

Observing Titan with amateur equipment

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Abstract

We survey the observations of Titan that can be made using equipment available to amateur astronomers. Off-the-shelf hardware includes spectrometers and photometers that can detect Titan's infrared light curve and potentially its clouds. CCD spectra and photometry (both photoelectric and CCD), even with small (20cm) telescopes, are useful for monitoring seasonal changes in Titan's haze. Recent remarkable advances in automatic stacking of thousands of short-exposure images obtained with webcams may even permit Titan's disk to be resolved. We additionally report some observations made with amateur equipment mounted on the 1.64m Gerard P. Kuiper telescope on Mt. Bigelow.

1 Introduction

Titan, with a visual magnitude of about 8 is, unlike the Galilean satellites, too faint to observe with the naked eye. The Galileans, of similar size but twice as close to us (as well as the Sun), are intrinsically bright enough (magnitude ~5) to be detected with the naked eye, although the glare of nearby Jupiter usually makes this impossible. A small telescope, or a very good pair of binoculars, allows Titan to be seen as a brownish dot near Saturn, and its movement night-to-night makes it obvious – to us, as well as to Huygens in the 17th century – that it is a satellite of that body.

Titan's atmosphere, like those of the other planets, is a dynamic object whose full understanding requires constant monitoring (e.g. Lorenz and Mitton, 2002). Although much of our understanding of them derives from the detailed, but brief, observations during the Voyager encounters and more recently by space-borne observatories and large ground-based telescopes with adaptive optics systems, there remains much to be gained from simple observations. Even during the Cassini tour, continued monitoring from the ground has an important role to play, since months may pass between consecutive Titan encounters. Thus not only is Titan a topical target for amateurs to observe, but careful work can make a meaningful contribution to Titan science.

A prime example of such monitoring is the work of Wes Lockwood and colleagues at Lowell Observatory who have obtained a consistent photometry dataset of the outer planets and Titan over some 30 years, a dataset which has helped understanding of Titan's seasonal cycle (e.g. Lorenz et al., 1999). Another example is the discovery of cloud activity on Titan (Griffith et al., 2000). Only continued monitoring permitted the detection of anomalous brightening attributable to weather activity. The changes in Titan's brightness due to seasonal change is only a few per cent at visible wavelengths; the rotational light curve has a variation of around 10% in the near-infrared, while variations due to cloud activity may be a little lower.

As discussed in [11], dramatic improvement in the capability/cost ratio of home computers and in the availability of reasonably priced CCD cameras (driven largely by camcorder requirements) have put sensitive instrumentation in the hands of many amateur observers. Further, the explosion of the internet has made it far easier for like-minded amateurs to contribute observations to a common database and to follow up targets of particular interest. Many organisations exist which support and encourage amateur observations, such as the AAVSO (Association of Amateur Variable Star Observers), ALPO (Association of Lunar and Planetary Observers), the BAA (British Astronomical Association). In the areas of variable star observing, and supernova detection, these organisations are well established as major contributors. In planetary science, the IOTA (International Occultation Timing Association) has successfully collated amateur observations to obtain otherwise unobtainable datasets, a good example being the 1989 occultation of Titan by 28 Sag. In addition to consulting these organisations, interested amateurs can participate in the Cassini Saturn Observation Campaign, and a web search on topics such as 'amateur spectroscopy' will yield many useful links.

In this article, we briefly survey various types of observations that can be made with amateur equipment. First we describe spectroscopy, then visible and infrared photometry, and finally discuss the possibility of resolving Titan. We should note that most of these techniques can be applied to Uranus and Neptune as well: Uranus is both larger and brighter, while Neptune is comparable in terms of size and brightness, but is easier than Titan in that scattered light from Saturn is not a problem. An amateur might therefore do well to try some of these techniques first on Uranus and Neptune before Titan.

2 Spectroscopy

It was through the analysis of Titan's spectrum that Titan's atmosphere was discovered by Kuiper in 1944. Titan is noticeably brownish – this is due to the thick organic ('tholin') haze created by the action of ultraviolet light on methane – the spectrum (see Figure 1) has a pronounced upslope to the right (i.e. a 'red' colour). Longward of about 600nm, strong absorption bands are present due to methane. The atmosphere is dark in these bands. In between the bands (e.g. at 940nm, about the wavelength of a TV remote control), the atmosphere is partly transparent, and a variation in brightness of around 10%

occurs during one Titan orbit due to variations in brightness across Titan's surface.

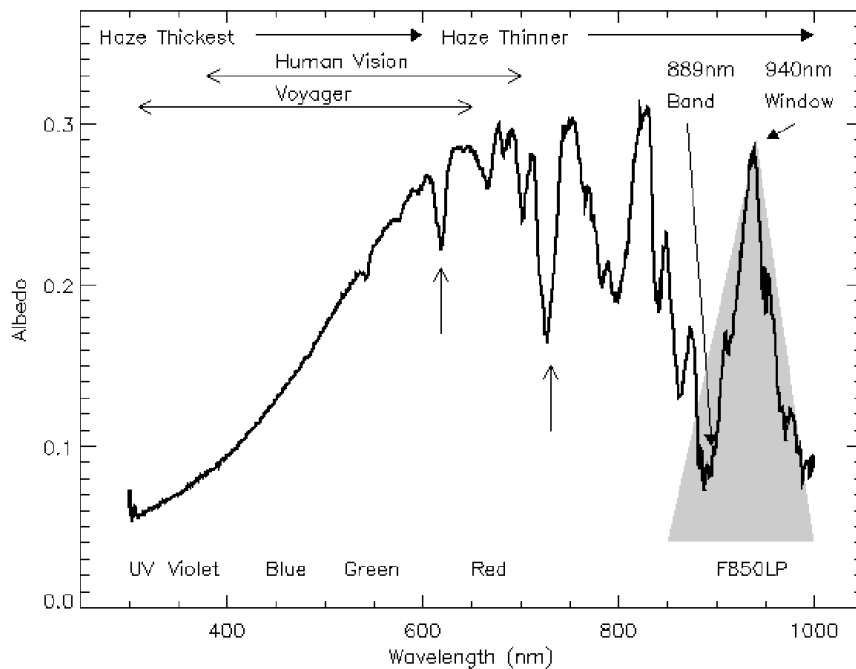


Figure 1: Annotated spectrum of Titan (from Karkoschka, 1995) showing the reddish colour and the methane absorption bands (after Lorenz and Mitton, 2002)

At least part of a spectrum crudely like that above can be obtained fairly easily, using a transmission diffraction grating to perform slitless spectroscopy with a CCD camera and a 20cm telescope (Lorenz, 2002). Essentially, a diffraction grating ('Rainbow Optics' make a convenient grating that is mounted in a 1.25 inch filter mount) is placed in the optical path from the telescope, either to the eye or to a CCD or other camera. The grating disperses part of the light into a streak, and the separate streaks for Saturn, its rings, and Titan are readily seen. The absorption bands of methane are easy to spot (use of a yellow or red filter may help eliminate the effect of second-order dispersion, enhancing contrast at long wavelengths).

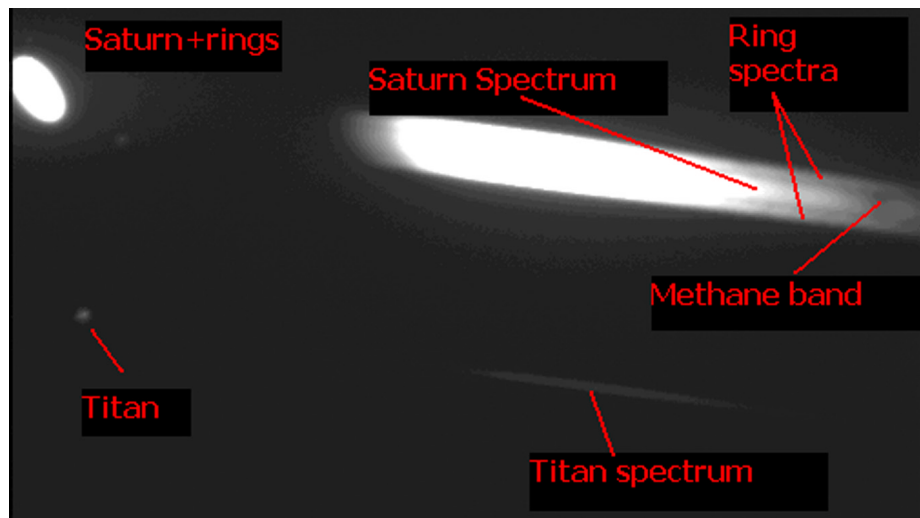


Figure 2: Saturn and Titan observed through a diffraction grating on a 20cm telescope (by Lorenz). Saturn at top left has light smeared into a bright streak – with this dispersion direction the separate spectra of Titan and the rings can be seen – Saturn’s spectrum has methane bands while the rings do not. Titan and its spectrum are much fainter, but close study with image processing tools shows methane bands there too.

Higher resolution spectra can be obtained with other designs such as fibre-optically coupled spectrographs now available to amateurs ([3],[6]; see also www.sivo.com) or conventional slit instruments such as the Santa Barbara Instrument Group (SBIG) spectrograph ([4] - see www.sbig.com) and that constructed by one of us (Fujii – see Figure 3). Because of the increasing transparency to longer wavelengths, changes are easier to detect in the near-IR than at visible wavelengths. A detector that is sensitive in the IR is therefore particularly advantageous.

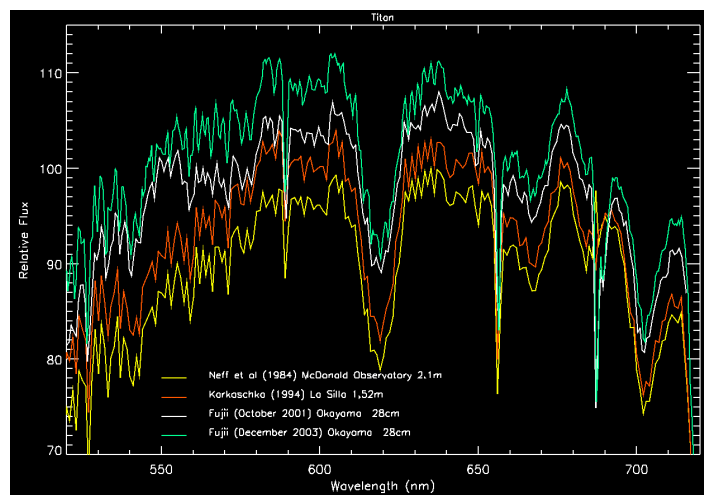


Figure 3: Green to near-IR spectra of Titan, showing the prominent methane absorption band at 619nm. The top two curves (green, white) are taken with a 28cm telescope and a home-built spectrometer. Lower curves (yellow, red) are professional spectra taken from the literature: curves are offset for clarity. Clearly the amateur equipment is capable of supporting detailed scientific analysis. Spikes at 580, 655 and 687nm are terrestrial absorptions.

3 CCD photometry of Titan

Brightness variations can also be detected with CCD photometry. Titan is tidally locked to Saturn and so presents the same side to it, while the longitude visible from Earth varies by about 23 degrees from one night to the next. An attempt to measure Titan's light curve, i.e. its night-to-night variations using a 30cm telescope with V and I broadband filters (Lorenz et al., 2003) was inconclusive - there was considerable scatter in both absolute and relative (V-I) photometry. It is possible, but unlikely, that Titan variations may have been a significant contributor to the scatter.

Antonin Bouchez^[2] has reported considerably better results using a 35cm telescope (at an urban Los Angeles observing site!) and narrowband filters at 750, 795, 825 and 890nm, which isolate methane bands (whose brightness should not change day-to-day) and windows (which should). In particular, the 750/795 and 825/890 flux ratios show a consistent light curve of around 5% amplitude (the respective flux ratios have a mean of 2.5 and 4.2 respectively, although this will depend on the exact bandpass of the filters used and the spectral sensitivity of the camera.) Bouchez et al. used a Santa Barbara Instruments Group ST-9E with a plate scale of about 1 arcsecond per pixel: exposure times of only 5-10s were necessary.

In addition to the expected light curve, the data in Bouchez (2004) has indicated that several observations had anomalously high ratios, indicating the possible presence of clouds.

4 Photoelectric photometry of Titan

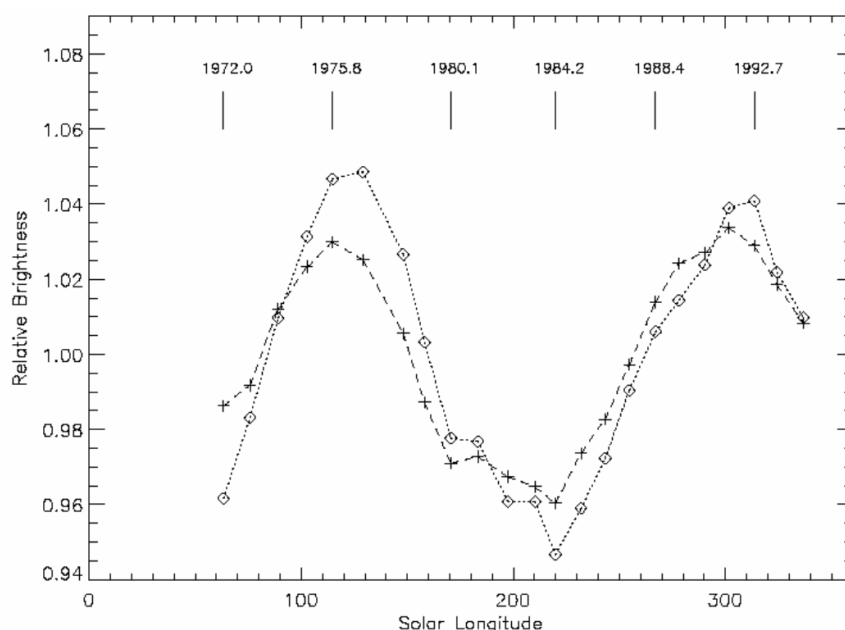


Figure 4: Measurements of Titan's disk-integrated brightness by Lockwood (from Lorenz et al., 1999) showing the +/- 5% variation in brightness at blue (diamonds) and the +/-3% variation in yellow light. Historical variations of Titan's brightness are also discussed in Anderson (1977).

Although the proliferation of CCD cameras makes CCD photometry, where image processing software is used to measure the light from Titan and to subtract the scattered light background by summing pixels, rather widespread, the inherent simplicity and precision of photoelectric photometry (wherein a single filtered photodiode or photomultiplier detector is used to measure the light levels) is an attractive alternative. Lockwood's data (see Figure 4) showing a clear twice-per-Titan-year seasonal variation in blue and yellow light was acquired this way.

We have experimented with an Optec Inc., SSP-4 photometer (approx \$2500), which is equipped with H and J (1.6 and 1.3 micron) filters. Note that the use of filters is particularly important in the near-IR, not only in providing a standard wavelength for measurement, but also in minimising the sky absorption due to atmospheric water vapour. Unfortunately, 8-12 inch telescopes do not gather enough light for this instrument to give robust results - recall that the flux falls off rapidly with wavelength.

We have used an SSP-4 photometer on the Gerard P. Kuiper 1.64m Cassegrain telescope on Mt. Bigelow, near Tucson. This telescope (better known as the '61-inch') was erected by the discoverer of Titan's atmosphere primarily to perform a survey of the lunar surface in preparation for the Apollo landings. These days it is relatively undersubscribed, and thus not difficult to obtain time for modest projects such as Titan photometry. Access to the 61-inch was made somewhat difficult in 2003 due to the large forest fire that engulfed the Catalina Mountains, wiping out the village of Summerhaven a few km from the Bigelow site.

The standard aperture on the SSP-4 is in fact rather small, such that with the substantial focal length of the 61-inch, fluctuations in seeing and focus, plus occasional tracking drifts, meant that the Titan contribution within the aperture varied strongly with time. We may also note that while optically very dim, the red-painted low-wattage tungsten lighting in the observatory dome is a very strong source of 1-2 micron radiation, and thus great care had to be taken to avoid stray light.

Because of the fluctuating Titan contribution, the usual approach of manually reading off the flux result from the LED display on the instrument was frustratingly ineffective. Owing to these problems, and to obtain a time series output for stellar occultations, such as the November 2003 occultation (sadly, the Bigelow site was clouded out) some custom firmware was provided to us by Gerry Persha of Optec, such that the integration result was streamed continuously to a serial port for capture by a PC. Initial attempts to salvage the small-aperture data with statistical analysis have proven unsuccessful - we plan to conduct further observations in the future with a larger aperture, which should be more tolerant of tracking and seeing effects.

5 Occultation measurements

An important opportunity for amateur observers to contribute to understanding Titan is during stellar occultations, when Titan passes between us and a star. As the starlight is refracted through Titan's

atmosphere, the variation of density with height in the atmosphere can be determined from the way the light level varies with time.

Although we report no new results of our own here (we were clouded out during the November 2003 occultation), it is pertinent to mention the significant contribution from amateur observers during stellar occultations by Titan. CCD and photoelectric photometry can provide high signal-to-noise light curves, which when assembled with those from other sites, can perform ‘tomography’ of the density structure of Titan’s stratosphere, typically from around 200-400 km altitude. The interested reader is referred to the website of Bruno Sicardy at the Observatoire de Paris, Meudon for further details^[13].

Video records are also possible for bright stars (and image intensifiers are becoming available which expand the range of stars applicable for this technique), although traditional video recording gives poor signal-to-noise. We note it is also particularly important to obtain accurate (0.1s) timing during such events.

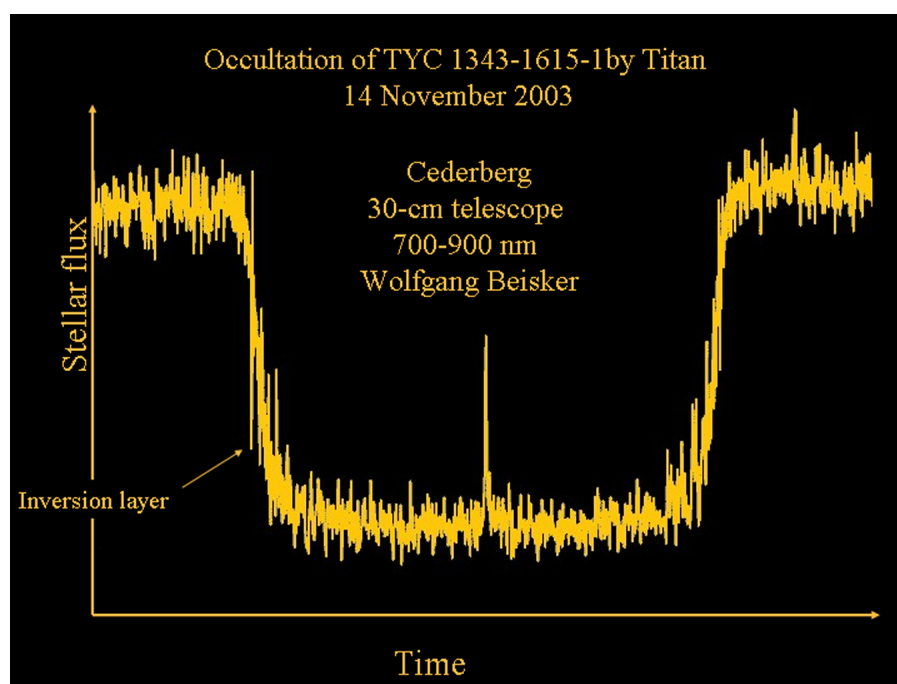


Figure 5: Occultation light curve from occultation of an 8.6 magnitude star in November 2003 observed with a 30cm telescope. (Figure Bruno Sicardy). The event takes a few minutes – the light level measured in a circle containing Titan drops from (Titan plus star) to (Titan only), but as it does so shows scintillation spikes indicating an inversion layer. The strong central flash is caused by light refracting around Titan’s atmosphere, even though the star is directly behind Titan: the exact shape of the central flash can allow measurement of Titan’s winds.

6 Resolving Titan

Only in the last decade or so have instrumented telescopes been able to observe Titan as more than a dot in the sky (i.e. resolve it, or perceive details smaller than Titan itself.) The Hubble Space Telescope and ground-based

facilities with adaptive optics systems have transformed our understanding of Titan by providing resolved images (typically 10-20 pixels across Titan's 0.8 arcsecond disk). Although Titan's disc is smaller than the typical seeing limit of ~ 1 arcsecond, it should be noted that seeing limitations due to atmospheric turbulence are less severe for small telescopes (since the wave front is more likely to remain coherent across a small telescope aperture.) The usual effect is for the image to wiggle around, rather than be itself distorted. Short-exposure or video imaging can also be used to 'freeze' the motion of fast-moving targets such as Earth-orbiting spacecraft, as well as the apparent motion of targets due to seeing. Observations with short exposure times, such as video records and the human eye, can therefore perceive details smaller than the typical seeing limit.

Although an individual frame with an exposure time of well under a second is usually too faint to be useful, multiple frames can be shifted and added. Furthermore, free software is available to select the sharpest images from a sequence obtained with a video or web-camera, such that remarkable images may be generated from hundreds of stacked frames with only modest effort. Previously unknown details on the surface of the planet Mercury have been obtained this way.

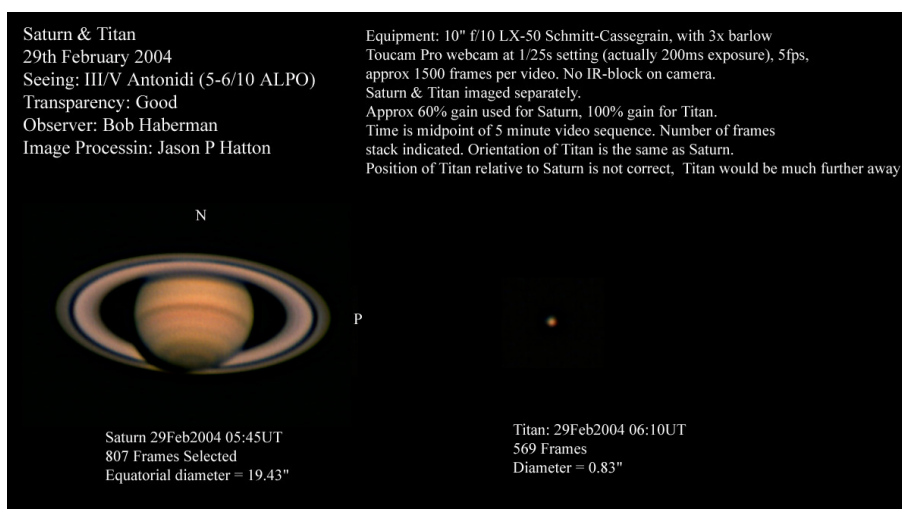


Figure 6: Images of Saturn and Titan acquired by Bob Haberman of San Francisco using a webcam and a 25cm telescope, processed by Jason Hatton. Considerable detail on Saturn is visible, and Titan is perceptibly round and reddish.

There is of course a trade-off, in that smaller telescopes have less light-gathering ability, and thus lower signal-to-noise (to achieve a useful image, individual frames must receive a statistically useful number of photons to permit the image alignment for stacking.) Furthermore, small telescopes are subject to the diffraction limit. A 20cm telescope at 500nm wavelength has a diffraction (Dawes) limit of about 3 microradians, or about 0.5 arcseconds, so Titan is barely resolved, although it is well known that the Dawes limit may be a pessimistic estimate when extended objects such as planetary bodies are being observed.

Nonetheless, under good conditions, skilled observers may be on the threshold of resolving Titan in a reproducible way. Images of Jupiter by

several observers, obtained by stacking several hundred images from a ~\$200 webcam show details on the surface of Ganymede (only twice the size of Titan as seen from the Earth) As yet no credible resolved images of Titan have been published, but trial observations under poor conditions (see Figure 7) suggest that this may soon change. A key diagnostic will be whether a difference in brightness between north and south hemispheres can be perceived – this asymmetry should have the north darker in blue, but brighter in the near-infrared.

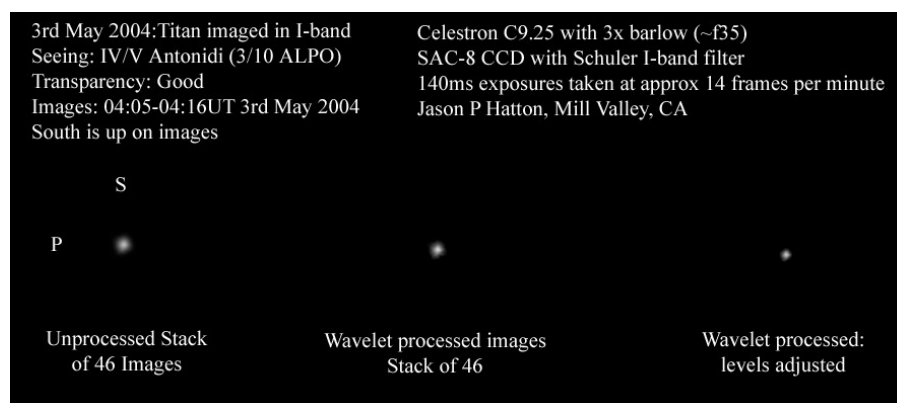


Figure 7: Near-infrared image of Titan acquired in moderately poor conditions by Jason Hatton, showing promise that Titan can be resolved.

Even the human eye can make a contribution, although a problem with non-instrumental observations is their repeatability and thus their believability. We may note that evidence of limb darkening (the apparent darkness of the edge of Titan's disk, and thus the inferred presence of an atmosphere) was found with an 18cm telescope by the gifted Catalan astronomer Comas Sola in 1907. Using a rather larger telescope, Dollfus and Lyot also resolved Titan's disk, providing sketches of subtle cloud patterns (these were confirmed by other observers at the same telescope). In the modern era, it may be that amateurs are able to perform observations of the same fidelity as these historical pioneers, but can offer an electronic record of their observations that may make their contribution more useful.

7 Conclusions

We have surveyed how small telescopes and relatively inexpensive instrumentation can make useful contributions in the study of Titan and the outer planets. Even small telescopes can make a useful contribution, providing care is taken to ensure precision measurements. Titan presents a range of challenges to the amateur, who may settle for a simple spectrum to reproduce Kuiper's discovery of Titan's atmosphere or steady photometry to measure seasonal changes. Dedicated and well-equipped amateurs may be able to detect Titan's light curve with precision photometry or spectroscopy – this light curve was discovered by professional astronomers only twelve years ago.



Acknowledgements

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- [12] Additional resources may be found at <http://www.lpl.arizona.edu/~rlorenz>
- [13] <http://calys.obspm.fr/~sicardy/>