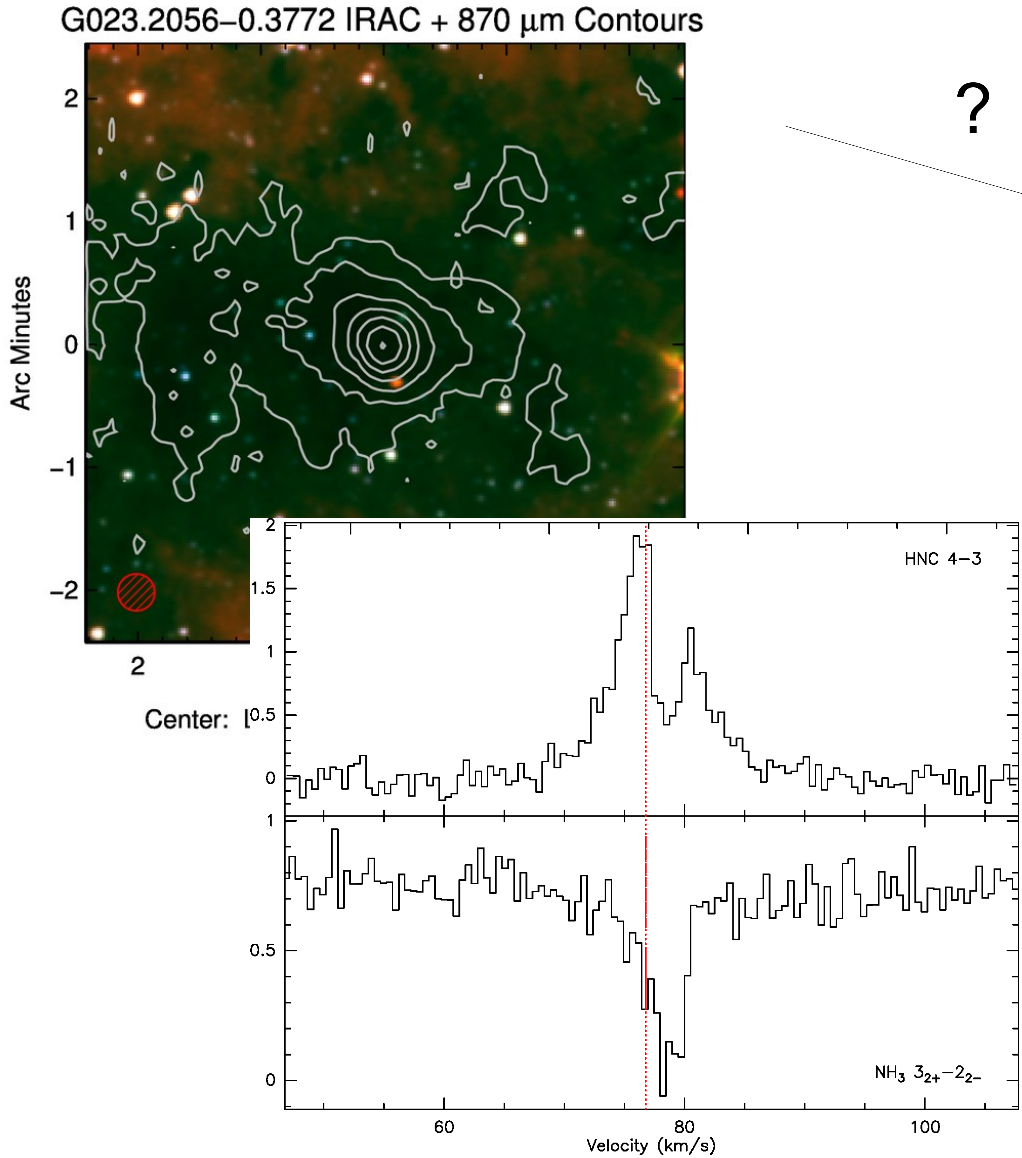
SOFIA follow-ups of ATLASGAL massive clumps

Friedrich Wyrowski, Rolf Güsten, Karl Menten, Helmut Wiesemeyer & Silvia Leurini

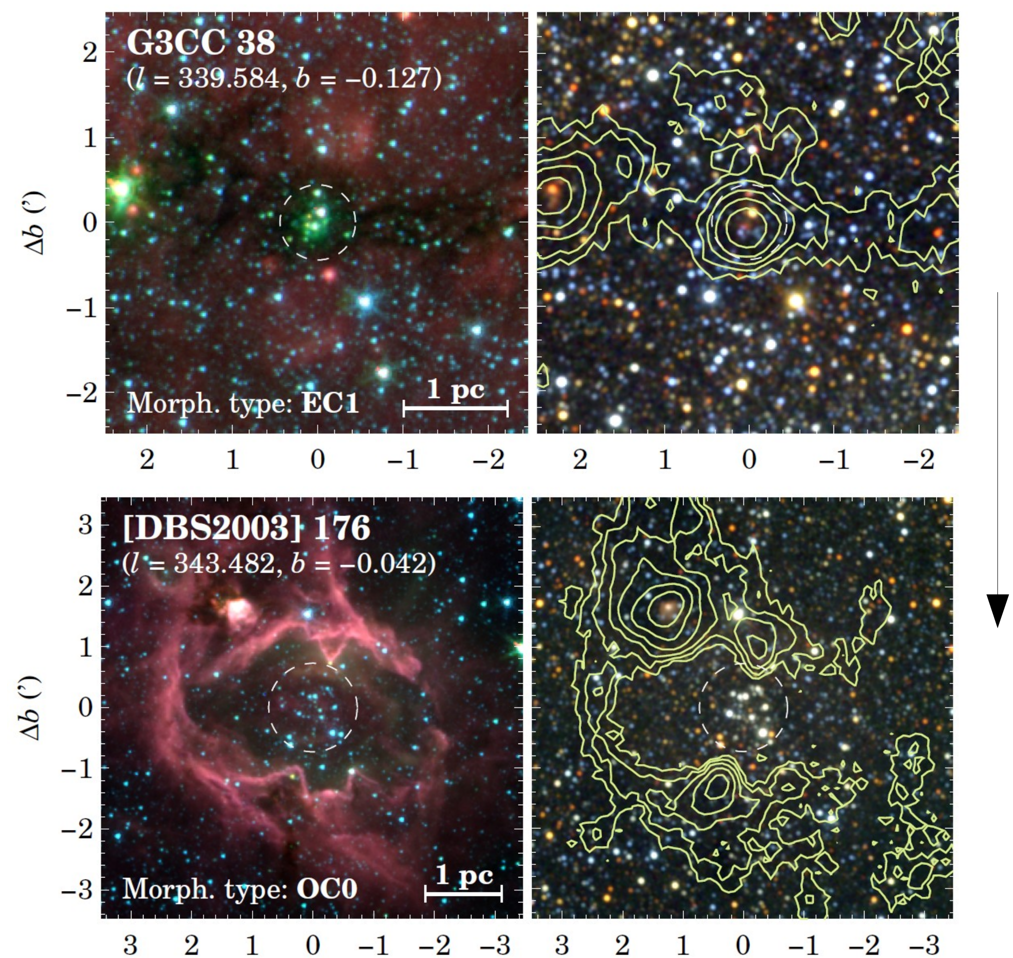
MPIfR Bonn

Massive clump evolution

Infall is a fundamental process in SF!



?



Morales+2013

Outline

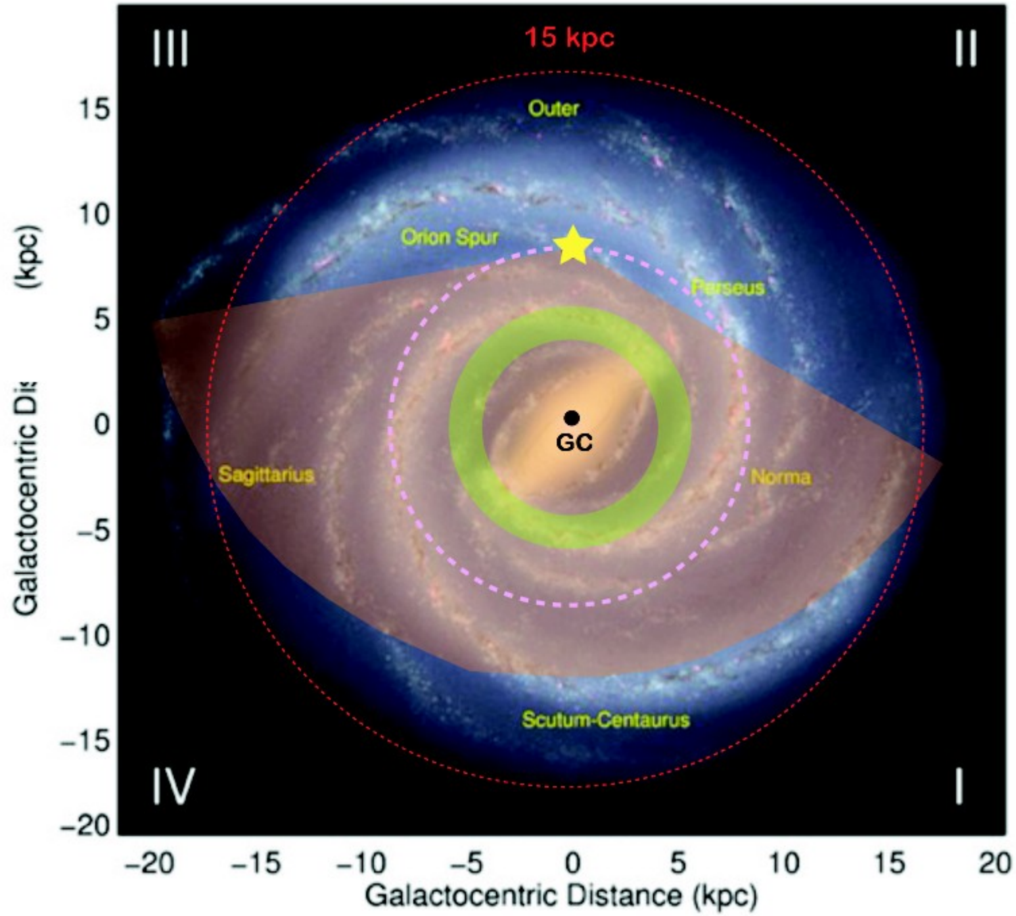
- The ATLASGAL survey
- Molecular line follow-ups
- How to probe infall
- Previous ammonia results
- New ammonia observations
- The extended sample
- Comparing ammonia with other high density probes
- New modeling of profiles
- APEX-SOFIA synergies

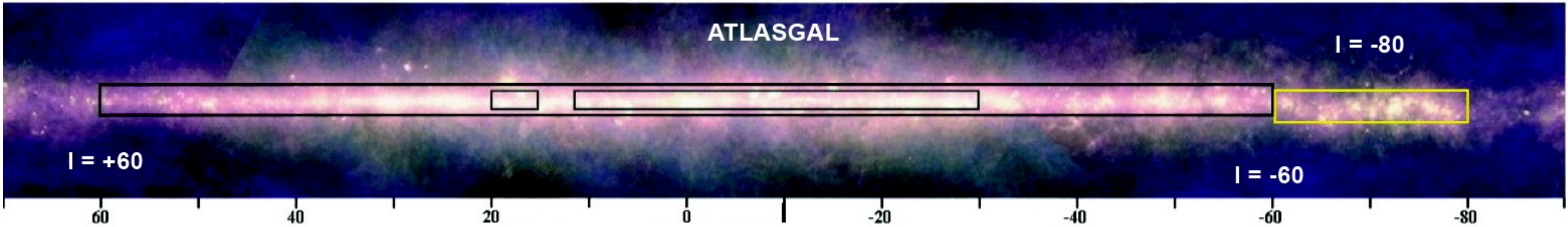
Overview of the ATLASGAL Survey
Submillimetre Emission: Structure of the Dust

Max-Planck-Institut für Radioastronomie

- **APEX 870 μm continuum survey of the inner Galactic plane (300° < l < 60°, |b| < 1.5°)**
- **APEX: 12-m Single-dish Submillimetre Telescope located on the Chajnantor Plateau**
- **LABOCA: Large APEX BOlometer CAmera (MPIfR)**
- **295 elements at 870 μm**
- **FoV = 11′, an angular resolution of ~19″ and sensitivity of ~60 mJy/beam**

Complementary to Herschel/HiGAL
&
Pathfinder to ALMA MSF science

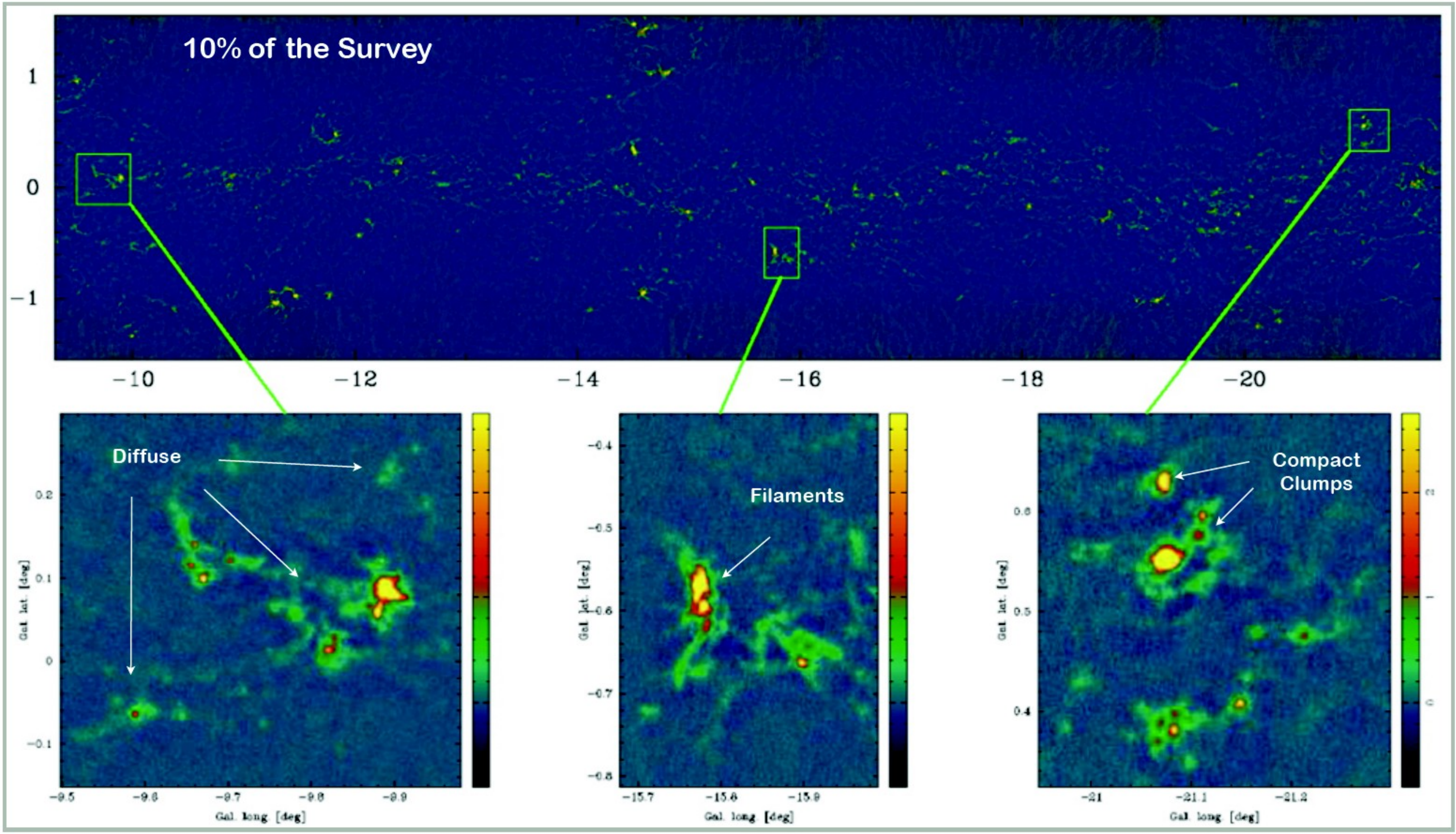




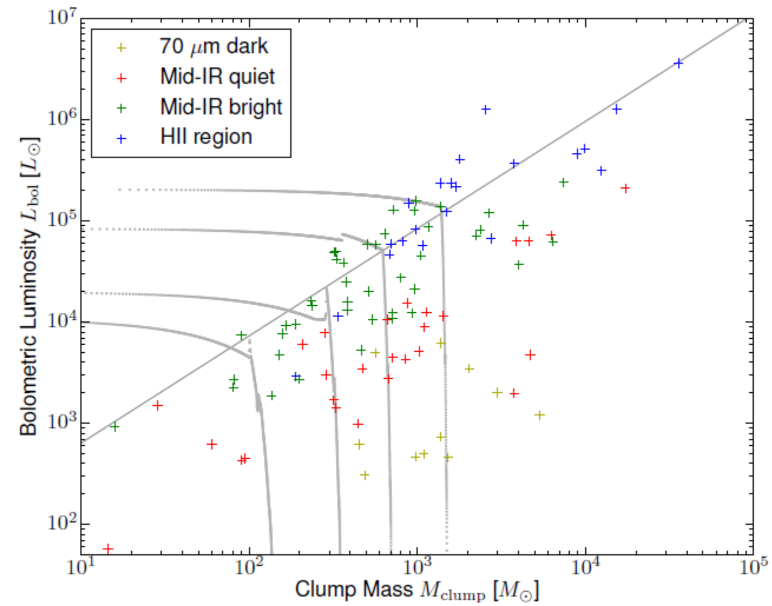
Overview of the ATLASGAL Survey

Submillimetre Emission: Structure of the Dust

Max-Planck-Institut für Radioastronomie



Molecular line follow ups



König+2015

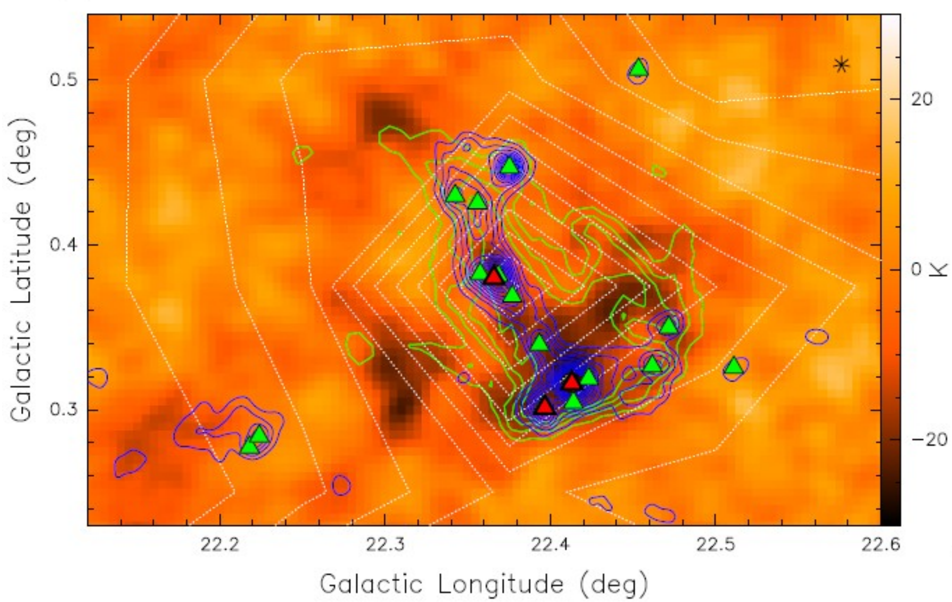
- Dust continuum is important but molecular line information is indispensable !
- Effelsberg/Parkes NH_3 (Wienen+'12, '15):
  - Kinematic distances, temperatures
- IRAM 30m/ATNF-Mopra/APEX (Wyrowski/Csengeri):
  - 3 & 0.85mm line surveys: Physical & chemical conditions (CO, Giannetti+2014)
- Herschel/HIFI: 100 ATLASGAL sources currently observed in water lines → ATLASGAL water legacy (Wyrowski+; IRAS17233: Leurini+2014)
- MALT90 (Jackson+2013): Mopra Galactic Plane Survey of high density regions. large program:
  - → about 2000 ATLASGAL clumps mapped at 3mm
- SEDIGSM (Schuller+): APEX ^{13}CO(2-1) survey of southern Galactic Plane

ATLASGAL @ SOFIA

concerted effort on several fronts

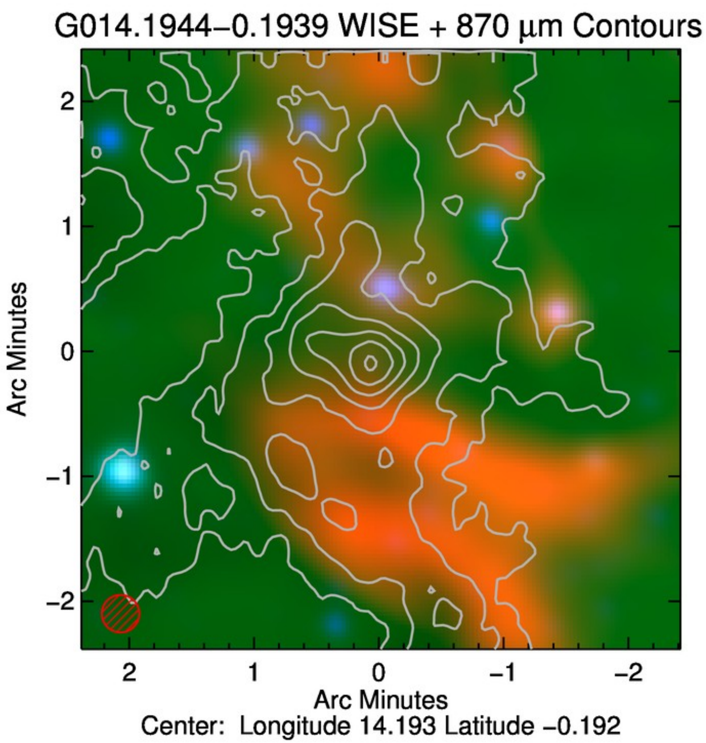
- Massive clumps selected in several GMCs (e.g. Wienen+2015)
- Observe multiple sources without changing flight directions
- Multi-semester project
- → statistical significant sample covering range of evolutionary stages

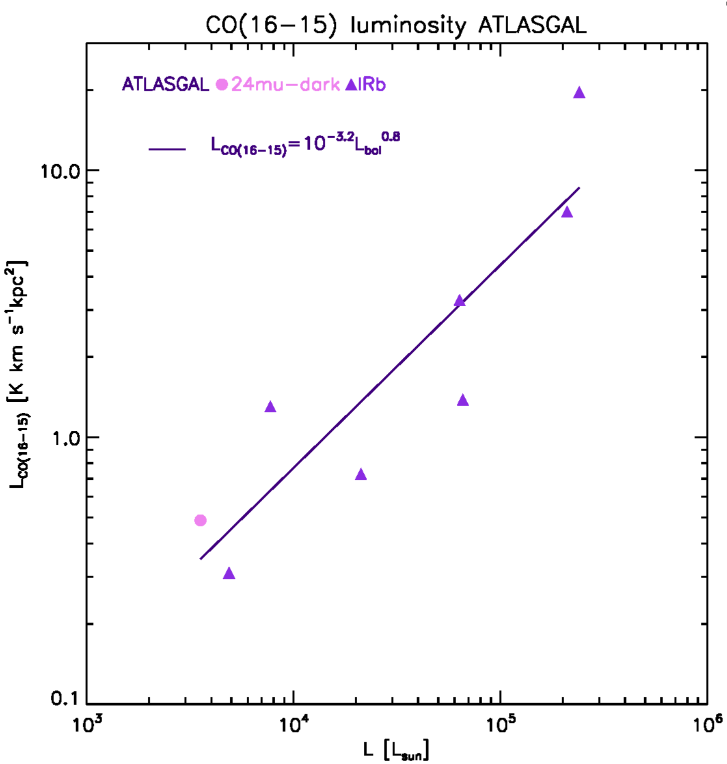
- Cooling budget: OI/CII (e.g. Leurini talk)
- High-*J* CO: (11-10)/(16-15)
- Ammonia infall study

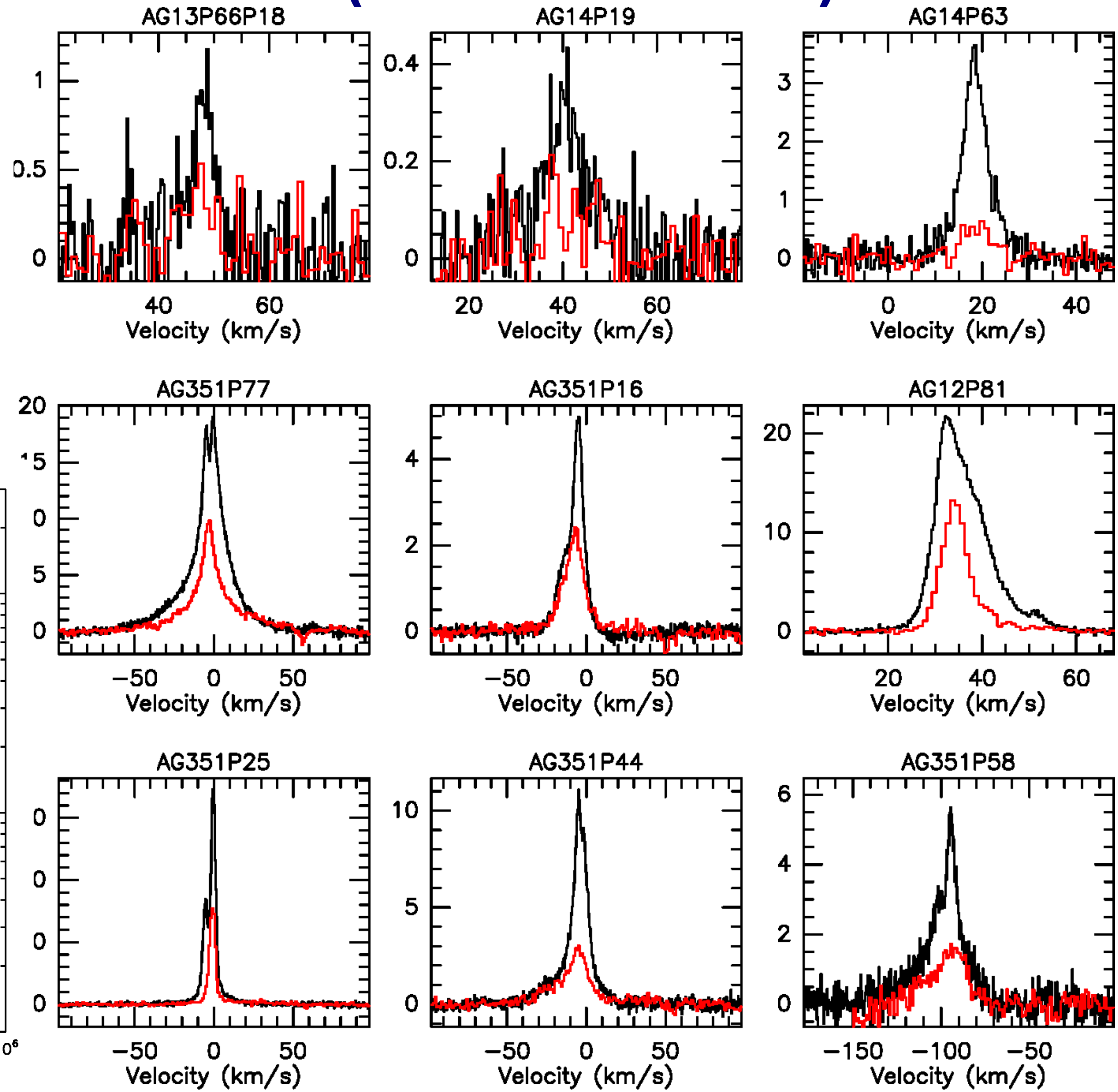


Wienen+2015: HI+870mu+^{13}CO

SOFIA follow-ups (CO teaser)







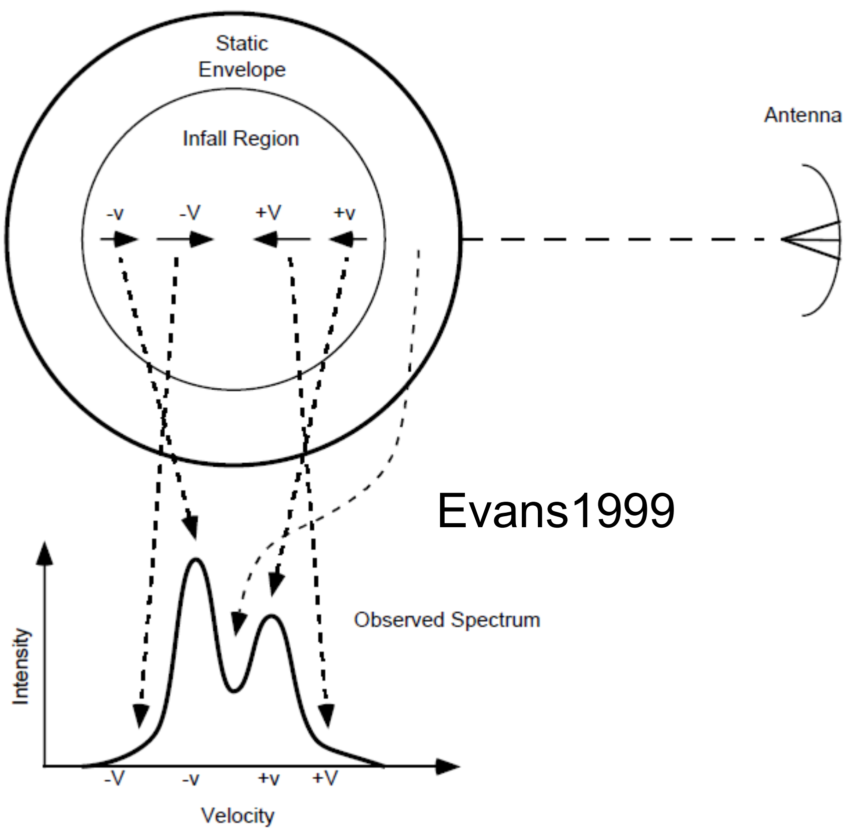
Search for infall

I: Blue-skewed profiles

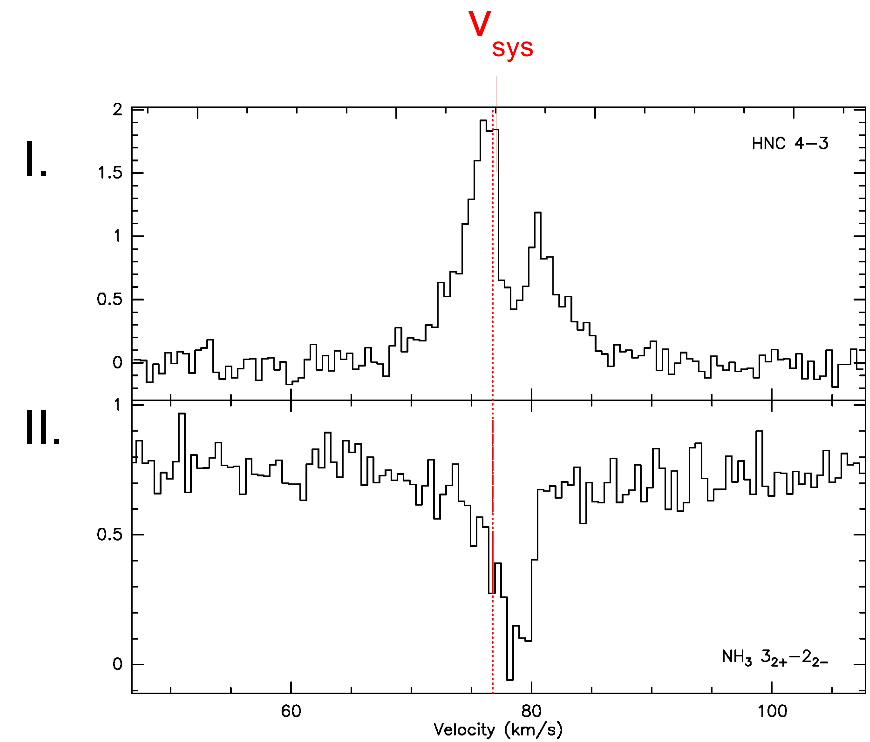
Needs excitation gradient, right tau

II: red-shifted absorption

Needs high critical density, central continuum



Evans1999



The story so far: Ammonia@1.8THz

Wyrowski+2012

- 3 absorption line detections in science verification
- All redshifted with respect to v_sys
- **τ** ~ 1

Table 2. Line parameters from Gaussian fits to the NH_3 lines. Nominal fit errors are given in brackets. In addition, the velocity of $C^{17}O$ (3–2) lines observed with the APEX telescope are given.

Source	T_{peak} (K)	Δv (km s^{-1})	$V_{LSR}^{NH_3}$ (km s^{-1})	$V_{LSR}^{C^{17}O}$ (km s^{-1})
W43-MM1	−0.96 (0.22)	5.3 (0.8)	99.7 (0.4)	97.65 (0.06)
G31.41+0.31	−1.18 (0.29)	3.7 (0.8)	99.4 (0.4)	97.02 (0.04)
G34.26+0.15	−3.38 (0.56)	5.5 (0.6)	61.2 (0.3)	58.12 (0.03)

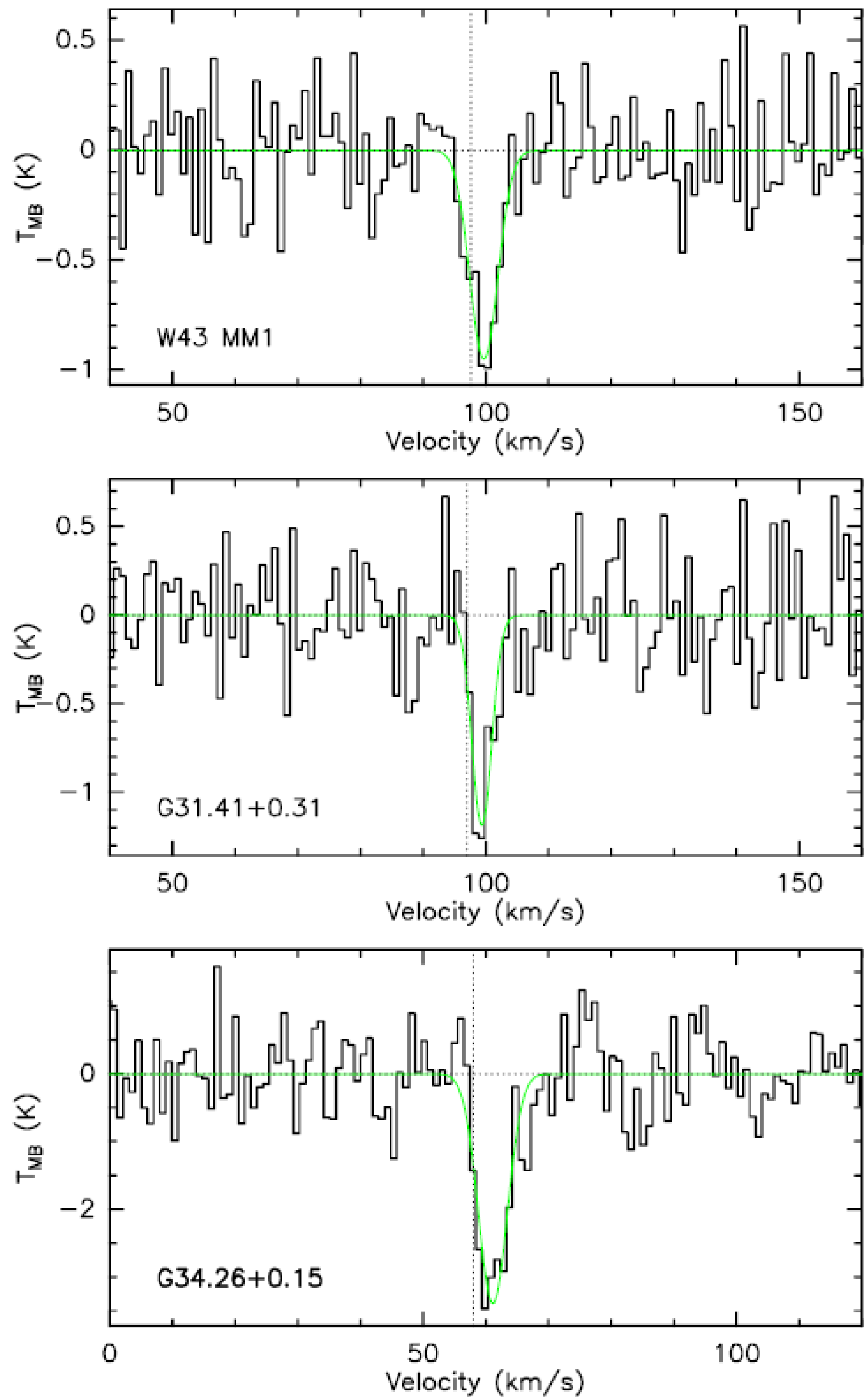


Fig. 2. NH_3 spectra of the observed sources. Results of Gaussian fits to the line are overlaid in green. The systemic velocities of the sources, determined using $C^{17}O$ (3–2) are shown with dotted lines.

G34: comparison to VLA absorption

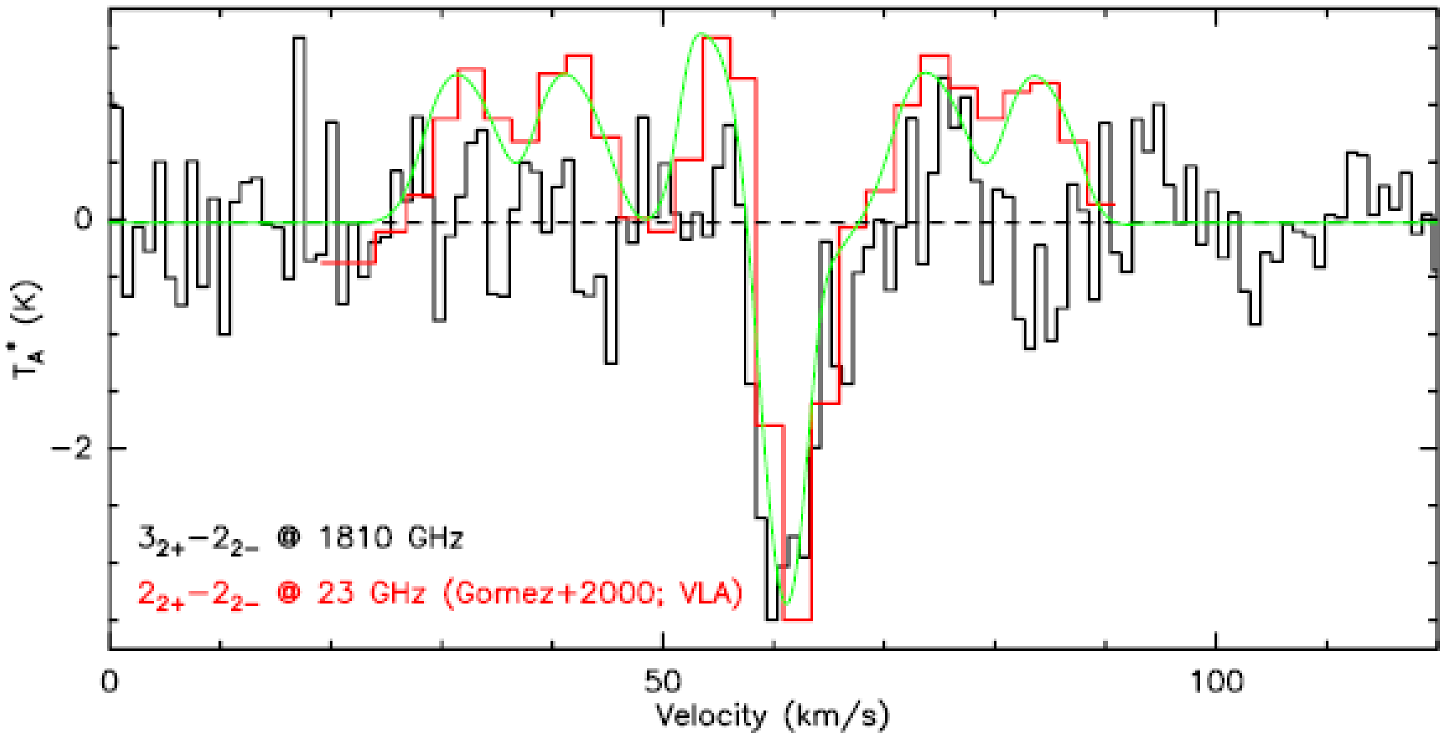


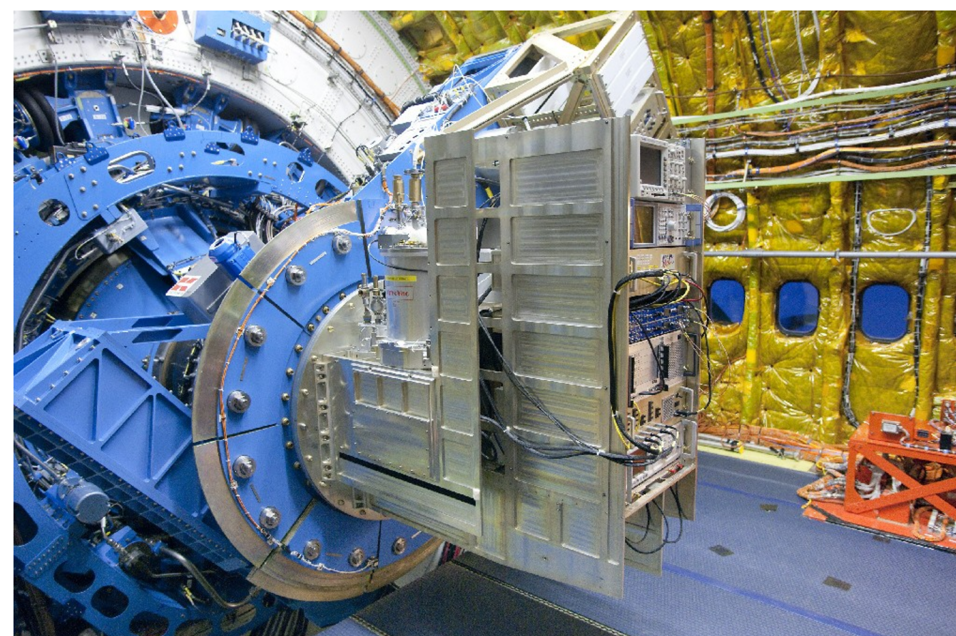
Fig. 3. G34.26+0.15 SOFIA NH_3 spectrum compared with the VLA NH_3 (2,2) spectrum taken from Gómez et al. (2000) which was integrated over the region which shows absorption. A two-component hyperfine fit to the (2,2) spectrum is shown in green.

Infall Results

- 3 clear detections of Ammonia line-of-sight infall consistent with results from cm-absorption and/or blue-skewed emission profiles
- More direct probe of infall that can be extended to earlier stages of SF without cm background continuum and cases where other species are depleted
- Infall rates of 3-10 x 10^{-3} $M_{\odot}$/yr (if spherical)
- Next step: extend to more sources and stages, in particular earlier ones

SOFIA Observations

- GT and cycle 1 science flights
- GREAT:
  - L1, various lines
  - NH_3 3_{2+}-2_{2-} 1810.379 GHz LSB
  - AFFTS/XFFTS:1.5/2.5 GHz
  - Chopped observations of 9 sources



Cycle I: a) continuation to Infrared dark clouds

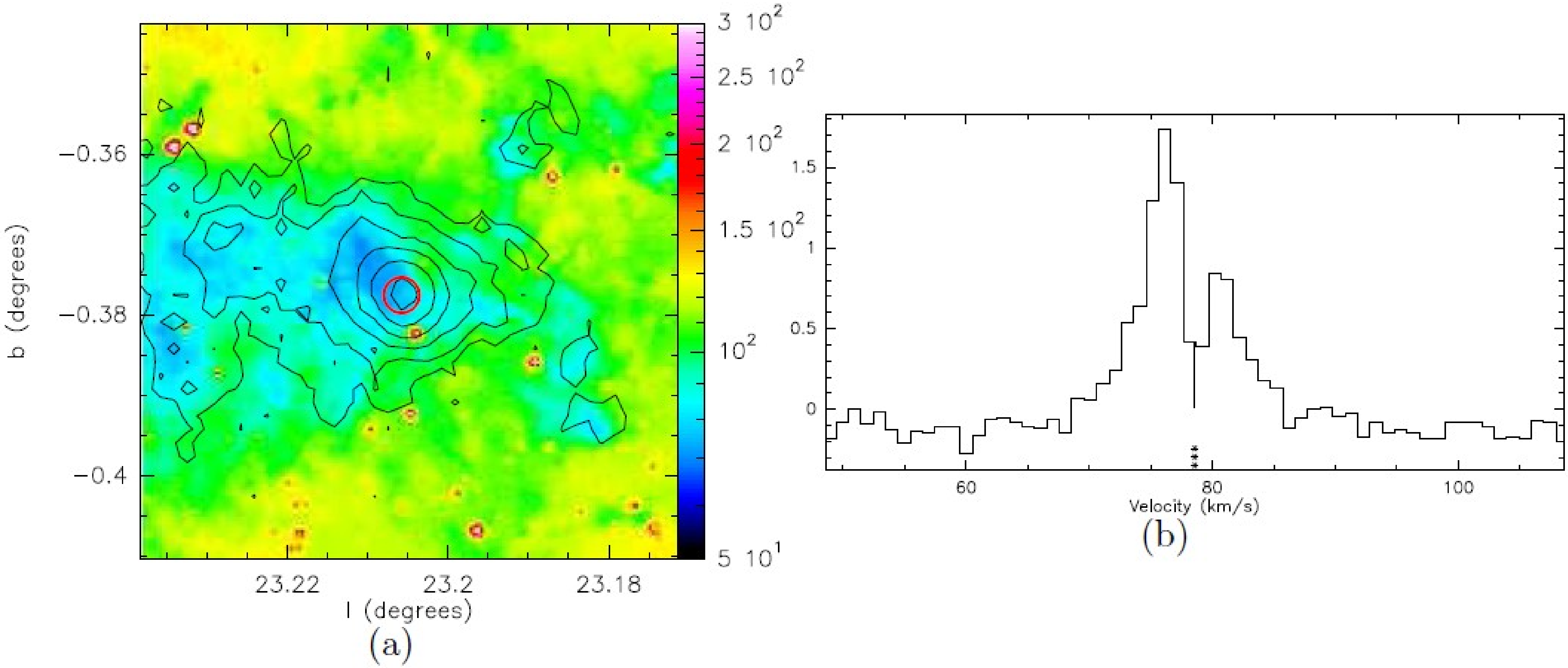
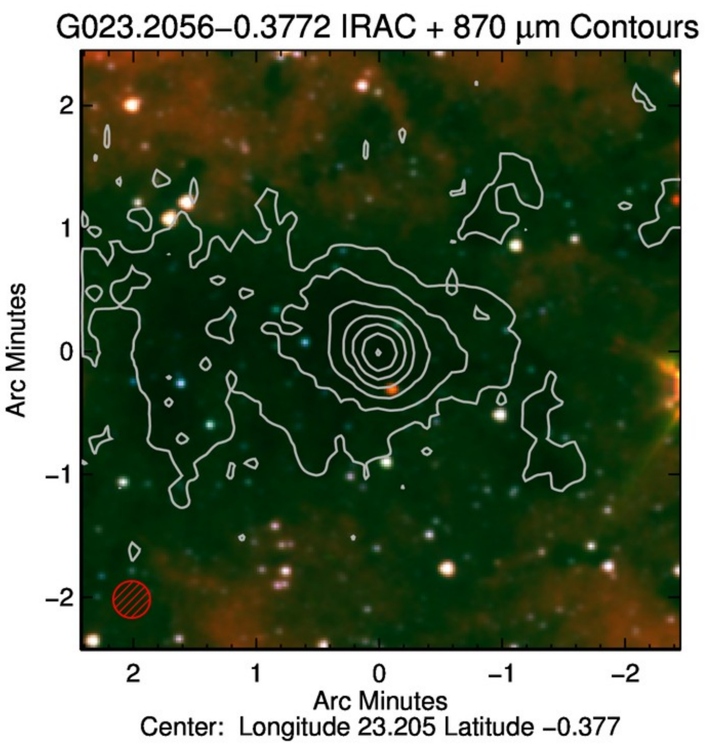


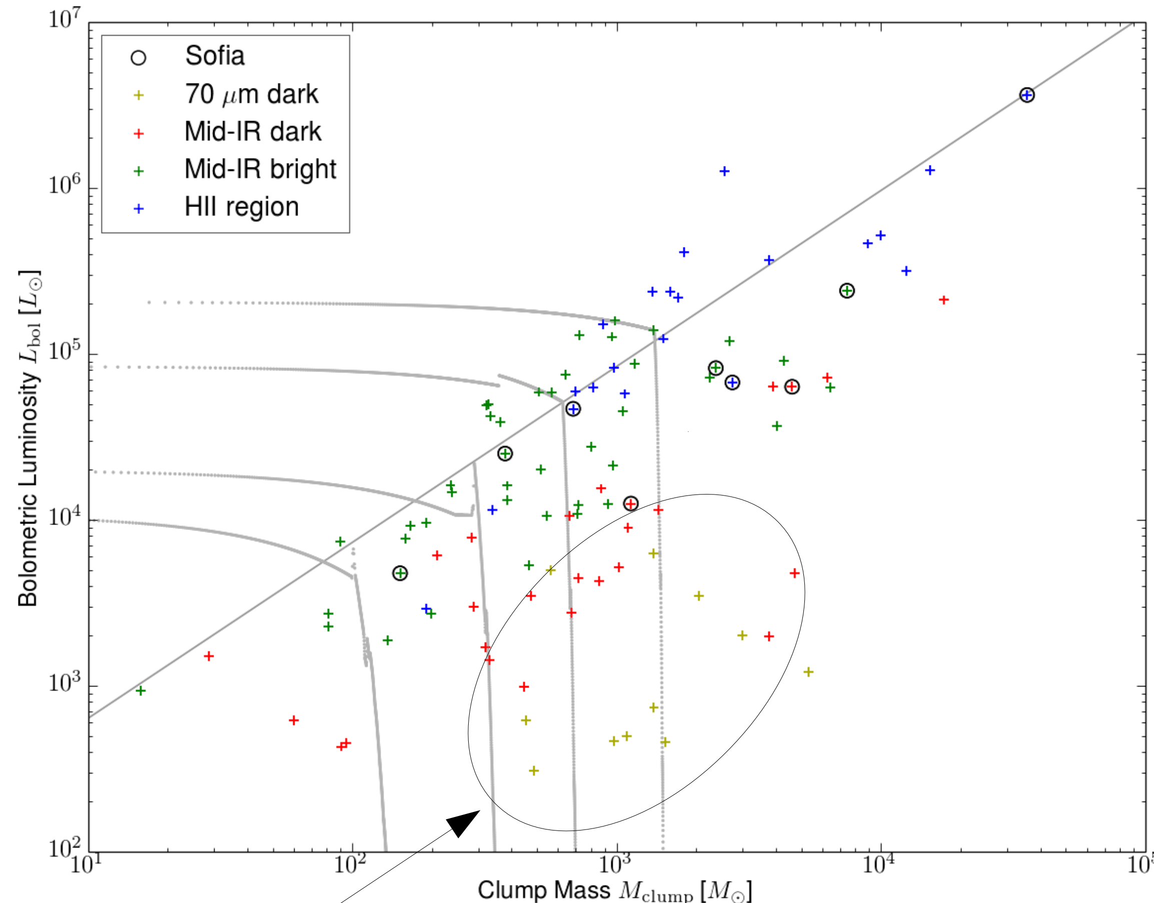
Figure 2: IRDC G23.21-0.38: (a) ATLASGAL 870 μm dust continuum as contours on GLIMPSE 8 μm MIR emission in color, SOFIA beam in red. (b) APEX HNC (4–3) spectrum of this clump with systemic velocity indicated.

Cycle I: b) filling in further stages:

- G35.20-0.74: submm brightest, northern massive young stellar object, fulfilling Lumsden+ MSX color criteria
- G327.3/G351.58: hot cores/ultracompact HII regions with high luminosity (up to $2x10^5$ $L_\odot$)

New SOFIA results: sample





König+2015

No/too weak SOFIA 1.8THz continuum ! → 572 GHz

New SOFIA results: continuum

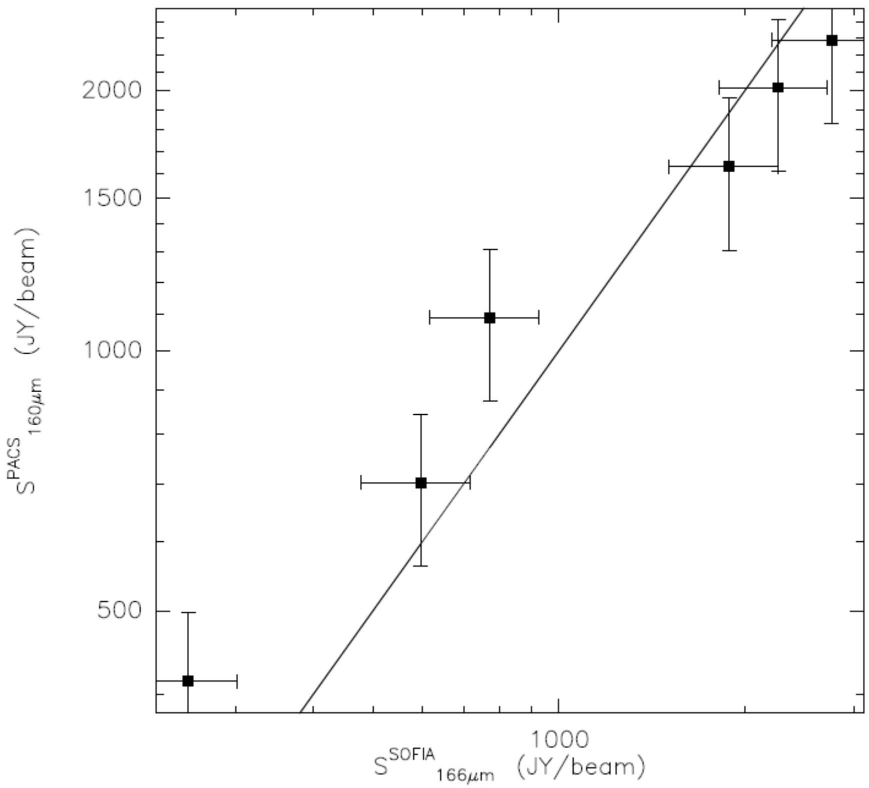


Fig. 2. Comparison of GREAT continuum levels with PACS 160 μm flux densities with nominal 20% errors.

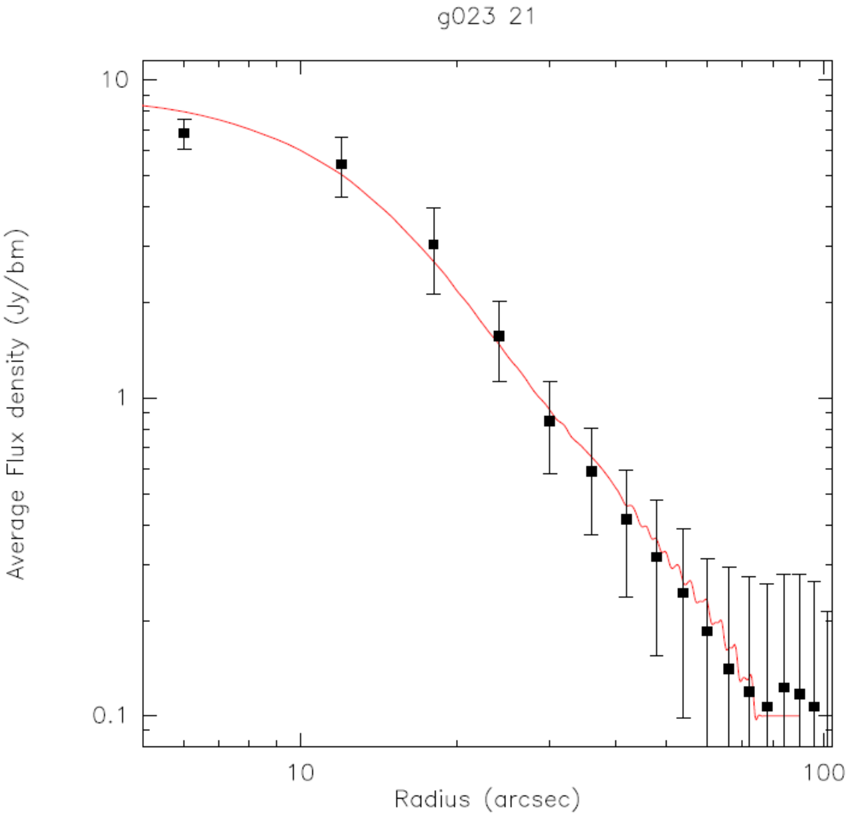


Fig. 3. Example of constraining the radial physical structure with the help of the ATLASGAL submm dust continuum radial profiles.

New SOFIA results: lines

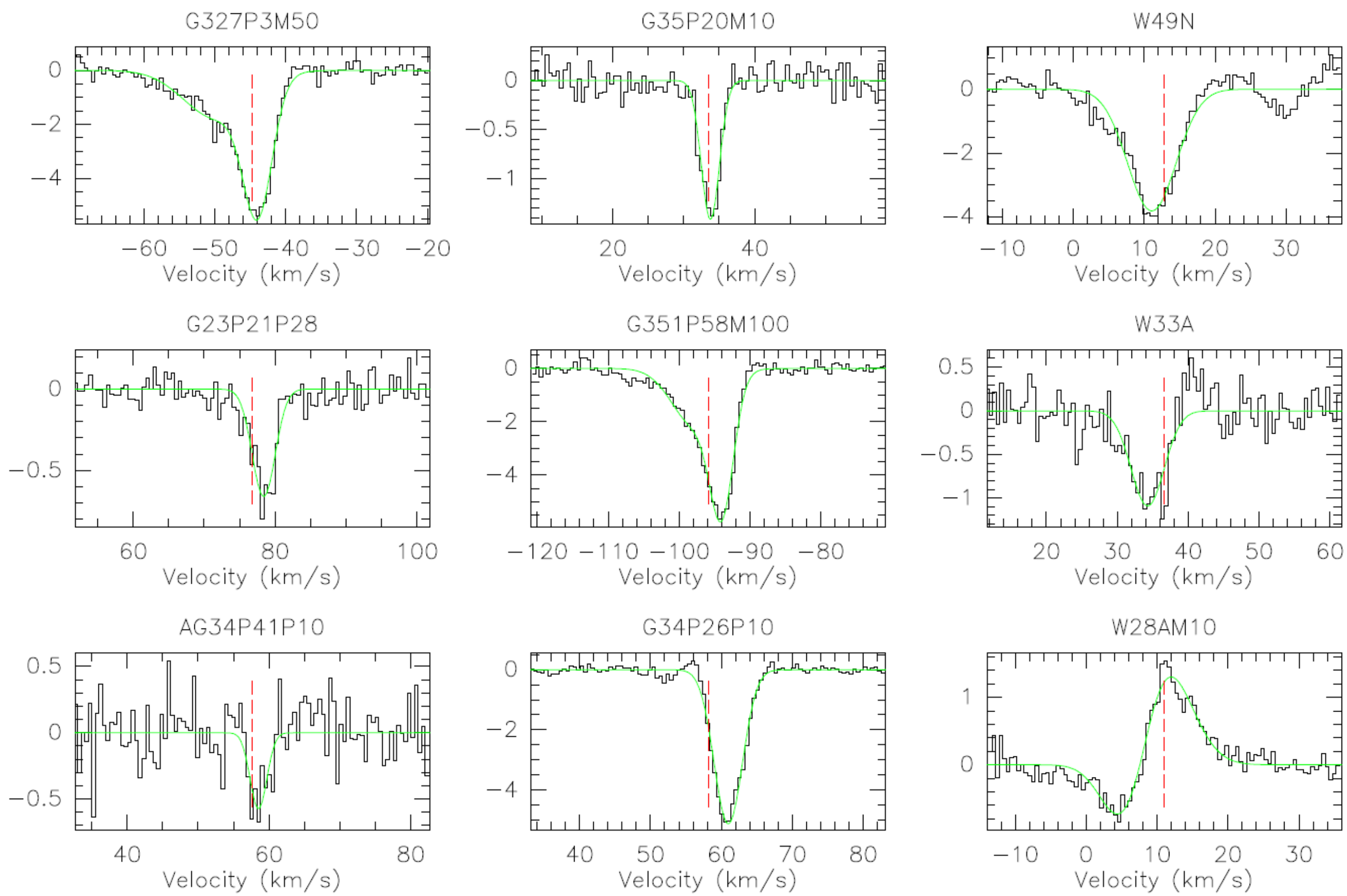
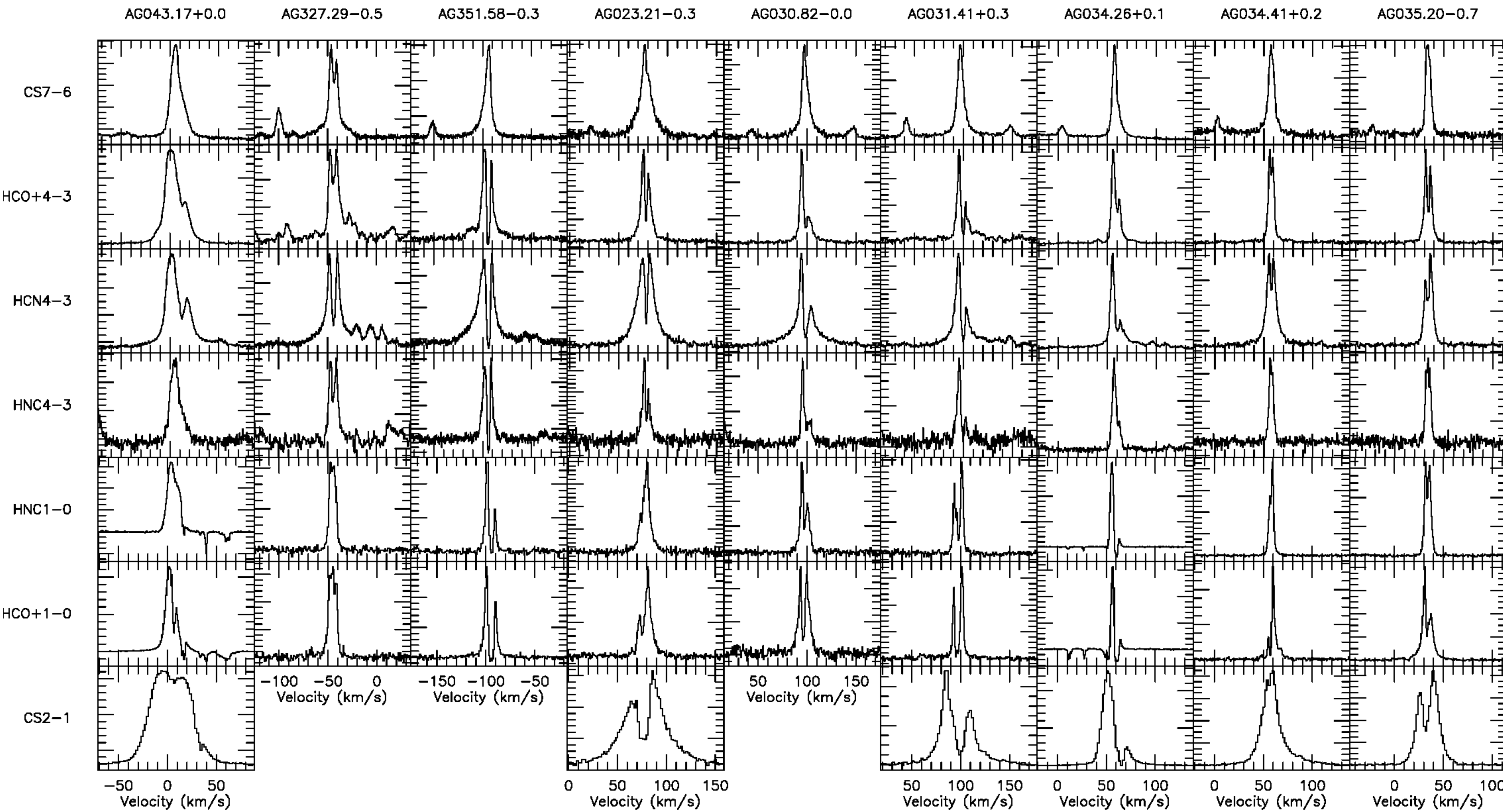


Fig. 1. NH_3 $3_{2+} - 2_{2-}$ spectra of the observed sources. Results of Gaussian fits to the line are overlaid in green. The systemic velocities sources, determined using $C^{17}O$ (3–2), are shown with dotted lines.

- 5 new 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

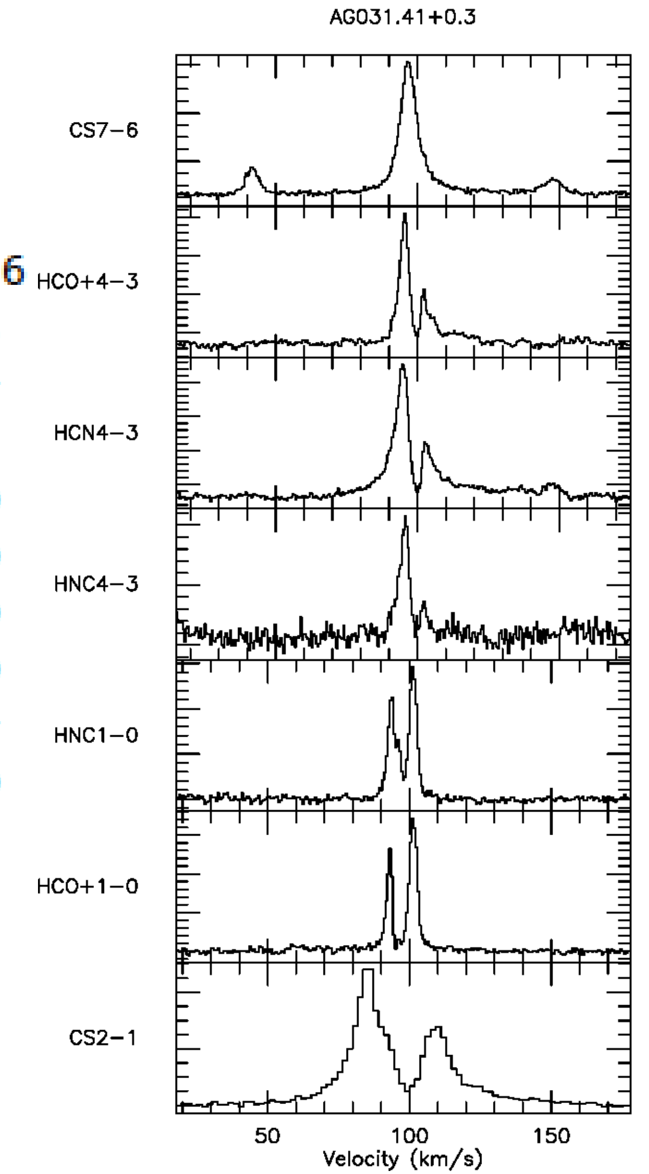
Complementary ground based data



How consistent are different probes ?

	1-0				4-3			7-6
	nh3	hco+	hnc	cs	hnc	hcn	hco+	cs
G327.29-0.58	o	o	o		o	o	o	+
G351.58-0.35	++	++	++		o/r.a.	o/ra	o/ra	-
G23.21-0.38	++	--	--	--	++	o	++	o
G34.41 irdc43	++	--	--	o	o	o	+	o
G35.19-0.74	+	++	o	--	o	--	++	o
g31.41	++	--	-	++	++	++	++	o
g34.26	++	r.a.	r.a	++	++	++	++	+
w43mm1/g30.82	++	+	++		++	++	++	o

→ Ammonia and HCO^+ (4-3) show best correspondence

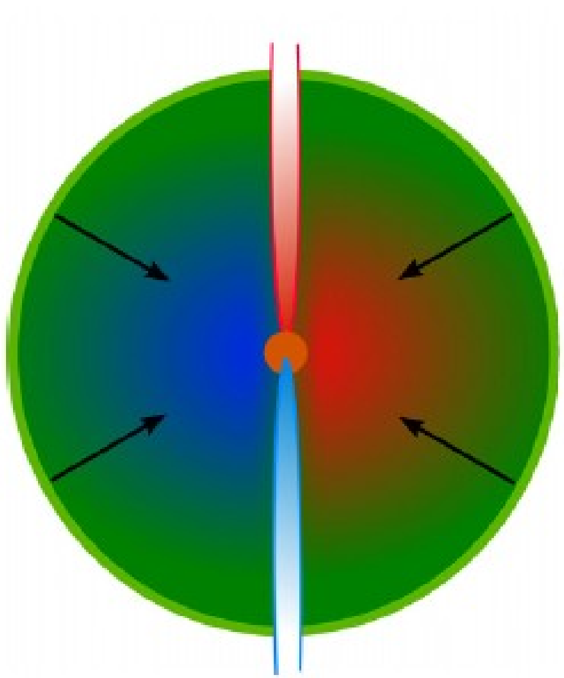


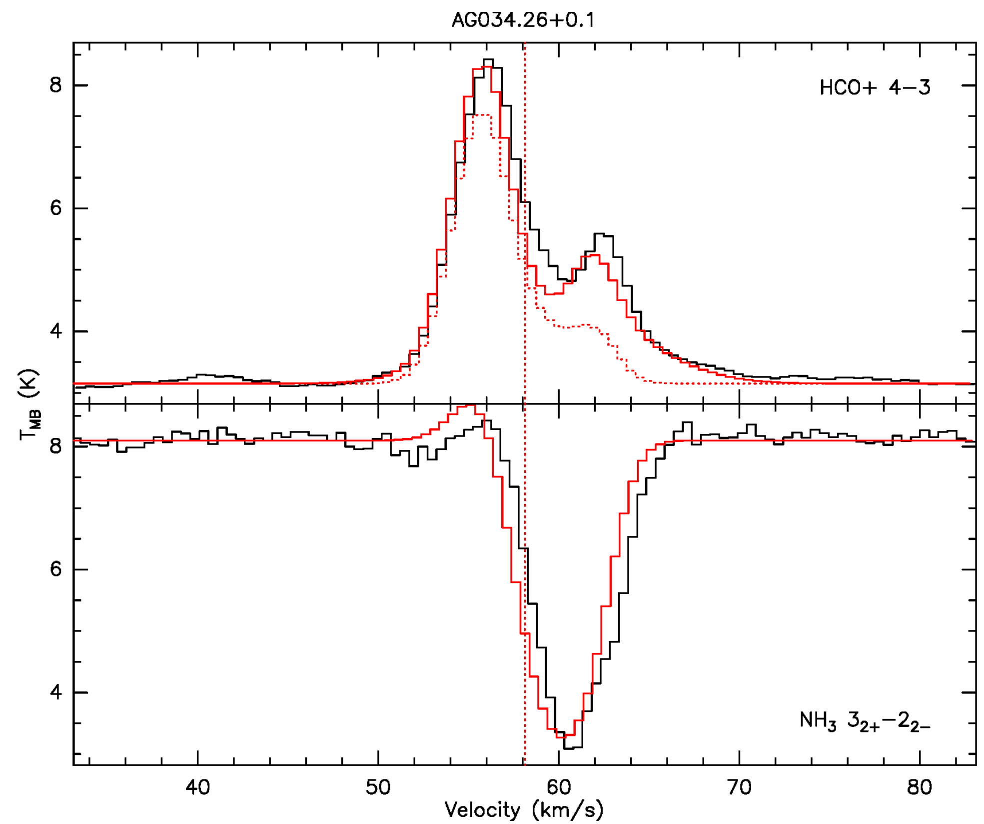
Modeling

- Fit dust continuum (ATLASGAL) with density power law ($n \sim r^{\alpha}$ α=1.5 – 2.2)
- Temperature structure dictated by inner heating source (luminosities known from SED fits, König+2015)
- → Adjust ammonia abundance and velocity structure in spherical RATRAN models
- Modelling of new sources results in infall with fractions of free-fall of 5 – 25 %. The ammonia abundance are in the range of 0.2 – 2 x 10^{-8}.
- But how consistent are models of NH_3 and HCO^+?

New SOFIA modeling
Outflow component

HCO^+ usually probing additional outflow component
→ RATRAN modification of Mottram+2013

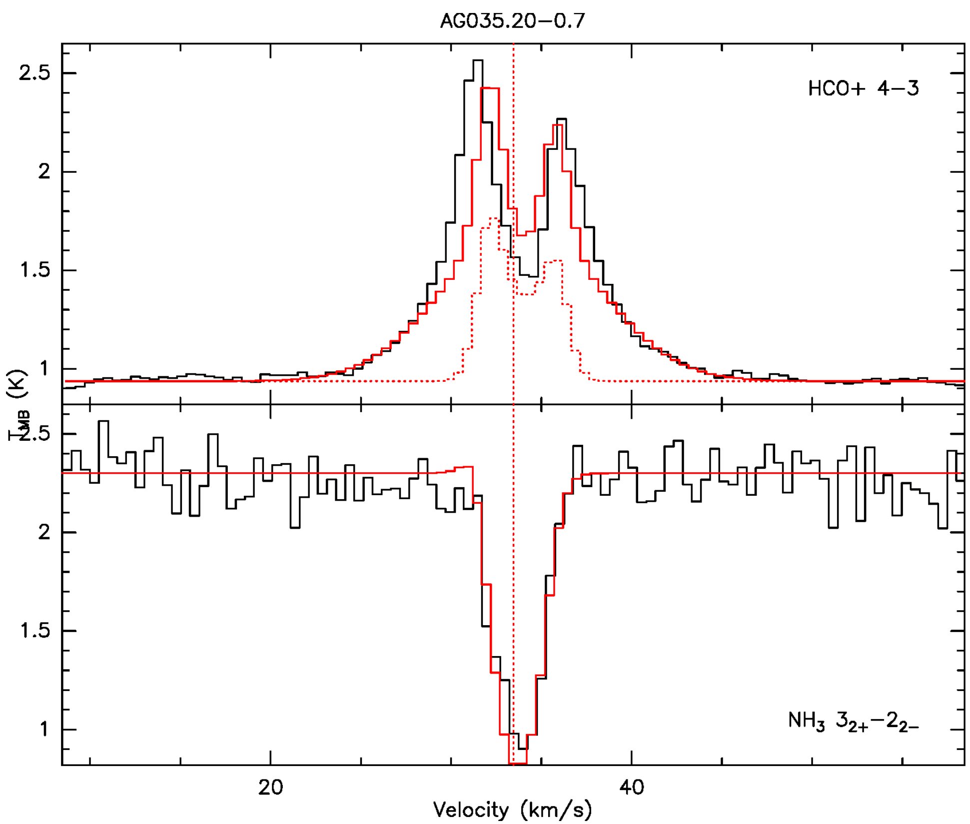




Additional parameter:
- outflow widths/strength
- HCO^+ abundance

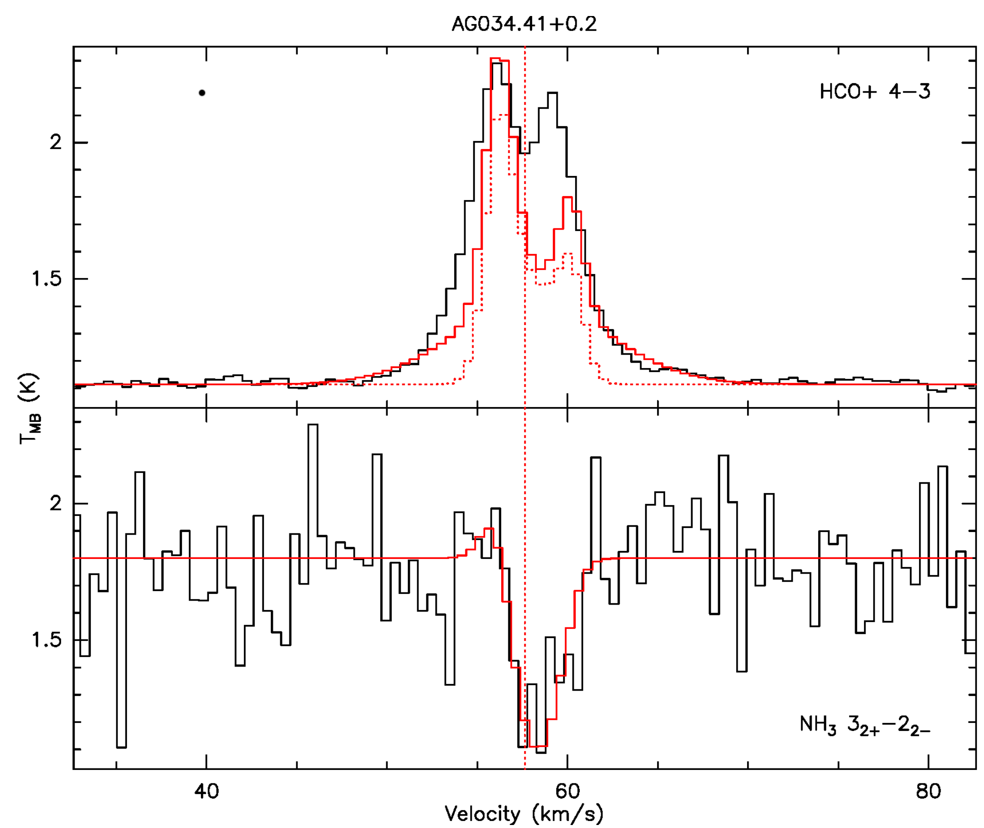
New SOFIA modeling

Outflow component



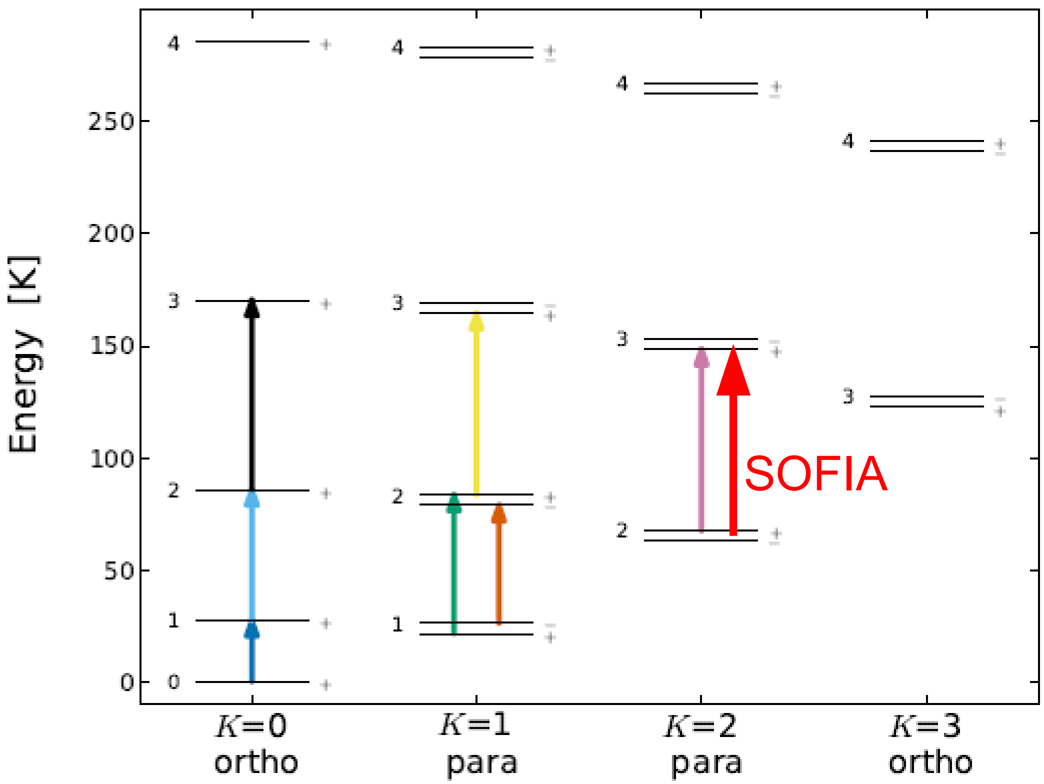
Also this clump shows consistent results!

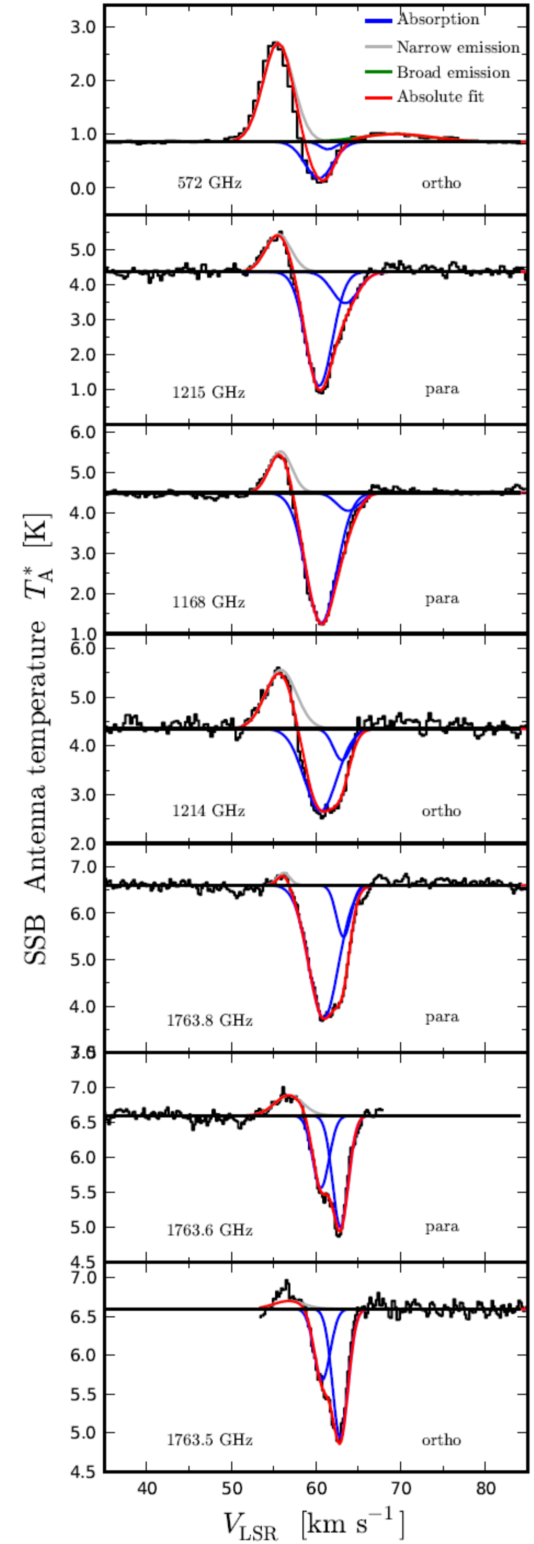
But many cases do not work with this simple geometry. Complicated outflows? Additional low density outer layer (Lopez-Sepulcre+2010)?



Herschel G34.26 results

Hajigholi+2015





- Different excitation traces different v
- SOFIA opportunities:
  - GS 572 GHz @ 90% transmission
  - 1214 GHz (201-100, 211-110) @ 65%
  - 2355 GHz (4-3 lines) @ 63%

APEX-SOFIA synergies

- Mid vs. High J CO
- Blue-skewed self-absorbed high density probes vs. red-shifted absorption studies
- CO/CI cooling vs. CII/OI
- Complex molecules vs. hydrides
- Similar beamsizes in APEX submm windows and with SOFIA THz RX
- Imaging: CHAMP+/LASMA vs. UPGREAT

Summary & Outlook

- Infall on clump scales ubiquitous through wide range of evolutionary stages
- Ammonia and HCO^+ (4-3) show best correspondence but HCO^+ stronger affected by outflows
- Continue filling in stages (populating the M-L diagram)
- Study infall across clumps (upGREAT)
- Add additional lines to cover larger excitation range (new single pixel RXs)