

STIS IMAGE CUBES OF TITAN. A. Cheng^{1,2,3} and E. F. Young⁴ and P. Corlies⁵ and C. A. Nixon², ¹UC Berkeley, angelviolinist@berkeley.edu, ²Planetary Systems Laboratory, NASA Goddard Space Flight Center, Greenbelt, MD 20771, ³Center for Research and Exploration in Space Science and Technology II (CRESST II) ⁴Southwest Research Institute, Boulder, CO 80302. ⁵Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139

Introduction: Titan, Saturn's largest moon, is the only satellite with a dense atmosphere, consisting of primarily nitrogen and methane [1]. The distribution of methane in Titan's atmosphere is a useful constraint on atmospheric dynamics [2], chemistry [3], and the coupling between the surface and atmosphere [4]. Further, UV-photolysis of this methane also leads to the formation of significant hazes in Titan's atmosphere [5]. These hazes have profound impacts on the energy balance of the atmosphere [6], can help trace global circulation [7], and are important for understanding the composition of Titan's surface [8] and the mixing of organic materials with surface liquid reservoirs [9]. Thus, understanding the global distribution of methane and hazes has important implications for interpreting the Titan system.

We present an HST/STIS data set (Program 12900 [10]), part of a campaign that included simultaneous Keck/OSIRIS, HST/STIS and Cassini/VIMS image cubes to provide visible and IR wavelength coverage from two viewing geometries (Earth-based and Cassini-based). The STIS image cubes extend the wavelength coverage to the 0.6 - 0.95 μm range, with the intent of characterizing haze distributions.

The objective of this work is to process the STIS image cubes to help make them useful to the general community. We present algorithms to identify and replace hot pixels, to determine the orientation of Titan's principal axes, determine the latitude and longitude of points on Titan's disk, and transform the image cubes onto a rectangular (lat, lon) grid.

Observations: STIS program 12900 consists of three image cubes taken with the G750M grating, each obtained in a single orbit on April 5, 2013, at wavelengths centered at 620, 720 and 890 nm, having a spectral resolution of $R \sim 12000$ (see Figure 1). Each cube includes methane absorption bands and adjacent

continuum regions. The intent is to provide vertical resolution: the contribution functions at these wavelengths peak at altitudes from Titan's surface to around 70 km (at $\lambda = 890$ nm), permitting sensitivity to Titan's near-surface methane content. Additionally, measurements of Titan's continuum offer sensitive constraints on the haze abundance. The STIS slit was scanned across Titan's disk, incremented by 0.05'' per step to cover Titan's entire disk.

Data processing/reduction: The STIS x2d FITS files contained numerous hot pixels from cosmic ray hits. We identify the hot pixels as regions where the difference between the x2d array and a median-filtered array were greater than $3\text{-}\sigma$, where σ is a robust estimation of the noise at each pixel. The median values were extracted from a $3 \times 3 \times 3$ volume ($\lambda \times \text{RA} \times \text{DEC}$) in each image cube.

To understand the spatial distribution of methane and the aerosols, the proper orientation of Titan must also be calculated. The orientation of the celestial frame relative to the STIS array is given by the 'PA_APER' and 'ORIENTAT' keywords in the FITS header. The center and radius of Titan's disk were determined by limb fitting, specifically, by taking a radial gradient of Titan's disk (summed over all wavelengths in a cube), finding limb points (local minima near the limb in the radial gradient), and fitting a circle to the limb points. Titan's disk illumination was over 99.95% during these observations, so Titan's disk should be nearly a circle. We used a $10\times$ oversampled version of Titan's disk for the limb-fitting procedure.

The latitude and longitude of each point in the disk can be calculated given three parameters: the latitude and longitude of the sub-observer point and the orientation of the Titan's north pole vector, projected maps can be generated that will permit studies of the spatial distribution of Titan's atmosphere (see Figure 3).

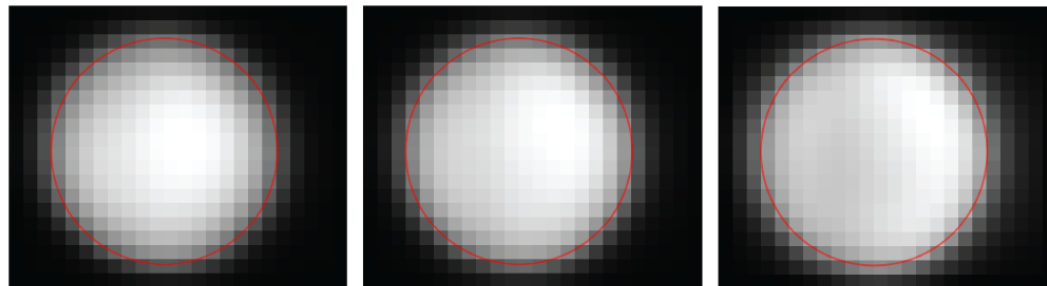


Figure 1: Three image cubes centered at 620 nm (left), 720 nm (center), and 890 nm (right). Best fitted circle is overlaid.

Results/Discussion: The resulting images show a comparison of the HST data before and after hot-pixel removal (see Figure 2). We then project this cube using the methodology described above to map the latitude and longitudes observed (see Figure 3). Finally, sampling points near the center of Titan's disk and the limb show significant variations in the absorption band depth, suggesting variations in the methane opacity of Titan's atmosphere between these points. A compass rose is also overlaid (see Figure 4).

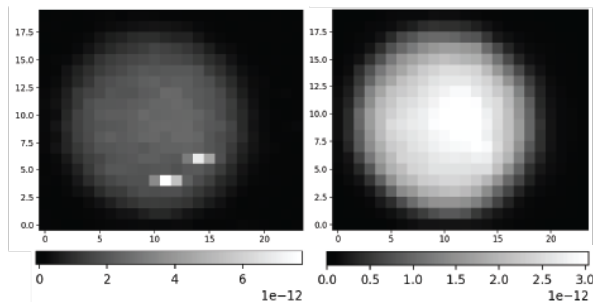


Figure 2: Before (left) and after (right) hot pixels are removed with the median filter. Right image has been renormalized after hot pixel removal.

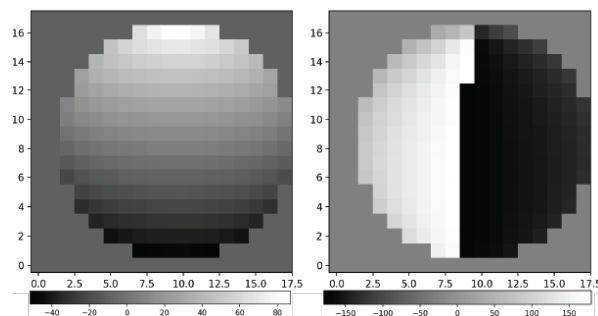


Figure 3: Latitude (left) and longitude (right) of Titan as seen from Hubble.

Conclusions/Future Work: Masking cosmic ray hits and characterizing the viewing geometry helps to enable radiative transfer investigations of Titan's atmosphere and surface. These STIS cubes may be used in future work in conjunction with Cassini VIMS and Keck/OSIRIS cubes to map the 3-d distributions of haze and methane. In particular, the STIS cubes may help map aerosols, which are more effective scatterers at shorter wavelengths, and are often anti-correlated with methane distributions in spectra which only cover near-IR wavelengths, permitting valuable constraints on the methane and haze distributions of Titan's atmosphere.

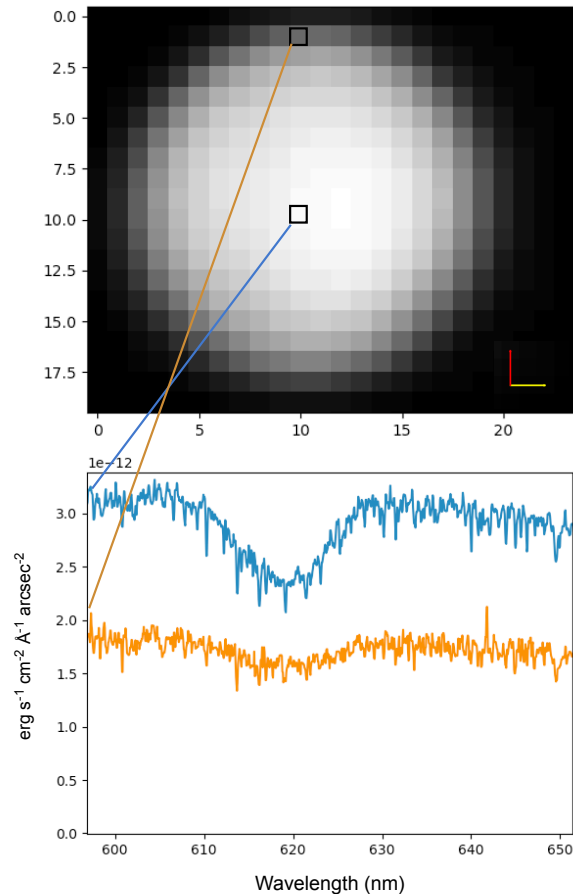


Figure 4: Shown above is a median filtered STIS image of Titan's disk summed over all wavelengths. Red indicates North. Shown below is Titan's spectra extracted from the center (blue) and northern limb (orange).

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