MESS
Mass loss of Evolved StarS

First spectroscopic results

Leen Decin
PACS
Leuven, Belgium

Mike Barlow
SPIRE
London, UK

on behalf of the MESS consortium

UCL

KATHOLIEKE UNIVERSITEIT LEUVEN

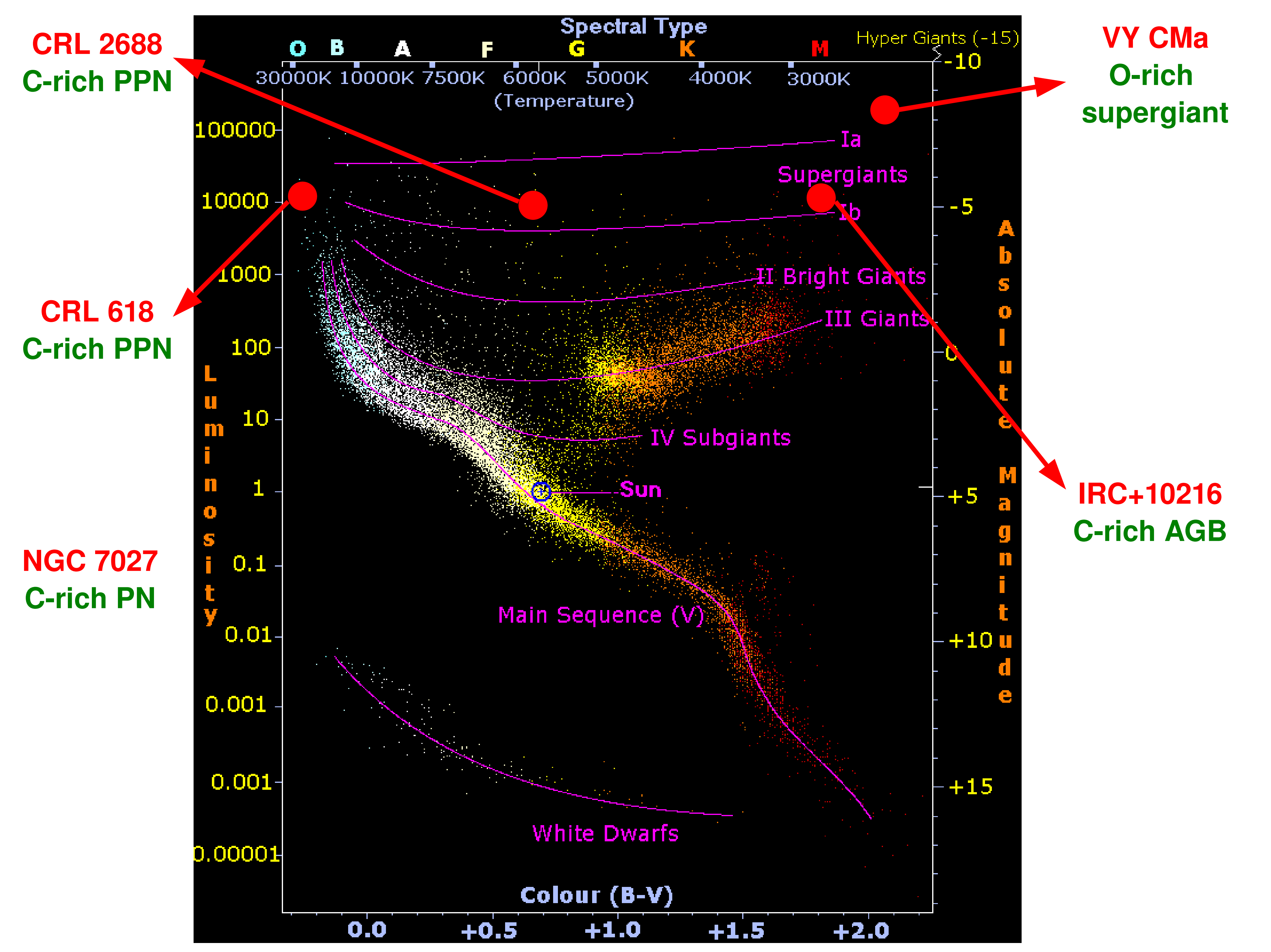
MESS
Mass loss of Evolved StarS

PACS MESS team:

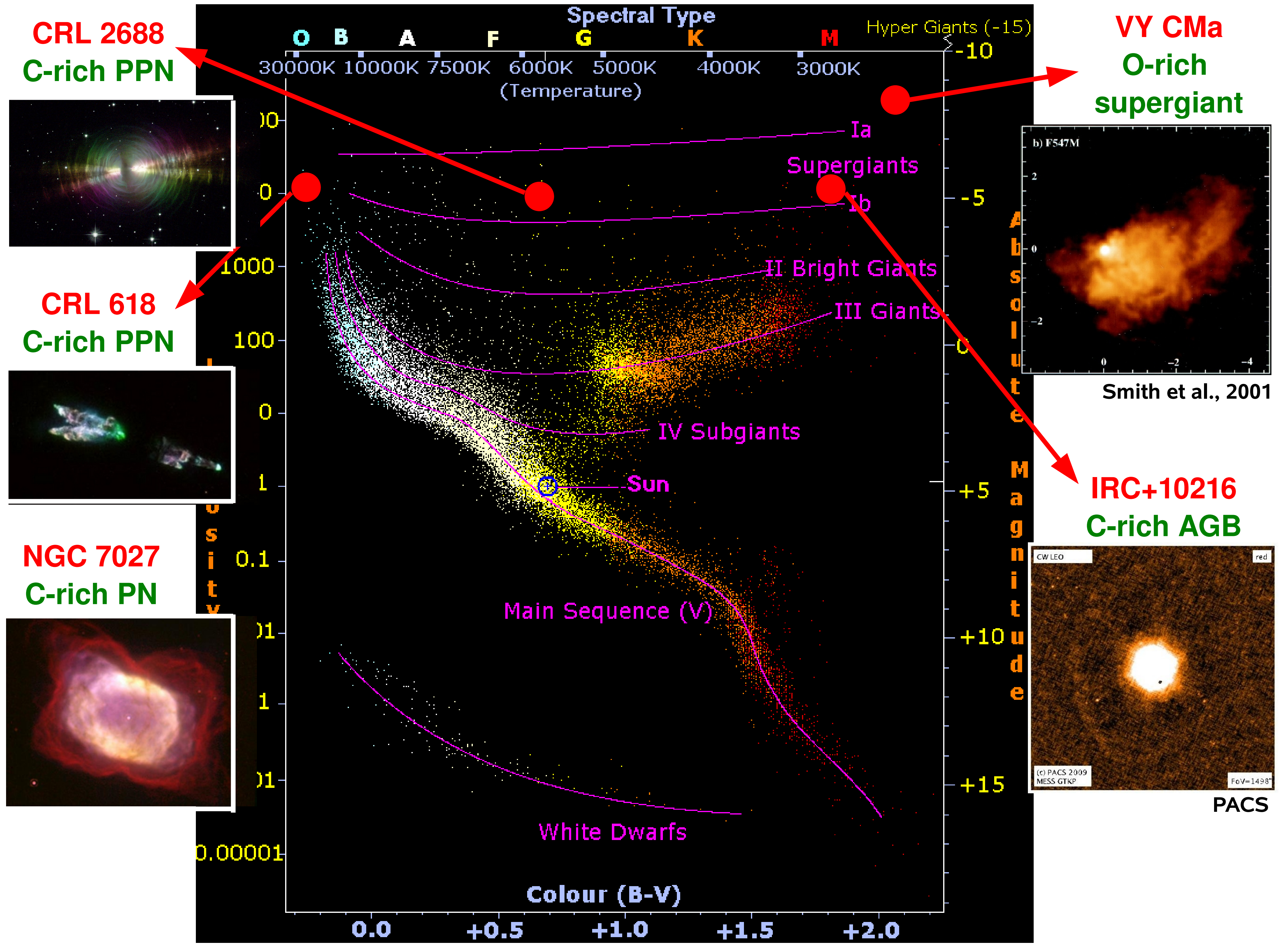
Martin Groenewegen(PI)
Christoffel Waelkens (co-PI PACS)

Pierre Royer
Bart Vandenbussche
Christophe Jean
Elvire De Beck

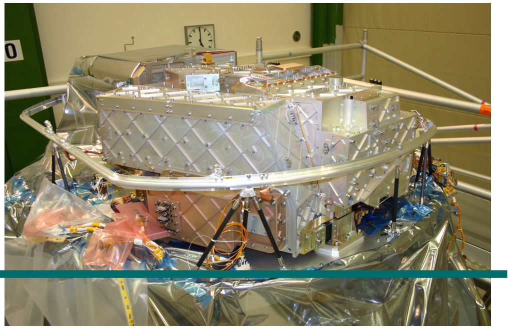
Joris Blommaert
Franz Kerschbaum
Pedro Garcia Lario
Jose Cernicharo
Djazia Ladjal
Griet van de Steene
Hans Van Winckel
Oliver Krause
Angela Baier
Jeroen Bouwman
Thomas Henning
Damien Hutsemekers
Goeran Olofsson
Thomas Posch
Gregor Rauw
Eva Verdugo



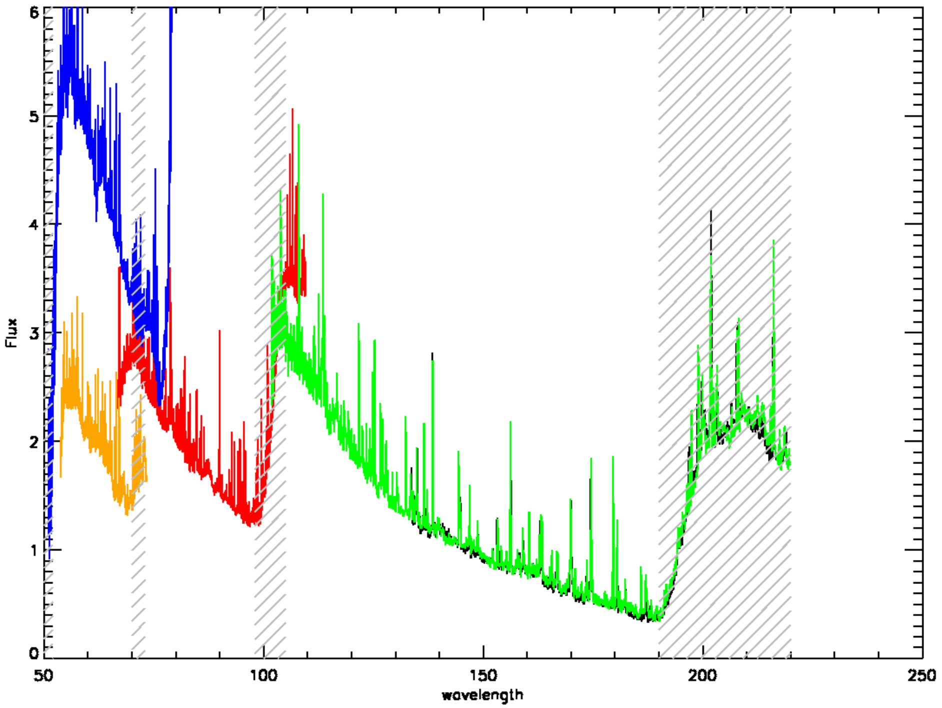
CRL 2688
C-rich PPN
CRL 618
C-rich PPN
NGC 7027
C-rich PN
VY CMa
O-rich
supergiant
IRC+10216
C-rich AGB
Spectral Type
O B A F G K M
Hyper Giants (-15)
30000K 10000K 7500K 6000K 5000K 4000K 3000K
(Temperature)
Ia
Supergiants
Ib
II Bright Giants
III Giants
IV Subgiants
Sun
Main Sequence (V)
White Dwarfs
Luminosity
100000
10000
1000
100
10
1
0.1
0.01
0.001
0.001
0.00001
Absolute Magnitude
-10
-5
0
+5
+10
+15
Colour (B-V)
0.0 +0.5 +1.0 +1.5 +2.0


CRL 2688
C-rich PPN
CRL 618
C-rich PPN
NGC 7027
C-rich PN
Spectral Type
O B A F G K M
Hyper Giants (-15)
30000K 10000K 7500K 6000K 5000K 4000K 3000K
(Temperature)
Ia
Supergiants
Ib
II Bright Giants
III Giants
IV Subgiants
Sun
Main Sequence (V)
White Dwarfs
1000
100
0
1
0.1
0.00001
-10
-5
0
+5
+10
+15
Absolute Magnitude
Colour (B-V)
0.0 +0.5 +1.0 +1.5 +2.0
VY CMa
O-rich
supergiant
b) F547M
Smith et al., 2001
IRC+10216
C-rich AGB
CW LEO
red
(c) PACS 2009
MESS GTKP
PACS

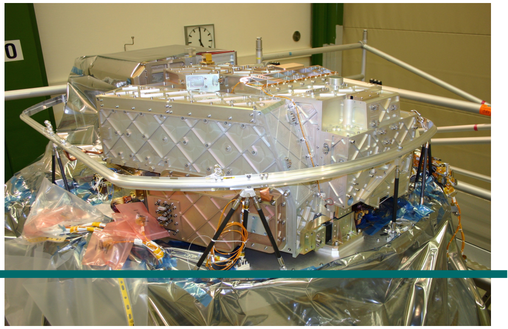
PACS observations

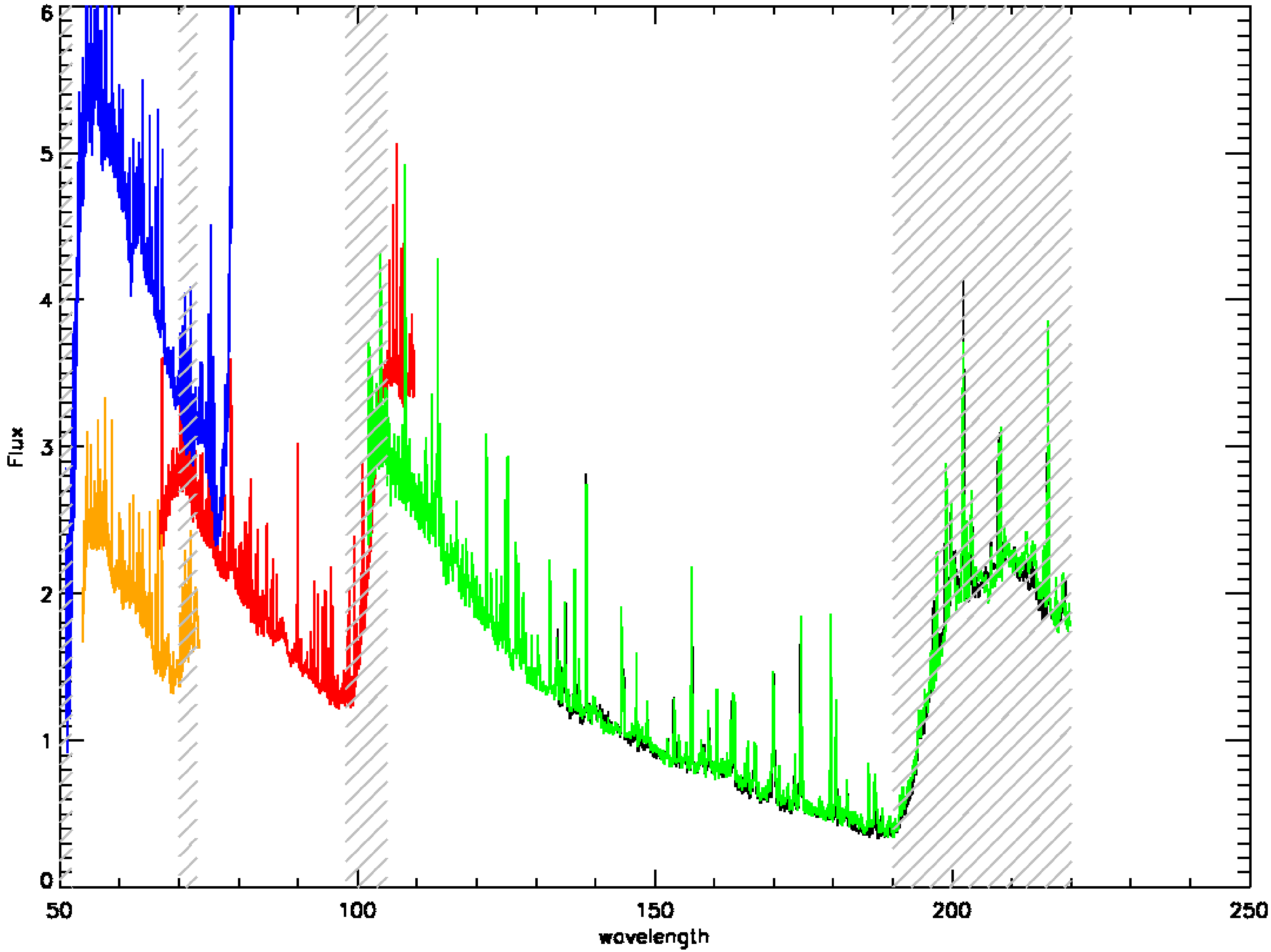


* SED mode, including high-resolution B3A (51-70 µm)
  ⟶ 1h30 / full spectrum
* `standard' processing (cfr. Demo at DP workshop)
* only central spaxel displayed
* continuum divided / subtracted
* caveats due to light leaks of each spectral order (see talk A. Poglitsch)

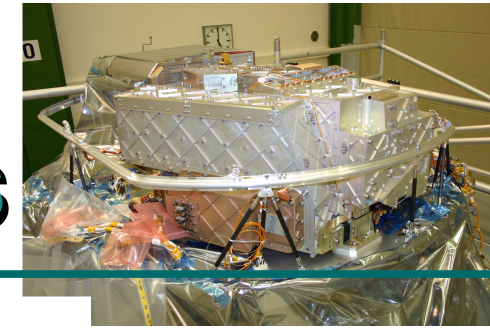


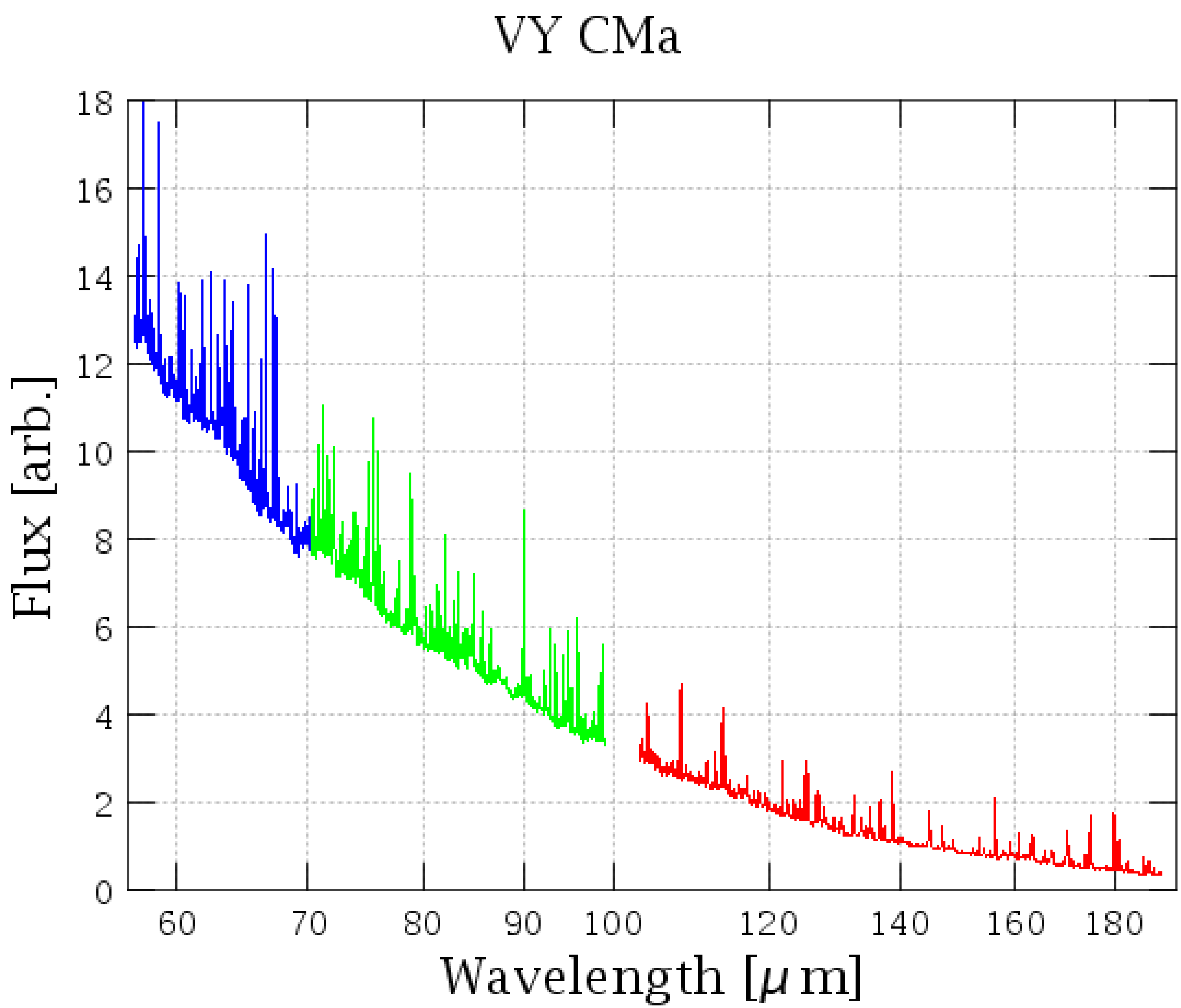
PACS observations

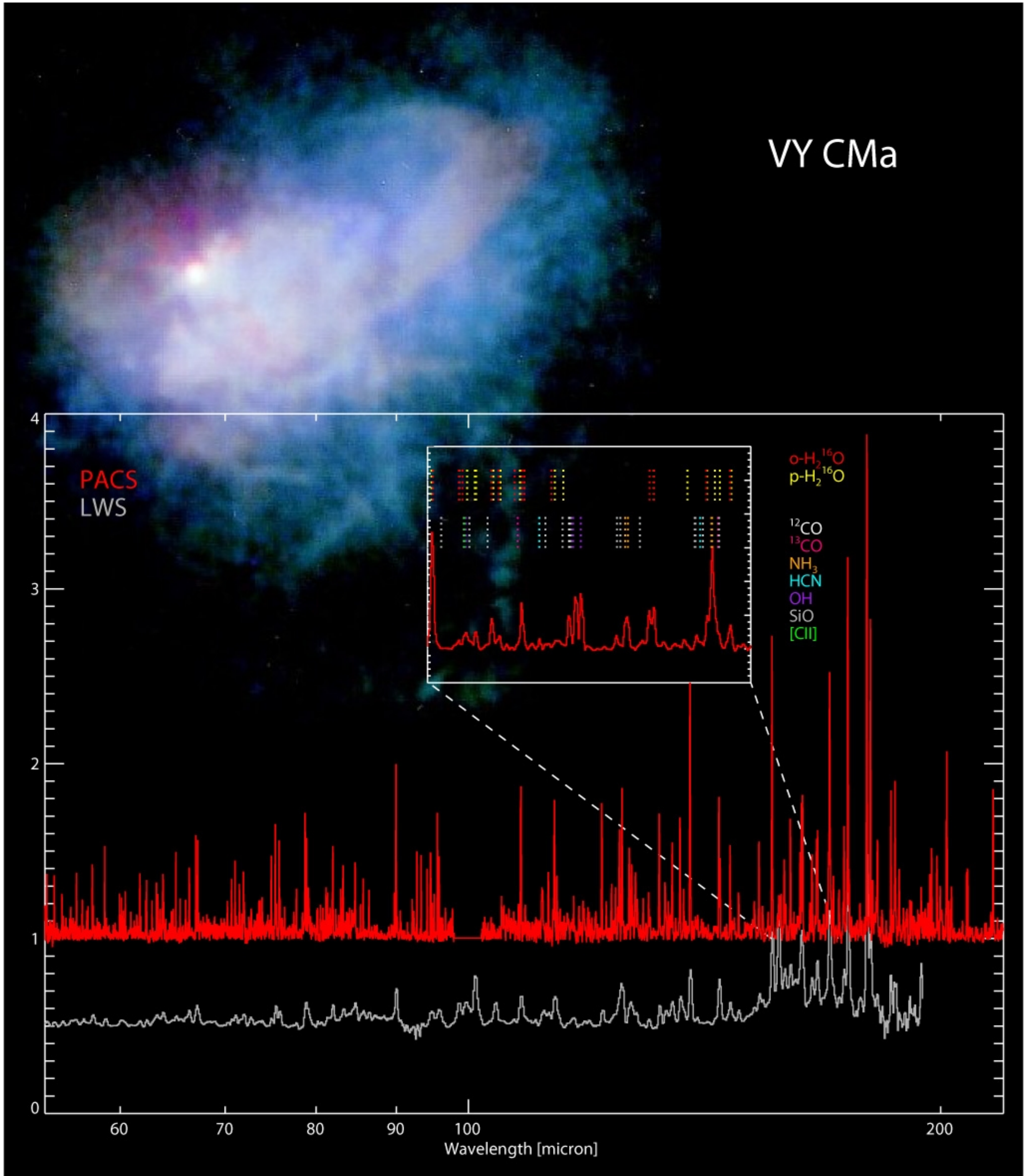




PACS observations





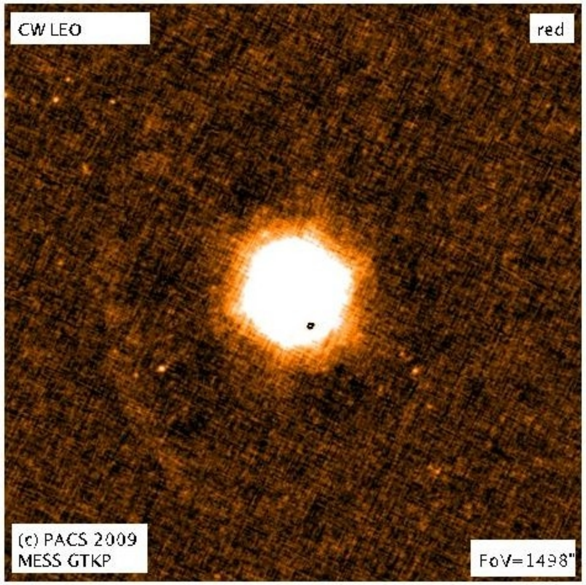


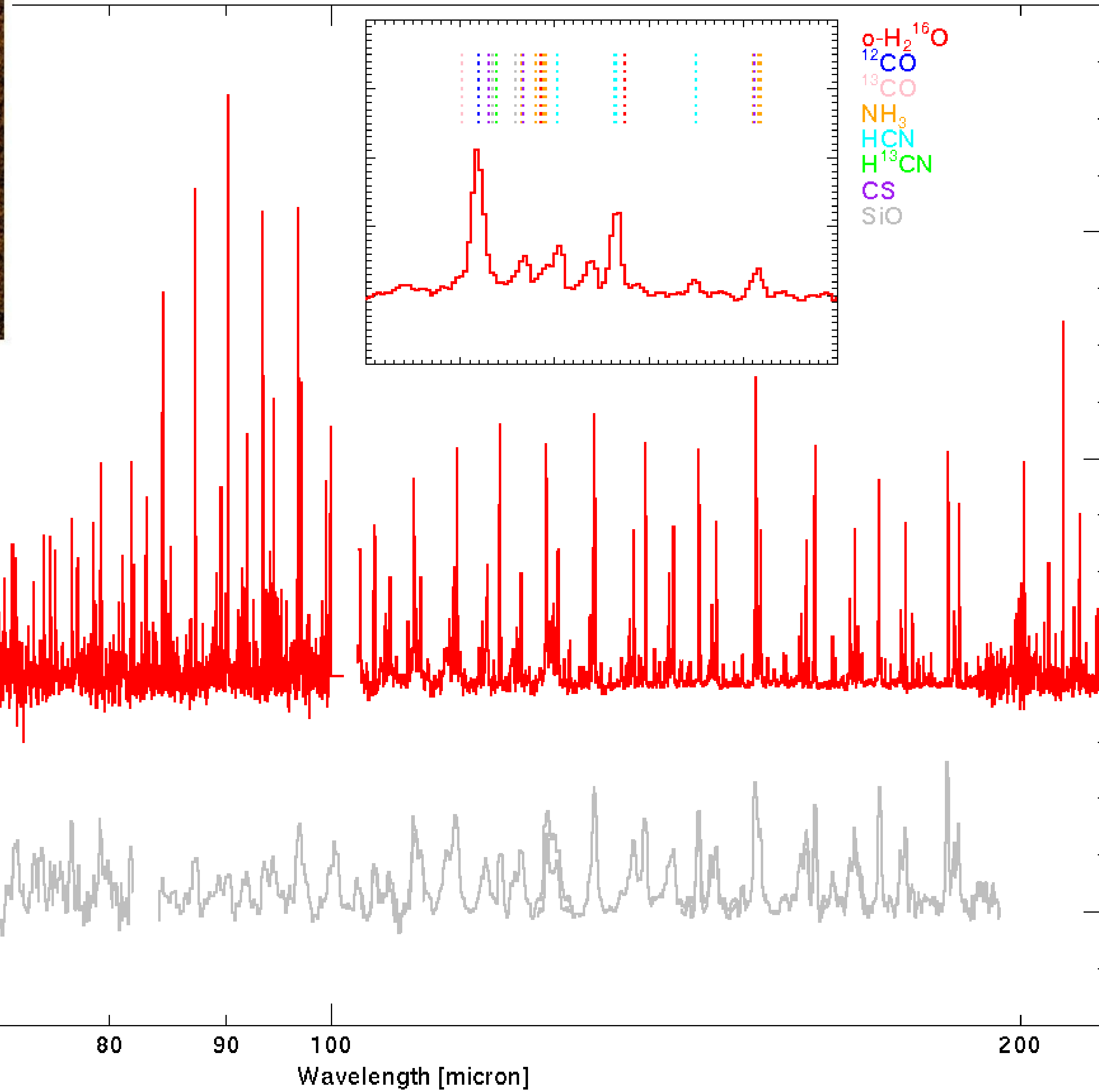
ESA-PR
27/11/2009

Spectral movie VY CMa

IRC+10216

Spectral movie IRC+10216



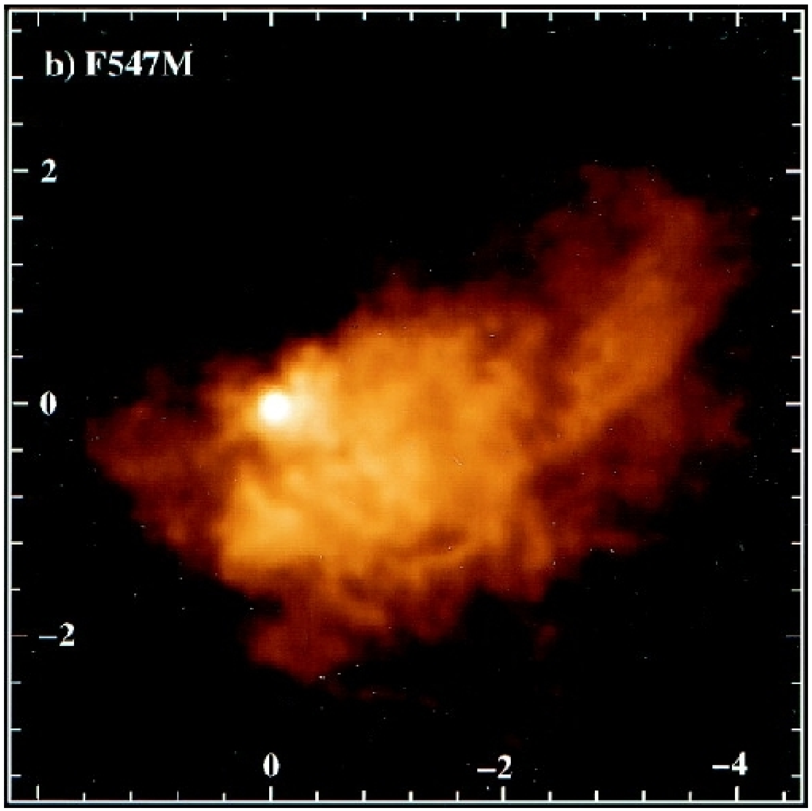


First spectroscopic results

Molecular inventory

VY CMa	IRC+10216
TOTAL: ~250 unblended	TOTAL: ~250 unblended
o-H_2O } 2/3 of all lines	$H^{12}CN$ } 1/2 of all lines
p-H_2O } 2/3 of all lines	$H^{13}CN$ } 1/2 of all lines
^{12}CO	^{12}CO
^{13}CO	^{13}CO
NH_3	o-H_2O
OH	p-H_2O?
SiO	NH_3
HCN	SiS
[C II]	SiO
[O I]	CS
+ unidentified lines	+ unidentified lines

First modeling results of VY CMa



1D-non-LTE modeling

$T_* = 2800K$

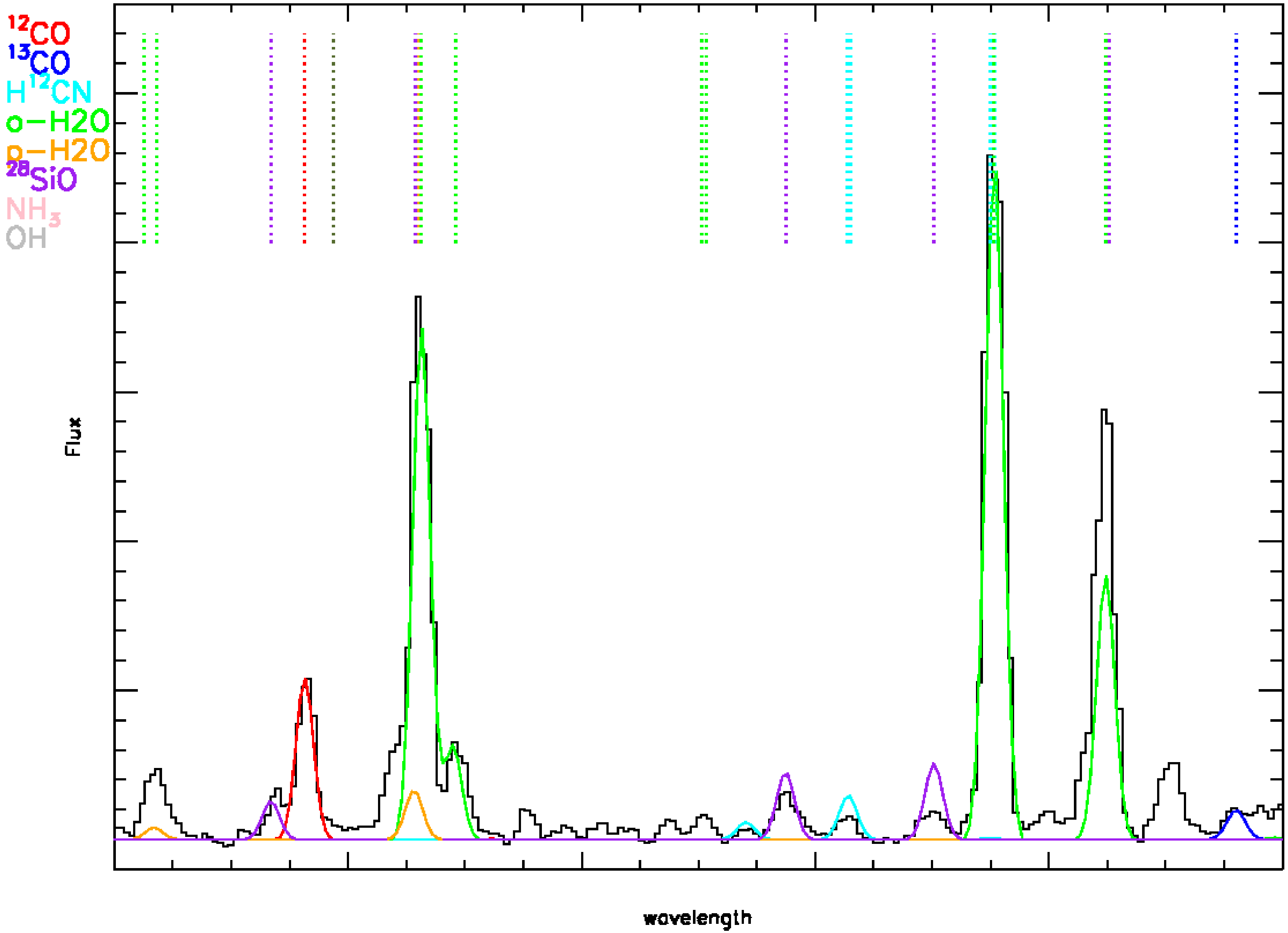
$M_* = 15\ M_{sun}$

$L_* = 3 \cdot 10^5\ L_{sun}$

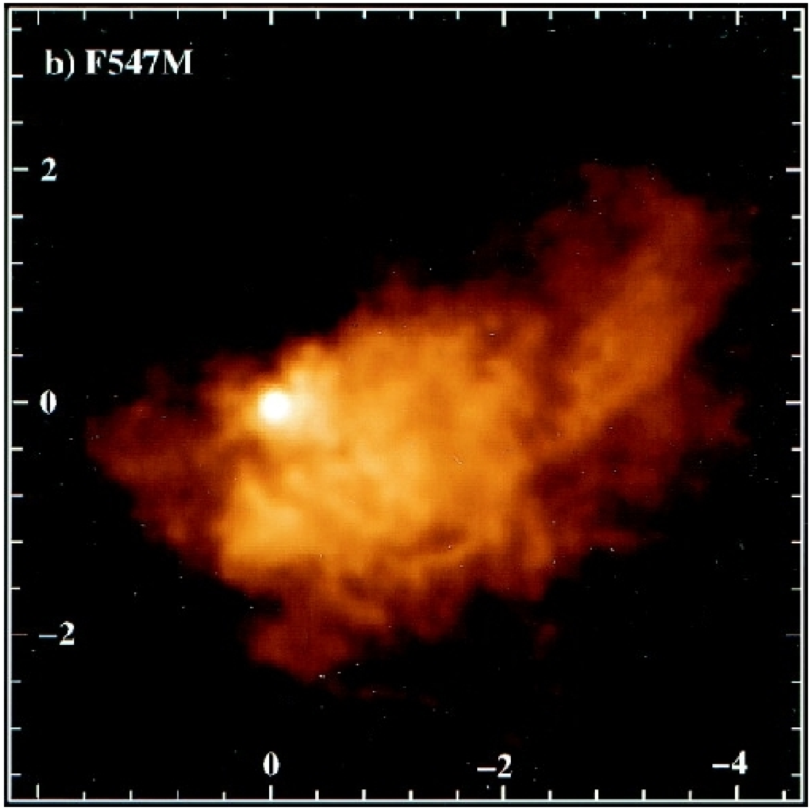
$D = 1140$ pc

$[CO/H_2] = 3 \cdot 10^{-4}$

First modeling results of VY CMa



First modeling results of VY CMa



1D-non-LTE modeling

$T_* = 2800K$

$M_* = 15\ M_{sun}$

$L_* = 3 \cdot 10^5\ L_{sun}$

$D = 1140\ pc$

$[CO/H_2] = 3 \cdot 10^{-4}$

$\dot{M} = 1.5 \cdot 10^{-4}\ M_{sun}/yr$

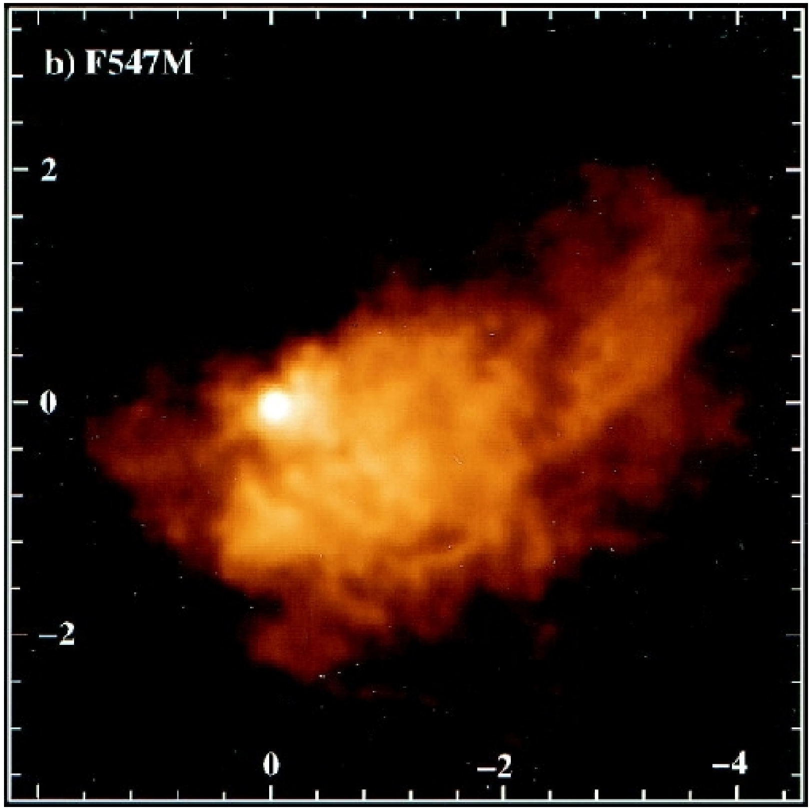
$^{12}C/^{13}C = 60$

$[SiO/H_2] = 2 \cdot 10^{-4}$

$[H_2O/H_2] \approx 9 \cdot 10^{-4}$

$[HCN/H_2] = 3 \cdot 10^{-6}$

First modeling results of VY CMa



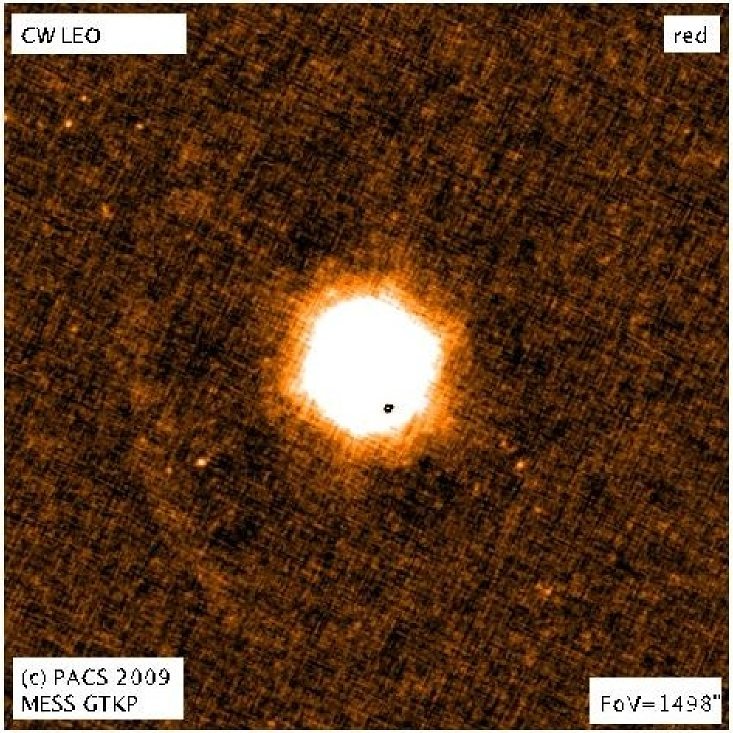
1D-non-LTE modeling

$T_* = 2800K$
$M_* = 15\ M_{sun}$
$L_* = 3 \cdot 10^5\ L_{sun}$
$D = 1140\ pc$
$[CO/H_2] = 3 \cdot 10^{-4}$

$\dot{M} = 1.5 \cdot 10^{-4}\ M_{sun}/yr$
$^{12}C/^{13}C = 60$
$[SiO/H_2] = 2 \cdot 10^{-4}$
$[H_2O/H_2] \approx 9 \cdot 10^{-4}$
$[HCN/H_2] = 3 \cdot 10^{-6}$

non-equilibrium chemistry

First modeling results of IRC+10216



→

1D-non-LTE modeling

$T_* = 2050K$

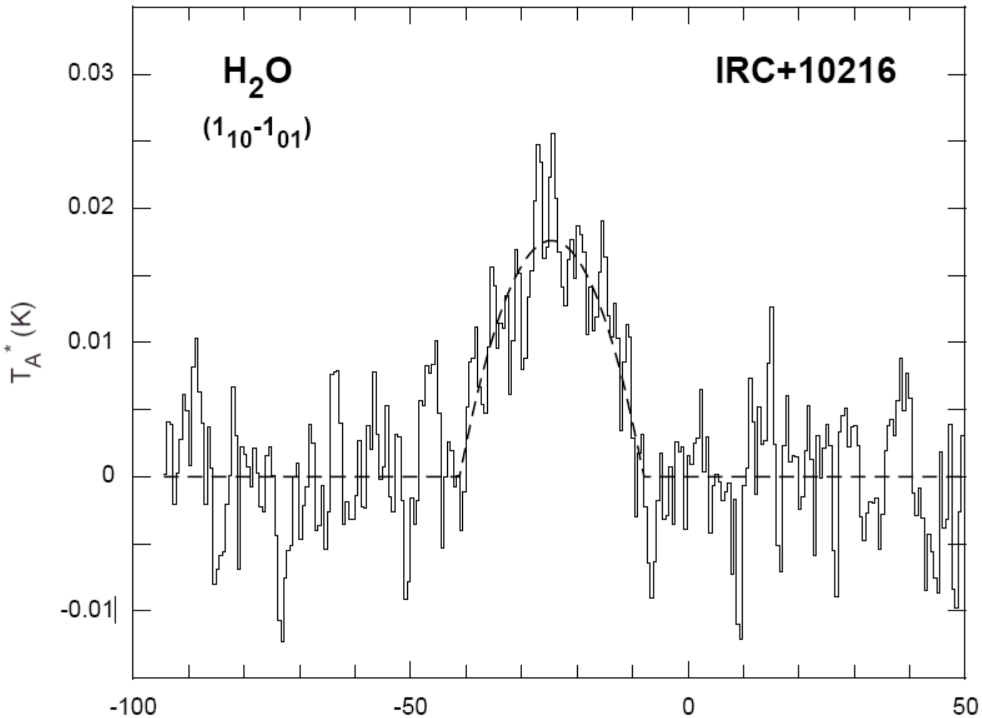
$M_* = 1\ M_{sun}$

$L_* = 1 \cdot 10^4\ L_{sun}$

$D = 125\ pc$

$[CO/H_2] = 1 \cdot 10^{-3}$

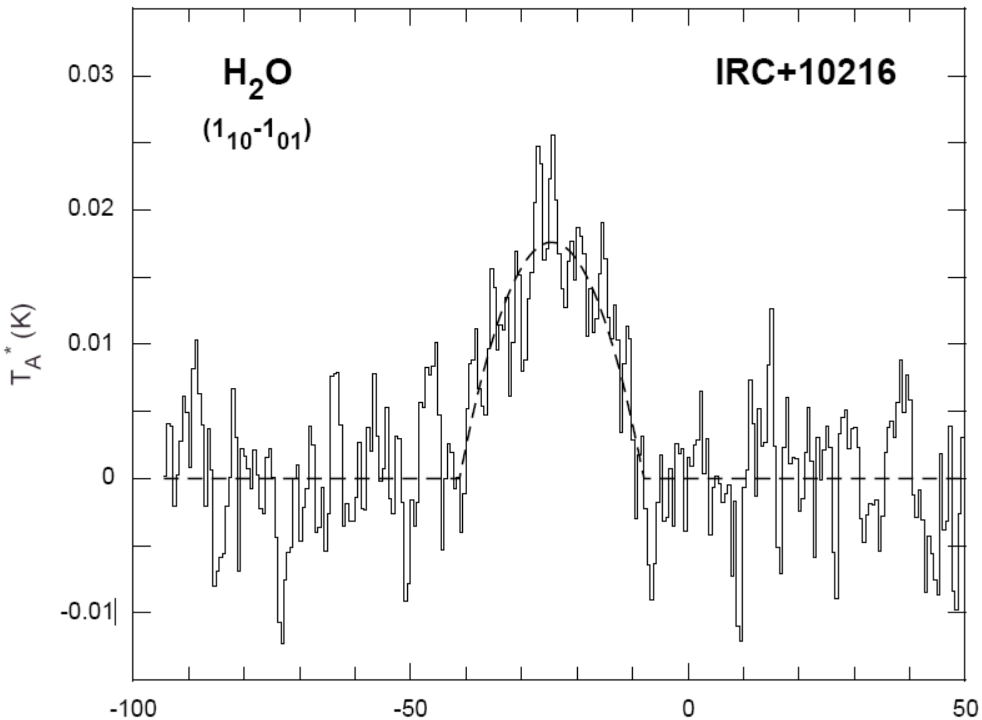
First modeling results of IRC+10216



SWAS: Melnick et al. 2001, Nature

vaporizing orbiting icy bodies

First modeling results of IRC+10216



SWAS: Melnick et al. 2001, Nature

↓

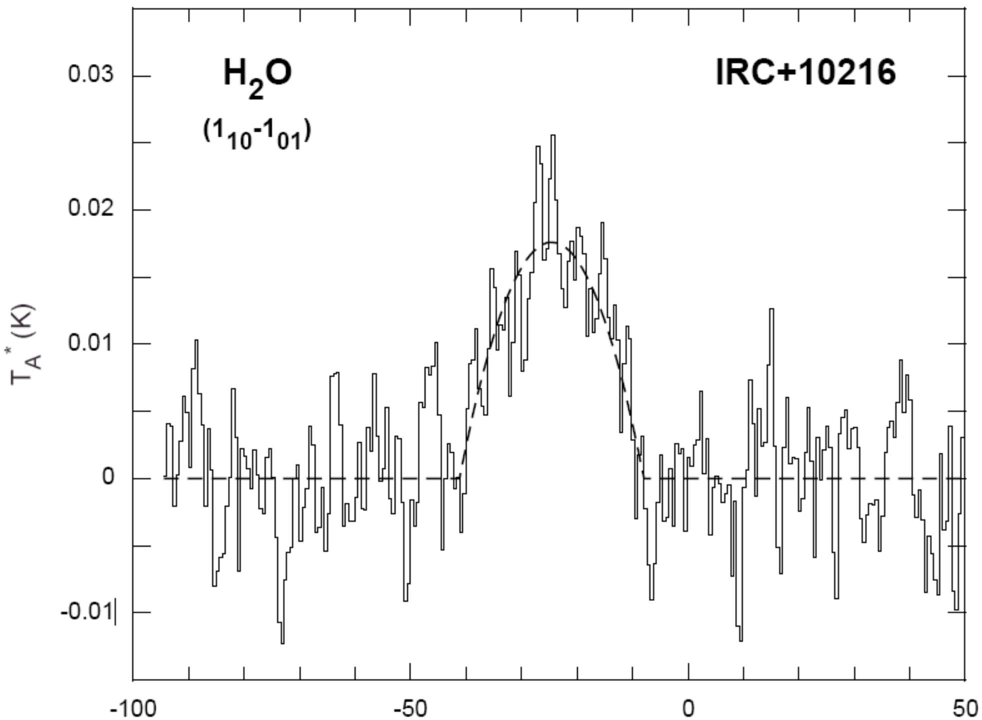
vaporizing orbiting icy bodies

Agundez et al. 2006
Gonzales-Alfonso et al. 2007

↓

non-equilibrium chemistry
Fischer-Tropsch catalysis on metallic grains
photodissociation+radiative association

First modeling results of IRC+10216

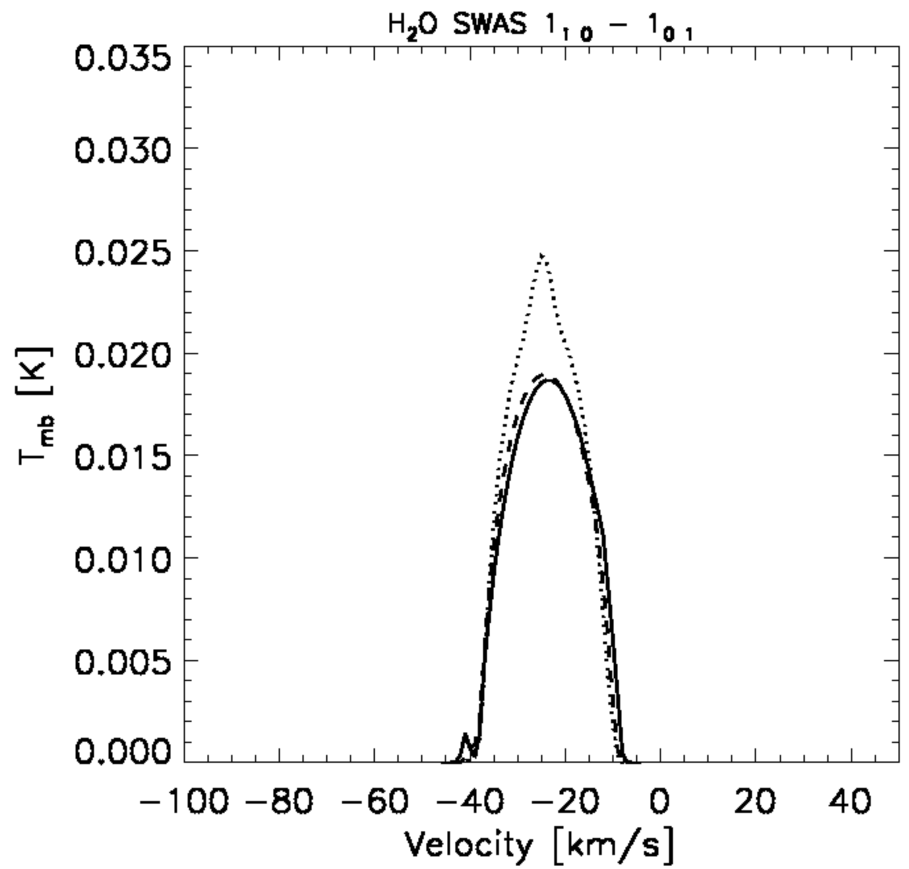


SWAS: Melnick et al. 2001, Nature

vaporizing orbiting icy bodies

Agundez et al. 2006
Gonzales-Alfonso et al. 2007

non-equilibrium chemistry
Fischer-Tropsch catalysis on metallic grains
photodissociation+radiative association

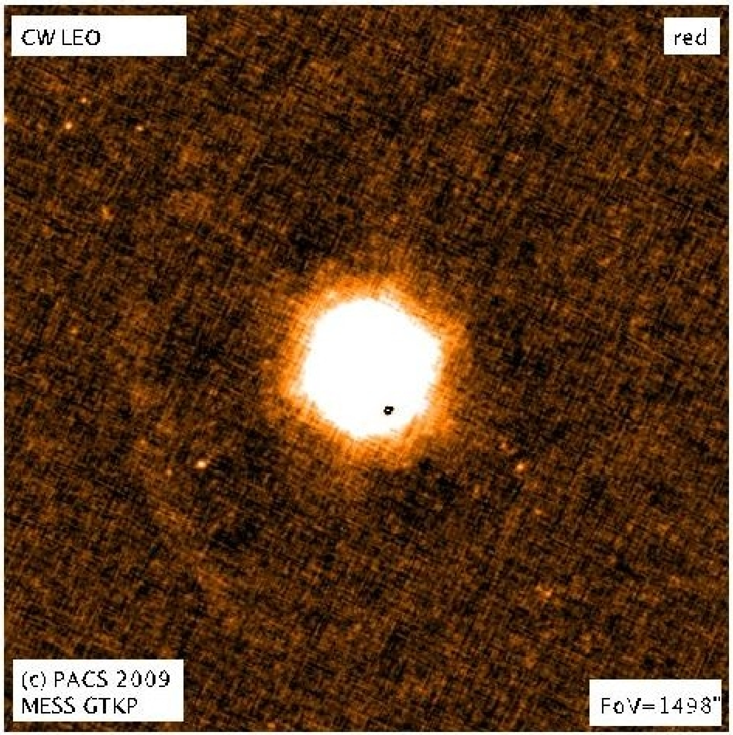


`comet'

non-equilibrium chemistry

photodiss. + rad. assoc. (outer envelope)

First modeling results of IRC+10216



1D-non-LTE modeling

$T_* = 2050K$

$M_* = 1\ M_{sun}$

$L_* = 1 \cdot 10^4\ L_{sun}$

$D = 125$ pc

$[CO/H_2] = 1 \cdot 10^{-3}$

$\dot{M} = 3 \cdot 10^{-5}\ M_{sun}/yr$

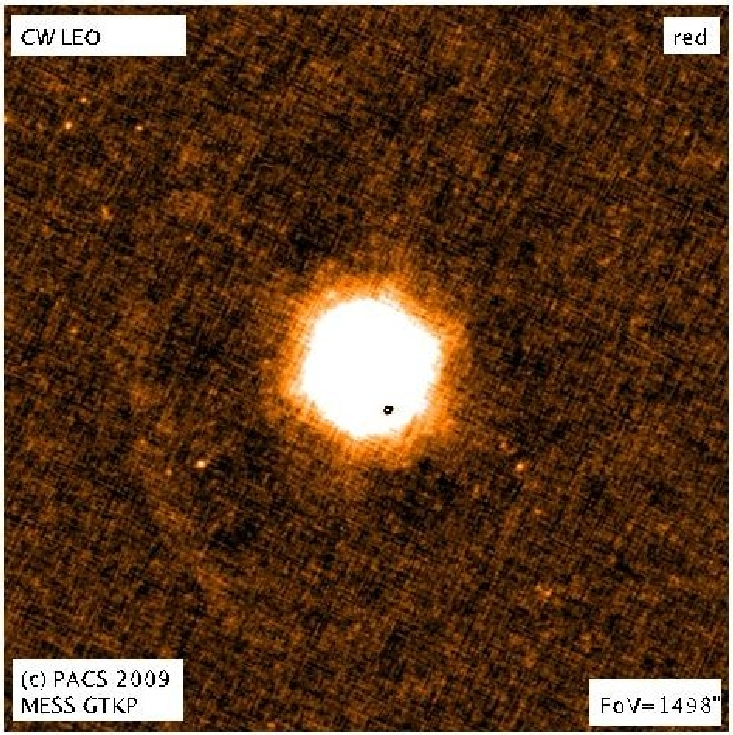
$^{12}C/^{13}C = 50$

$[H_2O/H_2] = 4.1\ 10^{-8}$ from $4.5\ 10^{14}$cm onward ← non-equilibrium chemistry

$[H_2O/H_2] = 5.4\ 10^{-8}$ from $2.1\ 10^{15}$cm onward ← (comet hypothesis and Fischer-Tropsch)

$[H_2O/H_2] = 1.5\ 10^{-6}$ from $4.3\ 10^{16}$cm onward ← (photodissociation + radiative association)

First modeling results of IRC+10216



1D-non-LTE modeling

$T_* = 2050K$

$M_* = 1\ M_{sun}$

$L_* = 1 \cdot 10^4\ L_{sun}$

D = 125 pc

$[CO/H_2] = 1 \cdot 10^{-3}$

$\dot{M} = 3 \cdot 10^{-5}\ M_{sun}/yr$

$^{12}C/^{13}C = 50$

non-equilibrium chemistry ← $[H_2O/H_2]$ = 4.1 10^{-8} from 4.5 10^{14}cm onward

(comet hypothesis and Fischer-Tropsch) ← $[H_2O/H_2]$ = 5.4 10^{-8} from 2.1 10^{15}cm onward

(photodissociation + radiative association) ← $[H_2O/H_2]$ = 1.5 10^{-6} from 4.3 10^{16}cm onward

+ SPIRE AND HIFI

SPIRE FTS Spectra of MESS Evolved Objects

M. Barlow, UCL
On behalf of the MESS Consortium, SPIRE SAG6
and the SPIRE FTS team

FTS Team:
P. Imhof, T. Fulton, E. Polehampton, B. Swinyard, D. Naylor, J-P. Baluteau, K. Isaak, L. Spencer, S. Jones, D. Benielli, R. Wesson, A. Rykala, G. Savini, C. Surace, S. Leeks, C. Wilson, D. Rigopoulou, N. Rangwala, T. Lim, G. Makiwa, M. Griffin, P. Panuzzo, P. Ade

+SAG6 members and consultants:
B. Sibthorpe, G. Olofsson, H. Gomez, H. Walker, L. Dunne, M. Cohen, P. Hargrave, R. Ivison, W. Gear, J. Yates, M. Matsuura, J. Cernicharo, D. Witherick

GOAL: To help characterise molecular and dust properties in the 200-670µm region, via the acquisition of high S/N FTS spectra of evolved objects of known chemistry (C/O ratio). The results could also aid the interpretation of the spectra of ISM and extragalactic sources.

Five luminous evolved MESS targets observed so far with the SPIRE FTS during a hybrid PV/SD phase:

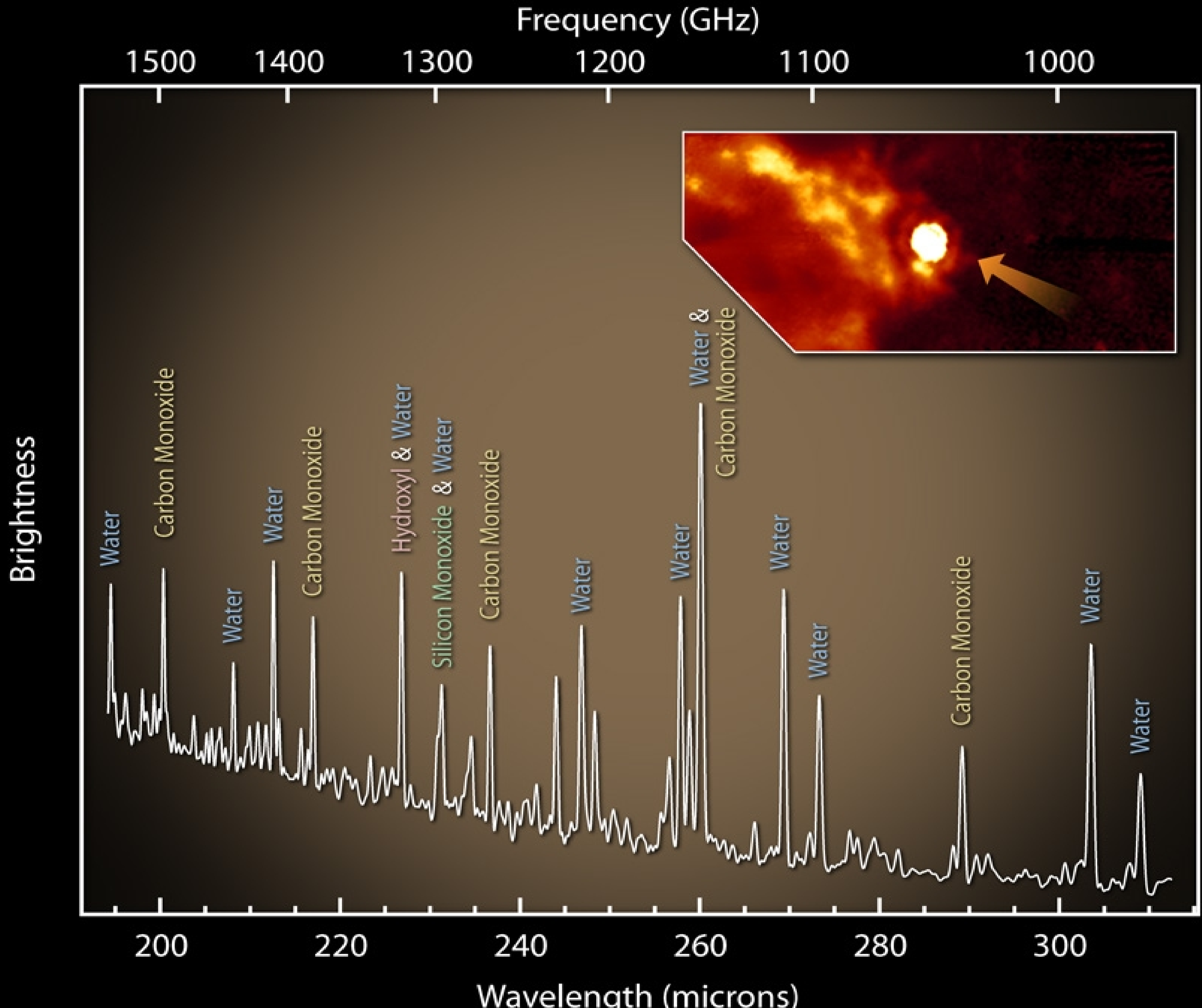
VY CMa: O-rich self-obscured M supergiant (Teff~2800 K)

IRC+10216 (CW Leo): self-obscured carbon star

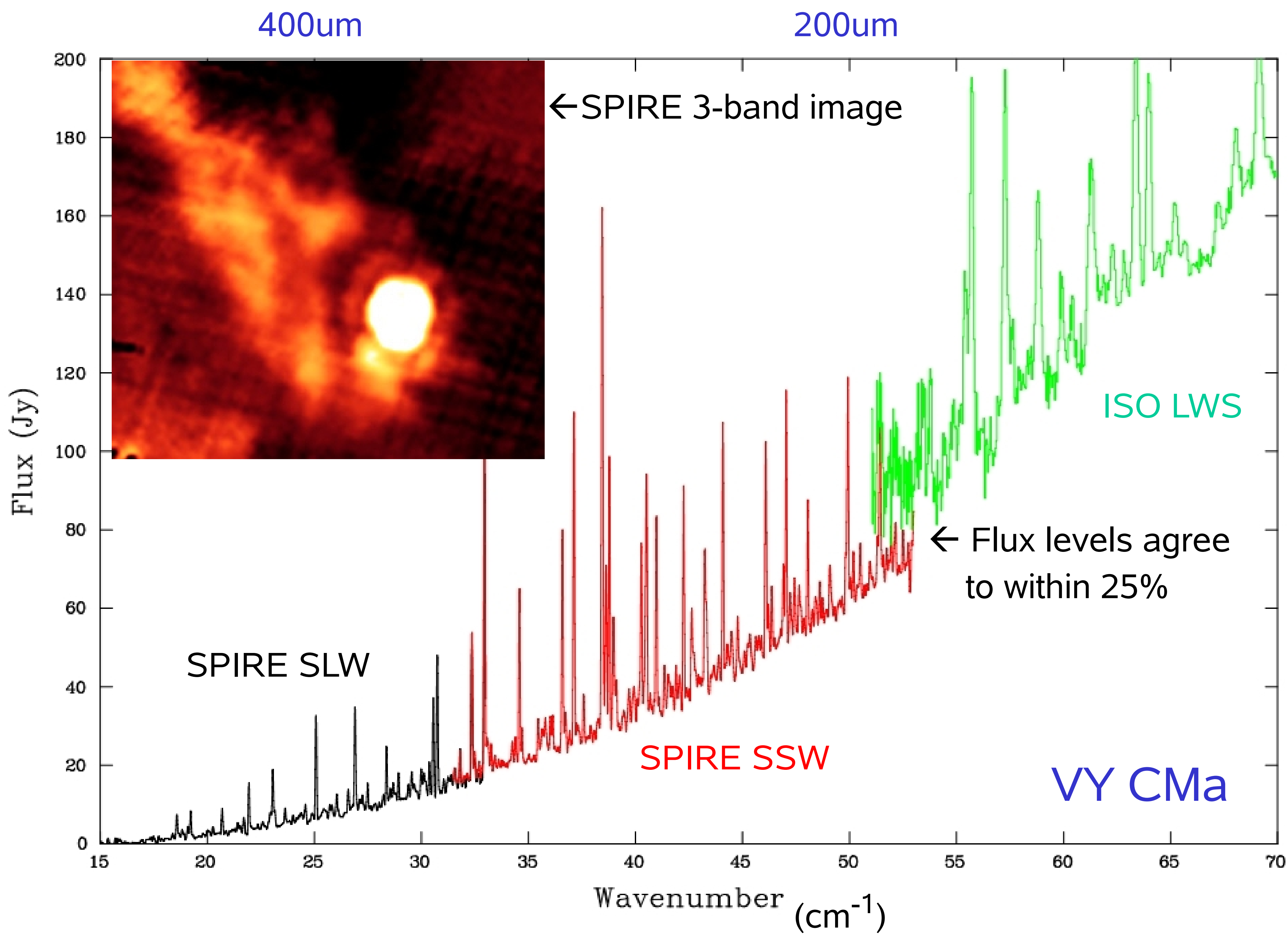
AFGL 2688: C-rich bipolar post-AGB object (A/F-type star)

AFGL 618: C-rich bipolar post-AGB object (early B-type star)

NGC 7027: C-rich planetary nebula (150,000 K central star)

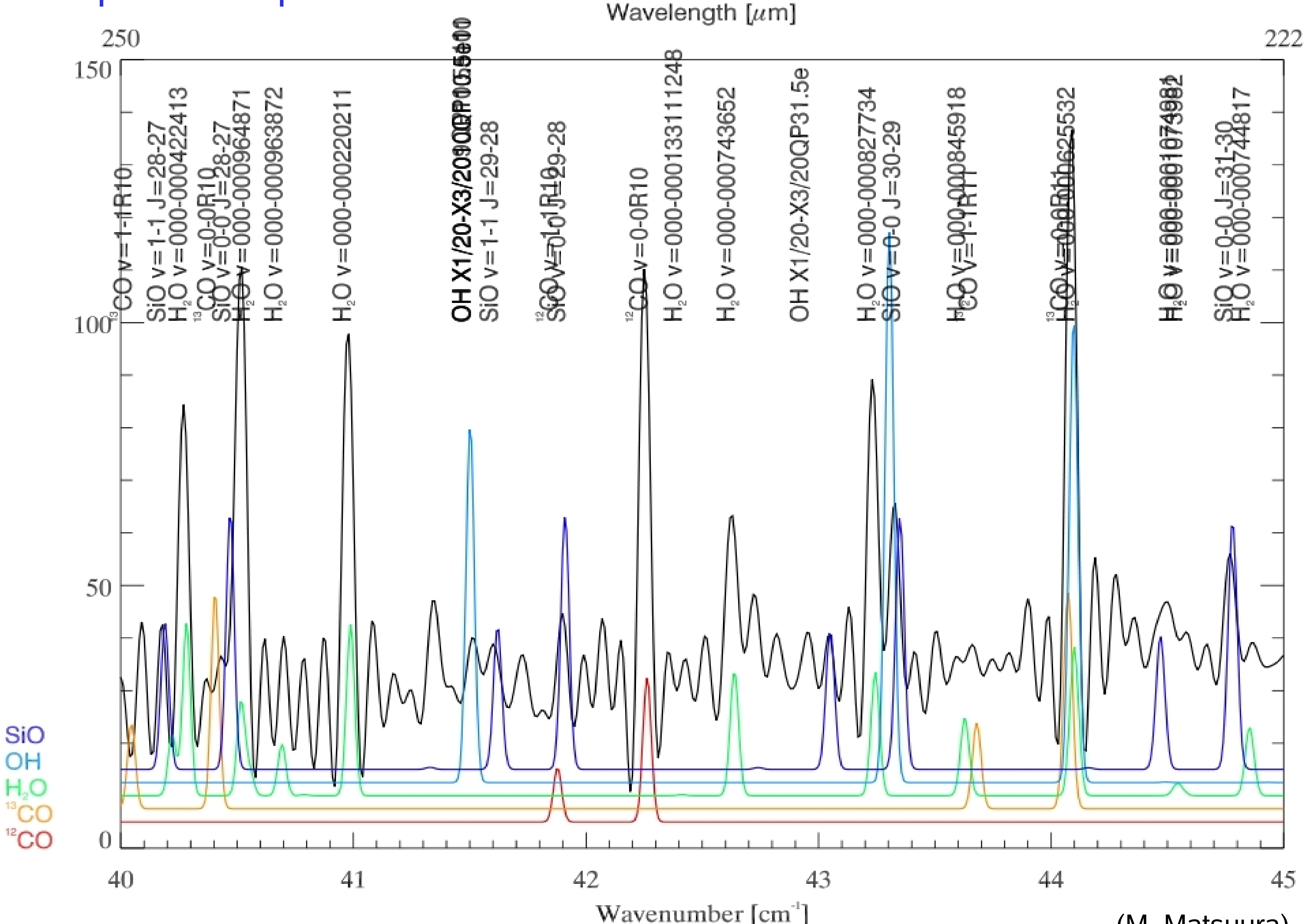


VY Canis Majoris

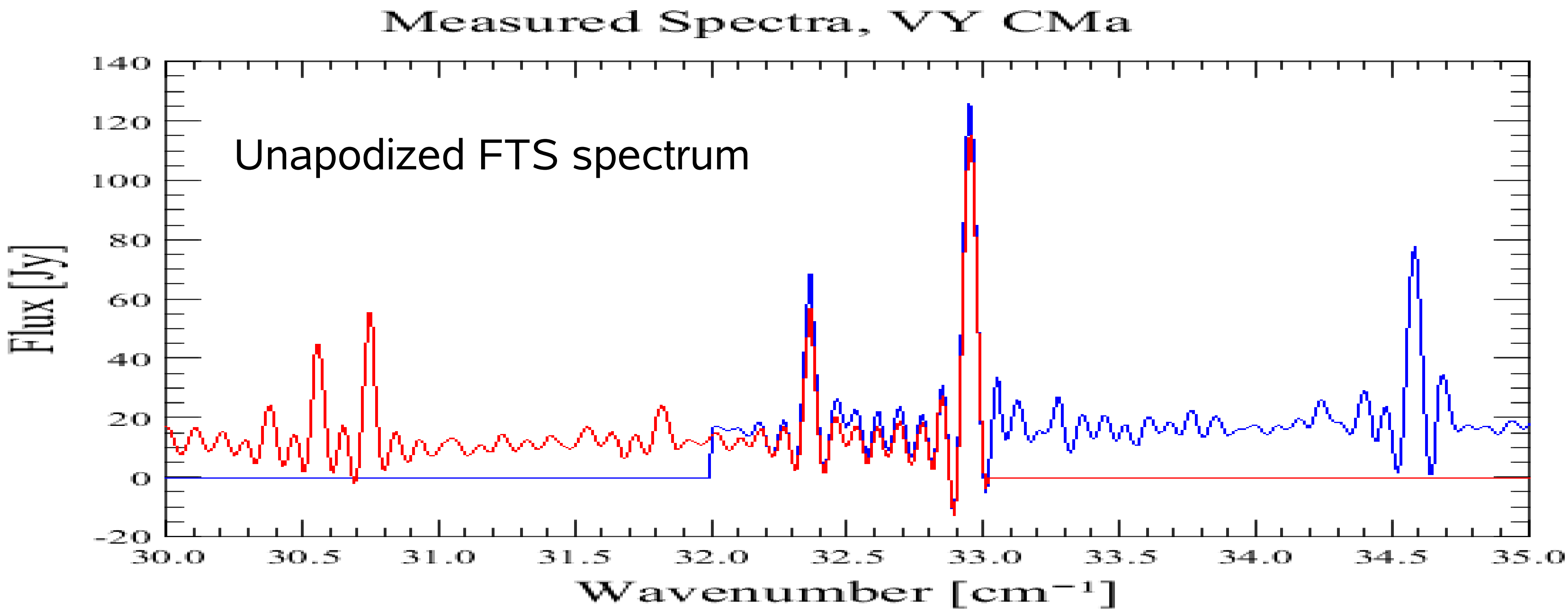

400um
200um
←SPIRE 3-band image
← Flux levels agree to within 25%
ISO LWS
SPIRE SLW
SPIRE SSW
VY CMa
Flux (Jy)
Wavenumber (cm-1)
0
20
40
60
80
100
120
140
160
180
200
15
20
25
30
35
40
45
50
55
60
65
70

Unapodized spectrum

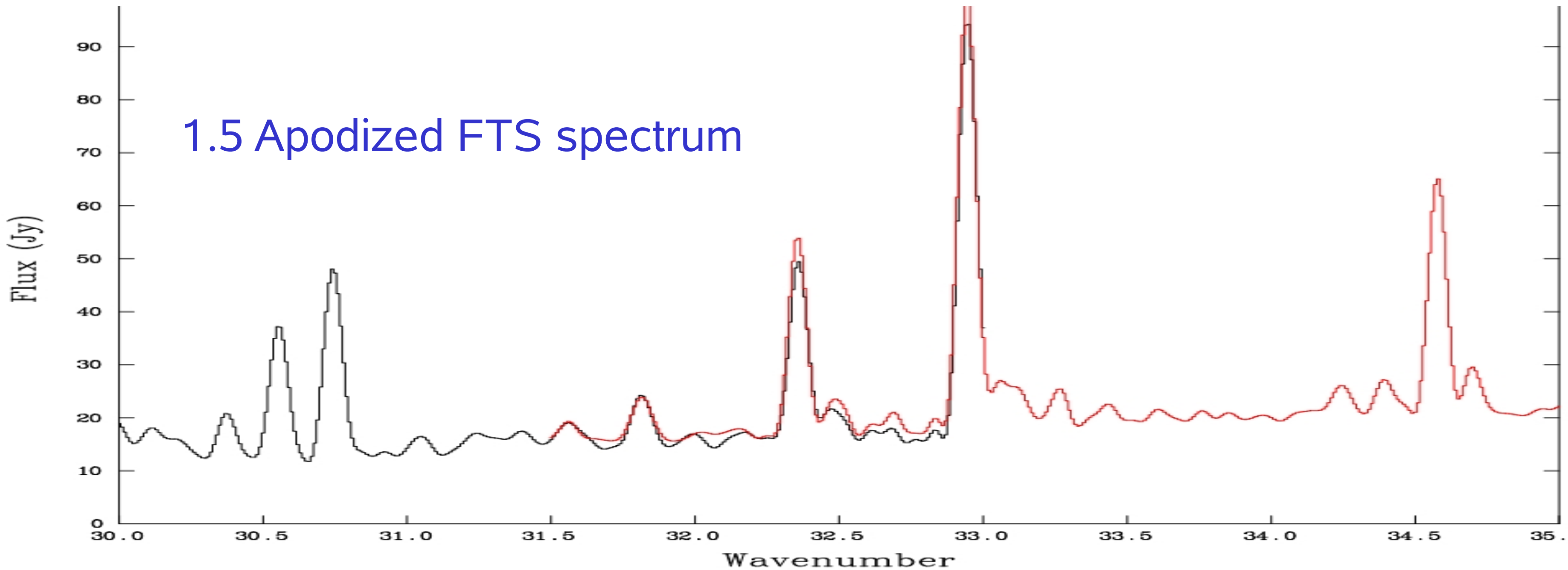
VY CMa



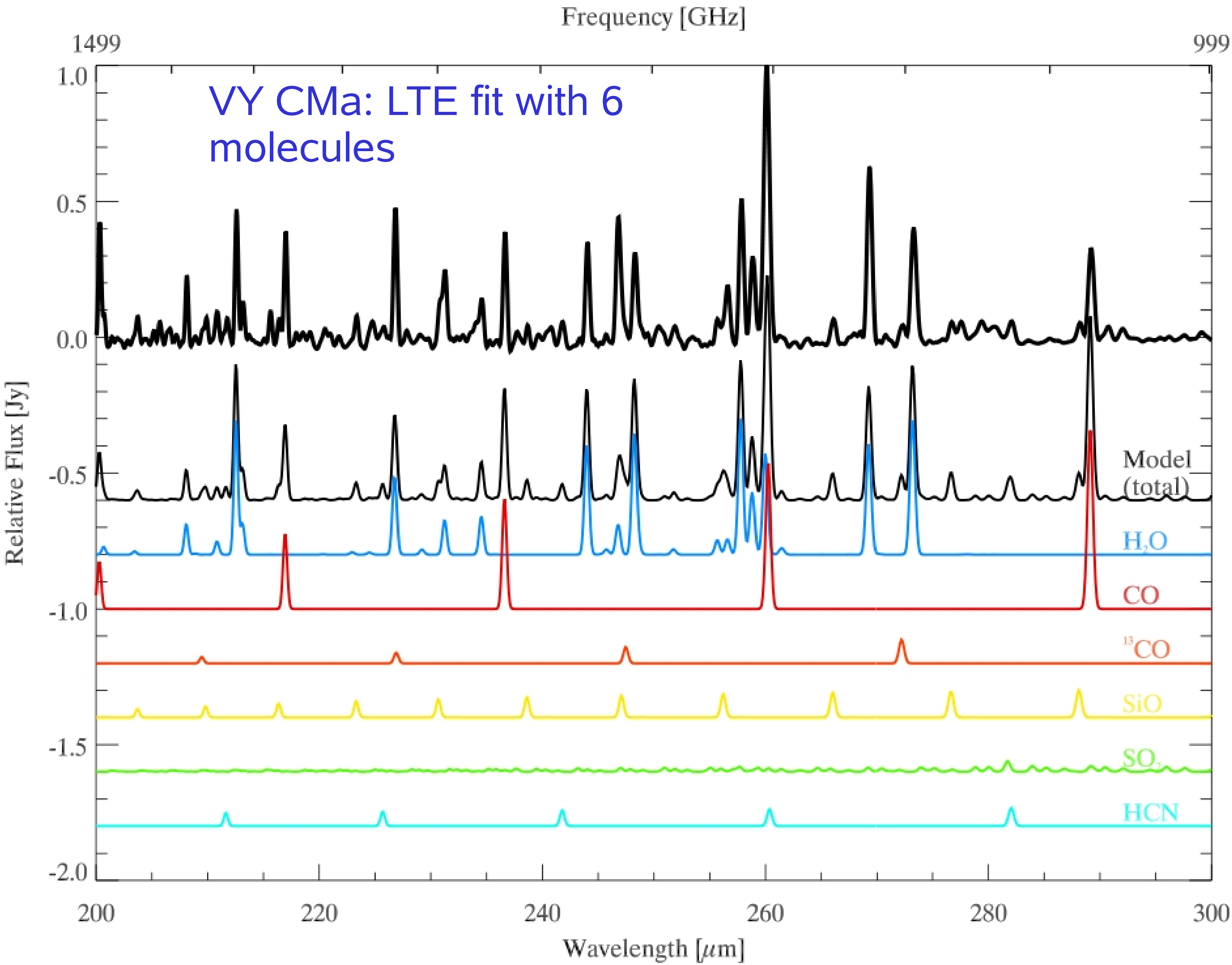
(M. Matsuura)

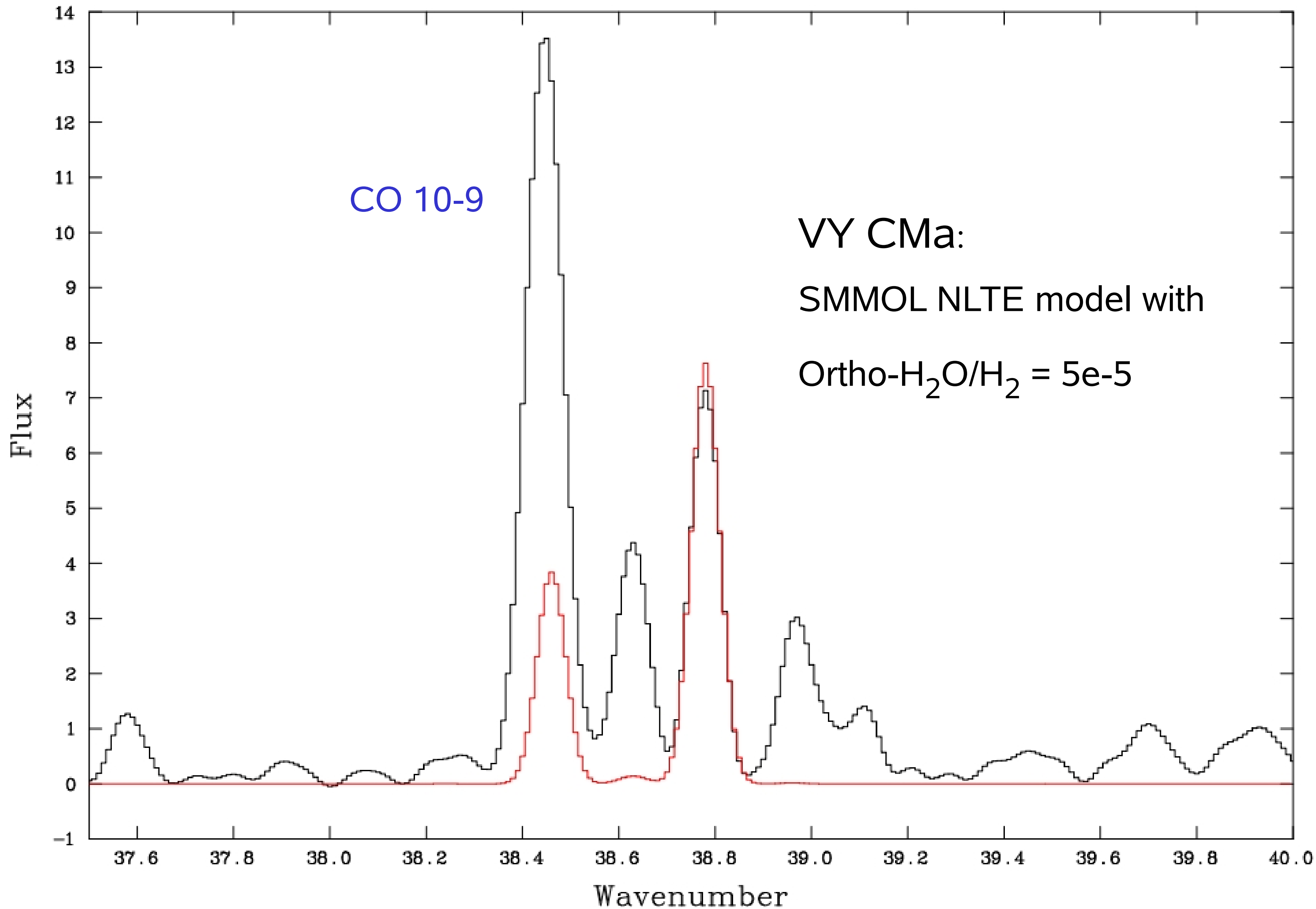


Measured Spectra, VY CMa
Unapodized FTS spectrum
Flux [Jy]
140
120
100
80
60
40
20
0
-20
30.0 30.5 31.0 31.5 32.0 32.5 33.0 33.5 34.0 34.5 35.0
Wavenumber [cm⁻¹]



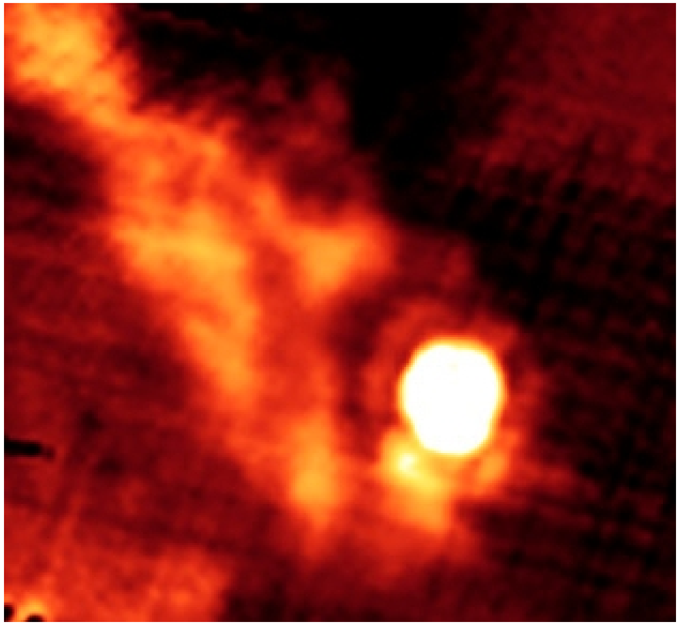
1.5 Apodized FTS spectrum
Flux (Jy)
90
80
70
60
50
40
30
20
10
0
30.0 30.5 31.0 31.5 32.0 32.5 33.0 33.5 34.0 34.5 35.0
Wavenumber


VY CMa: LTE fit with 6 molecules
Frequency [GHz]
1499
999
Relative Flux [Jy]
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
Model (total)
H2O
CO
13CO
SiO
SO2
HCN
200
220
240
260
280
300
Wavelength [μm]


CO 10-9
VY CMa:
SMMOL NLTE model with
Ortho-H_2O/H_2 = 5e-5
Flux
Wavenumber
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
−1
37.6
37.8
38.0
38.2
38.4
38.6
38.8
39.0
39.2
39.4
39.6
39.8
40.0

VY CMa: species detected in the SPIRE FTS range:

(~230 emission lines from 14.6 – 52 cm^{-1}; 192-685μm)



o-H_2O

p-H_2O

^{12}CO

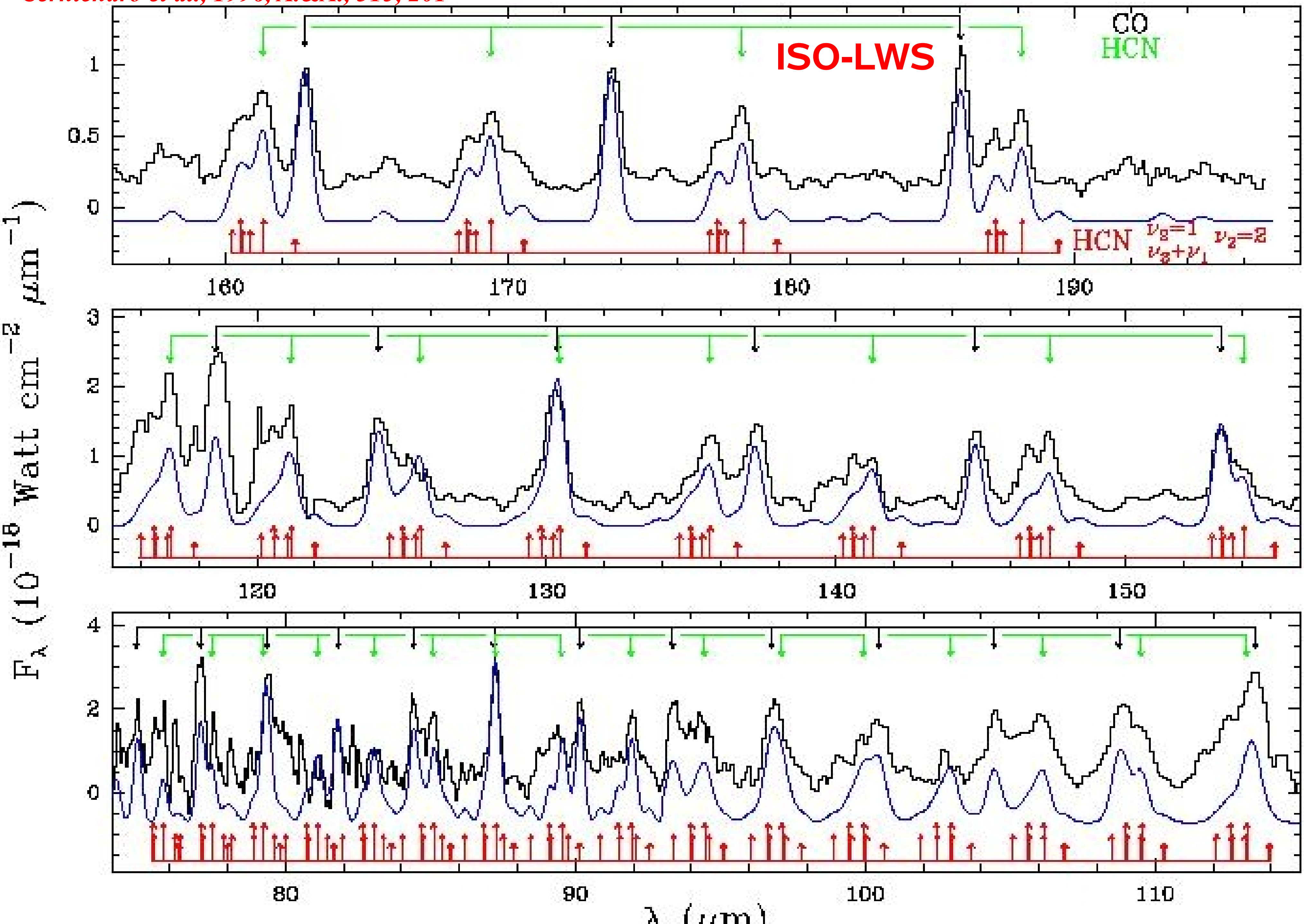
^{13}CO

SiO

HCN

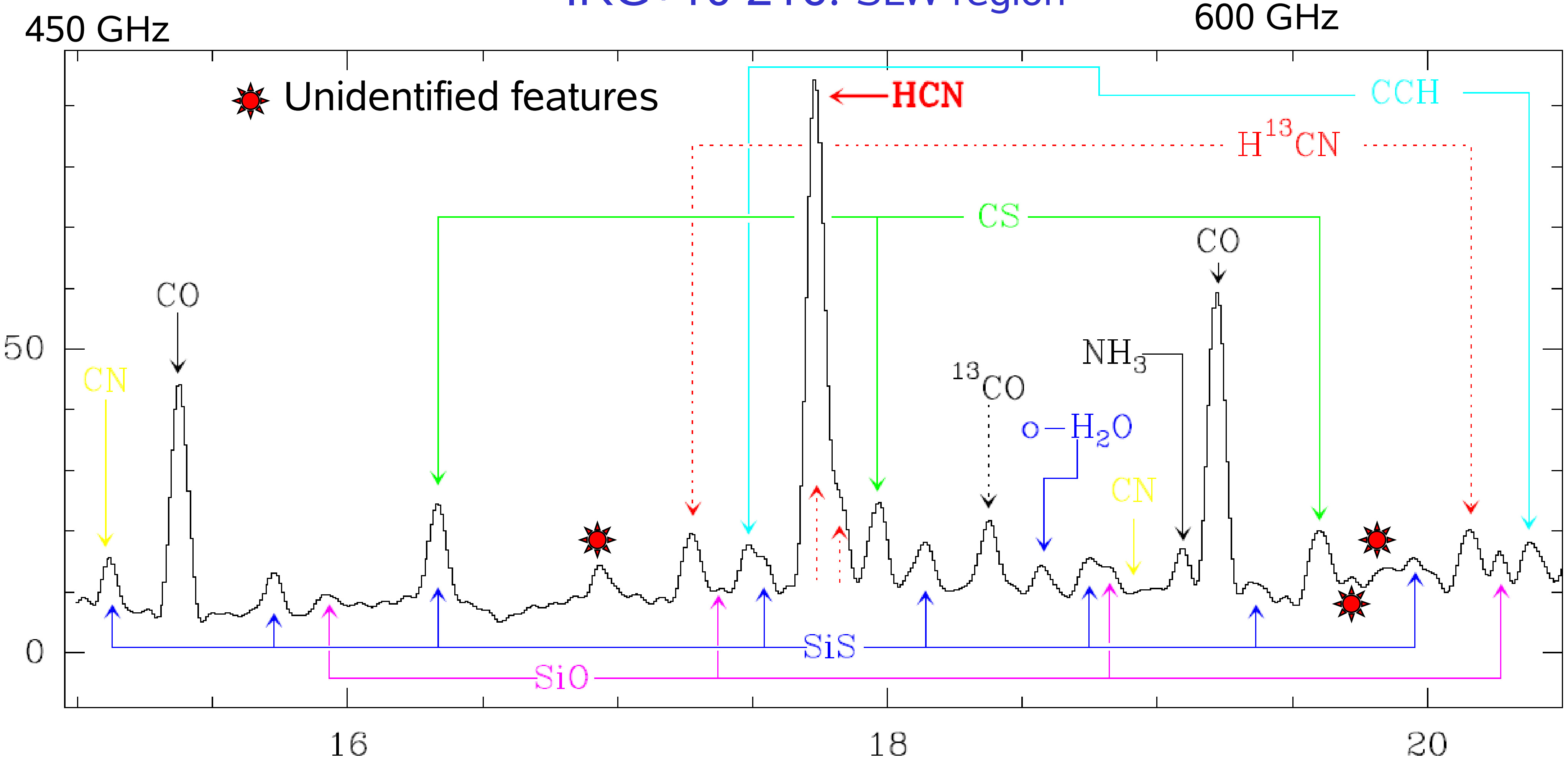
+ background forest of weak lines, possibly due to SO_2 and CH_3OH

Cernicharo et al., 1996, A.&A., 315, 201



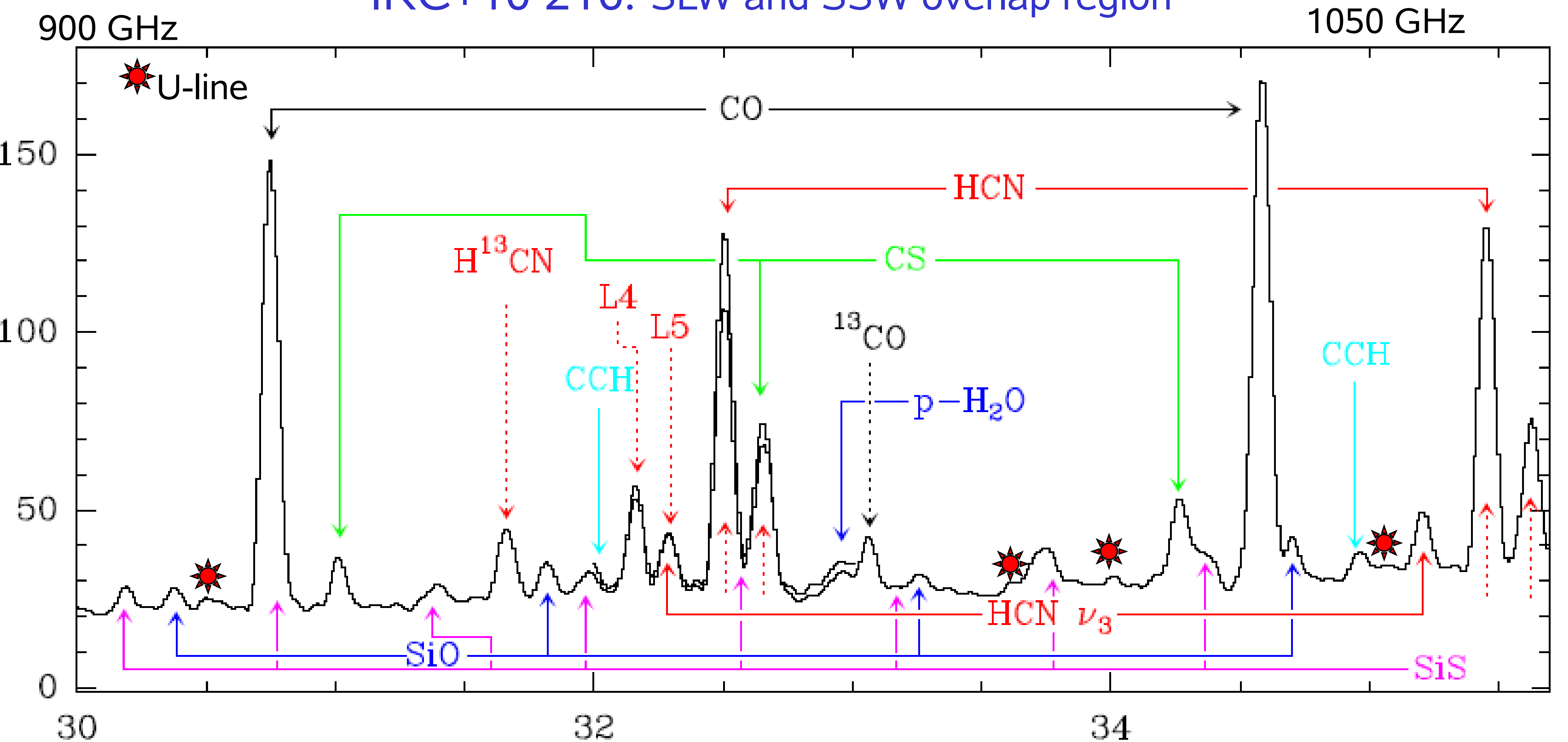
IRC+10216: C-rich Circumstellar Envelope :: HCN (in all ν) + CO; λ/Δλ~300

IRC+10 216: SLW region

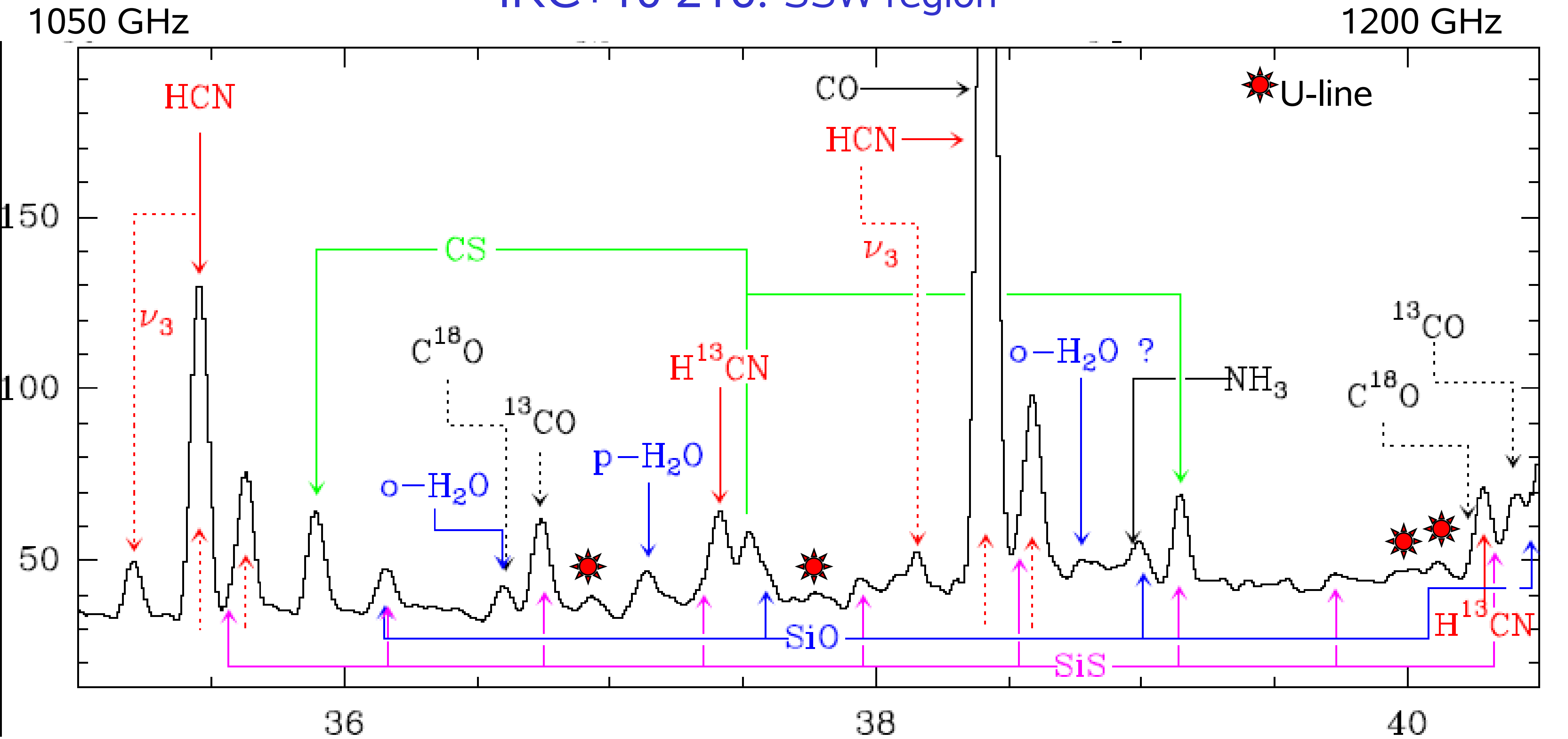


(ids: J. Cernicharo)

IRC+10 216: SLW and SSW overlap region



IRC+10 216: SSW region



Species detected so far in the FTS spectrum of IRC+10216(~250 emission lines):

^{12}CO, ^{13}CO, $C^{18}O$

HCN, $H^{13}CN$

SiS

SiO

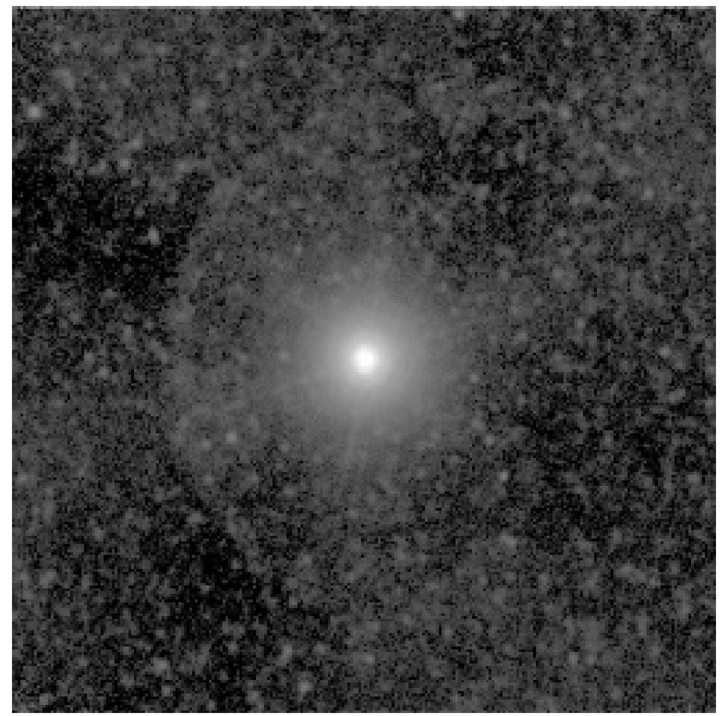
o-H2O, p-H2O

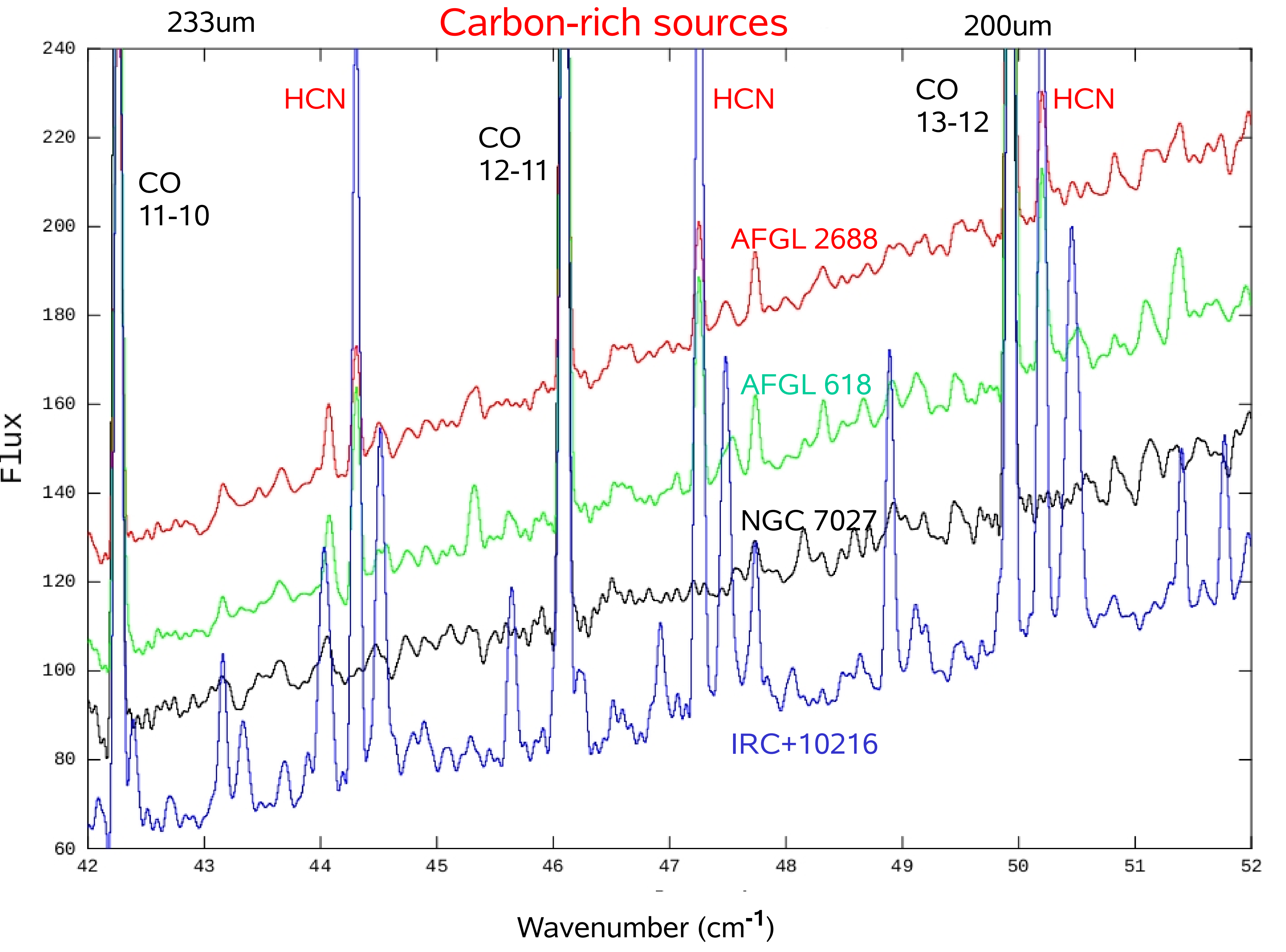
NH_3

CCH

CS

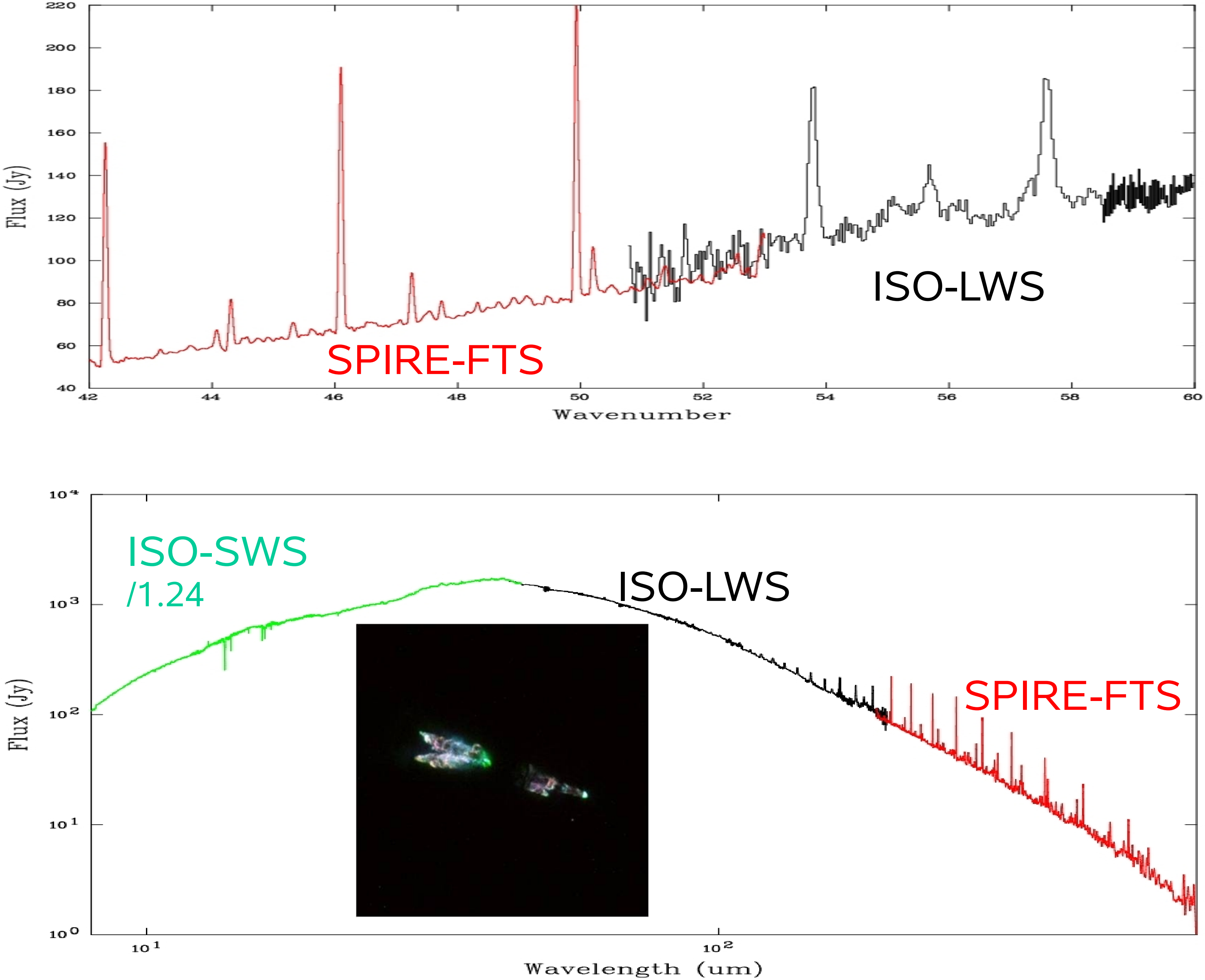
HCl (2 lines; also detected with PACS)



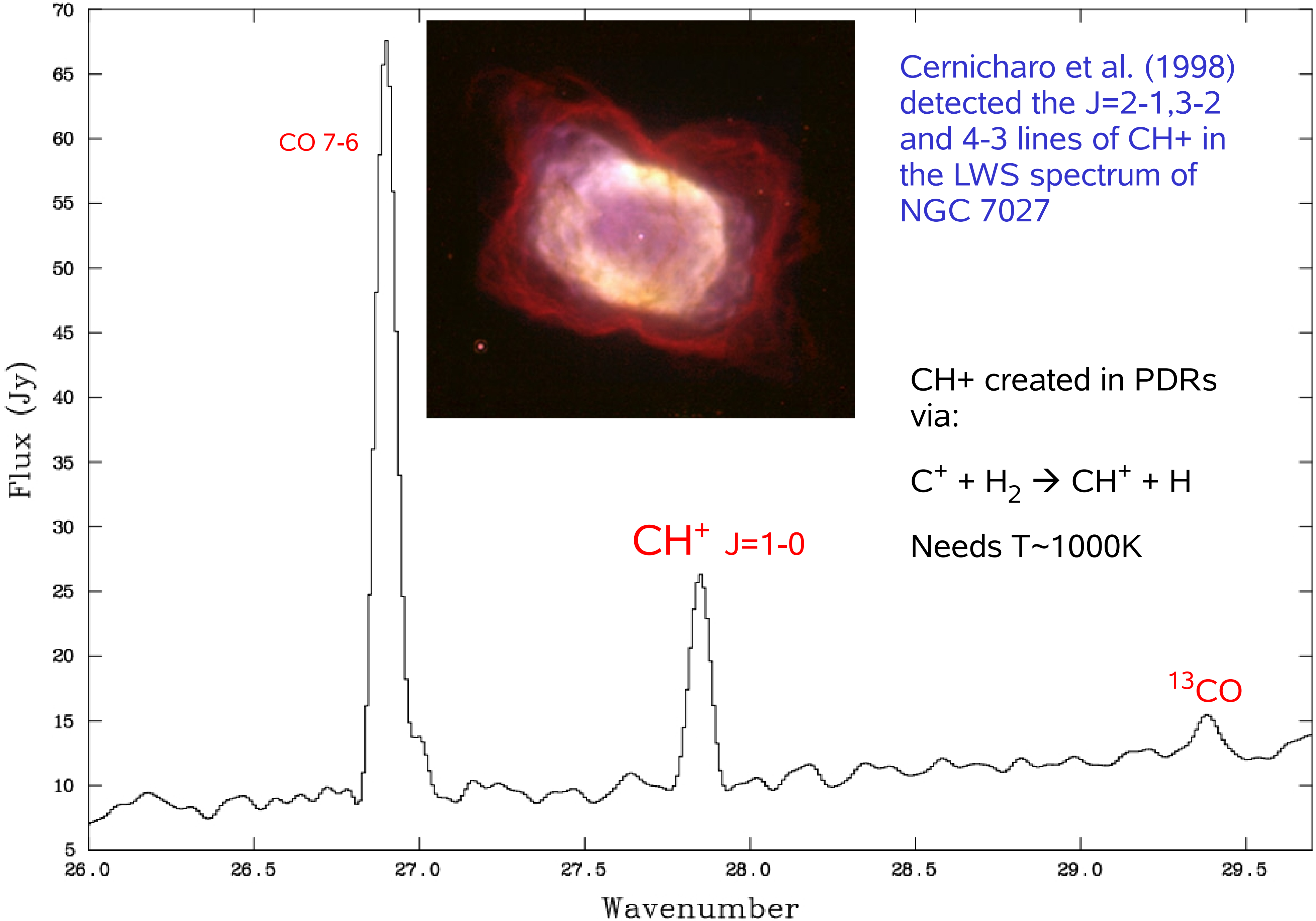


Carbon-rich sources
233um
200um
CO
11-10
HCN
CO
12-11
HCN
CO
13-12
HCN
AFGL 2688
AFGL 618
NGC 7027
IRC+10216
Flux
Wavenumber (cm-1)
240
220
200
180
160
140
120
100
80
60
42
43
44
45
46
47
48
49
50
51
52

AFGL 618


ISO-LWS
SPIRE-FTS
Flux (Jy)
Wavenumber
ISO-SWS
/1.24
ISO-LWS
SPIRE-FTS
Flux (Jy)
Wavelength (um)

NGC 7027



Cernicharo et al. (1998) detected the J=2-1,3-2 and 4-3 lines of CH+ in the LWS spectrum of NGC 7027

CH+ created in PDRs via:

$C^+ + H_2 \rightarrow CH^+ + H$

Needs T~1000K

SPIRE FTS:

Sensitivity is at least 2-3 times better than pre-launch estimates.

Absolute flux calibration is already very good from 200-550um.

Excellent spectral survey tool.

Analysis of PACS & SPIRE Spectrometer Data:

Joint RT effort underway to produce models that will fit both the PACS and SPIRE data, in order to determine molecular abundances, excitation mechanisms & temperatures and mass loss rates.

Accurate RSRFs are needed for each spectrometer in order to search for and characterise dust spectral features.