A FRESH LOOK AT EXPLORING THE NEPTUNE SYSTEM AND BEYOND. H. B. Hammel[1], C. J. Hansen[2], L. J. Spilker[2], T. R. Spilker[2], N. Strange[2], J. Stansberry[3], and K. Khurana[4] [1]Space Science Institute (4750 Walnut Avenue, Suite 205, Boulder, CO 80301; hbh@alum.mit.edu), [2]Jet Propulsion Laboratory, [3]University of Arizona, [4]University of California Los Angeles.

Introduction: Exploration of the local ice giant Neptune has been stymied by a perception that an orbiter (i.e., a Galileo- or Cassini-like flagship mission) is required for major scientific progress. We assert that advances in our understanding of these systems (atmospheres, rings, and moons)—as well as our understanding of the denizens of the Kuiper Belt—have changed dramatically since Voyager (Fig. 1), thus a simple spacecraft equipped with modern technology will yield significant new ice-giant system science. We describe a mission that flies by the Neptune system and continues on to explore a Kuiper Belt object.

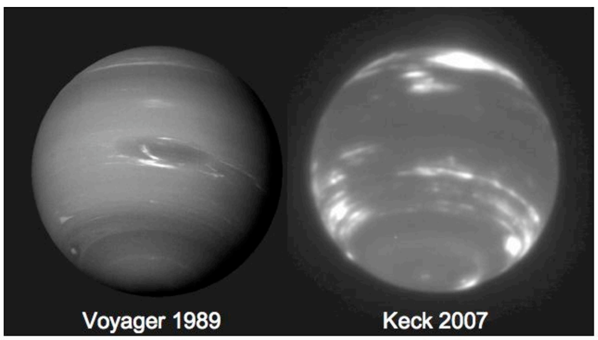

Fig. 1. Neptune then and now. Nearly all aspects of the Neptune system have evolved considerably in the decades since the Voyager flyby, as have the technologies available to flight missions. Although the Voyager image is at visible wavelengths and the Keck image is in the near infrared, visible HST images reveal the changes are intrinsic, not due to wavelength [1,2].

Scientific Motivation: Recent and ongoing space programs exist for terrestrial planets (Earth, Mars, Venus) and for gas giants (Jupiter, Saturn), but not for the intermediate-sized planets. Yet these ice giants, along with gas giants, were key players in the evolution of our circumstellar disk. The formation of Uranus and Neptune, and in particular their subsequent migration to their present locations, dynamically sculpted the distribution of the nascent Kuiper Belt. Indeed, the peregrinations of the ice giants in our Solar System may have affected the early history of the Earth (Fig. 2), perhaps leading to Earth's habitability today [3].

Clues to ice giant formation and evolution, hidden in their chemistry and in the chemistry and evolutionary history of Triton and other ice-giant satellites, will provide inputs for studies of extrasolar planetary disk evolution. The Neptune system thus yields rich scientific return in a broad sense, in addition to detailed knowledge of the intrinsic Neptune environment itself.

Community Support for a Neptune Mission. A Neptune mission is one of the top-ranked missions in the Planetary Decadal Survey [4] and was discussed in the related community contributions [5], but was deferred to later decades, perhaps due to the aforementioned assumption that a flagship-class orbiter mission was required. A Neptune/Triton mission is one of four named flagship missions in the 2006 Solar System Exploration Roadmap [6]. Two different Neptune missions were selected for "Vision Mission" studies in 2004. Neptune is named a giant-planet priority in the Outer Planets Pathways document [7].

Flyby Discovery Opportunities: Some aspects of the Neptune system were not probed at all by Voyager and/or cannot be observed from Earth, e.g., Triton's northern hemisphere; smaller moons; detailed structure within the ring system; and Neptune's interior and magnetic field. Furthermore, a flyby mission gives us the opportunity to go on to a KBO, and the trajectory bending angle from the mass of Neptune opens up a large cone of space for numerous potential KBO targets. We list below just a few of the measurement objectives that are accessible to a Neptune flyby, but are impossible from L2, from near-Earth orbit, and from Earth even with a 30-m telescope.

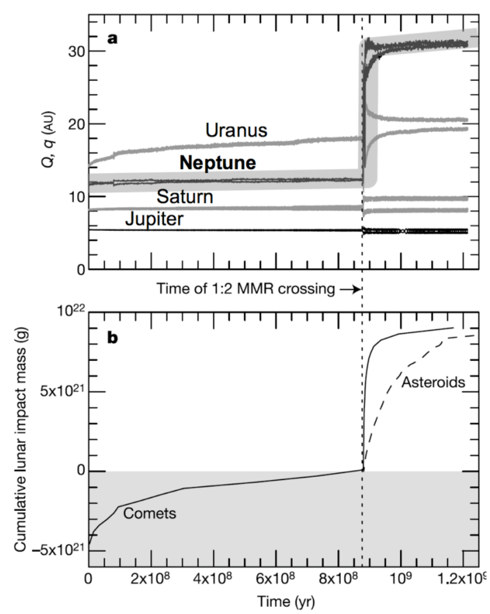

Fig. 2. Neptune and solar system evolution. Ice-giant migration may have triggered the late heavy bombardment in the inner Solar System. Adapted from [3].

Neptune. Discovery opportunities for a Neptune flyby include: detection of small-scale cloud distribution and its relationship to large-scale structure seen from Earth; high phase-angle coverage of the atmosphere; detection of atmospheric lightning; magnetic field measurements; first detailed infrared map; and refined gravitational moments for interior models. A months-long approach-phase movie will produce major advances in dynamical studies.

Triton. Discovery opportunities for a Triton flyby include: significantly improved geologic map; detection of surface evolution, volatile migration, and atmospheric structure changes; detection of a magnetic field; and the first detailed infrared map of Triton.

Ring system. Discovery opportunities during a Neptune system flyby include images, as well as high phase-angle coverage, of the detailed structure and evolution of Neptune's unique arc-dominated rings.

Nereid and other small moons. Discovery opportunities during a Neptune system flyby include the first detailed images and high-phase angle coverage of these distant tiny bodies.

KBOs. Discovery opportunities for a KBO fly-by include: a geologic map; determination of the surface ice distribution; detection of surface and atmospheric structure; detection of a magnetic field; and a detailed infrared map.

Mission Concept: We propose a Neptune flyby tailored to include a close flyby of the large captured moon Triton, followed by a flyby of a Kuiper Belt Object. In addition to a highly focused science package, we envision a mission profile that takes advantage of current instrument technology; current spacecraft technology *(New Horizons heritage);* and a simple yet capable payload. Several favorable launch opportunities exist in the next decade (Fig. 3). At Neptune's large heliocentric distance and beyond, we require nuclear power.

Notional Budget: We have identified avenues toward a preliminary mission design that fits within the expected New Frontiers cost envelope. We list here design concepts that assist with meeting this cost.

- Use simple spacecraft with current heritage (e.g., New Horizons, hereafter "NH"). Advantages: experience base and corporate knowledge are available; no miracle developments are required.
- Identify many trajectories, some of which offer mass relief. Advantage: NH's Star 48 upper stage is likely not needed.
- Use smaller Atlas V launch vehicle. Advantage: can use the 541 instead of the 551; this looks promising for some trajectories.
- Use the market-based approach for payload development. Advantages: Cassini followed this protocol for power, mass, dollars, with the result that no instruments over-ran or were descoped from payload; approach permits us to scale instrument requirements to available funding.
- Offer KBO flyby option as Phase F extended mission, not as part of the primary mission.

Summary: *Neptune and its moon Triton are compelling flyby targets*. They are both dynamic worlds, rife with opportunities for new science discoveries. We have identified trajectories with reasonably short trip times and low approach velocities. *A post-Neptune KBO encounter permits a rich suite of outer-solar-system comparative planetology.* Neptune's mass enables numerous potential KBO targets for a subsequent flyby. When combined with New Horizons exploration of Pluto and a KBO, this mission's study of Triton and a different KBO will double the number of small outer Solar System bodies to be studied in detail by spacecraft. *A Neptune-KBO flyby is feasible within the New Frontiers line.* Key science can be addressed by an instrument package based on New Horizons heritage. We identify avenues for cost savings in development, operations, and the launch vehicle.

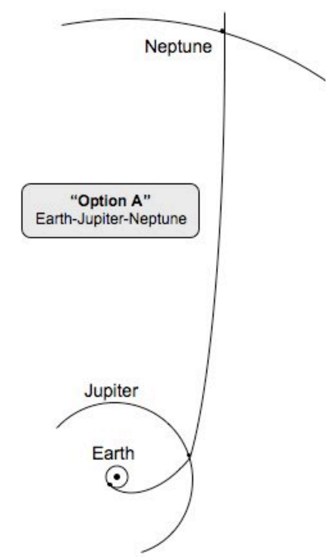

Fig. 3. Sample trajectory. We have identified a suite of possible trajectories with relatively short trip times, launch windows in the next decade, and reasonable flyby velocities. For example, "Option A" has a total trip time to Neptune of 8-11 years (cf. Voyager's 12 years) with a Neptune approach velocity of 12-20 km/sec (cf. Voyager's 17 km/sec).

References: [1] Hammel, H. B. et al. 1995. *Science, 268,* 1740-1742. [2] Sromovsky, L. A. et al. 2002. *Icarus, 156,* 16-36. [3] Gomes, R. et al. (2005). *Nature, 435,* 466-469. [4] National Research Council (2003). *New Frontiers in the Solar System*…, National Academy Press, Washington, D.C. [5] Hammel, H. B. et al. (2002). *ASP Conference Proceedings, 272,* 297-322. [6] NASA Science Mission Directorate Roadmap (2006). http://solarsystem.nasa.gov/multimedia/downloads/SSE_RoadMap_2006_Report_FC-A_med.pdf. [7] Outer Planets Assessment Group (2006). http://www.lpi.usra.edu/opag/pathways_07_06.pdf.