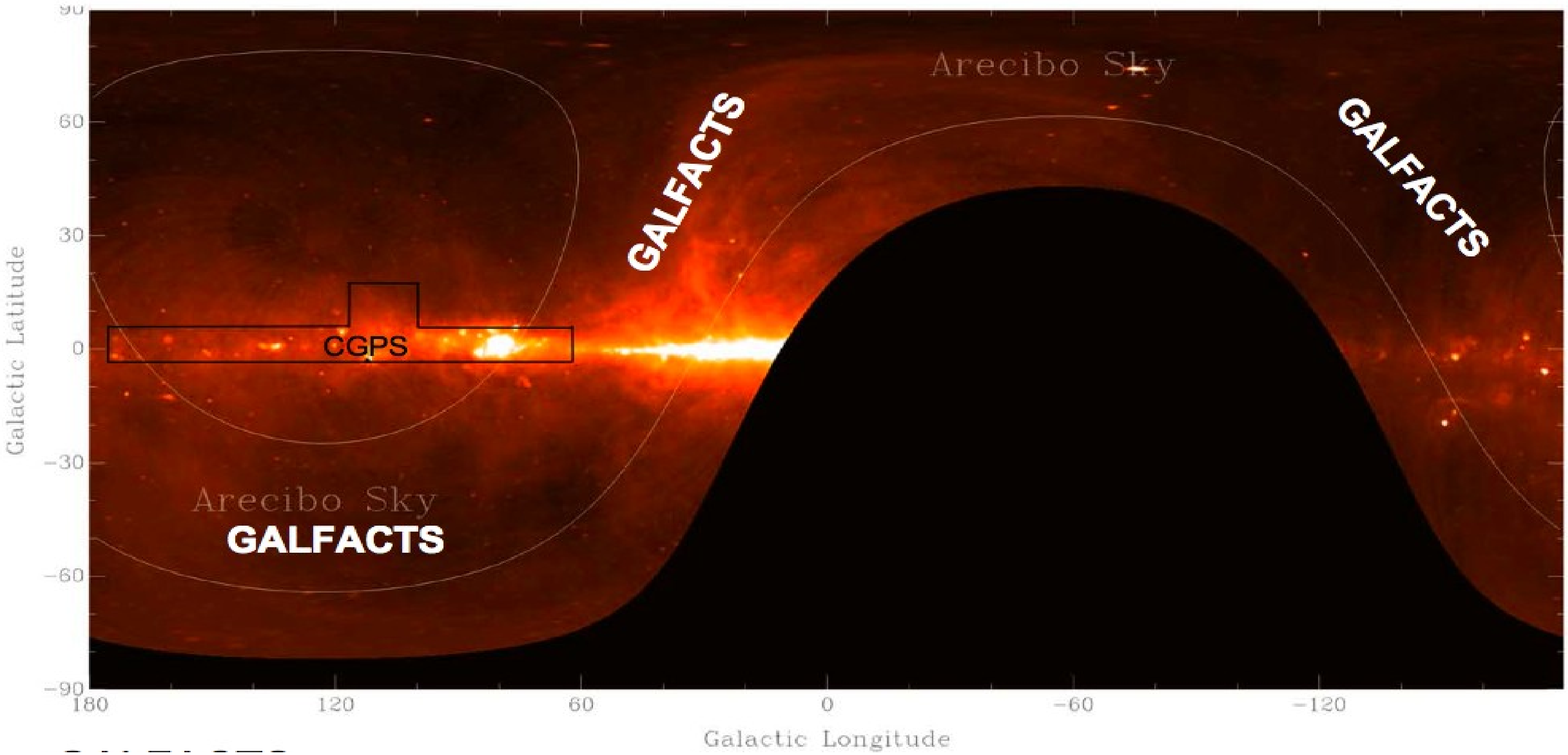
# GALFACTS

a large-area spectro-polarimetric survey on Arecibo

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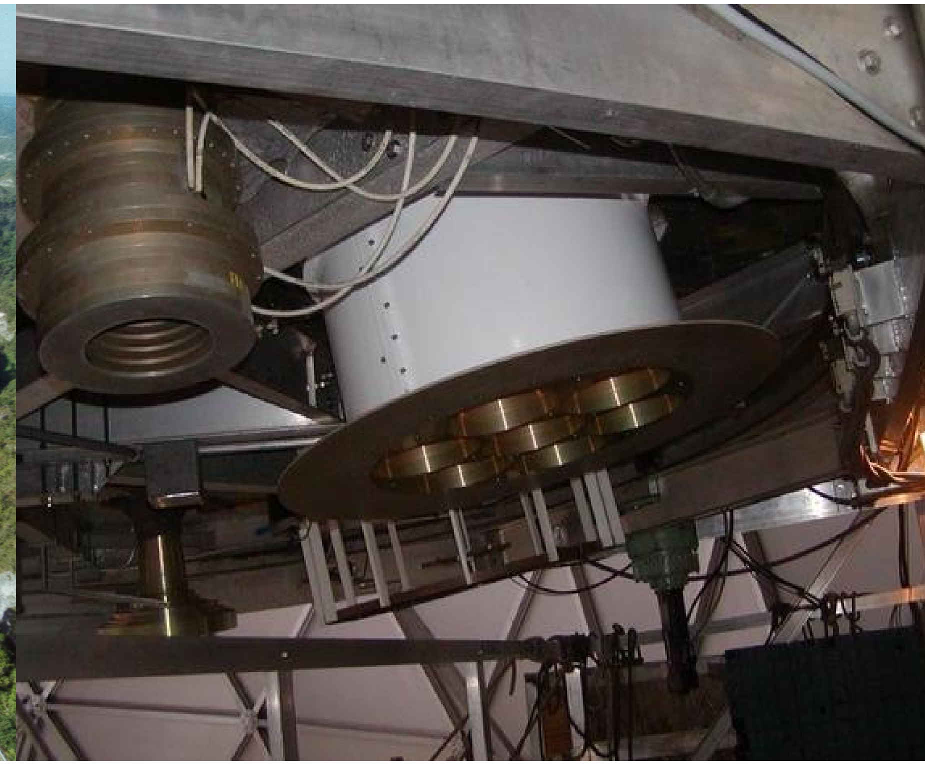
# **G**alactic **ALFA C**ontinuum **T**ransit **S**urvey

Taylor & Salter 2011, arxiv.org:1008.4944



www.ras.ucalgary.ca/GALFACTS

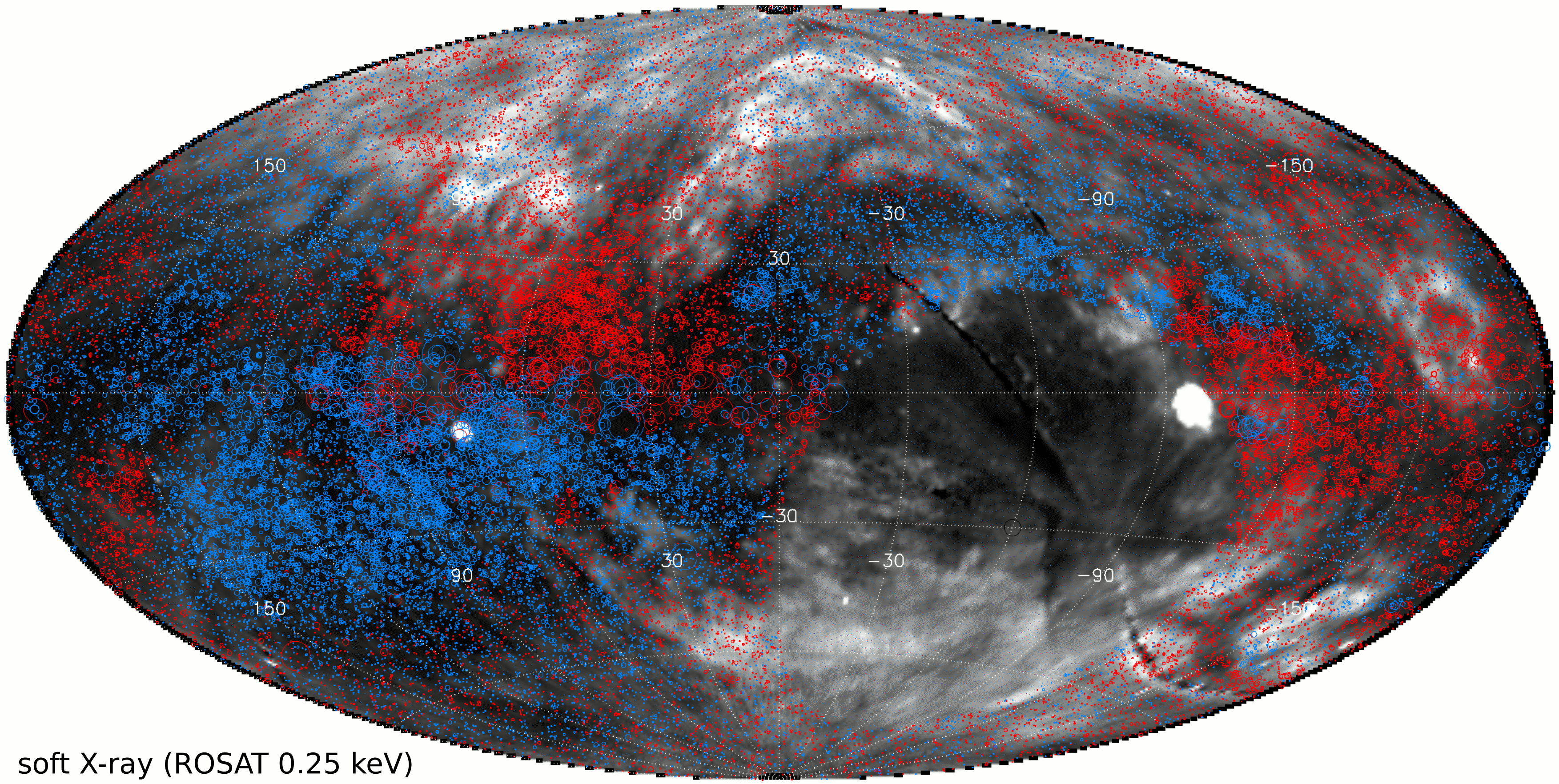
Measuring the Galactic magnetic field and its role in the Galaxy

Image the diffuse polarization in the Galaxy & effects of the Faraday Screen

Polarization properties of the extragalactic source and evolution of magnetism

Scientific pathfinder to SKA Cosmic Magnetism Key Science

# Background source RMs trace ISM



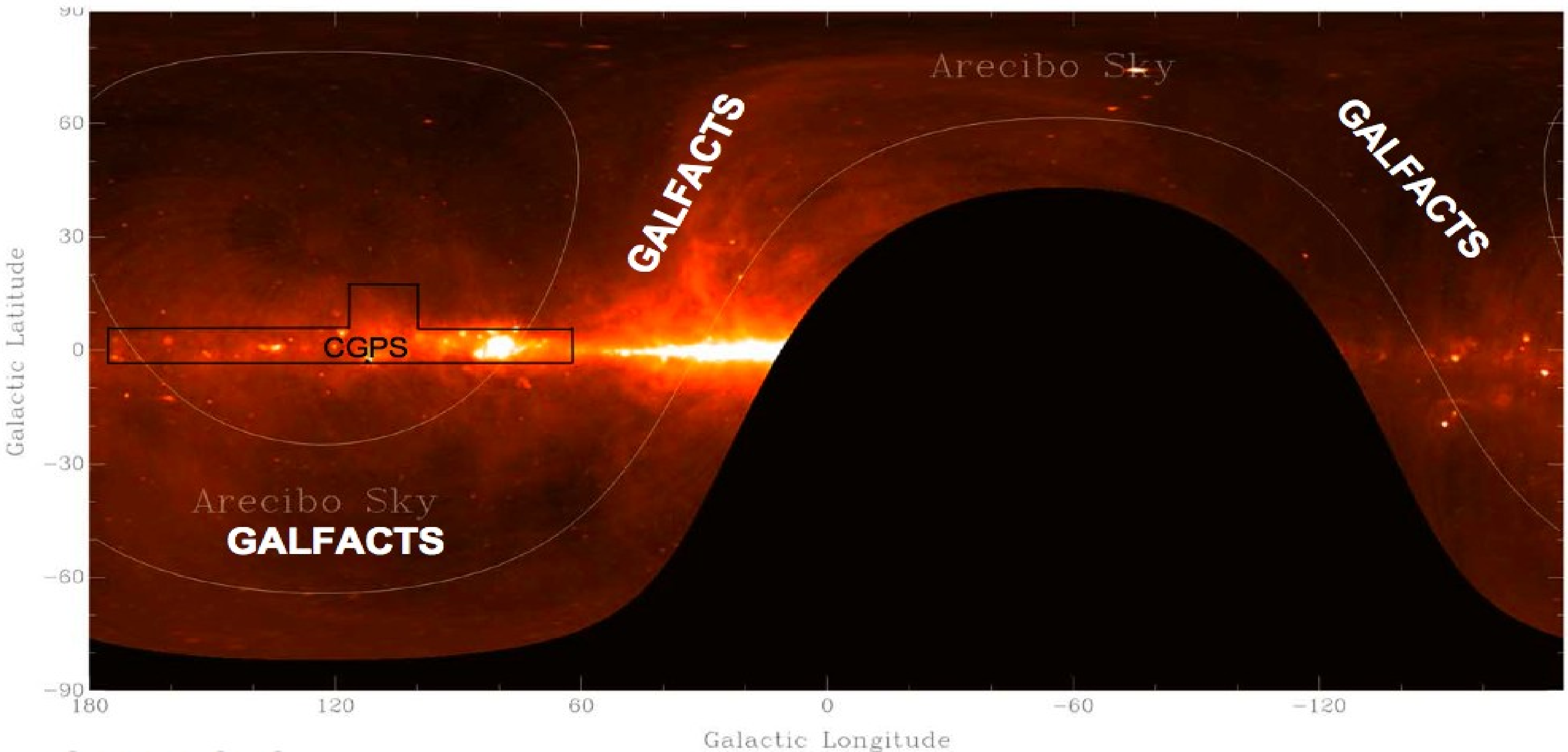

soft X-ray (ROSAT 0.25 keV)

Stil, Taylor & Sunstrum (2011) ApJ, 726, 4

# GALFACTS

Observations

Declination range -0.8-37.8 degrees; 32% sky




8000 channels/300 MHz

3.5’ beam; centre 1375MHz; 1ms time sampling

Total observation time ~ 1600 hours.

1 sigma Stokes I (all band) 90 microJy

8 runs of 29 day x 6.25 hours (4 North of zenith, 4 South of zenith)

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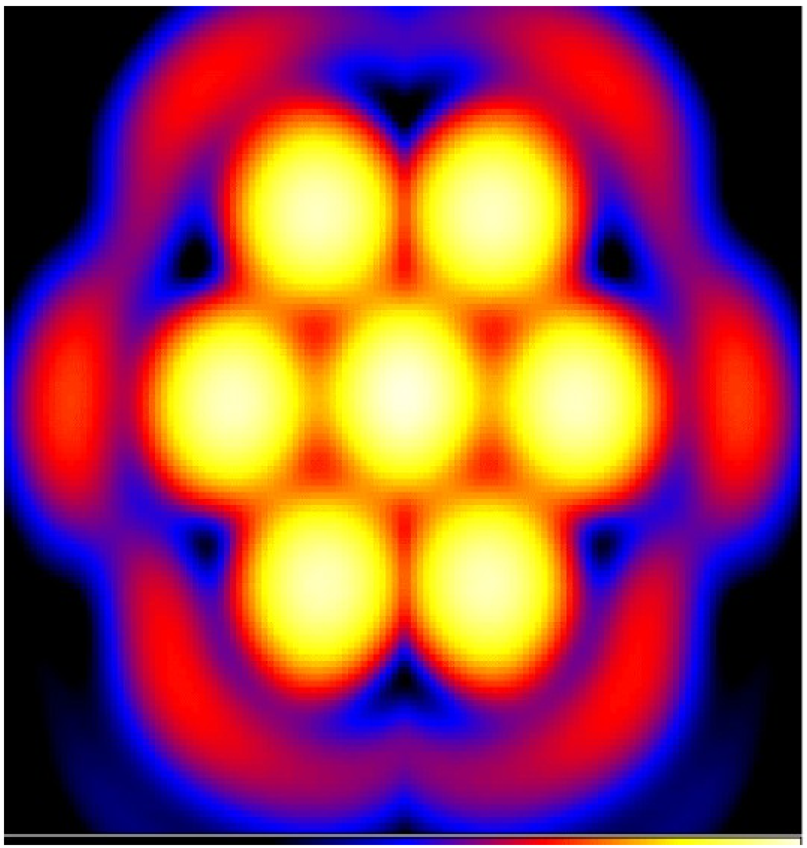
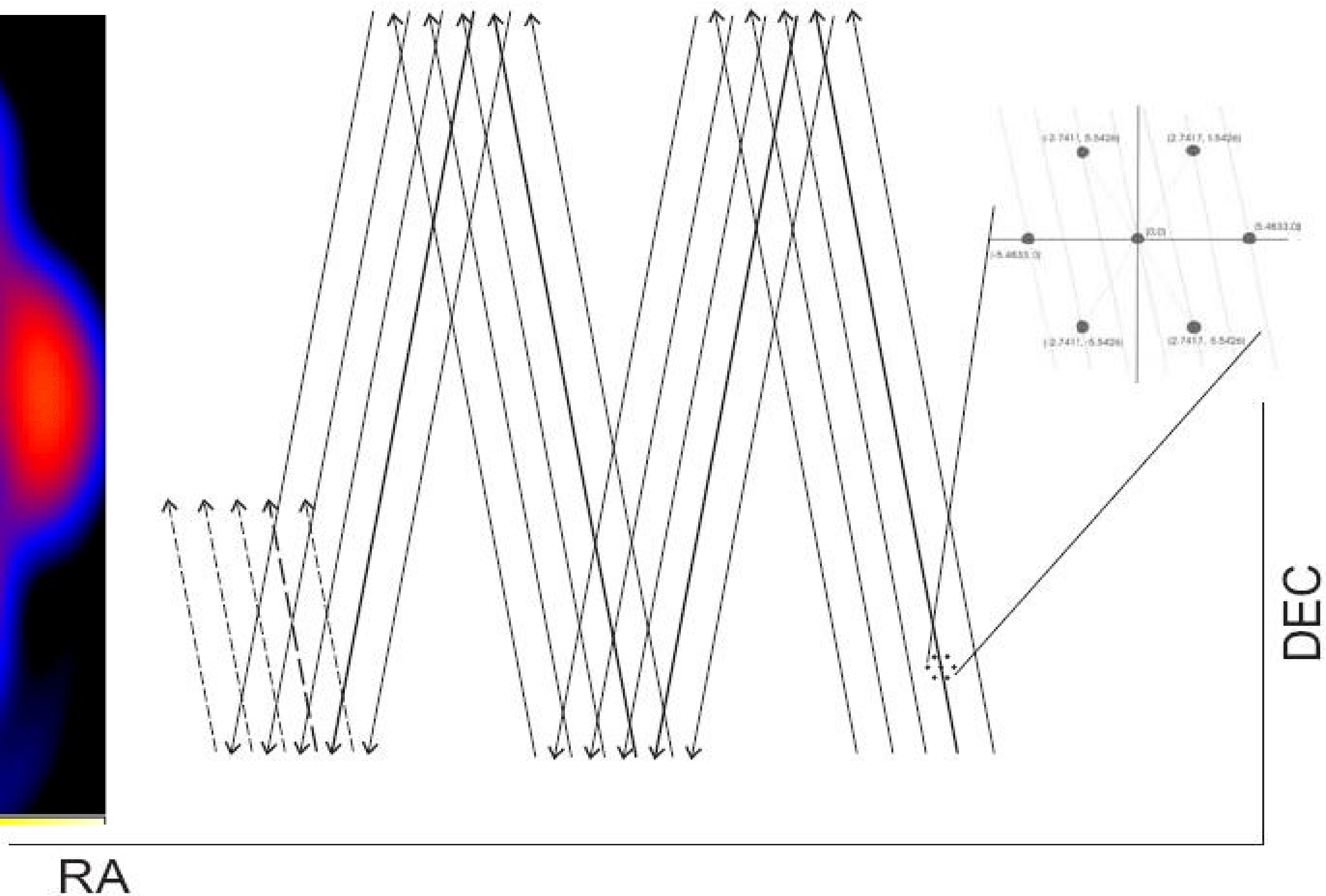
Declination range -0.8-37.8 degrees; 32% sky






Scan rate = 1.53 degrees/minute
Track separation = 1.83’

# GALFACTS

Data Challenges

Andrecut, Guram, George, Taylor, ADASS 2011

ALFA spectrometer raw data ~460MB/s
~ 3 Petabytes for full project

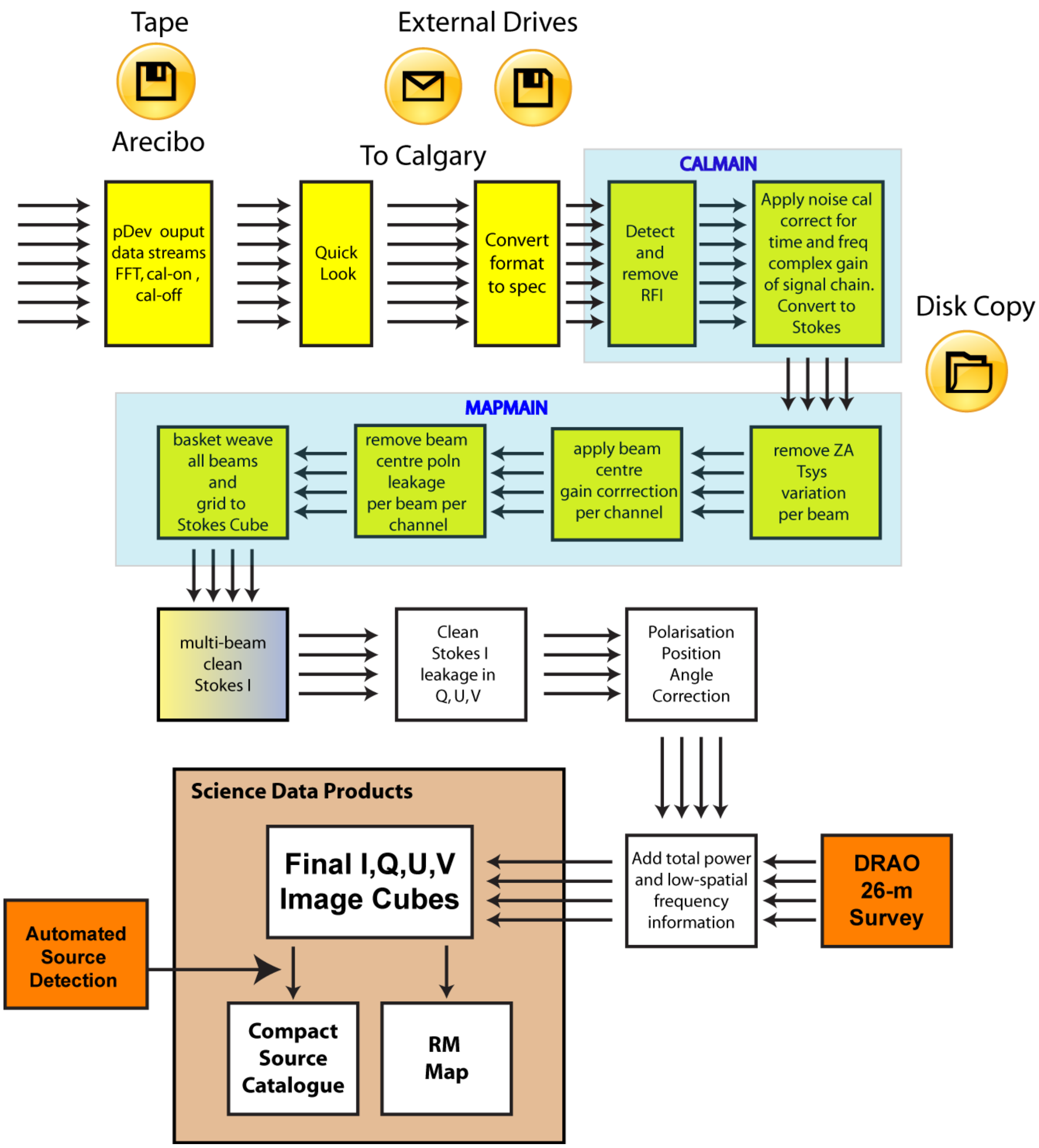
9.9 TB/day reduced to 800 GB/day after time/freq decimation at Arecibo

Data is compressed into 2 streams:

- 140TB total frequency averaged
- 40TB total time averaged, 0.2s (5 TB per run)

How do you transport 200TB of data, 25TB at a time, from Puerto Rico to Calgary?

25TB at 1MB/s would take 303 days.



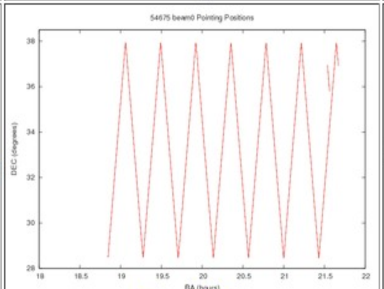
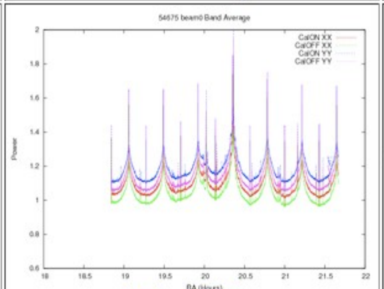
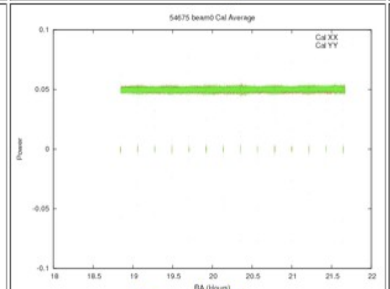
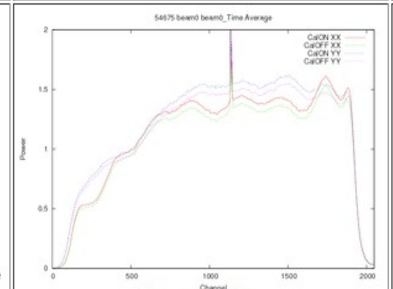
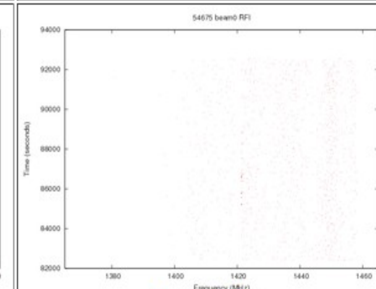
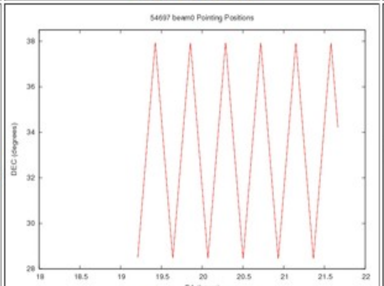
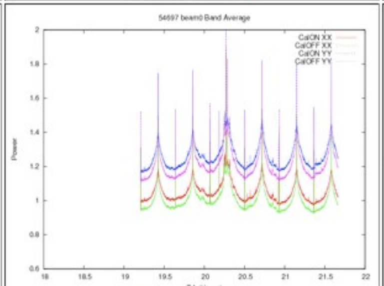
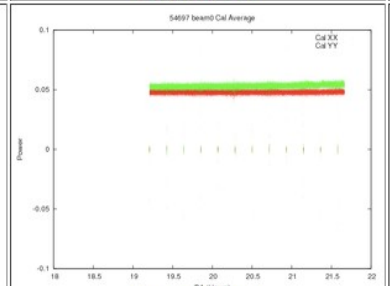
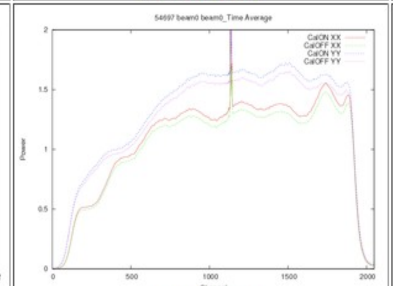
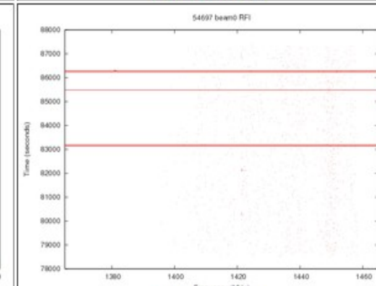
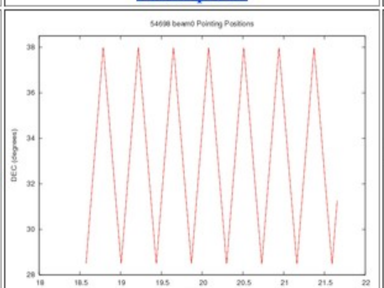
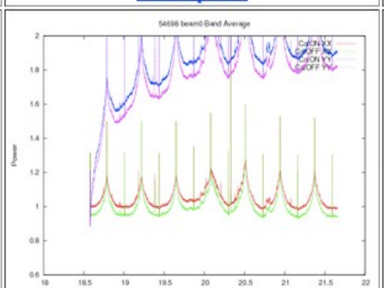
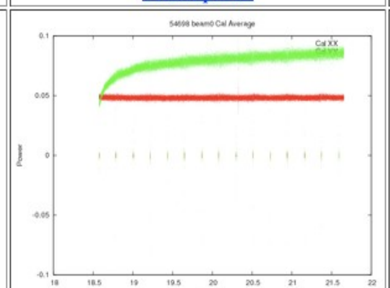
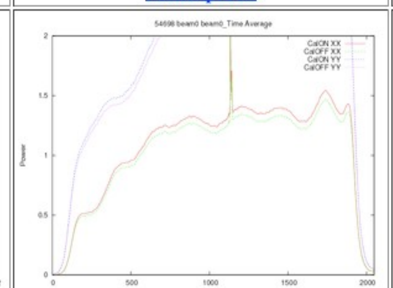
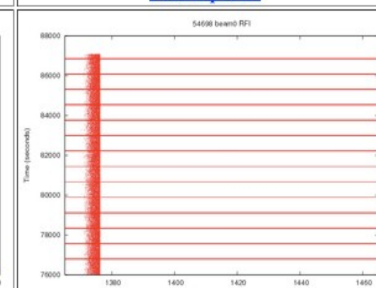
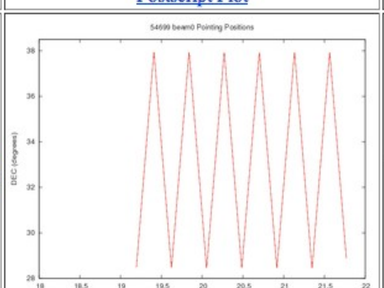
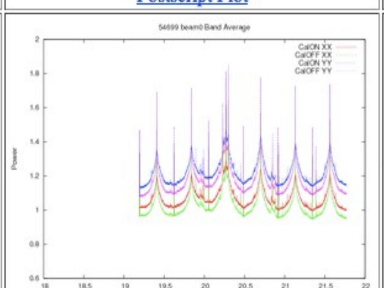
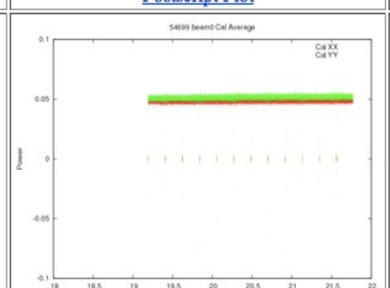
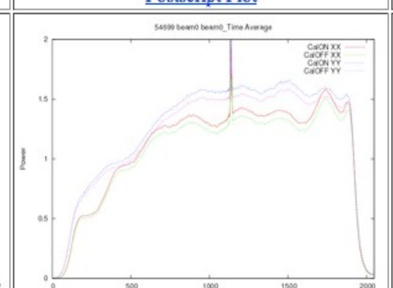
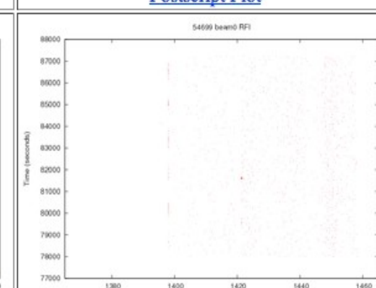
http://tatanka.ras.ucalgary.ca/projects/a2186/quality/Dfield/beam0.html

# A2186.igalfa_d beam0 WAPPS Data Quality Heuristics

main

beam0 beam1 beam2 beam3 beam4 beam5 beam6

54675 54697 54698 54699 54700 54702 54703 54704 54705 54706 54712 54713 54714 54716 54717 54720 54721 54732 54733 54734 54742 54743 54745 54746 54747 54748 54749 54750

| | Pointing Plot | Band Average | Cal Average | Time Average | RFI Detection |
|---|---|---|---|---|---|
| **54675 beam0** |  Postscript Plot |  Postscript Plot |  Postscript Plot |  Postscript Plot |  Postscript Plot |
| **54697 beam0** |  Postscript Plot |  Postscript Plot |  Postscript Plot |  Postscript Plot |  Postscript Plot |
| **54698 beam0** |  Postscript Plot |  Postscript Plot |  Postscript Plot |  Postscript Plot |  Postscript Plot |
| **54699 beam0** |  Postscript Plot |  Postscript Plot |  Postscript Plot |  Postscript Plot |  Postscript Plot |

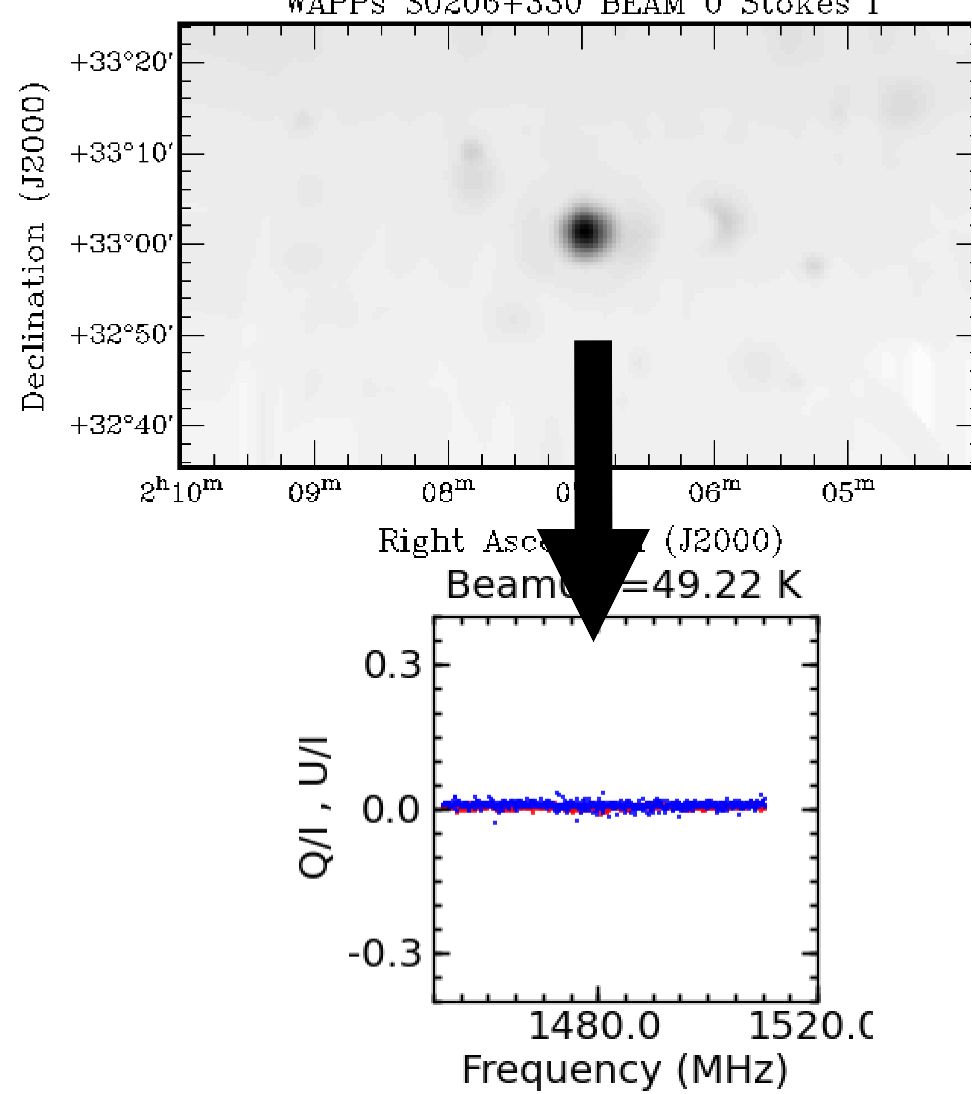
# Calibration

High flux density (S > 500mJy)

Small angular size (unresolved with NVSS)

Isolated (6' from nearest NVSS source)

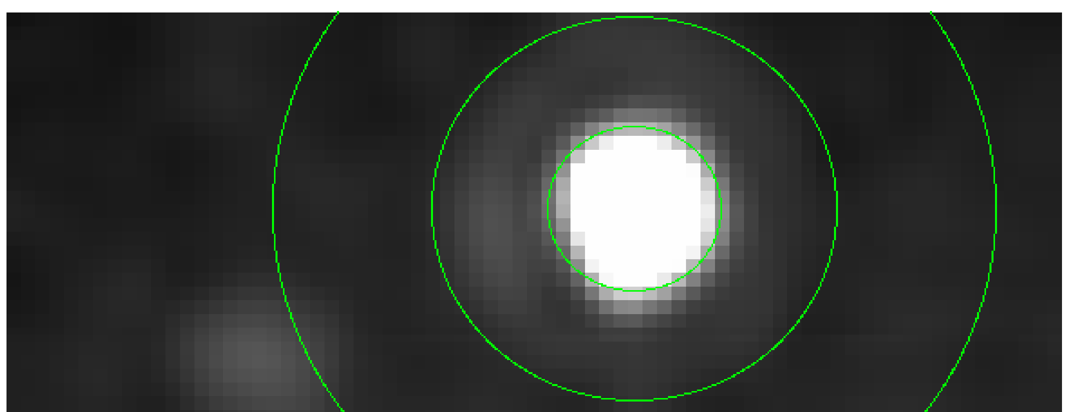
Cover varying declinations




| RA | DEC | $I_{int}$ mJy | $I_{interr}$ mJy | $P_{int}$ mJy | $P_{interr}$ mJy | $I_{peak}$ mJy/beam | $P_{peak}$ mJy/beam | % Polar. | Pol. angle deg |
|---|---|---|---|---|---|---|---|---|---|
| 02 06 56.65 | +33 01 27.7 | 808.0 | 24.2 | 0.38 | 0.42 | 791.4 | 0.48 | 0.40 | 81.7 |
| 02 17 01.84 | +28 04 58.2 | 1023.5 | 35.0 | 11.31 | 0.50 | 896.4 | 9.89 | 1.10 | 88.6 |
| 02 26 10.34 | +34 21 30.4 | 2894.4 | 86.8 | 7.39 | 0.44 | 2825.5 | 7.05 | 0.25 | 62.8 |
| 02 38 12.44 | +27 25 27.1 | 636.9 | 19.1 | 6.63 | 0.43 | 624.4 | 6.39 | 1.04 | 11.4 |
| 02 50 56.59 | +21 21 20.0 | 819.4 | 24.6 | 0.90 | 0.41 | 805.5 | 0.91 | 0.11 | 77.9 |
| 03 11 35.17 | +30 43 20.9 | 965.6 | 29.0 | 4.68 | 0.42 | 955.9 | 4.56 | 0.48 | 52.6 |
| 03 30 34.79 | +36 39 41.2 | 579.1 | 17.4 | 0.70 | 0.48 | 564.7 | 0.74 | 0.12 | -79.2 |
| 03 40 08.54 | +32 09 01.3 | 1611.6 | 50.5 | 34.31 | 1.29 | 935.7 | 19.59 | 2.12 | -71.1 |
| 03 52 33.43 | +22 20 20.1 | 576.6 | 17.3 | 18.09 | 0.43 | 558.8 | 17.00 | 3.14 | 35.2 |

# Calibration

- For each source/beam and channel fit a Gaussian to the source – embarrassingly parallel
- There regions used: within beam, 1st side-lobe and some  background region
- Background NVSS sources removed
- Return parameters of source



Stokes I image of a typical calibration source. Shown are the regions used for extraction.

# Calibration Output

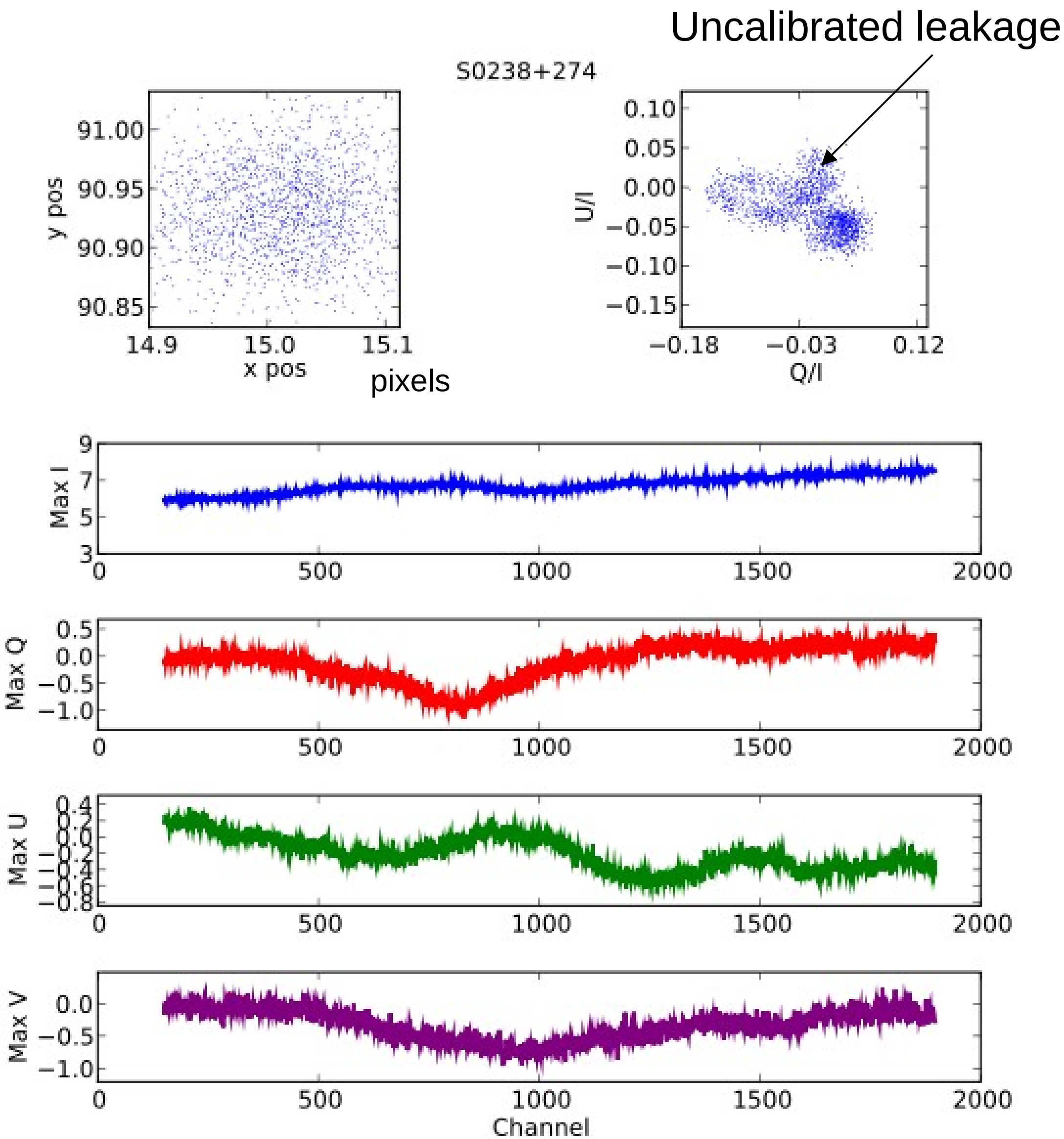
Example of diagnostic plots produced.

Typical of the run 1 MOCK observations and are for S0238+274 (PI =1%) .

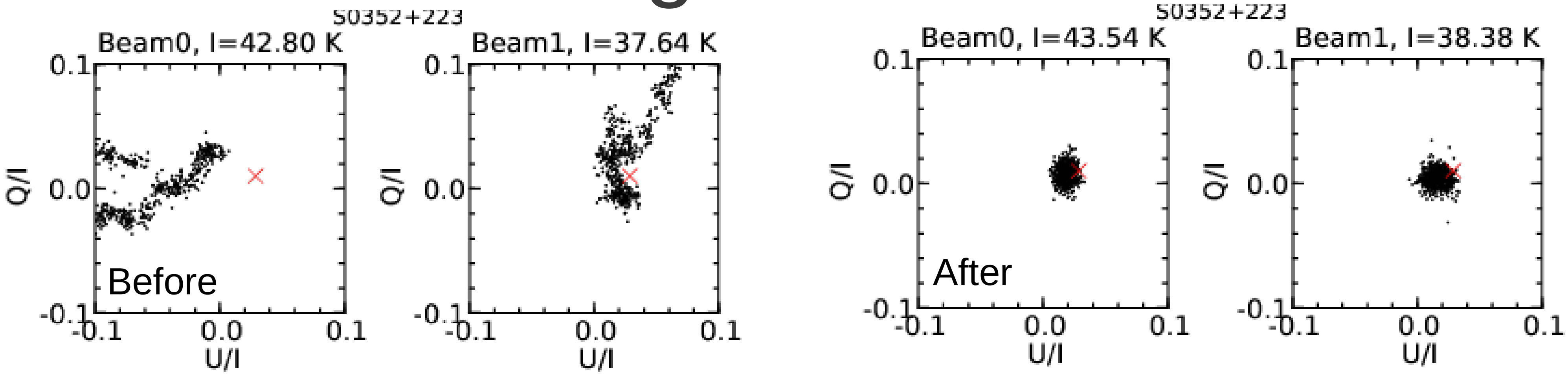
The polarization pattern seen in the U/I vs Q/I plot is due to leakage

Use S0226+343 as a reference source (small P in NVSS) for leakage – remove pattern

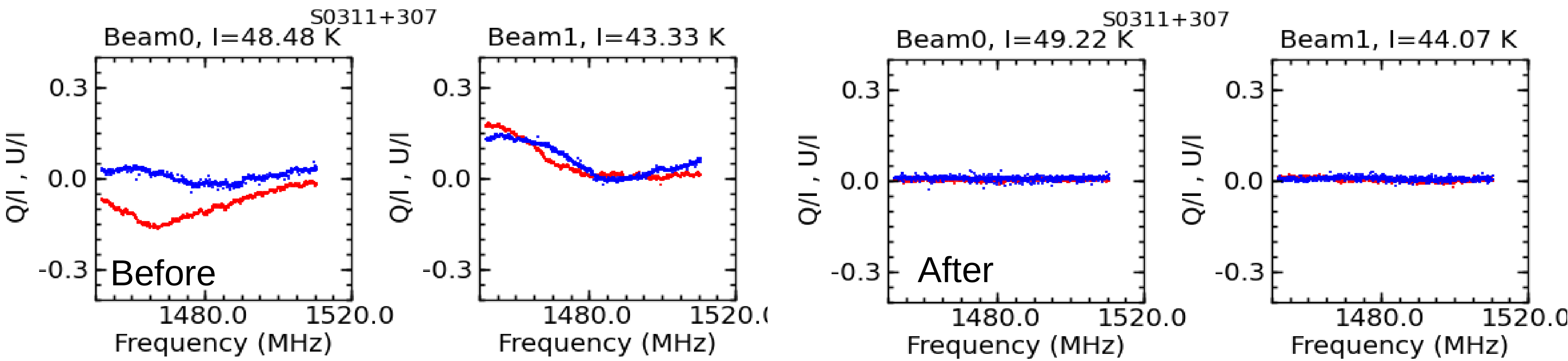
For V perform fit of the V vs I data to derive the leakage



# Leakage Correction

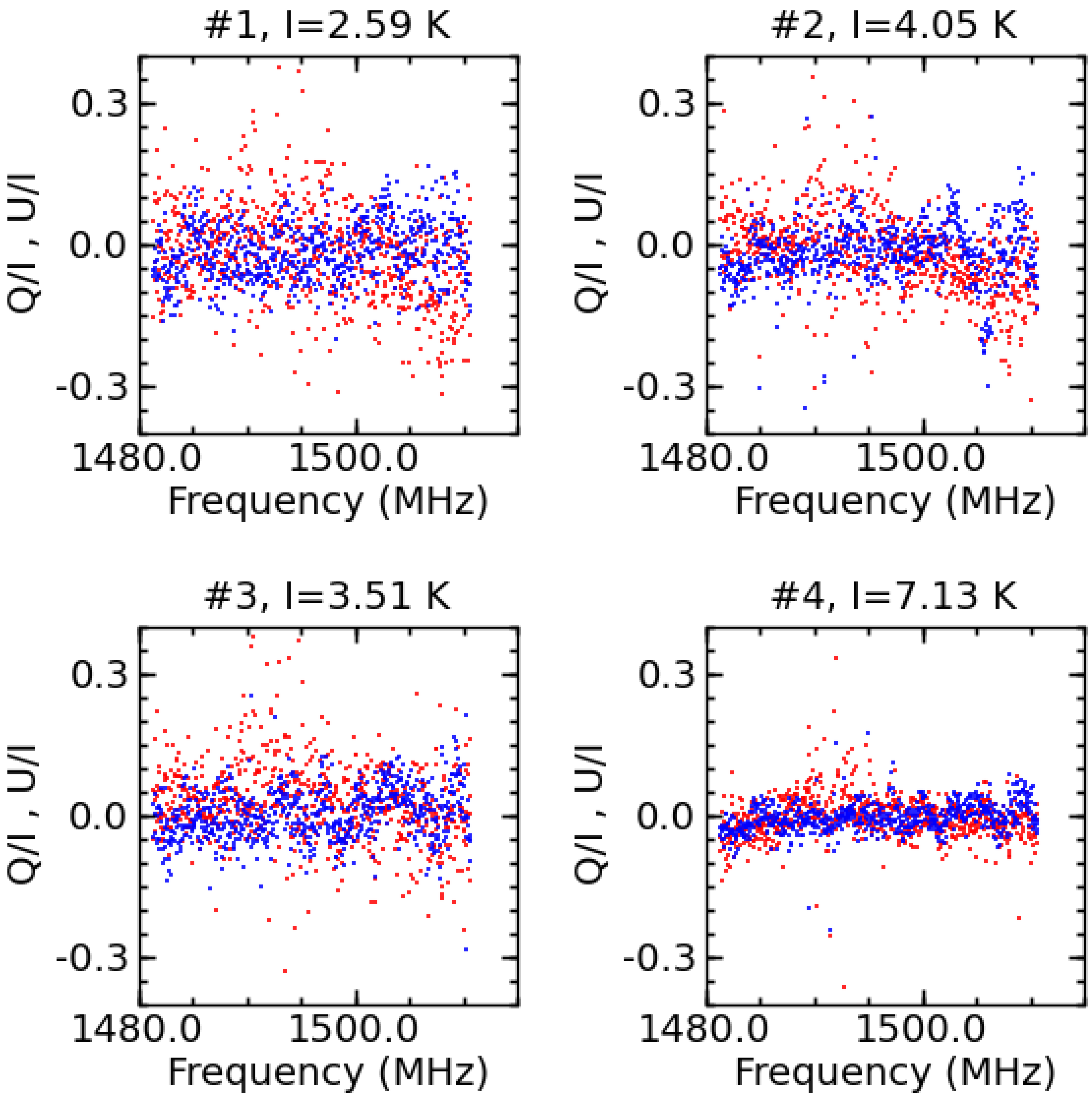



Red cross corresponds to the polarization value determined from the NVSS (PI NVSS = **3.14%**)
Mean distribution over all beams (after cal): PI = **2.41**




red curve U/I blue curve is Q/I

# Un-polarized NVSS Sources

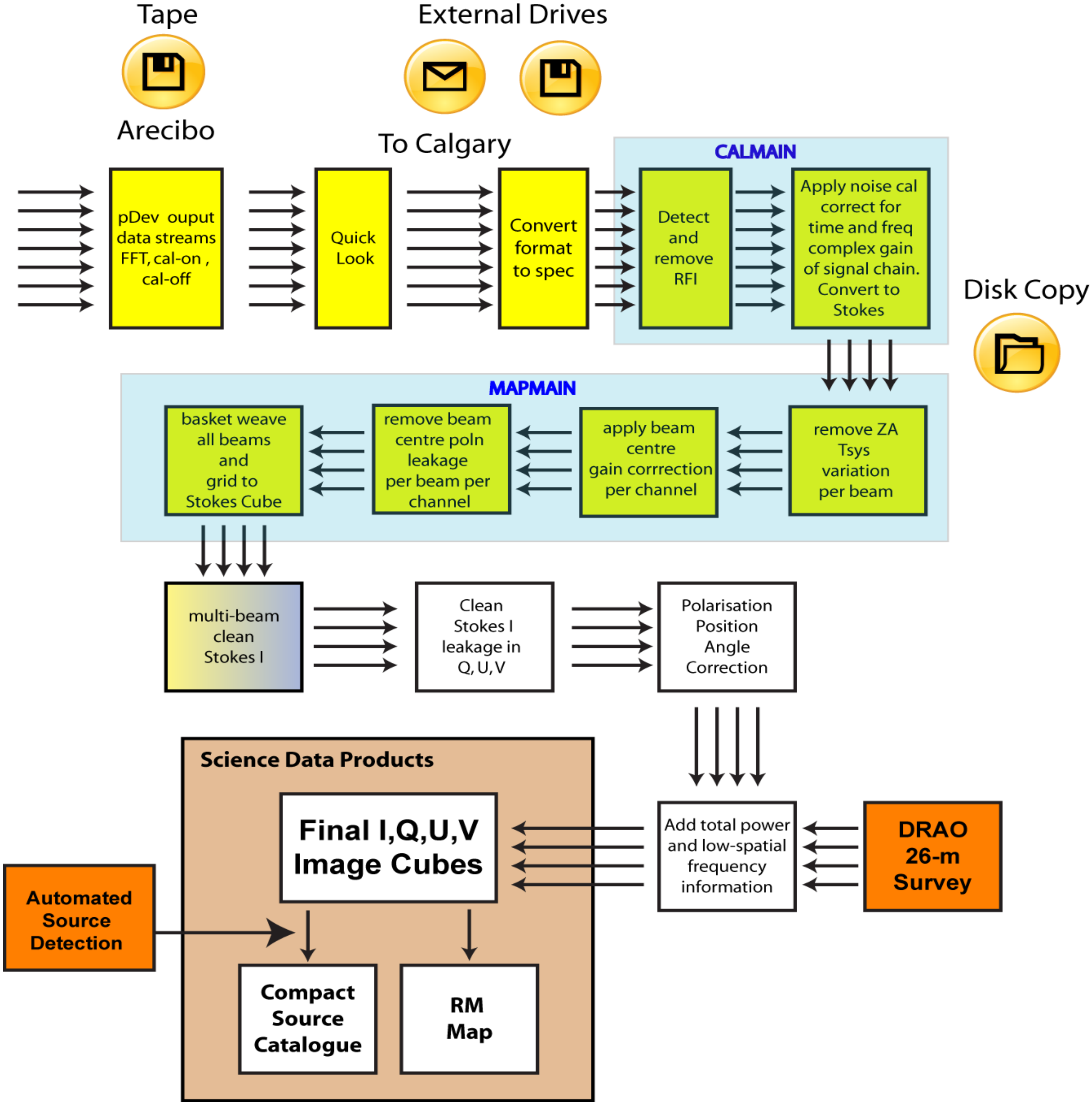



19 unpolarized Sources in the NVSS that cover range that have:

Stokes I > 200mJy
P (bias cor) < 0.3mJy

Median Π = **4.46%**

**Simple leakage correction not good enough**



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# RFI rejection

Andrecut, Guram, George, Taylor, ADASS 2011

## Frequency Domain

- Since the goal is to detect channels with large power values, comparing to their neighbors, an obvious strategy is to use first order differences (or equivalently the first derivative) in the frequency domain.
- At each time $t$ the data is transformed as following:

$$\delta_{n,t} = s_{n+1,t} - s_{n,t}, \quad n = 0, 2, ..., N-2.$$

- The detection method is based on a Gaussian model for the amplitude of the new variable $\delta_{n,t}$.
- In such a model, one establishes a threshold to distinguish the RFI-contaminated state from the RFI-free state, and the data exceeding some threshold is rejected.
- The threshold is calculated using an adaptive method.
- We assume that $f_{n,t}$ is a binary rejection flag, such that $f_{n,t} = TRUE$ if the data in channel $n$ at time $t$ is bad (RFI-contaminated), and respectively $f_{n,t} = FALSE$ if the data is good (RFI-free).

# RFI rejection

## Time Domain

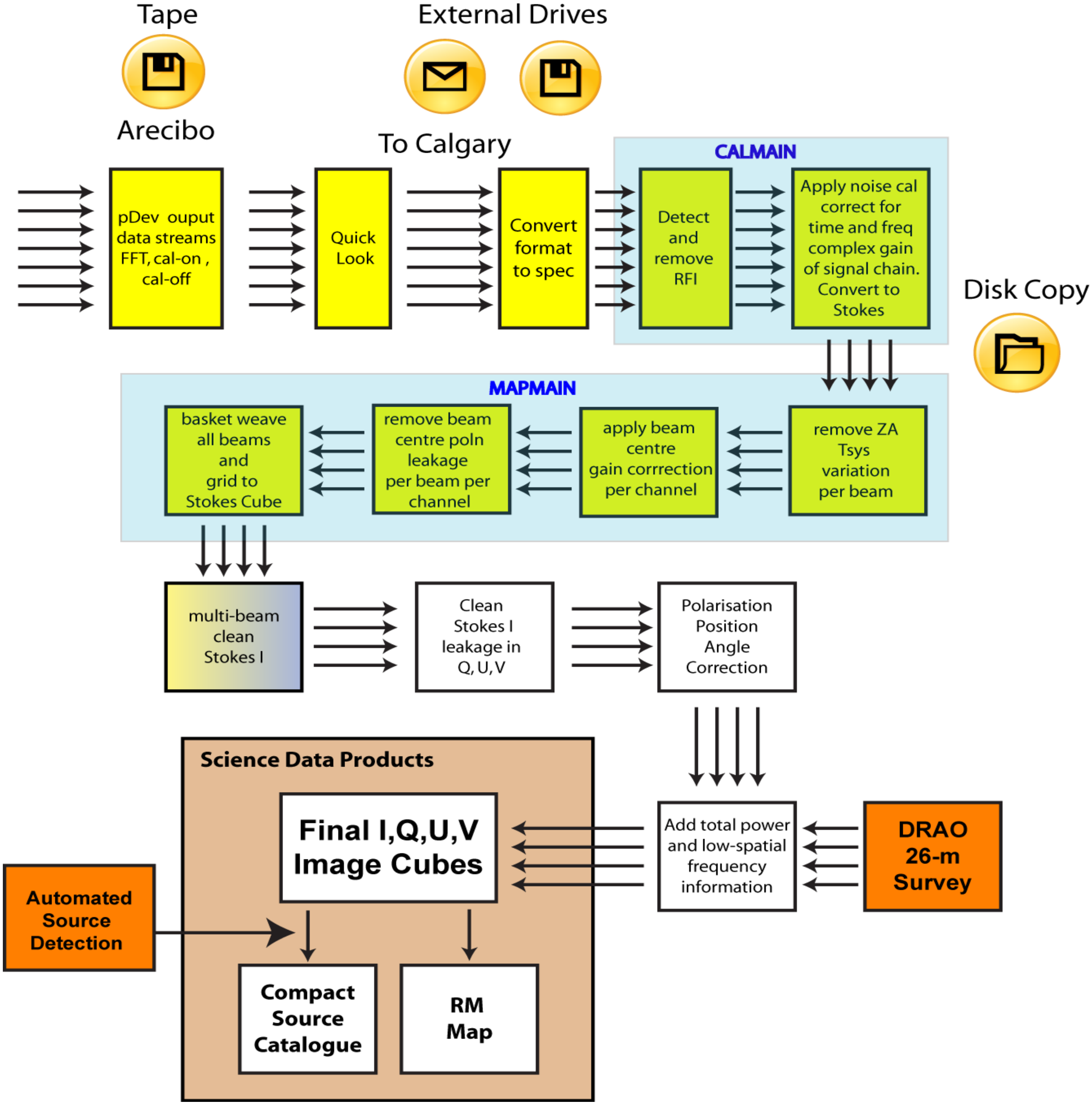
- The first method uses the standard deviation of the difference signal in frequency domain:

$$\sigma_t = \sqrt{\frac{1}{N-2}\sum_{n=0}^{N-2}(\delta_{n,t} - \mu_t)^2}, \quad t = 0, 1, ..., T-1.$$

- The second method works with the band average signal:

$$\mu_t = \frac{1}{N}\sum_{n=0}^{N-1} s_{n,t}, \quad t = 0, 1, ..., T-1.$$

- We use the second order differences (or the second derivative), instead of the first order differences.
- As for the frequency domain, the method assumes a Gaussian model for the new difference variables, and the data exceeding some threshold is rejected.
- We assume that $g_t$ is a binary rejection flag, such that $g_t = TRUE$ if the data at time $t$ is bad (RFI contaminated), and respectively $g_t = FALSE$ if the data is good.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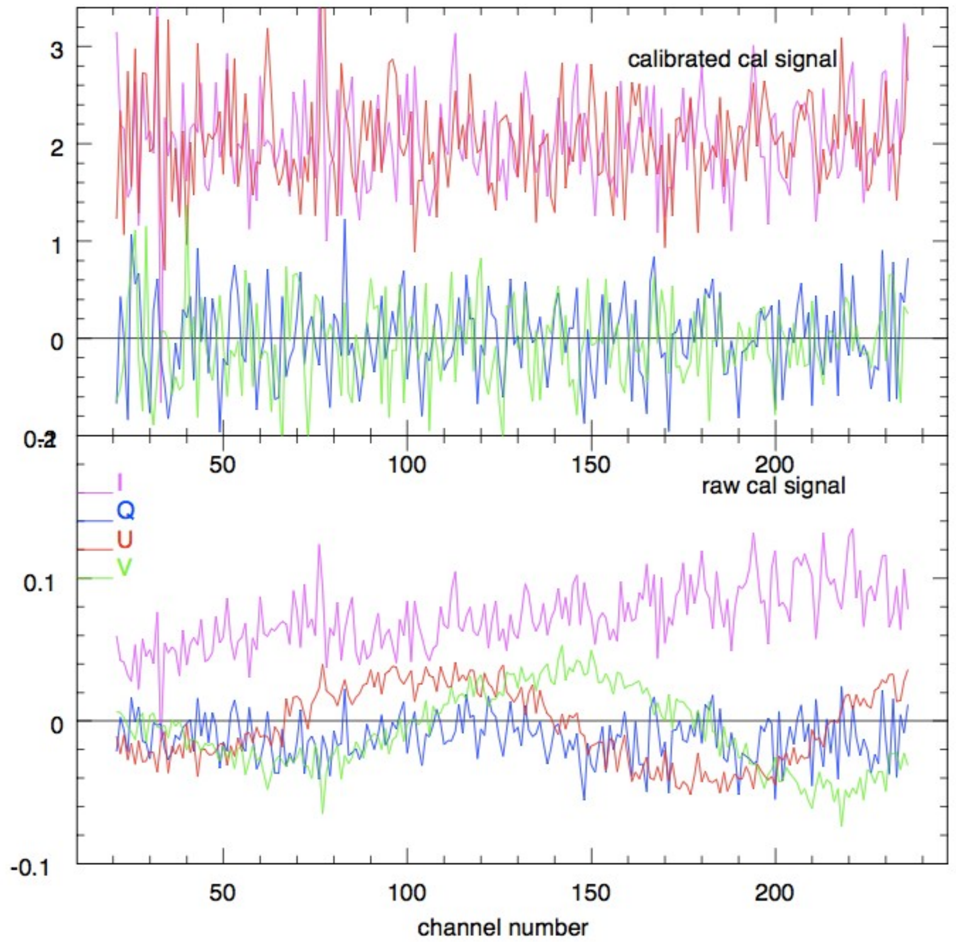
# Gain Cal

$$A_I(\nu) = A_{xx} + A_{yy} = \Big(G_x(\nu)^2 + G_y(\nu)^2\Big) T_{cal}$$

$$A_Q(\nu) = A_{xx} - A_{yy} = \Big(G_x(\nu)^2 - G_y(\nu)^2\Big) T_{cal}$$

$$A_U(\nu) = A_{xy} + A_{yx} = G_x(\nu) G_y(\nu) 2 T_{cal} \cos\phi(\nu)$$

$$A_V(\nu) = i(A_{xy} - A_{yx}) = G_x(\nu) G_y(\nu) 2 T_{cal} \sin\phi(\nu)$$



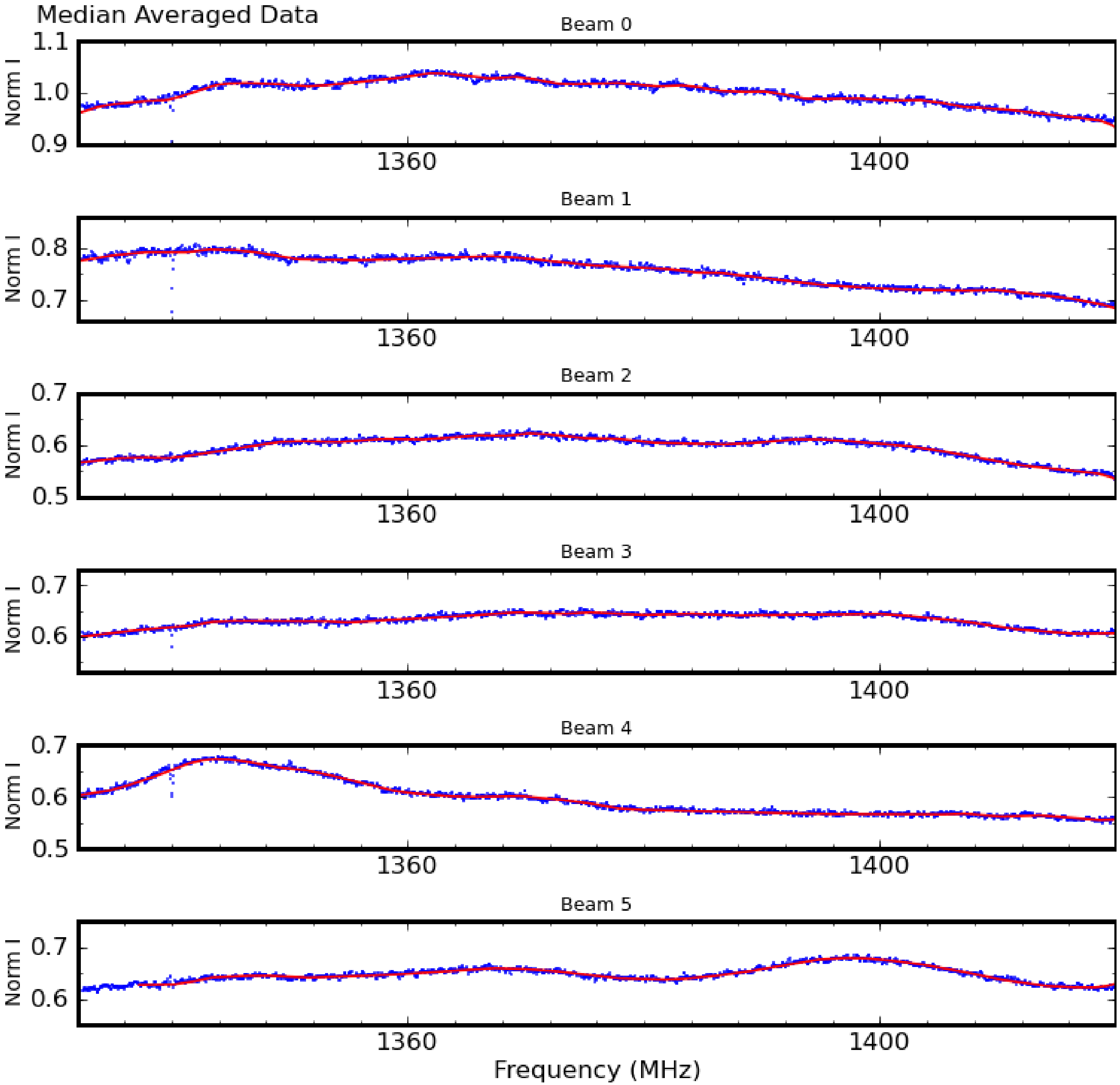

$$\begin{bmatrix} I' & Q' & U' & V' \end{bmatrix} \begin{bmatrix} \frac{(g_x^2+g_y^2)}{2} & \frac{(g_x^2-g_y^2)}{2} & 0 & 0 \\ \frac{(g_x^2-g_y^2)}{2} & \frac{(g_x^2+g_y^2)}{2} & 0 & 0 \\ 0 & 0 & 2g_xg_y\cos\phi & -2g_xg_y\sin\phi \\ 0 & 0 & 2g_xg_y\sin\phi & 2g_xg_y\cos\phi \end{bmatrix} = \begin{bmatrix} I & Q & U & V \end{bmatrix}$$

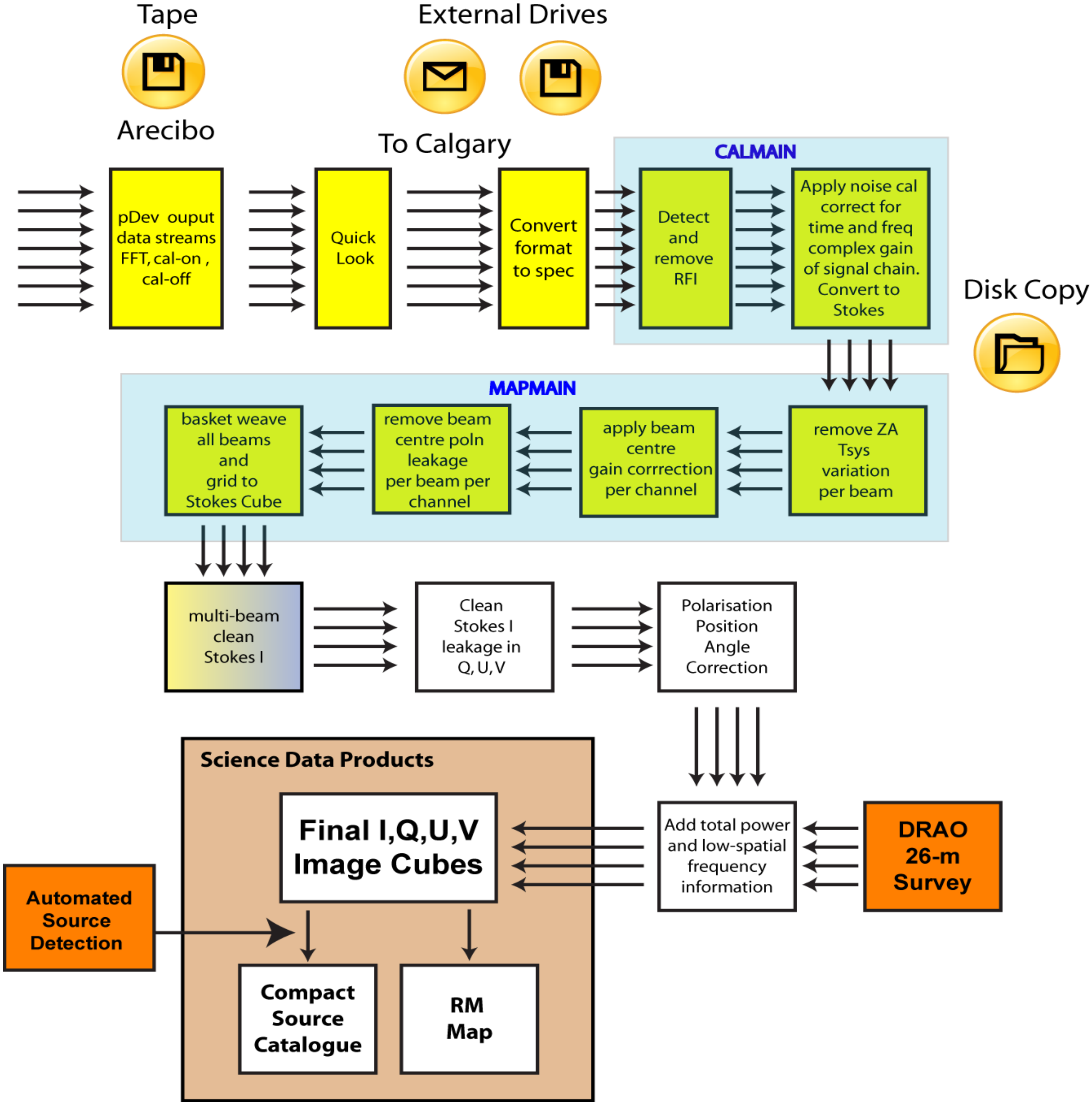
# Beam Gain Correction

Use (completely sampled in each beam) calibrator observations

Normalize all the beam responses with respect to the central beam from individual beam maps of calibrator source

Use these values to normalize the main GALFACTS data

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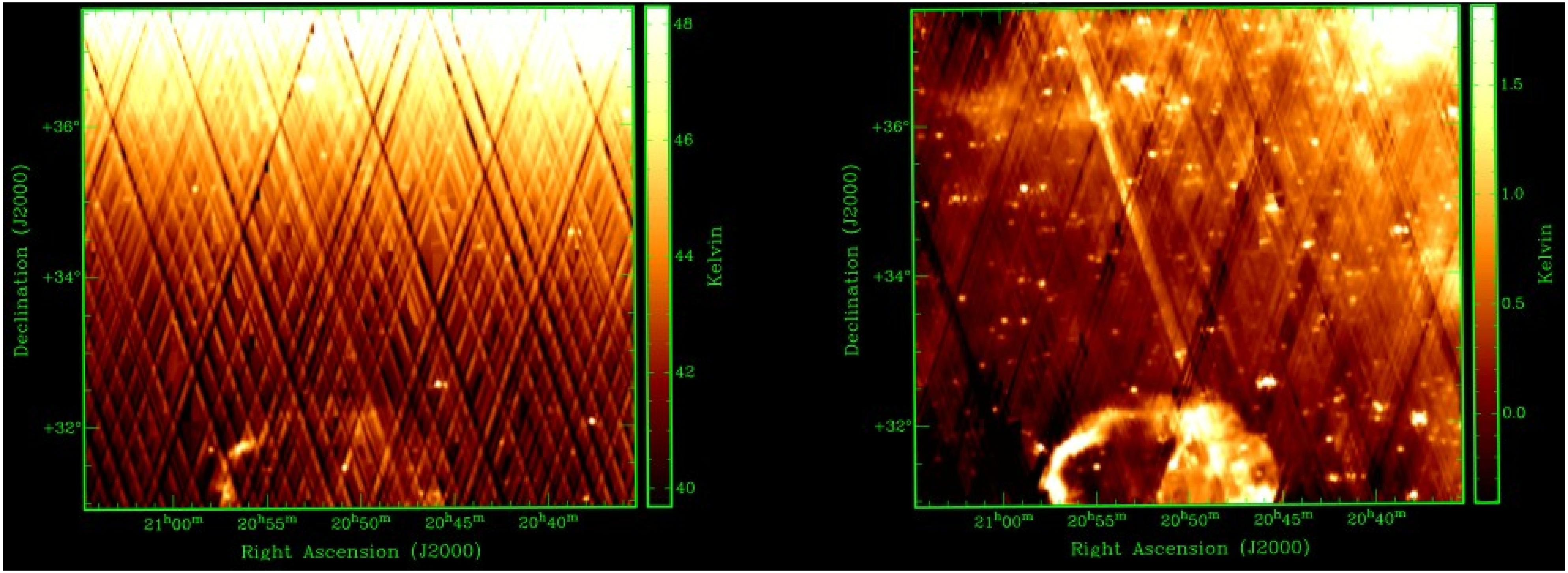
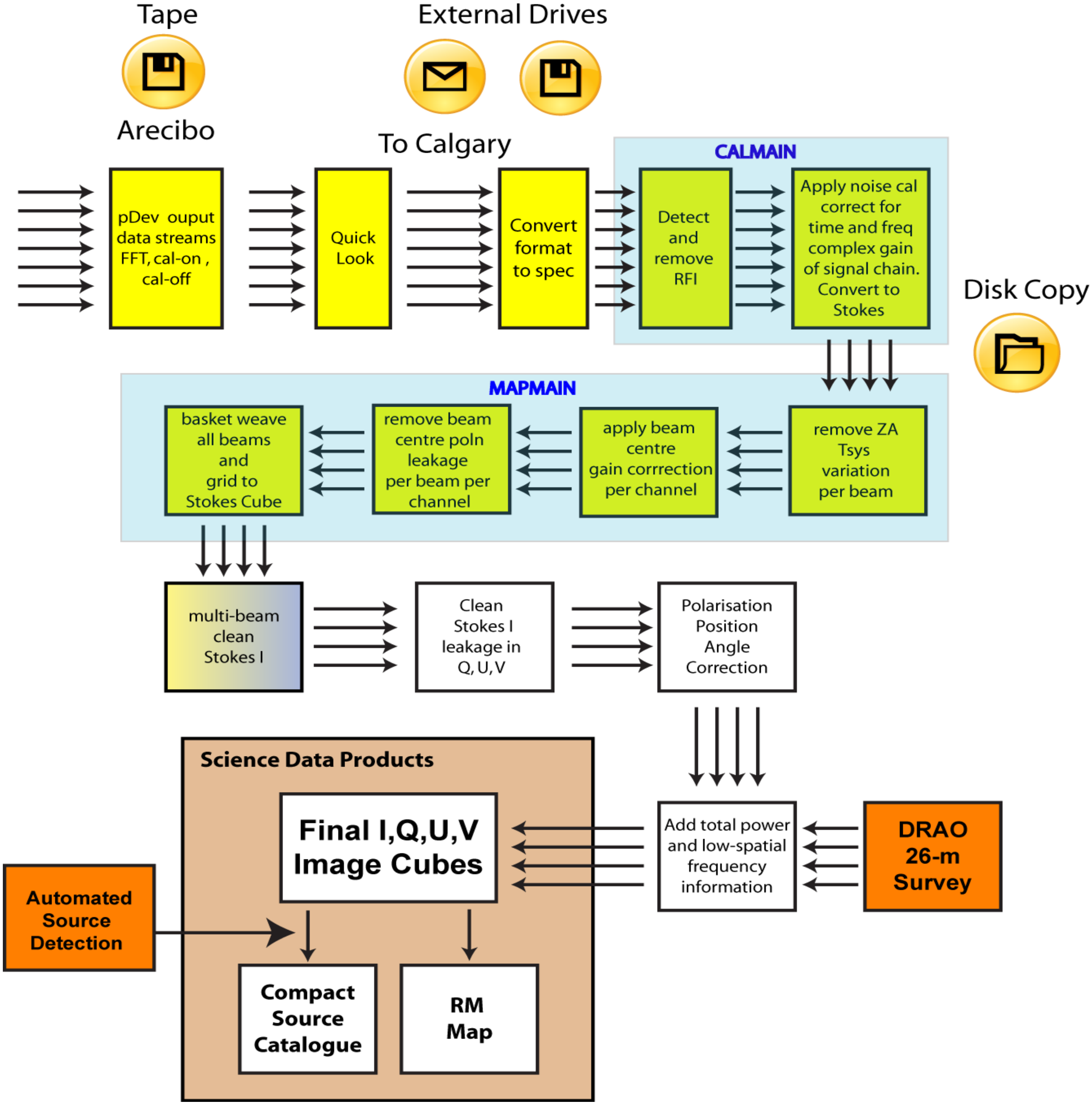
# Declination Dependent Background Removal

- System temperature increases with declination (spillover effect)
- Bin per day per beam data into small declination bins
- Reject on source points from the bins
- Fit a polynomial to the binned data and subtract the fit from the original data





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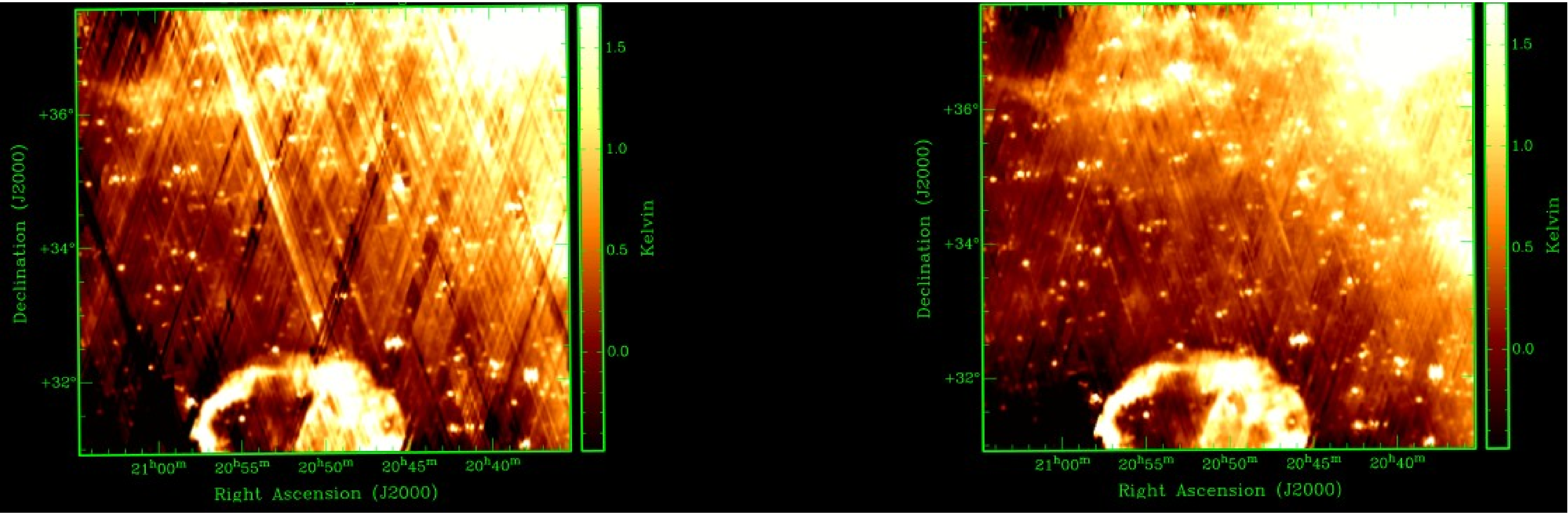
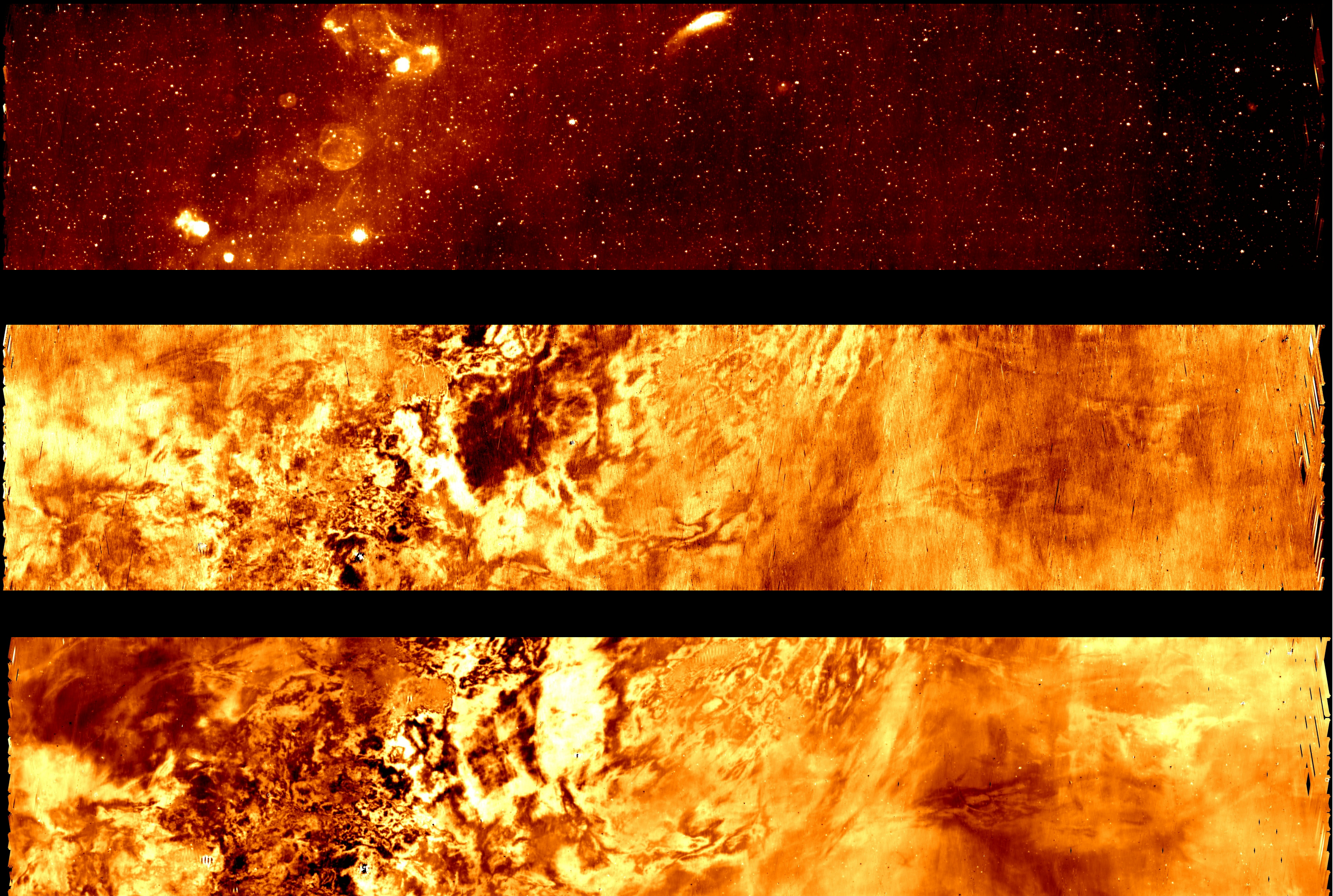
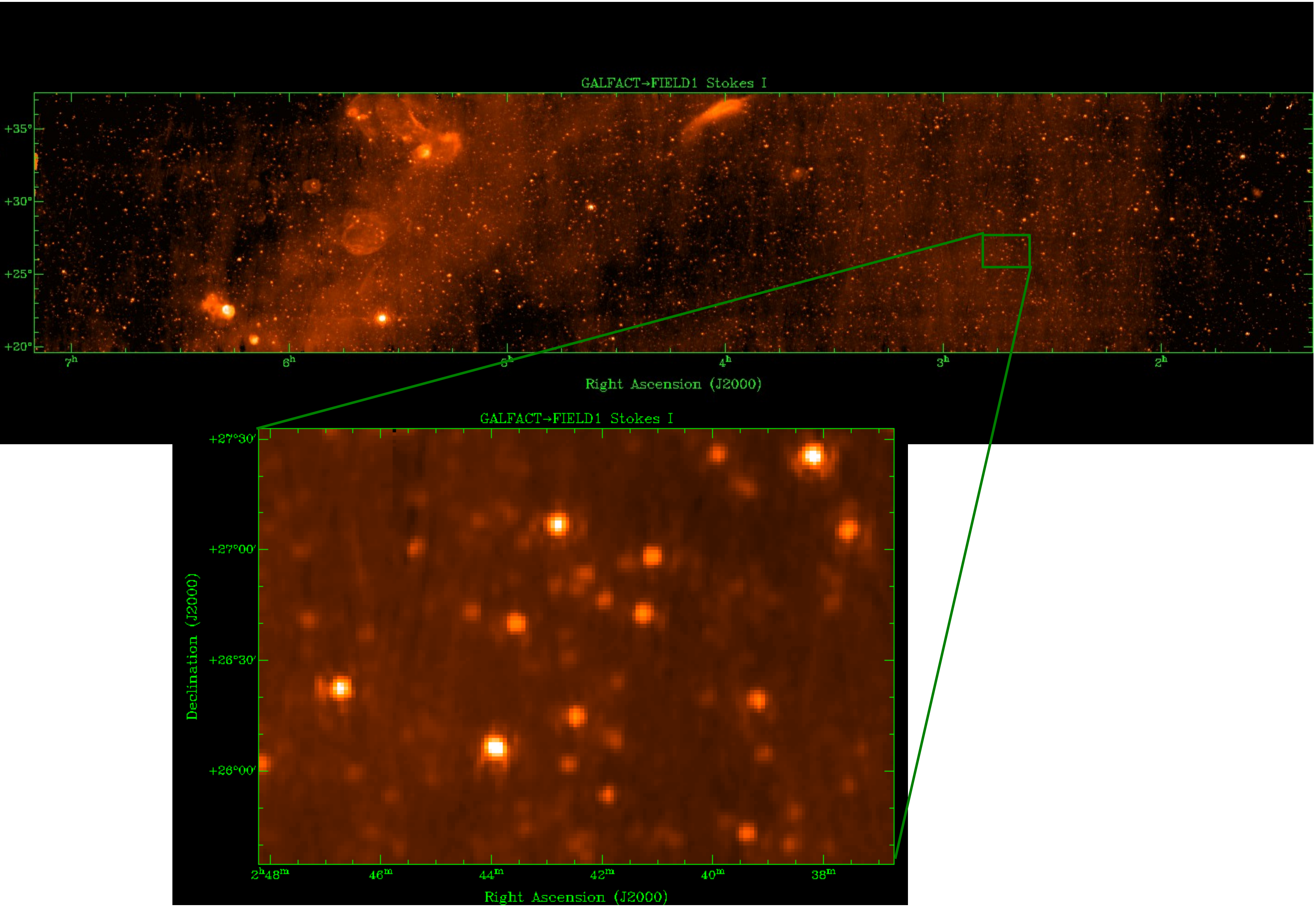
# Basketweaving

Basic assumption: observation of same point on the sky should give same value

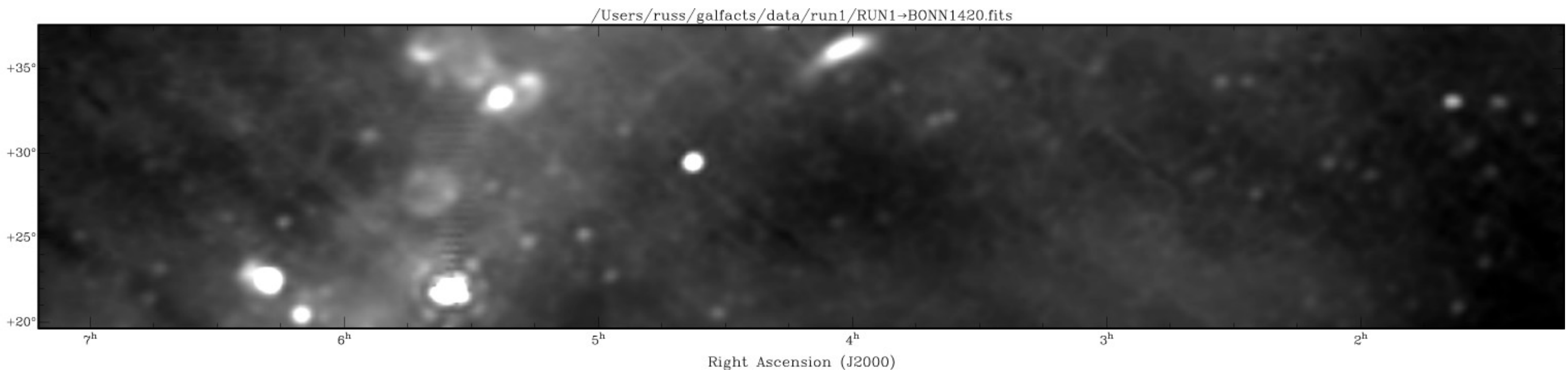
- Find the crossing points between various tracks and fit the differences at these points with a progressively increasing polynomial
- Subtract this polynomial (Chebyshev) times the loop gain from the original data. Iterate over the data until improvement become too small
- Change the polynomial order by one and repeat all the steps

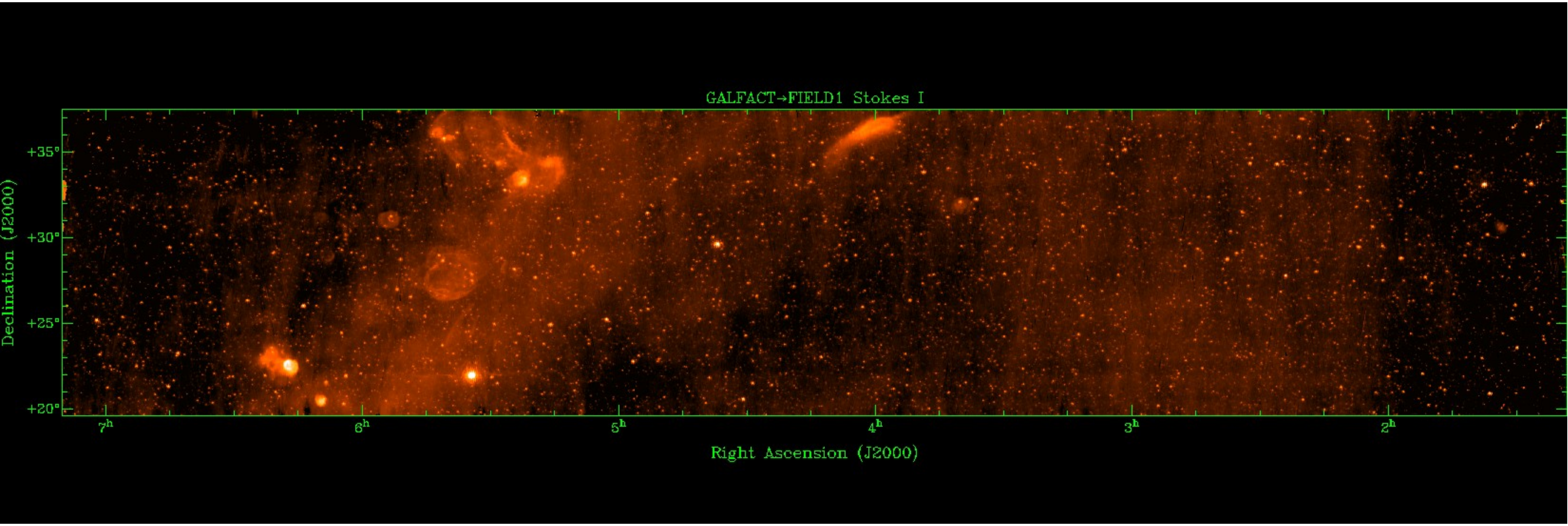




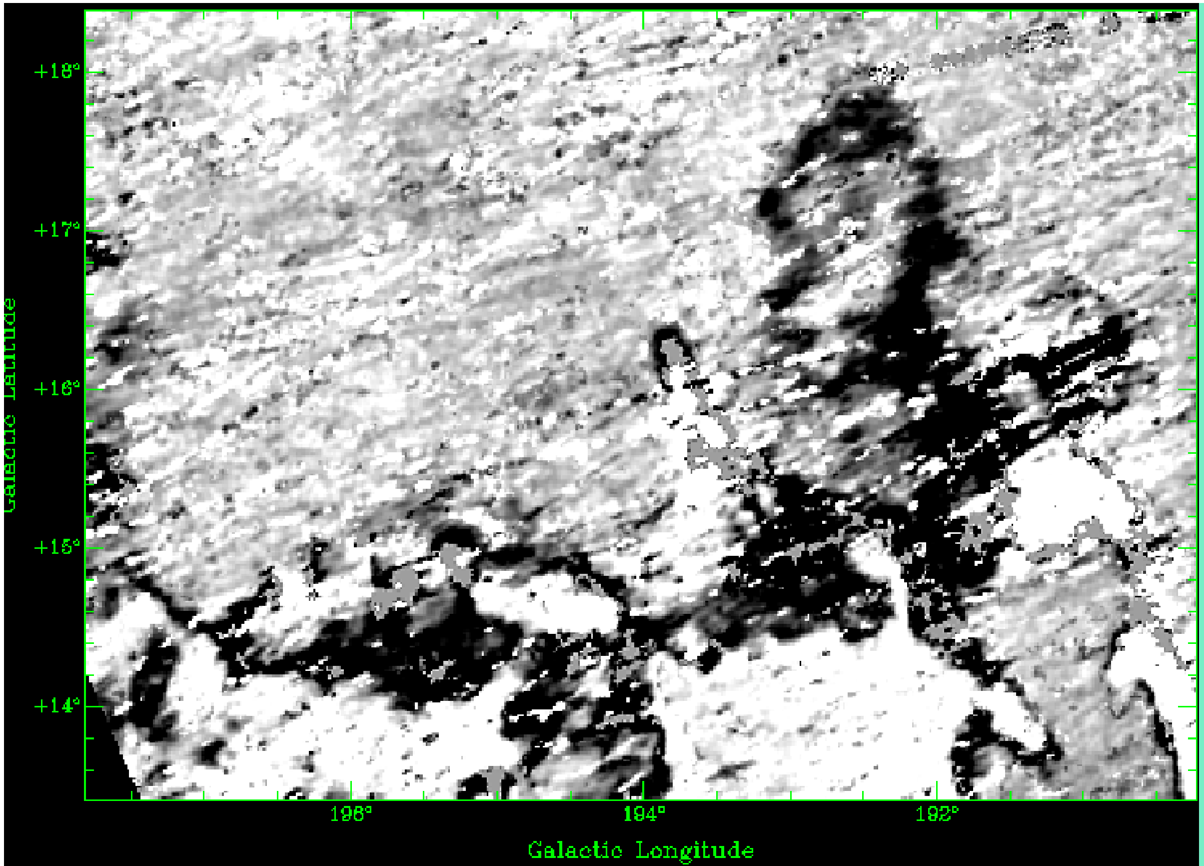

GALFACT→FIELD1 Stokes I
+35°
+30°
+25°
+20°
7h
6h
5h
4h
3h
2h
Right Ascension (J2000)
GALFACT→FIELD1 Stokes I
+27°30′
+27°00′
+26°30′
+26°00′
Declination (J2000)
2h48m
46m
44m
42m
40m
38m
Right Ascension (J2000)

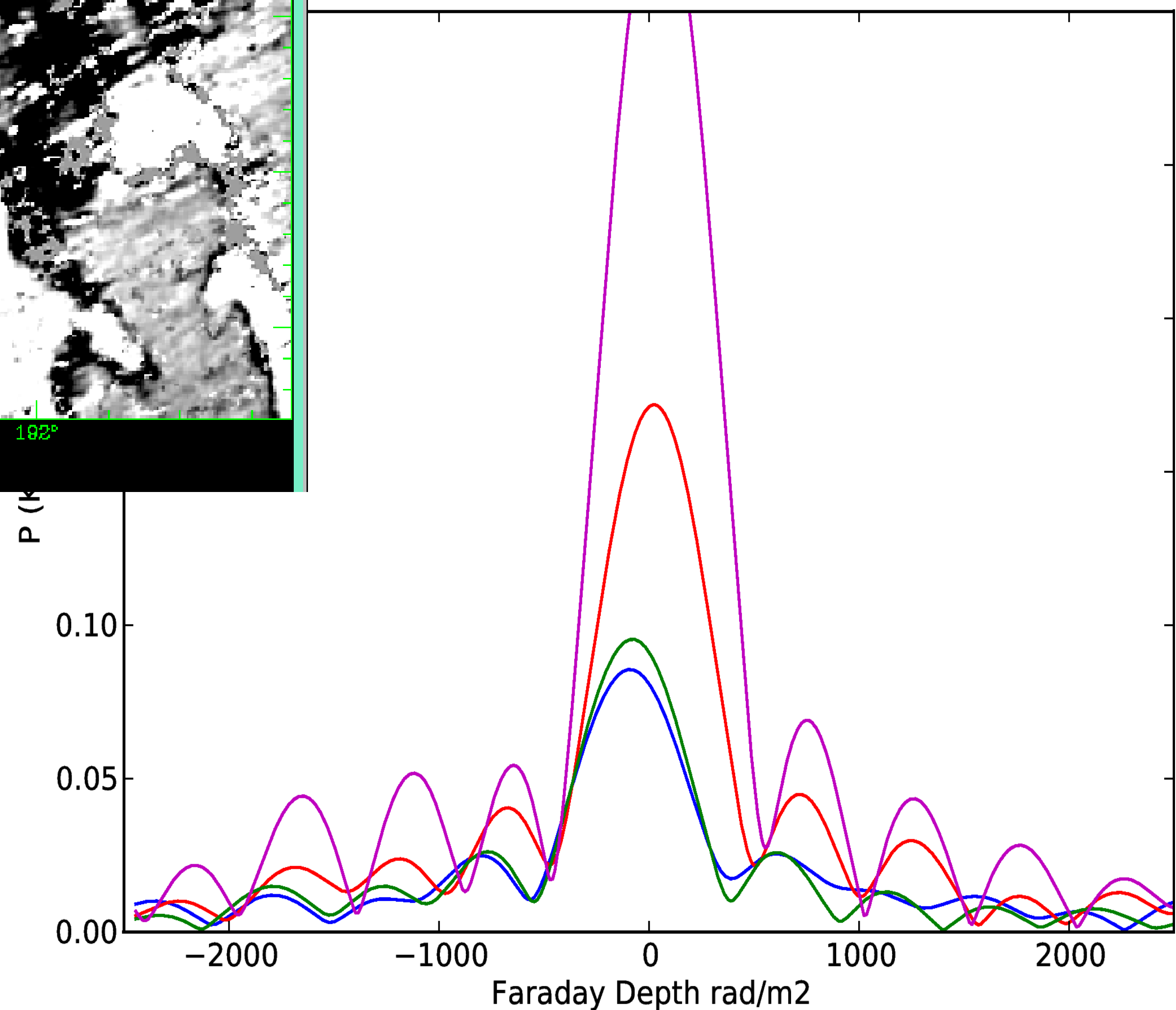
# Effelsberg Survey Comparison



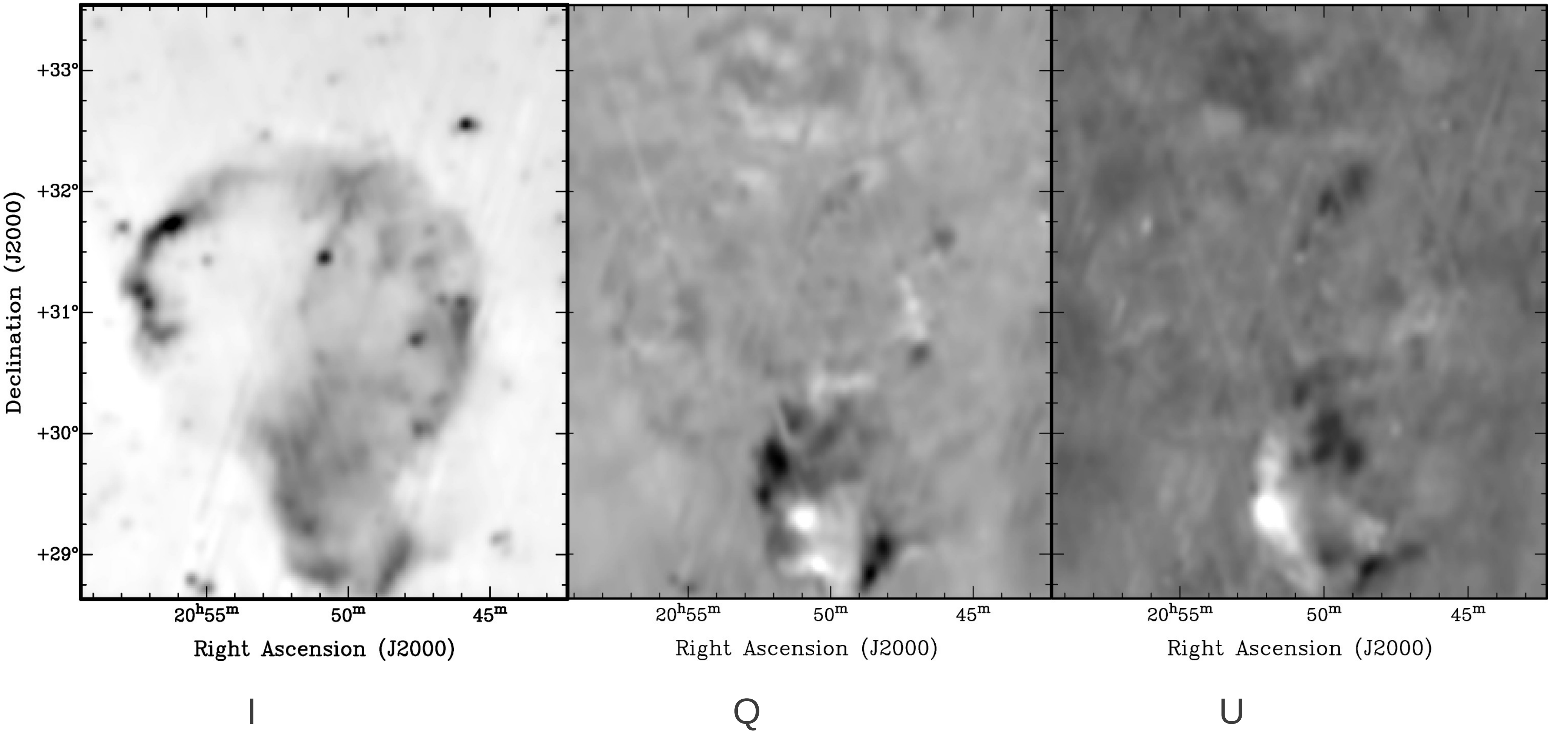



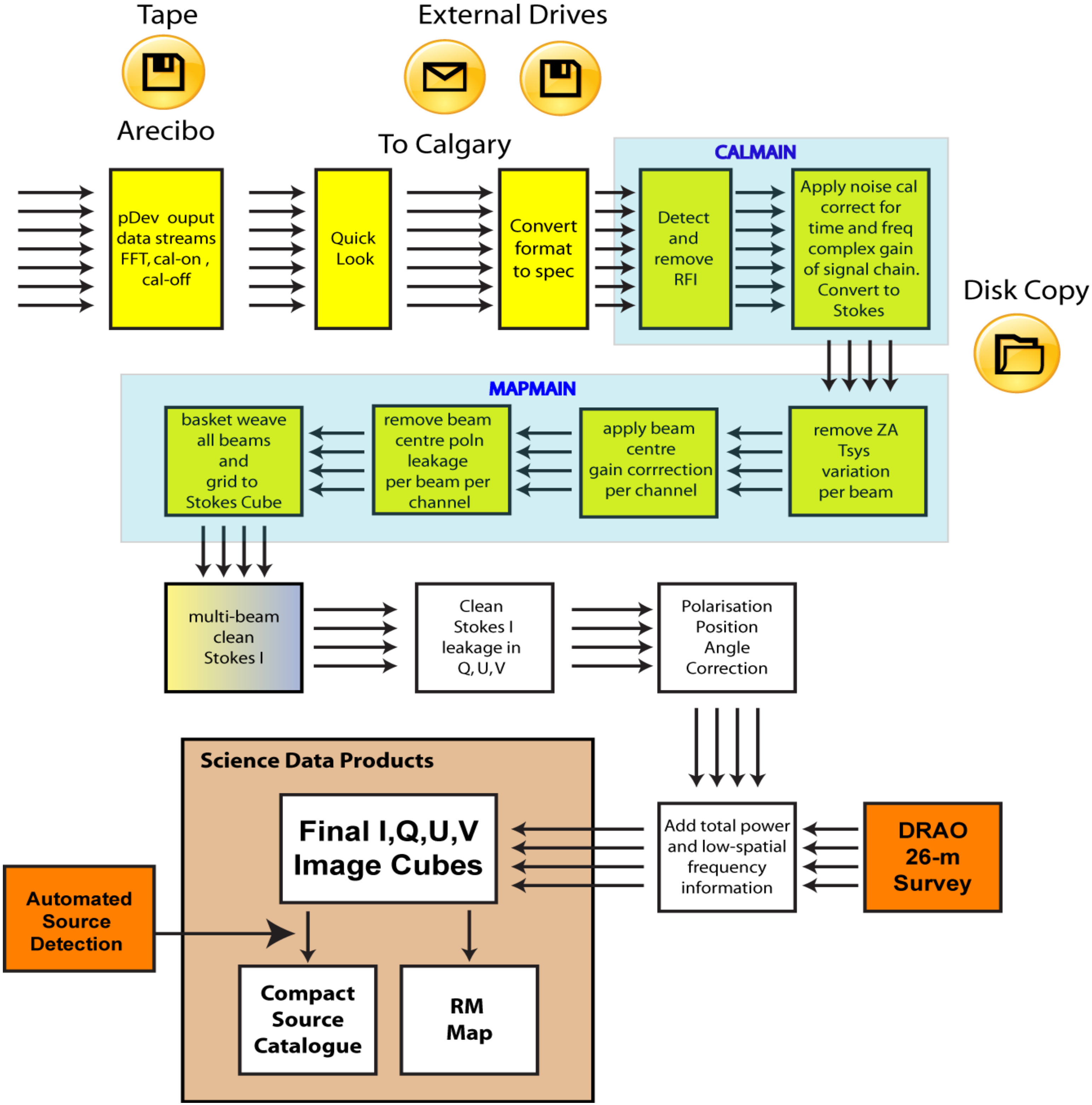
# Rotation Measure Loop in N1



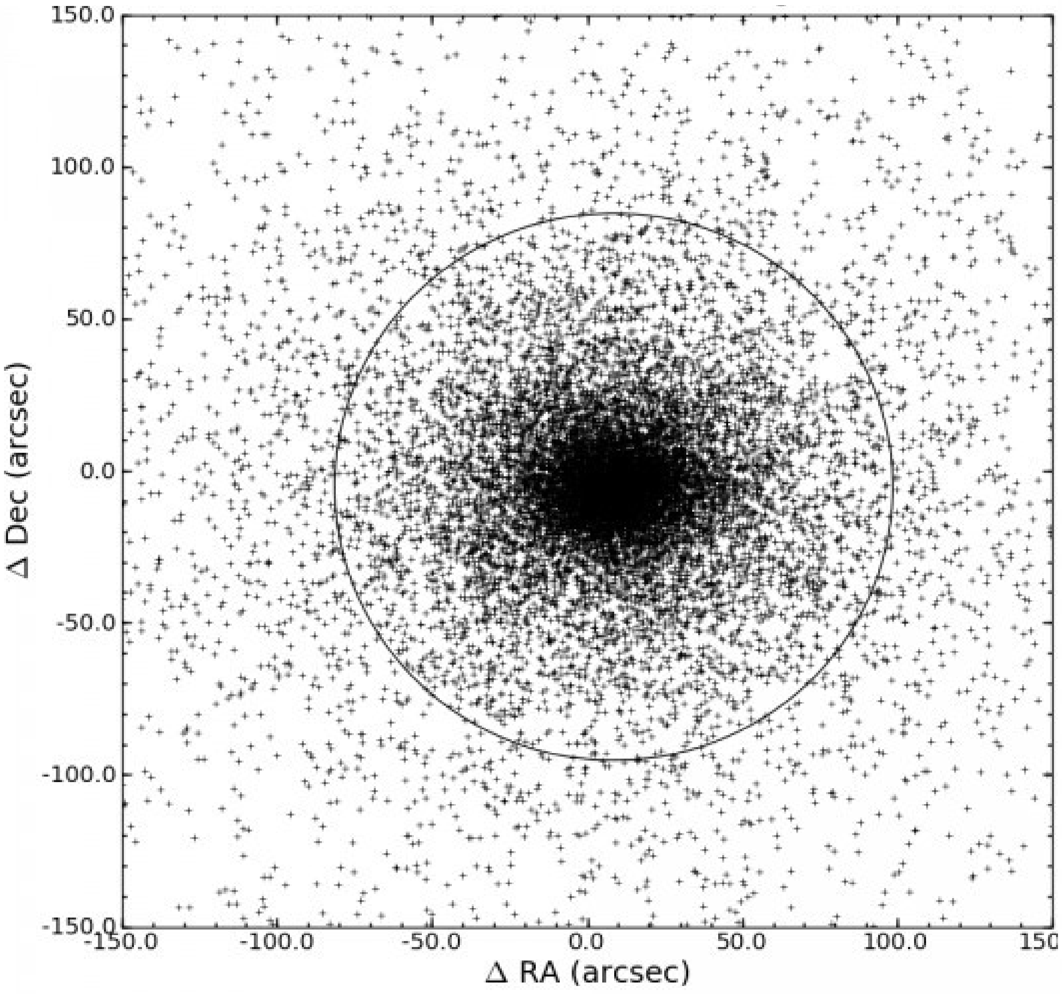



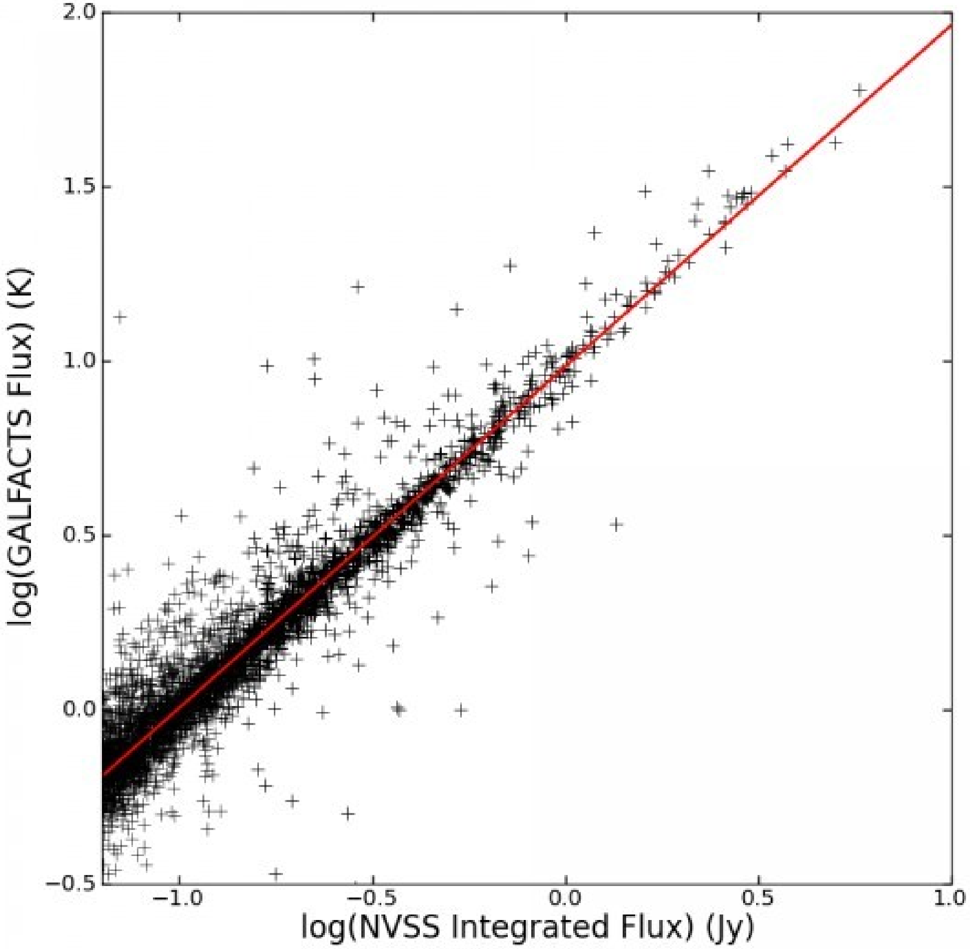
# D Field Cygnus Loop




Tape
Arecibo
External Drives
To Calgary
pDev ouput data streams FFT, cal-on , cal-off
Quick Look
Convert format to spec
CALMAIN
Detect and remove RFI
Apply noise cal correct for time and freq complex gain of signal chain. Convert to Stokes
Disk Copy
MAPMAIN
basket weave all beams and grid to Stokes Cube
remove beam centre poln leakage per beam per channel
apply beam centre gain corrrection per channel
remove ZA Tsys variation per beam
multi-beam clean Stokes I
Clean Stokes I leakage in Q, U, V
Polarisation Position Angle Correction
Science Data Products
Final I,Q,U,V Image Cubes
Add total power and low-spatial frequency information
DRAO 26-m Survey
Automated Source Detection
Compact Source Catalogue
RM Map

# Automated Source Finding – compare with NVSS




mean position offset :

$\Delta\alpha$ = 8.63" ± 0.01, $\Delta\delta$ = -4.44" ±0.01

Gradient of 9.5231 K/J for sources with NVSS flux > 150 mJy

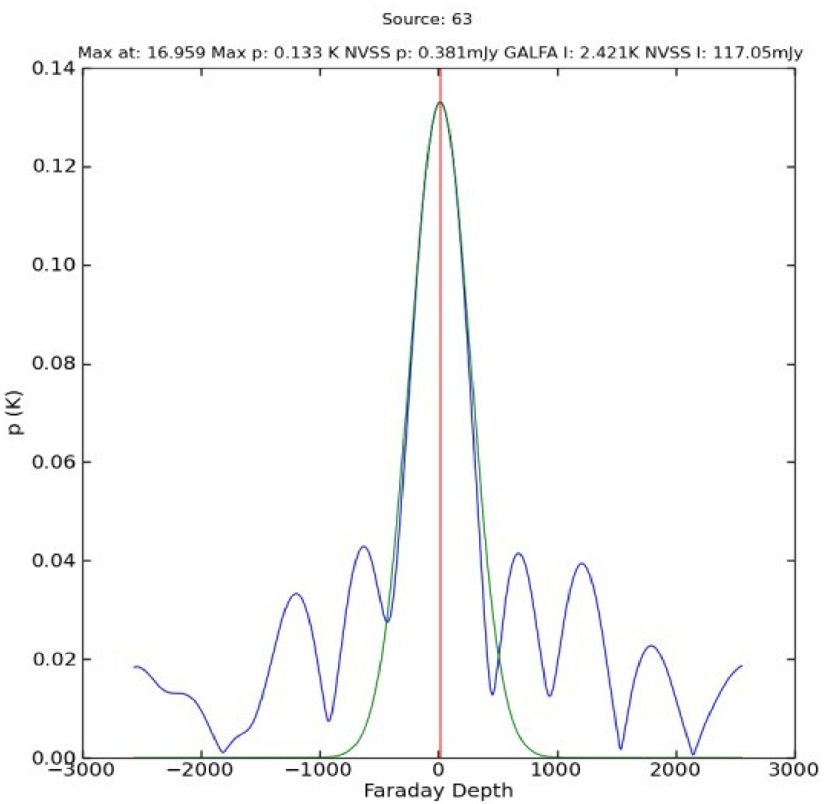
# Automated RMs

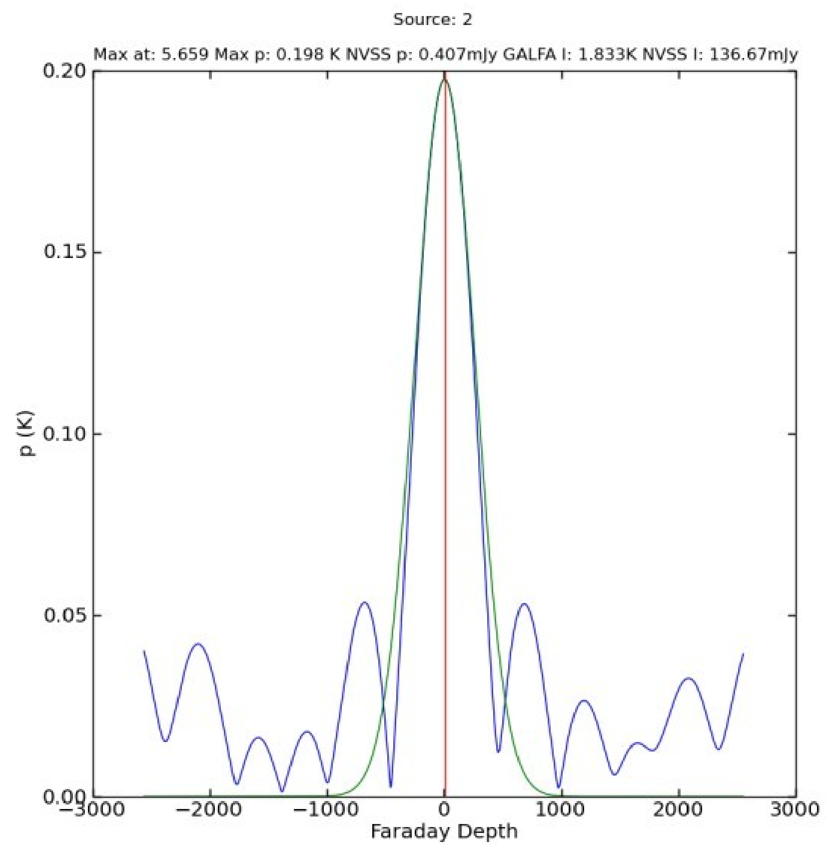
Sources are found in Stokes I image

Instead of making RM cube of whole dataset (computational expensive) – make RMs of detected sources

Highly parallel – bash script that keeps track of jobs submitted and what next (uses desktops aswell as cluster)

Currently dominated by leakage terms on source



# GALFACTS Project Portal