The Cosmic Cycle of Dust and Gas in the Galaxy : from Old to Young Stars
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Molecular complexity in the star-forming region W43-MM1

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Outline

I. Scientific context

High-mass star formation & Complex molecules

Presentation of W43-MM1

I. Data

ALMA Dataset

Continuum emission : substraction

II. Analysis and results

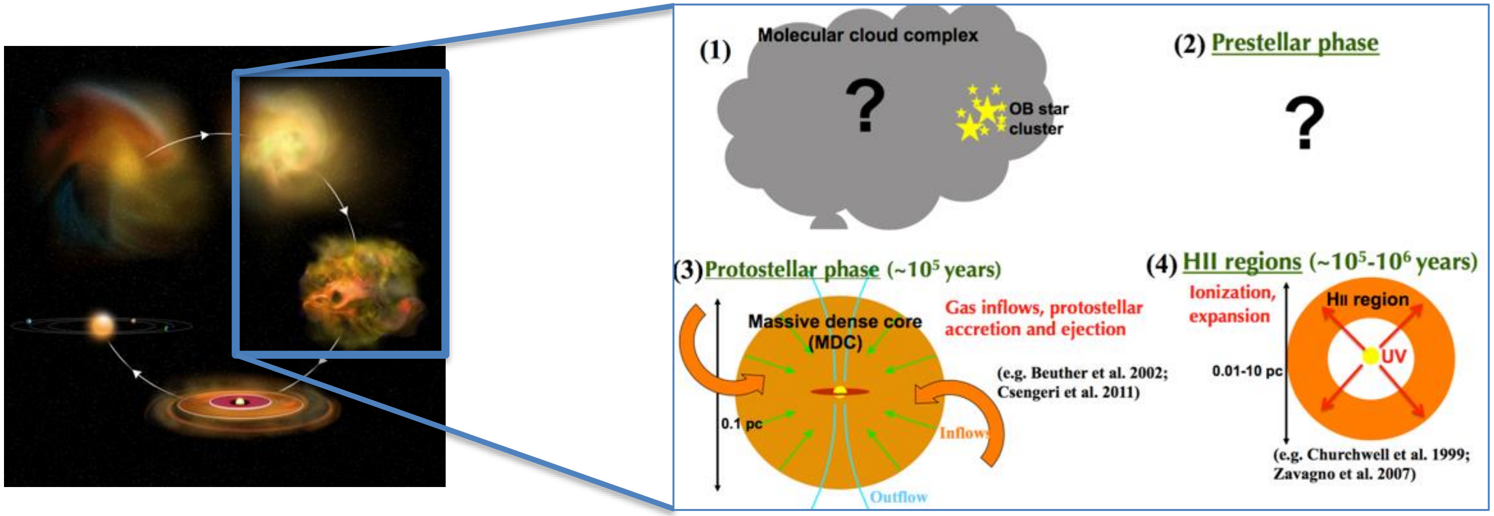
Protostellar activity in W43-MM1

Method we use to identify the molecular lines

Molecular content & analysis of a massive prestellar core candidate

Conclusion

Massive star formation



Radiation pressure overcome the accretion

Is an equivalent phase of low-mass stars prestellar cores exists for high-mass stars?

Difficulties to find high-mass prestellar cores :

- *Number of high-mass stars lower than the number of low-mass stars*
- *Lifetime : 1-7x10^4 yr for prestellar cores vs 3x10^5 yr for protostars (Tigé et al. 2017)*
- *Formation in clusters*

Complex molecules

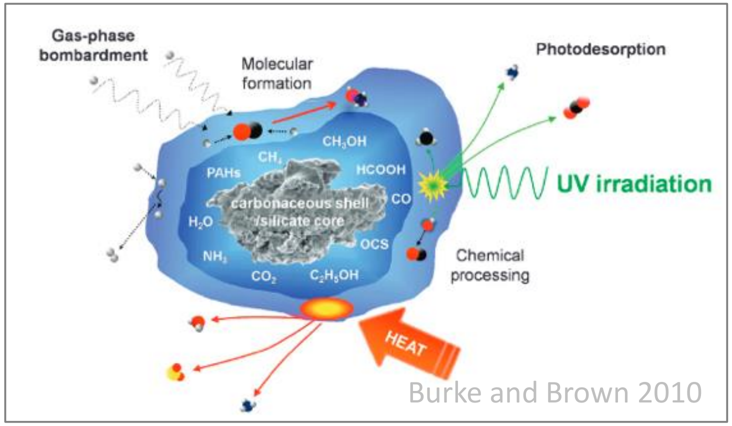
New radio-telescopes provides high spectral sensitivity

Number of Atoms										
2	3	4	5	6	7	8	9	10	11	12+
H_2	C_3	c-C_3H	C_5	C_5H	C_6H	CH_3C_3N	CH_3C_4H	CH_3C_5N?	HC_9N	C_6H_6
AlF	C_2H	l-C_3H	C_4H	l-H_2C_4	CH_2CHCN	$HCOOCH_3$	CH_3CH_2CN	$(CH_3)_2CO$		$HC_{11}N$
AlCl	C_2O	C_3N	C_4Si	C_2H_4	CH_3C_2H	CH_3COOH?	$(CH_3)_2O$	NH_2CH_2COOH?		PAHs
C_2	C_2S	C_3O	l-C_3H_2	CH_3CN	HC_5N	C_7H	CH_3CH_2OH			C_{60}^{+}?
CH	CH_2	C_3S	c-C_3H_2	CH_3NC	$HCOCH_3$	H_2C_6	HC_7N			
CH^+	HCN	C_2H_2	CH_2CN	CH_3OH	NH_2CH_3	$HOCH_2CHO$	C_8H			
CN	HCO	CH_2D^+?	CH_4	CH_3SH	c-C_2H_4O					
CO	HCO^+	HCCN	HC_3N	HC_3NH^+						
CO^+	HCS^+	$HCNH^+$	HC_2NC	HC_2CHO						
CP	HOC^+	HNCO	HCOOH	NH_2CHO						
CSi	H_2O	HNCS	H_2CHN	C_5N						
HCl	H_2S	$HOCO^+$	H_2C_2O							
KCl	HNC	H_2CO	H_2NCN							
NH	HNO	H_2CN	HNC_3							
NO	MgCN	H_2CS	SiH_4							
NS	MgNC	H_3O^+	H_2COH^+							
NaCl	N_2H^+	NH_3								
OH	N_2O	SiC_3								
PN	NaCN	CH_3								
SO	OCS									
SO^+	SO_2									
SiN	c-SiC_2									
SiO	CO_2									
SiS	NH_2									
CS	H_3^+									
HF	H_2D^+									

ISM

≈

200 molecules detected



Reactions : gas phase + on grains

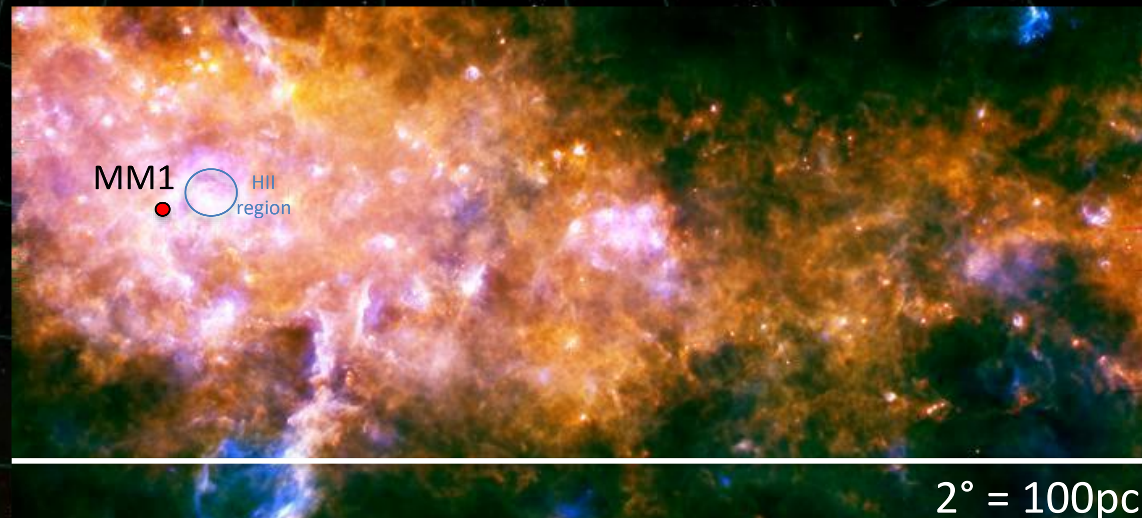
Relative distribution of molecules
Physical conditions
→ Understanding of the chemistry of the ISM

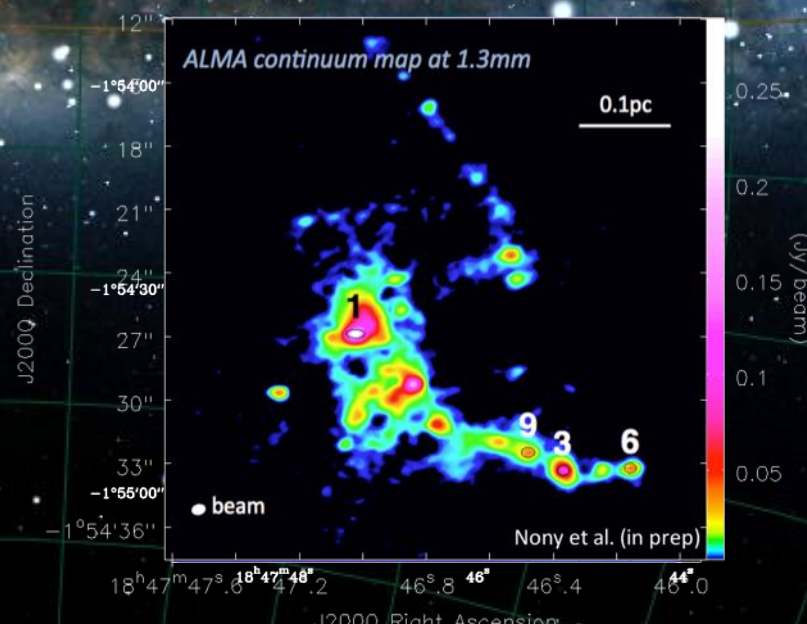
W43-MM1

Distance : 5.5kpc from the sun
Location : Galactic bar

l = 30°
b = 0°

Aquila





Most massive core of W43 (≈3600$M_{\odot}$)
SFE ≈ 0.25$M_{\odot}$/yr *(Motte et al. 2003)*

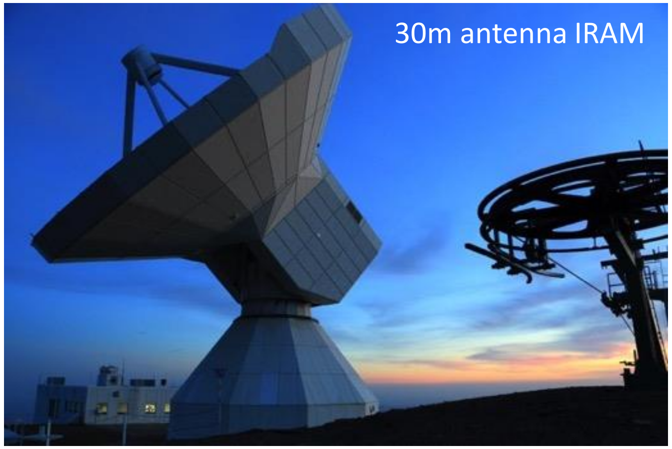
OH, H2O and CH3OH masers → stellar activity

Several cores at the same distance and with the same high resolution

Dataset : Observations

Projects 2013.1.01365.S and 2015.1.01273
(Cycle 2 and 3, ALMA+ACA)
Mosaic of 33 fields
Band 6 (1.3mm)
Total bandwidth : 4 GHz
Spectral resolution : 122-976 kHz
Spatial resolution : 0.5" (2400 AU)

→ Distribution of molecules
Cores characterization

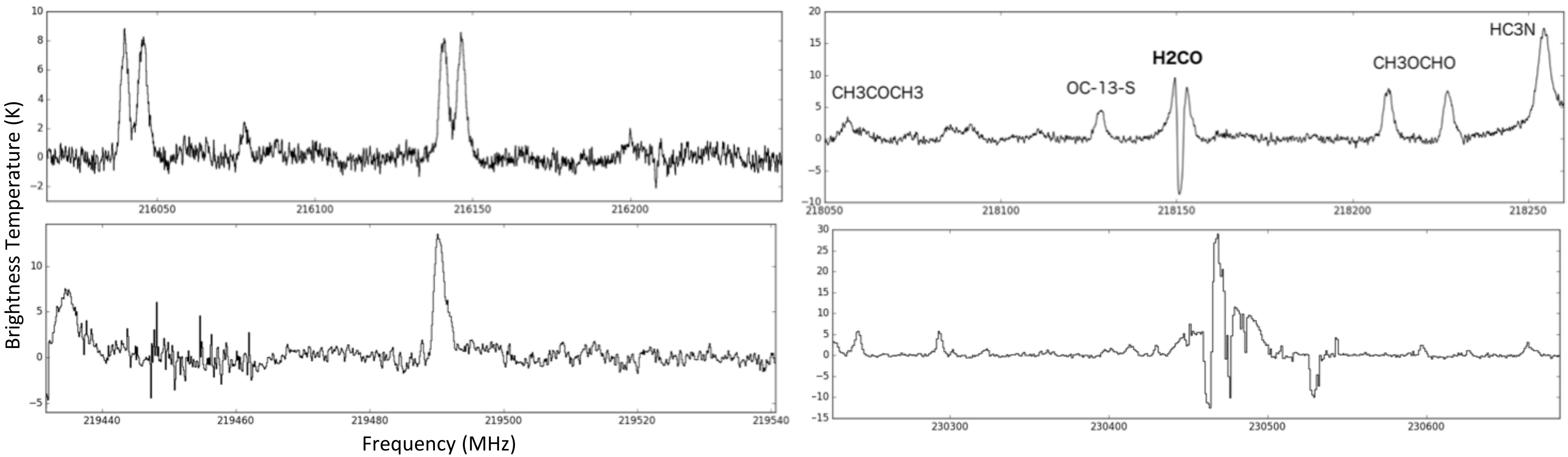


Project 019-17
Bands : 1.3mm, 2mm, 3mm
Total bandwith : 154 GHz
Spectral resolution : 195 kHz
Spatial resolution : 9-30" (0.2-0.8 pc)

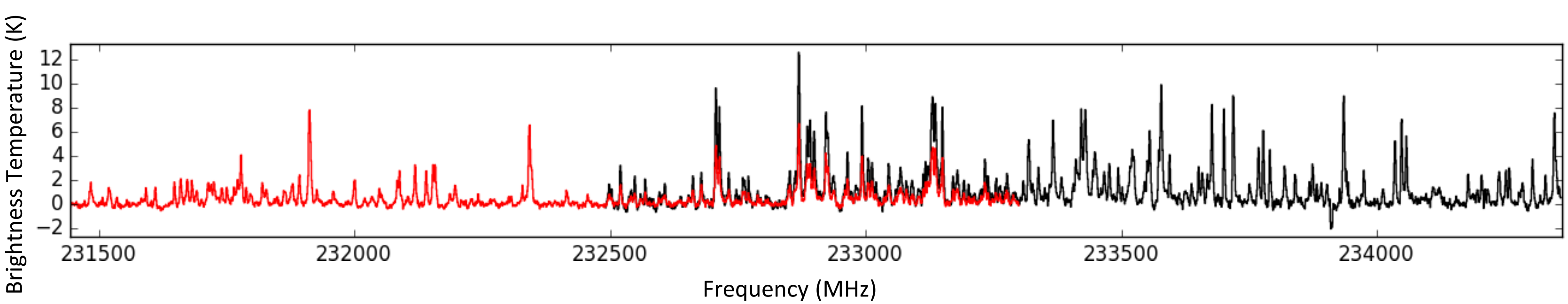
→ Molecular complexity

Dataset : ALMA Spectra

7 narrow bands (160-520 MHz), centred on lines of interest near 220 GHz

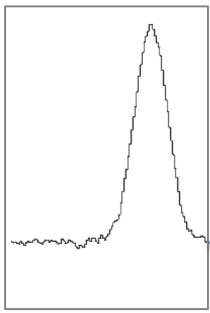


2 large "continuum" bands (≈1.9GHz) :



Continuum : Difficulties to determine the level

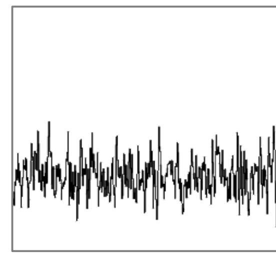
- Extreme cases



Noise << Molecular emission

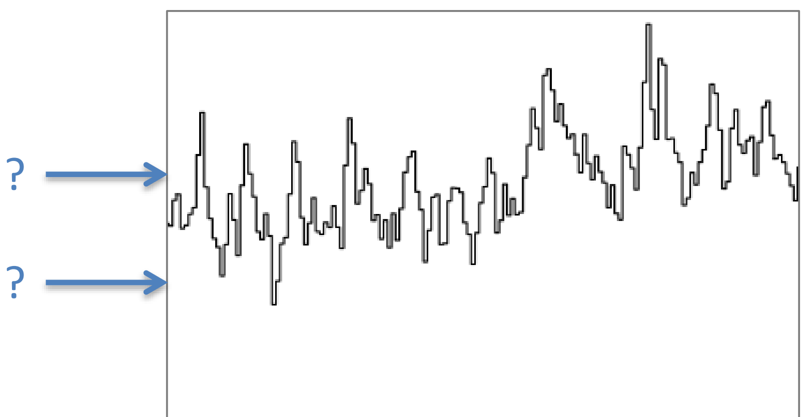
Continuum
=
channels of
minimum emission

Noise >> Molecular emission



Continuum
=
mean of channels

- More complex (realistic) spectra

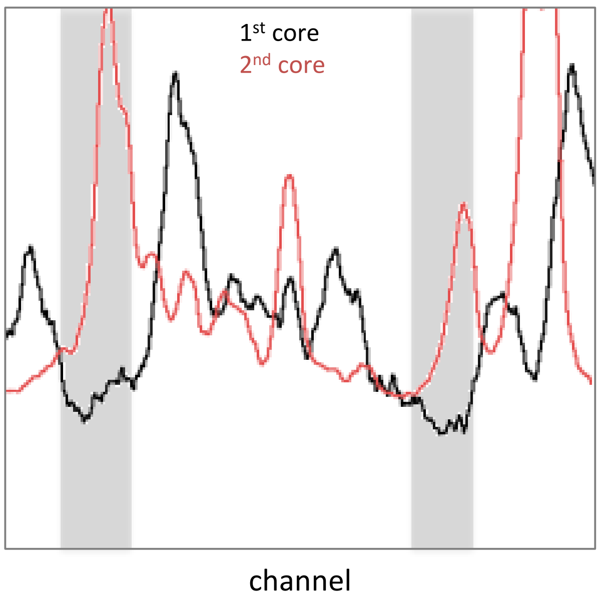


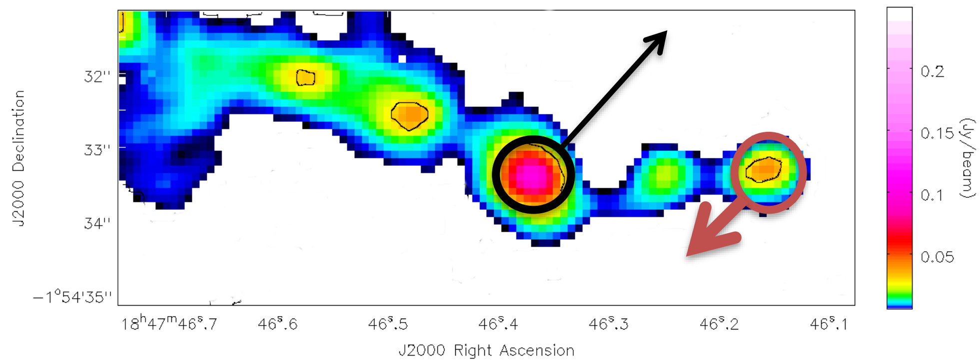
Minimum Mean

Statistical method to determine the continuum level

Continuum : Necessity to work by pixels

- Each source is different from the others





1st core continuum channels are not the same as for the 2nd core, because of :

- a different velocity (Doppler effect)
- a different molecular content

Must treat each source independently !

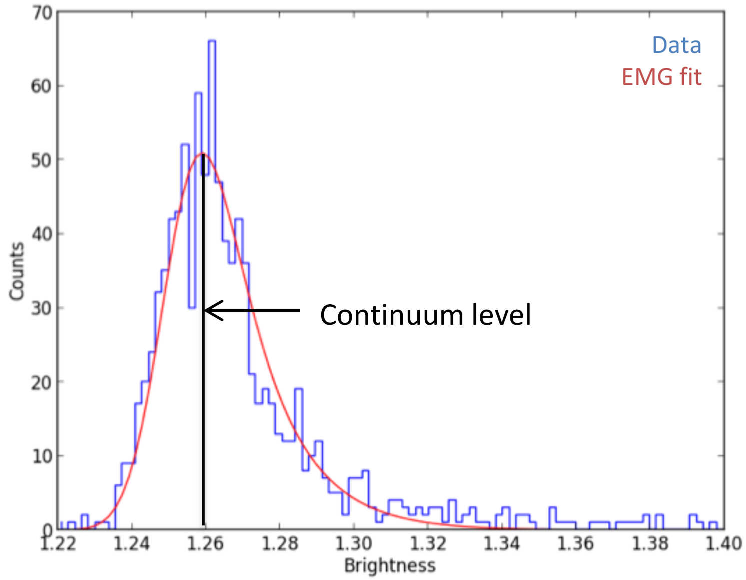
First continuum map
or
A lot of sources

→ Automatic method to determine on each pixel

Continuum : Subtraction method

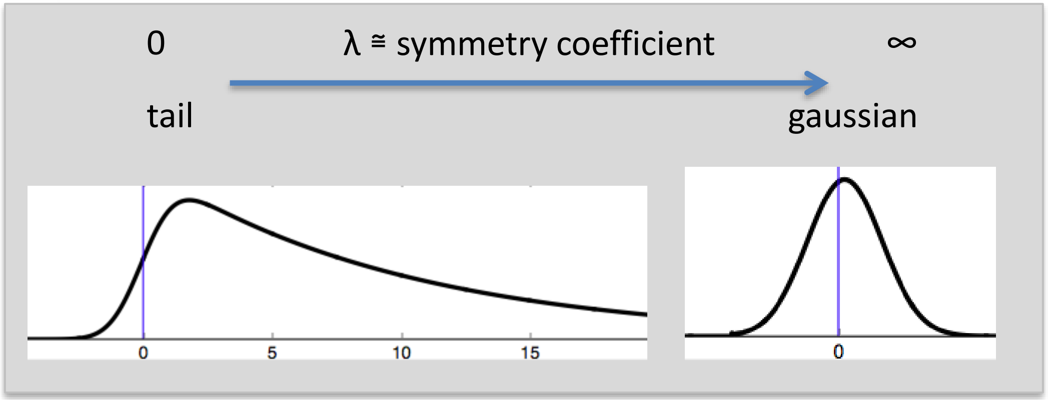
Use the distribution of intensity on each pixel :

- Gaussian part → Noise
- Tail → Molecular emission (right) or absorption (left)



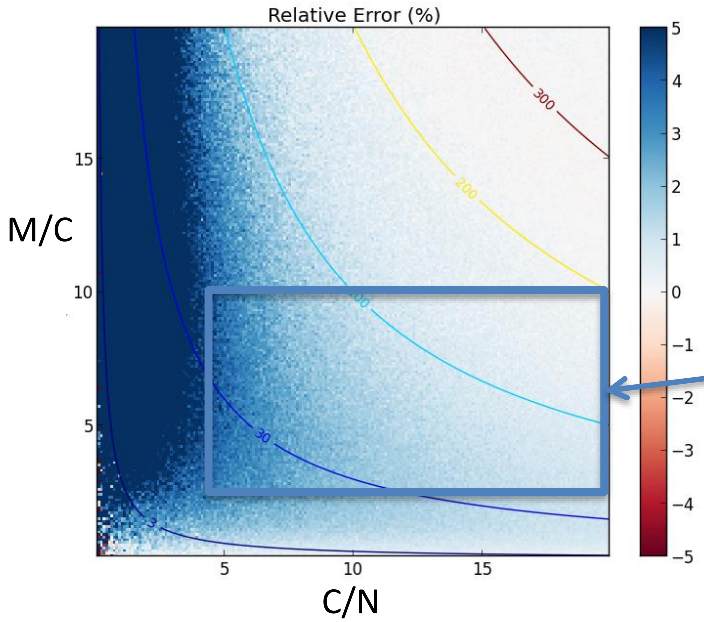
Well fitted by the Exponentially Modified Gaussian (EMG) :

$$f_{EMG}(x) = Ae^{\frac{\lambda}{2}(2\mu+\lambda\sigma^2-2x)} erfc(\frac{\mu+\lambda\sigma^2-x}{\sqrt{2}\sigma})$$



Continuum : Error estimation by simulation

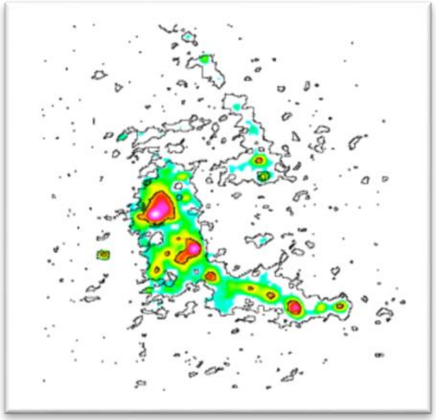
Sanchez-Monge et al. (2017) → can't estimate the error with the fit → Simulation
Use of synthetic spectra with fixed lines parameters (FWHM, density ...) based on observations.



Different relative errors for different ratios C:N:M

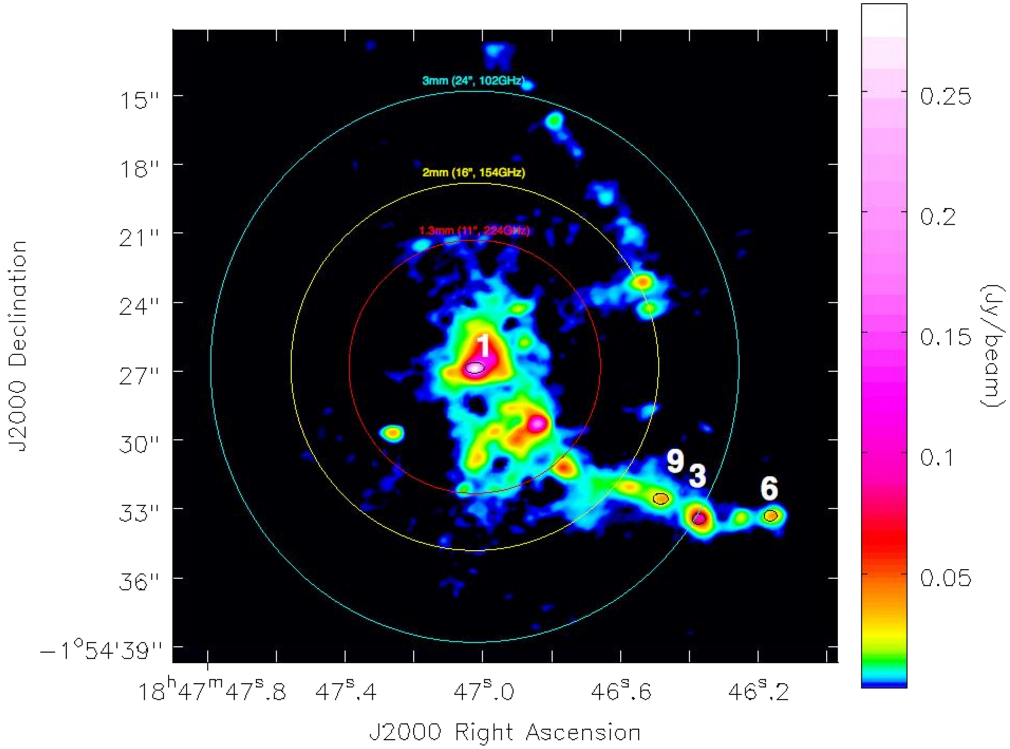
- C = continuum value
- N = rms
- M = maximum of molecular lines emission

Error < 2% for continuum > 3σ
Error < 1% for main sources



contours : 1%, 2% error

Continuum map reveals high-mass cores



Continuum map reveals 131 sources, including 13 high-mass protostellar cores with masses from 16 to 100 $M_\odot$ *(Nony et al. in prep).*

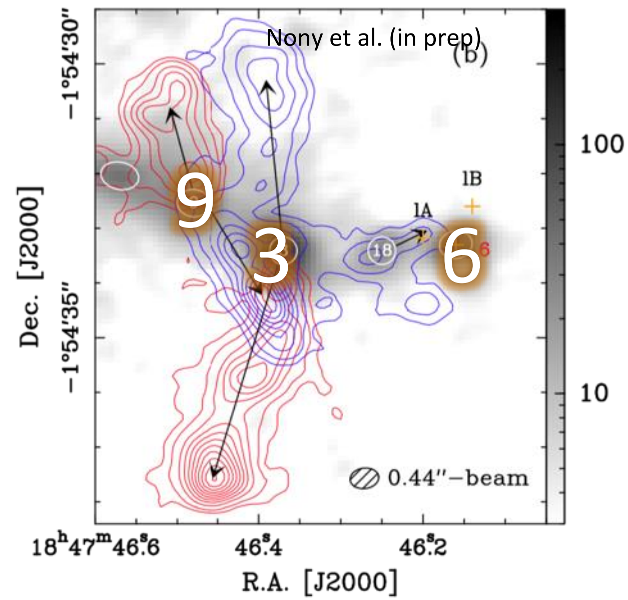
Protostellar activity of W43-MM1

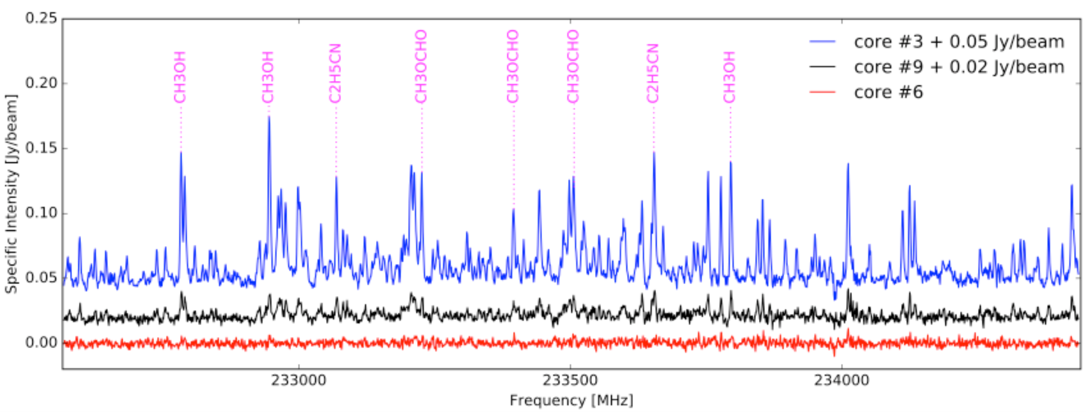
3 cores selected for the analysis

Core	RA [J2000]	Dec. [J2000]	FWHM [AU]	$S^{int}_{1.3mm}$ [mJy]	$\overline{T}_{dust}$ [K]	M_{core} $M_\odot$
1	18:47:47.02	-1:54:26.86	2300	592 ± 6	74 ± 2	102 ± 5
3	18:47:46.37	-1:54:33.41	1200	222 ± 2	45 ± 1	59 ± 2
6	18:47:46.16	-1:54:33.30	1300	94 ± 1	23 ± 2	56 ± 9
9	18:47:46.48	-1:54:32.54	1600	87 ± 3	50 ± 1	18 ± 1

Core #3 and 6 have the same mass (60$M_\odot$) in the same size (1300AU).

Outflows from core #3, but core #6 shows no outflow





Rich molecular content in core #3, while core #6 shows poor molecular content.

What is the identity of core #6?

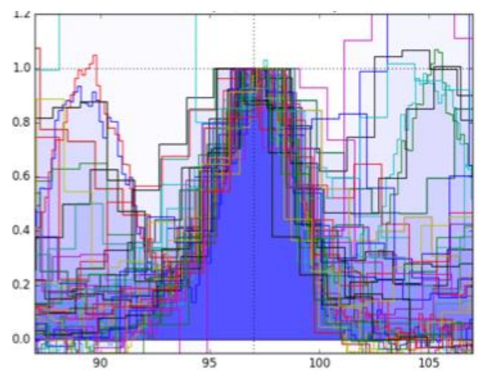
Identification method

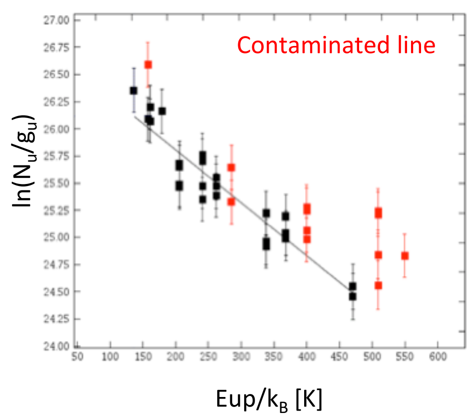
For each molecule :

- Identification of transitions based on CDMS and JPL databases
- Superposition of the corresponding lines normalised

Lines without contamination have :

- same velocity
- same dispersion

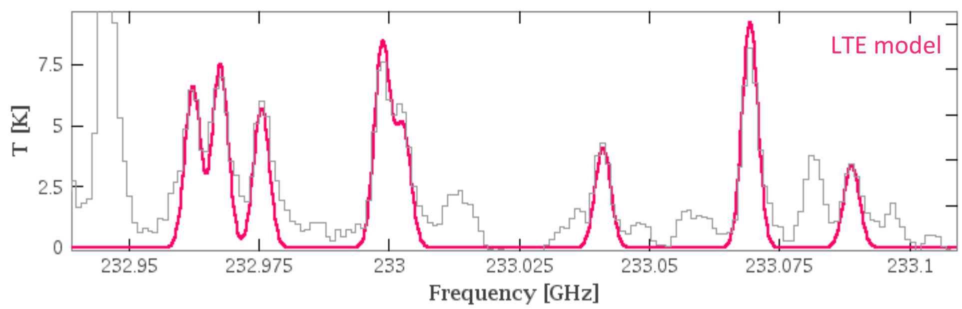


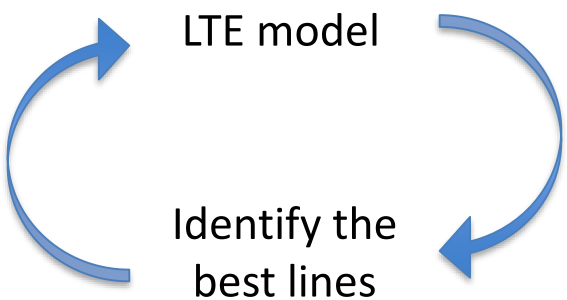


Rotationnal diagram :

(e.g. Goldsmith and Langer 1999)

$$\ln\left(\frac{N_u}{g_u}\right) = \ln\frac{3k_B W}{8\pi^3 \nu S \mu^2} = \ln\left(\frac{N}{Q(T_{ex})}\right) - \frac{1}{T_{ex}}\frac{E_u}{k_B}$$





Detected species in cores #3, #6, and #9

	Core #3		Core #6		Core #9	
	Tex [K]	N x10^{15} [cm^{-2}]	Tex [K]	N x10^{15} [cm^{-2}]	Tex [K]	N x10^{15} [cm^{-2}]
CH_3OH *	302 ± 60	8000 *	39 †	? *	344 ± 92	2000 *
$^{13}CH_3OH$	210 ± 43	120 ± 20	1 transition		205 ± 42	37 ± 8
$CH_3^{18}OH$	161 ± 52	29 ± 4	not detected		92 ± 50	3.9 ± 1.4
CH_3CHO	150 ± 60	11 ± 1	30 ± 15	4 ± 2	110 ± 62	2.1 ± 0.5
CH_3OCH_3	145 ± 8	190 ± 20	1 transition		185 ± 40	50 ± 10
C_2H_5OH	91 ± 8	47 ± 7	not detected		67 ± 12	9 ± 3
CH_3OCHO	195 ± 25	180 ± 20	74 †	6 †	256 ± 115	40 ± 10
$^{13}CH_3CN$	131 ± 62	0.9 ± 0.2	not detected		154 ± 55	0.2 ± 0.1
$HC(O)NH_2$	180 ± 60	2.5 ± 0.6	not detected		110 ± 40	0.5 ± 0.1
C_2H_5CN	206 ± 15	9 ± 1	not detected		190 ± 70	1.9 ± 0.4

† high uncertainty
* optically thick

25 species identified in ALMA data
→ Possibility to map their distribution

Other species detected			
CO	$C^{18}O$	H_2CO *	$H_2{}^{13}CO$
SiO	**CH_3COCH_3**	^{13}CS	**$H_2C^{34}S$**
OCS *	$O^{13}CS$	$OC^{33}S$	SO
DCN	HC_3N	**C_2H_3CN**	

Typical values of hot cores for cores #3 and 9
Core #6 is colder

Δv ≈ 3 km/s for core #6
Δv ≈ 5 km/s for core #3 and 9

80% of lines identified

Conclusion

W43-MM1 may contain a good high-mass prestellar core candidate:

- No outflow observed (no sign of star formation)
- Colder than nearby hot cores of the same masses.

Prospects

Modelization of the source #6.
Identification of more species with ALMA core #1 and 30m spectra analysis.
Maps and molecular content (N, Tex) of all high-mass cores : put an evidence on the evolution of the cores?

Thank you !