Planet Investigators: citizen scientists as key collaborators in processing and mining *Hubble* images of the Solar System.
M. J. Mutchler[1], A. Conti[1], S. Deustua[1], A. Viana[1], M. H. Wong[2], and P. L. Gay[3], [1]Space Telescope Science Institute, [2]University of California, Berkeley, [3]Southern Illinois University, Edwardsville.

Introduction: In 15 years of service, the Wide Field Planetary Camera 2 (WFPC2) onboard the *Hubble Space Telescope* (HST) obtained over 10,000 frames of Solar System images. Since standard data reduction pipelines are typically not optimized for moving- target data, our "planet pipeline" uniformly reprocesses and catalogs this WFPC2 image collection to make it more immediately science-ready. We intend to include images from Hubble's other cameras later.

Some of our processing steps engage citizen scientists to perform visual inspections. Our corresponding database enables robust queries which are more specific to planetary science, helping archival researchers quickly find and utilize the prepared images within our collection for a wide range of scientific analyses. We welcome suggestions (especially from veteran HST users) on the optimal treatment and organization of this data collection, and also to identify a broad range of analyses that might only be possible with visual inspections by citizen scientists. Our processed images and associated catalogs will be made available as High Level Science Products (HLSP) in the Mikulski Archive for Space Telescopes (MAST).

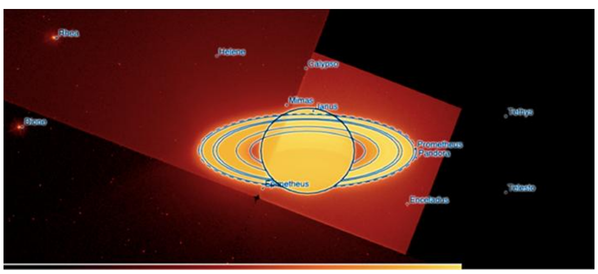

Figure 1: Drizzled WFPC2 mosaic of Saturn and moons, with catalog "finder chart" overlayed.

Special data processing: Our processing includes additional steps, beyond the basic calibrations performed by the standard pipelines, which are idiosyncratic enough that that they can be a significant barrier to faster and deeper analyses by scientists unfamiliar with HST data. Unlike fixed-target data, where rejection of artifacts is accomplished by combining multiple images, cleaning up moving target images requires an ability to distinguish real objects from artifacts in single images. For the initial rejection of bad pixels, cosmic rays, and star trails, we use single-image rejection techniques based on Laplacian edge detection [1]. Then each image is visually inspected to identify missed rejections of artifacts, and also unintentional rejections of real objects or features. The inspections also record secondary and serendipitous objects and features in each image, to form a comprehensive catalog. Overlayed finder charts are used to help verify which satellites were detected in each frame, and possibly help reveal the presence of known or unknown asteroids or Kuiper belt objects (Figure 1). Dynamic planetary surface features such as storms, vortices, satellite umbrae, volcanoes, and craters can also be recorded. Each of the objects and features recorded will be assessed for overall data quality. Secondary objects in these images have a higher probability of being somehow non-optimal: poorly placed, barely detected or over-exposed (saturated), so it is important to discern which of these "extra" observations may be useless.

Engaging citizen scientists: Many moving-target image processing and analysis steps still rely on visual verification and acuity. Since our data set is large, the notion of manually inspecting every frame would have seemed prohibitive just a few years ago. But we can now rely on the fast-growing population of citizen scientists for several of the tasks described above -- and we feel challenged to identify even more advanced eyeball-driven tasks. Our "Planet Investigators" website (Figure 2) will allow people to assist us in verifying our artifact rejections and object catalogs [3].

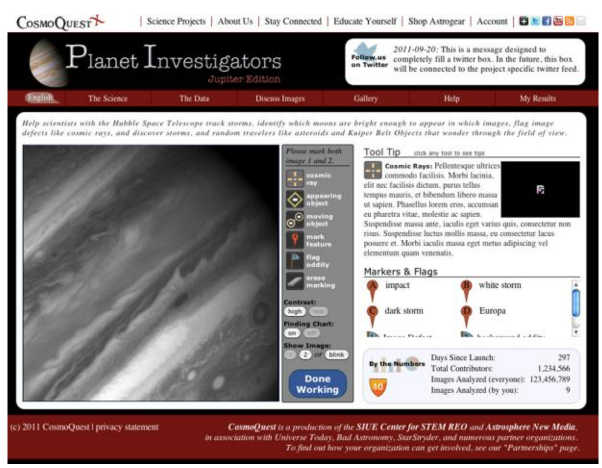

Figure 2: CosmoQuest's "Planet Investigators" interface for inspection of planetary Hubble images: PlanetInvestigators.org

It is now easily possible to have each image inspected multiple times, and set up iterative processes that can converge on the optimal output with greater confidence. Also, most Solar System objects fit on the higher-resolution Planetary Camera (PC), which means that the much larger adjacent Wide Field (WF) data was in many cases ignored, and may have never been inspected by human eyes. The possibility of citizens discovering Solar System objects in these often unexamined “bonus” fields is also tantalizing.

High Level Science Products: Using our refined rejection masks, we include all four WFPC2 chips to produce clean and undistorted mosaic images. We will optimally resample both Planetary Camera (PC) and Wide Field (WF) data by drizzling them to a common pixel scale, partly chosen to enable later image deconvolutions. Interpretation of solar system observations relies on time-variable properties such as observing geometry, solar orientation, etc. For each image, we obtain ephemeris data from the JPL Horizons website, associating the keywords in Table 1 with the image data. These keywords are then used to calculate the conversion between counts/sec in the image data into reflectivity, or I/F, following Sromovsky & Fry [2]. This planetary meta-data is already available in our online database, and will also be stored in the FITS header of each data product.

Table 1: Ephemeris meta-data stored for each image, gathered from the JPL Horizons website: http://ssd.jpl.nasa.gov/?horizons

Horizons keyword	Description
1	Astrometric R.A. and DEC (J2000)
6	Satellite offset and PA from primary
10	Illuminated fraction
13	Target angular diameter
14	HST sub-longitude/latitude
15	Sun sub-longitude/latitude
17	North pole position angle & distance
19	Heliocentric range (and rate of change)
20	HST range (and rate of change)
21	One-way light time
24	Phase angle
26	HST-primary-target angle
39	Uncertainty in range and range rate

Enhanced database: We created a database which provides access to the raw science data and our High Level Science Products (HLSP), and resolves issues that make standard MAST queries of planetary data prone to incompleteness. Our web-accessible interface allows robust queries which are more specific to planetary science, utilizing our standardized target names, meta-data, catalogs, and data quality ratings (Figure 3). Our database will allow archival researchers to mine this large data collection more effectively.

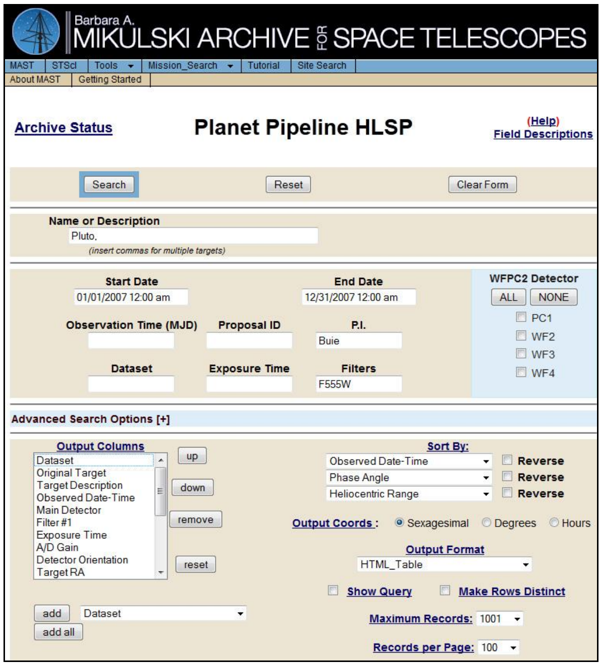

Figure 3: Planet Pipeline search interface within the Mikulski Archive for Space Telescopes (MAST): http://archive.stsci.edu/prepds/planetpipeline

Next steps: Beyond our initial data processing, we have further analytical steps in mind, which also rely on visual inspection by citizen scientists. For example, a deprojection (or mapping) tool would enable the tracking of storms and cloud features, and the creation of color composites of rotating targets. An aperture photometry tool would enable studies of satellite and small body phase curves and rotational light curves. But we also welcome suggestions on projects that could be done with our prepared data, which might only be possible with the engagement of the growing population of citizen scientists.

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References:

[1] van Dokkum, P.G. (2001) PASP 113, 1420–1427. [2] Sromovsky, L., Fry, P. (2002) Icarus 157, 373–400. [3] Gay, P.L., et al. (2013) LPSC Meeting, Houston