(Issues of radio and optical reference-frame alignment)

EFFECT OF CORE SHIFTS ON GROUP DELAYS

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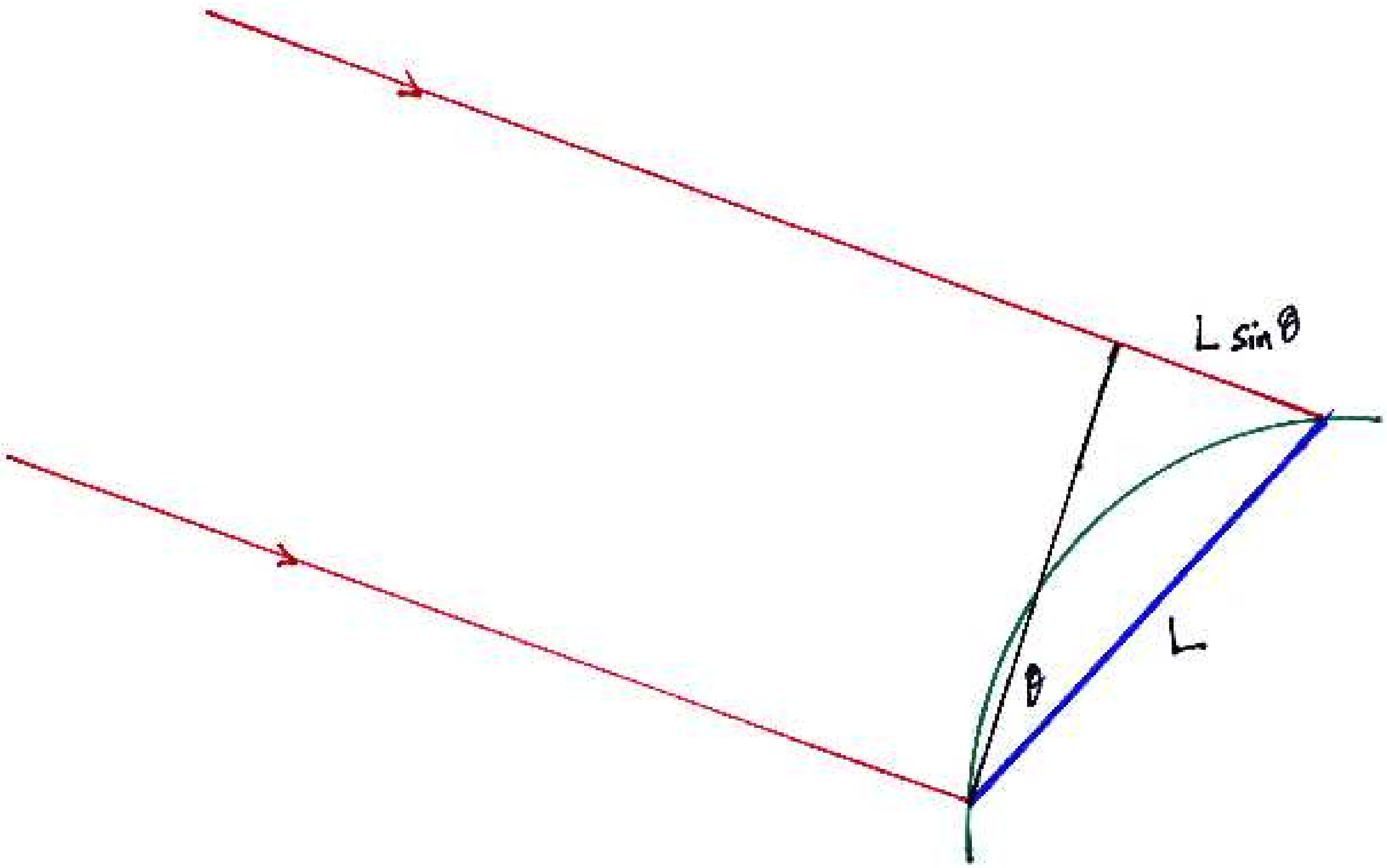
Radio VLBI provides the highest precision astrometry routinely available in astronomy

Differential astrometry using interferometer (relative) phase

Global astrometry using interferometer delay

ICRF2 based on interferometer delay positions of radio sources

Precisions quoted to $\sim 50 \mu as$



Total path difference: **L** $sin\theta$

Differential path difference for small angular offset $\Delta\theta$ (in resolution direction):

$$\textbf{Path}\ \ \Delta l \qquad = \qquad \mathbf{L}\ cos\theta\ \Delta\theta$$

$$\textbf{Delay}\ \Delta\tau \qquad = \qquad 1/c\ \mathbf{L}\ cos\theta\ \Delta\theta$$

$$\textbf{Phase}\ \Delta\phi \qquad = \qquad 2\pi\nu/c\ \mathbf{L}\ cos\theta\ \Delta\theta$$

An interferometer measures $\Delta\phi$ only modulo 2π

Can measure delay using the frequency-dependence of $\Delta\phi$

$$1/2\pi\ \mathbf{d}/\mathbf{d}\nu[\Delta\phi] \quad = \quad \Delta\tau \qquad \textbf{(group delay)}$$

Reference points in the presence of extended source structure

Differential astrometry:

Use image to evaluate baseline phase corrections relative to a reference point in the image(s).

“Core” frequently used as the reference point.

Relative astrometry refers to the separation of the reference points

Global astrometry

1) Assume “naked core” – extended structure can be neglected (low structure index)

Global astrometry refers to the “core”

2) Use image to evaluate baseline delay corrections relative to a reference point in the image.

Global astrometry refers to the reference point in this image

IVS = International VLBI Service

Determination of source positions, Earth orientation, station positions,......

Use group-delay measurements at 8.4 GHz (ionospheric correction determined from 2.3 GHz)

Upgrade program: VLBI2010

1. **Use precision group-delay measurements determined from 2 – 14 GHz**
2. **Use precision group-delays to resolve ambiguities in $\Delta\phi$**
3. **Gain further precision by using ambiguity-resolved $\Delta\phi$**

What is the effect of “core-shifts” on this process ?

Frequency-dependent core-shift: $\Delta\theta = \Delta\theta_o + \Delta\theta_r \nu^{-\beta}$ ($\Delta\theta_o =$ **"jet base"**; $\beta = 1/k$)

Phase $\Delta\phi(v) \;=\; 2\pi\nu/c\ \mathbf{L}\ cos\theta\ [\Delta\theta_o + \Delta\theta_r \nu^{-\beta}]$

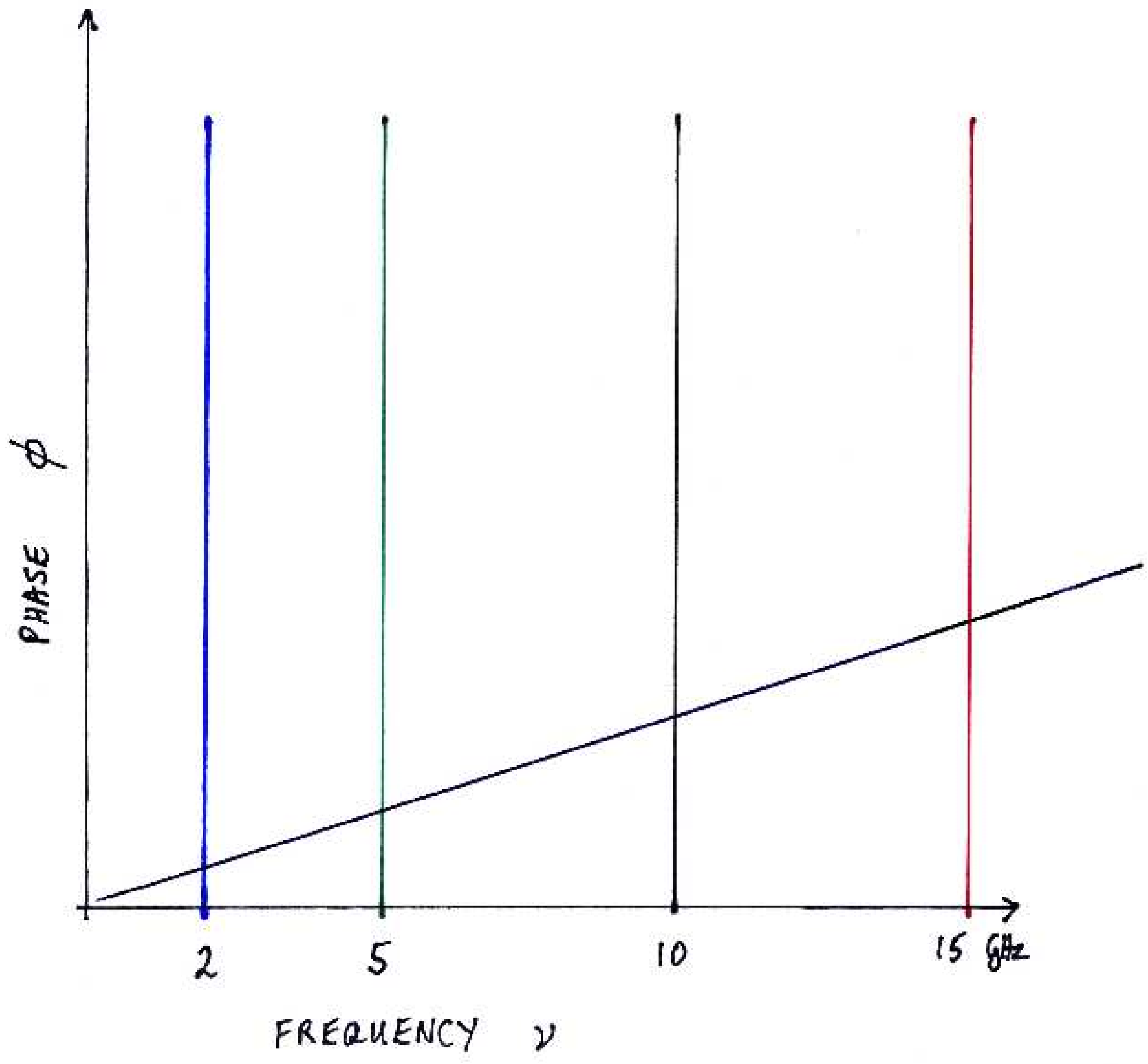
$$\textbf{Group delay} = 1/2\pi\ \mathbf{d/d}\nu[2\pi\nu/c\ \mathbf{L}\ cos\theta\ [\Delta\theta_o + \Delta\theta_r \nu^{-\beta}]\ ]$$

$$= 1/c\ \mathbf{L}\ cos\theta\ [\Delta\theta_o + (1-\beta)\Delta\theta_r \nu^{-\beta}]$$

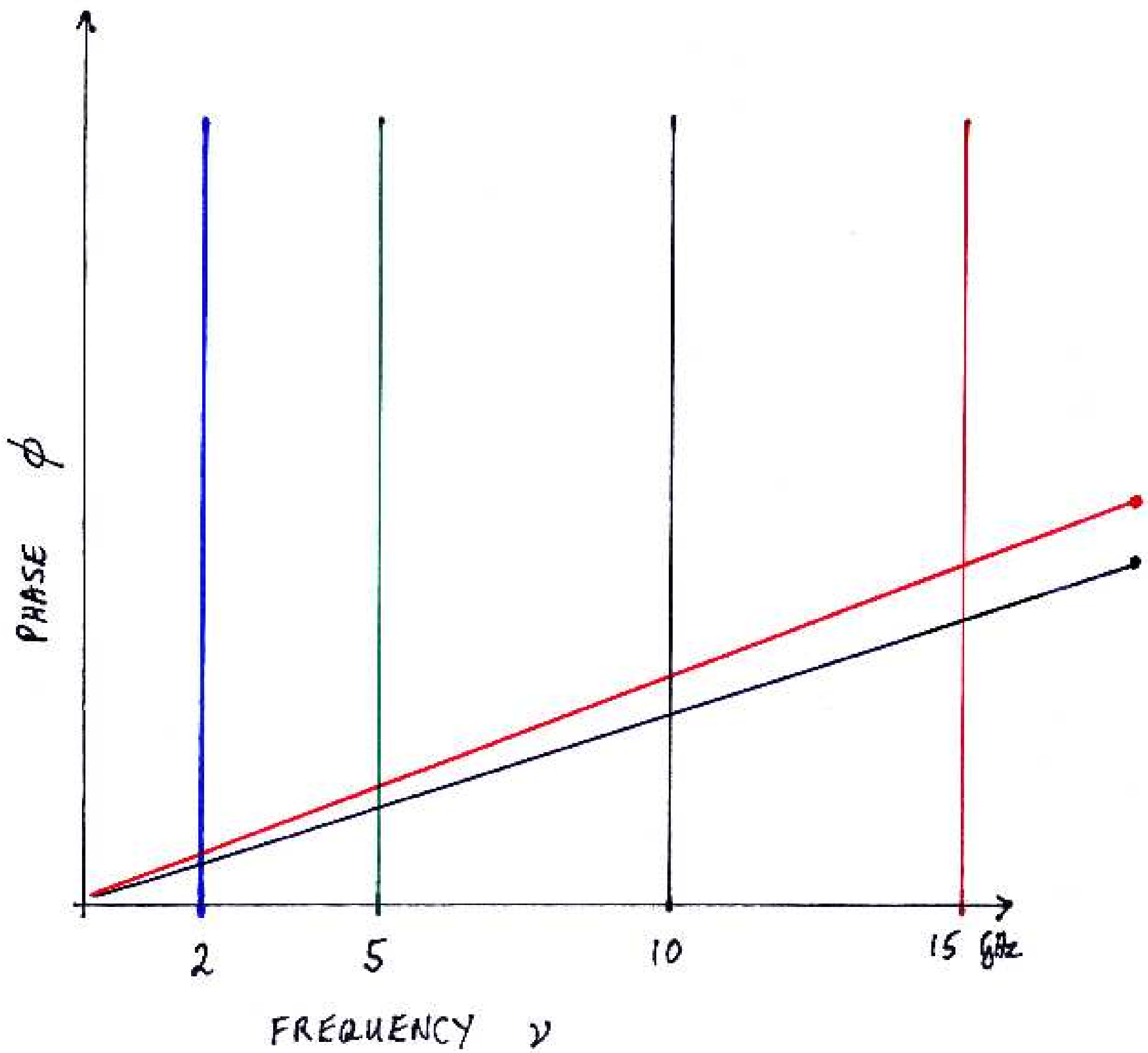
Note that the group delay responds to a diluted core shift, $(1-\beta)\Delta\theta_r \nu^{-\beta}$

In the case of $\beta = 1$ **the core shift has no effect on the group delay:**

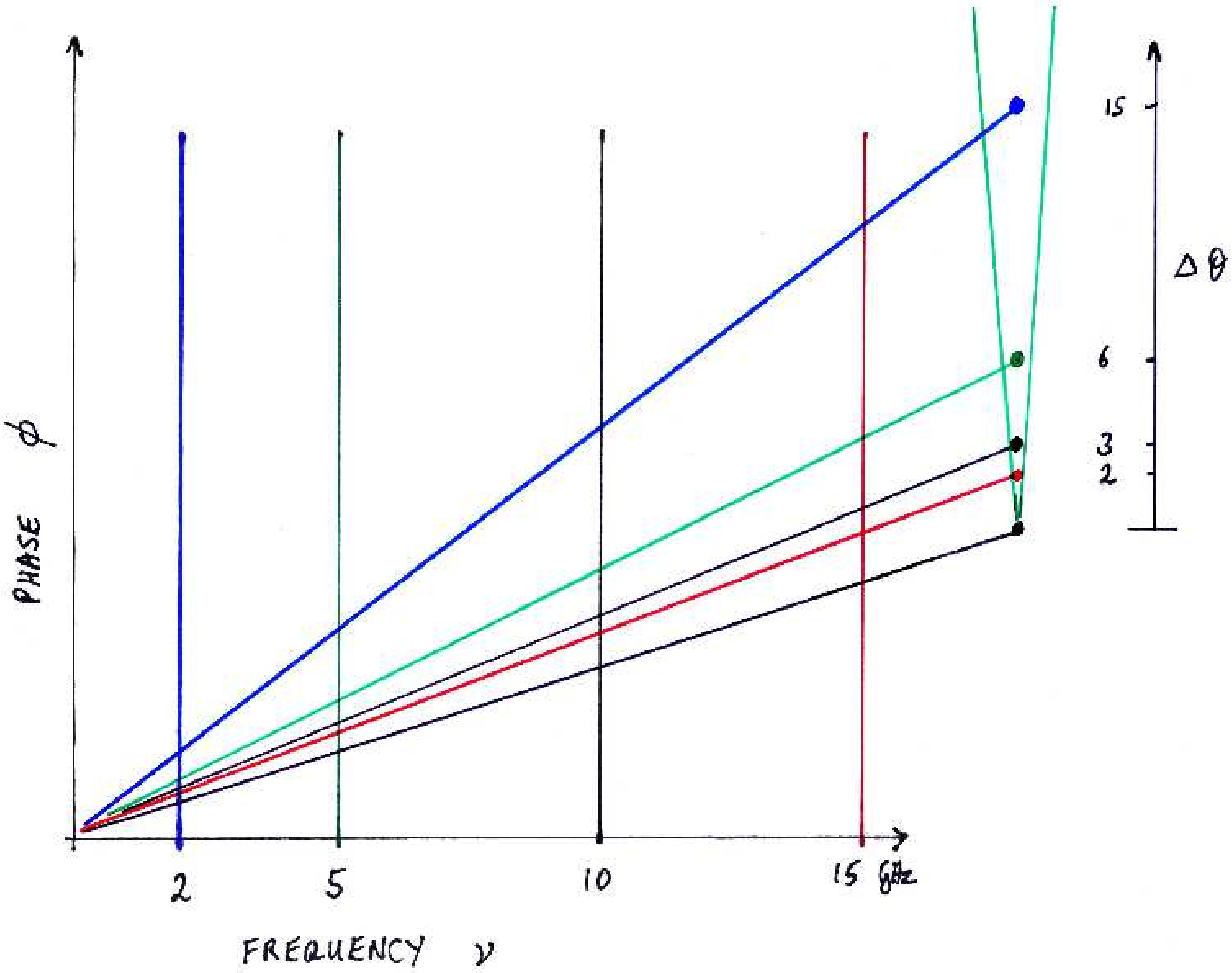
the group delay measures only the position of the jet base, $\Delta\theta_o$**.**



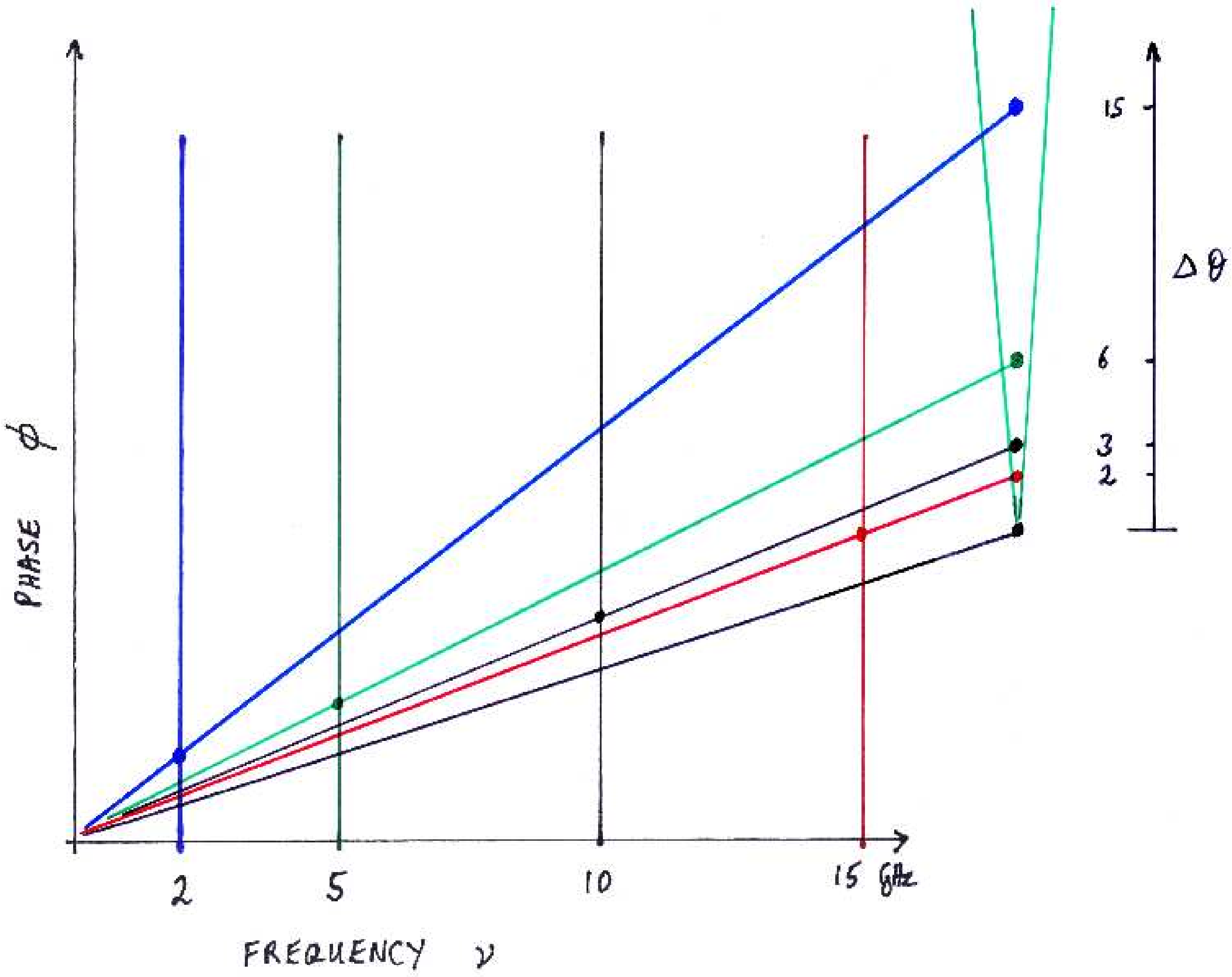
Phase response to an offset point



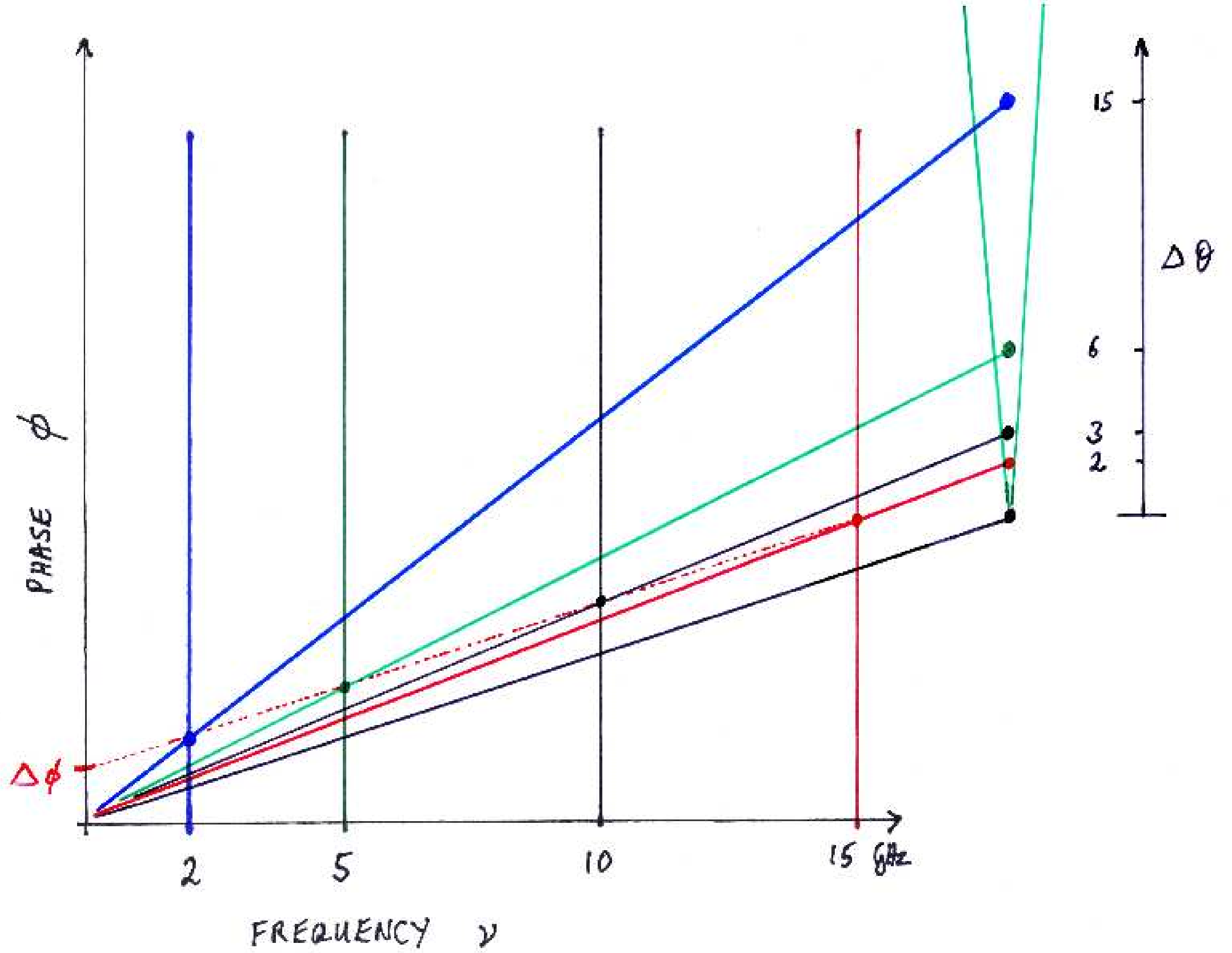
Phase response to 2 offset points



Phase response to different core positions



Phase response to a frequency-dependent core position



Phase gradient (group delay) for $\beta = 1$

Consequences of group delay reduced core-shift response

1) Group delay 8.4 GHz positions are closer to the jet base than the 8.4 GHz "core" position

2) Ionospheric correction using 2.3 GHz delay measurements are not quite correct

3) If $\beta = 1$ group delay positions at any frequency give the position of the jet base

4) If $\beta = 1$ the ionospheric correction using 2.3 GHz delay measurements IS correct

Note that (3) & (4) apply to all ICRF2 positions and VLBA Calibrator Survey positions !

5) If $\beta = 1$, IVS2010 precision group delays give the position of the jet base

6) If $\beta = 1$, IVS2010 total phase measurements give the position of the core at the frequency at which the phase is taken (14 GHz ?) but will require knowledge of the (constant) phase offset: $2\pi\nu/c\ \mathbf{L}\ cos\theta\ [\Delta\theta_r]$

Note that, if you determine the position of a source wrt an ICRF source position using relative phase measurements, the relevant position for the ICRF source is NOT the (listed) group delay position but, rather, the "core" position at the frequency at which you make the measurement !