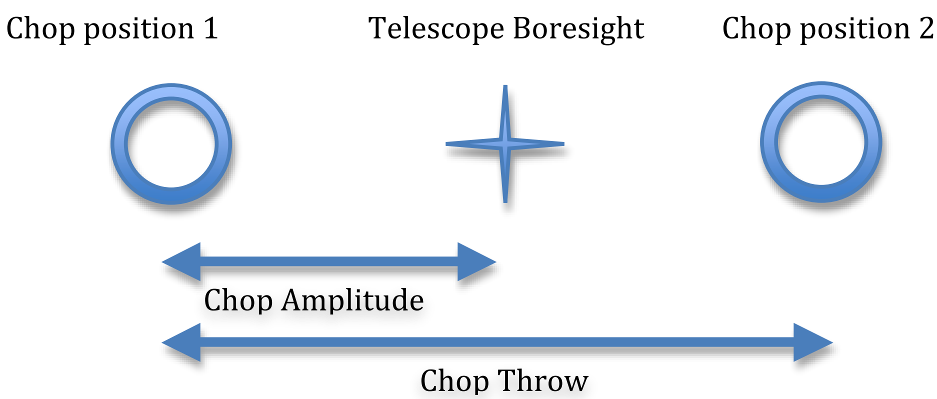
How FORCAST Acquires Observations

W. Vacca – 13 Aug. 2011

Because the sky is so bright in the mid-infrared (MIR) relative to astronomical sources, the way in which observations are made in the MIR is considerably different from the (more familiar) way they are made in the optical. Any raw image of a region in the MIR is overwhelmed by this sky "background" emission. (The situation is similar to trying to observe in the optical during the day. The bright daylight sky swamps the detector and makes it impossible to see astronomical sources in the raw images.) In order to remove the background from the MIR image and detect the faint astronomical sources, observations of another region (free of sources) are made and the two images are subtracted. However, the MIR is highly variable, both spatially and – more importantly – temporally. It would take far too long (on the order of seconds) to reposition a large telescope to observe this "sky background" region: by the time the telescope had moved and settled at the new location, the sky background level would have changed so much that the subtraction of the two images would be useless. In order to avoid this problem, the secondary mirror (which is considerably smaller than the primary mirror) of the telescope is tilted, rather than moving the entire telescope. This allows observers to look at two different sky positions very quickly (on the order of a few – 10 times per second), because tilting the secondary by an angle θ moves the center of the field imaged by the detector by θ on the sky. Tilting the secondary between two positions is known as "chopping". FORCAST observations are typically made with a chopping frequency of 4 Hz. That is, every 0.25 sec, the secondary is moved between the two observing positions.

Chopping can be done either symmetrically or asymmetrically. **Symmetric chopping** means that the secondary mirror is tilted symmetrically about the telescope optical axis (also known as the boresight) in the two chop positions. The distance between the two chop positions is known as the chop throw. The distance between the boresight and either chop position is known as the chop amplitude and is equal to half the chop throw.

Symmetric Chop:

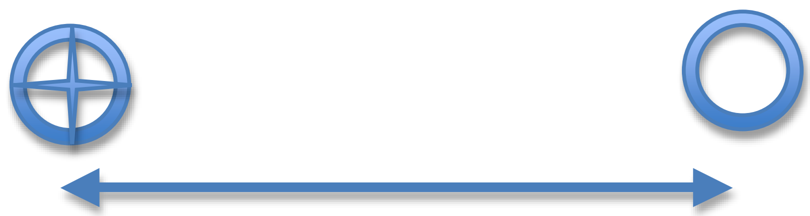


Asymmetric chopping means that the secondary is aligned with the telescope boresight in one position, but is tilted away from the boresight in the chop position. The chop amplitude is equal to the chop throw in this case.

Asymmetric Chop:

Chop position 1 / Telescope Boresight

Chop position 2



Chop Throw = Chop Amplitude

Unfortunately, moving the secondary mirror causes the telescope to be slightly misaligned, which introduces optical distortions (notably the optical aberration known as coma) and additional background emission from the telescope (considerably smaller than the sky emission but present nonetheless) in the images. The optical distortions can be minimized by tilting the secondary only tiny fractions of a degree. The additional telescopic background can be removed by moving the entire telescope to a new position and then chopping the secondary again between two positions. (Subtracting the two chop images at this new telescope position will remove the sky emission but leave the additional telescopic background due to the misalignment; subtracting the result from the chop-subtracted image at the first telescope position will then remove the background.) Since the process of moving to a new position is needed to remove the additional background from the telescope, not the sky, it can be done on a much longer timescale. (The variation in the telescopic backgrounds occurs on timescales on the order of tens of sec to minutes, much slower than that the variation in the sky emission.) This movement of the entire telescope, on a much longer timescale than chopping, is known as nodding. The two nod positions are usually referred to as nod A and nod B. The distance between the two nod positions is known as the nod throw or the nod amplitude. (They are the same.) For FORCAST observations, nods are done every 5 - 30 sec. The chop-subtracted images at nod position B are then subtracted from the chop-subtracted images at nod position A. The result will be an image of the region, without the sky background emission or the additional emission resulting from tilting the secondary during the chopping process. The sequence of chopping in one telescope position, nodding, and chopping again in a second position is known as a chop/nod cycle.

Again, because the MIR sky is so bright, deep images of a region cannot be obtained (as they are in the optical) by simply observing the region for a long time with the detector collecting photons (integrating) continuously. As stated above, the observations require chopping and nodding at fairly frequent intervals. Hence deep observations are made by “stacking” a series of chop/nod images. Furthermore, MIR detectors are not perfect, and often have bad pixels or flaws. In order to avoid these defects on the arrays, and prevent them from marring the final images, observers employ a technique known as “dithering”. Dithering entails moving the position of the telescope slightly with respect to the center of the region observed each time a new chop/nod cycle is begun, or after several chop/nod cycles. When the images are processed, the observed region will appear in a slightly different place on the detector. This means that the bad pixels do not appear in the same place relative to the observed region. The individual images can then be registered and averaged or medianed, a process that will eliminate (in theory) the bad pixels from the final image.

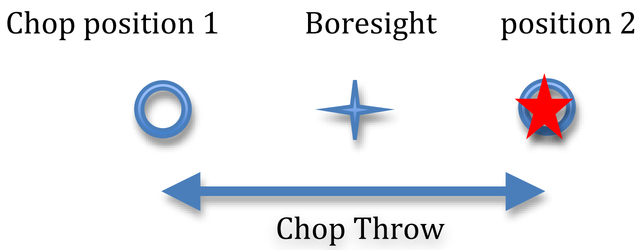
Symmetric Chopping:

FORCAST acquires astronomical observations in two symmetric chopping modes: two-position chopping with no nodding (C2) and two-position chopping with nodding (C2N). Dithering can be implemented for either of them; two-position chopping with nodding and dithering is referred to as C2ND. The most common observing methods used are C2N and C2ND. Since C2ND simply involves slight movements of the telescope position after each chop/nod cycle, let us deal with the C2N mode. FORCAST can make two types of C2N observations: Nod_Match_Chop and Nod_Perp_Chop. The positions of the telescope boresight, the two chop positions, and the two nod positions for these observing types are shown below.

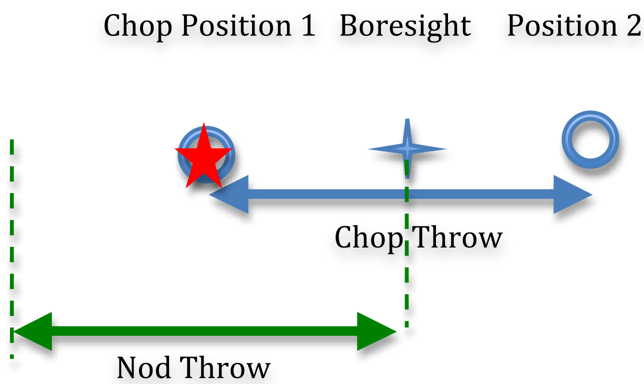
Nod_Match_Chop (NMC):

In this case, the telescope is pointed at a position half of the chop throw distance away from the object to be observed, and the secondary chops between two positions, one of which is centered on the object. The nod throw has the same magnitude as the chop throw (hence the name “Nod_Match_Chop”), and is in a direction exactly 180 degrees from that of the chop direction. The final image generated by subtracting the images obtained for the two chop positions at nod A and those at nod B and then subtracting the results will produce three images of the star, one positive and two negative, with the positive being twice as bright as the negatives.

Nod A:

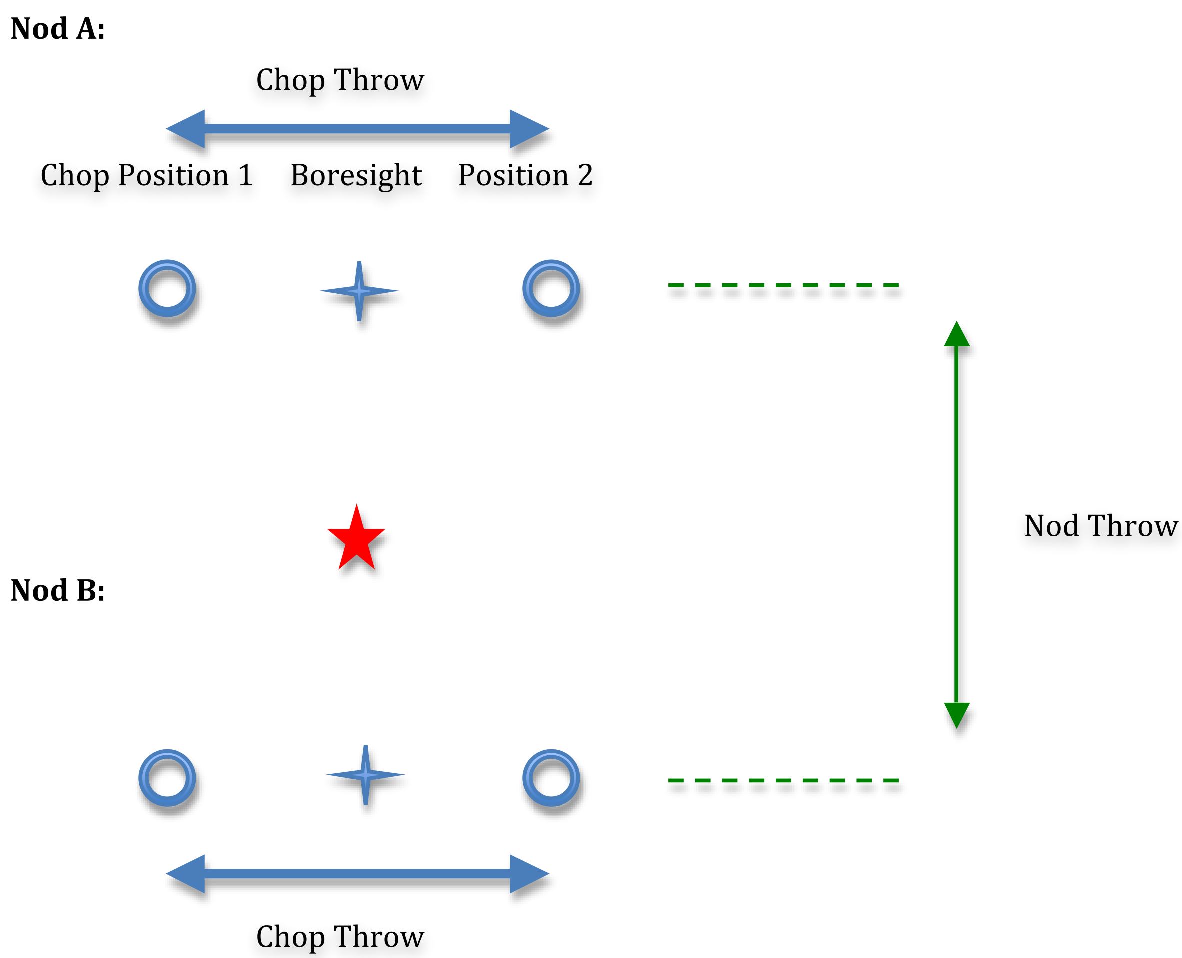


Nod B:



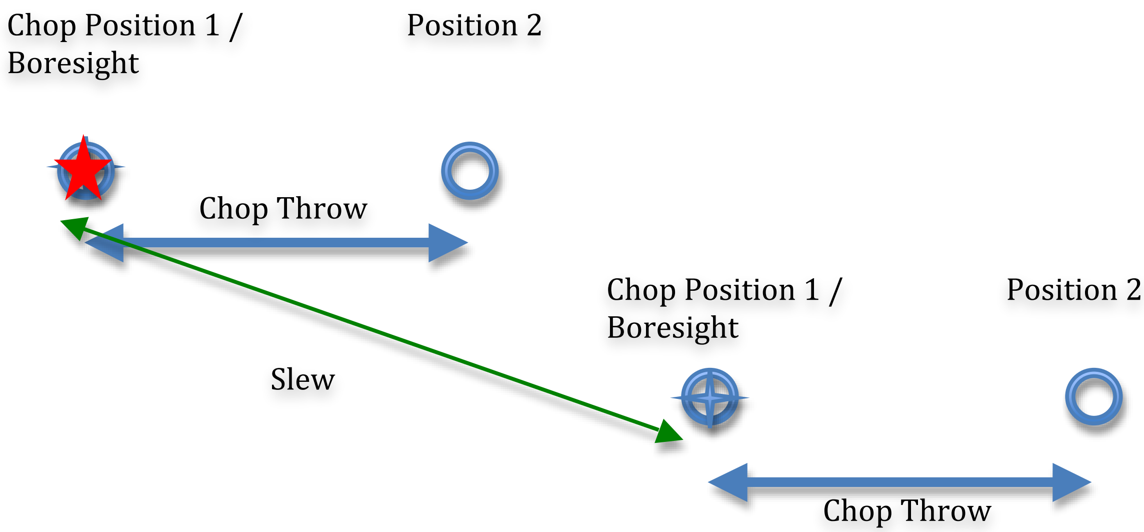
Nod_Perp_Chop (NPC):

In this case the telescope is offset by half the nod throw from the target in a direction perpendicular to the chop direction, and the secondary chops between two positions. The nod throw usually (but not necessarily) has the same magnitude as the chop but is in a direction perpendicular to the chop direction (hence the name Nod_Perp_Chop). The final image is generated by subtracting the images obtained for the two chop positions at nod A and those at nod B and then subtracting the results; it will therefore have four images of the star in a rectangular pattern, with the image values alternating positive and negative.



C2NC2:

FORCAST also has an asymmetric chop mode, known as C2NC2. In this mode, the telescope is first pointed at the target (position A). In this first position, the secondary is aligned with the optical axis (or boresight) for one observation and then is tilted some amount (often 180-480 arcseconds) for the second (asymmetrically chopped) observation. This is an asymmetric C2 mode observation. The telescope is then slewed some (usually large) amount away from the target, usually to some sky region without sources (position B), and the asymmetric chop pattern is repeated. C2NC2 observations are taken as a series of 8 (C2) files in the sequence A B A A B A A B. Again, the time between slews is typically 30 sec.


Chop Position 1 /
Boresight
Position 2
Chop Throw
Slew
Chop Position 1 /
Boresight
Position 2
Chop Throw