

Atacama Large Millimeter Array

CASS Radio Astronomy Summer School 2017



Dr. Katie Jameson
RSAA-ANU

CARMA

(Combined Array for Millimeter Astronomy)



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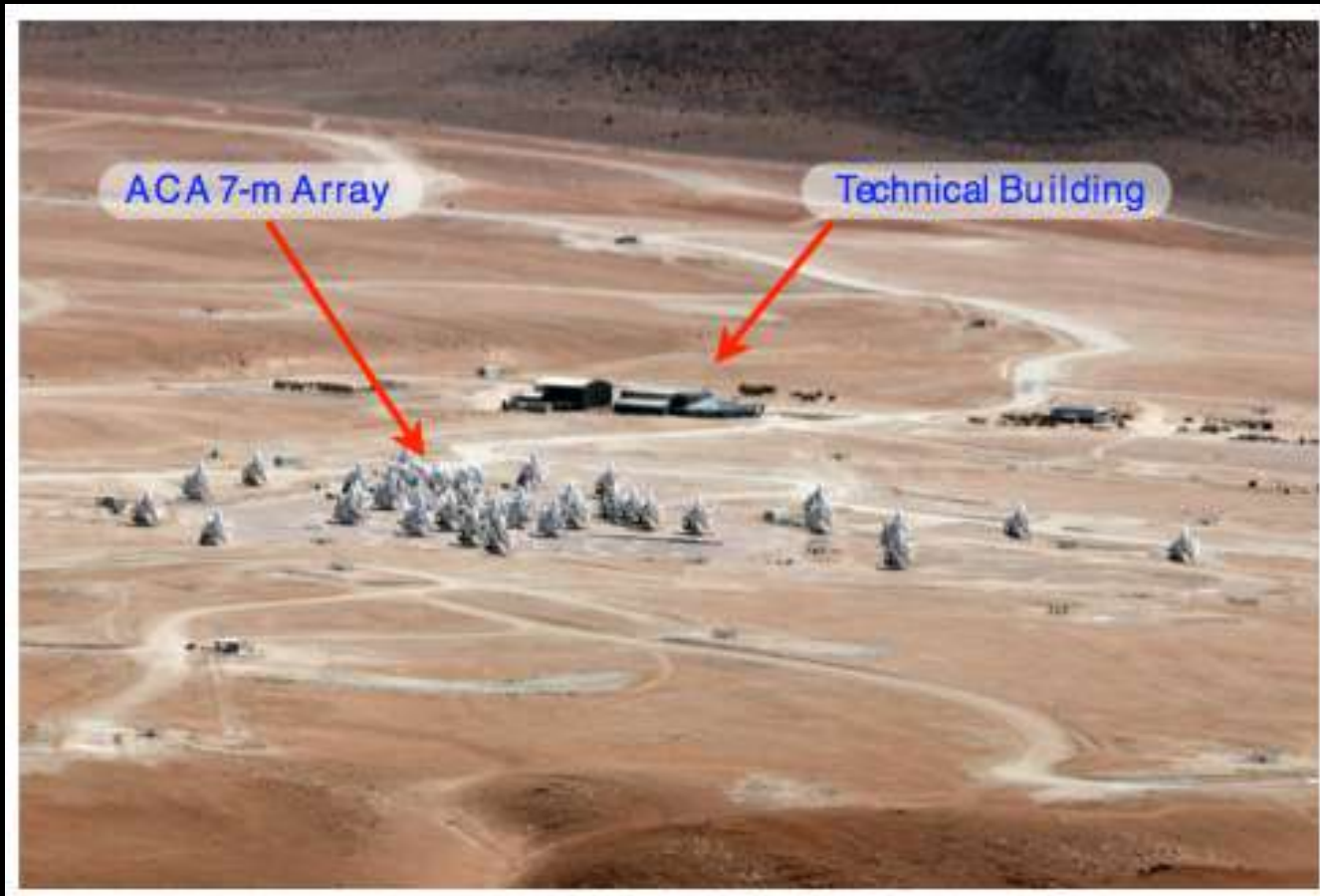


12-m Array



one of the more extended array configurations with max baseline $\sim 16\text{km}$

Atacama Compact Array (ACA) and Total Power (TP)



mm vs. cm observations: know your enemy



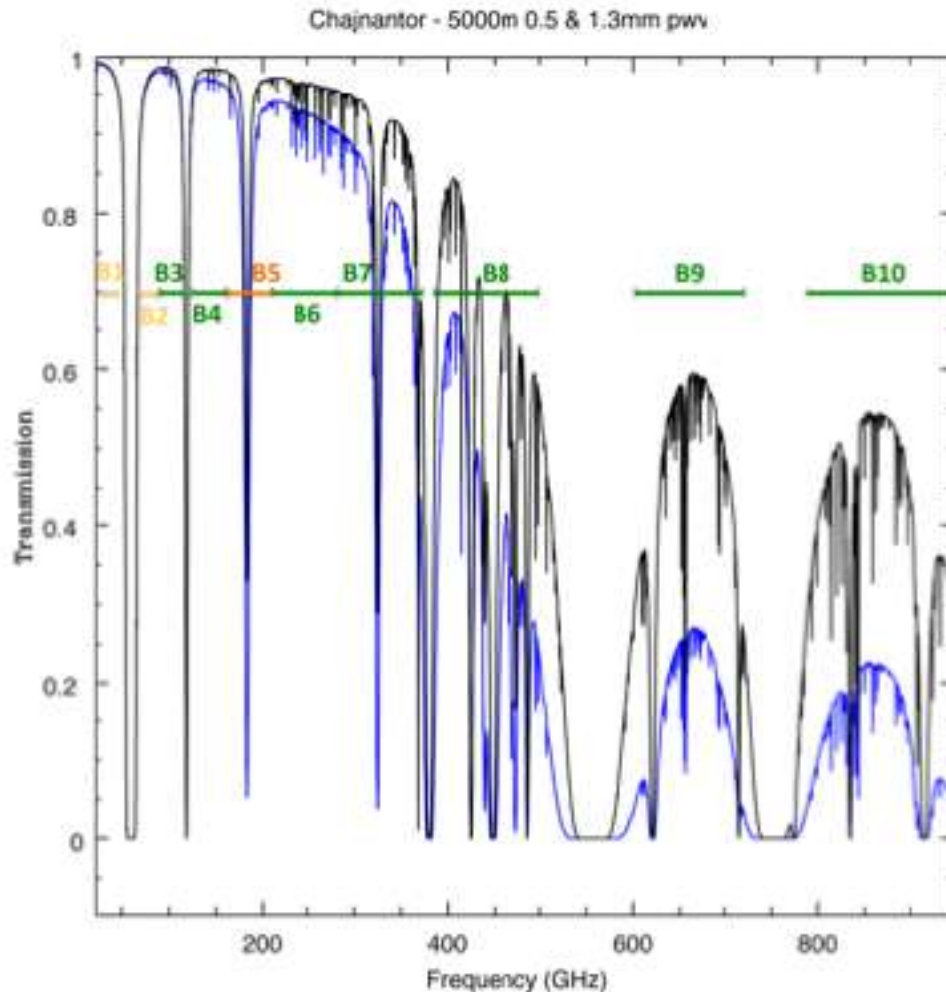
mm



cm

ALMA Bands:

Atmospheric Windows at Chajnantor



Band 3: 3mm

^{12}CO , ^{13}CO , C^{18}O (2-1)

Band 6: 1mm

^{12}CO (1-0)

^{13}CO , C^{18}O (1-0), CS (2-1)

ALMA at Full Operation

(not quite there, yet...)

	Specification
<i>Number of Antennas</i>	<i>50×12 m (12-m Array), plus 12×7 m & 4×12 m (ACA)</i>
<i>Maximum Baseline Lengths</i>	<i>0.15 - 16 km</i>
<i>Angular Resolution (")</i>	<i>$-0.2'' \times (300/\nu \text{ GHz}) \times (1 \text{ km} / \text{max. baseline})$</i>
<i>12 m Primary beam (")</i>	<i>$\sim 20.6'' \times (300/\nu \text{ GHz})$</i>
<i>7 m Primary beam (")</i>	<i>$\sim 35'' \times (300/\nu \text{ GHz})$</i>
<i>Number of Baselines</i>	<i>Up to 1225 (ALMA correlators can handle up to 64 antennas)</i>
<i>Frequency Coverage</i>	<i>All atmospheric windows from 84 GHz - 950 GHz (with possible extension to ~30 GHz)</i>
<i>Correlator: Total Bandwidth</i>	<i>16 GHz (2 polarizations × 4 basebands × 2 GHz/baseband)</i>
<i>Correlator: Spectral Resolution</i>	<i>As narrow as $0.008 \times (300/\nu \text{ GHz}) \text{ km/s}$</i>
<i>Polarimetry</i>	<i>Full Stokes parameters</i>

ALMA Resolutions

Table 1: *Receiver Bands and Selected Properties*

Cycle 4 Receiver Bands					Most Compact			Most Extended		
Band	Frequency (GHz)	Wavelength (mm)	Primary Beam (FOV: °)	Continuum Sensitivity (mJy/beam)	Angular Resolution (")	Approx. Max. Scale (") (see P.24)	Spectral Sens. ΔT_{line} (K)	Angular Resolution (mas)	Approx. Max. Scale (") (see P.24)	Spectral Sens. ΔT_{line} (K)
3	84-116	2.6-3.6	73-53	0.095	4.4-3.2	34-25	0.075	78-57	0.93-0.68	230
4	125-163	1.8-2.4	49-38	0.13	3.0-2.3	23-18	0.10	53-41	0.63-0.48	310
6	211-275	1.1-1.4	29-22	0.13	1.8-1.4	14-11	0.11	31-24	0.37-0.29	315
7	275-373	0.8-1.1	22-16	0.24	1.35-0.99	10.6-7.8	0.19	43-32	0.48-0.35	180
8	385-500	0.6-0.8	16-12	0.46	0.96-0.74	7.6-5.8	0.36	53-41	0.46-0.36	115
9	602-720	0.4-0.5	10-8.5	2.3	0.61-0.51	4.8-4.0	1.73	34-29	0.30-0.25	525
10	787-950	0.3-0.4	7.8-6.5	5.2	0.47-0.39	3.7-3.1	4.0	26-22	0.23-0.19	1240

ALMA Cycle 5

21 March 2017 Cycle 5 Call

20 April 2017 Proposal Deadline

Results announced July 2017

Observations begin Oct. 2017

- Same proposal type as Cycle 4
 - ≤ 50 hrs 12-m array time, ≤ 150 ACA stand-alone time
 - Typically 5 hrs 12-m array time, but encouraging > 10 hrs
 - Large Programs: > 50 and ≤ 600 hrs 12-m, > 150 and ≤ 450 ACA
 - VLBI in Band 3 (3 mm) and Band 6 (1.3 mm)

ALMA Cycle 5

Anticipated Capabilities

- Number of Antennas:
 - ≥ 43 antennas in 12-m array
 - ≥ 10 7-m antennas (for short baselines)
 - 3 12-m antennas for single-dish maps in ACA
- Receiver Bands 3, 4, 5, 6, 7, 8, 9, 10 (3 mm – 0.35 mm)
- 12-m Array Configurations
 - Max. baselines range from 0.15 km to 16 km ($\sim 4''$ to $0.02''$)
 - Max. baseline for Bands 8, 9, 10 = 3.6 km
 - Max. baseline for Band 7 = 8.5 km
 - Max. baseline for Bands 3, 4, 5, 6 = 16 km

ALMA Cycle 5

Anticipated Capabilities

- Non-standard Modes:
 - Band 8, 9, 10 and Band 7 with max. baseline > 5 km
 - Longest baseline of 16 km in all Bands
 - Polarization, spectral scans, frequency switching
 - Solar observations
 - VLBI
- New in Cycle 5:
 - Band 4 polarization
 - Band 5

Management of ALMA

Joint ALMA Operations (JAO)
Headquarters in Santiago, Chile



ALMA Regional Centers (ARCs)

North American ALMA Science Center (NAASC) at NRAO Charlottesville, U.S.

EU-ARC at ESO Garching, Germany

East Asian ARC (EA-ARC) at NAOJ Tokyo, Japan



Astronomers from non-partner countries may choose any ARC for support

Time Availability

33.75% North America

33.75% Europe

22.5% East Asia

10% Chile

Open Skies Proposals:

- Assigned to a panel and treated identically
- Unaffiliated time charged to PI's or Co-PI's will be split to 4 regions according to time shares up to 5% of total ALMA time (any over 5% will be charged to NA)
- PI of Open Skies proposal selects the ARC they wish to use for support

Cycle 4 Results

- ~1600 proposals from 30 countries
- 50% increase in time requested from Cycle 3
 - Requested ~12,000 hrs for 12-m (out of 3000)
 - ~6000 hrs for ACA (out of 1800)



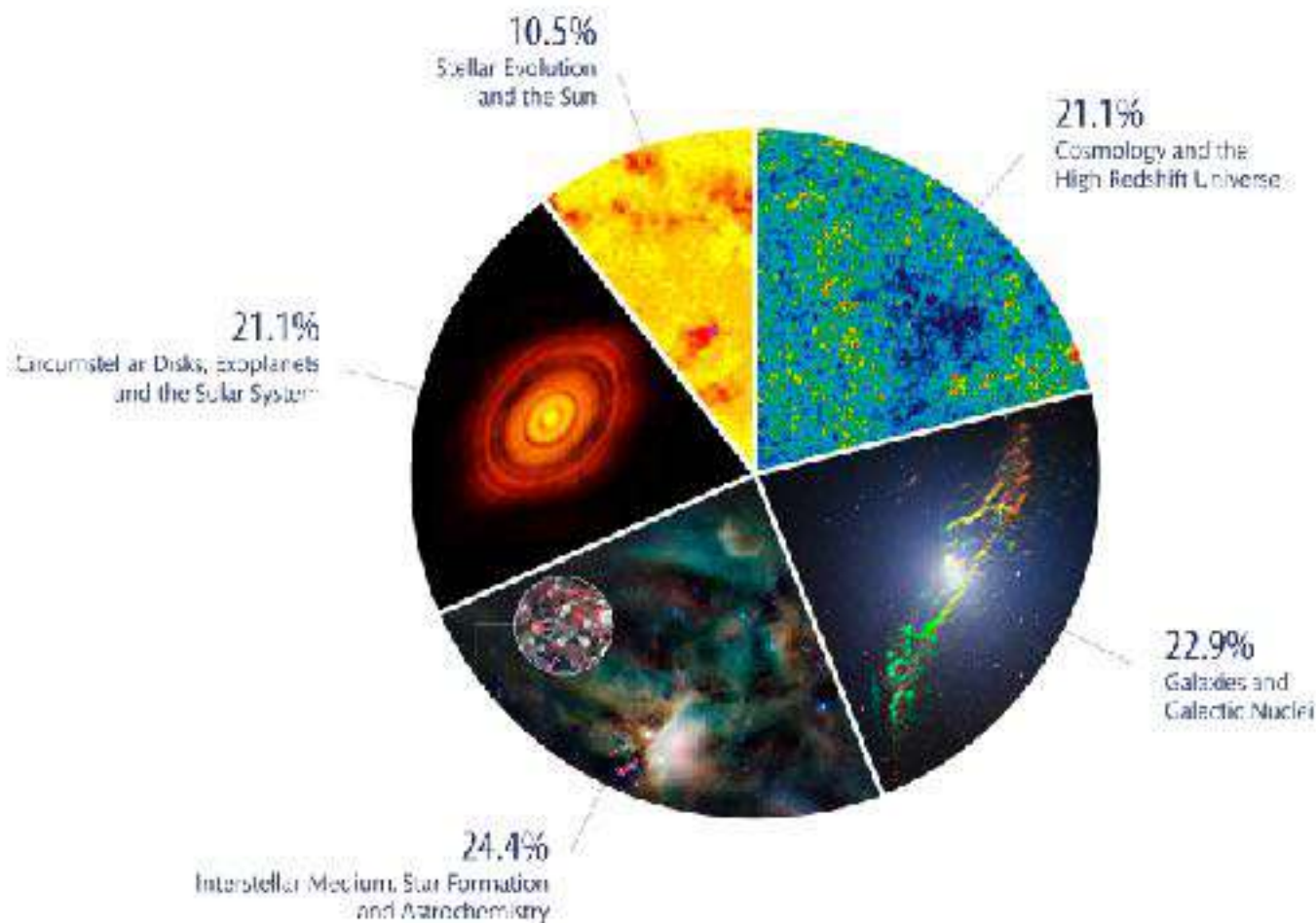
Cycle 4 Results

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- 50% increase in time requested from Cycle 3
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Cycle 4 Results

Accepted Proposals by Science Categories



ALMA Observing Tool (AOT)

ALMA Observing Tool (CycledPhase4 (u3)) - Spying on our Neighbors: Peering into Low-Metallicity Molecular Clouds in the Small Magellanic Cloud (2015-1-00581.5 last submitted 2015-04-23 07:32:54)

File Edit View Tool Search Help

Project Structure: Proposal Program

Editors: Spectral Spreads Technical Justification

Enter a Technical Justification for this Science Goal, paying special attention to the parameters reproduced below.

Sensitivity

Requested RMS over 2,000 km/s is 13.08 mJy For a peak flux density of 350.00 mJy, the S/N is 23.3

Achieved RMS over the total 2.576 GHz bandwidth is 135.71 uJy For a continuum flux density of 10.00 mJy, the achieved S/N is 29.8

For a peak line flux of 350.00 mJy, the achieved S/N over 1/3 of the source line width (3.00 km/s / 3 = 1.00 km/s) is 18.0

Line width / bandwidth used for sensitivity (3.00 km/s / 2,000 km/s) = 0.150

Note that the bandwidth used for sensitivity is longer than 1/3 of the linewidth.
The S/N achieved for a resolution element that allows the line to be resolved will be lower than that reported.

Spectral Dynamic Range (continuum flux / line rms) 0.73

Justify your requested RMS and resulting S/N for the spectral line and/or continuum observations.

For line observations also justify the bandwidth used by the sensitivity calculation.

We have optimized our science for a total investment of ~1 hour of 12m-brady time, including overheads, to produce a 149-pointing mosaic map of Y22. We have designed the experiment to cover part of the area spectroscopically mapped with Herschel in (01) and (01). This area also has spectroscopic maps from Spitzer IRS (Sandstrom et al, 2012) and deep continuum imaging from

Overview

Contextual Help

- Please ensure you and your co-Is are registered with the [ALMA Science Portal](#)
- Create a new proposal by either:
 - Clicking on the [New Proposal](#) link in the toolbar
 - Or clicking on this [link](#)
- Click on the [Proposal](#) tree node and complete the relevant fields.

Phase 1: Science Proposal



Click on the overview steps to view the contextual help



ALMA Observing Tool (AOT)

The screenshot shows the ALMA Observing Tool (AOT) interface. The title bar reads "ALMA Observing Tool (CycledPhase1 (u3)) - Spying on our Neighbors: Peering into Low-Metallicity Molecular Clouds in the Small Magellanic Cloud [2015-100581.5 last submitted 2015-04-23 07:32:54]". The menu bar includes "File", "Edit", "View", "Tools", "Search", and "Help". The "Project Structure" pane on the left shows a tree view with "Proposal" expanded, containing "Planned Observing" and "ScienceGoal (Map 12CO2-)", with "Technical Justification" selected. The "Editors" pane on the right shows the "Technical Justification" tab. The main text area contains the following content:

Enter a Technical Justification for this Science Goal, paying special attention to the parameters reproduced below.

Sensitivity

Requested RMS over 2,000 km/s is 13.08 mJy For a peak flux density of 350.00 mJy, the S/N is 23.3

Achieved RMS over the total 2.576 GHz bandwidth is 135.71 uJy For a continuum flux density of 10.00 mJy, the achieved S/N is 29.8

For a peak line flux of 350.00 mJy, the achieved S/N is 23.3

Line width / bandwidth used for sensitivity (1.00)

Note that the bandwidth used for sensitivity is large. The S/N achieved for a resolution element that allows the full use of the received data is lower than that reported.

Spectral Dynamic Range (continuum flux / line rms) 0.73

Justify your requested RMS and resulting S/N for the spectral line and/or continuum observations.

For line observations also justify the bandwidth used by the sensitivity calculation.

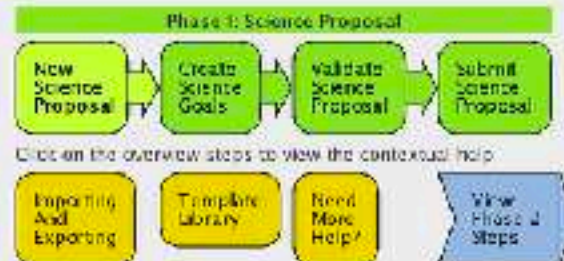
We have optimized our science for a total investment of ~1 hour of 12m-brady time, including overheads, to produce a 149-pointing mosaic map of Y22. We have designed the experiment to cover part of the area spectroscopically mapped with Herschel in (01) and (02). This area also has spectroscopic maps from Spitzer IRS (Sandstrom et al, 2012) and deep continuum imaging from

Justify need for ACA and TP

Overview

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 - ◆ Clicking on the icon in the toolbar
 - ◆ Or clicking on this [link](#)
- Click on the tree node and complete the relevant fields.





**ALWAYS SUBMIT ISSUES TO
THE HELP DESK**

<https://help.almascience.org>



WHEN IN DOUBT, ASK THE HELP DESK

<https://help.almascience.org>

ALMA Archive

<http://almascience.eso.org/aq/>



ALMA Science Archive Query

Query Form

Results Table

Search

Reset

[Query Help](#)

Position

Source name (Resolver)
Source name (ALMA)
RA Dec
Galactic
Angular resolution
Largest angular scale
Field of view

Energy

Frequency
Bandwidth
Spectral resolution
Band

Time

Observation date
Integration time

Polarisation

Polarisation type

Observation

Line sensitivity (10 km/s)
Continuum Sensitivity
Water vapour

Project

Project code
Project title
PI name
Proposal authors
Project abstract
Publication count
Science keyword

Publication

Bibcode
Title
First author
Authors
Abstract
Year

Options

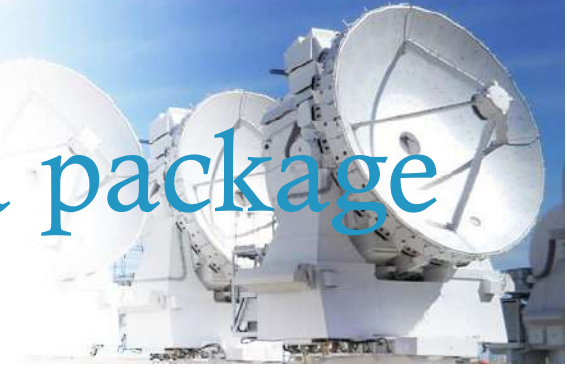
View:

- ☒ raw data
- ☐ project
- ☐ publication
- ☐ public data only
- ☒ science observations only

More details at the Science Portal Documentation:

<https://almascience.nrao.edu/alma-data/archive>

The scripts in the PI data package



Example of directory structure after unpack:

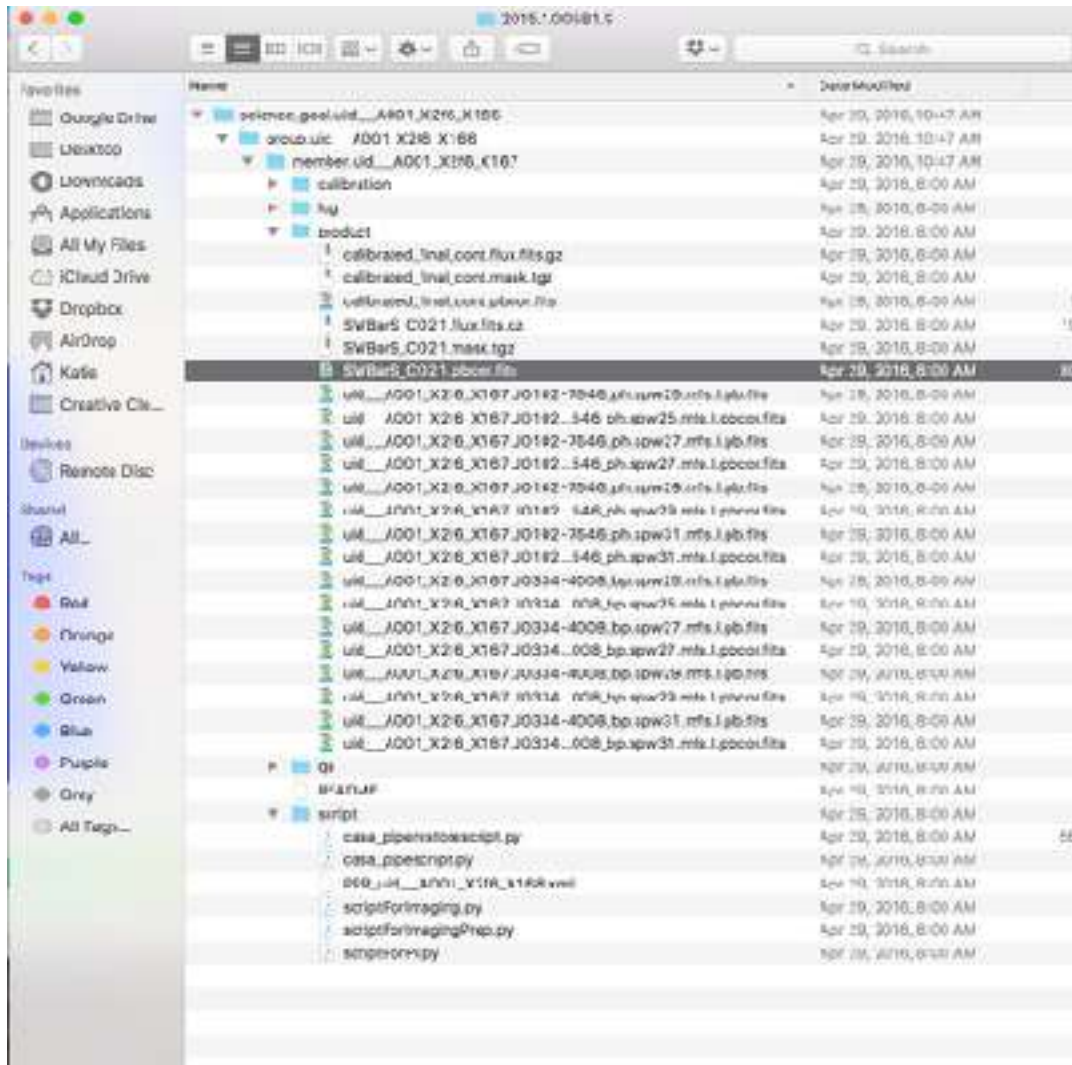
```
2012.1.01234.S/science_goal.uid___A001_X12345_X123/  
group.uid___A002_X6789ab_X6789member.uid___A002_Xcdef1_X234/
```

With subdirectories:

```
calibrated calibration log product qa raw script README
```

More details at the Science Portal Documentation:
<https://almascience.nrao.edu/alma-data/archive>

Data from the ALMA Archive



Data will have been imaged in the velocity resolution you specified in your sensitivity calculation in your proposal

Science Goal, SB, EB, OUS...?

PI defines **Science Goals** in the Observing Tool (OT)



Execution creates

ExecBlock 1

ExecBlock 2

...

ExecBlock n

until required sensitivity reached

Scheduling Blocks (SBs) in Observation Unit Sets (OUSs)

- SB is a prototype of an atomic (c.a. 0.5h) observation to reach a science goal

Credit: D. Petry (ESO)

ALMA QA



QA consists on 3 (+1) steps:

- ❑ **QA0** At the time of data acquisition: *Atmosphere, Antennas, Front-ends, Connectivity, Back-ends...*
- ❑ **QA1** Monitor slowly varying array performance parameters: *arrays, antennas, calibration sources*



If OUS completed

- ❑ **QA2** Confirm that Science Goal was met;
request additional data and iterate if not
(implies **full calibration + generation of standard science products**)



If QA2 PASS

MemberOUS data is delivered to the PI



If problem reported by PI

- ❑ **QA3** re-reduction of the data, possibly replacing products in the archive

ALMA Data Processing



TWO PROCESSING MODELS COEXIST:

1. Semi-automatic calibration and imaging:

- The analyst edits the output of a script generator and processes data.

2. Data calibration with automated pipeline + script generator for imaging:

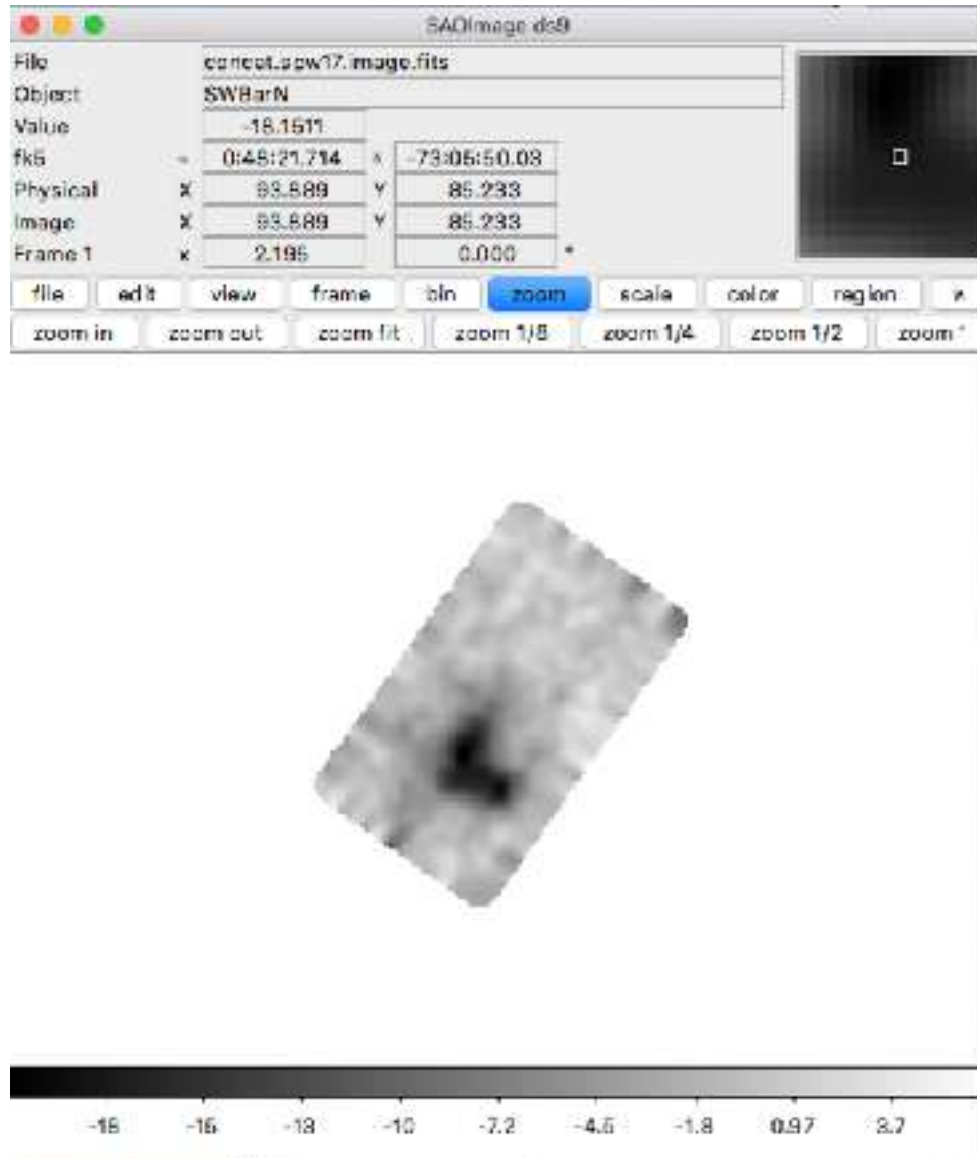
- Calibration is performed by the pipeline and analysts take care of imaging.

FUTURE:

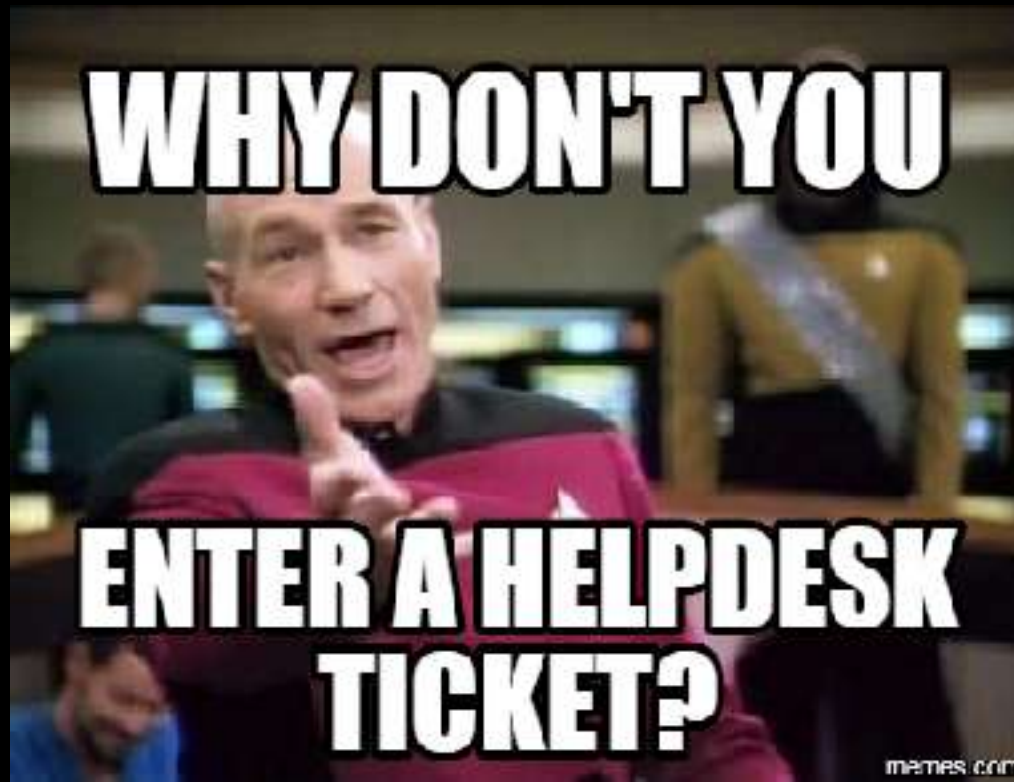
(1) (2) & Fully automated pipeline including imaging



Check Your Calibrated Data!



Bad baseline calibration
in TP data



**ALWAYS SUBMIT ISSUES TO
THE HELP DESK**

<https://help.almascience.org>

**DIDN'T ENTER HELP DESK
TICKET**



**DEATH STAR GOT BLOWN
UP**



WHEN IN DOUBT, ASK THE HELP DESK

<https://help.almascience.org>



- Built specifically for ALMA/JVLA data
- Not backwards compatible/very sensitive to exact version used
- Some documentation exists
- Still many black boxes

You should now be able to request that you be re-sent your calibrated data.

The scripts in the PI data package



```
project_id/  
└─ sg_ouss_id/  
    └─ group_ouss_id/  
        └─ member_ouss_id/  
            └─ README.txt  
            └─ product/  
            └─ calibration/  
            └─ qa/  
            └─ script/  
            └─ log/  
            └─ raw/
```

READ THIS FIRST

the FITS cubes of all images

calibration tables

diagnostic summary and plots

calibration and imaging scripts

calibration and imaging log files

created when ASDMs are unpacked

More details at the Science Portal Documentation:

<https://almascience.eso.org/documents-and-tools/cycle3/ALMAQA2Products3.0.pdf>

The scripts in script folder

Filename	Origin	Purpose
uid*.ms.scriptForCalibration.py (optional)	script-generator/ analyst	calibrates a single EB (ASDM); results in one uid*.ms.split.cal
PPR*.xml (optional)	ALMA Pipeline	controlled the run of the ALMA Pipeline; contains the list of ASDMs
casa_piperestorescript.py (optional)	ALMA Pipeline	calibrates all pipeline-processed EBs; results in one uid*.ms.split.cal per EB
casa_pipescript.py (optional)	ALMA Pipeline	enables user to rerun the Pipeline from scratch results in one uid*.ms.split.cal per EB
scriptForFluxCalibration.py (optional)	script-generator/ analyst	adjust the flux calibration of several EBs close in time which use same phase calibrator; prepare imaging; results is calibrated.ms
scriptForImaging.py	script-generator/ analyst	create all imaging products for the MOUS; results in (among others) *.fits files for all images
scriptForPI.py	added in packaging	Perform all necessary steps to create all uid*.ms.split.cal MSs

Run



- ① **READ the README!**
- ② Go to 'scripts' folder
- ③ Start the corresponding CASA version:
 - `casapy-XX`
 - `casapy-XX --pipeline`
- ④ Optional to delete intermediate files:
 - `SPACESAVING=N`
- ⑤ `execfile('scriptForPI.py')`

The scripts in the PI data package



```
project_id/  
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    └─ group_ouss_id/  
        └─ member_ouss_id/  
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More details at the Science Portal Documentation:

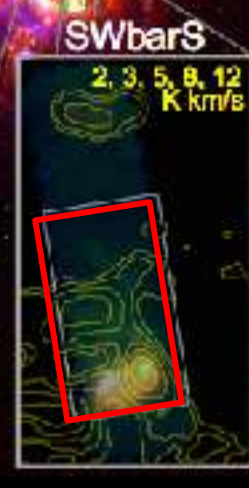
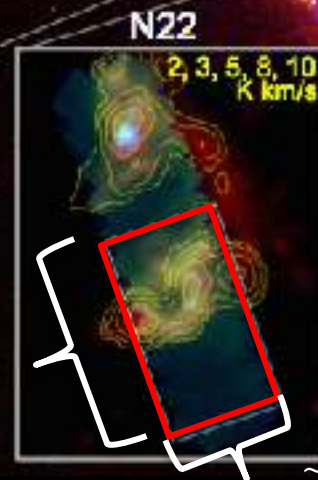
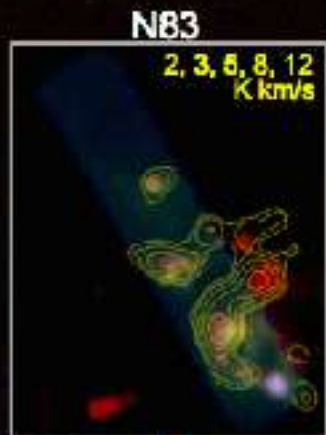
<https://almascience.eso.org/documents-and-tools/cycle3/ALMAQA2Products3.0.pdf>

PACS 160 μm
MIPS 24 μm
MCELS H α

SW Bar ALMA Survey

Cycle 2 PI: Jameson

PACS 160 μm $\odot \sim 10''$
PACS [CII] $\odot \sim 10''$
PACS [OI] $\odot \sim 10''$
APEX ^{12}CO (2-1) $\odot \sim 20''$



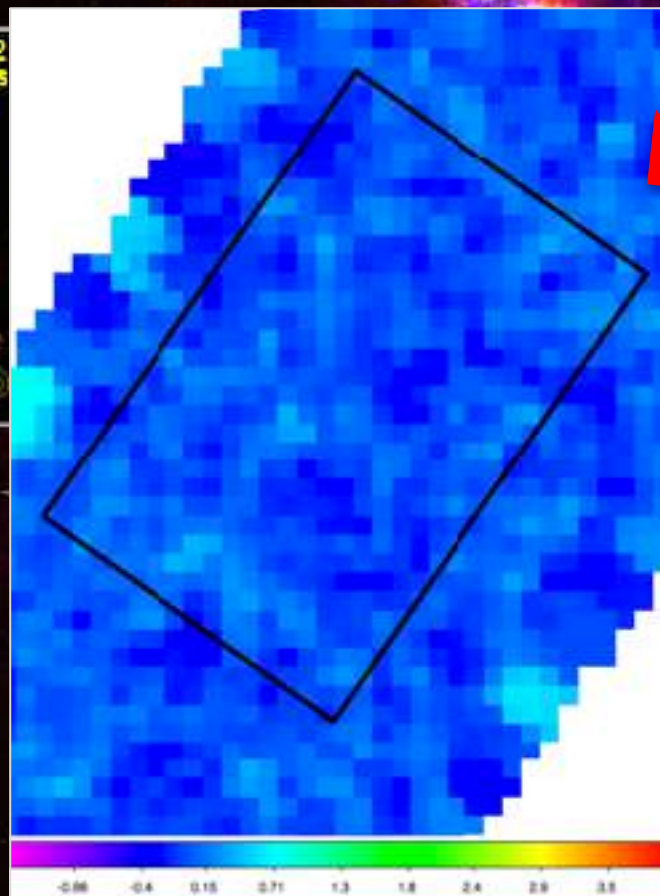
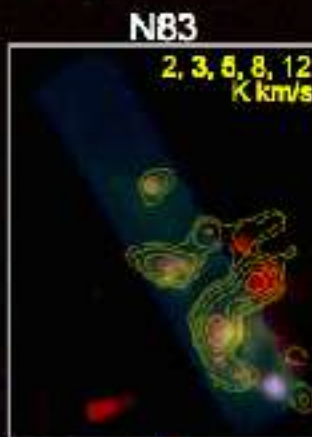
^{12}CO , ^{13}CO , C ^{18}O (2-1)
 $\sim 7''$ ACA resolution (~ 2 pc)

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MCELS H α

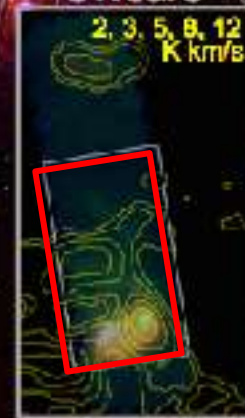
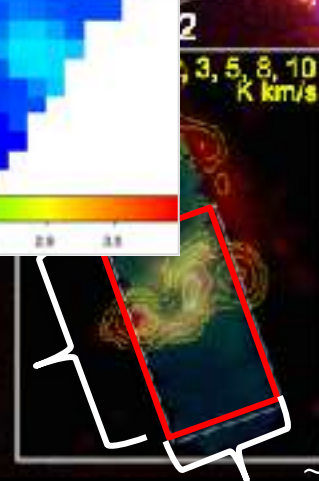
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APEX ^{12}CO (2-1) $\Theta \sim 20''$



SWbarN



^{12}CO , ^{13}CO , C^{18}O (2-1)
 $\sim 7''$ ACA resolution (~ 2 pc)

3.6'
 ~ 65 pc

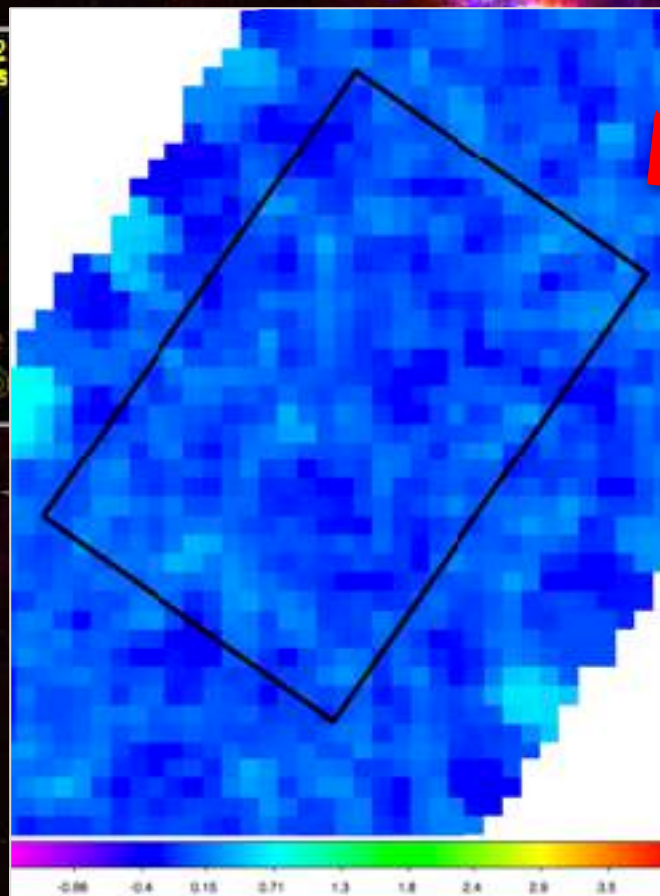
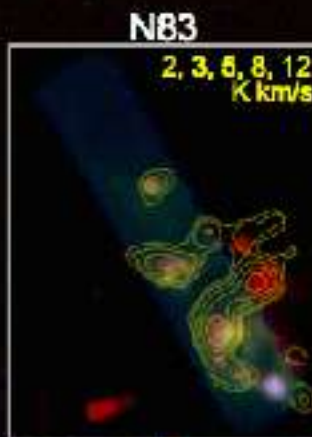
1.6'
 ~ 30 pc

PACS 160 μm
MIPS 24 μm
MCELS H α

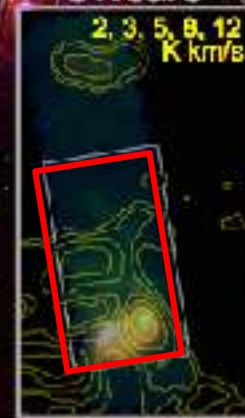
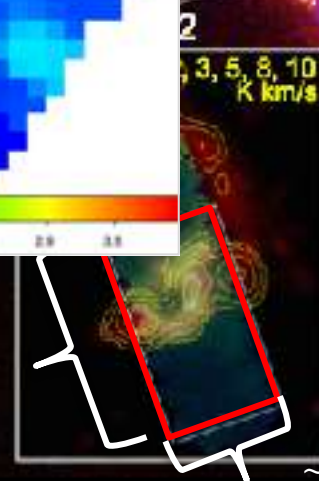
SW Bar ALMA Survey

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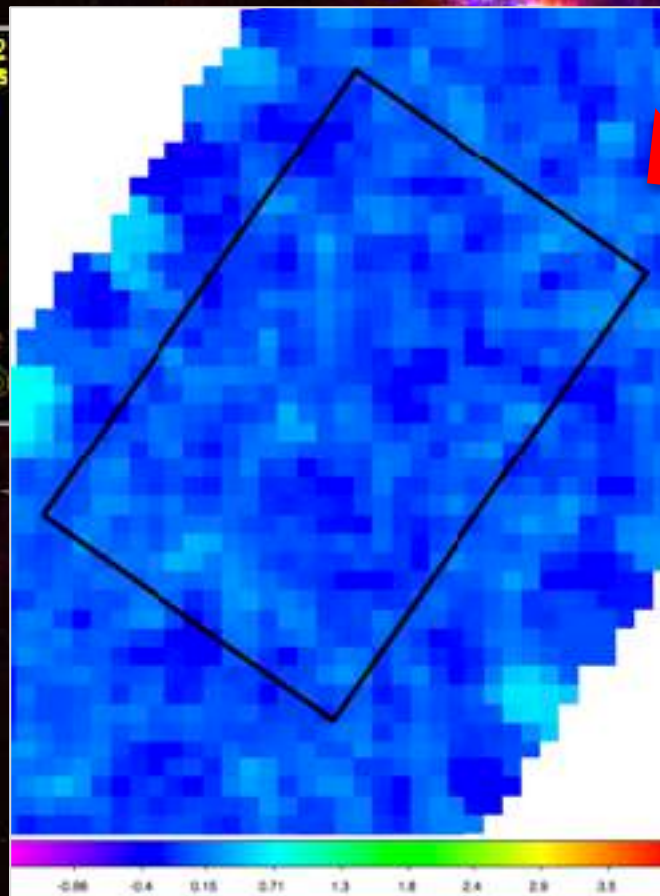
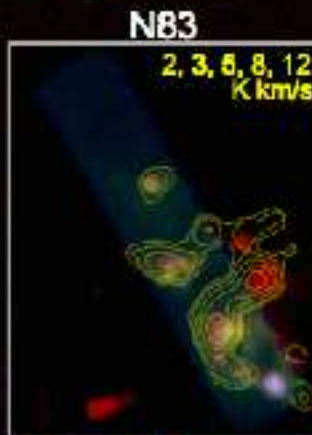
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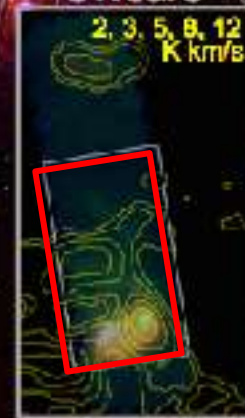
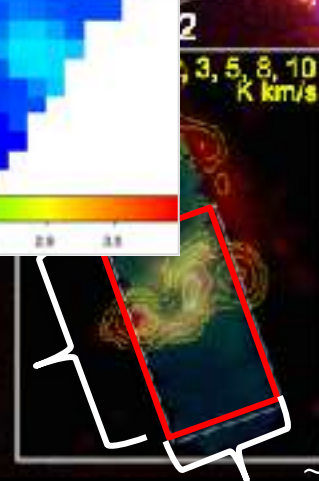
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SWbarN



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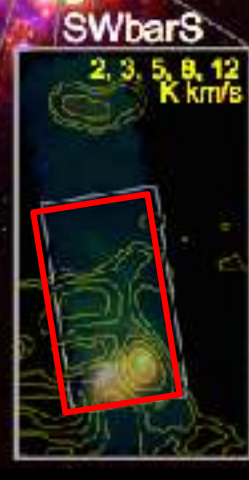
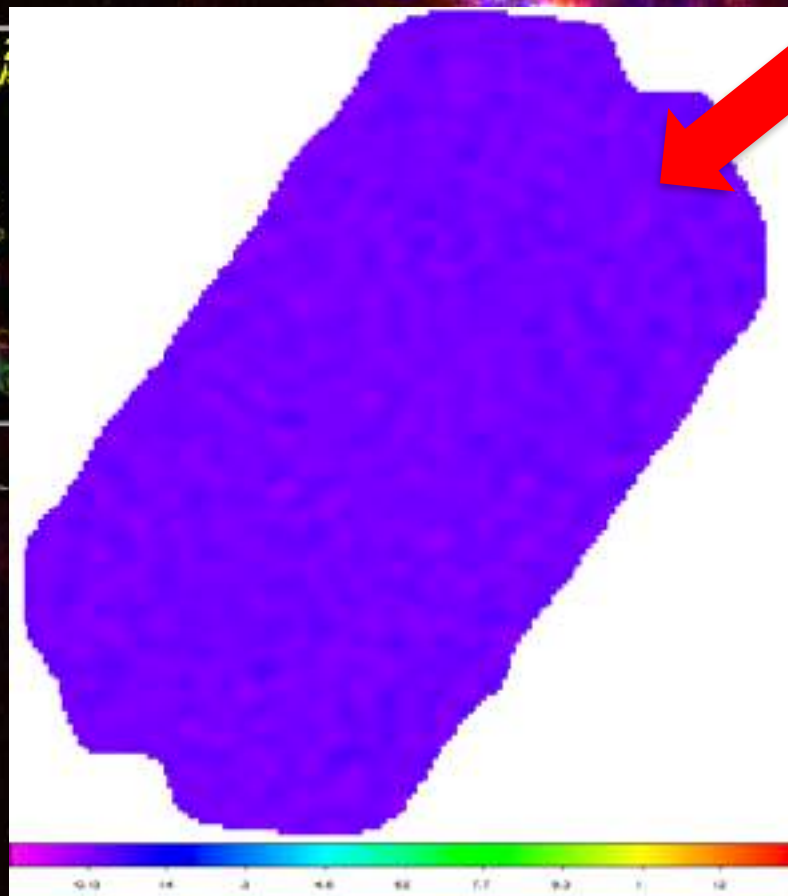
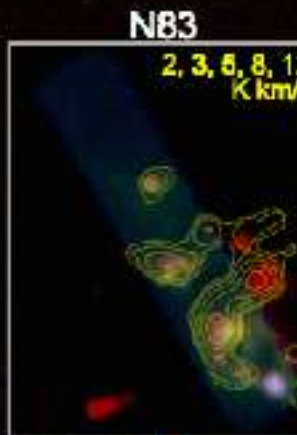
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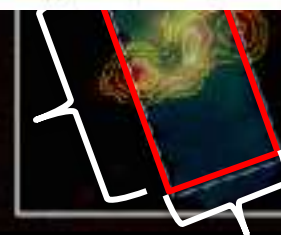
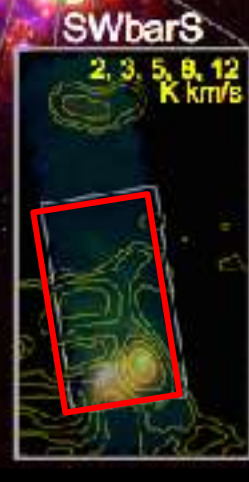
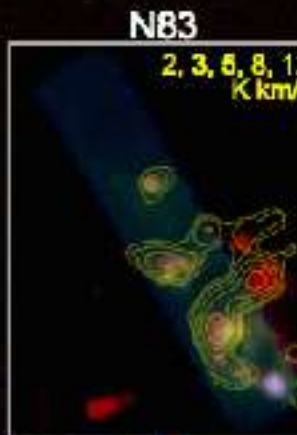
1.6'
 ~ 30 pc

PACS 160 μm
MIPS 24 μm
MCELS H α

SW Bar ALMA Survey

Cycle 2 PI: Jameson

PACS 160 μm $\Theta \sim 10''$
PACS [CII] $\Theta \sim 10''$
PACS [OI] $\Theta \sim 10''$
APEX ^{12}CO (2-1) $\Theta \sim 20''$



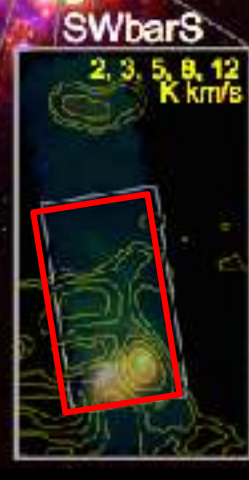
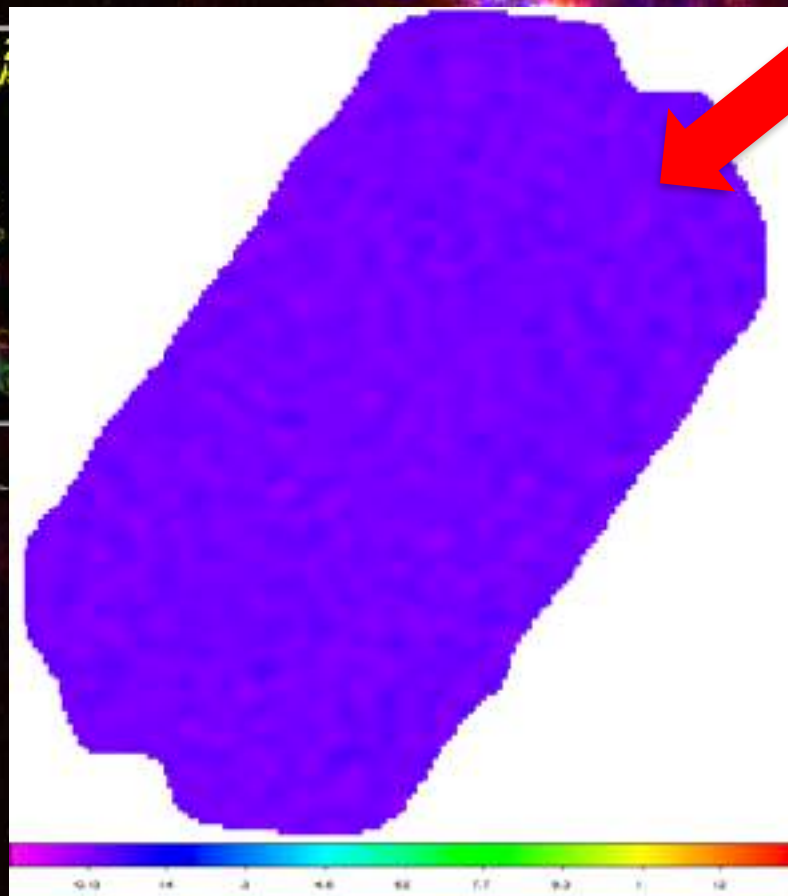
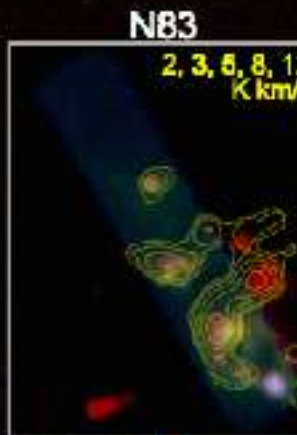
^{12}CO , ^{13}CO , C ^{18}O (2-1)
~7" ACA resolution (~2 pc)

PACS 160 μm
MIPS 24 μm
MCELS H α

SW Bar ALMA Survey

Cycle 2 PI: Jameson

PACS 160 μm $\Theta \sim 10''$
PACS [CII] $\Theta \sim 10''$
PACS [OI] $\Theta \sim 10''$
APEX ^{12}CO (2-1) $\Theta \sim 20''$



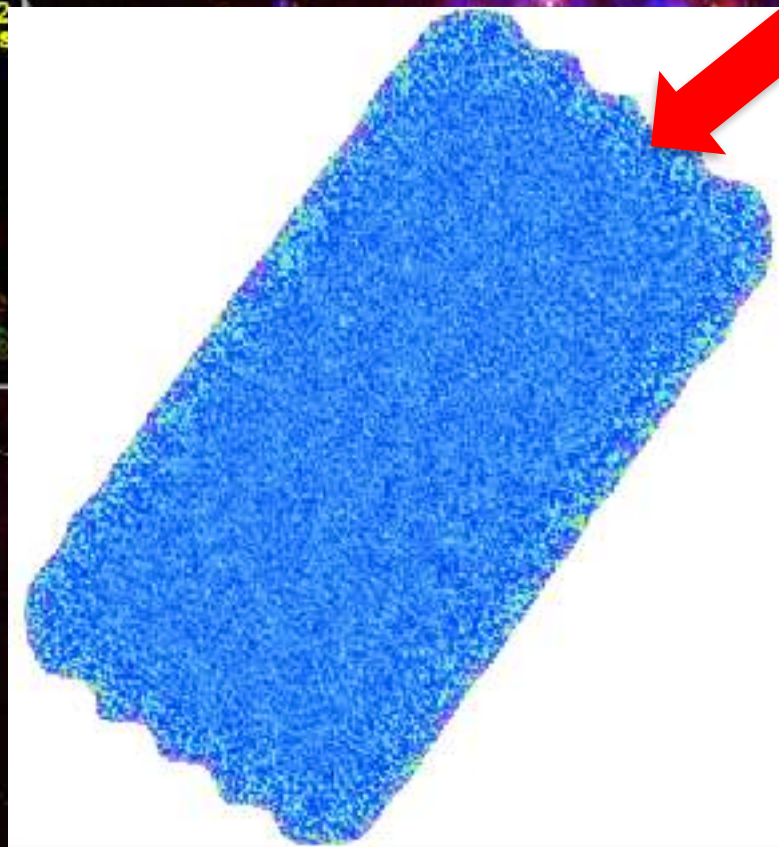
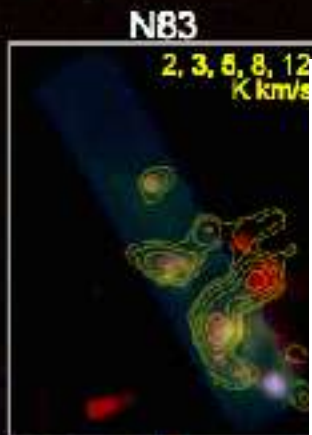
^{12}CO , ^{13}CO , C ^{18}O (2-1)
 $\sim 7''$ ACA resolution (~ 2 pc)

PACS 160 μm
MIPS 24 μm
MCELS H α

SW Bar ALMA Survey

Cycle 2 PI: Jameson

PACS 160 μm $\Theta \sim 10''$
PACS [CII] $\Theta \sim 10''$
PACS [OI] $\Theta \sim 10''$
APEX ^{12}CO (2-1) $\Theta \sim 20''$



^{12}CO , ^{13}CO , C ^{18}O (2-1)
 $\sim 7''$ ACA resolution (~ 2 pc)

3.6'
 ~ 65 pc

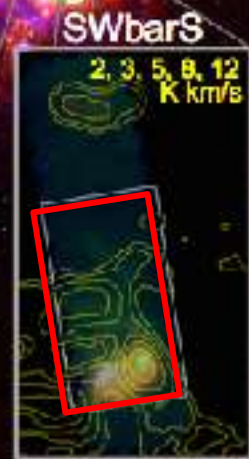
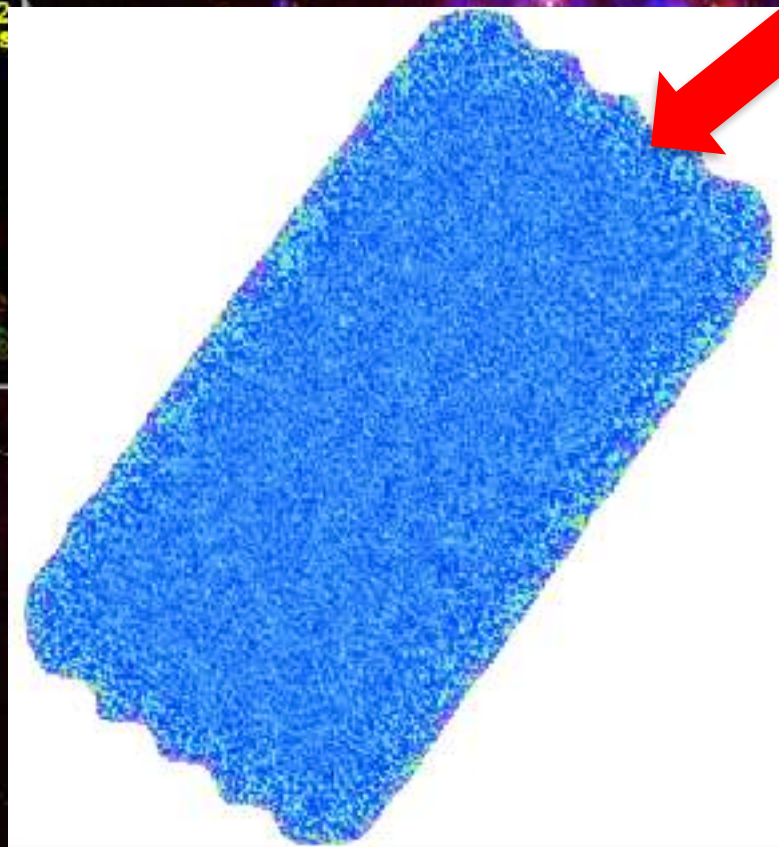
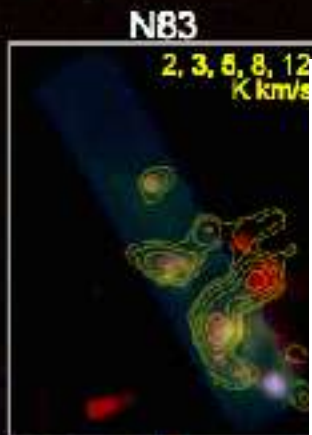
1.6'
 ~ 30 pc

PACS 160 μm
MIPS 24 μm
MCELS H α

SW Bar ALMA Survey

Cycle 2 PI: Jameson

PACS 160 μm $\Theta \sim 10''$
PACS [CII] $\Theta \sim 10''$
PACS [OI] $\Theta \sim 10''$
APEX ^{12}CO (2-1) $\Theta \sim 20''$



^{12}CO , ^{13}CO , C ^{18}O (2-1)
 $\sim 7''$ ACA resolution (~ 2 pc)

3.6'
 ~ 65 pc

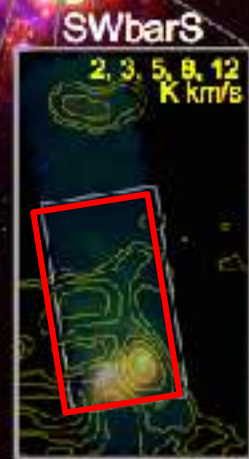
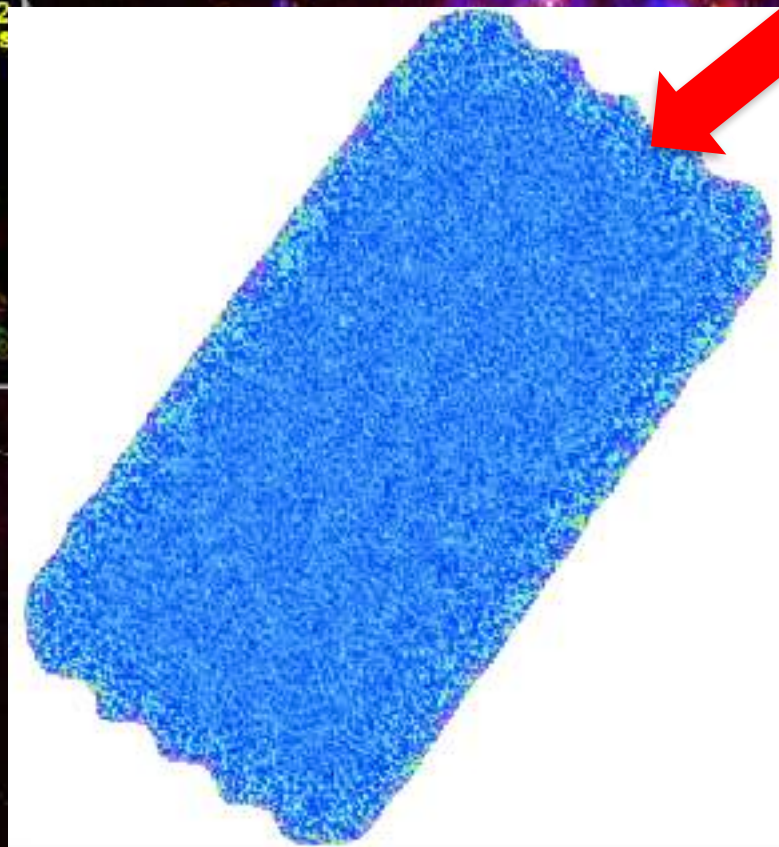
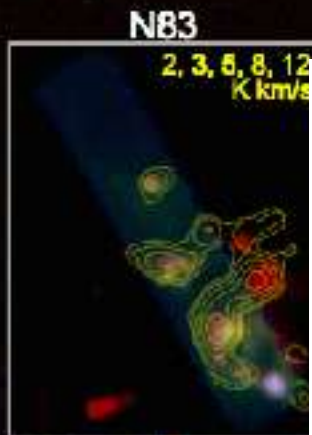
1.6'
 ~ 30 pc

PACS 160 μm
MIPS 24 μm
MCELS H α

SW Bar ALMA Survey

Cycle 2 PI: Jameson

PACS 160 μm $\Theta \sim 10''$
PACS [CII] $\Theta \sim 10''$
PACS [OI] $\Theta \sim 10''$
APEX ^{12}CO (2-1) $\Theta \sim 20''$



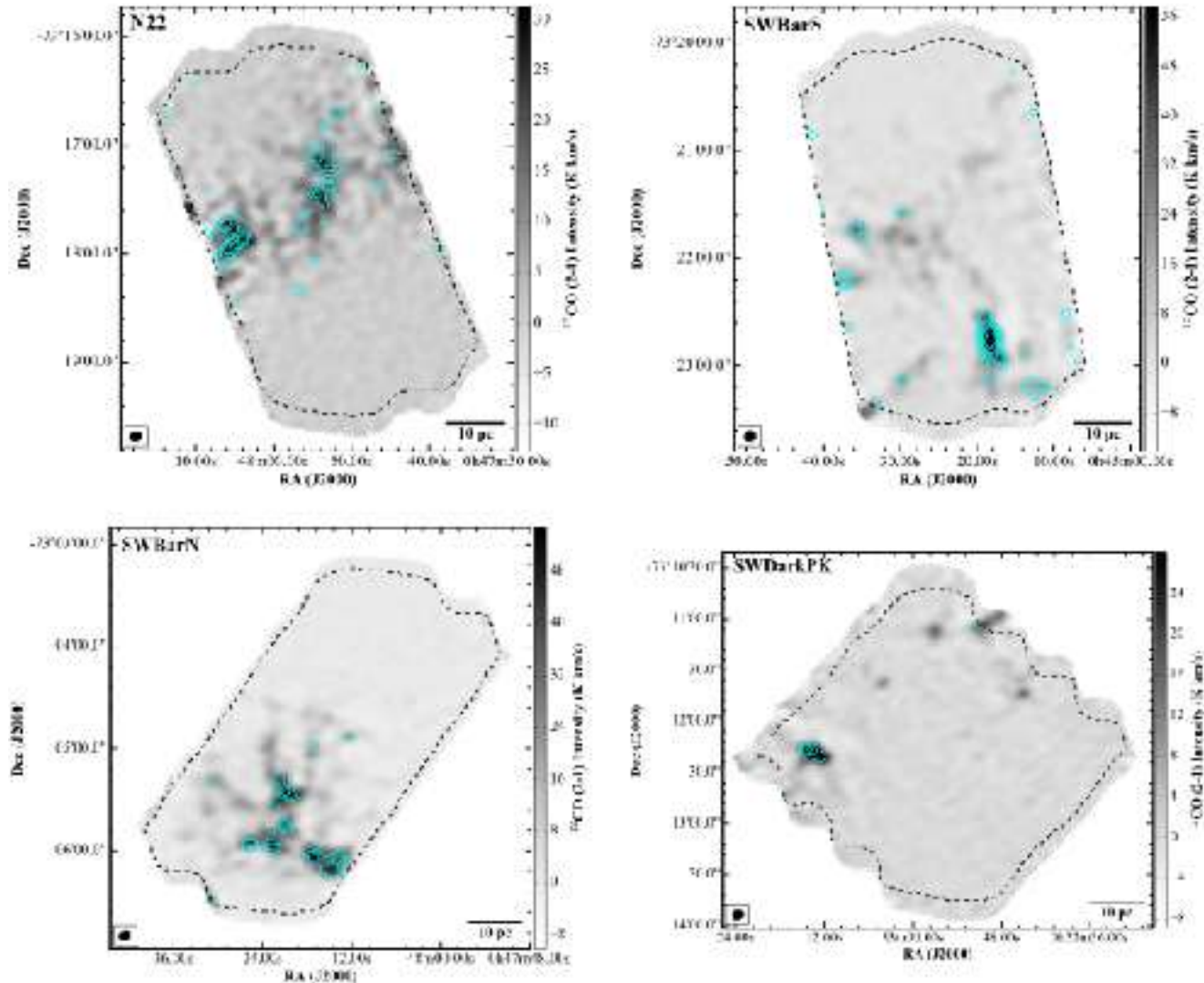
^{12}CO , ^{13}CO , C ^{18}O (2-1)
 $\sim 7''$ ACA resolution (~ 2 pc)

3.6'
 ~ 65 pc

1.6'
 ~ 30 pc

ALMA Survey of the Southwest Bar:

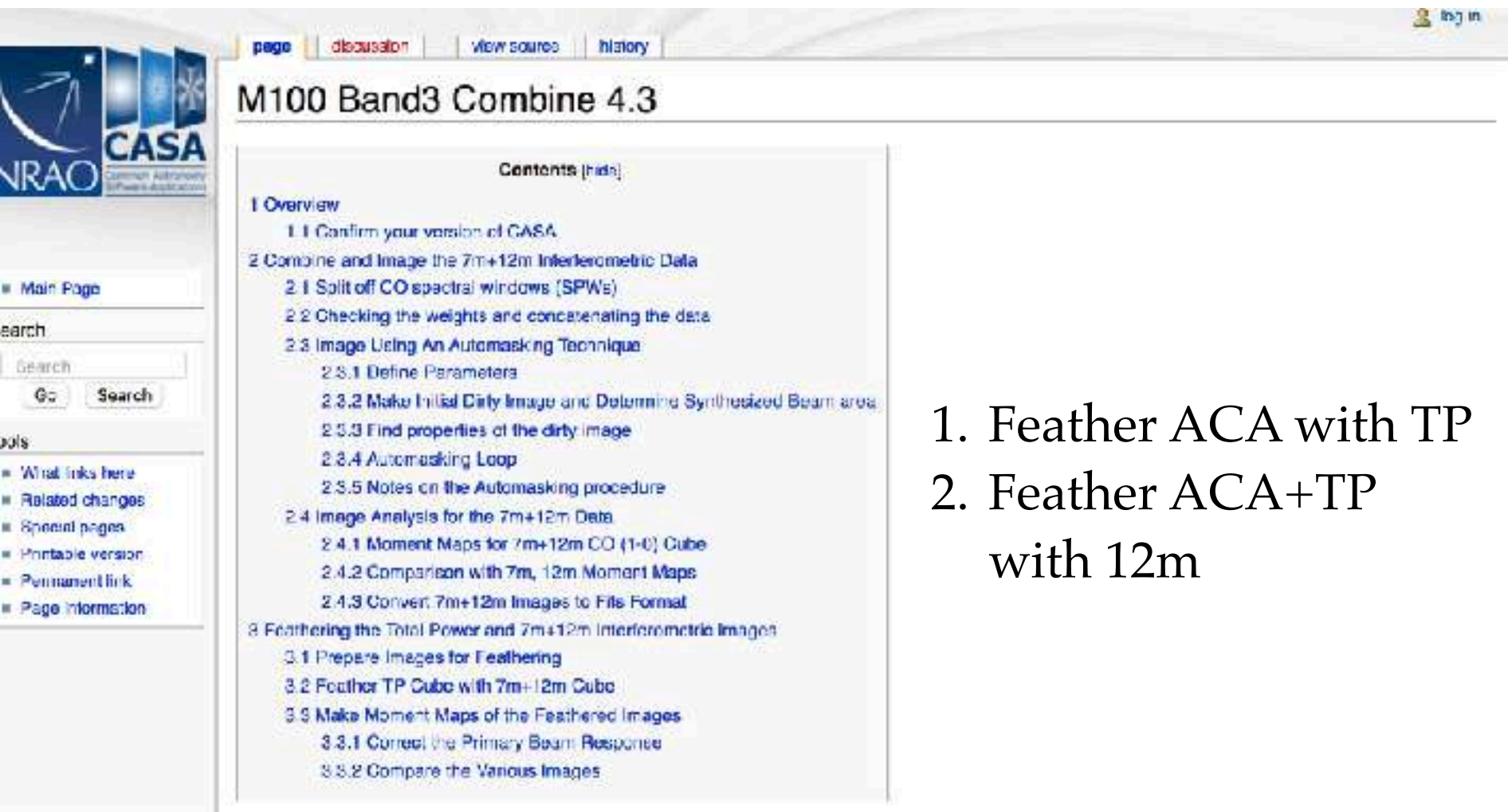
^{12}CO (2-1) ACA+TP Images



^{13}CO (2-1) contours: 2, 4, 6, 8, 10, 15 K km/s

Combining 12m/ACA/TP

https://casaguides.nrao.edu/index.php/M100_Band3_Combine_4.3



The screenshot shows the CASA M100 Band3 Combine 4.3 page. The left sidebar contains the NRAO and CASA logos, a search bar, and a list of links: Main Page, What links here, Related changes, Special pages, Printable version, Permanent link, and Page information. The main content area has a navigation bar with links for page, discussion, view source, and history. The title is "M100 Band3 Combine 4.3". Below the title is a "Contents [hide]" section. The contents list the following sections:

- 1 Overview
 - 1.1 Confirm your version of CASA
- 2 Combine and Image the 7m+12m Interferometric Data
 - 2.1 Split off CO spectral windows (SPWs)
 - 2.2 Checking the weights and concatenating the data
 - 2.3 Image Using An Automasking Technique
 - 2.3.1 Define Parameters
 - 2.3.2 Make Initial Dirty Image and Determine Synthesized Beam area
 - 2.3.3 Find properties of the dirty image
 - 2.3.4 Automasking Loop
 - 2.3.5 Notes on the Automasking procedure
 - 2.4 Image Analysis for the 7m+12m Data
 - 2.4.1 Moment Maps for 7m+12m CO (1-0) Cube
 - 2.4.2 Comparison with 7m, 12m Moment Maps
 - 2.4.3 Convert 7m+12m Images to Fits Format
- 3 Feathering the Total Power and 7m+12m Interferometric Images
 - 3.1 Prepare Images for Feathering
 - 3.2 Feather TP Cube with 7m+12m Cube
 - 3.3 Make Moment Maps of the Feathered Images
 - 3.3.1 Correct the Primary Beam Response
 - 3.3.2 Compare the Various Images

1. Feather ACA with TP
2. Feather ACA+TP
with 12m



ALWAYS SUBMIT ISSUES TO
THE HELP DESK

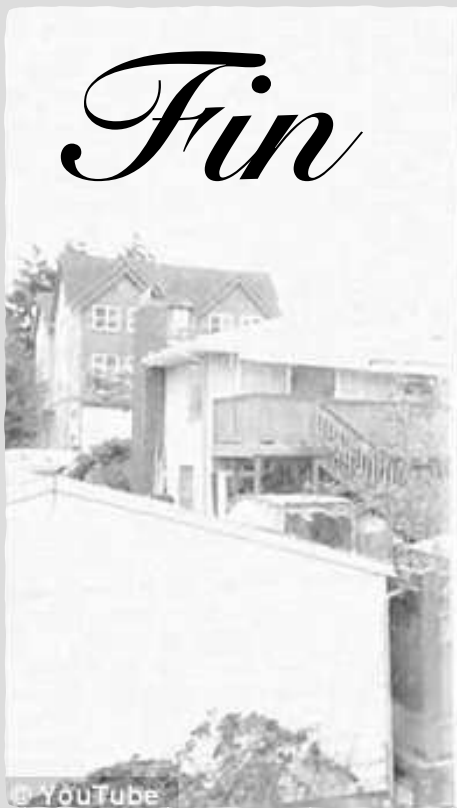
<https://help.almascience.org>



WHEN IN DOUBT, ASK THE HELP DESK

<https://help.almascience.org>

Fin



@ YouTube



I am free to go.
Yet I remain.