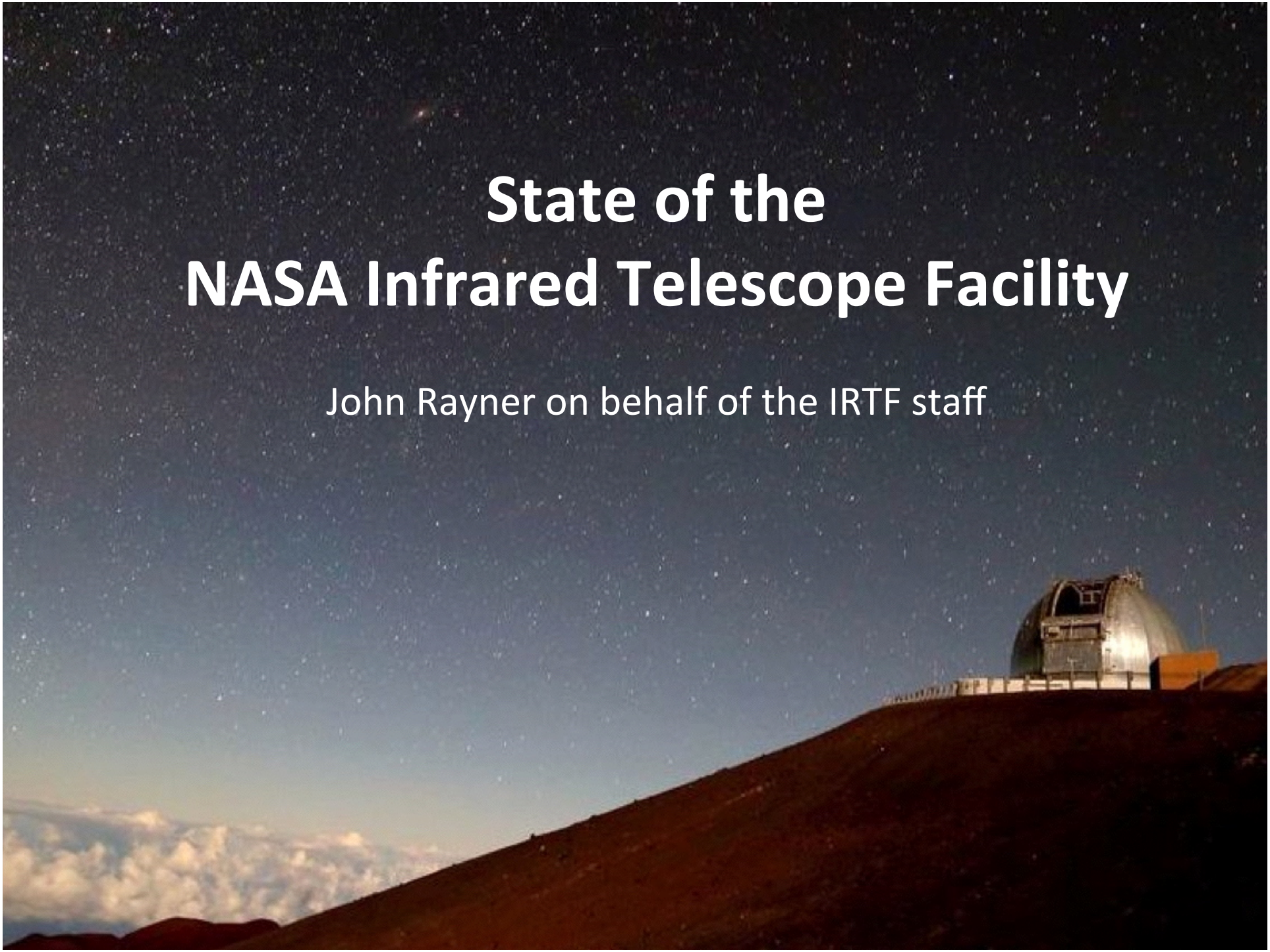
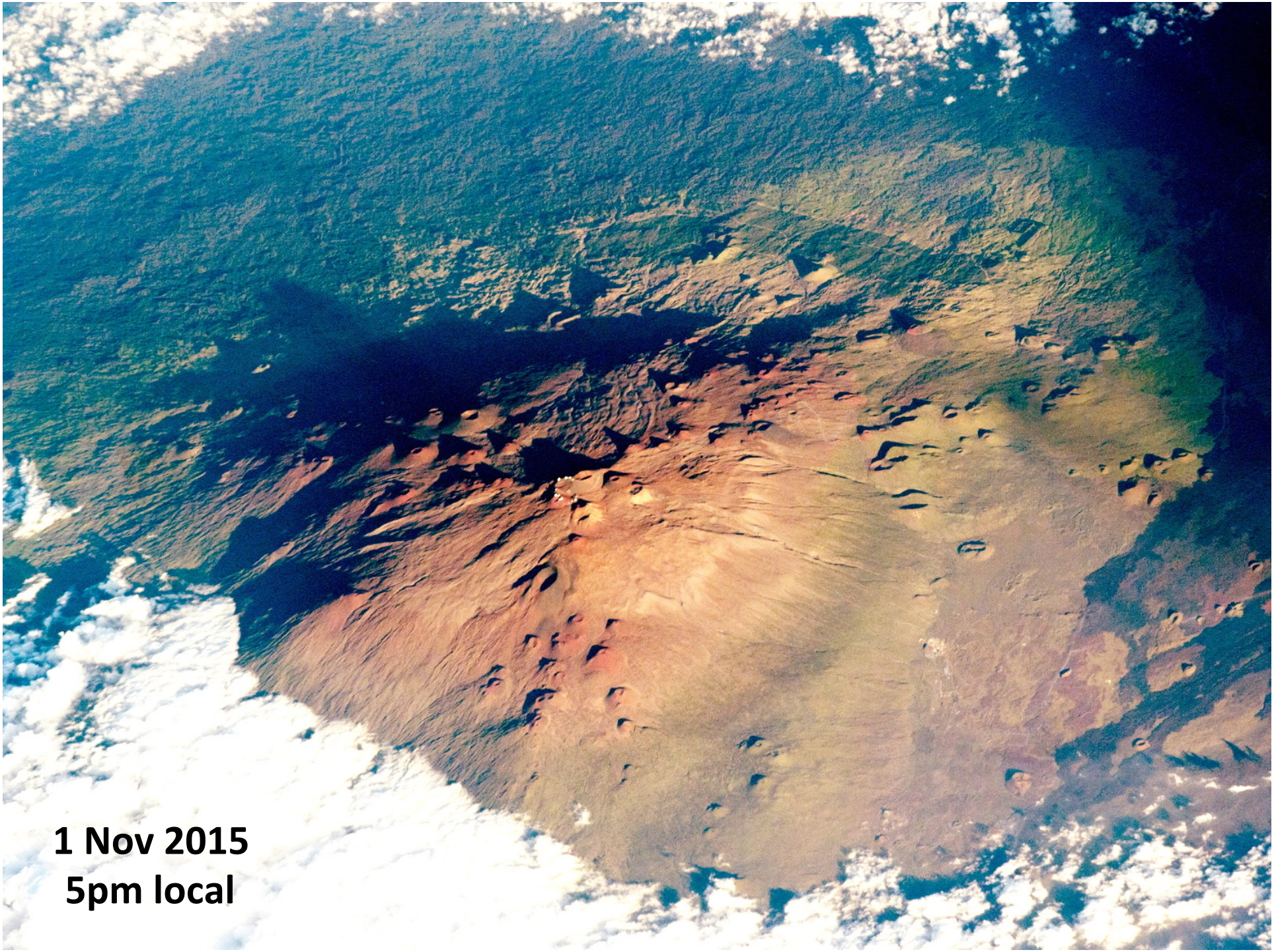
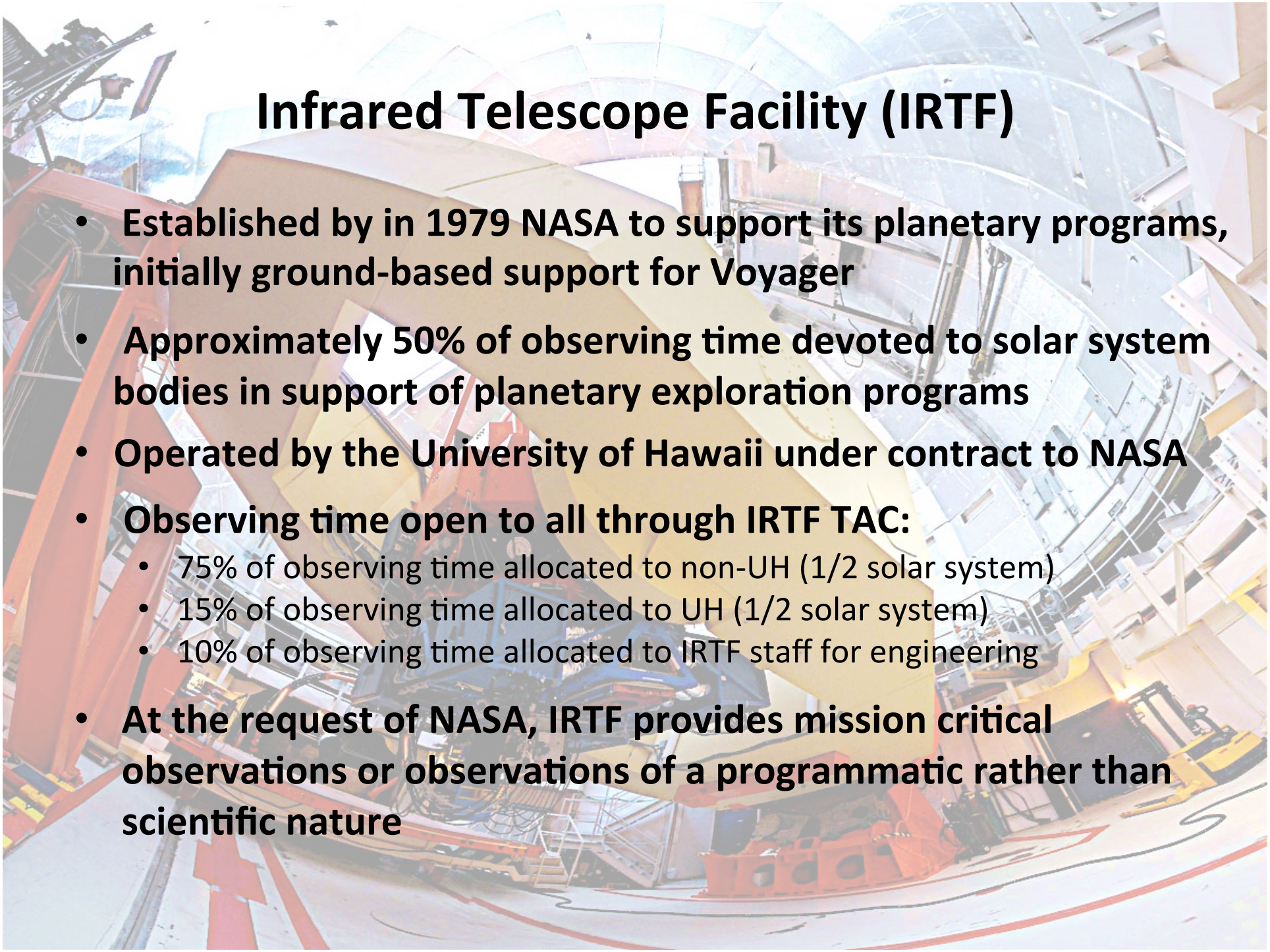


State of the NASA Infrared Telescope Facility

John Rayner on behalf of the IRTF staff

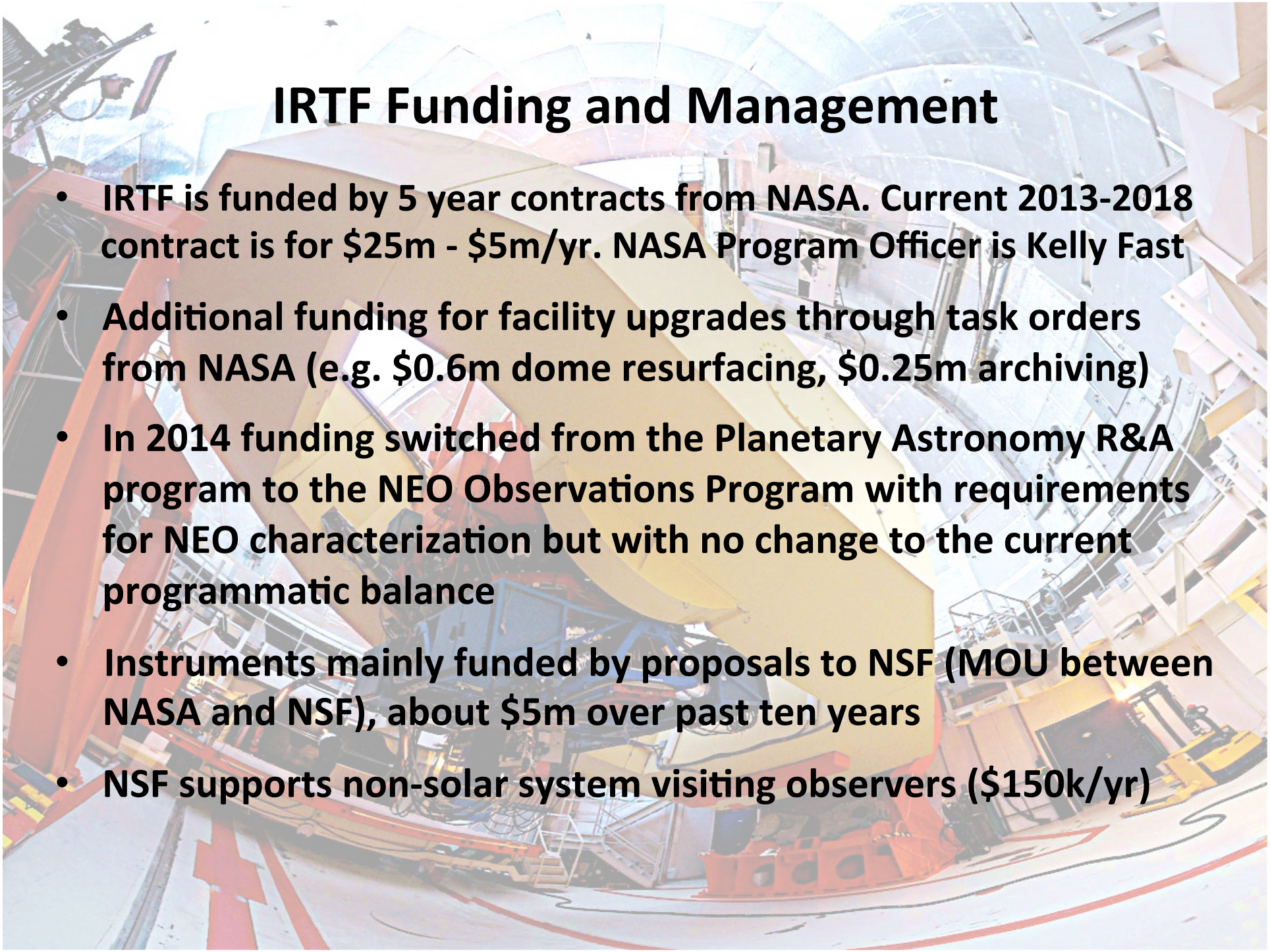

1 Nov 2015
5pm local





Infrared Telescope Facility (IRTF)

- **Established by in 1979 NASA to support its planetary programs, initially ground-based support for Voyager**
- **Approximately 50% of observing time devoted to solar system bodies in support of planetary exploration programs**
- **Operated by the University of Hawaii under contract to NASA**
- **Observing time open to all through IRTF TAC:**
  - 75% of observing time allocated to non-UH (1/2 solar system)
  - 15% of observing time allocated to UH (1/2 solar system)
  - 10% of observing time allocated to IRTF staff for engineering
- **At the request of NASA, IRTF provides mission critical observations or observations of a programmatic rather than scientific nature**



IRTF Funding and Management

- IRTF is funded by 5 year contracts from NASA. Current 2013-2018 contract is for $25m - $5m/yr. NASA Program Officer is Kelly Fast
- Additional funding for facility upgrades through task orders from NASA (e.g. $0.6m dome resurfacing, $0.25m archiving)
- In 2014 funding switched from the Planetary Astronomy R&A program to the NEO Observations Program with requirements for NEO characterization but with no change to the current programmatic balance
- Instruments mainly funded by proposals to NSF (MOU between NASA and NSF), about $5m over past ten years
- NSF supports non-solar system visiting observers ($150k/yr)

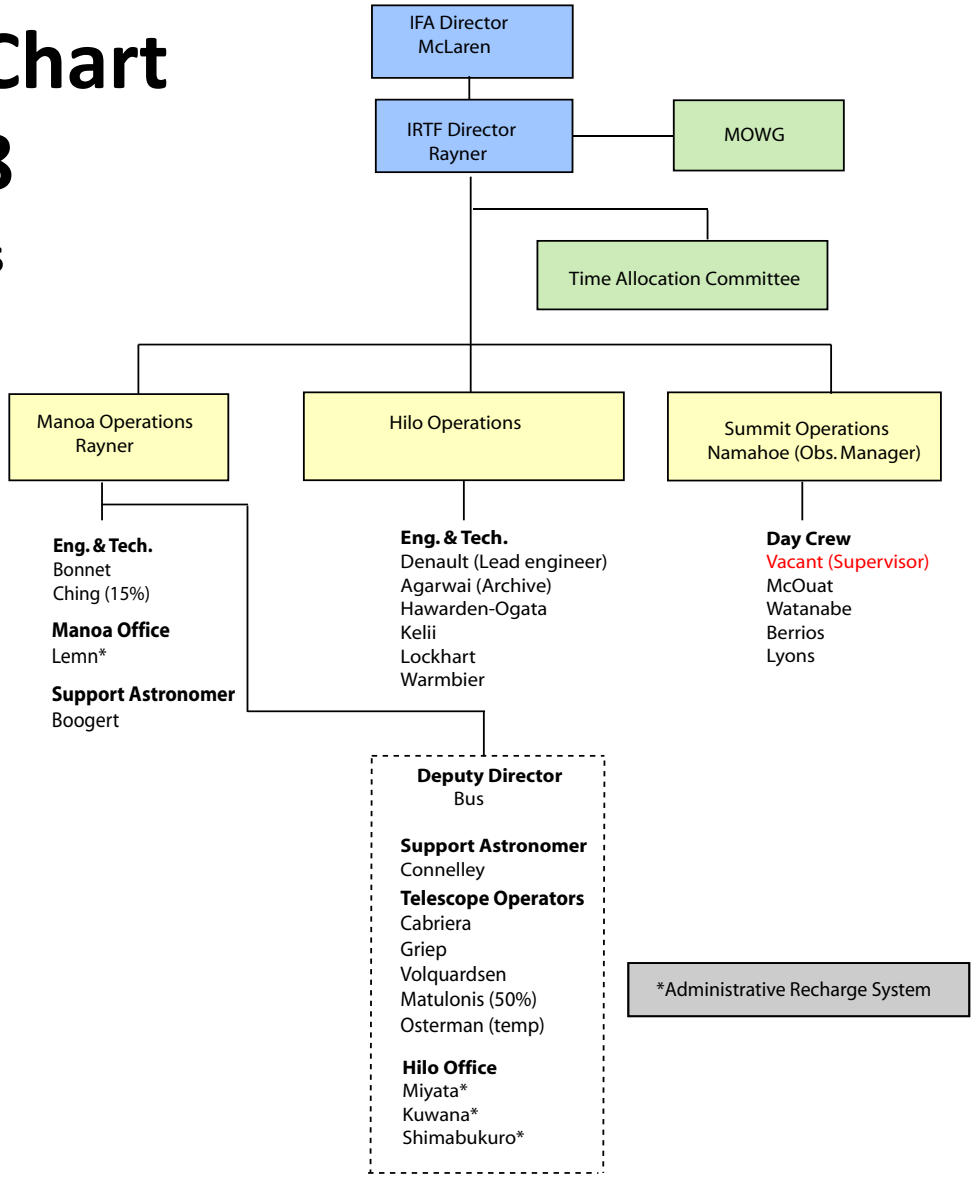


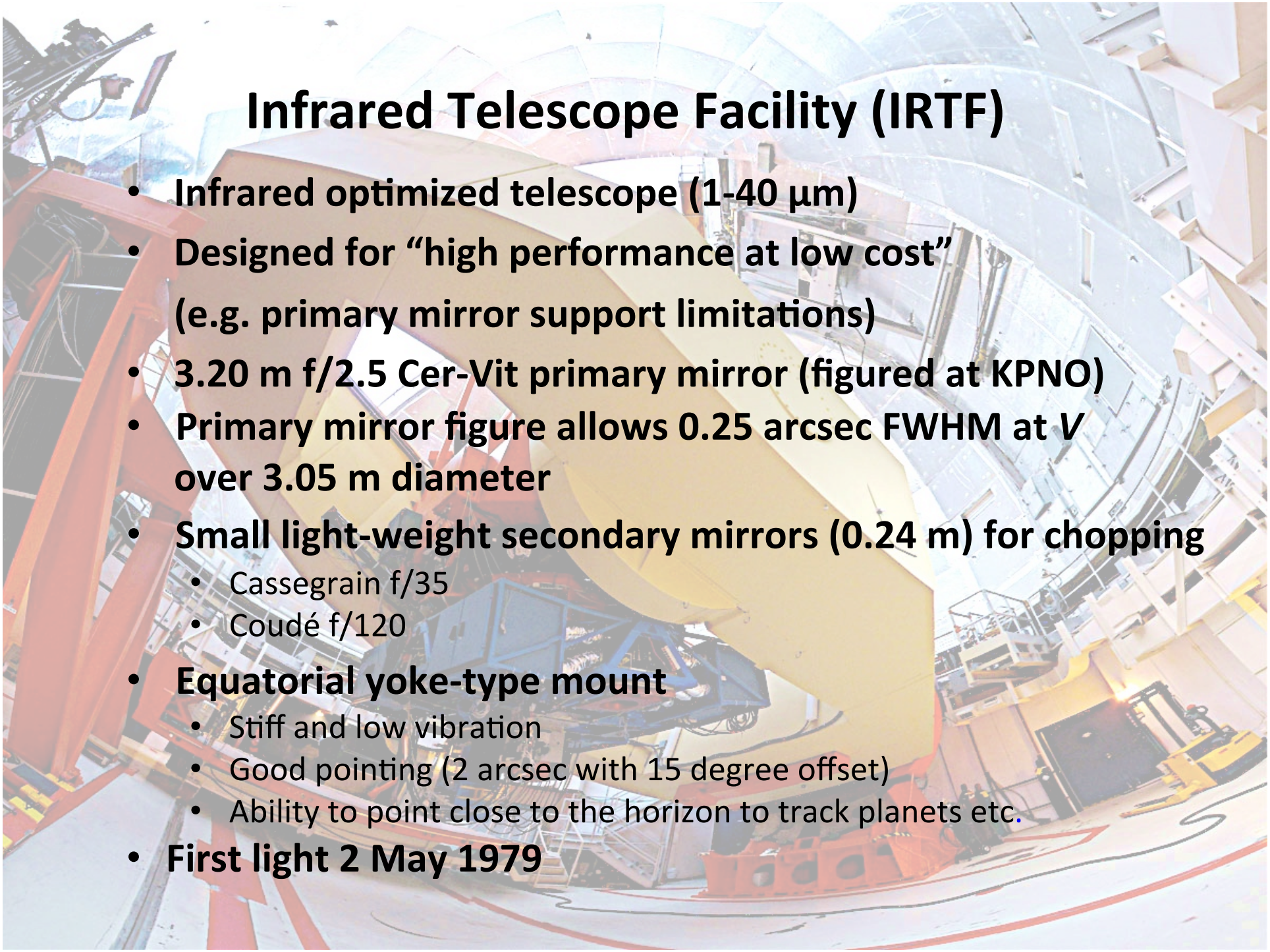
IRTF Funding and Management

- **Management and Operations Working Group (MOWG)**
  - NASA-appointed committee charged with overseeing IRTF performance, proposals and future directions
  - Program managers from NASA and NSF, IfA Director and IRTF users
  - Meetings are held twice a year jointly with the Keck MOWG
  - MOWG provides findings to NASA
- **Telescope Allocation Committee (TAC)**
  - Members selected from the community by the IRTF Director
  - Four solar system and four non-solar system astronomers
  - Members serve two year terms (four observing semesters)
- **No formal users committee (regular online feedback to IRTF)**

Staffing Chart 2018

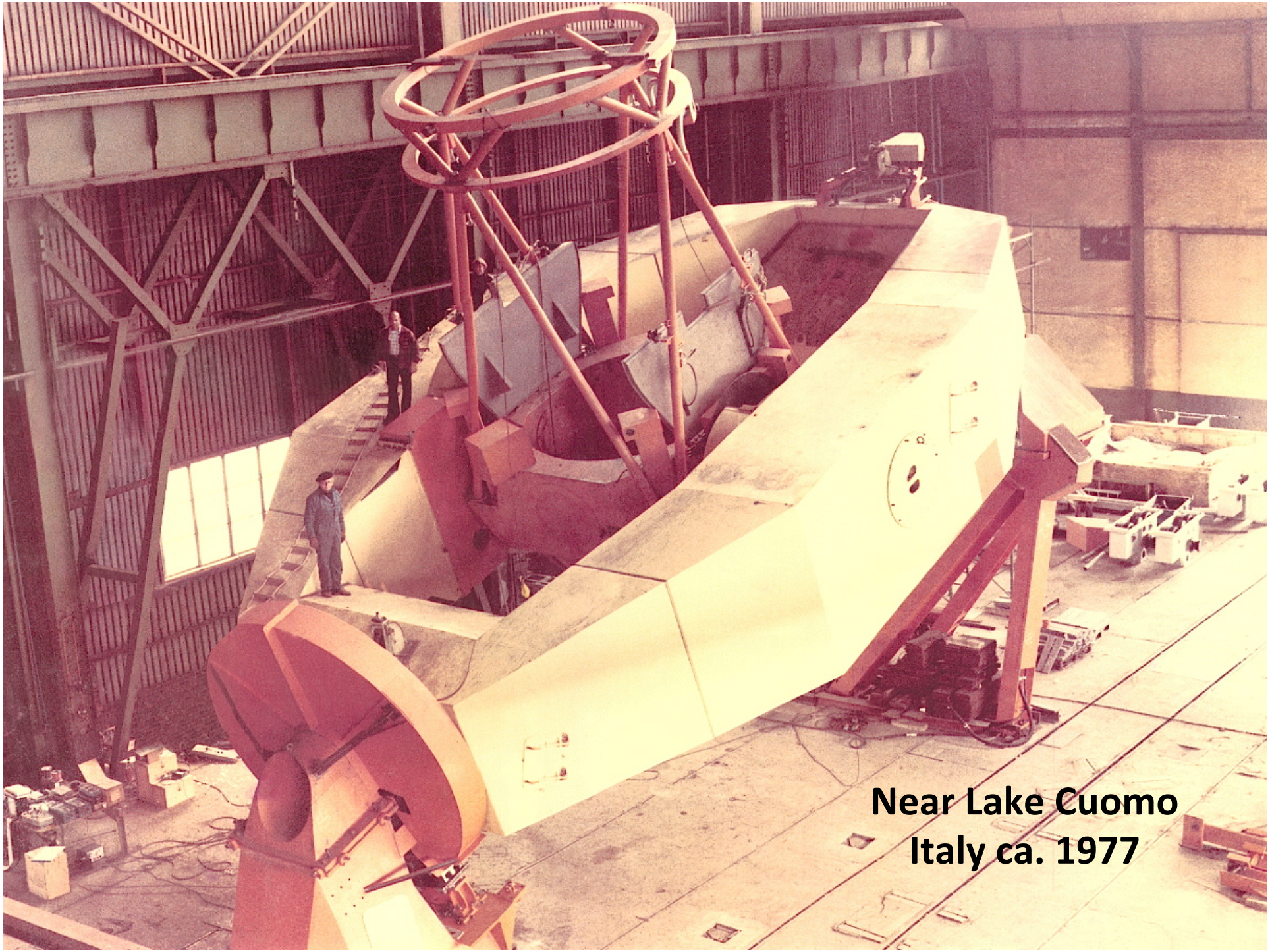
24 FTEs



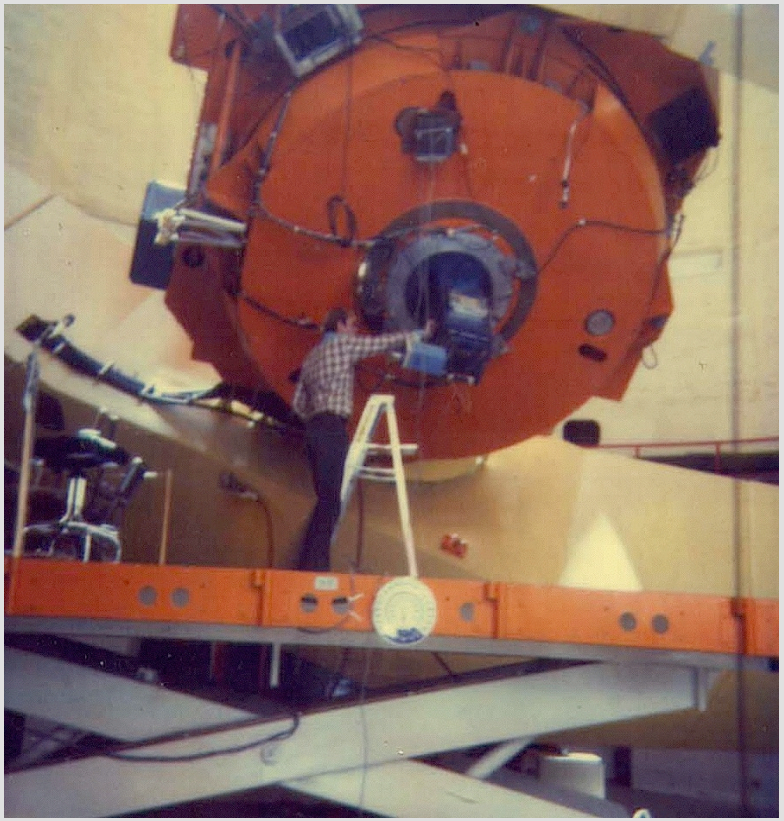


Infrared Telescope Facility (IRTF)

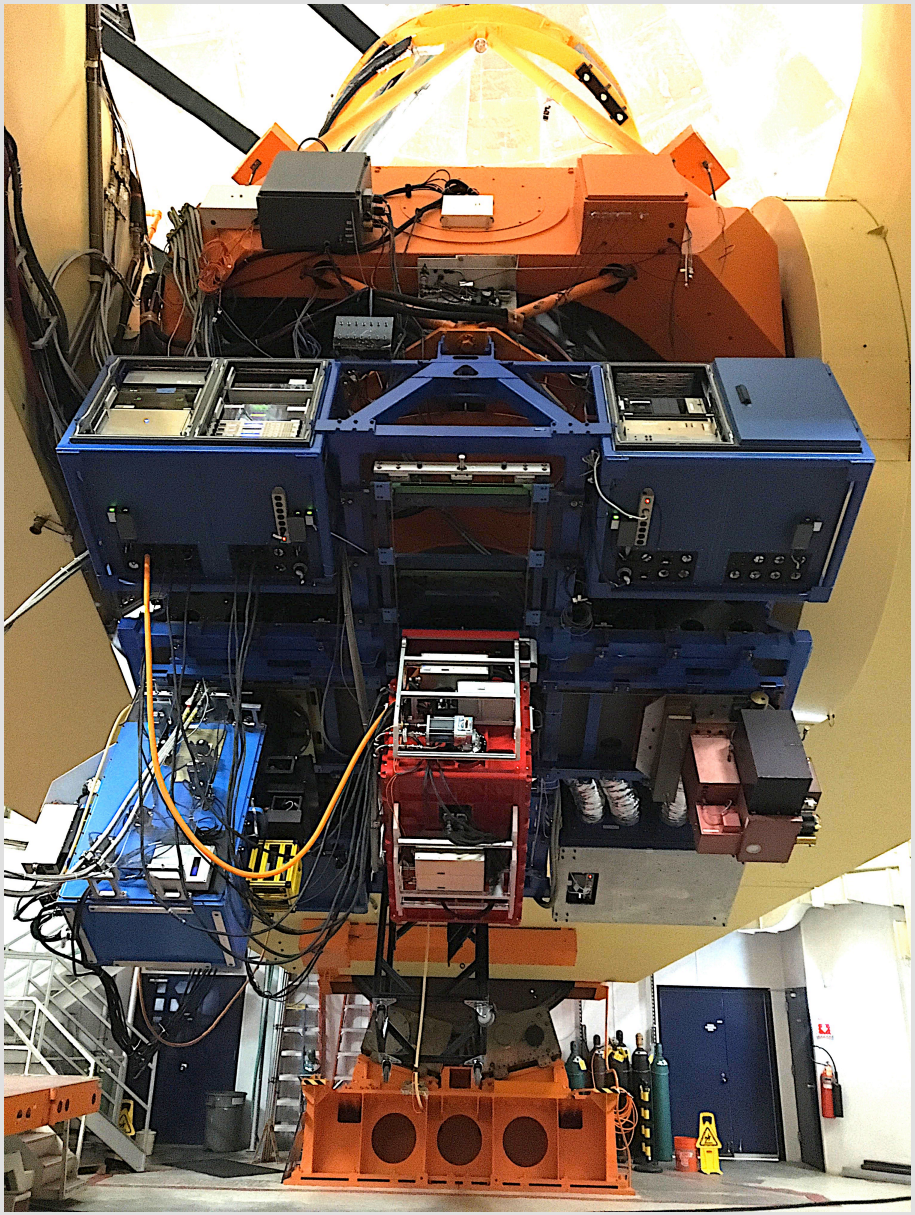
- **Infrared optimized telescope (1-40 µm)**
- **Designed for "high performance at low cost"**
  (e.g. primary mirror support limitations)
- **3.20 m f/2.5 Cer-Vit primary mirror (figured at KPNO)**
- **Primary mirror figure allows 0.25 arcsec FWHM at *V* over 3.05 m diameter**
- **Small light-weight secondary mirrors (0.24 m) for chopping**
  - Cassegrain f/35
  - Coudé f/120
- **Equatorial yoke-type mount**
  - Stiff and low vibration
  - Good pointing (2 arcsec with 15 degree offset)
  - Ability to point close to the horizon to track planets etc.
- **First light 2 May 1979**


Near Lake Cuomo
Italy ca. 1977

1984



2018



Current Facility Instruments

SpeX (55% telescope time)
- 0.7-5.3 µm R=50-2500 XD spectrograph
- IR guider and imager (60”x 60” FOV, 18 filters)
- First light 2000
- Upgraded in 2014 with H2RG and new array controller
- *Spextool data reduction pipeline available 2003*

MORIS
- Built in collaboration with MIT
- CCD camera and optical guider for SpeX (60”x 60” FOV, 9 filters)
- Fed from dichroic in SpeX for simultaneous optical/IR observations
- First light 2012

iSHELL (33% telescope time)
- 1.05-5.3 µm R=20,000-75,000 XD spectrograph
- IR guider and imager (42” FOV, 8 filters)
- First light 2016
- *Spextool data reduction pipeline available 2017*

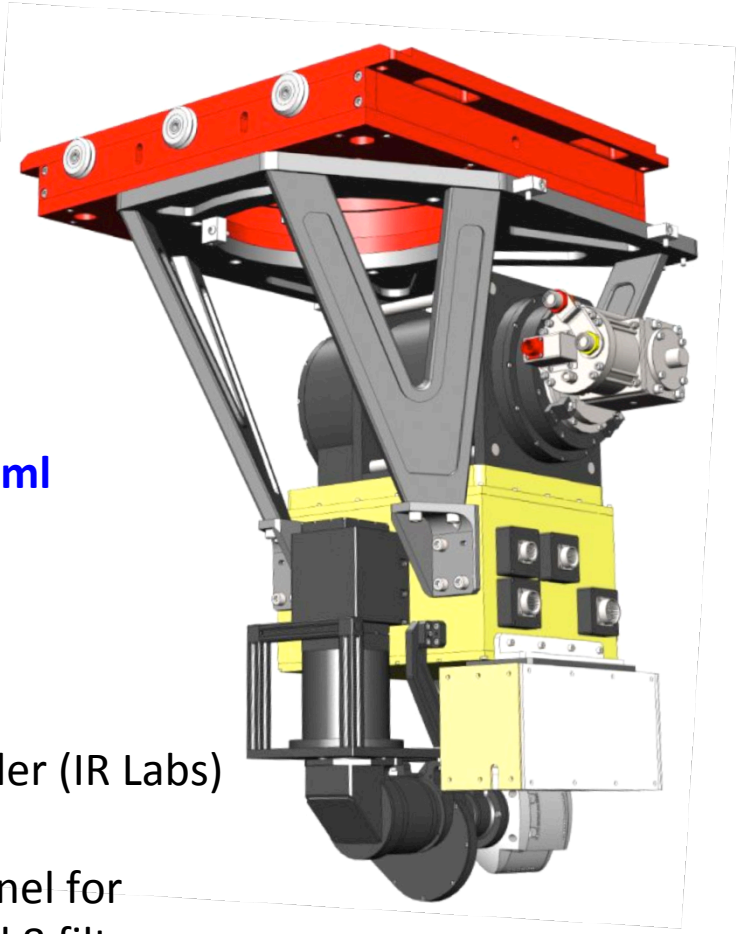
~~NSFCAM (5% telescope time)~~
- Optimized 1-5 µm imager with 28 filters, CVFs and polarimetry
- First light 1994 upgraded in 2006 with engineering grade H2RG and 0.04”/pix scale for AO, 81”x 81” FOV
- Destroyed in an accident 2010

MIRSI Upgrade

5-20 µm camera and spectrograph

- 320 x 240 Si:As IBC
- 85” x 64” FOV, 0.27”/pixel
- 12 discrete filters
- 8-15 µm CVF
- 8-14 µm R=200 grism
- 17-26 µm R=100 grism

https://www.cfa.harvard.edu/mirsi/mirsi_spec.html

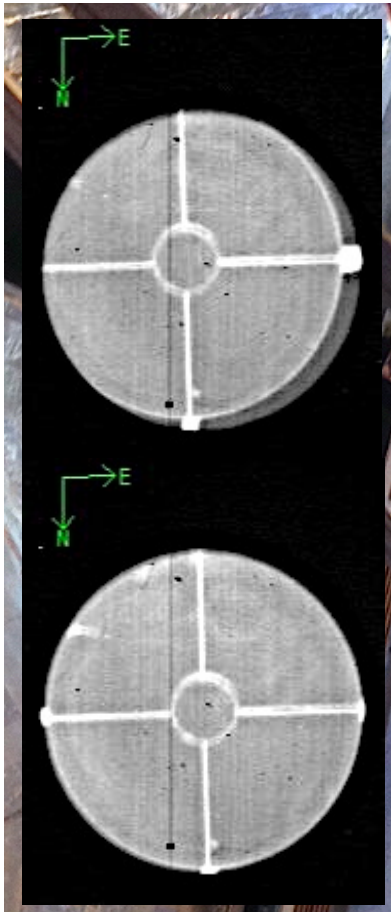


Upgrade (PI Dave Trilling, CoI Joe Hora)

- On long-term loan from Boston University
- First light 2002, last use 2011B
- Replace LN2/LHe cooling with closed-cycle cooler (IR Labs)
- New low-noise array controller (IRTF)
- **MOC** - simultaneous mid-IR + optical CCD channel for NEO albedos and diameters, 60” x 60” FOV and 8 filters

Commissioning expected 2018A

Secondary Mirror



- Hexapod top-end from tip-tilt project (1996)
- f/37 Zerodur mirror figured to match primary mirror and remove spherical aberration (2006)
- State-of-the-art chopping stage to be added in 2018

Visitor Instruments

Use requires collaboration with instrument team

TEXES (10% telescope time)

- Contact Tommy Greathouse
- 8-26 µm R=5,000-100,000 XD echelle spectrograph
- 256x256 Si:As BiB array
- First use on IRTF 2000

BASS (~2% telescope time)

- Contact Ray Russell
- 3-14 µm R=20-100 spectrograph
- Two 58-element BiB arrays
- First use on IRTF 1996

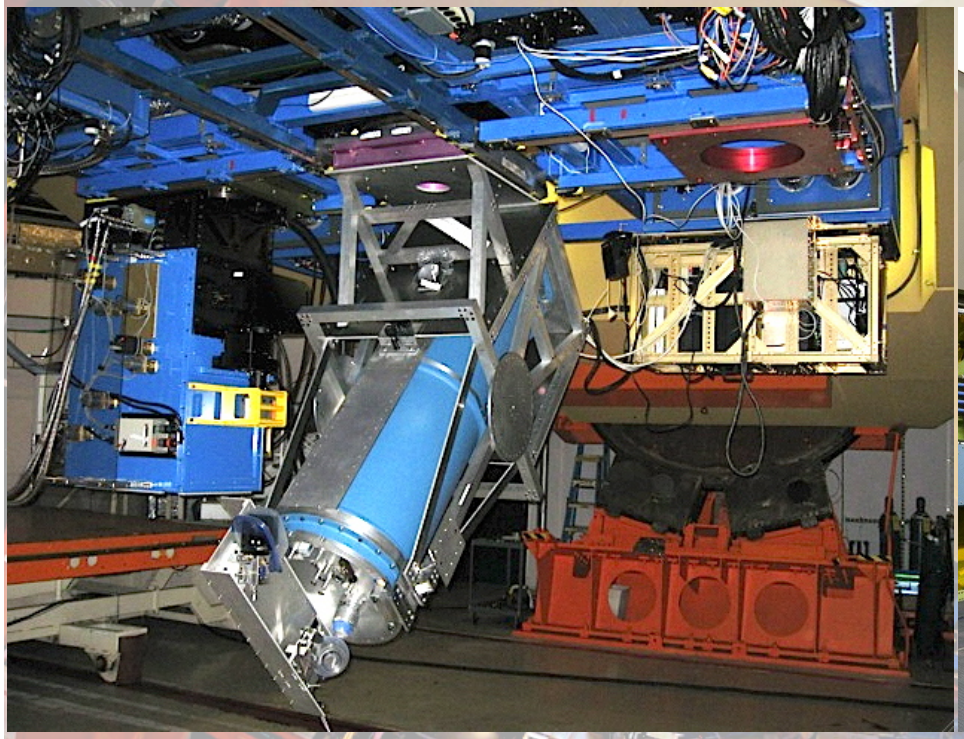
HIPWAC (~2% telescope time)

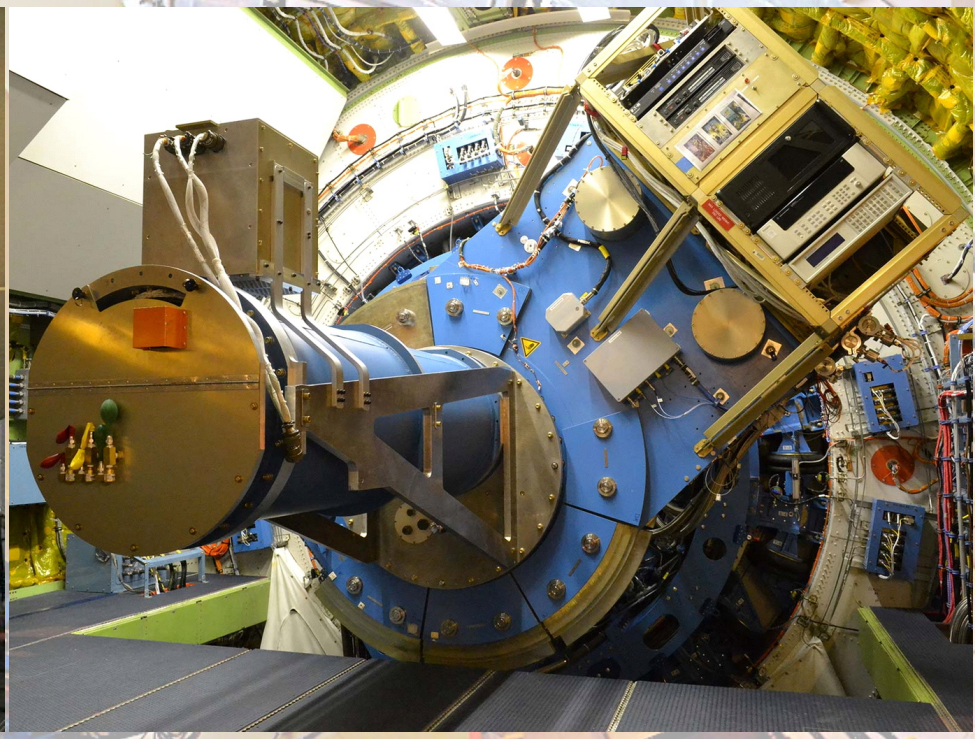
- Contact Tim Livengood
- 7-13 µm R≥10^6 heterodyne spectrogaph
- First use on IRTF 2000

Visitor Instruments Since ca. 1990

INSTRUMENT	*TYPE*
BASS	R=20-100 3-14 µm spectrograph
Big Mac	2-20 µm bolometer array
Celeste	Mid-IR spectrograph
CoCo	Cold coronagraph for NSFCAM
Celeste	R≈30,000 mid-IR spectrograph
EXES	High R mid-IR spectrograph
GSFC Heterodyne Spectrograph	$R>10^6$ mid-IR spectrogaph
HIFOGS	Low R mid-IR spectrograph
HIPWAC	$R>10^6$ mid-IR spectrogaph
IRSHELL	R=1000-30,000 5-25 µm spectrograph
MIRAC 1/2/3	Mid-IR cameras
MIRLIN	Mid-IR camera
MIRSI	Mid-IR camera and spectrograph
MIT CCD	Occultation CCD camera fed by NSFCAM
MOP	Multichannel 1-20 µm occultation photometer
OSCIR	Mid-IR camera
TEXES	R=5000-100,000 8-26 µm spectrograph
THIS	$R\approx10^7$ tunable heterodyne 7-19 µm spectrograph

IRTF as a platform for instrument development





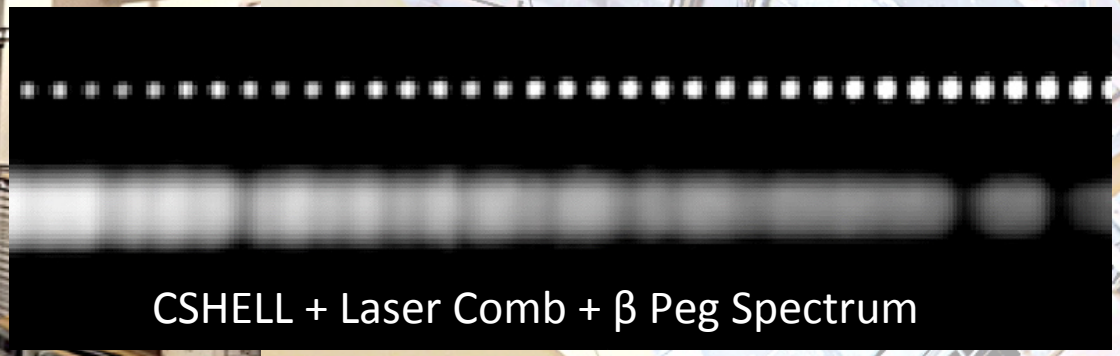
EXES on IRTF 2011

EXES on SOFIA 2014

Matt Richter *et al*.

IRTF as a platform for instrument development





CSHELL + Laser Comb + β Peg Spectrum

JPL/Caltech Astrocomb
2014 IRTF run

Plavchan, Beichman, Leifer, Vahala *et al*.

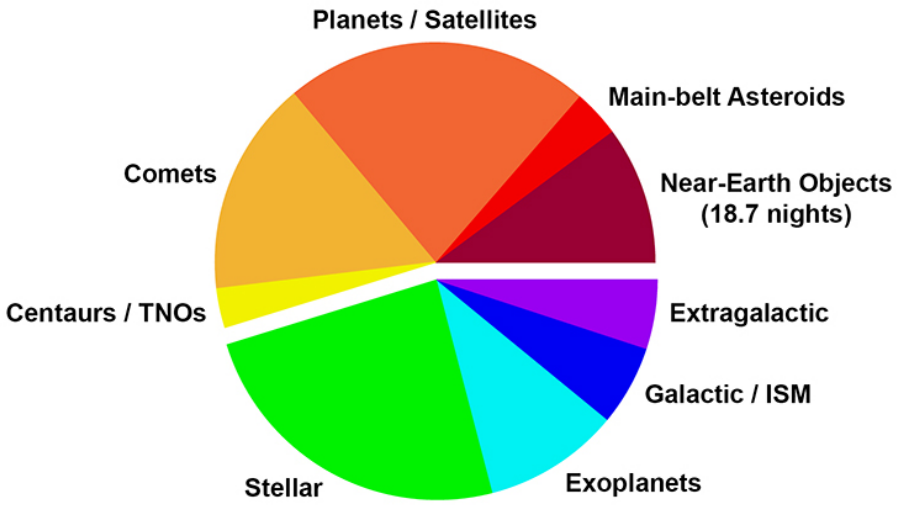
Recent Major Facility Upgrades

- Telescope Control System (TCS) replacement (2008)
- New secondary figured to remove spherical aberration (2010)
- HVAC upgrade to reduce dome seeing (2014)
- MIM reinforcement to mount large instruments (2016)
- Dome resurfacing (2018)
- New chopping secondary incorporated with hexapod (2018)
- Moveable counterweight upgrades to improve telescope balance, pointing and tracking (ongoing)
- Dome upgrades (ongoing)

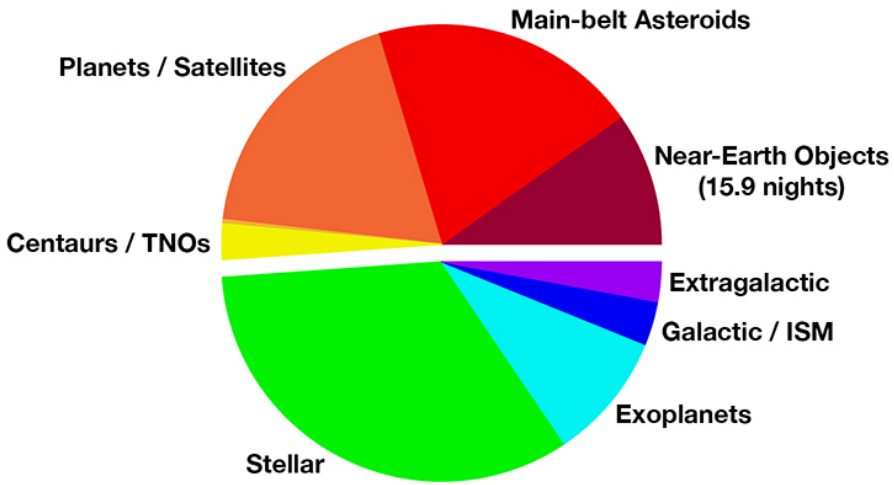


Distribution of Observing Time by Scientific Category

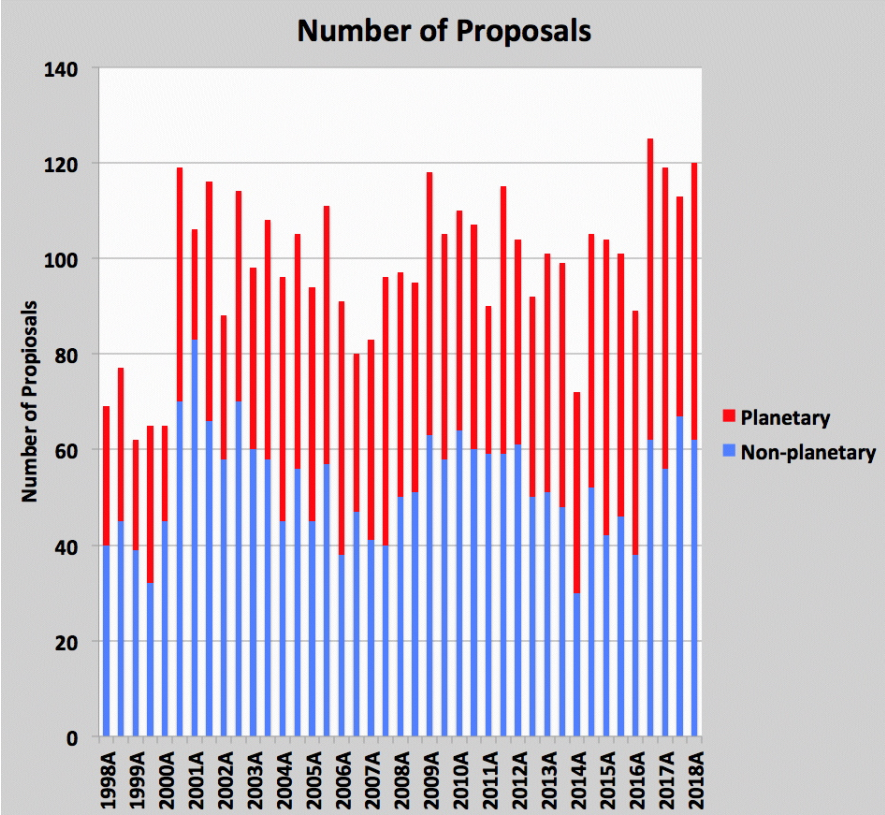
2017A

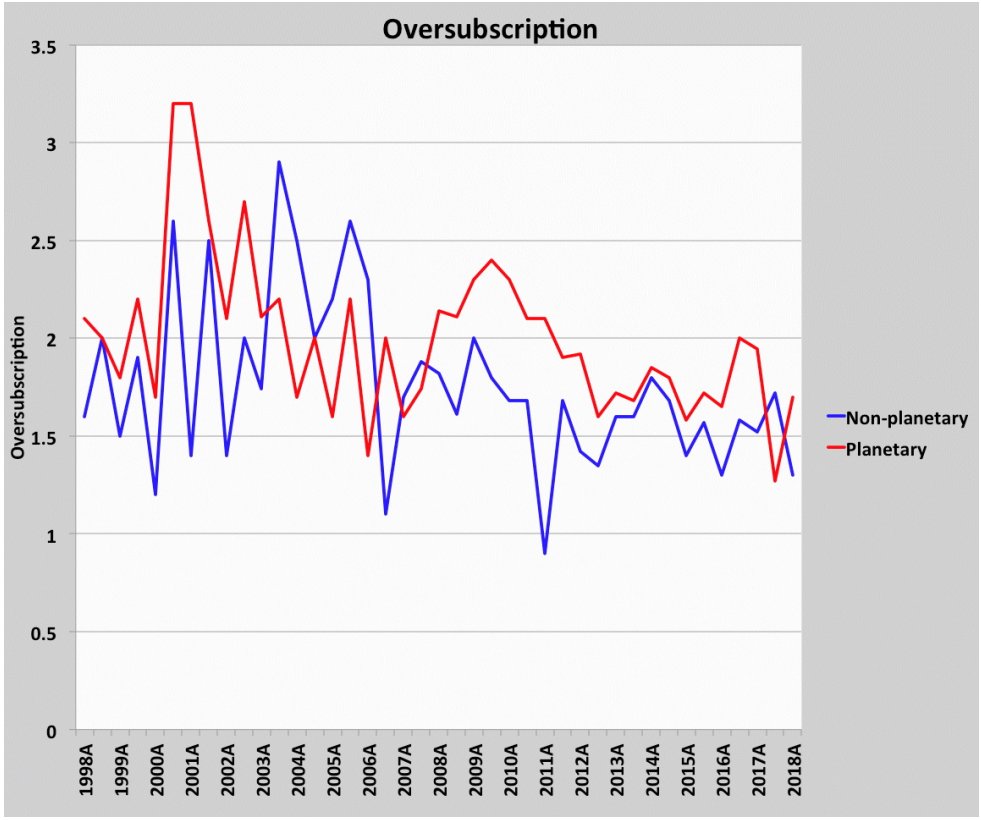


2017B

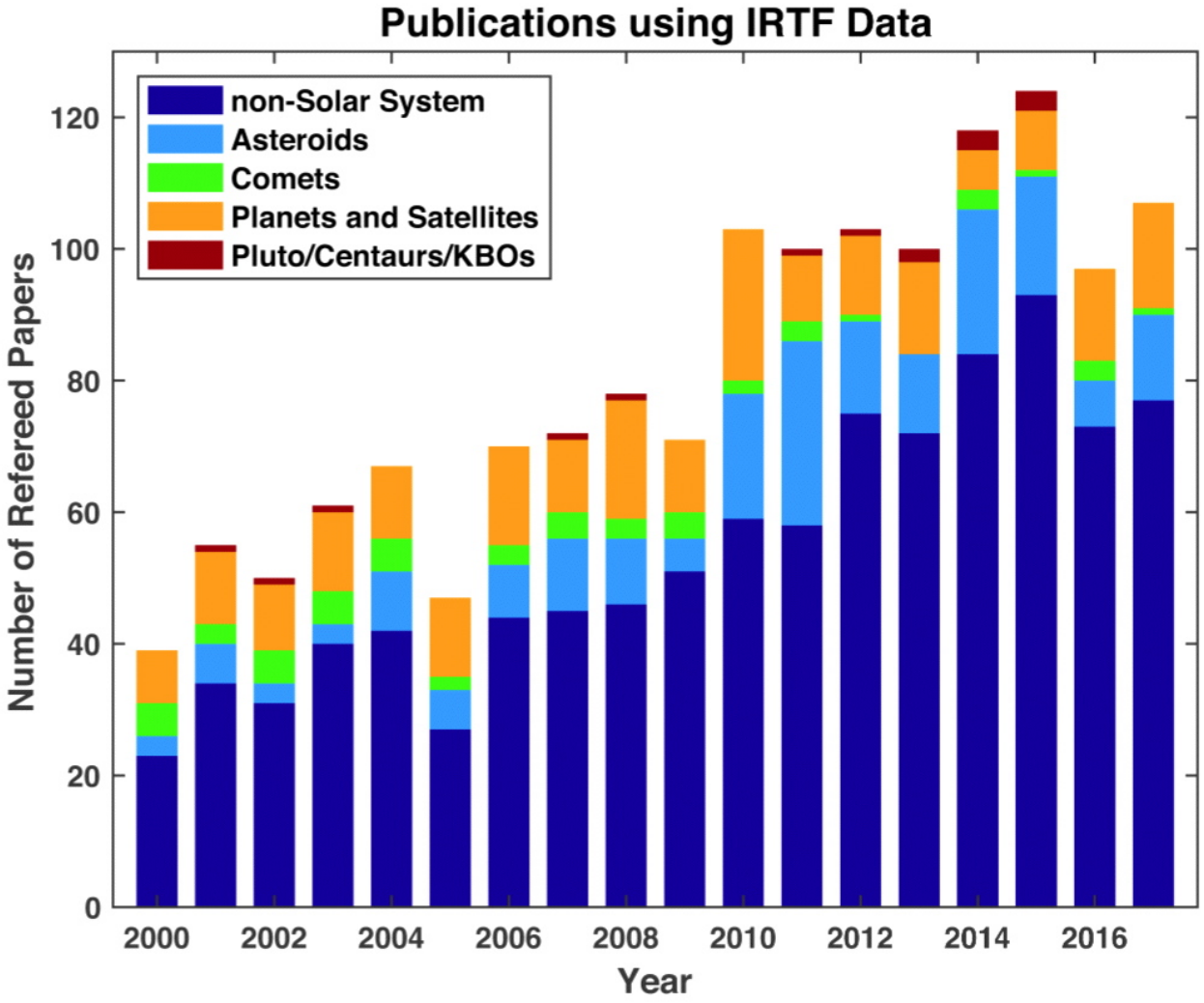


Telescope Proposals

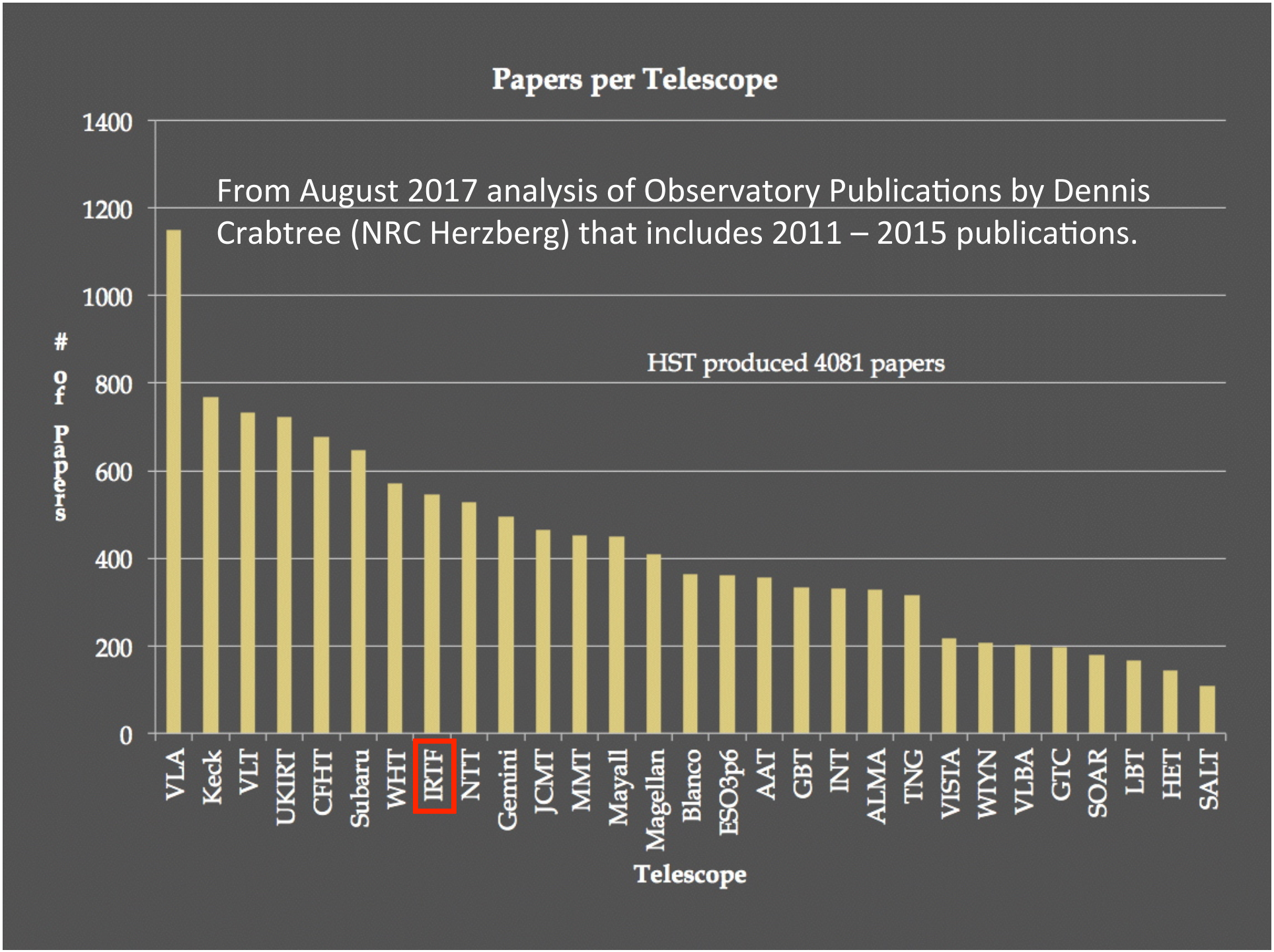


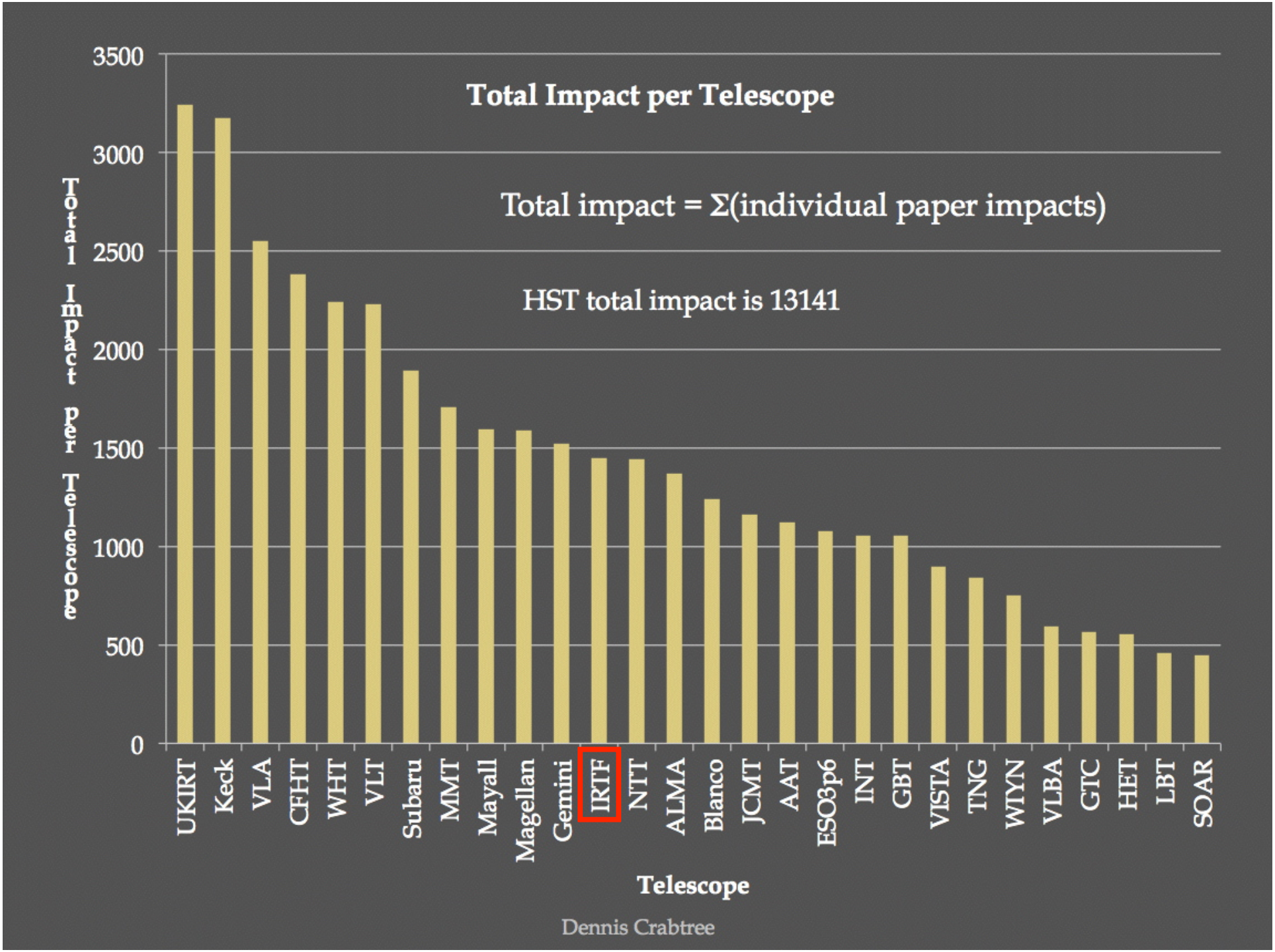


IRTF Bibliography

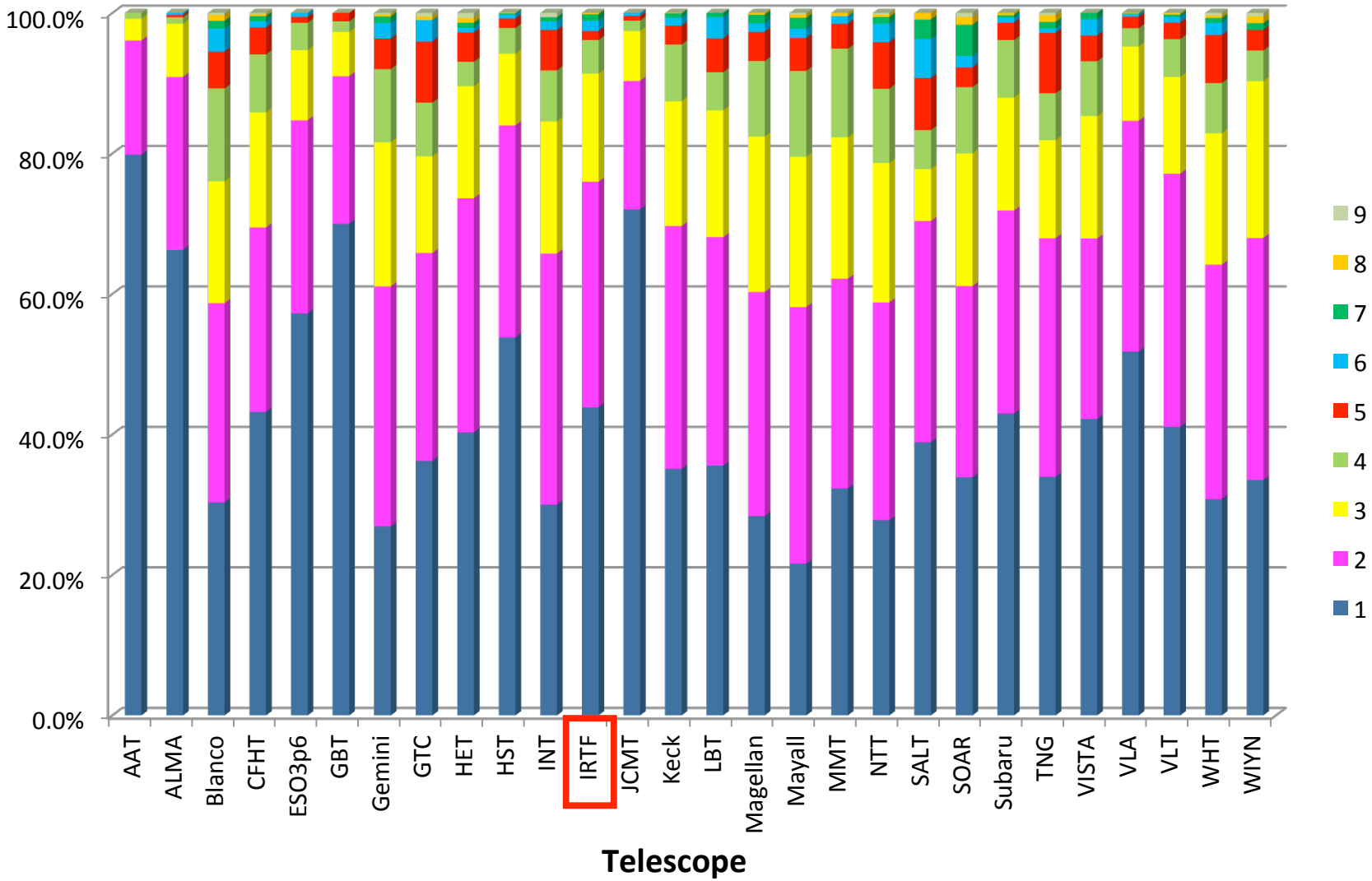


http://irtfweb.ifa.hawaii.edu/research/biblio/publications.html


Papers per Telescope
From August 2017 analysis of Observatory Publications by Dennis Crabtree (NRC Herzberg) that includes 2011 – 2015 publications.
HST produced 4081 papers
# of Papers
1400
1200
1000
800
600
400
200
0
VLA
Keck
VLT
UKIRT
CFHT
Subaru
WHT
IRTF
NTT
Gemini
JCMT
MMT
Mayall
Magellan
Blanco
ESO3p6
AAT
GBT
INT
ALMA
TNG
VISTA
WIYN
VLBA
GTC
SOAR
LBT
HET
SALT
Telescope

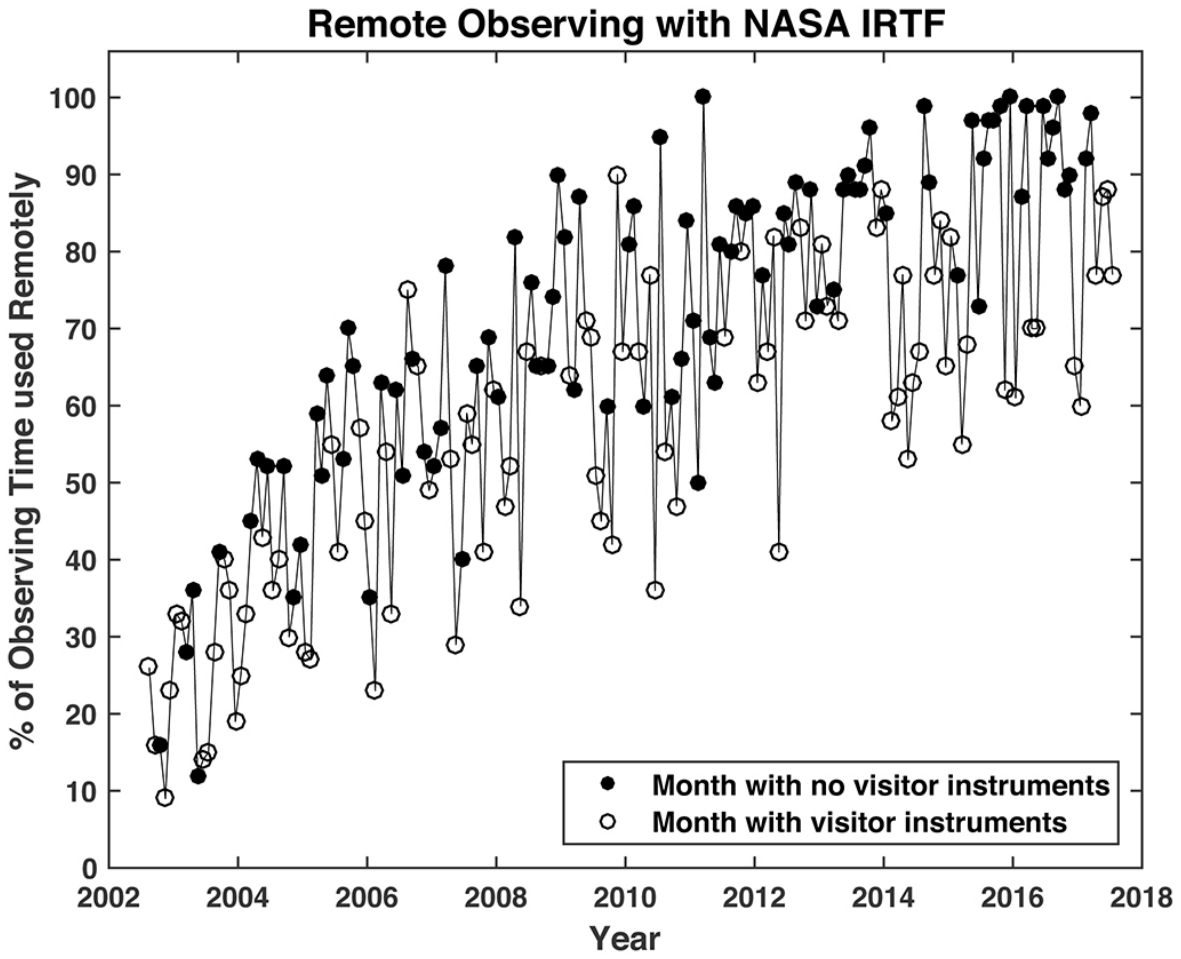

Total Impact per Telescope
Total impact = Σ(individual paper impacts)
HST total impact is 13141
Total Impact per Telescope
3500
3000
2500
2000
1500
1000
500
0
UKIRT
Keck
VLA
CFHT
WHT
VLT
Subaru
MMT
Mayall
Magellan
Gemini
IRTF
NTT
ALMA
Blanco
JCMT
AAT
ESO3p6
INT
GBT
VISTA
TNG
WIYN
VLBA
GTC
HET
LBT
SOAR
Telescope
Dennis Crabtree

Percentage of papers vs number of telescopes claiming paper



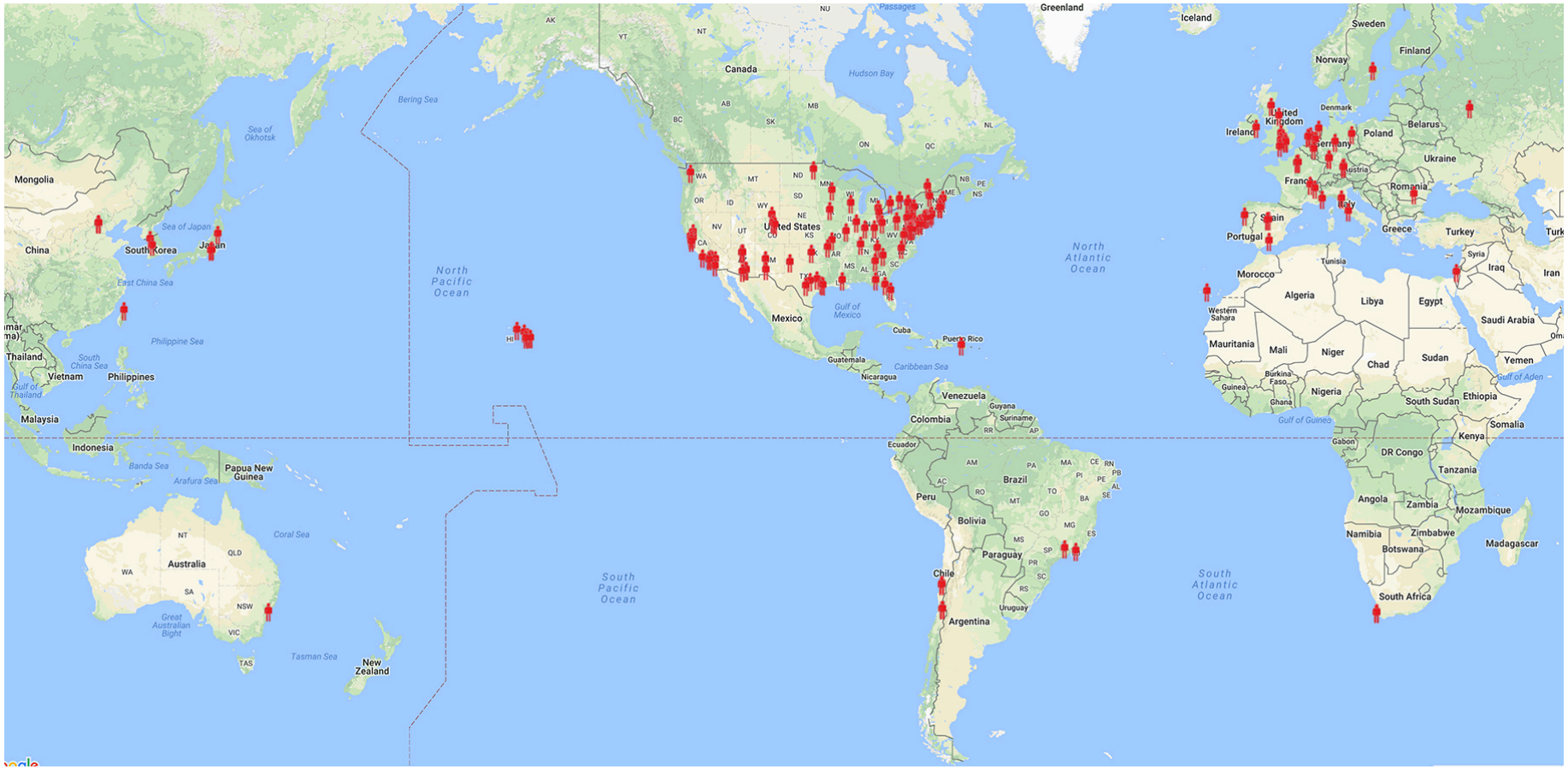
From analysis by Dennis Crabtree, 44% of papers in IRTF Bibliography utilize only one telescope (IRTF).

Remote Observing – 15 years



Over the past 2 years (08/15 – 07/17), 85% of the scheduled observing time on the IRTF has been used remotely. If we include only those months in which no visitor instruments are scheduled, this average increases to 95%.

Remote Observing – 15 years



This interactive map currently shows 176 locations from which IRTF observations have been obtained remotely. This map can be found at:

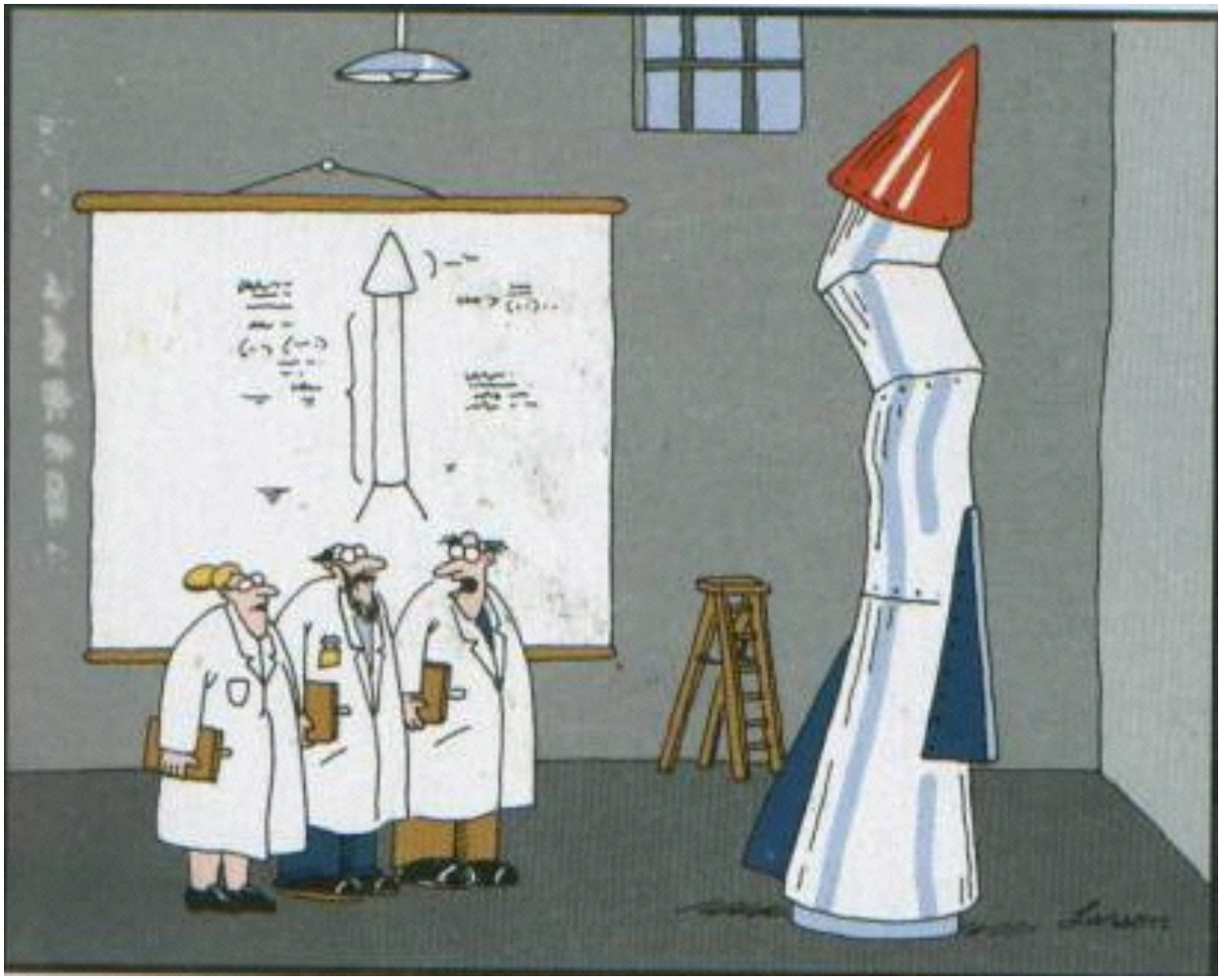
http://irtfweb.ifa.hawaii.edu/observing/remlocations.php

Telescope Scheduling

- **Remote observing and the ability to quickly change instruments with the MIM permits greater flexibility in scheduling the telescope**
  - Multiple programs per night
  - Short programs (> 30 min)
  - Programs requiring short runs over many nights
  - Short service observing programs executed by TO
- **Improved scientific productivity but the telescope is more difficult to schedule**
- **Target of Opportunity programs approved by TAC**
- **Rapid response possible by moving scheduled programs to engineering time**
- **Not enough staff for queue observing**

Telescope Scheduling

- **Target of Opportunity programs approved by TAC**
  - ToO programs currently limited to 12 hours each per semester for planetary and non-planetary programs
  - This limits impact on classically scheduled programs
  - ToO programs are ranked by TAC. If top ranked program is not activated time goes to lower ranked programs
- **Semester by semester scheduling is not optimum for time domain follow up**
  - Plan for mid-semester fast turn around proposals?
  - Take time from classical schedule to facilitate this, one night per month?

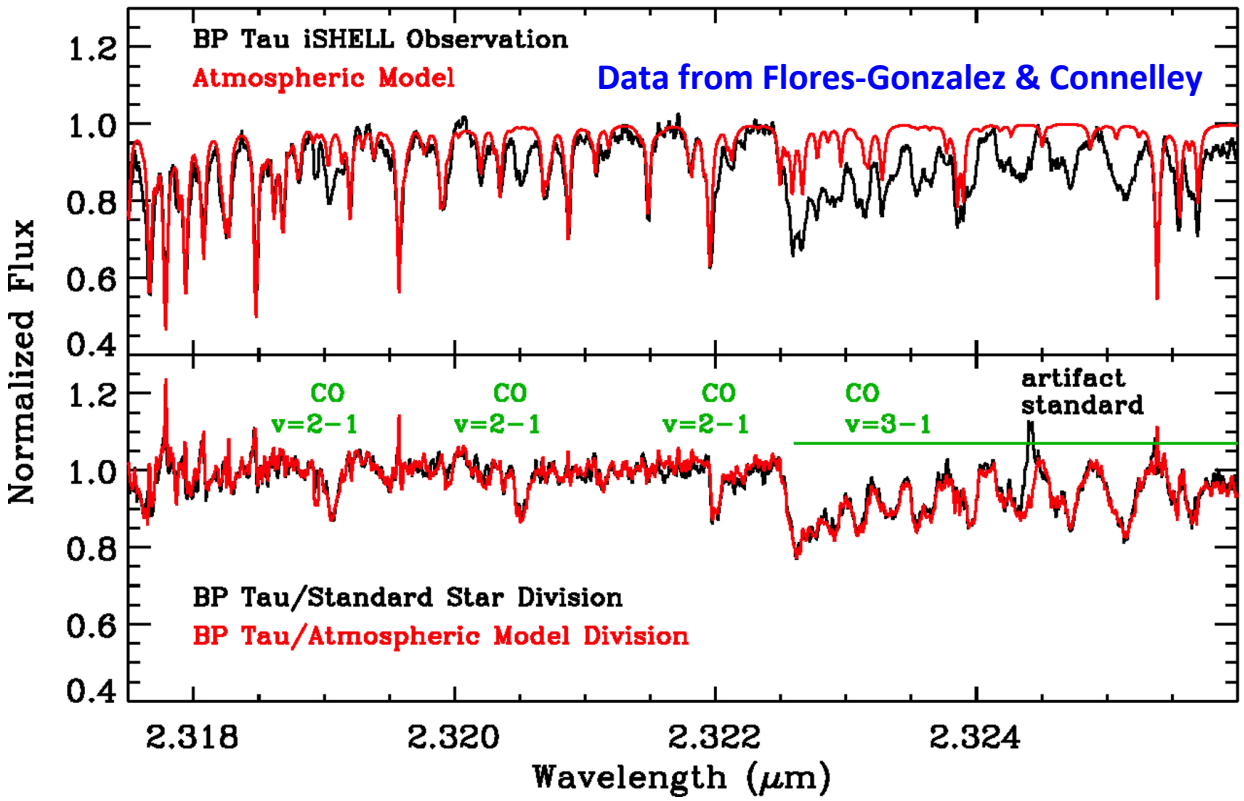


“It’s OK, we can always get the programmers to fix it in software”

Observing Data

- **To keep IRTF scientifically productive data needs to be reduced in an efficient and timely manner**
- ***Spextool* data reduction pipeline is now in routine use with both *SpeX* and *iSHELL* data**
- **One of the three IRTF support astronomers now specializes in data reduction for current and future instruments**
- **IRTF Data Archive in collaboration with Infrared Science Archive (IRSA) at IPAC**
  - Proprietary period 18 months
  - First release of *SpeX* data is Feb 1, 2018
  - First release of *iSHELL* data is Aug 1, 2018
  - *SpeX* data 2000-2016 will be made available after 18 month proprietary period in June 2019 but not from formal archive due to the archaic fits headers and incomplete metadata not meeting IRSA standards

Using atmospheric models to remove telluric features instead of standard stars (Boogert)



- IRTF code interfaces with LBLRT Models
- Fit iSHELL spectrum T Tauri star BP Tau K3 2.25-2.54 μm
- Code will be incorporated into *Spextool* initially for iSHELL only

Quality at least as good as division by A0V standard star

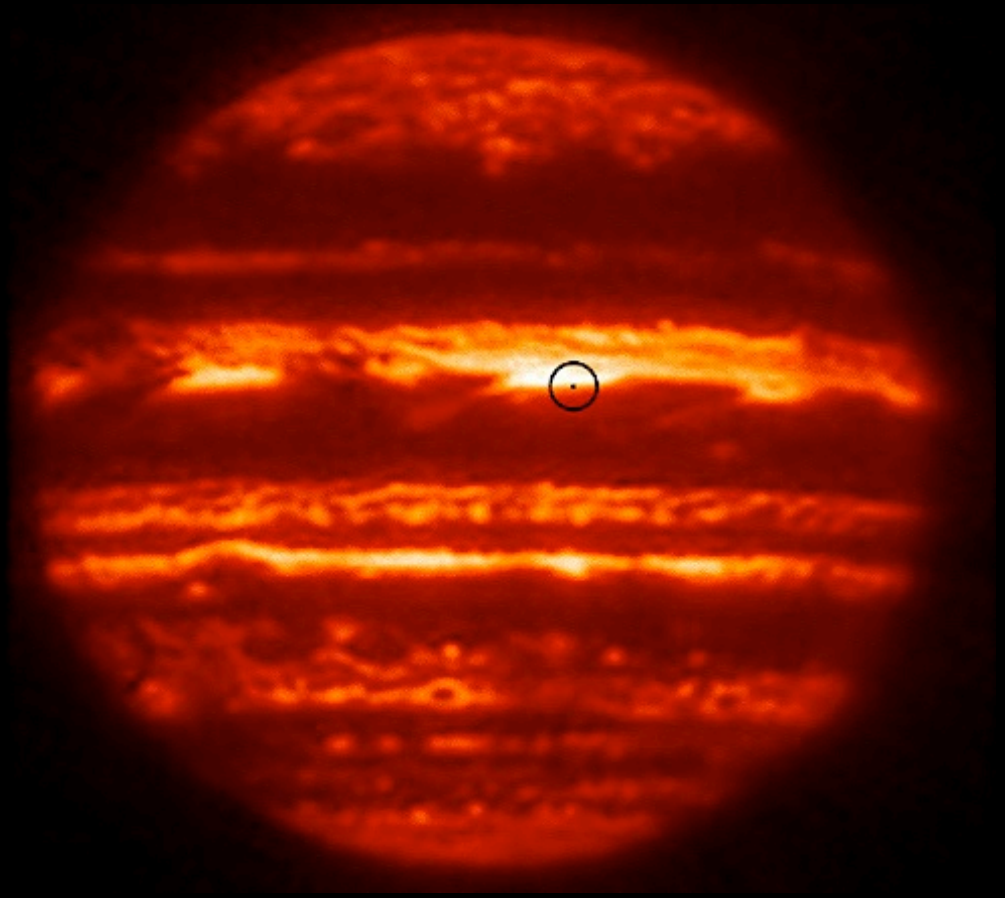
NASA Mission Support

- **IRTF Statement of Work**
  - Approximately 50% of observing time devoted to solar system bodies in support of planetary exploration programs
  - At the request of NASA, IRTF provides mission critical observations or observations of a programmatic rather than scientific nature
- **Mission support requests usually come in the form or requests for TAC time (i.e. not mandated)**
- **Occasional requests for coordinated campaigns to support NASA missions, e.g.**
  - SL9 impact (1994)
  - Galileo arrival at Jupiter (1995)
  - Deep Impact/Comet Tempel 1 (2005)
  - LCROSS impact (2009)

2017B Mission Support Programs

2017B007	Reddy	Physical Characterization of Small NEOs	Future NEO missions
2017B014	DeMeo	Spectral Measurements of Spacecraft Mission Candidates and Potentially Hazardous Asteroids	Future NEO missions
2017B015	Moscovitz	IRTF NEO Rapid Response: Close Encounters of the Asteroid Kind	Future NEO missions
2017B060	Bus	Spectral Measurements of Spacecraft Mission Candidates and Potentially Hazardous Asteroids	Future NEO missions
2017B026	Reddy	Physical Characterization of Spacecraft Mission Targets	Dawn + Destiny
2017B027	Emery	Near-infrared spectroscopy of the four L4 Trojan targets of NASA's Lucy mission	Lucy
2017B011	Johnson	Juno support observations: Measuring ionospheric flows and temperatures of the Jovian southern aurora	Juno
2017B067	Orton	Characterizing Jupiter's Atmosphere and Aurora to Support Juno Science Orbit Perijoves 8 and 10.	Juno
2017B068	Orton	Characterizing Short- and Intermediate-Term Variability in Jupiter Between Juno Perijoves 7 and 12	Juno
2017B080	Spencer	High Time Resolution Imaging of Io's Volcanoes to Understand their Influence of the Jovian Magnetosphere during the Juno Mission	Juno
2017B009	Stallard	Observations of Saturn's H3+ aurora in support of the Cassini Grand Finale orbits	Cassini
2017B053	Corlies	Continued investigation of seasonal changes in Titan's meteorology through cloud monitoring with IRTF SpeX	Cassini
2017B074	Orton	Near-Infrared Support for Cassini in its Final Proximal Orbits	Cassini
2017B110	Mumma	Sensitive Hemispheric Maps of Methane and Related Gases on Mars: Synergies with Observations from ExoMars Trace Gas Orbiter	ExoMars TGO

Galileo high gain antenna problem



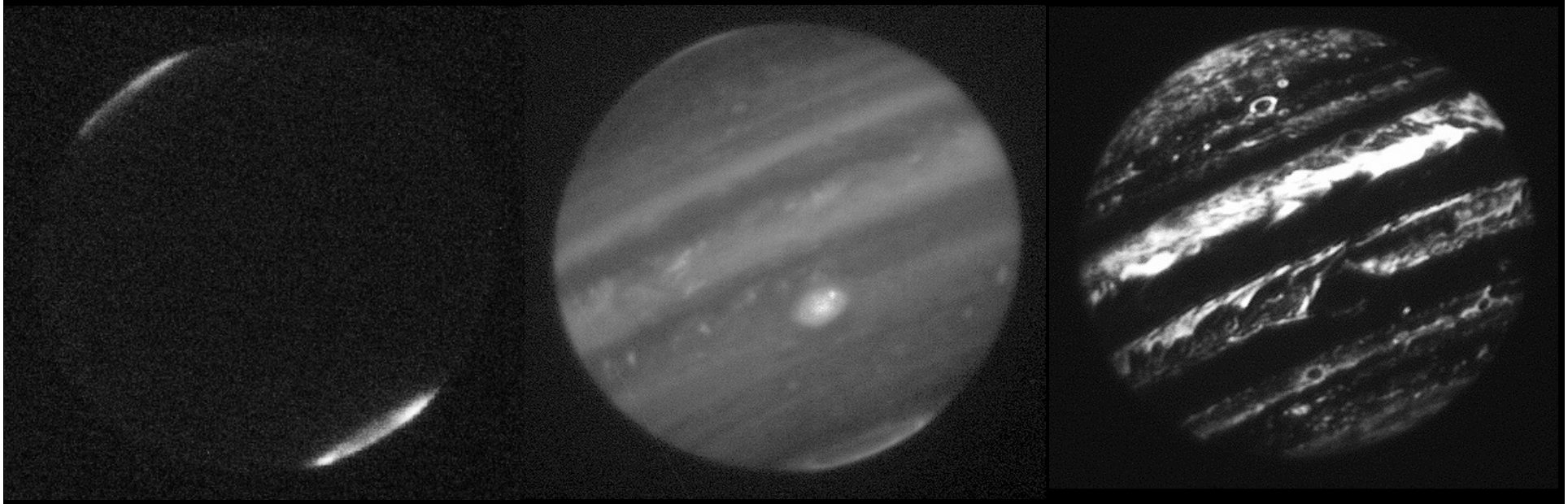
21 November 1995
5 µm Jupiter NSFCAM image (256x256 InSb array)
Targeting for Galileo probe atmospheric entry site



7 December 1995
NSFCAM image of probe entry site on day of entry. Image taken 9 degrees from Sun

JUNO SUPPORT

3.42 µm ′3.8 µm 5.1 µm



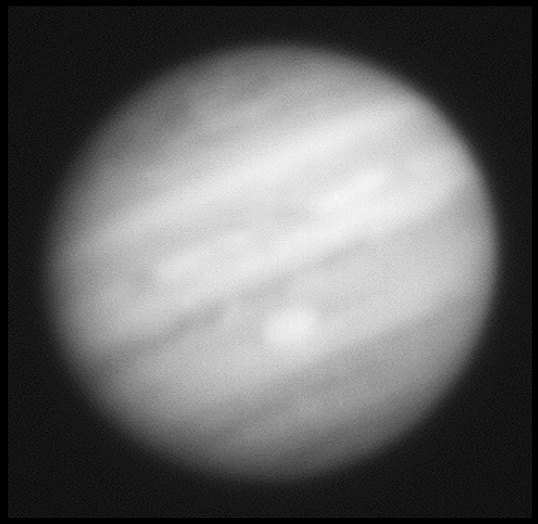
March 2017 Jupiter at opposition

SpeX imaging, Orton *et al.*

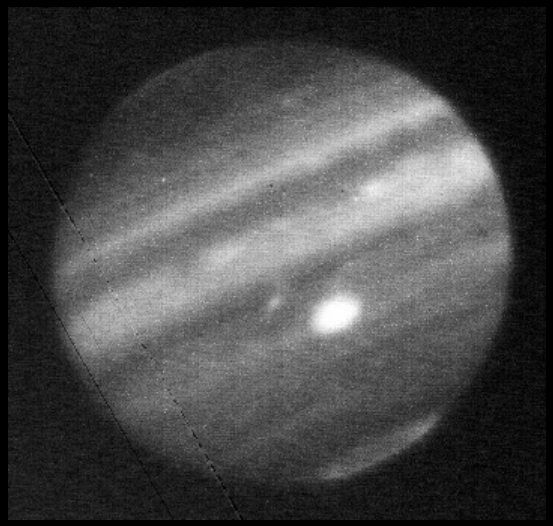
https://junoirtf.space.swri.edu/browse

JUNO SUPPORT

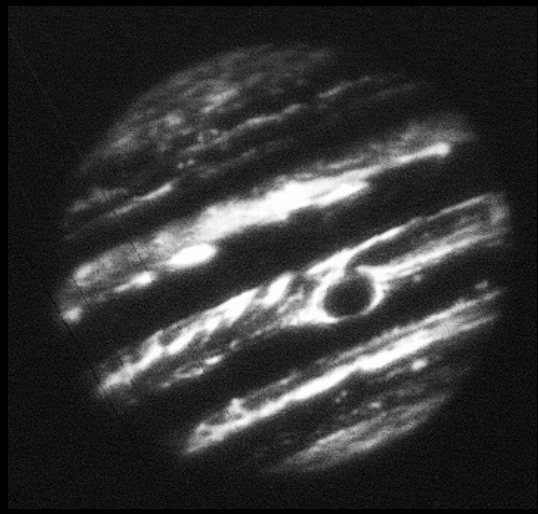
H 1.65 µm



L' 3.8 µm



5.1 µm

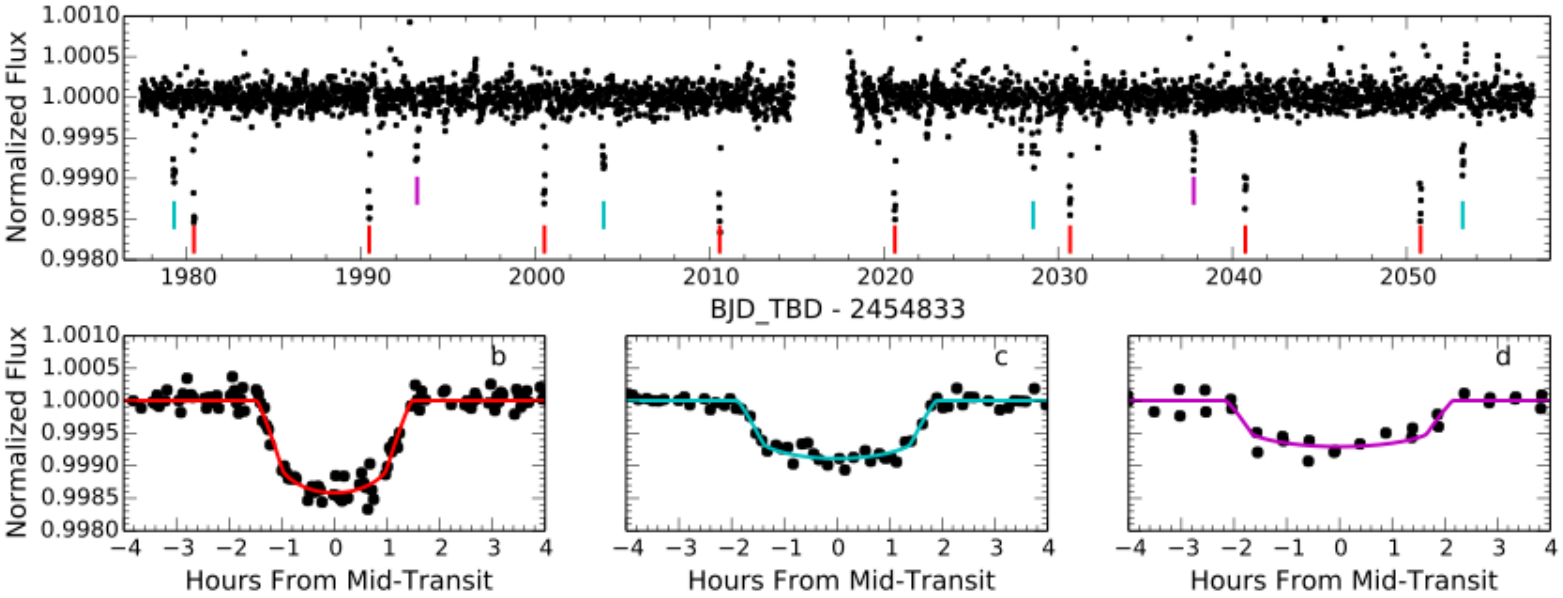


July 2017 Jupiter daytime observing

SpeX imaging, Orton *et al.*

https://junoirtf.space.swri.edu/browse

Kepler Mission Support: Characterizing Planet Hosts



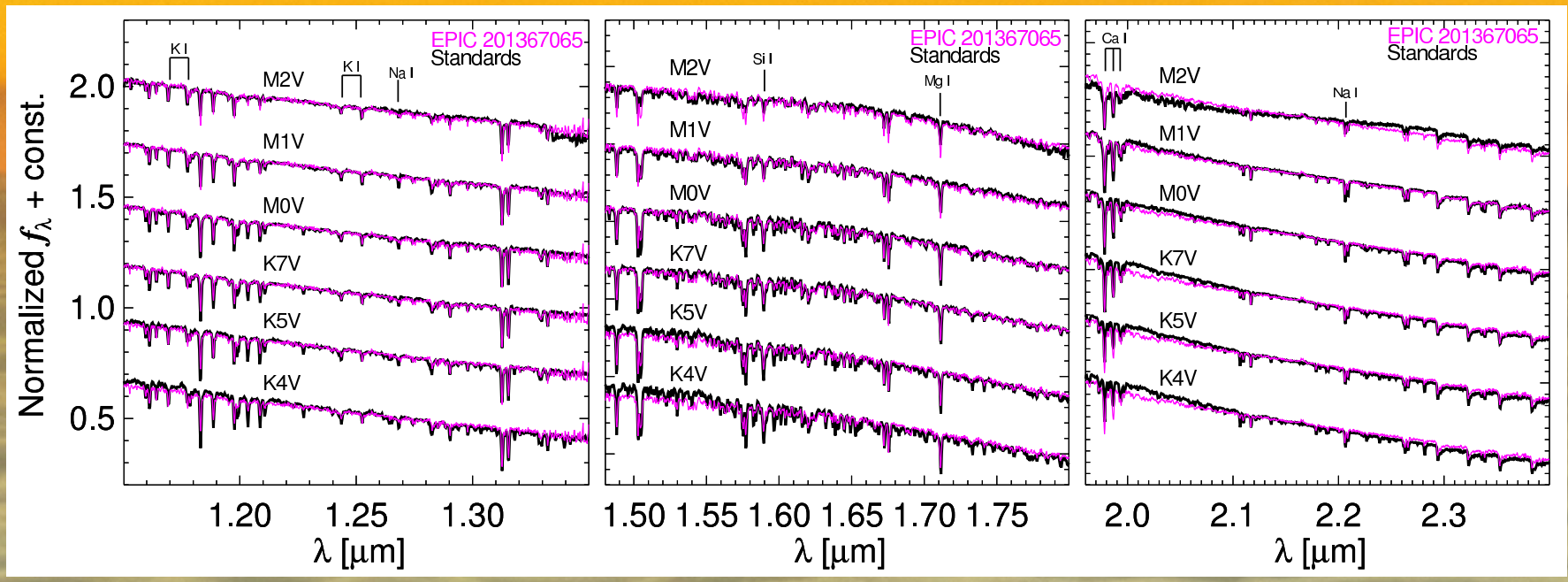
P = 10 days
R_p = ? R_{Earth}
T_{eq} = ? K

P = 25 days
R_p = ? R_{Earth}
T_{eq} = ? K

P = 45 days
R_p = ? R_{Earth}
T_{eq} = ? K

K2-3: Phased Light Curves

Crossfield *et al.* 2015



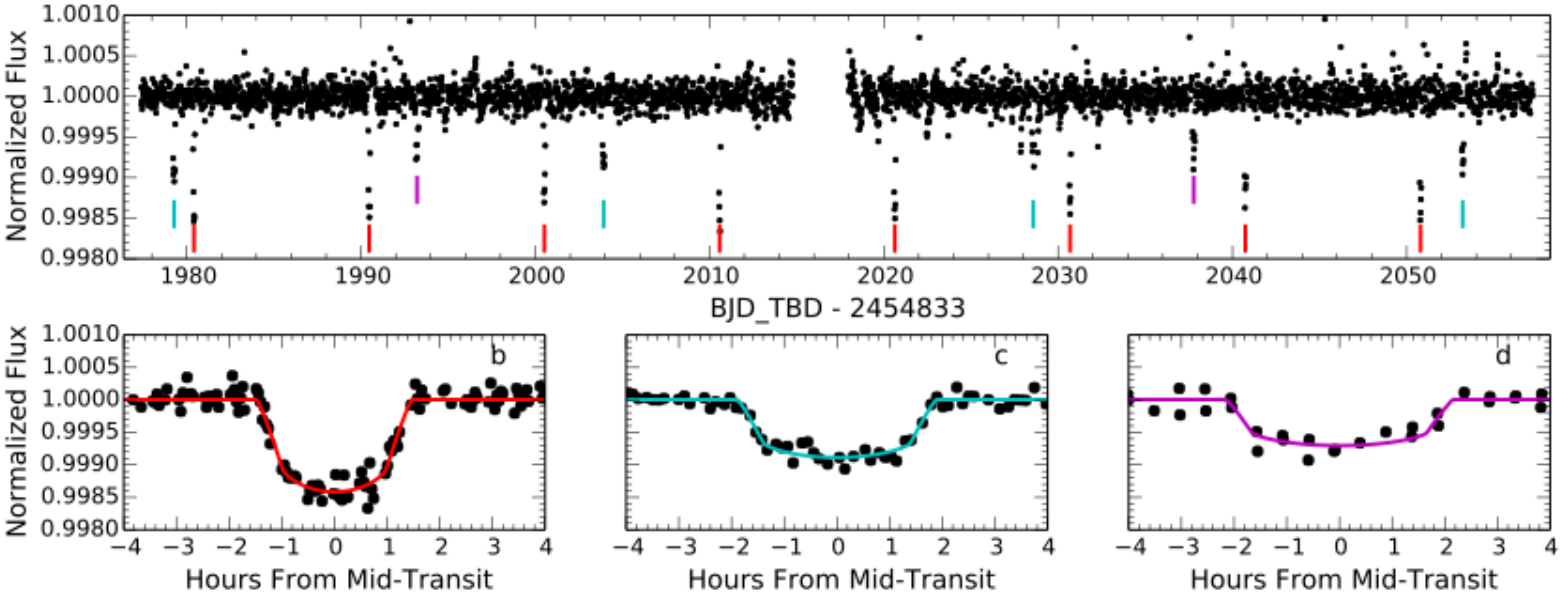
K2-3: Spectra for Stellar Parameters

T_{eff} = 3800 K

R_* = 0.56 R_{sun}

[Fe/H] = -0.32

K2-3: Planet Properties



P = 10 days
R_p = 2.1 R_{Earth}
T_{eq} = 470 K

P = 25 days
R_p = 1.7 R_{Earth}
T_{eq} = 350 K

P = 45 days
R_p = 1.5 R_{Earth}
T_{eq} = 280 K

Host star is *nearby & bright* (V=12.2, K=8.5)
⇒ mass & atmosphere followup possible

Crossfield *et al.* 2015

Future Plans

- **Goal is to maintain IRTF as an irreplaceable asset for NASA and to maximize scientific productivity**
- **Focus on upgrades to the existing 3-m telescope:**
  1. Next ten years (2028)
  2. Beyond 2028 (current Master Lease ends in 2033)

Potential Future Plans to 2028

- **Improve image quality**
  - Low-order AO system
  - Active mirror support (mirror bender)
- **Improve telescope tracking and pointing**
- **Deploy high-order AO**
  - Adaptive secondary (high throughput, low emissivity)
  - For use with all facility instruments improving spectrograph point source sensitivity 1-2 mag.
  - Optimized 1-5 µm imager
- **New focal plane instruments**

Image Quality Error Budget (WFE)

1. Optics

- Diffraction 0.24
- Optical figure 0.03
- Mirror support 0.40

0.47 µm

2. Seeing

- Free atmosphere 0.95
- Image jitter 0.14
- Dome seeing 0.38

0.96 µm

3. Alignment

- Static 0.15
- Dynamic 0.05

0.16 µm

4. Focus

0.90 µm

Total WFE 1.15 µm (RSS) without defocus

1.46 µm with defocus

Observed WFE 1.15 µm
(0.7" FWHK at *K*)

Image Quality Error Budget (WFE)

1. Optics

- Diffraction 0.24
- Optical figure 0.03
- Mirror support 0.40

0.47 µm

2. Seeing

- Free atmosphere 0.95
- Image jitter 0.14
- Dome seeing 0.38

0.96 µm

3. Alignment

- Static 0.15
- Dynamic 0.05

0.16 µm

4. Focus

0.90 µm

Low-order AO

Observed WFE 1.15 µm
(0.7" FWHK at *K*)

Total WFE 1.15 µm (RSS) without defocus
1.46 µm with defocus

Image Quality Error Budget (WFE)

1. Optics

- Diffraction 0.24
- Optical figure 0.03
- Mirror support 0.40

0.47 µm

Mirror bender driven by low-order AO

2. Seeing

- Free atmosphere 0.95
- Image jitter 0.14
- Dome seeing 0.38

0.96 µm

3. Alignment

- Static 0.15
- Dynamic 0.05

0.16 µm

4. Focus

0.90 µm

Low-order AO

Observed WFE 1.15 µm (0.7" FWHK at *K*)

Total WFE 1.15 µm (RSS) without defocus
1.46 µm with defocus

Image Quality Error Budget (WFE)

1. Optics

- Diffraction 0.24
- Optical figure 0.03
- Mirror support 0.40

0.47 µm

Mirror bender driven by low-order AO

2. Seeing

- Free atmosphere 0.95
- Image jitter 0.14
- Dome seeing 0.38

0.96 µm

High-order AO

Dome thermal upgrade. Vents?

3. Alignment

- Static 0.15
- Dynamic 0.05

0.16 µm

4. Focus

0.90 µm

Low-order AO

Observed WFE 1.15 µm (0.7" FWHK at *K*)

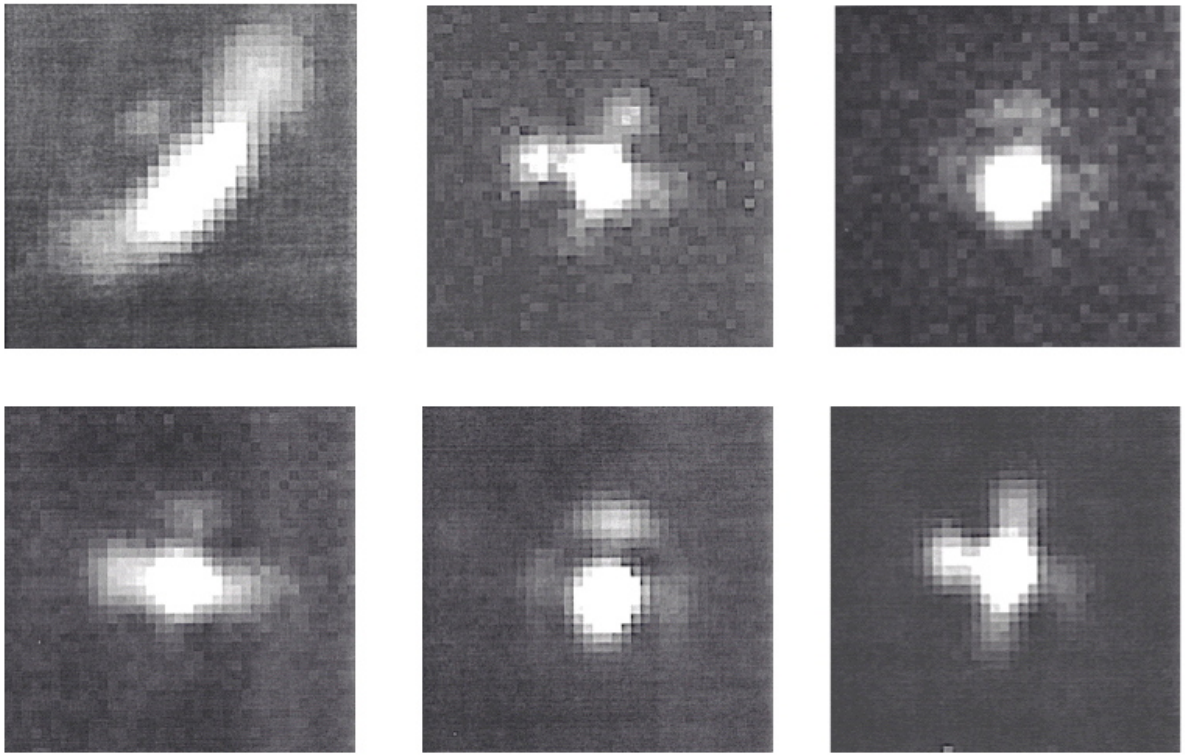
Total WFE 1.15 µm (RSS) without defocus

1.46 µm with defocus

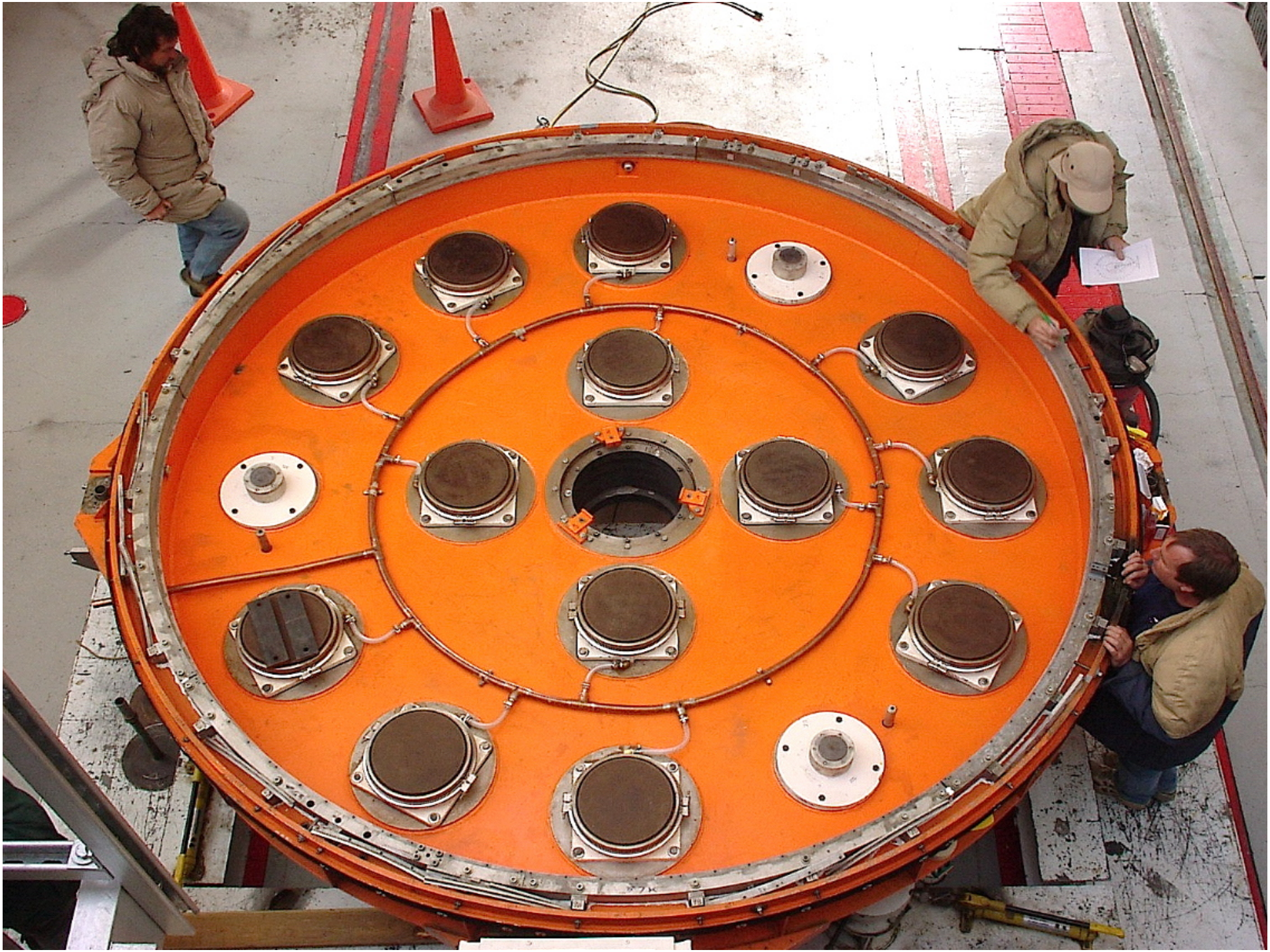
Low-order AO

- **Image quality changes when telescope slews**
  - Focus changes (defocus)
  - Collimation changes (coma)
  - Mirror support changes (astigmatism)
- **Fix with Shack-Hartmann sensor in off-axis guider**
  - 3 x 3 pupil slice imaged onto CCD, closed-loop ~ 1 min
  - Drives telescope focus and secondary hexapod
  - More advanced system could drive mirror bender active support to fix astigmatism
- **A simple system to correct low order terms would increase the efficiency of all instruments on the telescope and is easily funded from IRTF operations funds**
- **Result in better understanding of telescope performance for higher order AO systems**

Astigmatism due to mirror support



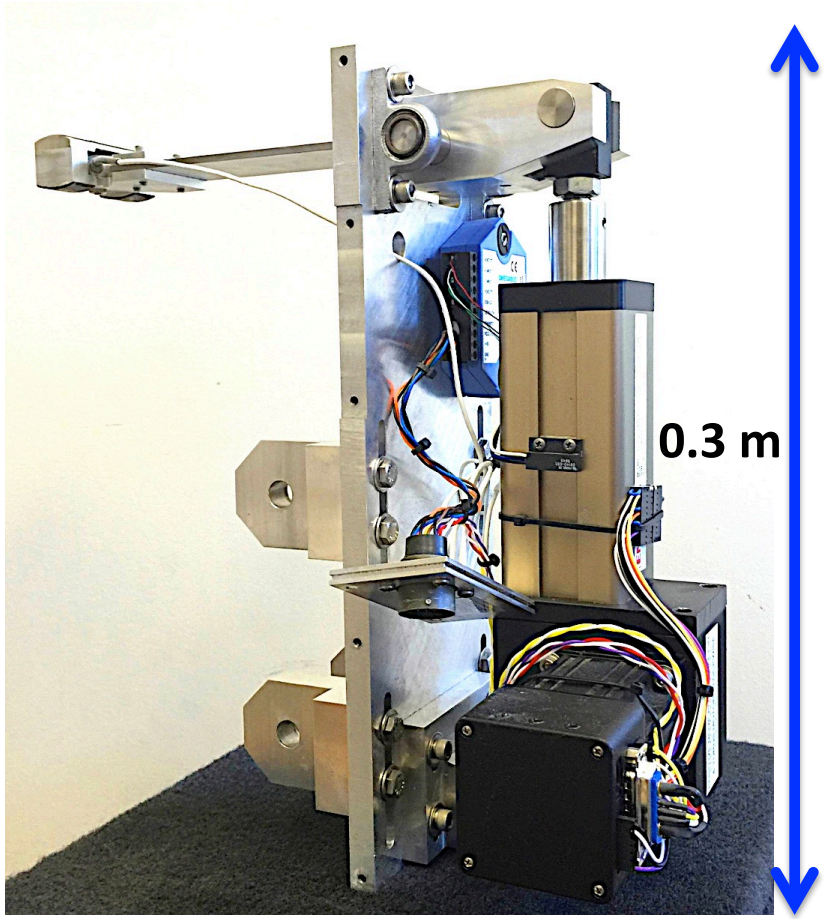
- Short exposure *L'* images at different telescope positions, up to 1μm WFE
- Ideally we would like to remove astigmatism to reduce the stroke required on DM in any higher order AO system





Primary Mirror Bender

- Image quality specification 1” FWHM (1975) – met but not adequate for diffraction-limited imaging in NIR
- Mirror bender concept proposed by Earl Pearson, designer of original mercury ring support
- Built and tested in 2000 but decided to improve dome seeing and fix spherical aberration first
- Eight units around perimeter of primary driven closed-loop by low-order AO Shack-Hartman sensor



Potential New Facility Instruments

- **Spectrograph for small bodies, transients, time domain (*SPECTRE*)**
  - R~100
  - Three channels 0.4-4 μm
  - 5”x 5” IFU (no slit losses)
- **Optimized imager for general science (*NSFCAM* replacement)**
  - 0.4-0.9 μm channel and 0.9-5 μm channel
  - Fixed filters, CVF (R~100) and polarimetry
  - Seeing limited and AO capable modes, ~2’ x 2’ FOV
- **Multi-channel (>6) imager for time domain follow-up, transients and small body colors**
  - 0.4-2.5 μm, channel band-pass TBD
  - ~2’ x 2’ FOV
- ***Robo-AO* for Kepler and TESS follow-up, long-term planetary weather monitoring, asteroid multiplicity**
  - 0.6-1.8 μm
  - 5-10” instantaneous FOV

Potential New Facility Instruments

- ***MIRSI* further upgrade, NEO albedos, planetary atmospheres, general MIR science**
  - State-of-the-art MIR array (current detector is two decades old)
  - Rebuilt camera head for lower background operation, more filters and observing modes
- **Common fiber feed for 0.5-2.5 µm Coudé room instrument suite**
  - IFU spectrograph for fast characterization of sky survey finds, point-and-shoot capability
  - RV spectrograph

Potential Changes to Operations

- **Fast turn around proposals? Semester by semester scheduling is not optimum for time domain follow up**
- **Queue observing? Efficient but not universally popular. Would need additional staff to implement**
- **Explore synergies with other telescopes?**
  - Complementary instruments
  - Shared scheduling

Potential Future Plans beyond 2033

- **Full remote operation of telescope for rapid response**
  - Pick-off mirror plus instrument cluster
  - Telescope infrastructure upgrades
  - Cost ~$10m
- **HST-like image performance to complement larger telescopes**
  - High-order AO
  - Low-scatter primary and secondary mirrors
  - Light weight primary with reduced thermal inertia
  - New mirror support
  - Cost ~$15m
- **Larger replacement for IRTF?**
  - Probably requires a compelling new capability for NASA
  - Mauna Kea might not be an option
  - New Planetary Telescope (2000 study) - off-axis 6m and instruments cost estimate $100m