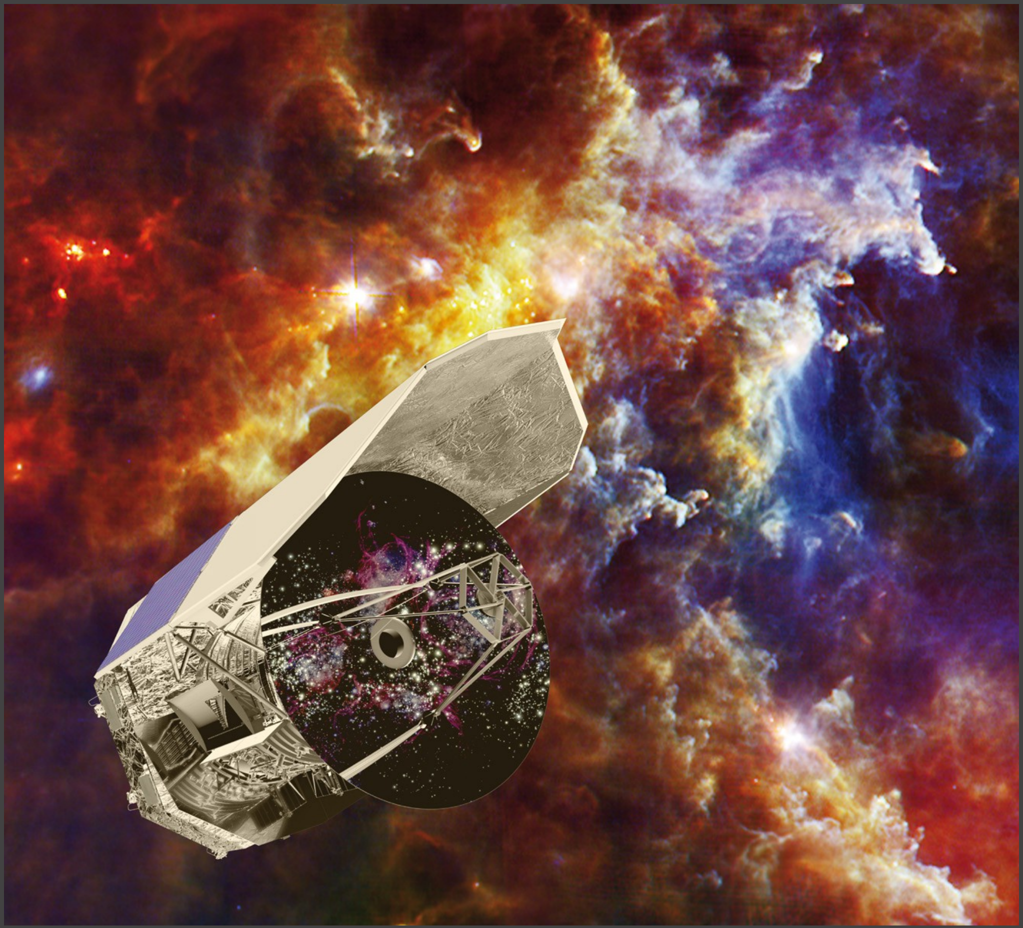
Water in high-mass star-forming regions with Herschel

Floris van der Tak



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university of groningen

The life cycle of gas in galaxies

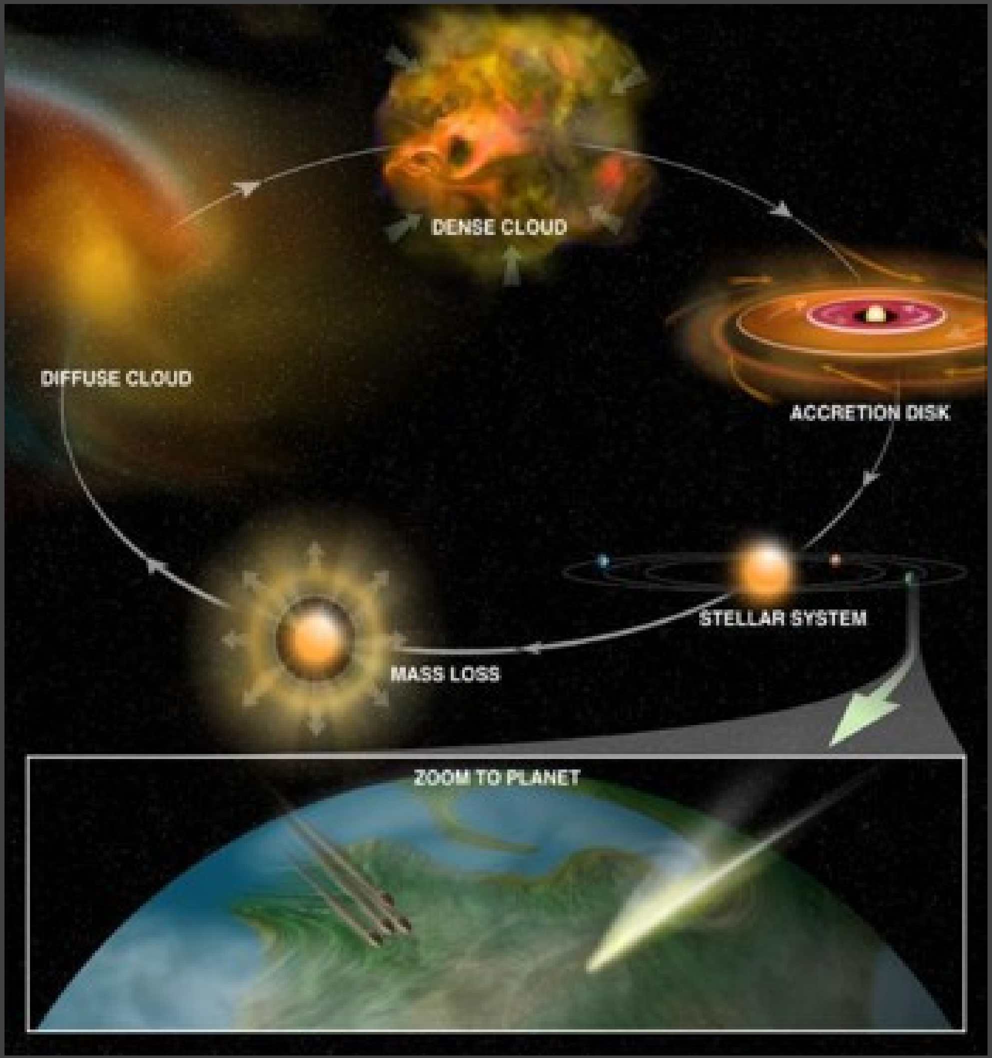

Image: Bill Saxton

- physical conditions – star formation rate
- raw material for planetary systems

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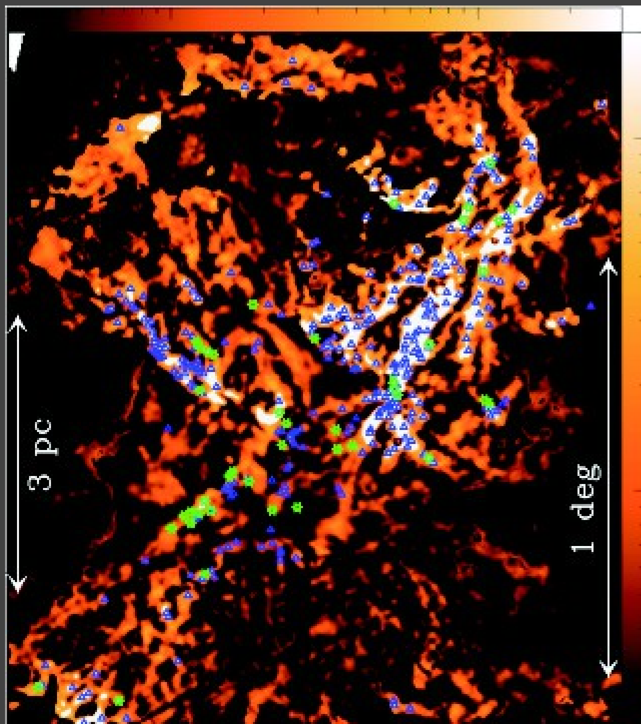
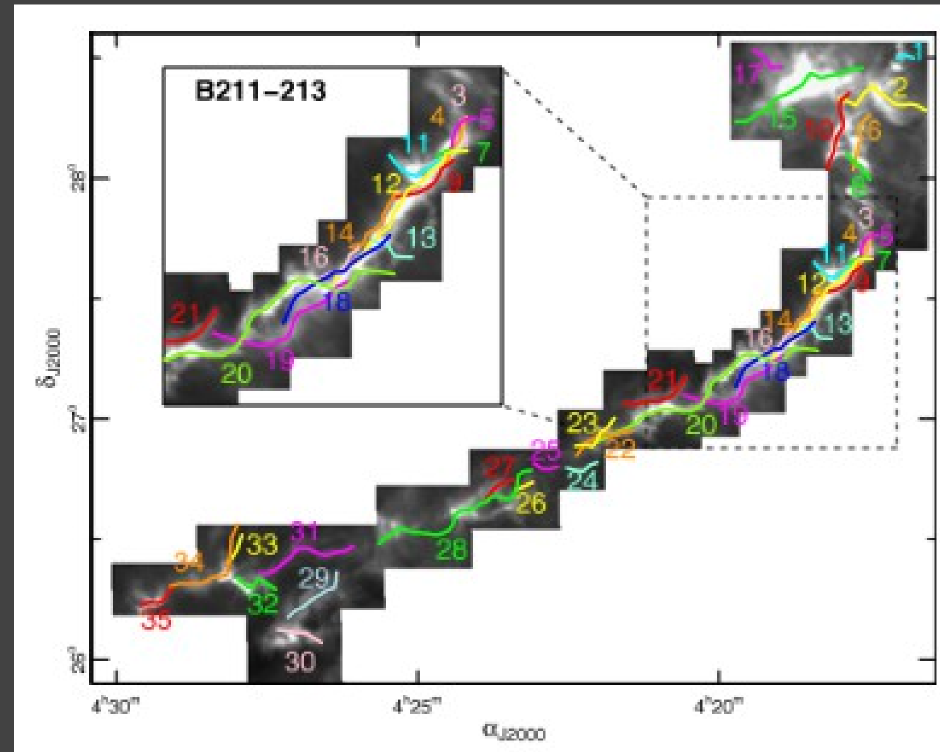
The cloud scale: PACS and SPIRE imaging





Velocity-coherent filaments form first (turbulence)

- cores condense by gravitational fragmentation

Core mass distribution similar to IMF

- decisive phase of low-mass star formation

André et al 2010; Hacar et al 2013

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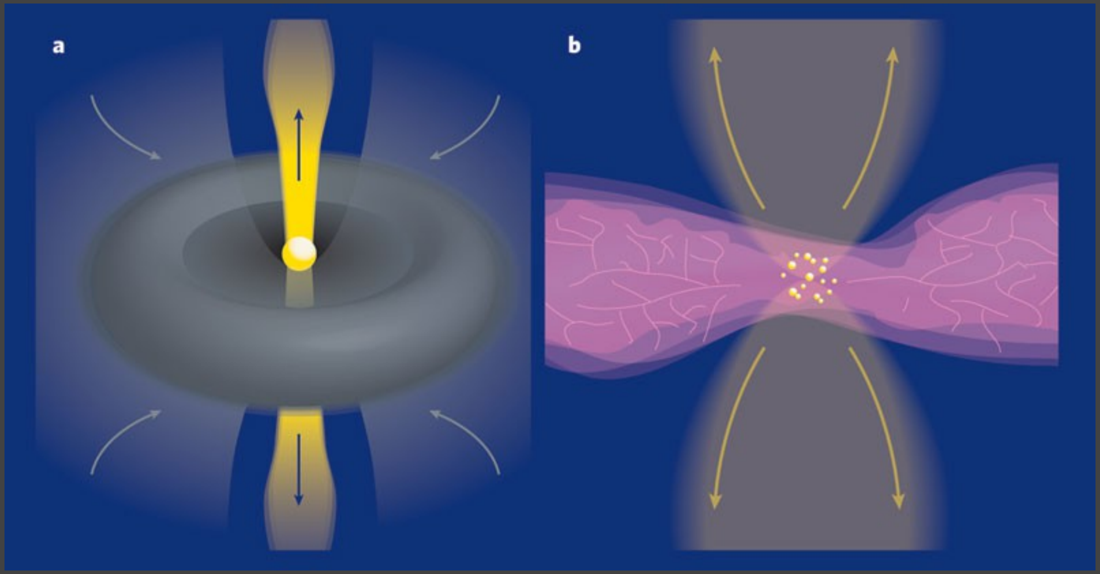
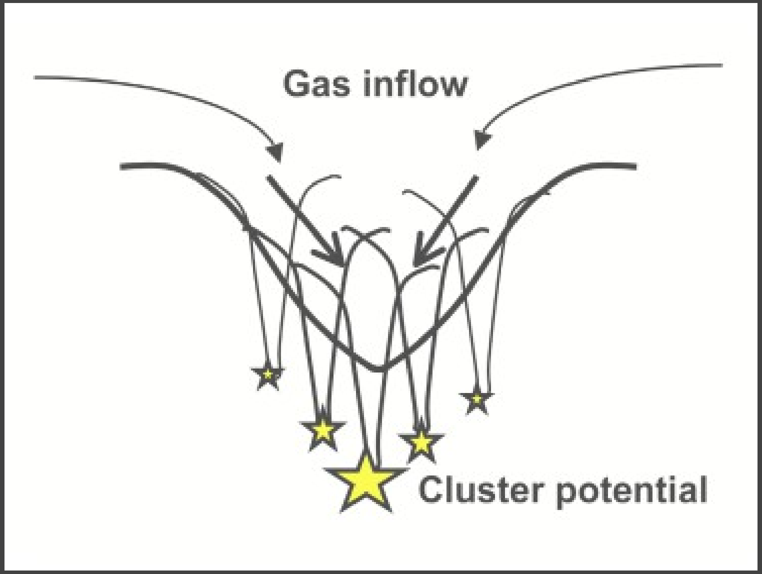
The formation of high-mass stars

- Must form from large reservoir: $M >> M_J$
  - monolithic collapse: turbulent reservoir
  - competitive accretion: replenish reservoir
  - (coalescence: only at very high mass / density)
- How do we distinguish?
  - M_J depends on temperature: need a good probe of T





Whitney 2005; Bonnell et al 2007

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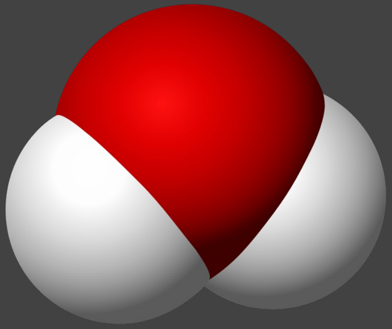
The importance of water

- A natural chemical filter
  - cold dust: freeze-out
  - warm gas: enhancement
  - probe of *energy injection*

- A versatile astrophysical tool
  - asymmetric: rich line spectrum
    - large range in radiative lifetimes
    - line ratios probe temperature *and* density
  - hydride: lines at high frequencies
    - sensitive to dust radiation



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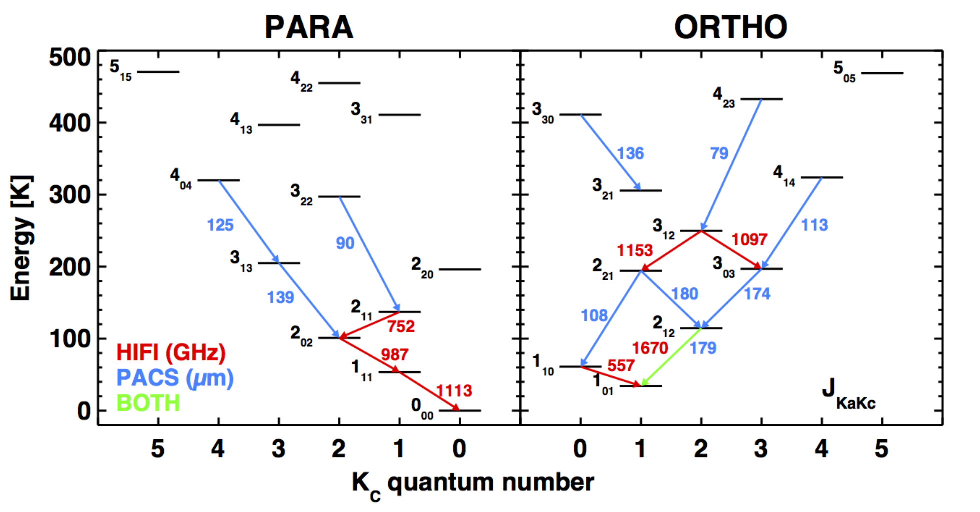
Herschel: A great opportunity…

- Interstellar H_2O: known since 1969
  - masers at 22, 183, 325, … GHz
  - great tool for kinematics and distances (SgrA*, NGC 4258)
- Thermal H_2O: observe from space
  - ISO / SWAS / Odin: large beam
  - Spitzer: only probe warm H_2O
- HIFI: A revolution
  - multiple lines (including ground states)
  - high spectral resolution
  - good angular resolution
- PACS: Complementary info
  - high-excitation lines
  - spatial distribution



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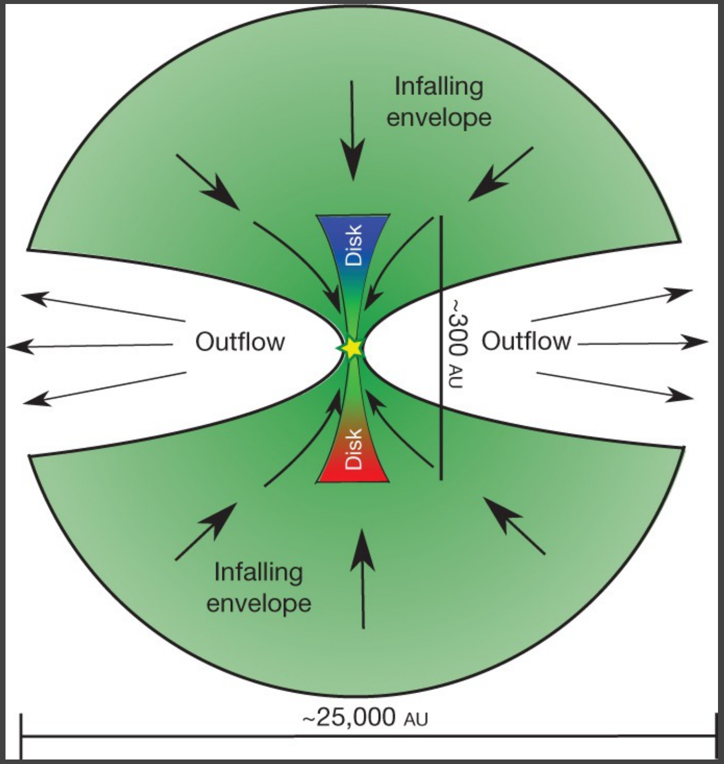
…especially for high-mass protostars

- Survey of 19 objects: L = 2000 – 400,000 L_0, d = 1.5 – 7.9 kpc
  - range of mid-IR brightness
  - signs of active star formation
- H_2O as a physical tracer
  - heating vs cooling
  - radiation vs mechanics
- Origin of H_2O emission & absorption
  - envelope
  - outflow
  - foreground
- trends with physical parameters
  - luminosity
  - mass
  - age



Tobin et al 2012

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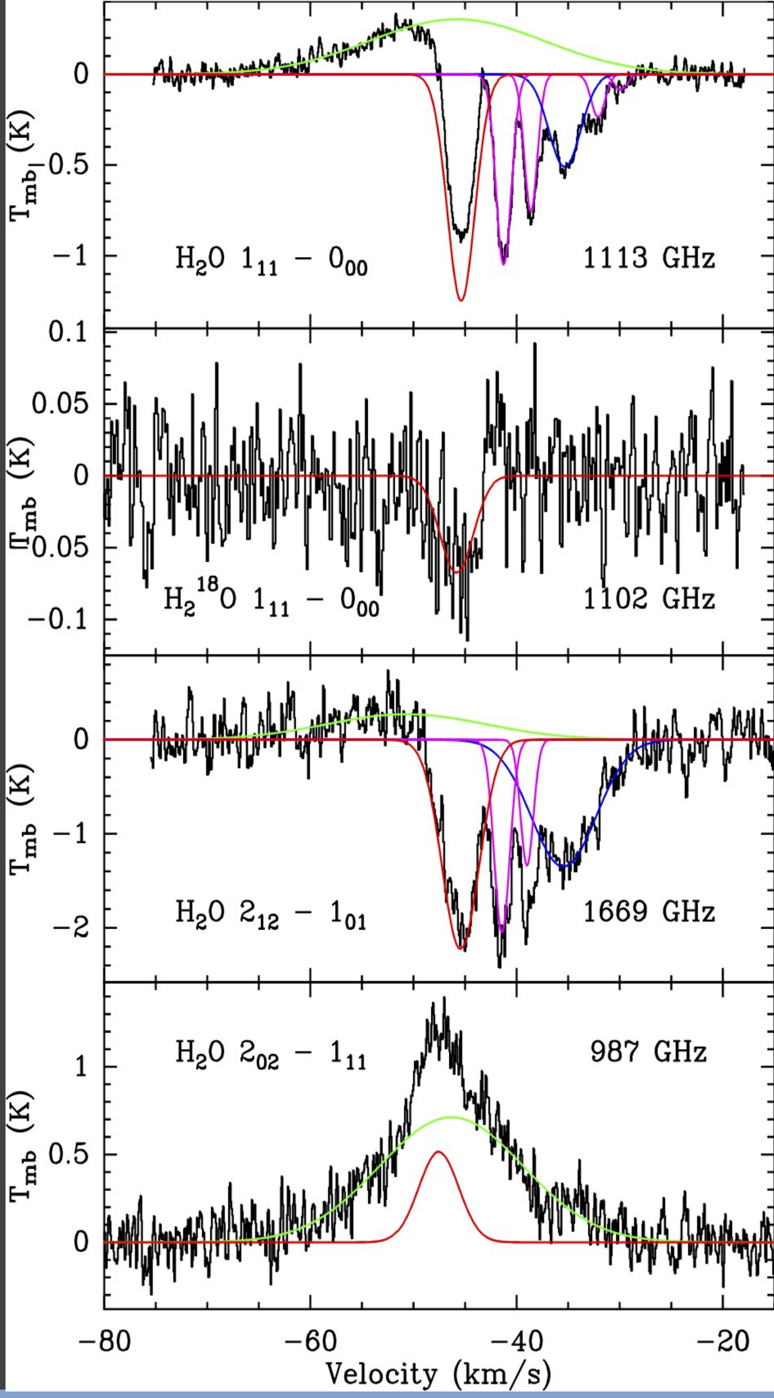
Line profiles: 4 components

- Continuum (100—3000 Jy)
  - cold, optically thick dust
- Envelope
  - at ground-based V_0, ΔV
  - emission or absorption
  - signs of infall & expansion
- Outflow
  - broad emission
  - usually blueshifted
  - directed toward us
- Foreground clouds
  - low column: UV dissociation
  - high o/p ratio: warm gas



Van der Tak et al 2013

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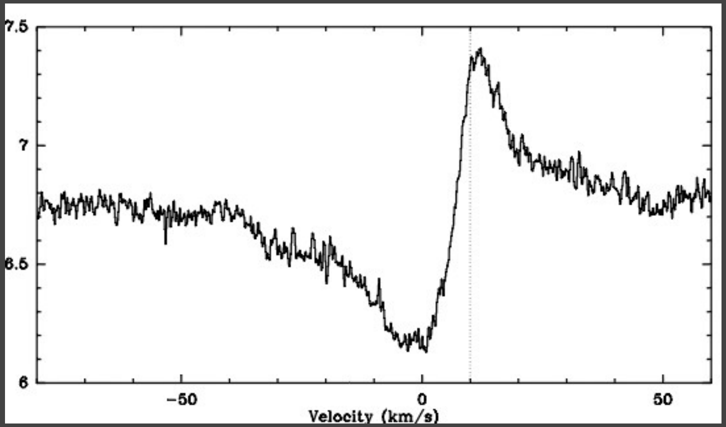
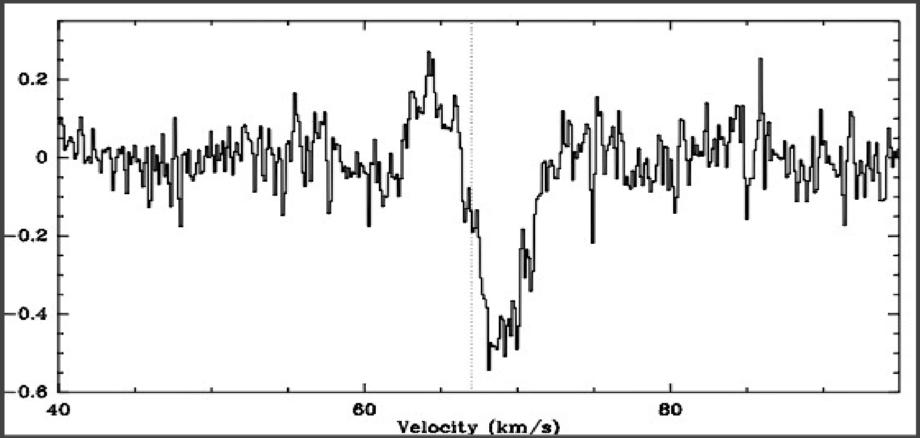
Signs of infall & expansion

- Infall signatures in excited-state line
  - infall only in inner envelope
- Signs of expansion in ground-state lines
  - expansion in outer envelope
- Combination of both seen in SgrB2 envelope
  - Rolffs et al 2010
- High spectral resolution essential!



Expansion profile



Infall profile

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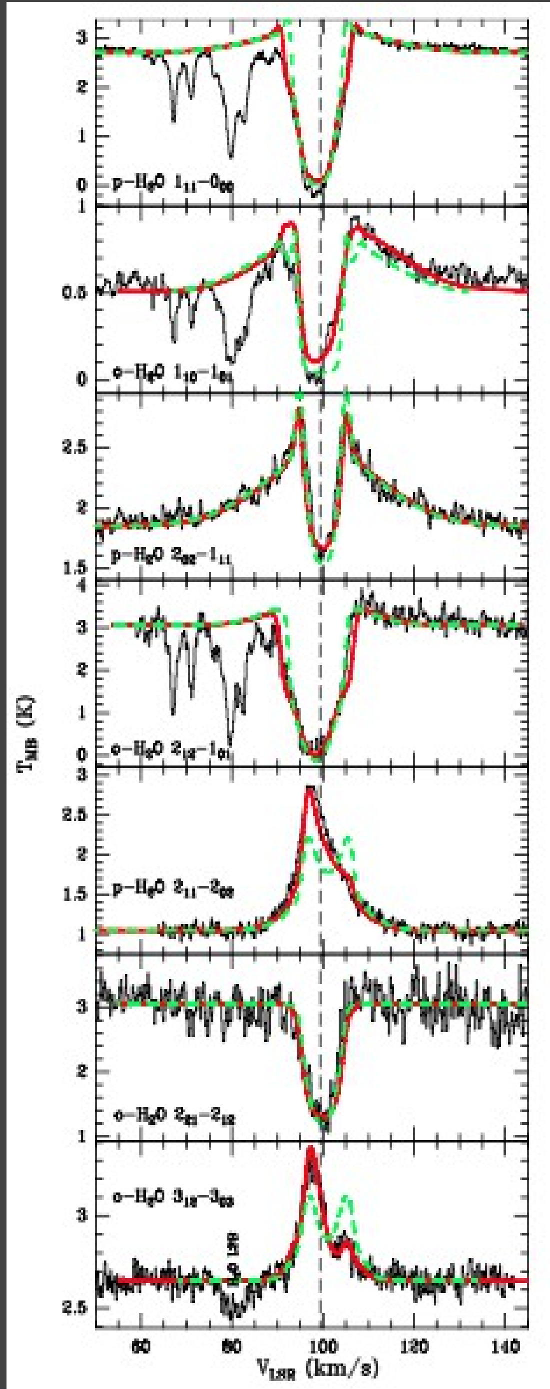
Detailed model for W43MM1

- Detect 14 (isotopic) H_2O lines
  - envelope / outflow / foreground
  - physical structure from continuum
  - radiative transfer modeling of lines
- Kinematics
  - supersonic turbulence
  - fast infall ~1 km/s
  - high accretion ~few 10^{-3} M_0/yr
- Chemistry
  - outer envelope: freeze-out
  - inner envelope: enhancement

Herpin et al 2012



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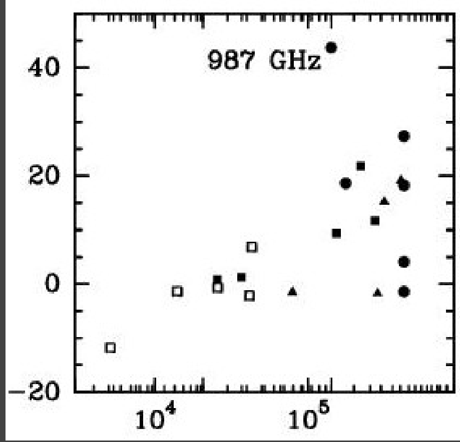
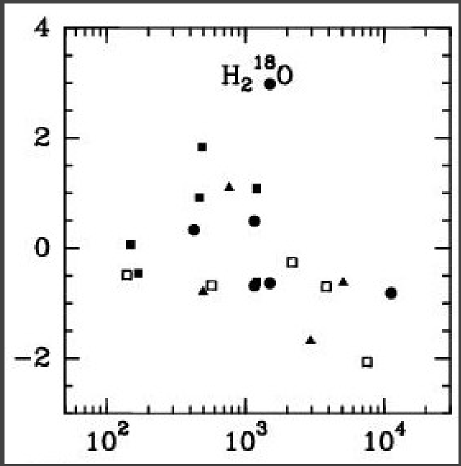
H_2O trends & thresholds

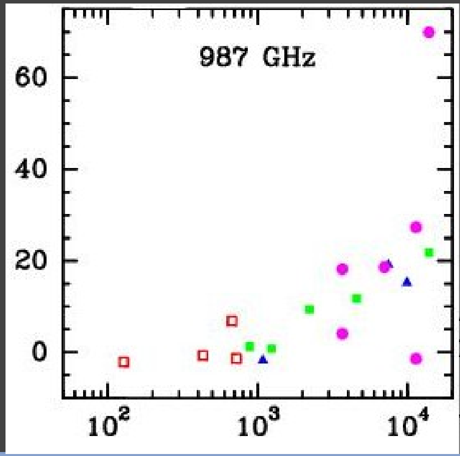
- *F*(987 GHz) increases with *L*
  - emission only
  - threshold (not correlation)

- $H_2{}^{18}O$ from emission to absorption with *M*
  - outer layers ~constant abundance

- *F*(987 GHz) increases with far-IR flux
  - temperature effect







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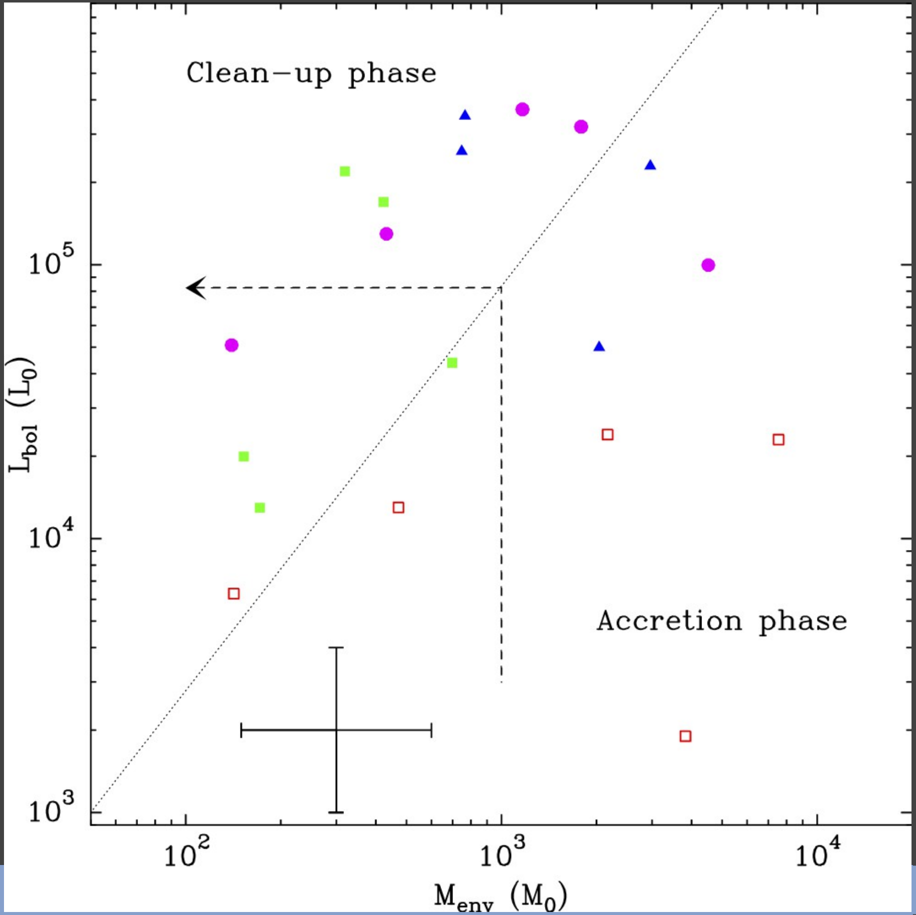
Evolutionary trends

- Molinari et al (2008) model: plot L_{bol} vs M_{env}
  - phase 1 = accretion
  - phase 2 = clean-up
  - similar to low-mass case
- Our sources:
  - weak mid-IR in phase 1
  - most others in phase 2
- Connection with H_2O:
  - absorption = sign of youth



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Water in high-mass star formation: summary

- Formation and destruction of H_2O
  - outer envelope: freeze-out
  - inner envelope: evaporation
  - outflow: gas-phase enhancement
  - foreground cloud: photodissociation
- Kinematic tracer
  - infall / outflow / expansion
  - radial variations of turbulence & infall
  - support for *monolithic collapse model*
- Evolutionary tracer
  - massive pre-stellar cores are rare
    - H_2O profiles show trend from absorption to emission
  - protostars: trends with luminosity & far-IR flux
    - from "accretion" to "clean-up" phase

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Conclusions

- Water: a great tracer of high-mass protostellar environment
  - various physical & kinematic components
  - contributes ~10% to cooling (Karska et al 2013)
- Line profiles change from absorption to emission with time
  - but signs of infall & expansion seen at all stages
- Ground state lines: no clear trends with *L*, *M*, or age
  - combined emission / absorption: hard to see in galaxies
- Excited state line increases with *L* and far-IR flux
  - traces average source temperature
  - seen out to high *z*

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The future: ALMA!

- Antenna 66 just delivered
  - Bands 3, 6, 7, 9 operating
  - and 4, 5, 8 coming up

- Band 5 great for star formation
  - dust: fragmentation, multiplicity
  - H_2O: kinematics, chemistry

Thanks to:

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