Enhanced Resolution with Two-Channel Deconvolution Codes

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1. Deconvolution Codes

In the last issue of *The Messenger*, Magain et al. (1997) presented impressive results obtained with a new deconvolution code. In this code, the novel idea of deconvolving with a narrower PSF (Snyder, 1990; Lucy, 1990) is combined with an astrometric capability to construct a more powerful two-channel code than that developed at the ST-ECF some years ago (Lucy, 1993, Hook & Lucy, 1993). In the ST-ECF code, the artefact of ringing around stars superposed on diffuse emission was eliminated by adding a second channel comprising only point sources, with the first channel then restricted to modelling the distributed emission. The great merit of this innovation was that the code is no longer faced with the impossible task of reconstructing δ-functions: the investigator designates certain objects (stars, AGN) as δ-functions and the code then proceeds to fit the data using its exact knowledge of their profiles in the image plane. Test calculations show that the amplitudes of these δ-functions yield high-precision, unbiased magnitudes, even for crowded fields (Hook & Lucy, 1993; Magain et al., 1997).

In an *ST-ECF Newsletter* article (Hook at al., 1994), we applied our code to an image of 3C 48 and found that the nuclear regions hosting the AGN were indeed restored free from the ringing strongly evident in a Richardson-Lucy restoration. In their Figure 1, using a simulated image, Magain et al. similarly exhibit their two-channel code's superiority relative to an R-L restoration.

Note that the successful elimination of ringing derives fundamentally from giving the code, via the 2nd channel, prior information that the image contains point sources. A single-channel code that deconvolves with a narrower PSF and with an appropriately finer pixellation than the observed image – i.e., with "correct" sampling – is still prone to this artefact, though with reduced amplitude and angular scale (Lucy, 1990).

2. Resolution

Astronomers define the resolution of a telescope as the separation A_1 of an equal component double star that is just discernible as double. With the same definition, one finds that single-channel deconvolution codes can indeed enhance resolution. However, there is a formidable S/N barrier against achieving high resolution with such codes (Lucy, 1992). Thus, if an astronomer concludes from a restored image that a factor 2 improvement in resolution is required by the science, then he must return to the telescope and acquire an image with a factor $2^8 = 256$ increase in signal.

For given S/N, there is a separation A_2 above which deconvolution can resolve a double star, and another separation $A_3 < A_2$ below which the image does not differ significantly from that of a single star. For intermediate separations, the slightly elongated image can be *decomposed* into two stars with a 2-channel code by suitably initiating the 2nd channel with two δ-functions. But one is then making the *hypothesis* or introducing *prior information* that the object is double. In contrast, when a double star is resolved at the telescope or with single-channel deconvolution, no hypothesis or prior information is required.

Having decomposed an elongated stellar image into two δ-functions, we can construct a "restored" image by convolving with a PSF of our choice. For example, we could choose the Airy function with 1st zero at 0.014″ and claim the imaging capability of a perfect 10-m space telescope – and the diffraction rings would be proof! In reality, of course, the space telescope, by revealing additional stars or extended emission, might well disprove the hypothesis underpinning the decomposition.

3. Compact Star Clusters

The degenerate case of a compact cluster is a close double star. For this case, numerical experiments at the ST-ECF indicate that, if the only limitation is photon statistics, decomposition into components is achievable with precision and without bias, even for sub-pixel separations.

Accordingly, the decomposition of ground-based images of compact clusters with a 2-channel code is potentially a powerful technique, even without an HST image as a guide as earlier envisaged (Lucy, 1993). Nevertheless, such decompositions are not unique, since any star can be replaced by two fainter ones with negligible separation. In this circumstance, we of course seek the simplest solution consistent with the data. However, if the decomposition is made interactively and sequentially and results in several tens of stars, one may suspect that independent workers will not find the same "simplest" solution. Clearly, procedures need to be formalised and preferably automated.

4. HST Proposals

When evaluating proposals for HST time, the TAC Review Panels are instructed to ask themselves whether the project can be done from the ground and to reject proposals when the answer is yes. As they stand, the strong claims by Magain et al. will therefore impact negatively on future proposals to use HST to resolve star fields in nearby galaxies. Accordingly, astronomers interested in such studies need to test whether what is possible in principle on the basis of photon statistics is in fact achievable in practice. There must be many fields that could be decomposed into stars with the Liège code and then compared to "ground truth" in the form of an image from the HST archive. Such tests should be carried out and evaluated by independent users.

The above concern does not arise for HST proposals to resolve structure in nebulae and galaxies. For such objects, we lack a physical model – the equivalent of the δ-functions for stars – and so ground-based images cannot be decomposed in the same way. We are therefore then left with the modest resolution enhancement achievable with a single-channel code, and this is not seriously competitive with post-COSTAR HST images.

References

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