# An Interstellar Neutral Atom Detector (INAD)

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**Abstract.** Direct detection of interstellar neutrals is a powerful technique for enlarging our knowledge about the media surrounding our solar system. We present in this paper a combination of two telescopes and a pointing device that would enable precise and detailed measurements of the density, velocity, temperature, and composition of the neutral particles that penetrate through the heliospheric bow shock and the heliopause.

## INTRODUCTION

The interstellar medium is commonly thought to be far away, beyond the termination shock of the supersonic solar wind at perhaps 80–100 astronomical units (AU) from the Sun, or beyond the heliopause, where the solar wind encounters the interstellar medium, at about 150 AU. Common conception has it that only distant Voyager, or eventually Interstellar Probe, has any expectation of reaching interstellar space. However, the inner edge of the interstellar medium is far closer. The solar wind does not affect neutral particles from the interstellar medium; they penetrate relatively undisturbed to within 3 AU of the Sun. Measurements made with an instrument such as INAD would reveal vital new data on the physical state and composition of the interstellar medium. The capability of INAD to observe the velocity distributions of He, H, and O will also allow to determine the deceleration and heating of inflowing interstellar gas through charge exchange interaction in the heliospheric interface region [Möbius et al., 2001].

INAD comprises three elements: the Neutral Interstellar Helium Telescope (NIHeT), dedicated to detecting and measuring the properties of interstellar Helium, the Neutral Atom Telescope (NAT) focused on measurements of Hydrogen, Oxygen and Carbon, and the Actuating Platform (AP) that orients the two telescopes in space, and permits, combined with spacecraft rotation, an almost complete coverage of the sky.

## NEUTRAL INTERSTELLAR HELIUM TELESCOPE (NIHET)

NIHeT is a high-sensitivity, high-angular-resolution version of Ulysses/GAS, which observed the local distribution function of interstellar He for the first time [Witte et al., 1992]. NIHeT has the necessary sensitivity, angular resolution, and background rejection to precisely measure the interstellar neutral He bulk flow parameters (flow vector, temperature, density), and to detect non-thermal tails in the He distributions.

### Principle of Operation.

Figure 1 illustrates NIHeT's principle of operation: particles enter the NIHeT analyzer through a multi-slit mechanical collimator [Taylor, 1993, Möbius et al., 1998] of 2° FWHM transmission and 65% transparency.

Following the first mechanical collimator, there is a set of cylindrical concentric plates, held at different potentials. The electric field between the plates changes the trajectory of charged particles, which are then absorbed by the second mechanical collimator, which is physically identical to the first. However neutral particles pass directly through both sets of collimators and hit a conversion surface covered with a thin layer of lithium fluoride (LiF).

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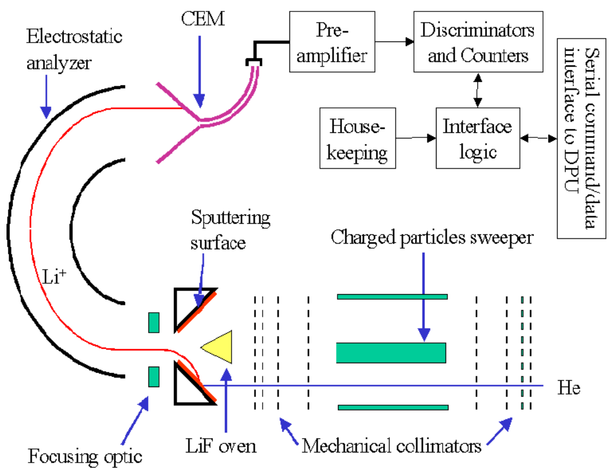


**FIGURE 1.** NIHeT principle of operation.

Upon impact, secondary positively charged ions are sputtered from the LiF surface [Witte et al. 1992], accelerated, and guided by ion optics to a channel electron multiplier (CEM), where they are counted by conventional electronics. The ion optical system eliminates most of the background photoelectrons and efficiently traps UV photons scattered or reflected from the LiF surfaces, which contribute noticeably to the background in Ulysses/GAS. The sputtering efficiency of positive ions from impacting atoms is energy dependent (Fig. 2), about 1% at 60 eV and $<10^{-4}$ below 20 eV. This $<10^{-4}$ efficiency prevents detection of the <16 eV interstellar H atoms.

Because sputtering efficiency degrades slightly with contamination of the LiF surface, new clean layers can be deposited in flight by evaporation of pure LiF from a heated supply, a technique used successfully by Ulysses/GAS.

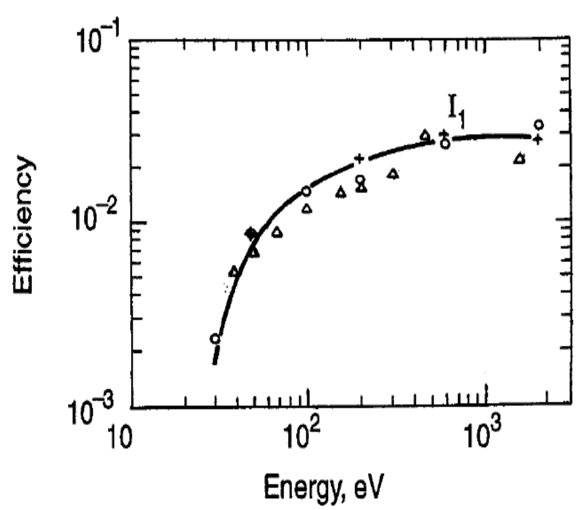


**FIGURE 2.** NIHeD Sputtering efficiency of secondary, positively charged ions ($I_1$) from a LiF surface after impact of a helium atom [Witte et al. 1992].

Two modifications significantly improve the performance of NIHeT over Ulysses/GAS: first, the collection area will be increased by a factor of 400, second, a significant reduction of the background level. The capability of the GAS-instrument to observe low particle fluxes was limited by a signal-to-noise ratio (SNR) not better than 10, due to background counts from the g-radiation of the RTG, from penetrating cosmic ray particles, and predominantly from UV-photons, which could reach the CEM after just one specular reflection in the collimator system. In NIHeT, however, only the cosmic ray background in the somewhat larger CEM will matter, as UV-photons as well as photo-electrons will be efficiently suppressed by the subsequent ion-optics, including a spherical electro-static analyzer (ESA). In addition, as the cosmic ray background is essentially omni-directional while the signal appears in a peaked, angular distribution (<15° FWHM), the background contribution can be easily determined and removed, producing a very low SNR. Finally, the conical Field of View (FoV) is collimated to 1° (FWHM from the combined collimating effect of the two multi slit mechanical collimators) to improve angular resolution.

## NEUTRAL ATOM TELESCOPE (NAT)

NAT is a mass-resolving neutral gas sensor that will produce images of the flow pattern of interstellar neutral O and H as well as neutral C. NAT has the necessary sensitivity, angular resolution, and background rejection (Table 1: NAT performance characteristics) to measure the interstellar neutral O and H bulk flow parameters (flow vector, temperature, density), detect non-thermal tails in the O distributions, and to search for neutral C from a dust or cometary origin. The necessary performance for interstellar gas detection was recently demonstrated with a prototype instrument [Wieser et al., 2001].

NAT basic design is the same as the zero-dimensional camera concept of NIHeT. The major difference is that after the collimator NAT uses the surface charge exchange technology that is necessary for multi species determination [Wurz 2000], and was successfully used in IMAGE/LENA [Ghielmetti et al., 1994; Wurz et al., 1995]. It also makes use of subsystems successfully flown on ACE and Cluster.

### Principle of Operation.

Figure 3 illustrates NAT's principle of operation: particles first traverse a collimator identical in form and function to the one foreseen for NIHeT. Neutral

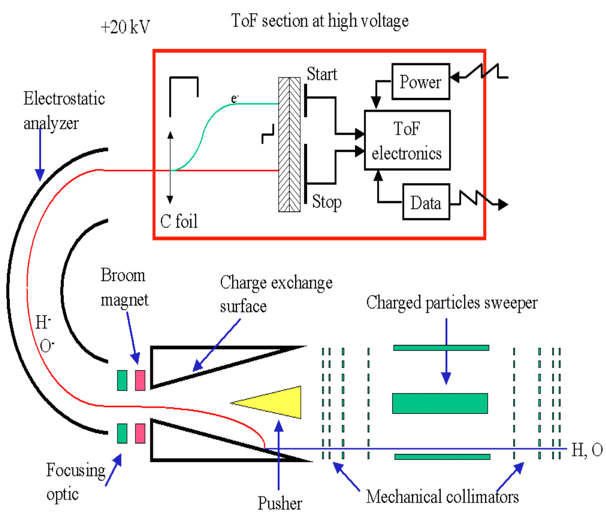


**FIGURE 3**. NAT principle of operation

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particles continue their trajectory, hit a conversion surface at shallow angle of ~10°, and are scattered approximately in specular direction. Upon reflection a fraction of the atoms become negatively ionized. Diamond (natural and synthetic), $BaZrO_3$, AlN, or MgO on a highly polished tungsten substrate have been shown to exhibit very good conversion efficiencies [Wurz et al., 1997, 1998, Jans et al., 2000, 2001, Wieser et al., 2002]. The newly born negative ions are accelerated and guided by ion optics, identical to NI-HeT, into a time-of-flight (TOF) section after a post-acceleration to 15–20 kV. The ion optical system eliminates most of the background photoelectrons and efficiently traps UV photons scattered or reflected from the conversion surfaces. In addition, a magnet is added to remove the low energy electrons produced from the conversion surface.

The negative ions enter the TOF section through a thin (˜ 2–3 $\mu g/cm^2$) C-foil and proceed to hit the Stop portion of a microchannelplate (MCP) detector. Secondary electrons emitted from the C-foil are accelerated and deflected on to the Start portion of the MCP. The TOF is derived from the timing difference between both signals. The mass of the incoming negative ion can be calculated from the time of flight knowing the length of the TOF section and the post acceleration potential. The TOF section has been adapted from the Cluster/CODIF, FAST/TEAMS and Equator-S/ESIC sensors [Möbius et al., 1998; Rème et al., 1997]. Because of the TOF technique, this sensor is inherently insensitive to Ly-α and secondary electron background.

## ACTUATED PLATFORM

The two instruments (NAT and NIHET) will be mounted on a common actuated platform that allows pointing in any direction, from parallel to anti-parallel to the spin axis of the spacecraft. Combined with the spacecraft spin, this movement points the two instruments through the full 4π celestial sphere. Actuated platform mechanisms have been flown successfully on numerous missions in the past, mostly as a telescope subsystem. A similar system (that uses the same motor, encoder, bearings, and flexible feedthroughs) is part of the TIMED/SEE instrument and is being developed for the telescope MDIS on the Messenger spacecraft.

The mechanism will be positioned so that the two instruments scan through the direction of the incoming interstellar neutral wind on every spacecraft rotation. The typical mode of operation will be a step of 1° every 15 min, fully controlled by the DPU. This operational mode results in 100% coverage of the sky (4π steradian) during each half of the orbit.

## INSTRUMENT PARAMETERS

The main characteristics of the INAD package are summarized in Table 1. Note the geometric factor is increased by a factor of 50 compared to Ulysses/GAS, because of the much larger entrance area. Note also the increased angular resolution by factor of 8, resulting from the new collimator design; the extreme improvement in signal-to-noise ratio, owning to the electrostatic analyzer; and the capability of measuring atoms other then Helium, possible because of the charge exchange surface coupled with time-of-flight.

The INAD package has been optimized to achieve the largest geometric factor at the smallest possible mass and power consumption, while using as much as possible of existing subsystems, for reliability and cost optimization. Total mass is estimated to be around 6.5 kg, maximum power 5W.

**TABLE 1.** INAD performance characteristics

| | NIHeT | NAT | Ulysses/GAS |
|---|---|---|---|
| Atoms measured | He, O and Ne | O, H, C | He |
| Energy range | 30–130 eV [up to > 1 keV] | 5–600 eV | 30–130 eV |
| Angular Coverage | $4\pi$ | $4\pi$ | $4\pi$ |
| Angular resolution | $1°\times1°$ | $1°\times1°$ | $2°\times4°$ |
| Active area | 38 $cm^2$ | 38 $cm^2$ | 0.1 $cm^2$ |
| Signal/background | 40,000 | $>10^5$ | 10 |
| Geometric factor | $1\times10^{-2}$ $cm^2$ sr. | $1\times10^{-2}$ $cm^2$ sr. | $2\times10^{-4}$ $cm^2$ ster |
| M/ΔM [FWHM] | N/A | 10 | N/A |

## CONCLUSIONS

The neutral component of interstellar matter penetrates within 3 AU, and can therefore be reached and analyzed with a relatively contained effort. We described an instrument that has two hundred times more sensitivity than it's progenitor, and can measure for the first time the velocity distribution of interstellar Hydrogen and Oxygen. The required resources (6.5 kg, 5W) would be compatible with those available onboard a small satellite.

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