Astro2020 Science White Paper

Solar System's minor bodies: the role of the ngVLA

Thematic Areas: ☑Planetary Systems ☐ Star and Planet Formation
☐ Formation and Evolution of Compact Objects ☐ Cosmology and Fundamental Physics
☐ Stars and Stellar Evolution ☐ Resolved Stellar Populations and their Environments
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Abstract: Thermal observations of minor bodies in the Solar System are strongly indicative of fundamental properties linked to surfaces' nature and composition. In particular centimeter-wave continuum measurements, either spatially resolved or disk-averaged, provide an important access to depths several meters below the surface, reaching across the diurnal skin depth, a crucial region for thermal modeling. The sensitivity provided by the collective surface of the ngVLA is necessary to achieve thermal detections on a sufficiently large number of small bodies (asteroids, Centaurs, Kuiper-Belt objects) to constrain the dynamical and physical evolution of different populations.

1 Rationale for the observation of Solar System minor bodies

Observations of small Solar System bodies are an essential component of planetary studies at large. On one hand, characterization of individual bodies (including composition of surfaces, interiors and -in some cases - atmospheres) provides insight into processes affecting surfaces, as demonstrated by the extensive observations of dwarf planets Ceres and Pluto by the *Dawn* and *New Horizons* spacecrafts, respectively.
On the other hand, global population studies on the distribution of orbital, compositional and physical properties can bring clues pertaining to the thermal, dynamical and collisional history of the early Solar System (see e.g., DeMeo & Carry (2014)), for example constraining planetary migration and the origin of some of the giant planets' moons. Such investigations are especially relevant for objects orbiting in the outer Solar System, such as Kuiper Belt Objects (KBOs), which are considered to be some of the most pristine remnants of the protoplanetary disk, and akin to planetesimals in debris disks observed in other planetary systems.

2 Thermal emission from small bodies

The thermal emission spectrum from a body's (sub)surface is determined by a large number of variables. Those include orbital and rotational parameters as well as radiative and thermal properties characteristic of the texture, composition and topography of the surface material. Several thermal models have been developed to interpret thermal emission from small bodies, and allow to classify bodies' thermal behavior based on the value of a single parameter, the beaming factor η, representing the effective thermal inertia (e.g., Lagerros (1996)). In general, a low thermal inertia is indicative of a powdery nature while high thermal inertia can be linked to rock-like surfaces. Large-scale studies have shown that asteroids tend to display a much smaller effective thermal inertia than Trans-Neptunian objects (TNOs) (Delbo et al., 2015), which suggests that regolith depth (and overall surface processing) decreases with distance to the Sun. However relatively few measurements are available for TNOs, for which observations are challenging due to large distances and low temperatures. More TNO sources must be observed to lower observational biases and firmly establish correlations between physical and orbital properties, as well as differences across populations.

Thermal emission mapping, especially combined with monitoring on relevant timescales (diurnal/seasonal), provides the most informative thermal data as it allows one to disentangle the effects of local hour and latitude from geographically-tied features. Since only a few dozens of Solar System minor bodies are larger than 0.1" in apparent size, this technique has rarely been performed.

In the absence of maps, disk-averaged thermal observations combined with optical photometry allow one to retrieve the bolometric Bond albedo and effective diameter through the radiometric method (Lebofsky, 1989). While the results from this method depend on the assumed thermal model, it is the most effective technique to estimate sizes of a large number of otherwise spatially unresolved bodies, which can in turn be used to constrain the collisional history for different populations of small bodies (Schlichting & Sari, 2011). In addition, combination of thermal photometry at different wavelengths is essential to adjust thermal models for a given body, further improving the robustness of the interpretation models (Brown & Butler, 2018).

3 The unique contributions of cm-wave observations and the Next Generation Very Large Array

The specificity of cm-wavelengths lies in the ability to access deep depths below the surface and beyond the diurnal skin depth. The combination of cm-wavelengths measurements across a large spectral range with other thermal measurements is essential to capture the complete thermal structure in the upper meter of surface material, and determine variations of properties with depth which can be related to ongoing processing, differentiation or formation history.

The sensitivity of the New Generation Very Large Array (Murphy, 2018) is necessary to obtain cm-wave measurements with a SNR better to what can be obtained with the VLA or ALMA, giving access to objects with smaller apparent sizes. This would allow one to derive fundamental surface properties (thermal inertia, conductivity and albedo, as well as equivalent size) on crucial size ranges which cannot yet be included in thermal studies, removing possible size-related biases in our understanding of populations at large. The ngVLA's proposed wide spectral range would seamlessly complement the mm-wavelength coverage already offered by ALMA and extend down to 1.2 GHz, probing depths of several meters, well beyond typical skin depths.
An excellent spatial resolution would surpass the ability of ALMA to detect thermal spatial features (including at depths not probed by ALMA), on smaller targets, and to separate the thermal emission from contact binary systems, which are relatively frequent amongst TNOs.

In addition to measuring continuum thermal emission, ngVLA's spectral coverage is also adequate to target the OH 18-cm maser emission, which has been regularly observed in comets (Crovisier et al., 2002). OH is of particular interest as it has a relatively long lifetime and is the photodissociation product of water, and hence can be used to derive a comet's water outgassing rate. It should be noted that this OH line corresponds to a solar-pumped maser transition, for which excitation strongly depends on its heliocentric velocity. Water atmospheres are not expected in the outer Solar System, but water outgassing has been suggested for Ceres, and for some objects of the Centaur class. OH detection would provide a strong proof of the reality of transient outgassing events, which would carry significant implications for the composition and surface processes on those bodies.

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