The Essentials of Chopping and Nodding

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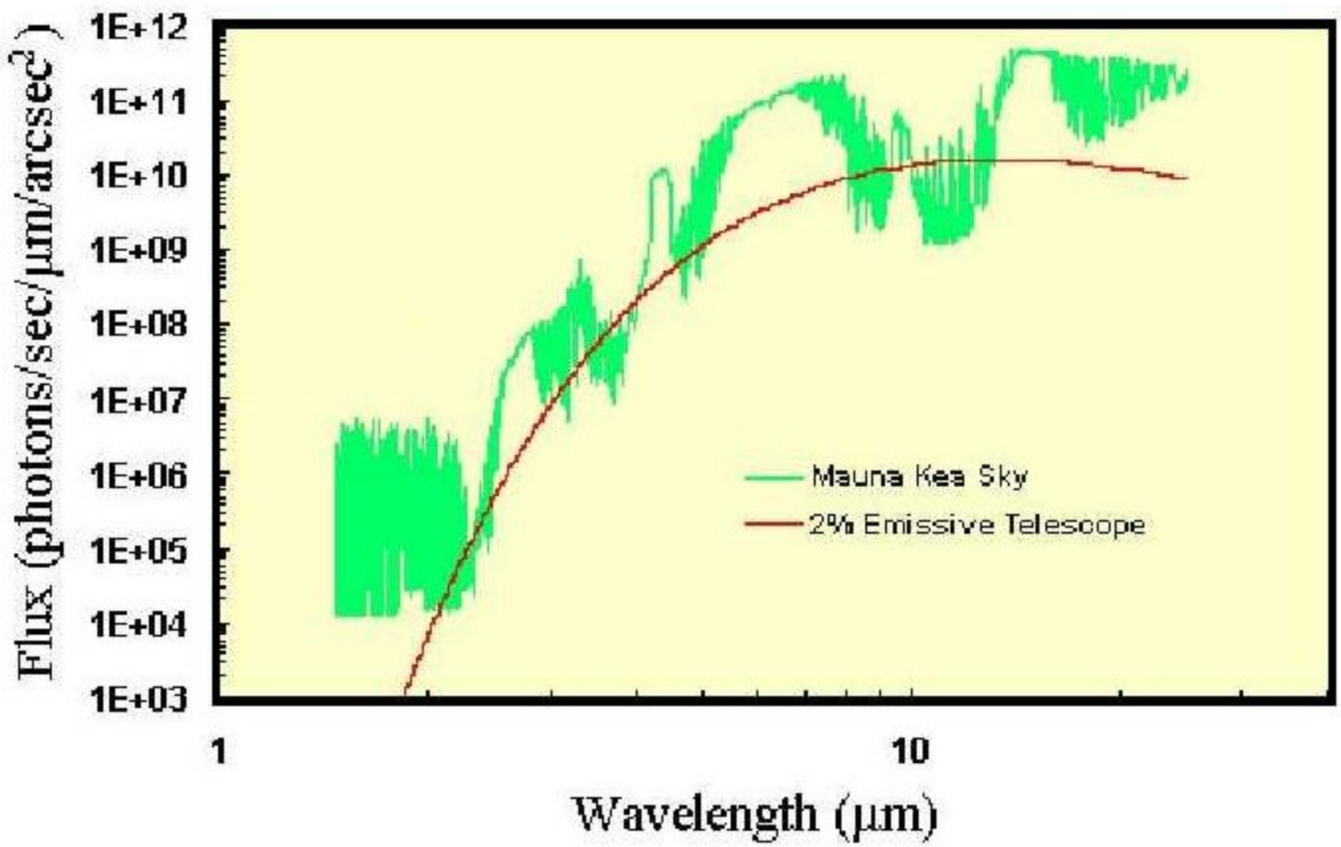
Journey of a thermal IR photon

- Through the Atmosphere
  - Photon has to be in an atmospheric window
  - No clouds! They absorb source photons, give off non-source photons
  - High water vapor = decreased sensitivity at $\lambda > 25\mu m$
- Through the Telescope and Camera
  - Telescope is at about -30C (240K), λ_{peak}=2898/240=12μm
  - Emission from whole optical system is peaked at 12μm
  - Ideally MIR cameras are fully reflective (except window and filters)
  - Detector not at focal plane. Re-imaging optics to cool detector, filters and stop stray emission

Thermal IR arrays

- Background radiation dominates at MIR
- Even bright standard stars are an order of magnitude fainter than the background
- Normal MIR observations: 1 source photon for every 100,000 background photons
- This means detector wells fill VERY quickly
  - Example: For OSCIR at IRTF, the BG emission at 10μm is typically ~4×10^{13} photons/sec/cm^2. Given the high QE of the detector and a well depth of 22×10^6 electrons, the well fills to 100% in 60 ms!
- Detectors must be able to perform short integration times (2-100 milli-sec)
- Unlike CCDs (charge-shift readout), thermal IR detectors have discrete sub-array readout amplifiers = Fast!
- Short integration times and fast readouts require fast electonics and high data rate handling

So, we need to get rid of atmosphere + telescope background emission…



The Chop-Nod Technique

The sky background is brighter and more *variable* in infrared:

- At J,H,K (1-2μm) sky is stable enough to get sky frame every ~60-120s
- At L (3μm, beginning to be background-limited), stable over ~20sec
- At M (5μm, a bit more bg-limited), stable for only ~10sec
- Beyond 10μm, stable of only a fraction of a second (fully bg-limited)

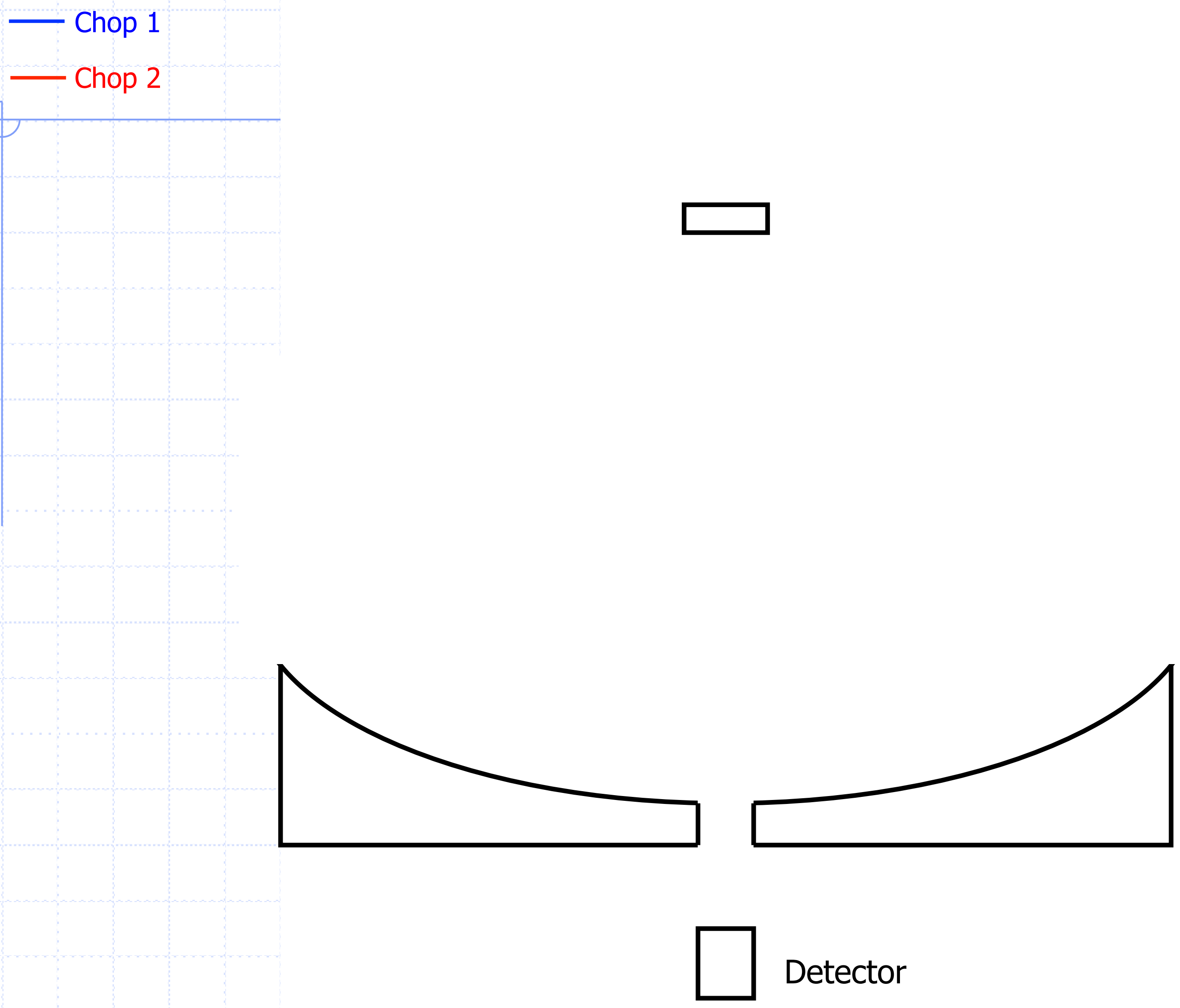
"Chopping"

- Refers to differencing the source frame and a nearby patch of sky
- This is done by moving the secondary mirror @1-20 Hz
- MAIN EFFECT: Removes Sky Background

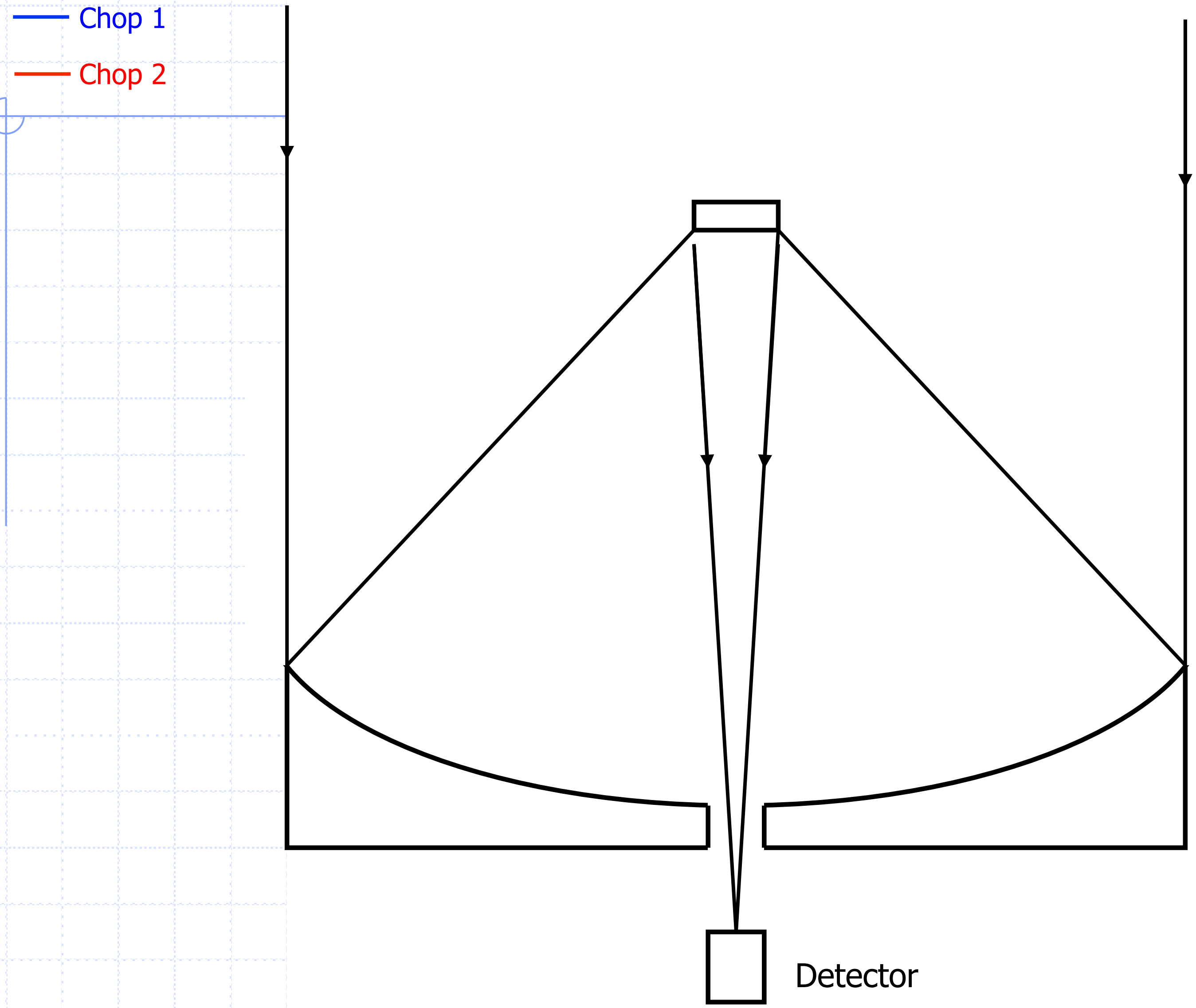
"Nodding"

- Refers to moving the whole telescope
- Performed once every 10-120 seconds
- MAIN EFFECT: Removes thermal pattern of telescope and optics

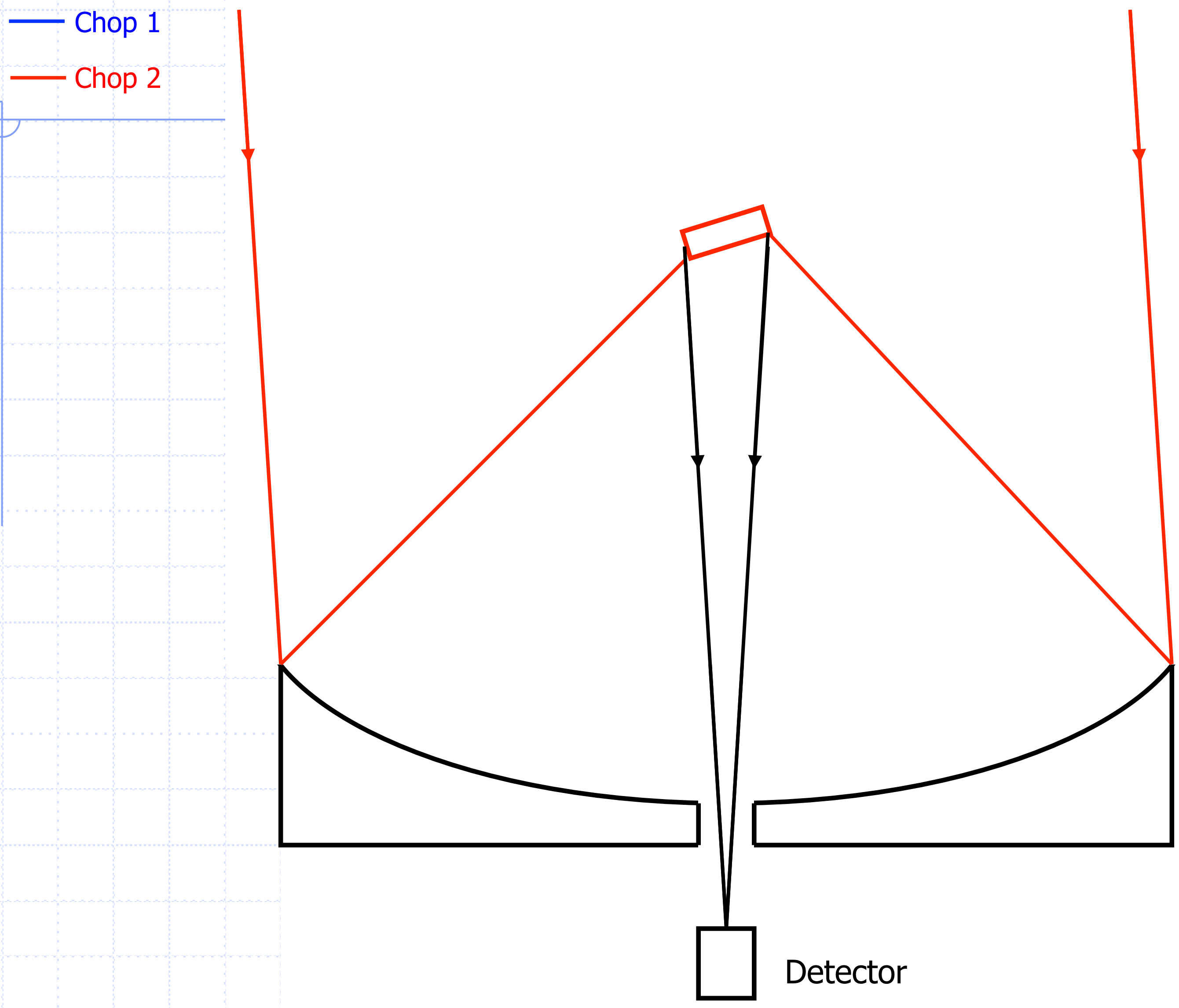
The Chopping (or Wobbling) Secondary

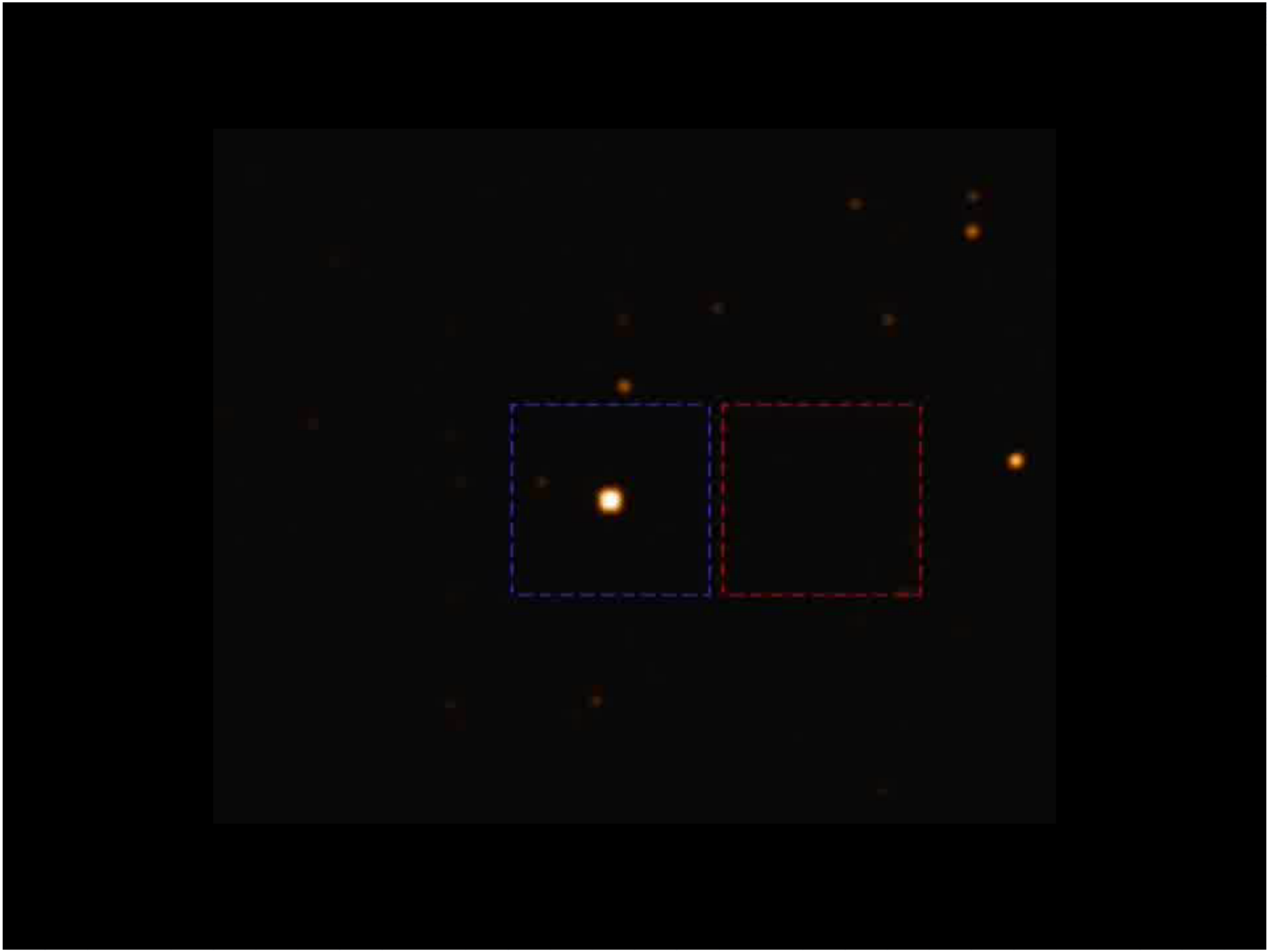


The Chopping (or Wobbling) Secondary

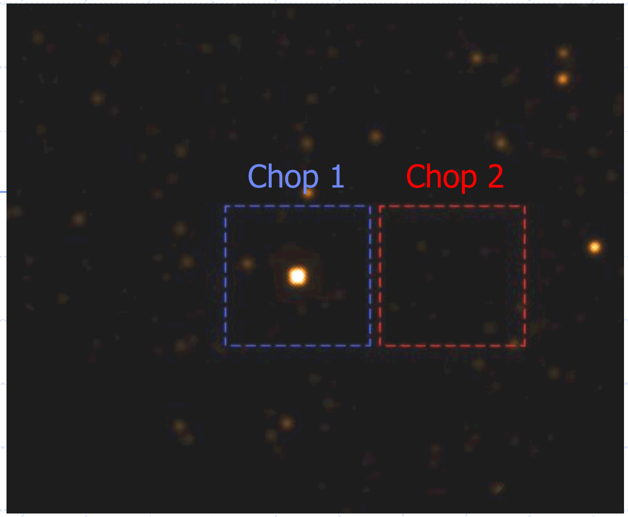


The Chopping (or Wobbling) Secondary

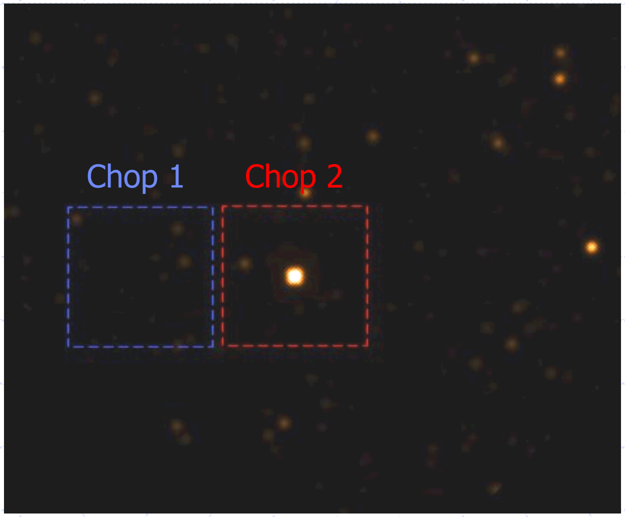




Nod A



Nod B



$$\text{Signal}_{NodA} = \text{Chop1} - \text{Chop2}$$

$$= (\text{Source} + BG_{Sky} + BG_{Tele,Chop1}) - (BG_{Sky} + BG_{Tele,Chop2})$$

$$= \text{Source} + (BG_{Tele,Chop1} - BG_{Tele,Chop2})$$

$$\text{Signal}_{NodB} = \text{Chop2} - \text{Chop1}$$

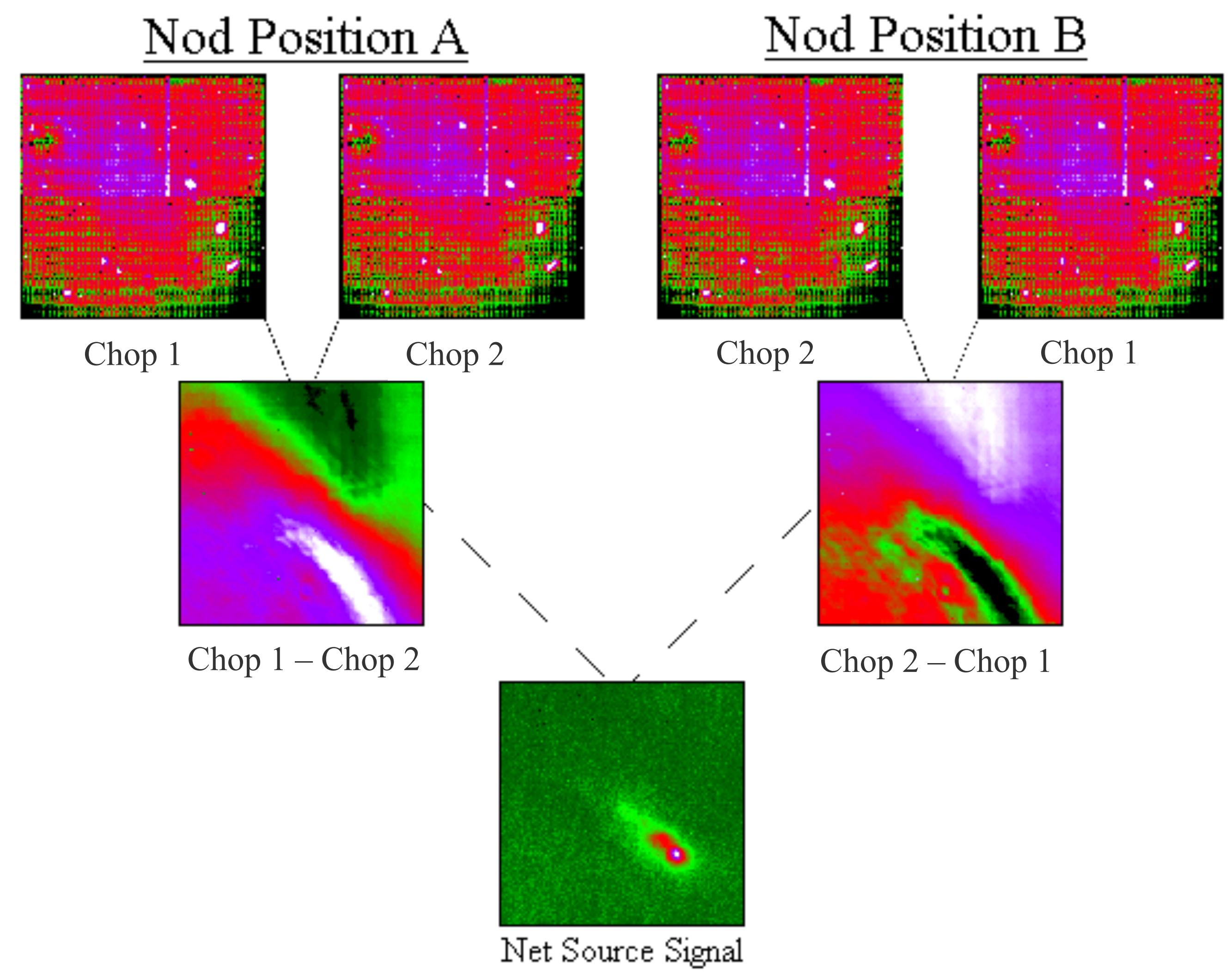
$$= (\text{Source} + BG_{Sky} + BG_{Tele,Chop2}) - (BG_{Sky} + BG_{Tele,Chop1})$$

$$= \text{Source} + (BG_{Tele,Chop2} - BG_{Tele,Chop1})$$

$$\text{Net Source Signal} = \text{Signal}_{NodA} + \text{Signal}_{NodB}$$

$$= \text{Source} + (BG_{Tele,Chop1} - BG_{Tele,Chop2}) + \text{Source} + (BG_{Tele,Chop2} - BG_{Tele,Chop1})$$

$$= 2 \times \text{Source}$$


Nod Position A
Nod Position B
Chop 1
Chop 2
Chop 2
Chop 1
Chop 1 – Chop 2
Chop 2 – Chop 1
Net Source Signal

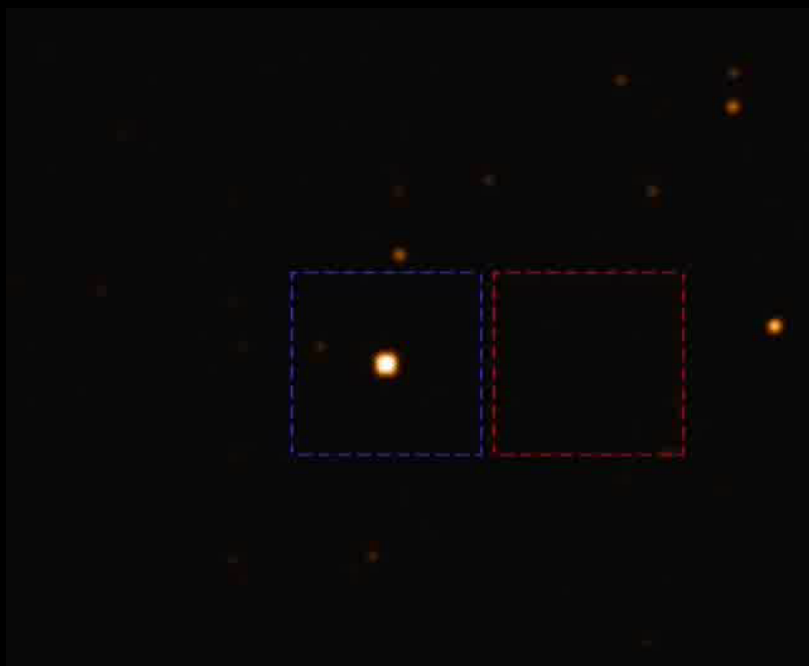
FORCAST data is composed of multiple parts

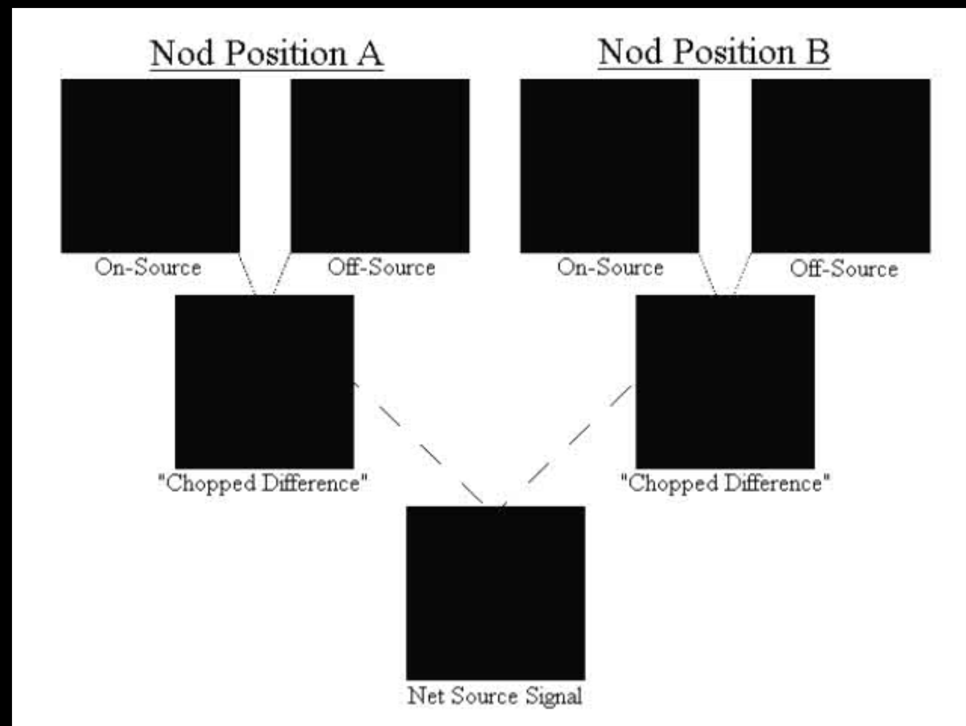
Co-adds are saved of the source and ref frames in each nod (typically~30s for science targets)

- On the plane, these can be displayed so that you can watch the S/N grow, check IQ and its variability, know when sky is not stable, etc.

FORCAST FITS files have 4 extensions, one for each source and ref frame for each nod position

FORCAST saves a FITS file every nod cycle (typically every 60s)




Nod Position A
Nod Position B
On-Source
Off-Source
On-Source
Off-Source
"Chopped Difference"
"Chopped Difference"
Net Source Signal