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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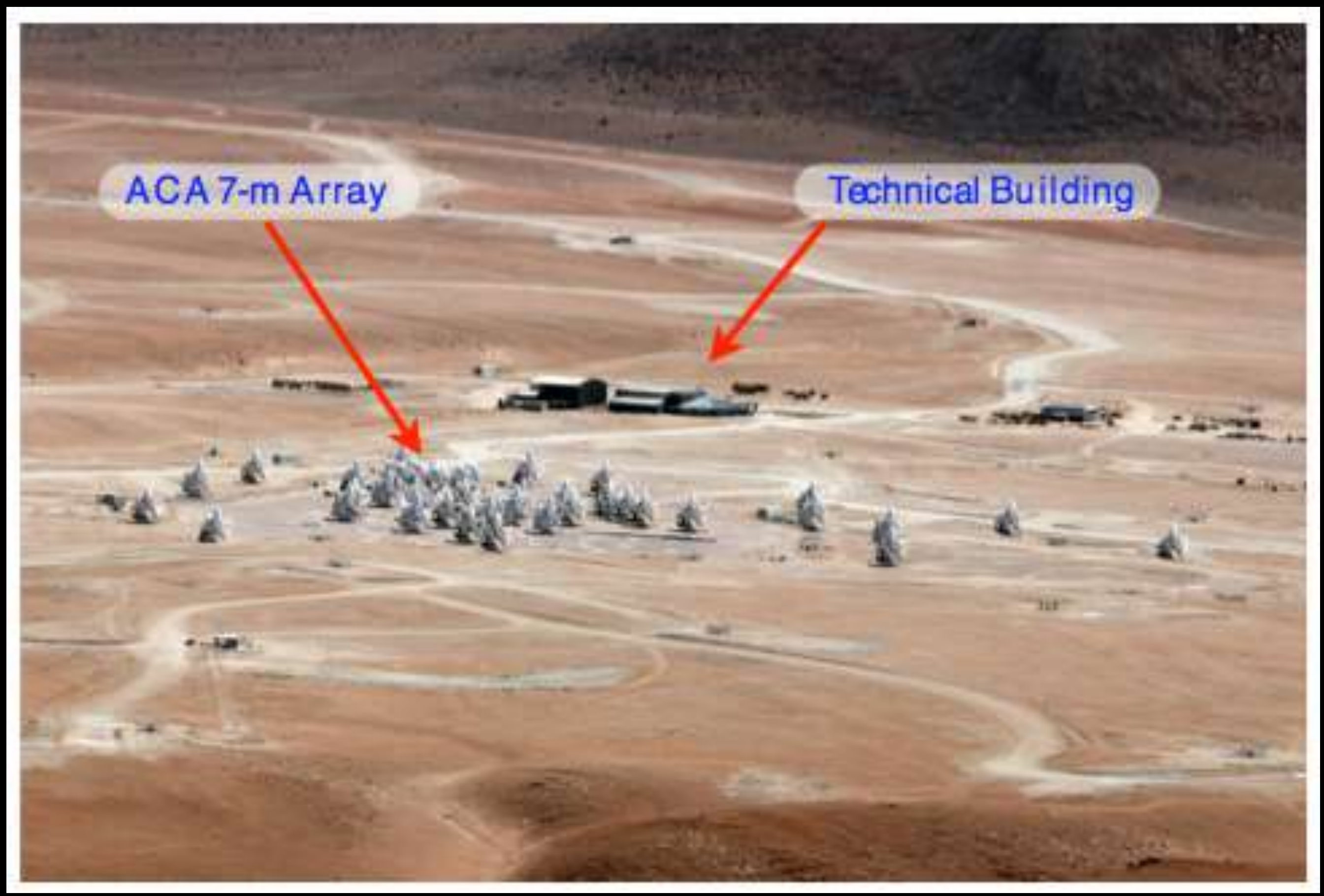
12-m Array

one of the more extended array configurations with max baseline ~16km

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

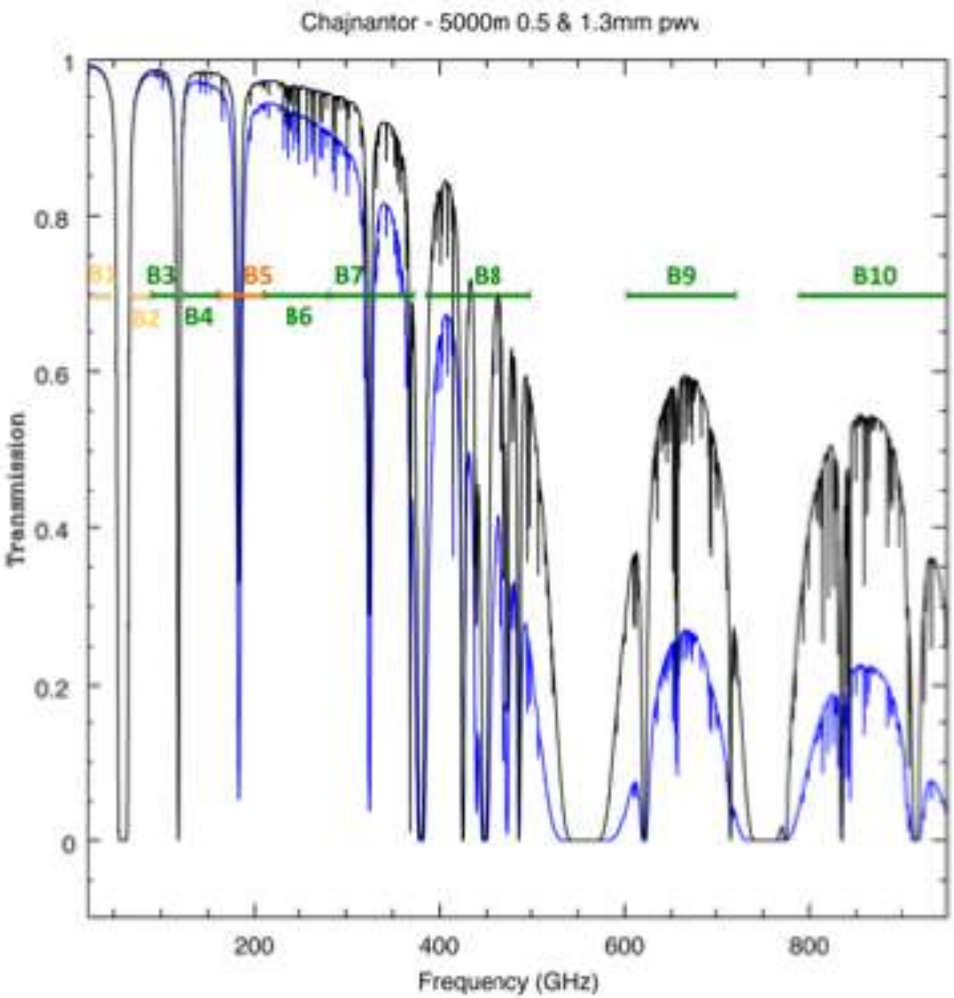


mm vs. cm observations: know your enemy

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

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)

https://almascience.nrao.edu/news/alma-cycle-5-pre-announcement

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 (~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

https://almascience.nrao.edu/news/alma-cycle-5-pre-announcement

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

https://almascience.nrao.edu/news/alma-cycle-5-pre-announcement

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

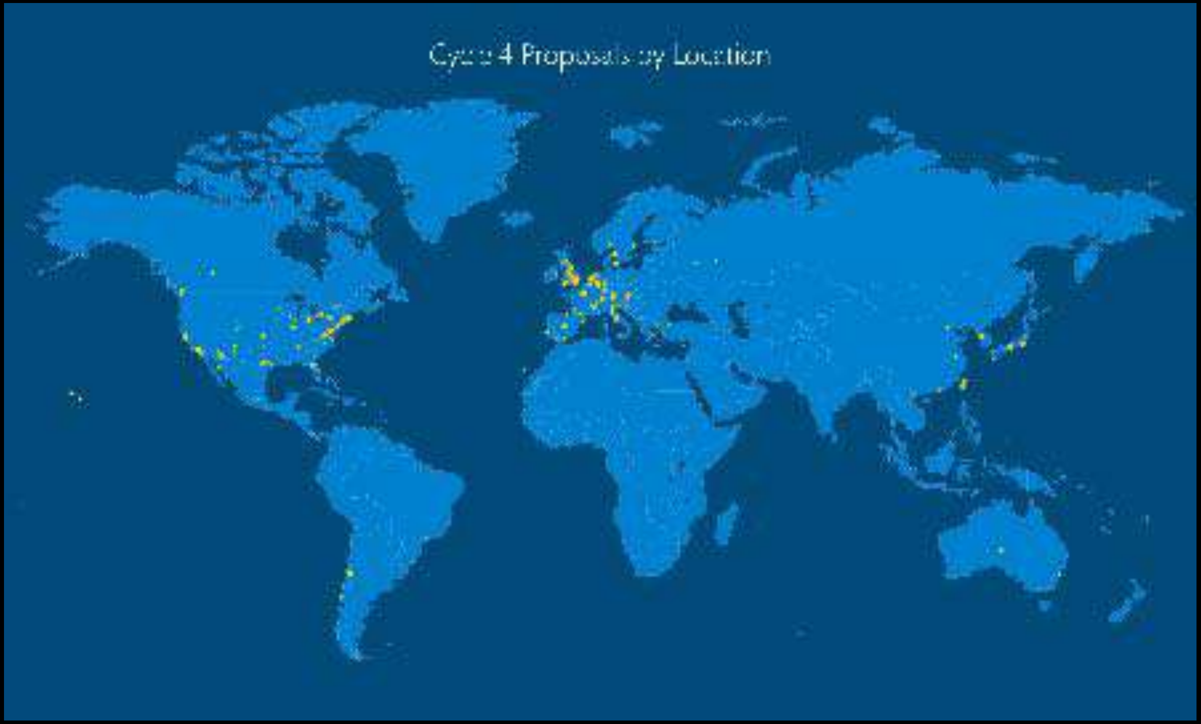
33.75% North America
33.75% Europe
22.5% East Asia
10% Chile

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

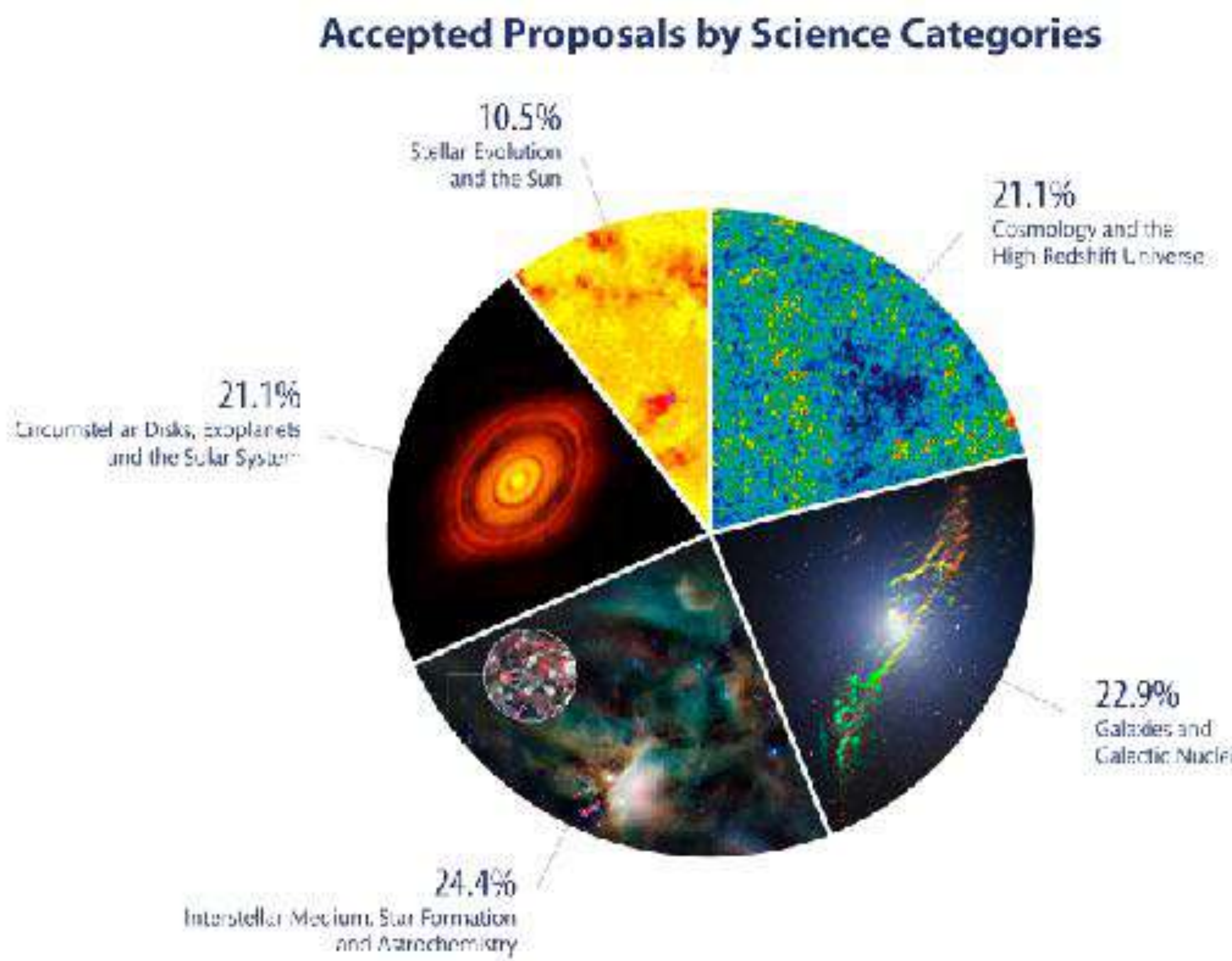
- ~1600 proposals from 30 countries
- 50% increase in time requested from Cycle 3
  - Requested ~12,000 hrs for 12-m (out of 3000)
  - ~6000 hrs for ACA (out of 1800)



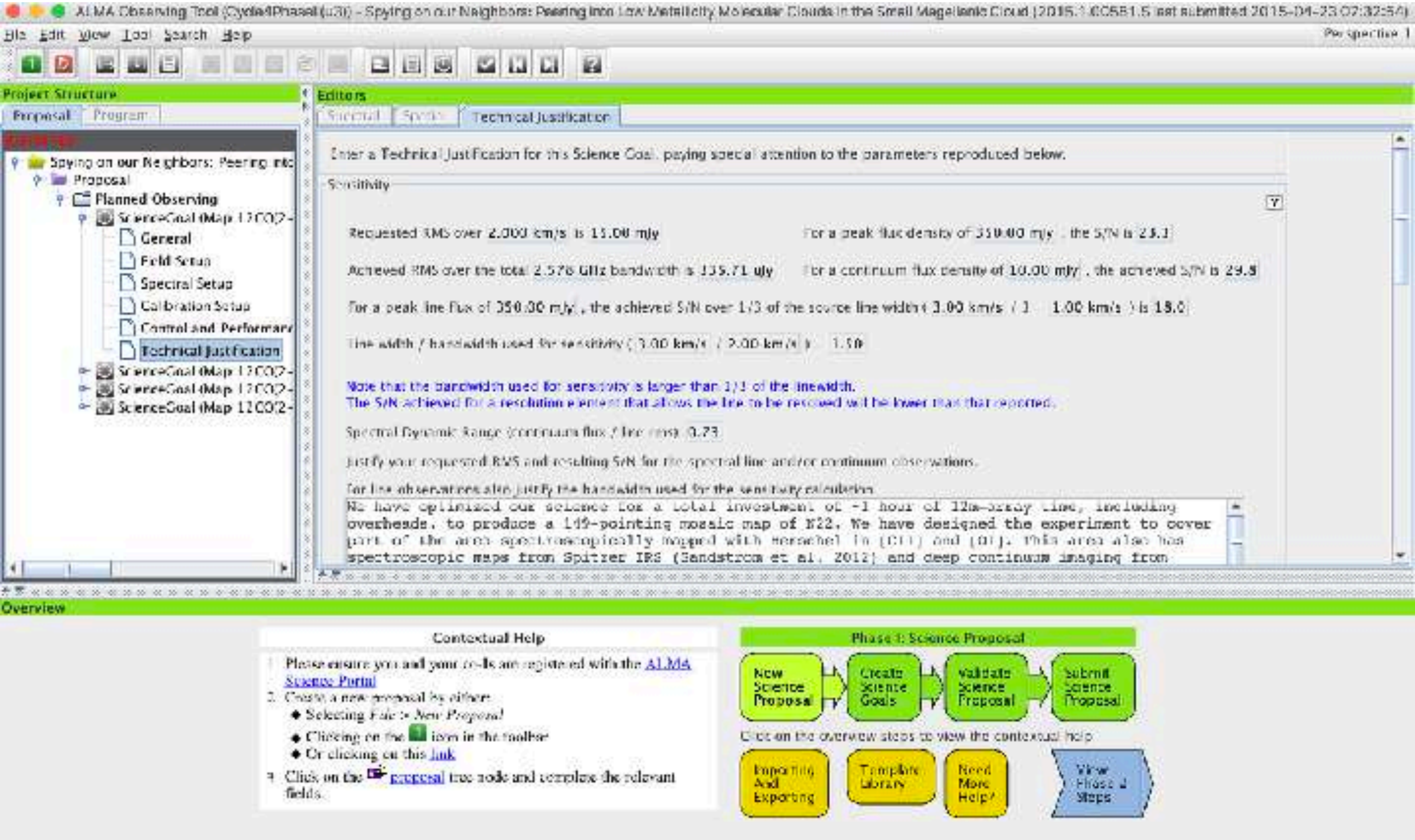
Cycle 4 Results

- ~1600 proposals from 30 countries → **Cycle 5: ~1700 proposals**
- 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)

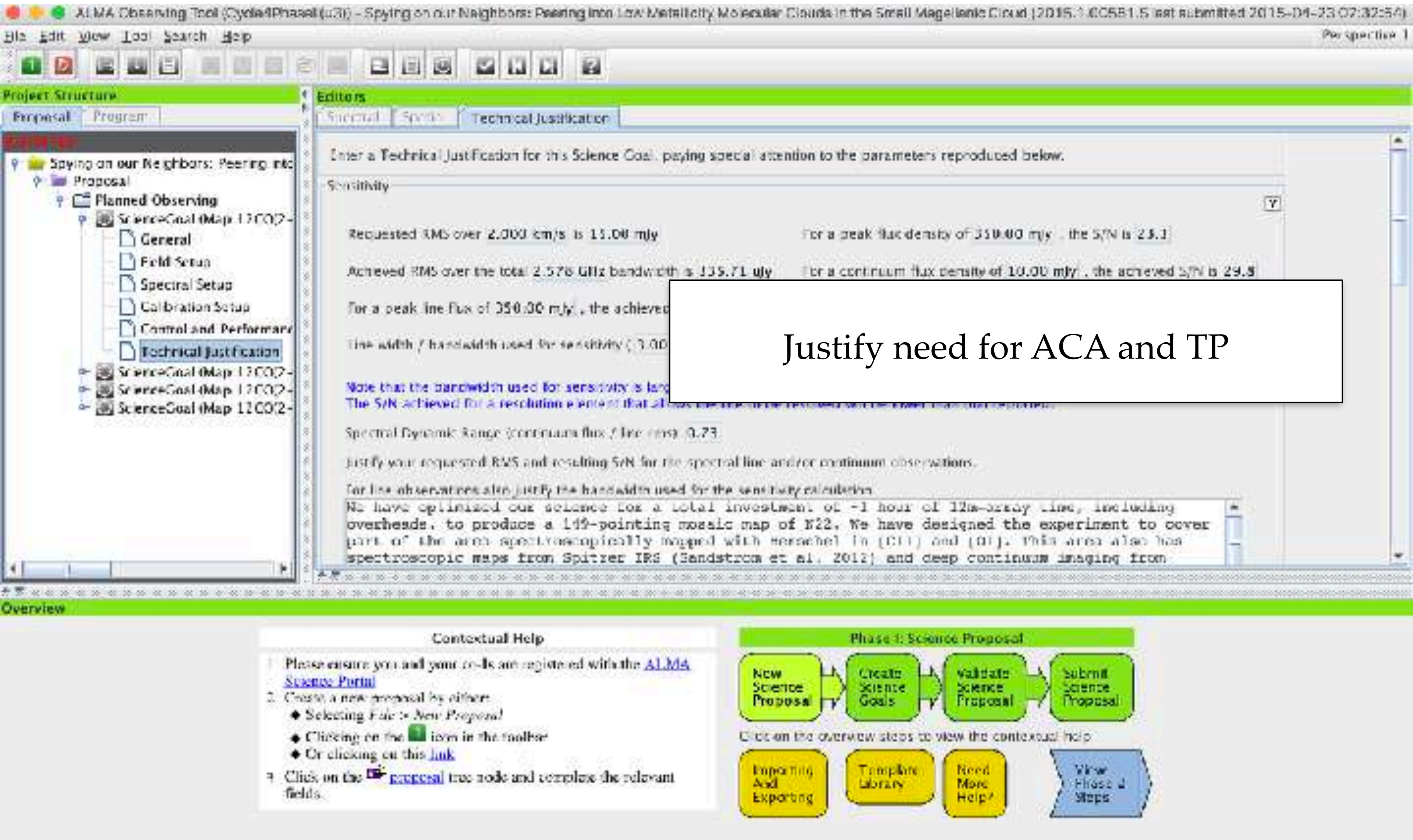
Cycle 4 Results



ALMA Observing Tool (AOT)



ALMA Observing Tool (AOT)



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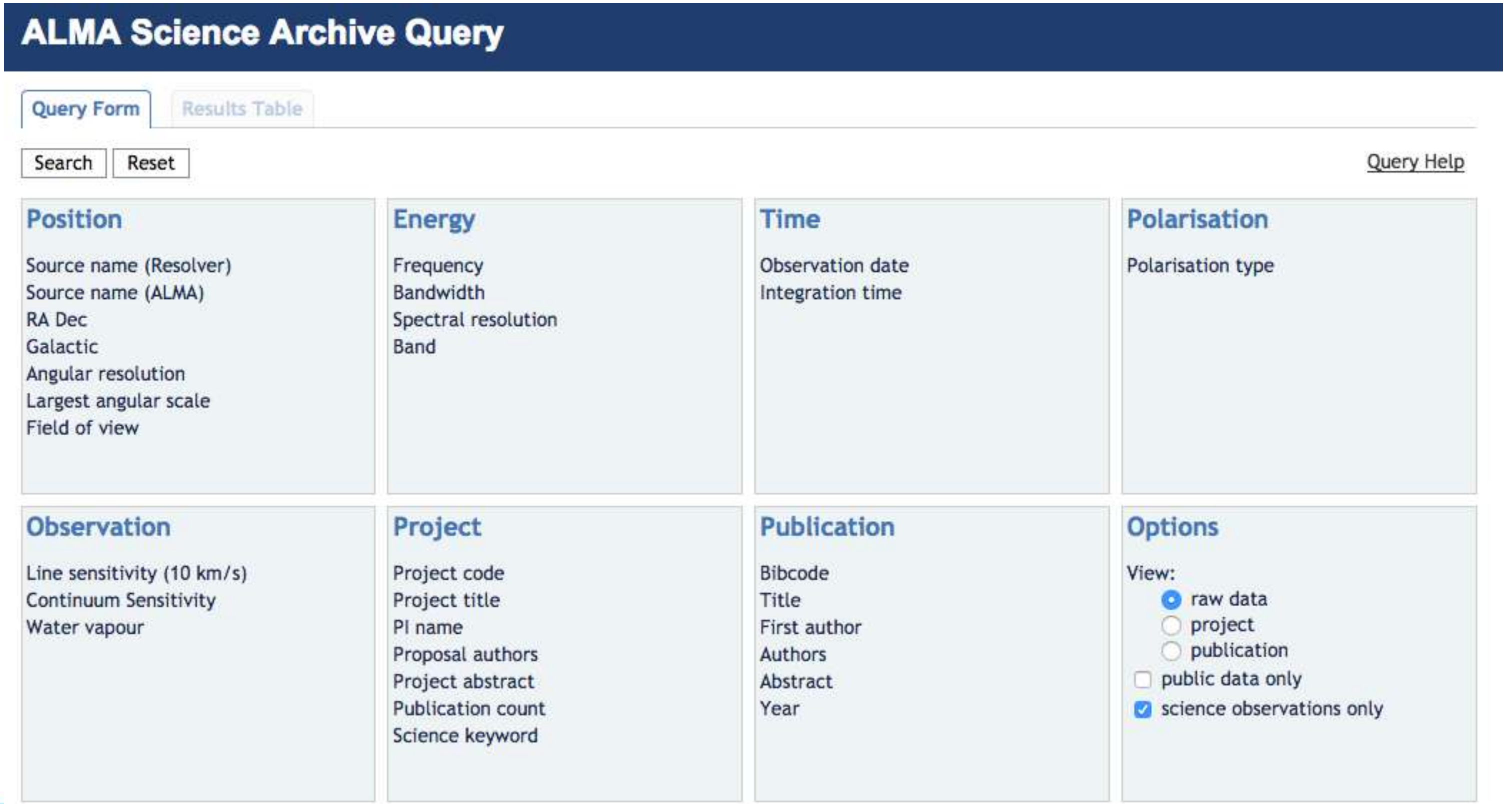
ALMA Archive

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
- [x] 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/
```

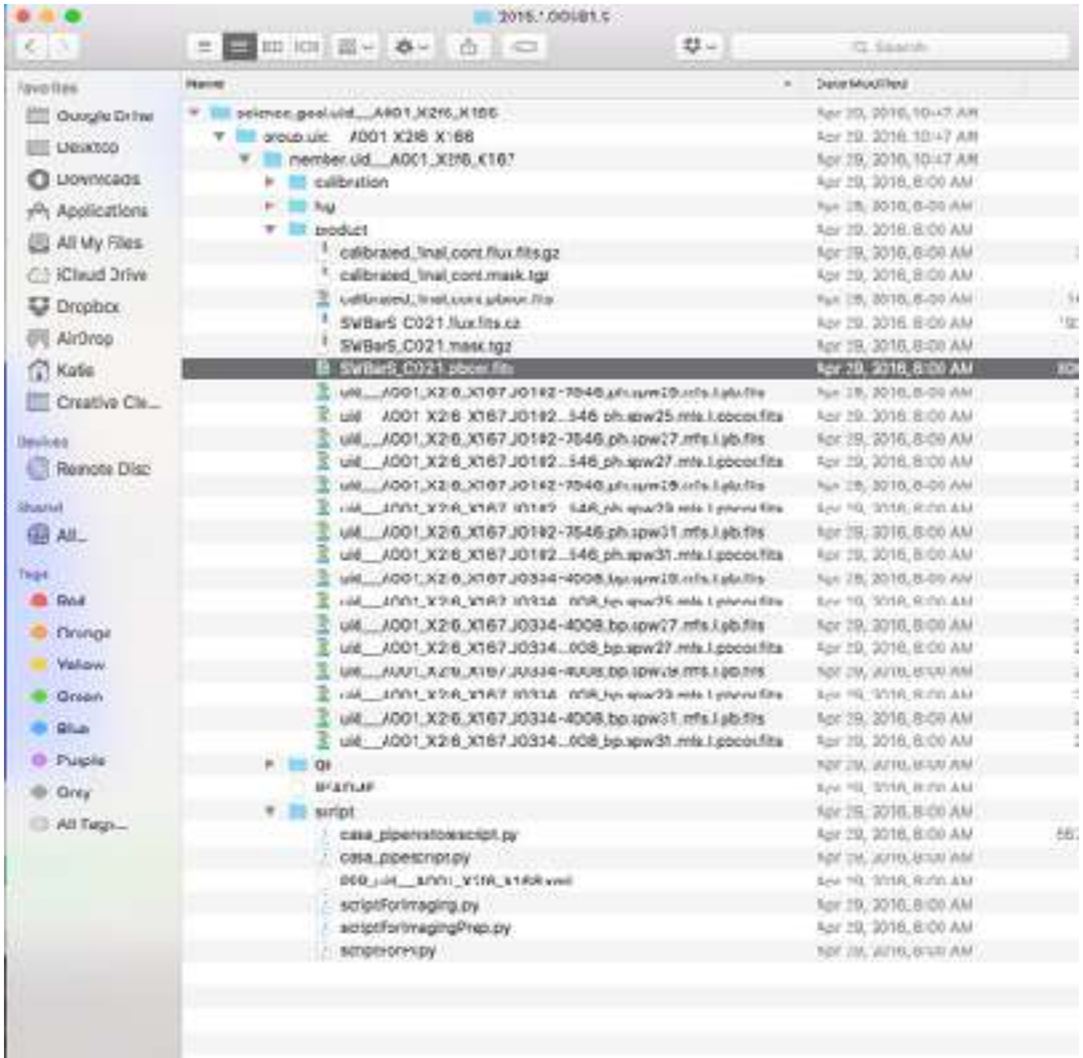
With subdirectories:

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

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

EUROPEAN ARC
ALMA Regional Centre || Allegro

Data from the ALMA Archive

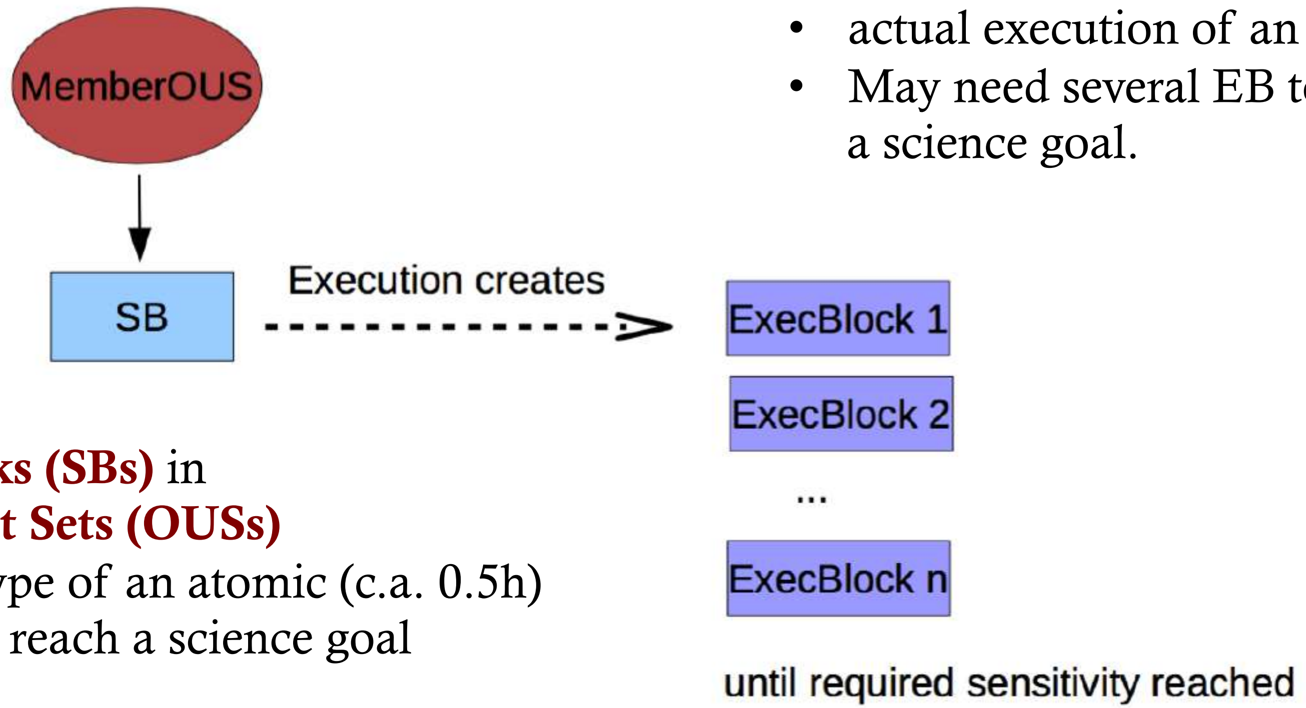


Data will have been imaged in the velocity resolution you specified in your sensitivity calculation in your proposal

Science Goal, SB, EB, OUS…?

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

Execution Block (EB):
- actual execution of an SB
- May need several EB to reach a science goal.



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

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Credit: D. Petry (ESO)

ALMA Data Processing

TWO PROCESSING MODELS COEXIST:

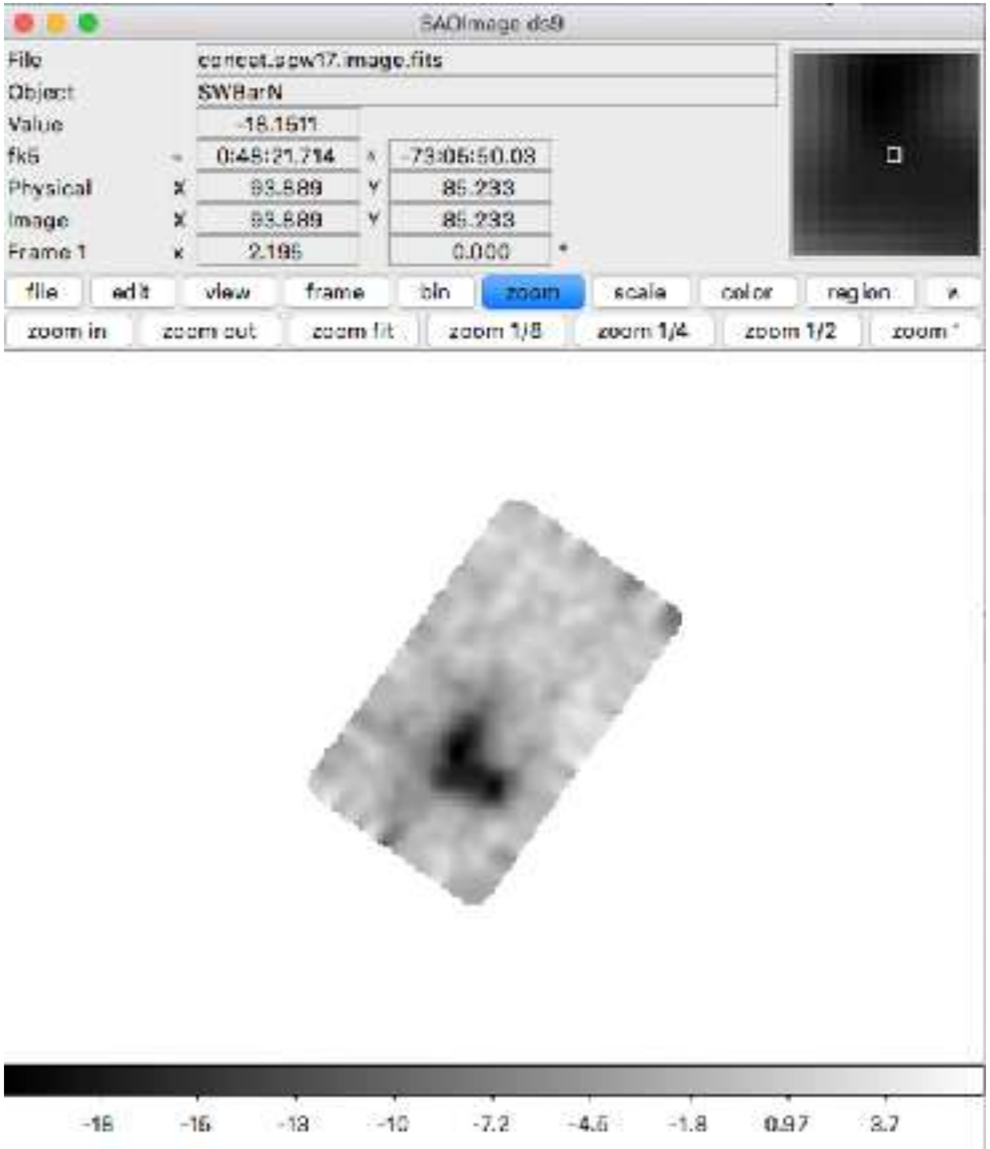
1. **Semi-automatic calibration and imaging:**
    - The analyst edits the output of a script generator and processes data.

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

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CASA

Common Astronomy
Software Applications

- 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/
```

README.txt	**READ THIS FIRST**
product/	the FITS cubes of all images
calibration/	calibration tables
qa/	diagnostic summary and plots
script/	calibration and imaging scripts
log/	calibration and imaging log files
raw/	created when ASDMs are unpacked

More details at the Science Portal Documentation:
https://almascience.eso.org/documents-and-tools/cycle3/ALMAQA2Products3.0.pdf
c

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ALMA Regional Centre || Allegro

Credit: D. Petry (ESO)

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

Credit: D. Petry (ESO)

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

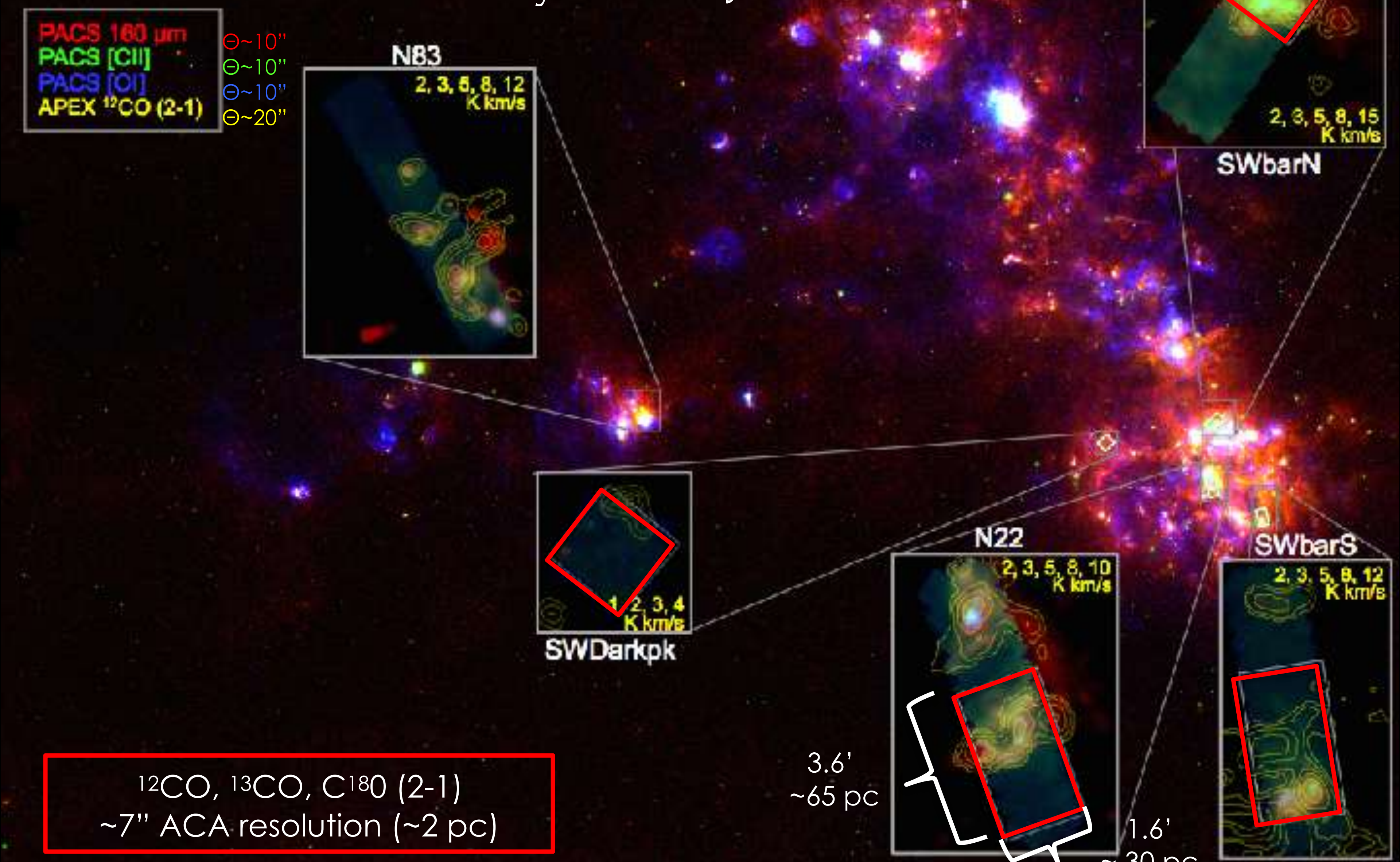
```
project_id/
└→ sg_ouss_id/
    └→ group_ouss_id/
        └→ member_ouss_id/
            ├→ README.txt          READ THIS FIRST
            ├→ product/            the FITS cubes of all images
            ├→ calibration/        calibration tables
            ├→ qa/                 diagnostic summary and plots
            ├→ script/             calibration and imaging scripts
            ├→ log/                calibration and imaging log files
            └→ raw/                created when ASDMs are unpacked
               calibrated/         created when scriptForPI.py is run
```

More details at the Science Portal Documentation:
https://almascience.eso.org/documents-and-tools/cycle3/ALMAQA2Products3.0.pdf

Credit: D. Petry (ESO)

SW Bar ALMA Survey

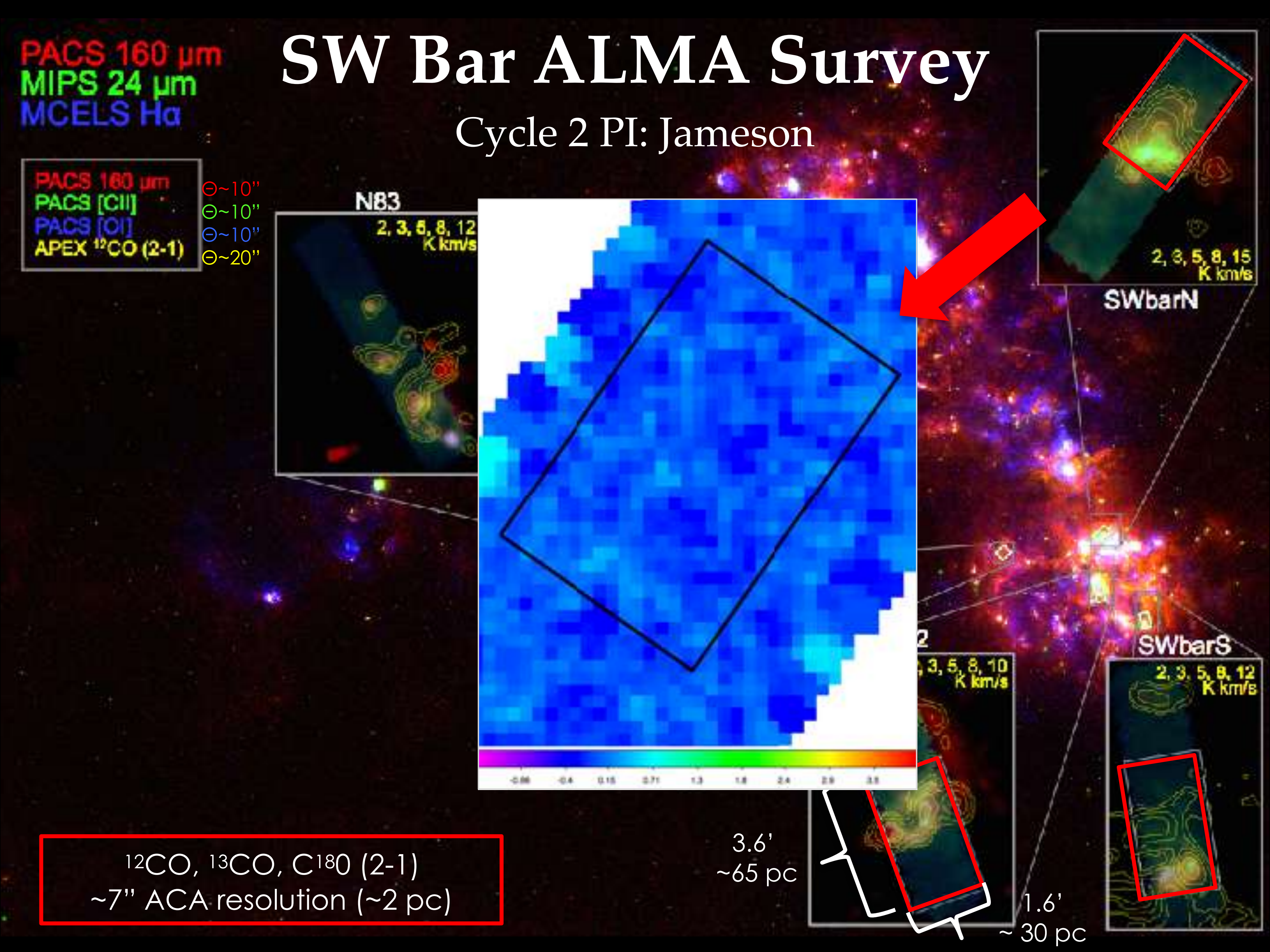
Cycle 2 PI: Jameson



12CO, 13CO, C180 (2-1)
~7'' ACA resolution (~2 pc)

SW Bar ALMA Survey

Cycle 2 PI: Jameson

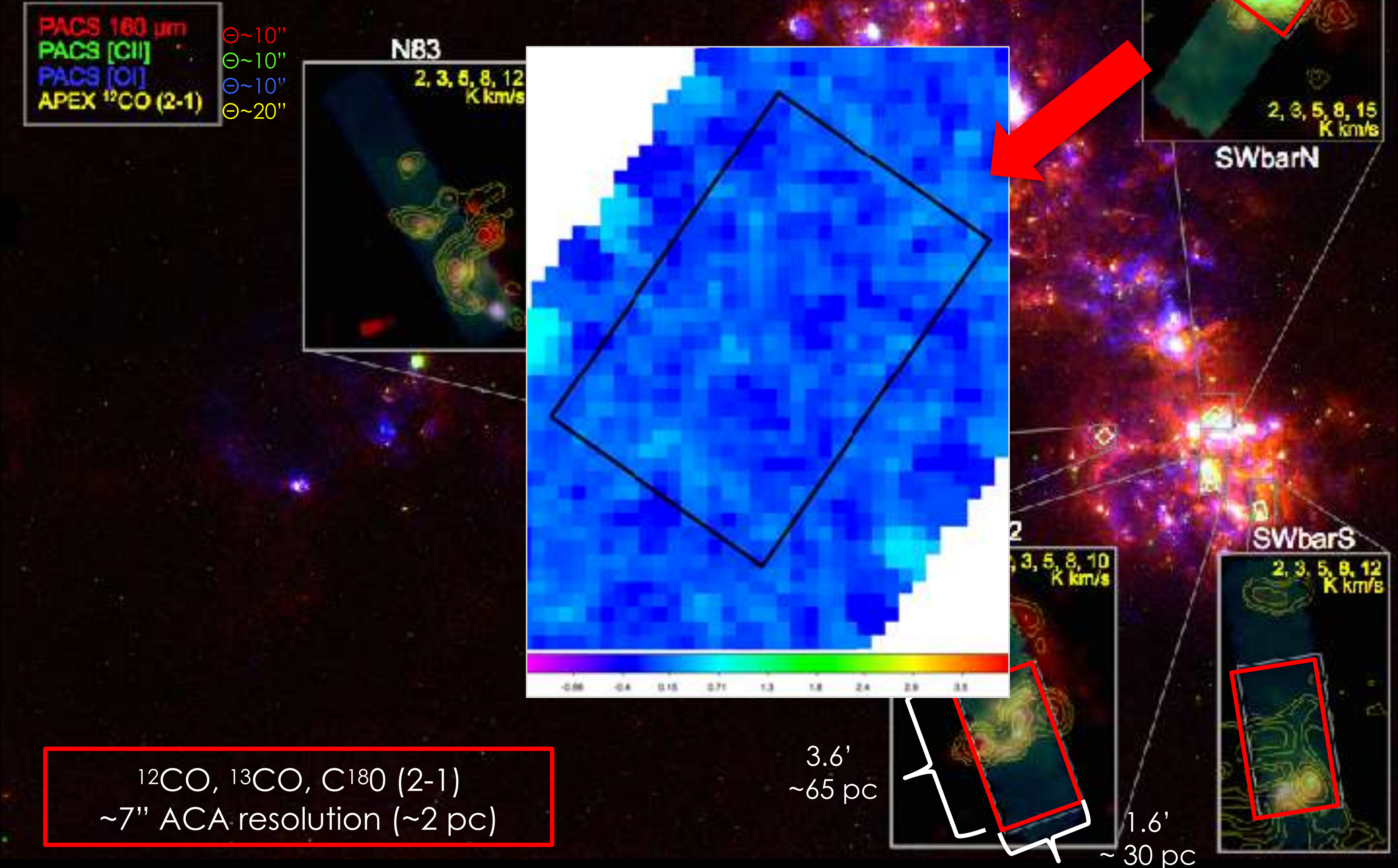


^{12}CO, ^{13}CO, $C^{18}0$ (2-1)

~7'' ACA resolution (~2 pc)

SW Bar ALMA Survey

Cycle 2 PI: Jameson



^{12}CO, ^{13}CO, C^{18}0 (2-1)
~7" ACA resolution (~2 pc)

SW Bar ALMA Survey

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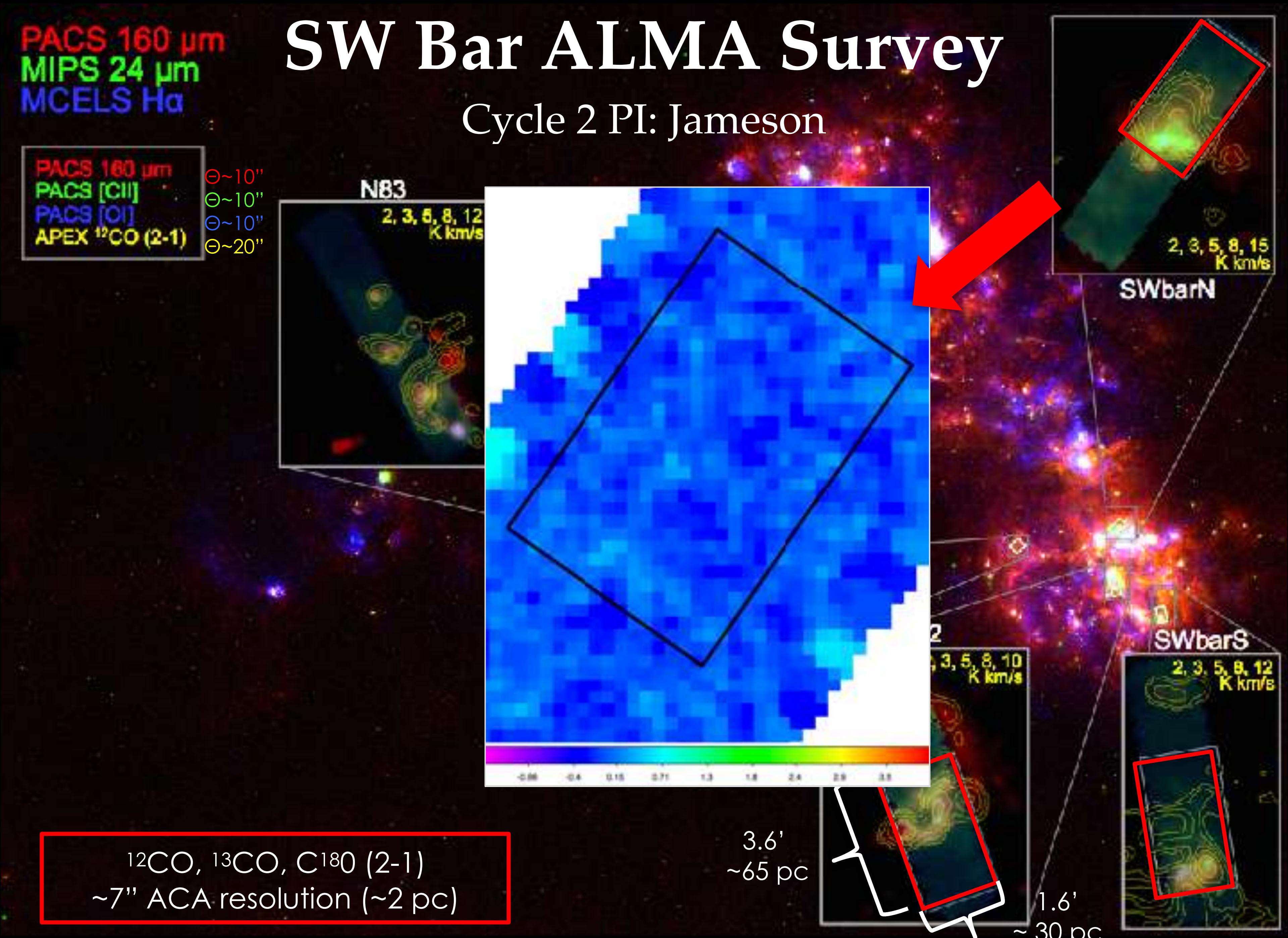

^{12}CO, ^{13}CO, C^{18}0 (2-1)

~7'' ACA resolution (~2 pc)

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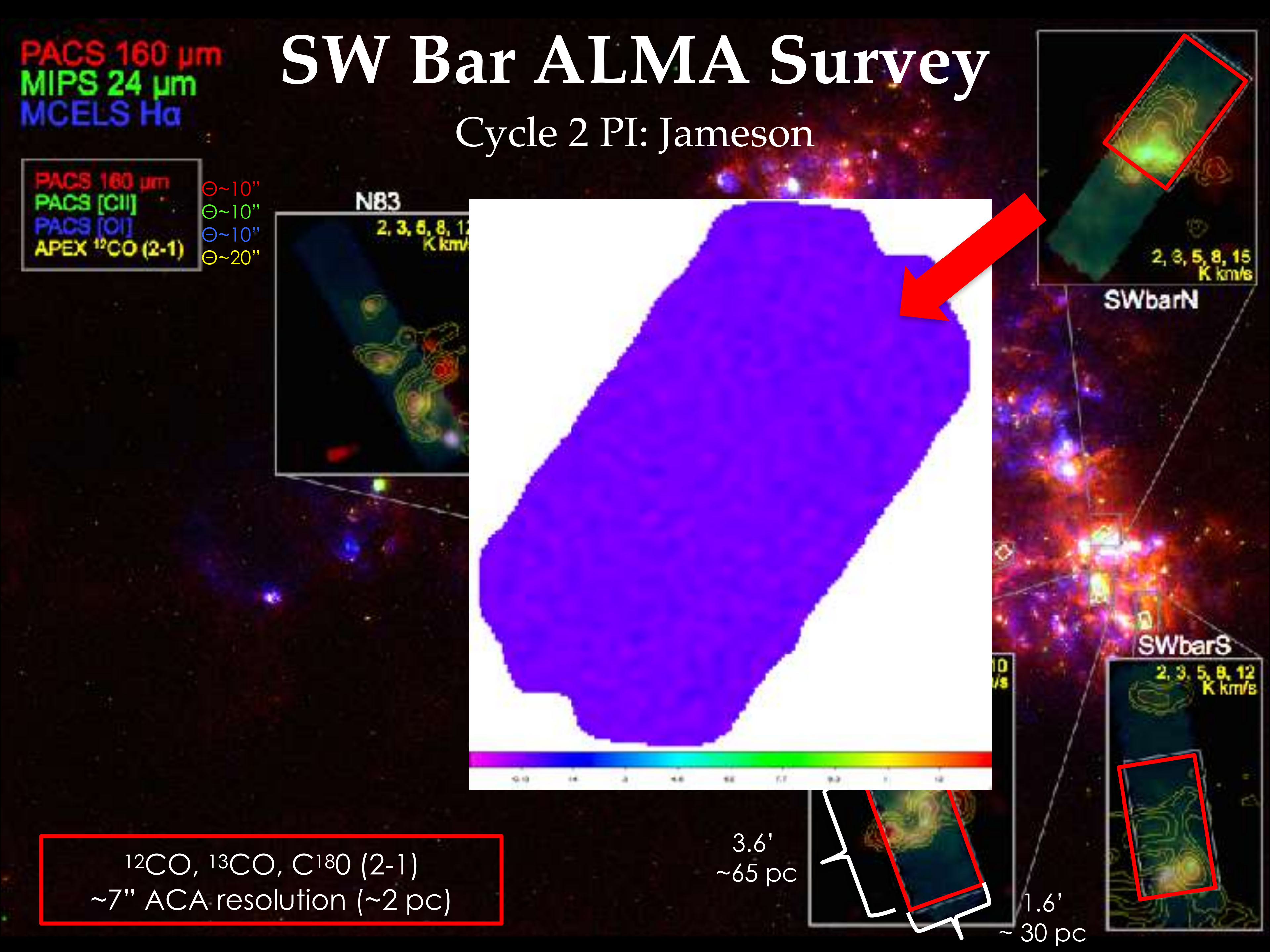
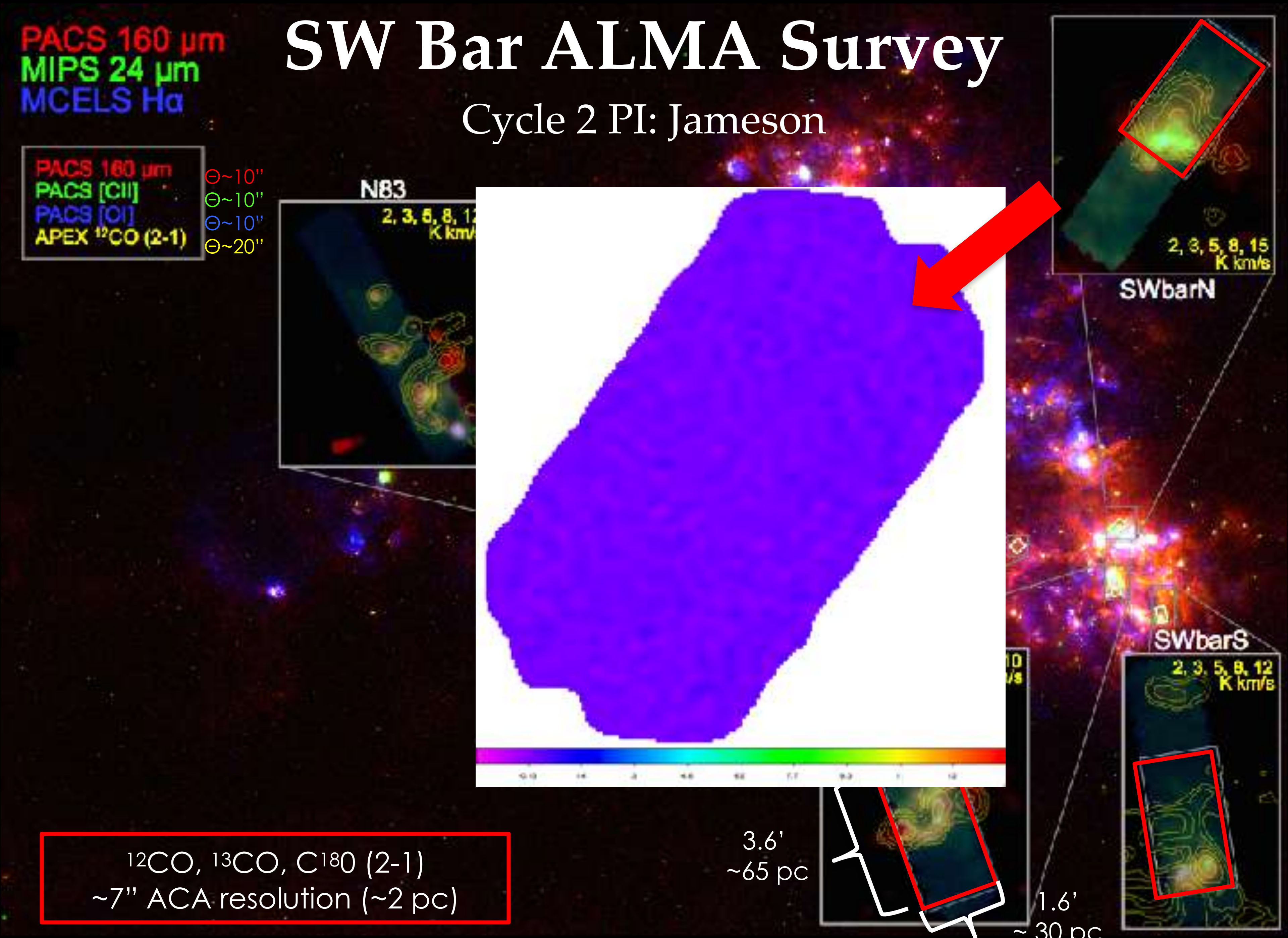
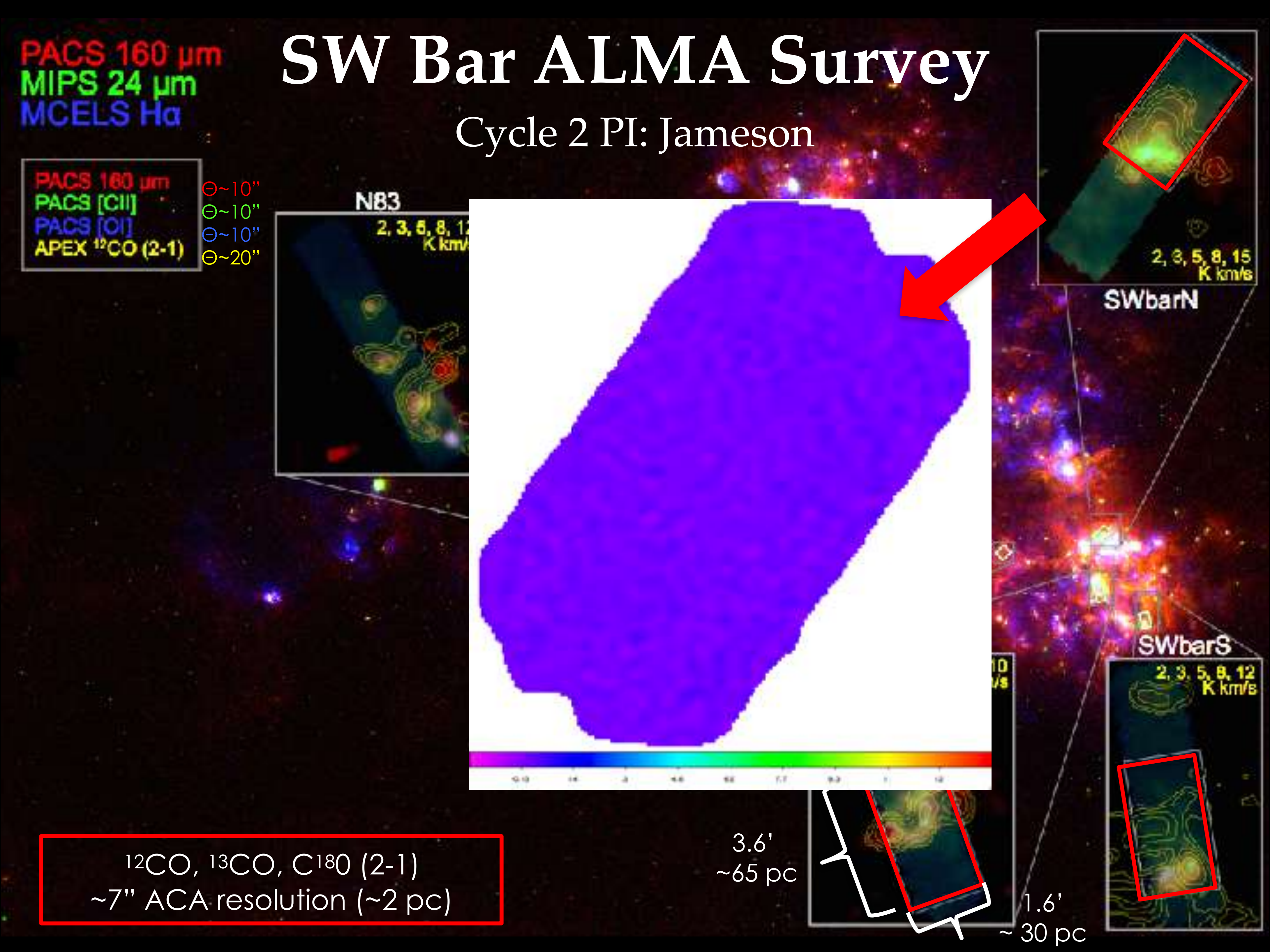


SW Bar ALMA Survey

Cycle 2 PI: Jameson

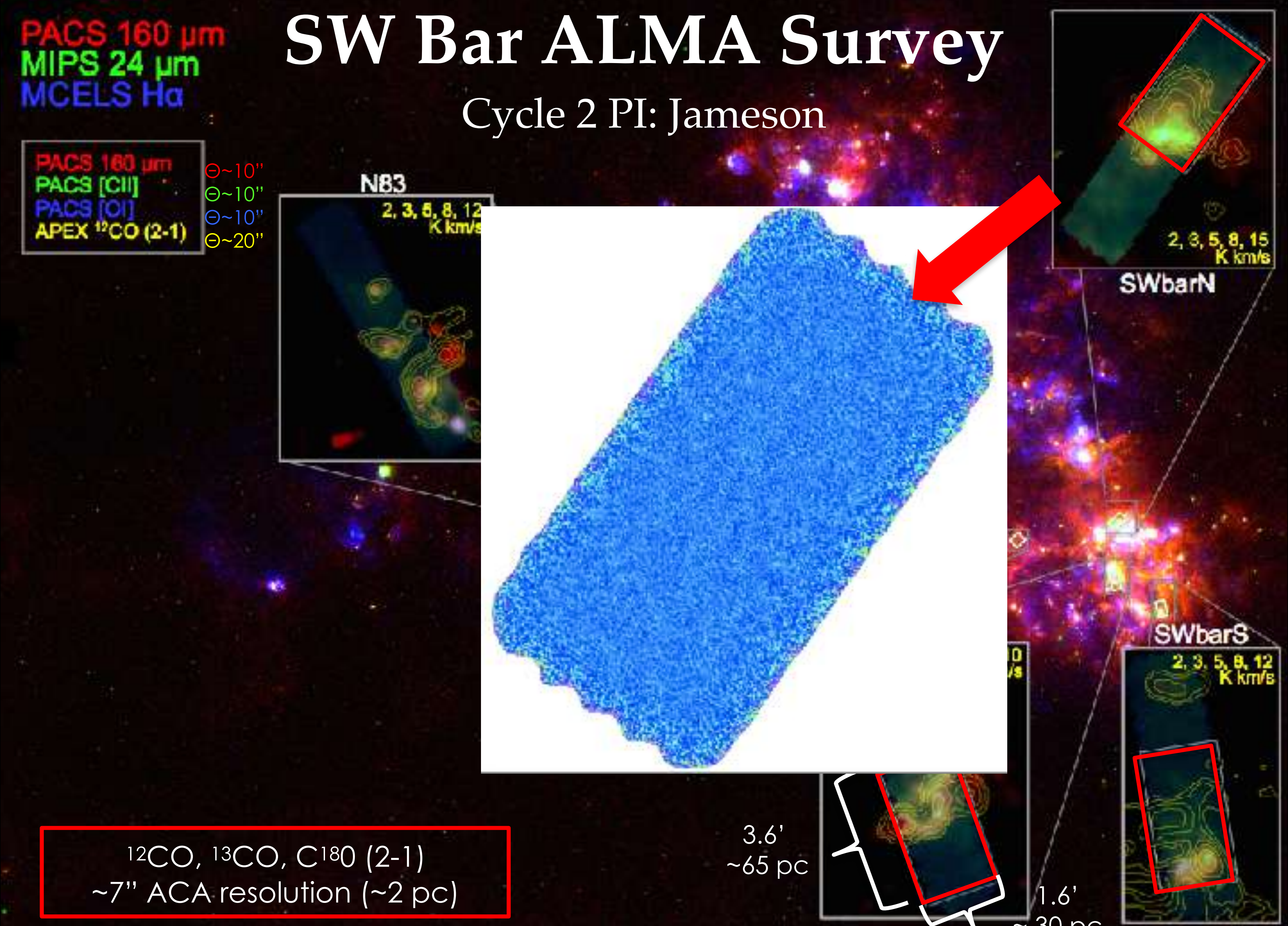


^{12}CO, ^{13}CO, $C^{18}0$ (2-1)
~7" ACA resolution (~2 pc)


SW Bar ALMA Survey
Cycle 2 PI: Jameson
PACS 160 μm
MIPS 24 μm
MCELS Hα
PACS 160 μm
PACS [CII]
PACS [OI]
APEX 12CO (2-1)
Θ~10"
Θ~10"
Θ~10"
Θ~20"
N83
2, 3, 5, 8, 12
K km/s
2, 3, 5, 8, 15
K km/s
SWbarN
SWbarS
2, 3, 5, 8, 12
K km/s
12CO, 13CO, C18O (2-1)
~7" ACA resolution (~2 pc)
3.6'
~65 pc
1.6'
~ 30 pc

SW Bar ALMA Survey

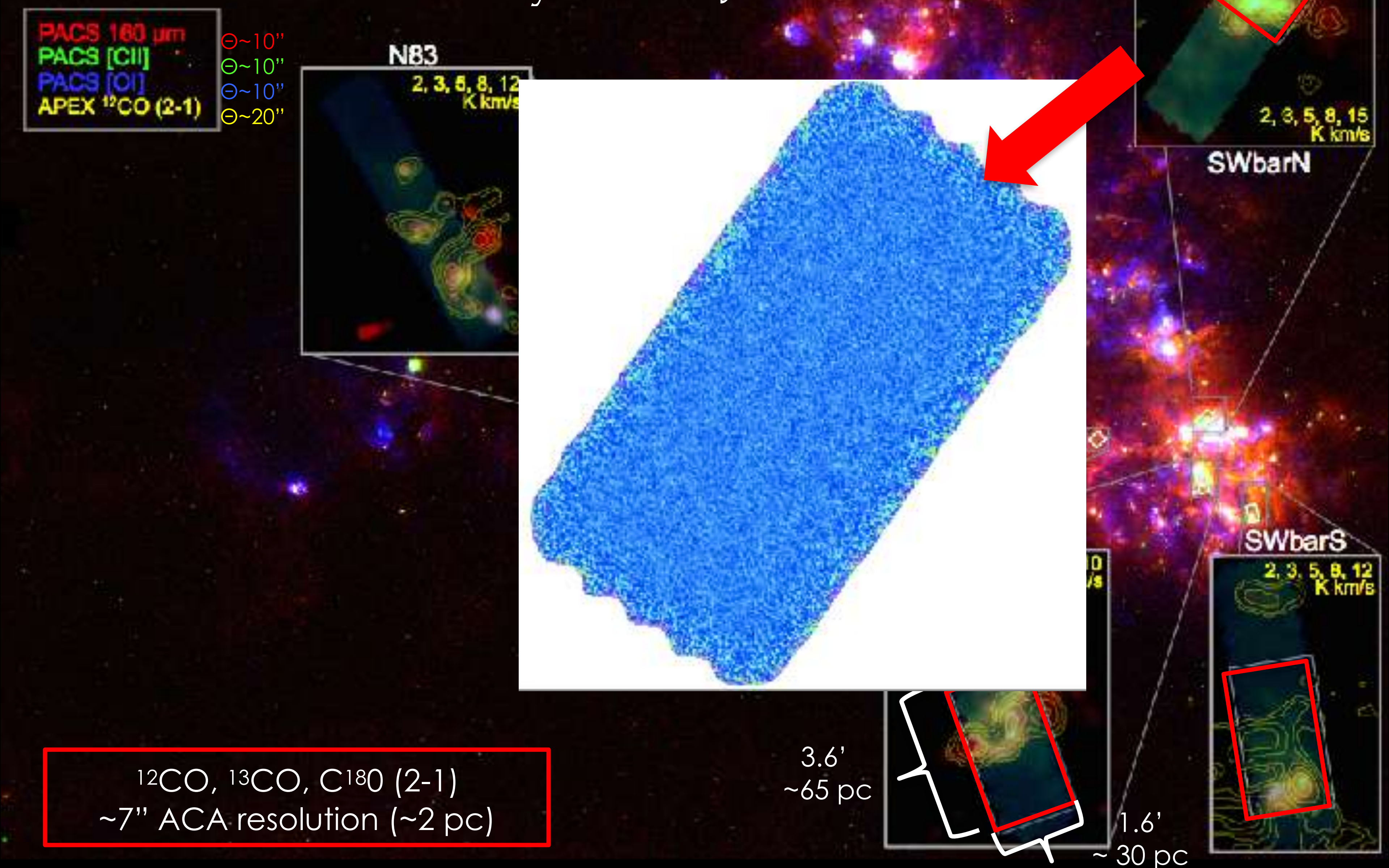
Cycle 2 PI: Jameson



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

SW Bar ALMA Survey

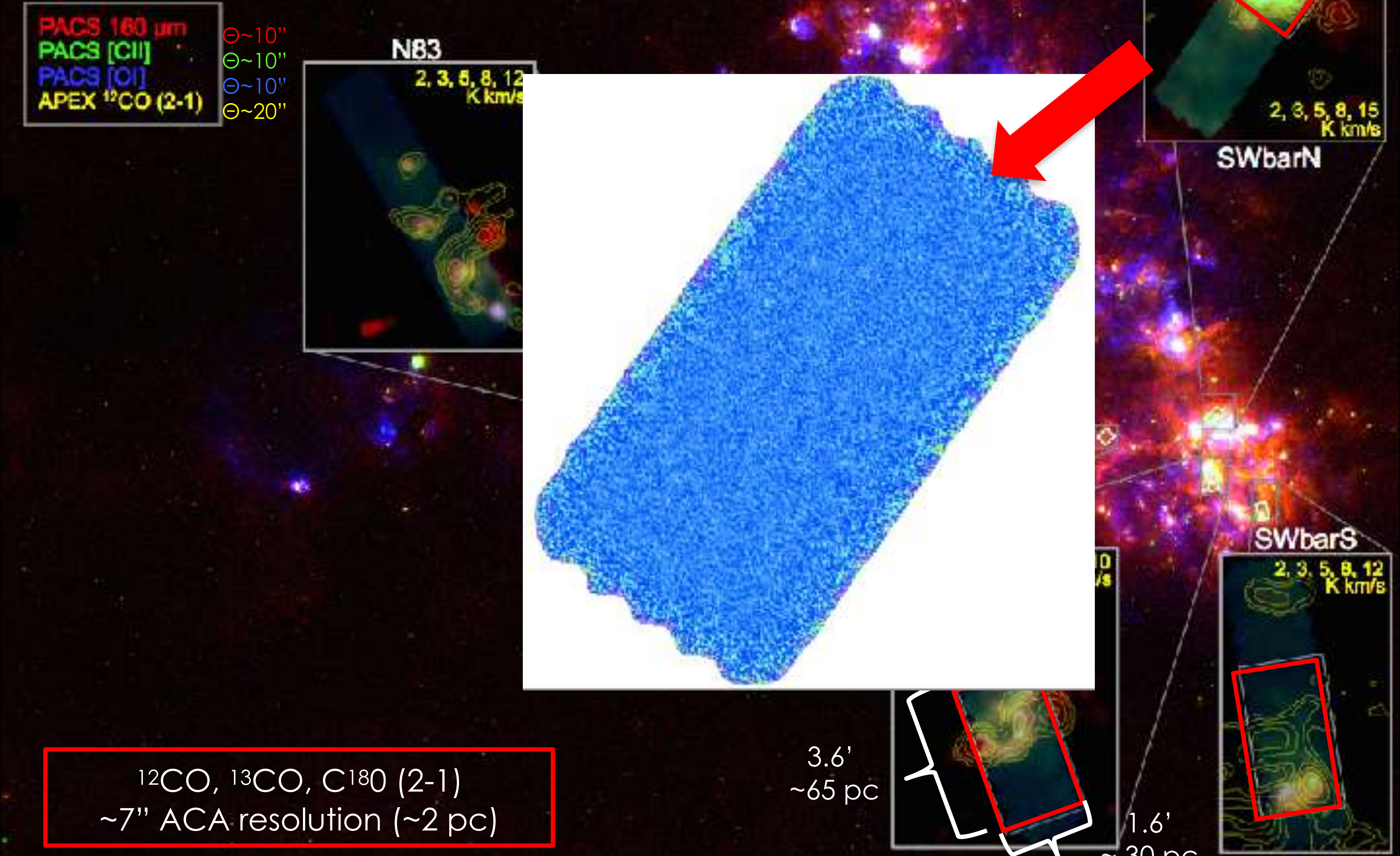
Cycle 2 PI: Jameson



^{12}CO, ^{13}CO, C^{18}0 (2-1)
~7'' ACA resolution (~2 pc)

SW Bar ALMA Survey

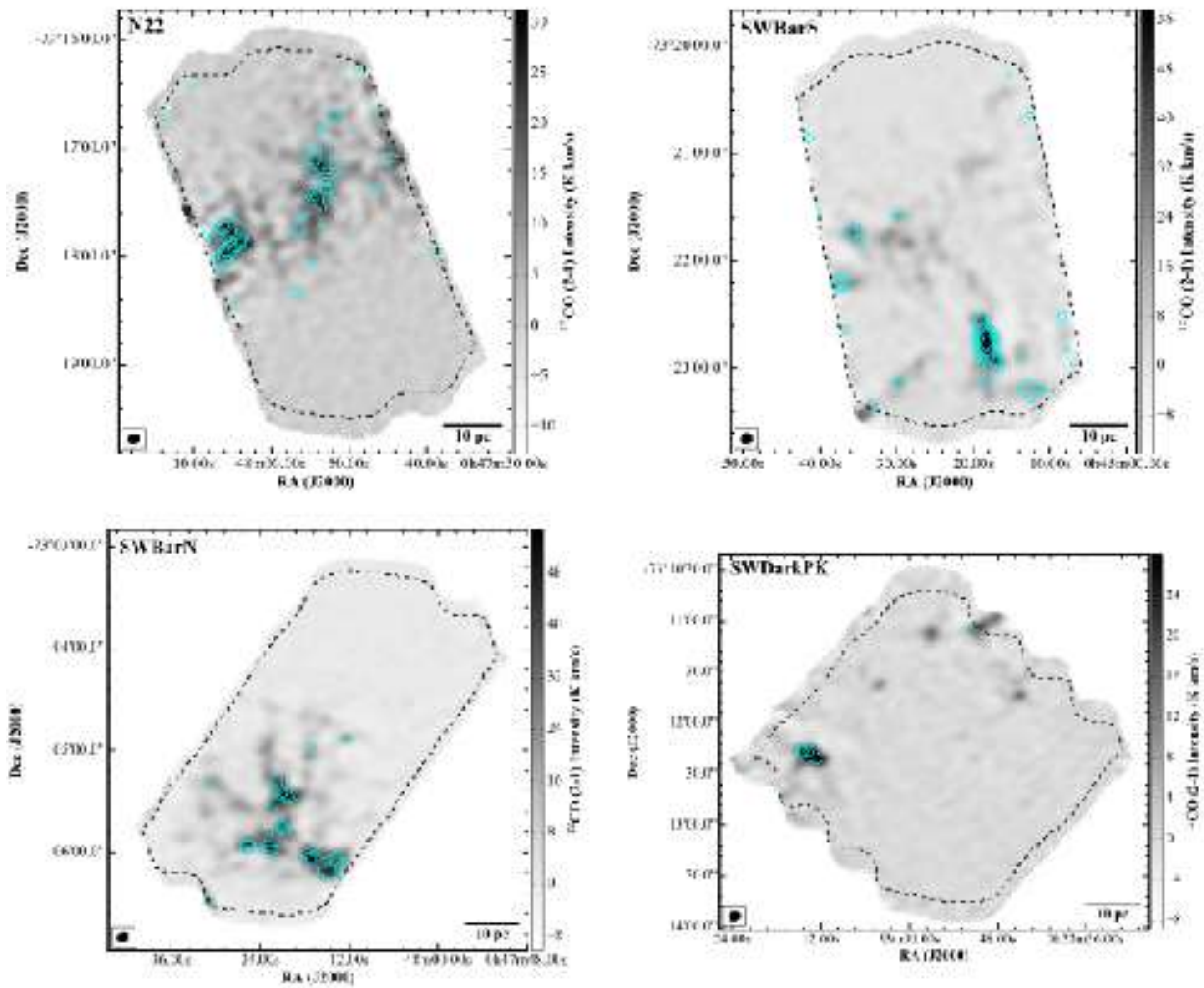
Cycle 2 PI: Jameson



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

ALMA Survey of the Southwest Bar:

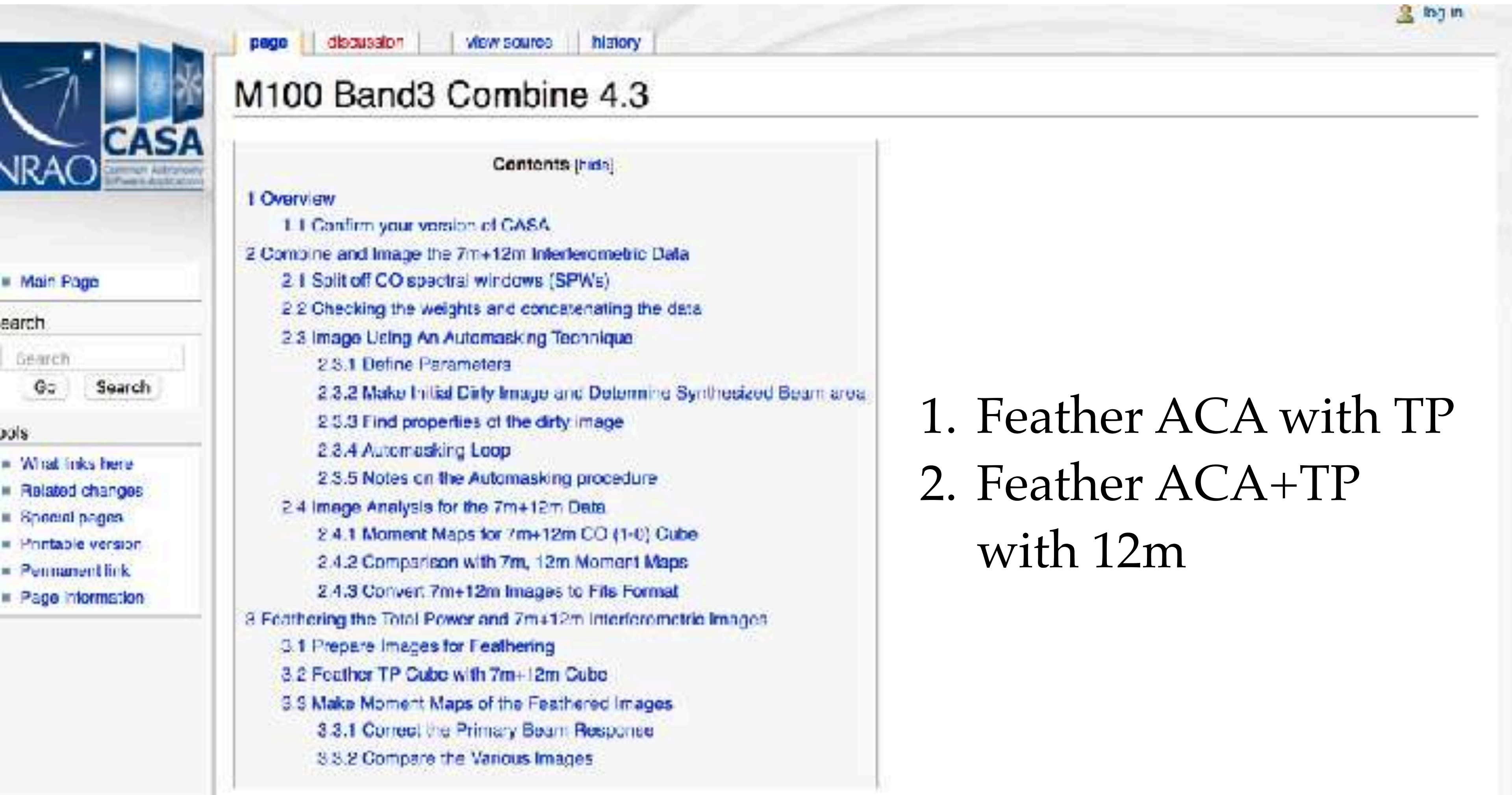
^{12}CO (2-1) ACA+TP Images



^{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



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

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Fin
I am free to go.
Yet I remain.
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