Preliminary Design of the Continuous ADRs for the Primordial Inflation Explorer (PIXIE)

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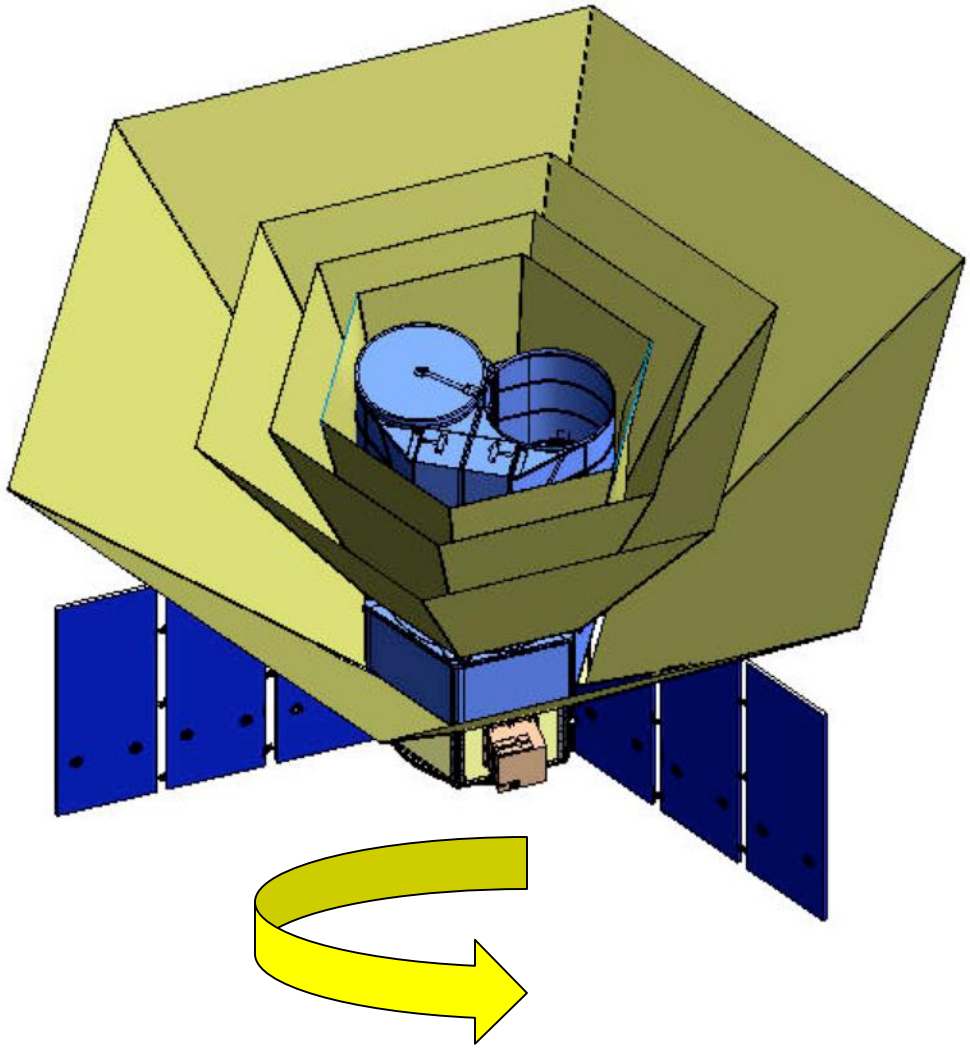
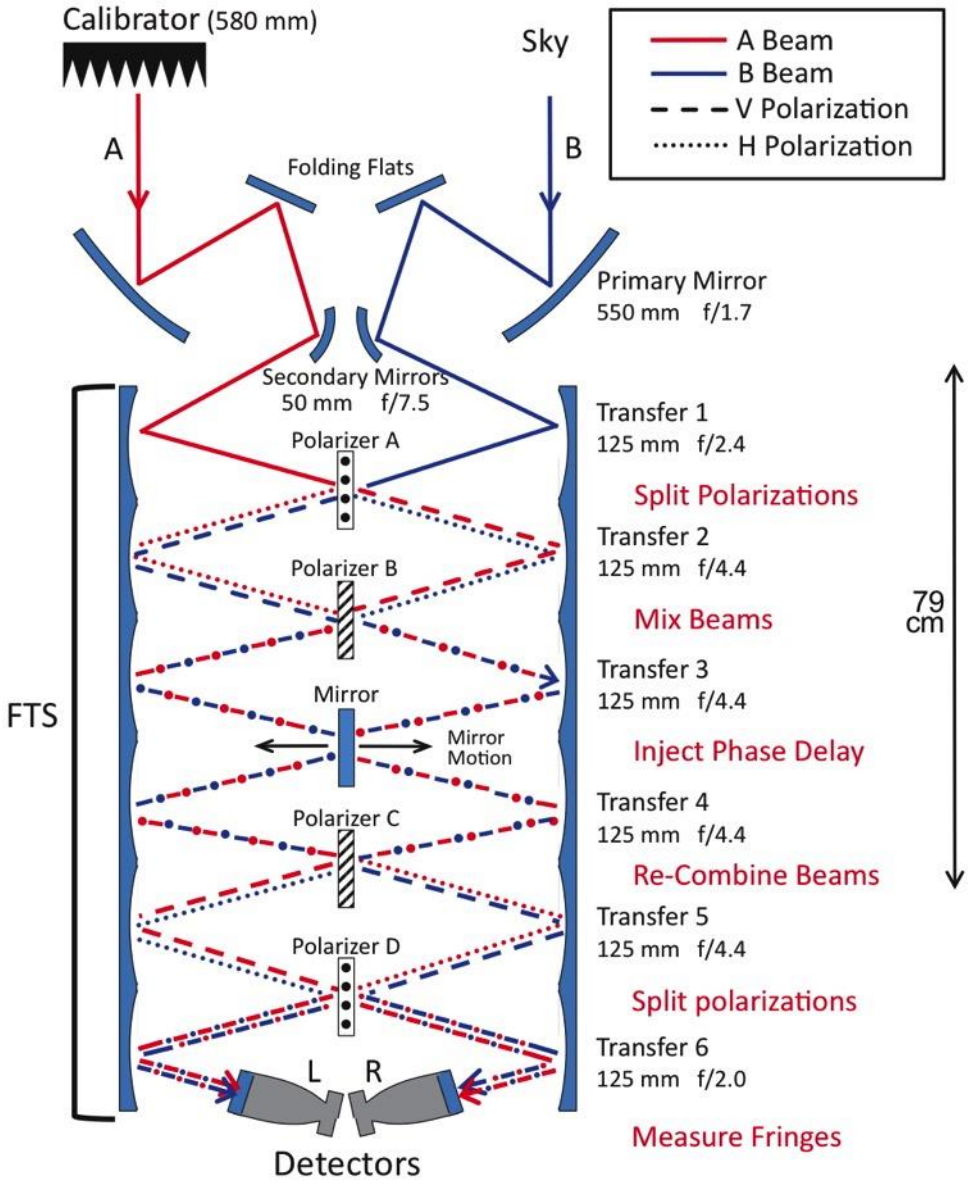
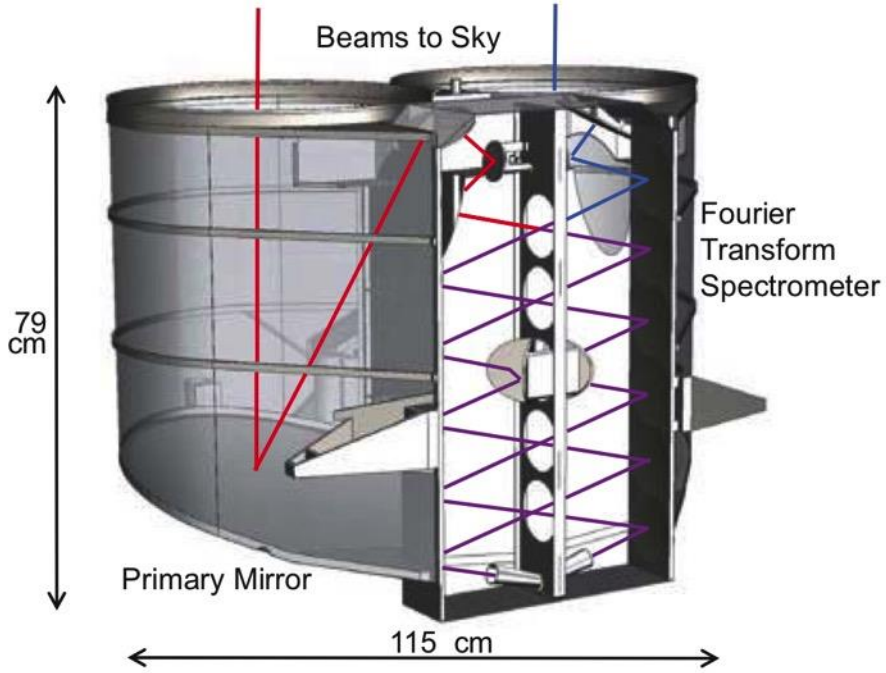
PIXIE Architecture

- Orbit
  - L2
  - Zenith-pointing
  - 1 rpm spin
  - Continuous sky scan
- Cryogenic system
  - 2 radiatively cooled shields
  - 2 actively cooled shields
  - Stirling/JT cryocooler
  - ADR system
    - 2.725 K telescope (iADR)
    - 100 mK detectors (dADR)
    - Continuous cooling required



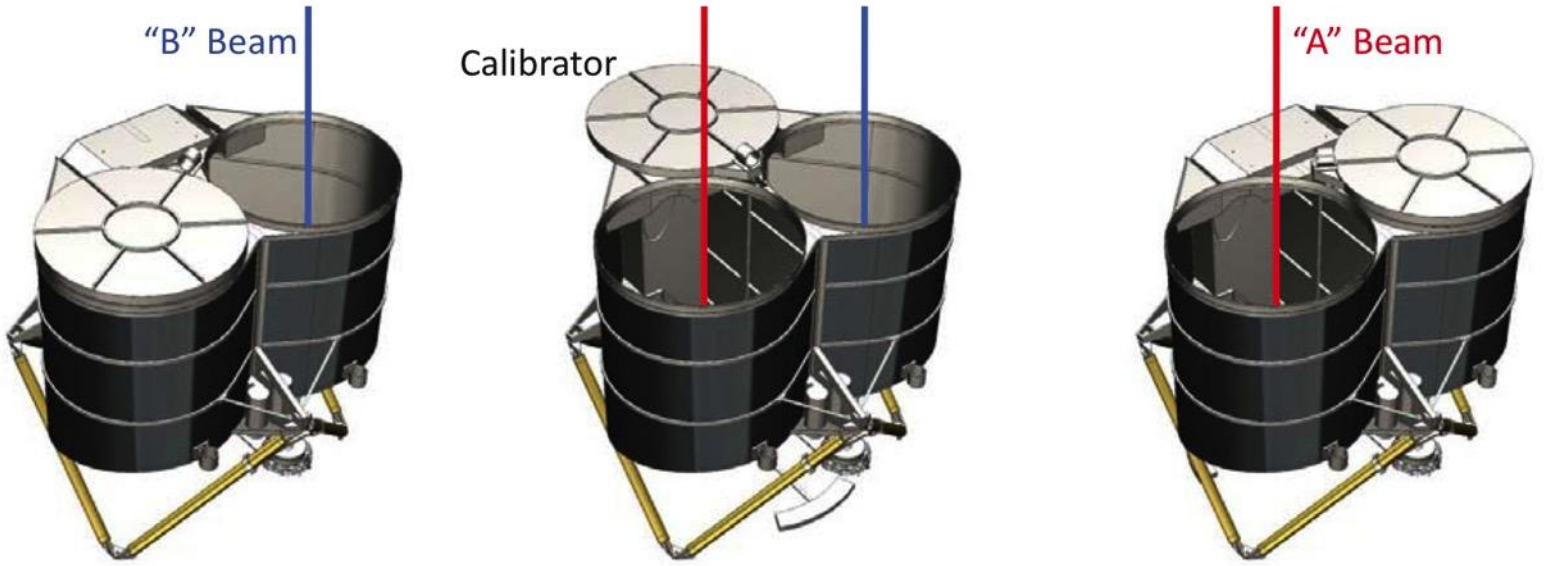
PIXIE Optical Path





Measurement Strategy

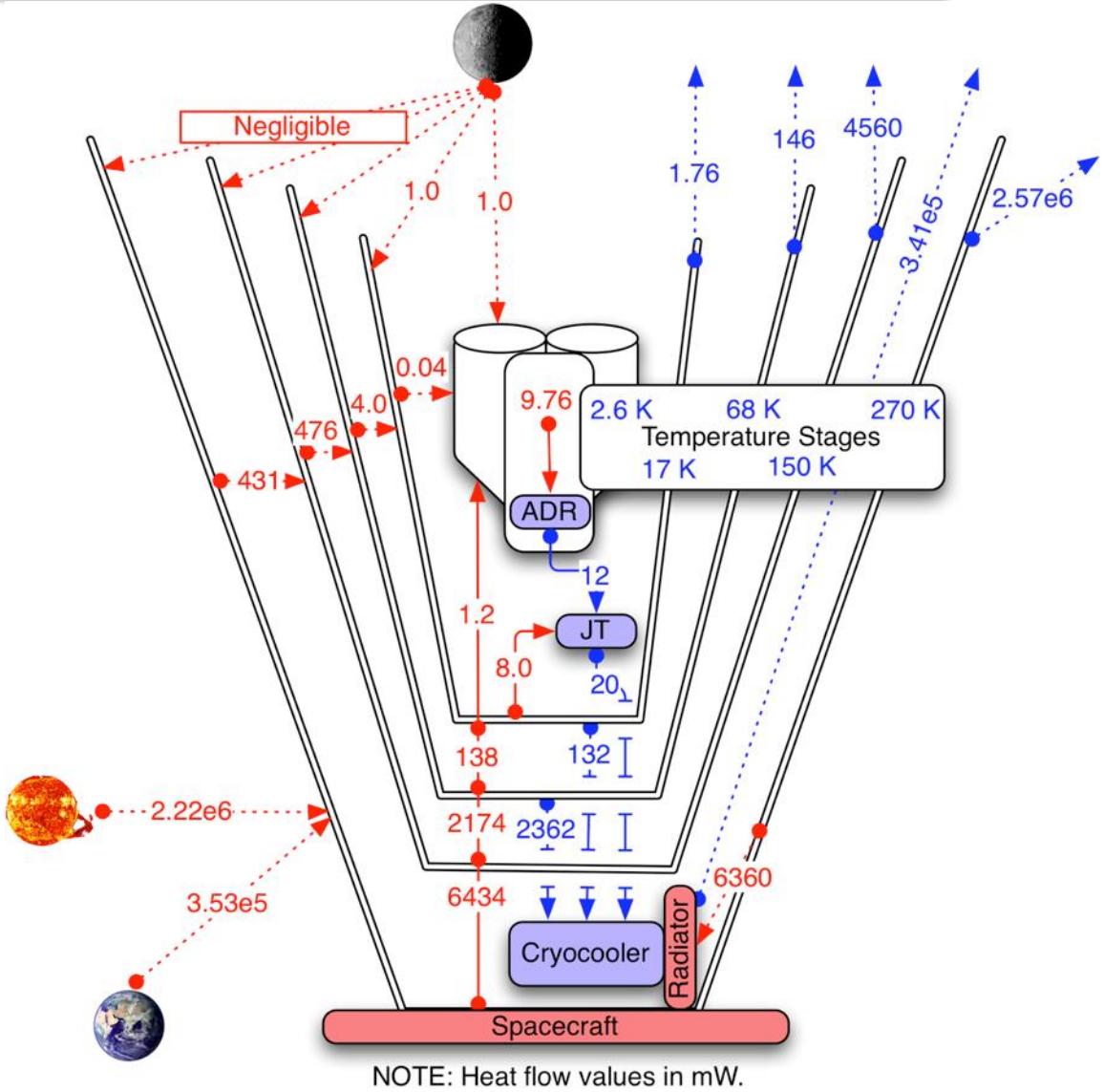
- PIXIE operates as a nulling polarimeter which is sensitive only to the *differences* between two nearly identical sources



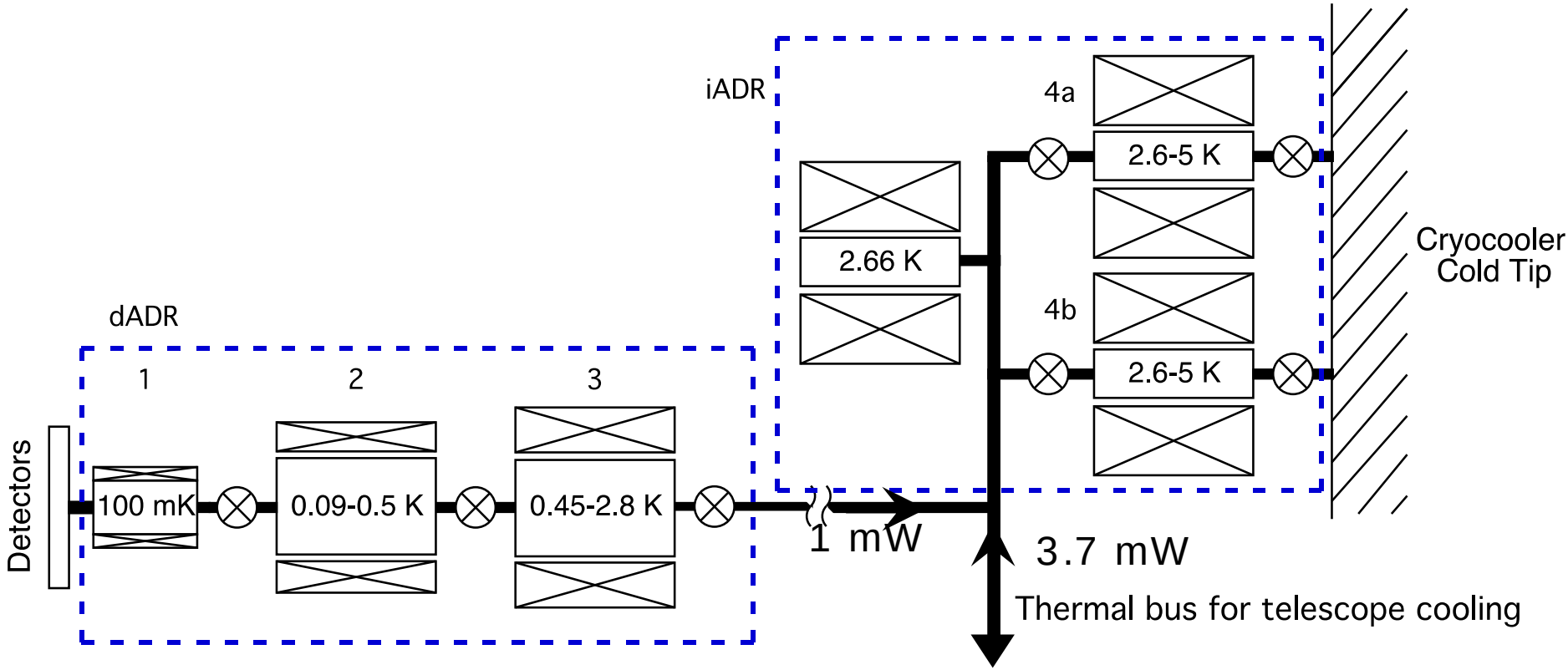
- FTE produces a rotating fringe pattern at twice the s/c spin rate (4 rpm)
  - Allows separation of instrumental effects that appear at the spin rate
- Optical components and calibrator are systematically varied in temperature to identify any effect on detector output

Thermal Map

- Heat inputs to 2.7 K
  - 1.2 mW from 17 K
  - 1.0 mW from dADR
  - 2.5 mW from temperature control of optics
  - Total of 4.7 mW
- Current design has 100% margin on 100 mK and 2.7 K loads
- iADR will output 12 mW at 4.5 K

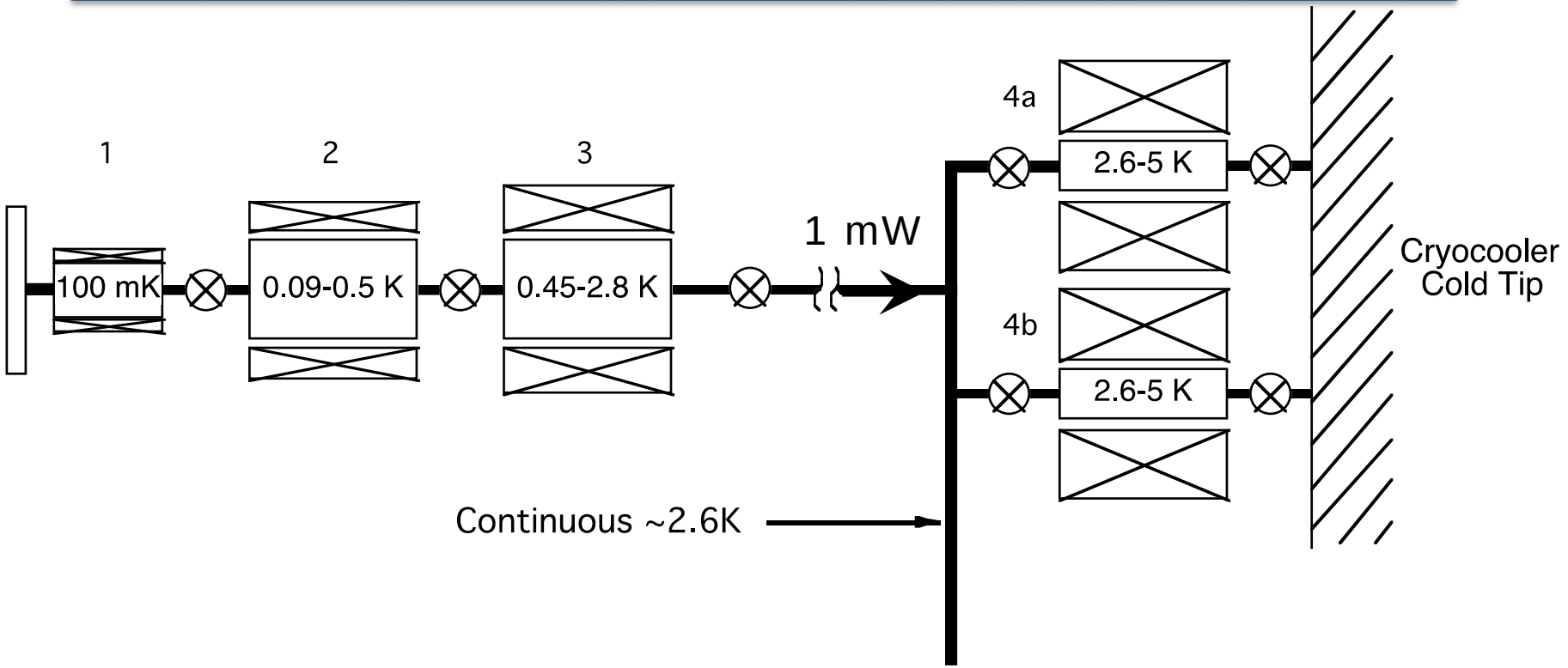


ADR Assemblies



- Parallel configuration for iADR can achieve near continuous heat rejection
  - Maximizes cooling power at 2.6 K
- Carnot efficiency: 9.4 mW in at 2.6 K -> 16 mW at 4.5 K
  - Goal is peak heat rejection rate of 20 mW

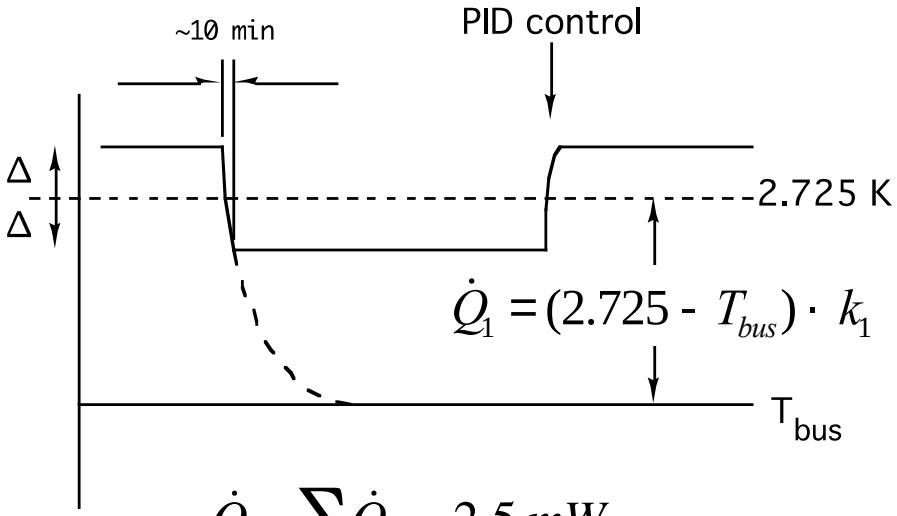
ADR System Schematic



- 3-stage dADR uses constant 2.6 K heat sink
- 2 μW detector heat load at 100 mK

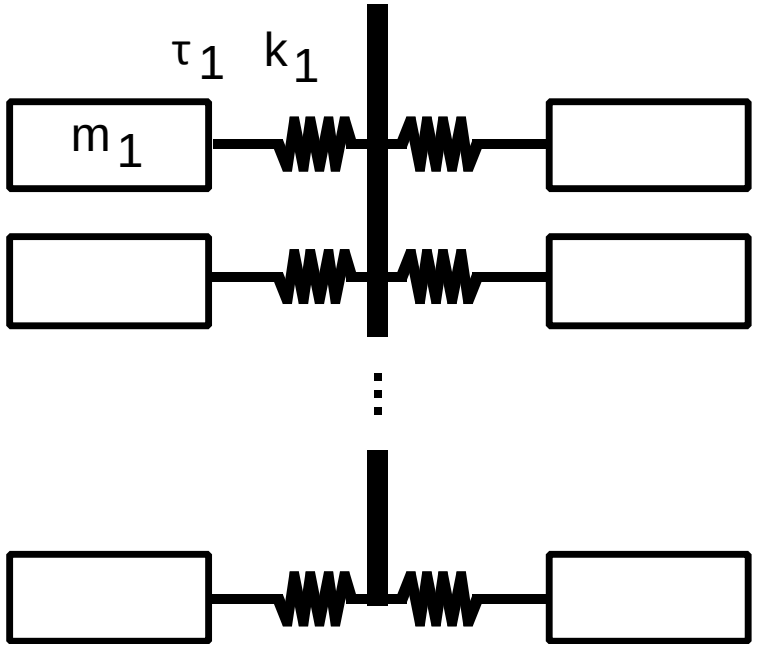
Optics Temperature Control

- Telescope/optics are connected to the 2.6 K thermal bus with a tailored k
  - Temperature controlled to $2.725 \pm \Delta$
    - Δ varies from 5-10 mK for most components, 20-100 mK for calibrator
  - Transition time must be shorter than period of temperature variations
- Optimize thermal bus temperature to give smallest entropy usage ($\dot{Q}$/T)
  - Peak heat load (all optics at elevated temperature) is 2.5 mW



$$\dot{Q} = \sum_n \dot{Q}_n = 2.5\ mW$$

$$for\ T_{bus} = 2.66\ K$$



ADR Design Parameters

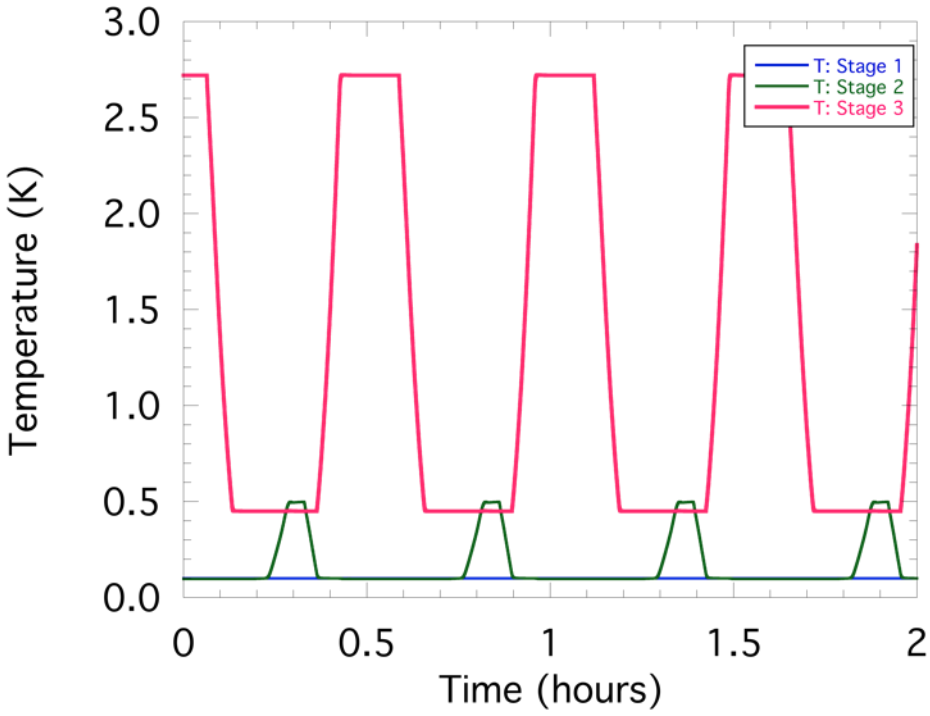
PIXIE ADR			Hitomi ADR		
Stage	**Refrigerant**	**B field (T)**	**Stage**	**Refrigerant**	**B field (T)**
1	60 g, CPA	0.2	1	270 g, CPA	2
2	60 g, CPA	1			
3	60 g, GLF	3	2	150 g, GLF	3
5	60 g, GLF	3			
4a	150 g, GLF	3	3	150 g, GLF	3
4b	150 g, GLF	3			

- Detectors are not sensitive to magnetic fields, so magnets have only basic shielding to minimize interactions between stages

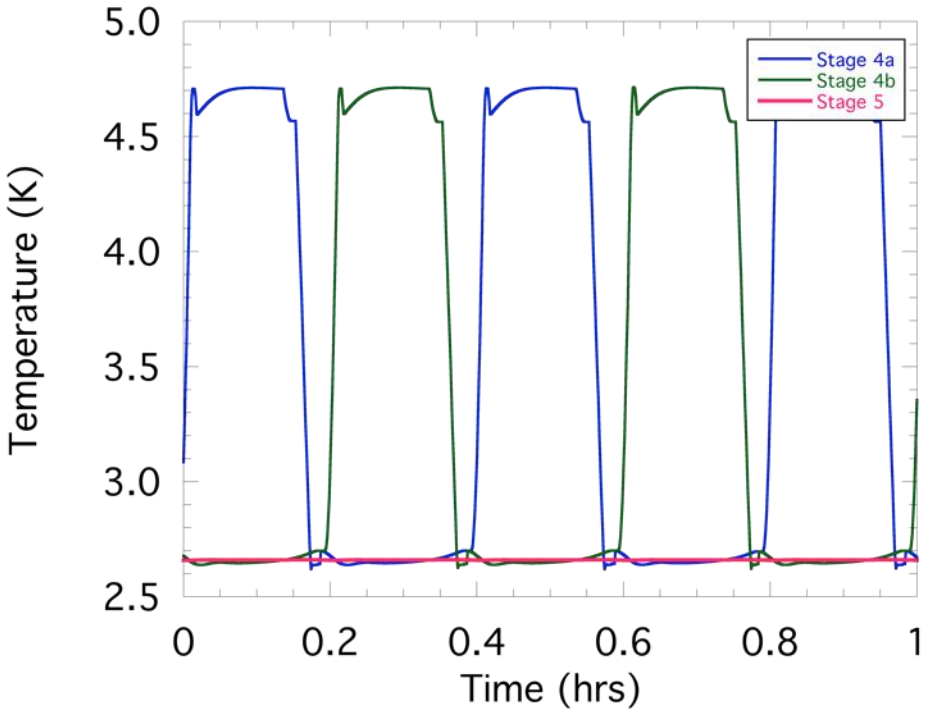
ADR Operation

- iADR was modeled for 9.4 mW continuous heat input
  - Peak heat reject rate is ~20 mW
- iADR and dADR are purposely synchronized to maintain stable temperature pattern

dADR



iADR



Summary

- Continuous cooling of the detectors and telescope are key requirements for PIXIE
- Two 3-stage ADR assemblies provide continuous cooling at 100 mK and 2.66 K
- High efficiency and near-continuous heat rejection are key to meeting power allocation for Stirling/JT cryocooler
  - Drives choice of parallel upper stages