



Pluto Occultation with SOFIA on 29 June 2015 in Support of New Horizons Fly By: Occultation Evidence for Haze

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Outline



- Background
- The 29 June 2015 data.
- What it means for Pluto and its atmosphere
- Some problems that needed to be solved
- Summary
- A special thanks





Background

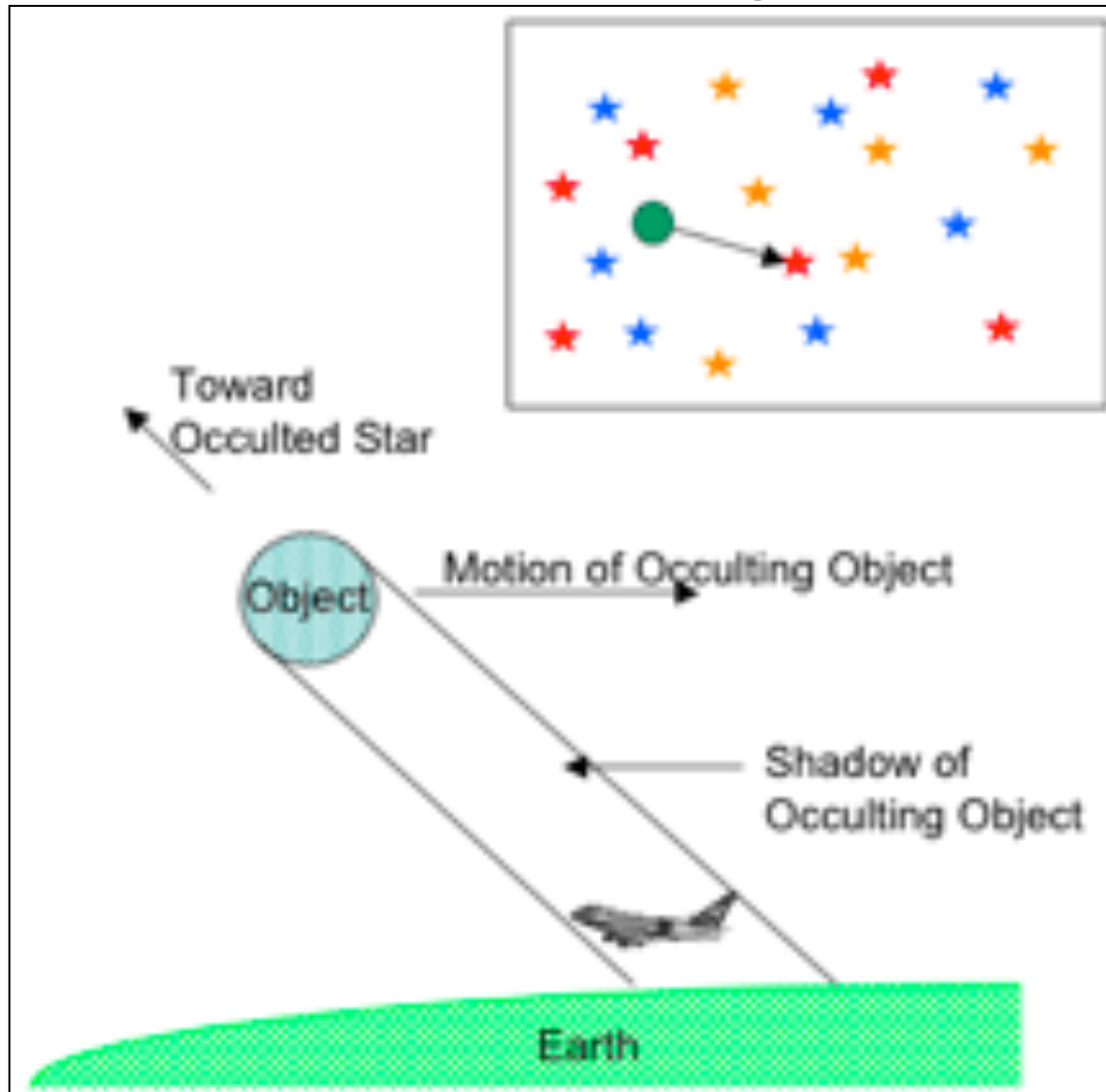


- When a Star goes behind a Planet (Occultation), we can learn about the Atmosphere of the planet by measuring how the radiation disappears and reappears.
- On SOFIA the FLITECAM camera, HIPO occultation camera and the Focal Plane Camera (FPI+) can operate simultaneously by use of dichroic beam splitters.
- Made Simultaneous observations at 4 wavelengths of Pluto Occultation of 29 June 2015 from New Zealand
- Highest Priority request from the New Horizons team was 2 micron observations including a central flash
- I was lucky enough to be on the flight.





Occultations can best be done from a Flying Observatory

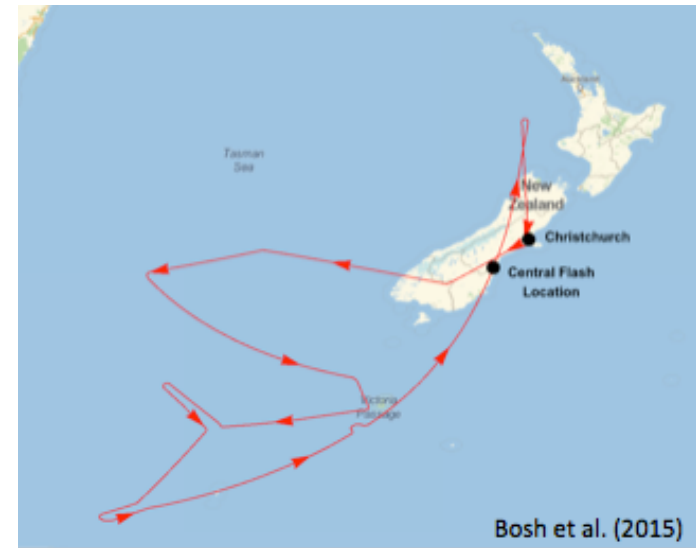




Pluto Occultation on 29 June 2015



- Occultation of 12-mag star by Pluto on 2015 June 29 in support of New Horizons.
- Goal was to be within 25 km of center of Pluto shadow of 2400 km. (1 milli-arcsec and 100 milli-arcsec)
- Ground shadow moves 90,000 Km/hr. Plane 900 Km/hr.
- Final ground-based shadow updates required course adjustments of 200 km (8 milli-arcsec)
 - Updates to shadow path kept coming even after the plane took off.
 - Mobility of SOFIA was key to getting the observation

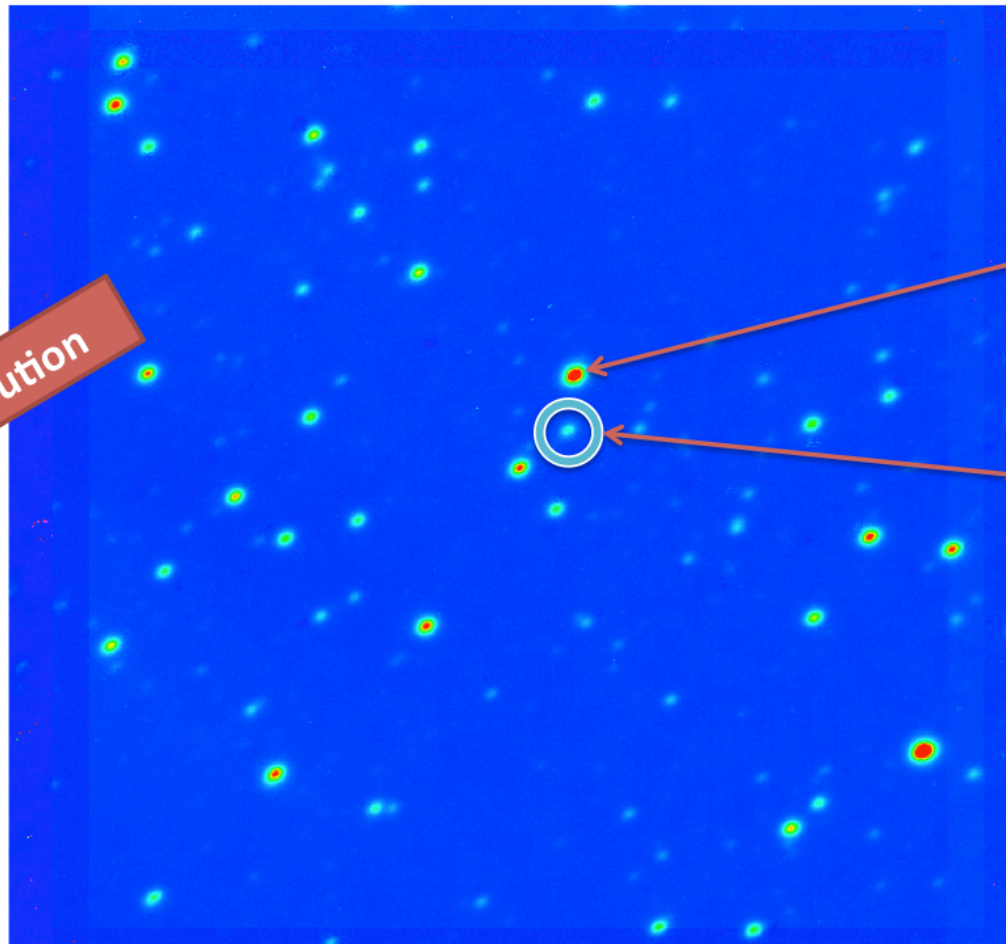




Pluto and Occ. Star at 1.8 microns 5 hrs before the Occultation



Not For Distribution



Occultat
Star

Pluto





FliteCam team during Occultation





Ted, Mike & Ryan during Pluto Flight

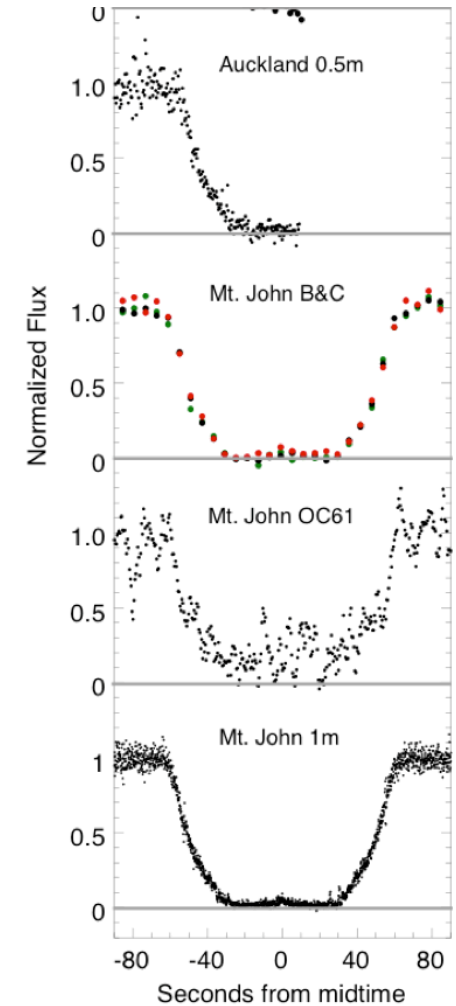
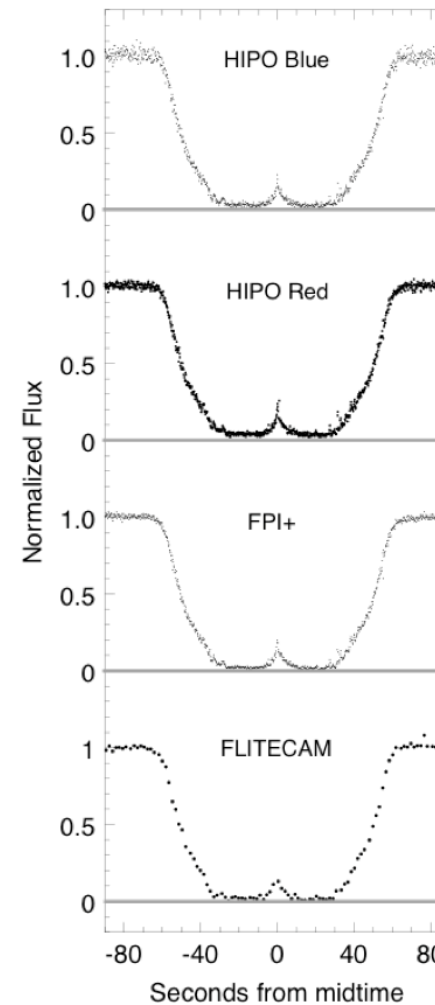




Science Highlight: Pluto Occultation



- Detection of strong “central flash” confirms accuracy of course corrections (within ~20 Km of Pluto center)
- Light curves show effect of mostly refraction in a thin atmosphere.
- Stability of Pluto’s atmosphere over last 25 years determined.
- Comparison of multi-wavelength observations allows detailed analysis of atmospheric profiles and aerosol or haze content.





Little or no change in last 25 years of

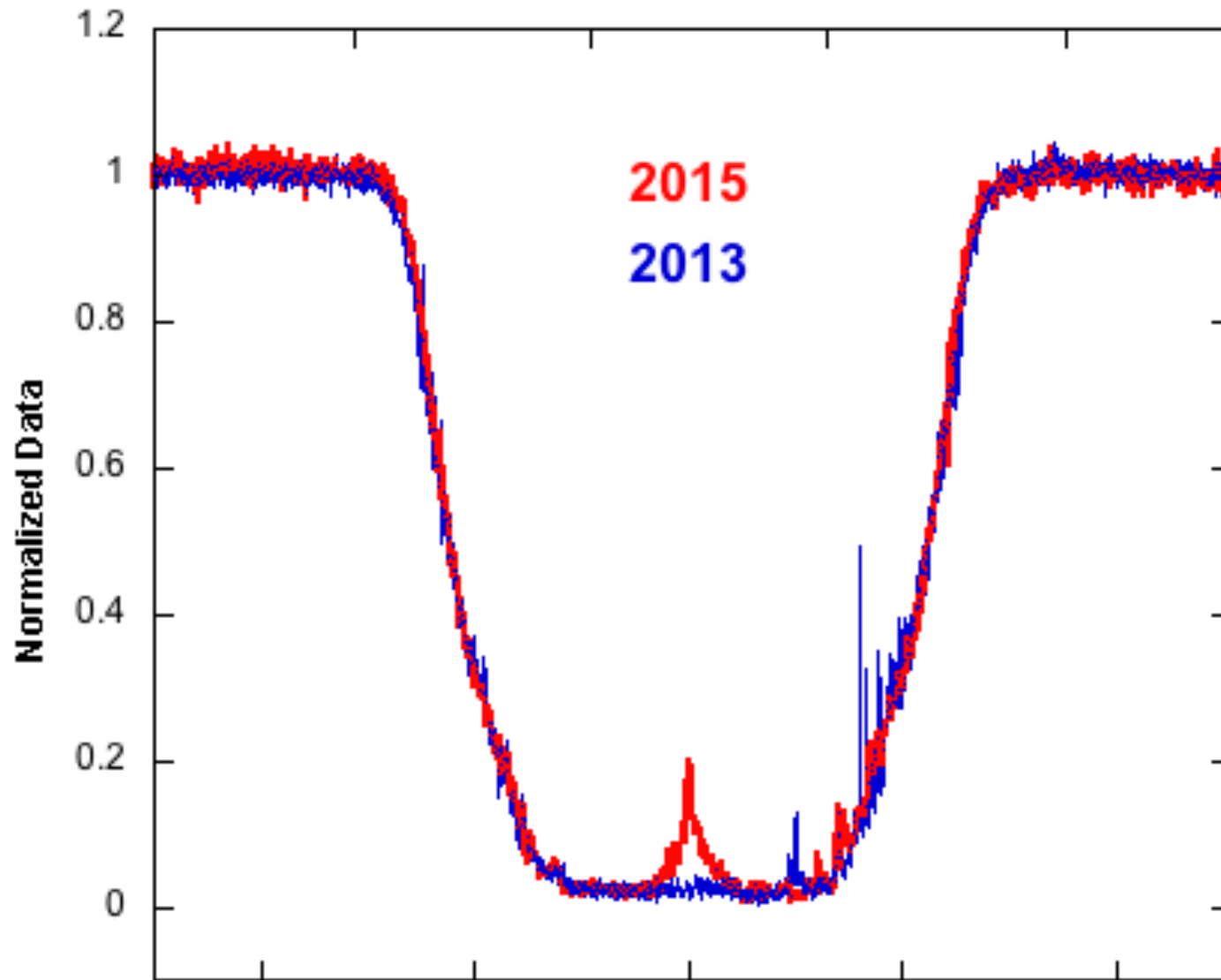


Pluto Atmosphere

- Pluto is moving away from the Sun
- Some people suggested a change might occur (ie atmosphere would decay)
- Little evidence from Occultation data for any change over ~ 15 years. Some change earlier, density was ~ 2 times higher.



Comparison with earlier results

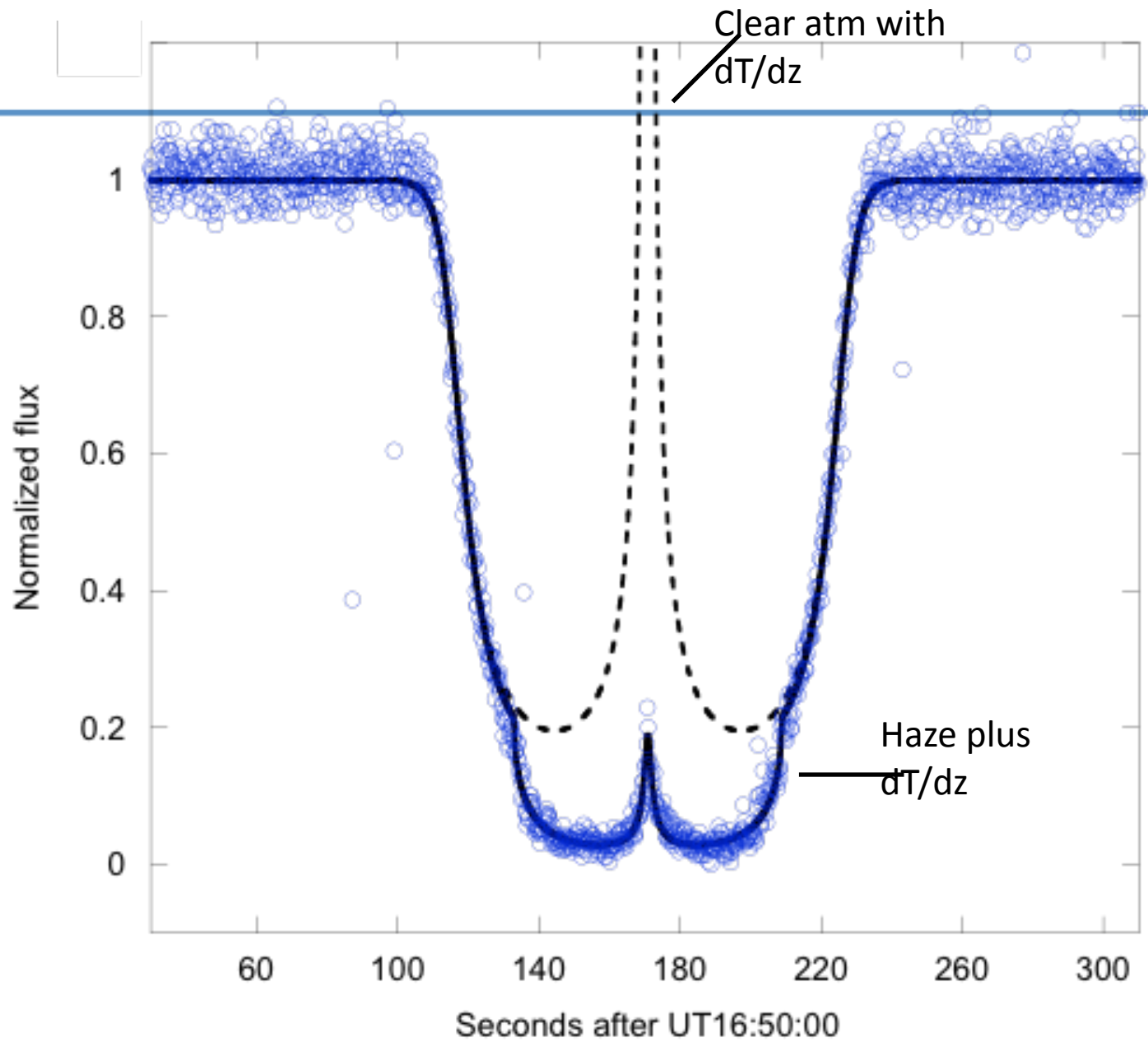




Central Flash and Depth Suggest Particle Haze is Present



- No atmosphere would produce a square occultation
- A Clear atmosphere would produce large central flash and extra emission at the bottom of the light curve.
- The refraction starts at 10 to 20 Km above the surface outside the surface of the planet.





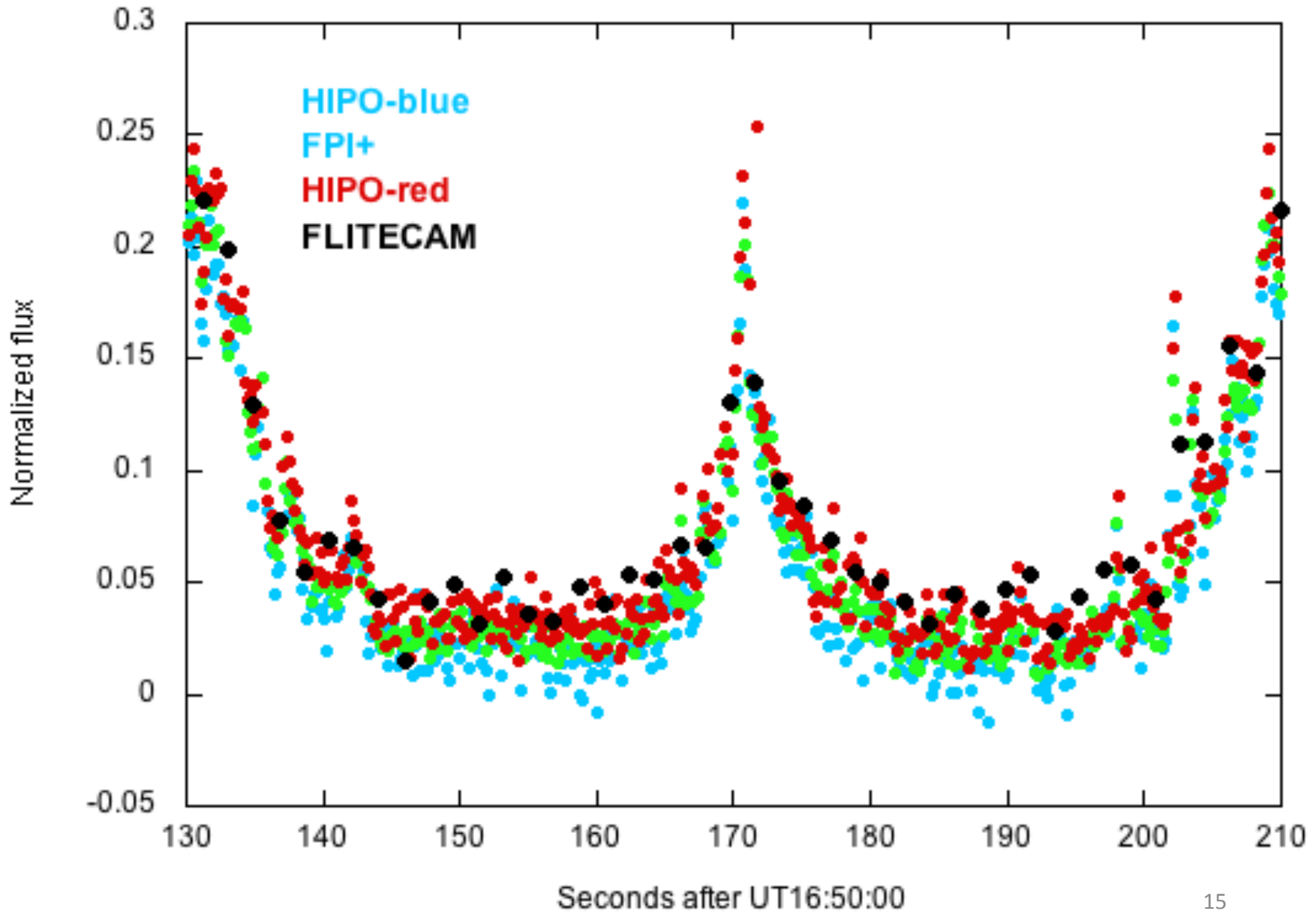
The Blue to Infrared curves show the presents of dust or haze



- Blue curve shows smallest excess emission at the bottom (cloudy or not clear)
- Infrared shows the highest excess emission (clearest atmosphere because IR sees through the dust)



Light curve minimum flux





Summary of color data



- 1.8 micron data show the least effect of dust in the light curves (relatively low central flash is due to long integration time)
- Similar trend was shown in 2002 from Hawaii MKO data (Elliot et al 2002)
- Amount of dust needed is similar to haze seen by NH
- A model without dust, using temperature and pressure gradients, results in a Pluto radius smaller than that measured by NH by 50 km. Also does not explain the 1.8 micron data.





Some Problems that needed to be solved



- Position update of Pluto and the occultation star.
- The aircraft damage the day of the occultation.
- The weather and where to land.
- Two problems with FliteCam (Electronics and extra background from engine emission)



The Position Updates



- Position updates kept coming even after we took off.
- Measurements were being made from around the world (Chile, Arizona) and analyzed at MIT
- Changed the flight path by 200 km (Mostly due to Pluto bright spot)
- Worked out how to do the navigation on the practice flight the night before.
- Corrections hand off had a coordinate issue which got solved.
- Hit the target within 20 Km (0.001 arc sec and ~3 sec of time)





Damage to the Aircraft



- On the afternoon of the day of the occultation the Aircraft was damaged by the bottom bar of the back flap of the cryogen truck.
- Wind gust knocked out a window and put a ~2 inch dent in the skin.
- The SOFIA maintenance team with the help of Air New Zealand made the repair and cleared certification before take off.





Weather and where to land



- This was an issue as the position got updated.
- The most critical was the practice flight the night before.
- Landing anywhere other than Christchurch would not allow a cryogen fill.
- An early take off and landing with a short flight (~4 hr) gave us the best chance to avoid fog, which is quite common in Christchurch (~5-10%)
- We did not care where we landed on the occultation flight



Issues with FliteCam (electronics)



- FliteCam was shipped down to New Zealand with known intermittent issues with the array drive electronics.
- When FliteCam was powered up the array drive electronics did not work.
- Luckily, the IRTF had sent us there drive electronics as a back-up.
- 3 days before the Occultation the FliteCam team (Chris Johnson, UCLA) transferred the IRTF spear and got it working



Issues with FliteCam (Extra



background from Engine emission)

- On the practice flight we noticed extra background at 2.1 microns that was variable as the plane tipped and depended on telescope elevation.
- Reduce the signal to noise by greater than factor of 3.
- This effect had been noticed in the commissioning, but was not fully characterized.
- I called Bill Vacca, and he suggested using the H(wide) blocker which had a central wavelength of 1.8 microns.
- Observations on the Pluto field with this filter were made at the beginning of the Occultation flight. Ryan Hamilton quickly reduced the data and it showed the same noise as K, but over 2 times better signal on the Occ. star.
- From Pluto atmospheric models we also knew that the Pluto signal to noise was probably even a further 30% larger.
- The PI Mike Person decided we would use the 1.8 micron filter.





Issues with FliteCam



(background and starting to solve where it was coming from)

- The 200 km position change was north which made the elevation higher and reduced the extra background, but it was still there.
- Ryan Hamilton suggested we put the pupil viewing mode in after we obtained the data. We all agreed.
- Results are shown on the next slide with a comparison to an earlier study by Breault (BRO).



Comparison of Breault (BRO)

Calculations and Pupil Plane images

- Emission on the top of Primary Predicted



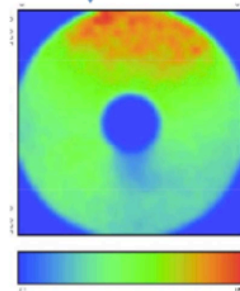
Stray Light Images



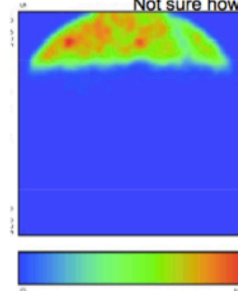
TA Corresponding (5-7 μ m) model diagrams from BRO (1998) PM reflecting plume

Note: scale change \rightarrow 1/214 for this diagram

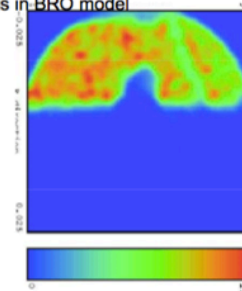
Model assumes Level 500 contamination \rightarrow
12,000 x 50 micron particle, sq. ft. = 0.1m²
Not sure how much wing flex is in BRO model



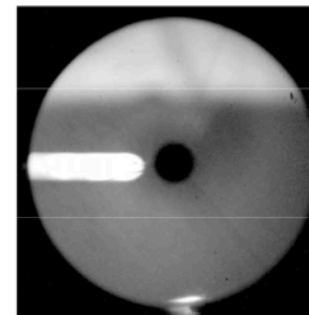
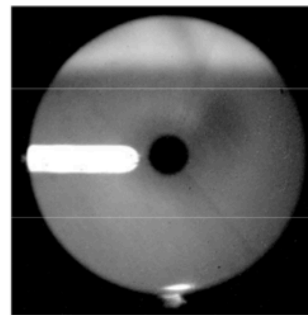
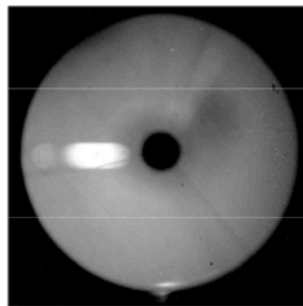
EL (deg) 40



25



20



Courtesy of P. Waddell





FliteCam Background



- At 40 deg elevation the extra background was coming from the aft spider
- Work by Patrick Waddell and Bill Vacca, showed that it was probably hot ($T \sim 600$ to 700K) emission coming from the aft outboard engine(#1) on the left side reflected off the unfinished bottom of the spider vain.
- Baffles are now being prepared to eliminate the reflection.
- Patrick Waddell may speak about this on a later teletalk.





Summary



- SOFIA has provided data on Pluto through an Occultation two weeks before The New Horizon flyby that can be used to help monitor Pluto's atmosphere for years to come.
- SOFIA can do great science and carry out unique experiments





Special Thank You



- SOFIA would not have been possible without years of tireless work and genius of Hans-Peter Roeser (DSI Stuttgart) and Nans Kunz (NASA Ames)
- Both started working on SOFIA in the 1980's
- Both passed way within the last year





Backup





Results

Atmospheric change
Atmospheric haze

