

Multi-frequency polarimetry of a complete sample of extragalactic radio sources

- Products and provenance information -

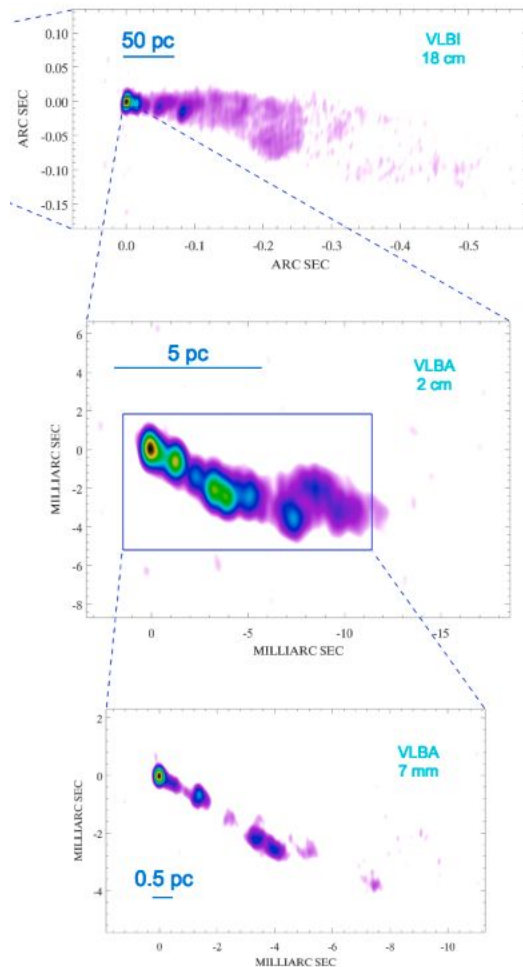
V. Galluzzi

INAF- Osservatorio Astronomico di Trieste



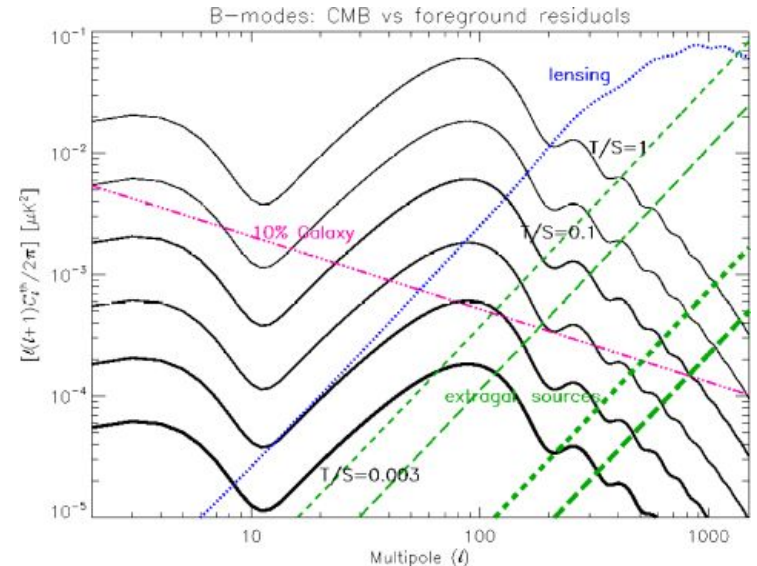
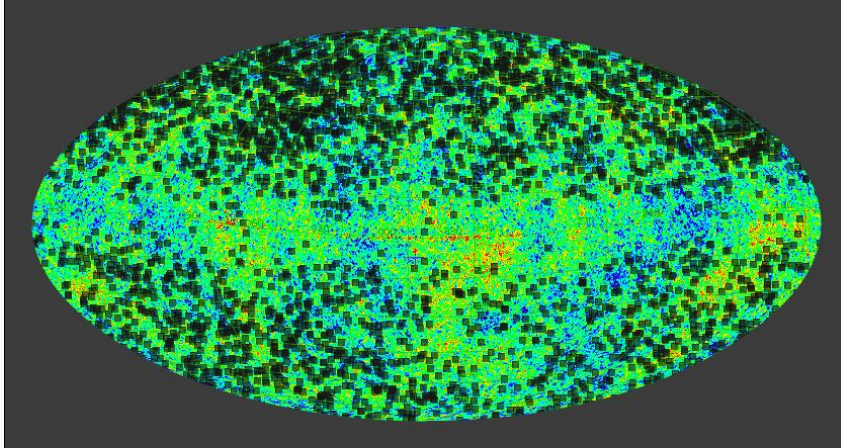
Scientific context

- The high-frequency (> 20 GHz), bright flux density (> 200 mJy) extragalactic radio sources (ERSs) population is dominated by blazars.
- Multi-frequency (and multi-epoch) polarimetry is invaluable to study magnetic fields and plasma in the inner and unresolved regions of their relativistic jets



Scientific context

- ERSs constitute an important foreground for CMB, such studies are also crucial for Cosmology, e.g. in the search for primordial B-modes associated to inflation in the Early Universe



Observations



ATCA observations (project id: C2922, PI: M. Massardi)

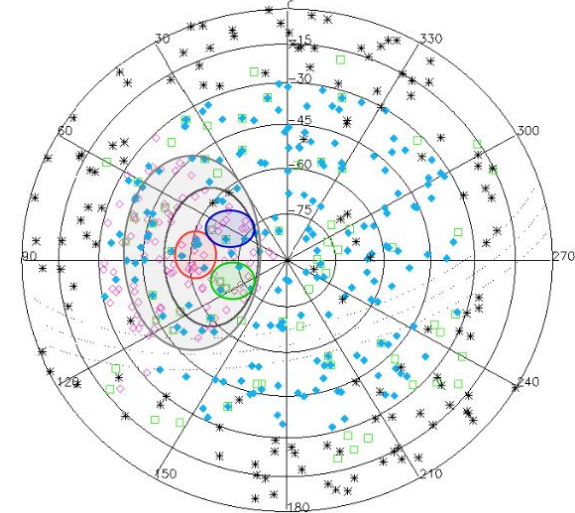
Epoch	Allocated time	Frequencies	# objects	region
Sep. 2014	21 h	[5.5;38] GHz	53	$b < -75^\circ$
Mar.-Apr. 2016	26 h	[5.5;38] GHz	51	$-75^\circ \leq b < -65^\circ$
	14 h	2.1 GHz	104	$b < -65^\circ$
July 2016*	5 h	33-35 GHz	35	$b < -75^\circ$

- ◇ Faint PACO
- Spectrally-selected PACO
- * ATCA calibrators
- ◆ Bright PACO



ALMA Cycle 3 observations
(project id: 2015.1.01522.S , PI: V. Galluzzi)

SG – Epoch	Time allocated	Frequencies	# objects	Region (J2000)
1 – 24/08/2016	3.0 h	97.5 GHz (4 spw)	14	(05:06:44 , -61:09:41)
2 – 22/09/2016	3.5 h	97.5 GHz (4 spw)	9	(06:35:46 , -75:16:16)
3 – 27/09/2016	3.5 h	97.5 GHz (4 spw)	9	(03:24:04 , -73:20:47)



Data products

- Level 0:
 - a. raw visibilities (ATCA observations available through the Australia Telescope Online Archive, ATOA, in the MIRIAD RPFITS format; ALMA observations available through the ALMA Science Archive, ASA, in the ASDM format);
- Level 2:
 - b. calibrated visibilities (available on request for ATCA observations in the MIRIAD UVFITS format, while for ALMA observations they can be generated from raw observations through the “script for PI” in the MS format);

[ATOA Search](#)

Use this form to generate a summary list of observations from the Australia Telescope Compact Array, Mopra (MOPUS data), Parkes radio telescope (other than pulsar observations) and VLBI observations.
For a summary report select **Report Type = Scans summary**. To list and download data files select **Report Type = Matching files**.

[Expand instructions](#) [ATOA Home Page](#)

Search **Reset**

Project Codes Observer Surname Source Name Report Type Sort Order Page Size

OPAL Source or Observations Table Name Choose File No file chosen

Observation Date

From Day Month Year Hour Minute Calendar

To Day Month Year Hour Minute Calendar

Source Position (J2000)

Right Ascension Declination Search Window (arcminutes)

Array (for ATCA only)

Any
Any standard 6m
Any standard 1.5m
Any standard 750m
Any standard compact
6A
6B
6C
6D
1.5A
1.5B
1.5C

Bandwidth

Any
Any standard 6m
Any standard 1.5m
Any standard 750m
Any standard compact
6A
6B
6C
6D
1.5A
1.5B
1.5C

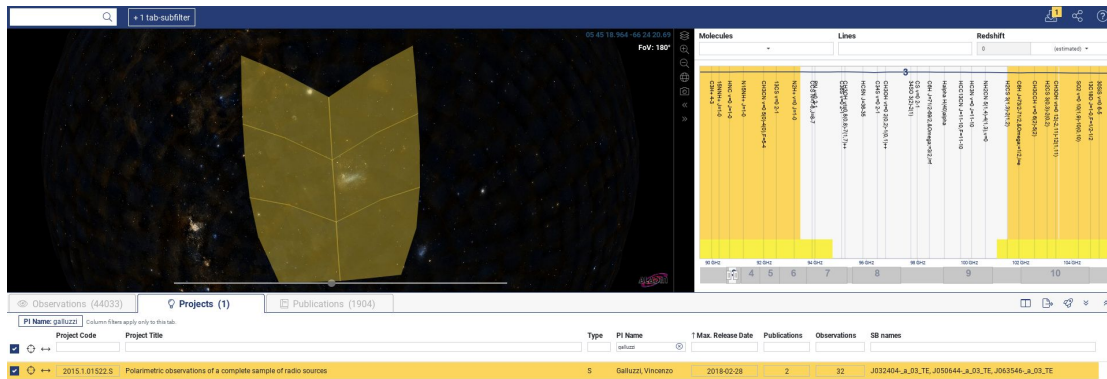
R Channels

Any
Any standard 6m
Any standard 1.5m
Any standard 750m
Any standard compact
6A
6B
6C
6D
1.5A
1.5B
1.5C

Frequency Range

Any
Any standard 6m
Any standard 1.5m
Any standard 750m
Any standard compact
6A
6B
6C
6D
1.5A
1.5B
1.5C

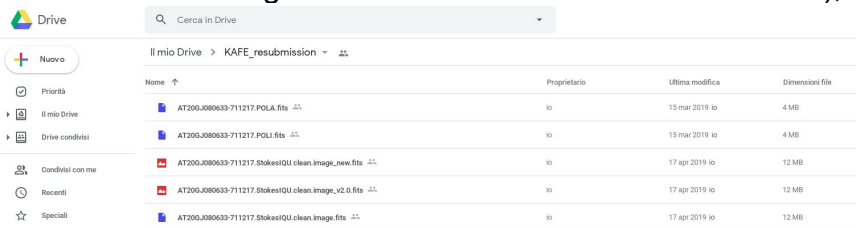
Search **Reset**



Data products

- Level 3:

- c. Stokes' I, Q and U maps for each source in the sample (FITS files available on request; for ALMA observations, thumbnails are published as supplementary material of a dedicated paper, while IQU CASA image cubes can be downloaded from ASA);



Nome	Proprietario	Ultima modifica	Dimensioni file
AT200J080639-711217.POLA.fits	io	15 mar 2019 io	4 MB
AT200J080639-711217.POLI.fits	io	15 mar 2019 io	4 MB
AT200J080639-711217.StokesIQU.clean.image_new.fits	io	17 apr 2019 io	12 MB
AT200J080639-711217.StokesIQU.clean.image_v2.0.fits	io	17 apr 2019 io	12 MB
AT200J080639-711217.StokesIQU.clean.image.fits	io	17 apr 2019 io	12 MB

☒ readme ☒ product ☒ auxiliary ☐ raw ☐ raw (semipass) ☐ external

Project / OUSet / Executionblock

Request 1653659408390

Project 2015.1.01522.S

Science Goal OUS uid://A001/X340/X4f

Group OUS uid://A001/X340/X50

Member OUS uid://A001/X340/X51

SB J050644_a_03_TE

☒ readme

☒ product

☐ product

☐ product

☐ product

☐ product

☐ product

☐ product

[member.uid A001 X340 X51.README.txt](#)

[2015.1.01522.S uid A001 X340 X51_001_of_001.tar](#)

[member.uid A001 X340 X51.Pol_Cal.Stokes.clean.image.fits](#)

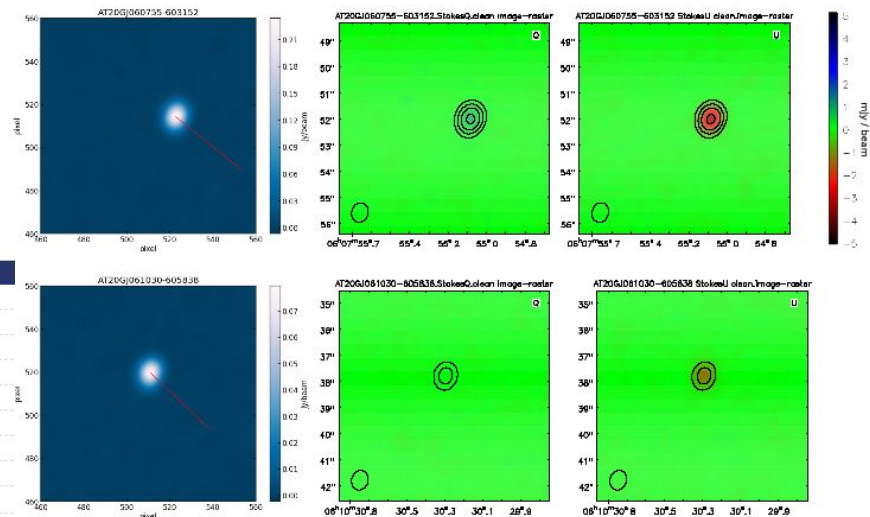
[member.uid A001 X340 X51.Source_10.StokesIQU.clean.flux.fits.gz](#)

[member.uid A001 X340 X51.Source_10.StokesIQU.clean.image.pbcor.fits](#)

[member.uid A001 X340 X51.Source_11.StokesIQU.clean.flux.fits.gz](#)

[member.uid A001 X340 X51.Source_11.StokesIQU.clean.image.pbcor.fits](#)

[member.uid A001 X340 X51.Source_12.StokesIQU.clean.flux.fits.gz](#)



Data products

- Level 4:

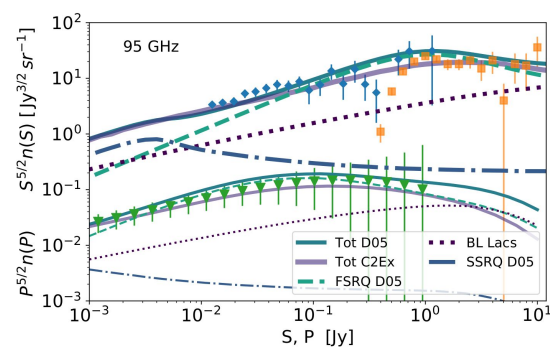
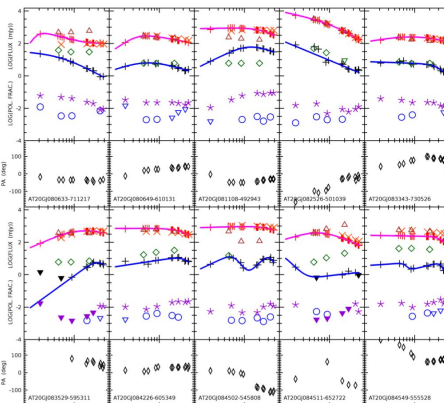
- various catalogues reporting full-Stokes' flux densities and parameters resulting from SED fitting (published as supplementary material of papers or available through VizieR);
- various plots and tables reporting statistical estimators (e.g. mean and quartiles) of spectral indexes, polarization fractions and rotation measures (the code used for generating them has been mainly written in IDL and is available on request);
- normalized source counts in total intensity and polarization at 20 and 95 GHz (tables are in the papers; the code is publicly available in a [gitlab repository](#));
- contamination forecasts due to extragalactic radio sources on CMB angular power spectra at 20 and 100 GHz (plots are reported in dedicated papers; the code is publicly available in the same [gitlab repository](#)).

JMNRAS/465/4085/catalog
Post annotation

PACO radio sources complete sample polarimetry (Galluzzi+ 2017)
Full catalogue of I and P flux density, polarisation fractions, angles, and fit parameters (53 rows)

start AladinLite plot the output query using TAP/SQL

Full	RAJ2000 "hms"	DEJ2000 "dms"	AT20G	RAJ2000 deg	DEJ2000 deg	Flag	L m5000	L m9000	L m18000	L m24000	L m33000	L m38000
1	03 24 04.02913	-73 20 47.0033	J032404.732047	051 016788	-73 3463898		0.29	0.59	0.96	1.84	2.31	2.59
2	03 32 43.11027	-72 49 04.8853	J033243.724904	053 179626	-72 8180237		1.41	2.29	2.04	2.18	2.72	3.22
3	04 30 28.17987	-67 03 16.8199	J043028.670316	055 117416	-67 0546722		0.43	0.91	0.52	0.31	0.07	0.53
4	03 55 47.85993	-66 45 33.7007	J035547.664533	058 949416	-66 7593613		1.40		1.64	0.92	0.33	0.28
5	04 08 20.54907	-65 45 08.2123	J040820.654508	062 085621	-65 7522812		0.12	0.62	3.05	4.48	5.58	6.01
6	04 08 48.75000	-75 07 20.1122	J040848.750720	062 203125	-75 1222534	a	1.35	4.40	4.32	3.06	2.28	2.80
7	04 25 06.90133	-66 46 50.1103	J042506.664650	066 278756	-66 7805862		0.33		1.14	1.53	2.60	2.18
8	04 28 10.86927	-64 38 23.6134	J042810.643823	067 045289	-64 6398926		3.23		3.16	5.51	5.11	3.42
9	04 33 34.05960	-60 30 14.1998	J043334.603014	068 391915	-60 5039444		2.13	1.75	2.39	1.77	0.47	0.49
10	04 47 91.8167	-69 52 17.5030	J044047.695217	070 199661	-69 8715286		0.40	0.51	1.95	2.13	3.21	3.88
11	05 04 01.68993	-60 49 52.9918	J050401.604953	076 007041	-60 8313866		1.39	2.52	3.19	4.44	4.44	4.72
12	05 05 43.52967	-79 14 39.5930	J050543.791439	076 431374	-79 2443314	<	0.07	0.62	0.89	0.80	0.81	1.48
13	05 06 43.89113	-61 09 40.9846	J050644.610941	076 683288	-61 1613846		4.05	3.94	5.46	5.54	5.40	5.31
14	05 07 54.69927	-61 04 42.9942	J050754.610442	076 977914	-61 0786095		1.64	1.52	4.22	5.14	6.64	6.90
15	05 16 37.95960	-72 37 07.8074	J051637.723707	079 158165	-72 6188354		3.75	2.59	1.35	1.30	2.01	2.28
16	05 16 44.88093	-62 07 06.0910	J051644.620706	079 187004	-62 1183586		6.73	6.61	6.54	6.83	7.55	7.83
17	05 22 34.42547	-61 07 57.1361	J052234.610757	080 643439	-61 1325378		3.45	2.29	1.45	1.64	1.69	2.40



Ancillary products

- ATCA observation schedules (available on request or directly accessible to all registered ATCA observers).
- calibration scripts (exemplar MIRIAD scripts for ATCA data are also published in the PhD thesis) and imaging scripts;
- diagnostics plots produced during the execution of scripts (image files in png or jpeg);
- observations and processing log files (human-readable .txt files).

CABB Scheduler - c2922_5ghz_newvg.sch

The screenshot shows the CABB Scheduler interface with a list of observation times on the left and scan parameters on the right.

File Edit Tools

Sched Listing

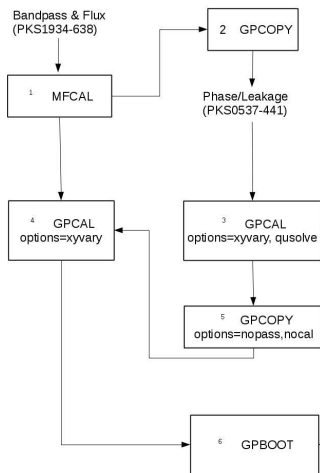
Scan Parameters

Source: 0537-441
RA (hms): 05:38:50.362
Dec (dms): -44:05:08.94
Epoch: J2000
CalCode: C
ScanLength: 00:01:00
ScanType: Dwell
Pointing: Global
Observer: mm
Project: C2922
Time: 05:31:32
TimeCode: LST
Date: 28/03/2016

Freq1 5500MHz
Freq2 9000MHz

New Scan Search Cal
Delete Pick Source

Data rate = 1.130G/h, or 4GB every 3h33m



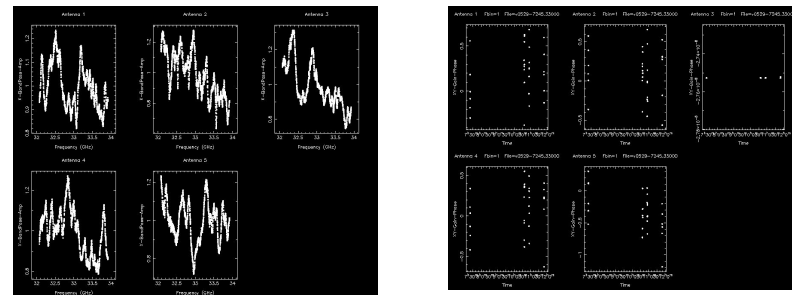
```

frequency="18000"
BandLea_cal="n0538-4405"
PhaFlu_cal="v0529-7245"

mfcalf vis=$BandLea.cal.$frequency refant=3 interval=0.1
gpccopy vis=$BandLea.cal.$frequency out=$PhaFlu.cal.$frequency options="nocal"
gpccopy vis=$PhaFlu.cal.$frequency refant=3 interval=0.1 nbin=2 flux="1.229,4.871E-03,-1.899E-02,2.899E-03" options="xyvary,qusolve,nopol"
#boot vis=$PhaFlu.cal.$frequency $PhaFlu.cal.$frequency select="source($PhaFlu_cal)" flux="1.2622,18.0,0.0009" device=xs

while read src; do
  if [ $src != $PhaFlu_cal ] && [ $src != $BandLea_cal ]; then
    gpccopy vis=$PhaFlu.cal.$frequency out=$src.$frequency
    fi
    uvspec vis=$src.$frequency options=nobase stokes="i" axis="ch,amp" device="Plots$frequency/fluxesI $src.$frequency"/png
    uvspec vis=$src.$frequency options=nobase stokes="q" axis="ch,amp" device="Plots$frequency/fluxesQ $src.$frequency"/png
    uvspec vis=$src.$frequency options=nobase stokes="u" axis="ch,amp" device="Plots$frequency/fluxesU $src.$frequency"/png
    uvspec vis=$src.$frequency options=nobase stokes="v" axis="ch,amp" device="Plots$frequency/fluxesV $src.$frequency"/png
    uvplt vis=$src.$frequency stokes=i options=nobase axis="uvdist,amp" device="Plots$frequency/Amplitude$src.$frequency"/png
    urflux vis=$src.$frequency stokes="i,q,u,v"
done < IIIIotIIIGT_180240Hz_indexlist_g0529.log

#####Diagnostics_1#####
uvplt vis=$PhaFlu.cal.$frequency stokes="i,q,u,v" axis="real,img" options="nobase,nofav" device="Plots$frequency/Diagnostics/scatter_plot_flux_cal.$frequency"/png
#####Diagnostics_2#####
uvplt vis=$PhaFlu.cal.$frequency axis="time,parang" options=nobase device="Plots$frequency/Diagnostics/PhlCal_parang.$frequency"/png
uvplt vis=$PhaFlu.cal.$frequency axis="ch" device="Plots$frequency/Diagnostics/Phase_ch.$frequency"/png
urflux vis=$PhaFlu.cal.$frequency stokes="i,q,u,v" axis="real,img" options="nobase" device="Plots$frequency/Diagnostics/scatter_plot_I_Phase_cal.$frequency"/png
uvplt vis=$PhaFlu.cal.$frequency stokes="q,u,v" axis="real,img" options="nobase" device="Plots$frequency/Diagnostics/scatter_plot_QU_Phase_cal.$frequency"/png
gpplt vis=$PhaFlu.cal.$frequency axis=phase options=xgain device="Plots$frequency/Diagnostics/phase_and_xgain.$frequency"/png
gpplt vis=$PhaFlu.cal.$frequency axis=amp options=bandpass device="Plots$frequency/Diagnostics/bandpass_phase_cal.$frequency"/png
gpplt vis=$PhaFlu.cal.$frequency axis=phase options=gains device="Plots$frequency/Diagnostics/phase_cal_gains.$frequency"/png
  
```



Provenance information: motivations

- The main reason is represented by the fact that radio polarimetry involves more calibration steps and presents more potential sources of systematics with respect to standard observations in total intensity. Thus, additional diagnostics is usually addressed to provide indicators about data quality (e.g. statistics of leakage terms solutions and Stokes' parameters flux densities)
- The variety of data products ranging from observations to more advanced ones (e.g., catalogues and source counts) particularly require traceability information.

gpcal: Revision 1.22, 2016/05/01 22:31:05 UTC

Applying bandpass corrections to 0537-441.5500

Number of antennae: 6

Reading the data ...

Number of solution intervals: 30

Total visibilities read: 450

Number visibilities accepted: 300

Iter= 1, Amplit/Phase Solution Error: 0.092

Iter= 1, Polarisation Solution Error: 0.022

Iter= 1, Overall Solution Error: 0.575

Iter= 2, Amplit/Phase Solution Error: 0.012

Iter= 2, Polarisation Solution Error: 0.000

Iter= 2, Overall Solution Error: 0.008

Iter= 3, Amplit/Phase Solution Error: 0.000

Iter= 3, Polarisation Solution Error: 0.000

Iter= 3, Overall Solution Error: 0.000

I flux density: 4.3039

Percent Q: -1.084

Percent U: -0.588

Leakage terms:

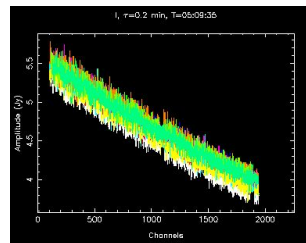
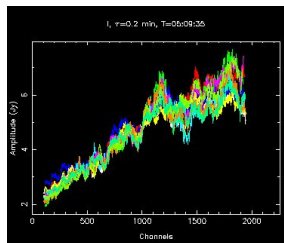
Ant 1:Dx,Dy = (0.00042, -0.00371), (0.00095, -0.00404)

Ant 2:Dx,Dy = (0.00249, 0.00323), (-0.00131, 0.00252)

Ant 3:Dx,Dy = (0.00457, -0.00583), (-0.00700, -0.00714)

Ant 4:Dx,Dy = (-0.00842, -0.00802), (0.00948, -0.00940)

Ant 5:Dx,Dy = (0.00188, 0.01660), (-0.00118, 0.01579)



ADMIN/AS/665/085/catalog

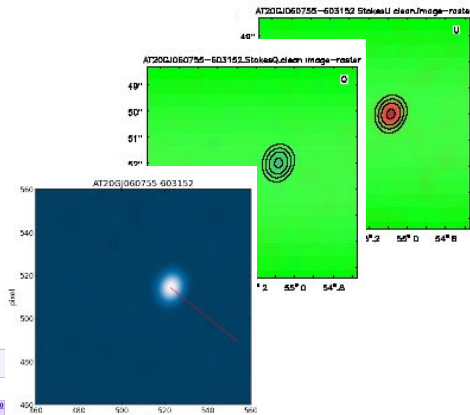
Data annotation

Full catalogue of I and P flux density, polarization fractions, angles, and fit parameters (33 rows)

plot the output

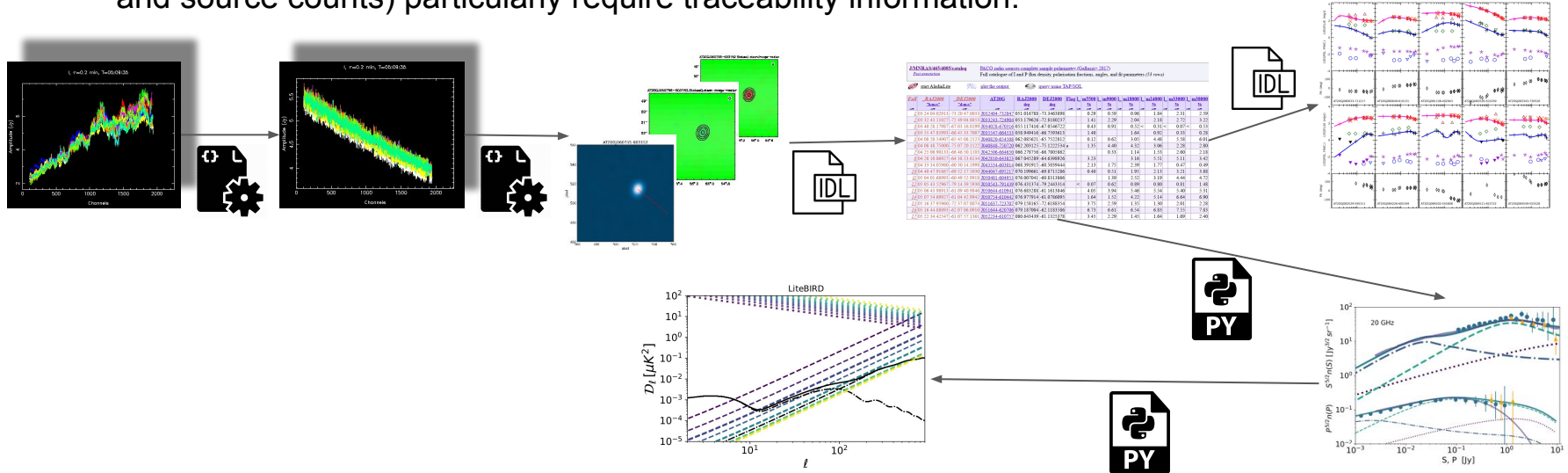
query using TAP.SOL

File	RAJ2000	DECJ2000	AT285	RAJ2000	DECJ2000	Elarg_L	u_L5000	L_u10000	L_u10000	L_u10000	L_u10000	L_u10000	L_u10000
	h:m:s	d:m:s	deg	deg	deg	arcsec	arcsec	arcsec	arcsec	arcsec	arcsec	arcsec	arcsec
001 24 04 029113.77 29 47 0013	2012408.722017	051 016788.73 3461899	0.29	0.59	0.96	1.84	2.31	2.59					
001 32 43 110277.77 49 04 0013	2012344.220903	053 190636.77 8180237	1.41	2.39	2.04	2.18	2.72	3.22					
001 40 25 17867.47 03 16 51399	2012612.631116	055 171416.47 0546722	0.43	0.93	0.52	0.31	0.07	0.33					
001 55 47 819991.46 45 13 7807	2015541.664333	058 949416.46 77994613	1.40	1.64	0.92	0.33	0.28						
001 58 35 44907.47 08 21 1133	2015058.854500	060 385621.46 7522812	0.12	0.62	3.05	4.48	1.58	6.01					
004 08 48 75005.75 07 30 11172	2040848.229720	062 201251.75 1322534	1.35	4.40	4.32	3.06	2.28	2.80					
004 23 06 901131.46 46 50 11033	2042066.664505	064 78736.46 7803862	0.33	1.14	1.53	2.40	2.18						
004 30 30 605077.46 38 25 5114	2042361.648322	067 763709.46 4399926	3.23	3.16	5.51	5.11	3.42						
004 33 54 059060.40 30 14 1990	2043334.602014	068 391915.46 5059444	2.13	1.75	2.39	1.77	0.47	0.49					
004 40 47 91867.40 22 17 5050	2044021.602217	070 199661.46 8715286	0.40	0.51	1.95	2.13	3.21	3.88					
005 01 01 489091.40 49 12 5913	2050451.690553	076 807061.46 8313666	1.39	2.52	3.19	4.48	4.72						
005 05 43 528677.79 14 39 5930	2050543.791439	076 433374.79 2443314	<	0.07	0.62	0.89	0.80	0.81	1.48				
005 08 43 989111.41 09 40 9140	2050841.610511	076 483281.41 1613846	4.05	3.94	5.46	5.54	5.40	5.31					
005 07 54 699077.46 04 42 3842	2052514.610142	076 977954.46 0780695	1.64	1.52	4.22	5.14	6.64	6.90					
005 16 37 919060.72 37 07 8074	2051631.724302	079 158145.72 6188354	3.75	2.59	1.35	1.80	2.01	2.28					
005 16 45 818991.41 07 06 0902	2051648.630708	079 187062.41 1181586	6.79	6.61	6.54	6.45	7.55	7.83					
005 22 34 42547.41 07 57 1361	2052234.610752	080 844349.41 1325370	3.45	2.59	1.45	1.64	1.69	2.40					



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Provenance information: goals

1. ensure quality and reliability
2. keep the traceability of the data products
3. provide more information to the final user
4. reproduce or reprocess the data
5. debug a pipeline
6. find contact information
7. acknowledge people

Provenance information: sources

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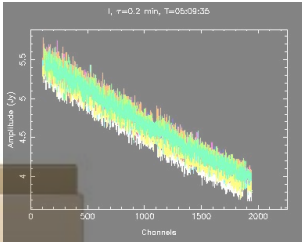


Published papers

- human readable only;
- high level provenance information;
- the most complete source of provenance information.

Provenance information: sources

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Data products

- human and machine readable info;
- traceability information may be really fine-grained;
- info typically limited to the considered data product.

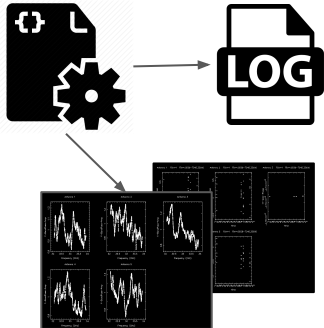
HISTORY MFCAL: MfCal: \$Revision: 1.20 \$, \$Date: 2017/05/08 02:31:10 \$
HISTORY MFCAL: Executed on: 2019-12-13T16:50:41.0
HISTORY MFCAL: Command line inputs follow:
HISTORY MFCAL: vis=0537-441.5500
HISTORY MFCAL: flux=3.5155,4.0,0.0796
HISTORY MFCAL: refant=2
HISTORY MFCAL: interval=0.1
HISTORY GPCOPY: Miriad gpcopy: Revision 1.13, 2015/10/29 01:31:39 UTC
HISTORY GPCOPY: Executed on: 2019-12-13T16:50:47.0
HISTORY GPCOPY: Command line inputs follow:
HISTORY GPCOPY: vis=j0529-7245.5500
HISTORY GPCOPY: out=0537-441.5500
HISTORY GPCAL: gpcal: Revision 1.22, 2016/05/01 22:31:05 UTC
HISTORY GPCAL: Executed on: 2019-12-13T16:50:47.0
HISTORY GPCAL: Command line inputs follow:
HISTORY GPCAL: vis=0537-441.5500
HISTORY GPCAL: refant=2
HISTORY GPCAL: interval=0.1
HISTORY GPCAL: nfbn=2
HISTORY GPCAL: options=xyvary,nopol
HISTORY GPCAL: I flux density: 3.6266
HISTORY GPCAL: I flux density: 3.6031
HISTORY GPCAL: I flux density: 3.6521

some output from
GPCAL:

E.g., in the case of visibilities
processed with MIRIAD,
HISTORY keywords capture all
the runned tasks

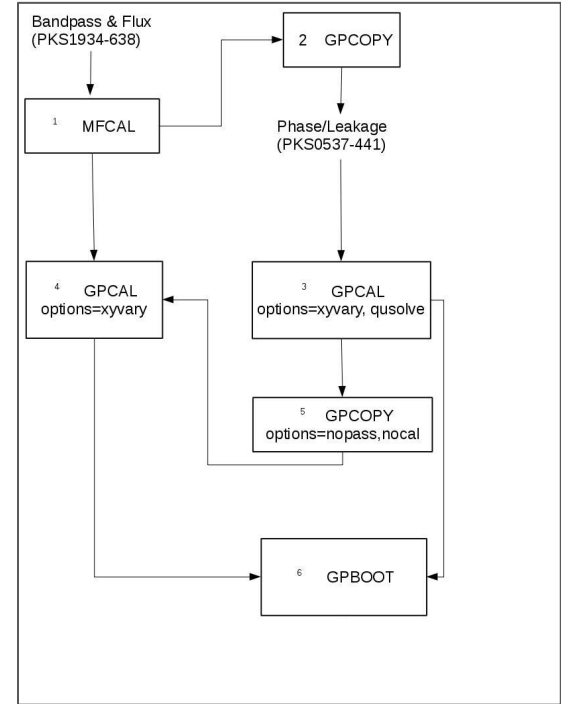
Provenance information: sources

1. ensure quality and reliability
2. keep the traceability of the data products
3. provide more information to the final user
4. reproduce or reprocess the data
5. debug a pipeline
6. find contact information
7. acknowledge people



Ancillary products

- human readable info;
- traceability and quality metrics information may be really accurate;
- info typically limited to the data they are associated to.



Example of a calibration schema in MIRIAD adopted by the project

Conclusions

- Given the scientific scope of this (and of similar) project(s), the criticalities in data calibration and the variety of data products typically involved, the data discovery of such datasets could be significantly bolstered by showing to archive miners a clear tree diagram showing the products and a bunch of quality metrics metadata.
- As calibration, imaging and flux density extraction recipes are far from being definitive, a significant fraction of archive miners would be able to re-process data, hence the exploitation of the Provenance DM at an higher granularity level may be considered.