Deep Impact Continued Investigations (DI3)

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Deep Impact Spacecraft

- Medium Resolution Imager (MRI)
  - 8 broad and narrowband filters
    - OH, CN, C\textsubscript{2} and continuum
  - 10 \(\mu\)rad/pix

- High Resolution Imager (HRIVIS)
  - 8 filters (colors)
  - 2 \(\mu\)rad/pix

- Near-IR Spectrometer (HRIIR)
  - \(\lambda\) \~ 1.05 - 4.8 \(\mu\)m
  - \(R = \delta\lambda/\lambda\) \~ 250 to 700
  - Capture H\textsubscript{2}O, CO\textsubscript{2} and CO

- Impactor Targeting System (ITS)
  - \~MRI (destroyed at Tempel 1)
Deep Impact Primary mission
Comet Tempel 1 – July 4, 2005
Deep Impact eXtended Investigation
Comet Hartley 2 – Nov 4, 2010

- CO₂
- H₂O Vapor
- Ice

Gases in Coma of Hartley 2

- Carbon Dioxide
- Water Vapor
- Hydrocarbons
Post-Hartley 2 Activities

• Spacecraft and all (non-vaporized) instruments are healthy

• Retargeted for third flyby in 2020
  – Near-Earth asteroid 2002 GT
  – Potentially hazardous object
  – Not enough fuel to reach another comet

• Cruise science
  – Use as a remote observatory for bright comets
  – Plenty of interesting candidates in the next few years

• Low-cost science
  – Developed sequences that are reused for every comet
  – Minimal staffing
  – Low priority for DSN time (limits amount of data obtained)
Spacecraft is a Unique Asset

• Proven high-quality instruments
  – Optimized for cometary science
  – New IR calibrations completed in 2012
• Only facility that can directly observe CO$_2$
  – Also measure H$_2$O and CO at the same time
  – Direct comparison of three major comet species
• Atmosphere is not a factor (weather, telluric lines, etc)
• During windows, can continuously observe
  – High cadence observations, long-term monitoring
    • 15 min sampling for ~1 week with MRI imaging
    • 15 min sampling for ~2 days with IR scans
• Different viewing geometry from Earth- or space-based
  – Complementary data
  – Fill in gaps when Earth can’t observe (e.g., ISON)
Comet C/2009 P1 Garradd

- Served as proof of concept for remote observations
- Bright Oort cloud comet
- Observed Feb 20 – Apr 10, 2012
  \[ r = 1.74 \text{ to } 2.11 \text{ AU}, \quad \Delta = 1.88 \text{ to } 1.30 \text{ AU} \]
- Highlights:
  - Measured Afp and OH, CN production rates (in progress)
  - Measured rotational properties undetected from Earth
  - First simultaneous detection of \( \text{H}_2\text{O}, \text{CO}_2 \) and CO
  - In conjunction with ground-based data, showed uncorrelated behavior between \( \text{H}_2\text{O} \) and CO
    - Abundance ratios depend on when it is observed!
Garradd Results - Rotation

- Lightcurve variability
  - 10.39 hr period (single peak)
  - 1% in cont., 4% in CN
  - Sensitive because of monitoring
  - Peaks for different species are offset
    - Different sources
      - Two small outbursts
- Spiral arcs constrain pole direction (points away from Di)
  - RA ~ 227°  Dec ~ +27°
  - Obliquity ~60°
  - Gas velocity ~700 m/sec
Garradd Results – IR Spectra

• Observed Mar 26-27 and Apr 2-3, 2012
• Detected H$_2$O, CO$_2$ and CO for the first time
  
  $Q_{H2O} = 4.9 \times 10^{28}$ mol/sec  
  $Q_{CO2} = 4.1 \times 10^{27}$ mol/sec  
  $Q_{CO} = 2.9 \times 10^{28}$ mol/sec  

  – Highest CO/H$_2$O ever observed inside the snow line (60%)
Garradd Results – IR Spectra

- CO/H₂O from DI differed from ground-based measurements
- Follow-up with ground-based data showed H₂O and CO differ temporally
  - H₂O peaks 2-3 months before perihelion
  - CO increases monotonically
    - Never seen before
    - CO₂ measured by DI, but trend is unknown
- Interpretation: A heterogeneous nucleus experiencing a seasonal effect OR rapid pre-perihelion water loss globally exposed less altered material containing CO
- Need frequent monitoring of relative abundances to truly understand behavior

Feaga et al. 2013, submitted to Astron. J.
Comet C/2011 L4 PanSTARRS

• Bright, well observed long-period comet
• Were scheduled to observe October – December 2012
  – Inbound, shortly after crossing ice line
  – Cancelled due to request from NASA HQ to shut down the spacecraft
  – Survived, but with very minimal support
• Scheduled to get observations in September 2013
  – Outbound, near the ice line
Comet C/2012 S1 ISON

- Unique sungrazing comet discovered at large distance
- Priority for NASA
- Observed Jan 17 – Mar 10, 2013
  \[ r = 5.2 \text{ to } 4.5 \text{ AU} \]
  \[ \Delta = 5.7 \text{ to } 3.9 \text{ AU} \]
- Faint, but shows activity
  - No gas detected in narrowband filters or in IR spectra
- Current observations
  - Observing now with MRI (July 6 – 11, 2013)
  - IR spectra scheduled for July 19-20 and ~Aug 11-16, 2013
- Filling in gap where ISON is not observable from Earth
Future Comet Observations

Planned/desired observations, pending funding and DSN time

• Comet 2P/Encke
  – Stable, short period orbit
    • Should be thermally evolved
    • Good comparison to the Oort cloud comets
  – Would be valuable to obtain measurements of dominant species
  – Window available Dec 2013 – Feb 2014

• C/2013 A1 Siding Spring
  – Makes a close approach to Mars in Oct 2014
  – NASA may be interested in the dust hazard
Future Comet Observations

- C/2012 K1 PanSTARRS
  - Bright long period comet
  - Makes a close approach (0.12 AU) to DI in Aug 2014
  - Multiple observing windows straddle the snow line

- 67P/Churyumov-Gerasimenko
  - Support for the Rosetta mission

- 19P/Borrelly
  - Deep Space 1 target
  - Extended window Jan – Sept 2015
Final Considerations

• We’ve shown that DI observations combined with ground-based observations are very powerful
  – We are putting together a web page outlining our observation windows and goals
  – We invite ground-based observers to provide input regarding their observations, for setting up collaborations and comparative studies
  – Dennis Bodewits is coordinating this

• Although HQ is looking more favorably on DI (thanks Lindley Johnson), it still has low priority
  – We request that SBAG recognize DI as a unique low-cost asset that contributes to the NASA mission, to minimize the risk of the spacecraft being shut down while it is still providing high-quality science.