Neutral and Ion Measurements in the Ionosphere and Thermosphere: Neutral Wind, Ion-drift, Temperatures and Composition

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LONG-TERM GOALS

To measure the following ionosphere-thermosphere parameters: wind and ion-drift vectors, neutral and ion temperatures, and neutral and ion compositions; spatial resolution of parameter features less than 10 km.

To develop new spectrometers, ion sources, detectors, and electronics to support the goal above with sufficient flexibility to enable other areas of science and engineering; for example, nano-satellite applications (e.g., CubeSats) for multi-point measurements of the ionosphere-thermosphere system; ground-based miniaturized mass spectrometer applications; situational awareness for spacecraft in space; and others.

OBJECTIVES

To have enablers for the stated goals above that require minimal power and space, yet provide the required sensitivity-dynamic range for particle flux and also the required ranges in energy, angle, and particle mass.

To develop an instrument suite for CubeSats or other nano-satellite configurations requiring measurements of winds, ion-drifts, temperatures, plus ion/neutral composition. This suite, called WINCS (Wind Ion Neutral Composition Suite) currently under construction, uses WTS, IDS, NMS, and IMS to measure winds, ion-drifts, neutral and ion mass composition, respectively.

To develop an energy-angle ion spectrometer with wide FOV to enable measurements of fluxes and energy spectra of ions and neutrals incident on an orbiting spacecraft from widely varying and unknown directions in space.

To obtain low-energy ion and electron detectors with operating voltages that are lower than those of present detectors.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 2009	**Annual**	**00-00-2009 to 00-00-2009**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Neutral And Ion Measurements In The Ionosphere And Thermosphere: Neutral Wind, Ion-drift, Temperatures And Composition	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **NASA Goddard Space Flight Center,Detector Systems Branch/Code 553,Greenbelt,MD,20771**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Code 1 only

14. ABSTRACT
To measure the following ionosphere-thermosphere parameters: wind and ion-drift vectors, neutral and ion temperatures, and neutral and ion compositions; spatial resolution of parameter features less than 10 km.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**5**	

APPROACH

1. Develop the Wind-Temperature Spectrometer (WTS) technique based on the Gas Kinetic Method (GKM) - now a feasible experimental method. WTS measures the angular distribution of the neutral air stream and the neutral atom energy distribution at least at one angle near the peak flux angle. Three measurement schemes based on the SDEA (Small-Deflection Energy Analyzer), previously developed by the PI, were implemented:

a) Single angle-energy spectrometer with ion source for spinning spacecraft - spin axis perpendicular to ram vector to support University of Colorado (CU) DANDE mission (PI/NASA-GSFC/concept & ion optics, Marcin Pilinski/CU/mechanical design, Hollis Jones/NASA-GSFC and Scott Palo/CU for electronics).

b) Two mutually perpendicular angle-energy spectrometers and two ion sources to use in the WINCS package (Andrew Nicholas/NRL/Application, Fred Herrero/NASA-GSFC/concept & ion optics, Ted Finne/NRL/mechanical design, Hollis Jones/NASA-GSFC/electronics).

c) Two energy-angle spectrometers fused into a cross configuration (Crossed-SDEA) to operate with only one ion source in a very small volume (currently flying on ANDE) (Andrew Nicholas/NRL/ Application, Fred Herrero/concept & ion optics, Ted Finne/NRL/mechanical design, Hollis Jones/NASA-GSFC and Ivan Galysh for electronics).

2. Develop the Gated-Electrostatic Mass Spectrometer for satellite and sounding rocket applications (Andrew Nicholas/NRL/Application, Fred Herrero/NASA-GSFC/basic concept & design; Co-I Hollis Jones/NASA-GSFC/detector & timing electronics; Patrick Roman/MEI, Inc./mechanical drawings, assembly, laboratory).

3. Develop a low-power approach to detection and timing of the new MCP electron pulse of 10^7 electrons/pulse for applications to WTS and GEMS (Hollis Jones/NASA-GSFC/Co-I at Goddard).

4. New item: Develop a static-energy-angle analyzer (SEAA) with wide angle (30°x6°) with field widening ion lens for a working FOV of 130°x40° with an energy resolution of 0.2 eV (Andrew Nicholas/NRL/Application, Fred Herrero/NASA-GSFC/concept & design; Brian Tennyson/SMCM[1]-summer intern at NASA-GSFC/SIMION simulations).

WORK COMPLETED

Design new comparator circuit for MCP pulse detection in WTS for DANDE and ANDE, and test the new circuit.

MCP pulse detector circuit with selected electronics components delivered to CU for DANDE WTS and to NRL for ANDE WTS.

Design, construction and test/calibration of the energy-analyzer of the DANDE WTS instrument.

[1] * SMCM is St. Mary's College of Maryland, St. Mary's City, Maryland. Mr. Brian Tennyson is a physics-math major beginning his 3rd year at SMCM this fall.

Design, construction and test/calibration of the Crossed-SDEA WTS for the NRL ANDE mission.

Delivered two operational Crossed-SDEA WTS instruments to NRL for the ANDE mission following calibrations in February 2009.

A new ion source was designed and built to provide improved signal levels in calibrations beginning September 2009. Two vacuum chambers now exist providing multiple ports each with its own differentially pumped ion source for the simultaneous calibrations of up to four separate spectrometers.

SEAA was conceived early July 2009 and SIMION simulations to establish energy resolution and basic geometry carried out by end of July. In August, the design and addition of field-widening ion lens to SEAA enabled a net field-of-view of 130°x40° with energy resolution of 0.2 eV.

RESULTS

Established energy resolution of SDEA using the DANDE WTS instrument calibration of Nov 2008. Design energy resolution of 0.074 was matched by measured 0.075 value. Established the technique for measuring energy resolution of charged-particle spectrometers. Detailed report in preparation.

Measured energy resolution of Crossed-SDEA was not acceptable, but it was made marginally acceptable with modified acceleration voltages in the analyzer. Erik Syrstad/USU with graduate student improved on modifications suggested by the PI to increase the Crossed-SDEA performance – USU simulations of the modified Crossed-SDEA show energy resolution better than 0.1. A poster paper will be given at the Fall AGU meeting, December 2009 – a very significant improvement of the Crossed SDEA.

New capability: Measurement/monitoring of all ions and neutrals incident on a spacecraft from all directions in space. Enabled by Static-Energy-Angle Analyzer (SEAA) with a working FOV of 130°x40° with an energy resolution of 0.2 eV enabled by field widening ion lens. Three such SEAAs span 360°x40° - small modifications will provide FOV to cover the entire sphere.

New capability: The ram sensor, a new application for the Crossed-SDEA WTS instrument. Submitted for a patent from NRL by Andrew Nicholas, Ted Finne, and NRL attitude control personnel in conjunction with the PI. A low-power, small mass, small volume sensor for new attitude control applications.

IMPACT/APPLICATIONS

WINCS will implement the first measurements of the full neutral wind vector in the thermosphere coupled with the ion-drift vector and composition of the ionosphere and the thermosphere. Its small size (< 500 gm) and low-power (< 1 W) makes WINCS compatible with nanosats and a strong candidate for future ionosphere-thermosphere investigations using a constellation of 50 to 100 nanosats.

One of the new capabilities enables measurement/monitoring of all ions and neutrals incident on a spacecraft from all directions in space, of importance to spacecraft situational awareness and many other applications in active experiments in space.

The use of the Crossed-SDEA WTS as a ram sensor in attitude control applications will enable more functionality in the smallest of satellites now flown – the CubeSat. Indeed, it is already signed up to fly as such in some NRL CubeSats.

RELATED PROJECTS

DipTE CUbeSat (NSF CubeSat program) project of Stanford Research Intl., Menlo Park, CA – PI is Dr. Russell Cosgrove in collaborations with U. Arkansas, Embry-Riddle Univ., and NASA GSFC.

NRL Space Weather CubeSat project using WINCS.

NRL sounding rocket experiments using modified spectrometers operating with the WINCS electronics box.

PUBLICATIONS

“The Gas Kinetic Method for Measurements of the Neutral Wind Vector, Temperature and Densities in the Thermosphere”, (the GKM, originally developed in 1985 by the PI, is described in detail in this paper) submitted to the J. Appl. Physics, refereed, June 2009.

PATENTS

The four entries constitute patent applications during the project year submitted through the Technology Office at the NASA Goddard Space Flight Center:

Crossed Small Deflection Energy Analyzer (SDEA) for Wind/Temperature Spectrometer (WTS); Inventors: F. A. Herrero and T. T. Finne; NASA GSFC NTR 5026363; Patent application under preparation by NASA GSFC New Technology Office.

WATS: Wind and Temperature Spectrometry of the Upper Atmosphere in Low-Earth-Orbit; F. A. Herrero; NASA GSFC NTR 5026896.

The Corner Cathode: Making Collimated Electron Beams with a Small Number of Electrodes; F. A. Herrero and P. A. Roman; NASA GSFC NTR 5026918.

An Instrument Suite for the Vertical Characterization of the Ionosphere-Thermosphere System from 100 km to 700km Altitude; F. A. Herrero, H. H. Jones, T. T. Finne, A. Nicholas; NASAGSFC NTR 5025703.

HONORS/AWARDS/PRIZES

Hollis H. Jones, NASA Goddard AETD Award for Innovative Technology Development, July 2009, Applied Engineering and Technology Directorate, NASA GSFC, Greenbelt, Maryland.