Time Variability of Molecular Emission in the Circumstellar Envelopes of Evolved Stars

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See Poster by D. Teyssier P78,

See Poster by M. Groenewegen P42

The origin of this talk : The line survey of IRC+10216 May 2010

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Herschel/HIFI: first science highlights

Astronomy & Astrophysics
Special feature

LETTER TO THE EDITOR

A high-resolution line survey of IRC +10216 with *Herschel*/HIFI[⋆,⋆⋆]

First results: Detection of warm silicon dicarbide (SiC_2)

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ABSTRACT

We present the first results of a high-spectral-resolution survey of the carbon-rich evolved star IRC+10216 that was carried out with the HIFI spectrometer onboard *Herschel*. This survey covers all HIFI bands, with a spectral range from 488 to 1901 GHz. In this letter we focus on the band-1b spectrum, in a spectral range 554.5−636.5 GHz, where we identified 130 spectral features with intensities above 0.03 K and a signal-to-noise ratio >5. Detected lines arise from HCN, SiO, SiS, CS, CO, metal-bearing species and, surprisingly, silicon dicarbide (SiC_2). We identified 55 SiC_2 transitions involving energy levels between 300 and 900 K. By analysing these rotational lines, we conclude that SiC_2 is produced in the *inner* dust formation zone, with an abundance of $\sim 2 \times 10^{-7}$ relative to molecular hydrogen. These SiC_2 lines have been observed for the first time in space and have been used to derive an SiC_2 rotational temperature of ~204 K and a source-averaged column density of $\sim 6.4 \times 10^{15}$ cm^{-2}. Furthermore, the high quality of the HIFI data set was used to improve the spectroscopic rotational constants of SiC_2.

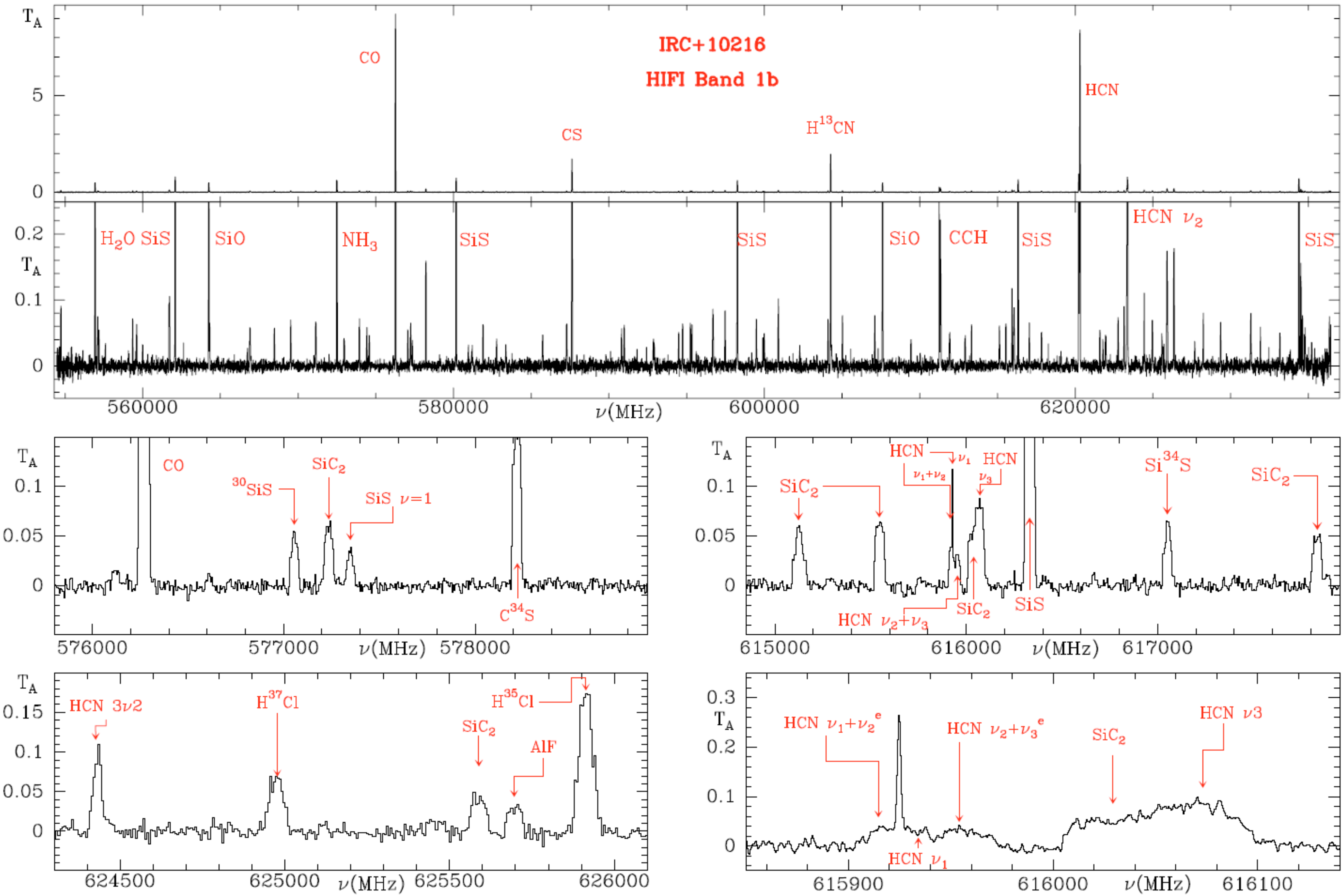
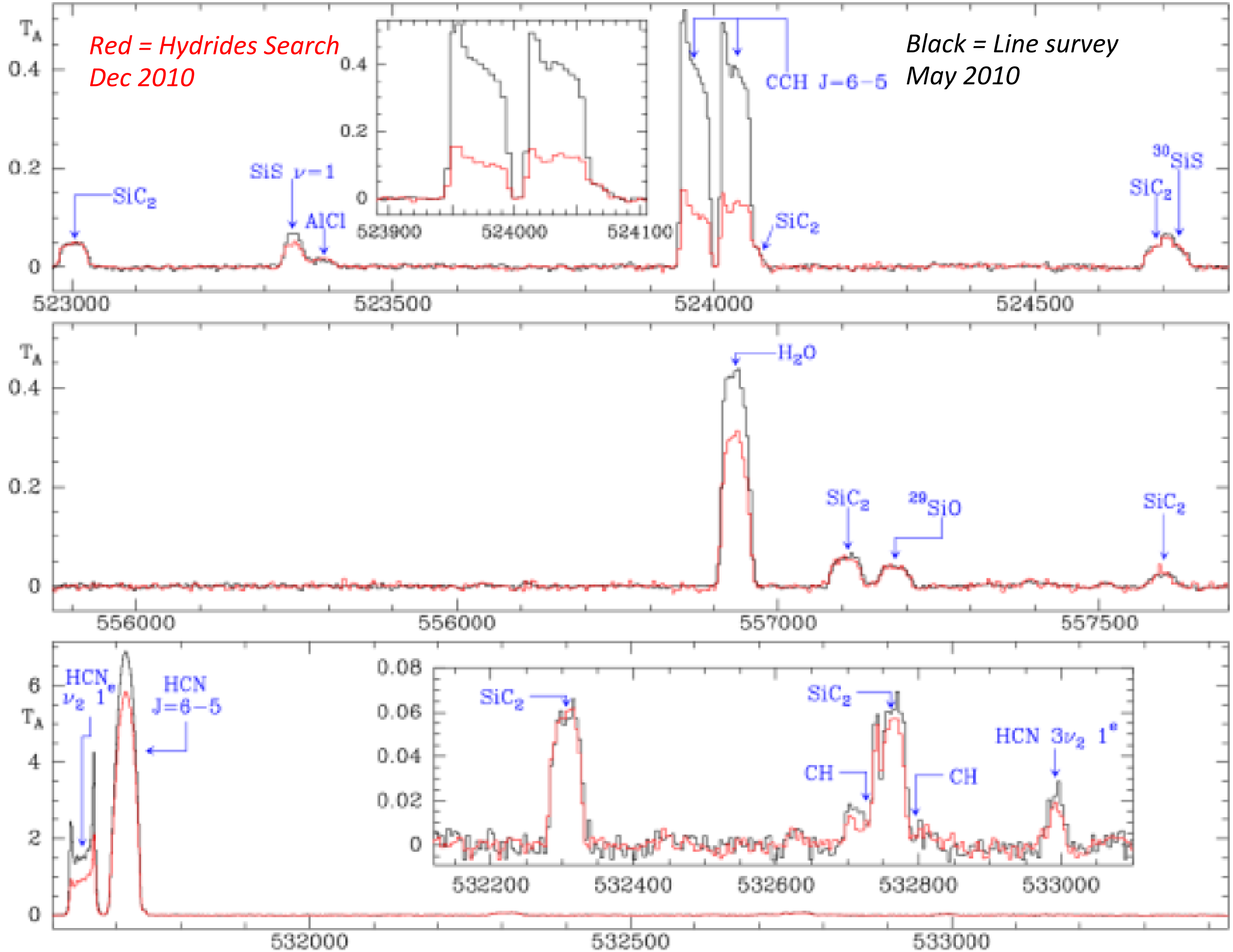
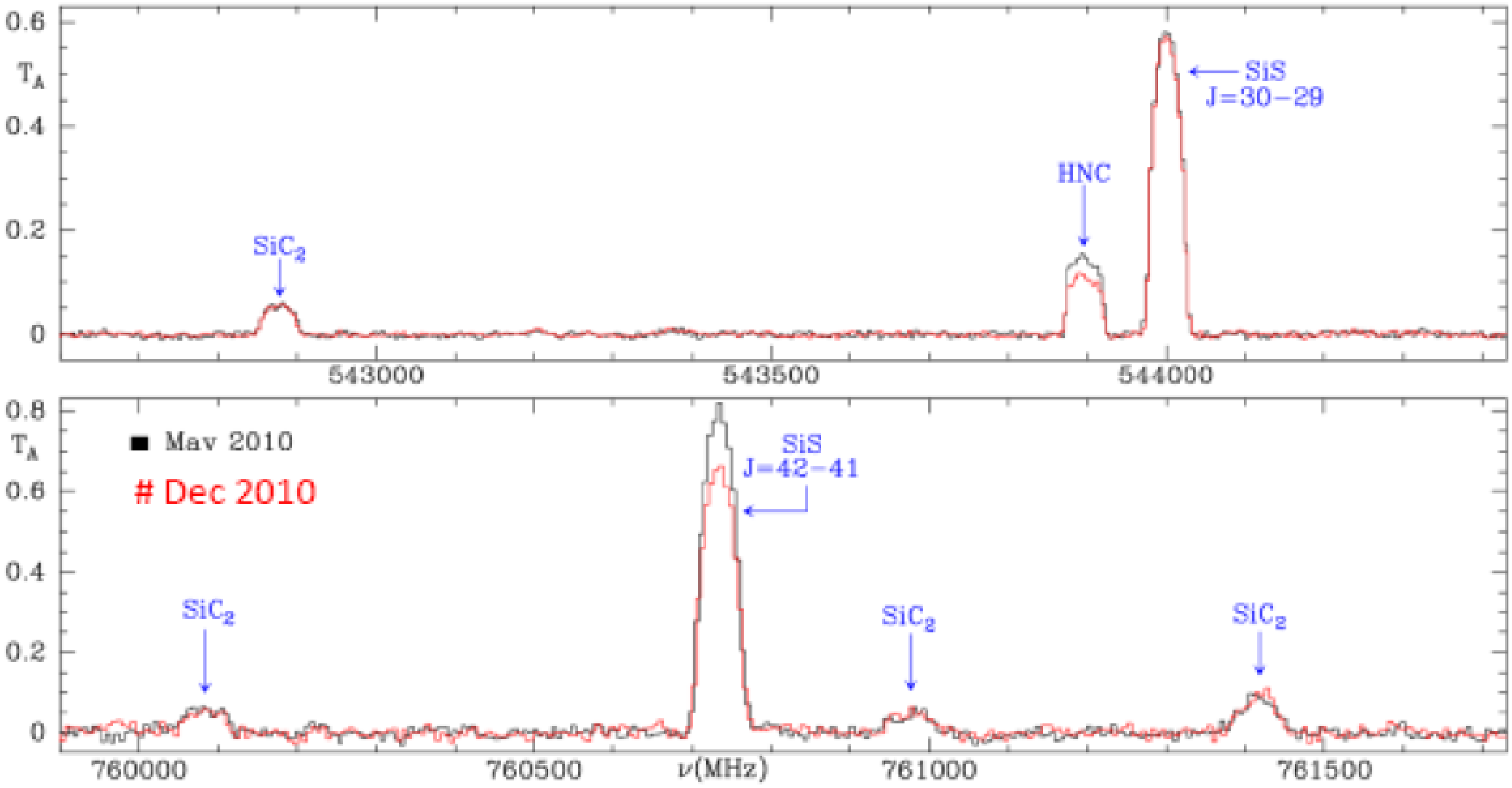


Fig. 1. Spectra of IRC +10216 observed with HIFI band 1b. *The two upper panels* present the complete spectrum on two different intensity scales. The panels below show different 3 GHz wide ranges of the survey. All data have been smoothed to a spectral resolution of 2.8 km s^{-1} except for *the right bottom panel*, which shows the spectrum around several vibrational lines of HCN with the nominal WBS resolution (1.1 MHz, ≃0.5 km s^{-1}).

Unexpected observation of anomalous line intensity fluctuations during the search for Hydrides in IRC+10216. No maser lines

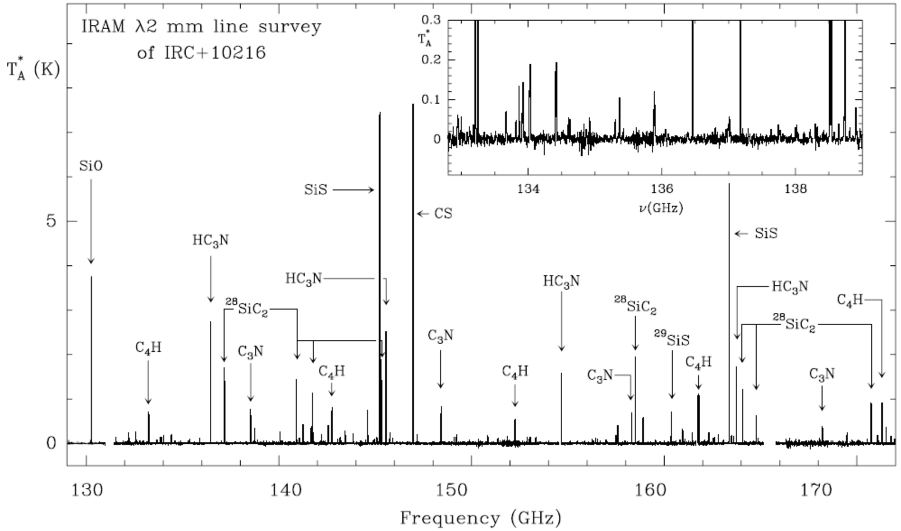


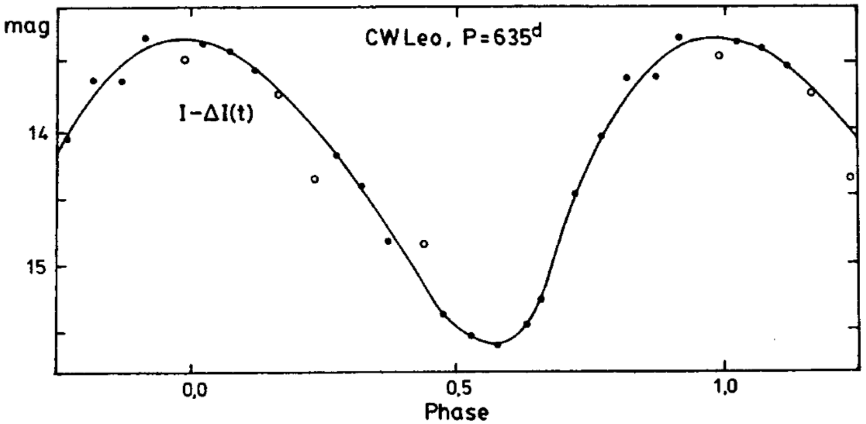
Some lines had identical intensities, other were showing important intensity fluctuations



J. Cernicharo, M.Guélin, C. Kahane
2000 A&A Supp. Series, 142, 181

A 2 mm molecular line survey of the C-star envelope IRC+10216





Alksnis 1989; period = 635 days

2.4. Time variability

IRC+10216 is known to be a Mira-type variable with a periodicity of 1.71 yr. Its 10 μm flux varies by a factor of 2 between minimum and maximum. Because of the calibration method described above, it was important to check for time-related intensity variations. Depending on the relative importance of radiative and collisional excitation, the millimeter line intensities may or may not follow the infrared flux variations. Among the 2-mm lines, the most likely to be affected are: *i)* those of CS, HC_3N, SiO and SiS, four species whose IR lines are known to be optically thick, as well as *ii)* the vibrationally excited lines of C_4H and HCN (Lucas & Cernicharo 1989). These lines were observed at several occasions during the 10 yr-long observing period. The ground-state mm lines, observed at a resolution of $\simeq 2$ km s^{-1}, were found to have stable shapes and intensities (within 20% which is consistent with our calibration uncertainty). The $v = 1, J = 3-2$ line of CS and several mm lines of vibrationally excited C_4H were observed with a good signal-to-noise ratio at different IR-phase periods in the course of our survey. We saw no intensity variations > 20% which could be correlated with the IR flux phase. However, the strong $\nu_2 = 1, J = 2-1$ line of HCN near 177 GHz shows factor of 2 intensity variation with time; this line, however, is known to be masering (Lucas & Cernicharo 1989).

Intensity comparisons are more difficult for weaker lines. We can only quote an upper limit of 20%, which represents the scatter of the intensities recorded at different epochs for the 0.3 − 0.5 K lines. Most of this scatter is probably related to calibration errors, since we found no obvious relation with the IR flux variations.

TIME MONITORING OF THE SiS (J=4-3, 5-4, AND 6-5) EMISSION FROM IRC+10216

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Introduction

We have monitored the SiS (J=4-3, 5-4, and 6-5) emission from. IRC+10216. Our aim was to find a correlation between the properties of the lines and the IR flux. The observations were performed with the Onsala 20 m telescope between March 1980 (JD≈2 444 300) and September 1987 (JD≈2 447 060) with emphasis on the period May 1984 to April 1986 during which data were taken every 3-4 months. This interval corresponds to approximately one period of the IR light curve of IRC+10216. The frequency ranges used in order to cover the investigated lines of the SiS molecule were: 72.6 GHz (J=4-3), 90.8 GHz (J=5-4) and 108.9 (J=6-5). The backends consisted of a 512x1 MHz filterbank and a high resolution 256x0.25 MHz filterbank.

Data analysis

At a first glance at the data one clearly sees the line shape variation of the J=5-4 line, figure 1. It is less obvious in the J=6-5 line and not apparent in the J=4-3 line. The time scale of the changes is in the range of that of the IR light curve of IRC+10216. As a

From Miras to Planetary Nebulae. Which Path to Stellar Evolution? International Colloquium, held in Montpellier, France September 4-7, 1989. Editors, M.O. Mennessier, A. Omont; Publisher, Editions Frontieres, Gif sur Yvette, France, 1990. ISBN # 2-86332-077-7. LC # QB806 .I583 1989, P. 170, 1990

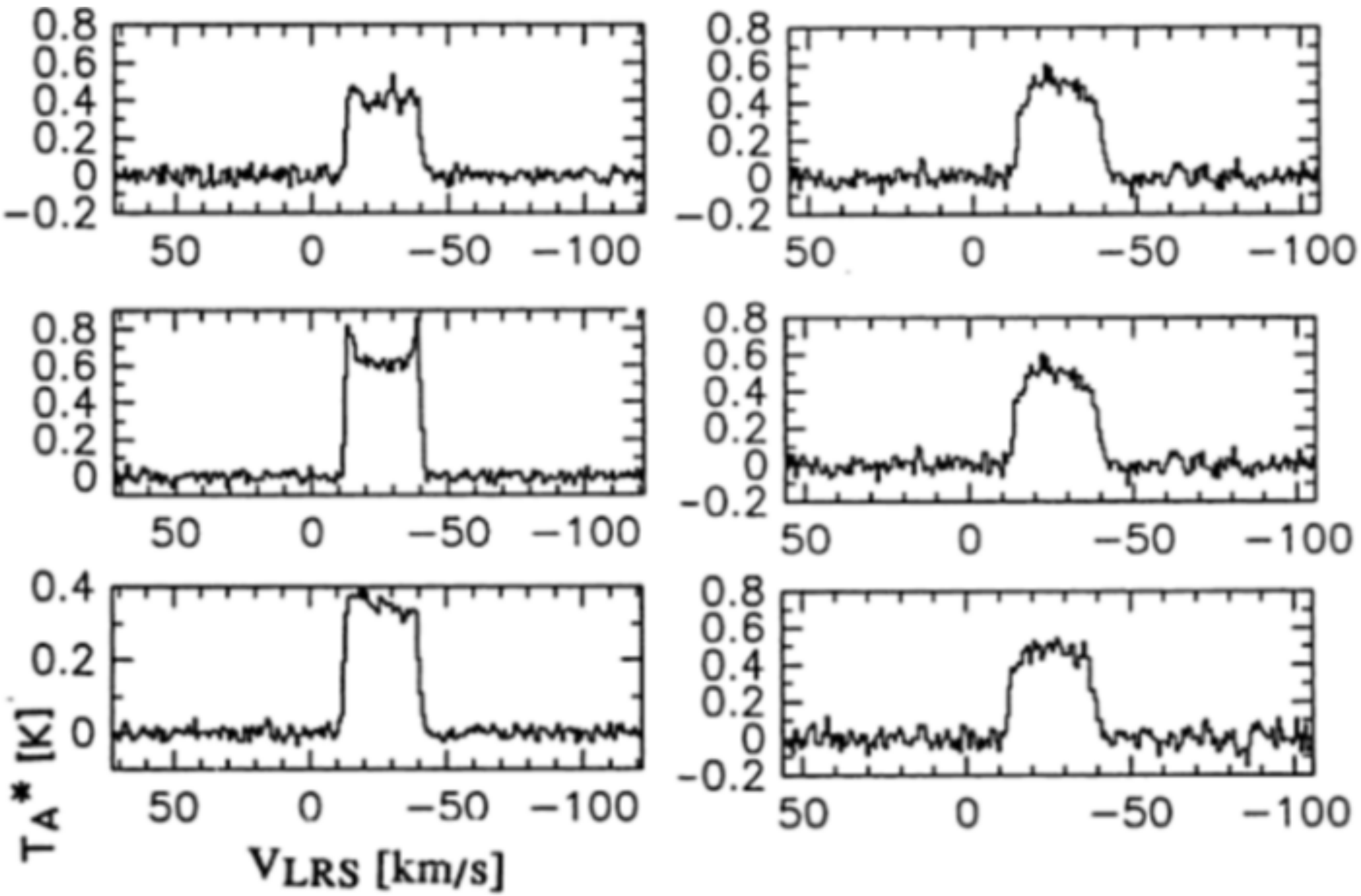
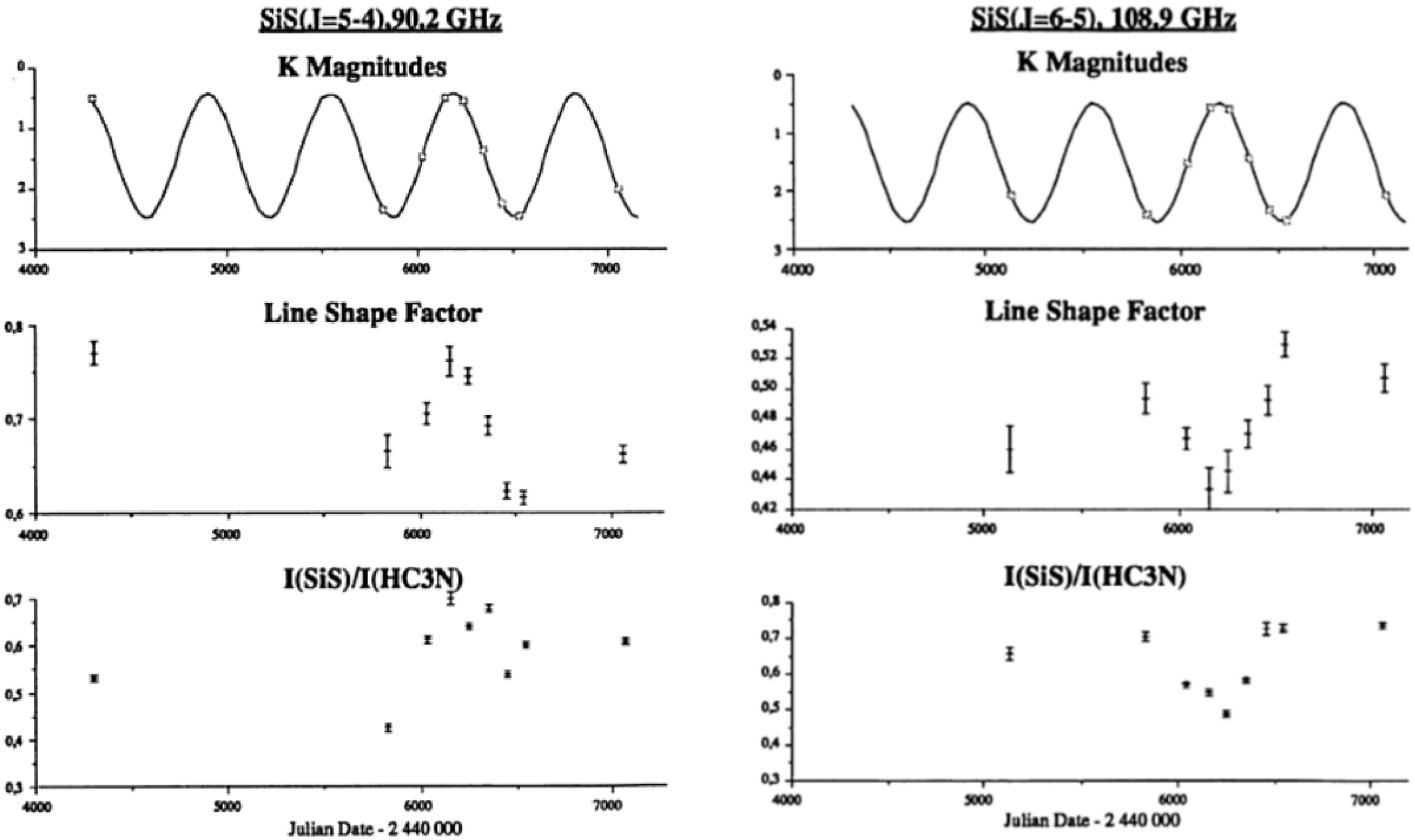


Figure 1. Spectra of the J=5-4 and 6-5 transitions at a minimum light, maximum and a subsequent minimum.

Many SiS v=0 lines are masering (Fonfría et al., 2006, ApJ, 646, L127)



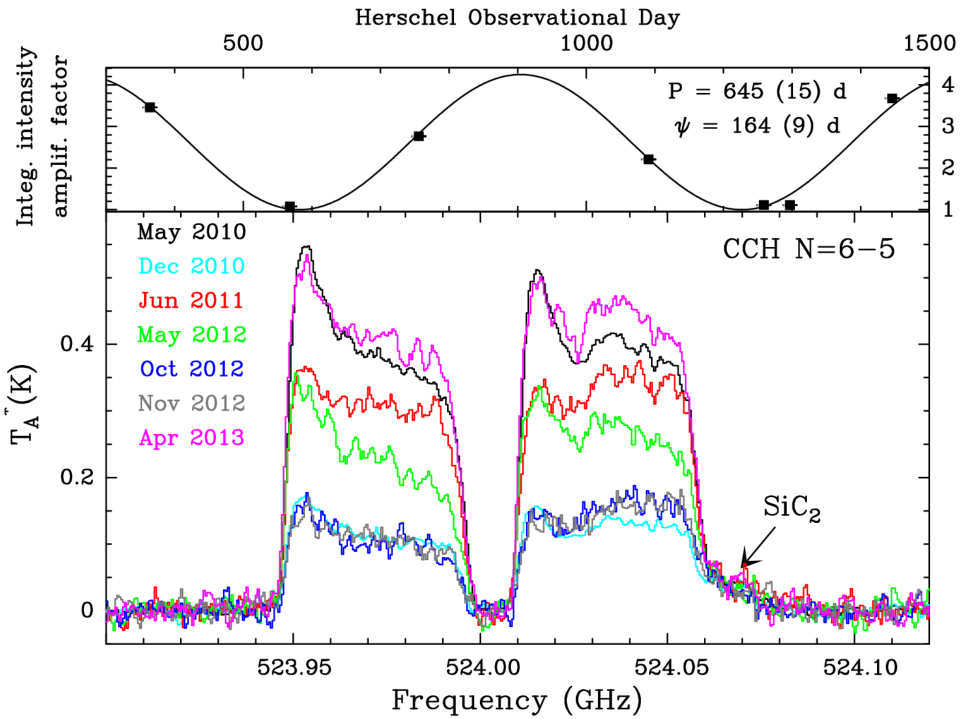
SiS(J=5-4),90,2 GHz
K Magnitudes
Line Shape Factor
I(SiS)/I(HC3N)
Julian Date - 2 440 000
SiS(J=6-5), 108,9 GHz
K Magnitudes
Line Shape Factor
I(SiS)/I(HC3N)
Julian Date - 2 440 000

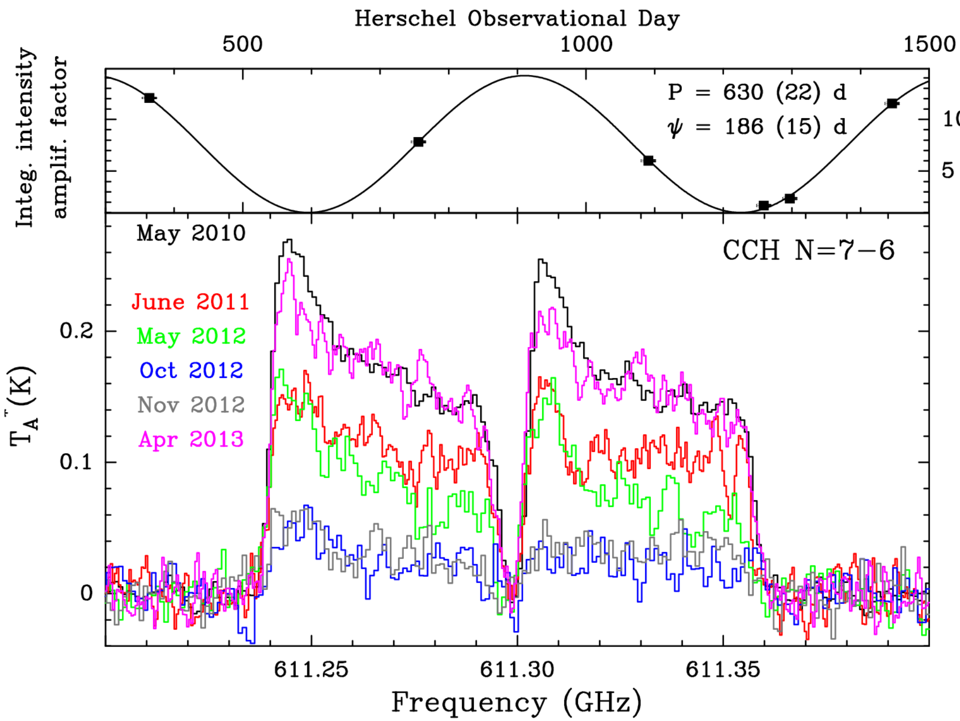
A MOLECULAR TIME MONITORING OF IRC+10216

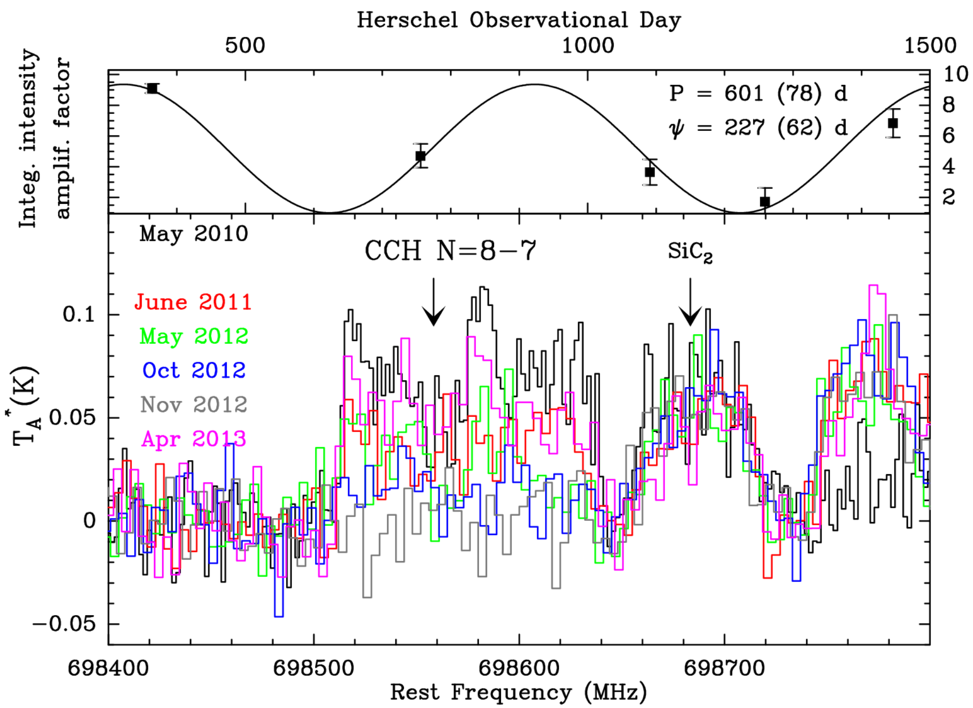
- A Total of five observing runs with HIFI/SPIRE/PACS
- Lines selected on the basis of variations observed between the line survey and the hydrides proposal
- Full scans with SPIRE and PACS. All bright lines observed and monitored
- Complemented with 12 observing sessions every 2 months with the 30-m radio telescope. Selected lines of CCH/HNC/SiS/SiO and whole 3mm band. CCH J=4-3 & J=3-2 and HNC J=3-2

CCH variability

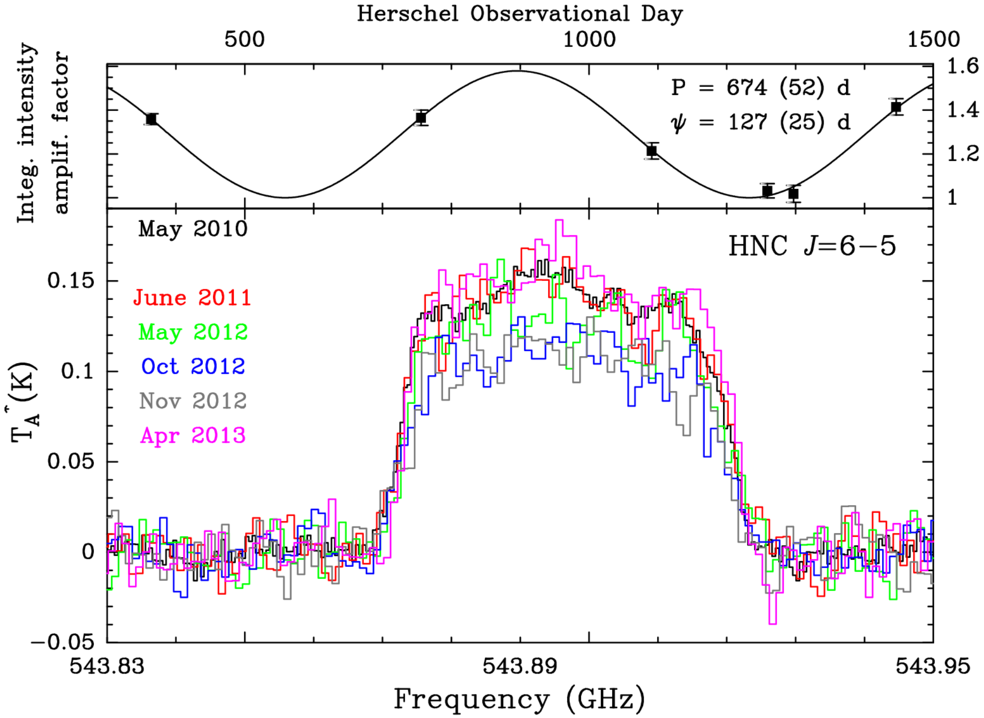
See also Poster P78

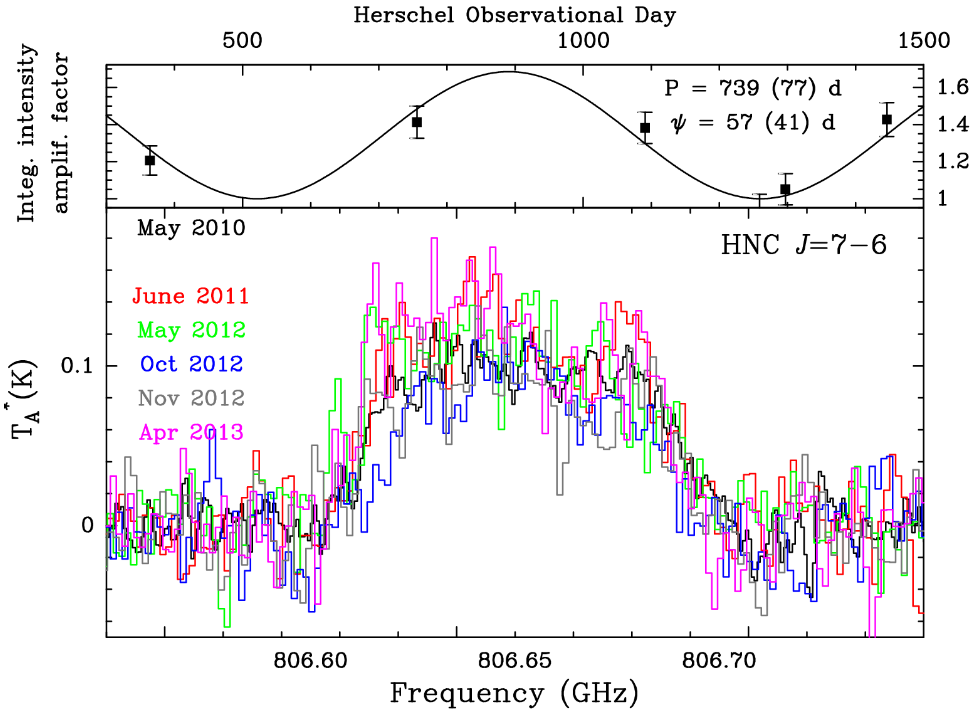


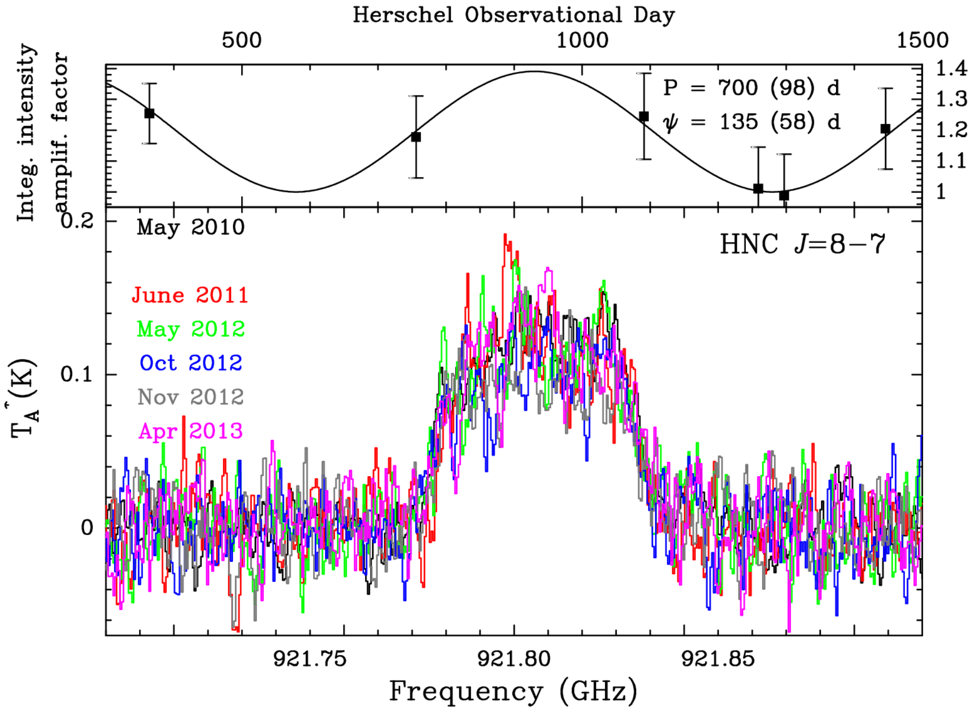


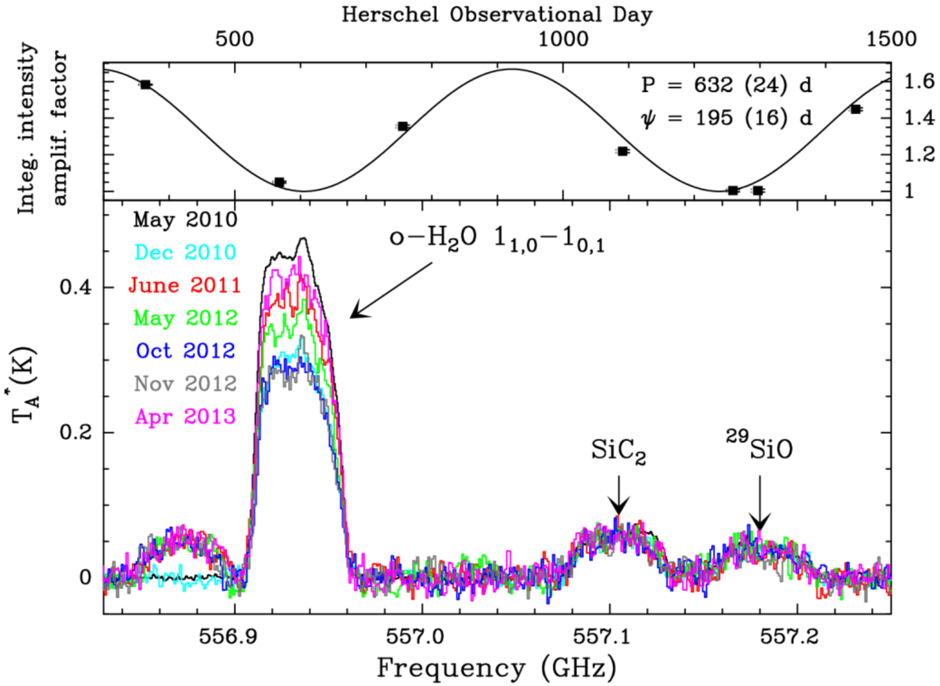


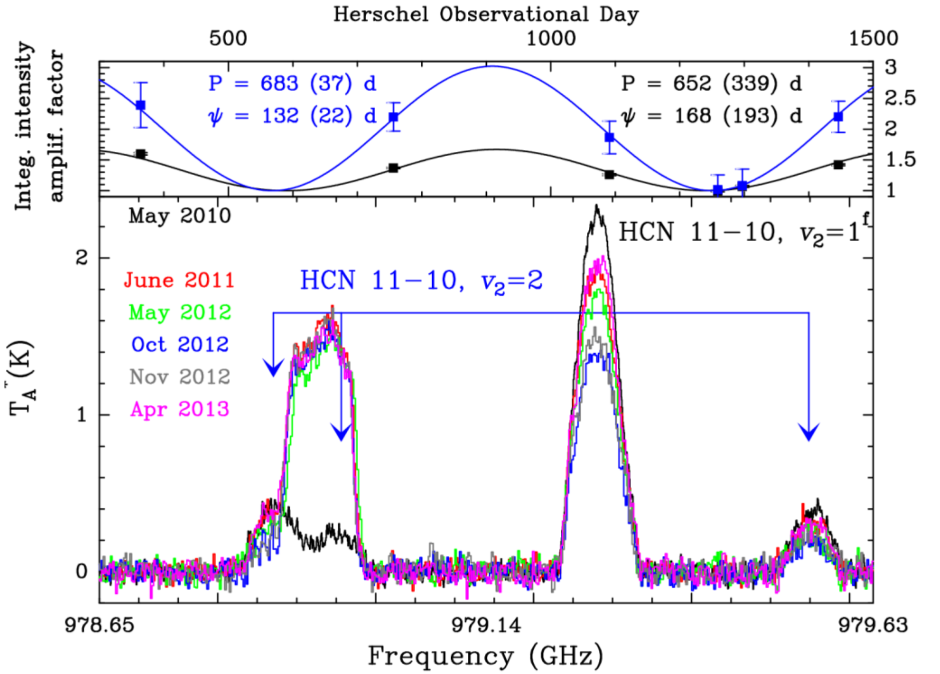
HNC VARIABILITY





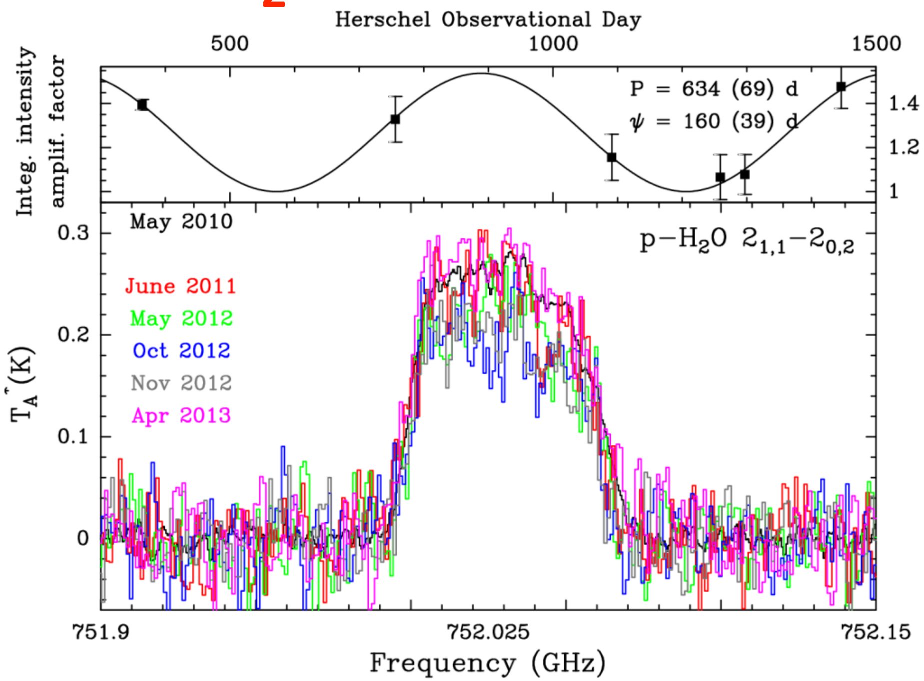


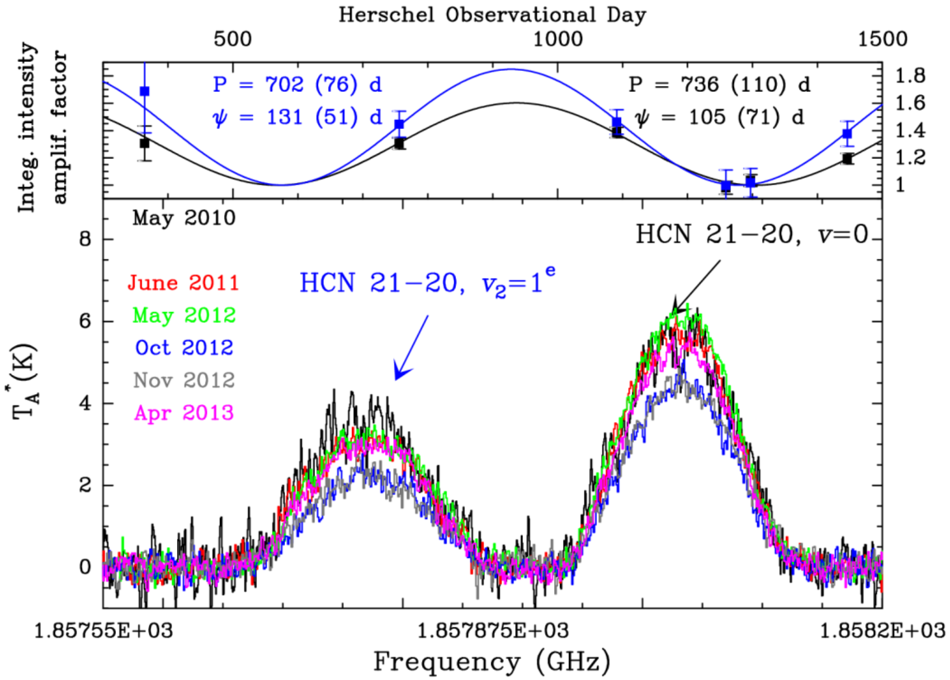


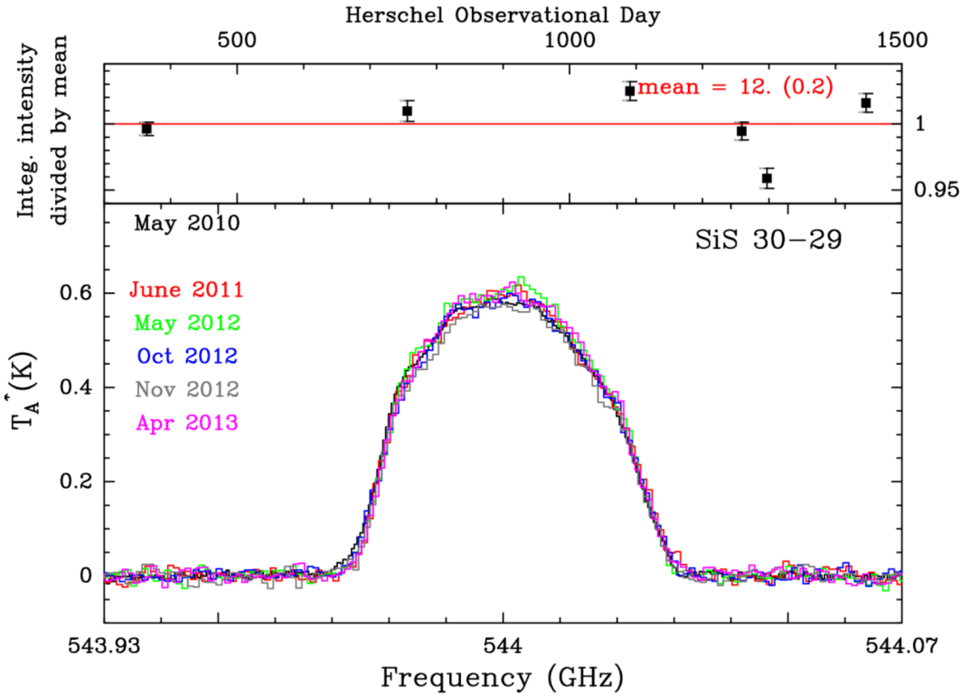


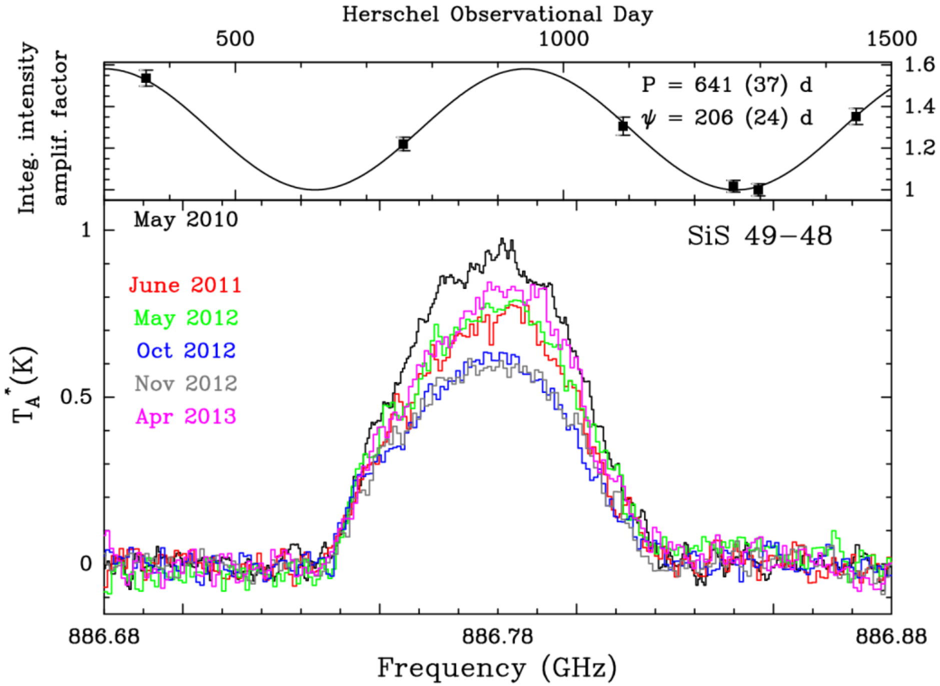
H_2O VARIABILITY

HCN VARIABILITY

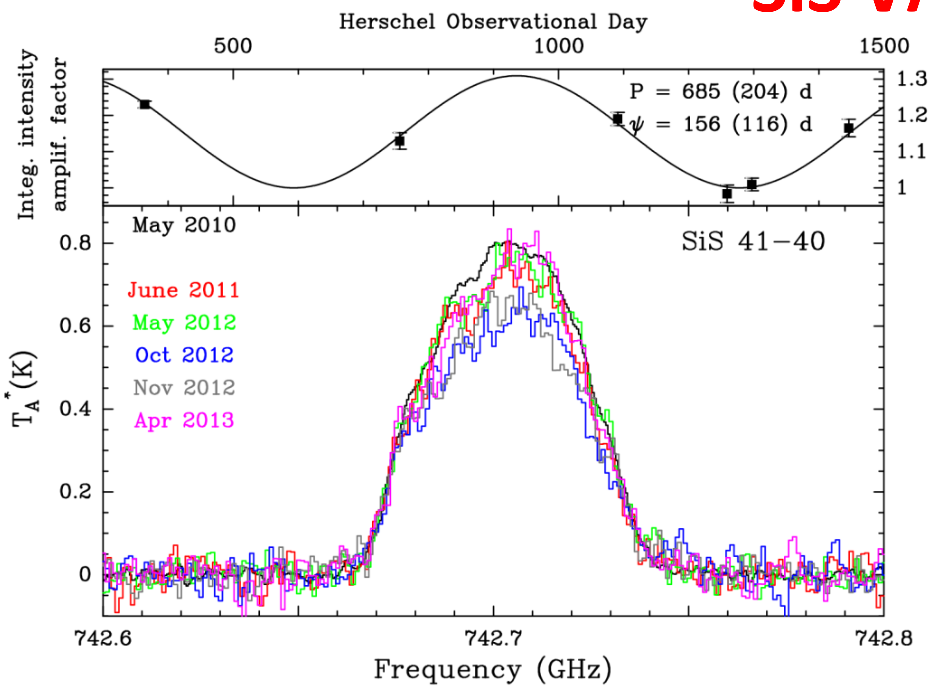


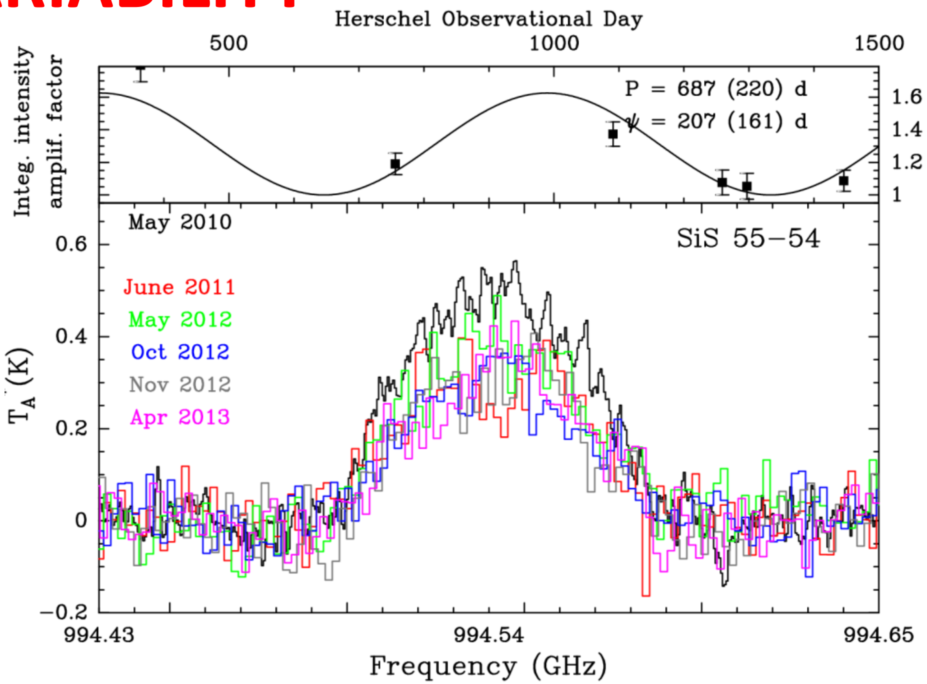


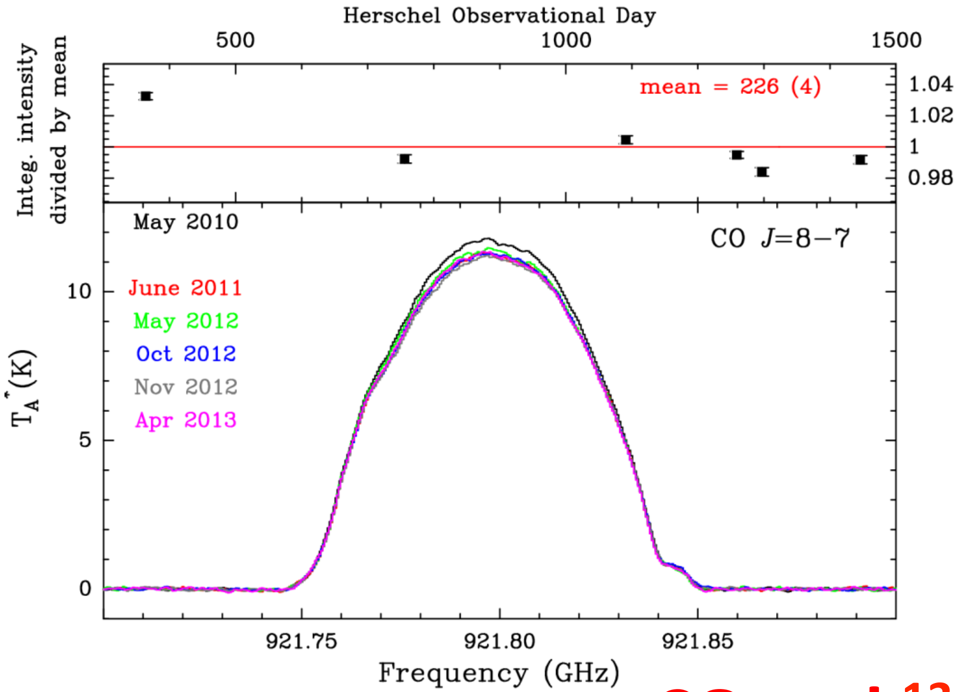


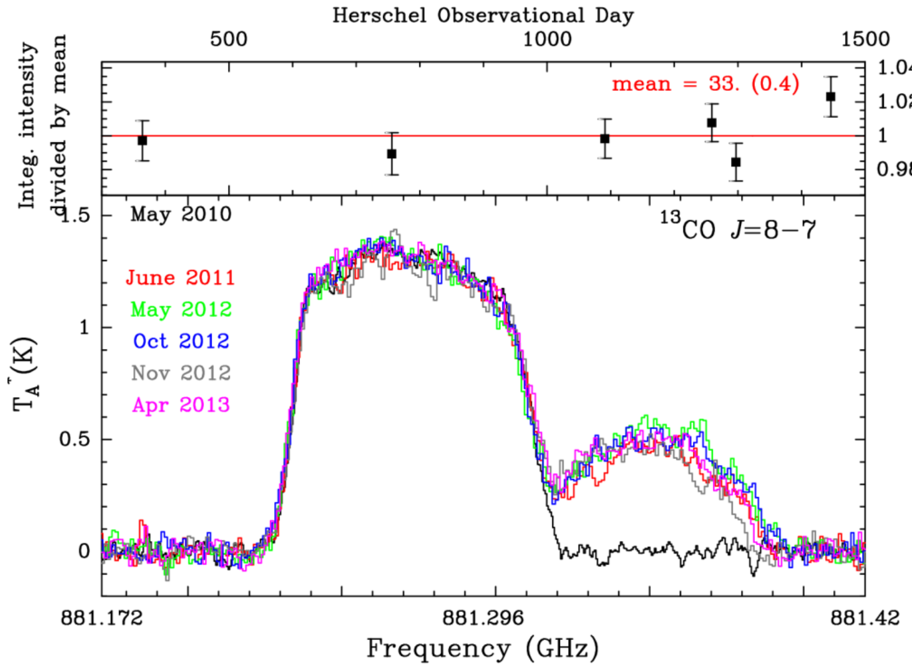


SiS VARIABILITY

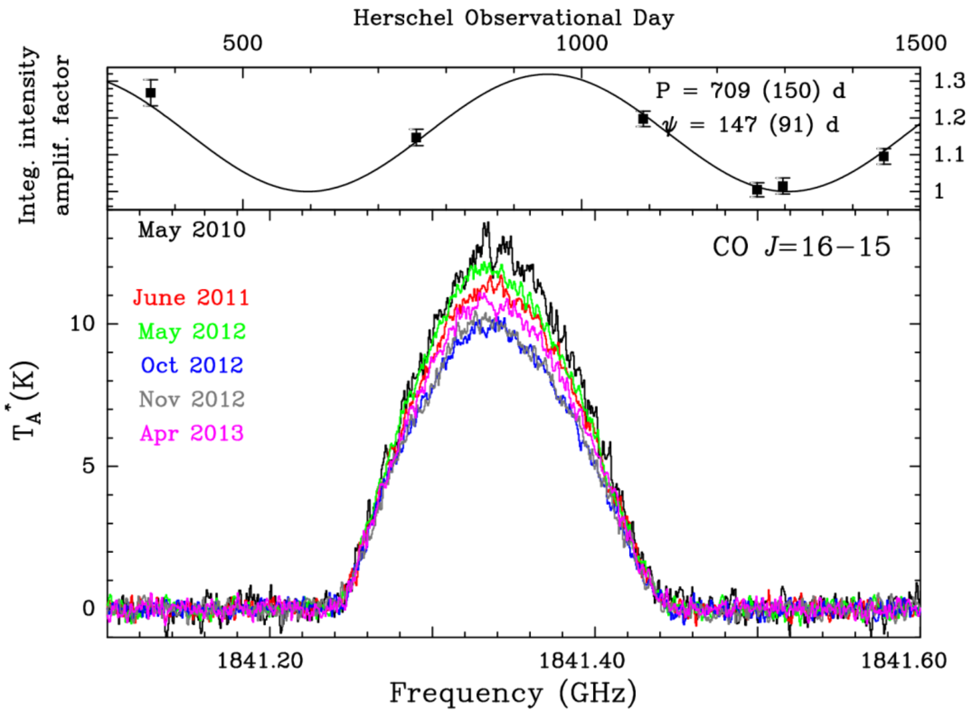


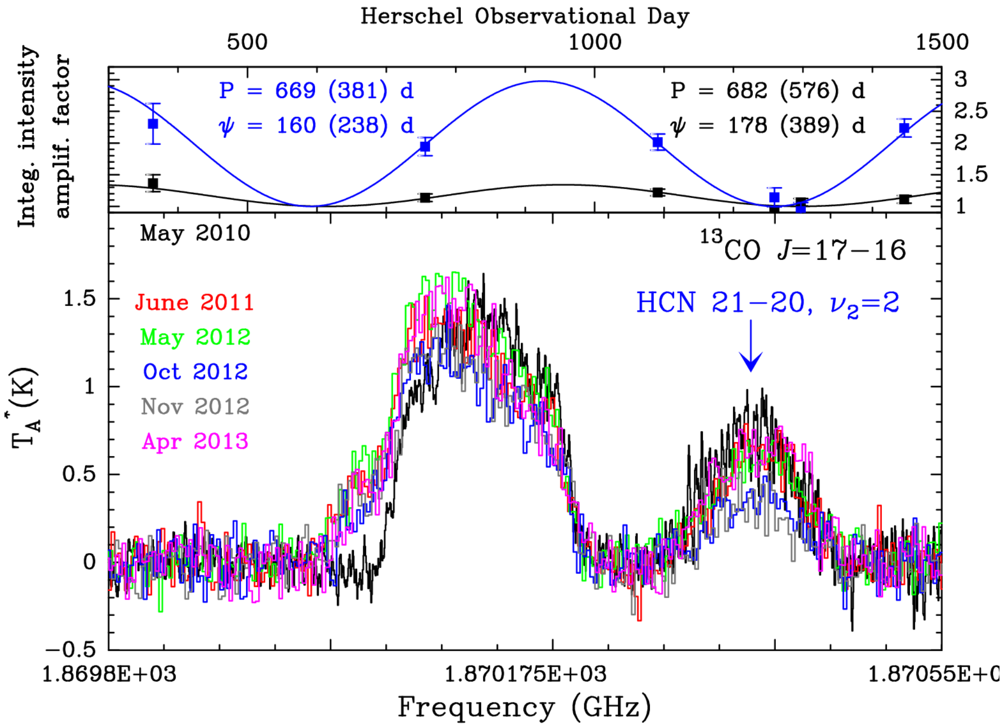


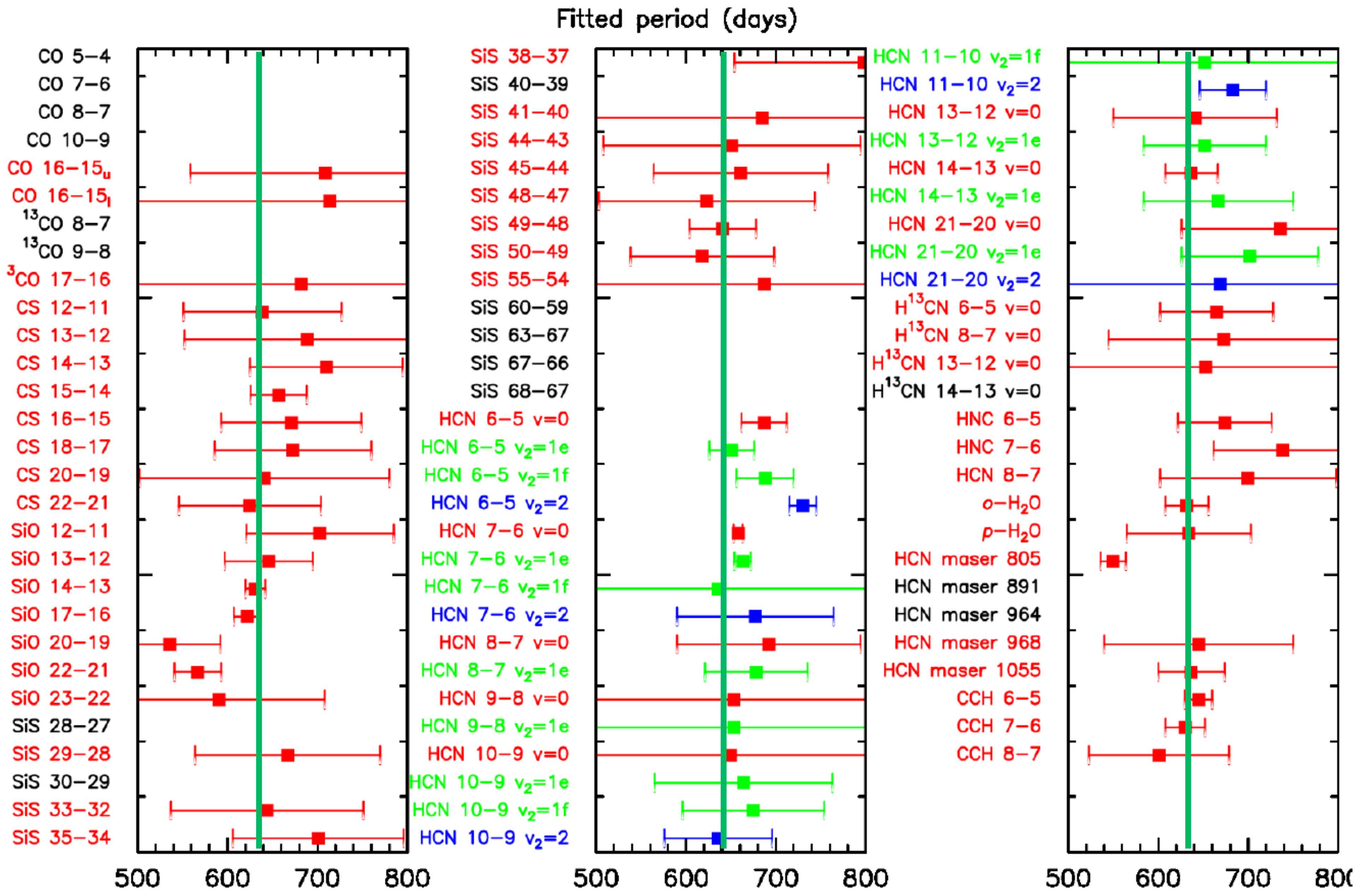




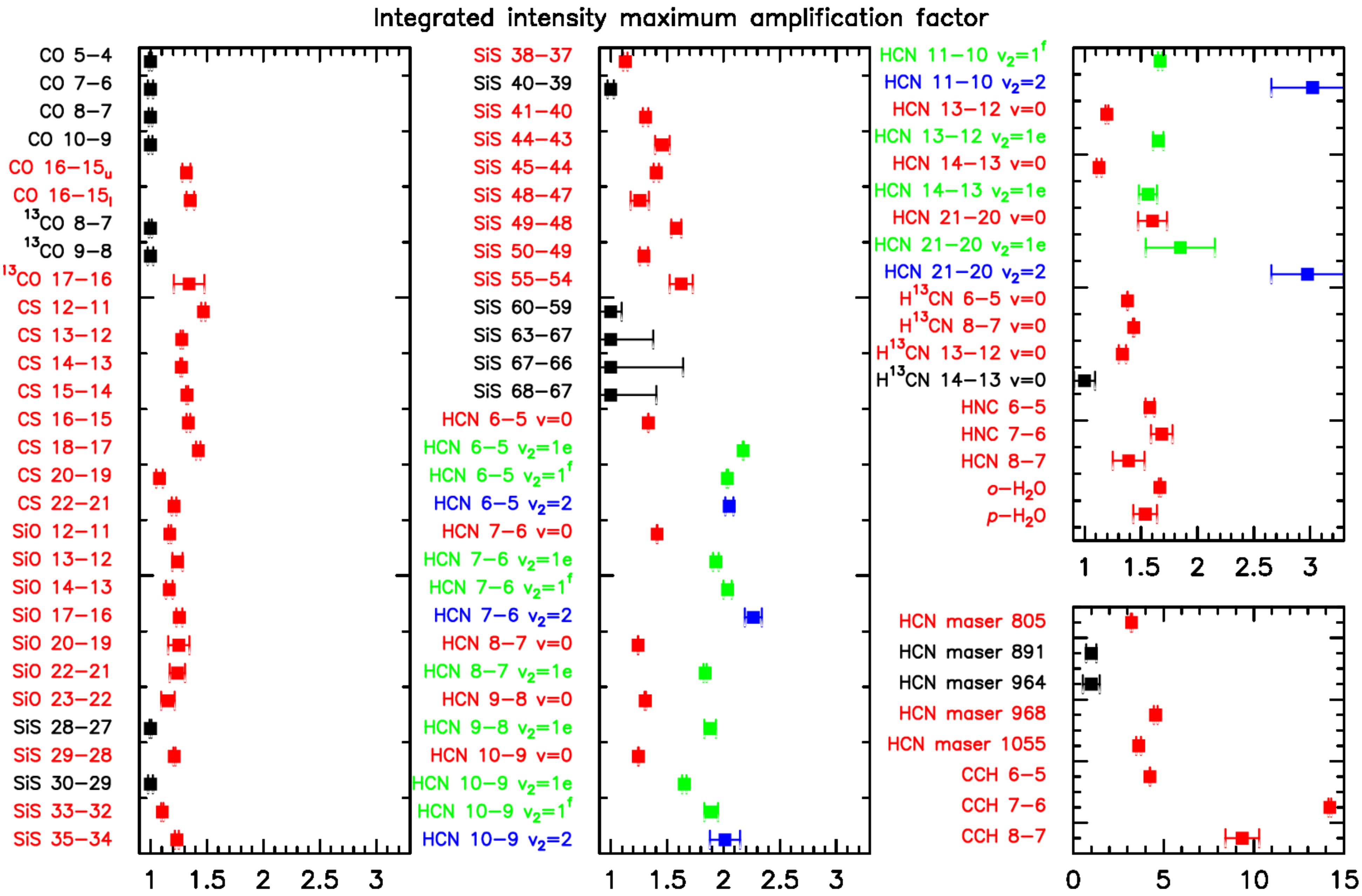
CO and ^{13}CO VARIABILITY





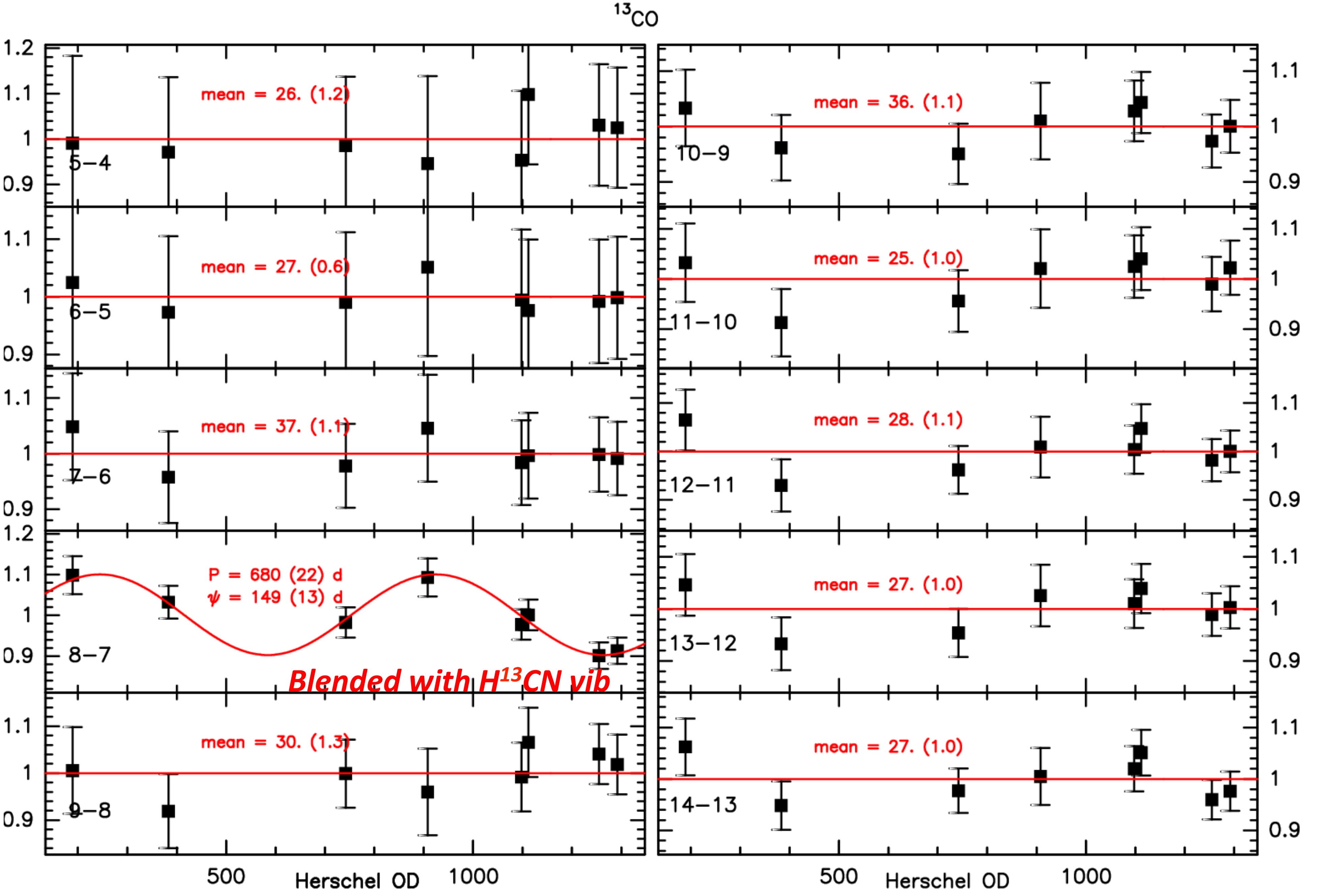


Fitted period (days)
CO 5−4
CO 7−6
CO 8−7
CO 10−9
CO 16−15u
CO 16−15l
13CO 8−7
13CO 9−8
3CO 17−16
CS 12−11
CS 13−12
CS 14−13
CS 15−14
CS 16−15
CS 18−17
CS 20−19
CS 22−21
SiO 12−11
SiO 13−12
SiO 14−13
SiO 17−16
SiO 20−19
SiO 22−21
SiO 23−22
SiS 28−27
SiS 29−28
SiS 30−29
SiS 33−32
SiS 35−34
SiS 38−37
SiS 40−39
SiS 41−40
SiS 44−43
SiS 45−44
SiS 48−47
SiS 49−48
SiS 50−49
SiS 55−54
SiS 60−59
SiS 63−67
SiS 67−66
SiS 68−67
HCN 6−5 v=0
HCN 6−5 v2=1e
HCN 6−5 v2=1f
HCN 6−5 v2=2
HCN 7−6 v=0
HCN 7−6 v2=1e
HCN 7−6 v2=1f
HCN 7−6 v2=2
HCN 8−7 v=0
HCN 8−7 v2=1e
HCN 9−8 v=0
HCN 9−8 v2=1e
HCN 10−9 v=0
HCN 10−9 v2=1e
HCN 10−9 v2=1f
HCN 10−9 v2=2
HCN 11−10 v2=1f
HCN 11−10 v2=2
HCN 13−12 v=0
HCN 13−12 v2=1e
HCN 14−13 v=0
HCN 14−13 v2=1e
HCN 21−20 v=0
HCN 21−20 v2=1e
HCN 21−20 v2=2
H13CN 6−5 v=0
H13CN 8−7 v=0
H13CN 13−12 v=0
H13CN 14−13 v=0
HNC 6−5
HNC 7−6
HCN 8−7
o−H2O
p−H2O
HCN maser 805
HCN maser 891
HCN maser 964
HCN maser 968
HCN maser 1055
CCH 6−5
CCH 7−6
CCH 8−7
500
600
700
800

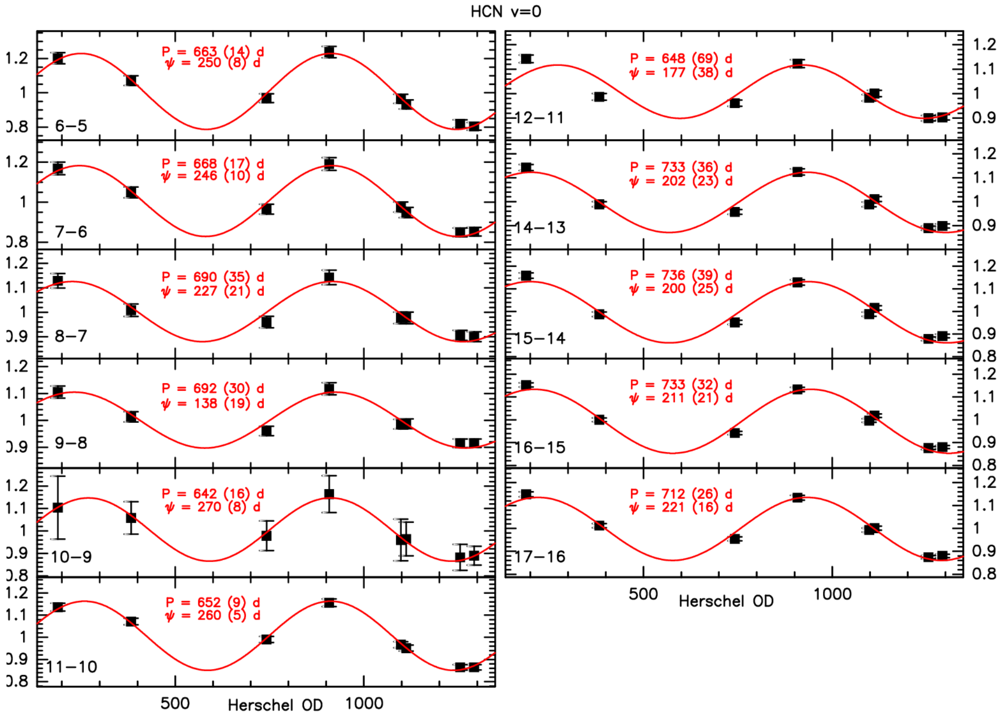


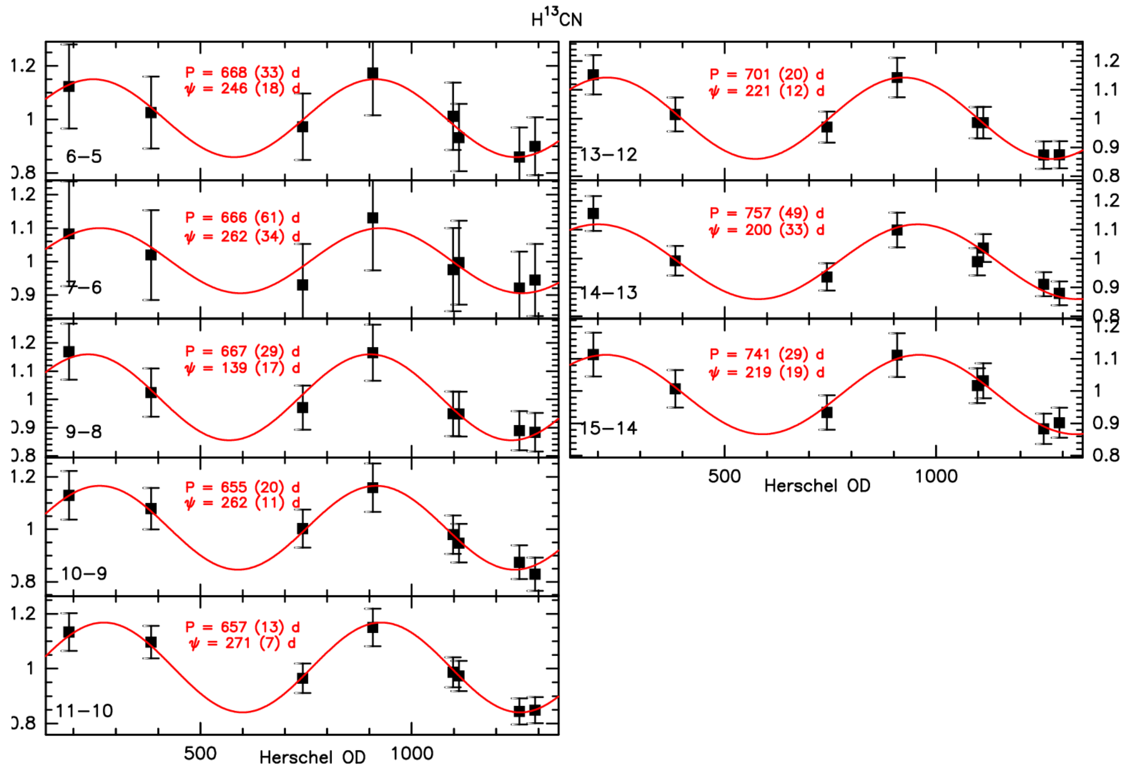
Integrated intensity maximum amplification factor
CO 5–4
CO 7–6
CO 8–7
CO 10–9
CO 16–15u
CO 16–15l
13CO 8–7
13CO 9–8
13CO 17–16
CS 12–11
CS 13–12
CS 14–13
CS 15–14
CS 16–15
CS 18–17
CS 20–19
CS 22–21
SiO 12–11
SiO 13–12
SiO 14–13
SiO 17–16
SiO 20–19
SiO 22–21
SiO 23–22
SiS 28–27
SiS 29–28
SiS 30–29
SiS 33–32
SiS 35–34
1 1.5 2 2.5 3
SiS 38–37
SiS 40–39
SiS 41–40
SiS 44–43
SiS 45–44
SiS 48–47
SiS 49–48
SiS 50–49
SiS 55–54
SiS 60–59
SiS 63–67
SiS 67–66
SiS 68–67
HCN 6–5 v=0
HCN 6–5 v2=1e
HCN 6–5 v2=1f
HCN 6–5 v2=2
HCN 7–6 v=0
HCN 7–6 v2=1e
HCN 7–6 v2=1f
HCN 7–6 v2=2
HCN 8–7 v=0
HCN 8–7 v2=1e
HCN 9–8 v=0
HCN 9–8 v2=1e
HCN 10–9 v=0
HCN 10–9 v2=1e
HCN 10–9 v2=1f
HCN 10–9 v2=2
1 1.5 2 2.5 3
HCN 11–10 v2=1f
HCN 11–10 v2=2
HCN 13–12 v=0
HCN 13–12 v2=1e
HCN 14–13 v=0
HCN 14–13 v2=1e
HCN 21–20 v=0
HCN 21–20 v2=1e
HCN 21–20 v2=2
H13CN 6–5 v=0
H13CN 8–7 v=0
H13CN 13–12 v=0
H13CN 14–13 v=0
HNC 6–5
HNC 7–6
HCN 8–7
o–H2O
p–H2O
1 1.5 2 2.5 3
HCN maser 805
HCN maser 891
HCN maser 964
HCN maser 968
HCN maser 1055
CCH 6–5
CCH 7–6
CCH 8–7
0 5 10 15

SPIRE FTS
All Medium excitation lines of HCN, CO, CS, SiS

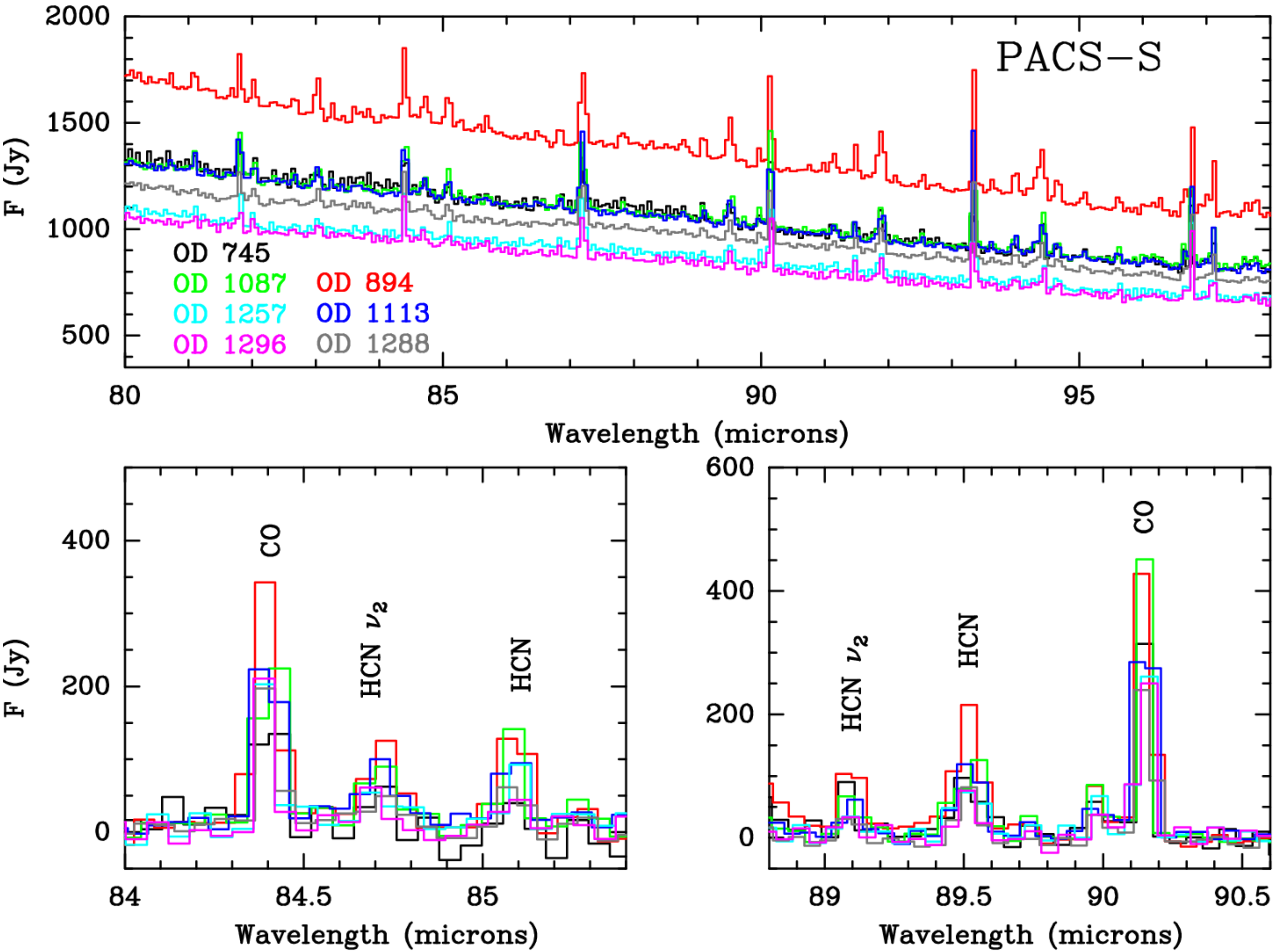


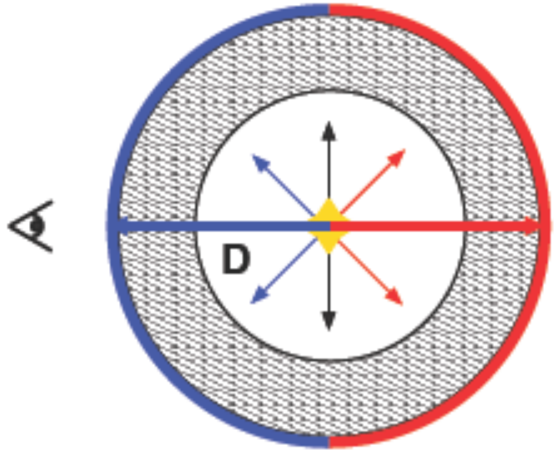
^{13}CO
mean = 26. (1.2)
5−4
mean = 27. (0.6)
6−5
mean = 37. (1.1)
7−6
P = 680 (22) d
ψ = 149 (13) d
8−7
Blended with H13CN vib
mean = 30. (1.3)
9−8
mean = 36. (1.1)
10−9
mean = 25. (1.0)
11−10
mean = 28. (1.1)
12−11
mean = 27. (1.0)
13−12
mean = 27. (1.0)
14−13
1.2
1.1
1
0.9
500
1000
Herschel OD


HCN v=0
P = 663 (14) d
ψ = 250 (8) d
6−5
P = 648 (69) d
ψ = 177 (38) d
12−11
P = 668 (17) d
ψ = 246 (10) d
7−6
P = 733 (36) d
ψ = 202 (23) d
14−13
P = 690 (35) d
ψ = 227 (21) d
8−7
P = 736 (39) d
ψ = 200 (25) d
15−14
P = 692 (30) d
ψ = 138 (19) d
9−8
P = 733 (32) d
ψ = 211 (21) d
16−15
P = 642 (16) d
ψ = 270 (8) d
10−9
P = 712 (26) d
ψ = 221 (16) d
17−16
P = 652 (9) d
ψ = 260 (5) d
11−10
Herschel OD

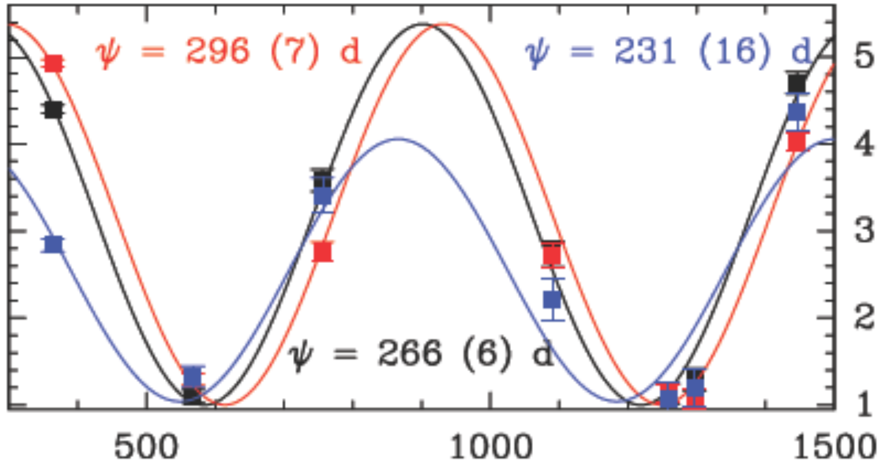

H13CN
P = 668 (33) d
ψ = 246 (18) d
6−5
P = 701 (20) d
ψ = 221 (12) d
13−12
P = 666 (61) d
ψ = 262 (34) d
7−6
P = 757 (49) d
ψ = 200 (33) d
14−13
P = 667 (29) d
ψ = 139 (17) d
9−8
P = 741 (29) d
ψ = 219 (19) d
15−14
P = 655 (20) d
ψ = 262 (11) d
10−9
P = 657 (13) d
ψ = 271 (7) d
11−10
Herschel OD

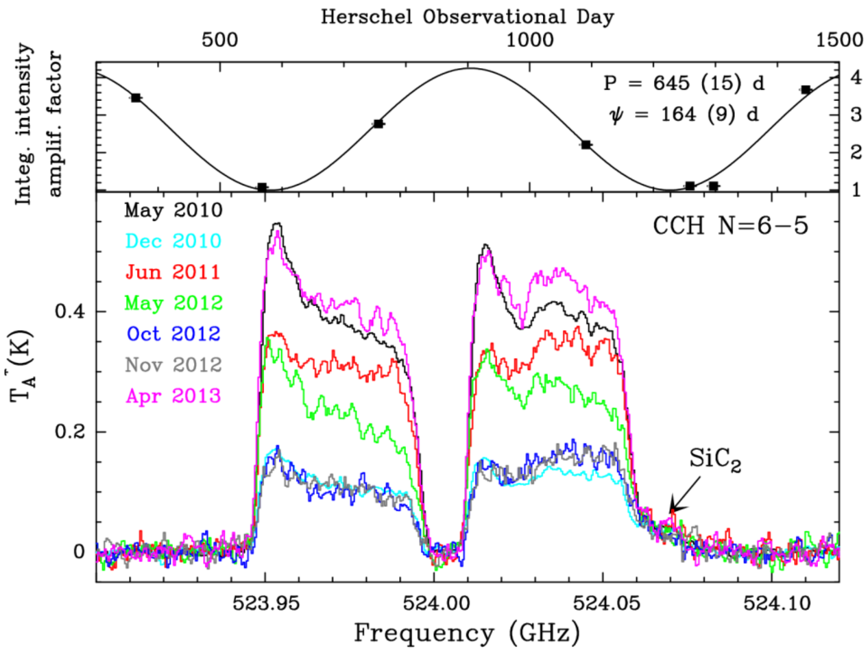
PACS
High-J lines of HCN, CO, CS, SiS


PACS−S
OD 745
OD 1087
OD 894
OD 1257
OD 1113
OD 1296
OD 1288
F (Jy)
Wavelength (microns)
CO
HCN ν2
HCN
F (Jy)
Wavelength (microns)
HCN ν2
HCN
CO
Wavelength (microns)

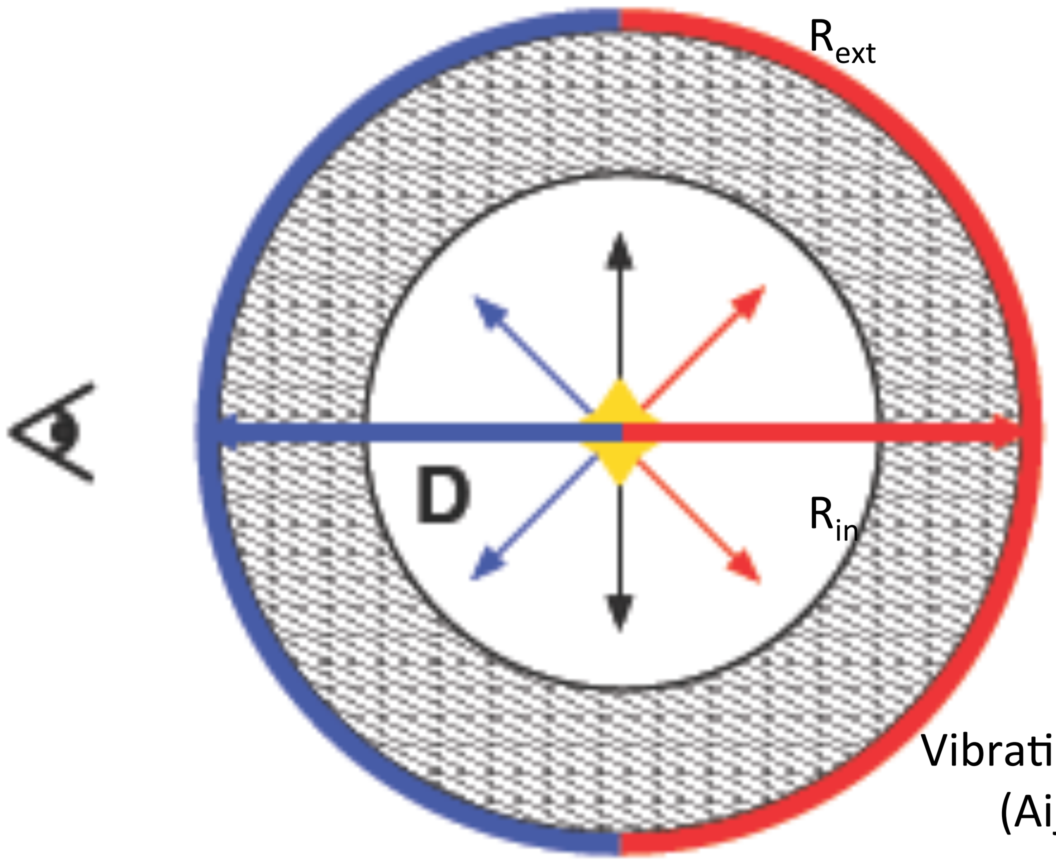


Very preliminary analysis of time lags





See Poster by Teyssier et al. P78



Time to cross the shell=$(R_{ext}$-$R_{in})/c$= a few days

Vibrational Einstein coefficients (Aij) ~ 0.1-1 s^{-1}

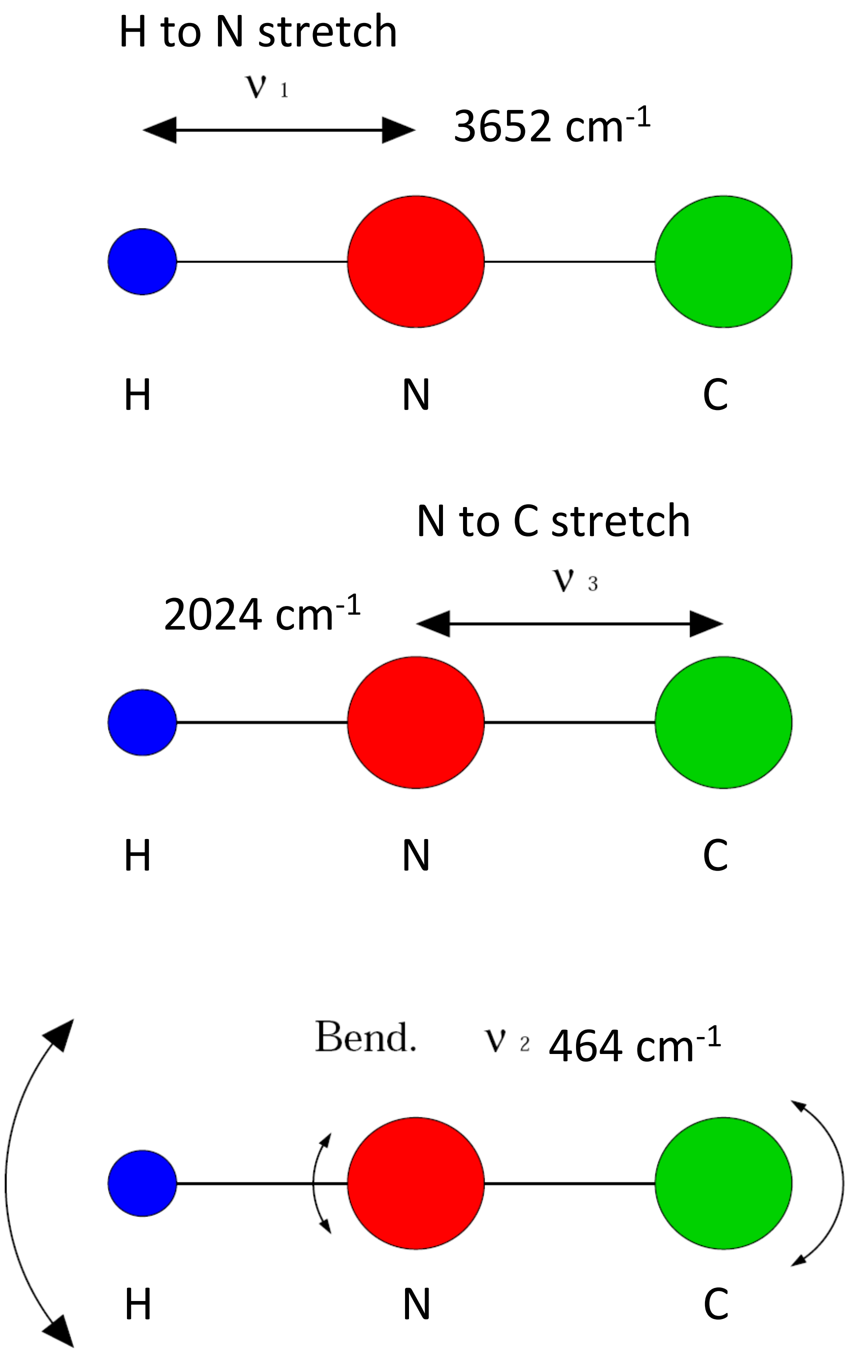
Collisions ~ 1-3 10^4 x10^{-10} ~ (1-3) 10^{-6} s^{-1} (3-10 days)

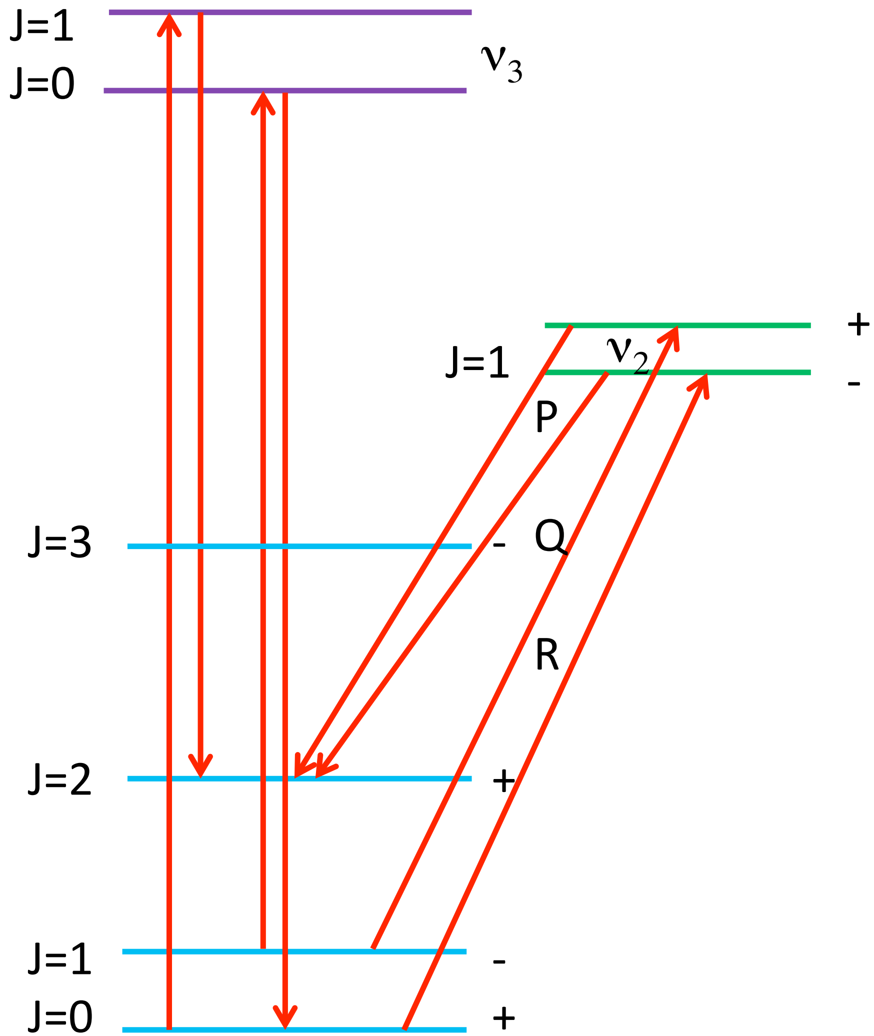
Rotational Aij ~ 10^{-3} – 10^{-7} s-1 (hours to weeks). Depending on J and on the molecule.

Can we continue to assume
d n(J,v)/ dt = 0 ?????
in presence of an IR flux perturbation ?

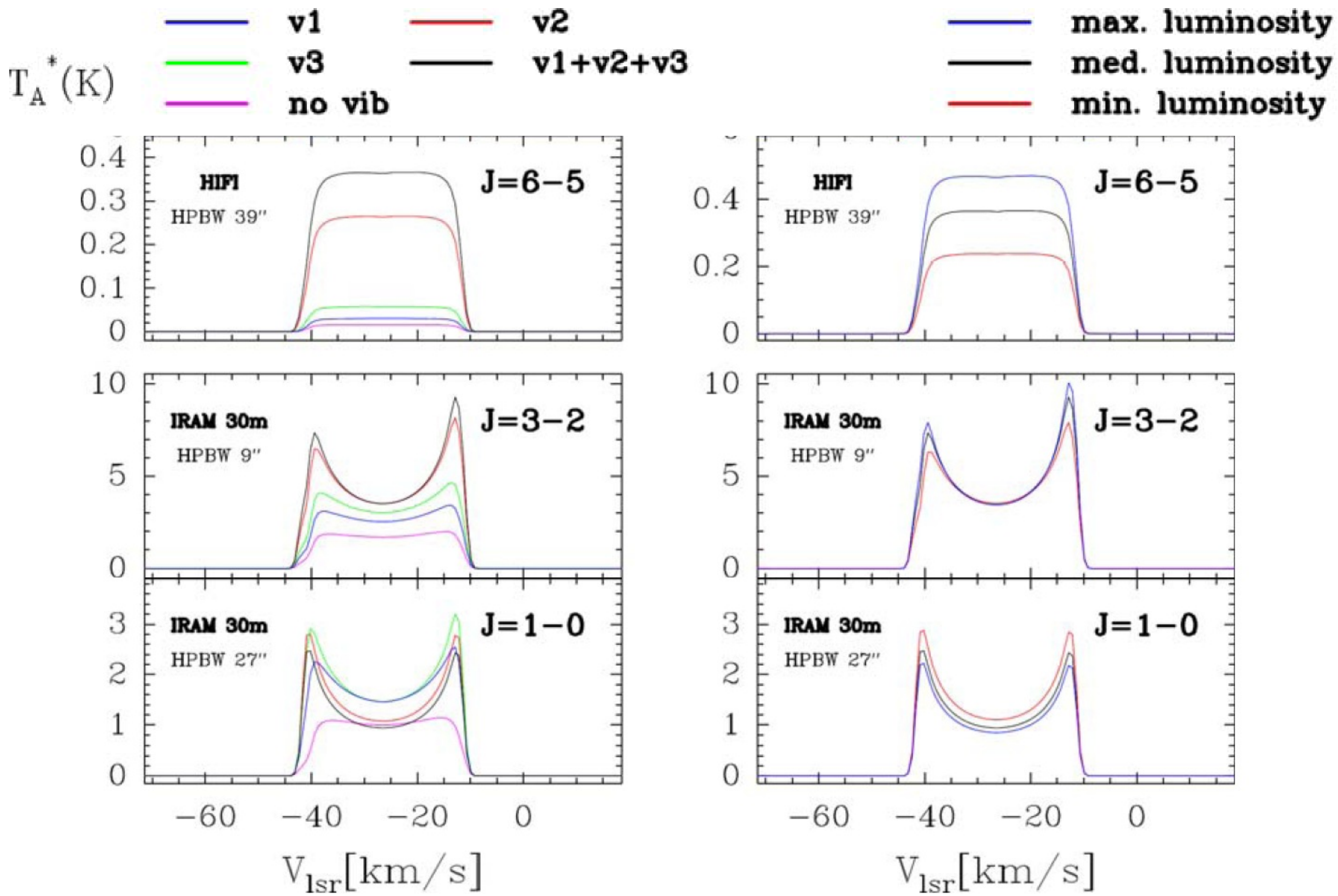
Phase lag between different points of the CSE has to be included in RT equations

HNC, an example of IR pumping

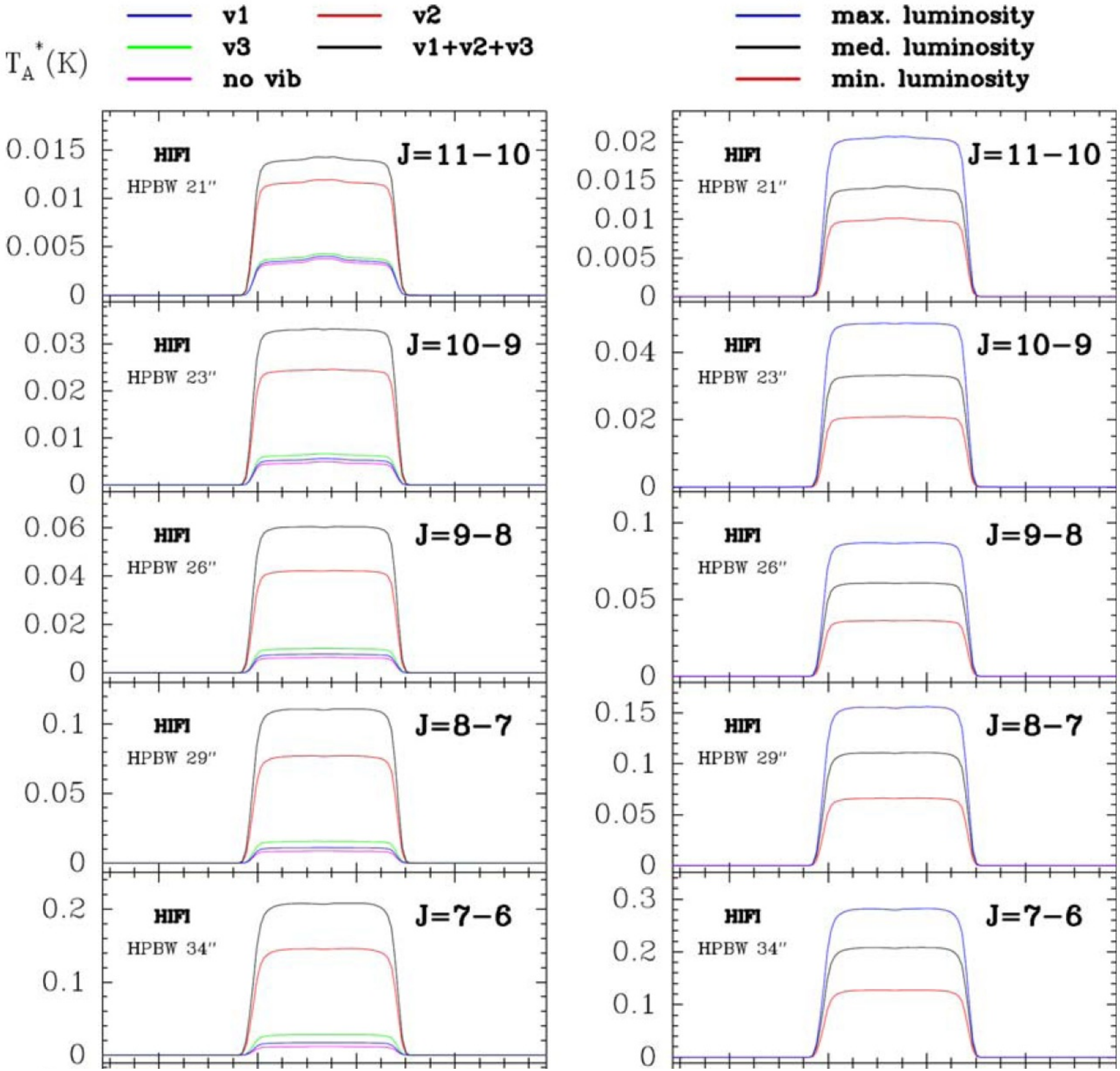




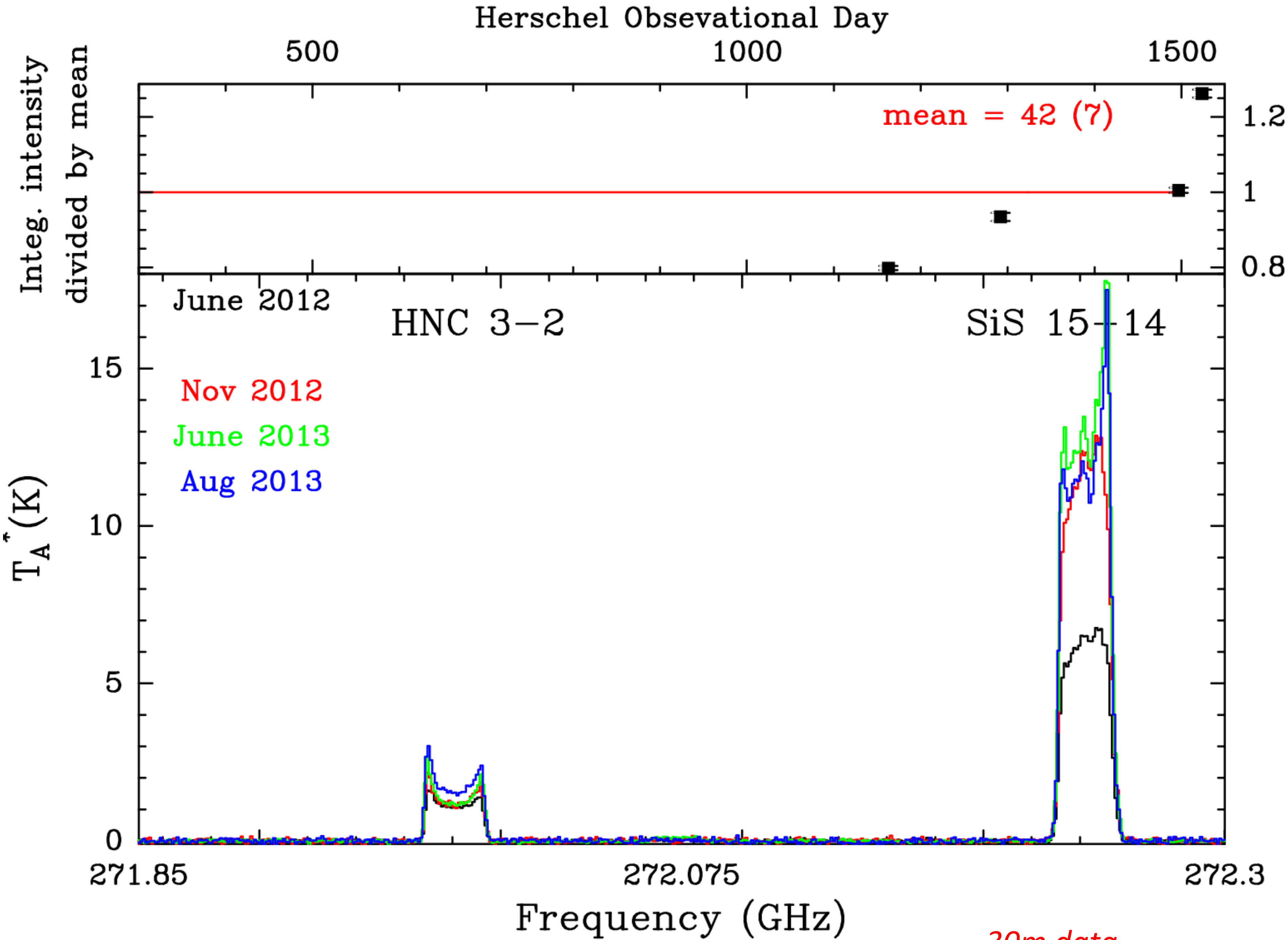
HNC Daniel et al., 2012, 542, A37
CCH De Beck et al., 2012, 539, A108



v1
v2
v3
v1+v2+v3
no vib
max. luminosity
med. luminosity
min. luminosity
T_A*(K)
HIFI
HPBW 39″
J=6−5
IRAM 30m
HPBW 9″
J=3−2
IRAM 30m
HPBW 27″
J=1−0
−60
−40
−20
0
V_lsr[km/s]



v1
v2
v3
v1+v2+v3
no vib
max. luminosity
med. luminosity
min. luminosity
T_A^*(K)
HIFI
HPBW 21″
J=11−10
HPBW 23″
J=10−9
HPBW 26″
J=9−8
HPBW 29″
J=8−7
HPBW 34″
J=7−6



Herschel Obsevational Day
500
1000
1500
mean = 42 (7)
1.2
1
0.8
Integ. intensity divided by mean
June 2012
HNC 3−2
SiS 15−14
Nov 2012
June 2013
Aug 2013
15
10
5
0
T_A^*(K)
271.85
272.075
272.3
Frequency (GHz)

30m data

Conclusions

- Most molecular Lines in evolved stars can not be used as standard calibrators. Stellar phase is a real concern and a physical basic parameter for any realistic model.
- Determination of isotopic abundance ratios have to be done from simultaneous observations.
- Radiative Transfer in molecular lines affected by infrared pumping has to include a time dependency to account for the infrared flux variations. High-J lines of all molecules affected by IR pumping, even CO.
- If the lines are arising from shells at a given distance from the star the delay between the blue (rear) and red components (front) fluctuations could provide, through a detailed RT analysis, some information on the distance => spatial knowledge of the origin of the emission is needed.
- Molecules abundant in the inner and external regions "could" be less affected by the infrared variations at large distance in the low-J lines. Molecules abundant only in the external regions of the envelope are strongly affected by the infrared flux variations for all J*s*.
- Some molecules do not show any evident variation of the emerging flux (SiC_2 for example). Probably depends on the vibrational dipole moments.