# The ALMA Archive and Data Reduction

### **George Bendo**

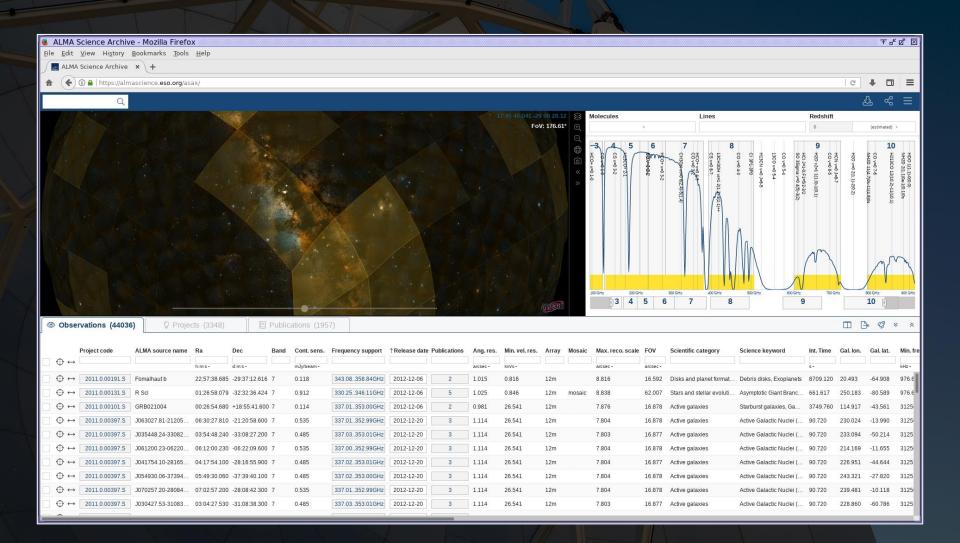
UK ALMA Regional Centre Node Jodrell Bank Centre for Astrophysics The University of Manchester

# Kazi Rygl

Italian ALMA Regional Centre Node INAF - Istituto di Radioastronomia



The ALMA Science Archive was updated within the past year. The website is <u>https://almascience.eso.org/asax/</u>. The default view shows the entire contents of the archive.



#### The interface has three sections:

- The sky viewer
- The spectral viewer
- The results table

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Project code       ALMA source name       Ra       I $↔$ $↔$ $h.ms.*$ $h.ms.*$ $↔$ $2011.0.00191.S$ $Fomalhautb$ $22.57.38.685$ $↔$ $2011.0.00131.S$ $R.Scl$ $01.265.58.079$ $↔$ $2011.0.00131.S$ $R.B021004$ $00.2654.680$ $↔$ $2011.0.00397.S$ $J063027.81-21205$ $06.30.27.810$ $↔$ $2011.0.00397.S$ $J035448.24.33082$ $035448.240$ $↔$ $2011.0.00397.S$ $J061200.23.06220$ $06:12.00.230$	Dec         Band         Cont. sens.         Frequency support           dms-         mJybeam-         mJybeam-           29:37:12.616         7         0.118         343.08.358.84GHz           32:32:36.424         7         0.912         330.25.346.11GHz           +18:55:41.600         7         0.114         337.01.353.00GHz           -21:20:58.600         7         0.535         337.03.353.01GHz           -33:08:27:200         7         0.485         337.03.353.01GHz           -06:22:09.600         7         0.535         337.00.352.99GHz	arcsec         km/s           2012-12-06         2         1.015         0.816           2012-12-06         5         1.025         0.846           2012-12-06         2         0.981         26.541           2012-12-06         3         1.114         26.541           2012-12-02         3         1.114         26.541           2012-12-20         3         1.114         26.541           2012-12-20         3         1.114         26.541	Array         Mosaic         Max. reco. scale         FOV           Array         Mosaic         Aar. reco. scale         FOV           12m         8.816         16.592           12m         8.838         62.007           12m         7.876         16.878           12m         7.804         16.878           12m         7.804         16.878           12m         7.803         16.877           12m         7.804         16.878	7     8     9       Scientific category     Science keyword       Disks and planet format     Debris disks, Exoplanets       Stars and stellar evoluti     Asymptotic Giant Branc       Active galaxies     Starburst galaxies, Ga       Active galaxies     Active Galactic Nuclei (       Active galaxies     Active Galactic Nuclei (       Active galaxies     Active Galactic Nuclei (	IO         IO           Int. Time         Gal. Ion.         Gal. Iat.         Min. fre           s-         Secondary         Secondary         Secondary         Secondary           8709.120         20.493         -64.908         976.6         Secondary           661.617         250.183         -80.589         976.6         Secondary           3749.760         114.917         -43.561         3125           90.720         230.024         -13.990         3125           90.720         23.094         -50.214         3125           90.720         214.169         -11.655         3125
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Project code       ALMA source name       Ra       I	Dec         Band         Cont. sens.         Frequency support           dms-         mybbeam-         mybbeam-         mybbeam-           293712.616         7         0.118         343.08.358.84GHz           32.32.36.424         7         0.912         330.25.346.11GHz           +18.55.41.600         7         0.114         337.01.353.00GHz           -21.20.56.00         7         0.535         337.01.352.99GHz           -33.08.27.200         7         0.485         337.00.352.99GHz           -28.16.55.900         7         0.485         337.02.353.01GHz           -337.39.40.100         7         0.485         337.02.353.00GHz           -28.06.42.300         7         0.535         337.01.352.99GHz	arcsec         km/s           2012-12-06         2         1.015         0.816           2012-12-06         5         1.025         0.846           2012-12-06         2         0.981         26.541           2012-12-06         2         0.981         26.541           2012-12-06         3         1.114         26.541           2012-12-20         3         1.114         26.541           2012-12-20         3         1.114         26.541           2012-12-20         3         1.114         26.541           2012-12-20         3         1.114         26.541           2012-12-20         3         1.114         26.541           2012-12-20         3         1.114         26.541           2012-12-20         3         1.114         26.541           2012-12-20         3         1.114         26.541	Array         Mosaic         Max. reco. scale         FOV           Array         Mosaic         Max. reco. scale         FOV           arcsec -         arcsec -         arcsec -           12m         8.816         16.592           12m         mosaic         8.838         62.007           12m         7.876         16.878           12m         7.804         16.878	7     8     9       Scientific category     Science keyword       Disks and planet format     Debris disks, Exoplanets       Stars and stellar evoluti     Asymptotic Giant Branc       Active galaxies     Starburst galaxies, Ga       Active galaxies     Active Galactic Nuclei (	IO         IO           III. Time         Gal. Ion.         Gal. Iat.         Min. fre           s-         Sal. Iat.         Min. fre         Sal. Iat.         Min. fre           s-         Sal. Iat.         Min. fre         Sal. Iat.         Min. fre           s-         Sal. Iat.         Min. fre         Sal. Iat.         Min. fre           s-         Sal. Iat.         Min. fre         Sal. Iat.         Min. fre           s-         Sal. Iat.         Min. fre         Sal. Iat.         Min. fre           s-         Sal. Iat.         Min. fre         Sal. Iat.         Min. fre           s-         Sal. Iat.         Min. fre         Sal. Iat.         Min. fre           s-         Sal. Iat.         Min. fre         Sal. Iat.         Min. fre           Sal. Iat.         Sal. Iat.         Min. fre         Sal. Iat.         Min. fre           Sal. Iat.         Sal. Iat.         Sal. Iat.         Min. fre         Iat. Iat.         Sal. Iat.           Sal. Iat.         Sal. Iat.         Sal. Iat.         Min. fre         Sal. Iat.         Sal. Iat.           Sal. Iat.         Sal. Iat.         Sal. Iat.         Sal. Iat.         Sal. Iat.         Sal. Iat. <t< td=""></t<>
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#### The results table actually has three tabs:

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	Project Code	Project Title	Туре	PIName	↑ Max. Release Date	Publications	Observations	SB names
$\leftrightarrow$								
$\leftrightarrow$	2011.0.00236.S	The Dynamics of Massive Starless Cores	S	Tan, Jonathan	2013-01-23	4	4	Project236_ES_v2_ks
$\leftrightarrow$	2011.0.00268.S	Metallicity of a Submillimeter Galaxy at z=5	S	Nagao, Tohru	2013-02-09	3	1	LESS J0332-2756
$\leftrightarrow$	2011.0.00454.S	(Why) Is CenA a source of Ultra High Energy Cosmic Rays: Shock acceleration, jet and UHECR composition	S	Nagar, Neil	2013-02-14	1	6	Band 6 CenA - CO knot S1
$\leftrightarrow$	2011.0.00851.S	The Origin of the Destroyed Minor Planet at G29-38: a Main Belt or Kuiper Belt Analog?	S	Farihi, Jay	2013-02-14	1	2	G29-38 Band 6 RA=23: Run x2, G29-38 Band 7 RA=23: Run x5
$\leftrightarrow$	2011.0.00294.S	More than LESS: The first fully-identified submillimetre survey	S	Smail, Ian	2013-02-15	19	122	Targets1-16, Targets112-126, Targets17-32, Targets33-48, Targets49
$\leftrightarrow$	2011.0.00510.S	Probing the Molecular Outflows of the Coldest Known Object in the Universe: The Boomerang Nebula	S	Sahai, Raghvendra	2013-03-13	2	2	B3 1 SB of 1 - Boomerang Nebula CO 1-0, B6 1 SB of 1 Boomerang N
$\leftrightarrow$	2011.0.00131.S	Piecing the shell together: ALMA and the detached shell around R Scl	S	Maercker, Matthias	2013-03-29	5	3	R Sci B3 Spec 1: Run x2, R Sci B6: Run x3, R Sci B7: Run x4
$\leftrightarrow$	2011.0.00367.S	Outflow Entrainment in HH 46/47 v0.6	S	Mardones, Diego	2013-03-30	1	1	HH46/47 12CO HH46/47 C17O
$\leftrightarrow$	2011.0.00808.S	Probing the vertical structure of Saturn's storm with ALMA	S	Cavalie, Thibault	2013-04-23	0	1	GROUP_1_SB: Run directly after GROUP_2_SB GROUP_2_SB: Run
$\leftrightarrow$	2011.0.00101.S	Shedding Light on Distant Starburst Galaxies Hosting Gamma-ray Bursts v9	S	Wang, Wei-Hao	2013-05-01	2	2	GRB021004, GRB080607
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#### The results table actually has three tabs:

- Observation
- Project

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⊕ ↔ 2013ApJ77996T Tan, Jonathan C. ApJ 2013 The Dynamics of Massive Starless Cores with ALMA	2013-01-23 1	4 Tan, Jonatha	n C.; Kong, Shuo; Butler, Michael J.	Caselli, Paola; Font
C ↔ 2016ApJ828100F FengE, Siyi ApJ 2016 Outflow Detection in a 70 µm Dark High-Mass Core	2013-01-23 1		Beuther, Henrik; Zhang, Qizhou; Li	
↔ 2016ApJ82194K Kong, Shuo ApJ 2016 The Deuterium Fraction in Massive Starless Cores and Dynamical Implications	2013-01-23 1		ſan, Jonathan C.; Caselli, Paola; Fo	
⊕ ↔ 2012A&A542L34N Nagao, T. A&A 2012 ALMA reveals a chemically evolved submillimeter galaxy at z = 4.76	2013-02-09 1	1 Nagao, T.; Ma	iolino, R.; De Breuck, C.; Caselli, P	; Hatsukade, B.; Saig
↔ 2014MNRAS.444.1821F Farihi, J. MNRAS 2014 ALMA and Herschel observations of the prototype dusty and polluted white dwarf G29-38	2013-02-14 1	2 Farihi, J.; Wya	tt, M. C.; Greaves, J. S.; Bonsor, A.;	Sibthorpe, B.; Panić, O.
↔ 2016A&A586A45S Salomé, Q. A&A 2016 Star formation efficiency along the radio jet in Centaurus A	2013-02-14 1	6 Salomé, Q.; S	alomé, P.; Combes, F.; Hamer, S.; H	leywood, I.
⊕ ↔ 2017ApJ_840_78D Danielson, A.L. R. ApJ 2017 An ALMA Survey of Submillimeter Galaxies in the Extended Chandra Deep Field South: Spectroscopic Redshifts	2013-02-15 1	122 Danielson, A	L. R.; Swinbank, A. M.; Smail, Ian;	Simpson, J. M.: Case

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MacKenzie, Todd P.; Scott, Douglas; Swinbank, Mark

Simpson, J. M.; Swinbank, A. M.; Smail, Ian; Alexander, D. M.; Brandt,

Lindroos, L.; Knudsen, K. K.; Fan, L.; Conway, J.; Coppin, K.; Decarli,

Thomson, A. P.; Ivison, R. J.; Simpson, J. M.; Swinbank, A. M.; Smail,

MNRAS 2014 An ALMA survey of submillimetre galaxies in the Extended Chandra Deep Field South: radio properties and the far-infrared/ra.

Searches can be done in one of two ways. The best way to start a search, especially for a single object, is to use the search menu that is displayed when hovering over the rectangle with the magnifying glass.

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The other method is to type in search criteria in the entry fields above each column in the results table. This can also be done after initially setting up a search using the search menu.

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When the number of results in the results table changes, the map and spectrum panels will automatically adjust to show the observed fields and spectra in more detail.

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	⊕ • ⊕				-11:33:06.185		0.234	215.81232.69GHz		0	4.725	0.159	7m		28.085			Disks around low-mass			-2.557	122.078
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	⊕ •	→ 2018.1.01131.S			-11:33:06.183		0.915	250.91268.10GHz	2020-02-21	1	4.346	0.634	7m		25.668	38.467	ISM and star formation	Outflows, jets and ioniz	302.400	224.606	-2.557	564.495
	⊕ •			07:03:43.158	-11:33:06.183	6	0.073	217.11233.47GHz	2020-08-24	1	0.968	0.183	12m		9.345	25.846	ISM and star formation	Outflows, jets and ioniz	302.400	224.606	-2.557	141.132
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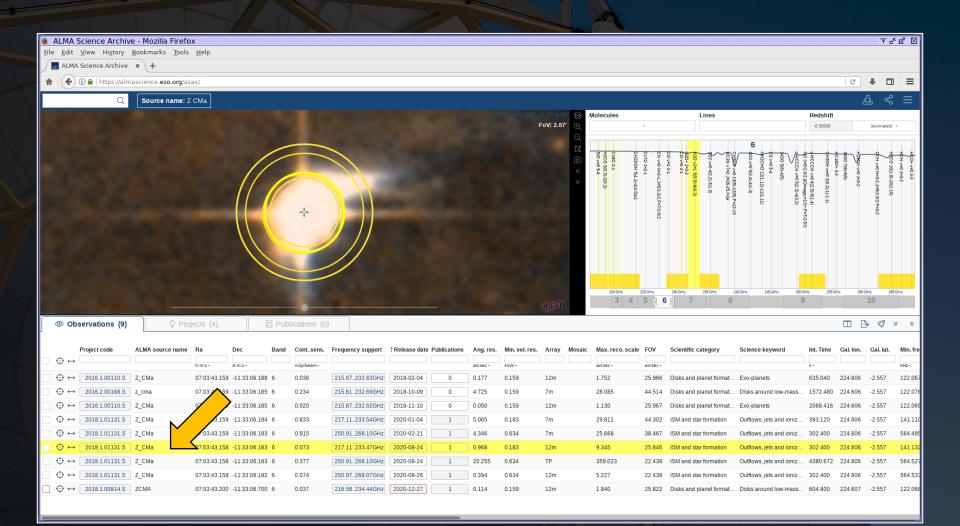
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The map display can be adjusted to display different wavebands. The spectrum can be adjusted to show broader or narrower frequency ranges, to show different spectral lines, and to show those lines at different redshifts.

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Hovering over an entry in the results table will highlight the row, the field in the map panel, and the frequency ranges in the spectrum panel.



The results from a search can be sorted by any column. The results can also be further filtered.

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Clicking on the checkbox next to an observation will select the data for download. The row will change to orange as will the field in the map panel and the frequency range in the spectral plot.

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Proprietary data can be selected but cannot be downloaded. The checkbox will appear red when these data are selected. Other data (such as for programs where the observations are not yet complete or where the data are in QA3) cannot be selected.

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	Φ	$\leftrightarrow$	2016.2.00168.S	z_cma	07:03:43.159	-11:33:06.185	6	0.234	215.81232.69GHz	2018-10-09	0	4.725	0.159	7m	28.085	44.514	Disks and planet format	Disks around low-mass	1572.480	224.606	-2.557	122.078
	Φ	$\leftrightarrow$	2016.1.00110.S	Z_CMa	07:03:43.159	-11:33:06.185	6	0.020	215.87232.62GHz	2018-11-10	0	0.050	0.159	12m	1.130	25.967	Disks and planet format	Exo-planets	2068.416	224.606	-2.557	122.069
	Φ	$\leftrightarrow$	2018.1.01131.S	Z_CMa	07:03:43.159	-11:33:06.184	6	0.833	217.11233.54GHz	2020-01-04	1	5.065	0.183	7m	29.811	44.302	ISM and star formation	Outflows, jets and ioniz	393.120	224.606	-2.557	141.110
	Φ	$\leftrightarrow$	2018.1.01131.S	Z_CMa	07:03:43.159	-11:33:06.183	6	0.915	250.91268.10GHz	2020-02-21	1	4.346	0.634	7m	25.668	38.467	ISM and star formation	Outflows, jets and ioniz	302.400	224.606	-2.557	564.495
~	Φ	$\leftrightarrow$	2018.1.01131.S	Z_CMa	07:03:43.158	-11:33:06.183	6	0.073	217.11233.47GHz	2020-08-24	1	0.968	0.183	12m	9.345	25.846	ISM and star formation	Outflows, jets and ioniz	302.400	224.606	-2.557	141.132
	Φ	$\leftrightarrow$	2018.1.01131.S	Z_CMa	07:03:43.158	-11:33:06.183	6	0.377	250.91268.10GHz	2020-08-24	1	20.255	0.634	TP	359.023	22.439	ISM and star formation	Outflows, jets and ioniz	4380.672	224.606	-2.557	564.527
	Φ	$\leftrightarrow$	2018.1.01131.S	Z_CMa	07:03:43.158	-11:33:06.182	6	0.074	250.97268.07GHz	2020-08-26	1	0.394	0.634	12m	5.227	22.438	ISM and star formation	Outflows, jets and ioniz	302.400	224.606	-2.557	564.533
-	$\oplus$	$\leftrightarrow$	2018.1.00814.S	ZCMA	07:03:43.200	-11:33:06.700	6	0.037	216.58234.44GHz	2020-12-27	1	0.114	0.159	12m	1.840	25.822	Disks and planet format	Disks around low-mass	604.800	224.607	-2.557	122.068

The interface has several other options as well. These include saving the search results (or a link to those results), accessing documentation, and adjusting the display.

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	<ul><li>⊕</li><li>⊕</li><li>⊕</li></ul>	F ↔ ↔	Project code	ALMA source name Z_CMa z_cma	Ra h:m:s- 07:03:43.159 07:03:43.159	Dec d:m:s- -11:33:06.188	Band 3 6 5 6	Cont. sens. mJy/beam - 0.036	Frequency support	2018-02-04 2018-10-09	0	arcsec • 0.177	Min. vel. res. km/s- 0.159	Array Mosaic	3 4 Max. reco. scale arcsec - 1.752	5 6 FOV arcsec - 25.966 44.514	Scientific cate	egory net format	Science keyv	rword d low-mass	9 Int. Time 5 - 635.040	e Gal 0 224	1 . Ion. ( 4.606 - 4.606 -	0 <i>C</i> <i>G</i> <i>G</i> <i>G</i> <i>G</i> <i>G</i> <i>G</i> <i>G</i> <i>G</i>	Min. fre kHz • 122.06
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	$ \begin{array}{c} \oplus \\ \oplus \\$	$\begin{array}{c} F \\ \leftrightarrow \end{array} \begin{bmatrix} \\ \bullet \end{array} \\ \begin{array}{c} F \\ \bullet \end{array} \\ \bullet \end{array} \\ \bullet \end{array} \\ \begin{array}{c} F \\ \bullet \end{array} \\ \begin{bmatrix} F \\ \bullet \end{array} \\ \\ \\ \begin{bmatrix} F \\ \bullet \end{array} \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\$	Project code 2016.1.00110.S 2016.2.00168.S 2016.1.00110.S	ALMA source name Z_CMa z_cma Z_CMa Z_CMa	Ra h:ms- 07:03:43.159 07:03:43.159 07:03:43.159 07:03:43.159	Dec d:mts- -11:33:06.1885 -11:33:06.185	Band 3 6 5 6 5 6 4 6	Cont. sens. mJy/beam - 0.036 0.234 0.020	Frequency support 215.87.232.63GHz 215.81.232.69GHz 215.87.232.62GHz	2018-02-04 2018-10-09 2018-11-10 2020-01-04	0	arcsec - 0.177 4.725 0.050	Min. vel. res. km/s - 0.159 0.159 0.159	Array Mosaic 12m 7m 12m	3 4 Max. reco. scale arcsec - 1.752 28.085 1.130	<b>FOV</b> arcsec- 25.966 44.514 25.967 44.302	Scientific cate Disks and plar Disks and plar	egory net format net format ormation	Science keyv Exo-planets Disks around Exo-planets	yword d low-mass s and ioniz	9 Int. Time 5- 635.040 . 1572.48 2068.41	e Gal 0 224 80 224 16 224 0 224	1. lon. 0 4.606 - 4.606 - 4.606 -	<b>Gal. lat.</b> -2.557 -2.557	Min. fre kHz • 122.06 122.07 122.06
	$ \begin{array}{c} \oplus \\ \oplus \\$	$\begin{array}{c} F \\ $	2016.1.00110.S 2016.2.00168.S 2016.1.00110.S 2018.1.01131.S	ALMA source name Z_CMa Z_CMa Z_CMa Z_CMa Z_CMa	Ra h.m.s- 07:03:43.159 07:03:43.159 07:03:43.159 07:03:43.159 07:03:43.159	Dec d:m:s- -11:33:06.188 -11:33:06.185 -11:33:06.185 -11:33:06.184	Band 6 5 6 5 6 4 6 3 6	Cont. sens. mJy/beam - 0.036 0.234 0.020 0.833	Frequency support 215.87.232.63GHz 215.81.232.69GHz 215.87.232.62GHz 217.11.233.54GHz	2018-02-04 2018-10-09 2018-11-10 2020-01-04 2020-02-21	0	arcsec - 0.177 4.725 0.050 5.065	Min. vel. res. km/s - 0.159 0.159 0.159 0.183	Array Mosaic 12m 12m 12m 7m 7m	3 4 Max.reco.scale arcsec - 1.752 28.085 1.130 29.811	5 6 FOV arcsec - 25.966 44.514 25.967 44.302 38.467	Scientific cate Disks and plar Disks and plar Disks and plar ISM and star fo	egory net format net format ormation ormation	Science keyu Exo-planets Disks around Exo-planets Outflows, jets	yword d low-mass s and ioniz s and ioniz	9 Int. Time 5- 635.040 . 1572.48 2068.41 . 393.120	e Gal 0 224 80 224 16 224 0 224 0 224	1. lon. 0 4.606 - 4.606 - 4.606 -	<b>Gal. lat.</b> -2.557 -2.557 -2.557 -2.557	Min. fre kHz - 122.061 122.074 122.069 141.110
	$ \begin{array}{c} \oplus \\ \oplus \\$	$F$ $\leftrightarrow \leftrightarrow$ $\bullet \leftrightarrow$ $\bullet \leftrightarrow$ $\bullet \leftrightarrow$ $\bullet \leftrightarrow$ $\bullet \leftrightarrow$ $\bullet \leftrightarrow$	2016.1.00110.S           2016.2.00168.S           2016.1.00110.S           2018.1.01131.S	ALMA source name Z_CMa Z_CMa Z_CMa Z_CMa Z_CMa Z_CMa	Ra h.ms- 07:03:43.159 07:03:43.159 07:03:43.159 07:03:43.159 07:03:43.159	Dec d:mus - -11:33:06.1885 -11:33:06.1855 -11:33:06.1845 -11:33:06.184	Band           3         6           5         6           5         6           4         6           3         6	Cont. sens. mJy/beam • 0.036 0.234 0.020 0.833 0.915	Frequency support 215.87.232.63GHz 215.81.232.69GHz 215.87.232.62GHz 217.11.233.54GHz 250.91.268.10GHz	2018-02-04 2018-10-09 2018-11-10 2020-01-04 2020-02-21 2020-08-24	0	arcsec - 0.177 4.725 0.050 5.065 4.346	Min. vel. res. km/s - 0.159 0.159 0.159 0.159 0.183 0.634	Array Mosaic 12m 12m 12m 12m 12m 7m 7m 7m	3 4 Max.reco.scale arcsec - 1.752 28.085 1.130 29.811 25.668	FOV arcsec - 25.966 44.514 25.967 44.302 38.467 25.846	Scientific cate Disks and plar Disks and plar Disks and plar ISM and star fo	egory net format net format ormation ormation	Science keyu Exo-planets Disks around Exo-planets Outflows, jets Outflows, jets	wword d low-mass s and ioniz s and ioniz s and ioniz	9 Int. Time 5- 635.040 . 1572.48 2068.41 . 393.120 . 302.400	e Gal 0 224 80 224 16 224 0 224 0 224 0 224	1. Ion. 0 4.606 - 4.606 - 4.606 - 4.606 -	<b>Gal. lat.</b> -2.557 -2.557 -2.557 -2.557 -2.557 -2.557	Min. fre kHz - 122.067 122.067 122.067 141.110 564.493
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The new page displays the data associated with the entries selected in the search interface. Data are sorted by Science Goal, Group OUS, and Member OUS. (A Member OUS is a unit of data containing one SB.)

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Each Member OUS (or SB) may have the following files available for download:

readme A text file with very basic information

product Final images and image cubes

auxiliary A file containing logs, quality assurance information, scripts, and calibration tables

raw Raw visibility data

external Enhanced data products (including enhanced images or visibility data) created after the data delivery

Each file can be individually selected for download, or subsets of data can be selected for download. Proprietary data cannot be downloaded without logging in and without being delegate access to the data.

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When data download is started, two options are available.

- The download script can be executed in a Linux/Mac console to download data. The file must be made executable using chmod before doing this. When the file is executed, the data will be downloaded to the current directory.
  - If the script is interrupted, it is possible to restart the downloads from where they were stopped by restarting the script.
- The other download option is the file list. The file list is just a set of links directly to the data.
  - The individual results in the ALMA request handler page include links that can also be clicked on to download the data.

When ALMA archival data are downloaded and unpacked, the files will generally be sorted into a multi-layered directory structure like the following example:

```
2018.1.01131.5
  science_goal.uid___A001_X135b_X60
     group.uid A001 X135b X68
        member.uid / A001/X135b X6b
           calibration
           log
           product
           qa
           raw
           script
```

The directories contain the following files:

calibration Calibration plots and tables

log Log files

product Fully processed images

qa

raw

Raw data (ASDM format)

Quality assurance information

README

A text file with information from calibration and imaging as well as general file information

script

Data processing scripts

Raw ALMA data consist of the amplitudes and phases for the combined signals from pairs of antennas. These are called visibility data.

CASA data, including the visibility data, are stored in object oriented file systems rather than individual fits files. The directories contain multiple binary tables.

The raw visibility data are in a format labelled ASDM, but for data processing, CASA converts these data to a format referred to as measurement sets.

#### Contents of an example measurement set:

ANTENNA/ ASDM ANTENNA/ ASDM CALATMOSPHERE/ ASDM CALWVR/ ASDM CORRELATORMODE/ ASDM RECEIVER/ ASDM SBSUMMARY/ ASDM SOURCE/ ASDM STATION/ CALDEVICE/ DATA DESCRIPTION/ FEED/ FIELD/ FLAG CMD/ HISTORY/ OBSERVATION/ POINTING/ POLARIZATION/

PROCESSOR/ SOURCE/ SPECTRAL WINDOW/ STATE/ SYSCAL/ SYSPOWER/ table.dat table.f1 table.f10 table.f11 table.f12 table.f13 table.f14 table.f15 table.f16 table.f17 table.f17 TSM1 table.f17 TSM2

table.f17 TSM3 table.f17 TSM4 table.f18 table.f19 table.f2 table.f20 table.f20 TSM0 table.f21 table.f21 TSM1 table.f21 TSM2 table.f21 TSM3 table.f21 TSM4 table.f22 table.f22 TSM1 table.f22 TSM2 table.f23 table.f23 TSM1 table.f23 TSM2

table.f24
table.f24\_TSM1
table.f24\_TSM2
table.f24\_TSM3
table.f24\_TSM4
table.f3
table.f3
table.f4
table.f5
table.f6
table.f7
table.f8
table.f9
table.info
table.lock
WEATHER/

The contents of a measurement set can be viewed in text format using the listobs command. The following command creates a text file that contains the output from listobs:

listobs(vis='uid\_\_\_A002\_Xd98580\_X354.ms.split.cal', listfile='uid\_\_\_A002\_Xd98580\_X354.ms.split.cal.listobs') The raw visibility data from the archive need to be recalibrated before they can be used to create new images.

The goal of visibility calibration is to apply the following corrections:

- Calibrate phase versus frequency
- Calibrate amplitude versus frequency
- Calibrate phase versus time
- Calibrate amplitude versus time

These corrections are derived from up to three different calibration sources:

- Bandpass calibrator (bright quasar)
- Flux calibrator (bright quasar or Solar System object)
- Phase calibrator (quasar near the science target)

Later versions of ALMA data (from Cycle 3 and later) are mainly pipeline-calibrated.

Older versions of ALMA data (from Cycle 2 and earlier) as well as some complex data from later cycles are distributed with manual calibration scripts.

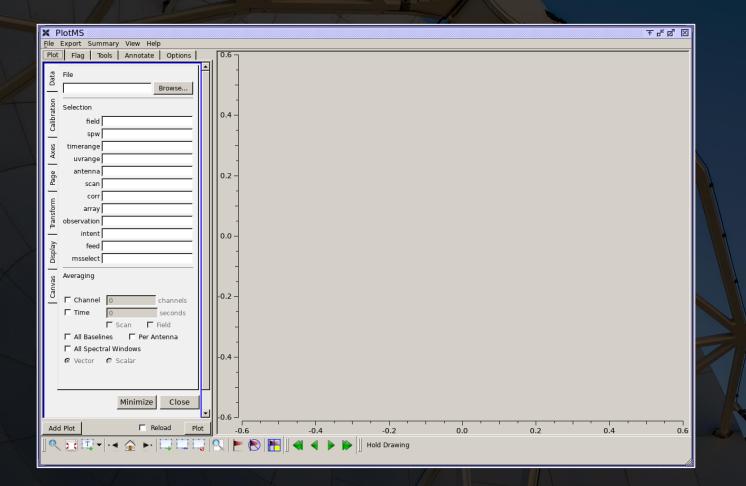
If the script directory contains files ending in scriptForCalibration.py, then the data were manually calibrated. Otherwise, the data were pipeline calibrated.

To recalibrate the data for making images, do the following:

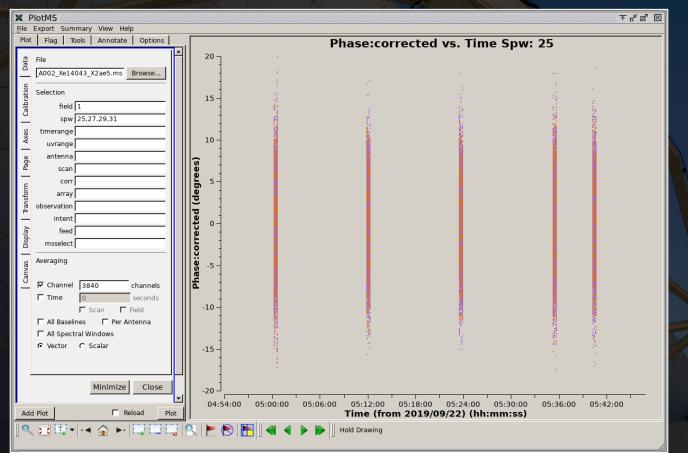
- 1. Go to the script directory.
- Start CASA in a terminal. For pipeline-processed data, use the --pipeline option when starting CASA. (When starting CASA from the app on a Mac, quitting CASA in the terminal and then restarting it with this option works.)
- 3. Execute the script ending in scriptForPI.py using execfile.

The calibrated visibility data will be placed in a new directory called calibrated.

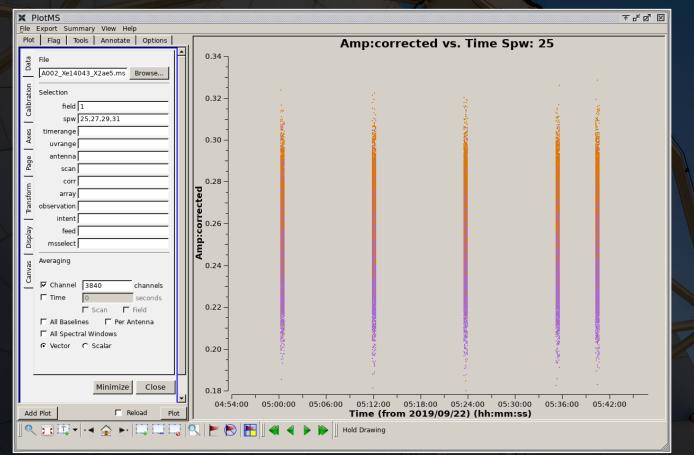
The CASA tool plotms can be used to visually inspect the visibility data. This is useful for checking the quality of the data after it has been calibrated.



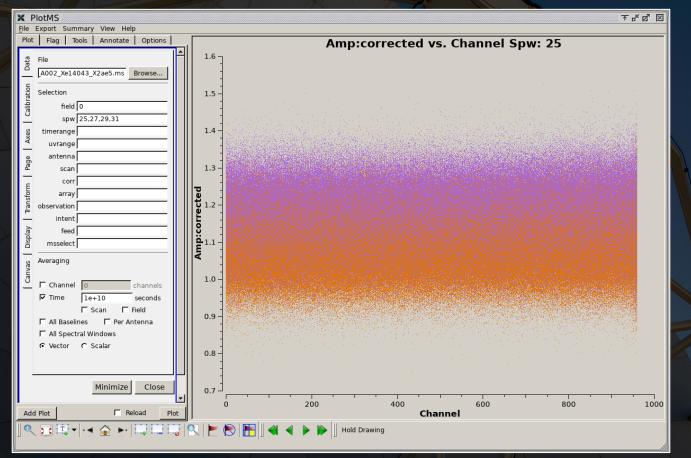
- Plot phase versus time for the phase calibrator
- Plot amplitude versus time for the phase calibrator
- Plot amplitude versus channel for the bandpass calibrator
- Plot amplitude versus uv distance for the flux calibrator



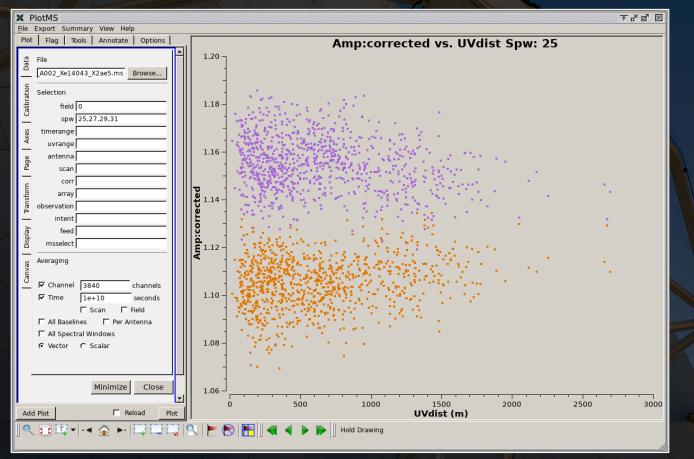
- Plot phase versus time for the phase calibrator
- Plot amplitude versus time for the phase calibrator
- Plot amplitude versus channel for the bandpass calibrator
- Plot amplitude versus uv distance for the flux calibrator



- Plot phase versus time for the phase calibrator
- Plot amplitude versus time for the phase calibrator
- Plot amplitude versus channel for the bandpass calibrator
- Plot amplitude versus uv distance for the flux calibrator



- Plot phase versus time for the phase calibrator
- Plot amplitude versus time for the phase calibrator
- Plot amplitude versus channel for the bandpass calibrator
- Plot amplitude versus uv distance for the flux calibrator



For pipeline-processed archival data, ALMA provides (for all science targets within a Scheduling Block):

- Continuum-subtracted image cubes with the original spectral resolution.
- Continuum images for each spectral window (spw).
- A single continuum image using data from all spws.

For manually-processed archival data, the images in the archive may vary from project to project.

It may be appropriate to re-image ALMA data for multiple reasons:

- The continuum channel selection could be optimized.
- The channel width in the image cube could be altered to improve the S/N of the line emission.
- The parameters used to create the image need to be altered.
- Data from multiple Scheduling Blocks need to be combined.

ALMA images are created with the CASA task tclean. Using an iterative process, tclean simultaneously converts the visibility data into images and performs deconvolution steps to make the beam Gaussian.

To do this, tclean needs to be able to identify the location of source emission and model it. This can be done interactively or non-interactively.

## tclean example (continuum imaging):

```
tclean(vis='uid____A002_Xd98580_X354.ms.split.cal',
  imagename='ZCMa_continuum',
 field='2',
  imsize=[320,320],
  cell='0.15arcsec',
  phasecenter=2,
  specmode='mfs',
  spw='25,27,29,31,33,35,37,39,41:300~959,43:0~85;115~959,45',
  outframe='LSRK',
  deconvolver='hogbom',
  chanchunks=-1,
  niter=500,
  cycleniter=500,
  threshold='0mJy',
  weighting='natural',
  gridder='standard',
  restoringbeam='common',
  pbcor=True,
  interactive=True)
```

For creating image cubes of spectral line emission, it is often useful to subtract the continuum emission from the visibility data. This can be done using uvcontsub, as shown in the example below:

```
uvcontsub(vis='uid___A002_Xd98580_X354.ms.split.cal',
field='2',
spw='43',
fitspw='43:0~85;115~959')
```

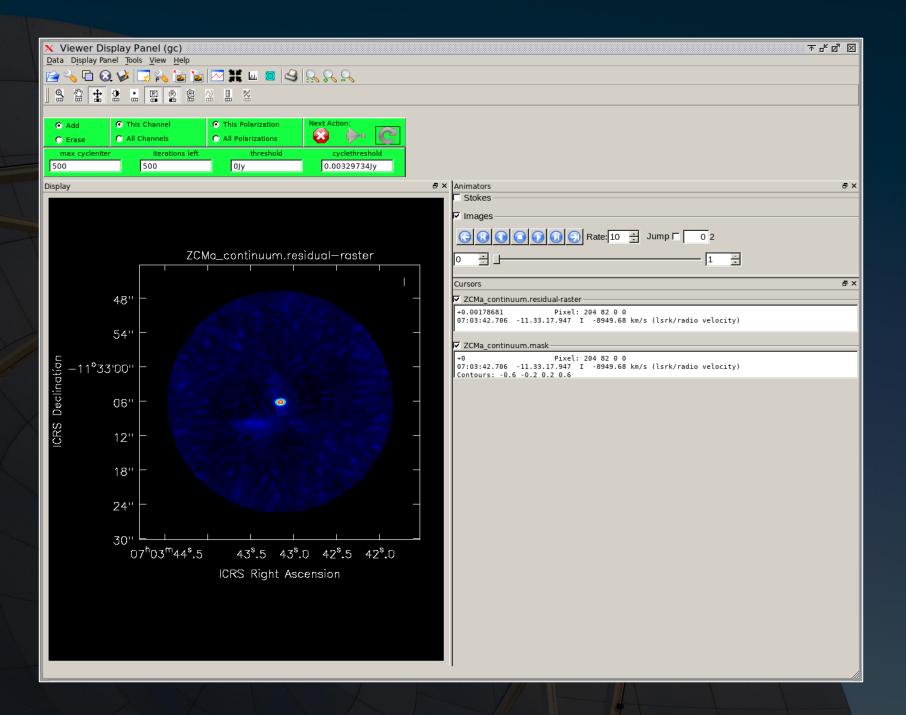
## tclean example (spectral line imaging):

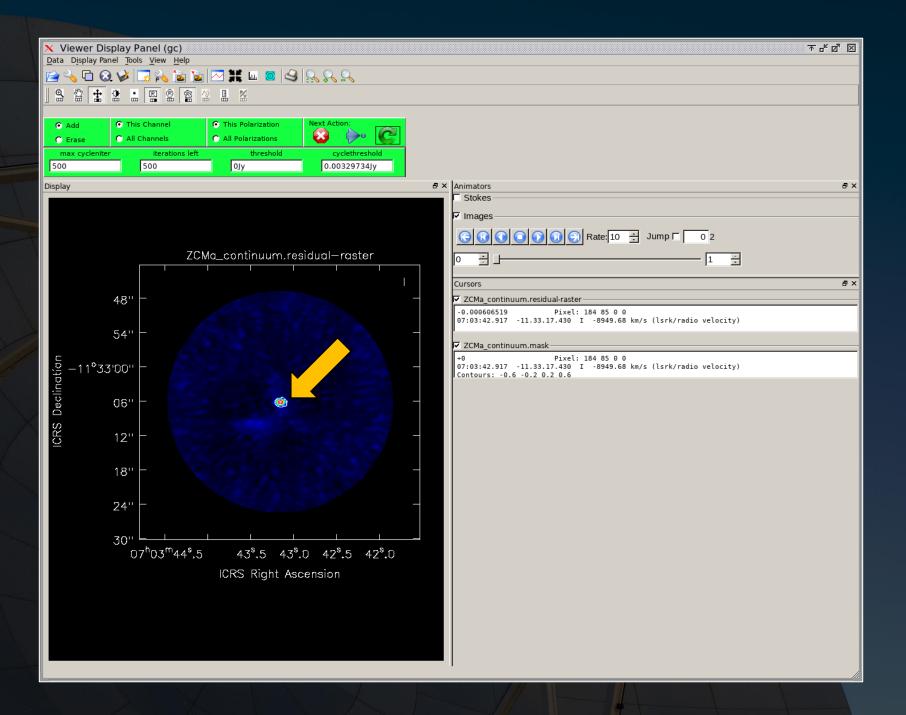
```
tclean(vis='uid A002_Xd98580_X354.ms.split.cal.contsub',
  imagename='ZCMa_spw45_cube',
  field='0',
 imsize=[320,320],
  cell='0.15arcsec',
  phasecenter=0,
 specmode='cube',
  spw='0',
  start=40,
 nchan=160,
  width=1,
 outframe='LSRK',
  restfreq = '231.2206GHz',
  deconvolver='multiscale',
 scales=[0,5,15],
  chanchunks=-1,
  niter=500,
  cycleniter=500,
  threshold='0mJy',
  weighting='briggs',
  robust=0.5,
  gridder='standard',
  restoringbeam='common',
  pbcor=True,
  interactive=True)
```

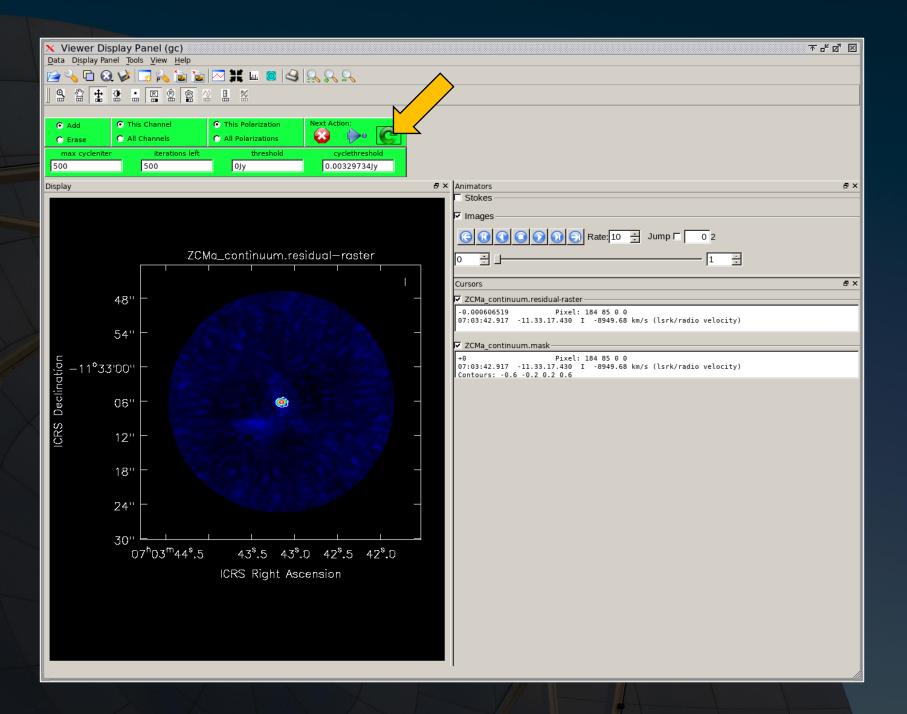
## Important points on tclean settings:

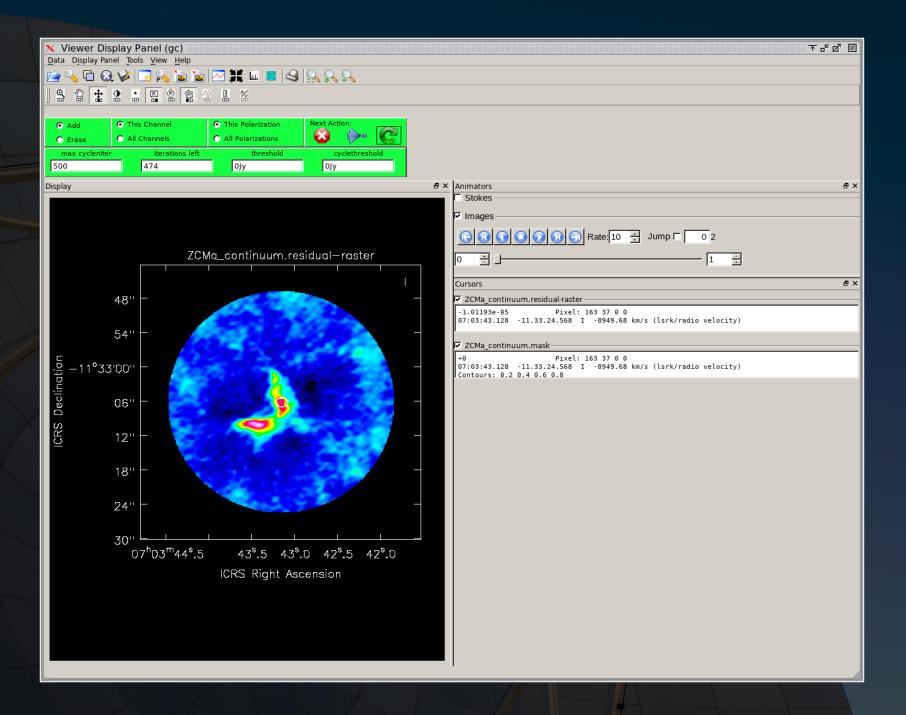
- The cell value should be at least 2× (and preferable 3-4×) smaller than the size of the beam.
- The primary beam (PB) correction needs to be applied (using pbcor=True) to measure accurate flux densities for sources near the edge of the field.
- The channel width for spectral cubes may be adjusted to optimize line detection (often by using wider channels) or to measure detail in line shapes (by using narrower channels).
- The gridder parameter should be set to "standard" for single pointings and "mosaic" for multiple pointings.

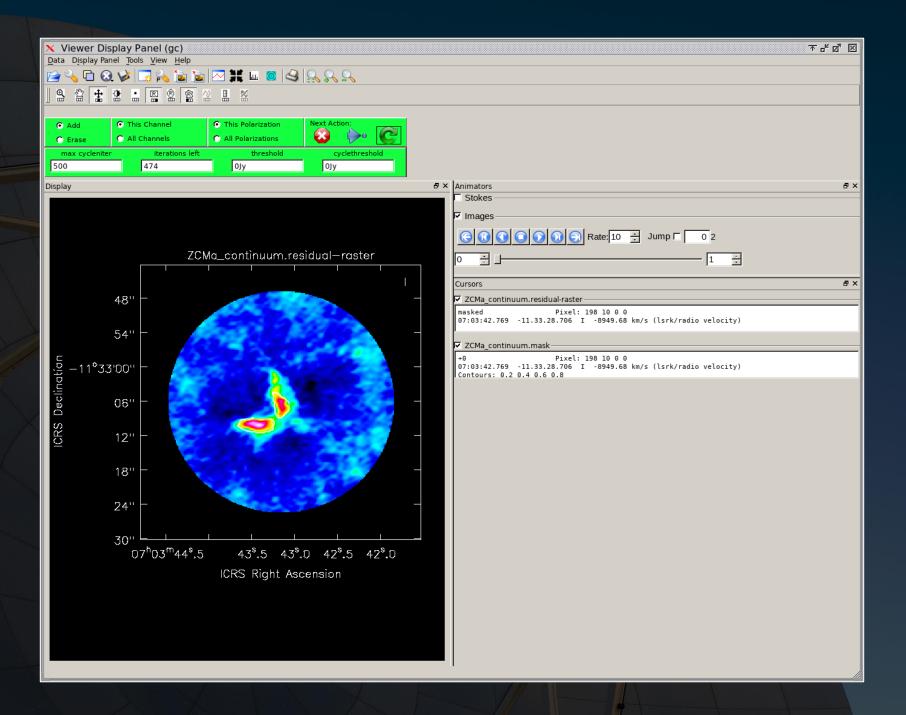
- The weight option is very important. Three standard options are used in radio interferometry.
  - Natural weighting is based on not altering the weights of data points in the uv plane. This results in images with more large-scale structure.
  - Uniform weighting is based on altering the weights to account for the lack of data on long baselines in the uv plane (thus making the uv plane appear "uniform"). This results in images with more small-scale structure, but ALMA image with uniform weights tend to look too noisy.
  - Briggs weighting allows for adjusting between these two extremes. The robust parameter can be used to adjust between these extremes, with "2" equivalent to natural and "-2" equivalent to uniform. A robust value of "0.5" is used to create most ALMA archival images.

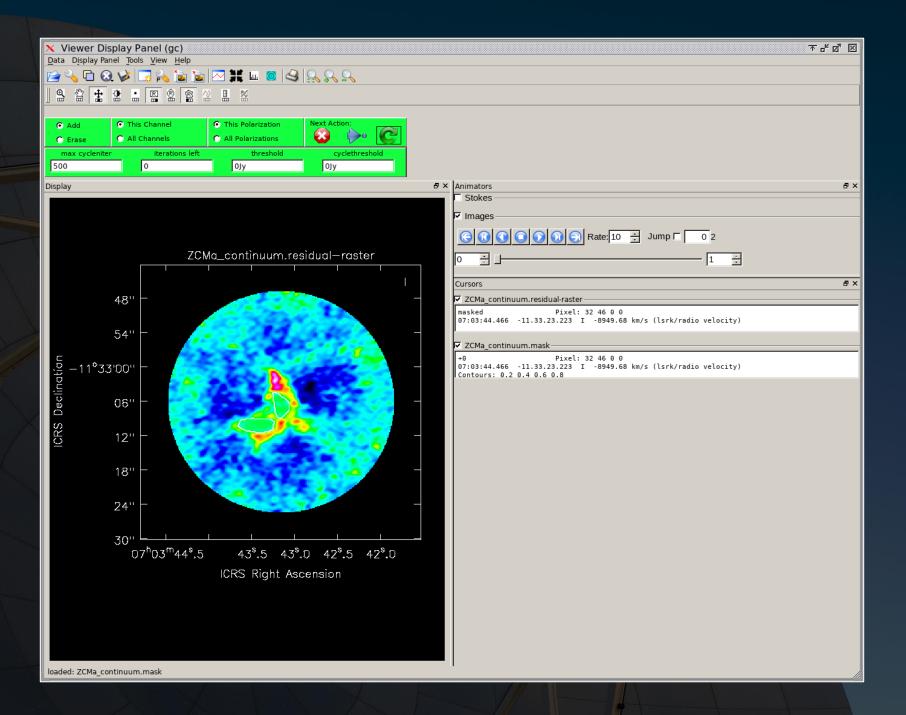


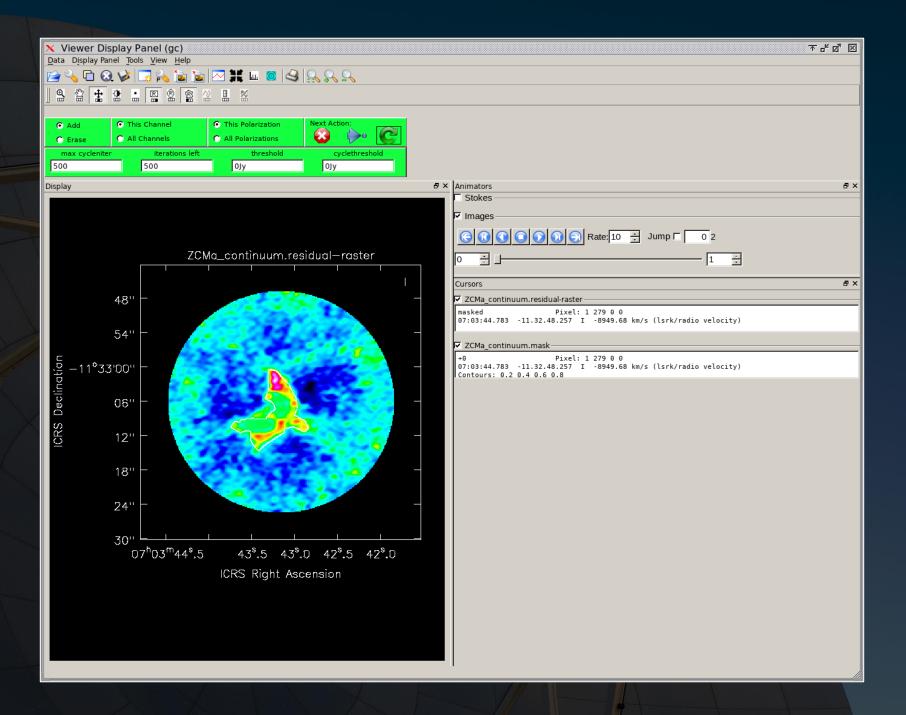


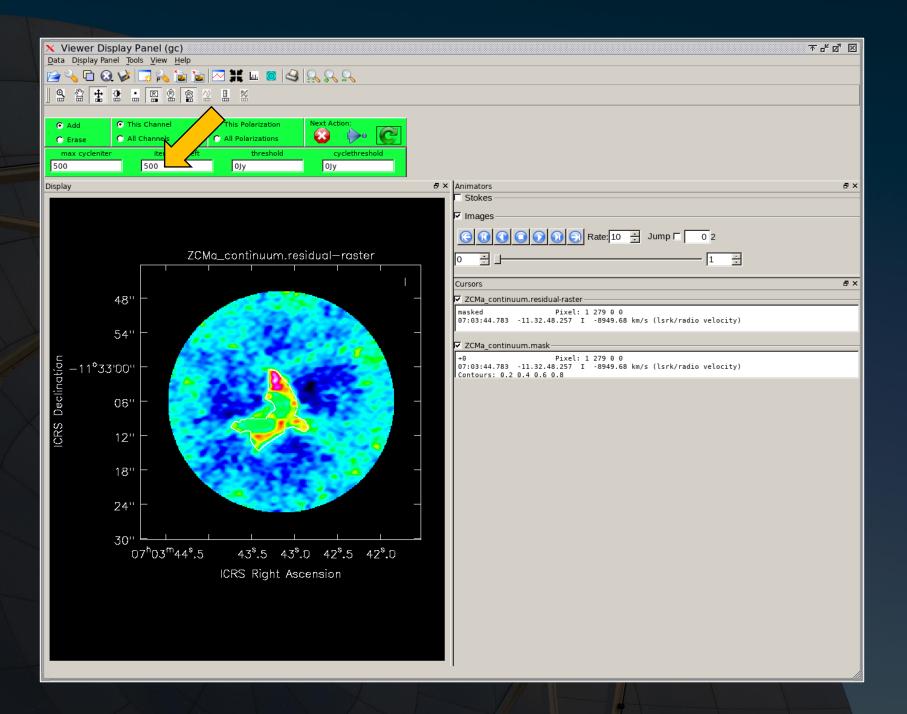


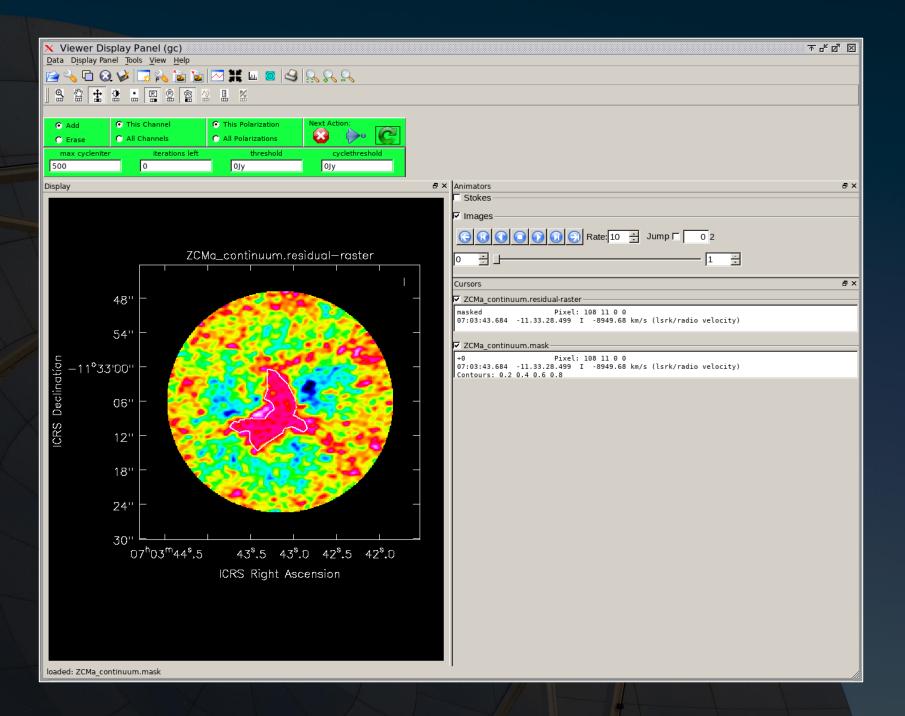


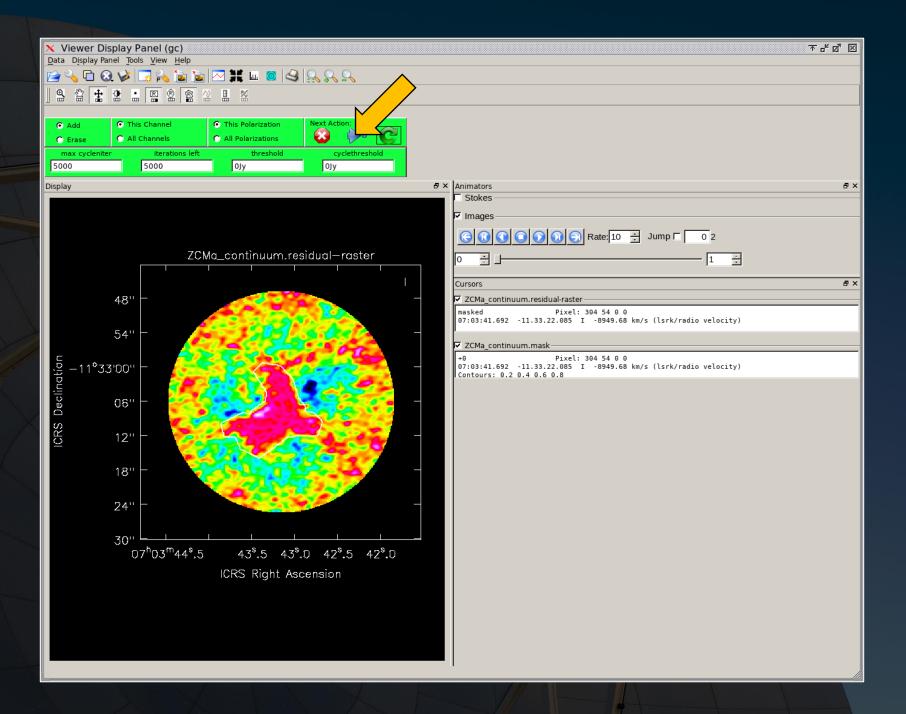


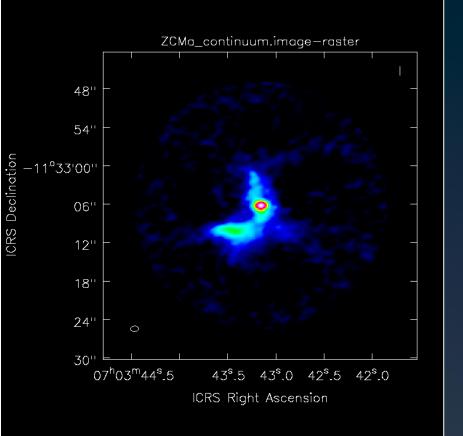


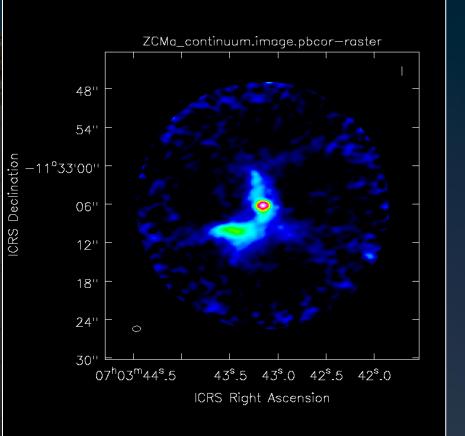


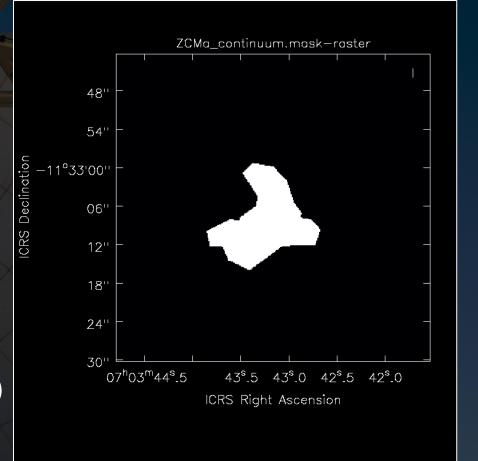




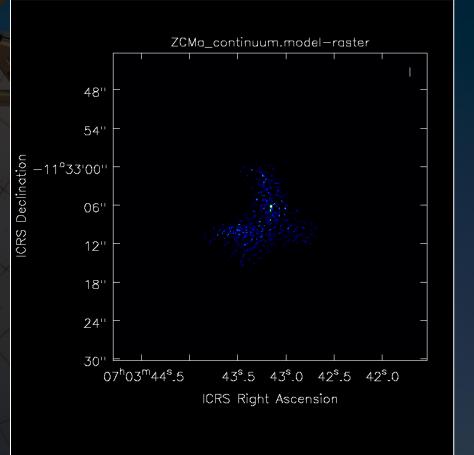


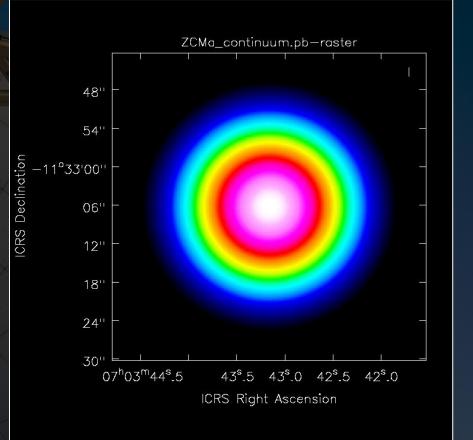


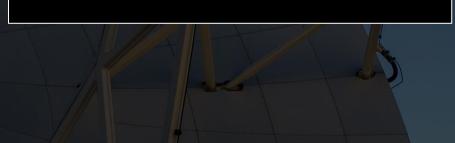


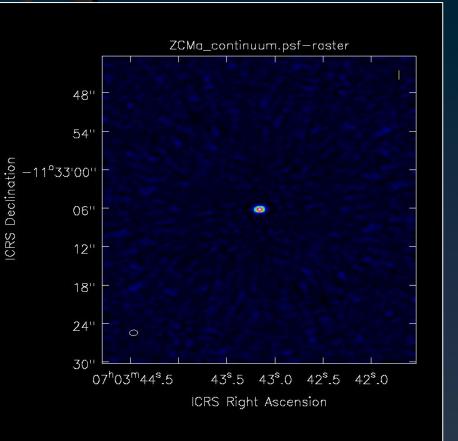


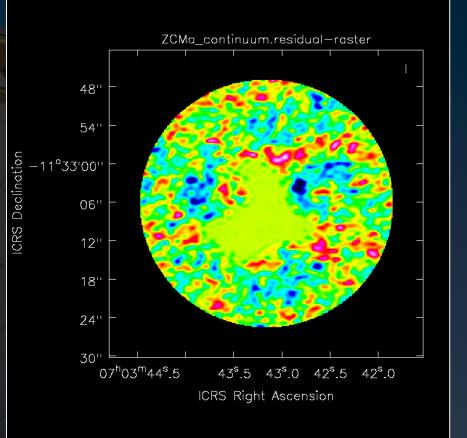








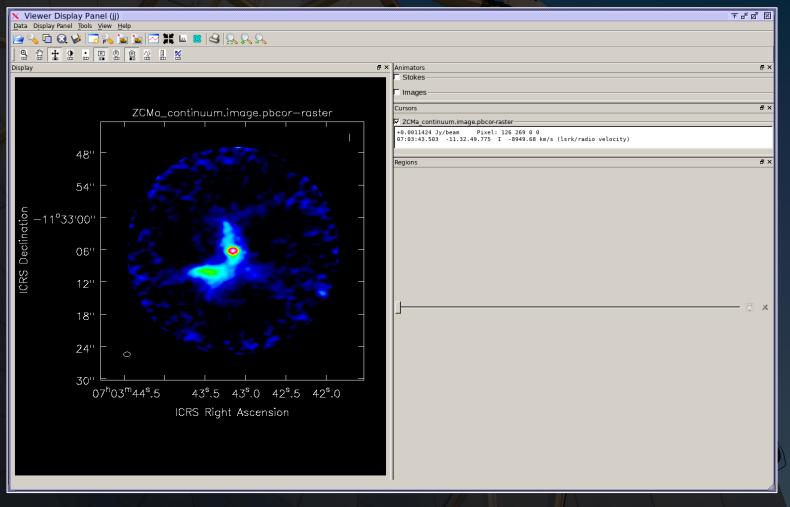






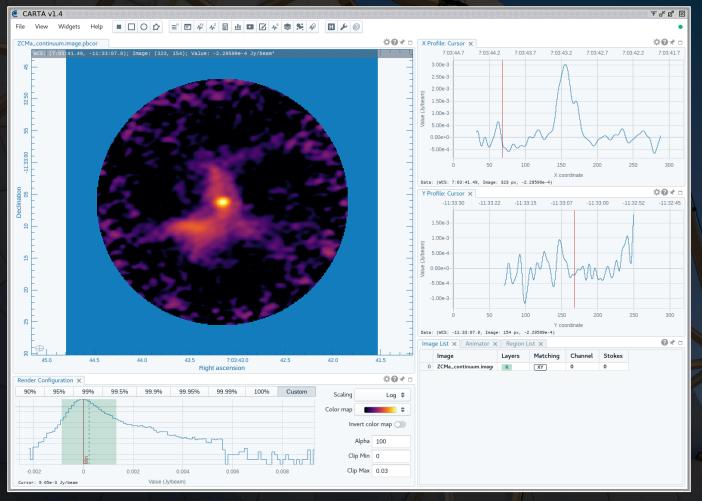
CASA creates images in an object oriented file structure format. Two image viewers are available to view these images:

- casaviewer
- CARTA



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Images can be exported to fits format using exportfits as in the example below:

exportfits(imagename='ZCMa\_continuum.image.pbcor',
 fitsimage='ZCMa\_continuum.image.pbcor.fits',
 dropdeg=True,
 history=False,
 overwrite=True)

Useful archive/data reduction websites:

ALMA Archive documentation: https://almascience.eso.org/alma-data/archive/archive-documentation

CASA guides: <a href="https://casaguides.nrao.edu/index.php/ALMAguides">https://casaguides.nrao.edu/index.php/ALMAguides</a>

I-TRAIN video tutorials: https://almascience.eso.org/tools/eu-arc-network/i-train Prior UK ARC Node workshops (with tutorials on using the ALMA archive, calibrating ALMA data, and imaging ALMA data):

UK ARC Node Meetings: http://www.alma.ac.uk/index.php/meetings/uk-arc-node-meetings

ALMA 2020 Virtual Workshop: http://www.alma.ac.uk/index.php/meetings/uk-arc-node-meetings/410alma-2020-virtual-workshop-for-new-postgraduate-students

ALMA 2021 Virtual Workshop: http://www.alma.ac.uk/index.php/meetings/uk-arc-node-meetings/443alma-2021-virtual-workshop