EL GTM y La búsqueda de vida fuera de la Tierra

Dr. Miguel Chávez Dagostino

Investigador Titular C - Astrofísica INAOE
Responsable Científico del GTM - México

TCJ-CIMAT 2021

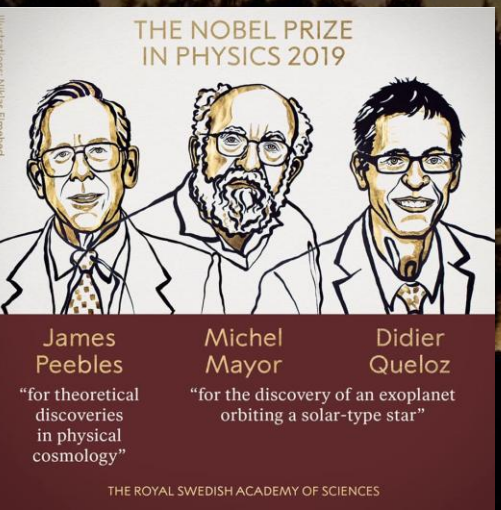
Nuestro sistema planetario:

8 planetas, 5 planetas enanos y mucho mas...

4410 planetas!

3253 sistemas planetarios múltiples

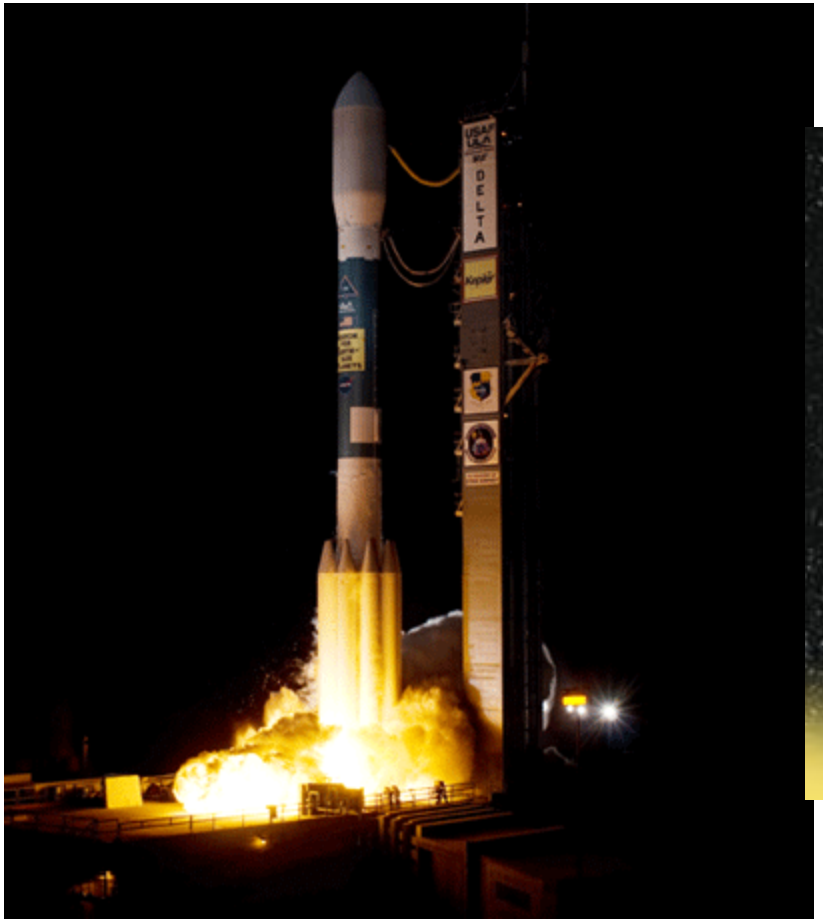
Hasta ayer!

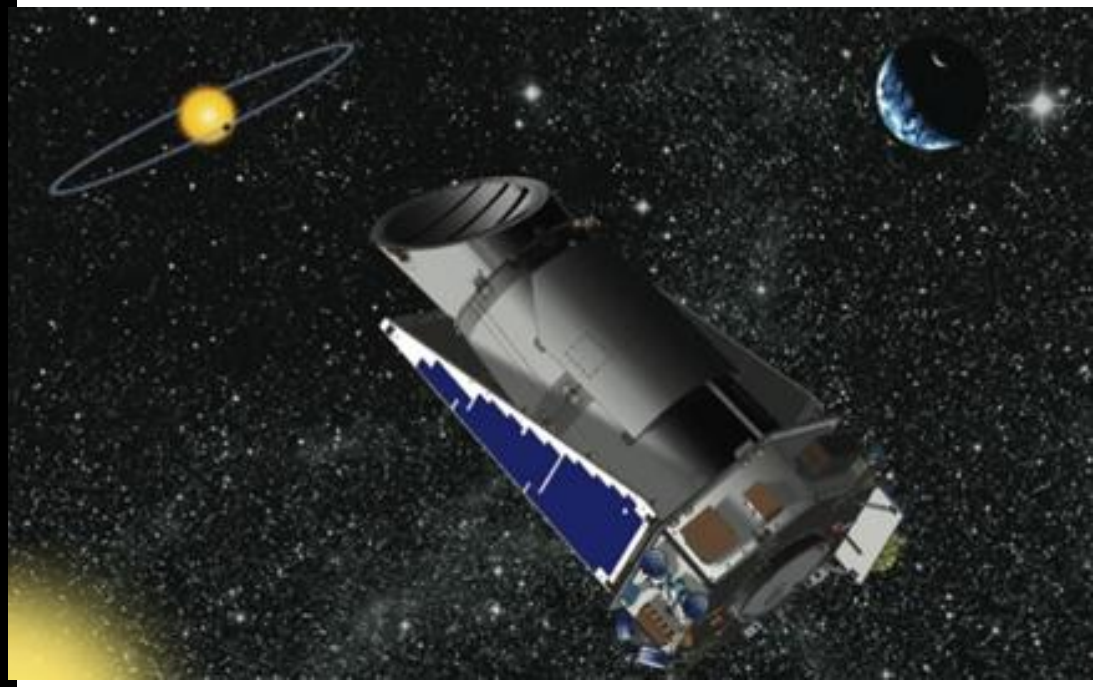


Michel Mayor & Didier Queloz
Geneva Observatory
Premio Nobel de Física 2019

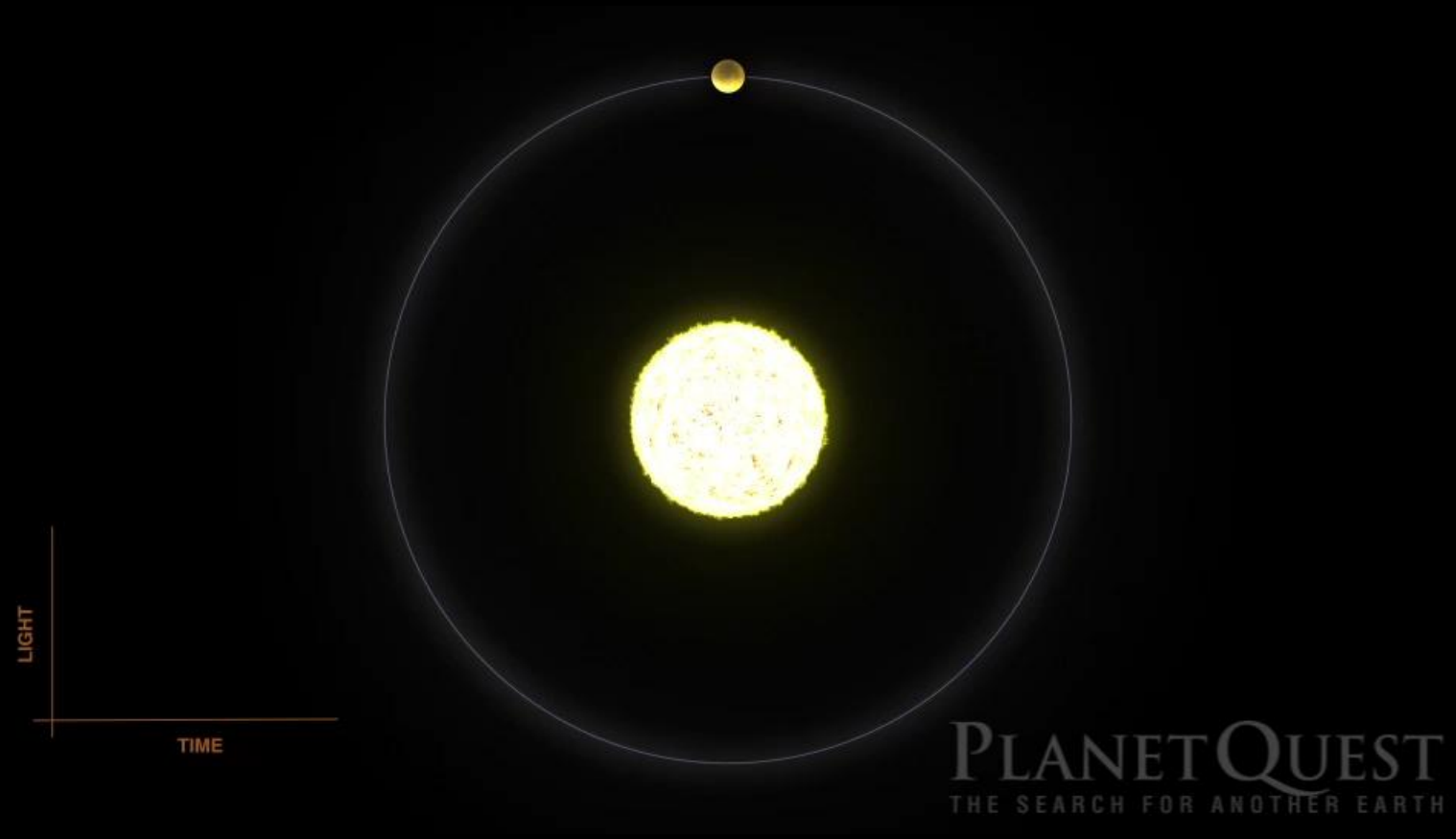
Tránsitos exoplanetarios y La misión Kepler (2009-2013, K2 continuación hasta 2018)

En búsqueda de planetas habitables

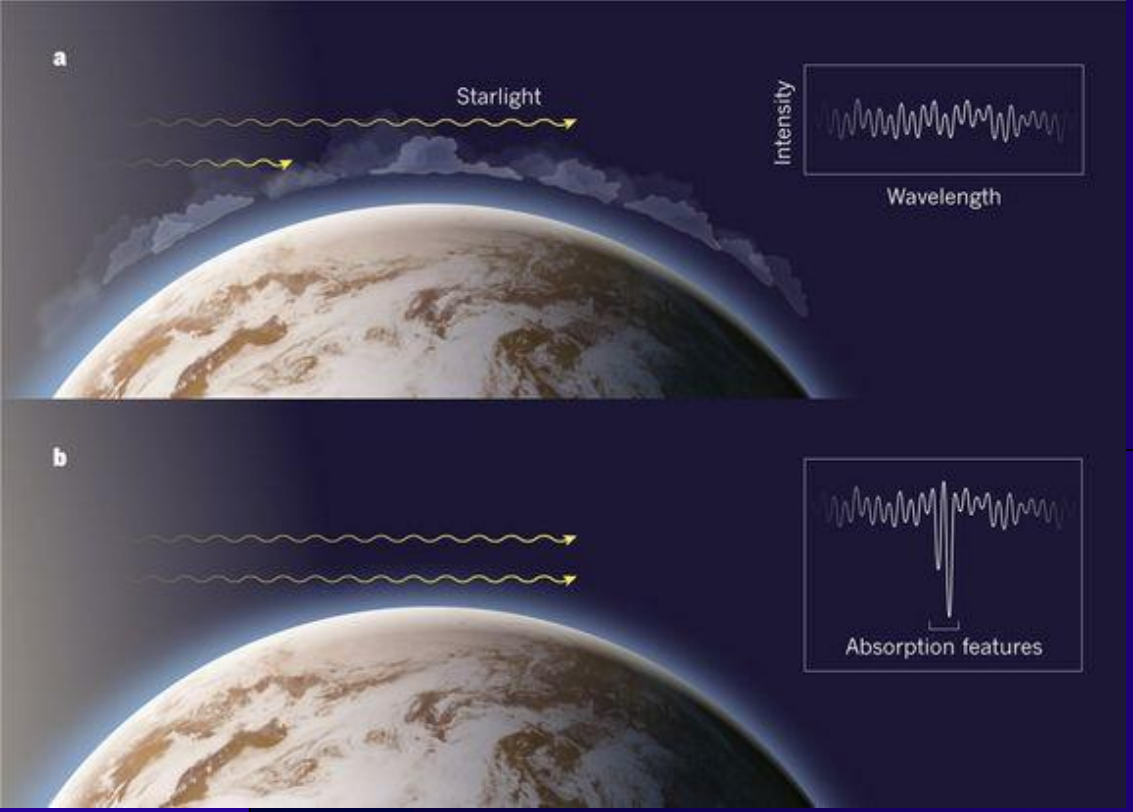


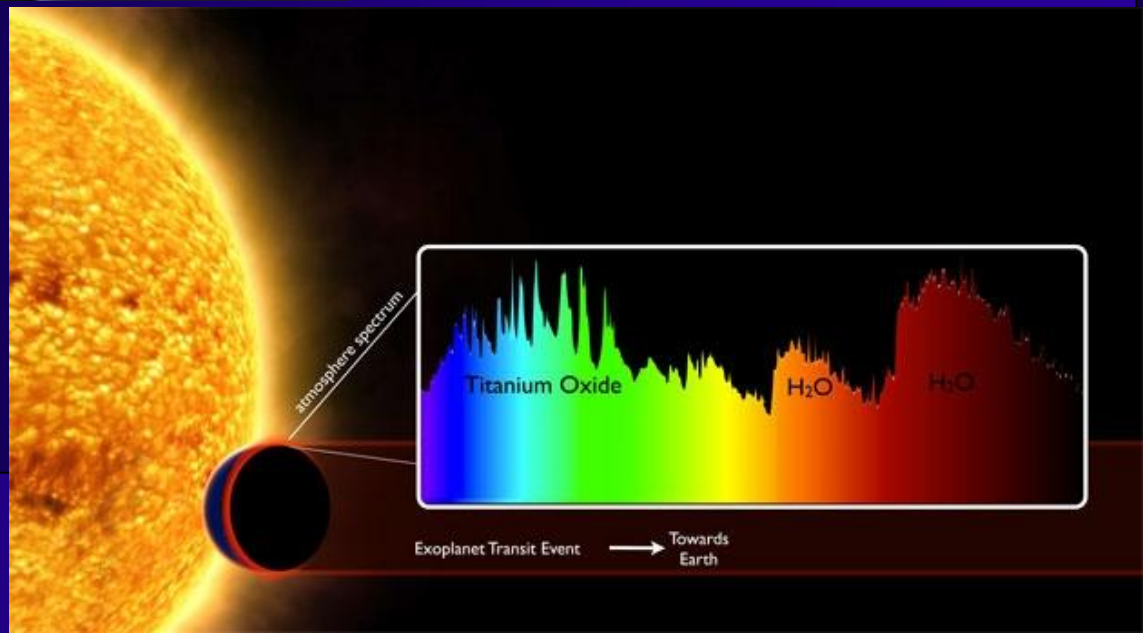


Tránsito: un planeta

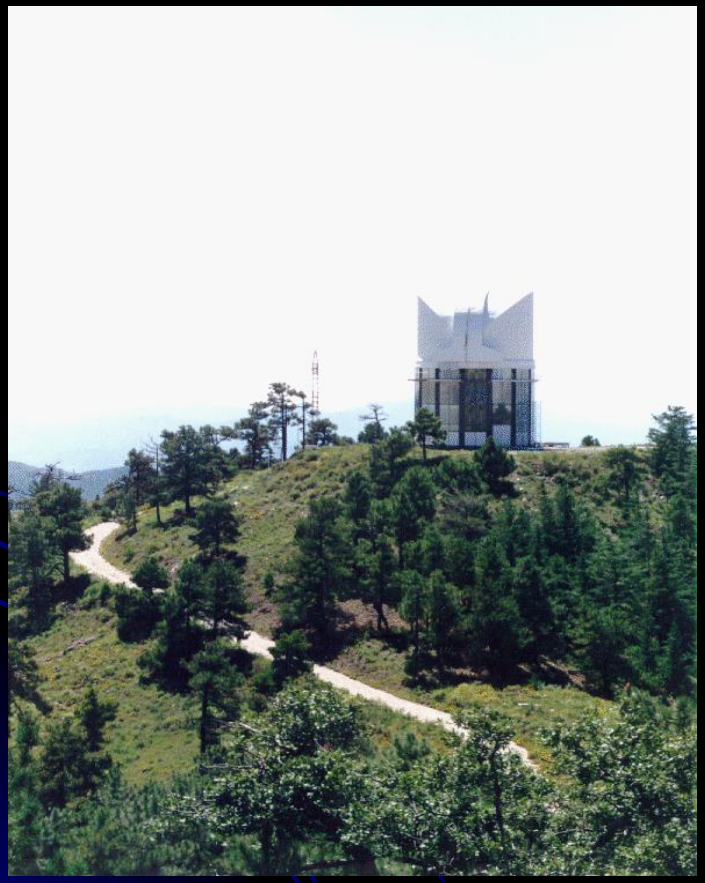


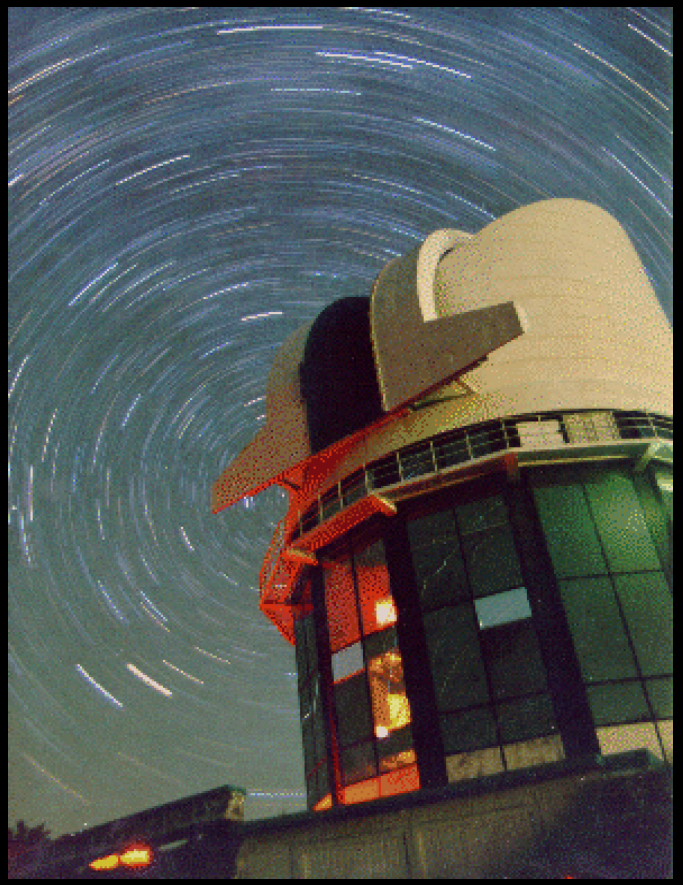
Espectroscopia de Transmisión



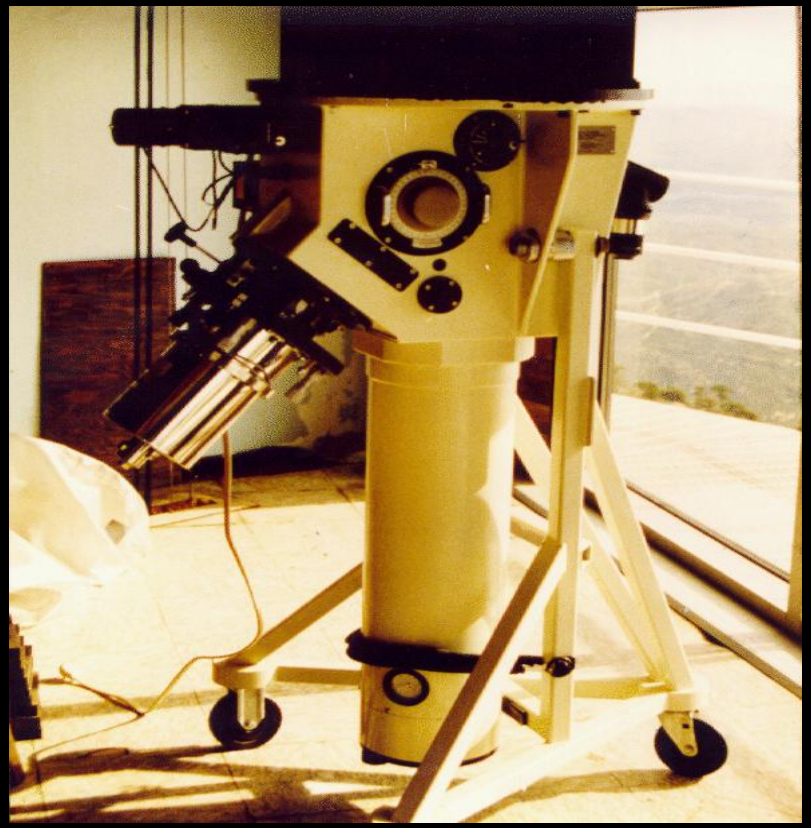


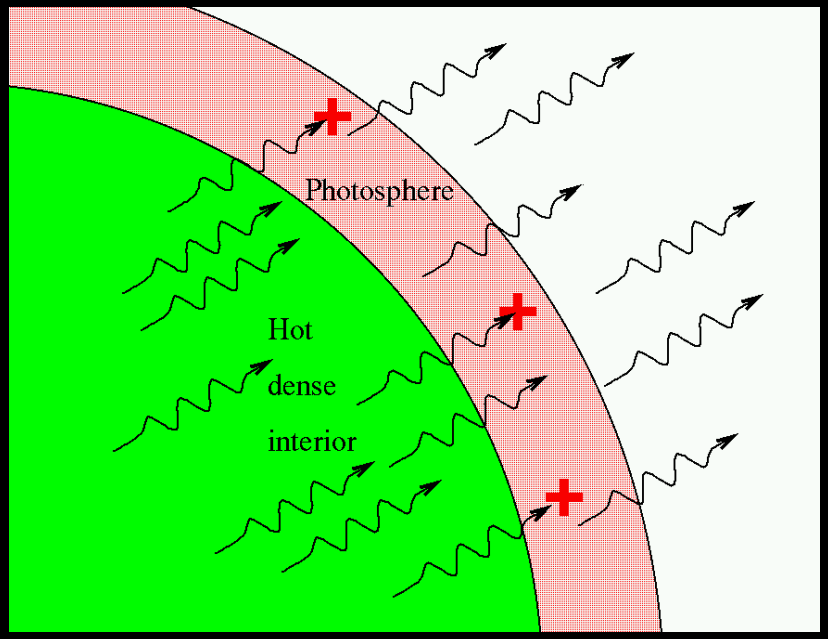
Observatorio GH operado por el INAOE en Cananea, Sonora

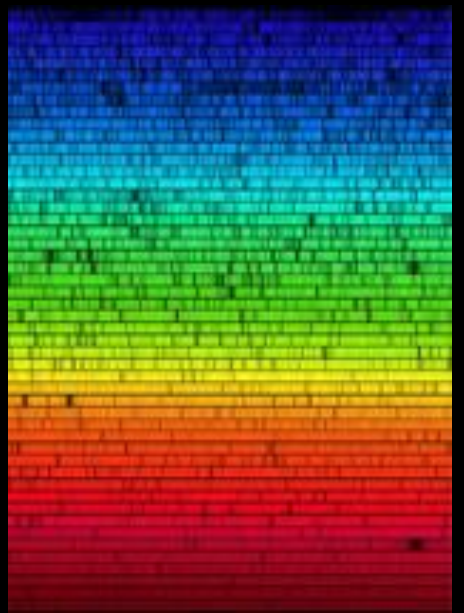




Espectroscopia



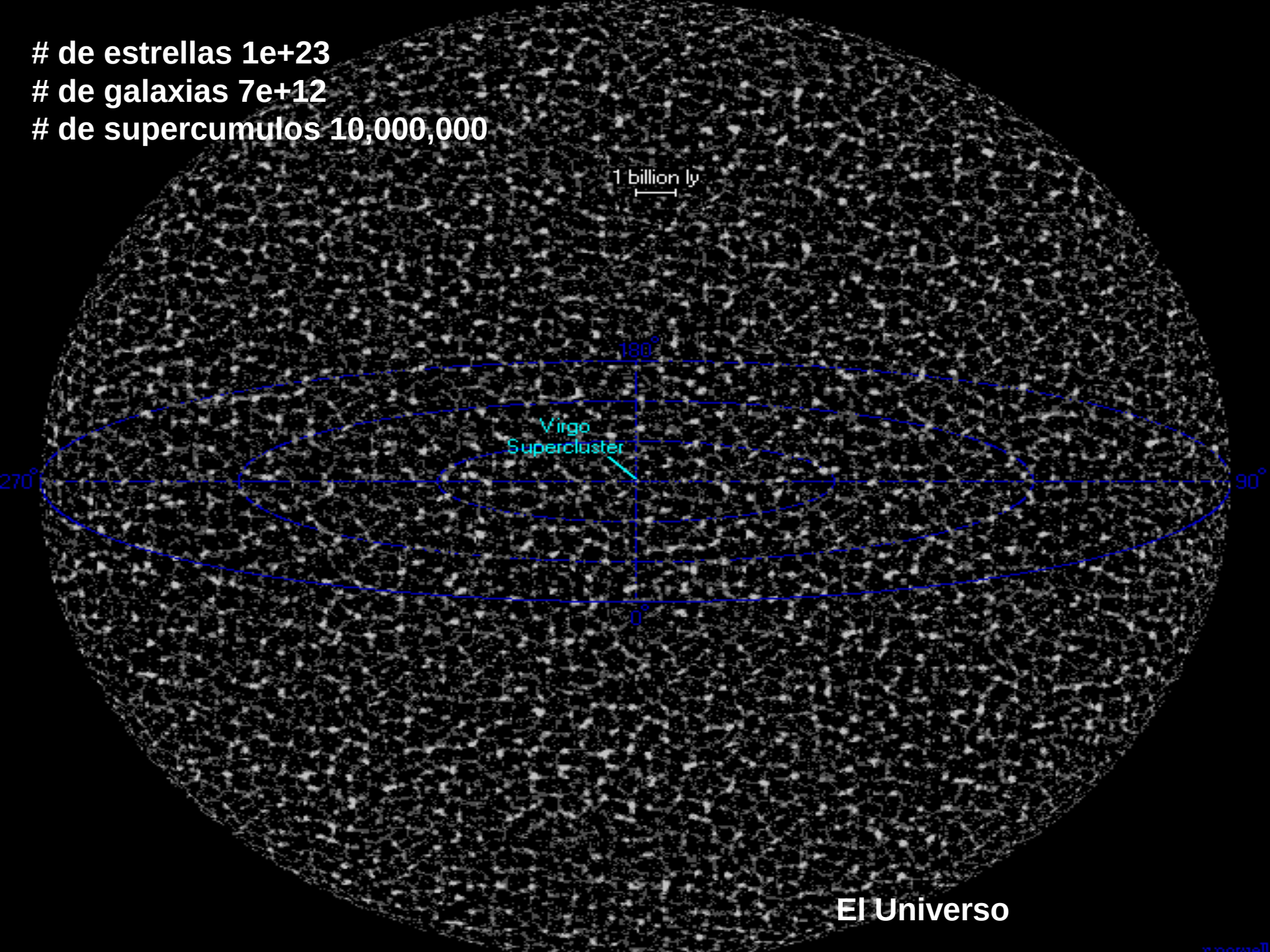

Photosphere
Hot
dense
interior



El caso de WASP-6b

Detection of Na, K, and H_2O in the hazy atmosphere of WASP-6b
(Carter et al. MNRAS, Abril 2020)

de estrellas 1e+23
de galaxias 7e+12
de supercumulos 10,000,000



El Universo

¿Qué es la Astrobiología?

La Astrobiología es la **ciencia** que estudia el origen, evolución y distribución de la vida en el universo. Integra conocimientos de la biología, física, química, astronomía y geología que nos permiten entender como surgió la vida en la Tierra, cómo evolucionó, la interacción entre el planeta y los organismos vivos, los procesos que dieron lugar a la formación de nuestro planeta, los lugares en el espacio dónde puede originarse la vida y las técnicas con las que podríamos detectar la presencia de vida en otros planetas.

1953: Exobiología (Marte) → **1995: Astrobiología**
1998: Instituto de Astrobiología de la NASA
2000-2002: SMCVE → **SOMA**

ADN: El código de la vida

Tabla periódica SIN estrellas

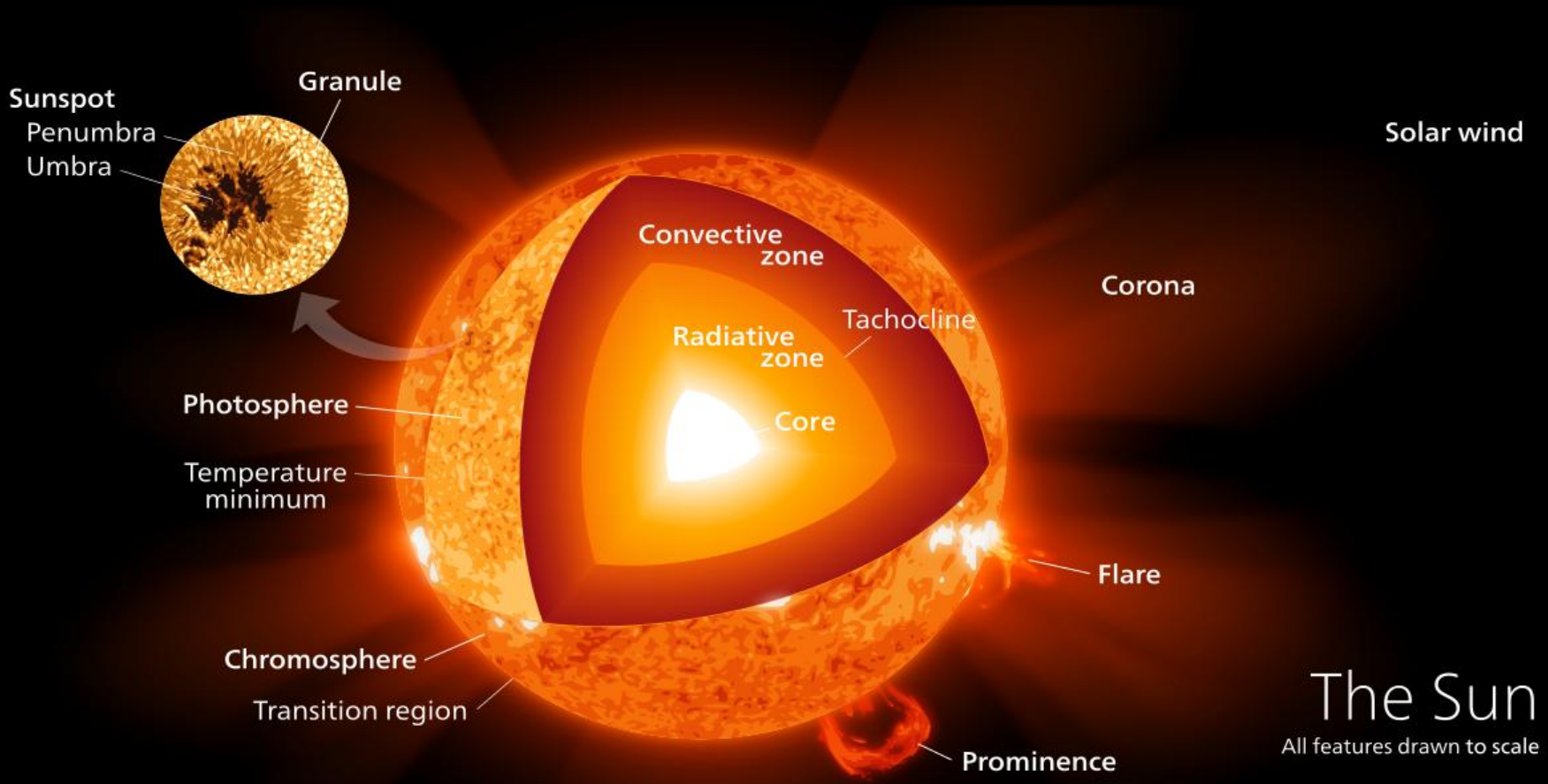
H	He	Li

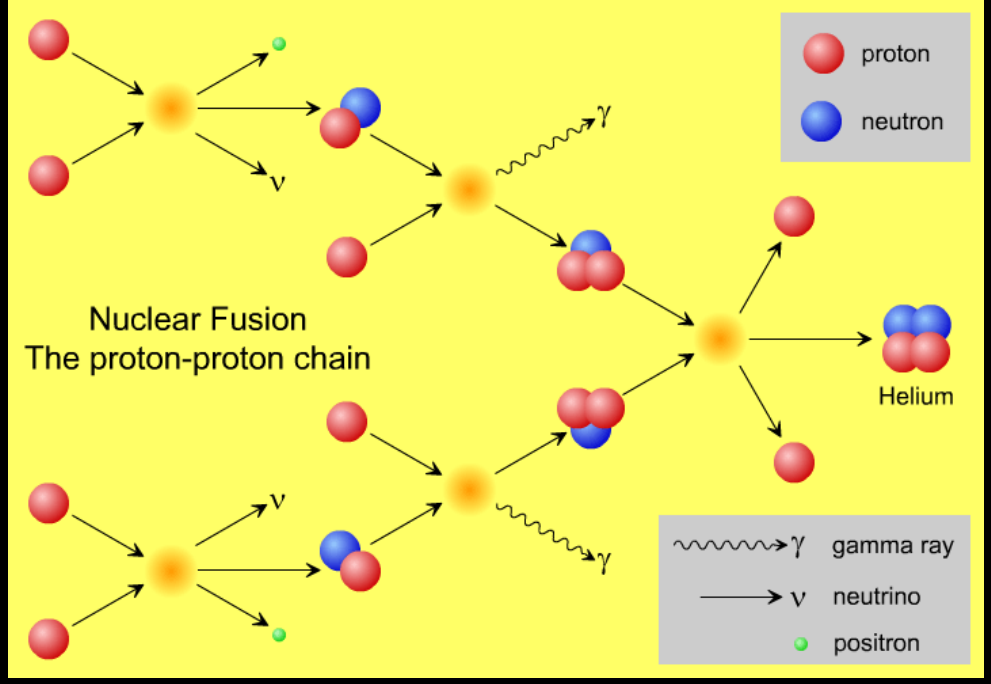
The Origin of the Solar System Elements

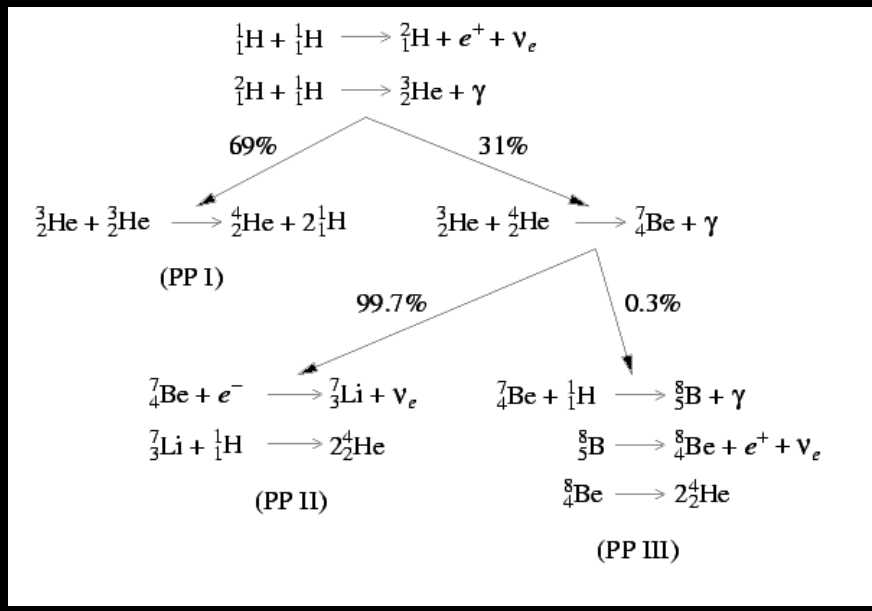
1 H		big bang fusion 					cosmic ray fission 										2 He
3 Li	4 Be	merging neutron stars 					exploding massive stars 					5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg	dying low mass stars 					exploding white dwarfs 					13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba		72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra																
			57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
			89 Ac	90 Th	91 Pa	92 U											

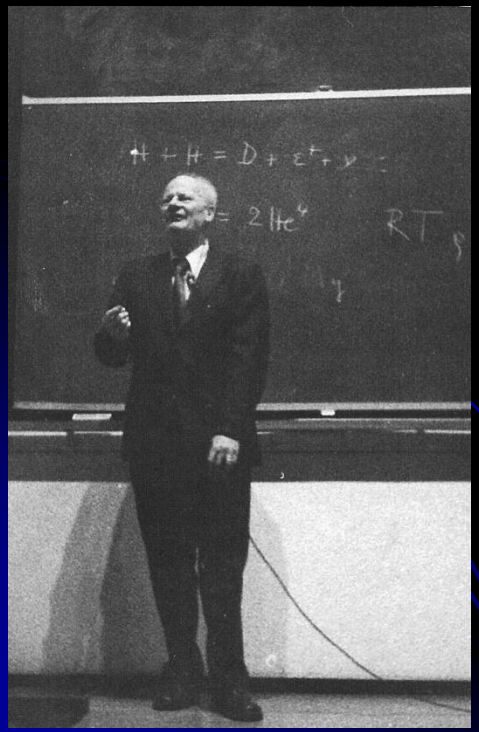
Energía nuclear

Interior solar ~ 14,000,000 K



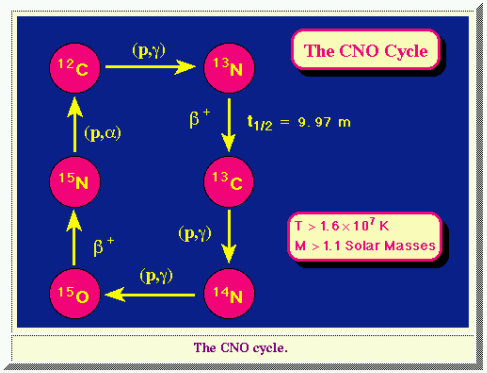






The Reactions of the CNO Cycle

In stars the primary constituents are hydrogen and helium, but there are usually (much) smaller amounts of heavier elements present. In particular there can be Carbon (C), Nitrogen (N), and Oxygen (O) ions. If these are present, they can participate in the sequence of reactions illustrated in the figure below.

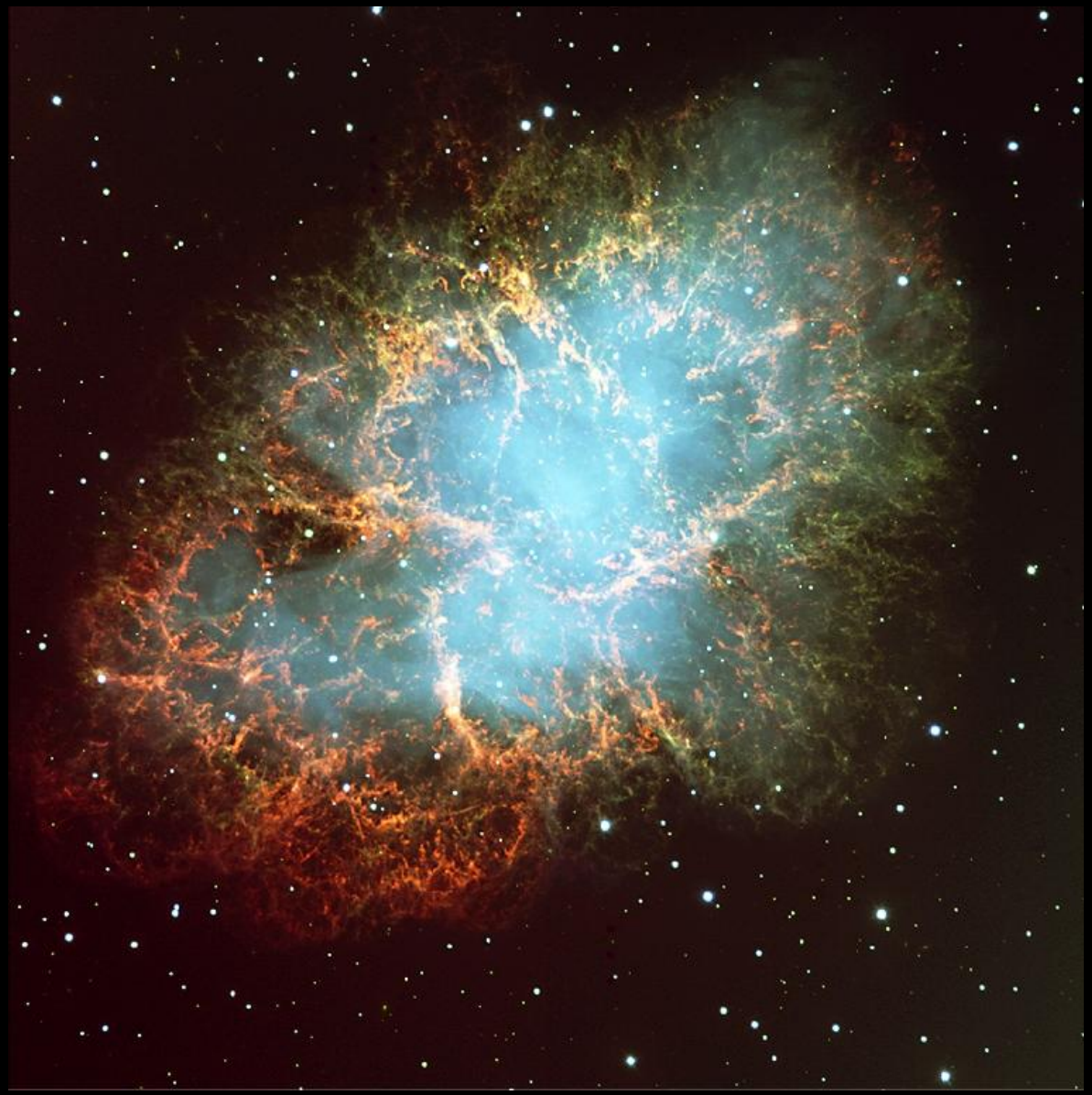


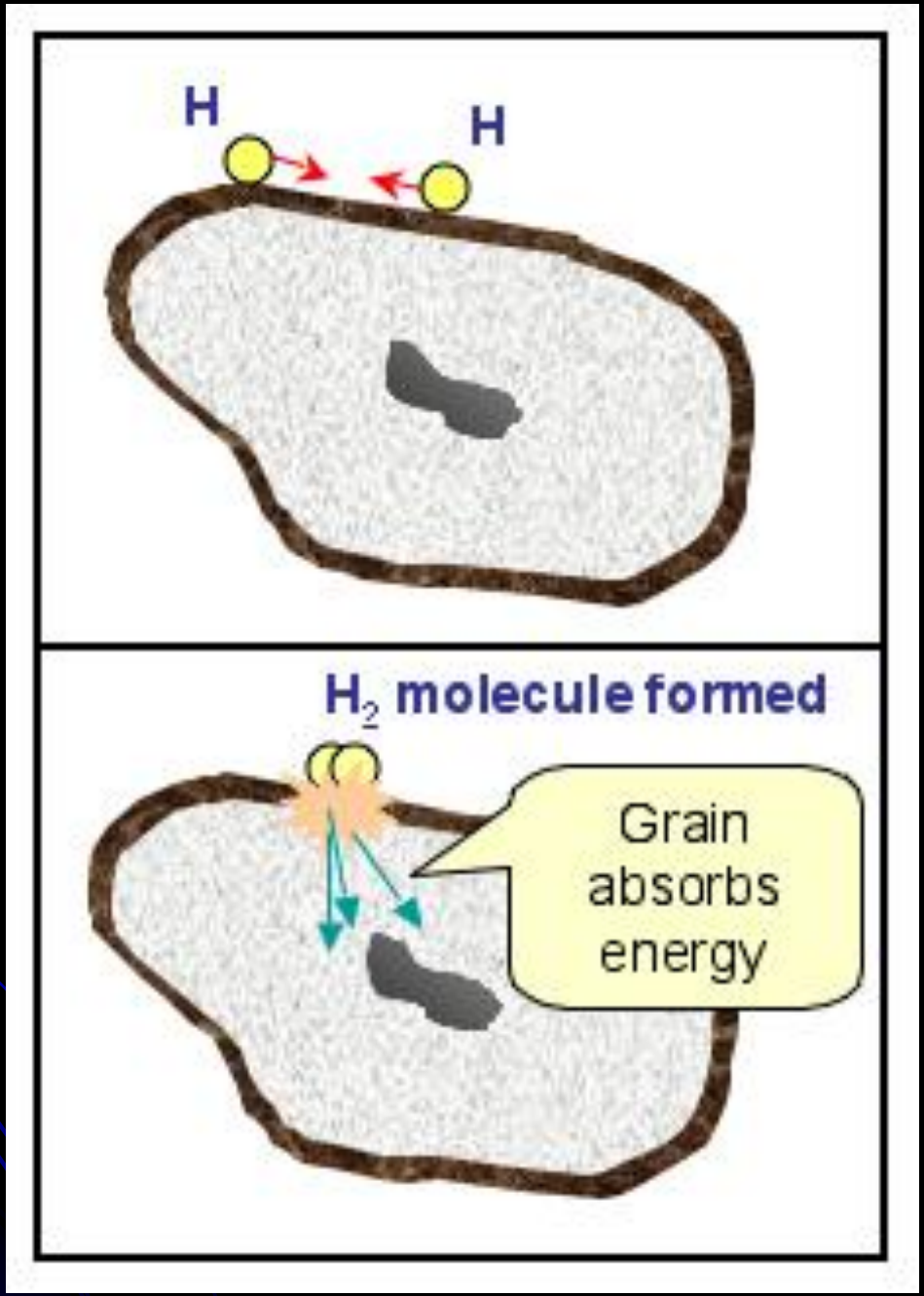
The CNO cycle.

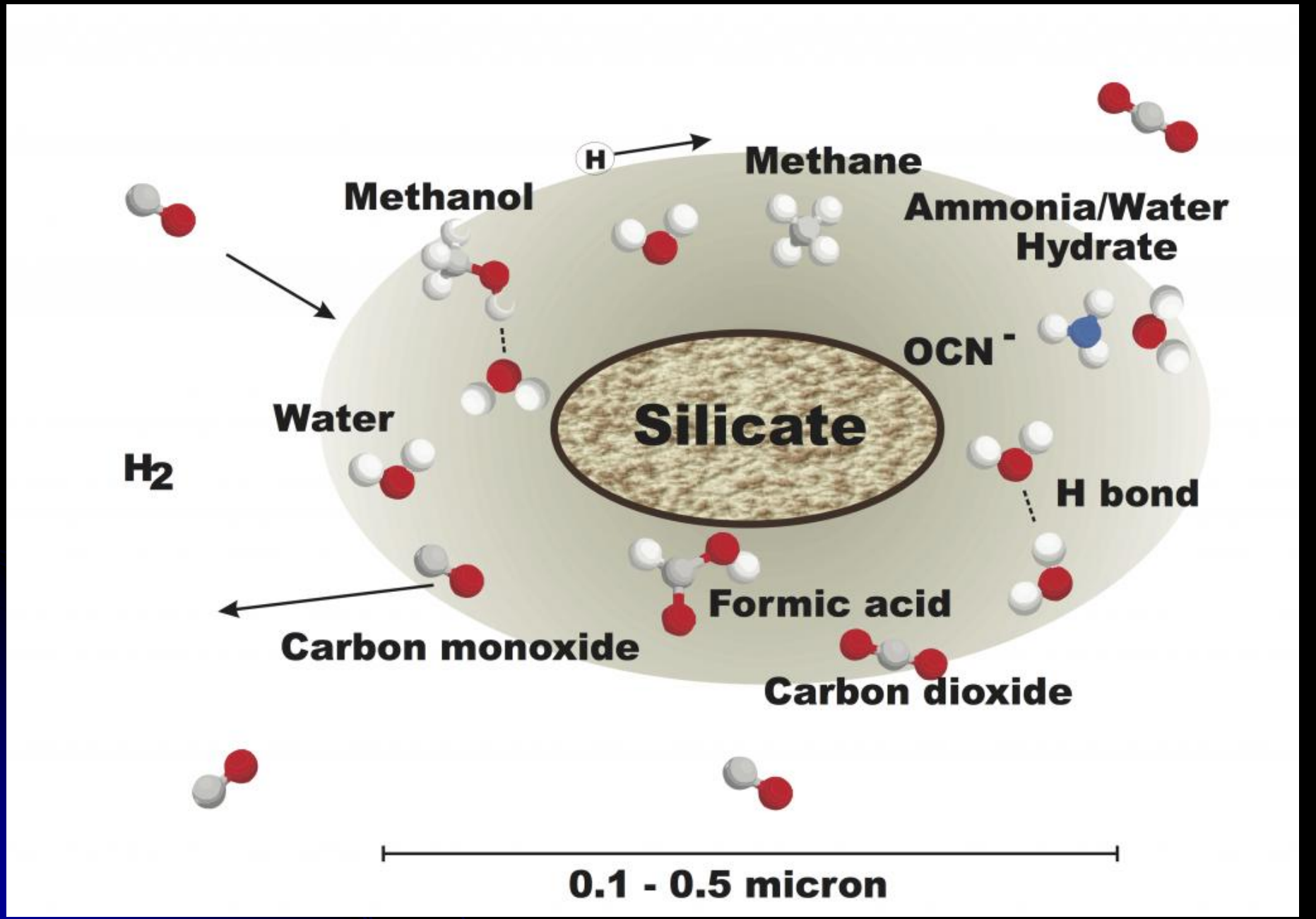
In this diagram beta+ indicates a beta decay and the notation (a,b) means that the nucleus captures the particle labeled by "a" and emits the particle labeled by "b".

G. Gamow
y el efecto tunel!

10^{-434} !

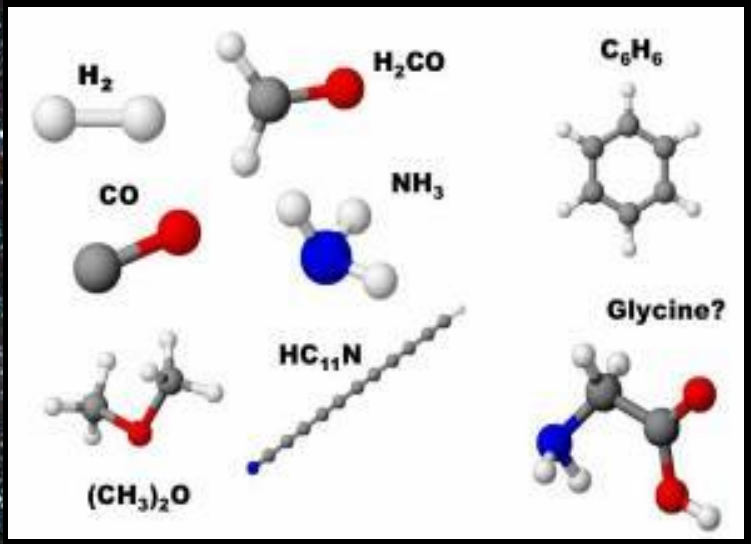



H
H
H_2 molecule formed
Grain absorbs energy


H
Methane
Methanol
Ammonia/Water
Hydrate
OCN -
Water
Silicate
H2
H bond
Formic acid
Carbon monoxide
Carbon dioxide
0.1 - 0.5 micron

Formación de estrellas; Mj

$$M_J = \left(\frac{5kT}{Gm}\right)^{3/2}\left(\frac{3}{4\pi\rho}\right)^{1/2}$$

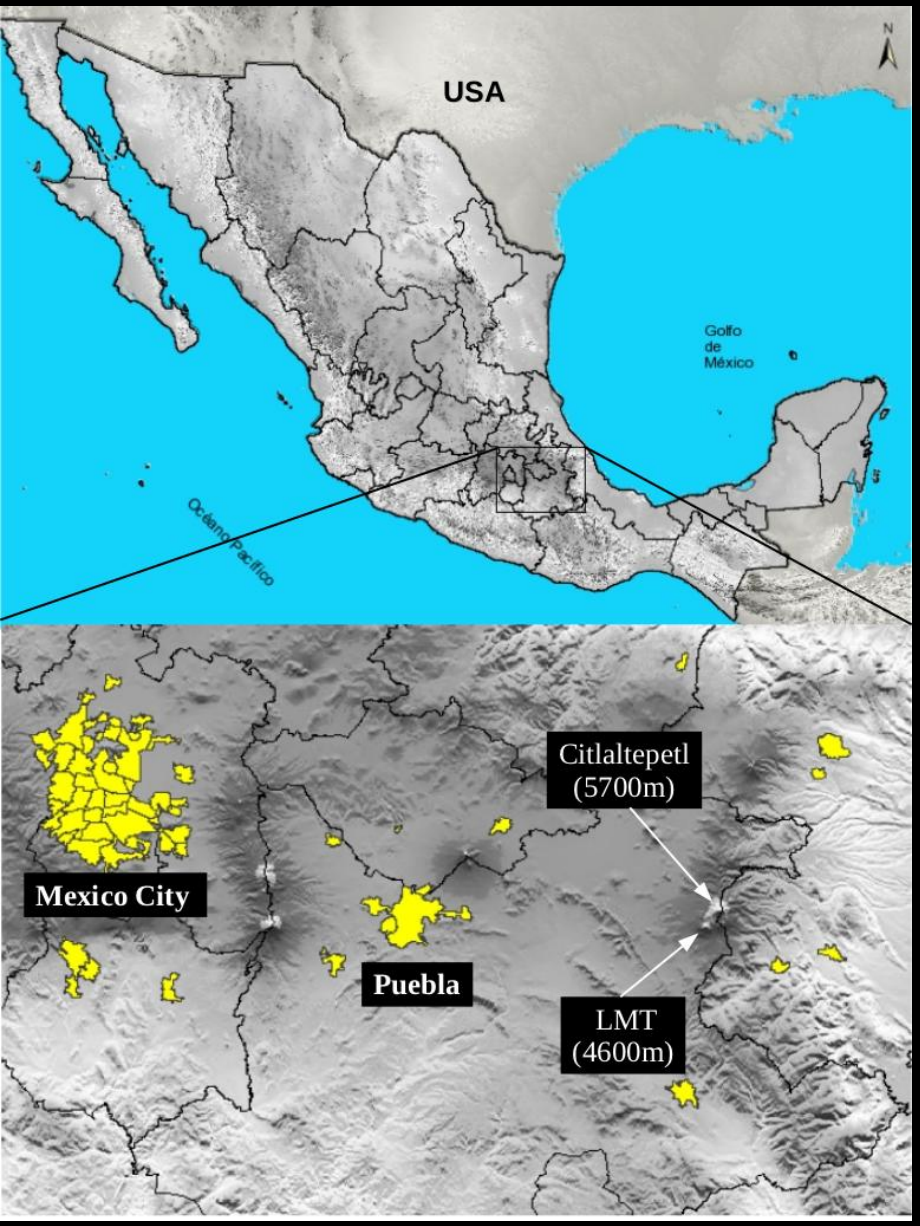


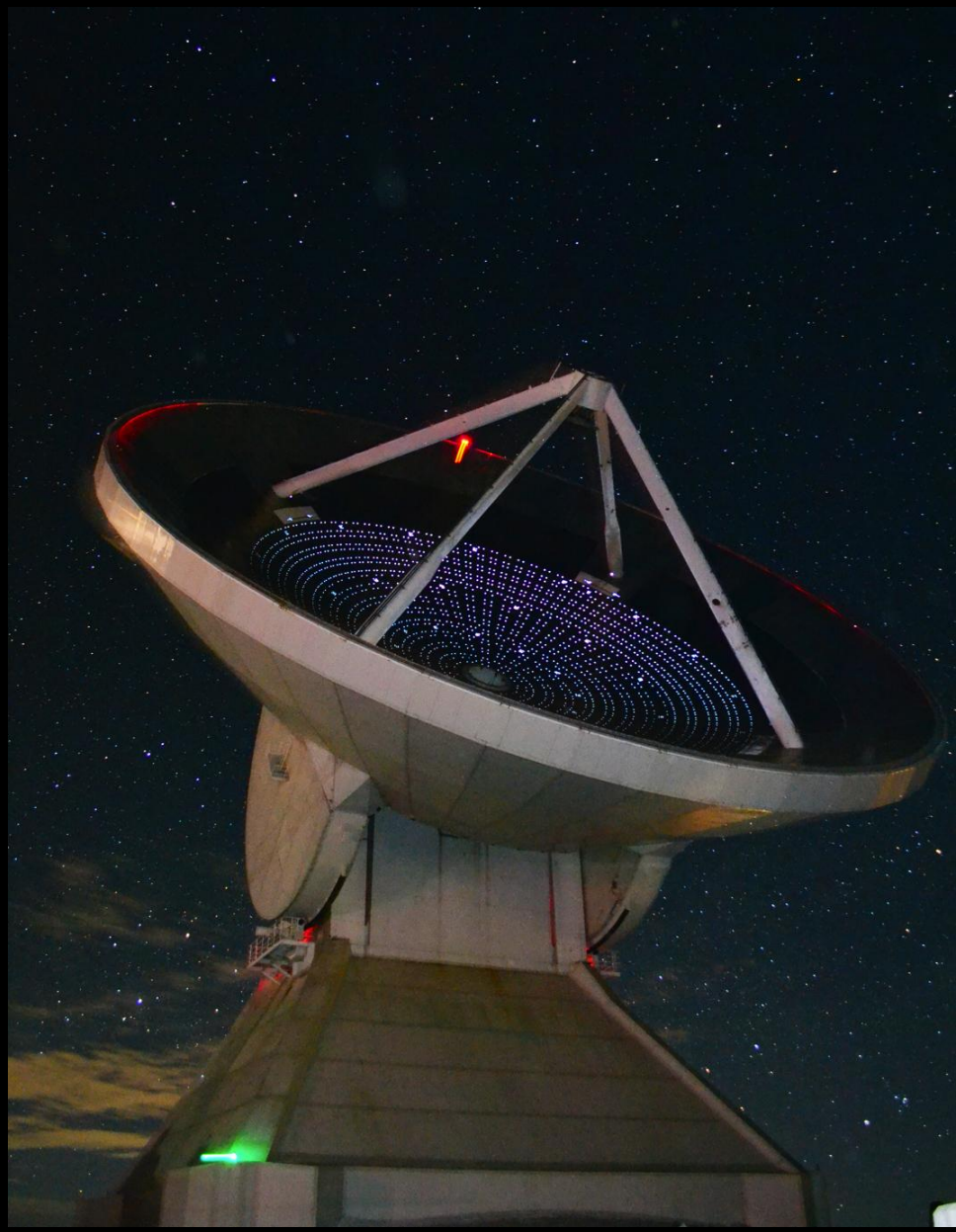
Las estrellas nacen en oscuras nubes moleculares gigantes

iCOMs en el medio interestelar

2 atoms		3 atoms		4 atoms	5 atoms	6 atoms	7 atoms	8 atoms	9 atoms	10 atoms	11 atoms	12 atoms	>12 atoms
H_2	HD	C_3^+	AlNC	C_3H	C_5	C_5H	C_6H	CH_3C_3N	CH_3C_4H	CH_3C_5N	HC_9N	C_6H_6	$HC_{11}N$
AlF	FeO	C_2H	SiNC	C_3N	C_4H	H_2C_4	CH_2CHCN	$HCOOCH_3$	CH_3CH_2CN	$(CH_3)_2CO$	CH_3C_6H	C_3H_7CN	C_{60}
AlCl	O_2	C_2O	HCP	C_3O	C_4Si	C_2H_4	CH_3C_2H	CH_3COOH	$(CH_3)_2O$	$(CH_2OH)_2$	C_2H_5OCHO	$C_2H_5OCH_3$	C_{70}
C_2	CF^+	C_2S	CCP	C_3S	C_3H_2	CH_3CN	HC_5N	C_7H	CH_3CH_2OH	CH_3CH_2CHO	CH_3OCOCH_3		C_{60}^+
CH	SiH	CH_2	AlOH	C_2H_2	H_2CCN	CH_3NC	CH_3CHO	C_6H_2	HC_7N	CH_3CHCH_2O			
CH^+	PO	HCN	H_2O^+	NH_3	CH_4	CH_3OH	CH_3NH_2	CH_2OHCHO	C_8H				
CN	AlO	HCO	H_2Cl^+	HCCN	HC_3N	CH_3SH	C_2H_4O	HC_6H	CH_3CONH_2				
CO	OH^+	HCO^+	KCN	$HCNH^+$	HC_2NC	HC_3NH^+	H_2CCHOH	CH_2CHCHO	C_8H^-				
CO^+	CN^-	HCS^+	FeCN	HNCO	HCOOH	HC_2CHO	C_6H^-	CH_2CCHCN	C_3H_6				
CP	SH^+	HOC^+	HO_2	HNCS	H_2CNH	NH_2CHO	CH_3NCO	H_2NCH_2CN	CH_3CH_2SH				
SiC	SH	H_2O	TiO_2	$HOCO^+$	H_2C_2O	C_5N		CH_3CHNH					
HCl	HCl	H_2S	C_2N	H_2CO	H_2NCN	HC_4H							
KCl	TiO	HNC	Si_2C	H_2CN	HNC_3	HC_4N							
NH	ArH	HNO		H_2CS	SiH_4	H_2C_3O							
NO	N_2	MgCN		H_3O^+	H_2COH^+	H_2CCNH							
NS	NO^+	MgNC		SiC_3	C_4H^-	C_5N^-							
NaCl		N_2H^+		CH_3	HCOCN	HNCHCN							
OH		N_2O		C_3N^-	HNCNH								
PN		NaCN		PH_3	CH_3O								
SO		OCS		HCNO	NH_4^+								
SO^+		SO_2		HOCN	H_2NCO^+								
SiN		SiC_2		HSCN	NCCNH$^+$								
SiO		CO_2		H_2O_2									
SiS		NH_2		C_3H^+									
CS		H_3^+		HMgNC									
HF		SiCN		HCCO									

El Gran Telescopio Milimétrico

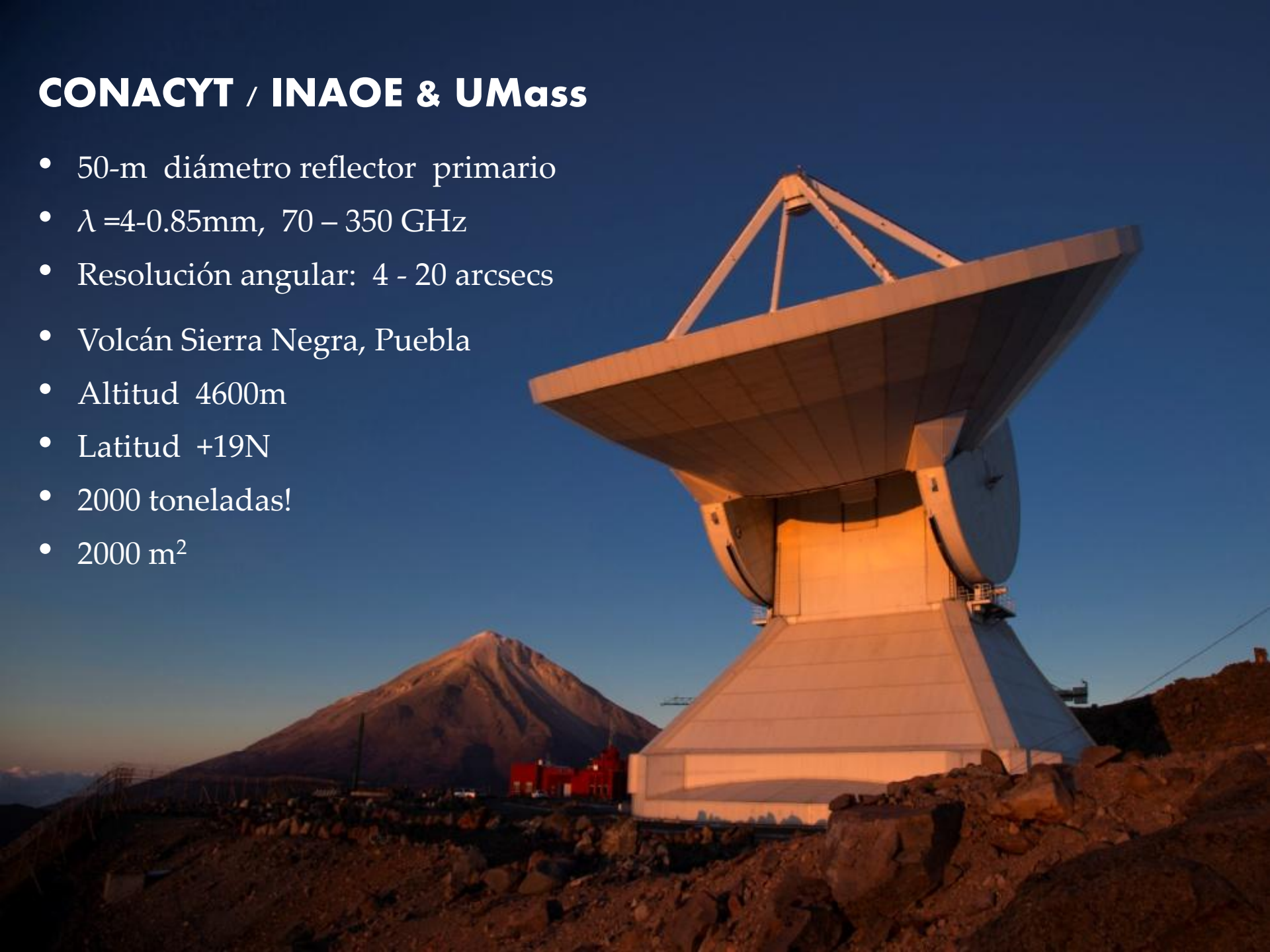




El GTM

CONACYT / INAOE & UMass

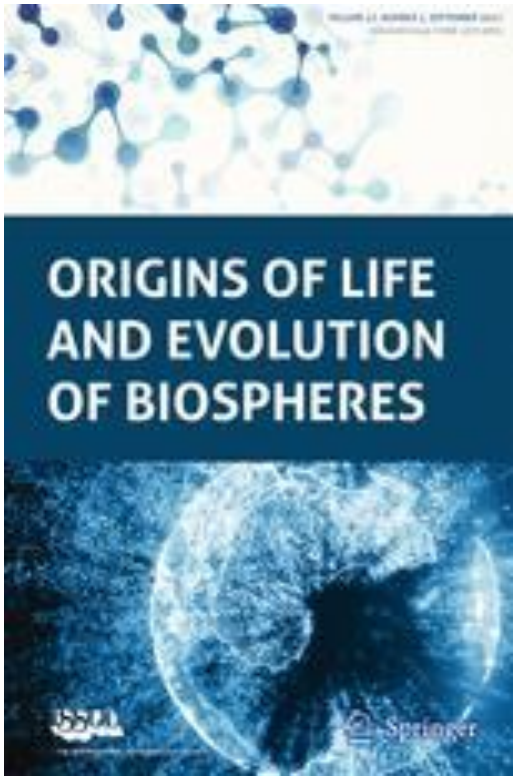
- 50-m diámetro reflector primario
- λ =4-0.85mm, 70 – 350 GHz
- Resolución angular: 4 - 20 arcsecs
- Volcán Sierra Negra, Puebla
- Altitud 4600m
- Latitud +19N
- 2000 toneladas!
- 2000 m^2



The Large Millimeter Telescope/El Gran Telescopio Milimétrico:

A New Instrument for Astrobiology

William M. Irvine et al. (2003)



67th International Astronautical Congress (IAC), Guadalajara, Mexico, 26-30 September 2016.

IAC-16-34015

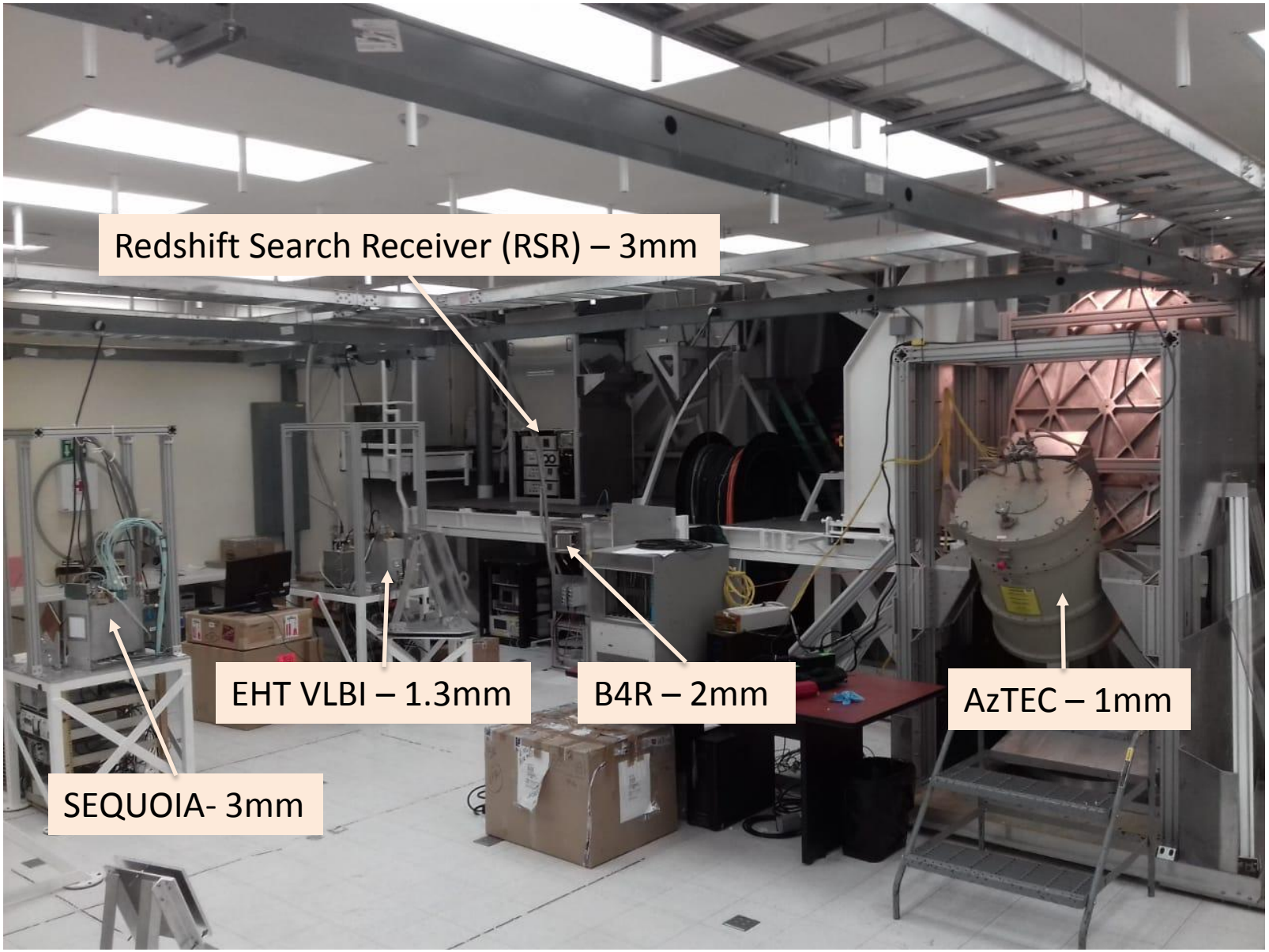
ASTROBIOLOGY WITH THE LARGE MILLIMETER TELESCOPE

Miguel Chávez Dagostino[a*], Arturo Gomez Ruiz[a], David Hughes[a], Min Yun[b], F. Peter Schloerb[b], Gopal Narayanan[b], Grant Wilson[b], David Gale[a]

[a] *Instituto Nacional de Astrofísica, Óptica y Electrónica, Luis Enrique Erro1, Santa María Tonantzintla, Puebla 72840, México*
[b] *Department of Astronomy University of Massachusetts, Amherst, MA 01003, United States of America*

* Corresponding Author (mchavez@inaoep.mx)

LMT Receiver Room (100 m^2)



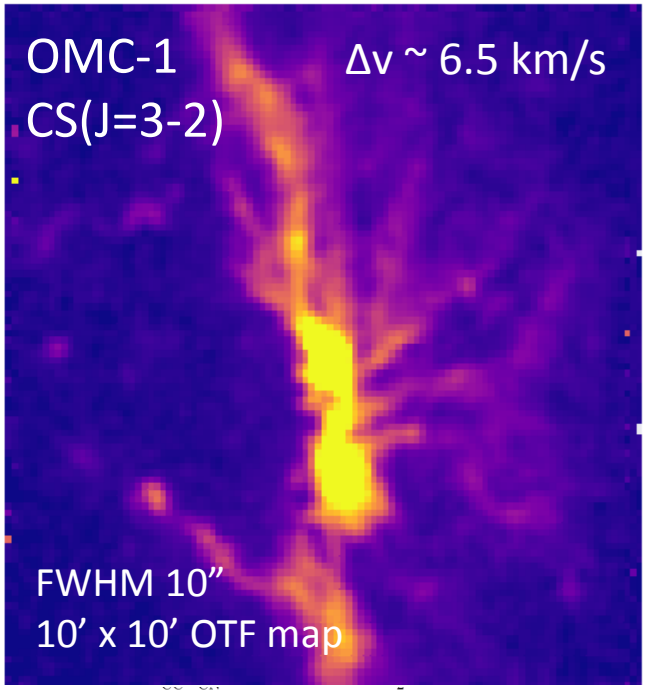
Molecule	Isotopomer or v-state	Number of Observed Transitions
SiS	SiS	2
	^{29}SiS	2
	^{30}SiS	2
	Si^{34}S	2
	Si^{33}S	2
	^{29}Si^{34}S	2
	^{30}Si^{34}S	1
	SiS $v = 1$	2
	SiS $v = 2$	2
	SiS $v = 3$	1
SiO	SiO	1
	^{29}SiO	1
	^{30}SiO	1
SiC	SiC	3
SiN	SiN	5
SiC_2	SiC_2	12
	SiC_2 $\nu_3 = 1$	2
	$^{29}SiC_2$	11
	$^{30}SiC_2$	8
	Si^{13}CC	16
SiC_3	SiC_3	5
ClNa	ClNa	4
	^{37}ClNa	2
ClK	ClK	4

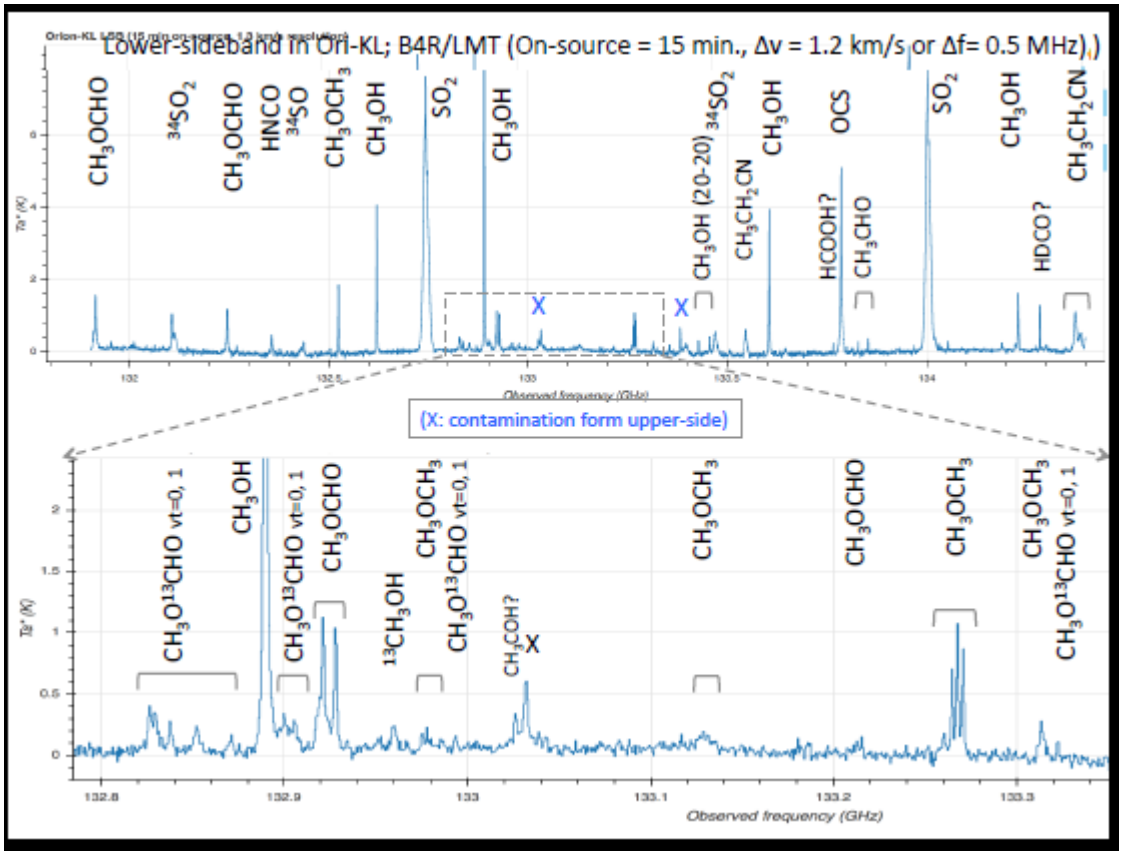
Molecule	Isotopomer or v-state	Number of Observed Transitions
CP	CP	4
PN	PN	1
CS	CS	1
	CS $v = 1$	1
	^{13}CS	1
	C^{34}S	1
	C^{33}S	1
	^{13}C^{34}S	1
C_2S	C_2S	8
C_3S	C_3S	5
	$C_3^{34}S$	1
H_2S	H_2S	1

B4R: 125 – 163 GHz

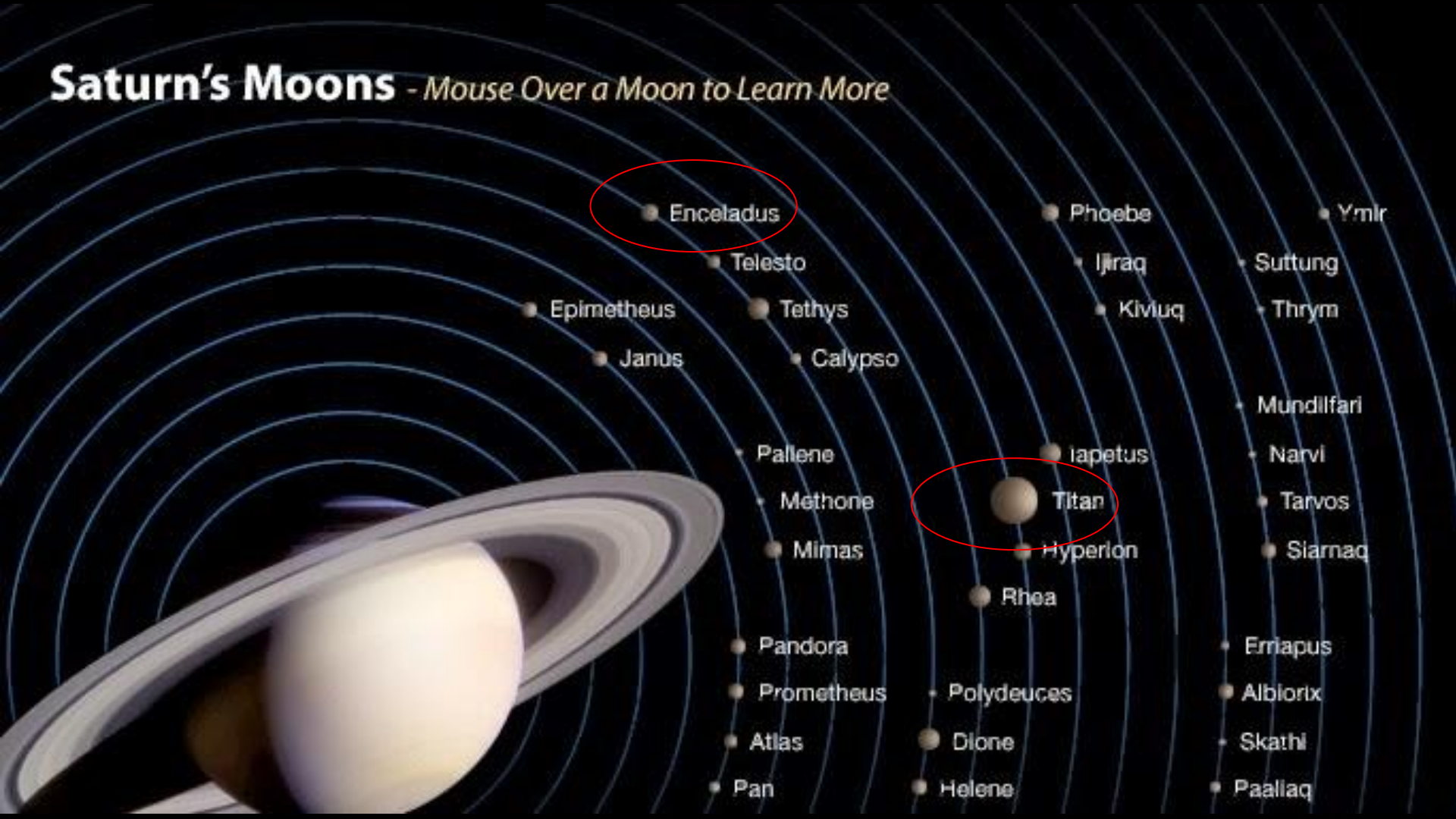
Resolution: 0.19 km/s or 88.5 KHz at 140 GHz.

Velocity-Integrated Intensity Map

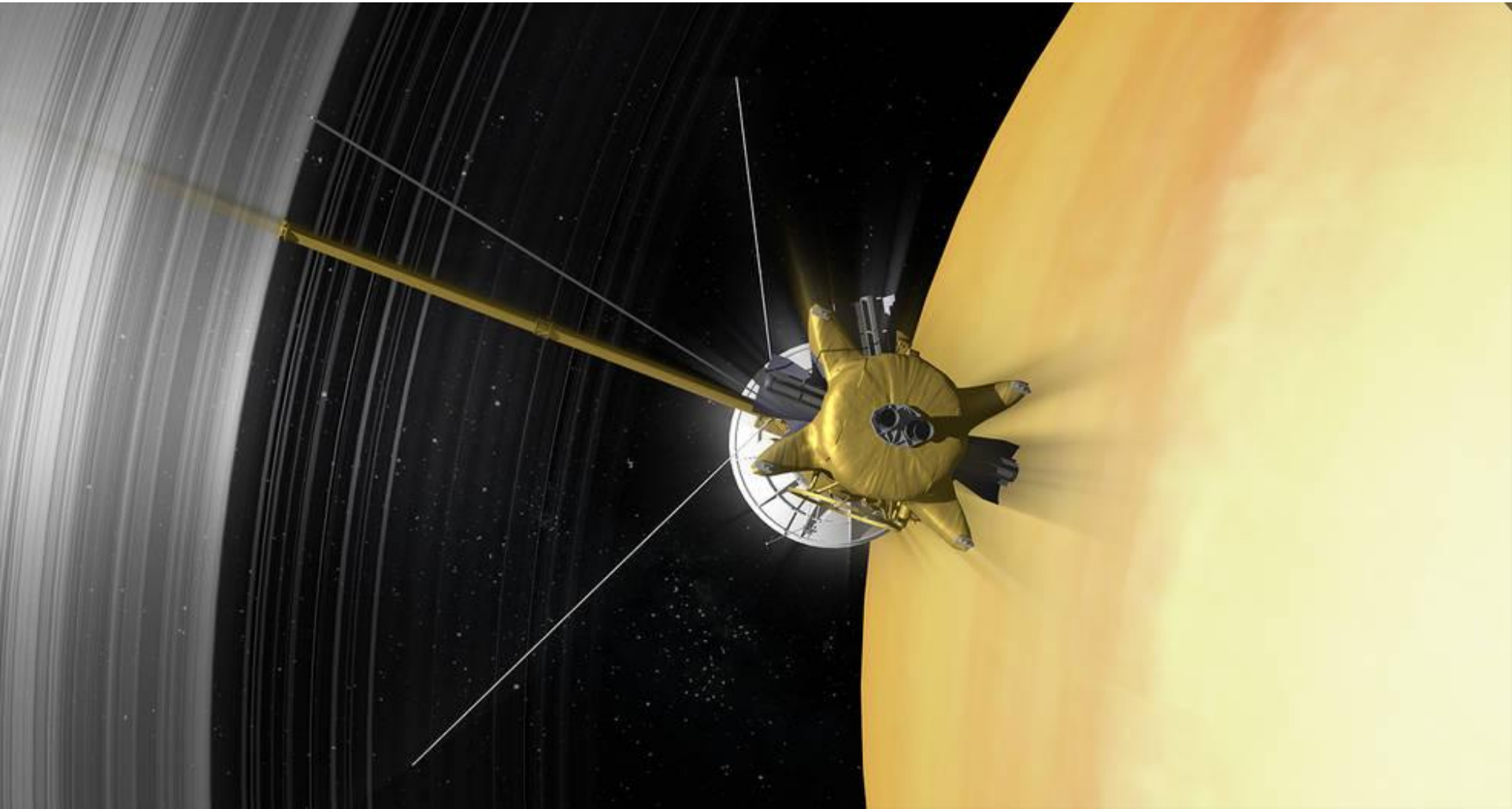




La familia de Saturno (+62 lunas)



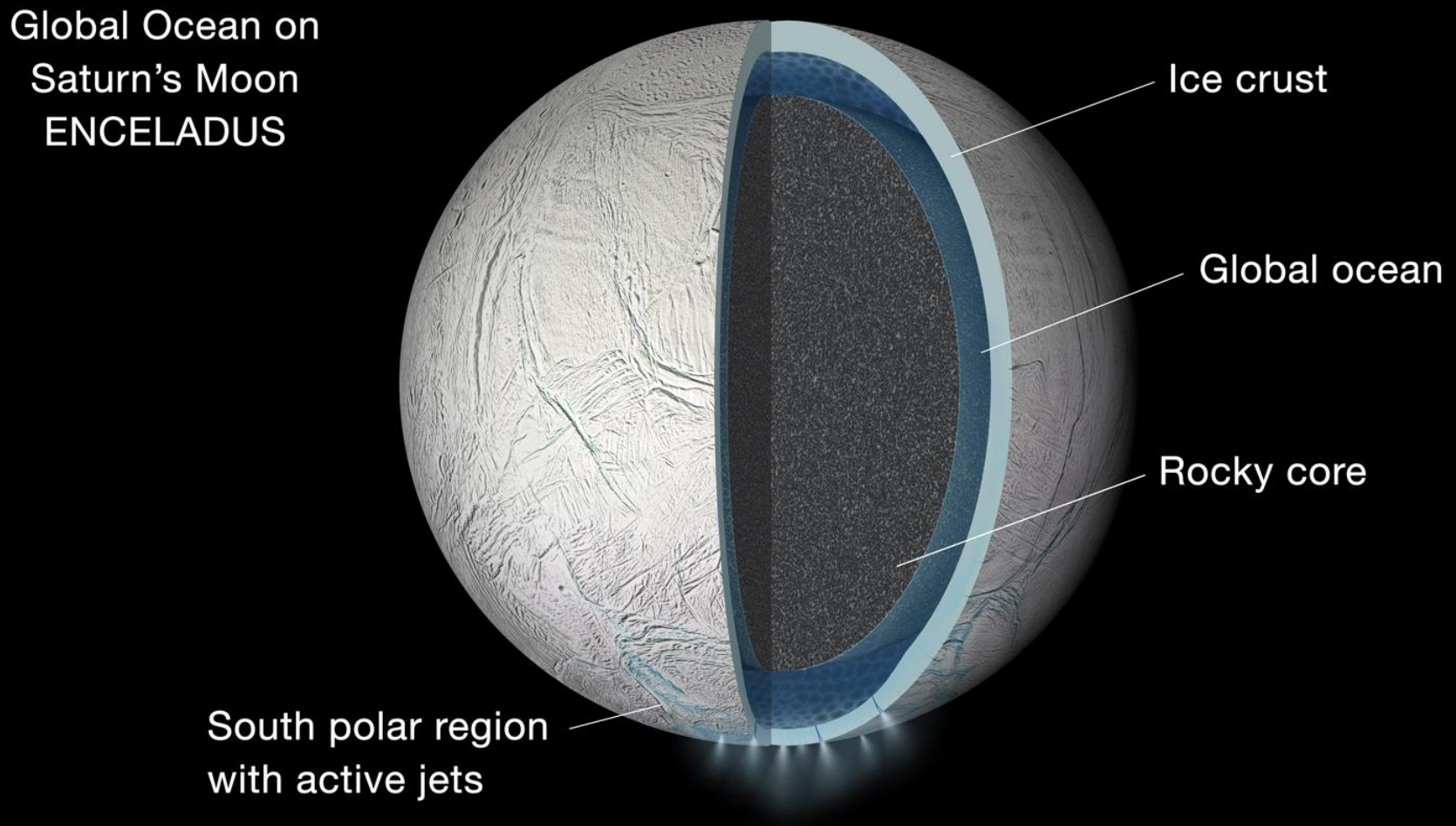
La Misión Cassini
(1997-2017)

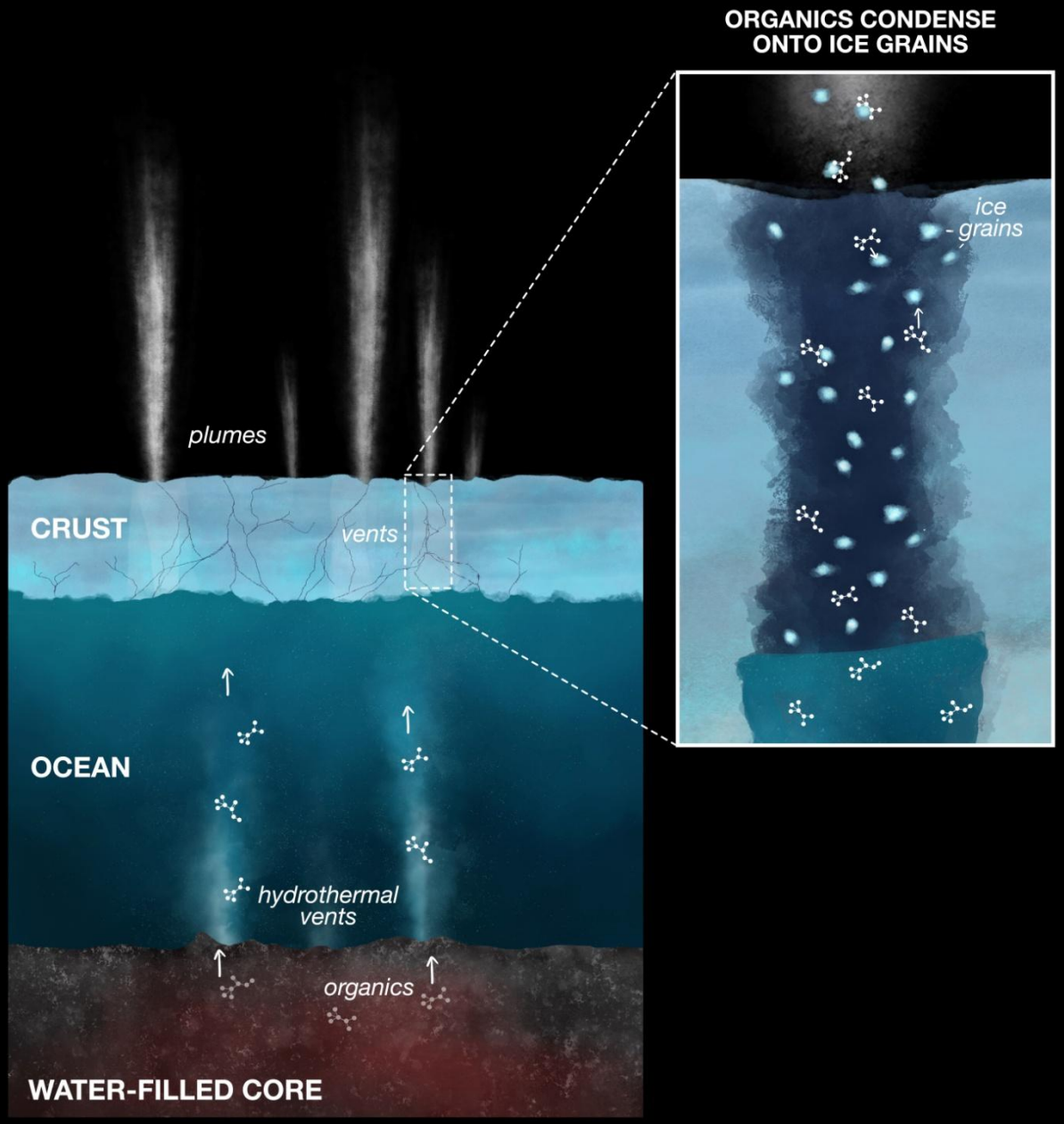


Searching for biomarkers

Encelado: Plumas de gas!

Enceladus
Cassini (INMS+UVS)




ORGANICS CONDENSE
ONTO ICE GRAINS
ice
grains
plumes
CRUST
vents
OCEAN
hydrothermal
vents
organics
WATER-FILLED CORE

ENCELADUS

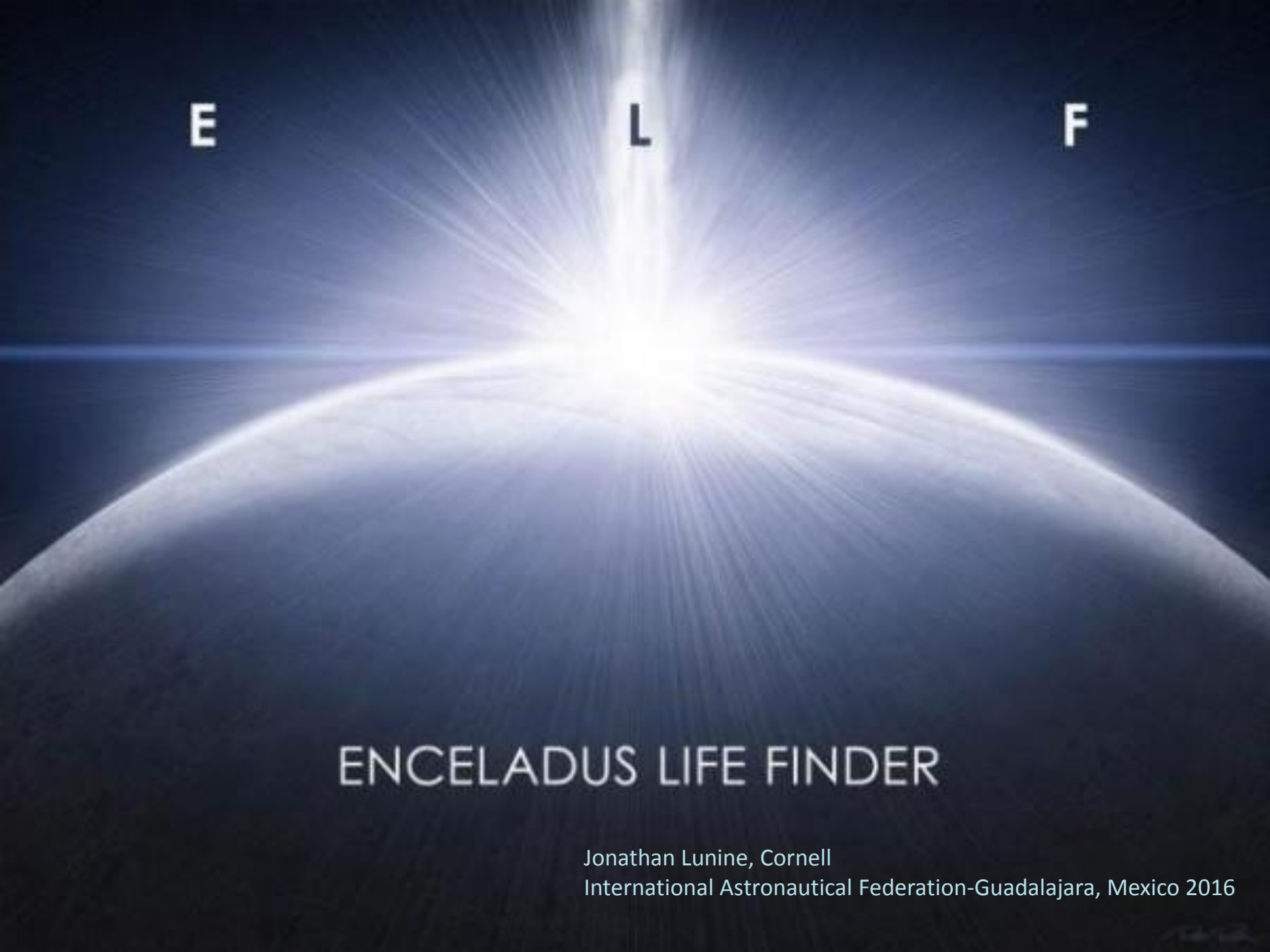
Table 1 | INMS determination of plume composition on 9 October 2008

Species	Volume mixing ratio
H_2O	0.90 ± 0.01
CO_2	0.053 ± 0.001
CO	[0.044]
H_2	[0.39]
H_2CO	$(3.1 \pm 1) \times 10^{-3}$
CH_3OH	$(1.5 \pm 0.6) \times 10^{-4}$
C_2H_4O	$< 7.0 \times 10^{-4}$
C_2H_6O	$< 3.0 \times 10^{-4}$
H_2S	$(2.1 \pm 1) \times 10^{-5}$
^{40}Ar	$(3.1 \pm 0.3) \times 10^{-4}$
NH_3	$(8.2 \pm 0.2) \times 10^{-3}$
N_2	< 0.01
HCN	$< 7.4 \times 10^{-4}$
CH_4	$(9.1 \pm 0.5) \times 10^{-3}$
C_2H_2	$(3.2 \pm 2) \times 10^{-3}$
C_2H_4	< 0.012
C_2H_6	$< 1.7 \times 10^{-3}$
C_3H_4	$< 1.1 \times 10^{-4}$
C_3H_6	$(1.4 \pm 0.3) \times 10^{-3}$
C_3H_8	$< 1.4 \times 10^{-3}$
C_4H_2	$(3.7 \pm 0.8) \times 10^{-5}$
C_4H_4	$(1.5 \pm 0.6) \times 10^{-5}$
C_4H_6	$(5.7 \pm 3) \times 10^{-5}$
C_4H_8	$(2.3 \pm 0.3) \times 10^{-4}$
C_4H_{10}	$< 7.2 \times 10^{-4}$
C_5H_6	$< 2.7 \times 10^{-6}$
C_5H_{12}	$< 6.2 \times 10^{-5}$
C_6H_6	$(8.1 \pm 1) \times 10^{-5}$

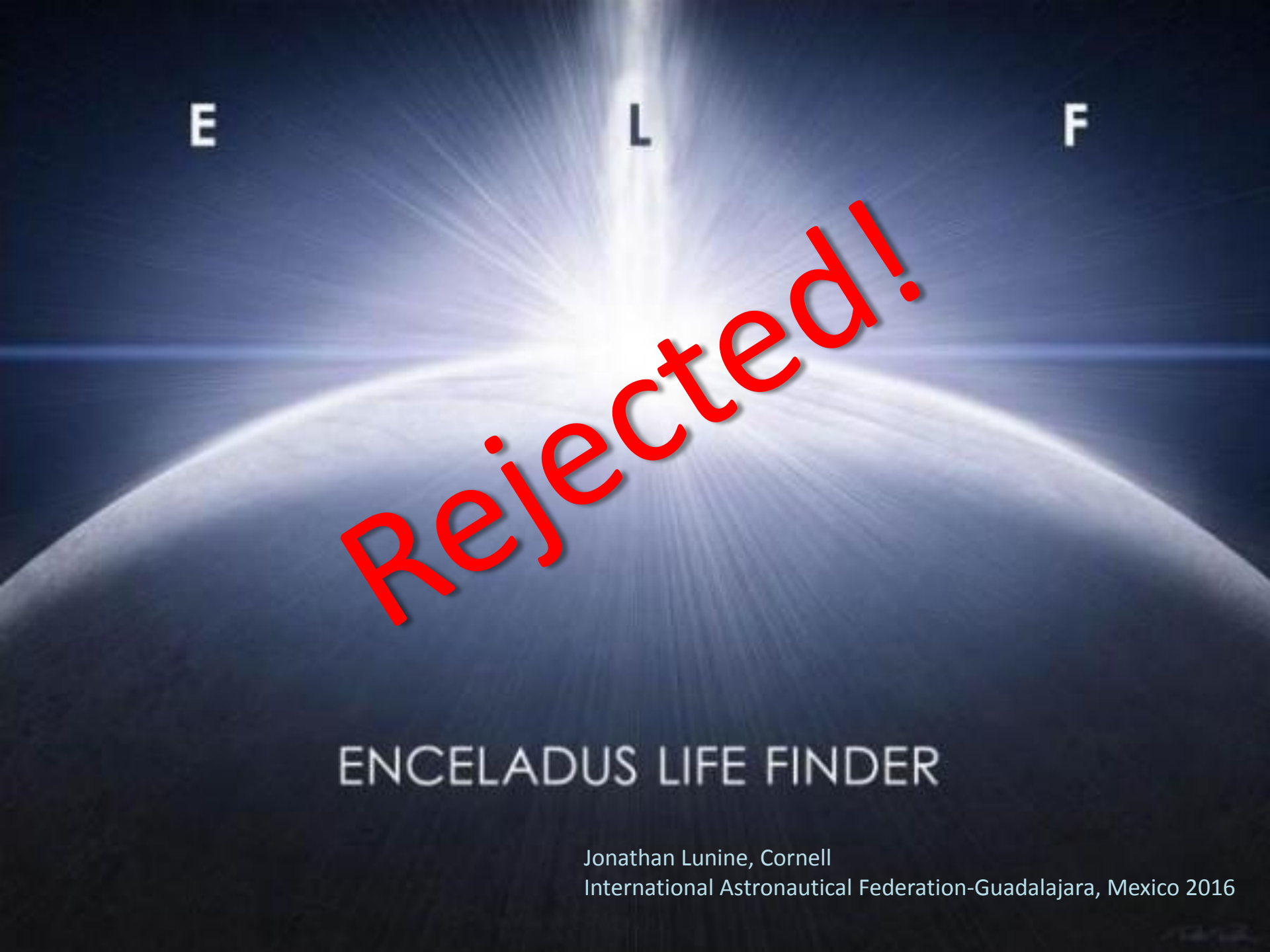
Agua

Componentes orgánicos

Fuente de energía!



Jonathan Lunine, Cornell
International Astronautical Federation-Guadalajara, Mexico 2016



Jonathan Lunine, Cornell
International Astronautical Federation-Guadalajara, Mexico 2016

Observable molecules with the LMT

@3, and 1mm (SEQUOIA and 1mm receiver, 85-115.6GHz, 210-280GHz)

Based on the mass fractions of Waite et al. 2009), a column density of water of Hansen et al. (2011-UVS; N_{H2O} =1 x 10^{16} cm^{-2}) and assuming LTE and optically thin transitions, we find that:

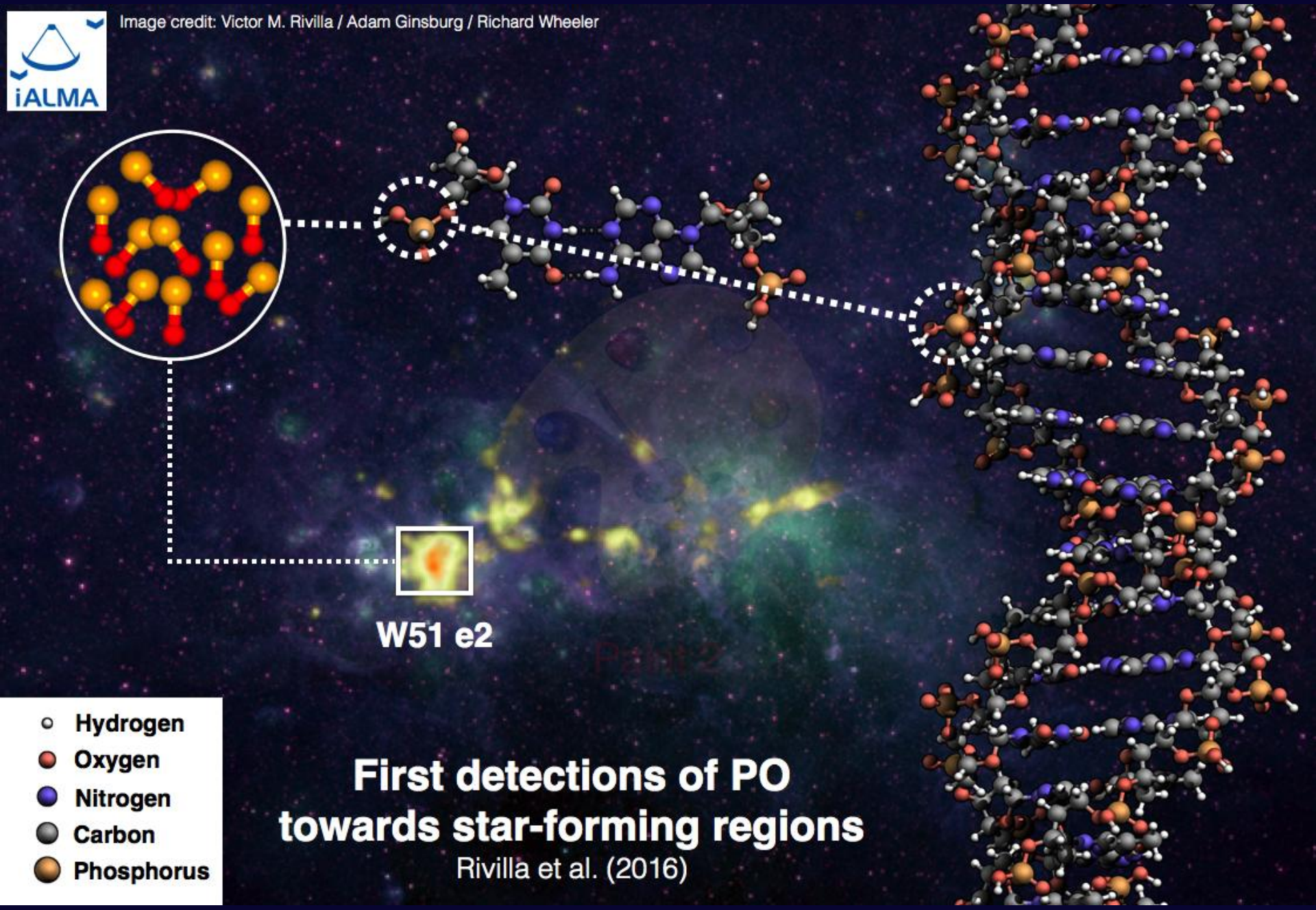
H_2CO, CO, CH_3OH, H_2S, HCN, CH_3CCH (C_3H_4), and H_2O

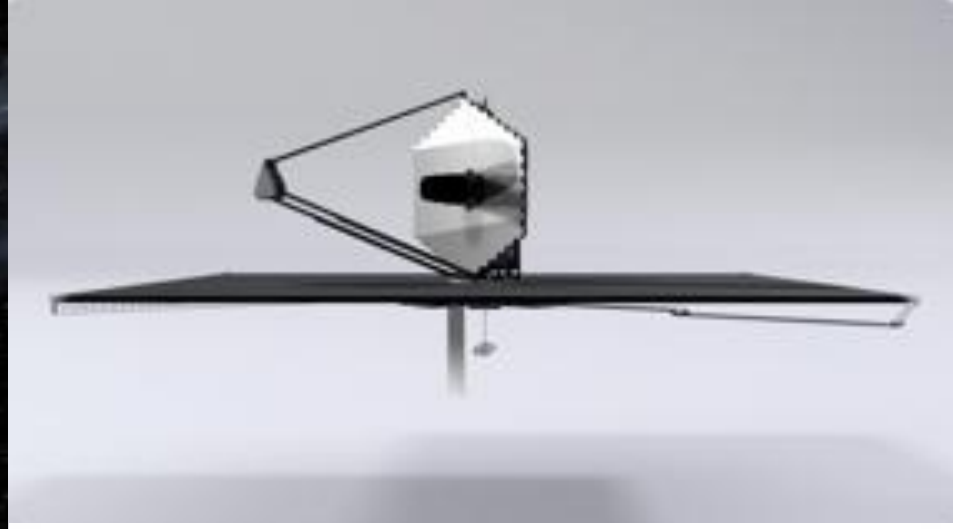
are detectable down to an rms~0.15 mK (O. Vega)

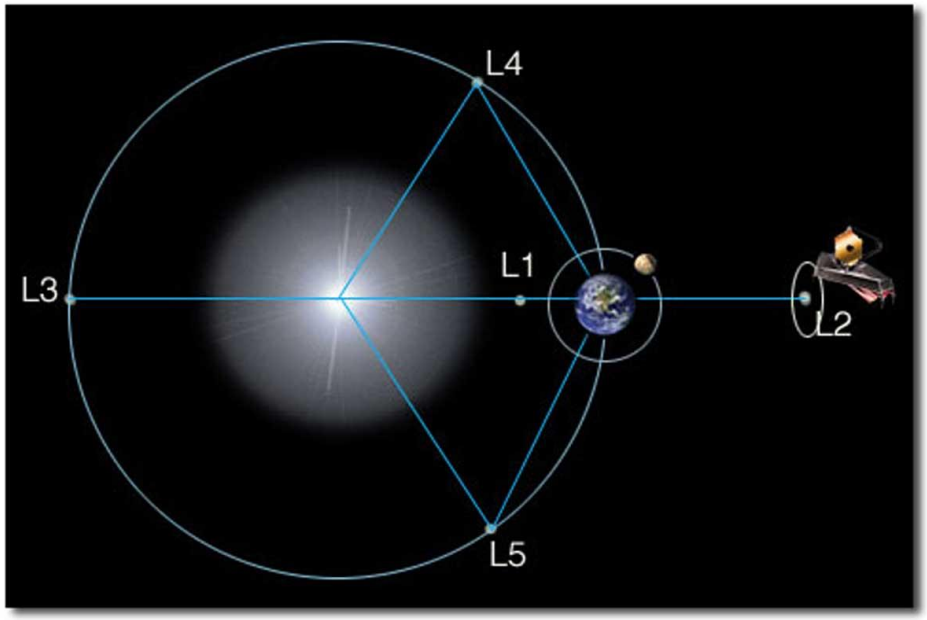
+PO!

Molecule	MHz	transition	T_R
H_2CO			
	218222.195	*3(0,3)-2(0,2)	4.0
	225697.781	*3(1,2)-2(1,1)	5.0
CO			
	115271.202	1-0	60.0
	230538.000	2-1	70.0
CH_3OH			
	107013.770	*3(1,3)-4(0,4) A++	4.5
	229758.811	*8(-1,8)-7(0,7) E	10.6
	240938.94	*5(0,5)-4(0,4) A++ $_t$=2	10.3
	240952.07	*5(2,4)-4(2,3) E $_t$=2	10.5
	250924.342	*11(3,8)-11(2,9) A-+	50.1
	252252.807	*10(3,8)-10(2,9) A+-	55.9
H_2S			
	216710.437	*2(2,0)-2(1,1)	0.32
HCN			
	88631.8473	*1-0 F=2-1	17.2
	265886.431	*3-2	20.
C_3H_4			
	102546.023	*6(1)-5(1)	0.29
	102547.983	*6(0)-5(0)	0.33
H_2O			
	183310.087	*3(1,3)-2(2,0)	10. 0

And so on…….


iALMA
Image credit: Victor M. Rivilla / Adam Ginsburg / Richard Wheeler
W51 e2
Hydrogen
Oxygen
Nitrogen
Carbon
Phosphorus
First detections of PO
towards star-forming regions
Rivilla et al. (2016)

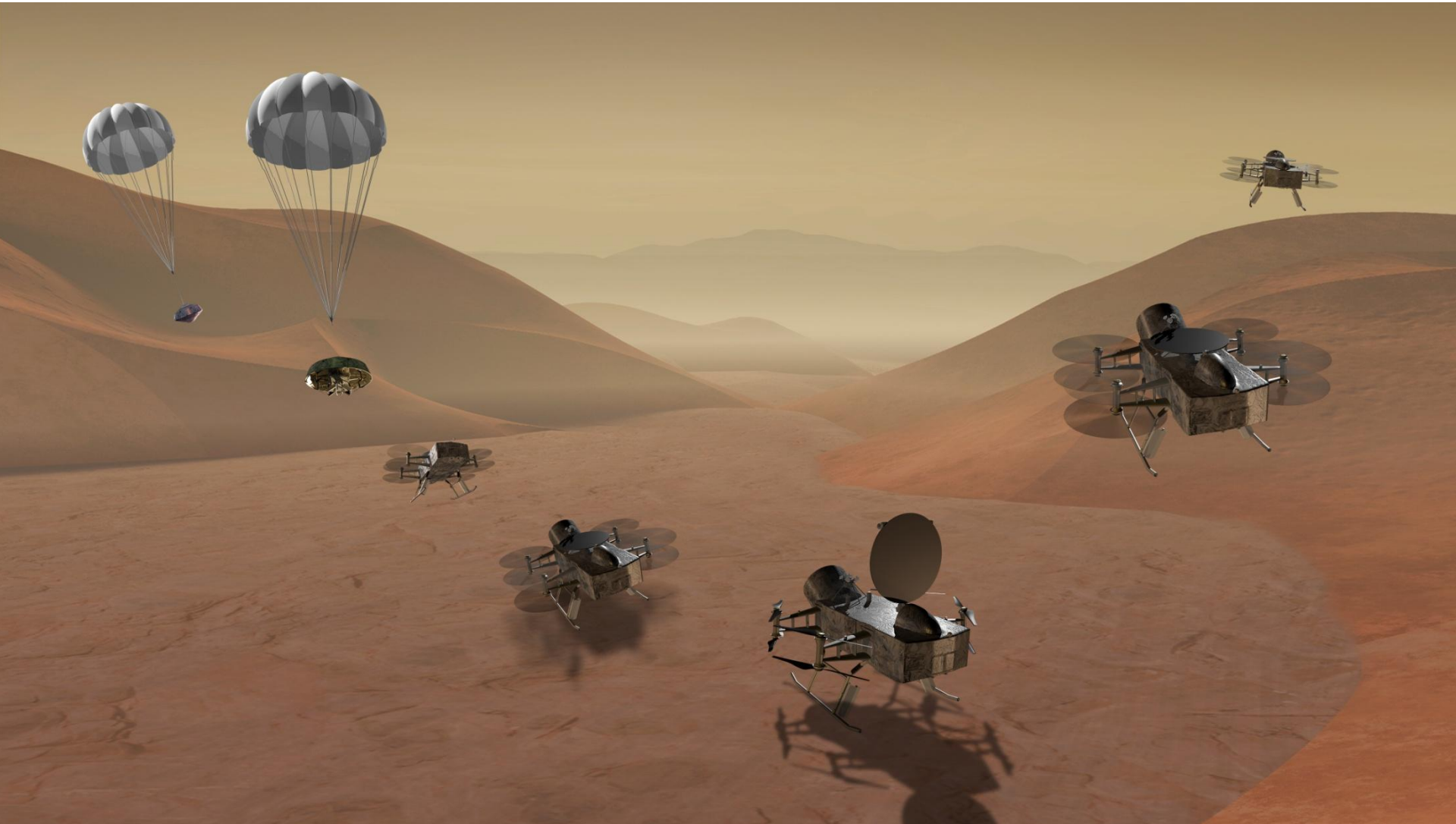




LUVOIR

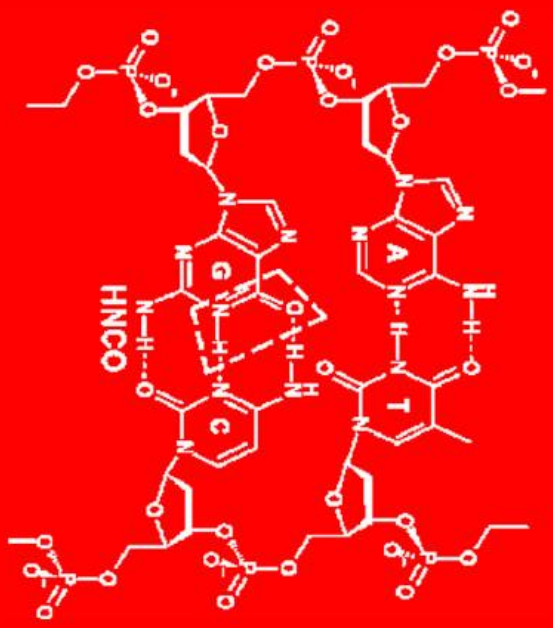
TITAN

Dragonfly: Aceptado-28 junio 2019!



New quests in stellar astrophysics IV
astrochemistry, astrobiology and the origin of life
Puerto Vallarta, Mexico, March 31st - April 5th, 2019

Edited by: M. Chávez Dagostino, E. Bertone, O. Vega and R. M. Chávez Dagostino



MEMORIE DELLA
SOCIETÀ ASTRONOMICA ITALIANA
JOURNAL OF THE ITALIAN ASTRONOMICAL SOCIETY
Vol.90 - N°4 - 2019

Gracias!