Dust and metallicity with UVEX

UVEX Community Workshop, Caltech, 14 March 2023

Broad areas

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Photometry:

- Sensitive maps of dust extinction.
- Metallicities of ~300×10^6 stars.

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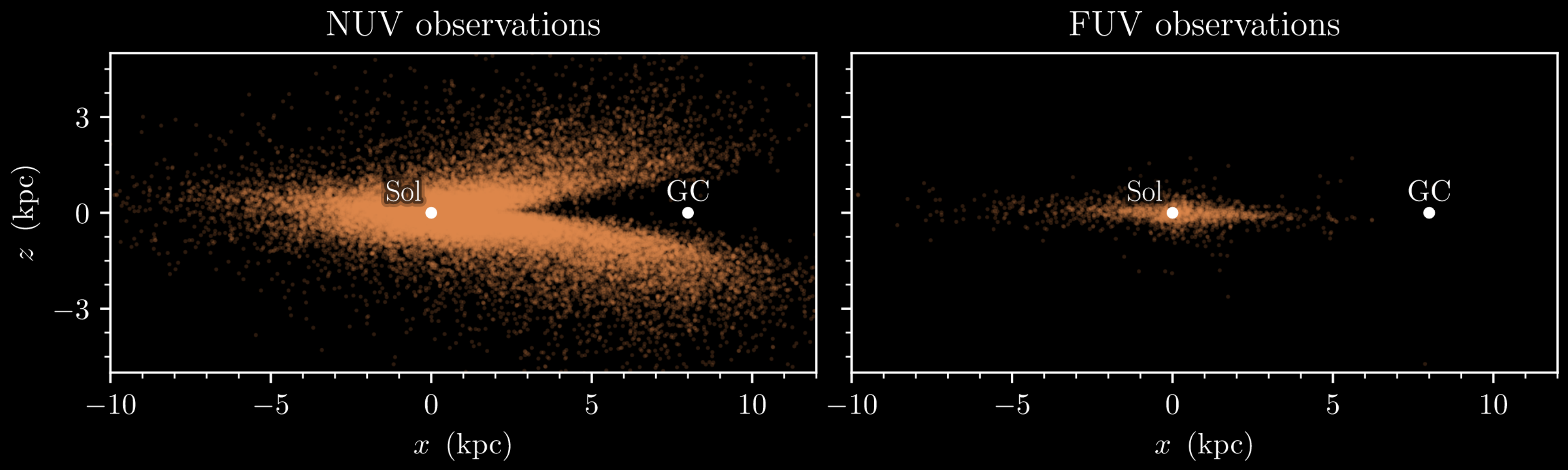
Spectroscopy+Photometry:

- Variation in dust extinction curve.

UVEX all-sky survey

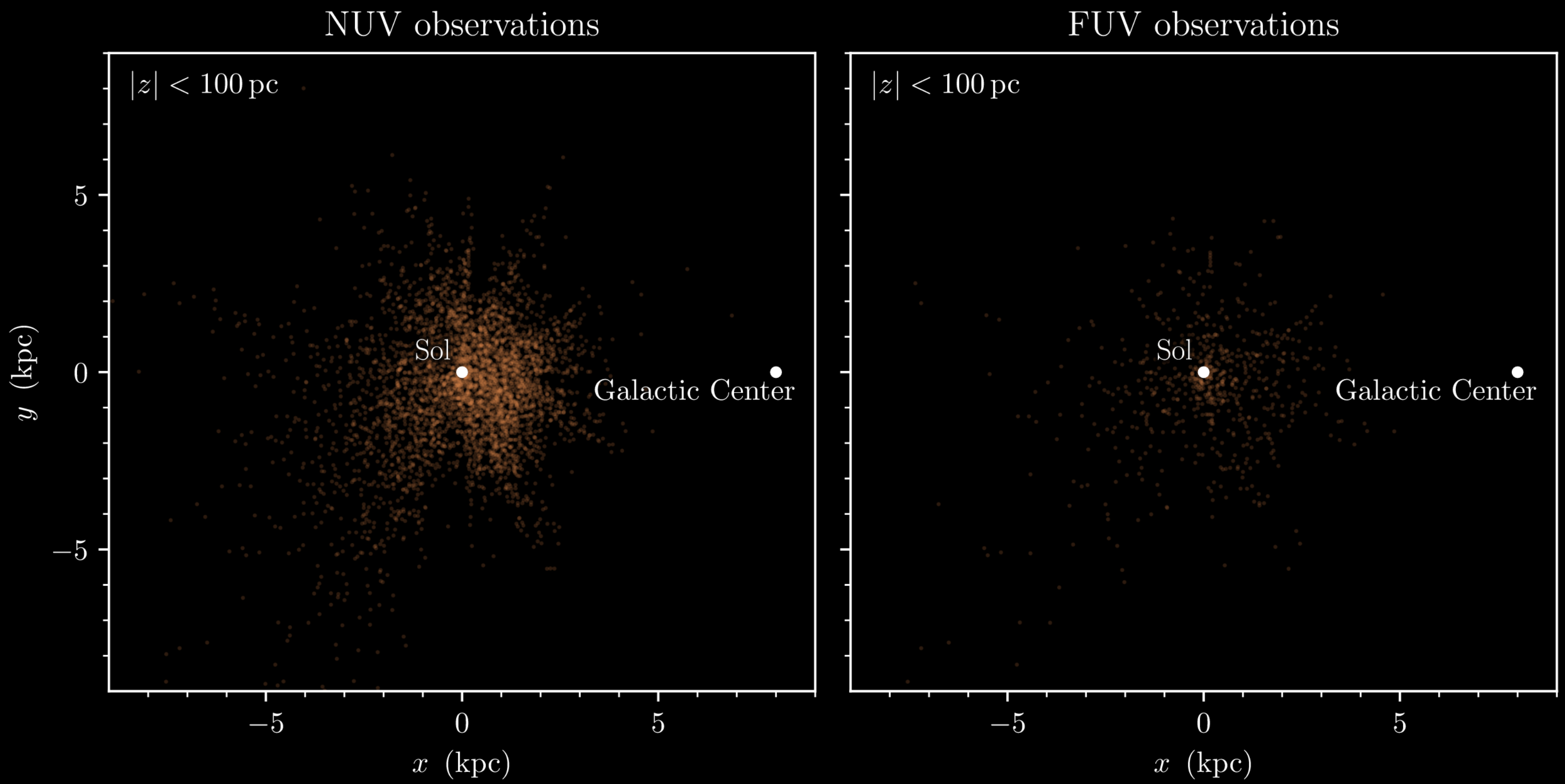


~300 million stars observed in NUV.

~25 million stars observed in FUV.

(Kulkarni *et al.* 2022)

UVEX all-sky survey



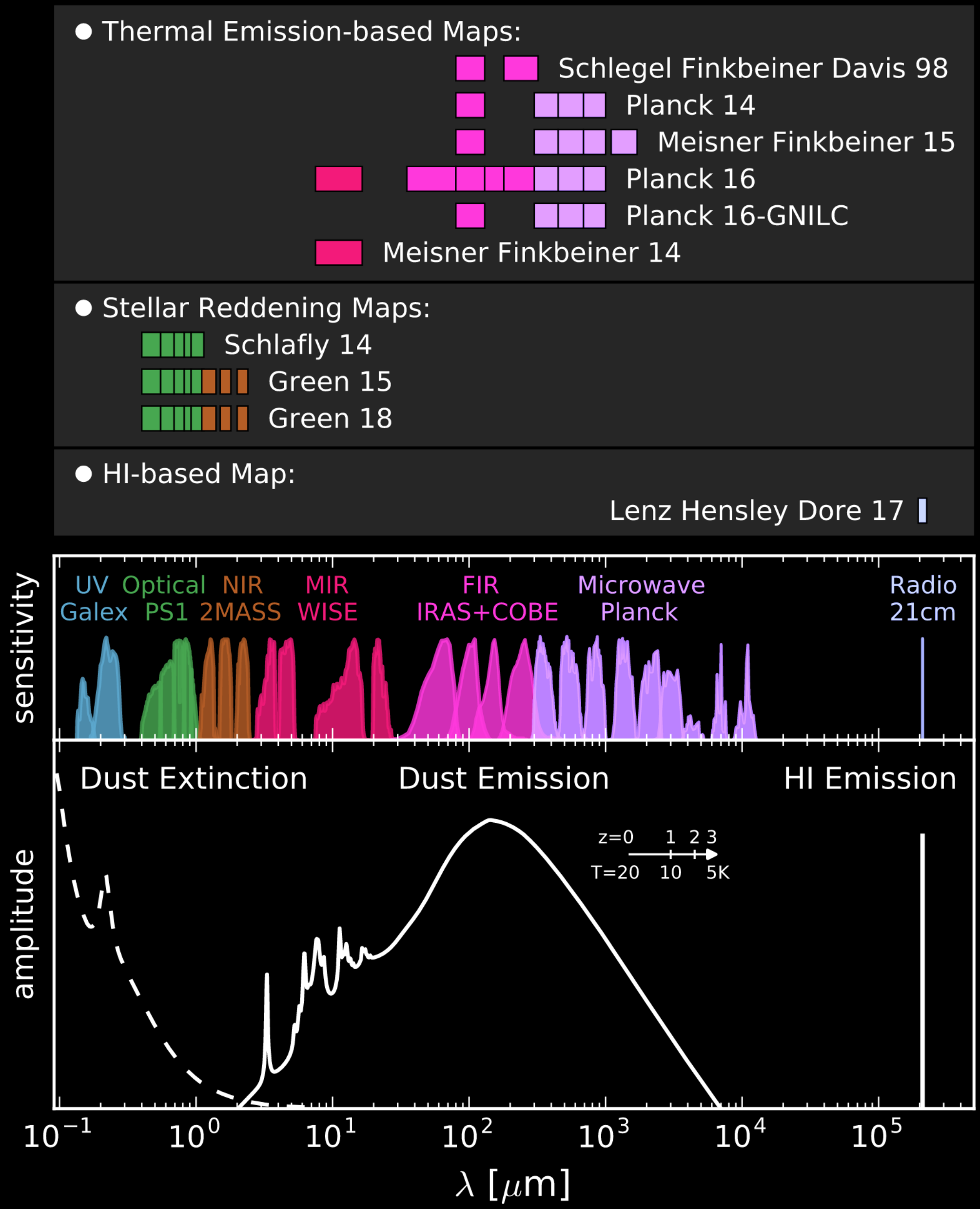
(Kulkarni *et al.* 2022)

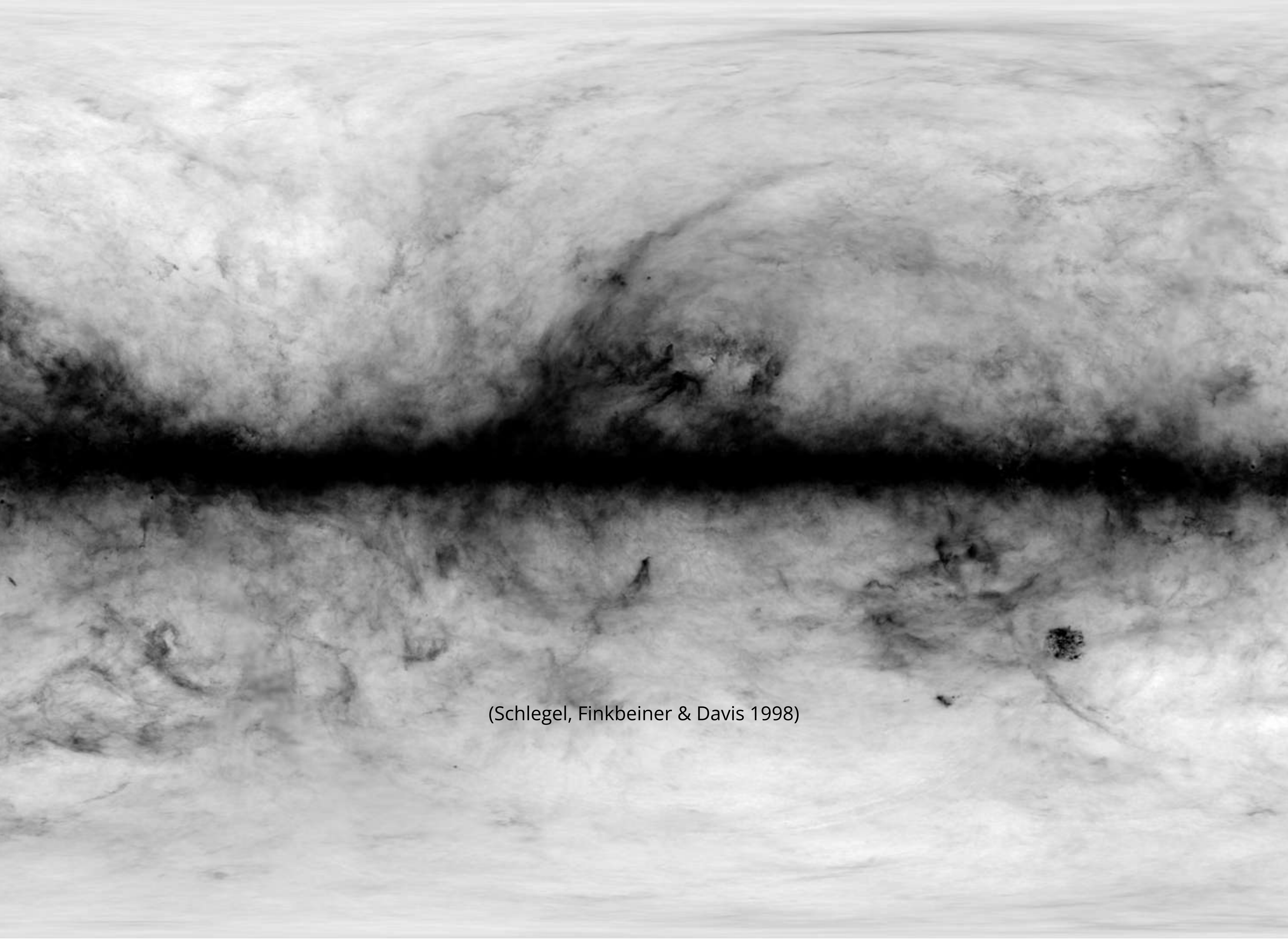
Mapping dust extinction

Dust mapping methods

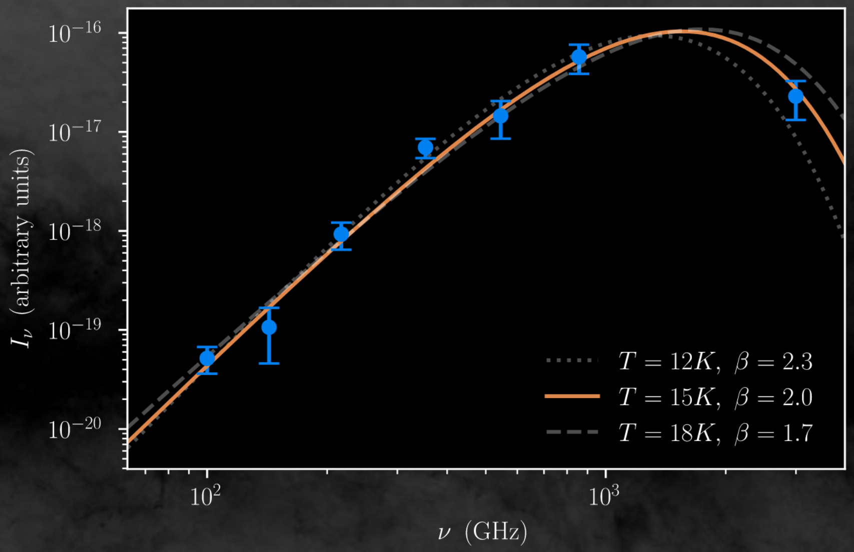
(Chiang & Ménard 2018)

1. Thermal emission (FIR)
2. Stellar extinction (Optical/NIR)
3. HI emission (21 cm)





(Schlegel, Finkbeiner & Davis 1998)



FIR emission

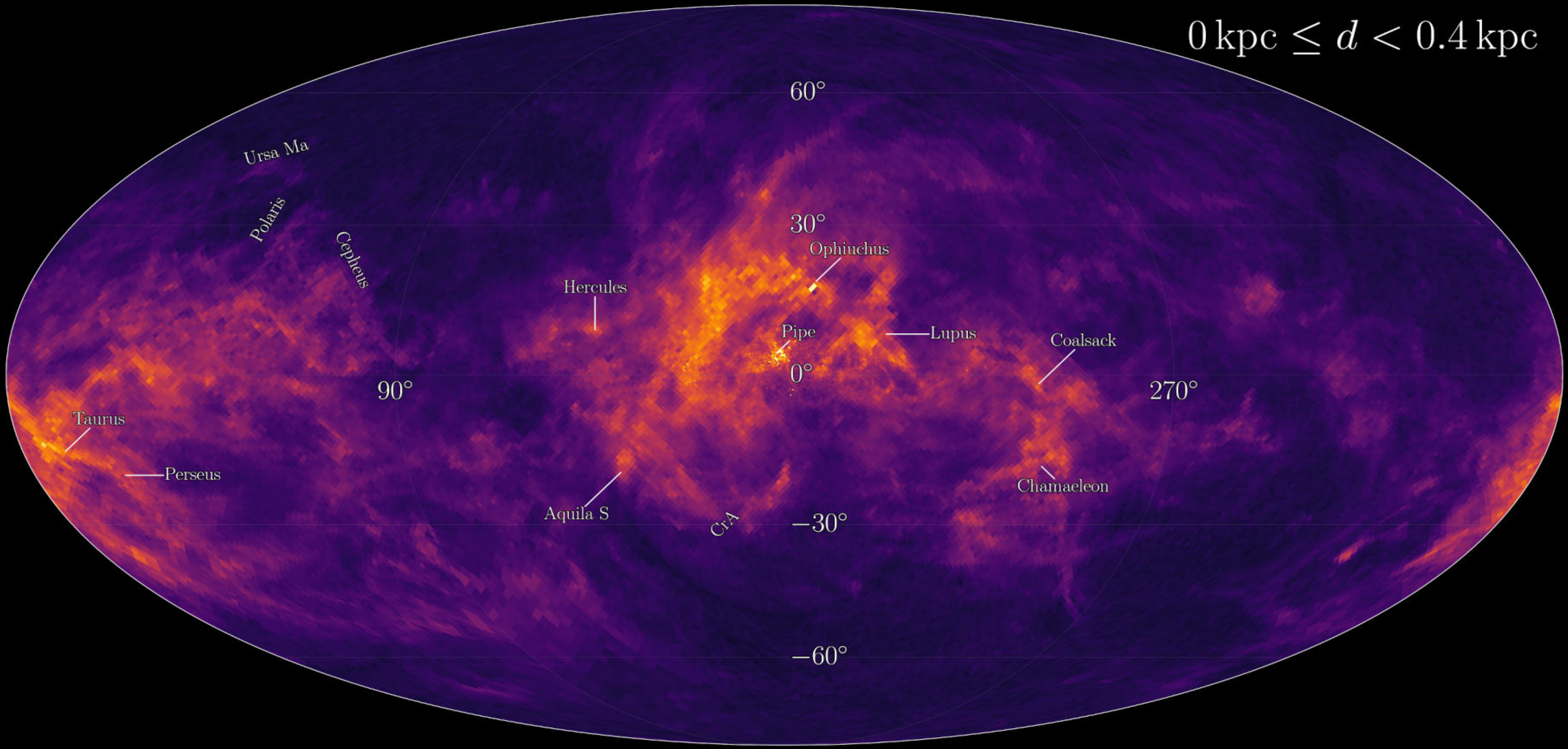
Model emission as modified blackbody:

$$I_\nu(\nu, T, \beta) = \overbrace{\sigma}^{\text{columndensity}} \underbrace{\kappa(\nu, \beta)}_{\text{low}-\nu\text{ cutoff}} \overbrace{B_\nu(\nu, T)}^{\text{blackbody}} .$$

$(\kappa \propto \nu^\beta)$

(Schlegel, Finkbeiner & Davis 1998)

3D dust from 220 million stars with Gaia XP spectra



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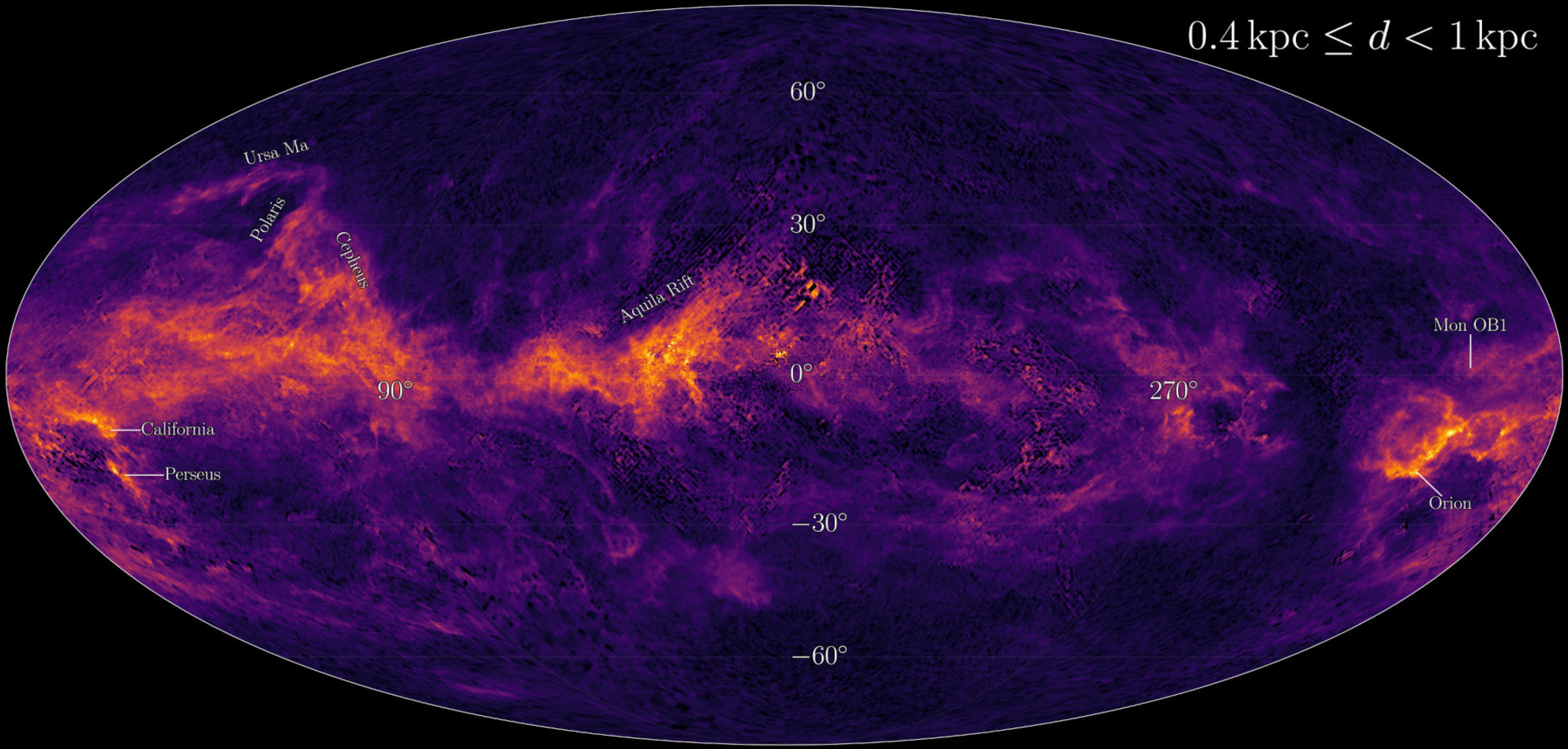

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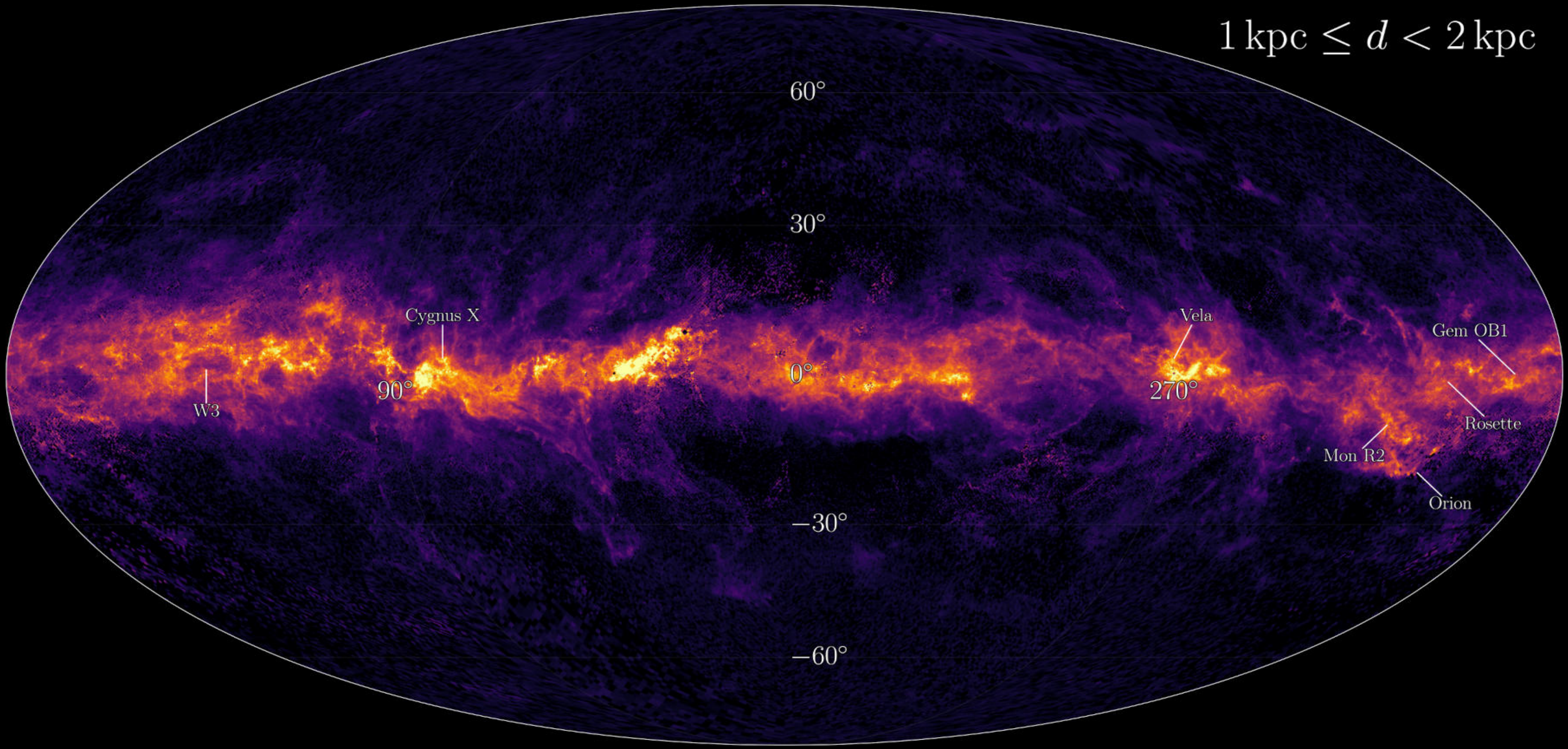

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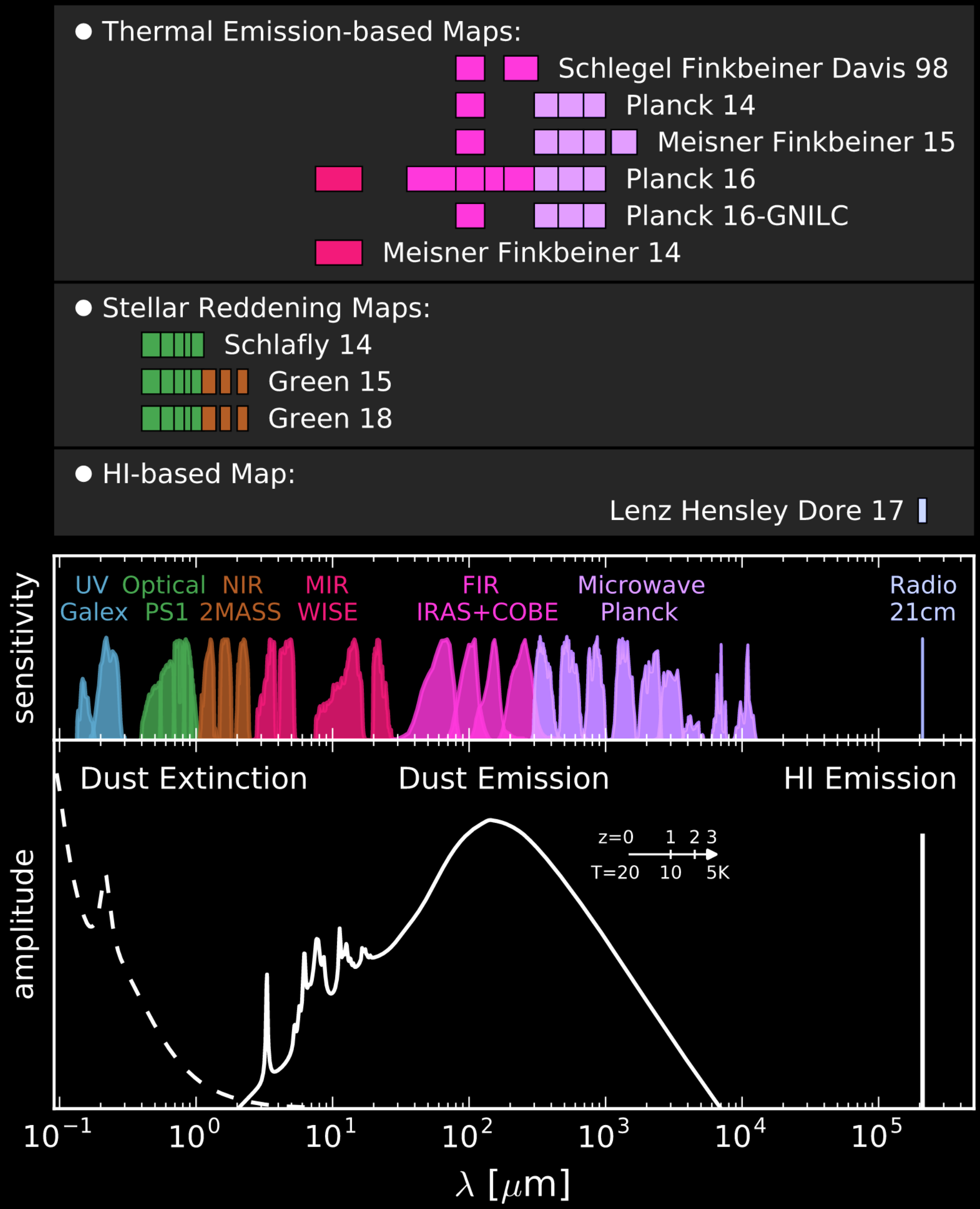

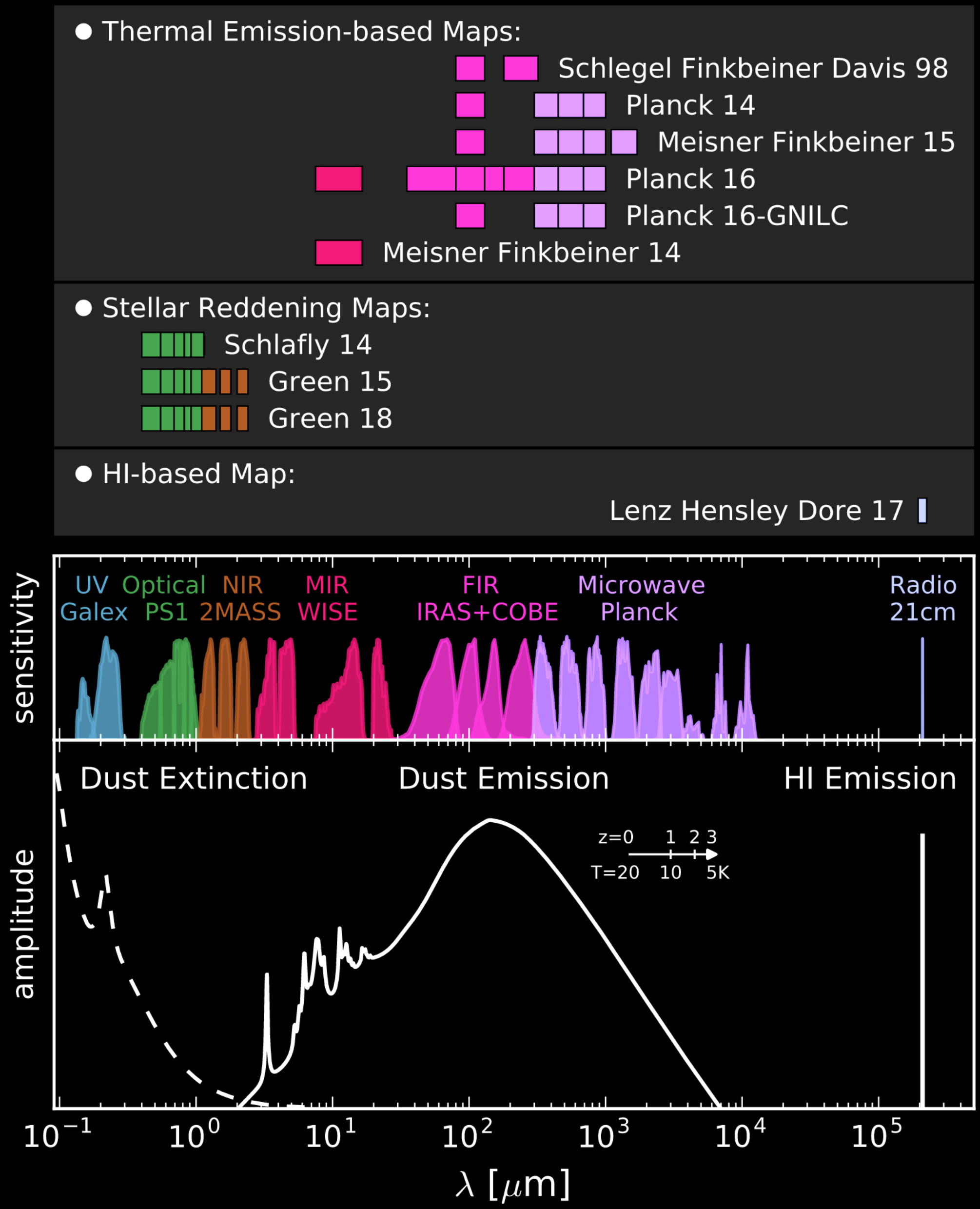

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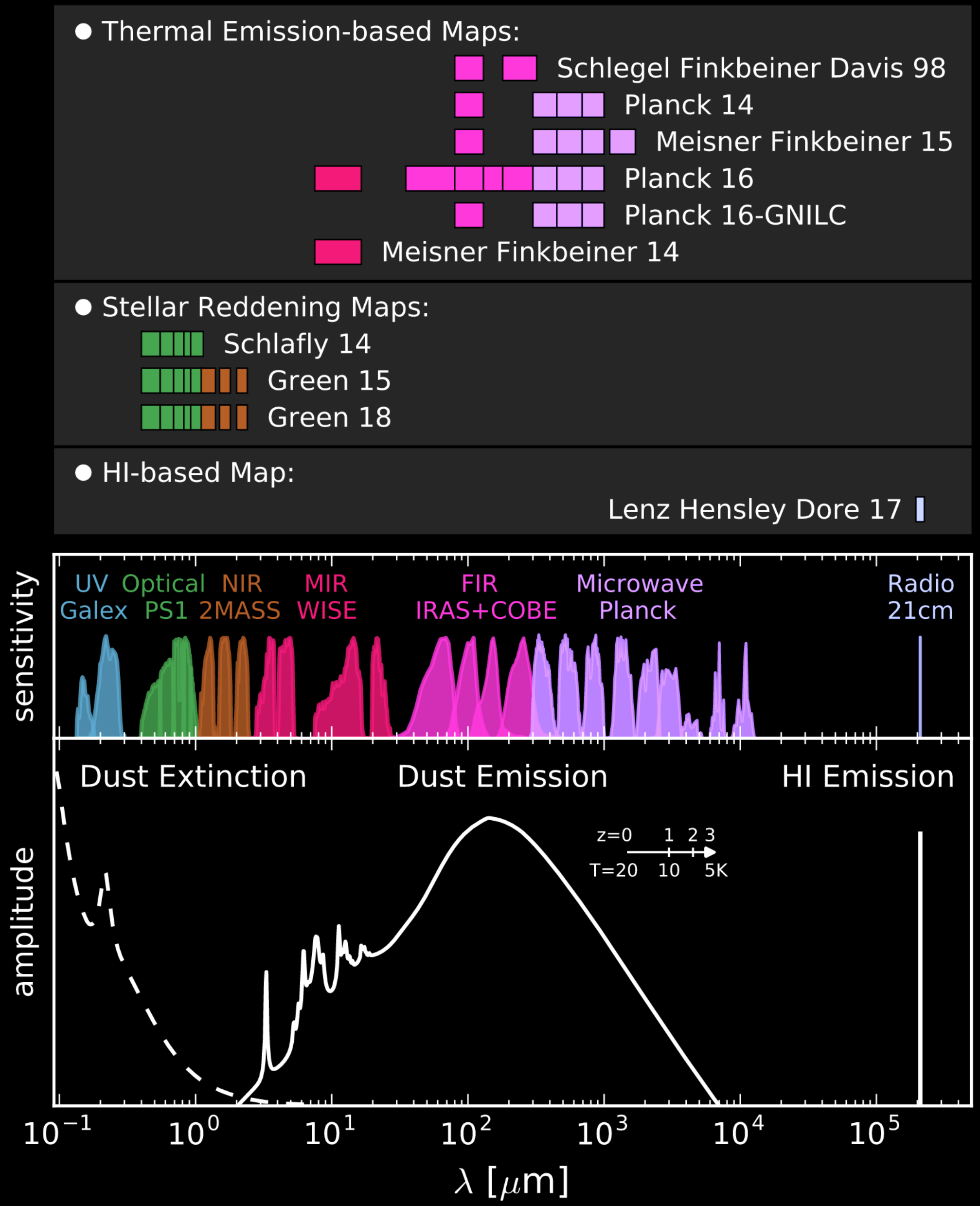
Advantages of stellar extinction method:

- Directly measures what we want to know: extinction.
- 3D extinction: stars trace dust at different distances.



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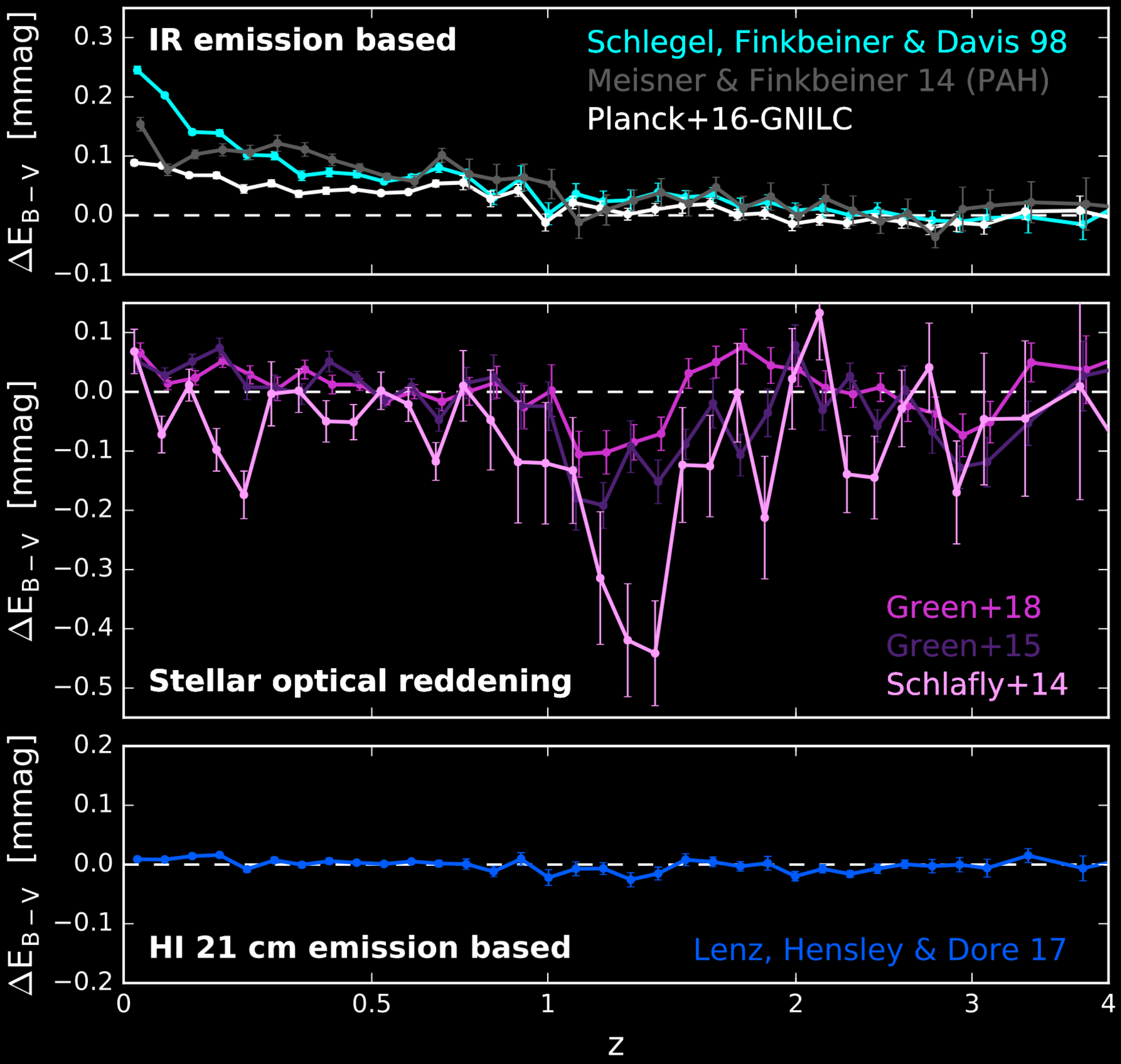
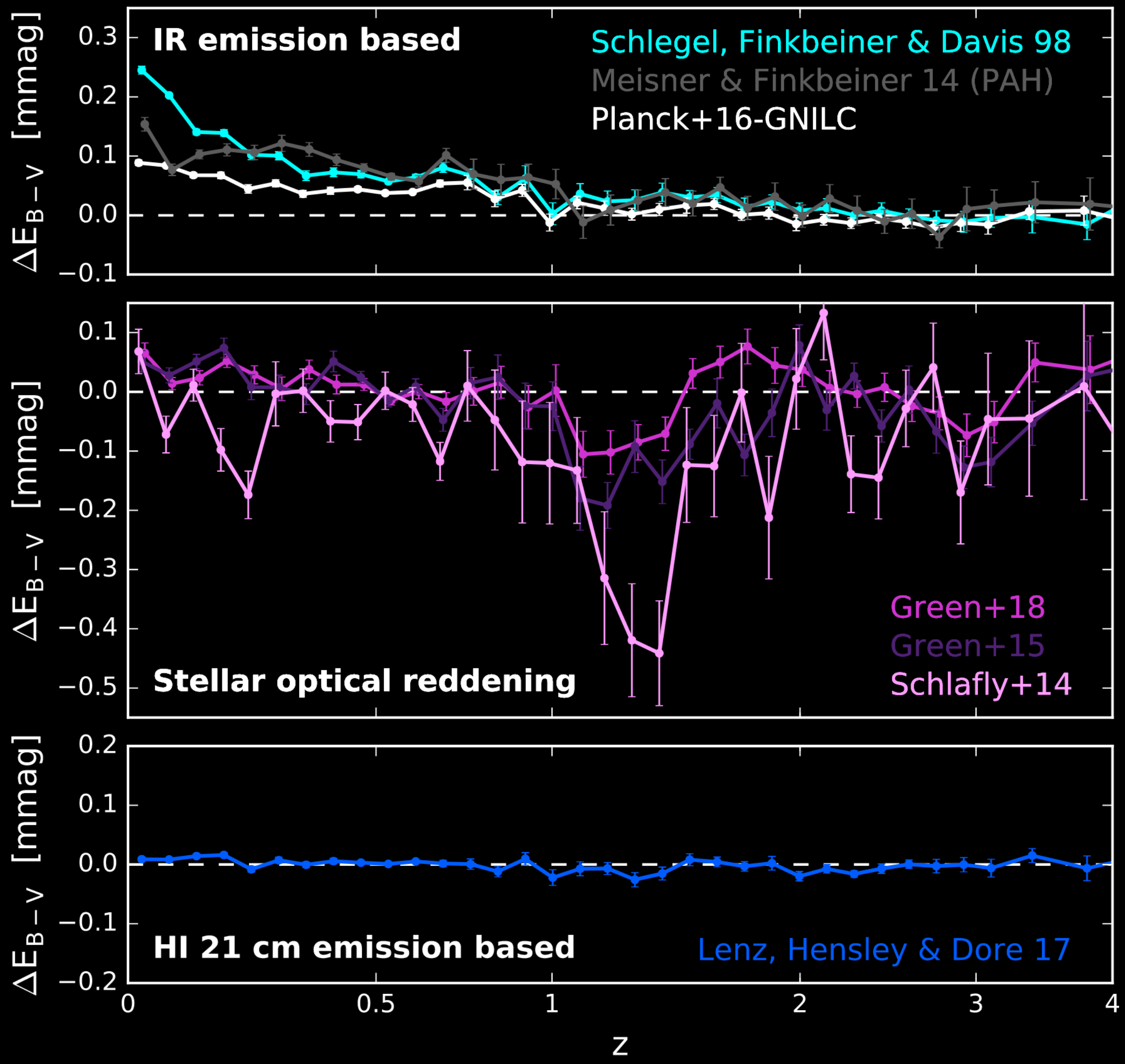
Note: lack of UV photometry in stellar-based dust maps.



Contamination from large-scale structure

(Chiang & Ménard 2018)



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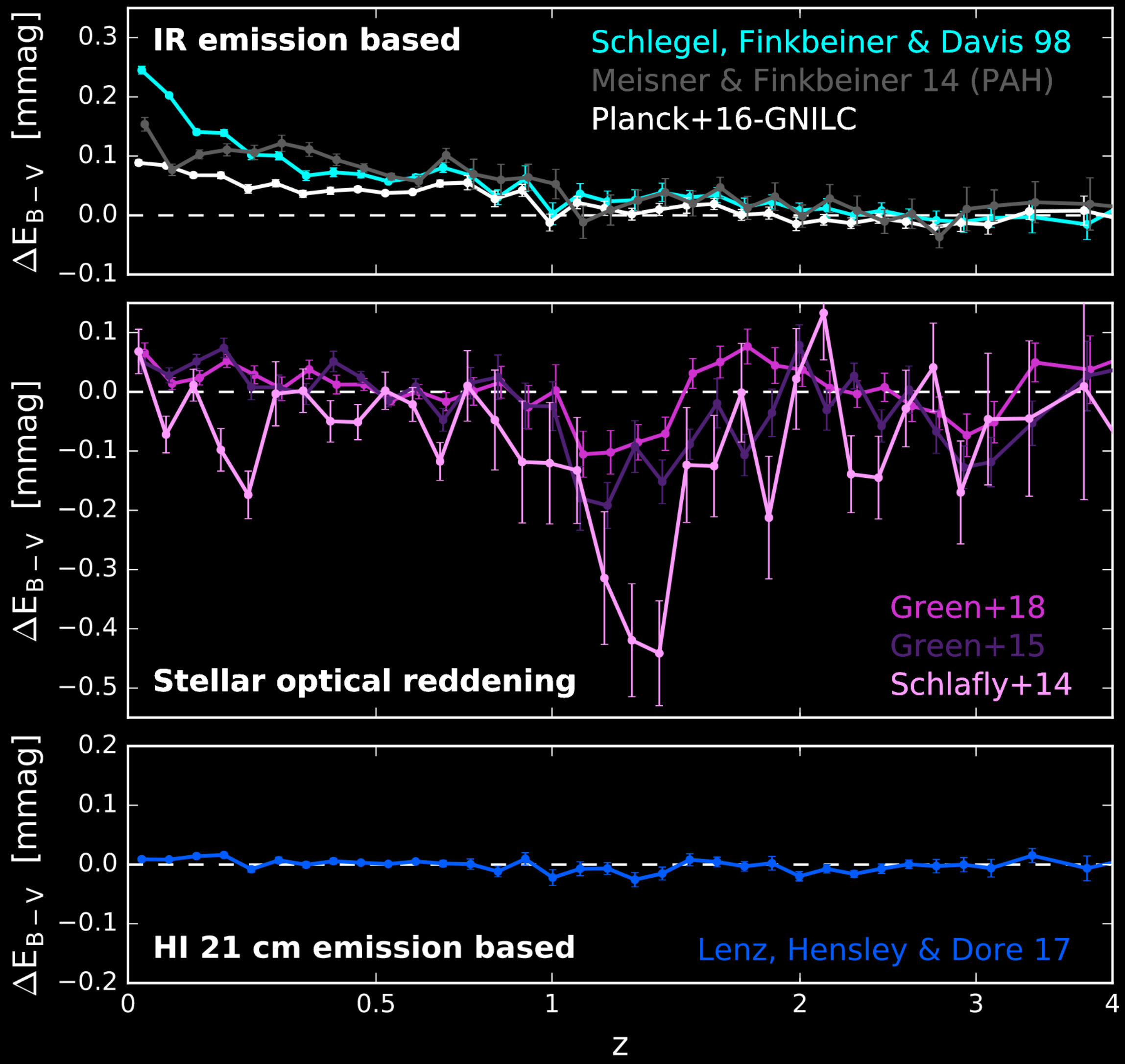
FIR maps contaminated by emission from low-z galaxies.



Contamination from large-scale structure

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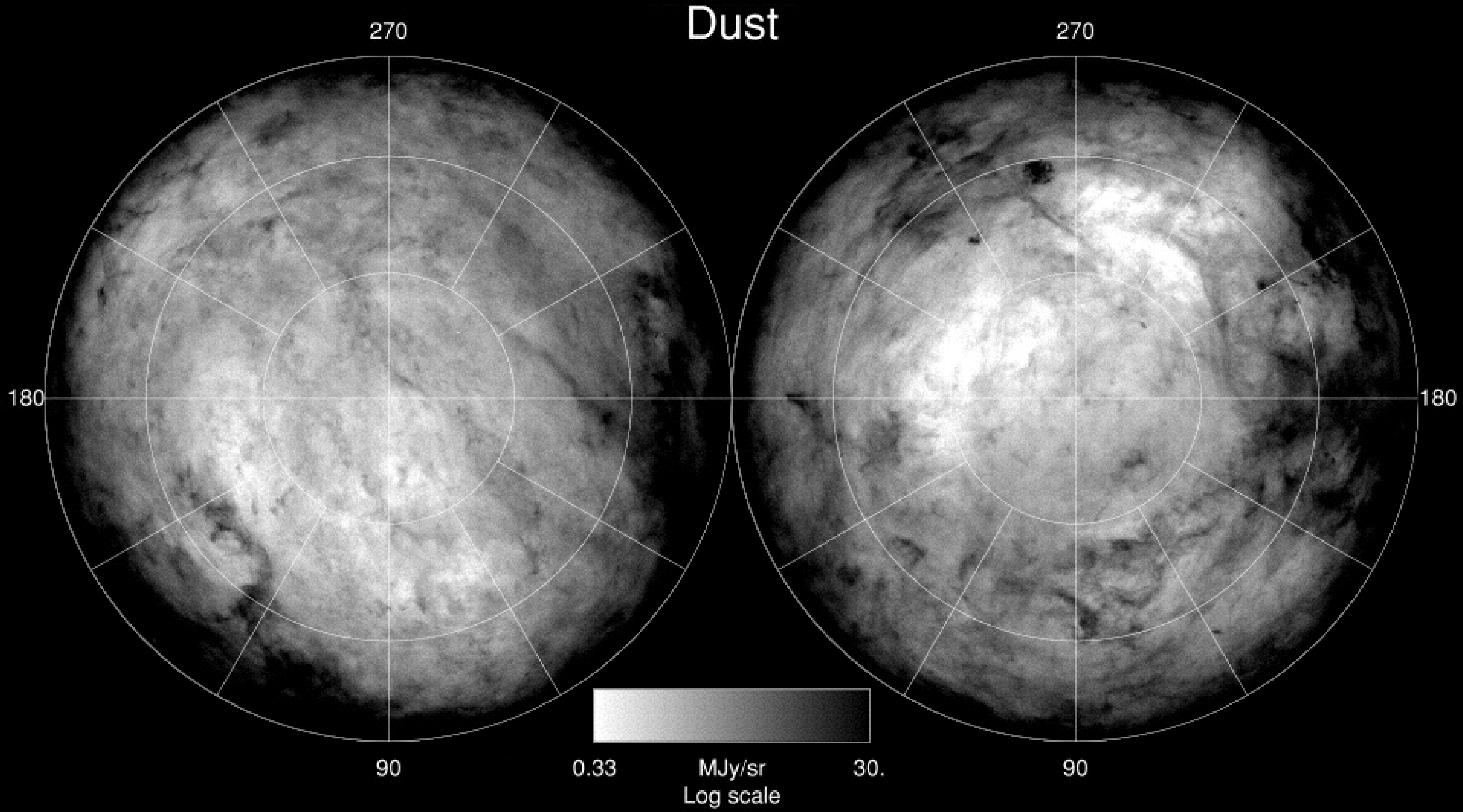
FIR maps contaminated by emission from low-z galaxies.

Star-based maps contaminated by z ~ 2 QSOs, though careful cleaning can help (*e.g.*, Mudur *et al.* 2022).

Extragalactic astronomy: low-extinction regions



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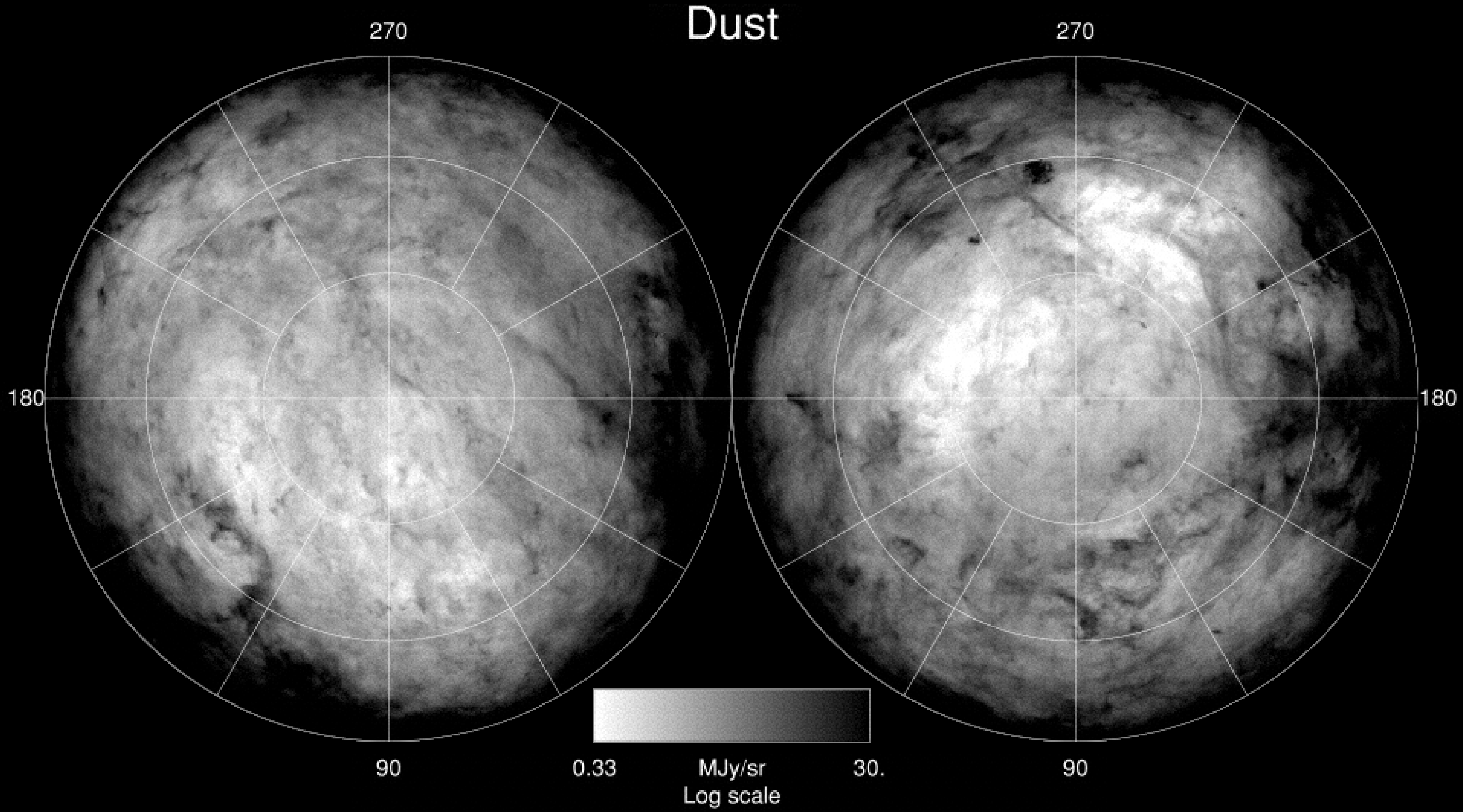

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UV more sensitive to dust than optical/NIR.

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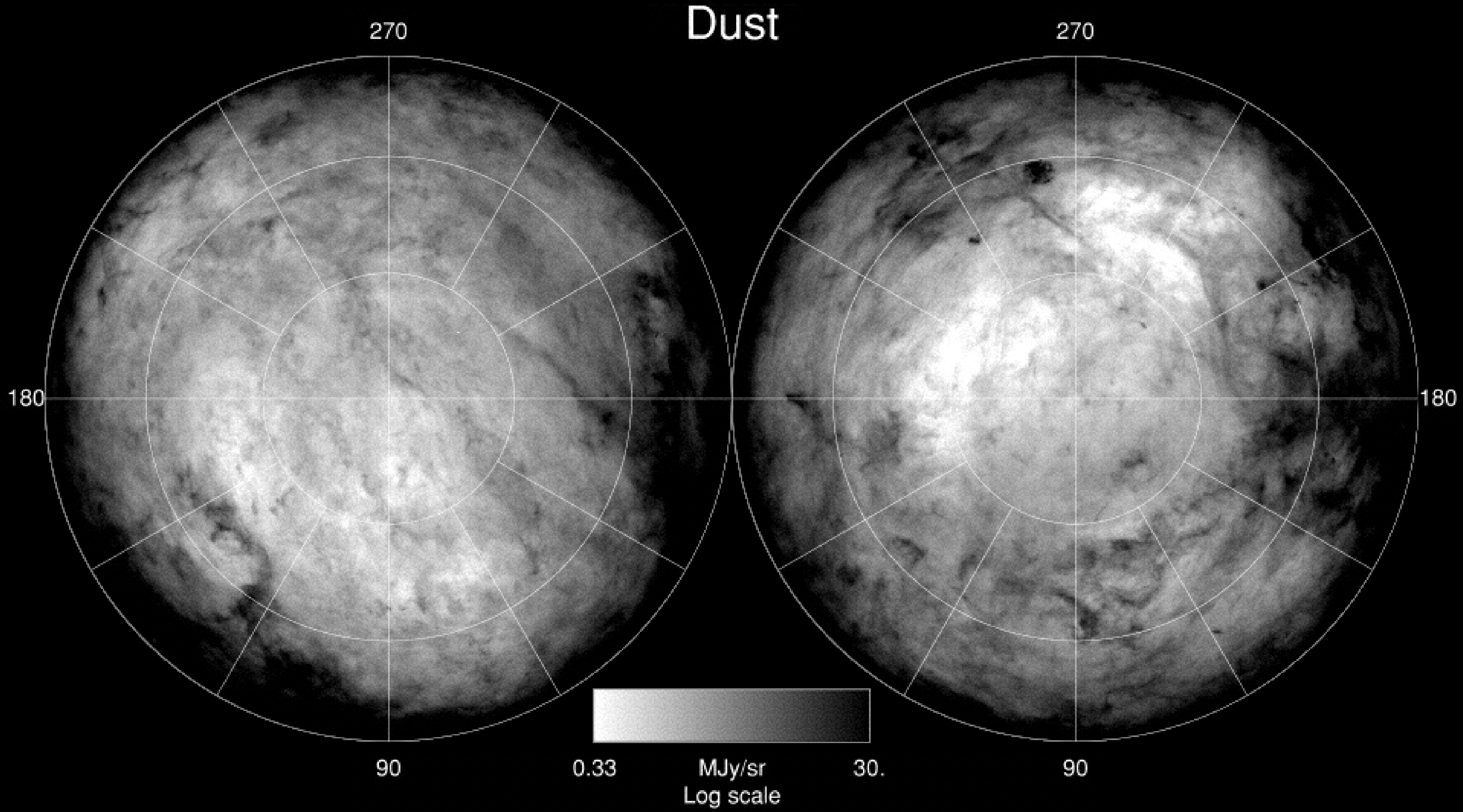


(Schlegel, Finkbeiner & Davis 1998)

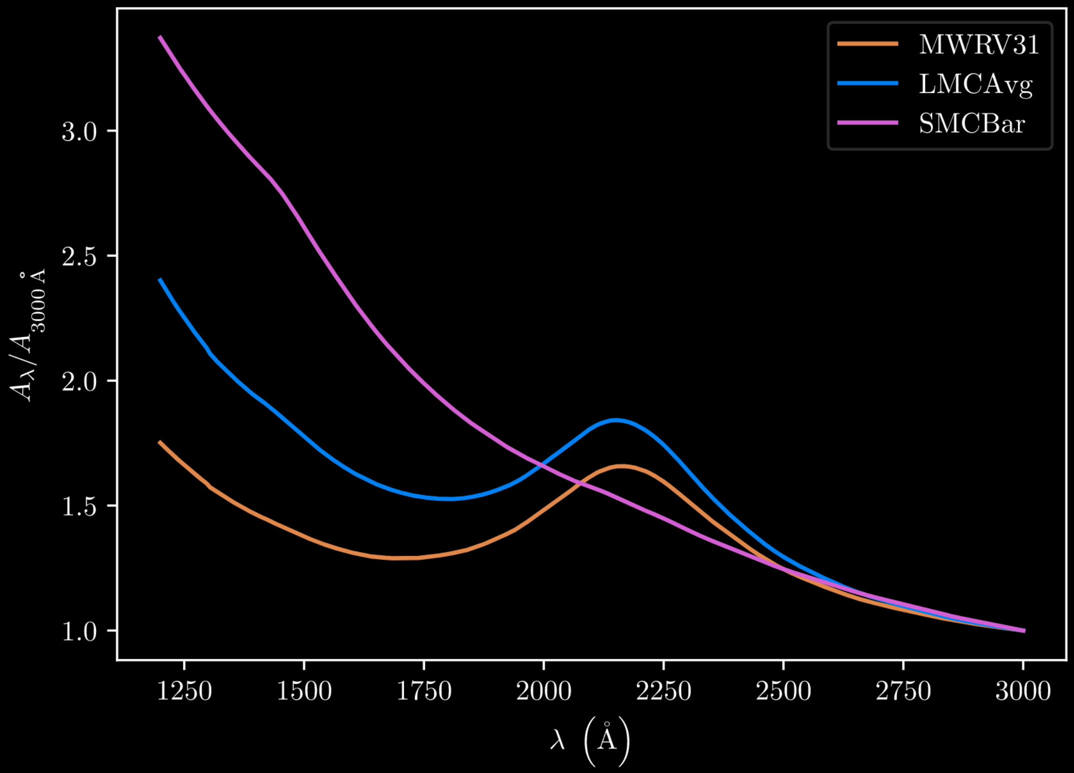
UV more sensitive to dust than optical/NIR.

⇒ UVEX will help most in low-extinction regions.

Variation in dust properties

Dust extinction curves (with photometry)

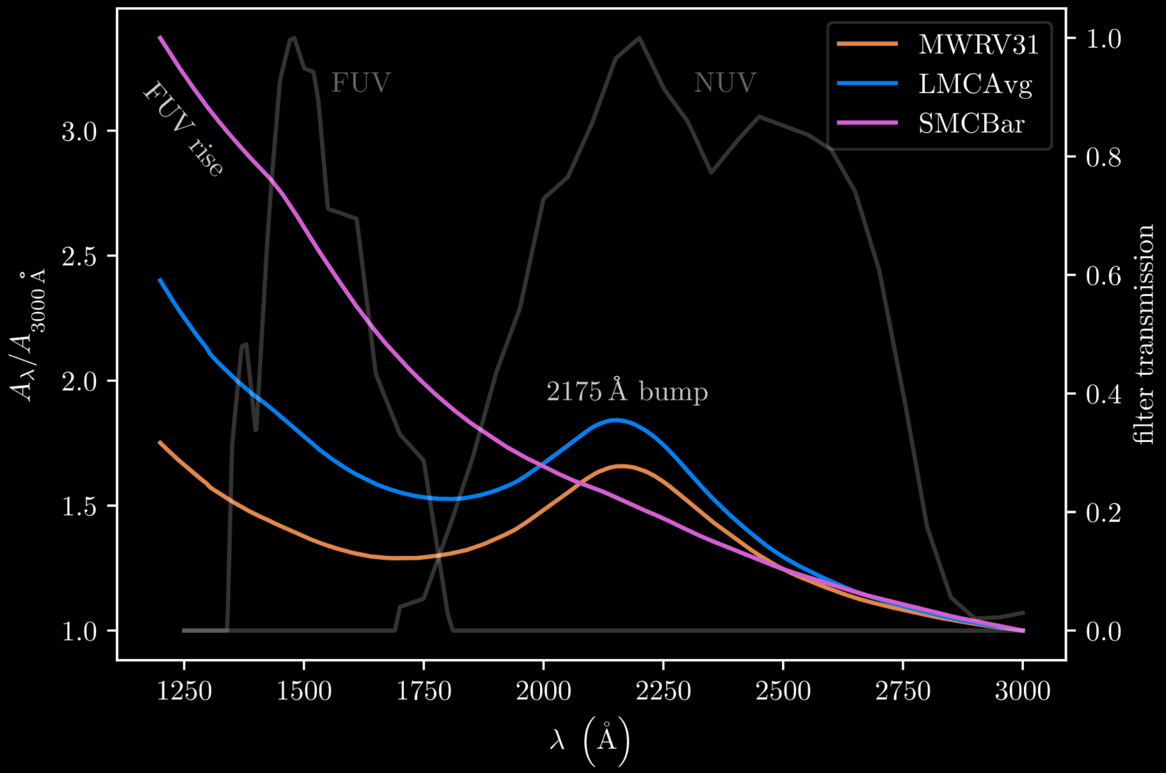
Extinction vs. wavelength varies with environment.



Dust extinction curves (with photometry)

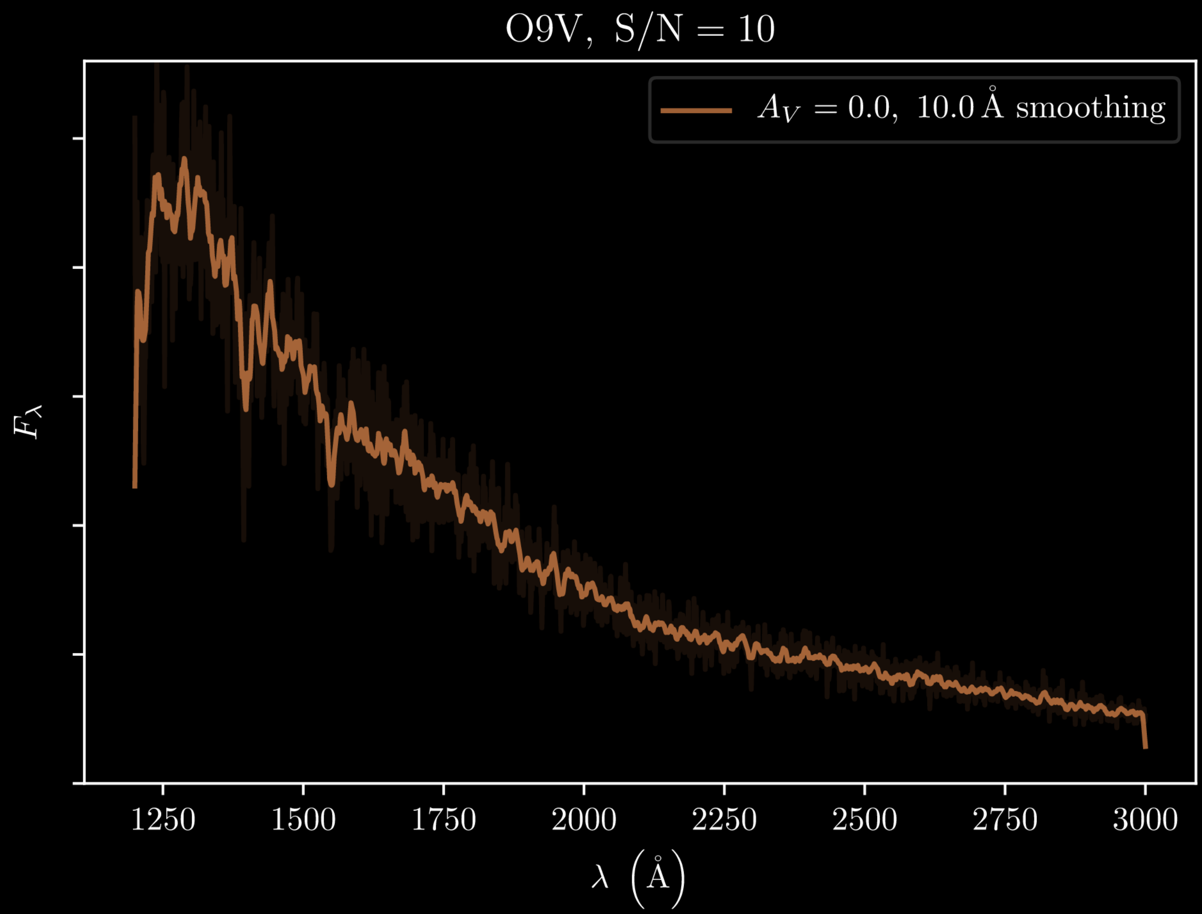
Extinction vs. wavelength varies with environment.

NUV and FUV bands sensitive to different dust features.



Dust extinction curves (with spectroscopy)

O9V spectrum



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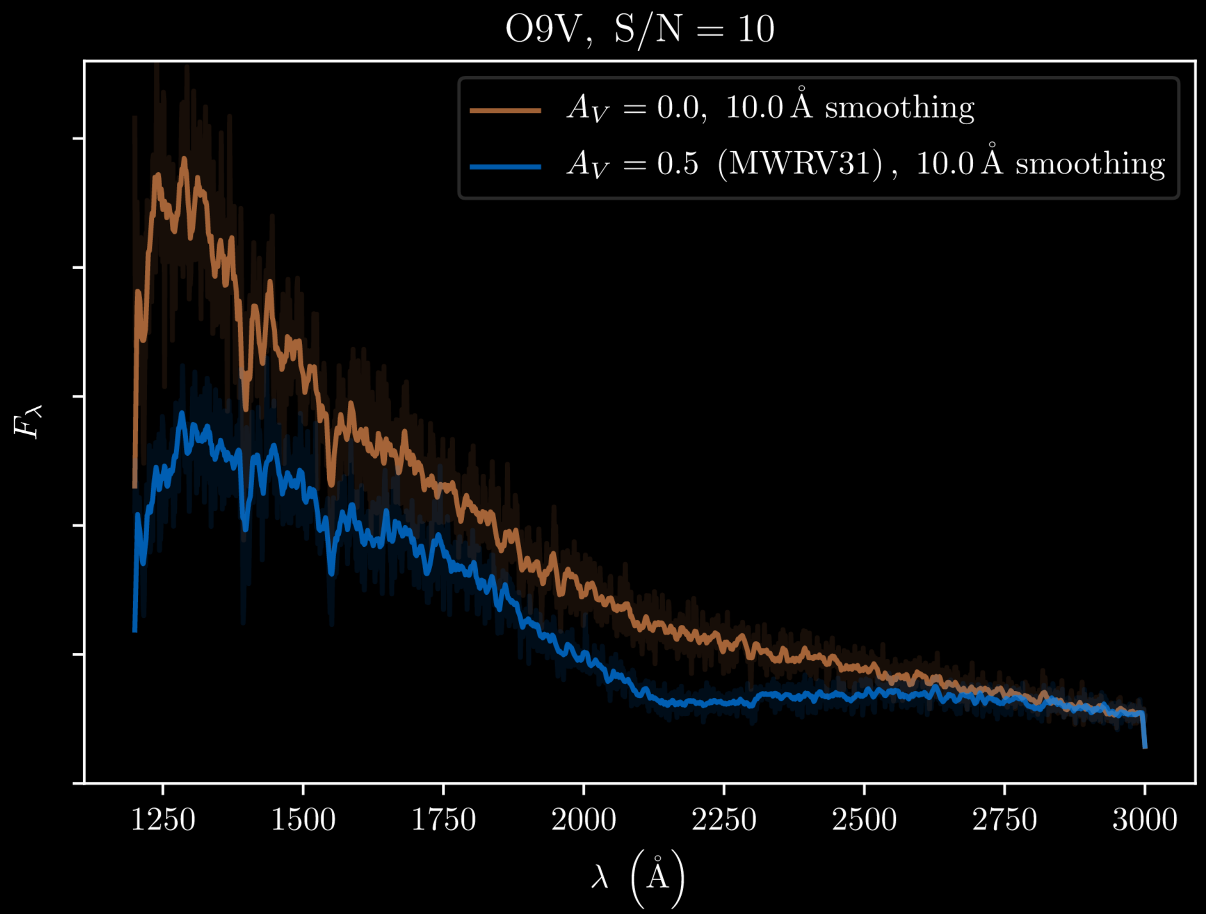

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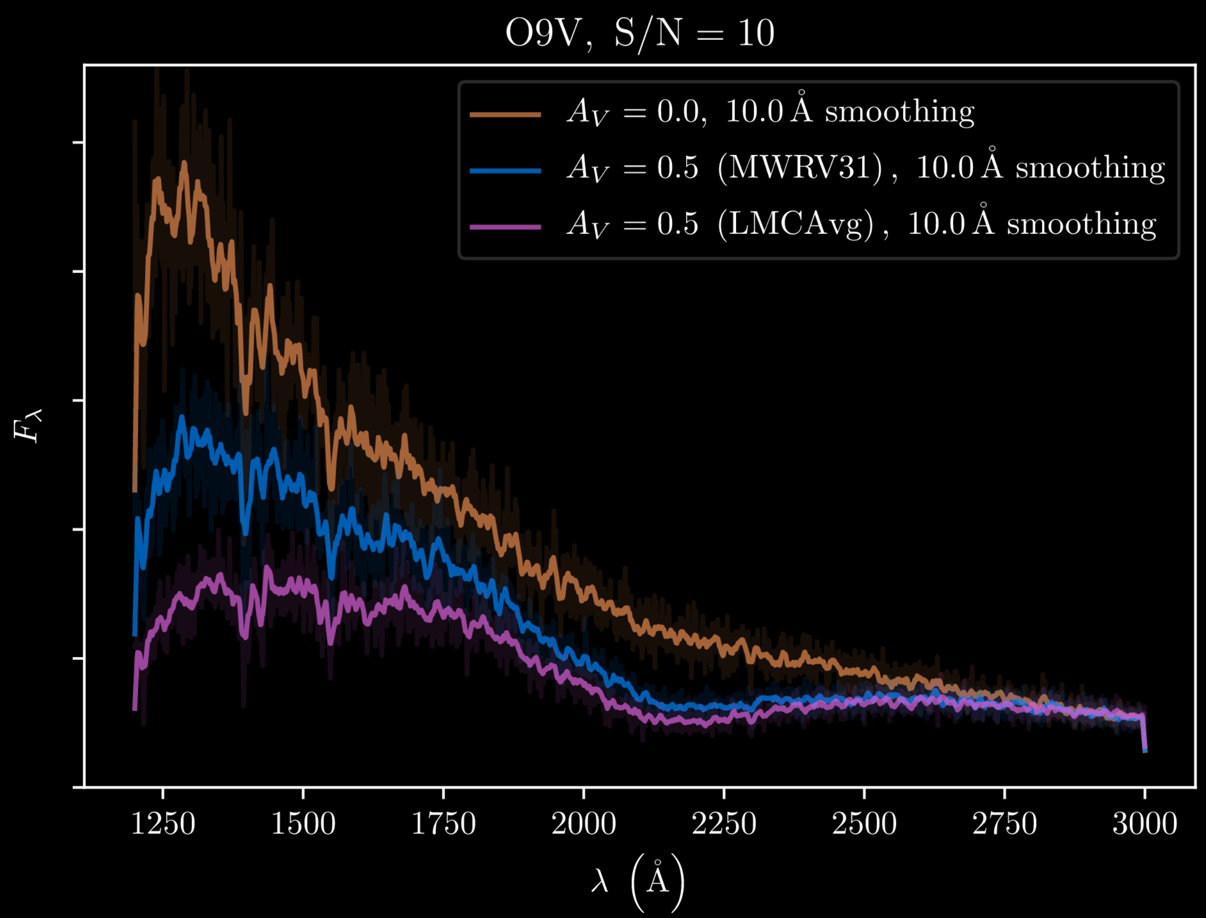

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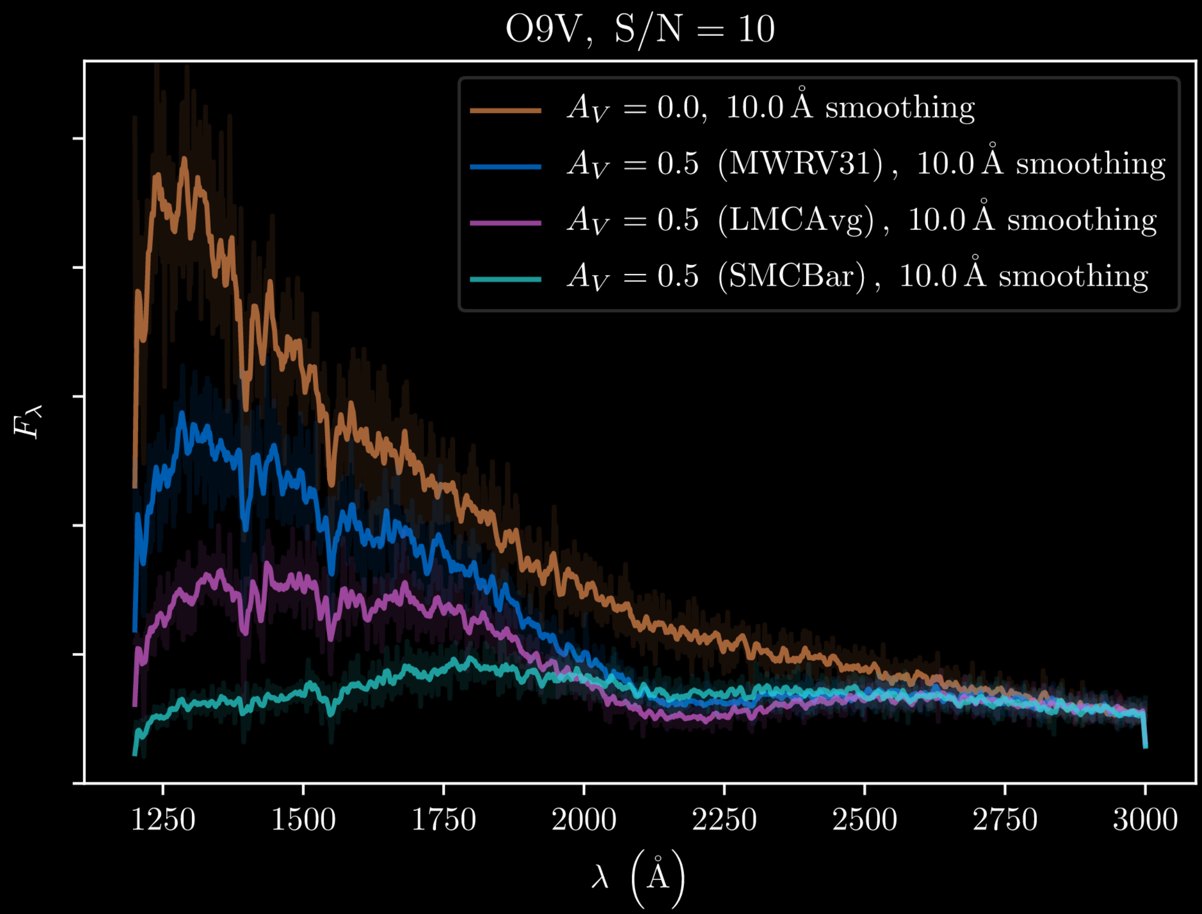

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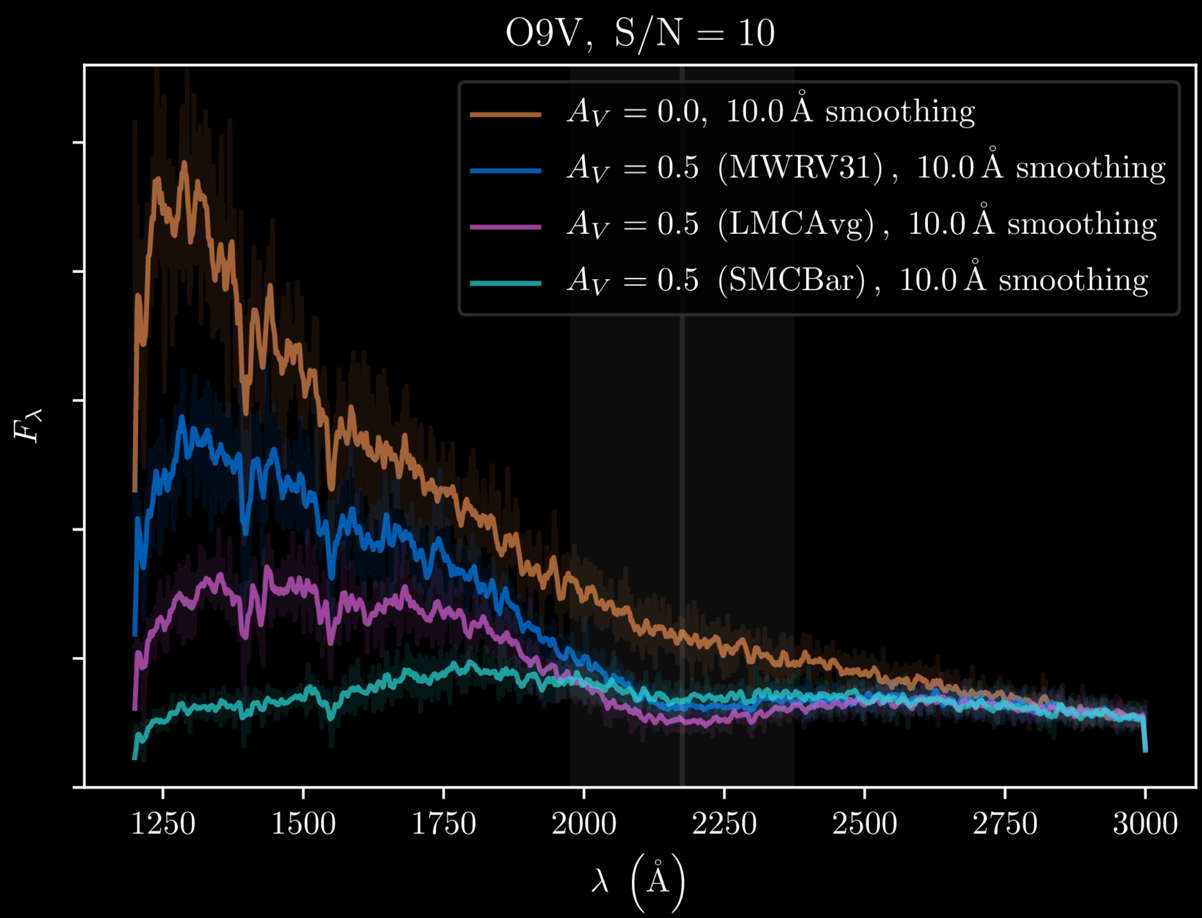

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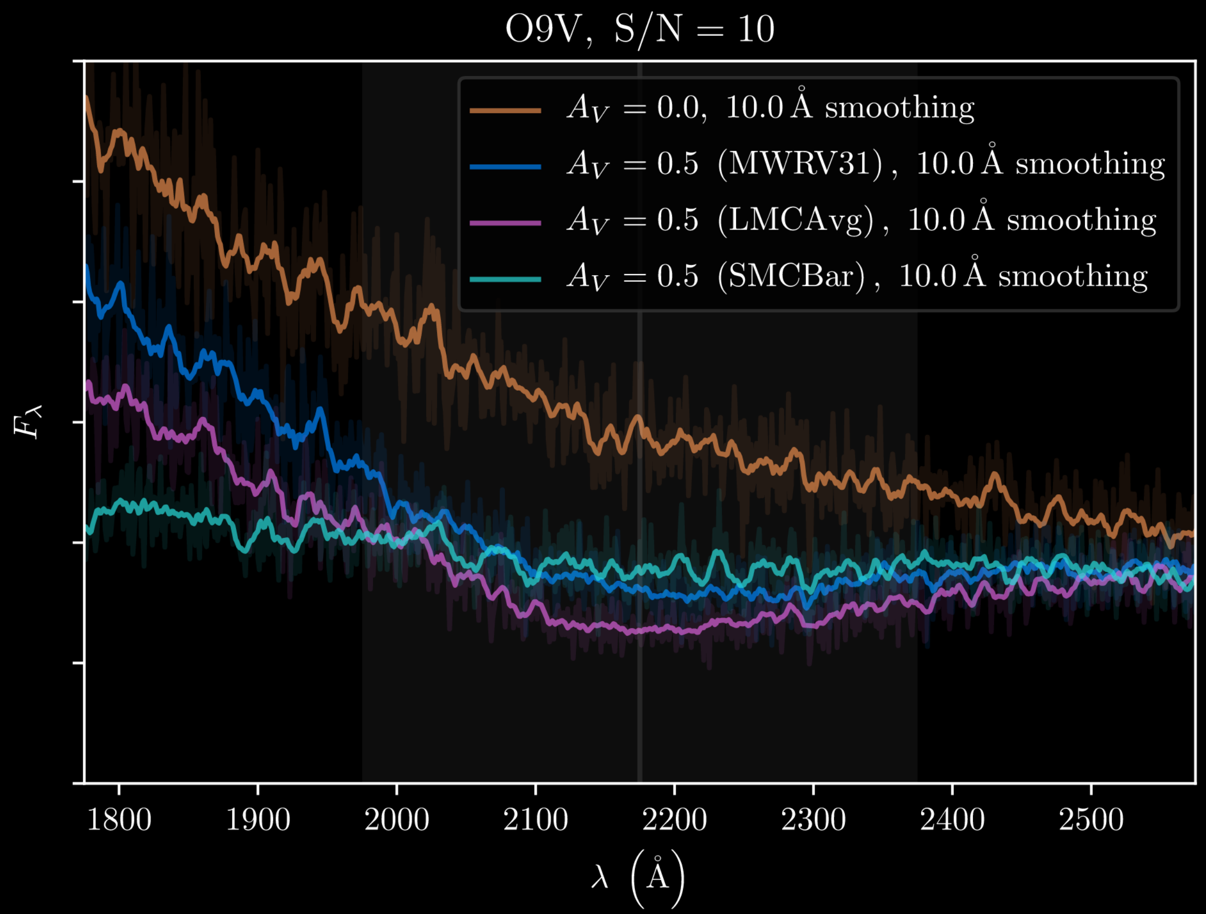

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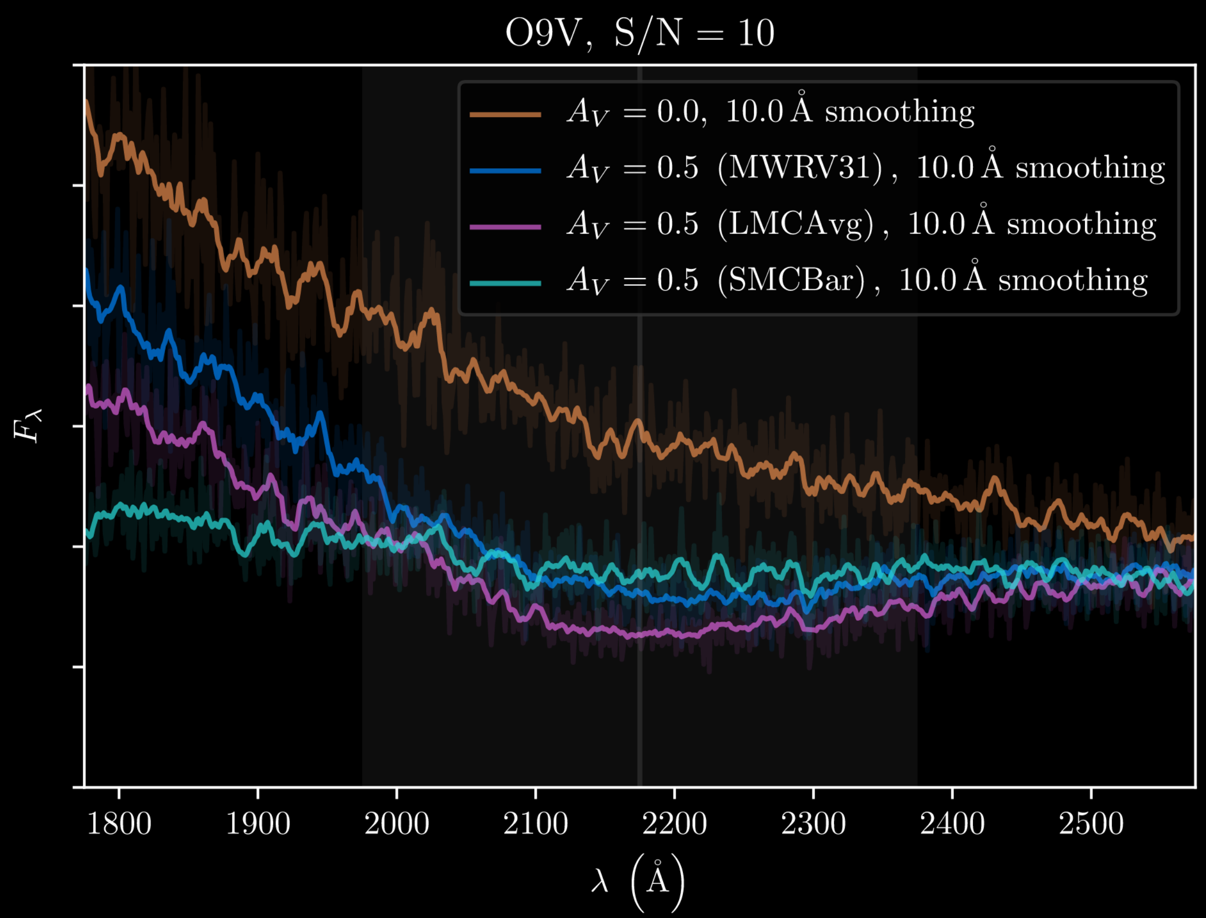
UVEX will add ~1000 UV spectra of O/B stars in low-metallicity environments (LMC/SMC).



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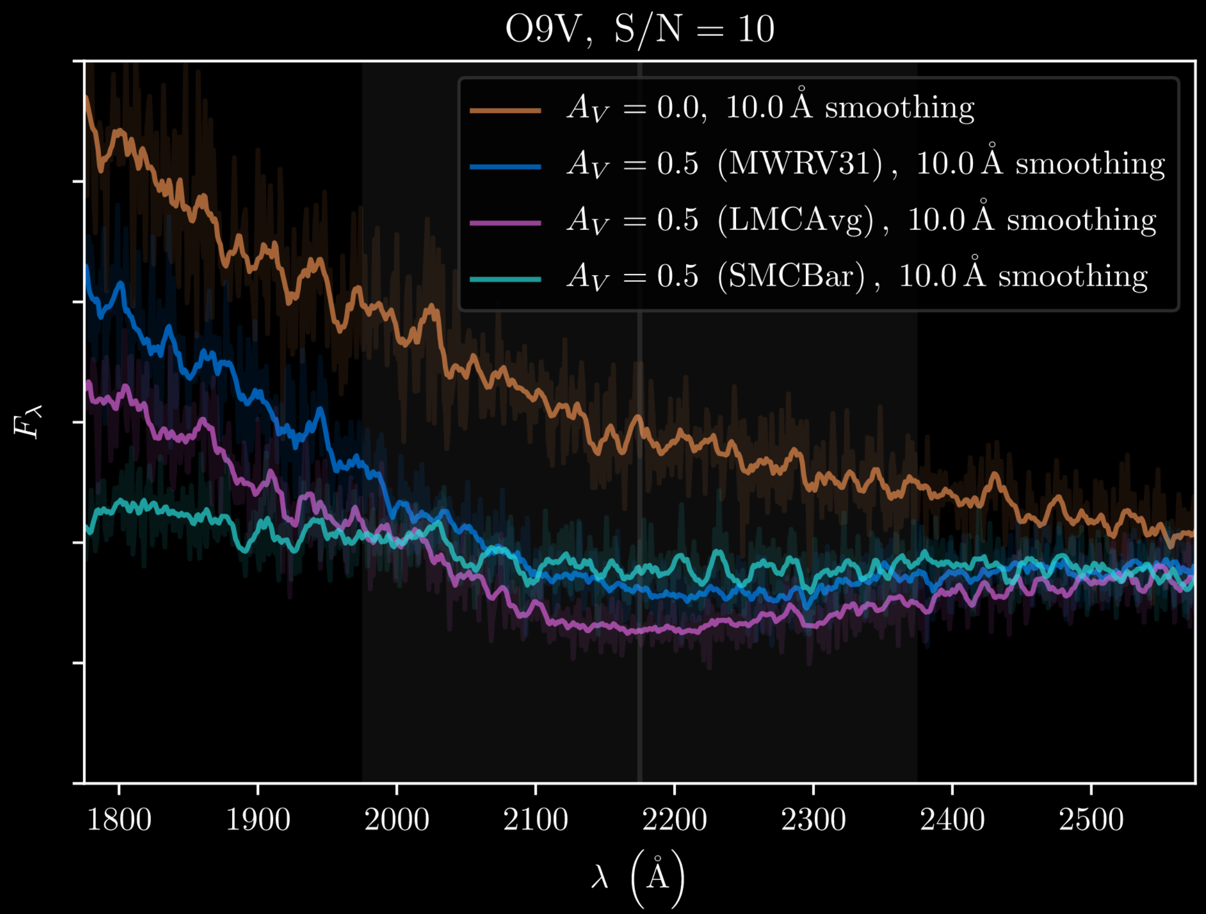
(compare with ~hundreds now)



Photometric metallicities

Metallicity as a key to understanding galaxy formation history

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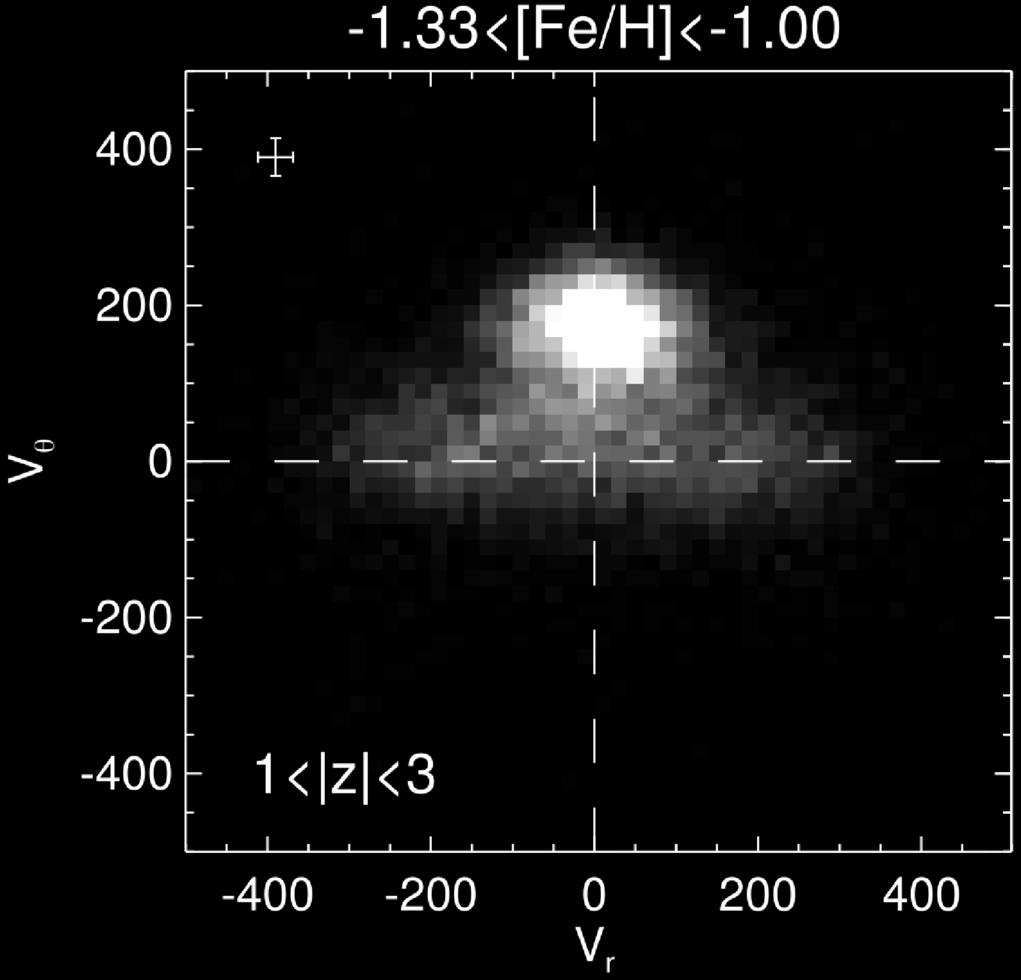
Gaia Enceladus (a.k.a. "The Sausage")

Highly radial population of stars — identified in kinematic & metallicity space.

(Belokurov *et al.* 2018)

Metallicity as a key to understanding galaxy formation history



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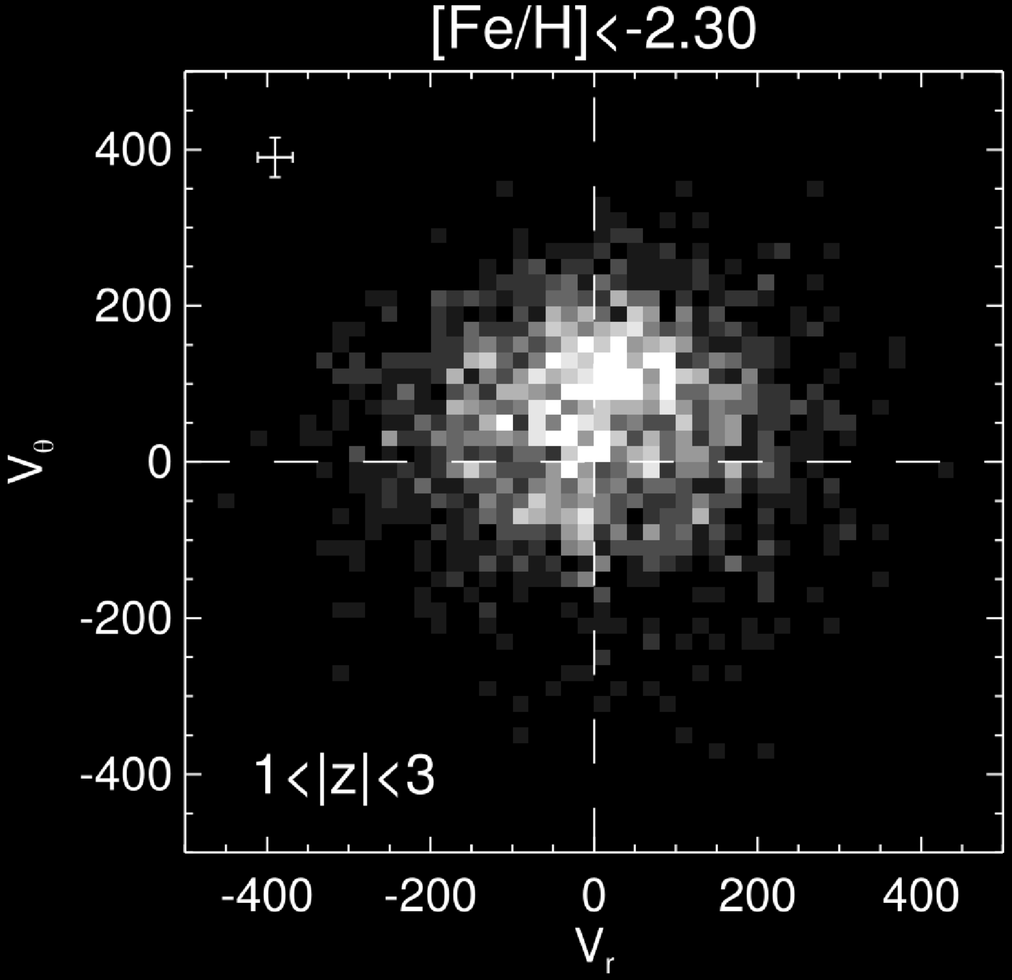

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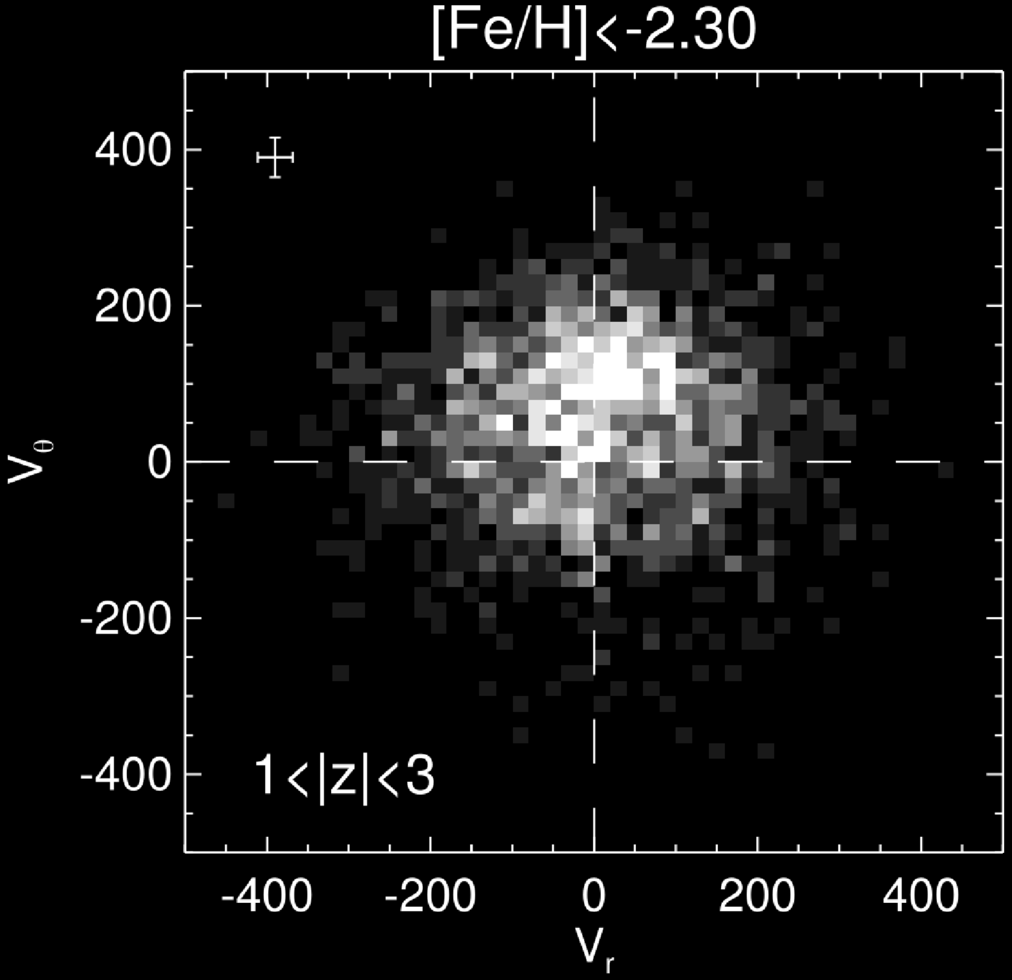

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Merger 8-11 Myr ago.

UV excess method

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At fixed optical color, UV color correlates with metallicity.

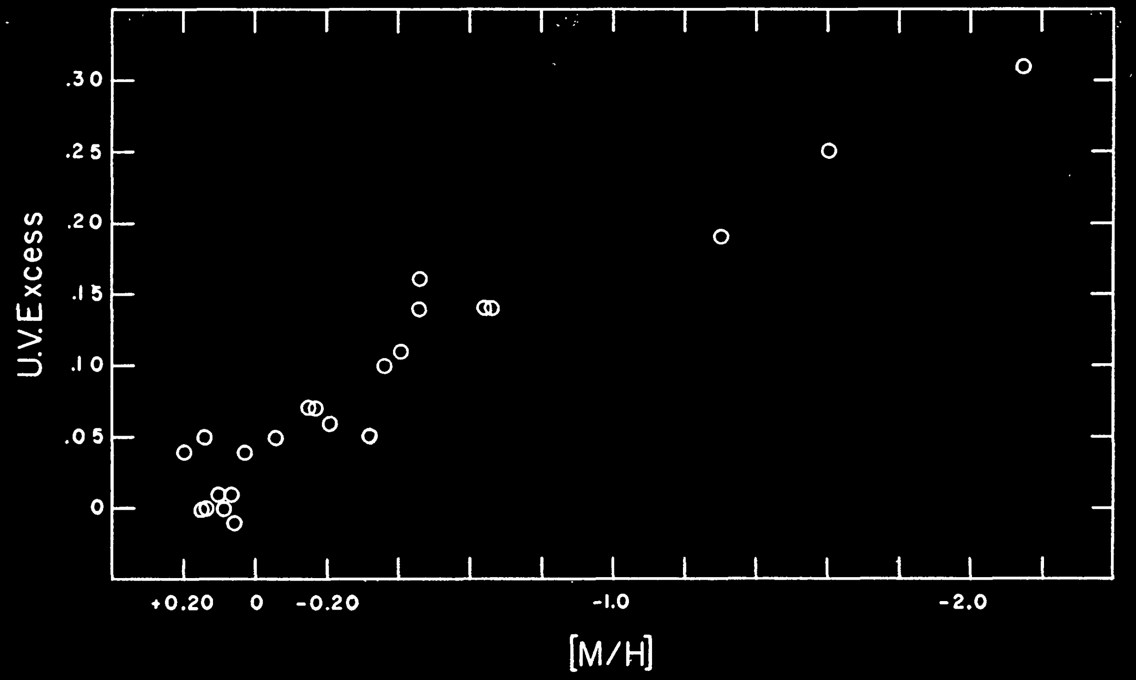


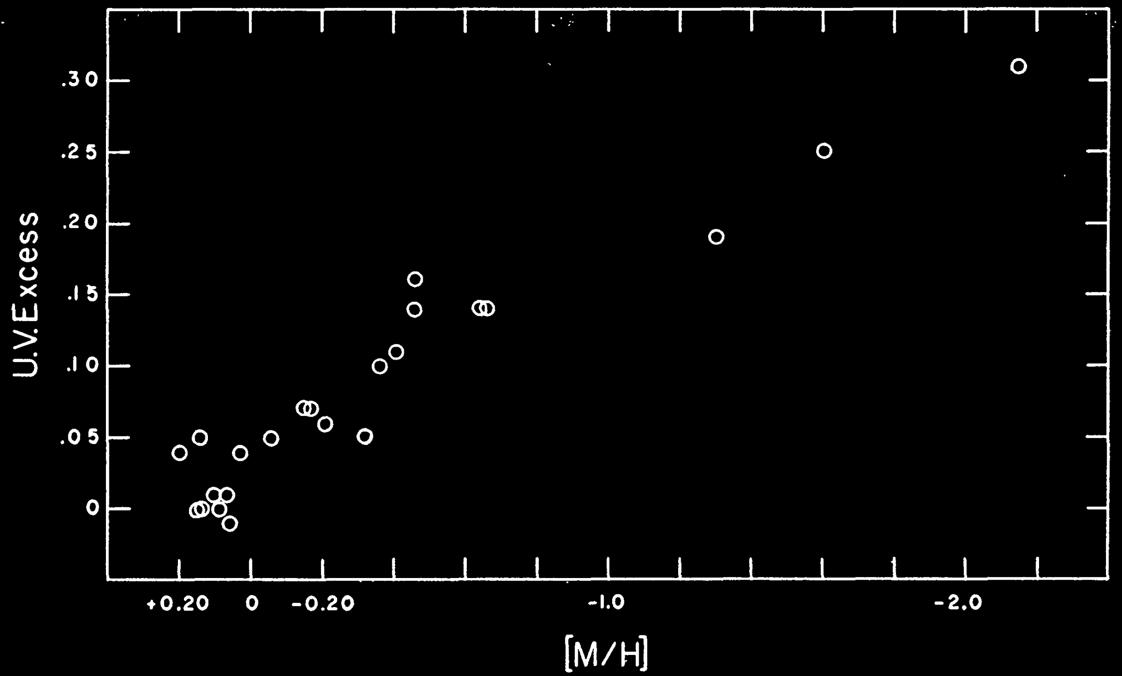
FIG. 1.—The metal deficiency plotted against ultraviolet excess for late F and early G dwarfs

(Wallerstein & Carlson 1960)

UV excess method

At fixed optical color, UV color correlates with metallicity.

UV line blanketing: more metals ⇒ fainter UV.



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SDSS Tomography

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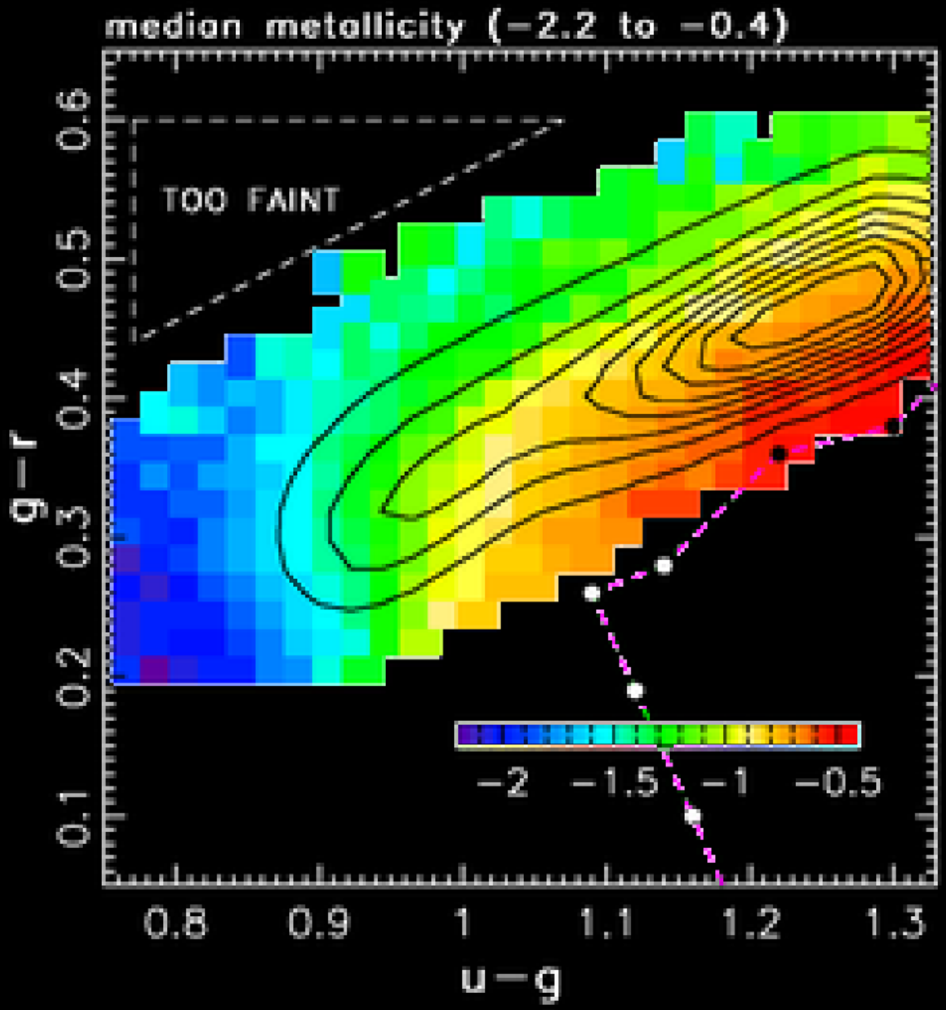
Measured [Fe/H] of ~2 million stars using u-g color excess at fixed g-r.



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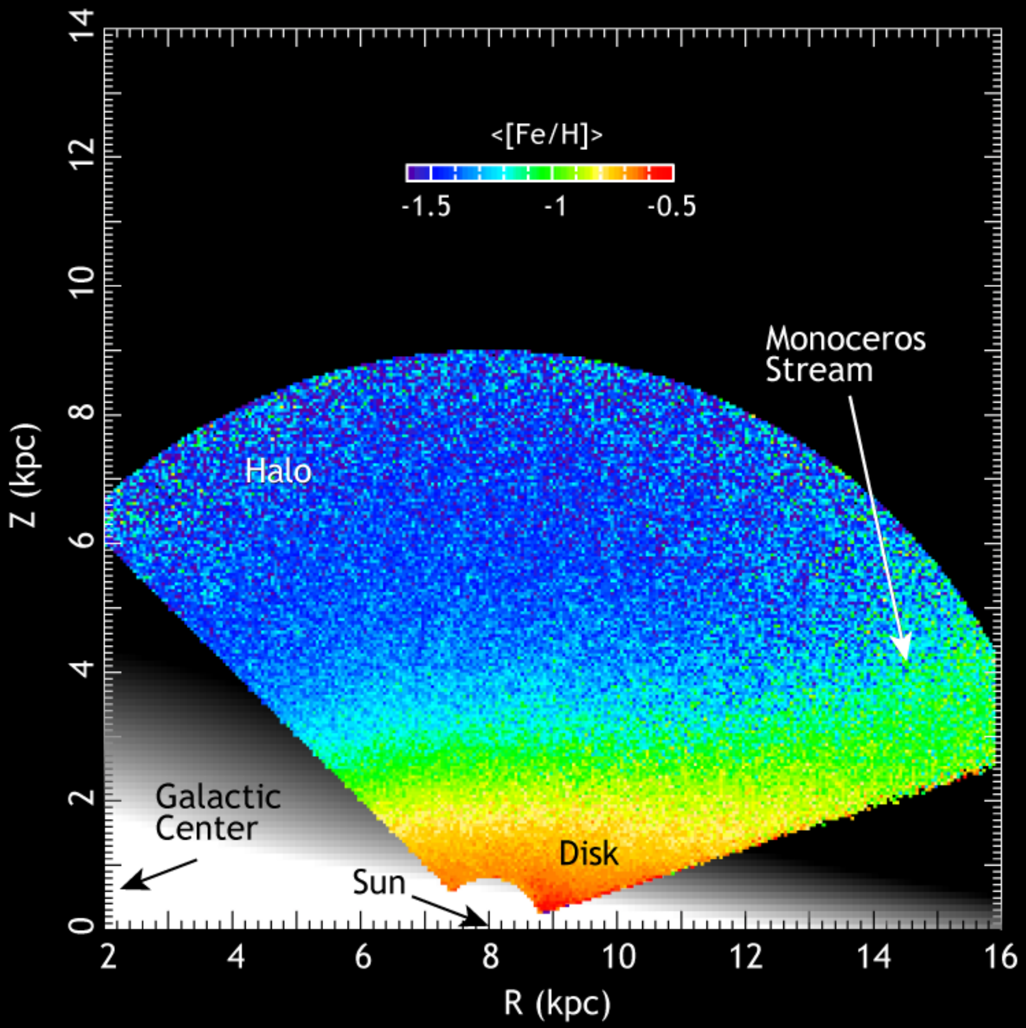

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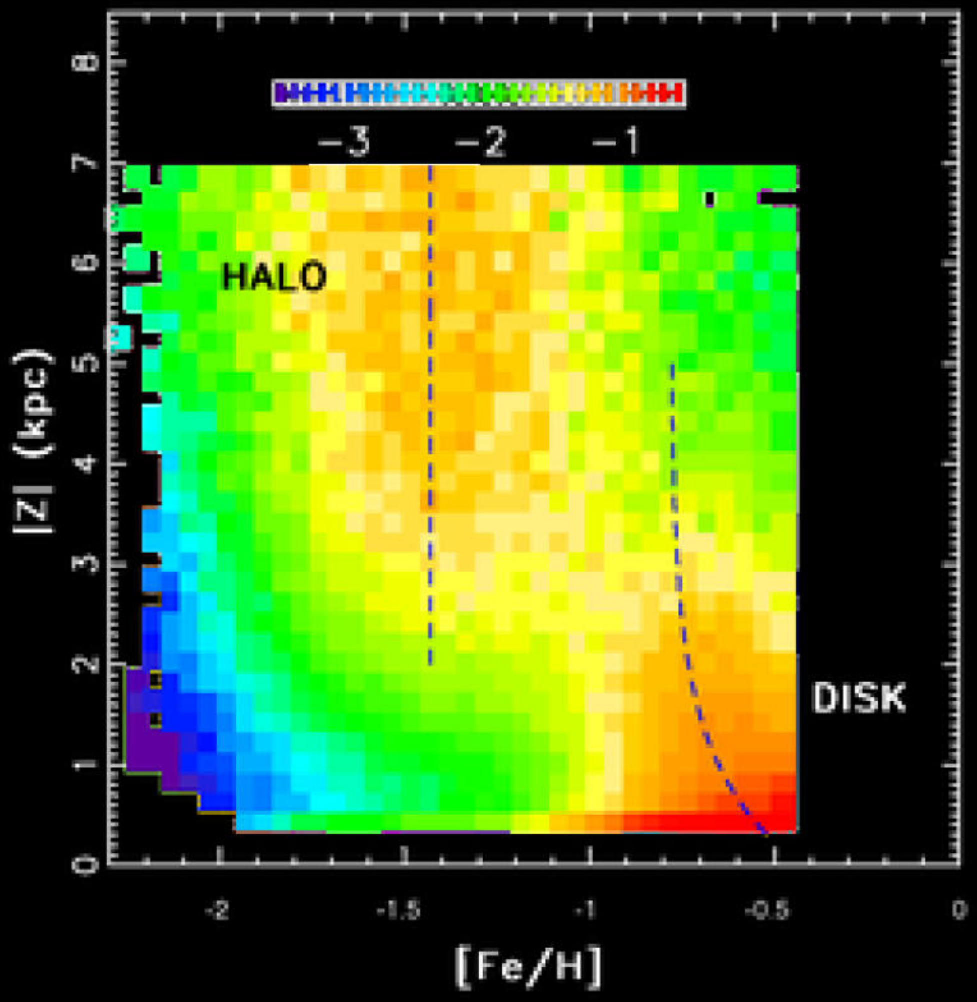
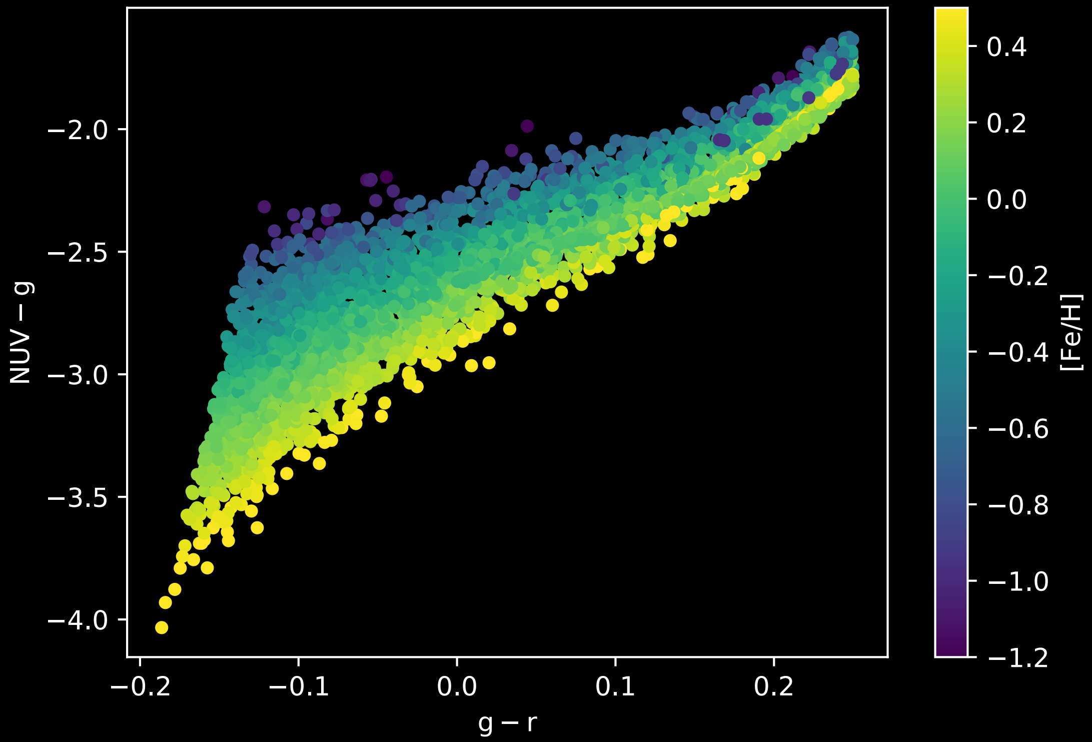


NUV vs. u

Precision of metallicity measurement:

$$\sigma_{[\mathrm{Fe/H}]} \sim \sigma_{\mathrm{color}} \left(\frac{\mathrm{d}\,(\mathrm{color})}{\mathrm{d}\,[\mathrm{Fe/H}]} \right)^{-1}$$



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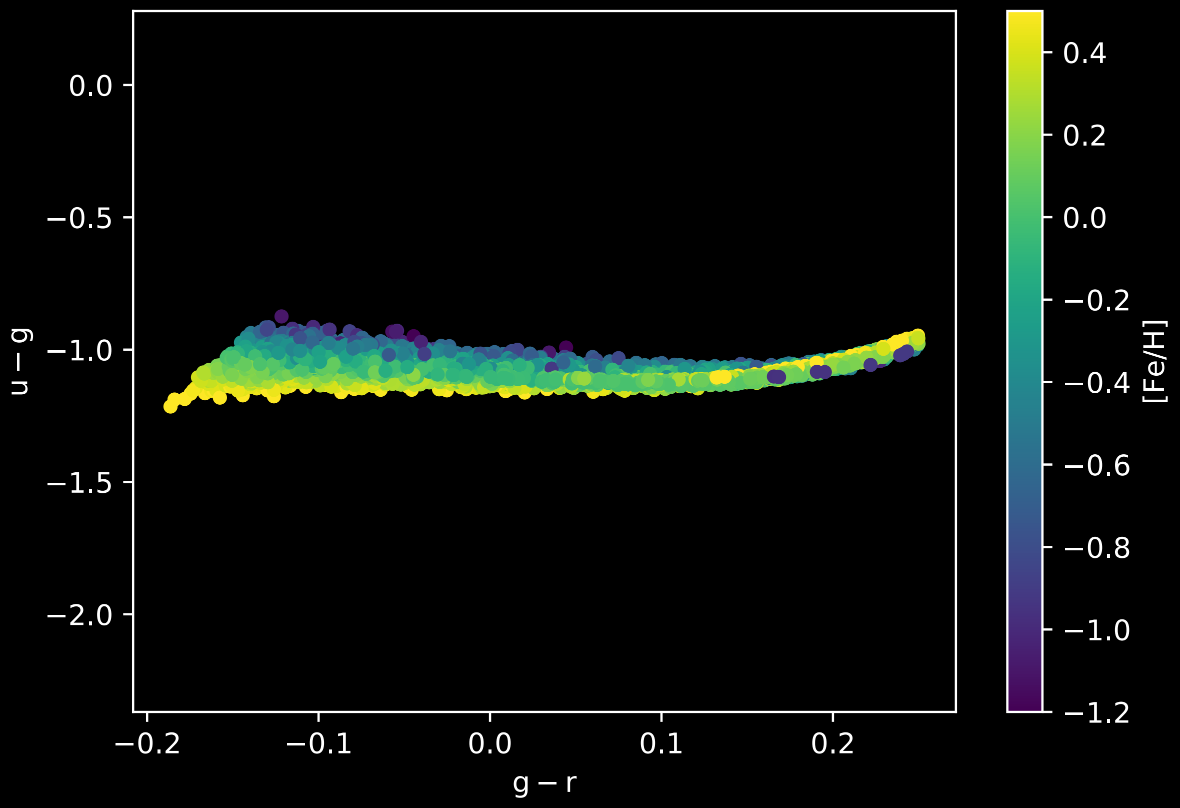

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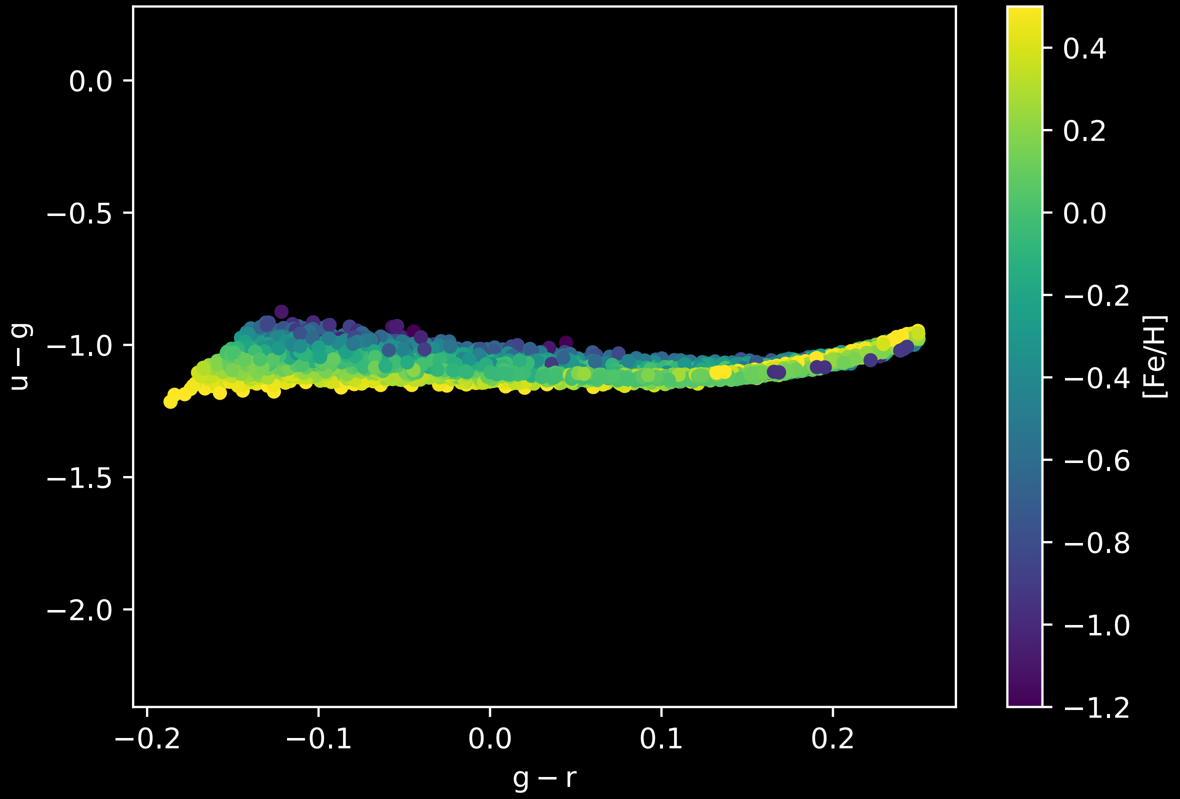
NUV ~6× more sensitive to metallicity than u.



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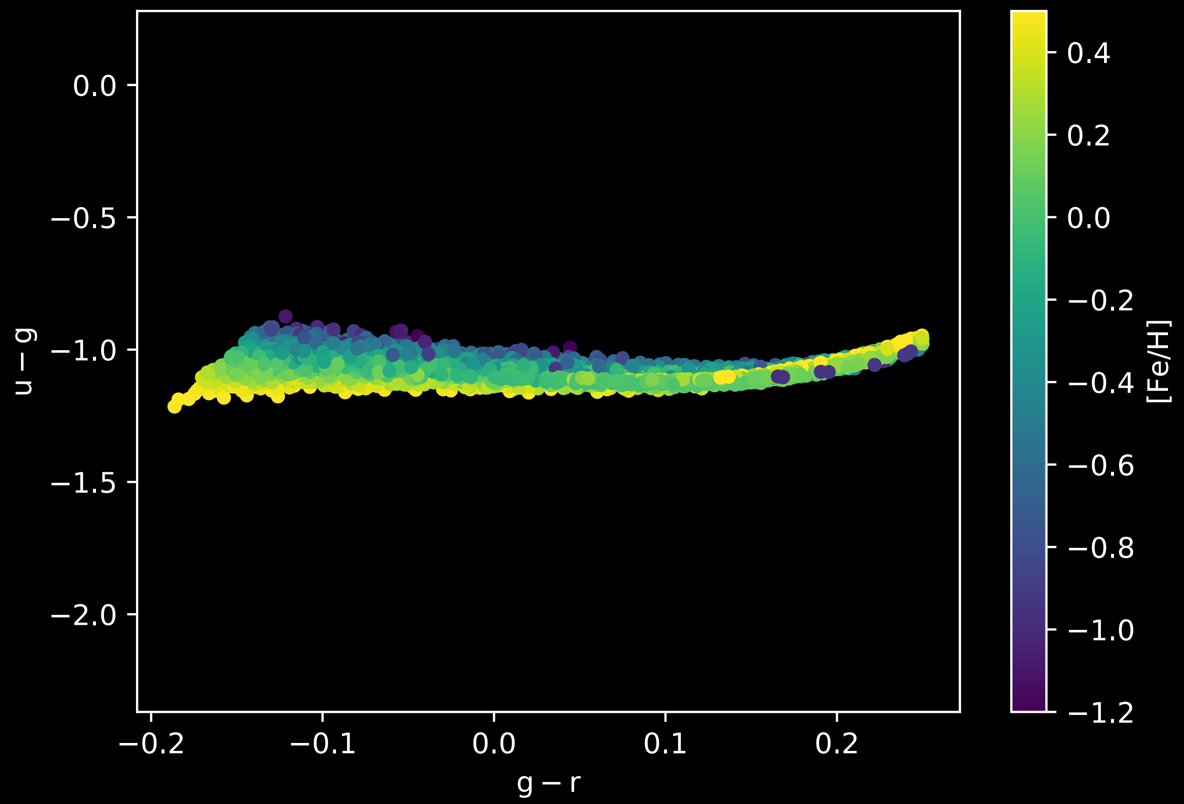
More rigorous formalism: Fisher forecasting.



Fisher forecasting

$$\frac{1}{\sigma^2_{[\mathrm{Fe/H}]}} \sim \frac{1}{\sigma^2_{\mathrm{color}}} \left(\frac{\mathrm{d}\,(\mathrm{color})}{\mathrm{d}\,[\mathrm{Fe/H}]} \right)^2$$

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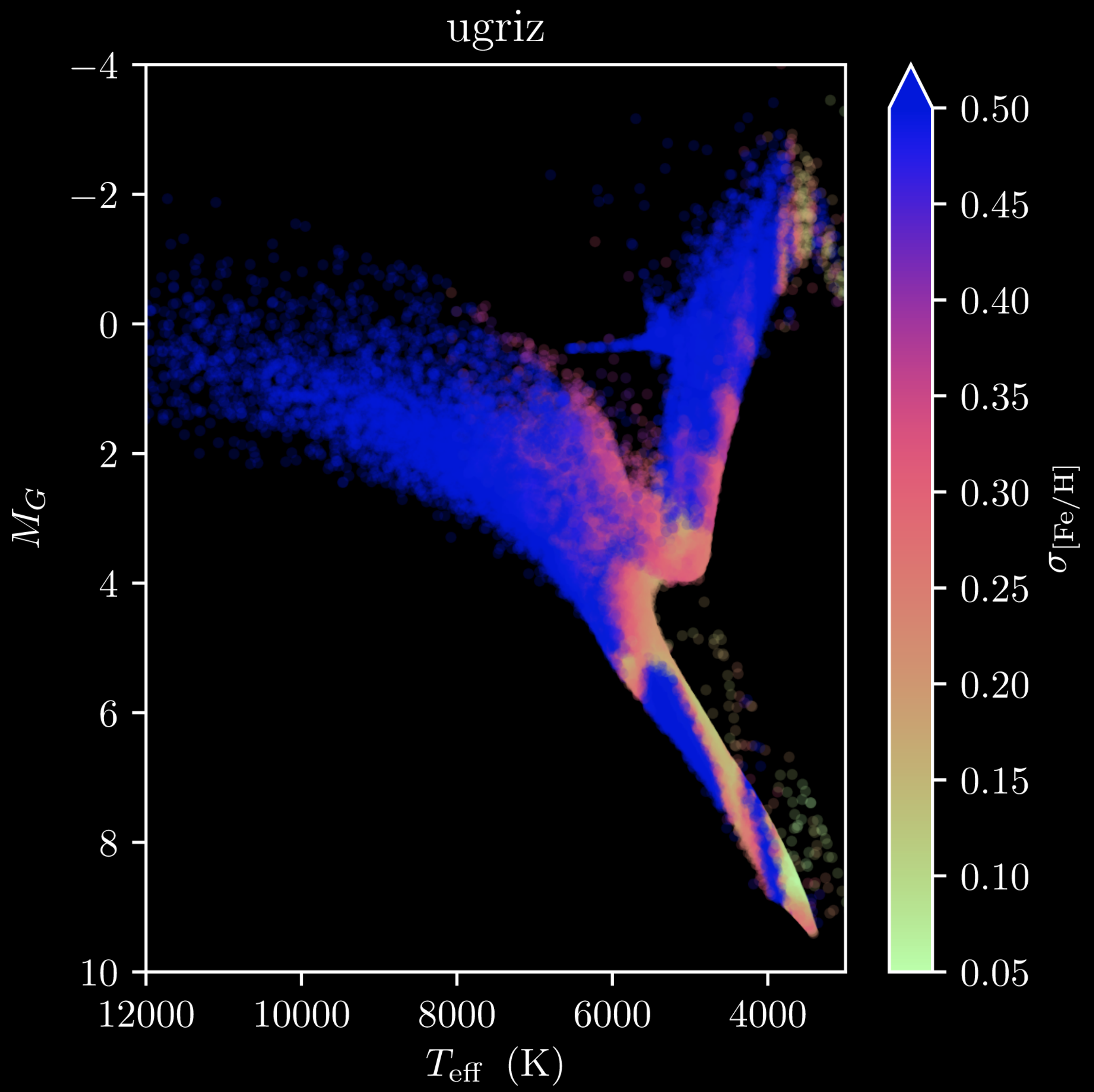
$$\Sigma^{-1}_{\text{stellar params}} \sim \left(\frac{\partial(\text{colors})}{\partial(\text{stellar params})} \right)^T \Sigma^{-1}_{\text{colors}} \left(\frac{\partial(\text{colors})}{\partial(\text{stellar params})} \right)$$

[Fe/H] precision

Typical metallicity precision across the HRD, using:

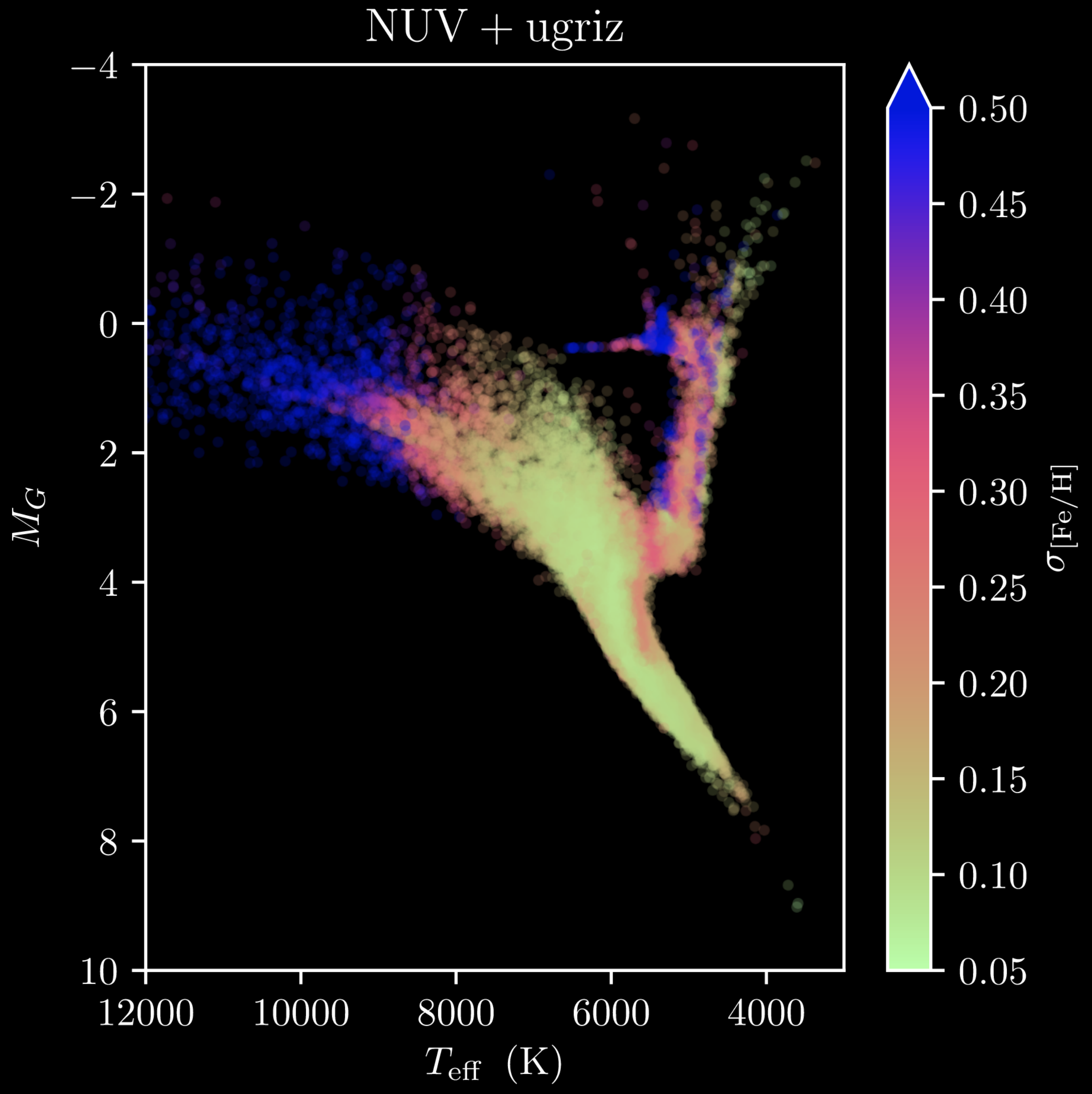
LSST



[Fe/H] precision

Typical metallicity precision
across the HRD, using:

LSST + NUV



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Typical metallicity precision across the HRD, using:

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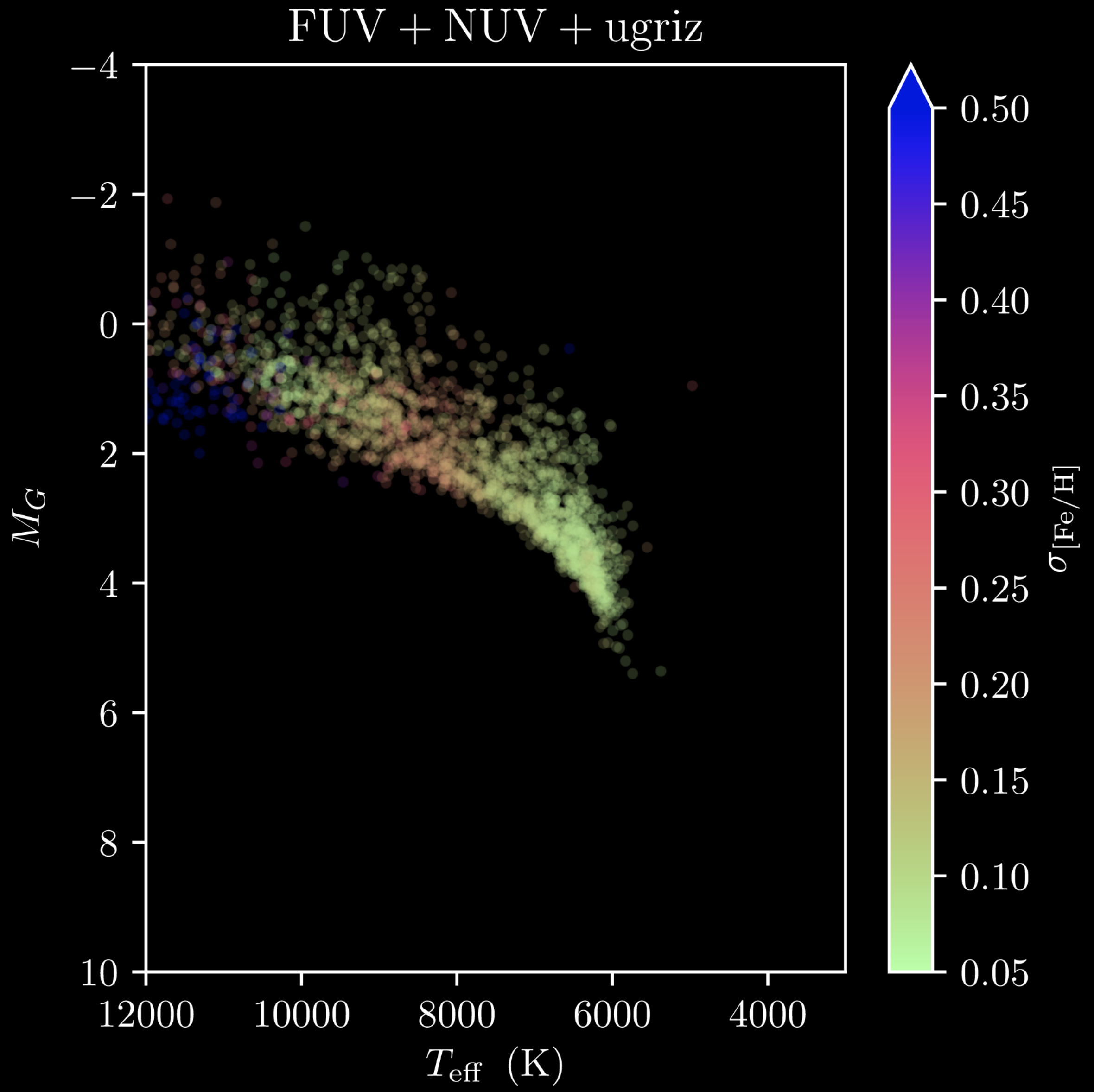
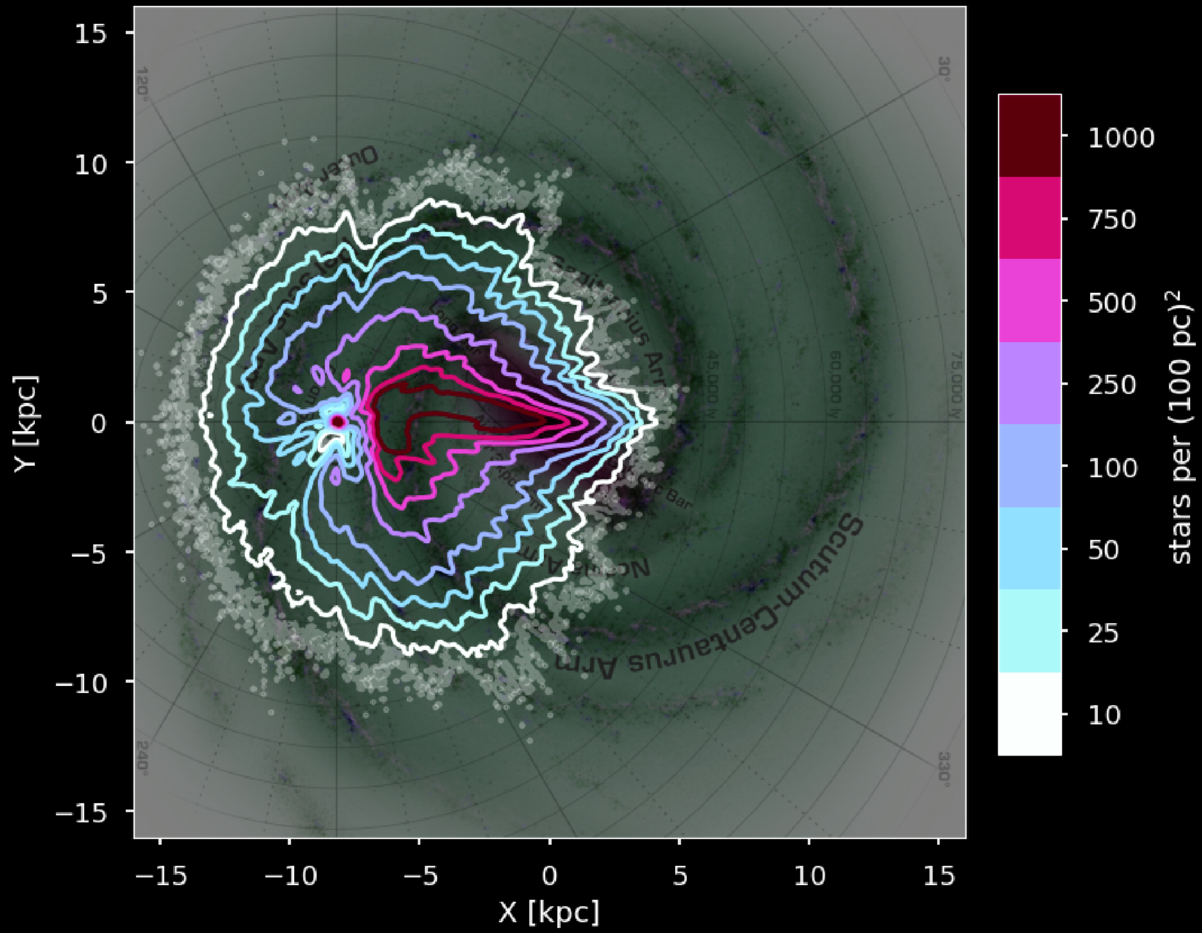


Comparison with spectroscopic surveys



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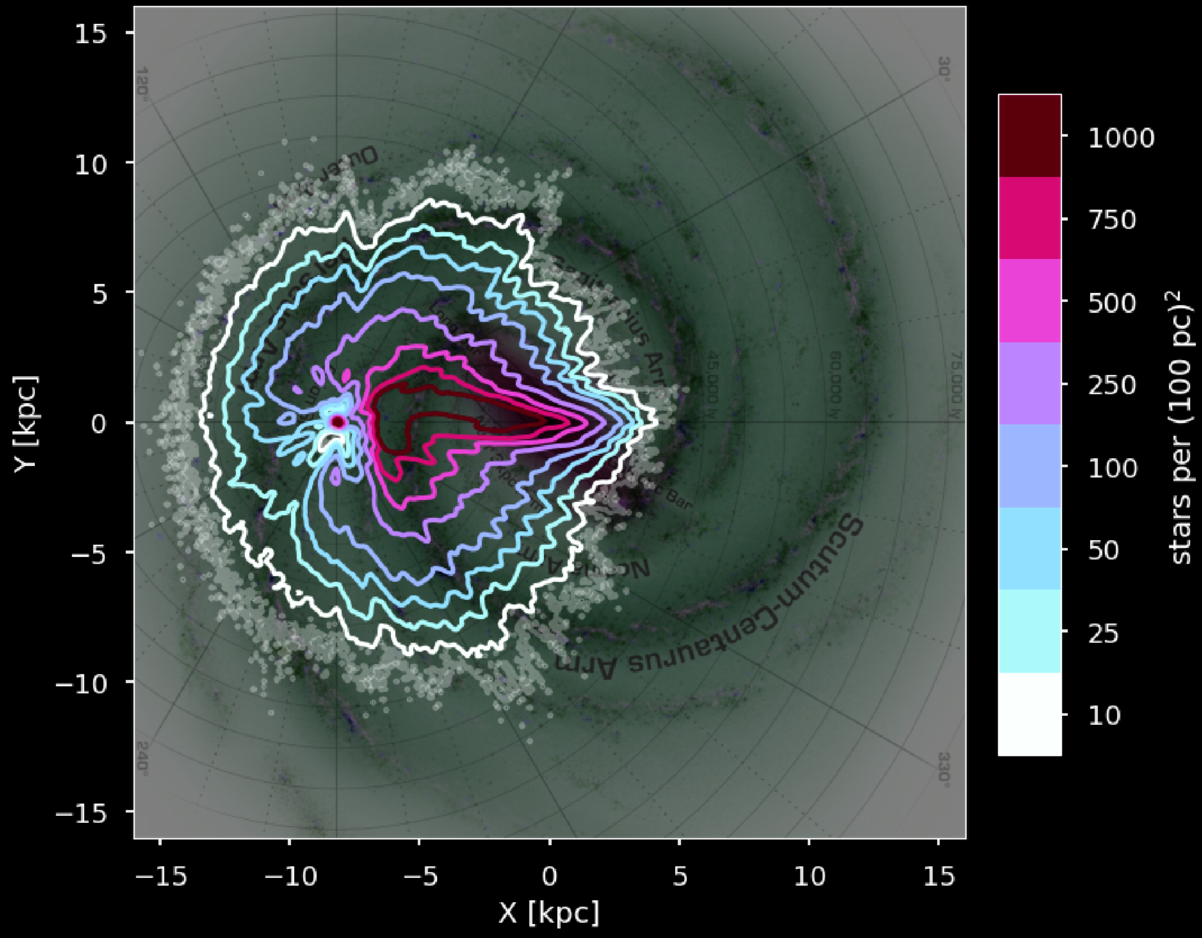

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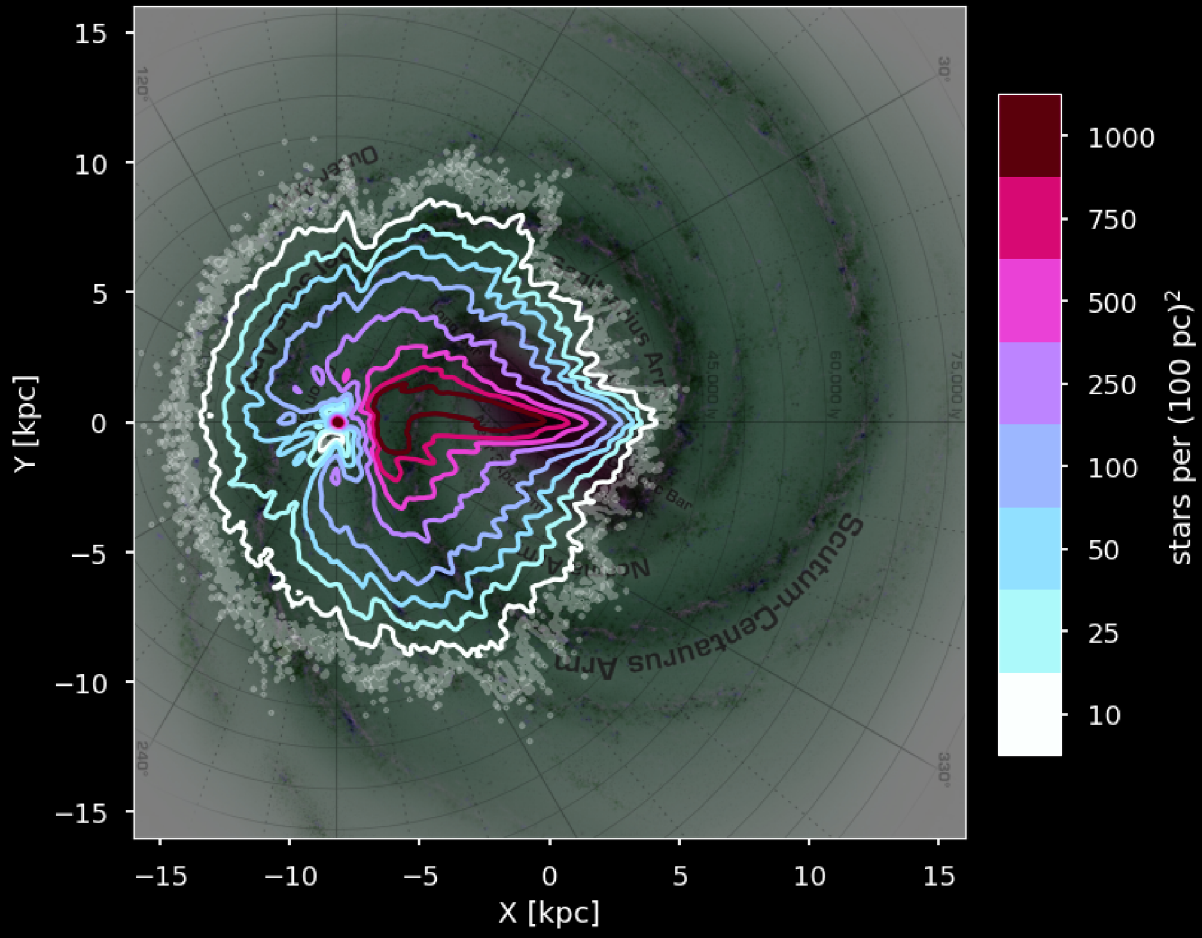
Comparison with spectroscopic surveys

SDSS-V Galactic Genesis: ~6×10^6 high-resolution NIR spectra.



(Kollmeier *et al.* 2017)

Comparison with spectroscopic surveys

SDSS-V Galactic Genesis: ~6×10^6 high-resolution NIR spectra.

UVEX NUV + LSST (South) or PS1 (North): ~300 million stars.

Stellar models

Empirical stellar models

Accurate stellar photometric & spectral models required.

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Small fraction of stars have high-resolution spectroscopy.

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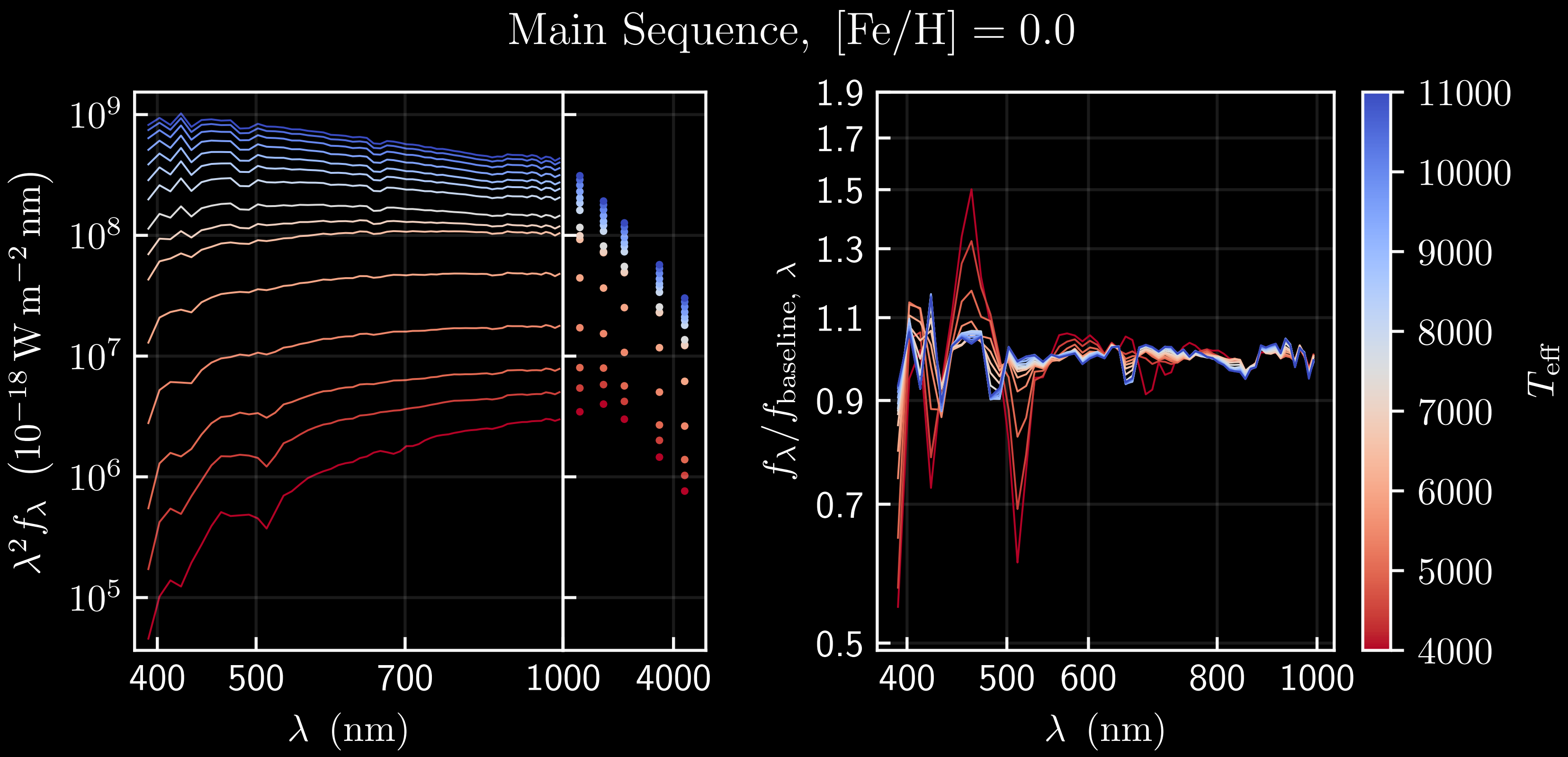
⇒ “Learn” empirical stellar model.

Learned stellar models of Gaia XP spectra



(Zhang, Green & Rix 2023)

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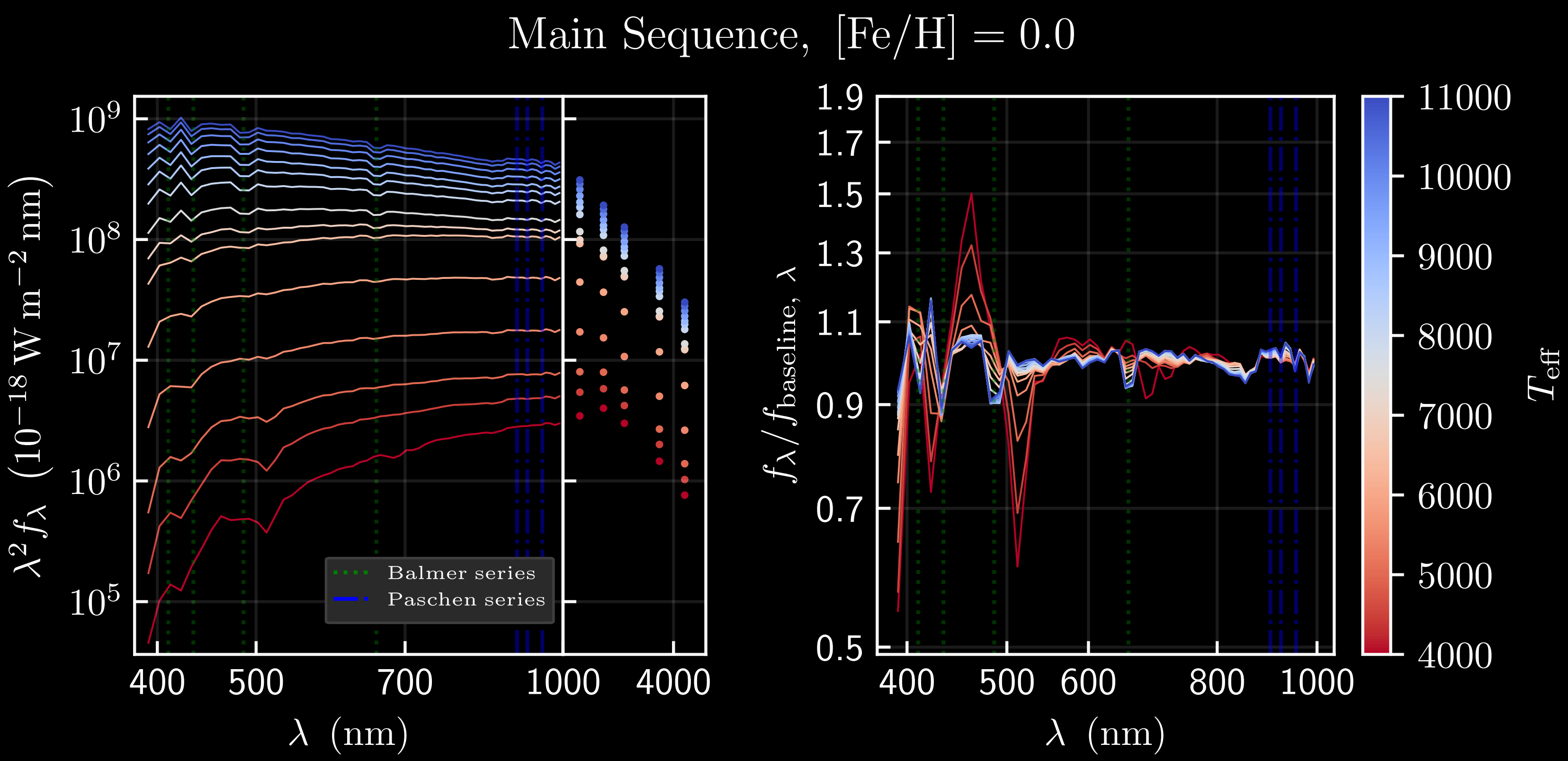

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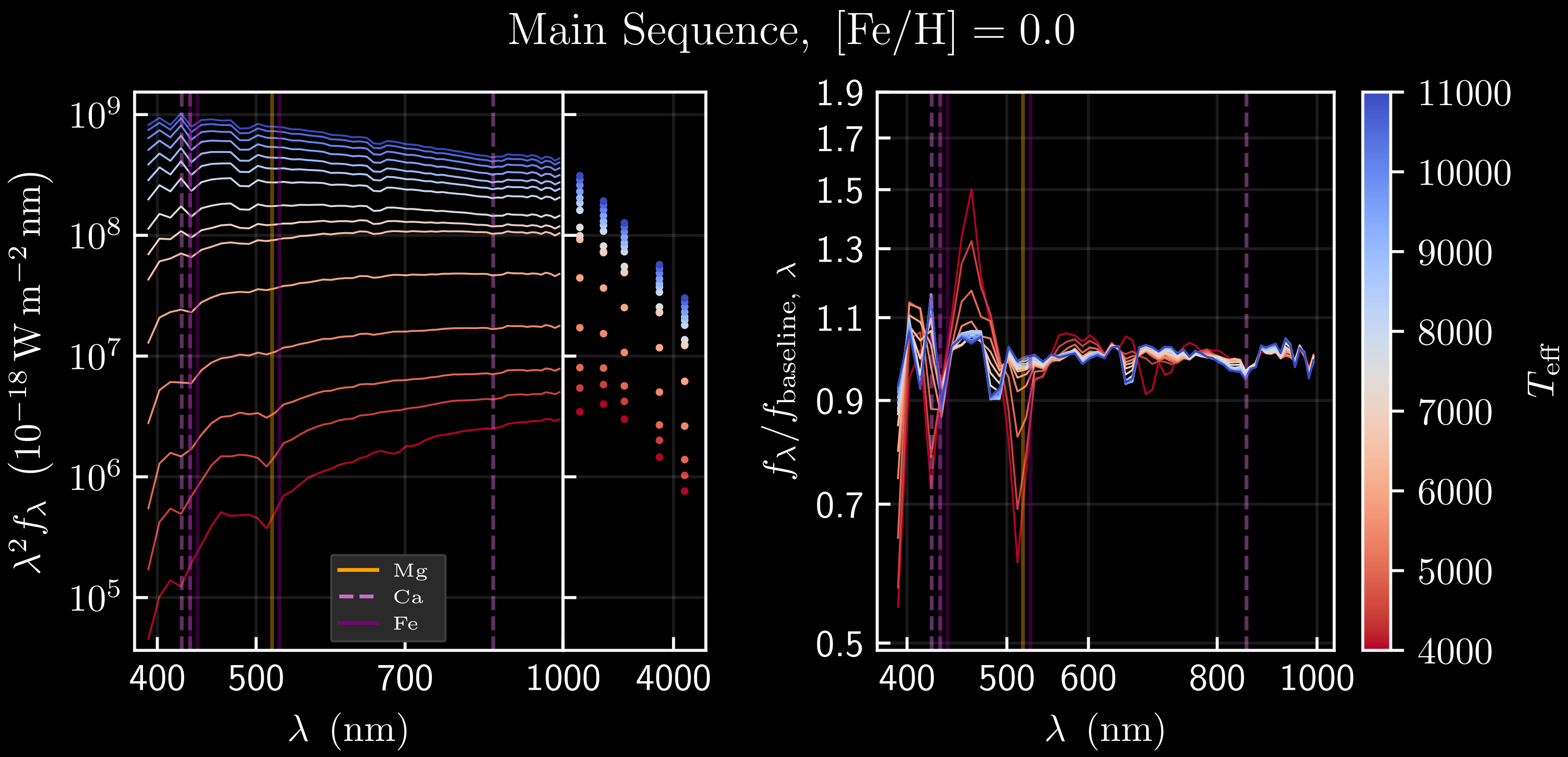
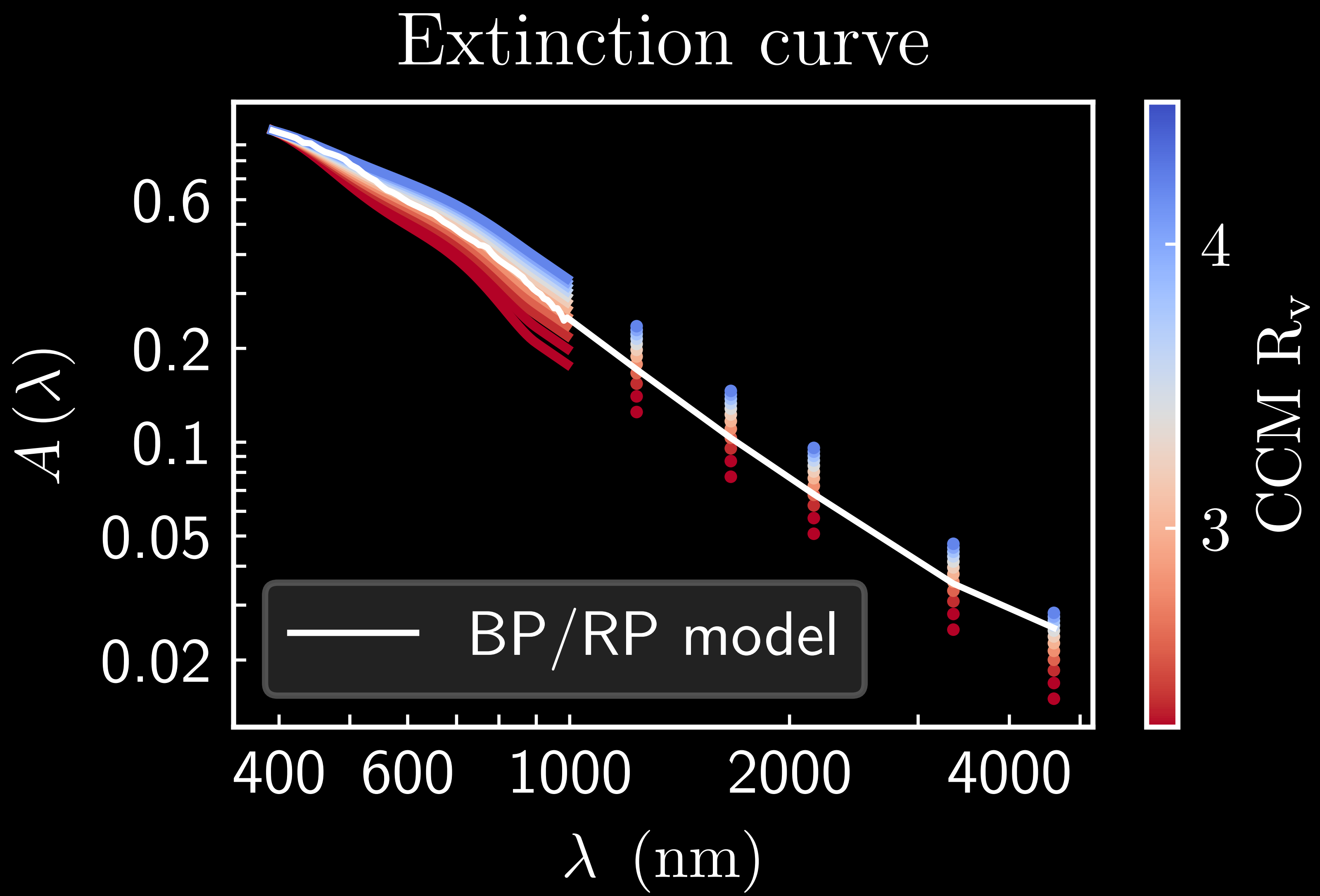


(Zhang, Green & Rix 2023)

Learned extinction curve



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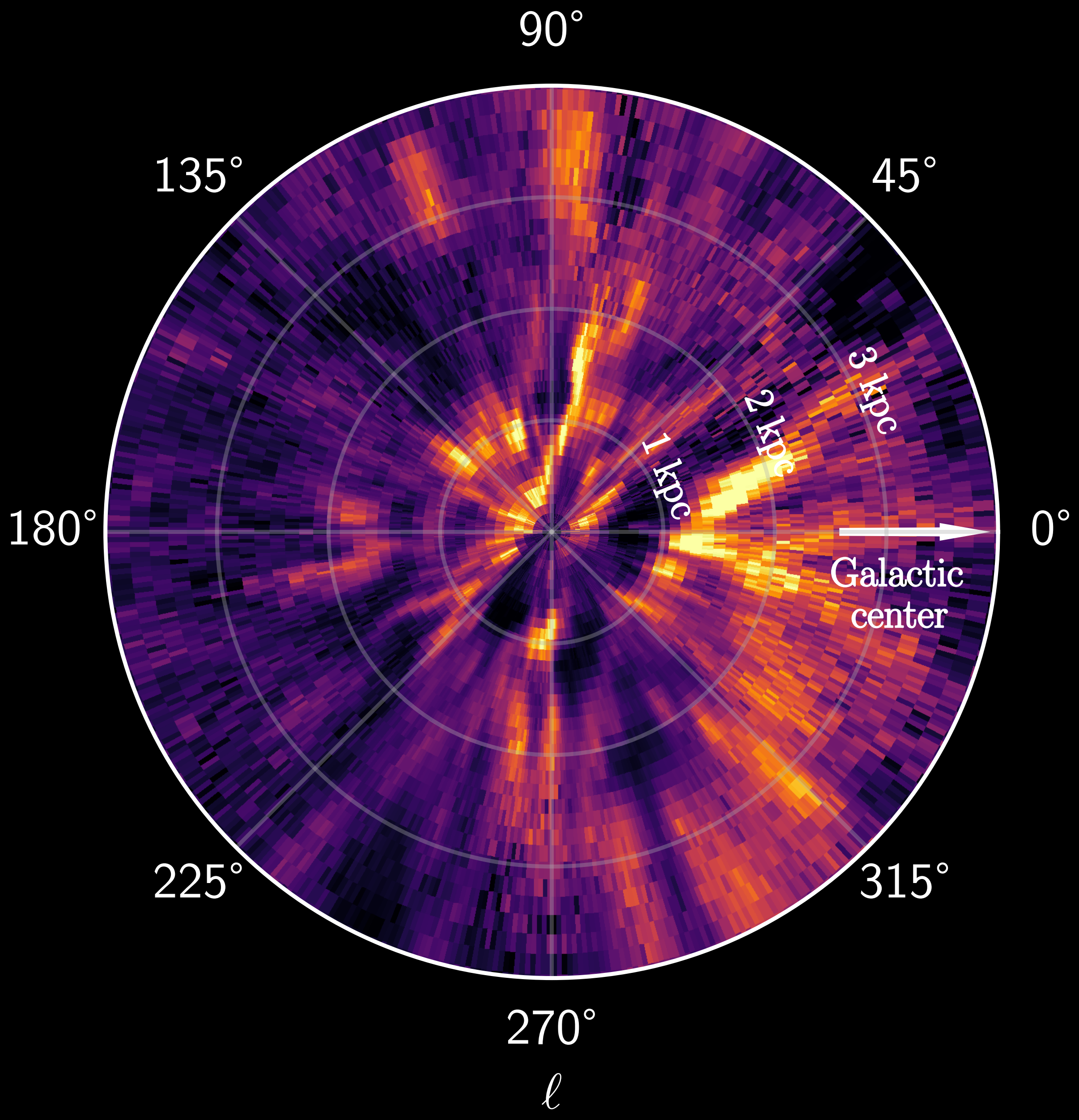

3D dust map based on 220 million Gaia XP spectra

Uses empirical model learned from the 1% of data with LAMOST spectra.

(Zhang, Green & Rix 2023)

Summary

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Dust maps: high sensitivity at low extinction.

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Variation in dust extinction curve.

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Photometric metallicities of ~300 million stars using UV excess.