Oddball Snowballs: Gemini Observations of Main-Belt Comets

Henry H. Hsieh
Planetary Science Institute & Academia Sinica IAA (ASIAA)

"Planets, Exoplanets, and Planet Formation with Gemini LLP programs" Splinter Session

Photo credit: gohawaii.com
Main-Belt Comets

- Comets conventionally assumed to come from outer solar system due to icy content
- MBCs recently discovered to exhibit cometary activity but have orbits placing them in the main asteroid belt
- Numerical simulations indicate orbits are largely dynamically stable, suggesting in situ formation
Main-Belt Comets

- If activity is due to sublimation, would imply that ice is still present today in main belt

- If MBCs are “native” to the main belt, may be able to use them as tracers of ice in inner solar system

- Could constrain properties of the protosolar disk (snow line) and give insights into primordial terrestrial water delivery
MBCs vs. Disrupted Asteroids


(596) Scheila

331P/Gibbs

311P/PANSTARRS
MBCs vs. Disrupted Asteroids

**MBCs**
- exhibit sublimation-driven activity
- contain volatile material (ice)
- activity perhaps triggered by collisional excavation of subsurface ice, but then sustained by sublimation
- **should show periodic activity**

**Disrupted asteroids**
- exhibit comet-like dust emission that is not due to sublimation
- activity does not indicate presence of volatile material
- disruptive processes include impacts, rotational disruption, etc.
- activity not expected to be periodic
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**Active Asteroids**
Gemini and MBCs: Historical Highlights

- Asteroid 118401 (1999 RE70) (now 176P/LINEAR) discovered to be active during classical observations by Gemini North on 2005 November 26

- Was third MBC to be discovered and still only MBC to be discovered via a targeted search (37 observed that night + standard stars!)

- Discovery from limited data set implied that many more similar objects should exist; led to MBCs being recognized as a new class of comets (Hsieh & Jewitt, 2006)
Gemini and MBCs: Historical Highlights

- Gemini North and South used to obtain spectra of sixth MBC (first discovered by Pan-STARRS 1), 288P/2006 VW139, in 2011.
- Aim was to search for direct evidence of outgassing (CN), but was unsuccessful.
- To date, no successful detections of gas from MBCs from any ground- or space-based telescope; gas production likely too weak to be detected.

Hsieh et al. (2012)
Gemini and MBCs: A Brief History

- Gemini North observing campaigns used to measure phase functions of MBC nuclei (required observations of $m_r = 23-26$ mag targets over multiple months)
- Needed for computation of nucleus sizes, high-sensitivity activity searches, computation of ejected dust masses, and estimation of dust production rates

MacLennan & Hsieh (2012)

Hsieh (2014)
Gemini LLP Goals


- Monitor MBC targets that pass through perihelion for reactivation to confirm that activity is sublimation-driven

- Characterize properties of each MBC's active episode and study activity evolution by comparing to previously observed active episodes

- Characterize the physical properties of MBC nuclei

- Targets: 133P/Elst-Pizarro, 176P/LINEAR, 238P/Read, 259P/Garradd, 288P/(300163) 2006 VW₁₃₉, 313P/Gibbs, 324P/La Sagra, and 358P/PANSTARRS
Gemini LLP Observing Strategies

- Use Gemini's unique ability to get periodic deep snapshot observations of faint targets/features over extended periods of time from either hemisphere.

- For activity monitoring, observe ~monthly when approaching perihelion to constrain activation point, and continue observing monthly through expected activity period.

- For nucleus characterization, observe multiple times per month over several months during target's brightest expected period to get sparse sampling of lightcurve and adequate sampling of phase angles.
Gemini LLP Observing Strategies
Key LLP Outcomes

• Observed reactivations of five MBCs (CBETs 4307, 4388, 4661)
  - confirmed recurrent activity for two MBCs (259P and 358P) for first time, bringing total to seven with confirmed recurrent activity
  - obtained data for six MBCs that can be directly compared with previous epochs over the same orbital arcs

• Obtained data for constructing nucleus phase functions and estimating nucleus sizes for two MBCs without previous measurements; one analysis complete and one in progress

• Performed preliminary direct photometric comparisons of activity strengths for two MBCs; others in progress; dust modeling analyses in progress
Activity Mapping - Pre-LLP

133P

176P

238P

259P
Activity Mapping - LLP Observations
Activity Mapping - Pre-LLP
Activity Mapping - LLP Observations

288P

313P

324P

358P
Nucleus and Reactivation of 358P

- 358P nucleus found to have effective radius of $r_N = 0.32 \pm 0.03$ km
- Start of activity constrained to shortly before first activity detection on 2017 November 8 ± 4 when object was at a true anomaly of $\nu = 316^\circ \pm 1^\circ$ and $R = 2.54$ au; first confirmed reactivation
- Initial dust production rate found to be $dM/dt \sim 2.0 \pm 0.6$ kg s$^{-1}$

Hsieh et al. (2018a)
Reactivation of 238P

- Initial dust production rate for 238P found to decrease from $1.4 \pm 0.6$ kg s$^{-1}$ in 2010-2011 to $0.7 \pm 0.3$ kg s$^{-1}$ in 2016

- Start of activity found to be at $\nu = 302^\circ \pm 12^\circ$ in 2010-2011 and $\nu = 297^\circ \pm 21^\circ$ in 2016, suggesting minimal change in depth of ice from one apparition to the next

Hsieh et al. (2018b)
Reactivation of 288P

- Initial dust production rate for 288P found to actually increase from $3.5 \pm 0.4$ kg s$^{-1}$ in 2000 to $5.6 \pm 0.7$ kg s$^{-1}$ in 2016; dust modeling in progress to confirm increase.

- Start of activity found to be at $\nu = 332^\circ \pm 4^\circ$ in 2000 and $\nu = 333^\circ \pm 4^\circ$ in 2016, also suggesting minimal change in depth of ice from one apparition to the next.

Hsieh et al. (2018b)
Ongoing Work

• Complete photometric and dust modeling comparisons of activity strength for six MBCs for which appropriate data were obtained

• Complete characterization of 313P nucleus and activity

• Continue activity and nucleus characterization work under newly awarded LLP programs GN-XXXXX-LP-104 and GS-XXXXX-LP-104 (starting in 2019B), including newly discovered MBCs and newly recognized "near-Earth" MBCs (NEMBCs)
Thanks to...

• Gemini Observatory for supporting LLP programs and the organizers of this AAS splinter session

• Many staff at Gemini North and South over the years for observing support (especially Tony Matulonis who was the operator for my classical observing run in 2005)

• The NASA Solar System Observations program for funding support for this research (grants NNX16AD68G and 80NSSC19K0869)

• The indigenous Hawaiian community for the opportunity to conduct observations on Maunakea