FORCAST Imaging: Modes & Strategies

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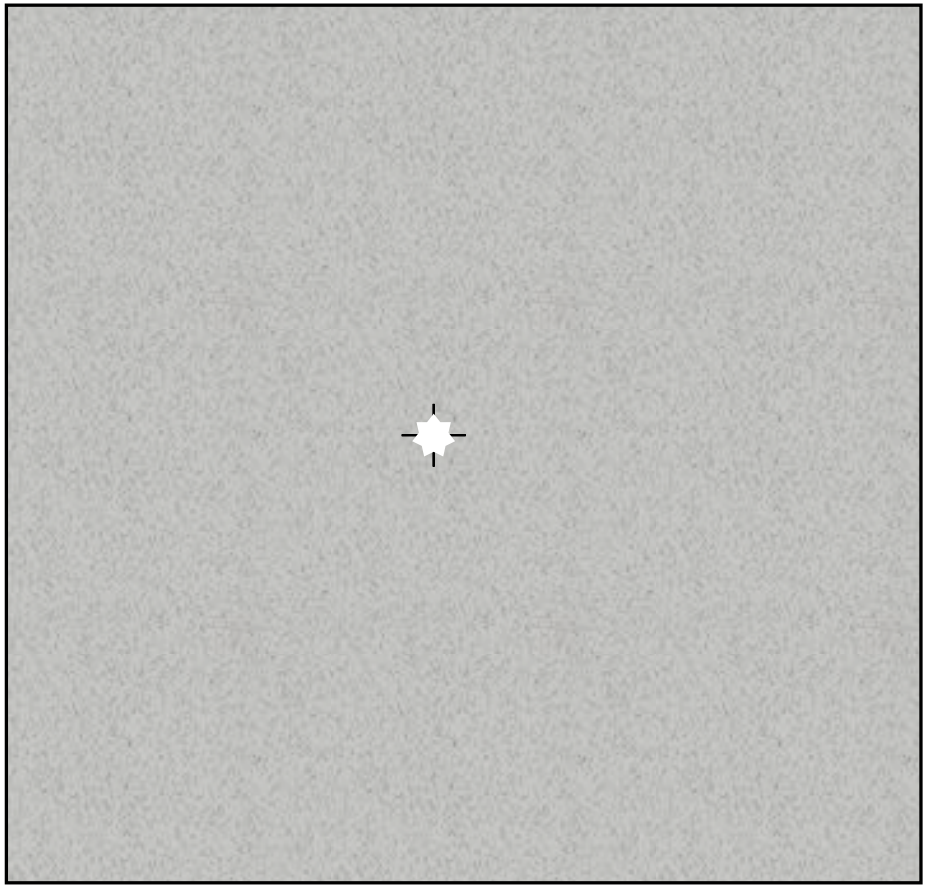
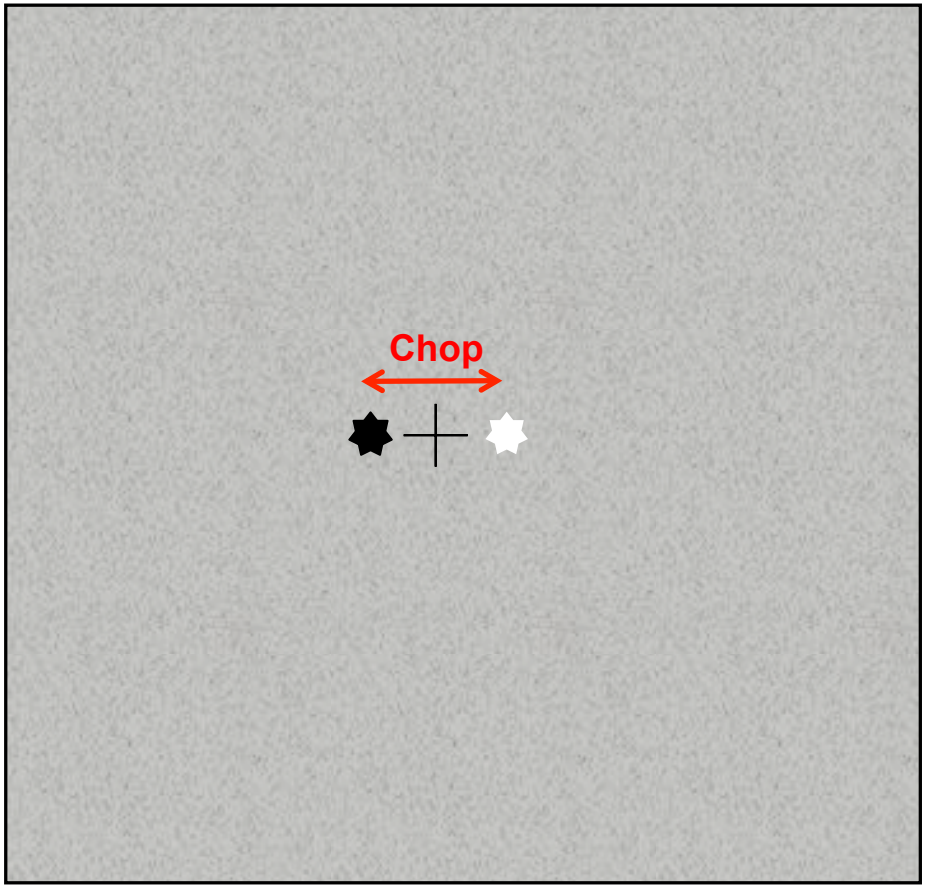
Symmetric vs. Asymmetric Chopping



- With no chopping, source would be located on center of frame at the telescope optical axis

Symmetric vs. Asymmetric Chopping

Symmetric Chop



- If you turn on the chopper the mirror would back and forth about the telescope optical axis

Symmetric vs. Asymmetric Chopping

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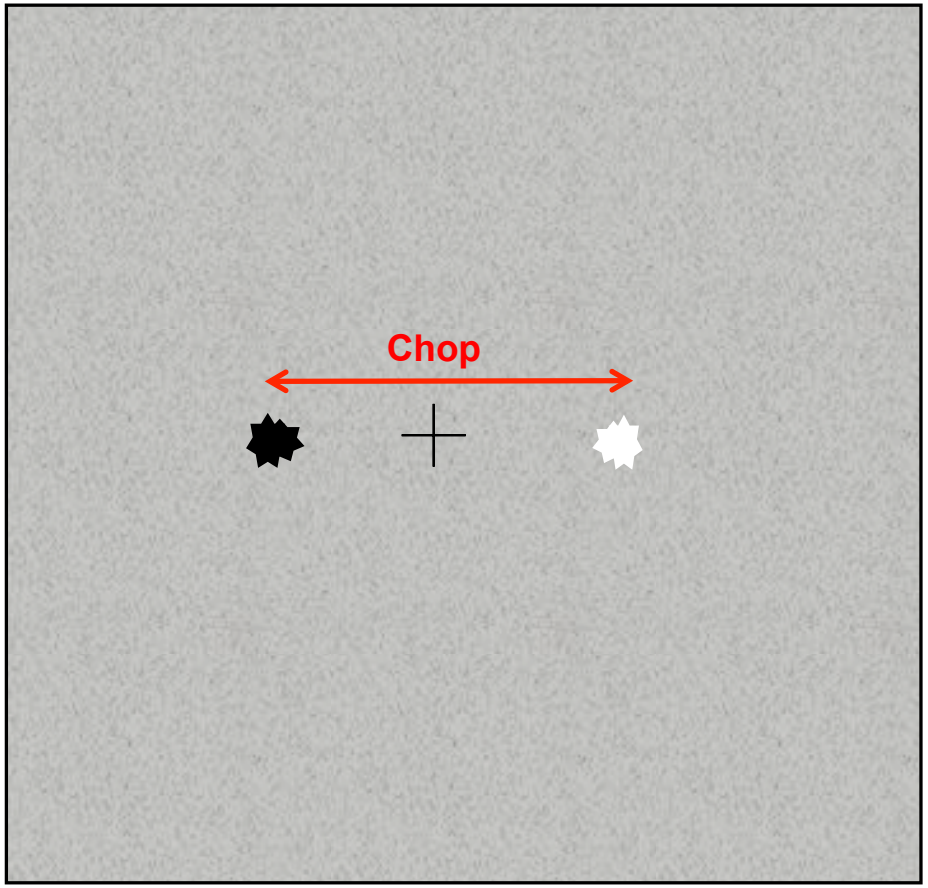

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- However, this means that the larger the chop, the farther from the optical axis, introducing coma

Symmetric vs. Asymmetric Chopping

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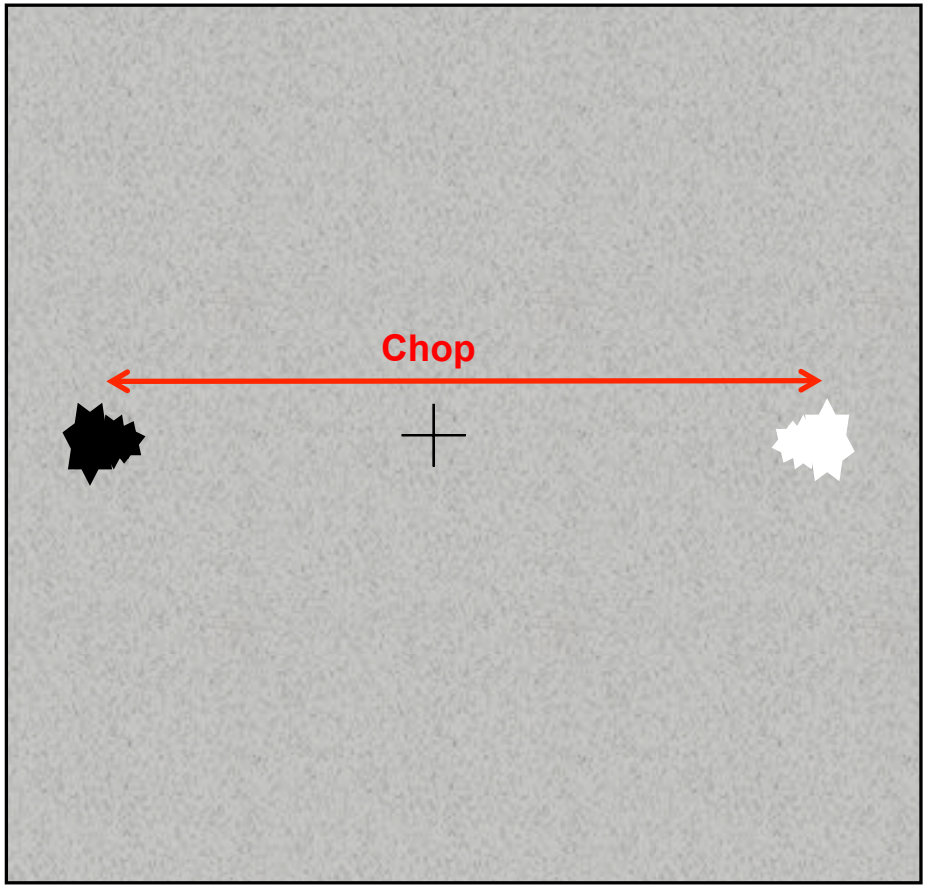
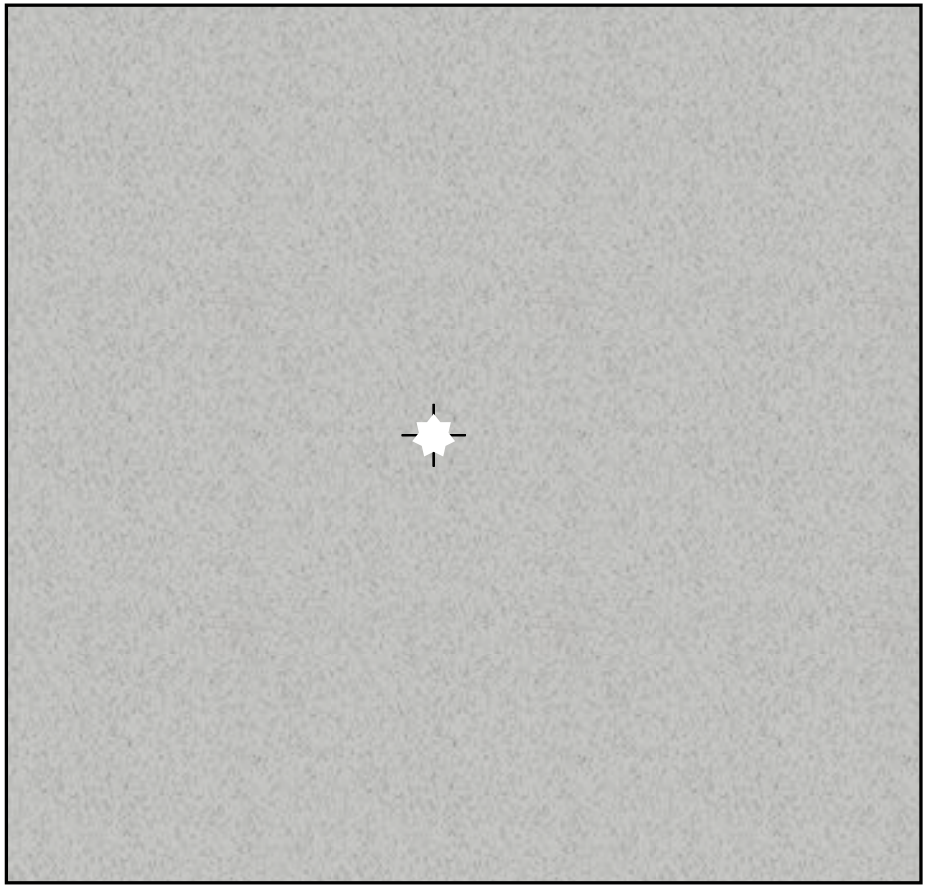


- If you turn on the chopper the mirror would back and forth about the telescope optical axis
- However, this means that the larger the chop, the farther from the optical axis, introducing coma
- Coma is equal in magnitude in both beams but opposite in direction
- We believe that for every 1’ from the optical axis, there is 2” of coma (added in quadrature)

Symmetric vs. Asymmetric Chopping

Asymmetric Chop



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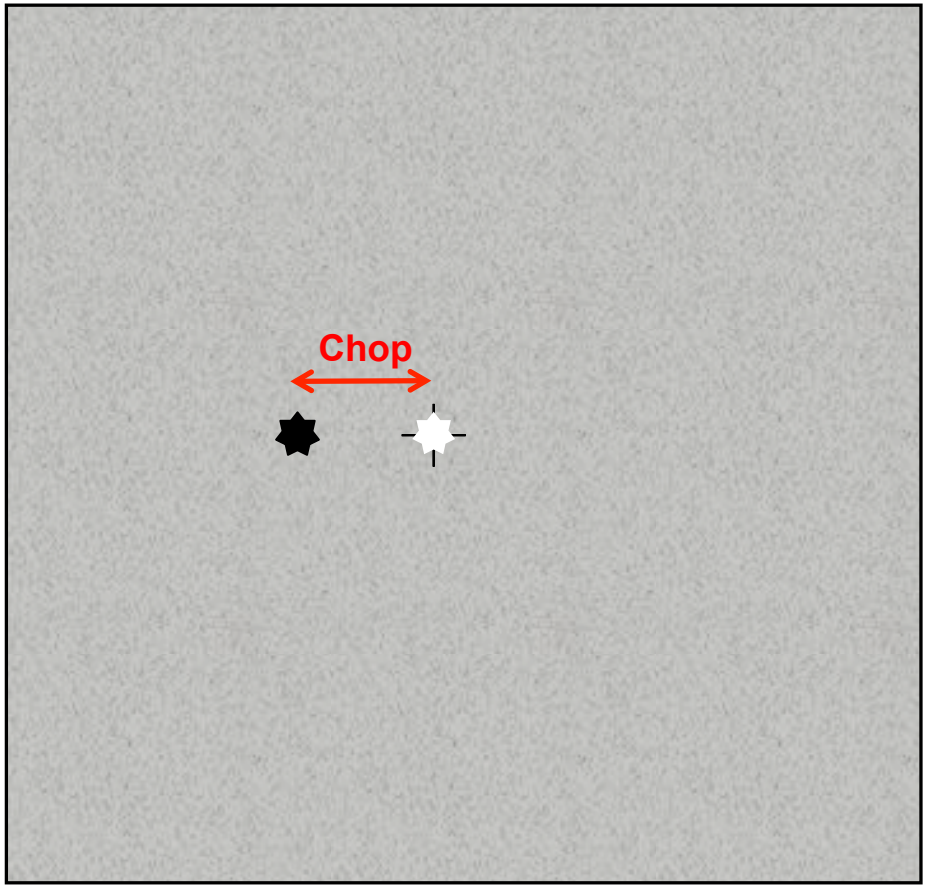

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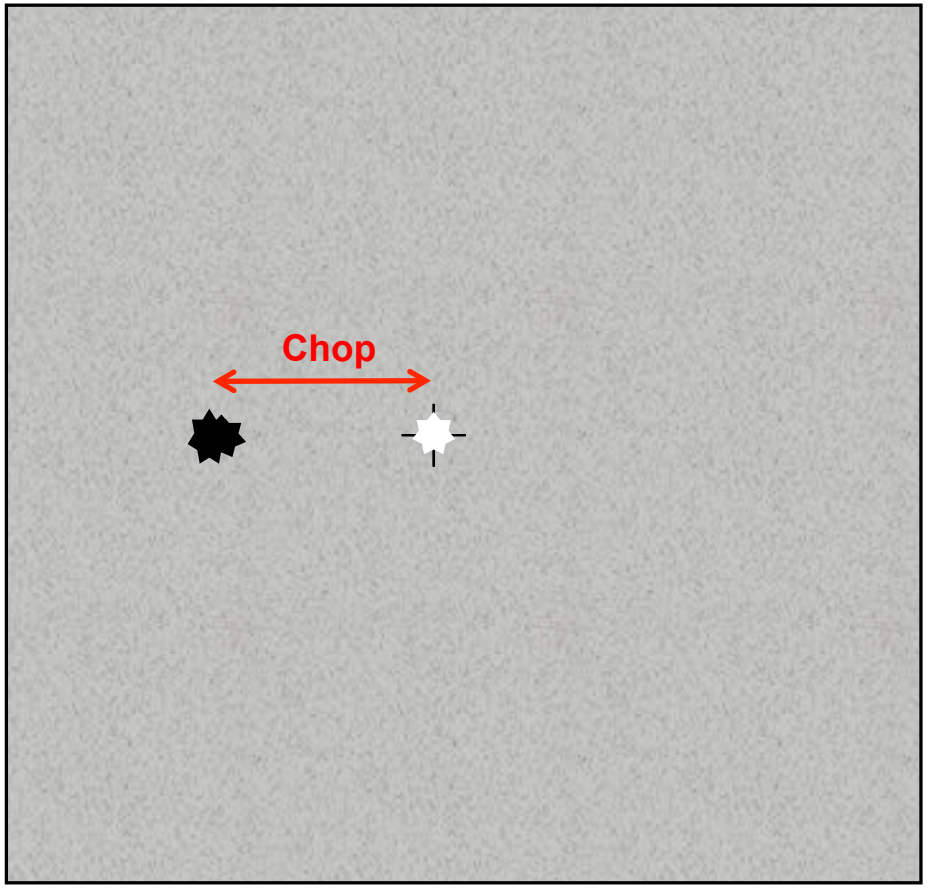

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- Therefore coma only is introduced into the off-axis position

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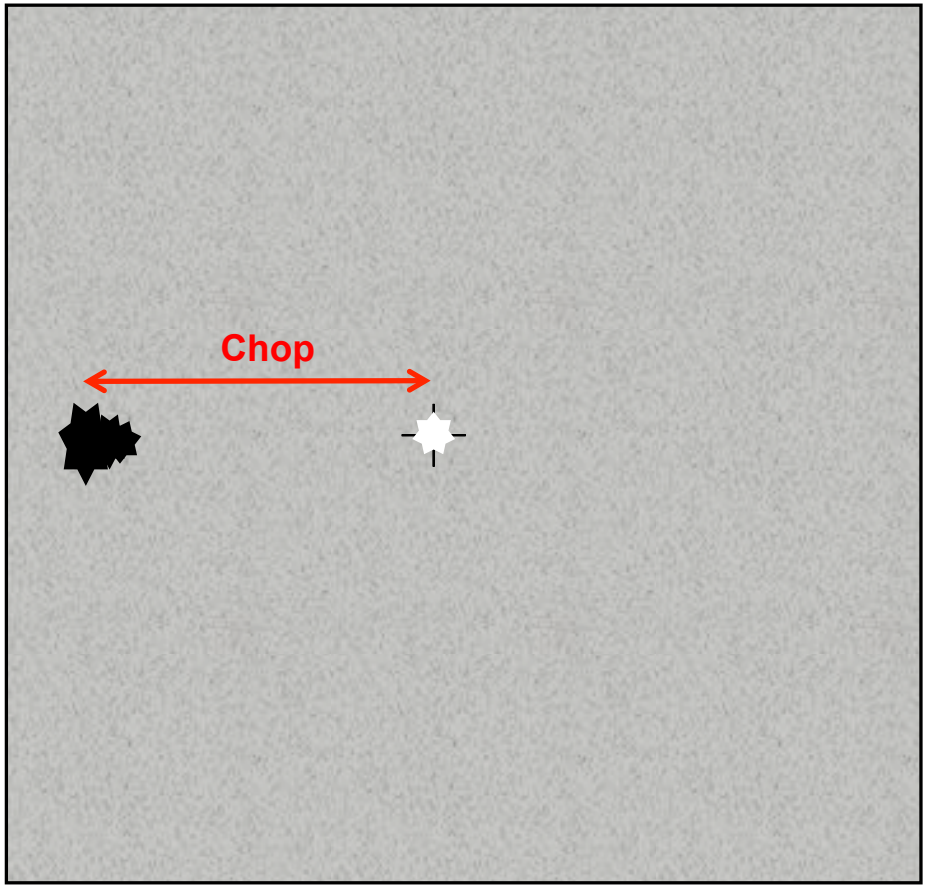

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IMAGING MODE CONFIGURATIONS

FORCAST Chop-Nod Configurations

Symmetric (most observations):

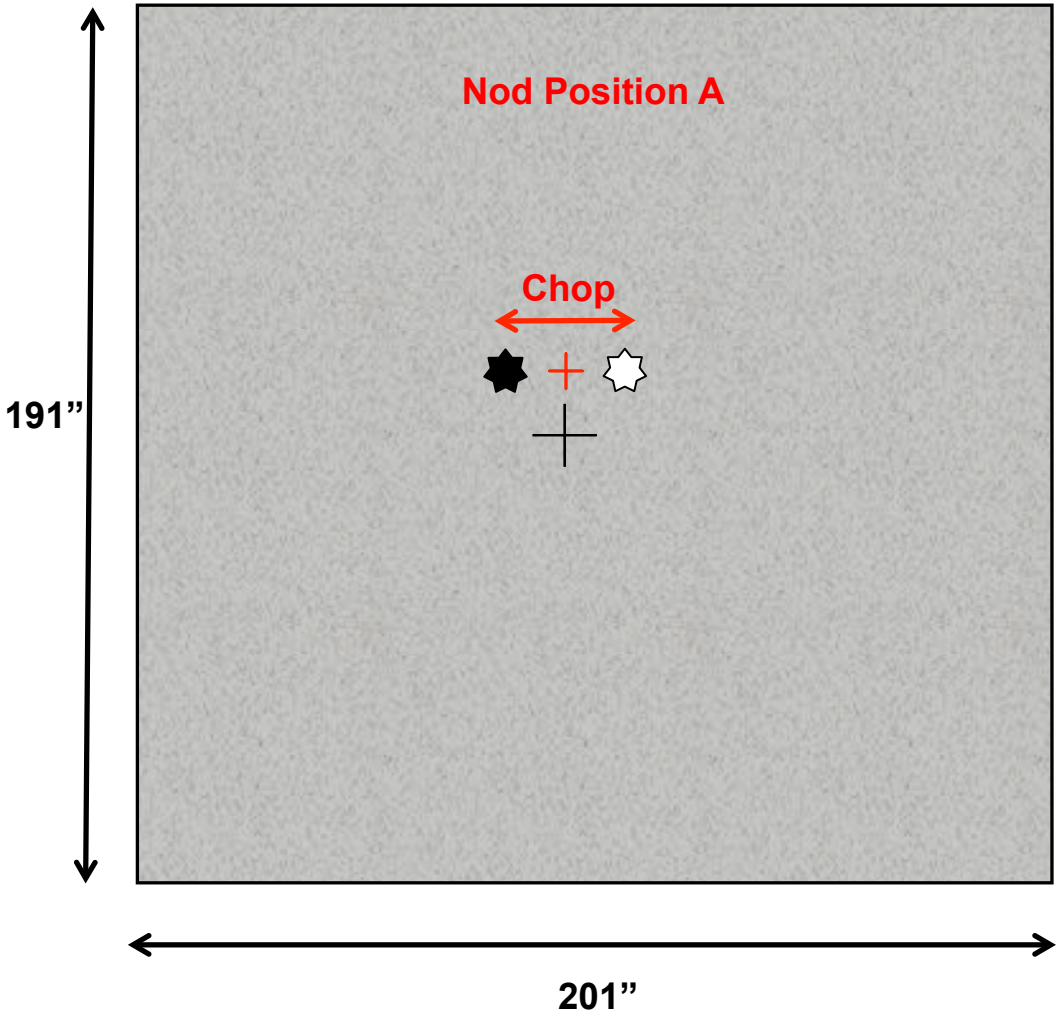
- Nod Perpendicular to Chop (NPC)
- Nod Match Cop (NMC)

Asymmetric (very extended sources, crowded regions):

- Large Chop with Large Nod (C2NC2)

Nod Perpendicular to Chop (NPC)

Point Source



- Set up chop/nod params in Array coordinates
- Chop and nod throws are equal magnitude
- Typically chop in x (90^{o}), nod in y (180^{o}), though can be other way too
- Chop/nod is symmetric about array center (1/2 nod offset done automatically)

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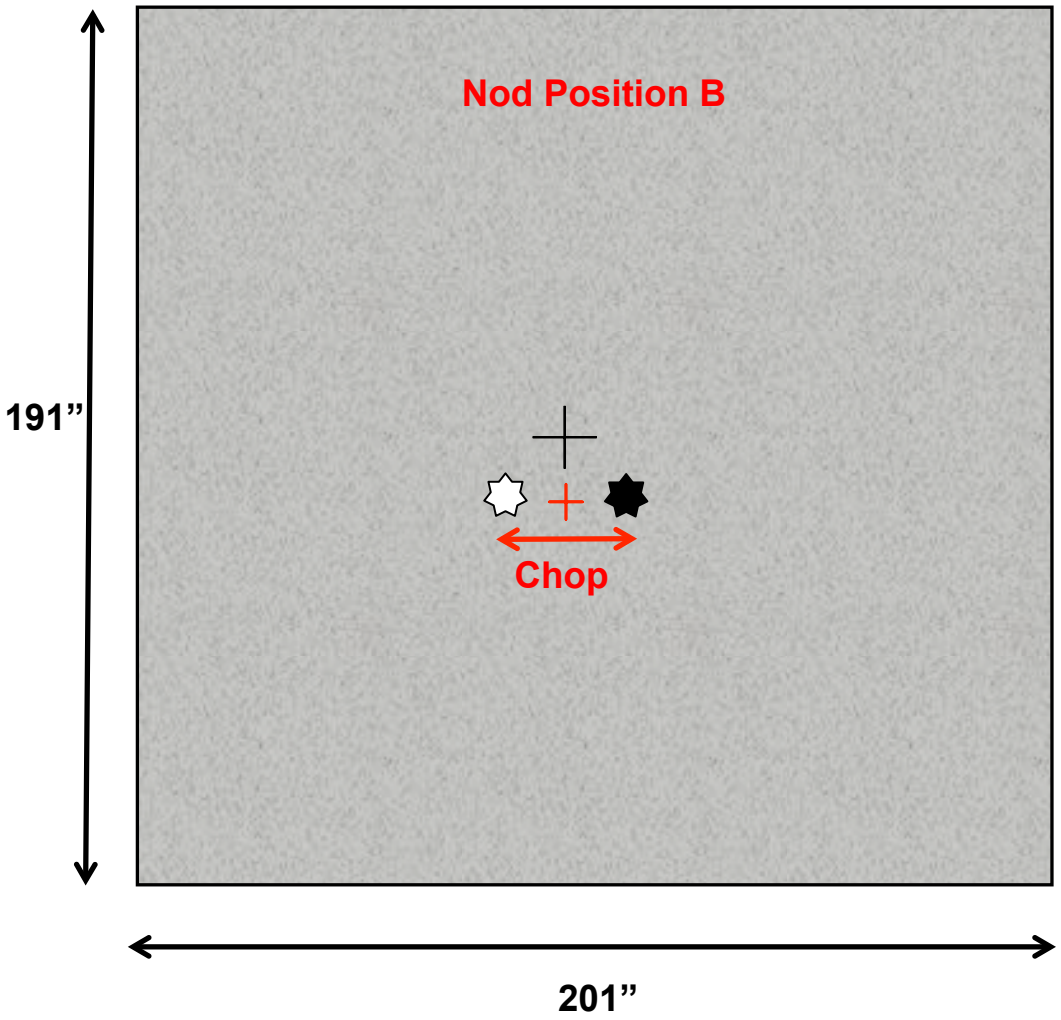

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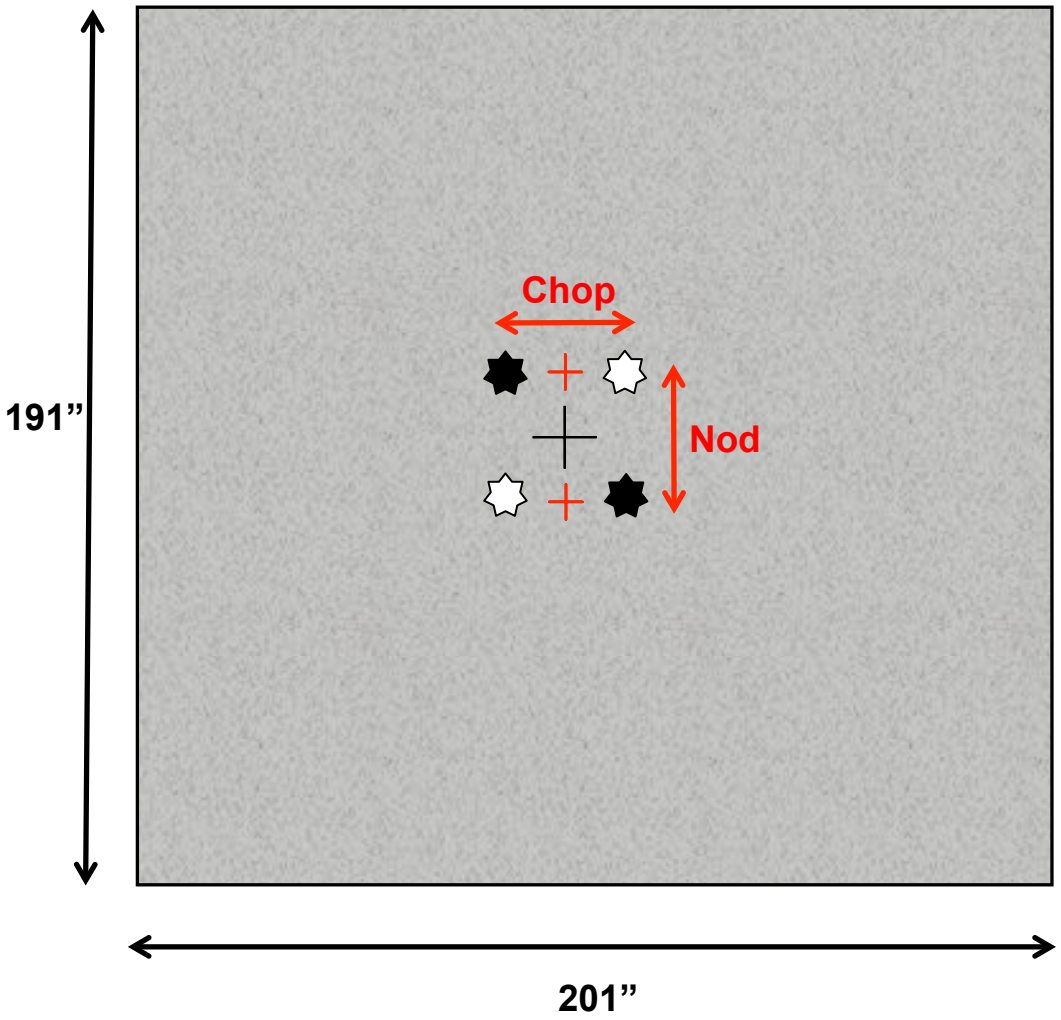

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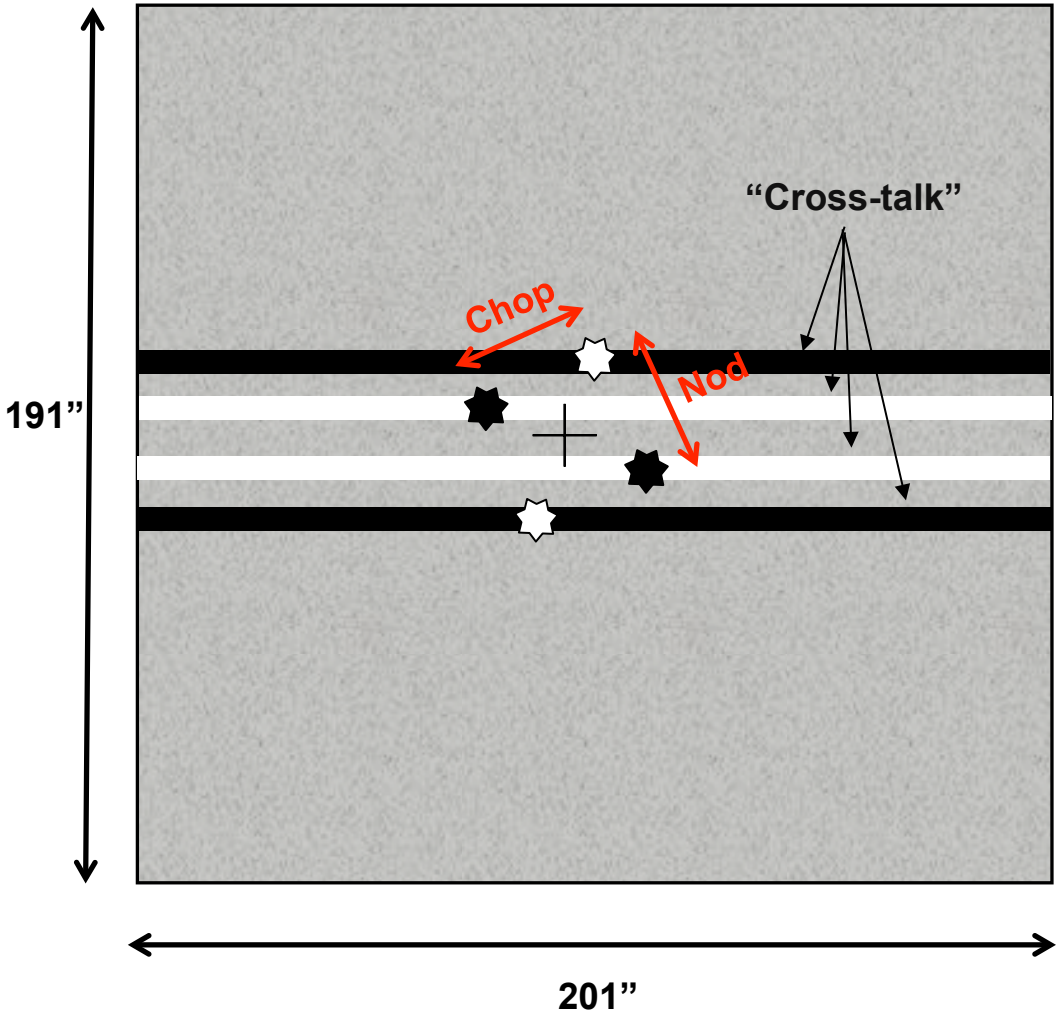

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- Chop and nod throws are equal magnitude
- Typically chop in x (90^{o}), nod in y (180^{o}), though can be other way too
- Chop/nod is symmetric about array center (1/2 nod offset done automatically)
- For bright point sources, a 30^{o} tilt (i.e. chop 120^{o} and nod 210^{o}) will help avoid cross-talk effects from one instance contaminating the others

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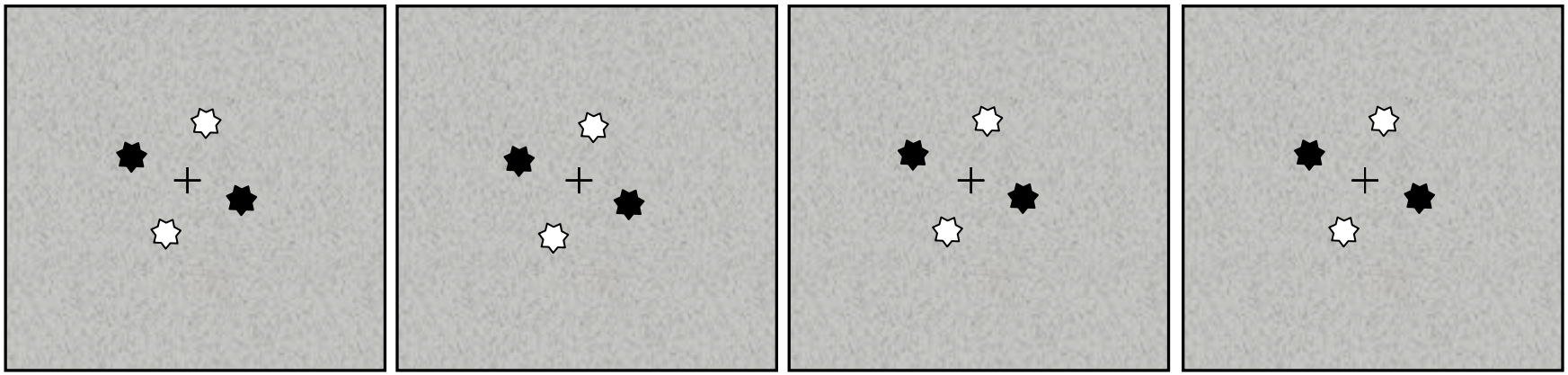
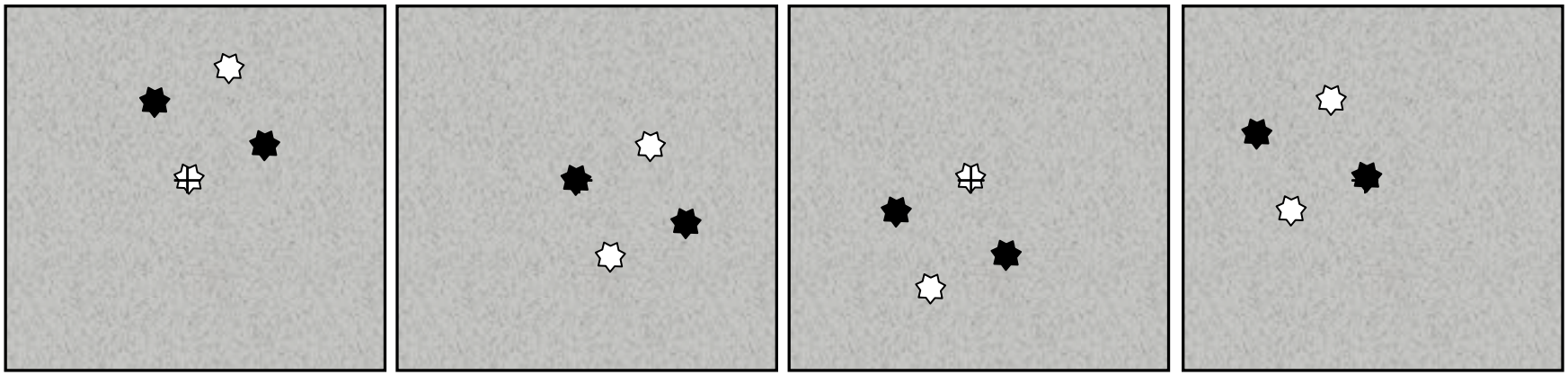


- In post-processing, the final NPC image is created by a process called “image folding”
- First the image is cloned 4 times

Nod Perpendicular to Chop (NPC)

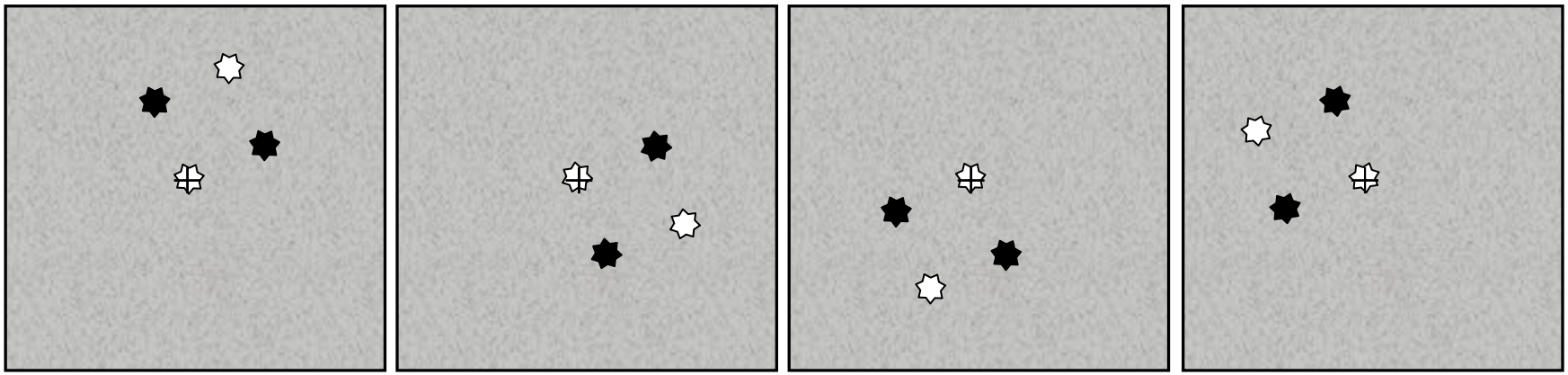
Point Source



- The images are shifted to put each of the four “sources” in the center of the array

Nod Perpendicular to Chop (NPC)

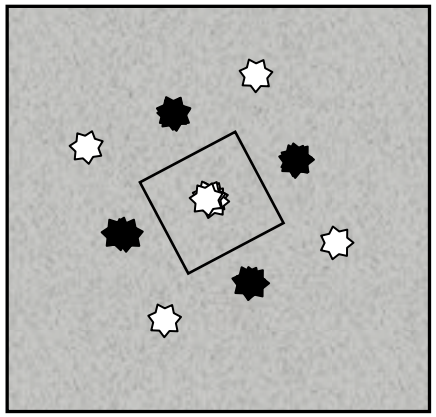
Point Source



- The two images with the negative source at the center are multiplied by -1 to make them positive.

Nod Perpendicular to Chop (NPC)

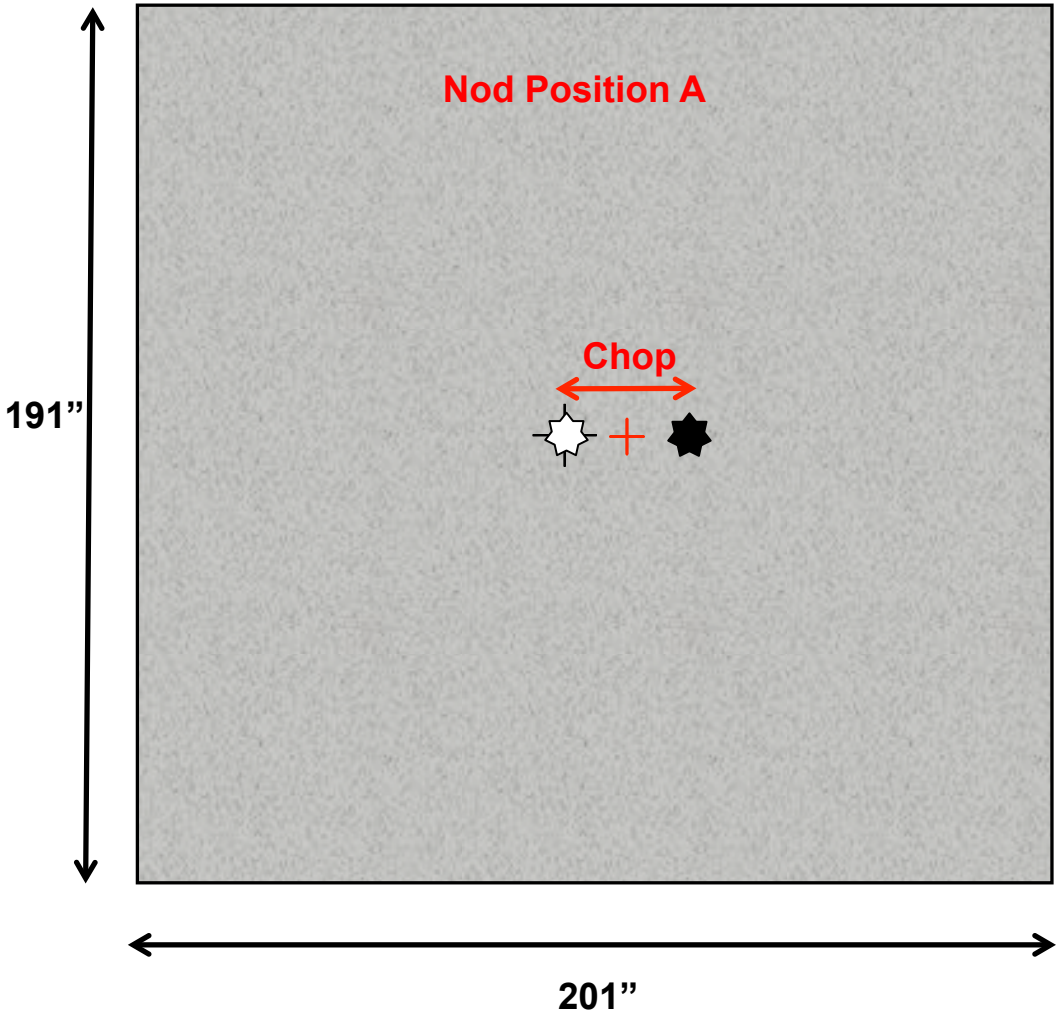
Point Source



- Then all four images are coadded
- The central source in the pattern is the final “image” of the source

Nod Match Chop (NMC)

Point Source



- Set up chop/nod params in Array or Sky coordinates
- Chop and nod throws are equal magnitude
- Typically chop in +x (90^{o}), nod in -x (270^{o}), though it can be any angle
- Setup ½ chop offset from center of array (done automatically)

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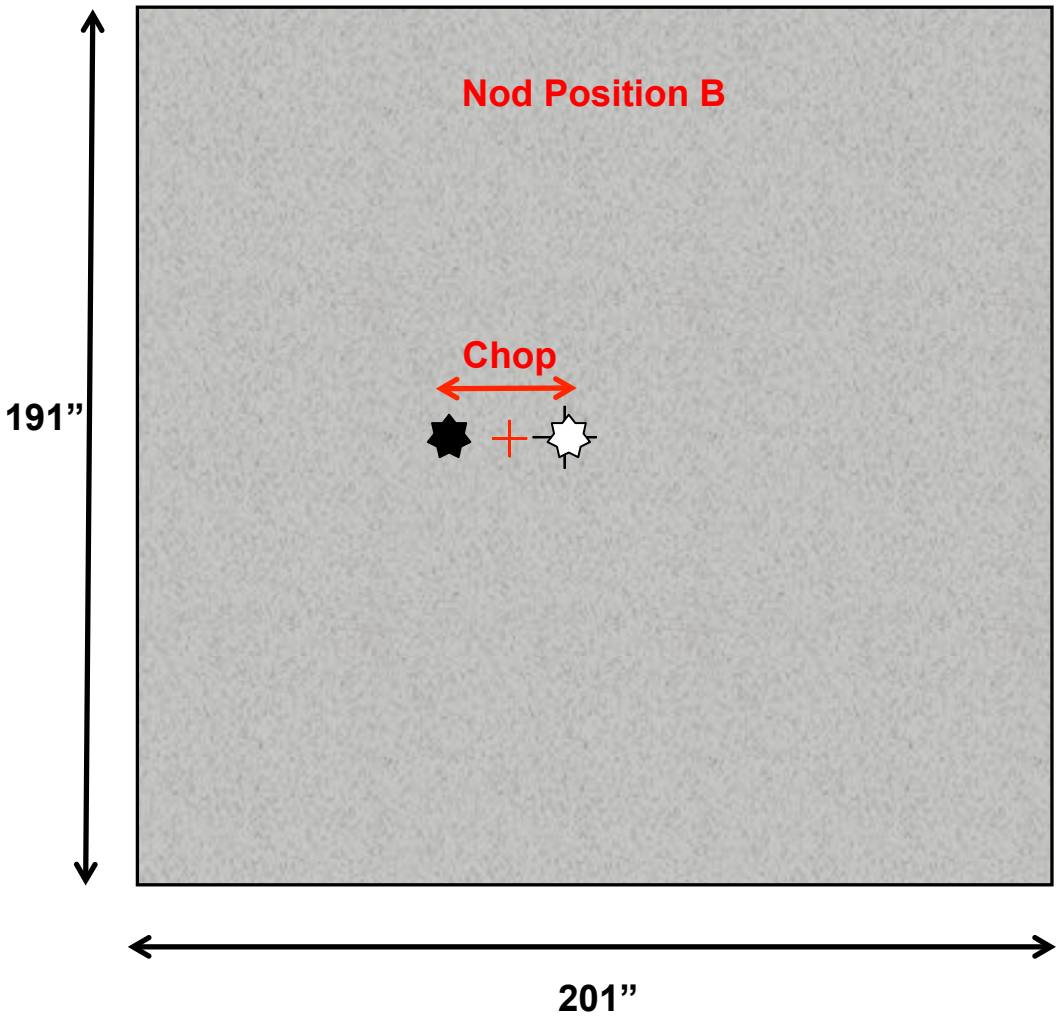

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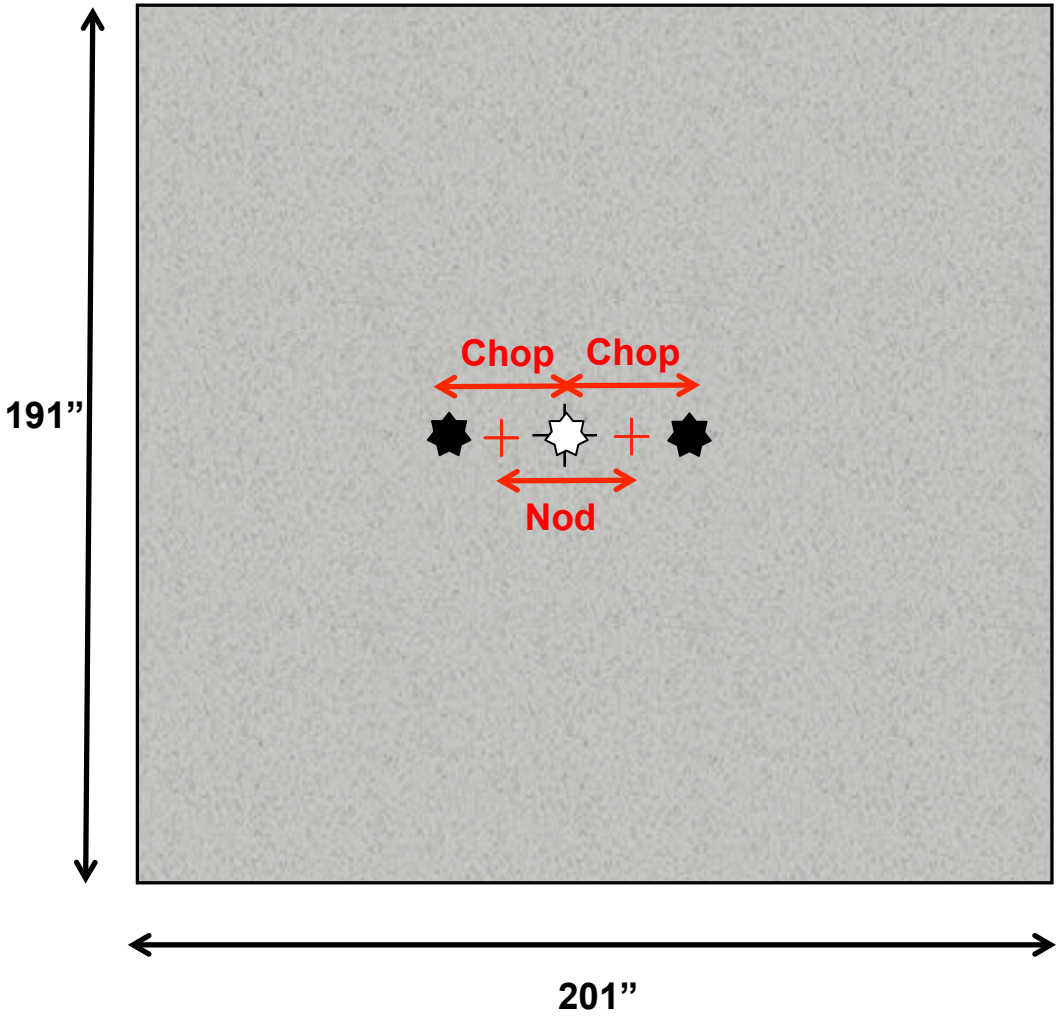

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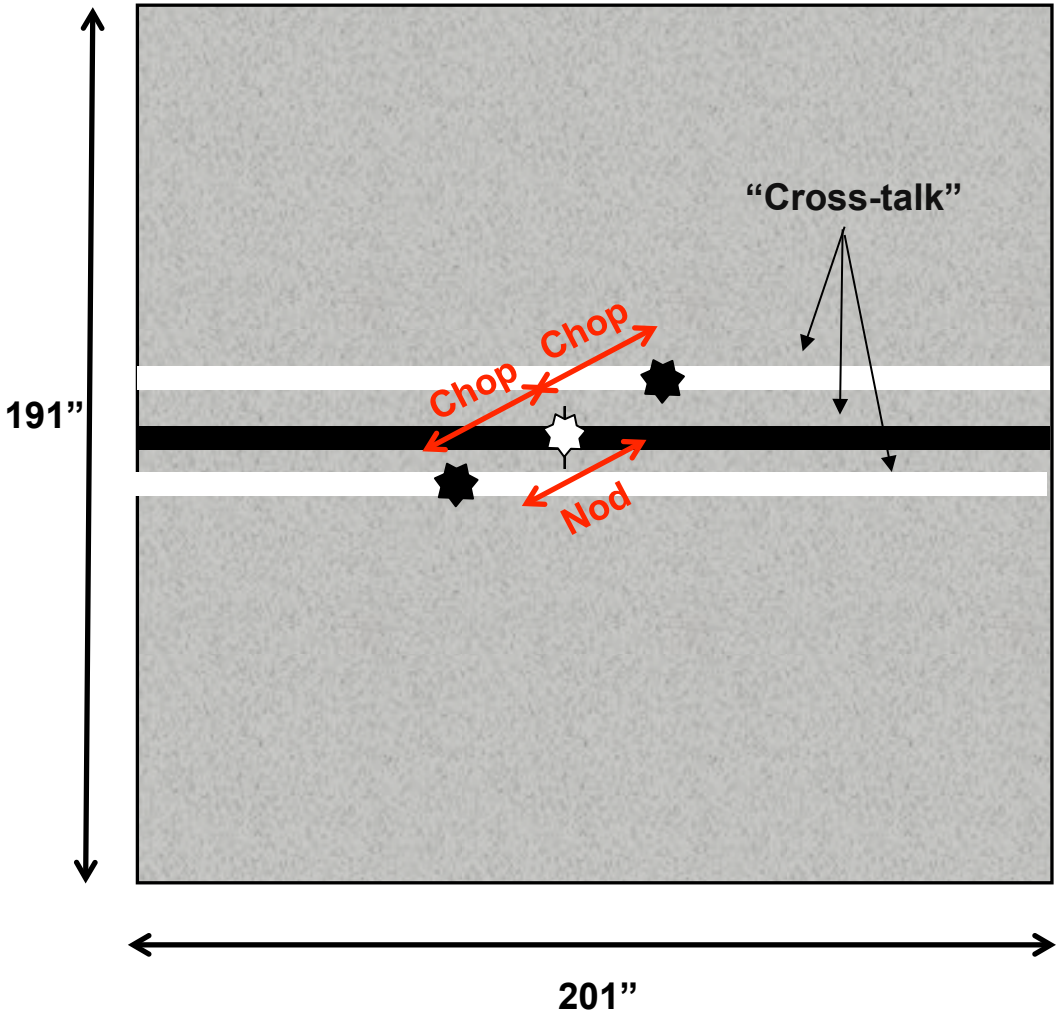

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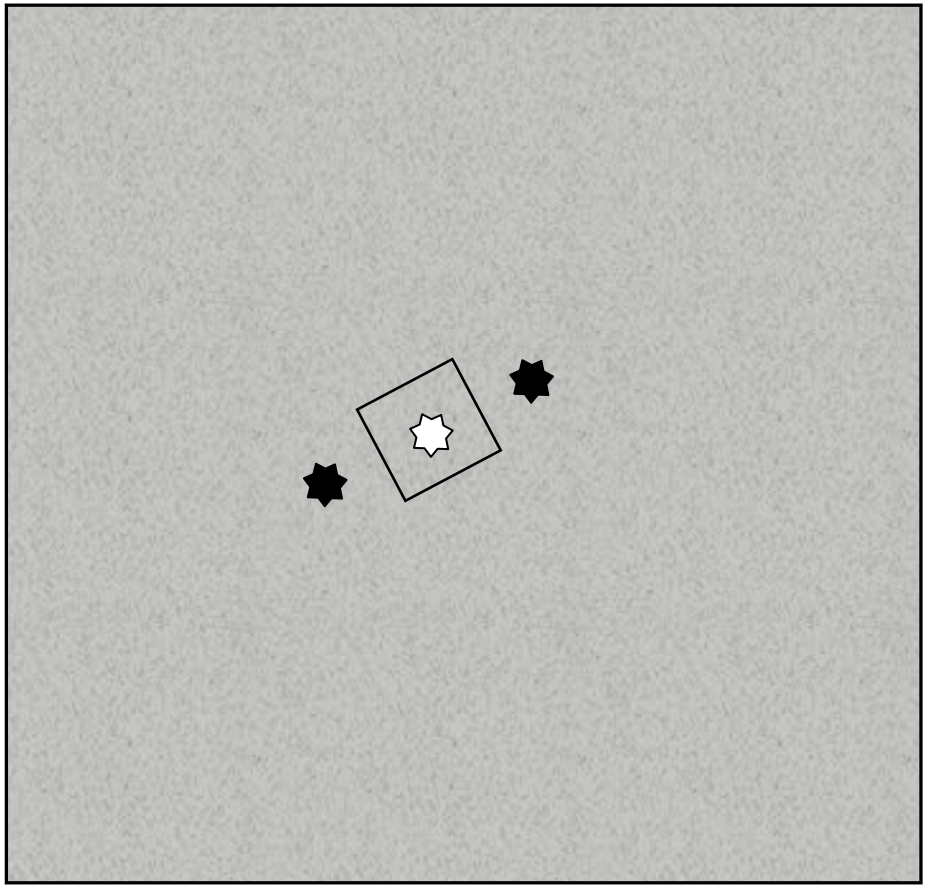
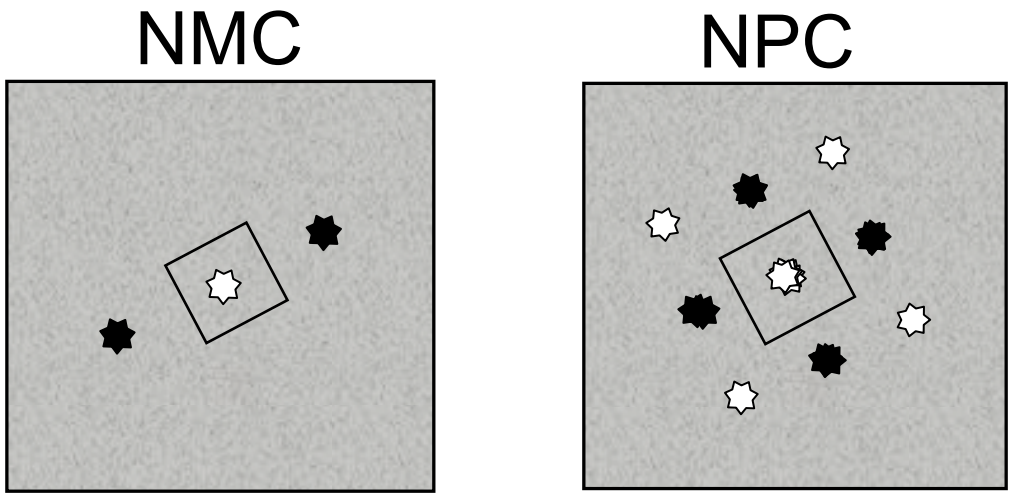


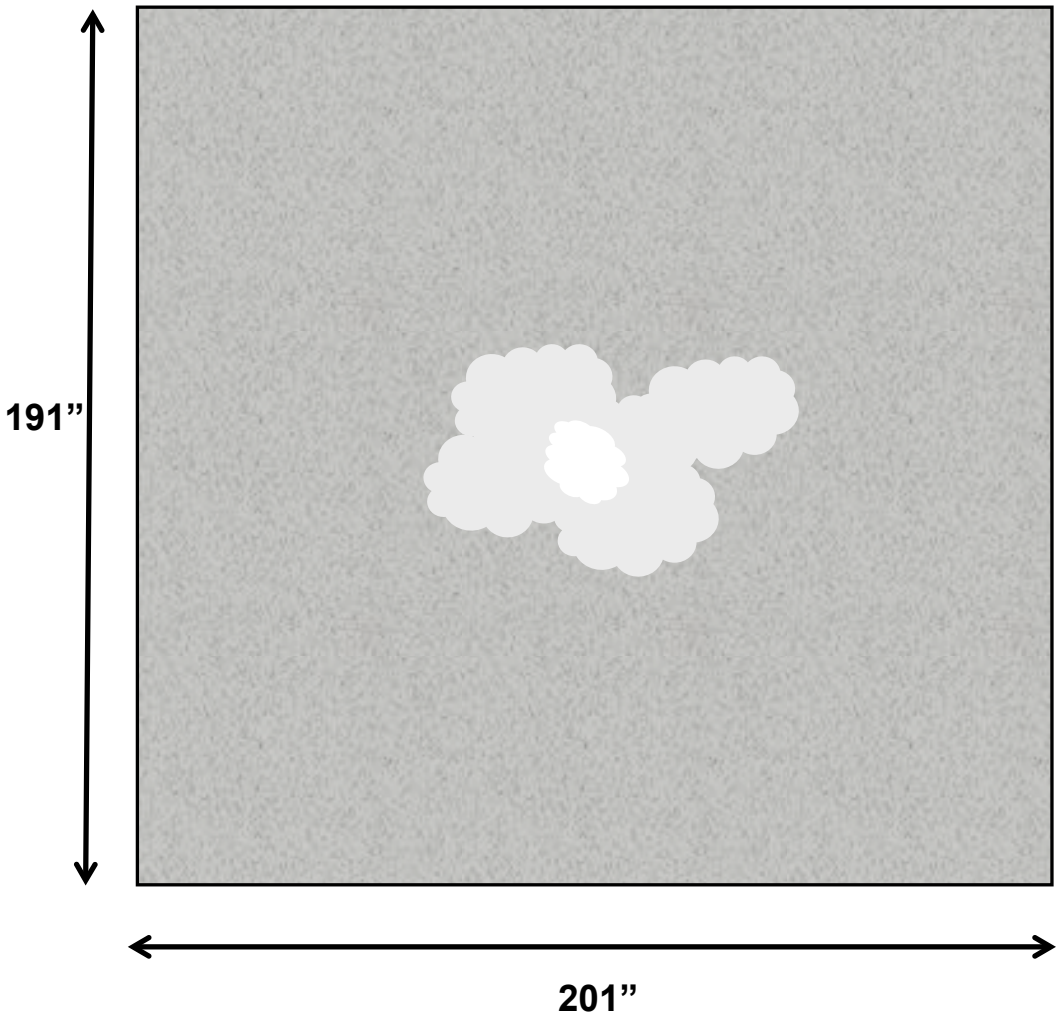
- In post-processing, no “image folding” is needed (unlike NPC)

S/N of NMC vs. NPC



- This source in the center of these two images has THE SAME S/N!
- If observing faint sources, NMC yields instantaneous x2 S/N (on-the-fly)

Nod Perpendicular to Chop (NPC)
Extended Source



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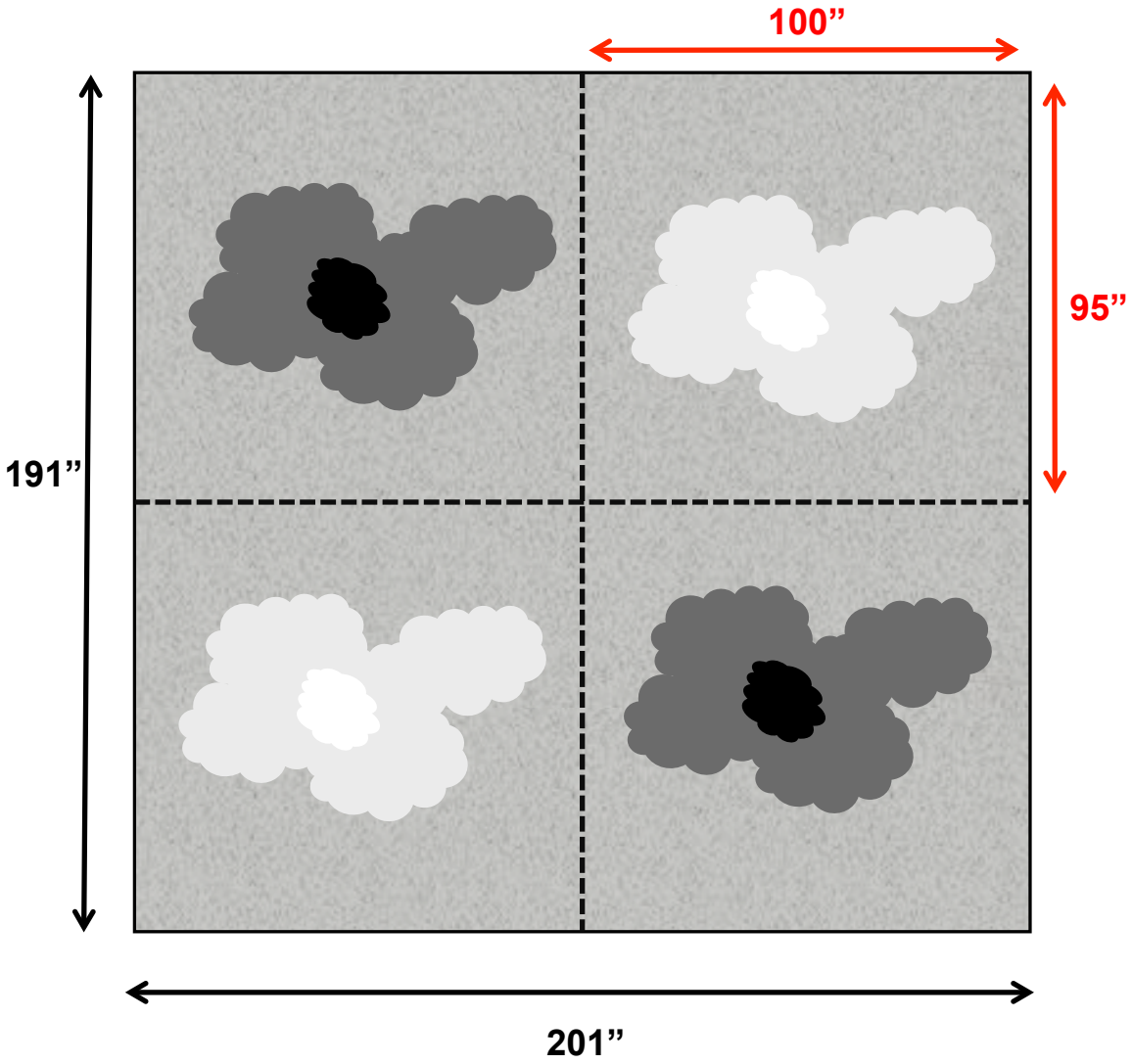

- Largest effective FoV and maximum source size can be 95” (smallest dimension because of rotation)

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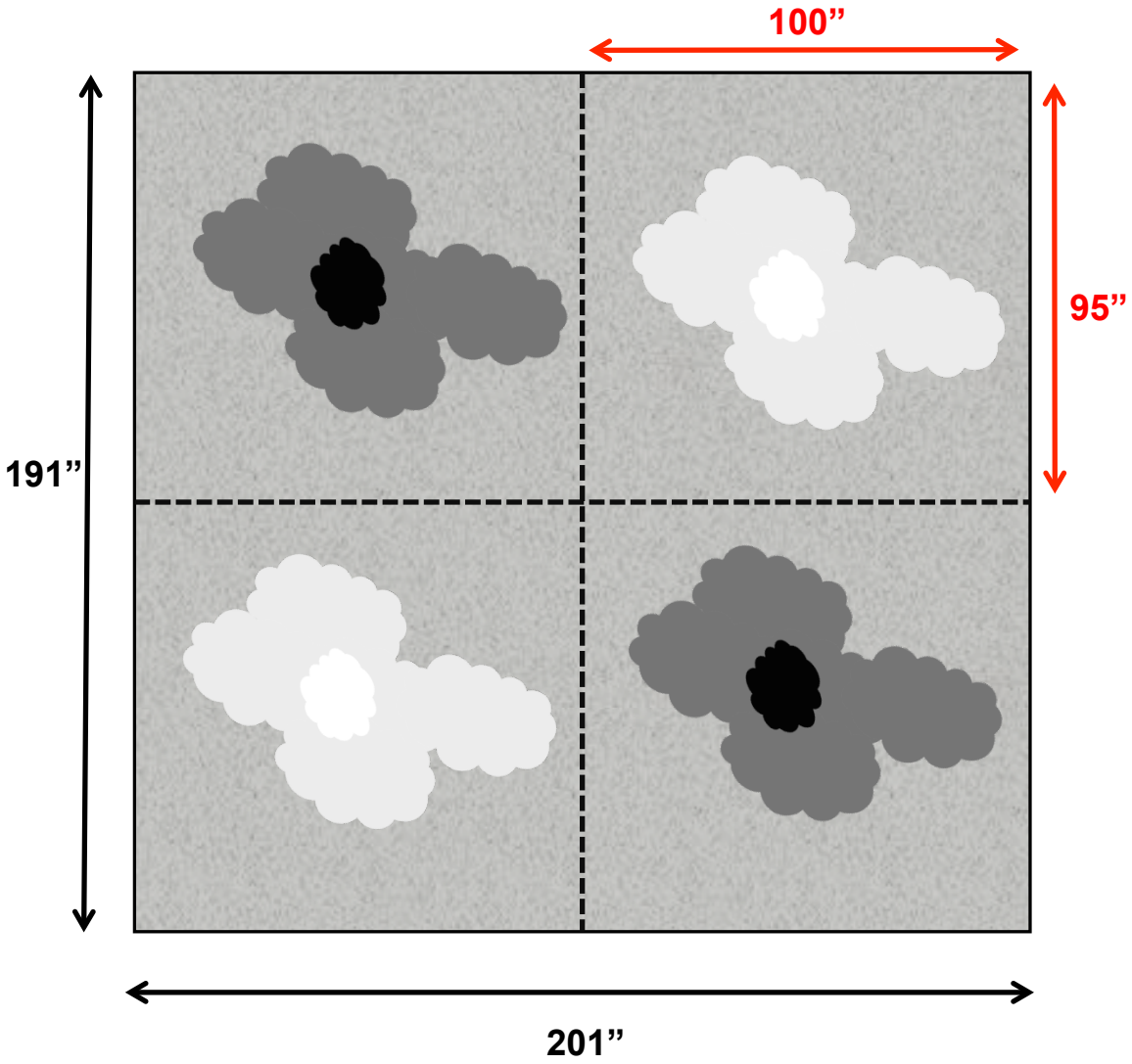

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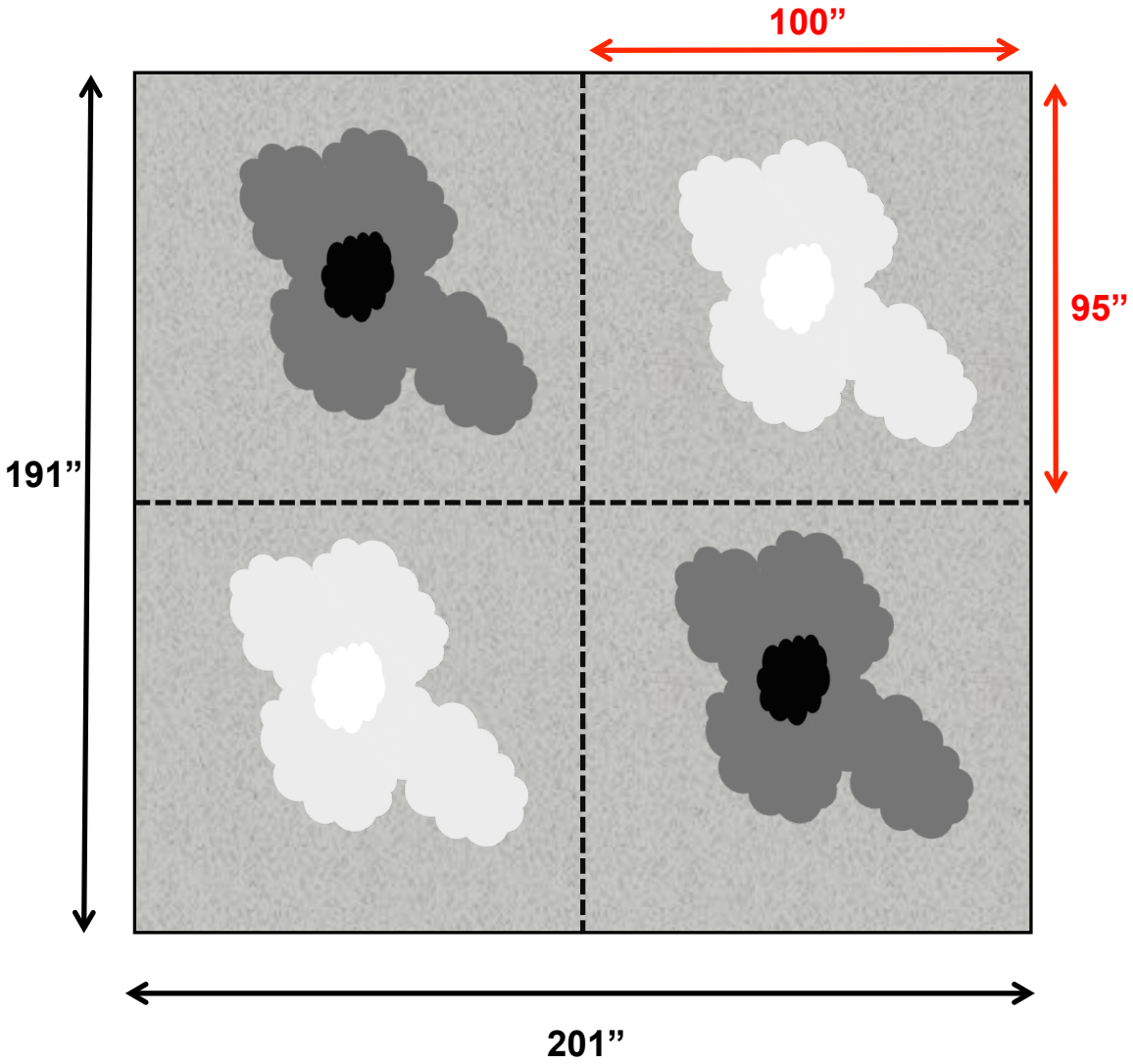

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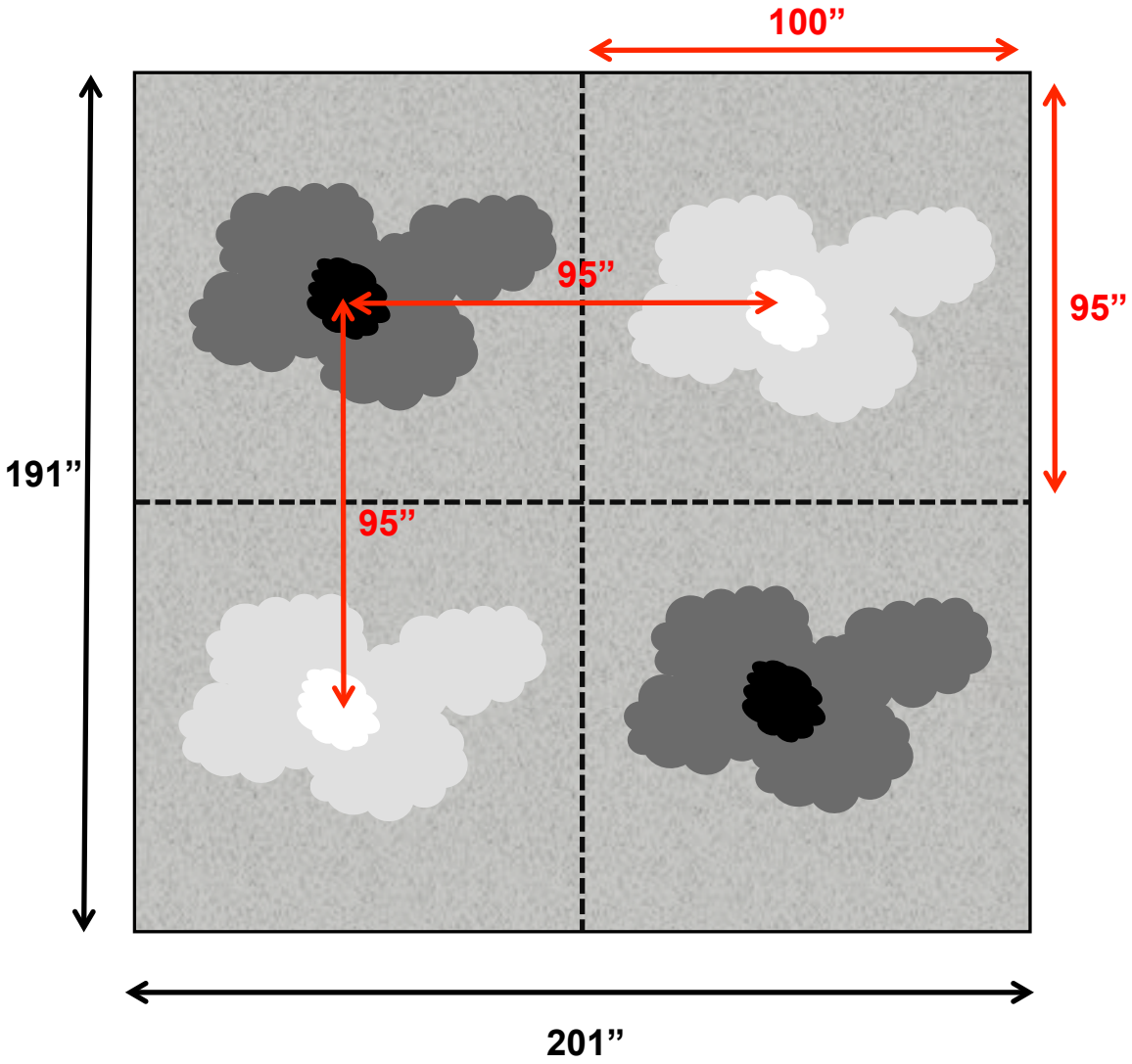

- Largest effective FoV and maximum source size can be 95” (smallest dimension because of rotation)
- Max chop/nod throw is ~95” (1.6’)
- Max introduced coma is ~1.6”

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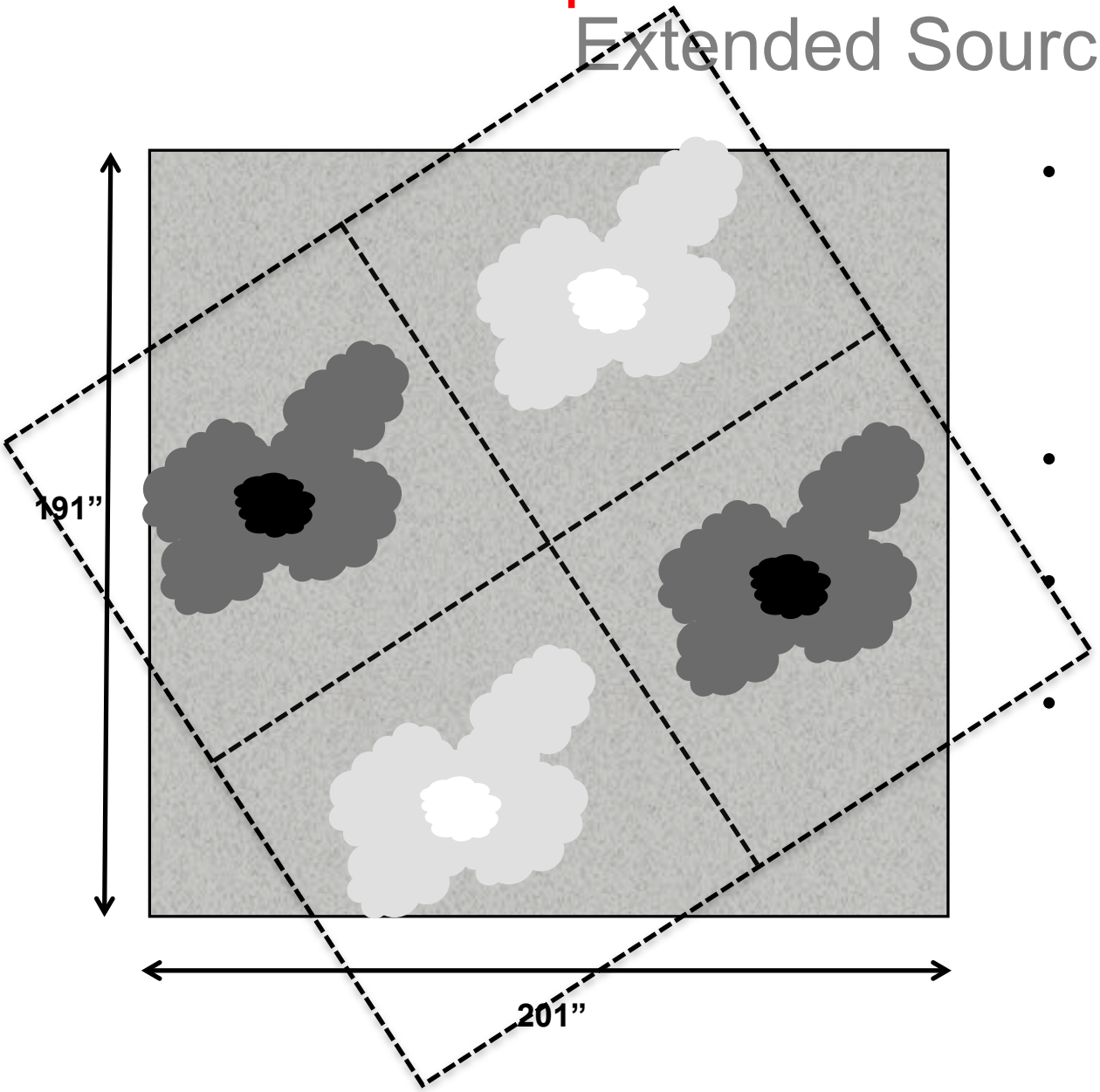
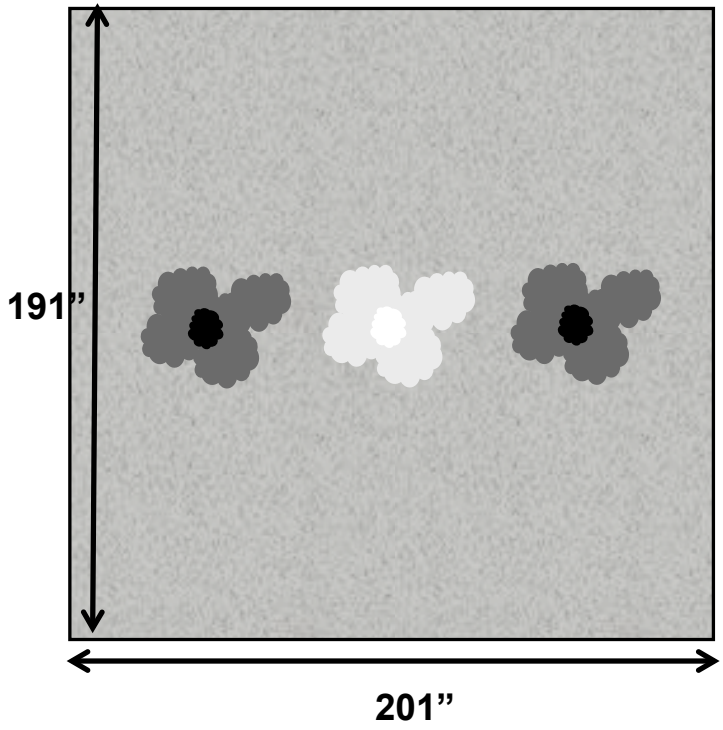


- Largest effective FoV and maximum source size can be 95” (smallest dimension because of rotation)
- Max chop/nod throw is ~95” (1.6’)
- Max introduced coma is ~1.6”
- If source is really bright, to avoid artifacts chop/nod pattern should be tilted (but decreases FoV and max allowed source size)

Nod Match Chop (NMC)
Extended Source



- Unlike NPC mode, negative sources are NOT coadded with the positive source (no gain in S/N)
- Therefore source sizes up to the size of the FoV can be imaged in NMC (i.e. you can chop on-array or off-array)

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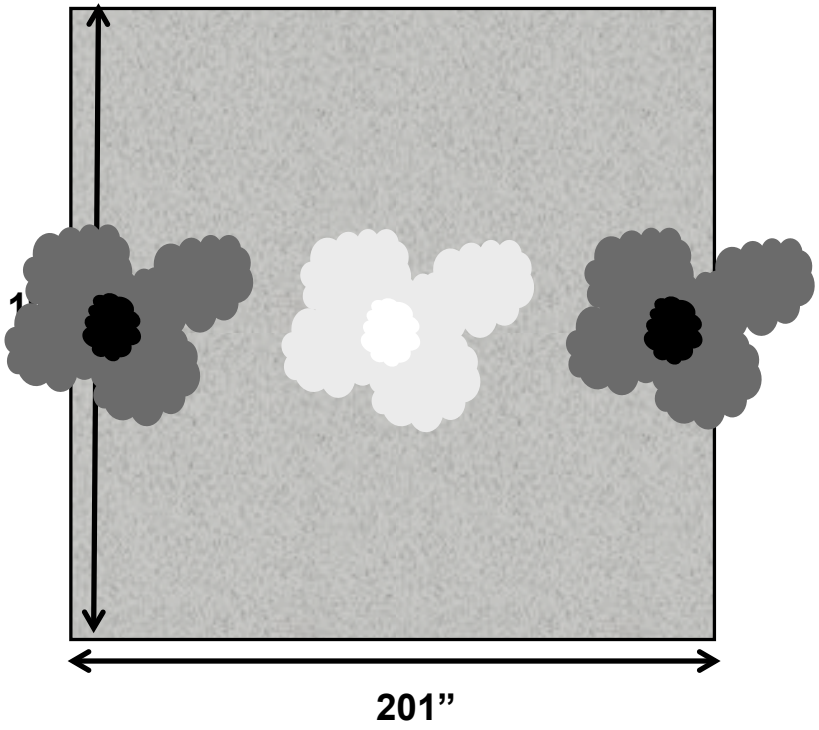

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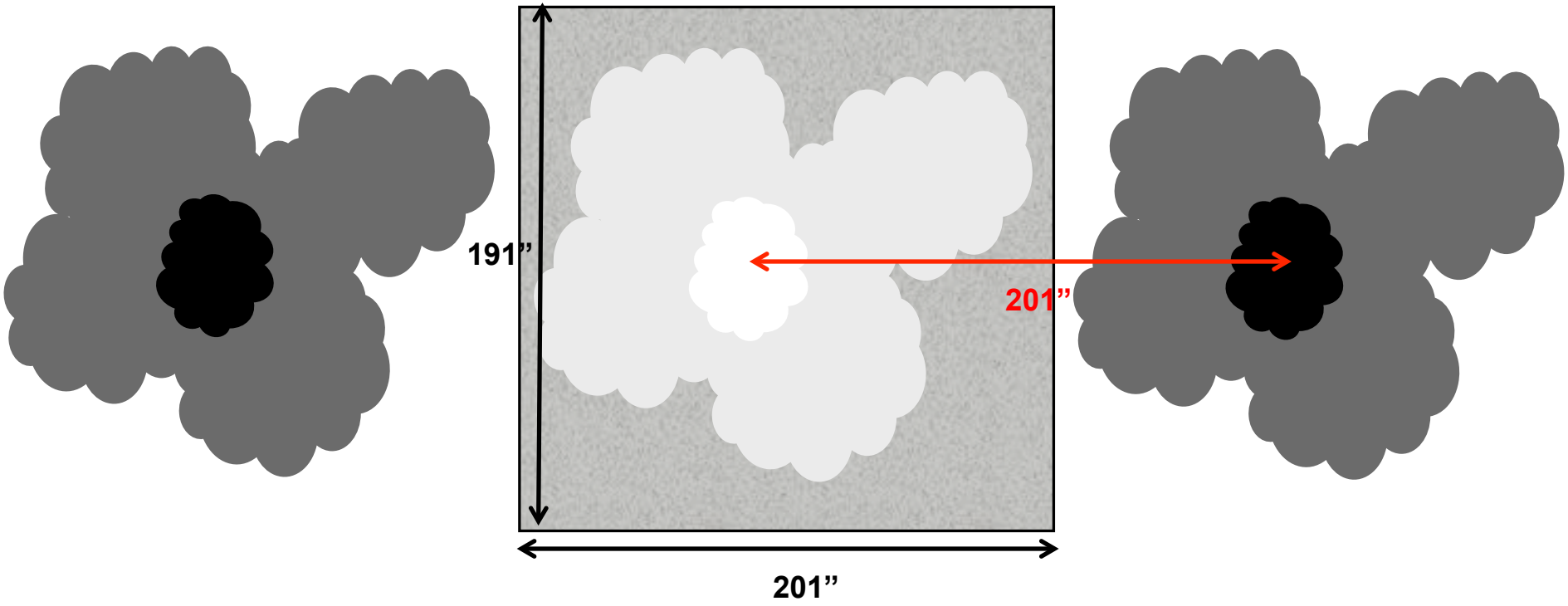
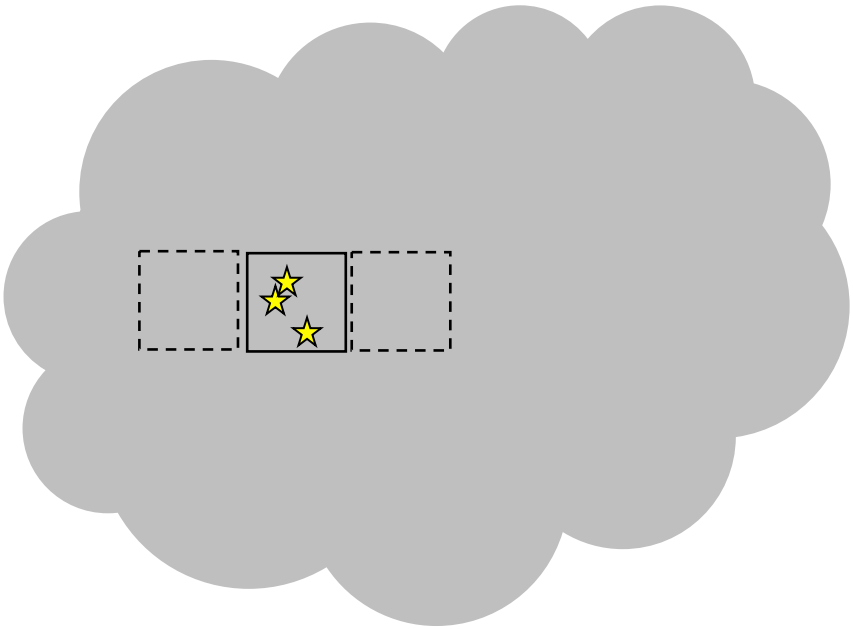


- Unlike NPC mode, negative sources are NOT coadded with the positive source (no gain in S/N)
- Therefore source sizes up to the size of the FoV can be imaged in NMC (i.e. you can chop on-array or off-array)
- The larger the chop, the more coma (max 3.4” of coma at 201” throw)

Large Asymmetric Chop with Large Nod (C2NC2)

Extended Source



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- Successfully used to image Orion BN/KL region

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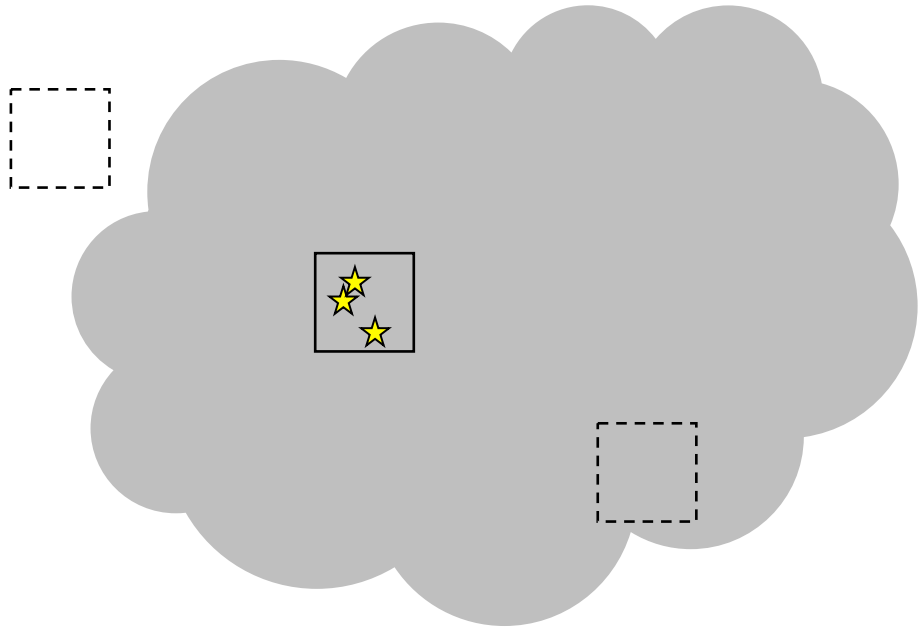

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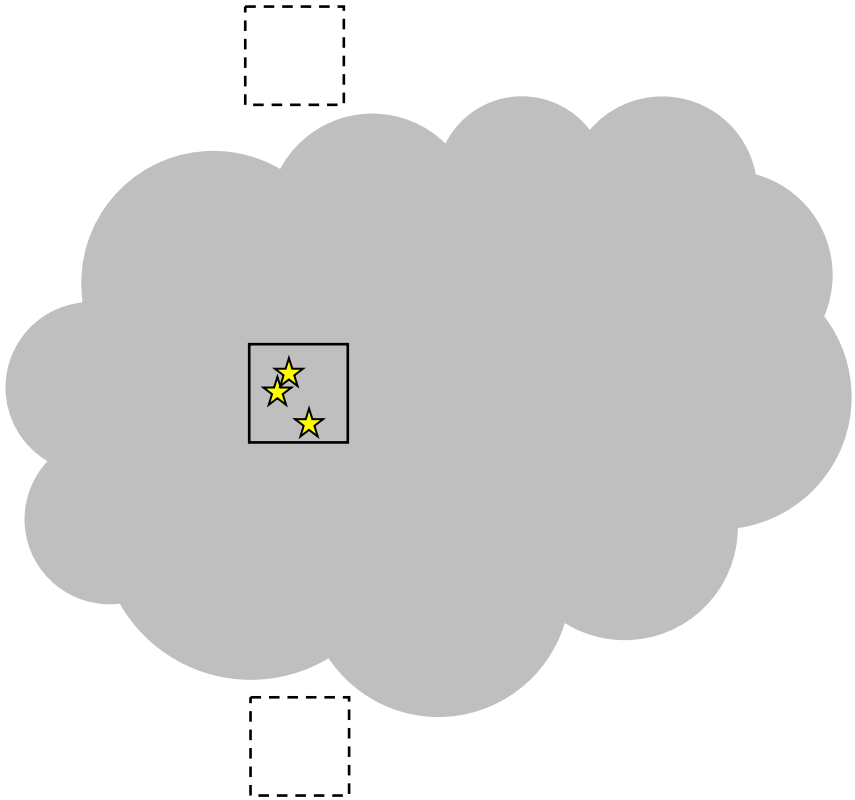

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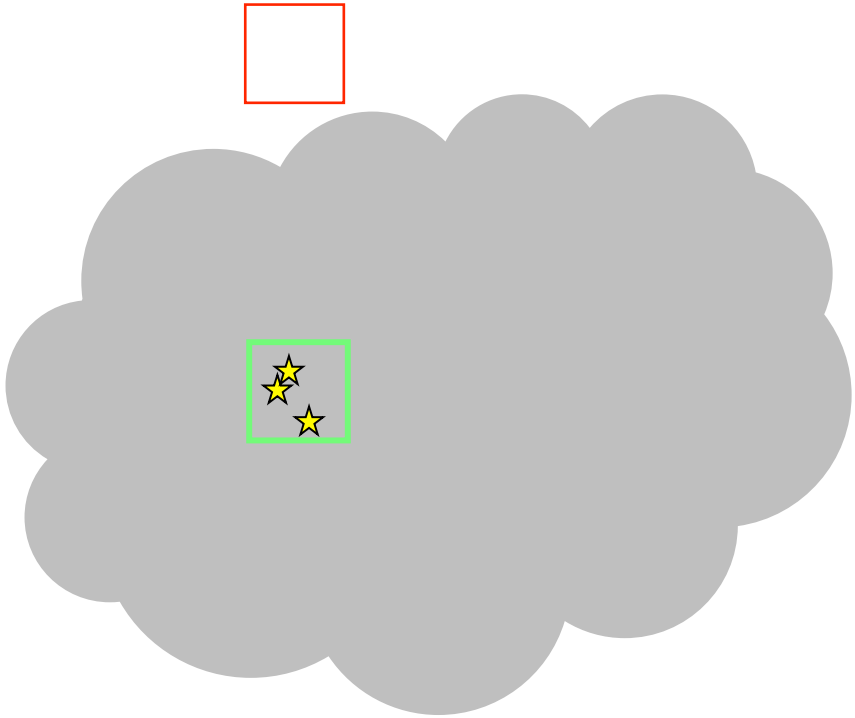

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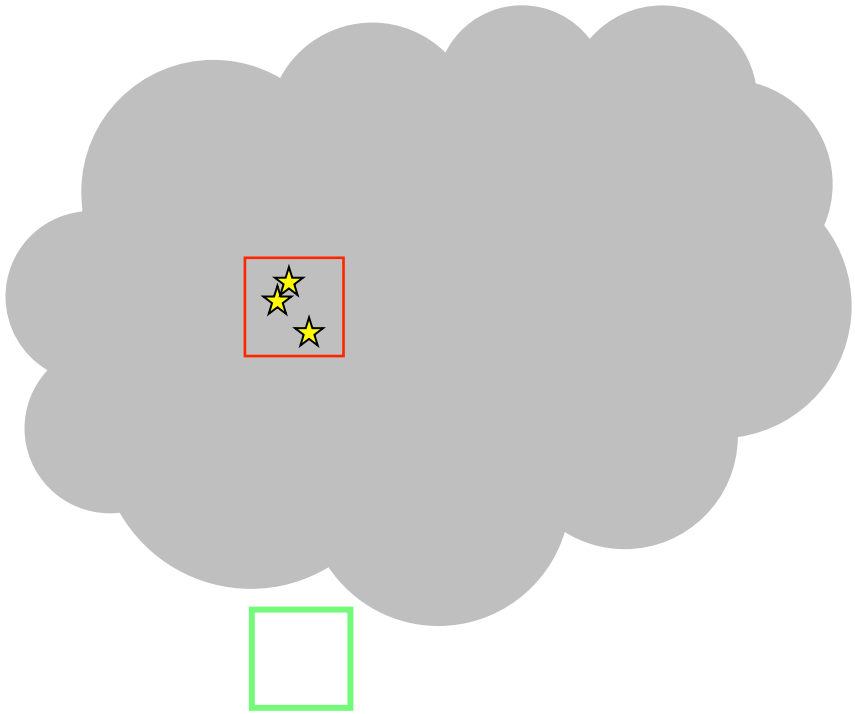

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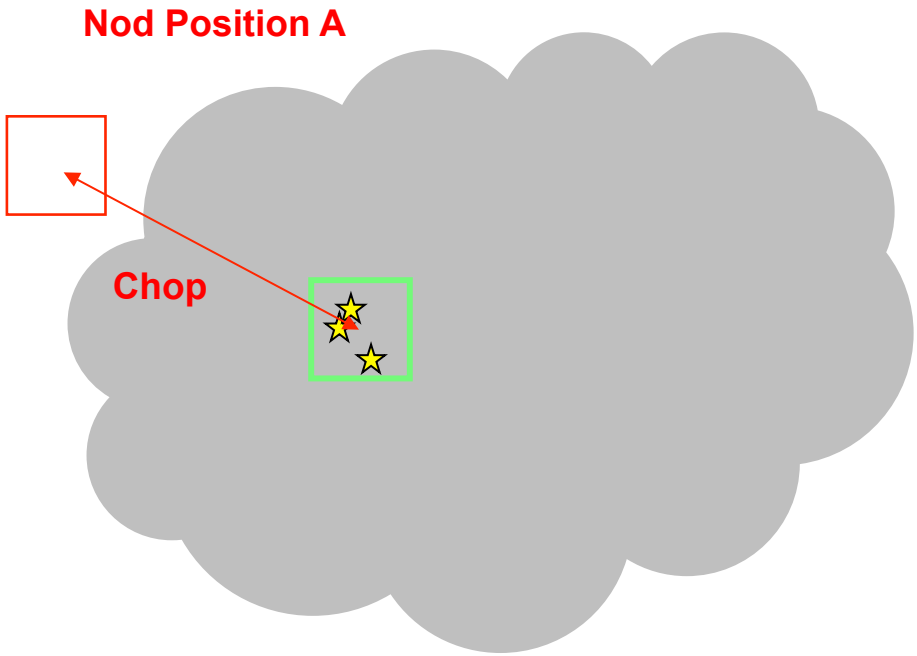

Large Asymmetric Chop with Large Nod (C2NC2)

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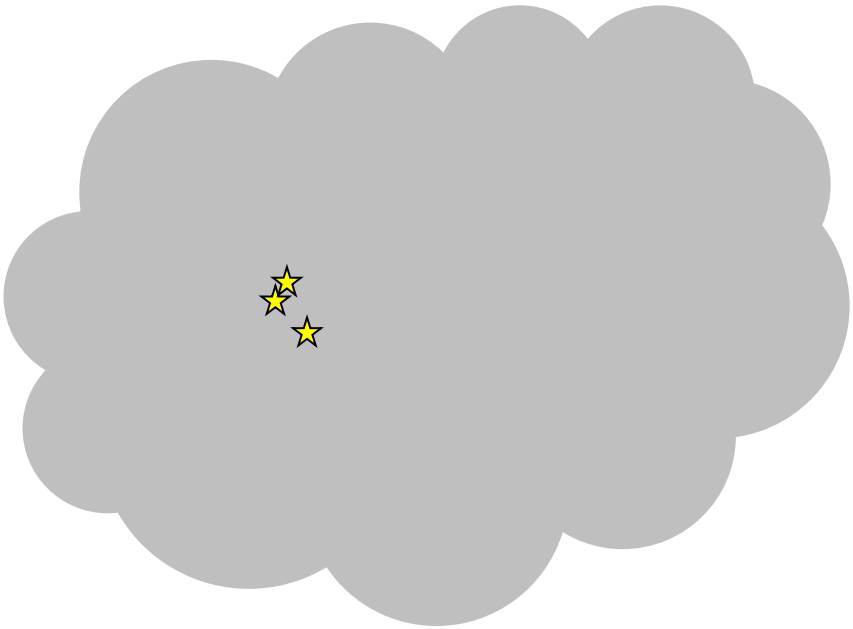
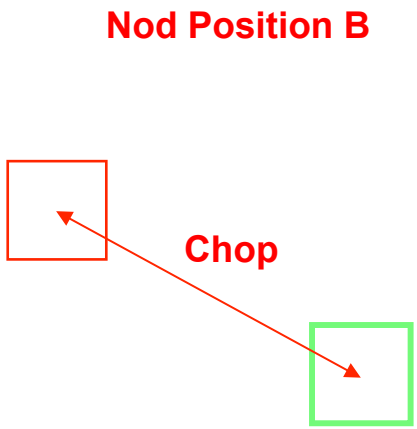
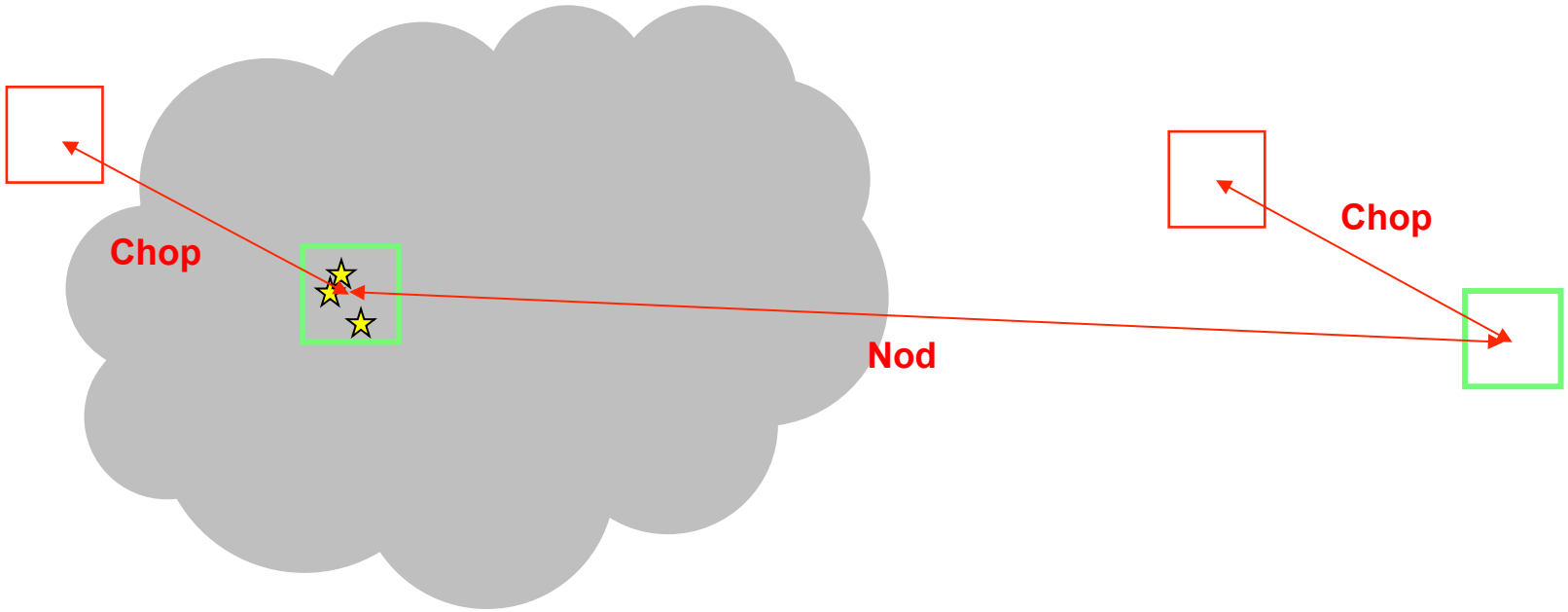




Large Asymmetric Chop with Large Nod (C2NC2)

Extended Source



- Set-up is in Sky coordinates
- Chop throws up to 290” (4.8’) allowed without restrictions on chop angle, max 420” (7’) allowed with restrictions
- Nod throws up to 30’ allowed, no angle restrictions
- S/N and efficiency much lower in this mode than NPC/NMC

Imaging Efficiencies

NMC/NPC Mode: 70%

C2NC2 Mode: 20%

- These values include S/N, chop efficiency, nod efficiency, and observing efficiency

- SPT calculates this for you

Example:

- **SITE** tells me that my source will take **100s of exposure time** to reach my target S/N
- If I use **NMC or NPC mode** this will take 100s/.70 = **143s of flight time**
- If I use **C2NC2 mode**, this will take 100s/.20 = **500s of flight time**

Which imaging mode should I use?

Nod Match Chop (NMC)

Advantages:

- “Instantaneous data reduction”
- Factor of 2 better S/N on-the-fly than NPC (good for faint sources)
- Allows imaging of sources up to the size of the full array (~190” in diameter)
- Flexibility over NPC for strategic use of chop direction

Disadvantages:

- If there is bad turbulence, nod will not accurately match chop and data is useless
- At large chop throws, coma starts to become an issue

Nod Perpendicular to Chop (NPC)

Advantages:

- Less risk of data loss from turbulence or telescope control issues
- Because of a small maximum limit to chop throws, coma effects are minimal

Disadvantages:

- Factor of 2 worse S/N on-the-fly than NMC (not as good for faint sources)
- More post-processing intensive than NMC
- Limited to use on sources less than ~95” in diameter

Large Asymmetric Chop with Large Nod (C2NC2)

Advantages:

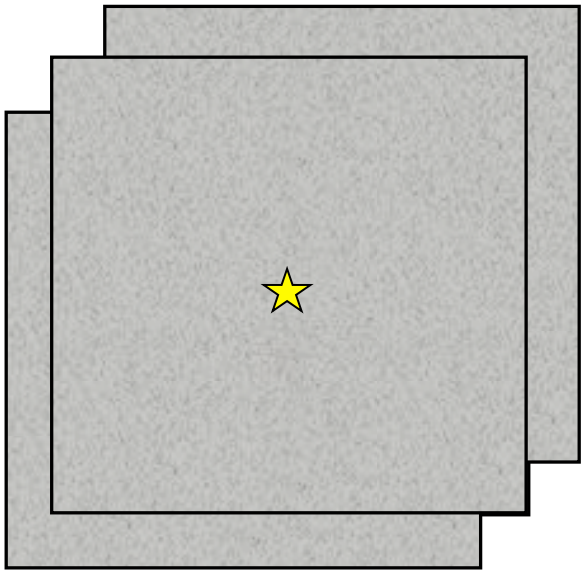
- Provides best image quality for observations requiring large chop throws
- Provides a way to image very large areas or sources within very large areas

Disadvantages:

- S/N worse than NMC/NPC
- Much less efficient than NMC/NPC
- For chop throws >290” (4.8’), backup chop angles are needed

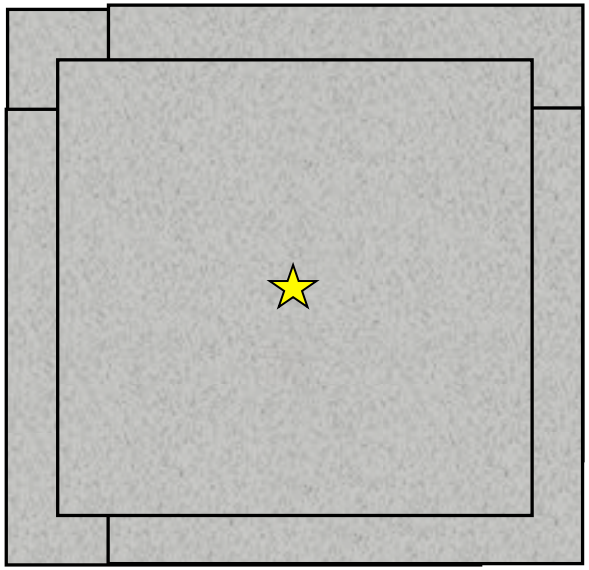
Dithering

- **Def: Moving the telescope with small offsets (typically 10-30”) between images**
- **3 or 5-element pattern typical (9, custom also available)**



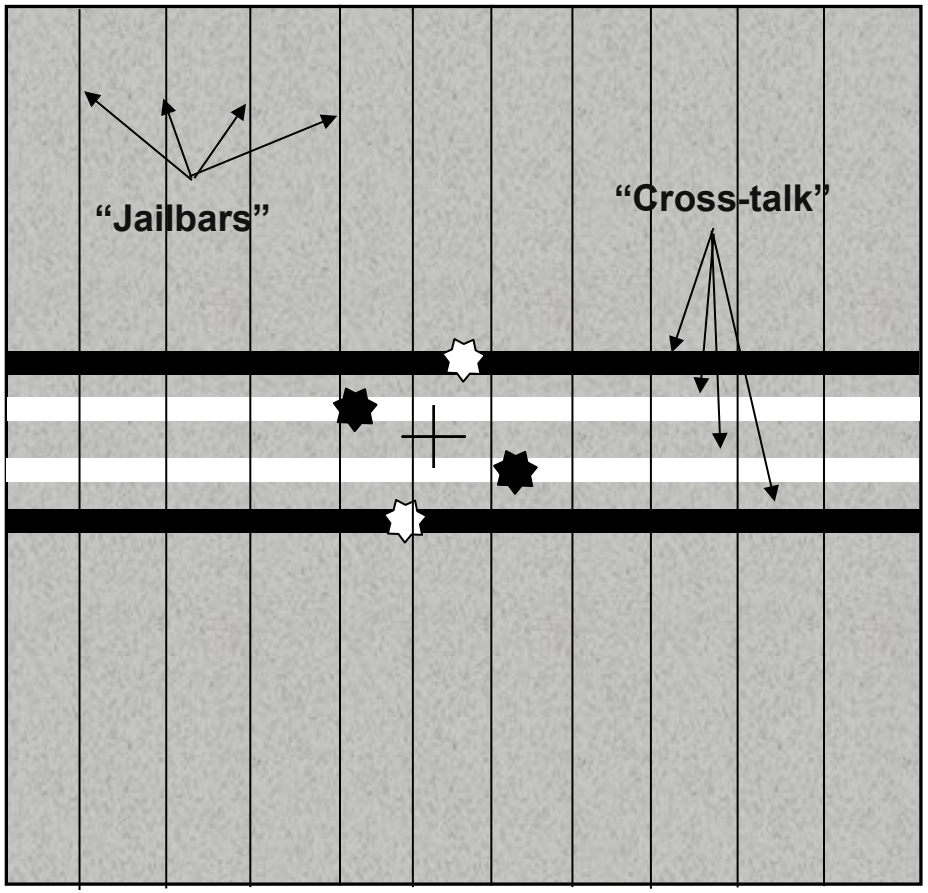
Dithering

- **Def: Moving the telescope with small offsets (typically 10-30”) between images**
- **3 or 5-element pattern typical (9, custom also available)**
- **Helps remove effects of bad pixels**



Dithering

- **Def: Moving the telescope with small offsets (typically 10-30”) between images**
- **5-element pattern typical (3, 9, custom also available)**
- **Helps remove effects of bad pixels**
- **Will remove jailbar noise (but not cross-talk!)**



Strategy for Compact (D<85”) Sources

Bright, isolated:

- Use NPC or NMC with smallest possible chop-nod throws (improves efficiency and image quality)
- Dithering can also be used (recommend)

Faint, isolated:

- Use NMC with smallest chop-nod throws possible
- No dithering

Crowded field (or nearby extended emission):

- Try to use NMC in Sky coordinates to choose optimal chop-nod direction
- If necessary, use C2NC2 with smallest possible chop throw
- Dithering recommended if target is bright

Strategy for Extended (85”<D<190”) Sources

Bright, isolated:

- Use NMC with smallest chop-nod throws possible (improves efficiency and image quality)
- Dithering can also be used (recommend)

Faint, isolated:

- Use NMC with smallest chop-nod throws possible
- No dithering

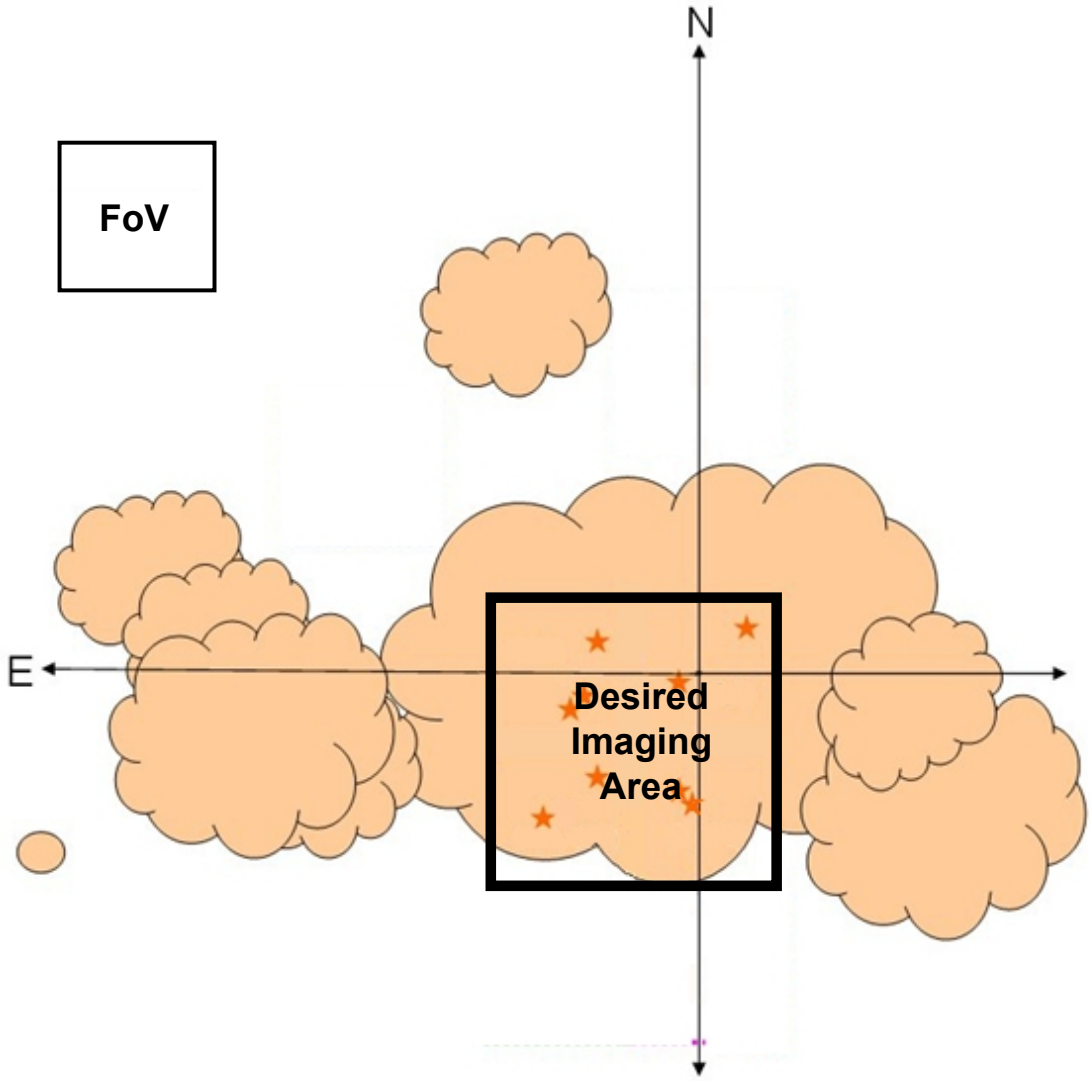
Crowded field (or nearby extended emission):

- Try to use NMC in Sky coordinates to choose optimal chop-nod direction
- If too crowded, *or if optimal image quality is desired*, use C2NC2 with smallest possible chop throw
- Dithering recommended if target is bright

Strategy for Extended (D>190”) Sources

- Mosaicking will be necessary
- Use C2NC2 with smallest chop-nod throws possible (improves efficiency and image quality)
- Dithering recommended for bright sources, not faint

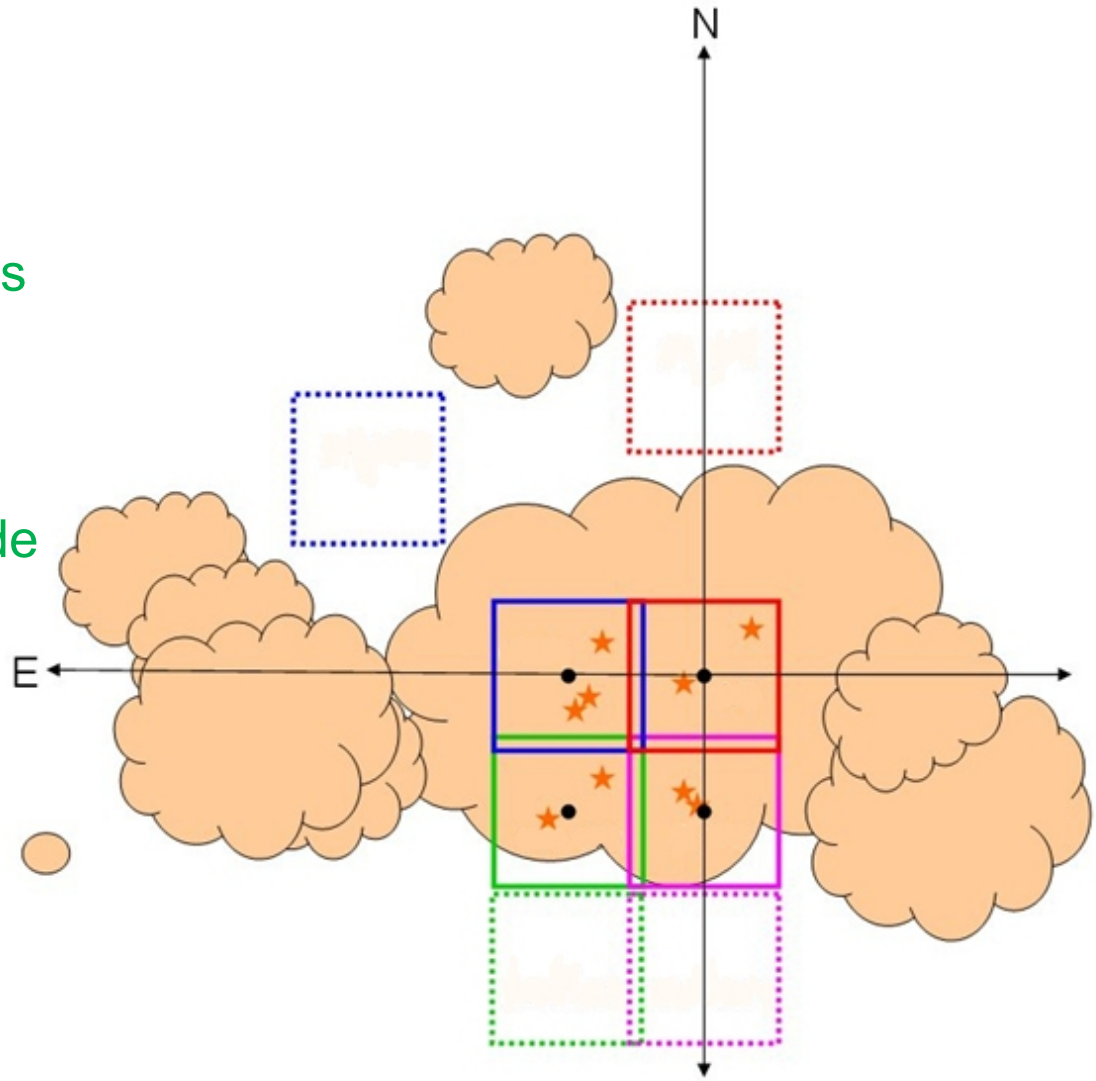
Strategy for Extended (D>190”) Sources



Strategy for Extended (D>190”) Sources

Mosaicking:

- There should be appreciable overlap of bright structure/sources (guarantees proper registration)
- Chopping can change direction and magnitude from one mosaic position to another
- Nods (not pictured) should be far enough away to sample clean sky
- Dither can be done at each mosaic position



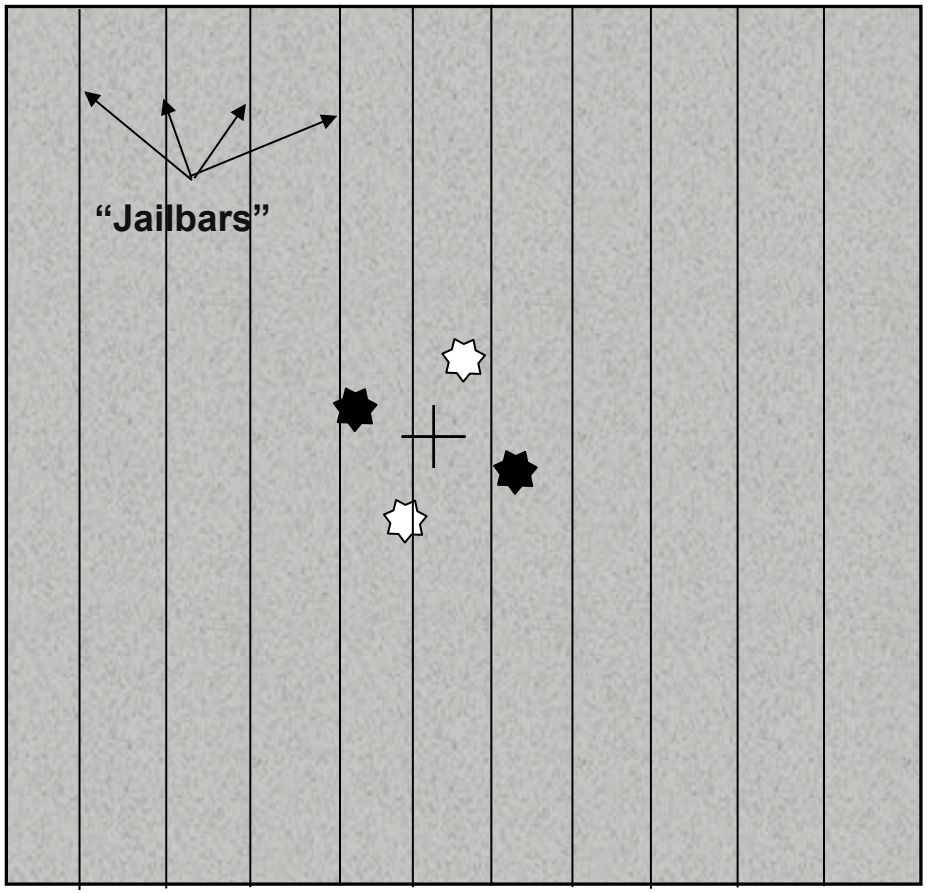
Common data problems and how to mitigate them

or

What the heck is that in my data?

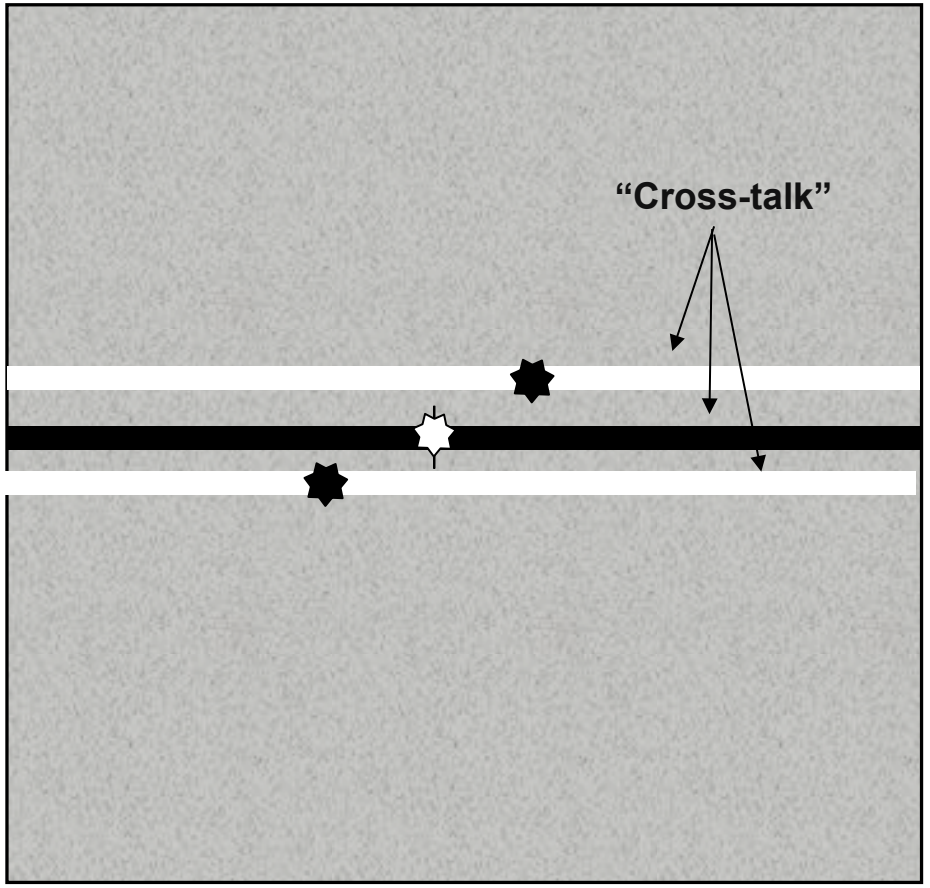
“Jailbars”

- For compact sources (D<30”), a routine used during pipeline will remove
- For larger sources, one needs to dither to remove



“Cross-talk”

- Effect is always present but linked to flux of object
- Feature is a couple of percent source flux, so only seen when source is bright
- Incline chop-nod pattern to mitigate secondary effects
- Cross-talk is not taken out by the pipeline (there is no “fix”)

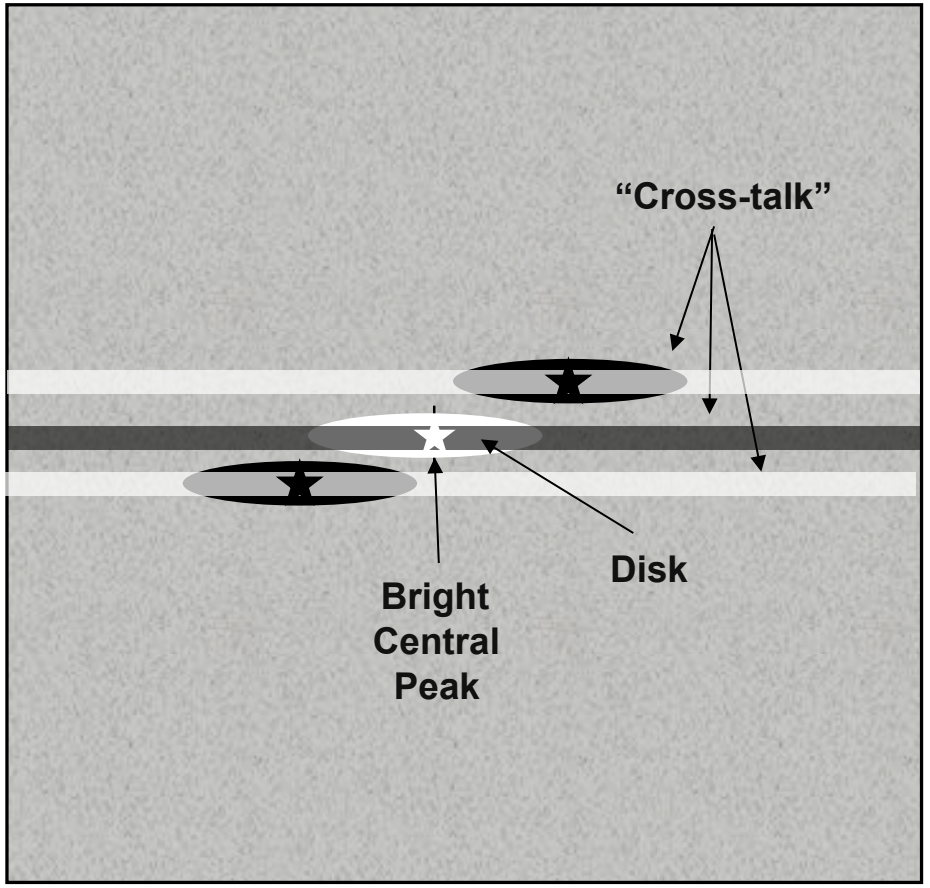


“Cross-talk”

- Cross-talk due to bright sources can affect the appearance of the extended emission on the field

- Cross-talk can also cause a dynamic range problem
- VERY bright sources can negatively change the responsivity of the whole array, making detection of other sources/emission on the field more difficult

Example: Trying to observe a disk around a bright peak



“Gyro Drift” (Pointing Drift)

- **Over time, the location of a source on the FORCAST array drifts**
- **This is a telescope issue (solutions are being investigated)**
- **However, right now this creates a problem for the detection of very faint sources that would require more than ~20m of minutes to get a 3-sigma detection**

“LOS Resets” (Field Rotation)

- Telescope is not on an equatorial mount, so sky appears to rotate
- Neither the telescope nor FORCAST has a de-rotator
- Sky stays fixed for periods of time, but occasionally telescope needed to “reset”
- The time between resets depends on the direction of the airplane and the location of the source in the sky
- Can be as little as 5 min, can be as long as an hour or more
- Generally sources nearer the north celestial pole rotate fastest

“LOS Resets” (Field Rotation)

- **Because it is difficult to place a source EXACTLY on the optical axis, LOS resets change where the source is located on the array**
- **Extended sources appear to rotate on the array as well**
- **This all makes detection of faint sources (especially faint extended sources) difficult, especially if the source is a fast rotator – it may be impossible to coadd images before and after LOS resets**
- **For instance, if your source needs an LOS rewind every 10 minutes, you need to be able to detect it with S/N>3 in 10 minutes**

WCS Inaccuracies

- With point in accuracies, pointing drift, LOS rewinds, etc. the actual pixel coordinate referred to by the RA and Dec in the header is not very helpful to a certain level
- It is beneficial to use the dichroic mode to take a quick snapshot of a source with the 11um filter in the SWC when taking longer wavelength data with the LWC
- Use ground-based or Spitzer 8um data with the 11um data to back out astrometric info for the LWC data

Note to Basic Science PIs

- Don’t forget that your observations were taken in a “PI observation” mode
- This means that your project is a joint project with the FORCAST group, and you need to include Terry Herter (FORCAST PI) on your papers
- Given the state of development at that time of the data acquisition, data pipeline, reduction software/ cookbook, etc. it is likely that you will NEED to call upon the FORCAST group for help