ASTRONOMY FROM WIDE-FIELD IMAGING

Part Sixteen:

CONFERENCE SUMMARY AND RESOLUTIONS

AN OVERVIEW OF WIDE FIELD IMAGING

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ABSTRACT. Wide field imaging can be subdivided in terms of wavelengths, the kinds of emission sought, data types, richness of field, detector types, astronomical objects to be investigated, and probably other ways. These are surveyed with special reference to the talks given in Potsdam, ending with a handful of issues about which disagreement, or at least discussion, persists.

Wide field can mean many things. V. Lipovetsky defined it as imaging with 10^{7-8} elements or pixels per field. There are other possibilities. For neutrinos, gravitational radiation, cosmic rays, and (some kinds of) gamma rays, the whole sky is a single (very wide) field. At the other extreme, the HST 'wide field' camera covers about 2′ and needs nearly 4 x 10^7 exposures to survey the sky. In between, the POSS and ESO/SERC Schmidt plates see 6° at a gulp, interestingly similar to the roughly 6° sharp central cone of human vision (you can test this by holding a book at a measured distance from your face and counting how many times your eyes jump in reading a line).

1. Wavelength Bands

The gamma-ray sky was first surveyed by Cos B, which saw about 30 sources (not all of which have yet been identified). The Compton GRO is increasing this by at least an order of magnitude and is finding new classes of sources. The American Vela satellites and corresponding Soviet ones found about 30 burst sources up to 1974. The BATSE total is nearly 1000 and increases by about one per day.

Uhuru provided the first X-ray map, with about 300 sources. There followed Ariel 5 and HEAO-1 (~ 10^3 source) and Einstein with ~ 10^4, leading up to ROSAT at some 6 x 10^4 sources. It also has identified several new categories, including the very soft transients (Truemper). AXAF and XMM should further enrich the X-ray sky.

The 'unobservable' ultraviolet, shortward of Lyman α, has proven surprisingly rich, with some 400 sources so far in the ROSAT catalogue (Truemper) and additions and confirmations coming from EUVE. Between Lyα and the shortest wavelengths accessible from ground lies a bit of virgin territory. IUE is capable of detecting 10^{4-5} sources, but there has been no systematic survey. The TRUST concept, described in a Rome group poster here, is one possibility.

The 1969 2μ survey revealed ~ 3000 near infrared sources, a number to be increased enormously by 2MASS and DENIS (roughly H, I, J, K) now in progress (Epchtein). IRAS, with more than 10^5 sources, was the far IR successor to the AFGL rocket survey with 10^4. A gap remains from 2 - 12 μ.

The millimeter and submillimeter regions remain unsurveyed, presumably because of the

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enormous mismatch between typical beam sizes and 4π.

The second-generation radio catalogs like 3C contained about 300 sources, increasing to 1000 in Parkes, 3000 in 4C, and 10,000 in OSU. The VLA survey beginning this year is expected to map 10^6 sources at 20 cm by the end of the century. Low frequency catalogs are much less populous, for instance about 100 galactic plane sources from CLRO at 10 - 100 MHz, and a comparable number of polar cap ones in 8C. The problem is again beam size, but in the opposite direction. The radio inventory includes some 1000 pulsars: they do it with correlators, as well as mirrors.

Optical surveys, catalogs, and atlases (see Lipovetski for the proper distinction, which I have not observed) come last, because there are so many of them. In the following list, there is, roughly, an order of magnitude increase in numbers of stars associated with each of (a) invention of the telescope, (b) use of photography, and (c) modern scanning methods. Helvelius, the last professional naked eye astronomer, lived well into the telescopic era. He would probably not have liked CCDs either. First the whole, or half, sky catalogs:

Name	Date	Positional Accuracy	Number of stars
Hipparchus	-127	1000"	850
Ptolemy	+138	900"	1022
Soochow	1193	3600"	1440
Tycho	1601	120"	c. 1000
Helvelius	1660	120"	c. 1000
Flamsteed	1689	10"	10^4
Bradley	1755	2"	10^4
Carte du Ciel	1890+	0.4"	10^5
BD, CD, SAO, Perth	"	0.5"	10^5
Modern astrographs	1970+	0.2"	2×10^5
HIPPARCOS	1990+	0.002"	2×10^5
Tycho	1990+	0.03"	10^6
HST Guide Star	1985+	0.5"	2×10^7

The modern astrographic projects include remeasuring Cape (CPC2) and Yale zones, the USNO AC, NIRS and SIRS, and programs at Pulkova-Toviso, Sydney, and Hamburg, where the current inventory (Zacharias) includes remeasuring the AGK2 plates to m = +12, remeasuring AC zone plates, e.g. Vatican, to provide better proper motions, tying Hipparcos/Tycho to optical ground based and radio VLBI systems, and assorted efforts at optical identifications. The USNO menu (Money) is quite similar.

There exist many catalogs with more restricted purposes, starting with FC(1879) and its modern successor, the FK5 meridian circle catalog, containing 1500 bright stars located to better than 0.03", and the AGK1 (1880), 2(1930), and 3(1960) astrographic catalogs with 180,000 stars at lesser precision, discussed by Roeser & Taff. AGK3U (Taff) will be the first Schmidt astrographic catalog. PIRS (Kiev and Budapest) extends the sequence down to m = 12 - 14, to provide a bridge down to 'radio stars' and the VLBI coordinate systems. There are proper motion catalogs from Luyten, Lick, Yale (also a parallax catalog), and USNO (the PPM). The Yale Bright Star, Washington Double Star, DAO Spectroscopic Binary, and HD (spectral) catalogs are other examples, while diffuse objects appear in NGC, IC and subsequent publication.

Of optical surveys, the most famous are POSS I and II and the ESO/SERC 48" Schmidt projects (still under way). Other Schmidt programs exist at KISO, Abastumani, and ESO, including the objective prism survey (Comte). A small subset of the interesting modern special-purpose surveys includes (a) those for QSOs, beginning with the 10,000 sq. degrees examined by PG, and continuing with the projects at Calar Alto and Byurakan (Stepanian), (b) redshift surveys of the future — the Sloan Digital, 2dF (Taylor), LITE (Vigroux), DEEP, and the Spectroscopic Survey Telescope (SST), (c) optical identifications of objects found at other wavelengths, (d) searches for rare objects like brown dwarfs (Tinney), faint blue galaxies, and low surface brightness galaxies (Phillipps), and (e) hunts for variable objects like flare stars (at Sofia), ones microlensed by compact halo objects (OGLE and MACHO, described by Marshall), and supernovae, with four modern Schmidt surveys, POSS II, UK Schmidt, CTIO Curtis Schmidt, and CERGA (described by Pollas) that have each found more than 50. I am currently betting on Pollas to be the first to match Fritz Zwicky's lifetime total of 120.

2. Types of Emission and Data

Wide field imaging can record diffuse emission (e.g. COBE), extended emission (e.g. IRAS and some optical and radio maps of the Milky Way), sources (stars, galaxies, clusters ...), and line emission. Marcelin described an Hα mapping project, and Hartley suggested the use of Tech pan film with a suitable filter and Schmidt telescope for a true all-sky survey. All of the sky has been surveyed in the 21 cm line of HI, and somewhat less in CO. I wonder whether an X-ray line survey (presumably Fe XXV Ly α analog) would be a practical proposition?

The data most often sought are astrometric, as reviewed by van Altena. Approximate photometry is an automatic byproduct, but precision work is not and requires significant additional effort (Chen), significant improvement of the apparent magnitudes of the 2×10^7 stars in the HST Guide Star Catalog being currently just a gleam in the eye of STScI staff (Lasker).

Polarimetry in wide fields is nearly-virgin territory. The Bonn project is an important first step, but 'wide' = $10'$. Wide field spectroscopy, in contrast, is a well-established discipline, using objective prisms (Schuecker), grisms, and multi-object (or multi-fiber) spectrographs (Vettolani, Broadbent). The HD catalog, after all, was the product of a wide-field, objective prism survey, with a telescope that still exists (now in Torun, Poland). Finally, if morphology is your goal, even very simple algorithms can be remarkably effective, as Okamura reminded us.

3. Richness of Field and Measuring Machines

The complexity of your image can be parametrized in several ways. The ratio of field size to beam size ranges from one (early radio and IR astronomy) up to 10^8 (large optical plates). Confusion sets in when an attempt is made to recover more than about one source per 25 beam areas (but can itself be used to good effect, as in Tonry's work on galactic surface brightness fluctuations and Scheuer's P(D) method for counting radio sources). Finally, the ratio of interesting to dull objects on your plate can range from one (Carte du Ciel) down to 10^{-4} (QSO searches) or even $\leq 10^{-7}$ (brown dwarfs).

These considerations are a major driver in the construction of measuring engines (Monet), which can be thought of as scanning densitometers with some of the software hard-wired in. One participant suggested that "a Schmidt telescope is the front end of a measuring machine" ("only" being implied, but not stated). Galaxy at ROE and its successors, COSMOS, and SuperCOSMOS, came first. Others are APM (IoA, Cambridge), PMM (USNO Flagstaff), APS (Minnesota), MAMA (Paris), SkiCat (JPL-Caltech-Palomar), and GAMMA (STScI). In many cases, the acronym is better established than exactly what it stands for.

4. Detector Types

You have two choices — analog (all radio receivers and photographic plates) and digital (CCDs and everything used shortward of optical wavelengths). The dominant problems are quantum efficiency and pixel numbers respectively. Monet reviewed some of the tradeoffs.

Mosaics (Sekiguchi) are the only solution to the pixel problem in the foreseeable future. An array with 10^7 elements is operating at KISO, and 10^8 pixel mosaics are under development at NAOJ for the Sloan DSS and Subaru. All have filling factors much less than unity, because the CCD chips cannot be abutted on all four sides at present.

Given pixel sparsity, the issue of over vs. undersampling the field becomes important. The range in use is at least from 0.3"/px at La Laguna (Aparicio) to 1.67"/px at Beijing (Chen). Numerical simulations and experience indicate that you gain very little beyond 1.5 px/FWHM. Decisions also have to be made (Monet) about front vs. back illumination of the chip (back is generally the best choice, especially for UV) and scan vs. stare observing modes (scan has many advantages, but you lose angular resolution away from the central declination of the field). Flat fielding remains an art at least as arcane as that of sloshing developer.

A 14" square Schmidt plate rejoices in some 10^9 pixels, with filling factor = one. But the quantum efficiency is low and the dynamic range limited. Tech Pan film emulsion makes some progress on the first point, and Hartley indicated that digital adding can push limiting magnitudes into the same range as those for a CCD on the same telescope. Photographic adding is a much more subtle process, largely the province of David Malin (who, significantly, started life as a chemist).

Unexpected by most participants was what came to be called 'the Kodak problem'. Spectroscopic plates are currently used for Schmidt surveys, astrographs, other photographic sky patrols (Sonneberg, Calar Alto, Ondrejov, Odessa, Dushanbe, Crimea, ...), and some sorts of spectroscopy. Plates bearing emulsions in the IIa, 103a, and IV-N series are no longer available. The IIIs remain (but Monet reports supply line problems).

Possible substitutes in various contexts include ORWO plates (Ohnesorg), Russian blue-sensitive ones (Sheglov), and Tech pan film with various filters (Parker). A 'Tech pan B' film without red sensitivity struck many as an addition to the arsenal worth asking for.

Finally, I believe the community should be prepared for the possibility of all or most photographic materials of any kind disappearing in the next 10-20 years, as digital and electronic replacements arrive for home movies, advertising art, medical imaging, and many other applications. This could happen quickly — Ou sont les LPs d'hier?

5. Astronomical Objects

Potential targets for wide field imaging include comets, cosmology, and all the territory between. I touch here on only a few striking points. And in many cases, the item I have pulled from a particular talk was not the one the speaker meant to emphasize.

Solar system projects include the searches for Pluto and planet X, and inventorying of comets and asteroids (Marsden), especially those in earth-crossing orbits (Maury). Apart from early warning of potential impacts on earth, major goals are identification of dynamically interesting families of orbits and finding objects that can trace the chemical evolution of the solar system.

HD was the quintessential wide-field stellar project. Nothing similar is currently underway, but we can, for instance, achieve a complete census of carbon stars in the Magellanic Clouds (Azzopardi) as well as in the halo of our galaxy.

Stellar population programs seek to trace out the IMF (Tinney, who finds with others no very persuasive brown dwarf candidates) and to separate Milky Way stars into bulge, thick and thin disks on the basis of location, metallicity and kinematics (Robin, Yamagata, Soubiran). There seemed to be some disagreement between the latter two on whether each population has its own vertical gradient of [Fe/H] as opposed to fixed-composition components, differentially sampled with distance from the galactic plane. The sample that extends further from the plane is probably to be preferred.

Wide field star counts and proper motion measurements can be used to probe galactic rotation, mass as a function of R and Z, and dynamical history of the galaxy (Majewski, Odenkirchen). An interesting result is that halo field stars and globular clusters seem to consist of two or more discrete groupings, evidence that the Milky Way partly formed through a sequence of accretion and merger events. One group of globular clusters thus identified features retrograde orbits, but those of our dwarf spheroidal companions are apparently direct (Scholz).

Moving outside the Milky Way, we can still carry out population studies, but also surface photometry, velocity mapping, comparison of star clusters with field, and so forth. Within the SMC, the stars have become more metal rich with time, but the populations are spatially and dynamically mixed (apart from the youngest ones being lumpier). The LMC is a good deal more complicated (Hatzidimitriou, Kontizas, Azzopardi). The two galaxies apparently last met about 10^8 ago.

Giant elliptical galaxies (Capaccioli) could be the results of mergers of compact groups (Longo); but our dwarf spheroidal companions (Eskridge) are not just mini-gEs. Somewhat disconcertingly, the inventory of galaxies is already incomplete at 5 Mpc from us (Schmidt), just as the stellar one is incomplete beyond 5 pc (and the numbers of objects in the complete samples are rather similar). The local luminosity function is of the Schechter form. So is the global one (Vettolani), but both characteristic slope α and brightness at the bend M*, vary among samples selected, for instance, for presence or absence of emission lines.

On larger scales, the voids are empty at least to a density contrast of 10:1 compared to walls (Hopp, de Lapparent). There is undoubtedly real structure out to scales of 100-150 h^{-1} Mpc, to which the correlation functions, $\xi(r)$ and $\omega(\theta)$ are not very sensitive (de Lapparent, Broadbent, Vettolani, Roche). It remains uncertain whether larger-scale structures exist (Schuecker), but there seems to be no backfall onto the Great Attractor from the Perseus-Pisces region (Watanabe).

X-ray clusters come with the X-ray gas radius both much smaller and much larger than that of the distribution of galaxies, the latter constituting a new class of source found by ROSAT (Hasinger). Sources at 1-2.4 keV have now been counted down to where N(S) turns over, partly by using the rest of the field in long exposures taken for other purposes. Resolved sources add up to at least 75% (and maybe 100%) of the background in that energy band. The resolved sources include optically-identified, clustered QSOs and largely unidentified, less clustered Seyferts (Hasinger). Roche also proposed faint blue galaxies as background contributors.

The main cosmological result from wide-field imaging of galaxies, clusters and active nuclei at large redshift is that EVERYTHING evolves. H_o is somewhere between 45 ±10 (Schueker) and 83 ±30 (Watanabe) km/sec/Mpc, a result with which I think we can all agree. A generation ago, an insensitive cosmological test was one that couldn't even rule out steady state. Now it is one that cannot rule out standard, biased cold dark matter!

6. Issues not yet Resolved — Calibrations

Positional calibration is, of course, the essence of astrometry. The state of the art (Roeser) is 0.035" for the bright stars and 0.15" for the fainter ones in FK5. FK5 is now known to be inertial (non-rotating) to much better than the angular velocity of the Milky Way (a surprise to many participants). HIPPARCOS will improve relative positions to 0.002", but is not inertial at all. Patching small areas of the sky together into big ones remains a problem. At some level, the sky is a potato rather than a sphere. And the assumption that the plate scale from Schmidts is linear leads to cyclones and typhoons everywhere away from the center (Taff). It is universally assumed that long focus astrographs do not share this problem. Van Altena addressed how further progress can be made in the post-plate era.

Magnitude and flux calibrations are also fundamental. Two cases where something must have gone wrong are (a) Schmidt survey galaxy counts as done with APM and SkiCat (Djorgovski), the latter displaying significantly fewer faint galaxies, and (b) the angular correlation function of galaxies as measured by APM and COSMOS (Fong), the latter showing much less large scale power. The problem may be non-uniform calibration for faint galaxies from one plate to another on APM. The faint galaxy excess is normally attributed to evolution and the large scale power to effects of exotic dark matter or initial perturbations in the universe. I hope it is not the case that the universe has been closed by calibration errors.

7. Digitization, Recognition, Classification, Data Compression, Storage

Monet pointed out that CCD users can learn a good deal from (the mistakes of) plate digitization programs. Murtagh provided a very broad introduction to recognition and classification methods, both parametric (model-based) and non-parametric (computer discovery). Two widely used ones are neural nets (Odewahn, Serra-Ricart), for which you need a large training set, and must avoid having the program memorize, rather than learn, the material (a lot like some students), and decision trees (Djorgovski), which require you to know roughly what you are looking for ab initio, but then can separate galaxies from stars down to only 1^m above the plate limit. Other schemes include fuzzy logic, parameter refinement, and expert systems.

Data can be compressed before storage, and some methods are better than others (Richter), though you always lose something. Wavelet transforms are clearly the wavelet of the future (Bijaoui) and have applications in recognition as well as compression (de Lapparent). Monet asked whether you have to save pixels (hoping, I think, that the answer was no); but Lasker reported that many users want them. For instance, the APM can find low surface brightness galaxies, but you need 'pixelated' data (Phillipps), not to be confused with 'pixilated'.

8. Archiving and Data Bases

The cliches are true. Archiving is easy; retrieval is difficult (consider the contents of your own office). And you get what you pay for (Kurtz). If this is at most 1-2% of a typical mission cost (Pirenne), then you will have more than a shoebox full of CD ROMs, but far from a full-service system.

Currently-operating archives include the pioneering Centre de Données Astronomiques de Strasbourg, a bibliography of wide-field images stored throughout the world (Tsvetkov), the National Space Science Data Center (the baseline for Kurtz's cost estimates), and the spectrum and images archives from IUE and HST, for the last of which, especially, we can say that access is cheap, but processing is expensive. Methods of archiving are evolving with great rapidity, and it is essential that programs and data bases be both interactive for human users and able to interrogate (and answer) each other readily (Pirenne, Bonnarel). FITS as a standard for image transfer is a good omen in this respect, having come originally from the astronomical community.

9. Interpretations and Exhortations

In the end, none of these impressive tools, from CCDs to FITS, can be any better than the thought we put into them. In the days when only 2/3 or so of 3C radio sources had optical identifications, it was clear from the flux density distributions that "we live in a local minimum in the distribution of empty fields". Any effort to interpret this as a cosmological datum would have been misguided. Related misconceptions have been expressed (not by anyone at Potsdam!) as "these results were obtained with a computer, and so they must be right", and "this analysis was done by physicists, who are used to taking everything into account". CCDs are no substitute for good judgement on what to observe, and algorithms cannot replace understanding.

Given the frequency of past meetings on wide-field imaging, surveys, and related issues, it is likely we shall all meet again soon somewhere. Until then, au revoir and farewell (in the official language of the IAU), auf wiedersehen (in that of our magnificent local hosts), hasta la vista, arrivaderci, dovidenja, farvel, valete, and, as the ancient Egyptians said, May you live, prosper and be healthy.