PRINCIPLES OF IMAGING USING ARRAYS

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Since diffraction-limited imaging with a single aperture yields angular resolution $\sim \lambda/D$, the attainment of high angular resolution with single apertures requires the construction of correspondingly large monolithic apertures, the whole surface of which must be figured to much less than a wavelength. At the longer wavelengths, it is impossible to build a sufficiently large single aperture: for example, at λ21 cm, arcsecond resolution requires an aperture of diameter $\sim$ 50 km. At the shorter wavelengths, the atmosphere imposes a natural limit in resolution of about one arcsecond. However, another route is possible: that of using synthetic apertures to image the sky. The problem of figuring synthetic apertures is considerably simpler, and can be implemented in a computer. Synthetic apertures are now in use in many fields, e.g. radio-interferometry, radar imaging, magnetic resonance imaging. Radio-interferometric techniques developed in radio-astronomy over the past forty years are now being applied to optical and IR astronomical imaging by a number of groups.

At the begining of this century, Michelson investigated the use of interferometry for high resolution measurements of stellar diameters. This relies upon the van Cittert-Zernike theorem, which states that for an incoherent object, the coherence of the electric field far from the object is the Fourier transform of the sky brightness function. In 1960, Ryle pointed out that one could synthesize a large aperture by collecting coherence samples with an interferometer using many different spacings of the elements, and then Fourier-transforming the resulting sampled coherence function in a computer to make an image. Ryle's concept of a synthetic aperture holds for all wavelengths but the technology required for the measurements differs considerably. These differences will be addressed in the following talks.

Sampling of the coherence function over the synthesized aperture can be accomplished either by physically moving the interferometer elements or by allowing the rotation of the earth to do so or by a combination of both approaches. As long as the light can be interfered coherently, the elements may be an arbitrarily large distance apart.

Two generic problems afflict the measured coherence function: first, the sampling is often incomplete, and second,the calibration of the coherences may be uncertain because of the effects of the Earth's atmosphere or uncertainties in the geometry of the interferometer. The first problem may be addressed using deconvolution algorithms which can use a priori information about the sky brightness to interpolate missing values of the coherence

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function. Examples of such algorithms are CLEAN, the Maximum Entropy Method, the Gerchberg-Saxton-Papoulis algorithm, and the Lucy algorithm. The second problem is of varying importance in different applications. A good rule of thumb is that for wavelengths shorter than about 30 cm (including IR and optical), imaging at better than arcsecond resolution requires some countermeasures to the neutral atmosphere. In other regimes, countermeasures are necessary for high quality imaging. The geometric uncertainties are worst for long baselines (note the similarity to the problem of figuring a single aperture). Most of the effective techniques are related to the concept of closure phase introduced by Jennison about 30 years ago. Since calibration errors are predominantly associated with the interferometer elements, rather than pair of elements, a sum of the observed coherence phase around any closed loop of interferometers will be invariant to those errors. A similar observable can be derived for the coherence amplitudes. High-resolution imaging therefore uses these closure quantitites rather than the observed coherences as constraints on the final image.

Pearson and Readhead (1984) have discussed these techniques in more detail for radio-astronomy; as discussed above, the same procedures apply equally well at other wavelengths.

References

Pearson, T.J. and Readhead, A.C.S., 1984, *Ann. Rev. Astron. Astrophys.* **22**, 97-130.