A NEW FRONTIERS MISSION CONCEPT FOR THE EXPLORATION OF URANUS. S. J. Saikia[1] and I. J. Daubar[2], E. Jens[3], M. B. Syal[4], M Bunte[5], C. Cook[6], E. Decrossas[7], A. Dove[8], D. Farnocchia[7], J. Jonsson[7], J. M. Mihaly[9], A. Ollila[10], M. C. Palucis[11], M. J. Poston[12], G. Vardaxis[13], M. S. Veto[14], C. J. Budney[7], K. Mitchell[7], [1]School of Aeronautics and Astronautics, Purdue University, West Lafayette, Indiana 47907-2045, sarag@purdue.edu, [2]University of Arizona, Tucson, AZ, [3]Department of Aeronautics and Astronautics, Stanford University, Stanford, CA, [4]Department of Geological Sciences, Brown University, Providence, RI, [5]School of Earth and Space Exploration, Arizona State University, Tempe, AZ, [6]Department of Physics, University of Idaho, Moscow, ID, [7]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, [8]Center for Microgravity Research and Education, University of Central Florida, Orlando, FL, [9]California Institute of Technology, Pasadena, CA 91109, [10]Department of Earth & Planetary Sciences, University of New Mexico, Albuquerque, NM, [11]Department of Earth and Planetary Science, The University of California, Berkeley, Berkeley, CA, [12]School of Chemistry and Biochemistry, Georgia Institute of Technology, Atlanta, GA, [13]Department of Aerospace Engineering, Iowa State University, Ames, IA, [14]School of Earth and Space Exploration, Arizona State University, Tempe AZ.

Introduction: We present a mission concept – MUSE (Mission to Uranus for Science and Exploration) – to explore Uranus. The mission would consist of a 14-year interplanetary trajectory and a one-year nominal science mission. This mission concept accomplishes high-priority science goals as set forth by the most recent Planetary Sciences Decadal Survey [1].

Uranus is one of a class of planets called "ice giants," "Ices" in this context refer to volatile materials that are solid at the low temperatures of the outer Solar System (e.g., water, ammonia, and methane). Ice giants are distinguished from the gas giants by a lack of large hydrogen and helium envelopes, which Jupiter and Saturn possess. Humankind's last close encounter with Uranus was Voyager 2 in 1986. As a result of that flyby, only mere hours in duration, our understanding of the planet expanded enormously [2]. However, only a dedicated mission will help us to answer the outstanding scientific questions on Uranus. Ice giants also have a growing relevance to exoplanet studies. The Kepler mission has revealed vast numbers of exoplanets in our galaxy, and Uranus-sized planets outnumber any other type [3].

Science Objectives: The scientific objectives of MUSE are to: (1) Determine the vertical atmospheric zonal wind speeds, composition, and structure; temporal evolution of atmospheric dynamics. (2) Understand the basic structure of the planet's magnetosphere as well as the planet's interior. (3) Determine abundances of H_2O, noble gases, and isotopic ratios. (4) Determine both the core distribution and the penetration depth of the atmospheric zonal flow. (5) Remote sensing observations of large satellites. (6) Determine horizontal distribution of atmospheric thermal emission. (7) Measure the magnetic field and determine how the tilted/offset/rotating magnetosphere interacts. (8) Remote sensing observations of outer irregular small satellites.

Mission Requirements: The mission is designedwithin the constraints of an 'enhanced' New Frontiers mission with a cost cap to $1.5B in FY2015$. The cost was enhanced and use of advanced stirling radioisotope generator (ASRGs) was permitted, in contrast to the constraints of a normal New Frontiers mission [1]. The scientific goals required the science orbit to be highly inclined. The arrival orbit would be highly inclined relative to Uranus's north pole, due to the obliquity of the planet. A roughly polar orbit is best suited for all the science investigations except for the satellite and ring system investigations.

Science Instruments: Science instruments on the orbiter and the probe are summarized in Table 1. A medium angle camera and far/near infrared mapping spectrometer will provide global tracking of clouds, winds, chemical composition, and thermal emission of the atmosphere, while a magnetometer and a Doppler imager will probe the magnetic field and interior of the planet, respectively.

Orbiter	**Probe**
Medium Angle Camera	Mass Spectrometer
Mid/Far Infrared Mapping Spectrometer	Atmospheric Structure Instrument Package
Magnetometer	Nephelometer
Doppler Imager	Ultra Stable Oscillator

Table 1: Science instruments in the Uranus orbiter and the probe.

Orbiter: The MUSE is three-axis stabilized spacecraft, like Cassini, and consists of a cylindrical bus 3 m long by 1.6 m wide, allowing the entire spacecraft to fit in an ATLAS V 551 launch vehicle. The spacecraft is powered by four ASRGs combined with two ion batteries. Figure 1 shows the MUSE spacecraft in launch configuration.

Probe: The entry probe considered for the mission is similar to the Galileo Probe: a 45° blunt cone and designed to operate in the pressure range of 5-100 mbar. The instruments are very similar to the design in Ice Giants Decadal Study [4]. The total mass of the probe is 150 kg (with margins). The probe was considered to be donated, and hence the cost for the probe development was not included.

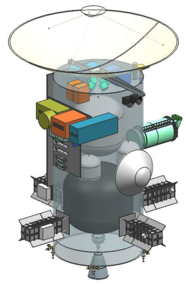

Fig. 1: MUSE Spacecraft launch configuration with undeployed magnetometer boom.

Internplanetary Mission Design: An Atlas 551 is used as the launch vehicle for the mission. An Earth-Mars-Jupiter gravity assist trajectory with two Deep Space Maneuvers (ΔVs = 414 and 312 m/s respectively) was found to be feasible with a launch date of 03/02/2014, and time-of-flight of 14 years. The largest single event ΔV required, 800 m/s, is during the Uranus Orbit Insertion (UOI) on 03/01/2033.

Orbiter Science: The UOI burn takes the spacecraft from its interplanetary trajectory and places it in a 90-day (25.6 R_U) capture orbit. The initial capture orbit is highly eccentric with a semi-major axis of 81 Uranus radii (R_U). Upon arriving at periapse in the 90-day orbit, after a complete revolution of Uranus, a period reduction maneuver is performed to place the spacecraft into a 16-day primary science orbit. Fig. 2 gives a depiction of the capture and science orbits. The nominal mission consists of 17 science orbits (Fig. 2). On every orbit, the spacecraft will cross through the ring plane and will go into Earth/Sun occultation. Spacecraft disposal at mission end is a 30 m/s ΔV maneuver as required by the New Frontiers Announcement of Opportunity [1]. The design of the science orbit was driven by the requirements of the instruments on board the spacecraft. Each instrument had a need to be either farther or closer to the planet for their science For example, the Doppler Imager required an orbit far enough from the planet for a long enough period of time to get multiple whole-disk exposures of the planet. The visible camera needed to be close enough to the planet and its rings in order to get high resolution imaging. During the nominal science orbit, all instruments except the Doppler imager (i.e., the MAC, IMS, and magnetometer) will be active. On every orbit, the spacecraft will cross through the ring plane and will go into Earth/Sun occultation. The first day of each nominal science orbit (near orbit periapsis) would be used for occultation measurements, including radio science, high resolution imaging, and when possible, opportunistic imaging of Uranus' satellites and rings. In addition, the mission could also take advantage of an opportunistic flyby of Umbriel—one of the five major Uranian satellites—from a distance of ~10 R_U at closest approach on one of its science orbits.

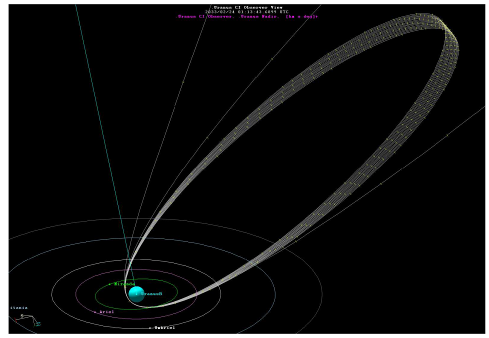

Fig. 2. Spacecraft's science orbits, probe's trajectory with respect to the Uranus system. The blue line pointing toward the upper left represents the Sun-Earth direction.

Probe Science: In addition to the orbiter spacecraft, this mission is carrying a probe to perform atmospheric measurements. It will be released 30 days prior to the orbital insertion burn. At 90 minutes prior to the beginning of the UOI burn, the probe would enter the atmosphere of Uranus and start transmitting data back to the spacecraft. The probe instruments (Table 1) can take measurements on noble gas abundances, isotopic ratios, temperature, pressure, gravity, density, cloud presence as a function of depth, and radio tracking for gravity science.

Mission Cost: JPL's Team-X's quasi-grassroots models are used to generate the most likely cost estimates. The total cost of the MUSE mission is $1328.6M, which is less than the cost cap of $1424.5M in FY13$.

Background and Acknowledgement: The work presented in this paper was completed as an academic exercise during the summer 2013 session of the NASA's 25th Annual Planetary Science Summer School.

References: [1] Squyres S. et al. (2011), Vision and Voyages for Planetary Science in the Decade 2013–2022, National Academies Press. [2] Bergstralh J. T. et al. (ed.) (1991) Uranus. University of Arizona Press, Tucson, AZ. [3] Batalha N. M. et al. (2013) The Astrophysical Journal Supplement Series, 204(2), 24. [4] Hubbard W. B. (2010) Ice Giants Decadal Study, NASA. [5] NASA. (2009) Announcement of Opportunity: New frontiers 2009.