An Introduction to Radio Interferometry

5-5 Error recognition

You can find relevant material on my personal webpage

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Types of errors (I) origin

- Absolute flux errors
- Passband errors (rarely need to face this)
- Complex gain or delay errors
- Other additive errors (RFI, other instrumental emission or standing wave, etc)

Types of errors (II) form

Additive errors

$$\widetilde{V(u,v)} = V(u,v) + \epsilon(u,v)$$

Multiplicative errors

$$\widetilde{V(u,v)} = V(u,v) \cdot \epsilon(u,v)$$

Types of errors (II) form

Additive errors

$$\underbrace{\widetilde{V(u,v)}}_{\text{Observed complex visibility}} = \overbrace{V(u,v)}^{\text{Actual complex visibility}} + \underbrace{\epsilon(u,v)}_{\text{Additive error}}$$

Multiplicative errors

$$\widetilde{V(u,v)} = V(u,v) \cdot \underbrace{\epsilon(u,v)}_{\text{Multiplicative error}}$$

Types of errors (II) form

Additive errors

Actual complex visibility

Error is superimposed on the image

$$\underbrace{\widetilde{V(u,v)}}_{\text{Observed complex visibility}} = V(u,v) + \underbrace{\epsilon(u,v)}_{\text{Additive error}} \Longrightarrow \quad F.T.\left(\widetilde{V(u,v)}\right) = F.T.\left(V(u,v)\right) + F.T.\left(\epsilon(u,v)\right)$$

Multiplicative errors

$$\widetilde{V(u,v)} = V(u,v) \cdot \underbrace{\epsilon(u,v)}_{\text{Multiplicative error}} \Longrightarrow \quad F.T.\left(\widetilde{V(u,v)}\right) = F.T.\left(V(u,v)\right) * F.T.\left(\epsilon(u,v)\right)$$

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Observed complex visibility

Additive error

Radio frequency interference (RFI), antennae cross-talk, additive correlator offset, receiver noise, etc

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Multiplicative error

Atmospheric and/or ionospheric amplitude/phase errors, etc. When the calibratin is imperfect, which is always the case, the forms of the residual calibration errors are mostly multiplicative.

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For the complex visibility $\widetilde{V_{ij}(t)}$ taken with antennae i and j

Baseline based: $\epsilon_{ij}(t) = g_{ij}(t)$, complex variable

Antenna based: $\epsilon_{ij}(t) = A_i(t)A_j(t)e^{\phi_i(t)}e^{-\phi_j(t)}$, → $A_i(t)$: real variable, antenna-based ampplitde error

$\phi_i(t)$: real variable, antenna-based phase error

Recognizing errors

- There is no rule of thumb. Rely on the first principles.
- Easier when the source structure is simpler. You can observe a bright, compact source (called check source) near your target source for the purpose of diagnosing errors.
- The errors that have large effects on one or a few visibility points are more easily seen in the visibility domain. Those that have effects on a large number of visibilities (e.g., all the visibilities that are associated with a specific antenna) may be seen in the visibility or image domain.

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Recognizing errors

For examples of the effects of antenna position errors or delay errors, see Figure 7-10 in this link

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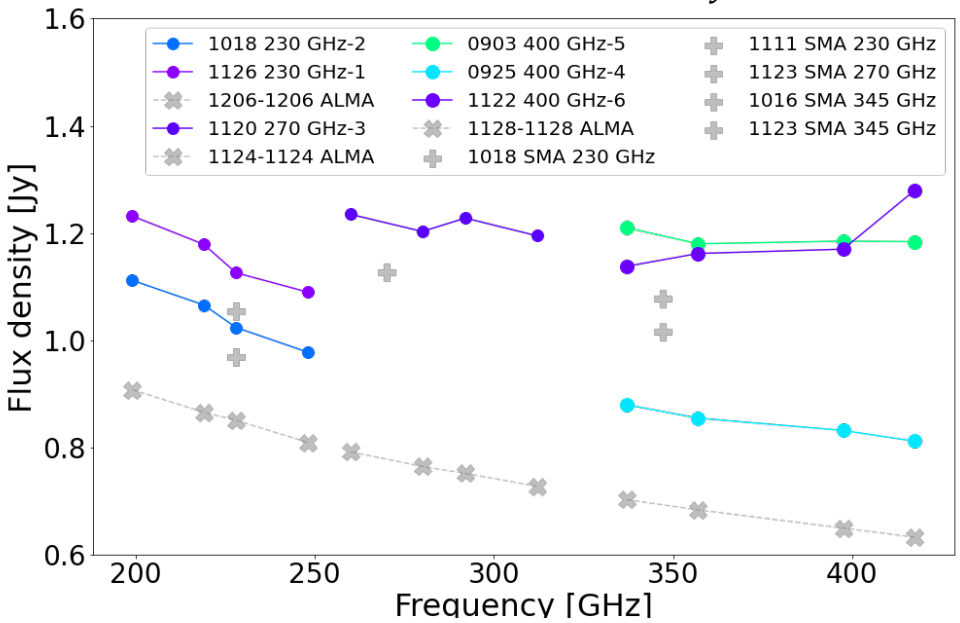
Absolute flux issues

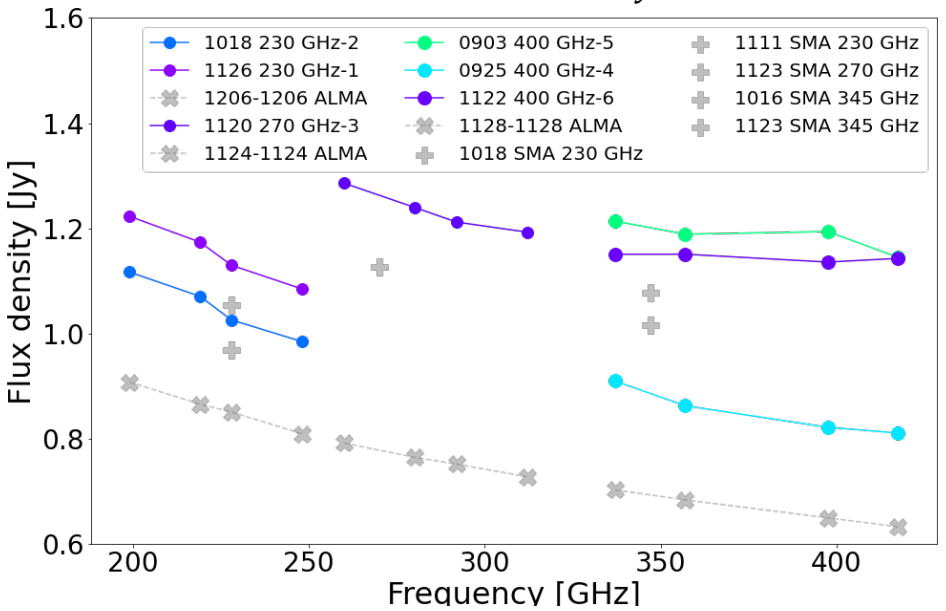
(after applying T_{sys}, calibrating gain amplitude, and referencing the calibrated amplitudes to an absolute flux standard) Multiplicative

Unexpected time variation (e.g., compare with multi-epoch observations)

Flux density of J0418+380 (coarse T_{sys}^{eff} application)



Flux density of J0418+380 (fine T_{sys}^{eff} application)



(Chung, Chia-Ying, Master's thesis, 2023, NTU)

Absolute flux issues

Unexpected time variation (e.g., compare with multi-epoch observations)

Unexpected frequency variation (e.g., unphysical spectral indices)

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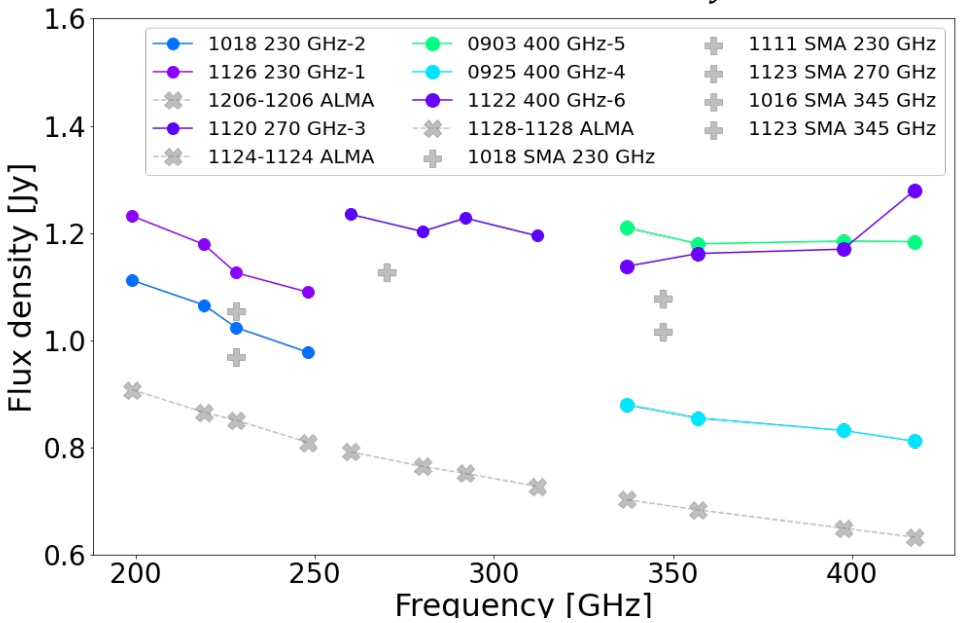

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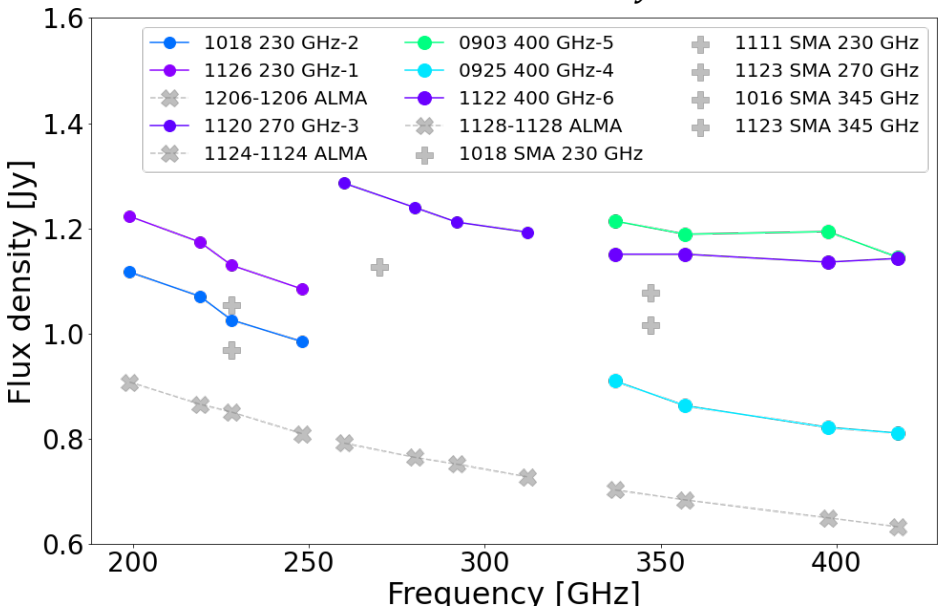

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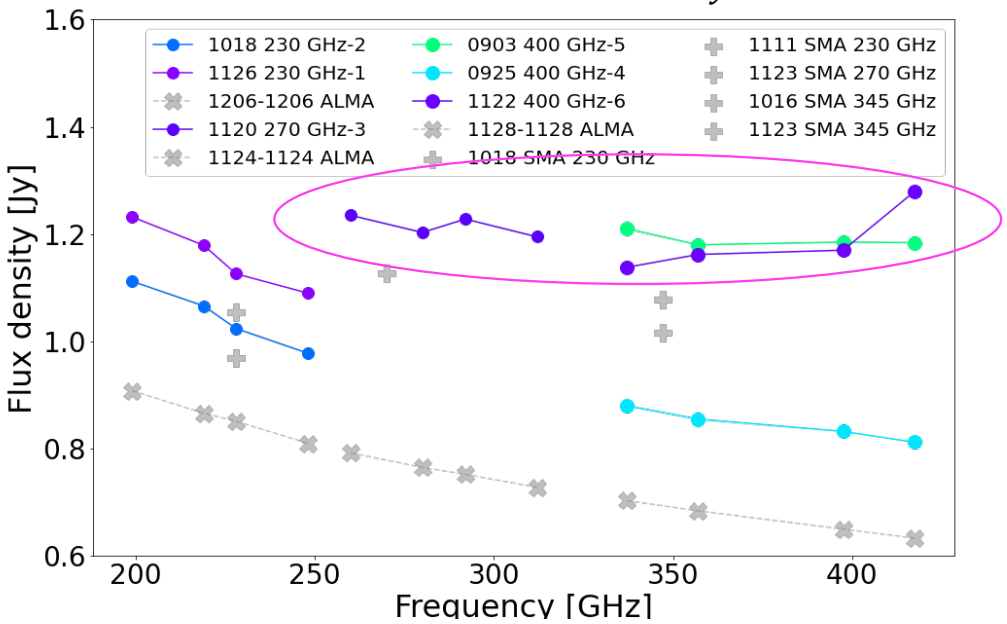

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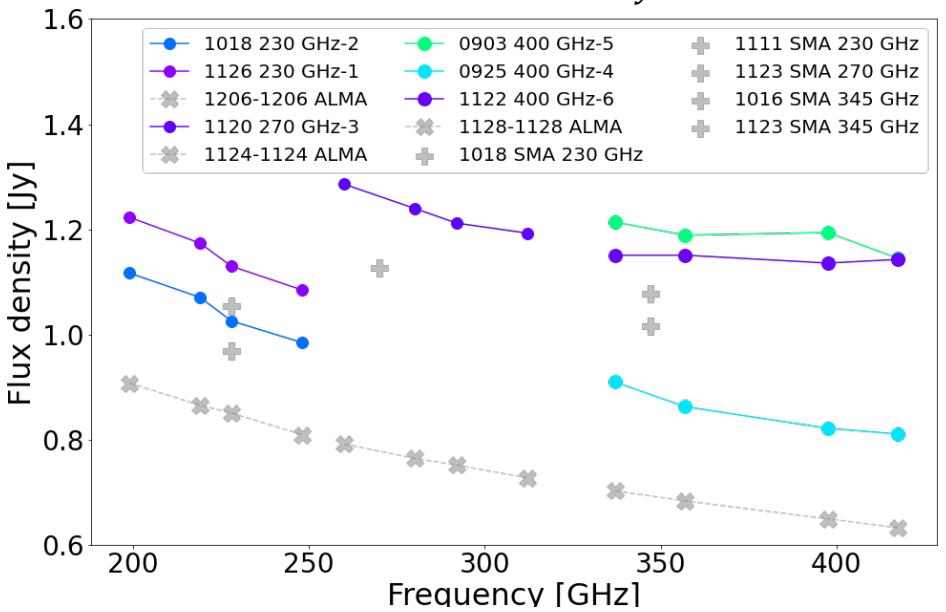

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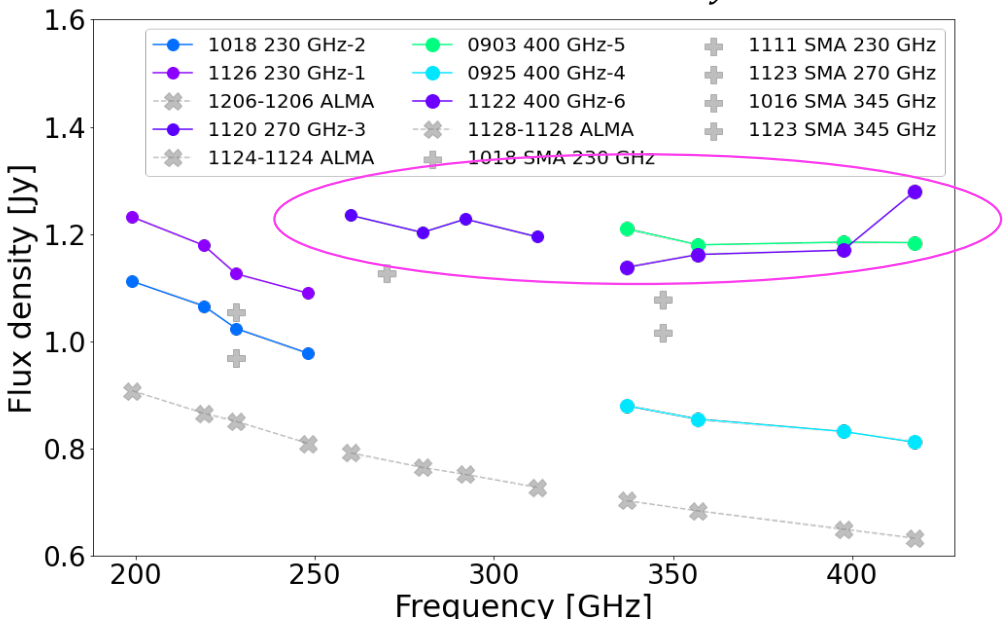

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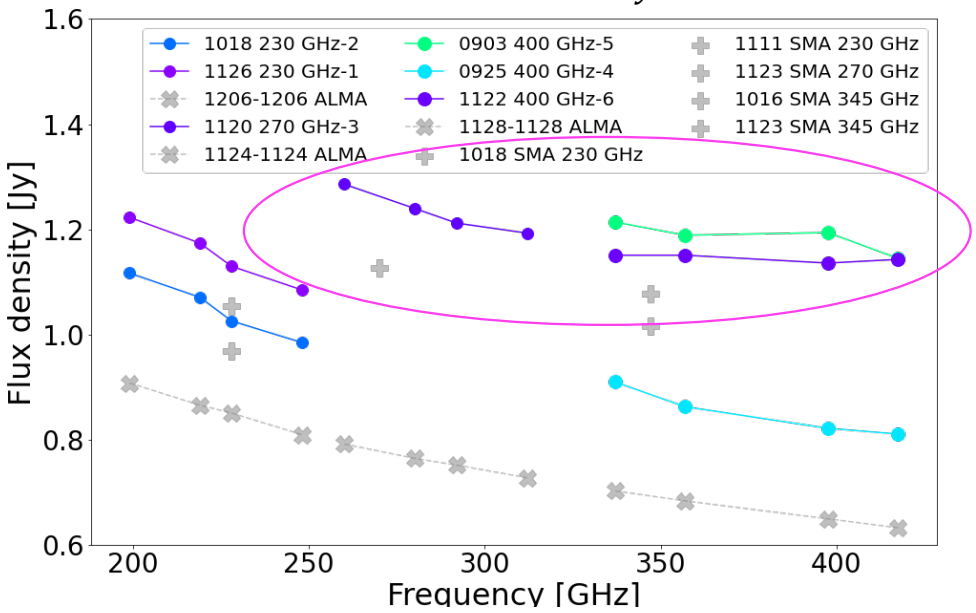

(Chung, Chia-Ying, Master's thesis, 2023, NTU; thanks to the help of Dr. Mark Gurwell @ SAO CfA to track down the exact problem)

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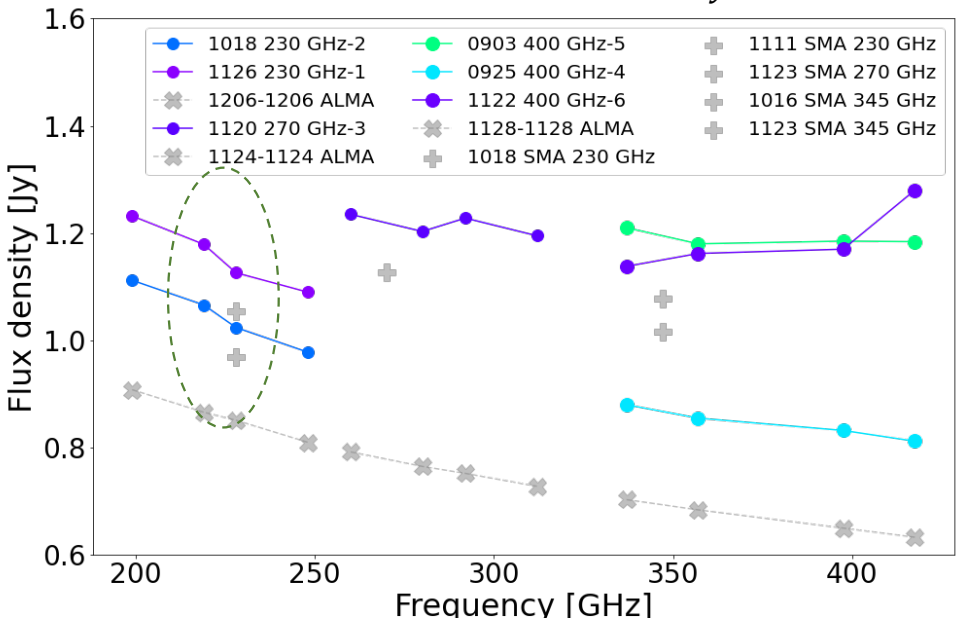

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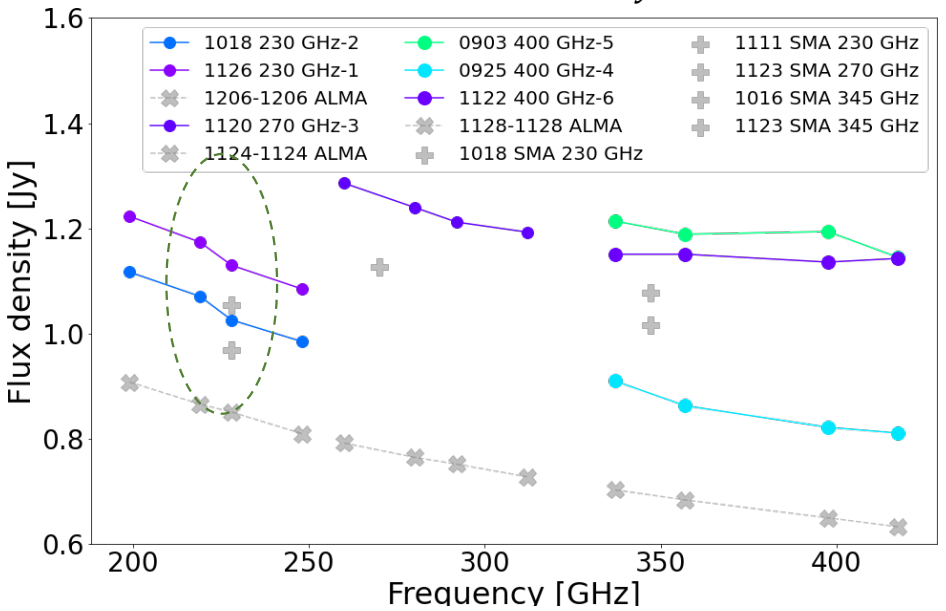

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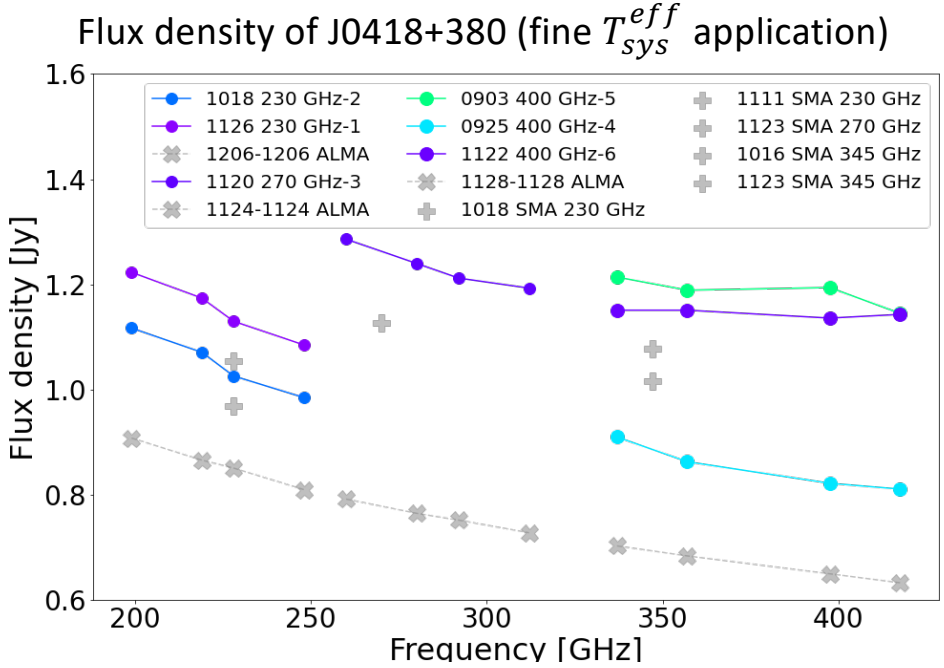

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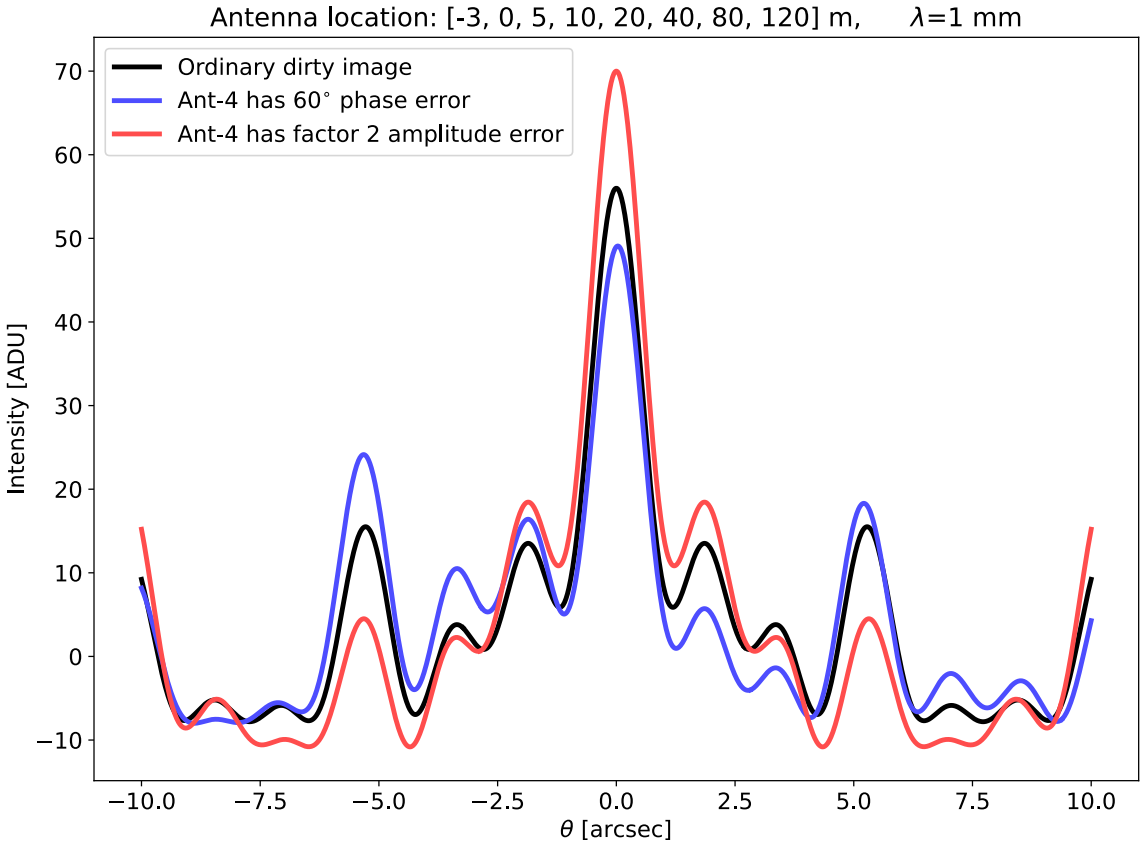
Is the noise level reasonable? (compare with the theoretical noise level) [Hard. Becareful if you go deeper here]

Effective of multiplicative errors in the image domain



Antenna-based amplitude error:
symmetric residual

Antenna-based phase error:
asymmetric residual

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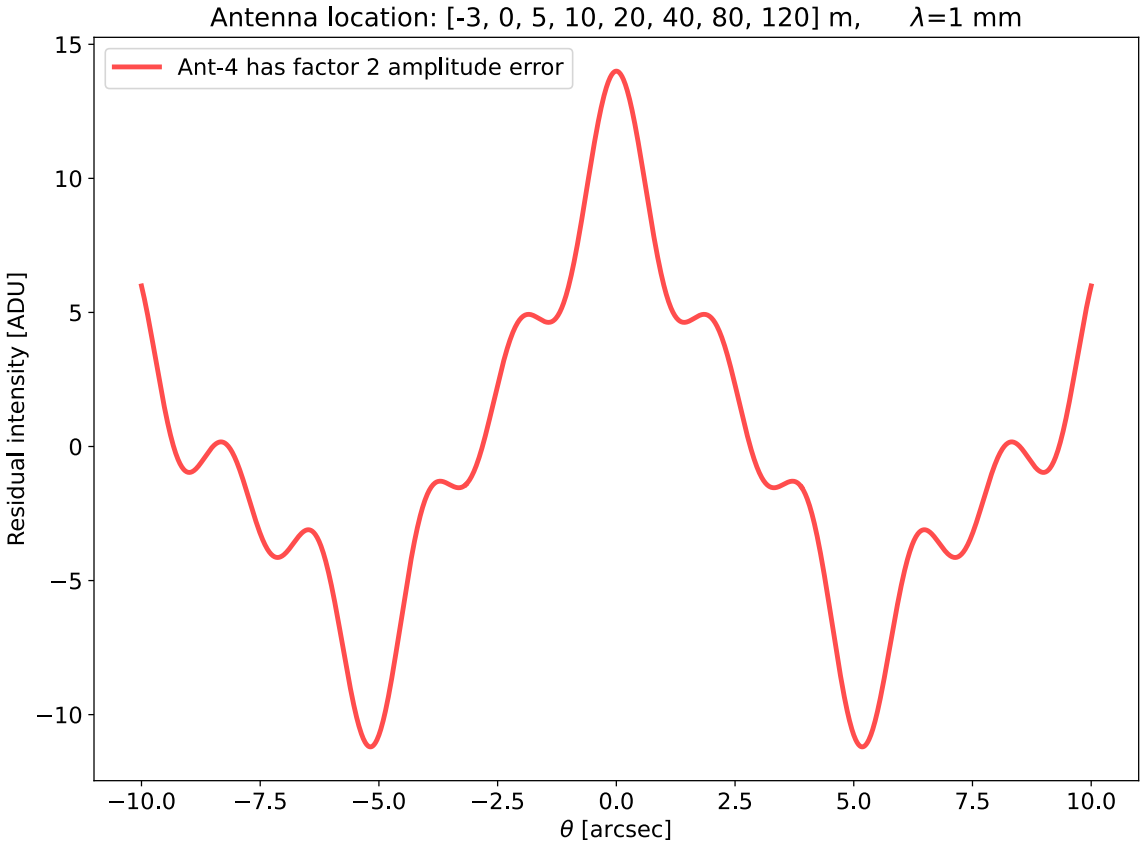

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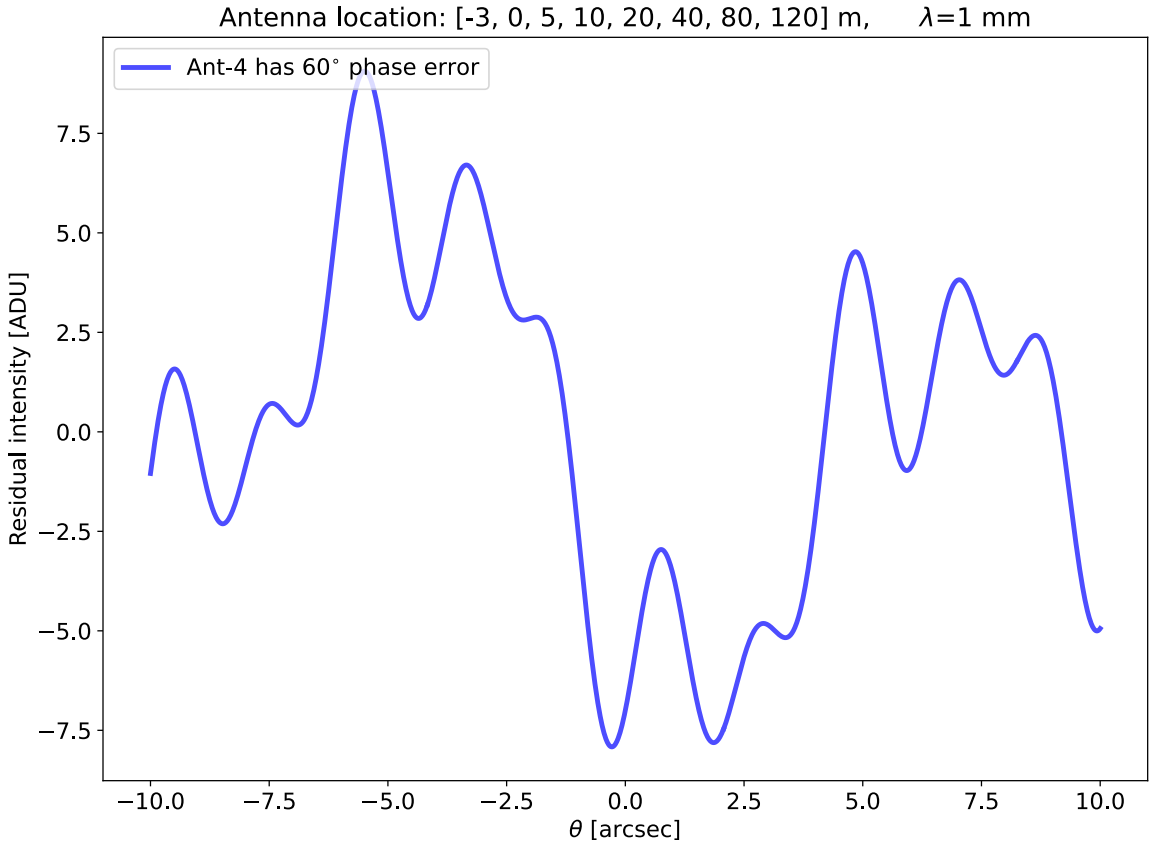

Antenna-based amplitude error:
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Antenna-based phase error:
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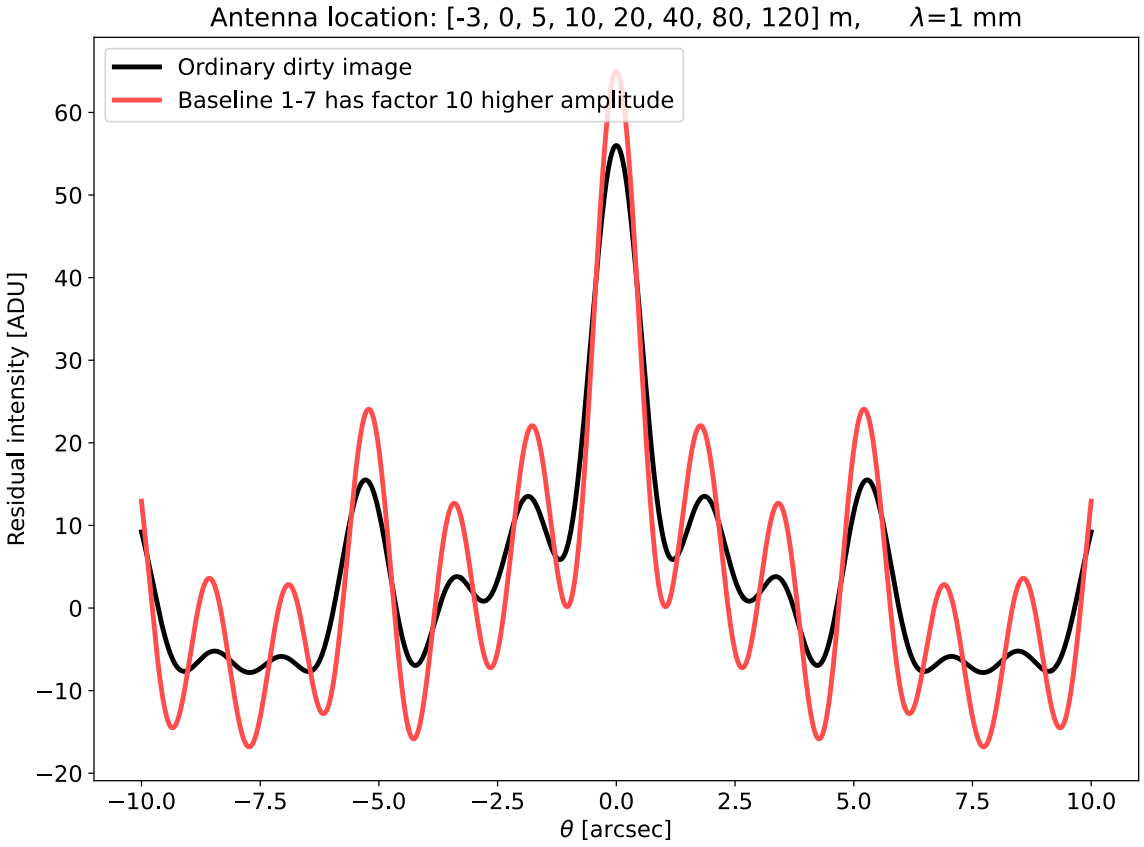
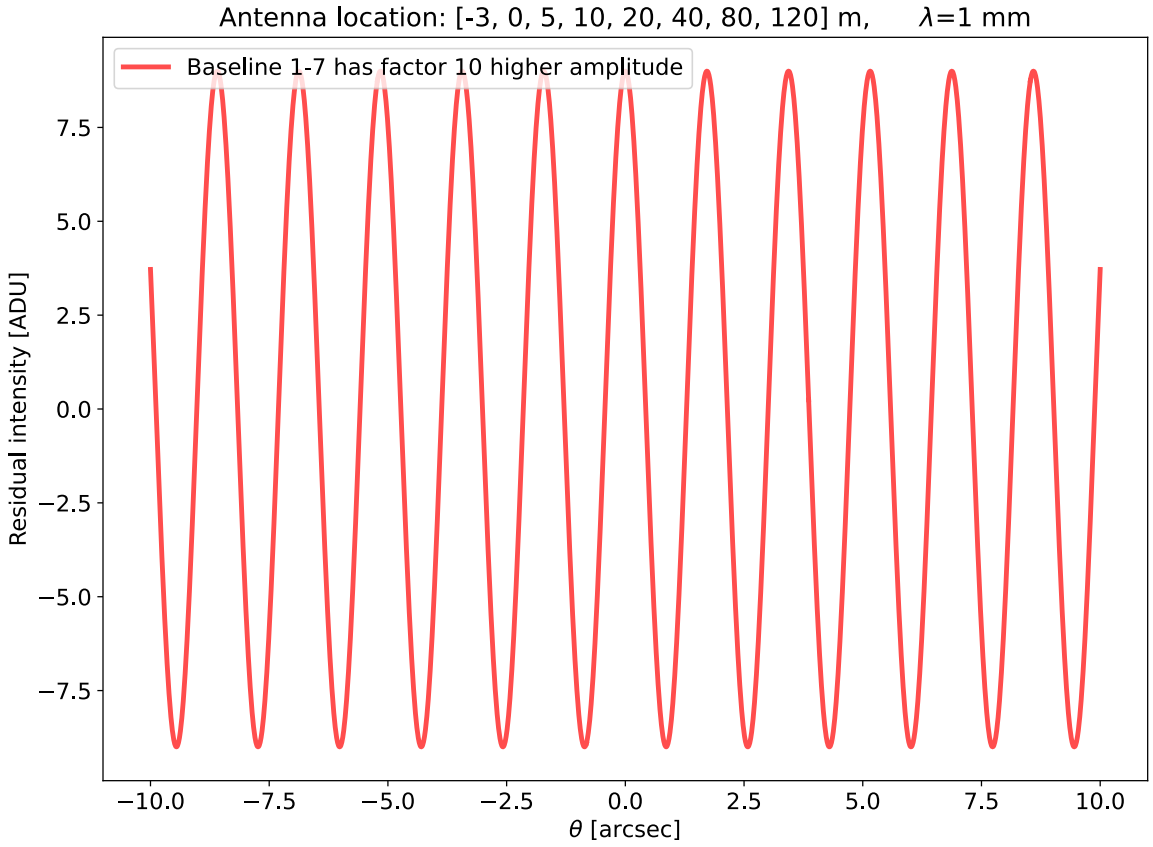
Effective of additive errors in the image domain



A high amplitude visibility point:
stripes

Effective of additive errors in the image domain



A high amplitude visibility point:
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1. There are various sources of errors. They can be roughly categorized into additive errors and multiplicative errors.
2. The effects of additive errors are superimposing some artificial intensity distributions onto your image; the effects of multiplicative errors are convolution in the image domain.
3. There is no rule of thumb on which is the best way of treating the errors. You need to know your science case and the effects of the errors very well. Then you can logically decide whether you can calibrate out the errors, trash the affected data, or live with the errors as a compromisation.