Determining filter parameters by observing stars

Mike Lampton
Michael Richmond
Jan 5, 2006

This document based on the powerpoint presentation Filter parameters using stars alone? written by Mike Lampton and last updated Oct 31, 2003.

Contents

- Introduction
- The basic idea
- Detailed simulations

Introduction

We will measure the properties of each filter/detector combination very carefully before launch, on the ground. However, once the focal plane is exposed to the vacuum of space, it is possible that the filters might change slightly. **Is there any way to track changes in filter properties over the duration of the mission?**

The answer is yes. In fact, there are two methods by which one can monitor the filter bandpasses throughout the mission:

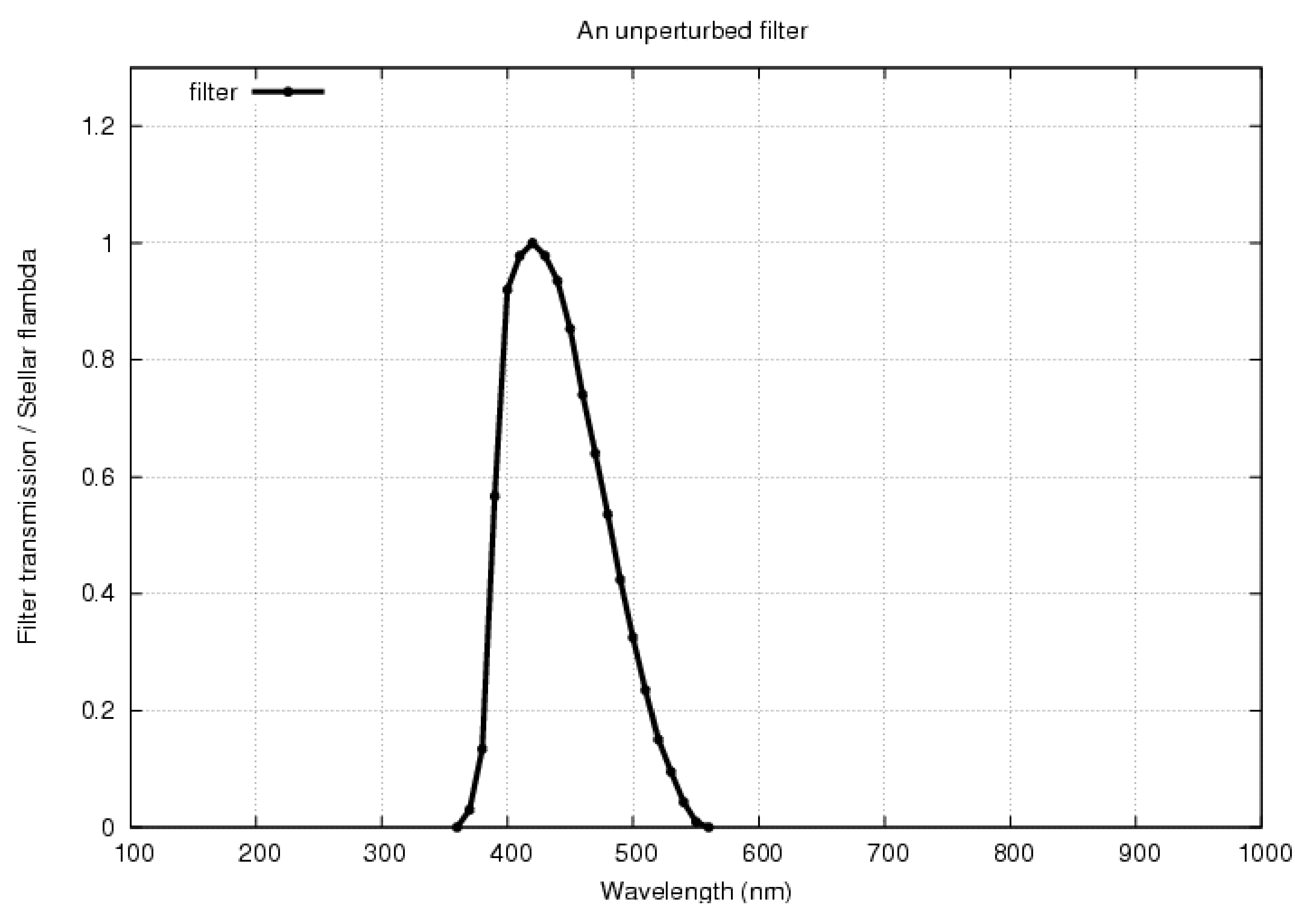
1. illuminate the focal plane with LEDs covering a range of wavelengths
2. illuminate the focal plane with stars spanning a range of temperatures

In both cases, one must know the spectra of the light source very well.

This document describes the second method: using observations of stars to monitor changes in filter bandpasses.

The basic idea

Consider a single filter/detector combination; for example, a Bessel B-band filter in front of an optical CCD. On the ground, we measure precisely the overall transmission curve.

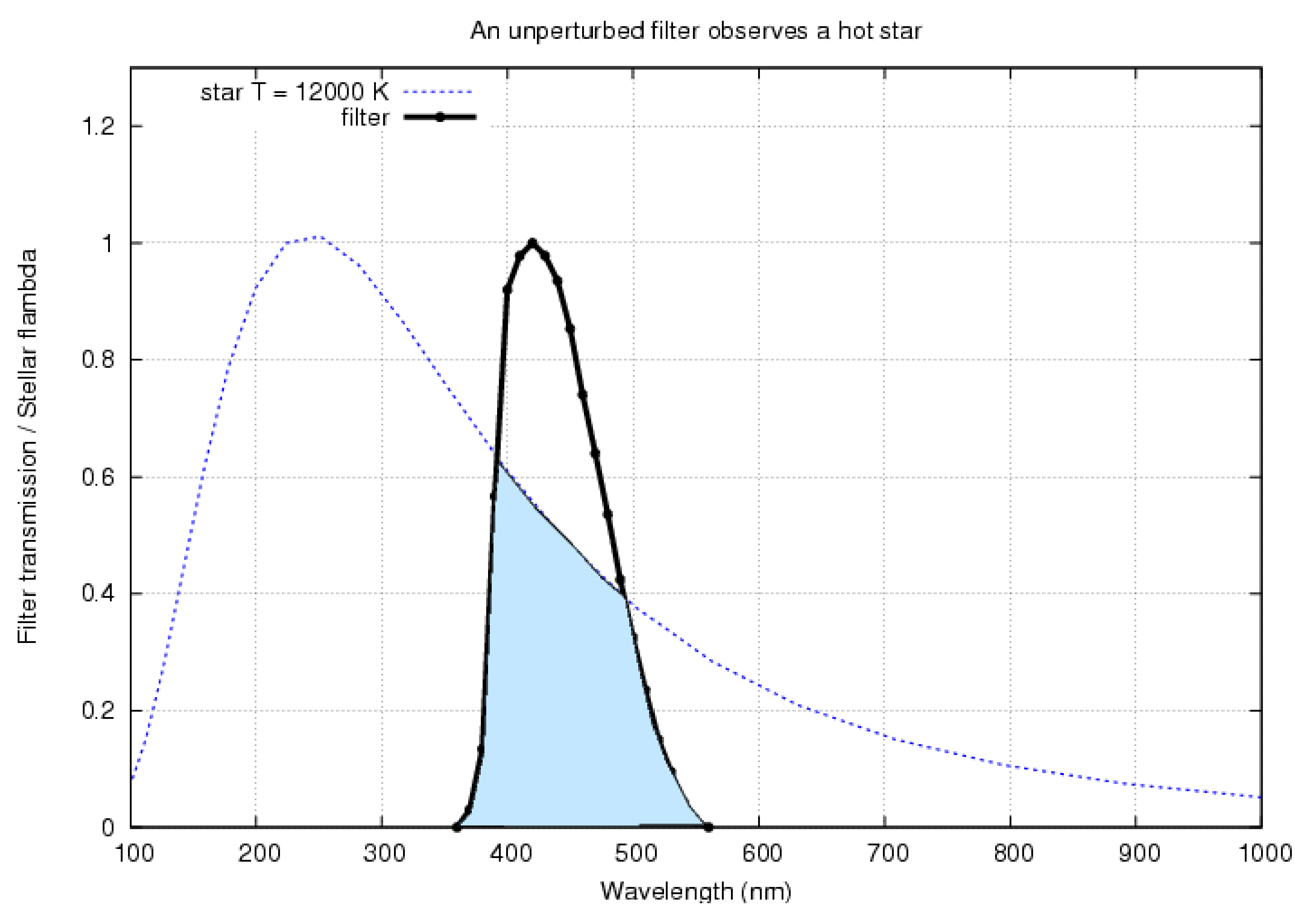


Once the telescope is in space, we observe a set of carefully selected stars. Ideally, these stars should

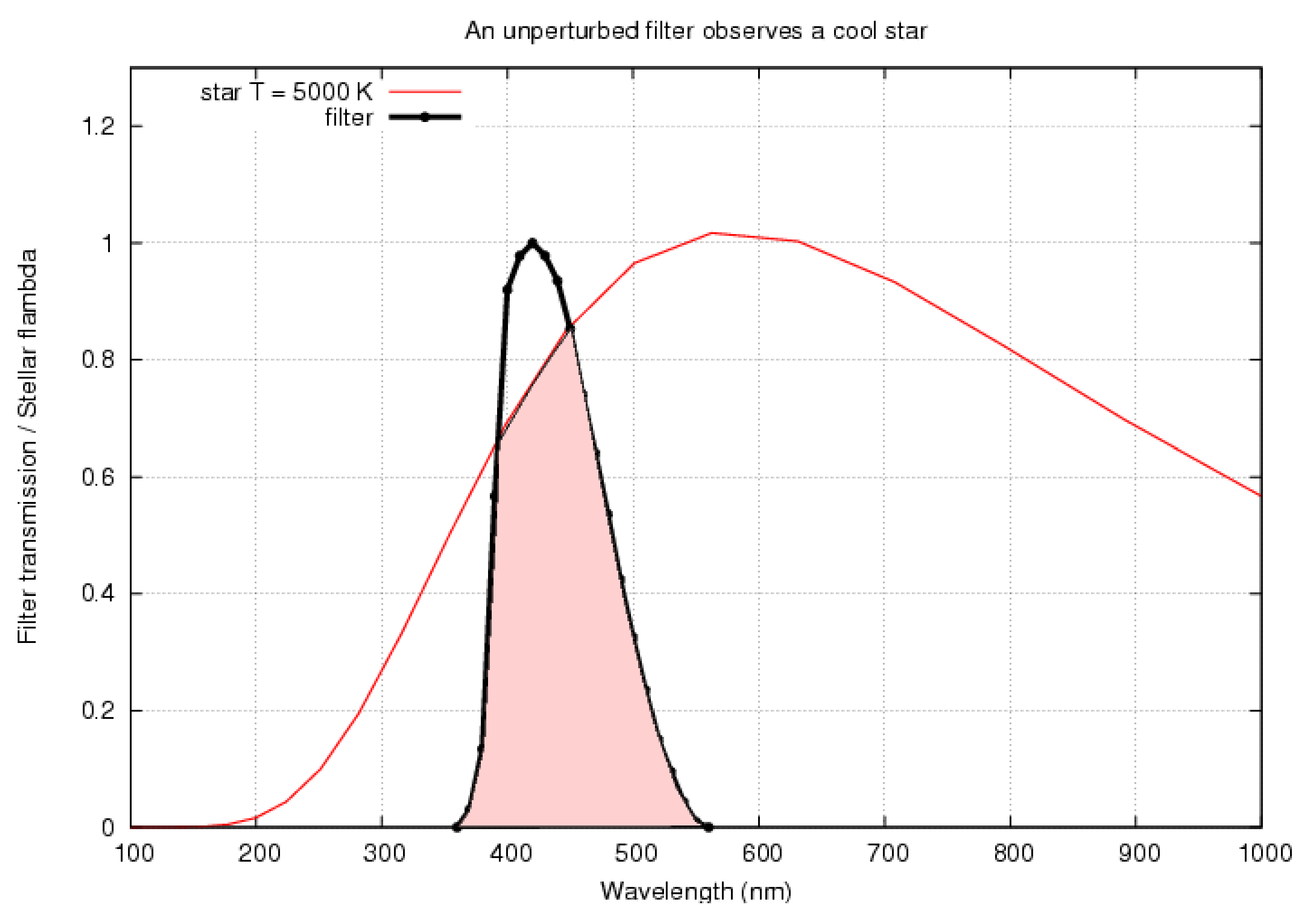
- cover a wide range of temperatures
- have very accurately measured spectra
- be far from any contaminating companions
- lie within a small region of the sky

We plan to pick a suitable set of stars well before launch and study them from the ground. A reasonable set might contain 10 stars with effective temperatures ranging from 50,000 K to 3,000 K. For the purposes of this discussion, we will approximate their spectra to be simple Planck curves. In the graphs which follow, we will plot stellar spectra in terms of the flux per unit wavelength, sometimes abbreviated as *flambda*.

When we observe one of these stars through a particular filter/detector combination, the signal we measure is a convolution of the passband with the stellar spectrum. Suppose we look at a hot star, the spectrum of which has a peak to the blue of the filter. We will measure the convolved flux.

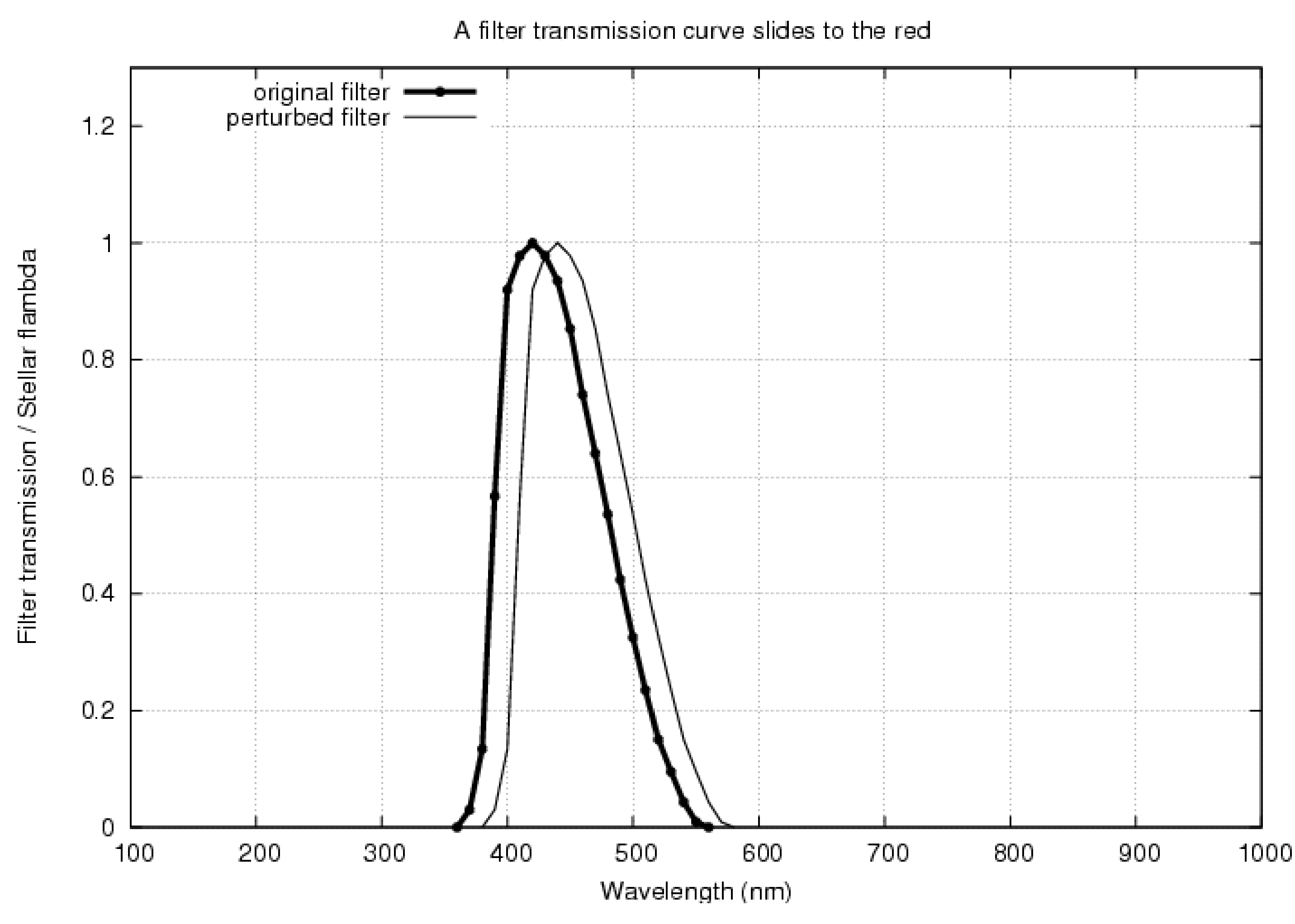


We can also observe a cool star, the spectral peak of which falls to the red of the filter.

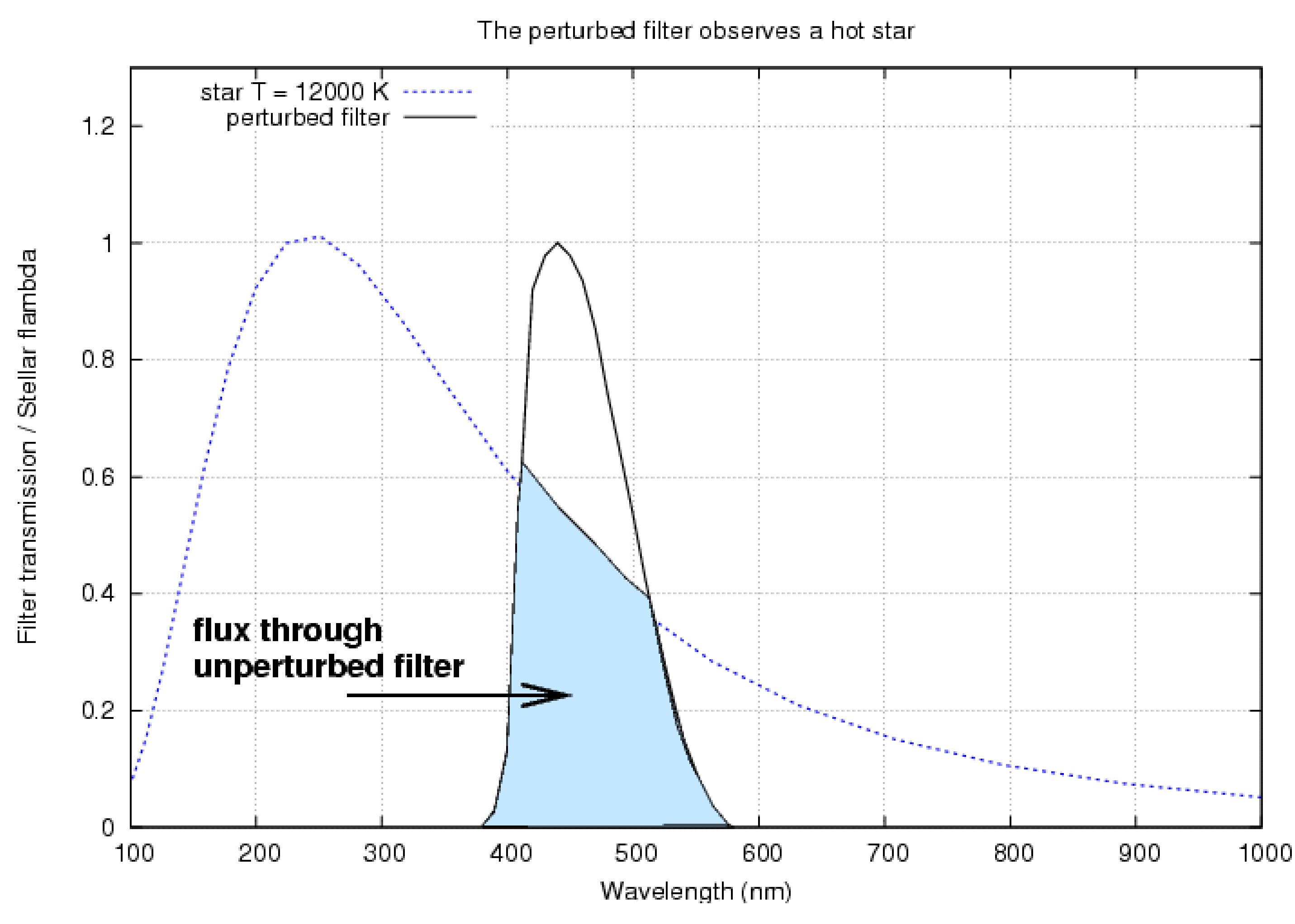


Now, if we know the overall passband of the filter/detector combination, and we know the spectra of the stars *in a relative sense* (without having to know the absolute number of ergs per second per square centimeter per Angstrom), then we can compute the ratio of the convolved fluxes from the two stars. If our knowledge of the filters and detectors is accurate, that ratio ought to match the ratio of the observed fluxes.

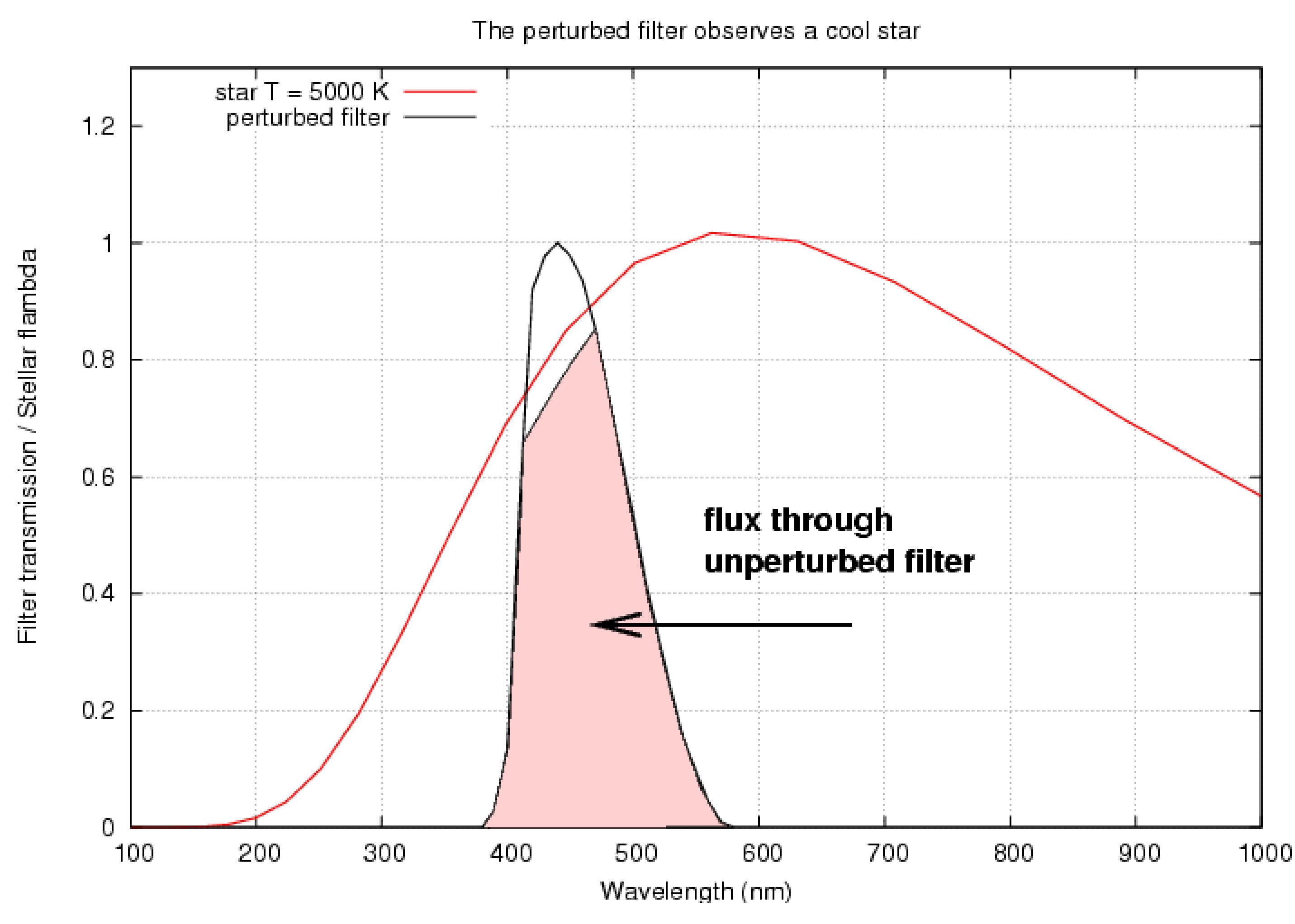
But what if the overall instrument passbands shift as a result of the environment on orbit? Suppose that the filter transmission curve slides as a unit to the red by, say, 10 nm.



When we observe the hot star, we will detect a smaller overall flux, since the filter has moved away from the peak of the spectrum.



When we observe the cool star, on the other hand, we will detect a larger overall flux than before, since the filter has moved towards the peak of the stellar spectrum.



Since the perturbed filter yields a smaller flux for the hot star, but a larger flux for the cool star, the **ratio** of the fluxes will change by a larger amount than either flux individually.

Our plan, then, is to observe stars covering a range of temperatures through each filter/detector combination. We will repeat these measurements at intervals to see if the ratios of the observed fluxes of the stars change. If they do change, we know that the overall passbands are moving.

Detailed simulations

How well can we determine these changes in the overall passbands? We show below the results of a simple simulation.

We begin with a model for the typical transmission curve of some filter/detector combination. We have chosen a slightly asymmetric shape similar to the standard Johnson-Cousins "B" band, with a sharp drop to the blue and a more gradual decline to the red. We assume that the perturbations are small enough that the shape remains nearly the same, so that we can characterize any filter with three parameters:

- the zeroth moment: integral under the curve, describing the total "light-gathering grasp" of the filter
- the first moment: the effective wavelength
- the second moment: a measure of the width of the filter

For SNAP cosmology, the most dangerous perturbation is an undetected shift in the effective wavelength of a filter, which leads to systematic errors when one compares supernovae at different redshifts.

In our simulations, we picked

- a set of stars with perfect blackbody spectra corresponding to temperatures of
    - 3000, 4000, 5000, 6000, 8000, 10000, 15000, 20000, 40000, 80000 Kelvin
- a set of filters with unperturbed central wavelengths of
    - 420 nm, 600 nm, 800 nm, 1000 nm, 1200 nm, 1400 nm
- exposure times chosen to yield S/N = 100 for each star

We first made a set of simulated observations through the unperturbed filters, which served as a baseline. We then perturbed the filters by known amounts, observed the stars through the perturbed filters, and recorded the fluxes.

The question is, how well can one use the perturbed fluxes to reconstruct the effective passbands of the perturbed filters? We created a program to use least-squares fitting techniques to sift through the observations for each filter and extract the three best-fitting parameters. We then compared those fitted parameters to those which we actually used to shift the filters.

The results can be summarized succinctly:

- we can recover the zeroth moment (overall light grasp) reasonably well: typically to better than 1%, except for the filters farthest into the near-IR
- we can recover the first moment (central wavelength) very well: better than 1% in all cases
- we can recover the second moment (filter width) poorly: to roughly 10% in the optical, but much worse in the infrared

We conclude that tests of this nature can be valuable in detecting and removing systematic errors in the photometry of supernovae at different redshifts, one of the key components of SNAP's cosmological mission.