IS THE IMAGING PROBLEM IDENTICAL IN ALL WAVE BANDS?

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One aim of this meeting is to tempt us to study methods of imaging in wavebands outside our own. This might seem perverse since the imaging problems in the radio and optical/IR regions appear at first sight to differ profoundly in several ways: the rapid evolution of radio imaging over the last forty years has been largely ignored in optical imaging whilst the well developed theory and measurements of atmospheric fluctuations for the optical regime have been disregarded by radio astronomers; there have been long and exacting searches for the best sites for optical telescopes, but rarely for radio telescopes; the instrumental techniques appear to differ in many and complicated ways.

But such a view is quite mistaken. The problem is not only the same one but is much more nearly the same than could be expected a priori. The apparently complicated nature of the comparison arises mainly from the wide range of wavelengths in each regime, from 0.4 - 20 μm in the optical/IR and 0.4 mm - 10 m in the radio.

In space no one doubts that the problems are virtually identical. Only the photon fluxes differ, which introduces several interesting issues which there is no time to pursue here. From the ground the main problem is the atmosphere, in particular its irregular variations in refractive index. At optical/IR wavelengths this arises from turbulence in dry air giving fluctuations in density. At cm wavelengths the fluctuations in water vapour content predominate, whilst at wavelengths greater than $\sim$10 cm the effects of the ionosphere become overwhelming. In each case there is a spectrum of scales in the turbulence. Qualitatively there are three scales which are distinct in their effects on an image from an optical telescope. The very smallest scales give scattering over wide angles but the depth of the phase fluctuations is so shallow that little power is scattered from the incident wave and their effects can be ignored. On intermediate scales, but still smaller than the size of the telescope, speckles arise in the image if the phase fluctuations are significant ($\sim$1 rad). The largest scales produce phase tilts across the whole telescope and corresponding shifts in the image. The overall behaviour of the image is determined by the ratio of these last two effects, which depends mainly on the relative size of the telescope and the scale at which the phase variations reach $\sim$1 rad. The slope of the power spectrum of the turbulence is a second but usually somewhat less important factor.

The theoretical expectation for the turbulence in the dry atmosphere is for a Kolmogoroff spectrum. This is well confirmed experimentally, the chief arguments centering on the inner and outer scales of the turbulence. Somewhat surprisingly, the observed spectra of the phase fluctuations at cm and m wavelengths, corresponding to the water vapour and ionospheric components, also have very similar slopes. Whilst there is no theoretical explanation for

D. McNally (ed.), Highlights of Astronomy, Vol. 8, 549–550.

https://doi.org/10.1017/S1539299600008285 Published online by Cambridge University Press

this, it simplifies the description of the atmospheric turbulence to a single quantity, Fried's parameter r_o, the separation of two points for which the rms phase difference is ~2.6 rad, or for which the long-exposure seeing disk has an angular size $\theta \sim \lambda/r_o$.

Fig. 1 shows the variation of r_o/λ across the whole wavelength range from 0.1 μm to 10 m. The three sets of curves correspond to excellent and rare seeing, good seeing and very poor seeing (e.g. 0.5, 1 and 3 arcsec seeing for $\lambda = 500$ mm). They delimit the range of seeing for > 90% of the time on good sites, or rather on the sites where telescopes have been built; no radio array has yet been constructed on a site which has been adequately tested for radio seeing. The straight lines show telescopes of different sizes. This picture illustrates the familiar fact that a 1 m telescope is larger than r_o in the visual, giving speckled images, but smaller than r_o in the infra-red, giving diffraction limited images. It also shows results which are unfamiliar in this notation:

1. all radio dishes built so far are smaller than r_o.
2. many radio arrays are larger than r_o. Some may be larger than r_o at short cm wavelengths and metre wavelengths but smaller than r_o at intermediate wavelengths.
3. the numerical values of r_o/λ at optical and short cm wavelengths are very similar.

The second of these points clarifies the apparent complexity of comparisons between the atmospheric problems at optical and radio wavelengths. The problem is the same one; only r_o/λ changes rapidly with λ.

The third point suggests something more interesting. A 1 m telescope at λ500 μm is very similar to a 40 km radio telescope at λ2 cm. The imaging properties of radio arrays of this size such as the VLA with 27 × 25 m dishes, using aperture synthesis and closure phase or self-calibrations techniques are excellent, giving diffraction limited images with high dynamic ranges. This tells us that if an array of small apertures over 1 m baselines is used in the optical, then diffraction limited images of equal quality must also be achievable. The prospects for resolutions in the optical and IR equivalent to those in radio VLBI are even more exciting.

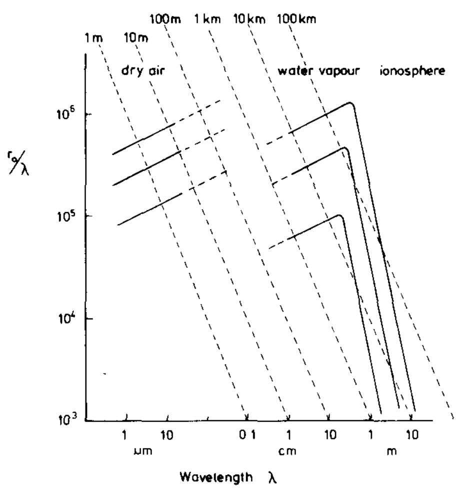

Figure 1. Atmospheric seeing as a function of wavelength.

https://doi.org/10.1017/S1539299600008285 Published online by Cambridge University Press