Astrochemistry with the SKA – and how CRAF protects radioastronomy from interference

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Astrochemistry

Image credit: Robert Gendler, Jim Misti, Steve Mazlin

What is astrochemistry ?

- Subfield of astrophysics at the border to chemistry: molecular astrophysics

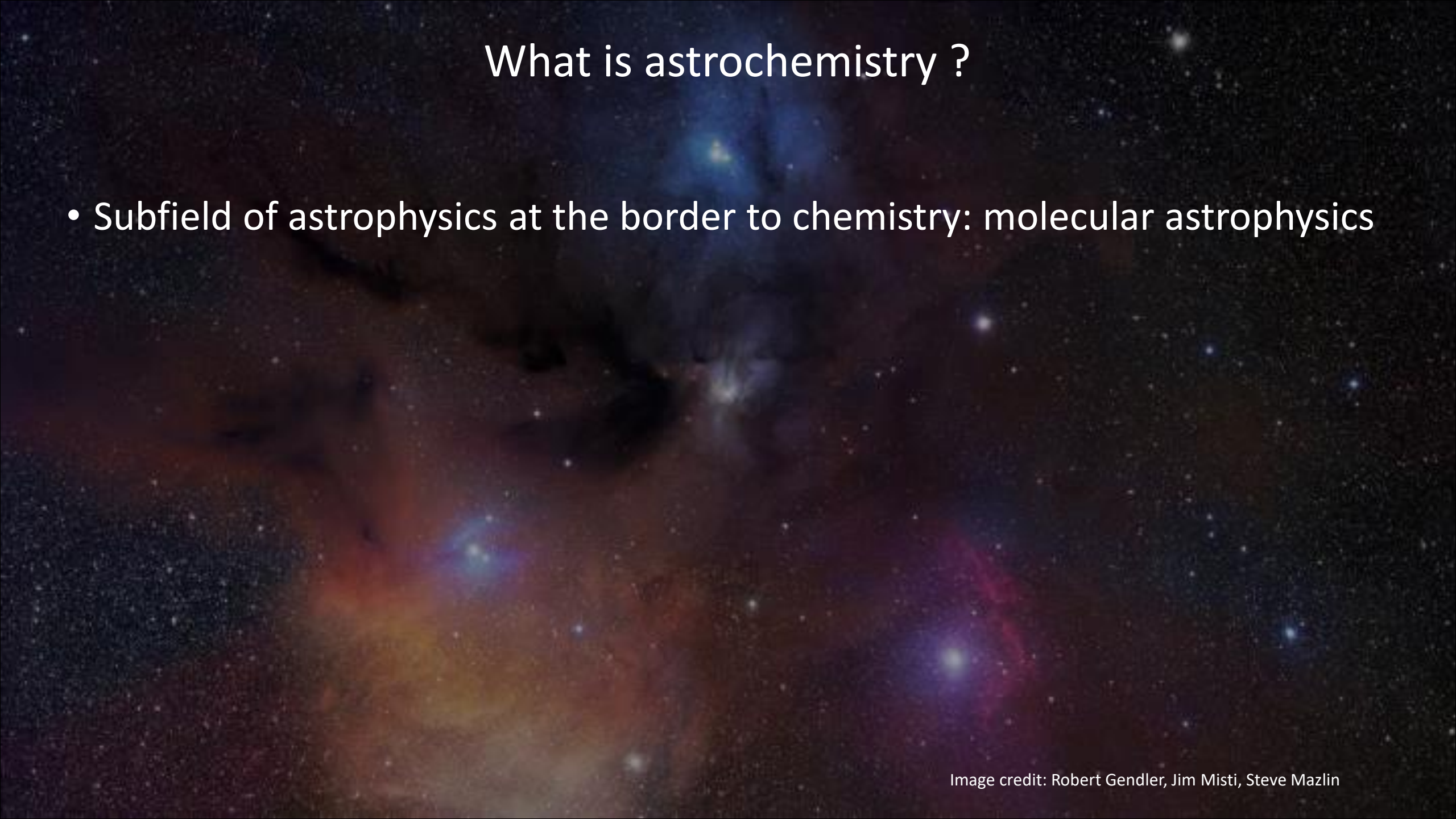


Image credit: Robert Gendler, Jim Misti, Steve Mazlin

What is astrochemistry ?

- Subfield of astrophysics at the border to chemistry: molecular astrophysics

- Studies abundances and reactions of molecules, and their interaction with radiation

Image credit: Robert Gendler, Jim Misti, Steve Mazlin

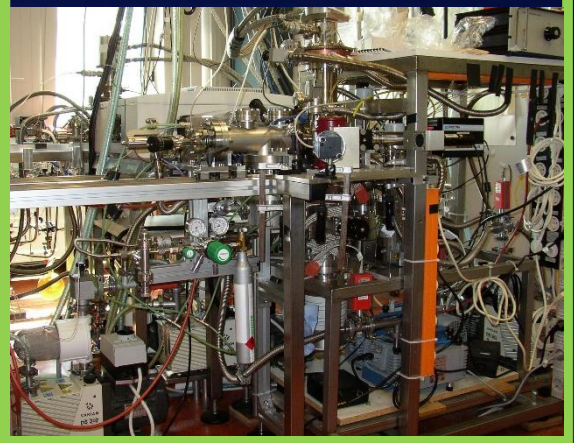
What is astrochemistry ?

- Subfield of astrophysics at the border to chemistry: molecular astrophysics
- Studies abundances and reactions of molecules, and their interaction with radiation
- A tool for understanding physical processes

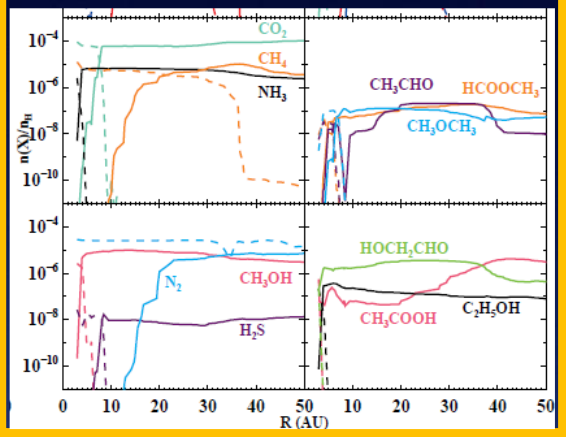
Image credit: Robert Gendler, Jim Misti, Steve Mazlin

The three pillars of astrochemistry

Lab experiments



Chemical modeling



Observations

The quest for a molecular inventory of space

- To date, more than 200 molecules have been identified in space

2 Atoms		3 Atoms		4 Atoms	5 Atoms	6 Atoms	7 Atoms
CH	CP	H_2O	N_2O	NH_3	HC_3N	CH_3OH	CH_3CHO
CN	NH	HCO^+	MgCN	H_2CO	HCOOH	CH_3CN	CH_3CCH
CH^+	SiN	HCN	$H3^+$	HNCO	CH_2NH	NH_2CHO	CH_3NH_2
OH	SO^+	OCS	SiCN	H_2CS	NH_2CN	CH_3SH	CH_2CHCN
CO	CO^+	HNC	AlNC	C_2H_2	H_2CCO	C_2H_4	HC_5N
H_2	HF	H_2S	SiNC	C_3N	C_4H	C_5H	C_6H
SiO	N_2	N_2H^+	HCP	HNCS	SiH_4	CH_3NC	c-C_2H_4O
CS	CF^+	C_2H	CCP	$HOCO^+$	c-C_3H_2	HC_2CHO	CH_2CHOH
SO	PO	SO_2	AlOH	C_3O	CH_2CN	H_2C_6	C_6H^-
SiS	O_2	HCO	H_2O^+	l-C_3H	C_5	C_5S	CH_3NCO
NS	AlO	HNO	H_2Cl^+	$HCNH^+$	SiC_4	HC_3NH^+	HC_5O
C_2	CN^-	HCS^+	KCN	H_3O^+	H_2CCC	C_5N	
NO	OH^+	HOC^+	FeCN	C_3S	CH_4	HC_4H	
HCl	SH^+	SiC_2	HO_2	c-C_3H	HCCNC	HC_4N	
NaCl	HCl^+	C_2S	TiO_2	HC_2N	HNCCC	c-H_2C_3O	
AlCl	SH	C_3	CCN	H_2CN	H_2COH^+	CH_2CNH	
KCl	TiO	CO_2	SiCSi	SiC_3	C_4H^-	C_5N^-	
AlF	ArH^+	CH_2	S_2H	CH_3	CNCHO	HNCHCN	
PN	NS^+	C_2O	HCS	C_3N^-	HNCNH	SiH_3CN	
SiC		MgNC	HSC	PH_3	CH_3O		
		NH_2	NCO	HCNO	NH_3D^+		
		NaCN		HOCN	H_2NCO^+		
				HSCN	$NCCNH^+$		
				HOOH	CH_3Cl		
				l-C_3H^+			
				HMgNC			
				HCCO			
				CNCN			

McGuire, 2018, ApJ SS 239, 17

8 Atoms	9 Atoms	10 Atoms	11 Atoms	12 Atoms	13 Atoms	Fullerenes
$HCOOCH_3$	CH_3OCH_3	$(CH_3)_2CO$	HC_9N	C_6H_6	c-C_6H_5CN	C_{60}
CH_3C_3N	CH_3CH_2OH	$HO(CH_2)_2OH$	CH_3C_6H	n-C_3H_7CN		C_{60}^+
C_7H	CH_3CH_2CN	CH_2CH_2CHO	CH_3CH_2OCHO	i-C_3H_7CN		C_{70}
CH_3COOH	HC_7N	CH_3C_5N	CH_3COOCH_3			
H_2C_6	CH_3C_4H	CH_3CHCH_2O				
CH_2OHCHO	C_8H	CH_3OCH_2OH				
HC_6H	CH_3CONH_2					
CH_2CHCHO	C_8H^-					
CH_2CCHCN	CH_2CHCH_3					
NH_2CH_2CN	CH_3CH_2SH					
CH_3CHNH	HC_7O					
CH_3SiH_3						

The quest for a molecular inventory of space

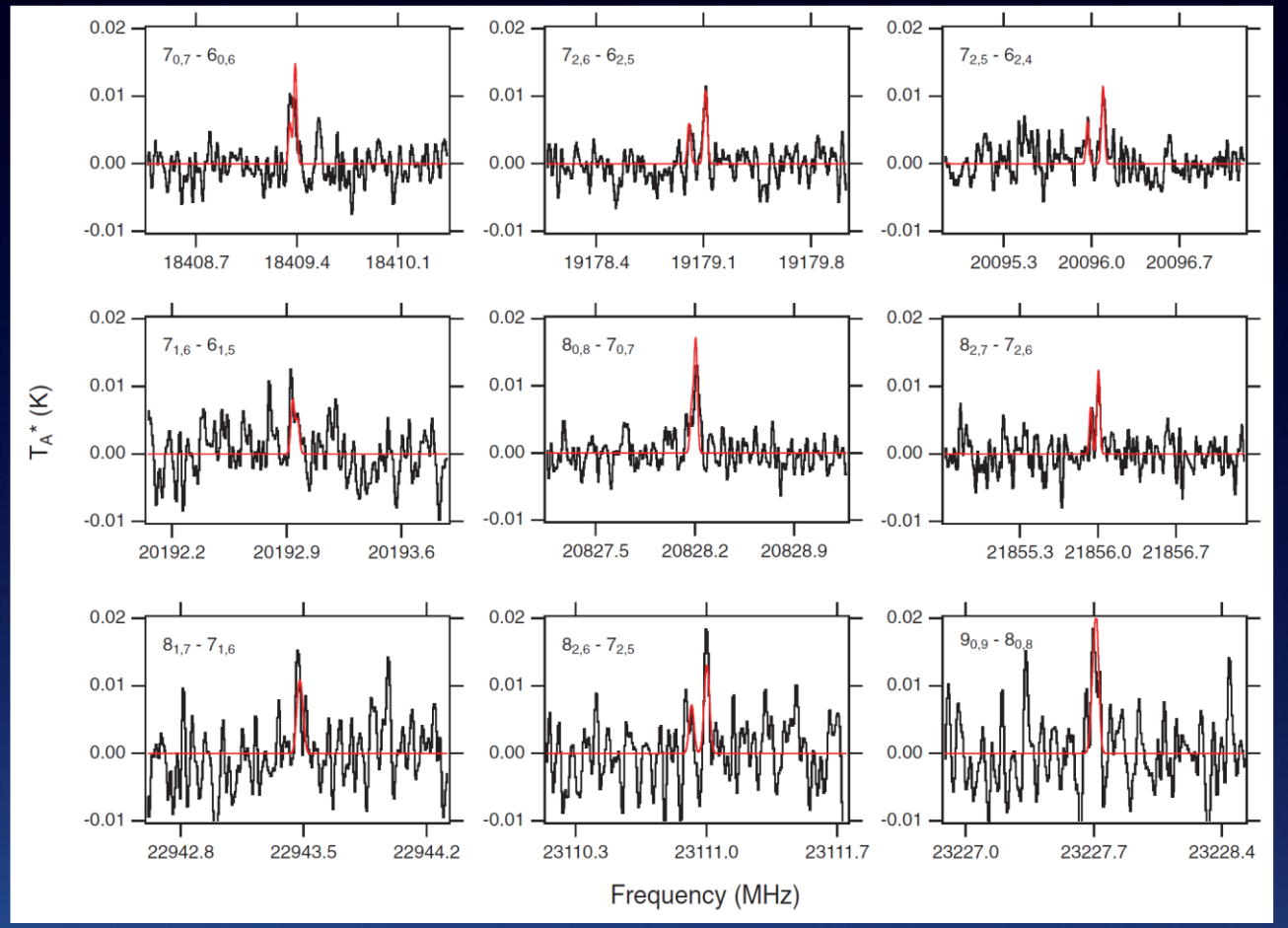
- To date, more than 200 molecules have been identified in space
- Rotational transitions of larger, heavier species occur at longer wavelengths

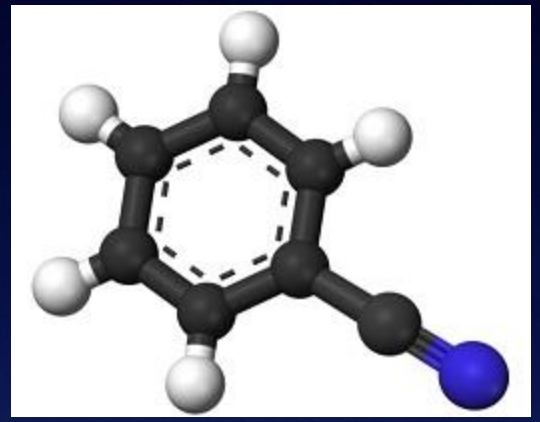
The quest for a molecular inventory of space

- To date, more than 200 molecules have been identified in space
- Rotational transitions of larger, heavier species occur at longer wavelengths
- Many recent new detections achieved at wavelengths longer than 4mm/ frequencies below 80 GHz with Yebes and Green Bank telescopes

Recent molecules detected in 20-50 GHz range

Aromatic molecule: Benzonitrile c-C_6H_5CN

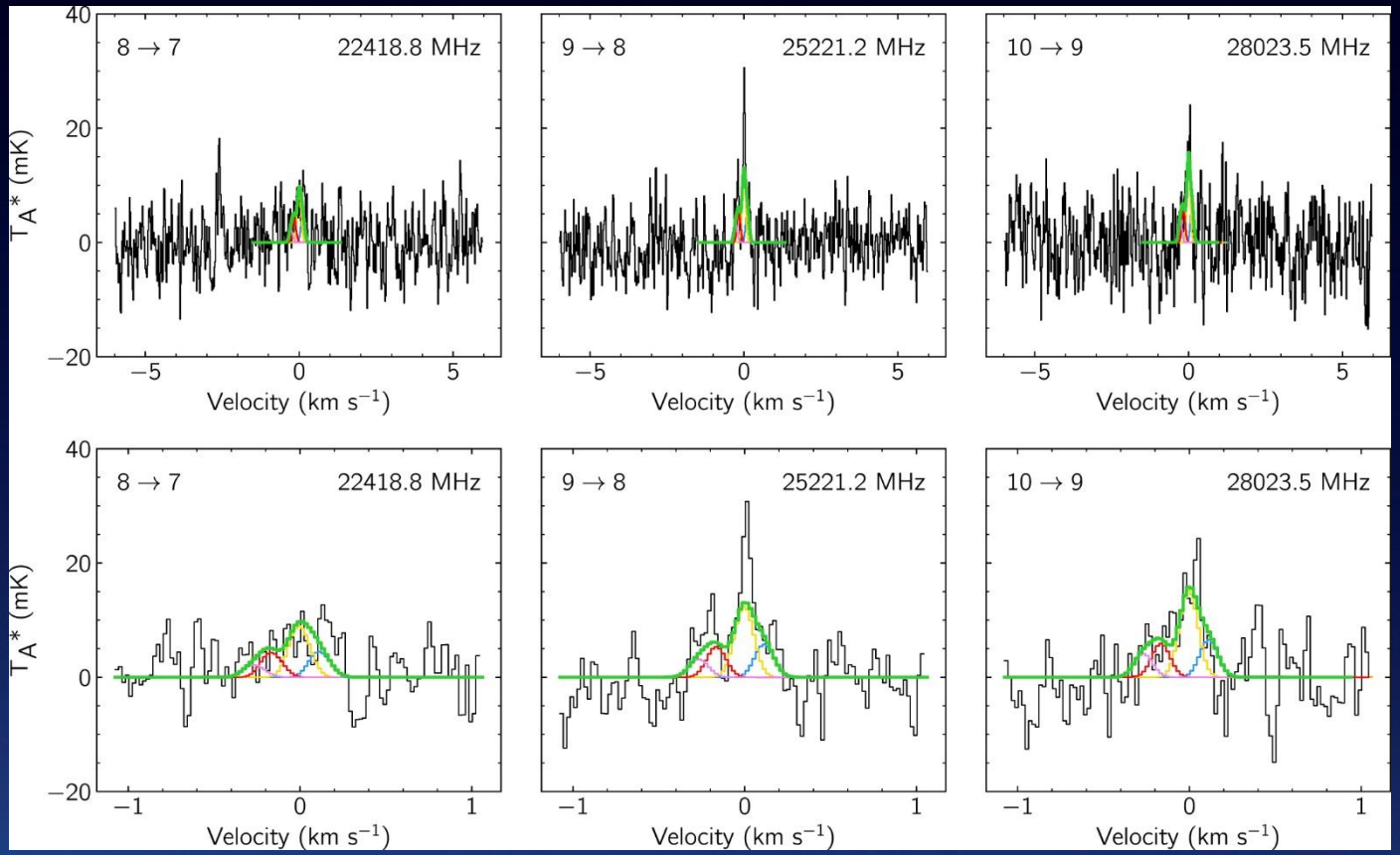




McGuire et al. 2018, Science 359, 202-205

Recent molecules detected in 20-50 GHz range

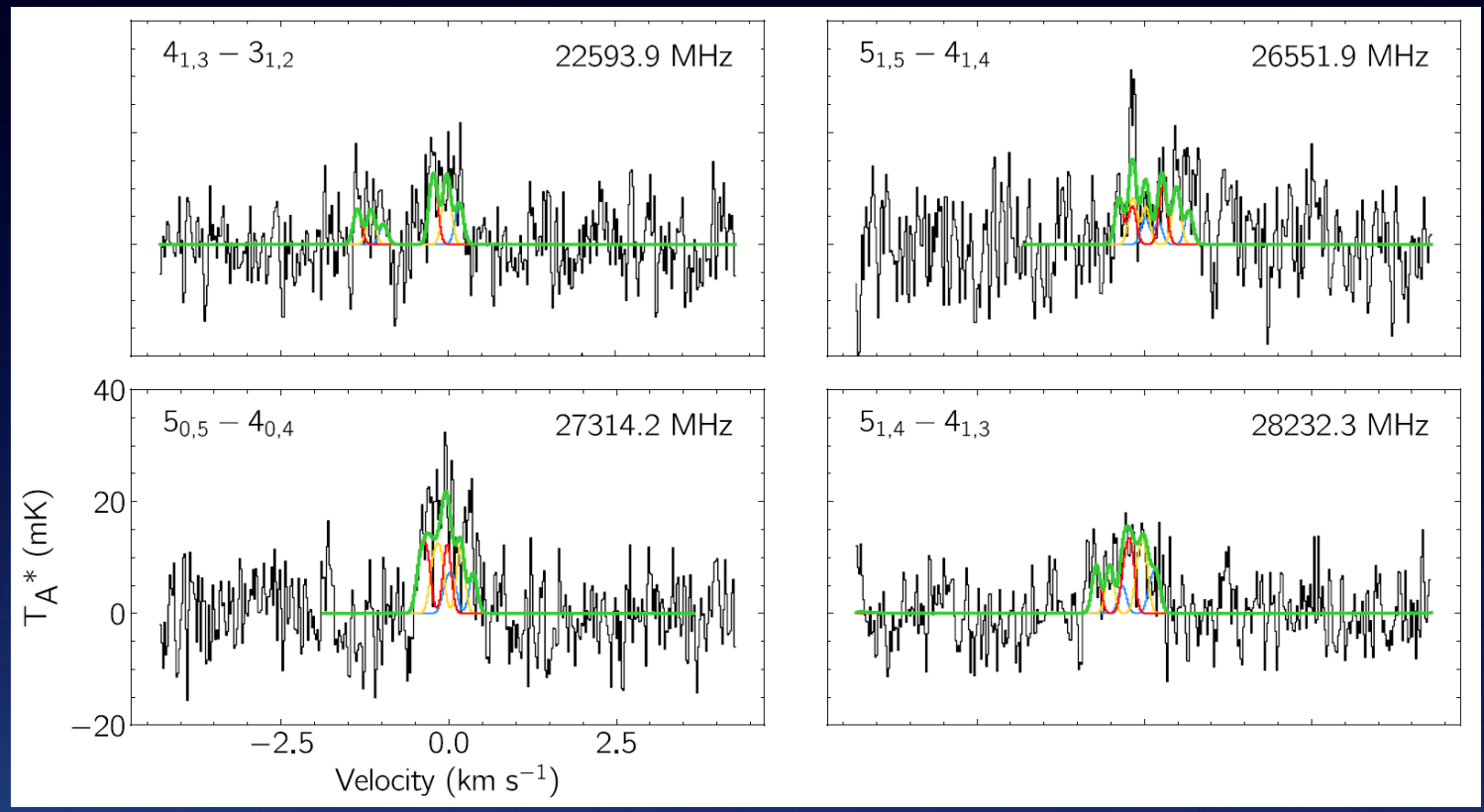
Isocyanodiacetylene HC_4NC (isomer of HC_5N)



Xue et al. 2020, ApJL 900, L9,
see also Cernicharo et al. 2020, A&A 642, L8

Recent molecules detected in 20-50 GHz range

Propargyl cyanide $HCCCH_2CN$

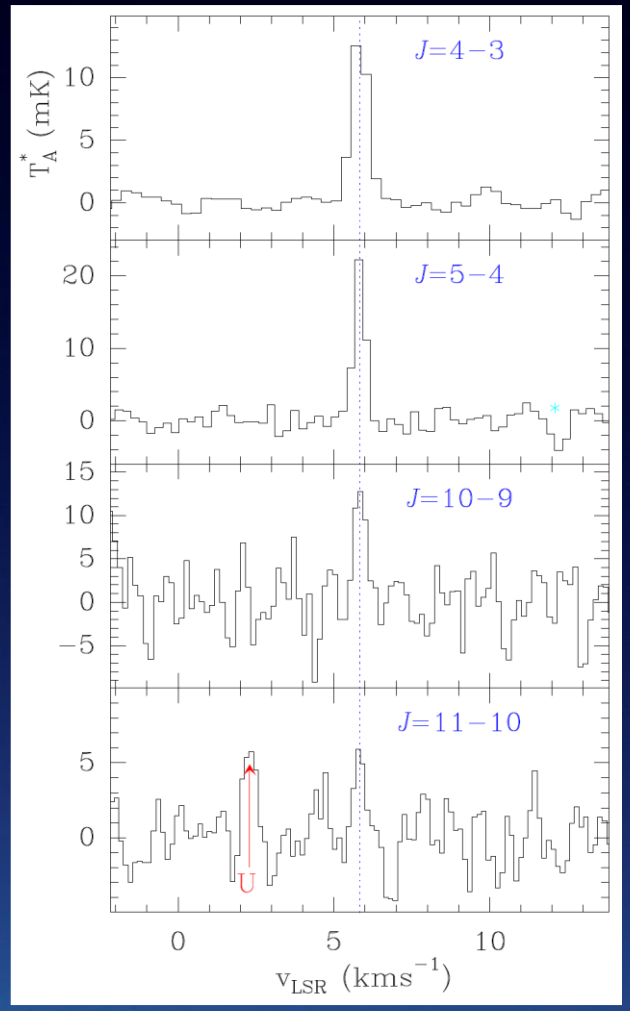


McGuire et al. 2020, ApJL 900, L10

see also Marcelino et al. 2021, A&A 646, L9

Recent molecules detected in 20-50 GHz range

HC_3O^+



$J_u - J_l$	ν_{obs} $^{(a)}$ (MHz)
4–3	35684.590
5–4	44605.748
10–9	89209.744
11–10	98130.286

Cernicharo et al. 2020, A&A 642, L17

Recent molecules detected in 20-50 GHz range

2021	$c\text{-}C_5H_5CN$ cyanocyclo-pentadiene	**Interstellar detection of the highly polar five-membered ring cyanocyclopentadiene** M. C. McCarthy, K. L. K. Lee, R. A. Loomis, A. M. Burkhardt, C. N. Shingledecker, S. B. Charnley, M. A. Cordiner, E. Herbst, S. Kalen, Remijan,
2021	$HC_{11}N$ cyanopenta-acetylene Astromolecule of the Month	**An inves tech** R. Shi Cord Lee, C. M
2021	$HC{\equiv}CCH{=}CHC{\equiv}N$ trans-cyanovinyl-acetylene	**cya an** K. S
2021	$H_2C{=}CHC_3N$ vinylcyanoacetylene	

2021	$C_{10}H_7CN$ 2-cyanonaphthalene	**D** Shir M. A Rei
2021	CH_2CHCCH vinyl acetylene	**Disc of ten** J. Cerni Marce Gallego, P. de
2021	$H_2CCCHCCH$ allenyl acertylene	**Disc H_2CCCH** J. Cernicha Tercero, Tercero, J. and P. de
2021	CH_2CCH propargyl radical	**Discover (CH_2CCH) abundant ra species for c** M. Agúndez, Marcelino, J. D. Gallego, P. de Vicente, and J. Cernicharo. A&A 647:L10 (2021).

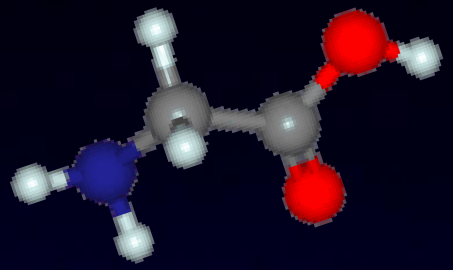
2021	$c\text{-}C_5H_5CN$ cyanocyclo-pentadiene	**Interstellar detectio five-mem cyanocycl** M. C. McCarthy, K. A. M. Burkhardt, C. Charnley, M. A. Kalenskii, E. F Remijan, and B. A 5:17
2021	$HC_{11}N$ cyanopenta-acetylene Astromolecule of the Month	**An investigatio techniques det** R. A. Loom Shingledet Cordiner, E. Lee, E. R. W C. McCart As
2021	$HC{\equiv}CCH{=}CHC{\equiv}N$ trans-cyanovinyl-acetylene	**Disc cyanovin and viny in GO** K. L. K. I I. R. C Shingle M. C.
2021	$H_2C{=}CHC_3N$ vinylcyanoacetylene	**cya and i** K. S

2021	$H_2CCCHCCH$ allenyl acertylene	**Discovery of allenyl acetylene, $H_2CCCHCCH$, in TMC-1 - A study of the isomers of C_5H_4** J. Cernicharo, C. Cabezas, M. Agúndez, B. Tercero, N. Marcelino, J. R. Pardo, F. Tercero, J. D. Gallego, J. A. López-Pérez, and P. deVicente. A&A 647:L3 (2021).
2021	CH_2CCH propargyl radical	**Discovery of the propargyl radical (CH_2CCH) in TMC-1: One of the most abundant radicals ever found and a key species for cyclization to benzene in cold dark clouds** M. Agúndez, C. Cabezas, B. Tercero, N. Marcelino, J. D. Gallego, P. de Vicente, and J. Cernicharo. A&A 647:L10 (2021).
2021	NCS thiocyanogen	**TMC-1, the starless core sulfur factory: Discovery of NCS, HCCS, H_2CCS, H_2CCCS, and C_4S and detection of C_5S** J. Cernicharo, C. Cabezas, M. Agúndez, B. Tercero, J. R. Pardo, N. Marcelino, J. D. Gallego, F. Tercero, J. A. López-Pérez, and P. de Vicente. A&A 648:L3 (2021).
2021	HCCS thioketenyl radical	**TMC-1, the starless core sulfur factory: Discovery of NCS, HCCS, H_2CCS, H_2CCCS, and C_4S and detection of C_5S** J. Cernicharo, C. Cabezas, M. Agúndez, B. Tercero, J. R. Pardo, N. Marcelino, J. D. Gallego, F. Tercero, J. A. López-Pérez, and P. de Vicente. A&A 648:L3 (2021).
2021	H_2CCS thioketene Astromolecule of the Month	**TMC-1, the starless core sulfur factory: Discovery of NCS, HCCS, H_2CCS, H_2CCCS, and C_4S and detection of C_5S** J. Cernicharo, C. Cabezas, M. Agúndez, B. Tercero, J. R. Pardo, N. Marcelino, J. D. Gallego, F. Tercero, J. A. López-Pérez, and P. de Vicente. A&A 648:L3 (2021).

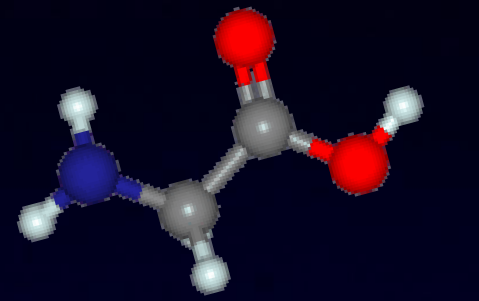
www.astrochymist.org

Perspectives for SKA-mid (band 6)

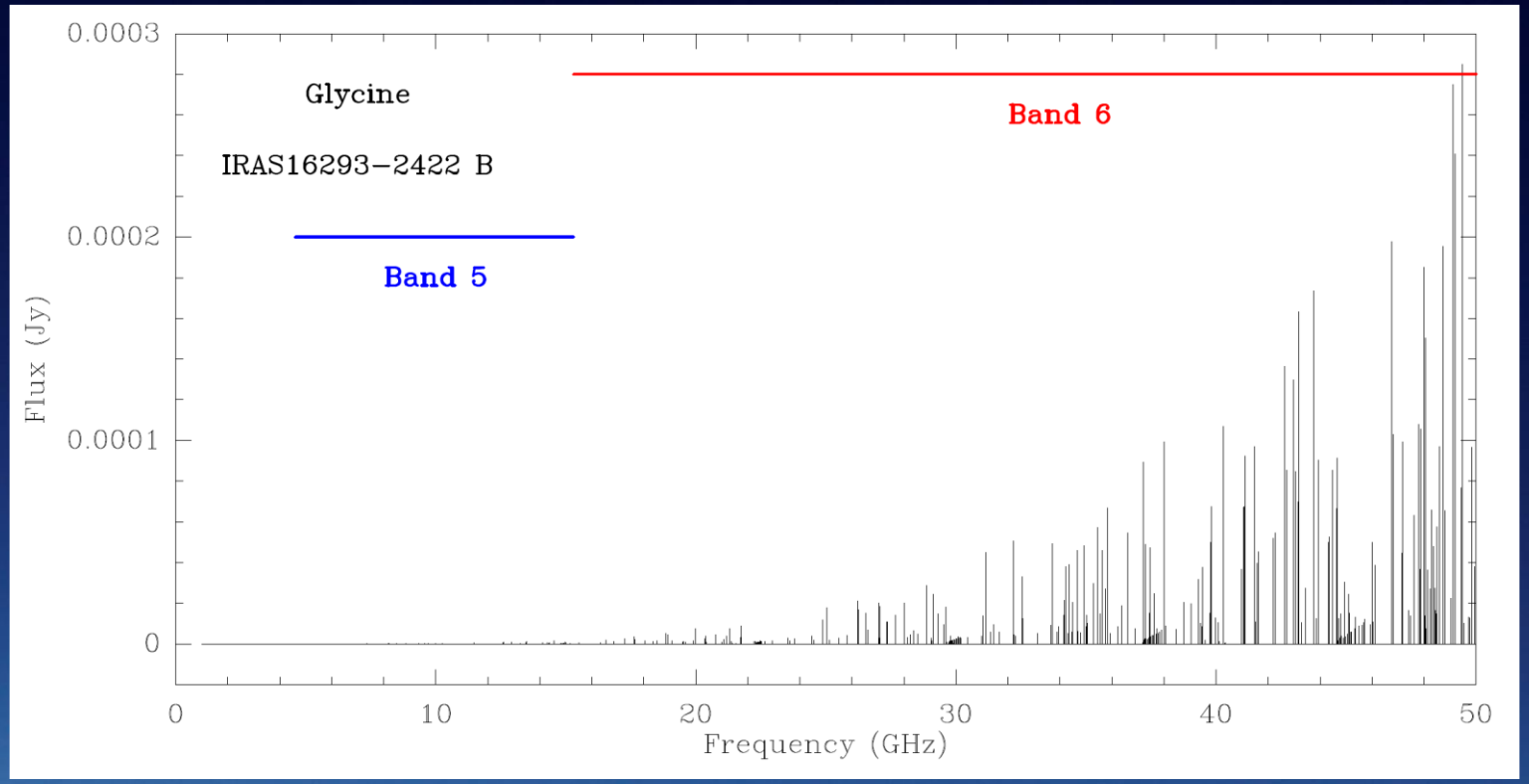
- A wealth of new molecules has recently been detected in this range
- Most of these are however just detections, no spatial information
- Potential for SKA:
  - Higher sensitivity
  - Mapping capabilities
  - Probing different environments, not just the brightest targets



Prebiotic molecules with the SKA

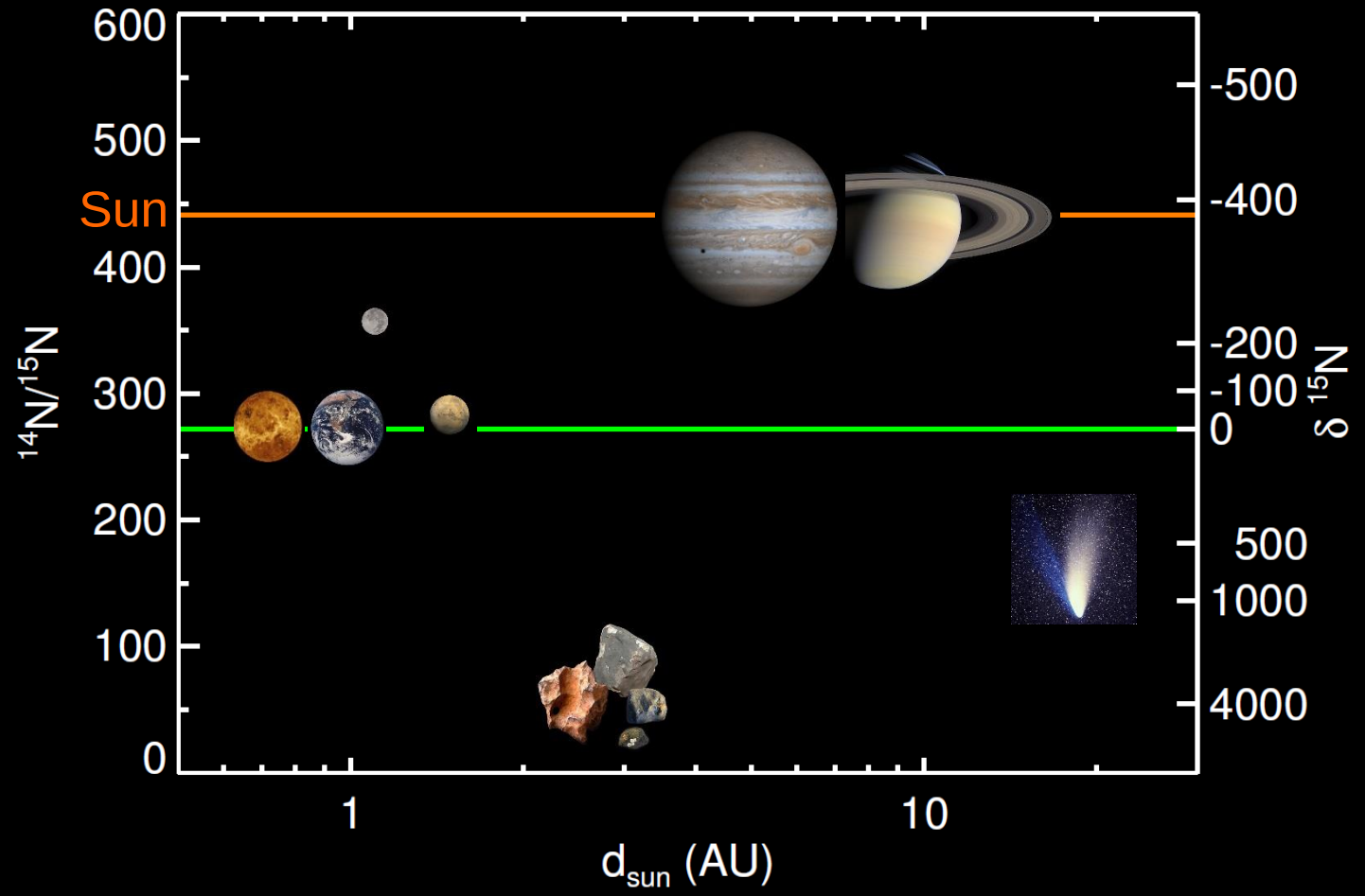


- Strong interest in prebiotic molecules like amino acids and their precursors
- Glycine has been detected in meteorites and comets, but not yet in the ISM
- Only attempted at (sub-)mm ⟶ new opportunity with SKA!



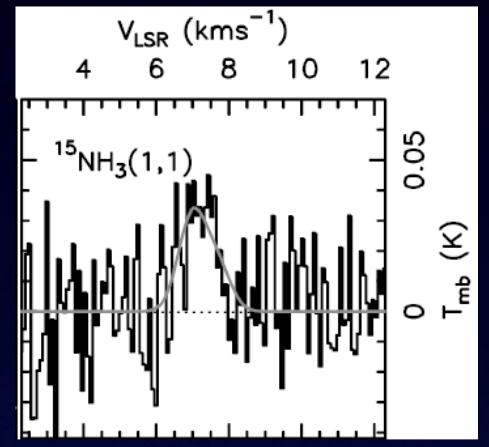
SKA Memo 20-01
Conway et al.

Probing isotopic variations?



$^{14}NH_3/^{15}NH_3$ in star-forming regions

- Lines in the 22-23 GHz range
- Only two direct measurements to date (Lis et al. 2010)
- Project with Yebes 40m: only 1 tentative detection
  Problem: beam dilution (86'' at 22 GHz)
- Effelsberg 100m or GBT beams still fairly large
  (34'' at 22 GHz). Project for 2 prestellar cores (1 detection)
  and comet Wirtanen (non-detection).
- VLA is an option, but sensitivity is an issue.
  Surveys remain difficult.



→ SKA an interesting opportunity if frequencies become available!

Committee for Radioastronomy Frequencies (CRAF)

International spectrum management

- Allocation of frequency spectrum resources is the sovereign right of national governments (in Switzerland: BAKOM/OFCOM)

- Radiowaves do not respect national borders

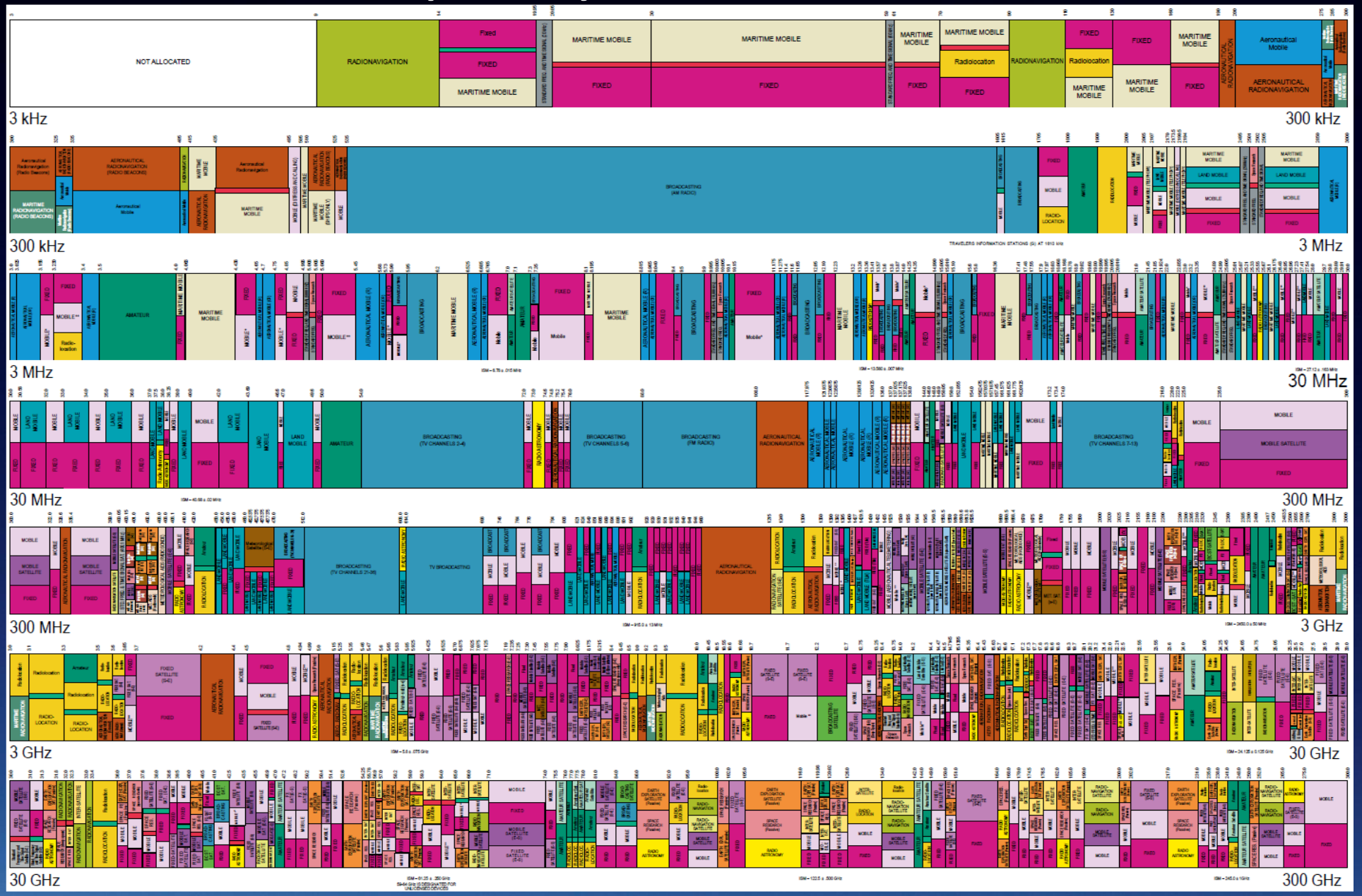
  → international regulations required!

- **International Telecommunication Union (ITU):**
  Agency of United Nations responsible for coordination of radiocommunication services and harmonization of radiofrequency spectrum at international level

  Assisted by regional telecom organizations (e.g. CEPT)

European Conference of Postal and Telecommunications Administrations (CEPT)

Frequency allocation chart

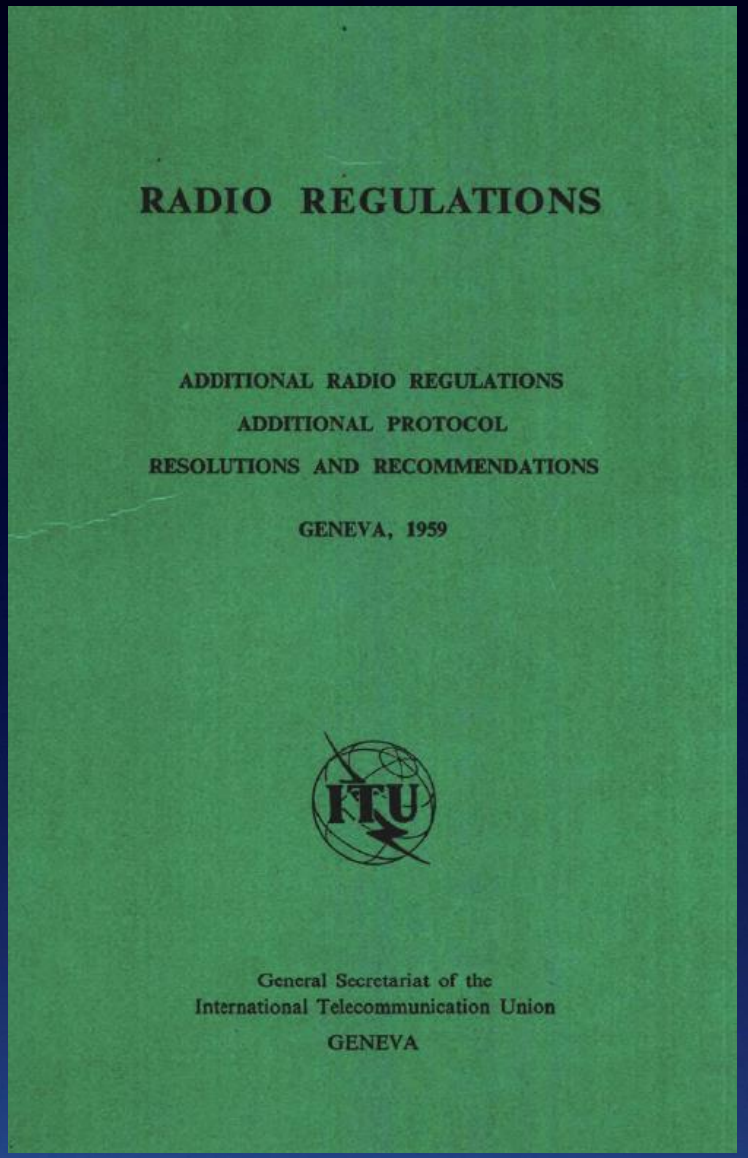


Radioastronomy Service (RAS)

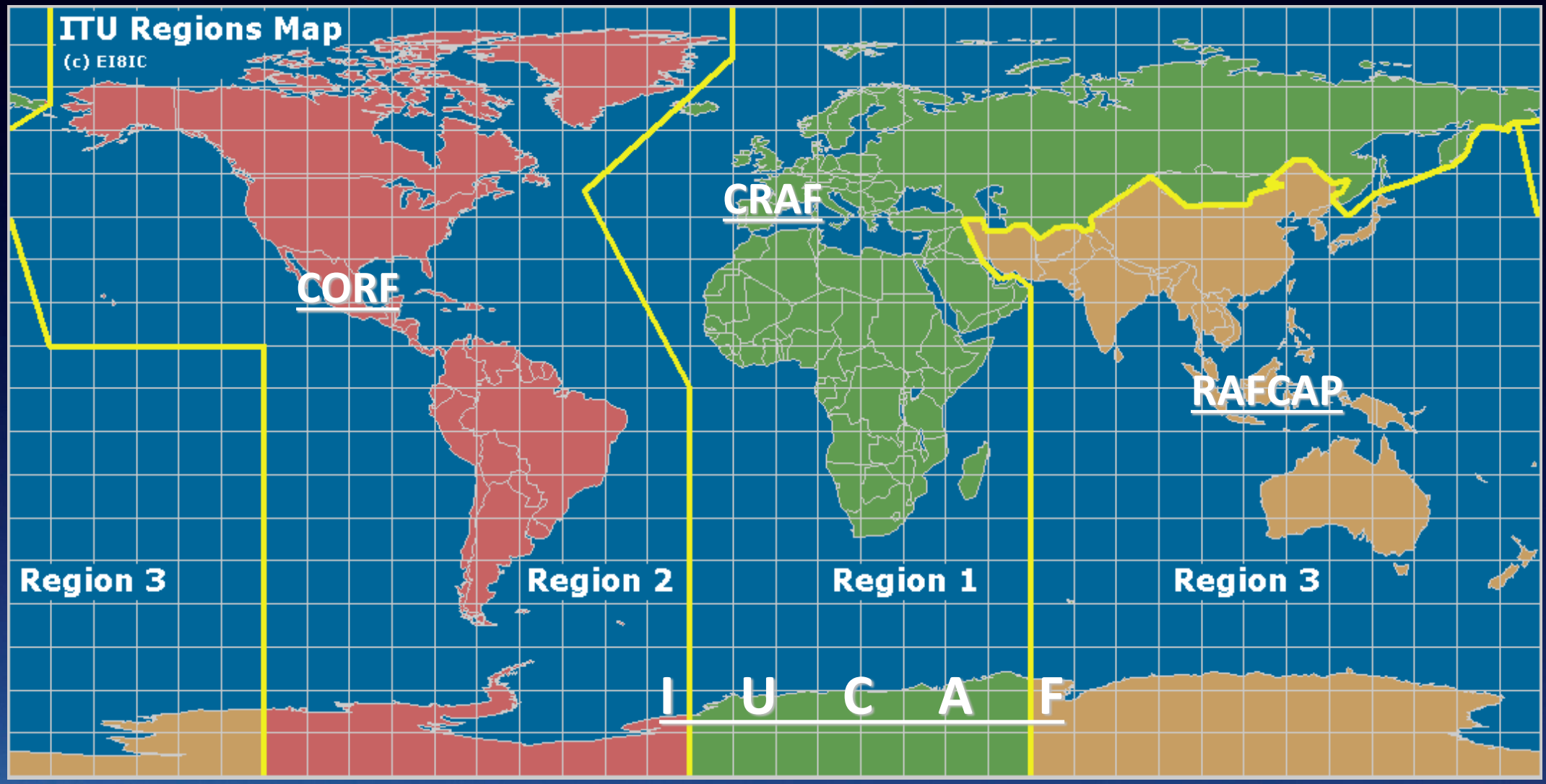
- Radio Astronomy recognized as (passive) *radiocommunication service* in 1959 creating legal basis to seek protection from interference

- Series of frequency bands allocated to RAS. Some bands provide exclusive allocation ("all emissions prohibited"), some do not.

- RAS interests have to be continuously protected as new or higher frequency applications become available



Radioastronomy represented by regional committees



What is CRAF?

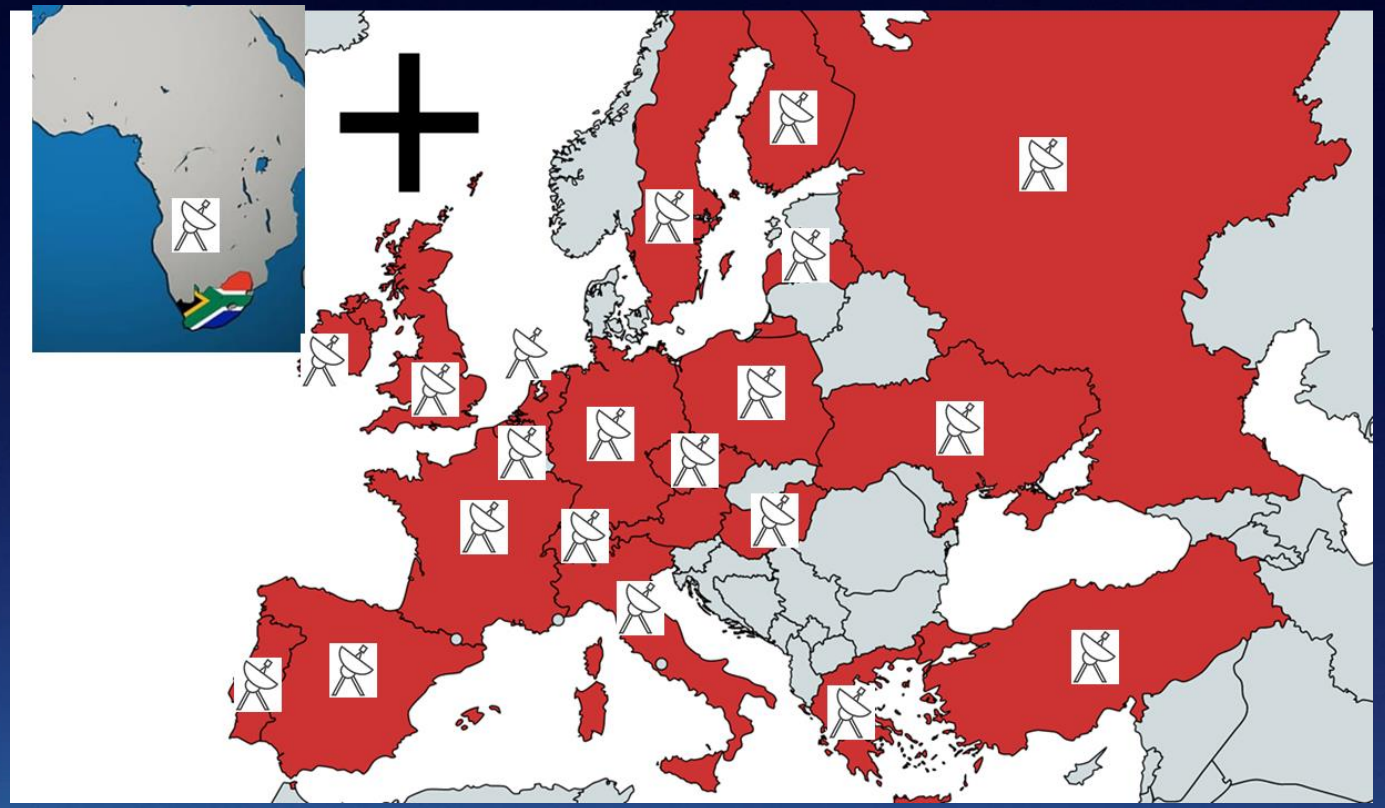
CRAF – COMMITTEE ON RADIO ASTRONOMY FREQUENCIES

EUROPEAN SCIENCE FOUNDATION

- Committee on radio astronomy frequencies is an expert committee of the European Science Foundation and was established in 1988

- 22 member countries and several international organi-zations with observer status - including SKAO!

- A lot more info: www.craf.eu



Representation at CRAF
on behalf of Swiss Commission for Astronomy (SCFA)
of the Swiss Academy of Sciences (SCNAT)

Until November 2020:
Christian Monstein, ETHZ

Since December 2020:
Axel Murk (IAP) and **Susanne Wampfler** (CSH), University of Bern

Need your support and may need YOUR expertise!