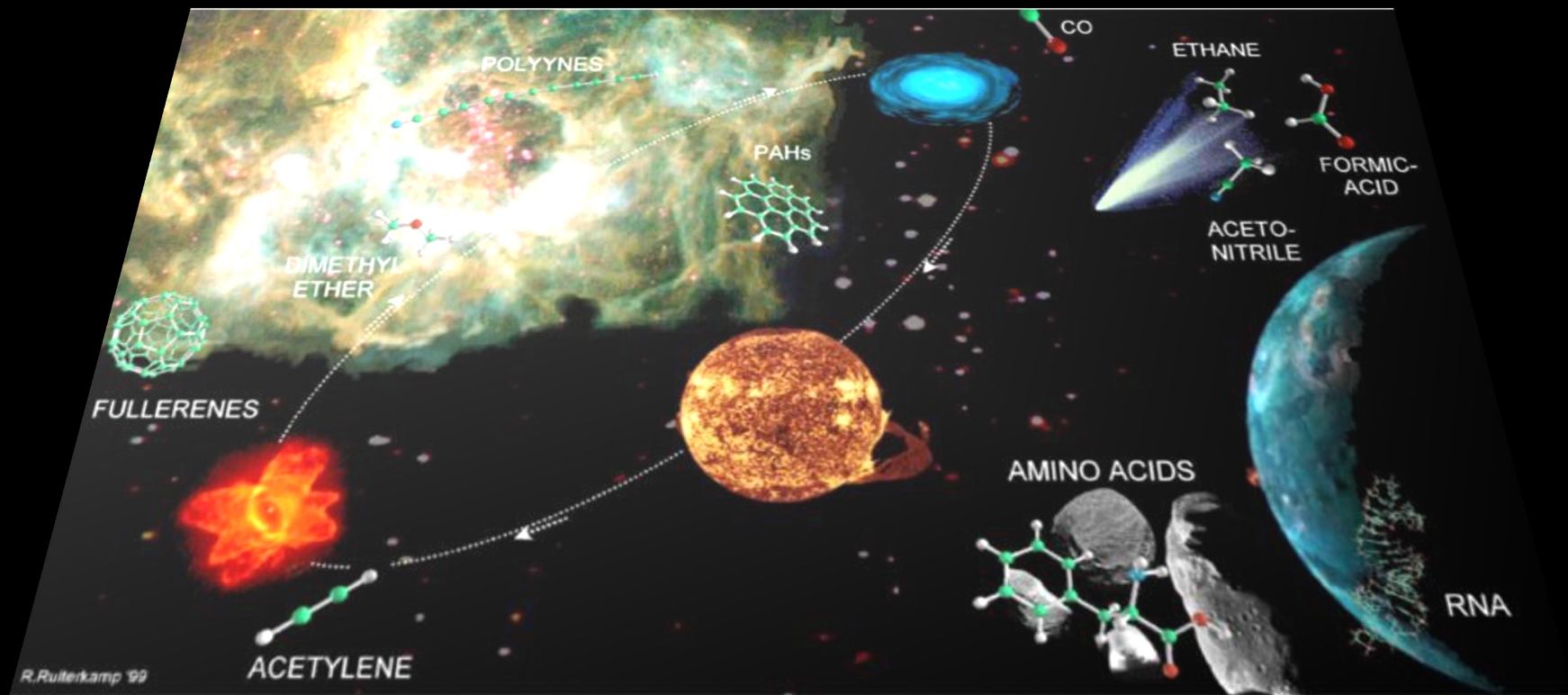


Molecules in Space



Marcelino Agúndez

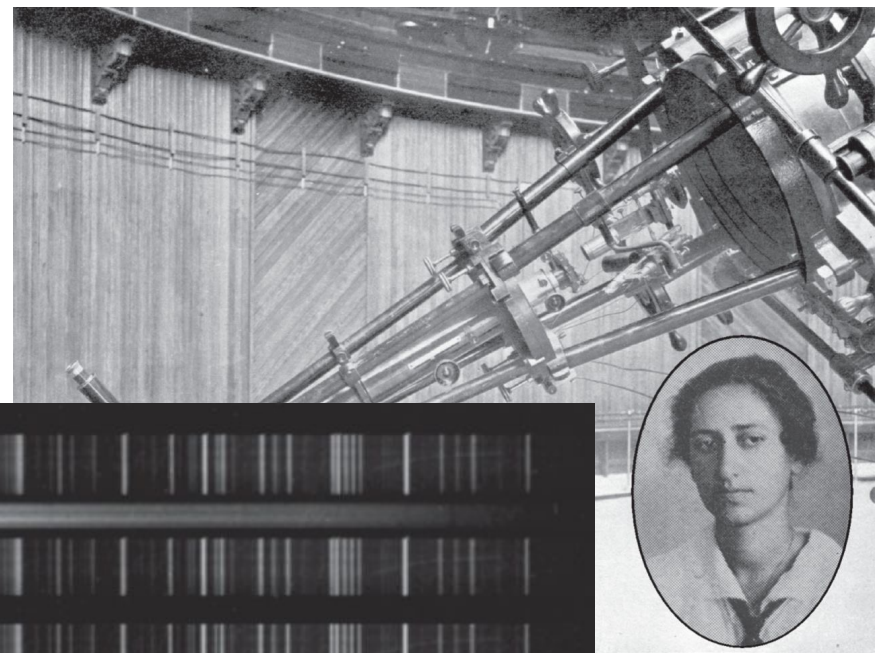
Instituto de Física Fundamental, CSIC, Madrid



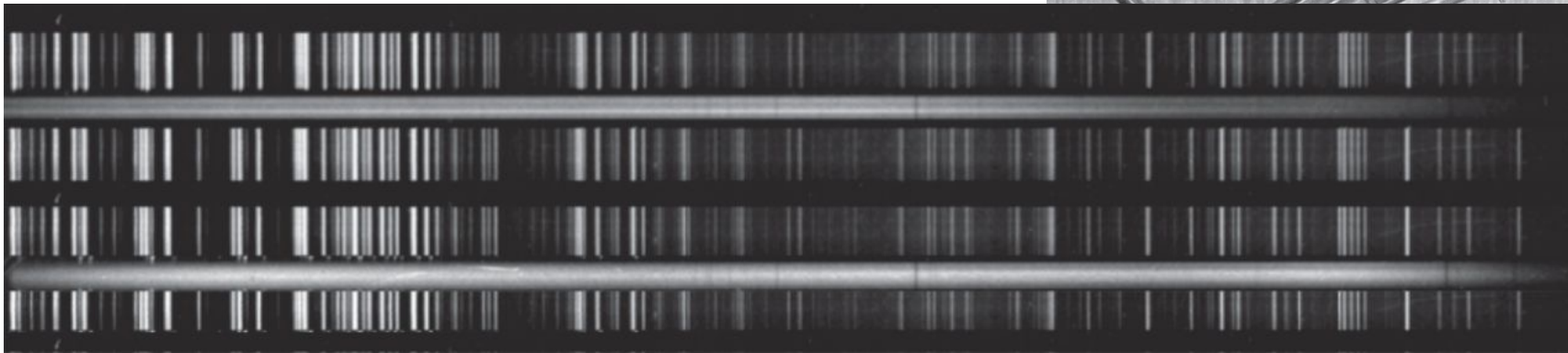
CSIC

CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

Early observations of molecules in the interstellar medium



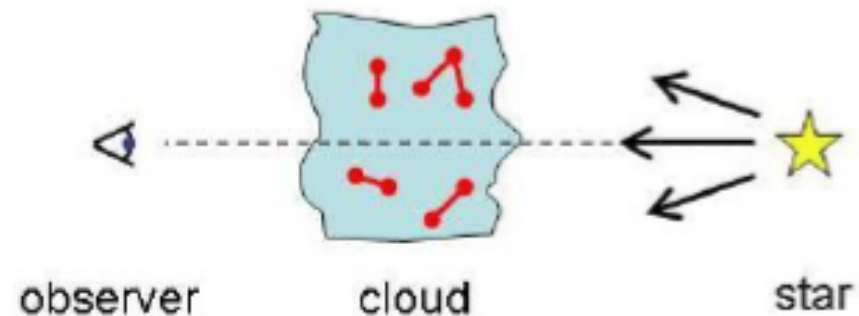
Plates of ζ Persei obtained by Mary Lea Heger at Lick Observatory in 1919



UNIDENTIFIED INTERSTELLAR LINES*

BY PAUL W. MERRILL

In stellar spectra, observers recognize three types of absorption lines, distinguished by the place of origin: (1) stellar lines, formed in the gases immediately overlying the star's photosphere; (2) terrestrial lines, introduced by the Earth's atmosphere; (3) detached or interstellar lines, originating between the star and the Earth. For about thirty years only four lines of group 3 were known: H and K of ionized calcium; D1 and D2 of neutral sodium. A brief history of observations of these lines was given.



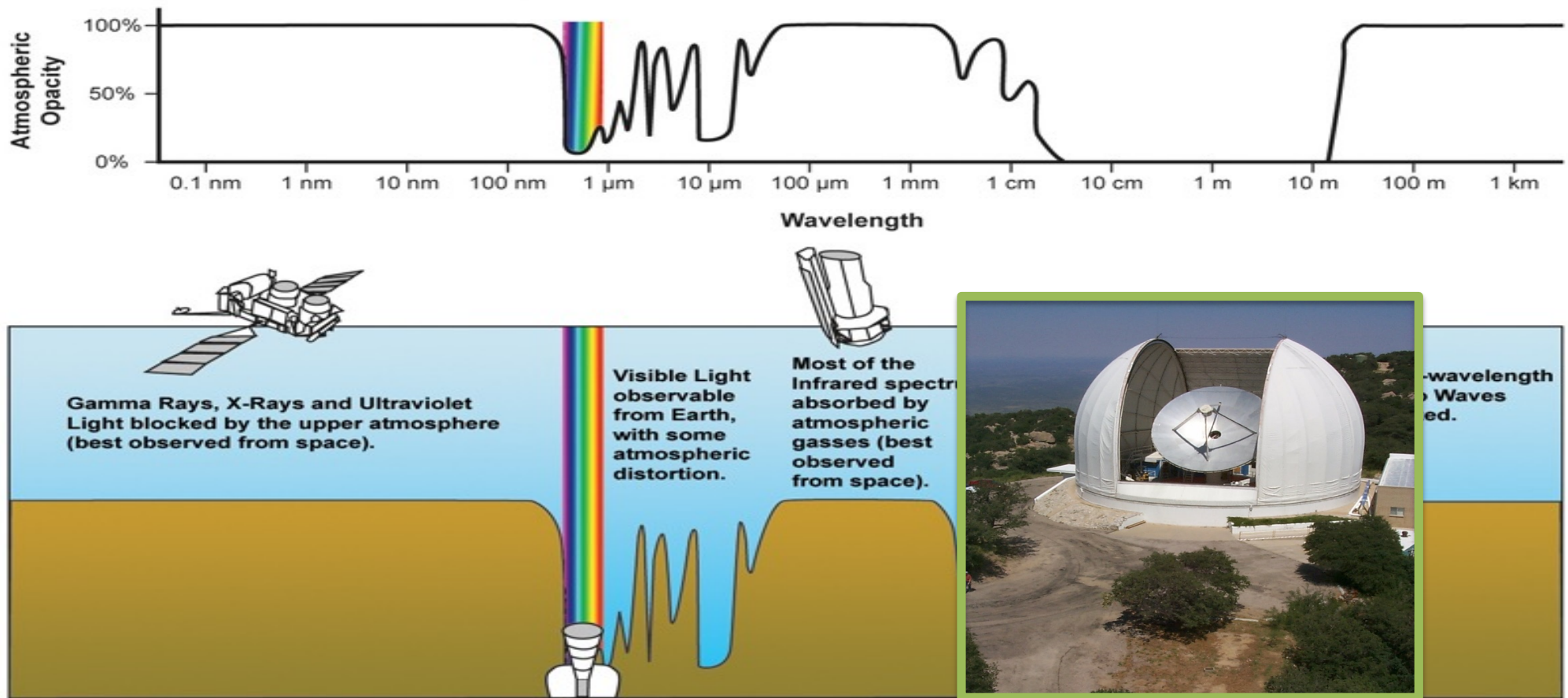
Merrill 1934, PASP, 46, 206

unidentified interstellar lines

McKellar 1940, PASP, 52, 307

evidence of molecular origin of some unidentified interstellar lines (CH, CH⁺, CN)

Radioastronomy and the boom of molecular detections



The opening of the radio window in the 1950s and 1960s led to:

- Discovery of H line at 21 cm
- Discovery of quasars
- Discovery of pulsars
- Discovery of the Cosmic Microwave Background
- Boom of molecules in space

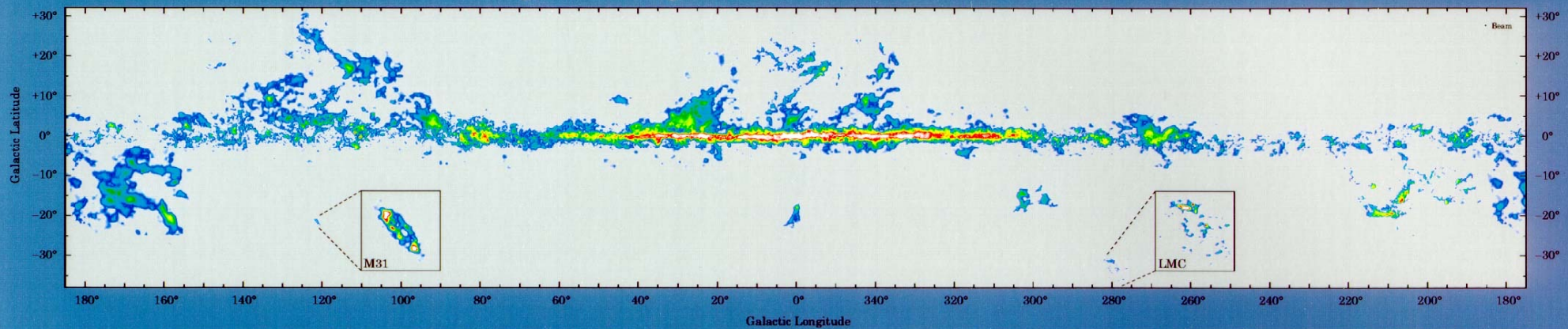
Most of the (barionic) mass in our galaxy is in stars
Around 10 % is in interstellar clouds

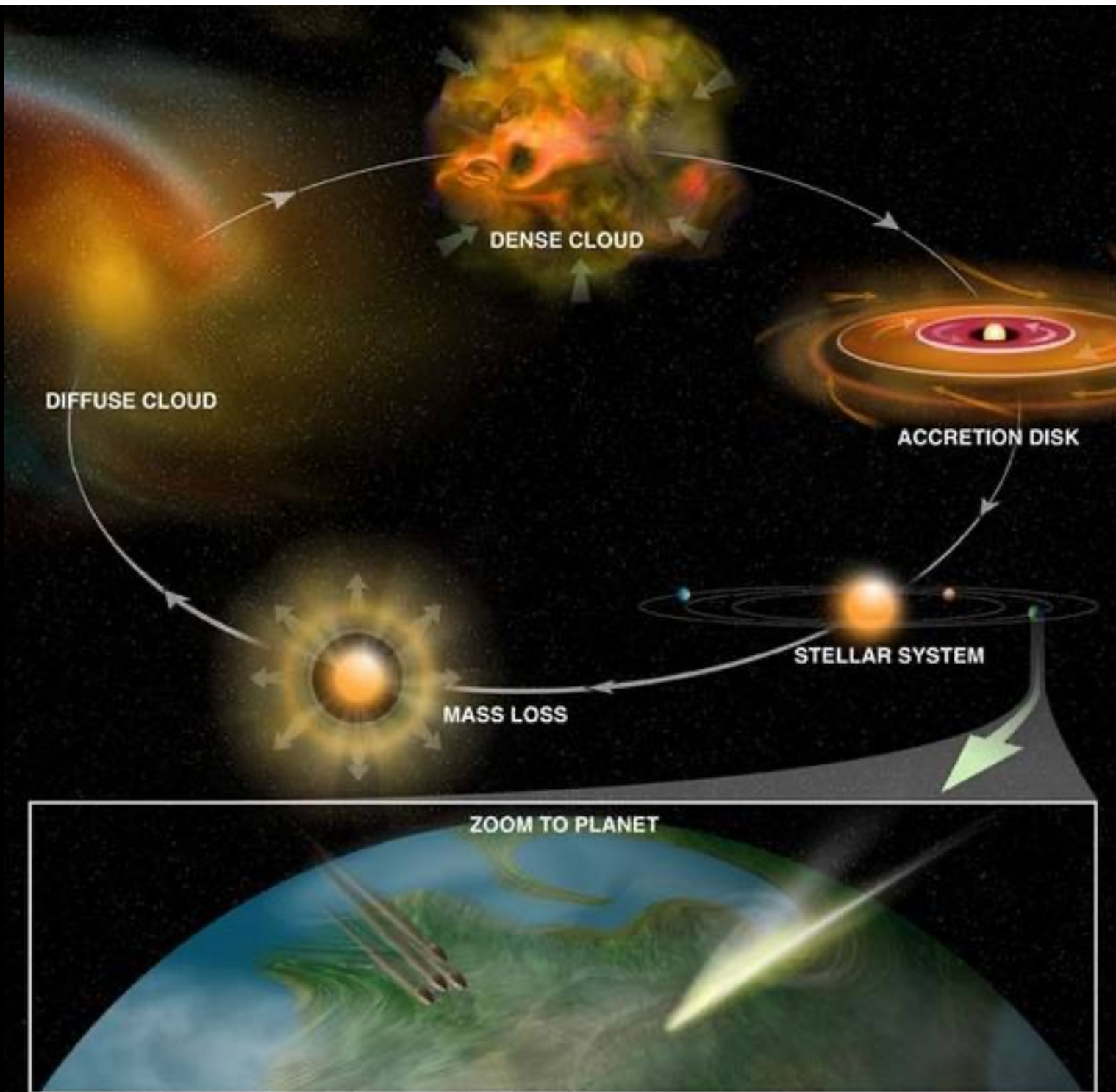
In our galaxy, molecular clouds account for 1 % of the interstellar volume
20 % of the interstellar mass

Molecular clouds occur in regions of transformation !

Dame, Hartmann, & Thaddeus (2001)

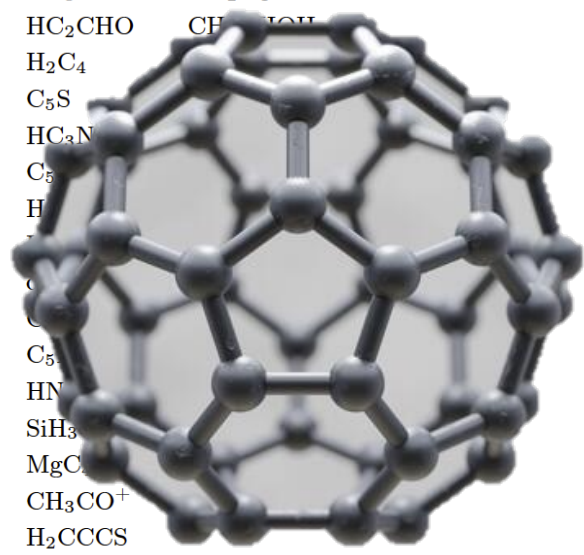
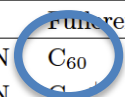
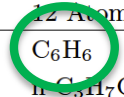
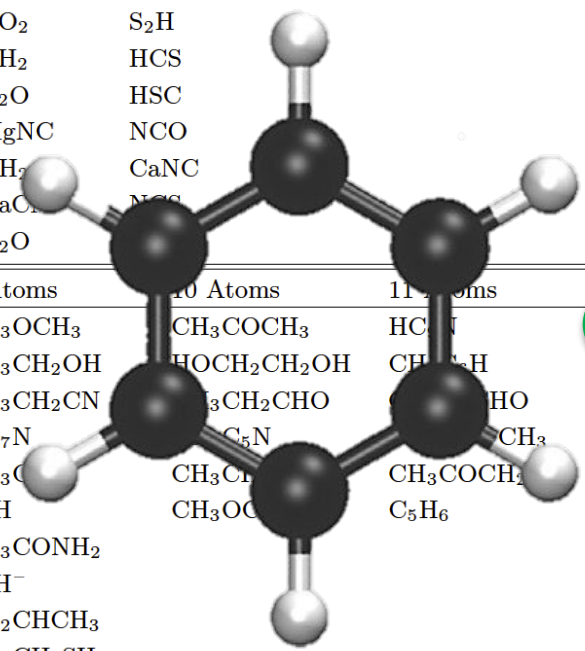
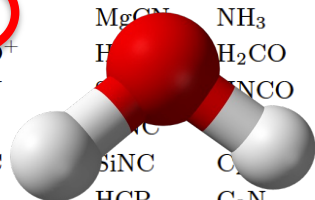
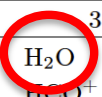
The Milky Way in Molecular Clouds



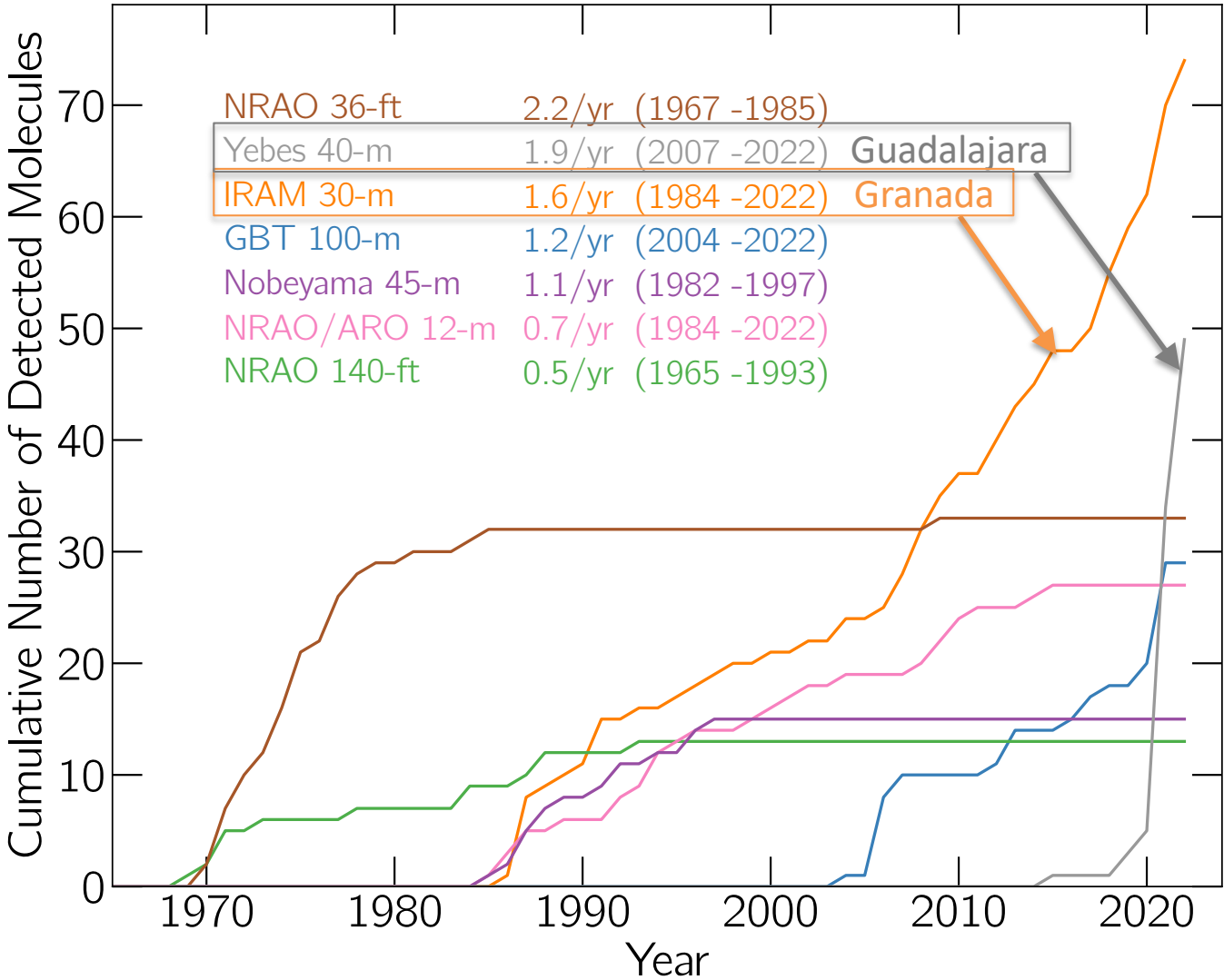


Moléculas detectadas en el espacio
(McGuire 2021)

2 Atoms		3 Atoms	4 Atoms		5 Atoms		6 Atoms	7 Atoms	
CH	NH	H ₂ O	MgCN	NH ₃	SiC ₃	HC ₃ N	C ₄ H ⁻	CH ₃ OH	CH ₃ CHO
CN	SiN	HCO ⁺	H ₂ CN	H ₂ CO	CH ₃	HCOOH	CNCHO	CH ₃ CN	CH ₃ CCH
CH ⁺	SO ⁺	HCN	H ₂ CN ⁺	H ₂ NCO	C ₃ N ⁻	CH ₂ NH	HNCNH	NH ₂ CHO	CH ₃ NH ₂
OH	CO ⁺	OCS	H ₂ NC	H ₂ CO	PH ₃	NH ₂ CN	CH ₃ O	CH ₃ SH	CH ₂ CHCN
CO	HF	HNC	SiNC	C ₃ H	HCNO	H ₂ CCO	NH ₃ D ⁺	C ₂ H ₄	HC ₅ N
H ₂	N ₂	H ₂ S	HCP	C ₃ N	HOCN	C ₄ H	H ₂ NCO ⁺	C ₅ H	C ₆ H
SiO	CF ⁺	N ₂ H ⁺	CCP	HNCS	HSCN	SiH ₄	NCCNH ⁺	CH ₃ CN	c-C ₂ H ₄ O
CS	PO	C ₂ H	AlOH	HOCO ⁺	HOOH	c-C ₃ H ₂	CH ₃ Cl	HC ₂ CHO	CH ₂ CHO
SO	O ₂	SO ₂	H ₂ O ⁺	C ₃ O	l-C ₃ H ⁺	CH ₂ CN	MgC ₃ N	H ₂ C ₄	CH ₂ CHO
SiS	AlO	HCO	H ₂ Cl ⁺	l-C ₃ H	HMgNC	C ₅	HC ₃ O ⁺	C ₅ S	CH ₂ CHO
NS	CN ⁻	HNO	KCN	HCNH ⁺	HCCO	SiC ₄	NH ₂ OH	HC ₃ N	CH ₂ CHO
C ₂	OH ⁺	HCS ⁺	FeCN	H ₃ O ⁺	CNCN	H ₂ CCC	HC ₃ S ⁺	C ₅ H	CH ₂ CHO
NO	SH ⁺	HOC ⁺	HO ₂	C ₃ S	HONO	CH ₄	H ₂ CCS	H ₂ C ₄	CH ₂ CHO
HCl	HCl ⁺	SiC ₂	TiO ₂	c-C ₃ H	MgCCH	HCCNC	C ₄ S	C ₅ H	CH ₂ CHO
NaCl	SH	C ₂ S	CCN	HC ₂ N	HCCS	HNCCC	CHOSH	C ₅ H	CH ₂ CHO
AlCl	TiO	C ₃	SiCSi	H ₂ CN		H ₂ COH ⁺		C ₅ H	CH ₂ CHO
KCl	ArH ⁺	CO ₂	S ₂ H					C ₅ H	CH ₂ CHO
AlF	NS ⁺	CH ₂	HCS					HN	CH ₂ CHO
PN	HeH ⁺	C ₂ O	HSC					SiH ₃	CH ₂ CHO
SiC	VO	MgNC	NCO					MgC	CH ₂ CHO
CP		NH ₂	CaNC					CH ₃ CO ⁺	CH ₂ CHO
		NaCl	NCS					H ₂ CCCS	CH ₂ CHO
		N ₂ O						CH ₂ CCH	CH ₂ CHO
8 Atoms		9 Atoms	10 Atoms	11 Atoms	12 Atoms	13 Atoms	PAHs	Fullerenes	
HCOOCH ₃	CH ₃ OCH ₃	CH ₃ COCH ₃	HC ₇ N	C ₆ H ₆	C ₆ H ₅ CN	1-C ₁₀ H ₇ CN	C ₆₀		
CH ₃ C ₃ N	CH ₃ CH ₂ OH	HOCH ₂ CH ₂ OH	CH ₃ C ₅ H	i-C ₅ H ₇ CN	HC ₁₁ N	2-C ₁₀ H ₇ CN	C ₆₀		
C ₇ H	CH ₃ CH ₂ CN	CH ₃ CH ₂ CHO	CH ₃ C ₅ N	1-C ₅ H ₅ CN		C ₉ H ₈	C ₇₀		
CH ₃ COOH	HC ₇ N	CH ₃ CH ₂ CHO	CH ₃ C ₅ N	2-C ₅ H ₅ CN					
H ₂ C ₆	CH ₃ C ₅ N	CH ₃ COCH ₂ CHO	CH ₃ COCH ₂ CHO						
CH ₂ OHCHO	C ₈ H	CH ₃ COCH ₂ CHO	C ₅ H ₆						
HC ₆ H	CH ₃ CONH ₂								
CH ₂ CHCHO	C ₈ H ⁻								
CH ₂ CCHCN	CH ₂ CHCH ₃								
NH ₂ CH ₂ CN	CH ₃ CH ₂ SH								
CH ₃ CHNH	HC ₇ O								
CH ₃ SiH ₃	CH ₃ NHCHO								
NH ₂ CONH ₂	H ₂ CCCHCCH								
HCCCH ₂ CN	HCCCHCHCN								
CH ₂ CHCCH	H ₂ CCHC ₃ N								



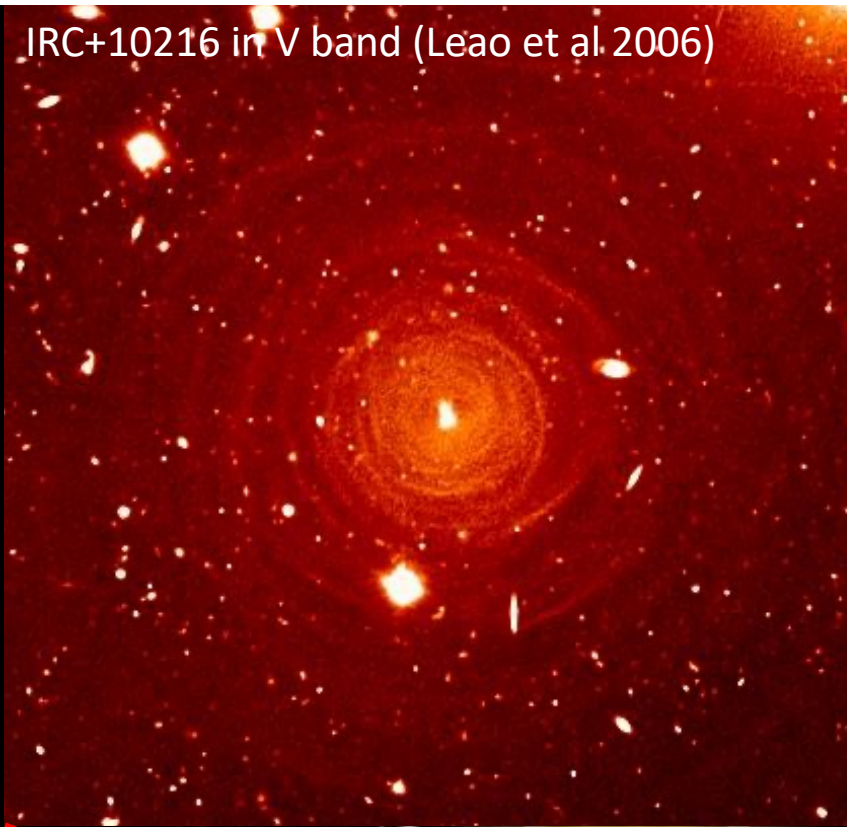
Molecules detected in space by telescope facility



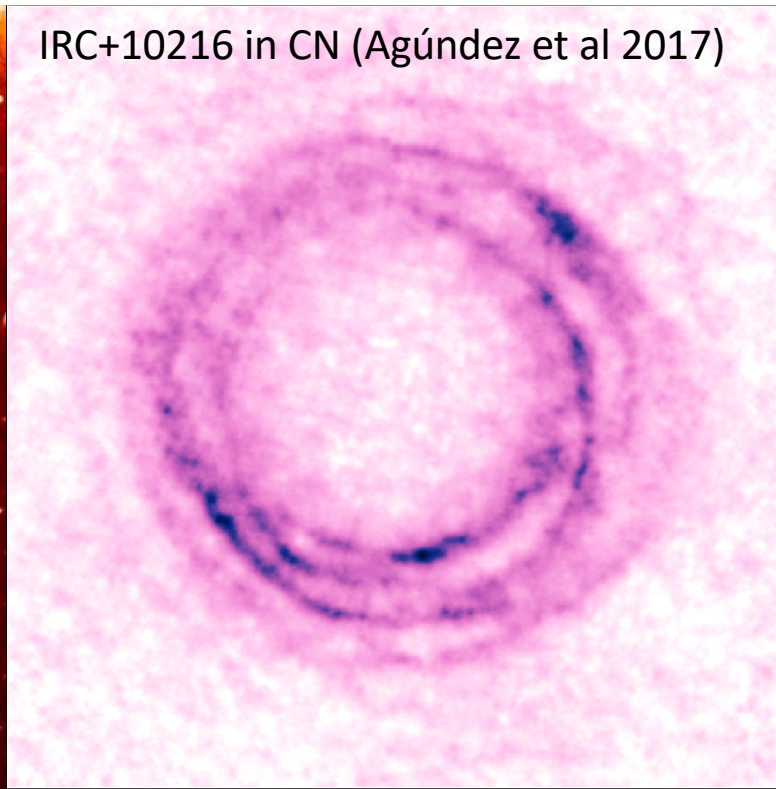
Molecules in galaxies

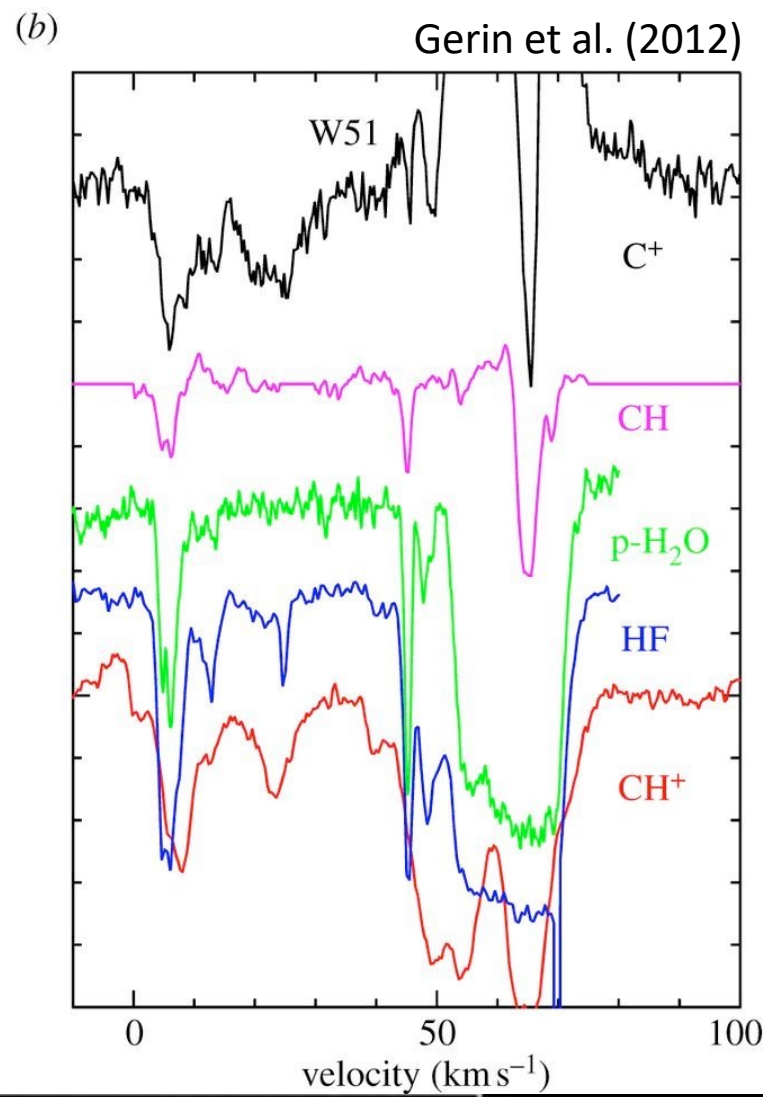
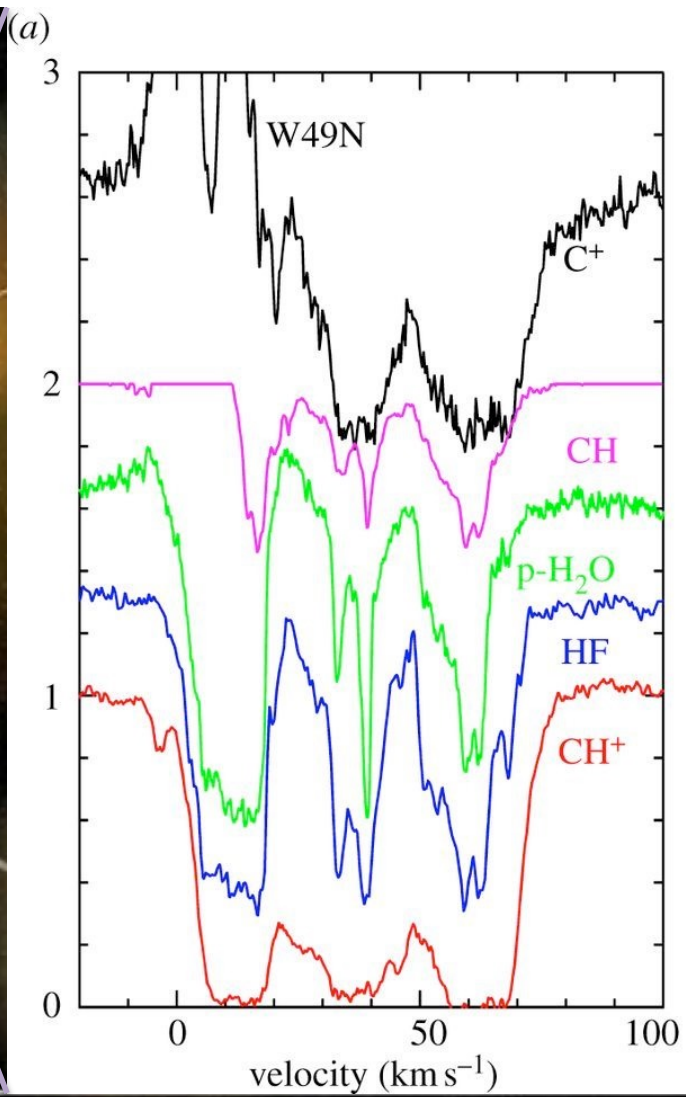


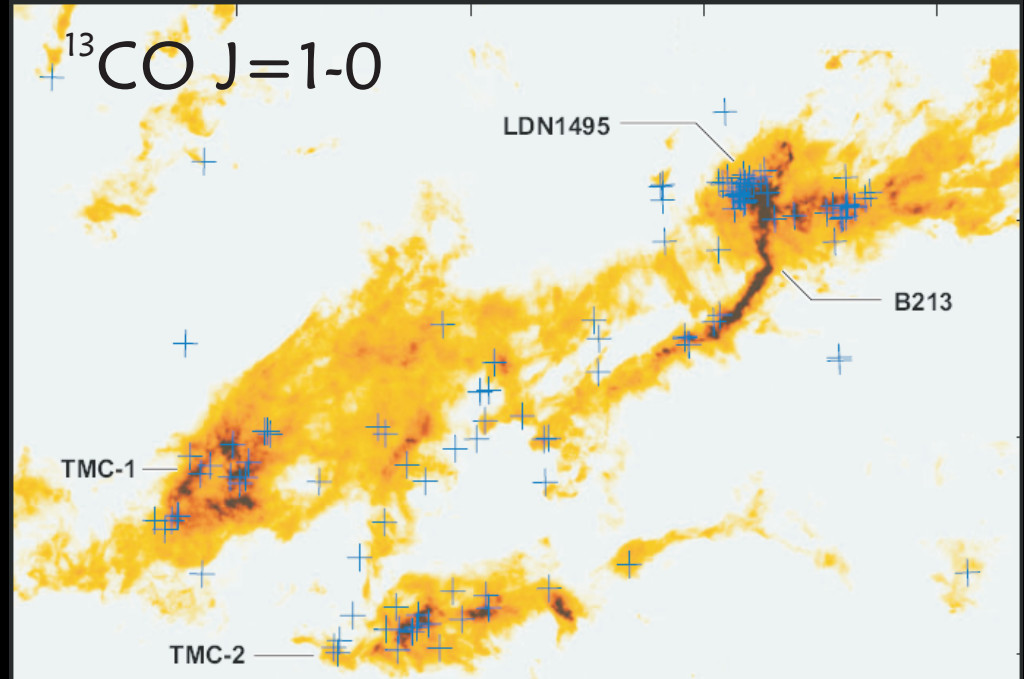
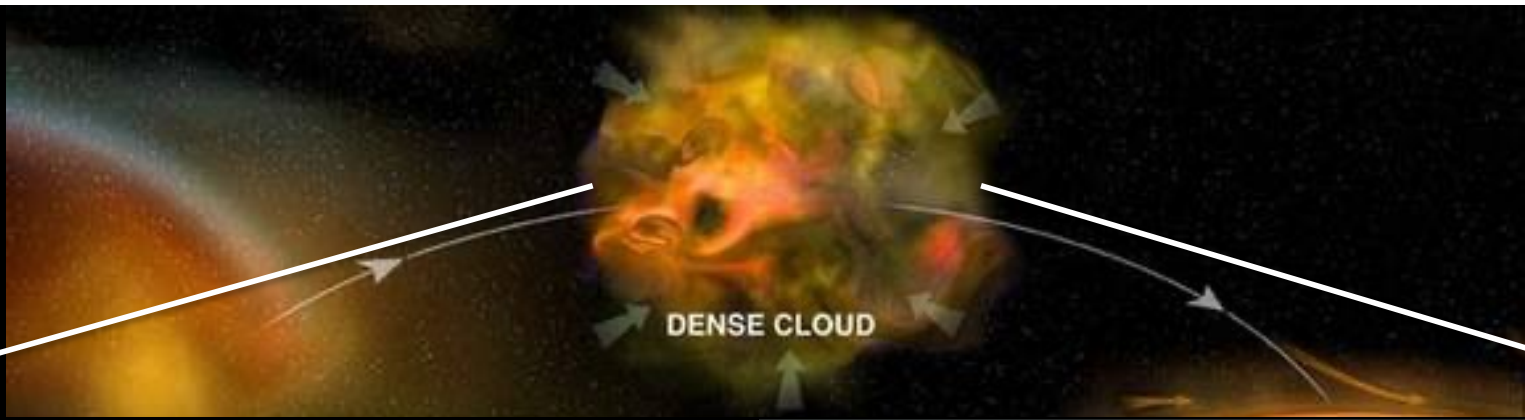
IRC+10216 in V band (Leao et al 2006)

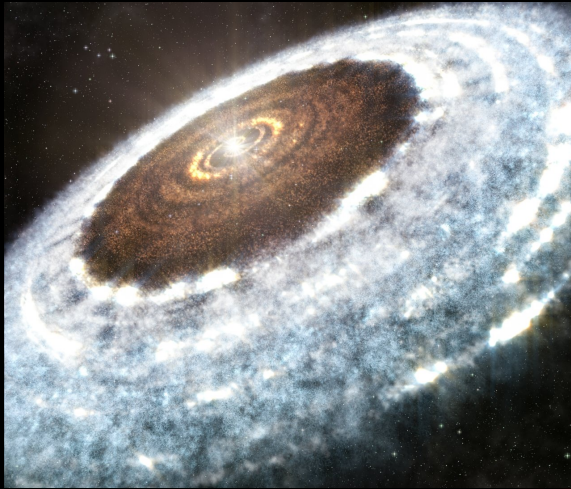


IRC+10216 in CN (Agúndez et al 2017)

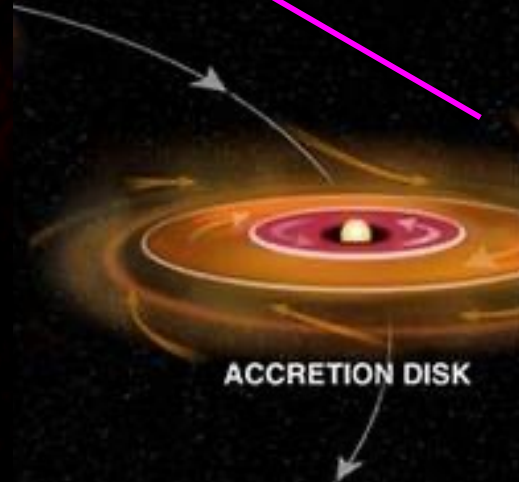




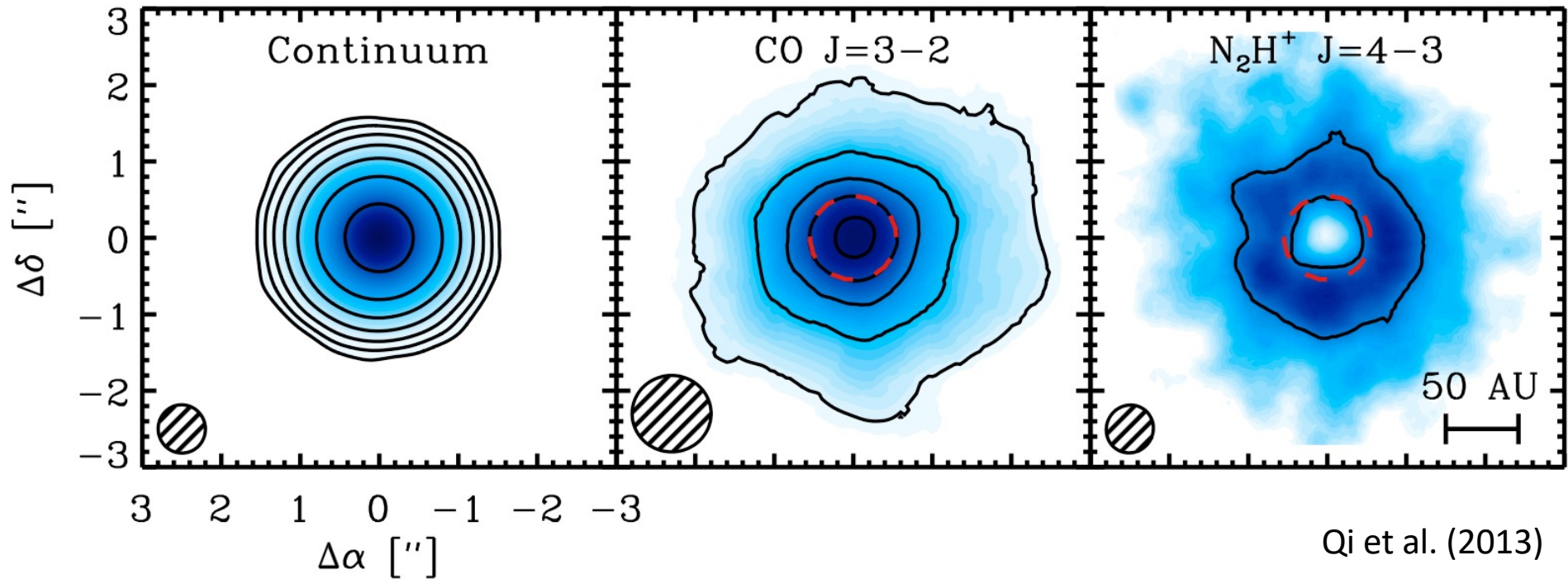




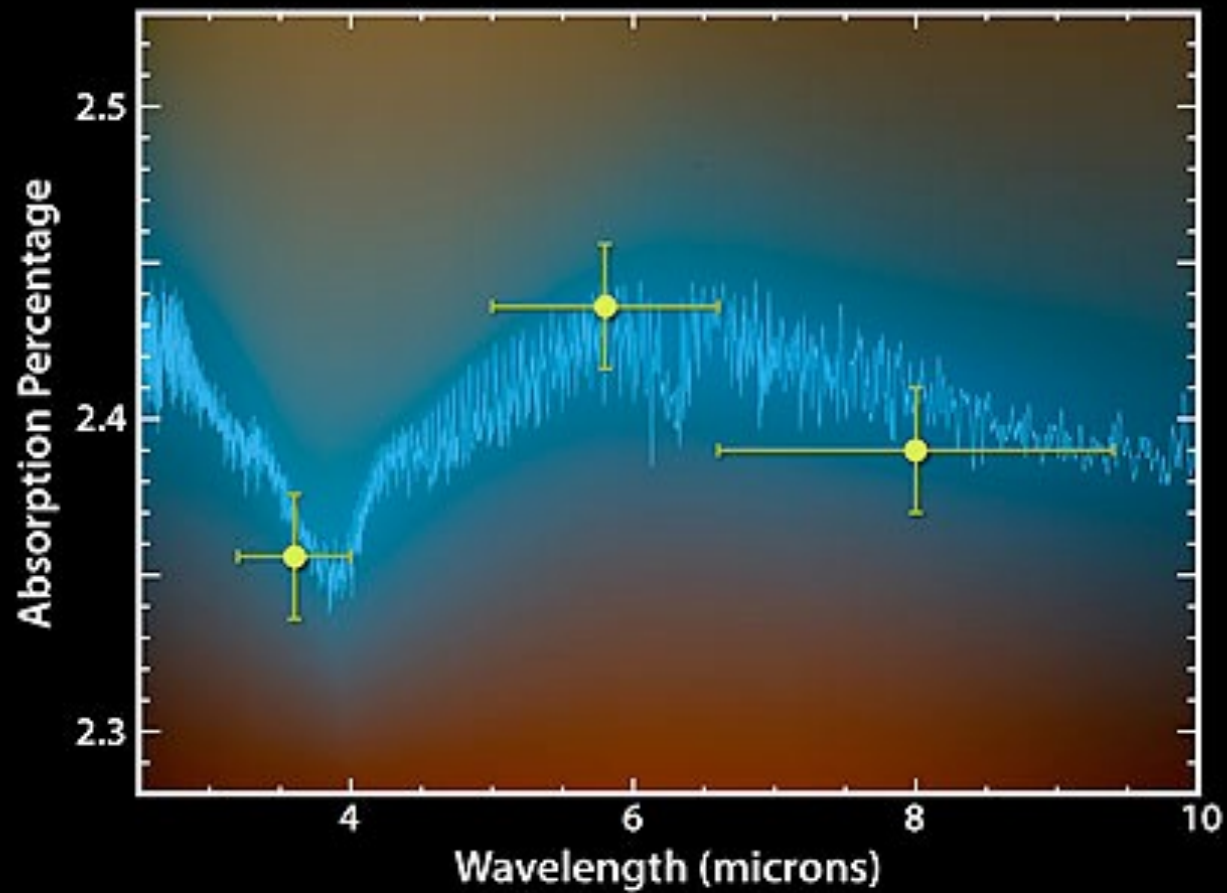
HL Tau
ALMA Partnership 2015



ACCRETION DISK



Qi et al. (2013)



Water Signatures in Exoplanet HD189733b

Spitzer Space Telescope • IRAC

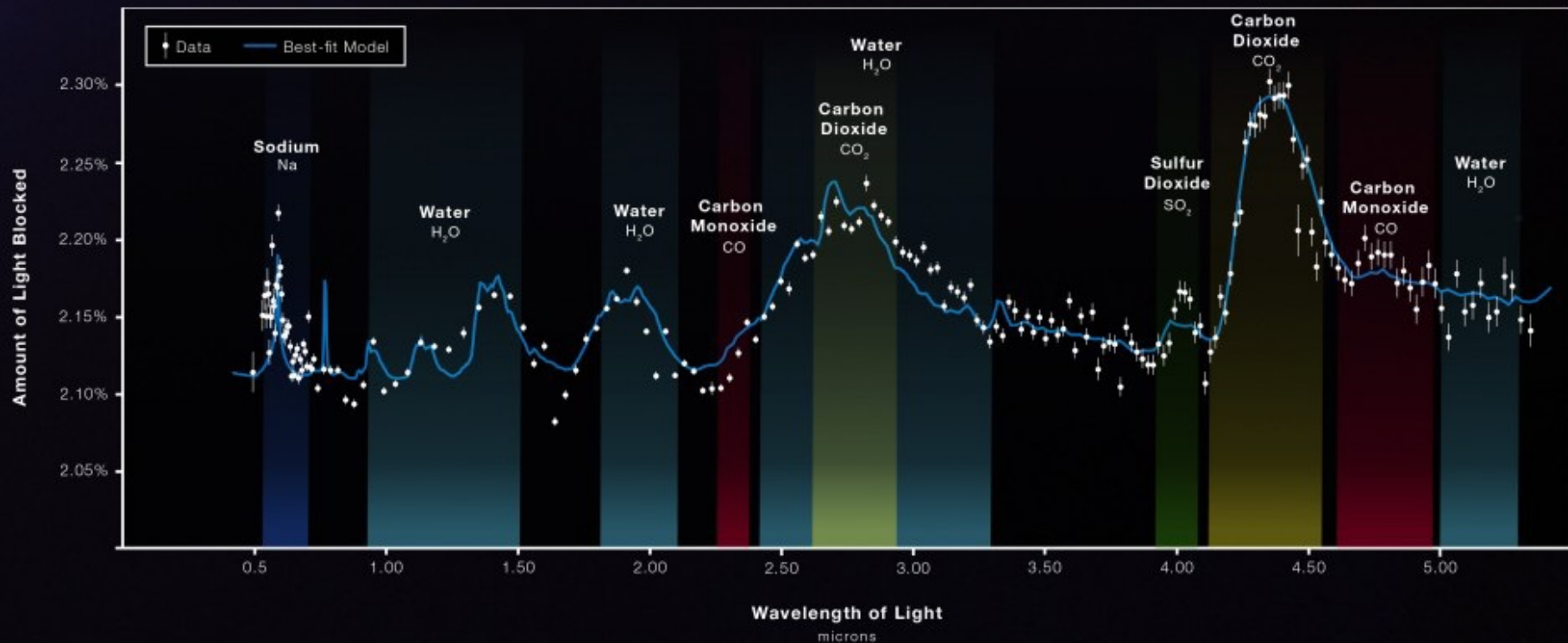
NASA / JPL-Caltech / G. Tinetti (Institute d'Astrophysique de Paris)

ssc2007-12a



HOT GAS GIANT EXOPLANET WASP-39 b ATMOSPHERE COMPOSITION

NIRSpec PRISM



WEBB
SPACE TELESCOPE