3D extinction mapping of molecular clouds & better photometry matching

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3D extinction mapping of molecular clouds & better photometry matching

Galactic Structure:
Introduction
Distance Determination
3D Extinction – Naïve & IPHAS
3D Extinction - Bayesian

Symmetric Catalogue Matching:
Introduction
Asymmetry & Symmetrisation
Photometric & Astrometric Distributions
First Results

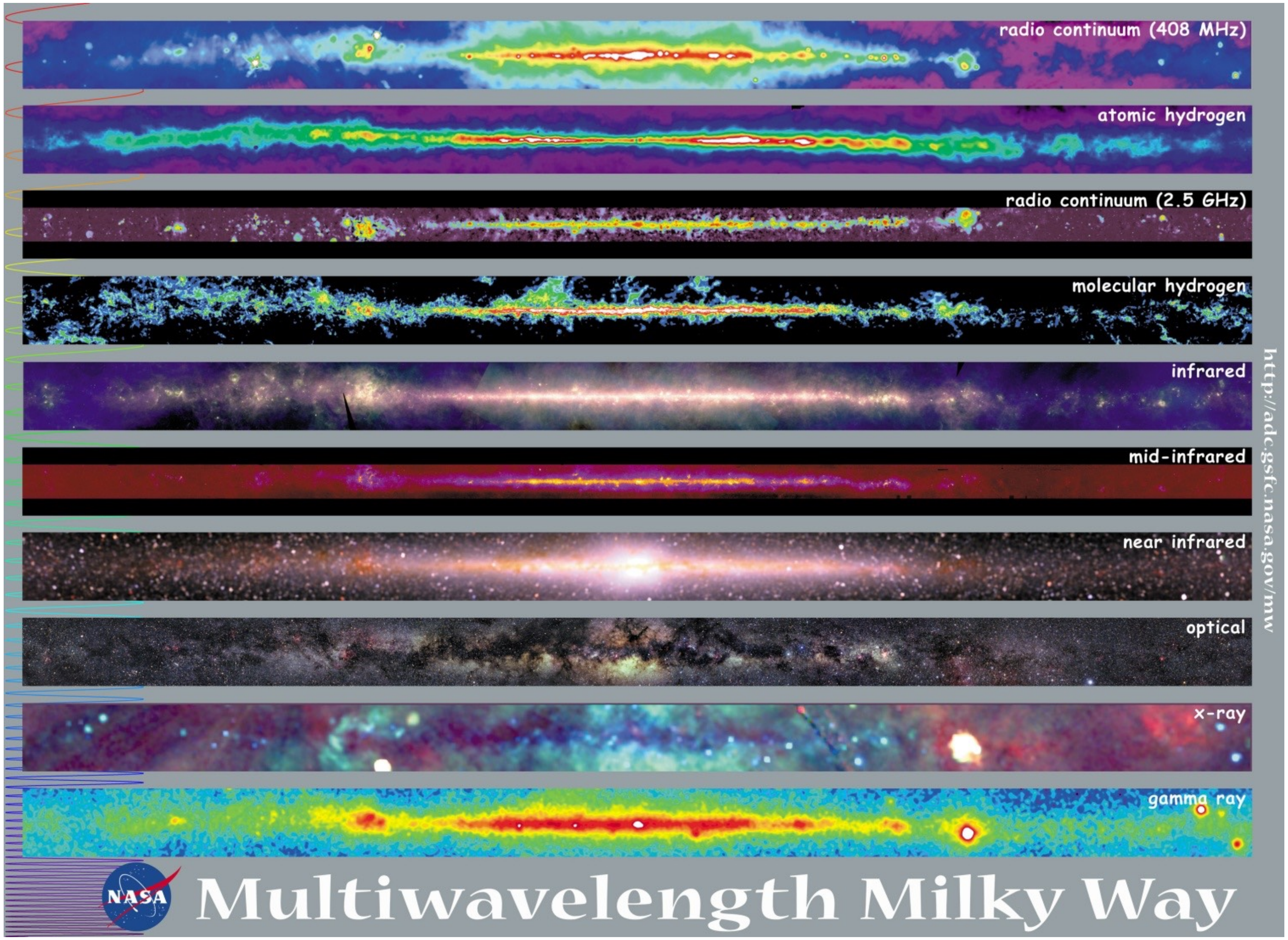
Introduction

ESA/NASA

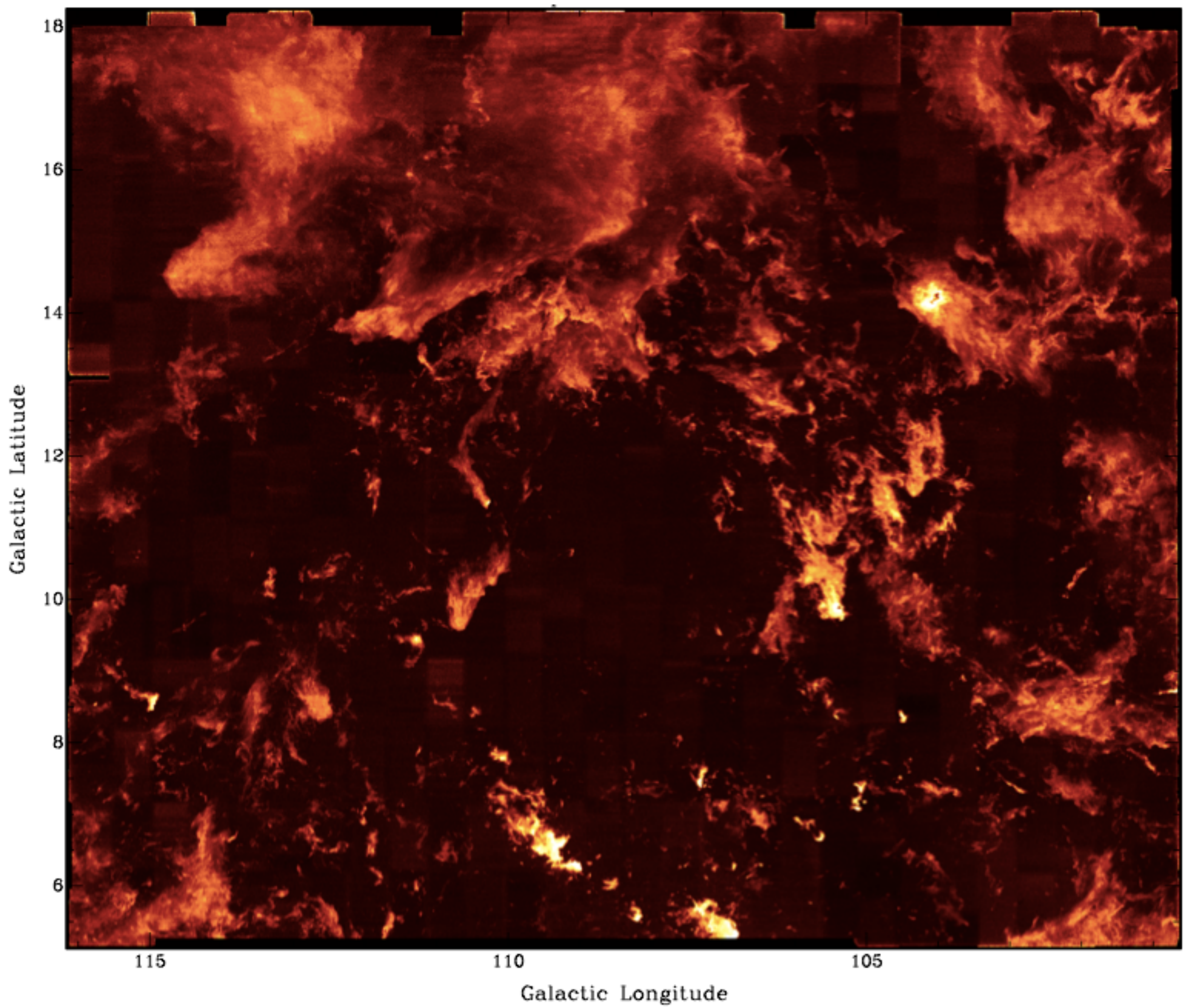
Introduction

Bruno Gilli/ESO

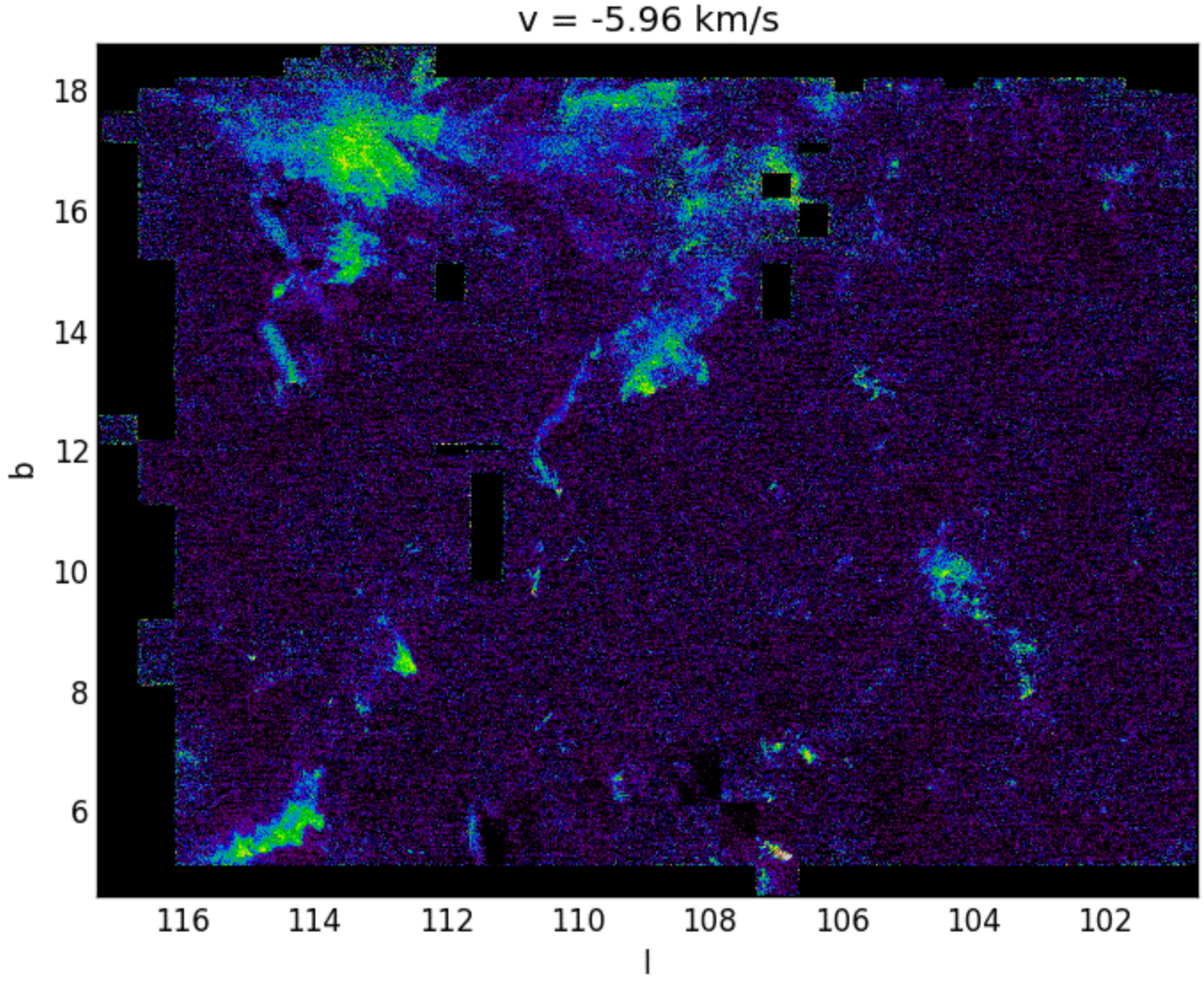
Introduction



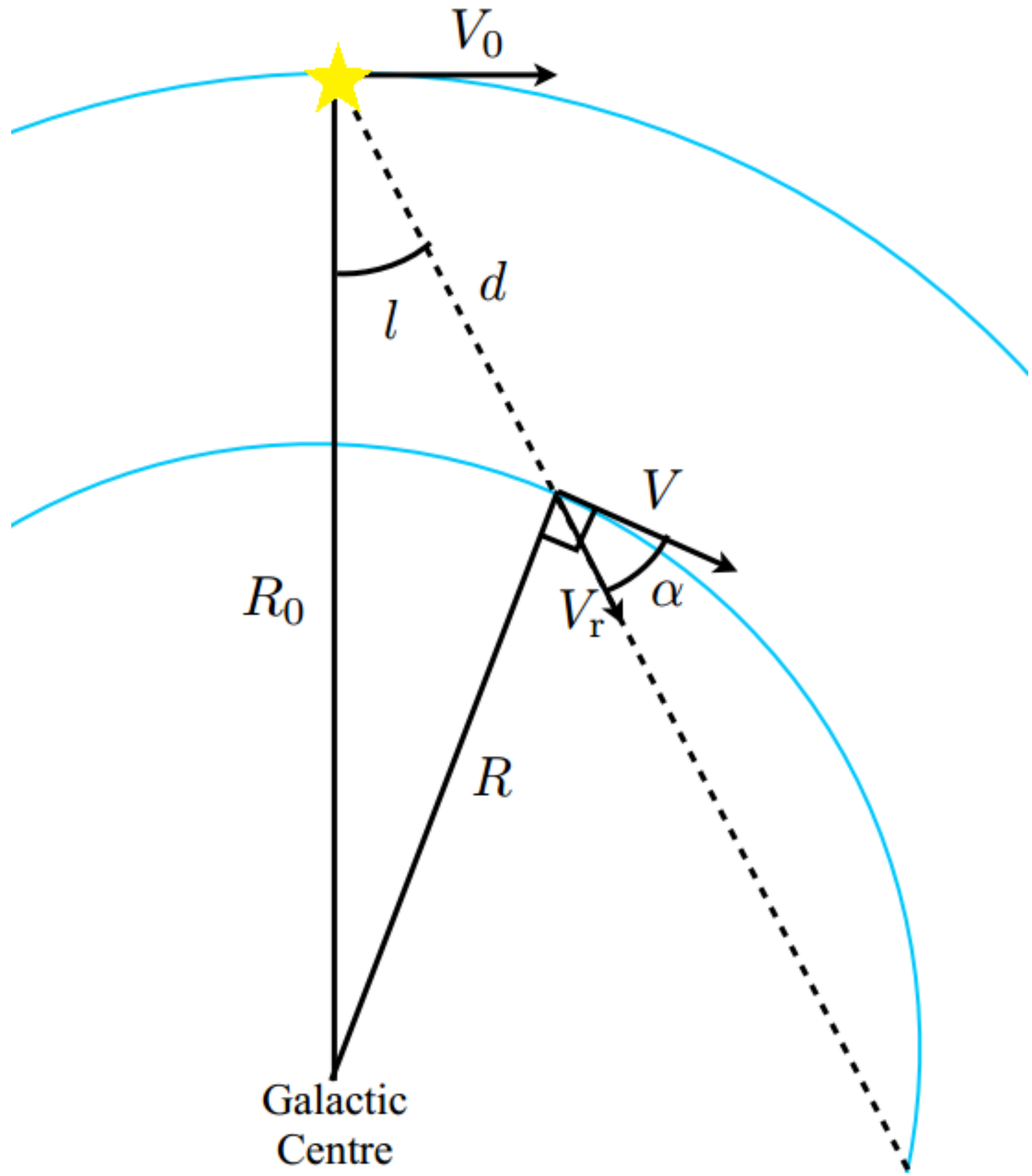
Mapping the Milky Way



Mapping the Milky Way



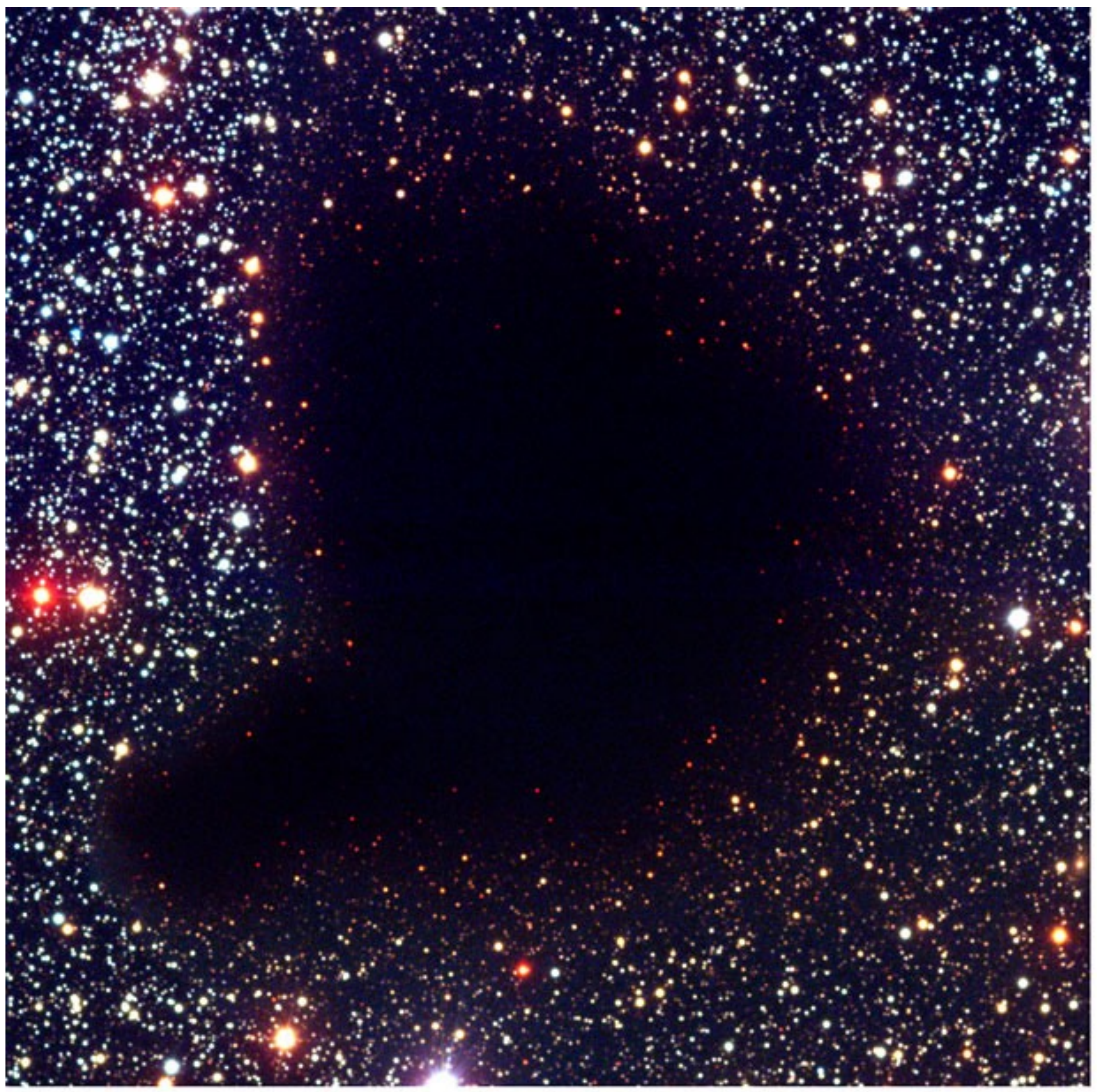
Distance Determination



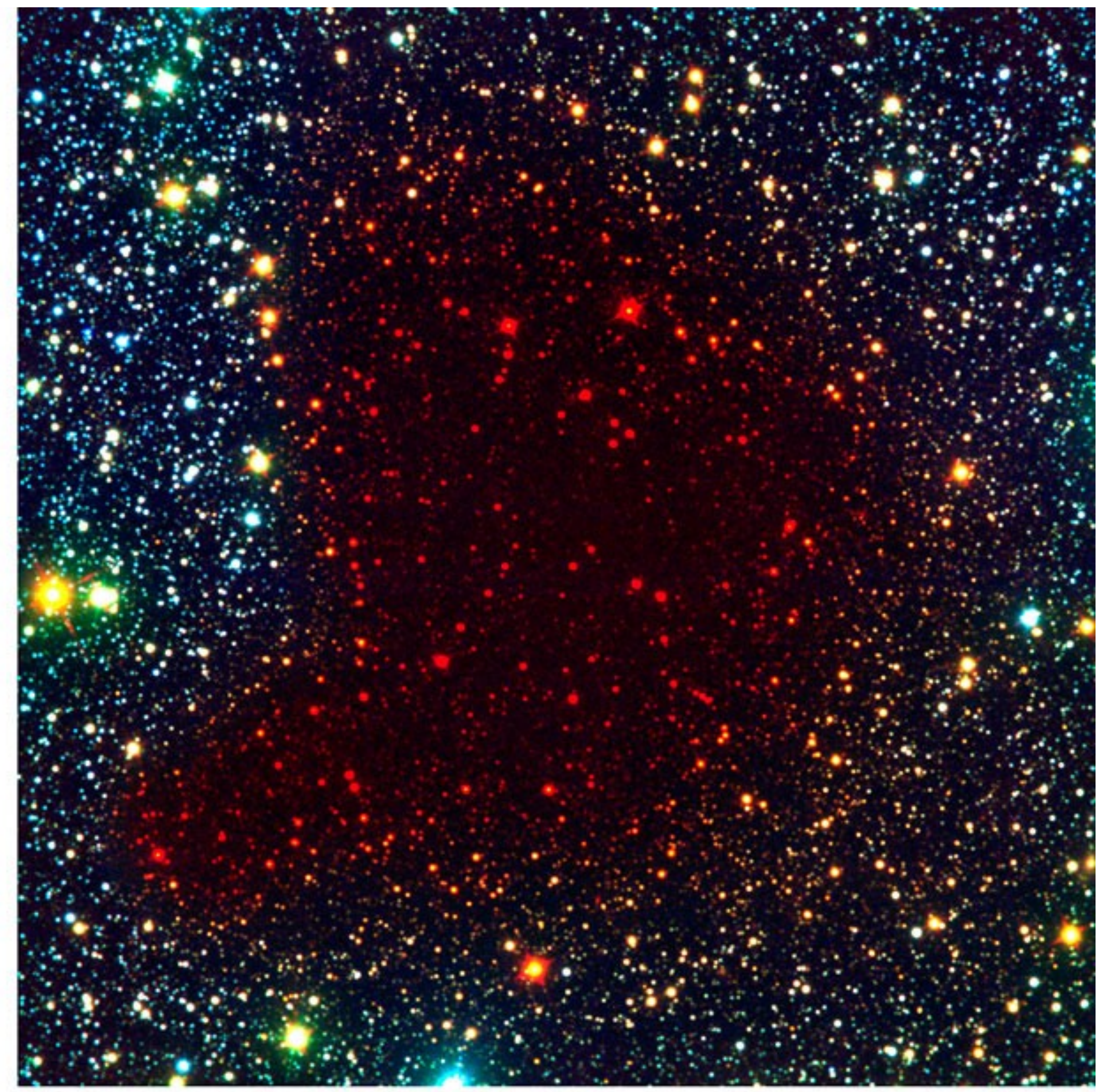
Distance Determination

APOD/NASA

Distance Determination



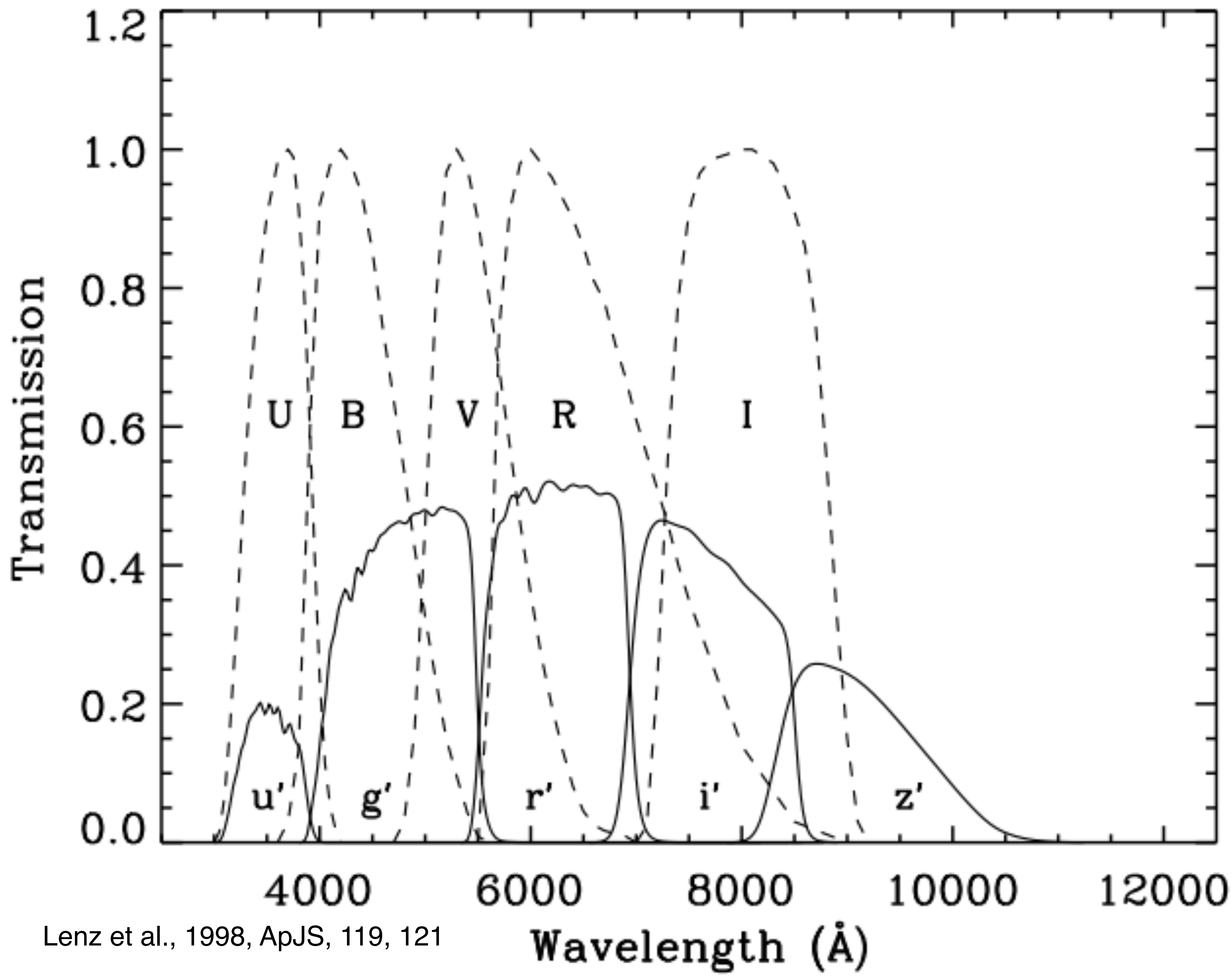
B, V, I



B, I, K

ESO

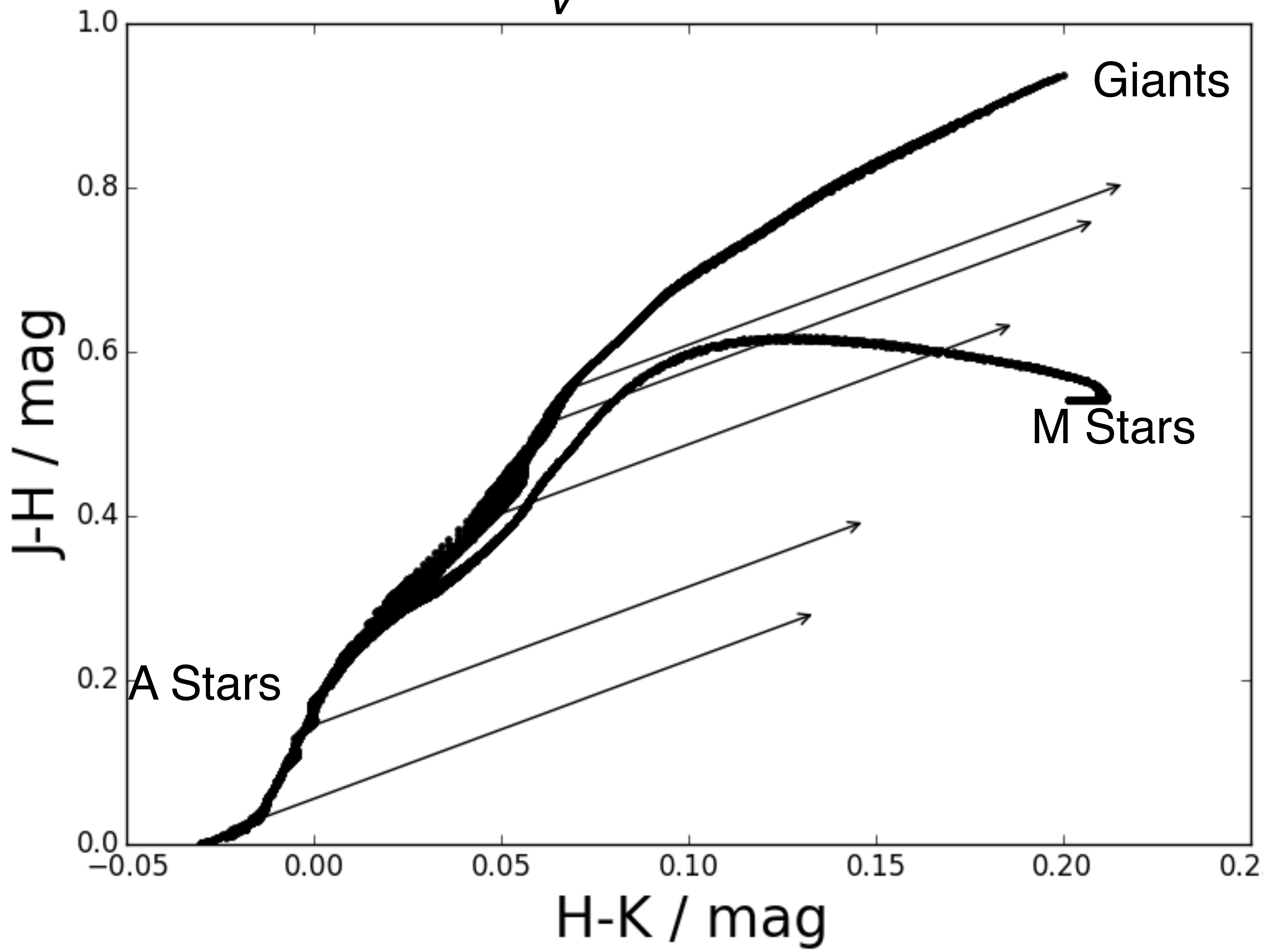
3D Extinction



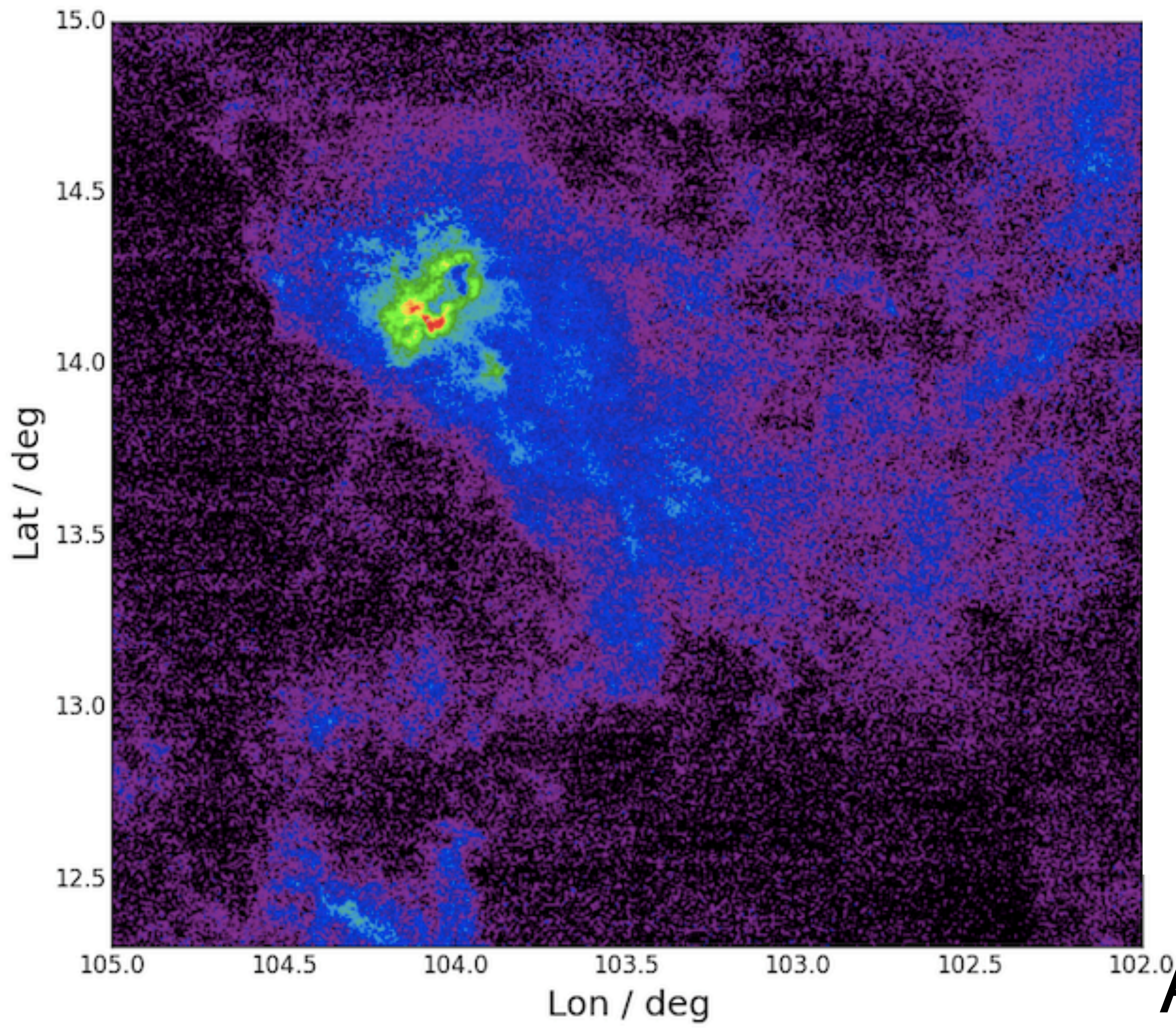
Lenz et al., 1998, ApJS, 119, 121

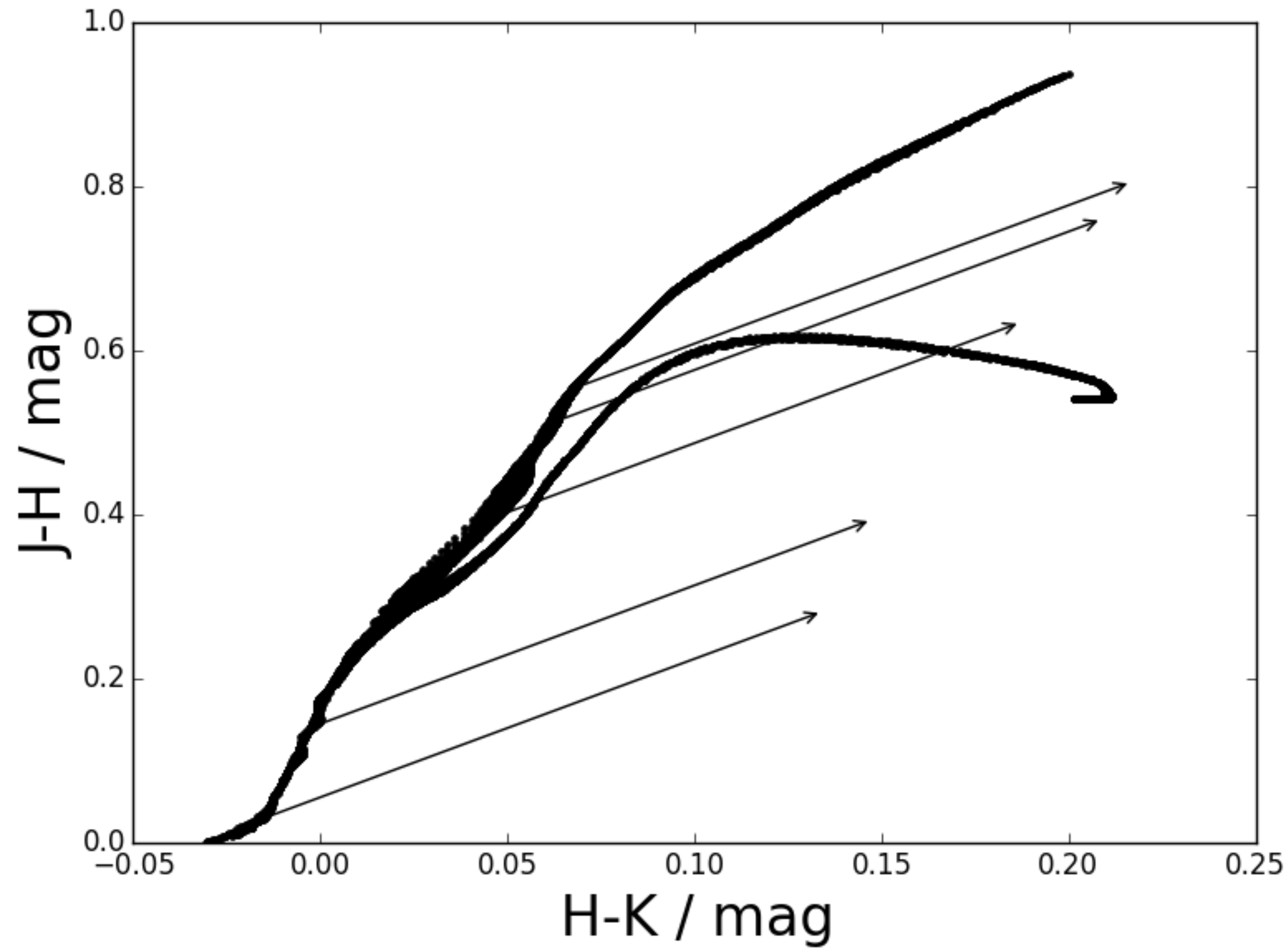
3D Extinction

$$m_\lambda = M_\lambda + \frac{A_\lambda}{A_V} A_V + 5\log_{10}(d) - 5$$



3D Extinction – Naive Approach





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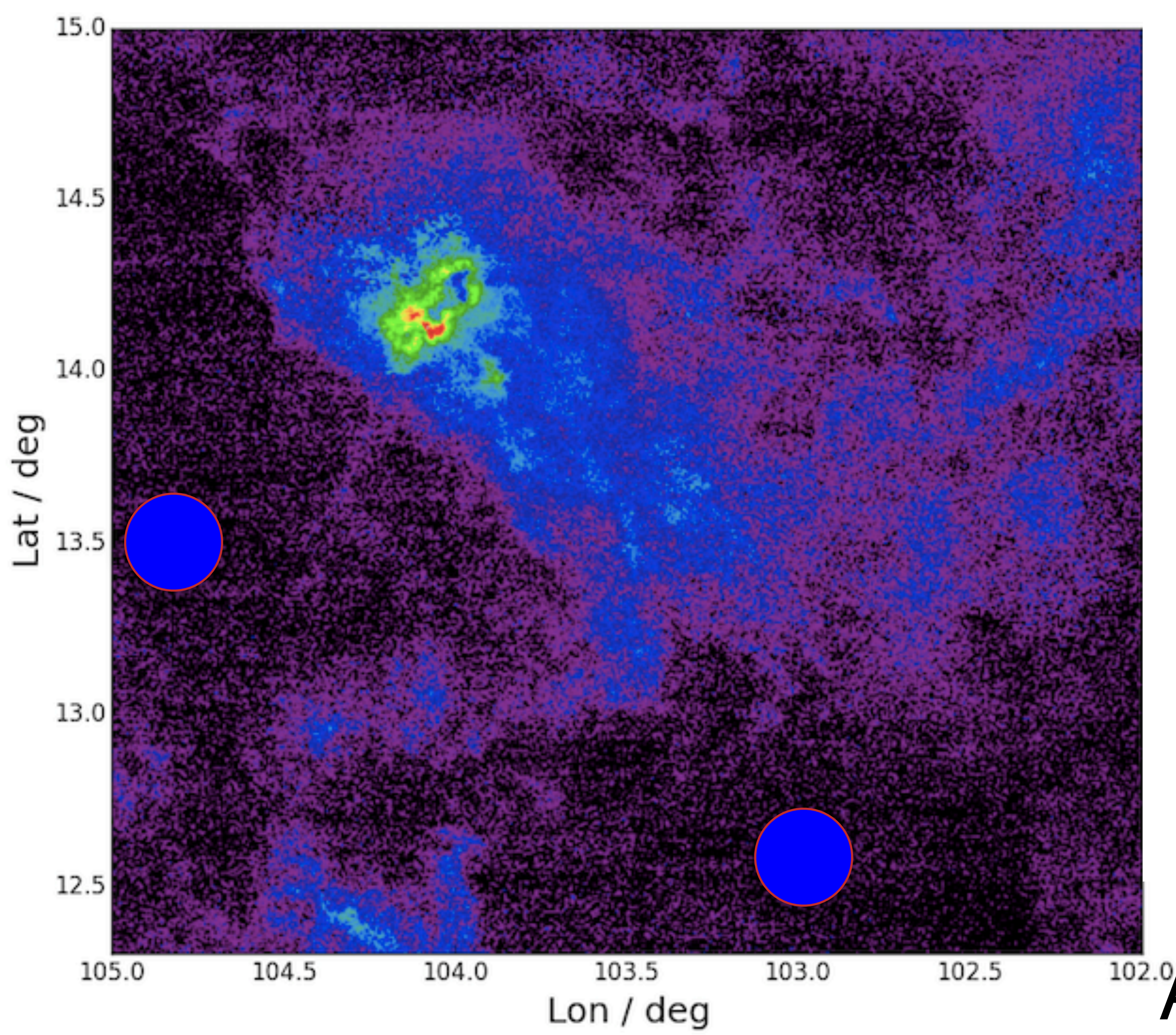
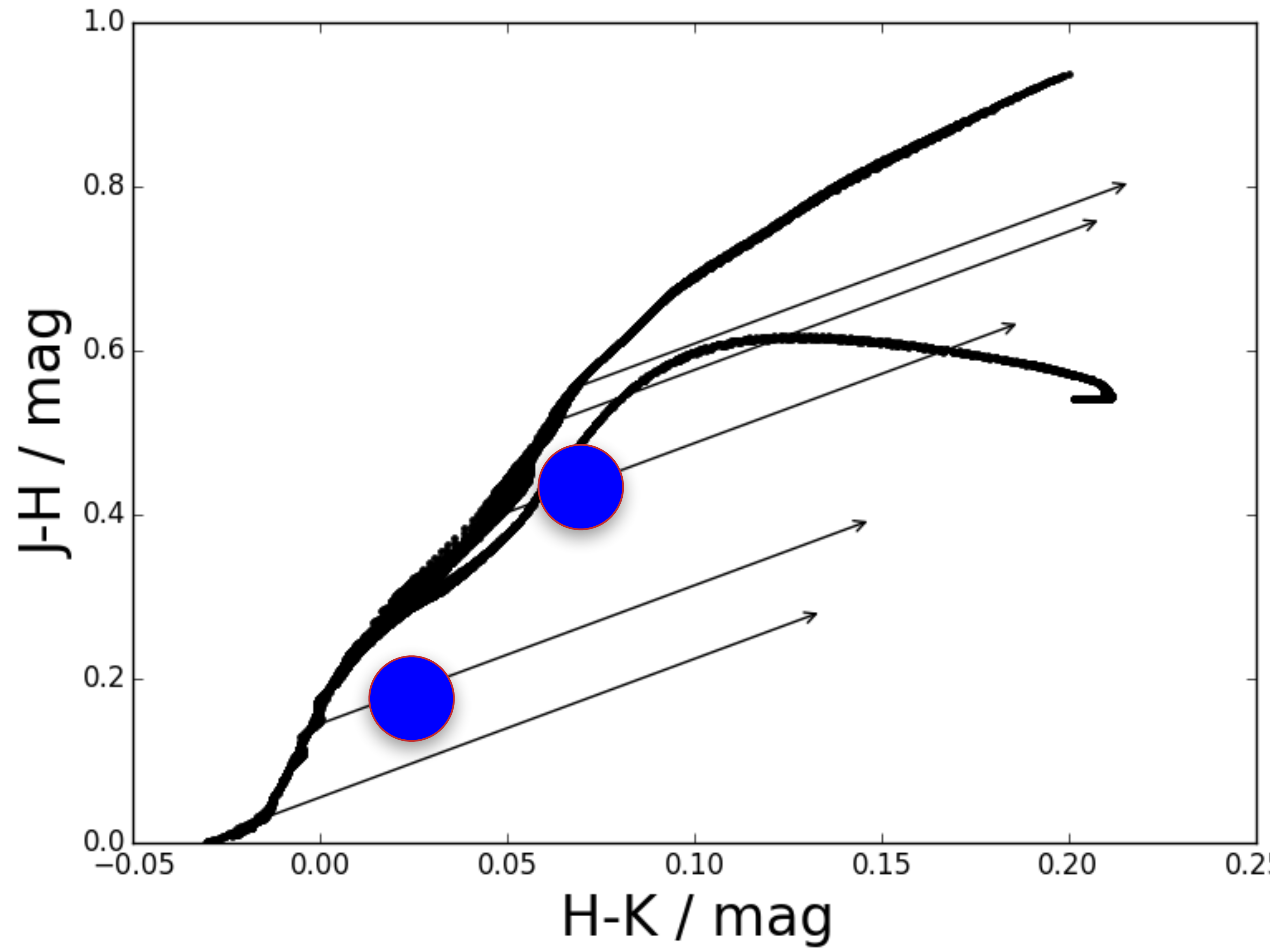
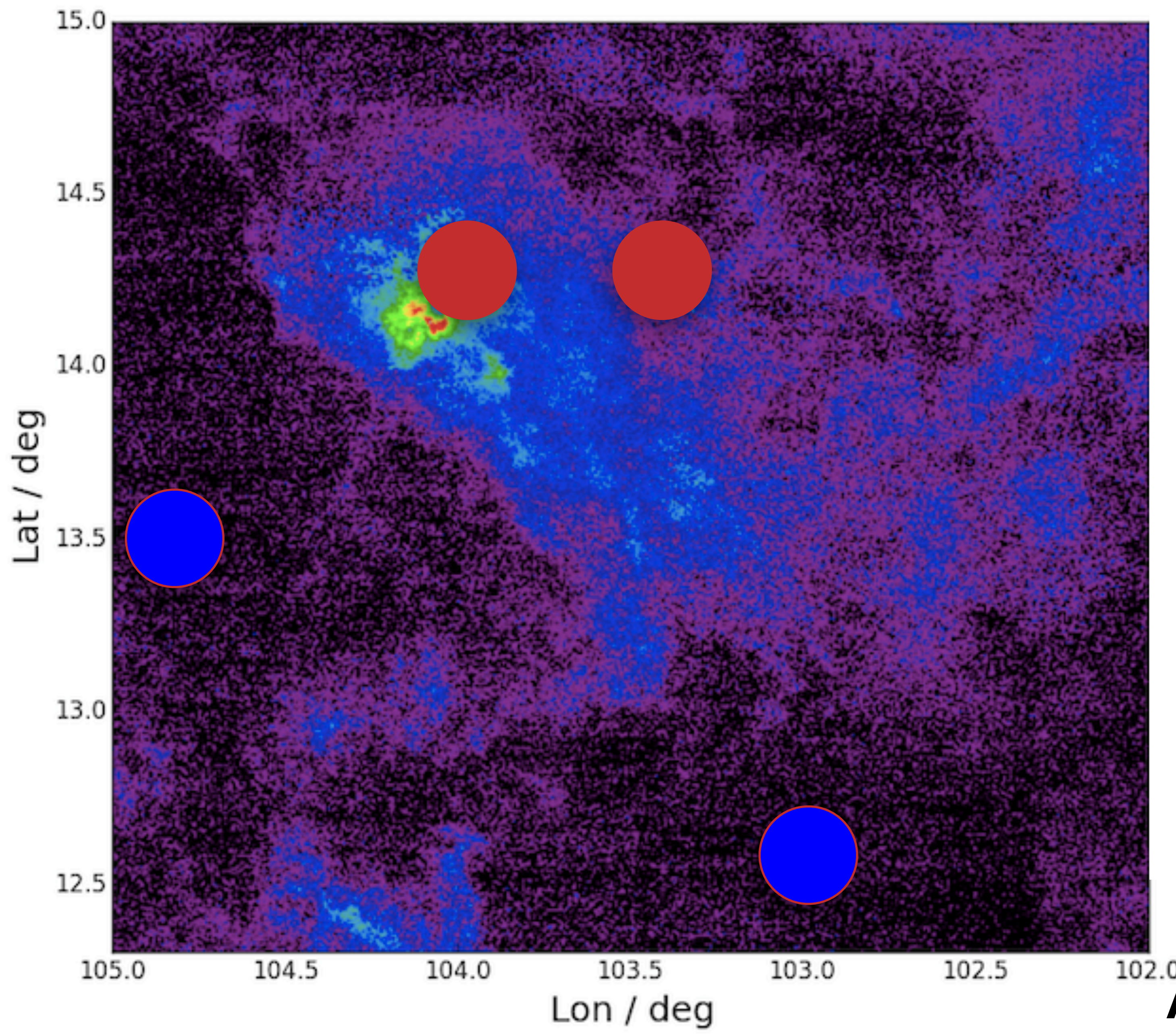
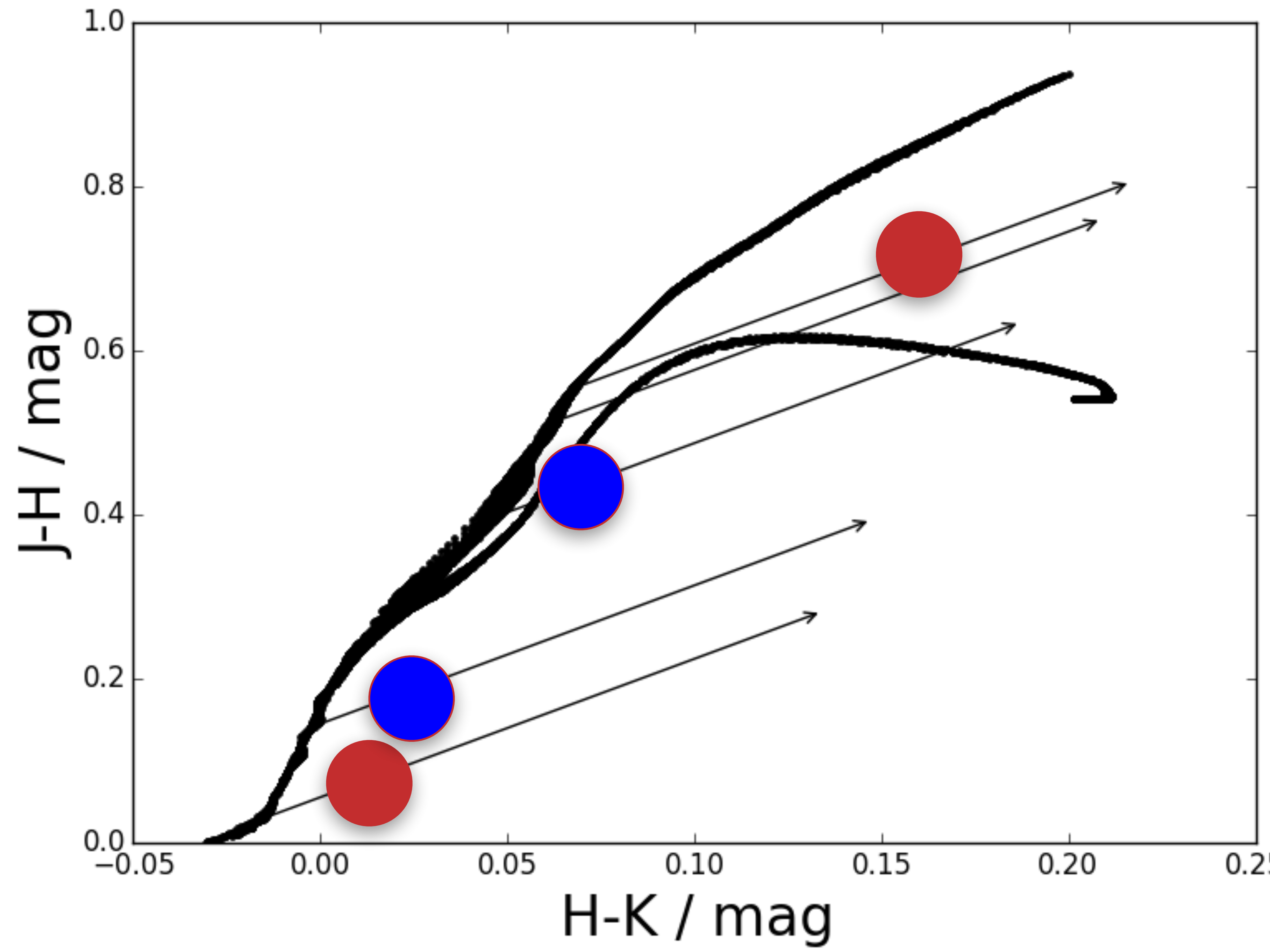
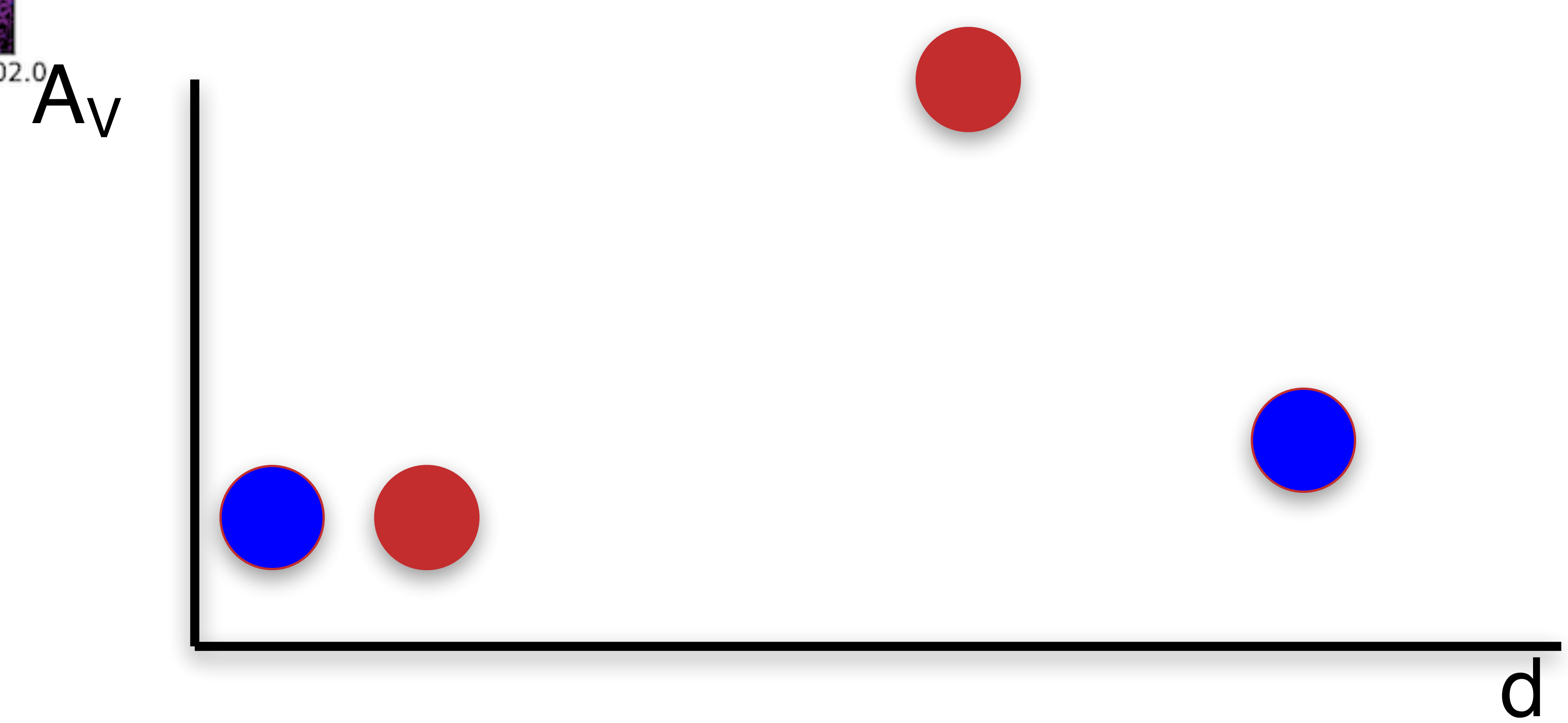




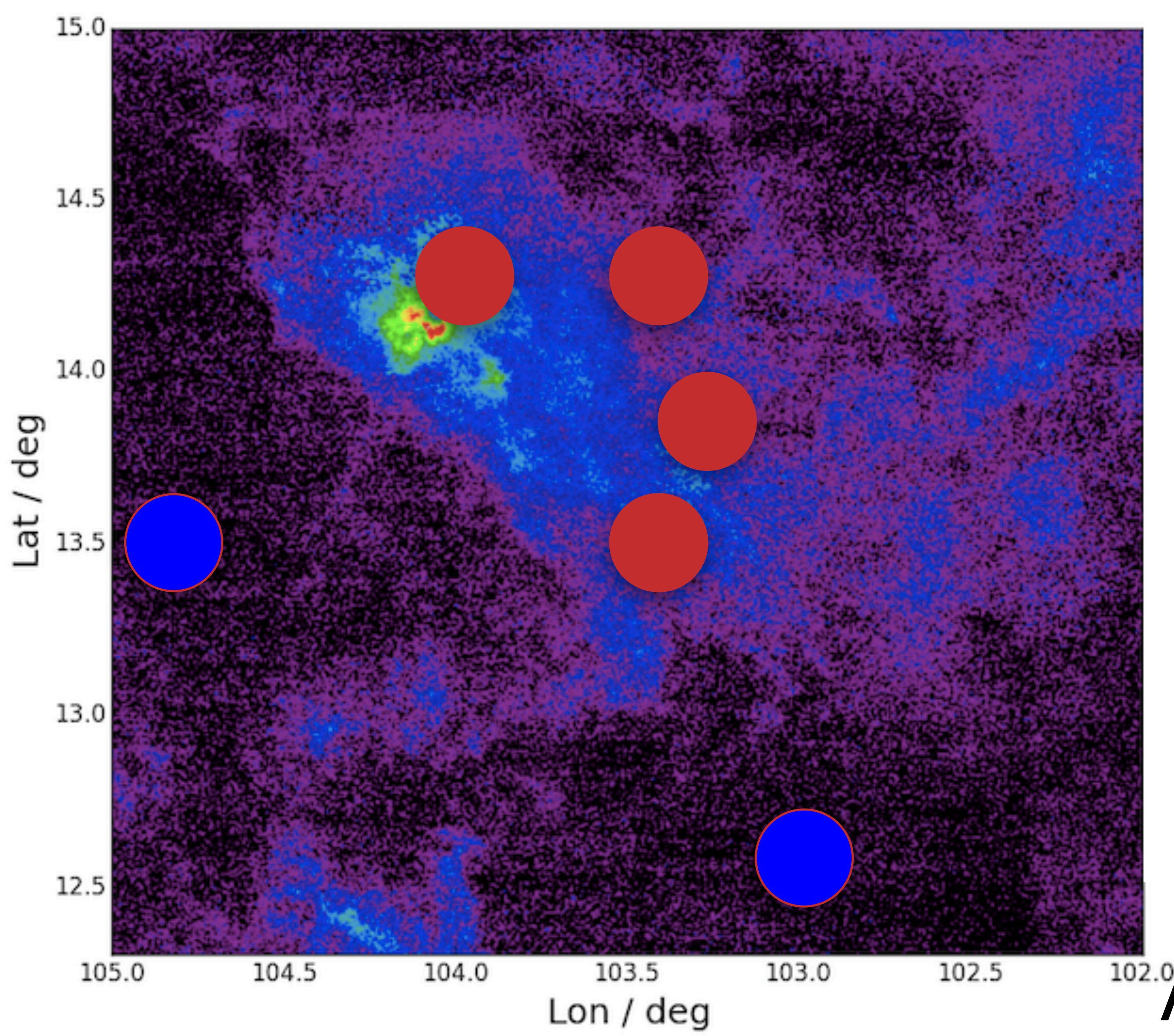
3D Extinction – Naive Approach

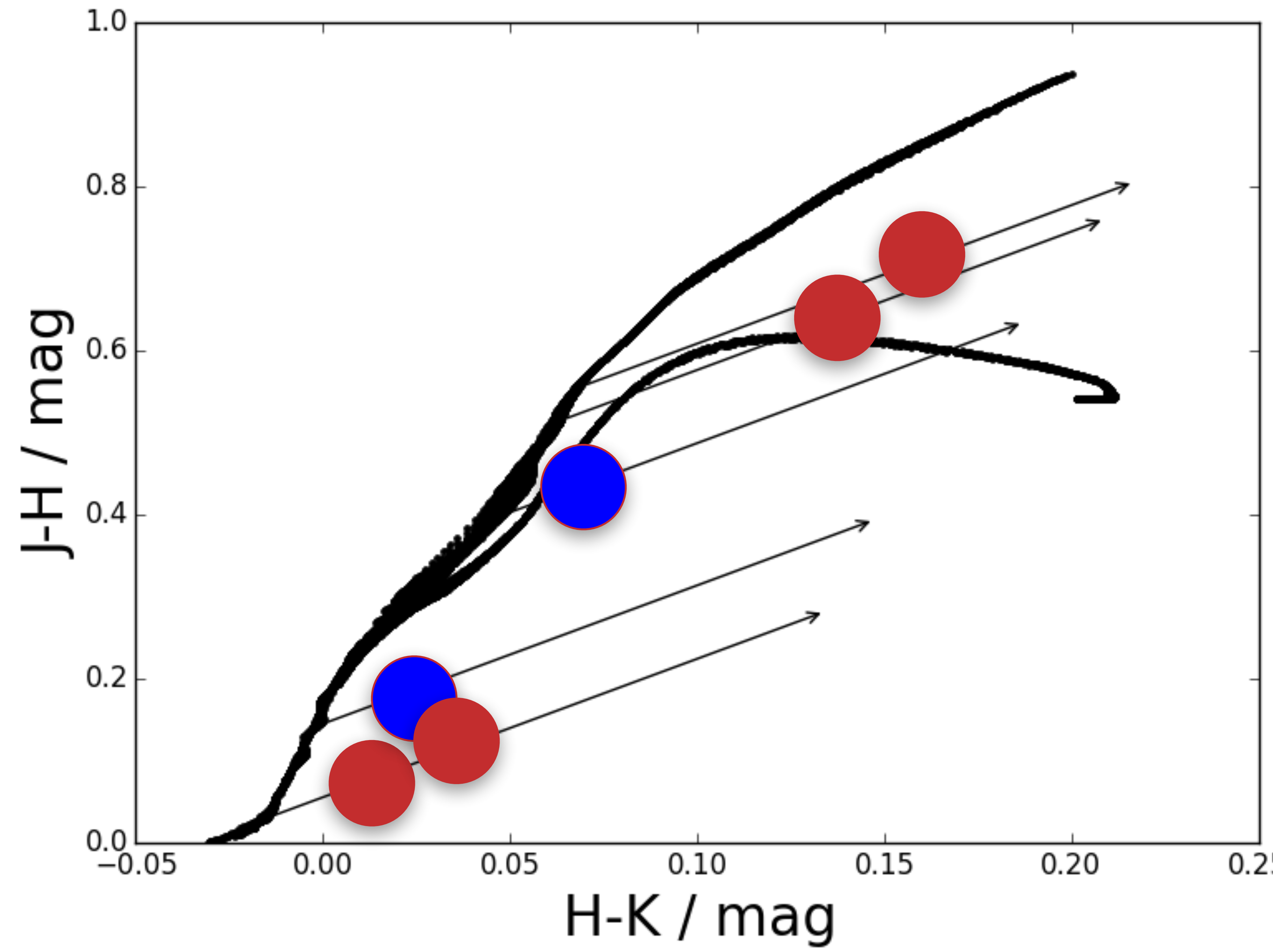


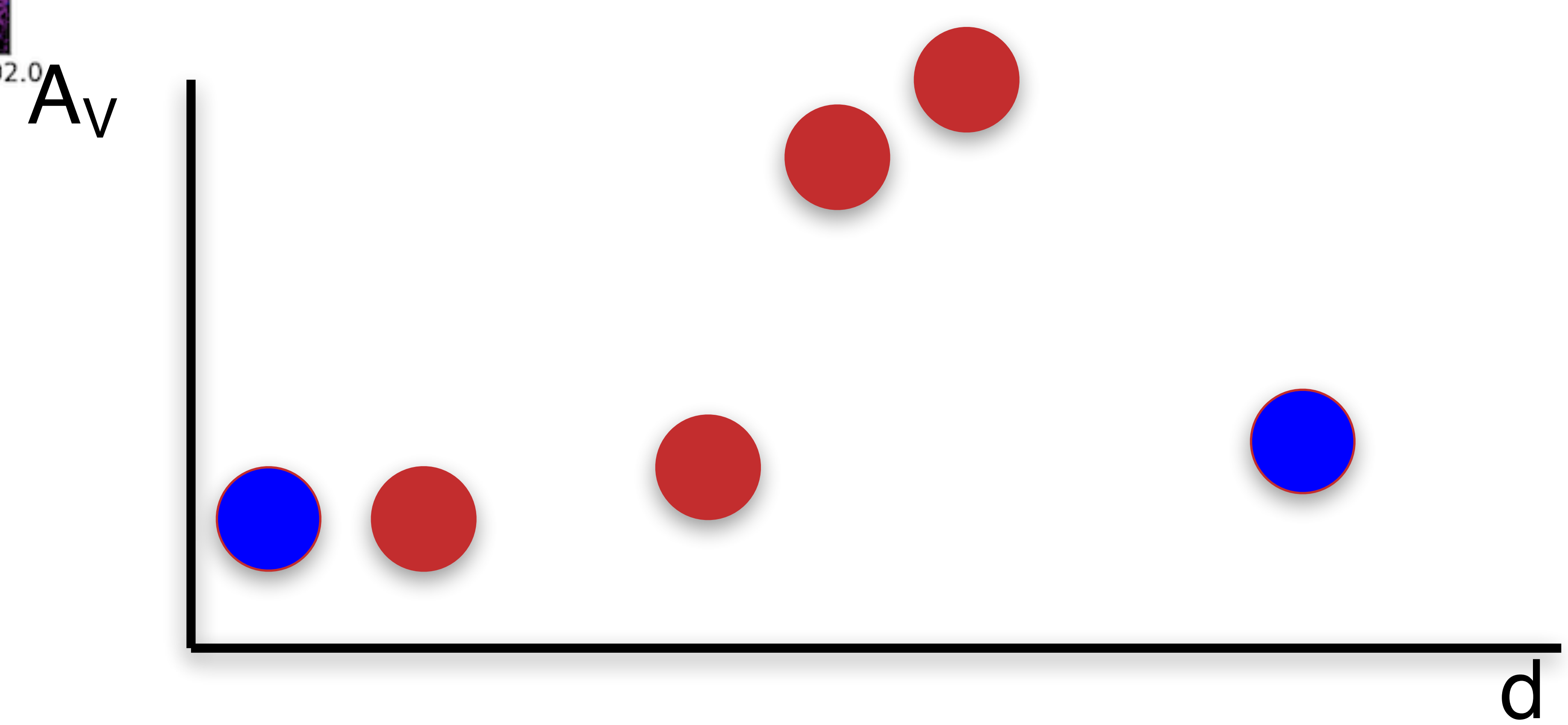




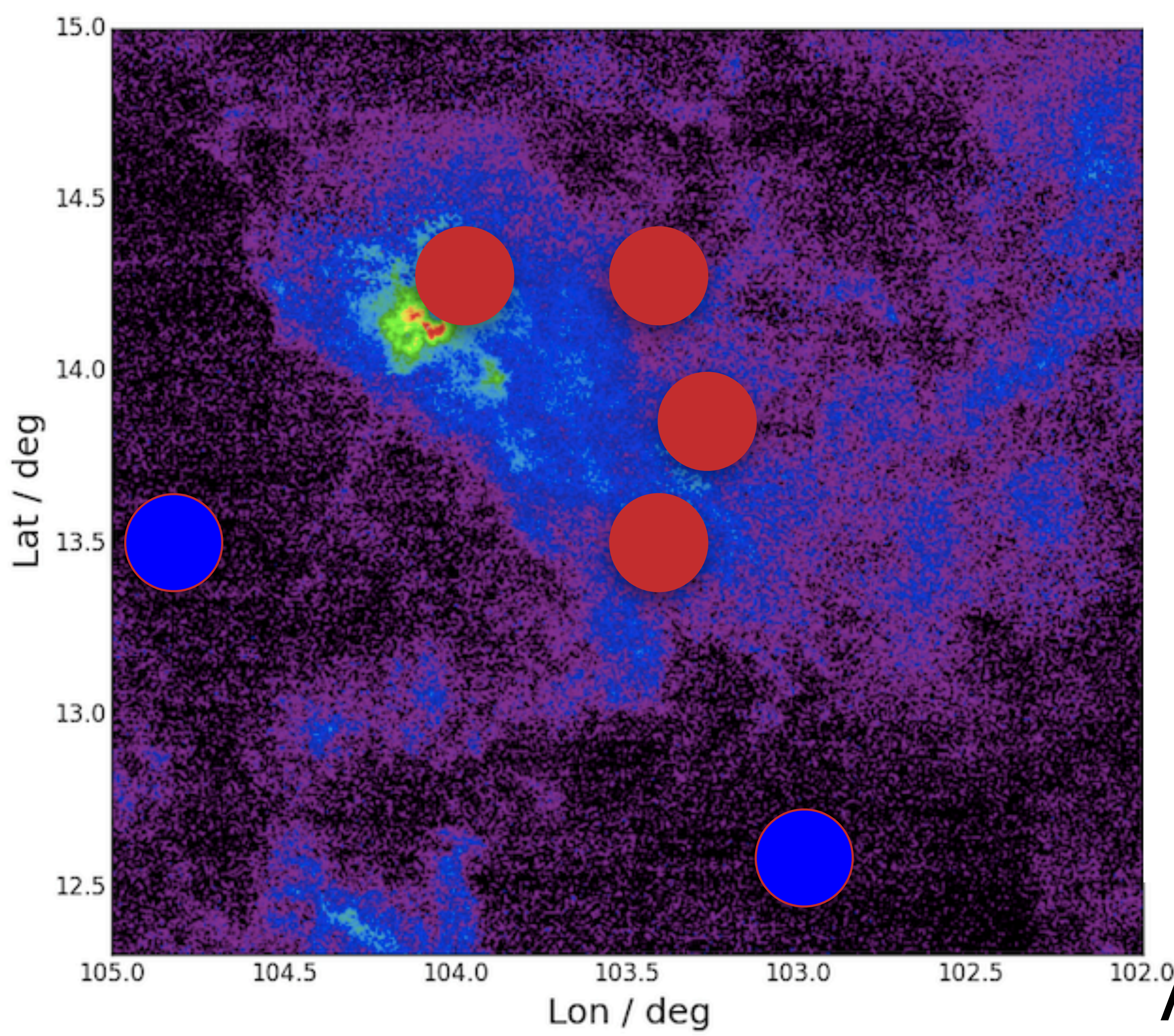
3D Extinction – Naive Approach

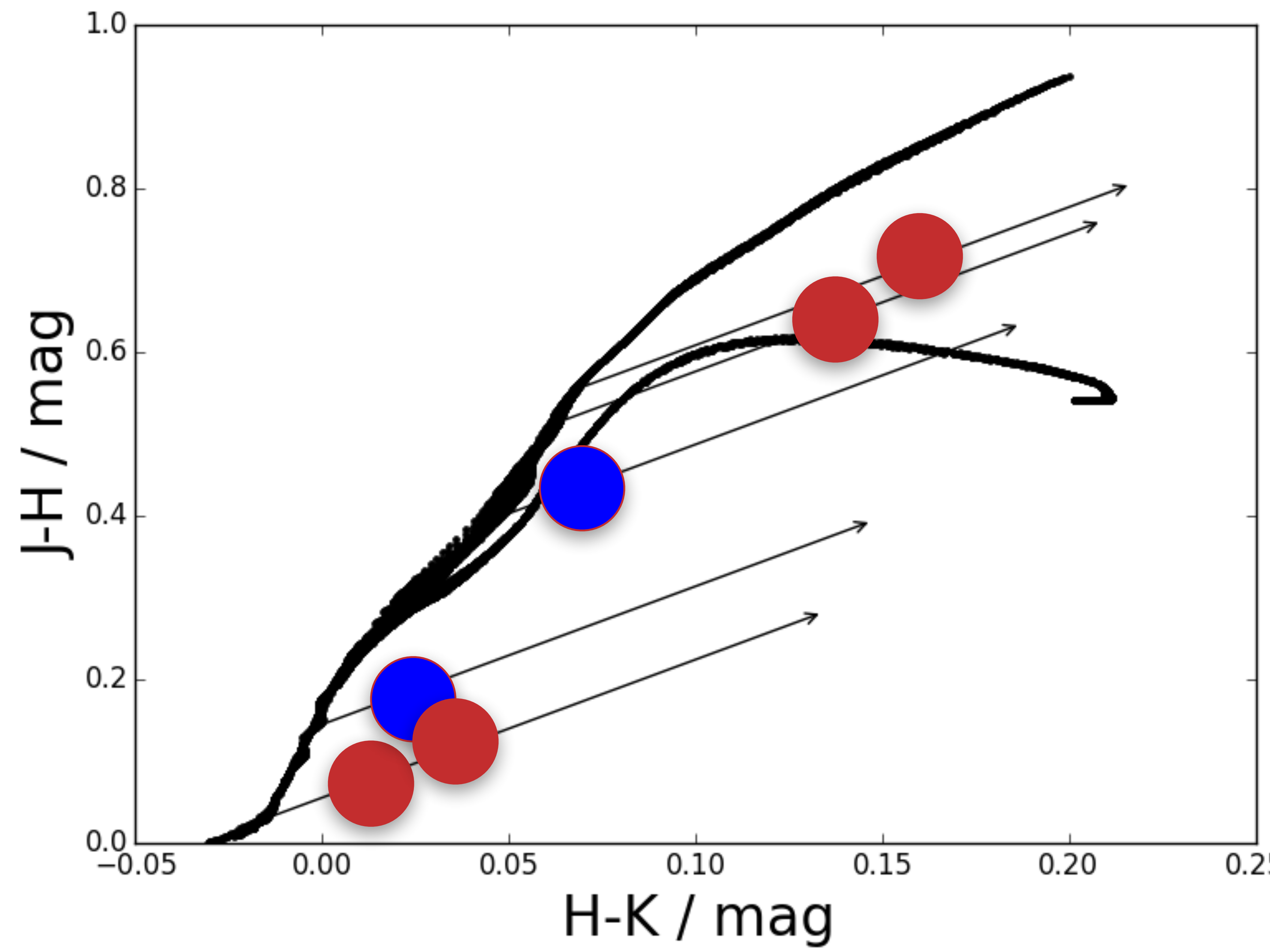


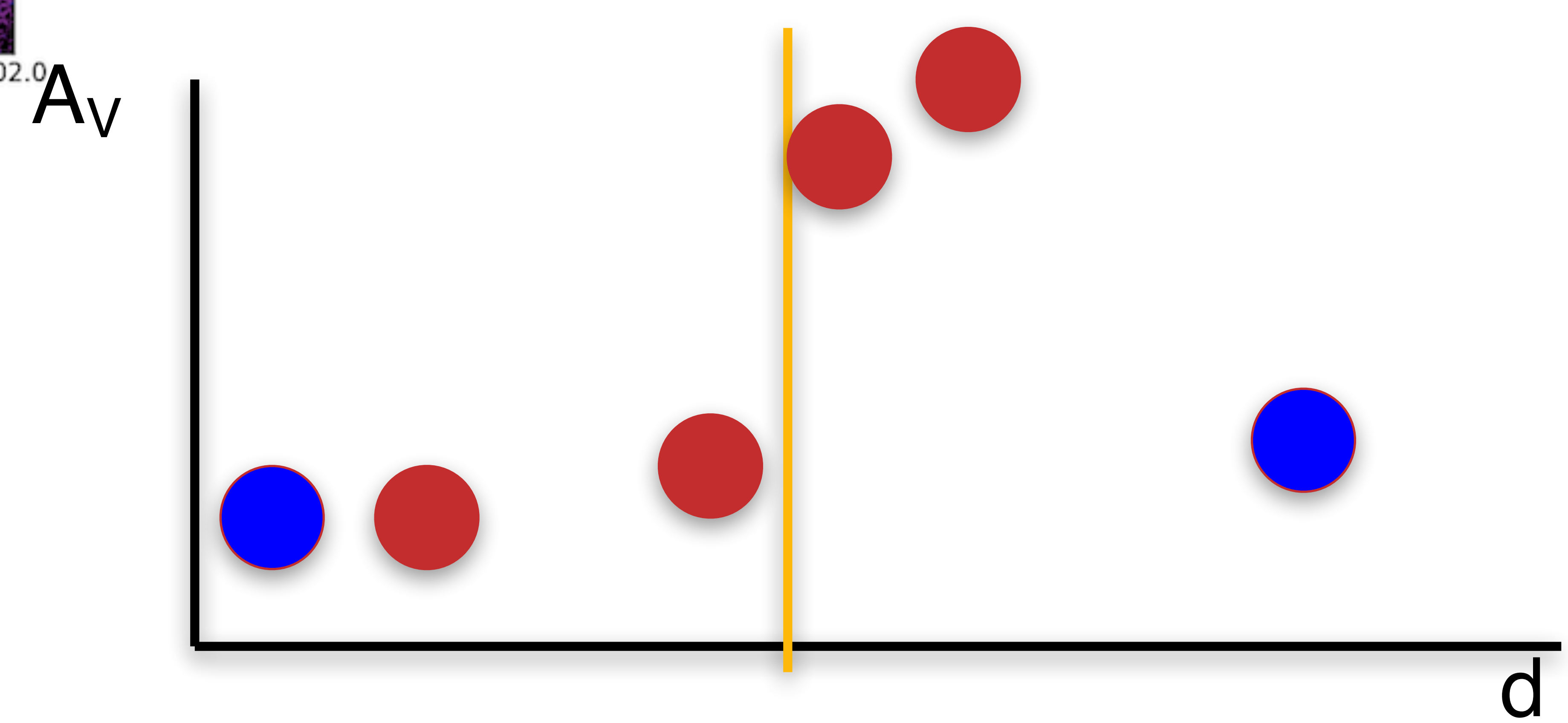




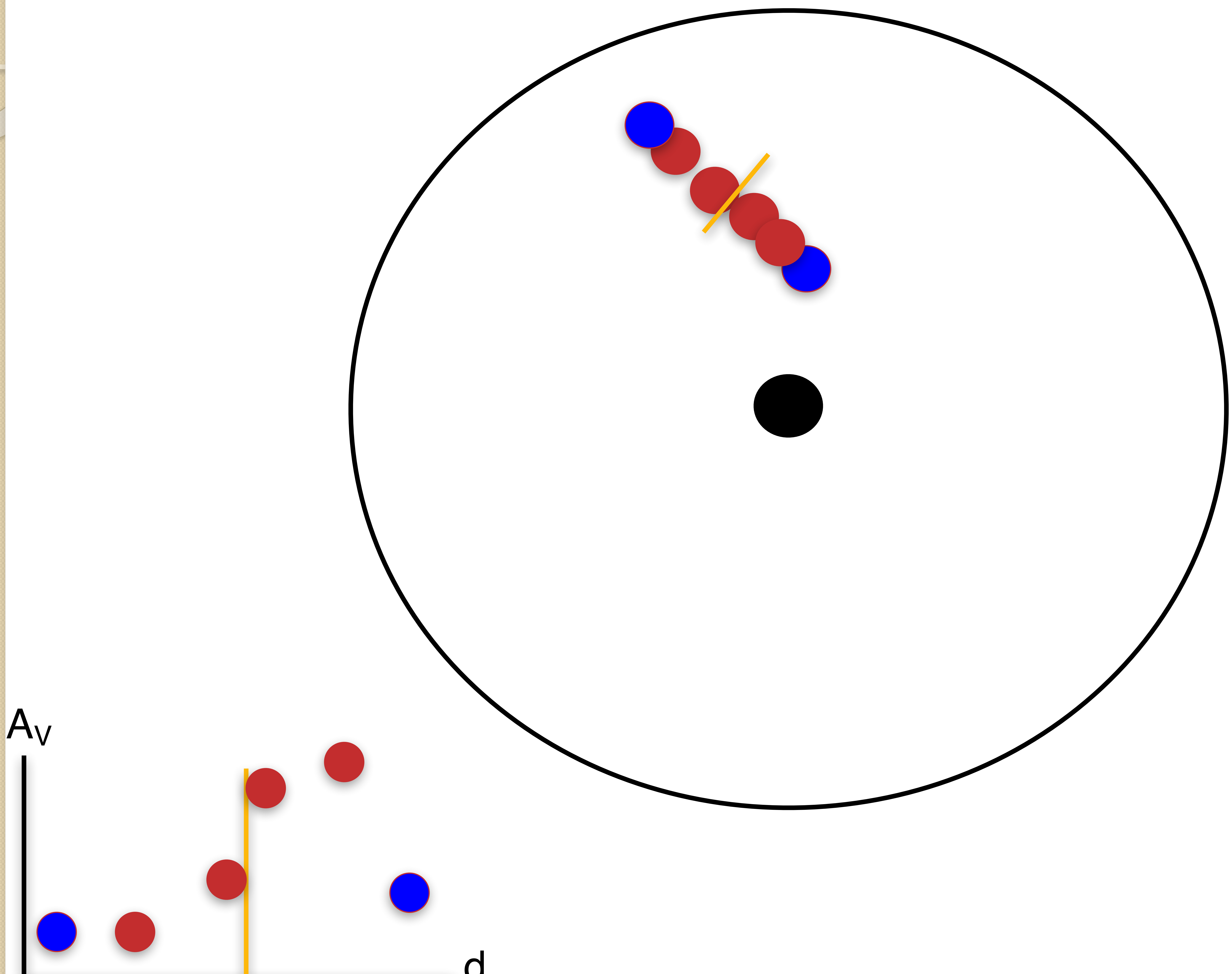
3D Extinction – Naive Approach



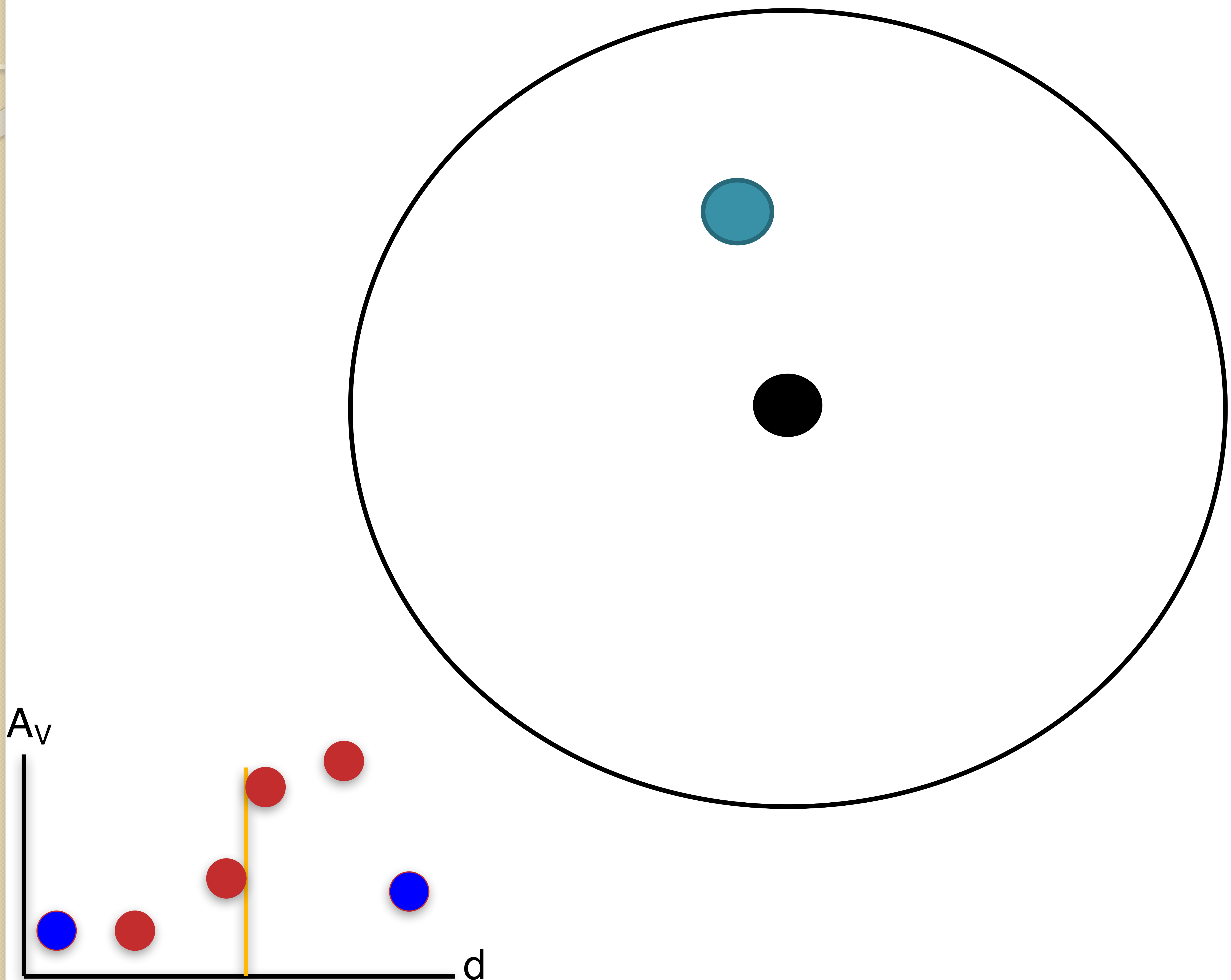




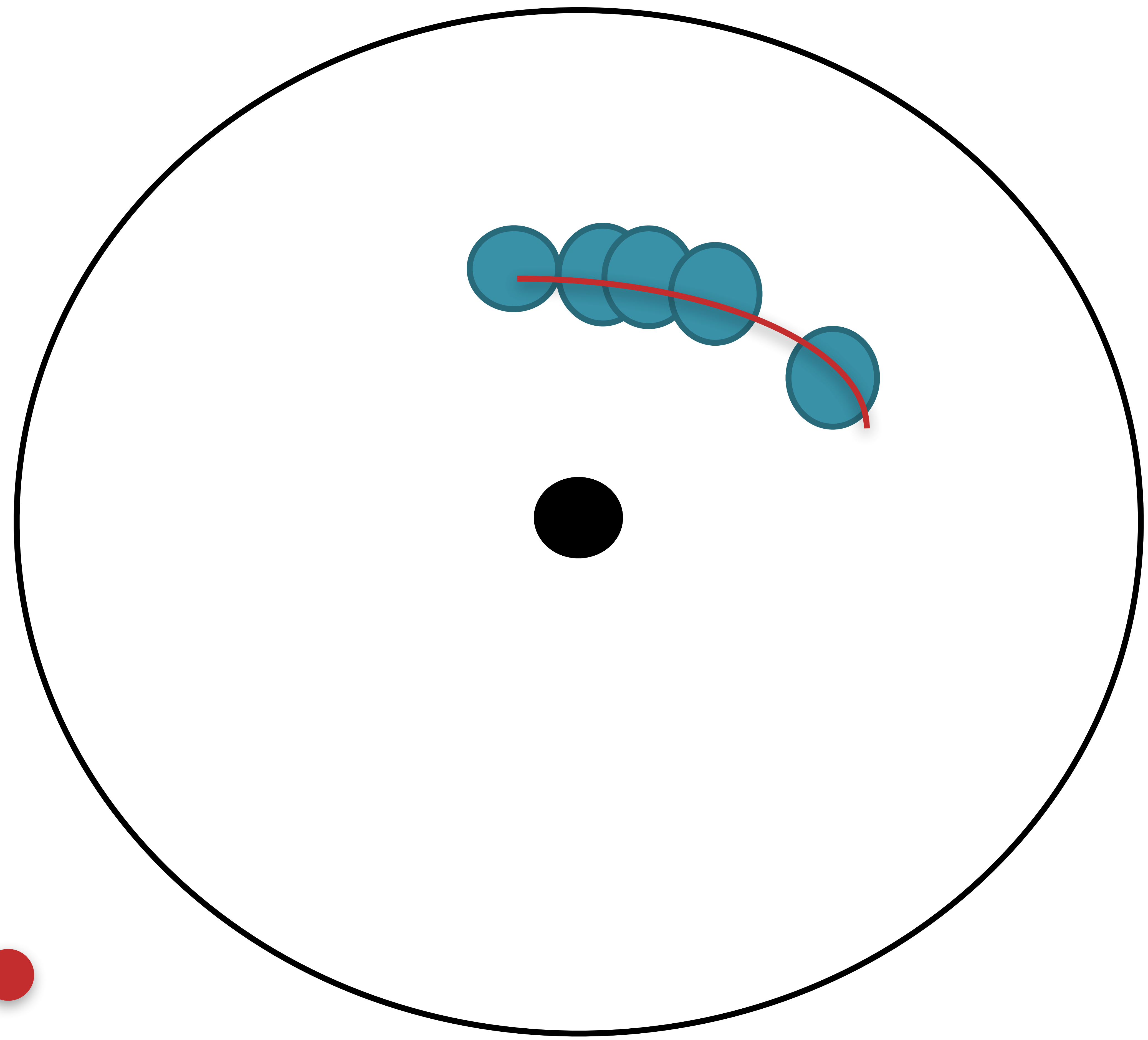
3D Extinction – Naive Approach

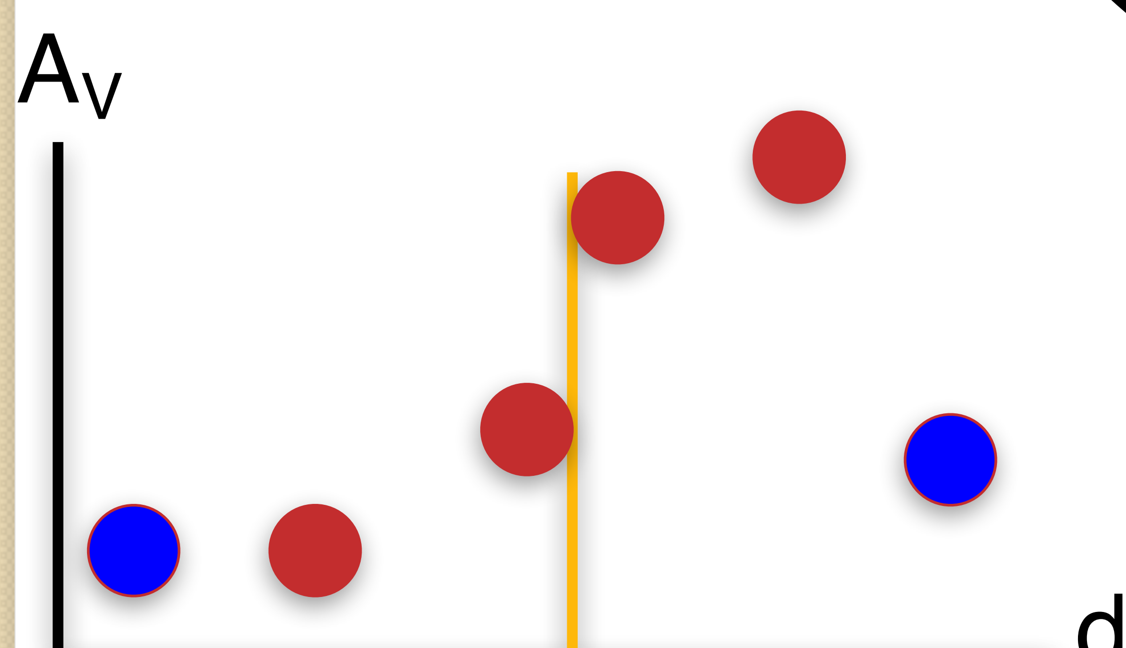


3D Extinction – Naive Approach

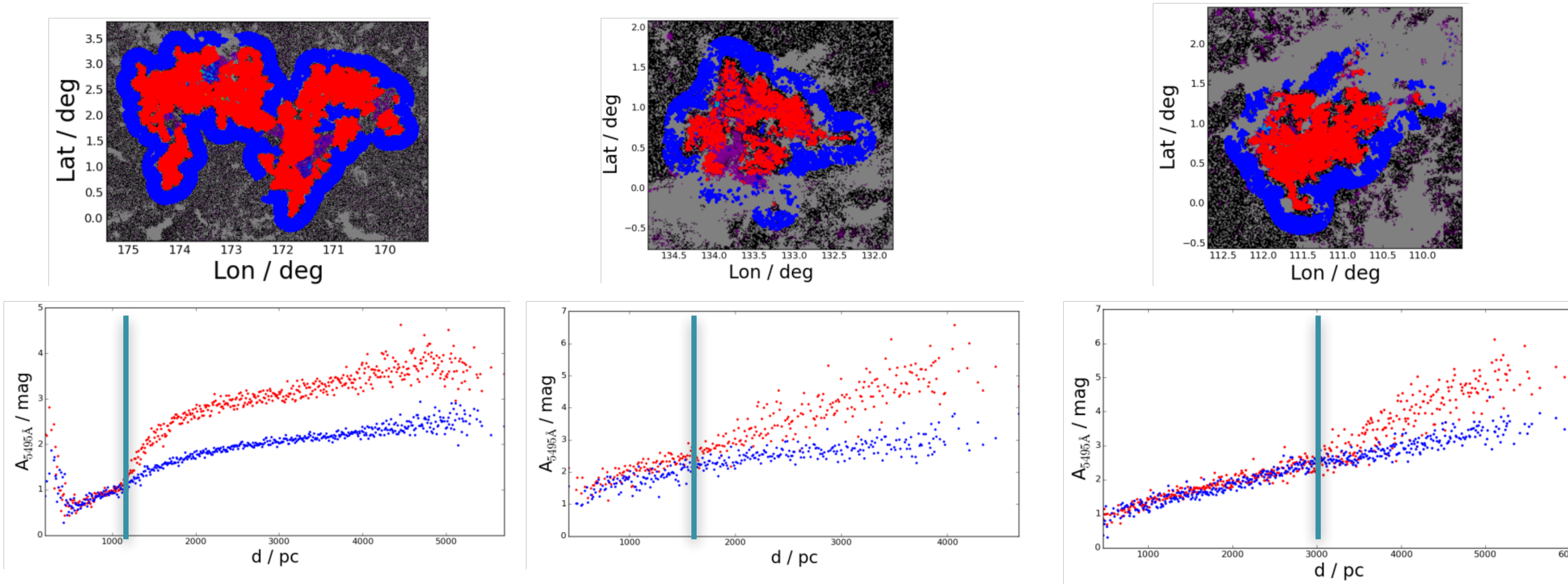


3D Extinction – Naive Approach

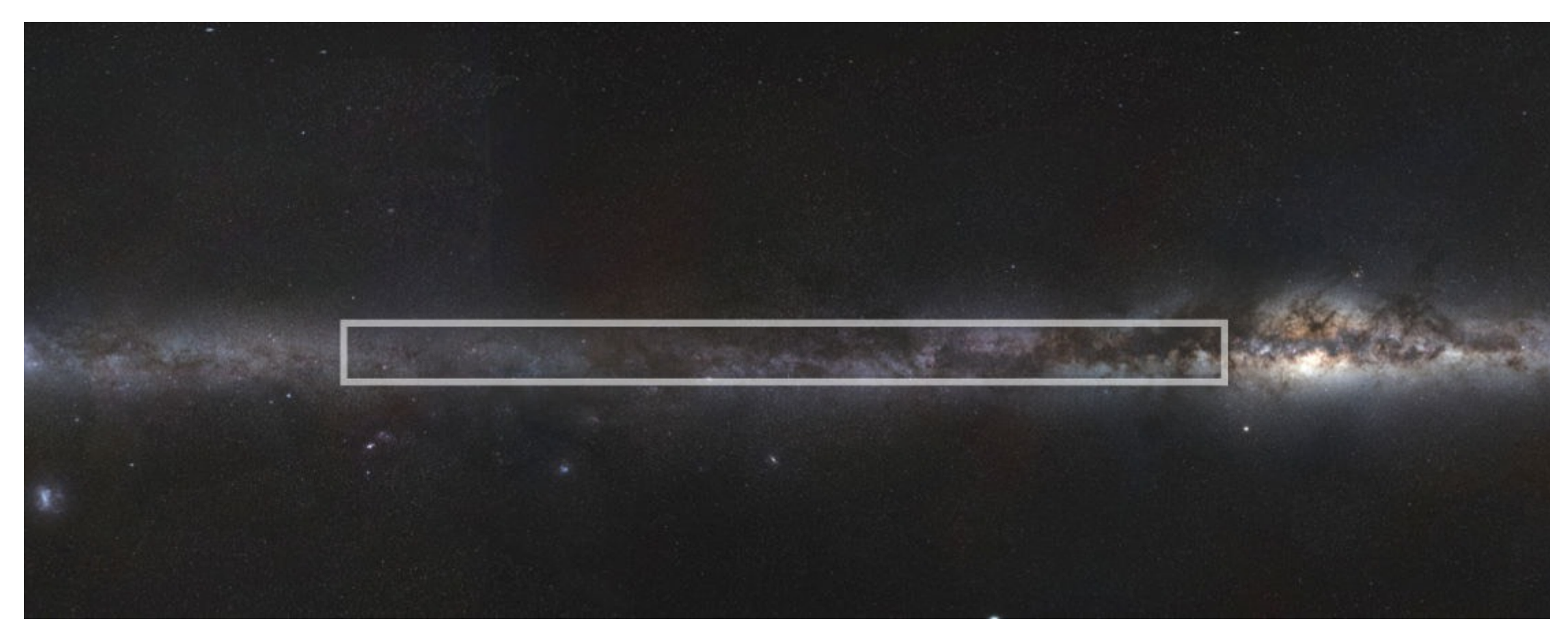




3D Extinction – IPHAS



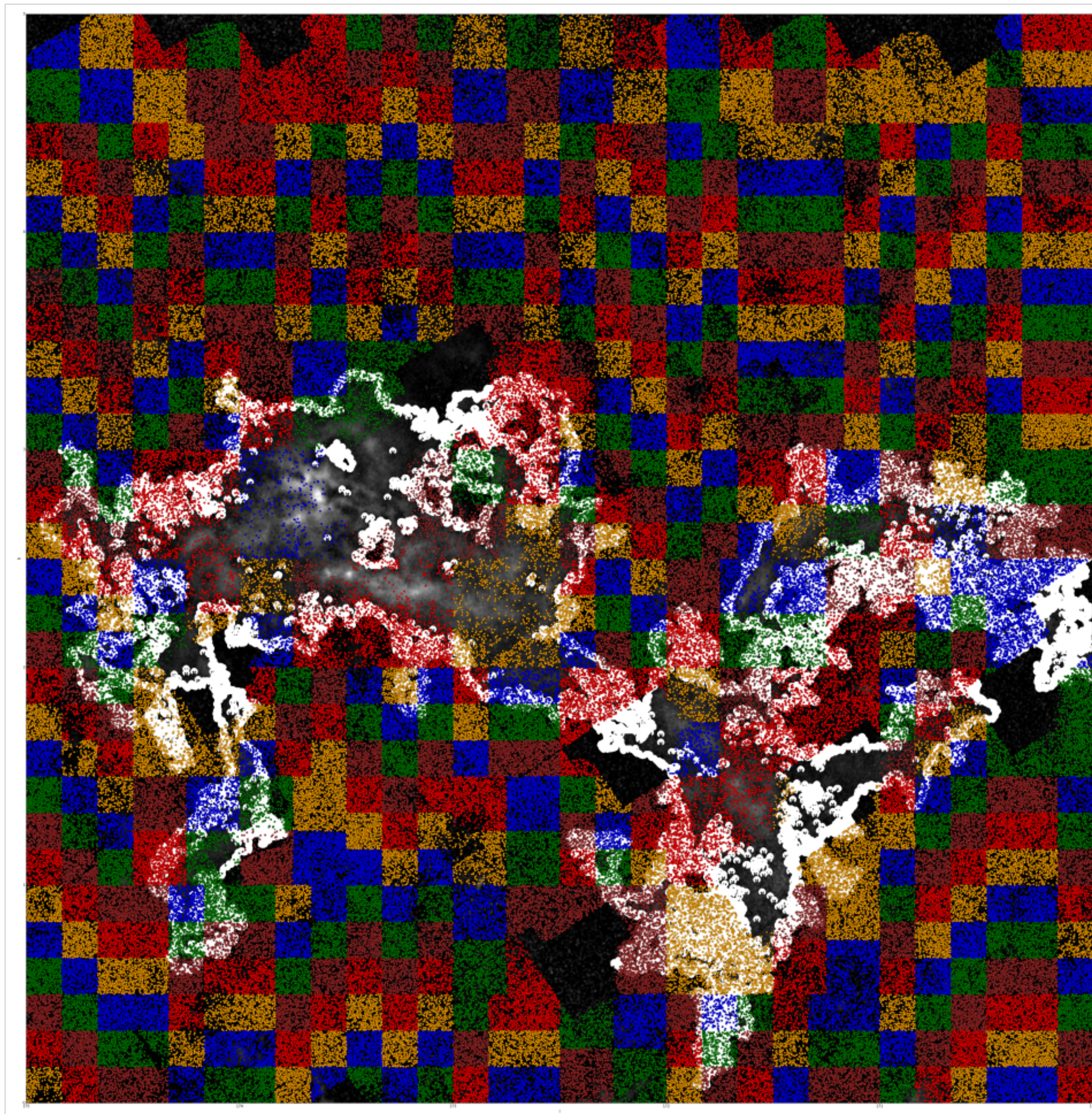
Cloud	Literature Distance	Sale et al. 2014[1] Distance
Sh 2-235	1.8kpc[2]	1.2kpc
W3	1.95kpc[3]	1.7kpc
NGC7538	2.7kpc[4]	3kpc

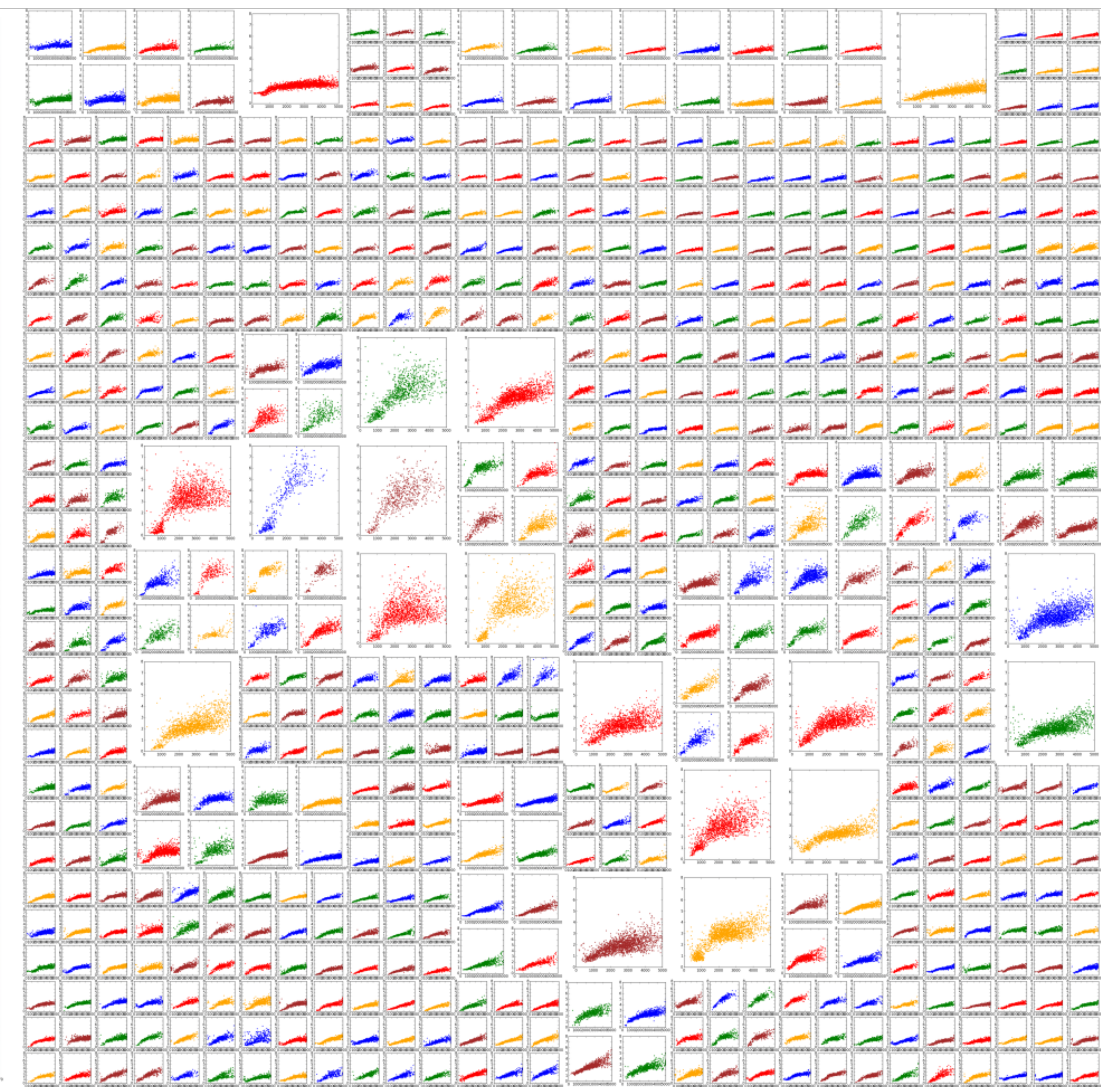


Brunier, ESO

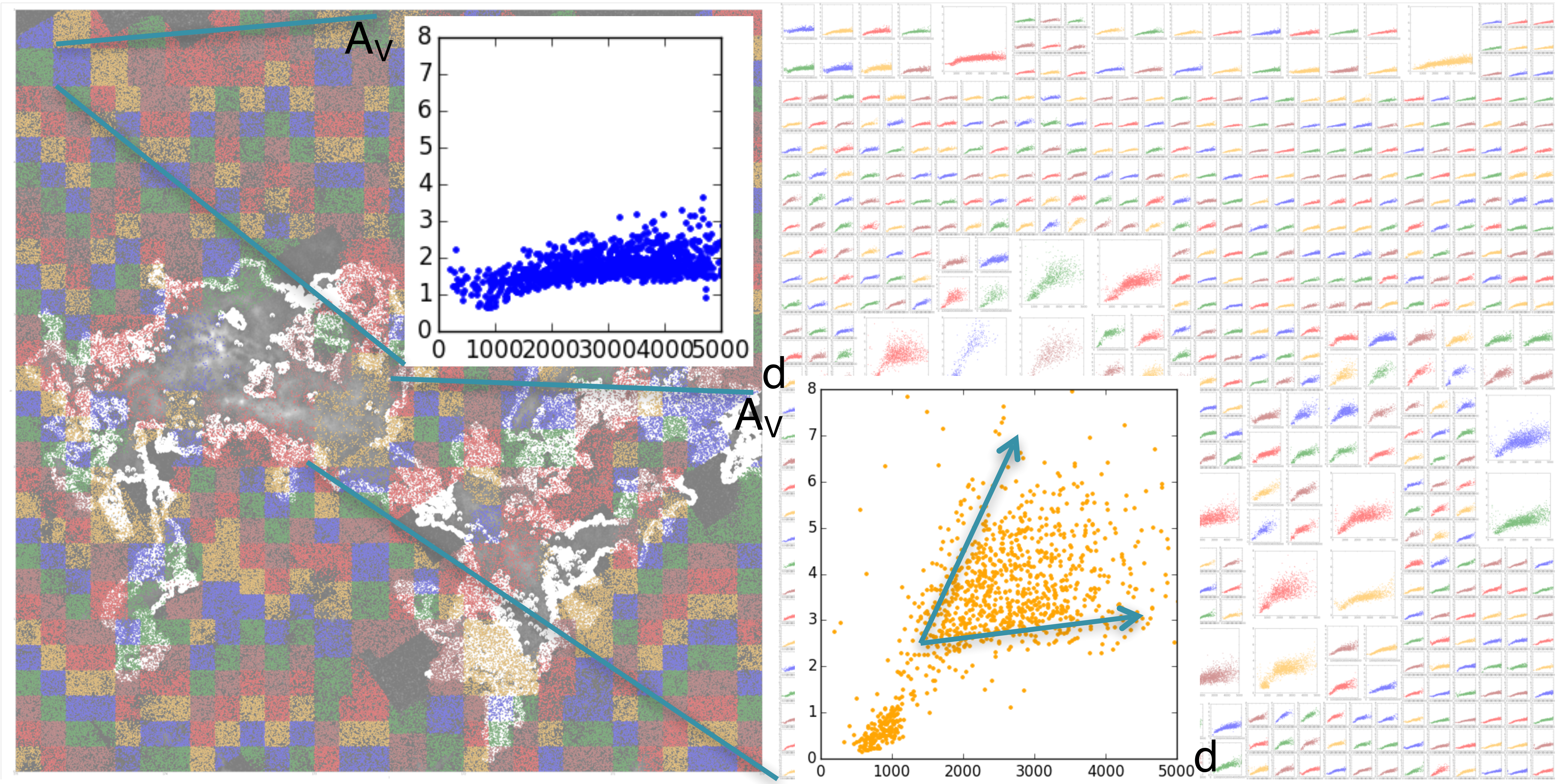
1. Sale, S. et al., 2014, MNRAS, 443, 2907
2. Evans N. II, Blair G. ,1981, ApJ, 246, 394
3. Xu Y. et al., 2006, Science, 311, 54
4. Moscadelli L. et al., 2009, ApJ, 693, 406

3D Extinction – IPHAS

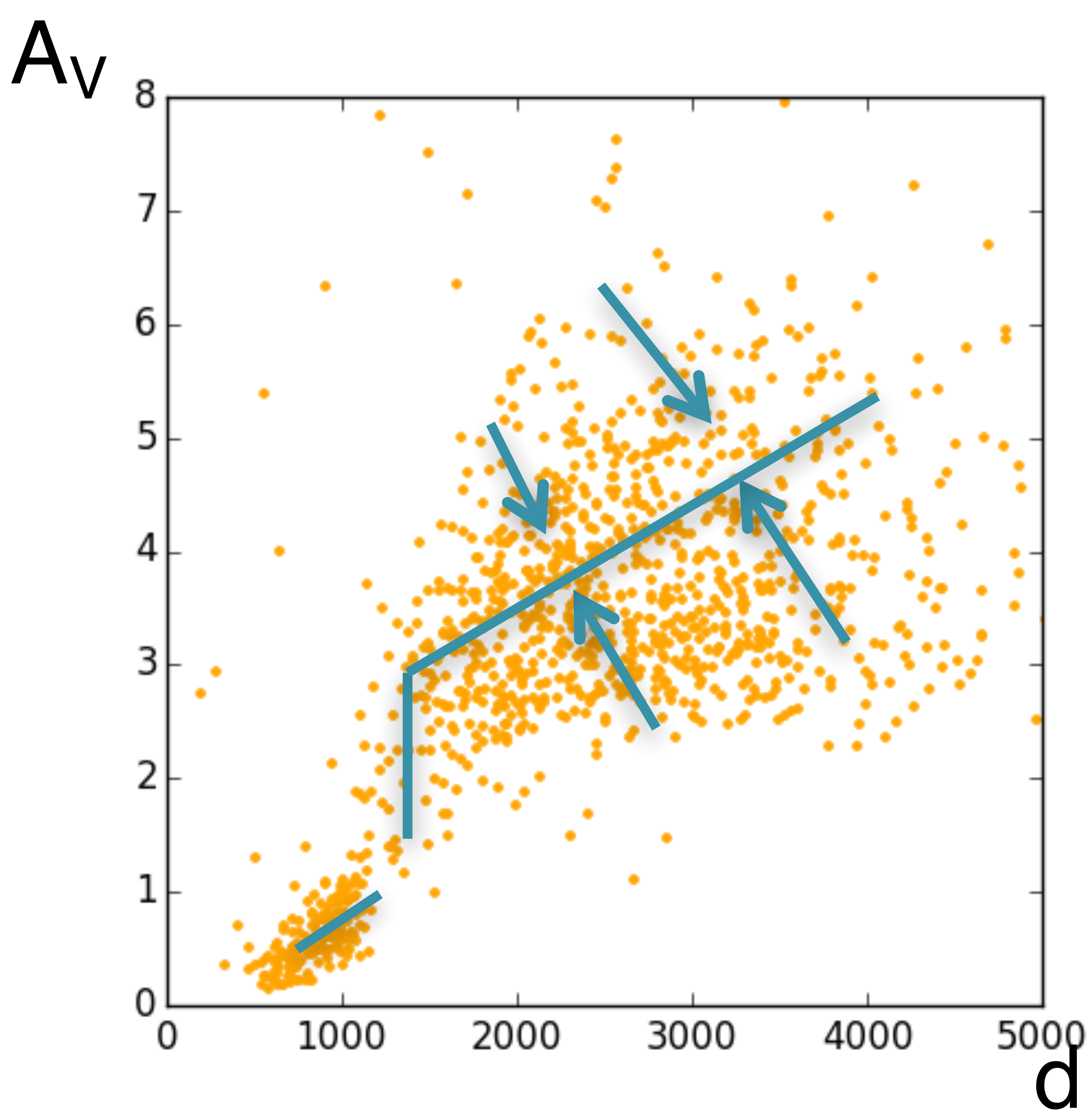


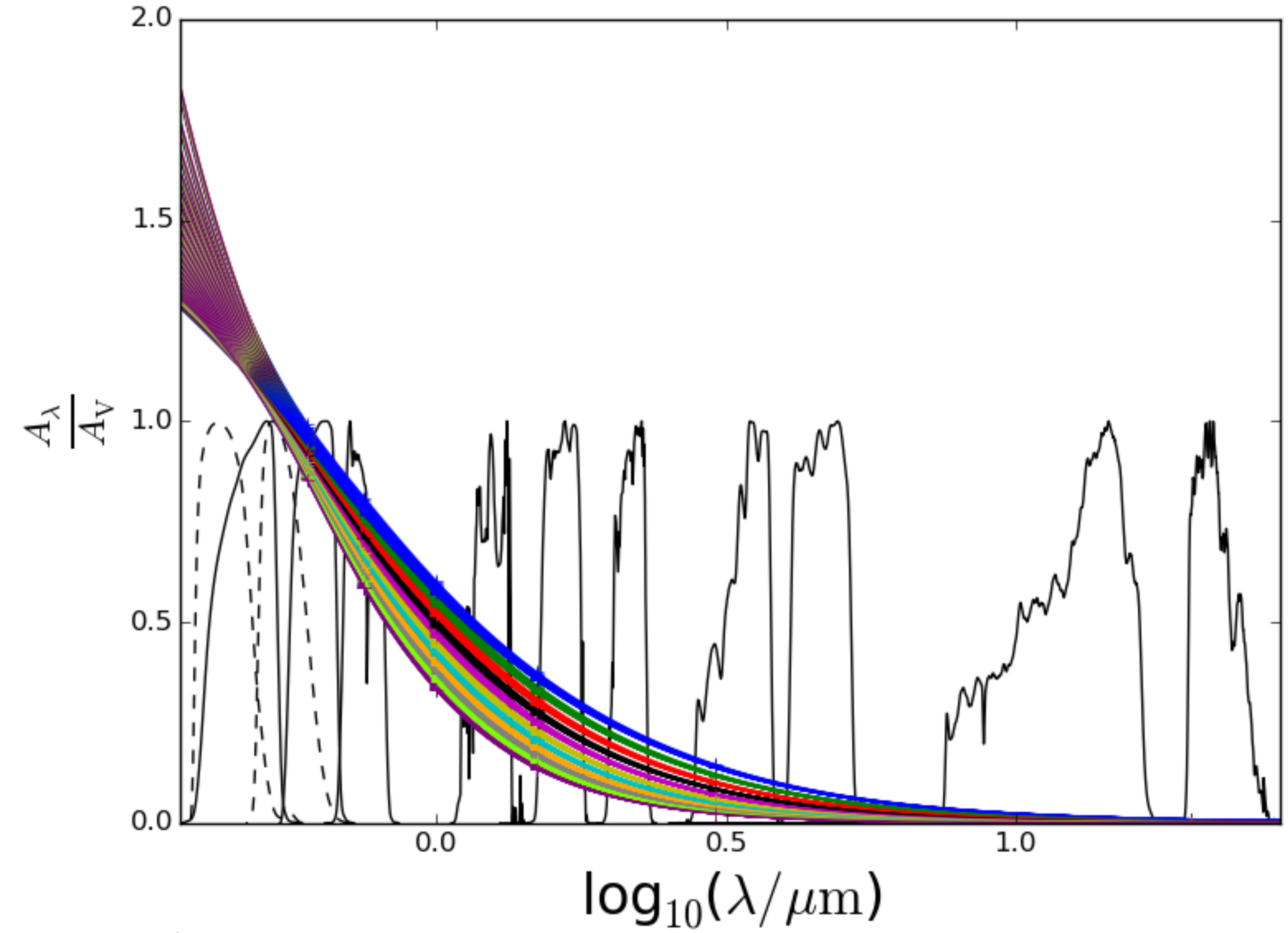


3D Extinction – IPHAS



3D Extinction – IPHAS





$$A_\lambda = \frac{A_\lambda}{A_V} A_V = \left(\frac{k(\lambda - V)}{E(B-V)} R_V^{-1} + 1 \right) A_V$$

$$k(\lambda - V) = \frac{E(\lambda - V)}{E(B-V)} = \frac{0.349 + 2.087 \cdot R_V}{1 + (\frac{\lambda}{0.507})^{\alpha}},$$

$$k(\lambda - V) = c_1 + c_2 \lambda^{-1} + c_3 \frac{\lambda^{-2}}{(\lambda^{-2} - \lambda_0^2)^2 + \lambda^{-2}\gamma^2} + c_4 F$$

Fitzpatrick E., Massa D., 2009, ApJ, 699, 1209
Fitzpatrick E., Massa D., 1990, ApJS, 72, 163

3D Extinction – Bayesian

- p(M) – the prior
- p(M I D) – the posterior
- p(D I M) – the likelihood
- p(D) – normalisation

$$p(M \mid D) = \frac{p(D \mid M)\,p(M)}{p(D)}$$

3D Extinction – Bayesian

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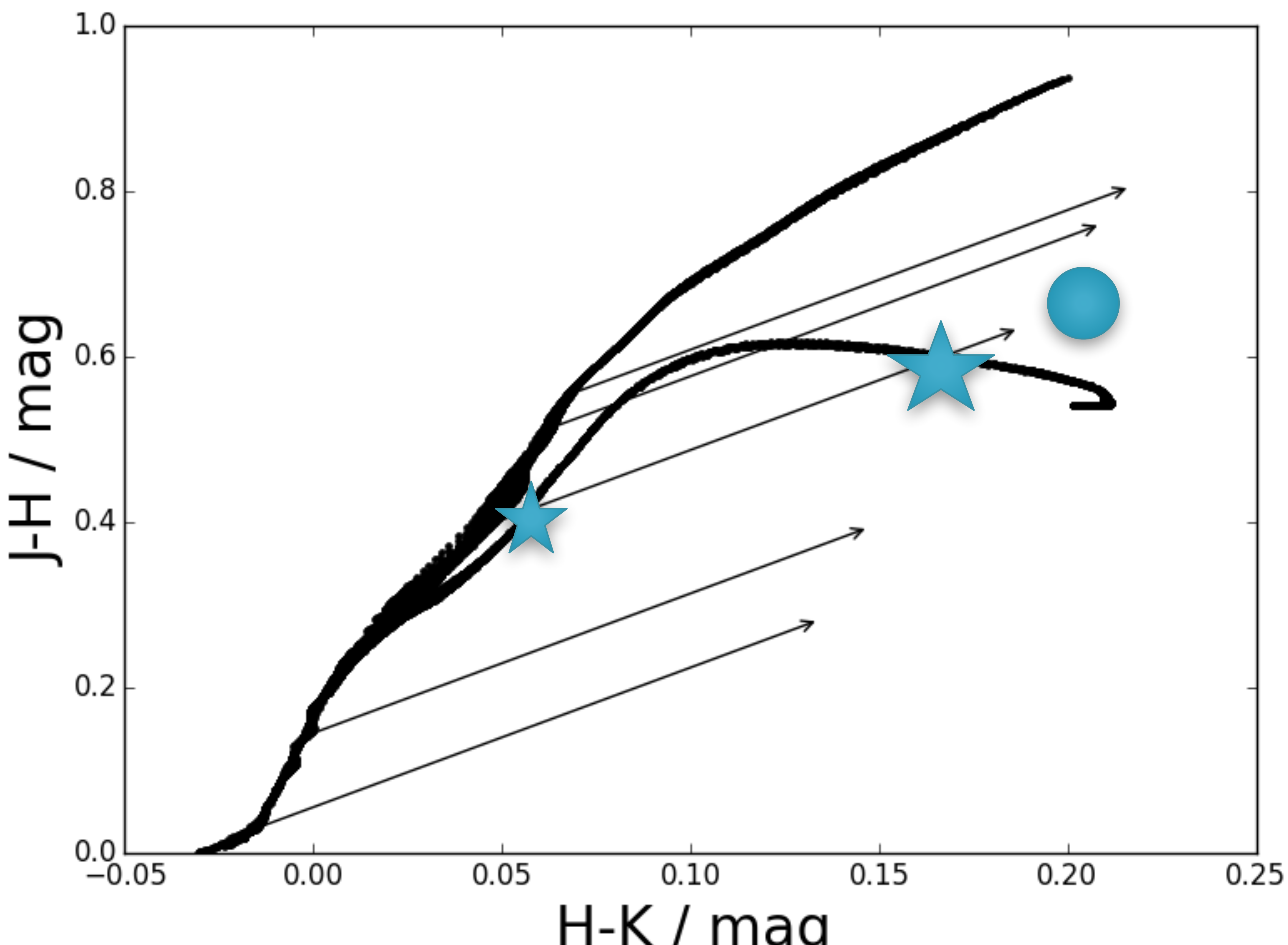
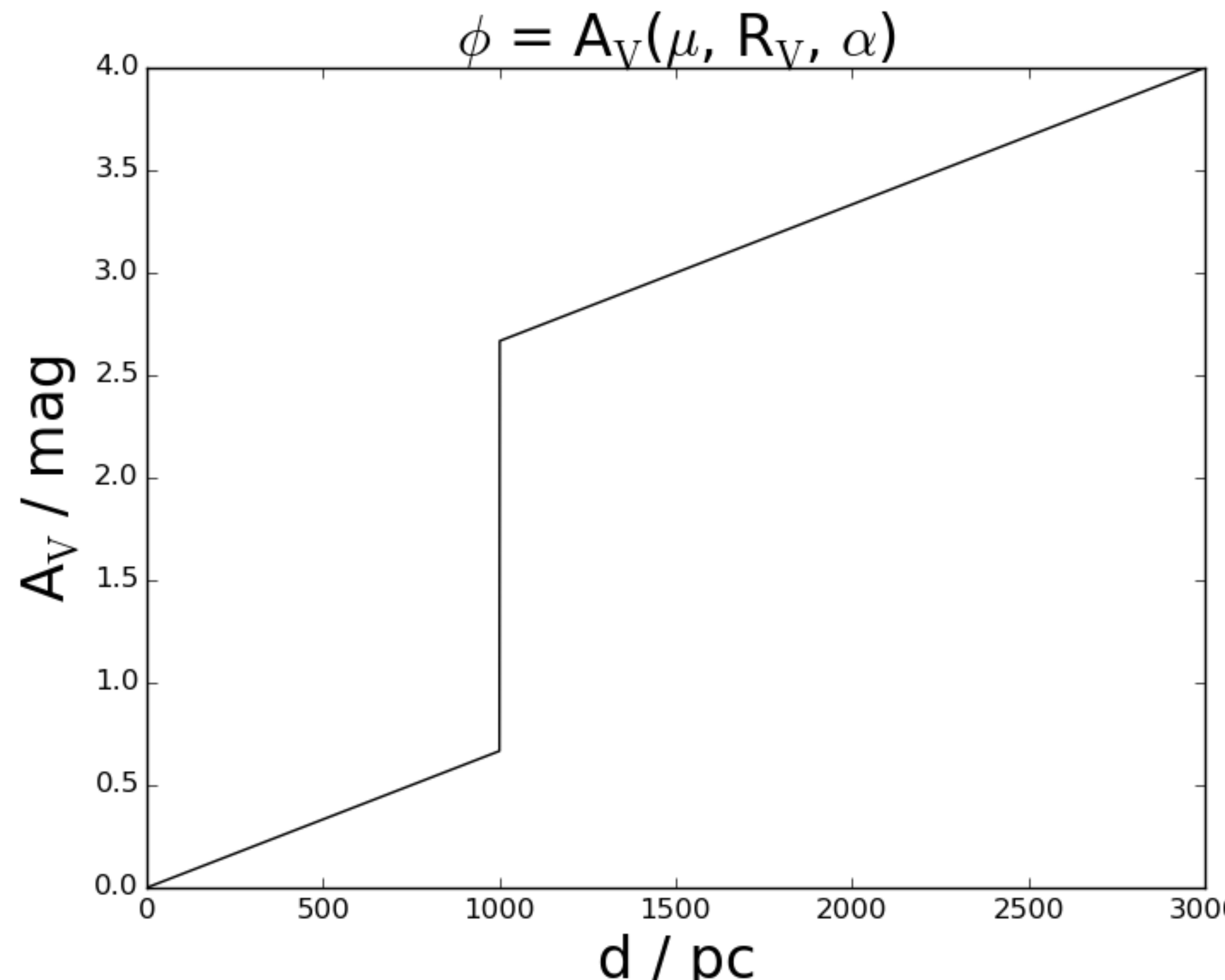


3D Extinction – Bayesian

$$p(\phi|\{\mathbf{D}\}) = \prod_i \iint \frac{p(\mathbf{D}_i|\phi,\mu,\mathbf{\Theta})\, p(\phi,\mu,\mathbf{\Theta})}{p(\mathbf{D}_i)}\, \mathrm{d}\mathbf{\Theta}\, \mathrm{d}\mu$$

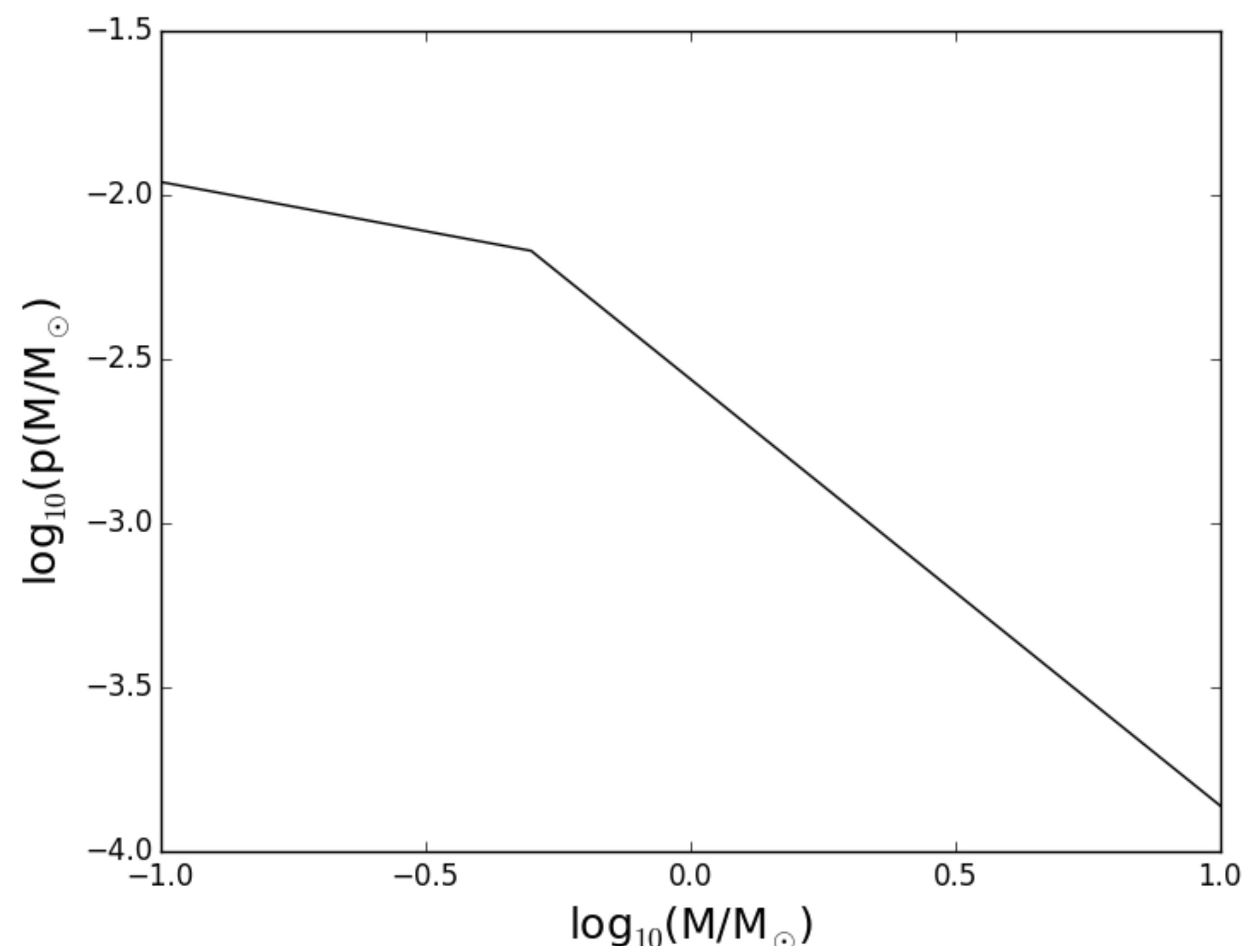
$$p(M \mid D) = \frac{p(D \mid M)\, p(M)}{p(D)}$$



$$\phi = \begin{cases} A_{V,\mathrm{ISM}}(\mu, R_{V,\mathrm{ISM}}, \alpha_{\mathrm{ISM}}) & \mu < \mu_{\mathrm{cloud}} \\ A_{V,\mathrm{ISM}}(\mu, R_{V,\mathrm{ISM}}, \alpha_{\mathrm{ISM}}) + A_{V,\mathrm{cloud}}(R_{V,\mathrm{cloud}}, \alpha_{\mathrm{cloud}}) & \mu \geq \mu_{\mathrm{cloud}} \end{cases}$$

3D Extinction – Bayesian

$$p(\phi|\{\mathbf{D}\}) = \prod_i \iint \frac{p(\mathbf{D}_i|\phi,\mu,\mathbf{\Theta})\, p(\phi,\mu,\mathbf{\Theta})}{p(\mathbf{D}_i)}\, \mathrm{d}\mathbf{\Theta}\, \mathrm{d}\mu$$

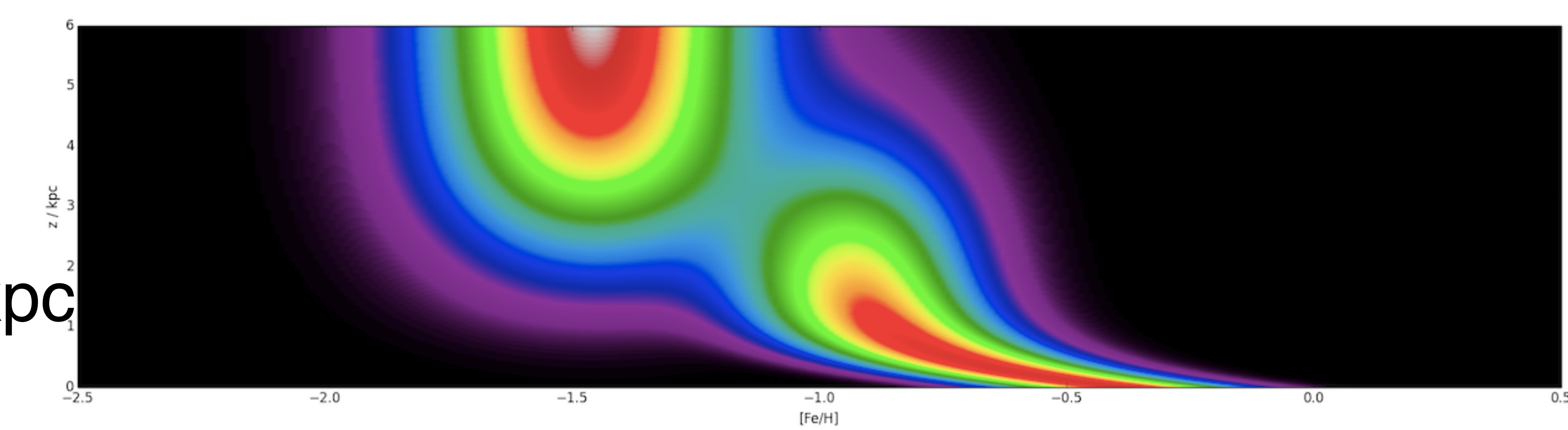


$$p(age) \propto const$$

$$p(q=0) = 0.5$$

$$p(q>0) = \frac{0.5}{N}$$

z/kpc



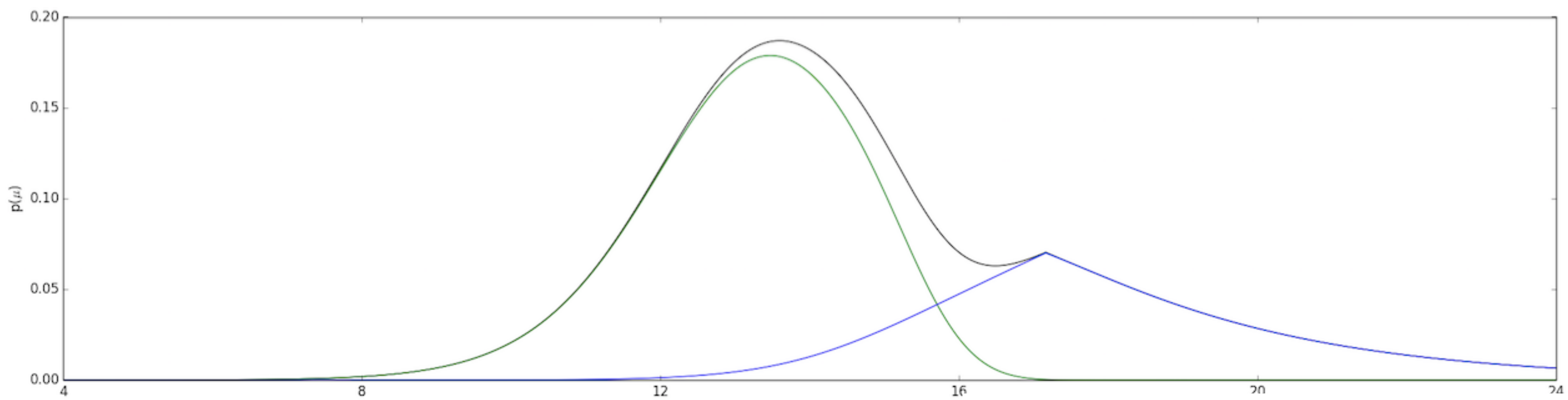
[Fe/H]

Kroupa P., 2001, MNRAS, 322, 231
Green G.. et al., 2014, ApJ, 783, 114
Bell C. et al., 2014, MNRAS, 445, 3496
Dotter A. et al., 2008, ApJS, 178, 89
Allard F,. Homeier D., Freytag B., 2011, ASPCS, 448, 91

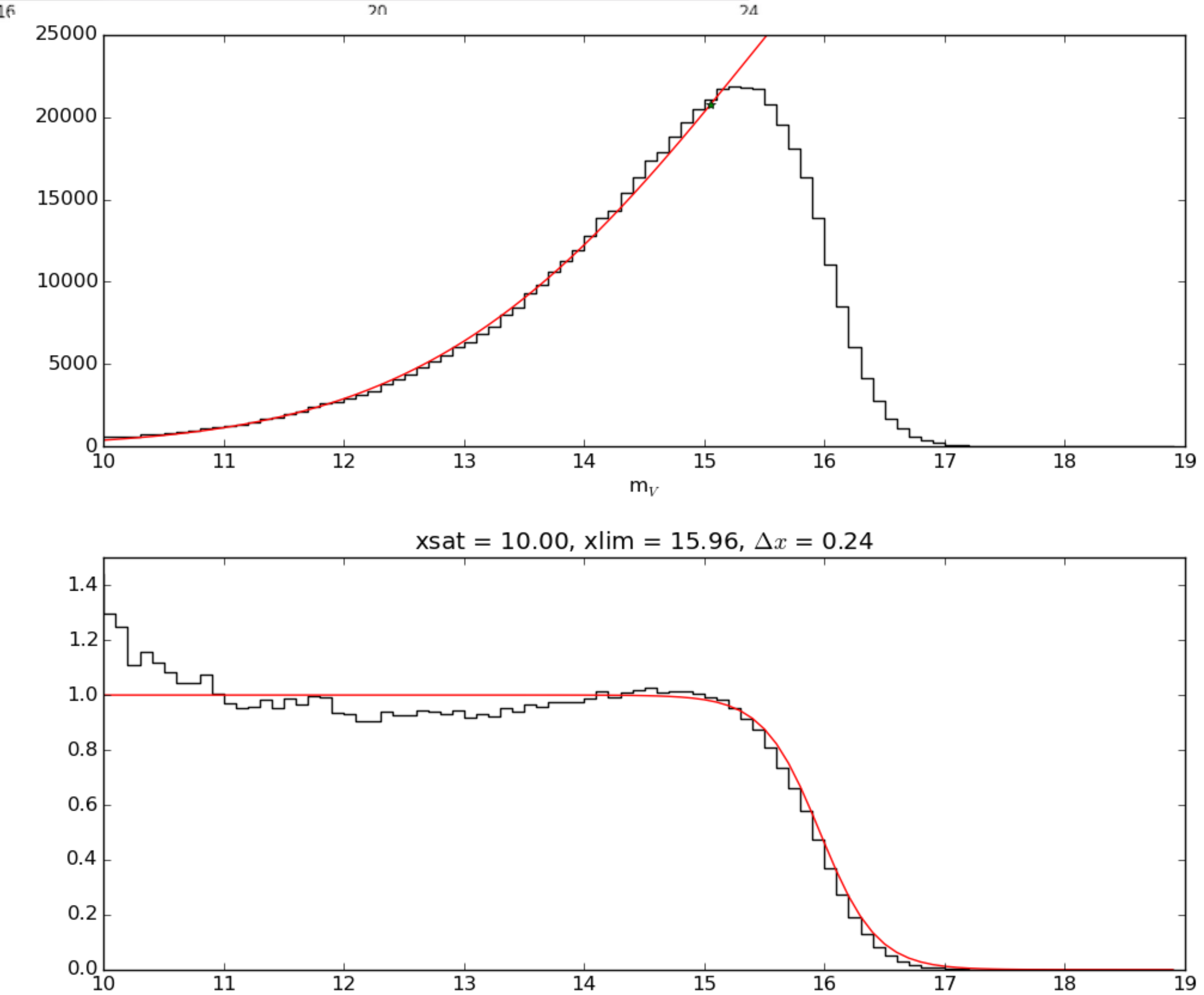
3D Extinction – Bayesian

$$p(\phi|\{\mathbf{D}\}) = \prod_i \iint \frac{p(\mathbf{D}_i|\phi,\mu,\mathbf{\Theta})\, p(\phi,\mu,\mathbf{\Theta})}{p(\mathbf{D}_i)}\, \mathrm{d}\mathbf{\Theta}\, \mathrm{d}\mu$$

p(μ)



μ



m_V /mag

$$p(A_{V,\mathrm{ISM}}|\mu) \propto e^{\frac{-(A_{V,\mathrm{ISM}} - A_V{}'(\mu))^2}{2\sigma^2_{A_V{}'(\mu)}}}$$

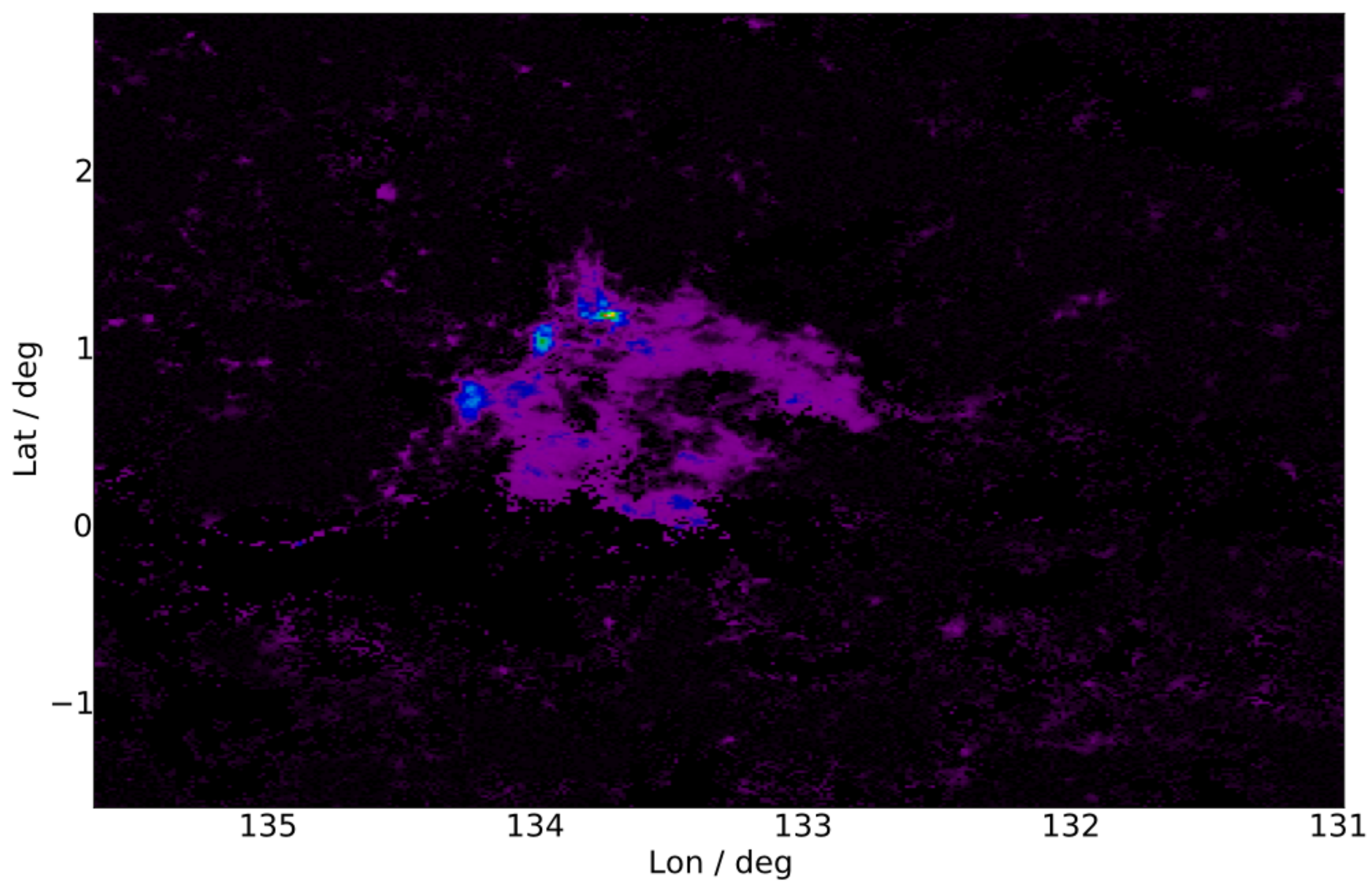
$$A_V{}'(\mu) = A_{V,W_{12\mathrm{CO}}} \frac{\int_0^\mu n_{\mathrm{ISM}}\, \mathrm{d}\mu}{\int_0^\infty n_{\mathrm{ISM}}\, \mathrm{d}\mu}$$

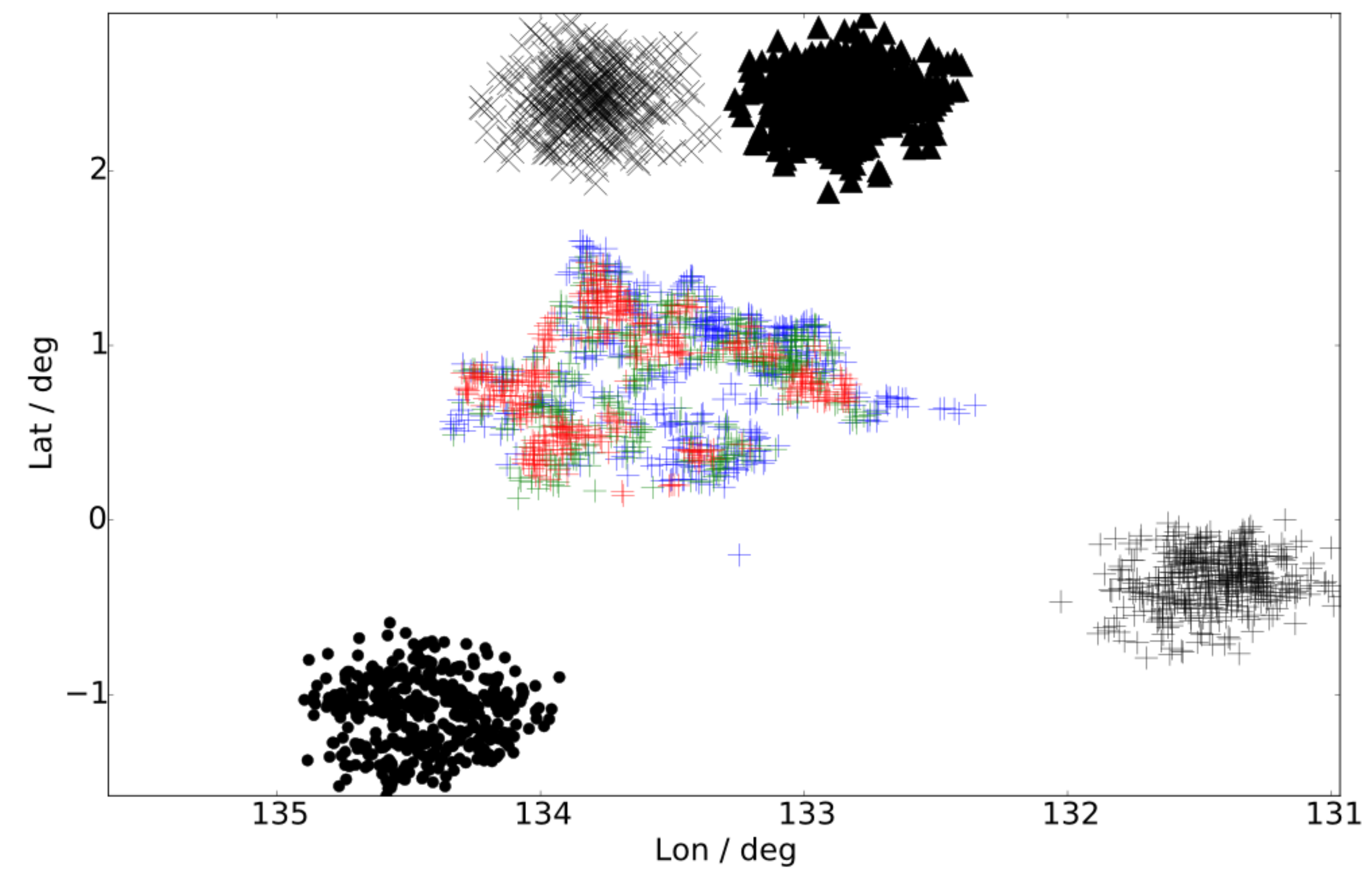
$$A_{V,W_{12\mathrm{CO}}} = R_V \cdot (0.189 + 0.016\, W_{12\mathrm{CO}})$$

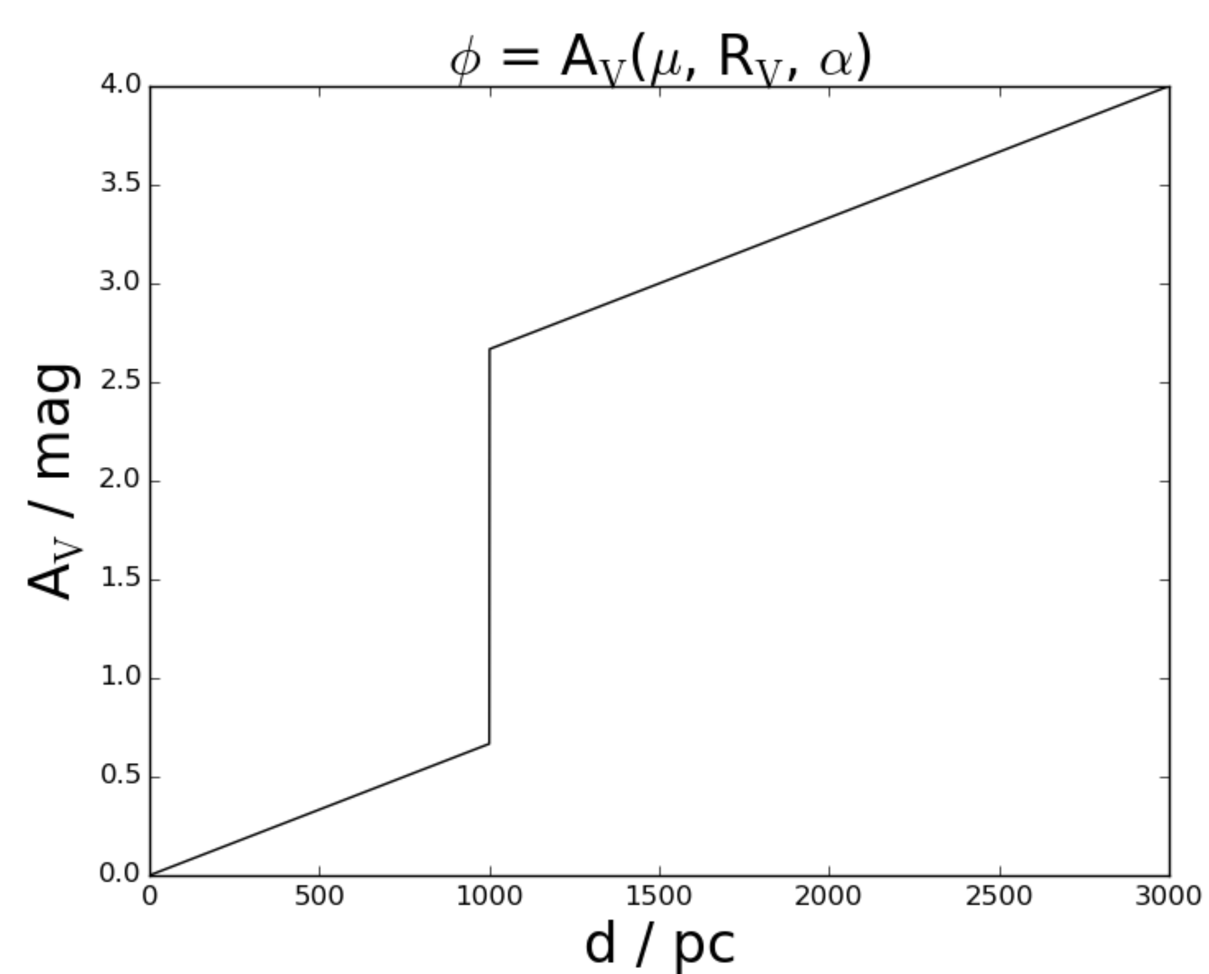
Jurić M. et al., 2008, ApJ, 673, 864
Green G. et al., 2014, ApJ, 783, 114
Sesar B., Jurić M., Ivezić Ž., 2011, ApJ, 731, 4
Robin A. et al., 2003, A&A, 409, 523
Güver T, Özel F., 2009, MNRAS, 400, 2050
Pineda J., Caselli P., Goodman A., 2008, ApJ, 679, 481

3D Extinction – Bayesian

$$p(\phi|\{\mathbf{D}\}) = \prod_i \iint \frac{p(\mathbf{D}_i|\phi,\mu,\mathbf{\Theta})\,p(\phi,\mu,\mathbf{\Theta})}{p(\mathbf{D}_i)}\,\mathrm{d}\mathbf{\Theta}\,\mathrm{d}\mu$$



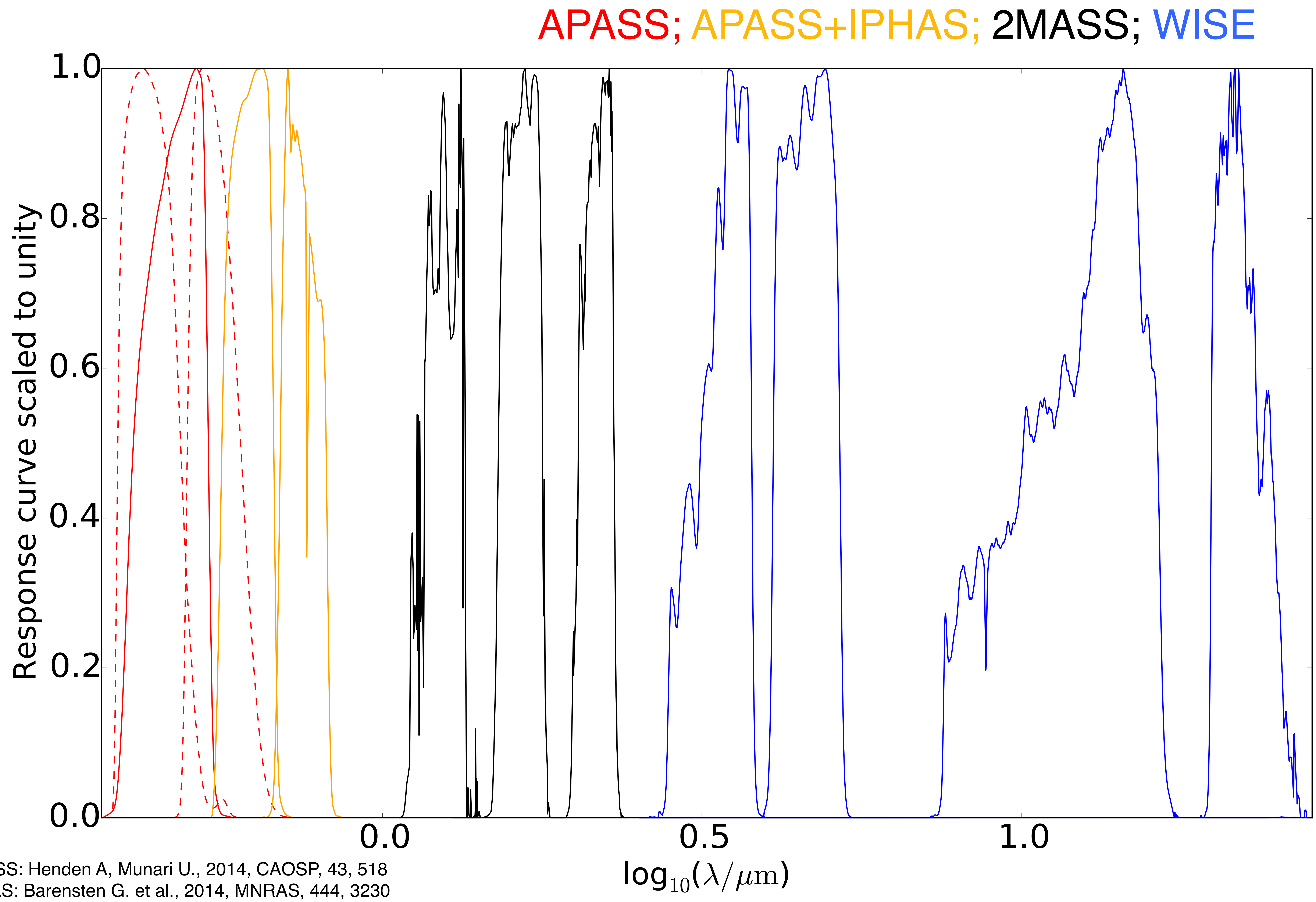




3D Extinction - RESULTS

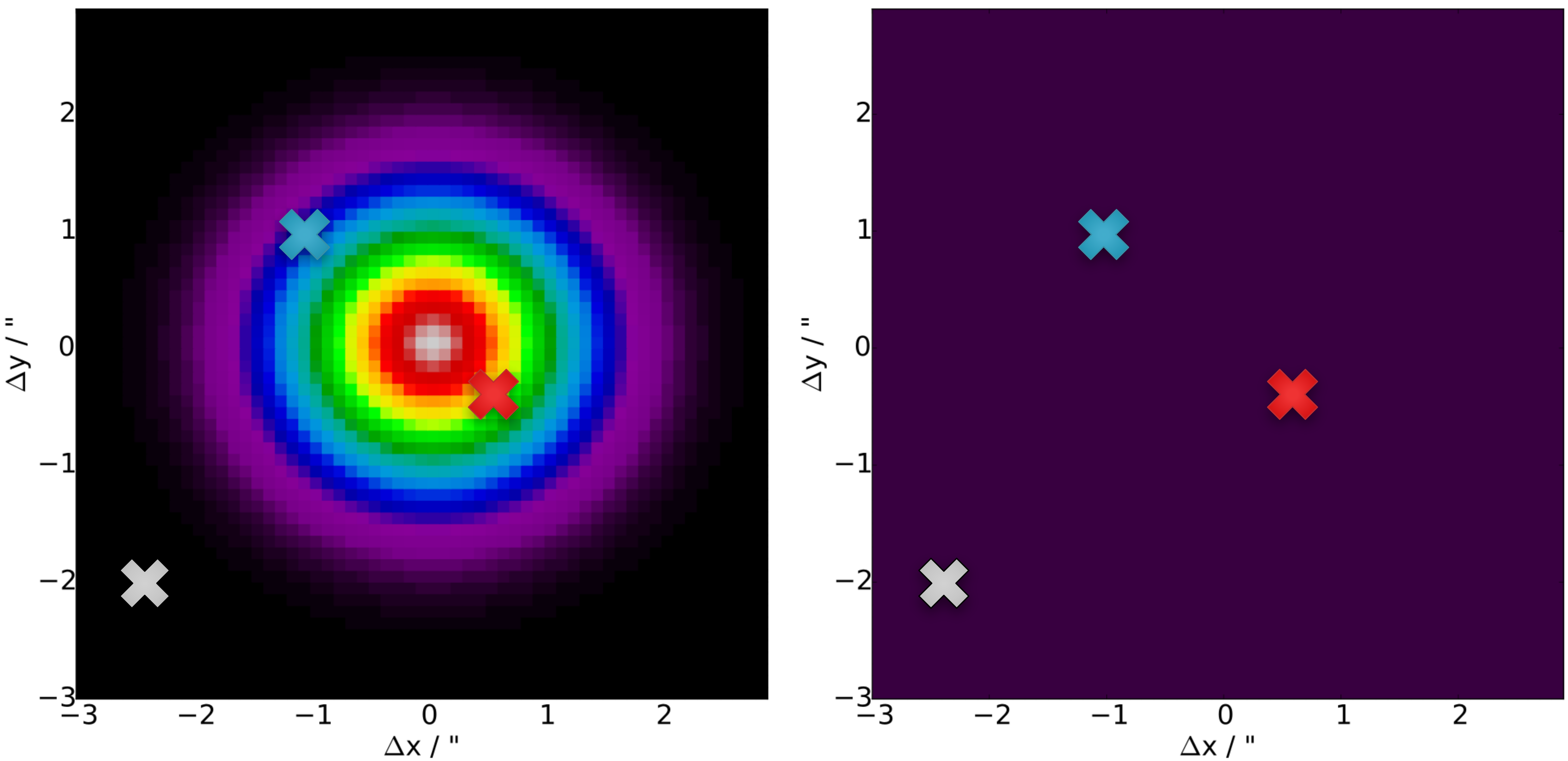
- Just kidding, no results yet
- The answer is probably 42, or something

Symmetric Probabilistic Catalogue Matching - Intro

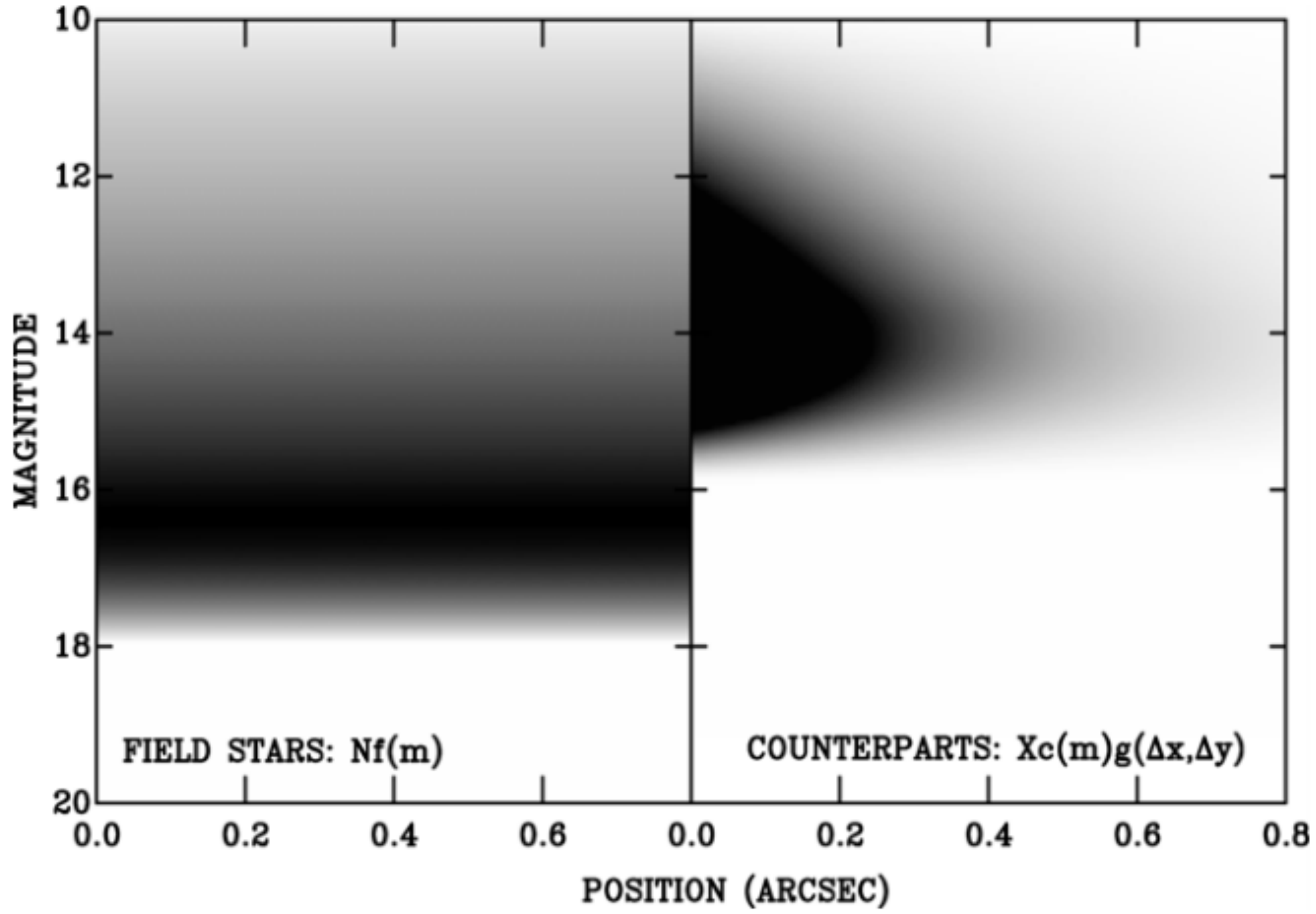


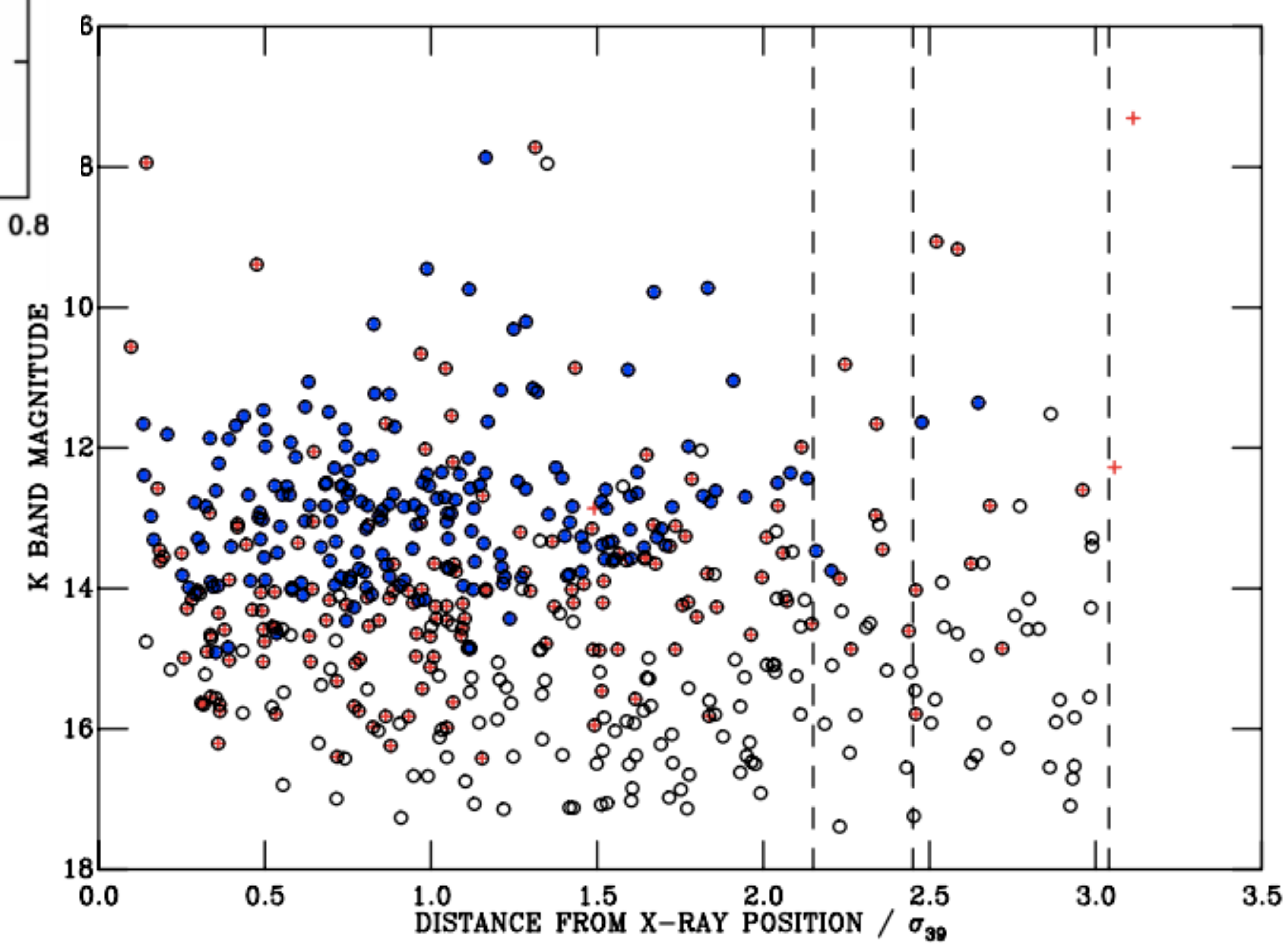
APASS: Henden A, Munari U., 2014, CAOSP, 43, 518
IPHAS: Barensten G. et al., 2014, MNRAS, 444, 3230
2MASS: Skrutskie M. F. et al., 2006, AJ, 131, 1163
WISE: Wright E. L. et al., 2010, AJ, 140, 1868

SPCMatching - Intro



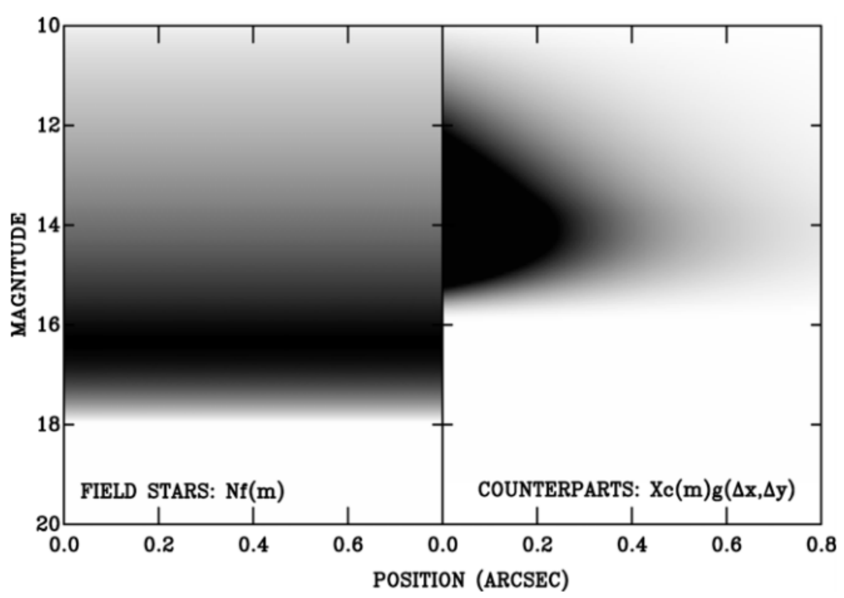
SPCMatching – Asymmetry

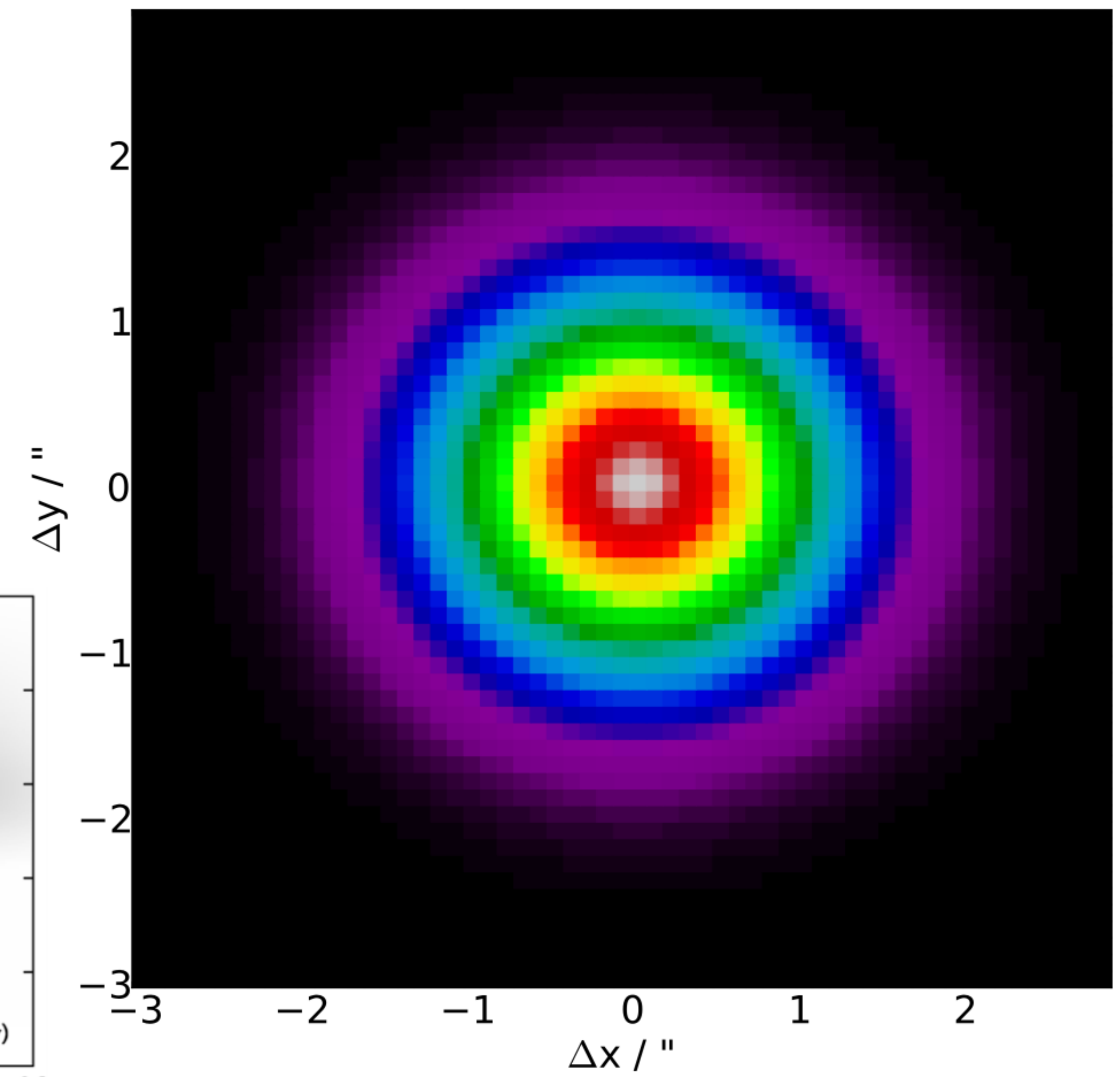


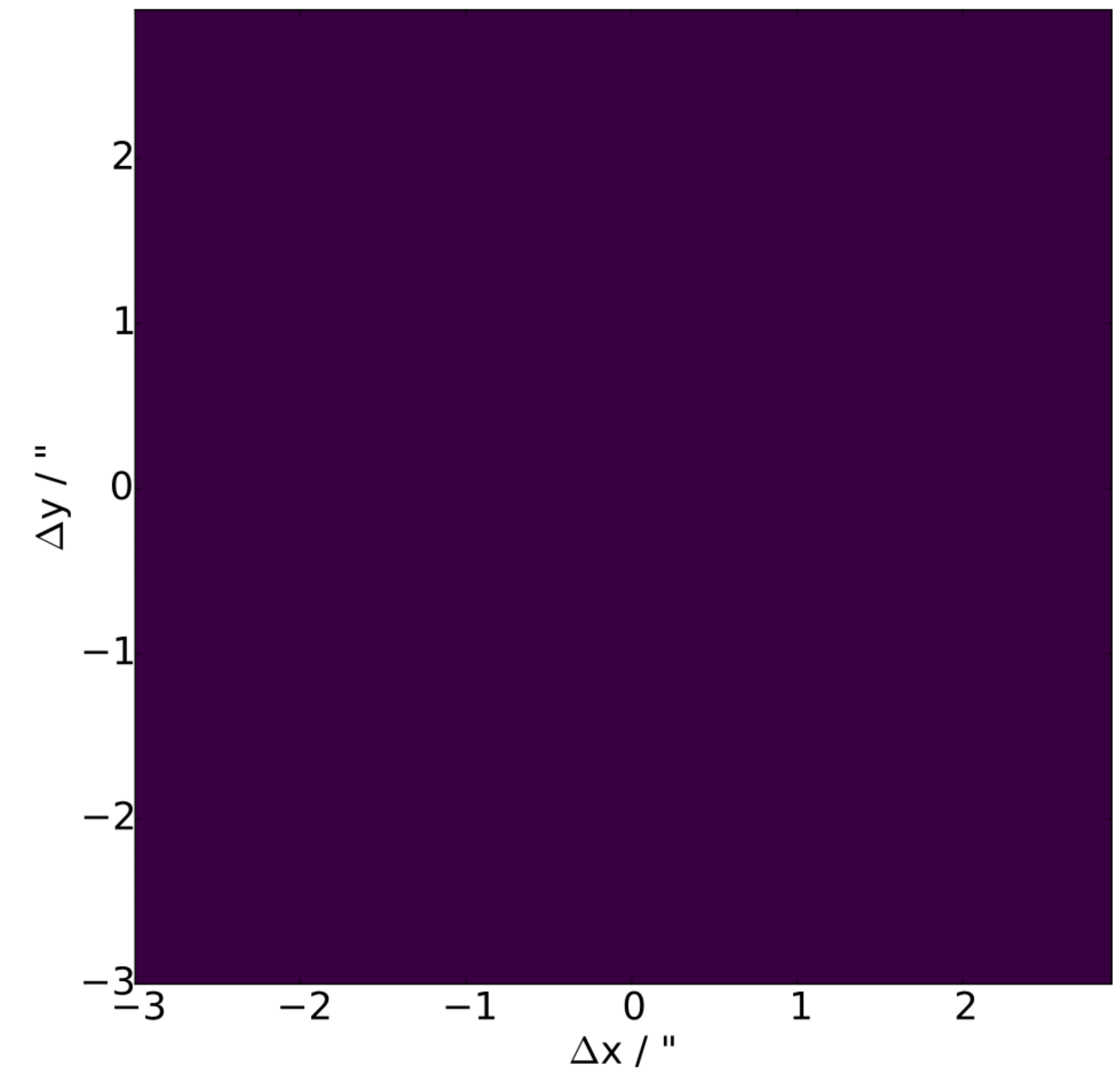


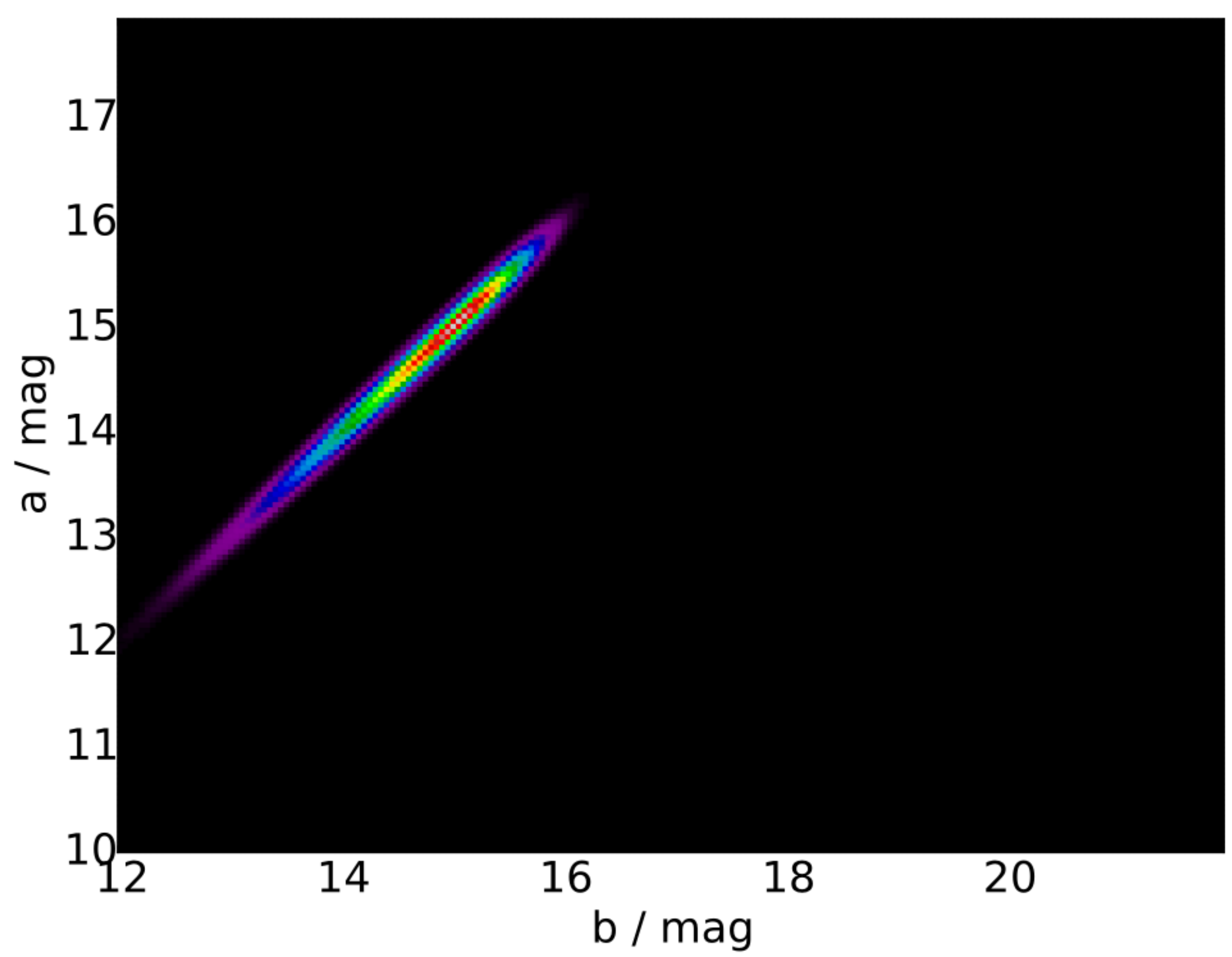
Naylor T., Broos P. S., Feigelson E. D., 2013, ApJS, 209, 30

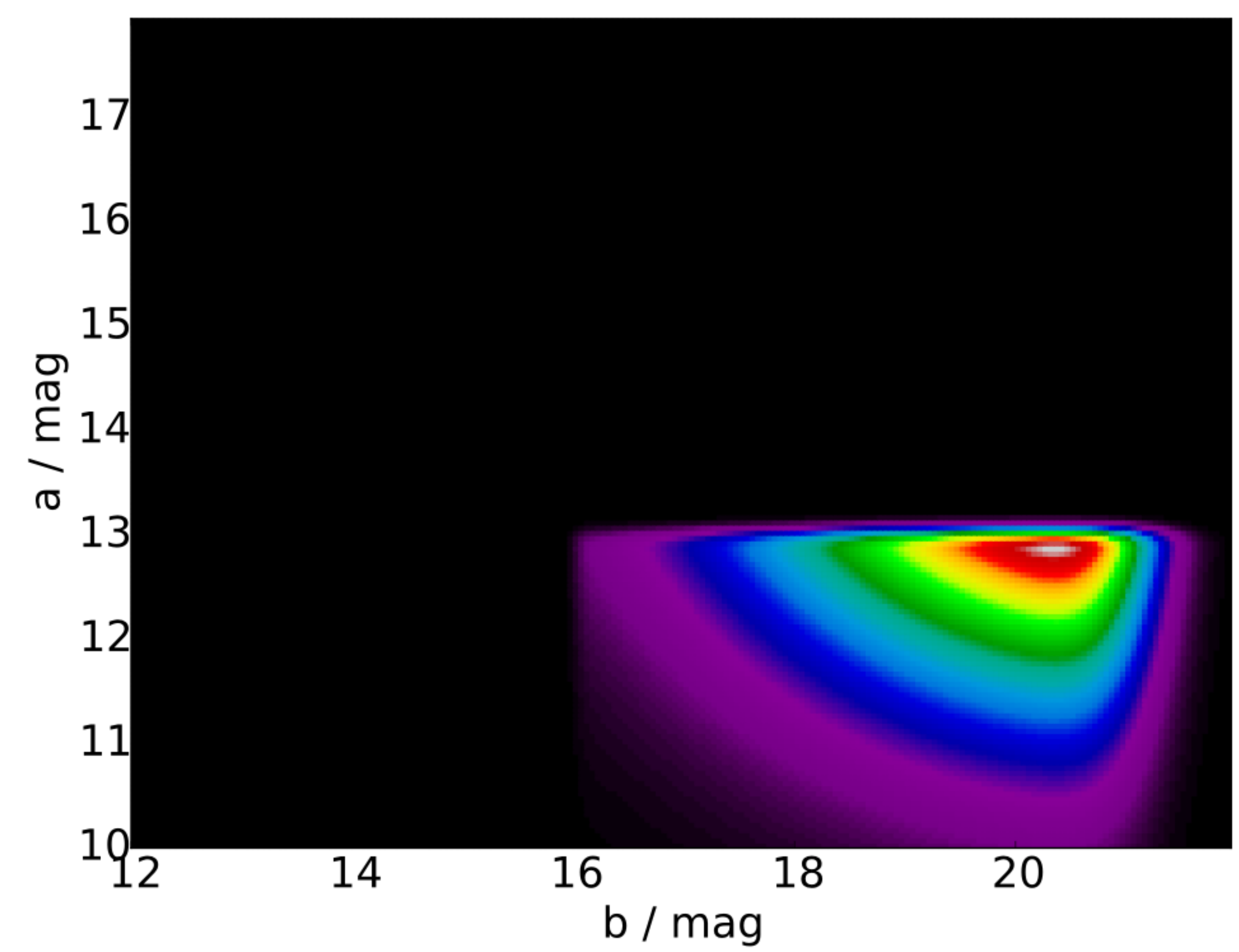
SPCMatching – Symmetrisation











SPCMatching – functions

$$p(\sigma, \lambda, M|\gamma, \phi) = K \prod_{\delta\notin\sigma\cap\delta\in\gamma} N_\gamma f_\gamma(m_\delta) \prod_{\omega\notin\lambda\cap\omega\in\phi} N_\phi f_\phi(m_\omega) \prod_{i=1}^{M} N_C G(\Delta x_{\sigma_i\lambda_i}, \Delta y_{\sigma_i\lambda_i}) p(m_{\sigma_i}, m_{\lambda_i})$$

Normalisation

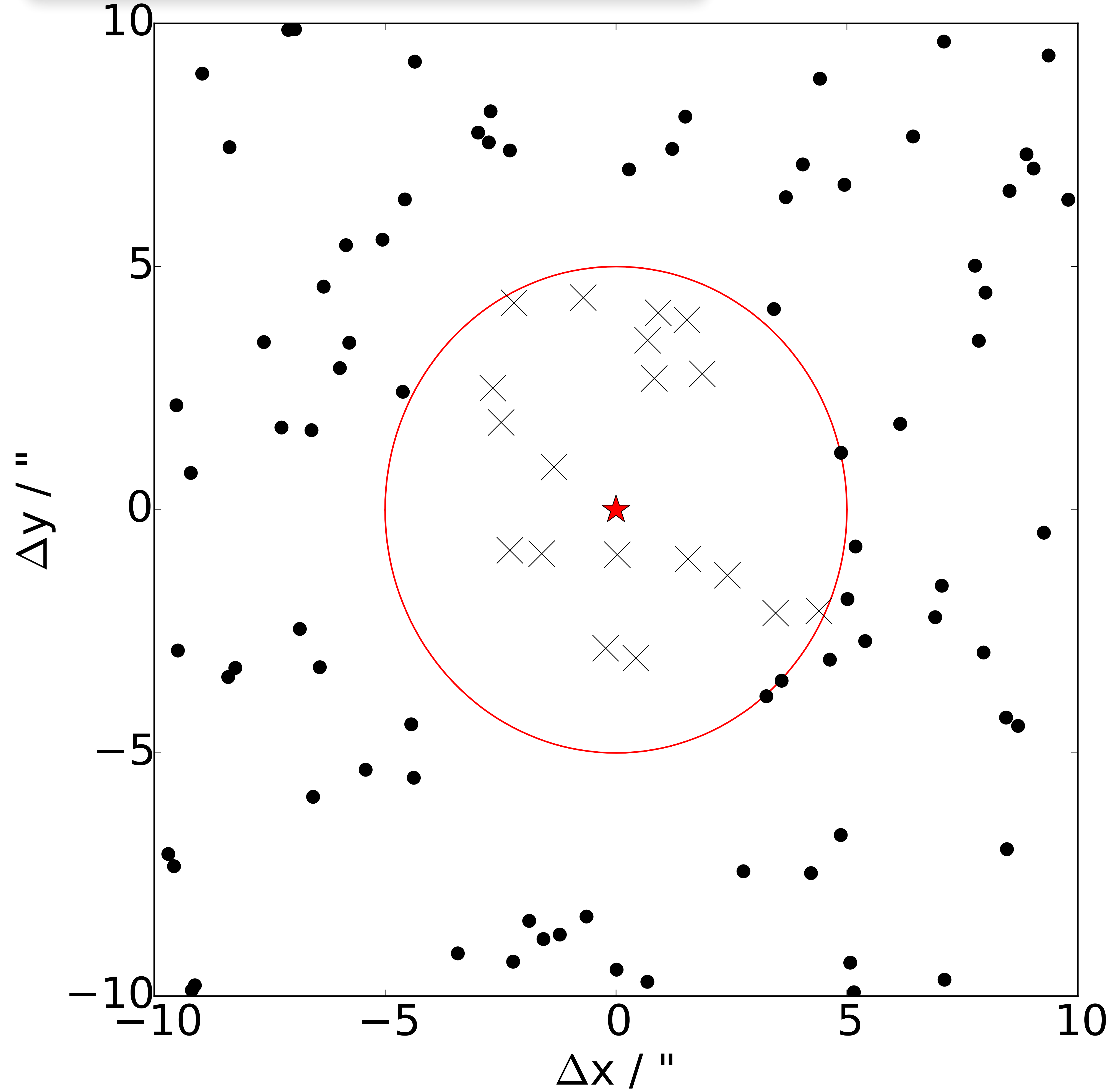
Field star magnitude distribution and number density

Counterpart position distribution and number density

Counterpart magnitude distribution

SPCMatching – functions: f

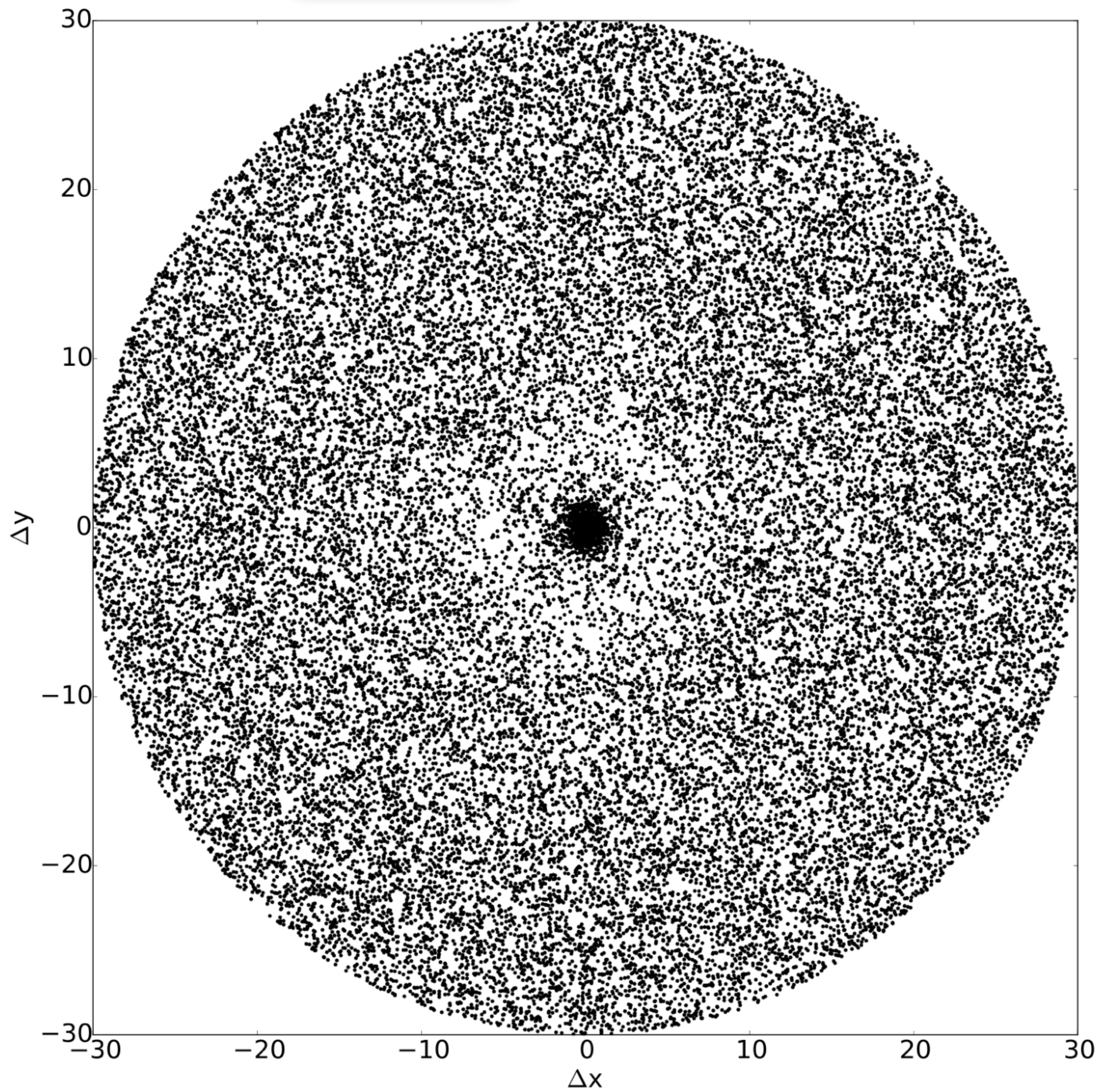
$$p(\sigma, \lambda, M|\gamma, \phi) = K \prod_{\delta \notin \sigma \cap \delta \in \gamma} N_\gamma f_\gamma(m_\delta) \prod_{\omega \notin \lambda \cap \omega \in \phi} N_\phi f_\phi(m_\omega) \prod_{i=1}^{M} N_C G(\Delta x_{\sigma_i \lambda_i}, \Delta y_{\sigma_i \lambda_i}) p(m_{\sigma_i}, m_{\lambda_i})$$



SPCMatching – functions: c

$$p(\sigma, \lambda, M|\gamma, \phi) = K \prod_{\delta \notin \sigma \cap \delta \in \gamma} N_\gamma f_\gamma(m_\delta) \prod_{\omega \notin \lambda \cap \omega \in \phi} N_\phi f_\phi(m_\omega) \prod_{i=1}^{M} N_C G(\Delta x_{\sigma_i \lambda_i}, \Delta y_{\sigma_i \lambda_i}) p(m_{\sigma_i}, m_{\lambda_i})$$

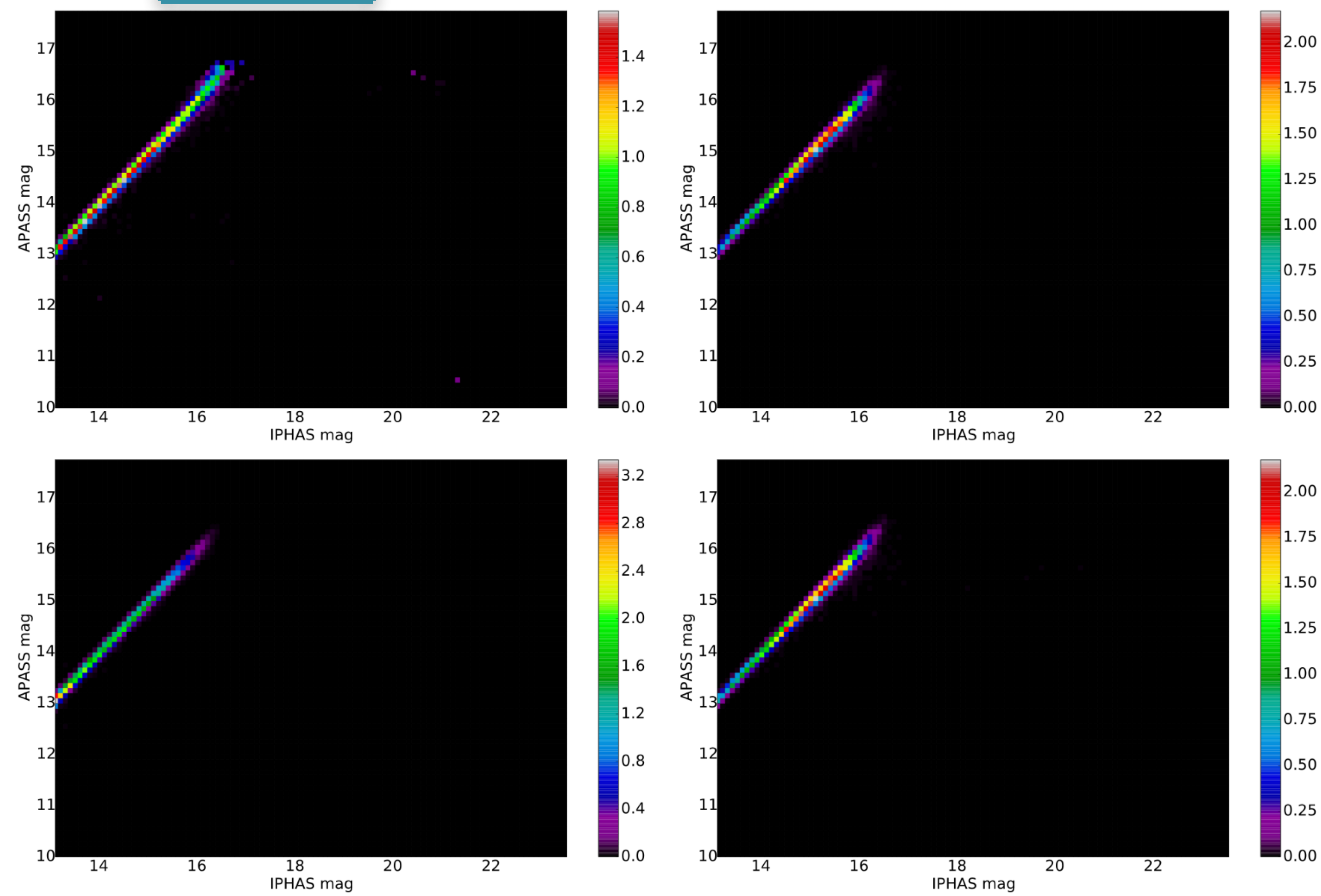
$$p(m_k, m_l) = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} p(m_k|m_a) p(m_l|m_b) c(m_a, m_b) \, \mathrm{d}m_a \, \mathrm{d}m_b$$



SPCMatching – functions: c

$$p(\sigma,\lambda,M|\gamma,\phi) = K \prod_{\delta\notin\sigma\cap\delta\in\gamma} N_\gamma f_\gamma(m_\delta) \prod_{\omega\notin\lambda\cap\omega\in\phi} N_\phi f_\phi(m_\omega) \prod_{i=1}^{M} N_C G(\Delta x_{\sigma_i\lambda_i}, \Delta y_{\sigma_i\lambda_i}) p(m_{\sigma_i}, m_{\lambda_i})$$

$$p(m_k,m_l) = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} p(m_k|m_a)p(m_l|m_b)c(m_a,m_b)\,\mathrm{d}m_a\,\mathrm{d}m_b$$



$$Z_{c,\beta}c_\gamma(m|m_\beta) = Z_\beta b_\beta(m) e^{A_\beta N_\phi F_\phi(m)} - (1 - Z_{c,\beta}C(m|m_\beta))A_\beta N_\phi f_\phi(m)$$

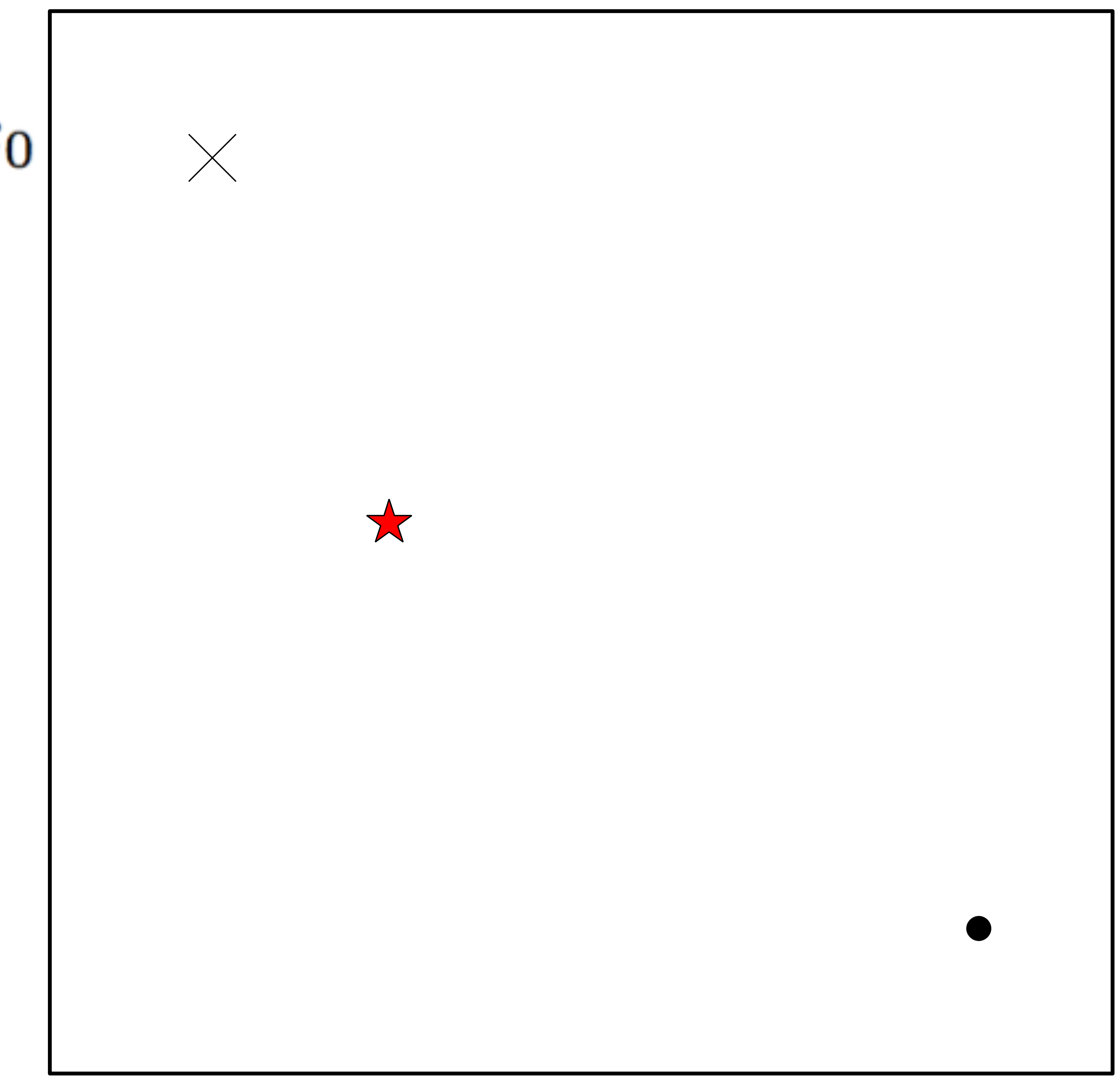
SPCMatching – functions: g

$$p(\sigma, \lambda, M|\gamma, \phi) = K \prod_{\delta \notin \sigma \cap \delta \in \gamma} N_\gamma f_\gamma(m_\delta) \prod_{\omega \notin \lambda \cap \omega \in \phi} N_\phi f_\phi(m_\omega) \prod_{i=1}^{M} N_C G(\Delta x_{\sigma_i \lambda_i}, \Delta y_{\sigma_i \lambda_i}) p(m_{\sigma_i}, m_{\lambda_i})$$

$$G(\Delta x_{kl}) = \int_{-\infty}^{+\infty} f(x_0 - x_k) g(x_l - x_0) \mathrm{d}x_0$$

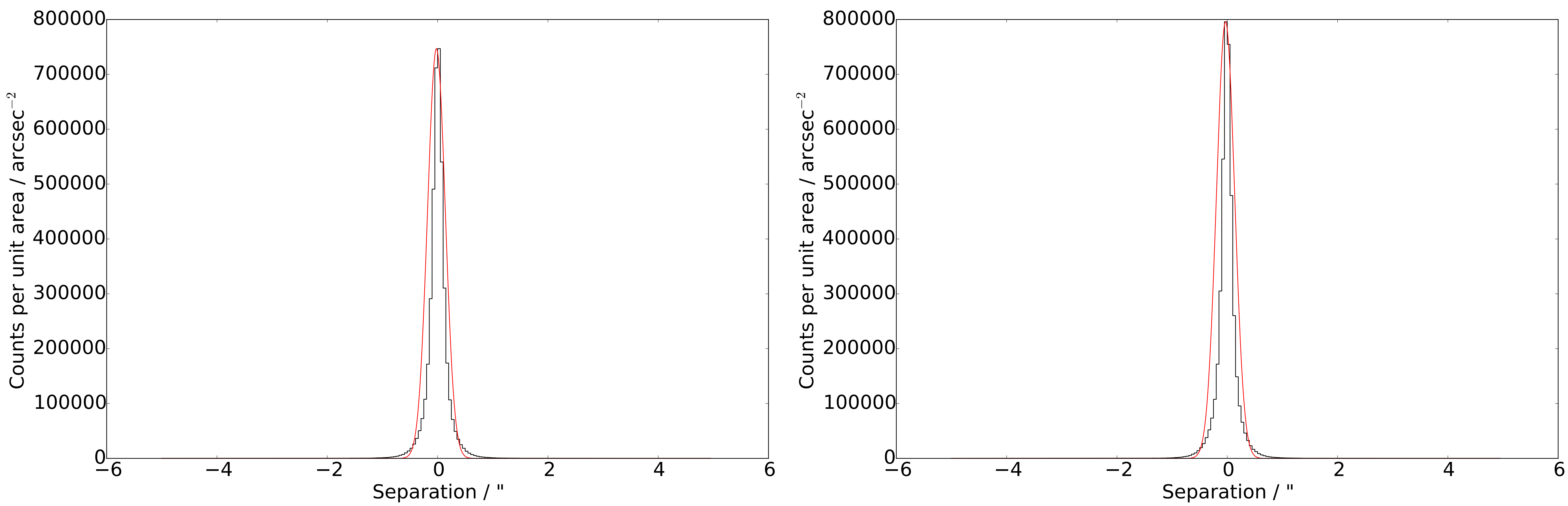
↓

$$G(\Delta x_{kl}) = \int_{-\infty}^{+\infty} f(\Delta x - x) g(x) \mathrm{d}x$$



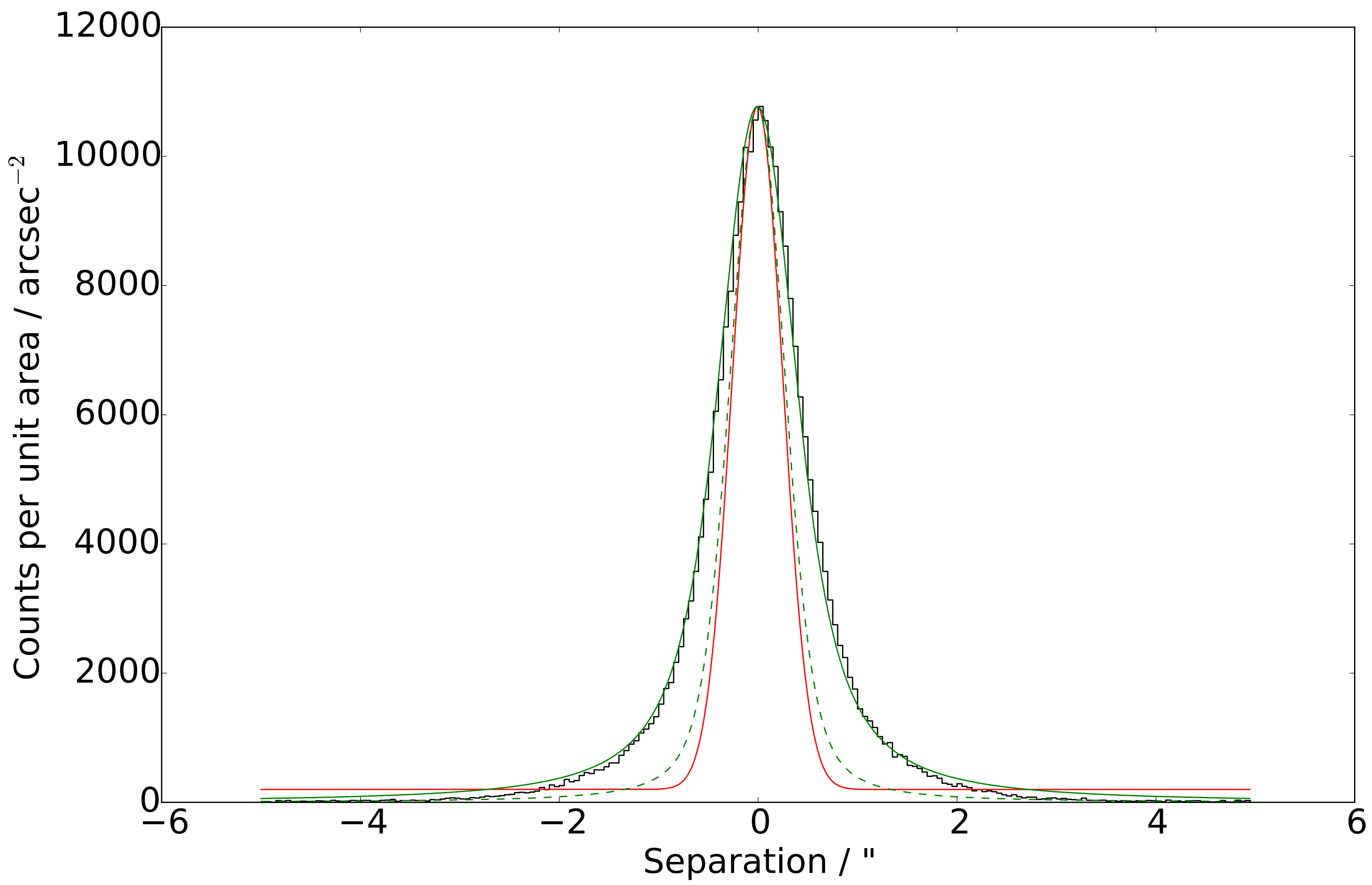
SPCMatching – functions: g

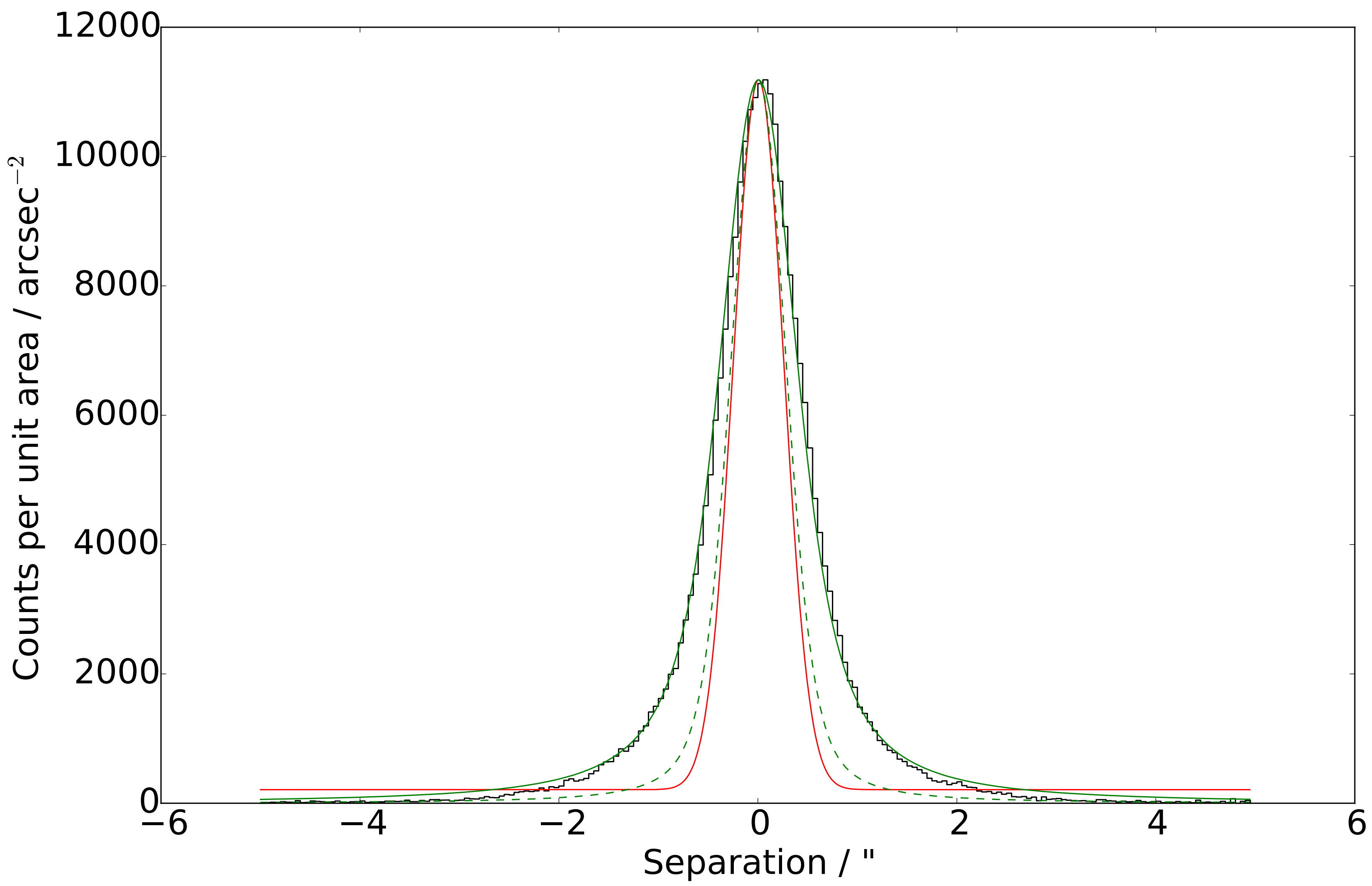
$$p(\sigma, \lambda, M|\gamma, \phi) = K \prod_{\delta \notin \sigma \cap \delta \in \gamma} N_\gamma f_\gamma(m_\delta) \prod_{\omega \notin \lambda \cap \omega \in \phi} N_\phi f_\phi(m_\omega) \prod_{i=1}^{M} N_C G(\Delta x_{\sigma_i \lambda_i}, \Delta y_{\sigma_i \lambda_i}) p(m_{\sigma_i}, m_{\lambda_i})$$



SPCMatching – functions: g

$$p(\sigma, \lambda, M|\gamma, \phi) = K \prod_{\delta \notin \sigma \cap \delta \in \gamma} N_\gamma f_\gamma(m_\delta) \prod_{\omega \notin \lambda \cap \omega \in \phi} N_\phi f_\phi(m_\omega) \prod_{i=1}^{M} N_C G(\Delta x_{\sigma_i \lambda_i}, \Delta y_{\sigma_i \lambda_i}) p(m_{\sigma_i}, m_{\lambda_i})$$





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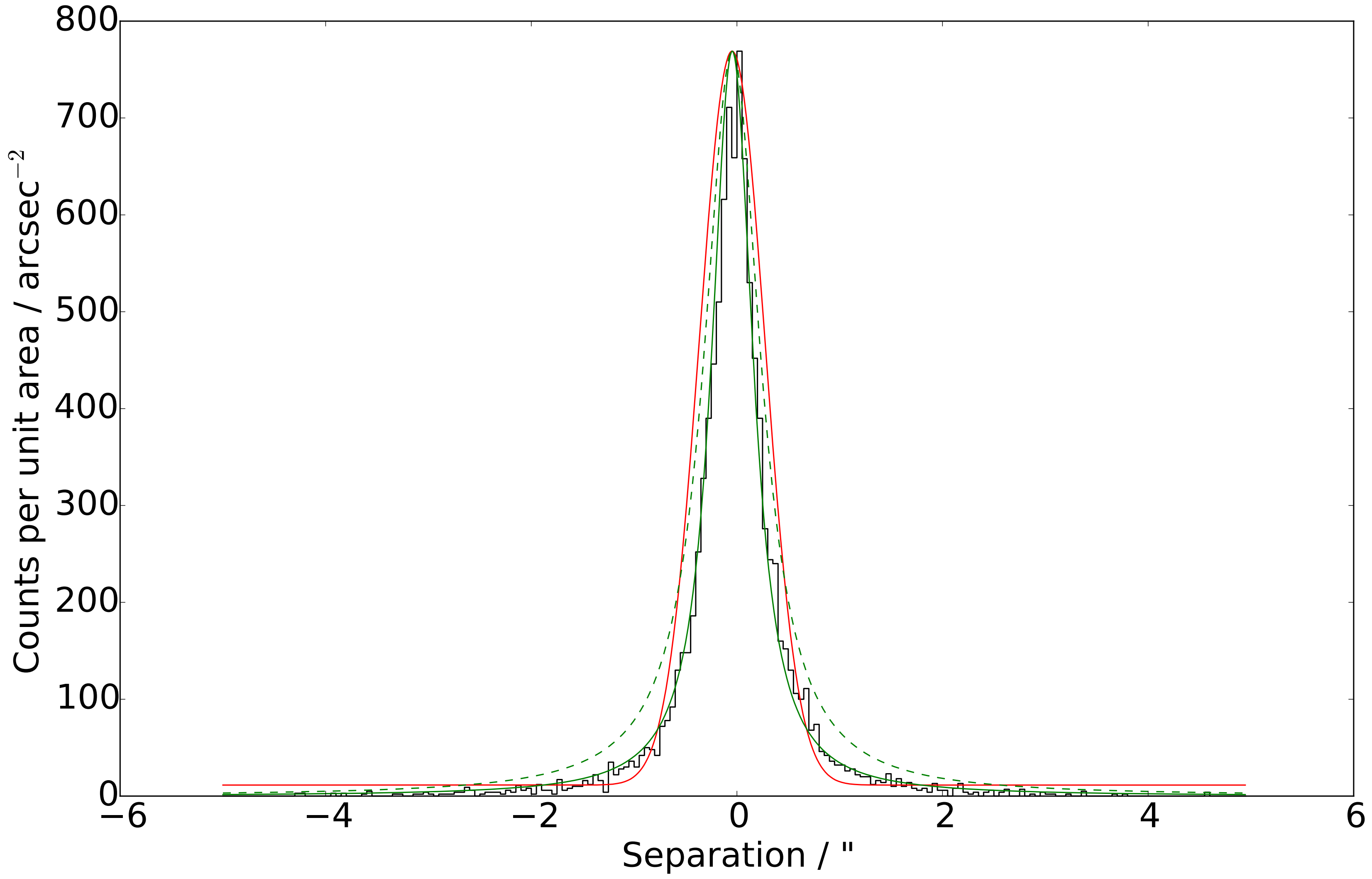

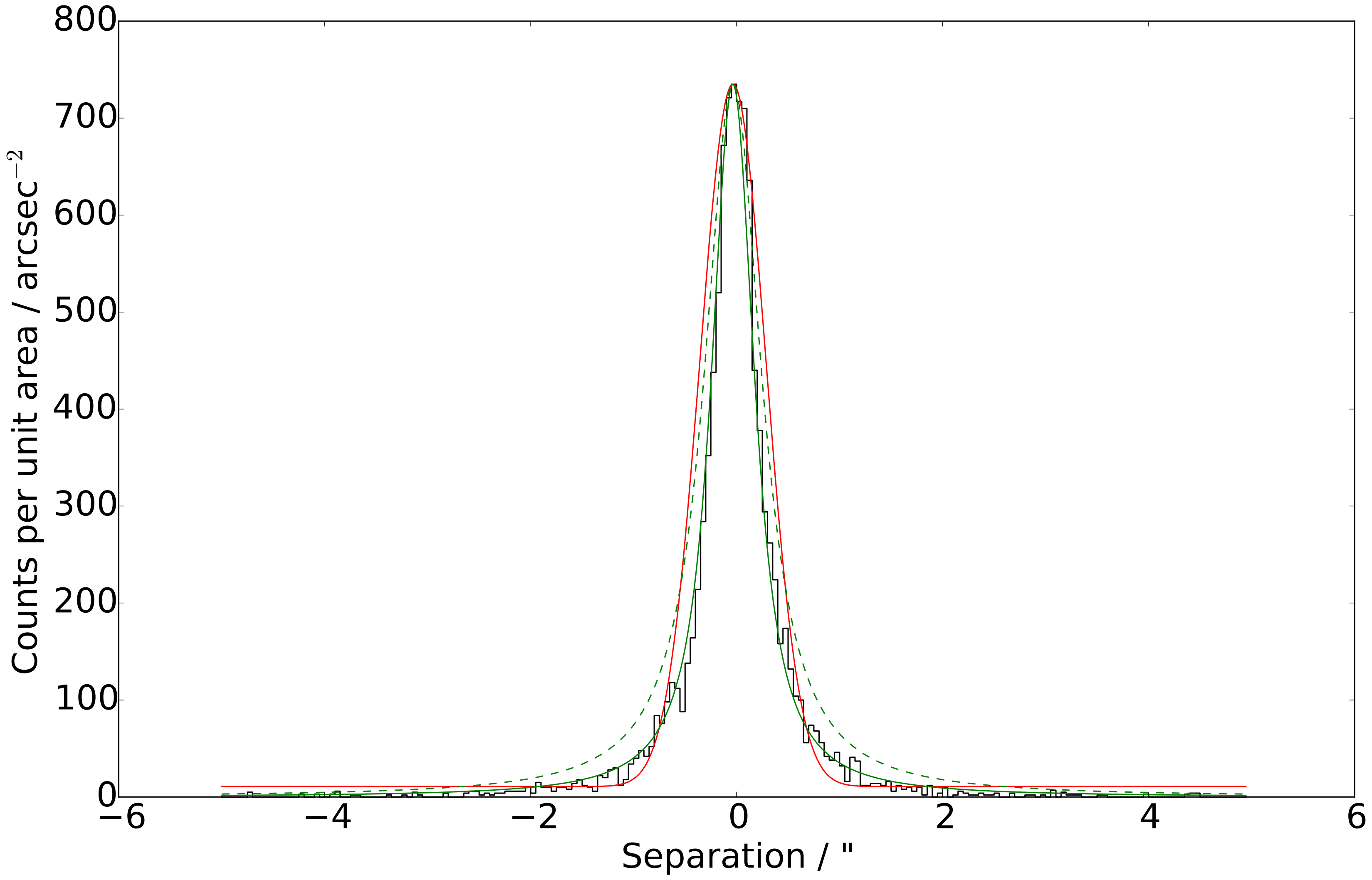

SPCMatching – functions: g

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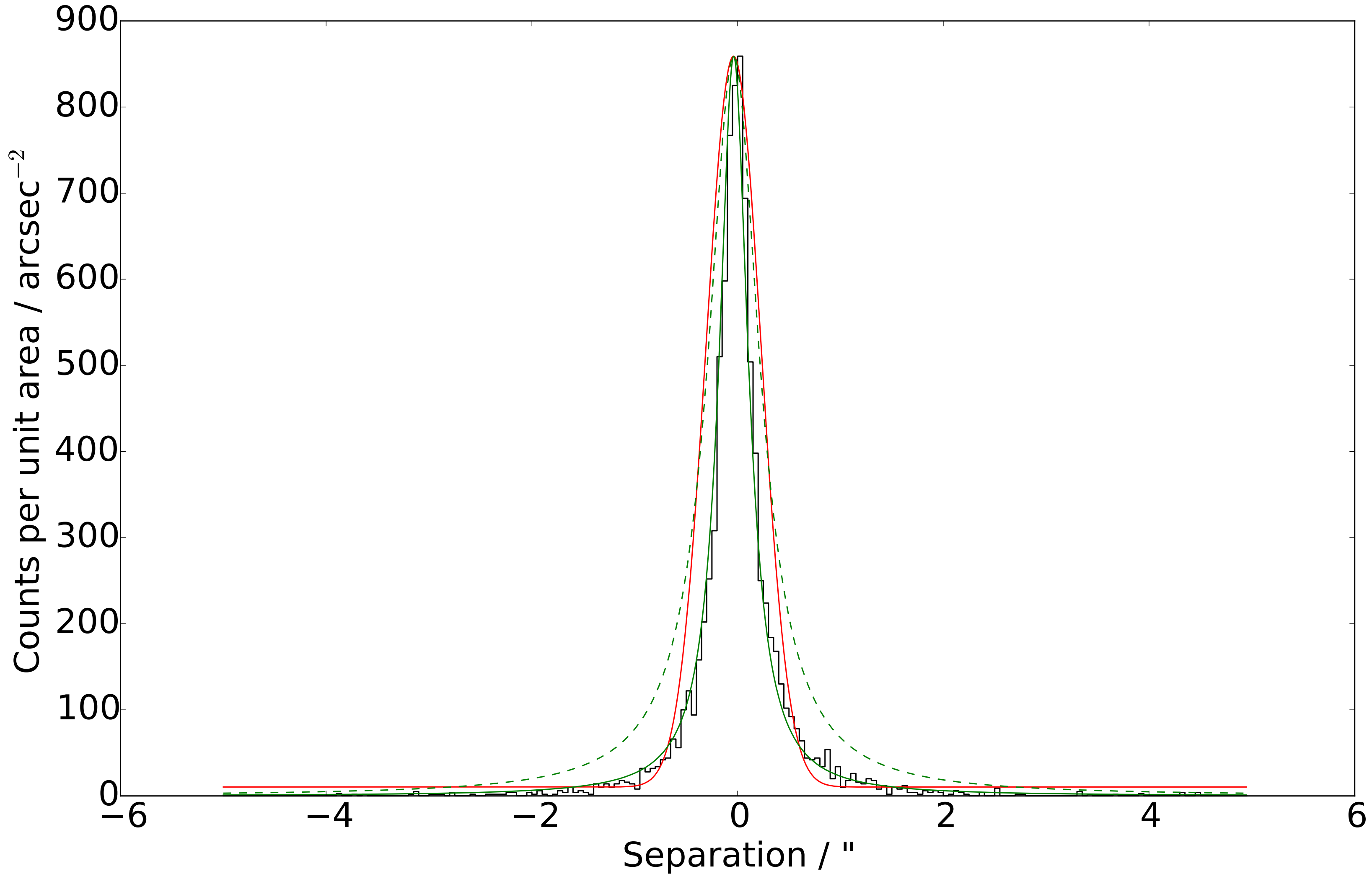
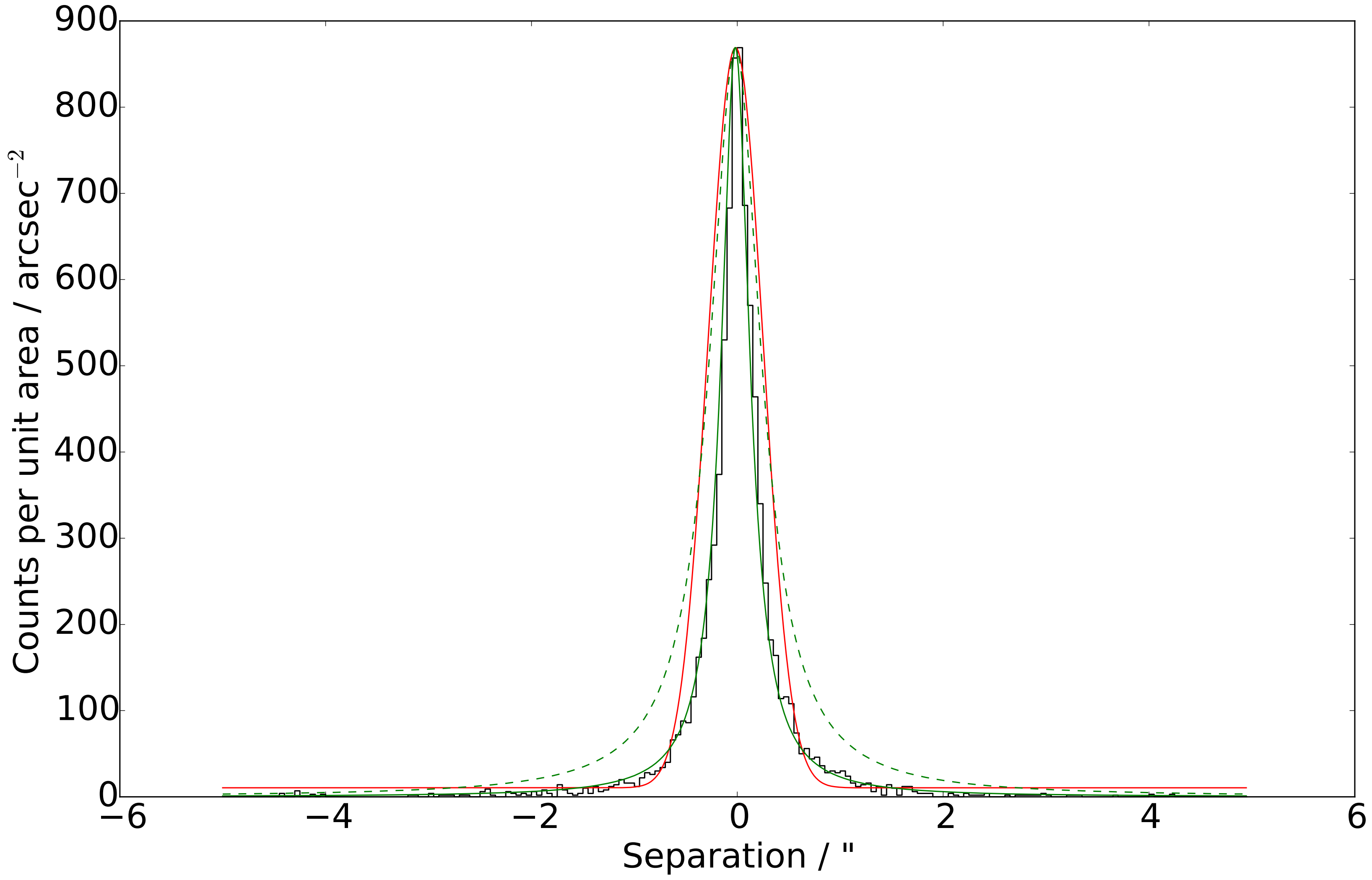
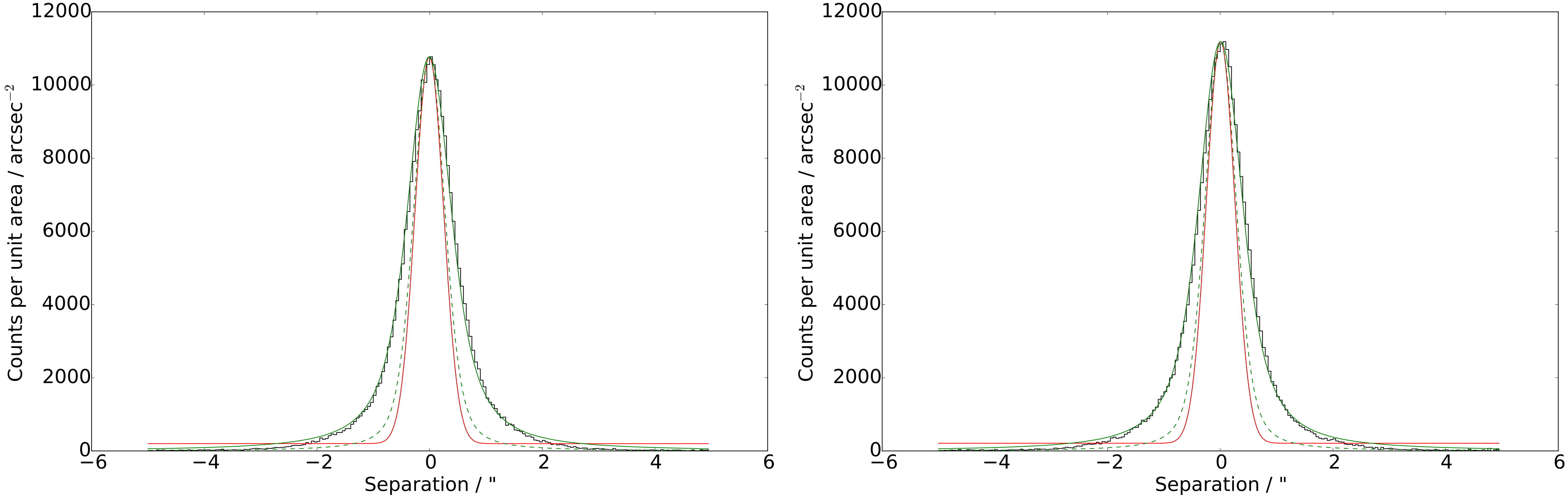


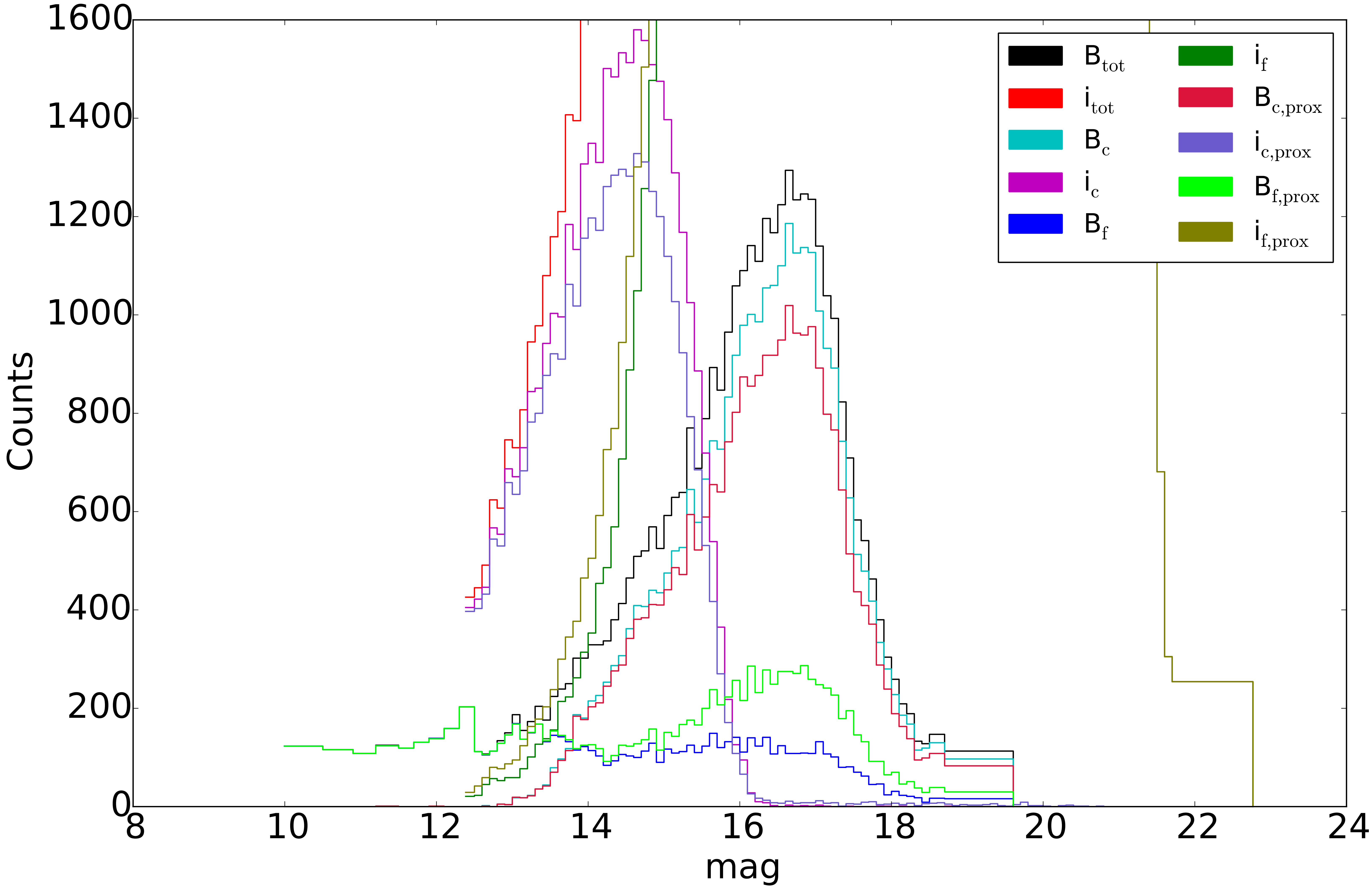


SPCMatching – functions: g

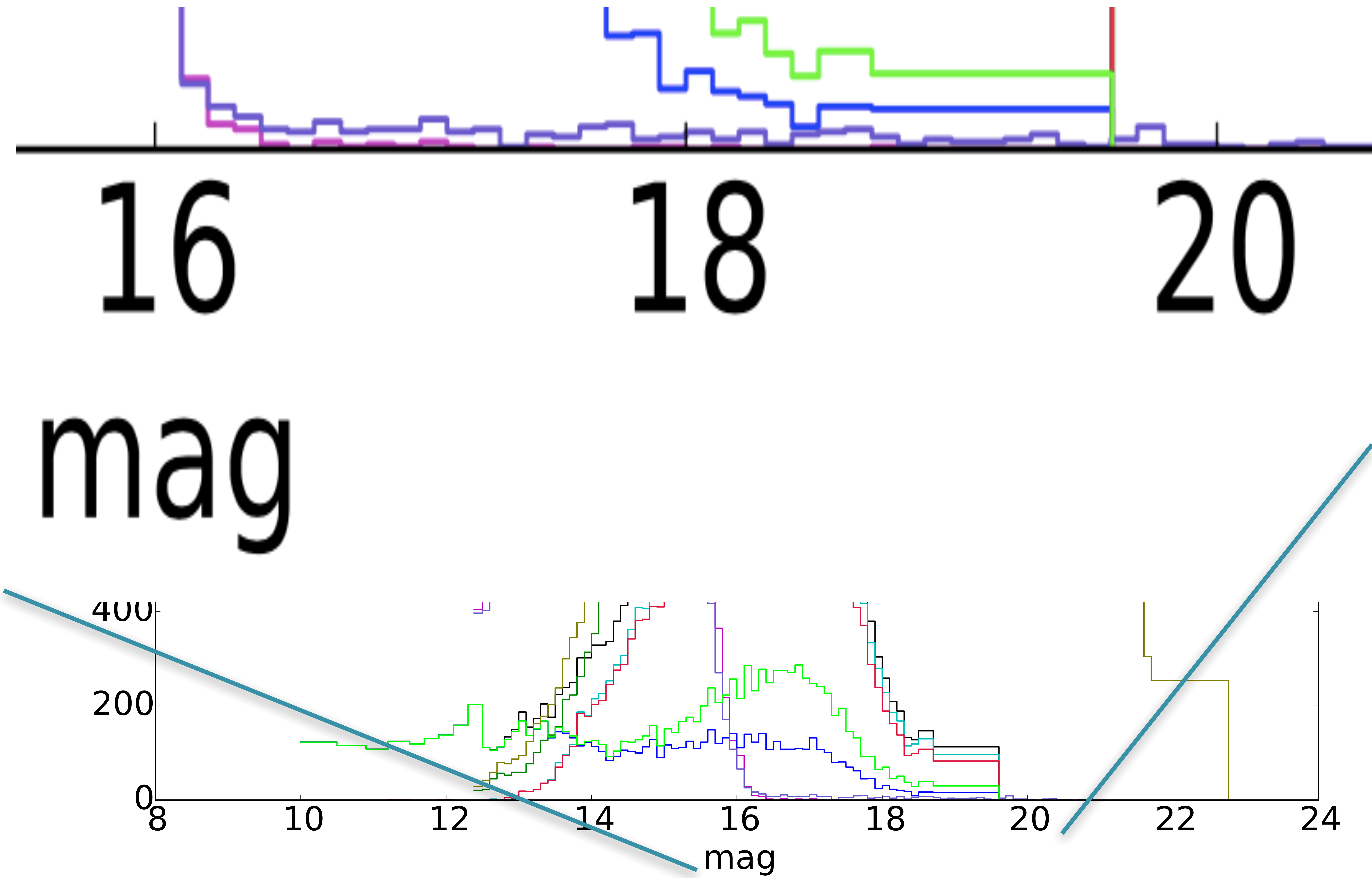
$$p(\sigma, \lambda, M|\gamma, \phi) = K \prod_{\delta \notin \sigma \cap \delta \in \gamma} N_\gamma f_\gamma(m_\delta) \prod_{\omega \notin \lambda \cap \omega \in \phi} N_\phi f_\phi(m_\omega) \prod_{i=1}^{M} N_C G(\Delta x_{\sigma_i \lambda_i}, \Delta y_{\sigma_i \lambda_i}) p(m_{\sigma_i}, m_{\lambda_i})$$



SPCMatching – Results



SPCMatching – Results



3D Extinction + Catalogue Matching Conclusions

- Powerful technique to analyse galactic structure
- Allows for kinematics and distances simultaneously
- Applicable to wide range of data sources, e.g., 2MASS+IPHAS
- Allows for probing of fundamental properties of the ISM, e.g., R_V

- Symmetrised method for more accurate catalogue matching
- Avoids faint star mismatches
- Allows for more reliable and distant photometric matches for poor quality data