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NASA IRTF and Synergies with SOFIA

Eric Becklin

SOFIA/USRA Chief Scientific Advisor

Professor Emeritus UCLA

NASA IRTF: Future Directions Workshop

Biosphere 2, Tucson AZ

Feb. 14, 2018

Outline of Material

- Overview of SOFIA and Connections to IRTF
- A few Planetary Science Synergies
- A few Astrophysics Science Synergies
- Some Suggestions

Overview of SOFIA

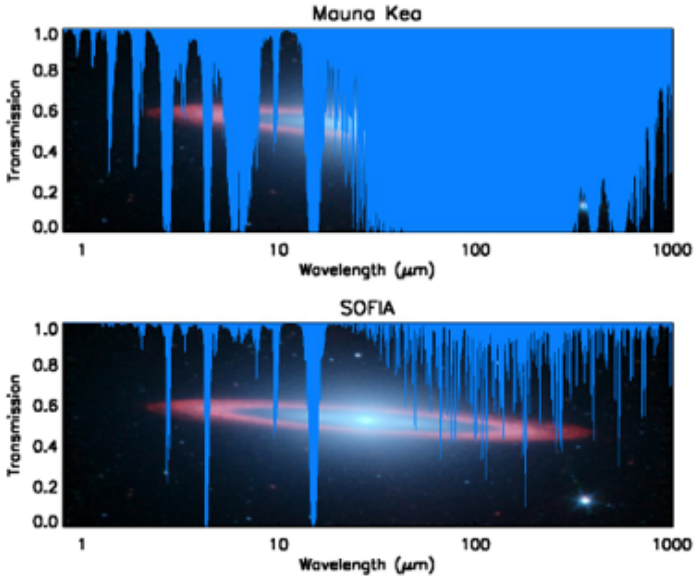
* SOFIA is 2.5 meter telescope in a modified B747SP aircraft
  - Optical-mm performance
  - Obscured IR (30-300 microns) most important
- Joint Program between the US (80%) and Germany (20%)
- Operating in the Stratosphere
- ~ 100 flights and 800 science hours per year
- 6 science instruments (no longer offer HIPO and FLITECAM)
- Data analysis funding of about ~$9K/hour
- The present instruments with most potential for science overlap and most synergy with IRTF are EXES, FORCAST and the FPI+
- In the near future HIRMES could have some synergies (R~100,000 at 28 to 122 microns using TES Bolometers, a FP spectrometer and grading: H. Moseley GSFC PI)

EXES on SOFIA and TEXES on IRTF were developed together by John Lacy, Matt Richer and others

- EXES selected by SOFIA in 1998: John Lacy also built a very similar instrument for ground based telescopes (TEXES) from NSF funds.
- Grading Spectrometers with R~100,000 and 5 to 28 microns
- EXES was commissioned at IRTF in~2011 before going on SOFIA.
- Both instr. used common software and reduction tools
- John dropped out of EXES and Matt Richer took over as PI
- Good science is now produced by both instruments!!

IRTF vs SOFIA

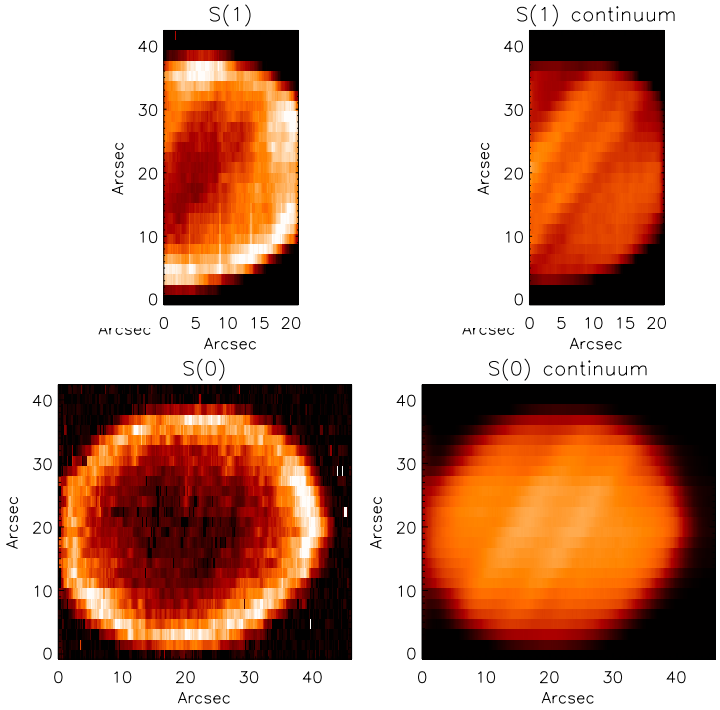
If you can observe something with the IRTF, you should always use it. There may be exceptions, but they are rare.



- The cost of SOFIA is 50 times larger per hour than IRTF
- The image quality of IRTF is always better at lambda < 25 microns
- Only if you are observing a time dependent object such as a nova, supernova or comet does it make sense to use SOFIA in regions where you can observe with the IRTF. (I do have such an example)

Selected Examples of Planetary Synergies

Ortho/para H_2 maps on Jupiter With Exes



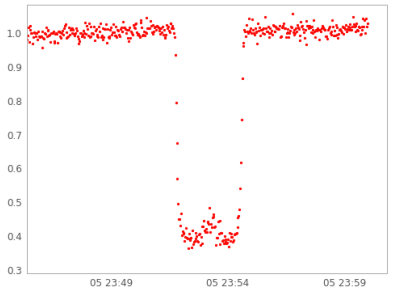
- Spectral maps by stepping slit position across extended sources
- Stratospheric emission from H_2; limb brightening
- S(0) at 28.3um is unobservable from ground.
- S(1)/S(0) gives temperature, with long latency
- Combined with other temperature measures, maps convective motion into the stratosphere and circulation

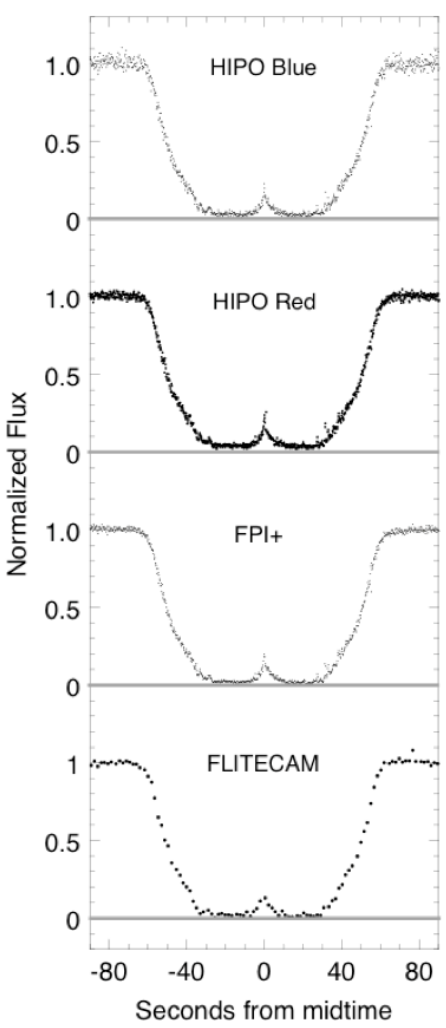
Stellar Occultations

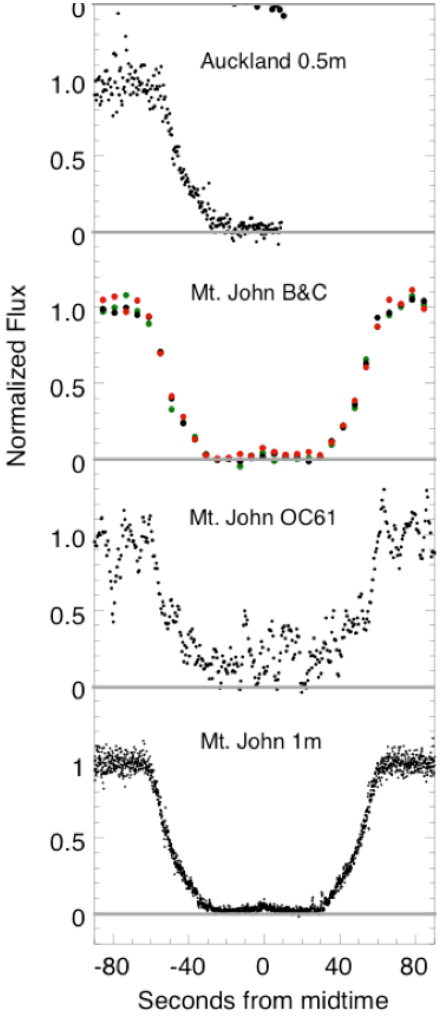
- When a Star goes behind a Planet (Occultation), we can learn about the Atmosphere of the planet by measuring how the radiation disappears and reappears.
- On SOFIA the FLITECAM camera, HIPO occultation camera and the Focal Plane Camera (FPI+) can operate simultaneously by use of dichroic beam splitters.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

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 the atmosphere.
- Stability of Pluto’s atmosphere over last 15 years determined. Change had occurred between 1988 and 2000.
- Comparison of multi-wavelength observations allows detailed analysis of atmospheric profiles and aerosol or haze content. The haze results agree with the New Horizon’s images.
- The same team observed Triton, the moon of Neptune, with the same instrumentations in 6 October 2018 from Dayton FL. !.8 micron data shown red data below.
- In the future only can use FPI+ at 0.4 to 1.1 microns





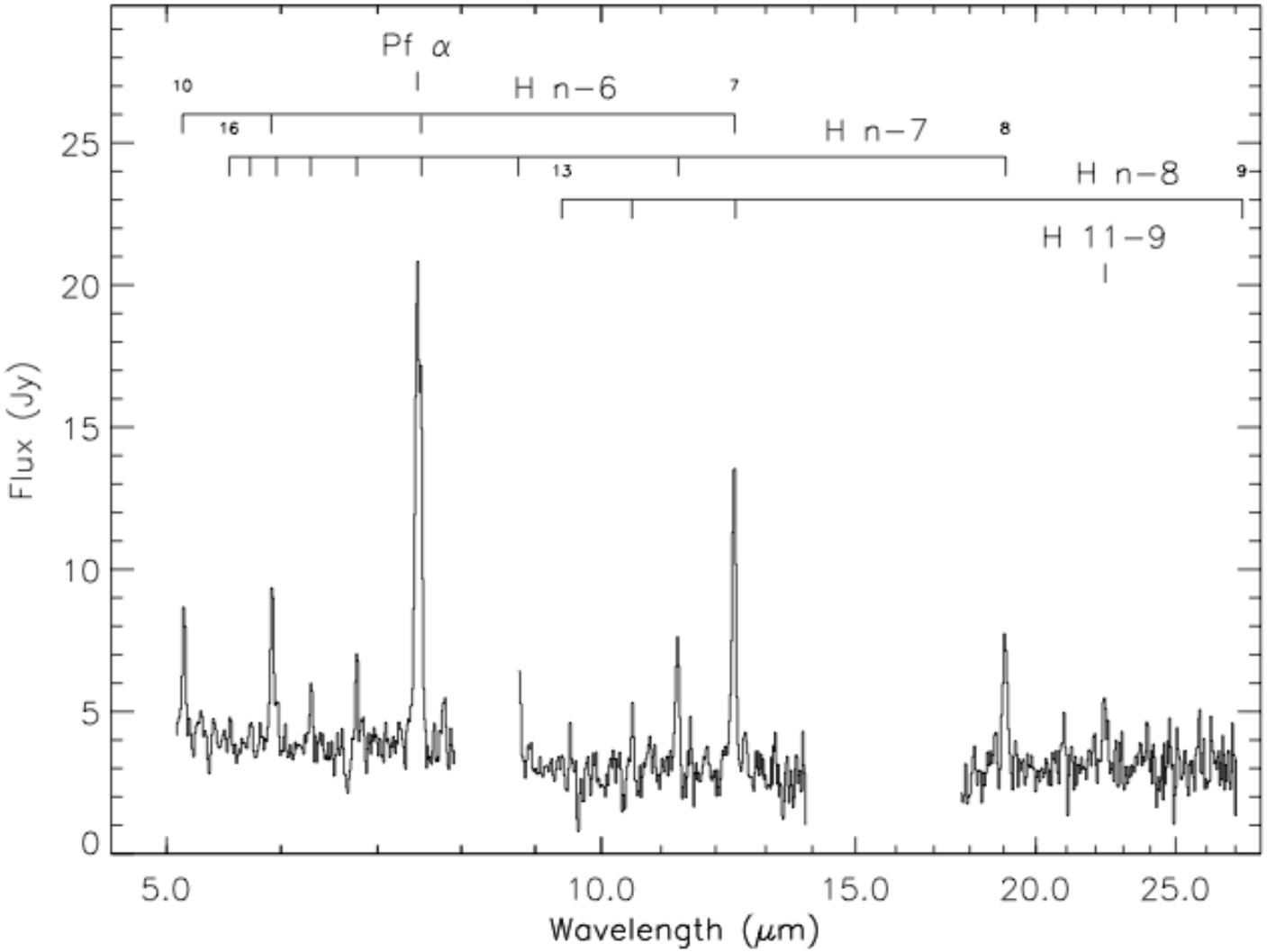


Astrophysics Synergies

Nova Del Outburst of 2013 with FORCAST GRISMS

- On 13 Aug 2013 V339 Del was discovered to be in outburst.
- Goal was to look for strong IR metallic forbidden lines.
- Observations were taken on 10 Sept 2013, 24 days after maximum visible light.

Nova Del with FORCAST GRISMS



Nova Del

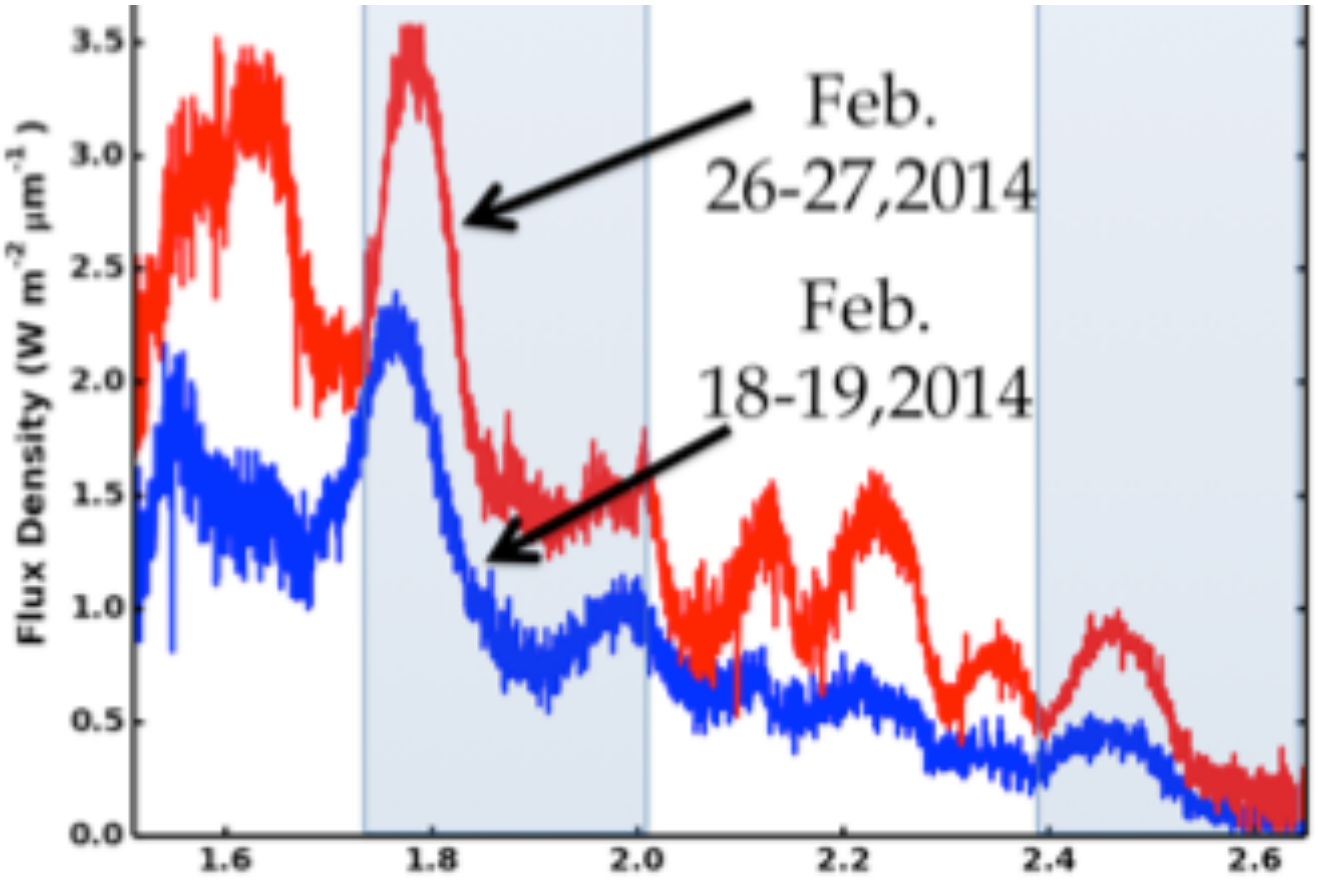
* Only Hydrogen lines were seen

- The density is too high (>E7 per cc) and the metal lines are quenched.
- Team is surprised that [NeII] is not seen based on other novae.
- These beautiful results could only be obtained if all the bands were obtained on that date.
- Paper published. Gehrz etal 2015ApJ,812,132, including IRTF.

Supernova 2014J in M82

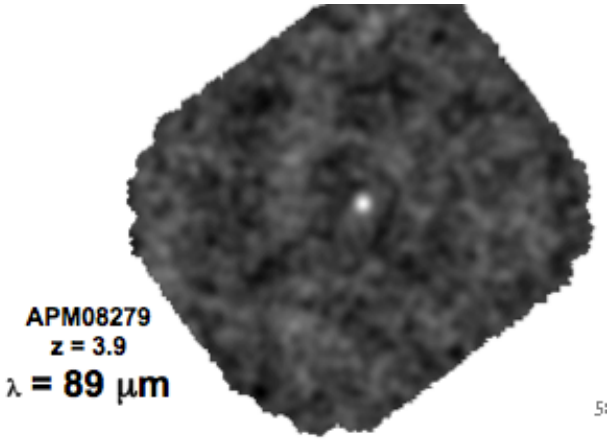
- A Target of Opportunity (Approximately 4 ToO teams including Kirschner etal)
- Used FliteCam during its commissioning.
- Observed the R~1200 spectra in the 1 to 3 micron region on two flights at t(0)~36 days and t(0)~44 days.
- Paper written by Vacca etal including all other ToO team members. (2015ApJ,805,66)
- Strong line of Ionized Cobalt seen at ~1.8 microns. First good detection of this line, including wavelength changes. 1st 3 micron spectrum.

FLITECAM and HIPO together (FLIPO): Supernova 2014J in M82 (Vacca etal ApJ 2015)



SOFIA Detects a z=3.9 Galaxy with HAWC+

HAWC+ on SOFIA has detected a z=3.9 lensed galaxy in the 53, 89 & 154 microns continuum. At a rest wavelength of 11,18 & 31 microns, this measurement helps determine the AGN contribution to this very luminous galaxy



Riechers etal have used the HAWC+ Bolometer camera on SOFIA (Dowell PI) to detect the z=3.9 lensed galaxy APM08279 in the continuum at 89 microns.

Using the Lissajous scanning and image reconstruction a signal to noise of ~ 10 to 1 was obtained in about half an hour.

This is near the SOFIA background sensitivity limit at this wavelength.

The SOFIA measurements at rest wavelengths of 10.8, 18.2, 31.4 microns can be used to help constrain the AGN component and associated hot dust of this extremely luminous early universe galaxy.

Some suggestions to the IRTF

- Make sure you use your resources wisely. I worry about AO on IRTF, because gains are small relative to 8-10 meter and you need a big team and pick the low hanging fruit first. Ie focus and dome thermal control.
- SOFIA has extensive team doing data reduction and pipeline of data from most instruments. Reduced data will be stored at IPAC. This includes EXES data. Suggest working with SOFIA team lead by Bill Vacca to get at least TEXES and maybe other spectrometer data pipeline reduced.
- The HAWC+ data on Z~4 galaxy was taken scanning SOFIA in a Lissajous pattern. IRTF might want to consider this mode for mapping with MIRSI on IRTF
- A supernova goes off in the Milky Way every ~30-50 years. Are we ready in the IR? SOFIA: No; IRTF ??

Summary

- SOFIA and IRTF have worked together in the past and should continue into the future.
  - TEXES and EXES where developed together by John Lacy
  - Unique Observations of 1.8 micron ionized cobalt in Supernova 2014J supplemented by IRTF observations.
  - Pluto Occultation of 29 June 2015 at 4 wavelengths showed a haze and stable atmosphere.



The NASA Infrared Telescope Facility on Maunakea



- SOFIA is now the only facilities giving routine use by the community for far-IR and sub-millimeter astronomy.

BACK-UP

GD165B: 1st L dwarf star Discovered at the IRTF

In late 1980's Ben Zuckerman and I used the IRTF to search for possible Brown Dwarfs around nearby White Dwarfs. One cool companion was found around the White Dwarf GD165. 1988 Nature.



Left to Right: Keck1 under construction, Eric, Ben, IRTF

Resolved point source at a distance of 4.5 arcsec (120 au) with a Temperature of ~2100K and a Luminosity of ~10^{-4} L_{sun}.

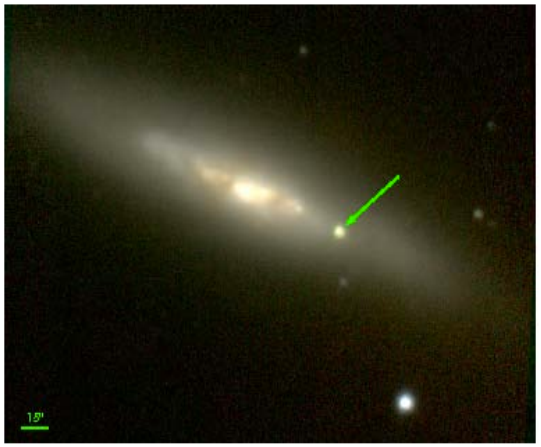
Later shown to be a physical companion

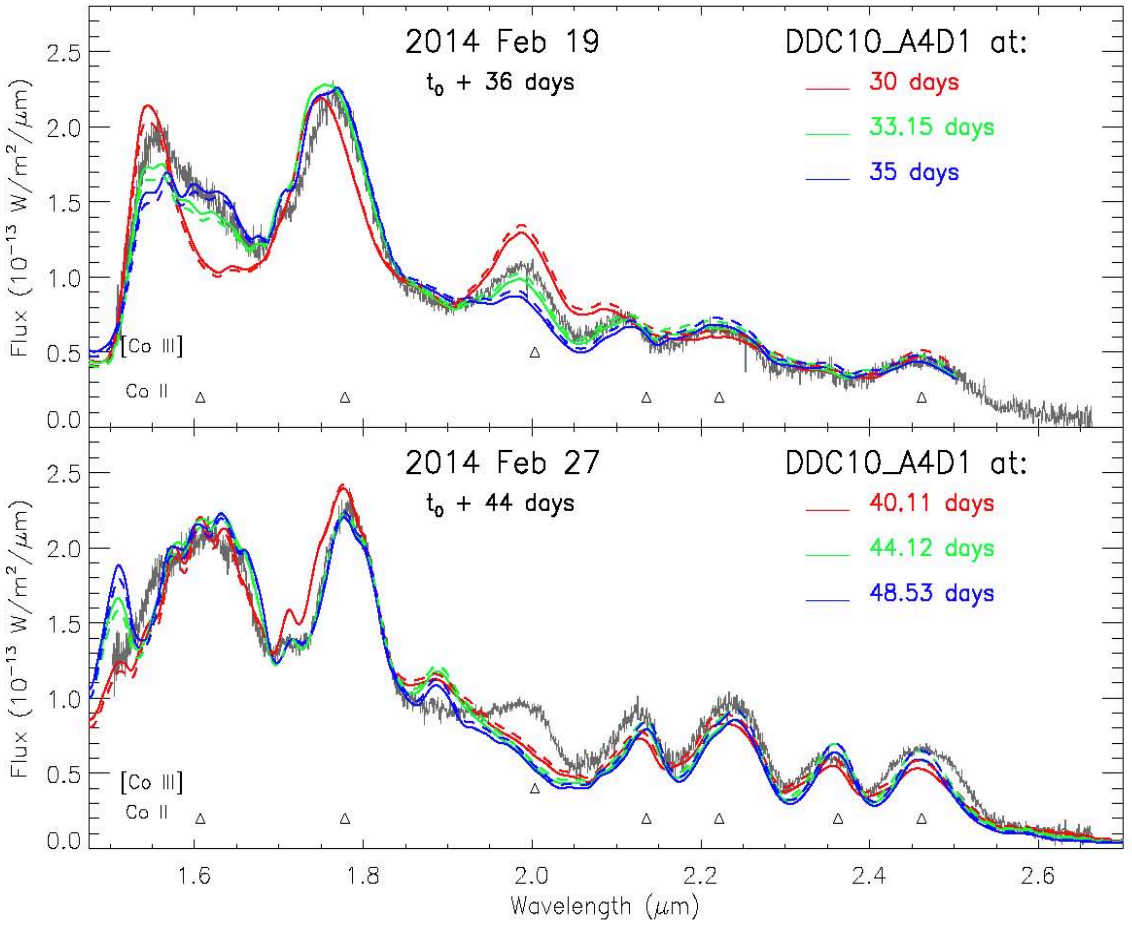
Spectra in 0.7 to 1.0 micron region by Kirkpatrick and Henry showed a very red spectrum with strange features; later classified as first "L" type object

GD165B was the first new classification of stars in over 80 years

Probably the first imaged Brown Dwarf or substellar object outside the solar system.

FLITECAM observes Type Ia SN 2014J





FLITECAM spectra of SN 2014J taken on days of 36-44 compared with the model by Dessert et al. (2014). Mainly Cobalt and some contribution from Fe and Ni.

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 25 Km/s. Plane .3 Km/s.
- 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



