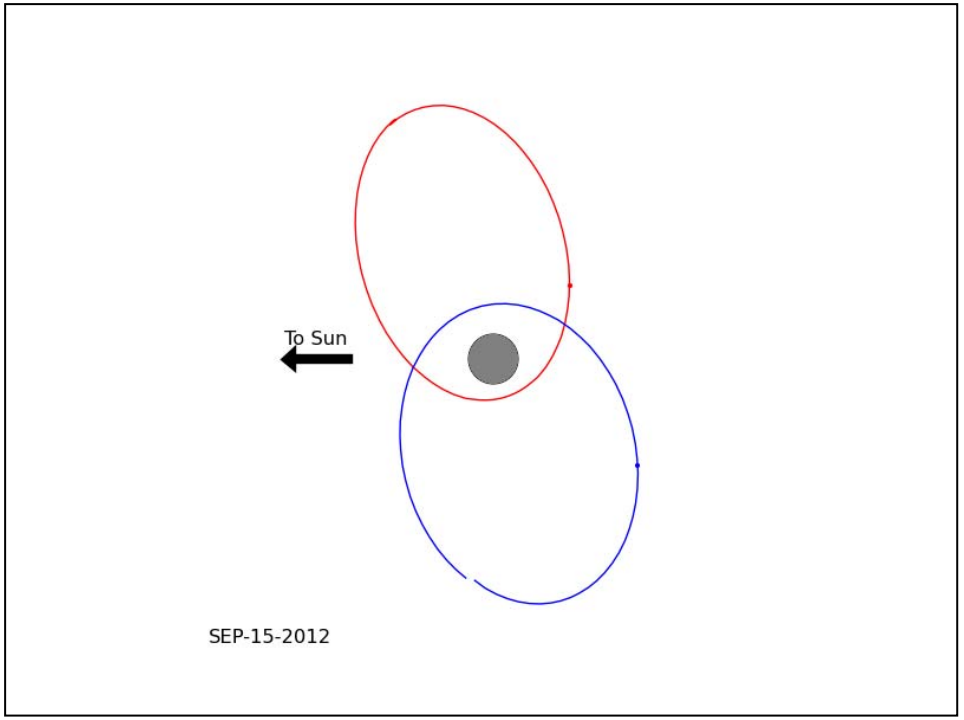
- Designed to provide long range (5-20$R_E$) radial and azimuthal separations.

Lunar Orbits:

- P1 : retrograde, P2: prograde. Designed to result in large range of separations over multiple angles to the Sun-Moon vector.



# ARTEMIS: Orbit Optimization (continued)



# ARTEMIS: Data Relay and Descopes

FOR ALL PURPOSES DATA RELAY IS SIMILAR TO THEMIS

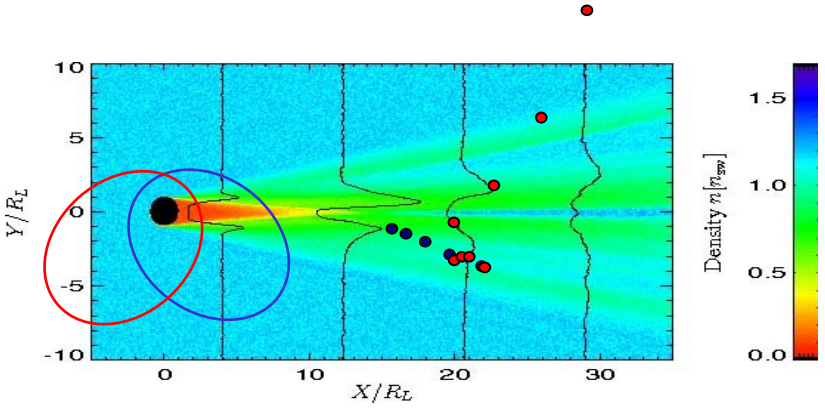
- DSN 24m dish provides:
  - 350Mbits/day at 16kbps over 3 hrs (achievable)
  - 6 hrs of Fast Survey and 5 Particle Bursts of 8min duration per orbit
- Day period orbits have max of 3.5hrs of shadows (similar to Earth orbits of THEMIS)
- Data accumulation strategy (burst, store-and-dump) works identical to THEMIS
- Thermal and power considerations are identical to THEMIS

DESCOPES

- Mission can also be accomplished with one probe
  - First comprehensively instrumented measurements at lunar wake
  - Correlations with inner satellites (THEMIS, Geotail)

CLOSURE

- Flights of ARTEMIS through hybrid simulations demonstrate importance of kinetic scale measurements



# Role of scientists in mission definition

SCIENTISTS PROVIDE THE KEY IDEA THAT IS THE MISSION DRIVER

- A compelling reason, distilled in a phrase that can capture the imagination of team

SCIENTISTS ARE KEY TO MISSION SUCCESS

- Provide the glue between team members (galvanizing team)
- Science presence in technical trades, decissions is key for efficient decision making and optimization of science per dollar

THERE ARE NO REAL FUNDING LIMITS IF A SCIENCE IDEA IS GOOD

- THEMIS started as a University Explorer ($12M) and was encouraged to aim higher

SCIENCE TARGETTED AT LOW COST MISSIONS CAN HAVE HIGH PAYOFF:

- Low profile => spend more time doing science rather than reviews
- Acceptable risk is higher => allows more innovative ideas to be developed and flown
- Hands-on, quick turnaround => Ideal for student training
- Frequent opportunities => Ideal for harboring teams preparing for bigger projects

EXAMPLE: NSF MICROSAT OPPORTUNITY: FEBRURARY 2009

- Time to start is: summer
- Ideas?