SOFIA: Molecules and star formation in the Milky Way

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GREAT results of the early science flights with SOFIA, the airborne observatory

The Stratospheric Observatory for Infrared Astronomy (SOFIA) has completed its first series of science flights using the German Receiver for Astronomy at Terahertz Frequencies (GREAT). The scientific results are now being published in a special issue of the European scientific journal *Astronomy & Astrophysics* (Volume 542, 10 May) along with reports on GREAT's advanced technologies. They demonstrate the instrument's versatility, include first detections of interstellar molecules and important spectral lines in space, and address the different stages of star formation. SOFIA is operated by NASA and the German Aerospace Center (Deutsches Zentrum für Luft und- Raumfahrt; DLR).

The first series of astronomical observations with GREAT were successfully completed in November last year. Now, six months later, the scientific results have been published in a special issue of the prestigious European scientific journal *Astronomy & Astrophysics*. An international group of scientists report on the first astronomical results as well as the technologies employed on board SOFIA in 22 articles. GREAT was developed by a consortium of German research institutes led by Rolf Güsten (Max Planck Institute for Radio Astronomy, MPIfR).

An airborne observatory

SOFIA, a joint project between NASA and DLR, carries a 2.7-metre telescope in a modified Boeing 747SP aircraft, and is the world's largest airborne infrared observatory. SOFIA flies at altitudes of up to 13,700 metres to enable detection of radiation at far-infrared wavelengths, which would otherwise be impossible due to absorption by water vapour in the atmosphere. The SOFIA observatory and the GREAT instrument provide a window to the far-infrared skies for high-resolution spectroscopy, and GREAT’s technology allows reaching higher frequencies and sensitivities than ever before.

"The high resolving power of the GREAT spectrometer allows us to analyse and study interstellar gas and the stellar life cycle, from a protostar's early embryonic phase while still embedded in its parental cloud, to an evolved star’s death, when the stellar envelope is ejected back into space," says Rolf Güsten from the Max Planck Institute for Radio Astronomy, Principal Investigator of the GREAT project. "This stunning collection of first scientific results is the reward for many years of development work, and underlines the huge scientific potential of airborne far-infrared spectroscopy.”

GREAT provides new scientific insights

Many of the contributed papers study the star formation process in its earliest phases – from when the protostellar molecular cloud contracts and condenses to the moment in which the embryonic star vigorously interacts with its surrounding parental molecular cloud, tearing it apart and ionising it. The high spectral resolution capabilities of GREAT enabled the calculation of the velocity field of gas in the parental molecular clouds, which is tracked by the important ionised carbon spectral line in several star forming regions.

GREAT detected the velocity signature of the motion of the infalling gas (collapse) in three protostellar envelopes, directly examining the dynamics of forming stars. Two molecular species were detected for the first time ever in space: OD, an isotopic substitute of hydroxyl (OH), in which with the hydrogen atom is substituted by the heavier deuterium, and the mercapto radical

SH. Crossing a technological barrier, observations of the ground-state transition of OH at 2.5 terahertz (120 microns wavelength) allow the exploration of new astrochemical territories.

The remnant envelope of an evolved star, ionised by its hot stellar core, was also investigated, as was the violent shock interaction of a supernova remnant with its surrounding interstellar medium. Furthermore, researchers also studied the circumnuclear accretion disc, which is ultimately feeding the black hole in the centre of the Milky Way, and star formation in the circumnuclear region of the nearby galaxy IC342.

Exceptional results

“The rich harvest of scientific results from this first observing campaign with SOFIA and the GREAT instrument gives a first glimpse of the tremendous scientific potential of this observatory,” states Alois Himmes, DLR’s SOFIA programme manager. SOFIA will take advantage of rapid instrument innovations, allowing instruments like GREAT to be continuously adapted to the latest technologies, and thus promising exciting astronomical observations in the coming years.

Note that results and papers based on early science observations with the FORCAST receiver (mid-infrared camera) on board SOFIA were published in the US *Astrophysical Journal Letters* (Band 749) and were covered in a separate press release.

Video: SOFIA science flight on 12-13 April 2011

About GREAT

GREAT, the German Receiver for Astronomy at Terahertz Frequencies is a receiver for spectroscopic observations in the far infrared spectral regime at frequencies between 1.25 and 5 terahertz (60-220 microns), which are not accessible from the ground due to absorption by water vapour in the atmosphere. GREAT is a first generation German SOFIA instrument, developed by the Max-Planck Institute for Radio Astronomy (MPIfR) and KOSMA at the University of Cologne, in collaboration with the Max Planck Institute for Solar System Research and the DLR Institute of Planetary Research. Rolf Güsten (MPIfR) is the Principal Investigator for GREAT. The development of the instrument was financed by the participating institutes, the Max Planck Society and the German Research Foundation (Deutsche Forschungsgemeinschaft; DFG). .

About SOFIA

SOFIA, the Stratospheric Observatory for Infrared Astronomy is a joint project of the National Aeronautics and Space Administration (NASA) and the Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR; German Aerospace Centre, grant: 50OK0901). The project is being carried out under the auspices of DLR, with funds provided by the Federal Ministry of Economics and Technology (Bundesministerium für Wirtschaft und Technologie; BMWi) under a resolution passed by the German Federal Parliament, and with funding from the State of Baden-Württemberg and the University of Stuttgart. Scientific operations are coordinated by the German SOFIA Institute (DSI) at the University of Stuttgart and the Universities Space Research Association (USRA).

Contacts

Elisabeth Mittelbach
German Aerospace Center (DLR)
Communications, Space Administration
Tel.: +49 228 447-385
Fax: +49 228 447-386
Elisabeth.Mittelbach@dlr.de

Heinz-Theo Hammes
German Aerospace Center (DLR)
Space Administration, Space Science
Tel.: +49 228 447-377
Fax: +49 228 447-745
Heinz.Hammes@dlr.de

Norbert Junkes
Max Planck Institute for Radio Astronomy
Tel.: +49 228 525 399
Fax: +49 228 525 229
njunkes@mpifr-bonn.mpg.de

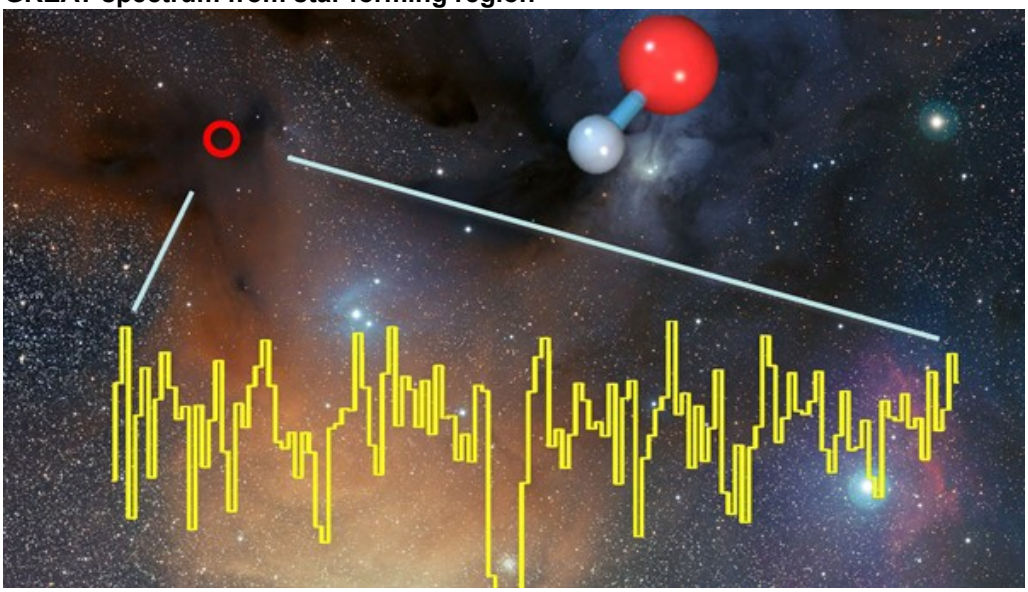
Dr Dörte Mehlert
German SOFIA Institute
Tel.: +49 711 685-69632
Fax: +49 711 685-63596
mehlert@dsi.uni-stuttgart.de

The Stratospheric Observatory For Infrared Astronomy, SOFIA

The Stratospheric Observatory For Infrared Astronomy, SOFIA, during its first test flight with its telescope exposed, on 13 July 2010. The German-built 2.5-metre infrared telescope is visible through the opening in the aircraft.

Credit: NASA/Jim Ross.

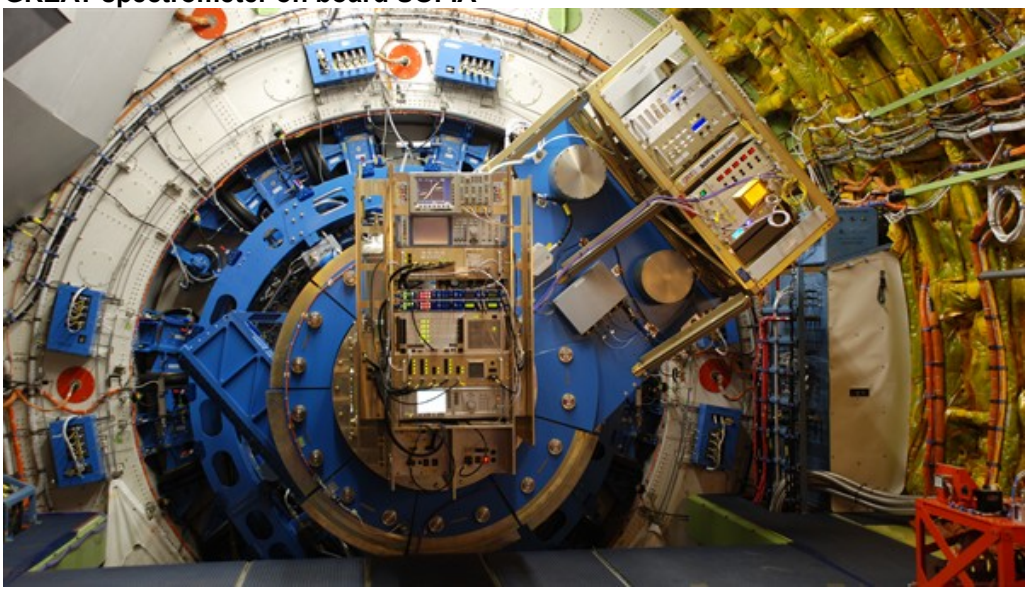
GREAT spectrum from star forming region



Optical colour image of the Rho Ophiuchi star forming region, about 400 light years from Earth, with dark filamentary dust clouds. The position of the optically invisible low-mass protostar IRAS16293-2422 around which interstellar deuterated hydroxyl OD has been detected is marked with a red circle. The absorption line spectrum, observed with GREAT on board SOFIA, displays the molecule's fingerprint at 1.3915 terahertz (or 215 microns wavelength). The inset shows the OD molecule (red: oxygen, grey: deuterium), an isotopic substitute of hydroxyl (OH) in which the hydrogen atom is replaced by the heavier deuterium. This deuterated molecule is an important marker in the formation of interstellar water and may serve as a chemical clock in the early star formation process. The bright yellowish star at the bottom left is Antares, one of the brightest stars in the sky. Below and to Antares' right is the globular cluster Messier 4.

Credit: Background: ESO/S. Guisard. Spectrum: MPIfR/B. Parise.

GREAT spectrometer on board SOFIA



The GREAT far-infrared spectrometer (the vertical structure in the foreground) is mounted to the telescope counterweight flange inside the pressurised cabin. During observations, GREAT rotates ±20 degrees from the vertical, while the telescope (invisible on the far side) and its counterweight (seen here in blue at an angle of 45 degrees) move between roughly 25 and 65 degrees from the vertical.

Credit: GREAT-Team (R. Güsten).

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