A review of (sub)mm band science and instruments in the ALMA era

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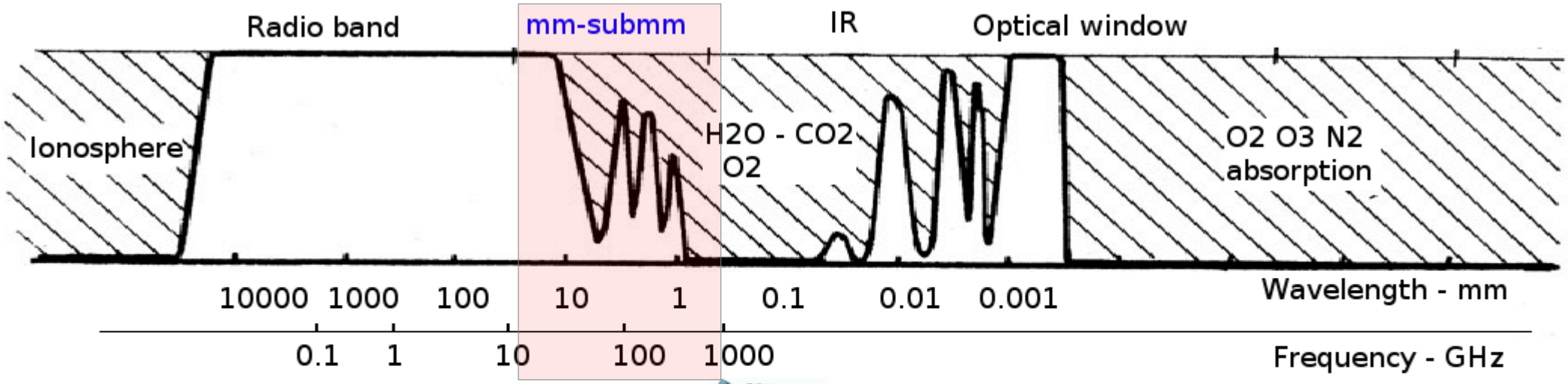
Italian node of European ALMA Regional Centre

EUROPEAN ARC

ALMA Regional Centre || Italian

SISSA – March 2018

Outline



Signals in the (sub)mm bands

Observing instruments: **Interferometers (ALMA)**

Science cases parade and proposals

Observing processes: **archives & images**
(with hands-on tutorial)

A project lifetime: phase 2 Observing process

PHASE II – Observing process

Scheduling Block

Each SG is converted into a **Scheduling Block, an observational unit including targets in the same sky region and their Calibrators to be observed with the same instrumental setup.** They are the minimum set of instructions to perform an observation.

Observations

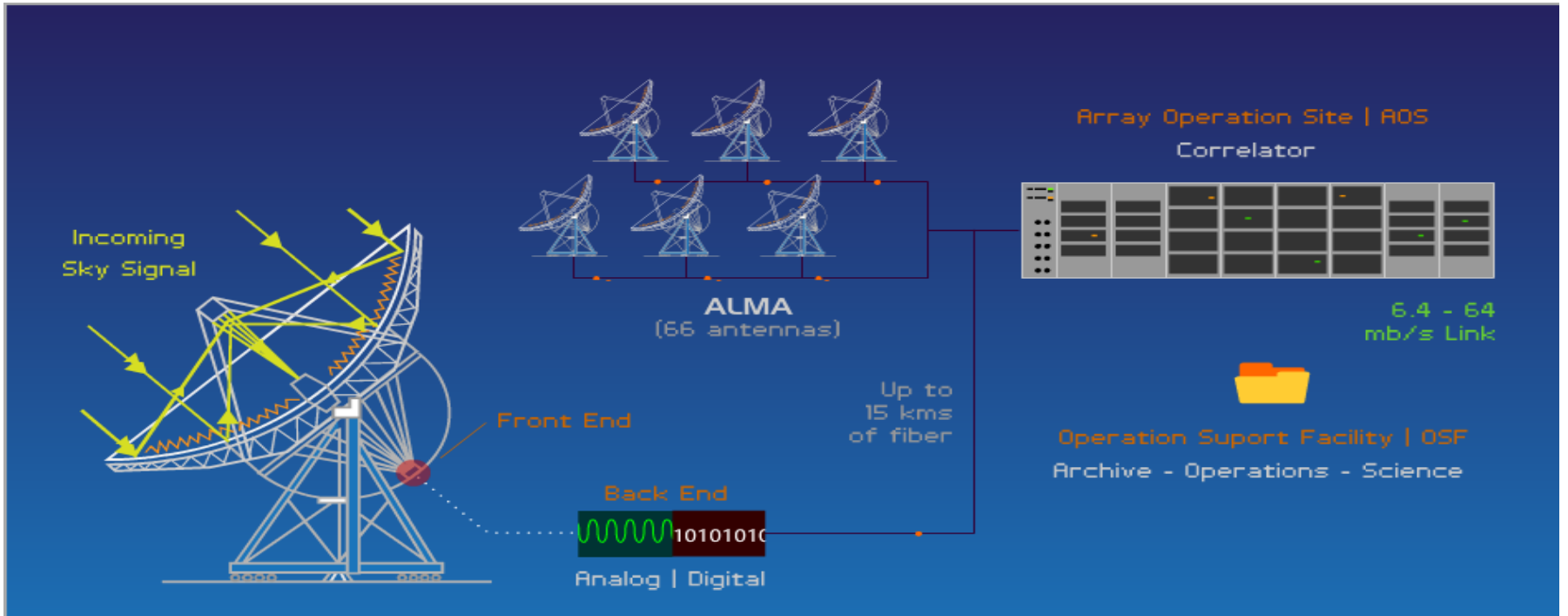
Projects are dynamically scheduled according to telescope configuration, weather, ranking, project status...

Quality assessment

QA0 and 1 = telescope conditions
QA2 = Check for PI sensitivity requests performed by ARC staff

Data archival and delivery

1 yr of proprietary period before data are public through the archive



Early Science Cycles

Early Science observations are conducted on a best effort basis to allows community to observe with incomplete, but already superior array, with priority given to the completion of the full ALMA capabilities

Initial ALMA Early Science cycles:

	Cycle 0 Sep. 2011 – Jan. 2013	Cycle 1 Jan. 2013 - May. 2014	Cycle 2 Jun. 2014 – Oct. 2015	Cicle 3 Oct 2015 - Oct 2016
Telescope				
Hours dedicated to Science	**800**	**800**	**2000**	**2100**
Antennas	**> 12x12-m**	**> 32x12m +9x7m+2TP**	**> 34x12m +9x7m+2TP**	**> 36x12m +10x7m+2TP**
Receiver bands	3, 6, 7, 9	3, 6, 7, 9	**+4, 8**	**+10**
Wavelengths [mm]	3, 1.3, 0.8, 0.45	3, 1.3, 0.8 0.45	+2, 0.7	
Baselines	up to 400 m	**up to 1000 m**	**up to 1500m**	**up to 10km**
Polarisation	single-dual	single dual	**full**	**full**
Proposal outcome				
Submitted	917	1133	1381	1578
Highest priority	112	198	354	402
Filler	51	93	159	236
Success rate	12% (18%)	17% (25%)	26% (37%)	25% (40%)

Pressure factors (highest priority projects)

- Cycle 1: Europe: 9.1 (global ALMA: 5.8)
- Cycle 2: Europe: 4.9 (global ALMA: 3.9)
- Cycle 3: Europe: 6.2 (global ALMA: 3.9)

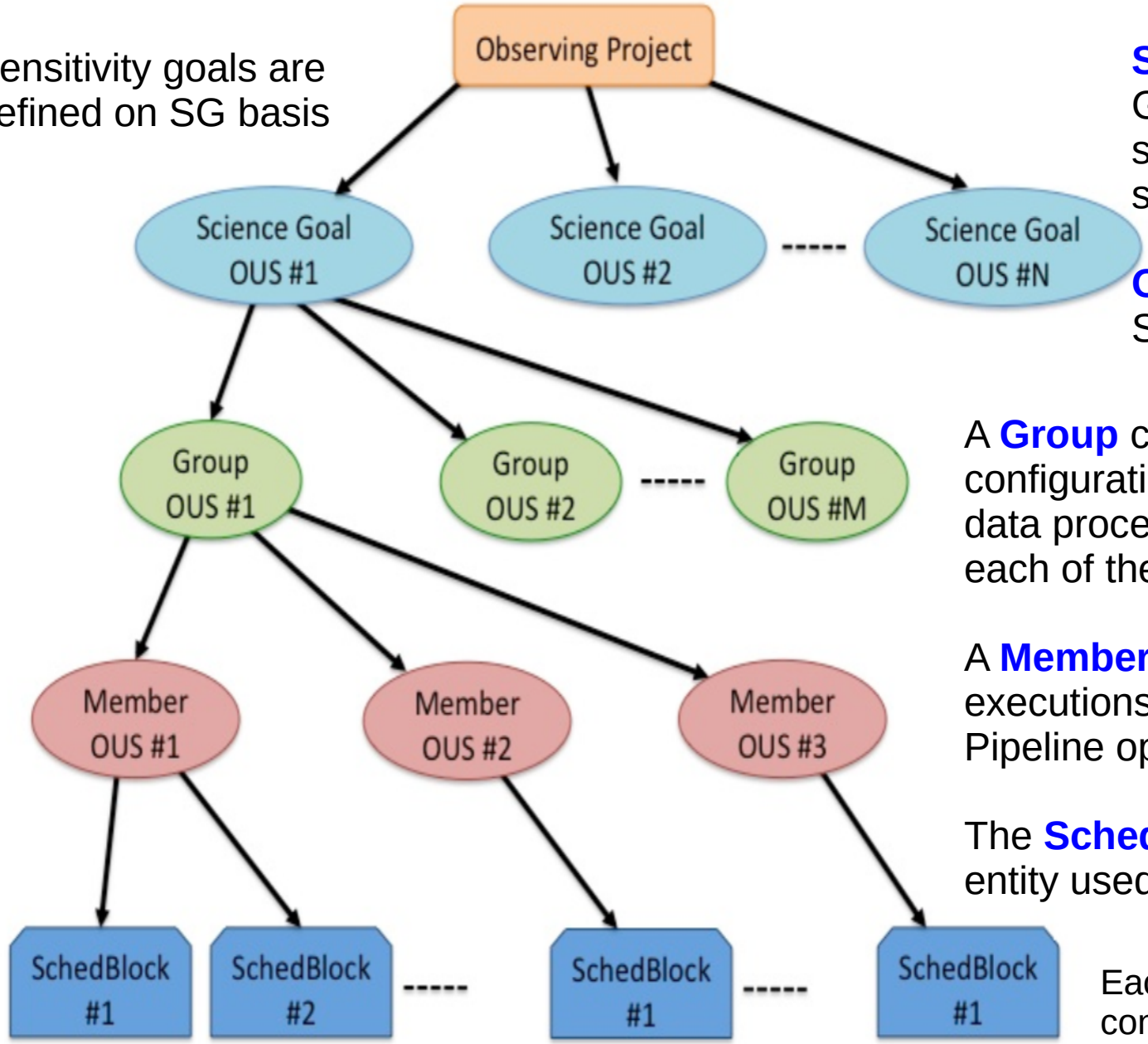
Reasons to use archived data

- Check if data are already available for a target
- Check the feasibility of a project looking for similar targets
- Retrieving information on a large sample of objects (e.g. statistics of populations, stacking, …)
- Retrieving information on a single object but with different configuration (e.g. multifrequency studies) or in different epochs (e.g. variability studies)
- Extracting unpublished information from existing data (e.g. finding additional spectral lines, targets in the same region/time of other observations,)
- **For ALMA in particular avoid the stress of competition and oversubscription**

	Proposal submission	Archive mining
Time to get data	✗	+
Amount of data	✗	+
Data homogeneity	+	✗
Adherence to idea	+	✗

Data structure

Sensitivity goals are defined on SG basis



Science goal:
Group of sources in the same sky region that share the same spectral setup

OUS= Observing Unit Set
Smallest unit for data processing

A **Group** can contain several configurations to be combined in data processing (e.g. several arrays), each of them is a Member.

A **Member** can contain multiple executions of a Scheduling Block. Pipeline operates at this level.

The **Scheduling Block** is the smallest entity used for observing

Each repetition of a Scheduling Block constitutes an **Execution Block**

Data Quality Assessment

The goal of ALMA Quality Assurance (QA) is to deliver to the PI a reliable final data product that has reached the desired control parameters outlined in the science goals, that is calibrated to the desired accuracy and free of calibration or imaging artifacts i.e. ALMA performs **science-goal-oriented service data analysis**

ALMA QA happens on 4 levels:
QA0: near-real time verification of weather and hardware issues carried out on each execution block immediately after the observation.

QA1: verification of longer-term observatory health issues like absolute pointing and flux calibration.

QA2: offline calibration and imaging (using CASA) of a completely observed MOUS. Performed by expert analysts distributed at the JAO and the ARCs with the help of a semi-automatic CASA pipeline. **Results are archived and given to the PI.**

QA3: (optional) PIs may request rereduction, problem fixes, possibly reobservation

Data format

ALMA Science Data Model (ASDM) **Final archived product from each observation**

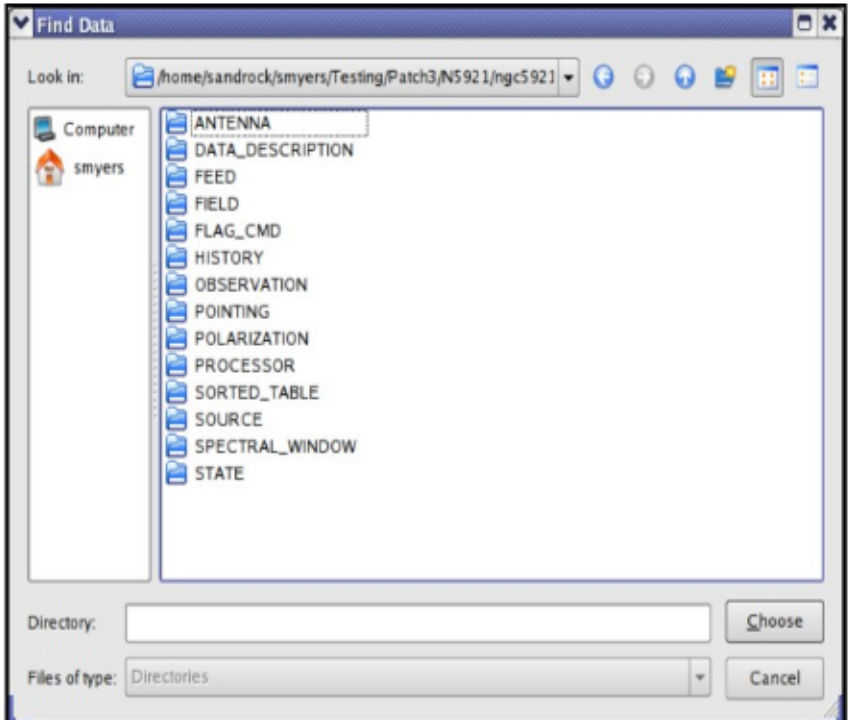
Each has an unique hexadecimal name (eg uid://A002/X2fed6/X3f).
Each contains the meta-data (headers, descriptions of the observation setup, etc), and the binary data (the raw data)

The first step of any data processing is importing the ASDM in the format suitable for the software used

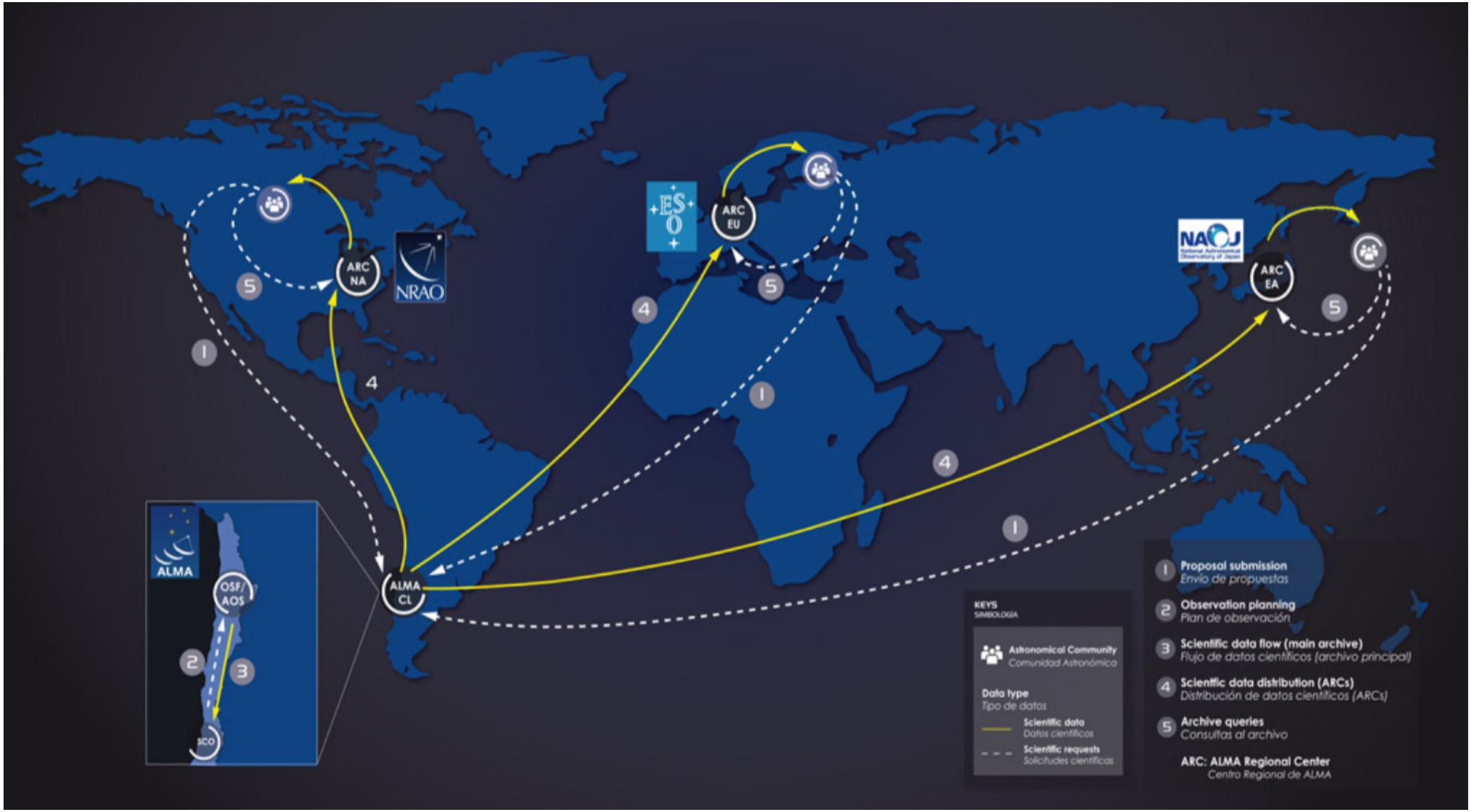
Measurement Set (MS)

Data format used in CASA

Constituted by several tables referring each other and collecting most (not all!) the information in the ASDM



ALMA data flow



Data is collected, reduced and archived.
All the “almost” raw data is archived.

Each ARC hosts an archive mirror.

The ALMA Archive - Tutorial

What is in the archive?

For each project the main deliverables are

Raw Data (in CASA readable MS), Calibration Scripts and Tables

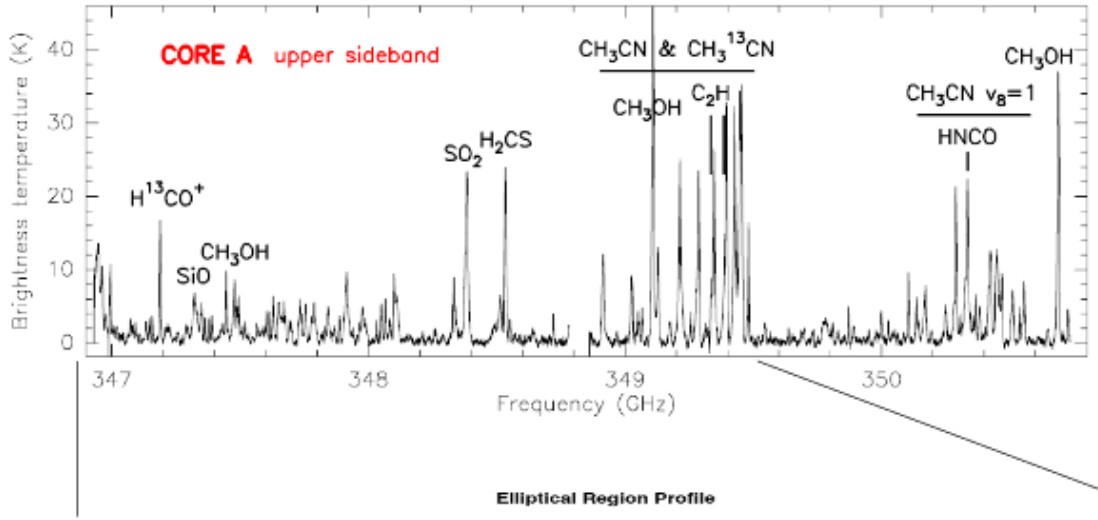
Users need to run CASA to generate the Calibrated Data.
The resulting calibrated data is considered science-ready.

Some Imaging Products are delivered too, as result of QA2 processing
(in Early Science provided on a best effort basis, not necessarily science-ready)
a) for Line Observations:
- continuum-subtracted (where needed) image cubes at the requested resolution
- a continuum image for all line-free channels (where possible)
b) for Continuum Observations:
- continuum image combining all SPWs

The main purpose is to measure the rms and verify the achievement of PI requests.

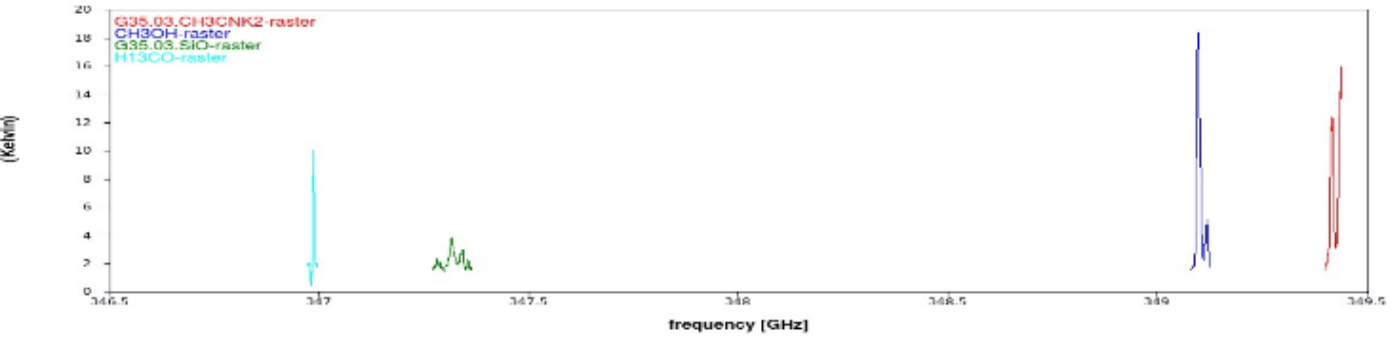
Images in the archive are provided as starting point on the way to obtain the final images and a valuable basis for archive researchers (i.e. they are not considered science-ready!!!)

What is in the archive?

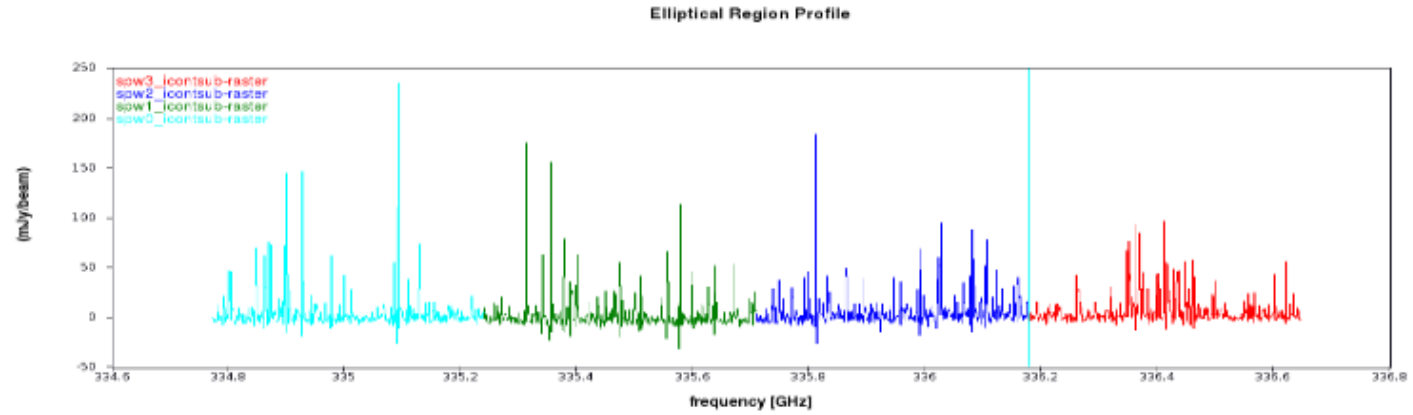


Images in the archive might cover only a fraction of the spectrum available

Spectrum observed
(and available in the raw data)



Imaged data for QA2



Different data and PI requests on different sources generate different products
In the archived images
but raw data contain the full spectral windows

What is in the packages?

When untarred, the Product Package standard directory structure contains

Untarred products only

```
|-- project_id/
| |-- sg_ouss_id/
| | |-- group_ouss_id/
| | | |-- member_ouss_id/
| | | | |-- README ..... important summary of the contents
| | | | |-- product/ ..... all the imaging products as result of QA2
| | | | |-- calibration/ ..... calibration and flagging tables
| | | | |-- qa/ ..... diagnostic plots generated during QA2
| | | | |-- script/ ..... the scripts necessary to regenerate the products
| | | | |-- log/ ..... CASA log files from QA2 calibration and imaging
```

Untarred ASDM (raw data)

```
| | | | |-- raw/ ..... for calibration move it in the products folder at the
                         right level  (follow the README)
```

In publications with ALMA data!

Acknoweledgement Statement:

“This paper makes use of the following ALMA data: ADS/JAO.ALMA#2011.0.01234.S. ALMA is a partnership of ESO (representing its member states), NSF (USA) and NINS (Japan), together with NRC (Canada), NSC and ASIAA (Taiwan), and KASI (Republic of Korea), in cooperation with the Republic of Chile. The Joint ALMA Observatory is operated by ESO, AUI/NRAO and NAOJ.”

(Can be found in the SP, on the ‘ALMA-Data’ page)

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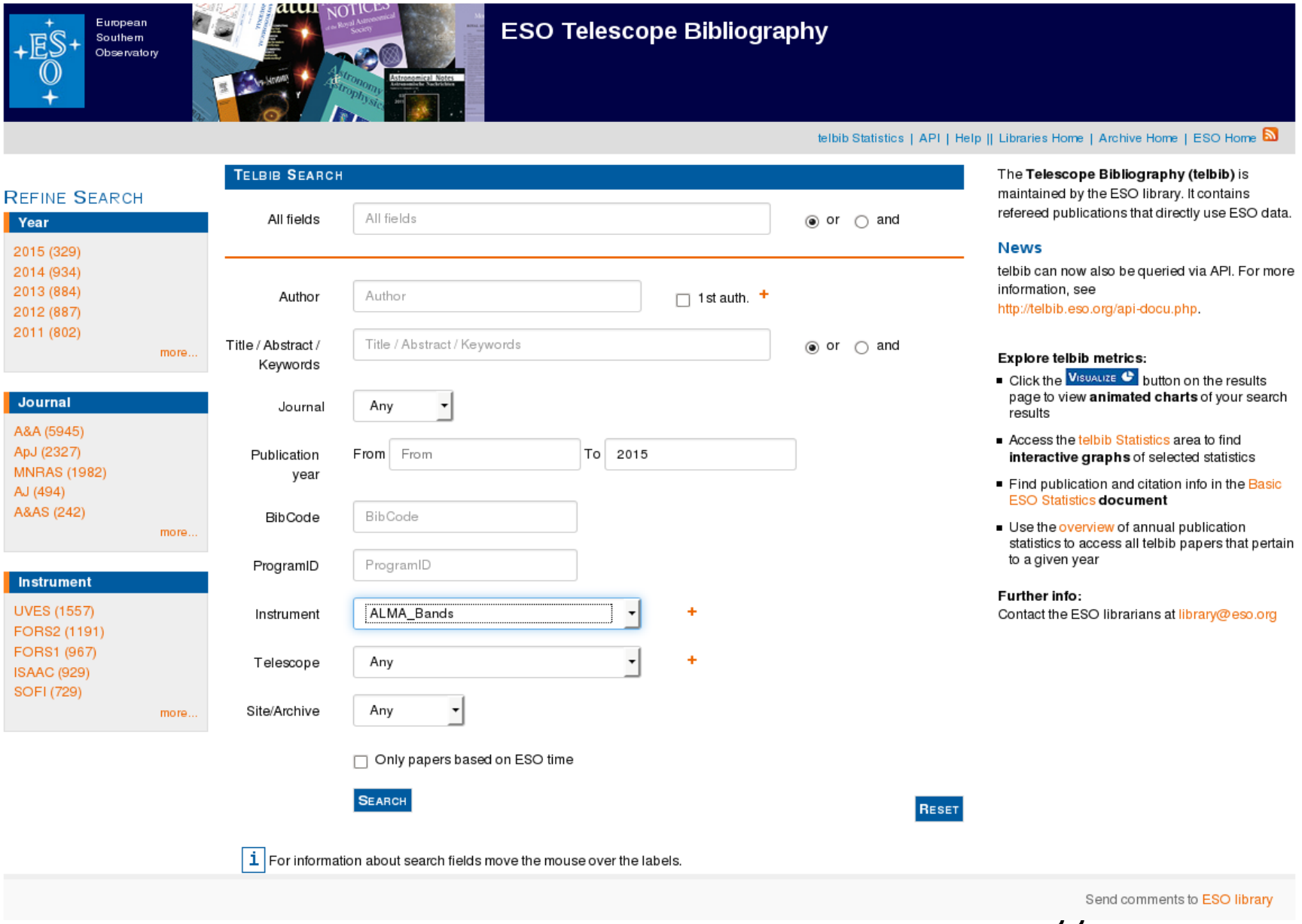
The ESO telbib

http://telbib.eso.org/



The ESO telbib

REFINE SEARCH

Year

2015 (40)
2014 (97)
2013 (65)
2012 (20)

Journal

ApJ (121)
A&A (54)
MNRAS (16)
Nature (11)
PASJ (6)
more...

Instrument

ALMA_Bands (222)
LABOCA (14)
XSHOOTER (6)
FORS2 (5)
SHFI (5)
more...

NEW SEARCH | EDIT SEARCH | VISUALIZE | EXPORT

Results **1** - **25** of **222** found for (instrument:ALMA_Bands) « Previous Next »

YEAR ▼	AUTHOR	TITLE	INSTRUMENTS	ACCESS TO DATA	FULLTEXT ADS
2015	Sakai, Yusuke et al.	An ALMA Imaging Study of Methyl Formate (HCOOCH3) in Torsionally Excited States toward Orion KL	***ALMA_Bands***	2011.0.00009.SV	2015ApJ...803...97S
2015	Brouillet, N. et al.	Antifreeze in the hot core of Orion. First detection of ethylene glycol in Orion-KL	***ALMA_Bands***	2011.0.00009.SV	2015A&A...576A.129B
2015	Saito, Toshiki et al.	ALMA Multi-line Observations of the IR-bright Merger VV 114	***ALMA_Bands***	2011.0.00467.S	2015ApJ...803...60S
2015	Olofsson, H. et al.	ALMA view of the circumstellar environment of the post-common-envelope-evolution binary system HD 101584	***ALMA_Bands***	2012.1.00248.S	2015A&A...576L..15O
2015	Sakai, Takeshi et al.	ALMA Observations of the IRDC Clump G34.43+00.24 MM3: DNC/HNC Ratio	***ALMA_Bands***	2011.0.00656.S	2015ApJ...803...70S
2015	Gullberg, B. et al.	The nature of the [C II] emission in dusty star-forming galaxies from the SPT survey	***ALMA_Bands***	2011.0.00957.S, 2011.0.00958.S, 2012.1.00844.S	2015MNRAS.449.2883G
2015	Rathborne, J. M. et al.	A Cluster in the Making: ALMA Reveals the Initial Conditions for High-mass Cluster Formation	***ALMA_Bands***	2011.0.00217.S	2015ApJ...802..125R

What to do after download?

```
[massardi@arcbl02 member.uid___A001_X120_X102]$ cd script/
[massardi@arcbl02 script]$ casapy-setup 42.2.30986-pipe-1-64b
[massardi@arcbl02 script]$ casapy --pipeline
...

CASA <2>: execfile('scriptForPI.py')
```

1) Untar the packages

2) Look at weblog and/or QA reports

3) Read the README file and follow the instructions: typically

   - Launch the correct CASA (with pipeline) version in the script folder
   - Run the “Script_for_PI” to generate the calibrated MS
   - Run the “Script_for_Imaging” to regenerate the images

4) Edit the scripts where needed according to your purposes

CASA

CASA (Common Astronomy Software Applications) is the designated data analysis package for ALMA and the JVLA.

Used for all offline processing of ALMA data.

CASA is developed by NRAO, ESO, and NAOJ (under NRAO management);
for details see http://casa.nrao.edu
e.g., Petry et al., 2012, "Analysing ALMA data with CASA", ADASS XXI, ASP conf., 461, 849

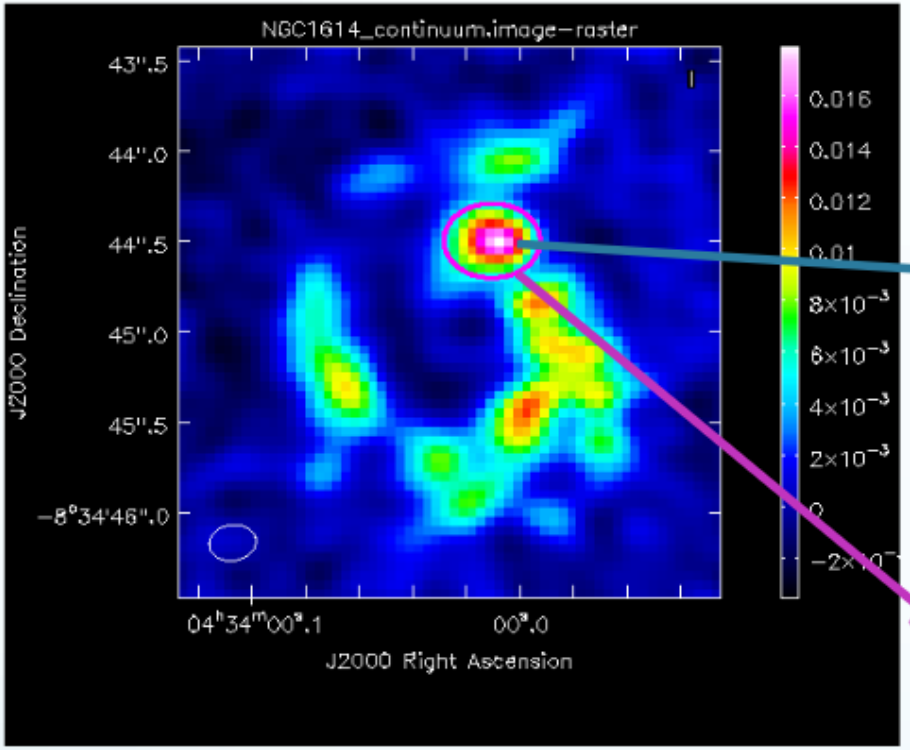
Latest release is CASA 4.7.1 .

The ALMA pipeline is an optional add-on of CASA, not available in all the past CASA versions.

CASA deals with data files in the Measurement Set (MS) structure.

- Tutorial on CASA
  - ssh -CX scheduler@ira.inaf.it
  - User: almauser#
  - Pwd: alma#passwd

Peak flux and flux density



In each pixel we measure the integrated flux in the synthesized beam (Jy/beam)

Cursors

NGC1614_continuum.image-raster

+0.017917 Jy/beam Pixel: 186 193 0 0
04:34:00.008 -08.34.44.498 I -7.38555 km/s (topo/radio velocity)

The flux density is the integrated flux over the selected area (Jy)

Regions

Properties | Statistics | Fit | File | Histogram

NGC1614_continuum.image

Stokes	Velocity	Frame	Doppler
I	-7.38555km/s	LSRK	RADIO
Frequency	**BrightnessUnit**	**BeamArea**	**Npts**
6.79564e+11	Jy/beam	23.3895	70
Sum	**FluxDensity**	**Mean**	**Rms**
6.656472e-01	2.845927e-02	9.509246e-03	1.019464e-02
Std dev	**Minimum**	**Maximum**	**region count**
3.701442e-03	3.815803e-03	1.791702e-02	1

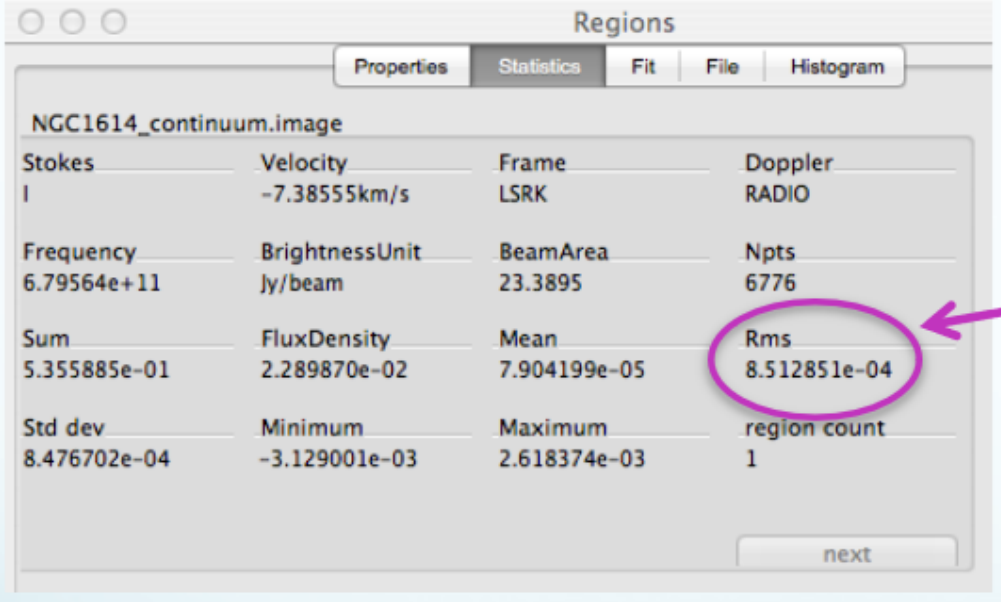
next

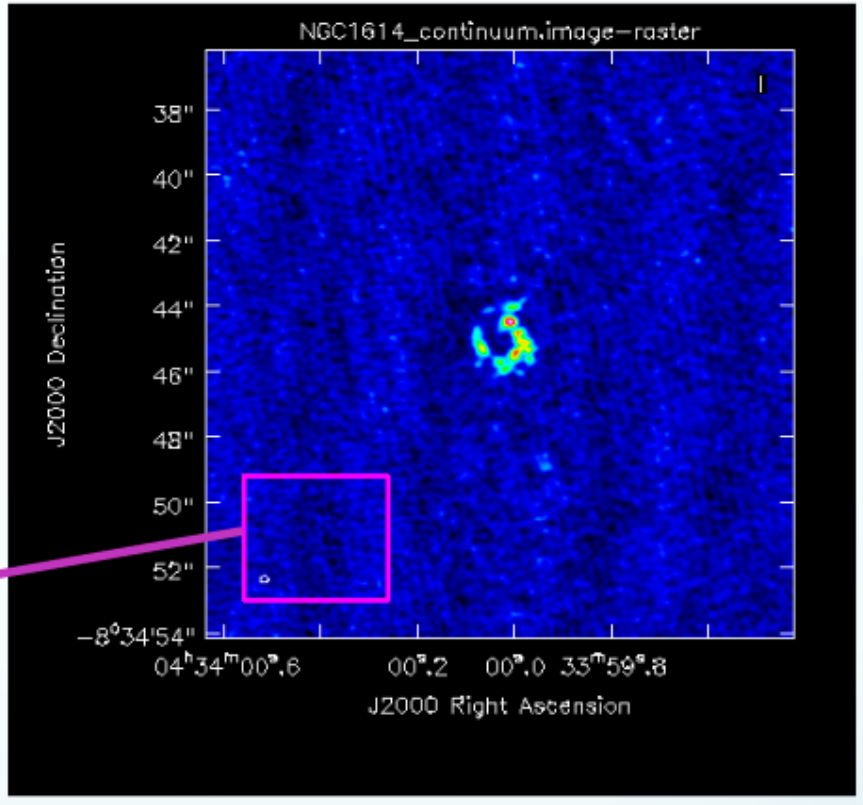
We measure: $F \pm 0.10 \times F$

for a 10% flux calibration accuracy

Image noise and flux errors

Measure the rms (Jy/beam) in an empty region:

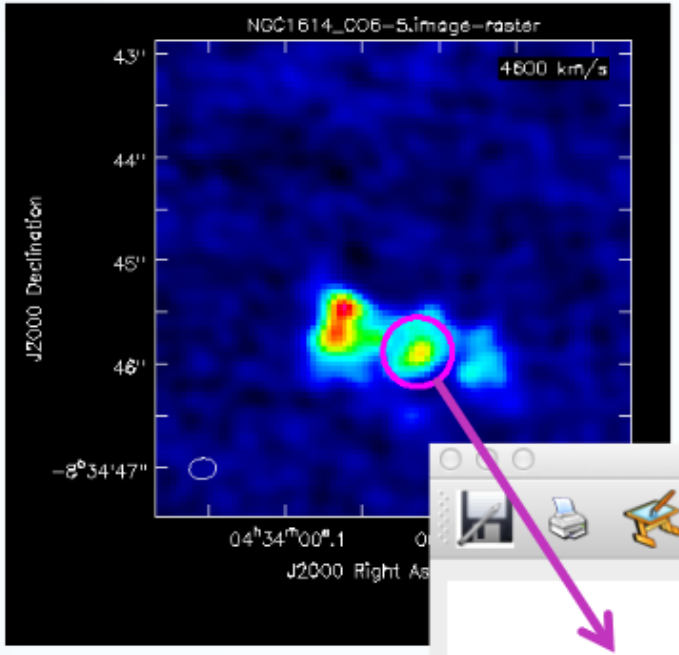


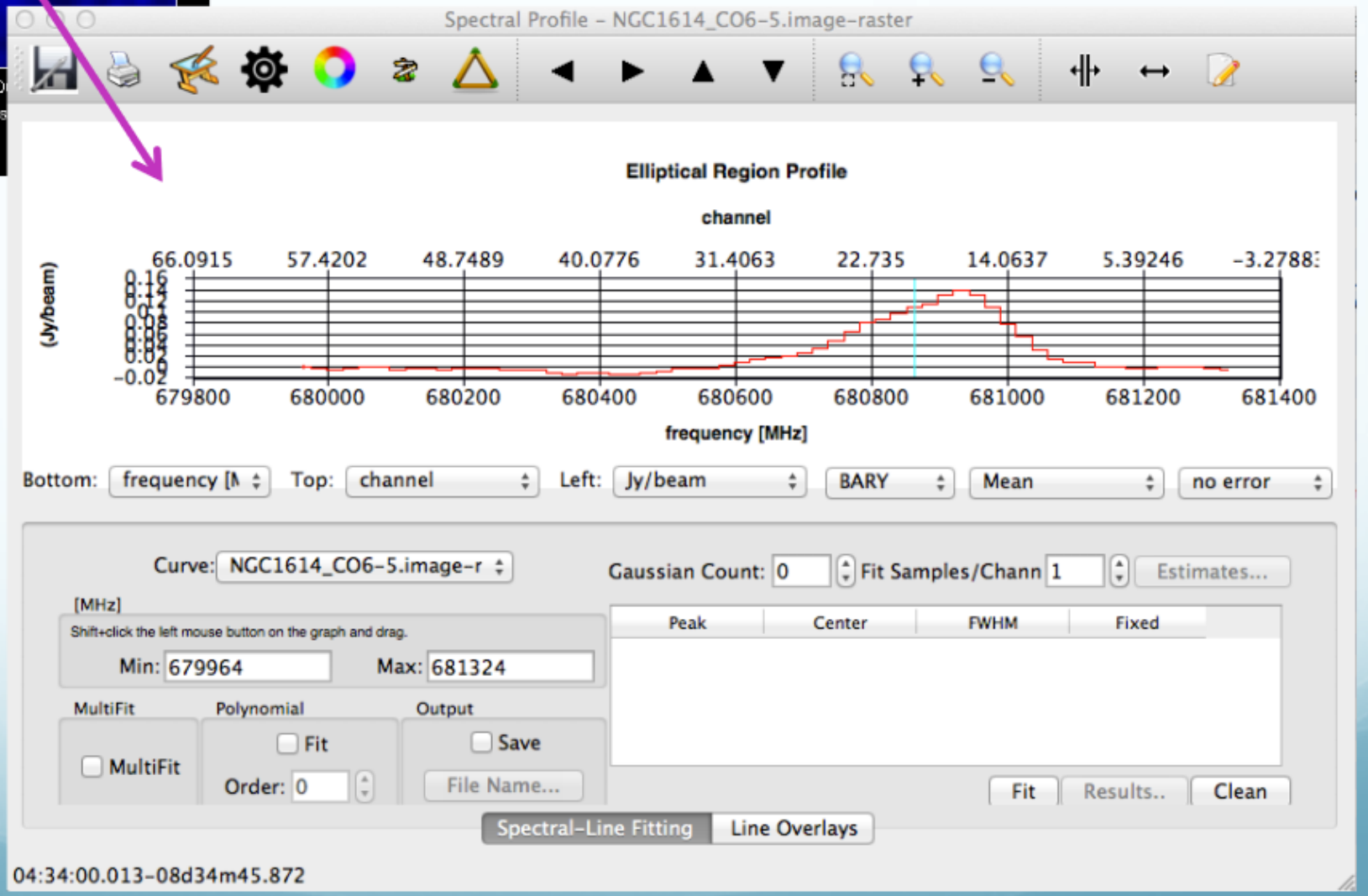


The uncertainty in the measured flux is:

$$\sqrt{(\text{rms})^2 + (0.10 \times F)^2}$$

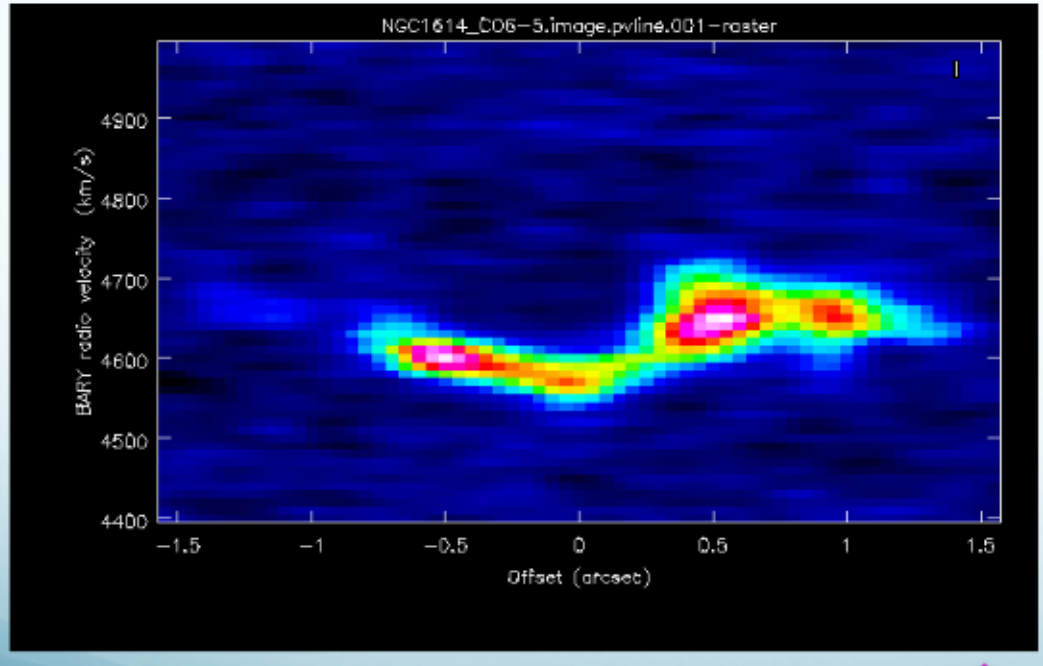
The spectral viewer

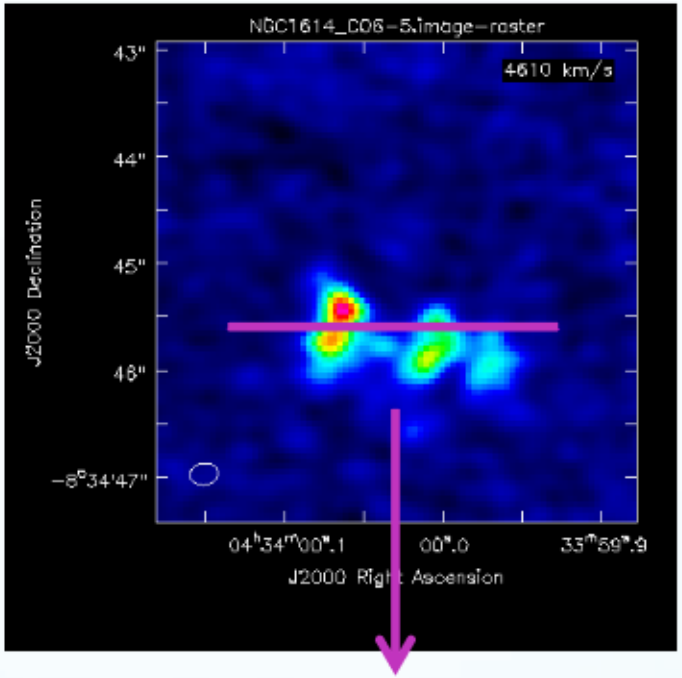


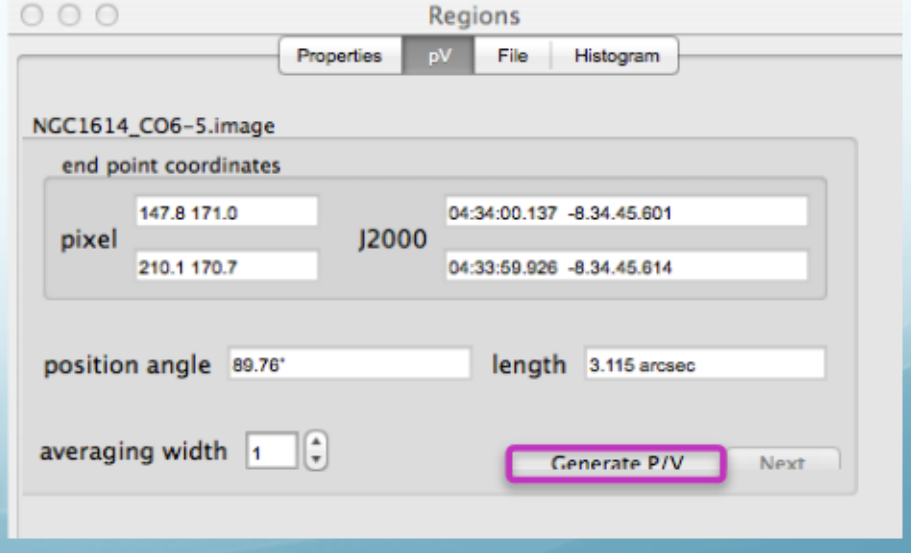


Position-velocity diagrams

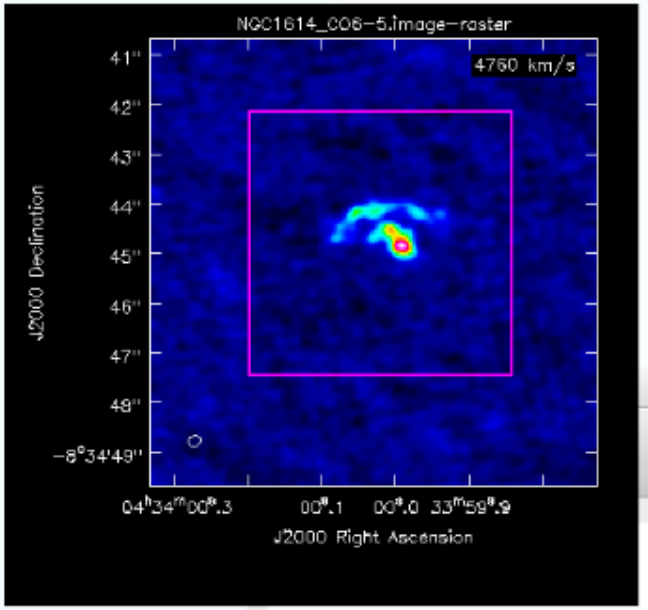
Slice along the selected direction,
to inspect the velocity distribution

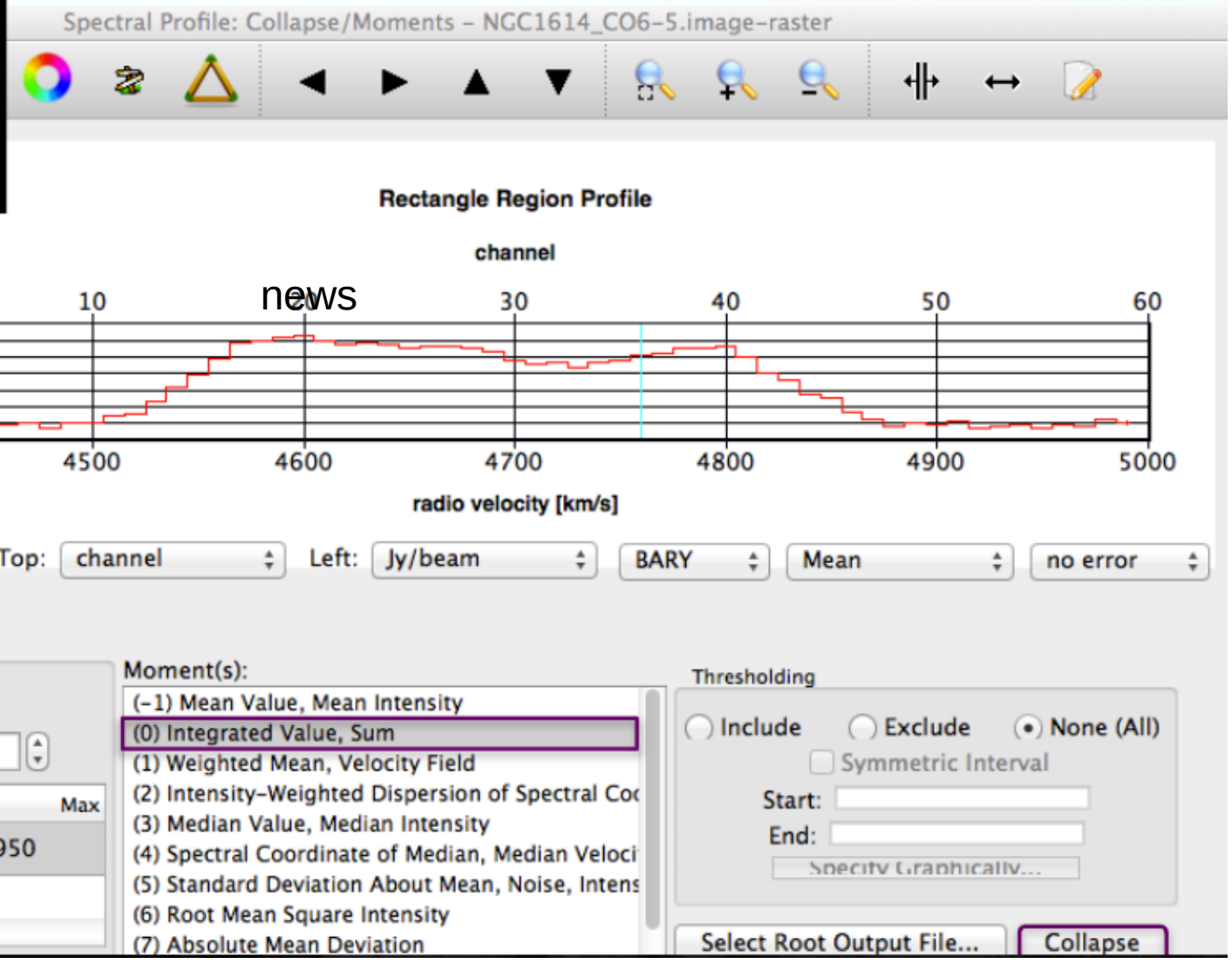






Moment maps

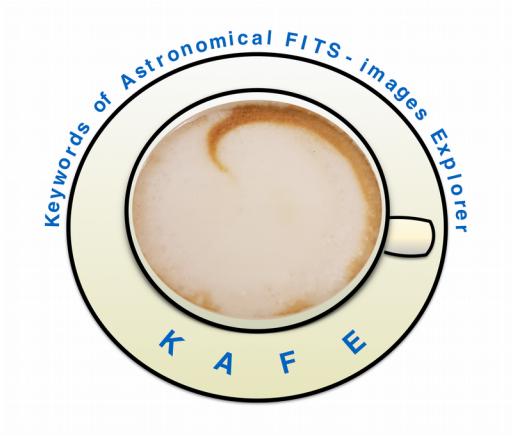




news

KAFE tutorial

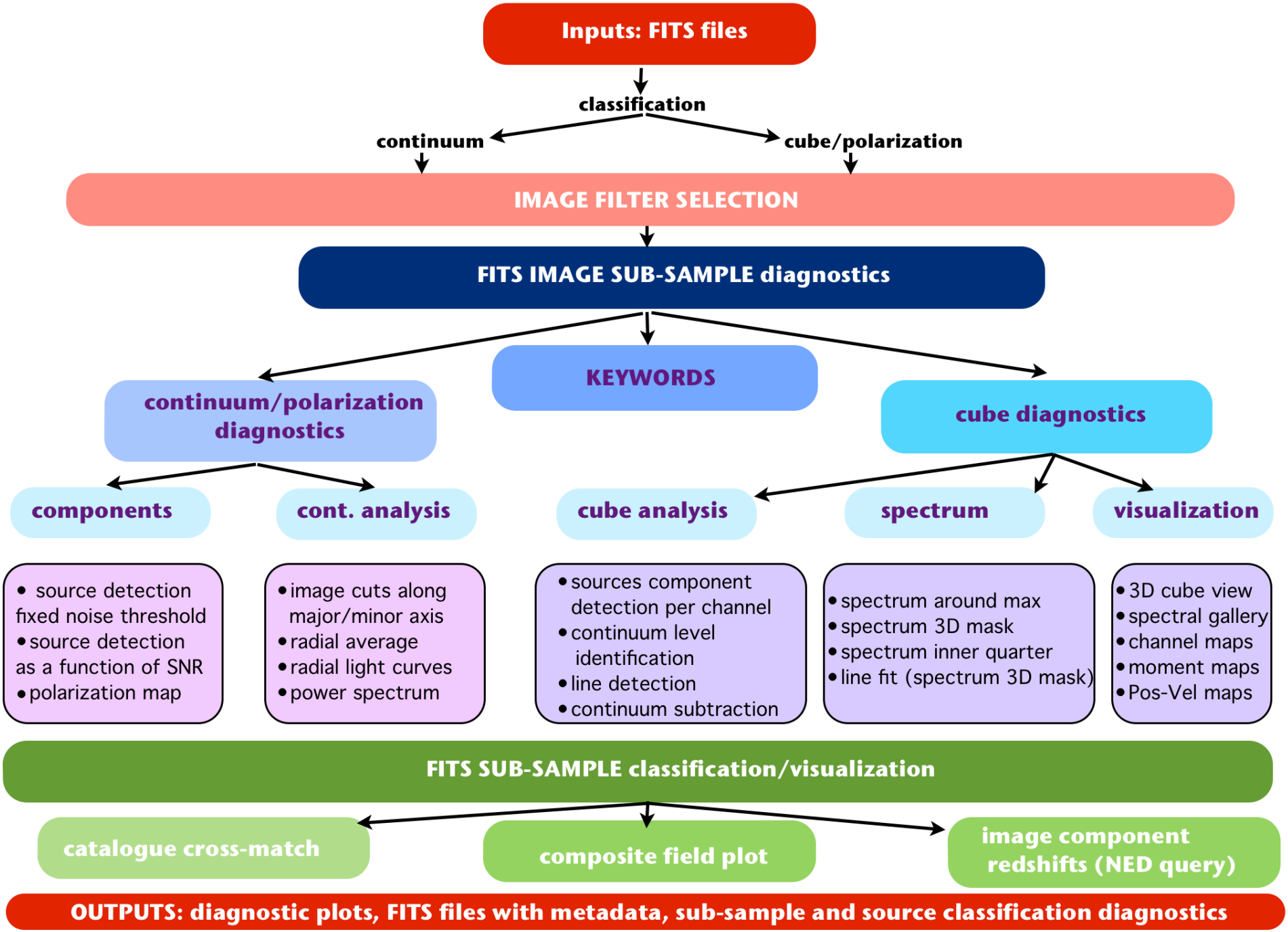
KAFE:
Keywords of Astronomical FITS-images Explorer

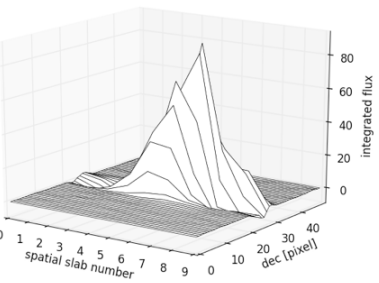


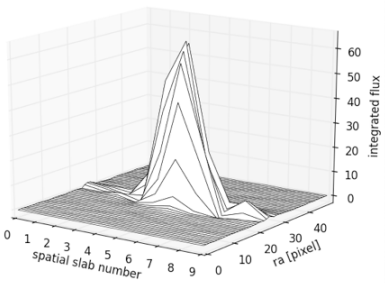
Burkutean et al. submitted

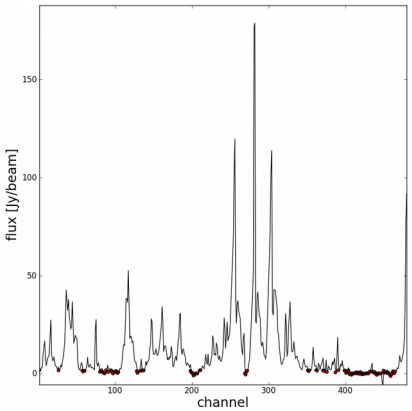
AIMS:

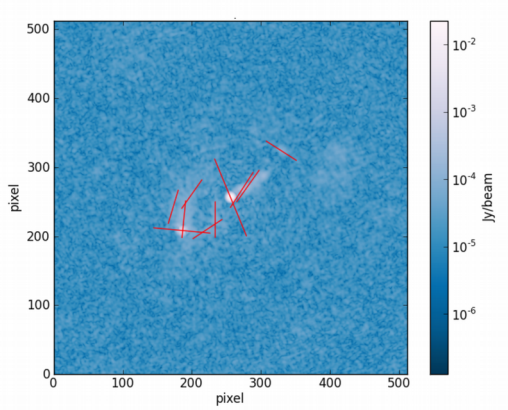
- provide advanced image analysis diagnostic plots in the spatial, spectral and temporal domain for user input FITS images
- offer AKF (Liuzzo et al. subm) keyword computation
- provide catalogue cross-matching
- minimal user input required (just tick the boxes) - the image computations and the required parameter settings are fully automated

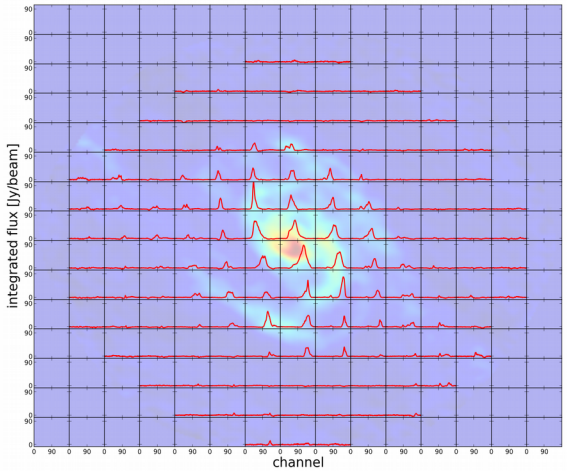

Inputs: FITS files
classification
continuum
cube/polarization
IMAGE FILTER SELECTION
FITS IMAGE SUB-SAMPLE diagnostics
KEYWORDS
continuum/polarization diagnostics
cube diagnostics
components
cont. analysis
cube analysis
spectrum
visualization
• source detection fixed noise threshold
• source detection as a function of SNR
• polarization map
• image cuts along major/minor axis
• radial average
• radial light curves
• power spectrum
• sources component detection per channel
• continuum level identification
• line detection
• continuum subtraction
• spectrum around max
• spectrum 3D mask
• spectrum inner quarter
• line fit (spectrum 3D mask)
• 3D cube view
• spectral gallery
• channel maps
• moment maps
• Pos-Vel maps
FITS SUB-SAMPLE classification/visualization
catalogue cross-match
composite field plot
image component redshifts (NED query)
OUTPUTS: diagnostic plots, FITS files with metadata, sub-sample and source classification diagnostics

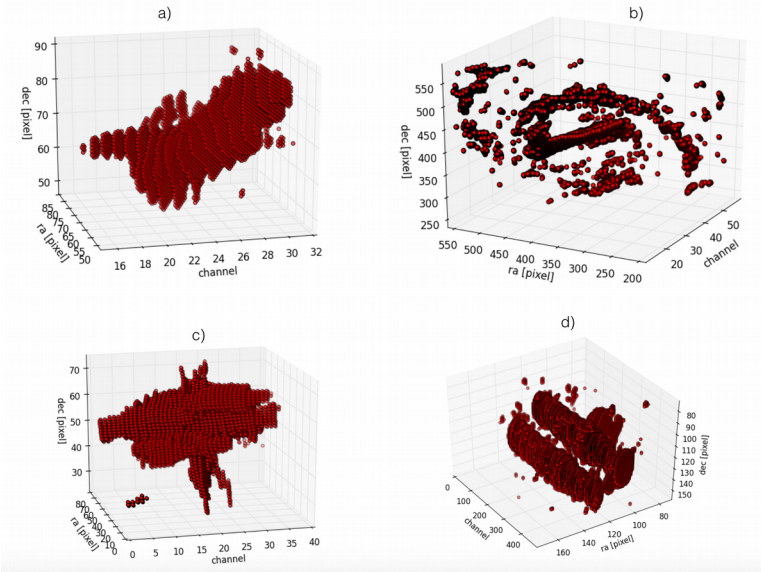

integrated flux
spatial slab number
dec [pixel]

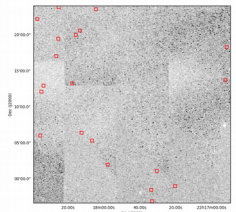

integrated flux
spatial slab number
ra [pixel]

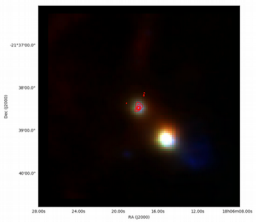

flux [Jy/beam]
channel

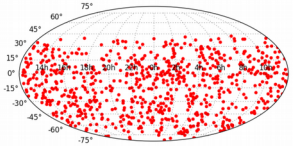

pixel
Jy/beam

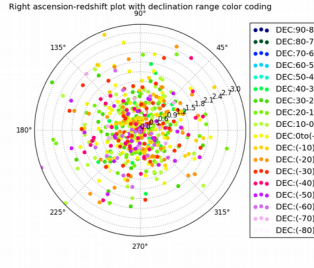

integrated flux [Jy/beam]
channel

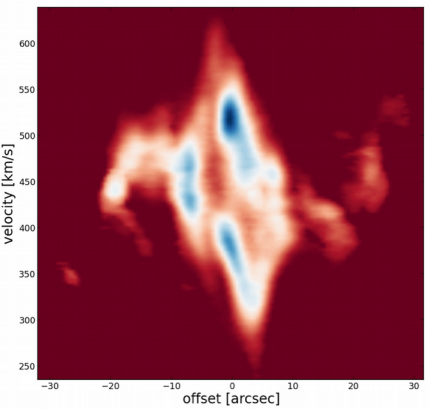

a)
b)
c)
d)
dec [pixel]
ra [pixel]
channel

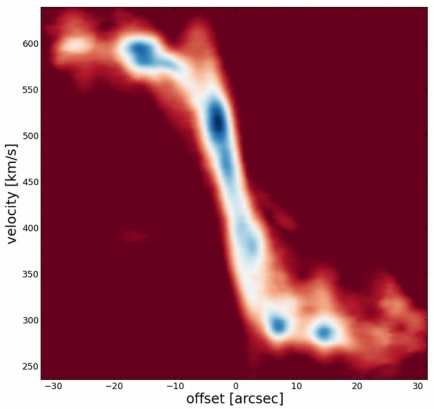


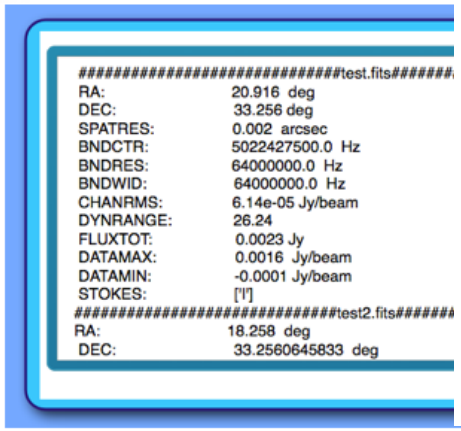


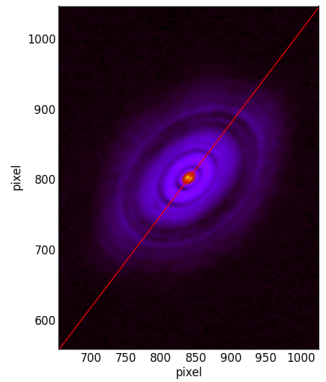


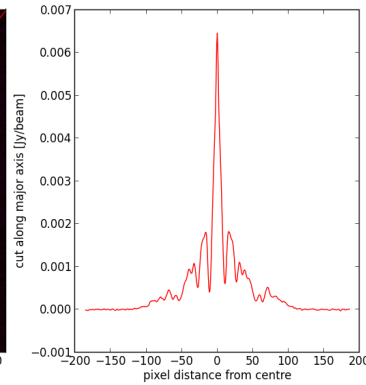

Right ascension-redshift plot with declination range color coding

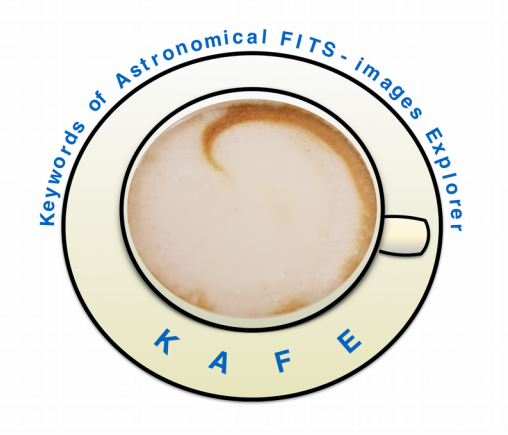

velocity [km/s]
offset [arcsec]


velocity [km/s]
offset [arcsec]


##########test.fits##########
RA: 20.916 deg
DEC: 33.256 deg
SPATRES: 0.002 arcsec
BNDCTR: 5022427500.0 Hz
BNDRES: 64000000.0 Hz
BNDWID: 64000000.0 Hz
CHANRMS: 6.14e-05 Jy/beam
DYNRANGE: 26.24
FLUXTOT: 0.0023 Jy
DATAMAX: 0.0016 Jy/beam
DATAMIN: -0.0001 Jy/beam
STOKES: ['I']
##########test2.fits##########
RA: 18.258 deg
DEC: 33.2560645833 deg


pixel
pixel


cut along major axis [Jy/beam]
pixel distance from centre



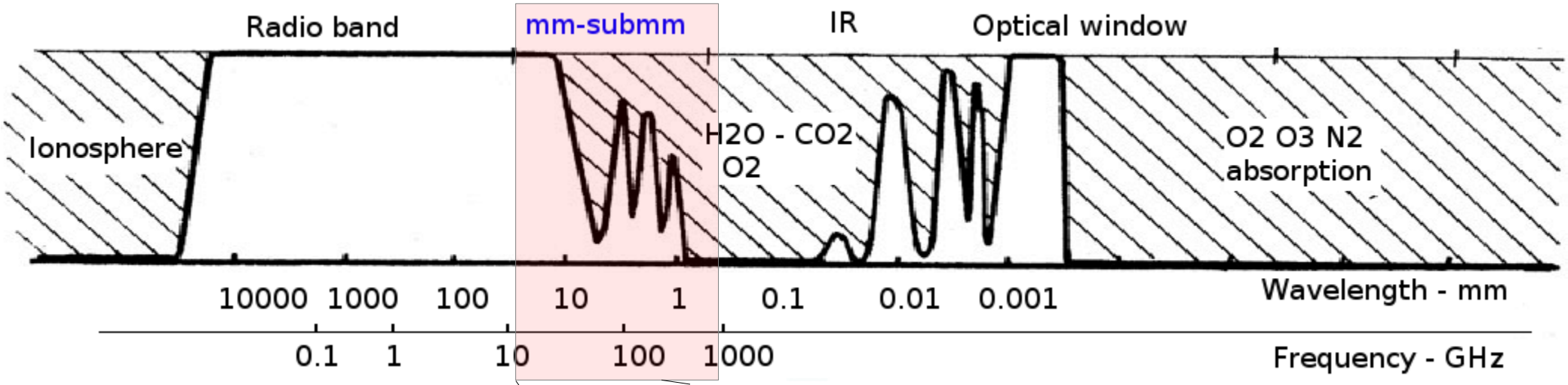
User cases for ALMA proposal preparation:

- inspect archival images through the advanced analysis plots to assess their scientific potential and support your own proposals
- create samples based on the catalog cross-match option and/or the uniform AKF keyword definitions

Please write to kafe@ira.inaf.it for access information to the web interface and the KAFE cookbook.

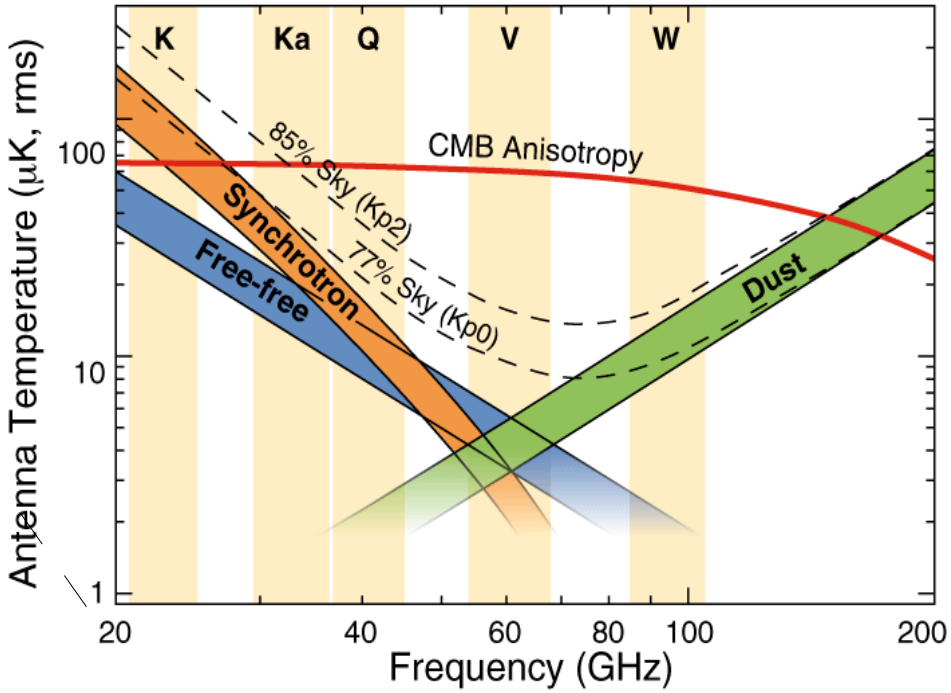
Summary

The signals



The (sub)mm band ranges between 30-1000 GHz

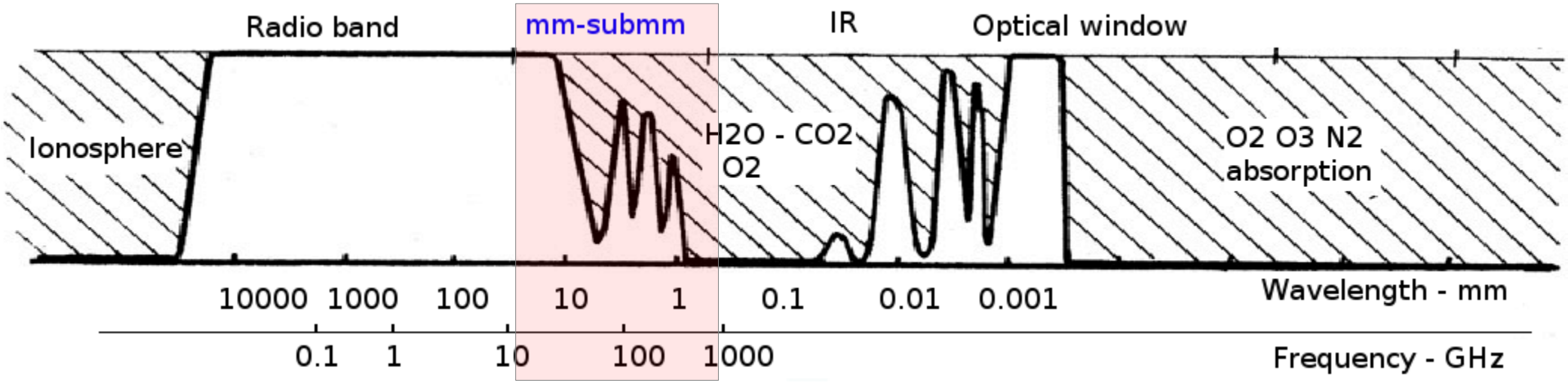
(Sub)mm signals: **synchrotron, dust emission, molecular lines, CMB**



The warm dust emitting at far–IR wavelengths is mostly heated by the UV-radiation field of young massive stars in star forming regions.

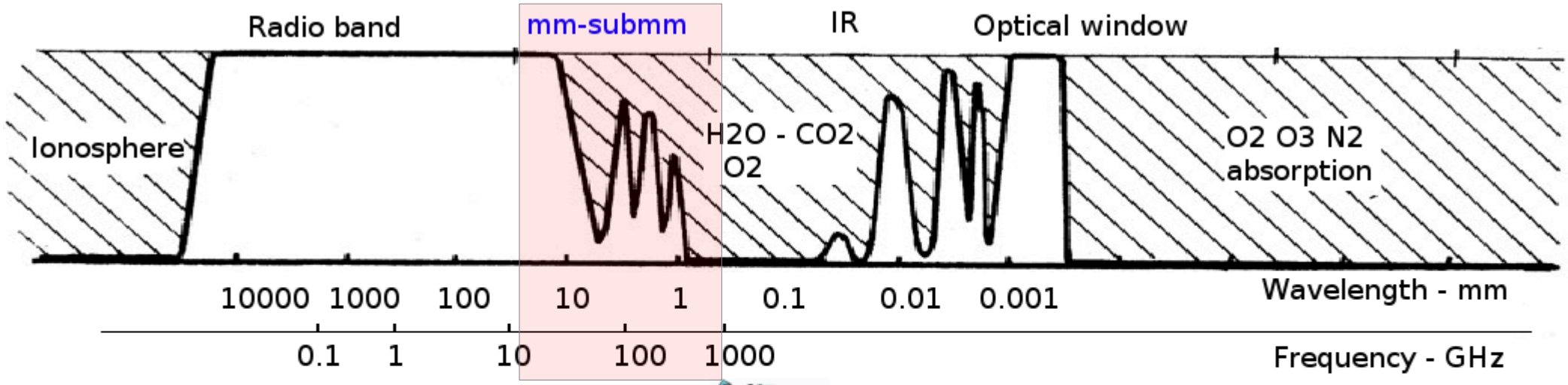
The far infrared luminosity is considered good tracer of star formation in galaxies.

The signals



The spectrum of each molecular cloud in the submm is rich of rotational molecular transition ladders and atomic fine structure lines, which shapes and relative abundances can be used to trace physical and dynamical properties of the ISM and the mechanisms of SF and AGN activity In the local and high-z Universe.

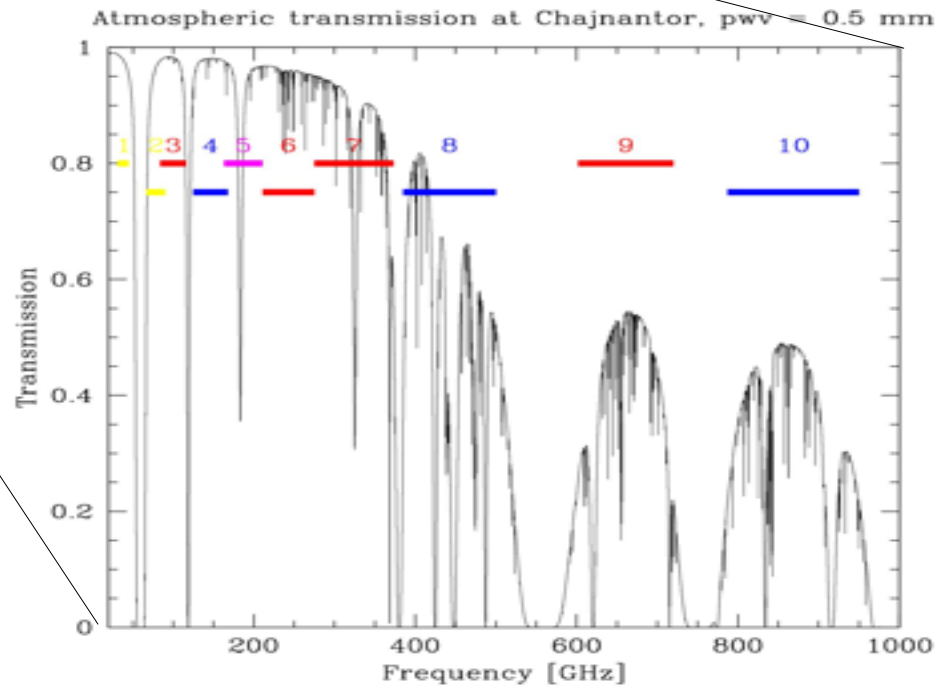
The instruments



Requirements: Excellent weather
Accurate antennas
Sensitive receivers

ALMA is a 50x12m + 12x7m+ 4x12m array operating in 10 bands between 30 and 1000 GHz in extremely dry site, reconfigurable to cover baselines up to 16km (and in the future mm-VLBI)

Reaches encompassed sensitivity and resolution thanks to the instrumental properties



Why should I go (sub)mm?

Why shouldn't I go (sub)mm?

Enjoy the new ALMA era!

ALMA science portal: almascience.eso.org

ALMA archive: almascience.eso.org/alma-data/archive

ALMA documents and tools: almascience.eso.org/documents-and-tools

Italian ARC node: www.alma.inaf.it

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