A Simultaneous 1 mm Survey of VY Canis Majoris and IRC +10216: Comparing the Chemistry of O-rich and C-rich Circumstellar Envelopes

HST image of VY CMa. Credit: NASA, ESA, and R. Humphreys

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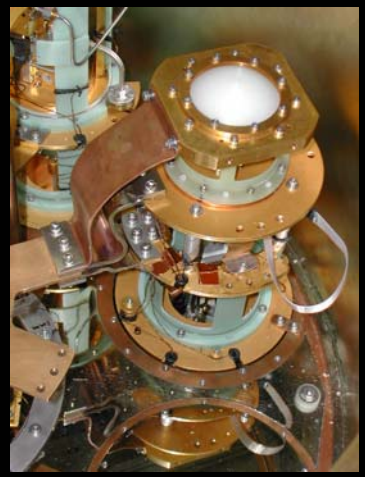
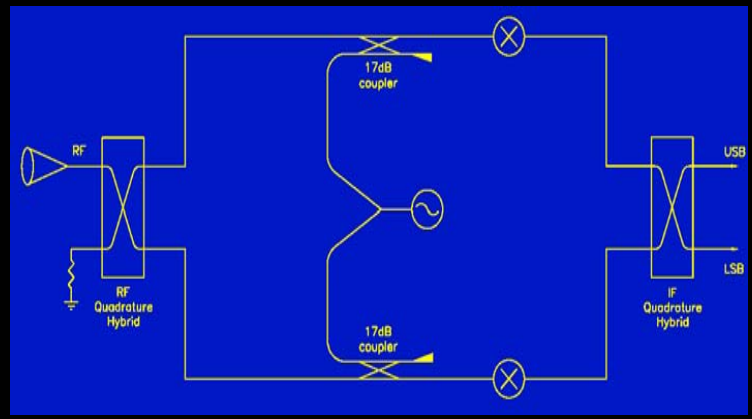
Motivation – a new instrument



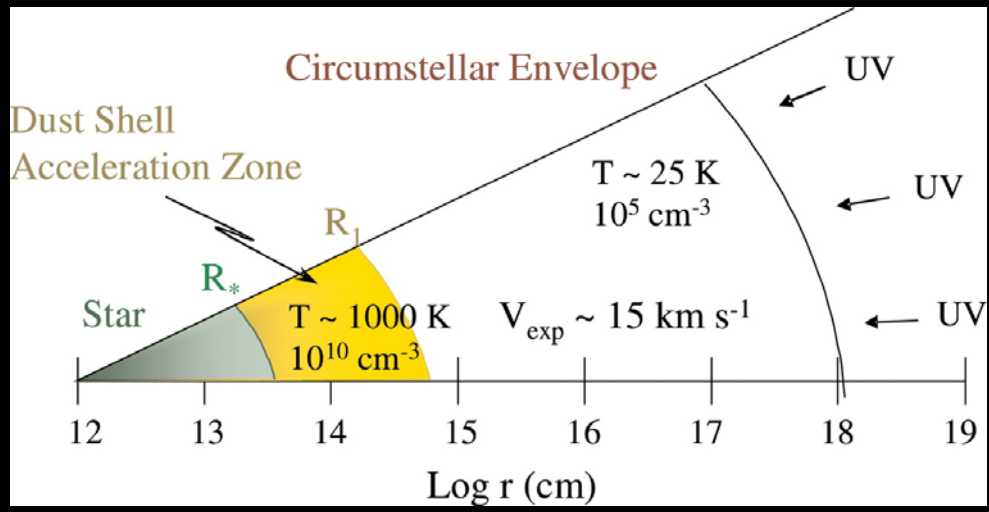


- Arizona Radio Observatory (ARO) 10 m Submillimeter Telescope (SMT), Mt. Graham
- Sideband separating mixer, electronic internal image rejection
- Developed for ALMA
- 215-280 GHz, 1.3 mm band
- High sensitivity (factor of 10 improvement in integration time over other telescopes, record T_{sys} = 107 K SSB)
- Low noise spectra in record time
- 2 GHz of filterbank bandwidth, at 1 MHz resolution

Optimal for a continuous spectral survey

Circumstellar Envelopes

- Chemistry determined by C/O ratio
- C > O
  - C-chain molecules
  - Metal cyanides and halides (e.g. NaCN, AlCl)
  - Well-studied
- C < O
  - Simple chemistry?
  - SiO, SO_2, CO
  - Few studies



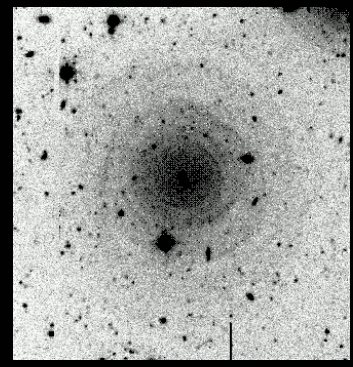
Goal: continuous, low-noise survey from 215-280 GHz of an O-rich and a C-rich CSE

- Nothing unexpected is missed
- The most sensitive survey to date
- Compare O-rich and C-rich CSE chemistry
- More fully characterize O-rich circumstellar chemistry

Target Objects

10”

(HST image, NASA, ESA, R. Humphreys)



400”

(CFHT, v-band, N. Mauron)

VY CMa

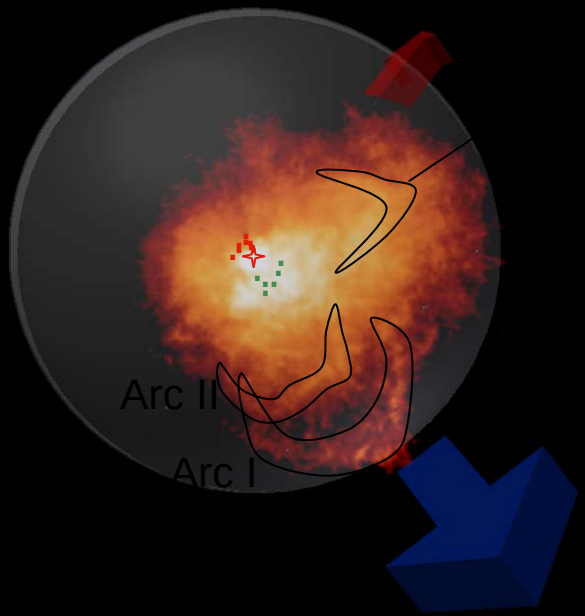
- Red supergiant
- oxygen-rich CSE
- M > 20 M_{sun}, T_{eff} ~2800 K
- distance = 1500 pc
- High mass-loss rate
- Most luminous IR source in the sky
- Well-known source of OH, SiO, H_2O masers

IRC +10216

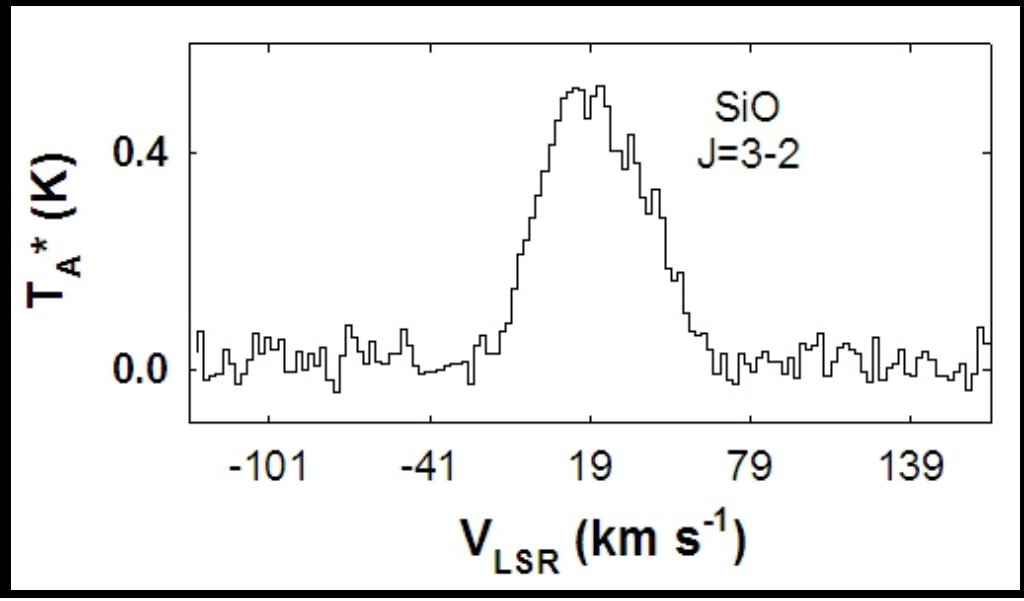
- AGB star
- Carbon-rich CSE
- Distance = 150 pc
- High mass-loss rate
- Most-studied CSE in mm observations
- Rich chemistry, 60+ molecules
- Unbiased surveys have been done in 2 & 3 mm but never in 1 mm

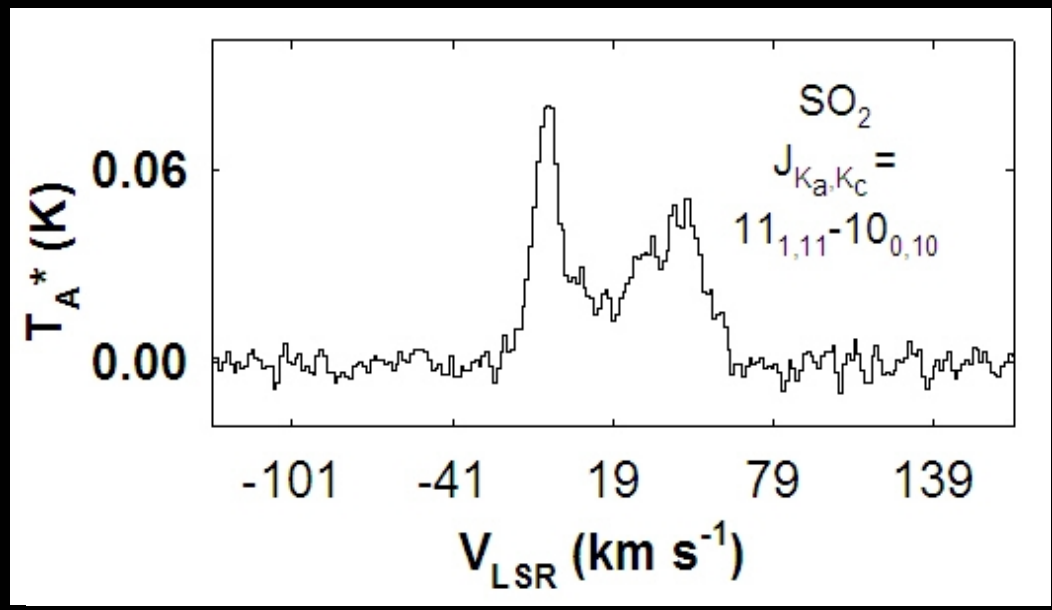
Kinematics of VY CMa

- Emission arises from three outflow regions
  - Spherical, blue-shifted, red-shifted
- Flows traced by atomic and OH maser emission
- Complex mass-loss makes survey particularly interesting

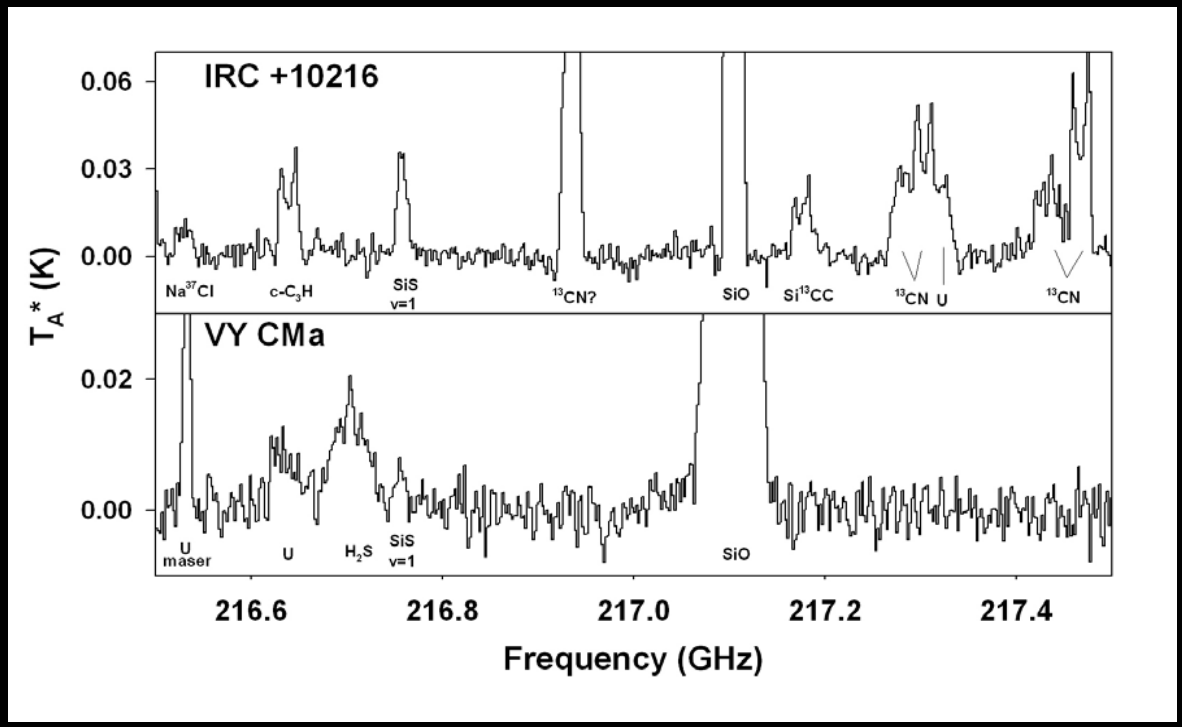


(Ziurys et al. 2007 *Nature*)





Observations



IRC +10216

- 250 lines observed
- 37 U-lines
- SiC_2, C_4H

VY CMa

- 83 lines observed
- 14 U-lines
- SO_2, SiO, SiS

- 1 GHz, dual polarization
- VY CMa observed 4-11 LST (max. elevation = 30º)
- IRC +10216 observed 11-15 LST (max elevation = 70º)
- System temps 150-400 K
- Peak-to-peak noise 5-12 mK (very low!)

Project Status: 80% complete

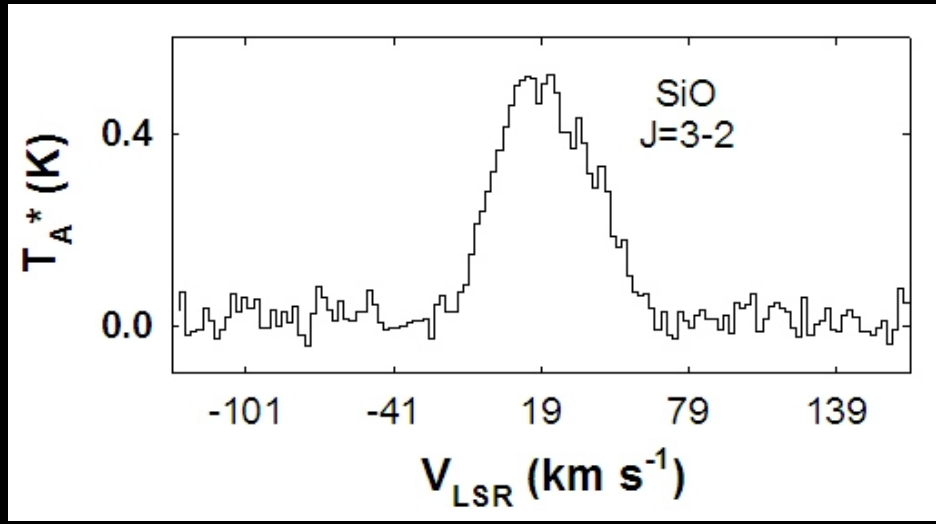
Data-taking should be finished by December 2008

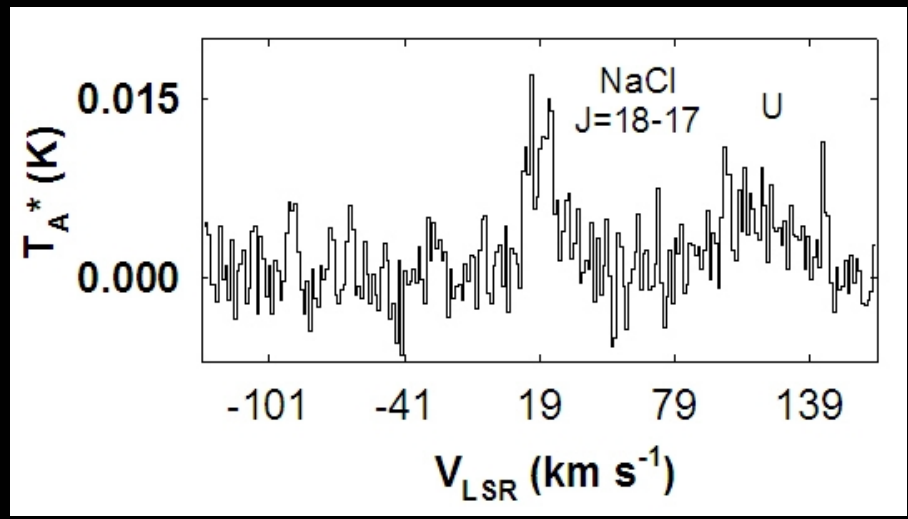
Lines are identified as data is collected

Results: Chemical Complexity in VY CMa Envelope

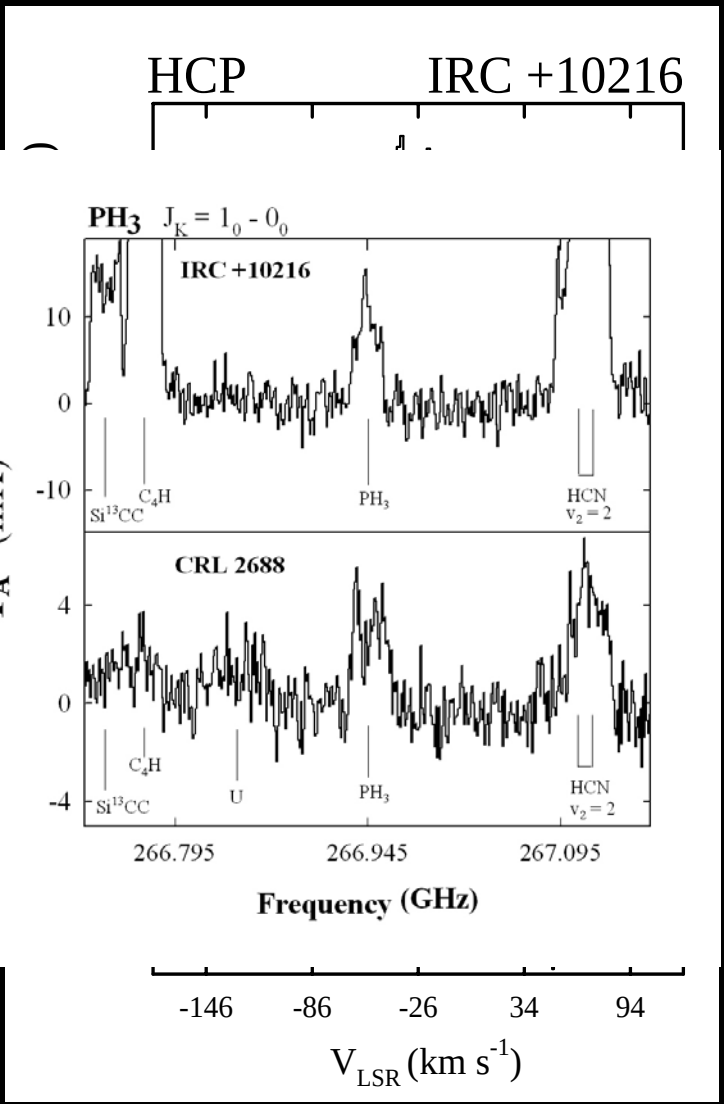
Table 1. Molecules Detected Towards VY CMa		
CO	SO_2	NH_3
CN	SO	PO
CS	H_2O	PN
HCN	SiO	NaCl
HNC	SiS	NS
HCO^+	OH	H_2S

- 18 molecules detected
- 8 detected for the first time in an O-rich envelope





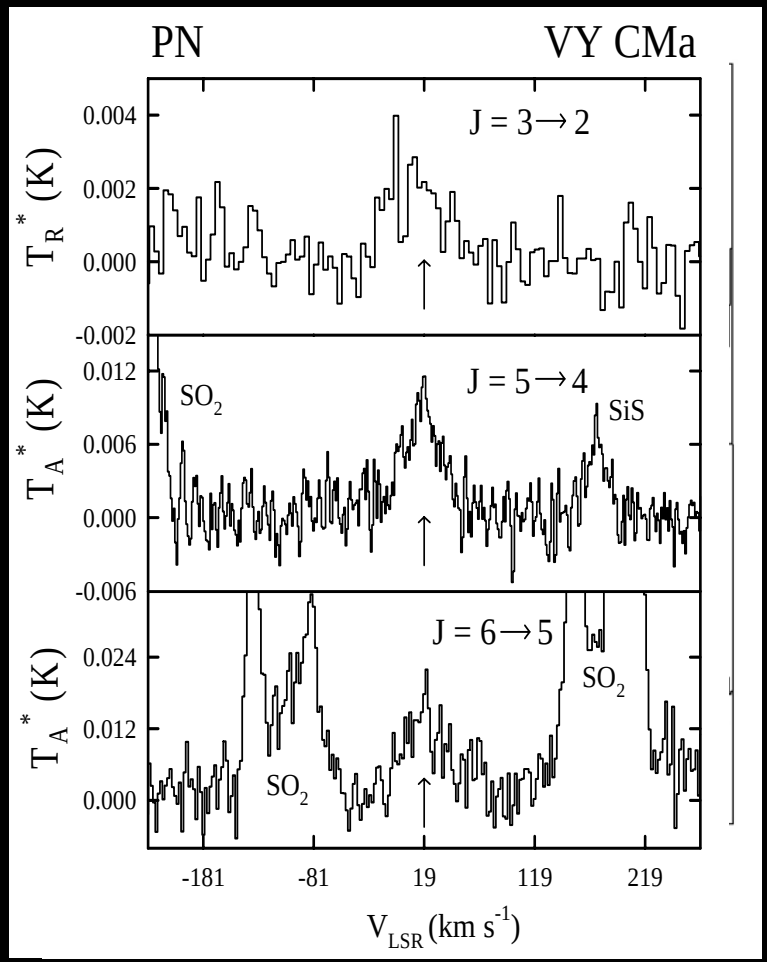
Results: P-Chemistry in IRC +10216



- Few phosphorus-bearing molecules observed in space (CP – IRC +10216, PN – Orion molecular cloud)
- PN definitively detected in CSE IRC +10216 (Milam et al., in press, 2008)
- HCP detected in IRC +10216 (Agundez et al. 2007; Milam et al., in press, 2008
- PH_3 tentatively detected in IRC +10216 (Tenenbaum & Ziurys 2008; Agundez et al. 2008)

Active phosphorus chemistry exists in circumstellar envelopes

Results: P-Chemistry in VY CMa



- PN detected in VY CMa (Milam et al. in press, 2008)
- First detection of PO in space, towards VY CMa (Tenenbaum et al. 2007)
- PO and PN have similar line profiles – small source size (~1“), spherical flow
- N_{tot}(PO, PN) ~ 2-3 $\times 10^{15}$ cm^{-2}

Active phosphorus chemistry exists in circumstellar envelopes

Results: Rich Carbon Chemistry in O-rich CSE

Carbon-Bearing Molecules in VY CMa

	Source Radius [a]			Abundance Relative to H_2		
Molecule	**Spherical Flow**	**Red Flow**	**Blue Flow**	**Spherical Flow**	**Red Flow**	**Blue Flow**
CO	1.3×10^{17} (6″)	1.0×10^{17} (4.5″)	1.9×10^{17} (9″)	4.0×10^{-5}	2.0×10^{-4}	8.0×10^{-5}
HCN	1.0×10^{17} (4.5″)	5.0×10^{16} (2.4″)	5.5×10^{16} (2.5″)	1.2×10^{-6}	7.5×10^{-6}	7.5×10^{-6}
HNC		3.0×10^{16} (1.4″)	3.0×10^{16} (1.4″)		5.0×10^{-8}	4.0×10^{-8}
CS	1.0×10^{16} (0.4″)	1.2×10^{16} (0.5″)	1.4×10^{16} (0.6″)	2.0×10^{-7}	6.0×10^{-7}	4.5×10^{-7}
HCO+	2.0×10^{17} (9″) [b]	1.9×10^{17} (9″)	2.3×10^{17} (10″)	4.0×10^{-9}	1.6×10^{-8}	1.0×10^{-8}

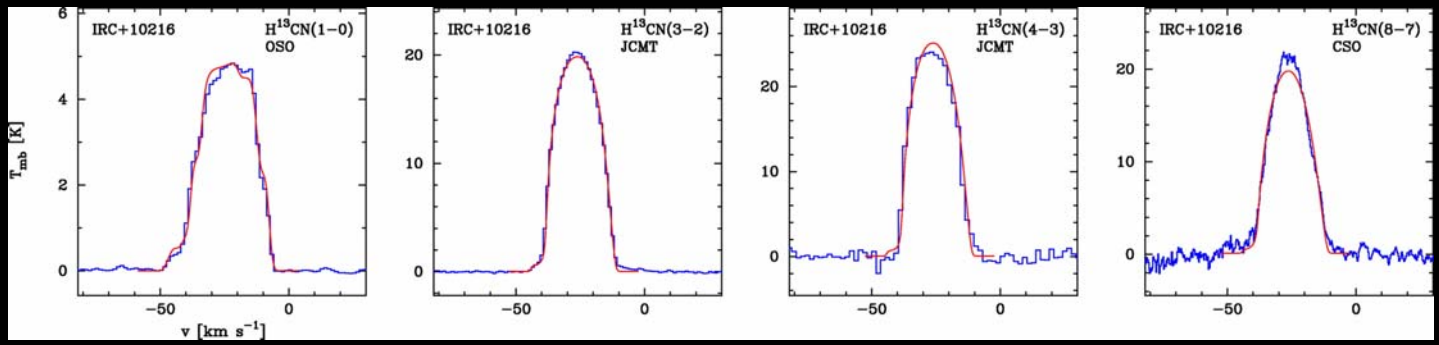
[a] source radius in units of cm(")

[b] HCO^+ can also be modeled by a shell distribution with a peak abundnace of $f_0 = 5 \times 10^{-9}$ at $r_{shell} = 1.4 \times 10^{17}$ cm (6.3") and $r_{outer} = 1.6 \times 10^{16}$ cm

- 6 carbon-containing molecules detected in VY CMa
- all the carbon is *not* in CO
- may be due to non-thermal equilibrium shock chemistry

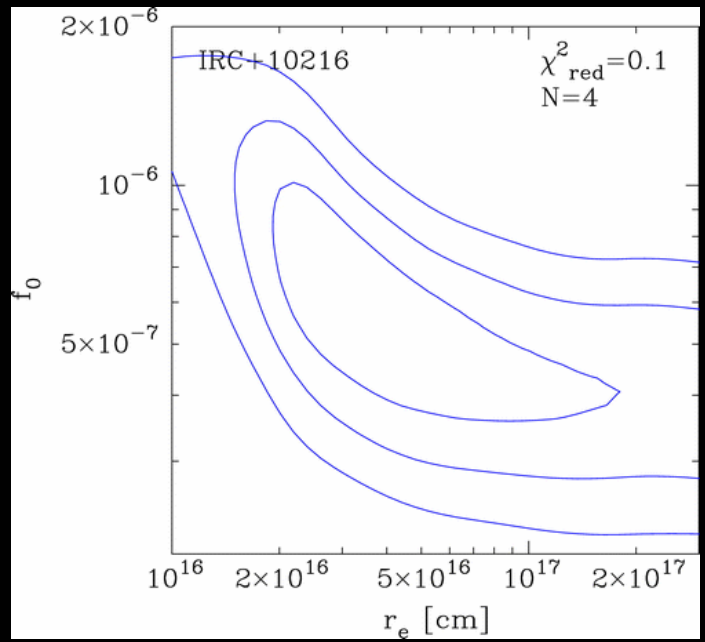
(Cherchneff 2006, *A&A*)

Analysis: Non-LTE Modeling



observed emission = blue; predicted emission = red (Schöier et al. 2007, *ApJ*)

- Radiative transfer modeling → determine abundance and distribution of molecules
- Monte Carlo approach
- Input known envelope parameters
  - expansion velocity
  - temperature gradient
  - density gradient
  - IR field
- Chi-squared analysis
- 3-D model can describe VY CMa's kinematics



Chi-squared analysis of $H^{13}CN$ model emission in IRC +10216 (Schöier et al. 2007, *ApJ*)

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