Wide-field Astronomy with Tech Pan Film - A Positive Outlook for Schmidt Photography

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Abstract. The introduction of film-based Kodak Technical Pan emulsion at the UKST has led to a new lease of life for deep, wide-field astrophotography. This is because the excellent imaging, resolution and low noise characteristics of Tech Pan typically yield a one magnitude depth gain over equivalent IIIa-F plates. Many new projects are underway to take advantage of the significant information gains. The cheap cost of film and ease of transportation gives direct economic benefits too. Tech Pan could also offer a medium term, competitive alternative to CCD mosaics for providing new, deep, wide-field surveys via stacking of several digitised exposures of the same field. A one magnitude gain could result from the stacking of just 6 Tech Pan films to yield an R $\sim$ 23.5–24. Even without digital co-addition the largest current CCDs cannot hope to match Tech Pan's inherent $\sim 3\,\mu$m resolution and the 40 square degree area coverage of the UKST.

1. Introduction

Kodak Tech Pan emulsion is an extremely fine grained, pan-chromatic film with extended red sensitivity (Kodak P-255, 1981). Though its astronomical promise was recognised early (Everhard 1981), tests at professional telescopes were discontinued when glass and film samples did not respond well to normal hypersensitisation techniques (West et al. 1981) leading to a prolonged lack of interest among professional astronomers. However, successful UKST tests were carried out in 1991 once hypersensitisation and technical problems associated with film use were solved. Films were obtained which exhibited excellent image quality and resolution and which, in good seeing, went about one magnitude deeper than equivalent IIIa-F emulsion on glass but with considerably lower grain noise. (Russell et al. 1992; Parker 1992). Tech Pan now accounts for $\sim$ 60 per cent of non-survey exposures. An exciting variety of astronomical projects are underway to take advantage of the superb imaging, low noise and fainter limits of Tech Pan.

2. Basic properties

Kodak publications P-255 (1981) and P-315 (1987) detail Tech Pan's basic prop-
erties; extremely fine, mono-disperse grain (~ 0.5 that of IIIa emulsions), low
rms diffuse granularity and high resolving power (~ 320 lines/mm c.f. ~ 200
for IIIa emulsions). The panchromatic spectral sensitivity is similar to that of
IIIa-F (except for a useful enhancement around Hα) allowing direct R-band com-
parisons. The modulation transfer function (MTF) and point spread function
(PSF), are also superior and it is capable of a wide contrast range dependant
on treatment (Kodak 1987). Finally Tech Pan's emulsion thickness on Estar is
only $\sim 11~\mu$m c.f. $\sim 20~\mu$m for IIIa's.

Sky limited Tech Pan R-band exposures (i.e. $D_{sky} \sim 1+$chemical fog)
were soon obtained in standard 1 hour exposure times. The gradient of the
characteristic curves at sky (the reference γ or contrast level) also gave almost
identical values to IIIa-F, i.e. $\gamma_{sky(4415)} = \gamma_{sky(IIIa-F)} = 2.0$ to within 3%
with $N_{sample} = 50$. The scientific gains are a direct consequence of these ba-
sic emulsion properties combined with the success at achieving effective long-
exposure speed via appropriate hypering, processing and exposure conditions
(Parker 1992).

3. First impressions count. A visual assessment comparison.

Plates 1a,b show a 2×1.5 arcmin area from consecutive Tech Pan and IIIa-F
exposures taken under survey conditions. Visual inspection of sky limited R-
band Tech Pan films reveals much improved image resolution compared with
top grade IIIa-F plates The clarity of images and features in extended objects
like galaxies (dust lanes etc) was quite stunning. Visual quality control indi-
cated about one magnitude depth gain with typical minimum image diameters
estimated to be ~ 20–$25~\mu$m cf. 30–$35~\mu$m for IIIa's.

Quantitative assessments to put these impressions on a firmer footing were
obtained by scanning several films with COSMOS, a fast measuring machine
(MacGillivray & Stobie 1984). The data were compared with IIIa-F data from
the same fields (Parker, Morgan & Phillips 1993). Both direct pixel 'mapping
mode' data (MM) and thresholded image-analysis mode (IAM) image parameter
data comparisons were made.

4. Results from COSMOS scans of Tech Pan films

Tech Pan yields a very uniform sky-background and very low grain noise with
sky-background intensity histograms from several film and equivalent IIIa-F
plate scans indicating a 3–4 fold reduction in noise to $\sim 0.8\%$ per pixel. Tech Pan
has 4 times as many grains per unit area which are half the size of IIIa emulsion
grains. This has a direct bearing on achievable S/N near the sky-background
following Poisson statistics.

For many applications it is also important to define star/galaxy separa-
tion as accurately as possible. COSMOS star/galaxy separation plots, such as
Log (image-area) versus isophotal magnitude, reveal improved star/galaxy sep-
aration with Tech Pan. Figs 1a,b give examples taken from the Virgo field
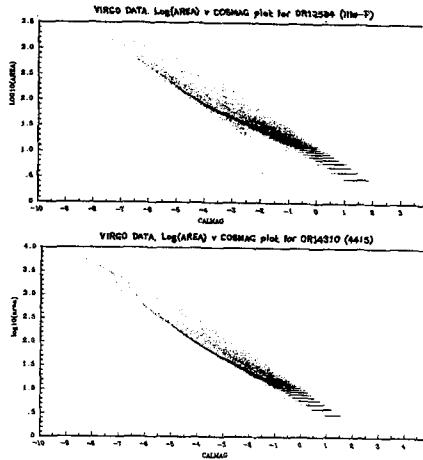comparison. The stellar locus is generally extremely well defined for Tech Pan

Figure 1.   Standard star/galaxy separation plots of Log(image-area) versus COSMOS isophotal magnitudes for the same Virgo cluster area for (a) IIIa-F UKST exposures and (b) Tech Pan.

data allowing separation to fainter magnitudes. Improved deep galaxy catalogues should result.

Number-magnitude counts from Tech Pan and IIIa-F COSMOS data of the same fields confirm the ∼ 1 magnitude gain for exposures taken under similar conditions (Phillips & Parker 1993). Low surface brightness (LSB) galaxy profiles obtained from COSMOS MM scans of Tech Pan film can also reach 26.5–27.0 R magnitudes per square arcsec (less than 0.4 % of the sky background) and ∼ 1–2 mags better than for IIIa-F. This excellent capability for detecting LSB features at very low isophotal thresholds should enable effective searches for LSB galaxies over large areas, especially if digital co-addition is employed. A number of such projects are already underway, (see Scharwzenberg, Phillipps & Parker, this meeting).

Magnitude plots of paired images from Tech Pan and IIIa-F COSMOS data gives good R-band magnitude agreement though there is inevitably a small colour term.

5.   A word on S/N and DQE

First DQE estimates of 'optimally' hypered Tech Pan UKST exposures indicated values ∼ 3–4 times those of IIIa-F, a remarkable result for a photographic emulsion if true. Cannon (1984) described the expected gains if a suitably fast, fine grained emulsion like Tech Pan were to become available. The number of grains in a Tech Pan image near the background is ∼ 4 times the number in the equivalent image on IIIa-F. This gives a factor two improvement in the linear dimension of the smallest detected extended objects at a given level of surface brightness. Thus if Tech Pan grains are assumed to be equally sensitive and the

same sky density is reached in the same exposure time as for IIIa-F (as is the case) then Tech Pan's DQE is increased by a factor 4 relative to IIIa-F. Our COS-MOS data indeed indicate improvements of a factor 3–4 in the sky-background noise, enabling much lower thresholds to be set.

Now for a photographic emulsion:

$$DQE = [K \times \gamma^2 \times (1/nt)]/[A \times \sigma_d^2] \tag{1}$$

where K is a constant and γ is the gradient of the D-logE curve, n is the number of photons per unit area per second and σ_d is the emulsion RMS diffuse granularity as measured with a scanning aperture A, usually $1000\mu^2$, (e.g. Eccles, Sim & Tritton 1983). Now we obtain: $\gamma_{4415} = \gamma_{IIIa-F}$ and reach sky in the same exposure time. Hence we can directly relate the DQEs of Tech Pan and IIIa-F. Using the above equation and taking ratios we find:

$$DQE_{4415}/DQE_{IIIa-F} = \sigma_{IIIa-F}^2/\sigma_{4415}^2 \tag{2}$$

Inserting the known values for σ (e.g. Eccles, Sim & Tritton, 1983) we obtain:

$$DQE_{4415} = DQE_{IIIa-F} \times 3.2. \tag{3}$$

This gives $DQE_{4415} \sim 10\%$ if we accept $DQE_{IIIa-F} \sim 3\%$, an oft quoted value for hypered IIIa-F (e.g. Kodak 1987).

5.1. Astrometry from original Tech Pan film exposures.

Unlike copy film, original film exposures are subjected to deformations at the UKST's focal surface. There have thus been concerns about Tech Pan's ability to mechanically recover and yield good astrometry. To address this, Evans (1993) used APM data to perform an astrometric evaluation of Tech Pan. Results indicate that glass based IIIa emulsions and Tech Pan provide essentially the same accuracy for relative astrometry. Repeat measures of the positions of stars measured from Tech Pan and IIIa-F exposures scanned at both 0° and 180° orientation gave σ(Tech Pan) ~ 0.04 arcsec and σ(IIIa-F) ~ 0.05 arcsec. Further studies on a larger set of exposures are underway (Evans, in preparation). These results are not altogether surprising. Kodak Q-34, 1970, shows Estar base to be extremely stable with excellent strength and thermal stability (it is only ~ 1.8 times worse than spectroscopic glass plates).

6. Co-addition of Tech Pan films - An alternative to a CCD mosaic?

Multi-exposure co-addition has already been used as an effective means of gaining greater depth. The result can be achieved either photographically (Malin 1981) or digitally (Marston 1988; Kemp, 1994). Digital co-addition allows greater control and quantification than photography which is limited by registration difficulties. Computers can also allow for rotation, translation etc in the co-addition process permitting better registration over a full UKST field. The technique is currently restricted by the relatively few exposures available for most UKST fields or to special fields where large numbers of plates already exist (Hawkins these proceedings).

According to Bland-Hawthorn et al. (1993), hereafter BSM93, R band CCD imaging on the UKST with a Loral chip should achieve an R ~ 25 limit at the

3σ level after ~ 1000 s whilst 36 stacked sky-limited IIIa-F exposures can easily reach R $\sim$ 24. Applicability to large areas is impractical with standard IIIa-F plates though as 36 exposures would be required to achieve the 2 magnitude depth gain necessary to compete with CCDs. However, Tech Pan 'R' exposures already go ~ 1 magnitude fainter than existing R survey material (i.e. to R ~ 23) thus the co-addition of 6 Tech Pan films would gain an extra magnitude to R $\sim$ 24 (with possible 3σ detections to ~ 25). The relative efficiencies of undertaking deep wide-area surveys with current CCDs, and the digital stacking of IIIa-F and Tech Pan films can be compared. The figures are summarised in Table 1, where the UKST CCD parameters are for a Loral 2048×2048 chip. The CCD limits refer to 3σ detections whilst the photographic limits are conservative though BSM93 claim 3σ detections to R ~ 25 from 36 stacked IIIa-F plates.

Table 1.   Summary of CCD versus photography at the UKST

Number of exposures	Depth in R	Estimated exp. time	Area coverage	Inherent Resolution	Number of Pixels	Telescope
1×Loral CCD	25	1000 s	0.57 sq.deg	15 μm	2048 × 2048	UKST
$\sim$ 160×Loral CCD	25	25 hr	40 sq.deg	15 μm	6.7×10^8	UKST
36×IIIa-F	24	36 hr	40 sq.deg	5 μm	1.8×10^{11}	UKST
6 × 4415	24	6 hr	40 sq.deg	~ 3 μm	8.4×10^{10}	UKST
1×IIIa-F	22	1 hr	40 sq.deg	5 μm	5×10^9	UKST
1 × 4415	23	1 hr	40 sq.deg	~ 3 μm	1.4×10^{10}	UKST
1×RCA CCD	24	300 s	0.05 sq.deg	~ 30 μm	512 × 320	AAT

Given the ease of transportation of Tech Pan film and the commissioning of the next generation of measuring machine, SuperCOSMOS (Miller et al. 1992), this technique could be a cost-effective medium term alternative to a UKST CCD mosaic for performing deep, large-area R-band surveys.

7.   Uses of Tech Pan at the UKST and future projects.

New prospects for projects with Tech Pan should exploit its excellent imaging, resolution and low noise characterstics. A major role would be as a superior replacement for IIIa-F for R-band imaging. Digital co-addition of multiple exposures of the same field could also be important.

Tech Pan has useful blue sensitivity too so that use of the UG1 'U' filter enables satisfactory U-band imaging with no significant red-leak detected. No loss in depth compared with IIIa-J U plates is evident whilst all the advantages of improved resolution etc are available (Parker, Morgan & Phillipps 1993).

Tech Pan is also an effective alternative to IIIa-F for objective-prism exposures. The spectral sensitivity of Tech Pan, being somewhat flatter than IIIa-F's, is better for high redshift QSO searches since the bumps in the IIIa-F spectral sensitivity can mimic QSO emission lines, preventing proper exploitation in this area. Preliminary results (Drinkwater 1993) indicate that the improved resolution and S/N do enable better feature discrimination. Objective-prism studies of the Magellanic clouds for planetary nebulae, carbon stars etc would also benefit from the greater S/N and resolution in the Tech Pan prism spectra.

The useful sensitivity peak of Tech Pan around Hα indicates that it could replace the coarse grained 098 and the IIIa-F emulsion for Hα narrow-band
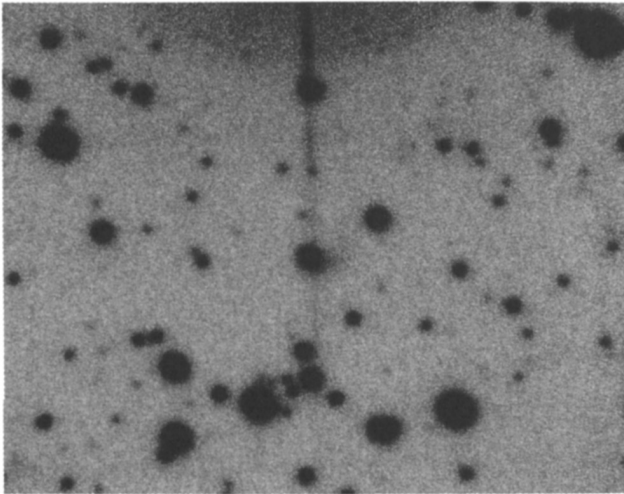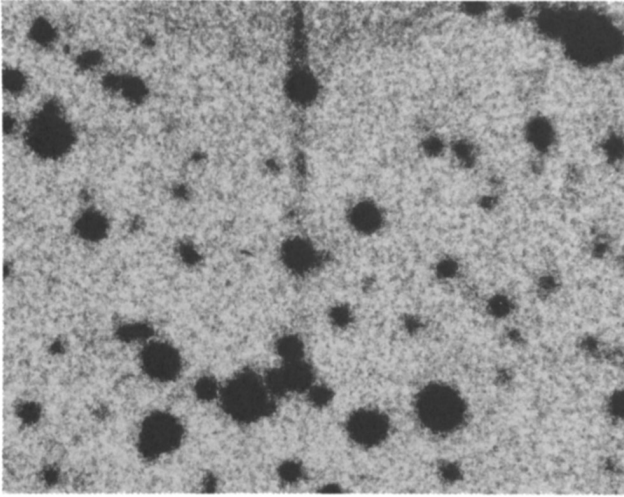
Plates 1a,b   Direct IIIa-F (above) to Tech Pan (below) image comparison from consecutive UKST exposures of the same survey field (field 263) taken under survey conditions.

imaging. COSMOS MM data from two Hα exposures of the same field indicate that the same depth is being achieved as with IIIa-F.

Finally, film provides a cheap means of follow-up exposures of transient phenomena, comets, fast moving asteroids, novae etc.

8.   The main advantages & disadvantages of Tech Pan

The fine grain and improved DQE from effective hypering and processing leads to better image quality, improved resolution, fainter isophotal limits, higher photometric accuracy, fainter magnitude limits and better detection of low surface brightness features. The reported scientific gains are the consequence. The cost of Tech Pan films is only ∼ 10% that of glass plates and the film has additional transportation, storage and handling benefits. The estar-base itself is extremely stable and strong (Kodak publication Q-34, 1977) and unlike glass plates can't be broken. Finally the hypered product stores extremely well in an inert atmosphere in cold storage with no apparent degradation in fog levels with long (∼ 1 month) storage times (Parker 1992).

Tech Pan film was proving difficult to copy though the problems have now largely been solved (Hadley, private communication). Film also needs careful mounting for proper scanning with a measuring machine such as SuperCOSMOS. Film tends to pick up dust easily (being more prone to static) and so needs proper storage and cleaning. Longer development times are required for Tech Pan as push-processing is used. The film can also 'kink' fairly easily making subsequent copying or machine scanning difficult so it still requires careful handling. Finally more halation effects are seen with bright images than with IIIa-F.

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Discussion

Lasker: I share your optimism that there will someday be a blue-sensitized Tech Pan, say 4415J. However, what if this doesn't happen? Have you considered a practically achievable blue filter? If so, what might it be?

Parker: I am not optimistic that a blue-sensitized Tech Pan emulsion will be made available by Kodak in the medium term, given the current Kodak problems. However a blue sensitive Tech Pan emulsion would be extremely valuable so this should be pursued vigorously! Manufacture of a suitable filter to isolate an approximation to the B-band from the panchromatic Tech Pan sensitisation has been considered. This is an expensive option due to the composite nature of such a filter. It is difficult to produce a uniform 14×14 arcsec^2 filter with the desired optical properties.

Murray: Can you say more about the astrometric performance of Tech Pan film? Specifically, how accurately can one map two exposures on the same field on to each other?

Parker: I have only performed crude comparisons based on COSMOS data which indicate consistency between COSMOS scans on two different Tech Pan films of the same field to better than 0.5 arcsec in α, δ. Dafydd Evans at RGO has performed more stringent astrometric tests and I urge you to contact him for details. His preliminary results are encouraging as he finds that the Tech Pan film yields results 'as good as and in some ways better' than from glass plates. From averaged positions of stars on plates and films (from 0° and 180° scans) he found $\sigma_{film} = 0.027''$, and $\sigma_{plate} = 0.026''$.