

The background of the slide is a reproduction of Raphael's fresco 'The School of Athens'. It depicts a group of ancient Greek philosophers in a grand, vaulted hall. Plato and Aristotle are the central figures, with Plato pointing upwards and Aristotle gesturing downwards. Other philosophers like Pythagoras, Euclid, and Socrates are also visible. The architecture features arches and classical columns.

**Bayesian inference of stellar parameters
and interstellar extinction using parallaxes
and multiband photometry**

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Objective

- *Self-consistent* estimation of stellar parameters using *all available* information
- Good inference requires
 - ▶ a *forward model*, $\text{Data} = f(\phi)$
 - ▶ a *probabilistic* representation of the results, $P(\phi \mid \text{Data})$

Notation:

\mathbf{p} = (“photons”) normalized SED, e.g. colours

Φ = astrophysical parameters (APs), here just A_V and T_{eff}

An opportunity and a problem

- *Opportunity:* parallaxes (ϖ) potentially permit estimation of absolute stellar magnitudes ...

$$q \equiv \boxed{V + 5 \log \varpi} = M_V + A_V - 5$$

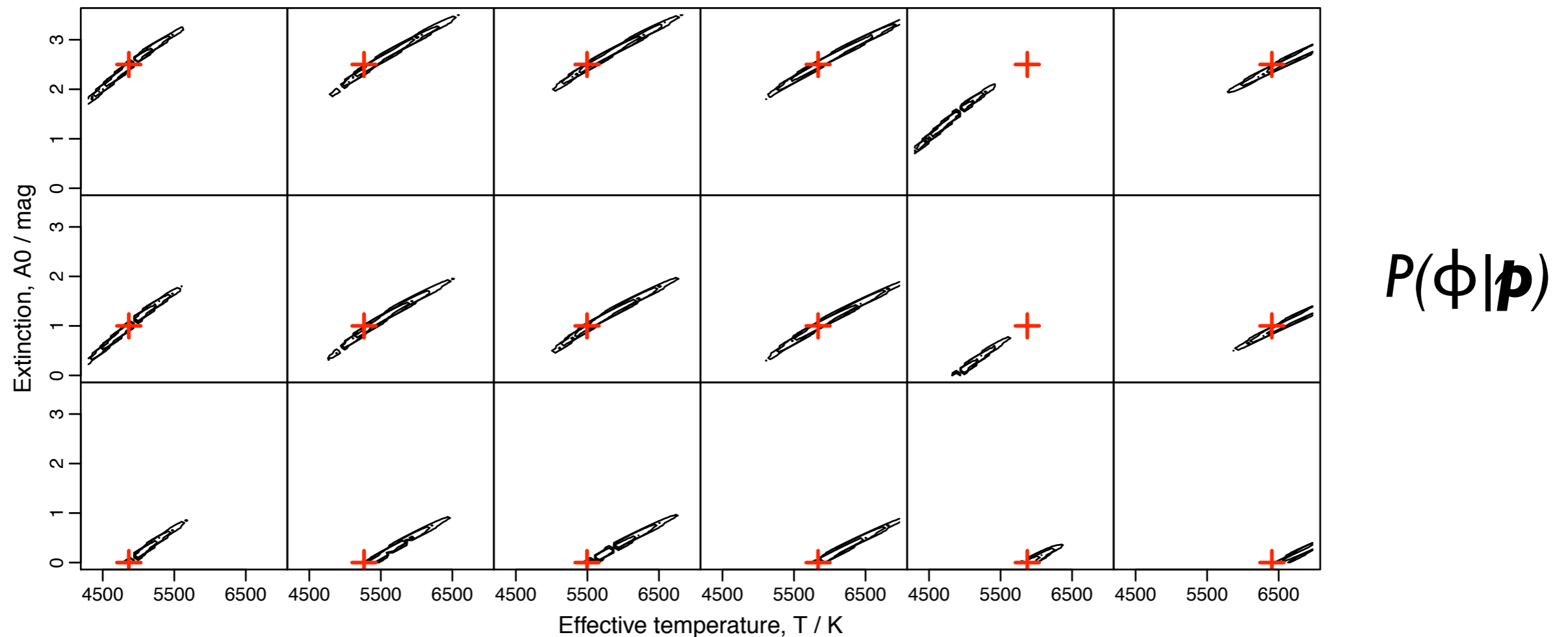
... but only if A_V can be estimated

- *Problem:* A_V is degenerate with T_{eff} when inferred from broad band photometry

AP estimation from BVJHK colours (only)

$$P(\mathbf{p}|\phi) \propto e^{-D^2/2} = \exp\left(-\frac{1}{2}[\mathbf{p} - \mathbf{f}(\phi)]^T \mathbf{C}_p^{-1} [\mathbf{p} - \mathbf{f}(\phi)]\right)$$

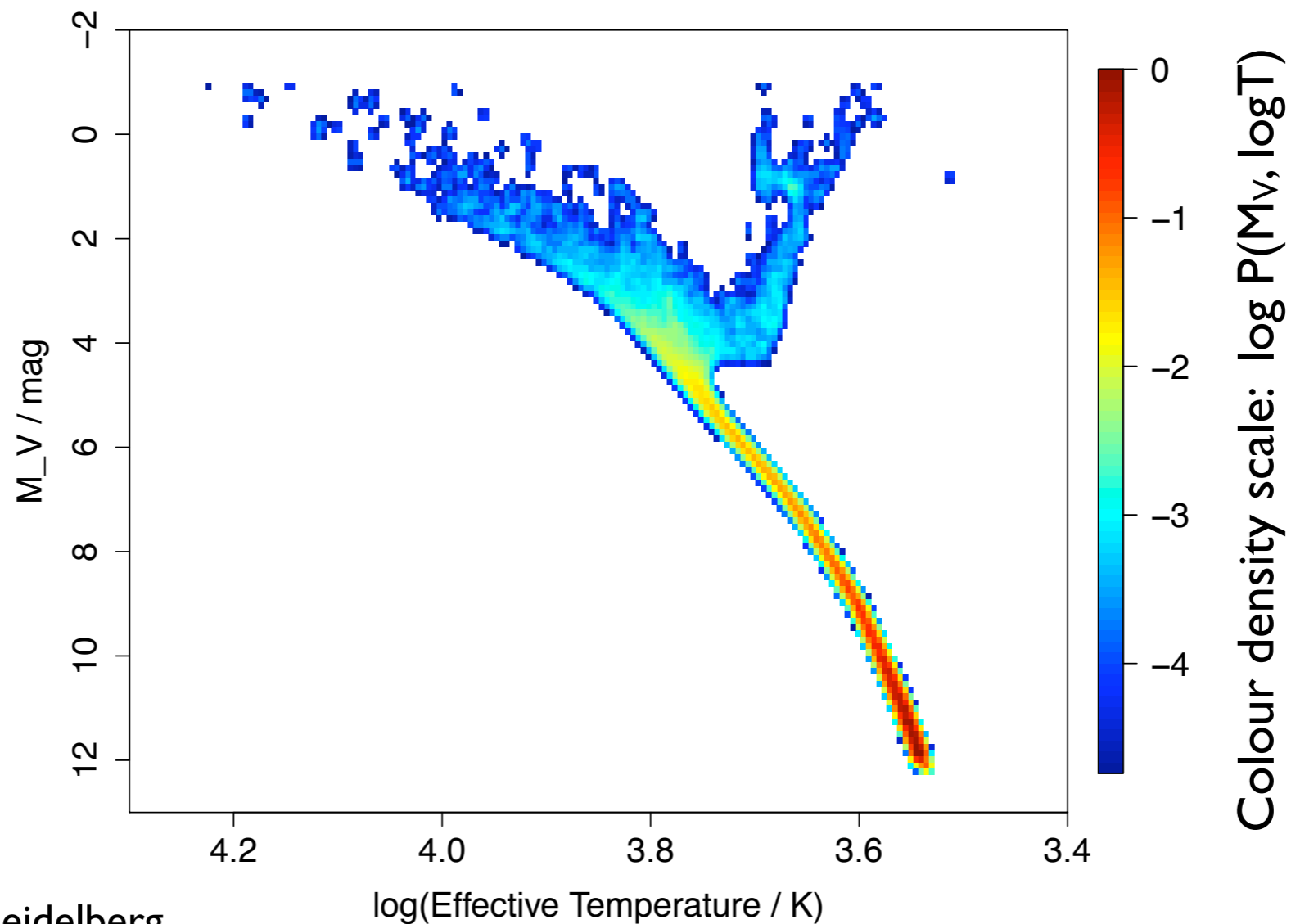
forward model
data covariance



- real data; “true” APs shown as red cross
- “true” T_{eff} from Valenti & Fischer (2005) from high-res. spectroscopy
- artificially reddened colours


Information beyond the spectrum

- Parallax and apparent magnitude: q constrains $M_V + A_V$
- HRD (“prior”) constrains M_V and T_{eff}
- spectrum: p constrains T_{eff} and A_V



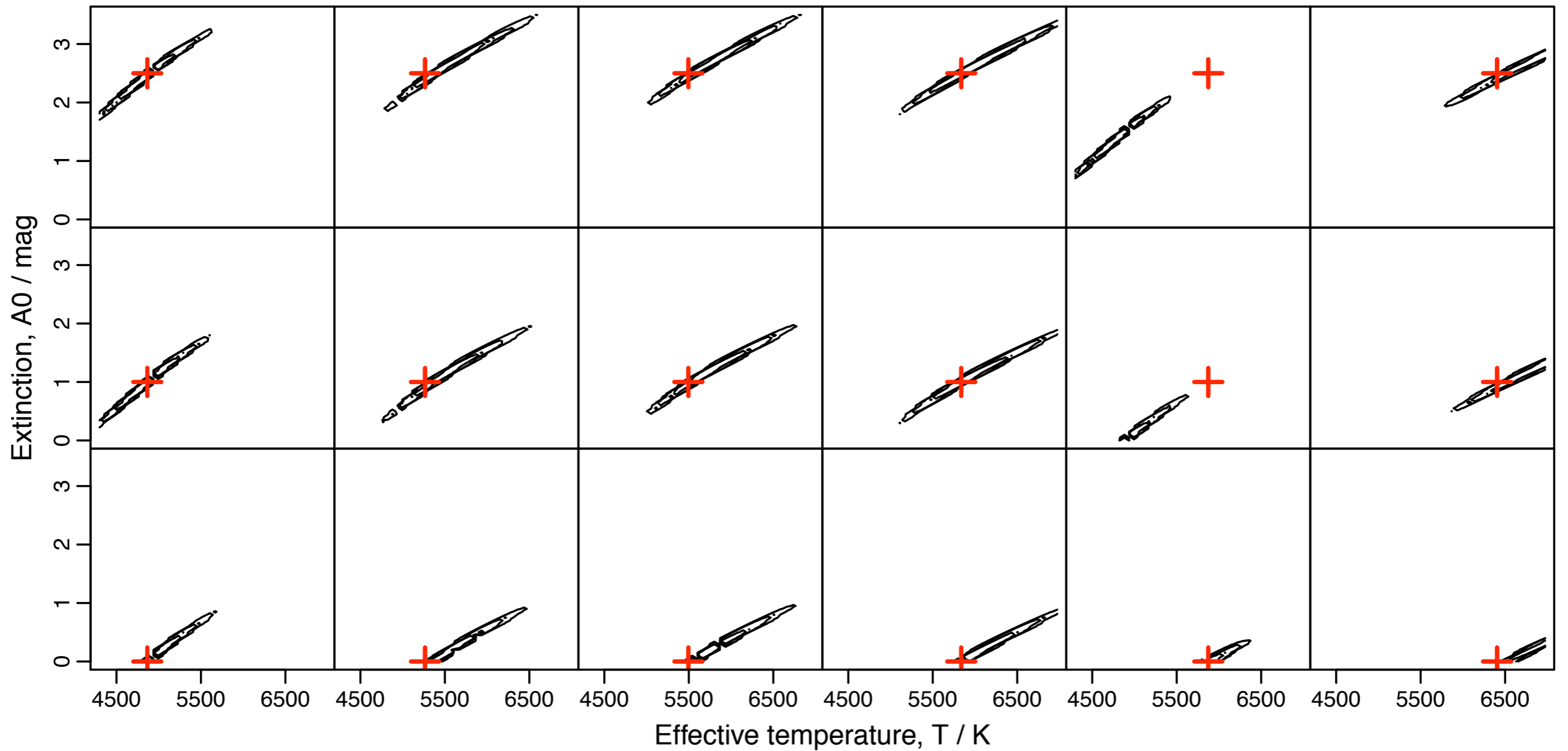
Probabilistic inference

$$\begin{aligned}
 P(A_0, T | \mathbf{p}, q) &= \frac{P(\mathbf{p}, q | A_0, T) P(A_0, T)}{P(\mathbf{p}, q)} && \text{Bayes' theorem} \\
 &= \underbrace{P(\mathbf{p} | A_0, T)}_{\text{likelihood}} \underbrace{\frac{P(A_0)}{P(\mathbf{p}, q)}}_{\text{priors}} \underbrace{\int_{M_V} \underbrace{P(q | M_V, A_0, T)}_{q \text{ constraint}} \underbrace{P(M_V, T)}_{\text{HRD prior}} dM_V}_{\text{HRD/q factor}}
 \end{aligned}$$

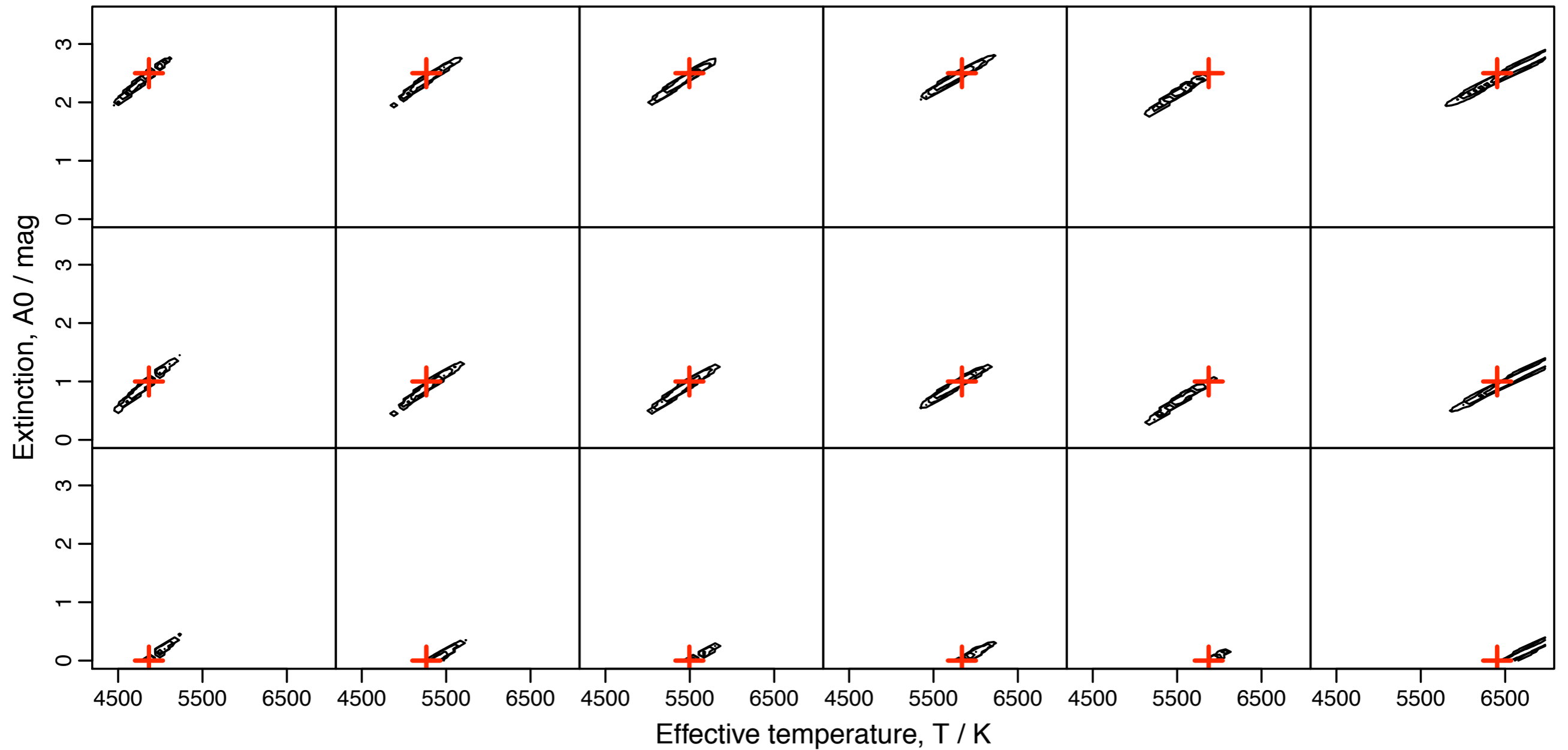


colour-only estimation

AP estimation from BVJHK colours

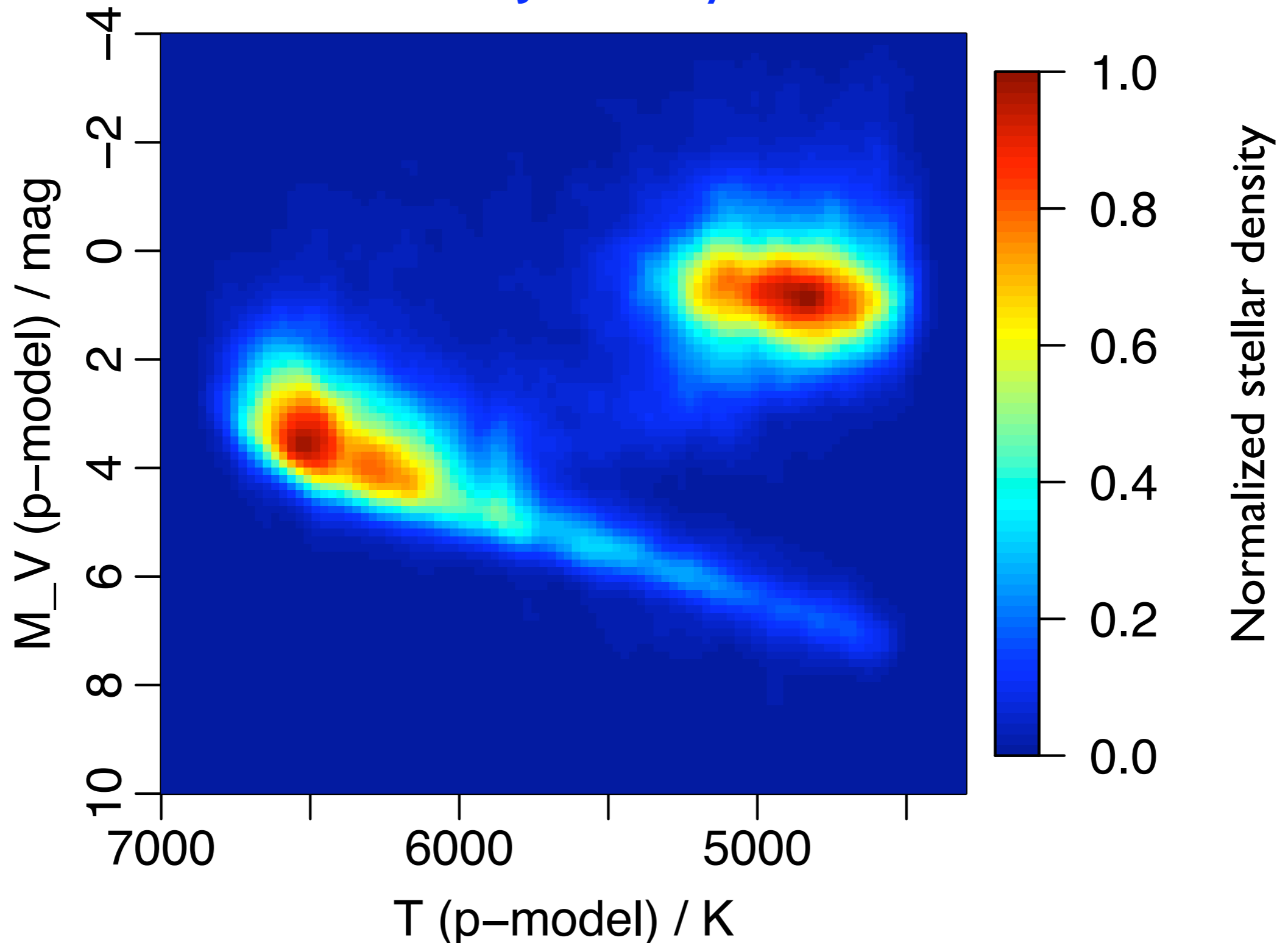


AP estimation from BVJHK colours + q, HRD



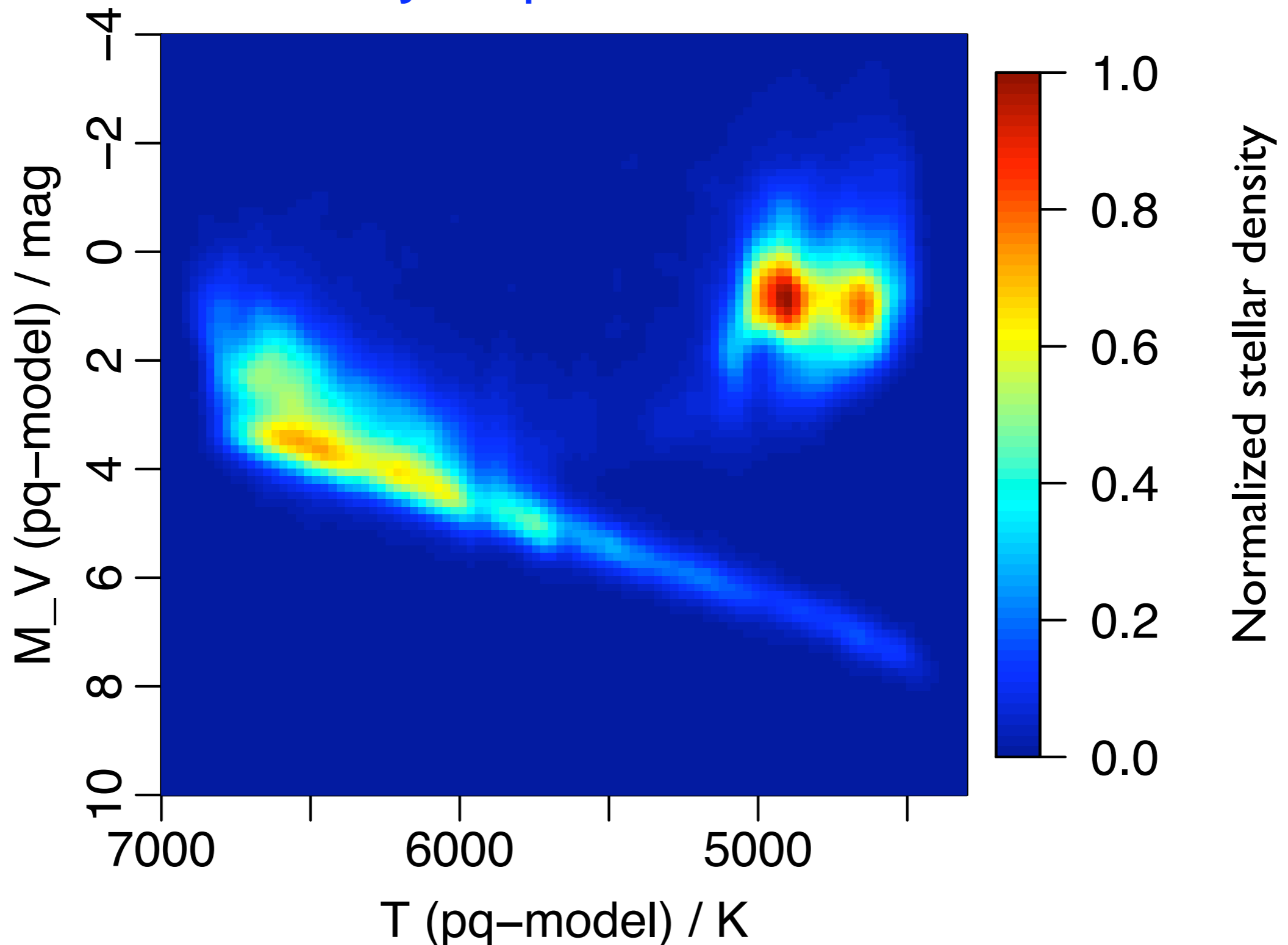
Application to 85 000 Hipparcos/2MASS stars

BVJHK only



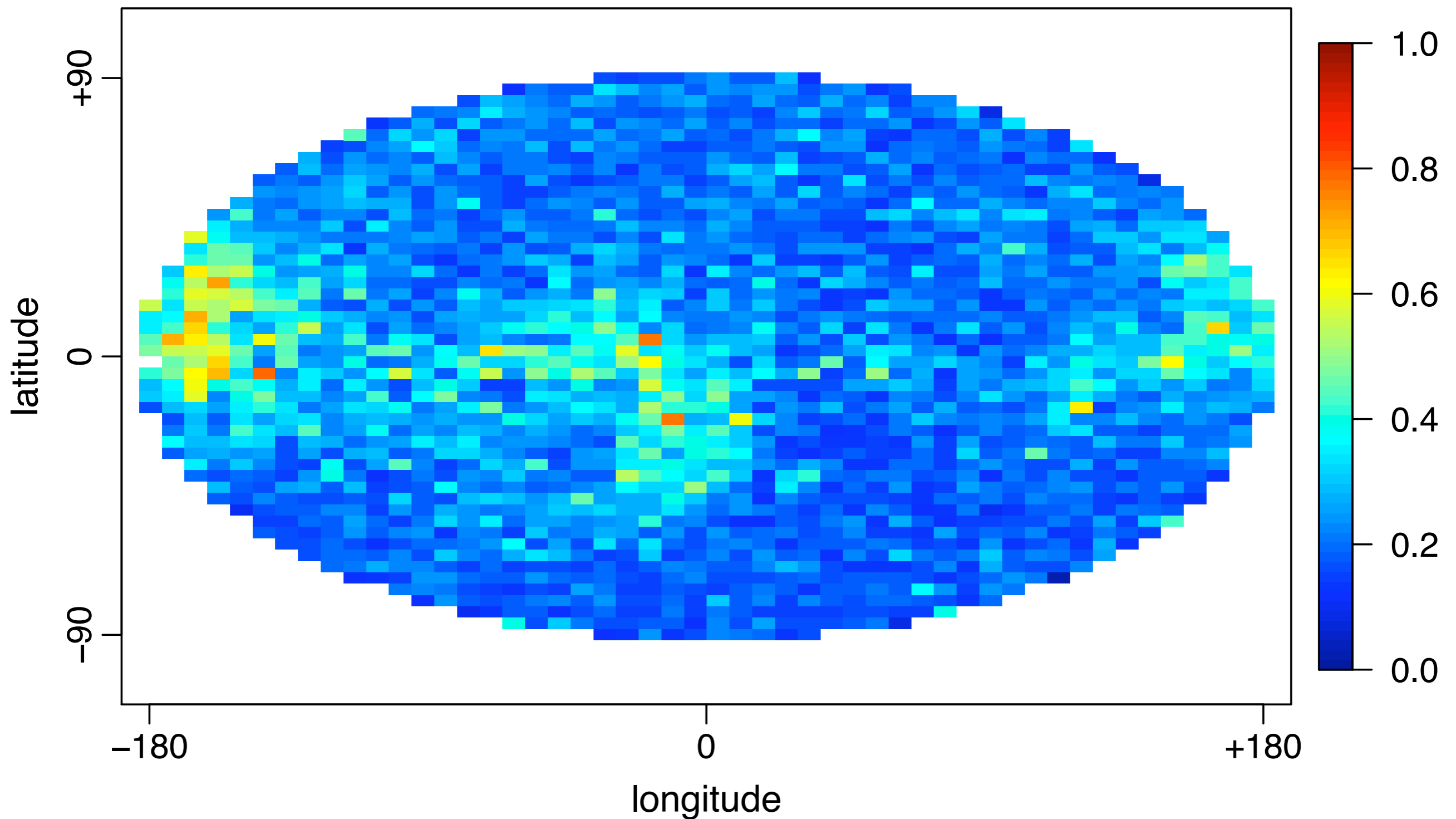
Application to 85 000 Hipparcos/2MASS stars

BVJHK, parallax, HRD



Derived extinction map

h2mqcat, Mollweide equal area projection, mean A0 pq-model



Drawbacks of conventional approaches

Why modelling of $y(\phi \mid \text{Data})$ (e.g. ANN, SVM) is a bad idea

- it's an inverse problem
 - ▶ may not be unique
 - ▶ cumbersome to fit and inflexible with heterogeneous inputs
- methods are invariably non-probabilistic
 - ▶ cannot recognize degeneracies, multiple solutions or give error bars in any sensible way
- cannot naturally/explicitly incorporate domain knowledge or prior information \Rightarrow inconsistent, unphysical solutions

Summary and Conclusions

- Good inference needs a *forward* model and a *probabilistic* model of the uncertainties
- You *do* have information beyond the SED, so use it!
- Use of parallax, HRD improves T_{eff} , A_V accuracy by 35% on Hipparcos/2MASS data (BVJHK)
- Method gives full PDF over solutions
- AP estimation by conventional (inverse) approach (e.g. with ANN, SVM etc.) has significant disadvantages
- Plan to use in Gaia data processing
- <http://tinyurl.com/qmethod> (MNRAS, in press)