Time-dependent Anion Chemistry in the CSE IRC+10216

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Why study anions ? (I)

They are good for our health!

Taroko , Taiwan

Why study IS anions ? (II)

- The presence of C-chain anions in interstellar space was predicted long ago on theoretical grounds (e.g. Herbst 1981)
- The first IS anion, C_6H^-, was identified in 2006 (McCarthy et al.)
- These anions are believed to be mainly formed by radiative attachment of an electron on a C-chain radical:

$$A + e \rightarrow (A^-)^* \rightarrow A^- + h\nu.$$

rate: kra

- The observation of IS anions offers the opportunity to test our understanding of radiative attachment reactions

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IRC+10216 (CW Leo) as chemical and spectroscopic laboratory

- **78 molecular species** detected to date
- Wealth of **linear C-chain** molecules and **radicals**
- All known **IS anions** observed there
- (Relatively) well constrained physical conditions
- **Expanding envelope** gives access to time dimension

I. C. Leão et al.: The CSE of IRC+10216

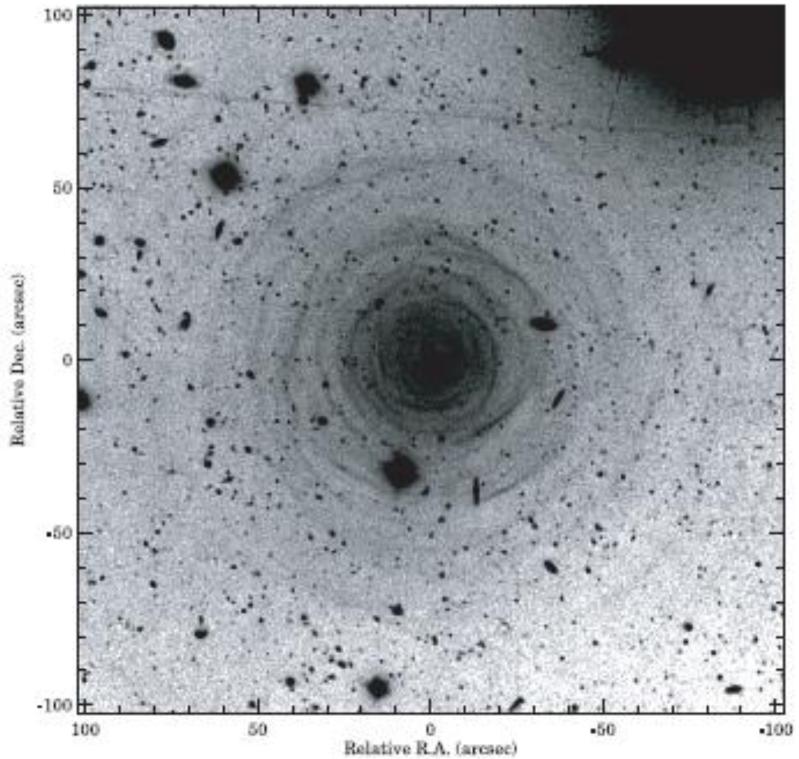

Fig. 3. FORS1 deconvolved *V*-band image of IRC+10216. North is up and East is left.

1 arcsec ~ 150 A.U.

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VLT –V-band optical image

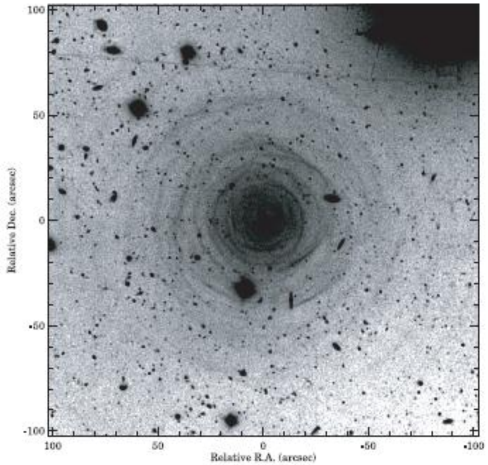
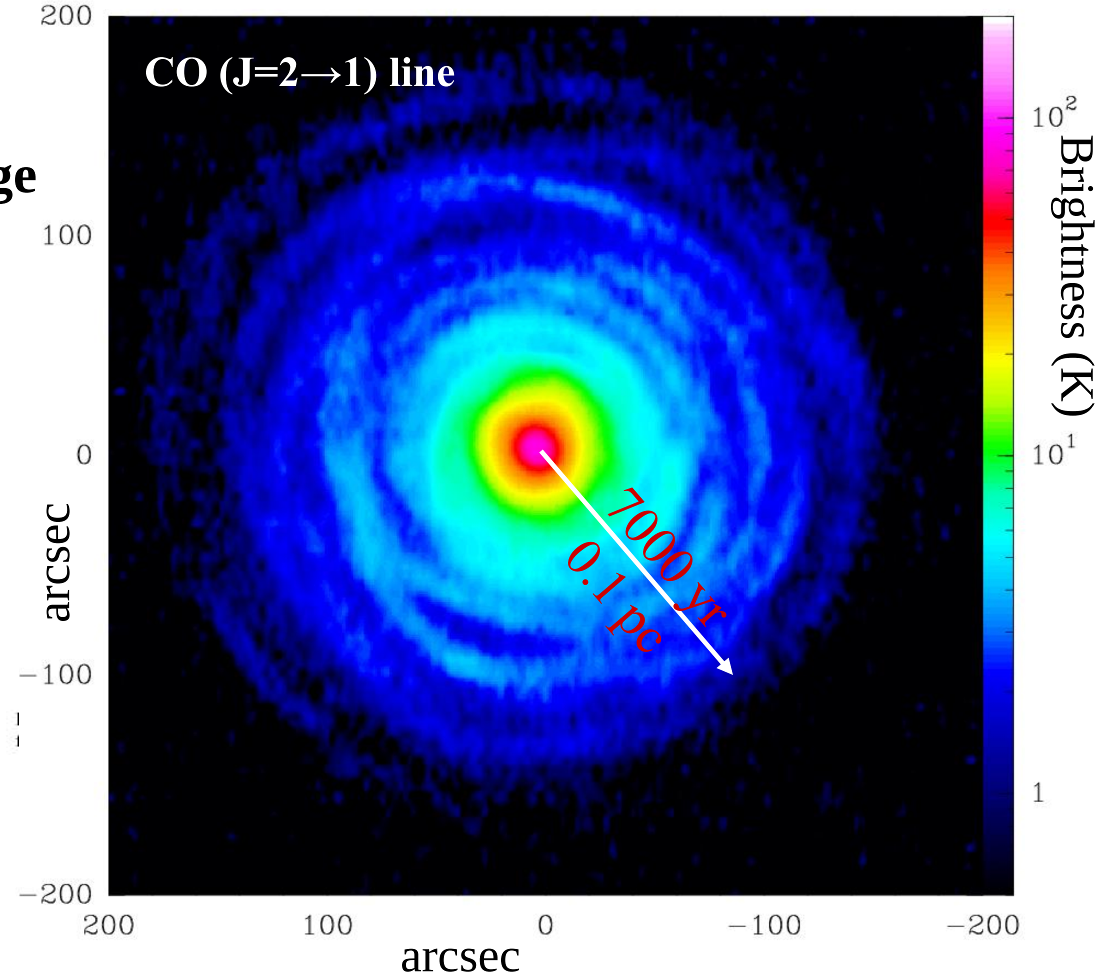


Fig. 3. FORS1 deconvolved *V*-band image of IRC+10216. North is up and East is left.



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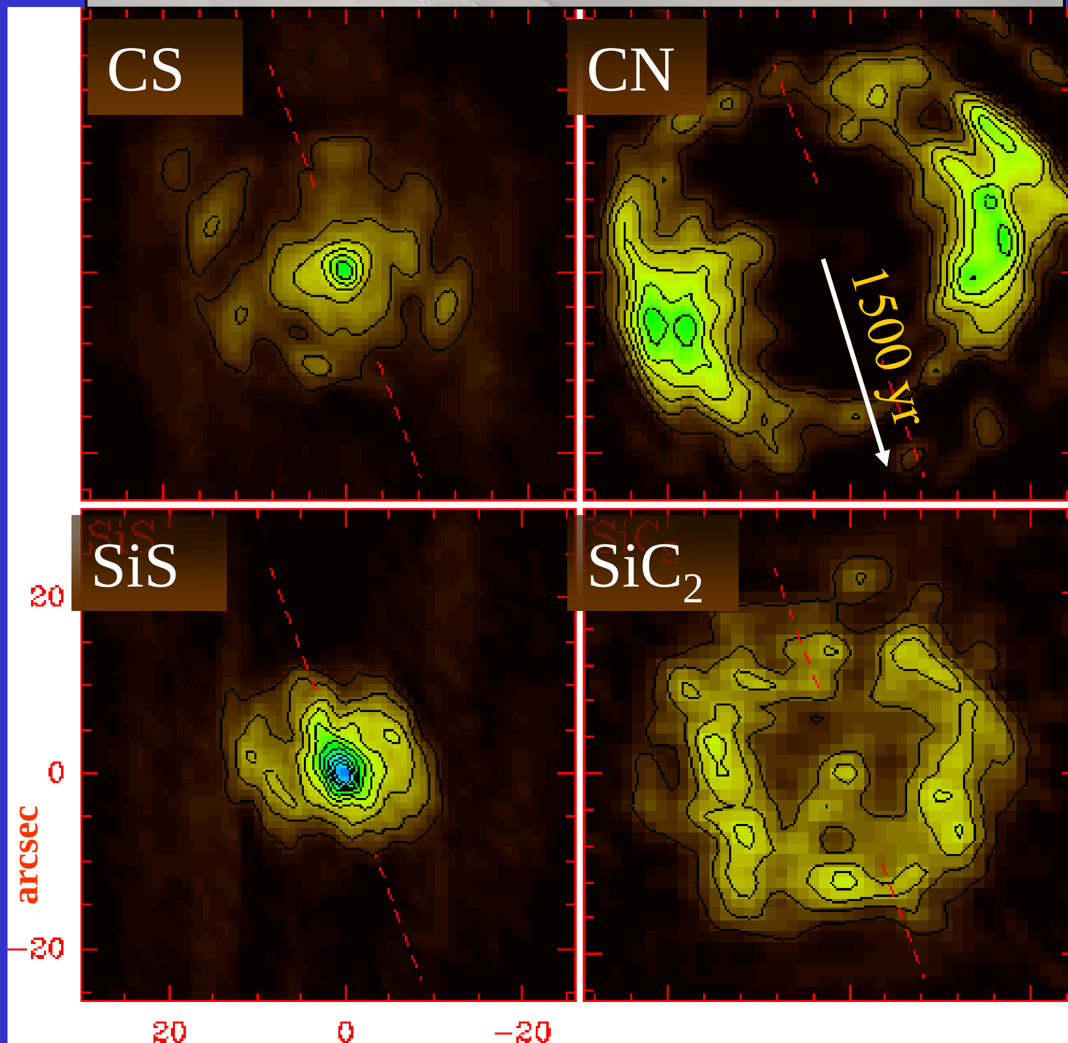
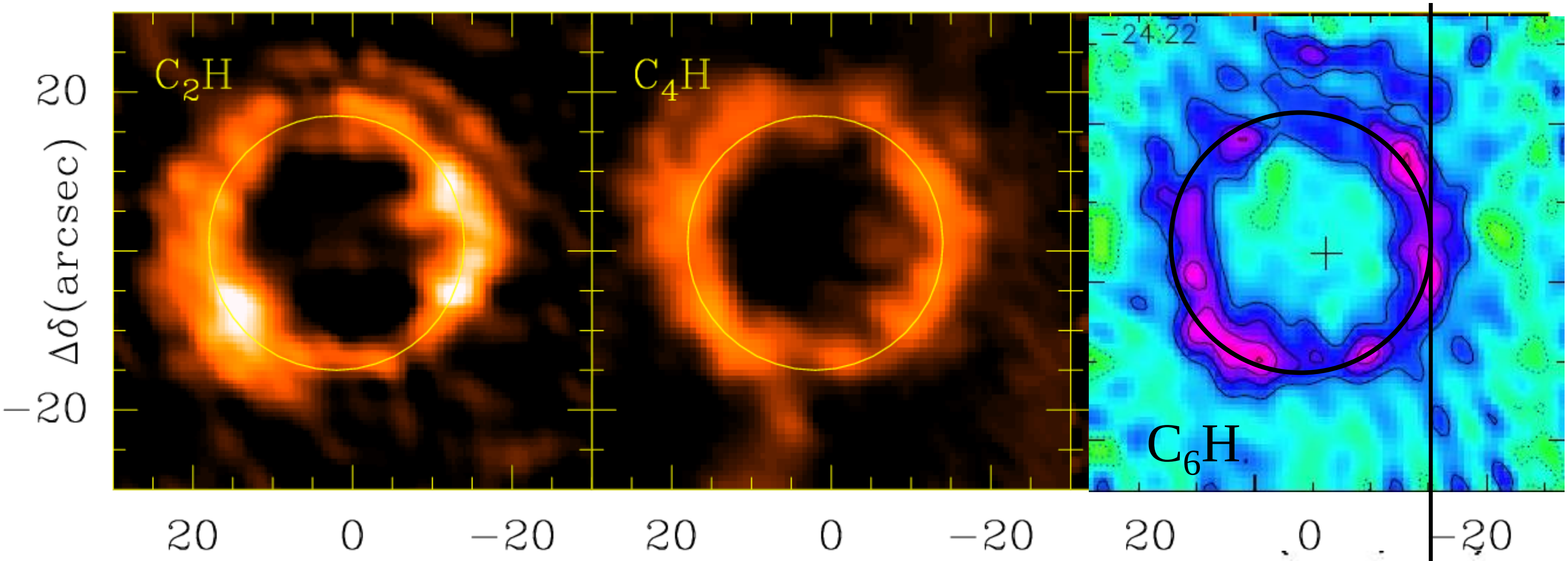
(Cernicharo et al. 2011)

Plateau de Bure interferometer

Emission at $v = v_{star} \pm 3$ kms^{-1}

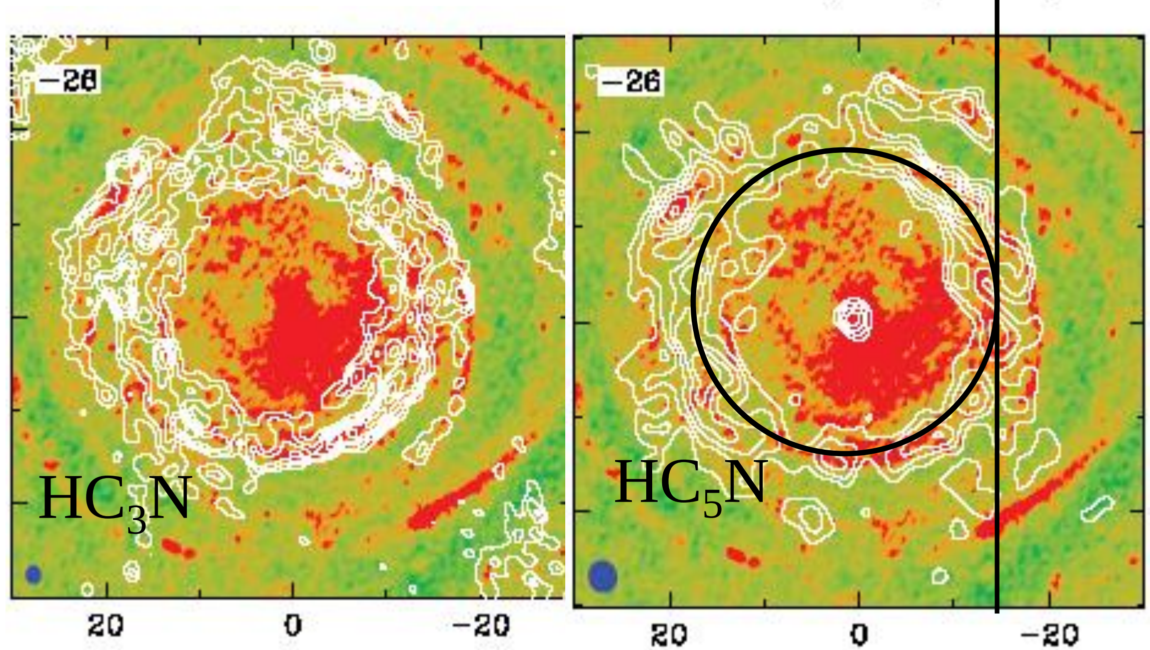


(*Lucas & Guélin 1995*)



Guélin et al. 2000

Emission at $v = v_{star} \pm 3\ kms^{-1}$

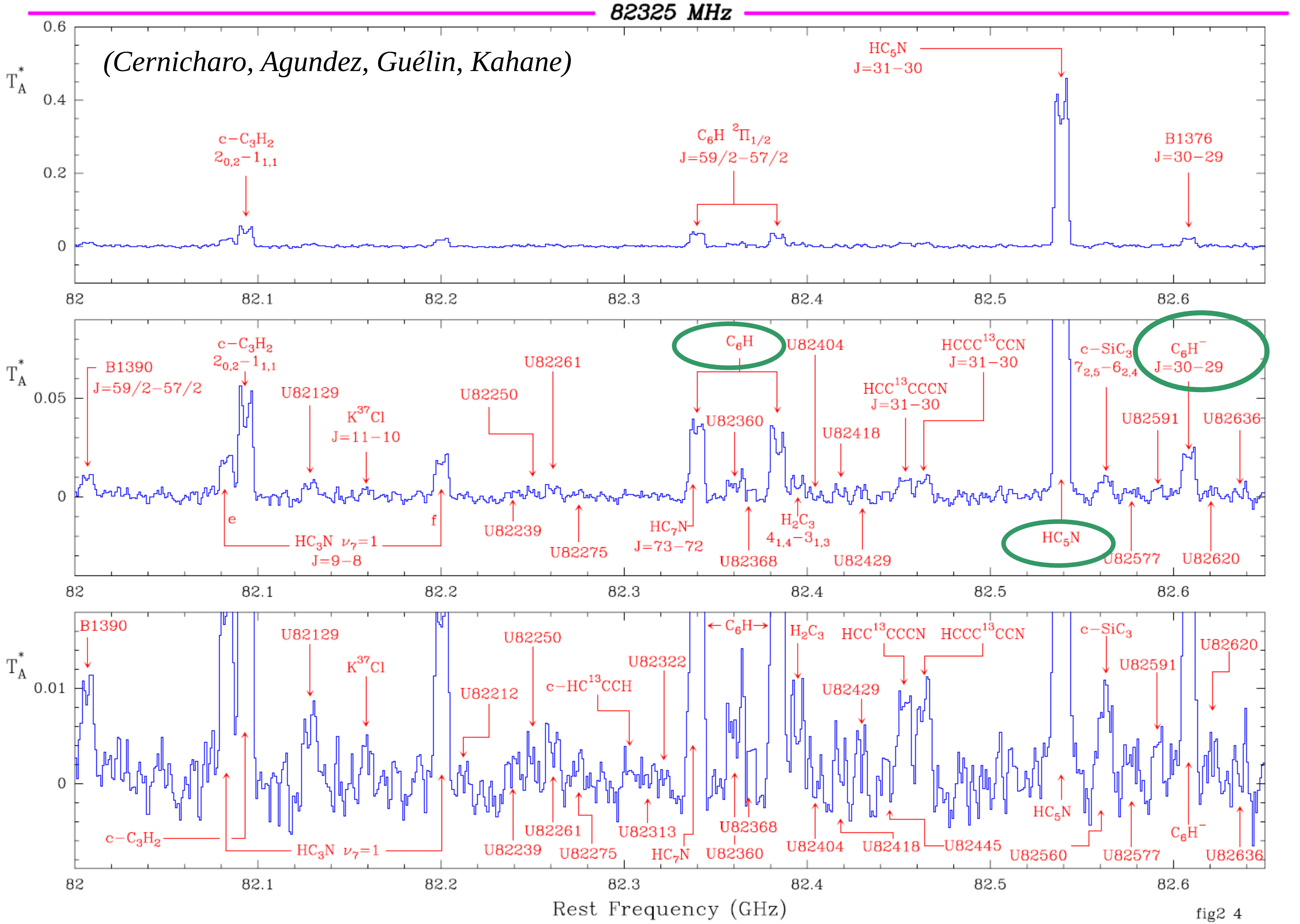


D-V-Trung & Lim 2006

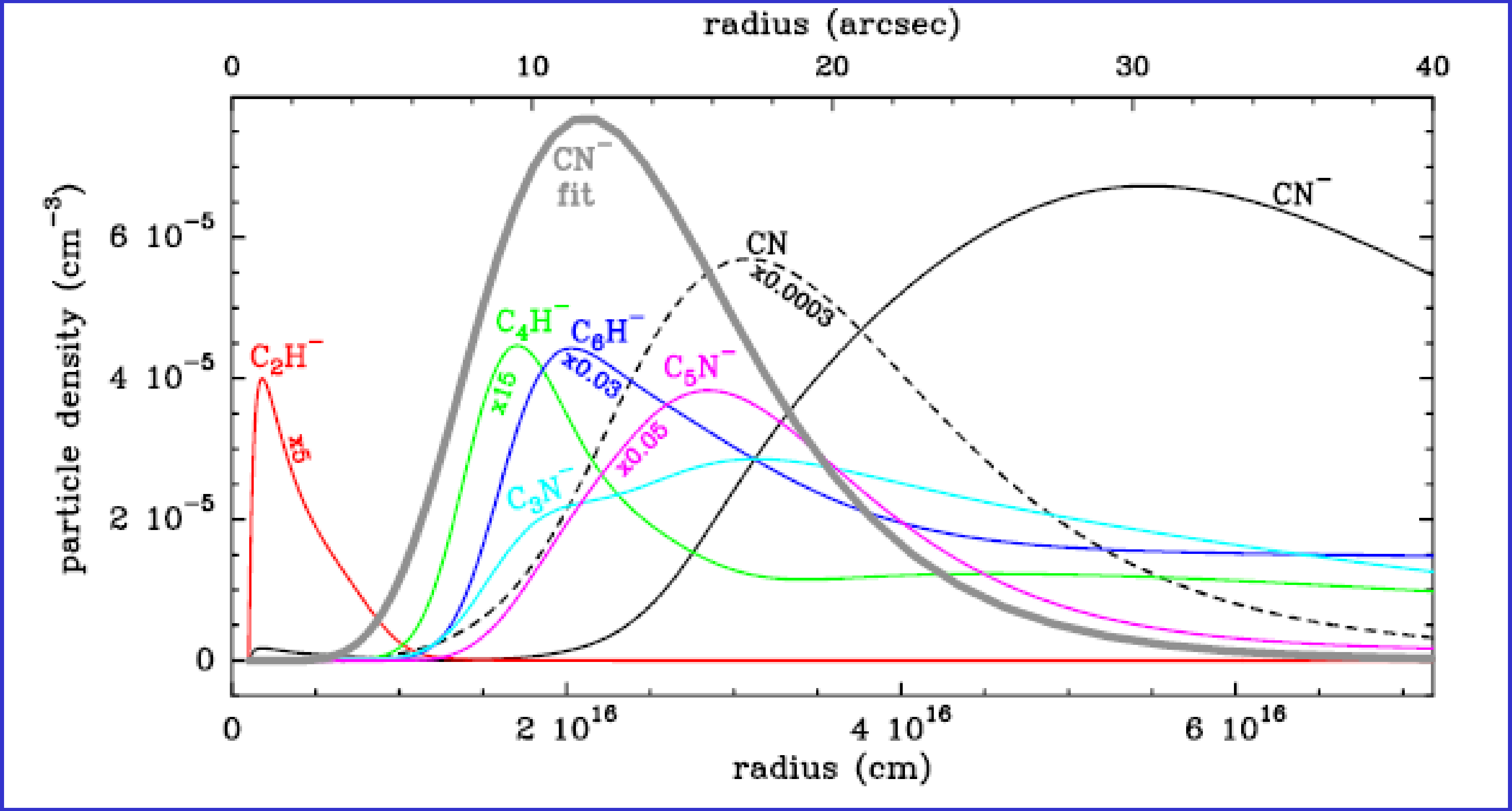
Observed interstellar anions (gas phase):

- *C_2H^- ?? IRC + 10216 (one single line!)*
- **C_4H^- IRC + 10216, L1527**
- **C_6H^- IRC+10216, Dark Clouds TMC1, Lupus-1A , L1512 (Auriga), Protostellar cores L1527, L1544, L1251A (Cepheus)**
- **C_8H^- TMC1, Lupus-1A, IRC + 10216**
- **C_3N^- IRC + 10216**
- **C_5N^- IRC+10216** *(no lab data yet!)*
- **CN^- IRC+10216**

Excerpt from IRC+10216 spectral survey with the IRAM 30-m tel

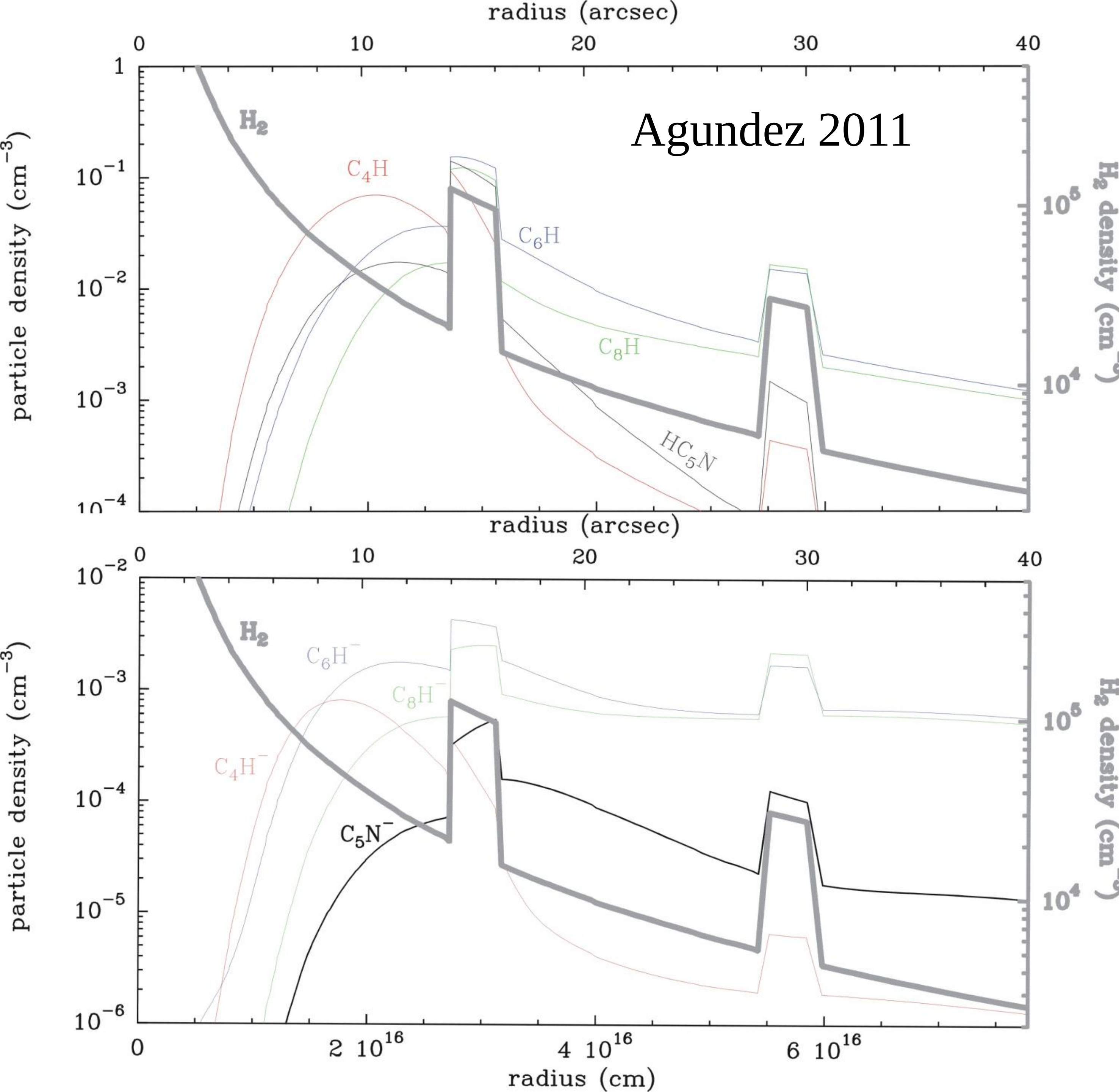


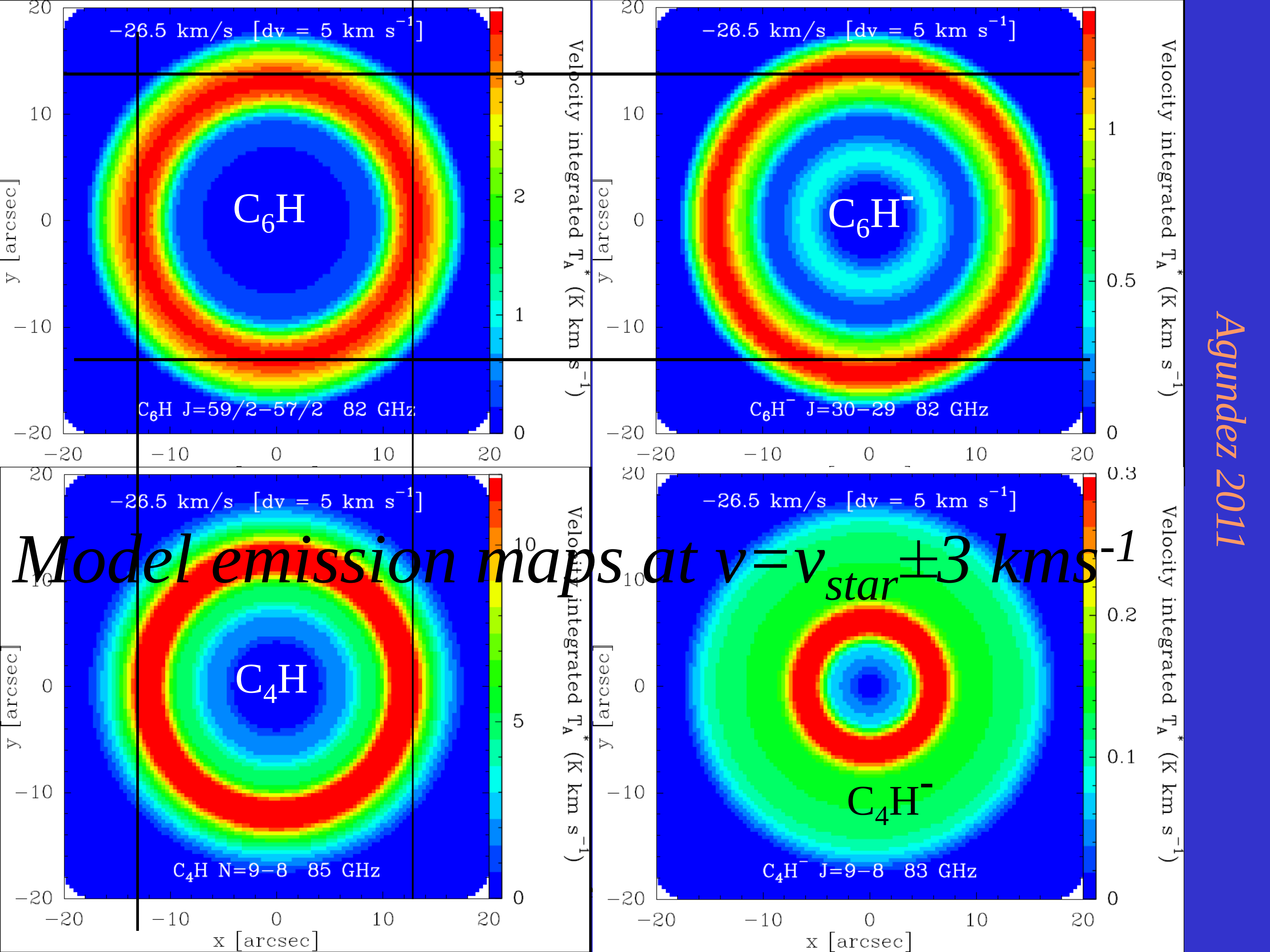
Expected model abundance of C-chain anions (smoothly decreasing density distribution)



Agundez et al. A&A 2010

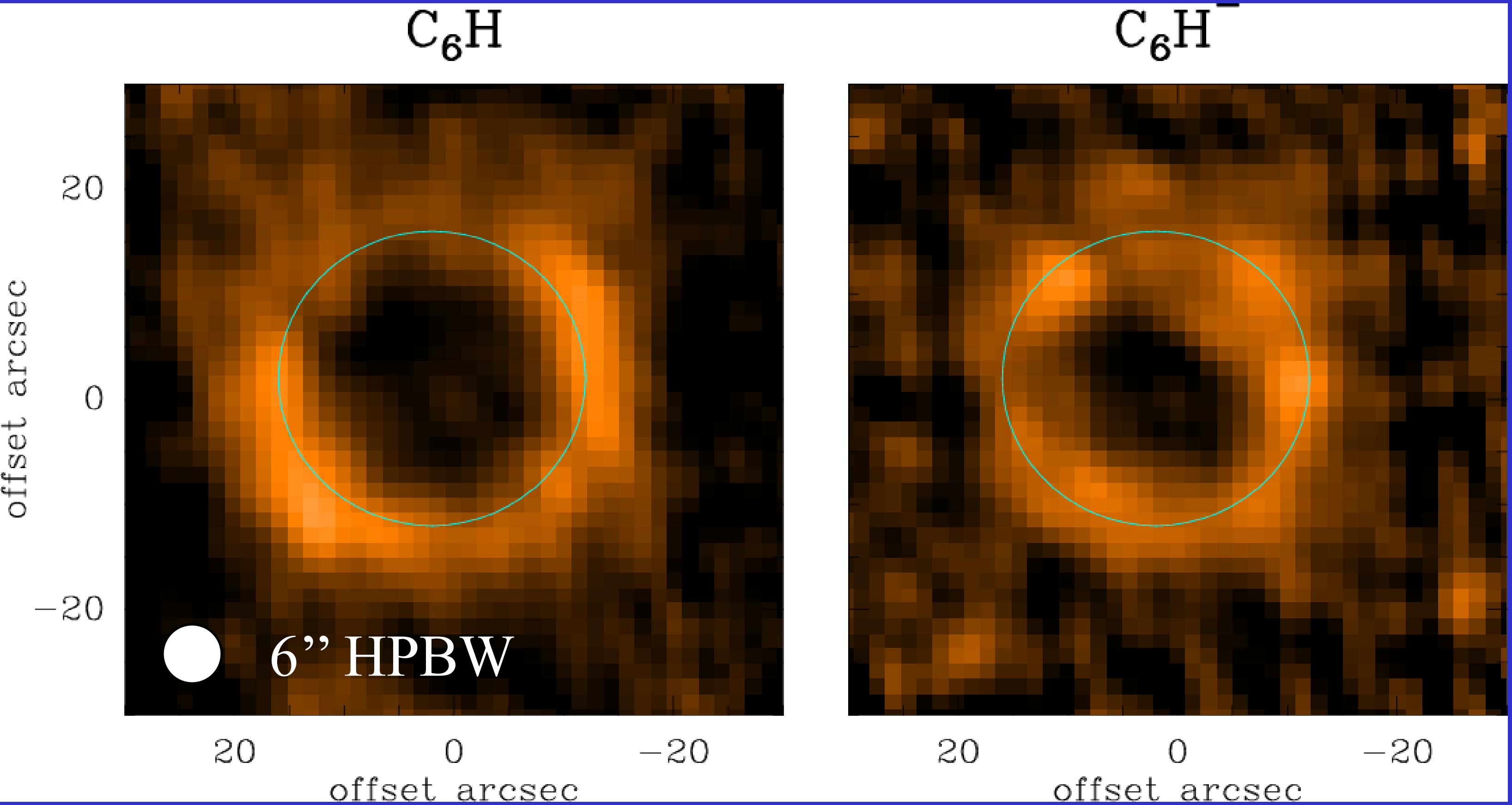
Expected molecular abundance for ringed density distribution





−26.5 km/s [dv = 5 km s−1]
C6H
C6H J=59/2−57/2 82 GHz
C6H-
C6H− J=30−29 82 GHz
C4H
C4H N=9−8 85 GHz
C4H-
C4H− J=9−8 83 GHz
Velocity integrated TA* (K km s−1)
x [arcsec]
y [arcsec]
Model emission maps at v=vstar±3 kms-1
Agundez 2011

First map of an anion *(PdBI, Guélin et al.)*



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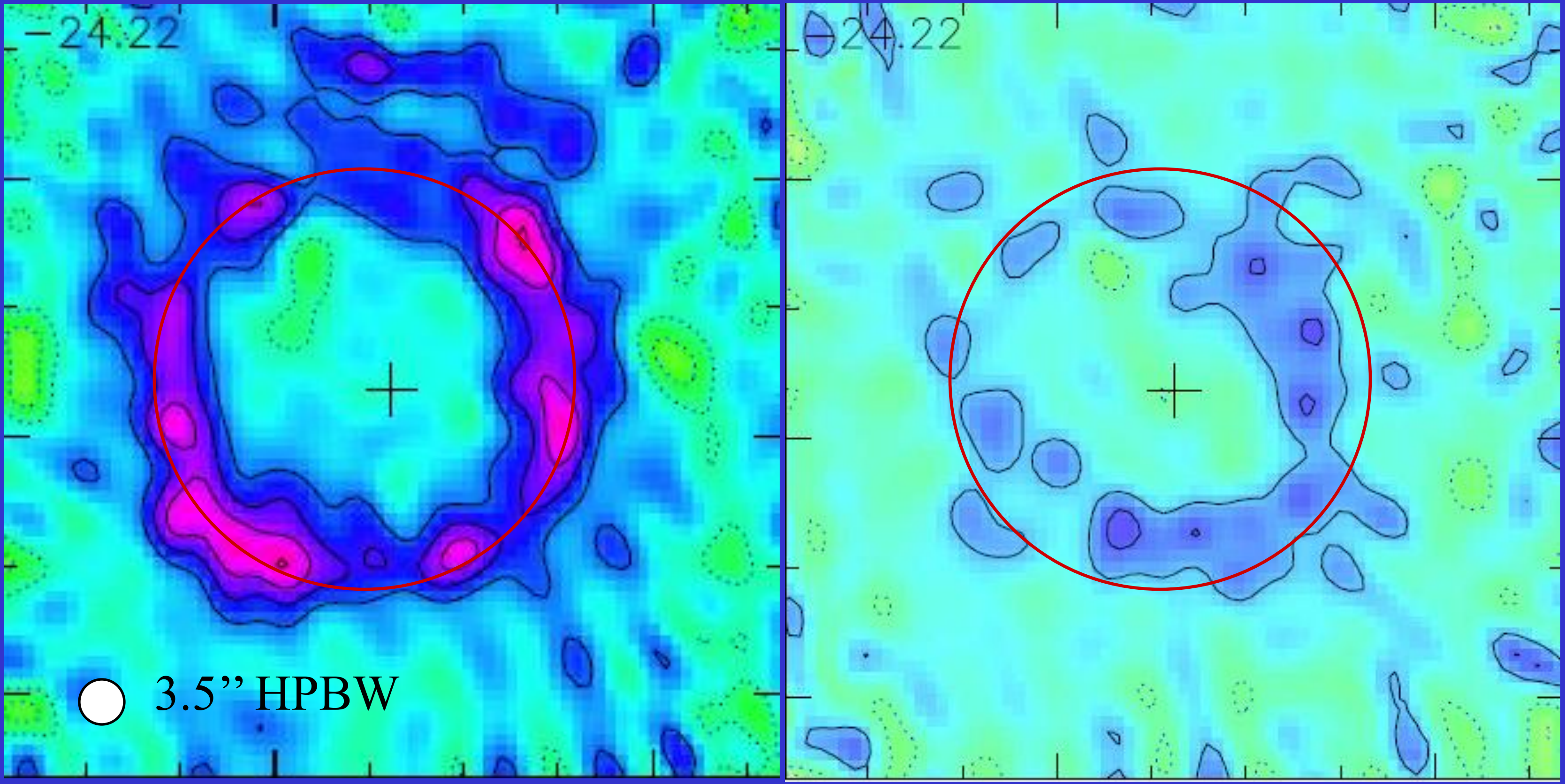
New high angular&spectral resolution map of anions *(PdBI, Guélin et al.)*



C_6H C_6H^-

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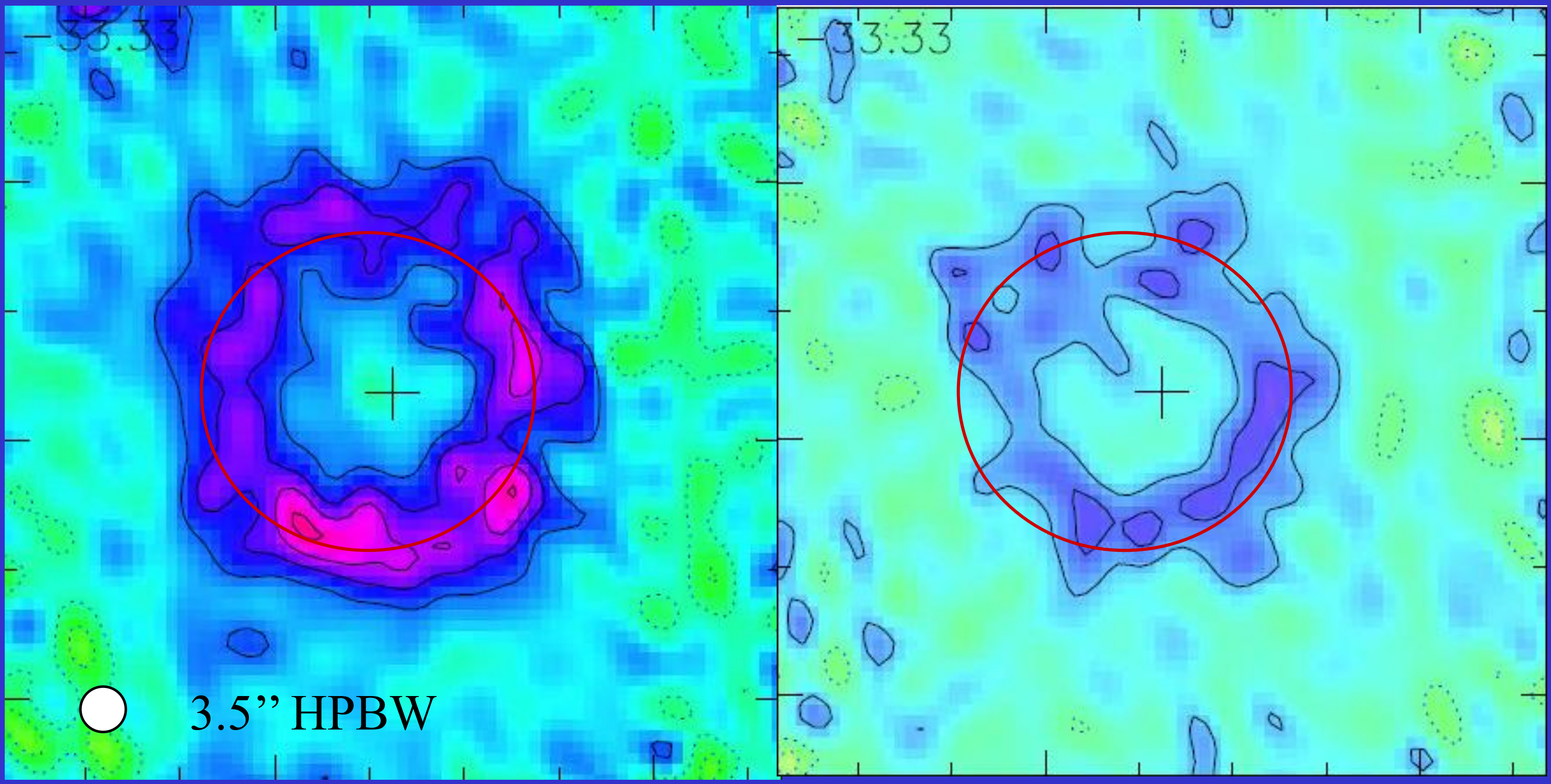
New high angular&spectral resolution map of anions *(PdBI, Guélin et al.)*



C_6H C_6H^-

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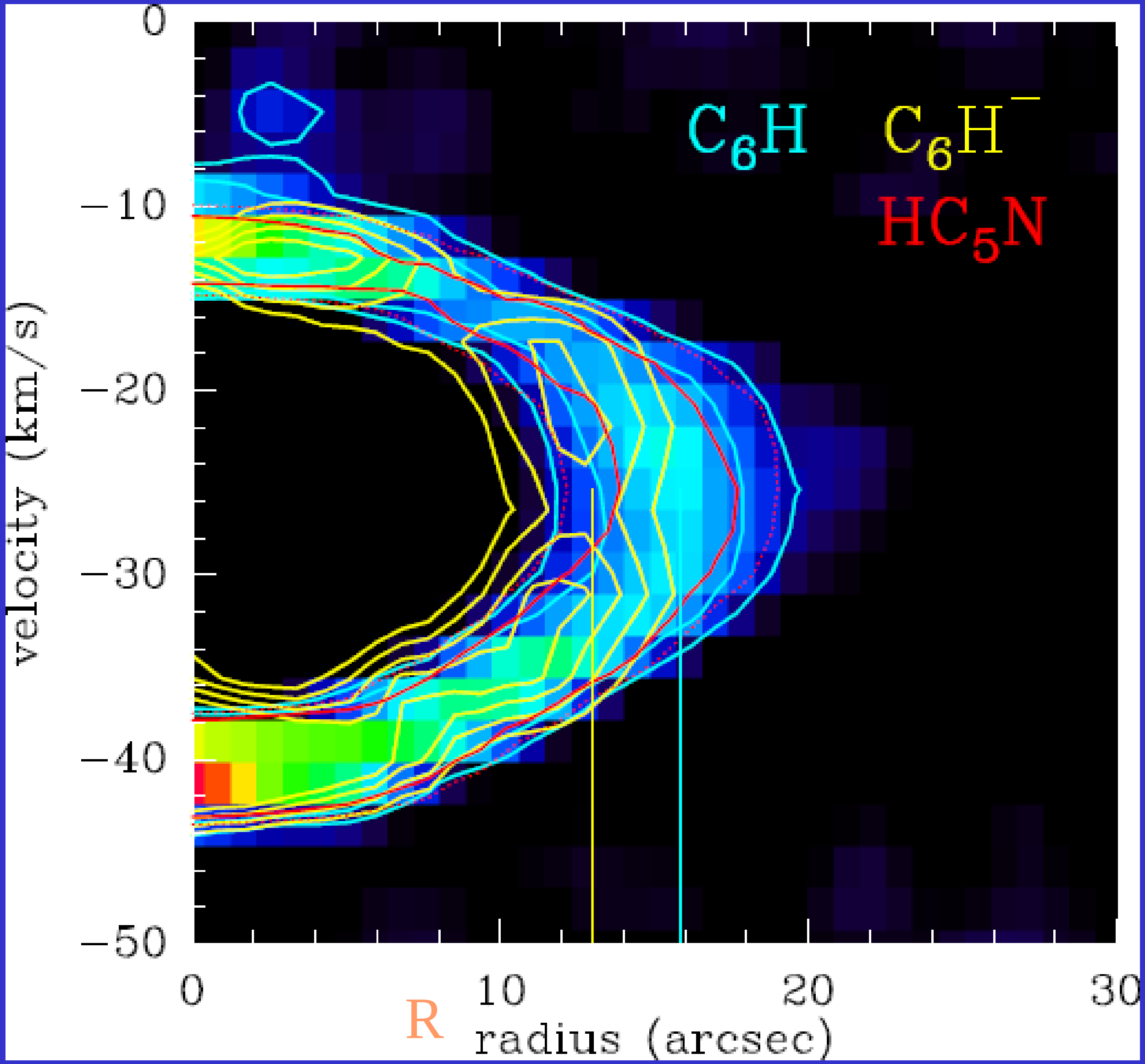
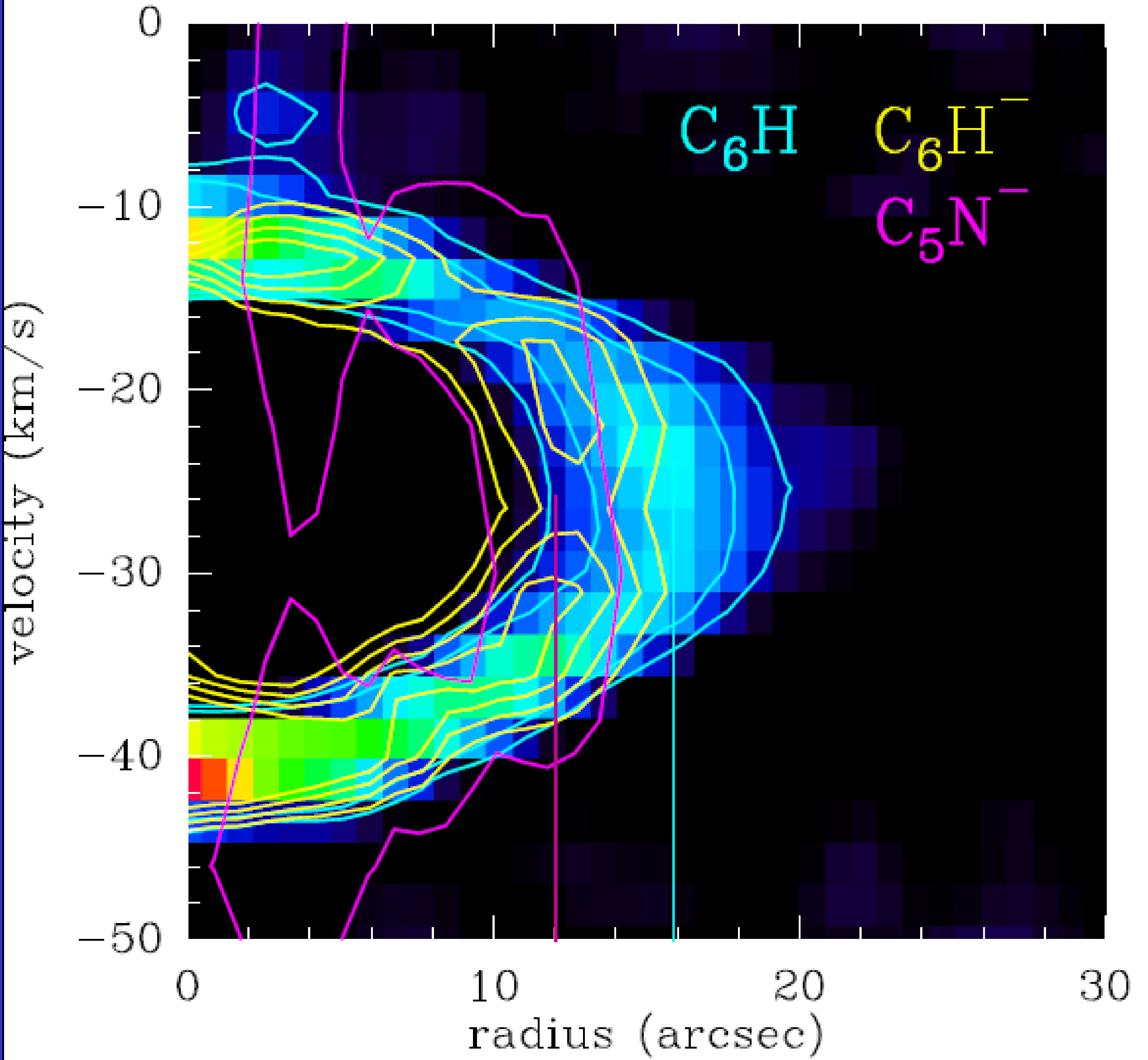
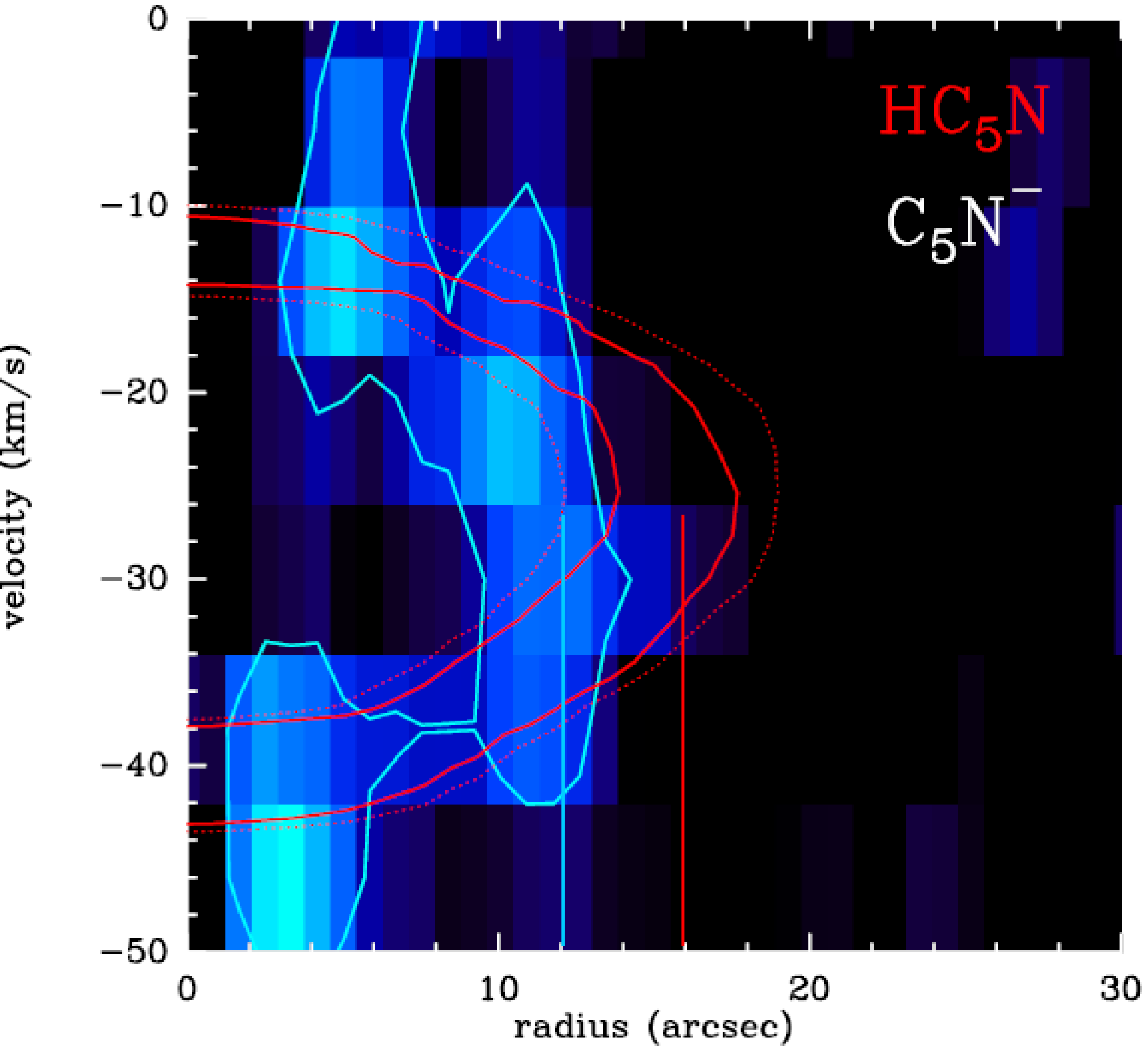
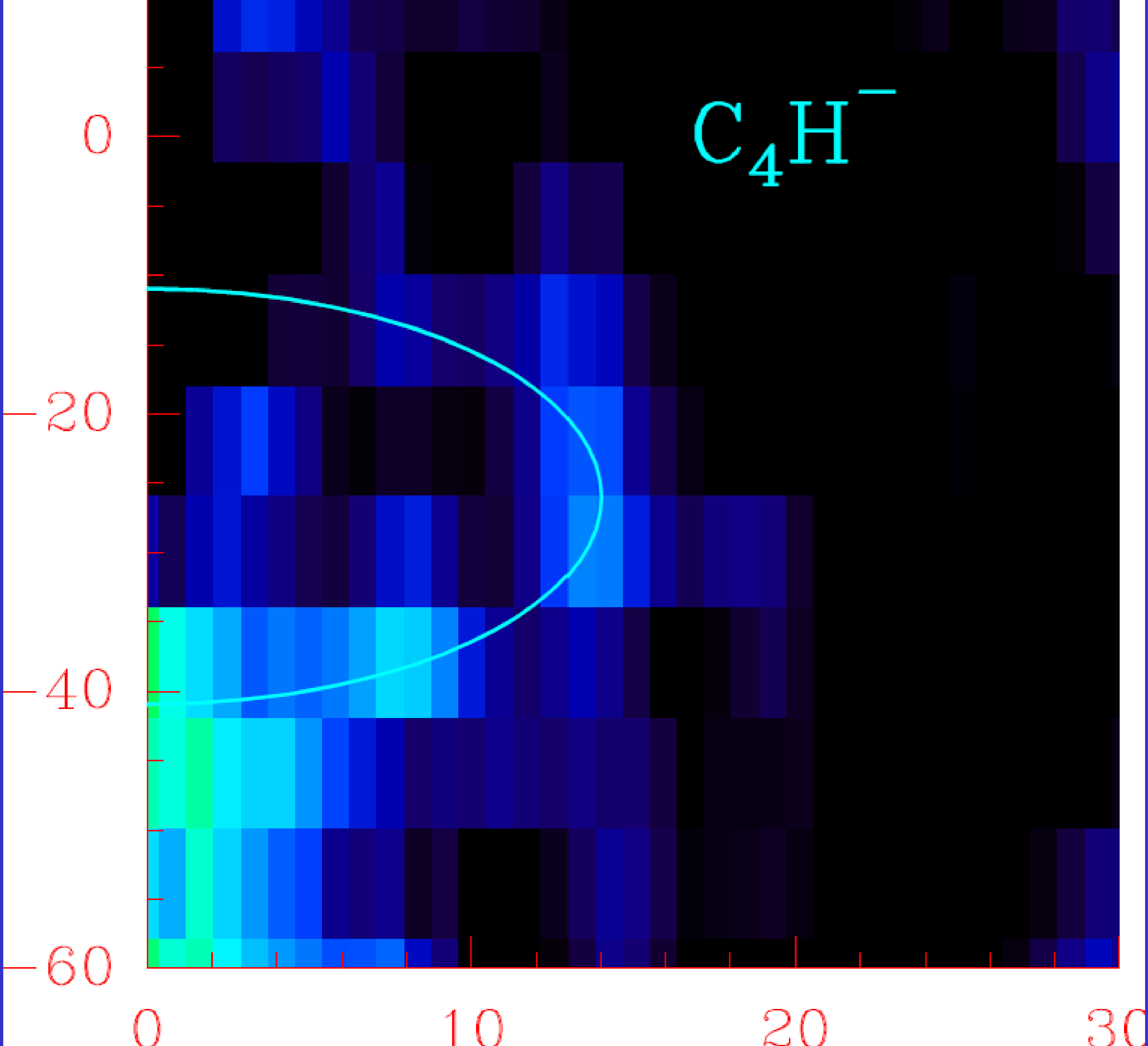
Average intensity in concentric rings of radius R, for each velocity channel





C6H
C6H−
C5N−
velocity (km/s)
radius (arcsec)
0
−10
−20
−30
−40
−50
0
10
20
30


HC$_5$N
C$_5$N$^-$
velocity (km/s)
radius (arcsec)
0
−10
−20
−30
−40
−50
0
10
20
30



C_4H^-
0
20
40
60
0
10
20
30

First conclusion

C_6H^- and C_5N^- appear at smaller radii (<u>much earlier</u>) than predicted.

C_4H^- appears further out (much later) tha predicted.

Neutral species	Activation Energy (eV)	**Anion / Neutral (%)**	**rate * k_{ra} (astro)** cm^3s^{-1}	rate ** k_{ra} (theor) cm^3s^{-1}
C_2H	3.0	<0.0014	$< 10^{-11}$	$2.0\ 10^{-15}$
C_4H	3.6	0.0074	$4\ 10^{-11}$	$1.1\ 10^{-8}$
C_6H	3.8	6.8	$3\ 10^{-8}$	$6.2\ 10^{-8}$
C_8H	4.0	26.	$1.5\ 10^{-7}$	$6.2\ 10^{-8}$
CN	3.8	0.25	$2\ 10^{-9}$	$1.4\ 10^{-17}$&
C_3N	4.6	0.42	$3\ 10^{-9}$	$2\ 10^{-10}$ @
C_5N	4.5	58. (?)	$5\ 10^{-7}$ (?)	

- * M. Agundez (PhD thesis 2009); rates scaled to 300 K
- ** Herbst & Osumara 2008, @Petrie & Herbst 1997
- @ Petrie 1996

Second conclusion

The observed abundances of C_4H^- and CN^- disagree with predictions based on direct electron attachment on C_4H and CN

Other formation mechanisms for CN^-?

- $CN + e \longrightarrow CN^-$
- $MgNC + e \longrightarrow CN^-$
- $C_n^- + N \longrightarrow CN^-$
  - dust grains ?

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Conclusions

- All 6 anions detected so far in gas phase have been seen in the **Circumstellar Envelope IRC+10216**
- Envelope expansion offers an unique opportunity to test the **time-dependence** of the chemistry
- Electron **radiative attachment rates k_{ra} can be constrained**
- There is definitively a **problem with the theoretical estimates of $k_{ra}(C_4H)$**
- **C_6H^- and C_5N^- appear at smaller radii (much earlier) than predicted. C_4H^- further out (much later)**
- **CN is probably mostly formed by another process: reaction of large C-anions (C_n^-) with N atoms, dissociative electron attachment on e.g. MgNC,..**
- **What's next? NCO- microwave spectrum recently observed at Harvard**