RRLs and SF M82

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An long story...

1. It is a follow-up of:
   - first detections with the VLA of SB galaxies (Jun-Hui paper)
   - observations of mm RRLs of Arp 220 using with IRAM-30m (Anantha paper)

2. The starting point: 408 MHz Merlin image of M82:

   the number of 'point' sources increases with increasing frequency

   Suggestion: free-free absorption (Pedlar et al.).
   Our question: could that be caused by a dense plasma which would be observable with mm RRLs?

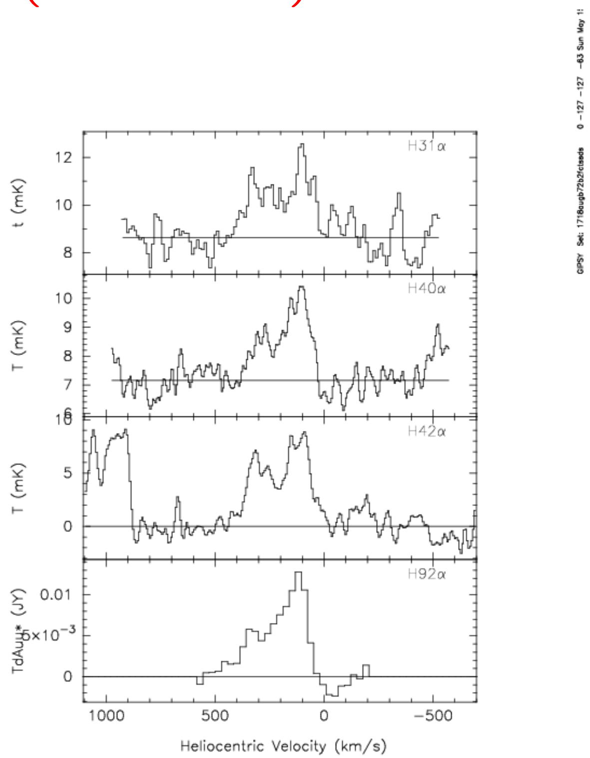
3. Test the hypothesis of a free-free absorption and the influence of density fluctuations (**compact HII regions**)

4. Use the IRAM-PdB (95-97) for M82 H40α (2.7" resolution)

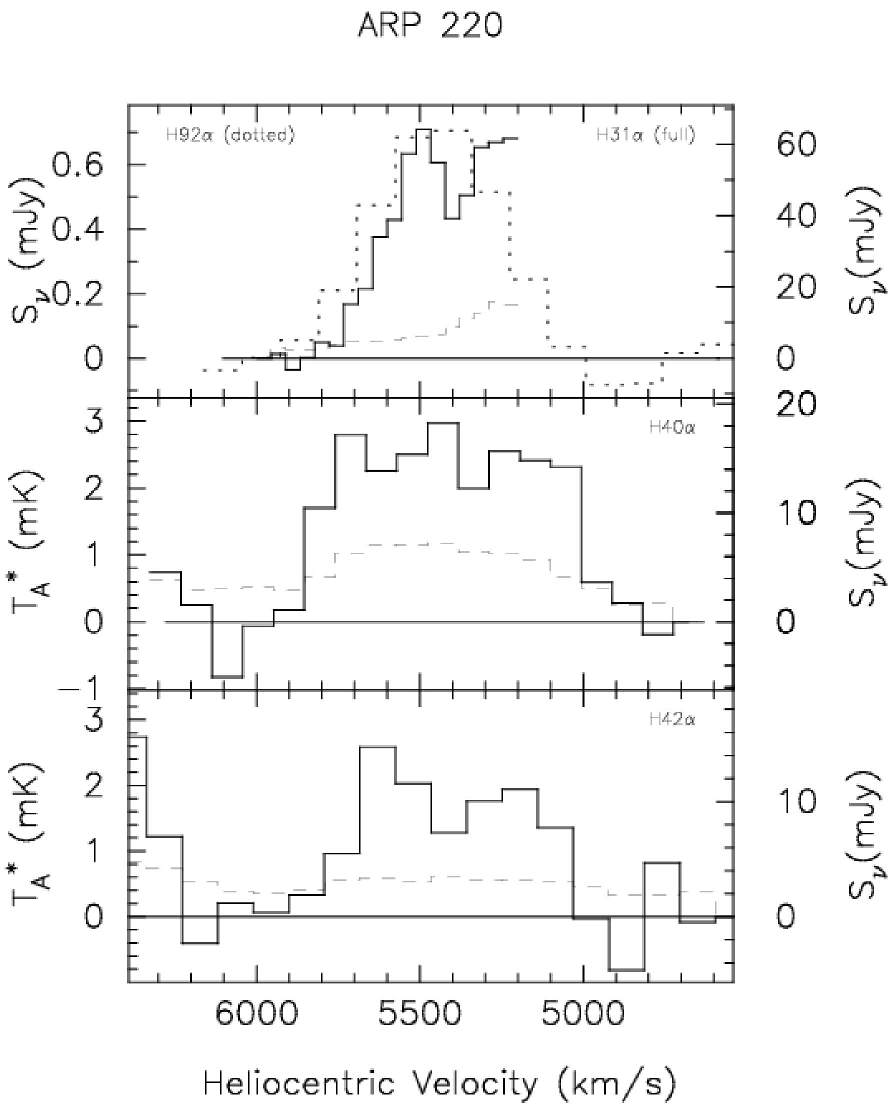
5. Use the IRAM-30m (98-01) for M82 (H42α,H40α,H31α,H29α)

Molecular lines.

H42α,H40α,H31α (IRAM-30m) H92α VLA



- **CH_3CCH 85.4 GHz** (probes $\sim 10^5$ cm^{-3} dense regions)
- **SO 99.3 GHz**
- **C_4H 85.7 GHz** (observed in galactic PDRs (*e.g. the horse head*)
  First extragal detection, TBC by observing other transitions
- **HC_3N 209.2 GHz ?** (could be blended with H31α)
- ...



ARP 220
H92α (dotted)
H31α (full)
H40α
H42α
S_ν (mJy)
S_ν(mJy)
T_A^* (mK)
Heliocentric Velocity (km/s)
6000
5500
5000

Note about our Arp220 H31α result

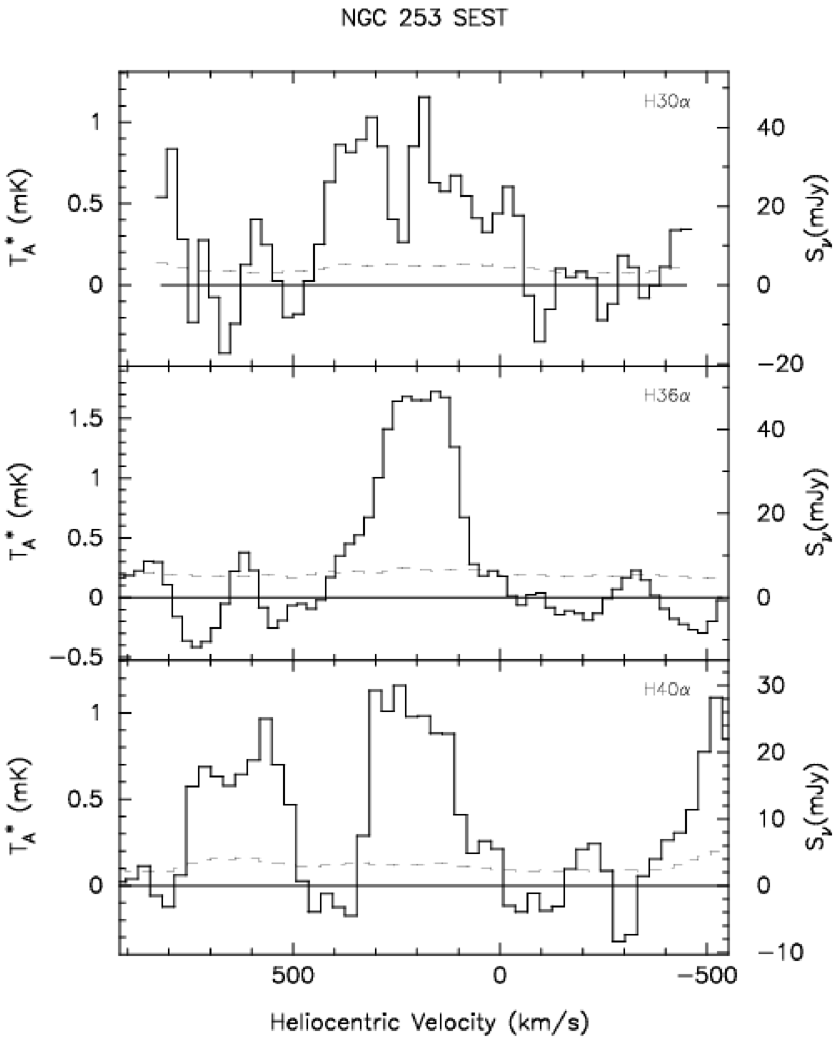
1. We indeed recognized the low S/N *(in particular at 3mm)*

2. Only a portion of the H31α spectrum had been observed (512MHz BW backend limitation)

but to convince ourselves about the H31α line result we re-observed H31α at the IRAM-30m with a new 1GHz backend.

Result with good S/N:

Line for ν_{rest} of H31α
with the expected width and velocity confirmed.



NGC 253 SEST
H30α
H36α
H40α
T_A^* (mK)
S_ν(mJy)
Heliocentric Velocity (km/s)
500
0
−500

Extra-galactic mm RRLs are difficult to observe!

1. with Jun-Hui at SEST we realized that H36α in NGC253 was *too easily detected* (too strong) when comparing to other RRLs.
   $\rightarrow$ *the lines must be very carefully selected!*

2. for M82: PdB H40α and OVRO H41α (Seaquist) not consistent between each other!
   H41α at anomalous velocity. Some of the regions of line emission have no continuum counterpart!

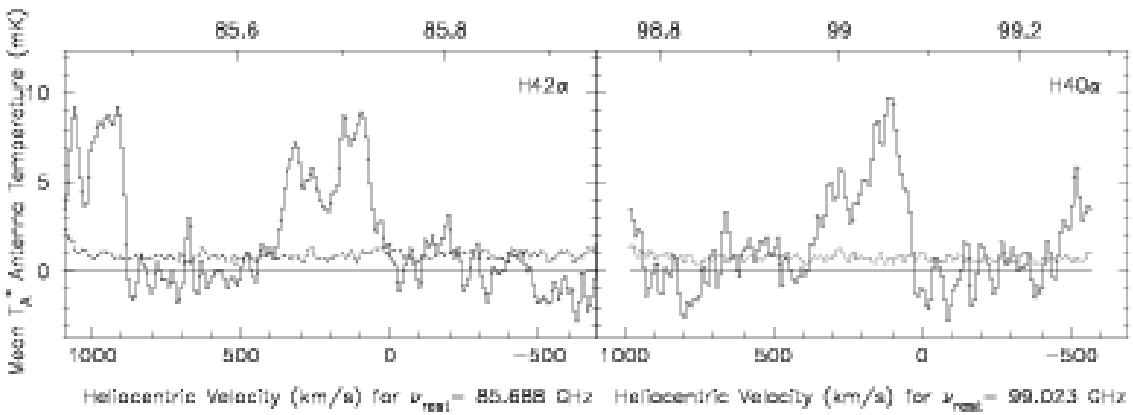
Issues:

- Lines are weak. starburst spectra full of molecular lines for the desired sensitivity.

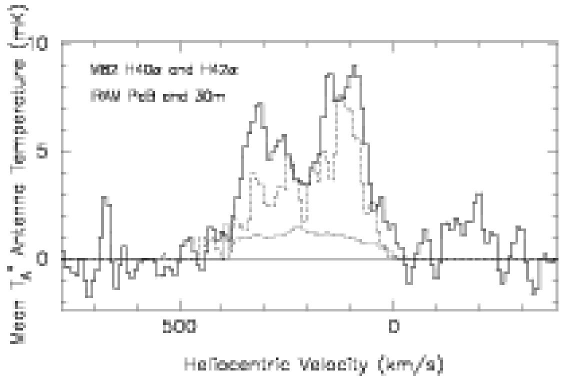
- ARP220 is the worth case for line blending ($\Delta V = \sim 1000$ km.s^{-1})
  SMA 1.3 mm survey: **H31α appears to be HC_3N**!

Does that mean there is no dense plasma?

H42α and H40α in M82



H42α is blended with C_4H!



Solutions to minimize these issues

- **high spatial resolution** $\Longrightarrow$ sensitive telescopes (PdB, ALMA)

- **get broad bands data** to disentangle the different lines

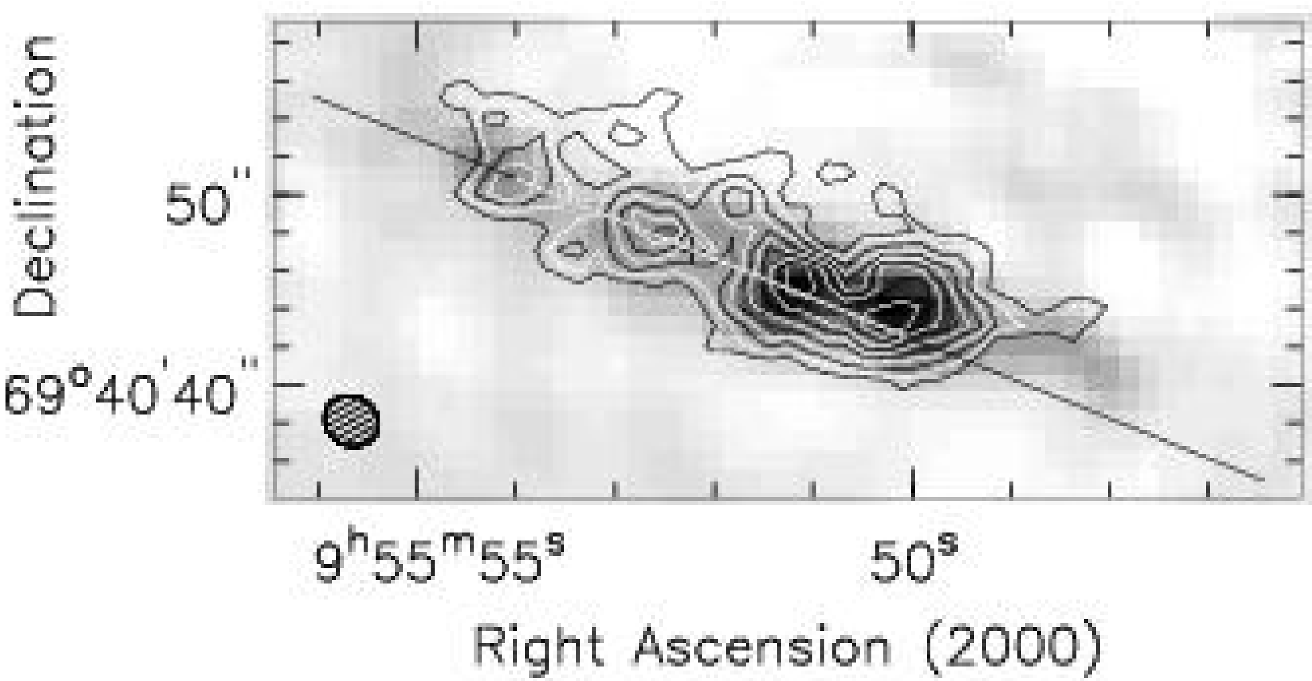
- **observe several RRLs** $\Longrightarrow$ different atm windows *(only $\sim$ one region clean enough per window given the RRL line frequencies)*

IRAM M82 H40α results

- Good spatial correspondance between the line and 8 & 100 GHz continuum emissions
- No anomalous velocities
- Excellent correspondance with the 12.8μm NeII line spatial morphology
- The H40α and HCN (the high vel. grad compnt) correspondance
  (HCN probes high density regions ($\geq 10^5 cm^{-3}$)

but only 2.7 arcsec resolution and relatively low S/N

H40α and 99GHz continuum



Why measuring mm RRLs

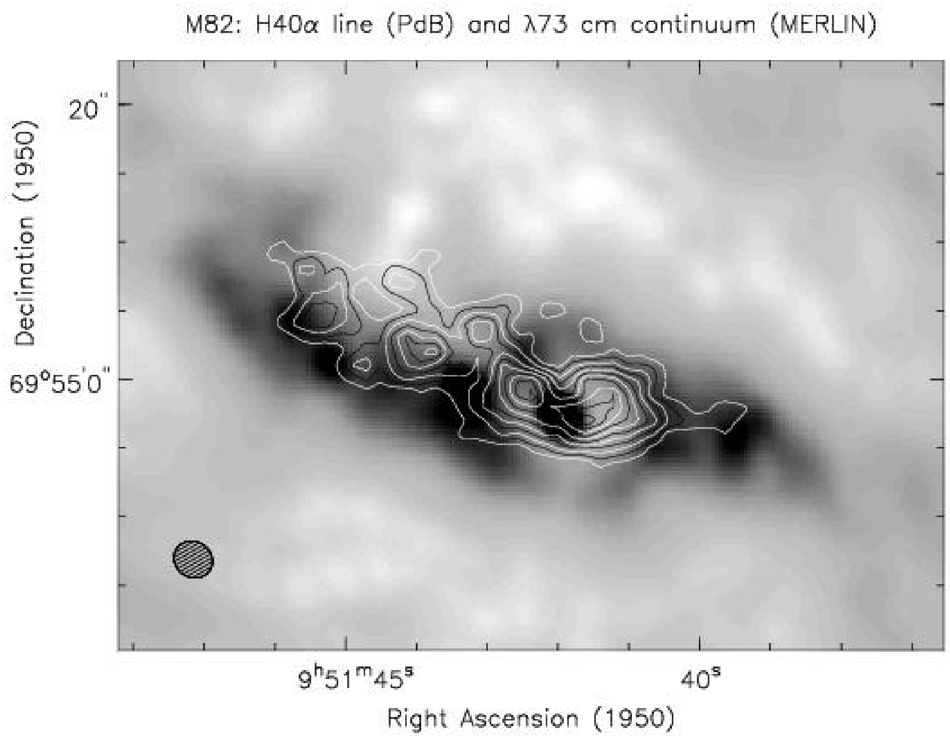
- Physical state of the plasma: multi-density components?

- Physical origin of the mm RRL emission:
  extended component, compact HII regions, PDRs?

- Relation with the atomic and molecular phases of the ISM

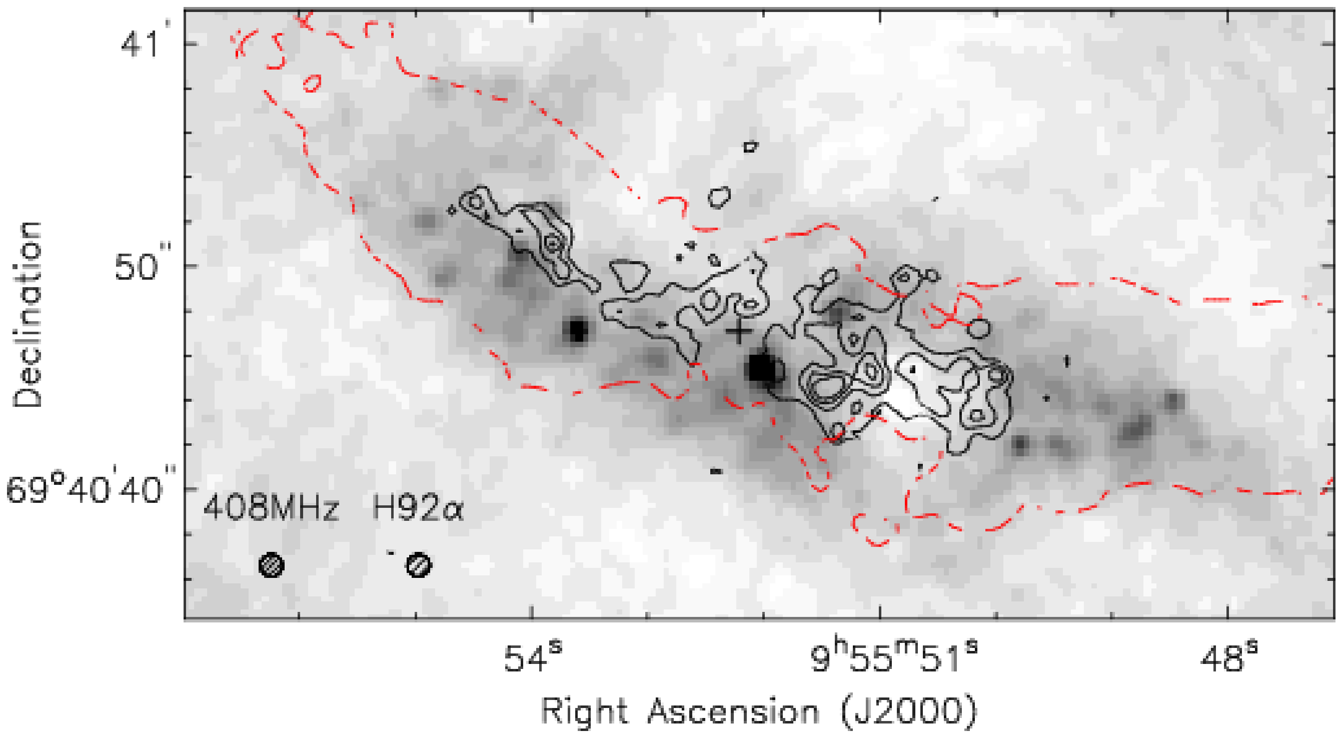
- SF of the massive stars: time-scales, rate and efficiency

H40α and 408 MHz continuum



H92α emission and 408 MHz continuum

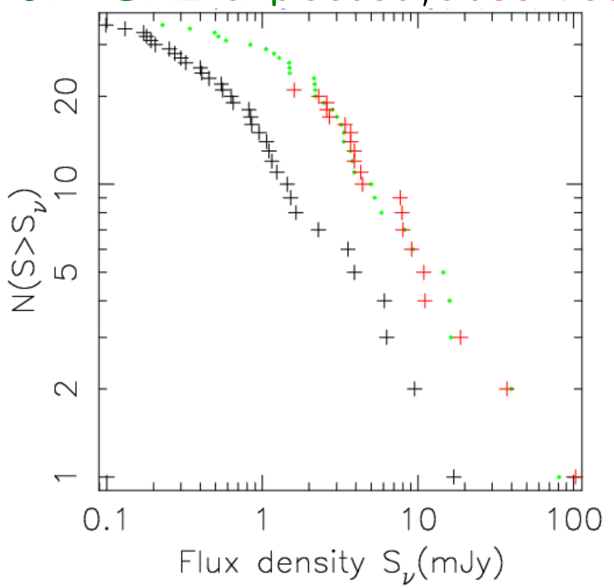
(molecular region at 10^3 to 10^4 cm^{-3})



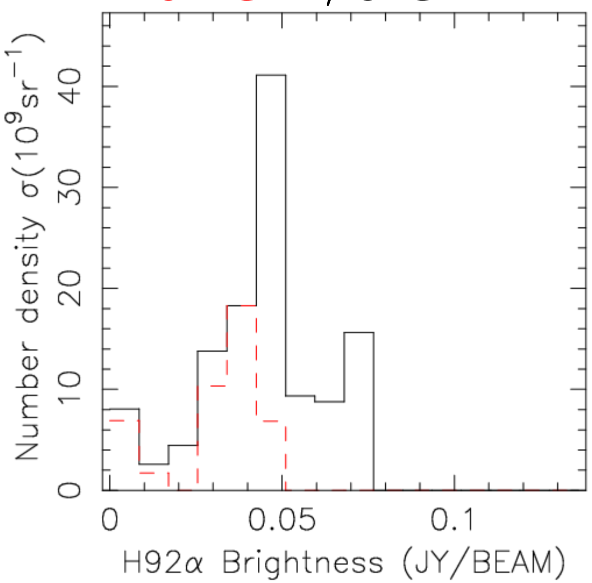
SNR Luminosity function and distribution

(at 5 GHz and 0.4 GHz)

0.4 GHz expected, observed



0.4GHz, 5 GHz



Free-free absorption, dense plasma and SNRs

1. SNR distribution correlates with H92α brightness distribution

2. But no SNR when $B_{H92\alpha} > 80$ Jy km.s^{-1} **(sharp cut-off)**

3. The massive stars do not seem to diffuse far away from their birth place

4. The difference between the luminosity functions at 0.4GHz and 5GHz can be explained by the free-free absorption from the H92α emitting regions (**density fluctuations** *(localized UCHIIs, PDRs) vs pure depth effects along line-of-sights)*.

$\Longrightarrow$ typical lifetimes UCHII in the range 1 to 4 Myr.

(vs ~ 0.1Myr in our Galaxy)

Nature of the mm RRLs emitting regions

1. A diversion: data reduction and analysis

2. Results

Data reduction and analysis

Facts: After more that 30 years Gipsy remains a unique tool in its way to appoach (astronomical) data!

- I still use Gipsy (its infrastructure, *i.e.* its user interface and data structure, plus several enrichments... event-driven GMP, visu tool, open to OO, ...)

- Most of the original works, e.g. for analyzing these M82 observations, were realized using Gipsy thanks to the pioneering (?) thoughts of the peoples who invented this infrastructure
  Example:the way I analyze multi-D images (a multi-line co-constrained profile analysis

- I have been attracted by this package from the very beginning, primarily because of its **data structure**.

- A diversion because **the key peoples are here**!
  I have my own questions to elucidate some points within a context that I discovered only very recently.

The context:

1. I am of the generation who learned *"math modernes"* at college the **set theory** as promoted by the french **Bourbaki school**

   When you use Gipsy you work (and think) in a multi-D space based on the concepts of **sets and subsets** *(the Gipsy Data Structure (GDS))*.

2. I promoted a MS-like structure for the ALMA data model

   (btw the first 'ASDM' datasets were produced in Gipsy by a simulator!)

   Being used to the **GDS** allows to capture easily how works the **MS**!

Why this connection between the GDS and MS ?

GDS is a generic meta-model: can be described mathematically using the theory of categories.
It is effectively a sheaf on a topological space.

- This topology is a CW complex, an Hausdorff space partitioned into open cells. *(points with the concepts of distinguishable, distinct, uniqueness of limits of sequences)*

- Sheaves are based on two axioms, local identity and gluing properties.

- Sheaves encode exactly the data needed to pass between local and global situations.

The GDS can be described using concepts from cohomology theory. It is also connected to mathematical logic.

With little improvements the structures inside the MS can be turned into sheaves.
This model may be seen as a set of topoi.

$\Longrightarrow$ towards a single generic approach (GDS, xMS meta-model) which has all of what we need when applied to our domain, radioastronomy.

My questions!

If you read the Gipsy documentation you will see the usage of

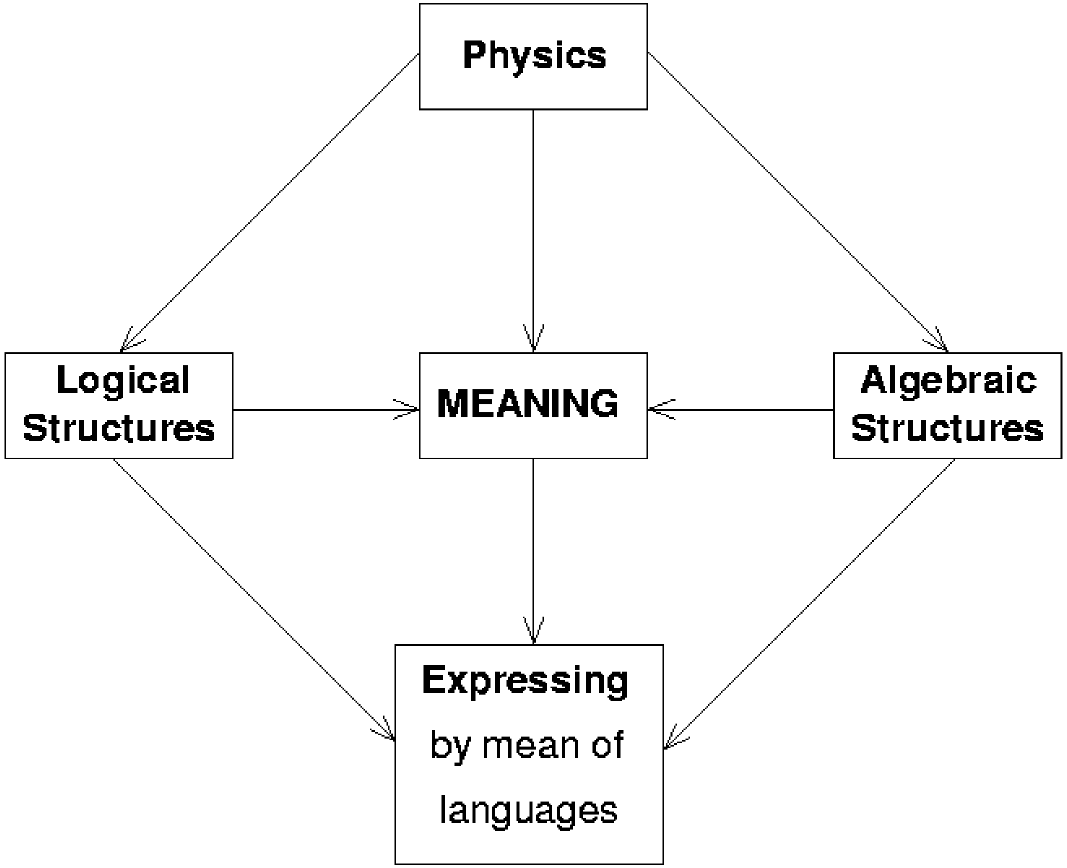
CW acronym for **C**oordinate **W**ord that you can take in category terms as sub-object identifier *(characteristic function when the category is* **Set**.

CW in topological space is for **C**losure finite **W**eak topology

Q1: Is this just a coincidence?

poly-crystalline data structure *(ref drawing in Gipsy doc)*

Q2: Were you aware of the work of Grothendieck? Is there a link with his crystalline cohomology?


Physics
Logical Structures
MEANING
Algebraic Structures
Expressing
by mean of
languages

From this diversion to a use-case!

What can we do with the glue?

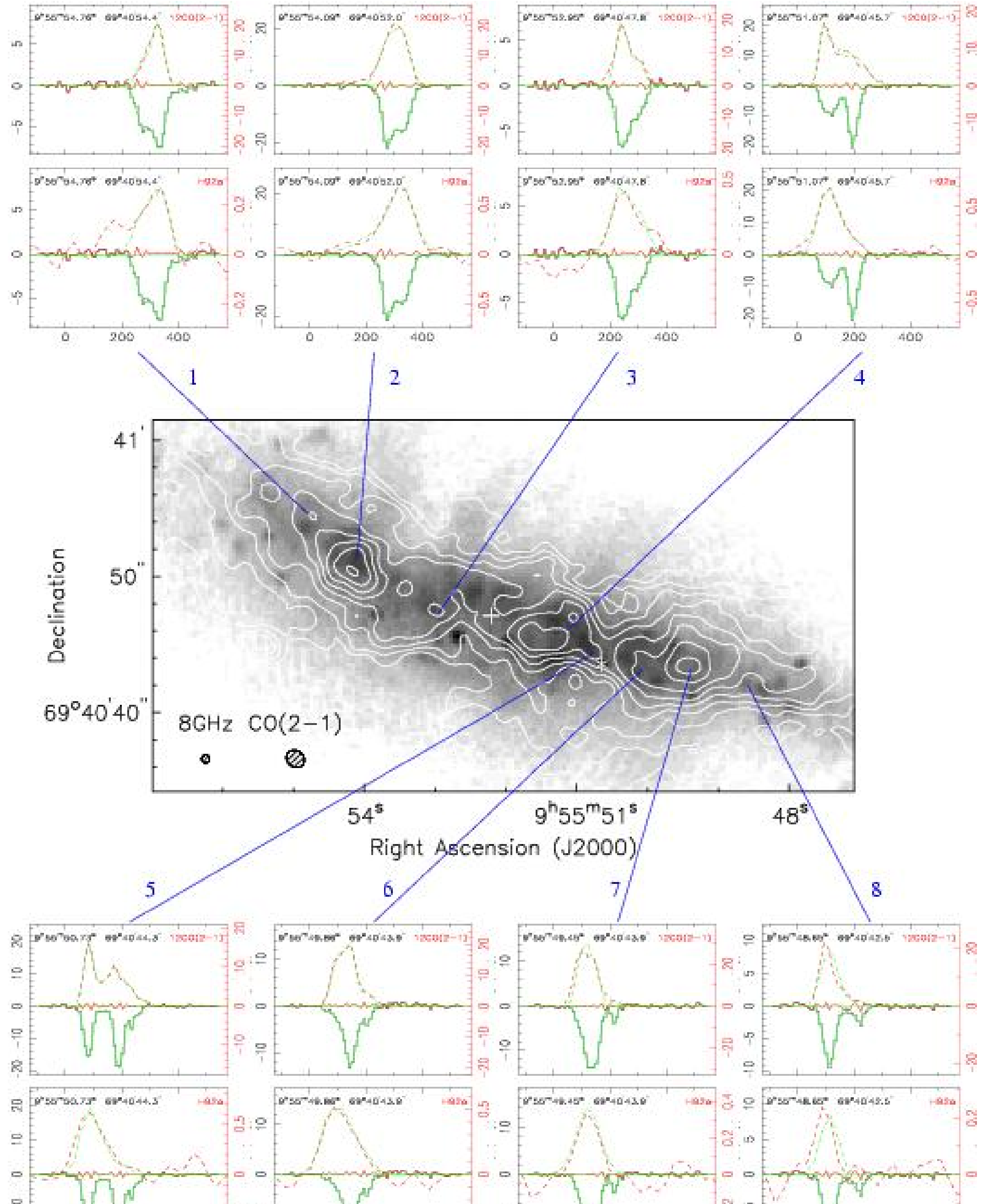
Strategy in data reduction:
factorize information, hopefully in a meaningful way.
But does not work always $\Longrightarrow$ look for emergence of new (unexpected) things.

Fact:
Millimeter data will be extremely rich in information *e.g.* the number of lines observed simultaneously.

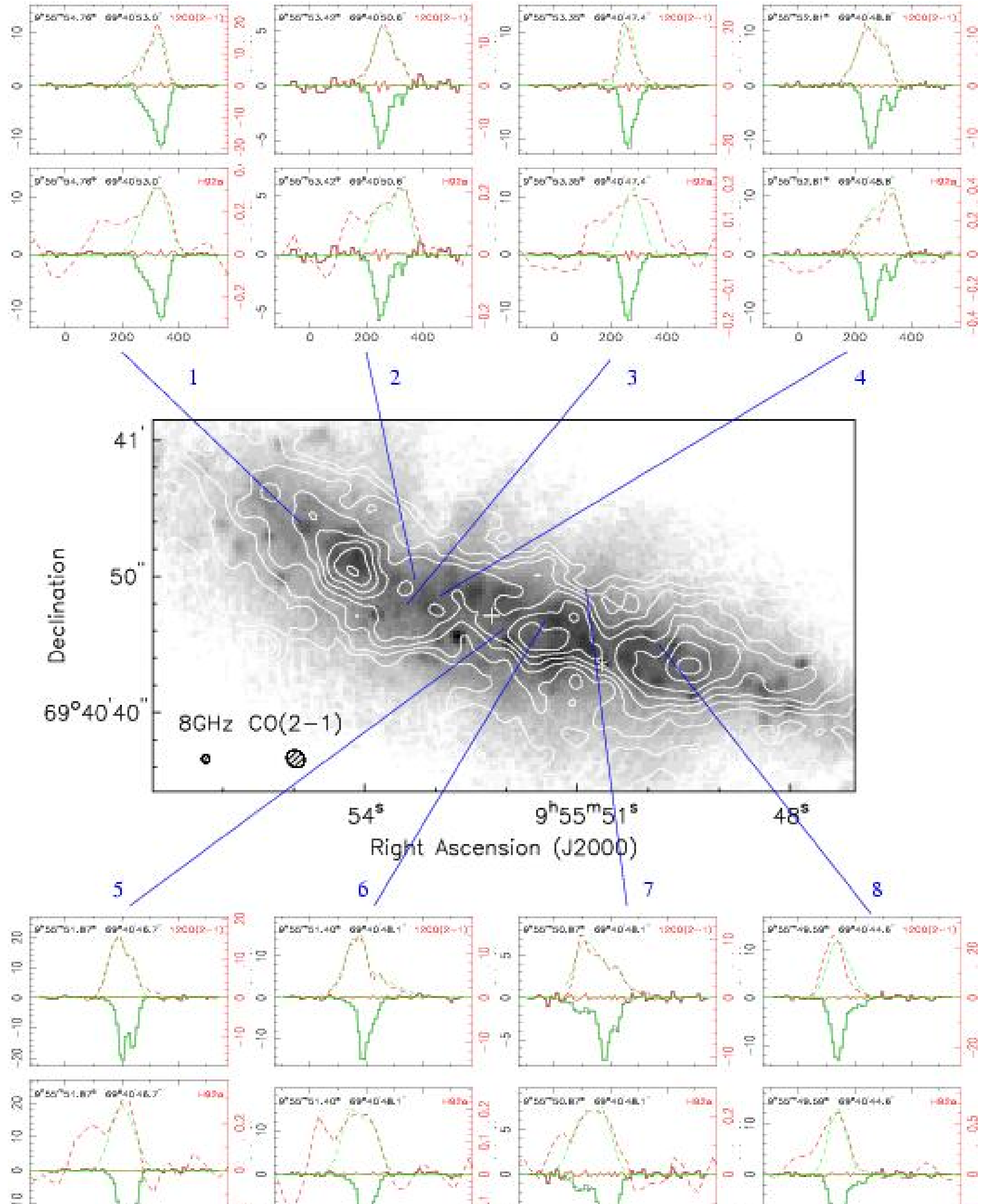
Objective:
build model theories, the two upper triangles (each commutes)

Example:
the co-constrained line profile analysis developed for M82

My suggestion:
use genericity (math) to re-use



1
2
3
4
41'
50"
69°40'40"
Declination
8GHz CO(2−1)
54s
9h55m51s
48s
Right Ascension (J2000)
5
6
7
8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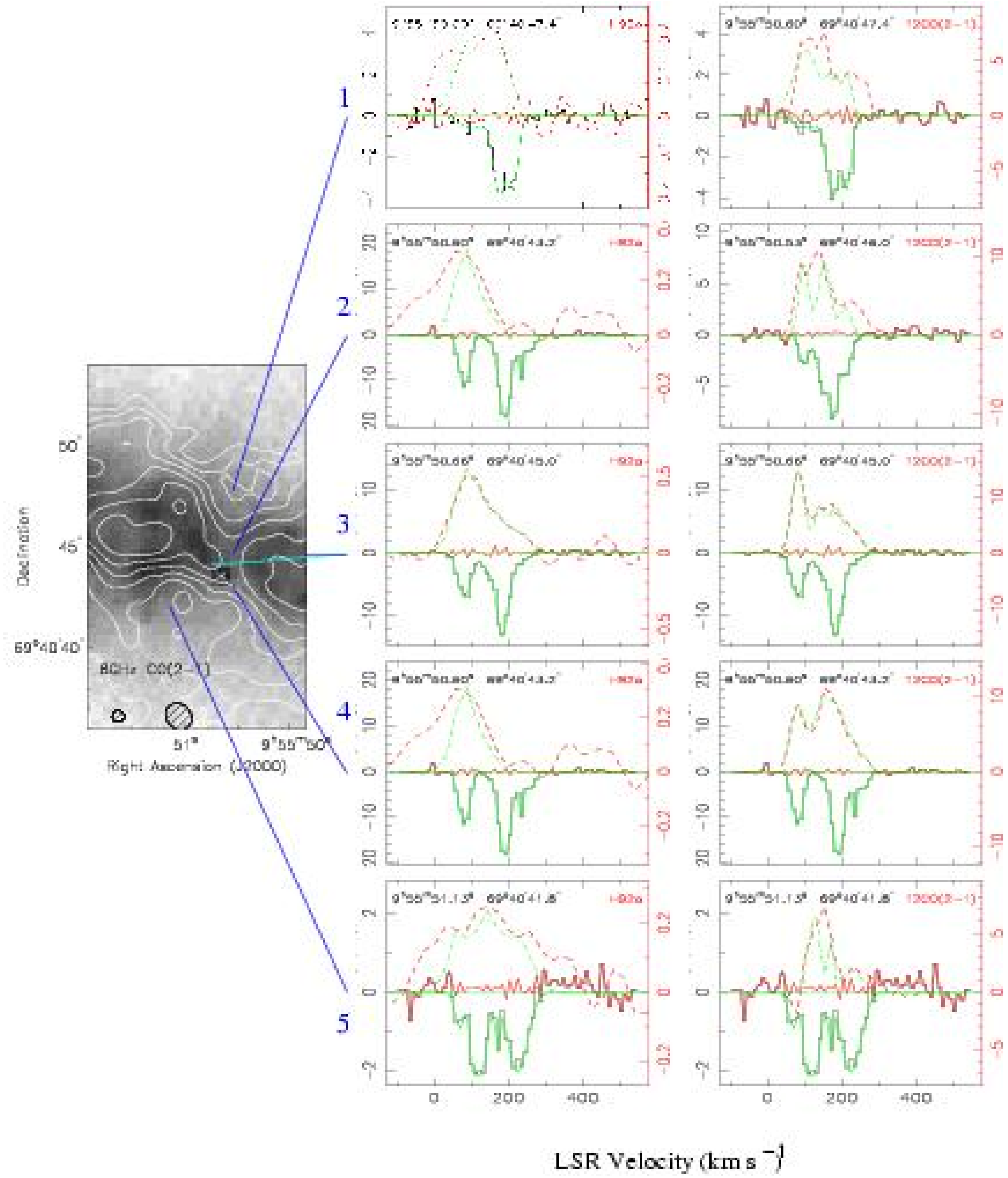

Declination
50"
45"
69°40'40"
6GHz CO(2−1)
51s
9h55m50s
Right Ascension (J2000)
1
2
3
4
5
H92α
12CO(2−1)
9h55m50.66s 69°40'45.0"
9h55m51.13s 69°40'41.8"
LSR Velocity (km s−1)

RRL emission, HI and molecular gas

H92α profiles can be represented on the basis of the HI spectral component model

1. common velocity positions and line widthes (same Δ_v if not co-constrained
2. perfectly co-extensive along the mid-plane (max brightness ridge) H92α and HI
3. away from this ridge extra component in H92α
    - connected to an Hα component farther away
    - represents few % of the total H92α emission
    - appears very near ($\pm 1''$ on either side of the ridge)

Conclusions

- cm+mm RRls reveal density fluctaions of the plasma
- most likely tight connection with the different density component revealed by the molecular lines
- not all in pressure equilibrium