The WISH view of the massive star formation

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WISH

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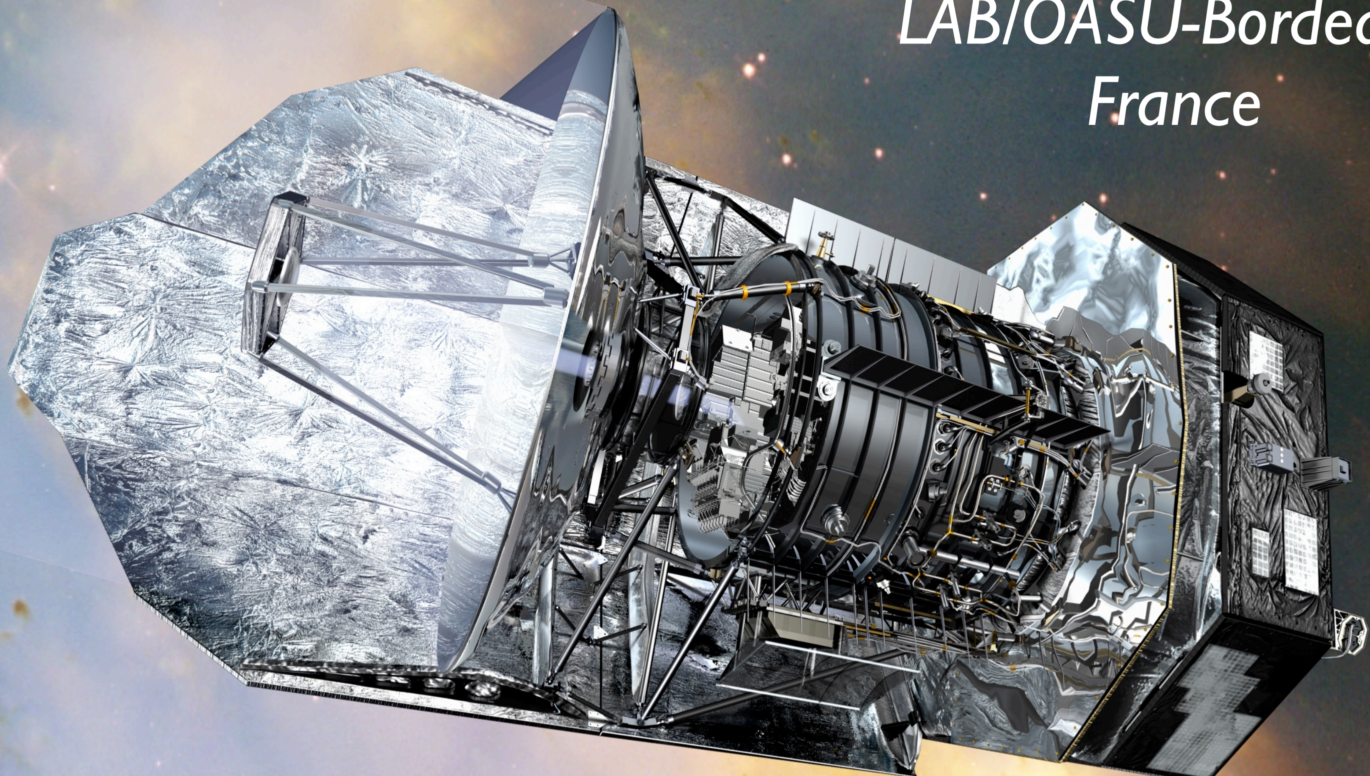

- **F. Herpin**, T. Jacq, J. Braine, A. Baudry, S. Bontemps (Bordeaux) + A. Karska (Leiden)
- **F. van der Tak**, Y. Choi, R. Shipman, W. Kwon, F.P. Helmich, (Groningen)
- **F. Wyrowski**, S. Leurini, T. Csengeri (Bonn)
- **L. Chavarria**, J. Goicoechea, F. Daniel, J. Cernicharo, (Madrid)

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SRON

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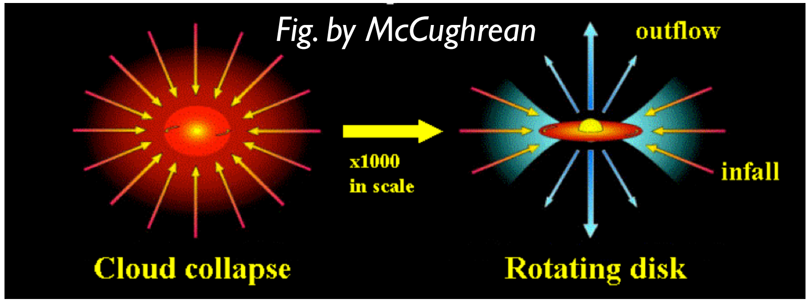
CENTRO DE ASTROBIOLOGÍA

The high-mass star formation puzzle

Formation of massive stars not well understood.
Classical scheme for low-mass star formation cannot be applied as such to OB stars.



Most problematic issue: **how to accumulate a large amount of mass infalling within a single entity despite radiation pressure.**

⟹ Models considering a protostar-disk system (e.g. Krumholz *et al.* 2005) now quite successfully address how the accretion of matter overcomes radiative pressure.

Two main theoretical scenarios have been proposed to form high-mass stars, both requiring the **presence of a disk** and **high accretion rates**:

(a) ***turbulent core model*** with a monolithic collapse scenario (Tan & McKee 2002, McKee & Tan 2003);

(b) highly dynamical ***competitive accretion model*** involving the formation of a cluster (Bonnel & Bate 2006)

➡ water might help cooling
➡ water = probe of the dynamics of the gas

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High-mass protostars observations

evolution

mIR-quiet HMPOs

IRAS05358+3543
IRAS16272–4837
NGC6334-I
W43-MM1
DR21(OH)

mIR-bright HMPOs

W3-IRS5
IRAS18089–1732
W33A
IRAS18151–1208
AFGL2591

Hot Molecular Cores

G327–0.6
NGC6334-I(N)
G29.96–0.02
G31.41+0.31

UC HII Regions

G5.89–0.39
G10.47+0.03
G34.26+0.15
W51N-e1
NGC7538-IRS1

- **pointed HIFI obs of 14 water lines**, including $H_2{}^{18}O$, $H_2{}^{17}O$

  ⇒ abundance + distribution of H_2O in envelopes

- **maps** : HIFI 1_{10}-1_{01} & 2_{02}-1_{11} mini-maps + 1_{11}-0_{00} large maps

  ⇒ water in massive outflows, filling, cooling & chemistry of intra-cluster gas

- Complementary PACS data

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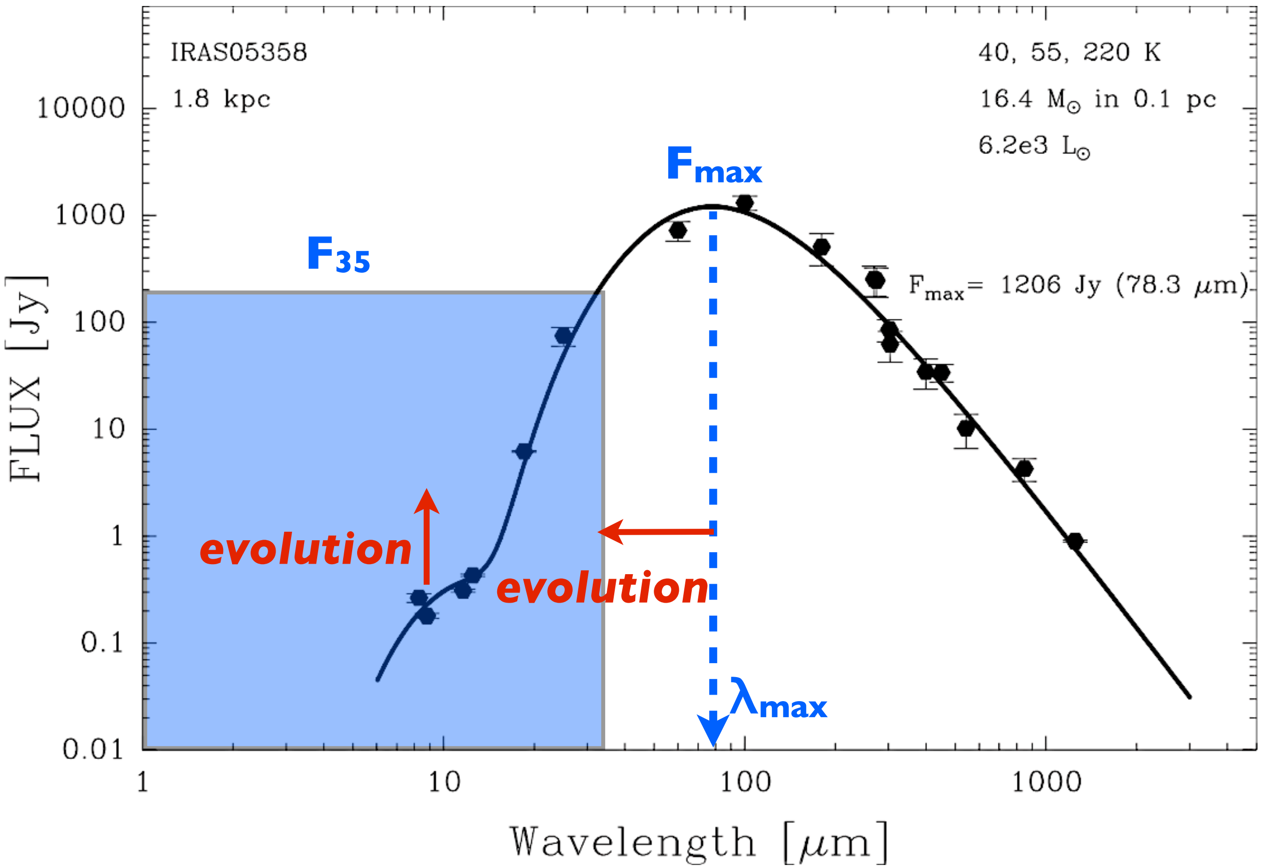
HMPOs: evolutionary status

Object	D (kpc)	L_{bol} ($L_\odot$)	M_{env} ($M_\odot$)	F_{12}[a] (Jy)	F_{21}[a] (Jy)	$L^{0.6}M_{env}^{-1}$	λ_{Fmax} (μm)	F_{35}/F_{total}
NGC6334I(N)	1.7	1.9×10^3	3826	0.0	0.6	0.02	152.9	1.0
W43-MM1	5.5	2.3×10^4	7550	0.94	3.8	0.05	110.6	1.8
DR21(OH)	1.5	1.3×10^4	472	0.3	3.5	0.6	92.4	3.0
IRAS16272-4837	3.4	2.4×10^4	2170	1.39	55.9	0.2	77.2	6.8
IRAS05358+3543	1.8	6.3×10^3	142	0.56	24.3	1.4	78.2	8.8

evolution



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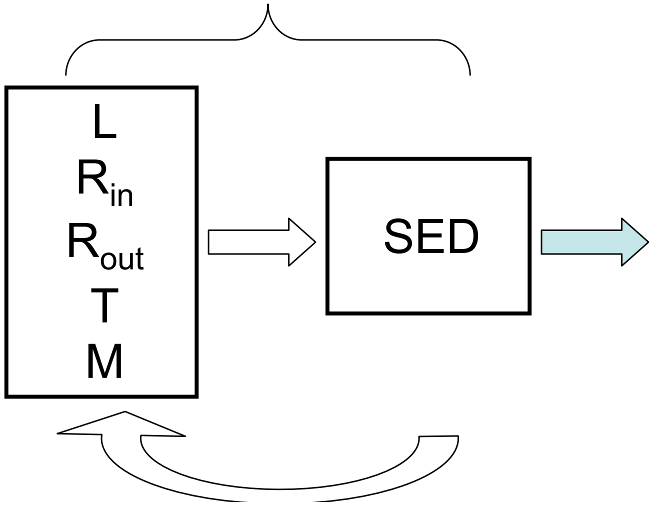
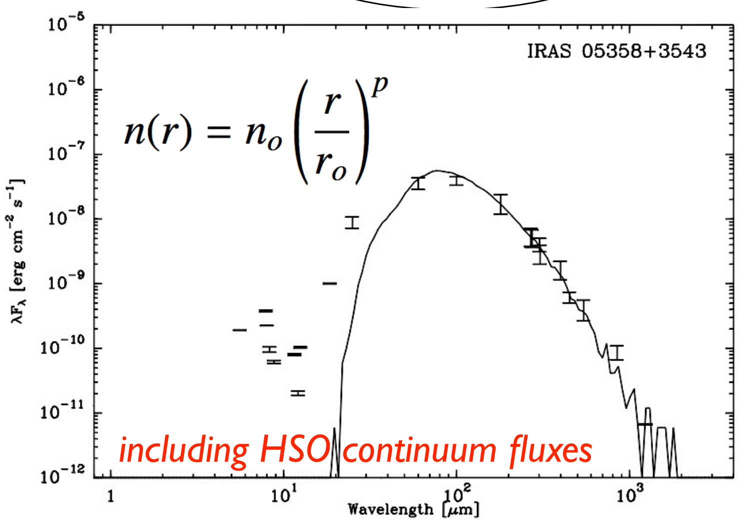
H_2O line profile analysis: modelling

Source model

Whitney-Robitaille (2003)

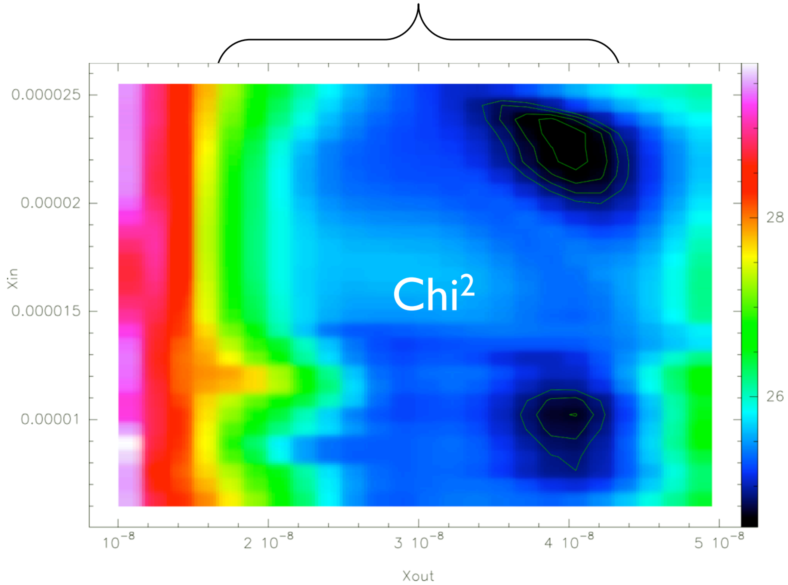


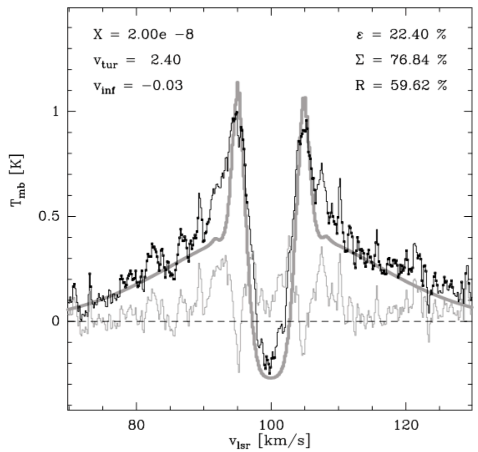


Line modeling

RATRAN

Hogerheijde & van der Tak (2000)





Water collisional rates:

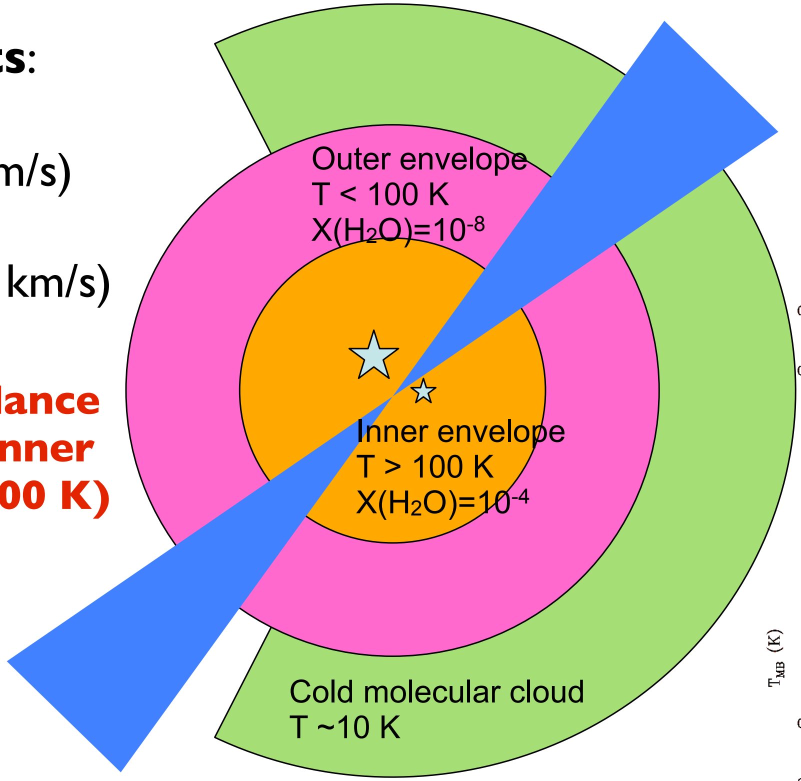
Daniel, Dubernet & Grosjean (2012) & BASECOL

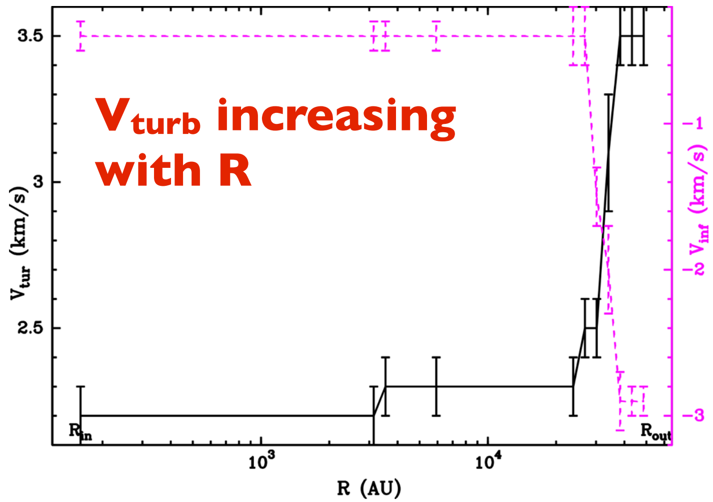
Lines fitting for mid-IR quiet MYSOs: W43MM1

Herpin et al (2012)

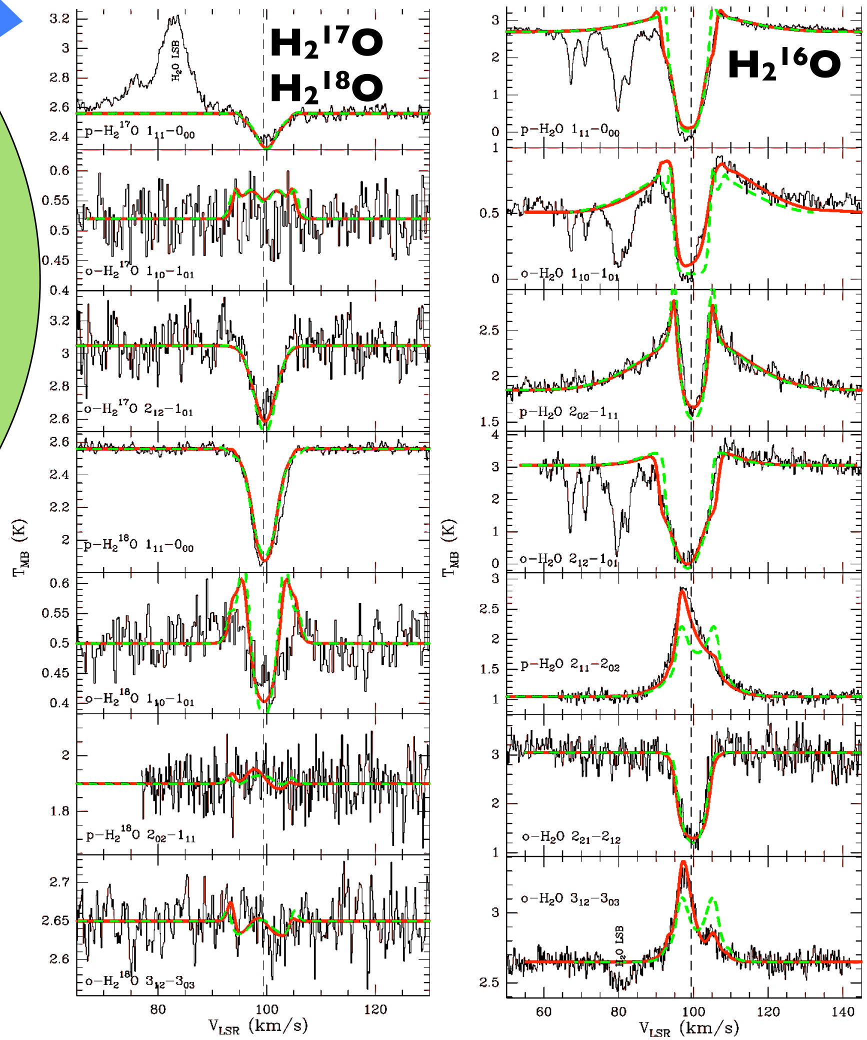
Components:
- **broad** (FWHM>10 km/s)
- **medium** (FWHM=5-10 km/s)

Water abundance jump in the inner envelope (> 100 K)





W43-MM1



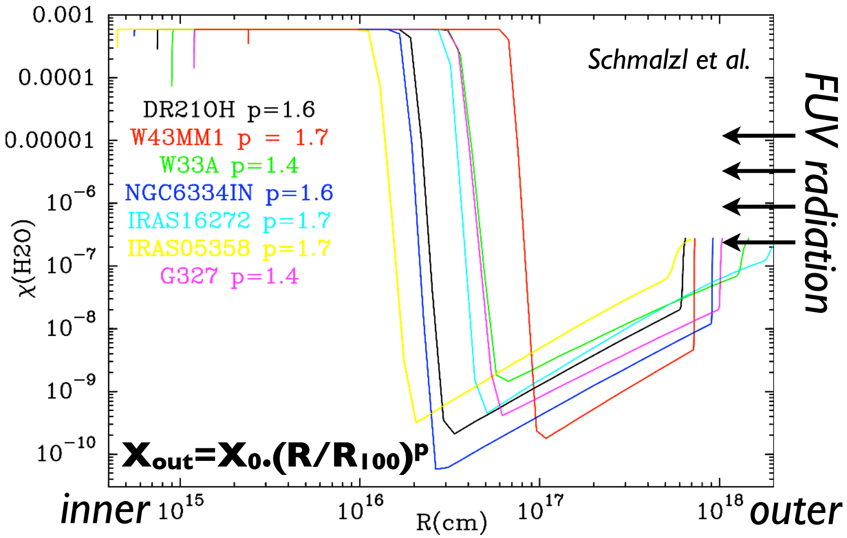
What about the other sources?

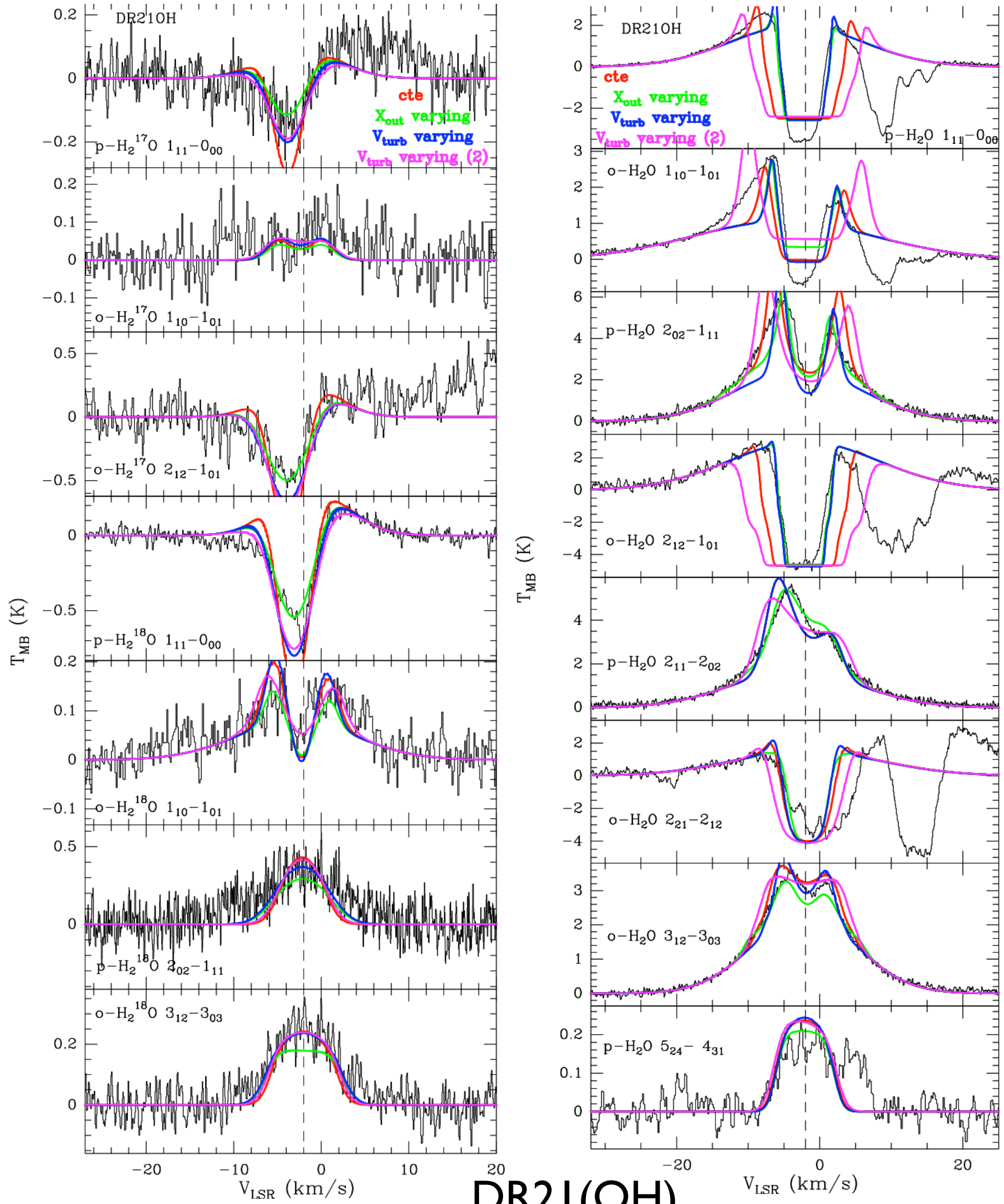
We test:

~~√X_{in}, X_{out}, V_{turb} = cte~~

√X_{in}, X_{out} = cte ; V_{turb}=f(R)

~~√X_{in}, V_{turb} = cte ; X_{out}=f(R)~~



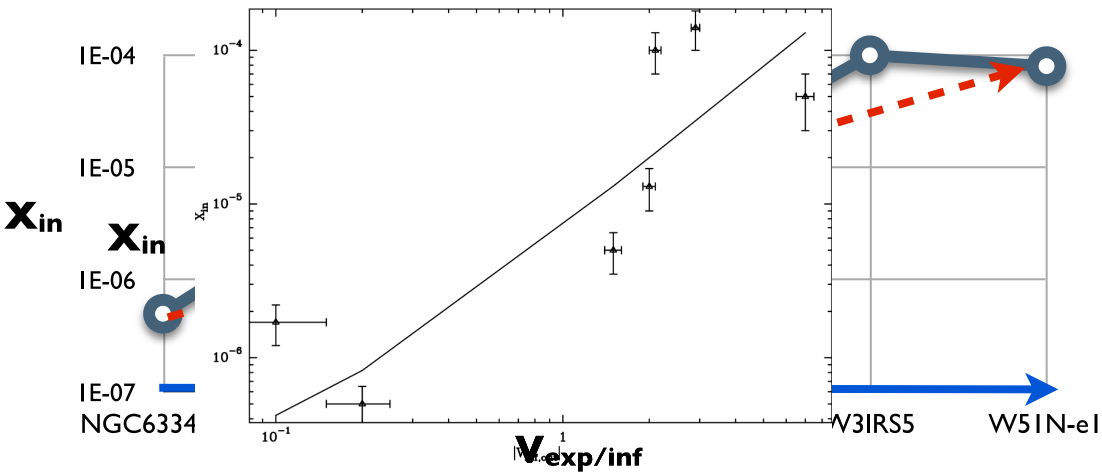


DR21(OH)

Abundances and dynamics results

evolution

	mid-IR quiet					*mid-IR bright*	*UCHII*
Parameter	**NGC6334I(N)**	**W43MM1**	**DR21(OH)**	**IRAS16272**	**IRAS05358**	**W3IRS5**	**W51N-e1**
X_{out}	a few 10^{-8}						
X_{in}	-						+
V_{turb}	2.1-2.5	2.2-3.5	2-3.2	2.0	1.5-2.4	2.0	3.5
$V_{exp/inf}$	-0.2	-2.9	-1.5	-0.1	+2.0	2.0	0 -(-7)



Chavarria et al. (2010)
Herpin et al. (2012)
Herpin et al. (in preparation)
Daniel et al (in preparation)

Abundances and dynamics results

Water

Object	χ_{out} 10^{-8}	χ_{in} 10^{-5}	M_{H_2O} [$M_\odot$]	M_{H_2O}/M_{env} 10^{-7}	$M_{H_2O,inner}/M_{H_2O,total}$ %
NGC6334I(N)	1.3	0.05	6.8×10^{-4}	1.8	4.8
W43-MM1	8.0	14	0.11	146	2.8
DR21(OH)	15	0.5	8.3×10^{-4}	17.6	11.5
IRAS16272-4837	6.6	0.17	1.8×10^{-4}	0.8	32.7
IRAS05358+3543	4.4	1.3	9.6×10^{-5}	6.8	42.7

Accretion

Object	$\Delta v_{br,max}$ [km/s]	$I_{out,987}$[a] [K.km/s]	$L_{tot}/(c.v_{inf})$ [$M_\odot.yr^{-1}$]	$\dot{M}_{acc}$ [$M_\odot.yr^{-1}$]	L_{acc} [$L_\odot$]
NGC6334I(N)	32.0	41(3)	7.6×10^{-5}	$2 - 3.5 \times 10^{-4}$	2.3
W43-MM1	35.5	30 (2)	1.6×10^{-4}	$3 - 4 \times 10^{-2}$	300
DR21(OH)	25.5	82 (2)	1.7×10^{-4}	$3.8 - 7 \times 10^{-4}$	1.0
IRAS16272-4837	31.1	11(2)	$1. \times 10^{-4}$	$1.3 - 2.8 \times 10^{-4}$	0.5
IRAS05358+3543	28.5	23(3)			

⇒ Accretion rates high enough to overcome the strong radiation pressure

= in aggreement with McKee & Tan (2002, 2003): massive molecular cloud cores, from which a few massive stars form, should be dominated by supersonic turbulence, with high accretion rate.

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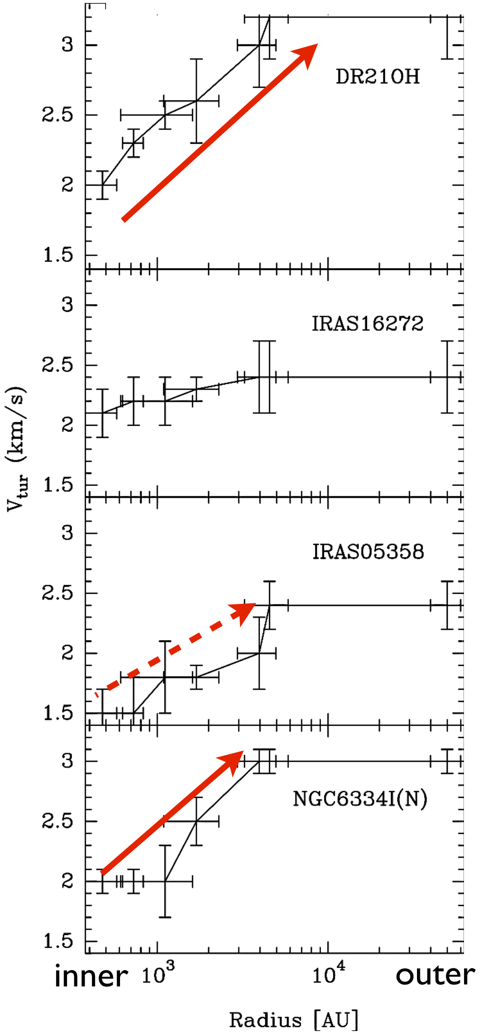
Turbulence variation with R

Object	$\Delta v_{br,max}$ [km/s]	$I_{out,987}$[a] [K.km/s]	I_{out}/I_{em1113} %	I_{out}/I_{em987} %	I_{out}/I_{em752} %	I_{out}/I_{em1097} %	$H_2{}^{18}O$ detected ?	V_{turb} (var?)
NGC6334I(N)	32.0	41(3)	100	61	70	64	+	2-3 (yes)
W43-MM1	35.5	30(2)	100	100	47	0	++	2.2-3.5 (yes)
DR21(OH)	25.5	82(2)	90	60	75	55	++	2-3.5 (yes)
IRAS16272-4837	31.1	11(2)	97	82	65	75	- -	2.2-2.4 (flat)
IRAS05358+3543	28.5	23(3)	75	80	75	70	-	1.5-2.5 (uncertain)



Highly supersonic turbulence, increasing with radius

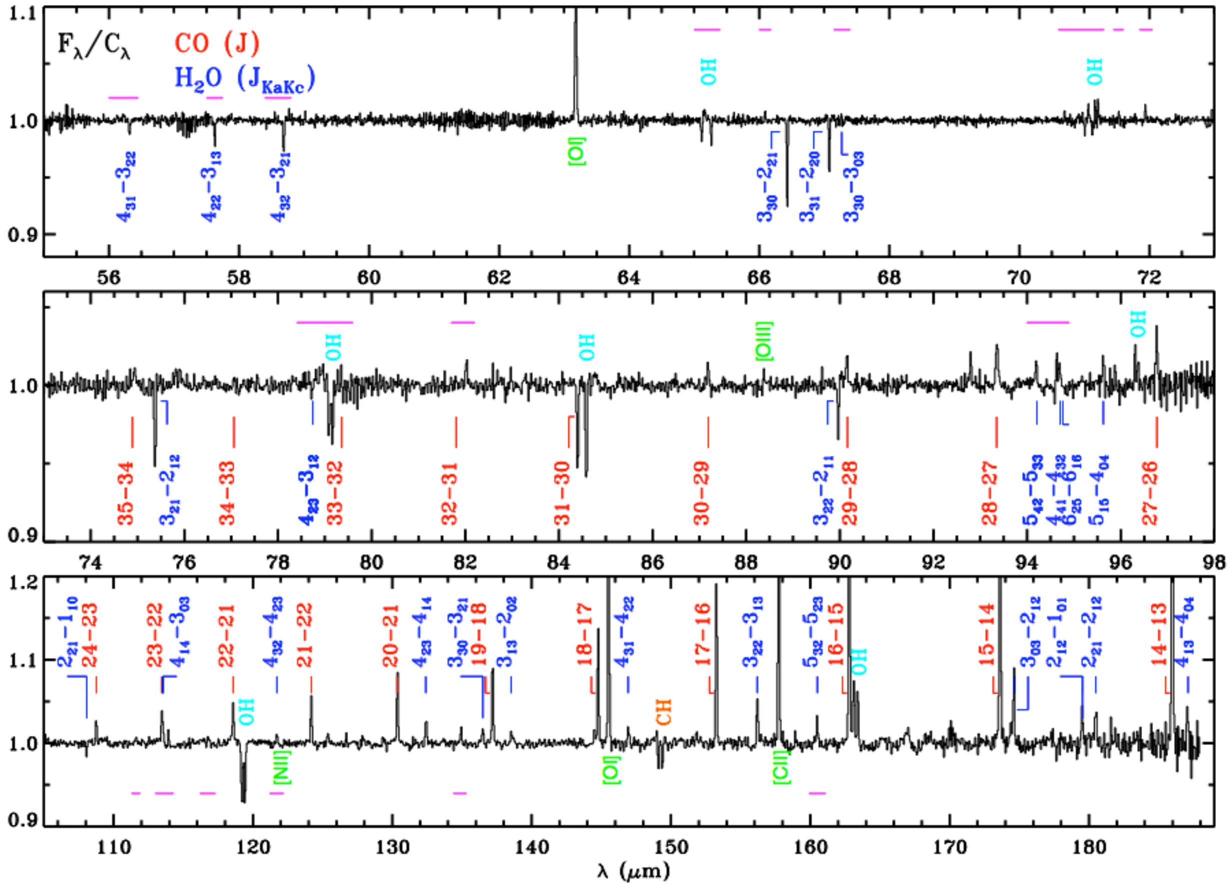
⟹ while not in clear disagreement with the competitive accretion scenario, this **behaviour is predicted by the turbulent core model** *(Krumholz & Bonnel 2009)*

PACS High-mass protostars observations

Karska, Herpin et al. (in revision)

W3 IRS5 d=2 10^3 pc; L_{bol}=2 10^5 $L_\odot$; M_{env}=4 10^2 $M_\odot$

see posters by Karska et al. Kwon et al.

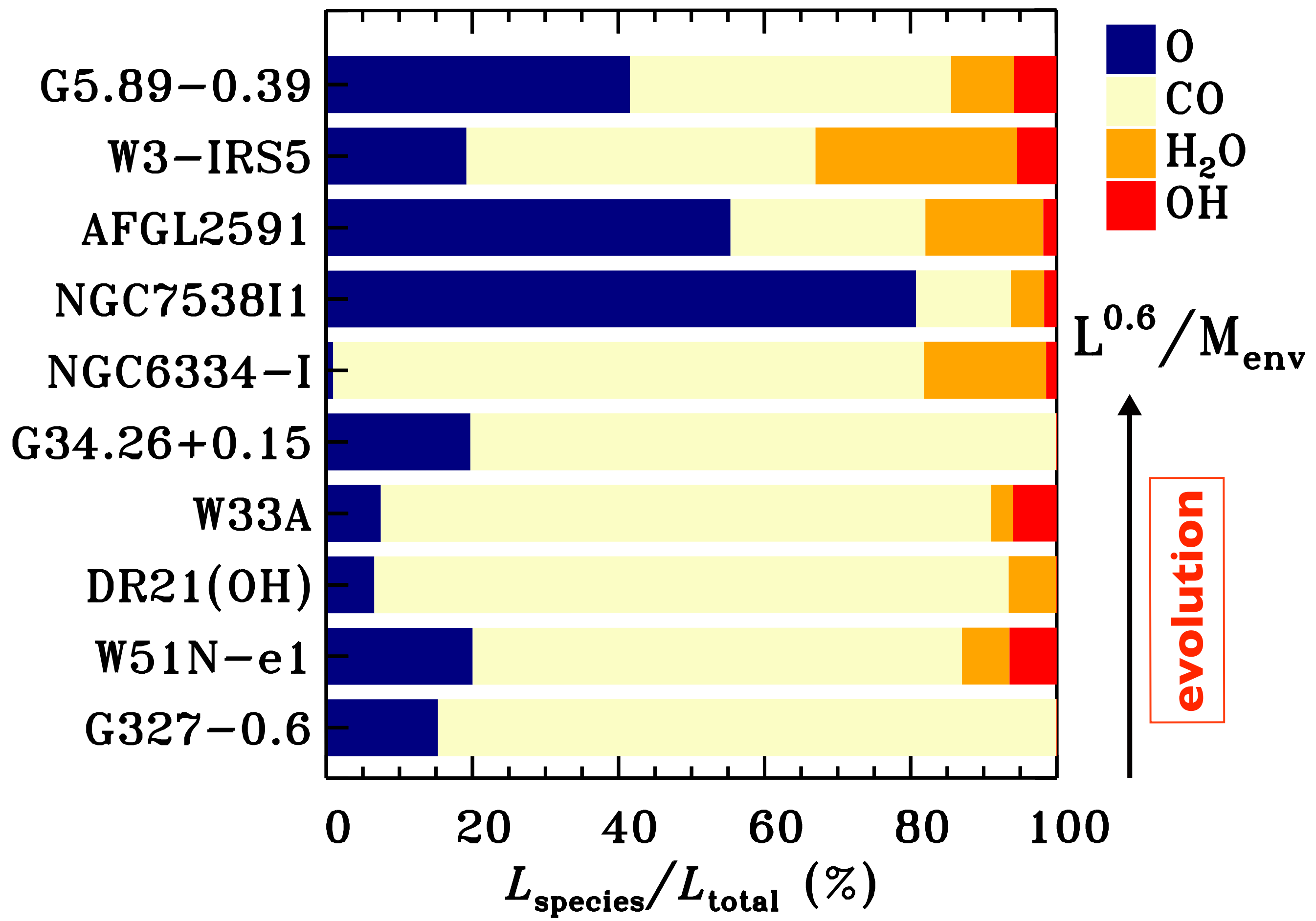


- **Rich molecular and atomic spectra in the 55-190 µm**

  CO, H_2O, OH, CH + OI, CII, OIII, NII

~50 lines of H_2O with E_{up} up to ~1000 K detected in W3 IRS5!

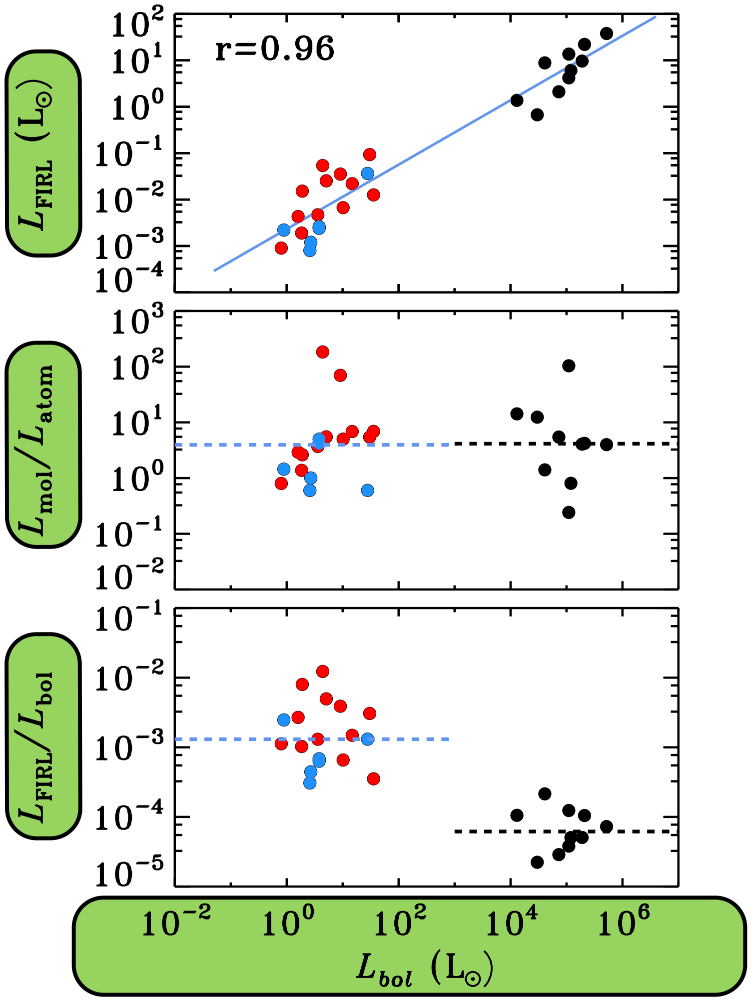
Evolution of far-IR gas cooling



- **CO dominates the cooling of young objects (median ~75%)**
- **[OI] increases for the more evolved sources (~20%)**
- **H_2O and OH - minor contribution (<1%)**

From low- to high-mass objects: far-IR gas cooling

Far-IR gas cooling



- **Far-IR line cooling strongly correlates with L_{bol}, in agreement with low-mass studies**

  (Nisini+2002, Karska+2013)

- **Ratio of molecular and atomic cooling ~4 for all sources**

- **Gas to dust cooling ratio decreases ~20 times for high mass sources**

  (H_2O in absorption)

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Conclusions

• water abundance jump = ***2-steps water abundance profile (≠low-mass)***
• massive protostars are not so dry, but not so wet... ⇒ ***water is not the key***, but help
• ***X_{in} increasing with evolution, $V_{exp,inf}$?*** W43MM1 a peculiar case, why?
⇒ origin of the overabundance of water
- hot core where H_2O ice evaporates
- shocks?

⟹ ***higher water abundance might be related to the large infall or expansion, high turbulence and the micro-shocks created by its dissipation***
• CO dominates the cooling of young objects, [OI] increases for the more evolved ones
• ***H_2O and OH have a minor contribution in the cooling***

• **high accretion rate**
⟹ ***high enough to overcome the radiation pressure*** due to the star luminosity (*Hosokawa & Omukai 2009*). ***Confirms McKee & Tan (2003).***

• **highly supersonic turbulence, increasing with radius**
⟹ while not in clear disagreement with the competitive accretion scenario, this ***behaviour is predicted by the turbulent core model (Krumholz & Bonnel 2009)***

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Thanks for your attention !

Thanks CNES for its financial support

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