Handling late changes to Titan science

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Cassini/Jet Propulsion Laboratory
• The spacecraft, the mission
• How Titan science gets planned
• Four examples of late additions/changes
  – What can be done to make this kind of change as easy to implement as possible? What lessons did we learn?
Extended Missions

- Main rings only 10m thick, with complex km-scale vertical structures
- Gravity binds ring particles into ephemeral streamers
- Titan has methane weather, subsurface water ocean
- Rare, Earth-sized storm wrapped around Saturn
- Saturn oscillations revealed by ring spiral waves
- Enceladus has subsurface water ocean; orbital tidal stress controls plume volume

Northern Summer Mission

- Saturn’s rotation rate
- Total mass of main rings
- Ring structures in 3D at high resolution
- Saturn gravity field sufficient to constrain formation theories
- Direct sampling of ring particles and Saturn’s upper atmosphere

Prime Mission

- European partnership for first outer-planet moon landing
- Methane clouds, rain, rivers, lakes, and seas on Titan
- Unexpected diversity among dozens of moons
- Enceladus salt-water plume creates E Ring
Planning starts when a trajectory is chosen.
Titan flybys occur every 1-2 months
### All Titan flybys planned in advance (jumpstart)

Maximize Titan science return by balancing science objectives across the entire set of flybys

Major resource to be allocated: pointing control
The formerly blank slate:
Detailed integration work starts with rough timeline...

<table>
<thead>
<tr>
<th>Start Time</th>
<th>End Time</th>
<th>Prime Activity</th>
<th>Obs. Detail</th>
<th>Op Mode</th>
<th>TLM Mode</th>
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<td>DFPW Normal</td>
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...Finished product contains more-detailed pointing

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Stacking new science on top of old (Radio Science using Low Gain Antenna)

Only three Radio Science gravity passes of Titan during Cassini’s final seven years RSS wants more, but pointing for all Titan flybys was already allocated. Could any useful science be done using the low gain antenna? Could this actually be implemented?
“Can we do this?” issues

• Science Team determined criteria for successful Low Gain Antenna science
  – On-board test: Could LGA gather “adequately precise” Doppler tracking? **YES**

• S/C Engineering office assessed risk from switching between the HGA and LGA
  – DSN tracking

• Test concept on board spacecraft
Integration and Command/Sequence Generation

• “Favorable to the LGA” pointing is the major issue
  – RSS rider cannot compel prime instrument to change pointing
  – Integration: see if specifying NEG_Z to Earth for (less constrained) secondary axis compatible with prime observation
  – Implementation: RSS uses delivered c-kernel pointing file to evaluate if RSS LGA criteria are met

• Most LGA opportunities to date have not met all the required criteria at this point
Final Project Review Involves Nav and Engineering

• Project manager wants to see unique/worthwhile science return in exchange for risk and additional workload

<table>
<thead>
<tr>
<th>Flyby</th>
<th>C/A Date</th>
<th>Sequence</th>
<th>OK in Integration?</th>
<th>Pointing Design Compatible?</th>
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<td>S82</td>
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<td>Yes</td>
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<td>S85</td>
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<td>T123</td>
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</table>

• Bottom line: piggybacking additional science adds additional workload, time, and coordination. Allow plenty of time when adding new capability during flight ops.
Accommodating a damaged instrument: dual timelines

- Two “10 pointer” flybys claimed by each instrument during jumpstart planning for most unique/important science
- Cassini Plasma Spectrometer (CAPS) turned off six months before CAPS Dec 2011 10-pointer
  - Sequence in implementation phase
    - Final approval in four months (Nov 8, 2011)
- Limited options:
  - Gamble that CAPS would be operational by Titan flyby
  - Quickly swap in another instrument for CAPS

Gee, it would be great if we could postpone this decision...why not create and develop two possible timelines to buy some time?
New observations for alternative timeline

Alternative Naming Scheme

Observations only in original timeline

Delete (repeatedly!)

ENGR_158SC_KPTYBIAS347_PRIME
SP_158NA_OBSERVE347 NA
CDA_158OT_RATE010005_RIDER
CAPS_158SA_SURVEY002_PRIME
INMS_158SA_SURVEYSEG002_INMS
MAG_158OT_SURVEY005_PRIME
MIMI_158CO_SURVEY003_MAPS
SP_158NA_TOSTSEG347 NA
SP_158TI_DEADTIME347_PRIME
CAPS_158TI_T99PTG001_PRIME
CIRS_158TI_T99PTG001_CAPS
CAPS_158TI_T99INBND001_PRIME
RPWS_158SA_OUTSURVEY002_PRIME
INMS_158TI_T99INBND001_INMS
RPWS_158TI_TITINRMED001_PRIME
MAG_158TI_MAGTITAN001_PRIME
MIMI_158TI_TITINOV001_RIDER
CAPS_158TI_T99CLOSE001_PRIME
INMS_158TI_TITAN79001_INMS
MIMI_158TI_TITCAOV001_RIDER
RPWS_158TI_TICA001_PRIME
MP_158TI_FLYBYT079 NA

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INMS_158SA_SURVEYSEG002_INMS
MAG_158OT_SURVEY005_PRIME
MIMI_158CO_SURVEY003_MAPS
SP_158NA_TOSTSEG347 NA
SP_158TI_DEADTIME347_PRIME
CIRS_158TI_FIRNADCMP01_PRIME
ISS_158TI_FIRNADCMP01_CIRS
UVIS_158TI_FIRNADCMP01_CIRS
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ISS_158TI_FIRLMBINT501_CIRS
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CIRS_158TI_GLOBMAP001_VIMS
ISS_158TI_CLOSAPP000_VIMS
MP_158TI_FLYBYT079 NA
More issues: epochs, inputs

• Different epoch types offered tradeoffs in flexibility and workload
  – Ground moveable block (no changes possible after sequence is radiated); or
  – Live moveable block
    • Changes possible until shortly before execution but
    • Two LMB epochs, real time commanding and many more ports for sequence file delivery add complexity
  – Given existing workload, choose simplicity
Dual Timeline Bottom line

• Dual (or more!) timeline development is complicated and work-intensive

• Building a software scheduling database that can accommodate dual (or more!) timelines will be expensive

• If you anticipate losing capability, strongly consider paying upfront to develop a more robust operations integration scheduling tool
Consumables: a growing concern for an extended mission

• Is science using too much hydrazine?
  – Early (jumpstart) estimate based on historical trends
  – Detailed (implementation) estimate based on actual pointing commands
    • Using too much? Only option is to yank the observation
    • Too late to make smart science choices, no time to redesign
Solution: Move analysis earlier in the process

- Instrument teams asked to develop and deliver detailed pointing designs during early integration phase
- AACS team agrees to run early analysis of hydrazine use
- Science planning annotates graph of hydrazine use, showing cost of each pointing command
• Proposed plan too expensive? Modify design or give time to another instrument
At the cost of some up-front work:

– Instruments get best shot at keeping their observations from being cut;
– Titan science doesn’t lose observing opportunities;
– Decisions based on science trades
– Project knows consumables are managed effectively
Whose science is higher priority?

• RADAR “10-pointer” observation would heat Visual and Infrared Mapping Spectrometer, impacting its observations
  – Not enough time for VIMS to cool down
  – VIMS heating model underpredicting heating by 2-3 degrees K (expected heating of 6 degrees K)
  – VIMS wanted to protect its science, asked RADAR to redesign to avoid heating
RADAR vs VIMS

• RADAR developed alternative observing strategies
  – Presentation described science enabled by each strategy and resulting heating
  – ALL teams welcome to comment

• Final decision at “core” meeting
  – One representative per instrument
  – Chosen design significantly heats VIMS but enables some VIMS science
  – VIMS found similar observation opportunity later in the mission with no heating issues
RADAR vs VIMS Bottom line

• Instrument teams worked together to find best science balance
If you want to make late changes:

• “Piggybacking” science opportunities on existing science for an in-flight mission is possible, but complex. If the science opportunities are of high enough priority, the work investment may be worthwhile, but doesn’t guarantee success and will take longer than expected.

• Database/software capability to handle multiple timelines will be expensive but adds flexibility in last-minute decision making. Missions that anticipate a greater likelihood of loss of capability leading to a need to replan science should consider this option.

• Tracking consumable use at higher fidelity early on is a wise investment of time.

• An experienced and tightly knit team, intimately familiar with each others’ instruments, can make the best possible decisions when science trades must be made.