The distribution of H_2O and CO in DR21

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A&A Letters, in press (Herschel special issue)

High-mass stars

- 1% by number, 99% by impact
  - major energy source for ISM
  - shape the Galactic environment
  - link to starbursts and early Universe

- Formation not well understood ...
  - low-mass stars: monolithic (disk) accretion
  - scale-up: requires high temperature / turbulence
  - alternatives: coagulation / competitive accretion

- ... due to instrumental limitations
  - large distance: need angular resolution
  - large extinction: need far-IR and submm range

Herschel and ALMA will revolutionize this field!

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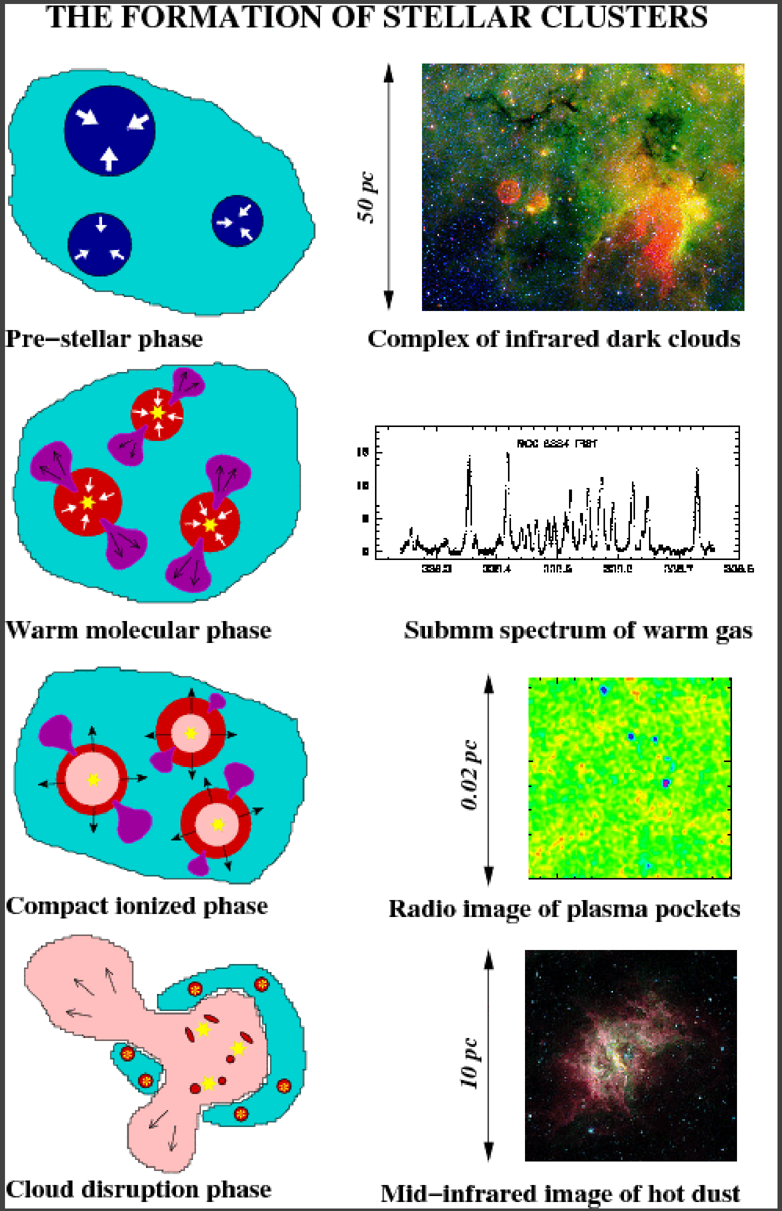
Phases of high-mass star formation



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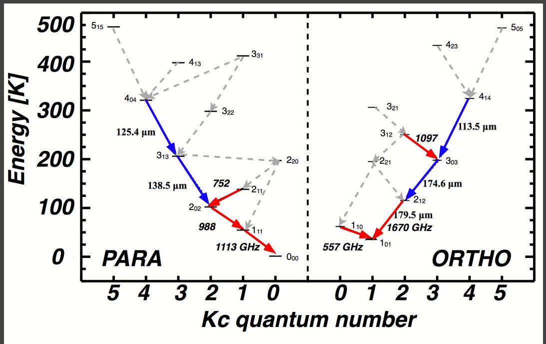
The role of water in star formation

- Versatile molecule, more active than CO
  - in clouds (gas): cools down collapsing clouds
  - in disks (ice): glues grains together into planetesimals
  - on planets (liquid): brings molecules together, key to life

- H_2O abundance varies strongly in star-forming regions
  - SWAS, ISO, Odin: 10^{-8} (cold) ... 10^{-4} (warm)
  - Spatial distribution not well known
  - Spitzer / ground-based: only see warm gas



- Major reservoir of oxygen
  - affects chemistry of many other species
  - cold dust surfaces / warm gas phase / photochemistry

Herschel: the first high-resolution view of the bulk H_2O

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WISH: water in star-forming regions with Herschel

- Key program in 429 hours of GT
  - goal: physical and chemical structure of SF regions
- Covers 90 sources
  - pre-stellar cores
  - protostars of low/high/intermediate mass
  - outflows
  - protoplanetary disks
- Uses HIFI and PACS spectroscopy
  - including small (2' x 2') maps
- Collaboration of >70 scientists
  - from >30 institutes world-wide

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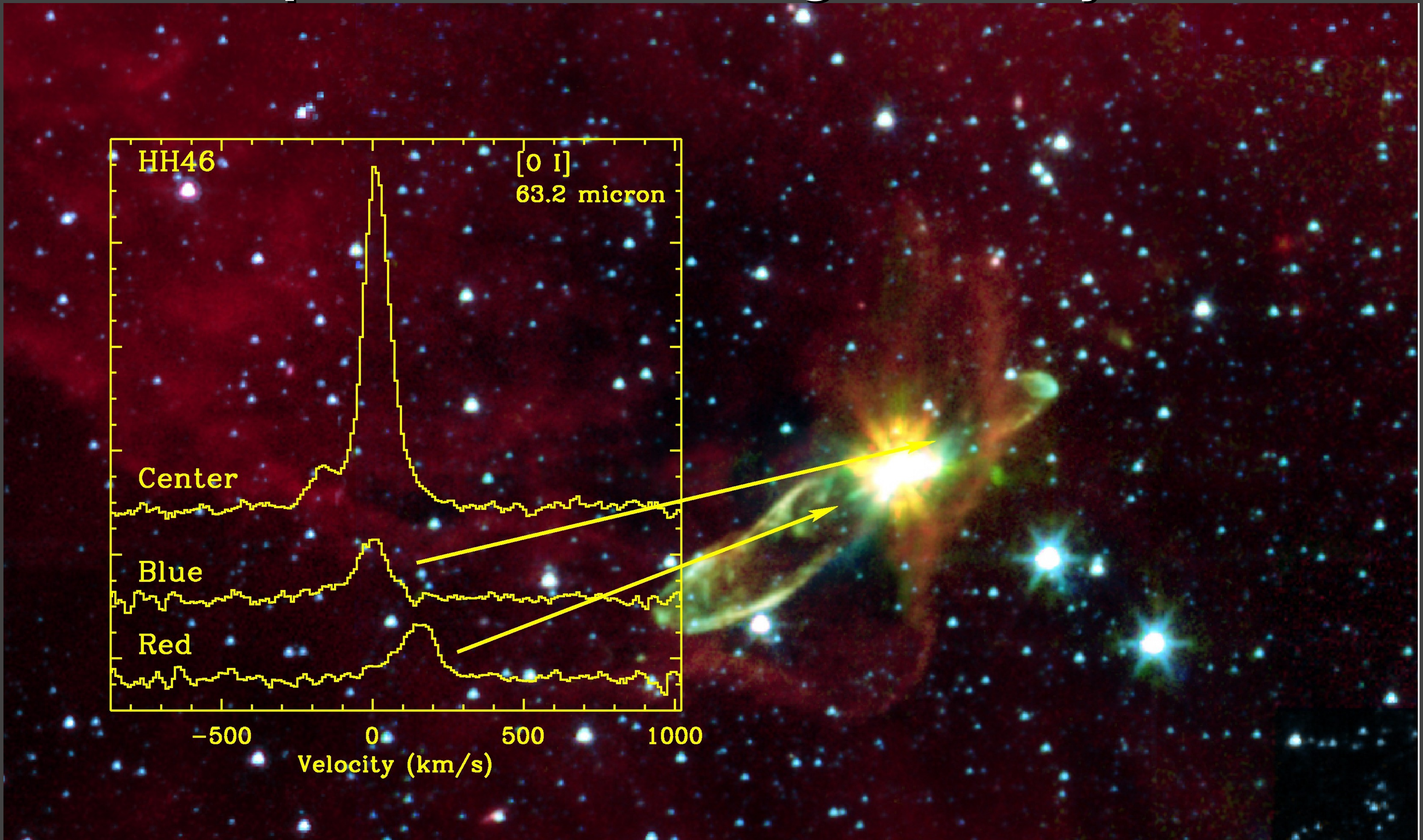
Low-mass protostar HH46: high-velocity [OI]



- Also CO and H_2O lines detected

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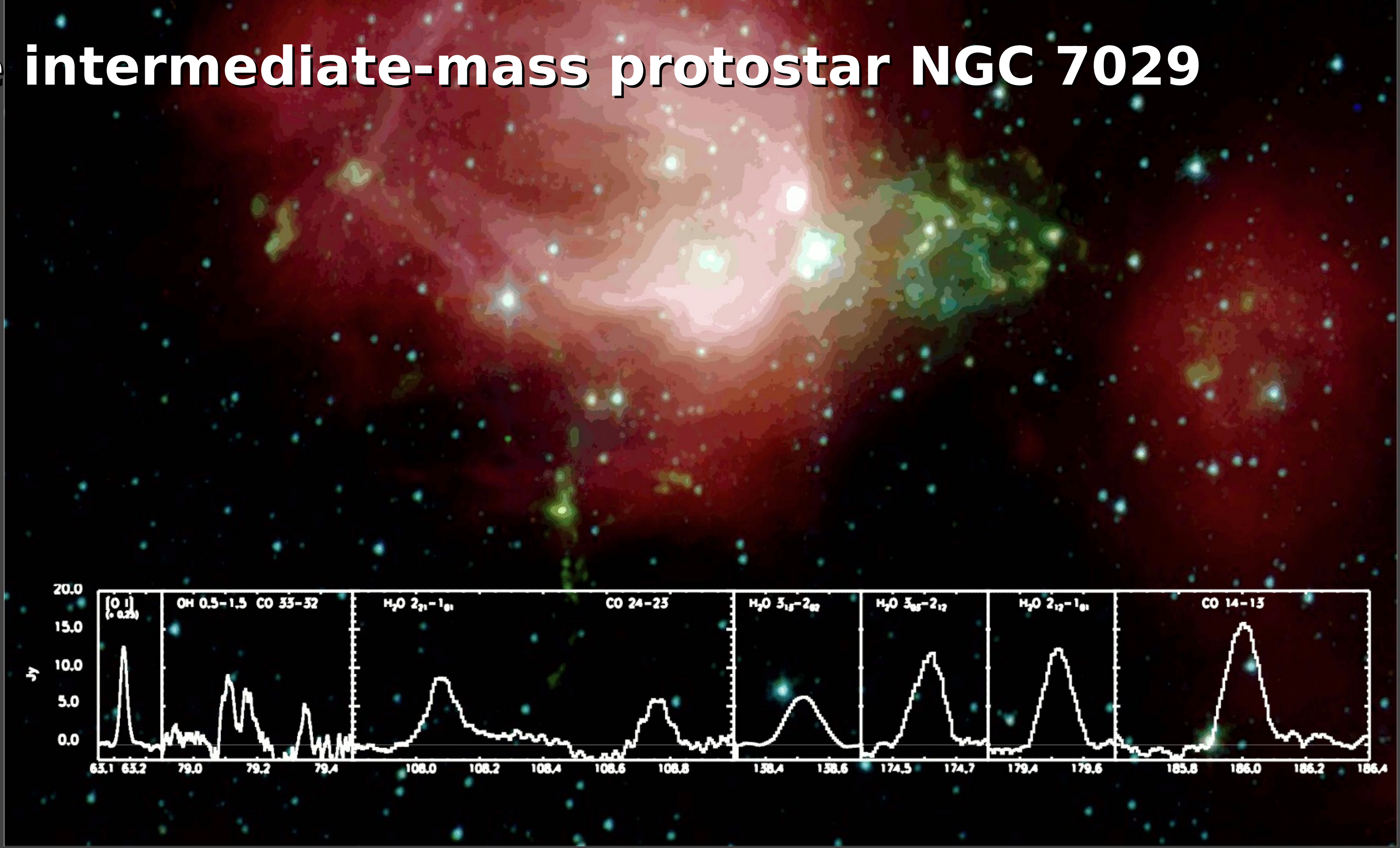
The intermediate-mass protostar NGC 7029



- Strong H_2O, CO, OH and O lines detected
  - Contributions from envelope and outflow
  - Need HIFI to disentangle these!

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High-mass star formation in WISH

- Subprogram with 127 hours of GT + 20 hours of MS time
  - goal: evolutionary connection between types of sources

- Observe 20 sources
  - infrared-dark cloud cores
  - protostars of low/high mid-IR brightness
  - hot molecular cores
  - ultracompact HII regions

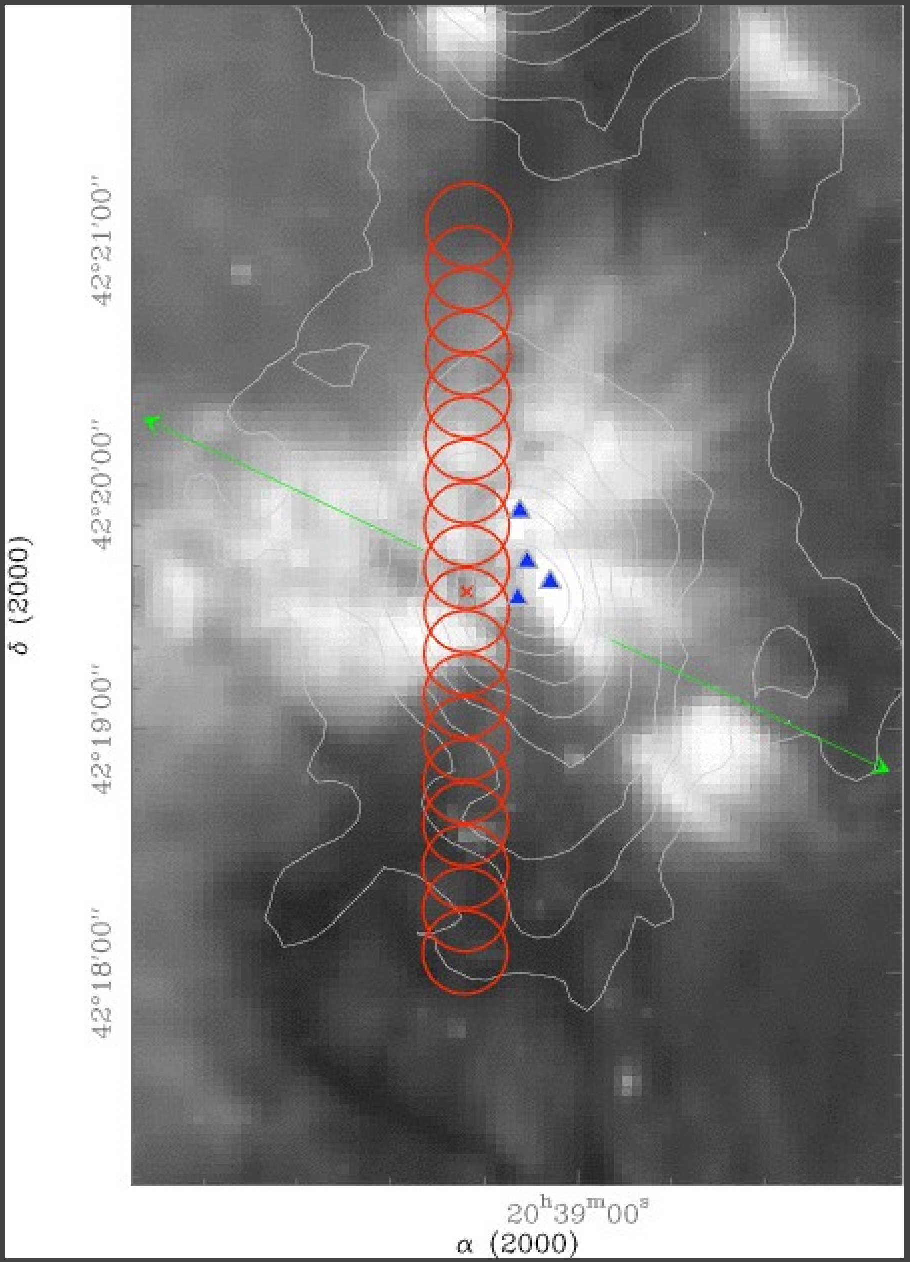
- Uses HIFI and PACS spectroscopy of 20 H_2O lines
  - and maps: clustered star formation

- Collaboration of scientists in Groningen, Bordeaux and Bonn
  - with associates world-wide

The DR21 region

- L = 45,000 L_0
- d = 1.7 kpc
- M = 800 M_0
- size ~0.3 pc
- Strong outflow
- Compact HII region

Observed with HIFI in June 2009 as part of PV program



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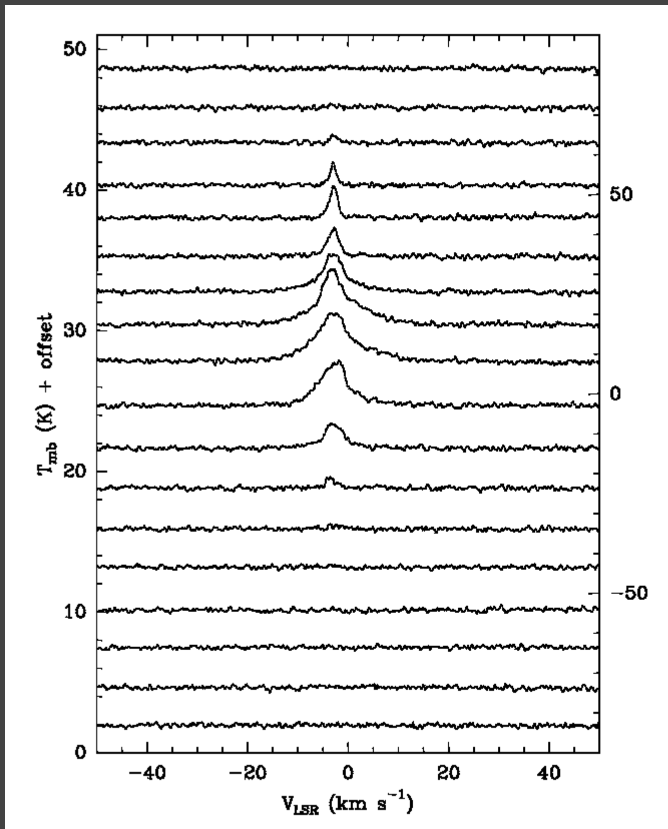
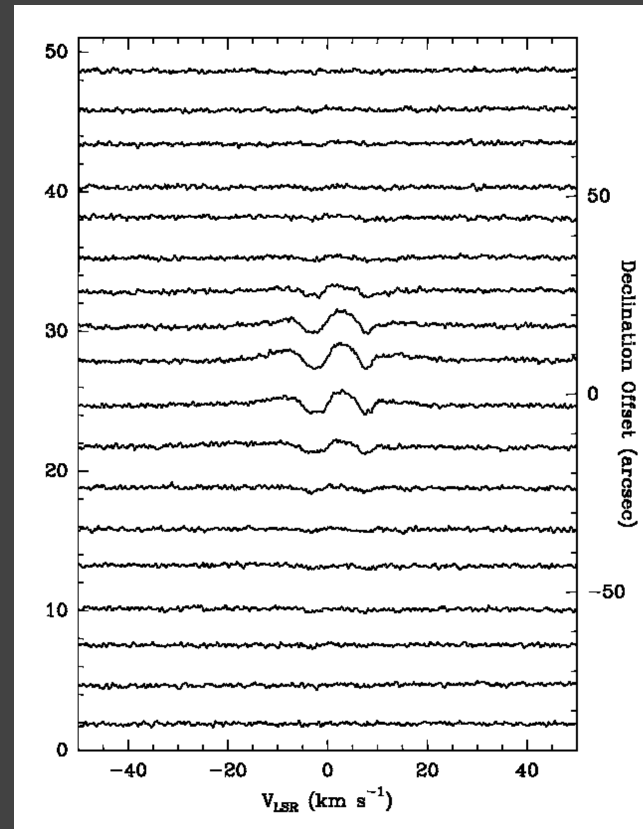
HIFI data: dust, ^{13}CO 10-9, H_2O 1_{11}-0_{00} @ 1100 GHz





- ^{13}CO pure emission; H_2O emission-absorption profile
- E_u = 293 / 53 K; n_c = 1e6 / 3e8 cm^{-3}
- Both dust and lines extended over ~1'

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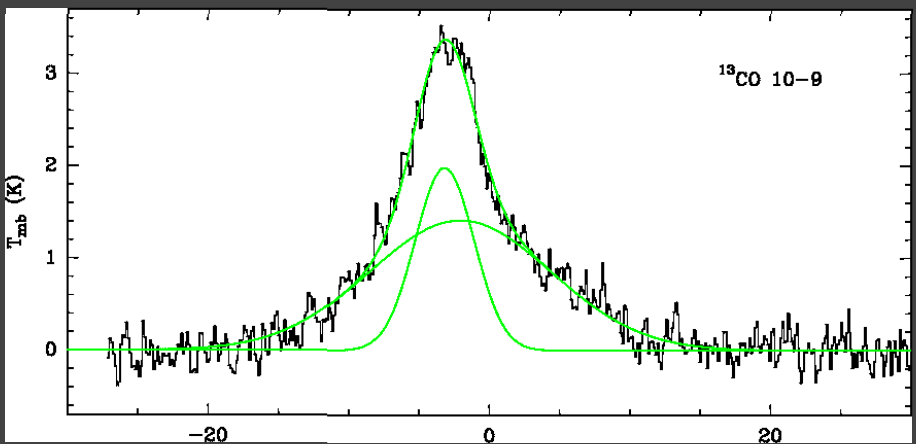
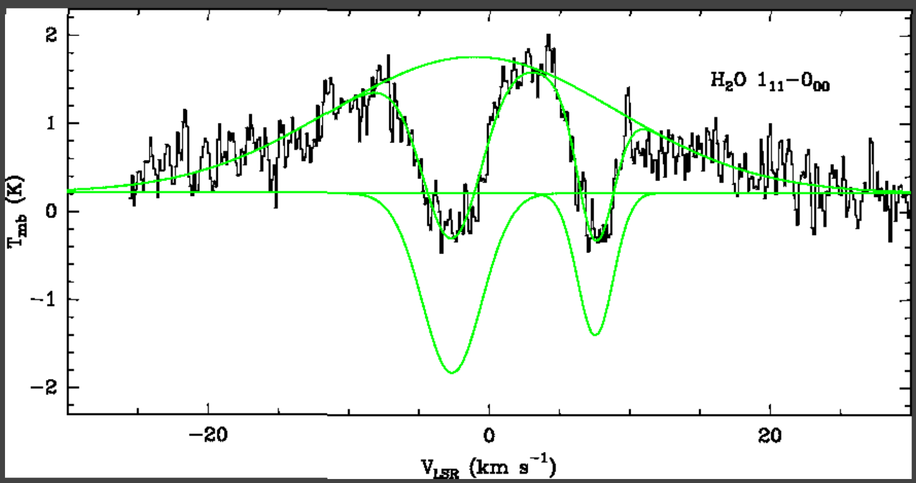
Central line profiles





- Dense core: ^{13}CO narrow emission; H_2O absorption at V = -3 km/s
- Outflow: broad emission in both lines
- Foreground cloud: H_2O absorption at V = +7 km/s
  - known from ground-based low-J CO spectra

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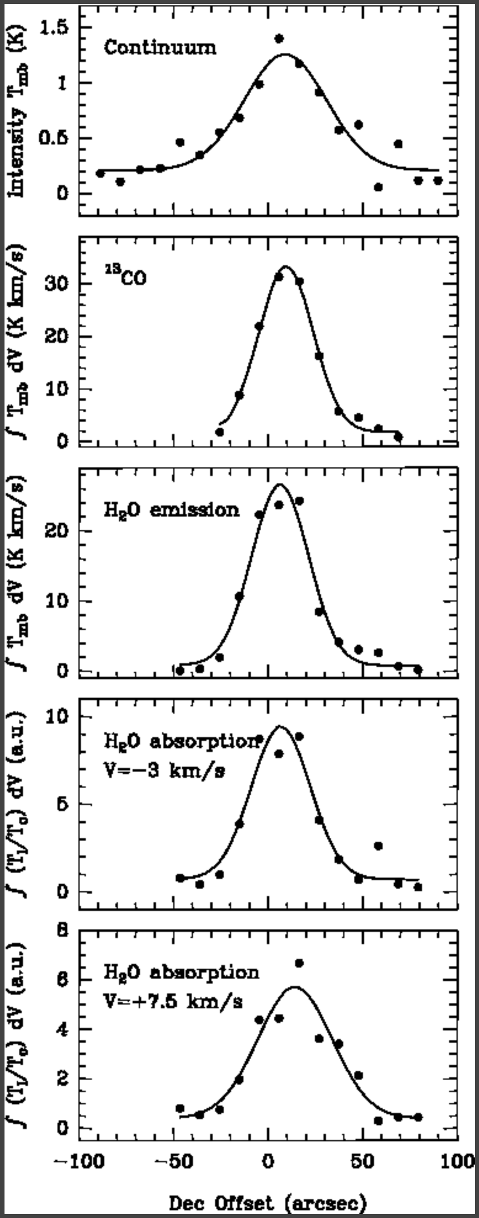
Spatial distribution

- Dust extended over 35'' FWHM
- Lines compact: 25'' or less
- Foreground absorption broader (~30'') and shifted ~10'' N
- Consistent with ground-based dust and CO maps



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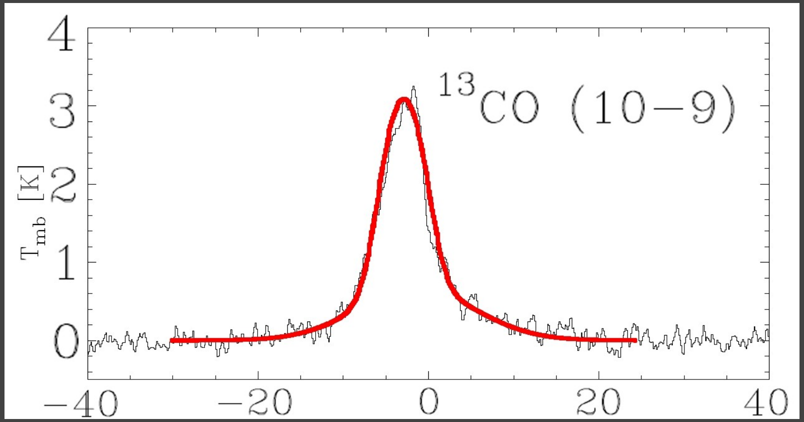
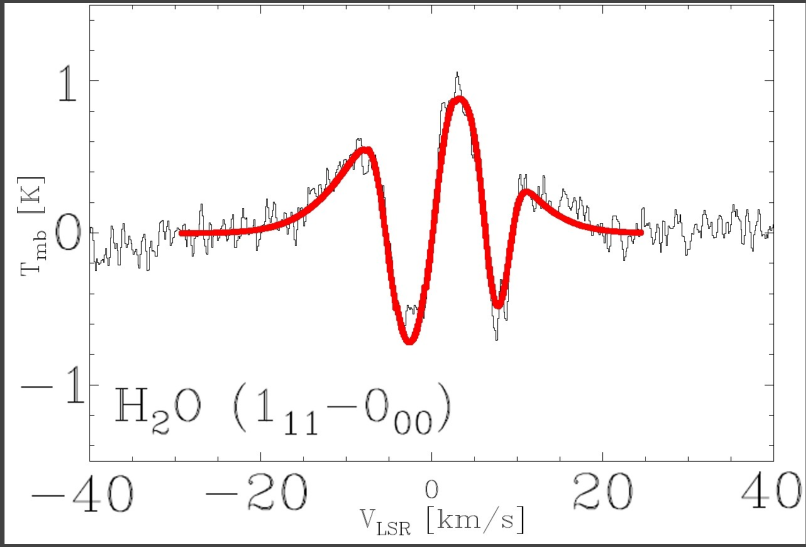
How much water?

- Model dense core with RATRAN
  - T = 23 .. 117 K
  - n = 2e5 .. 3e7 cm^{-3}
  - $^{13}CO/H_2$ = 8e-7, p-H_2O/H_2 = 2e-10: LOW
- Outflow & foreground: use RADEX
  - foreground: T=10 K, n=1e4 cm^{-3}
  - Find $N(^{13}CO)$ = 7e15 cm^{-2}, N(p-H_2O) = 4e12 cm^{-2}
  - outflow: T=200 K, n=3e4 cm^{-3}
  - Find $N(^{13}CO)$ = 5e16 cm^{-2}, N(p-H_2O) = 1e16 cm^{-2}



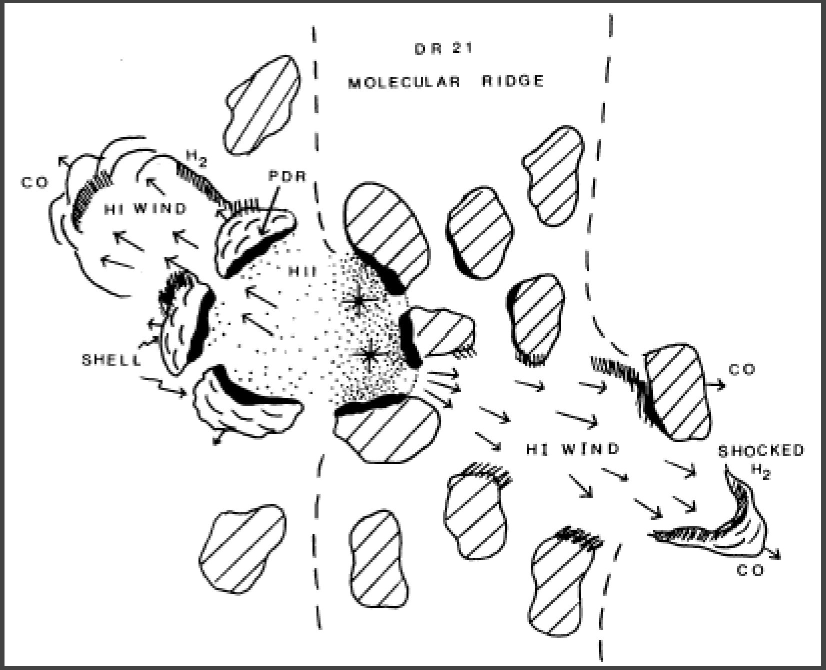


Formation and destruction of H_2O

- Adopt $^{12}C/^{13}C = 60$, $CO/H_2 = 2e\text{-}4$
  - p-$H_2O/H_2 = 4e\text{-}9$ in foreground, 7e-7 in outflow

- Low H_2O abundances in dense core and foreground
  - Core: high density → strong freeze-out on dust grains
  - Foreground: low extinction → rapid photodissociation

- Abundant H_2O in outflow
  - high temperature
    → grain mantle evaporation

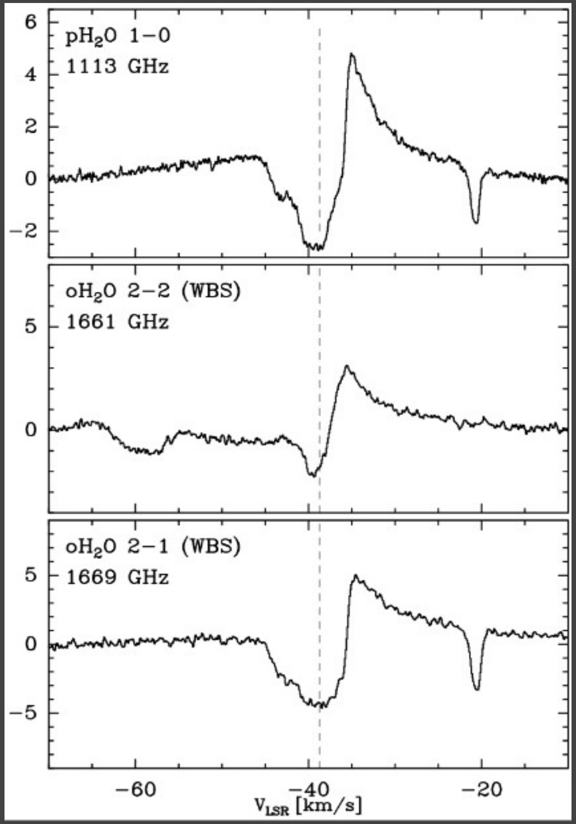


So what's next?

- Multi-line studies → abundance *profiles*, not radial averages
  - high-J lines: warm gas-phase boosts H_2O abundance

- Multi-source studies → trace H_2O *evolution* during MSF
  - massive pre-stellar cores
  - high-mass protostellar objects
  - hot molecular cores
  - ultracompact HII regions

- Related molecules (OH, H_3O^+, H_2O^+ …)
  - understand chemical impact of H_2O



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