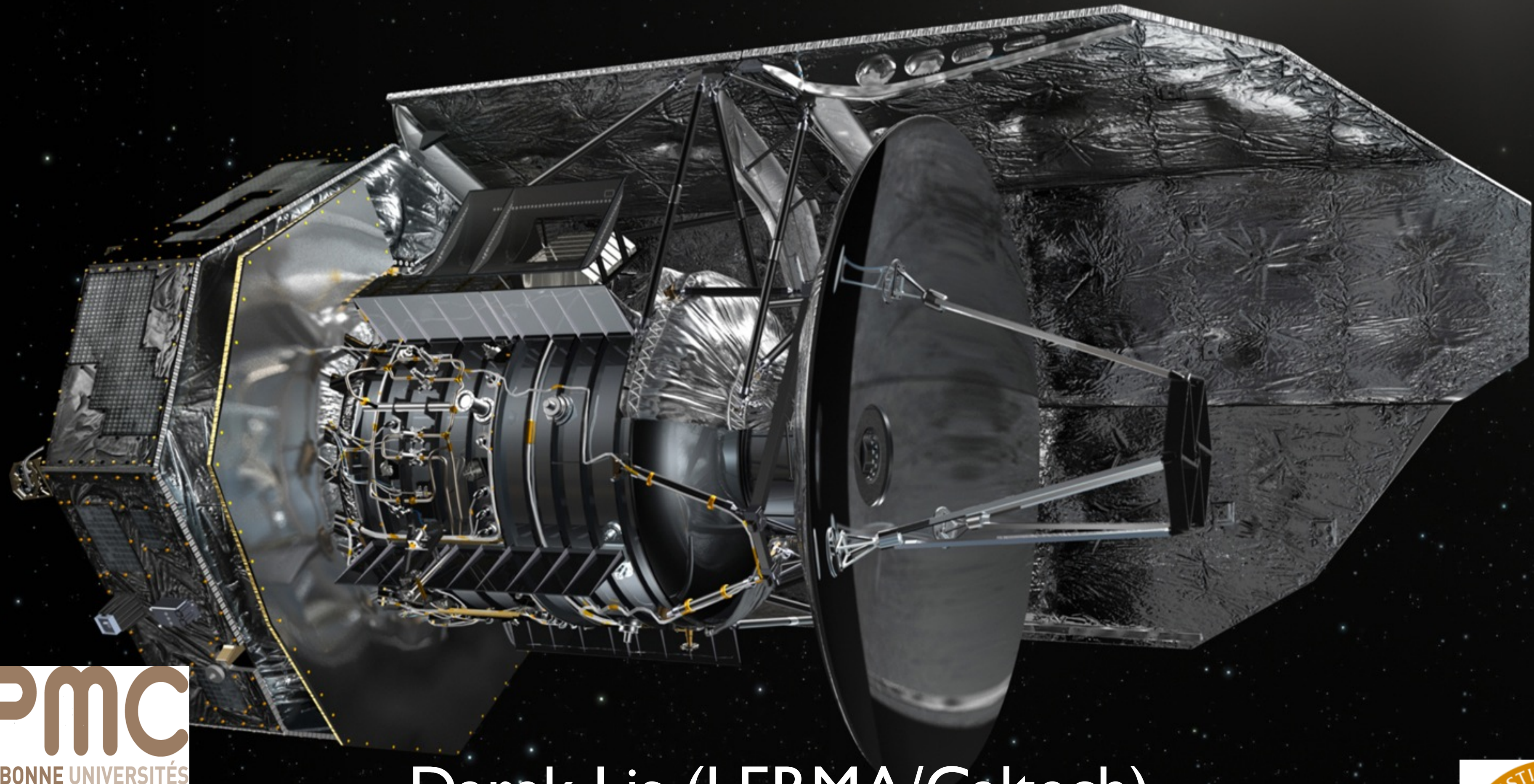
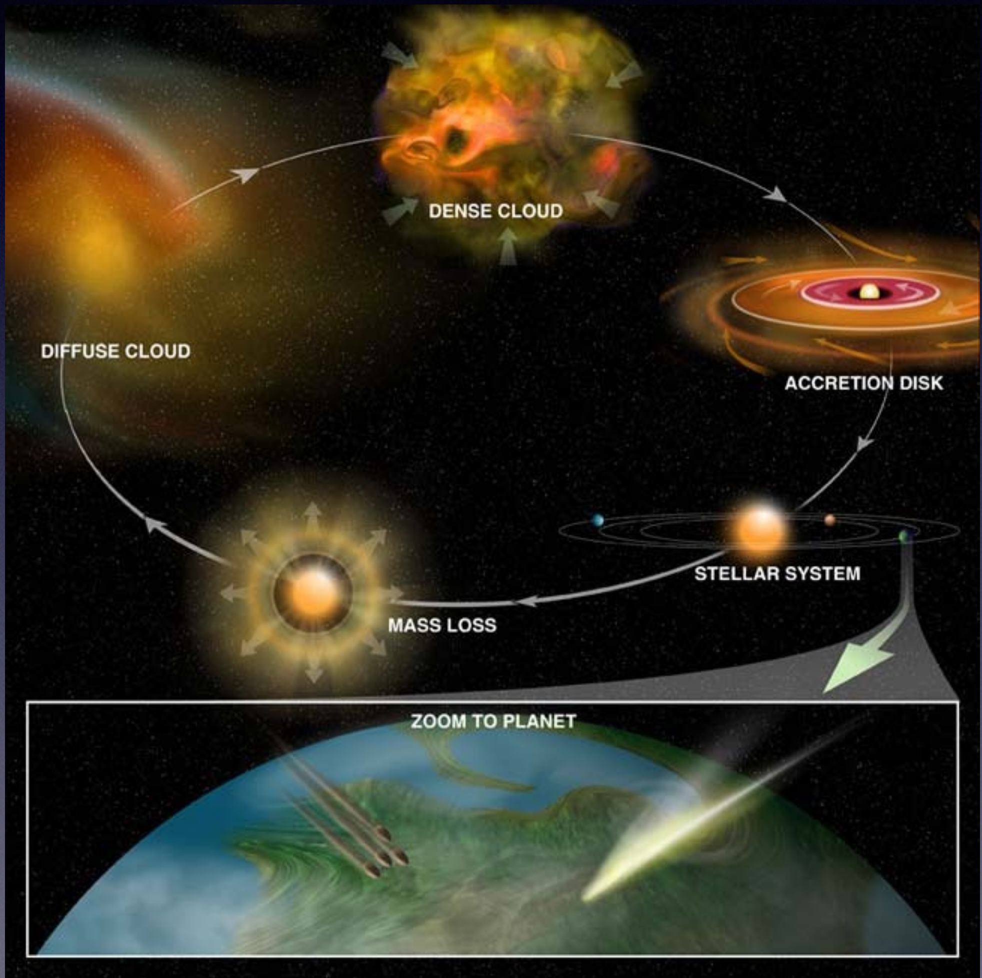
Herschel and ALMA Observations of a Prestellar Core/Outflow Interaction in L1689N



Darek Lis (LERMA/Caltech)

A. Wootten, M. Gerin, L. Pagani, E. Roueff, F.F.S. van der Tak, C. Vastel, C.M. Walmsley

Star Formation and Feedback

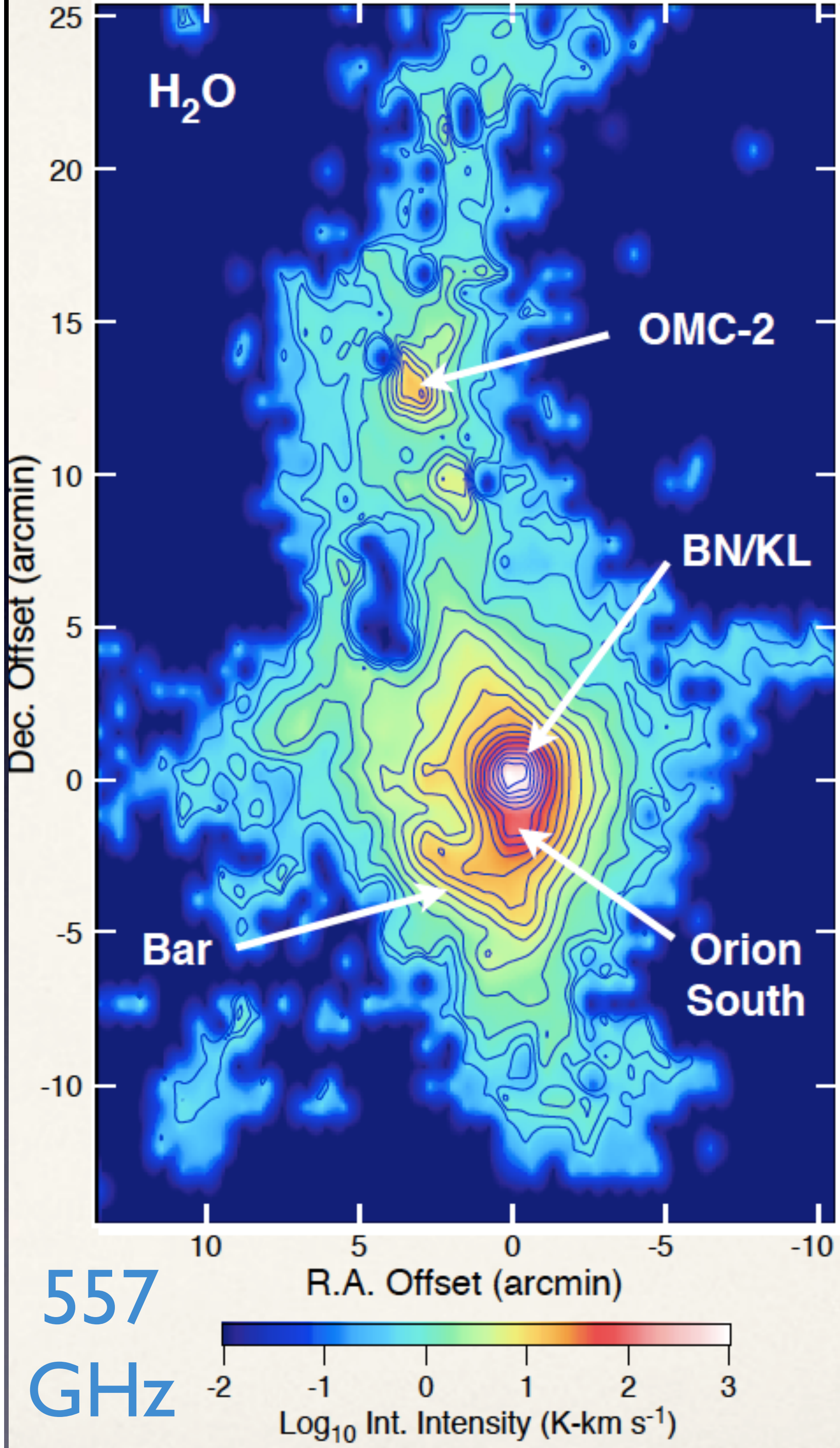


http://www.space.com

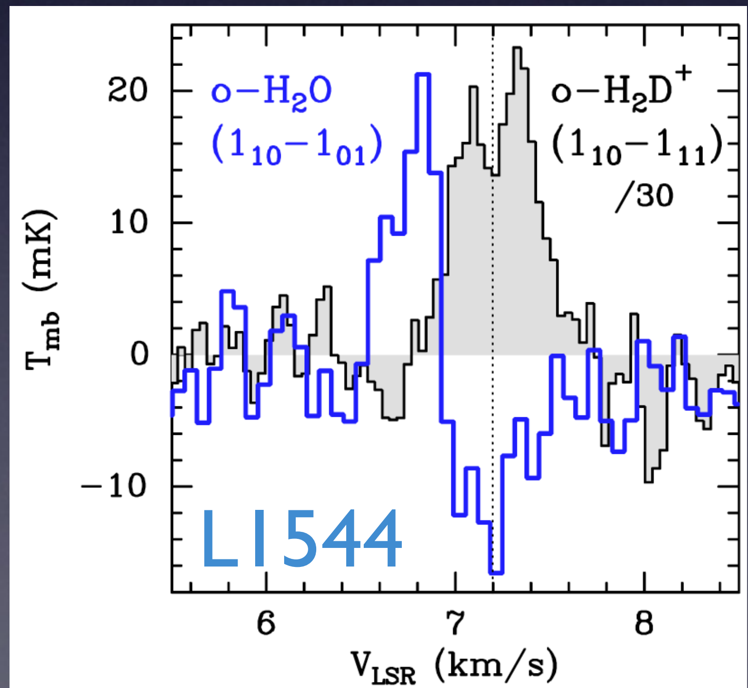
- Star formation occurs exclusively in the shielded interiors of molecular cloud cores, when gravity overcomes the thermal, magnetic, and turbulent pressure support
- Many stars form in groups or clusters, where objects at different evolutionary stages are often observed simultaneously
- Protostars inject copious amounts of mechanical energy (outflows, shocks) and radiation (UV, X-rays) into their surroundings
- What are the effects of this energy injection on the structure of the surrounding ISM?
- Does it lead to the second generation of star formation?

Tracers of Star Formation: Water

- Frozen in cold gas, abundance enhanced in warm gas—outflows, shocks—kinematics
- Derived water abundances often lower than the canonical value of 10^{-4}
- Also detected in a prestellar core (FUV photons produced by interactions $CR+H_2$)



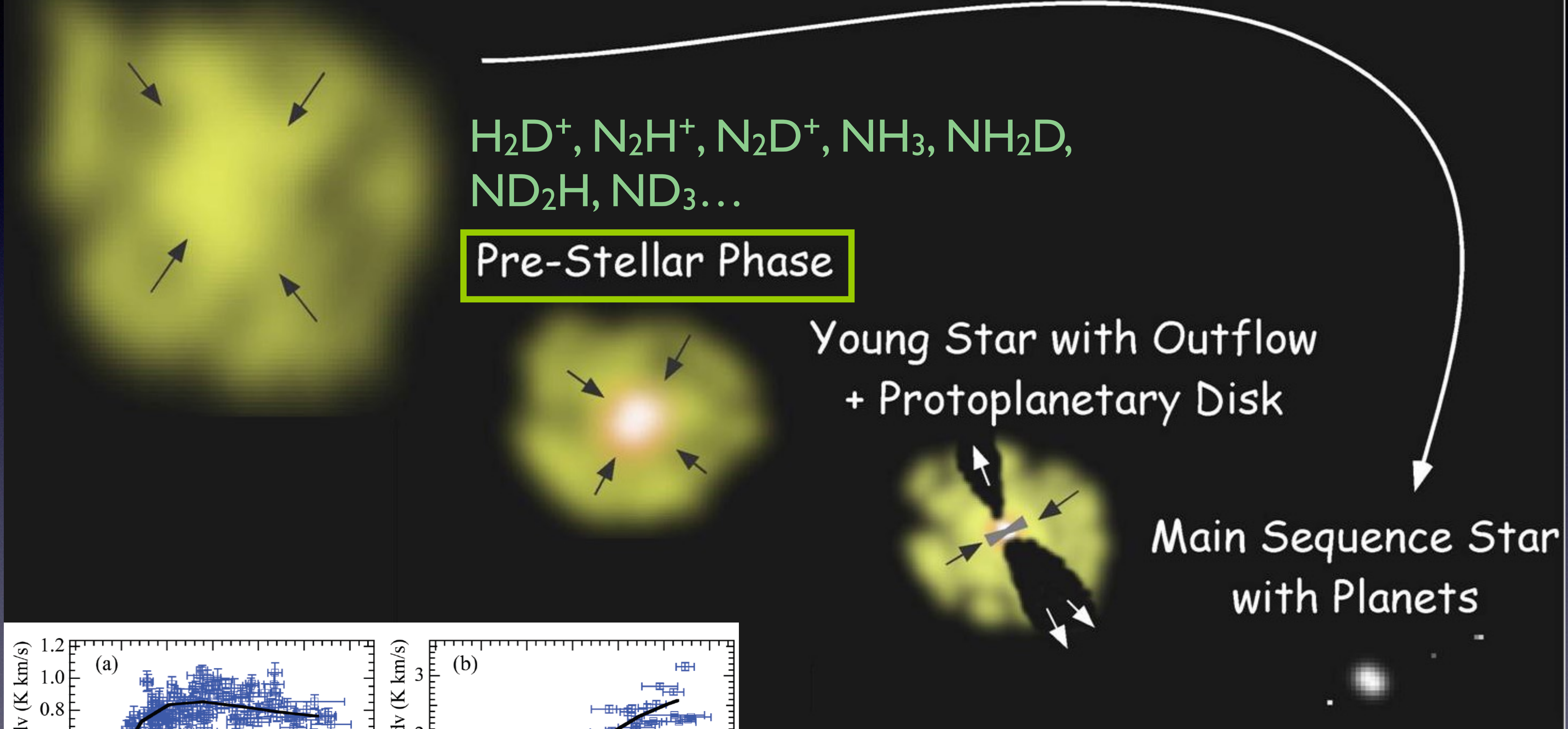
557 GHz



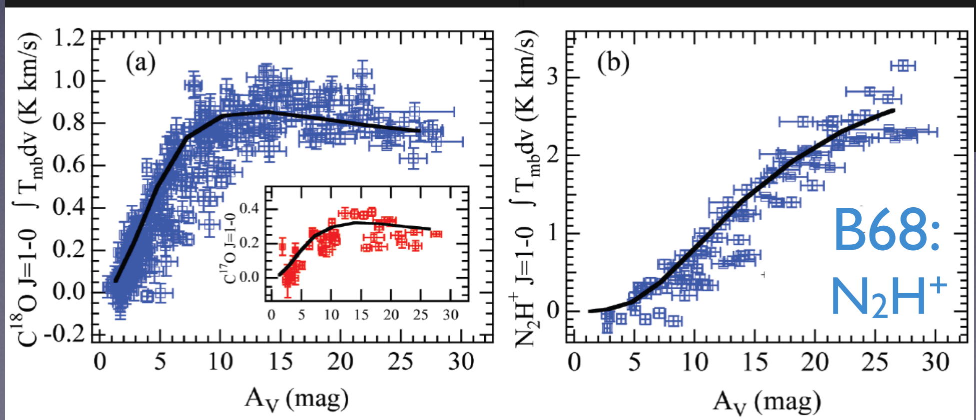
G. Melnick, V. Tolls

P. Caselli

Tracers of Star Formation: Deuterated Molecules



H_2D^+, N_2H^+, N_2D^+, NH_3, NH_2D, ND_2H, ND_3…

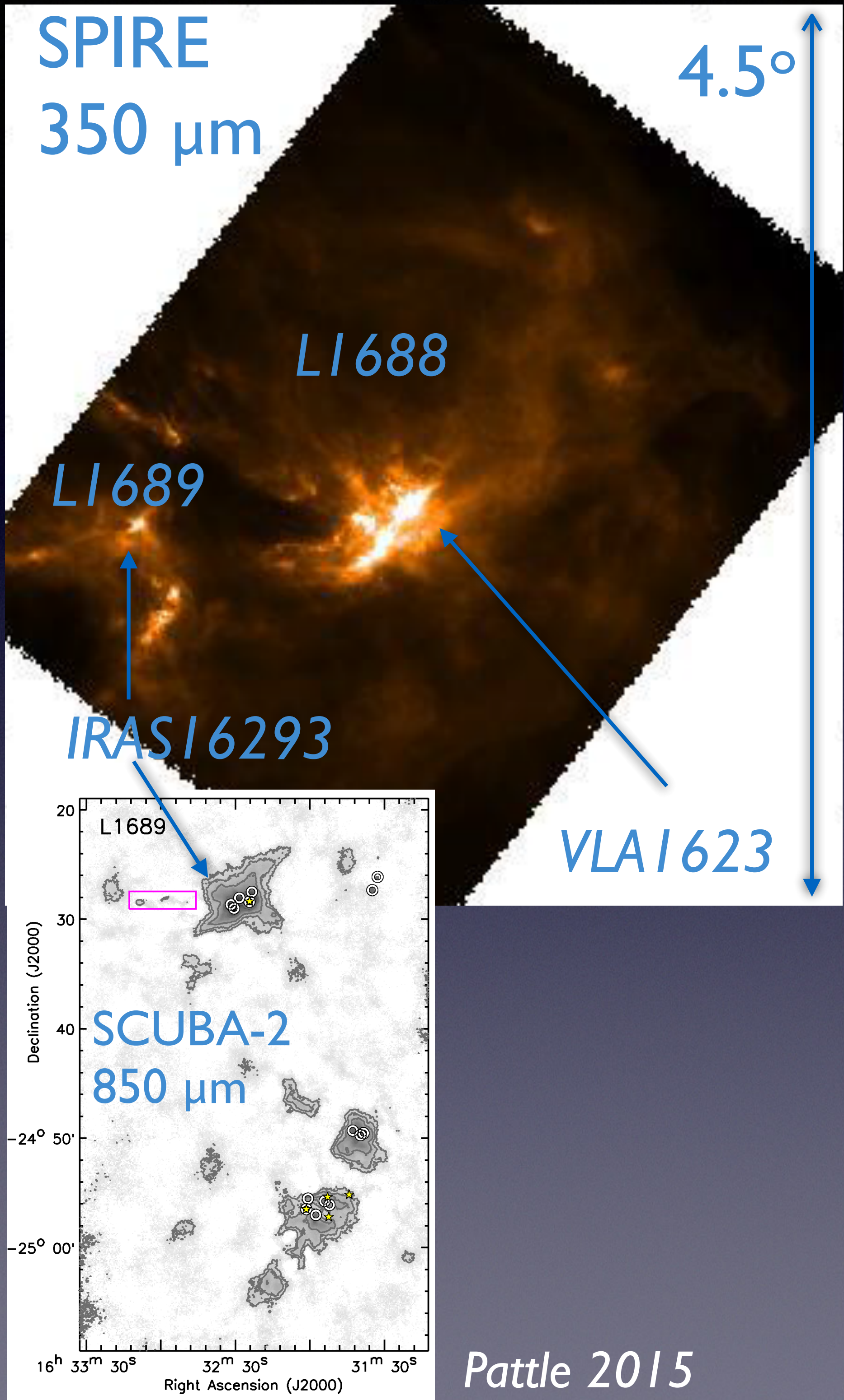


- Depletion, complete freeze-out
- Importance of the H_2 OPR—detailed models
- Good observational constrains needed

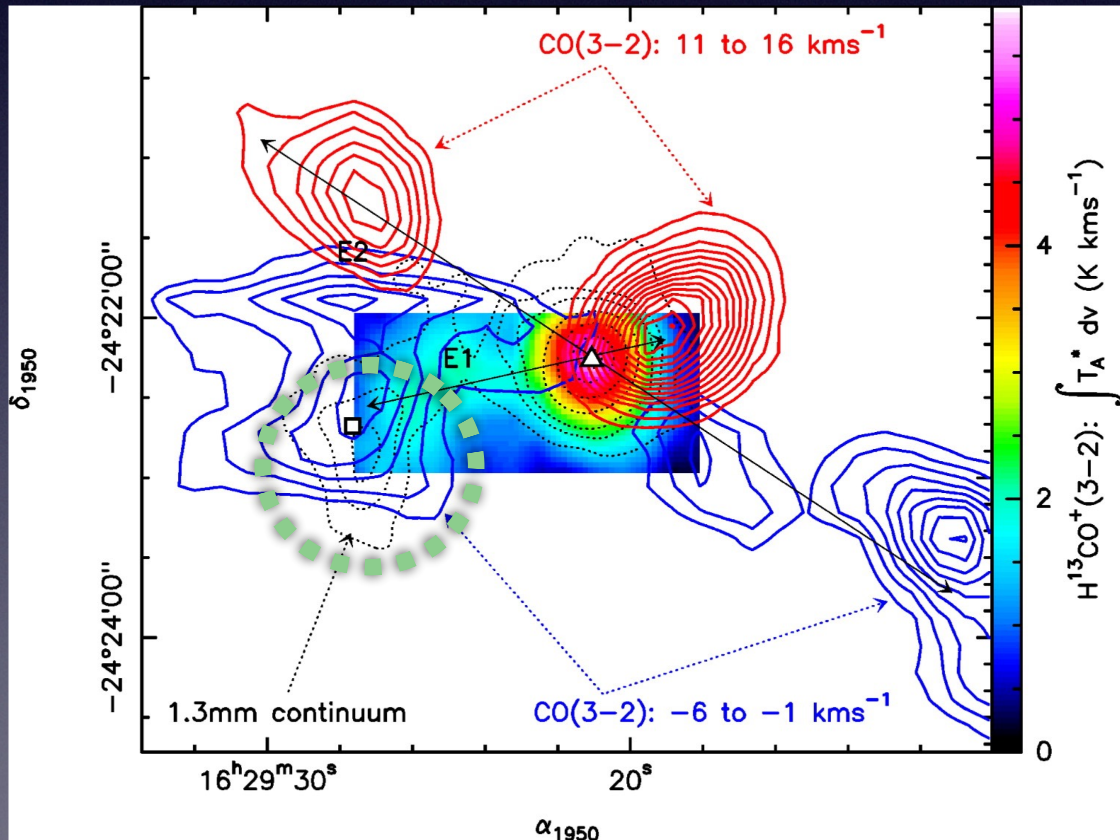
Bergin 2002, 2006; Walmsley 2004; Flower 2006…

The Source: L1689N

- Combined Herschel, ALMA ACA, and CSO observations of water emission and deuterated molecular tracers

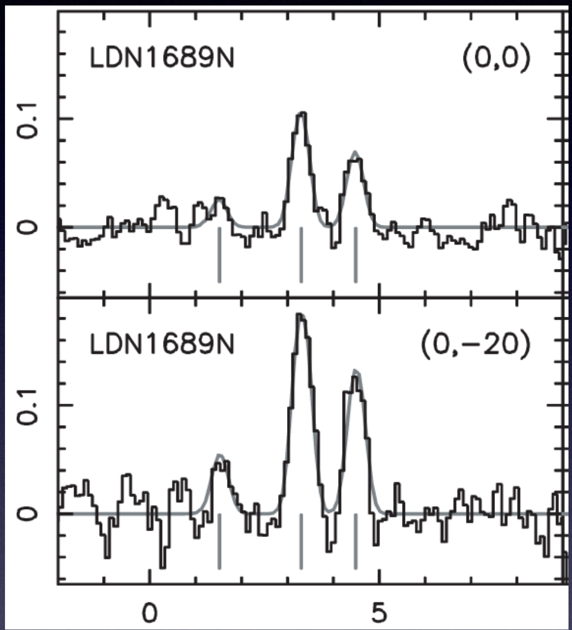


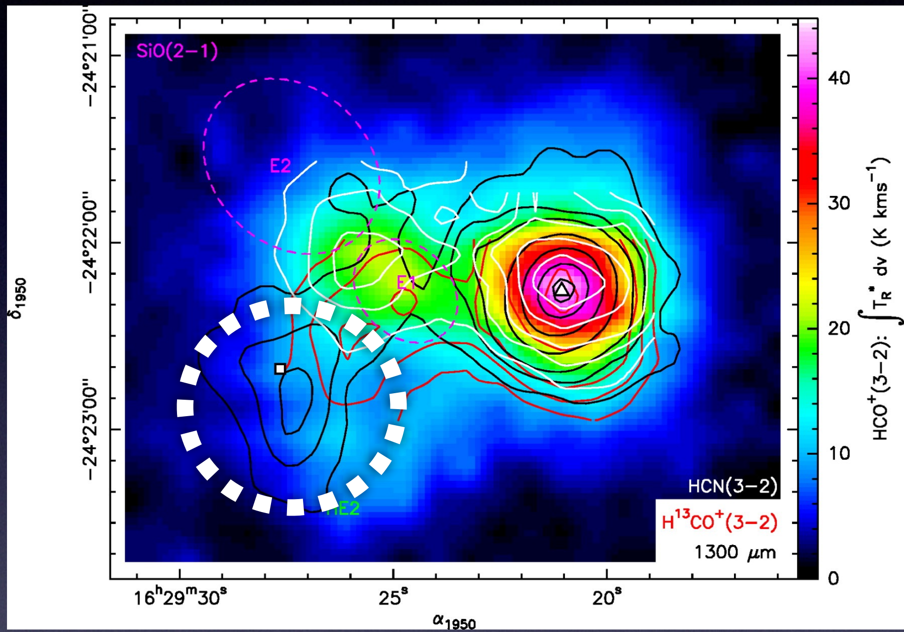
Pattle 2015

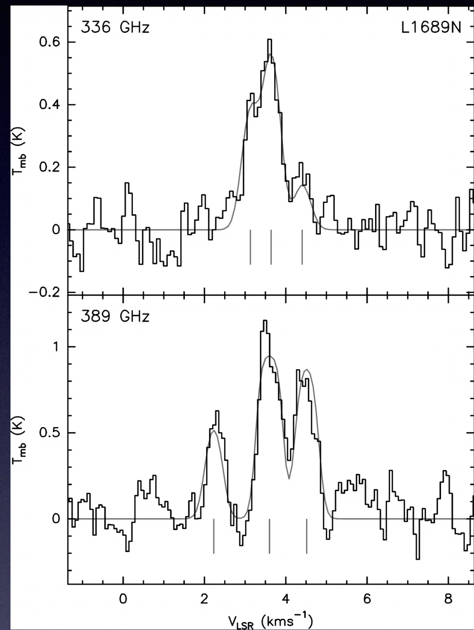


Lis 2002

L1689N: Deuteration





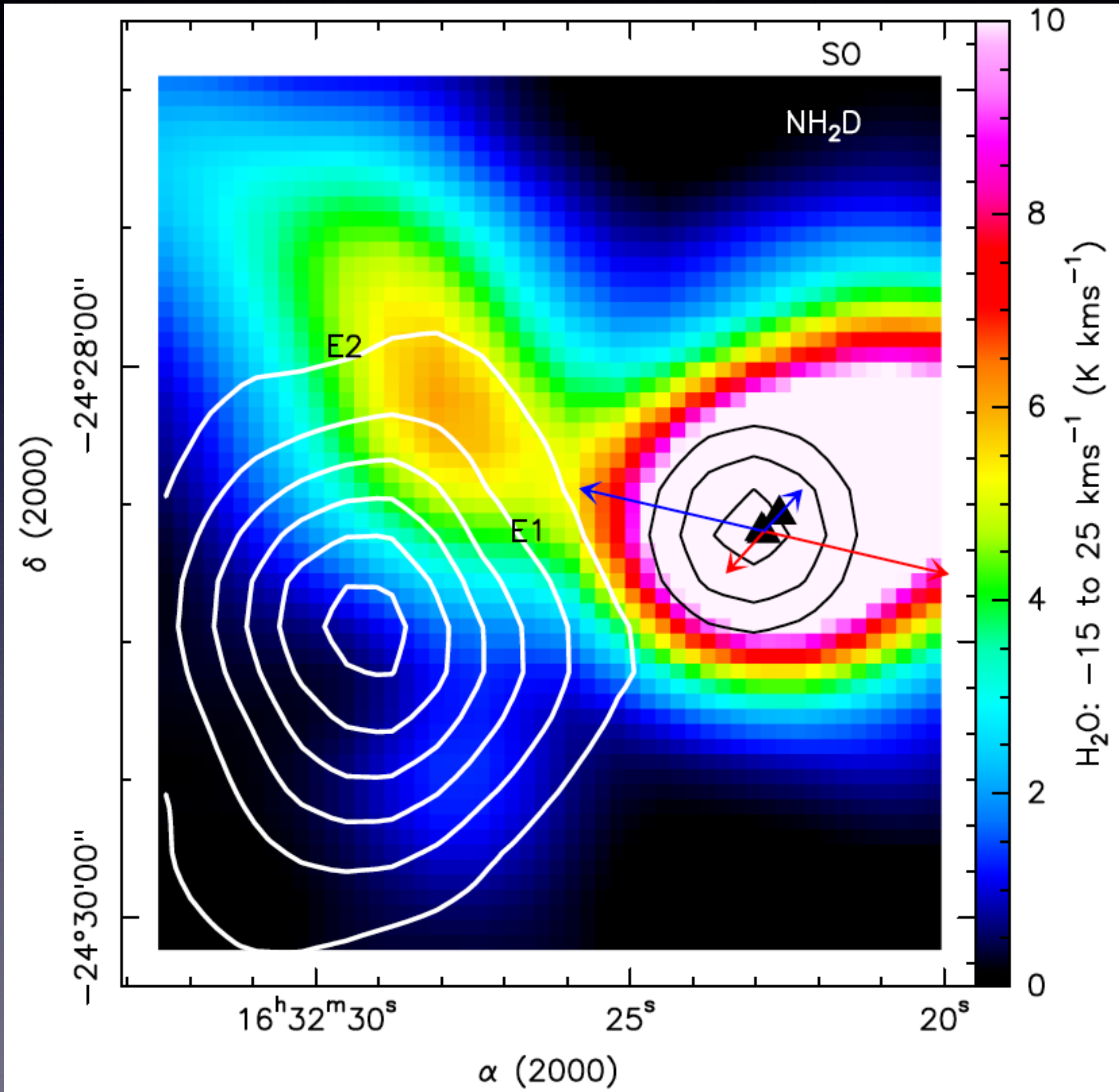


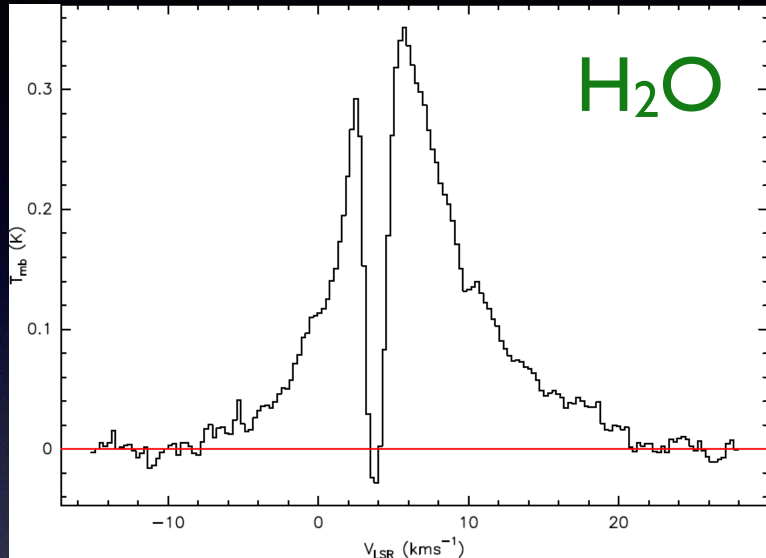
ND_3: Roueff 2005

ND_2H: Lis 2006

- One of the highest-deuteration prestellar cores known (e.g., ND_3)
- Does the outflow interaction have an effect on the physical structure and chemistry of the prestellar core

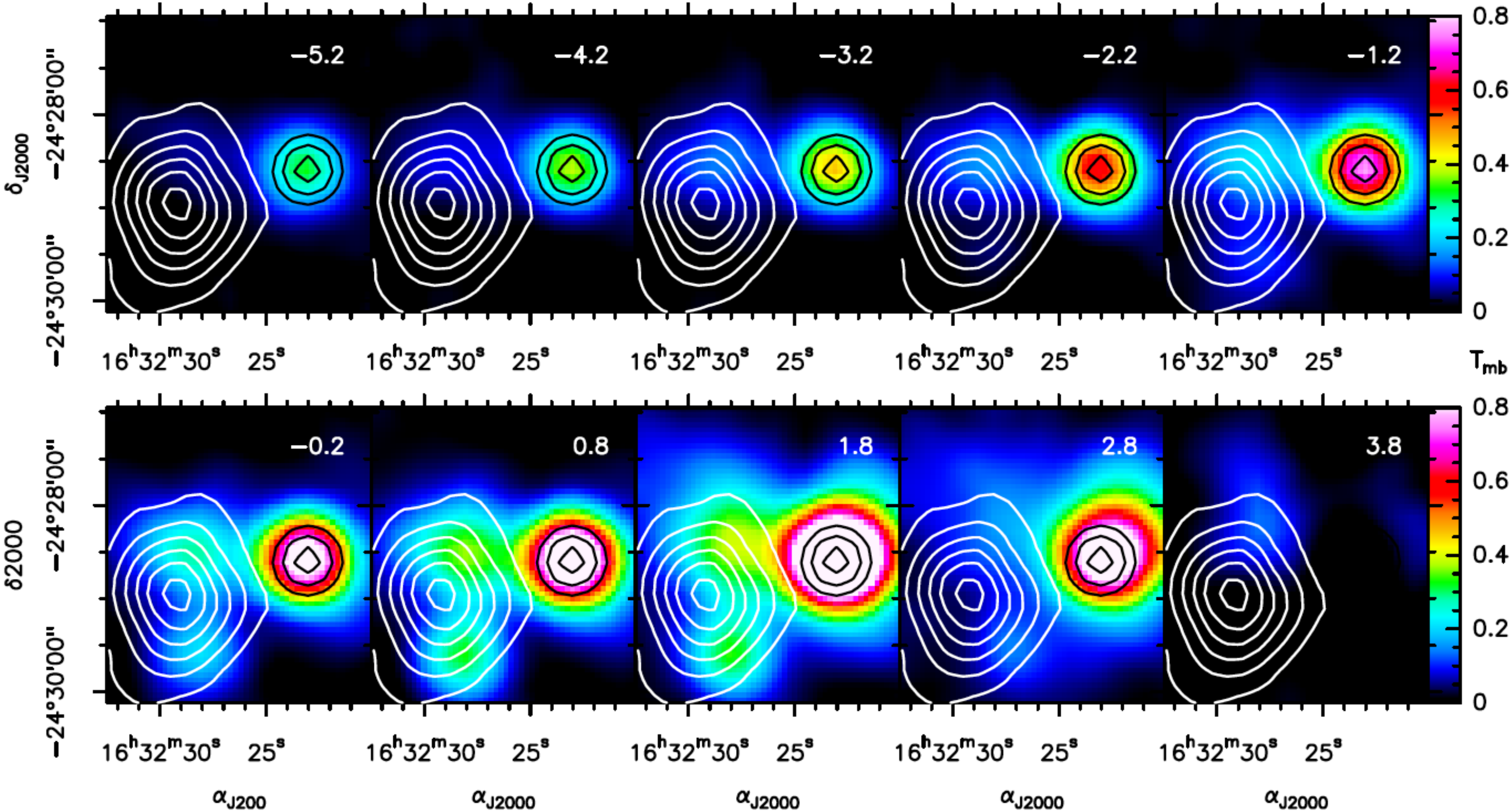
HIFI: Water and NH_2D





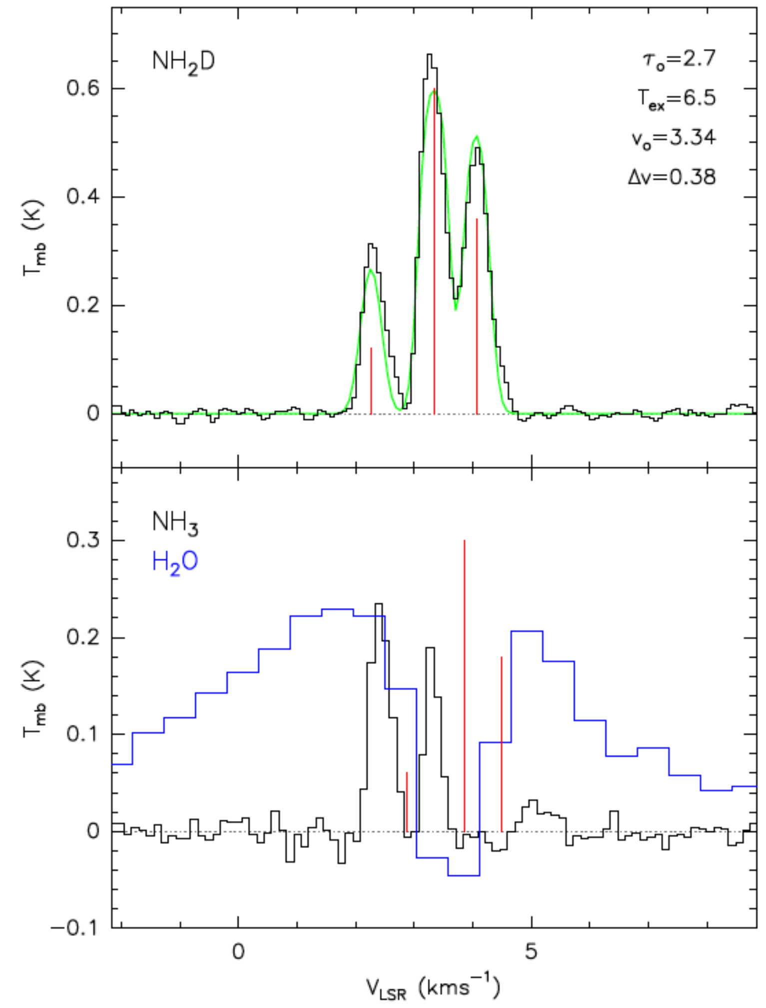
- Integrated 557 GHz water line emission shows the distribution of the outflowing material not contaminated by the envelope emission
- Water emission surrounds and avoids the prestellar core

Blueshifted Water Emission

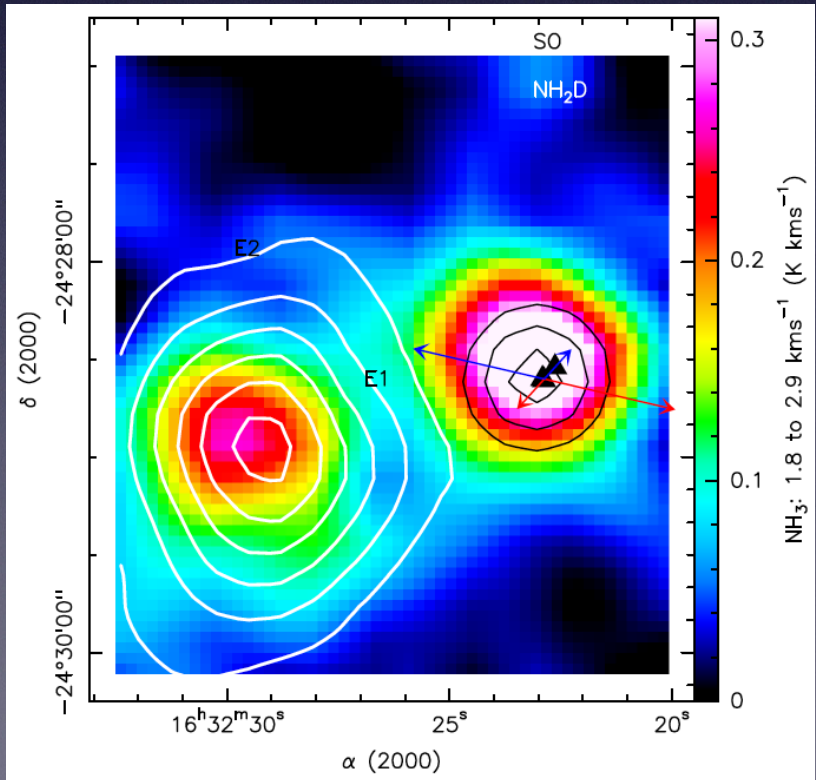


- Two secondary blueshifted water peaks to the NW and SW of the core

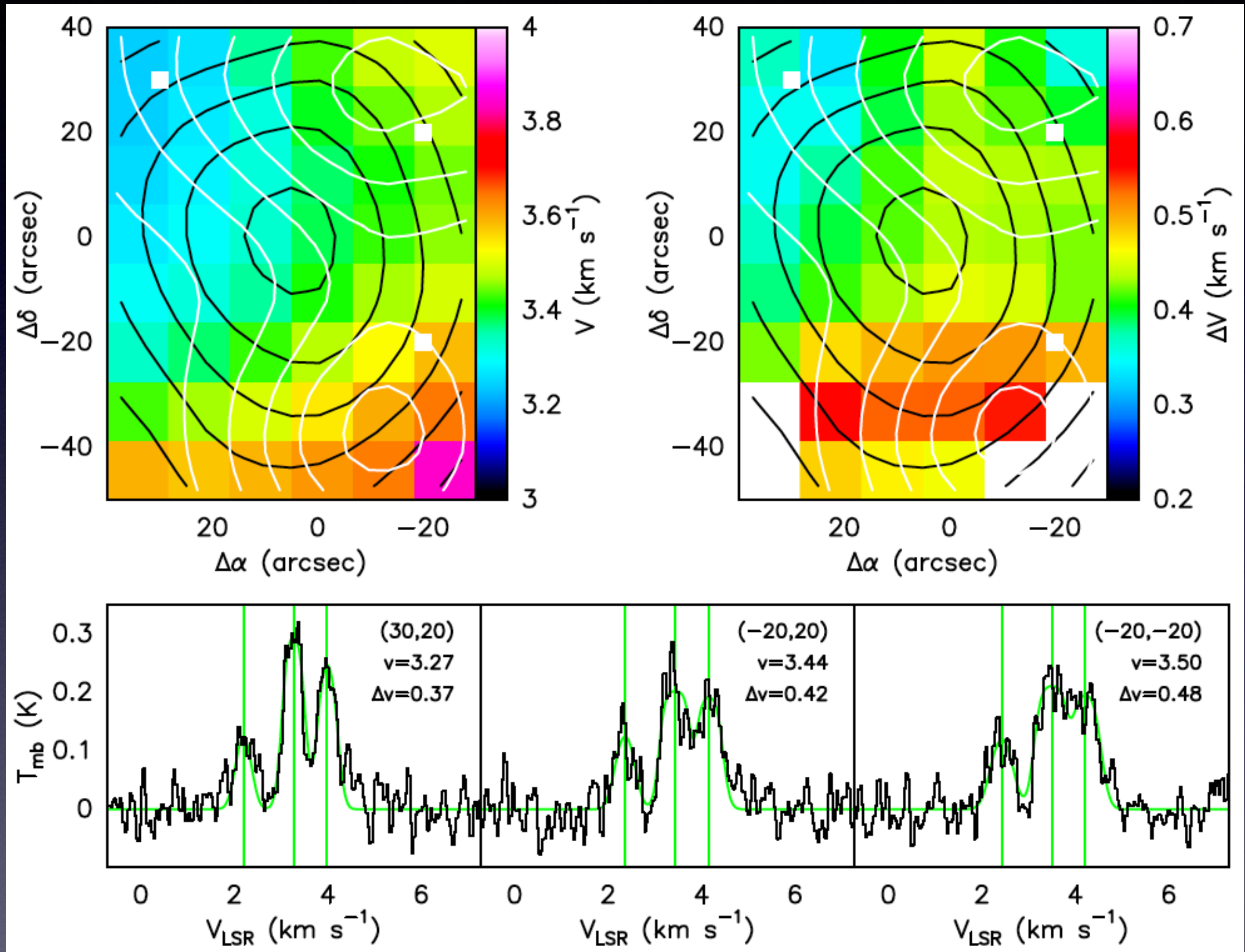
NH_2D vs. NH_3



- NH_2D: simple HFS pattern allows direct determination of the line opacity and excitation temperature
- NH_3 spectrum very peculiar, likely affected by the envelope absorption
- Shift between NH_3 and NH_2D

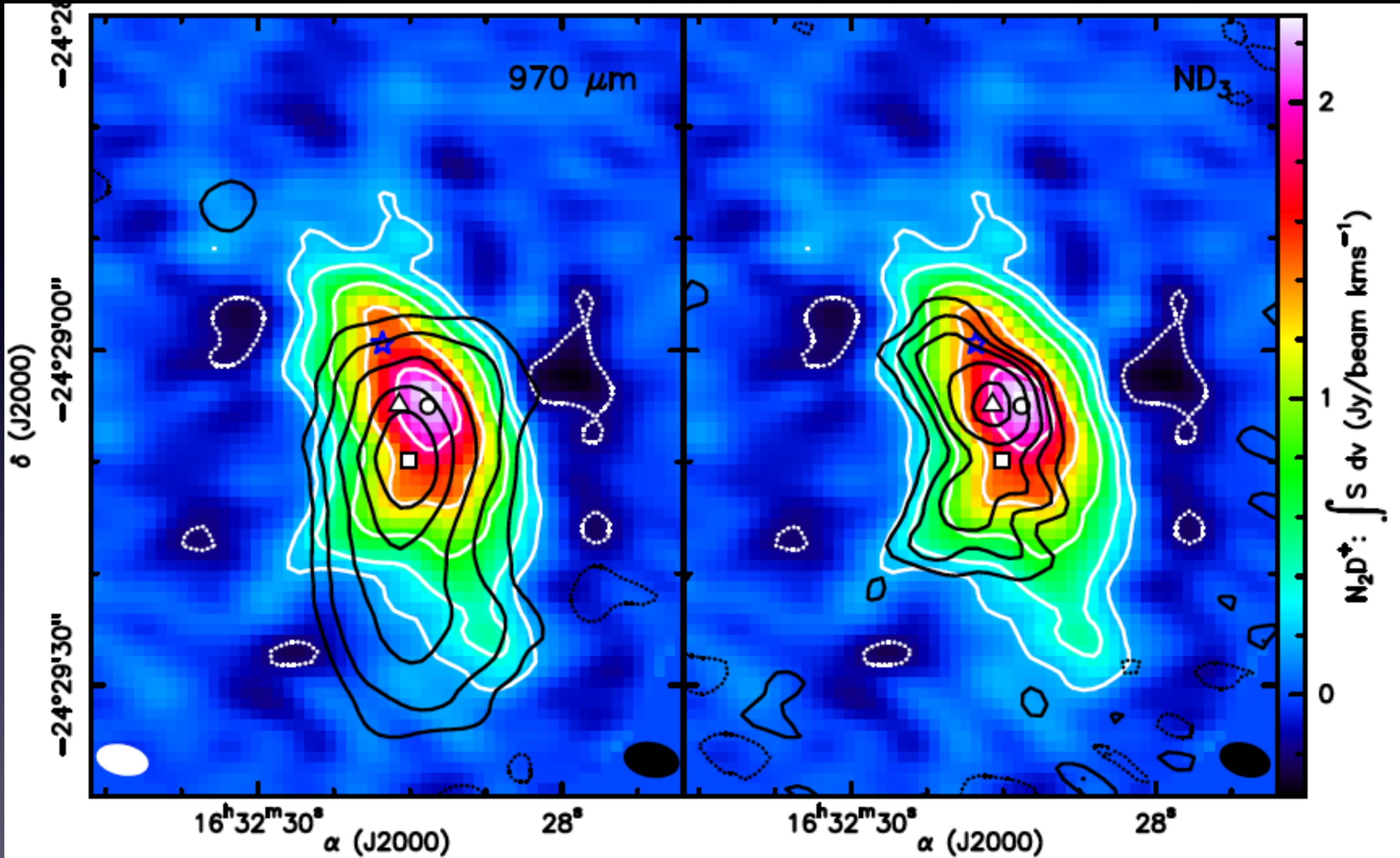


NH_2D Line Velocity and Width



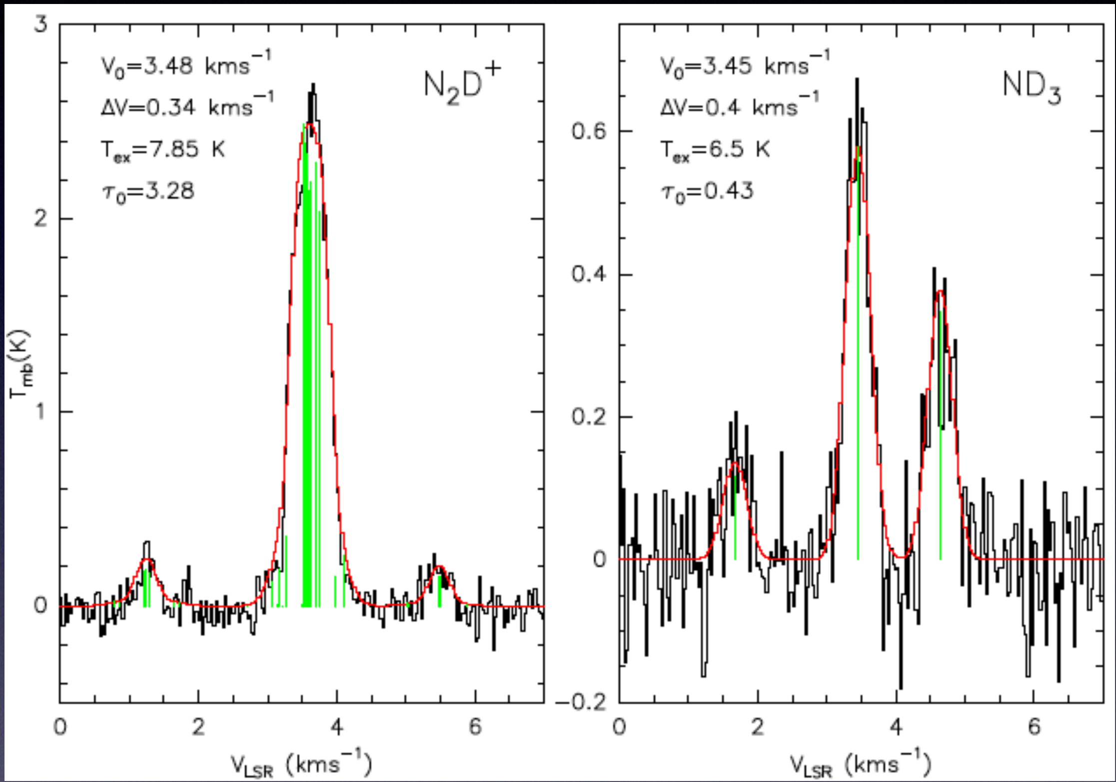
- Clear evidence for a variation in the NH_2D line center velocity and width across the core, correlated with the distribution of the blueshifted water emission
- Quiescent gas in the NE, evidence of interaction with the outflow in the W, SW

ALMA Compact Array



- High-SNR images of the 970 μm dust continuum emission, N_2D^+, and ND_3
- A dust source, 1540x840 au in size, detected by the ACA in the southern part of the core: $1.8-3.3\times10^{23}$ cm^{-2}, $1.1-1.9\times10^{7}$ cm^{-3}, $0.2-0.4$ $M_\odot$
- A much weaker secondary peak is found in the NE part of the core, associated with the source SMM19 of Pattle (2015)

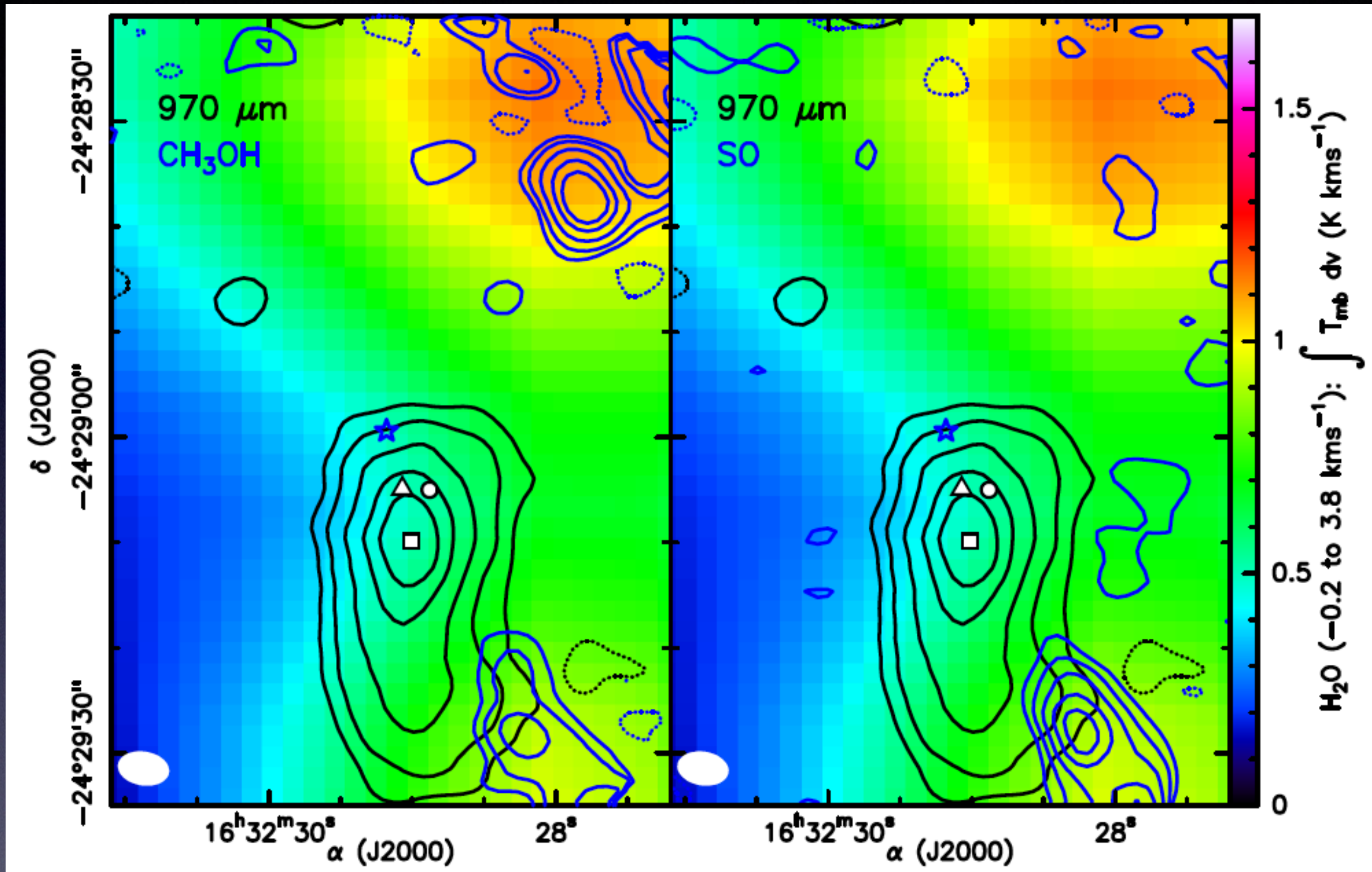
HFS Fits



Line	v_0 (km s^{-1})	Δv (km s^{-1})	T_{ex} (K)	τ_0
NH_2D	3.34	0.38	6.5	2.7
ND_3	3.45	0.40	6.5	0.43
N_2D^+	3.68	0.34	7.9	3.3

- Excitation temperatures consistent with the latest kinetic temperature estimates (Bacmann 2016: 11−16 K; Pagani 2016: 8−16 K)
- The ~0.4 kms^{-1} line width corresponds to H_2 thermal line width at 7 K; does not increase with radius
- Line broadening mainly non-thermal, turbulent motions dominant even in the quiescent part of the core
- Different from typical prestellar cores in Taurus and possibly related to the interaction with the outflow

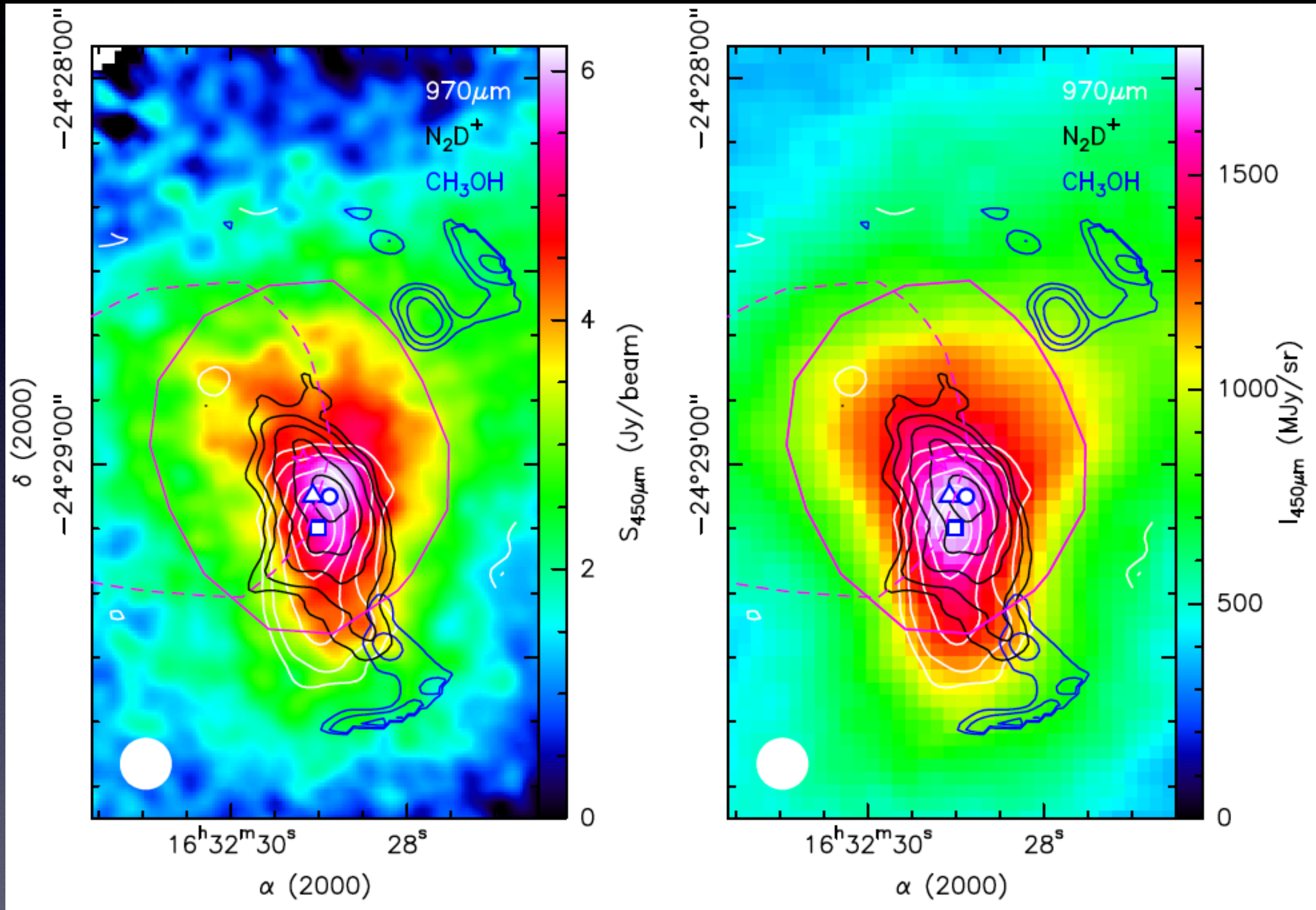
ACA: Outflow Tracers



- Lines of SO and methanol observed with the ACA; extended emission filtered out, requires total power data
- Emission associated with the NW and SW water peaks
- No emission detected toward the prestellar core

Single-Dish Dust Continuum

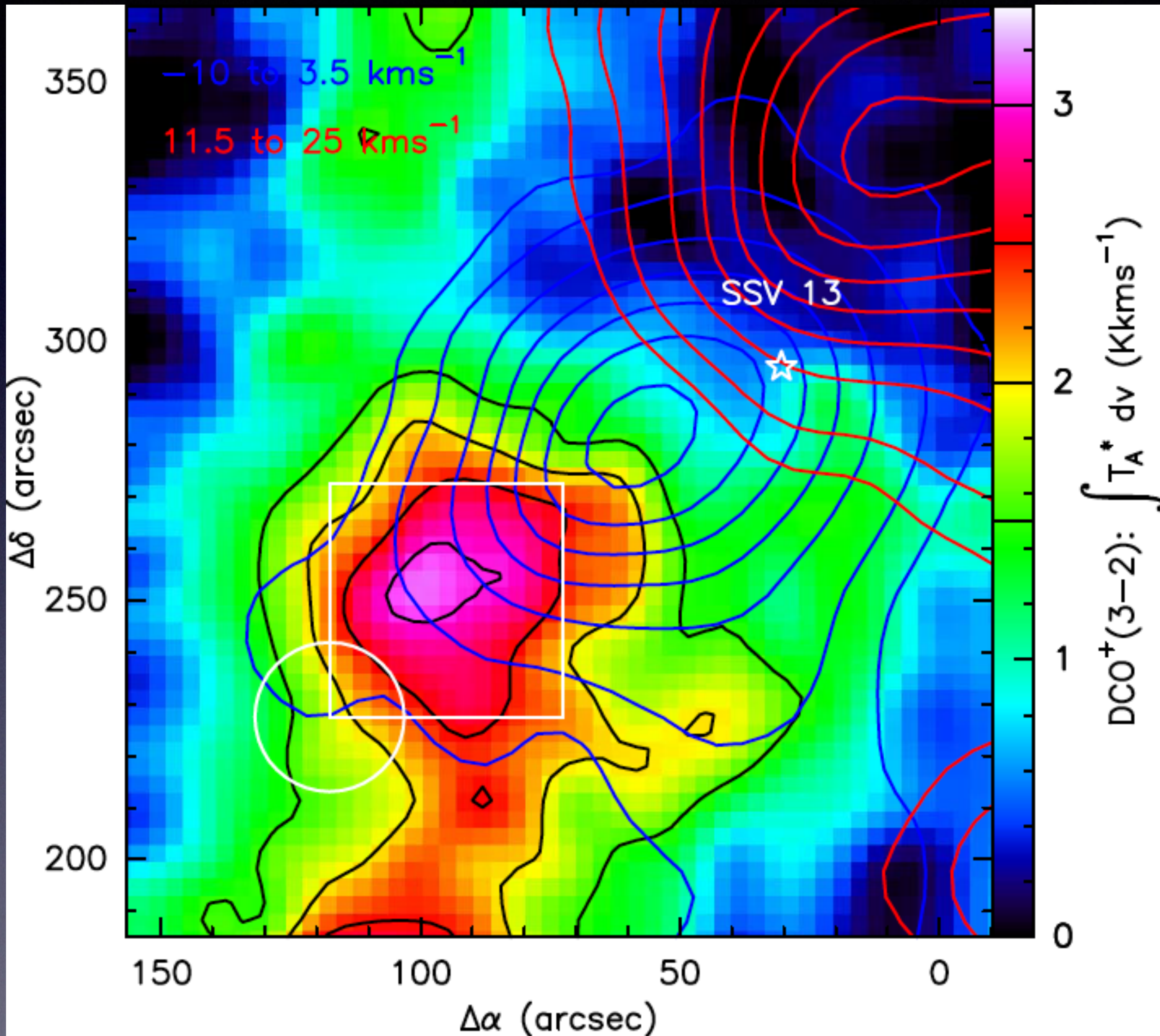
SCUBA 450 µm: Stark 2004



SCUBA-2 450 µm: Pattle 2015

- Strong single-dish continuum emission in the N/NE part of the core without ACA counterpart—likely filtered out by the interferometer
- Distribution of H_2D^+ emission (Pagani 2016) very different from other tracers

How Unique is L1689N?



- L1689N is the best studied, but *not the only source* of this type

Summary

- The outflow driven by IRAS16293, as traced by the high-velocity water emission, wraps around and avoids the prestellar core, affecting the kinematics of the dense gas
- Observed changes in the line center velocity and width provide clear evidence of interaction between the prestellar core and the blue lobe of the outflow
- The shock associated with the outflow might have already propagated through the NE part of the core (characteristic timescale: 10 kms^{-1}, 1000 yr → 2100 au)
- This shock compressed, dense gas, blueshifted with respect to the systemic velocity of the cloud is characterized by extended emission, which is largely resolved out by the interferometer

Summary

- The N_2D^+ emission observed with the ACA extends south from the single dish NH_2D peak
- ND_3 emission shows a similar morphology, with a small spatial offset
- A 970 μm dust continuum source, with a size of 1100 au and an H_2 mass of 0.2−0.4 $M_\odot$, is detected with the ACA, 5″ to the south of the N_2D^+ and ND_3 peaks
- None of the tracers studied here is correlated with the distribution of the H_2D^+ emission in the region (chemical effect—transformed completely into D_2H^+?)

Way Forward

- High-angular resolution ALMA data provide key information—chemical differentiation, density structure
- Next step in the analysis: merging of the 12-m, ACA and TP data to increase the spatial dynamical range
- ACA observations of NH_2D and ND_2H need to be completed

MNRAS 444, 2544–2554 (2014) doi:10.1093/mnras/stu1670

Collisional excitation of singly deuterated ammonia NH_2D by H_2

F. Daniel,[1★] A. Faure,[1] L. Wiesenfeld,[1] E. Roueff,[2] D. C. Lis[3,4] and P. Hily-Blant[1]

MNRAS 457, 1535–1549 (2016) doi:10.1093/mnras/stw084

Collisional excitation of doubly and triply deuterated ammonia ND_2H and ND_3 by H_2

F. Daniel,[1★] C. Rist,[1] A. Faure,[1★] E. Roueff,[2] M. Gérin,[3] D. C. Lis,[4,5] P. Hily-Blant,[1] A. Bacmann[1] and L. Wiesenfeld[1]

- Detailed radiative transfer modeling: collisional rates with H_2 now available for the ammonia isotopologues
- Spherically symmetric models clearly an approximation; 3D RT needed