DETECTING ASTEROID SATELLITES WITH LINC-NIRVANA AT THE LARGE BINOCULAR TELESCOPE.
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Introduction: Since Petit Prince was discovered orbiting asteroid (45) Eugenia in 1998 [1], earth-bound observatories have revealed over 200 asteroid companions. Beyond establishing a broad statistical sample to determine, for example, the binary fraction in different populations of objects, each individual discovery affords an opportunity to determine the mass of the primary. Mass leads to density [2] and density leads to composition and thus moves forward our understanding of our own solar system's formation, an understanding which is even more important as exoplanet researchers investigate formation processes for the many other planetary systems now being detected.

Discovery Rate: In Table 1, we give an inventory of asteroid companion discoveries to date. We restrict our discussion here to the first two categories given in that table: ground-based and space-based imagers. These two categories both fall into the broader category of earth-bound imagers. Although the development and operational aspects of ground-based versus space-based telescopes differ greatly, the instrumentation and techniques for high-angular-resolution optical/NIR imaging, in the study of asteroid satellites, is similar for both. This broader category, *earth-bound optical/NIR imaging*, is most relevant to our discussion of the potential impact of a new instrument in the discovery and study of asteroid companions.

Method	**Companions**	**Systems**[1]
Ground-based Imaging (NIR/AO)	39	34
Space-based Imaging (visible/CCD)	72	67
Radar	30	28
Photometric Lightcurve	89	88
Total	230	217

Table 1. Asteroid companions grouped by the method used for their discovery. The first two rows can also be considered as a single method, earth-bound imaging, which accounts for 111 of the companions discovered to date.

[1] May be triple or more.

Figure 1 provides the discovery rate for earth-bound optical/NIR imagers as a function of time. For a contrast of 10 magnitudes, the detection limit for K-band adaptive optics (AO) observations is currently about 0.5-arcsec separation of the components. Companions at smaller separations are detectable, but at lower contrast. As technology and observing techniques improve in this field, detection limits improve. Planetary scientists are looking forward to the next downward jump in detection limits that will come with the next wave in technology [3]: 25–40 meter telescopes, JWST, and, much sooner, the interferometric-imaging beam-combiner LINC-NIRVANA (L-N) for the Large Binocular Telescope (LBT) [4].

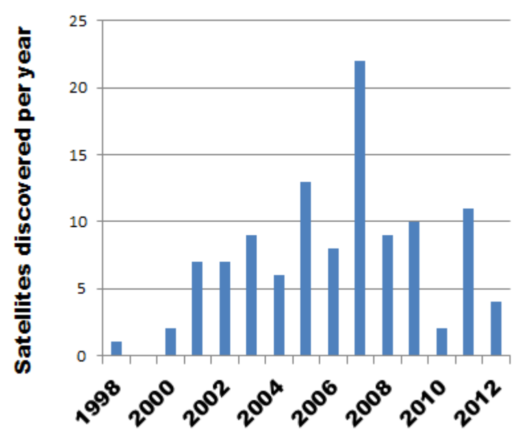

Figure 1. Satellite discoveries from earth-bound optical/NIR imagers (as defined in the text). Tabulation is from the web site maintained by W. Johnston[2].

LINC-NIRVANA: To date, all ground-based discoveries of asteroid satellites by imaging have been made using AO. Coaxial interferometers have been used in attempts to detect binarity [5], and in those cases the higher angular resolution provided by the interferometric technique plays a key role. We expect the situation for interferometers to improve substantially with L-N. As a Fizeau interferometer, it is funda-

[2] http://www.johnstonsarchive.net/astro/asteroidmoonsall.html

mentally an imager and therefore potentially more efficient at detection of close, faint companions than its coaxial counterparts.

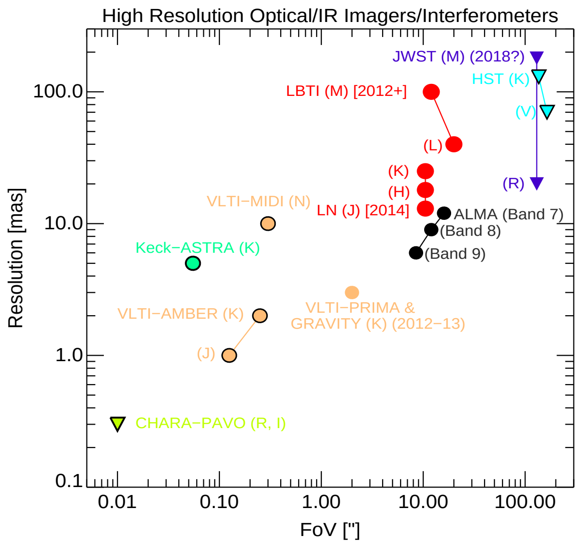

Figure 2. Observing facilities placed in resolution-FoV phase space. For facilities under construction, the estimated year of first light is given in parentheses.

Figure 2 places L-N in angular resolution versus field-of-view (FoV) phase space. As indicated in the figure, L-N in H-band will provide the same angular resolution as JWST in R-band. The L-N FoV is only one tenth in diameter of what is planned for JWST, however, this restricted FoV is more than adequate for what is needed to detect and study satellites orbiting asteroids.

Simulations: To test L-N suitability for detecting asteroid satellites, we analyzed simulations [6]. One example is given in Figure 3. These simulations have shown that for a binary system with a 10^{th} magnitude primary, L-N will be able to detect a 20^{th} magnitude companion (i.e., Δmag of 10) at a separation of 45 milliarcsecond, but only when perfect knowledge of the PSF is applied to the deconvolution. With a conservative estimate of our expected PSF knowledge, we still anticipate detections at a separation of 150 millarcsecond for a Δmag of 10. This equates to a factor of 3 improvement in separation, for that contrast ratio, over what is achievable with today's AO systems on 8–10 meter telescopes.

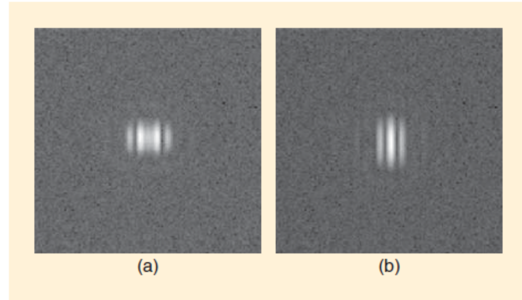

Figure 3. Two simulated images for L-N reprinted from M. Bertero [6]. The image on the right is the characteristic PSF of a point source imaged with LBT. The left-hand panel shows the image that would be produced by L-N of a binary. The members of this pair are faint (Vmag = 20), of equal brightness, separated from one another by 45 milliarcsecond, and, most important, they lie along the baseline connecting the two 8.4-meter mirrors of the LBT. An image taken at a position angle rotated by 90 degrees would appear much like the point source on the right and would not reveal the binary. The baseline changes angle as the sky rotates. Thus, with careful planning, a satellite search campaign can be performed on a single night at a variety of position angles for several asteroids.

References: [1] Merline W. J. et al. (1999) *Nature, 401*, 565–568. [2] Carry B. C. (2012) *Planetary & Space Science, 73*, 98–118. [3] Conrad A. R. et al. (2009) *Earth Moon & Planets, 105*, 115–122. [4] Herbst T. M. et al. (2008) *SPIE, 7014*, 70141A. [5] Delbo M. et al. (2009) *ApJ, 694*, 1228–1236. [6] Bertero M. et al. (2010) *IEEE Signal Processing Magazine, 27*, 110–115.