Water high resolution spectroscopic observations of massive protostars with Herschel

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WISH

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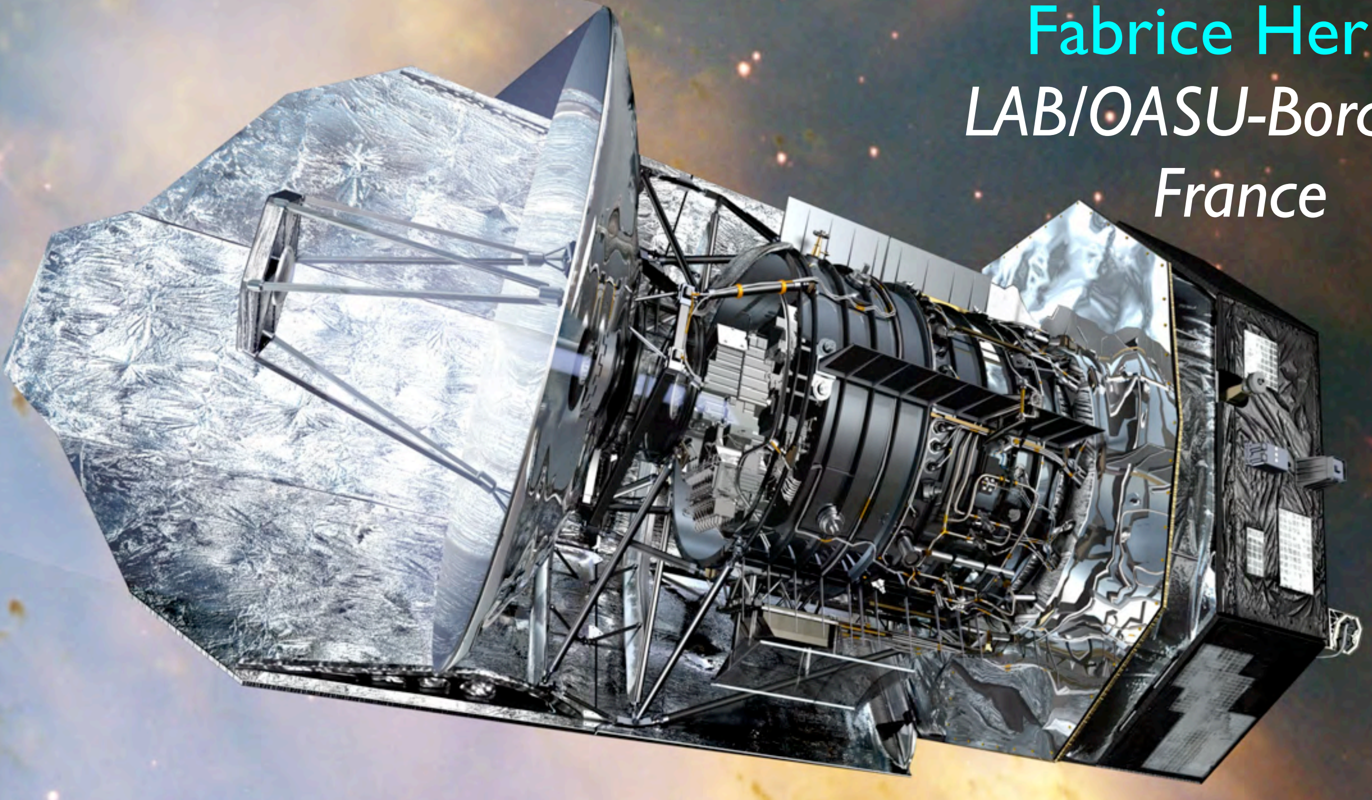

- **F. Herpin**, L. Chavarria, A. Baudry, S. Bontemps, J. Braine, T. Jacq (Bordeaux)
- **F. van der Tak**, Y. Choi, R. Shipman, F.P. Helmich, (Groningen)
- **F. Wyrowski**, S. Leurini, T. Csengeri (Bonn)
- J. Cernicharo, J. Goicoechea, F. Daniel (Madrid)

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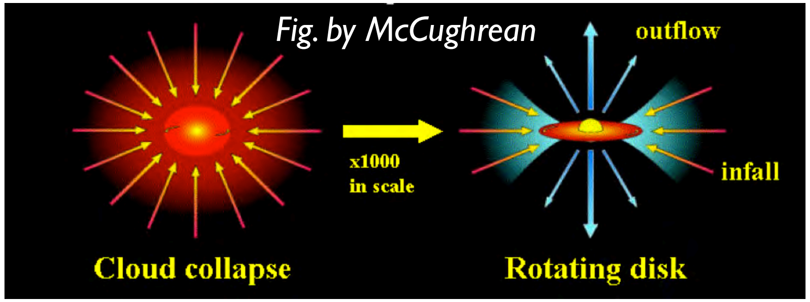
The high-mass star formation puzzle

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**:

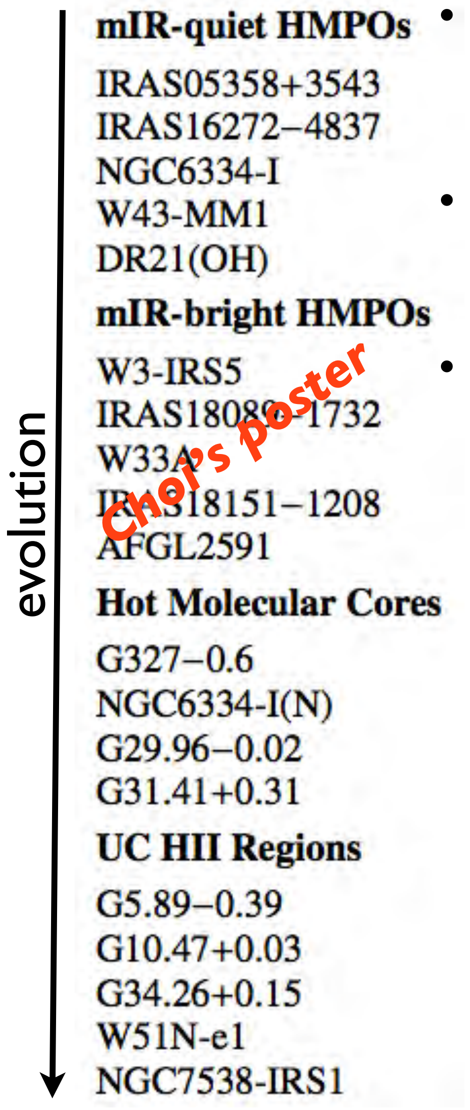
(a) ***turbulent core model*** with a monolithic collapse scenario (Tan & McKee 2002, McKee & Tan 2003);

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

➡ Water might help + water = probe of the dynamics of the gas

In the deeply embedded phase of star formation, it is **only possible to trace the dynamics of gas** through resolved emission-line profiles, such as obtained **with HIFI**.

Water Observations



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

Choi's poster

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

  ⇒ 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

Results: a survey of H_2O ground-state lines in the whole sample

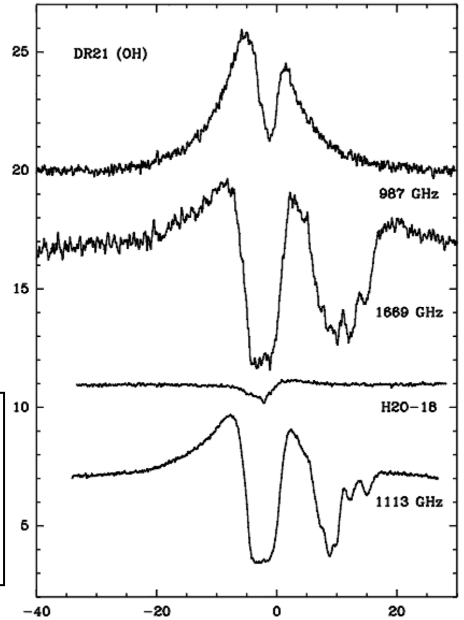
van der Tak et al. (in preparation)

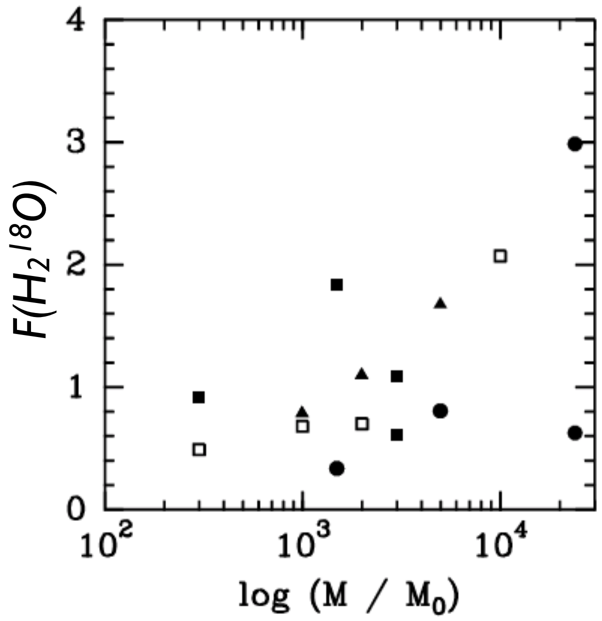
- H_2O as a physical tracer of:
  - heating / cooling
  - radiation / mechanics
- **investigate possible trends with physical parameters**:
  - luminosity
  - mass
  - age

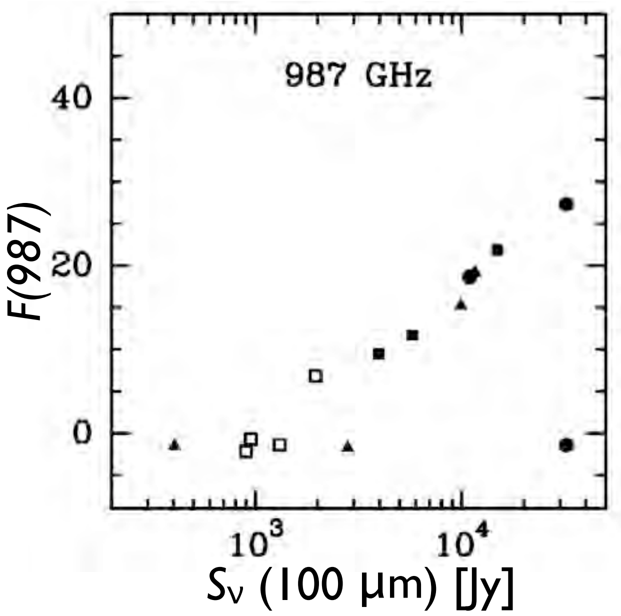
⟹ **some trends appear, e.g.:**

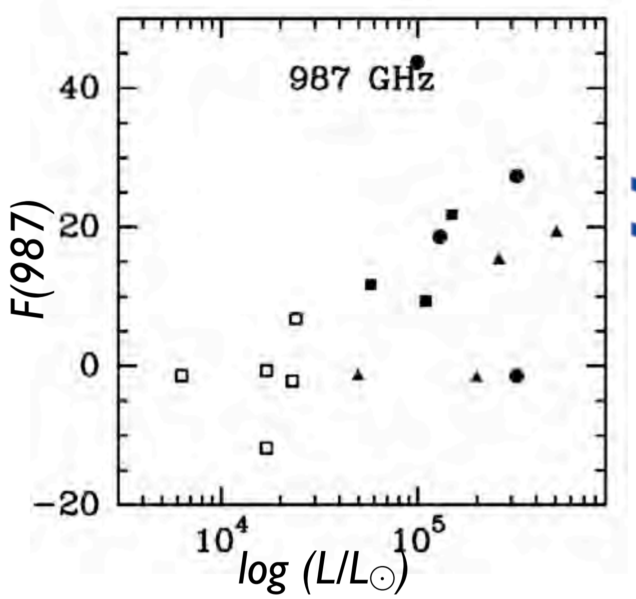
F(987) correlated with L, L/M and far-IR flux (60 and 100 µm)

⟹ ***temperature or age proxy (increase of the L/M with time) ?***





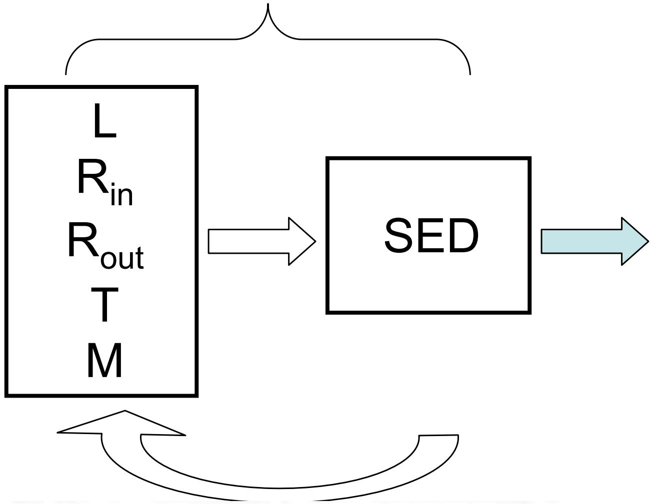




H_2O line profile analysis: modelling

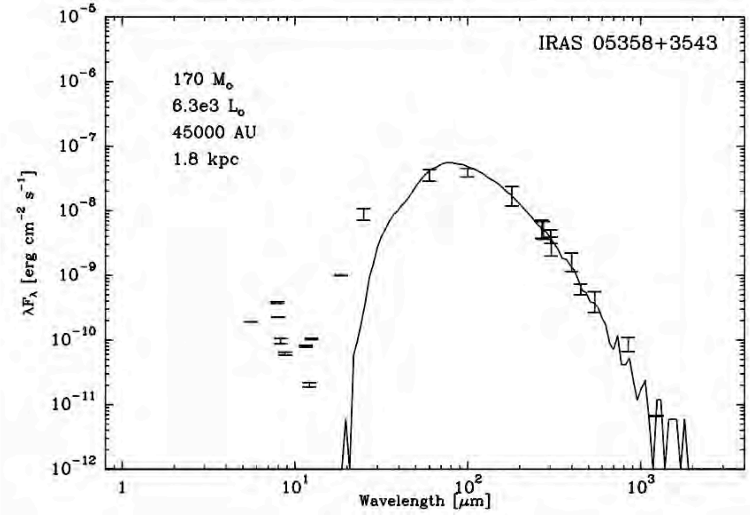
Source model

Whitney-Robitaille (2003)



L
R_{in}
R_{out}
T
M

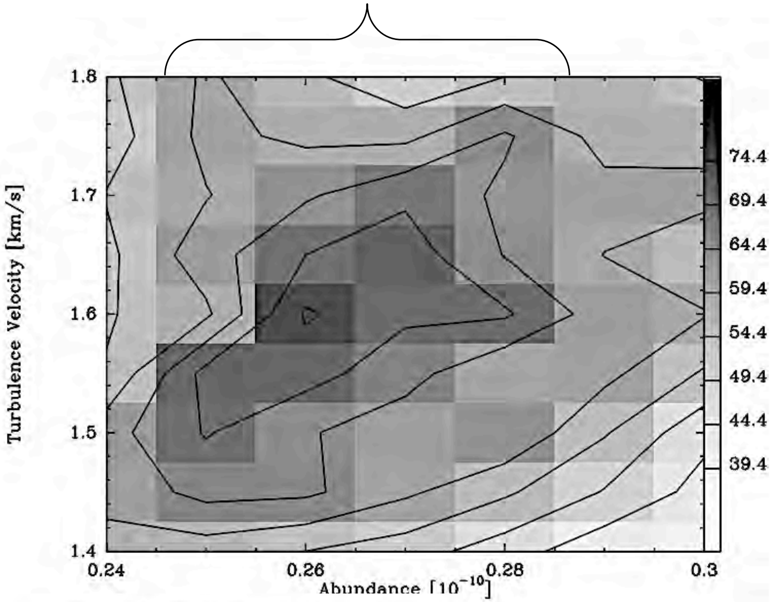
SED

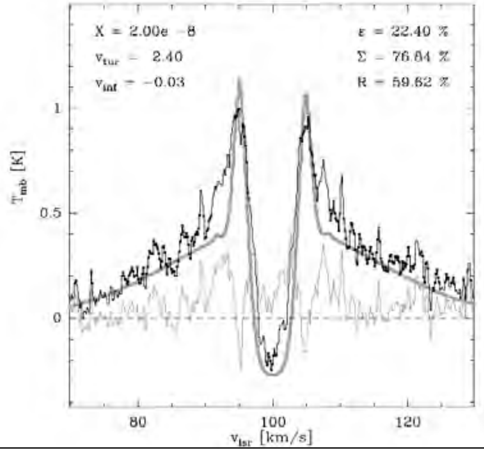


Line modeling

RATRAN

Hogerheijde & van der Tak (2000)

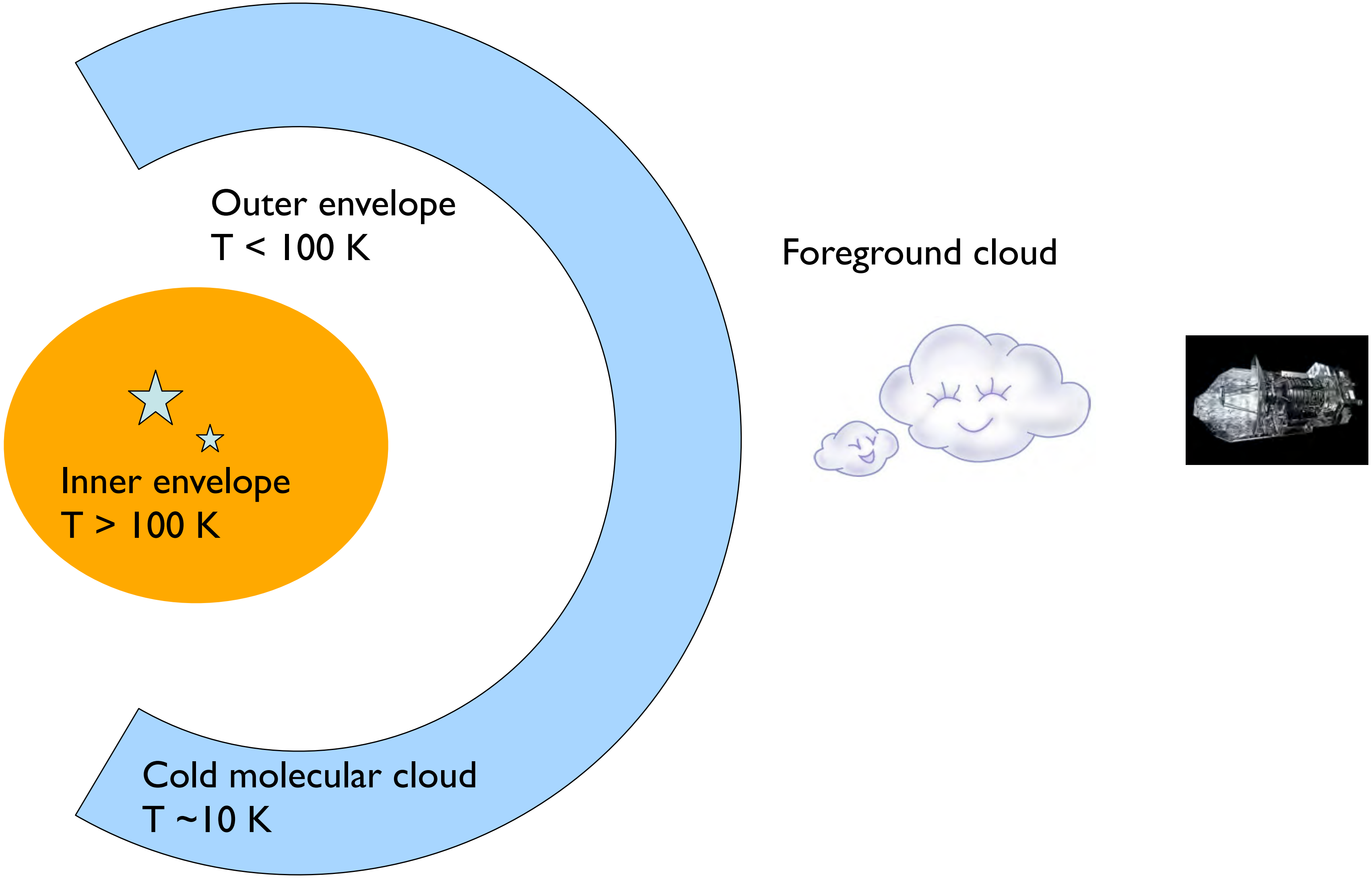




Water collisional rates:
Daniel, Dubernet & Grosjean (2012)
& BASECOL

Courtesy of Luis Chavarria

Terminology



Outer envelope
T < 100 K

Inner envelope
T > 100 K

Cold molecular cloud
T ~10 K

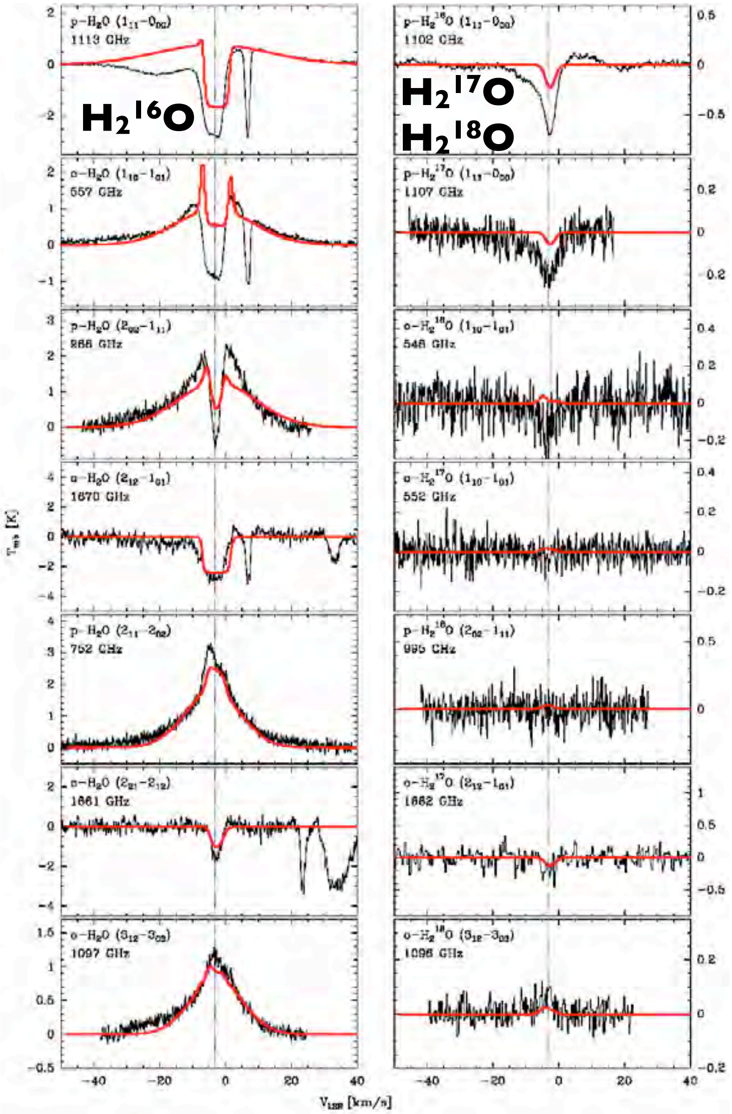
Foreground cloud

Courtesy of Luis Chavarria

Lines fitting for mid-IR quiet MYSOs….

Herpin et al (in revision), Herpin et al. (in preparation)

NGC6334I(N)



Components:

- **broad**

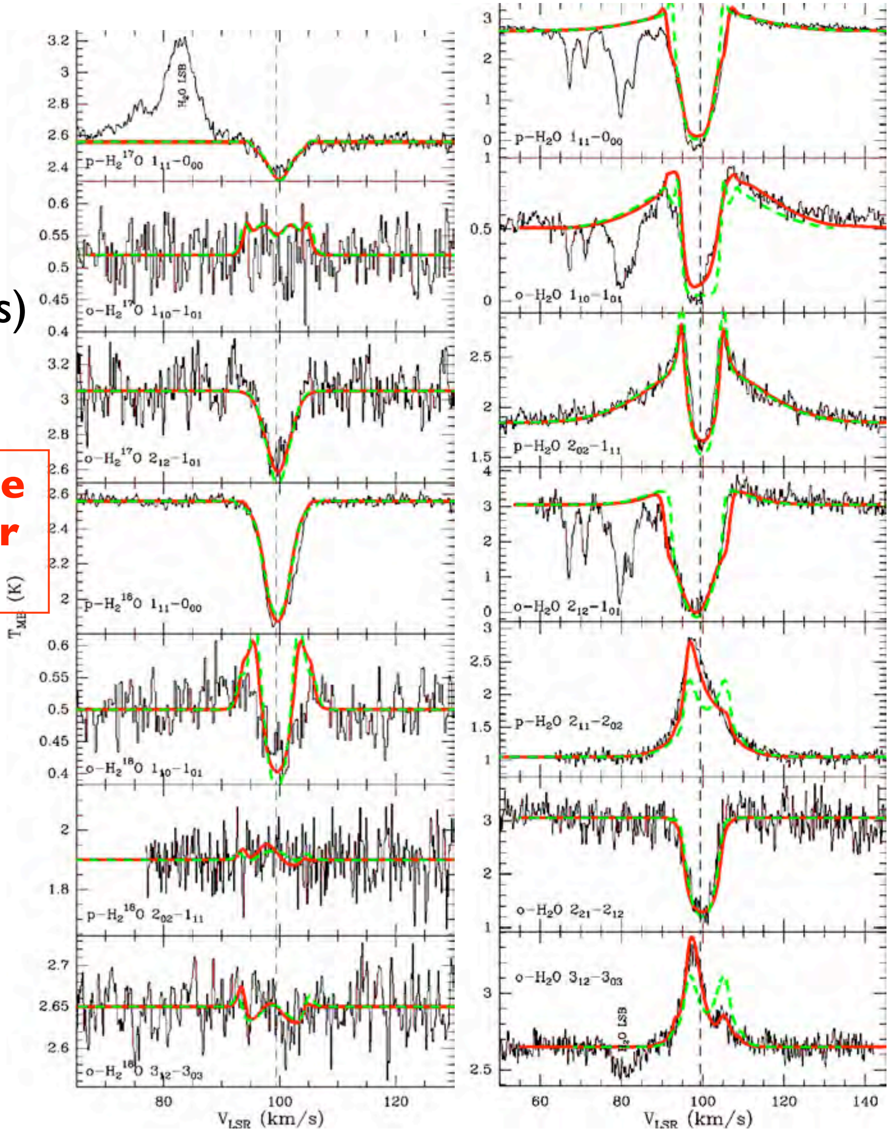
(FWHM>10 km/s)

- **medium**

(FWHM=5-10 km/s)

Water abundance jump in the inner envelope

W43-MM1



Abundances and dynamics results

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

evolution →

	mid-IR quiet					mid-IR bright	UCHII
Parameter	**IRAS05358**	**NGC6334I(N)**	**IRAS16272**	**W43MM1**	**DR21(OH)**	**W3IRS5**	**W51N-e1**
X_{out}	4×10^{-8}	4×10^{-9}	4×10^{-9}	8×10^{-8} (±1)	6×10^{-8}	2×10^{-8}	10^{-8}-10^{-9}
X_{in}	1×10^{-6}	4×10^{-7}	4×10^{-7}	1.4×10^{-4} (±0.4)	5×10^{-6}	1×10^{-4}	5×10^{-5}
V_{turb}	2.0	2.0	2.0	2.2-3.5	2.4	2.0	3.5
$V_{exp/inf}$	2.0	-0.1	-0.1	(-0.9) -(-2.9)	-0.2	2.0	0 -(-7)

Special case: W43MM1, infall and turbulence

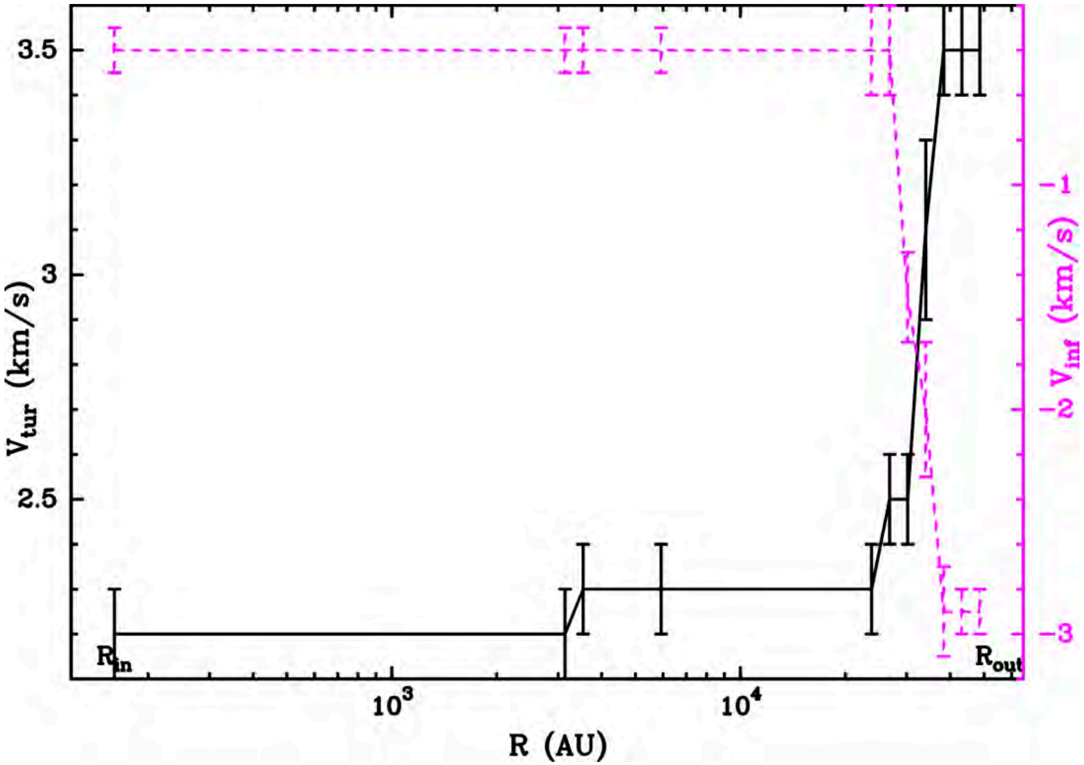
Herpin et al. (in revision)

We see: ***infalling + passively heated envelope + outflow***

- **Huge infall ($V_{inf,max}$ = -2.9 km/s) ⇒ high accretion rate**

⇒ **$\dot{M}$ = 3.5-4 10^{-2} $M_\odot$/yr** @ 5.7 − 7.3 × 10^{17} cm (38100-48800 AU) (spherical accretion assumed)

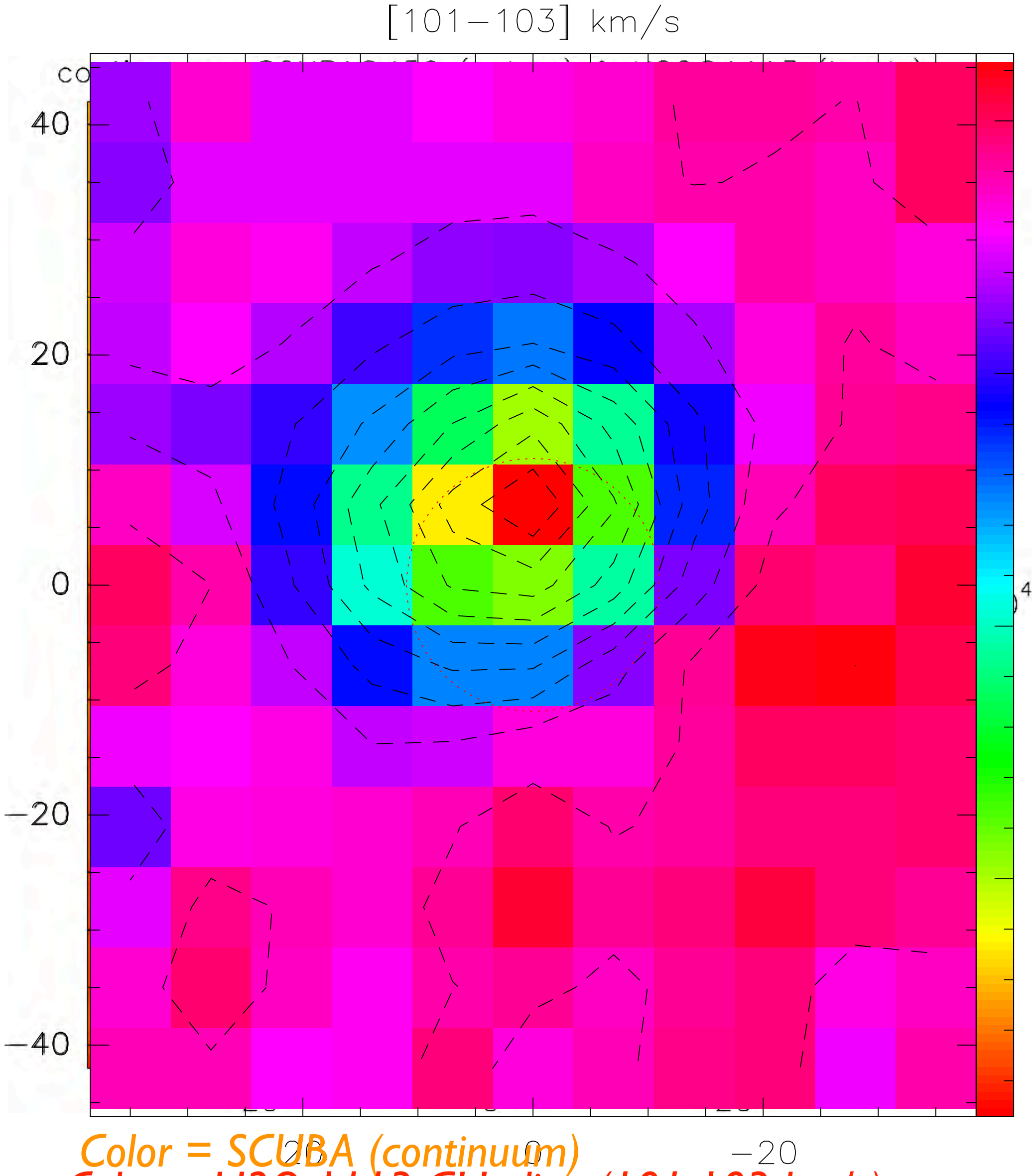
- **highly supersonic turbulence, increasing with radius**

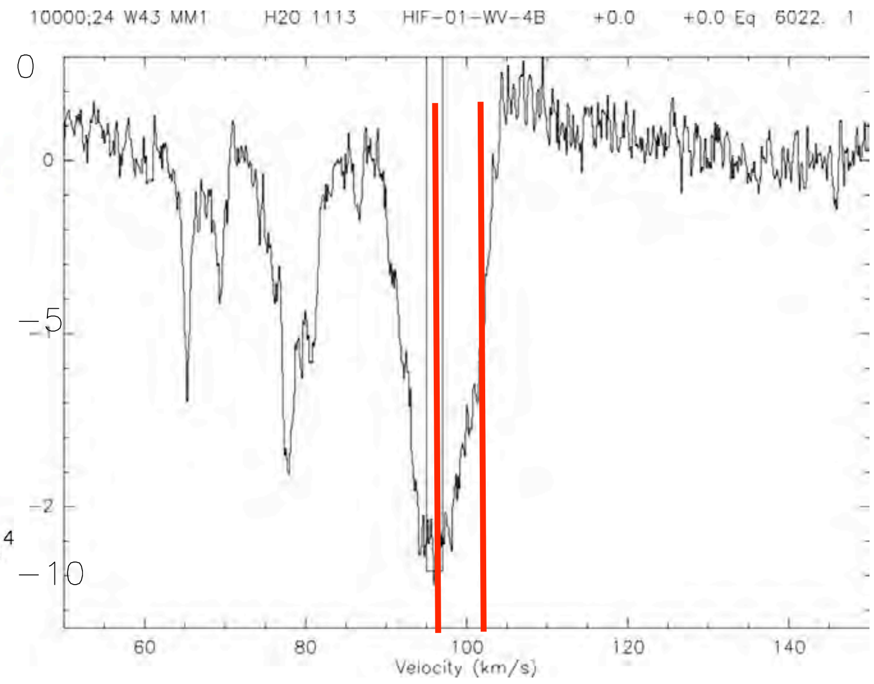


⇒ while not in clear disagreement with the competitive accretion scenario, this **behaviour is predicted by the turbulent core model**
(Krumholz & Bonnel 2009)

W43MM1maps: H_2O 1113 GHz

Herpin et al. (in preparation)





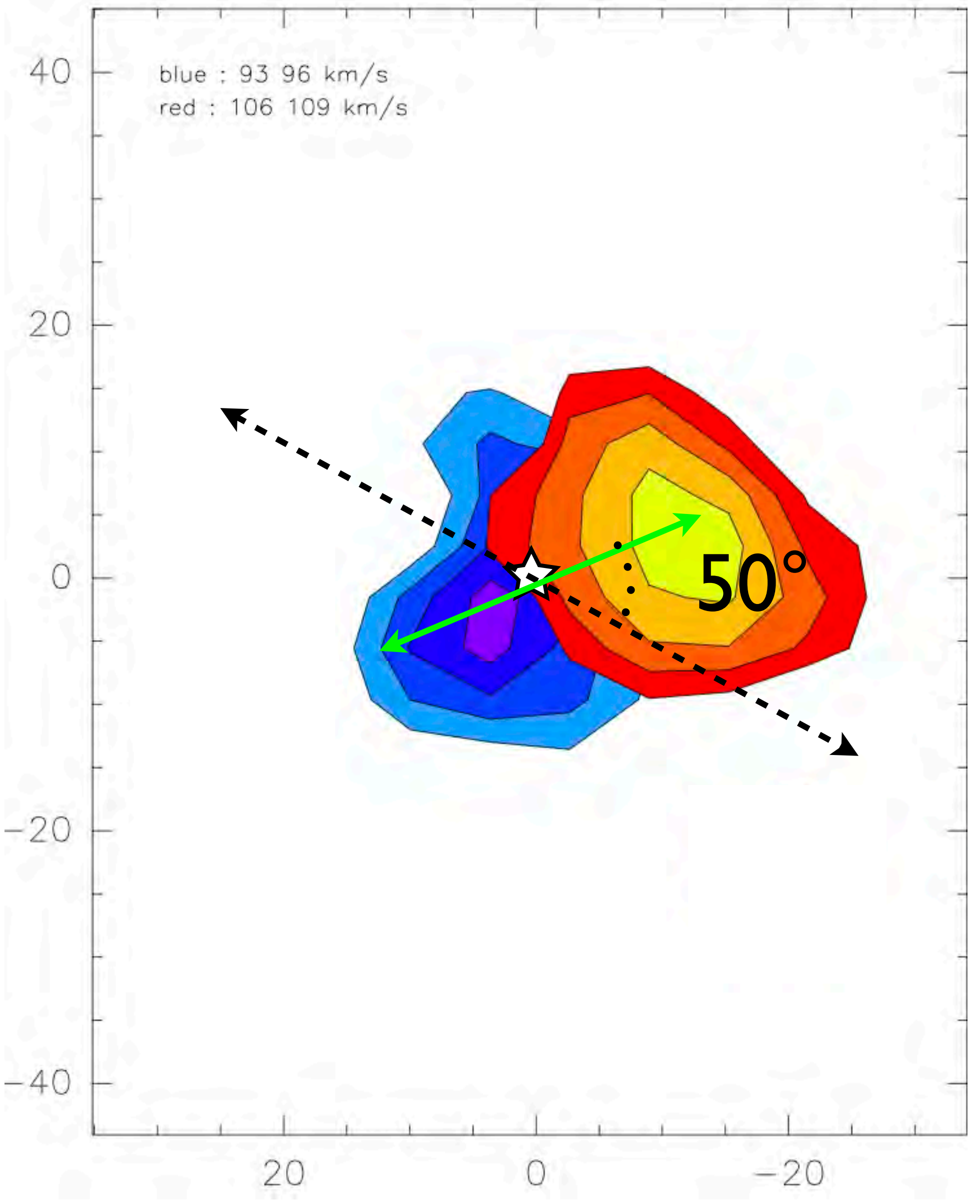
Color = SCUBA (continuum)

Color = H_2O 1113 GHz line (101-103 km/s)

Contours = H_2O 1113 GHz line (95-97 km/s)

W43MM1maps: H_2O 987 GHz outflow

Herpin et al. (in preparation)



H_2O column density

in the outflow (RADEX): 1.5×10^{16} cm^{-2}

Conclusions from W43MM1

• Lower mass limit of gaseous water = 0.11 $M_\odot$. More than 97% of this mass is in the inner part. Mass of oxygen trapped in H_2O and CO is around 3 $M_\odot$, 96% locked in CO and 4% in H_2O.

• **overabundance of water**. ***Origin ?***

- hot core where H_2O ice evaporates
- shocks (e.g. outflows)

⟹ ***higher water abundance might be related to the large infall, high turbulence and the micro-shocks created by its dissipation***

• huge infall ⟹ **high accretion rate**

Hosokawa et al. (2010): realistic accretion rates are much lower (by about one order of magnitude) than the values obtained from the simple formula we used.

⟹ more likely of the order of 10^{-3} $M_\odot$ yr^{-1} and accretion luminosity ≃ a few 10^3 $L_\odot$, hence consistent with the observed total (stellar +accretion) luminosity.

⟹ derived accretion rate, although uncertain, is high enough to overcome the radiation pressure due to the star luminosity (*McKee & Tan 2003; Yorke & Bodenheimer 2008*).

• **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*)

HERSCHEL SPACE OBSERVATORY

Thanks for your attention !

Thanks CNES for its financial support

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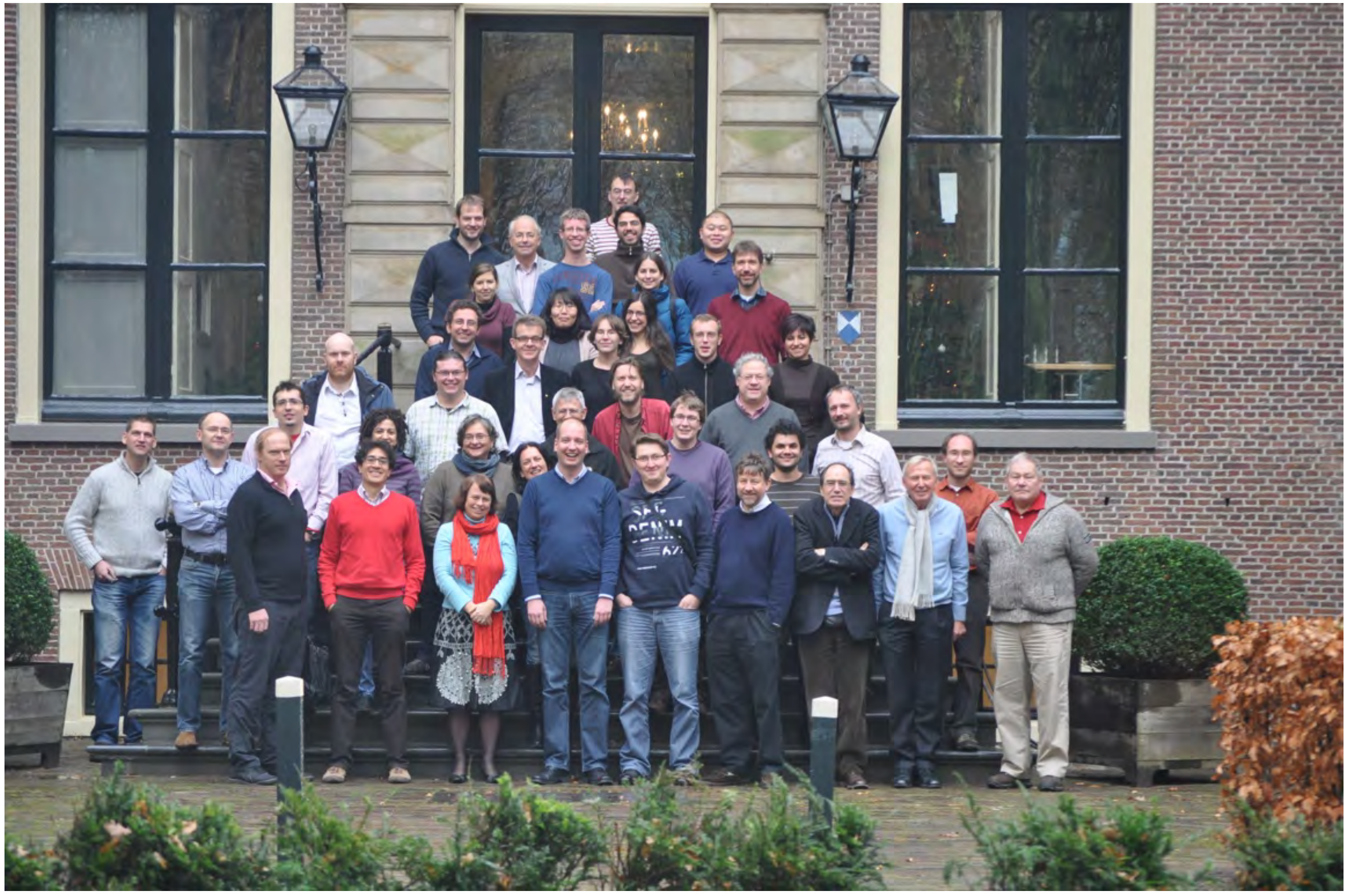
WISH Team



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