NASA’s Infrared Telescope Facility and NASA Planetary Science Programs

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Thank you!

• Local organizer Vishnu Reddy and team
• Kim Land and the Biosphere 2 team
• The University of Arizona
• IRTF’s John Rayner and team
• The Science Organizing Committee
• All of YOU!
Keck/IRTF (MOWG) Users Group

- Hears reports from observatory directors and staff twice a year on the status of NASA’s IRTF and NASA’s partnership in the Keck Observatory
- Composed of telescope users from the IRTF and Keck communities
- Produces findings for NASA
- One finding has been a need for THIS WORKSHOP!

• Those interested in serving in the future may contact Kelly Fast or Hashima Hasan
Did you know???

IRTF moonlights on prime-time television...
IRTF prominently featured on prime-time network television

“The Big Bang Theory”, CBS
The IRTF was once again prominently featured on Prime-time network television.

(Did they steal that poster from Ken’s House of Pancakes?)
There it is again! IRTF *prominently* featured on prime time network television!

“The Big Bang Theory”, CBS
IRTF just keeps showing up on major prime-time television!

“The Big Bang Theory”, CBS
NASA’s Infrared Telescope Facility (IRTF)

- The IRTF was established in 1979 to obtain infrared observations of interest to NASA, particularly in support of planetary exploration missions (Voyager and onward)
- NSF has been an important partner, supporting peer-reviewed instrument development and some visitor support where possible
- IRTF management and operations have been funded in NASA’s Planetary Science Division
- Programmatic have been implemented as an approximate 50/50 split between planetary science and astrophysics (non-Solar System) investigations
Planetary Science Division Update
Planetary Science Missions Events

Late 2017
- August 21 – Total solar eclipse seen across the US
- September 15 – Cassini enters Saturn – end of mission
- September 22 – OSIRIS-REx Earth flyby

2018
- May 5 - Launch InSight mission to Mars
- June 21-July 5 – Hayabusa 2 arrives at Ryugu
- August – OSIRIS-REx arrival at Bennu
- October – Launch of ESA’s BepiColombo to Mercury
- November 26 – Insight landing on Mars
- December 16 – Comet 46P/Wirtanen close approach to Earth (30 lunar distances)

2019
- January 1 – New Horizons flyby of Kuiper Belt object 2014 MU69

2020
- July – Launch of Mars 2020 rover mission to Mars
- July – Launch of ESA ExoMars rover mission to Mars
- July – OSIRIS-Rex retrieves a sample from Bennu
- December 7 – Hayabusa 2 re-entry operation on 16:54 UTC in Australia
- December – Landing of Mars 2020 rover on Mars

* Completed
Discovery and New Frontiers

- Address high-priority science objectives in solar system exploration
- Opportunities for the science community to propose full investigations
- Fixed-price cost cap full and open competition missions
- Principal Investigator-led project

- Established in 1992
- Open science competition for all solar system objects, except for the Earth and Sun

- Established in 2003
- Addresses high-priority investigations identified by the National Academy of Sciences
Discovery Program


New Frontiers Program

1st NF mission
New Horizons:
Pluto-Kuiper Belt
Launched January 2006
Flyby July 14, 2015
PI: Alan Stern (SwRI-CO)

2nd NF mission
Juno:
Jupiter Polar Orbiter
Launched August 2011
Arrived July 4, 2016
PI: Scott Bolton (SwRI-TX)

3rd NF mission
OSIRIS-REx:
Asteroid Sample Return
Launched September 2016
PI: Dante Lauretta (UA)
New Frontiers 4
Step 1 Selections (Dec. 2017)

- **Dragonfly** – PI Turtle (JHUAPL) - dual-quadcopter rotorcraft lander to explore prebiotic chemistry and habitability on Saturn’s moon Titan

- **Comet Astrobiology Exploration Sample Return (CAESAR)** – PI Squyres (Cornell) – sample return mission from nucleus of comet 67P/Churyumov-Gerasimenko for laboratory study of primitive Solar System materials

Phase A concept study reports due January 2019
## Planetary Science Deep Space SmallSat Studies: Awards

### Venus
- **Concept Title**
  - CUVE - CubeSat UV Experiment
  - Seismicity Investigation on Venus Using Airglow Measurements
  - Seismic and Atmospheric Exploration of Venus (SAEVe)
  - Cupid's Arrow

### Moon
- Innovative Strategies for Lunar Surface Exploration
- Lunar Water Assessment, Transportation, and Resource Mission
- Mini Lunar Volatiles (MiLUV) Mission
- CubeSat X-ray Telescope (CubeX) (also applicable to NEOs and Phobos/Deimos)
- Bi-sat Observations of the Lunar Atmosphere above Swirls (BOLAS)

### Small Bodies
- **CAESAR: CubeSat Asteroid Encounters for Science & Reconnaissance**
- Primitive Object Volatile Explorer (PrOVE)
- APEX: Asteroid Probe Experiment

### Mars
- **PRISM: Phobos Regolith Ion Sample Mission**
- Chariot to the Moons of Mars
- Aeolus - to study the thermal and wind environment of Mars
- Mars Ion and Sputtering Escape Network (MISEN)
- Mars Aerosol Tracker (MAT)

### Icy Bodies and Outer Planets
- **SNAP: Small Next-generation Atmospheric Probe**
- JUpiter MagnetosPheric boundary ExploreR (JUMPER)
SIMPLEx-2: Overview

- Solicits formulation and development of science investigations that require a spaceflight mission that can be accomplished using small spacecraft
  - ESPA-Class or smaller (< 180Kg)
  - Solicitation for secondary payload on specific primary missions, which will determine:
    - Launch readiness date
    - Initial release trajectory
  - Cost-capped missions
  - Continuously Open call with mission-specific deadlines
  - Foreign Participation will be allowed
Planetary Defense Coordination Office Update
Prior to mid-FY2014, IRTF was funded by the Planetary Astronomy Program

Since mid-FY2014, IRTF has been funded by the Near-Earth Object Observations (NEOO) Program

IRTF is a primary NEO physical characterization asset in the NEOO portfolio in the Planetary Defense Coordination Office

Programmatic changes have not been required for IRTF to fulfill its planetary defense role
Chelyabinsk Impact

February 15, 2013
1613 citizens injured
~$30 million damages

www.nasa.gov/planetarydefense
Planetary Defense Coordination Office

This office was established in January 2016 at NASA HQ to oversee planetary defense related activities across NASA, and coordinate both US interagency and international efforts and projects to address and plan response to the asteroid impact hazard.

Mission Statement:

Lead national and international efforts to:

- Detect any potential for significant impact of planet Earth by natural objects
- Appraise the range of potential effects by any possible impact
- Develop strategies to mitigate impact effects on human welfare
Planetary Defense Coordination Office

Administrator
Associate Administrator

Associate Administrator, Science Mission Directorate

Planetary Science Division Program Director

Lead Program Executive
Planetary Defense Officer

Public Communications

Policy Development

NEO Observation Program
Program Manager
Program Scientist

- Minor Planet Center/IAWN
- Center for NEO Studies @ JPL
- Catalina Sky Survey
- Pan-STARRS
- LINEAR/SST
- IRTF
- GSSR
- NEOWISE
- ...........

Interagency and Emergency Response Program Officer(s)

- Interagency coordination
- Emergency Response planning
- Interagency exercise

Mitigation Research Program Officer(s)

- SMPAG
- DART
- Short Warning Mitigation
- ...........

NEO Observation Program
- Officially established as a research program
- Formalized program documentation
- PDCO also includes emergency response and mitigation elements
NEO Observations Program

Detection and tracking of natural objects – asteroids and comets – that approach within 28 million miles of Earth’s orbit

US component to International Asteroid Warning Network
Has provided 98% of new detections of NEOs since 1998

Began with NASA commitment to House Committee on Science in May 1998 to find at least 90% of 1 km and larger NEOs

- That goal reached by end of 2010

NASA Authorization Act of 2005 increased scope of objectives:

- Amended National Aeronautics and Space Act of 1958 (“NASA Charter”) to add:
  “The Congress declares that the general welfare and security of the United States require that the unique competence of the National Aeronautics and Space Administration be directed to detecting, tracking, cataloguing, and characterizing near-Earth asteroids and comets in order to provide warning and mitigation of the potential hazard of such near-Earth objects to the Earth.”

- Made NEO detection, tracking and research 1 of 7 explicitly stated purposes of NASA!

- Provided additional direction:
  “…plan, develop, and implement a Near-Earth Object Survey program to detect, track, catalogue, and characterize the physical characteristics of near-Earth objects equal to or greater than 140 meters in diameter in order to assess the threat of such near-Earth objects to the Earth. It shall be the goal of the Survey program to achieve 90 percent completion of its near-Earth object catalogue within 15 years [by 2020]”
NASA’s NEO Search Program
(Current Survey Systems)

- **LINEAR/SST**
  - MIT/LL
  - 3.5 m
  - Moving to Australia

- **NEOWISE**
  - JPL
  - 0.4 m
  - Sun-synch LEO

- **Catalina Sky Survey**
  - U of AZ
  - Arizona
  - 1.5 m
  - 0.7 m

- **Pan-STARRS**
  - U of HI
  - Haleakala, Maui
  - 1.8 m
  - 1.8 m

- **ATLAS**
  - U of HI
  - Haleakala, Maui
  - Mauna Loa, HI
  - 0.5 m
  - 0.5 m
• Receives positional measurement of small bodies from observations made all over the world (and beyond)
• Responsible for identification, designation and initial orbit computation
• Now operating under the Planetary Data System’s Small Bodies Node

• Computes high-precision orbits of near-Earth objects
• Performs long-term analyses of possible future orbits of hazardous asteroids (Sentry) and computes orbits for new potential asteroid discoveries to determine any impact hazard (Scout)
• Predicts the impact time, location and geometry in the event of a predicted impact
Near-Earth Asteroids Discovered
Most recent discovery: 2018–Feb–09

It is estimated that ~2/3 of the NEAs >140m in size remain to be found.

*Potentially Hazardous Asteroids come within 7.5 million km of Earth orbit

https://cneos.jpl.nasa.gov/stats/

Alan Chamberlin (JPL/Caltech)
Primary NEO Characterization Assets and Enhancements

Radar (Goldstone and Arecibo)
- Increased time for NEO observations
- Streamlining Rapid Response capabilities
- Increased resolution (~4 meters)
- Improve maintainability

NASA Infrared Telescope Facility (IRTF)
- Increased call-up for Rapid Response
- Improving operability/maintainability
- Improve instrumentation for spectroscopy and thermal signatures

Spitzer Infrared Space Telescope
- Orbit about Sun, ~176 million km trailing Earth
- In extended warm-phase mission
- Characterization of comets and asteroids
- Thermal signatures, albedo/sizes of NEOs
- Longer time needed for scheduling
Discovery of the First Interstellar Object

- 1I/2017 U1 (ʻOumuamua)
- Discovered on October 19, 2017, by the Pan-STARRS1 telescope during near-Earth object survey operations
- Speed and trajectory indicate it originated outside of and is not bound to our solar system
  - Object is asteroidal in nature (no coma observed)
  - Object is highly elongated, with an axis ratio >3:1 perhaps 10:1
  - Observations suggest a surface reddened due to irradiation by cosmic rays over its history
PDCO Interagency Activities

Planetary Impact Emergency Response Working Group (PIERWG)

• Develop guidance to prepare for any potential impact of our planet by a large natural object, and
• Coordinate responsibilities and resolve preparedness and operational issues relating to interagency response and recovery activities at the national level

Detecting And Mitigating the Impacts of Earth-bound Near-Earth Objects (DAMIEN) Interagency Working Group

• Provide NEO Earth-impact response and recovery input into the National Planning Framework
• Develop a National NEO Preparedness Strategy and Action Plan
Impact Emergency Response Exercise #3 - Oct 25, 2016
Hosted by The Aerospace Corporation, El Segundo, CA

Representatives from:
- FEMA Region 9
- California Governor’s Office of Emergency Services
- U.S. Air Force/SMC
- FEMA HQ
- NASA PDCO

Impact scenario prepared and presented by:
- The Aerospace Corporation
- NASA PDCO
- JPL
- DOE National Laboratories

A report was released on the discussion of issues potentially faced by emergency managers under such a scenario.
UN Office of Outer Space Affairs
Committee on Peaceful Uses of Outer Space

Overview for NEO Threat Response

Inform in case of credible threat

Parent Government Delegates

Determine Impact time, location and severity

Potential deflection mission plans

International Asteroid Warning Network (IAWN)
www.iawn.net

Observers, analysts, modelers...

Space Missions Planning Advisory Group (SMPAG)
www.smpag.net

Space Agencies and Offices

United Nations COPUOS/OOSA
Near-Earth Asteroid 2012 TC4 Campaign
Close approach on Oct. 12, 2017 at <8 Earth radii

Goal - Exercise the Planetary Defense system

- Recovery and Follow-up: Recovery confirmed early August 2017
- Characterization: Light curves, photometry, spectroscopy, radar
- Modeling: orbit determination, threat assessment and impact modeling exercises
- Communications:
  - NASA management, White House, other agencies
  - Within the NEO community and with the public
- International Asteroid Warning Network (IAWN) participation
2012 TC4 - Results of Exercise:

- Astronomers from the U.S., Canada, Colombia, Germany, Israel, Italy, Japan, the Netherlands, Russia and South Africa tracked 2012 TC4
- Close approach occurred at about 27,200 miles
- Radar observations of 2012 TC4 showed it to be oblong of about 20 x 40 feet (6x12 meters) in size
- Light curve and then radar showed it tumbling with about a 12 minute period
- **Precision orbit determination was able to rule out any impact by 2012 TC4 for the foreseeable future**
Infrared Telescope Facility (IRTF)

Example planetary science and mission support highlights…
…from the edge of the Solar System inward
Supporting New Horizons Science on the Homefront

Pluto is the largest and most well-studied Kuiper Belt Object (KBO). Data from the New Horizons flyby on July 14th, 2015 put many years of ground-based observations of Pluto into context. Near-infrared spectral observations with the SpeX instrument at NASA’s Infrared Telescope Facility (IRTF) show that surface ices of nitrogen, methane, and carbon monoxide are preferentially located in a region now tentatively known as Tombaugh Regio. These long-term ground-based measurements of ices on the surface of Pluto show changes over time, putting the New Horizons flyby observations into context.

Large Kuiper Belt Objects (KBOs)

Ices present on the surface are nitrogen, methane, carbon dioxide, carbon monoxide, water, and ethane. The amount of nitrogen ice visible on Triton has increased during this period due to our changing view of Triton from Earth.

Triton, the largest moon of Neptune, is thought to be a captured KBO. It is a very similar object to Pluto in terms of size and surface composition. Long-term near-infrared spectral observations were made at the IRTF from 2000-2015.

Low-resolution spectral observations of the other large KBOs 2007 OR₁₀, Salacia, 2002 MS₄, and 2003 AZ₃₄ were made from IRTF from Fall 2015 - Spring 2016, expanding knowledge of the diverse KBO population.

Holler, Young, Grundy, Olkin, 2016. Icarus 267, 255-266.
Noting IRTF, Keck, and Other Ground-Based Contribution to Cassini

https://www.nasa.gov/feature/goddard/2017/ground-based-telescopes-support-cassini

How Two Ground-based Telescopes Support NASA's Cassini Mission

When NASA's Cassini spacecraft plunges into the atmosphere of Saturn on Sept. 15, ending its 20 years of exploration, astronomers will observe the giant planet from Earth, giving context to Cassini's final measurements.

"The whole time Cassini is descending, we'll be on the ground, taking data and learning about conditions on Saturn," said Don Jennings, a senior scientist at NASA's Goddard Space Flight Center in Greenbelt, Maryland, and a co-investigator for a Cassini instrument called the Composite Infrared Spectrometer.

https://www.osa-opn.org/home/newsroom/2017/september/cassini_s_earthbound_partners/
Heating of Jupiter’s upper atmosphere above the Great Red Spot observed by NASA’s Infrared Telescope Facility (IRTF)

- Temperature maps from IRTF reveal that the region above the Great Red Spot is hundreds of degrees hotter than its surroundings.
- This increase in temperature can not be explained by cooling from its accretion or solar energy.
- A new, yet unknown, energy source is required to resolve this “energy imbalance”.
- Above the Red Spot a storm-driven coupling process may be occurring, wherein acoustic and/or gravity waves transports energy between Jupiter’s lower and upper atmosphere.
- Juno observations may be able to uncover the answer.

PJ2: Discovery

- Before Juno’s safing event on PJ2, we got marble-movie results showing an outbreak in Jupiter’s North Temperate Belt (NTB)
- Follow-up by the ground-based observations from NASA’s Infrared Telescope Facility IRTF
PJ1 Results: Context

- With Jupiter 23° from the sun, JunoCam provided the highest-resolution visible contextual information to compare with JIRAM and MWR results.
- This included whole-disk images taken from the PJ1 approach and departure marble movies.
- IR imagery from NASA’s Infrared Telescope Facility (IRTF) used to verify JIRAM projection.
By measuring the deuterium enrichment of water reservoirs on Mars, it can be established how much water Mars lost over its history.

First-of-their-kind maps of deuterium enriched water relative to regular water were obtained using three ground-based observatories (W. M. Keck Observatory, NASA’s Infrared Telescope Facility, and ESO’s Very Large Telescope).

The maps reveal strong variations and a strong enrichment of the polar caps, indicative of great loss.

The new results indicate that Mars lost an ocean bigger than Earth’s Arctic ocean and covered almost 20% of the Martian surface.

Villanueva et al. 2015, Science
NASA assets combine forces to probe Comet ISON chemistry

Simultaneous observations of Comet ISON from NASA’s Infrared Telescope Facility (IRTF) and the MESSENGER spacecraft at Mercury are key to unlocking the secrets of the comet’s chemical formation and evolution.

MESSENGER measures daughter and granddaughter molecules that result from chemical processes (yellow)

IRTF measures parent molecules (red) in Comet ISON’s coma

Background image credit: G. Riehem
Kilometer-sized Asteroid 2014 JO25 Makes a Close Approach to Earth

On April 19, 2017 the potentially hazardous asteroid 2014 JO25 approached Earth at less than 4.6 times the distance to the Moon (1.8 million km). Discovered in 2014 by the Catalina Sky Survey, it was studied by other projects in the Near-Earth Object Observations program of the Planetary Defense Coordination Office during the approach.

Goldstone* and Arecibo radars measured it to be ~950 meters long. Its asymmetric, two-lobed structure might indicate a contact binary and is reminiscent of the target of ESA’s Rosetta mission, comet 67P/Churyumov-Gerasimenko.

JO25’s elongated orbit tilted below the plane of solar system is also not unlike a comet’s orbit. However, initial results from ground-based observations at NASA’s Infrared Telescope Facility reveal a spectrum similar to that of Ordinary Chondrites, the most common group of meteorites found on Earth.

This type of near-Earth object is difficult for our current ground-based optical surveys to detect and observe:

• Highly elliptical orbit with high velocity through the inner solar system
• Approaches Earth from the direction of the Sun, so ground-based telescopes cannot see it until after it crosses the Earth’s orbit

If an object of this size (~1 km) and velocity (33 km/s) were to impact Earth, it could result in a crater 10 km or more in size, with a much wider area of devastation and possible global effects on climate.

2015 TB145 - Halloween Asteroid Fly-by
“The Great Pumpkin”

- Discovered by Pan-STARRS on October 10
- Close Approach of 1.3 Lunar Distance predicted for October 31
- Immediately drew some media attention – “Discovered only 3 weeks before it may hit”
- IRTF observations determined object is likely a dead comet that has shed volatiles
- Observed by Arecibo and then bi-static with Greenbank receiving from Goldstone transmission
- Object is roughly spherical in shape and approximately 2,000 feet (600 meters) in diameter
- Resolution is ~4 meters
Multi-facility study of asteroid 2016 RB₁ during its near-Earth encounter

This near-Earth asteroid:

- was discovered 5 Sept 2016 by the Catalina Sky Survey, funded by NASA’s Near-Earth Object Observations Program
- passed south of Earth at a distance comparable to the orbit of geosynchronous satellites two days later
- is among the smallest observable in near-Earth space
- is representative of both the Earth-impacting population and the subset of asteroids that are accessible to spacecraft exploration

“Target-of-opportunity” observations were conducted from:

- Lowell Observatory’s Discovery Channel Telescope (DCT) — AZ
- NASA’s Infrared Telescope Facility (IRTF) — HI
- Center for Solar System Studies (CSSS) — CA

Lightcurves from DCT, IRTF, CSSS suggest a rapid rotation period of 96.1 sec.

Spectral data constrain albedo, composition. Inferred size of object is 3-9 meters. Data suggest a metal-rich composition.
Near-Earth Asteroid Close Approach Observed


- Discovery of asteroid triggered the existing NEO “target-of-opportunity” project at the NASA Infrared Telescope Facility (IRTF) on Mauna Kea, Hawaii, with the flexibility and capability to track near-Earth asteroids
- Closest approach of asteroid was within 9,200 miles of Earth’s surface
- Observations determined asteroid’s characteristics and hazard potential: At ~7 meters across, fragments unlikely to survive atmospheric passage
  - Records were set at IRTF during this encounter for tracking speed and for closest object ever observed
  - Movie on Nature website was #2 in hits for the week
  - Another asteroid, 2012 KP24, approached to within 32,000 miles of Earth and was similarly observed from IRTF on May 28, 2012

2012 KT42 Timeline
- T-23 hours: Discovery by Mt. Lemmon Observatory
- T-18 hours: Alerts sent and IRTF notified
- T-13 hours: IRTF interrupt formally requested
- T-11 hours: IRTF interrupt approved
- T-1 hour: Asteroid above horizon, IRTF measurements begin
- T-25 minutes: Tracking lock lost (5.6 R_earth)
- T=0: Closest approach at 3.3 R_earth

Charge for Workshop from the Planetary Science Division

- The IRTF has been important to NASA for supporting flight missions, strategic and decadal science, and planetary defense
- In the Planetary Science Division, IRTF has pursued decadal science, characterized mission targets, augmented mission science, and helped fulfill the planetary defense aspect of the amended NASA charter
- NASA must make careful choices about its use of taxpayer funds
- Is there a case that is compelling to NASA for IRTF in the future?
- Your findings will have the most value if they are relevant to NASA’s missions and strategic goals
Thank you again for your participation!

Questions?