Net Flux Radiometer for the Ice Giants. S. Aslam[1], R. K. Achterberg[2], V. Cottini[2], N. Gorius[3], T. Hewagama[2], P. Irwin[4], C. A. Nixon[1], A. A. Simon[1], G. Villanueva[1], and G. Quilligan[1]. [1]NASA/GSFC, Greenbelt, MD 20771 (shahid.aslam-1@nasa.gov), [2]University of Maryland, College Park, MD 20742, [3]Catholic University of America, Washington, DC 20064, [4]University of Oxford, Parks Road, Oxford OX1 3PU

Introduction: The recent Ice Giants Pre-Decadal Survey Mission Report, 2017 (IGPDS) [1] recommended the scientific importance and high priority of sending a mission with an orbiter and a probe to one of the ice giants with preferential launch dates in the 2029-2034 timeframe. Such a mission will advance our understanding of the Solar System, exoplanetary systems, planetary formation and evolution.

Ice giant meteorology regimes, in particular, depend on internal heat flux levels. Both incident solar insolation and thermal energy from the planetary interior, can have altitude and location dependent variations. Such radiative energy differences cause atmospheric heating and cooling, and result in buoyancy differences that are the primary driving force for Uranus and Neptune's atmospheric motions [2][3]. The three-dimensional, planetary-scale circulation pattern, as well as smaller-scale storms and convection, are the primary mechanisms for energy and mass transport in the ice giant atmospheres, and are important for understanding planetary structure, circulation, and evolution. These processes couple different vertical regions of the atmosphere, and must be understood to infer properties of the deeper atmosphere and cloud decks (Fig. 1).

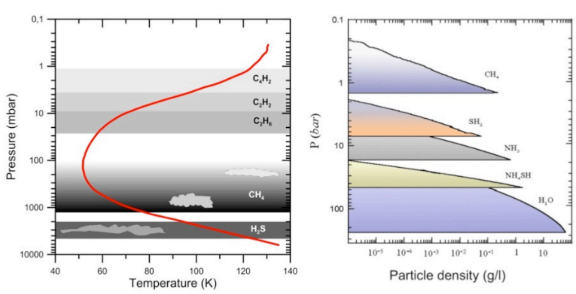

Figure 1. Neptune clouds and hazes. Left: Scheme of the hazes and upper cloud structure accessible to remote sensing. Right: Thermochemical model of the main cloud layers in Neptune as a function of compound abundances. The cloud densities represent upper limits, as cloud microphysical processes (precipitation) would almost certainly reduce the density by factors of $10^2/10^3$ or more. A similar scheme is valid for Uranus. Reproduced from "Scientific rationale for Uranus and Neptune *in situ* explorations" in Planetary and Space Sciences [4].

The atmospheres of Uranus and Neptune are expected to resemble Jupiter and Saturn's in the broad sense, with convective tropospheres giving way to radiatively regulated stratospheres at pressure levels of around 0.1 bar (~50 to 100 km altitude above the cloud tops). However, there are likely to be many differences in detail due to variations in composition and distance from the Sun. The solar constant drops from ~50 W/m^2 at Jupiter to 15 W/m^2 at Saturn, 3.8 W/m^2 at Uranus, and 1.5 W/m^2 at Neptune, leading to progressively colder atmospheric temperatures. While on Jupiter and Saturn ammonia, ammonium hydrosulfide (NH_4SH) and water are predicted to be key cloud-forming species in the troposphere, the colder atmospheres of Uranus and Neptune are expected to form clouds from methane ice and hydrogen sulfide or ammonia ice at observable pressure levels (Fig. 1). It is not known in detail how the energy inputs to the atmosphere–solar insolation from above and the remnant heat-of-formation from below interact to create the planetary-scale patterns seen on these ice giants [2].

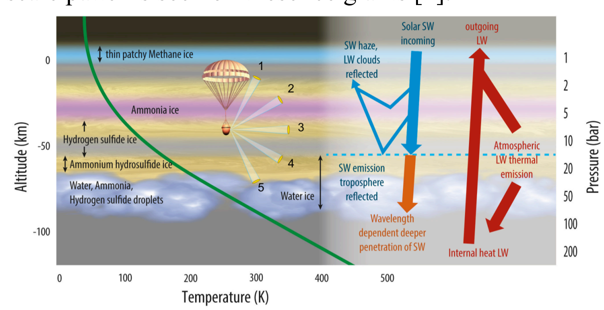

Figure 2. Cartoon of a probe descent through Neptune's poorly understood atmosphere. A NFR will reveal thermal structure, opacity sources, and help provide a global radiative balance (the transition altitudes are similar for Uranus). As the probe descends, seven boresighted spectral channels measure energy flux, sequentially and repetitively (clockwise and anti-clockwise) at five viewing angles. Each spectral channel samples different processes. Short Wave radiation - SW; Long Wave radiation - LW.

An understanding of circulation in these planetary systems requires knowledge of the vertical profile of radiative heating and cooling and also its horizontal distribution. *In situ* measurements with a Net Flux Radiometer (NFR), using judiciously chosen filter channels, will contribute to our understanding of the balance between the upward and downward radiation streams to evaluate effects due to primary opacity sources, and to establish the extent of solar heating e.g., above 1 bar pressure for Neptune (Fig. 2).

***In situ* Net Energy Flux Measurement:** For the ice giants, the thermal structure and the nominal NFR measurement regime extends from ~0.1 bar (near the tropopause which coincides with the temperature minimum) to ideally, if the probe can survive, 50 bar; IGPDS goals are 10 bar. Voyager 2 revealed a thin CH_4 ice cloud layer at ~1 bar on Neptune (Fig. 2). More recent observations show these CH_4 clouds to be transitory and patchy in the 400 mbar to 1 bar level believed to be associated with convective upwelling. The base of the water-ice cloud for solar O/H is expected to be at ~40 bar level, whereas for the $NH_3{\cdot}H_2O$ solution clouds ~80 bar. So far, for Uranus, only an upper limit is known for its heat flow based on Voyager 2. *In situ* probe measurements will help to define sources and sinks of planetary radiation, regions of solar energy deposition, and provide constraints on atmospheric composition and cloud layers.

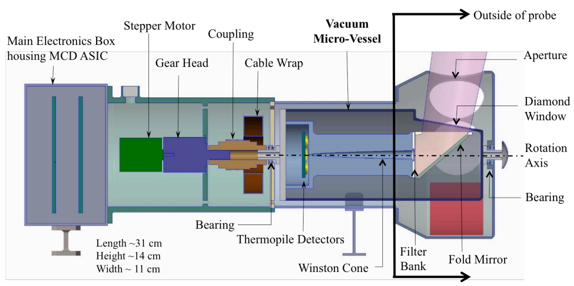

Figure 3. Side view section of the NFR concept showing only one Winston cone for clarity. Thermopile detectors, Winston cones, fold mirror and filters are housed in a vacuum micro-vessel with a diamond window to minimize rapid temperature excursions during probe descent.

Instrument Description: Fig. 3 shows the NFR concept. Fig. 4 shows the Winston cone non-imaging optics, detectors, filters and fold mirror all housed in a vacuum micro-vessel so as to mitigate rapid excursions of temperature during the probe descent. A close hexagonal packing arrangement of Winston cones gave us seven channels, with each Winston cone designed to give a 5° clear FOV. Uncooled single pixel thermopile detectors were chosen for good detection sensitivity of radiation flux. A stepper motor with the aid of a gearbox rotates the vacuum micro-vessel, to each of the five view angles, so that the diamond window on the micro-vessel has an unobstructed view through apertures in the outer housing into the atmosphere. The outer housing (not shown in Fig. 4 for clarity) accommodates hot and cold targets and a Light Emitting Diode for radiometric calibration for each sequence of measurements (5-views). The technical specifications of the NFR are given in Table 1.

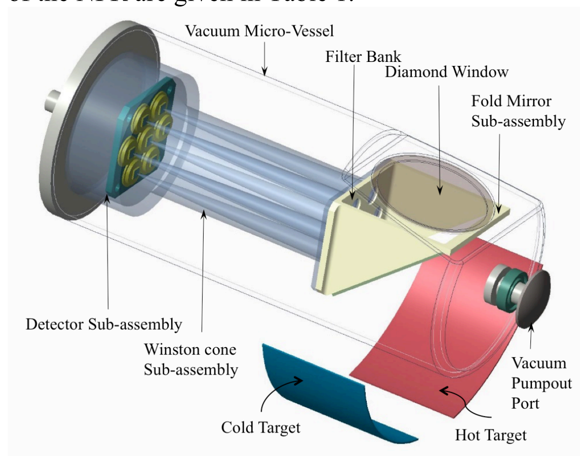

Figure 4. Internals of the vacuum micro-vessel.

Table 5. NFR technical specifications designed to meet the science objectives for net energy flux measurements in the atmospheres of Uranus or Neptune.

Parameter	NASA, Goddard NFR concept
Spectral range	0.2 to 300 µm
Optics	Non-imaging Winston cones
Channels	7 science + 1 dark
Field-Of-View	5 degrees
Viewing angles	±80°; ±45° and 0° relative to nadir/zenith
Detectors (uncooled)	7 thermopile pixels + 1 dark
Pixel size	0.5 mm diameter
Mass	~ 2.4 kg
Basic power	~ 5.2 W
Envelope	$(11 \times 31 \times 14)\ cm^3$
Data volume (90 mins)	670 kbits
Operating modes	36 ms integration
Observation strategy	Sequential rotation into five sky view angles

References: [1] Ice Giants Pre-Decadal Survey Mission Study Report (JPLD-100520). [2] Allison, M., et. al., 1991. Uranus atmospheric dynamics and circulation. Uranus p. 253-295. [3] Bishop, et al., 1995., Neptune and Triton by D. P. Cruikshank, et. al., ISBN-10: 0816515255. ISBN-13:9780816515257. p. 4272,838. [4] Mousis, O., et al., Scientific rationale for Uranus and Neptune in situ explorations, 2017. *Planetary and Space Science*, available on line 21 Oct, 2017, and in press.