Cooling

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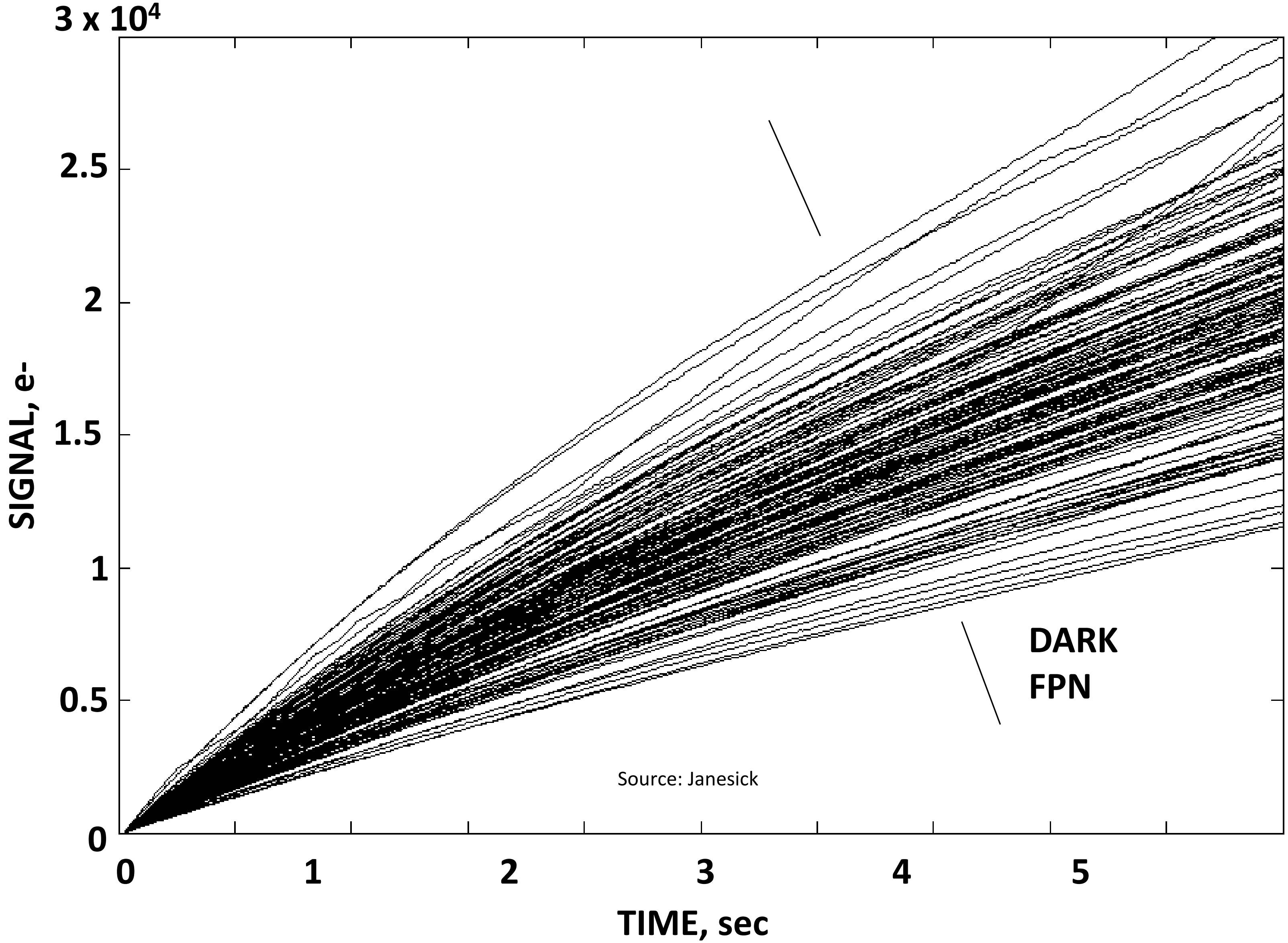
Cooling considerations

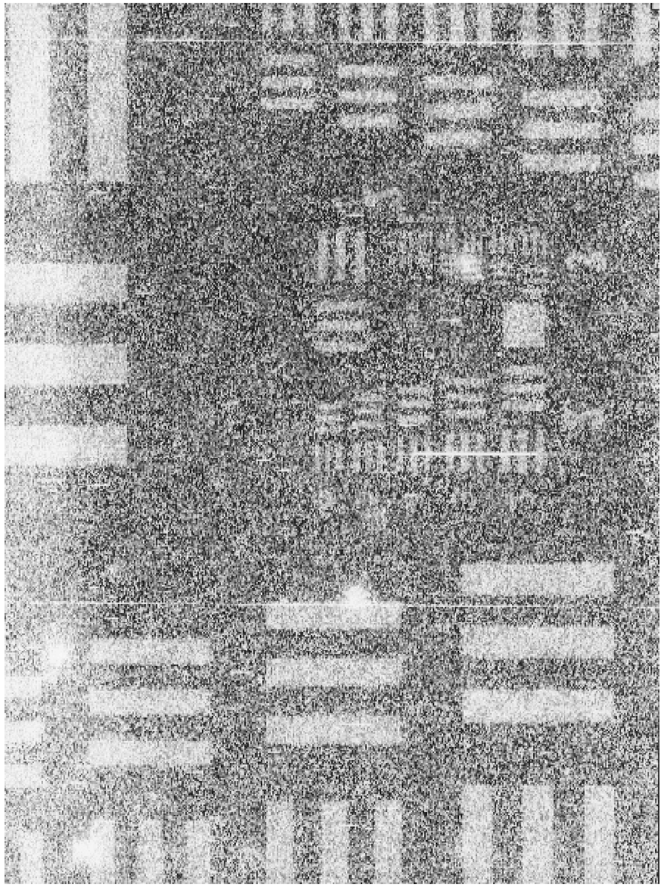
Key cooling considerations

- Dark signal Fixed Pattern Noise
- Dark shot noise control
  - RBI Management potentially
- Management of cosmetic defects

DARK CURRENT FPN (variation from pixel to pixel, large collection of pixels plotted)

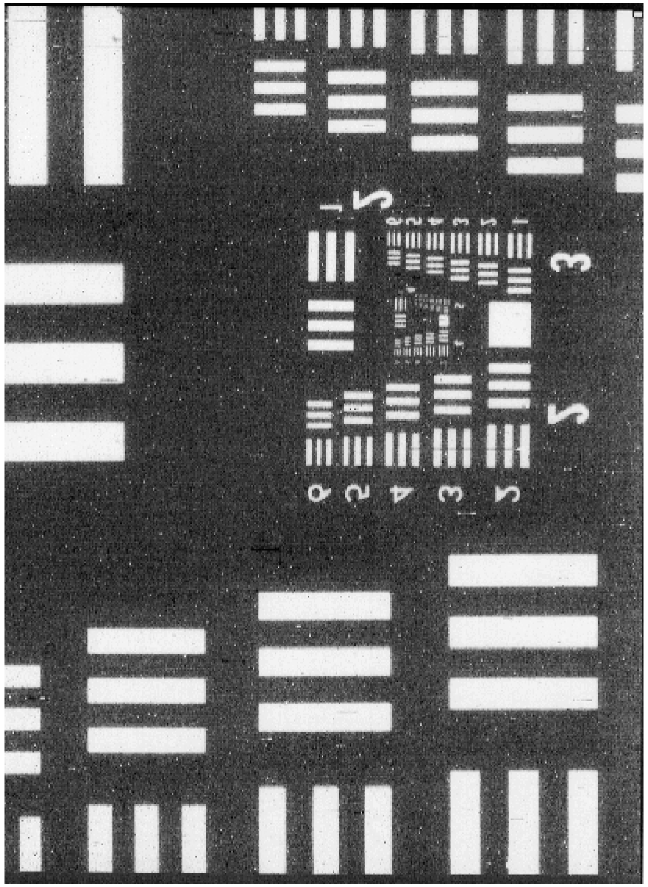


Dark Signal: Fixed Pattern Noise (DFPN) and removal



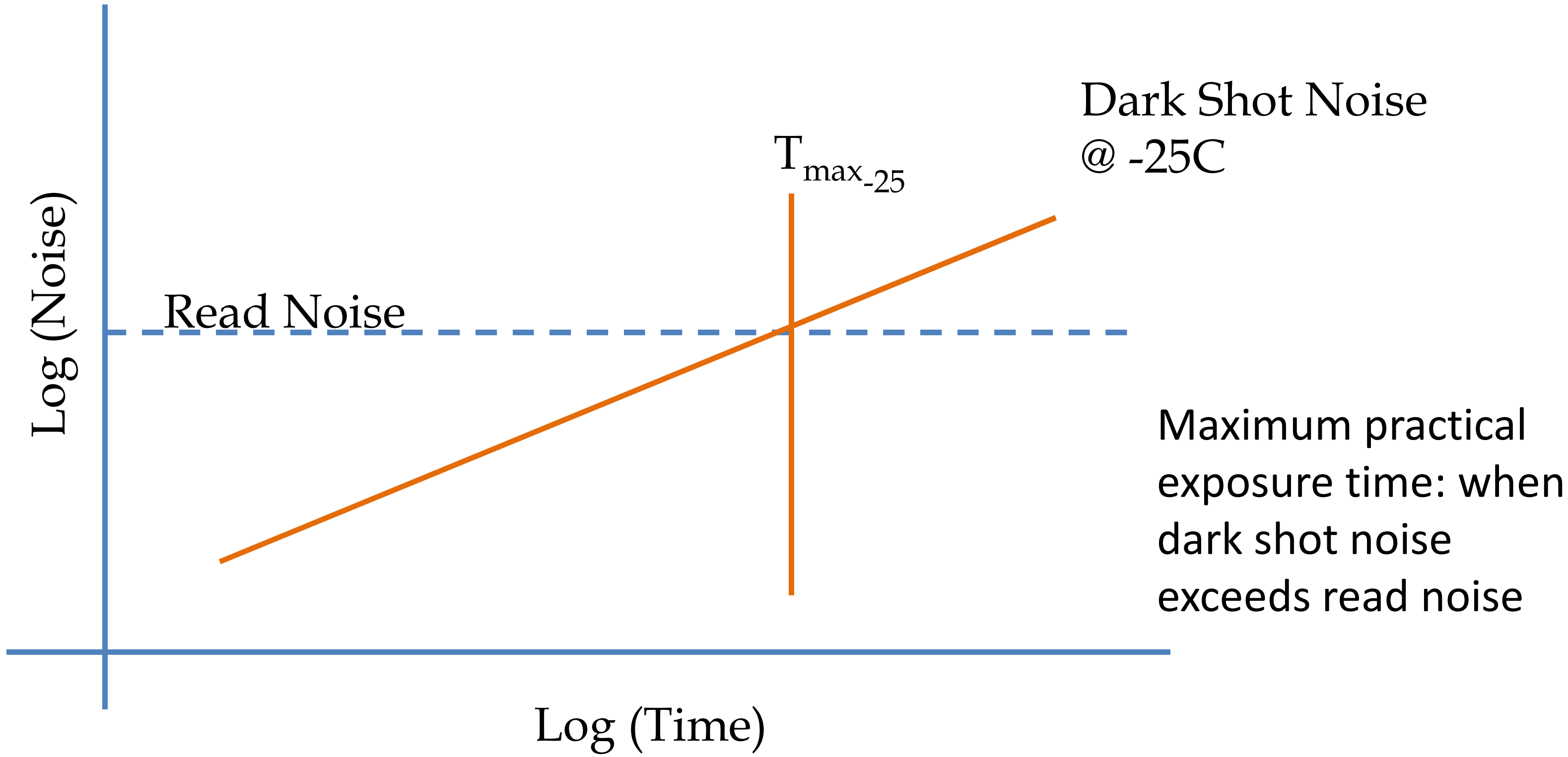
RAW IMAGE

Source: Janesick

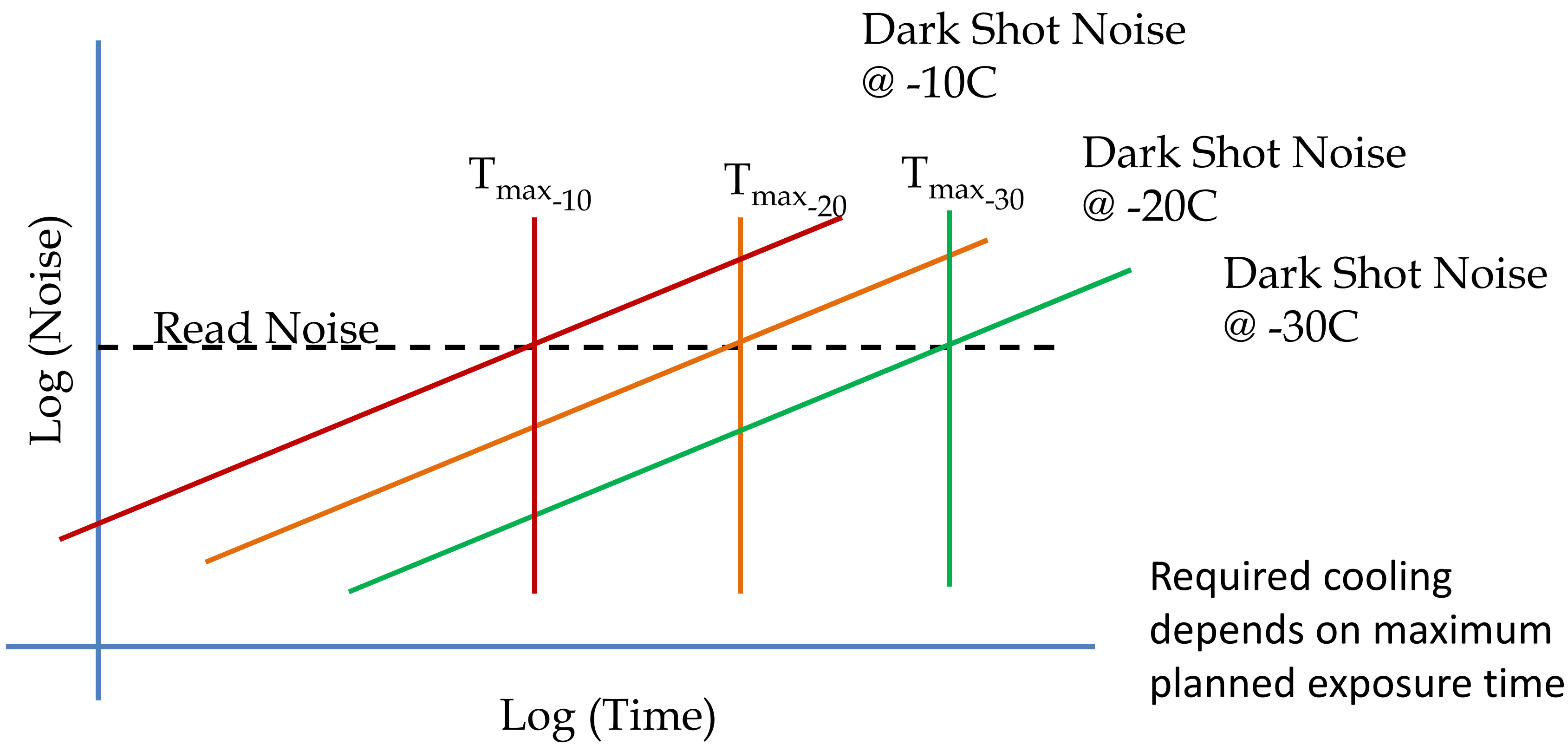


DESPIKED IMAGE
(Dark–subtraction removes DFPN when pixels are not saturated)

Dark Shot Noise: Dark signal is important



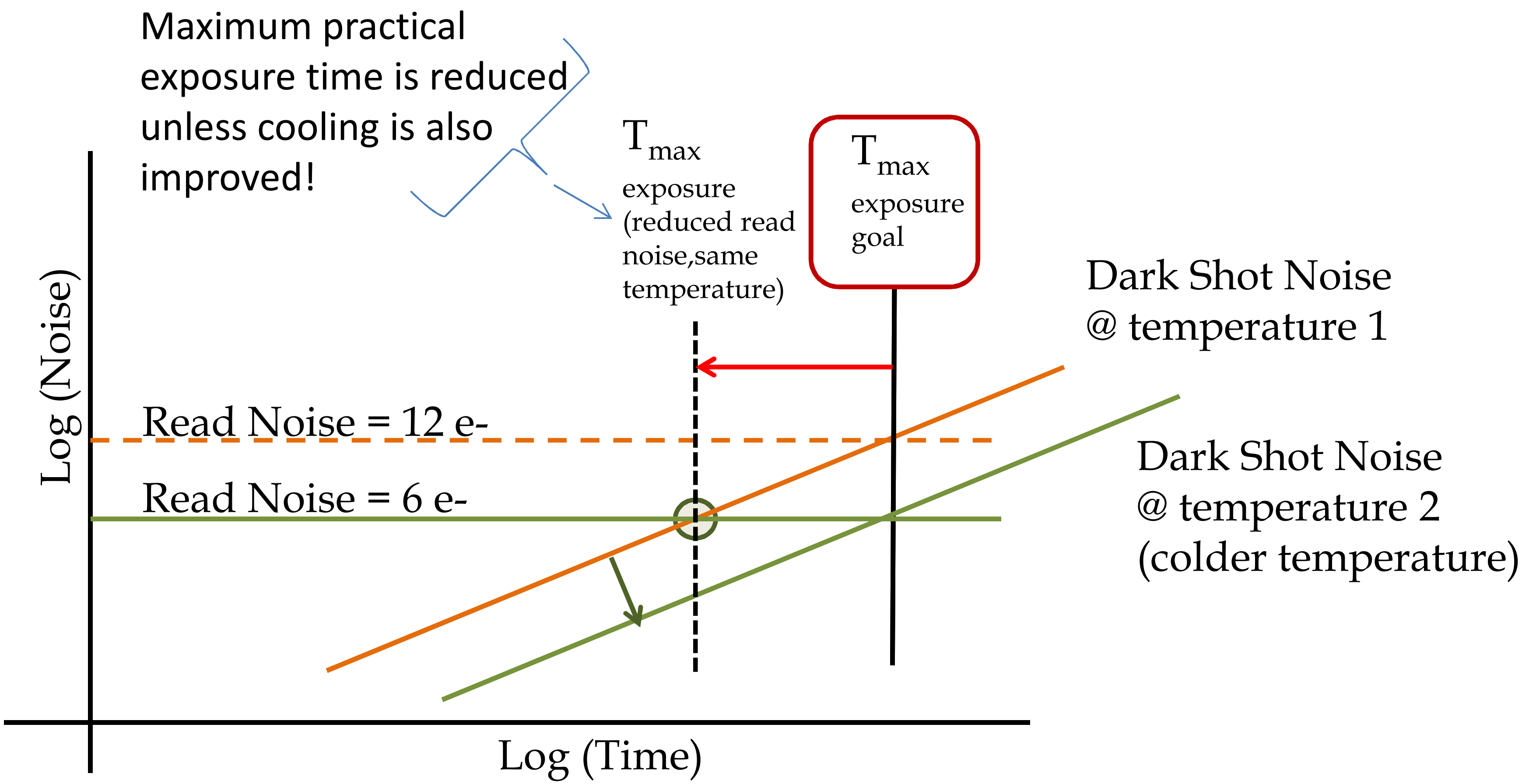
Dark signal limits maximum exposure time



Required cooling depends on maximum planned exposure time

Dark shot noise is NOT removed by dark subtraction
Only cooling can reduce dark shot noise for a given sensor

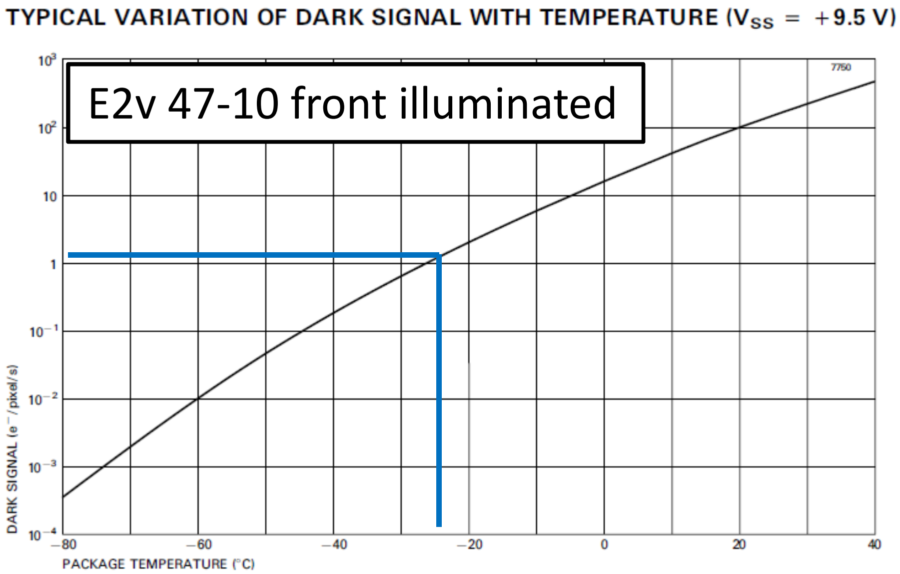
Dark Shot Noise management in Low Noise Camera Design

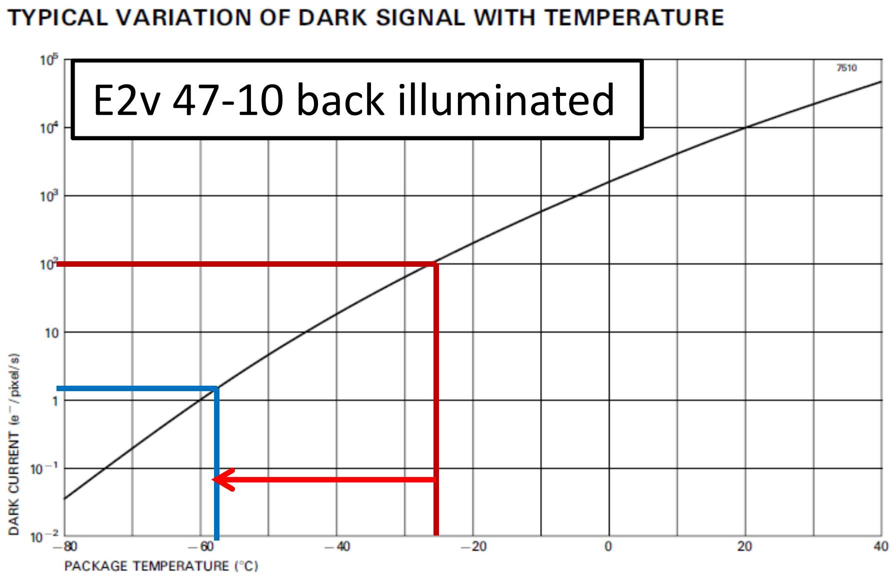


If you reduce the read noise:

need better cooling to exploit the improvement

Dark Signal: Front vs Back Illuminated (e2v 47-10 example)





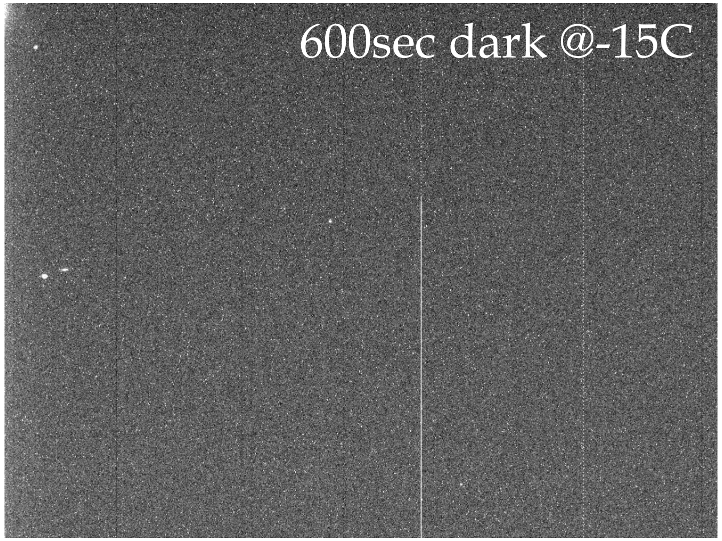
Front Illuminated:
@ -25C, ~1.1e-/pixel/sec

Back Illuminated:
@ -25C, ~100e-/pixel/sec

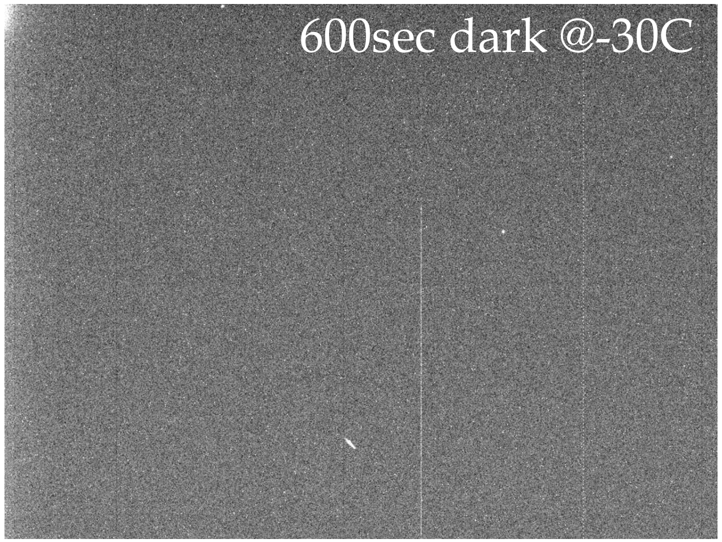
To reach 1.1e-/pixel/sec, must operate at -58C!!

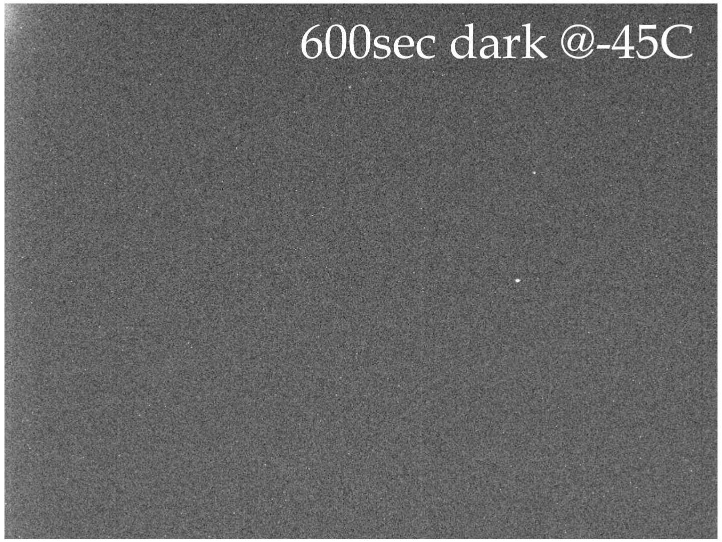
Dark Current is SIGNIFICANTLY higher for BSI CCD: ***requires much deeper cooling***!

Sensor Issues: Managing Cosmetic Defects via Cooling



Sensor was grade 1
when deployed
Some bad columns
developed later





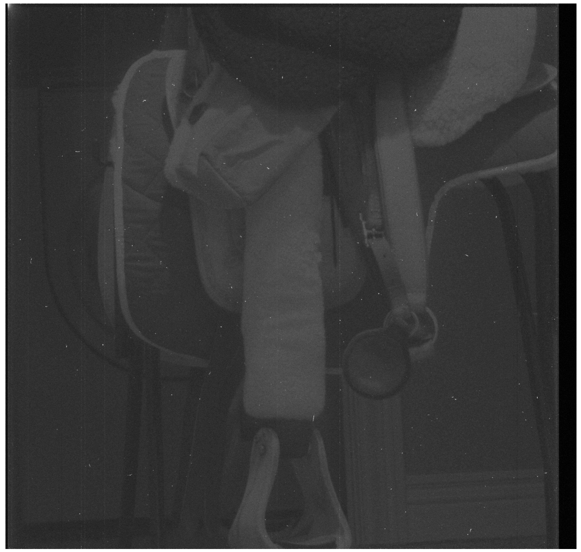
Sensor Issues: RBI

Long exposures in red and or with NIR: RBI issue

- Use "light-flood" and deep cooling to remedy: same as Cassini/Galileo

Image

5 Minute Dark
Immediately
following image



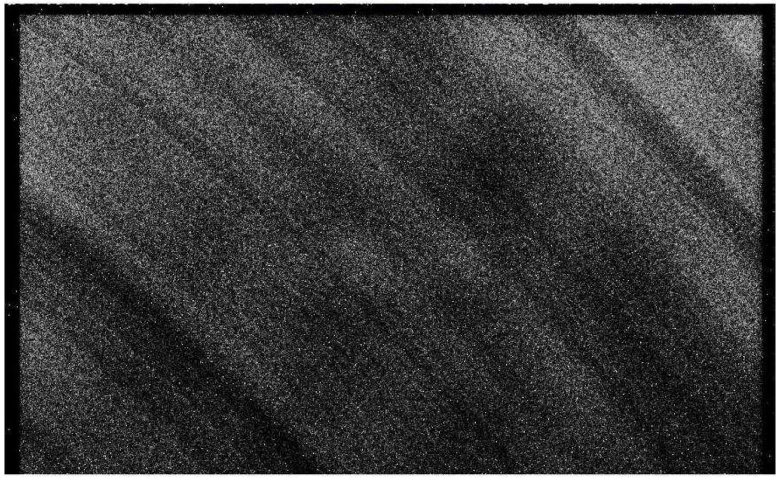
5 Minute Dark
One hour
following image

RBI Realities

- Full Frame CCDs such as e2v and Kodak exhibit RBI to some degree from bad to barely noticeable. It is a by-product of the materials used in the CCD manufacturing process
- Trapping sites capture photoelectrons and release the trapped charge slowly, as a function of temperature. This deferred charge creates a residual image.
- Traps can be filled prior to exposures to place sensor in known state.
  - Significant dark fixed pattern noise is observed from leakage from filled traps
  - Non uniformities from the trap leakage are removed by dark subtraction
- The filled traps leak at a rate higher than thermal generated dark signal when filled traps are operated at typical CCD operating temperature of -25C for KAF series CCDs. The leakage rate from filled traps can range from 5x to 10x more than the thermally generated current at the beginning of an exposure
- Substantially deeper cooling is required to limit the shot noise from the trapped charge leakage to remain below the read noise limit for a given length maximum planned exposure

Dark FPN from leaking traps

Raw image showing Dark FPN



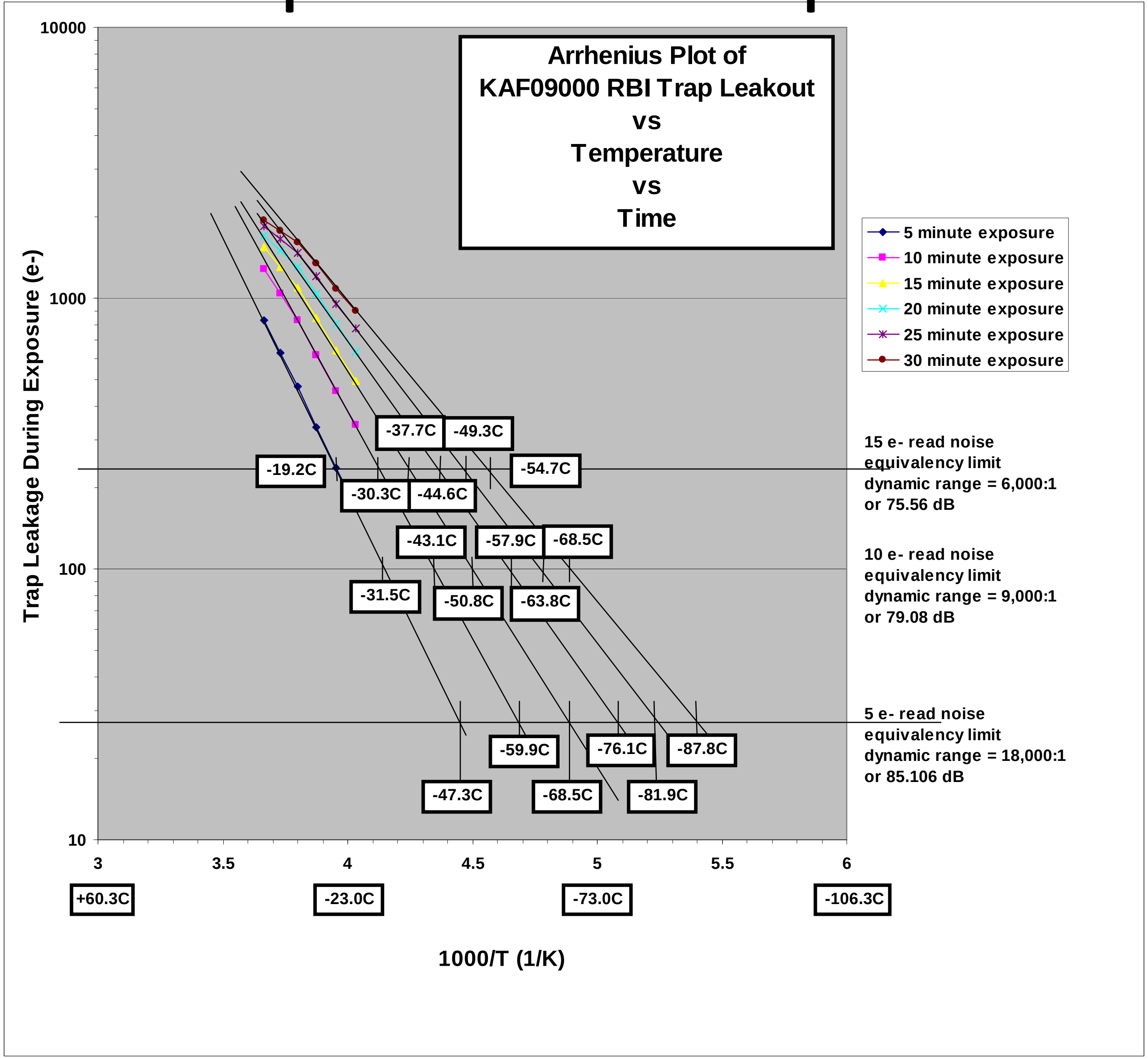
Dark image showing Dark FPN

Calibrated image showing Dark FPN removal

Dark Shot noise from leaking RBI traps

- Leakage from pre-filled RBI traps contributes to dark signal, hence dark shot noise
- Typically this signal is 3 to 10 time higher than thermal dark signal for exposures up to 30 minutes at typical operating temperatures (~-25C)
- This extra component of dark signal significantly increases the dark shot noise and typically establishes the maximum practical exposure time (defined as dark shot noise = read noise)

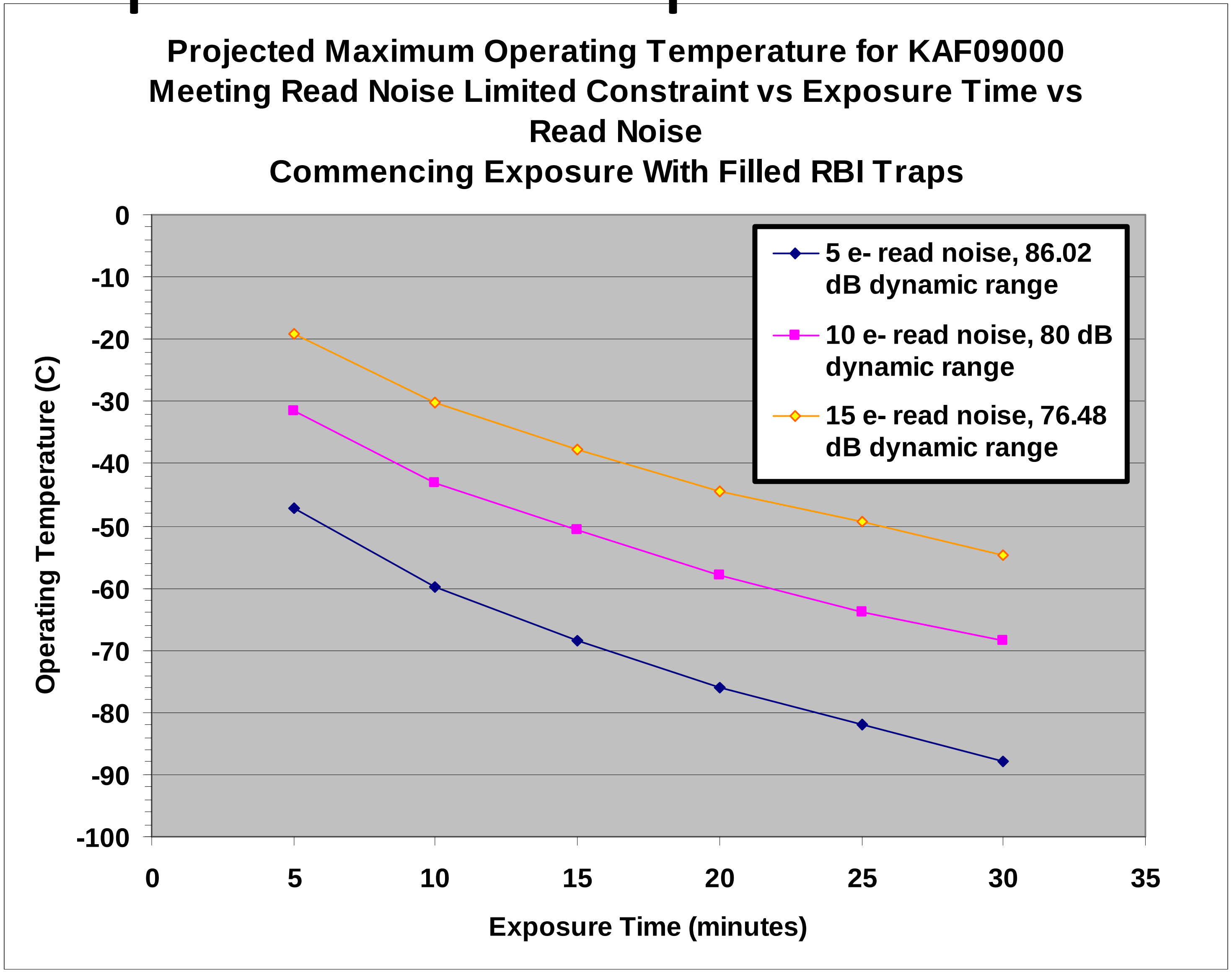
Empirical + Extrapolated Data



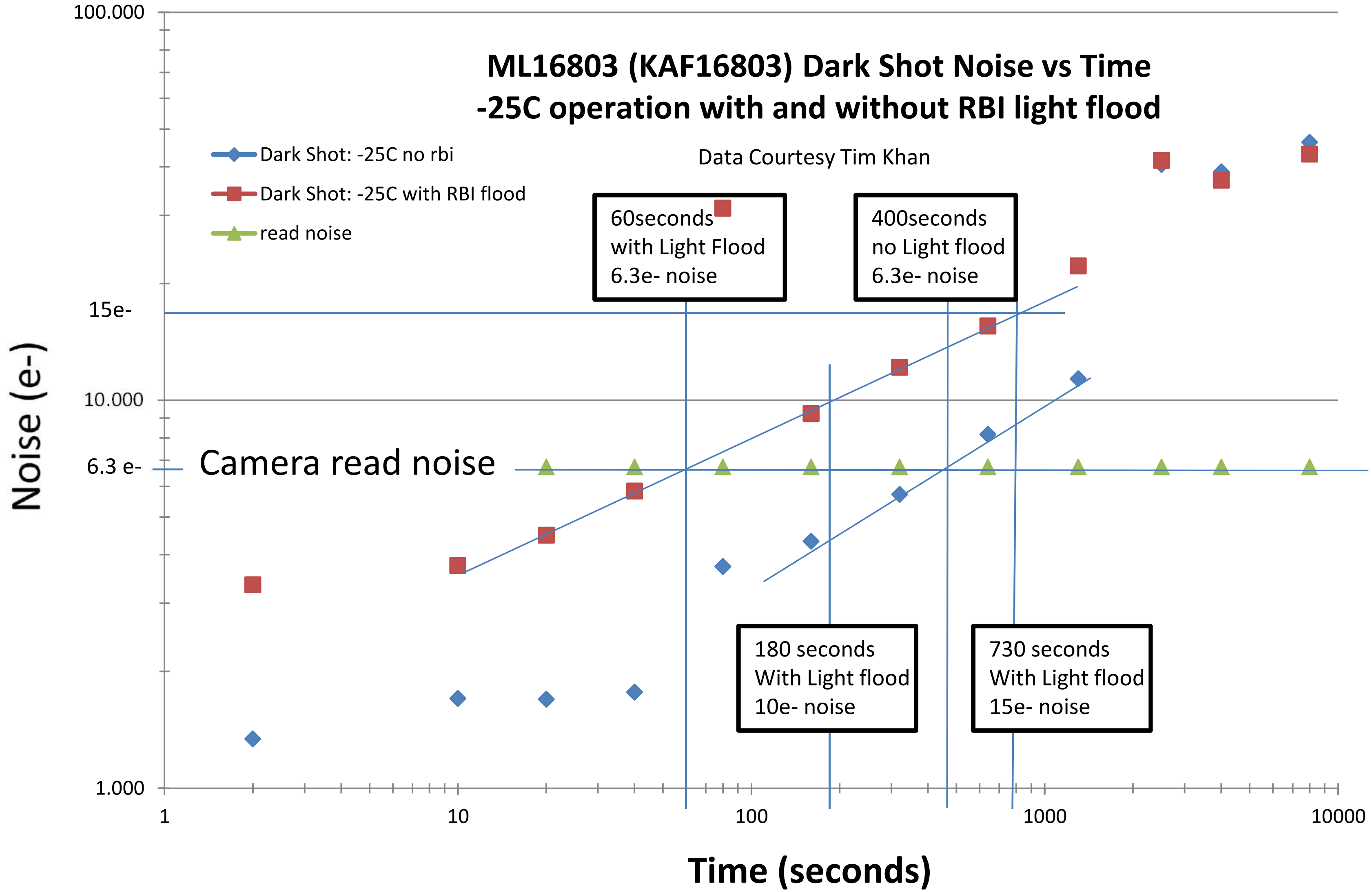
Arrhenius Plot of Trap Leakage (e-) vs Temperature for various exposures times

This shows the operating temperature necessary to attain arbitrary read noise limits for a given exposure duration

Empirical + Extrapolated Data

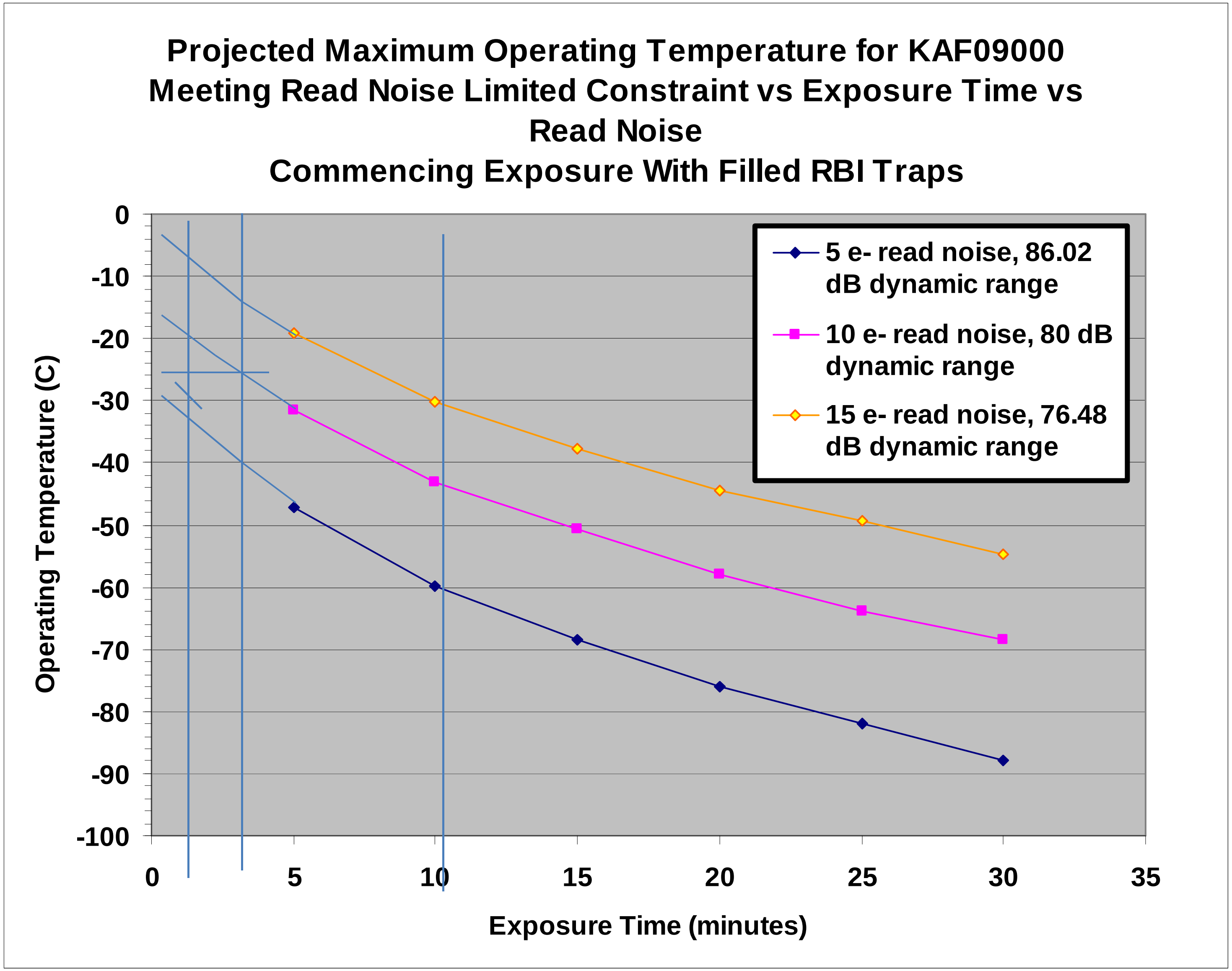


Empirical Data from KAF16803



‘16803 compared to ‘09000

‘16803	‘09000
1 minute @ 6 e- noise:	1 minute @ 6 e- noise:
-25C	-30C
180 sec @ 10 e- noise:	180 sec @ 10 e- noise:
-25C	-26C
730 sec @ 15 e- noise:	730 sec @ 15 e- noise:
-25C	-30C



Cooling Summary

- Most Dark FPN is removed by dark subtraction. Dark Shot noise can only be managed by cooling for a given sensor and exposure time
- BSI CCDs have much higher dark signal than front-illuminated: they need significantly deeper cooling (ie instead of -25C , need -58C operating temperature for same dark signal level for e2v 47-10). The e2v BSI CCDs (and others) also show RBI.
- KAF series sensors have RBI, with some very severe. To manage the RBI, these are flooded with NIR light to fill the trapping sites and flushed prior to exposures placing the sensor into a known state.
  - The filled traps leak during the exposure and need deep cooling to prevent the noise from the leaked charge exceeding the read noise of the camera for a given exposure time (~-87C for 30 minutes/ 5e- noise and KAF09000).
- Cosmetic defects can be mitigated by deep cooling. Significantly “cleaner” at -45C than at -15C
  - Defects can accumulate with time due to random high energy particle interactions.