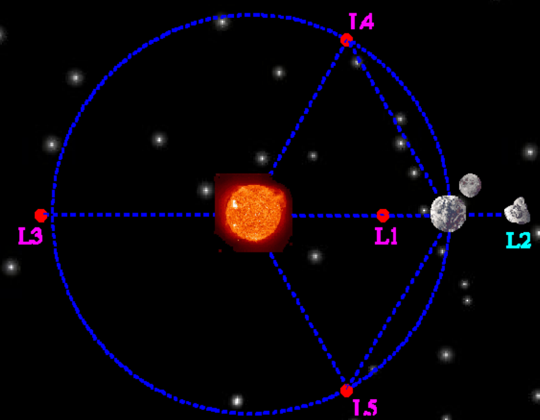

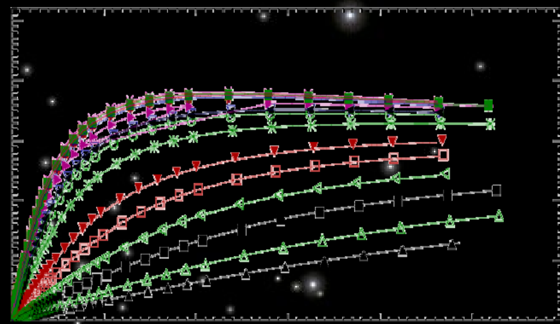

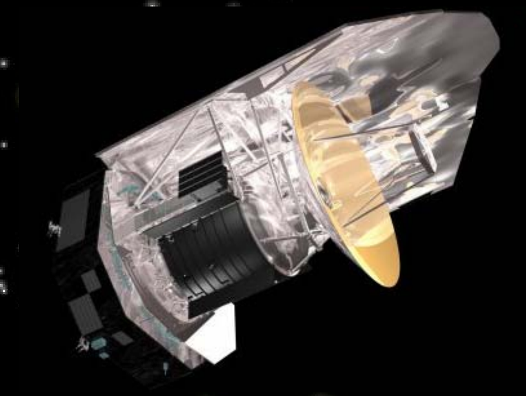

Understanding the Herschel-SPIRE bolometers

Adam Woodcraft
http://woodcraft.lowtemp.org
SUPA, University of Edinburgh

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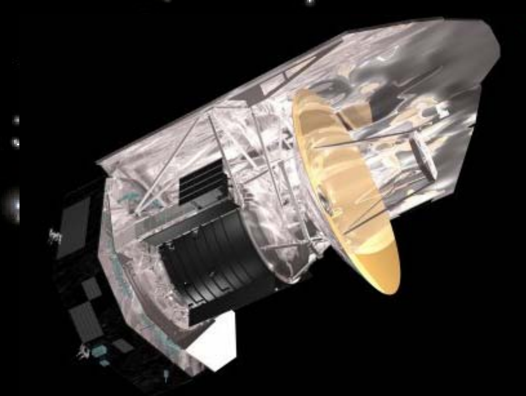
Credits

Hien Nguyen, JPL
James Bock, JPL
Matt Griffin, Cardiff
Bernhard Schultz, IPAC
Bruce Sibthorpe, Edinburgh
Bruce Swinyard, RAL

....plus many many more....



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Introduction

Introduction

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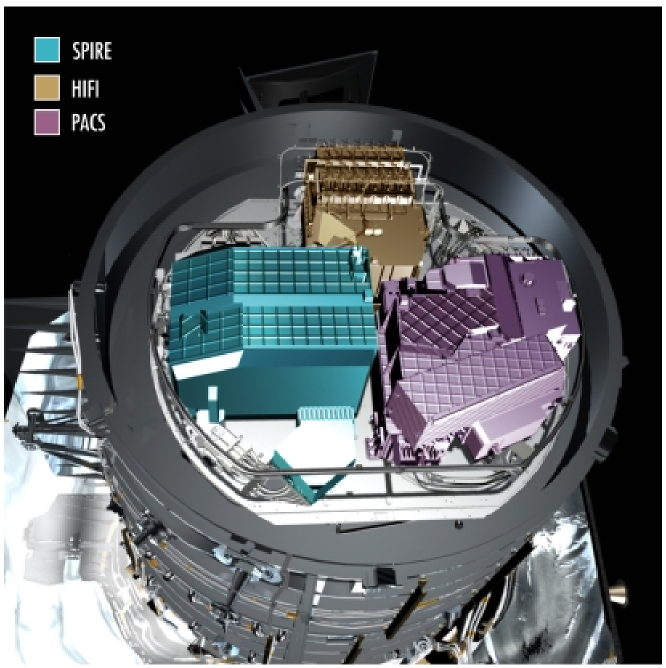
SPIRE: the Spectral and Photometric Imaging Receiver

- One of three instruments on the Herschel Space Observatory



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SPIRE: the Spectral and Photometric Imaging Receiver

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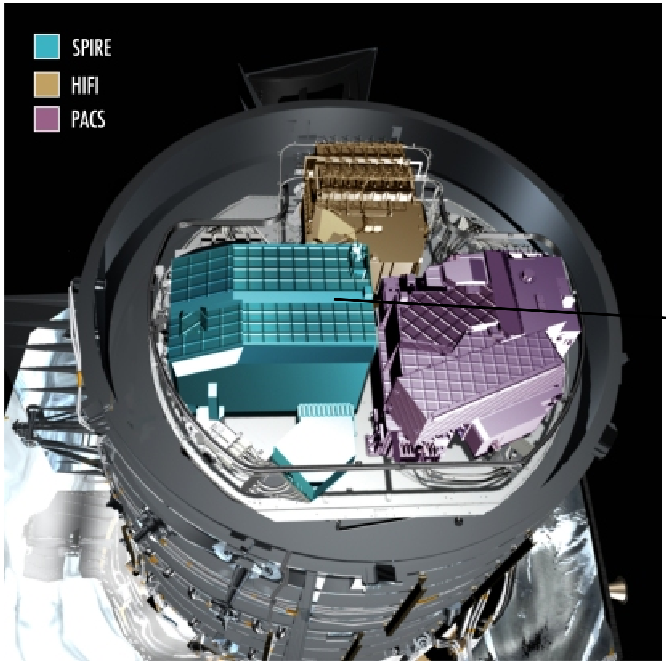

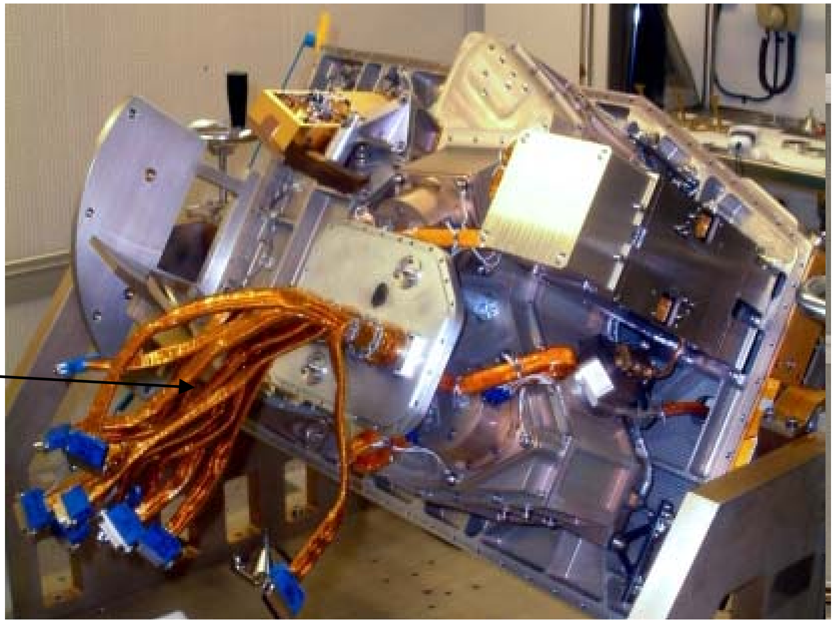

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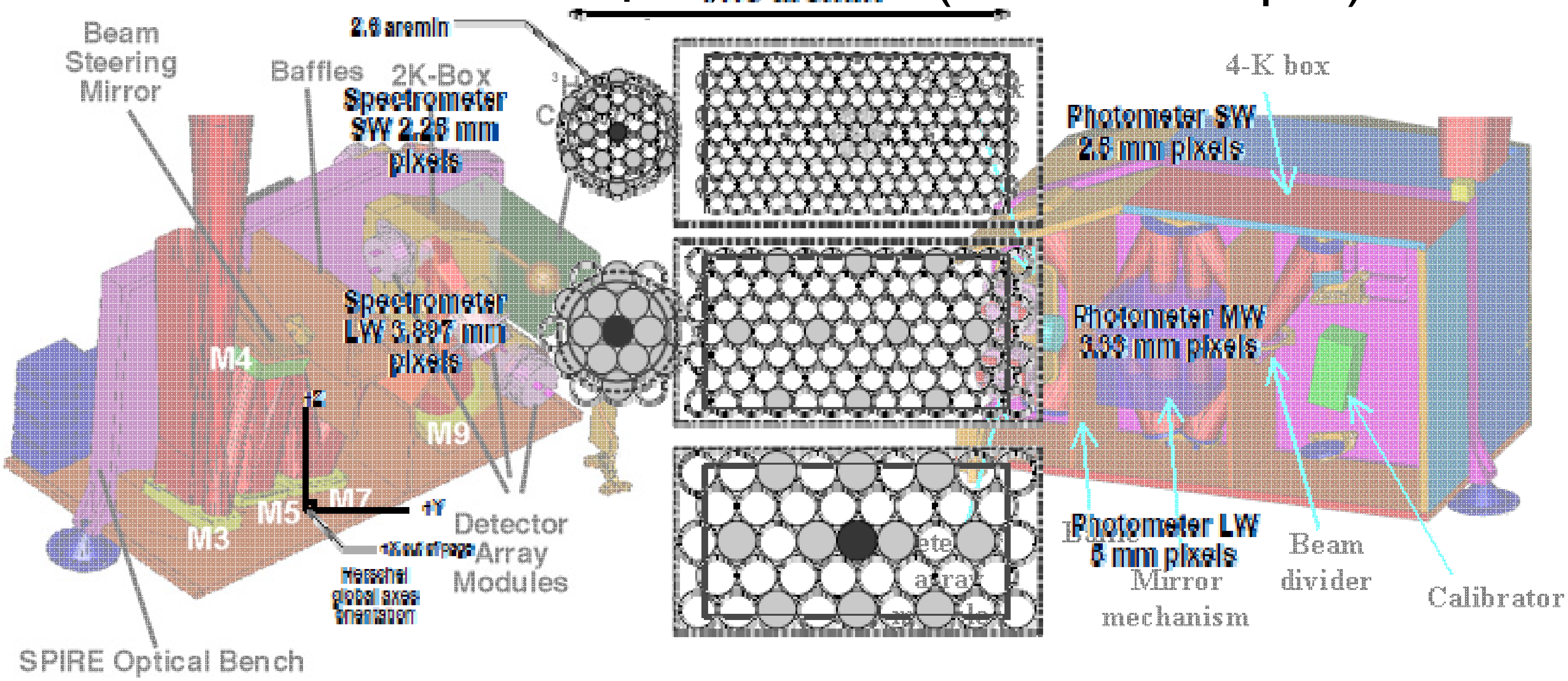
SPIRE contains five bolometer arrays

Three form a three-band imaging photometer (centre wavelengths approx. 250, 350 and 500 μm)

Two are part of an FTS (200 to 670 μm)



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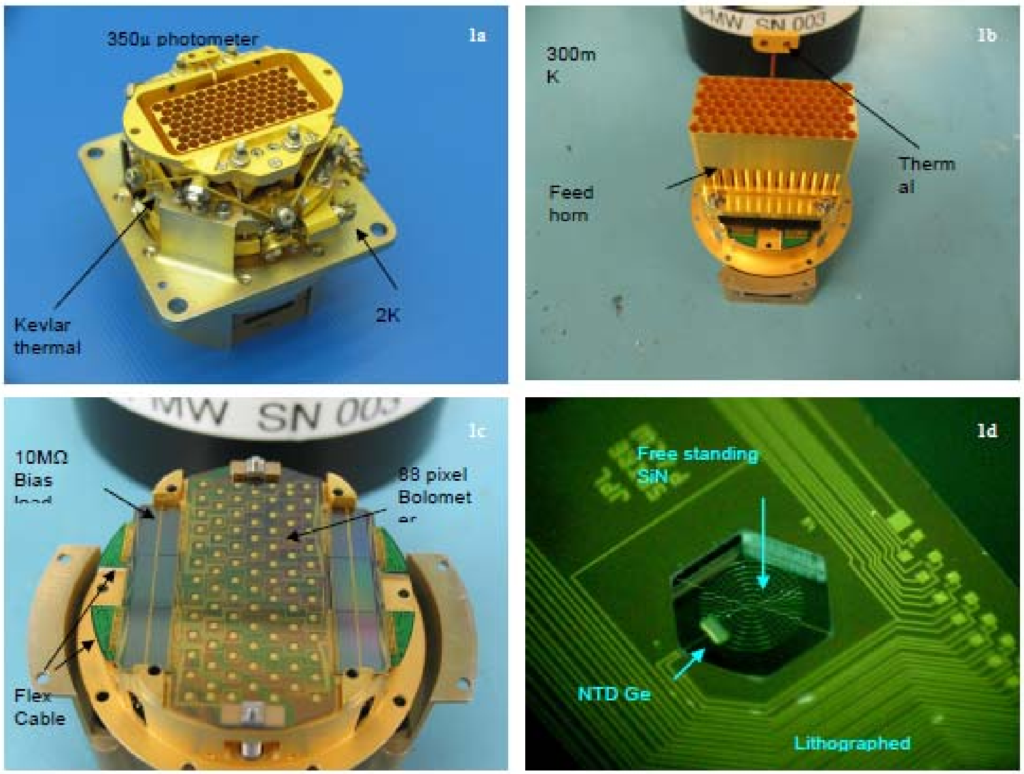
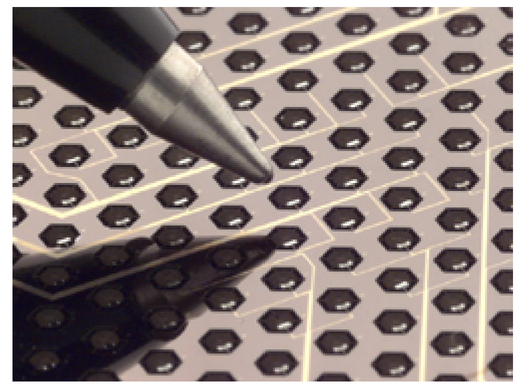
Introduction

Arrays: feedhorn coupled, NTD germanium thermistors, silicon nitride spiderweb bolometers



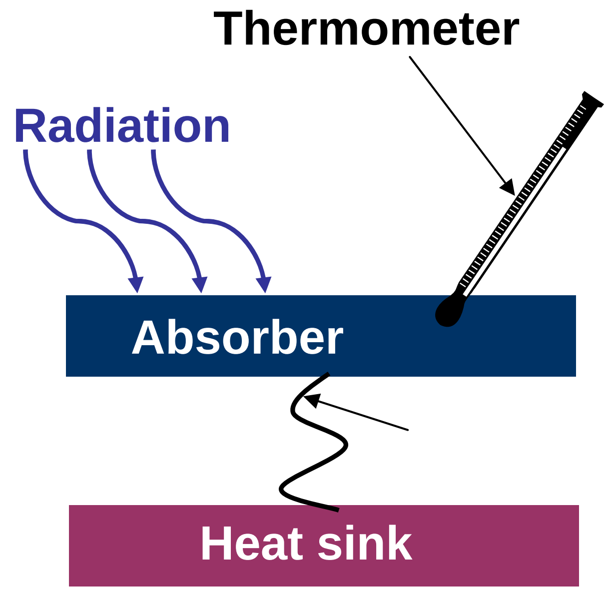


Measurements

Measurements

Bolometers are very simple devices
Operation is based upon well understood straightforward physics
Can describe behaviour with a simple model

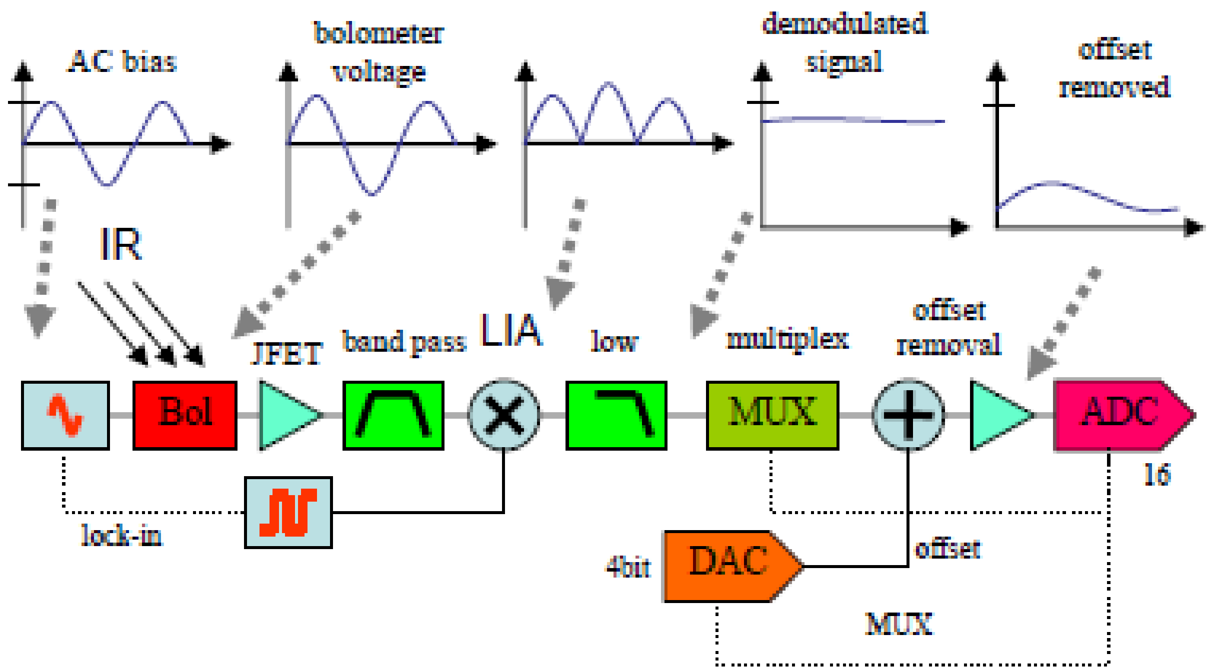
…in principle



Possibly in practise….but we have to prove it!
Many possible complications.

Measurements

Flight readout system is not simple! (for very good reasons)

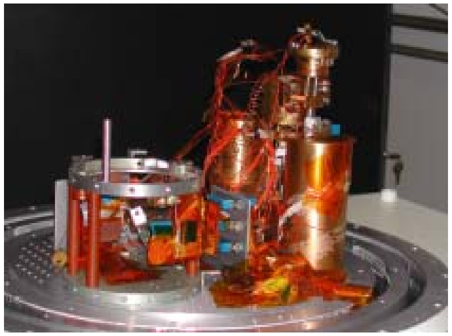


Have to worry about effects such as cable capacitance, JFET gains varying with bias frequency…

Measurements

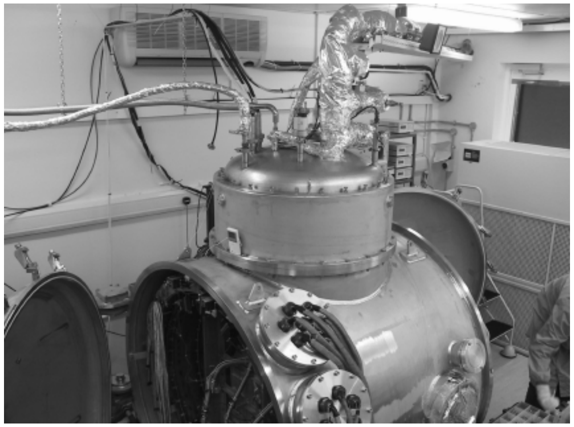
Load curves measured at JPL

- On each array individually
- DC bias
- Dark
- Optically loaded
- Pixels fully characterised



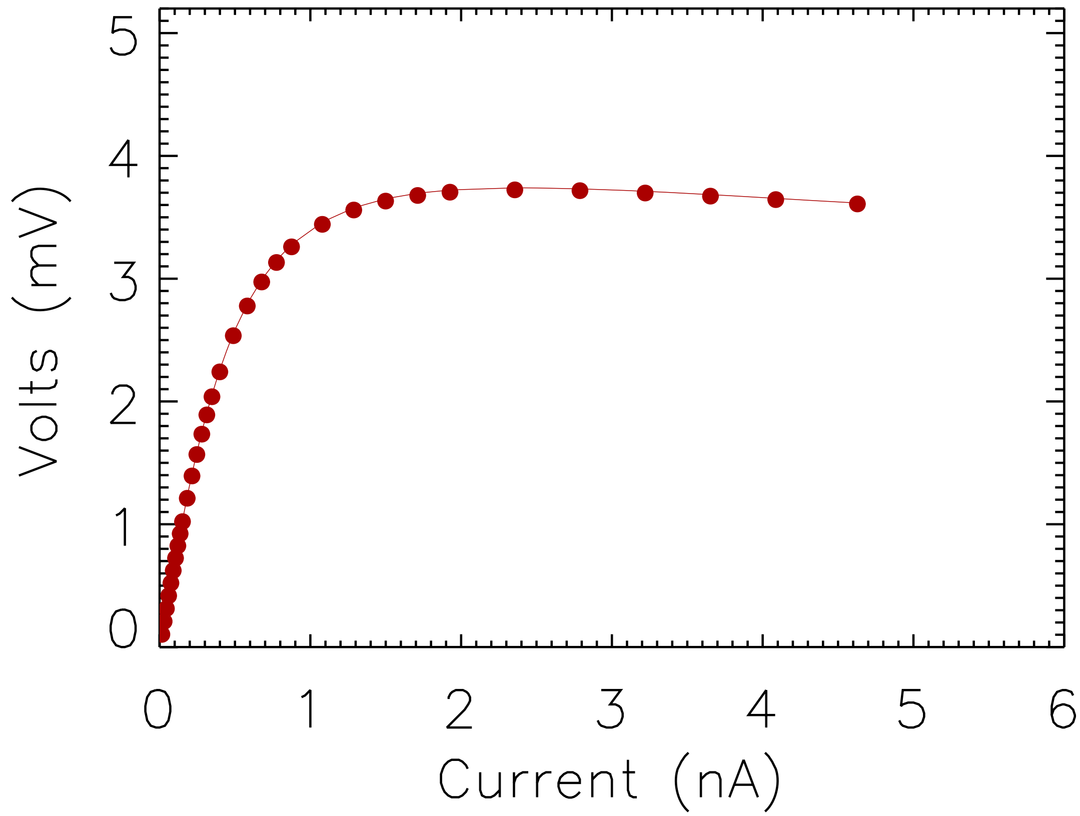
Load curves measured at RAL

- On arrays in the instrument
- AC bias (flight electronics)
- Dark (bolometers blanked off)
- Optically loaded (blackbody 6 to 15 K)



Measurements

What is a load curve?
Just a measurement of bolometer (thermistor) voltage as a function of bias current



Measurements

Why measure load curves?

- Give us the information we need to fully characterise the (static) properties of the bolometers
  - Can predict voltage for given
    - bias current
    - heat sink temperature
    - optical power

- So we can simulate their behaviour under different conditions
- Detect if changes have occurred post-launch
- Improve/simplify calibration

Measurements

Calibration can be done entirely empirically

- As usual for bolometer instruments
- (But empirical pipeline makes assumptions on bolometer behaviour; stability, ideal behaviour)

But if we can accurately model the detectors we can

- Check and possibly improve empirical corrections for
  - non-linearity
  - heat sink temperature variations
  - change in bias current/frequency
- Possibly even use the model directly for calibration

Information on detector/readout stability tells us how often (if at all) we need to recalibrate (PCAL/external source)

Measurements

Goals:

We would like to know:

- That the behaviour of the bolometers and readouts is self-consistent and stable with time
- Ideally, that the bolometers can be modelled with a simple model
  - What parameters to use with the model

We can try to show both using load curve measurements

Measurements

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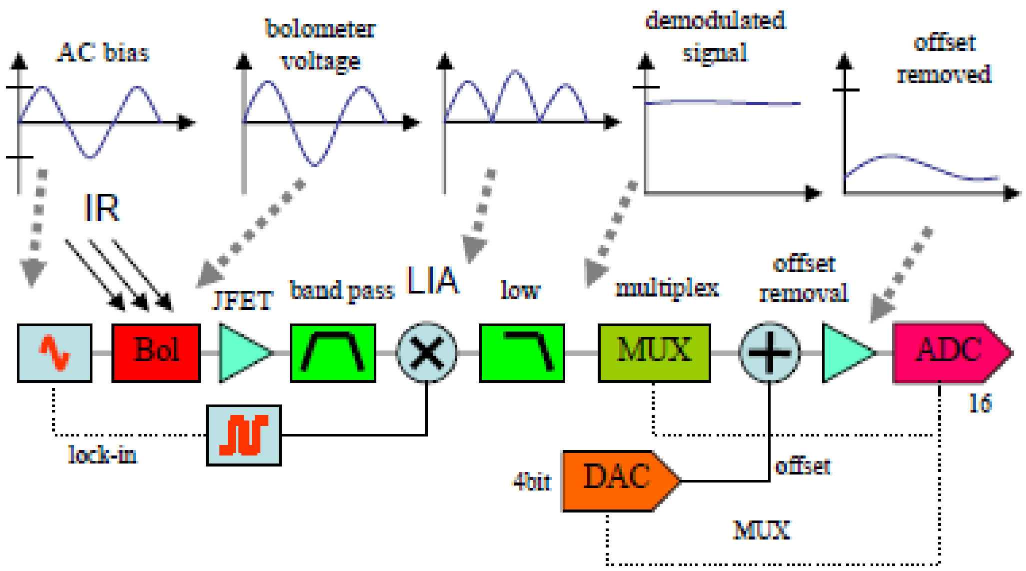
Why are the *instrument level* measurements (load curves) so useful?

- Tell us about performance of the arrays
  - In the instrument itself
- Give series of measurements over longer time period

- Characterisation of pixels while in the instrument gives us direct information on behaviour in flight
  - Don't have to allow for differences between readout system used in array level test (e.g. varying JFET gains, AC vs DC bias)

- But: readouts not optimised for this task

Measurements



Flight readout system is optimised for carrying out astronomical observations, not load curves

- Low noise (therefore AC bias)
- Sit at fixed bias value, measure small changes in bolometer voltage

Consistency

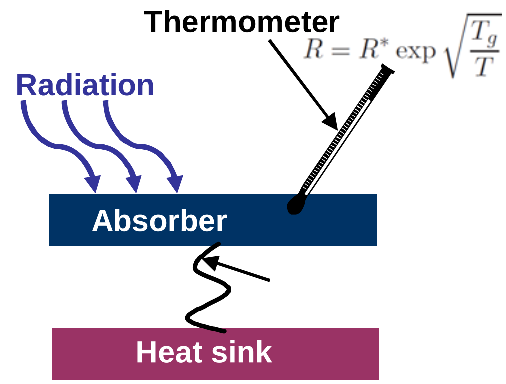
Consistency

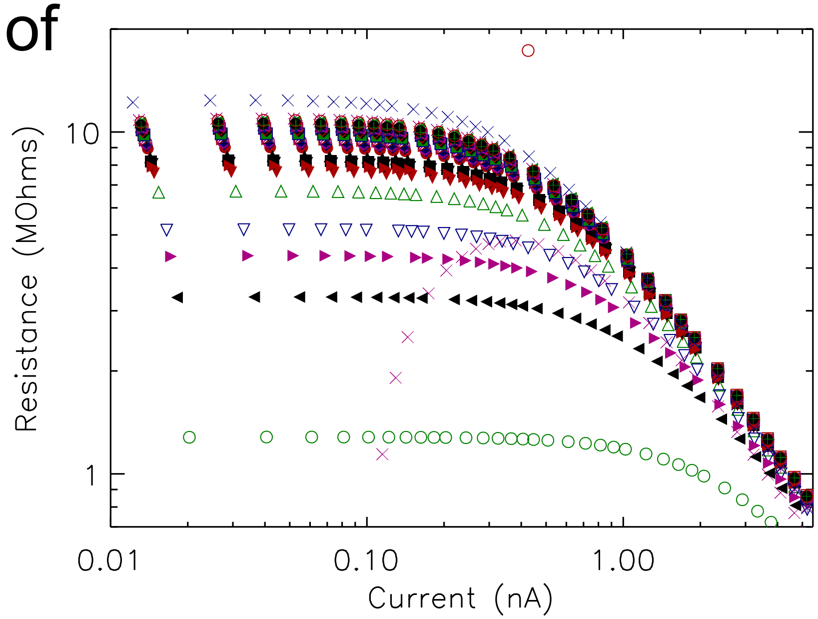
First step in characterisation: work out R(T) for each bolometer

- Take series of load curves at different heat sink temperatures
- Take resistance in limit of zero bias
- This only works in the absence of optical radiation

$$R = R^* \exp\sqrt{\frac{T_g}{T}}$$

- Need to automate: SPIRE has a lot of pixels!





Consistency

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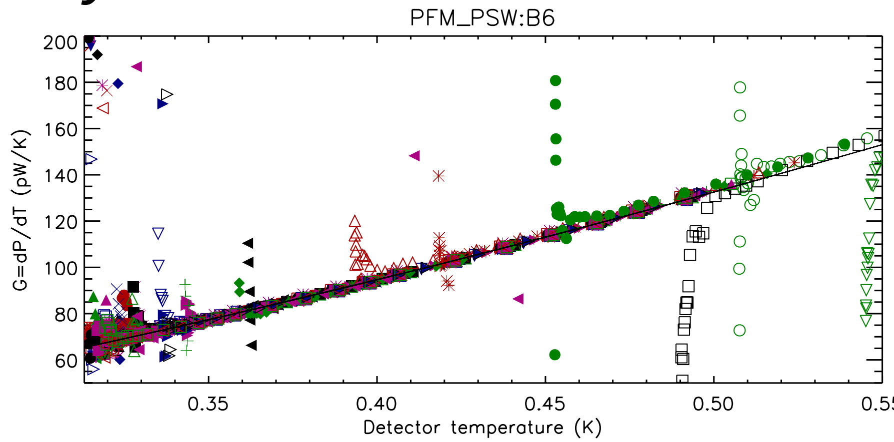
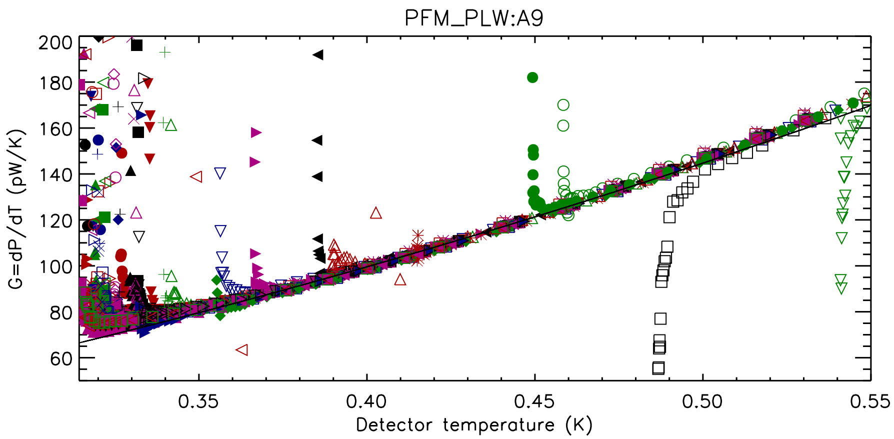
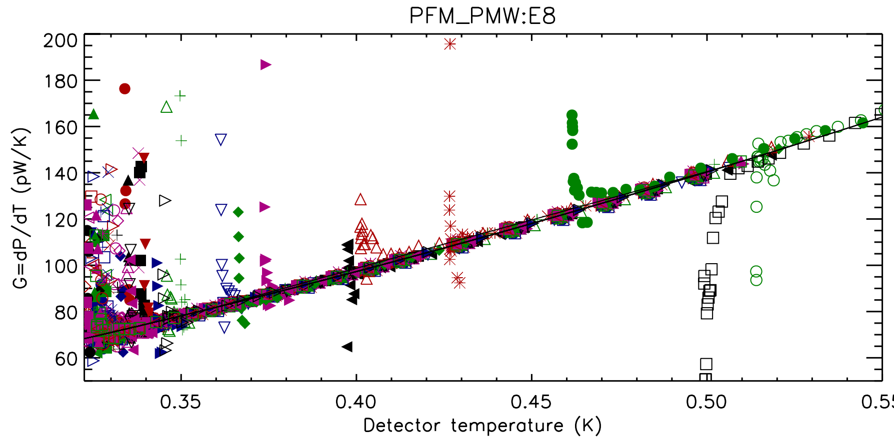
Now we can look at consistency without further analysis

- Plot G=dP/dT – can compare *any* load curve
- Measurements over:
    - ~ 4 months
    - two cooldowns
    - different bias frequencies
- Excellent agreement!







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Consistency

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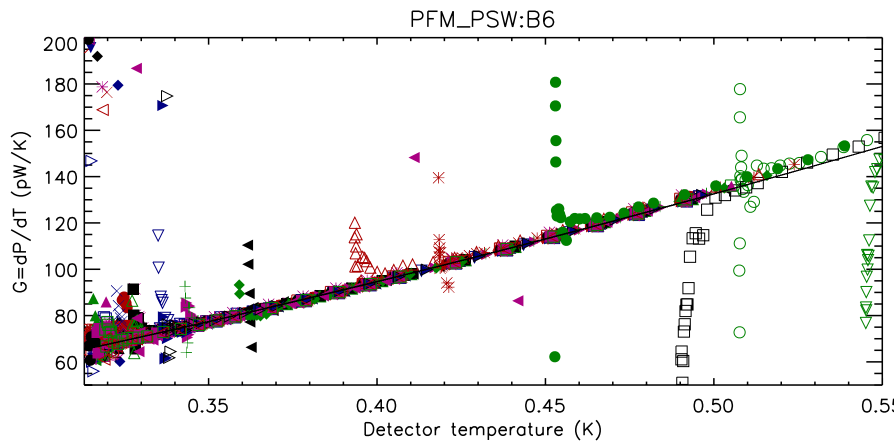
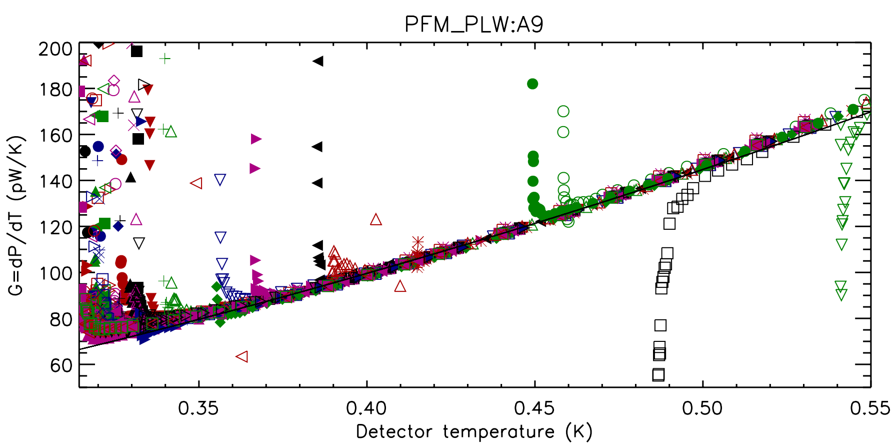
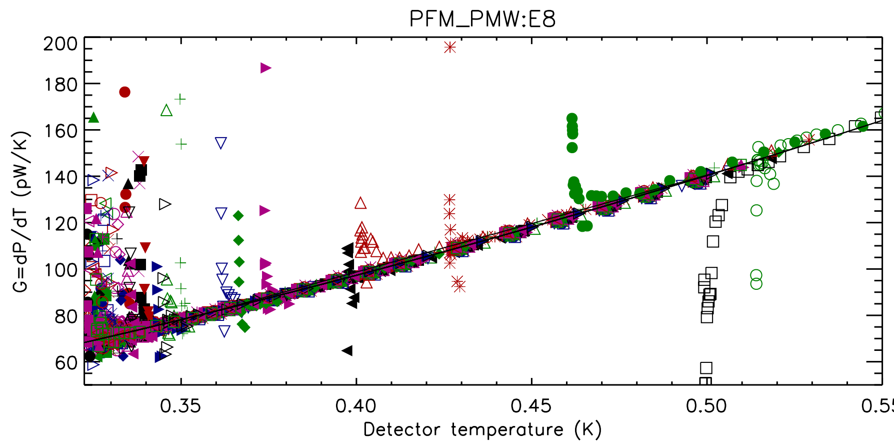
Therefore:

- Bolometers and readouts are stable
- We have suitably allowed for AC effects







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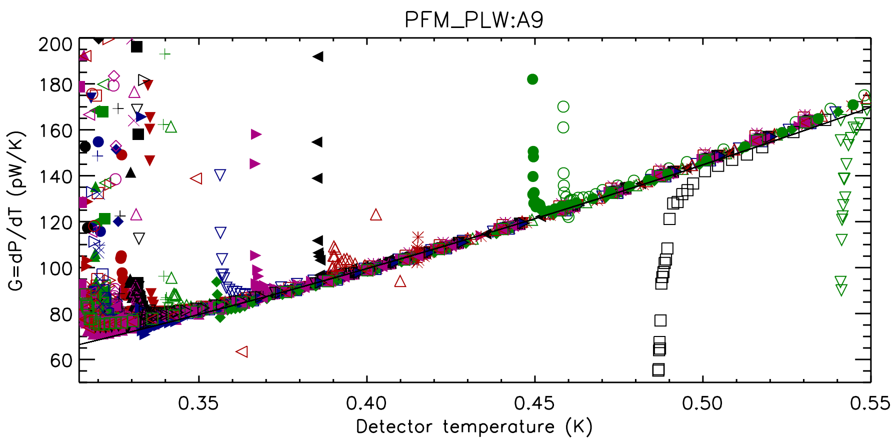
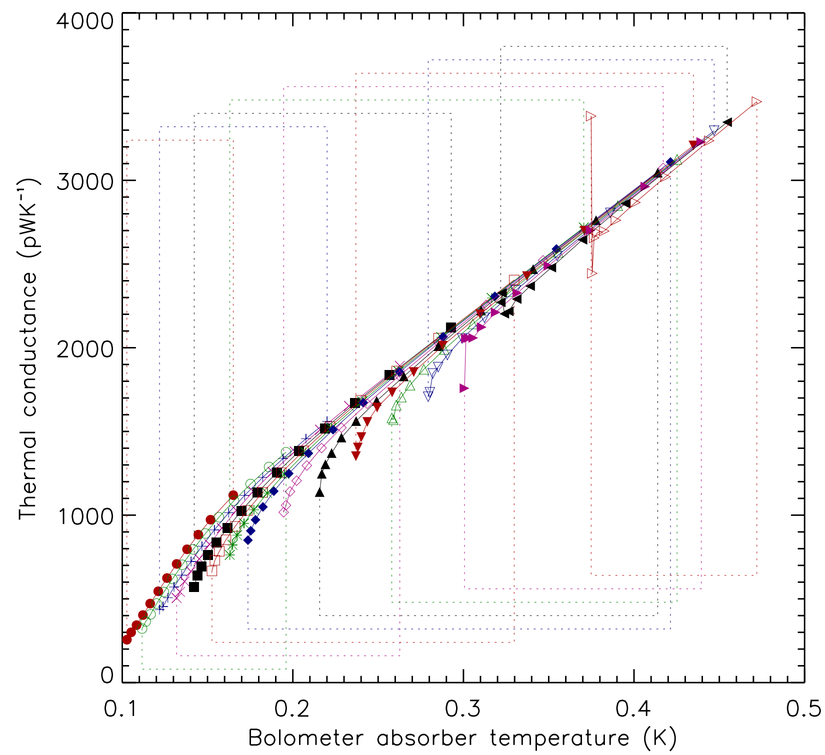
Therefore:

- Bolometers and readouts are stable
- We have suitably allowed for AC effects
- Bolometer resistance depends on temperature alone



Unlike for this non-SPIRE (100 mK) bolometer, showing E-field(?) effects



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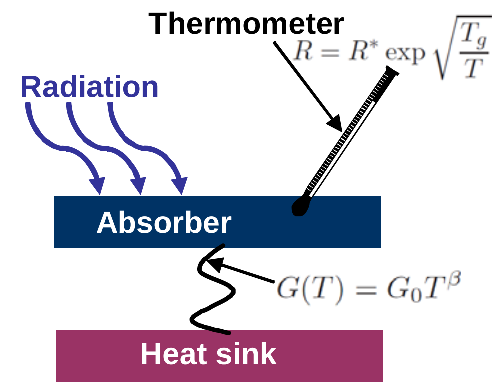
Thermal model

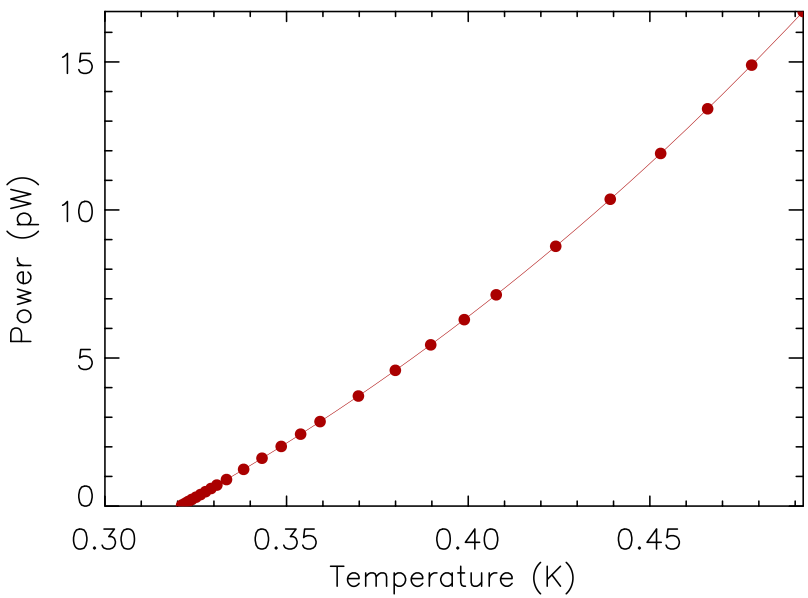
Thermal model

We can do further analysis with the thermal ("ideal bolometer") model



$$G(T) = G_0 T^\beta$$

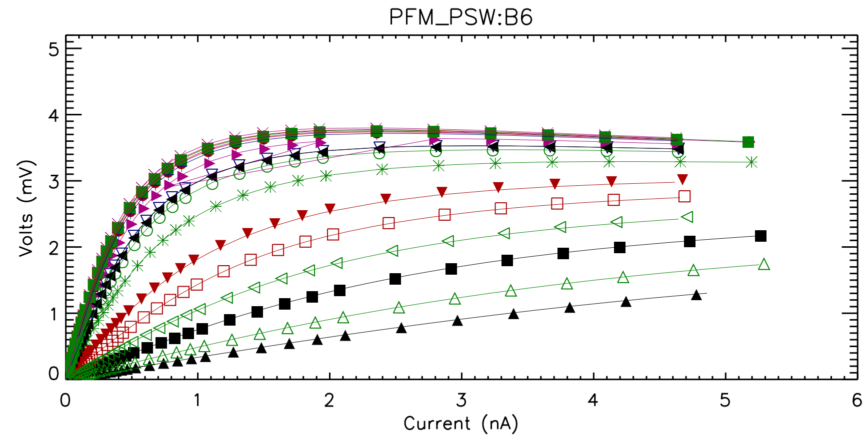
Having obtained R(T), we can get G(T) from any load curve by doing a non-linear fit to power vs temperature

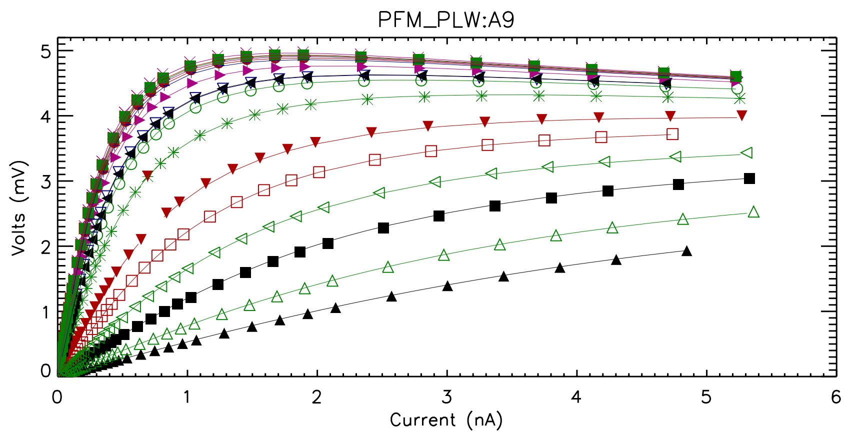


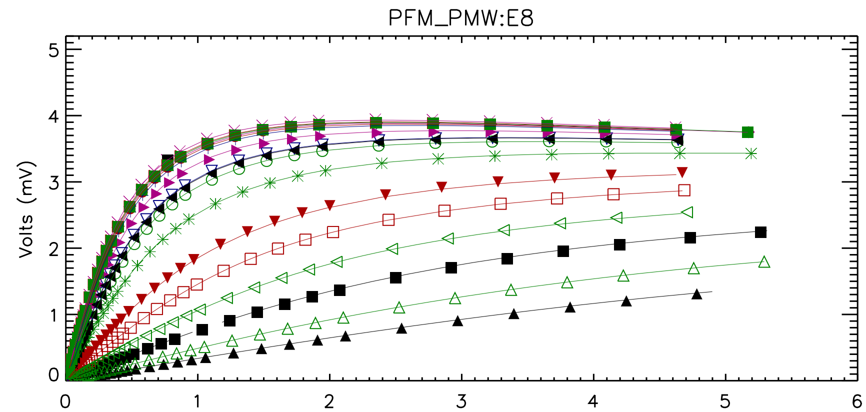
Thermal model

Results (plotted as voltage vs current)

- Turnover due to electrothermal feedback
- Very good fits
- These are *not* individual fits to each load curve; parameters taken from one load curve only
- So we can predict bolometer performance well







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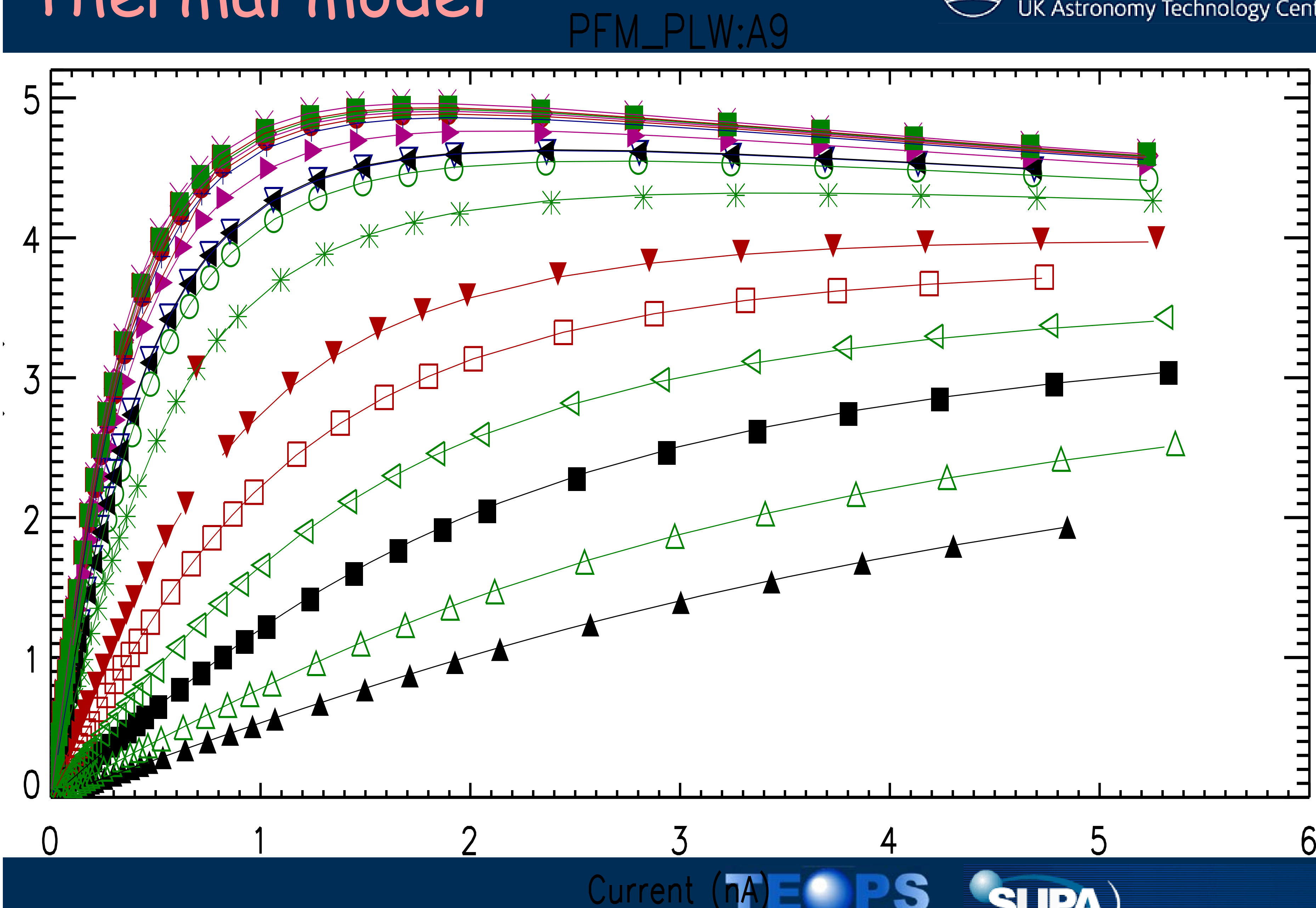

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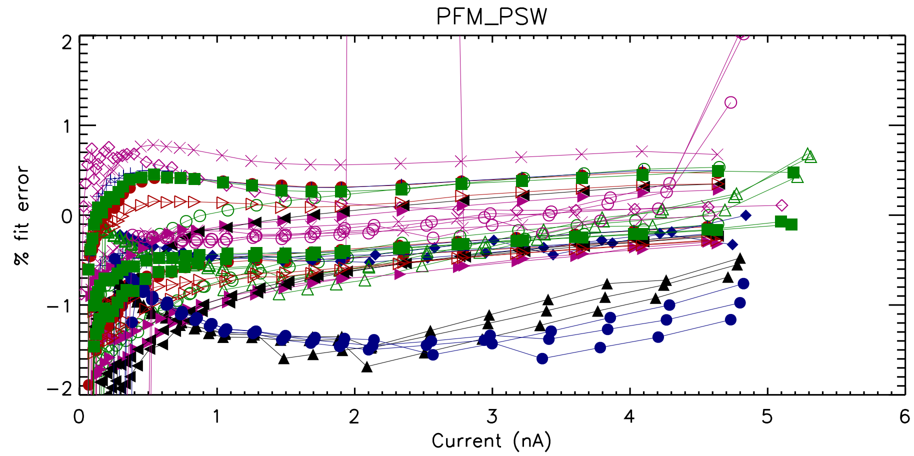
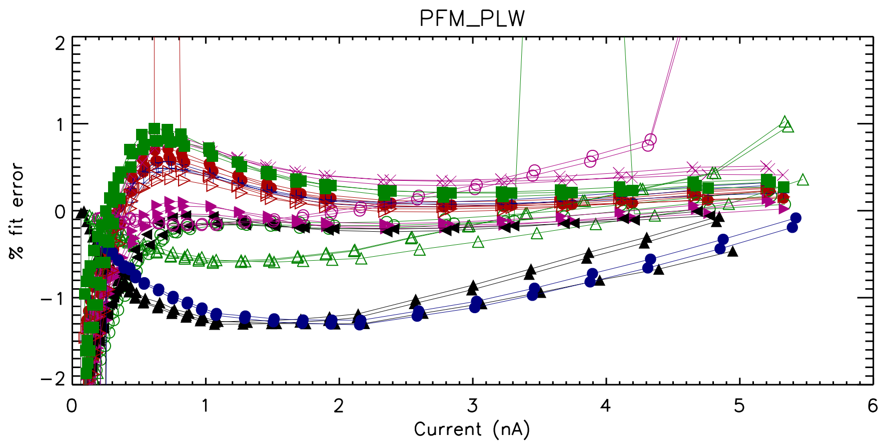
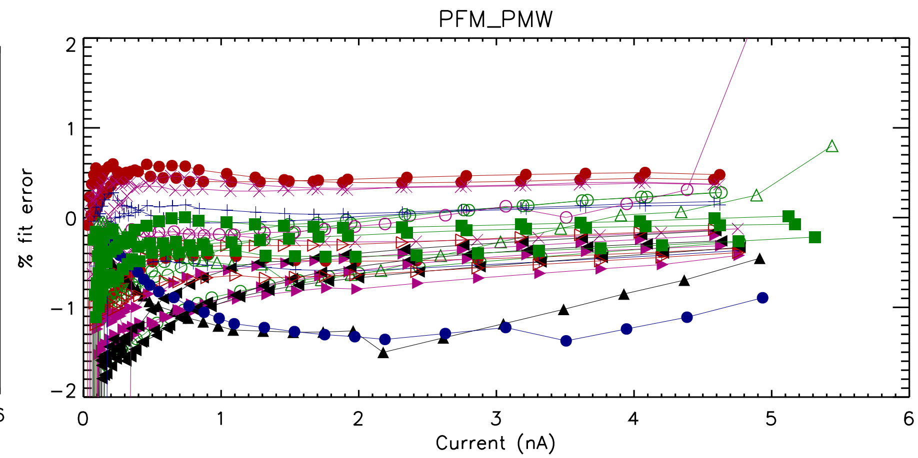
Errors in fits:



Current (nA)





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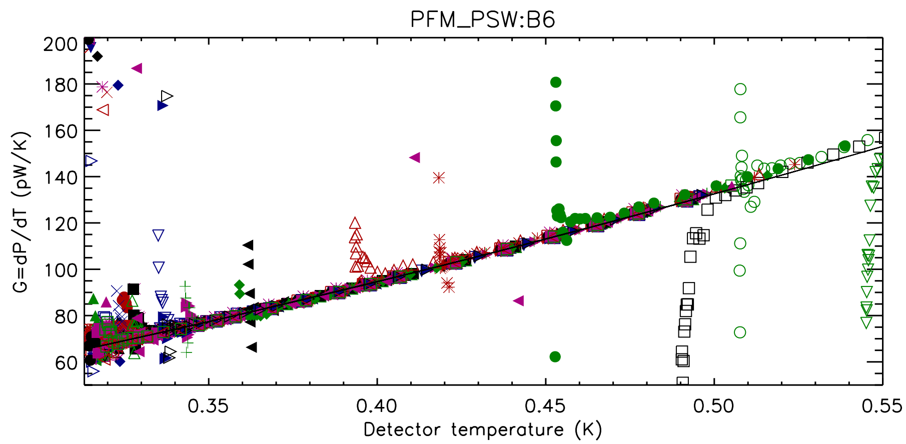
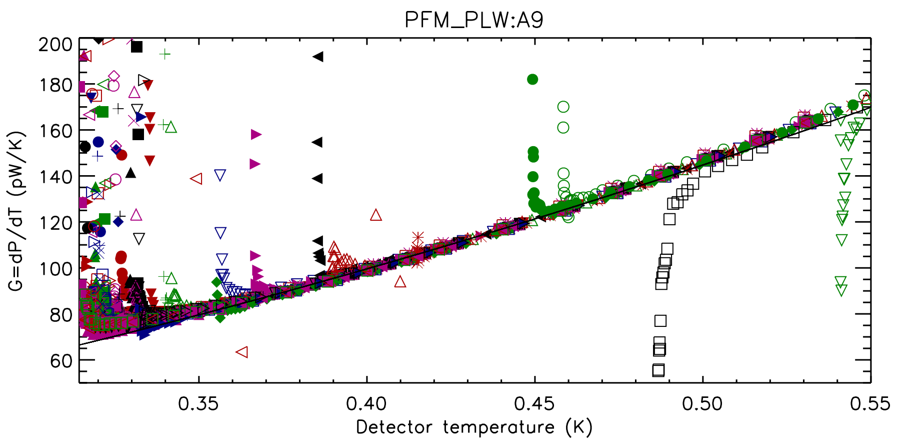
Actually; we already know this should work:

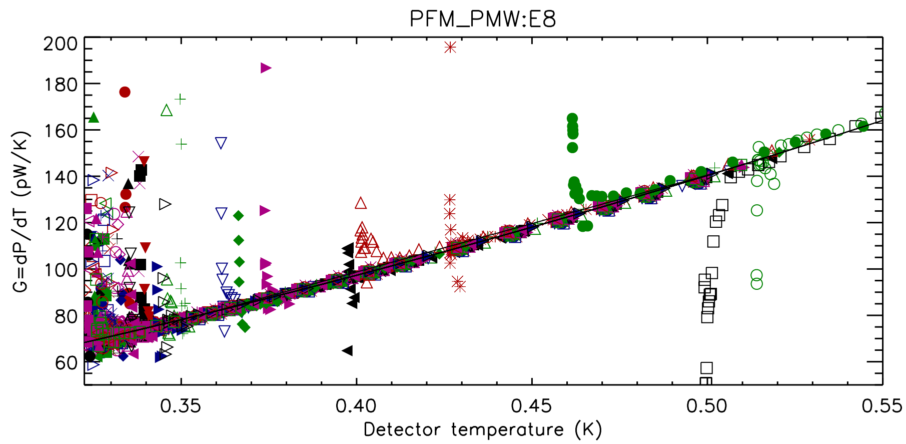
These plots showed that

$$G(T) = G_0 T^{\beta}$$

is a good assumption
(black lines show model fits)







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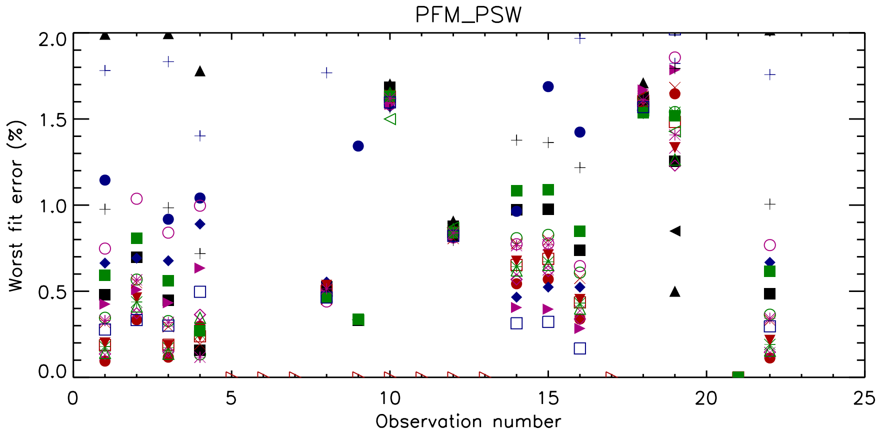
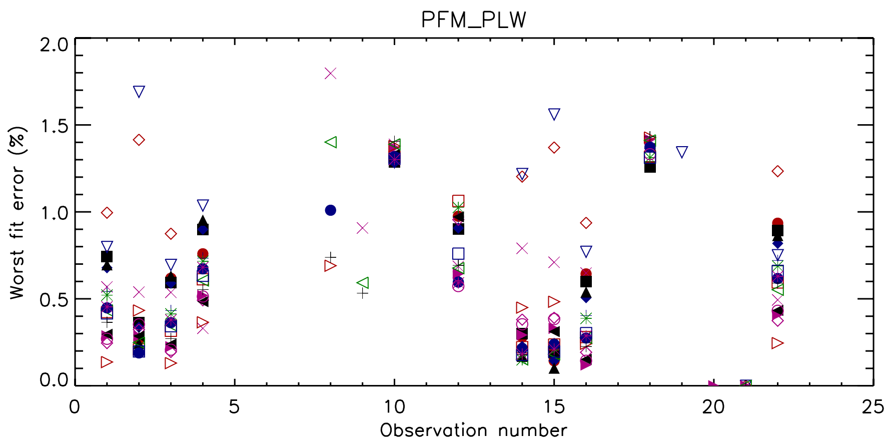
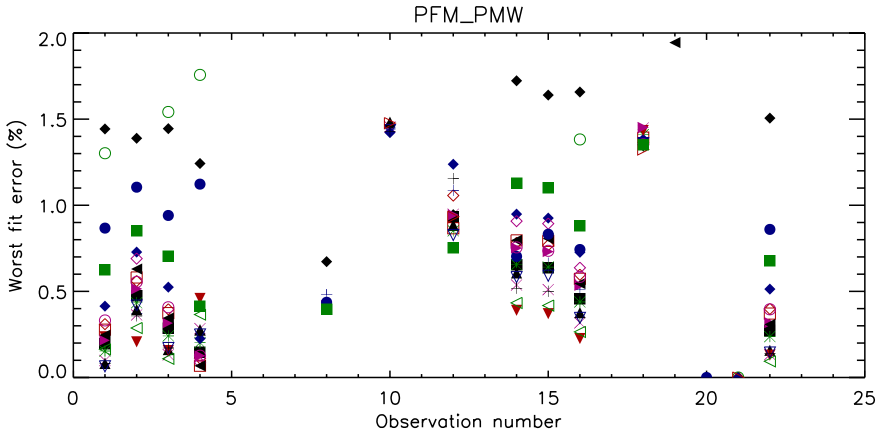
But so far I've only shown results for three bolometers – "typical results".

- How typical are they?

These plots show the maximum errors in fits to all blanked load curves for 75 bolometers







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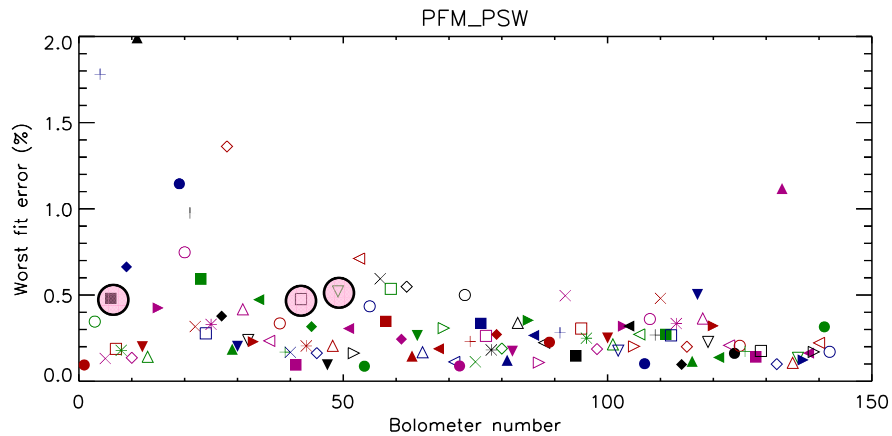
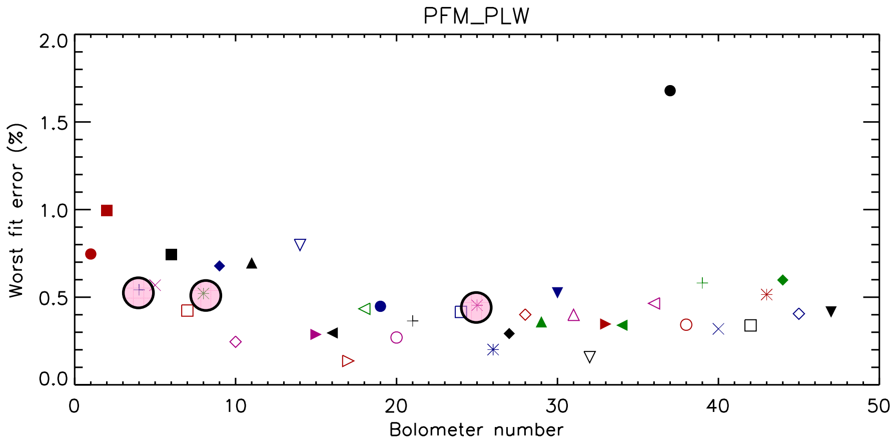
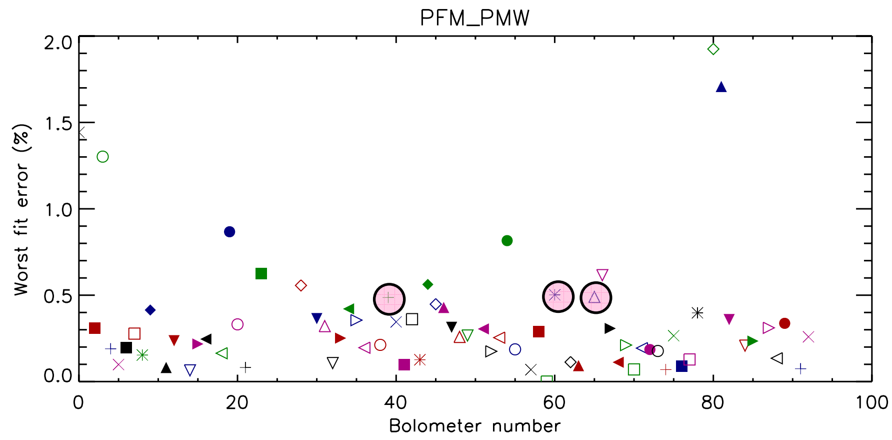
Here is the same thing for *all* bolometers for a single simultaneous measurement

My "typical" results highlighted here; worst case apart from outliers







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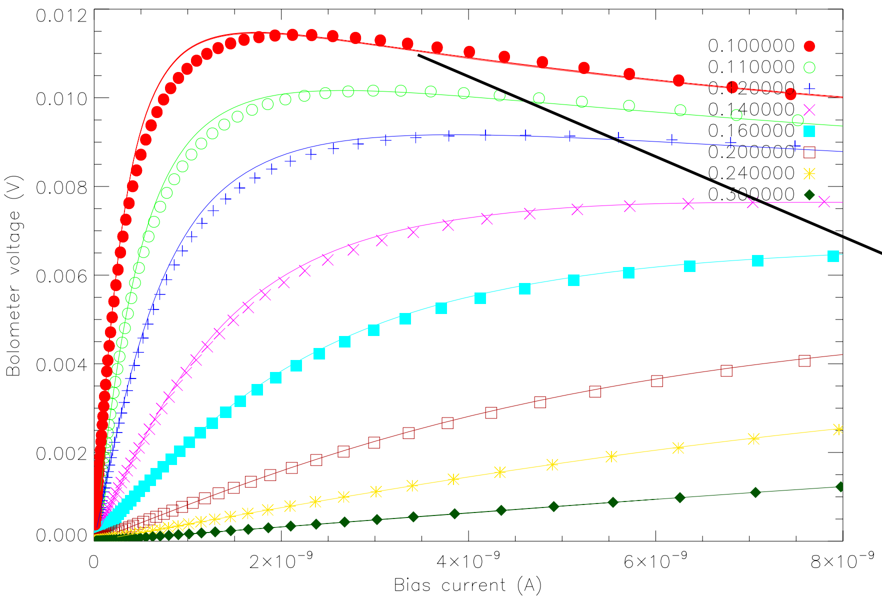
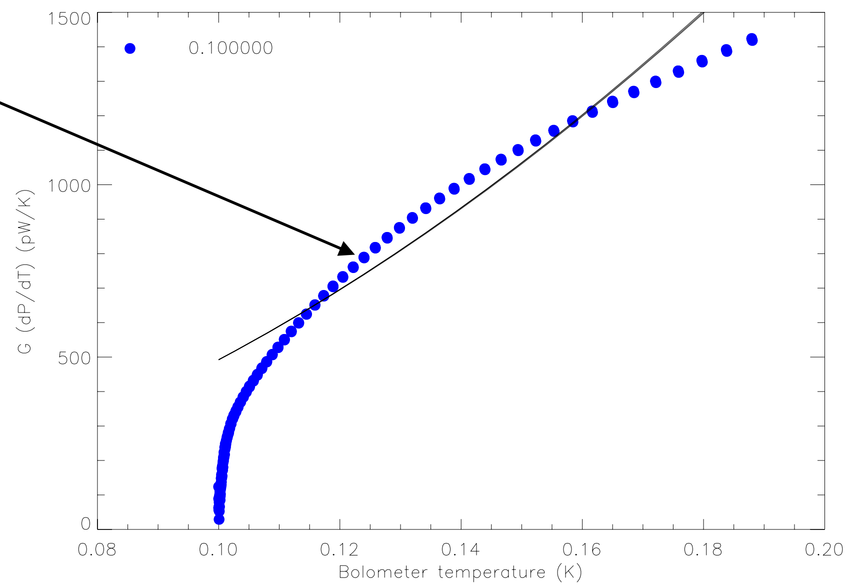
So the thermal model works very well.

• But just because the fits look good as voltage vs current doesn't mean all is well.

• Case study (for a 100 mK bolometer) below:



This fit is actually not very good!



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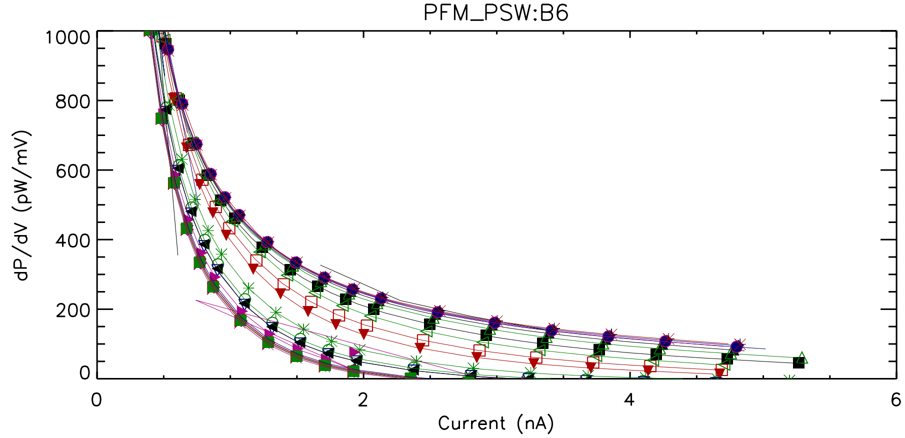
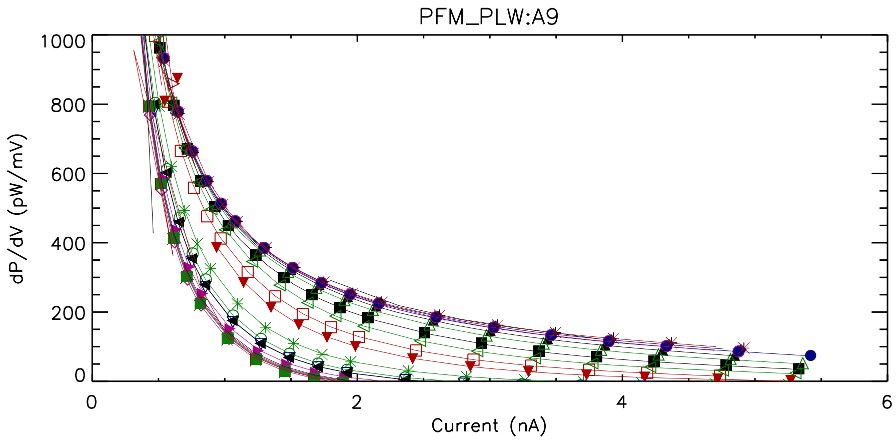
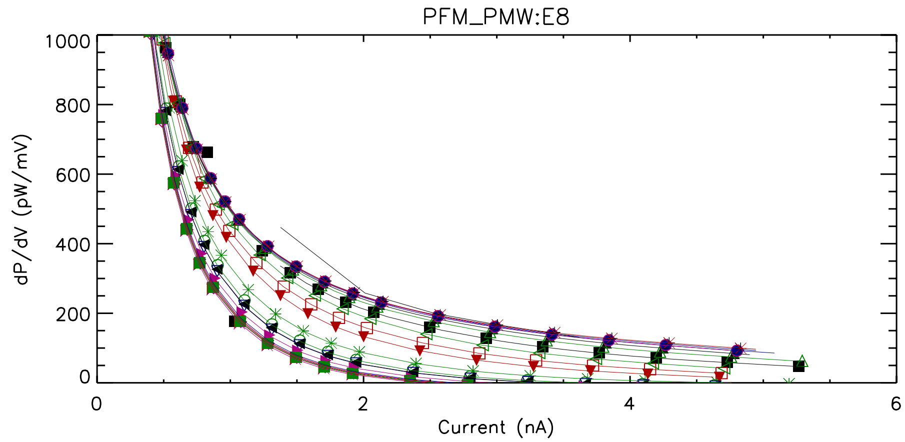
We know the model fits G(T) nicely here, but we really want to measure changes in optical power

- Look at voltage vs *electrical* power: good agreement







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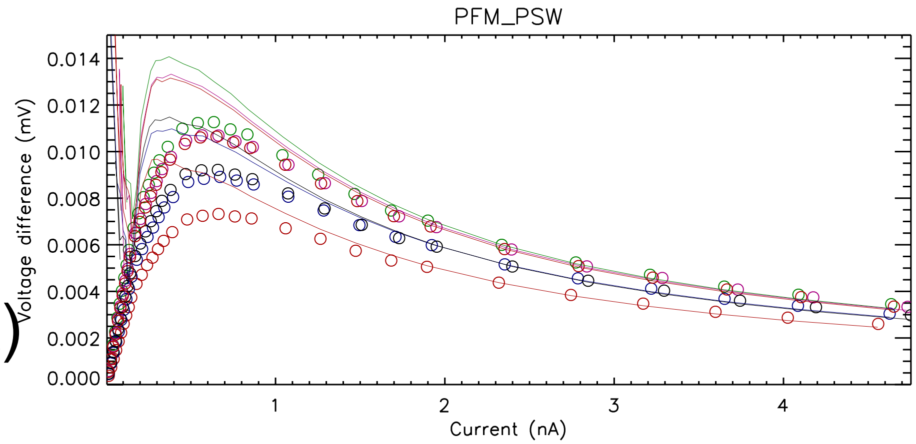
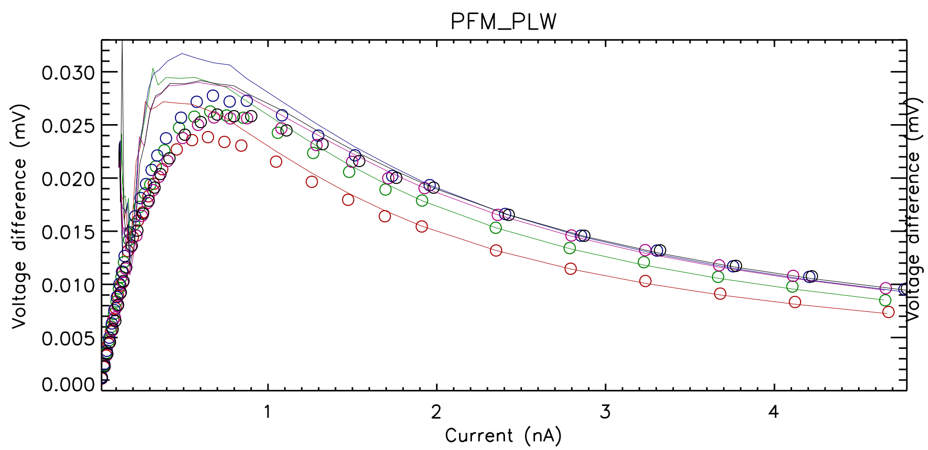
Thermal model

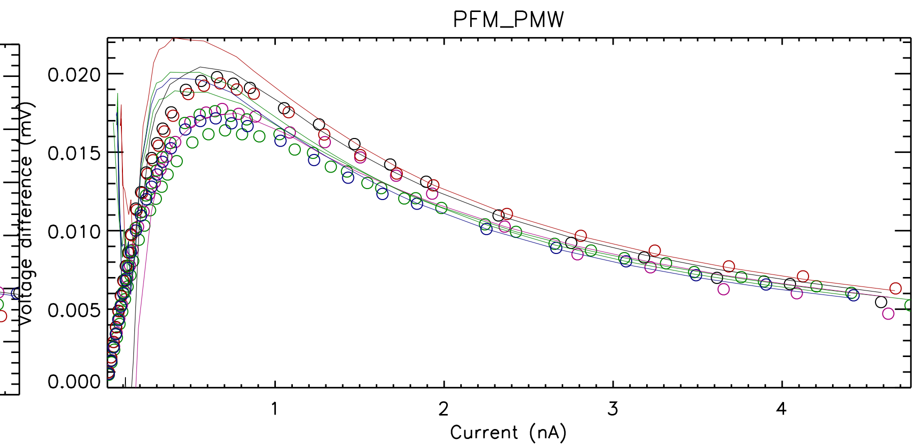
How about optical power?

- Take two load curves with similar optical power
- Compare voltage difference at fixed bias point between measurement and model



- Good agreement (above 1 nA) for ΔV for this ΔP





Thermal model

So the model works well.

We should be able to use it to allow for
- Effect of variations in heat sink temperature
- Non-linear response
- Changes in operating bias current and/or frequency

without any empirical terms

Conclusions

Conclusions

- The bolometers and readout systems are extremely stable
- We understand how to correct for AC bias effects in order to characterise the detectors using measurements in the instrument
- A simple bolometer model using parameters from this characterisation fits the measurements extremely well
- We can therefore predict the bolometer behaviour under difference conditions in flight
- Work on using the model to obtain absolute (absorbed) power measurements from the bolometers with no external calibration is showing promising results