Cycle 3 Science Highlights and Cycle 4 Preview

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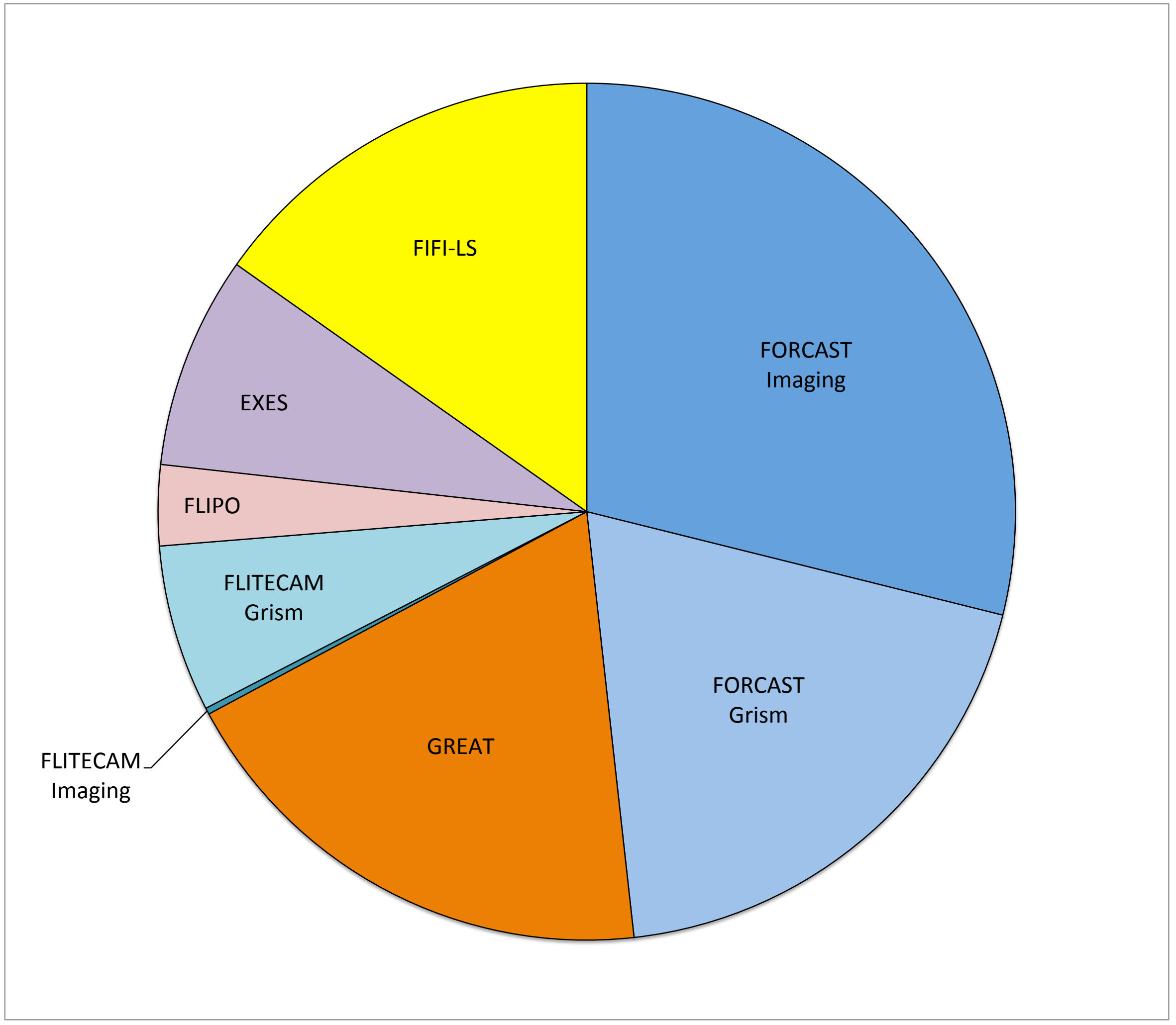
SOFIA Science Center

SOFIA Users' Group 18 November 2015

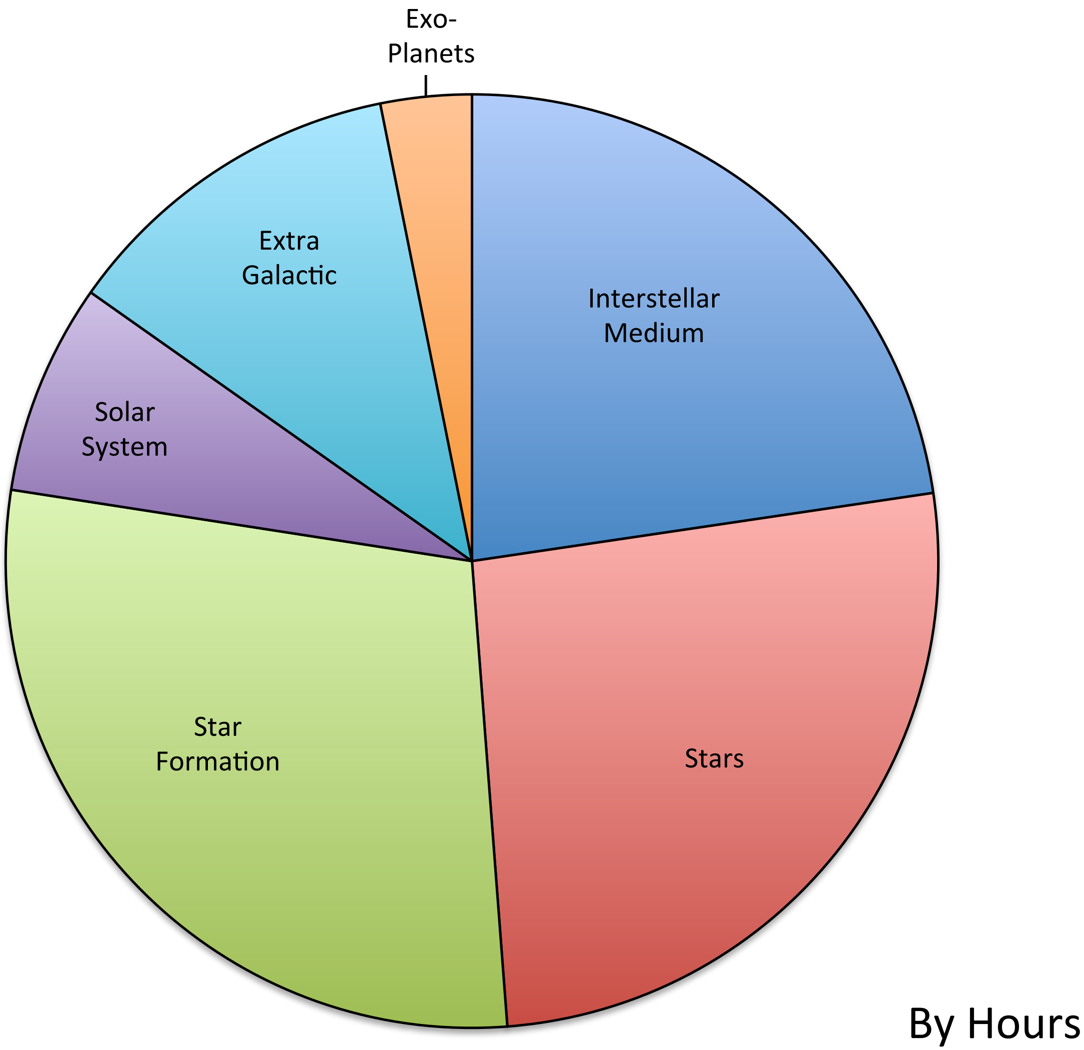
Cycle 3 Progress

Cycle 3 Awarded Time Distribution

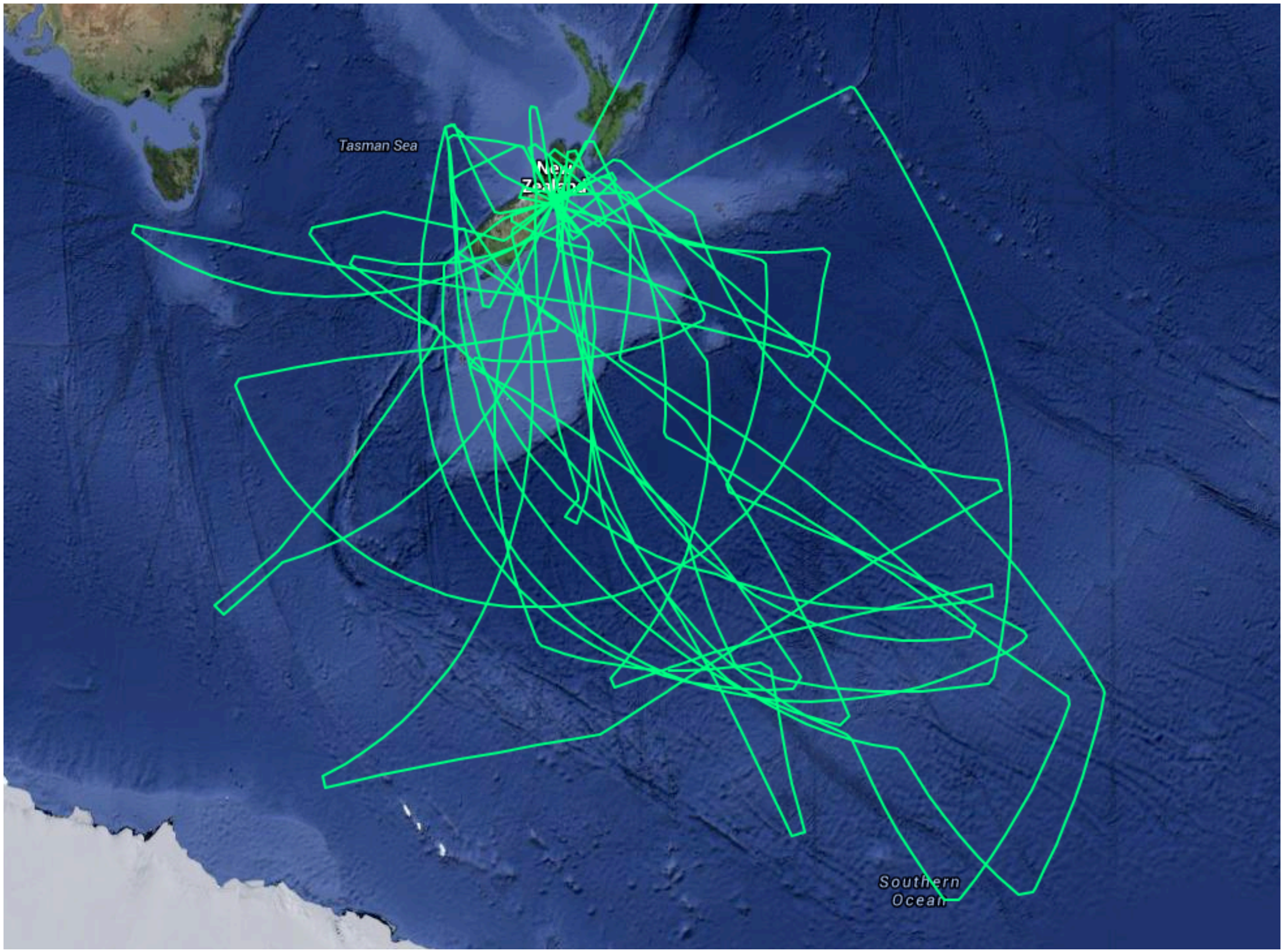


407.8 Hours US + 45.8 Hours DE = 453.8 Hours Total

Cycle 3 – Awarded Science Areas

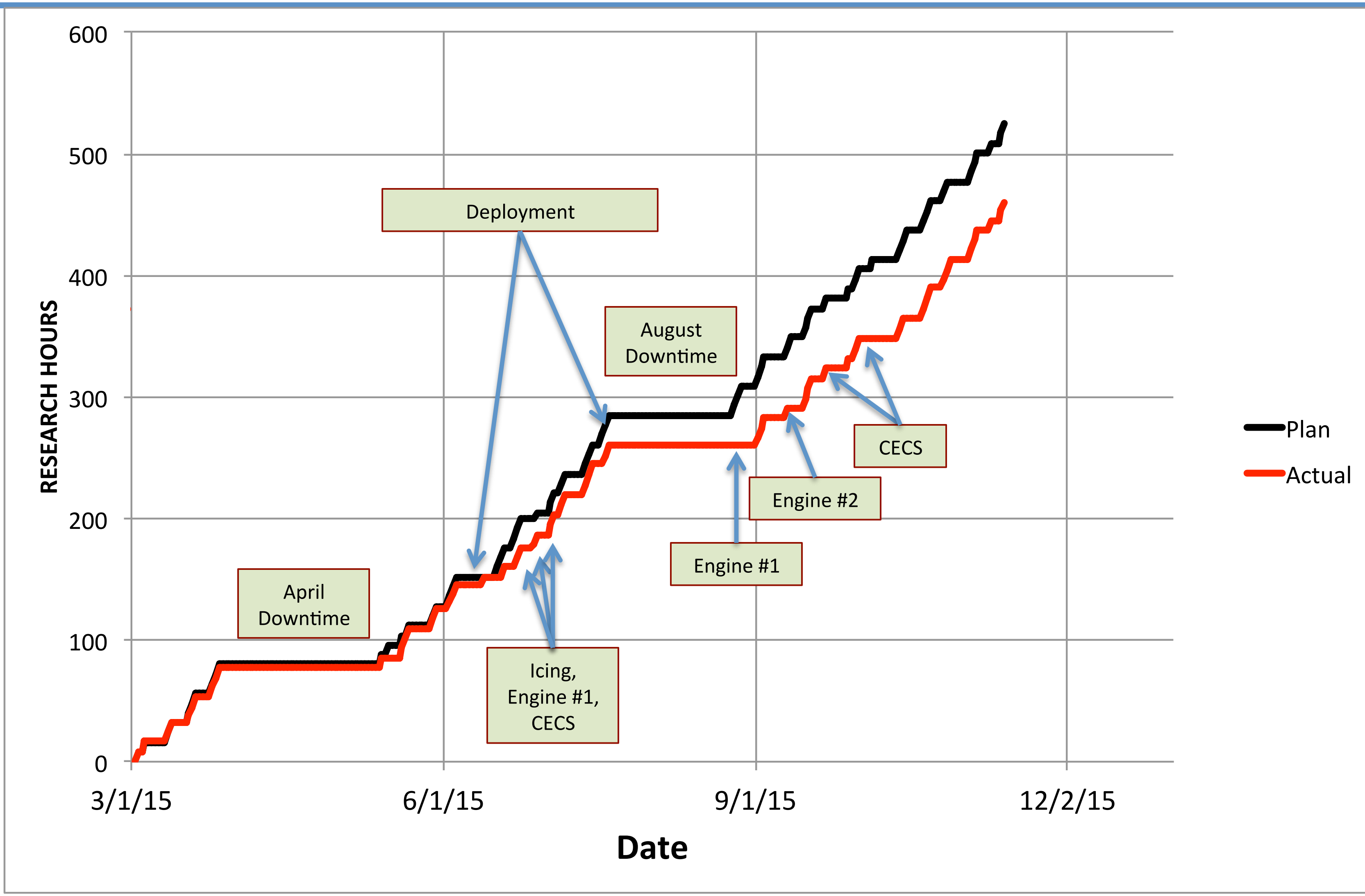


Deployment Flight Paths



Cycle 3 Cumulative Research Hours

Chart Revision 15 Nov 2015



Cycle 3 Summary Statistics

Campaign	Flights	Instrument	Flight Hours	GTO Hours	GI Hours	Cal Hours	DDT Hours	OTHER	Notes
OC3A	1	EXES	47.67	21.38	14.62	5.47	0.00	6.21	1 Cancelled
OC3B	8	FIFI-LS	75.63	12.85	44.25	9.50	0.91	8.12	
OC3C	6	FORCAST	53.45	3.22	29.87	12.70	0.00	7.62	
OC3D	7	FORCAST	66.22	6.08	40.91	12.83	0.00	6.39	3 Cancelled
OC3E	2	FLIPO	13.91	4.83	4.20	0.00	0.00	4.88	
OC3G	5	GREAT	47.69	14.92	16.26	3.50	8.00	5.02	1 Cancelled
OC3H	5	EXES	29.31	5.83	14.57	4.70	0.00	4.21	
OC3I	5	FORCAST	46.44	1.54	29.48	9.30	0.00	5.42	1 Cancelled
OC3J	3	FLITECAM	28.18	3.03	13.28	7.92	0.00	3.96	1 Cancelled
OC3K	9	FIFI-LS	74.15	20.70	30.58	13.13	0.00	9.73	
OC3L	9	FORCAST	83.47	6.81	50.35	16.82	0.00	9.49	In Progress
OC3M	10	GREAT	93.75	13.65	47.23	8.65	12.17	12.05	In Progress

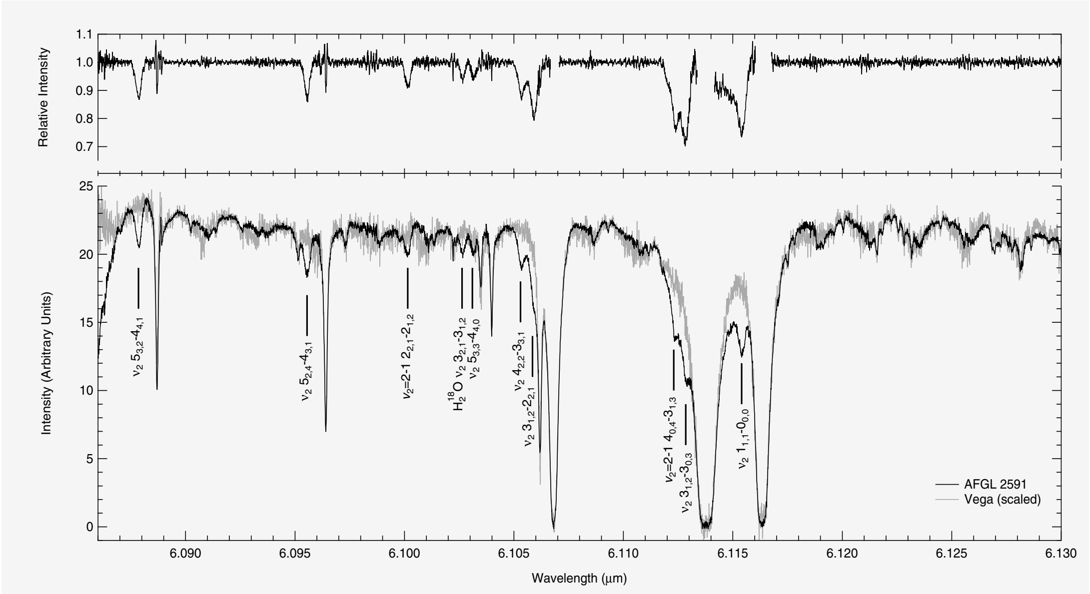
Totals	70		659.86	114.86	335.59	104.52	21.08	83.08

Details of Completion Rates for Individual Programs are Available for Examination

Science Highlights

EXES Detects H_2O in the AFGL 2591 Star Forming Region

- Water is one of the key components of the interstellar medium and protostellar environments.
- Most observations of H_2O (even from space) have been of ***emission*** from excited (hot) water.
- The important and dominant low excitation levels are best observed in ***absorption*** against a background source.
- Absorption observations require high spectral resolution– uniquely provided in the mid-IR by EXES
- First spectrally resolved observations of n_2 lines from H2O and $H_2{}^{18}O$.
- Water column density in outflow much higher than previously inferred.



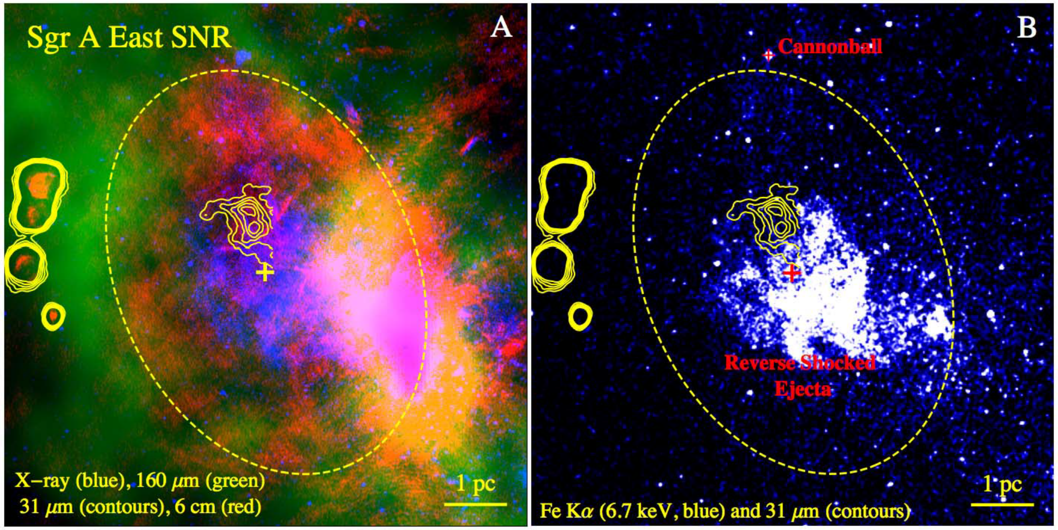
(A)Spectrum of AFGL 2591 divided by standard star spectrum showing residual water in disk of young star.

(B)Spectra of young star AFGL 2591 and standard star Vega. Most of the deep absorptions are due to H_2O in the Earth's atmosphere, but blue-shifted H_2O is present in the young star spectrum.

Indriolo et al. (2015)

FORCAST Observations of SNR at Galactic Center

- Where did the dust in the early universe come from?
- Does ejecta-formed dust survive the interaction with hot, shocked gas in supernova?
- Observations of Sgr A East remnant near the Galactic Center with FORCAST
- First discovery of dust in an older SNR that has survived the passage of the reverse shock
- Supports hypothesis that supernovae may have been responsible for the formation of the early dust

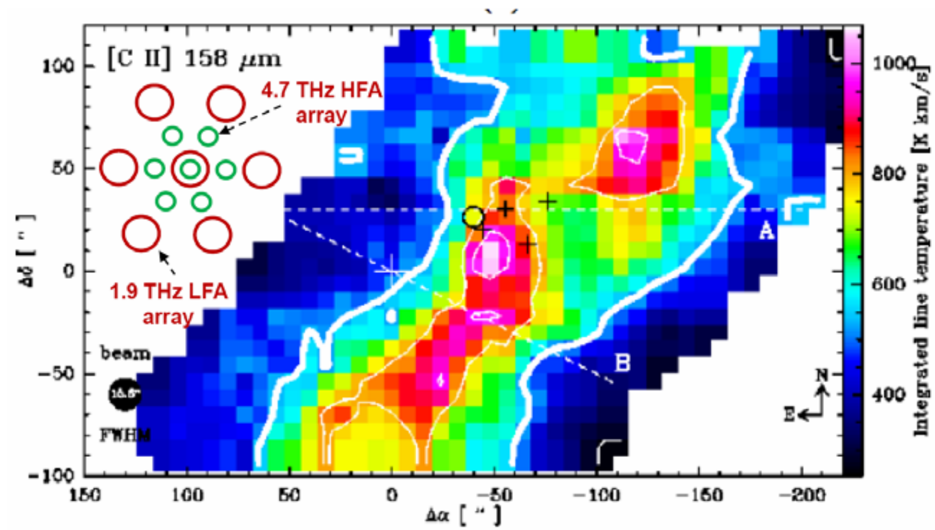


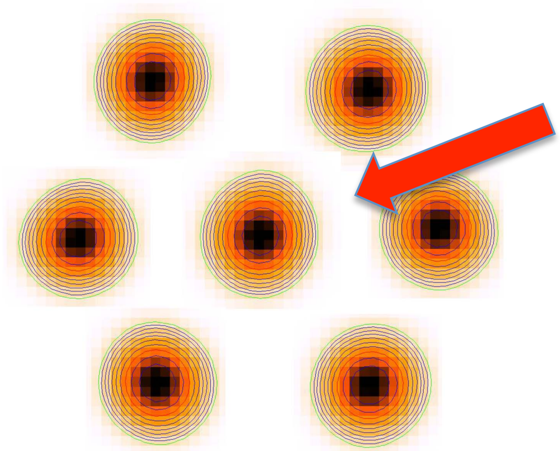
(A)Composite false-color image of the Sgr A East SNR overlaid with contours of the 31.5 μm emission east of the Circumnuclear Disk. Blue: 2 - 8 keV (Chandra), green: 160 μm (Herschel), red: 6 cm (VLA).
(B)Fe Kα (6.7 keV) emission from the SNR overlaid with the 31.5 μm emission

Lau et al. (2015) , Science

upGREAT

- upGREAT an enhancement of the GREAT heterodyne instrument developed by Rolf Güsten and collaborators.
- The instrument was commissioned in May 2015
- Compact heterodyne arrays
  - 7 pixels x 2 polarizations @ 1.9 THz
  - 7 pixels @ 4.7 THz [O I] (ready in 2016)
- Maps ***more than an order of magnitude faster*** than the previous instrument





What was one beam on the sky is now seven beams

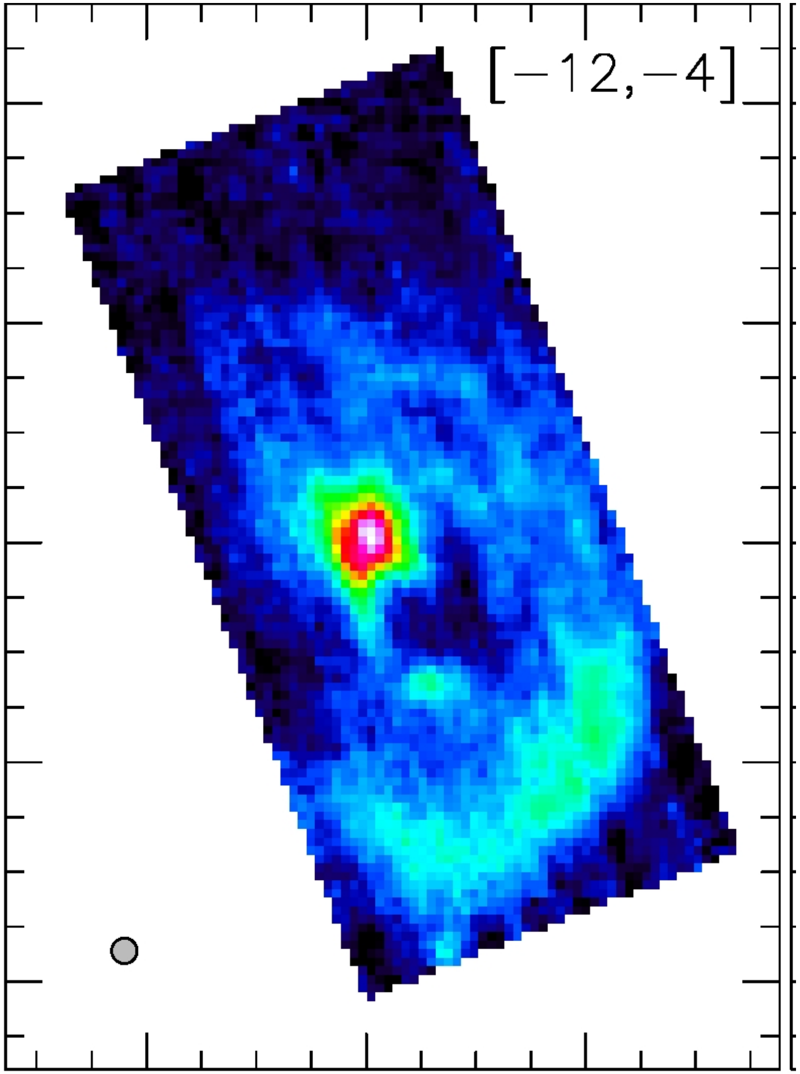
Measured upGREAT beam profiles

upGREAT Mapping of S106

- upGREAT is a 14-pixel array operating at the 158 mm Fine Structure Line of [C II]

- Able to produce velocity-resolved maps an order of magnitude faster than before

- Robert Simon and GREAT Consortium (MPIfR)



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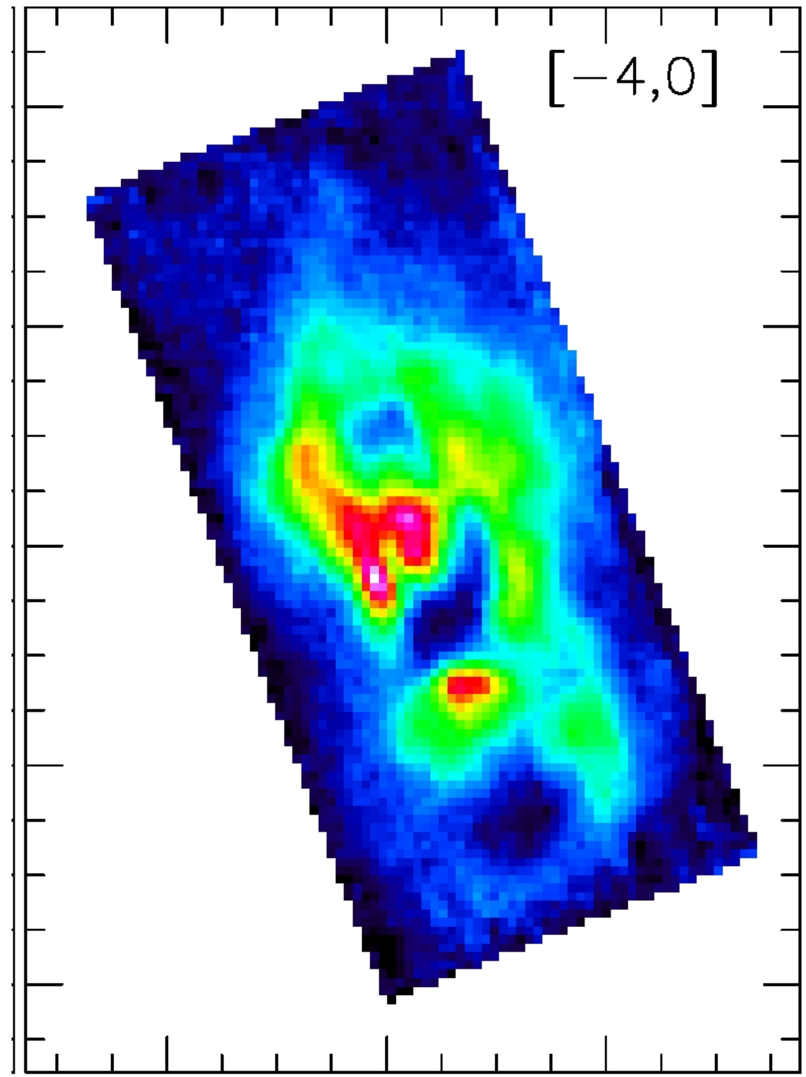

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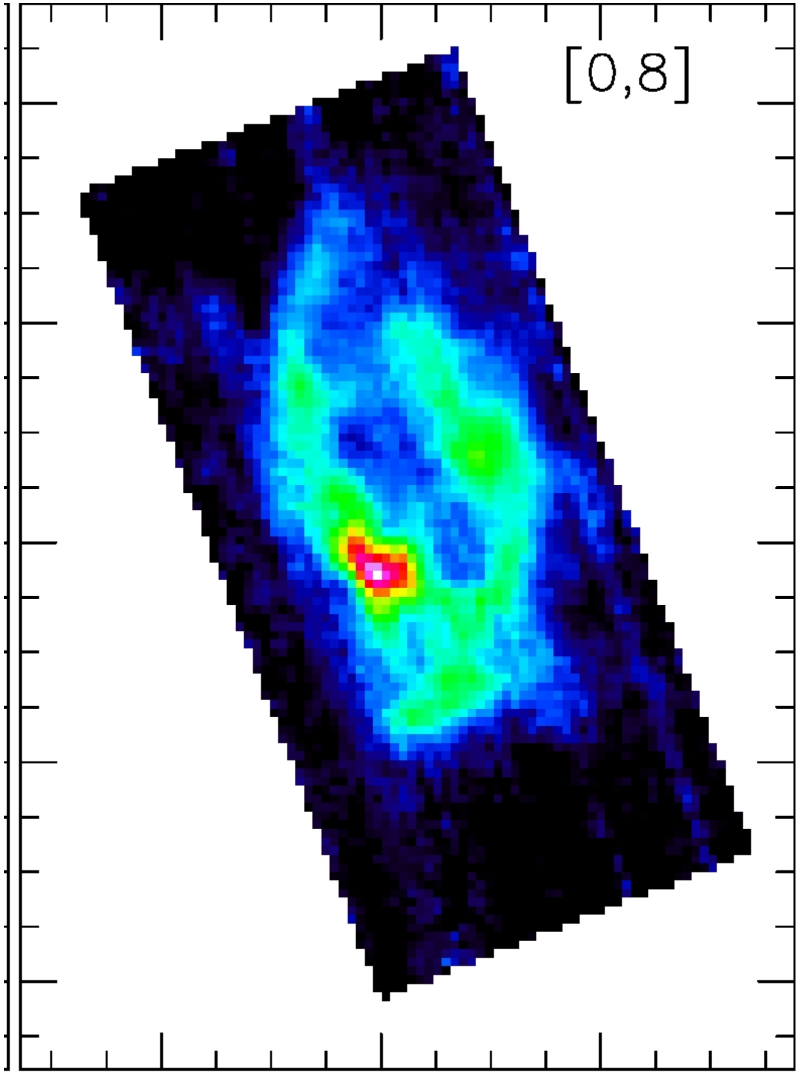
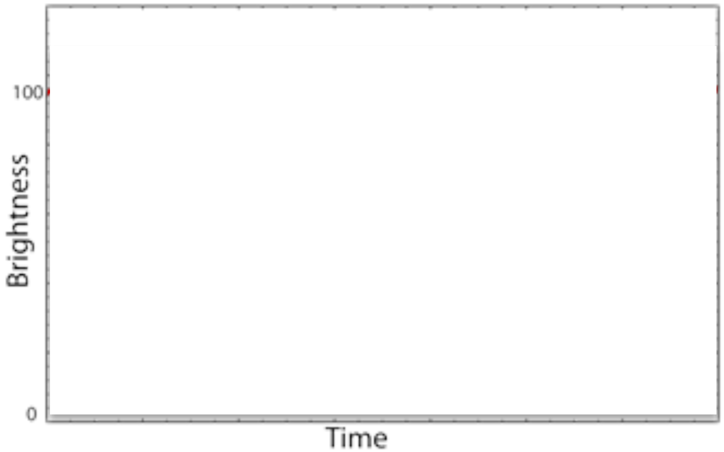
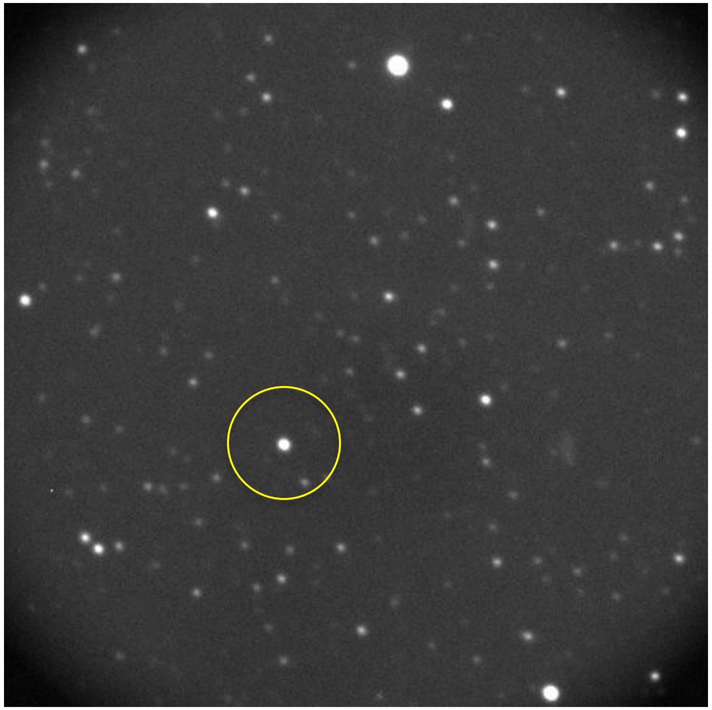


Science Highlight: Pluto Occultation

- Occultation of 12-mag star by Pluto on 2015 June 29
- Simultaneous SOFIA observations with HIPO, FLITECAM, & Focal Plane Imager.
- Final ground-based shadow updates required course adjustments of 230 km
- Detection of strong "central flash" confirms accuracy of course corrections
- Comparison of multi-wavelength observations will allow detailed analysis of atmospheric profiles and aerosol content.



As observed by SOFIA, the central bright flash represents starlight refracted by the atmosphere of Pluto when the star was completely behind the planet.



Focal Plane Imager+ observation of Pluto occultation event on UT 2015-06-29 16:55. Video is approximately 4X real time.

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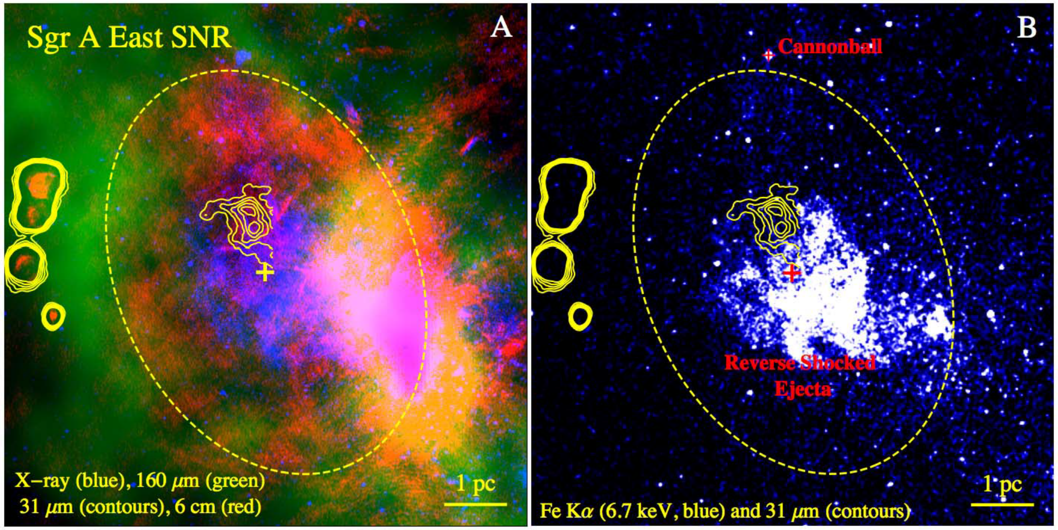

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Lau et al. (2015) , Science

Cycle 4 Preview

Cycle 4 Timeline

- Call issued: May 1
- Observers' Workshop: May 20-21, Mountain View
- Condensed workshop: June 3-4, Columbia MD
- Call update: June 8
- Proposal deadline: July 10
- US TAC: Aug 19-21
- German TAC: Sep 1-3
- Selection announcement: October 23

- Nominal Cycle 4 observing period:
  1 February 2016 – 2 February 2017.

Cycle Comparison

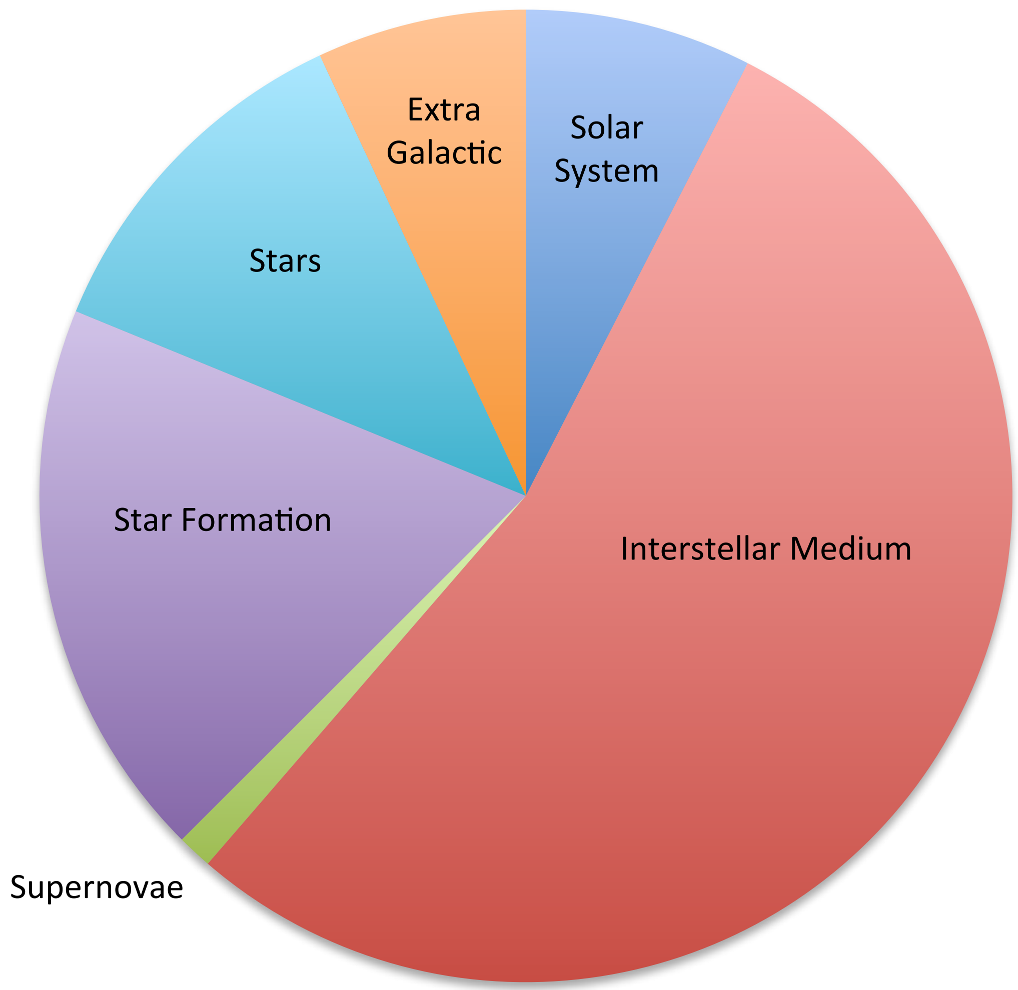
	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5
CfP Date	14-Nov-11	29-Apr-13	29-May-14	1-May-15	
Cycle Execution	Jun 2013- Feb 2014	Feb 2014- Feb 2015	Mar 2015 - Jan 2016	Feb 2016 - Jan 2017	Feb 2017 - Jan 2018
US Hours Offered	200	175	450	500	
DE Hours Offered	48	47	45	80	
US Proposals	132	89	122	155	
DE Proposals	39	27	31	30	
US Hours Requested	1293	545	1075	1582	
DE Hours Requested	186	67	104	150	
US Approved Proposals	42	62	63	80	
DE Approved Proposals	18	19	24	18	
US Hours Awarded*	178	165	419.5	478.3	62**
DE Hours Awarded*	52.5	43.8	45.8	80.4	
Hours Executed	149	173	280		

As of 10/31/2015

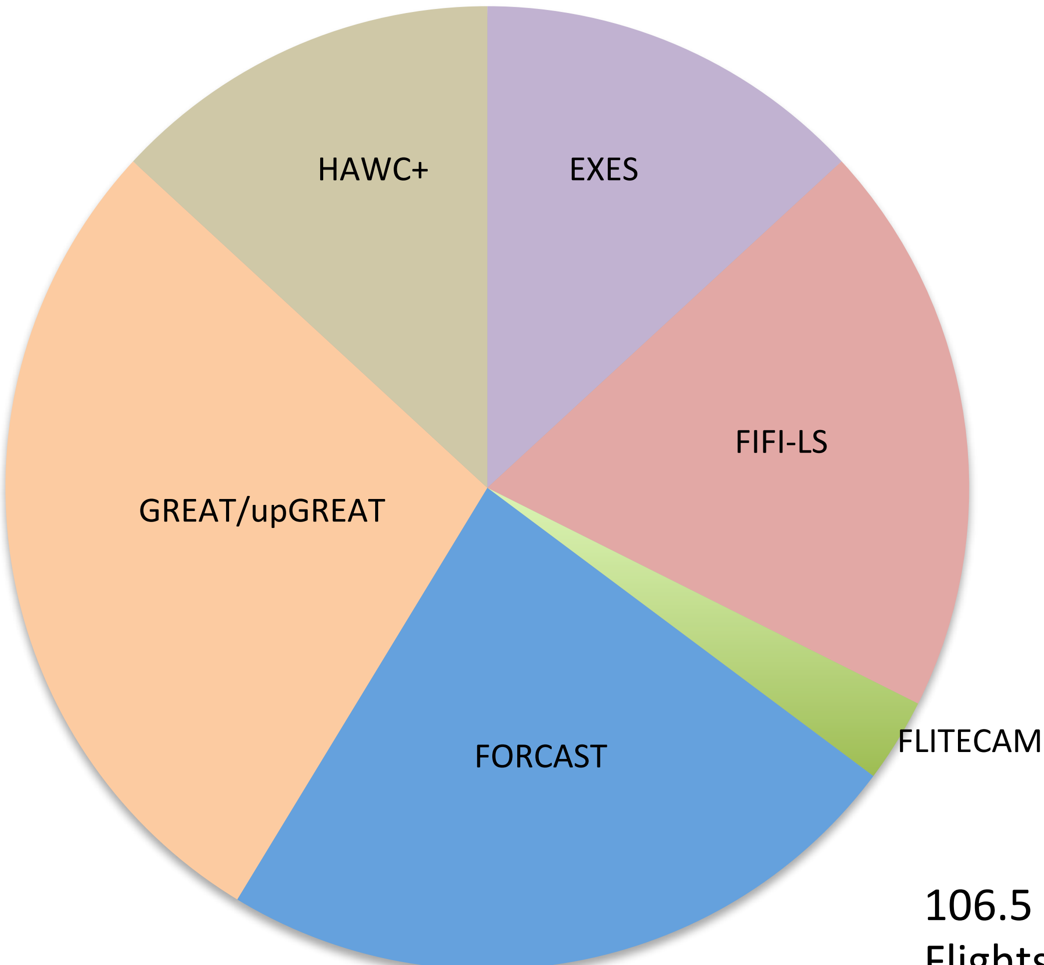
* Does not include "Do If Time"

**Deferred Cycle 4 time for large Impact Proposals

Cycle 4 Science Areas



Cycle 4 Instrument Distribution

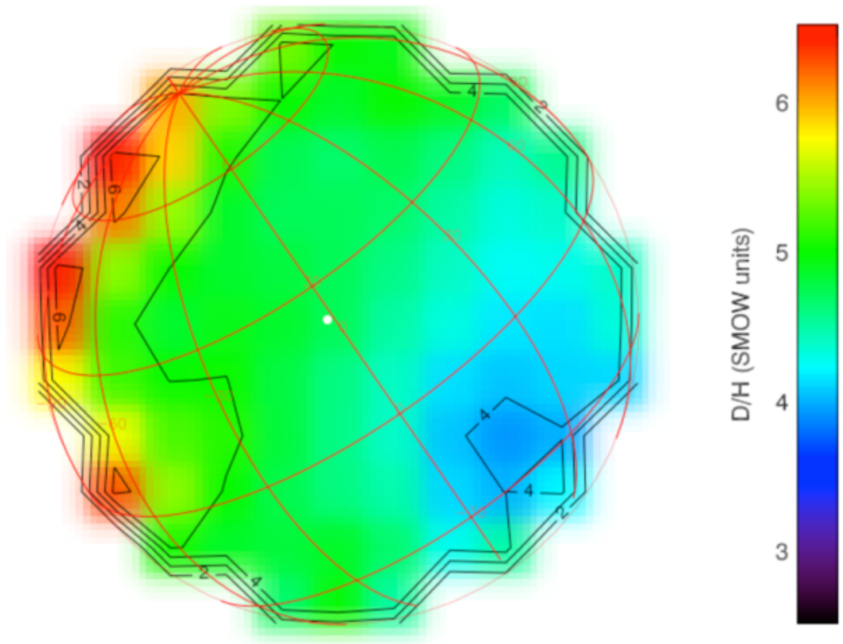


106.5 Science Flights

D/H Ratio on Mars

- What is the history of water on Mars?

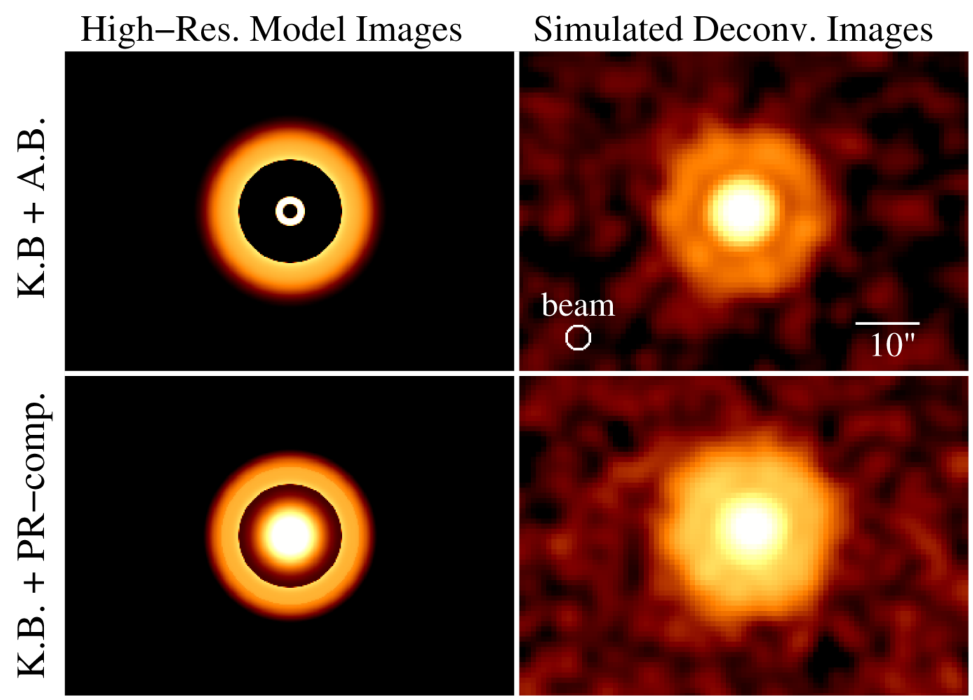
- Proposal 04_0018
  - Therese Encrenaz (LEISA, Paris Observatory)
- Measurements of H_2O and HDO at 7.2 mm with EXES will measure the D/H ratio of the outgassing water on Mars
- Observations will have sufficient angular resolution to study the sublimation/condensation cycle as well as the sources and sinks of water on the planet



Map of D/H ration on Mars inferred from EXES commissioning observations in April 2015. The proposed investigation will study position as well as seasonal variations in the D/H ratio.

Structure of Vega's Debris Disk

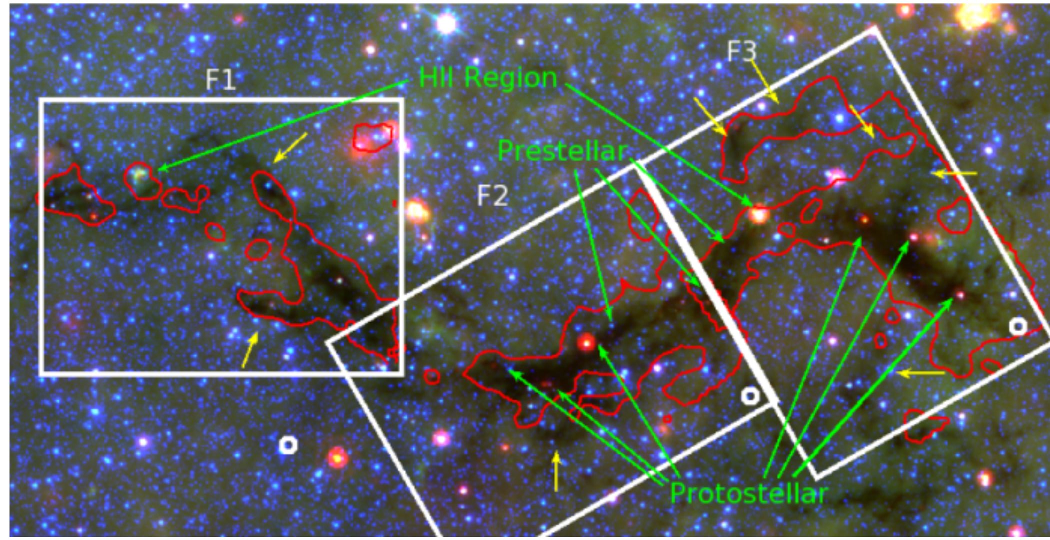
- Is Vega's debris disk sculpted by planets?
- Proposal 04_0065 Kate Su (Univ. Arizona)
- FORCAST observations at 35 mm will explore the possibility that the debris disk of the classic Vega system is shepherded by unseen planets.
- Observations will distinguish between competing models for the warm excess emission observed in photometry



Models of 35 mm emission from the debris disk of Vega. Upper panels show disk with Kuiper Belt (K.B.) and Asteroid Beld (A.B.). Lower panels have Kuiper Belt plus dragged-in Poynting-Robertson dust. Gaps in both models are due to unseen planets.

Magnetic Fields in High Mass Star Formation

- What is the role of magnetic fields in supporting dense filaments from gravitational collapse?
- Proposal 04_0068
  - Ian Stephens (Boston University)
- Observations with HAWC+ polarimeter will probe the magnetic field in the ***interior*** of filamentary infrared dark cloud



Spitzer 3.6, 8, & 24 mm observations of the Snake Infrared Dark Cloud. Proposed observations with HAWC+ at 214 mm are indicated by the white rectangles.

Impact Programs

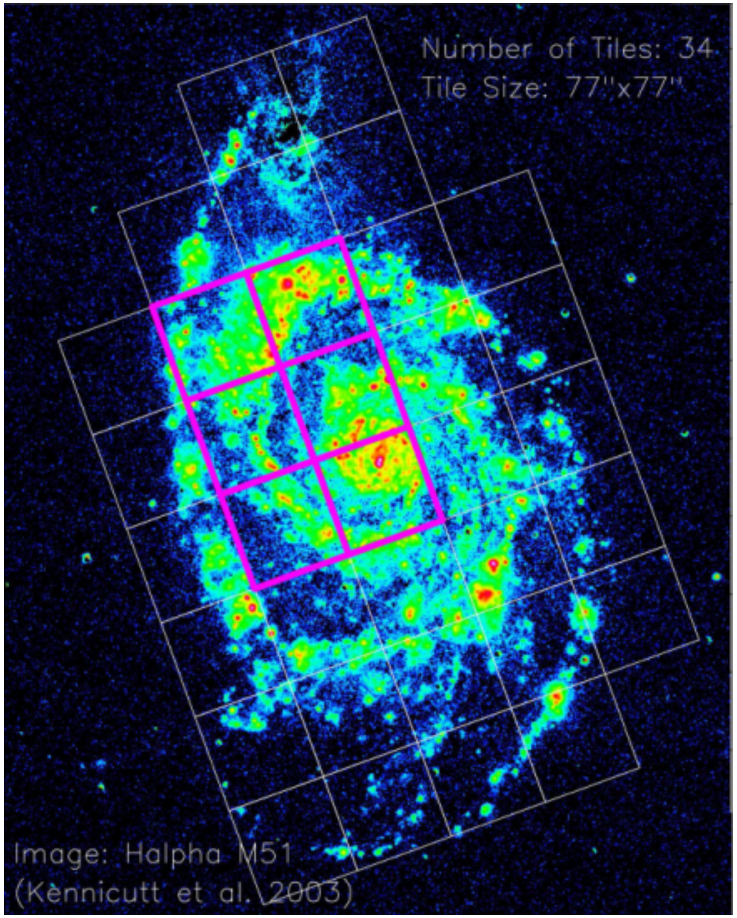
- Large, multi-year (2-3 cycles) programs, aimed at specific scientific questions of high potential impact (not, primarily, "just" surveys).
  - Anticipate selecting 2-3 with 100hr-class observing each
  - Any instrument combination (except no mix of FSI/PSI and SSI)

- Selected Impact Proposals
  - 04_0116 (Pineda); 04_0122 (Stutzki) - 74.5 hours
    - Joint Impact Proposal: A complete velocity resolved 3-D [CII] map of the M51 grand-design spiral galaxy: Unraveling the impact of spiral density waves on the evolution of the ISM and star formation.
  - 04_0066 (Tielens) - 75 Hours
    - The large scale [CII] emission from the Orion molecular cloud

Impact of Density Waves on Star Formation

- What is the role of density waves on star formation in grand design spirals?

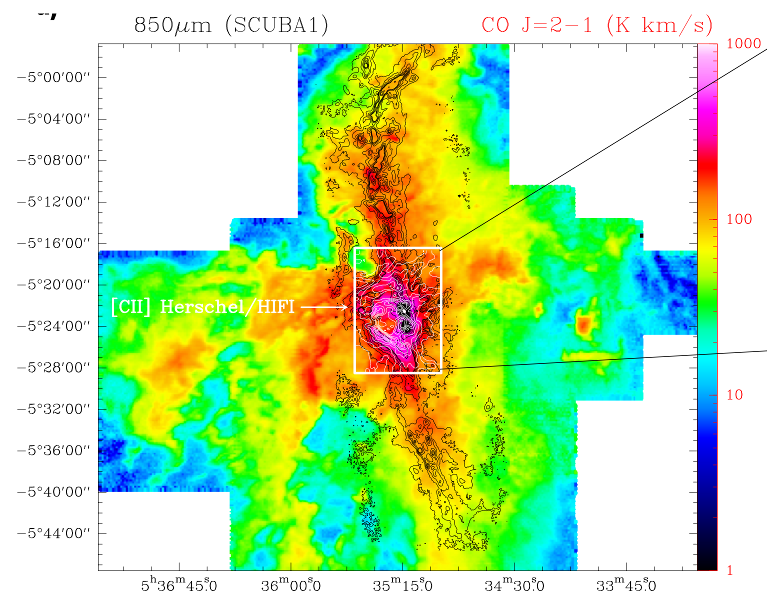
- Joint Impact Proposals:
  04_0116 Pineda (JPL)
  04_0122 Stutzki (Köln)
- Velocity-resolved observations of 158 mm [C II] line with upGREAT heterodyne spectrometer and mapping with FIFI-LS of inter-arm regions in classic spiral galaxy M51
- For the first time, the molecular gas will be mapped in the principal cooling line of the ISM.
- Project is also a demonstration of the technological advancements of SOFIA, providing mapping speeds more than an order of magnitude faster than Herschel.



Ha image of M51 identifying star formation regions. Proposed mapping grid for upGREAT is depicted by the squares

Large Scale [C II] Emission in the Orion Molecular Cloud

- What are the physical diagnostics that can be measured with the [C II] 158 mm emission line?
- Proposal 04_0066 (Tielens) to map 0.6 square deg of the Orion molecular cloud
  - Map is 20x the area of Herschel map and explores a much wider range of cloud environments.
- The investigation will explore:
  - The relationship between [C II] emission and near IR PAH emissions
  - Contribution of CO-dark gas to the [C II] emission
  - Kinematics and turbulence of [C II] emission in Photodissociation Regions



Colored image shows CO J=2-1 emission mapped by IRAM telescope. Proposed SOFIA mapping region covers the same extent. Existing Herschel mapped region is denoted by white box.

Cycle 4 Items Being Worked

- Southern Hemisphere Deployment
  - We are still exploring the possibility of bringing a third instrument on the Southern Hemisphere deployment
  - Will be covered in Presentation 5
- Final budget for FY 2016
  - Depends on the results of Congressional action
- HAWC+ Commissioning Schedule