POSTER ABSTRACTS for TUESDAY
Saturn Science Conference

1) Orton, Glenn: *Long-Term Variability of Temperatures and Clouds in Saturn from Ground-Based Observations of Thermal Emission*

G. Orton, L. Fletcher, J. Sinclair, T. Fujiyoshi, T. Greathouse, P. Yanamandra-Fisher, T. Momary, I. Aguilar, A. Spiga, and S. Guerlet

Measurements of Saturn's thermal emission between 5.1 and 24.5 µm have been recorded by ground-based observations from the early 1990's to the present. Our observations included mid-infrared thermal imaging and mapping spectroscopy of the CH_4 7.7-µm ν_4 band to sense stratospheric temperatures and H_2 collision-induced absorption in the 17-25 µm region to sense upper-tropospheric temperatures. Our images at 5.1 µm are sensitive to cloud opacity near the 2-3 bar pressure region.

Observations were made at the Infrared Telescope Facility (IRTF), the Subaru Telescope, the Keck I Telescope, the Gemini South Telescope and the Very Large Telescope. Prominent seasonal variability is easily detected in the observations by comparing emission in opposite hemispheres at wavelengths sensitive to both tropospheric and stratospheric temperatures. The stratospheric temperature differences do not coincide with predictions of a time-dependent radiative model (Guerlet et al. 2014, submitted to Icarus), but they could be reconciled by adding a source of stratospheric heating besides the CH_4 gaseous absorption in the current model.

Warm polar vortices in Saturn are prominent near and after solstice. Orton and Yanamandra-Fisher (2005, Science, 307, 696) differentiated between a broad region of heating due to a combination of radiation and dynamics that covers a region within 30° of the pole and a more compact dynamically driven phenomenon. As of this writing, Saturn's north pole, heading toward solstice in 2017, has not yet displayed the distinct arctic warming that is prominent in 1993, corresponding to Saturn's early spring. Orton et al. (2008, Nature 453, 196) detected a non-seasonal oscillation at low latitudes that appeared to have a period close to 14.7 years, half of Saturn's orbital period, but recent observations indicate a variation from this behavior, which is consistent with independent observations made by the Cassini CIRS investigation (Sinclair et al. 2014, Icarus 233, 281).

Imaging at 5.1 µm has revealed a detailed cloud structure representing variations of cloud opacity around Saturn's 2-3 bar pressure region that we have tracked since 1995 (Yanamandra-Fisher et al. 2001, Icarus 150, 189). Since that time, the zonal-mean narrow, dark bands have remained constant and are correlated with variations of zonal jets. We have identified long-term variations in the cloud opacity that do not appear to be immediately correlated with seasonal changes. In 2011, the storm latitude became the clearest atmospheric region (i.e. the brightest at 5.1 µm) ever detected. It is gradually returning to its pre-storm state, but at a very slow rate and remains the clearest region on the planet. The stratospheric "beacon" (Fletcher et al. 2011, Science 332, 1413) has subsided into a generally warm axisymmetric band.

2) Sylvestre, Melody: *Seasonal Variations in Saturn's Stratosphere from Cassini/CIRS Limb Observations*

Melody Sylvestre, Thierry Fouchet, Sandrine Guerlet, and Aymeric Spiga

Saturn's atmosphere features large seasonal variations of its insolation due to its obliquity (26.7 deg.) and to the rings shadow wrapping up a large fraction of the winter hemisphere. Hence, important seasonal changes are expected in temperature, photochemistry and dynamics, especially in the stratosphere where photochemical and radiative timescales are the shortest.

In order to improve our knowledge of seasonal variations in Saturn's atmosphere, we analyze limb spectra acquired by Cassini/CIRS in 2010 (Ls = 12 deg.) and 2012 (Ls = 31 deg.) during spring in the northern hemisphere to retrieve temperature and hydrocarbons abundances. The latitudinal coverage (from 79N to 70S) and the sensitivity of our observations to a broad range of pressure levels (from 20 hPa to 0.01 hPa) allow us to probe the meridional and vertical structure of Saturn's stratosphere. We compare our results to previous CIRS limb observations performed in 2005, 2006 and 2007 (from Ls = 312 deg. to Ls = 331 deg.) during the previous season (Guerlet et al. 2009). Our results show that in the northern hemisphere, the lower stratosphere (1 hPa) has experienced the strongest warming from winter to spring (+10 K). In contrast the southern hemisphere exhibits weak variations of temperature from summer to autumn. We investigate the radiative contribution in the thermal seasonal evolution comparing these results to our radiative-convective model (Guerlet et al., 2014). We show that radiative heating and cooling by atmospheric minor constituents is not sufficient to reproduce the measured variations of temperature, suggesting dynamical features. The measurements of the abundances of hydrocarbons such as ethane or acetylene and their comparison with the photochemical model of Moses et al. (2005) also give insights on the large scale dynamics. For instance, in winter, Guerlet et al. (2009) measured a local enrichment above the 0.1 hPa pressure level at 25N. Our measurements indicate that this anomaly has disappeared in spring, in contrast with the expected enhancement in photochemical production rates, suggesting a change in the atmospheric circulation.

3) Bjoraker, Gordon: *Oxygen Compounds in Saturn's Stratosphere During the 2010 Northern Storm*

G. L. Bjoraker, B. E. Hesman, R. K. Achterberg, D. E. Jennings, P. N. Romani, L. N. Fletcher, and P. G. J. Irwin

The massive storm at 40 degrees North latitude on Saturn that began in December 2010 has produced significant and long-lived changes in temperature and species abundances in the stratosphere throughout the northern hemisphere (Hesman et al. 2012a, Fletcher et al. 2012a). The northern storm region has been observed on many occasions between January 2011 and January 2013 by Cassini's Composite Infrared Spectrometer (CIRS). In this time period, temperatures in regions referred to as "beacons" (warm regions in the stratosphere at certain longitudes in the storm latitude) became significantly warmer than pre-storm values of 140K, peaking at 220K in May 2011 followed by gradual cooling. Hydrocarbon emission greatly increased over pre-storm values and then slowly decayed as the beacon cooled. Radiative transfer modeling has revealed that this increased emission is due to enhanced gas abundances for many of these species, rather than simply due to the temperature changes alone (Hesman et al. 2012b, Bjoraker et al 2012). In order to build a comprehensive picture of the changes to the stratosphere due to the 2010 northern storm we are now investigating the oxygen compounds in Saturn's stratosphere to determine if similar changes in these species occurred. The time evolution of stratospheric CO_2 and H_2O abundances in the beacon regions throughout 2011 and 2012 will be presented and compared with pre-storm measurements made in 2010.

4) Hesman, Brigette: *The Evolution of Hydrocarbon Compounds in Saturn's Stratosphere During the 2010 Northern Storm*

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The massive eruption at 40N (planetographic latitude) in December 2010 has produced significant and long-lived changes in temperature and species abundances in Saturn's northern hemisphere (Hesman et al. 2012a, Fletcher et al. 2012). The northern storm region has been observed on many occasions between January 2011 and June of 2012 by Cassini's Composite Infrared Spectrometer (CIRS). In this time period, temperatures in regions referred to as "beacons" (warm regions in the stratosphere at certain longitudes in the storm latitude) became significantly warmer than pre-storm values of 140K. In this period hydrocarbon emission greatly increased; however, this increased emission could not be attributed due to the temperature changes alone for many of these species (Hesman et al. 2012b, Bjoraker et al. 2012). The unique nature of the stratospheric beacons also resulted in the detection of ethylene (C_2H_4) using CIRS. These beacon regions have also led to the identification of rare hydrocarbon species such as C_4H_2 and C_3H_4 in the stratosphere. These species are all expected from photochemical processes in the stratosphere, however high temperatures, unusual chemistry, or dynamics are enhancing these species. The exact cause of these enhancements is still under investigation.
Ground-based observations were performed using the high-resolution spectrometer Celeste in May 2011 to confirm the CIRS detection of C_2H_4 and to study its spectral signatures at higher spectral resolution. In order to follow the evolution of its emission further observations were performed in July 2011 and March 2012. These observations are being used in conjunction with the CIRS observations to investigate the source of the approximately 100-fold increase of ethylene in the stratospheric beacon.

The time evolution of hydrocarbon emission from C_2H_2, C_2H_4, C_2H_6, C_3H_4, and C_4H_2 in Saturn's Northern Storm beacon regions will be presented.

References:

Bjoraker, G., B.E. Hesman, R.K. Achterberg, P.N. Romani. 2012, "The Evolution of Hydrocarbons in Saturn's Northern Storm Region", AAS DPS Conference, Vol. 44, #403.05.

Fletcher, L.N. et al. 2012, "The Origin and Evolution of Saturn's 2011-2012 Stratospheric Vortex", Icarus, 221, 560-586.

Hesman, B.E. et al. 2012a, "Elusive Ethylene Detected in Saturn's Northern Storm Region", The Astrophysical Journal, 760, 24-30.

Hesman, B.E. et al. 2012b, "Ethylene Emission in the Aftermath of Saturn's 2010 Northern Storm", AAS DPS Conference, Vol. 44, #403.06.

5) Achterberg, Richard: *Changes to Saturn's Zonal-mean Tropospheric Thermal Structure After the 2010-2011 Storm*

Richard K. Achterberg, Peter J. Gierasch, Barney J. Conrath, Leigh N. Fletcher, Brigette E. Hesman, Gordon L. Bjoraker, and F. Michael Flasar

We have used far-infrared (20 μm – 200 μm) data from the Cassini Composite Infrared Spectrometer to retrieve the zonal-mean temperature and hydrogen *para*-fraction in Saturn's upper troposphere from observations taken before and after the large northern hemisphere storm in 2010-2011. During the storm, zonal mean temperatures increased by about 3 K in the latitude band between roughly 25°N and 45°N planetographic latitude , while the zonal mean hydrogen *para*-fraction decreased by about 0.04 over the same latitudes, at pressures greater than approximately 300 mbar. These changes occurred over the same latitude range as the disturbed cloud band seen in visible images. The observations are consistent with low *para*-fraction gas being brought up from the level of the water cloud by the strong convective plume associated with the storm, while being heated by condensation of water vapor, and then advected zonally by the winds near the plume tops in the upper troposphere.

6) Sromovsky, Larry: *The Composition of Saturn's Storm Clouds: The Great Storm of 2010-2011 and Beyond*

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Saturn's Great Storm of 2010-2011 lofted deep atmospheric aerosols up to the visible cloud tops, exposing to remote observation normally hidden materials produced at great depths. Sromovsky et al. (2013, Icarus 226, 402-418) used near-infrared spectra of the storm obtained by the Cassini Visual and Infrared Mapping Spectrometer (VIMS) to show that the storm cloud contained a multi-component aerosol population comprised primarily of ammonia ice, with water ice the best-defined secondary component. The most likely third component is ammonium hydrosulfide or some weakly absorbing material similar to what dominates visible clouds outside the storm region. Their best horizontally homogeneous model has an optically thin layer of weakly absorbing particles above an optically thick layer of water ice particles coated by ammonia ice, supporting the hypothesis that these convective storms are powered by condensation of water and originate in the 10-20 bar depths of Saturn. Here we report on recent results of extending the spectral analysis to other storm regions.

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7) Mousis, Olivier: *Scientific Rationale and Concepts for an In Situ Saturn Probe*

O. Mousis, D. Atkinson, S. Atreya, A. Coustenis, L. N. Fletcher, D. Gautier, T. Guillot, R. Hueso, J.-P. Lebreton, J. I. Lunine, B. Marty, K. Reh, E. Venkatapathy, J. H. Waite, P. Wurz, and the ESA-M4 Saturn Probe team

Remote sensing observations meet some limitations when investigating the bulk atmospheric composition of the giant planets of our solar system, thus in situ measurements are needed. A remarkable example of the unique value of in situ probe measurements is illustrated by the exploration of Jupiter, where key measurements such as noble gases abundances and the precise measurement of the helium mixing ratio have only been made available through in situ measurements by the Galileo probe. Here we summarize the science case for in situ measurements at Saturn (see also Mousis et

al. 2014 for details) and discuss the possible mission concepts that would be consistent with the constraints of ESA M-class missions. This mission would greatly benefit from strong international collaborations. We intend to propose such a mission in response to the upcoming ESA M4 call.

8) Strycker, Paul: *Applying PCA Filtering to Bolide Detection in Video Observations of Saturn and Jupiter*

Impacts with giant planets provide an opportunity to characterize minor bodies in the solar system and to study their effects on planetary atmospheres. Video observations by amateur astronomers are essential for detecting these impacts and constitute the only three temporally resolved observations of short-lived bolide flashes on Jupiter (Hueso et al. 2013, A&A, 560, A55). Objects similar in size to these Jovian impactors (5-19 m) may be challenging to detect with amateur equipment when impacting Saturn, due to (1) its greater distance from Earth and (2) its smaller gravitational potential which results in impactors with a kinetic energy per kilogram that is approximately 36% that of Jovian impactors. The limiting factor in bolide detection is the ability to separate the planet's spatial and temporal signal from that of transient events. Current detection algorithms rely on the difference between individual frames and a reference image, which do not account for the variability in the planet's signal due to atmospheric seeing and imperfections in image registration.

This work addresses these issues with an alternative method of identifying the planet's signal based on principal component analysis (PCA). After confirming that the first several principal components (PCs) of a video do not contain a bolide's signal, a reconstruction of the data without these PCs, known as PCA filtering (Strycker et al. 2013, Nat. Commun., 4, 2620), will remove a large fraction of the planet's spatial and temporal signal. Presented here are preliminary comparisons between the difference-of-images and PCA-filtering methods applied to synthetic Saturnian bolide observations.

This work is based on observations made with the NASA/ESA Hubble Space Telescope, obtained from the Data Archive at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-26555. These observations are associated with program #9354. The author acknowledges partial support from the University of Wisconsin-Platteville and Concordia University Wisconsin.