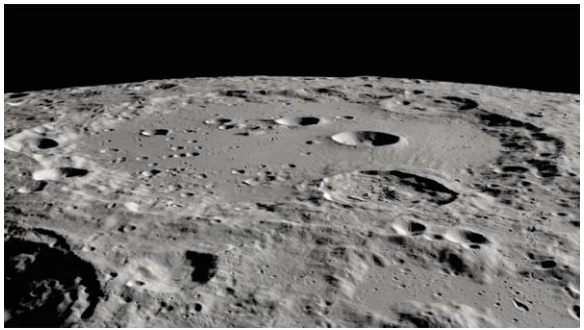
Stratospheric Observatory for Infrared Astronomy (SOFIA)

Margaret Meixner/Naseem Rangwala

March 15, 2021

Science Highlight: Water on the Moon

- First direct detection of molecular water on the sunlit surface
- Legacy Program will follow up on this discovery by mapping the distribution of water molecules across the lunar surface

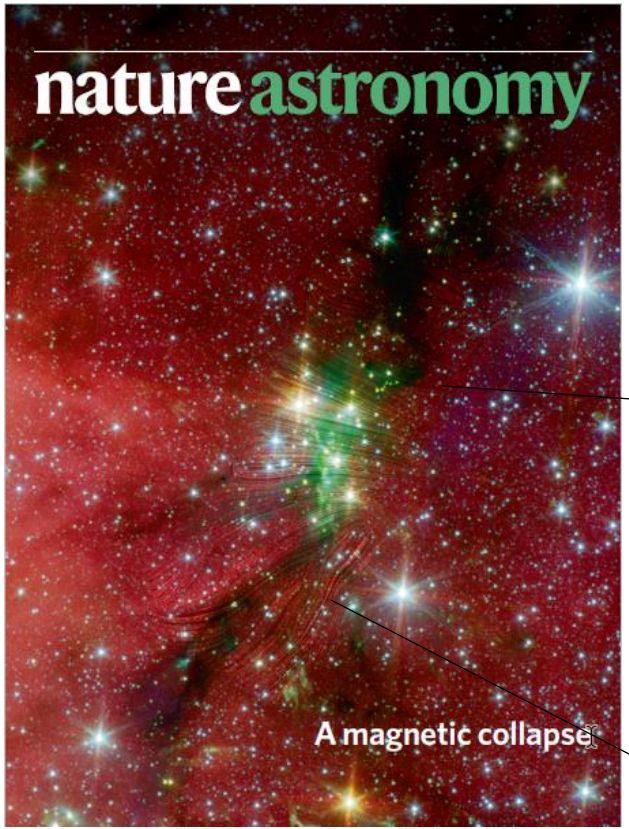


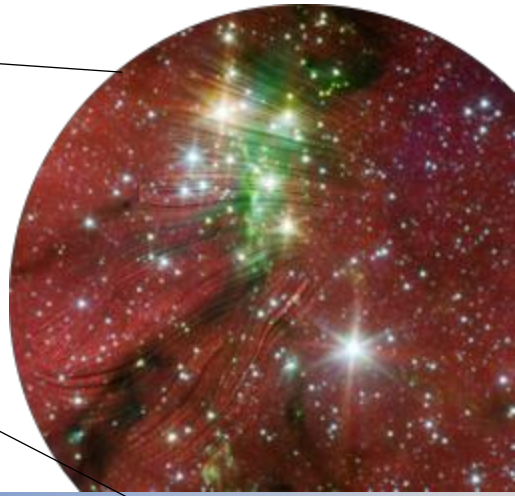
C.I. Honniball, et al., 2020

Science Highlight: Serpens South

- Gravitational collapse and cluster formation can occur even in the presence of relatively strong magnetic fields
- Legacy Program will study the large-scale magnetic polarization of filaments

Pillai, T.G., et al., 2020



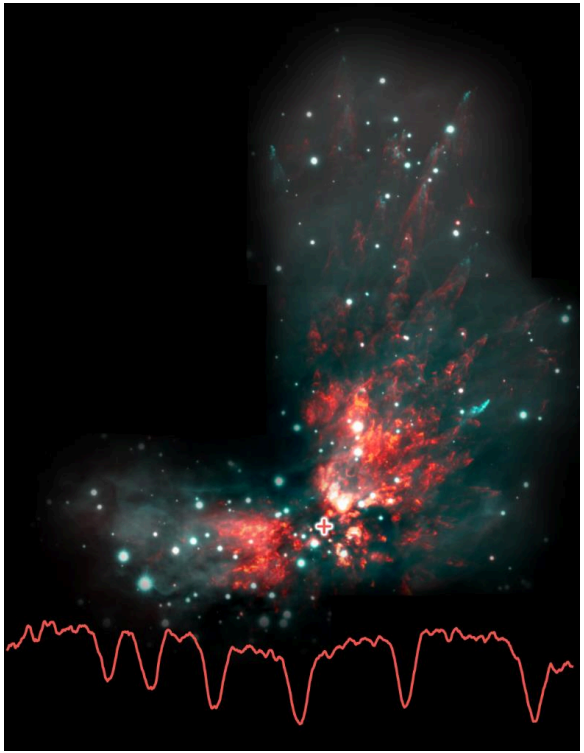


Science Highlight: Cold Quasar

- A galaxy's stellar population and black hole are growing at the same rate
- This challenges galactic evolution theories which predict black hole growth halts stellar growth

Cooke, K. C. et al., 2020

Science Highlight: HNC and H13CN

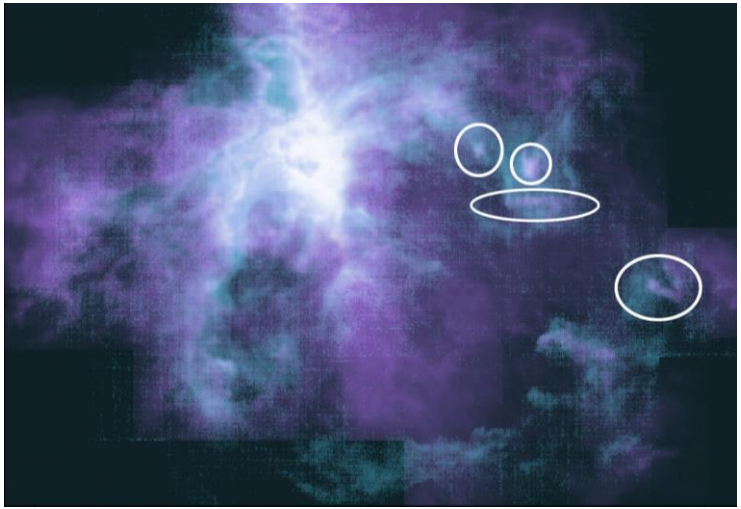


- SOFIA probes planet formation zone of hot cores
- The first detection of HNC and H13CN in the mid-infrared wavelengths
- This is part of a molecular line survey of Orion IRc2, which can provide a chemical inventory for star forming regions

Nickerson, Sarah, et al., 2021

First Signs of Feedback-Induced Star Birth in Orion

- A young star at the center of the nebula cleared an enormous bubble
- SOFIA and Radio and Millimeter Astronomy's, IRAM, reveal signs of star birth around the bubble's edges
- Several tiny globules of dense molecular gas are in the neutral expanding shell and potentially host conditions suitable for the formation of new low-mass stars
- One of the globules coincides with a known protostar



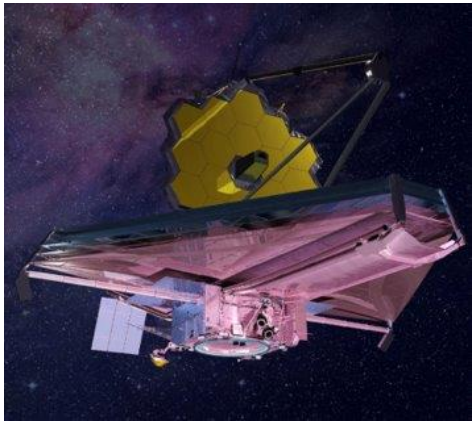
Pabst, C. H. M., et al., 2020

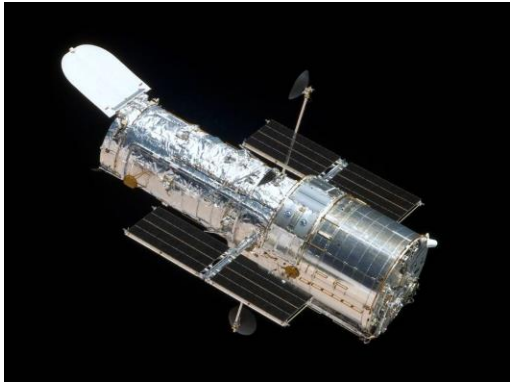
Observing Cycle 9: Overview

- Observing time remains highly competitive
  - Oversubscription rate: >4
- Increased research hours 25% compared to previous cycles
- Increasing observing time in the Southern Hemisphere

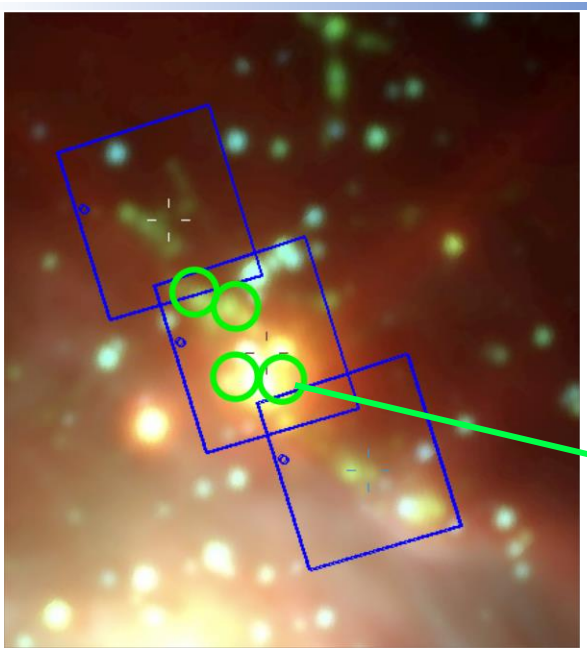
Observatory Partnerships

- 3 programs support JWST Early Release Science and Guaranteed Time Observations
- 3 programs joint with Greenbank Observatory
- 2 programs joint with Hubble





Joint SOFIA-Hubble DDT Programs



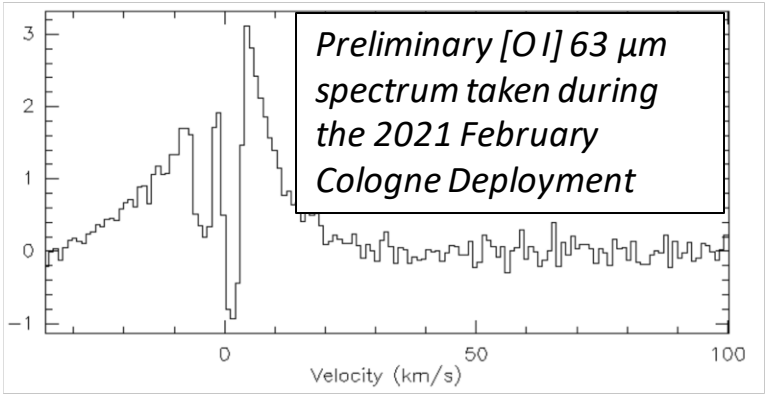
Spitzer image of NGC 2071 with HST /WFC3 coverage (blue) and 4GREAT coverage (green)

SOFIA will provide:

- Measurements of [OI] and four CO transitions of shock heated gas
- Radial velocities of shocked emission
- Measurements of the mass flow and heating by shocks

HST will provide:

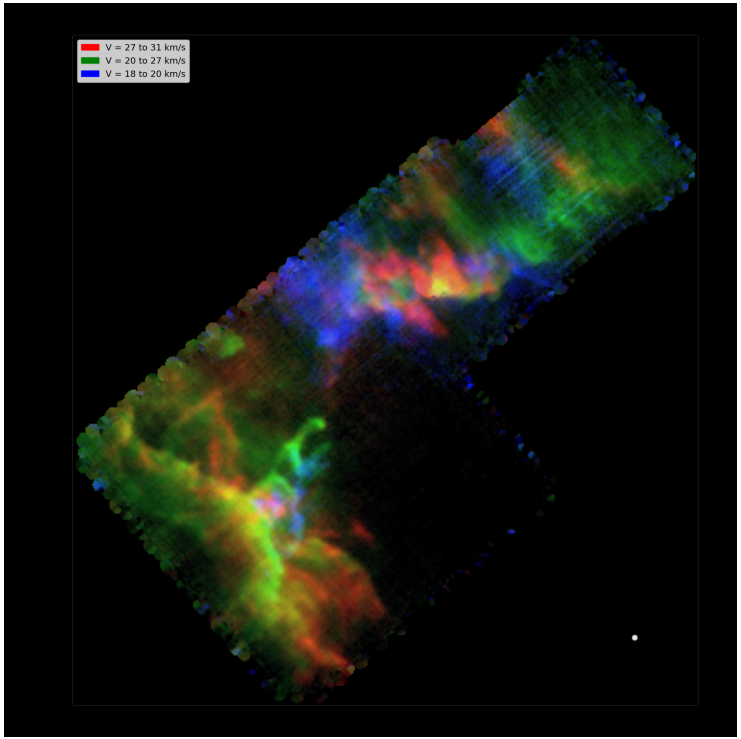
- Mechanical luminosity of the shocks
- A proper motion study of knots compared with a 2009 image
- Look for morphological changes in knots



Preliminary [O I] 63 μm spectrum taken during the 2021 February Cologne Deployment

Prioritizing Legacy Programs

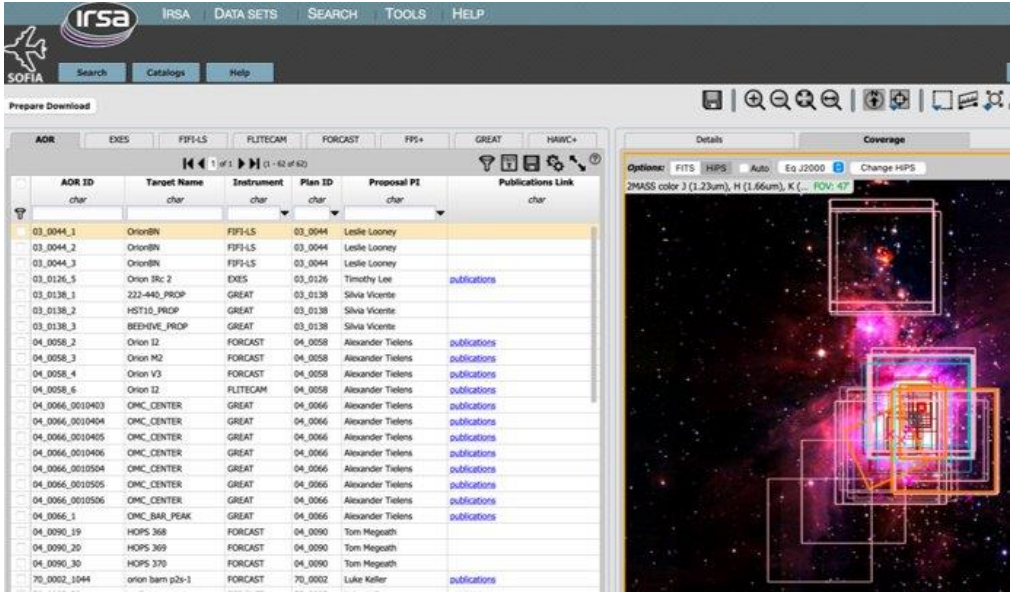
- HyGAL- Measuring the abundance of hydride molecules to understand the cosmic ray flux, the H_2 fraction, and the degree of turbulence in different regions in the galaxy
- Feedback- Studying massive stellar feedback in star-forming regions like the Eagle nebula
- Map the magnetic fields in the central 200 pc of the Milky Way



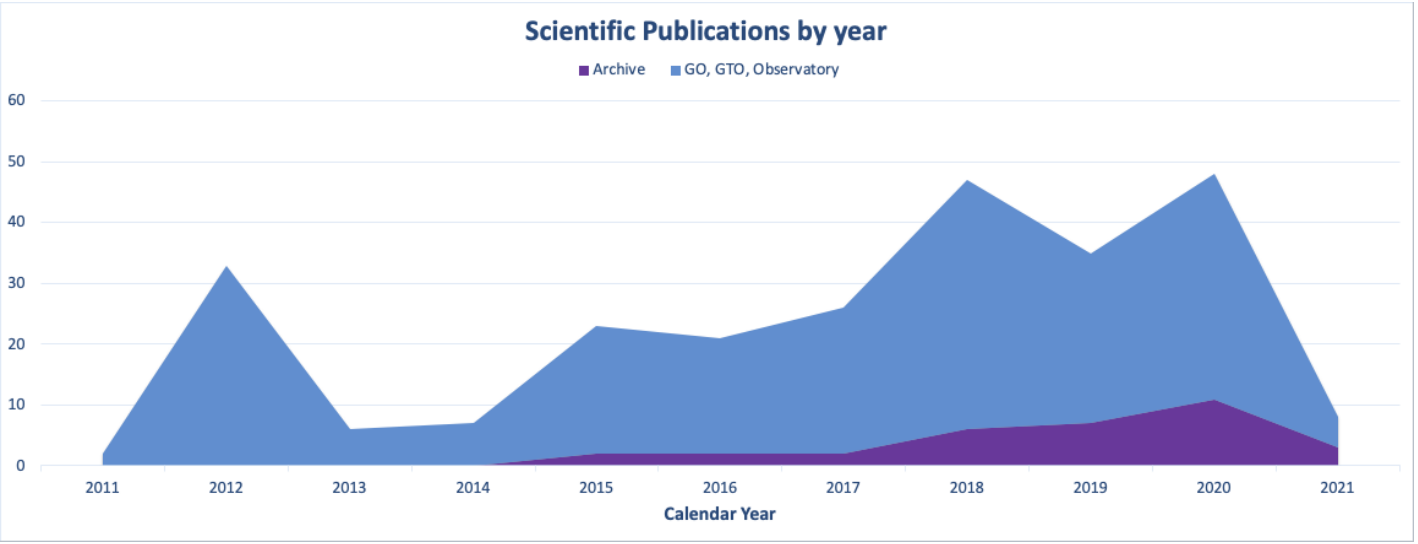
Karim et al, 2021; in prep

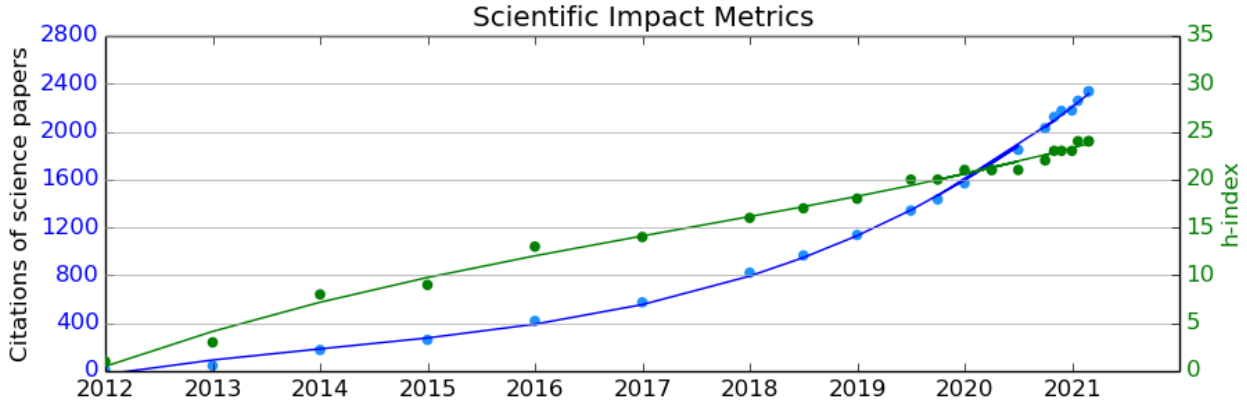
Increasing Archival Research

- Improving accessibility of data
  - Keyword, abstract searches
  - Curated data highlight pages on SOFIA website
- Increased funding for archival research
- 2021 archival call significantly oversubscribed compared to pilot
  - 42 proposals
  - Will continue annually
- Use of archival data is reflected in publication metrics



Science Metrics





Publication rate growing

Citations (impact) also growing

- Citations 2,337
- H-index 24

SOFIA
Stratospheric Observatory for Infrared Astronomy

Increasing Community Engagement: Virtual Workshops

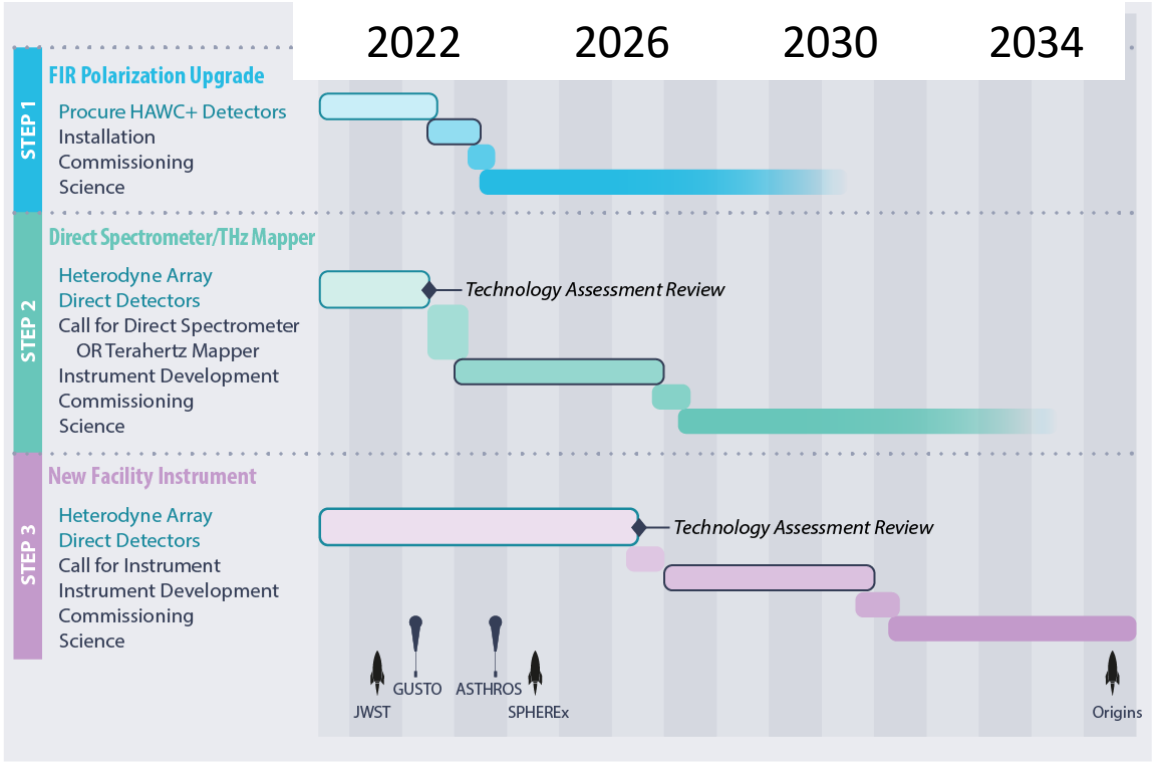
- Rock, Dust and Ice
- Interpreting solids in and around Solar System across all wavelengths
  - March 23-26, 2021
  - https://sofia-science-series.constantcontactsites.com
- Future workshop will focus on magnetic fields in filaments
- "Summer School" will support graduate students' use of SOFIA data

Rock, Dust and Ice:
Interpreting planetary data

- A plan for future scientific instrumentation on SOFIA
- Public report available for download:

https://www.sofia.usra.edu/sites/default/files/Other/Documents/instrument-roadmap-public.pdf

Notional Timeline



- Upgrade HAWC+
- Direct-detection 30-120 μm spectrometer
- Terahertz Mapper
- Sequential approach takes us into the next decade, through future FIR telescopes such as Origins

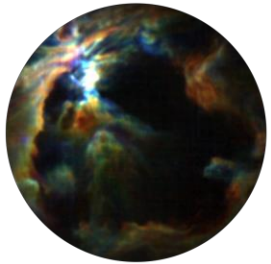
SOFIA Science Mission Summary

- SOFIA has a bright future: it continues making discoveries across astrophysics
- Big leap has been made and major plans in future address the Flagship Mission Review (FMR) report
- SOFIA project has posted a formal response to the FMR:

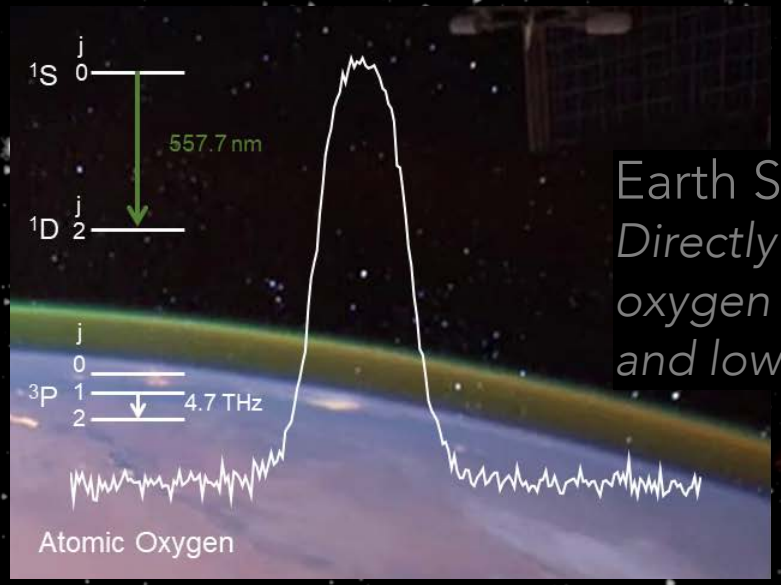
https://www.sofia.usra.edu/sites/default/files/Other/Documents/SOFIA_FMR_Response_30Sep2020.pdf

- Instrument Roadmap projects a 10-year future to enable discoveries
- Increasing opportunities for community engagement





SOFIA Interdisciplinary Impact



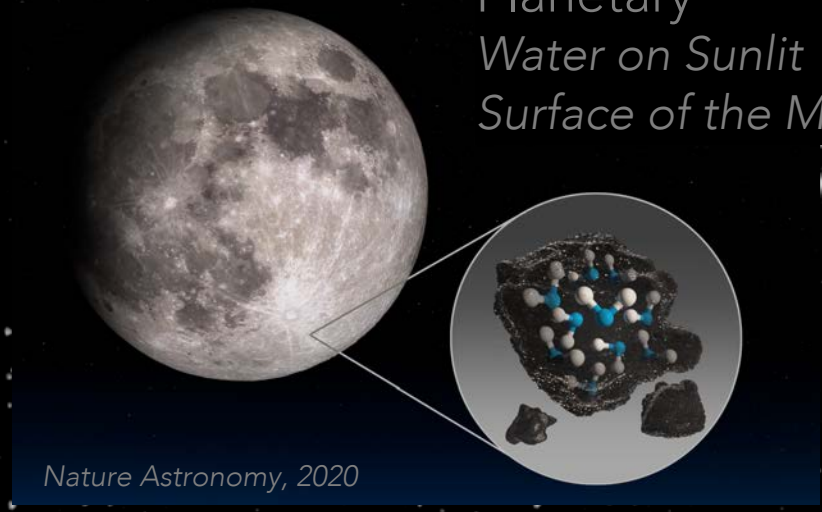
Earth Science

Directly measuring atomic oxygen in the mesosphere and lower thermosphere

Nature, 2021

Planetary

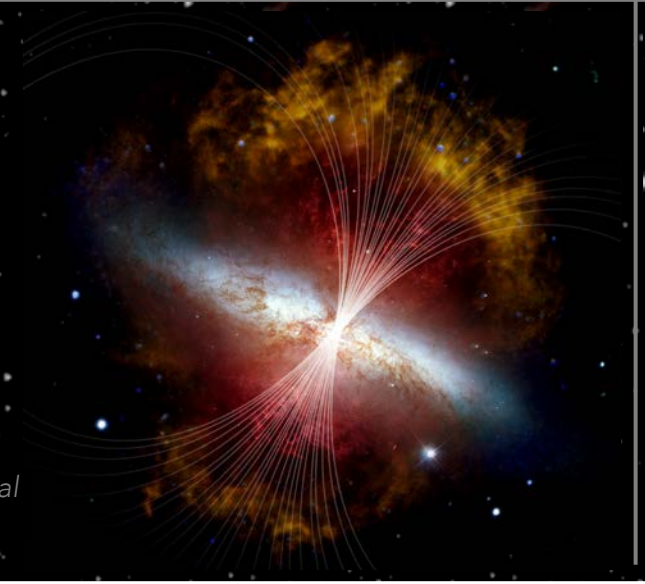
Water on Sunlit Surface of the Moon



Nature Astronomy, 2020

Heliophysics

Magnetic fields in a starburst galaxy



Submitted to the Astrophysical Journal Press Conference, AAS, 2021

Astrophysics

Magnetic collapse leading to star formation

Nature Astronomy, 2020

SOFIA Bold Initiatives 2020-2021

Presented to Astrophysics Advisory Committee, March 15, 2021

Presented by Naseem Rangwala, SOFIA Project Scientist

SOFIA Bold Initiatives

1	Pursue large coordinated legacy programs	→ **Increase scientific Impact**
2	Grow the SOFIA community and make it more scientifically diverse	
3	Increase the total number of flights in Southern Hemisphere to 50 annually	→ **Increase observing time** **Boost scientific productivity**
4	Build the operational capacity to plan for a 5th (weekly) contingency flight	
5	Make EXES a facility instrument Create path for a new German instrument	→ **Maximize scientific potential and bring on new capabilities**

★ Implement by end of FY 2021 before the release of Cycle-10 call for proposals

★ Make transformative changes to substantially increase SOFIA's scientific return by 2022 Senior Review

Increasing Observing Time for the Community

Bold Initiatives 3 & 4

- *Build the operational capacity to plan for a 5th (weekly) contingency flight*
- *Fly 50 flights (annually) in the Southern Hemisphere*

- SOFIA will be providing more observing time to the community in the extended mission (in upcoming cycles 9 & 10) within a lower operating budget of $80M
- Initiative in progress to add more contingency flights (annually) to significantly improve program completion rate thereby boosting publications

Magnetic Fields in Galaxy NGC 1068

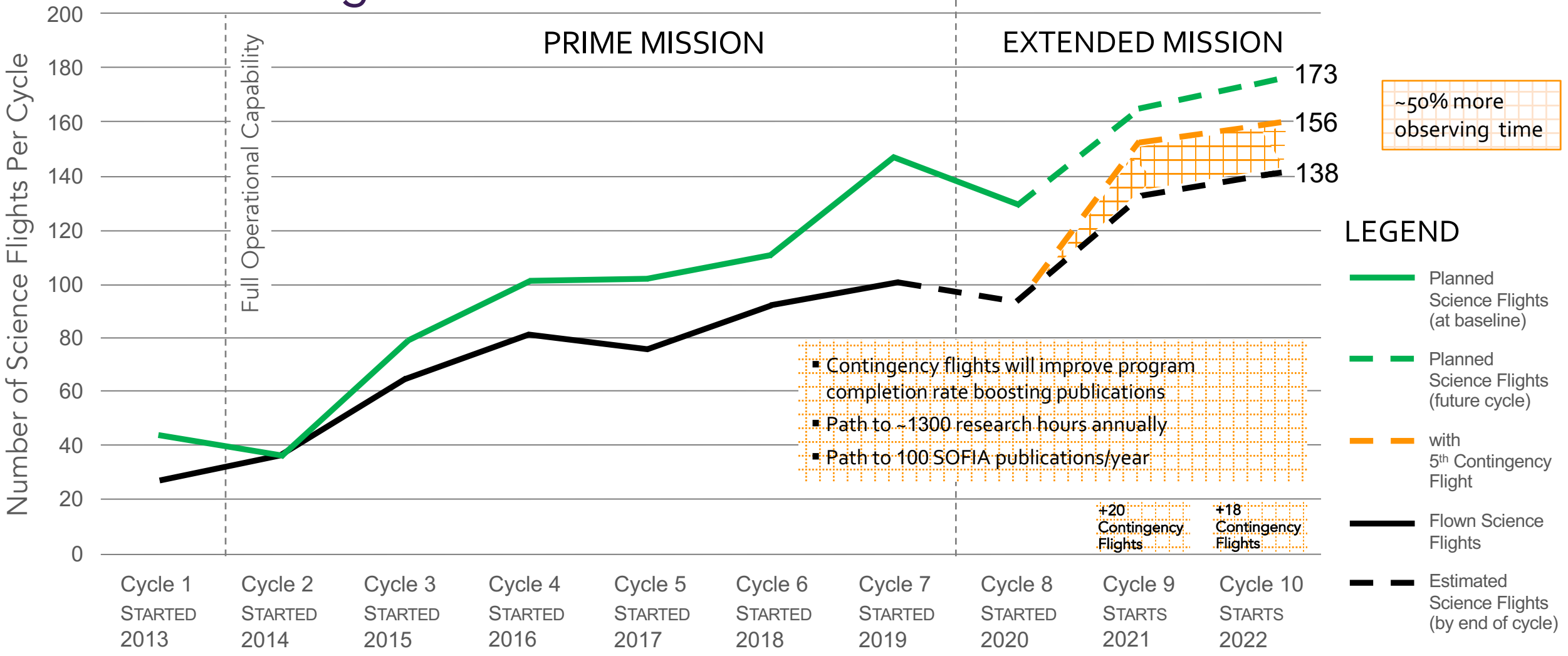
Credit: NASA/SOFIA; NASA/JPL-Caltech/Roma Tre Univ.

Magnetic Chaos Hidden Within the Whirlpool Galaxy

Credit: NASA/the SOFIA science team, A. Borlaff; NASA, ESA, S. Beckwith (STScI) and the Hubble Heritage Team (STScI/AURA).

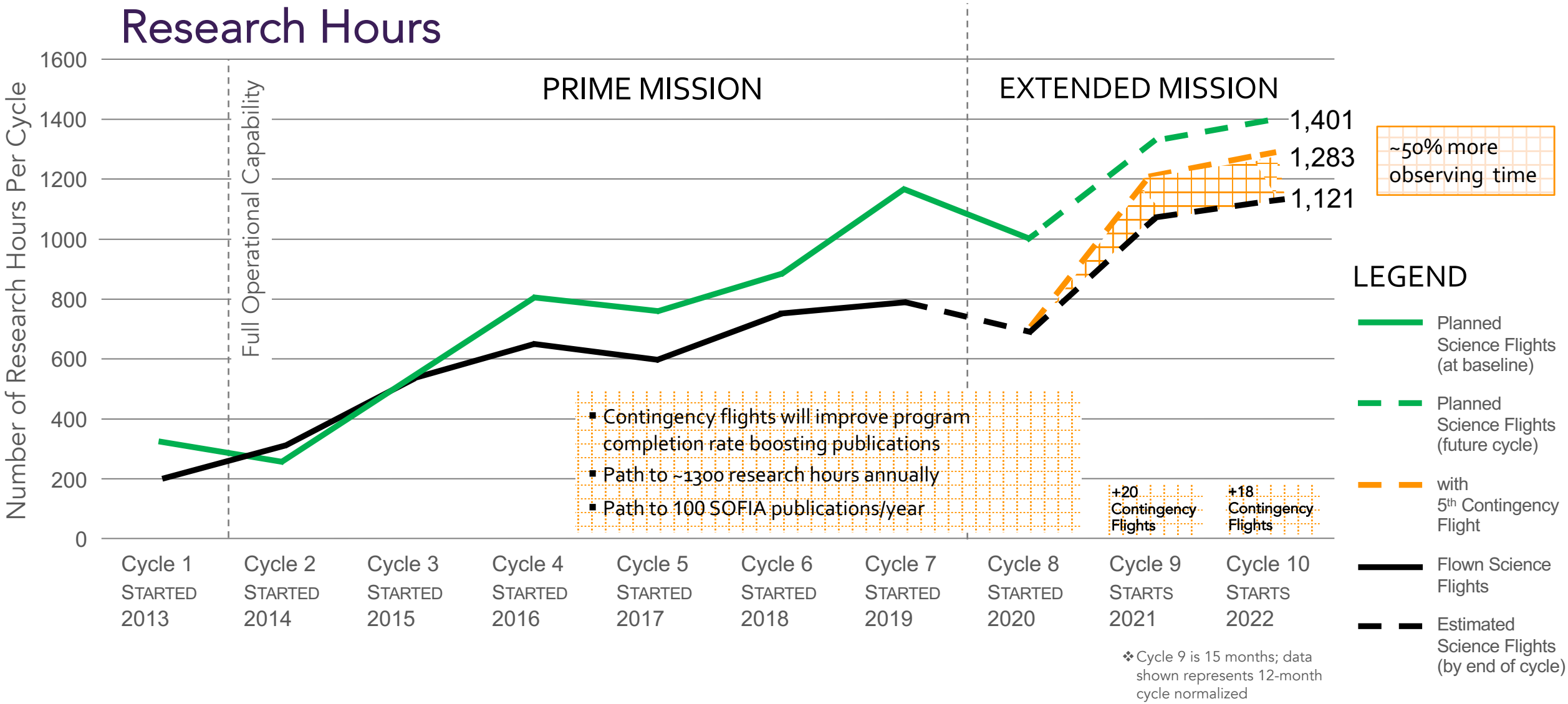
Increasing Observing Time

Science Flights



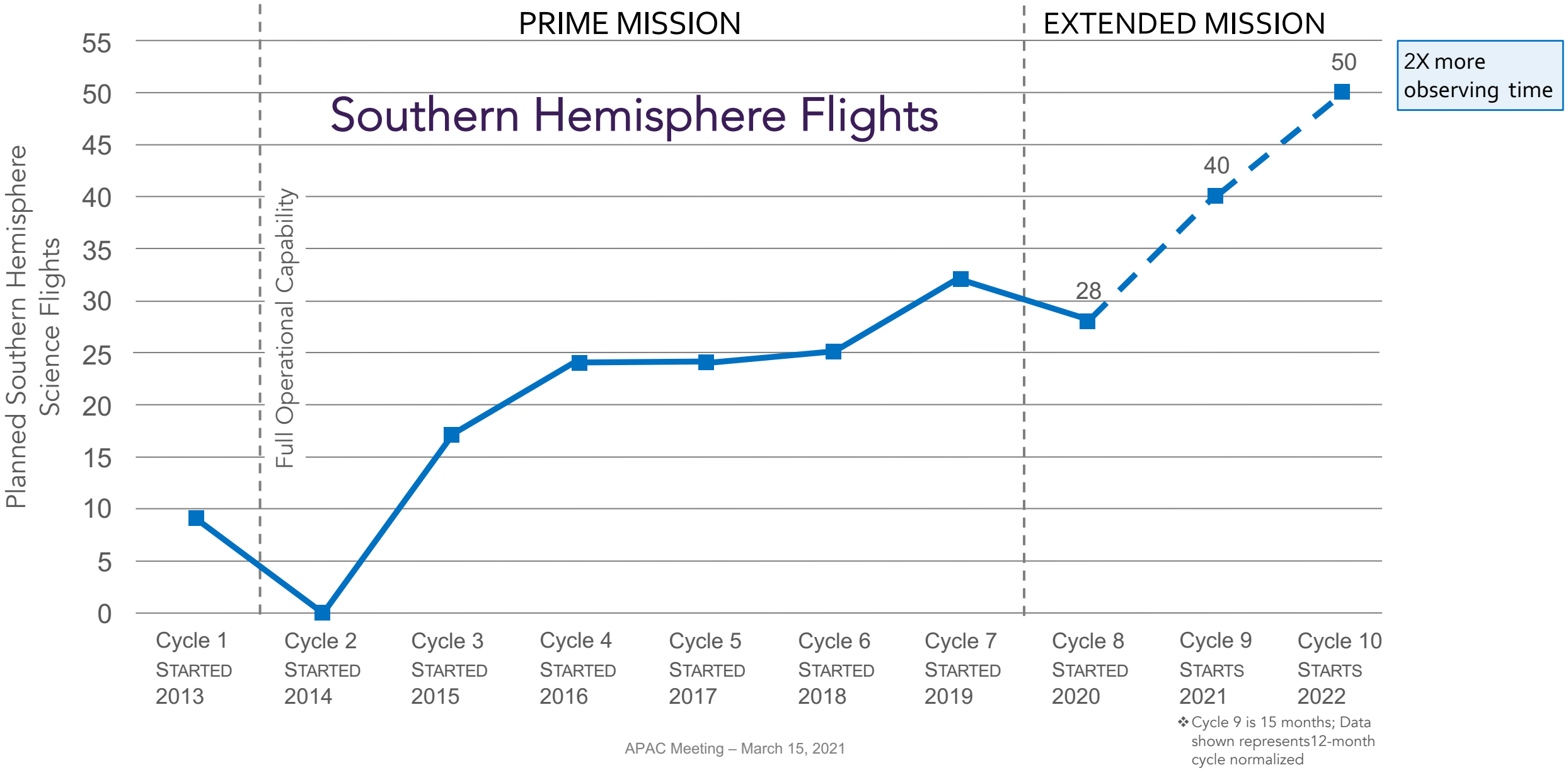
❖ Cycle 9 is 15 months; data shown represents 12-month cycle normalized

Increasing Observing Time



❖ Cycle 9 is 15 months; data shown represents 12-month cycle normalized

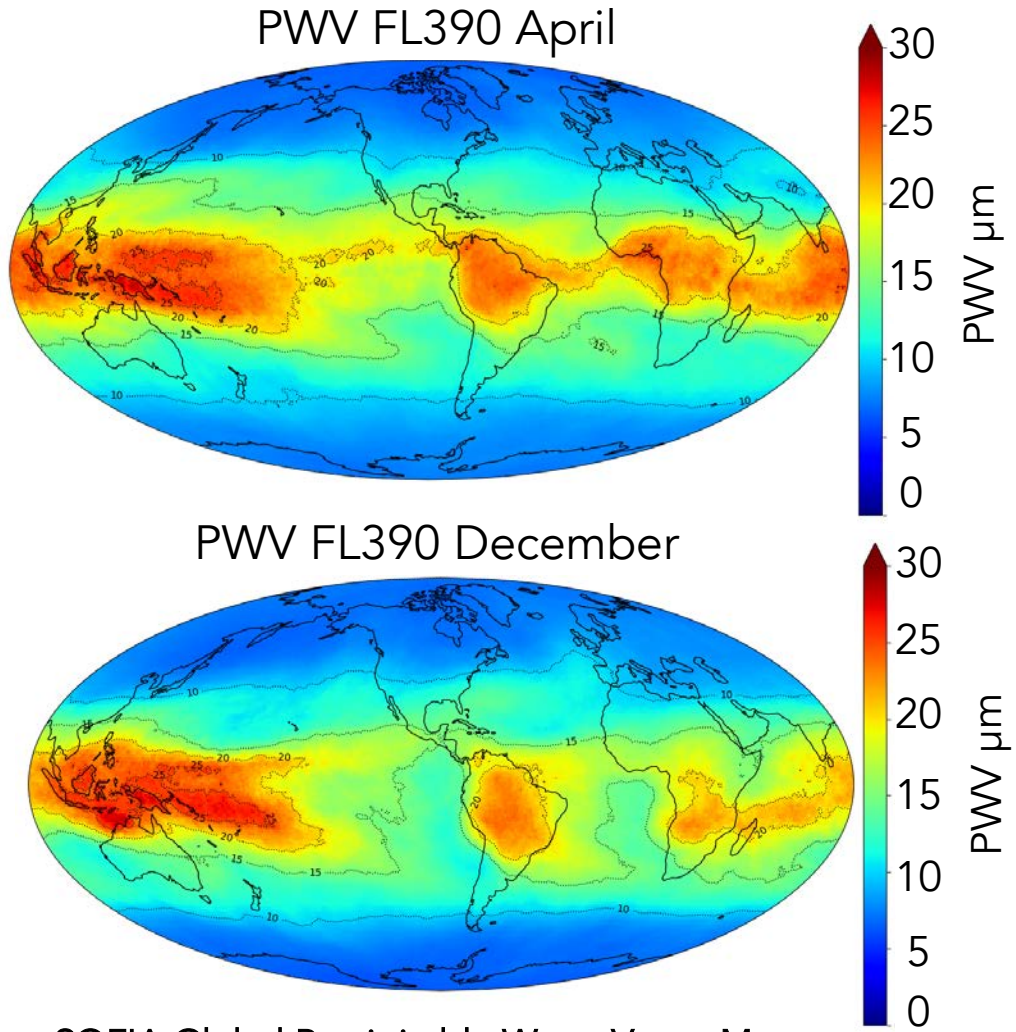
Fly 50 Flights in Southern Hemisphere Annually



Increasing Observing Time in the Southern Hemisphere

Status/Progress/Impact

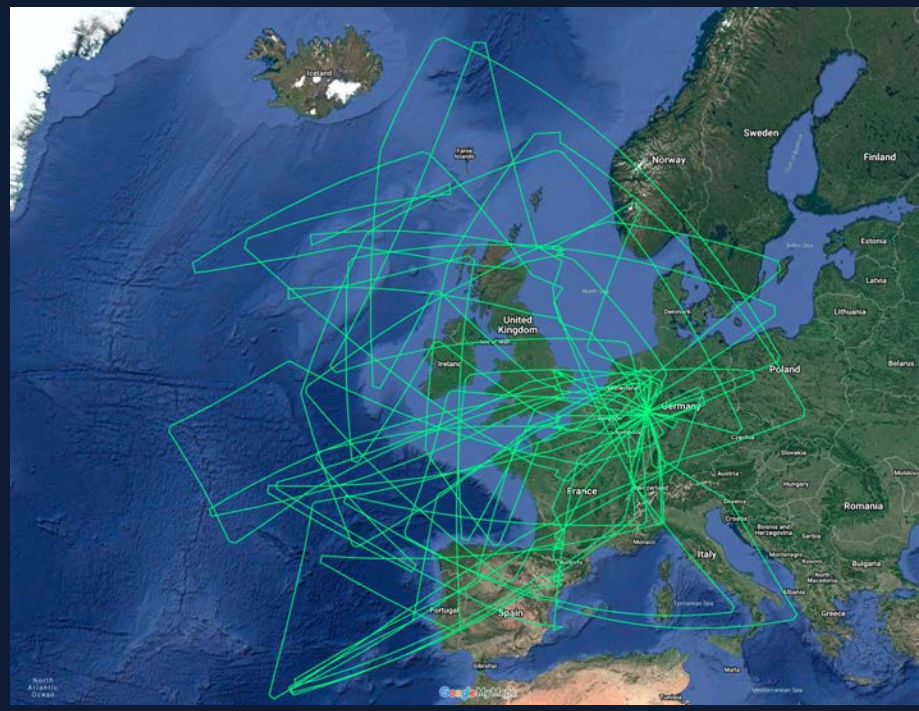
- 50 flights are in the planning schedule for Cycle-10
- 1 long (~30-32 flights) plus 2 "suitcase" deployments (~8-10 flights each) with different science instruments
  - Allows opportunity for all SOFIA instruments to observe the Southern Hemisphere skies
- Establishing alternate deployment sites for suitcase deployments
  - Tahiti: site survey complete; SOFIA can plan to deploy from this site
  - Argentina: survey on hold due to COVID-19
  - Chile: site survey planning under way
- First "suitcase" deployment planned for March 2022



SOFIA Global Precipitable Water Vapor Maps
Mission has developed tools to forecast water vapor anywhere in the world

Observatory Status: SOFIA Completed the First Multi-Flight Science Campaign from Germany

NASA/DLR Mission Management for the Germany Deployment at Cologne-Bonn Airport



SOFIA Planned Science Flight Paths in Germany

SOFIA Landing at Cologne-Bonn Airport, 2-4-21

Path to Higher SOFIA Productivity

Investment to substantially increase SOFIA's scientific output and impact

- 40-60% more observing time for the community
  - Adding contingency flights to boost program completion rate
  - Doubling observing time in the Southern Hemisphere
  - Establishing alternate deployment sites
- Impact to the Community and SOFIA
  - New archival call ($1.5M) in 2021 (~10x more proposal received!)
  - Enhanced science community engagement
  - Enhancing SOFIA data archive at IRSA
- Upgrading the HAWC+ instrument to increase mapping speed by a factor of 4
  - Allows bigger, more ambitious, legacy programs