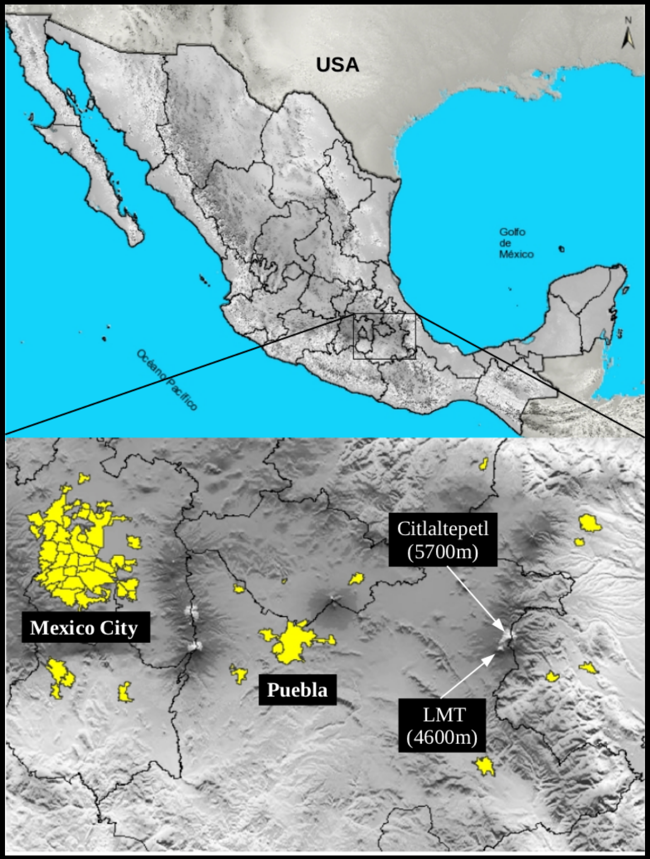
Gran Telescopio Milimétrico -*Alfonso Serrano*

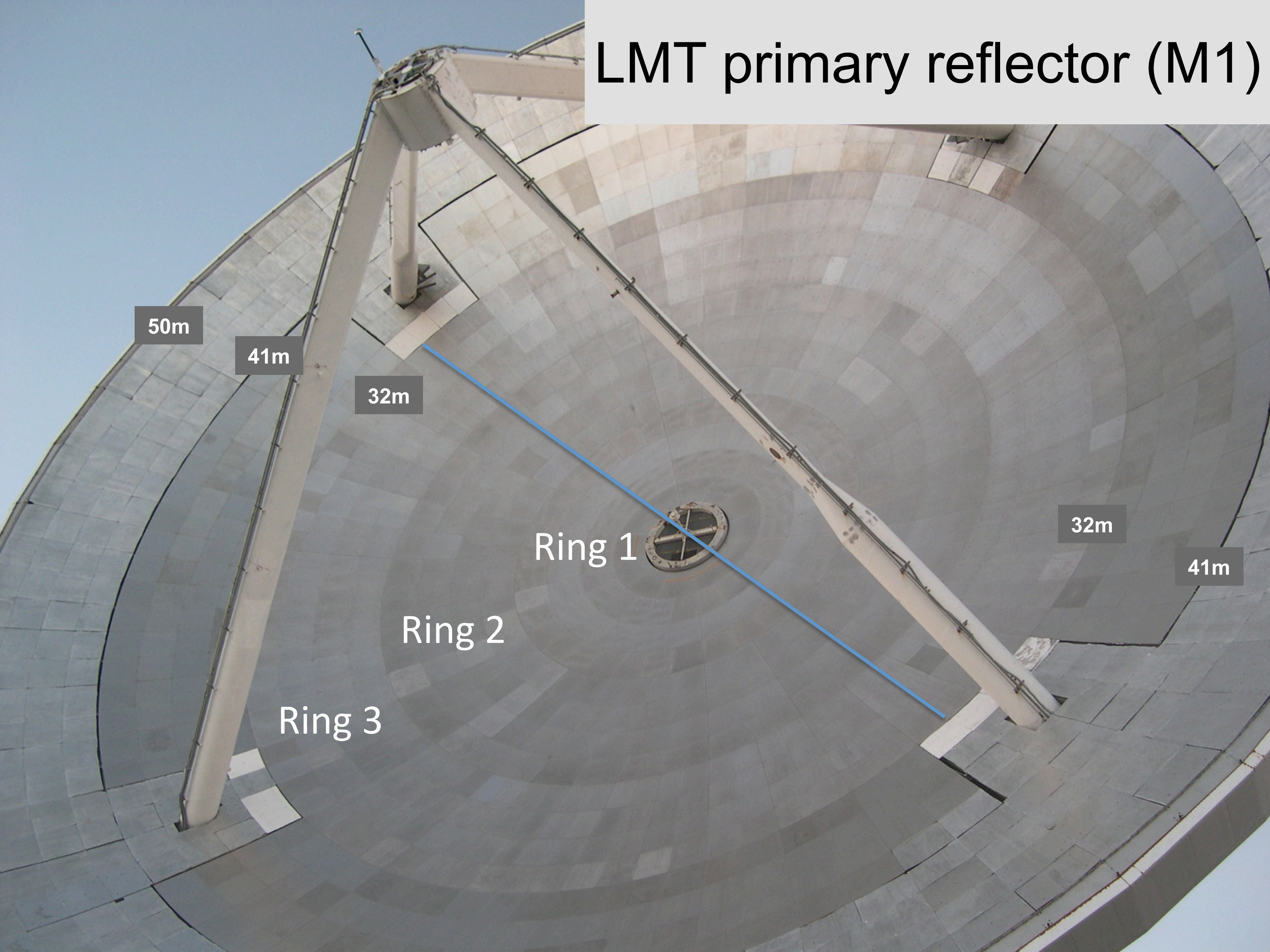


Miguel Chavez Dagostino
LMT/GTM Responsable Cientifico
Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE), Tonantzintla, Mexico

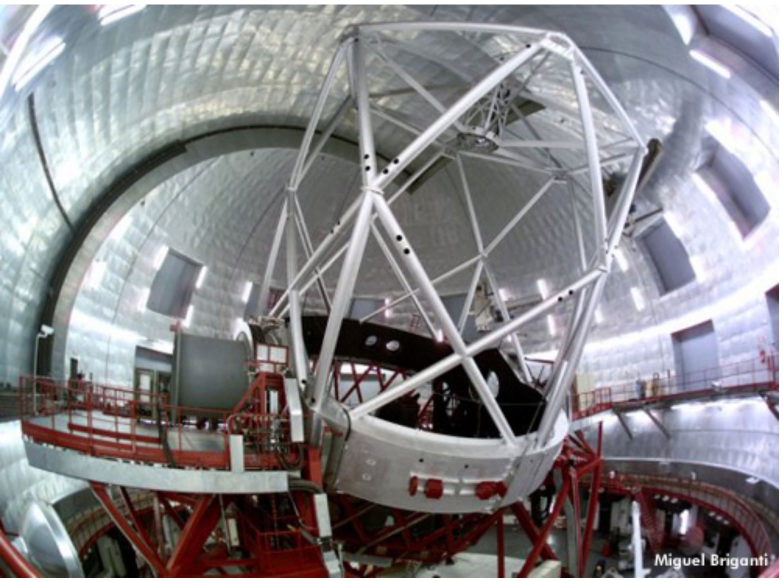

Pico de Orizaba (Citlaltépetl)
5740 m; 18832 ft
LMT / Sierra Negra (Tliltépetl)
4600m; 15091 ft
97º 18’ 53” W, +18º 59’ 06”
Puebla 2200m - 120 km from INAOE/Puebla to LMT


ow operational (>2013)
diameter M1 in 2017
bserving seasons complete,
s in preparation
d-risk Early Science Call for
mber/15– June/16
r sub-mm conditions
omplements SKA, JVLA,
, SPICA, JWST, TMT/GMT/ELT
coming decades
lmtgtm.org

LMT primary reflector (M1)



?


Miguel Briganti

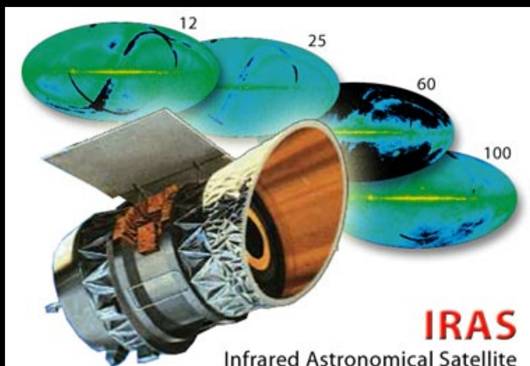
?

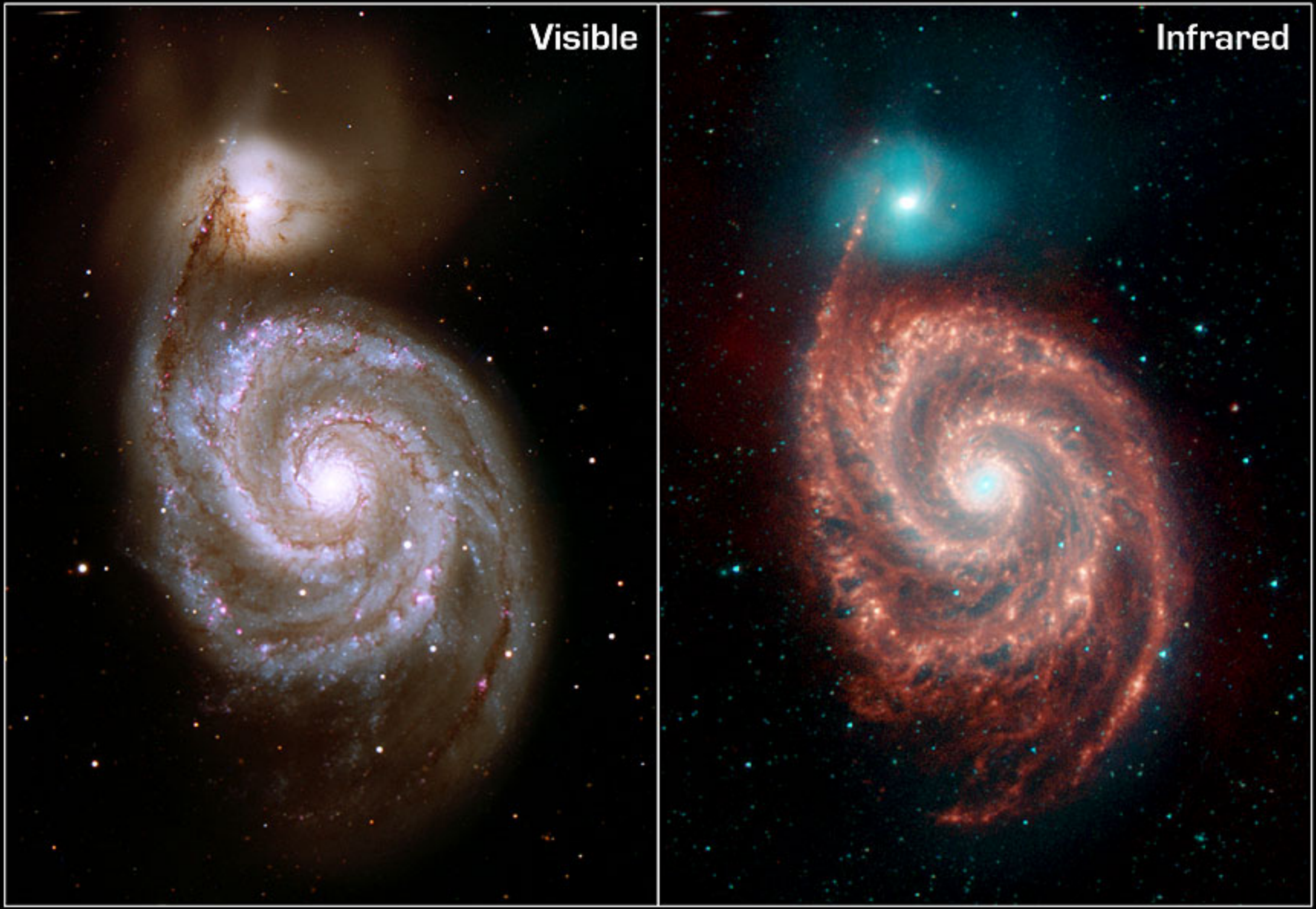
TRES CLASES DE “COSAS” OSCURAS

- Nubes Obscuras
  (Harold Weaver,1949, ApJ,110)
- Materia Obscura
  (M. E. Bailey, 1982, MNRAS, 201)
- Energía Obscura
  (Saul Perlmutter et al. 1999, PhRvL, 83)

NEBULOSA OBSCURA: LA VÍA LÁCTEA

Necesitamos otros “ojos”!





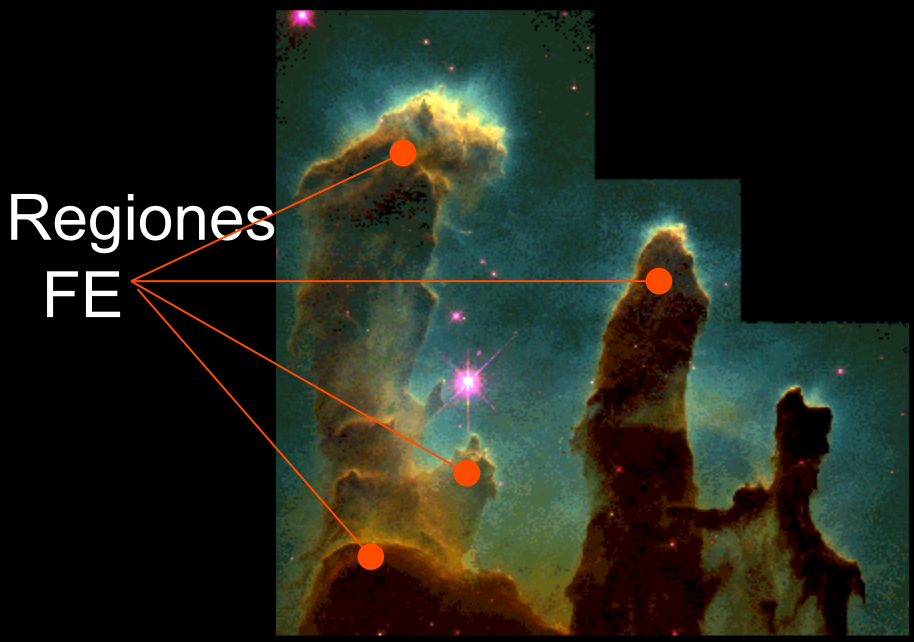
Spiral Galaxy M51 ("Whirlpool Galaxy")

Spitzer Space Telescope • IRAC

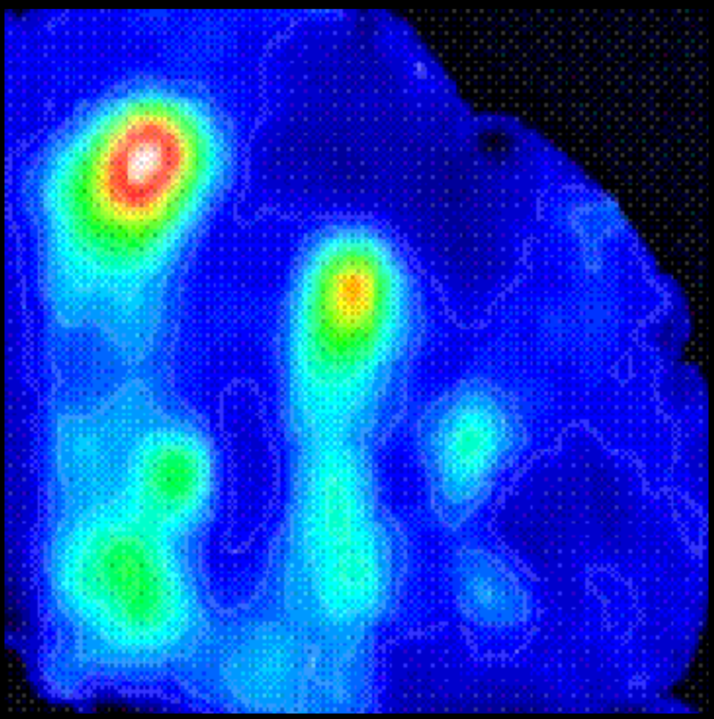
NASA / JPL-Caltech / R. Kennicutt (Univ. of Arizona)

ssc2004-19a

Observaciones sub-mm de regiones de formación estelar ópticamente oscurecidas



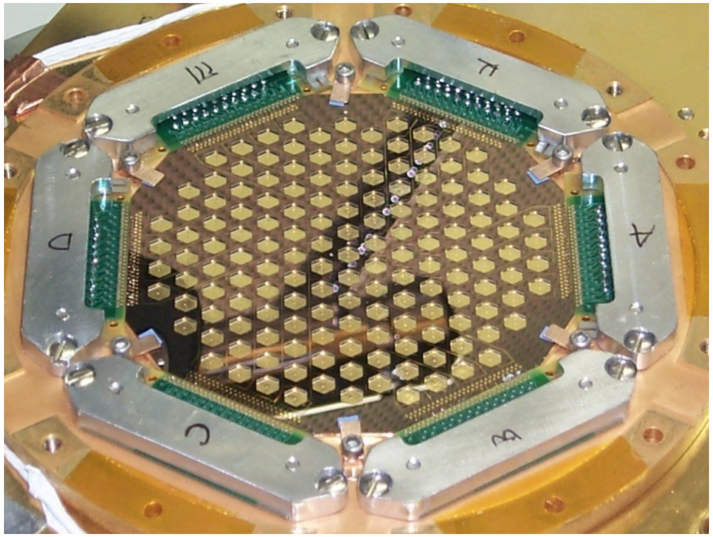
óptico HST



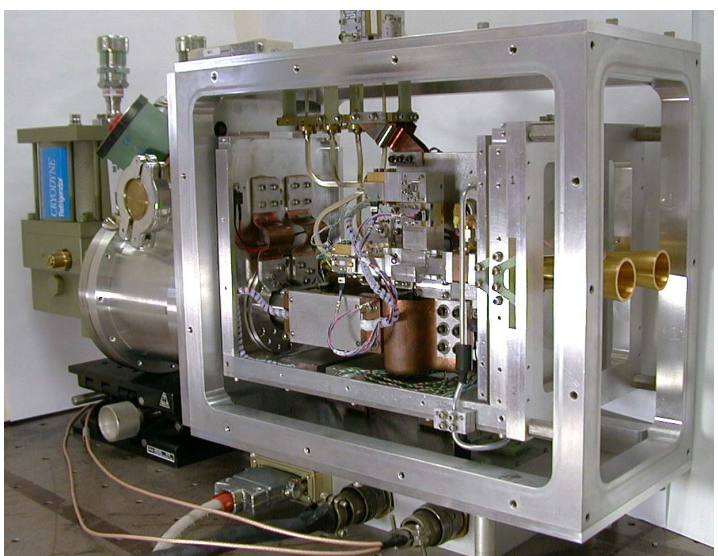
sub-mm 450μm

LMT_2013jul01.mov

LMT commissioning & 1st-light scientific instrumentation



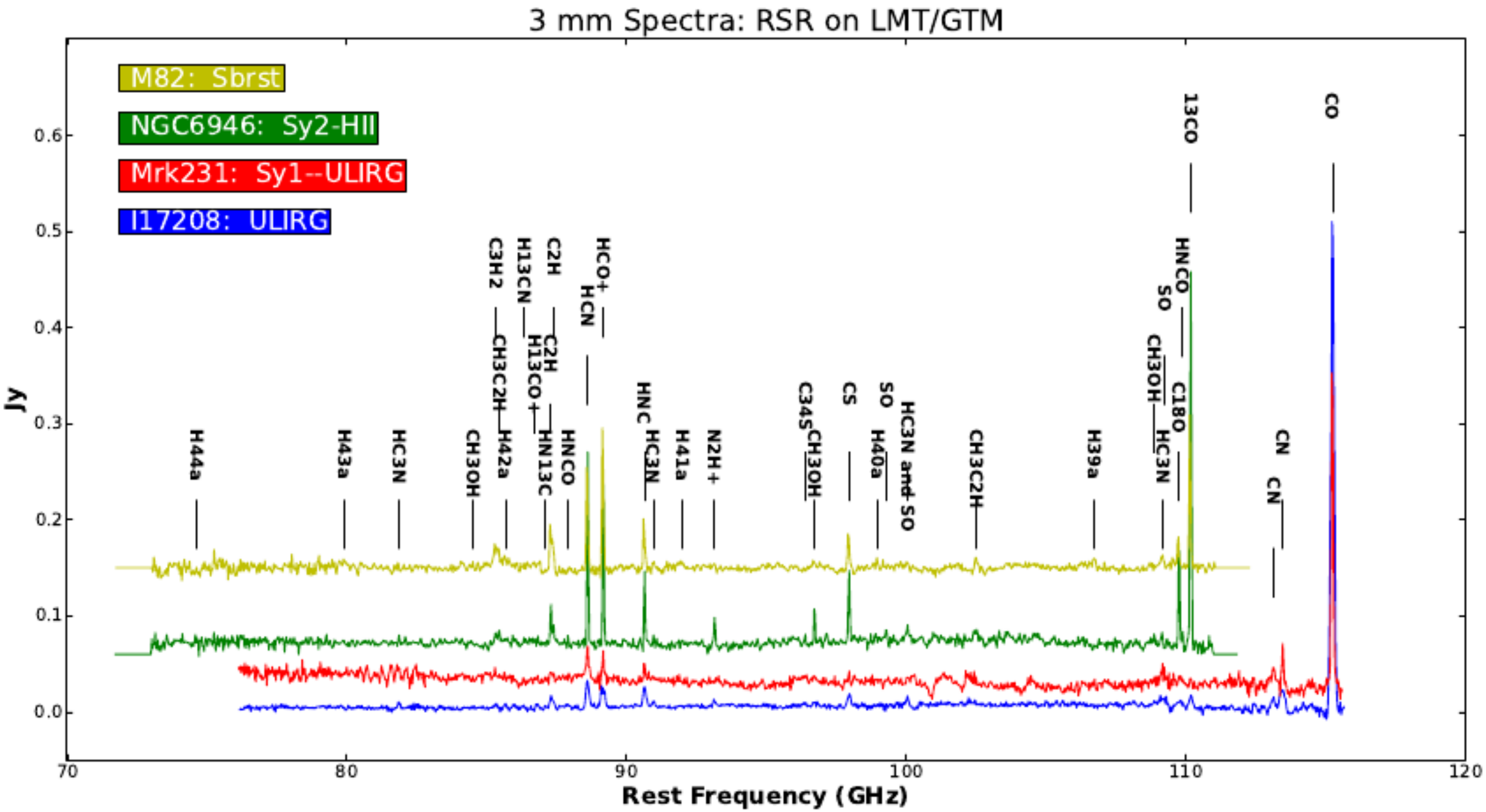
- **AzTEC** (P.I. Grant Wilson - UMASS)
- 1.1mm camera (144 pixels)
- 100 sq. arcmin/hr/mJy^2 (~ SCUBA2)
- wide-field & confusion-limited continuum mapping. Faster multi-frequency large-format KIDS camera (Toltec 2016).
- operational JCMT(2005), ASTE (2007-2008)



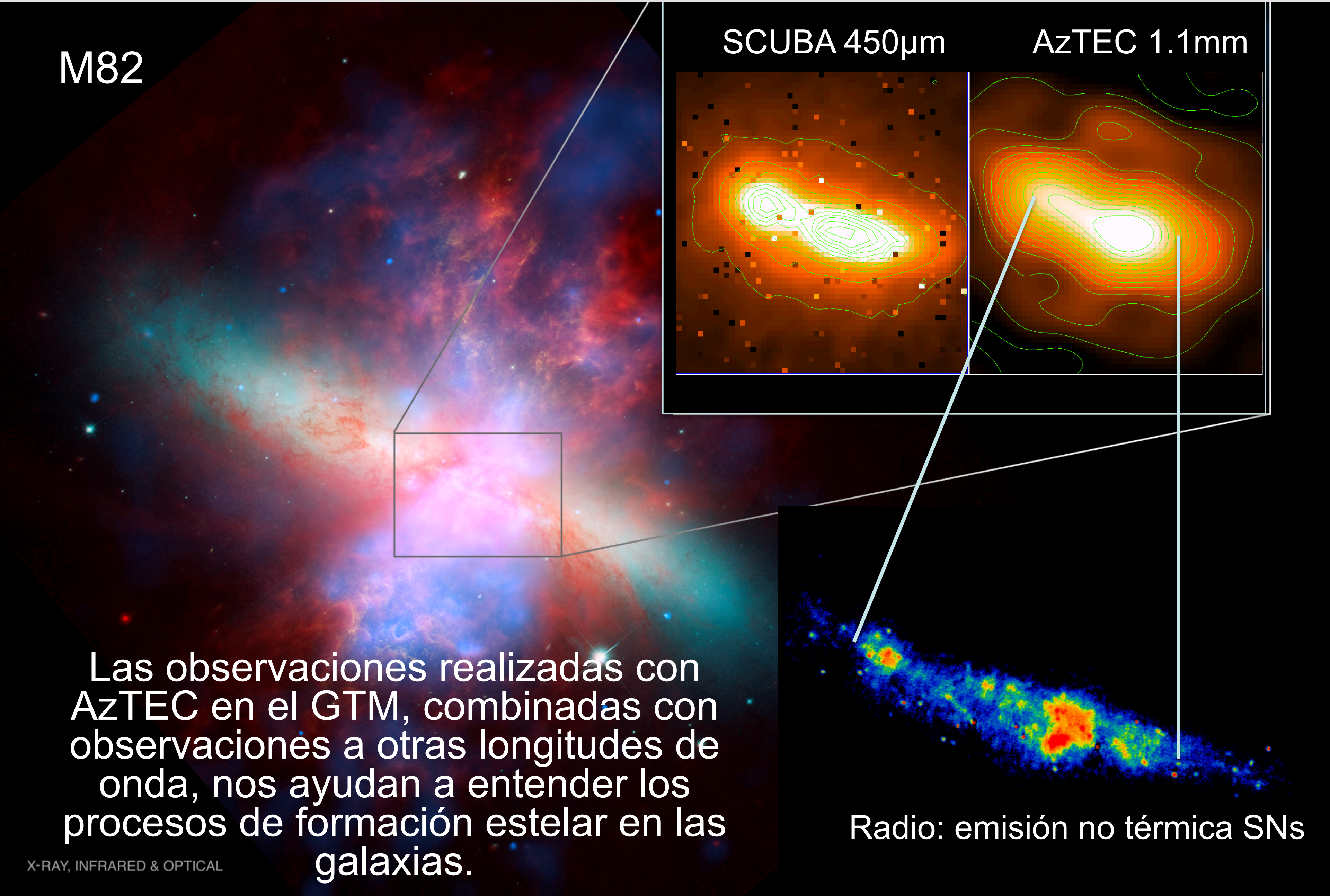
- **Redshift Seach Receiver** (P.I. Neal Erickson - UMASS)
- 75 – 111 GHz instantaneous bandwidth; ~100 km/s resolution; 2 pixel (2 pol).
- Receiver temp ~ 60K; stable baselines
- detect multiple molecular-lines without prior information on galaxy redshift
- operational FCRAO-14m (2007-2008)

Cuarto de Control GTM

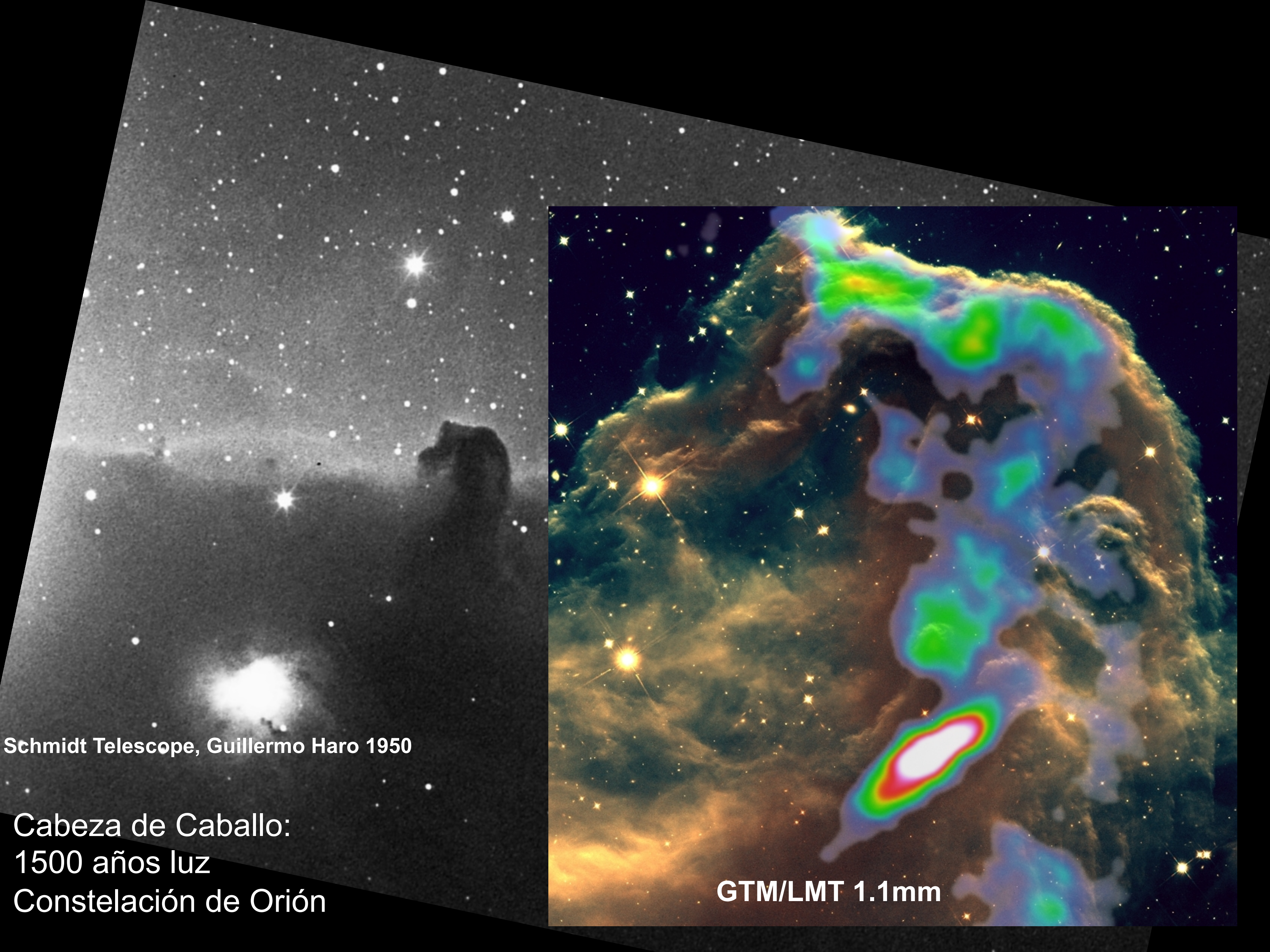
Daniel Rosa et al.



2014-ES2: Formación estelar en galaxias



Las observaciones realizadas con AzTEC en el GTM, combinadas con observaciones a otras longitudes de onda, nos ayudan a entender los procesos de formación estelar en las galaxias.


Schmidt Telescope, Guillermo Haro 1950
GTM/LMT 1.1mm
Cabeza de Caballo:
1500 años luz
Constelación de Orión

Monthly Notices of the Royal Astronomical Society
MNRAS 452, 1140–1151 (2015) doi:10.1093/mnras/stv1351

Early Science with the Large Millimeter Telescope: observations of dust continuum and CO emission lines of cluster-lensed submillimetre galaxies at $z = 2.0–4.7$

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Accepted 2015 June 15. Received 2015 June 15; in original form 2014 December 23

ABSTRACT
We present Early Science observations with the Large Millimeter Telescope, AzTEC 1.1 mm continuum images and wide bandwidth spectra (73–111 GHz) acquired with the Redshift Search Receiver, towards four bright lensed submillimetre galaxies identified through the *Herschel* Lensing Survey-snapshot and the Submillimetre Common-User Bolometer Array-2

★ E-mail: zavala@inaoep.mx

Monthly Notices of the Royal Astronomical Society
MNRAS 453, L88–L92 (2015) doi:10.1093/mnrasl/slv100

Early science with the Large Millimeter Telescope: dust constraints in a $z \sim 9.6$ galaxy

J. A. Zavala,[1]★ M. J. Michałowski,[2] I. Aretxaga,[1] G. W. Wilson,[3] D. H. Hughes,[1] A. Montaña,[1,4] J. S. Dunlop,[2] A. Pope,[3] D. Sánchez-Argüelles,[1] M. S. Yun[3] and M. Zeballos[1]

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Accepted 2015 July 21. Received 2015 July 20; in original form 2015 June 26

ABSTRACT
Recent observations with the GISMO (Goddard-IRAM Superconducting 2 Millimeter Observer) 2 mm camera revealed a detection 8 arcsec away from the lensed galaxy MACS1149-JD1 at $z = 9.6$. Within the 17.5 arcsec FWHM GISMO beam, this detection is consistent with the position of the high-redshift galaxy and therefore, if confirmed, this object could be claimed to be the youngest galaxy producing significant quantities of dust. We present higher resolution (8.5 arcsec) observations of this system taken with the AzTEC 1.1 mm camera mounted on the Large Millimeter Telescope *Alfonso Serrano*. Dust continuum emission at the position of MACS1149-JD1 is not detected with an r.m.s. of 0.17 mJy/beam. However, we find a detection ~11 arcsec away from MACS1149-JD1, still within the GISMO beam which is consistent with an association to the GISMO source. Combining the AzTEC and GISMO photometry, together with *Herschel* ancillary data, we derive a $z_{phot} = 0.7–1.6$ for the ... AzTEC detections are not associated ... S1149-JD1 we derive the following ... gnification and for cosmic microwave ... ninosity $<8 \times 10^{10}$ L$_\odot$, star forma- ... These limits are comparable to those ... ama Large Millimeter/submillimeter

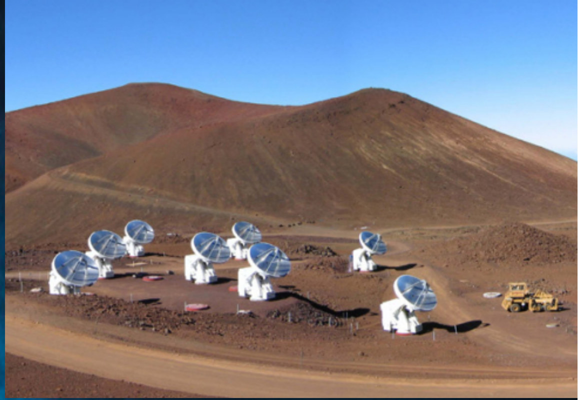
EARLY SCIENCE WITH THE LARGE MILLIMETER TELESCOPE: EXPLORING THE EFFECT OF AGN ACTIVITY ON THE RELATIONSHIPS BETWEEN MOLECULAR GAS, DUST, AND STAR FORMATION

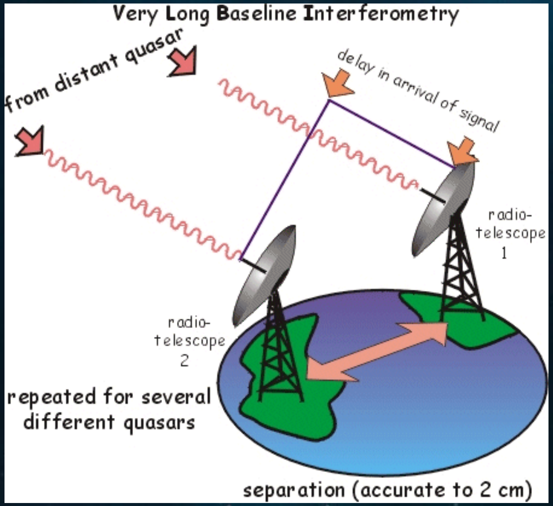
Allison Kirkpatrick[1], Alexandra Pope[1], Itziar Aretxaga[2], Lee Armus[3], Daniela Calzetti[1], George Helou[4], Alfredo Montaña[2], Gopal Narayanan[1], F. Peter Schloerb[1], Yong Shi[5], Olga Vega[2], Min Yun[1]

Draft version September 22, 2014

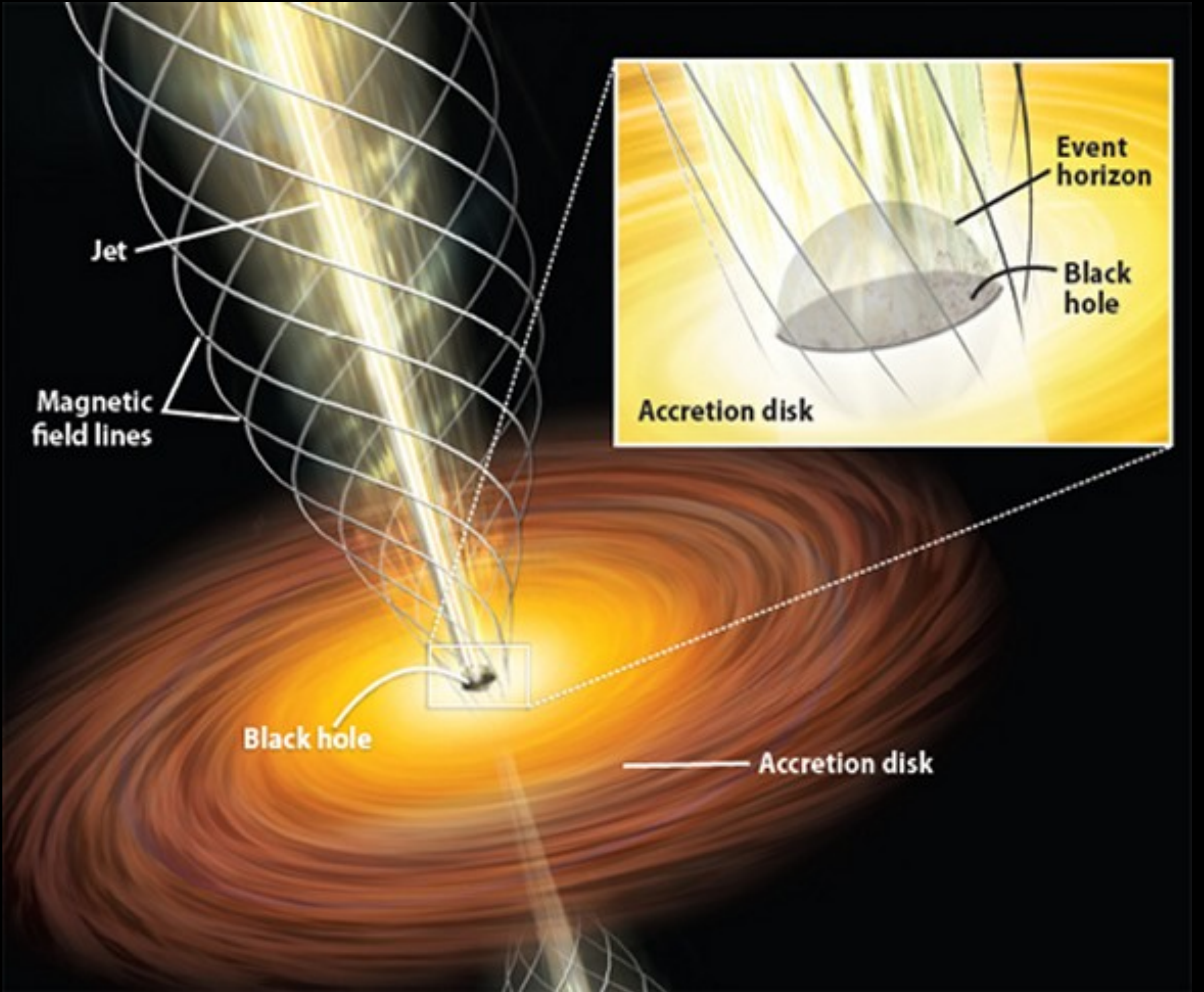
ABSTRACT
The molecular gas, H_2, that fuels star formation is difficult to observe directly. As such, the ratio of L_{IR} to L'_{CO} is an observational estimation of the star formation rate compared with the amount of molecular gas available to form stars, which is related to the star formation efficiency and the inverse of the gas consumption timescale. We test what effect an IR luminous AGN has on the ratio L_{IR}/L'_{CO} in a sample of 24 intermediate redshift galaxies from the 5 mJy Unbiased *Spitzer* Extragalactic Survey (5MUSES). We obtain new CO(1-0) observations with the Redshift Search Receiver on the Large Millimeter Telescope. We diagnose the presence and strength of an AGN using *Spitzer* IRS spectroscopy. We find that removing the AGN contribution to L_{IR}^{tot} results in a mean L_{IR}^{SF}/L'_{CO} for our entire sample consistent with the mean L_{IR}/L'_{CO} derived for a large sample of star forming galaxies from $z \sim 0-3$. We also include in our comparison the relative amount of polycyclic aromatic hydrocarbon emission for our sample and a literature sample of local and high redshift Ultra Luminous Infrared Galaxies and find a consistent trend between $L_{6.2}/L_{IR}^{SF}$ and L_{IR}^{SF}/L'_{CO}, such that small dust grain emission decreases with increasing L_{IR}^{SF}/L'_{CO} for both local and high redshift dusty galaxies.


SMT | Arizona
SMA | Hawaii
APEX | Chile



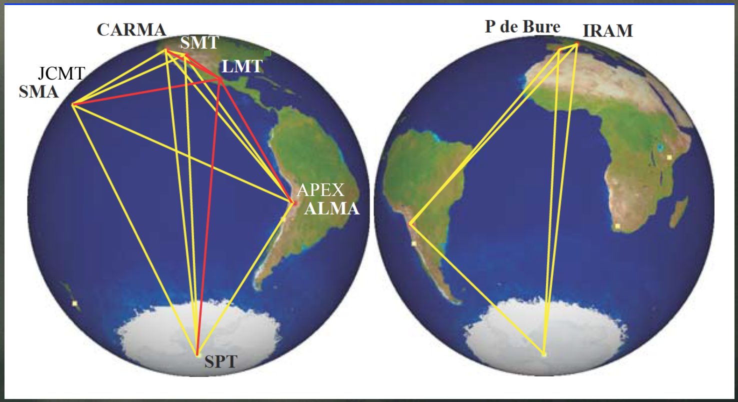


Very Long Baseline Interferometry
from distant quasar
delay in arrival of signal
radio-telescope 1
radio-telescope 2
repeated for several different quasars
separation (accurate to 2 cm)


Jet
Magnetic field lines
Black hole
Accretion disk
Event horizon
Black hole
Accretion disk

The New York Times | SCIENCE

Participación del GTM (INAOE, IRyA-UNAM y la UMASS) en el Telescopio del Horizonte de Evento (Event Horizon Telescope)



Black Hole Hunters

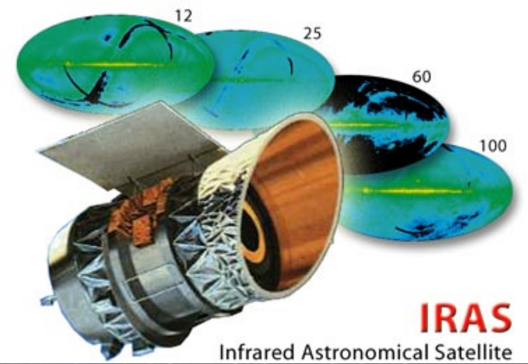
Aiming to make the first portrait of the hungry monster at the center of our galaxy, astronomers built “a telescope as big as the world.”

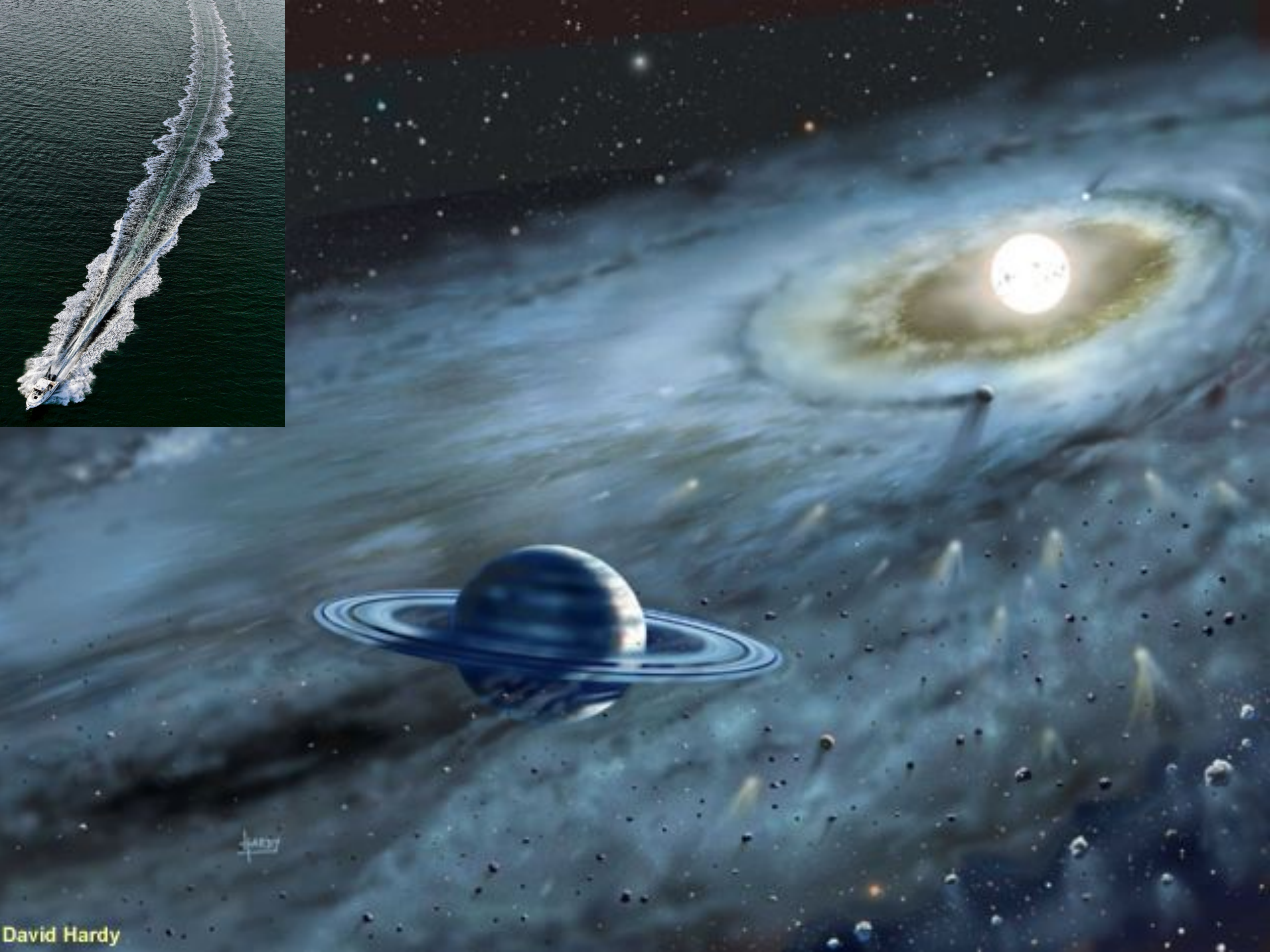
June 8, 2015

http://www.nytimes.com/2015/06/09/science/black-hole-event-horizon-telescope.html

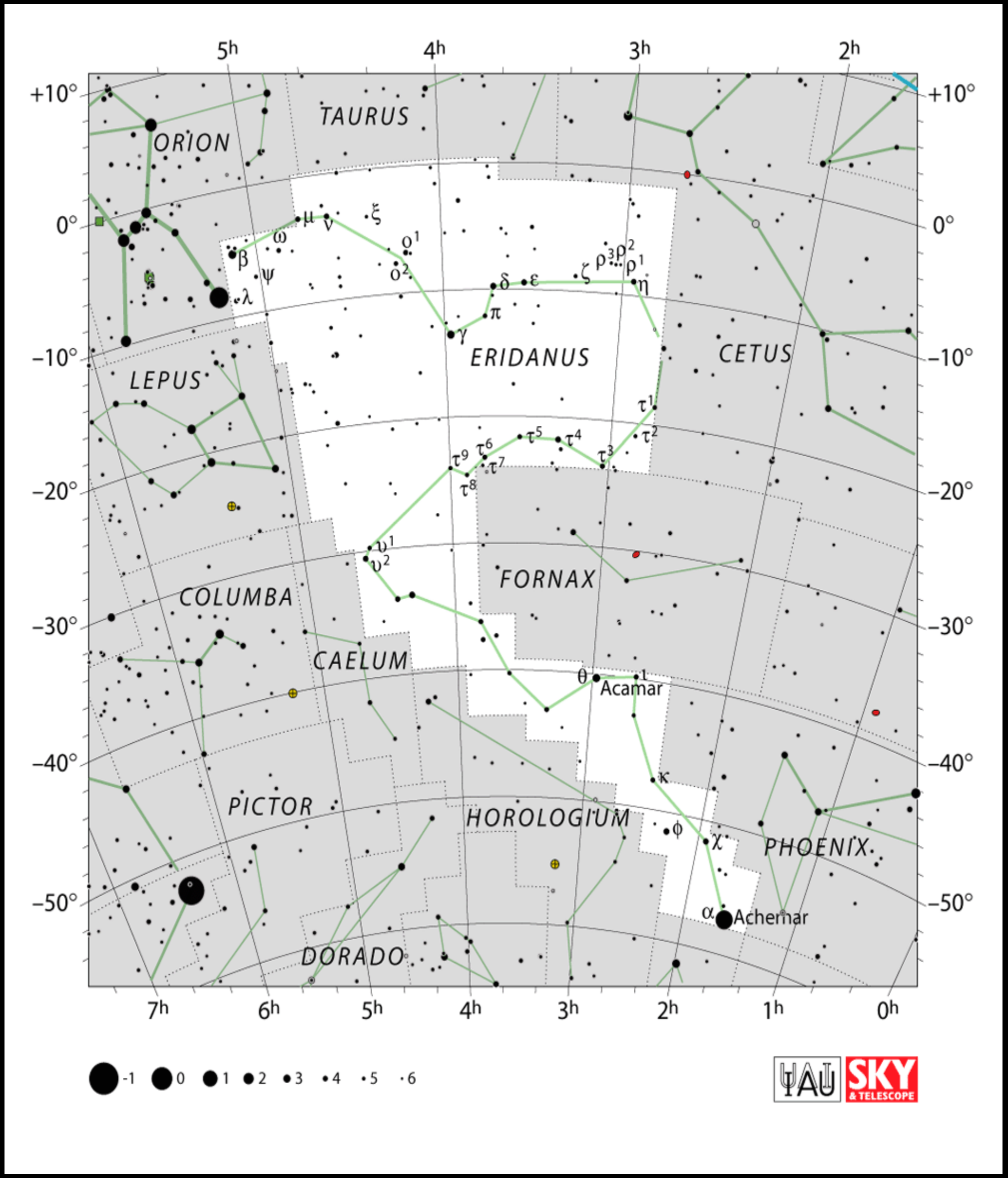
VEGA: 1984


0.0
0.25
0.5
0.75
1.0
Degrees
©2011 F. Espenak, www.AstroPixels.com


12
25
60
100
IRAS
Infrared Astronomical Satellite


David Hardy

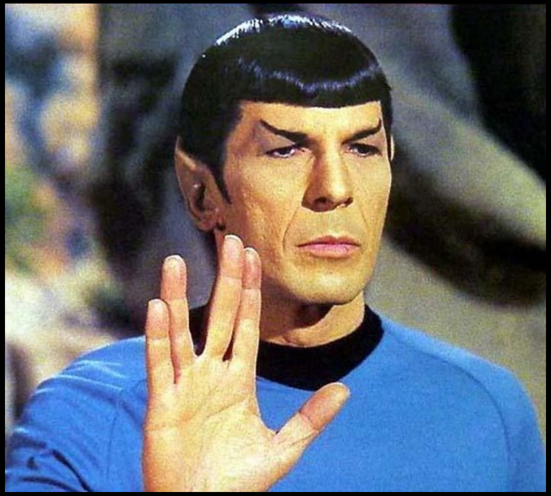
ε–Eridani is a relatively young, nearby, Sun-like star with t_{age} = 850 Myr , d = 3.22 pc, and spectral type K2 V. Its age and distance places it as one of the closest solar system analogues where we can study the early stages in the evolution of a planetary system similar to our own. The star is host to a bright, extended, almost face-on debris disk, which ranks among the finest examples of these objects so far discovered. The star has been proposed to host two giant exoplanets at semi-major axes of a few AU.

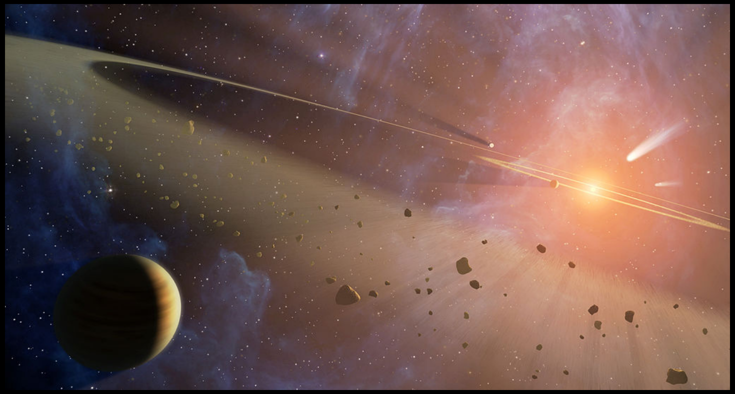


Muy popular en Ciencia Ficción:

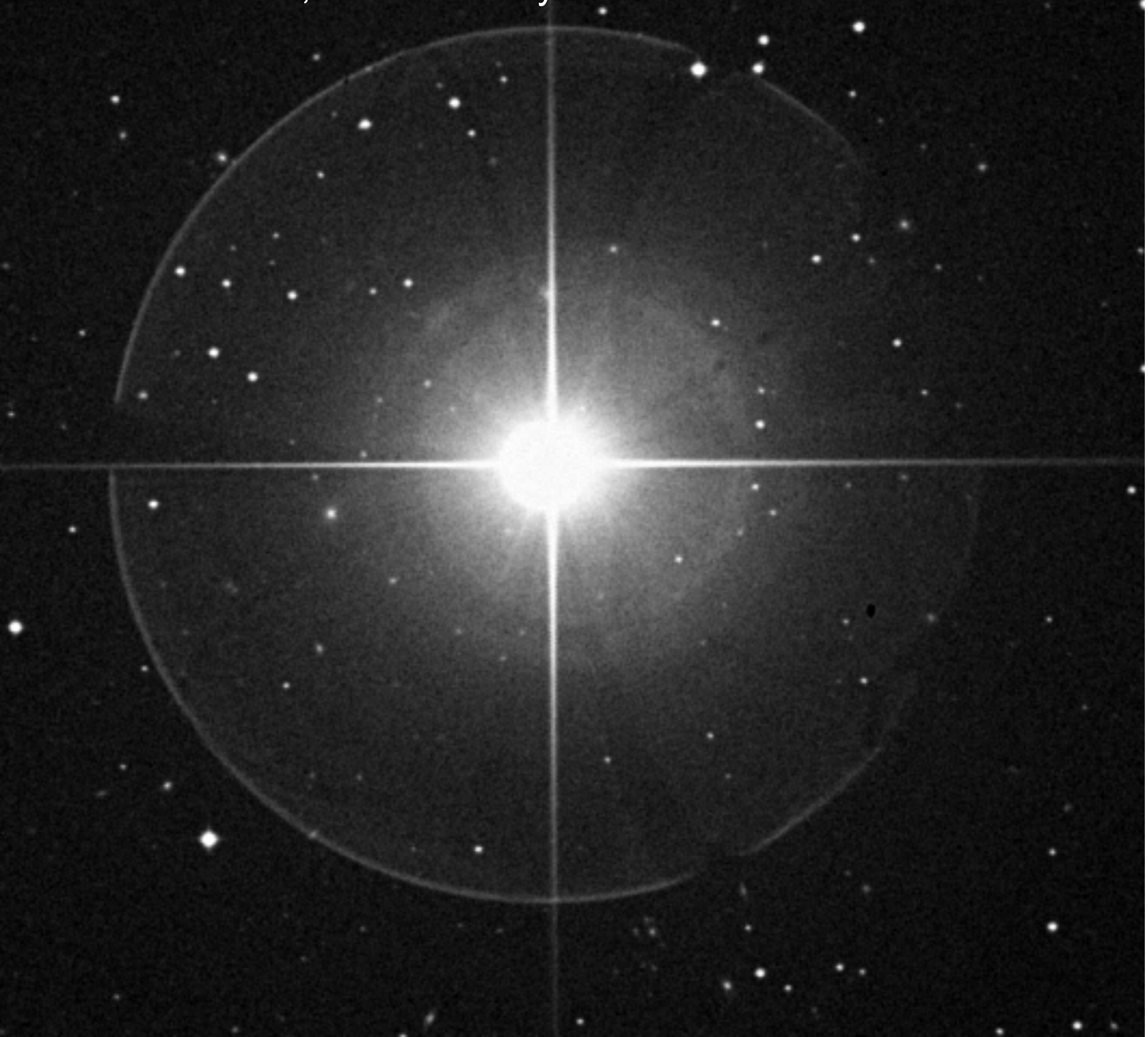
- Por su nombre
- Por su cercanía
- Por sus parámetros (parecidos al Sol)
- Por **posible** presencia planetaria

- En literatura, Cine, Televisión, videojuegos, etc.





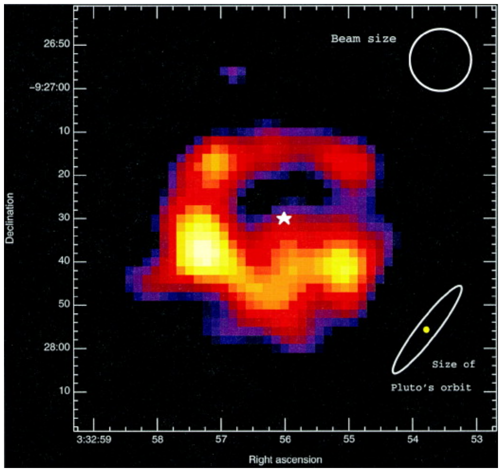
Eps-Eri: Among the neariest solar-like stars. It is one of the so-called "four-fab", discovered by IRAS

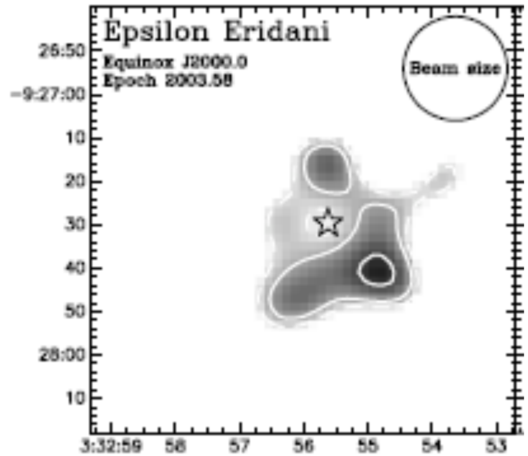


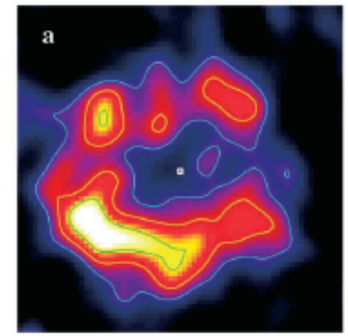
Gallery of previous (sub-)mm Observations

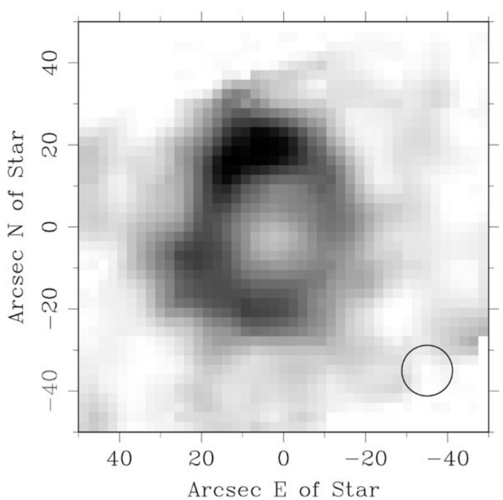
SCUBA, SIMBA, SCUBA, SHARCII, MAMBO, SCUBA2

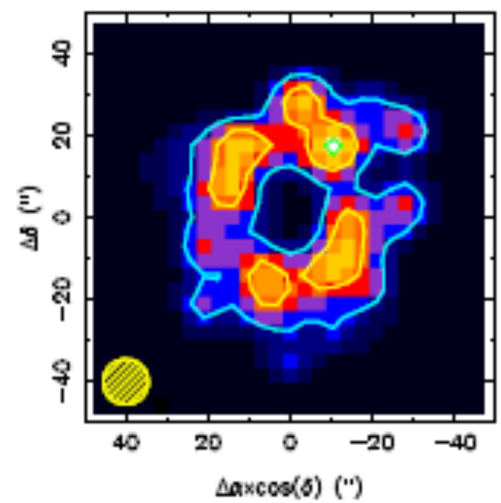
Greaves et al. (1998), Schutz e al. (2004), Greaves et al (2005), Backman et al. (2009), Lestrade & Thilliez (2015)

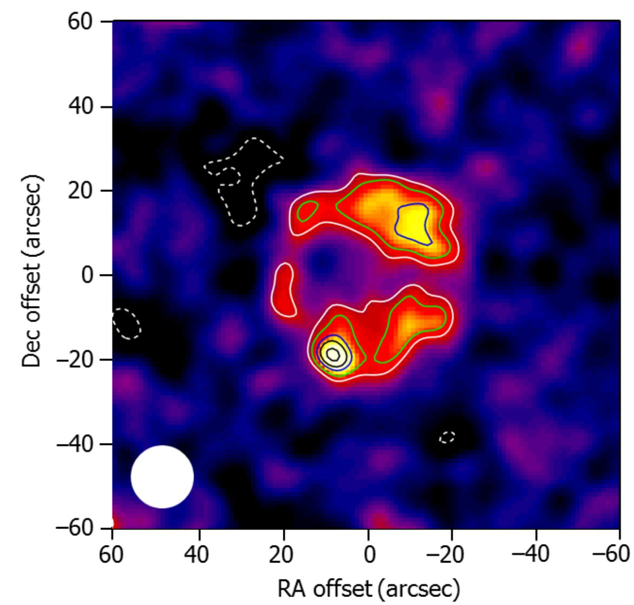


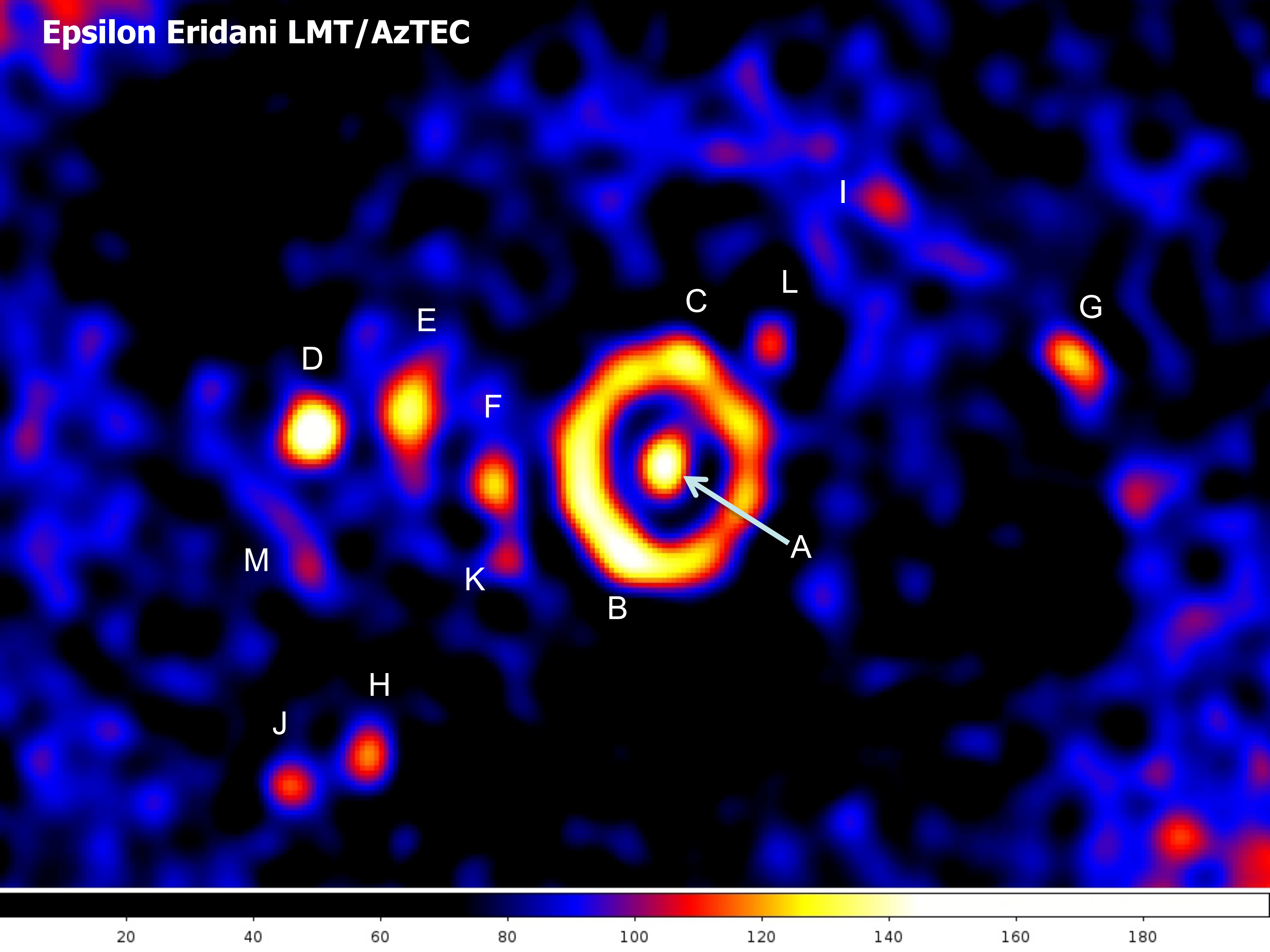











Epsilon Eridani LMT/AzTEC
I
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120
140
160
180

Productos académicos: Científicos

- **Operación Científica**
  - GTM en operación a partir de 2014: 167 propuestas científicas recibidas (convocatorias 2014-2015);
  - 57 propuestas 2015-ES4 (Sept. 2015); 60% I.P.´s México. Involucración de 77 investigadores + 25 estudiantes del INAOE, CRyA-UNAM, IA-UNAM, IA - UNAM Ensenada, Instituto de Geofísica, Unidad Michoacán – UNAM, Dept. de Astronomía, Univ. de Guanajuato y Univ. Nac. Auton.de Chiapas

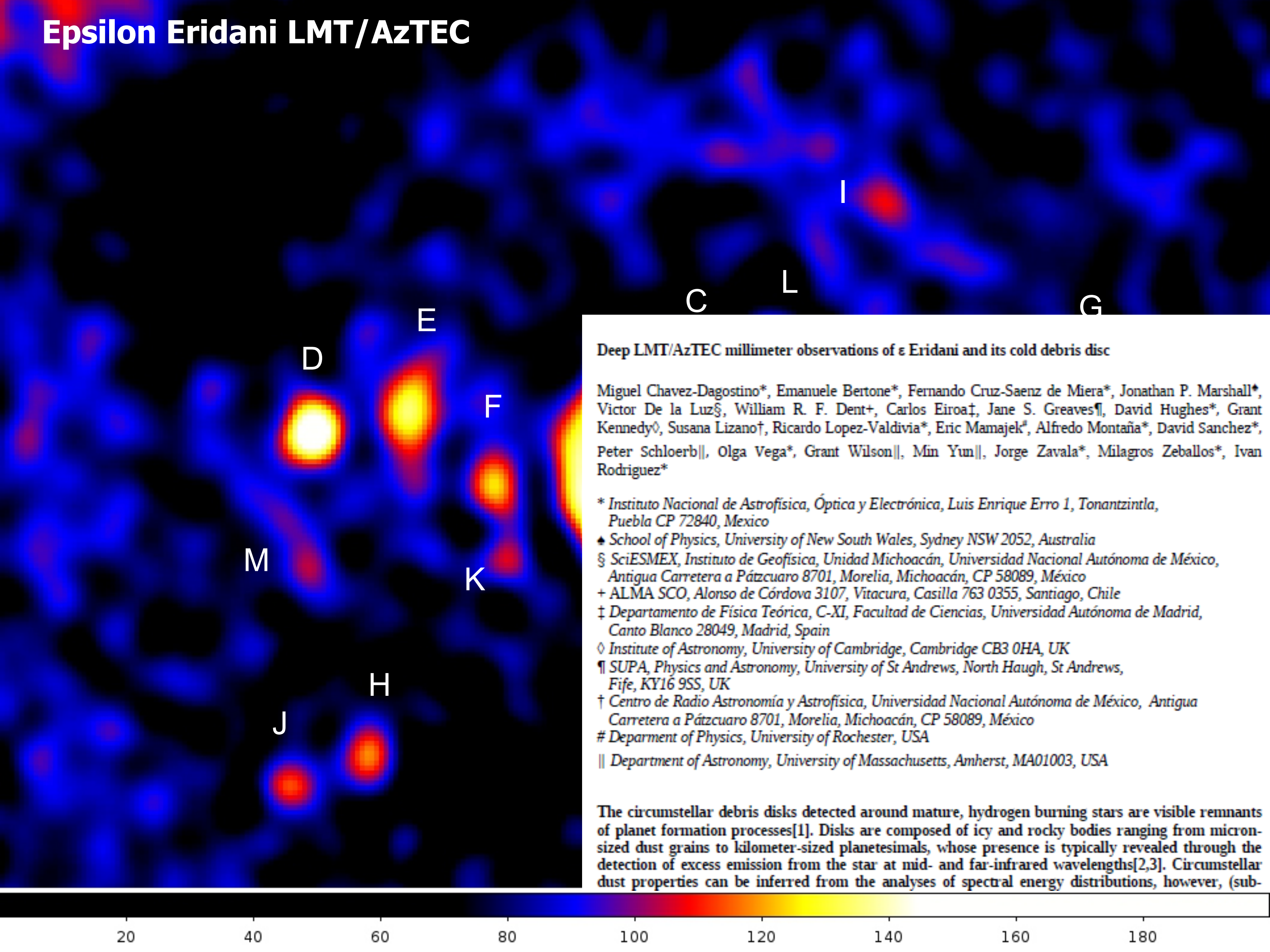
- **Articulos con arbitraje (revistas indizadas)**
  - AzTEC/RSR en el GTM (Dec 2014 – Oct 2015):
    - 4 publicados (2 por estudiante del INAOE) , 1 en prensa; 1 enviado ; 15 artículos en preparación
  - AzTEC/RSR/SEQUOIA en el FCRAO-14m, ASTE y JCMT (2008-2015)
    - 42 publicados (2 en Nature)
- **Recursos Humanos**
  - 3 CONACYT Catedráticos (2014) – GTM / INAOE para apoyar el desarrollo de la comunidad científica nacional involucrado en el GTM
  - INAOE (tésis relacionadas al GTM y la astronomía milimétrica – graduados 10 MSc y 6 PhD, en proceso 2 MSc y 7 PhD, CRyA-UNAM 1 PhD, IA-UNAM 1 MSc

- **Proyectos y colaboraciones nacionales e internacionales (CONACYT-NSF-RCUK)**
  - 2013 - Event Horizon Telescope (MIT, Harvard SAO) www.eventhorizontelescope.org
  - 2015 - CONACYT Fronteras de la Ciencia – Imágenes de agujeros negros super-masivos: Prueba de relatividad general en el límite de la gravedad extrema del horizonte de eventos (INAOE, IA-UNAM, ININ, CRyA-UNAM + MIT, Harvard SAO, UMASS (EE.UU), Max Planck Inst. (MPIfR, Bonn, Alemania), Nijmegen (Holanda), …
  - 2015 – CONACYT – RCUK: - Transferencia de tecnología y ciencia: Desarrollo de una camera del GTM de gran formato en 3 bandas para estudiar la formación y evolución de estructura en el universo

Trabajo en proceso: (50m con superficie activa-2017)

- Instalación del nuevo espejo secundario y su hexápodo
- Instalación de anillos 4 y 5 de la superficie primaria de 50-m de diámetro
- Instalación del nuevo sistema activo de control de los segmentos de la superficie en anillos 4 y 5

- Optimización de la conectividad:
- 0.5TB/noche (habrá uso diurno) ⇨ 1 TB
- Seguridad/operación científica (contacto ininterrumpido con GTM)
- Seguridad (problemas técnicos resueltos "on the spot")
- Transferencia de datos (backup) y link con, e.g. el EHT



Deep LMT/AzTEC millimeter observations of ε Eridani and its cold debris disc

Miguel Chavez-Dagostino*, Emanuele Bertone*, Fernando Cruz-Saenz de Miera*, Jonathan P. Marshall♠, Victor De la Luz§, William R. F. Dent+, Carlos Eiroa‡, Jane S. Greaves¶, David Hughes*, Grant Kennedy◊, Susana Lizano†, Ricardo Lopez-Valdivia*, Eric Mamajek#, Alfredo Montaña*, David Sanchez*, Peter Schloerb||, Olga Vega*, Grant Wilson||, Min Yun||, Jorge Zavala*, Milagros Zeballos*, Ivan Rodriguez*

** Instituto Nacional de Astrofísica, Óptica y Electrónica, Luis Enrique Erro 1, Tonantzintla, Puebla CP 72840, Mexico*
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§ SciESMEX, Instituto de Geofísica, Unidad Michoacán, Universidad Nacional Autónoma de México, Antigua Carretera a Pátzcuaro 8701, Morelia, Michoacán, CP 58089, México
+ ALMA SCO, Alonso de Córdova 3107, Vitacura, Casilla 763 0355, Santiago, Chile
‡ Departamento de Física Teórica, C-XI, Facultad de Ciencias, Universidad Autónoma de Madrid, Canto Blanco 28049, Madrid, Spain
◊ Institute of Astronomy, University of Cambridge, Cambridge CB3 0HA, UK
¶ SUPA, Physics and Astronomy, University of St Andrews, North Haugh, St Andrews, Fife, KY16 9SS, UK
† Centro de Radio Astronomía y Astrofísica, Universidad Nacional Autónoma de México, Antigua Carretera a Pátzcuaro 8701, Morelia, Michoacán, CP 58089, México
 # Deparment of Physics, University of Rochester, USA
|| Department of Astronomy, University of Massachusetts, Amherst, MA01003, USA

The circumstellar debris disks detected around mature, hydrogen burning stars are visible remnants of planet formation processes[1]. Disks are composed of icy and rocky bodies ranging from micron-sized dust grains to kilometer-sized planetesimals, whose presence is typically revealed through the detection of excess emission from the star at mid- and far-infrared wavelengths[2,3]. Circumstellar dust properties can be inferred from the analyses of spectral energy distributions, however, (sub-

Deep LMT/AzTEC millimeter observations of ε Eridani and its cold debris disc

Miguel Chavez-Dagostino*, Emanuele Bertone*, Fernando Cruz-Saenz de Miera*, Jonathan P. Marshall♠, Victor De la Luz§, William R. F. Dent+, Carlos Eiroa‡, Jane S. Greaves¶, David Hughes*, Grant Kennedy◊, Susana Lizano†, Ricardo Lopez-Valdivia*, Eric Mamajek#, Alfredo Montaña*, David Sanchez*, Peter Schloerb||, Olga Vega*, Grant Wilson||, Min Yun||, Jorge Zavala*, Milagros Zeballos*, Ivan Rodriguez*

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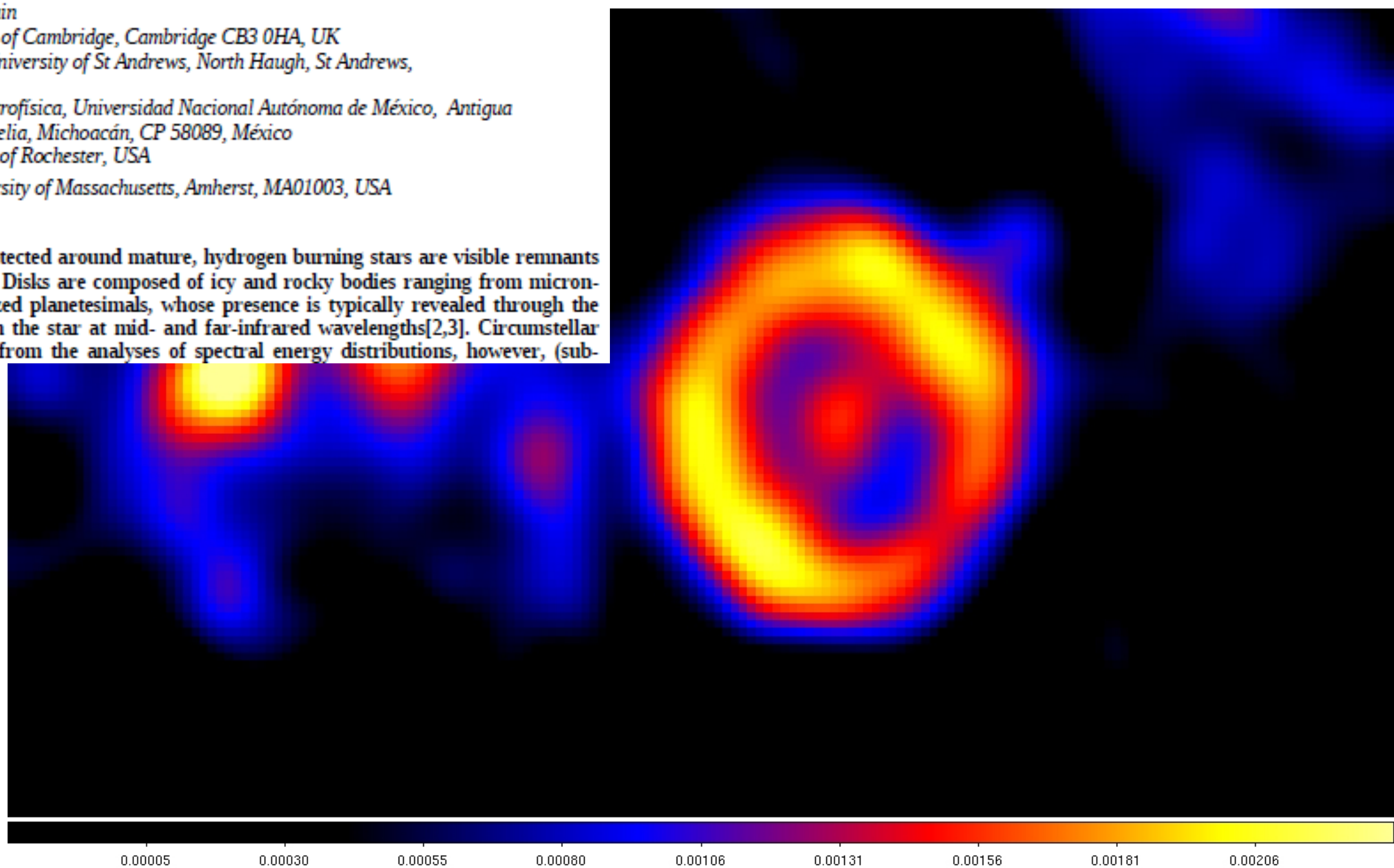


Tiempo de uso pleno

- A partir de los principios del año 2017
  - después de varios pruebas y actividades técnicas y científicas para verificar y caracterizar el aumento del desempeño del GTM de 50-m de diámetro
    - alienación de los 5 anillos de segmentos de la superficie de 50-m con el sistema activo de control
    - reconfiguración completa de los instrumentos científicos y instalación de sus nuevos espejos de acoplamiento
    - creación y implementación de un nuevo modelo de apuntado del telescopio y de calibración

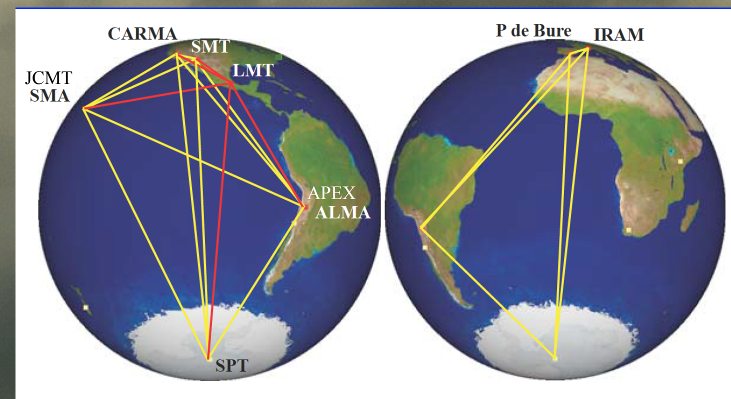
Large Millimeter Telescope Alfonso Serrano

- Mexico – USA collaboration: (INAOE, UMASS) - CONACYT Mega-Project
- World´s largest single-dish mm telescope; active 50-m LMT > 2017
- High-altitude site (4600m), Lat. +19 N
- λ = 0.85, 1.1, 1.4, 2.1 mm (Θ=4-11" FWHM)
- Shared-risk Early Science operations (as LMT 32-m > 2014) – 1mm imaging & 3mm spectroscopy; 3mm & 1.3mm VLBI
- LMT performance complements SKA, JVLA, ALMA, SPICA, JWST, TMT/GMT/ELT …. in coming decades

www.lmtgtm.org

The New York Times | SCIENCE

LMT (INAOE, UNAM-IRAF, UMASS) participates in Event Horizon Telescope



- 1.3mm VLBI image of SMBH in Gal. center & M87
- Black hole shadow size and shape encodes GR and the physics of black holes

Black Hole Hunters

Aiming to make the first portrait of the hungry monster at the center of our galaxy, astronomers built “a telescope as big as the world.”

June 8, 2015

http://www.nytimes.com/2015/06/09/science/black-hole-event-horizon-telescope.html

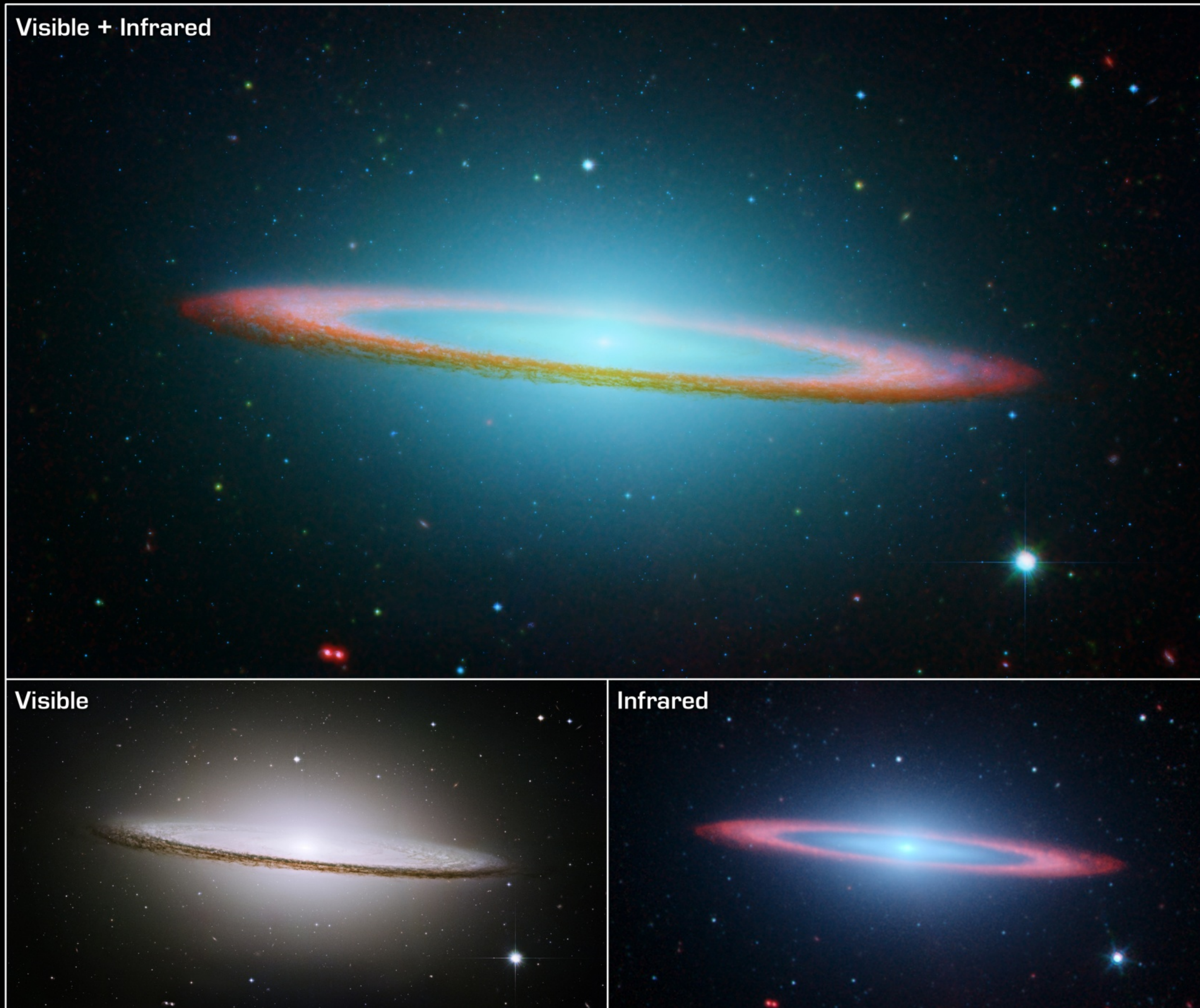
LMT scientific instruments

CURRENT

- AzTEC – 1.1mm 144 pixel continuum camera, mapping speed = 1 sq.deg / 1 mJy^2 / 100 hrs
- Redshift Search Receiver – dual polarization, dual-beam 3mm ultra-wideband (74-111 GHz, 37 GHz instaneous bandwidth, low-resolution 30 MHz) spectrometer, Tsys=100K
- 1.3mm VLBI receiver – "fast-track" development to participate in EHT, (fixed tuning to EHT frequency)

FUTURE

- SEQUOIA – 16 pixel 3mm spectrometer array, Tsys=100K
- 1.3mm facility-class VLBI receiver – (flexible in-band tuning)
- OMAR – One Millimeter Array Receiver (210-280 GHz, 8 dual-pol beams. (2 spectral modes: narrow band - 20 or 50MHz; wide band - 200, 400, or 800 MHz), Tsys = 150K
- TolTEC – 1.1, 1.4, 2.1mm (8000, 4000, 2000 pixels) continuum camera, simultaneous imaging, mapping speed at 1.1mm = 1400 sq. deg / $1mJy^2$ /100 hrs



Sombrero Galaxy/Messier 104

Spitzer Space Telescope • IRAC

Visible: Hubble Space Telescope/Hubble Heritage Team

NASA / JPL-Caltech / R. Kennicutt (University of Arizona), and the SINGS Team

ssc2005-11a


Jet
Magnetic field lines
Event horizon
Black hole
Accretion disk
Black hole
Accretion disk

NEW QUESTS IN STELLAR ASTROPHYSICS III: A PANCHROMATIC VIEW OF SOLAR-LIKE

Oral:

"Thanks to exoplanets, Sun-like stars have become important again"

Written:

"Thanks to transiting exoplanets, old stellar astronomers have become useful again"

D. Latham 2012

My version:

"Thanks to the discovery of IR excesses and exoplanets in main sequence stars, young and experienced astronomers, find in mature stars exciting targets"

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VOLUME 472

NEW QUESTS IN STELLAR ASTROPHYSICS III: A PANCHROMATIC VIEW OF SOLAR-LIKE STARS, WITH AND WITHOUT PLANETS

Edited by Miguel Chavez, Emanuele Bertone, Olga Vega, and Victor De la Luz

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Miguel Chavez, Emanuele Bertone,
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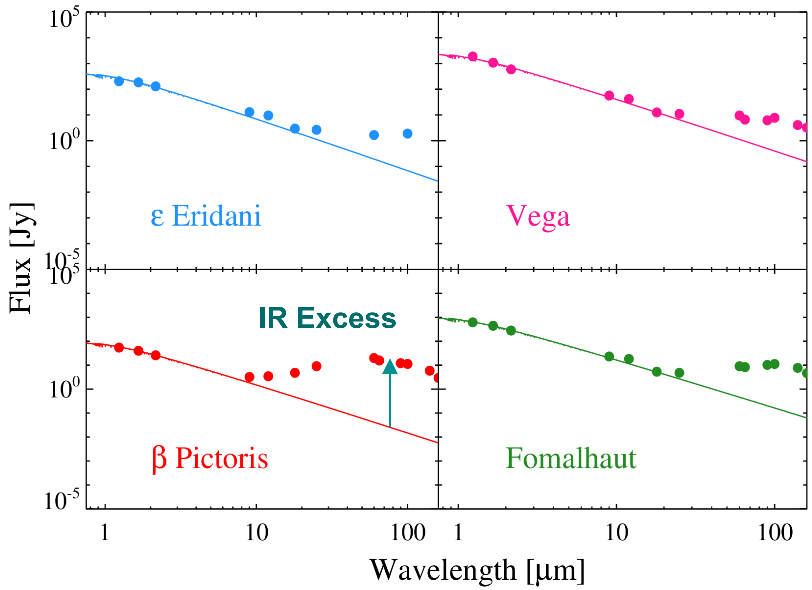
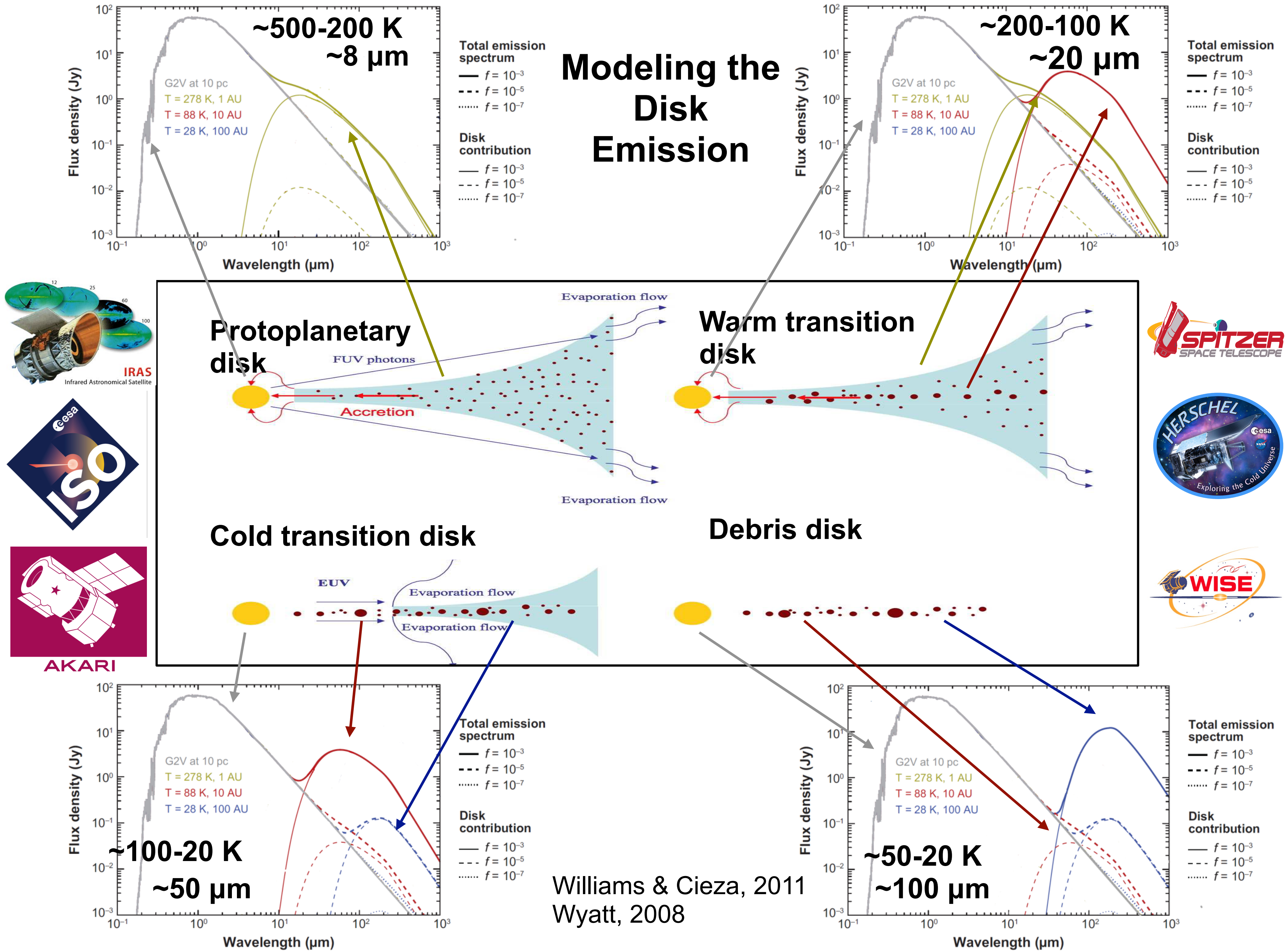
Study of Circumstellar (Debris) disks with the GTM/LMT



It all started with **Alpha-Lyrae** (Aumann et al. 1984). IRAS detected an IR excess well above the expected emission from the photosphere

Maximum emission at different wavelengths.
Different excess amplitudes.
Incidence: 20% in main sequence stars at MIR, FIR, and (sub)-mm wavelengths



Modeling the Disk Emission
~500-200 K
~8 μm
~200-100 K
~20 μm
~100-20 K
~50 μm
~50-20 K
~100 μm
Flux density (Jy)
Wavelength (μm)
G2V at 10 pc
T = 278 K, 1 AU
T = 88 K, 10 AU
T = 28 K, 100 AU
Total emission spectrum
f = 10−3
f = 10−5
f = 10−7
Disk contribution
f = 10−3
f = 10−5
f = 10−7
Protoplanetary disk
FUV photons
Accretion
Evaporation flow
Warm transition disk
Cold transition disk
EUV
Debris disk
IRAS
Infrared Astronomical Satellite
ISO
AKARI
SPITZER
SPACE TELESCOPE
HERSCHEL
Exploring the Cold Universe
WISE
Williams & Cieza, 2011
Wyatt, 2008

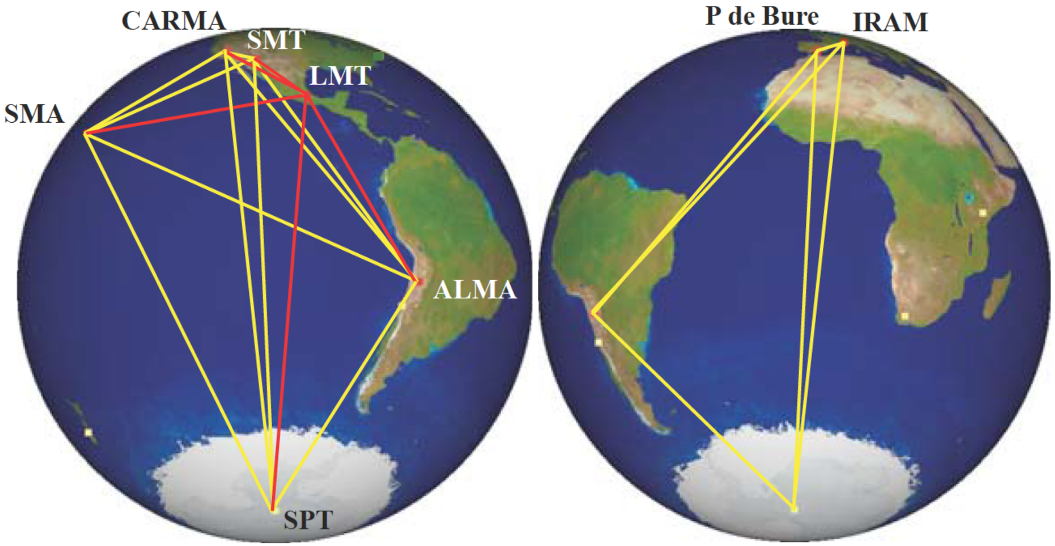
Oral: *"....the AzTEC camera's 6" beam at 1.1 mm will win over nearly all the images we have so far"*

Written: *"The future is exciting for submillimetre studies of debris discs. Not only has ALMA begun to show fine detail in some of the most famous systems, but the LMT is coming online in complementary wavebands. When the dish is complete, the resolution will for example be 6 arcseconds at 1.1 mm wavelength with the AzTEC camera. This is the same as the best achieved by Herschel, and ideal for giving a complete, detailed, high-fidelity images of nearby debris discs. "*

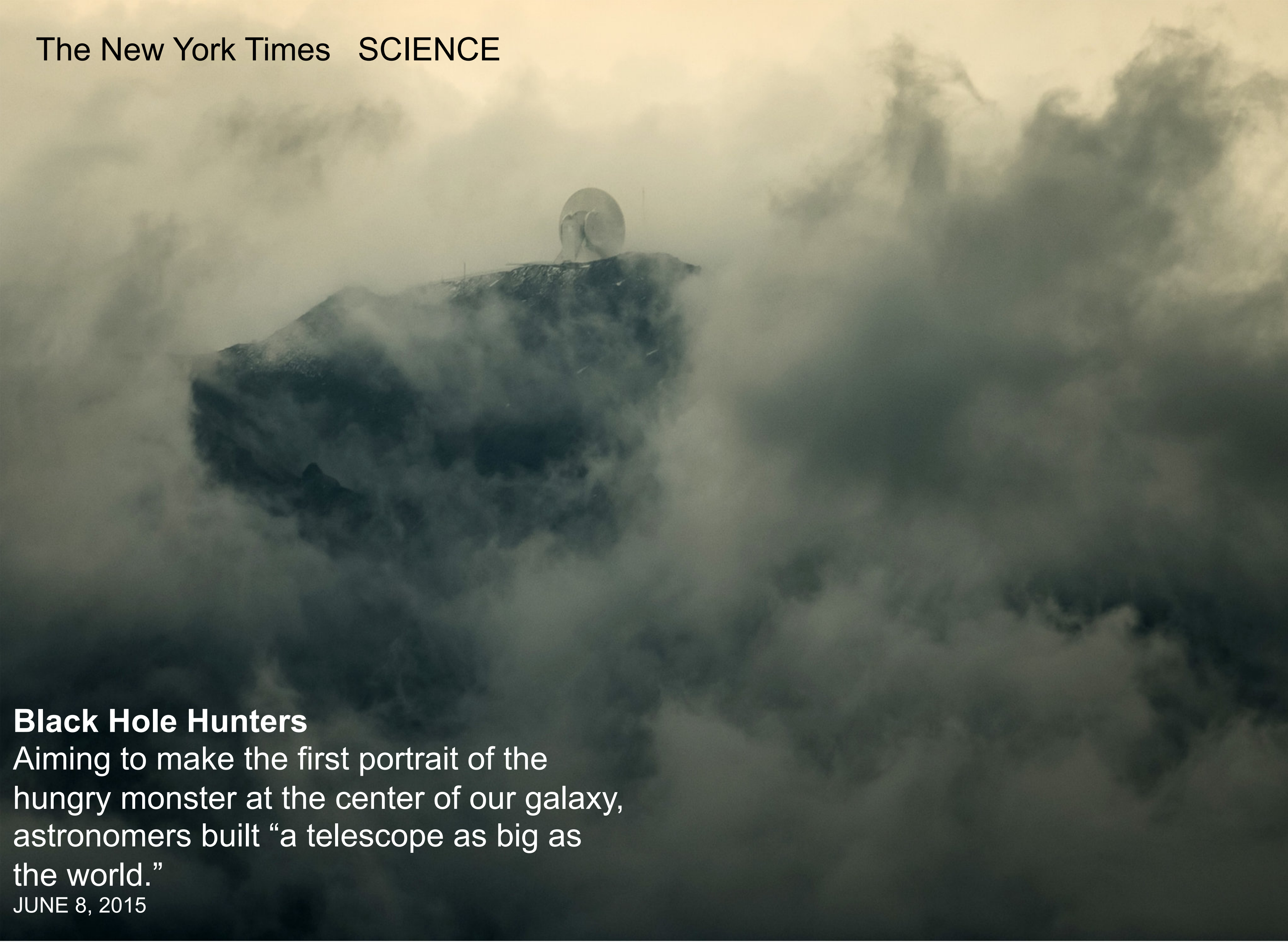
Gran Telescopio Milimétrico Alfonso Serrano

Informe

Event Horizon Telescope



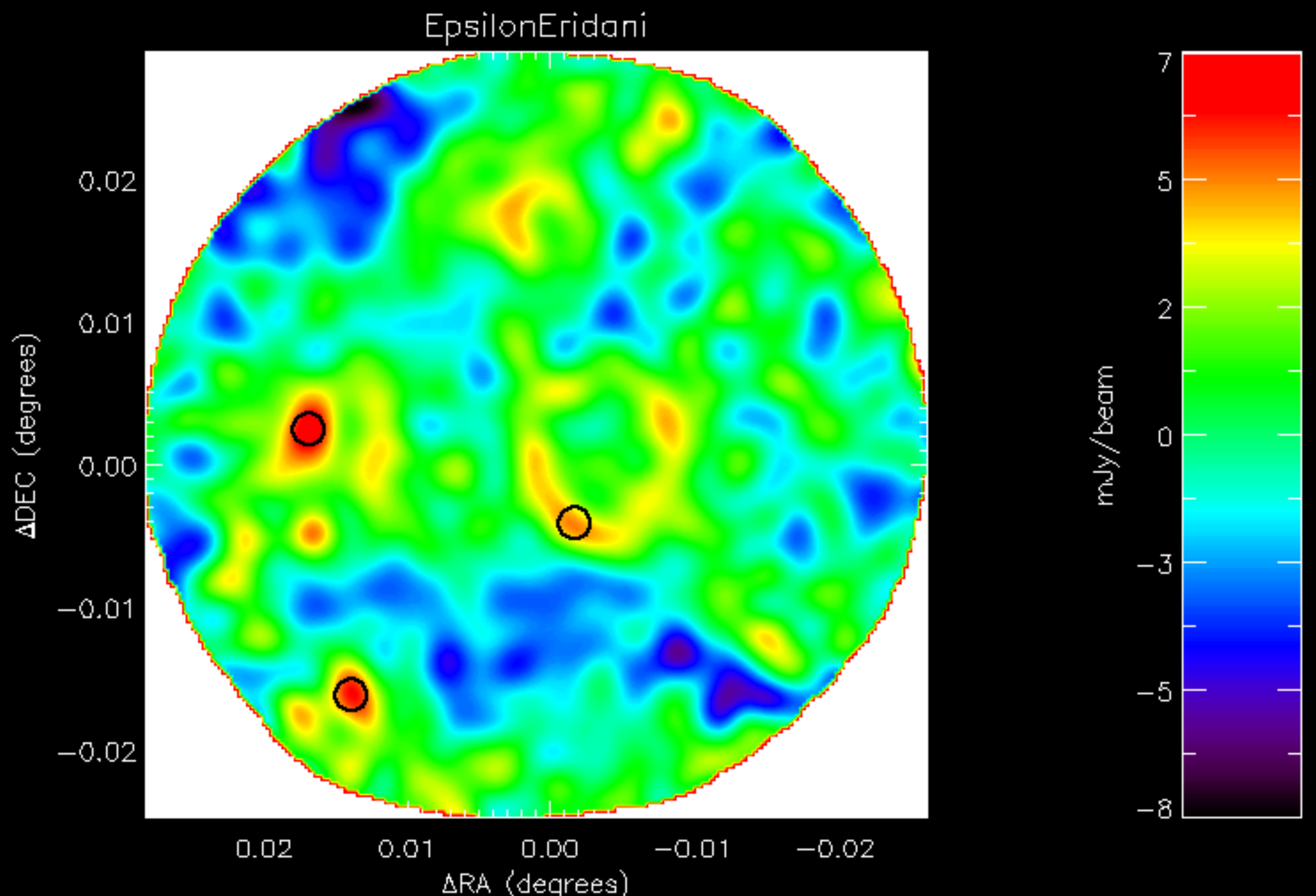
The New York Times   SCIENCE



Black Hole Hunters

Aiming to make the first portrait of the hungry monster at the center of our galaxy, astronomers built “a telescope as big as the world.”

JUNE 8, 2015


EpsilonEridani
ΔDEC (degrees)
0.02
0.01
0.00
−0.01
−0.02
ΔRA (degrees)
0.02
0.01
0.00
−0.01
−0.02
mJy/beam
7
5
2
0
−3
−5
−8

Acciones a realizar

- Completar el Plan de terminación del telescopio
  - Instalación del nuevo espejo secundario y su hexápodo (abril 2016)
  - Integración, alineación e instalación de los segmentos de los anillos 4 y 5 de la superficie primaria (diciembre 2016)
  - Fabricación y instalación del sistema activo de control de los segmentos de los anillos 4 y 5 (diciembre 2016)
- Operación científica del GTM de 50-m de diámetro
  - Lanzaremos la convocatoria en agosto 2016 para la temporada científica noviembre 2016 – junio 2017, solicitando observaciones con el GTM 50-m (en 2017)

Dinero requerido

- Inversión
  - 2015
    - Transferencia de los fondos asignados **$26.4 mdp** en 2015 a 2016 para la fabricación e instalación del sistema activo de control en anillos 4 y 5 de la superficie primaria
  - 2016
    - Inversión **$30 mdp** para hacer la mejora del sistema activo de control actual (336 actuadores) de los 3 anillos interiores
  - 2017
    - GTM ya en estado de operación como un telescopio de 50-m. Solicitudes de inversiónes futuras como es necesario para el mantenimiento, mejoras a la eficiencia operativa y desarrollo de nuevos instrumentos científicos a través de convocatoria apropriadas de CONACYT, NSF y de colaboraciones internacionales.

Productos academicos: Tecnológicos

Desarrollo de instrumentos cientificos del GTM

- diseño y fabricación de arreglos de detectores – tipo LEKIDS (lumped-element Kinetic Induction Devices) con sensibilidad a polarización
- Sistema criogénico de caracterización de detectores (LEKIDS, KIDS) de la nueva tecnología
- TolTEC y proto-tipo de TolTEC (arreglo de gran-formato – 17,000 pixeles, 1.1, 1.4, 2.1mm)
- SEQUOIA back-end electronics & readout – colaboración UMASS, INAOE con CRyA-UNAM, Morelia
- OMAR espectrógrafo (con fondos del NSF Advanced Technology Initiative - $1.5 M USD)
- Event Horizon Telescope – sistema VLBI á 1.3mm – nuevos instrumentos/ receptores, reloj atómico (maser), sistemas Mark 5C and Mark 6 para grabar los datos (con fondos del NSF Mid-Scale Innovation Program, $0.8M USD & € 1 M euros, E.U. Research Council)

otros

- MEGARA – Gran Telescopio de Canarias: sistema criogénico (opto-mecanicos)
- Sistema de visualización a frecuencias 0.1-1 THz para aplicaciones medicas

NEBULOSA OBSCURA: SACO DE CARBON (R. SULLIVAN, 1917, POP. ASTRONOMY, 24