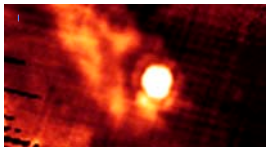
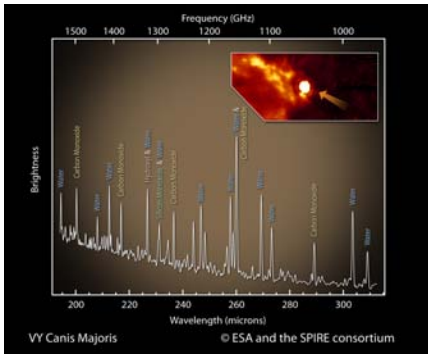


Unravelling the Complexity of the Red Supergiant VY CMa with the SPIRE Spectrometer and modelling



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Introduction

The Herschel SPIRE Fourier Transfer Spectrometer (FTS) enables the exploitation of a new wavelength range, 194-670 micron. This spectral range covers numerous water lines, which are particularly important for cooling O-rich winds.

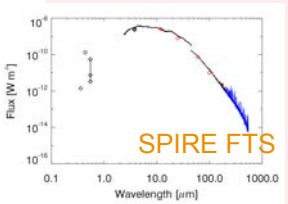
VY Canis Majoris is a very luminous self-obscured cool M supergiant (T~2800 K). It has a very strong wind, forming a circumstellar envelope around the central source. Since the star is the only heating source, it is ideal for testing radiative transfer codes, and molecular chemistry models.

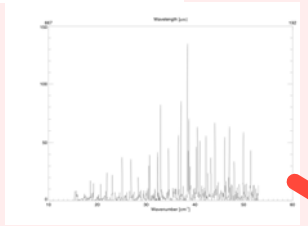
Observations and Analysis

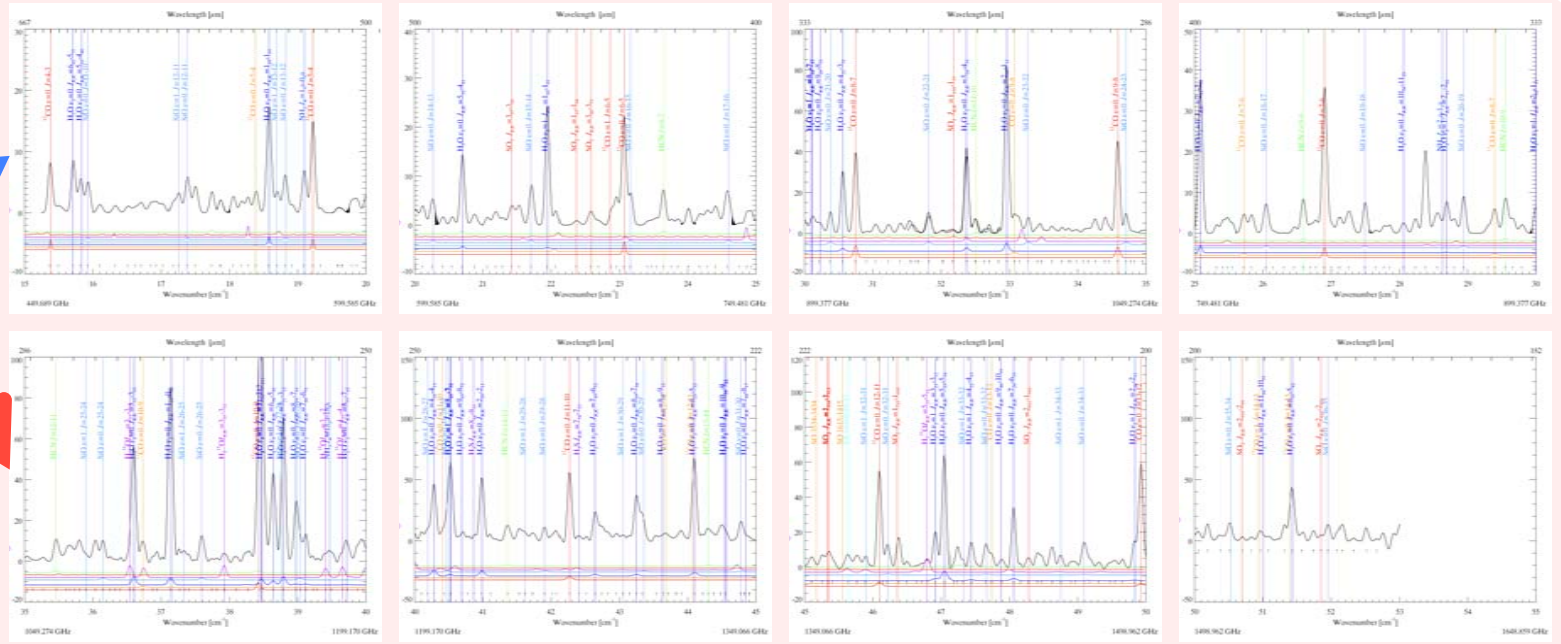
The **Herschel SPIRE FTS** acquired a spectrum of VY CMa on Nov 12th 2009. The on-source integration time was 3996 sec. The unapodized spectral resolution was 0.048 cm^{-1} ; after apodization the resolution is 0.07 cm^{-1}.

In total ,~300 lines were found in the SPIRE 15-53 cm^{-1} (190-670um) spectrum
~100 lines identified
H_2O: contributes at least 1/3 of the entire lines (39 $H_2{}^{16}O$ lines; 5 $H_2{}^{18}O$ lines)
Other molecules

- SiO, ^{12}CO, ^{13}CO, NH_3, HCN, CN, SO, SO







LTE model spectra to guide eyes
(arrows) detected lines

▪ Modeling the spectrum

We independently model the Herschel spectra of VY CMa using three different non-LTE models

- SMMOL (Rawlings & Yates 2001)
- GASTRoNOoM (Decin et al. 2006, 2010)
- 1Dart (Daniel & Cernicharo 2008)

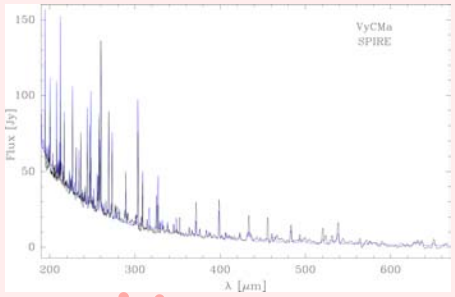
SMMOL is a line radiative transfer and level population code. It uses the accelerated Lambda iteration (ALI) schemes described by Scharmer and Carlsson (1985) and Rybicki and Hbeummer (1991) to solve the coupled level population and line radiative transfer problem exactly. SMMOL also uses a fine grid in position-velocity space to allow the inclusion of maser emission in the calculation of the level populations.

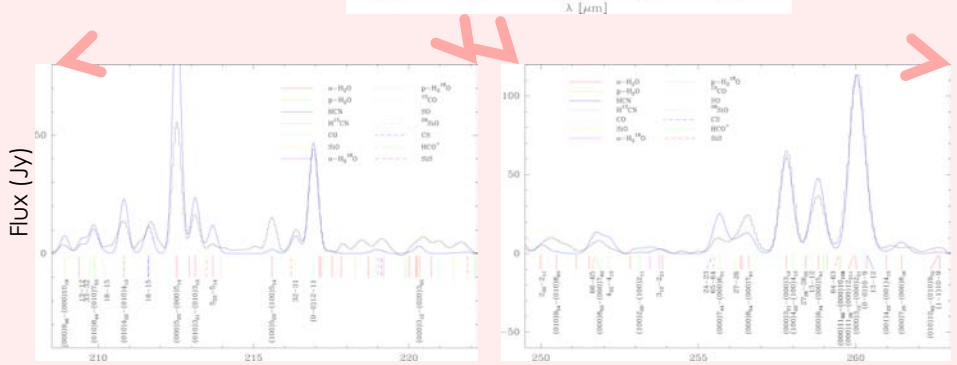
GASTRoNOoM is a non-LTE code. The kinetic temperature is calculated from the balance of cooling and heating, with the main contributions coming from adiabatic expansion, grain-gas collisions, and CO and H_2O ro-vibrational transitions. The conservation of momentum delivers the velocity structure. Further results can found in **Poster 2.30**

1Dart model was developed to solve radiative transfer by the ALI method. The Gauss-Seidel algorithm is used to increase the convergence speed.

1Dart

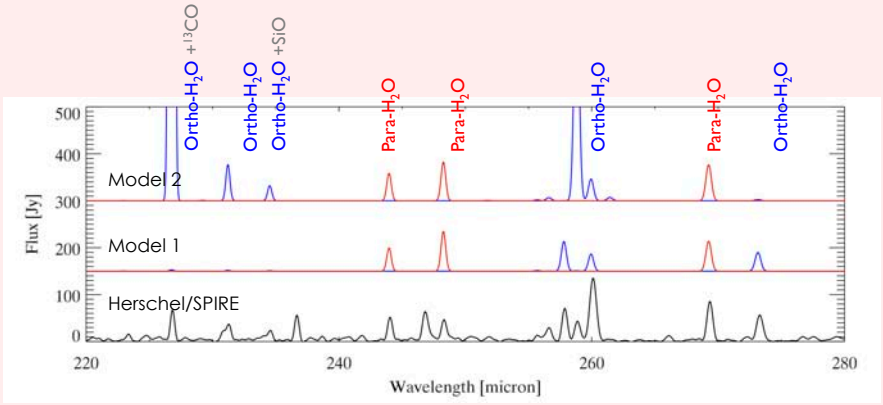
H_2O, $H_2{}^{18}O$, CO, ^{13}CO, HCN and SiO.





SMMOL

We are currently focusing on modelling the H_2O lines. We are able to fit with H_2O/H_2 = 1e-4 and an ortho:para ratio of 3:1



- Model parameters (SMMOL)
  - Distance: 1500 pc T_* = 2800 K τ (UV)=50
  - $dM/dt=2x10^{-4} M_\odot\ yr^{-1}$
  - R_{in}: $2x10^{14}$ cm (gas) R_{in} : $1.3x10^{15}$ cm (dust)
  - T_{in}: 2000 K
  - R_{out}: $6.8\ x10^{17}$ cm
  - ρ : $(r/R_{in})^{-2}$
  - T : $T_{in}*(r/R_{in})^{-0.5}$ (model 1) $T_{in}*(r/R_{in})^{-0.4}$ (model 2)
  - T_{sub} (H_2O): 100 K
  - $H_2O/H = 10^{-4}$
  - Ortho : para = 3: 1
  - κ (>250 micron): λ^{-2} (model 1) / λ^{-1} (model 2)

Possible H_2O maser lines in the SPIRE range

Ortho			Para		
Fq (GHz)	Wvn (cm^{-1})	Wvlen (micron)	Fq (GHz)	Wvnum (cm^{-1})	Wvlen (micron)
439.15	14.65	682.66	470.89	15.71	636.65
443.02	14.78	676.70	488.49	16.29	613.71
448.00	14.94	669.18	556.94	18.58	538.29
620.70	20.70	482.99	906.21	30.23	330.82
1146.62	38.25	261.46	916.17	30.56	327.22
1168.36	38.97	256.59	1097.37	36.60	273.19
1296.41	43.24	231.25	1146.62	38.25	261.46
1307.96	43.63	229.21	1153.13	38.46	259.98
1410.62	47.05	212.53	1168.36	38.97	256.59
1574.23	52.51	190.44	1322.07	44.10	226.76

Summary

- The Herschel SPIRE FTS has revealed numerous strong molecular lines in the 15-53 cm^{-1} (190-670 micron) spectrum of Vy CMa
  - About 100 lines are identified
  - 1/3rd are attributed to H_2O
- Non-LTE code is required to model these molecular lines
  - Optically thick H_2O lines
  - Some H_2O lines are likely to be masers
- The model results are being used to predict the line profiles that HIFI will see.