Applying PCA Filtering to Bolide Detection in Video Observations of Saturn and Jupiter

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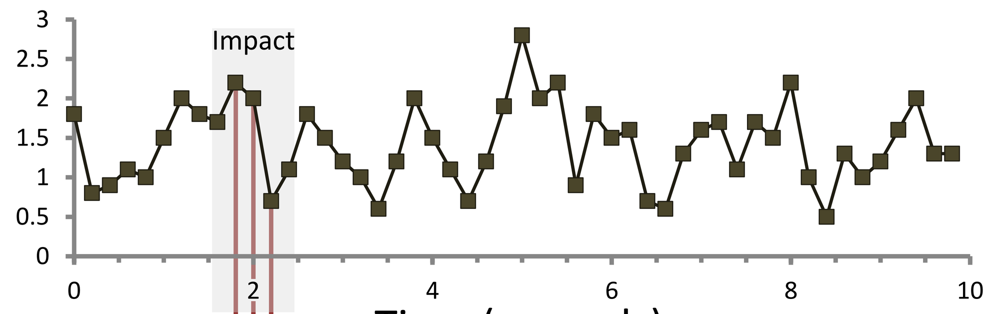
Abstract:

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 its greater distance from Earth and that its smaller gravitational potential 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 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.

Input Image:
Hubble Space Telescope Green Filter (F588N)

Beginning with 50 copies of this image as 0.2-s exposures, add:

- A one-second impact with a Gaussian light curve peaking at t = 2.0 s.
- Photometric scaling and diffraction for a 16-inch telescope aperture.
- Poisson noise and variable atmospheric transparency from 95-100%.
- Sub-pixel misalignment of the images from frame to frame.
- Variable atmospheric seeing, as shown here:



Frame 10: t = 1.8 s

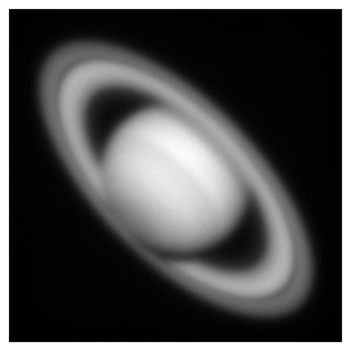
Frame 11: t = 2.0 s

Frame 12: t = 2.2 s

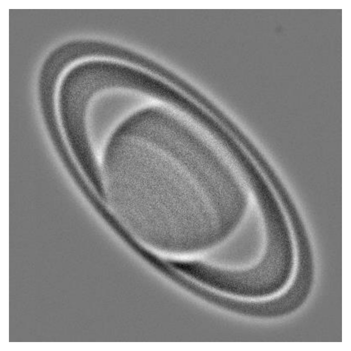
Synthetic Amateur Video Data

Principal Component Analysis (PCA)

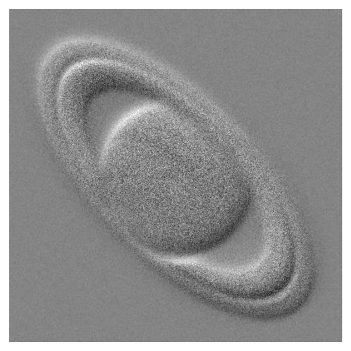
Principal components (PCs) are co-varying signals in a data set.
The largest covariance present is described by PC 1.
Performing PCA on the synthetic video data yields 50 PCs.
The first four PCs are shown with the causes of their signals:



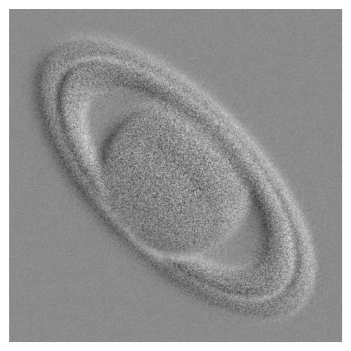
PC 1
Saturn



PC 2
Blurring from atmospheric seeing



PC 3
Frame-to-frame misalignment of Saturn along the major axis of Saturn's rings

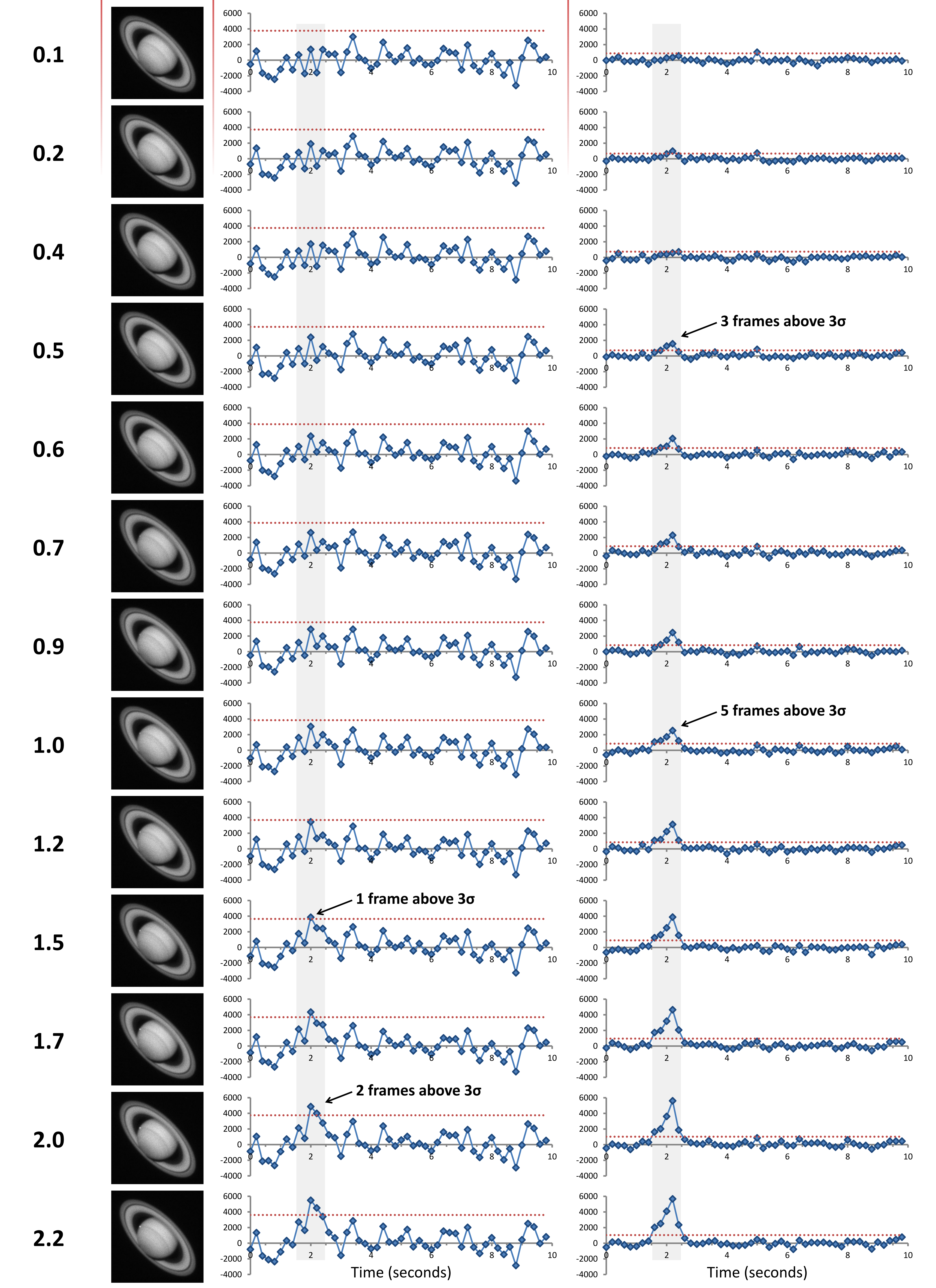


PC 4
Frame-to-frame misalignment of Saturn along the minor axis of Saturn's rings

PCA Filtering:

The signals from PCs 1-4 should be removed to search for transient events in the video.

Impact Signal to Noise	Clearest Impact Image	**Current Detection Method:** Median Image Subtraction	**Proposed Detection Method:** PCA Filtering (Removing PCs 1-4)



These extracted light curves of synthetic Saturnian bolides show that PCA filtering detects fainter impacts than subtracting the median image from each frame. Impact times are highlighted gray. The units for the vertical axes are photons. Dashed red lines mark the 3σ detection limit.