

ML4ASTRO3 FLASH TALK

Probabilistic Spectral Super-Resolution

Translating Gaia XP to high-resolution SDSS spectra with calibrated uncertainties

Andrija Župić · Universidade da Coruña

Minia Manteiga Outeiro, Nadia Blagorodnova

The Hallucination Trap

Generative models fall into a hallucination trap when translating blurred physics:

1. Physical Ambiguity (Aleatoric)

A falsely confident average where the astrophysics is genuinely degenerate.

2. Alien Inputs (Epistemic)

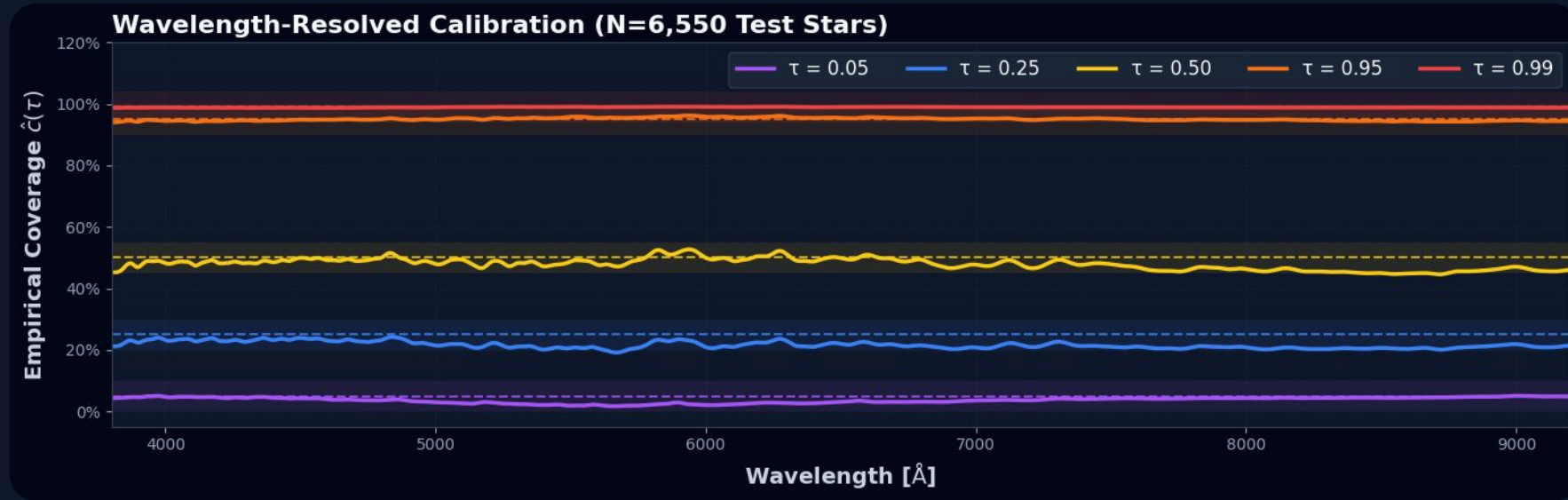
Guessing with confidence off the training manifold.

Capturing Aleatoric Ambiguity: Quantile Head

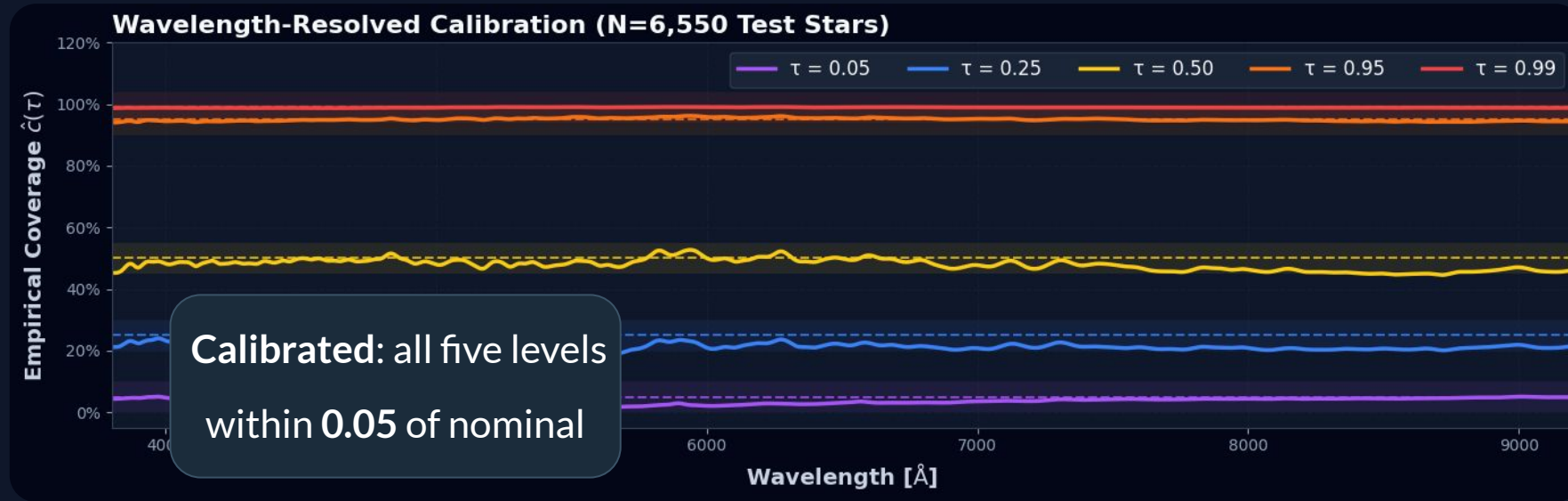


- ▶ We predict a **distribution**, not a spectrum: **5 quantiles** per pixel, trained with the pinball loss.
- ▶ 5 quantiles: **[5%, 25%, 50%, 95%, 99%]**

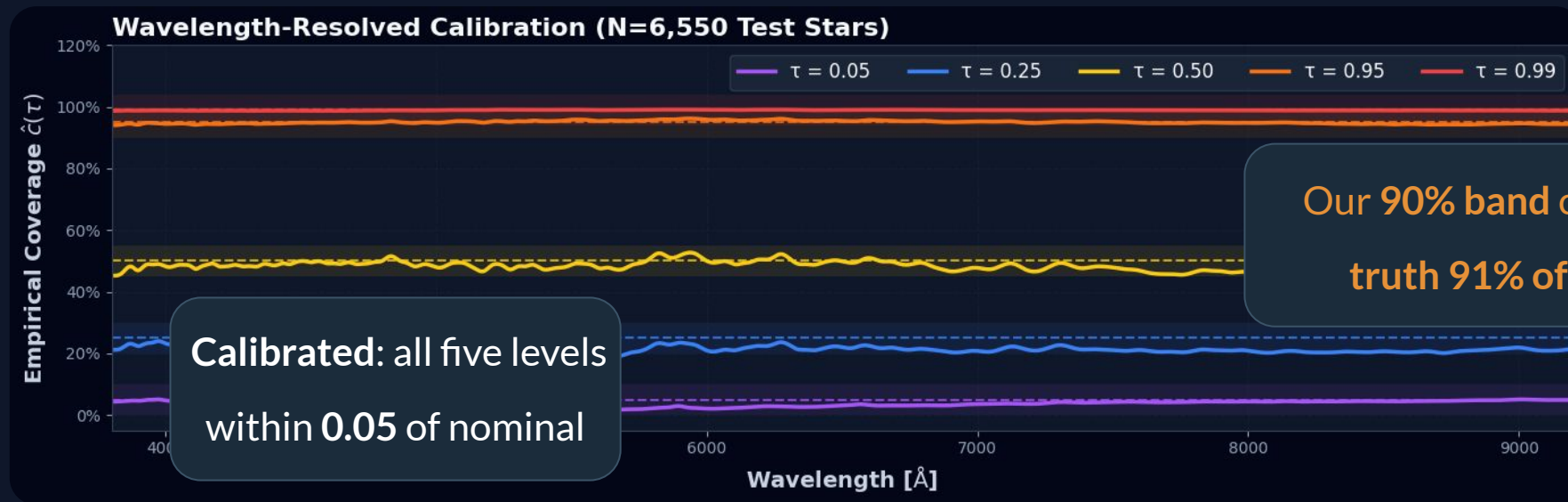
Capturing Aleatoric Ambiguity: Quantile Head



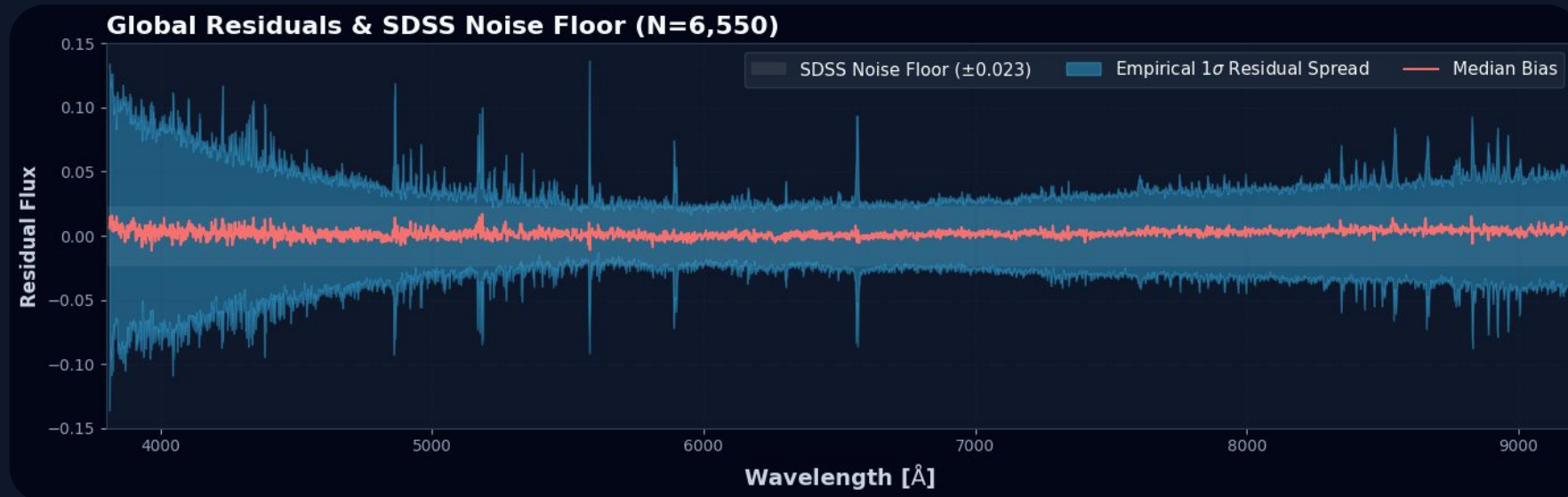
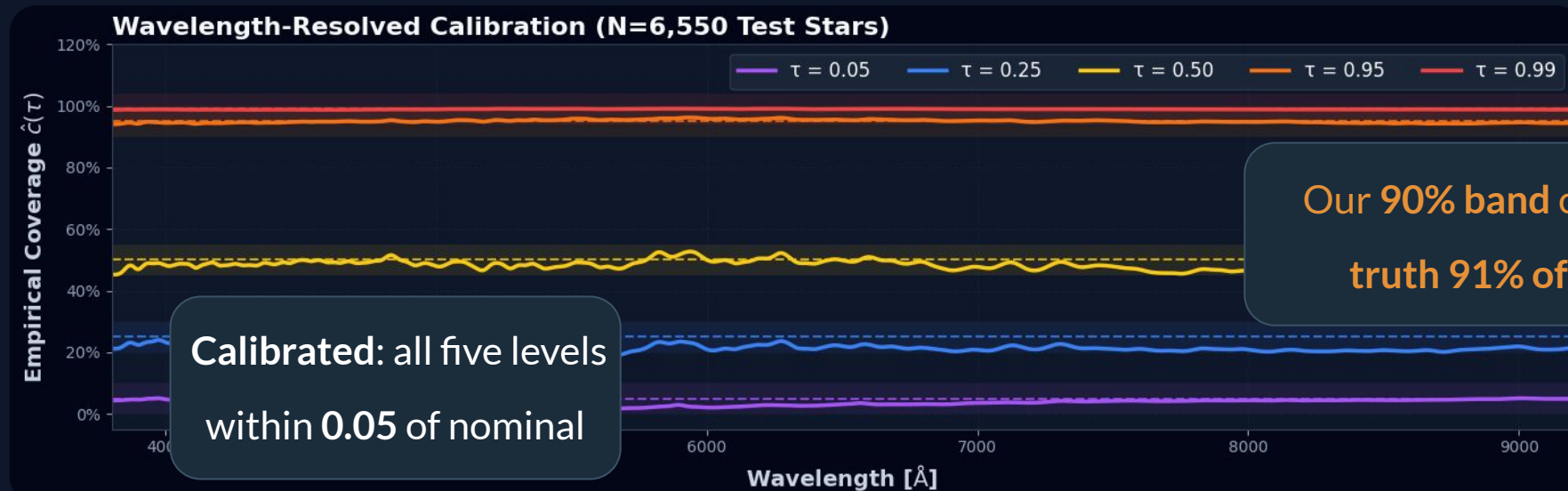
Capturing Aleatoric Ambiguity: Quantile Head



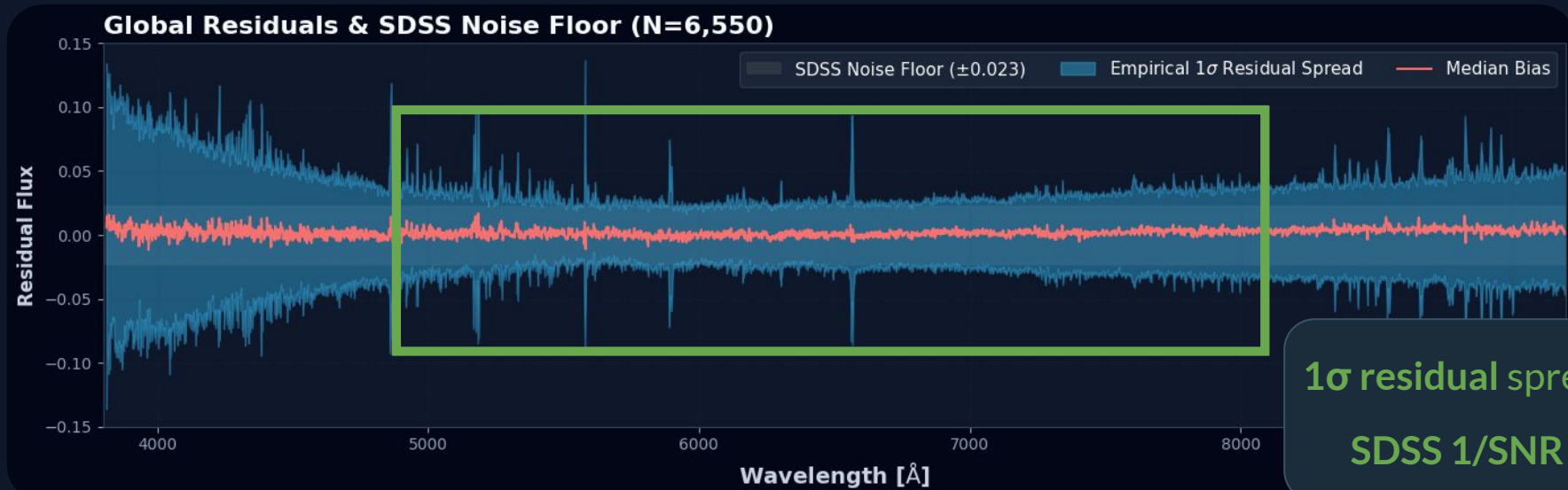
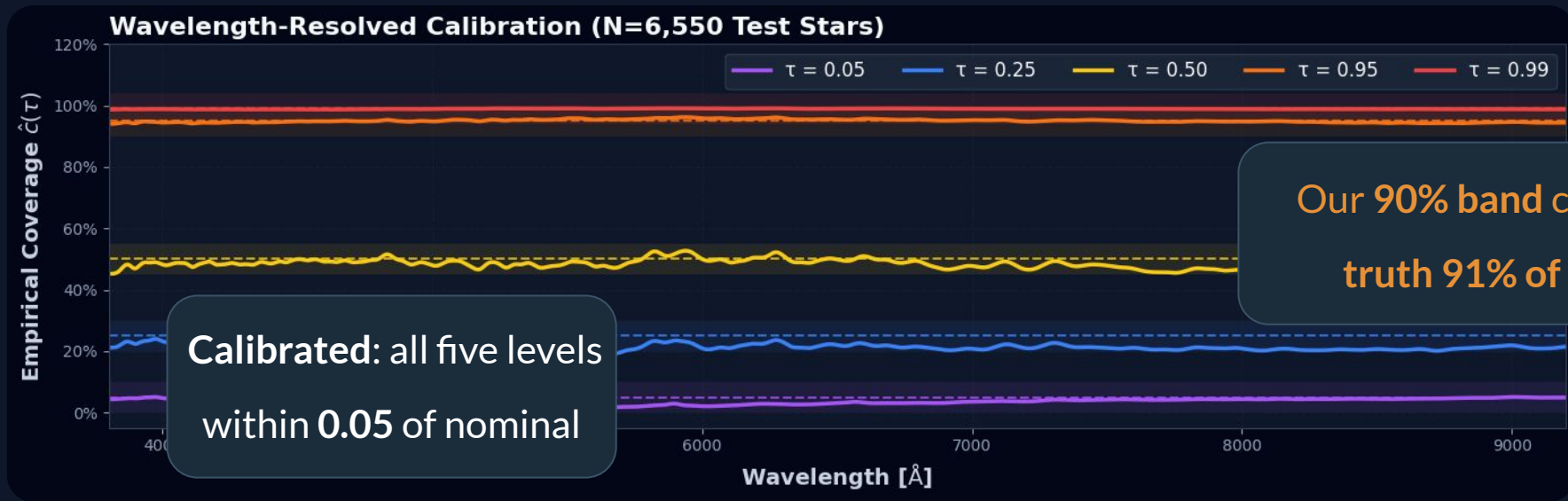
Capturing Aleatoric Ambiguity: Quantile Head



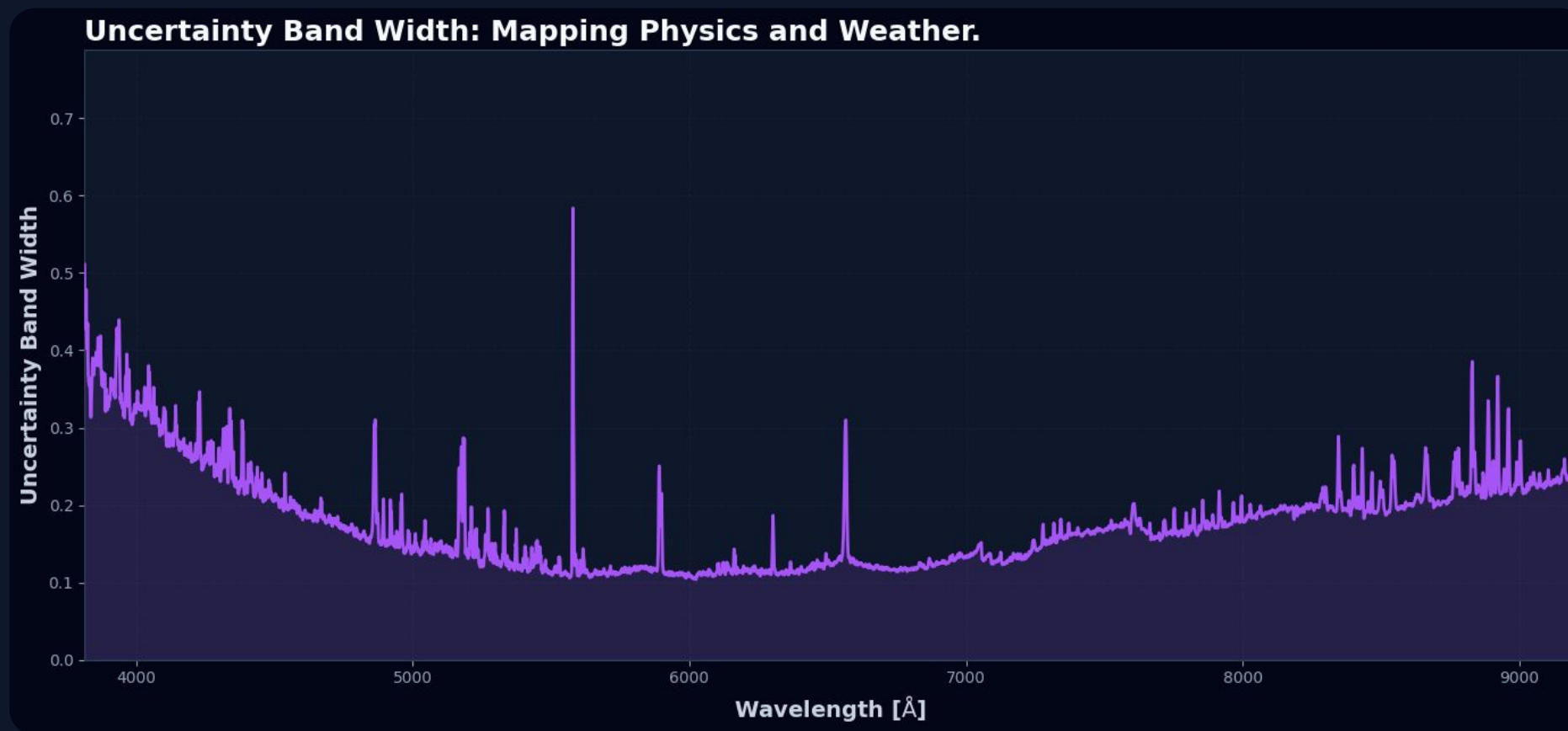
Capturing Aleatoric Ambiguity: Quantile Head



Capturing Aleatoric Ambiguity: Quantile Head

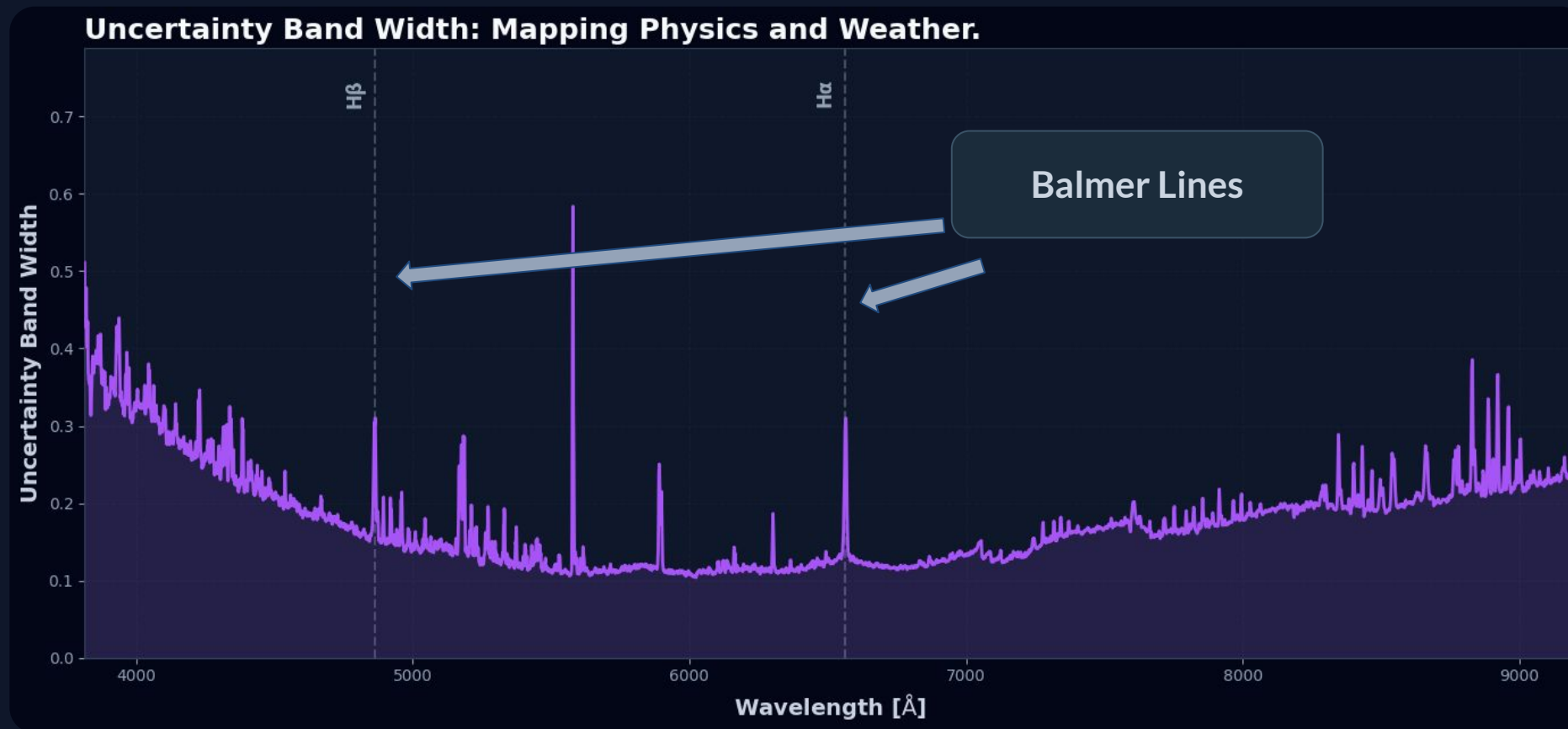


What the Band Found: The Weather & The Metals



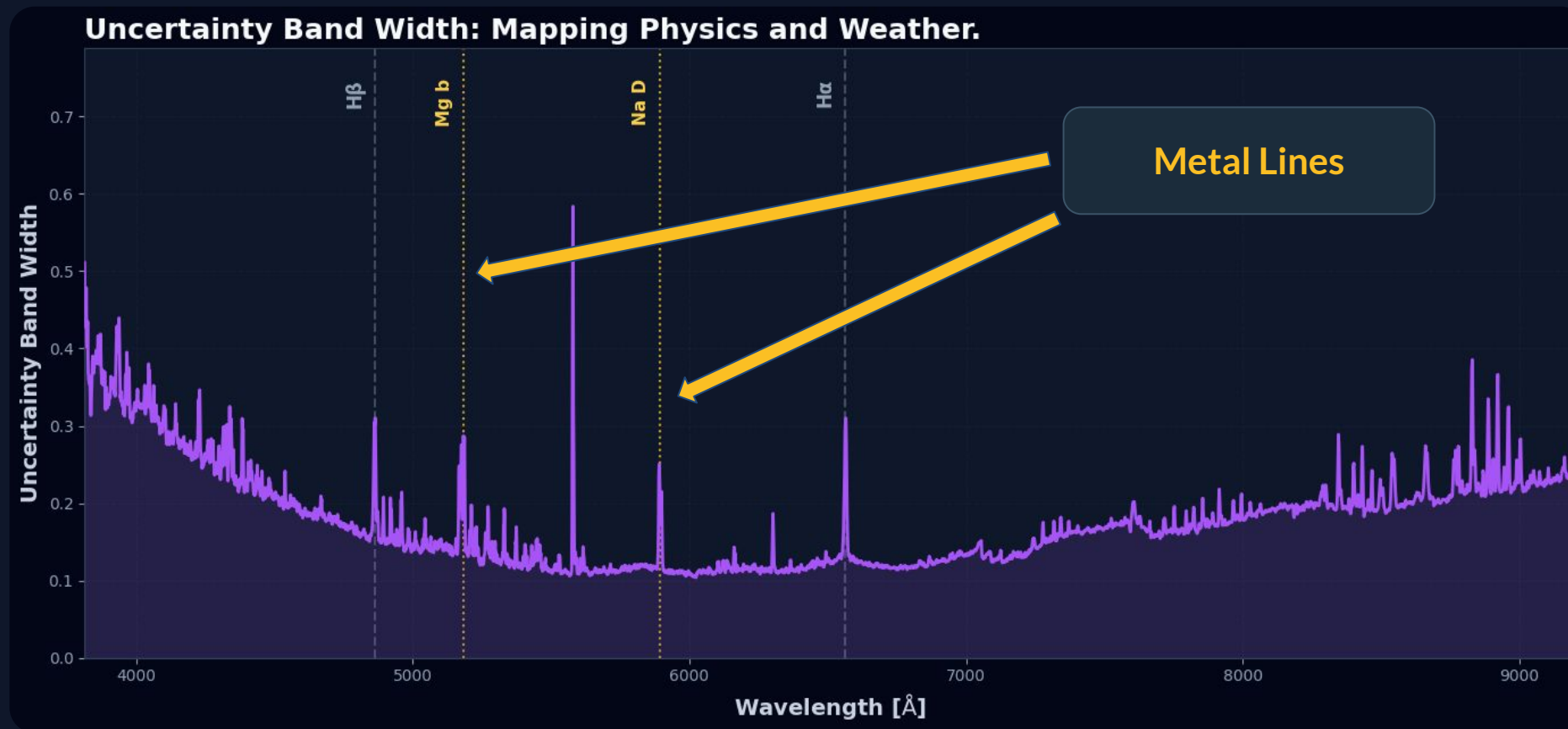
- ▶ The **band widens** where Gaia stops constraining the answer.
- ▶ A **smooth Gaia** curve might hide a **sharp SDSS line**, or it might just be **empty**. The uncertainty blows up to cover both possibilities.

What the Band Found: **The Weather** & **The Metals**



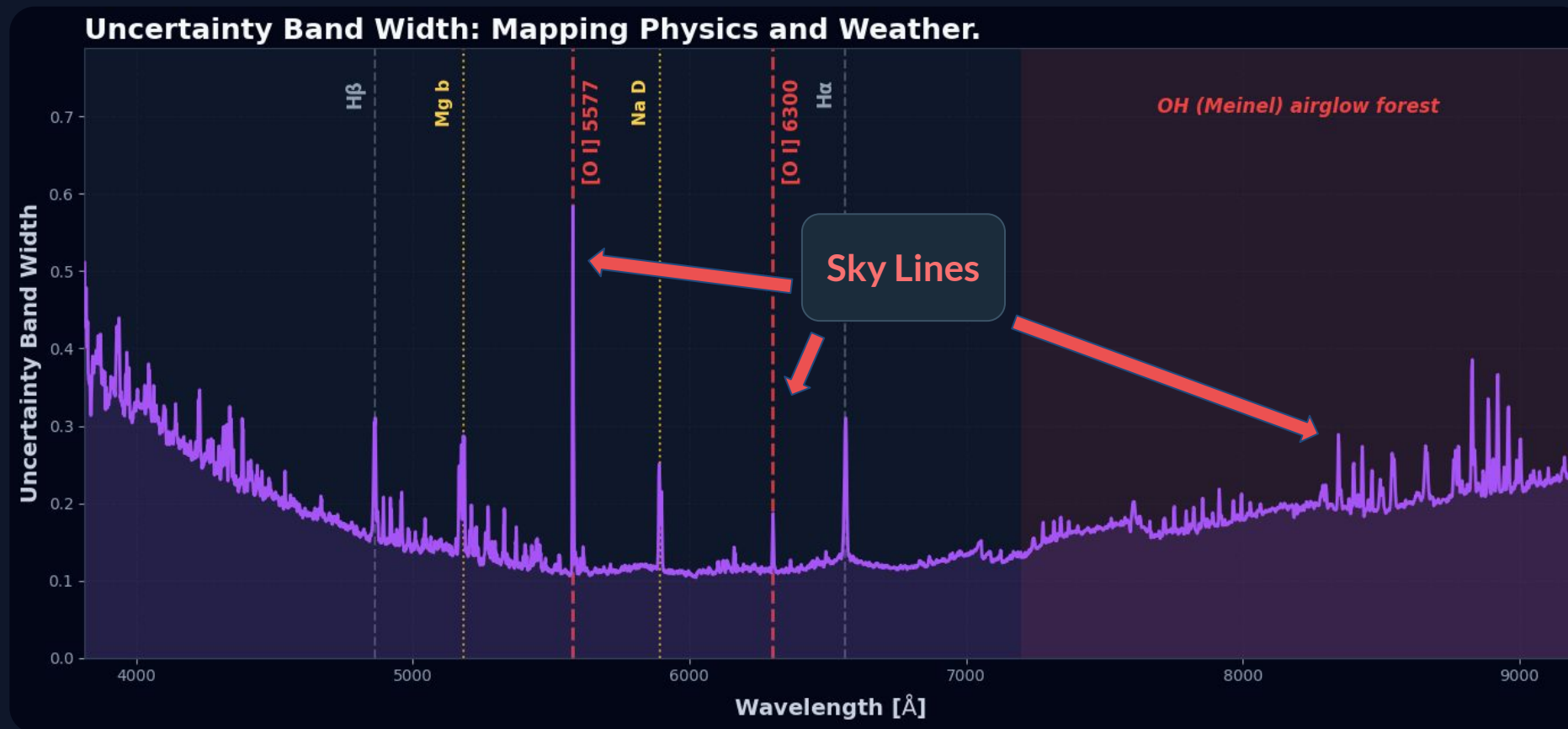
- ▶ The **band widens** where Gaia stops constraining the answer.
- ▶ A **smooth Gaia** curve might hide a **sharp SDSS line**, or it might just be **empty**. The uncertainty blows up to cover both possibilities.

What the Band Found: **The Weather** & **The Metals**



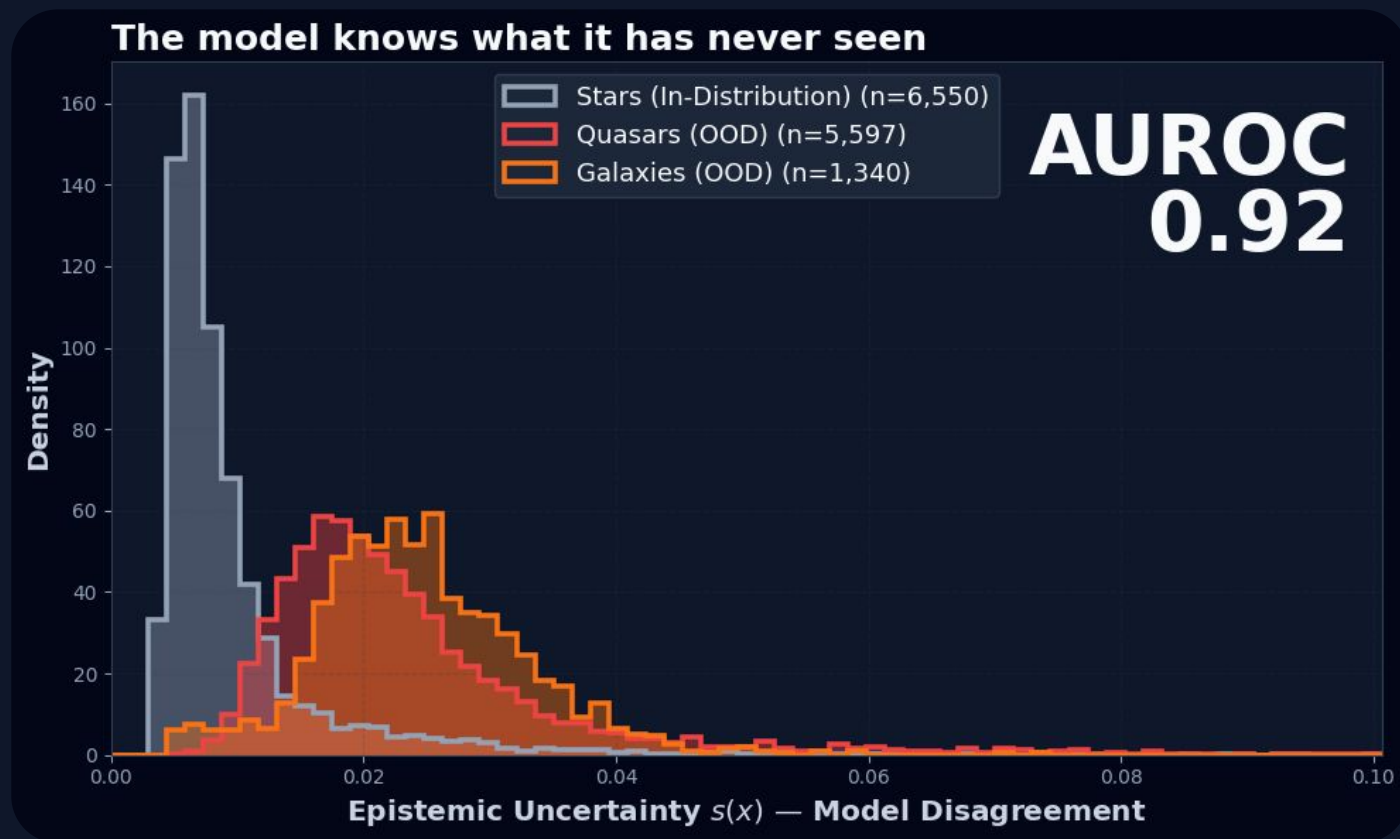
- ▶ The **band widens** where Gaia stops constraining the answer.
- ▶ A **smooth Gaia** curve might hide a **sharp SDSS line**, or it might just be **empty**. The uncertainty blows up to cover both possibilities.

What the Band Found: The Weather & The Metals



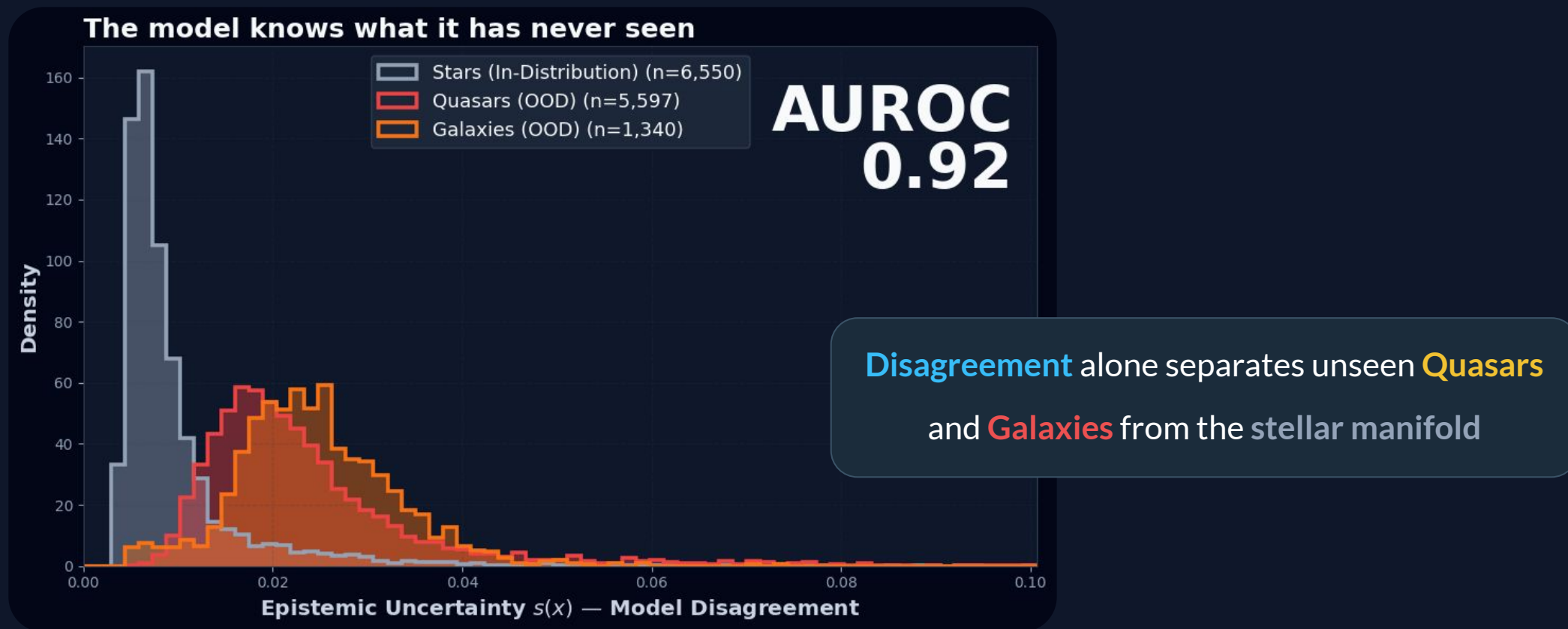
- ▶ The **band widens** where Gaia stops constraining the answer.
- ▶ A **smooth Gaia** curve might hide a **sharp SDSS line**, or it might just be **empty**. The uncertainty blows up to cover both possibilities.

Capturing Epistemic Ambiguity: Deep Ensemble



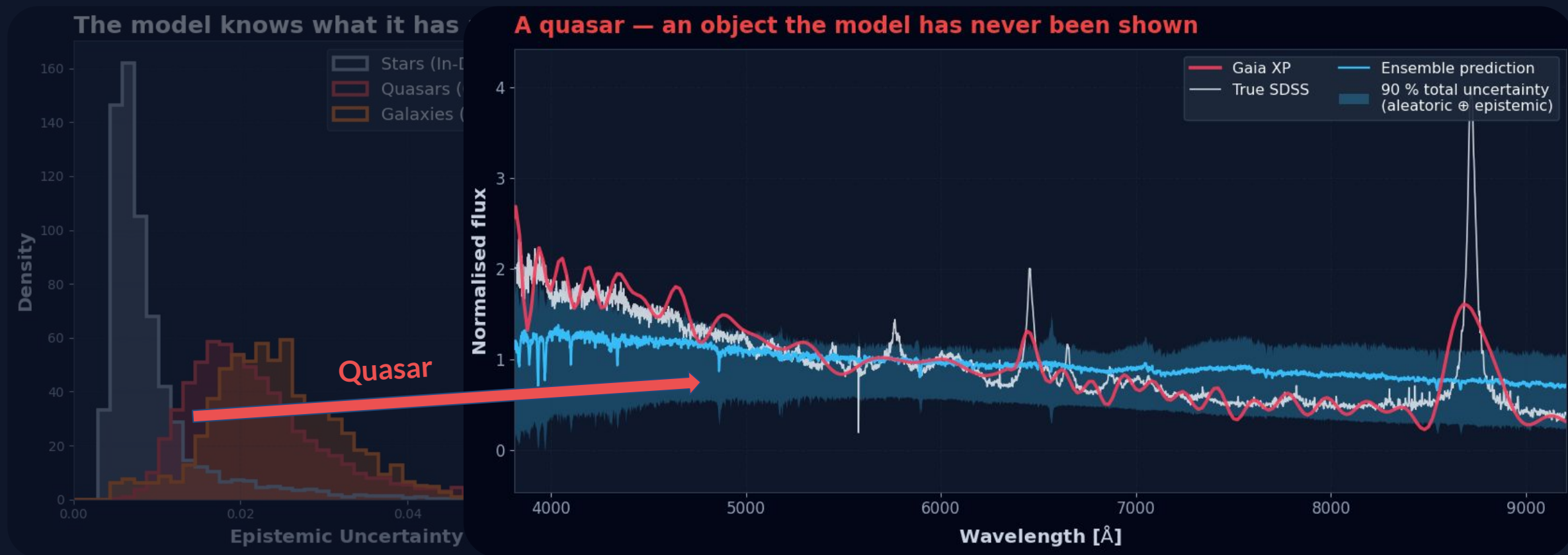
- ▶ 5 identical models trained only on stars with different random seeds.
- ▶ Model disagreement defines the epistemic uncertainty.

Capturing Epistemic Ambiguity: Deep Ensemble



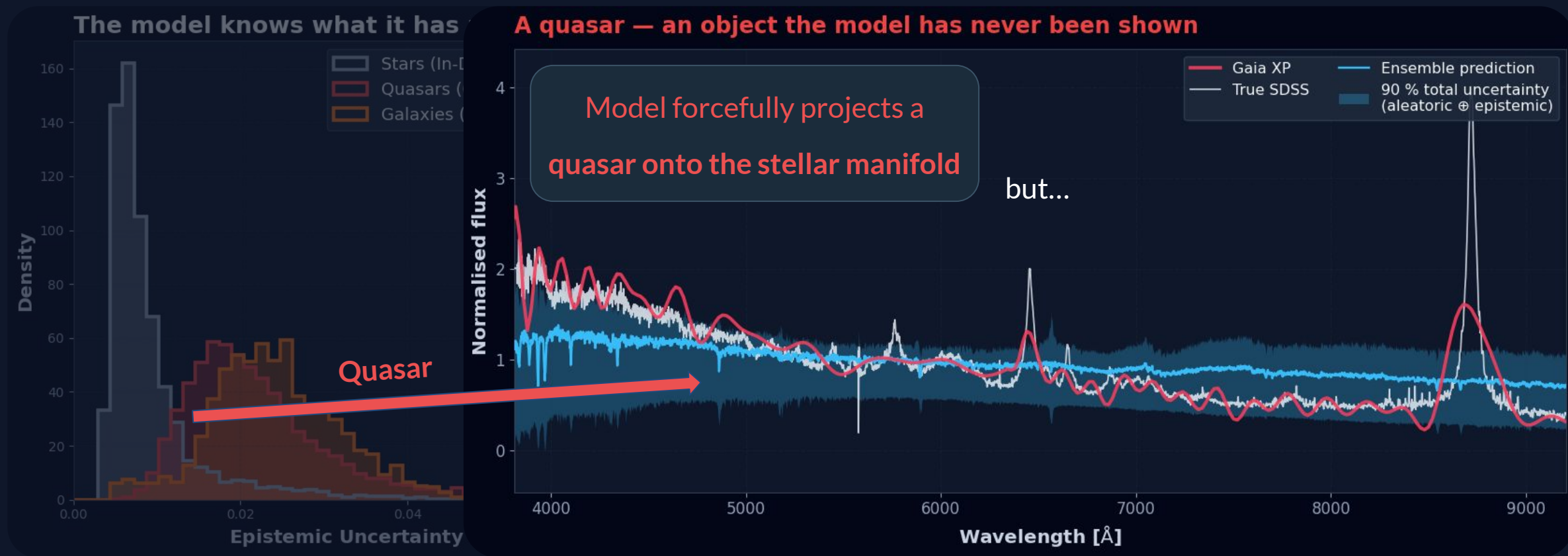
- ▶ 5 identical models trained only on stars with different random seeds.
- ▶ Model disagreement defines the epistemic uncertainty.

Capturing Epistemic Ambiguity: Deep Ensemble



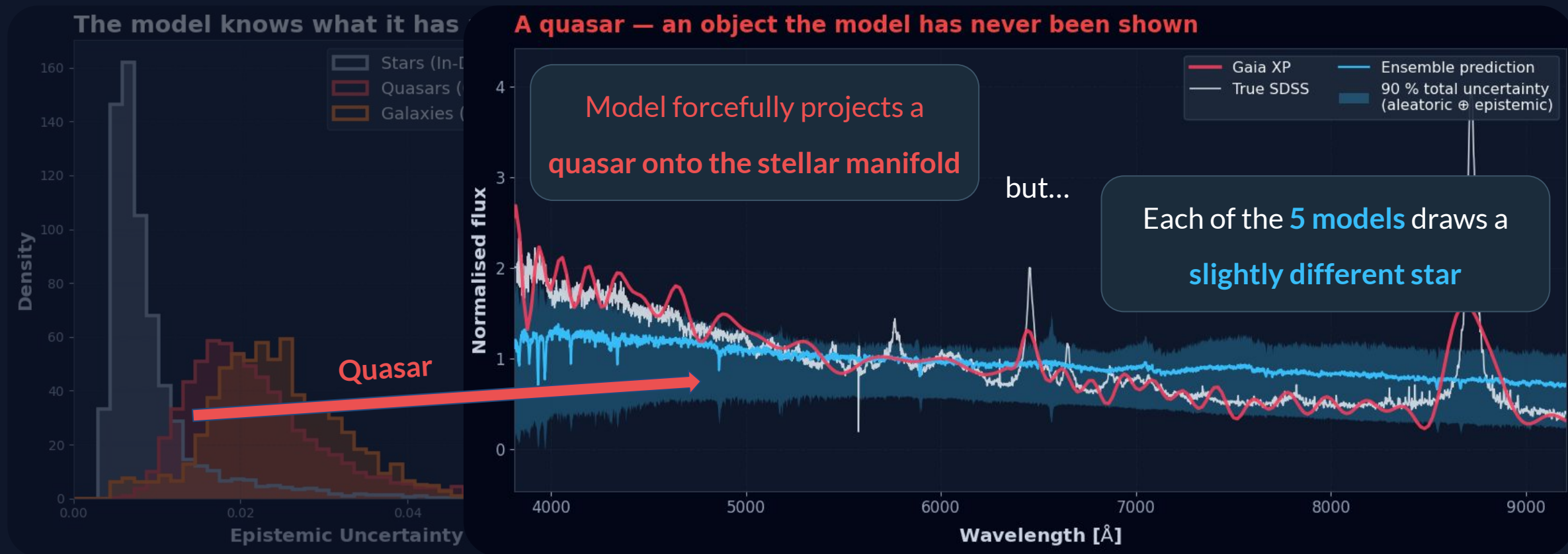
- ▶ 5 identical models trained only on stars with different random seeds.
- ▶ Model disagreement defines the epistemic uncertainty.

Capturing Epistemic Ambiguity: Deep Ensemble



- ▶ 5 identical models trained only on stars with different random seeds.
- ▶ Model disagreement defines the epistemic uncertainty.

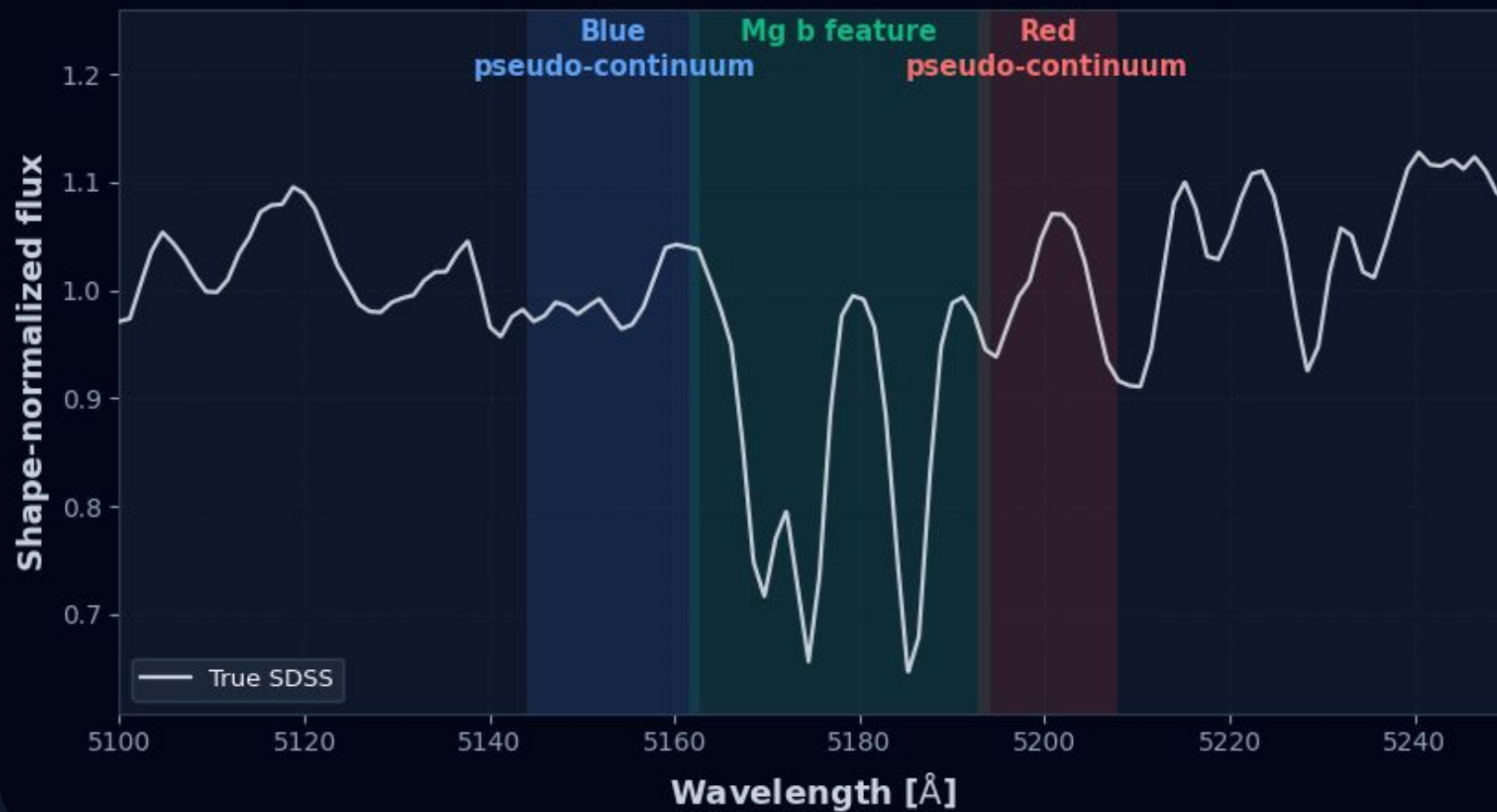
Capturing Epistemic Ambiguity: Deep Ensemble



- ▶ 5 identical models trained only on stars with different random seeds.
- ▶ Model disagreement defines the epistemic uncertainty.

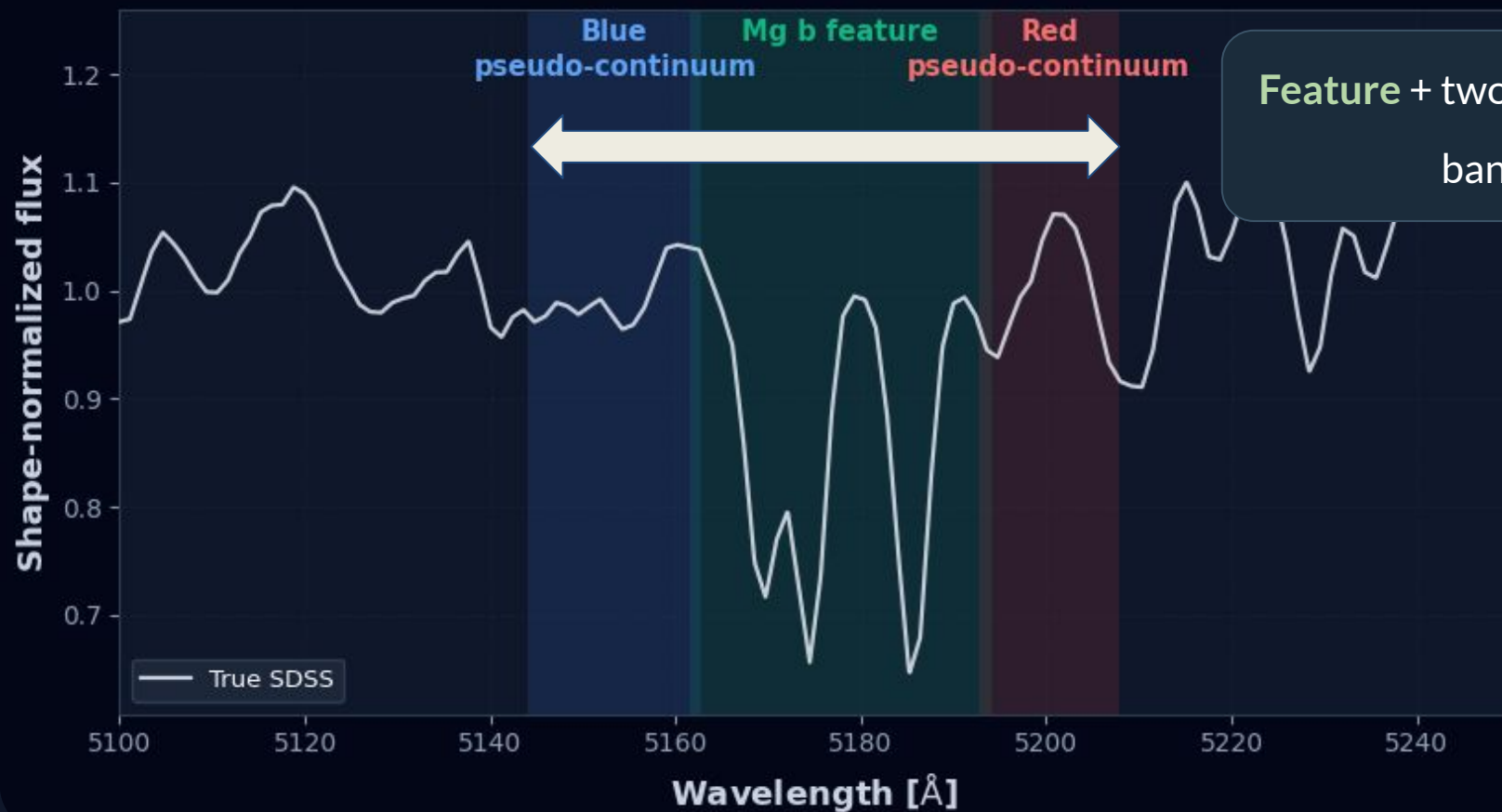
The **Payoff**: The **Mg b** Resolution Trap

Why Standard Mg b Fails in Gaia XP



The **Payoff**: The **Mg b** Resolution Trap

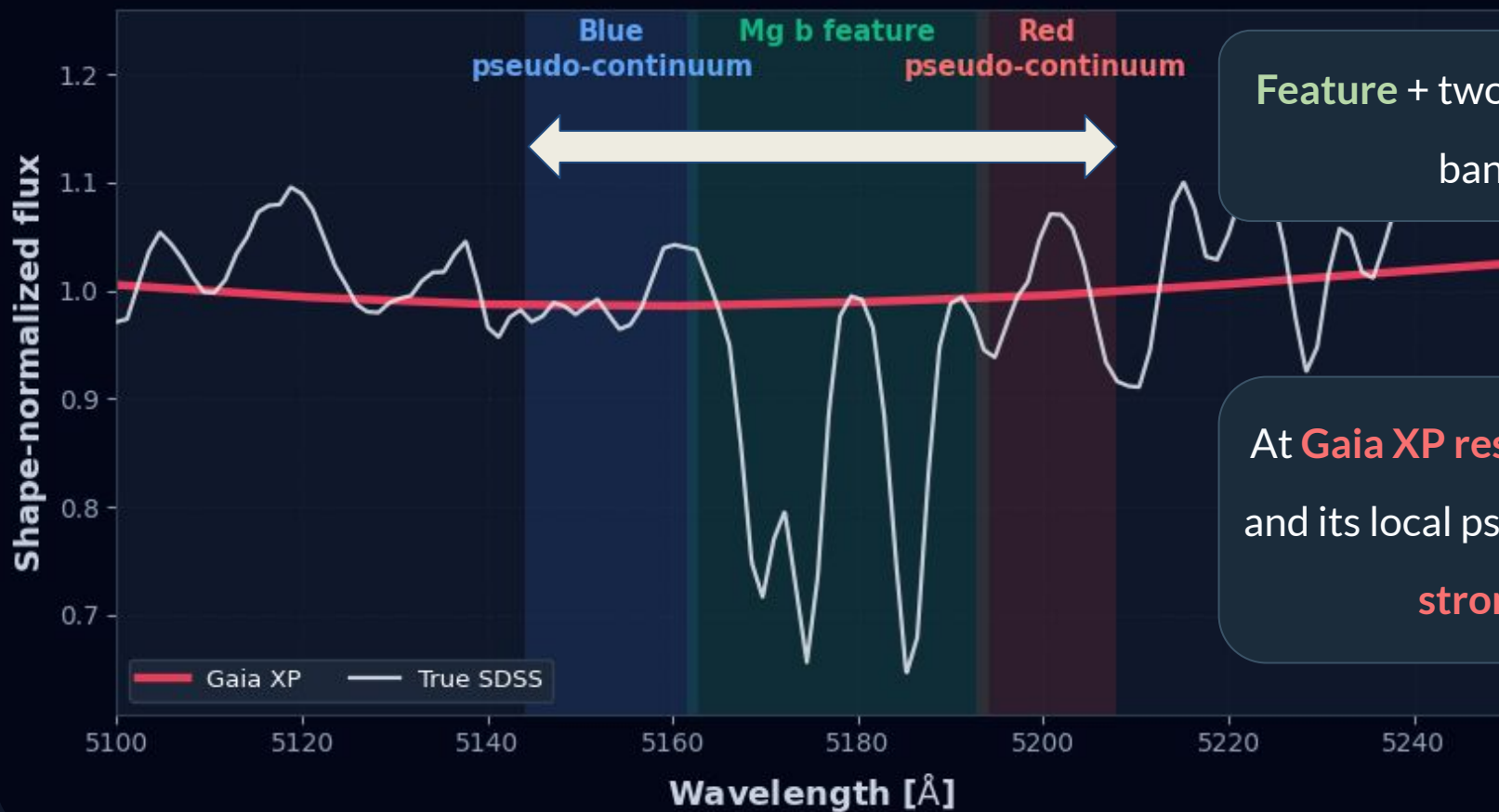
Why Standard Mg b Fails in Gaia XP



Feature + two pseudo-continuum
bands $\approx 64 \text{ \AA}$

The **Payoff**: The **Mg b** Resolution Trap

Why Standard Mgb Fails in Gaia XP

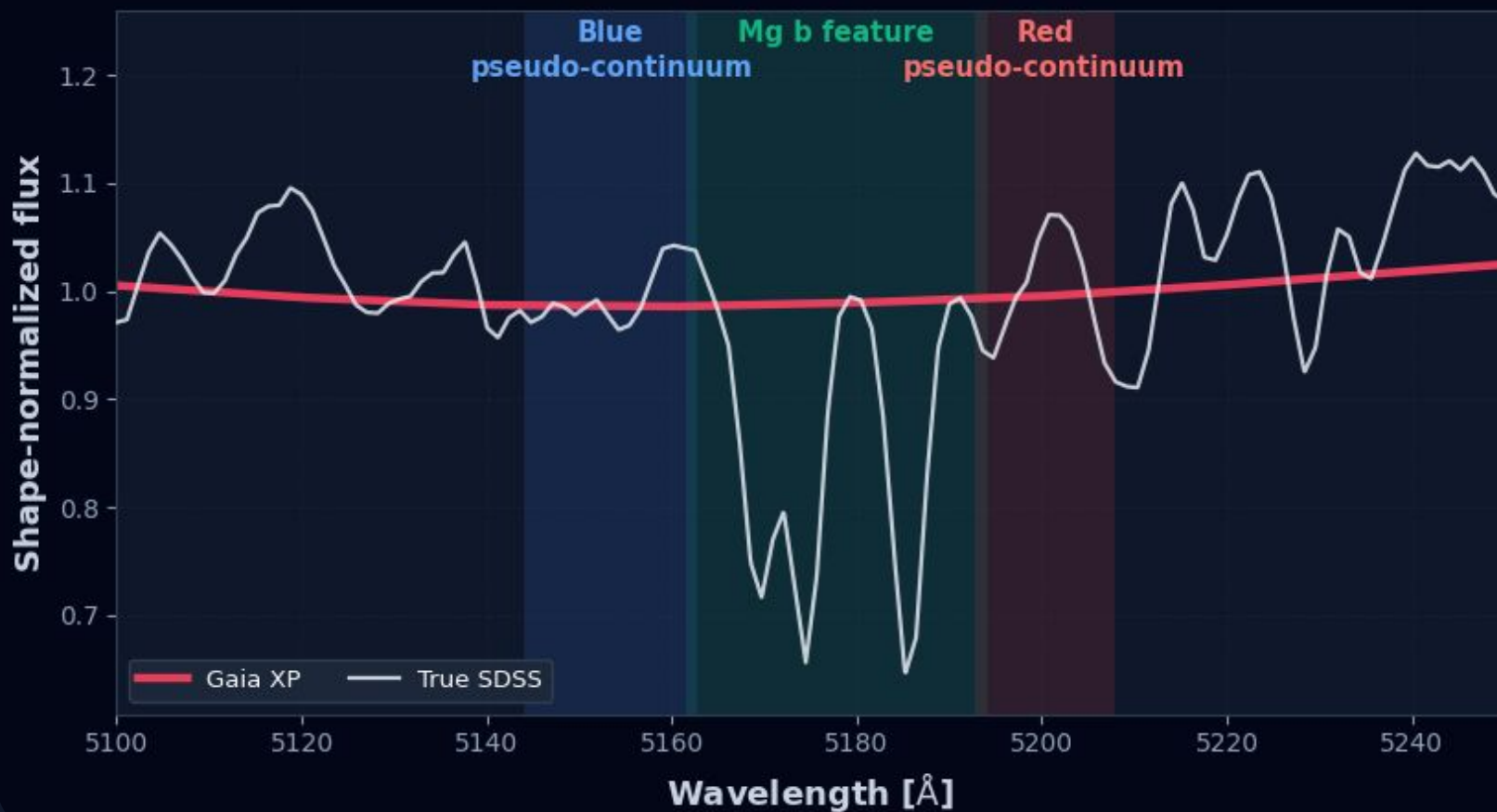


Feature + two pseudo-continuum
bands $\approx 64 \text{ \AA}$

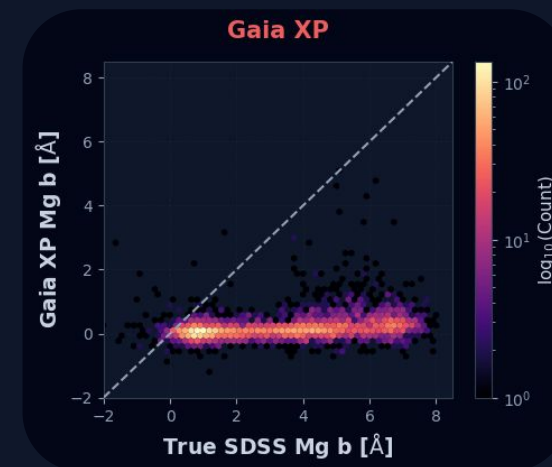
At **Gaia XP resolution**, the feature
and its local pseudo-continuum are
strongly mixed

The **Payoff**: The **Mg b** Resolution Trap

Why Standard Mg b Fails in Gaia XP

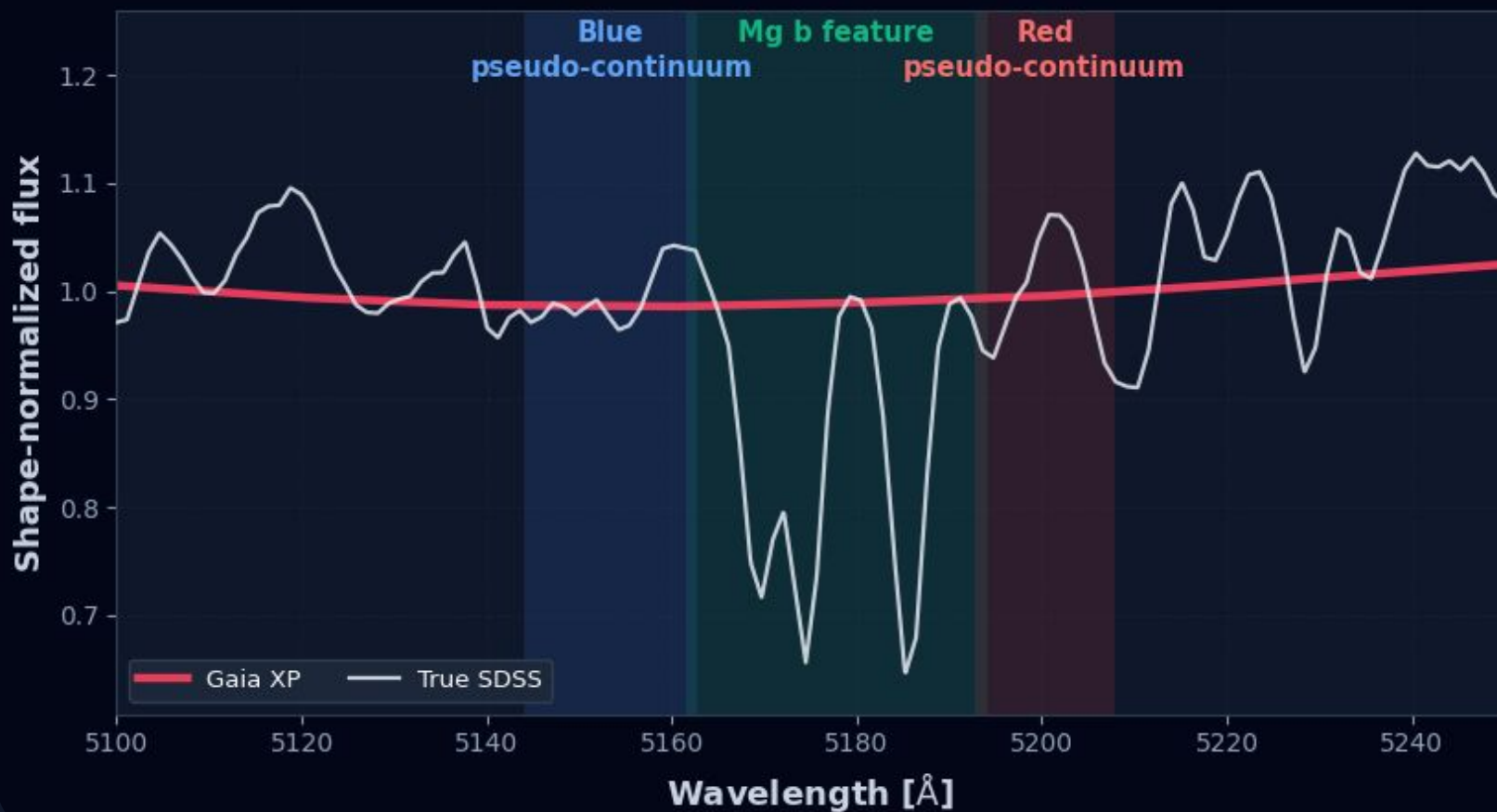


Mg b measured directly from the spectrum

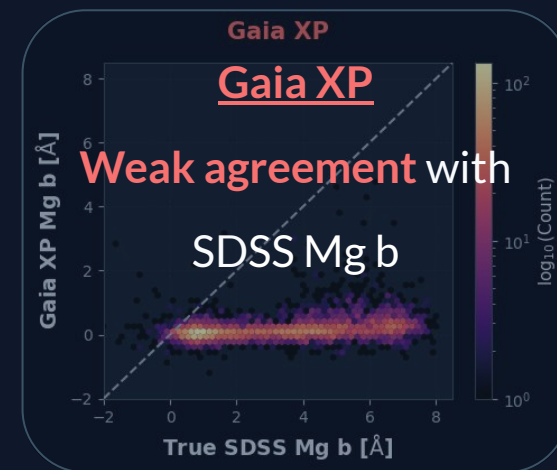


The Payoff: The Mg b Resolution Trap

Why Standard Mg b Fails in Gaia XP

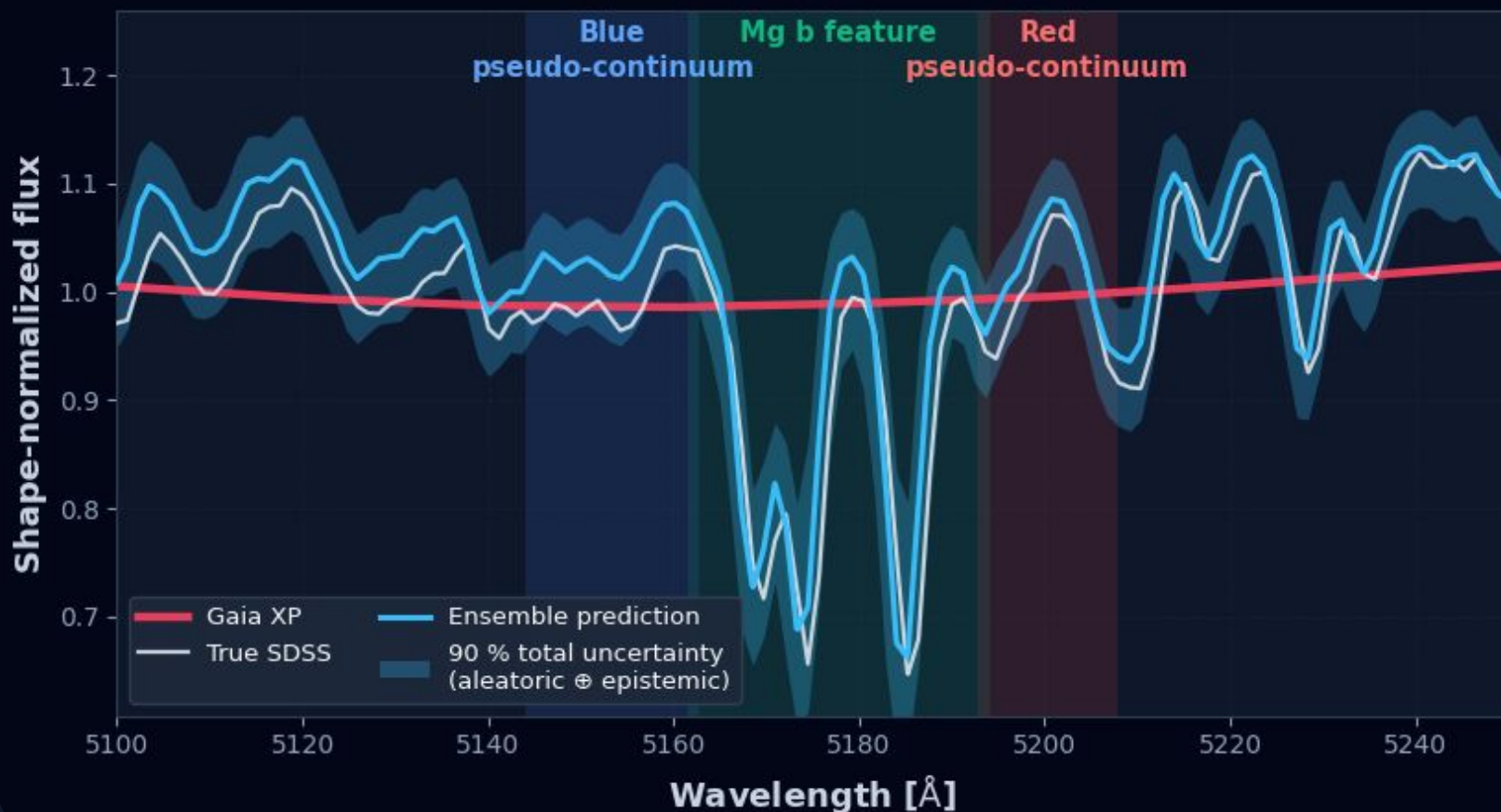


Mg b measured directly from the spectrum

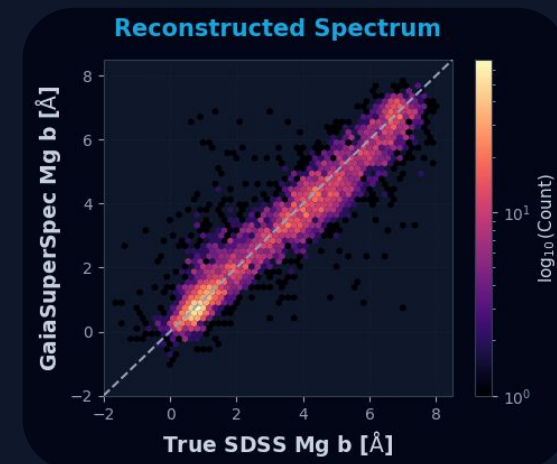
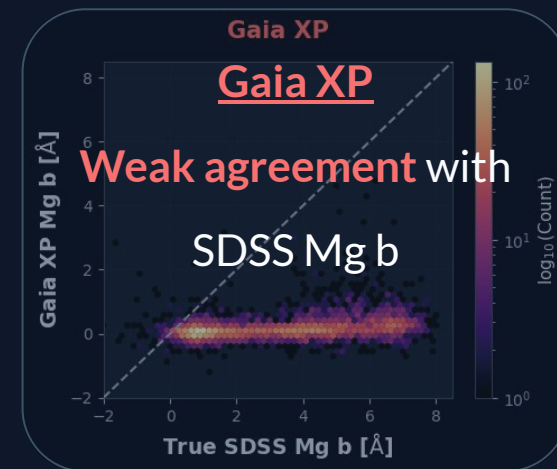


The Payoff: The Mg b Resolution Trap

Why Standard Mg b Fails in Gaia XP



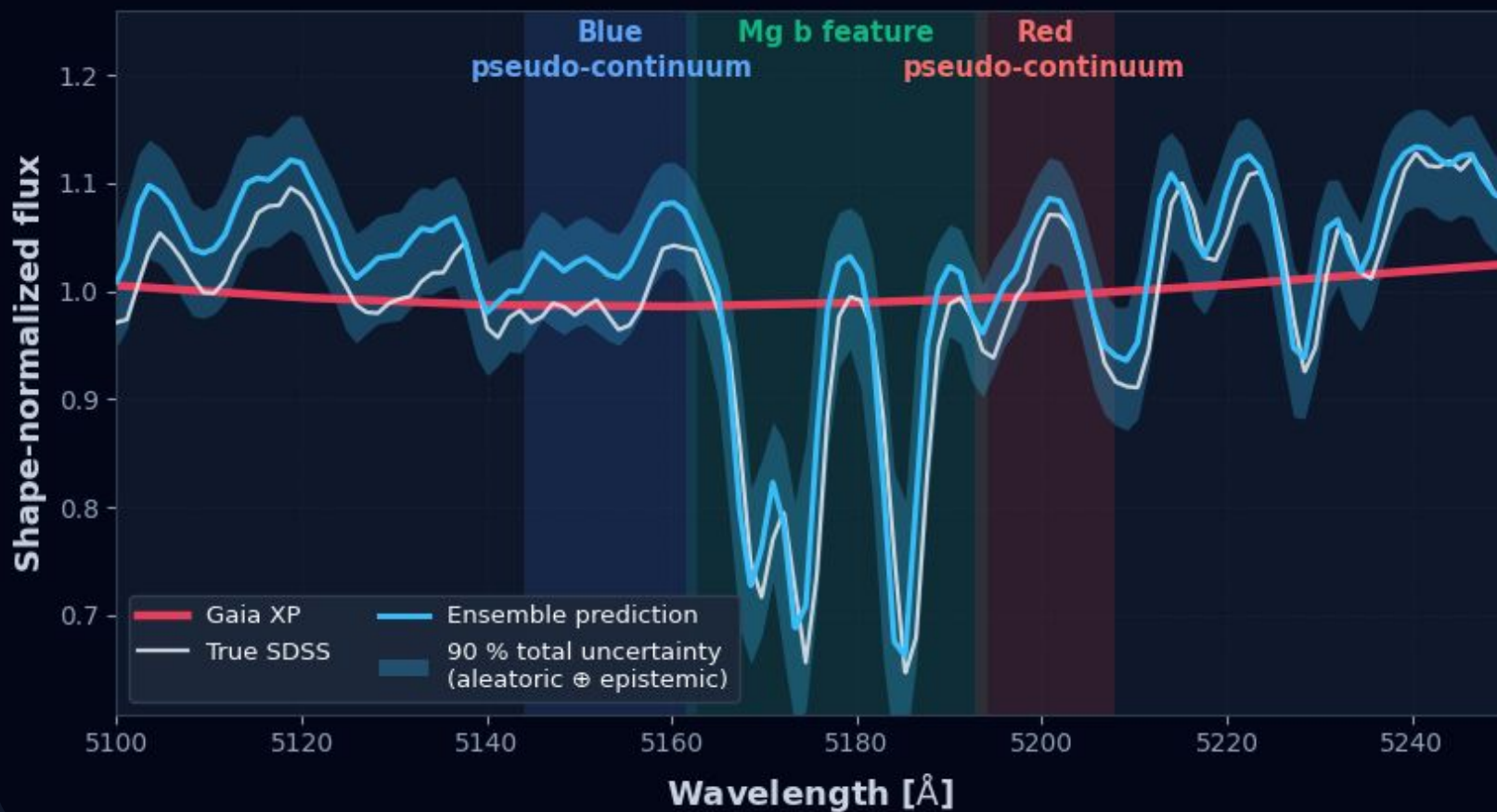
Mg b measured directly from the spectrum



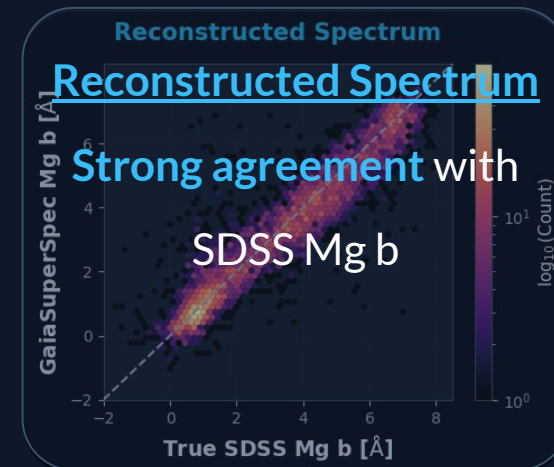
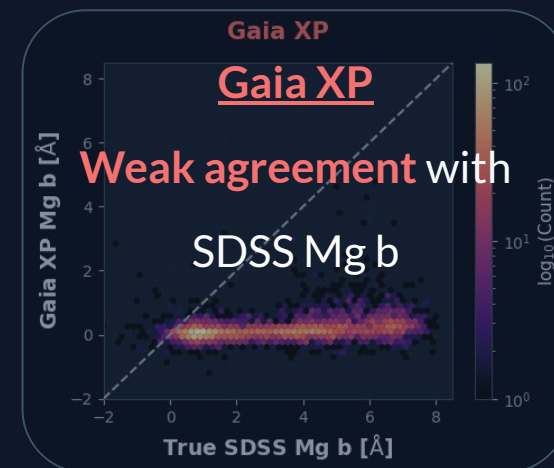
MAE: 3.11 → 0.50 Å

The Payoff: The Mg b Resolution Trap

Why Standard Mg b Fails in Gaia XP



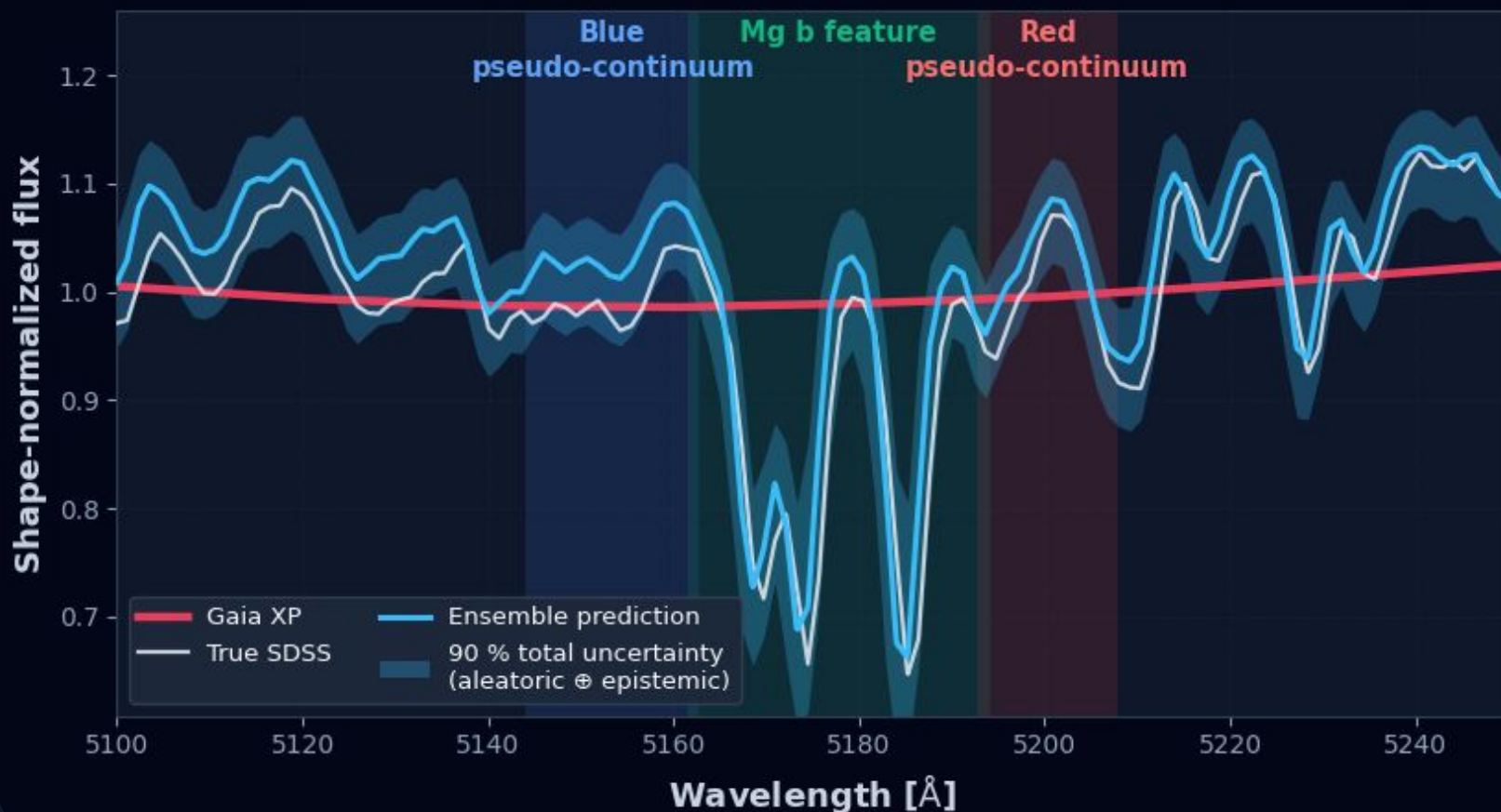
Mg b measured directly from the spectrum



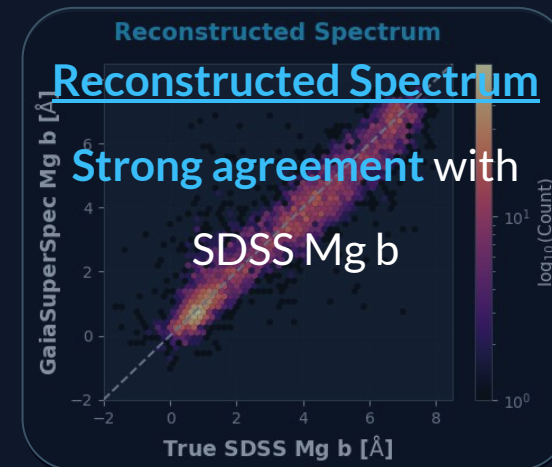
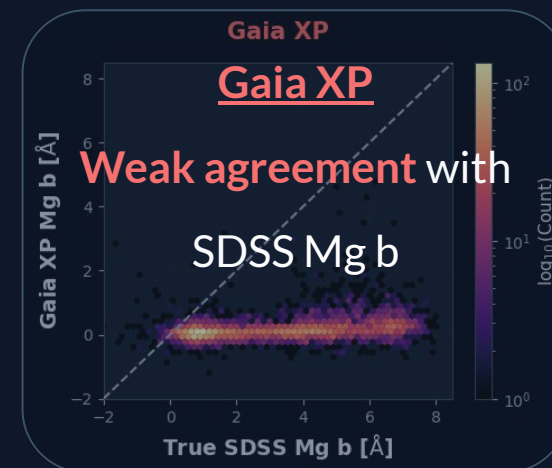
MAE: 3.11 → 0.50 Å

The Payoff: The Mg b Resolution Trap

Why Standard Mgb Fails in Gaia XP



Mg b measured directly from the spectrum

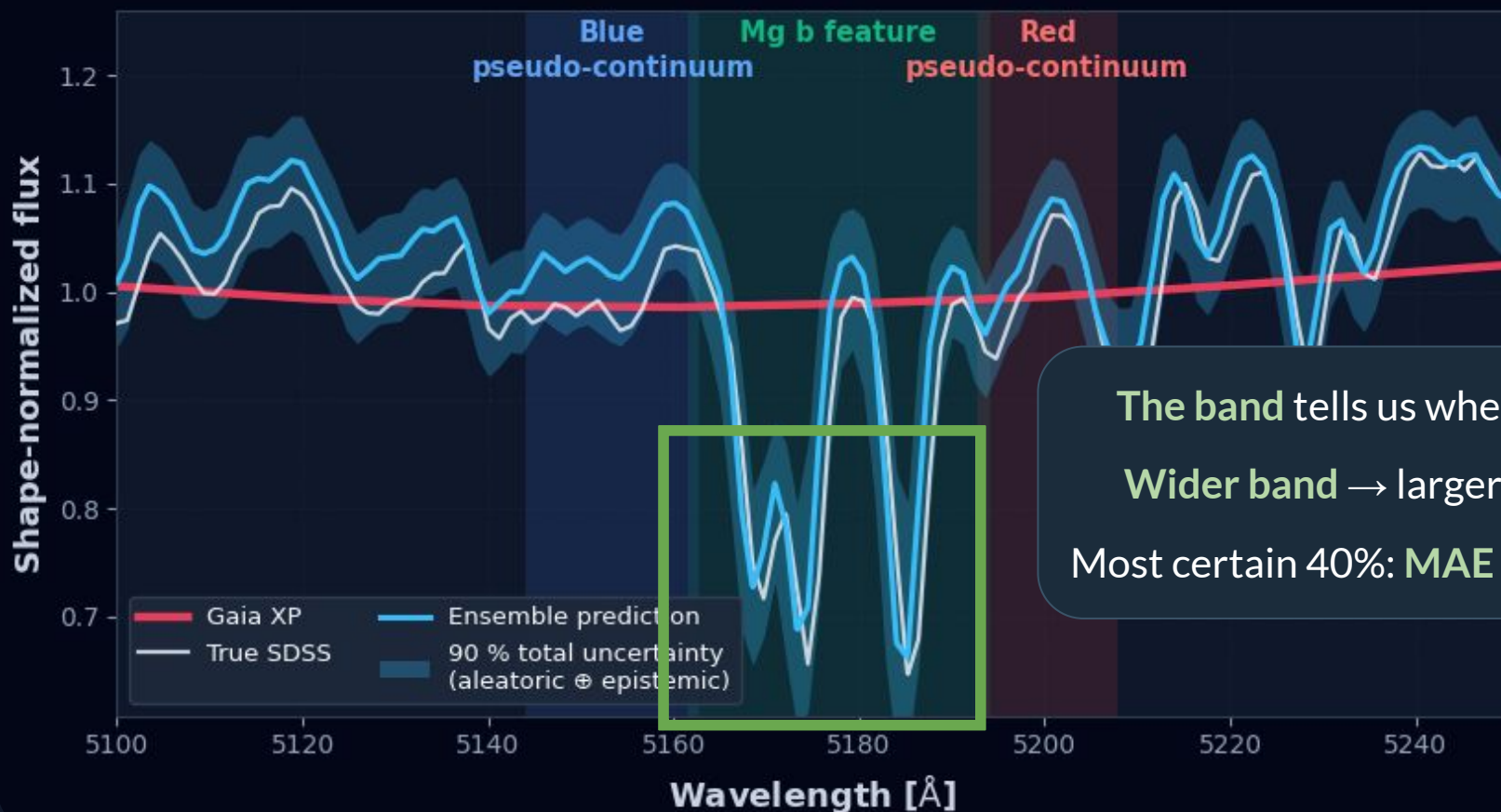


- ▶ The limitation is the spectral representation — not missing Mg information

MAE: 3.11 → 0.50 Å

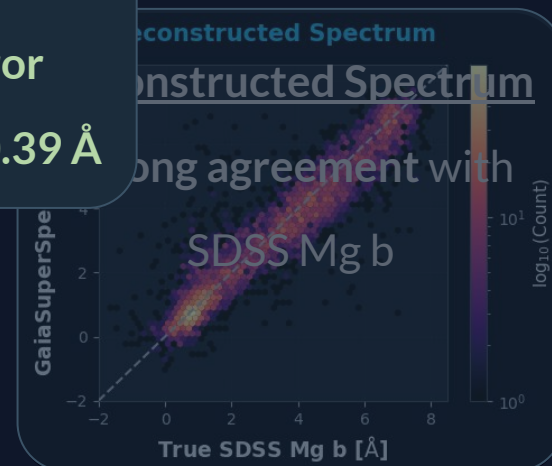
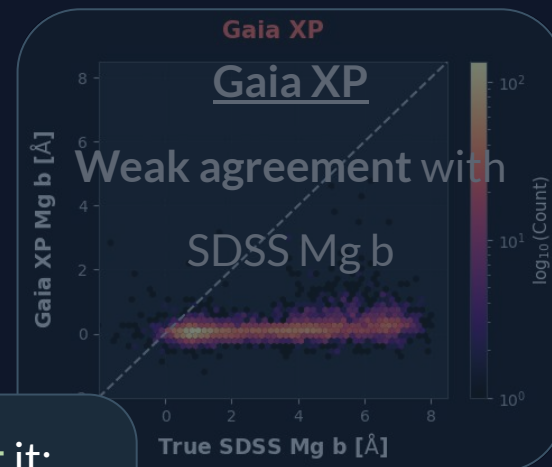
The Payoff: The Mg b Resolution Trap

Why Standard Mgb Fails in Gaia XP



The band tells us when to trust it:
Wider band → larger Mg b error
Most certain 40%: MAE 0.53 → 0.39 Å

Mg b measured directly from the spectrum



► The limitation is the spectral representation – not missing Mg information

MAE: 3.11 → 0.50 Å