A rich submillimetre molecular emission from the oldest nova-like object, CK Vul = Nova Vul 1670

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in collaboration with

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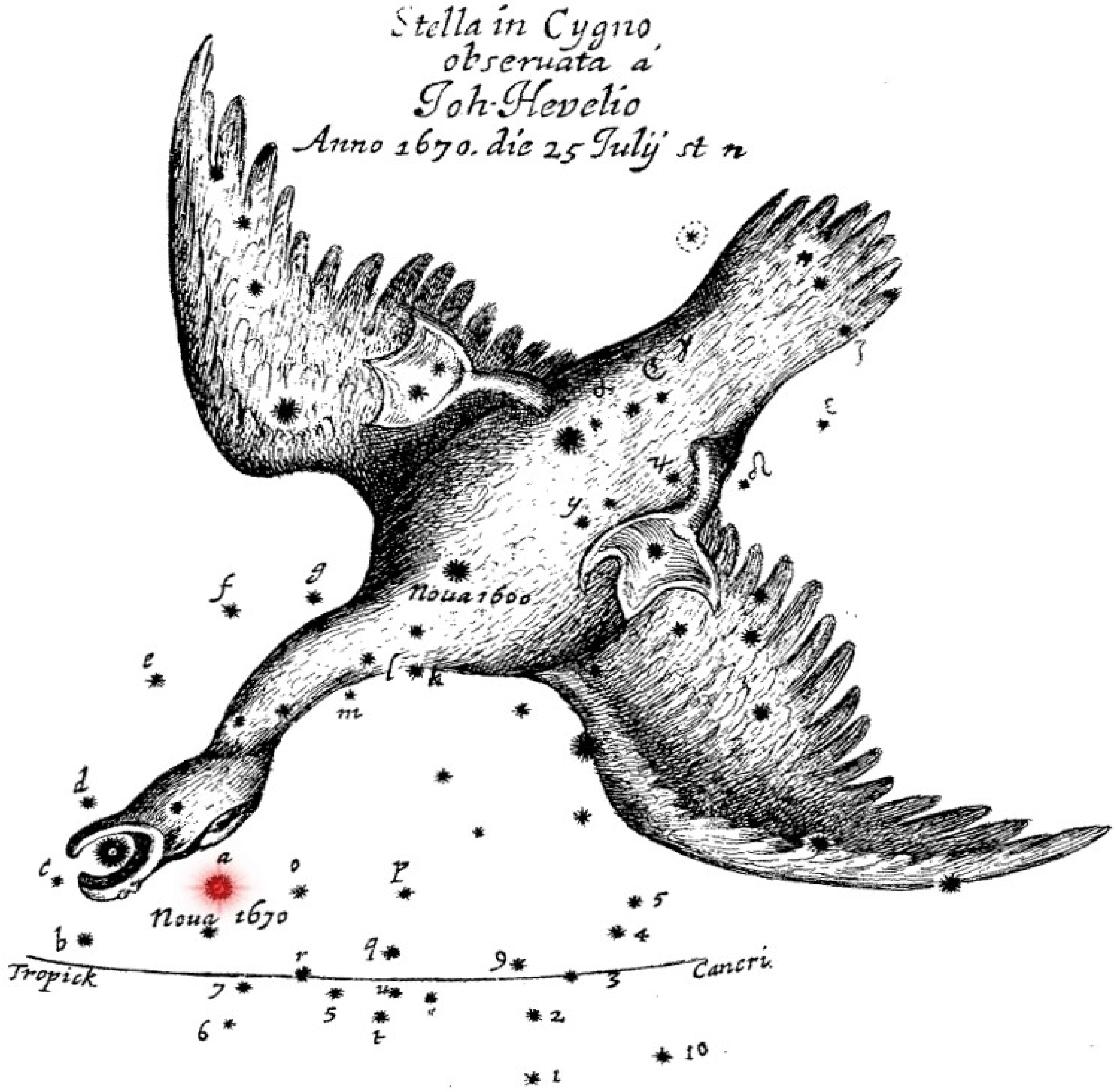
Nova Vul 1670 = CK Vul

Discovered on 20 June 1670 by Dom Anthelme in Dijon
a month later by
Jan Heweliusz (Johannes Hevelius) in Gdańsk

Observed in 1670-72 mostly by Jan Heweliusz and
Giovanni Cassini in Paris



Stella in Cygno
obseruata a'
Ioh. Hevelio
Anno 1670. die 25 Julij st n
Noua 1600
Noua 1670
Tropick
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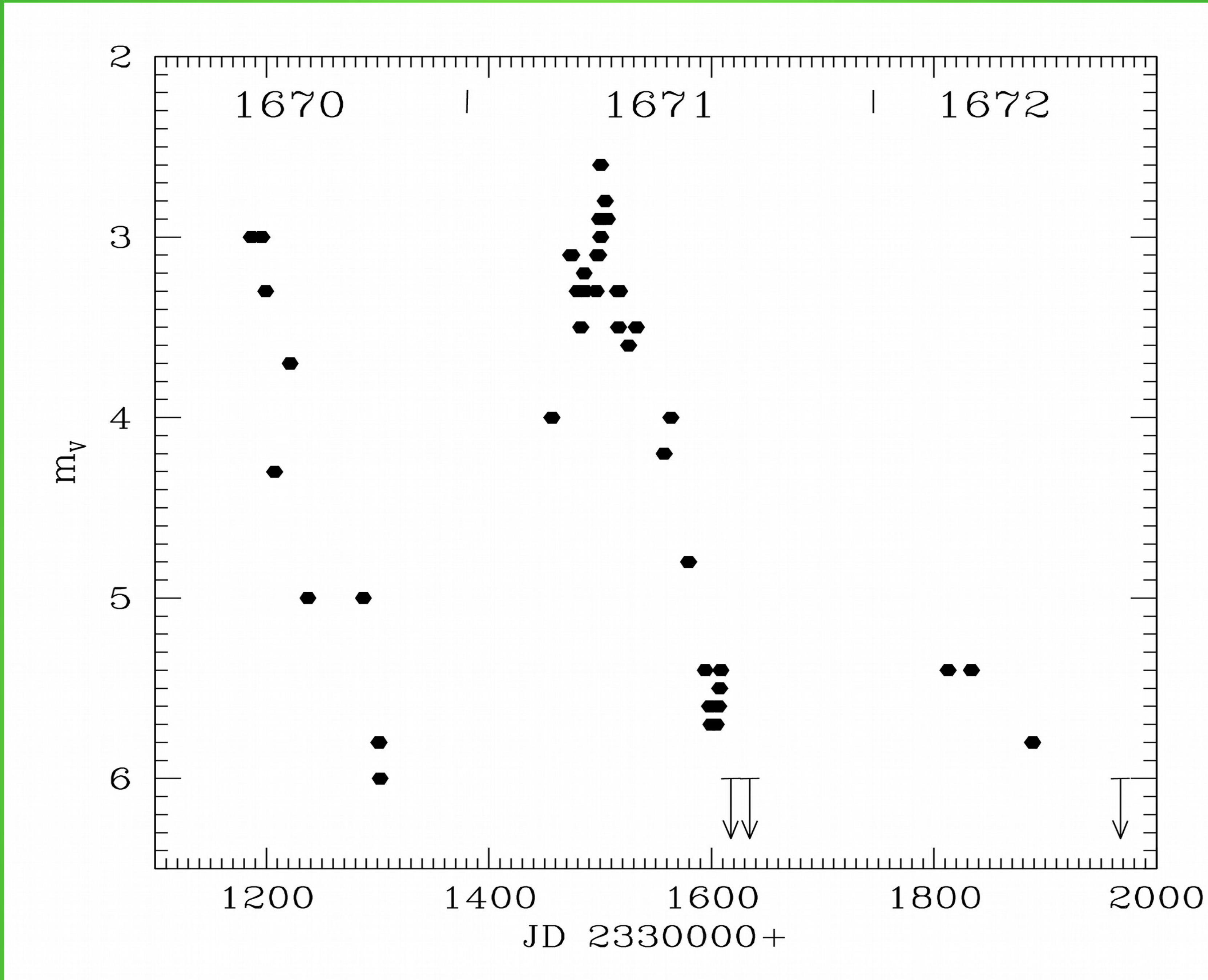

Light curve of Nova Vul 1670
(data from Hevelius, Cassini, et al.)

Nova Vul 1670 (CK Vul) - a classical nova?

Shara et al. (1985) discovered an U-shaped nebulosity seen in the Hα+[NII] lines and a possible (M_R = +10.4) central star.

Shara et al. (1986) invented a nova hibernation scenario.

Evans et al. (2002) found a far-IR excess, which was inconsistent with an old nova but perhaps indicating a final thermal pulse.

Hajduk et al. (2007) found a compact radio source and a bipolar nebula with a low-ionization spectrum indicating a shock ionization.

Kato (2003) and Tylenda et al. (2013) suggested a red-nova (stellar merger) nature on the basis of the light curve.

CK Vul:
a submillimetre source rich in molecules

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In April 2014 “we directed APEX towards CK Vul using a gap between two other projects. After only a few minutes, I was sure we discovered a new submillimtere-wave source that is very special” said in retrospect Tomek Kamiński, the leading author of the new study.

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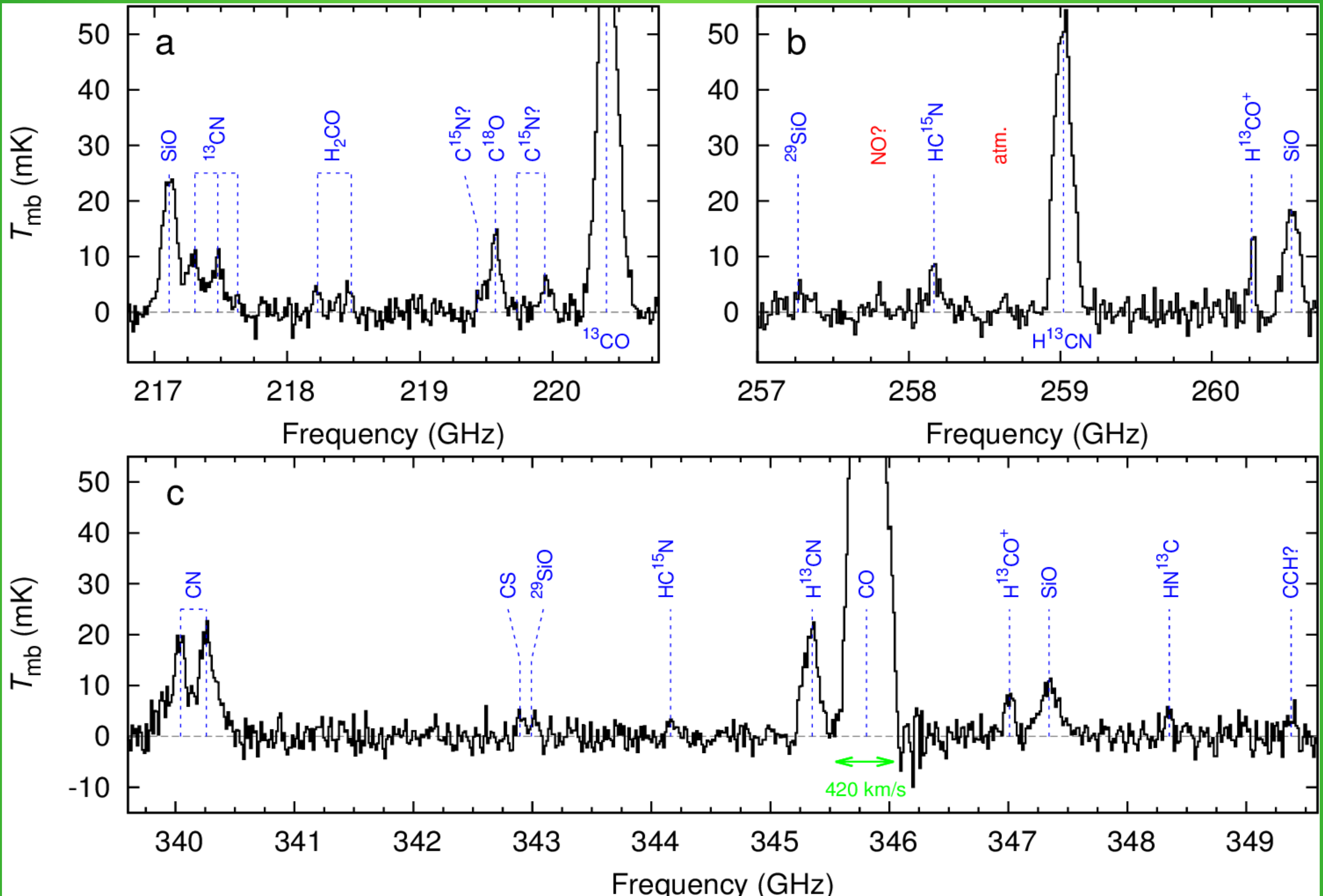
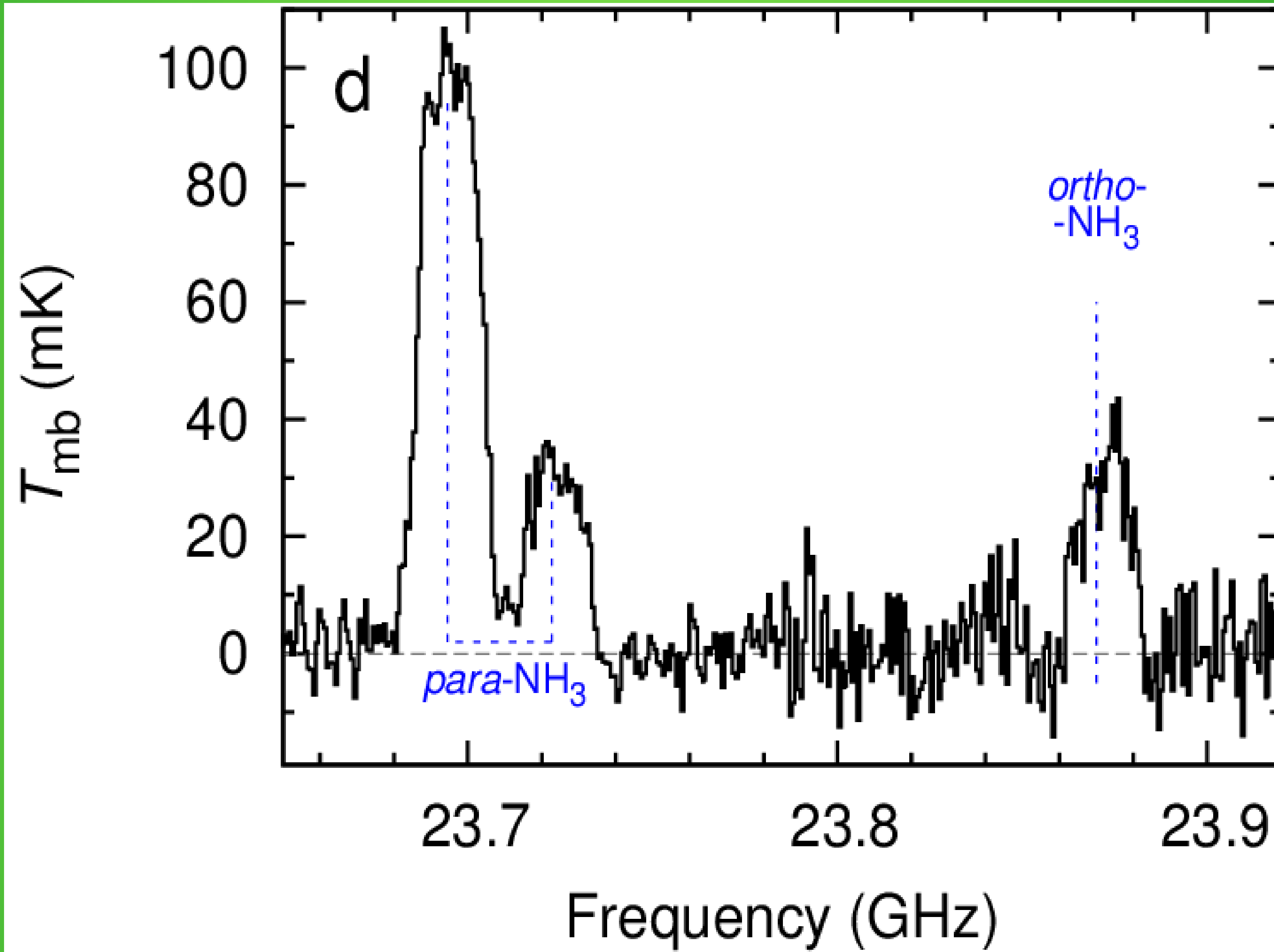
Kamiński, T., Menten, K.M., Tylenda, R., Hajduk, M., Patel, N.A., Kraus, A. *Nuclear ashes and outflow in the eruptive star Nova Vul 1670*, **Nature**, 520, 322

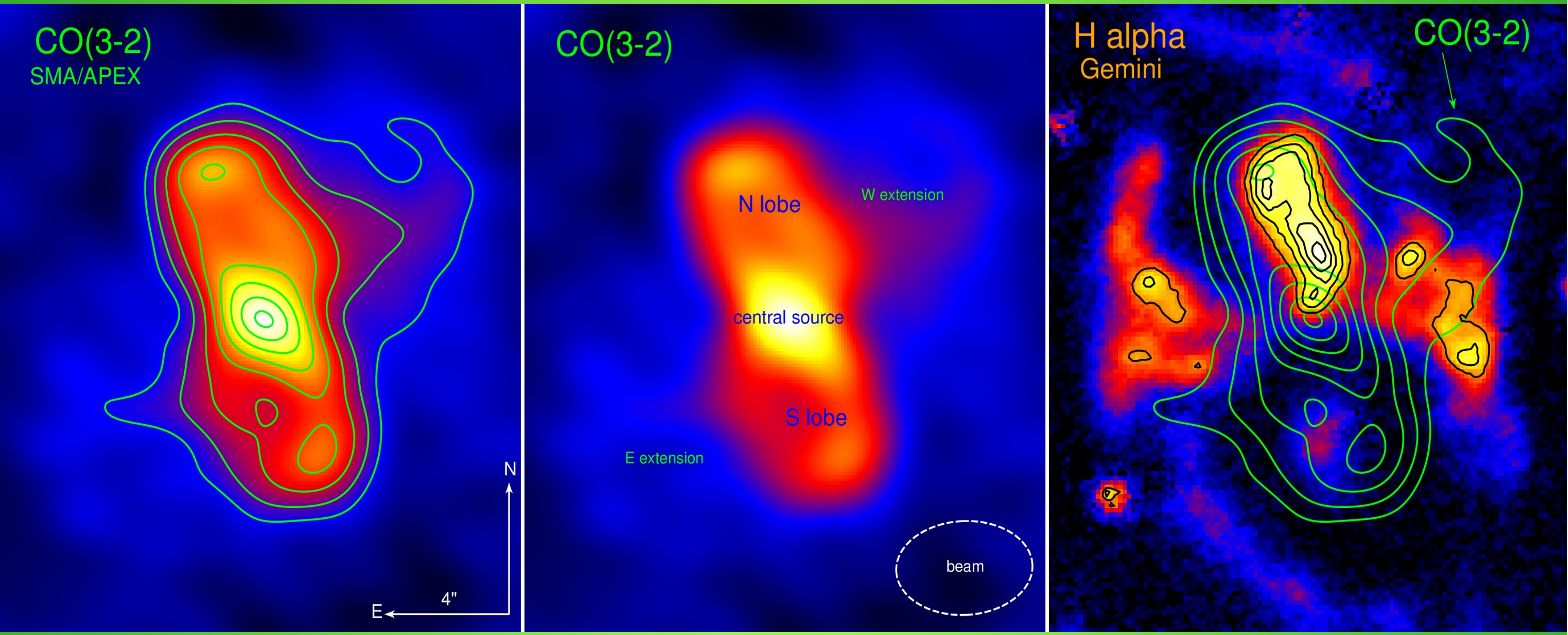


CK Vul as seen with APEX

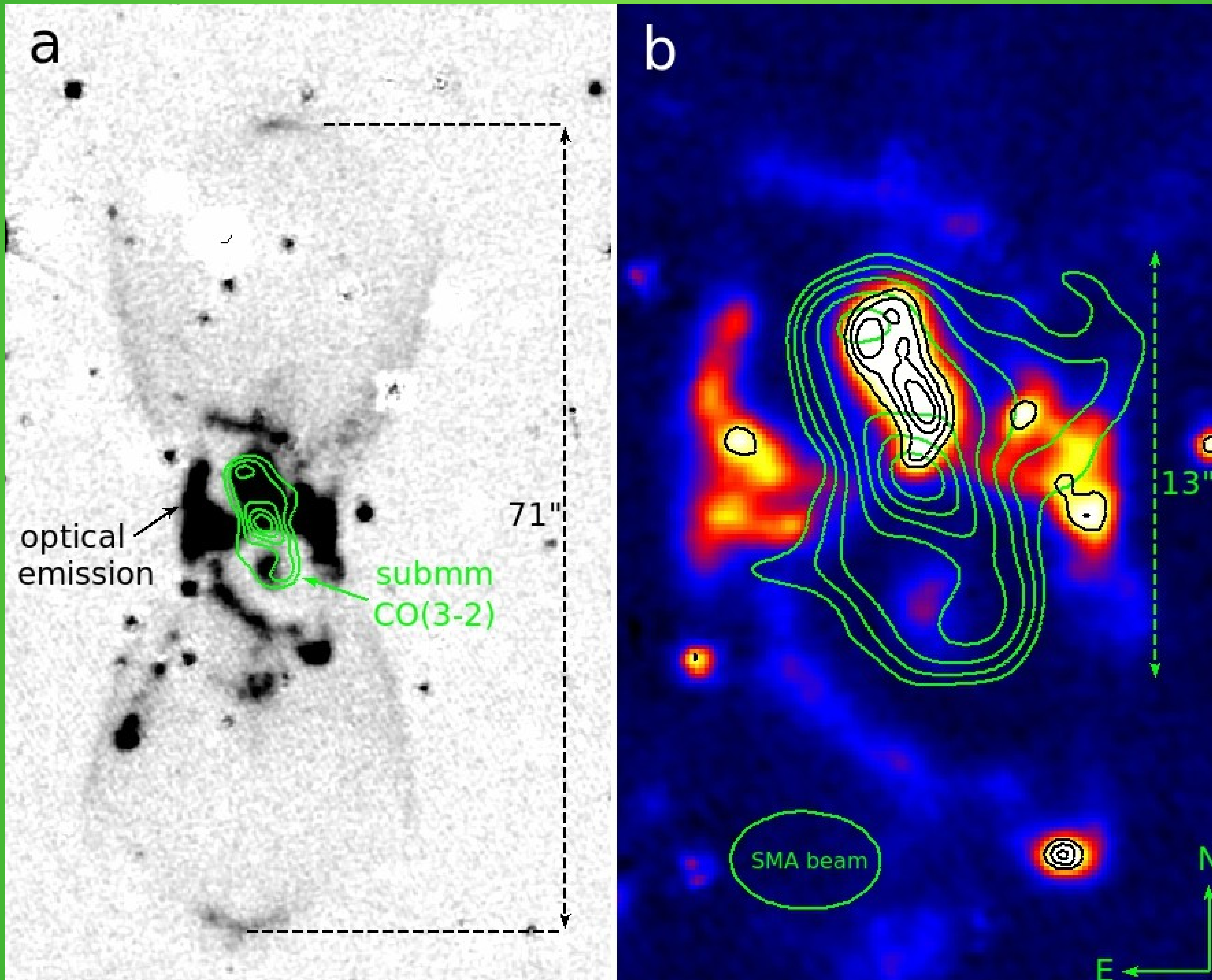


CK Vul as seen with 100-m Effelsberg

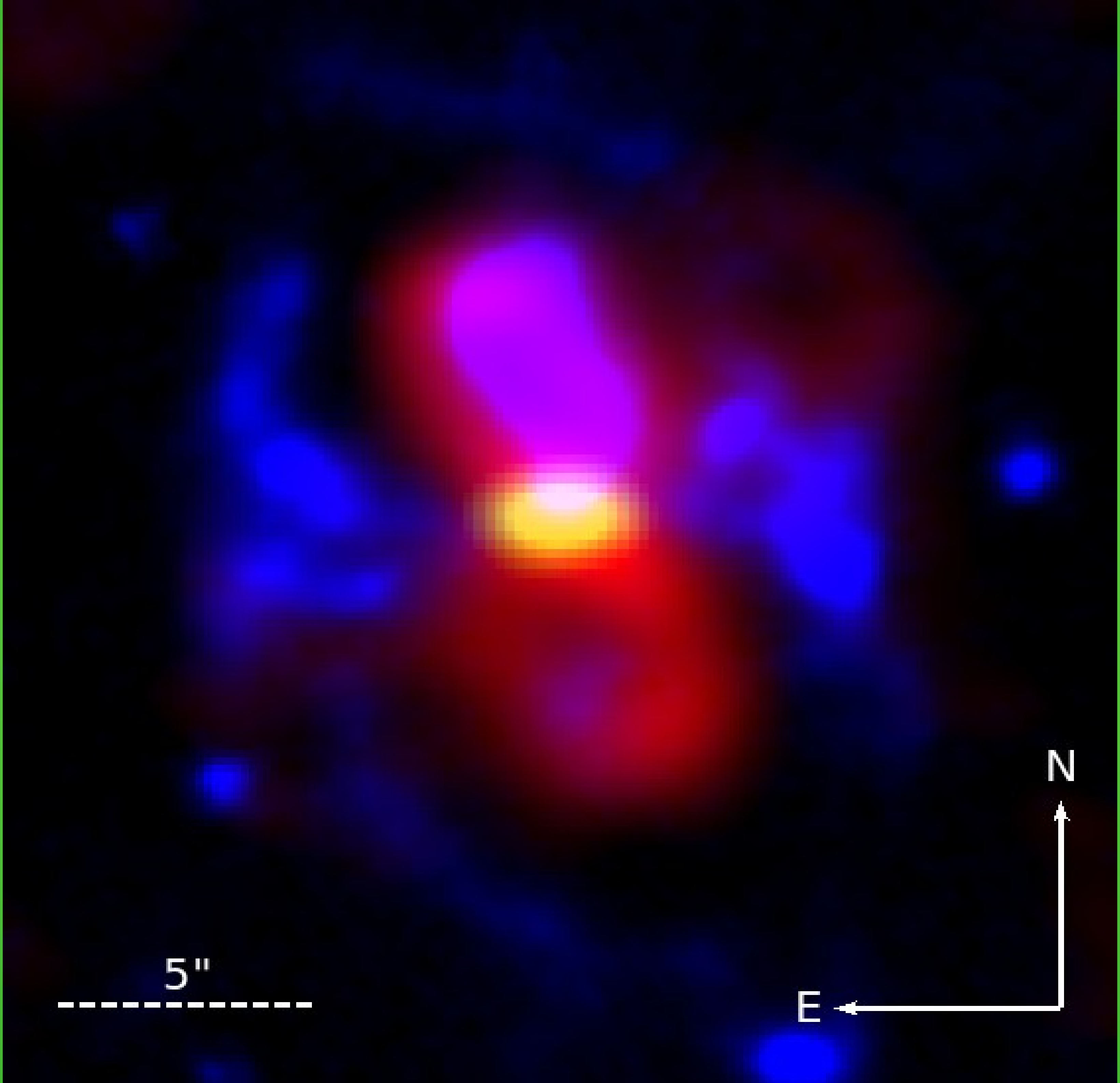
Molecule	Transition	Frequency lab. (MHz)	E_u (K)	A_{ul} (s^{-1})	Detect. SMA[a]	V_{LSR}[b] ($km\,s^{-1}$)	FWHM[c] ($km\,s^{-1}$)	$\int T_{mb}\,dv$[d] ($K\,km\,s^{-1}$)	Notes
NH_3	$J,K = 1,1$ *para*	23694.50	23.3	$1.68E-7$		−9.2 ±1.8	99.2±1.9	23.70±0.25	
NH_3	$J,K = 2,2$ *para*	23722.63	64.4	$2.24E-7$		−14.5 ±3.4	89.3±3.9	6.50±0.23	
NH_3	$J,K = 3,3$ *ortho*	23870.13	123.5	$2.57E-7$		−26.6 ±3.4	86.1±3.9	6.35±0.29	e
SiO	$J = 5-4$	217104.98	31.3	$5.20E-4$	✓	−16.0 ±2.8	78.8±3.0	4.29±0.14	f
^{13}CN	$N = 2-1, J = 3/2-1/2$	217297.72	15.7	$5.23E-4$	✓	8.2 ±7.1	79.3±9.7	1.73±0.12	g
^{13}CN	$N = 2-1, J = 5/2-3/2$	217456.59	15.7	$5.31E-4$	✓	−16.5 ±11.7	80.8±15.8	1.47±0.11	g
^{13}CN	$N = 2-1, J = 3/2-3/2$	217633.04	15.7	$1.14E-5$		12.3 ±7.0	33.1±7.0	$\lesssim$0.26	g
H_2CO	$J_{K_a,K_c} = 3_{0,3}-2_{0,2}$	218222.19	21.0	$2.82E-4$	✓	−0.7 ±17.4	25.0±21.7	$\lesssim$0.28	
H_2CO	$J_{K_a,K_c} = 3_{2,2}-2_{2,1}$	218475.63	68.1	$1.57E-4$	✓	25.4 ±9.0	21.7±10.8	$\lesssim$0.24	
$C^{15}N$?	$N = 2-1, J = 3/2-3/2$	219406.81	15.8	$3.46E-5$	✓	−41.3 ±8.6	34.7±8.8	$\lesssim$0.24	g h i
$C^{18}O$	$J = 2-1$	219560.35	15.8	$6.01E-7$	✓	−5.6 ±4.2	90.7±4.6	2.05±0.11	j
$C^{15}N$?	$N = 2-1, J = 3/2-1/2$	219722.80	15.8	$1.73E-4$	✓	−79.3 ±2.0	1.2±2.0	$\lesssim$0.17	i
$C^{15}N$	$N = 2-1, J = 5/2-3/2$	219933.63	15.8	$2.08E-4$	✓	−24.4 ±11.5	53.4±13.4	0.60±0.11	g
^{13}CO	$J = 2-1$	220398.68	15.9	$6.07E-7$	✓	−20.7 ±1.4	101.8±1.4	20.79±0.18	
H_2CO	$J_{K_a,K_c} = 3_{1,2}-2_{1,1}$	225697.78	33.5	$2.77E-4$		19.8 ±9.0	39.8±9.1	$\lesssim$0.57	
CN	$N = 2-1, J = 3/2-1/2$	226658.92	16.3	$2.85E-4$		−15.9 ±6.6	52.2±7.2	2.01±0.22	g
CN	$N = 2-1, J = 5/2-3/2$	226876.46	16.3	$3.43E-4$		−12.6 ±5.8	51.1±7.0	2.47±0.18	g
CO	$J = 2-1$	230538.00	16.6	$6.91E-7$	✓	−1.6 ±2.4	100.7±2.4	51.01±1.45	k
^{13}CS?	$J = 5-4$	231220.69	33.3	$2.51E-4$	✓	−62.0 ±5.9	98.9±6.2	1.31±0.19	l
^{29}SiO?	$J = 6-5$	257255.22	43.2	$8.78E-4$		−9.2 ±7.5	75.1±8.1	1.01±0.08	i l
$HC^{15}N$	$J = 3-2$	258157.00	24.8	$7.65E-4$		−44.4 ±8.0	69.2±8.6	0.46±0.12	
$H^{13}CN$	$J = 3-2$	259011.80	24.9	$7.72E-4$		−11.2 ±1.3	74.3±1.4	8.46±0.15	
$H^{13}CO^+$	$J = 3-2$	260255.34	25.0	$1.34E-3$		−17.8 ±1.9	18.8±2.0	0.56±0.07	
SiO	$J = 6-5$	260518.02	43.8	$9.12E-4$		−15.4 ±3.6	62.3±3.7	2.51±0.14	
HCN	$J = 3-2$	265886.43	25.5	$8.36E-4$		−5.7 ±2.4	74.1±2.5	16.45±0.69	
N_2H^+	$J = 3-2$	279511.73	26.8	$1.35E-3$		−42.7 ±6.1	83.4±7.5	1.27±0.07	
H_2CO	$J_{K_a,K_c} = 4_{1,4}-3_{1,3}$	281526.93	45.6	$5.88E-4$		17.8 ±13.5	83.9±21.2	0.49±0.05	
CS	$J = 6-5$	293912.09	49.4	$5.23E-4$		−8.7 ±3.7	49.5±3.9	0.53±0.06	
^{29}SiO?	$J = 7-6$	300120.48	57.6	$1.41E-3$		6.9 ±8.5	45.6±10.5	0.30±0.05	l
$C^{18}O$	$J = 3-2$	329330.55	31.6	$2.17E-6$		−16.1 ±17.1	76.1±18.0	1.68±0.38	i
^{13}CO	$J = 3-2$	330587.97	31.7	$2.19E-6$	✓	−10.0 ±2.0	97.9±2.0	20.40±0.51	
CN	$N = 3-2, J = 5/2-5/2$	339487.80	32.6	$8.18E-5$		−43.0 ±12.3	24.2±13.1	$\lesssim$0.28	g i
CN	$N = 3-2, J = 5/2-3/2$	340031.29	32.6	$1.15E-3$		−0.5 ±5.2	105.6±6.0	3.26±0.16	g
CN	$N = 3-2, J = 7/2-5/2$	340248.80	32.7	$1.24E-3$		−18.4 ±5.0	81.3±5.7	3.26±0.17	g
CS	$J = 7-6$	342882.85	65.8	$8.40E-4$		−52.5 ±8.4	65.0±9.3	$\lesssim$0.48	
^{29}SiO?	$J = 8-7$	342980.84	74.1	$2.12E-3$		33.5 ±0.3	62.0±0.3	$\lesssim$0.30	i l
$HC^{15}N$	$J = 4-3$	344200.11	41.3	$1.88E-3$		12.4 ±7.1	24.4±7.5	$\lesssim$0.25	i
$H^{13}CN$	$J = 4-3$	345339.77	41.4	$1.90E-3$	✓	−3.4 ±1.9	59.0±1.9	2.64±0.13	
CO	$J = 3-2$	345795.99	33.2	$2.50E-6$	✓	−13.1 ±0.7	92.9±0.7	47.03±0.34	
$H^{13}CO^+$	$J = 4-3$	346998.34	41.6	$3.29E-3$	✓	−5.8 ±4.5	39.9±4.8	0.69±0.19	
SiO	$J = 8-7$	347330.58	75.0	$2.20E-3$		−13.2 ±6.2	87.5±7.2	1.76±0.13	
$HN^{13}C$	$J = 4-3$	348340.90	41.8	$2.03E-3$		4.0 ±7.1	30.7±7.3	0.34±0.09	
CCH?	$N = 4-3, J = 9/2-7/2, 7/2-5/2$	349364.58	41.9	$7.26E-4$		0.1 ±34.7	38.8±63.0	$\lesssim$0.30	i
HCN	$J = 4-3$	354505.48	42.5	$2.05E-3$		−8.7 ±1.2	77.0±1.3	8.98±0.16	
HCO^+	$J = 4-3$	356734.22	42.8	$3.57E-3$		−17.1 ±5.8	27.2±6.2	0.71±0.11	
CS	$J = 8-7$	391846.89	84.6	$1.26E-3$		1.4 ±0.3	45.6±0.3	0.66±0.14	i
$HC^{15}N$	$J = 5-4$	430235.32	62.0	$3.75E-3$		−22.2 ±2.8	26.3±2.8	1.98±0.29	l
CO	$J = 4-3$	461040.77	55.3	$6.13E-6$		−22.7 ±2.1	89.2±2.2	28.95±0.73	
$H^{13}CN$	$J = 8-7$	690552.08	149.2	$1.61E-2$		−36.9 ±17.7	52.0±21.4	2.72±0.72	
CO	$J = 6-5$	691473.08	116.2	$2.14E-5$		−68.3 ±6.6	110.2±7.1	24.87±1.12	



Maps of the CO(3-2) emission from SMA/APEX

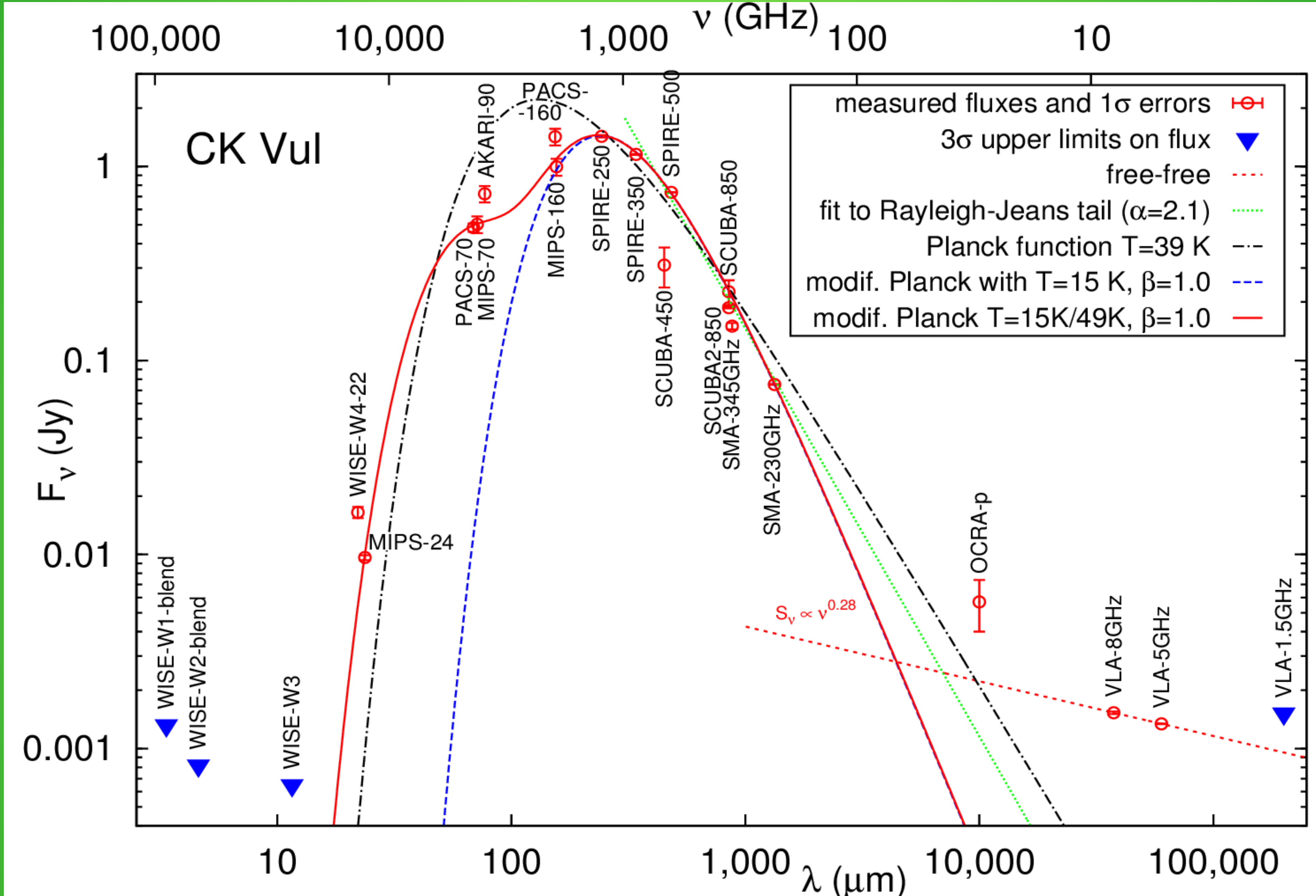


a
optical
emission
submm
CO(3-2)
71"
b
13"
SMA beam
N
E


N
E
5"

List of the detected molecules:

CO, ^{13}CO, $C^{18}O$,
CN, ^{13}CN, $C^{15}N$,
HCN, $H^{13}CN$, $HC^{15}N$, $HN^{13}C$,
H_2CO, HCO^+, $H^{13}CO^+$,
CS, SiO,
NH_3



ν (GHz)
100,000
10,000
1,000
100
10
CK Vul
1
0.1
0.01
0.001
F_ν (Jy)
10
100
1,000
10,000
100,000
λ (μm)
measured fluxes and 1σ errors
3σ upper limits on flux
free-free
fit to Rayleigh-Jeans tail (α=2.1)
Planck function T=39 K
modif. Planck with T=15 K, β=1.0
modif. Planck T=15K/49K, β=1.0
PACS-
-160
AKARI-90
SPIRE-500
SPIRE-250
SPIRE-350
MIPS-160
PACS-70
MIPS-70
SCUBA-850
SCUBA-450
SCUBA2-850
SMA-345GHz
SMA-230GHz
WISE-W4-22
MIPS-24
OCRA-p
$S_\nu \propto \nu^{0.28}$
WISE-W1-blend
WISE-W2-blend
WISE-W3
VLA-8GHz
VLA-5GHz
VLA-1.5GHz

SED of CK Vul

Physical conditions observed in CK Vul

Dust temperature: 15-50 K.

Dust luminosity: ~0.9 $L_\odot$ (this excludes a post-AGB hypothesis)

Molecular rotation temperature: 8-22 K

CO column density: 4 10^{17} cm^{-2}

With the observed dimensions and assuming the standard abundances the latter results in a mass of the molecular region of ~0.1 $M_\odot$ (this excludes a classical nova hypothesis)

Isotope ratios

	CK Vul	sun	nova	CNO-cycles
$^{12}C/^{13}C$	2-6	90	0.5-3	4-5
$^{14}N/^{15}N$	~26	270	0.3-50	$\sim 10^4$
$^{16}O/^{17}O$	>225	2680	0.3-10	5-500
$^{16}O/^{18}O$	~23	500	100-5000	$>10^4$

Hevelius Nova (Nova Vul 1670) as a red nova:

* light curve (three years lasting eruption with three maxima)

* strong molecular emission from CK Vul (no molecular emission was detected for 27 post-novae)

* mass of the dusty molecular region of CK Vul (~0.1 $M_{\odot}$)

* low luminosity remnant (~0.9 $L_{\odot}$ from dust in CK Vul)

* element abundances in the nebular region and isotope ratios in the molecular region of CK Vul

Thank you for your attention!