Proceedings SOFIA Upper Deck Science Opportunities Workshop, NASA Ames Research Center, Moffett Field, CA, June 22-23, 2004.

TOWARDS A SOFIA UPPER DECK RESEARCH FACILITY

Peter Jenniskens[1], Hansjuerg Jost[2], Ray W. Russell[3], Mike J. Taylor[4], Tim Castellano[5], Hans C. Stenbaek-Nielsen[6], Frans J.M. Rietmeijer[7]

[1]*The SETI Institute, 2035 Landings Drive, Mountain View, CA 94043, USA*
[2]*The BAER Institute, Mountain View, CA 94043, USA*
[3]*The Aerospace Corporation, Los Angelos, CA, USA*
[4]*Utah State University, Logan, UT, USA*
[5]*NASA Ames Research Center, Moffett Field, CA, USA*
[6]*University of Alaska, Fairbanks, AK, USA*
[7]*University of New Mexico Albuquerque, NM, USA*

ABSTRACT

The Stratospheric Observatory for Infrared Astronomy (SOFIA), an airborne infrared and submm observatory, will deploy on 8 hour nights a rate of 960 flight hours per year for 20 years once it is operational. During those flights, it will execute a rigorous observing program in astronomy. Serendipitous research is possible from the Upper Deck of the B747 aircraft, offering a window on the aircraft environment and into space from nine not yet occupied windows. In this paper, we briefly review some of the science questions that can be uniquely addressed from SOFIA with modest instrumentation. This will serve as a basis for further discussion during the 2004 SOFIA Upper Deck Enbabled Science workshop at NASA Ames Research Center.

INTRODUCTION

SOFIA is the Stratospheric Observatory for Infrared Astronomy - a world class astronomical observatory for infrared and submm astronomy. It is an airborne observatory with projected flight hours as much as 960 hours/year (8 hour nights) for 20 years.

The Upper Deck of the USRI operated B747 SOFIA may in the future facilitate experiments for serendipitous research during regular deployments, or in support of ongoing mid-IR and submm observations with the main telescope. Preferentially, this research will support NASA's and DLR's mission goals.

The SOFIA Upper Deck may, for example, facilitate some of the same instruments as currently developed for the NSF/NCAR HIAPER aircraft, which unlike SOFIA has short dedicated missions with a focus on specific atmospheric processes.

Serendipitous research on SOFIA should exploit the capability for long-term monitoring at altitude. In addition, short-term programs could benefit from the low extinction near the horizon (higher meteor rates), a better scintillation than on the ground (occultation observations), a much lower water vapor absorption (near-IR and mid-IR spectroscopy and photometry), a high cosmic ray background, and the unique ability to provide interactive experiments, for example for the collection of interplanetary dust particles and aerosols in the atmosphere.

Unique Earth Science research is possible due to frequent transitions of the tropopause.

There are also unique opportunities for education and public outreach, by facilitating student experiments, providing in-cabin video, and for sightings of transient phenomena on the sky (elves, aurora, fireballs).

No decision has yet been made to support such use of the Upper Deck at the present time. Better insight is needed into the most effective use of the facility and the requirements for those efforts not to interfere in any way with the operations of the astronomical observatory. This information will be used to work towards creating a multi-user facility that can accomodate existing instruments, well shielded from the rest of the aircraft.

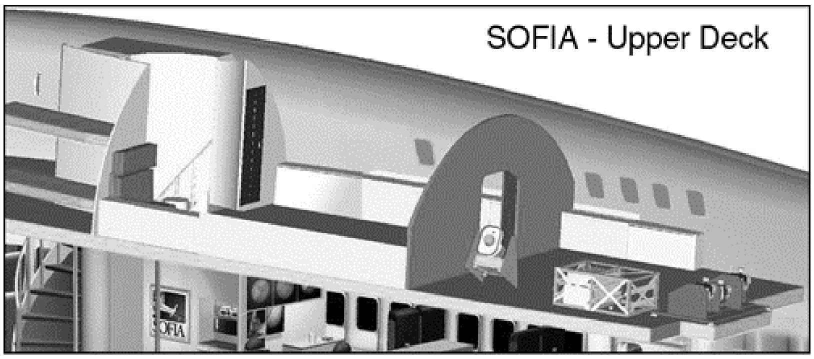

Fig.1. SOFIA's Upper Deck and placement of the Water Vapor Monitor, in an engineering drawing published on the DLR Sofia website. The partition is currently not being planned.

THE SOFIA UPPER DECK

There are 10 windows tilted at 27.8 degrees upward, which permit viewing ±40 degrees in azimuth and between 0 - 68 degrees in elevation, if equipped with the right window materials. This includes any position on the sky that can be reached by the SOFIA telescope. One observatory facility instrument (a water vapor monitor) has been installed permanently on the Upper Deck on the one before last window on the left hand side facing the cockpit,creating a presedent for other installations. The back of the upper deck also houses vacuum pumps that will pump on science instrument cryostat vacuum enclosures. There is easy access from the forward cabin, a large empty space, and ample power, while any weight acts as counter weight to balance the telescope.

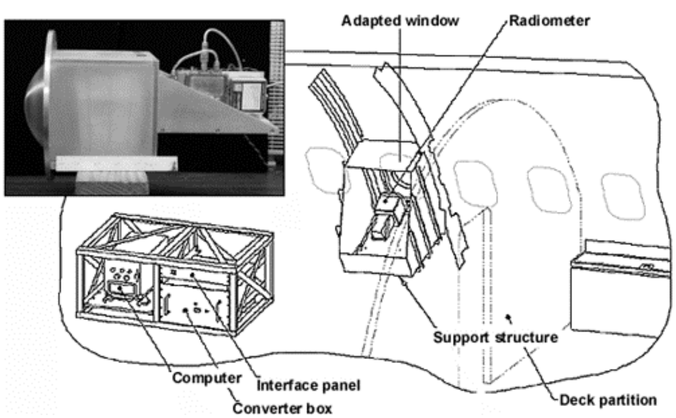

Fig.2. The Water Vapor Monitor and its placement on the Upper Deck. Drawing and image courtesy Tom Roellig, NASA Ames Research Center.

A critical part of SOFIA's operations is the Water Vapor Monitor of which Tom Roellig of NASA Ames Research Center is the Prinicipal Investigator.

The Water Vapor Monitor measures the water vapor content of the atmosphere integrated along the line-of-sight at a 40 degree elevation angle by making submm radiometric measurements of the center and wings of the 183.3 GHz rotational line of water. These measurements are then converted to the integrated water vapor along the telescope line-of-sight.

The monitor hardware consists of three physically distinct sub-systems: 1) a 12 lbs. radiometer head mounted in a pressure vessel, 2) an IF Converter Box Assembly, and 3) an operating computer,

which are mounted in a cabinet just under the radiometer head. The window plug contains a 5" size 0.15 inch thick stretched acrylic window suitable for optical observations.
The Water Vapor Monitor is powered on 15 VDC at 1.5 amps maximum, but taps power from a supply of 110V/60Hz. A flow of dry air is collected from the air ducts that keeps the windows free of frost.

This is a FAA approved setup that can be copied to accommodate other instruments.

POTENTIAL SOFIA UPPER DECK ENABLED SCIENCE IN ASTRONOMY

SOFIA's high cruising altitude will enable astronomical observations above 75 percent of the atmosphere, above nearly all of the water vapor column, and with a cloud-less low-extinction view on the horizon. This provides low scintillation for occultation studies, low absorption in the water vapor bands for near-IR, mid-IR, and submm observations, and 4 - 5 times higher meteor rates than are seen from the ground. Observations from the Upper Deck on SOFIA could help answer key science questions and issues as defined in the NASA Space Science roadmaps.

Space Science Fundamental Questions:

- How does life begin and evolve?
- Where do we come from? Where are we going?
- How does the Earth respond to solar interactions with the Earth's atmosphere and space environment.
- What are the impacts for humanity from space weather, changes of Earth's atmosphere, habitability of space.

Potential contributions of measurements based on the SOFIA Upper Deck:

- Determine any chemical precursors of life from exogenous delivered organics
- Support of regular SOFIA observatory program for relatively bright objects such as comets and gamma-ray bursts
- Learn how the Sun's family of planets and minor bodies originated from the compositional diversity of comets and asteroids
- Understand how the solar system evolved to its current diverse state from the search for extrasolar planets
- Characterize the cosmic and endogenous sources of matter (organic and inorganic) for potentially habitable environments in a long-term collection of stratospheric dust
- Explore the space environment to discover NEO hazards to Earth and meteor flux reporting during storms for satellite impact hazard mitigation

Examples:

Search for extrasolar planets: How frequent are planets? How large are known asteroids? The lower scintilllation onboard SOFIA makes it possible to perform occultation measurements at much higher precision than from the ground. Not inhibited by clouds, observations may include asteroid and kuiper belt occultations of distant stars, and perhaps even gravity lenzing by brown dwarfs. SOFIA Upper Deck research could contribute uniquely to survey-type observations of relatively bright stars, where accurate photometry rather than sensitivity is important, and could add to occultation capability with the main telescope by providing observations at other wavelengths.

Diversity of minor bodies: How do comets and asteroids differ in elemental and mineral composition? The rate of visible meteors per square degree is nearly independent from elevation as seen from the ground, but low extinction near the horizon causes rates to be 4-5 times higher in airborne observations. The effect is stronger for brighter fireballs. This enables the systematic study of meteoroid composition. In comparisson, current high-resolution cooled CCD spectrographs provide 1 usefull psectrum per Perseid shower in ground-based observations, and need 21 nights of sporadic observations for one spectrum. SOFIA: over 4 spectra per shower, less than 4 sporadic nights per spectrum. SOFIA also makes it possible to observe with Moonlight and in cloudy weather.

Interactive interplanetary dust collection: SOFIA will fly high enough to facilitate the collection of interplanetary dust particles and aerosols. What is responsible for the frequent (seasonable, annual, intra-annual) changes in collected interplanetary dust properties? The interactive capability makes it possible to frequently exchange the collection container for high temporal (and spatial) resolution of dust grain collection.

Wide field imaging support of SOFIA main facility: The upper deck could also facilitate wide field optical observations of comets during SOFIA mid-IR and submm observations. Mid-IR observations of the sky background can support the telescope operations by alerting the presence of clouds (imaging) and variations in carbon-dioxyde absorption (spectra).

POTENTIAL SOFIA UPPER DECK ENABLED SCIENCE IN EARTH SCIENCES

SOFIA will fly about 4 times a week about 8 hours. At the beginning, these flights will mostly be out of Moffett Field, CA. Only after a few years, deployments to the Southern Hemisphere are planned. SOFIA will mostly sample the tropopause region of the Earth atmosphere at cruise altitude, and initially many profiles in and out of Northern California. This flight pattern is well suited for Earth Science research. Observations from the Upper Deck on SOFIA could help answer key science questions and issues as defined in the Earth Science Enterprise Strategic Plan.

Earth Sciences Fundamental Questions:

- How is the Earth changing and what are the consequences for life on Earth?
- How is the global Earth system changing?
- What are the primary causes of change in the Earth system?
- How does the Earth system respond to natural and human-induced changes?
- How will the Earth system change in the future?

Potential contributions of measurements based on the SOFIA Upper Deck to the following programs:

- the Global Water and Energy Cycle
- the Carbon cycle
- Atmospheric Chemistry
- Aerosols
- Weather and Short-Term Climate Forecasting
- Long-Term climate Change

Beyond Earth Sciences, a SOFIA Upper Deck Research Facility could contribute to the following questions as well:

- Geodynamics and Other Solid Earth Activities
- Astrobiology Fundamental Question "What is the future of life on Earth and beyond?"
- Astrobiology Goal 6 - "Understand the principles that will shape the future of life, both on Earth and beyond. Elucidate the drivers and effects of ecosystem change as a basis for projecting likely future changes on timescales ranging from decades to millions of years"
- Sun Earth Connections Roadmap Quest II - How do the Earth and planets respond? Solar interactions with the Earth's Atmosphere and Space Environment. Comparative Space Environment."
- Sun Earth Connections Roadmap Quest III - "What are the impacts for humanity? Space Weather, changes of Earth's atmosphere, habitability of Space"

Examples:

Elemental transport through the tropopause: SOFIA will fly frequently through the tropopause, with a cruizing altitude in the lower stratosphere. The cross tropopause transport is not well understood. What drives water vapor concentration in the stratosphere? What chemistry occurs in the tropopause? What are the radiation properties ofthin clouds and aerosols.

Gas and aerosol collection: Aerosol collection and gas sampling are possible over long time baselines for studies of global climate change. SOFIA gives the opportunity to monitor gasses at night time, important for odd-nitrogen chemistry.

Polar Mesospheric Clouds: Polar mesospheric clouds (PMC), also known as noctilucent clouds, are created by ice crystals in the mesoshere. Observation from aircraft would allow the identification of PMC structure over spatial scales not possible from the ground and not yet done by spacecraft. By determining the variation in the clouds brightness with viewing angle we can infer the size of the scattering particles. The airborne observations will also add to the science attempted through the NASA AIM satellite intended for a study of PMCs and planned for launch in September 2006.

Airglow and gravity waves: Gravity wave structure in OH airglow can be observed over long baselines and long timescales.

Other science objectives may well be achieved, the topic of discussion at the first Workshop on future SOFIA Upper Deck enabled science (June 24-25, 2004) at NASA Ames Research Center.

Acknowledgements: We acknowledge support from NASA's APRA program and NASA’s Earth Science Enterprise to make this workshop possible.

REFERENCES

Chyba, C.F., P.J. Thomas, L. Brookshaw, and C. Sagan, Cometary Delivery of Organic Molecules to the Early Earth. *Science*, **249**, 366-373, 1990.

Des Marais, D.J., L.J. Allamandola, S.A. Benner S.A., et al., The NASA Astrobiology Roadmap. *Astrobiology* **3**, 219-235, 2003.

Jenniskens P., and R.W. Russell, The 2001 Leonid Multi-Instrument Aircraft Campaign - an early review. ISAS-SP 15, 3-15, 2003.

Jenniskens P., Preface. Preface to special issue of COSPAR session on “Meteor induced chemistry, ablation products, and dust in the middle and upper atmosphere” (Houston, Oct. 2002). Advances of Space Research 33, 1443, 2004.

Rietmeijer, F.J.M., Interrelationships among meteoric metals, meteors, interplanetary dust, micrometeorites, and meteorites. *Meteoritics Planetary Science*, **35**, 1025-1041, 2000.

Russell, R.W., G.S. Rossano, M.A. Chatelain, D.K. Lynch, T.K. Tessensohn, E. Abendroth, and D. Kim, Mid-Infrared spectroscopy of persistent Leonid trains. *Earth, Moon and Planets,* **82-83**, 439-456, 2000.

Schmidt G., Astrobiology Target of Opportunity: The Leonid Storms. *Astrobiology* **4**, 65-66, 2004.

Stenbaek-Nielsen,, H., and P. Jenniskens, Leonid at 1000 Frames per Second. *ISAS-SP*, **16**, 207-214, 2003.

Taylor, S., J.H. Lever, and R.P. Harvey, Numbers, types, and compositions of an unbiased collection of cosmic spherules. *Meteoritics Plan. Sci.*, **35**, 651-666, 2000.

E-mail address of P. Jenniskens: pjenniskens@mail.arc.nasa.gov
Manuscript received 2004 February 08; revised 2004 May 09; accepted 2004 May 09.