The Introduction of Tech Pan film at the UK Schmidt Telescope

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Abstract

Kodak Technical Pan (Tech Pan) emulsion on a film base has been in use at the U.K. Schmidt Telescope (UKST) since 1992. This material is extremely fine grained and its resolution is well matched to images produced by UKST under good conditions. Tech Pan yields wide angle photographs which are about 1 (stellar) magnitude fainter than equivalent IIIa-F plates but with considerably lower grain noise. A wide variety of new projects are underway which take advantage of this remarkable material. In this paper empirical results from experiments with Tech Pan from a number of sources are tied in with UKST experience to present an overview of the properties of the emulsion from an astronomical perspective. We compare Tech Pan's properties with equivalent IIIa-F emulsion to which it seems superior in almost every respect. This overview and groundwork are currently missing from the published astronomical literature. The technical background and developments leading to adoption of this material at the UKST are presented.

Keywords: instrumentation: detectors - methods: observational - techniques: photographic

1 Historical Background

Kodak Technical Pan (Tech Pan) is a fine-grained panchromatic emulsion produced since the early 1980s (Kodak 1981), though it was introduced somewhat earlier as 35mm solar patrol film (as special order SO-115). Available in a variety of small film formats, Tech Pan has been more recently made on thick (178μm) polyestar ('Estar') base in larger sizes suitable for use in large Schmidt telescopes. The thick base film product is known as Tech Pan type 4415. Coatings have also been produced on glass as special product 153-01. In all cases the emulsion is believed to be identical, though overcoats, coating weights and emulsion hardening may vary.

The film-based material, particularly the 35mm format, has been used by the amateur astronomy community for many years with great success (Martys 1984 and 1991). Smaller, professional telescopes have also used the film for specific purposes, e.g. asteroid studies with the Uppsala and Palomar 18 inch Schmidt telescopes (McNaught, Helin, private communications). The product's versatility is demonstrated by its use in professional astronomical photo-labs for photomicrography (Roberton 1984) and contrast enhanced copying (Hadley 1984 and Martys 1982). Though its potential as an astronomical detector was appreciated by Everhard (1981), tests at professional observatories were discontinued when the on-glass material did not respond to standard gas-phase hypersensitisation. At this time, large film sizes were not available, and even if they had been, they could not be readily accommodated at the curved focal surfaces of Schmidt telescopes.

The first successful UKST exposure of Tech Pan film was in March 1991 though routine use did not begin until 1992 when several remaining technical difficulties were overcome. Once appropriate hypersensitisation and other procedures were adopted (see below), sky-limited Tech Pan exposures were obtained with the red band OG590 ('OR') filter with exposure times similar to those used for equivalent IIIa-F plates. These films gave better imaging, finer resolution and were about 1 magnitude deeper than standard IIIa-F exposures to which they seem superior in almost every respect. Tech Pan has now replaced IIIa-F for most applications (with the exception of ongoing surveys) and accounts for 70 percent of all UKST non-survey work since 1992. Over 1400 film exposures have now been taken (as of March 1999) and, since January 1997, 60% of all exposures are on Tech Pan. An exciting variety of Tech Pan-based projects are now underway including the new AAO/UKST Hα survey of the Galactic Plane (Parker & Phillipps 1998a, 1998b). Such projects have offered a new lease of life for deep, wide field astrophotography with the UKST.

This paper details the background work that underlies this success and describes the remarkable properties of the emulsion by means of comparisons with what was the emulsion of choice for red light exposures, IIIa-F. The promising behaviour of Tech Pan in other wave-bands is the subject of an associated paper (Parker & Lee 1999, in preparation), and the colour equations that relate Tech Pan photometric behaviour to the equivalent IIIa-F emulsion are given in Morgan and Parker (1998). Finally, the astronomical utility of the emulsion, including estimates of its DQE (10%), are described in detail by Parker et al. (1999).

2 Properties of Tech Pan film

Astronomically, Tech Pan is a substantial improvement over the equivalent, long-established red-sensitive Kodak IIIa-F emulsion introduced as spectroscopic type 127-02 (Smith and Leacock 1973), though its blue green sensitivity is higher. Its superior imaging properties derive from its extremely fine, almost mono-disperse (equal-sized) grains, which are typically 0.5μm diameter, and which are illustrated in a series of micrographs by Smith et al. (1985). This, and the thinner coating, results in much lower rms diffuse granularity than IIIa-F and a resolving power of 320 line pairs/mm compared with 200 lp/mm for IIIa emulsions (Kodak 1981). The emulsion thickness on 178μm estar base is only 11μm compared with about 20μm for IIIa emulsions on glass which beneficially affects the image point spread function via the photon scattering properties through the emulsion layer.

Tech Pan's red sensitivity peaks around 650nm, betraying origins as a solar flare patrol film sensitized to Hα emission. Beyond this marked sensitivity peak, the spectral response does not extend quite as far into the red as IIIa-F. However, overall response is generally flatter through the visible region, reflecting an extensive effort by Kodak to provide uniform sensitivity at all visible wavelengths. Spectral sensitivity curves of IIIa-F and Tech Pan derived from Kodak Publication P-315 (1987) are presented in Fig. 1 which indicates the general similarity of response. Though not plotted here, the sensitivity also rises sharply short-ward of 450nm (see Ogura and Liller 1985 and the Kodak literature, e.g. Kodak 1987).

Tech Pan is also capable of wide contrast range depending on processing, a particular feature of fine grained emulsions. This has astronomical advantages but can lead to large-scale non-uniformities unless all stages of hypersensitisation, storage and processing are carefully controlled. The excellent cosmetic quality of routine UKST Tech Pan films has been confirmed quantitatively with measuring machine data, where non-astronomical background variations are shown to be extremely small (Phillipps and Parker, 1993).

The Estar base is extremely stable, having good strength, toughness and flexibility. Its static dimensional stability is excellent, with the thermal co-efficient of expansion of 0.001% per 1°F (Kodak 1970), about 1.8$\times$ worse than spectroscopic glass. Unlike plates, the film products have an abrasion-resistant gelatine overcoat which protects the emulsion from scratches. On the other hand, the non-emulsion side is easily scratched, unlike glass. Although the films cannot be broken they may kink and they attract dust through static rather well, so they still require careful handling.

Another benefit of Estar film is cost, which is about a tenth that of glass plates. These savings are compounded by obvious transportation, storage and handling advantages. Fuller specifications regarding Tech Pan can be found in Kodak technical publication P-255 (Kodak 1980), and for Estar base in Kodak technical publication Q-34 (Kodak 1970).

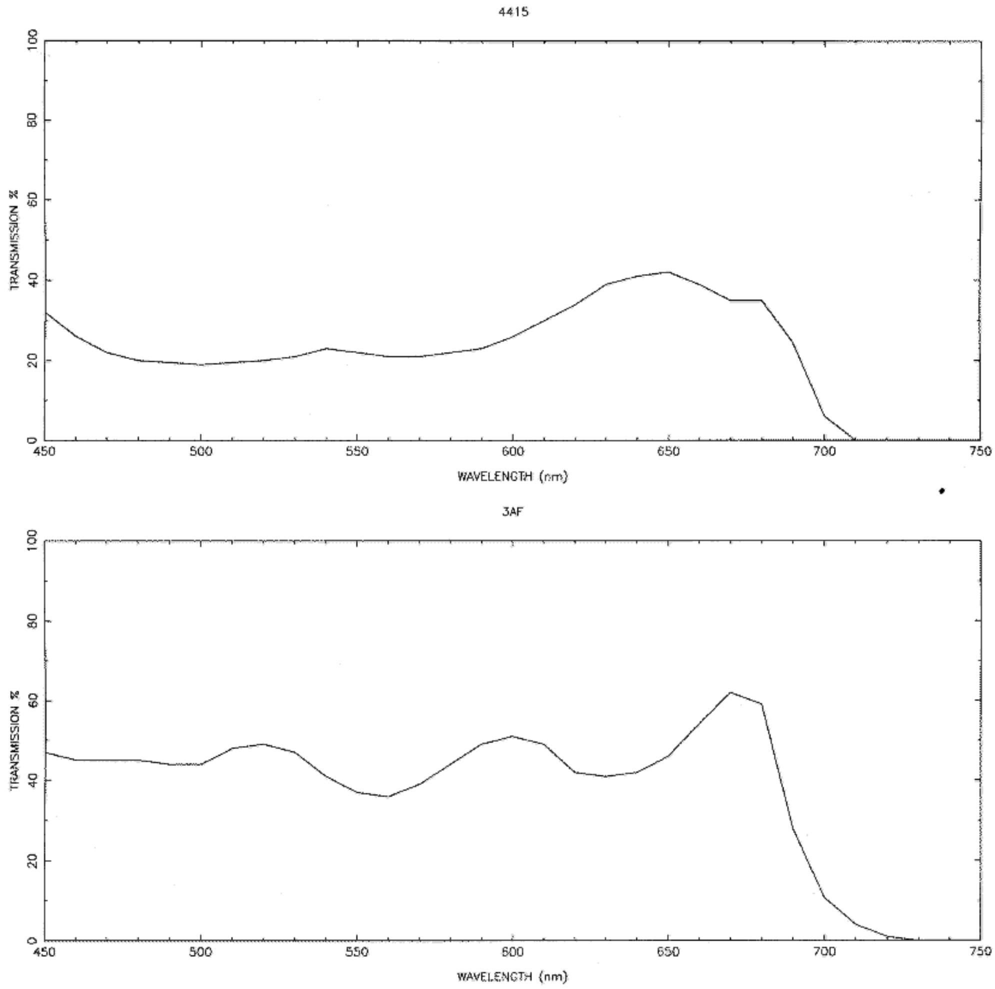

Figure 1: Normalised emulsion sensitivity curves for Tech Pan (top) and IIIa-F (bottom) assuming identical exposure conditions. Note that the Tech Pan response continues to rise into the UV (not shown) and that the normalistion is wrt this enhanced UV response.

2.1 Reproduction of image detail: The modulation transfer function (MTF)

The MTF is a measure of the ability of a photographic material to reproduce image detail and provides a more precise means of comparing different emulsions than associated parameters such as resolution and point spread function. MTF measures are obtained by exposing each material to a pattern of sinusoidally varying intensity (see Kodak 1987) and measuring how faithfully the material mimics the original pattern of modulations over a range of spatial frequencies.

The MTF reveals the loss of micro-contrast caused primarily by light scattering within the emulsion and base during exposure. The published MTF curves for Tech Pan and IIIa-F taken from Kodak (1987) show clearly the better response of Tech Pan over a wide range of spatial frequencies, especially at higher frequencies. Thus the superior detail seen in UKST Tech Pan exposures comes as no surprise. However, the fine grain implies that Tech Pan is inherently too slow to be useful at the low light levels of astronomy and it suffers severe low intensity reciprocity failure in its as-received state (Kodak 1981).

2.2 Eliminating Low Intensity Reciprocity Failure (LIRF)

Ideally a reproducible photographic density would result from any combination of flux level and time that gives the same total flux or 'exposure' at the emulsion. Though for most photographic materials this relationship holds for a wide range of 'snapshot' exposure times, it often breaks down when low light levels force long exposures. This effect is known as low intensity reciprocity failure (LIRF – see Kodak 1987).

Techniques to improve emulsion sensitivity to low intensity light are collectively known as hypersensitisation (hypering) and are widely used in astronomical photography. They generally involve removal of oxygen and water by prolonged nitrogen soak, nitrogen bake or vacuum treatment (outgassing), followed by immersion in gaseous hydrogen (reduction sensitization). Sometimes a mixture of 2 to 8% hydrogen-in-nitrogen (forming gas) is used, often at elevated temperature, to achieve these steps simultaneously.

Non-gaseous hypering techniques, particularly liquid silver nitrate or ammonia treatments work with some emulsions and have been applied to Tech Pan as reported by Walker (1980), Smith (1983) and Scott (1983, 1986). They were also tried by one of us (DFM) at the Anglo-Australian Telescope (AAT). Good long-exposure speed can be achieved, but poor uniformity and short post-hypering shelf life are a problem, and the process does not lend itself to batch treatments. This technique is not considered further. Gas phase hypering systems capable of handling many plates at once have proved simple and reliable and are standard in observatories doing photography. The science underlying gas phase hypersensitisation is now quite well understood (Babcock et al. 1975).

2.3 Gas hypersensitisation of Tech Pan on glass and Estar from previous studies

Early samples of Tech Pan in sizes large enough to be useful on professional telescopes were supplied on glass and were tested at UKST and the AAT. Unfortunately, they were found to be unresponsive to any variation on the standard hypering recipe, which is why further interest in this material lapsed. The influence of substrate on hypering response is still not understood. However, when it became available in 1991, large format film-based material was found to be very responsive to hydrogen hypering treatment, a fact long exploited by those able to use smaller film formats.

As one might expect for a process involving gaseous diffusion and chemical reduction, emulsion response to hypering depends critically on pressure, time and temperature of exposure in nitrogen and hydrogen. With Tech Pan, it was found by experiment that the most critical factor was the hydrogen soak time and temperature, the pressure being uncontrolled ambient corresponding to 1,200m, the altitude of the UKST. However, this simple relationship was not obvious from the literature on Tech Pan hypering (see Table 1). This probably reflects the wide variety of techniques used and because many of the subsequent sensitometric exposures were not carried out under controlled conditions, especially the elimination or absorption of moisture during exposure. This has been found to be critical with gas hypered IIIa-F and IIIa-J (Malin 1978).

Table 1: Summary of hypering tests carried out on Tech Pan obtained from the literature.

Author(s)	Hypering recipe	Baking Temp.	Developer & Time	Exposure Time	Format inches	Speed gain
Everhart(1980)	5hrs 8% FG	66°C	5mins D-19	20mins	4×5 film	~ 8
Marling(1980)	3days 8% FG	30°C	10mins FG-7	2-32mins	35mm film	~ 40
Everhart(1981)	4hrs 8% FG	60°C	5mins D-19	20mins	4×5 film	~ 9
Heudier(1981)	7hrs 2% FG	60°C	5mins D-19	20mins	4×5 film	~ 5
West et al(1981)	12-24hrs N_2	65°C	5mins D-19	1.5-60mins	6×9 glass	~ 2.5
Smith(1982)a	1hr Vac,2hrs H_2	67°C	5mins D-19	20mins	4×5 film	~ 11
Smith(1982)b	1hr Vac,2hrs H_2	67°C	5mins D-19	2hrs	4×5 film	~ 20
Scott(1983)	6hrs 5% FG	70°C	4mins D-19	10mins	4×5 film	~ 8.7
Conrad(1985)	Vac,2hrs H_2	67°C	5-10mins Var.	10mins	4×5 film	~ 16
Liller(1985)	18hrs 2% FG	65°C	5mins D-19	5mins	glass plates*	~ 8.7
Scott(1986)	5hrs 5% FG	70°C	4mins D-19	20mins	4×5 film	~ 8.8

*Various sizes

Most experimenters listed in Table 1 used forming gas (FG) with various hydrogen concentrations, and baking temperatures varied between $30 - 70$°C. Where the pure gases were used separately, the emulsion was often pre-treated with nitrogen or under vacuum for a few hours beforehand to remove oxygen and moisture. Interestingly, Liller (1985), showed that Tech Pan on glass can actually perform as well as film though substantially longer hydrogen baking times are needed. The final speed and contrast were also found to be strongly dependent on development conditions.

An effective, practical, hypering recipe and processing system was clearly required if the newly available large format Tech Pan on film was to compete with hyperered IIIa-F emulsion on glass. In the following sections we describe the important criteria involved, the literature on hypering processes and the system evolved at UKST.

2.4 The characteristic curve, contrast and photographic emulsion speed

The usual means of expressing the operating characteristics of a photographic process is the curve relating measured output density 'D' to the logarithm of the exposure 'E' used to generate it and is referred to as the characteristic curve. Quite often we use Log Intensity 'LogI' instead, where exposure 'E' = I $\times$ time. For astronomical purposes emulsion speed is conventionally defined as the exposure time needed to produce a given density above the background chemical fog level (Scott, 1983, and Conrad et al. 1985). The more familiar ASA and DIN speed definitions are inverse functions of exposure time and are not appropriate for the long exposures used in astrophotography. At the UKST we measure relative speeds between different emulsion batches by reference to a chosen 'speed point' on the characteristic curves generated from sensitometer exposures taken under identical conditions of exposure time and processing.

A KPNO-type laboratory sensitometer, (Schoening, 1976) was used to expose hypered samples of IIIa-F and Tech Pan under identical conditions and with an exposure time of 60 minutes. In practice, the relative sensitivity is usually measured at a density of 1.0 above chemical fog as this has been found to correspond to peak values of $(S/N)_{out}$ where differentiation between the sky background and the faintest detectable images is optimised (Eccles, Sim & Tritton, 1983). Ultimately it is measured output signal-to-noise $(S/N)_{out}$ and hence effective detective quantum efficiency (DQE) of the hypered, exposed and processed product that affect the utility of an emulsion for deep astrophotography. This is related to hypering effectiveness, associated fog level growth and reciprocity behaviour, together with other emulsion properties such as contrast and granularity.

Fig. 2 gives typical examples of two such curves derived from consecutive UKST Tech Pan and IIIa-F 'OR' 70 and 60 minute exposures from measurements of their KPNO step wedges impressed at the time

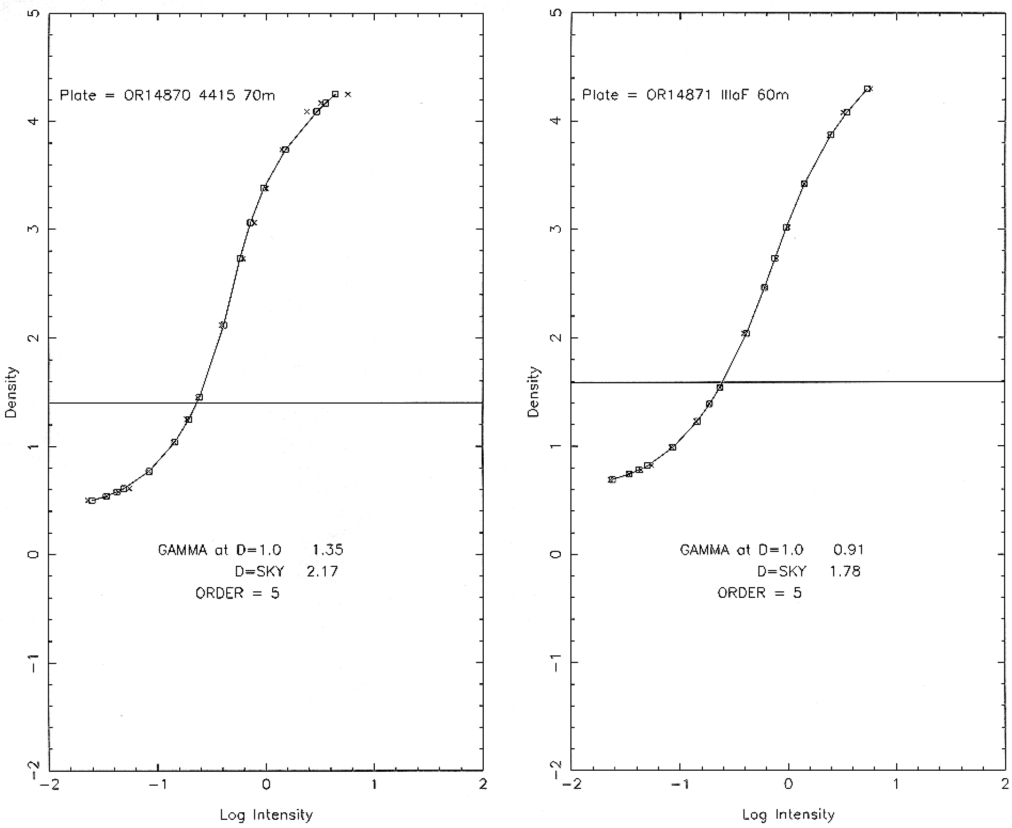

Figure 2: Direct comparisons between consecutive Tech Pan (left) and IIIa-F (right) UKST exposure characteristic curves obtained from their KPNO step wedge information. Exposures were taken through the same filter for 60 and 70 minutes respectively. The respective sky levels are indicated by the horizontal lines between a density of 1 and 2. The X-axis is LogI rather than LogE

of exposure. The slope of the straight line portion of these D-LogI curves is the contrast 'γ' while the sensitometric speed is usually expressed by some measure of the position of the D-LogI curve on the LogI axis. The sky level on both plots is indicated by the horizontal lines between a density of 1 and 2. Note the higher contrast at sky and steeper straight line portion of the Tech Pan D-LogI curve compared with the equivalent IIIa-F curve.

2.5 Emulsion fog, speed and LIRF

The emulsion chemical fog is the density found after development without exposure to light. It is generally used to indicate emulsion 'health' or freshness. All emulsions gradually fog on storage, though this is greatly reduced by low temperatures. However, this does not eliminate slow fog build-up from cosmic rays or from background radioactivity. The processing conditions, developer and development time also affect fog values (Conrad et al. 1985), though the most important source of chemical fog in fresh emulsions is hypering. Thus the fog level is used to monitor and govern the amount of hypering an emulsion can tolerate.

At the UKST we have found that for optimum results the chemical fog levels after hypering, exposure and development should not exceed 0.3 (ISO diffuse). Economics and practical difficulties of managing large numbers of hypered plates and films sometimes force this higher for less critical exposures. In practice, chemical fog level places a limit on either the vigour of the de-gassing cycle, or the extent of reduction sensitization with hydrogen. The art is to ensure complete de-gassing with small fog rise so that reduction sensitization can be as complete as possible, though it is usually measured only after both processes are complete. However, in general, the fog level can be used to monitor and govern the amount of hypering an emulsion can tolerate, though not all workers recorded the fog levels that their hypering tests produced.

However, it is important to recognise that the normal procedure of simply subtracting the measured level of chemical fog from the total density measurement can give misleading answers in relative speed determinations, as pointed out by Miller (1977). The chemical fog grains are not distributed uniformly between images of different densities. High image densities will include as image a contribution from some silver halide grains that would have developed as fog if the image had not been present, so, for relative speed measurements when the chemical fog level is affected by the process (e.g. hypering or developer tests, considered below), due allowance should be made for this. The higher the fog, the greater the importance of the effect. Miller convincingly demonstrates the apparent decrease in emulsion speed with extended hypering or development is entirely due to the failure to properly correct for chemical fog.

Smith (1982b), found that the apparent sensitivity of Tech Pan is a marked function of exposure duration, especially with unhypered material, confirming the information in Kodak Technical leaflet P-255 (1981). Of the hypering tests in the literature, most samples were exposed to laboratory sensitometers for typically 20 minutes and the quoted sensitivity gains refer to this exposure time. Though the unhypered film suffers severe LIRF, well hypered Tech Pan exhibits little LIRF with exposures ranging from 3 seconds to 2 hours, where the film still retains 70% of the sensitivity it had at 3 seconds. Everhart (1980) showed that hypered Tech Pan film only suffers $8 \pm 4\%$ sensitivity loss for 2–20 minute exposures, though he found the unhypered product loses half of its sensitivity over the same period. These laboratory tests have important implications for astronomical photography. Because LIRF is largely eliminated with the optimally hypered material the $(S/N)_{out}$ continues to increase uniformly with exposure until the sky background density reaches about 1.0 above fog—the 'sky limited' condition.

2.6 Effect of baking time on fog and speed levels

Baking in nitrogen prior to hydrogenation, as practiced at the AAT though not at the UKST, has the primary function of drying and de-oxygenating the emulsion, and a secondary sensitization function probably by enhancing the gold/sulphur sensitization applied during manufacture. Nitrogen baking times are generally much too short to have a significant effect on the chemical fog level. This is not the case when the chemically active hydrogen is present, either mixed with hydrogen (forming gas) or applied in the pure form later. Prolonged room temperature soak in nitrogen (Sim 1977), which is UKST practice, can lead to fog increases.

Though baking emulsions in the presence of hydrogen significantly improves long-exposure speed, there is an optimum baking time beyond which no further speed gain and often a decrease in measured speed is seen as the level of chemical (i.e. non-image) fog level continues to rise, though this is likely to be a measuring artefact – see Miller (1977). Developer type, time and temperature also affect fog values (Conrad et al. 1985), though the most important source of chemical fog is normally hypering.

In practice, chemical fog level places a limit on the extent of reduction sensitization with hydrogen. The art is to ensure complete removal of oxygen and water in nitrogen with small fog rise so that reduction sensitization with hydrogen can be as complete as possible. In general however, fog is only measured after both processes are complete.

2.7 Effect of development time on speed

Push processing is widely used to increase film speed in many applications, but unless a fog restrainer is used, the developer does not distinguish between chemical and latent image grains and increased development time therefore always increases chemical fog. Most Tech Pan sample tests reported in Table 1 were developed for 5 minutes in D-19, and the relative sensitivity was measured at a developed density of 1.0 above chemical fog.

Table 2: D-19 development time tests carried out on Tech Pan and IIIa-F for this paper

Sample number	Emulsion Type	Dev.time (mins)	Chemical fog level	γ_{fog+1}	Speed gain
5508	Tech Pan	5	0.19	2.66	1.00
5420	Tech Pan	10	0.38	2.37	2.19
5510	Tech Pan	15	0.83	2.06	1.55
5490	IIIa-F	5	0.28	2.00	2.34
5423	IIIa-F	5	0.35	2.22	1.62

The Kodak literature shows that the speed of unhypered Tech Pan is highly sensitive to developer choice, and Conrad et al. (1985) experimented with several different developers. D-19 was confirmed as the most useful but the sensitivity of hypered emulsion on film was found to be much higher if developing time was increased beyond the 5 minutes that has long been standard for IIIa and other emulsion types. Conrad found that processing hypered Tech Pan for 11 minutes in D-19 gave 1.8× more sensitivity than the same material processed for 5 minutes, though the fog level of his hypered material rose to a rather high 0.5. West et al. (1985) performed similar tests with unhypered and nitrogen baked Tech Pan on glass plates (5 mins in D-19) with the untreated emulsion giving a fog density of 0.08.

Thus, if the hypering recipe is adjusted to be effective but restrained to minimise fog rise, the additional speed gain from extended processing time is worthwhile, and it allows hypered Tech Pan to achieve long exposure sensitivity comparable with IIIa-F. Again, chemical fog rise is the limiting factor to extending processing times, and a processing time of 10 minutes in D-19 was adopted at the UKST after some experimentation. A development time of 15 minutes produced unacceptable chemical fog levels (see Table 2).

A sensitivity gain of 2.2 to 2.5 was typically found for optimally hypered Tech Pan samples developed for 10 minutes compared with Tech Pan developed for 5 minutes, and fog levels remained within the acceptable range of 0.3 to 0.5. This additional gain yielded a similar long exposure sensitivity (at density 1.0) to those routinely achieved with hypered IIIa-F, thus allowing the full potential of Tech Pan to be realised without an increase in exposure time. As a typical example of the improvement in depth and image quality offered by the well hypered Tech Pan film compared with the standard IIIa-F emulsion, Fig. 3 shows small 2.2×1.7 arc-minute image areas from two sets of consecutive Tech Pan and IIIa-F 60 minute exposures of UKST survey fields 263 and 430 taken under identical good 'survey' observing conditions.

2.8 Storage of hypersensitised Tech Pan film

One marked effect of hypering is on the product's 'shelf life', which is why manufacturers cannot supply hypered products. Generally the more severe the hypering the shorter the pre- and post-exposure shelf life. This instability is usually seen as a chemical fog rise, rather than speed loss. Baked and hydrogenated plates at the AAT, hypered to maximum speed, can become unusable in a few hours when stored at 20°C in nitrogen. The same emulsion hypered by the UKST method of prolonged nitrogen soak followed by hydrogenation is deliberately adjusted to produce slightly less sensitive plates, but they can remain usable for several months. For Tech Pan, Everhart (1980) found there was little speed loss in film hypered for 5 hours in 8% forming gas at 60°C and then stored in air for a few days at 10°C. Smith (1982a, 1983) and Conrad et al. (1985) stored hypered samples in dry nitrogen at −25°C for several weeks with no adverse effects, while Martys (1984) found that 4×5 inch film holds its sensitivity for several months if stored in air-tight containers in a deep-freeze, though unpredictable fog growth can occur.

Of course, it is difficult to assess the effectiveness of hypering in any absolute sense in these experiments, but they suggest that hypered Tech Pan stores well in an inert atmosphere under cold conditions.

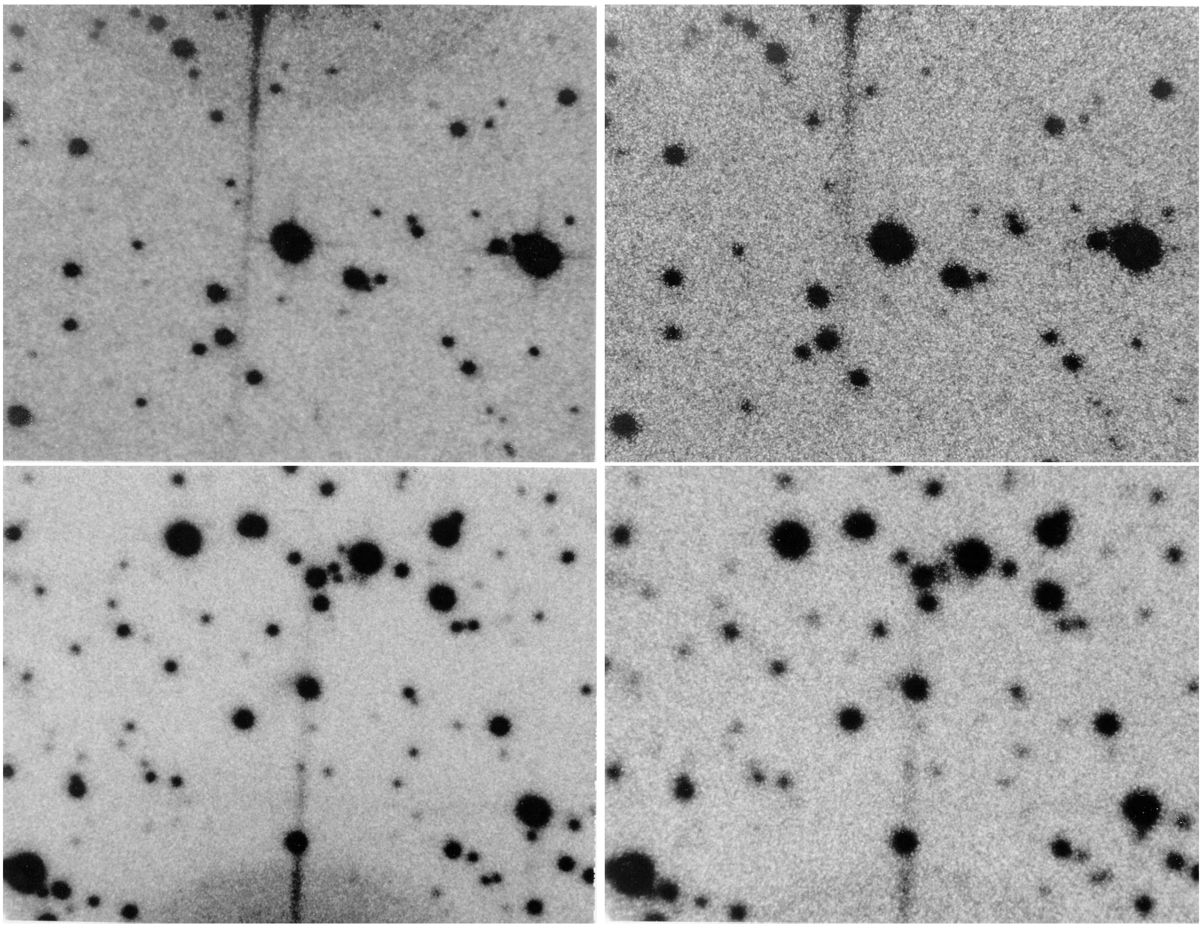

Figure 3: Direct image comparisons between two sets of consecutive Tech Pan and IIIa-F UKST exposures through the same filter. Tech Pan images are on the left in each case. Each image is 2.2×1.7 arc-minutes across taken from close to the field centres with NE to top left.

This is confirmed with our experience at UKST, which clearly shows that optimally hypered Tech Pan film keeps well for at least a month when stored in nitrogen-filled boxes at 4°C.

2.9 Tech Pan Hypersensitisation tests at the UKST

Given the large and interacting set of variables noted above it is not too surprising that the various tests described in the literature led ocassionally to conflicting results. No one set of experiments effectively combined the competing effects of LIRF, hypering recipe and processing conditions to the best advantage. Hypering experiments with Tech Pan film and glass samples were undertaken at UKST during 1981 and 1987 when this emulsion was being evaluated using standard hypersensitisation techniques, though the emulsion was not used in the telescope. The original sensitometric test plates and films were re-measured for this paper. It was found that the wide-field astronomical potential of Tech Pan was hidden in the data obtained in 1981 in the few samples baked in hydrogen at higher than normal temperatures. However, though hypering with pure hydrogen at room temperature had been adopted early at UKST (Sim et al. 1976 and Sim 1977), few of the tests had examined the effect of hydrogenation at elevated temperatures, partly because of safety issues and partly because hydrogen at room temperature had proved adequate for all other other emulsions tested to that time.

A Kitt Peak-type sensitometer with a tungsten lamp was employed for the UKST tests (Schoening 1976). A Schott RG 630 red filter was used for two sets of 1981 tests (samples 3217–3230 and 3289–3322) while for the 1987 tests (samples 4494–4559) a slightly wider OG 590 filter was used. The most pertinent results from the three test sample sets are presented in Table 3.

Since the exposure times within each sample set were identical, and similar to those used for standard UKST sky-limited exposures (60 minutes), relative speeds were derived from the ratio of the relative intensity at a density of 0.6 above fog, using the characteristic curves generated from the preserved test samples, compared with the exposure required to reach the same density above fog for the unhypered material. The exposure times were self consistent within each sample set (varying between 60 and 90 minutes) so the speeds between each set are indicative rather than being strictly comparable.

In the column 'Hypering recipe' in Table 3, nitrogen soaking (N) is given in days or fractions of days and the period in vacuum (V) or hydrogen (H) is given in hours. The speed_1 gain column gives speeds relative to an arbitrary unhypered sample of IIIa-F (batch No.2I9) exposed under identical conditions (applies only to samples 3217–3230). The speed_2 gain column gives speeds relative to unhypered Tech Pan on glass (sample 3230). Column 6 refers to the baking temperature of the emulsion samples in both Nitrogen and Hydrogen apart from the two asterisked samples where the Hydrogen 'bake' was at only 20°C. The 3 sets of emulsion test samples are ordered in terms of increasing Nitrogen, Hydrogen or vacuum soak times.

Most of the standard hypering recipes had little effect on the long exposure speed of Tech Pan on either film or glass, even with levels of treatment that would have completely fogged IIIa emulsions. Similar results were reported by West et al. (1981). Unexpectedly, the greatest gains were achieved with prolonged hydrogen soaking (in the case of samples 3217 and 4502, without prior nitrogen or vacuum treatment) or following a few hours of hydrogen baking (e.g. sample 3306 in the second set of tests at 60°C). The small effect of the removal of oxygen and water, which long experience showed was essential for the earlier generation of spectroscopic emulsions, seemed to be much less important with Tech Pan. These surprising results tie in well with the consensus on optimum Tech Pan hypering that has emerged from the literature (i.e. speed gains of 8 to 10 times after 2 hours hydrogen baking at 65°C).

As remarked by Smith (1982a), in comparing hypering results, a general rule of thumb in chemistry is that a first order reaction rate doubles with every 10°C temperature rise. Hence 16 hours hydrogen soak at 20°C in the first series of tests (sample 3217) is roughly equivalent to 1.5 hours at 60°C. The resultant speed gain of 18 times compares favourably with the Smith (1982b) gains of 20 times from Tech Pan film baked in hydrogen at 67°C for 2 hours after vacuum treatment.

The current UKST hypering recipe is to bake Tech Pan films in hydrogen at 35°C for 10 hours after a prolonged nitrogen soak of between 10 and 150 days, with 60 being typical. The length of nitrogen soak time appears to have little effect on the final film speed. This process was adopted by scaling the

Table 3: Summary of relevant hypering tests at the UKST between 1981 and 1987 during the early Tech Pan evaluation phase. Samples were developed in D-19 for 5 minutes at 20°C. Asterisked samples indicate that the hydrogen soaks were at 20°C and not 60°C as for the Nitrogen bake. Exposure times were either 60 or 90 minutes. See text for explanations of other terms.

Sample	Date	Emulsion	Format	Hypering recipe	Baking Temp.	Speed_1 gain	Speed_2 gain	Fog level
3229	8/8/81	IIIa-F	Glass	0N+0H	20°C	1.0	2	0.09
3230	8/8/81	Tech Pan	Glass	0N+0H	20°C	0.5	1.0	0.15
3217	5/8/81	Tech Pan	Film	0N+16H	20°C	11	18	0.26
3218	5/8/81	Tech Pan	Glass	0N+16H	20°C	2.5	4	0.16
3222	6/8/81	IIIa-F	Glass	0N+16H	20°C	13.5	21.5	1.07
3223	6/8/81	Tech Pan	Film	48V+0H	20°C	0.7	1.1	0.20
3224	6/8/81	Tech Pan	Glass	48V+0H	20°C	0.8	1.5	0.14
3225	7/8/81	IIIa-F	Glass	48V+0H	20°C	2	3.5	0.11
3226	7/8/81	Tech Pan	Film	48V+6H	20°C	3	5	0.31
3227	7/8/81	Tech Pan	Glass	48V+6H	20°C	1.5	3	0.15
3228	7/8/81	IIIa-F	Glass	48V+6H	20°C	17	27	0.25
3289	5/12/81	Tech Pan	Glass	0N+0H	20°C	-	1.0	0.17
3324	18/12/81	Tech Pan	Film	0N+0H	20°C	-	1.5	0.14
3318*	17/12/81	Tech Pan	Glass	0.25N+3H	60/20°C	-	2.5	0.17
3319*	17/12/81	Tech Pan	Film	0.25N+3H	60/20°C	-	3.5	0.25
3320	18/12/81	Tech Pan	Glass	0.25N	60°C	-	1.5	0.15
3322	18/12/81	Tech Pan	Film	0.25N	60°C	-	3	0.27
3306	11/12/81	Tech Pan	Glass	0.83N+4H	60°C	-	45	0.83
3300	8/12/81	Tech Pan	Glass	7.42N	60°C	-	5	0.16
4494	6/10/87	Tech Pan	Glass	0N+0H	20°C	-	1.0	0.12
4499	6/10/87	Tech Pan	Glass	0N+6H	20°C	-	7	0.14
4502	6/10/87	Tech Pan	Glass	0N+12H	20°C	-	12.5	0.18
4523	26/10/87	Tech Pan	Glass	26N+0H	20°C	-	2	0.13
4529	26/10/87	Tech Pan	Glass	26N+6H	20°C	-	7	0.14
4543	26/11/87	Tech Pan	Glass	51N+0H	20°C	-	4	0.12
4550	26/11/87	Tech Pan	Glass	51N+6H	20°C	-	5	0.14
4553	22/12/87	Tech Pan	Glass	77N+0H	20°C	-	2	0.12
4559	22/12/87	Tech Pan	Glass	77N+6H	20°C	-	7	0.14

best results from Tables 1 and 2 together with more recent experiments, trading off hydrogen baking temperature and time. The final adopted recipe, used with 10 minutes D-19 processing, gave excellent results in the telescope in terms of speed, LIRF, contrast and fog levels.

3 Practical considerations for UKST Tech Pan film use

The ability to use film-based emulsions in the UKST was seen as a cost-effective addition to normal operation in the late 1980s and was encouraged by Colin Humhpries and Ann Savage, successive Astronomers In Charge. However, though hypering and processing tests revealed its astronomical potential, several practical difficulties had to be overcome before hypered Tech Pan could be used routinely in the telescope. Specifically, modifications were required to the hypersensitisation plant, storage tins and handling frames to accommodate film, and other mechanical problems with mounting film in the telescope had to be addressed. Early experiments with mounting film (not Tech Pan) in the UKST met with only limited success (Humphries & Morgan 1988). It was the work of Russell et al. (1992) that finally demonstrated the viability of mounting Tech Pan successfully in the UKST.

3.1 Implementation of Tech Pan film hypering and processing procedures at the UKST

Once it was clear that the practical problems could be overcome, routine hypering of Tech pan required accurate temperature control of the hypering process at much higher temperatures than usually required for IIIa materials. The entire hypering system was refurbished in 1994 to achieve this and the normal six-plate hypering tins were modified to enable up to 12 films to be hypered simultaneously. The films themselves are supported on aluminium inserts which prevents contact between films while helping to maintain their flatness. The films are generally stored at 4°C in dry nitrogen until they are required.

Special film handling frames were constructed to allow use of the standard plate processing line. Identical processing chemistry is used although Tech Pan film is developed for 10 minutes, twice as long as plates. Once loaded into the handling frames the films can be treated in the same manner as glass plates. The processed films are susceptible to dust, and the Estar support scratches easily, so films are placed into clear plastic storage sleeves after processing to minimise dust accretion and then, together with a film stiffener sheet, inserted into normal plate storage envelopes. Films are only removed from their plastic sleeves for machine digitisation or photographic copying. Careful handling of the films is required as they can 'kink' leaving permanent indentations in the Estar which makes copying and machine scanning of the original films more difficult.

3.2 Mounting Tech Pan film in the UKST

The focal surface of the UKST is part of a sphere of radius 3.05m. Normally 1 mm thick glass plates are conformed to this surface by mechanical pressure and are held against a curved mandrel by a vacuum when the plate holder is inside the telescope. Because films are inherently more flexible they are difficult to simultaneously stretch and compress uniformly to the entire curved focal surface. For Tech Pan the film mounting problem eased when thick (178μm) Estar base became available in 356×356mm formats. The thicker base is much less flexible than the 100μm variety used initially facilitating easier handling and mounting. Nevertheless, initial trials still produced grossly de-focused images. A number of modifications were implemented from 1991 onwards and the film mounting system has been steadily improved so that all stages of film handling are now as simple as handling plates.

Though numerous and detailed, these minor plate-holder modifications should be applicable to any large Schmidt telescope equipped with vacuum backed plate-holders (e.g. the ESO schmidt, Reipurth 1996).

4 Conclusions and future work

The astronomical potential of Tech Pan and its good response to hypering is well documented in the literature. We have used these data and a series of initially inconclusive in-house experiments to arrive at a process that is convenient, reproducible and safe. Excellent long-exposure Tech Pan sensitivity was attained by a combination of drastically modified hypering procedures, including the use of hydrogen at elevated temperatures, and longer development times. Once it was clear that the hypering processes were successful, significant work was required to modify the plate holders to accept film.

We can now routinely exploit this inexpensive, fine grained, high contrast material to the full, enhancing the capabilities of the UKST (Parker et al. 1999). Particular benefits arise from work on low surface brightness objects (Phillipps and Parker 1993, Schwartzenberg, Phillipps and Parker 1995) and the digital stacking of multi-exposures of the same field, results which compare well with CCDs (Schwartzenberg, Phillipps and Parker 1996). The excellent imaging properties and sensitivity of the optimally hypered product, together with the enhanced sensitivity of the emulsion around Hα, has led to the new AAO/UKST narrow-band Hα survey of the Galactic-Plane, Magellanic clouds and selected regions (Parker and Phillipps 1998a, 1998b). This new survey is already leading to many exciting discoveries. Though consistently deep Tech Pan exposures are now routine on the UKST for a variety of passbands including U, V, R, OR and Hα, the full range of hypering possibilities, including vacuum treatment and baking, have not been explored. Our work shows that D-19 appears to give the best processing results but other developers may prove superior, perhaps with the addition of a fog suppressant. It is not known how well or even if this fine grained material resists the gold spot oxidation deterioration that severely affects many IIIa plates several years after processing. However, in the 6 years since Tech Pan was introduced at the UKST, no films have yet been shown to be affected.

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References

Babcock, T. A., Ferguson, P. M., Lewis, W. C. & James, T. H. 1975. Phot. Sci. Eng. 19, p49 & p211

Conrad, C. M., Smith, A. G., & McCuiston,W. B., 1985. AAS Photo-Bulletin. No. 38, 3

Eccles, M. J., Sim, M. E. & Tritton, K. P. 1983. 'Low level light detectors in Astronomy', Chapters 2 & 3, Cambridge University Press

Everhart, E. 1980. AAS Photo-Bulletin. No. 24, 3

Everhart, E. 1981. In 'Astronomical Photography', 117, Occasional reports of the Royal Observaory Edinburgh, Eds. J. L. Heudier and M. E. Sim

Hadley, B. W. 1984. In 'Astronomical Photography', 177, Occasional reports of the Royal Observatory Edinburgh, Eds M. E. Sim and K. Ishida

Heudier, J.L., Labeyrie, C., Maury, A. 1981. in 'Astronomical Photography', Occasional reports of the Royal Observatory Edinburgh, Eds. M. E. Sim and K, 113

Humphries, C. M. & Morgan, D. H. 1988. In 'Astrophotography', p234, Ed. S. Marx, Springer-Verlag, Heidelberg

Kodak Publication Q-34, 1970

Kodak Publication P-255. 1981
Kodak Publication P-315. 1987
Liller, W. 1985. AAS Photo-Bulletin. No. 39, 6
Malin, D. F. 1978. In 'Modern Techniques in Astronomical Photography', Proceedings ESO conference, Eds. R. M. West & J-R. Heudier, 107
Marling, J. B. 1980. AAS Photo-Bulletin. No. 24, 9
Martys, C. R. 1982. AAS Photo-Bulletin. No. 29, 11
Martys, C. R. 1984. In 'Astronomical Photography', Occasional reports of the Royal Observatory Edinburgh, Eds. M. E. Sim and K. Ishida, 135
Martys, C. R. 1991. J. Br. Astron. Assoc. 101, 4
Miller, W. C. 1977. AAS Photo-Bulletin. No. 16, 3
Morgan, D. H. & Parker, Q. A. 1998. 'Multiwavelength Sky Surveys', Kluwer, IAU Symp. 179, Eds. B. J. Mclean et al., 374
Ogura, K., & Liller, W. 1985. AAS Photo-Bulletin. No. 40, 11
Parker, Q. A., Phillipps, S. & Morgan, D. H. 1995. In 'Future Utilisation of Schmidt Telescopes', IAU Coll. 148, ASP conf. ser. 84, Eds J. M. Chapman, R. D. Cannon, S. J. Harrison & B. Hidayat, 129
Parker, Q. A., & Phillipps, S. 1998a. PASA, 15, 28
Parker, Q. A., & Phillipps, S. 1998b. A&G, 39, Issue 4, 10
Parker, Q. A, Malin, D. F., Cannon, R. D., Phillipps, S. & Russell, K. S. 1999. MNRAS, (submitted)
Phillipps, S. & Parker, Q. A. 1993. MNRAS, 265, 385
Reipurth, B, 1996, ESO Mesenger, 85, 8
Roberton, W. J., 1984. In 'Astronomical Photography', Occasional reports of the Royal Observatory Edinburgh, Eds M. E. Sim and K. Ishida, 191
Russell, K. S., Malin, D. F., Savage, A., Hartley, M. & Parker, Q. A, 1992. In 'Digitised Optical Sky Surveys', Kluwer, Eds H. T. MacGillivray & E. B. Thomson, 23
Schoening, W.E. 1976. Bull. Am. Ast. Soc. 11
Scott, R. L. 1983. AAS Photo-Bulletin. No. 33, 14
Scott, R. L. 1986. AAS Photo-Bulletin. No. 42, 6
Schwartzenberg, J. M., Phillipps, S. & Parker, Q. A. 1995. A&A, 293, 332
Schwartzenberg, J. M., Phillipps, S. & Parker, Q. A. 1996. A&A Suppl. Ser, 117, 179
Sim, M. E., Hawarden, T. G. & Cannon, R. D. 1976. AAS Photo-Bulletin. No. 11, 3
Sim, M. E. 1977. AAS Photo-Bulletin. No. 14, 9
Smith, A. G. 1982a. AAS Photo-Bulletin. No. 30, 6
Smith, A. G. 1982b. AAS Photo-Bulletin. No. 31, 9
Smith, A. G. 1983. AAS Photo-Bulletin. No. 34, 3
Smith, A. G. & Leacock, R. J. 1973. AAS Photo-Bulletin No. 7, 18
Smith, A. G., Phillips, C. A., Hahn, E. J. & Leacock, R. J. 1985. AAS Photo-Bulletin No. 39, 8
Walker, P. E. 1980. AAS Photo-Bulletin. No. 24, 7
West, R. M., Kurtanidze, O. M., Geonijan, L. A. & Kimeridze, G. N. 1981. AAS Photo-Bulletin. No. 28, 3