Tracing the chemistry in the clumpy shells around carbon-rich AGB-stars with the JVLA

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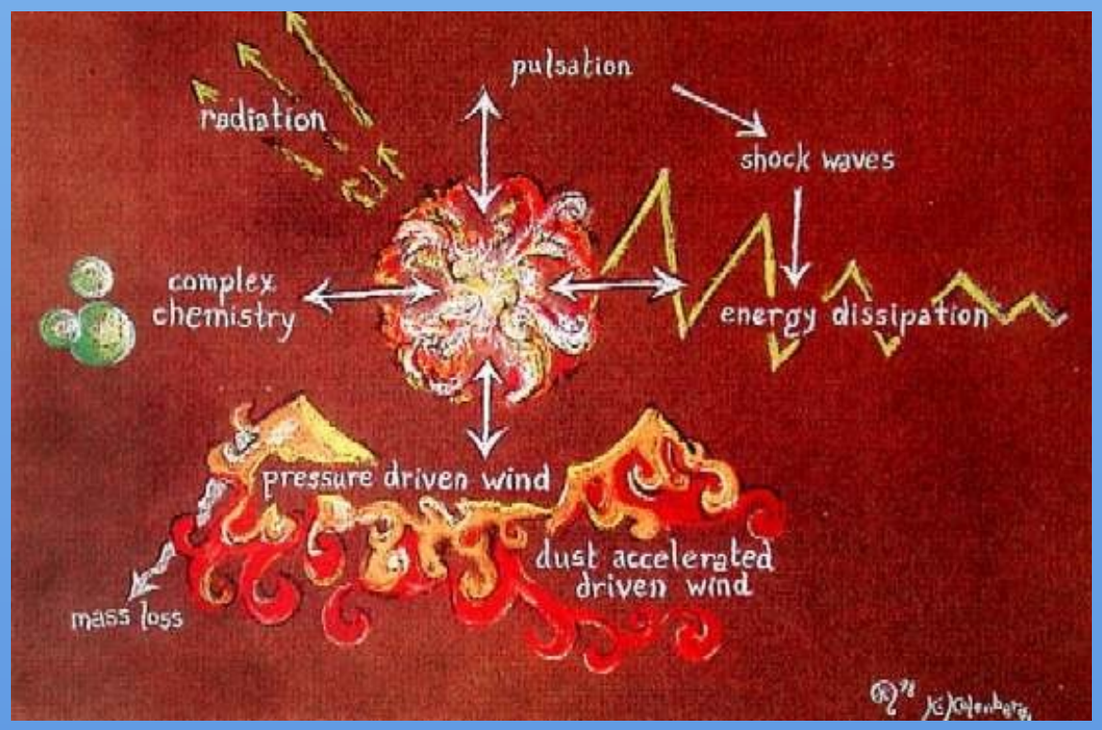
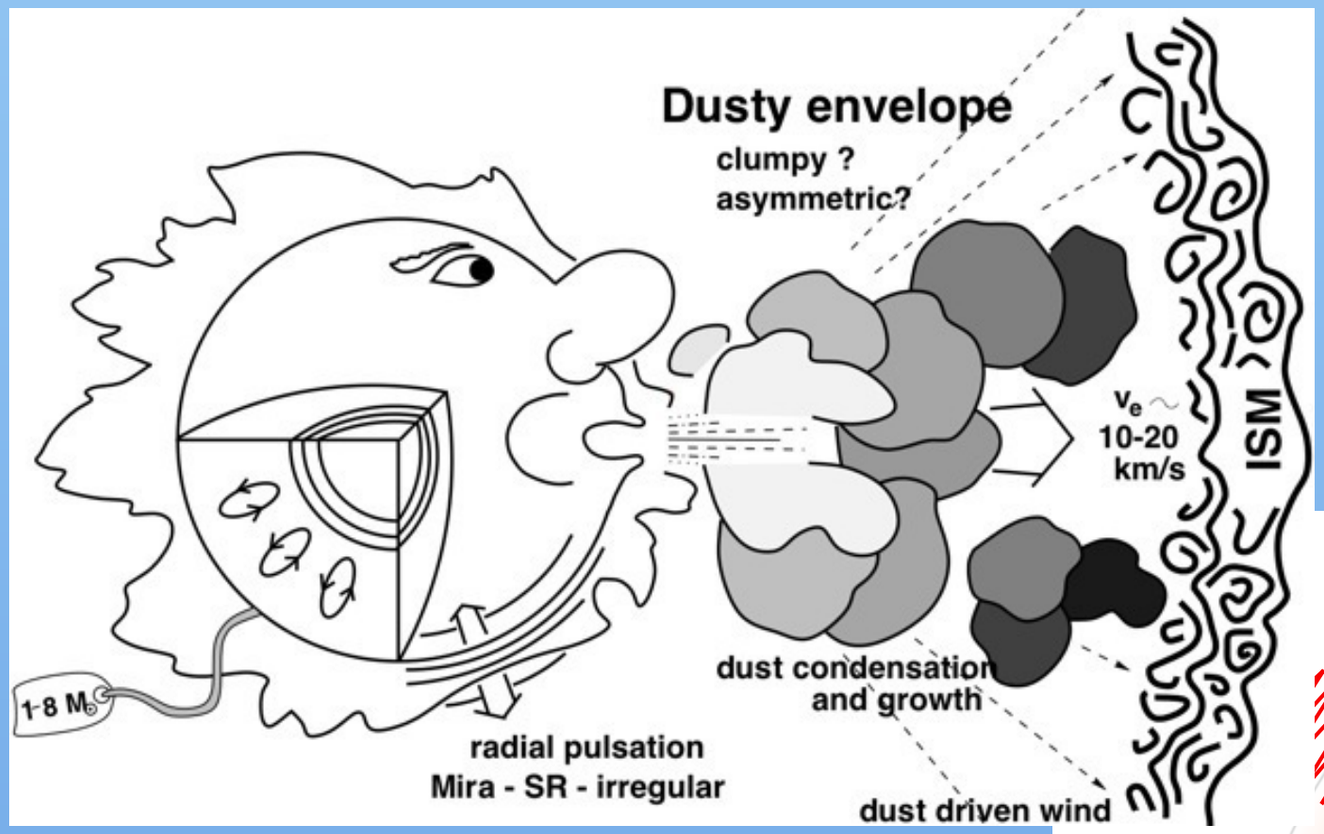
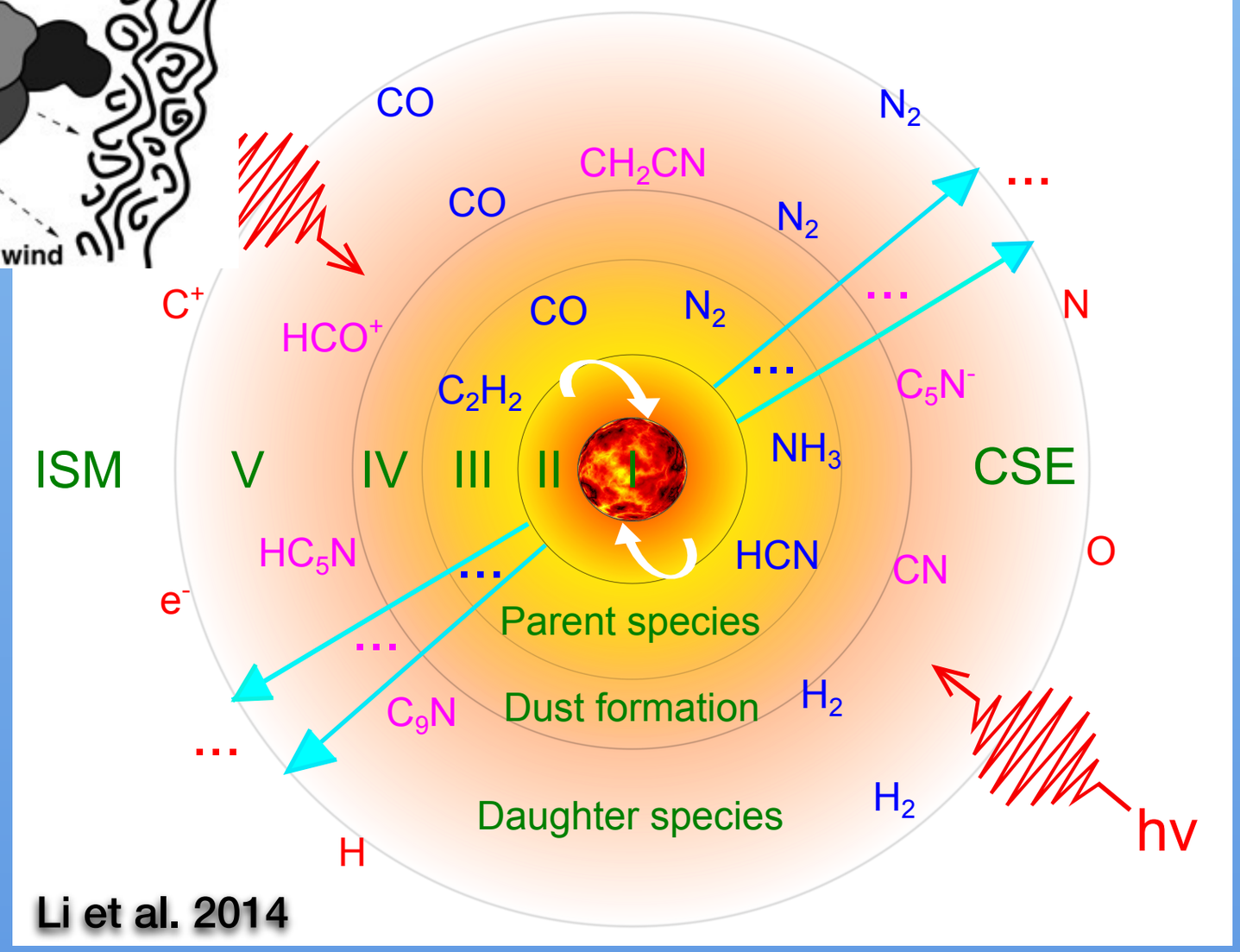
Overview

- AGB-stars and their circumstellar envelopes (CSE)
- The carbon star IRC+10216
- Carbon chemistry
- The JVLA survey of IRC+10216
- Results & future work

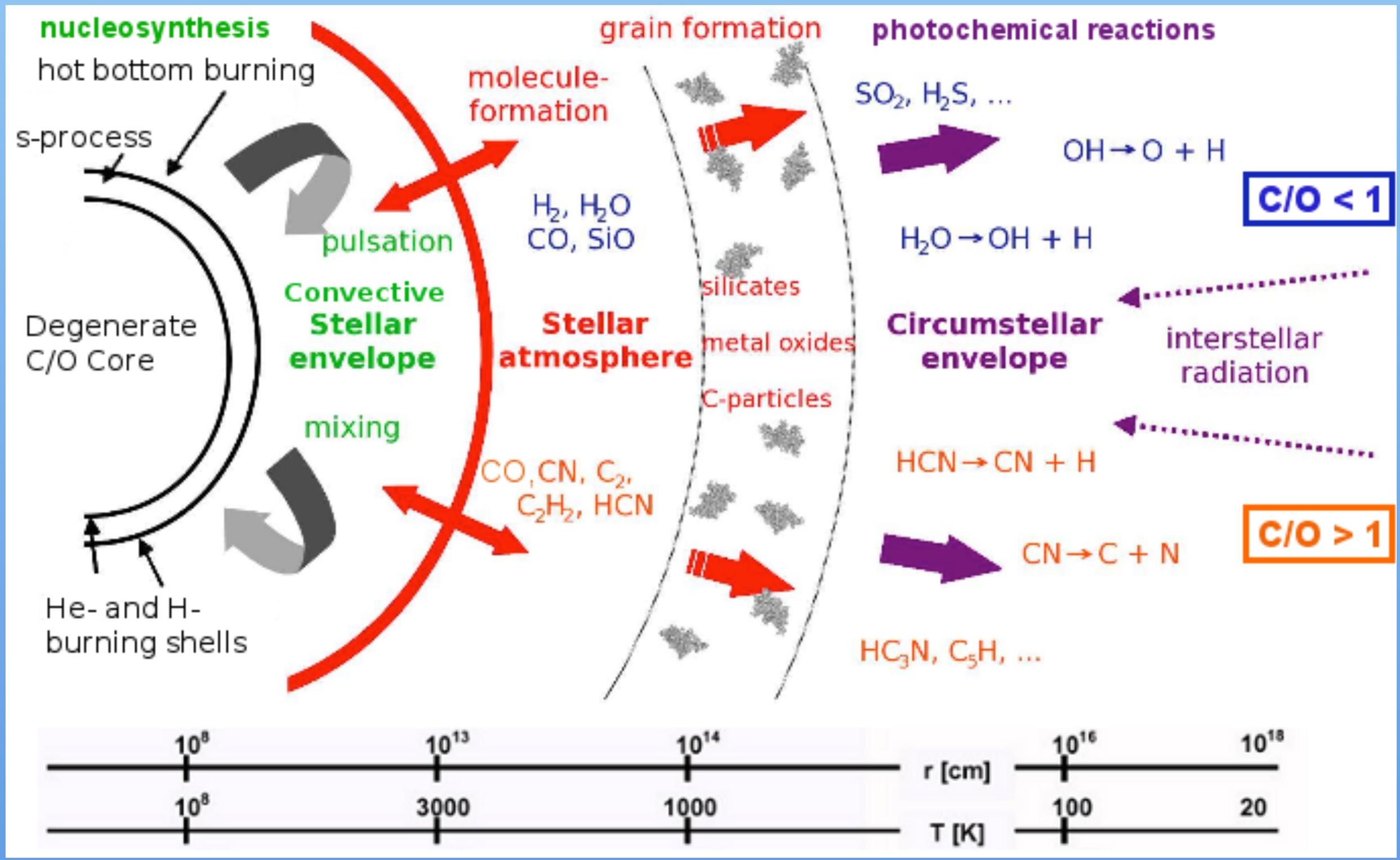


AGB stars and their circumstellar envelopes





Circumstellar envelope



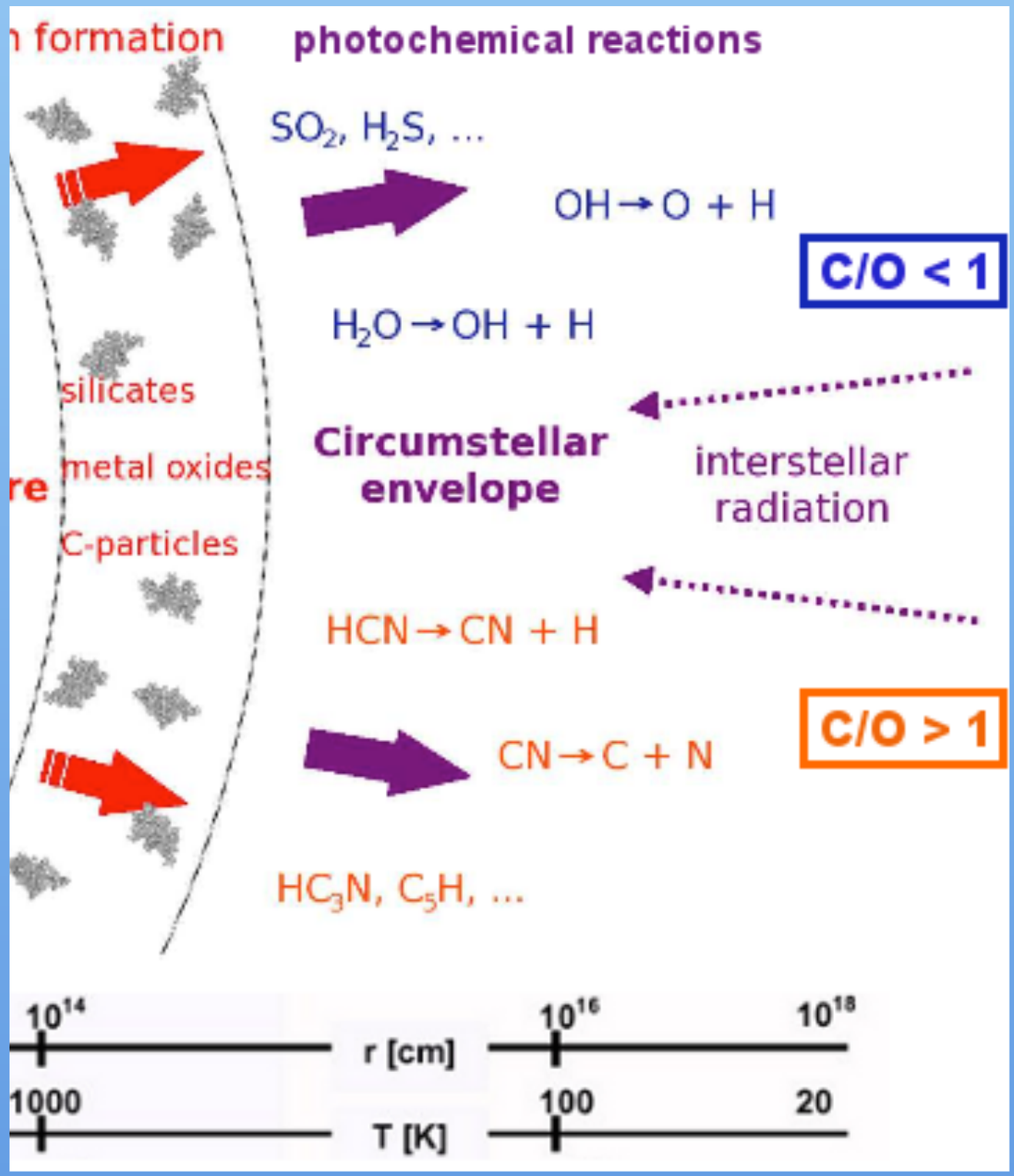
Adapted from Habing&Olofsson 2003, Maercker 2009, Decin et al. 2010 and J. Hron

Circumstellar envelope

- Evolution O-rich to C-rich
- Observations of molecules in CSE trace
  - Chemical processes
  - Physical conditions
  - Abundances and nucleosynthesis

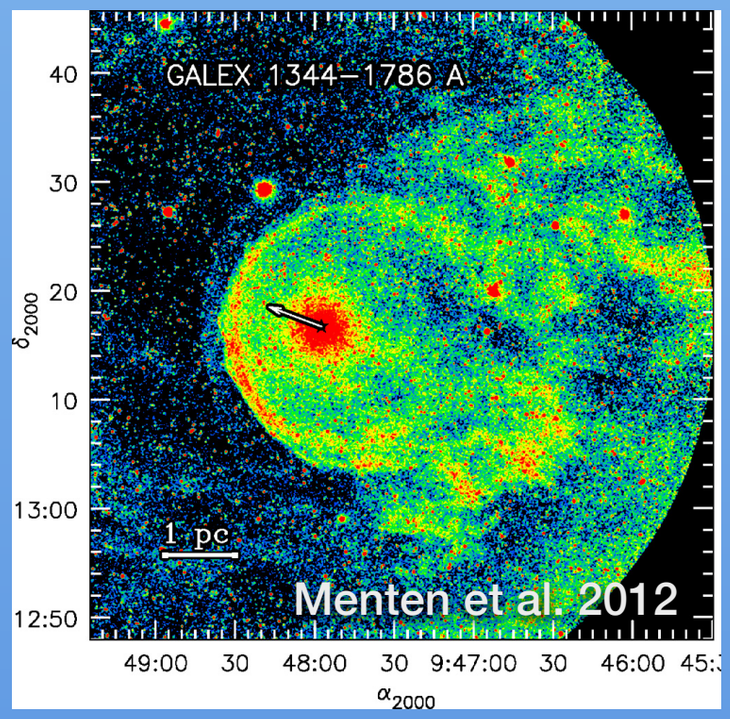
➡ dust-gas chemistry

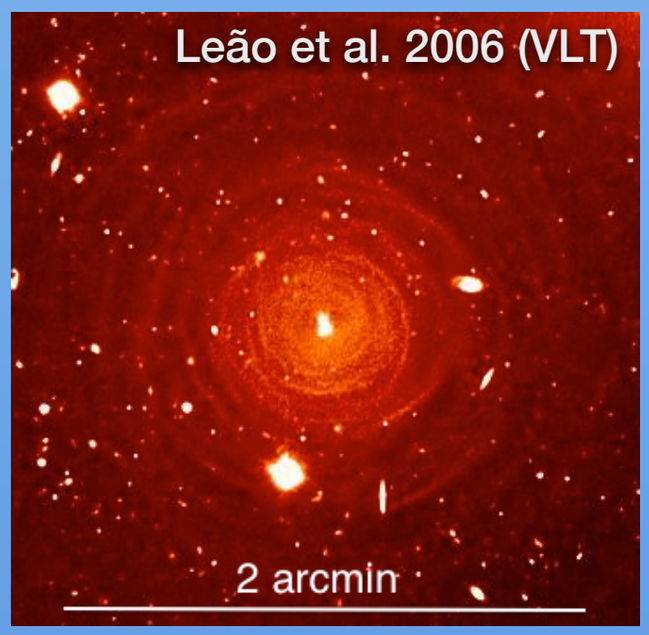
➡ UV-induced chemistry



The carbon star IRC+10216

- Prototypical carbon-rich AGB-star a.k.a. CW Leo
- Cool and luminous: ~2700 K, ~10 000 $L_\odot$
- Pulsation period: ~630 days
- Nearby: ~130 pc
- High mass-loss rate: 2×10^{-5} $M_\odot$ yr^{-1}
- Mass estimate: ~ 1 - 2 $M_\odot$
- C/O ~ 1.4
- more than 80 molecules detected





Molecule	Abundance relative to H_2			Reference
	1–5 R_*	→	2×10^{15} cm	
CS	4×10^{-6}	→	7×10^{-7}	(1)
SiO	.....		1.8×10^{-7}	(1)
SiS	3×10^{-6}	→	1.3×10^{-6}	(1)
NaCl[a]	.....		1.8×10^{-9}	(1)
KCl[a]	7×10^{-10}	→	5×10^{-10}	(1)
AlCl[a]	.....		7×10^{-8}	(1)
AlF	.....		1×10^{-8}	(1)
NaCN[a]	.....		3×10^{-9}	(1)
CO	.....		6×10^{-4}	(1)
C_2H_2	.....		8×10^{-5}	(2)
HCN	.....		2×10^{-5}	(2)
CH_4	.....		3.5×10^{-6}	(3)
NH_3	.....		2×10^{-6}	(4)
SiH_4	.....		2.2×10^{-7}	(3)
SiC_2	.....		2×10^{-7}	(5)
H_2O	.....		1×10^{-7}	(6)
HCl	.....		1×10^{-7}	(7)
HCP	.....		2.5×10^{-8}	(8)
C_2H_4	.....		2×10^{-8}	(9)
HF	.....		8×10^{-9}	(7)
PH_3	.....		8×10^{-9}	(10)
H_2S	.....		4×10^{-9}	(11)

Agúndez et al. 2012

The carbon star IRC+10216

- Isotopic ratios from isotopologues
- selective effects:
  - line opacities
  - photodissociation
  - chemical fractionation
  - radiative excitation

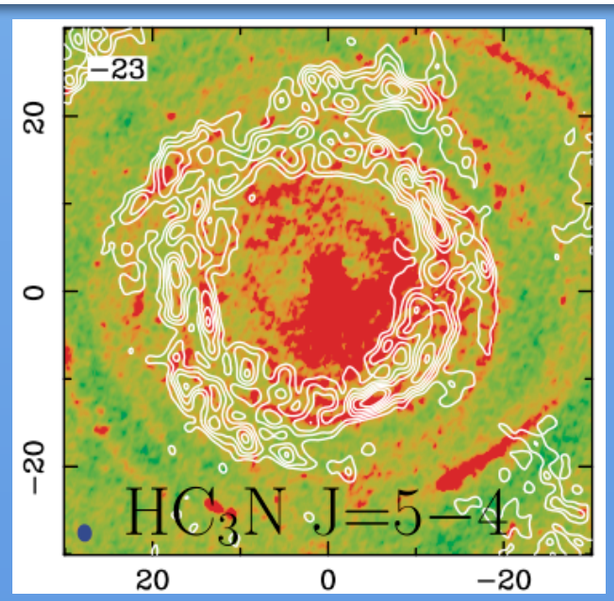
➡ observations & chemical models

- molecular abundance distribution from observations and models inconsistent

- density-enhanced shells: gas & dust

Ratio	Value	1 σ	Ref.[a]	Solar[b]
$Na^{35}Cl/Na^{37}Cl$ (7-6)	2.33	0.50	(1)	
$Al^{35}Cl/Al^{37}Cl$ (15-14)	2.15	0.33	(1)	
$Na^{35}Cl/Na^{37}Cl$ (8-7)	1.78	0.59	(2)	
$Al^{35}Cl/Al^{37}Cl$ (10-9)	3.17	0.79	(3)	
$Al^{35}Cl/Al^{37}Cl$ (11-10)	2.40	0.76	(3)	
$^{35}Cl/^{37}Cl$[c]	2.30	0.24	(1)	3.13
$^{12}C/^{13}C$	45	3	(3)	89
$^{14}N/^{15}N$	$>$ 4400		(4)	270
$^{16}O/^{17}O$	840	200	(5)	2610
$^{16}O/^{18}O$	1260	280	(5)	499
$^{24}Mg/^{25}Mg$	7.60	1.1	(6)	7.94
$^{24}Mg/^{26}Mg$	6.50	0.7	(6)	7.19
$^{29}Si/^{30}Si$	1.45	0.13	(3)	1.52
$^{28}Si/^{29}Si$[d]	$>$ 15.4		(3)	19.8
$^{34}S/^{33}S$	5.55	0.31	(3)	5.62
$^{32}S/^{34}S$	21.8	2.6	(3)	22.5

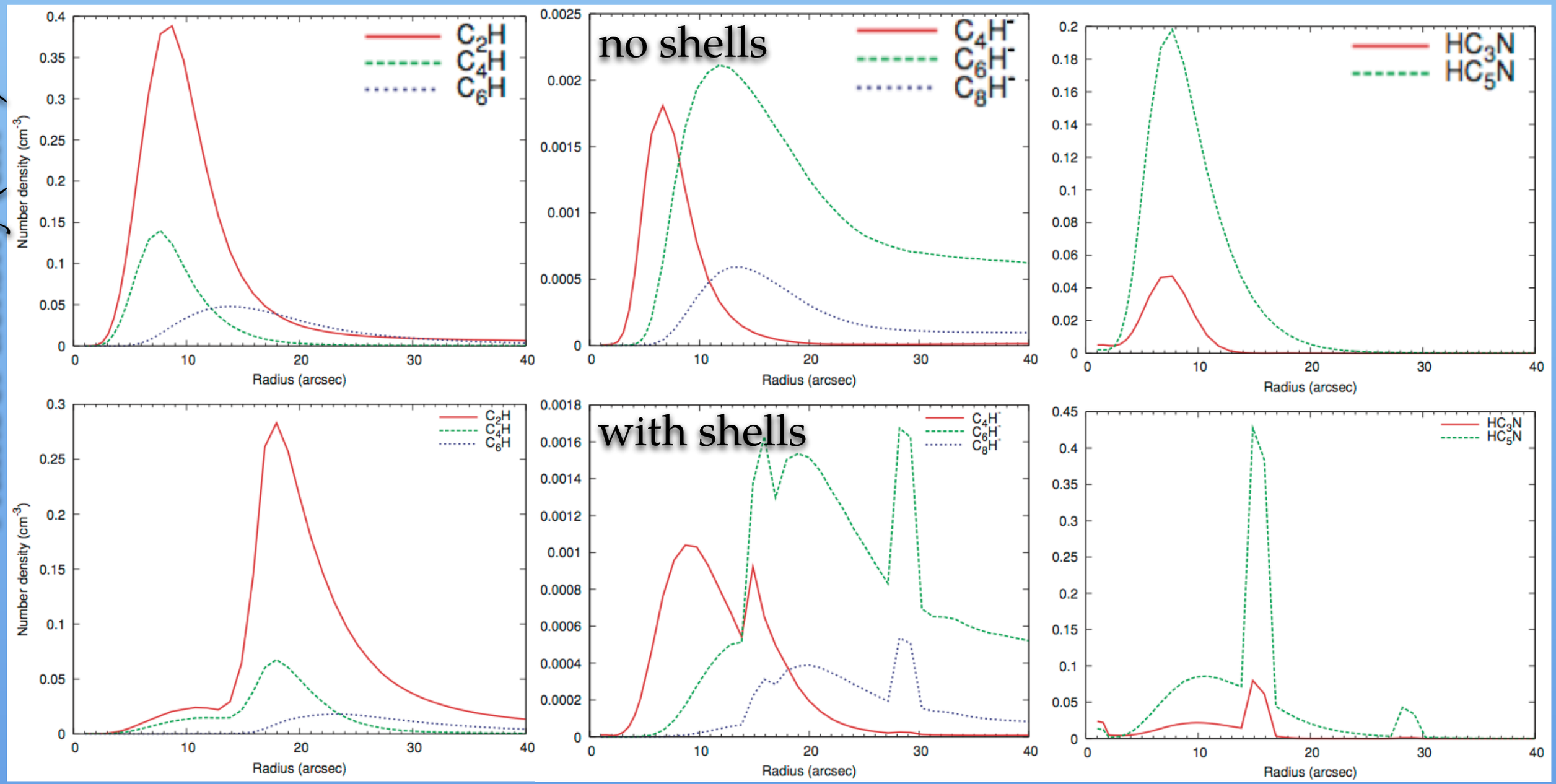
Kahane et al. 2000



Dinh-V-Trung&Lim 2008

The carbon star IRC+10216

- To what extent do density-enhanced shells influence the chemistry?



Cordiner&Millar 2009

- change of column densities ➡ change of abundances

Carbon Chemistry

- most abundant molecules after H_2 in carbon-rich CSE:
  CO (8×10^{-4}), C_2H_2 (8×10^{-5}), HCN (4×10^{-5}) Fonfria et al. 2008

Hydrocarbons

$C_2H_2 + hv \rightarrow C_2H + H$

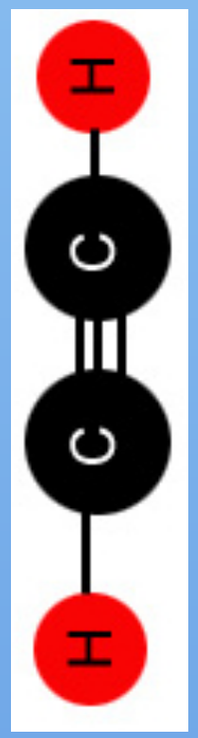
$C_2H + hv \rightarrow C_2 + H$

$C_2H + C_2H_2 \rightarrow C_4H_2 + H$

$C_4H_2 + hv \rightarrow C_4H + H$

$C_2H + C_2H \rightarrow C_4H + H$

$C_2H_2 + C_2 \rightarrow C_4H + H$



Negative Ions

$C_2H + e \rightarrow C_2H^- + hv$

$C_2H^- + H \rightarrow C_2H_2 + e$

Cyanopolyynes

$HCN + hv \rightarrow CN + H$

$CN + C_2H_2 \rightarrow HC_3N + H$

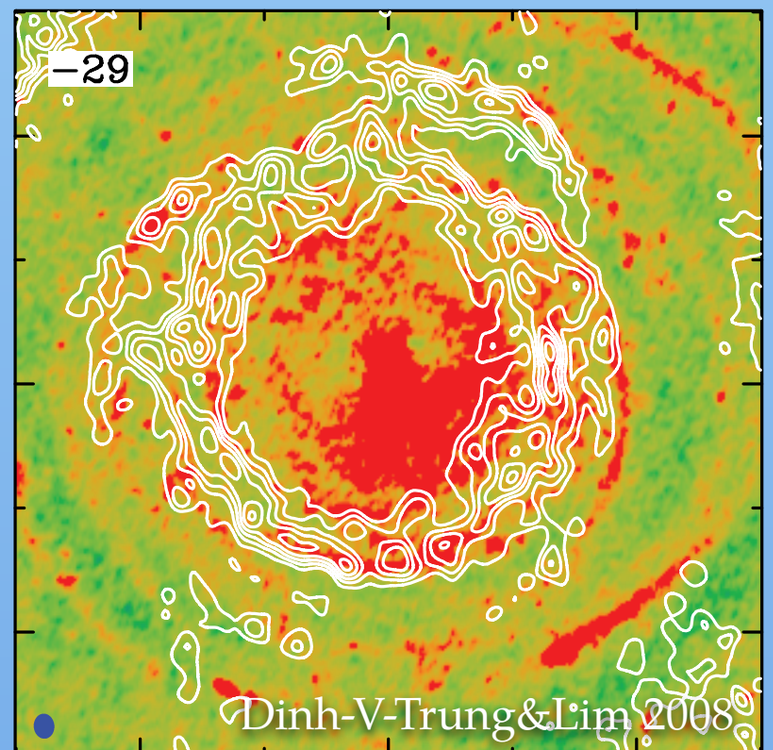
$C_3N + C_2H_2 \rightarrow HC_5N + H$

$HCN + C_2H \rightarrow HC_3N + H$

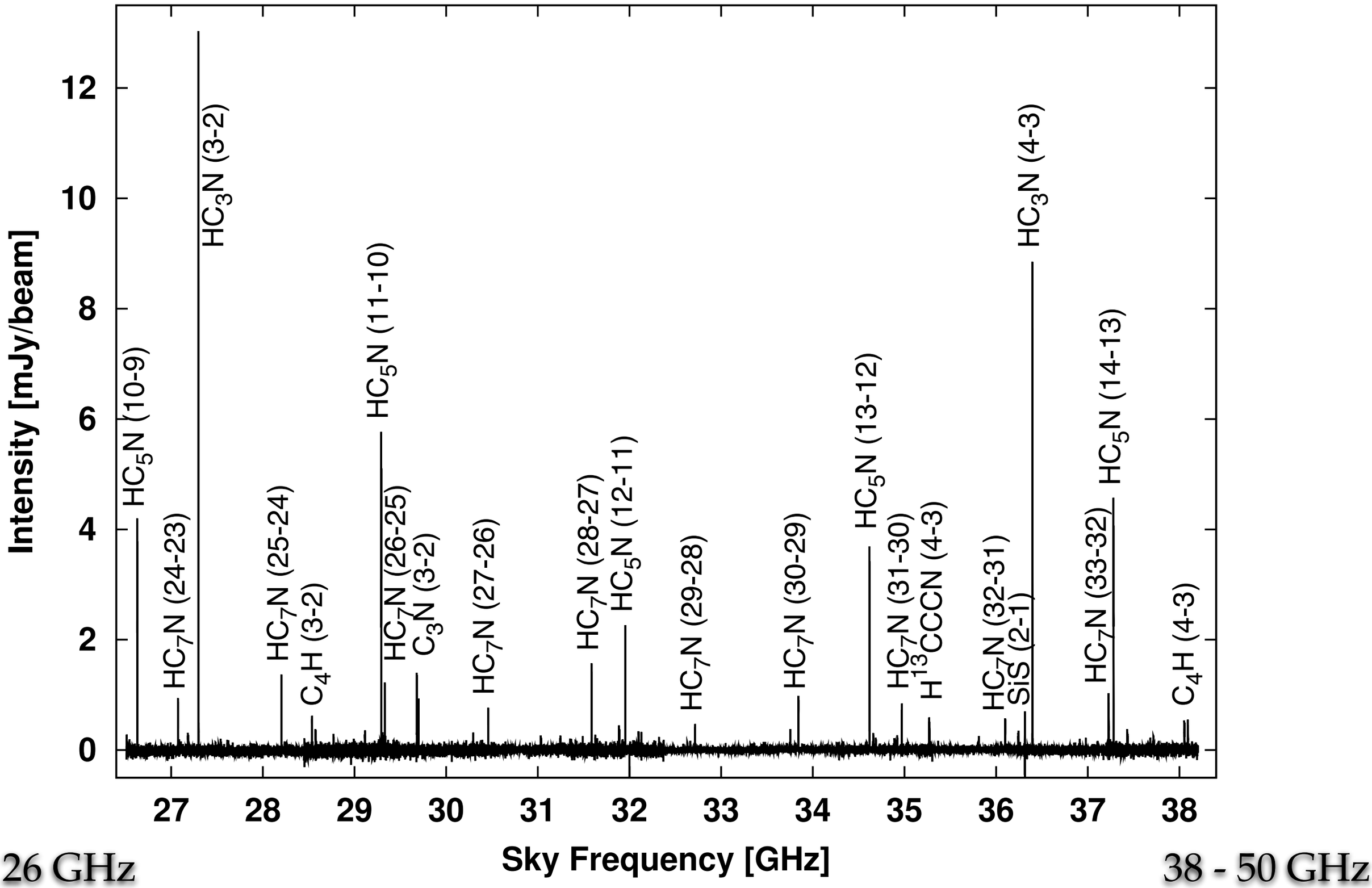
- cover many transitions of key molecules around carbon stars
- improve general carbon chemistry network, also nitrogen chemistry

The JVLA survey of IRC+10216

- Jansky Very Large Array, New Mexico, USA
- Interferometer: 27 antennas (25m)
- New receivers, new correlator
- Spectral and imaging survey of IRC+10216 in 2011 and 2013 (Mark Claussen, NRAO)
- Large coverage: 18 - 50 GHz
- Large bandwidth: 2 GHz
- ~ 51 hrs
- Unprecedented detail:
  - Resolution: ~1 arcsec
  - Sensitivity: ~1 mJy
- Data reduction with CASA
- Line identification



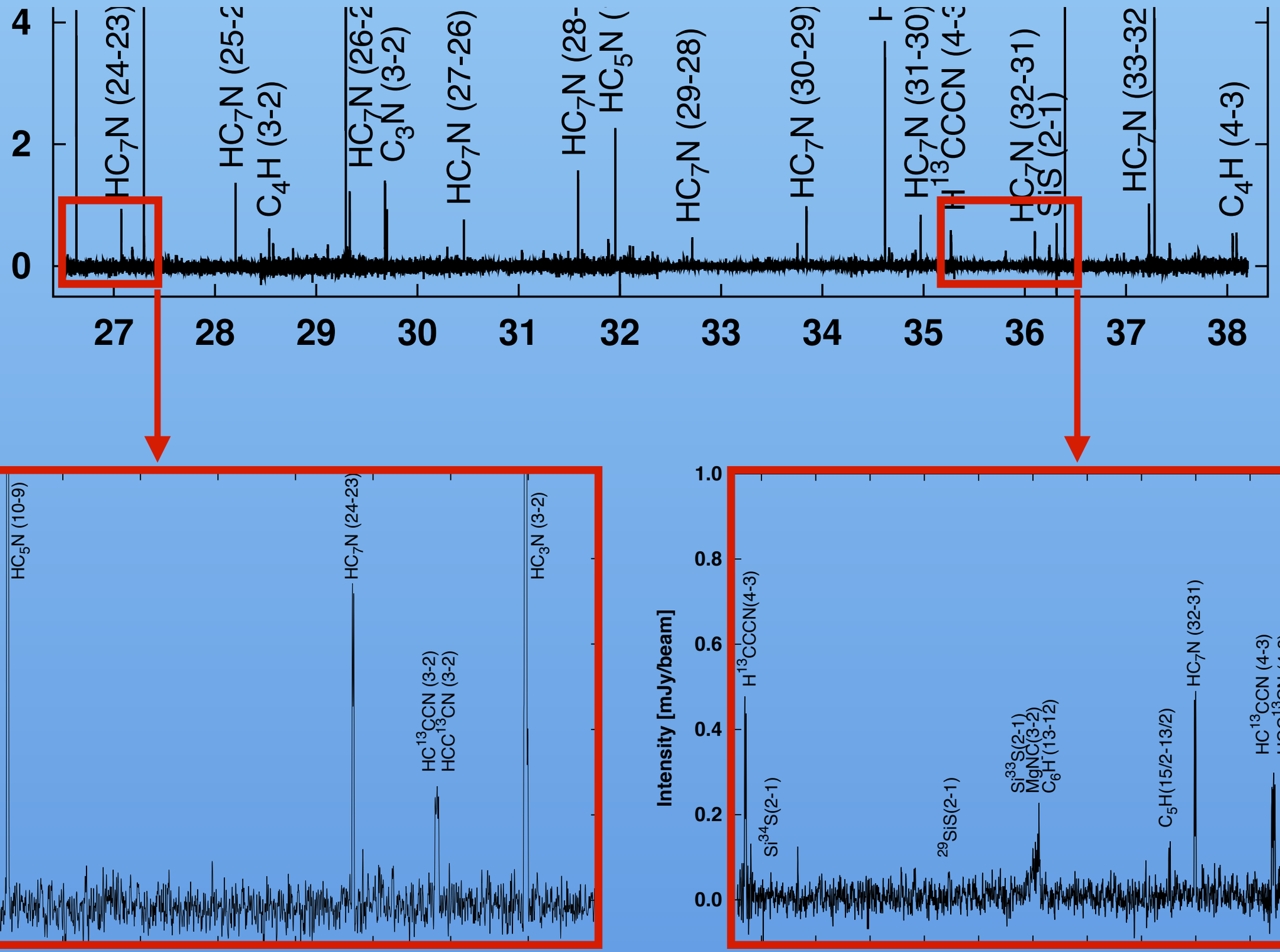
JVLA spectrum of IRC+10216



18 - 26 GHz

38 - 50 GHz

The JVLA survey of IRC+10216



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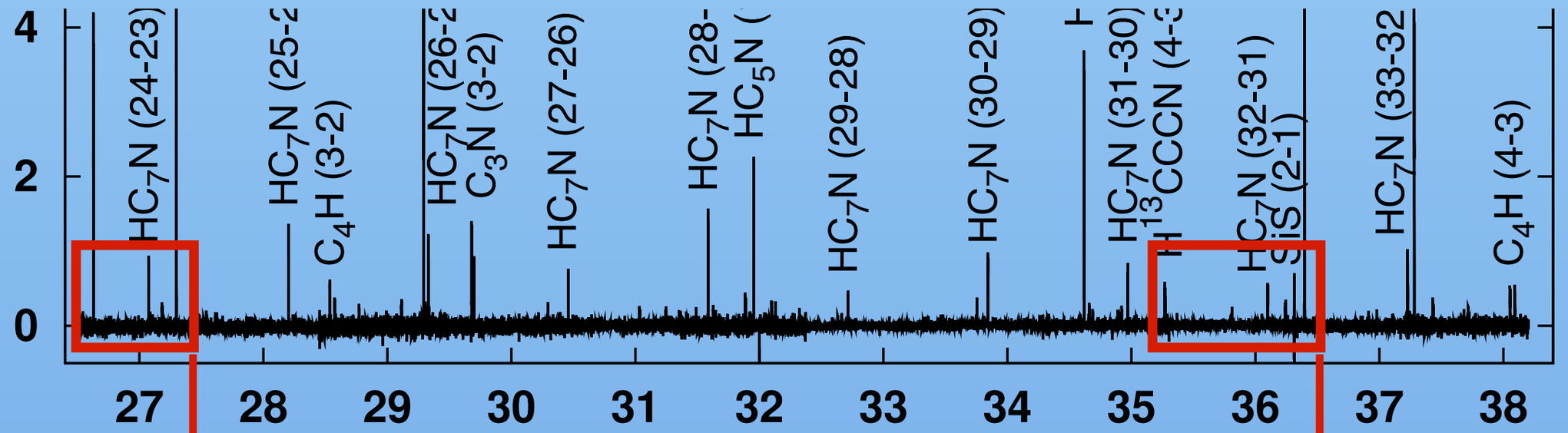
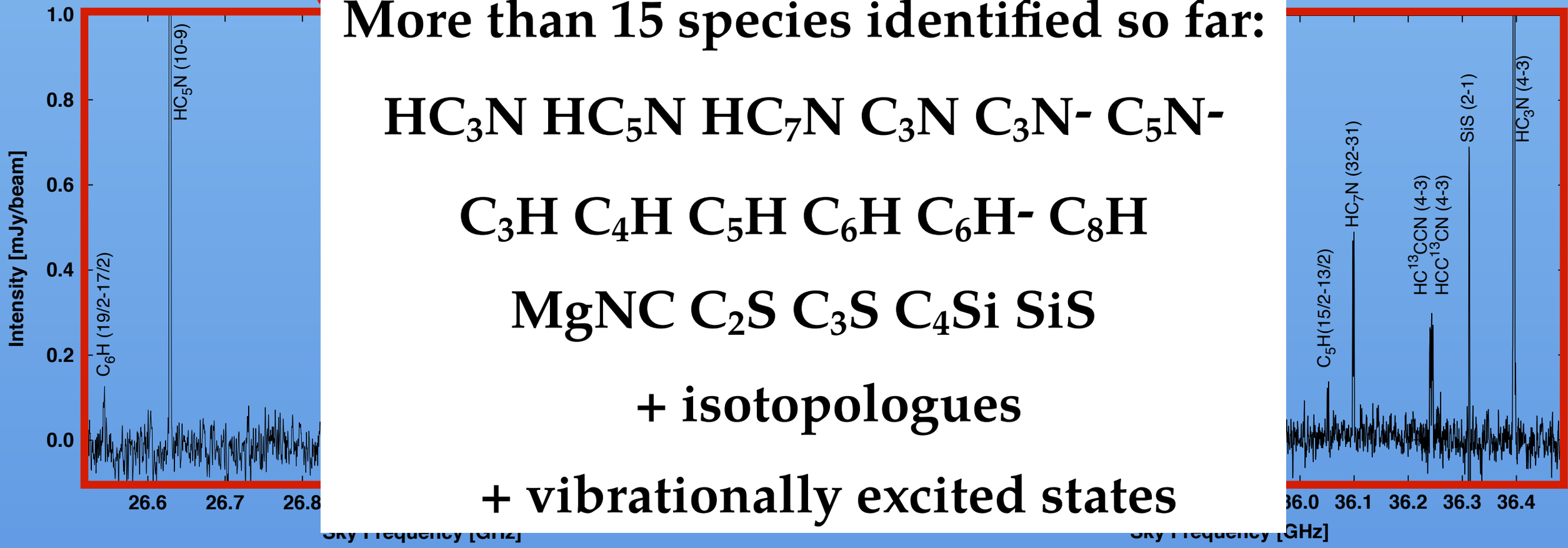




More than 15 species identified so far:

HC_3N HC_5N HC_7N C_3N C_3N^- C_5N^-

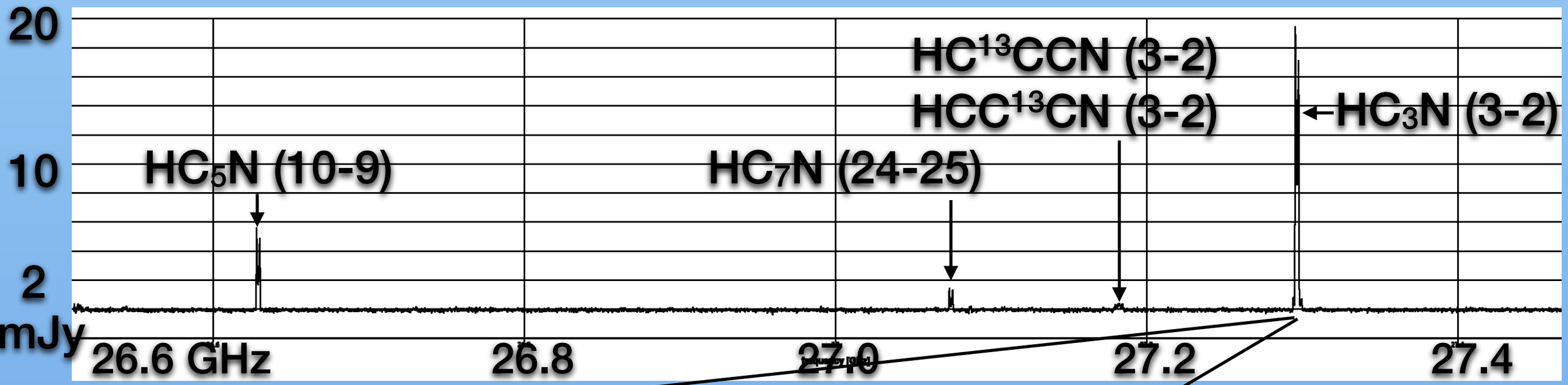
C_3H C_4H C_5H C_6H C_6H^- C_8H

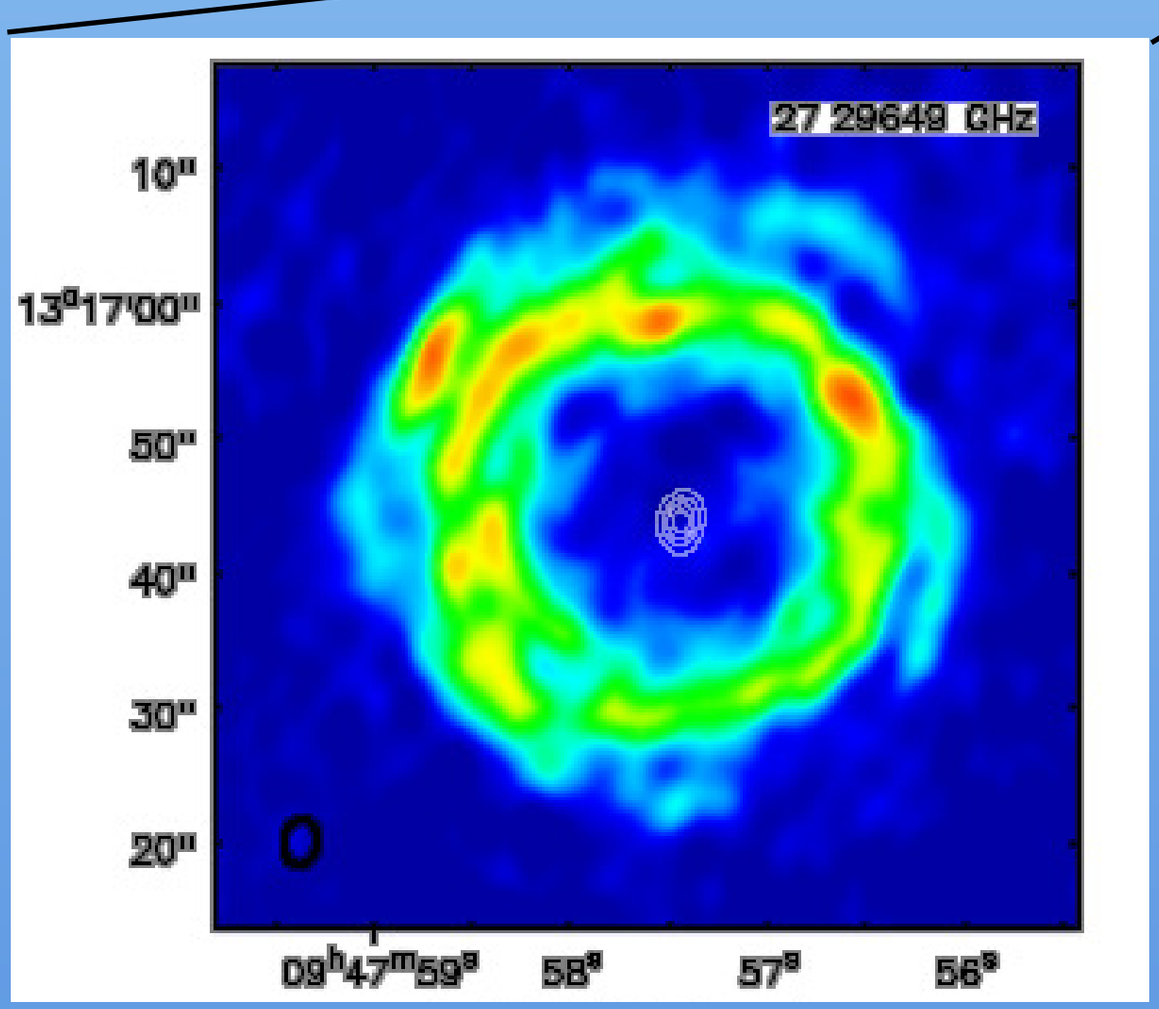
MgNC C_2S C_3S C_4Si SiS

+ isotopologues

+ vibrationally excited states

The JVLA survey of IRC+10216





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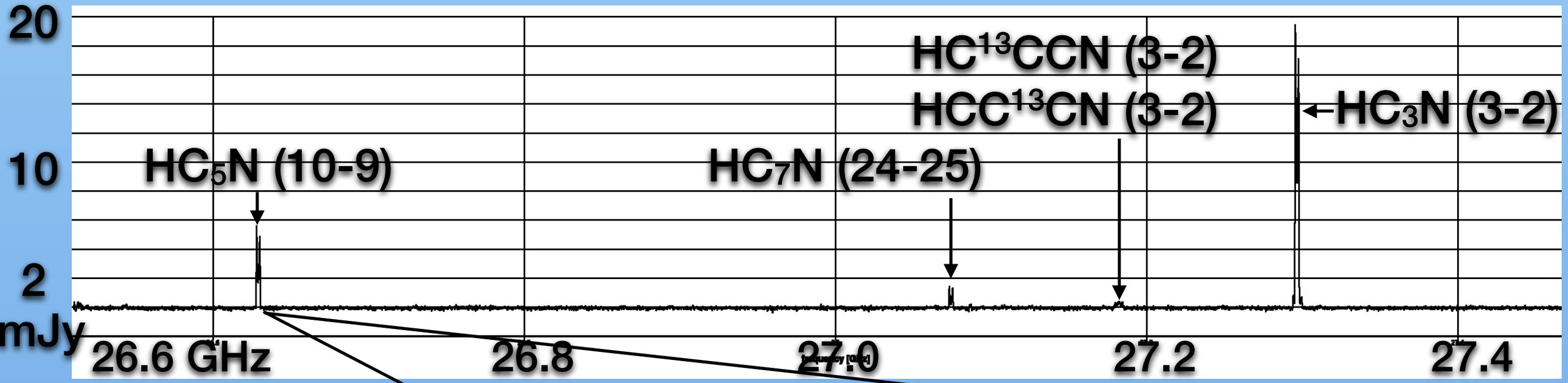

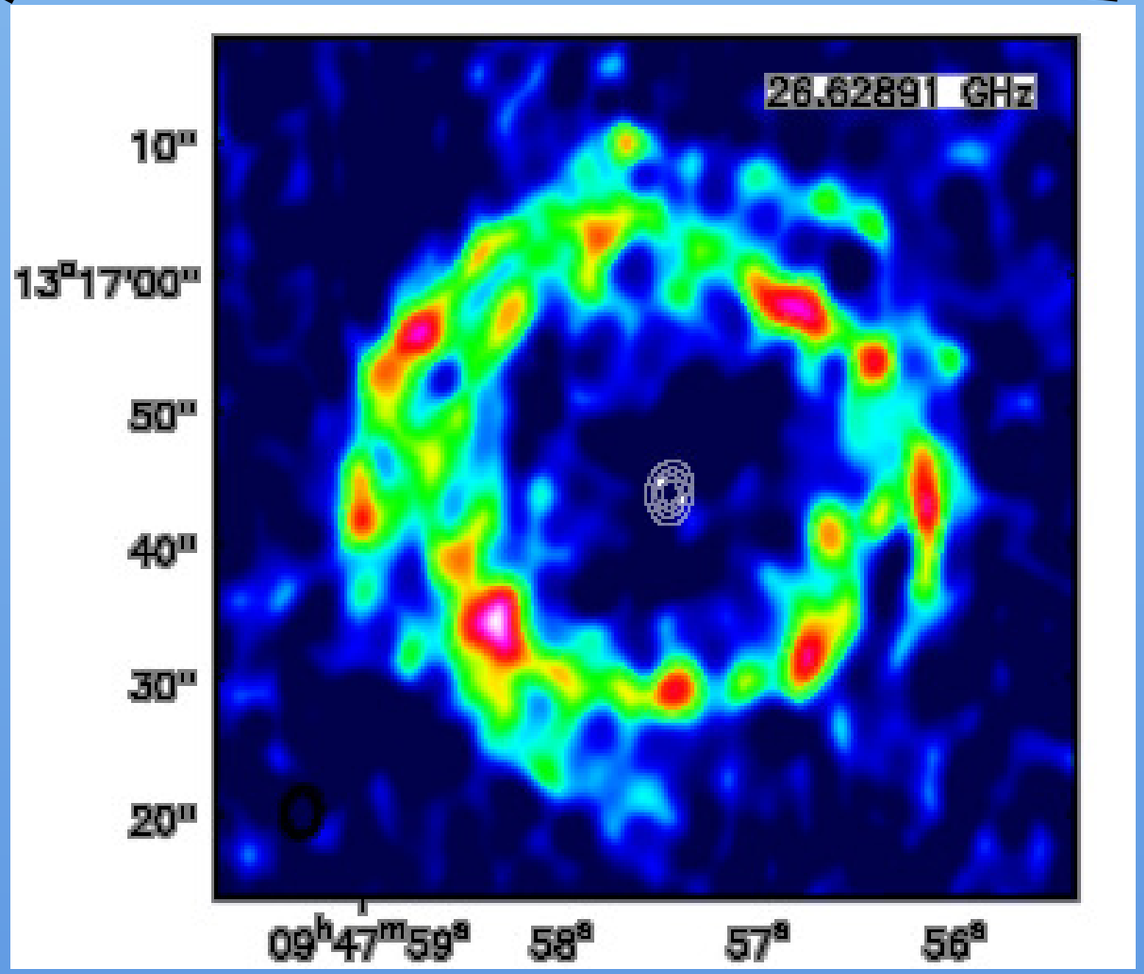

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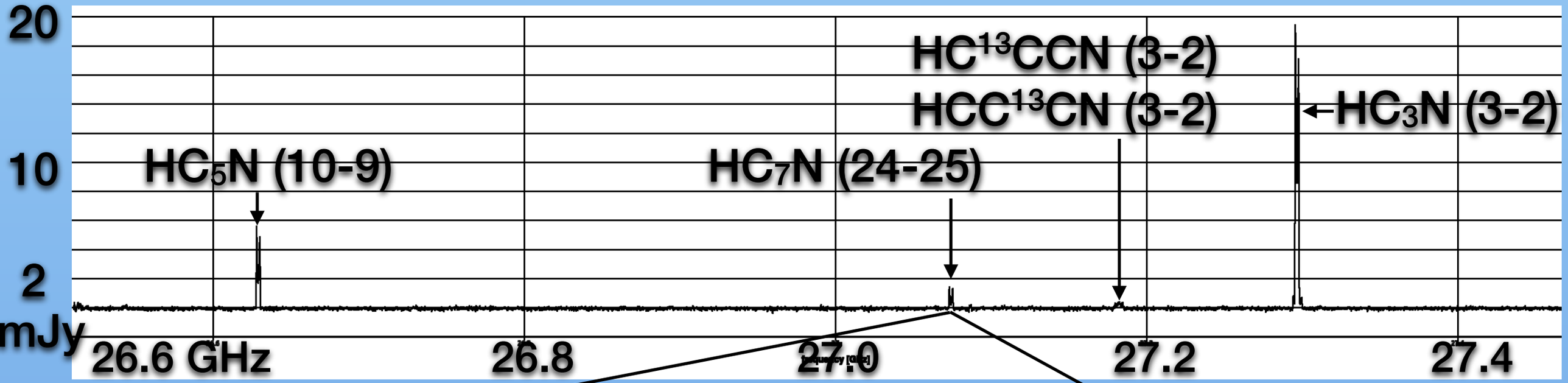
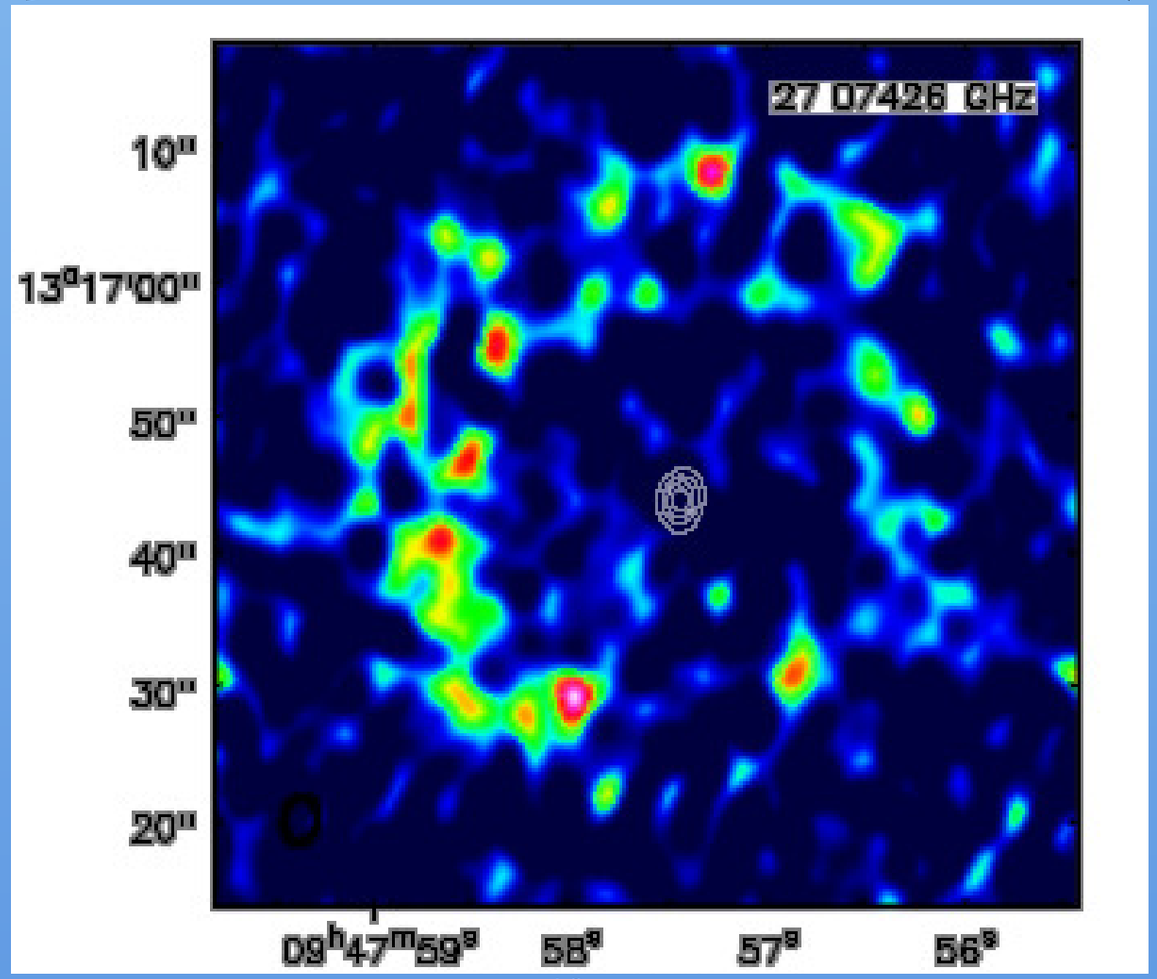
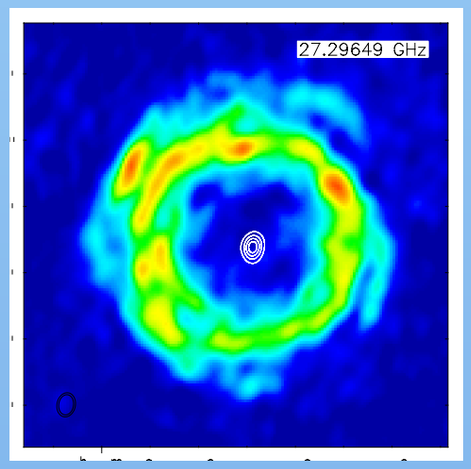
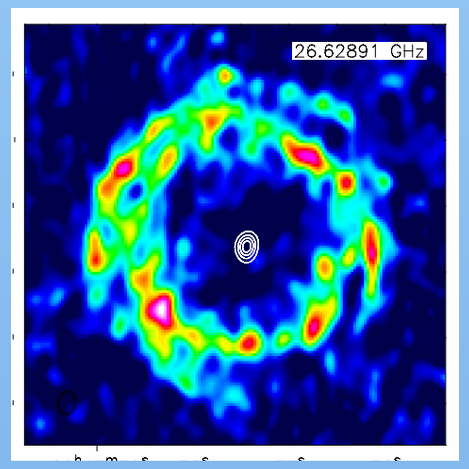
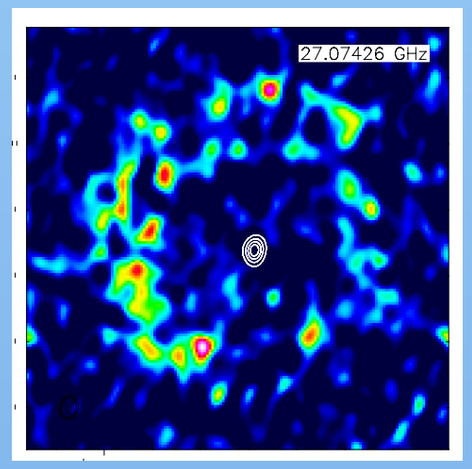




Future Work







- Calibrate whole survey, imaging synthesis of all spectral lines
- Complementary observations (APEX, ALMA, PdBI, Herschel)
- Large sample of carbon stars ➡ e.g. Elvire De Beck
- Compare to oxygen-rich stars ➡ e.g. Tomasz Kamiński
- Radiative transfer models (RATRAN)

➡ Improve knowledge of morphology and chemistry

➡ Abundances, nucleosynthesis