Wideband Mosaic Imaging for VLASS

Preliminary ARDG Test Report

U.Rau & S.Bhatnagar

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(1) Code Validation and Usage
(2) Noise, Weights, Continuum sensitivity
(3) Imaging parameters
(4) Understanding VLASS data
(5) Next steps
Code Validation – Test data

Goal: Test wideband mosaic imaging: Flat-sky intensity and spectral index.

(deconvolver = ‘mtmfs’ with griddler = ‘mosaic’ and ‘awproject’)

Simulations:

– L-Band VLA two-pointing mosaic, with one source. No w-term
– J1448-1602 predicted onto VLASS MS, with and without w-term

Real VLASS data:

– Original Calibrated MS: Test w-term position offsets & corrections
– Wideband self-cal using J1448 model: Test noise with conjbeams
– FixVis on Original MS: Test effect of putting the PB in the correct place.

[ Other Real data:
– G55 wideband single pointing, 3C286 wideband pointed mosaic, etc.. ]
Code Validation - Gridders

gridder = ‘awproject’

- Works correctly for continuum imaging with conjbeams=True and W. (when data are correct...)

- Bugs remain for cube imaging and using pointing table

- Uses a convolution function cache on disk
  - Compute once and re-use for entire VLASS imaging
  - Depends on imsize, cell, wplanes, and a few .casarc variables

- Memory use is as expected and can be predicted (serial and parallel)

gridder = ‘mosaic’

- conjbeams=T not working. (Deconvolution can eventually converge to the correct Int & Alpha after several major cycles, but undeconvolved sources will still be wrong.)

- No w-support (but KG may be working on a faceting idea...)

- Pointing table use not validated in these tests
Code Validation – PB models

PB models:

– awproject: Ray traced at spw centers. Linear Freq scaling.
  Supports parallactic angle rotation and squint

– mosaic: EVLA polynomial models with accurate frequency scaling.
  No parallactic angle or squint support

(The difference in frequency dependence has been evaluated. It's small.)
Noise - using StatWt

StatWt is an outlier detector that assumes the underlying signal is invariant.

In OTF mosaics, multiple pointings are supplied together as input => Sky x PB variations are seen as high 'noise' => downweighted.

Effect on imaging:

– Dips in the continuum mosaic PB pattern around all bright sources. (Can be as low as 0.4 for a 1 Jy source. It nulls out the 16 Jy 3C286)

– Locally-different data weights modify the shape of the PSF locally. (Extra deconvolution complications)

– Bright sources get artifically high error bars.

Suggested solutions:

– Run statwt on residuals (prototyped by Claire, with some success.)

– Modify statwt to use running mean statistics to be immune to underlying smooth variations?
Noise - conjbeams and wideband sensitivity

Reported Problem:

conjbeams=True increases the noise compared to conjbeams=False

Resolution:

– This is not a bug or a problem with the algorithm(s).

– Conjbeams = True is the spectral equivalent of PBCOR
  => Noise increases when you go from flat-noise to flat-sky.

– Wideband sensitivity naturally degrades away from the pointing center.

– For a mosaic, it will be across the entire mosaic.

  (Similar to why the PB spectral index is strong all over the mosaic)

[A cube-based approach with conjbeams=False, flat-sky norm and then a multiplication with a common beam will have the same effect.
(i.e. the idea we started trying out via Josh)]
Noise - conjbeams and wideband sensitivity

Tests: Is the noise increase consistent with expectations?

Calculations based on a Gaussian PB and linear Frequency scaling

=> Sensitivity worsens by ~10% at 0.1 PB level, compared to the center.

– Simulation: Input data had the same level of noise in all channels.

=> Noise increase at the edge matches the prediction.

– VLASS data: Higher frequency SPWs had more noise than lower ones

=> Noise goes up by ~ 50% at the PB = 0.1 level

(Confirmed the same levels as reported by Claire/Steve)

==> As of now, it looks like it’s a fundamental limit, given the data quality.
Imaging Parameters: Wprojplanes

Wprojplanes:

- 64 to 128 for BnA-config data.
- 64 or less for B-config data

Our tests: BnA data. J1448 at PB=0.68, or 5 arcmin from pointing center

- W=1 and W=64 showed a position shift of 0.3 arcsec. No shift for larger W
  (FixVis moved the phase center away from the source! Needed W=128...)

==> Need to re-visit this after the phase center corrections are sorted out.

==> Need to test on real B-config VLASS data.

(Our tests on BnA data with a uvrange limit to match B-config showed that not more than W=64 was needed.)
Imaging Parameters: Wprojplanes

W=1, 64, 128, before and after FixVis (compare to pointed obs). Cell = 0.3 arcsec
Imaging Parameters for VLASS

Imsize (and field-of-view per mosaic ‘tile’)

- Need a buffer of ~30 arcmin between the centers of edge pointings and the edge of the field of view being imaged.

  - This is to control PB aliasing since ‘awproject’ models sidelobes

- Tests with original VLASS imaging parameters (on simulated data) showed errors on-source because of strong PB aliasing

  => We used 10kx10k images at 0.3 arcsec pixels for 1 pointing

Cell size (and uv-range):

- We did **not** test effects of PSF undersampling (we used 3pix on minor axis).

- If VLASS needs to use 0.6 arcsec for all images (2pix/beam), please re-test.
VLASS data – J1448-1620, BnA, OTF & Pointed

Step 1: Image some VLASS data

- Wideband Mosaic imaging on originally calibrated VLASS data gave wrong intensity and spectral index.

Step 2: Self-Cal

- Use source model from pointed observation and the wide-field degridded data to predict model visibilities onto the OTF data.

- Bandpass amp/phase self-cal solutions.

  - Solutions didn’t make sense, but they ‘fixed the data’.
    => not very helpful.

- Antennas away from the array center had slopes in amp vs freq. (1 → 0.6)
- They also showed phase ramps per SPW (+/- 10 deg).

( With 1 strong source and a snapshot, effects due to delay, w-term, pointing offsets and phase-center mismatches can look similar. )
VLASS data – J1448-1620, BnA, OTF & Pointed

2 pointing mosaic

After bandpass selfcal

Original Calibration

1.38 Jy source + can see noise + increase in noise at beam edges ( ~50% )
Step 3: FixVis by ½ a pointing (suggested by Frank S.)

- For one pointing near the source, intensity and alpha were almost perfect.

J1448-1620 pointed observation: Intensity = 1.38 and alpha = -0.46
Original data: Intensity = 1.05 and alpha = -1.04 (pb gain 0.68)
FixVis data: Intensity = 1.31 and alpha = -0.45 (pb gain 0.52)

- But, artifacts around the source remained (dynamic range limited)

Step 4: Bandpass self-cal

- Solutions had no amplitude slopes any more.
- Phase ramps per spw (+/- 10 deg) remained (delay clunking?).

Application of the phase solutions reduced the artifacts.
VLASS data – J1448-1620, BnA, OTF & Pointed

1 pointing image + fixvis + selfcal == Correct intensity and spectral index.

Original Calibration + FixVis

After self-cal (mainly phase)

==>

Solution of FixVis (or similar) is required to get correct intensity and alpha.

==>

Phase calibration still required for dynamic range (delay clunking?).
VLASS data – Phase and Pointing centers....

Joint mosaic of a row of fixvis’d pointings => Wrong intensity and spectral index.

=> Investigate by imaging one pointing at a time, for 8 in a row.....
VLASS data – Phase and Pointing centers....

Yaxis: Phase and pointing center (arcmin)

Xaxis: Time (sec), PB gain seen by source.
VLASS data – Phase and Pointing centers....

**Xaxis:** Time (sec), PB gain seen by source.

**Yaxis:** Phase and pointing center (arcmin)

0.45 sec/integ
VLASS data – Phase and Pointing centers....

Yaxis:
Phase and pointing center (arcmin)

Xaxis:
Time (sec), PB gain seen by source.

0.45 sec/integ

3.31 arcmin/sec
X 0.45 sec/integ
= 1.48 arcmin / integ

– One-sided PB smearing
– Opposite direction per integration
VLASS data – Effect of PB smearing (Stokes I, Alpha)

Result of ASYMMETRIC PB smearing by 1.48 arcmin

![Graphs showing the effect of PB smearing on VLASS data for Stokes I and Alpha.](image-url)
VLASS data – Phase and Pointing centers....

Xaxis: Time (sec), PB gain seen by source.

Yaxis: Phase and pointing center (arcmin)

Asymmetric PB smearing is causing the observed errors in intensity and alpha.

So, can we go a bit further with fixvis, PER integration?
VLASS data – Phase and Pointing centers…

FixVis to match phase center with pointing center PER integration?

- Symmetric PB smearing

- Expect no error on avg PB gain or alpha (from external calculation)

** May not work for full-pol
VLASS data – Phase and Pointing centers...

Azimuth, Azimuth, Azimuth vs. Time

- Original Calibration
- FixVis by $\frac{1}{2}$ pointing (both integrations)
- FixVis by $\frac{1}{4}$ and $\frac{3}{4}$ pointing (per integration)
VLASS data – Phase and Pointing centers....
VLASS data – Mosaic images from 8 pointings in a row

Original Calibration. Intensity = 1.31 Jy, Alpha = -0.57 (should be 1.38, -0.48) (needs phase self-cal)
VLASS data – Mosaic images from 8 pointings in a row

FIXVIS on Original: Intensity = 1.34 Jy, Alpha = -0.56 (should be 1.38, -0.48) (needs phase self-cal)
VLASS data – Mosaic images from 8 pointings in a row

Simulation onto VLASS 8 pointing Measurement Sets (I = 1.38, a = -0.48)
Next Steps

(1) Number of $W$ planes for B-config; Effects of PSF undersampling

(2) Once parameters are established, computing costs have to be eval’d.

[ Before Imaging :
  – Statwt usage,
  – Need for better phase cal (delay clunking ?).
  – A pointing calibration table to rephase visibilities per integration to the middle of the range of pointing directions being smeared. ]

Further work from ARDG :

  – A report with the above details (as per the ARD test plan).
  – Reference data sets and scripts to image them.
  – ARD CASA tarball to test with + AWP usage tutorial by S.B. (if needed)
  – Implement usability improvements and initiate CASA merge.