Millimeter Radio Spectro-imaging

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GILDAS SOFTWARE

Agence Nationale de la Recherche
ANR
SCHISM

Millimeter Radio Observations

- Generalities:
  - The atmosphere is both aborbant and emissive
  - Signal = Transmission * Source + Atmosphere.

Optic	Source » Atmosphere	transparent
	Transmission ~ 1	
mm radio	Source « Atmosphere	fog
	Transmission can be small	

- Switched observations (ON-OFF observations, or others)

- Up to recently, two parallel approach:
  - Narrow band imaging
  - Wide band spectral survey

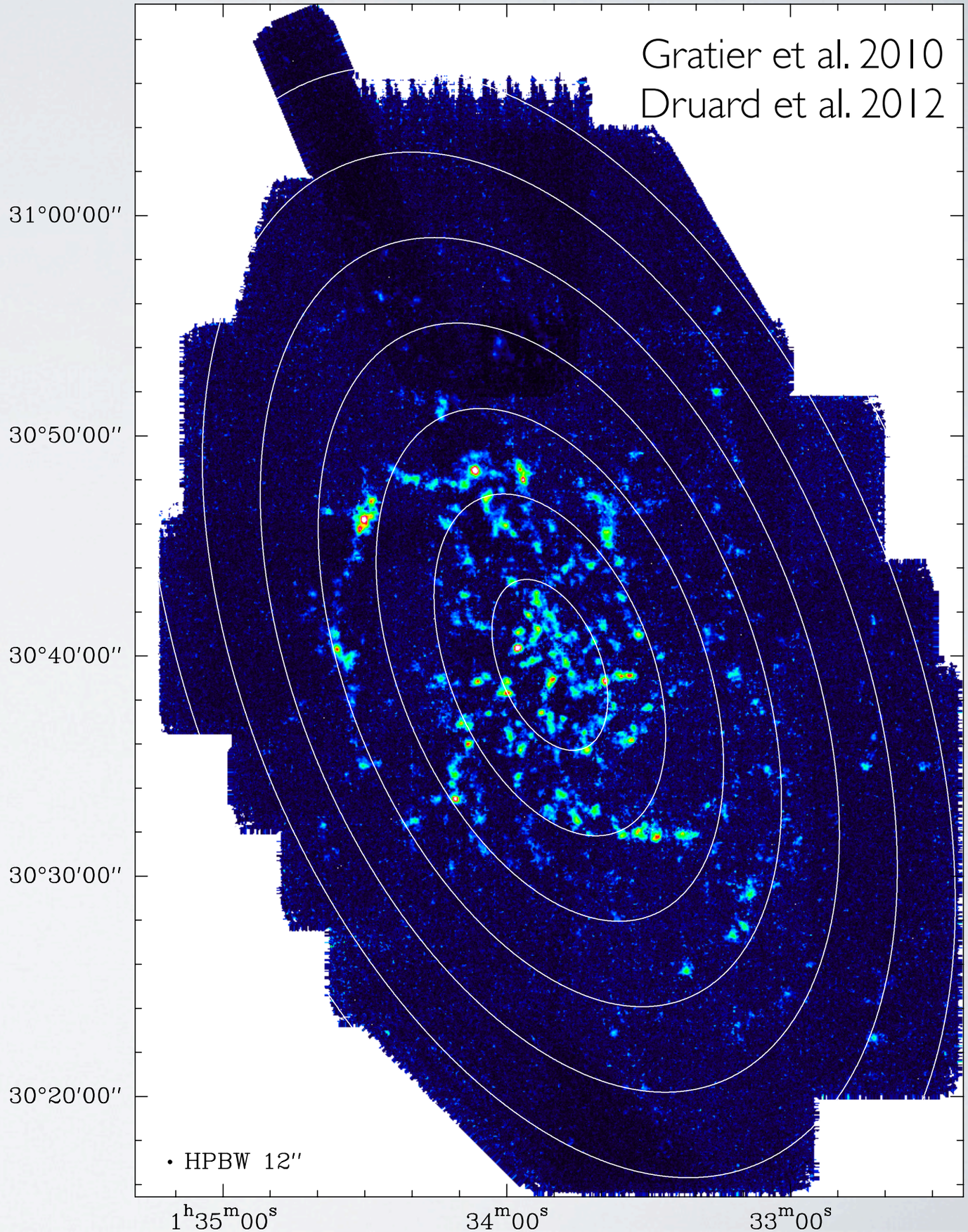
Wide Field Narrow Band

Single Dish

- CO emission in M33
  - Local Group Spiral Galaxy
  - FOV: 55' x 40' (0.78 sq deg)
  - beamsize: 12" :
    55 000 independent beams
  - 777 x 1121 pixels x 116 velocity channels (2.6km/s) : narrow band

- Observing time: ~ 400h
- 20 million spectra (100GB)
- Final product size : 385MB
- Ratio raw/final : 250

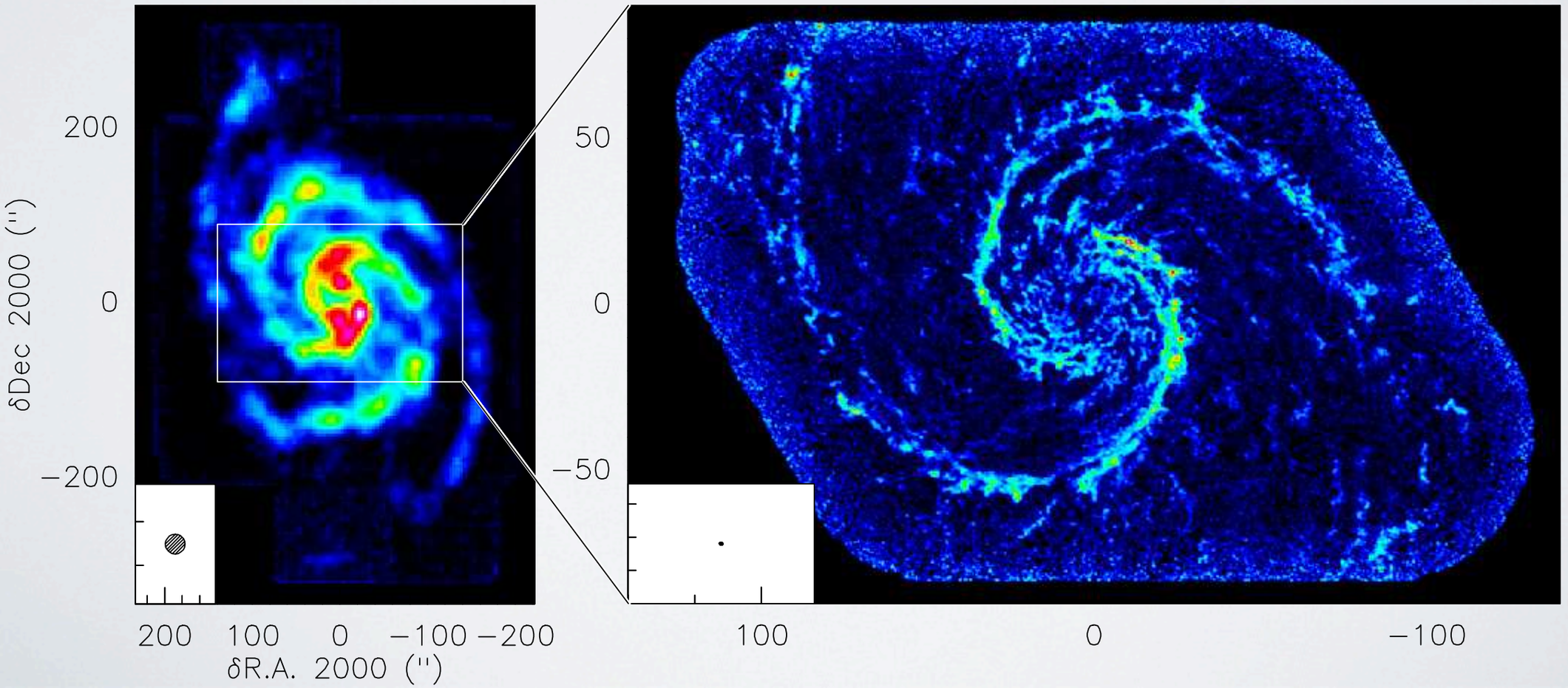
- Raw datarate : 250MB/h



Wide Field Narrow Band

Interferometry

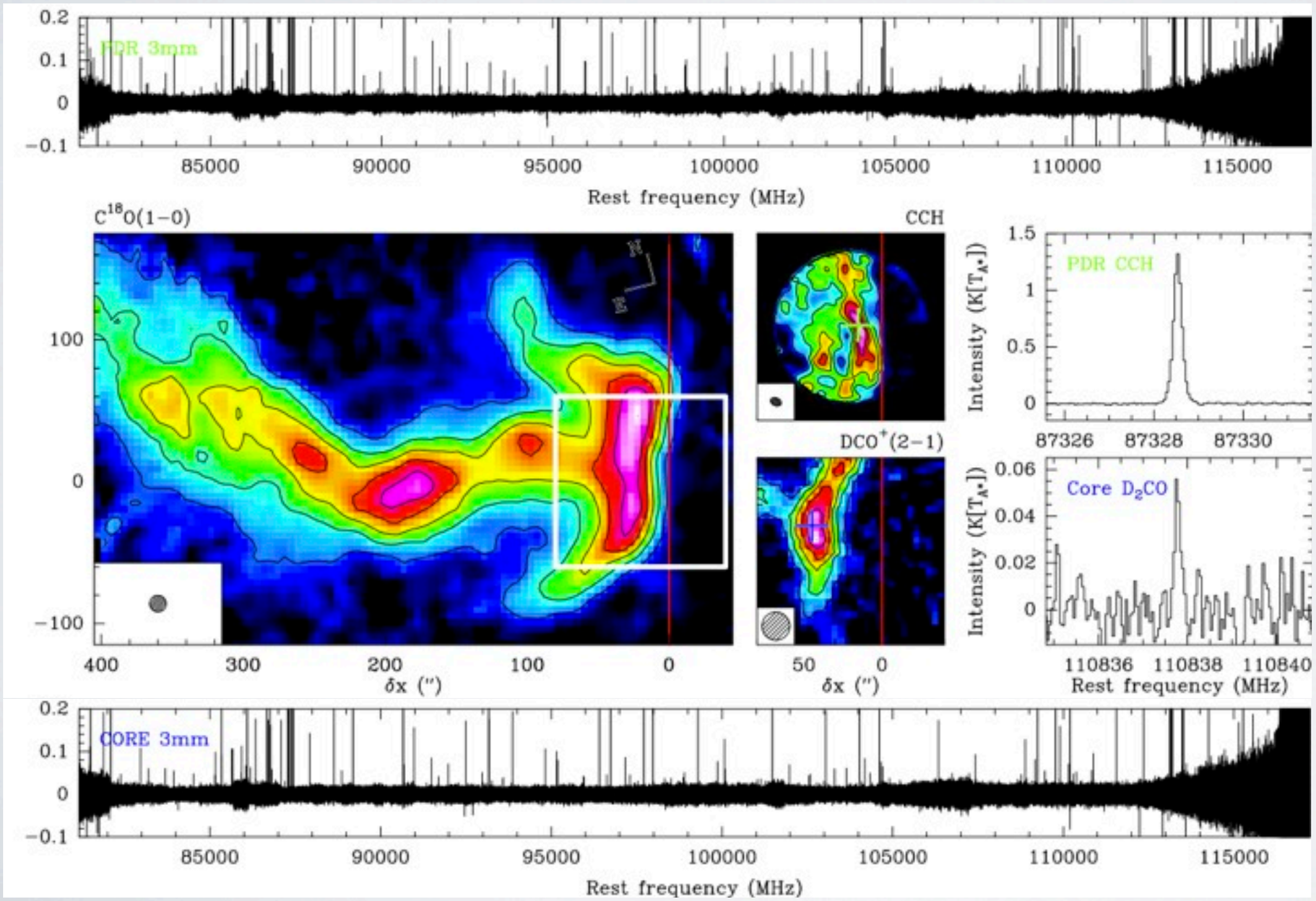
- CO emission in M51
- Pety et al., in prep as part of the PAWS project, PI: E.Schinnerer
  - 60 pointing mosaic
  - FOV: 10 square arcminute
  - Beamsize: 1" : 36 000 independant beams,
  - 935 x 601 pixels x 120 channels (5km/s)
  - Observing time: 170 hours at PdBI + 40 hours at IRAM-30m.
  - Raw data size: about 30 GB, ratio raw/final : 120, raw datarate: 180Mb/h



Single Pointing Spectral Surveys

Single Dish

- Molecular emission in the Horsehead Nebula
- Bandwith: 36 GHz, channel width: 49 kHz, 735 000 channel per spectrum
  ~10 x more info than in previous integrated images
- 30h observation per spectrum, median noise 8mK



Gratier el al. 2012
Guzman el al. 2012
Pety el al. 2012

SINGLE FIELD SPECTRAL SURVEYS

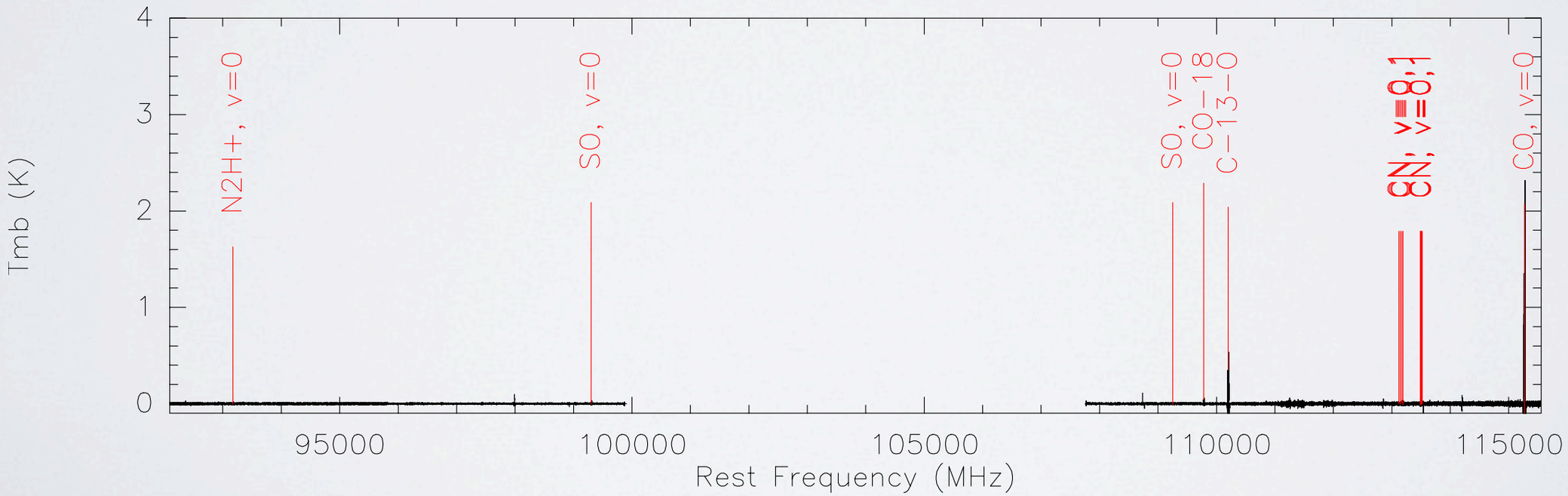
- Interferometry Project NOEMA
  - Upgrading the IRAM Plateau de Bure interferometer
  - by 2016: going from 6 to 10 antennas
    - ~ double collecting area
    - Better uv instantaneous coverage (4.4 more baselines).
    - Less configuration changes.
  - 2 x 2 x 8GHz at 2MHz resolution
    + high resolution mode: 1/4th total BW at 62kHz at 1, 2 and 3mm
    => spectral survey capabilities
- NOEMA data rates:
  - Average (Single-field) : 5.9 MB/s or 20.6 GB/hr or 495 GB/day.
  - Peak (Wide-field) : 264.0 MB/s or 928.1 GB/hr or 21.8 TB/day



WIDE FOV - WIDE BAND

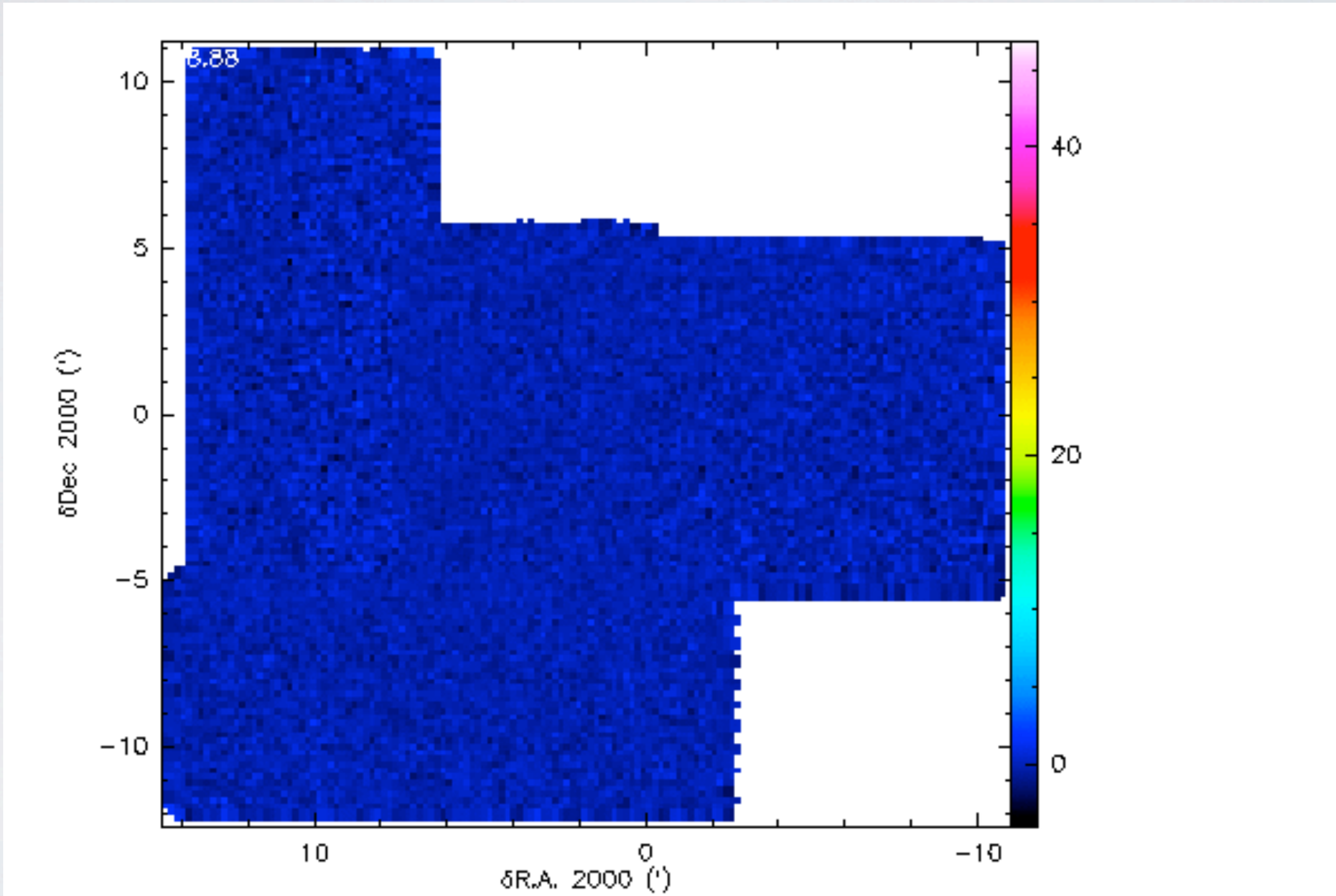
Single dish

- Starting now thanks to wideband receiver + spectrometers at IRAM 30m
  - EMIR+FTS : 2x16GHz @ 200kHz resolution
  - ~83 000 channels per spectrum
  - Many simultaneous lines
    - similar calibration => robust constraint on line ratios
- W49N HII region and diffuse clouds between W49N and the sun
  - Carte 20' x 25' @ 21"-27" resolution
  - Observing time: ~10h
  - Typical datarate : 16GB/h



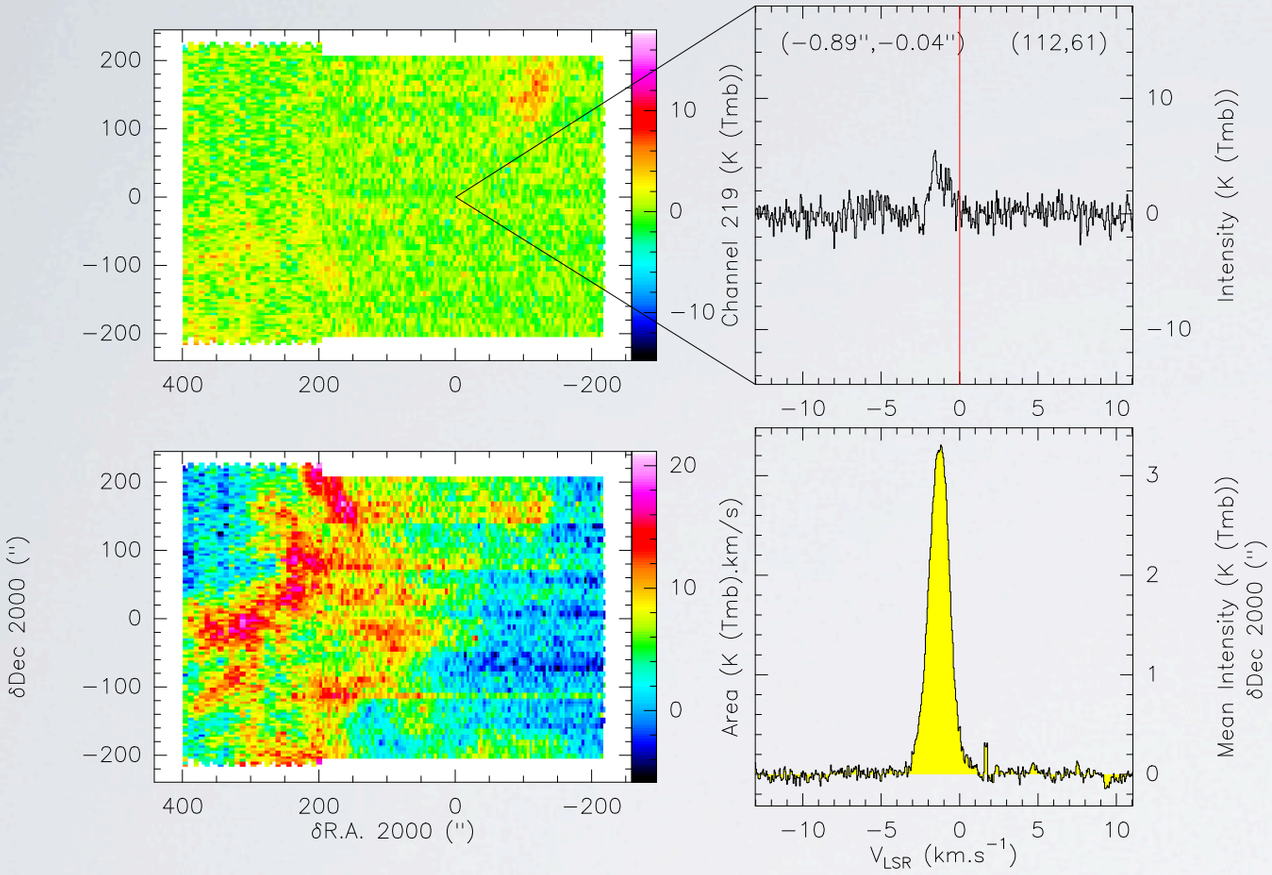
Wide FOV - Wide Band

- Complex structure of the diffuse medium
- velocity structure for each individual tracer
- eg $^{12}CO(1–0)$



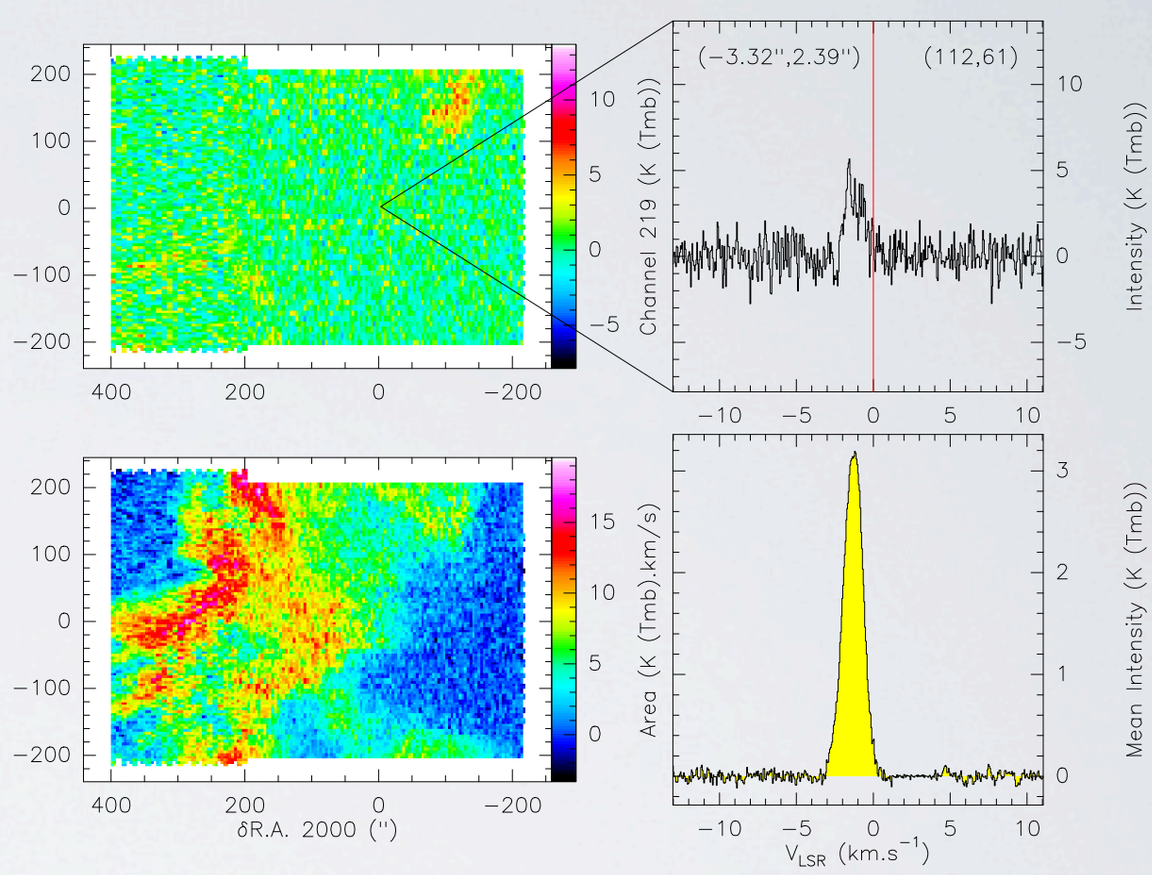
Data reduction Strategies

- Tools built for efficient data reduction
- Until now: windows + polynomial baselines



0 order polynomial fit on fixed window

=> Stripping

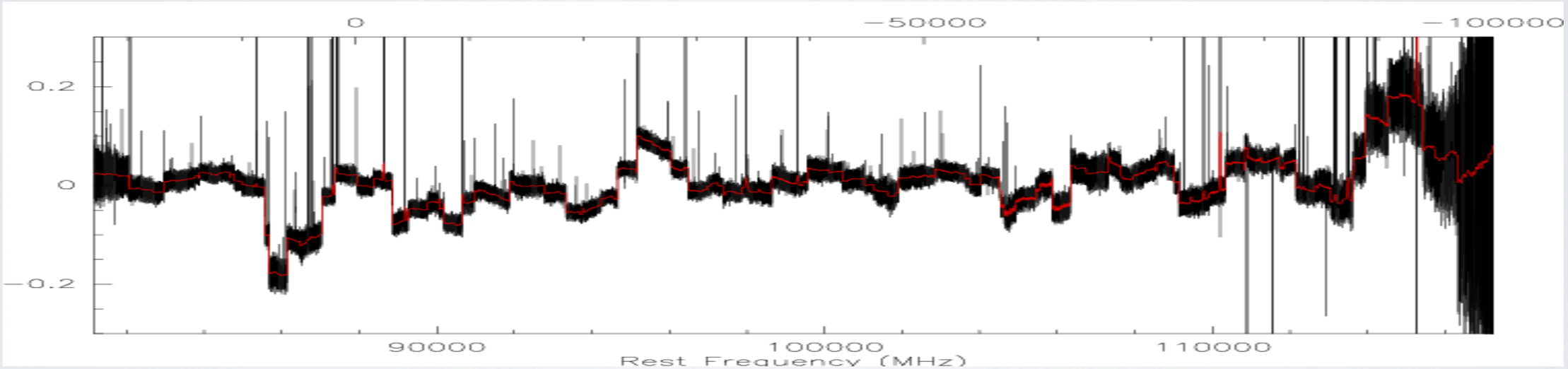


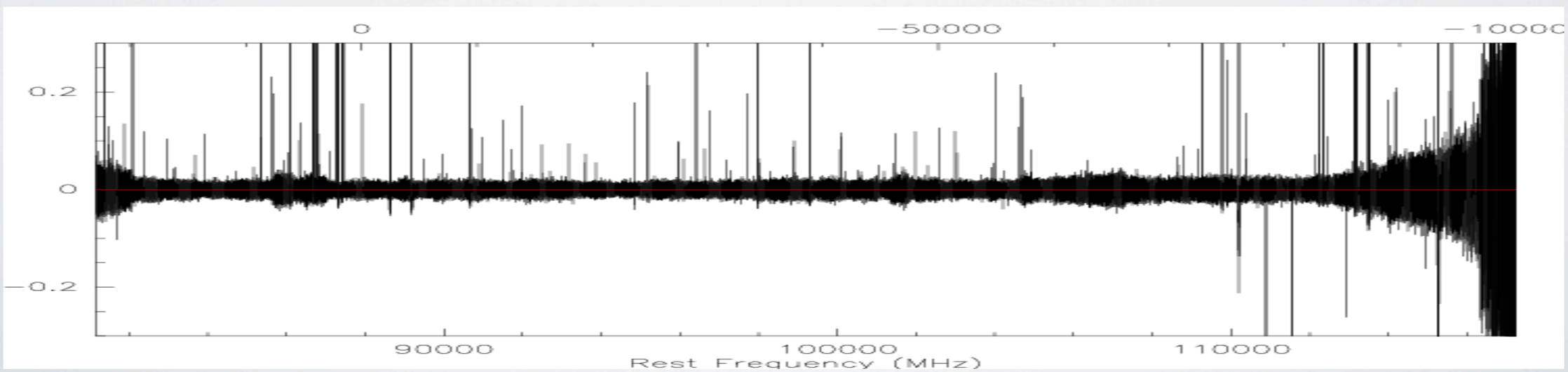
5th order polynomial fit on windows adapted from another tracer

=> Stripping mostly removed.

DATA REDUCTION STRATEGIES

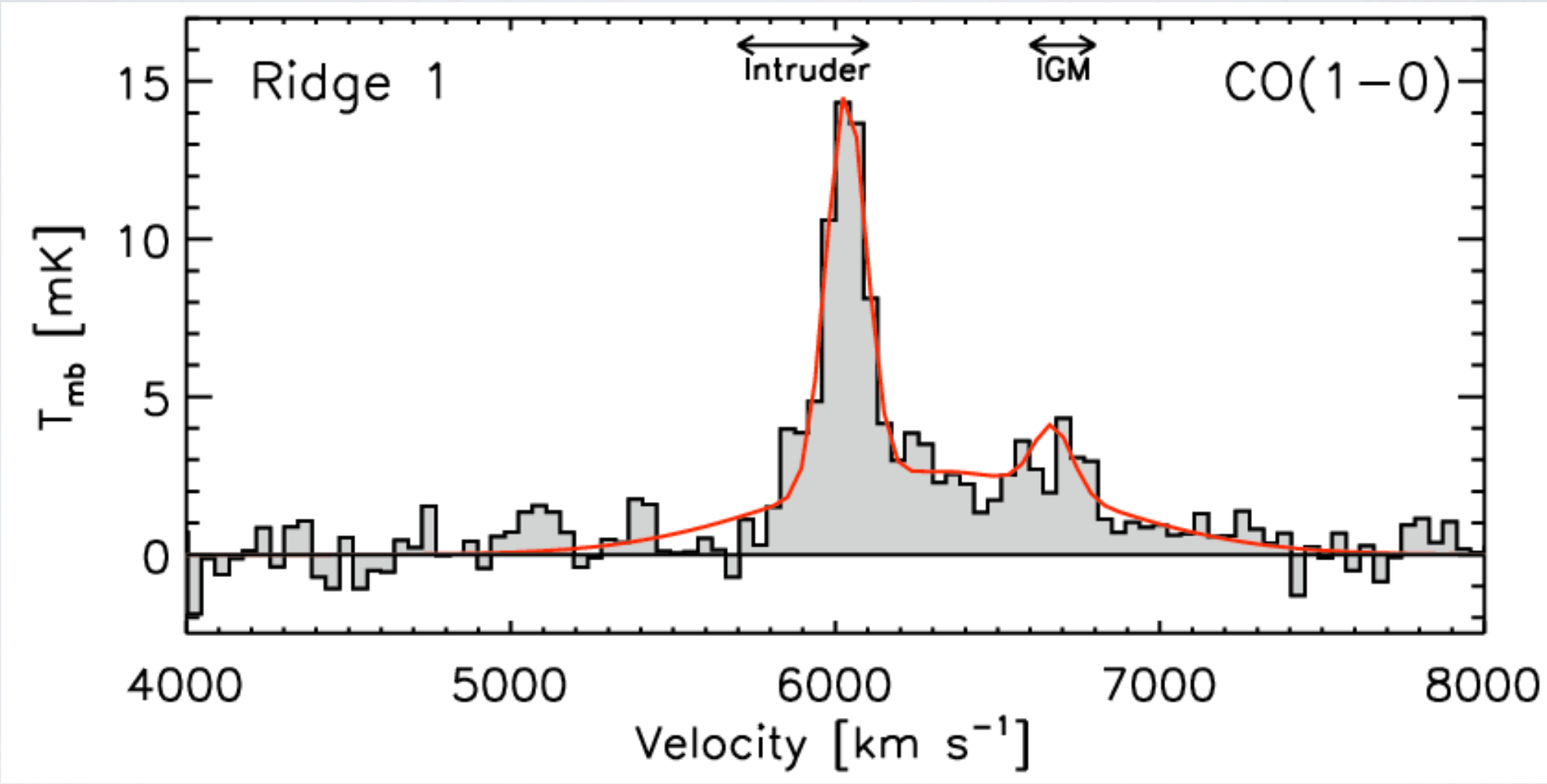
- With new receivers (large bandwidth) and many lines: traditional windowing + polynomial baselining not practical
- Looking into new possibilities
  - Wavelets (if signal frequency scales very different from frequency scale of systematic baselines)
  - Median filtering (coarse method, OK if signal is spreads on a tiny fraction of the channels)





Data reduction Strategies

- Example where previously cited method would not work
- Extragalactic : many hundred km/s wide lines
- e.g.: CO in the Stephan's Quintet (Guillard et al. 2012).

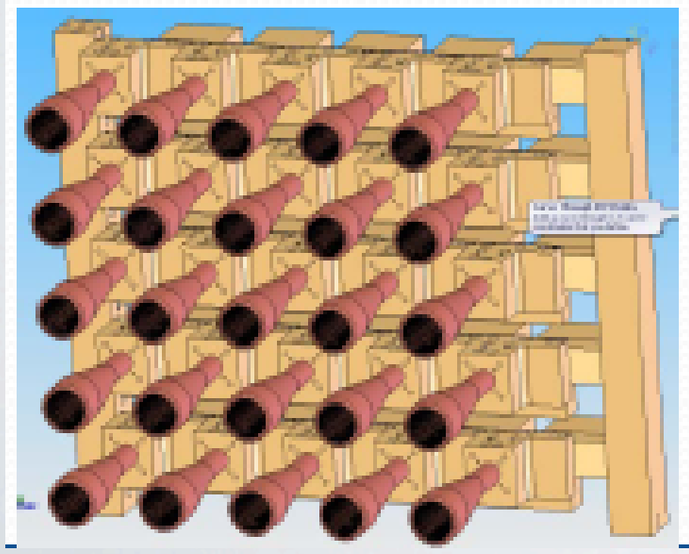


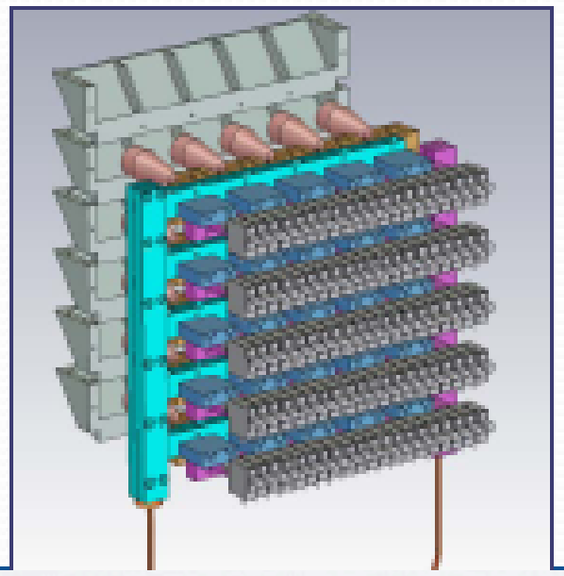
- Must have a way to tell signal from rest of systematics

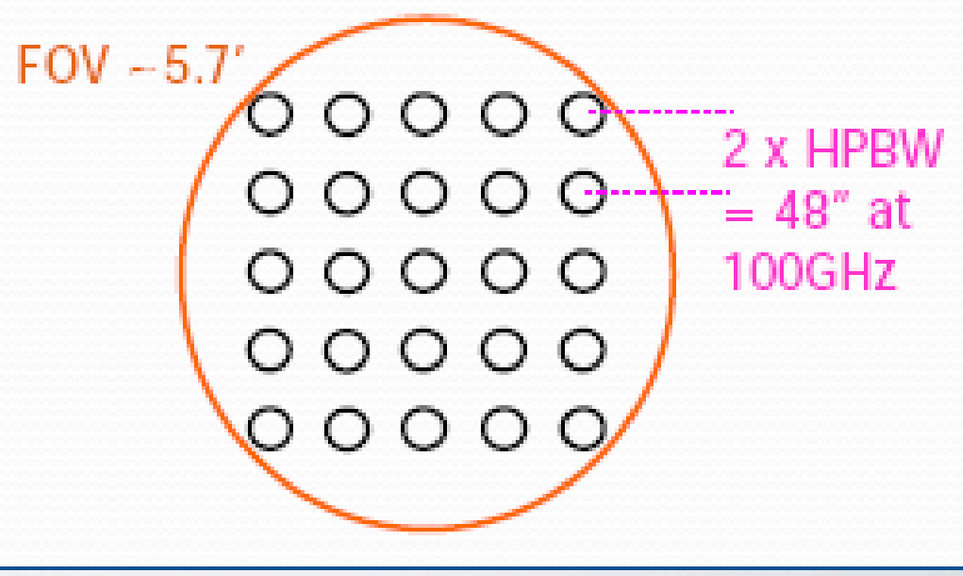
Future: Heterodyne Arrays

- At IRAM 30m in the near future: 25 beam 3mm array (A.L. Fontana et al.)
- Specifications
  - 3mm: 80-116 GHz (70-116 GHz if possible).
  - 25 beams × 2 polars × 1 side band × 4 GHz IF bandwidth.
  - Receiver SSB noise temperature: < 50K.
  - On-sky beam spacing: 2 × HPBW.
  - Derotator included.

- Impact on datareduction : added redundancy (see talk by H. Roussel)
- Typical datarate 100GB/h
  (400x narrow band imaging, 6x current wideband imaging)

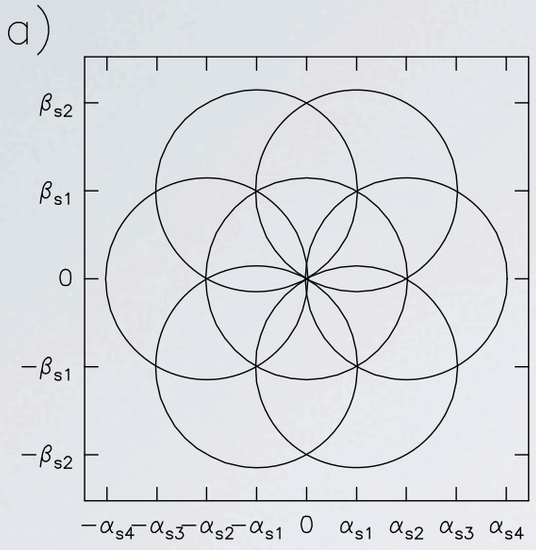




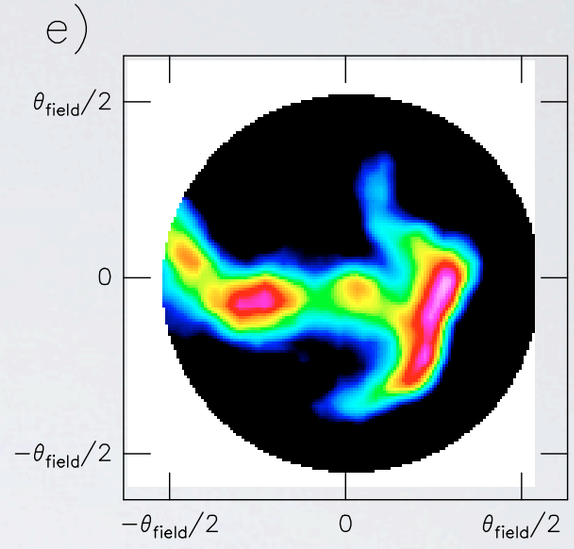


Future: WideField Interferometry

- On the Fly interferometry : NOEMA and ALMA



$I(\alpha,\beta)$



$I_{wide}(\alpha,\beta)$

Wide−field synthesis

Scanned interferometric observation

$V(u_p,v_p,\alpha_s,\beta_s)$

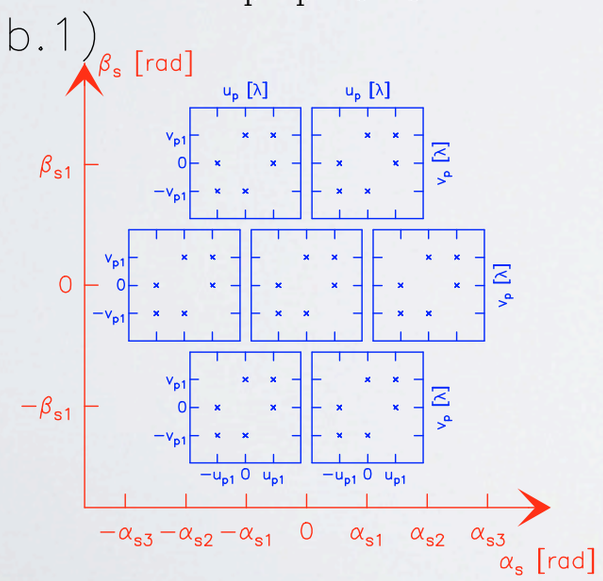
Fourier transform along α_s and β_s

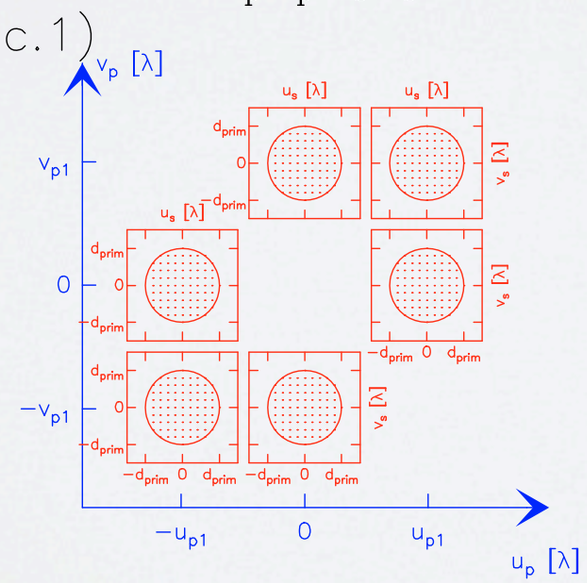
$V(u_p,v_p,u_s,v_s)$

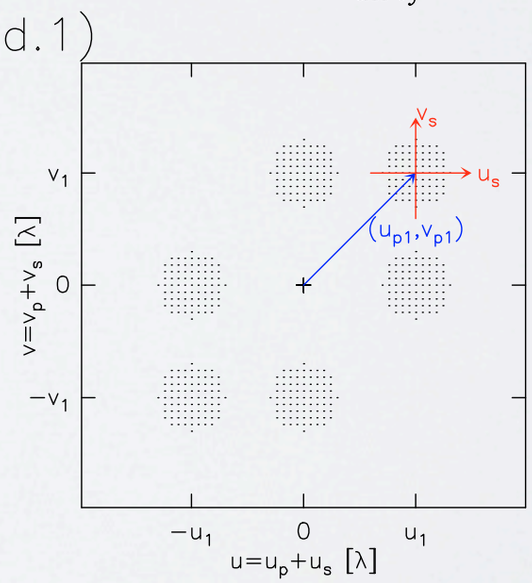
1. Shift
2. Average

$\langle V\rangle(u,v) = I_{dirty}(u,v)$

1. Fourier transform
2. Deconvolution







Pety and Rodríguez-Fernández 2010

Conclusion

- Spectral imaging in millimeter radioastronomy
- At present both in single dish and interferometry:
  - Narrow band (~100 channels) spectral imaging (~50000-100000 independant beams)
  - Wide band (~10^6 channels) spectral survey (~1-50 independant beams)

- Near future: both at the same time
  - Single dish : IRAM 30m heterodyne arrays
  - Interferometry : NOEMA + On The Fly

- Developement of new tools for datareduction
- Need for new efficient data reduction tools