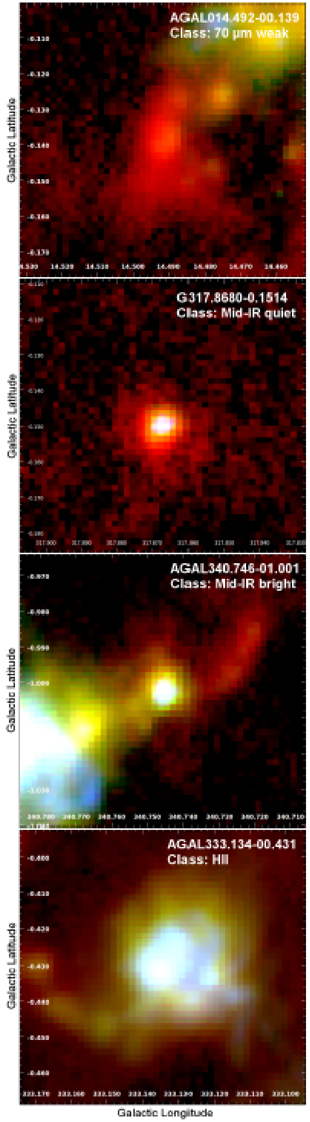
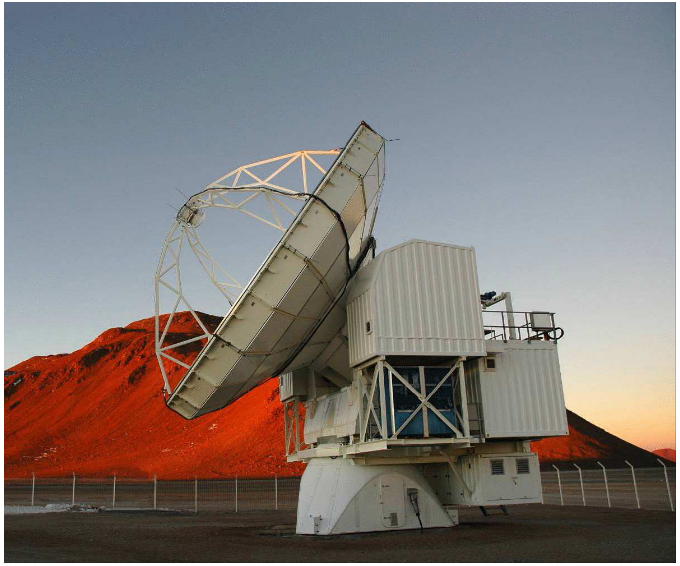
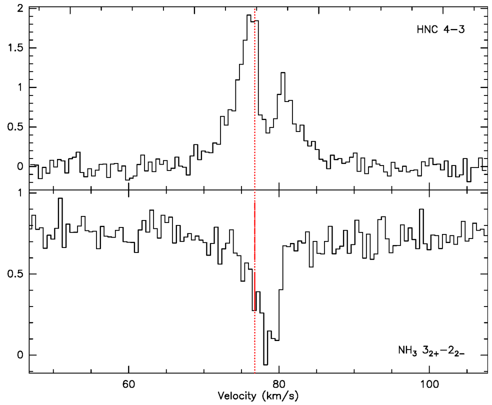


Fig. 2. Three color images of sample sources for each class sorted from youngest (top) to most evolved (bottom). Size: 5'×5'; red: ATLASGAL 870 μm; green: PACS 160 μm; blue: PACS 70 μm.



Infall studies towards star forming regions

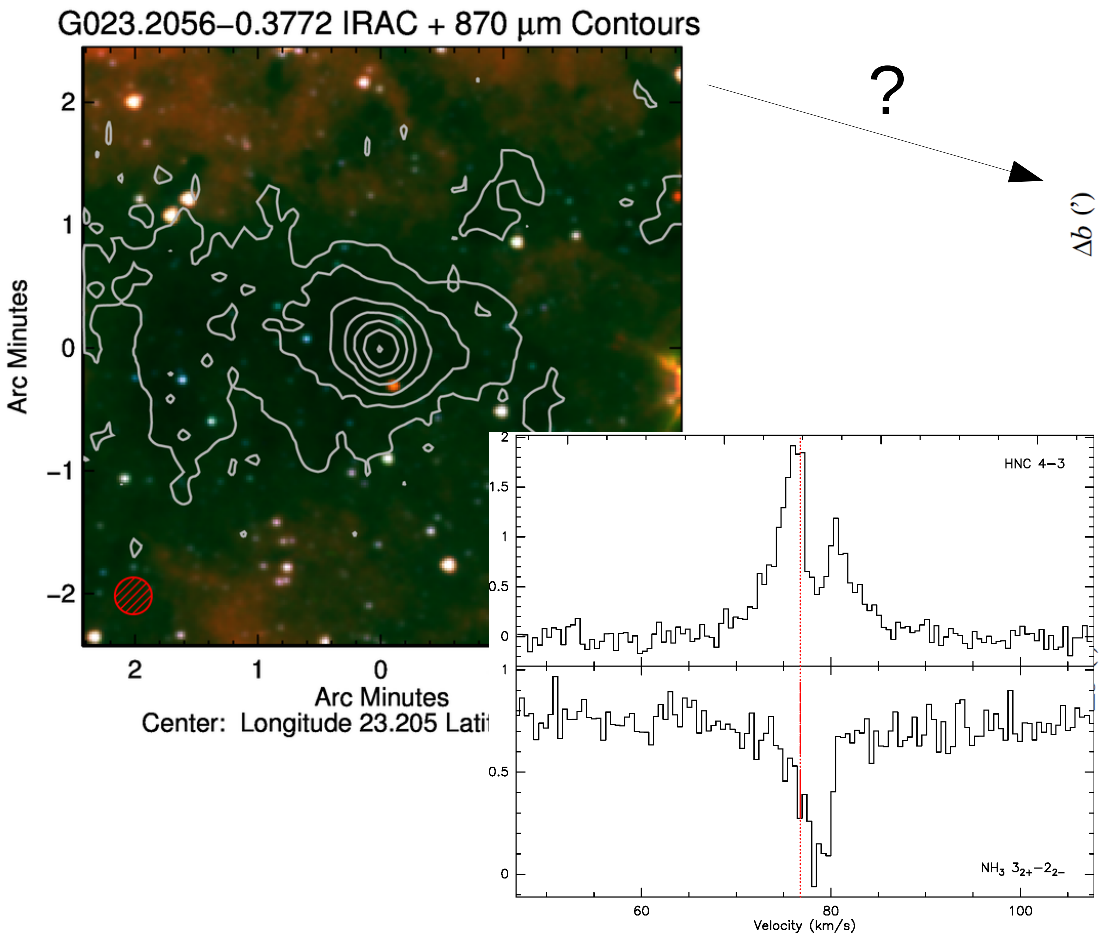
Friedrich Wyrowski, MPIfR Bonn

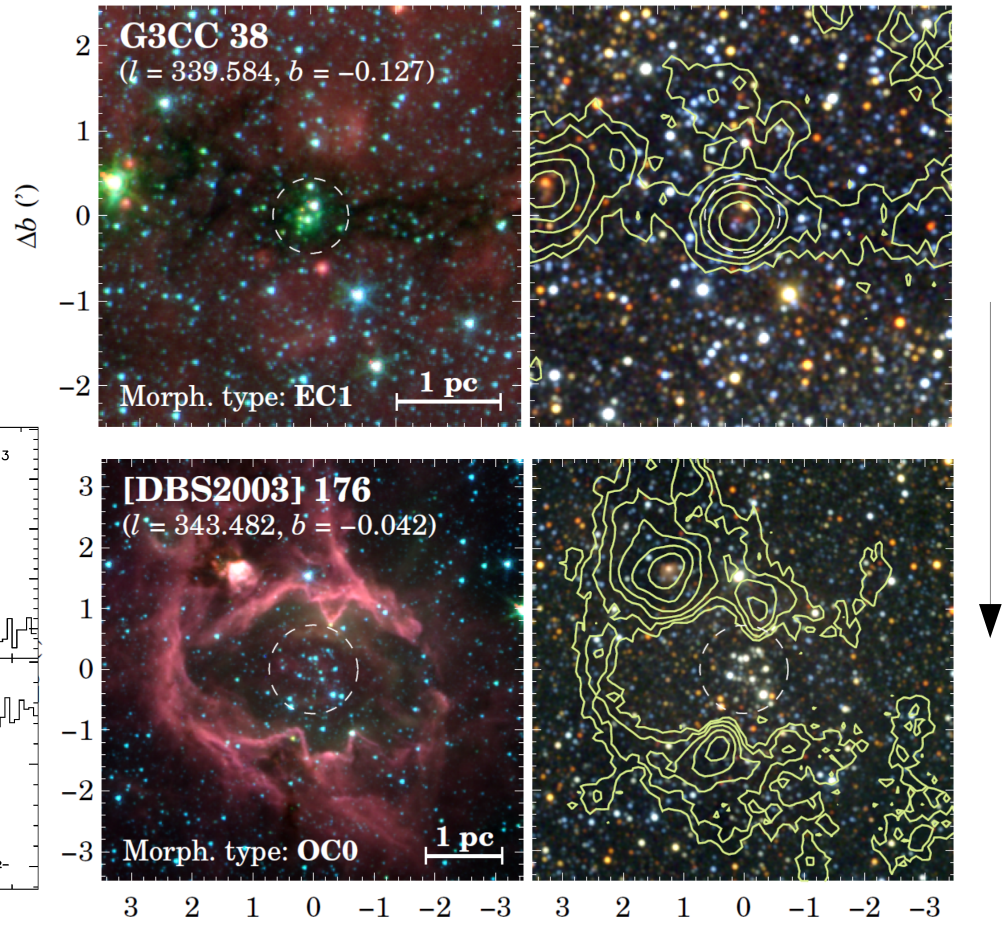


(High-mass) clump evolution

Infall is a fundamental process in SF!

ATLASGAL





Key questions

- What are the infall speeds? Are free-fall velocities measured or is the infall slowed down?
- Which parts of the clouds take part in the infall? Is the infall local or global?
- What is the velocity profile of the infall?
- What are the corresponding timelines, hence in which evolutionary stages can infall be measured?
- What are the infall rates and can they be converted into accretion rates? Are those rates compatible with model predictions?

Search for infall

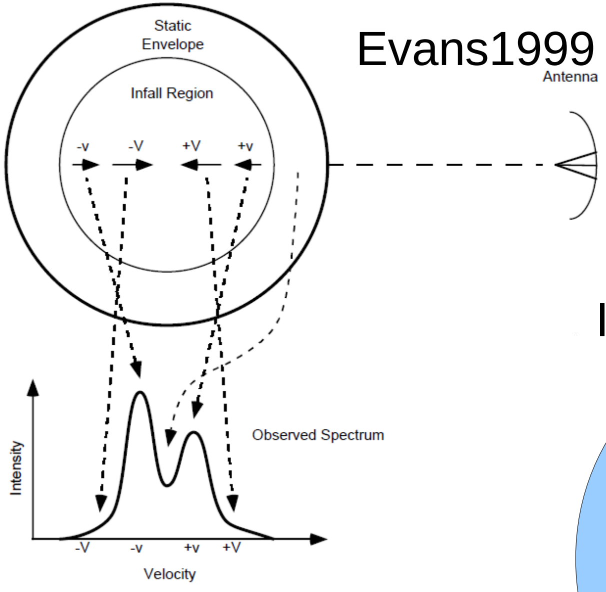
I: Blue-skewed profiles

Needs excitation gradient, right tau

II: red-shifted absorption

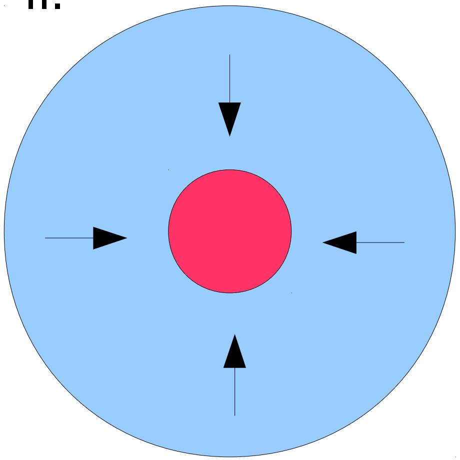
Needs high critical density, central continuum

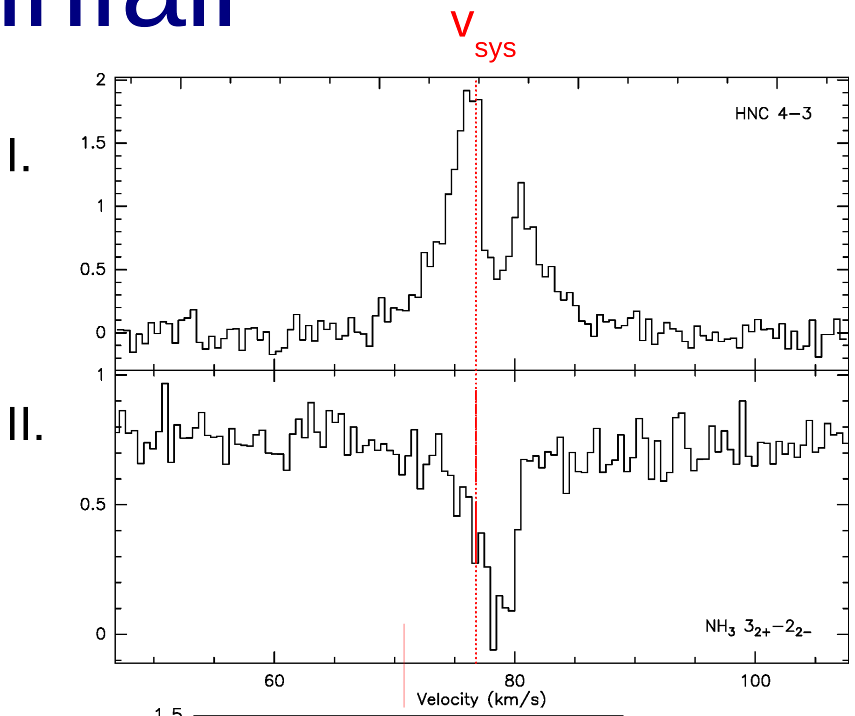
I.

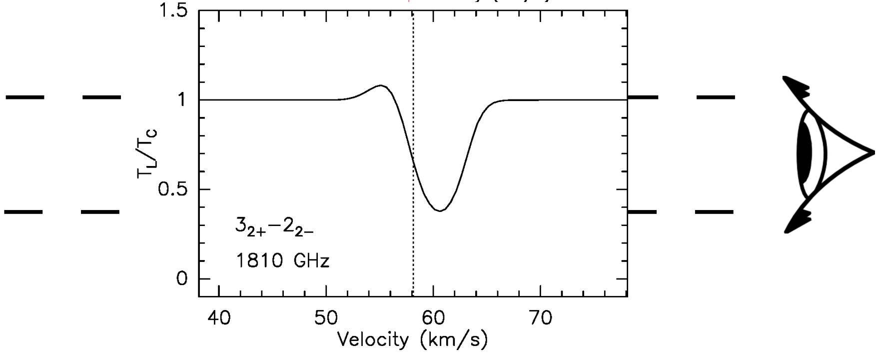


Evans1999

II.







Evidence for infall (II)

Observe infall as redshifted absorption in front of strong cm continuum from UCHIIRs:

- Zhang+Ho1997: W51
- Keto++, Sollins+2005: G10.62
- Beltran+2006: G24.78
- Beuther+2009: ATCA southern sources
- → Accretion of up to 10^{-3} $M_\odot$/yr
- Accretion even through UCHII?
- **Only late stage probed :-(**

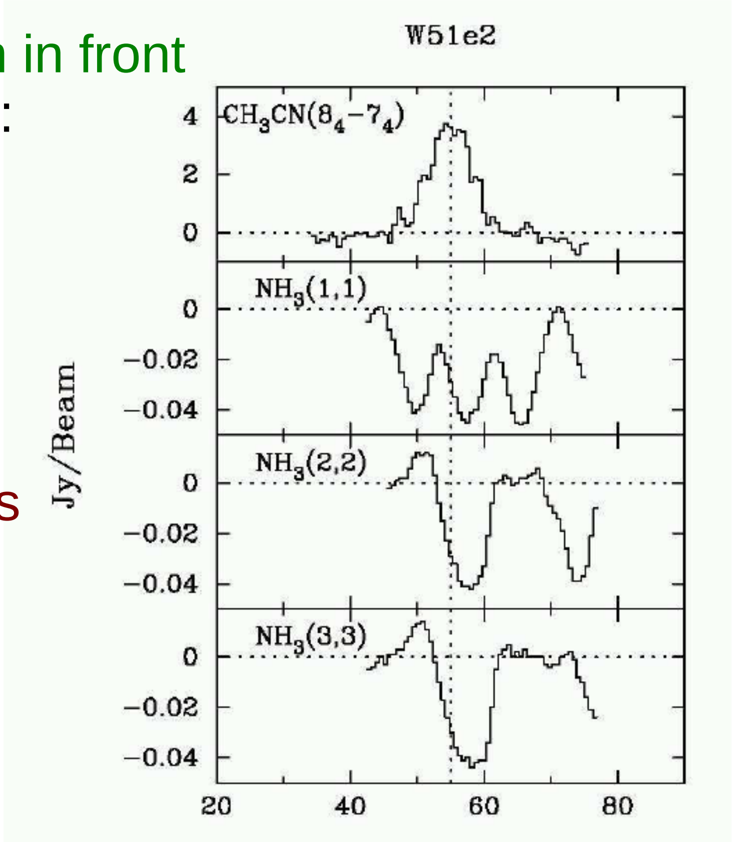


Figure 1: Infall signature towards W51e2 from VLA ammonia observations (Zhang et al. 1997). The absorption is seen against the strong cm background from the embedded ultracompact HII region.

A&A 658, A192 (2022)
https://doi.org/10.1051/0004-6361/202142811

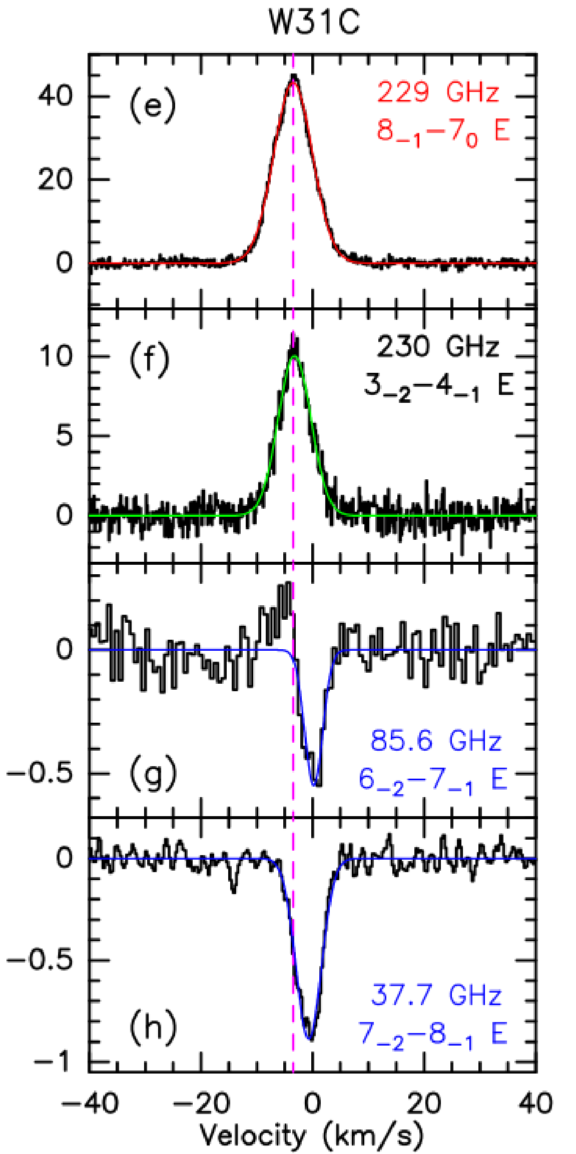
Astronomy & Astrophysics

Redshifted methanol absorption tracing infall motions of high-mass star formation regions

W. J. Yang[1], K. M. Menten[1], A. Y. Yang[1], F. Wyrowski[1], Y. Gong[1], S. P. Ellingsen[2], C. Henkel[1,3,4], X. Chen[5], and Y. Xu[6]

[1] Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, 53121 Bonn, Germany

- 37 CH_3OH transitions from 6 GHz to 236 GHz (Effelsberg, IRAM-30 m, APEX), overcooling + strong continuum: Redshifted absorption in 14 transitions in W31C (G10.6).
- Subset of lines also as redshifted absorption towards W3(OH).
- Mass infall rates of order 10^{-3} Msol/yr.



Infall in star forming regions

- New approach:
  - Employ absorption of THz lines in front of dust continuum as more straightforward tool *(previously only studies in the cm towards evolved stages, HII regions and mm/submm blue-skewed self-absorption)*
- Determine infall rates on LOS
- Probe abundances in envelope
- Study infall through the evolution of star forming clumps

Ammonia

- cm: Inversion lines
- FIR: Rotational lines, high n_{crit}
- overabundant in hot cores, apparently no depletion in cold sources
- → NH_3 3_{2+}-2_{2-} 1810.379 GHz

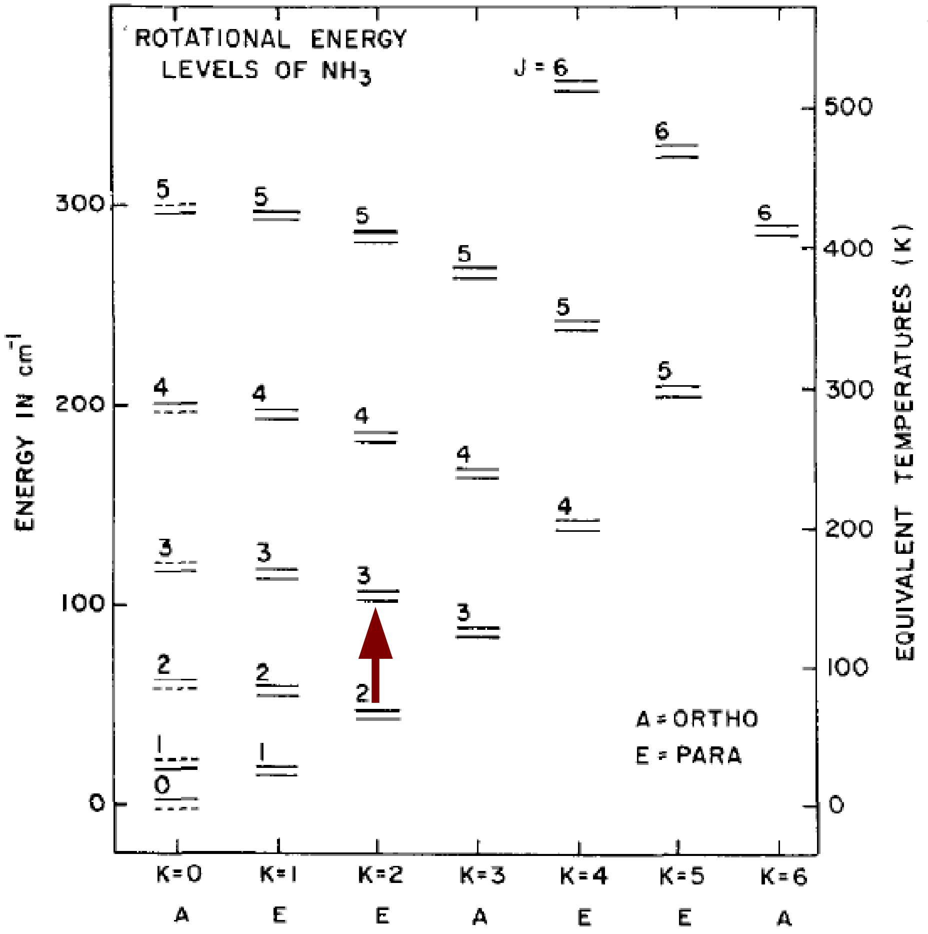
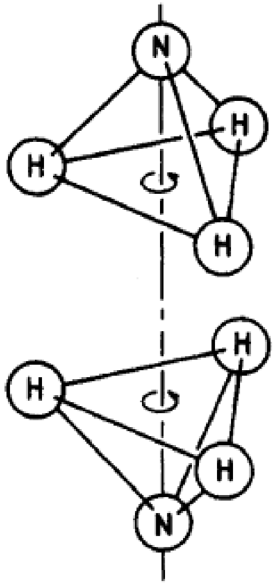


Figure 1 Energy level diagram of rotation-inversion states. *J* is the total angular-momentum quantum number, and *K* is the projected angular momentum along the molecular axis.



SOFIA results: Wyrowski+2012, 2016

Data from 2016:

- 5 redshifted absorption with shifts of 0.2 – 1.6 km/s with respect to $C^{17}O$
- 1 source dominated by outflow (G5.89), several blue wings
- 2 sources with blue shifted absorption

All data 2012/16:

- 8/11 clumps show red-shifted absorption

Clumps in IRDCs

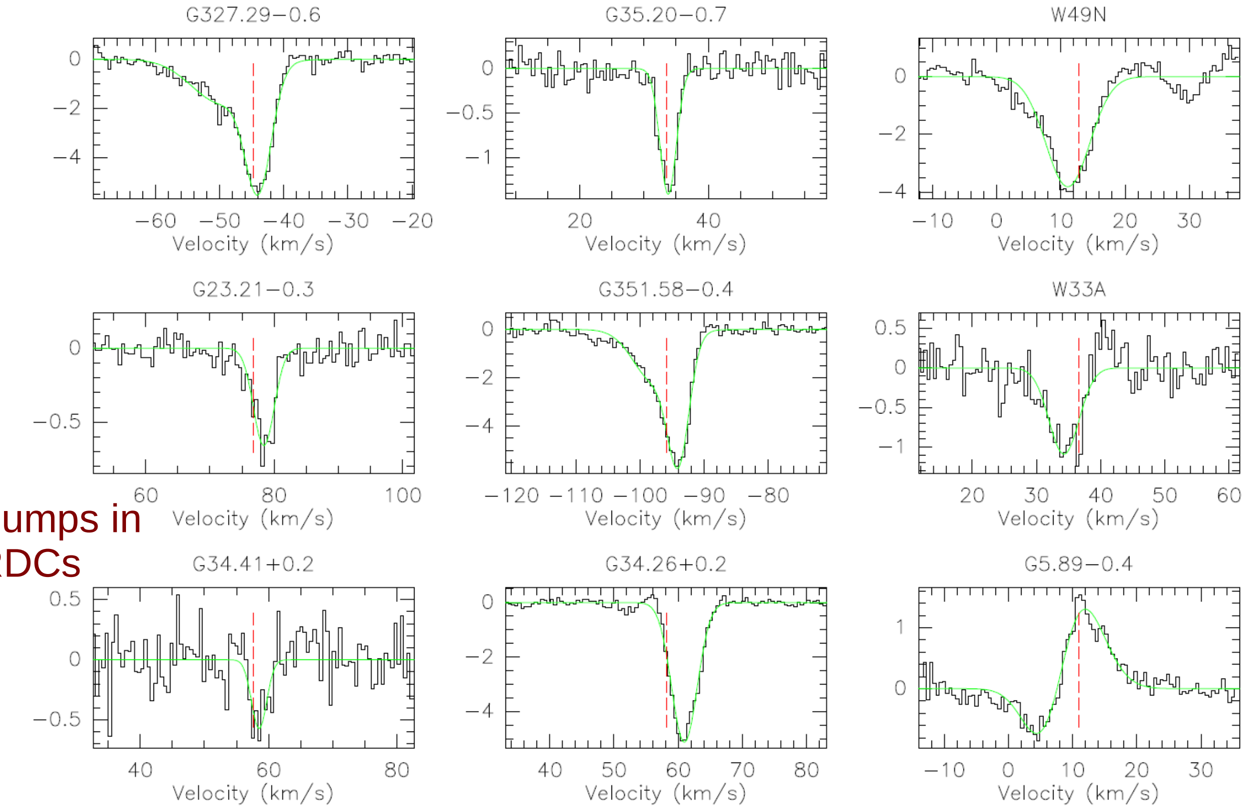


Fig. 2. NH_3 $3_{2+} - 2_{2-}$ spectra of the observed sources. Results of Gaussian fits to the line profiles are overlaid in green. The systemic velocities of the sources, determined using $C^{17}O$ (3–2), are shown with dotted lines. W49N shows in addition at 30 km/s the NH_3 $3_{1+} - 2_{1-}$ from the other sideband.

Modeling results

Wyrowski+2016

Source	R_{out} (pc)	α_n	n_{1pc} ($10^3 cm^{-3}$)	δv_t (km/s)	f_{ff}	$X(NH_3)$ 10^{-8}	$X(HCO^+)$ 10^{-10}	$\dot{M}$ (10^{-3} $M_\odot$/yr)
G34.26+0.2	0.8	-1.7	10	2.4	0.3	0.19	0.25	9
G327.29-0.6	2.	-1.9	10	2.3	0.05	0.5	0.2	4
G351.58-0.4	1.8	-1.9	15	1.5	0.1	1.5	0.2	16
G23.21-0.3	1.8	-2.0	4.5	1.0	0.2	1.5	0.5	8
G35.20-0.7	1.5	-1.6	5.5	1.5	0.03	0.35	0.3	0.3
G34.41+0.2	1.0	-1.6	5	1.5	0.1	0.15	0.4	0.7

- Spherical modeling of sources with n, T, v gradients results in infall with fractions of free-fall of 3 – 30 %. Clump scale probed. To further constrain models, → measure larger spatial range, more molecules/lines with different excitation

Herschel G34.26 NH_3 results

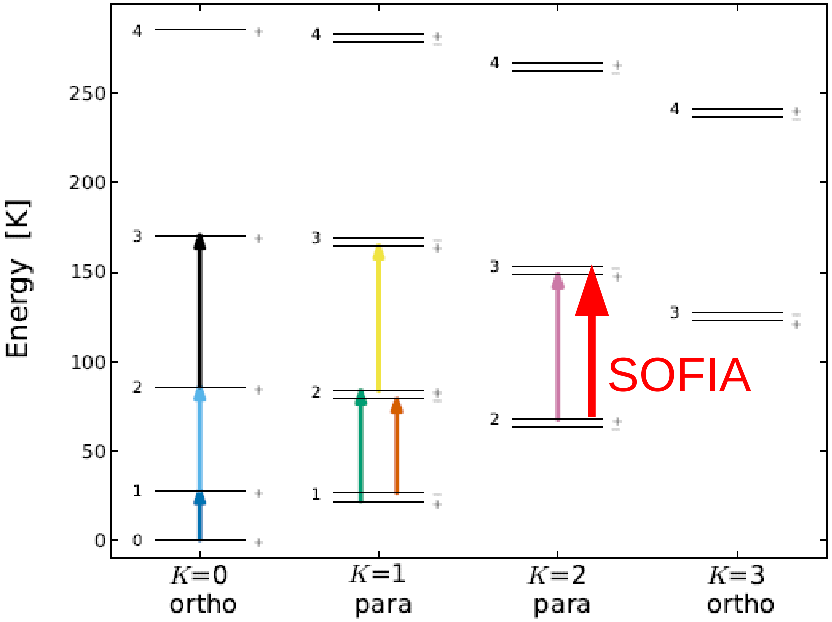
Hajigholi+2015

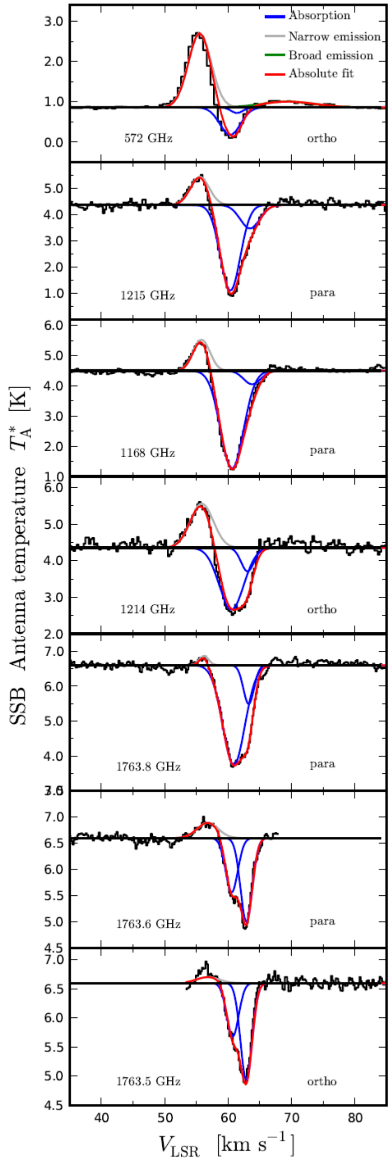
Different excitation traces different v

- → infall accelerating towards inner part of clum

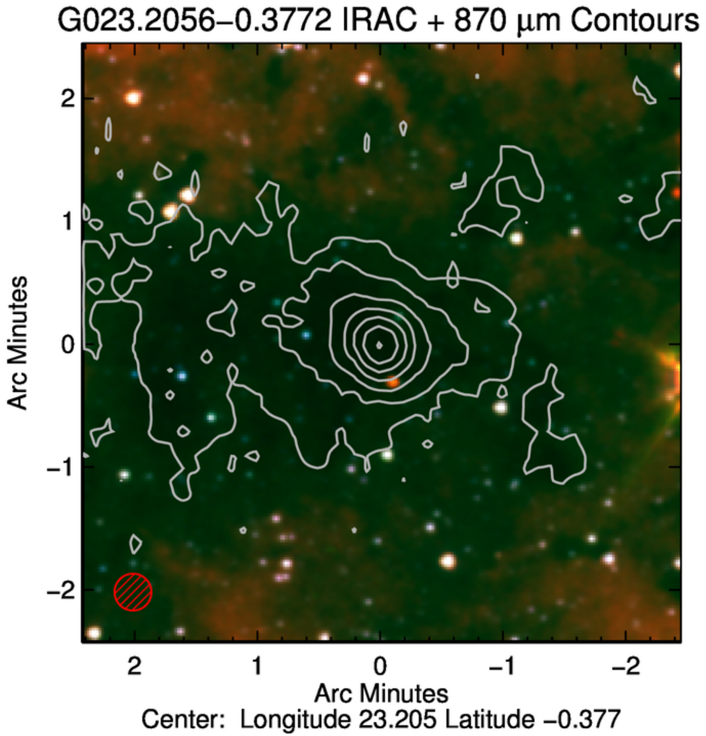
Other airborne opportunities:

- GS 572 GHz @ 90% transmission (4GREAT)
- 1214 GHz (201-100, 211-110 @ 65%
- 2355 GHz (4-3 lines) @ 63%

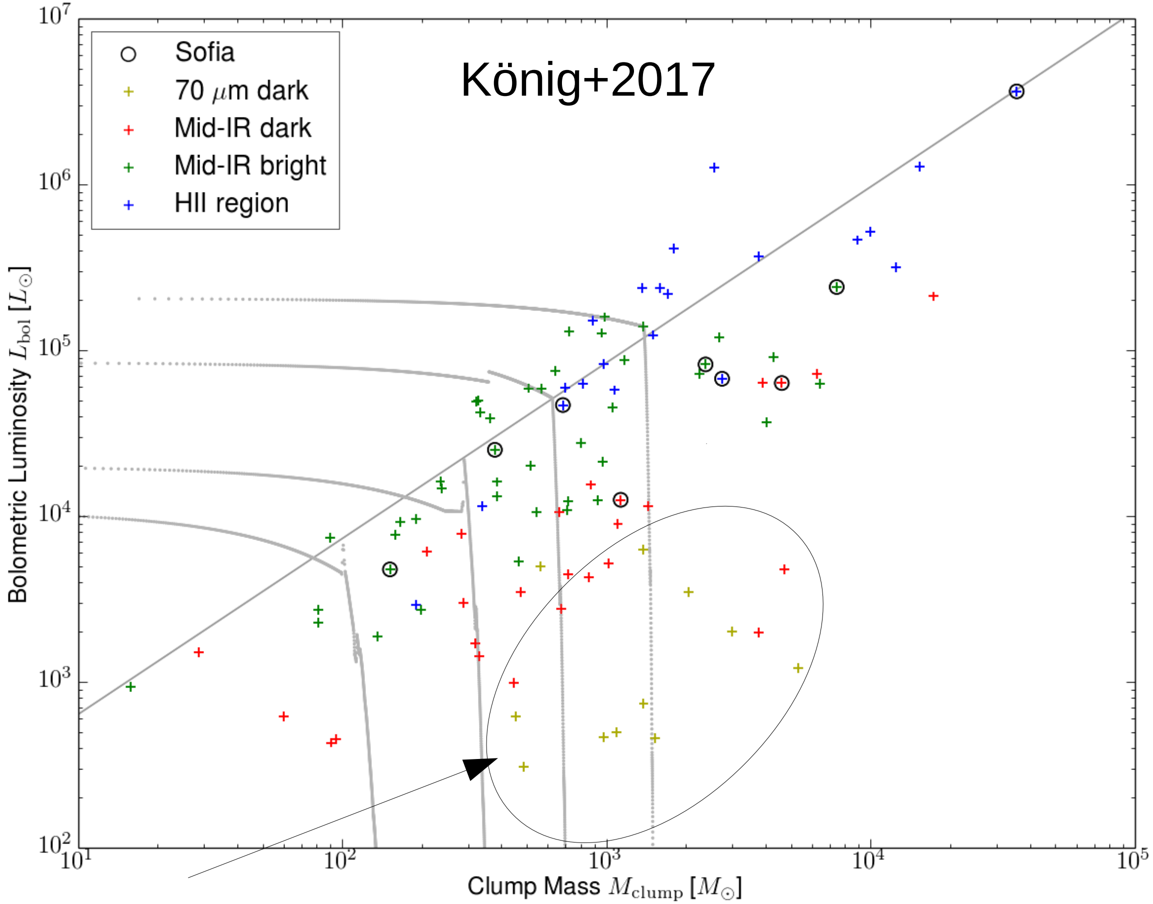




SOFIA results: sample

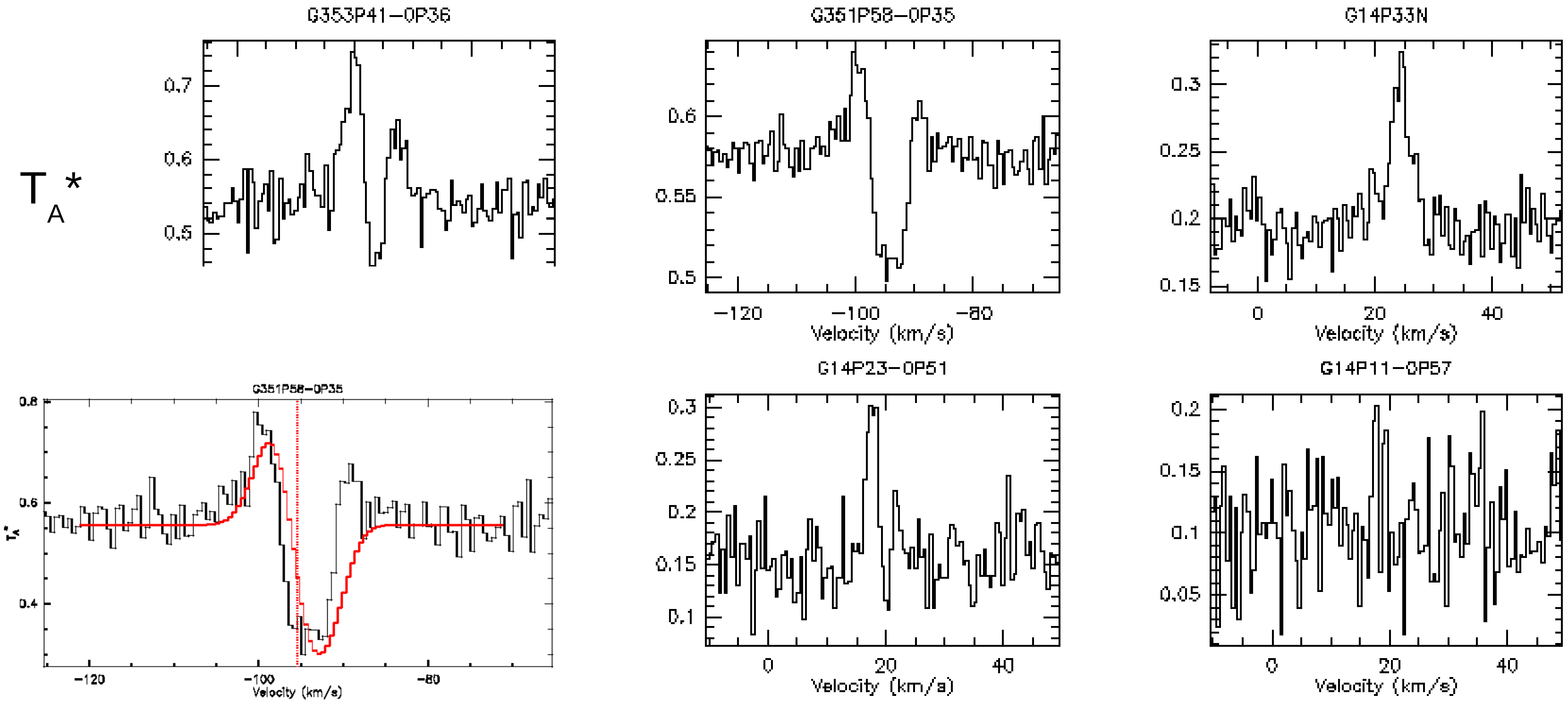


Mid-IR dark clump



70mu dark: No/too weak SOFIA 1.8THz continuum ! → 572 GHz

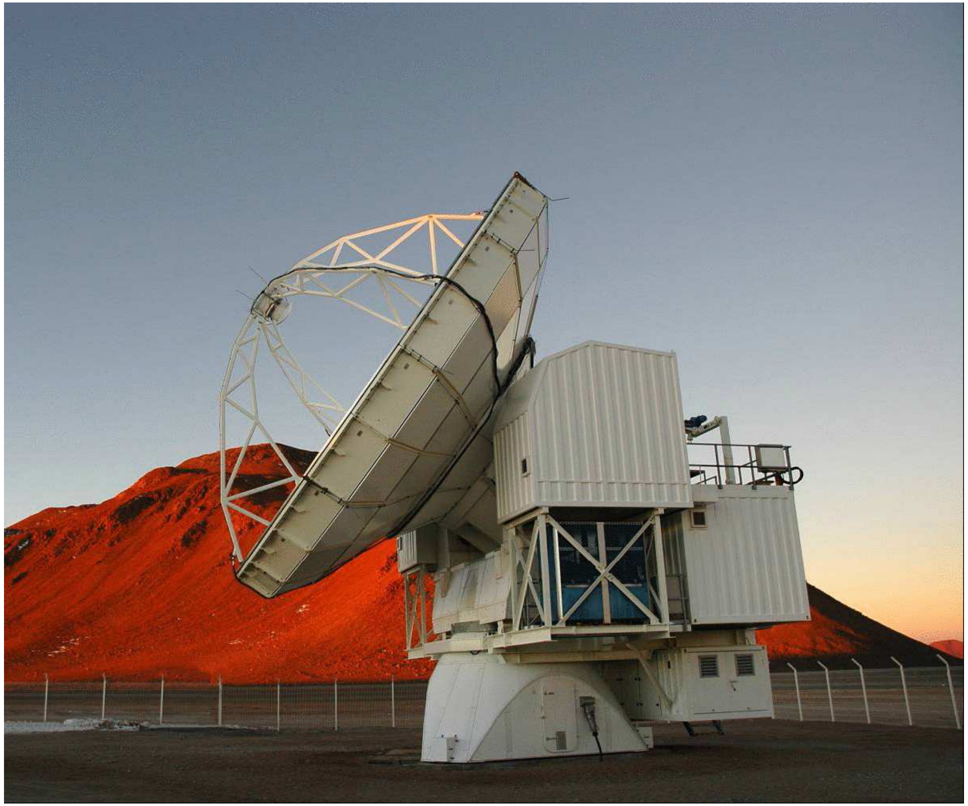
SOFIA o-NH_3 @ 572 GHz



RATRAN model

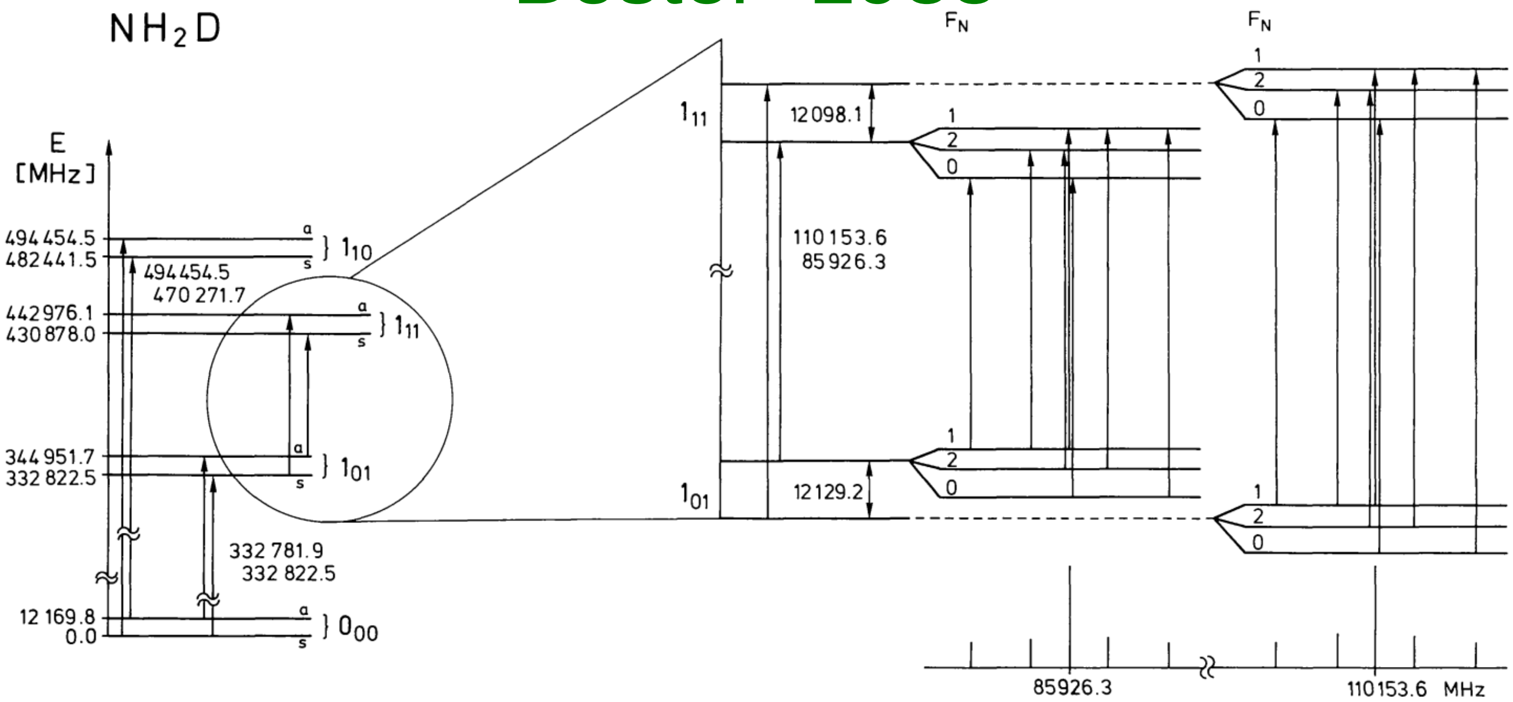
APEX (in a nutshell)

- 12m, modified copy of ALMA prototype, in operation since 2005
- At 5100m on Chajnantor Plateau (ALMA site), base in Sequitor@2500m with control room etc.
- MPIfR, hosted by ESO
- Surface ~ 12 micron
- Wobbling secondary
- BEs: many FFTSs
- Current FEs: Het. RXs: 160 - 700 GHz
- In commissioning: A-MKID camera
- Upcoming: 800 – 950 GHz, 3mm RX
- Planned: THz RX



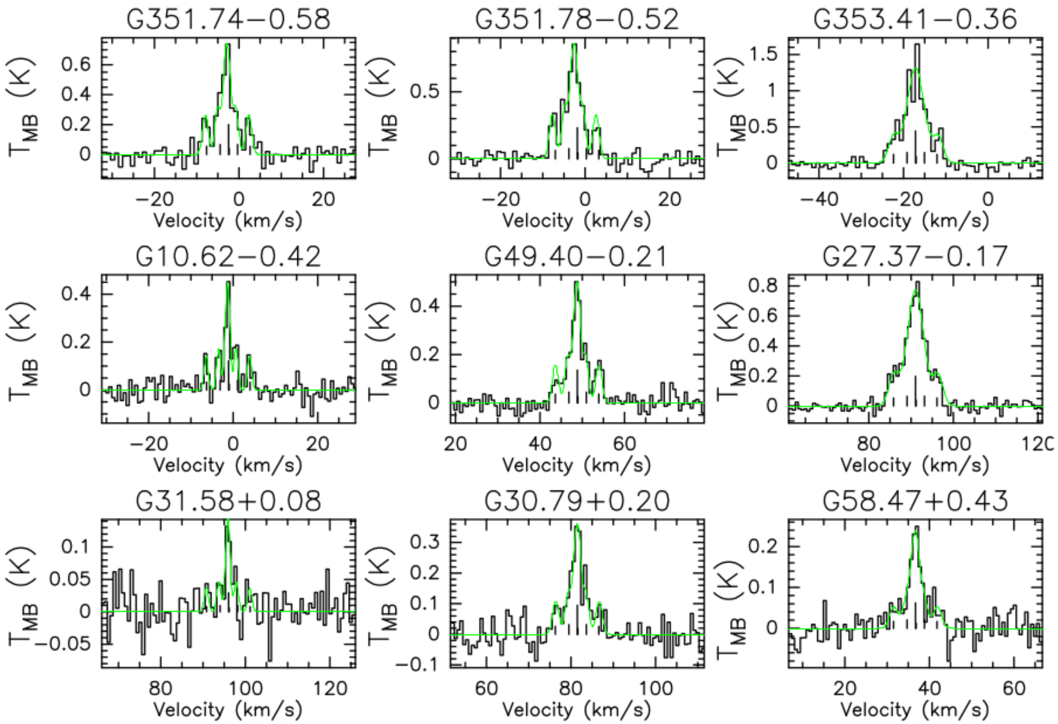
Alternative: NH_2D

Bester+1983

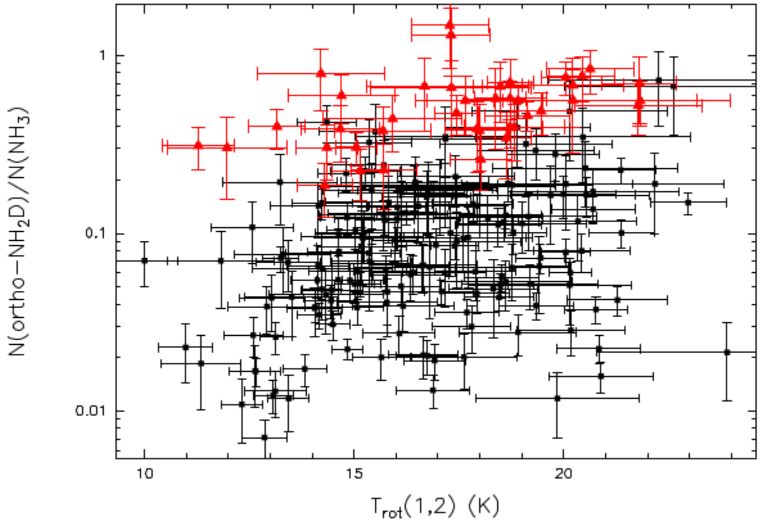


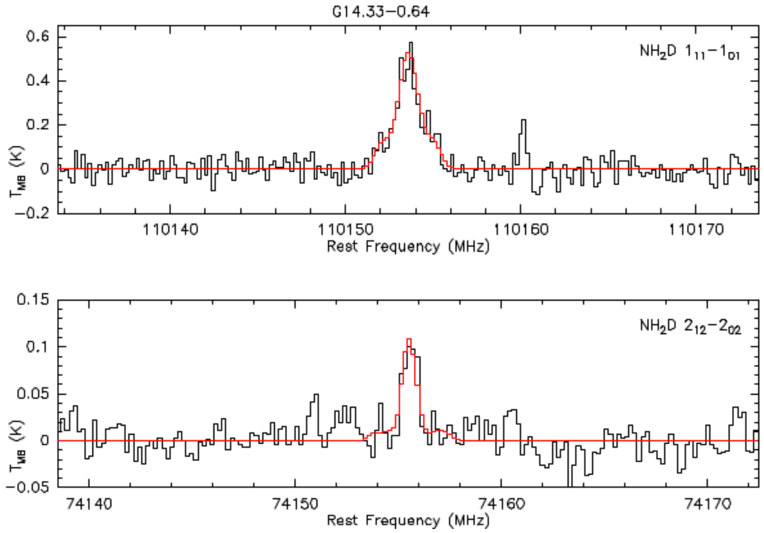
Deuterated ammonia in massive clumps

390/992 clumps - Wienen+2021, IRAM, Mopra



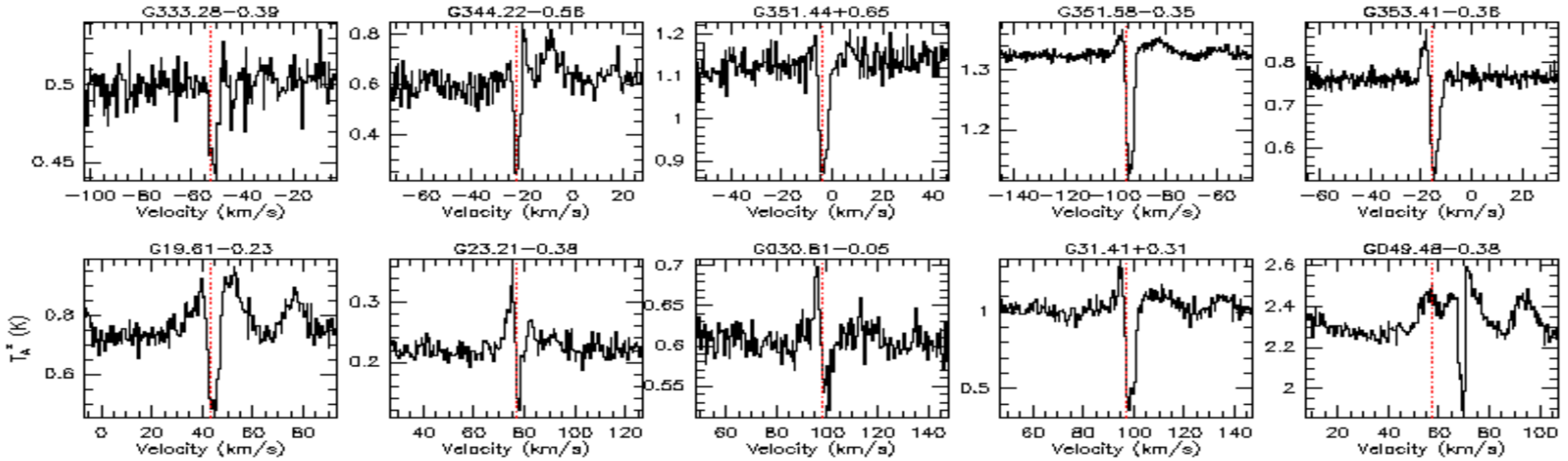
o-NH_2D 1_{11}-1_{01}





NH_2D with APEX

- Submm ground-state transitions at 332, 470,494 GHz (o,p)
- 470 GHz line turns partly in absorption: Potential new redshifted absorption tool



NH_2D modeling and mapping

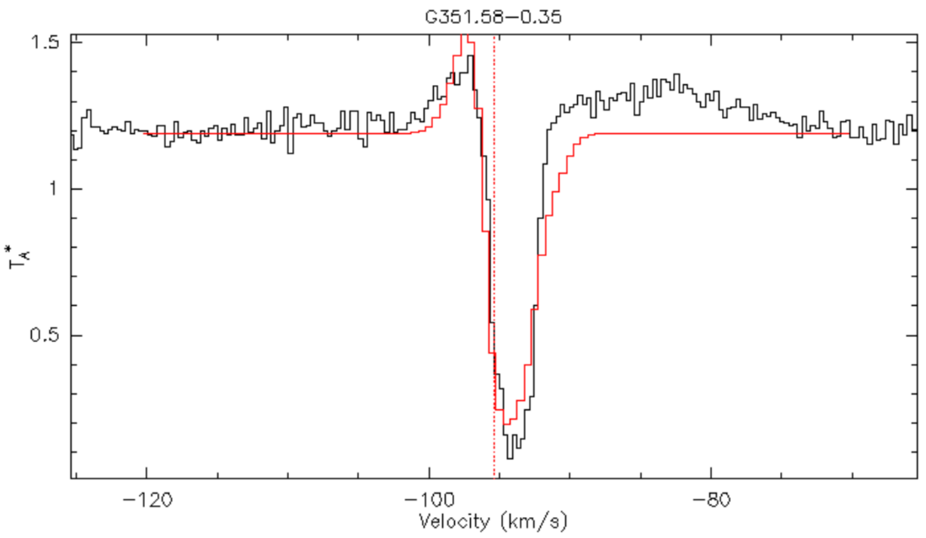
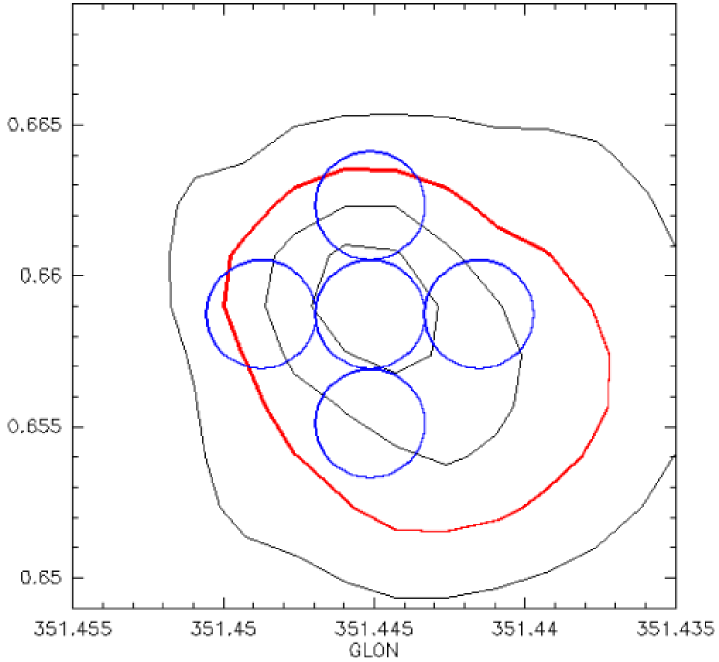


Figure 2: Spherical symmetric RATRAN model of the NH_2D 470 GHz ground state line constrained based on the ATLASGAL dust emission, SED fits of the clump and the NH_3 absorption profiles observed with SOFIA (see Wyrowski et al. 2016). Only the abundance has been adjusted for NH_2D. The systemic velocity is indicated with a red, dashed line.

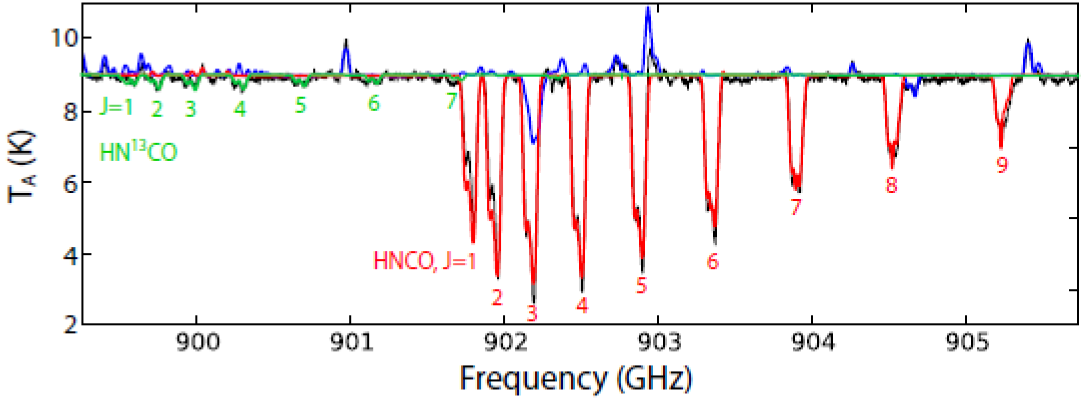


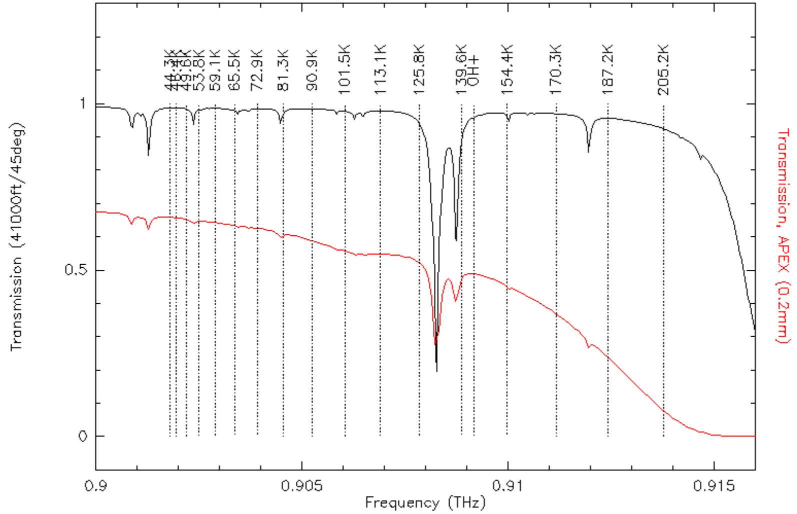
Mapping possible!

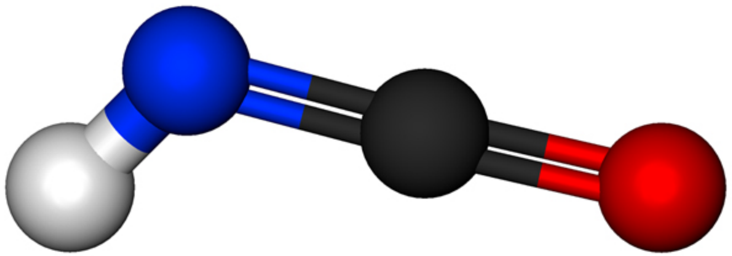
Probing infall with HNCO

- HNCO K_a = 1−0 Q-branches seen in absorption at 900 GHz (range in E)
- Possible from the ground, but only lower J lines

Neill+2014: SgrB2(N) with Herschel/HIFI







Probing infall with HNCO

Hernandez+2024 (to be subm.)

- APEX / CHAMP
- SOFIA / 4GREAT
- Bright ATLASGAL clumps
- 3mm lines Mopra/IRAM

Frequency (MHz)	Transition	E_{up} (K)	A_{ij} (s^{-1})	G_{up}
87597.330	$4_{1\,4} - 3_{1\,3}$	53.79	8.04×10^{-6}	9
87925.237	$4_{0\,4} - 3_{0\,3}$	10.55	8.78×10^{-6}	9
88239.020	$4_{1\,3} - 3_{1\,2}$	53.86	8.22×10^{-6}	9
901800.0807	$1_{1\,0} - 1_{0\,1}$	44.33	7.84×10^{-3}	3
901956.9168	$2_{1\,1} - 2_{0\,2}$	46.45	7.84×10^{-3}	5
902192.2068	$3_{1\,2} - 3_{0\,3}$	49.63	7.84×10^{-3}	7
902505.9937	$4_{1\,3} - 4_{0\,4}$	53.86	7.85×10^{-3}	9
902898.3350	$5_{1\,4} - 5_{0\,5}$	59.16	7.86×10^{-3}	11
903369.3023	$6_{1\,5} - 6_{0\,6}$	65.51	7.87×10^{-3}	13
903918.9817	$7_{1\,6} - 7_{0\,7}$	72.92	7.88×10^{-3}	15

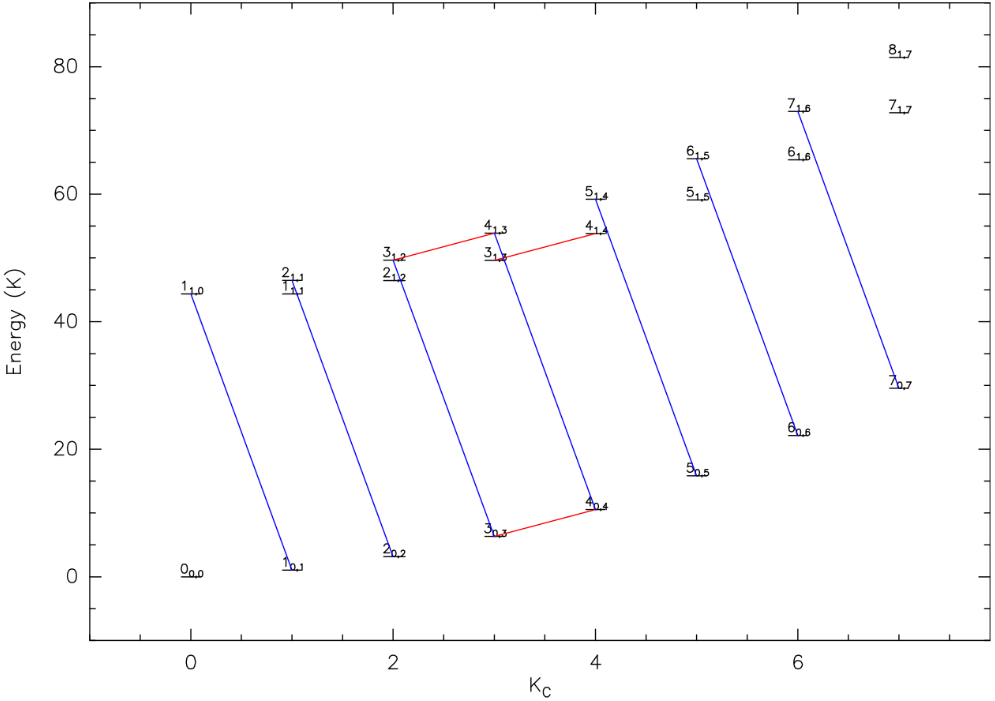
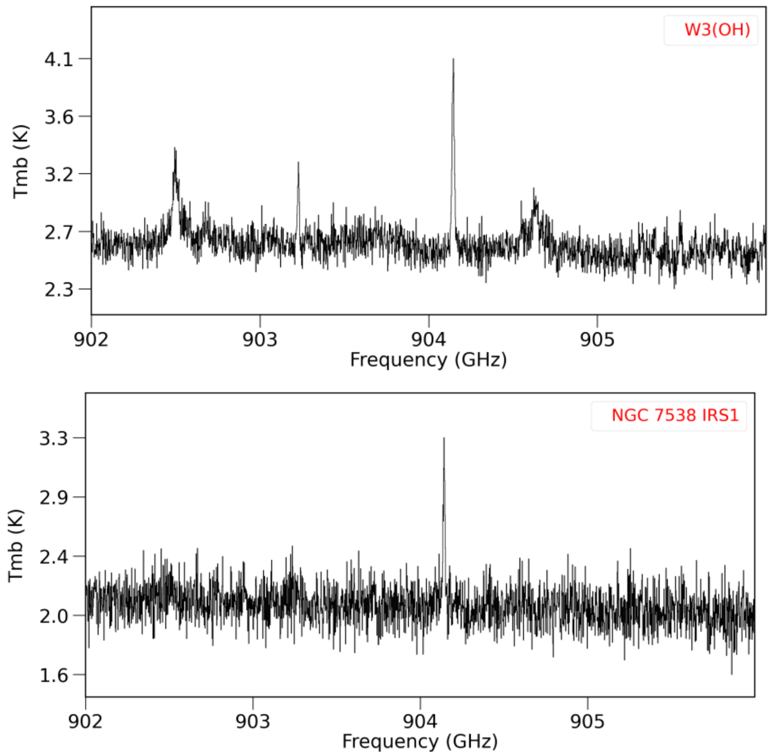


Fig. 1. HNCO energy level diagram for the transitions studied in this work. The observed transitions (in absorption) in the frequency range between ~902–904 GHz are indicated in blue color, while the transitions (in emission) at a frequency range between ~87–88 GHz are indicated in red color.

Probing infall with HNCO

Hernandez+2024 (to be subm.)



SOFIA / 4GREAT

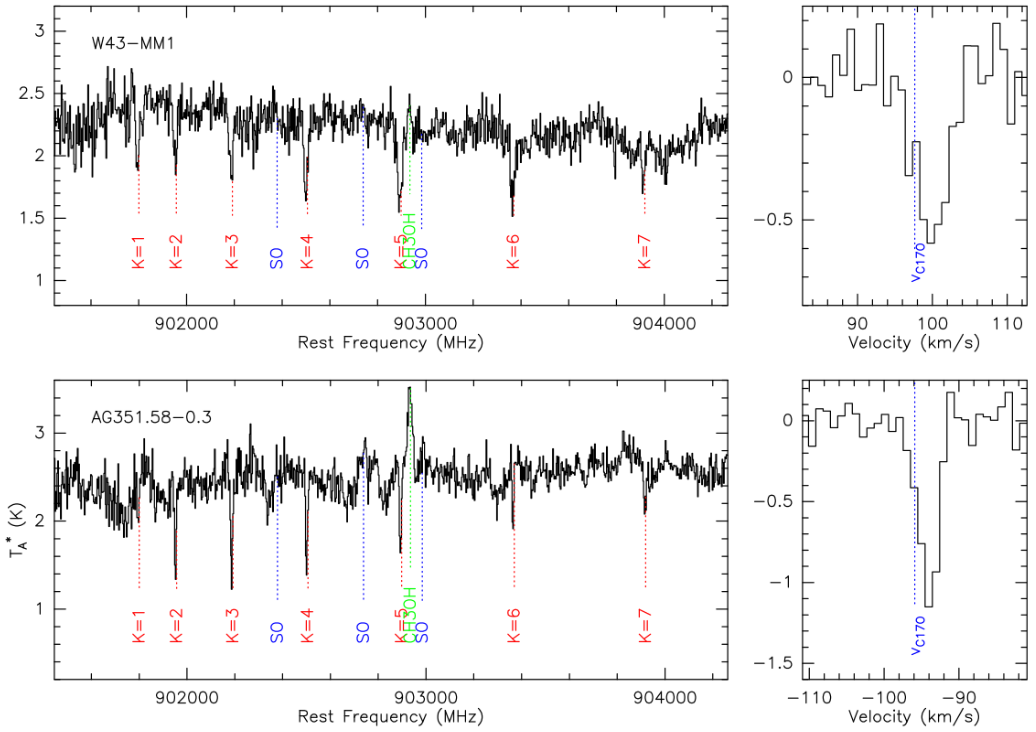


Figure 3: APEX observations of K_a=1-0 Q-branches of HNCO in W43-MM1 and AG351.58-0.3.

Probing infall with HNCO

Hernandez+2024 (to be subm.)

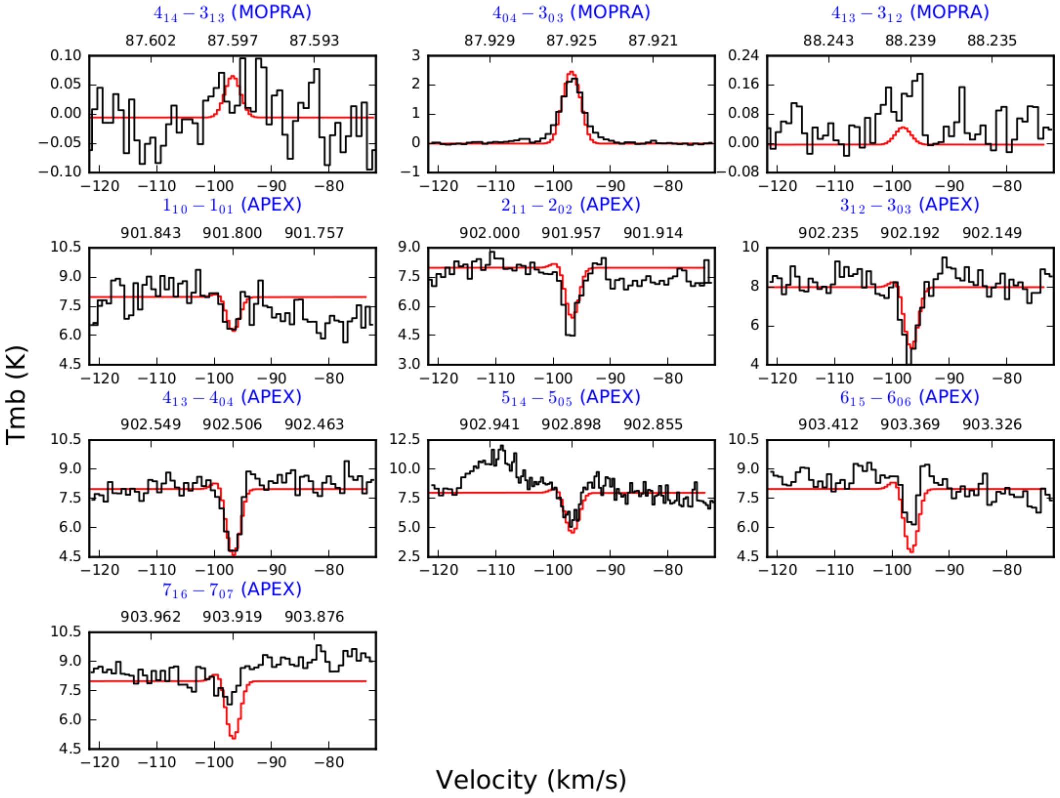
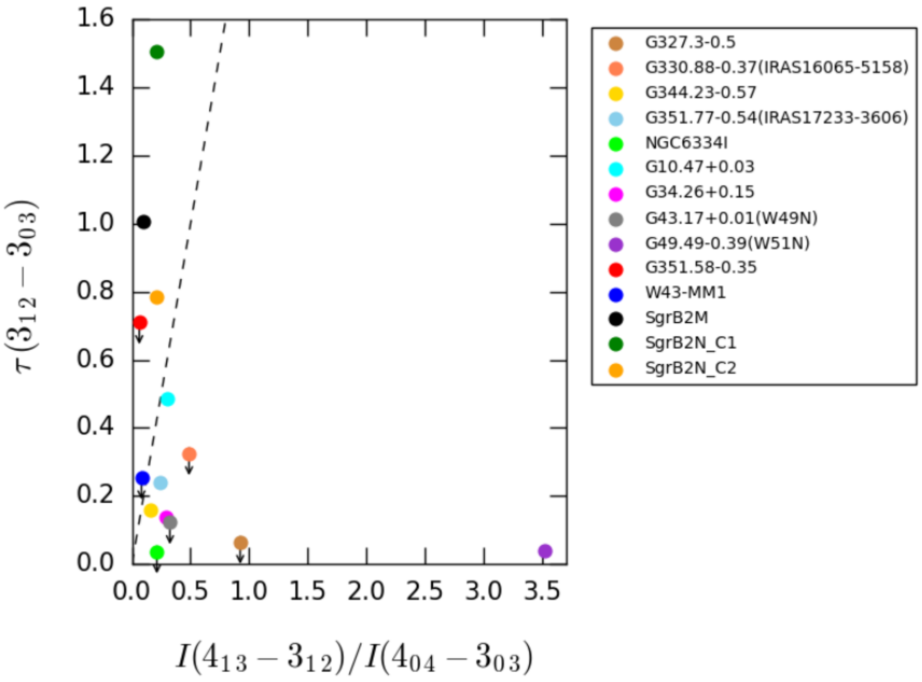


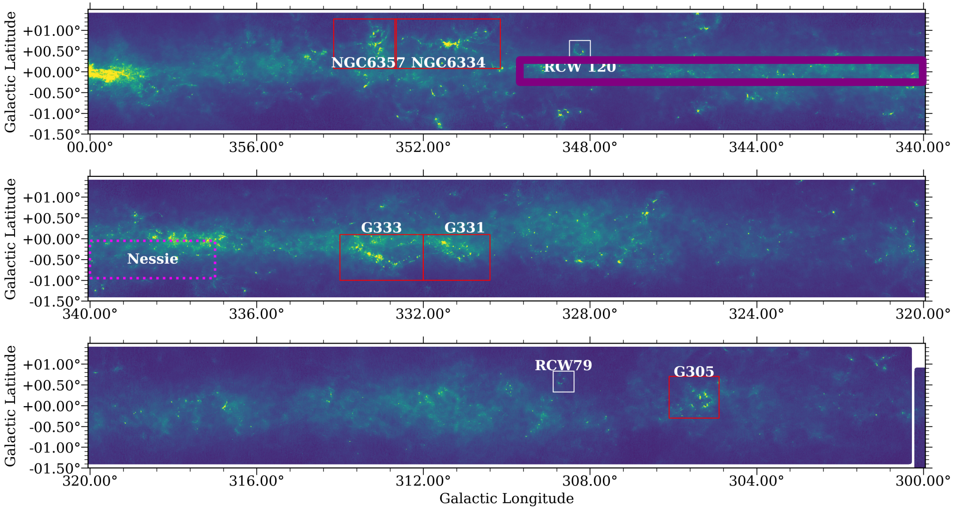
Fig. 7. HNCO transitions observed toward G351.58-0.35. The data is shown in black color, while the RATRAN model is shown in red color. The corresponding transitions and telescopes are indicated in blue color on top of each Figure.



→ nFLASH850, stay tuned!

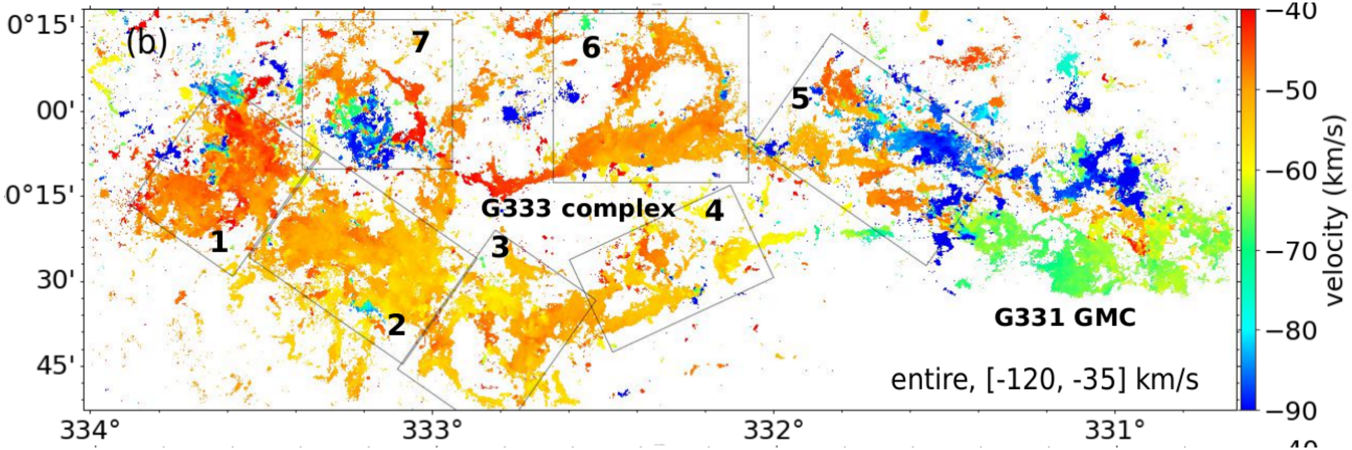
Large-scale kinematics: LASMAGAL

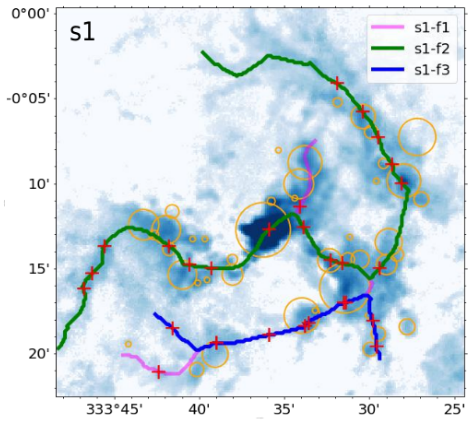
- LASMA 7pix, 345GHz, @ APEX
- Selected GMC and special regions in CO isotopologues
  - G305: Mazumdar+2021ab
  - G333: Zhou+2023ab
  - NGC6334: Neupane+ subm.
  - FEEDBACK regions
  - Far end of the Galactic Bar

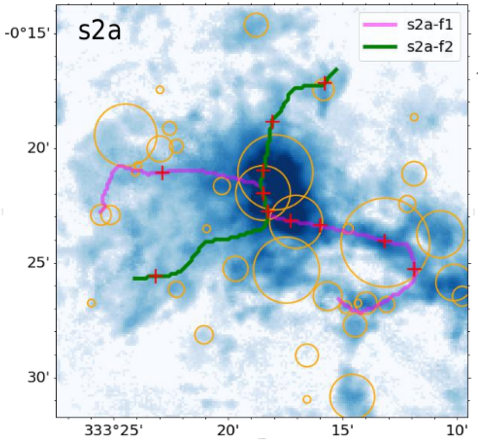


GMC G333 with LASMA

Zhou+2023

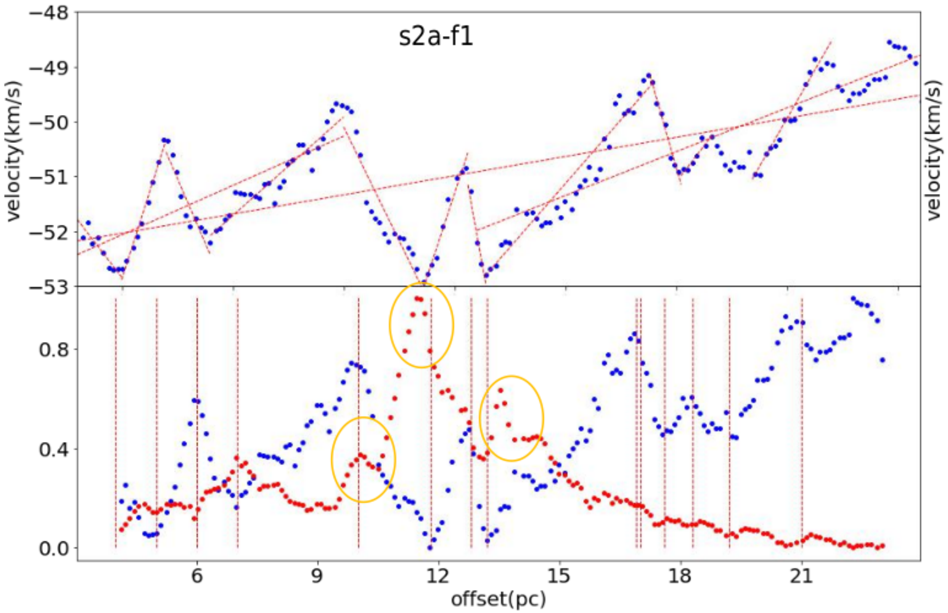


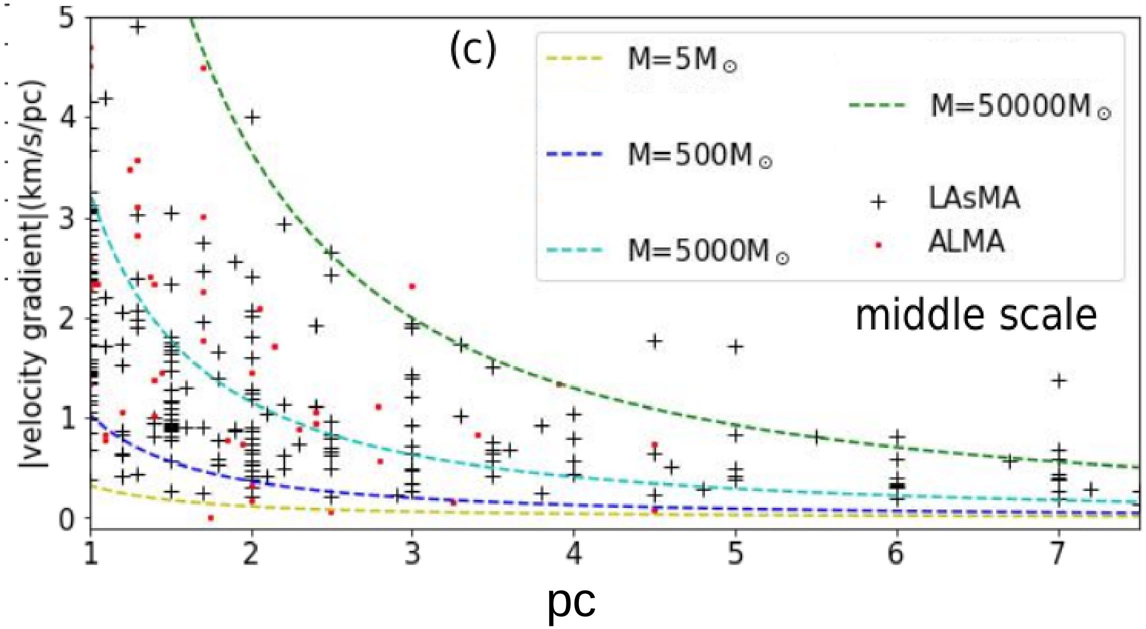




GMC G333 with LASMA

Zhou+2023 (+ALMA $H^{13}CO^{+}$)





"Funnel" structure of the velocity field in PPV space, indicative of a smooth, continuously increasing velocity gradient from large to small scales, and thus consistent with gravitational acceleration.

Atm. Transmission and past THz Rxs at Chajnantor plateau

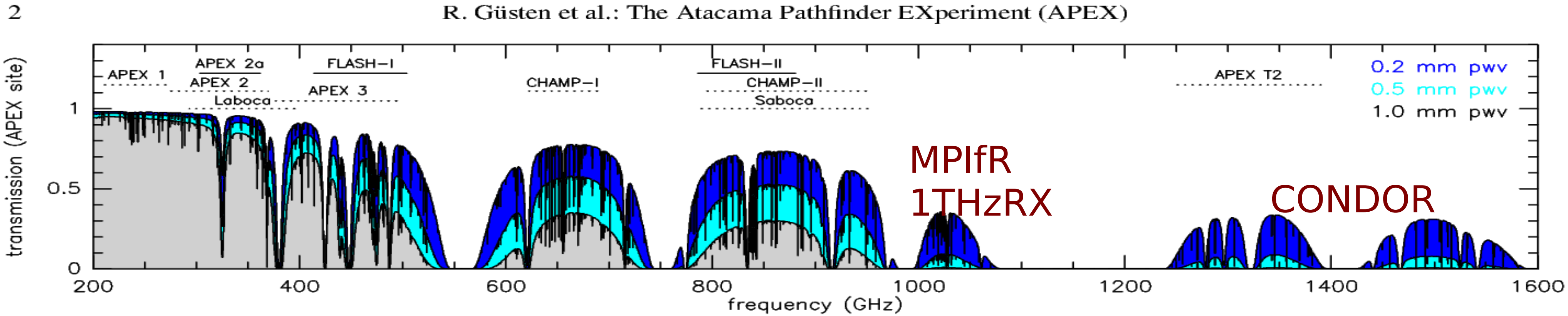
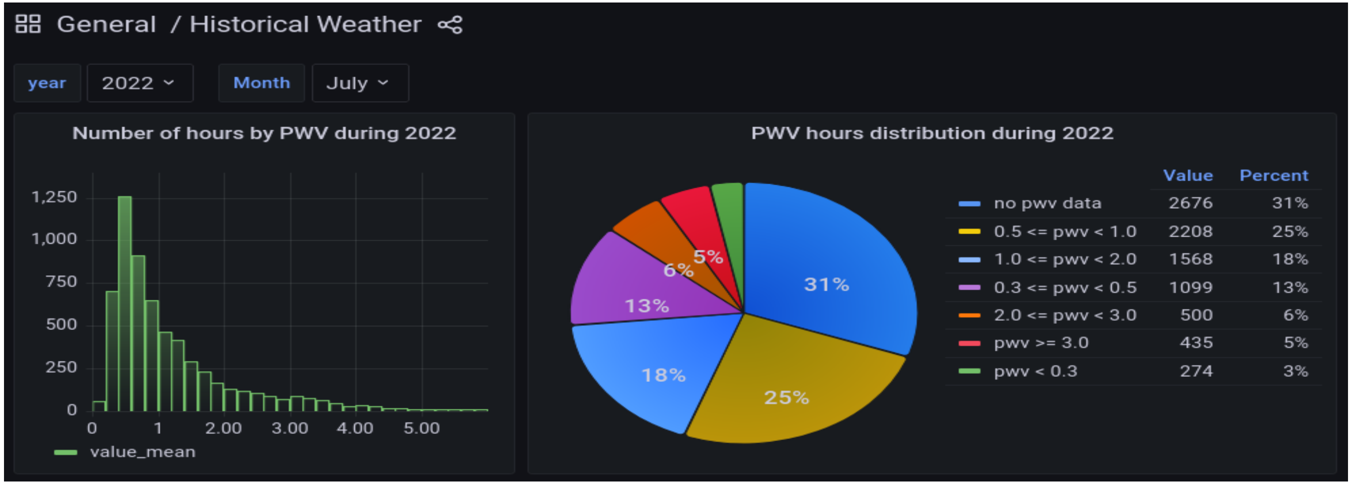


Fig. 1. Zenith transmission of the atmosphere above Llano de Chajnantor at submillimeter wavelengths. Using data from the ALMA site characterization data base covering the years 1995 to 2004, we calculate that the median column of precipitable water is about 1.2 mm and the 25 % quartile about 0.7 mm, including data taken during the Bolivian winters. During the winter months the median drops by a factor 2-3. The project plan requires that all atmospheric windows accessible from ground shall be covered by state-of-the-art instruments. We superimpose the frequency coverage of the APEX facility and PI receivers, as they are in operation now (solid lines) and as committed for delivery (dotted). Several contributions to this special issue are dedicated to our instruments.

THz from Chajnantor: more than a niche

- APEX website, historical weather: on average 250 hrs/yr of THz conditions
- Continuous access and readiness
- e.g. OH^+, NH^+, p-H_2D^+, CH (2-1), high-*J* CO, NII
- CCATp even more promising in terms of transmission



Summary & Outlook

- Infall seen in NH_3 on clump scales ubiquitous through wide range of evolutionary stages (8/11 show red-shifted absorption)
- Infall speed found as 3-30% fractions of free-fall
- Ammonia and HCO^+ (4-3) show best correspondence but HCO^+ stronger affected by outflows
- Deuterated ammonia, promising access to early stages
- HNCO: Needs special excitation in envelope, can be powerful tool
- Large scale kinematics from LASMAGAL CO observations
- APEX nFLASH850: HNCO, HDO, NH, NH_2