GRAVITY differential phases

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Define the complex visibility,

$$V = |V|e^{i\phi} = \int \int dxdy I(x,y) e^{-2\pi i u \cdot x}, \tag{1}$$

with $|V|$ the visibility amplitude and ϕ the visibility phase on a baseline with coordinates u. For a line flux f relative to a continuum flux of 1, we can write,

$$V = \frac{V_c + f V_l}{1+f}, \tag{2}$$

with V_c and V_l the continuum and line complex visibilities. When the object is marginally resolved, we can expand the exponential in the definition of the visibility. The resulting integrals are related to image moments – image total flux and centroid position for the first two. If we keep the first two terms in the expansion, we get,

$$|V|(1+i\phi) = \frac{|V_c|(1+i\phi_c) + |V_l| f (1+i\phi_l)}{1+f}, \tag{3}$$

where ϕ_c and ϕ_l are the continuum and line phases, and with error terms of order $(u \cdot x)^2$. From the real part, the visibility amplitude is $|V|(1+f) = |V_c| + f|V_l|$. From the imaginary part,

$$|V|\phi = \frac{|V_c|\phi_c + |V_l| f \phi_l}{1+f}. \tag{4}$$

The differential phase in GRAVITY is formed by subtracting the mean across the spectrum, which is essentially the continuum phase (especially after we apply various flattening methods): $\Delta\phi = \phi - \phi_c$. From the above, that is given by,

$$\Delta\phi = \frac{f}{|V|(1+f)} (\phi_l - |V_l|\phi_c). \tag{5}$$

The differential phase is that $\Delta\phi = 0$ away from the emission lines ($f = 0$), e.g. we have removed the continuum phase. As a result though, we now have a differential phase at the line which depends on both the line (ϕ_l) and and continuum (ϕ_c) phase. Note that everything in the differential phase equation is an observable except for $|V_l|$, ϕ_l, ϕ_c. As a result our differential phases measure phase information about the AGN. We also usually assume $|V_l| = 1$ (the BLR is pointlike) and $|V| = 1$ (an unnecessary assumption with up to $\simeq 20\%$ errors for NGC 3783 where the hot dust is extended).

The standard BLR photocenter and kinematic modeling assumption is that $\phi_c = 0$. In the same unresolved limit, $\phi_l \simeq -2\pi(u \cdot \bar{x}_{\rm BLR})$ where $\bar{x}_{\rm BLR}$ is the image photocenter (first moment of the image), and using $\phi_c = 0$ we find

$$\Delta\phi = -2\pi \frac{f}{1+f} u \cdot \bar{x}_{\rm BLR}. \tag{6}$$

That equation is wavelength-dependent, since the BLR photocenter positions $\bar{x}_{\rm BLR}$ should depend on wavelength. In the opposite limit setting $\phi_l = 0$, we would find:

$$\Delta\phi = -\frac{f}{1+f}\phi_c. \tag{7}$$

The continuum phase also induces a differential phase that depends on the line contrast. It should presumably be wavelength-independent, since the hot dust structure is unlikely to vary significantly over the narrow wavelength region spanned by a single emission line.

We have in the past fit for ϕ_c separately on each baseline for NGC 3783 using their measured values of $\Delta\phi$. As discussed at the meeting, in principle one could i) use these as additional information for model fitting / imaging, and ii) test their consistency with measured FT closure phases by summing ϕ_c over the appropriate baseline triangles.

One approach would be to fit the full expression in equation 5 to the data, substituting $\phi_l = -2\pi u \cdot \bar{x}_{\rm BLR}$, assuming $|V_l| = 1$, and including the measured values $|V|$ on each baseline along with f at each spectral channel:

$$-\frac{|V|(1+f)}{f}\Delta\phi = 2\pi u \cdot \bar{x}_{\rm BLR} + \phi_c. \tag{8}$$

Everything on the LHS is an observable, and the fit parameters are $\bar{x}_{\rm BLR}$ of each wavelength channel (independent of baseline) and ϕ_c of each baseline (independent of wavelength). That might be worth trying for 3C 273 (or NGC 3783 once we settle on data).