WHY SMALL IS BEAUTIFUL – AND HOW TO DETECT ANOTHER 10 BILLION SMALL MAIN BELT ASTEROIDS. Henning Haack[1], Philip R. Bidstrup[2], Rene Michelsen[3], Anja C. Andersen[2], and John Leif Jørgensen[4]
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Introduction: Estimates of the size distribution of main belt asteroids suggest that there is a population of approximately 10 billion objects in the meter to km range [1]. These objects have, so far, escaped detection. Current Earth-based telescopes have, except for a few objects, not been able to detect the faint and distant sub-kilometer asteroids in the main belt. Long intergration times cannot be used unless the object can be tracked – which is not possible for an unknown object. Small asteroids can be observed closeup from a spacecraft but, so far, missions to the asteroid belt have not had the ability to automatically detect previously unknown asteroids. Since small asteroids can only be observed from the spacecraft for a very limited time it is not possible to operate the spacecraft from the distant Earth – a fully autonomous mission is required. We have explored the possibilities to build such a fully autonomus spacecraft using existing technology and have named the mission proposal Bering.

Small asteroids are of great interest for a number of reasons: 1) Small low-gravity asteroids probably have less regolith cover thus providing a clearer picture of their interior structure and type 2) Due to the Yarkovsky effect small asteroids have shorter lifetimes [2] and therefore probably younger, less space weathered surfaces. 3) Small asteroids bridge the gap between the known big asteroids and the NEAs, meteoroids and meteorites. 4) Mapping the orbital parameters of small object may allow us to associate streams of small fragments with their parent asteroids thus further constraining the link between meteorites and asteroids and provide constraints on the transfer mechanics of material from the main belt to the inner Solar System 5) Due to their shorter lifetime smallest asteroids may be used to constrain the most recent collisional evolution of the asteroid belt. 6) Measuring the actual size distribution of asteroids in the main belt can be used to constrain models of the collisional evolution of main belt asteroids.

The Bering spacecraft: The main objectives for the Bering mission will be to detect small asteroids, determine their orbital parameters and spectral type. The aim is obviously not to detect all 10^{10} small asteroids but to aquire a statistically significant sample of the population. To accomplish this the Bering spacecraft has three main science instruments: 1) An array of ASCs (Advanced Stellar Compasses) [3] which are able to detect objects down to $M_v \approx 13$. 2) A science telescope, which can follow detected asteroids down to $M_v \approx 24$. 3) A multispectral imager within the science telescope which will be used to determine the spectral type of the detected asteroids.

The ASC was originally designed as a navigational instrument. Using a build-in star catalogue and planetary data base it is able to determine the attitude and position of a spacecraft without prior information. This ability has been utilized in a number of missions over the past six years (Ørsted, Champ, Proba, Grace, Smart-1 a.o.) In the Bering spacecraft we plan to further add the ability to compare the detected objects with the star catalogue in order identify previously unknown objects. This require that the star catalogue is complete down to objects as faint as the detection limit of the ASC and that the processing unit in the ASC can identify potential asteroids among a large number of known objects within a reasonable time. It is therefore not the aperture of the ASC that limits its ability to detect faint objects but rather the availability of an accurate star catalogue and the processing power of the ASC. The spacecraft will maintain a catalogue of priority objects from which the science telescope will choose objects to be observed. Each object will be observed repeatedly in order to determine its orbital parameters. Since the science telescope will be able to follow the detected asteroids down to $M_v \approx 24$ or to a distance of approximately 60.000 times the detection range – depending on viewing geometry – the asteroids can be followed for extensive periods of time. For some objects it will be possible to track them through a significant fraction of their orbital period as they orbit the Sun along with the spacecraft. Also, using the multi-spectral imager, each object will have its spectral type determined. Time permitting the science telescope will measure light curves and color variations with rotation and phase angle of selected asteroids.

A big advantage of the autonomus operation of the spacecraft is the limited need for Earth-based control. The spacecraft will downlink data from the detected asteroids. Unless encounters with preselected asteroids are included it is also unlikely that the spacecraft will acquire closeup images of any asteroids. The data will thus be restricted to orbital and spectral data.

Detection rates: Design of mission parameters is a non-trivial task since the spacecraft is going to study objects that are unknown from a population of objects that are also unknown,. First of all, we need to know if is possible, using available technology, to design a mission that will detect a significant number of asteroids. For this purpose we have simulated the mission using the best available models for the size distribution of main belt objects [1].

In order to simulate the Bering mission we need to know the density and velocity distribution of the small – unknown – main belt objects. We assume that the velocity distribution of small objects is identical to the velocity distribution of the large asteroids in the same location and that the size distribution used is valid throughout the main belt. By calculating the density of known objects as a function of heliocentric distance and height above the ecliptic we can then add small objects according to the chosen size distribution. Using different orbits for Bering we can calculate the number of new objects appearing within the detection range of the spacecraft per day.

Some objects may pass so close to the spacecraft that the angular velocity of the object exceeds the threshold of the ASC. In order to detect objects down to $M_v \approx 13$ the ASC telescope need to integrate for several seconds. If the asteroid move several pixels across the CCD in this time period it is possible that the asteroid escapes detection since the signal in each group of pixels is below the detection limit. This is particularly important for sub-meter objects that need to be very close to the spacecraft before their visual magnitude exceed the detection limit. Since the velocity difference is typically several km/s such close passages result in very high angular velocities. Objects moving too fast were therefore rejected as prospective detections before the effective detection rate was calculated (Table 1).

Where should Bering go? We have considered several different mission profiles which attempt to maximize the science output under different economic constraints. In the simplest, and cheapest, version all we need is an initial Δv sufficient to send the spacecraft into the main belt. In this configuration we don't need an onboard engine – all we need to do is to monitor the tracjectory along the way. A more ambitious mission would include several identical spacecraft that could either explore different parts of the main belt as well as the inner Solar System or possibly fly in formation. The latter would make it possible to determine very accurate orbital parameters for those objects visible by two spacecraft. A mission to the inner Solar System would be a great interest, too. Such a mission could detect asteroids too close to the Sun to be detected using Earth-based telescopes. Our preliminary tests suggest that the detection rate in the inner Solar System is comparable to that of the main belt as the much better lighting conditions compensates for the much lower expected densities of objects in the inner Solar System.

Mission simulation results: Table 1 shows the detection rate as a function of absolute magnitude and diameter of the detected asteroids for a simulated mission where Bering is in a circular orbit at 2.5 AU. Most of the detected objects are in the one to ten m diameter range. Sub-meter objects dominate the class of objects that exceed the ASC detection limit but these objects are often too close and thus escape detection because of their high angular velocities.

Table 1. Calculated detection rates for different choices of detection limit. The current technical limit is $M_v \approx 13$.

M_v	Detections/day
14	10.7
13	5.7
12	3.1
11	1.7
10	0.9

Conclusions: We infer that, based on the best available knowledge about the density of sub-km asteroids in the main belt it is possible to detect a significant number of small asteroids from within the main belt using one or more fully automated spacecraft. With a mission lifetime of a few years within the main belt a detection rate of 5/day would give us a few thousand objects total for the mission. This would allow us to constrain the size distribution of main belt objects from 1 m to 1 km in diameter. We would probably also detect a significant number of object for each of the main spectral types and thus be able to study the effects of space weathering and the link between asteroids and meteorites.

References: [1] Bottke W.F. et al. (2005) submitted to Icarus. [2] Bottke W.F. et al. (2002) In Asteroids III, Univ. Arizona Press, 395-408. [3] Betto et al. (2004) In: Astrodynamics, Space Missions, and Chaos, Ann. New York Acad. Sci, 107, 393-407.