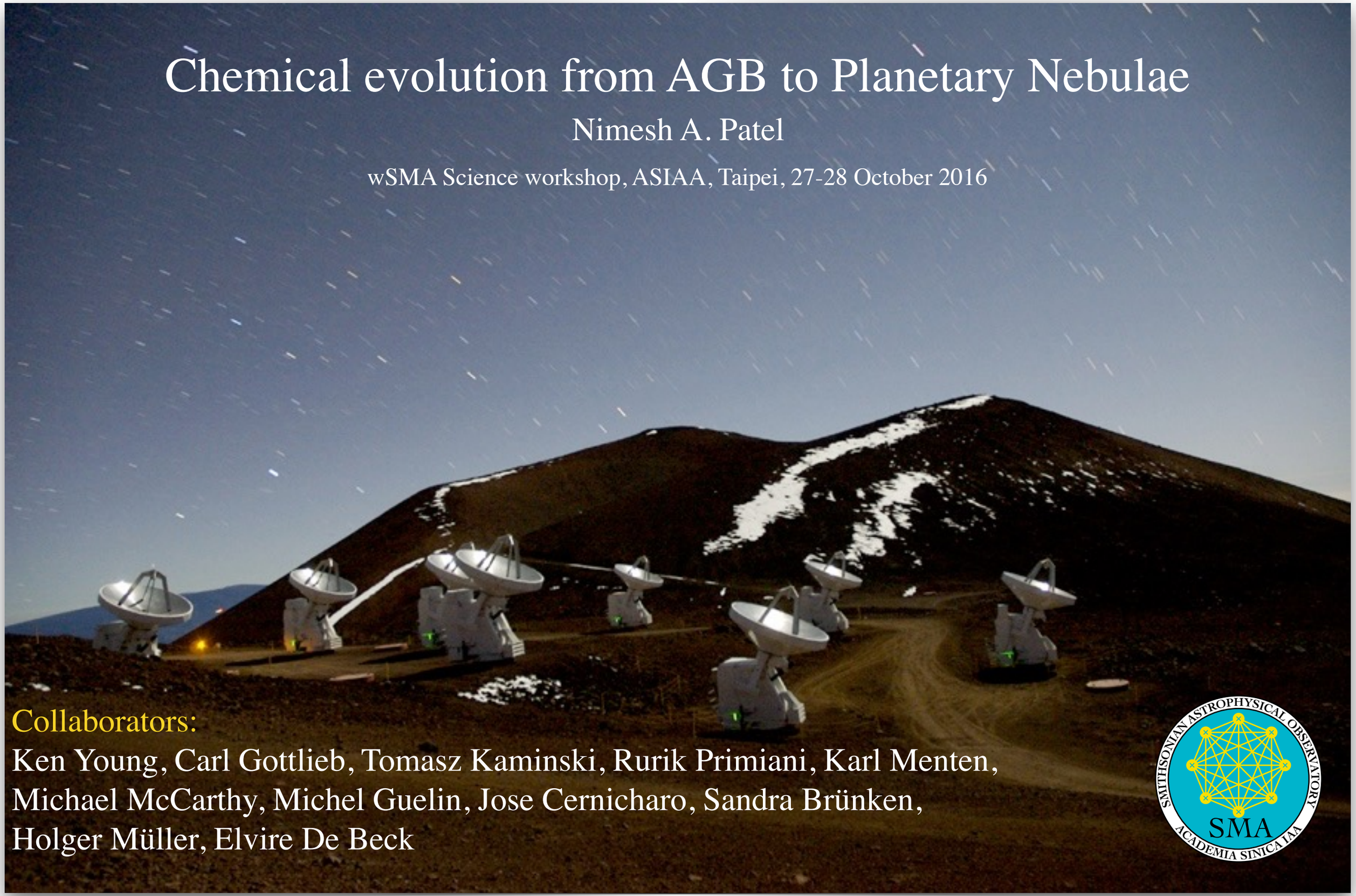
Chemical evolution from AGB to Planetary Nebulae

Nimesh A. Patel

wSMA Science workshop, ASIAA, Taipei, 27-28 October 2016



Collaborators:
Ken Young, Carl Gottlieb, Tomasz Kaminski, Rurik Primiani, Karl Menten,
Michael McCarthy, Michel Guelin, Jose Cernicharo, Sandra Brünken,
Holger Müller, Elvire De Beck

Outline

- Introductory overview
- SMA spectral-line surveys (with SWARM)
  - IRC+10216, VY CMa, IK Tau, CRL 618, NGC 7027, (CRL 2688)
- SAO Spectroscopy lab collaboration
- Summary and future outlook

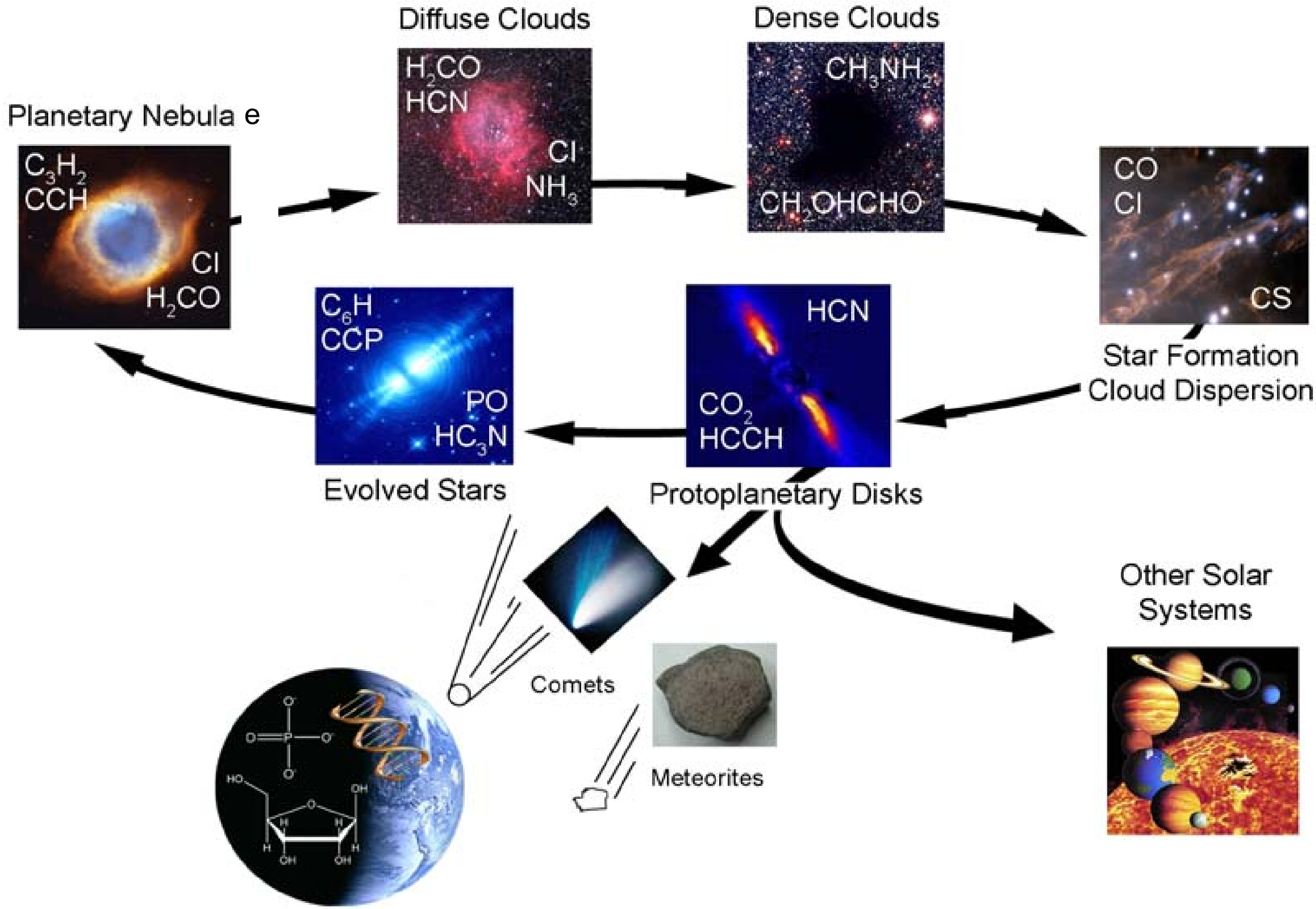
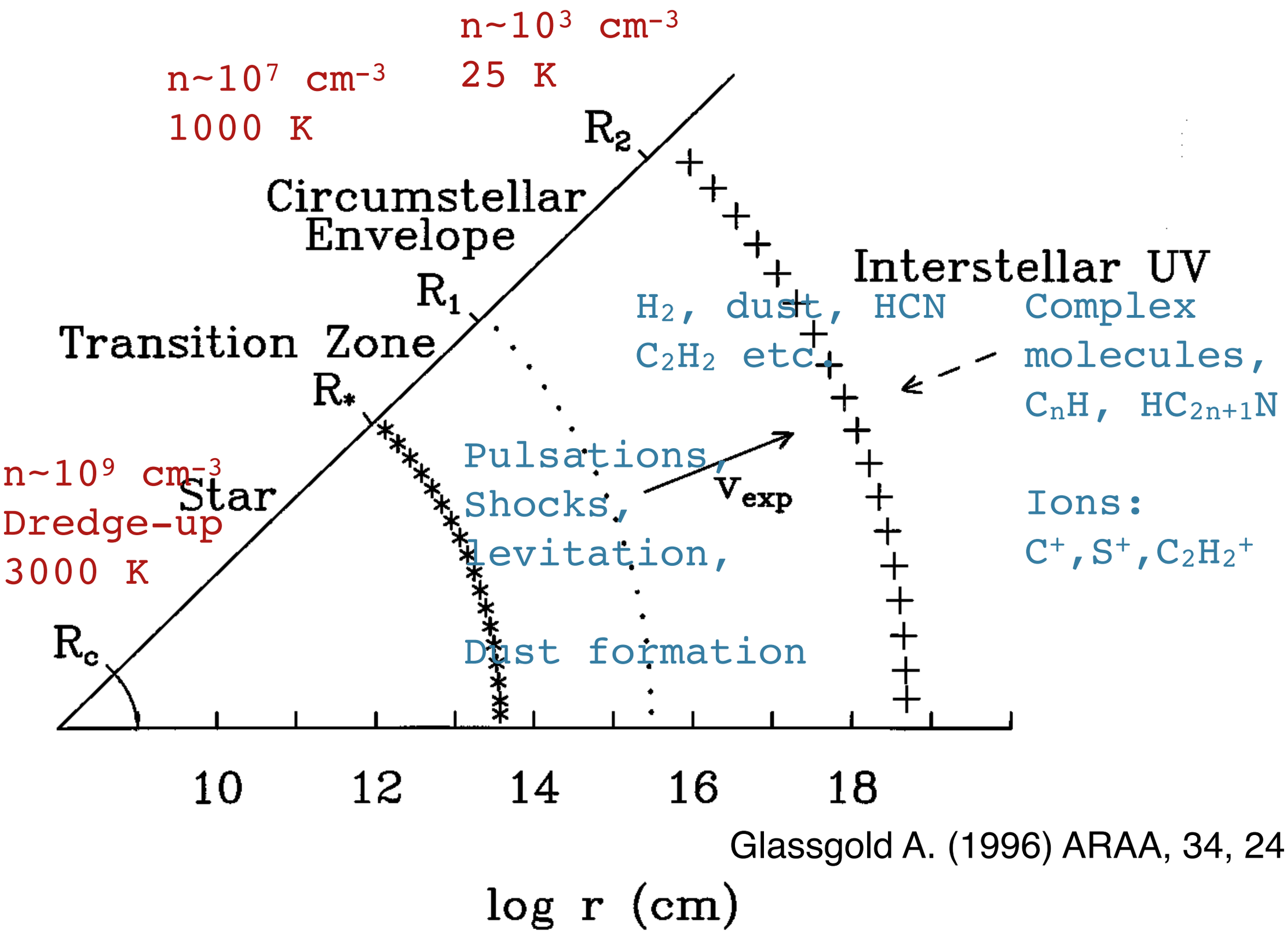


Figure 1: The life cycle of the interstellar medium and its relationship to planets and solar systems, as traced by molecular material.

Ziurys et al. 2010, Astro2010 Science White Paper

I. AGB stars (e.g. IRC+10216)

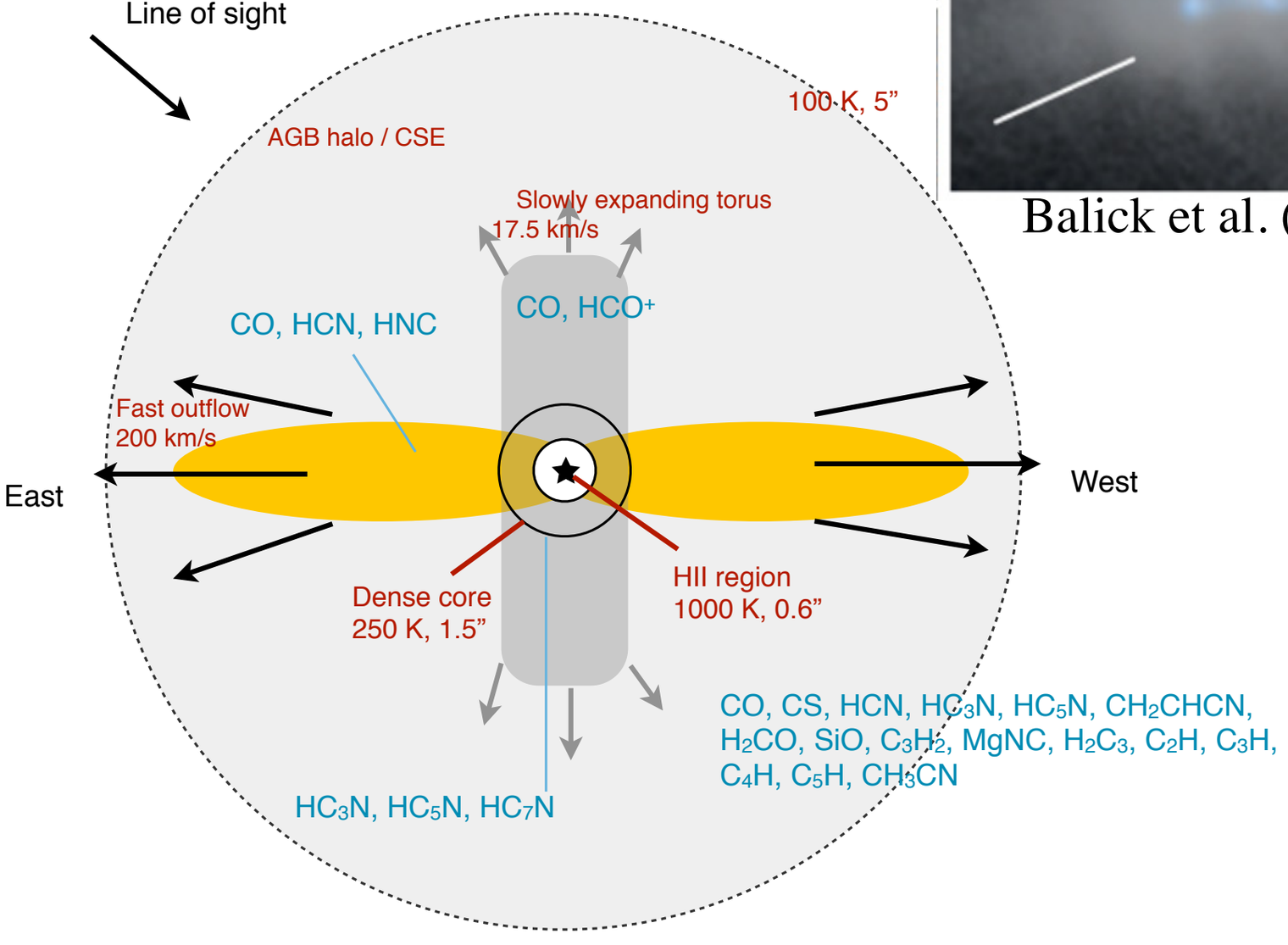


Glassgold A. (1996) ARAA, 34, 241

II. Proto Planetary Nebulae (e.g. CRL 618)

Distance~1.5 kpc

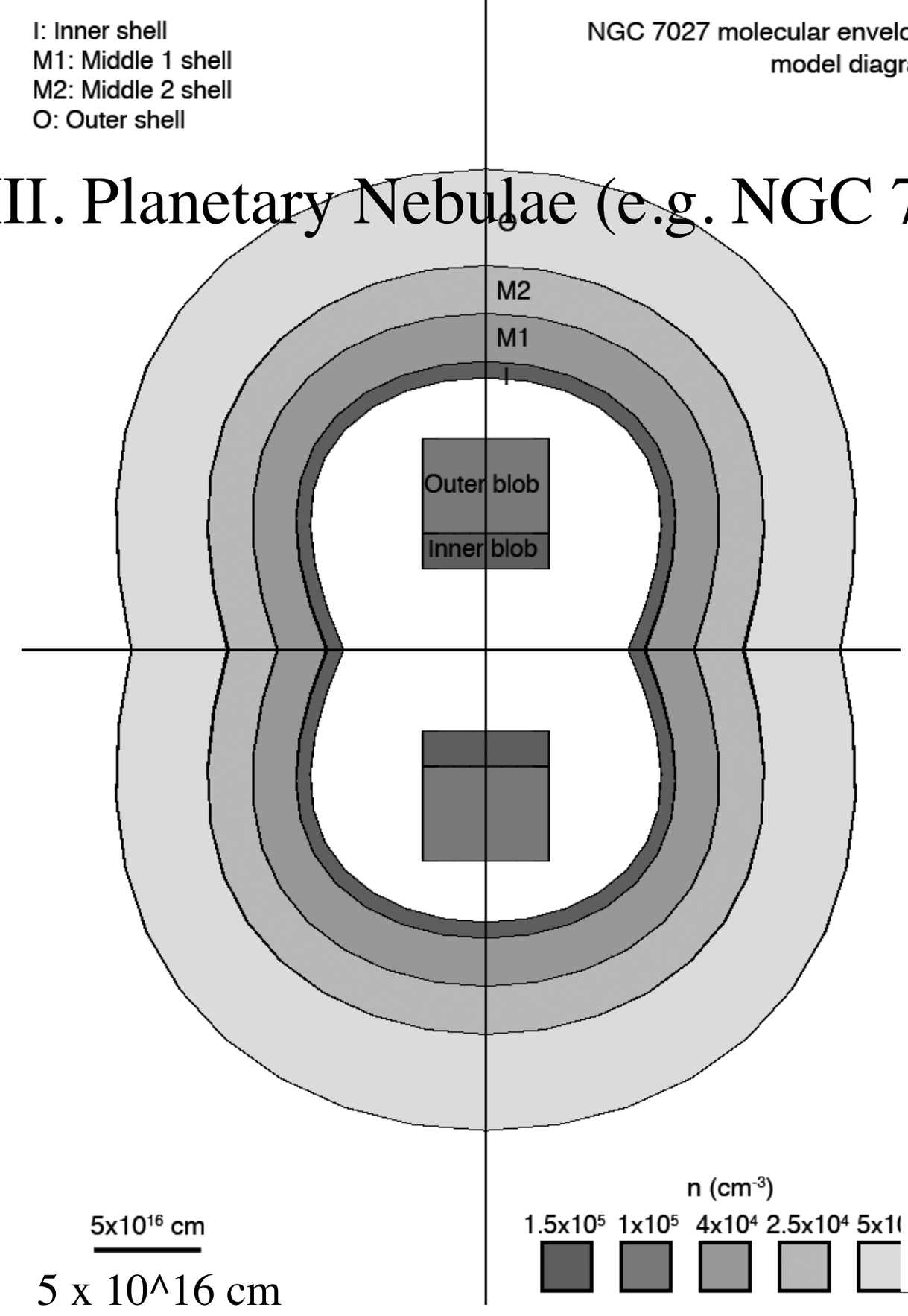
Balick et al. (2013) ApJ 772,20



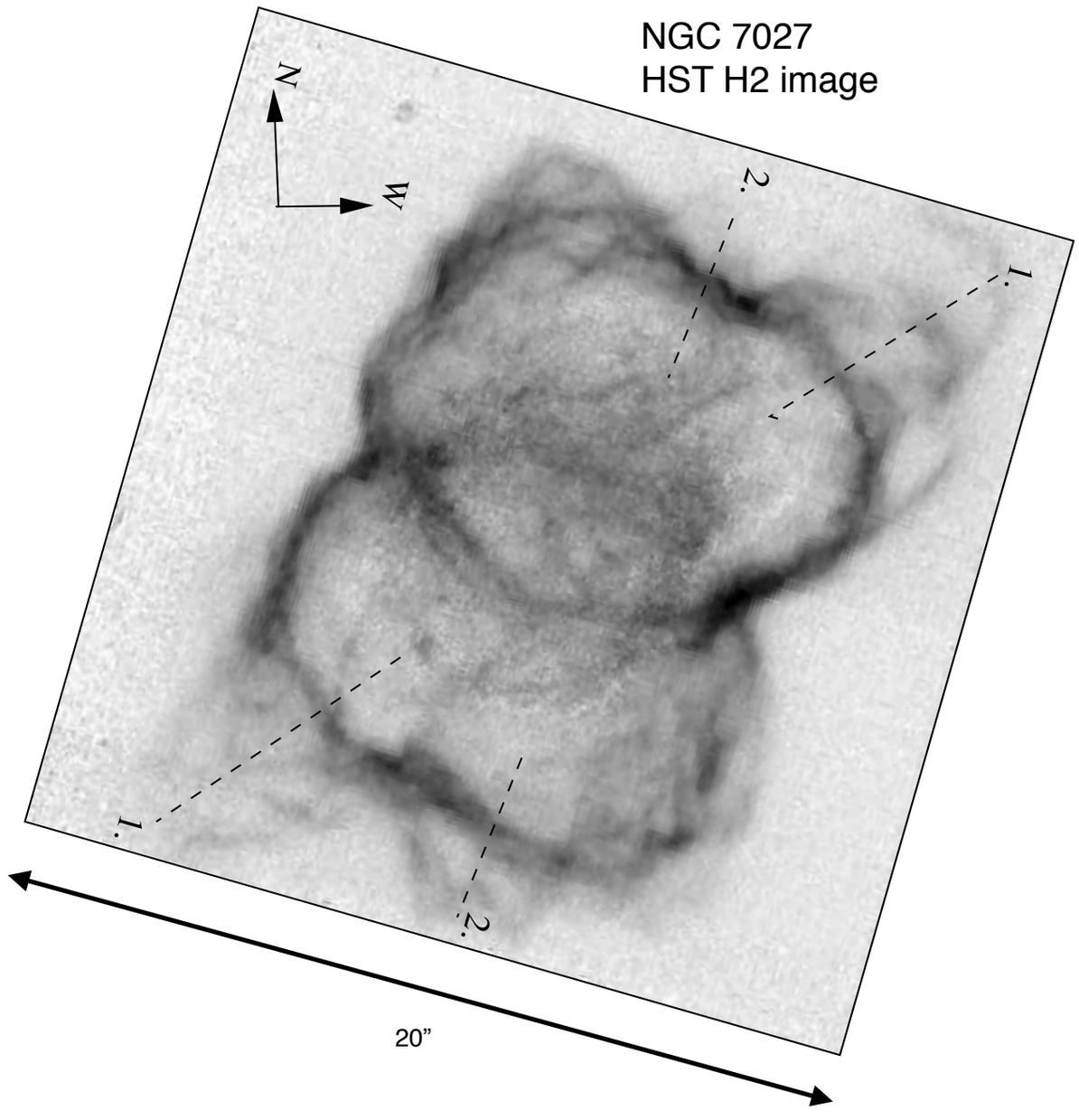
(The schematic figure was made before the SMA observations. We now find CN and CCH in the fast outflow.)

III. Planetary Nebulae (e.g. NGC 7027)

Distance ~ 900 pc



Santander-Garcia et al. (2012) A&A 545,A114



Latter et al. (2000)

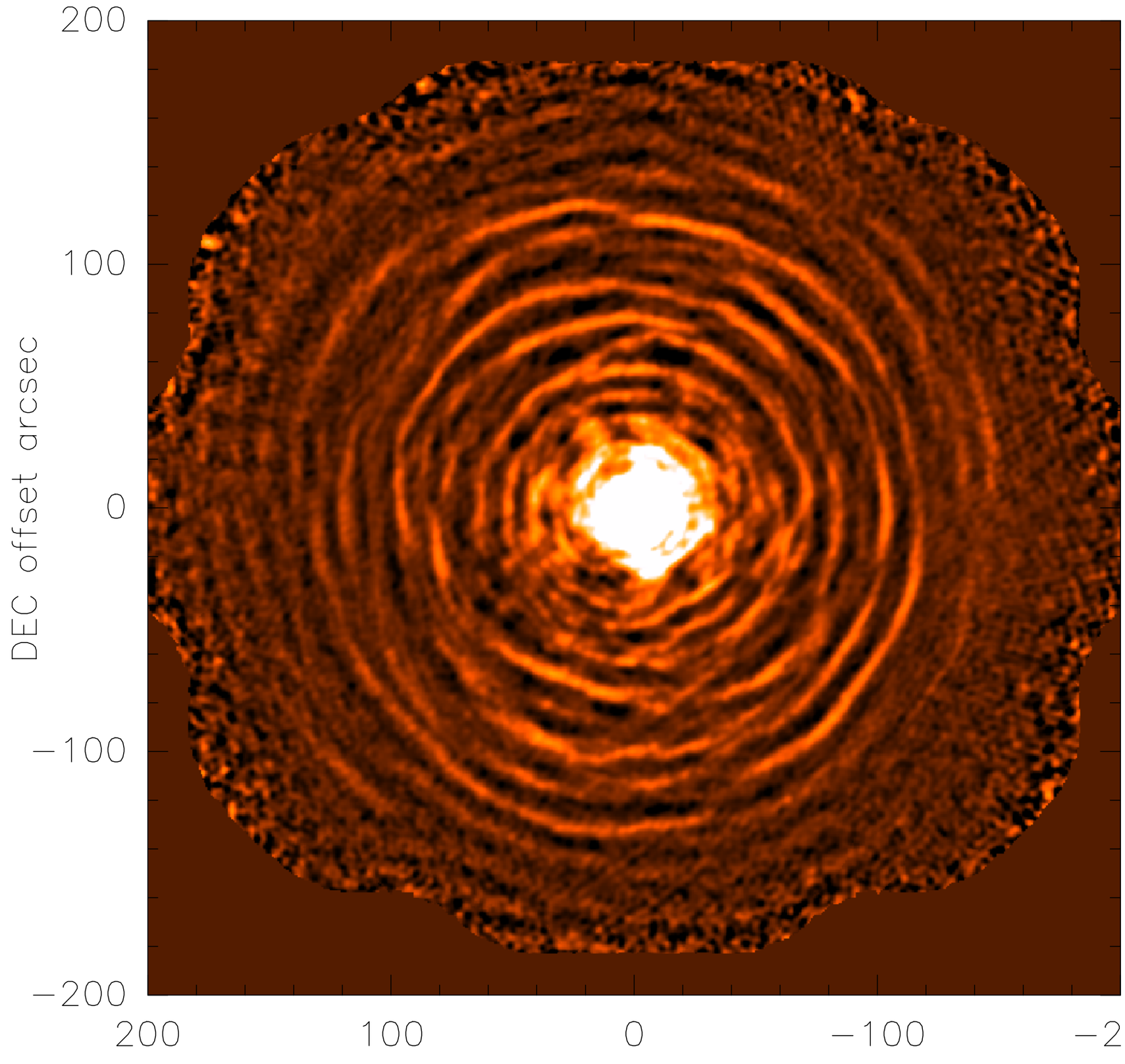
Latter et al. (2000) ApJ 539,783

NGC 7027

HST Legacy Archive, APOD 26 Sept. 2016, D. Cadrecha

IRC+10216 CO(2−1)

V=V*=−26.7 km/s Δv=2 km/s



SMA + IRAM 30m tel.

Guilen et al. (in prep.)

Line Survey of IRC+10216

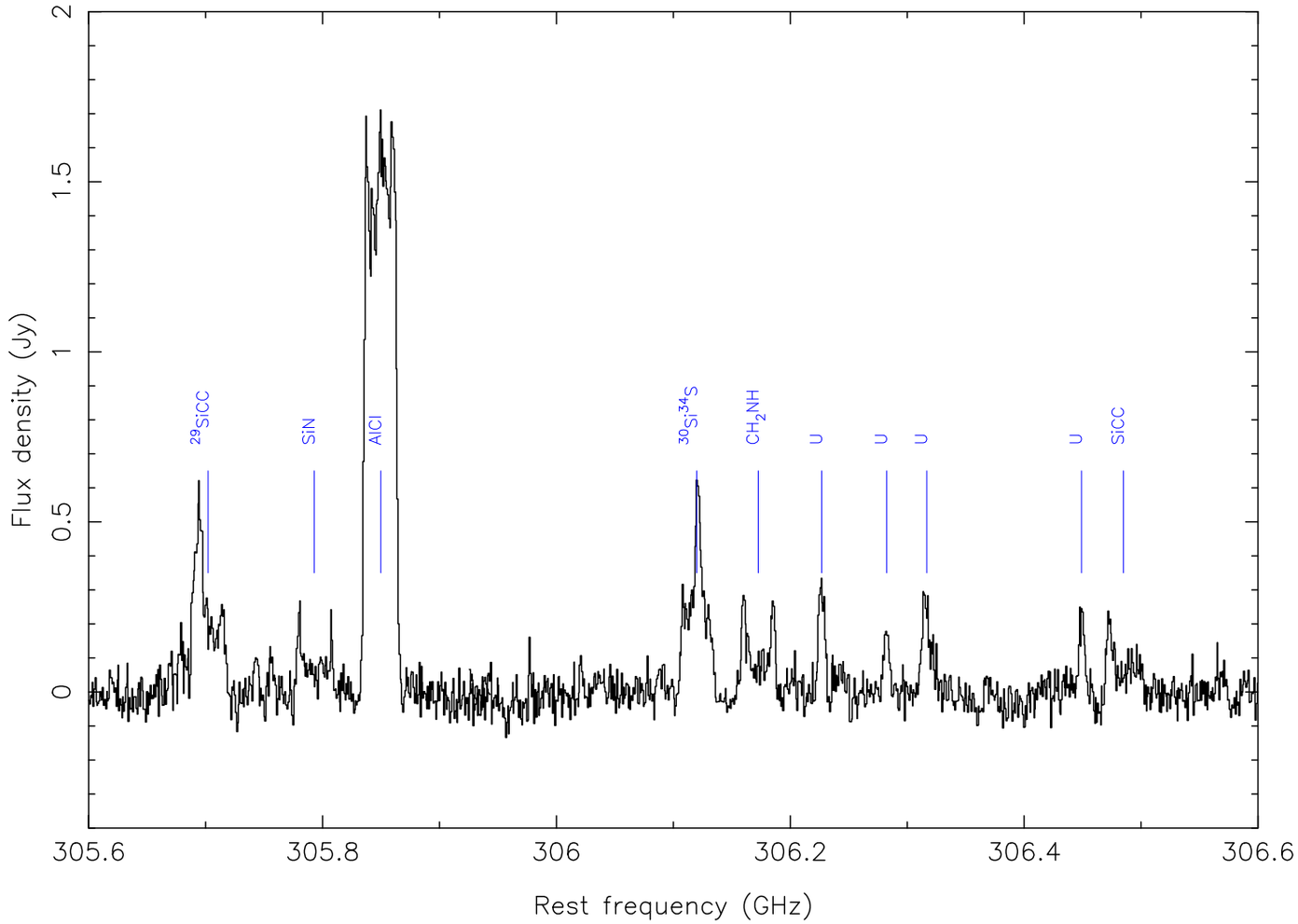
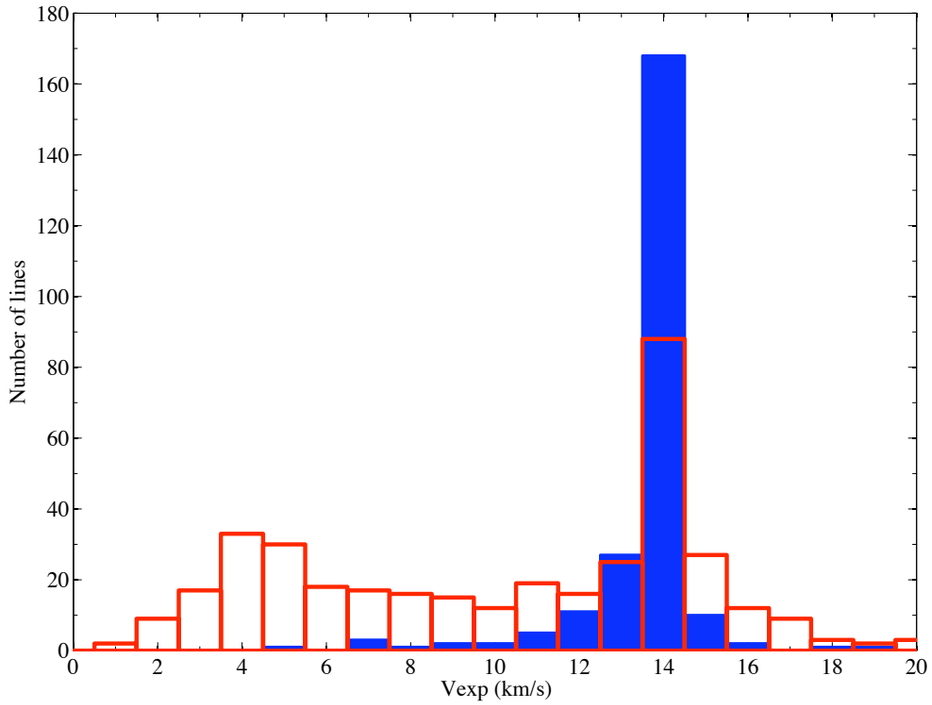
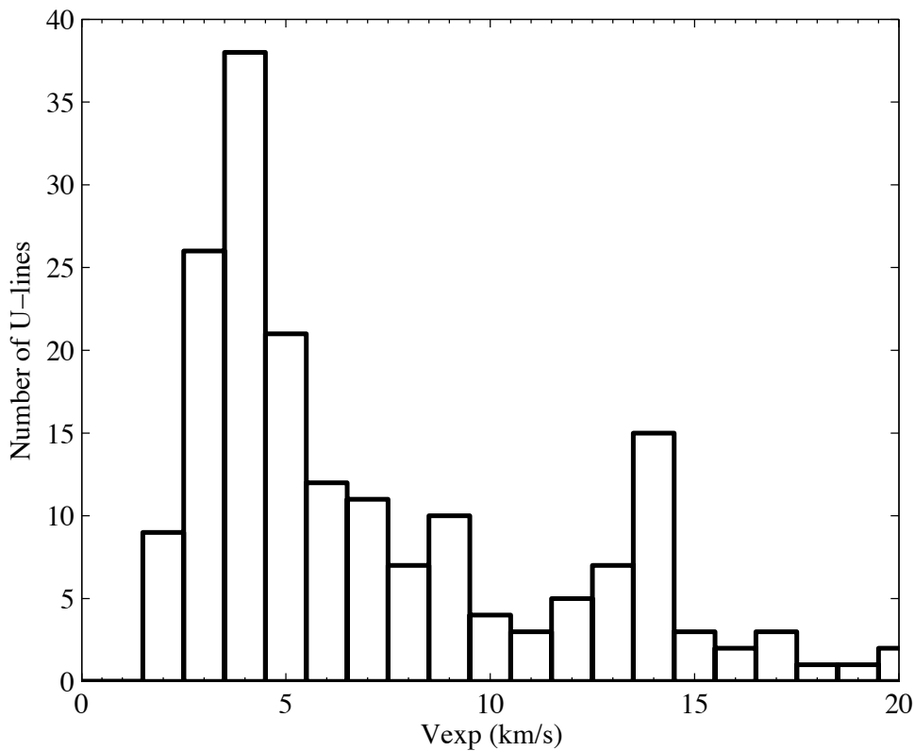
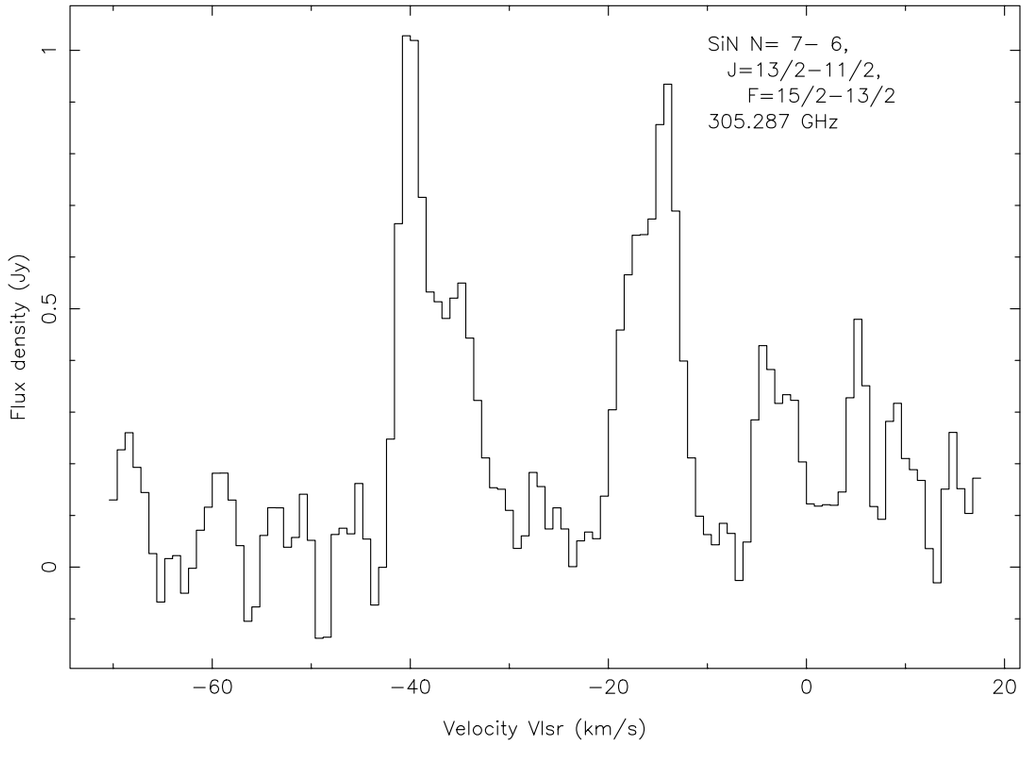


FIGURE 9. Sample spectrum from the SMA spectral line survey of IRC+10216 by Patel et al. [5]. In this particular spectrum, four narrow U lines with flux density of ≤ 0.3 Jy were observed between 306.2 and 306.5 GHz. The line profile of AlCl on the left at 305.85 GHz is an example of a species in the outer envelope that has reached the terminal velocity.





Patel et al. (2009) ApJ,692,1205
Patel et al. (2011) ApJSS,193,17



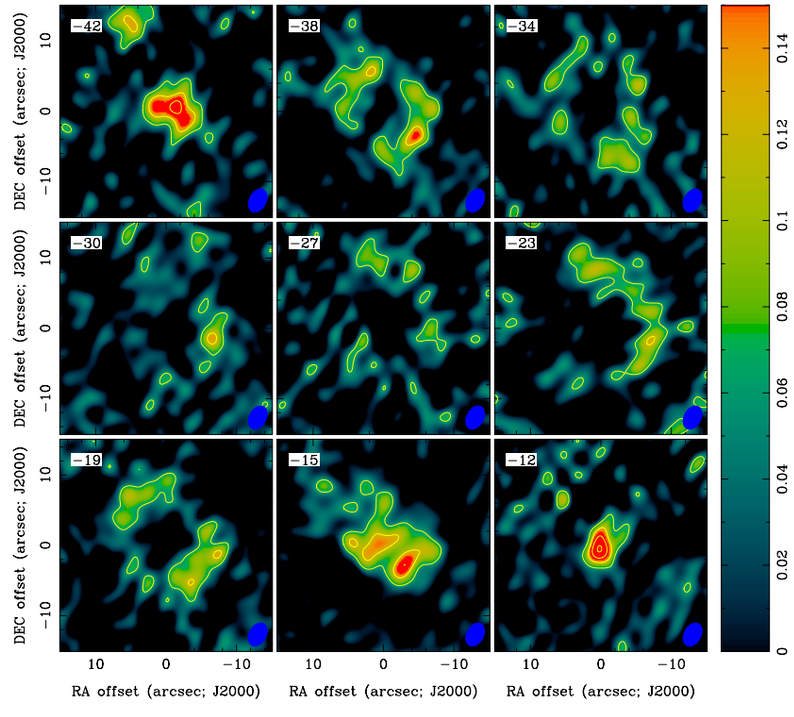
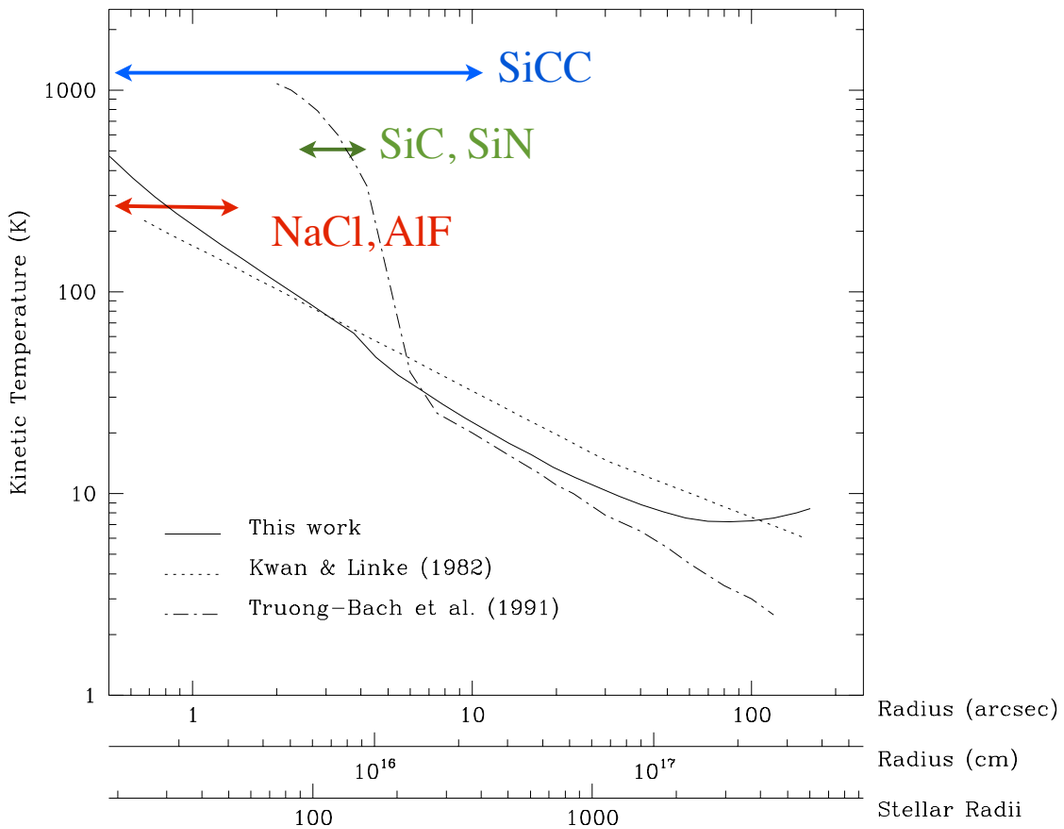
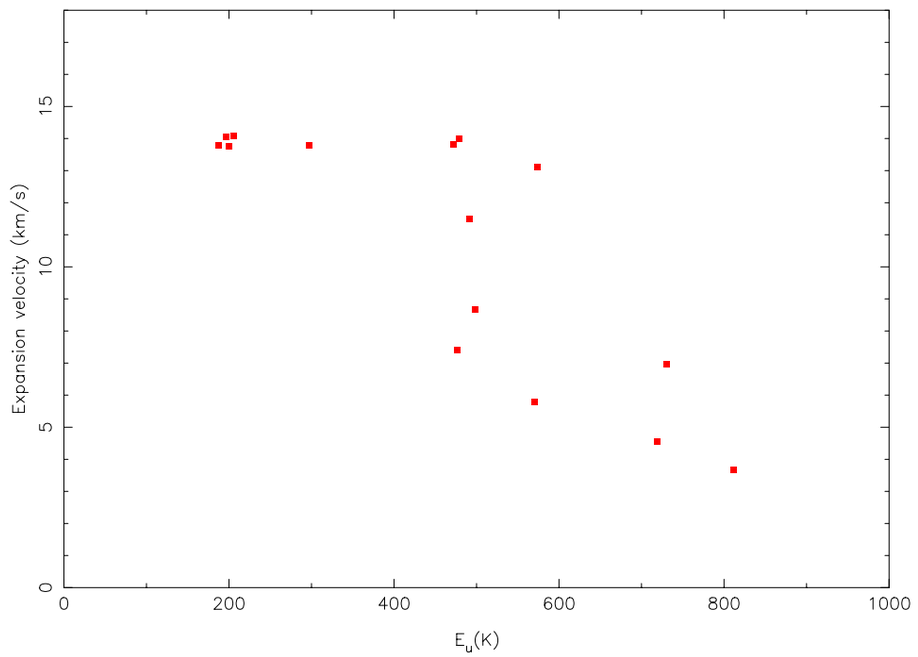


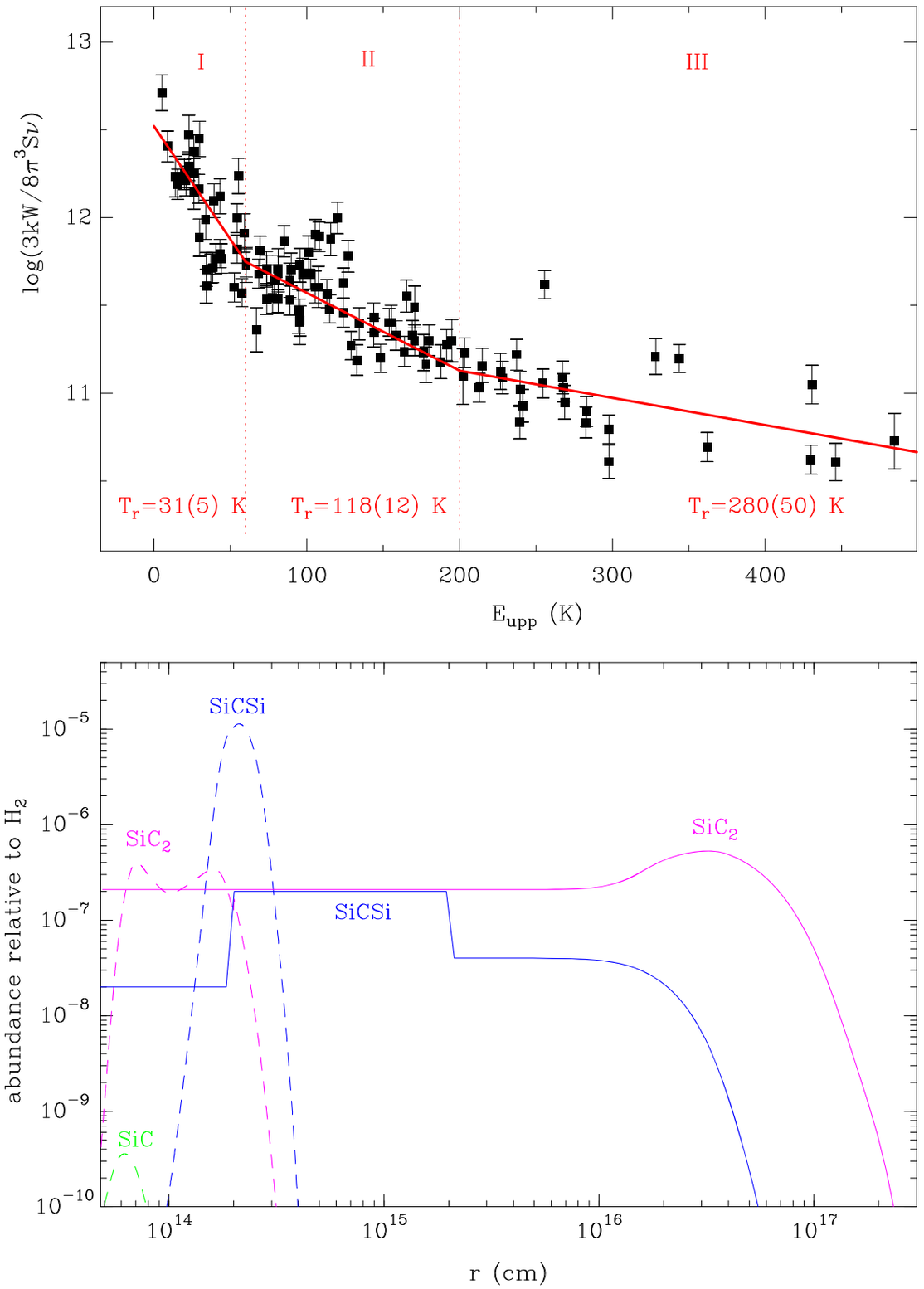
Figure 2: Spectrum and channel map of SiN emission near 305 GHz.

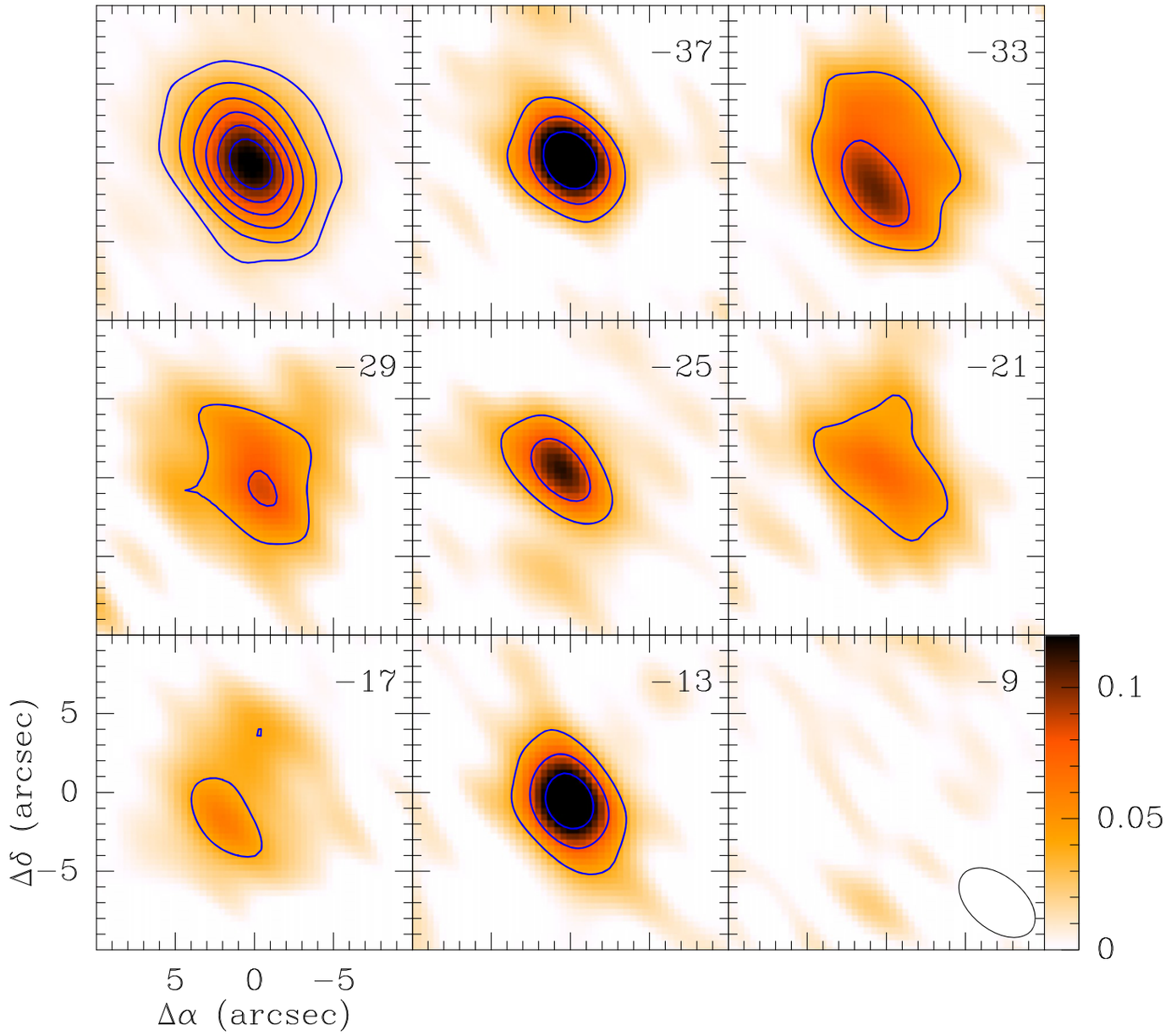
Patel et al. (2013) Life cycle of Dust conference, Taipei





Discovery of SiCSi in IRC+10216





- 112 lines, 80-350 GHz, with IRAM 30m (103) and SMA (9)
- 22 lines measured in the laboratory (McCarthy et al. 2015)
- Emission arises from a region 6” in radius; expanding shell
- Abundance of SiCSi is similar to that of SiCC due to the lower dipole moment and larger partition function, SiCSi lines are nearly a 100 times fainter than lines of SiCC.

J. Cernicharo, M. McCarthy, C Gottlieb et al., 2015, ApJ,806,L3

Metal Oxides in VY CMa

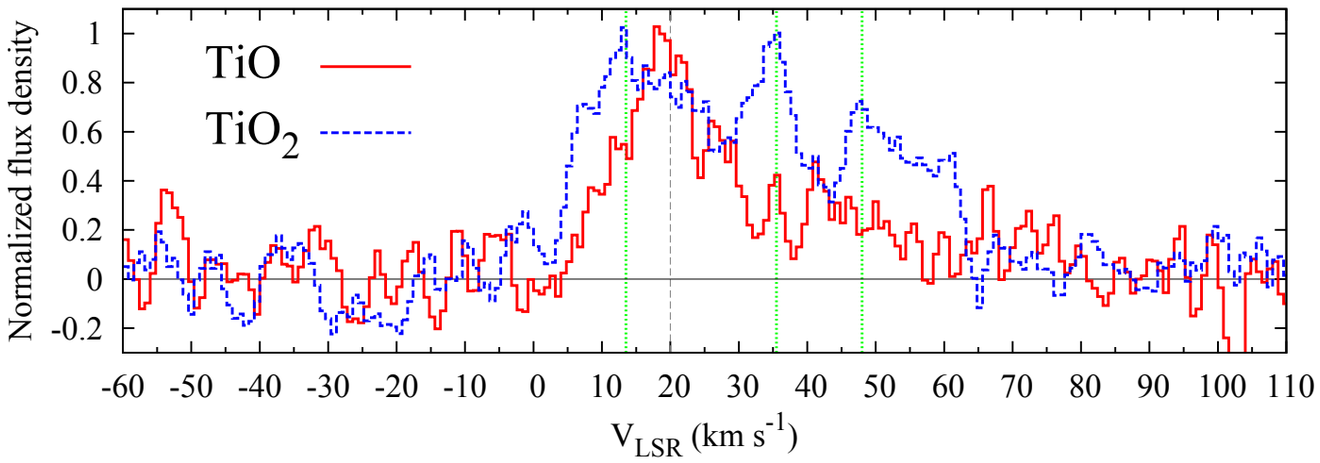


FIGURE 3. Line profiles of TiO (solid red line) and TiO_2 (dashed blue line) observed in VY CMa with the SMA [2]. The vertical dashed line (grey) marks the stellar systemic velocity, while the (green vertical dotted lines) mark three strongest velocity components in the profile of TiO_2. The line widths and profile shapes provide preliminary information on the regions of the source where the two molecules are observed: the interferometric maps provide a direct measure of the position and angular size, and together with the spectra describe the kinematics of the circumstellar envelope.

Kaminski et al. (2013) ApJSS 209,38
Kaminski et al. (2013) A&A 551, A113

SMA observations described so far, have led to subsequent work on Mira by Kaminiski et al. using ALMA, and is the basis for a grant in Laboratory Astrophysics from the NSF.

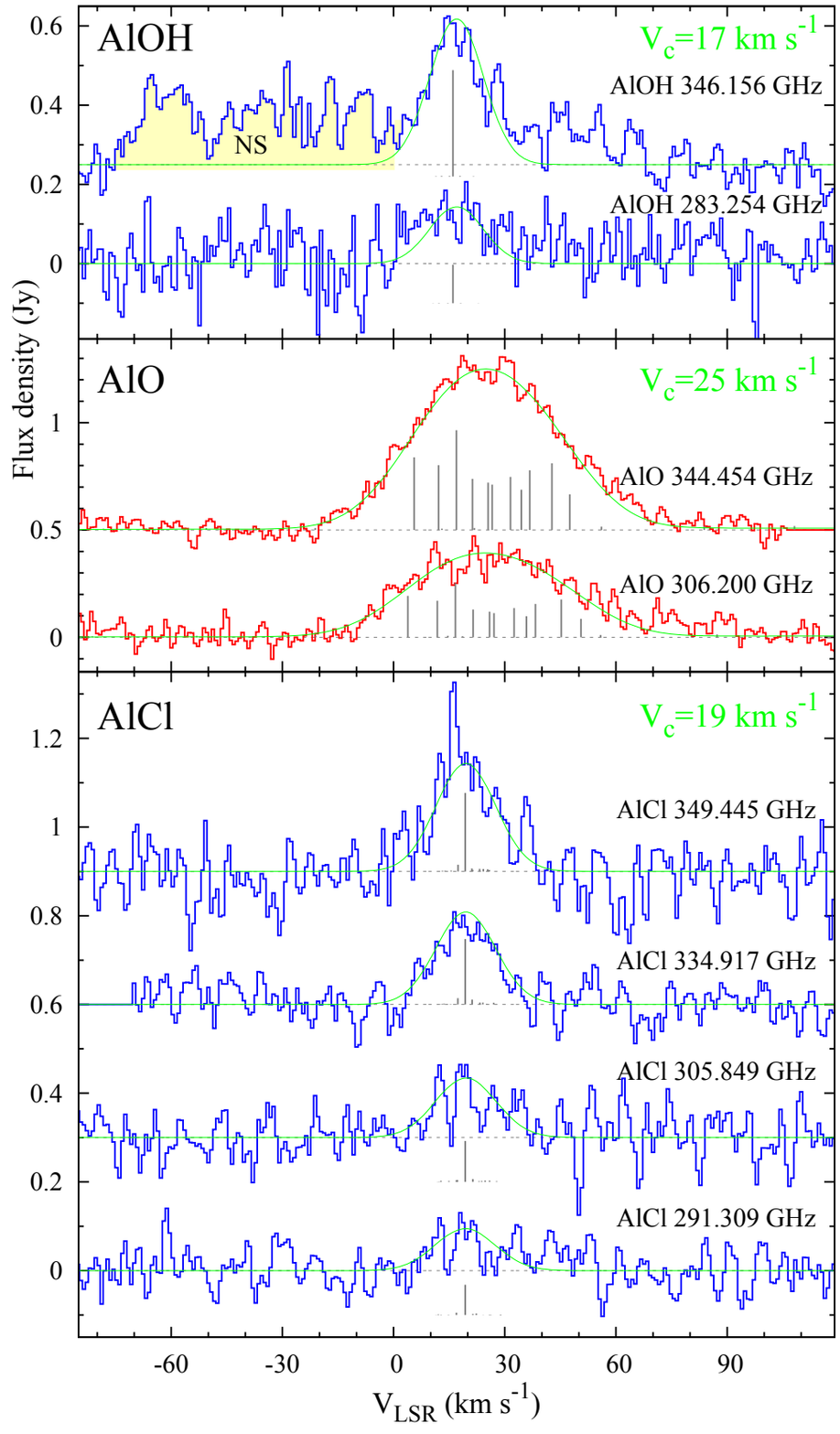
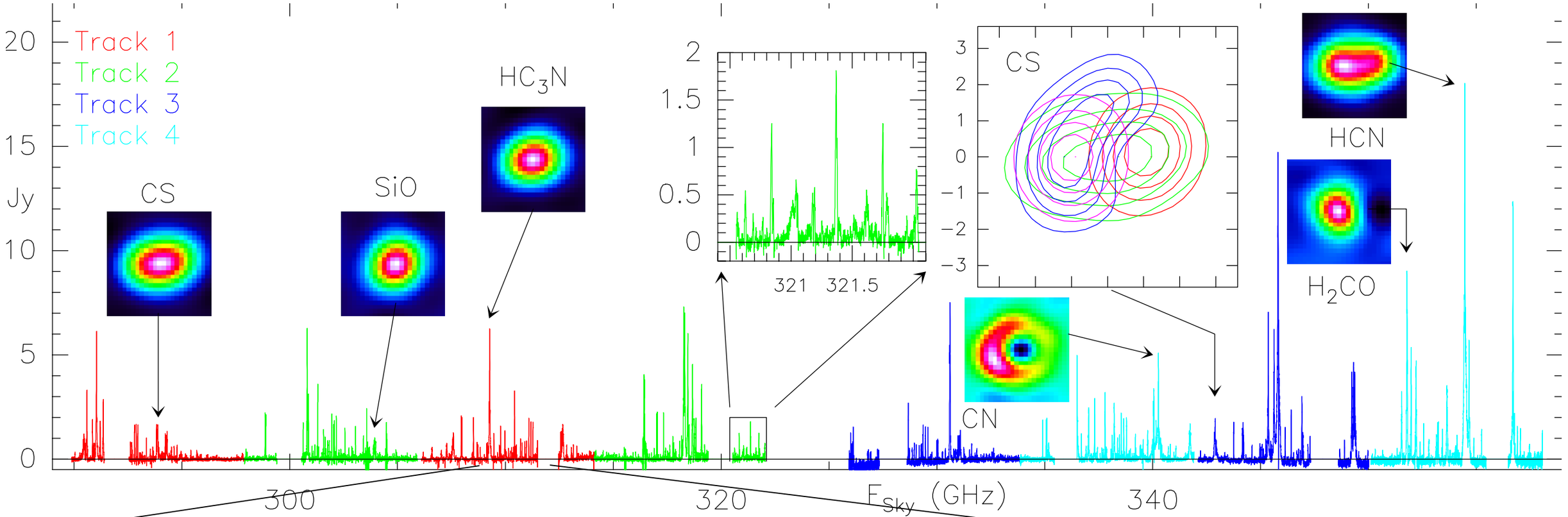
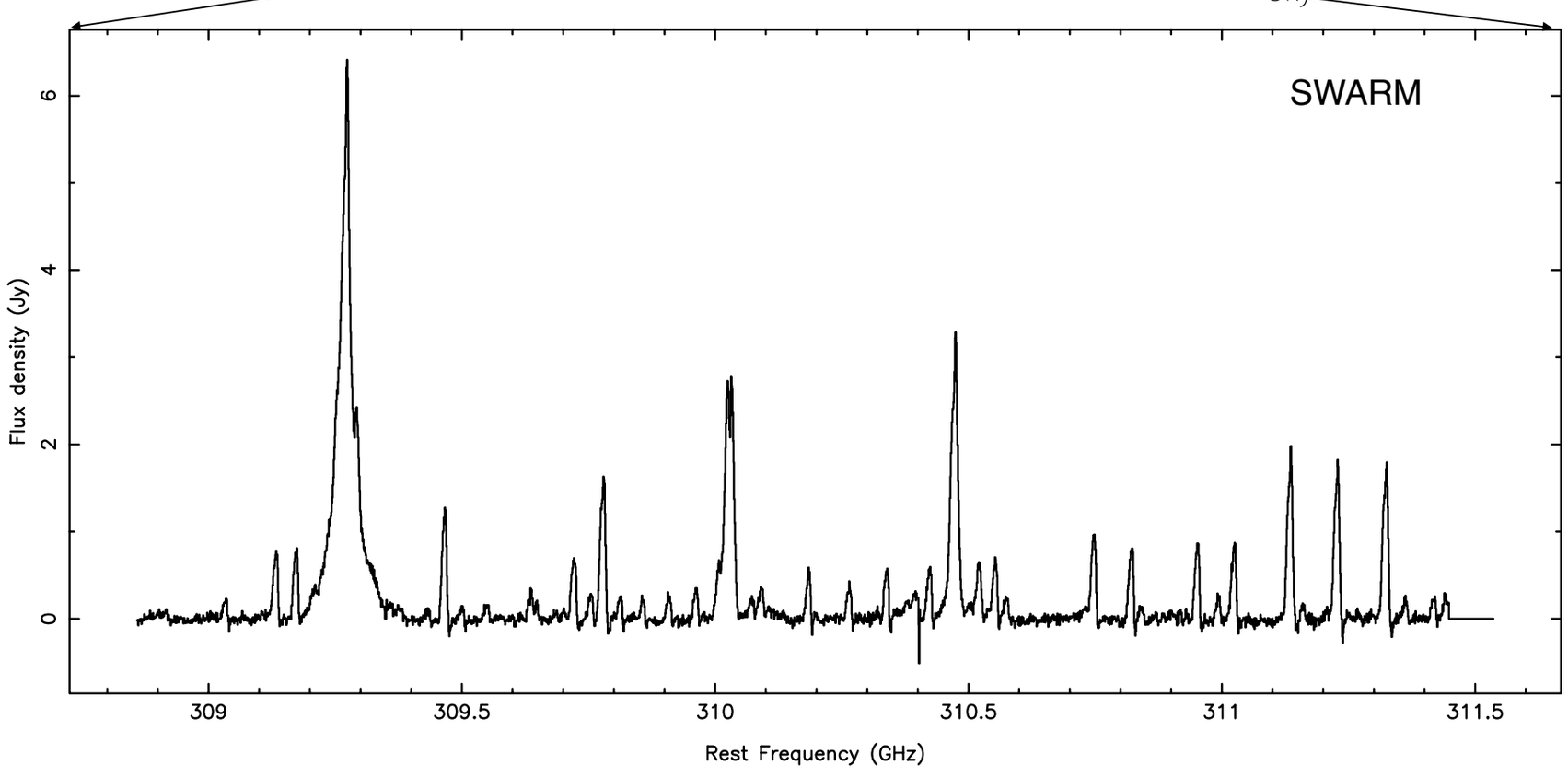


FIGURE 7. *Left:* Spectra of AlOH, AlO, and AlCl in VY CMa observed with the SMA [20].

Preliminary results from the CRL 618 SMA line survey (1 Jan - 5 Jan 2016) 2015B-S022





- ~1075 lines detected in 281.9-359.4 GHz range
- Most are from HCCCN and cyclic CCCHH
- Line identification and analysis ongoing
- Compact configuration, 3” angular resolution

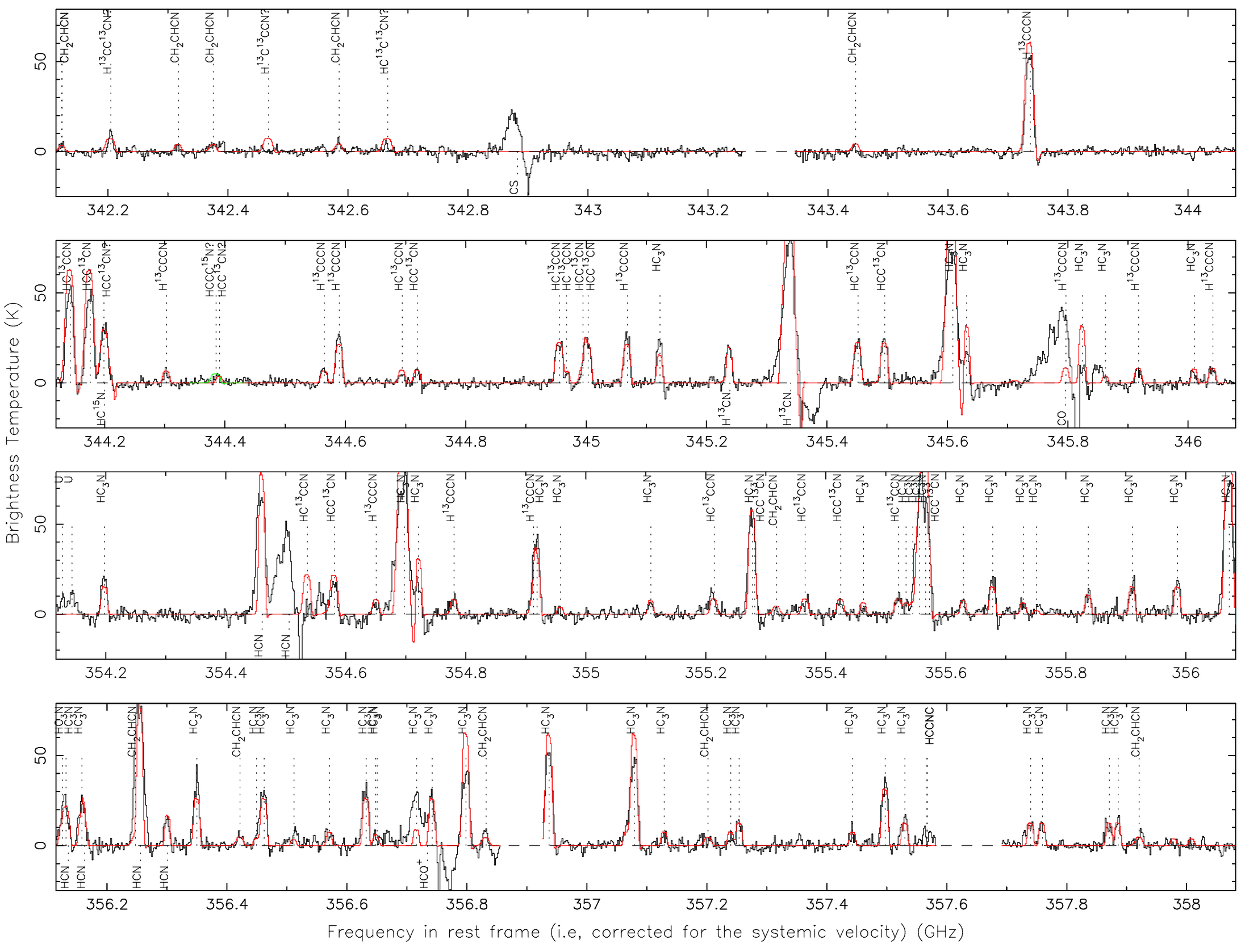
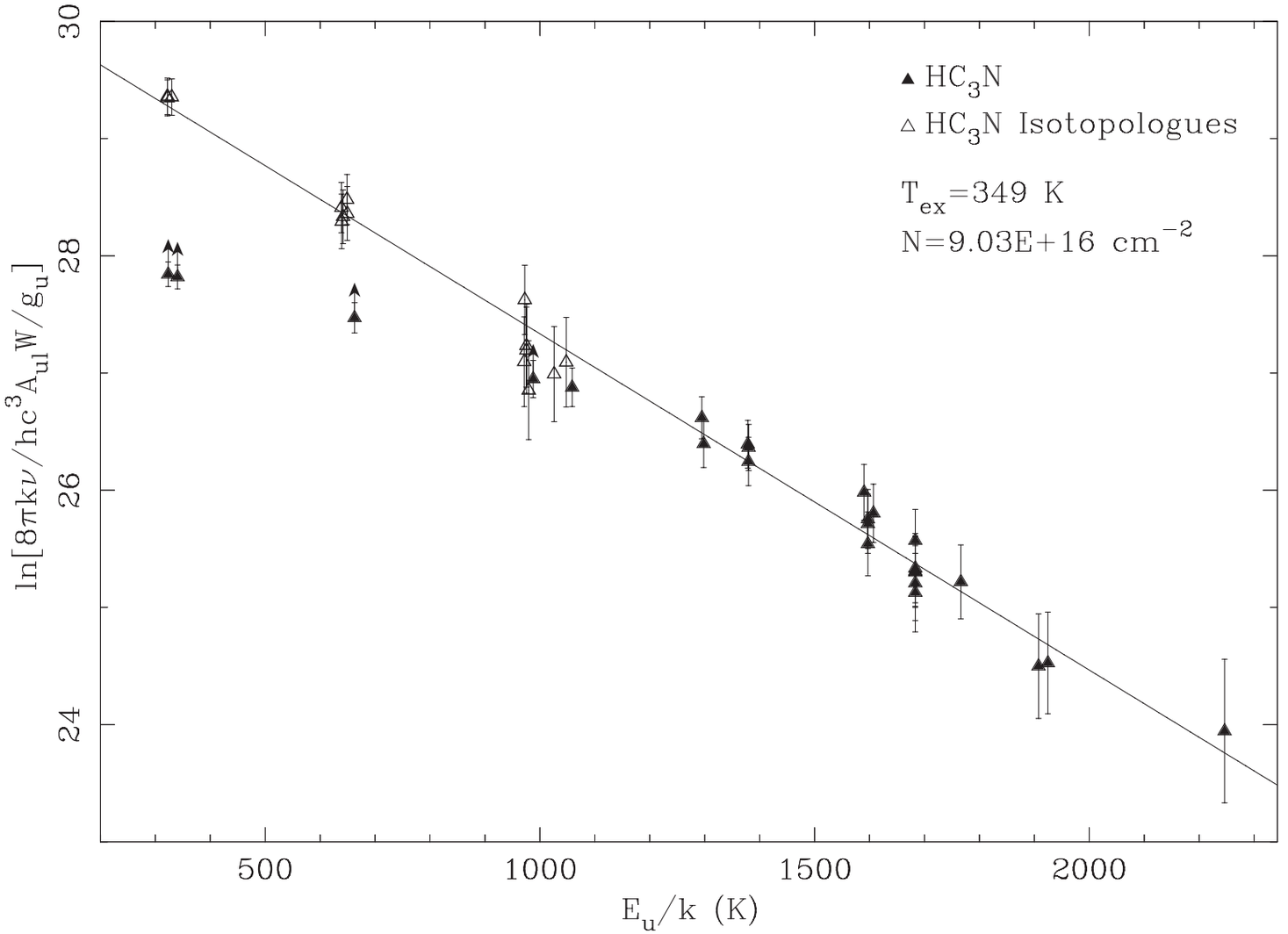


Figure 12. Fit of our model to the spectra. The black spectra are the same as those in Figure 3. Red spectra are derived from our model. The green spectrum shows the possible $HCCC^{15}N$ (0000) line at 344.3853481 GHz predicted from our model assuming an abundance ratio of $[HC_3N]/[HCCC^{15}N] = 150$.

Lee et al. (2013) ApJ, 770, 153

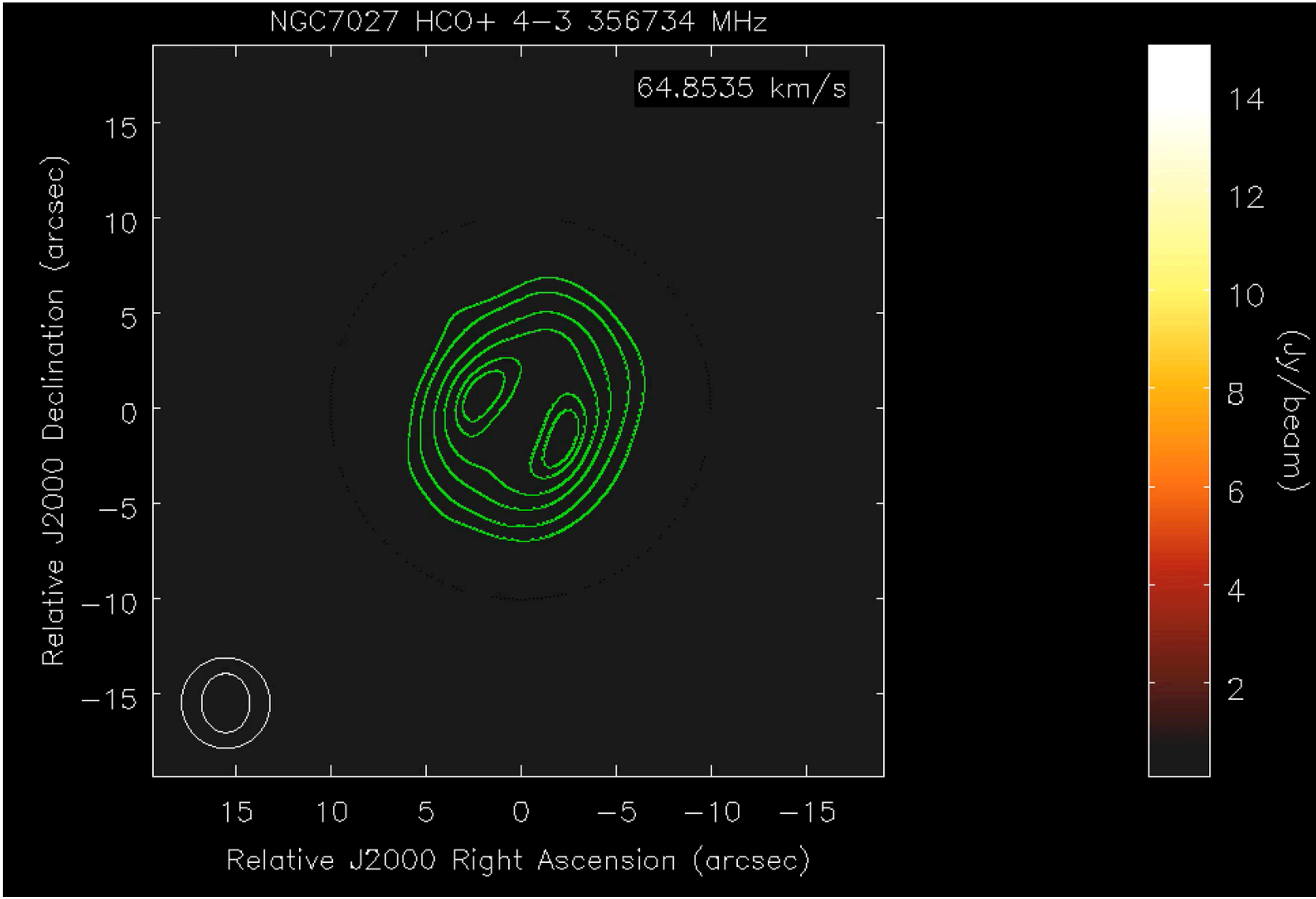
SMA
Ex+Vex
CRL618

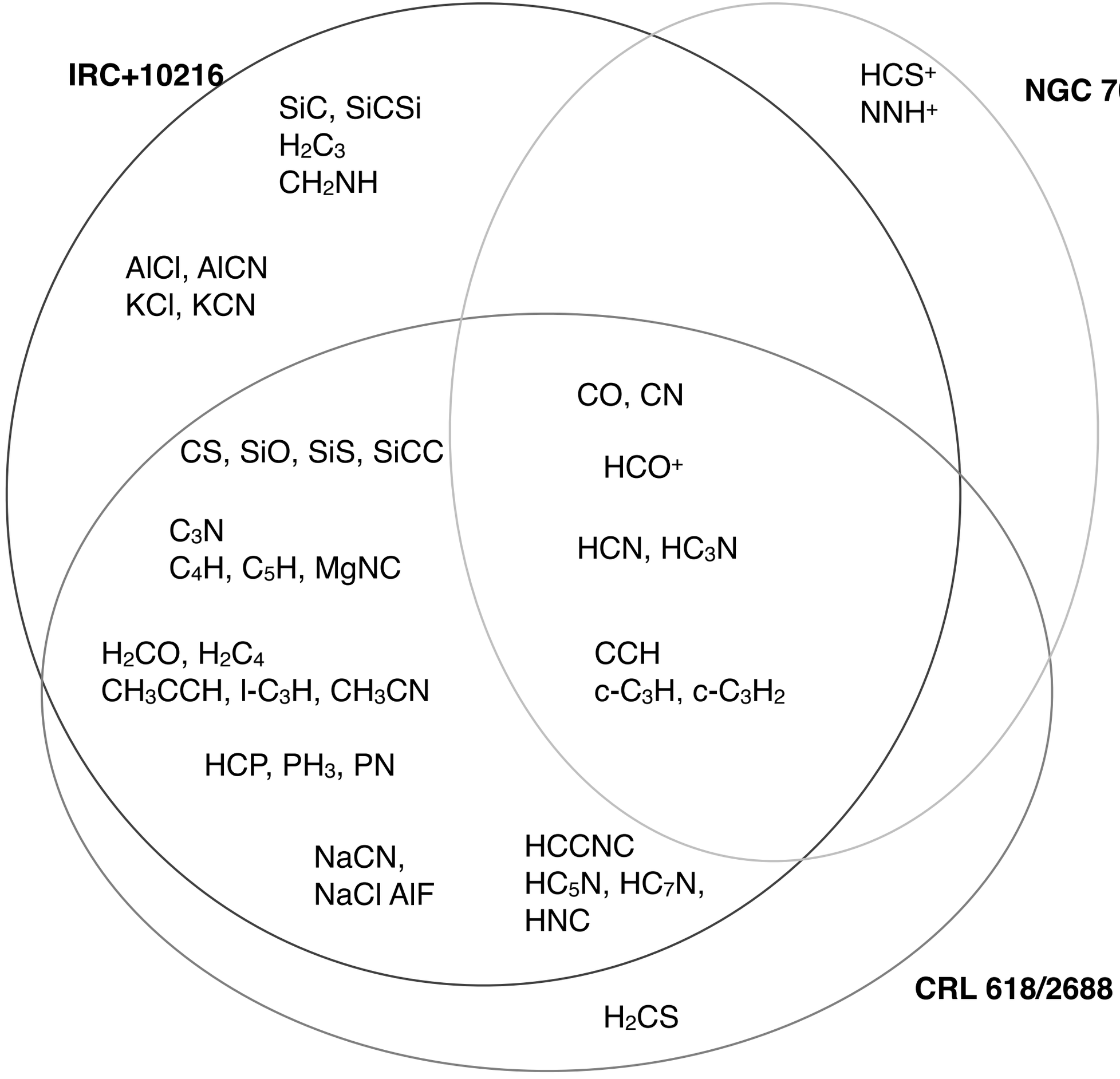


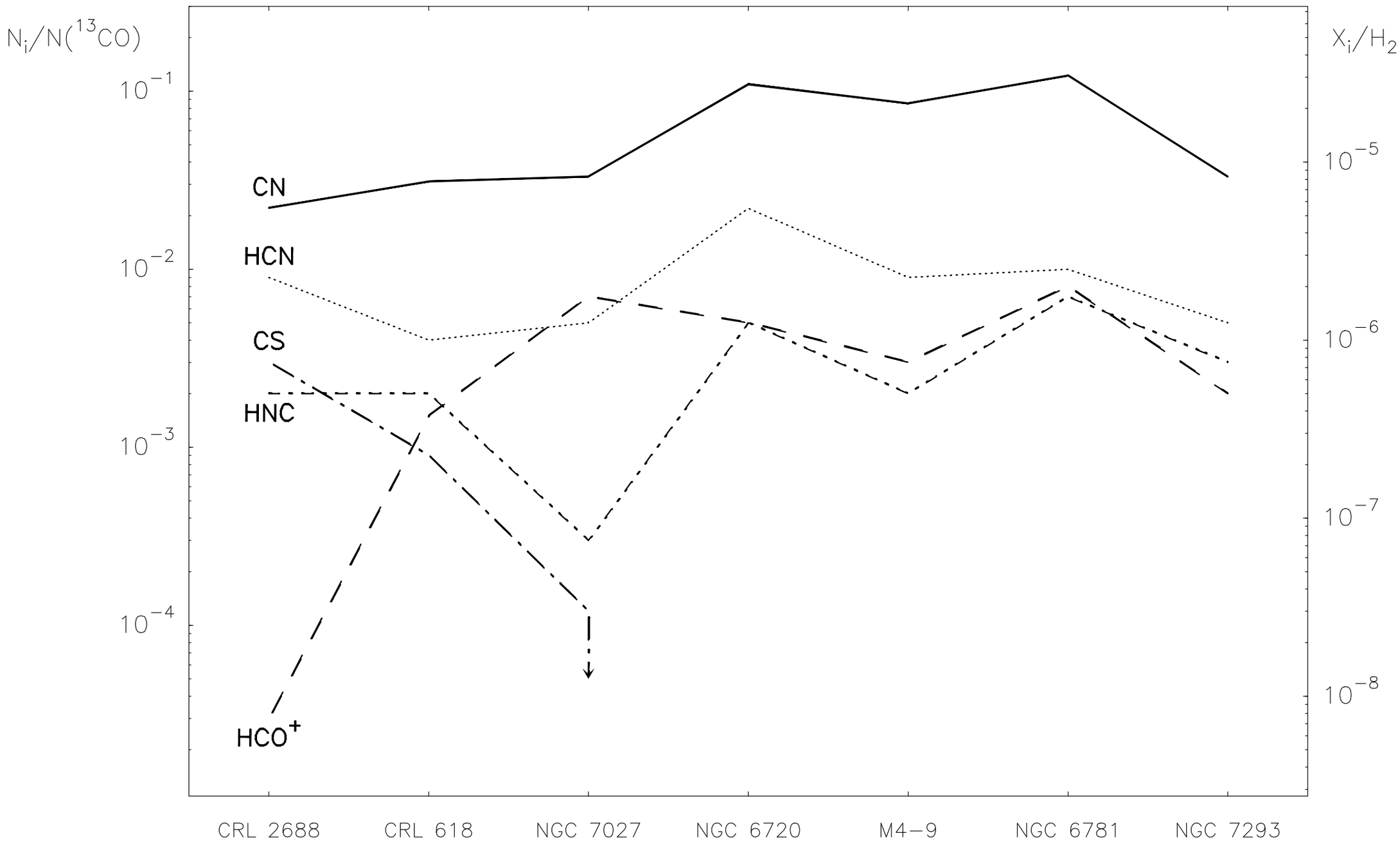
Lee et al. (2013)

Figure 10. Population diagram for HC_3N and its singly ^{13}C substituted isotopologues. The line intensity of the isotopologues has been multiplied by a factor of 10. The solid line is a linear fit to the data. The HC_3N data points with an upper arrow are not optically thin and thus excluded from the fitting.

- ^{13}C fractionation in HCCCN and HCCCCCN isotopologues as probe of formation of these cyanopolyynes (Taniguchi et al. 2016).
- From our CRL 618 line survey, a similar analysis of cyclic C3H2 (in the extended halo) which is complementary to the one for HCCCN by Lee et al. (in the dense core) is in progress.


NGC7027 HCO+ 4−3 356734 MHz
64.8535 km/s
Relative J2000 Declination (arcsec)
15
10
5
0
−5
−10
−15
15
10
5
0
−5
−10
−15
Relative J2000 Right Ascension (arcsec)
14
12
10
8
6
4
2
(Jy/beam)


IRC+10216
SiC, SiCSi
H_2C_3
CH_2NH
AlCl, AlCN
KCl, KCN
CS, SiO, SiS, SiCC
C_3N
C_4H, C_5H, MgNC
H_2CO, H_2C_4
CH_3CCH, l-C_3H, CH_3CN
HCP, PH_3, PN
NaCN,
NaCl AlF
HCCNC
HC_5N, HC_7N,
HNC
H_2CS
HCS^+
NNH^+
NGC 7027
CO, CN
HCO^+
HCN, HC_3N
CCH
c-C_3H, c-C_3H_2
CRL 618/2688

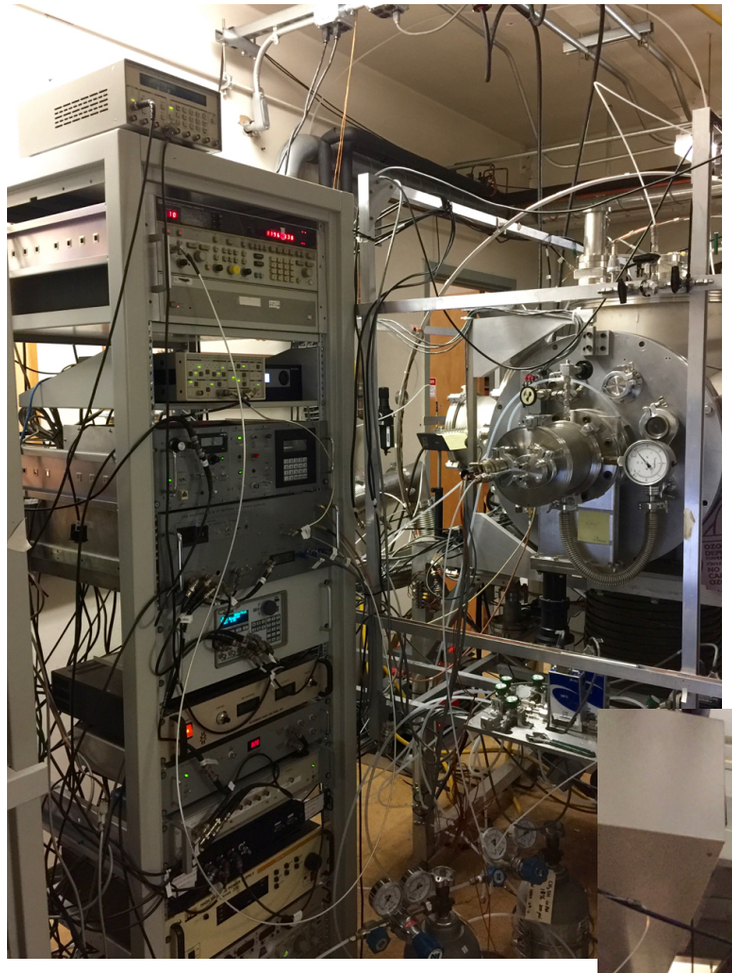


Bachiller et al. (1997) A&A, 324,1123

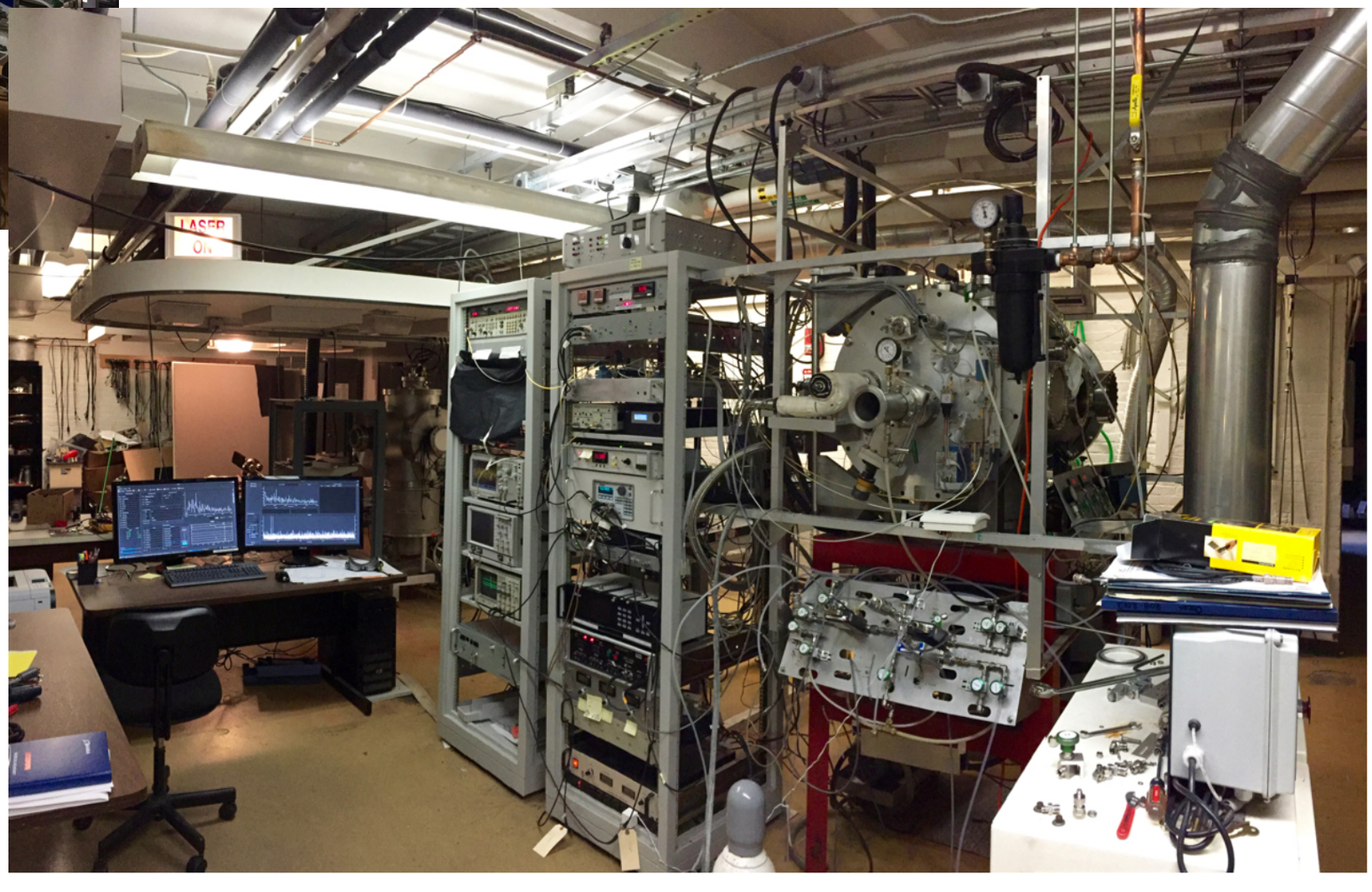
- From AGB to PPN: more CN bearing molecules; less refractory
- Si bearing molecules depleted in PPN & PN, already in grains
- H2CO in PPN: onset of grain surface chemistry

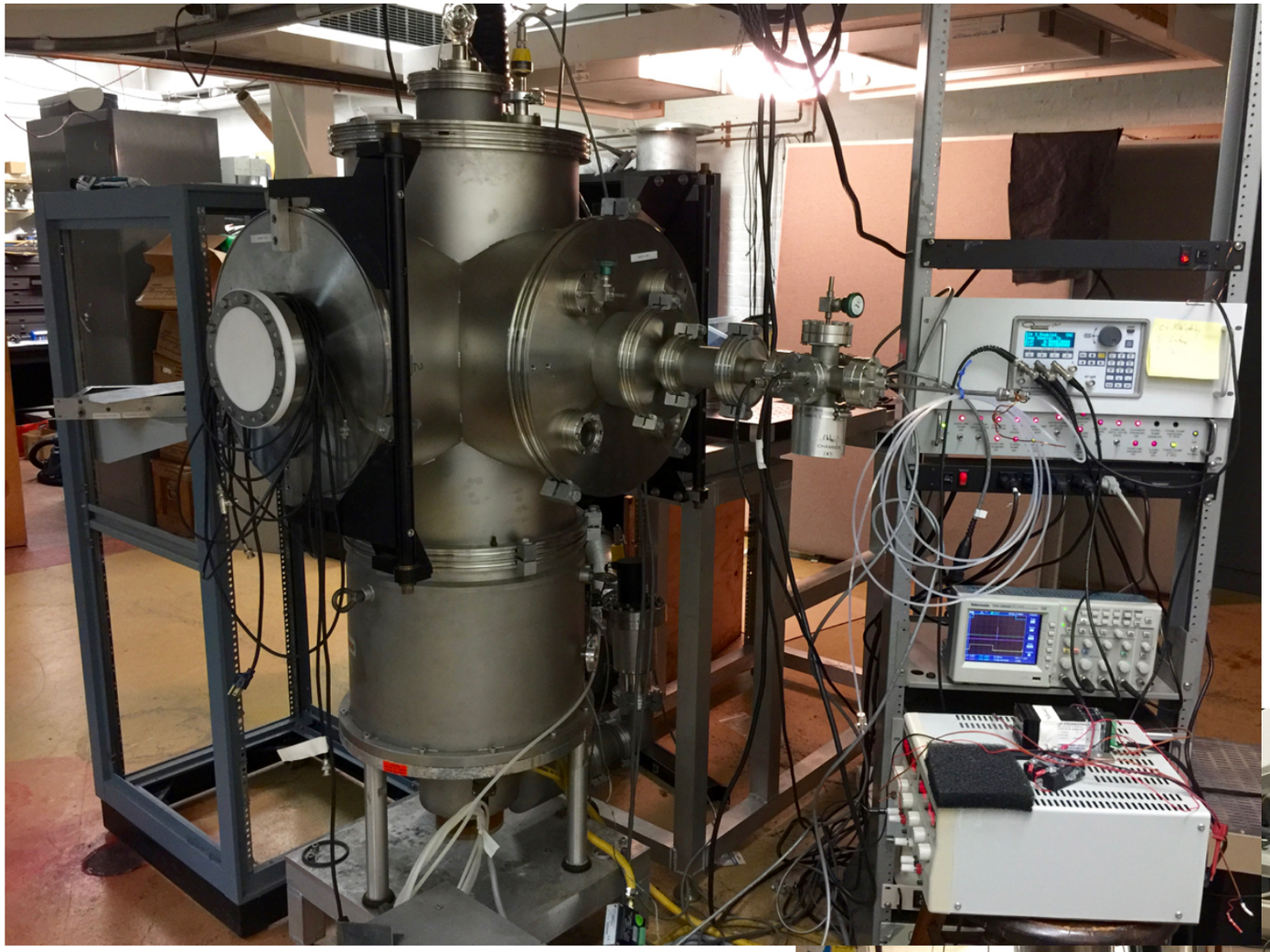
McCarthy group laboratory

(Harvard -> CfA)



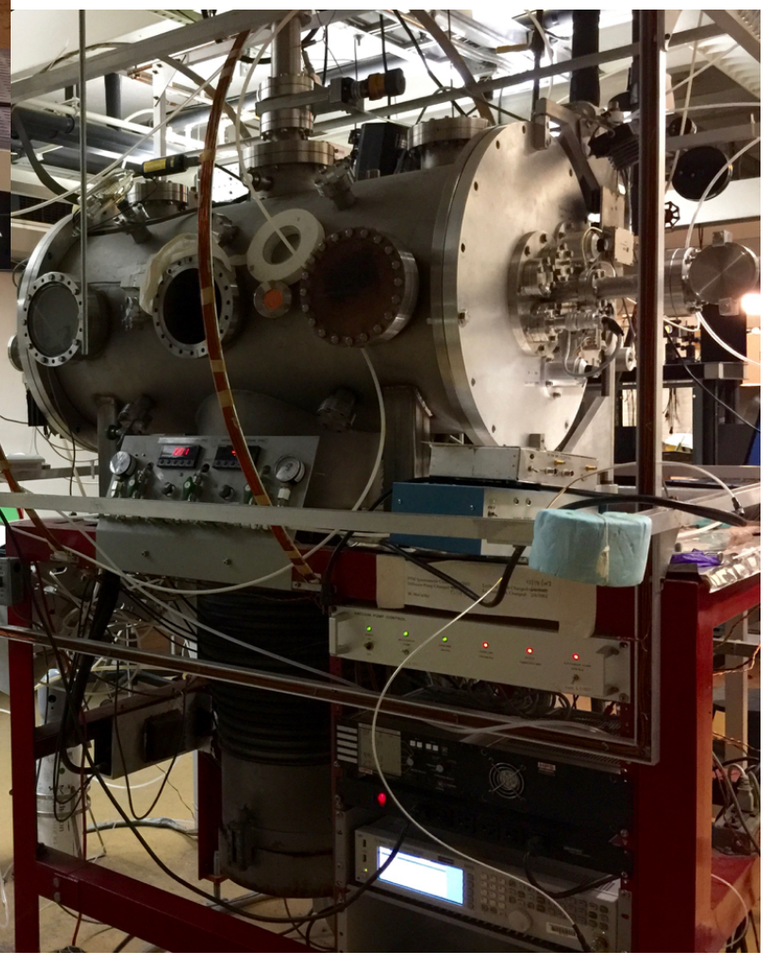
- Fourier transform molecular beam broadband and cavity spectrometers
- Laser ablation source for metal bearing molecules, e.g., TiO_2, TiO_3, Ti_2O, Ti_2O_3…
- Millimeter wave molecular beam spectrometer

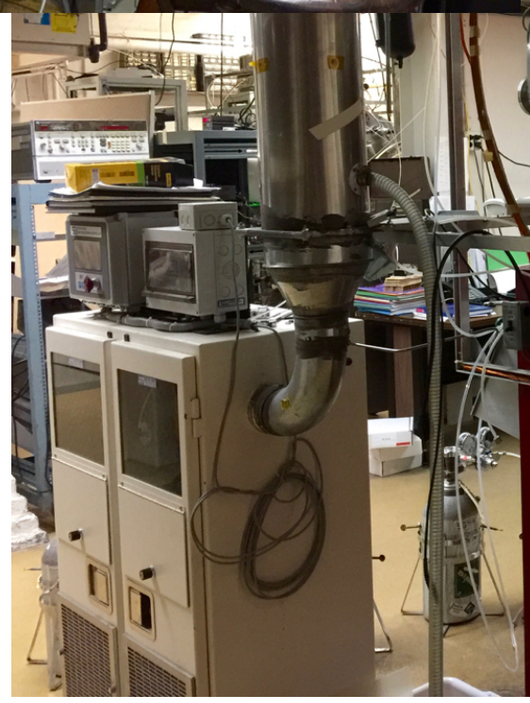




Planned new measurements:

- SiO_3,Si_2S,Si_2O,Si_3O
- Vibrationally excited SiCSi and SiC_2
- AlO_2, AlO_3, Al_2O_2, Al_2O_3…





Summary

- Wide bandwidth SMA spectral line surveys
  provide very rich data sets for astrochemistry research
- SAO spectroscopy lab studies: new molecules; identification of dust-grain seed particles progenitors; vibrationally excited transition frequencies
- Future SMA line surveys: CRL 2688, Ex &Vex observations of CRL 618; sample of carbon-rich AGB stars -
  How unique is IRC+10216?
- Time monitoring of vibrationally excited lines in Mira