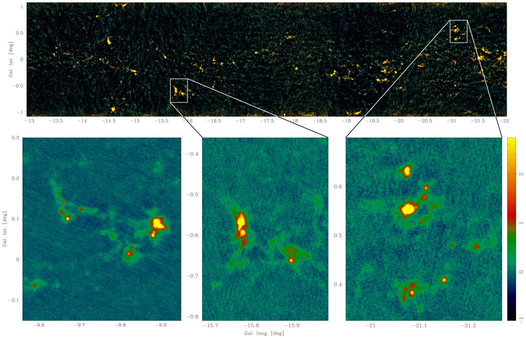
Unveiling the next generation of massive stars:

First results from ATLASGAL



F. Schuller, S. Bontemps, L. Bronfman, K. Menten,
M. Walmsley, F. Wyrowski and the ATLASGAL consortium

Unveiling the next generation of massive stars:

First results from ATLASGAL

- Outline -

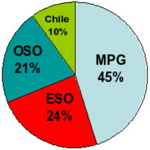
- APEX telescope and instruments
- introducing ATLASGAL
- census of high-mass star forming clumps
- ongoing follow-up projects
- future & perspectives, incl. data release

The APEX telescope

APEX : the Atacama Pathfinder Experiment

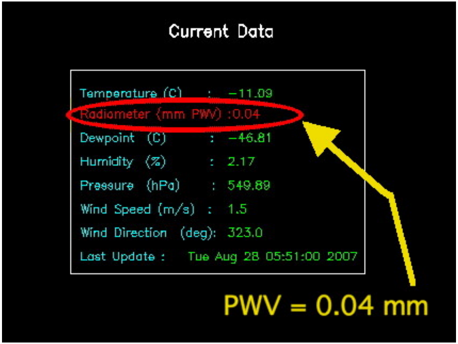
(Güsten et al. 2006, A&A **454**, L13)

- Single dish 12 m submm antenna
- Copy of ALMA VERTEX antenna
- + surface accuracy 15 μm rms
  $\Rightarrow \lambda = 200\ \mu\text{m} - 2\ \text{mm}$
- + 2 Nasmyth cabins
  $\Rightarrow$ many instruments
- Collaboration MPIfR/MPG + ESO + OSO + Chile



The APEX telescope

APEX : a submm site



APEX instruments

Bolometers

- **LABOCA**: 295 element at 870 μm, FoV = 11 arcmin
- **SABOCA**: 37 element at 350 μm, FoV = 1.5 arcmin
  Super-conducting bolometers (TES), multiplexing (SQUIDS)
- PI Instrument (Berkeley): **APEX SZ Camera** ($\rightarrow$ SZ effect)
  330 TES bolometers, λ = 1.4+2 mm, FoV = **20 arcmin** at 2 mm
- In development (Saclay): **ARTEMIS** (cf. PACS / Herschel)
  λ = 450 + 350 + 200 μm

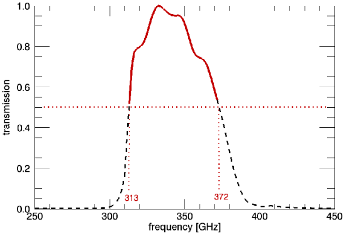
Heterodyne instruments

- **Facility**: 230 GHZ, 345 GHz, 670 GHz, 1.3 THz
- **PI**: FLASH (345 + 490 GHz), CHAMP+ (2$\times$7 pixels, 670+860 GHz)

APEX instruments: LABOCA

LABOCA : the Large APEX BOlometer CAmera

- Array with 295 bolometers
  λ = 870 μm (345 GHz)
  $\Delta\nu$ = 60 GHz
  Field of view: 11 arcmin
- APEX beam at 870 μm = 19″



- Instrumental sensitivity (NEFD) $\sim$ 50 mJy s$^{1/2}$
- Observing modes:
  - linear "on-the-fly" mapping ($>$ 1°), arbitrary angle
  - spirals and rasters of spirals
  - **pointing** on few Jy sources: one spiral **20 sec long**

APEX Telescope Large Area Survey of the Galaxy

ATLASGAL

Max-Planck-Institut für Radioastronomie

MAX-PLANCK-GESELLSCHAFT

ESO

European Southern Observatory

The APEX Telescope Large Area Survey of the Galaxy

Universidad de Chile

MPG : F. Schuller (PI), K. Menten, P. Schilke, F. Wyrowski, H. Beuther, T. Henning, H. Linz

ESO : M. Walmsley (co-PI), S. Bontemps, R. Cesaroni, L. Deharveng, F. Herpin, B. Lefloch, S. Molinari, F. Motte, V. Minier, L.-Å. Nyman, V. Reveret, C. Risacher, D. Russeil, N. Schneider, L. Testi, A. Zavagno

Chile : L. Bronfman (co-PI), Y. Contreras, G. Garay, D. Mardones

Motivation

The quest for the earliest stages of HMSF

- Large scale mapping of HMSF regions (e.g. Motte et al. 2007: 3 deg^2 in Cygnus X) $\Rightarrow$ only very few "real" high-mass star precursors
- The cold phase is very significant: ~50% of IR-quiet cores, but the lifetime of the *pre-stellar* phase is short, $\leq 5 \times 10^4$ yr.
- High-density gas is representing the gas which is going to form stars soon: high efficiency in the *dense* gas.

$\Rightarrow$ **Need for large scale survey in (cold) dense gas tracer** :
Only **Galaxy-wide** surveys can get significant samples

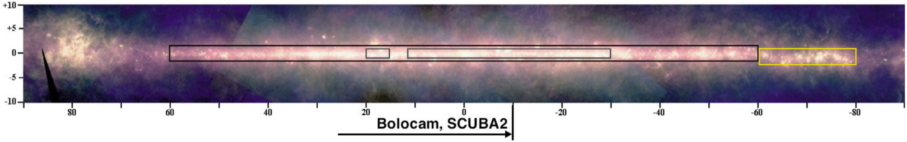
- Dust emission in the submm = the only optically thin tracer
  $\Rightarrow$ direct measure of column densities $\Rightarrow$ masses
  Unbiased view, detect all objects, all evolutionary stages
  BOLOCAM@CSO, SCUBA-2@JCMT, **LABOCA@APEX**

APEX Telescope Large Area Survey of the Galaxy

The 1st systematic survey of theGalactic Plane in submm

- Unbiased survey of the inner Galactic Plane at 870 μm, with LABOCA (295-bolometer array) at APEX (beam: 19″)
  $\rightarrow$ massive star formation throughout the Galaxy
  $\rightarrow$ pre-stellar initial mass function down to a few $M_\odot$
  $\rightarrow$ large scale structure of the cold ISM

IRAS 12+60+100 μm, $|l| \leq 90°$, $|b| \leq 10°$



- Mapping $-80° \leq l \leq 60°$, $|b| \leq 1.5°$, *r.m.s.* $\leq$ 50 mJy/beam

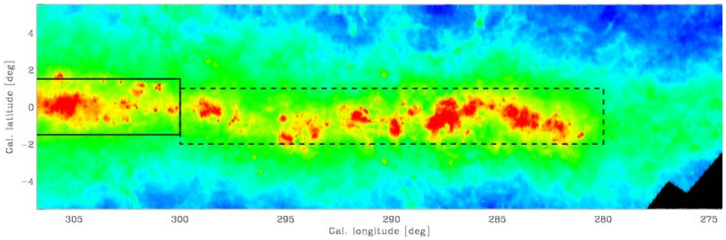
$\Rightarrow$ 420 deg^2, 5σ detection :

0.5 $M_\odot$ at 500 pc, 20 $M_\odot$ at 3 kpc, $\sim$100 $M_\odot$ at 8 kpc

(9 years lifetime of SCUBA : 30 deg^2 - Di Francesco et al. 2008)

Status of observations

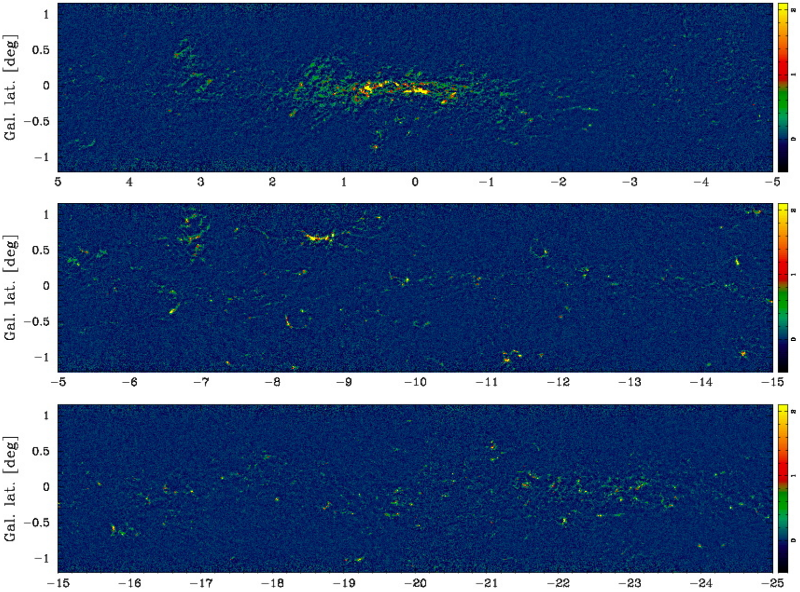
- **Started in 2007 : 95 deg^2** covered, $\sim$75 hours observing
  $-30° \leq l \leq +11.5°$ and $+15° \leq l \leq +21°$, with $|b| \leq 1°$
  (Schuller, Menten, Contreras et al. 2009, A&A 504, 415)
- **Large programme 2008–2009** :
  – cover $|l| \leq 60°$, $|b| \leq 1.5°$, 1-$\sigma \leq 50$ mJy/beam
  total = 360 deg^2
- **2010 (ongoing)** : mapping $-80° \leq l \leq -60°$, $-2° \leq b \leq +1°$



First results

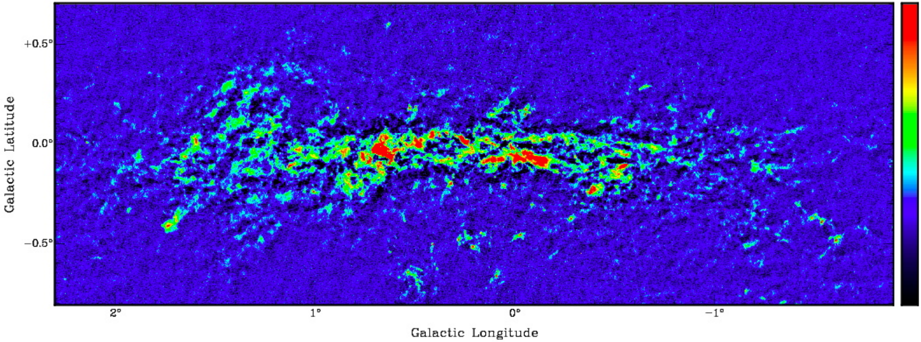
- First **unbiased view** of high density gas in the Galaxy
- Hints on the **nature** of the sources
- **Distance** determination and Galactic structure

Example maps: 60 deg^2



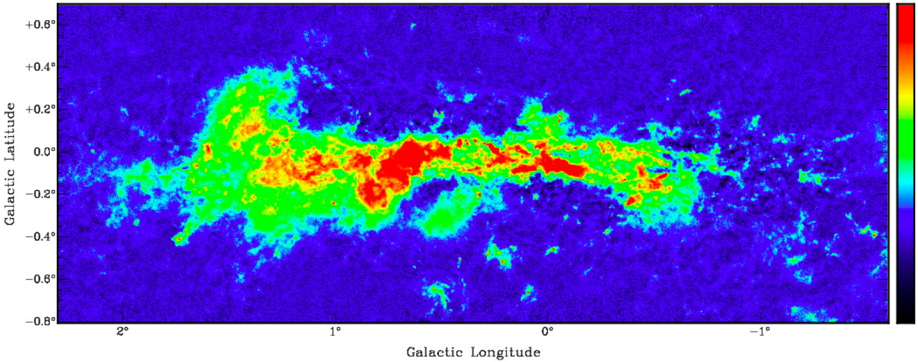
Example maps

The Central Molecular Zone



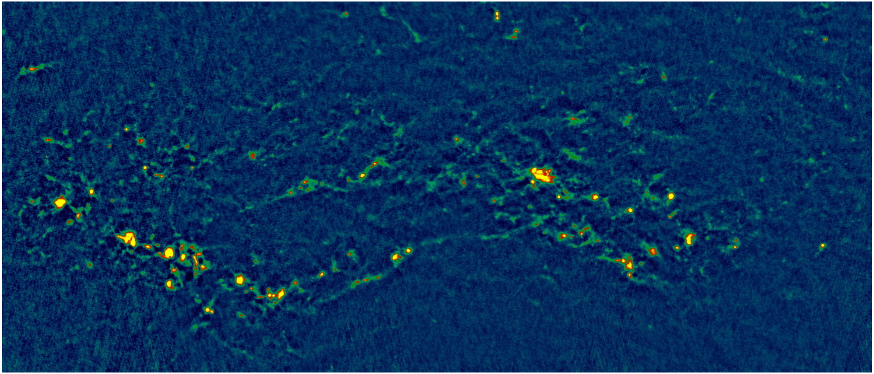
Example maps

The Central Molecular Zone



Example maps

Norma arm: compact sources and long filaments

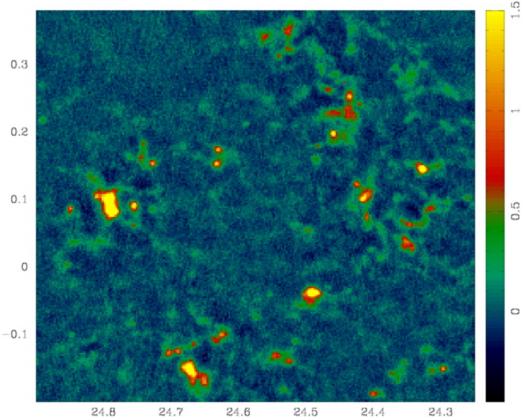


- Extended objects on arcmin scale
- Very long filaments, up to the degree scale!

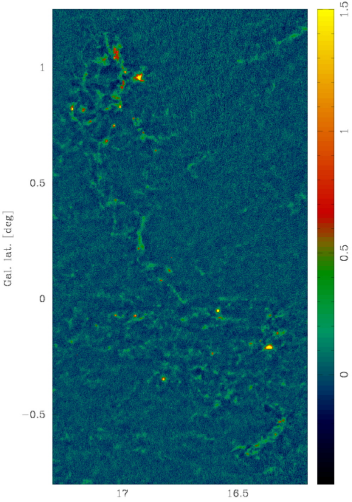
Extended objects

Extended objects, filamentary structures

From a few arcmin...



... up to degrees !

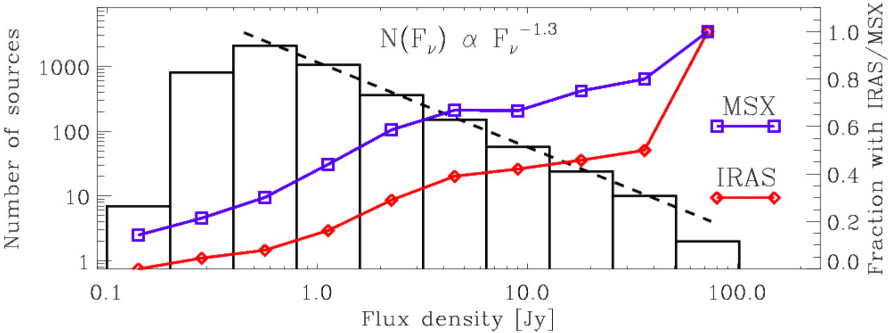


⇒ **Large scale** structure of the cold ISM

Compact sources

Survey for the earliest phases of high-mass stars and cluster formation

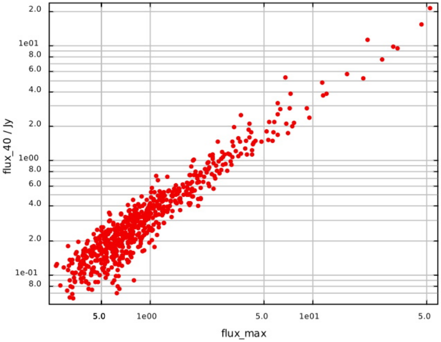
Flux distribution for >4500 sources in 95 deg^2



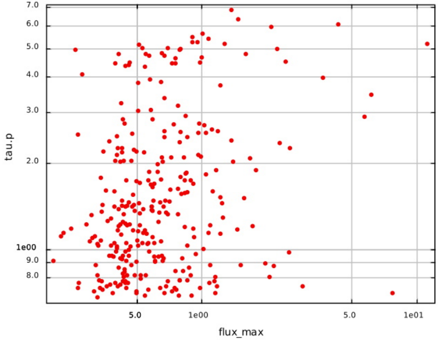
- 1670 with MSX, 600 with IRAS, 60% no bright IR (IRAS/MSX) *(Contreras et al. in prep.)*

Compact sources

BGPS (1.1 mm) (Rosolowsky et al. 2010) vs. ATLASGAL (870 μm)

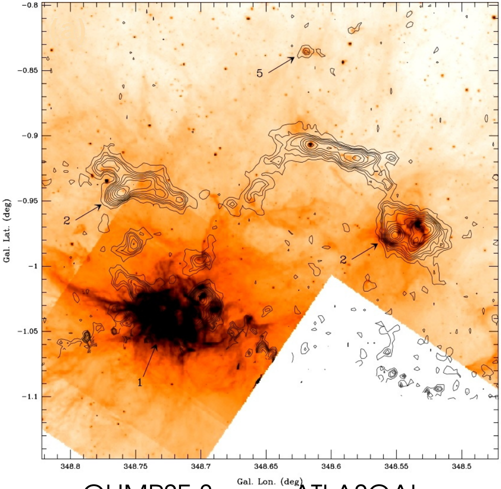


τ_{peak} IRDCs (Peretto & Fuller 2009) vs. ATLASGAL peak fluxes

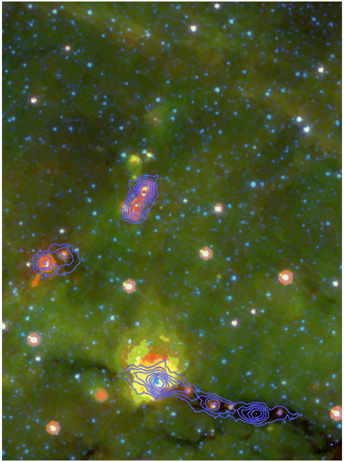


Compact sources

HII regions, YSOs, IR-quiet sources, IRDC...



GLIMPSE 8 μm + ATLASGAL



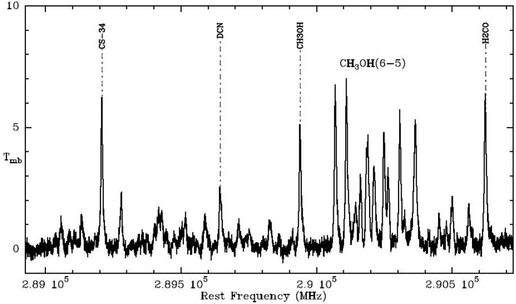
Spitzer + ATLASGAL

Compact sources

Sources in various stages

- *Evolved* objects : UCHII regions, embedded clusters...
- IR-quiet sources: starless or protostellar?
- We expect ∼**2000 precursors of high mass stars.** (Beuther, Henning, Bontemps, Motte, Wyrowski, et al.)

- IRAS 17233-3606 : hot molecular core ⇒ Rich chemistry (Schilke et al.)



(Leurini et al. 2006)

Distance determination: Method

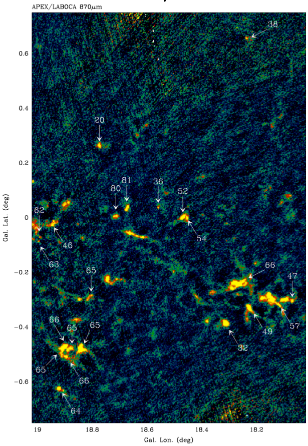
We need distances to derive physics

- ATLASGAL = continuum survey ⇒ no direct distance
- Dust emission = missing link between CO complexes and SF activity (e.g. young embedded clusters seen in IR surveys) → allows to recognize large complexes up to >5 kpc. (complete catalog of GMCs exists up to ∼1 kpc).
- use some public data, e.g. CS lines (Bronfman et al. 1996) → only IRAS sources, small sample
- recognize complexes e.g. in Galactic Ring Survey ⇒ V_{LSR}
- **heterodyne follow-ups, e.g. NH_3** ⇒ V_{LSR}
- extinction maps, Spitzer images ⇒ solve distance ambiguity

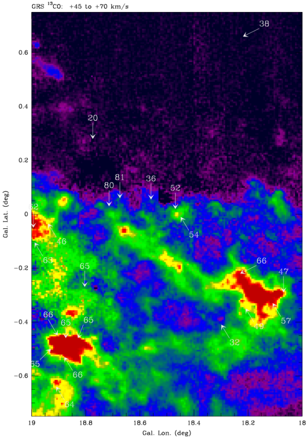
Distance determination: GRS data

Large complexes in the GRS data (^{13}CO)

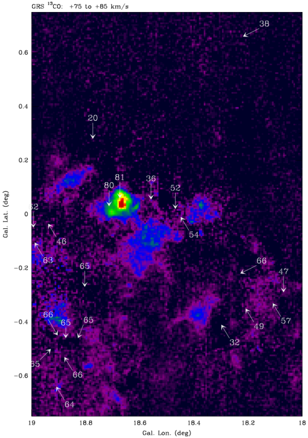
870 μm



^{13}CO 45–70 km/s



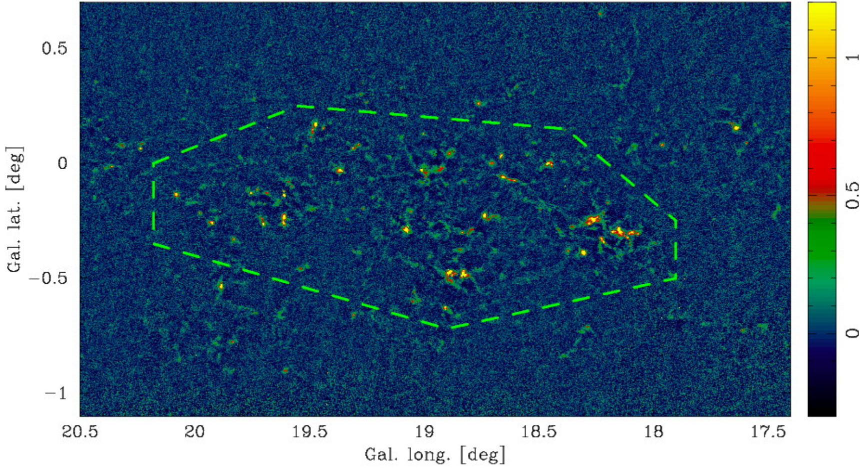
^{13}CO 75–85 km/s



Distance determination: First results

Kinematic distances derived from NH_3 spectra

New complexes revealed! Ex. around $l = +19°$, D $\sim$4 kpc



Distance determination: First results

Kinematic distances derived from NH_3 spectra

First results

- **New complexes revealed**! clearly seen in ATLASGAL: dust emission is optically thin $\Rightarrow$ traces the column density directly; not biased to neither warm regions (IR) nor to pure cold regions (CO).

Large scale Galactic structure :

- W43, G28, G23, G18.90 (*l* between 17 and 30 deg): could all be at the limit of the bar region

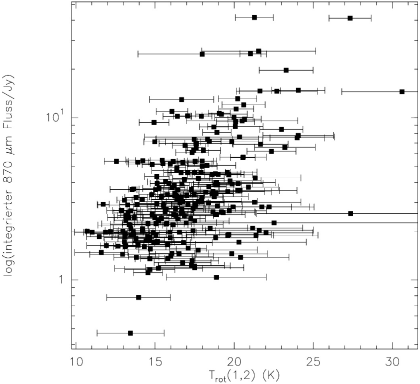
Distance determination: NH_3 lines

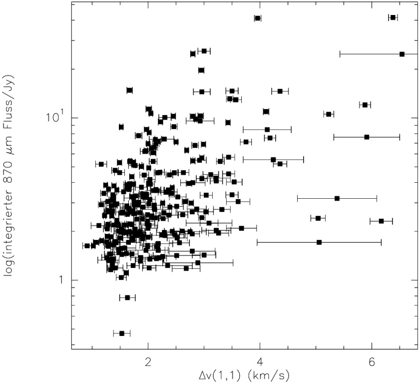
NH_3 (1,1), (2,2), (3,3) at Effelsberg + Parkes: >1000 sources done

(M. Wienen et al. in prep.)

Kinematic distances

+ gas temperature (T_{rot}) + turbulence (linewidth)





Heterodyne follow-up

Nature of the sources: **MOPRA** follow-up
(Wyrowski et al. in prep. ; Fallon et al. in prep.)

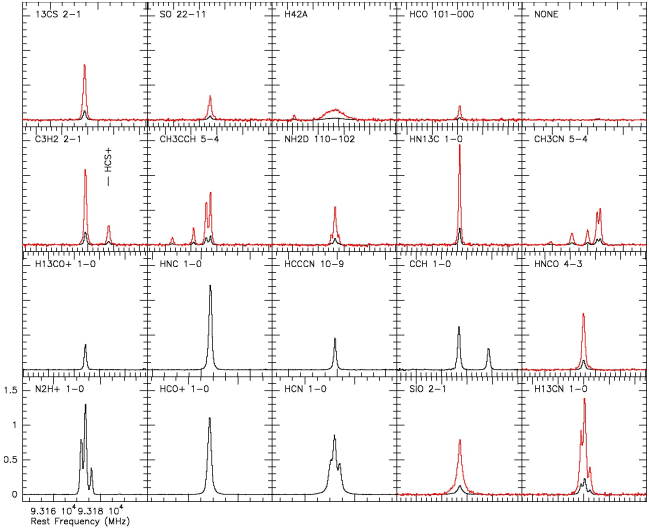
- $\lambda = 3$ mm, broad band spectrometer: 85–93 GHz
  $\Rightarrow$ CS, SO, HCN, HCO^+, HNC, N_2H^+, SiO, CH_3CN, NH_2D...
- Beam = 36″ (LABOCA: 19″), resolution δv =0.9 km/s
- Kinematic distances + GMC velocity dispersion
- Physical conditions: virial masses, T, n
- Kinematics: infall & outflow
- Chemical cond.: cold / hot core chemistry, chemical clocks

Follow-up of 630 ATLASGAL sources

- Flux limited samples, with/without mid-IR
- one non-detection: a planetary nebula

Heterodyne follow-up

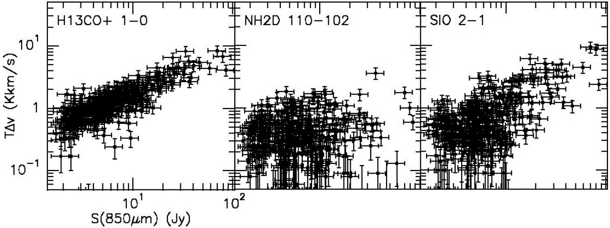
MOPRA "stacked" spectra



Heterodyne follow-up

MOPRA follow-up of >600 ATLASGAL sources

- Good correlation dust / gas



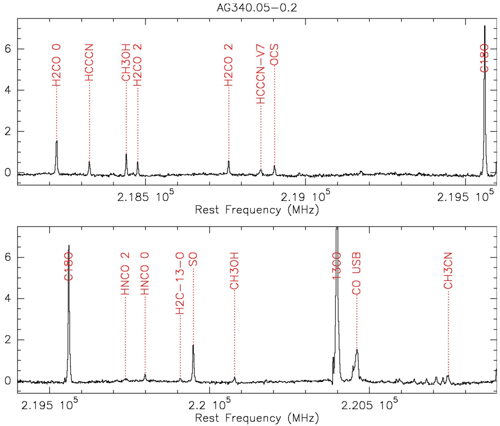
- + deuterium fractionation
- + signatures of shocks
- + ...

Work in progress !
(see poster by Wyrowski)

More with MOPRA : MALT 90

Heterodyne follow-up with APEX

Follow-ups with APEX-1 (230 GHz)

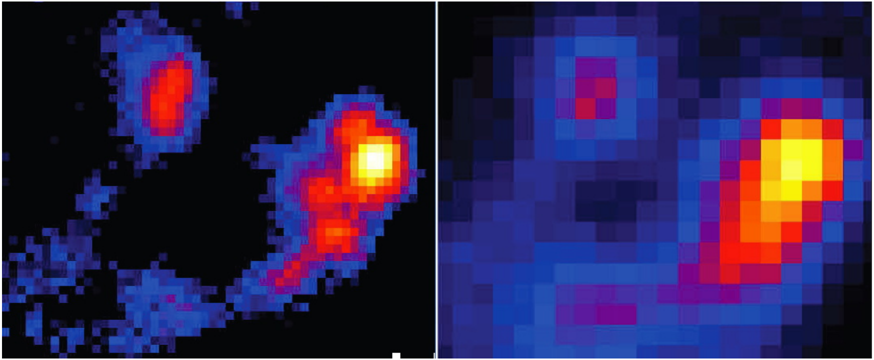


- So far: 170 sources observed
- very complementary to MOPRA:
  - similar resolution
  - same molecules, higher energy transitions

Follow-up observations with SABOCA

Mapping >100 ATLASGAL sources at 350 μm
(Troost et al. in prep.)

- **SABOCA** = Submillimeter APEX BOlometer CAmera, 37-bolometer array at $\lambda = 350\ \mu$m
- **resolution** $= 7.5''$ $\Rightarrow$ **study fragmentation**

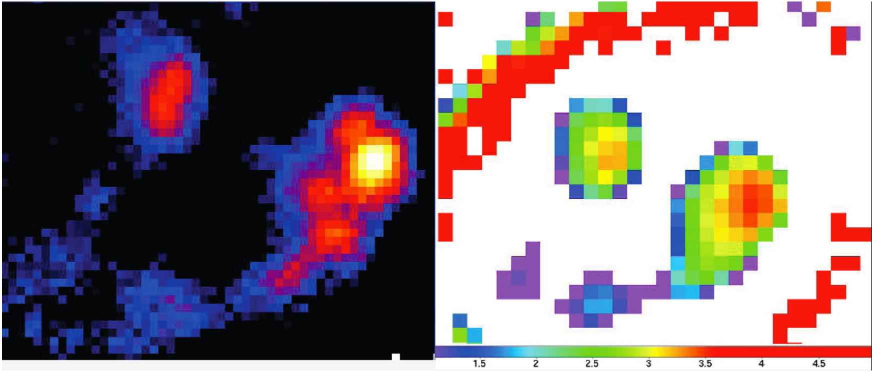


Follow-up observations with SABOCA

Mapping >100 ATLASGAL sources at 350 μm

(Troost et al. in prep.)

- SABOCA + LABOCA $\Rightarrow$ Spectral index
  $\rightarrow$ dust emissivity, temperature



Next steps

More follow-ups with APEX

- larger maps with SABOCA (but limited field of view - $1.5'$)
- deep maps with LABOCA : help recover extended emission
- Heterodyne instruments : $\nu = 230$ GHz – 1.3 THz

More spectral line follow-ups

- EMIR at IRAM 30 m: similar to MOPRA for the north
- high-resolution with ATCA

Combine data with other surveys

- Spitzer : GLIMPSE + MIPSGAL
- Herschel : Hi-GAL

Legacy value

- **Unbiased survey**, the only one covering $\pm 60°$ in Gal. long. (BOLOCAM and SCUBA-2 limited to $l \geq -10°$)

  $\Rightarrow$ Statistical studies on the scale of the Galaxy
  (ex.: importance of triggered star formation)
  (Deharveng et al. 2010; see Poster)

- Well developed synergy w. Herschel KPs HOBYS and HiGAL (common people: Molinari, Motte, Schuller, Bontemps, Zavagno)
- Compact source catalog will be merged with MIPSGAL and Hi-GAL $\Rightarrow$ ultimate homogeneous, complete, continuous database from 24 to 870 μm at spatial resolution $\sim 20''$

+ Data will be public!

High legacy value

Legacy value

Data products

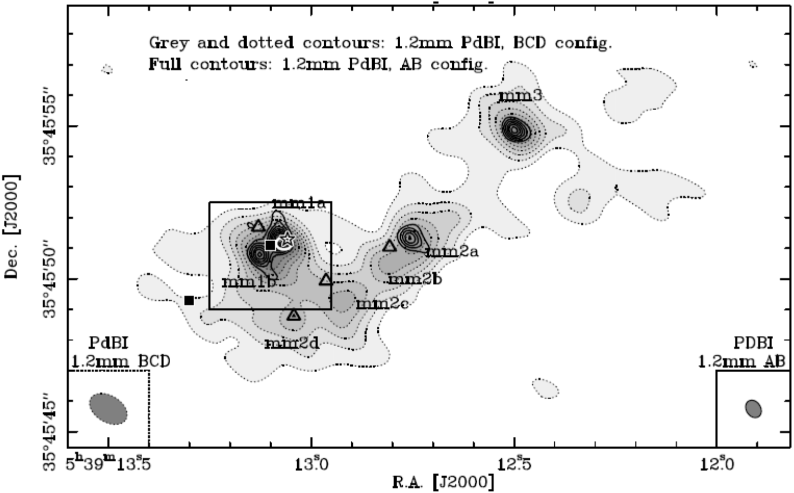
- Coming soon: calibrated maps
- Publish Compact source catalog version 1, incl. associations with IRAS, MSX and RMS
- Catalog of extended objects
- Association with Spitzer surveys (GLIMPSE / MIPSGAL)
- Association with Hi-GAL (60–500 μm)

ATLASGAL + Spitzer + Herschel
+ line identifications
$\Rightarrow$ **SEDs from 3 to 870 μm**
+ kinematic distances + sources nature

`www.mpifr-bonn.mpg.de/div/atlasgal/`

Perspectives

Near future: High resolution mapping with **ALMA**



IRAS 05358+3543; Beuther et al. 2007, A&A 466, 1065

Conclusion

The pathfinder for Galactic Star Formation
First unbiased Galactic plane survey at submm λ

- Characterize large scale structure of the Galaxy (cold ISM + star forming regions)
- **Only a systematic survey can provide well controled samples for follow-ups with ALMA**
- Only optically thin dust continuum can detect high column density objects in an unbiased way
- Only ATLASGAL will be complete (and completed !) in 2012
  $\rightarrow$ thousands of targets for high-resolution studies

Pathfinder for ALMA + Herschel, EVLA