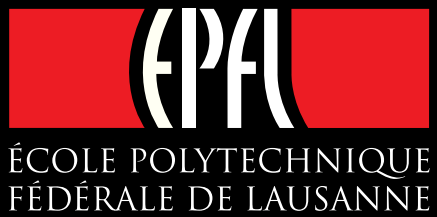
Machine learning for PSF characterisation and interpolation



Thibault Kuntzer

Frédéric Courbin

CEA

17 October 2016

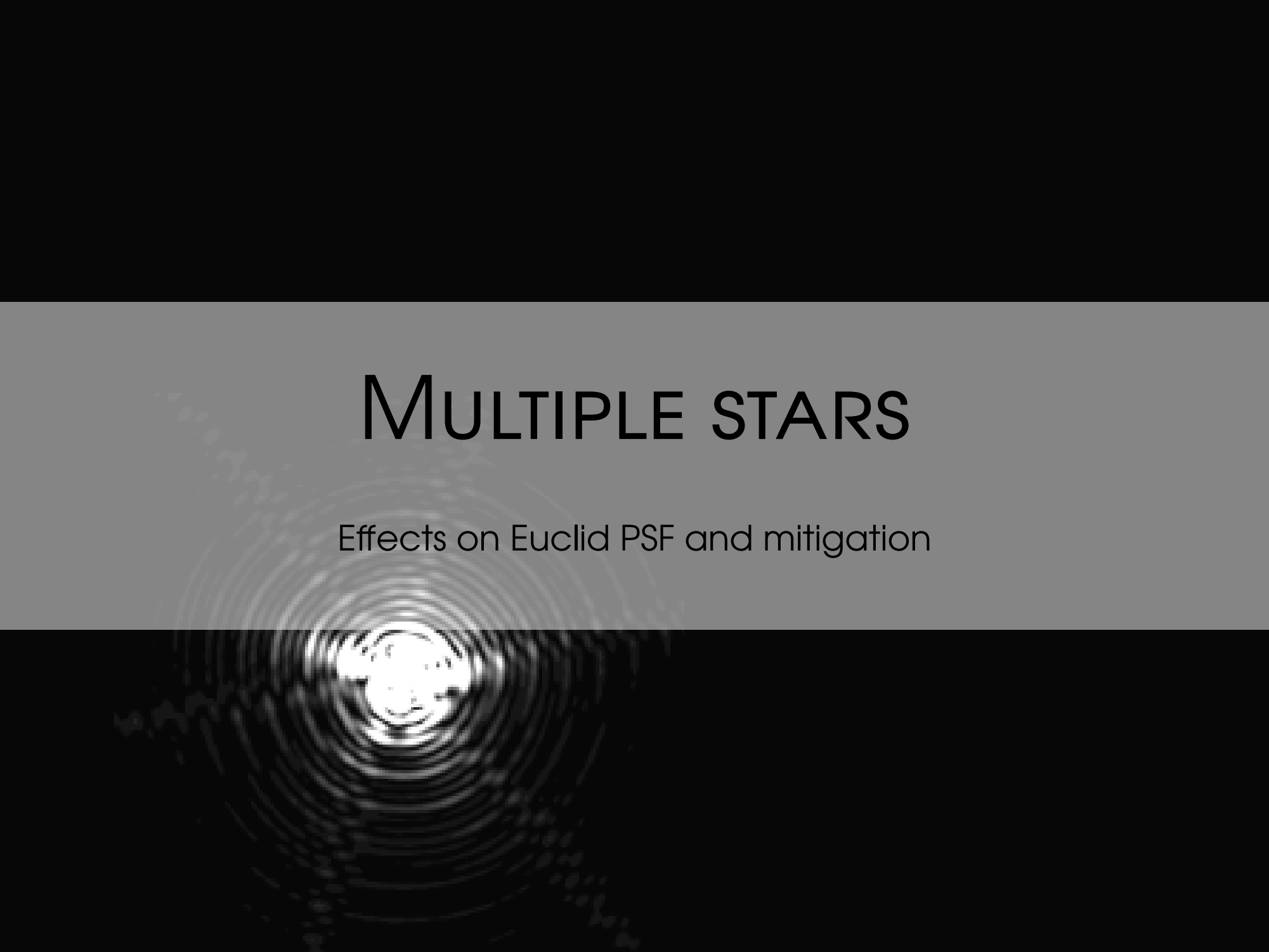
PDF available at **http://obswww.unige.ch/∼kuntzer/talks/cea_psf_kuntzer.pdf**

Outline

- Binaries issue, PSF systematics & mitigation
- Building a colour-magnitude diagram with one filter
- PSF interpolation revisited

Multiple stars

Effects on Euclid PSF and mitigation



PSF requirements and measurement

- Measured shear power spectrum

$$\hat{C} \approx (1 + \mathcal{M})C + \mathcal{A}, \qquad \mathcal{M}, \mathcal{A} \sim \langle |\delta e_{\mathrm{PSF}}|^2 \rangle, \langle \delta R^2_{\mathrm{PSF}} \rangle$$

- Science requirement for the PSF shape:

size rms (relative)	$\frac{\sigma(R^2)}{\langle R^2 \rangle} \leq 10^{-3}$
ellipticity rms	$\sigma(e_i) \leq 10^{-4}$
ellipticity	$e_i < 0.15$

From Paulin-Henriksson+2008

- Performance needed for measurement

size	$\sim 5\%$
ellipticity	$\sim 1\%$

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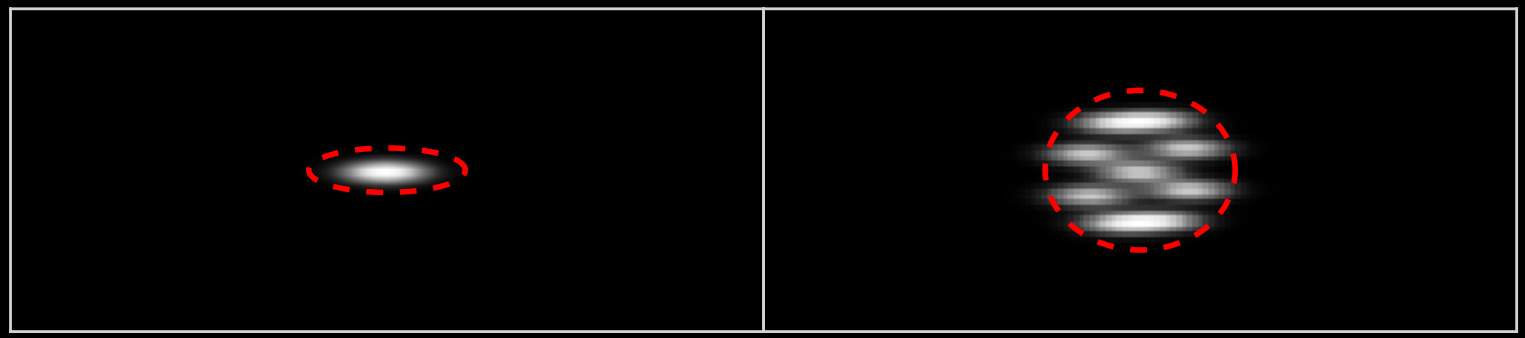

- Unresolved objects affect the convolution kernel
- Multiple stars are ubiquitous ($\gtrsim$ 35%)

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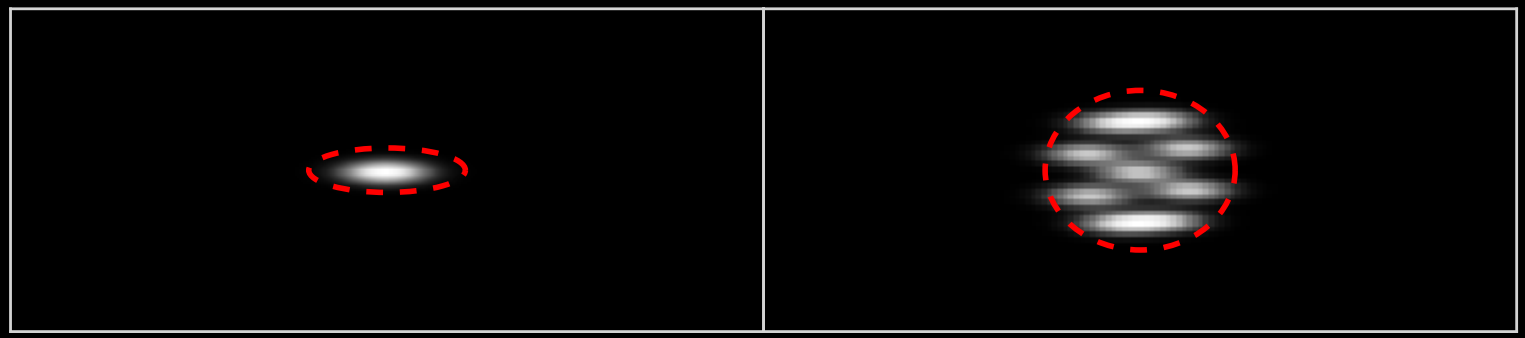

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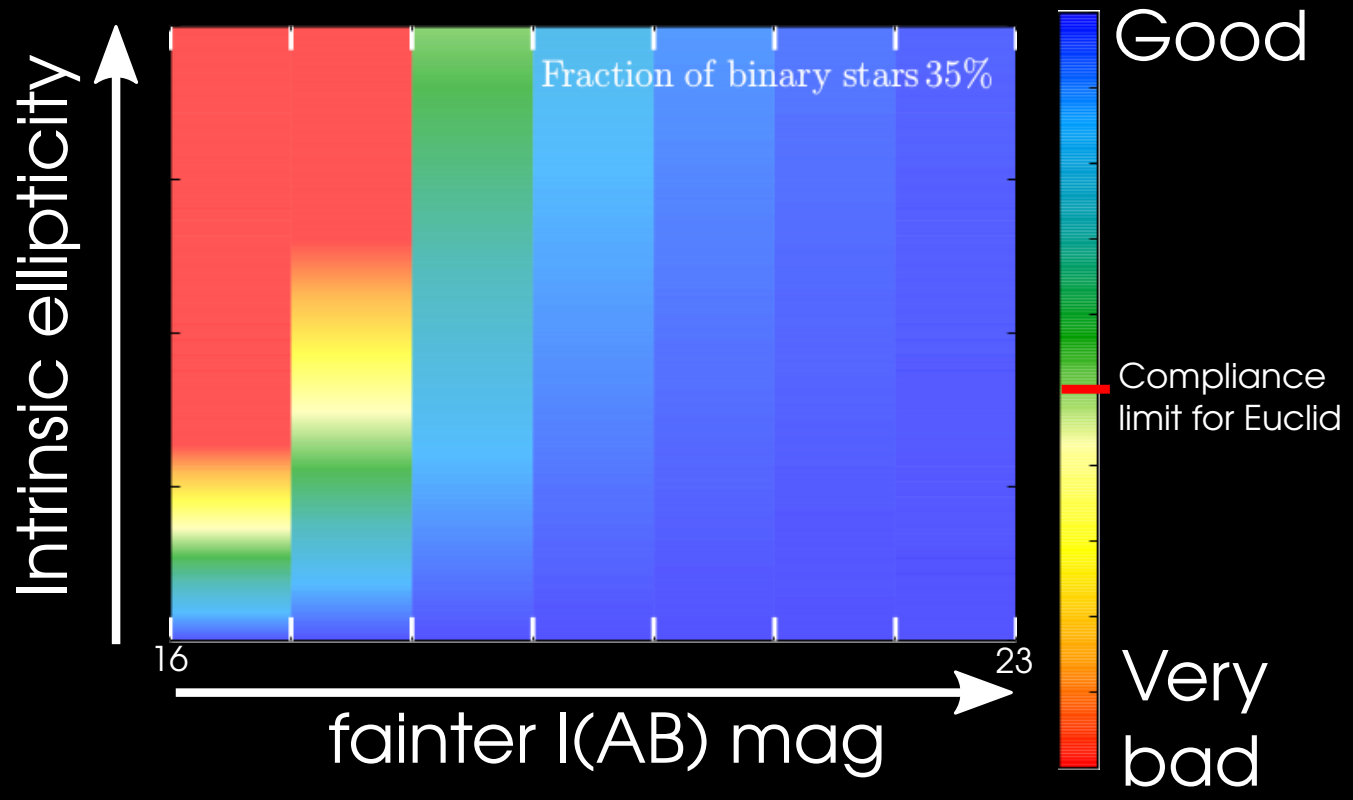
Predictions in an ideal world



- Stars $i(AB) \lesssim 18$: Non compliant
- Stars $i(AB) \lesssim 20$: Significant part of budget

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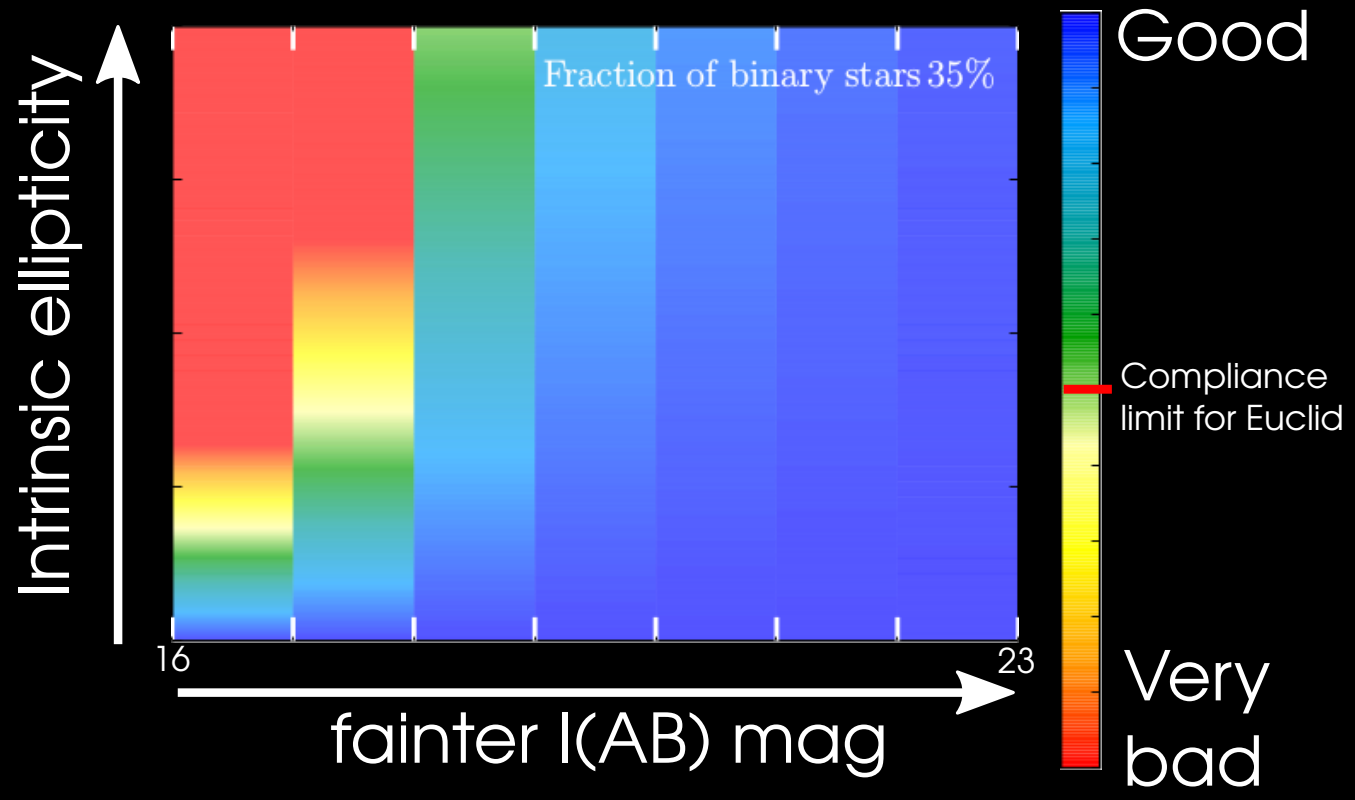

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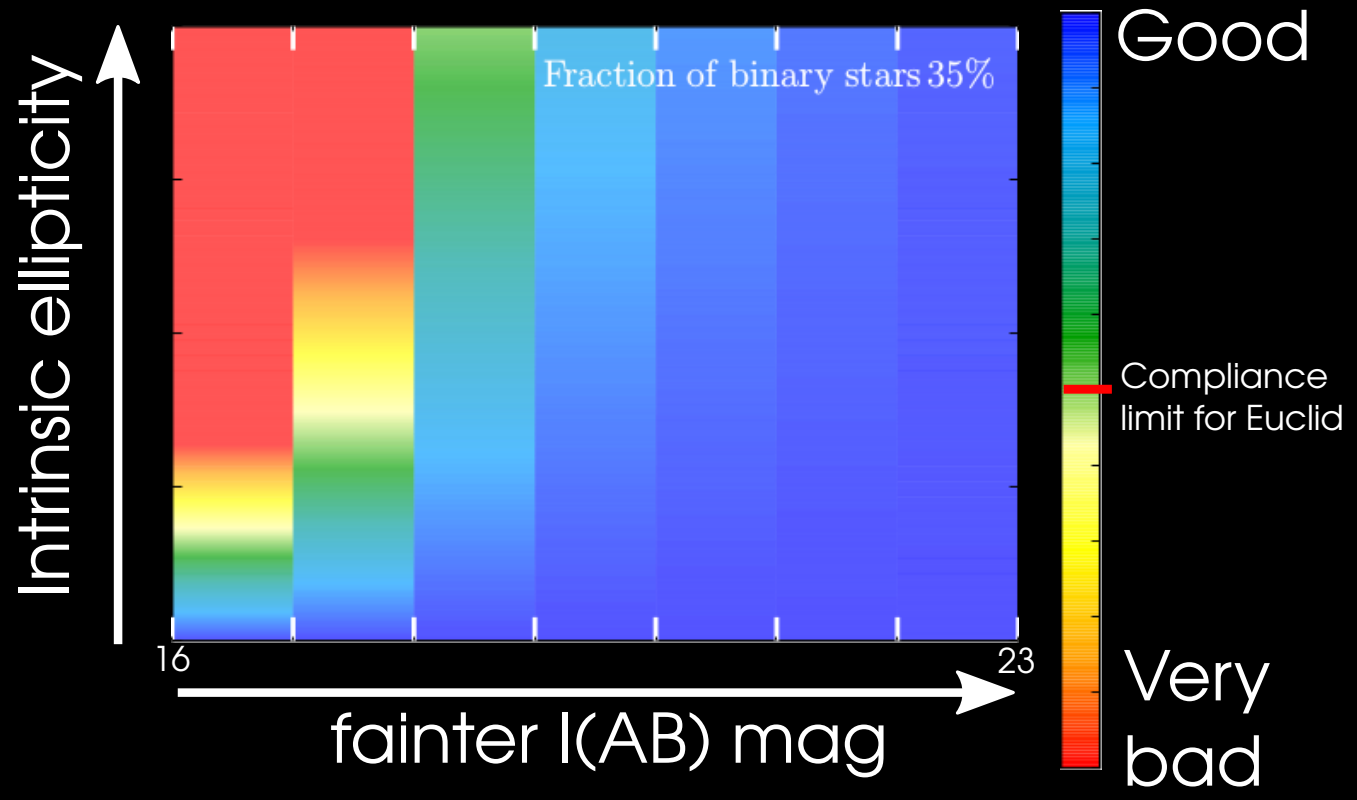

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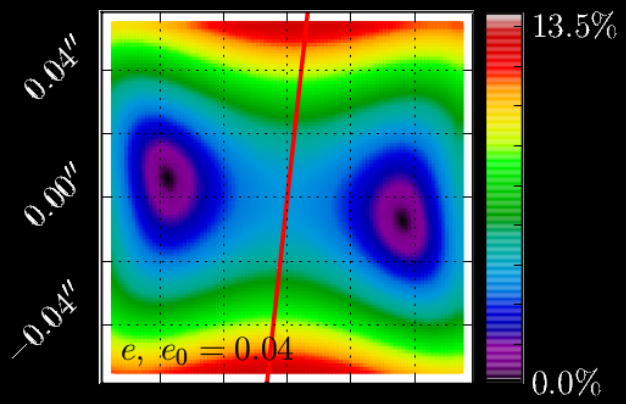
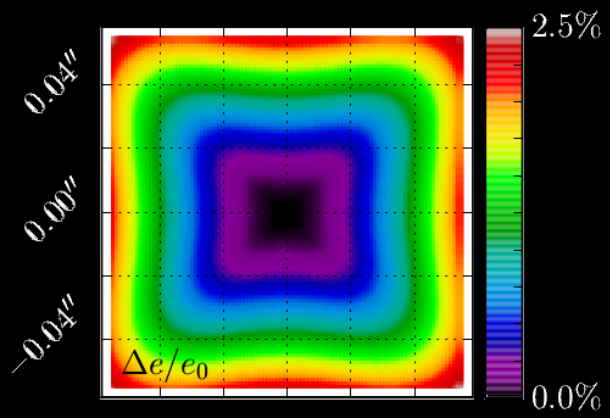
Alterations of the PSF due to a single companion

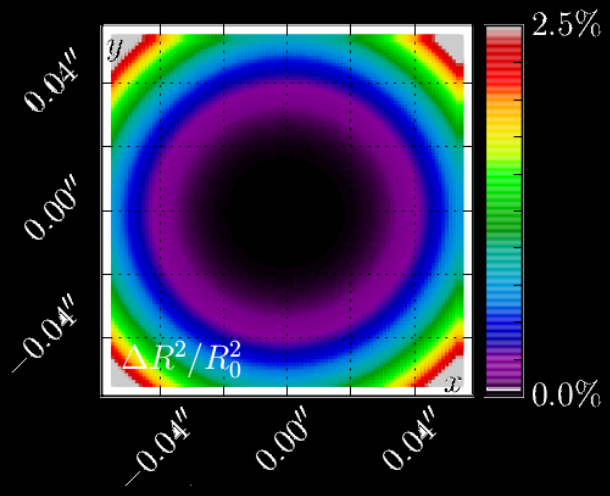
e



$\frac{\Delta e}{e_0}$



$\frac{\Delta R^2}{R_0^2}$



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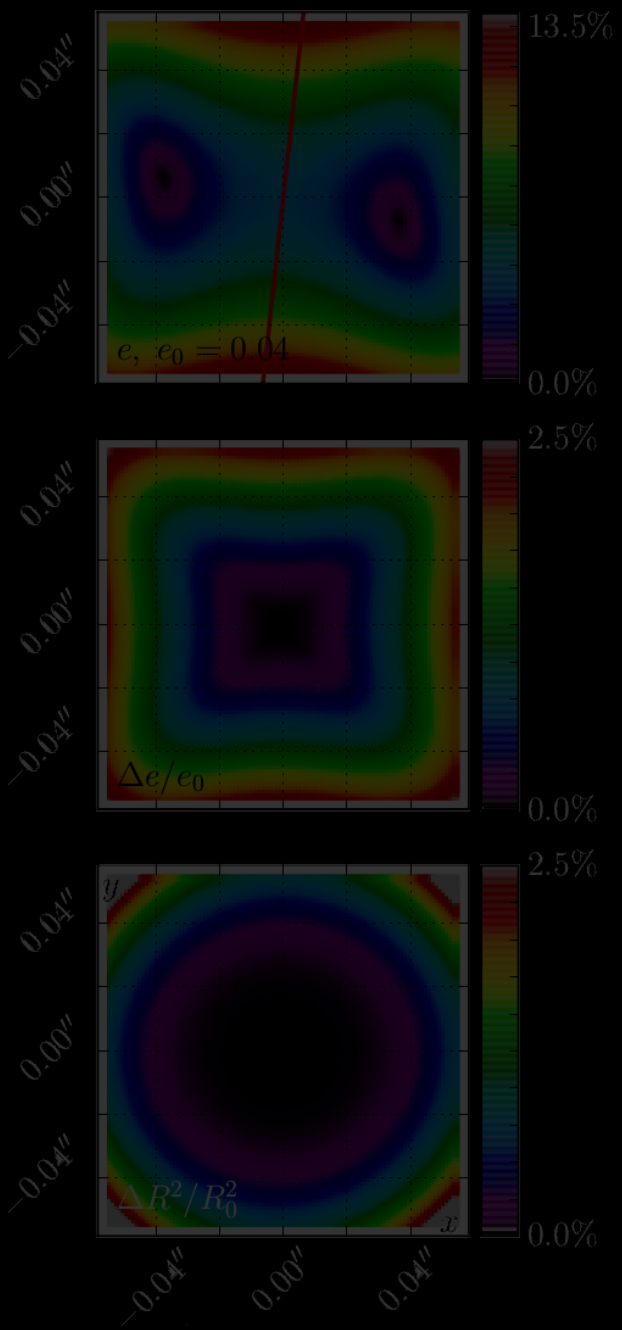
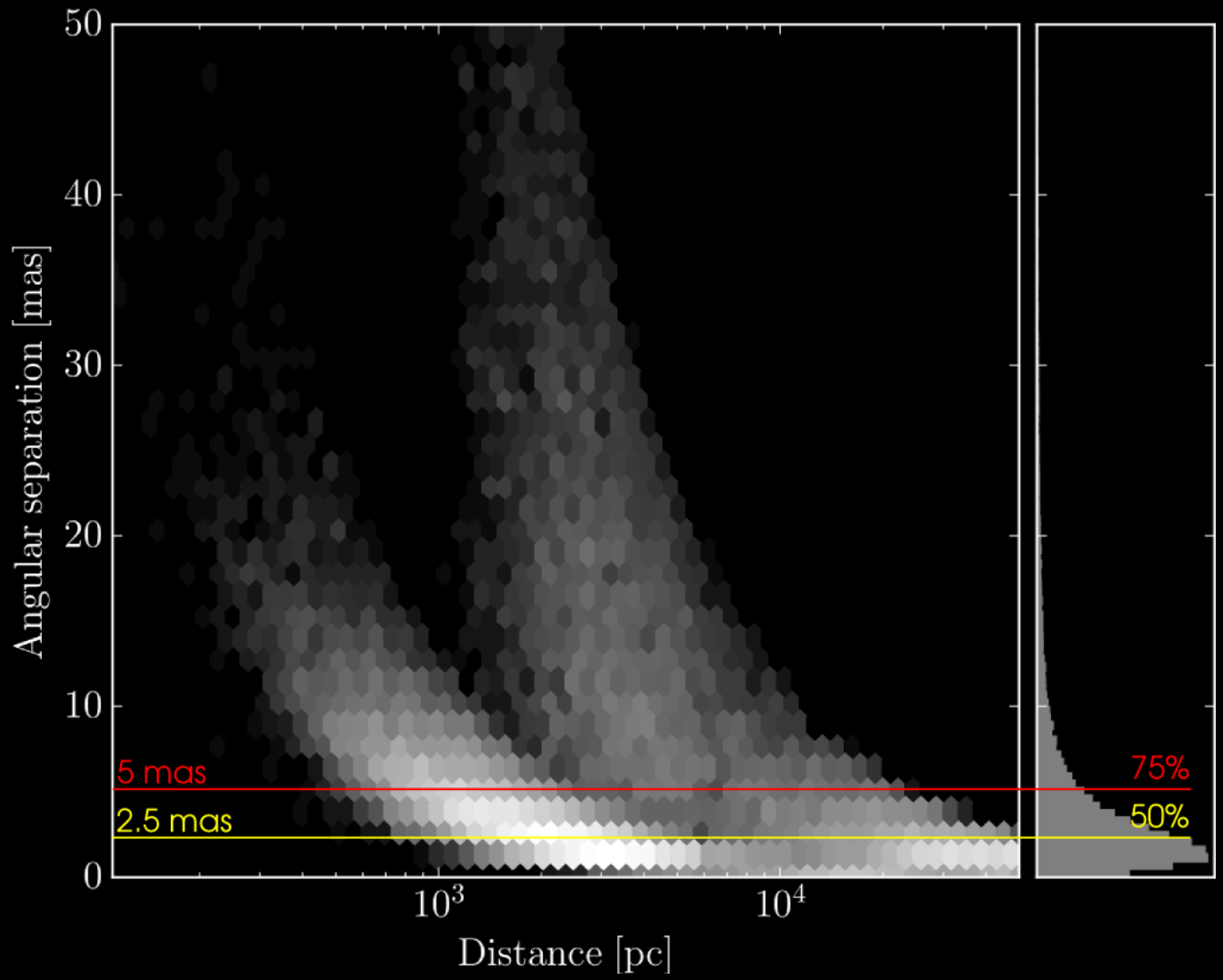


size	∼ 5%
ellipticity	∼ 1%

The binaries in the sky of Euclid



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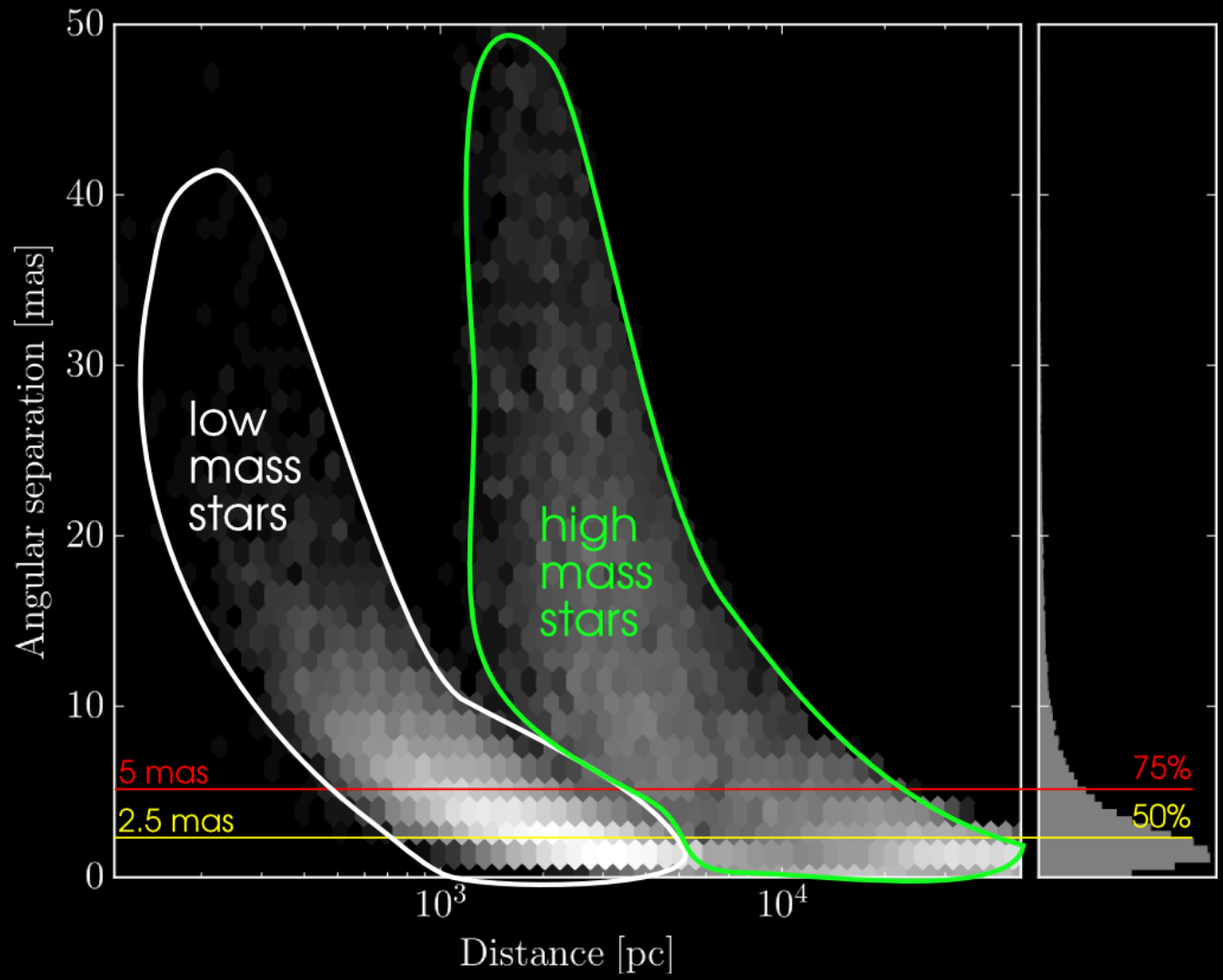

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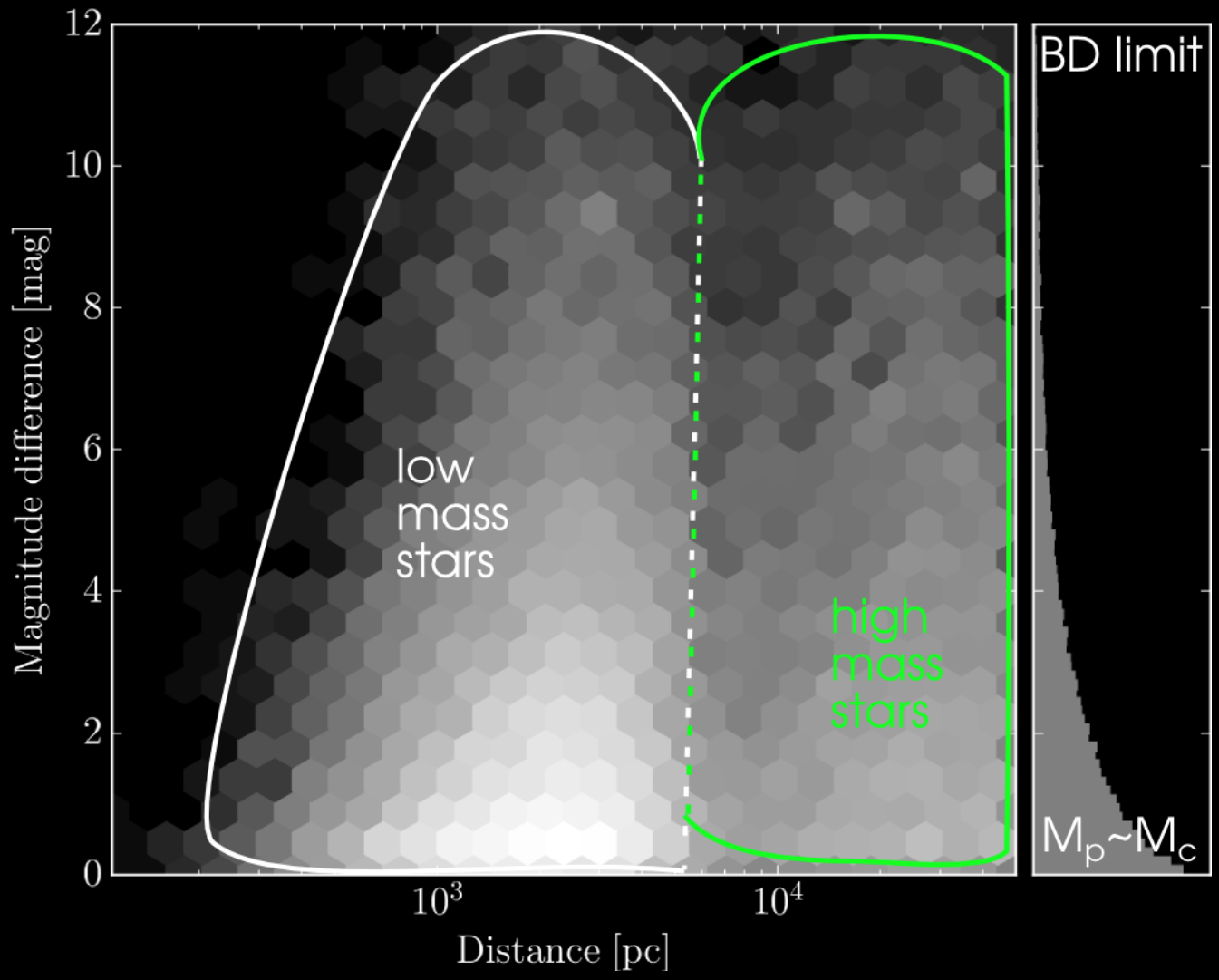

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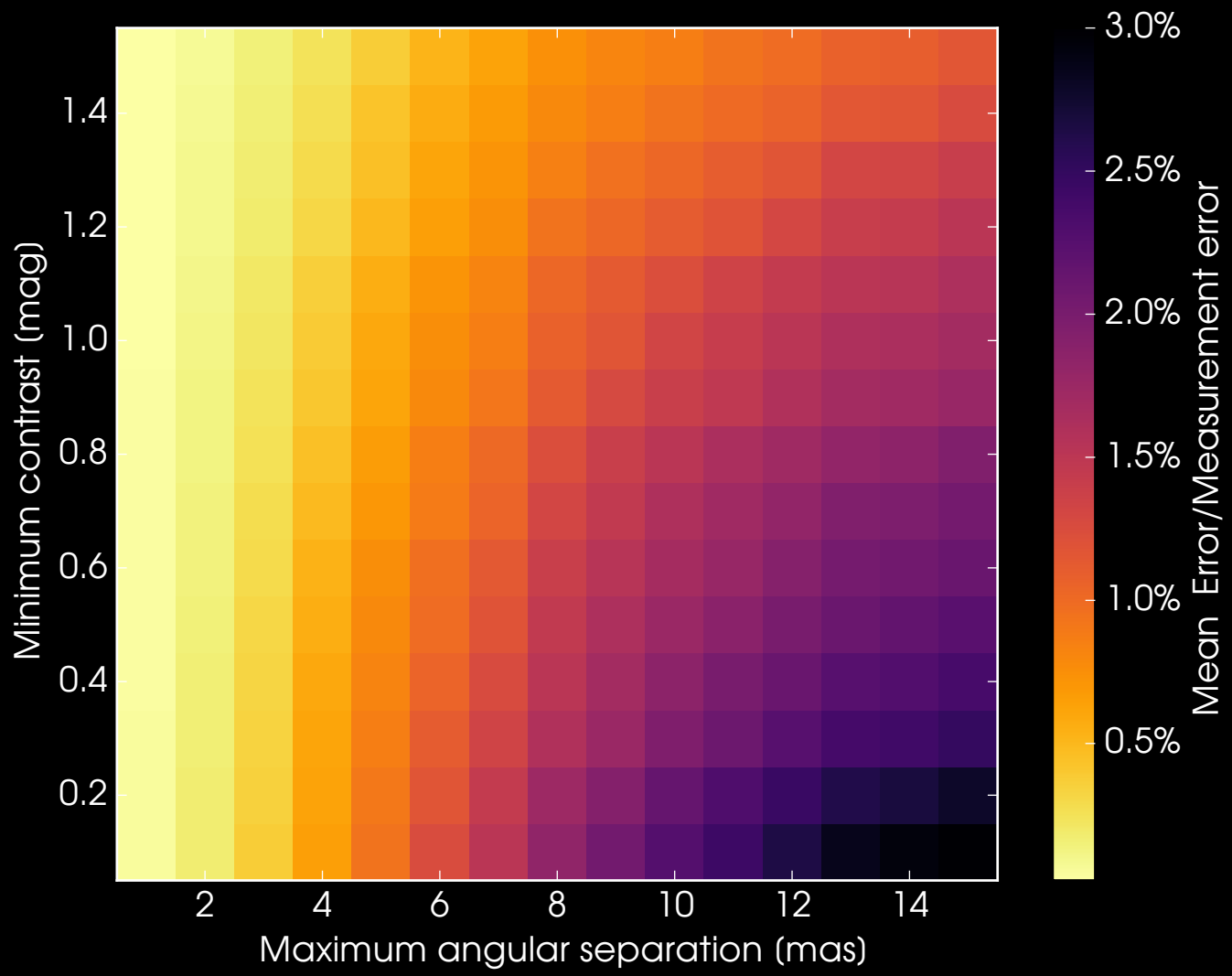
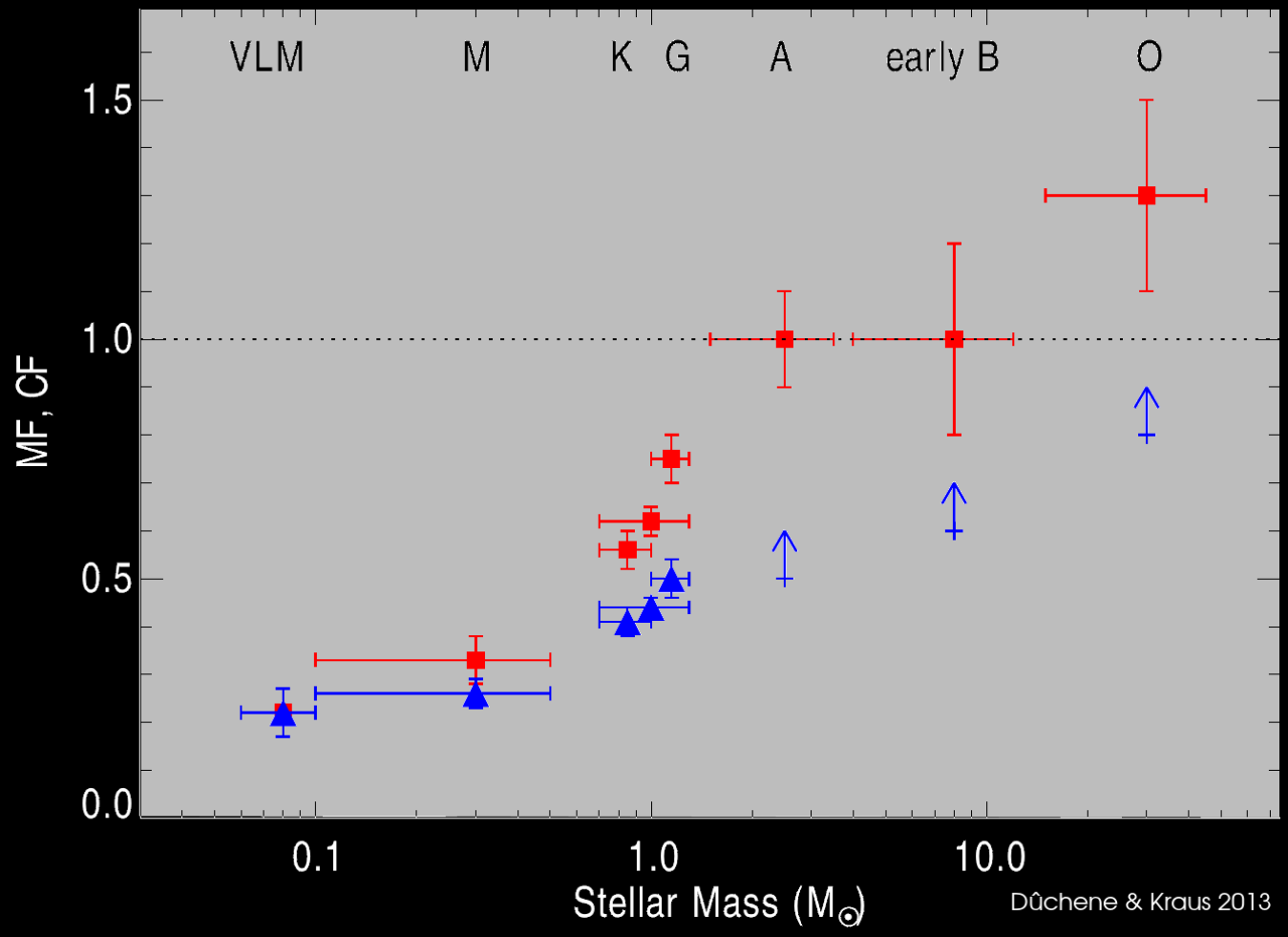
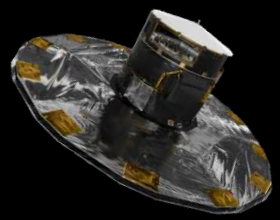


Identifying multiple stars?



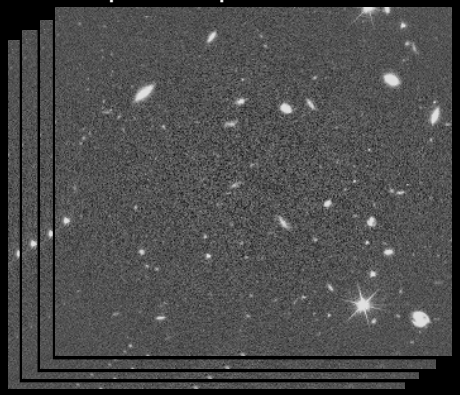


Star w/in specs => use!

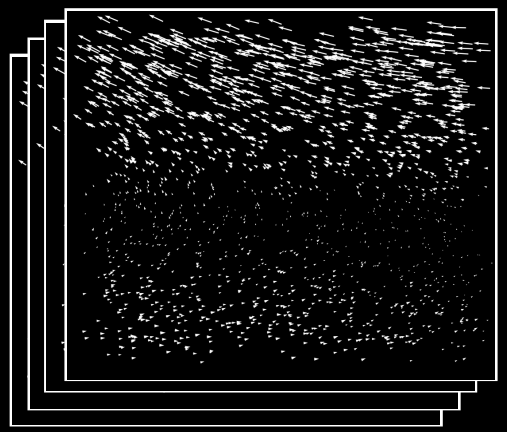
multiple star => reject!

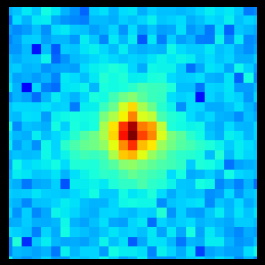
Identifying multiple stars?

Multiple exposures



PSF measurements





Spectral class

Cross exposure analysis

Correlated noise?

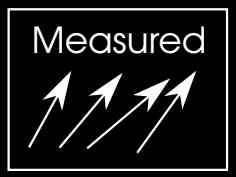
Not measurable: single star w/in specs => use!

Yes: might be a multiple star => reject!

P(binary) low => use!

P(binary) high => reject!

Exploiting correlated noise



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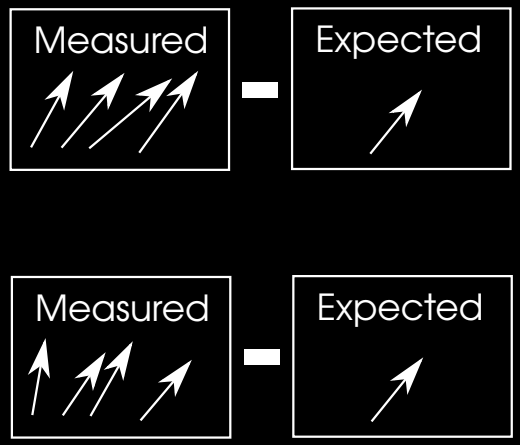

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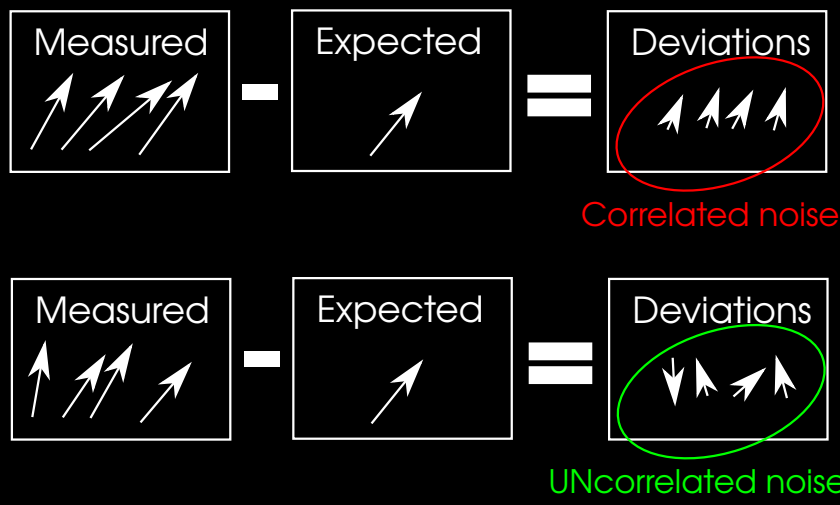
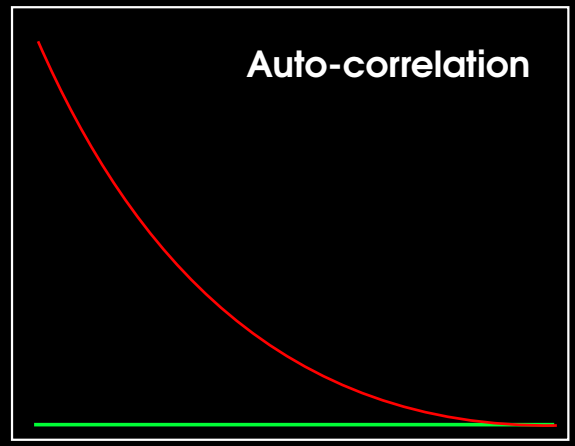


Data-driven



Model-dependent

Reconstructing the PSF field

For every star:

- Interpolate PSF parameter at position (Out-of-bag prediction)
- Measured PSF parameter − interpolated
- Infer binary presence from systematic bias

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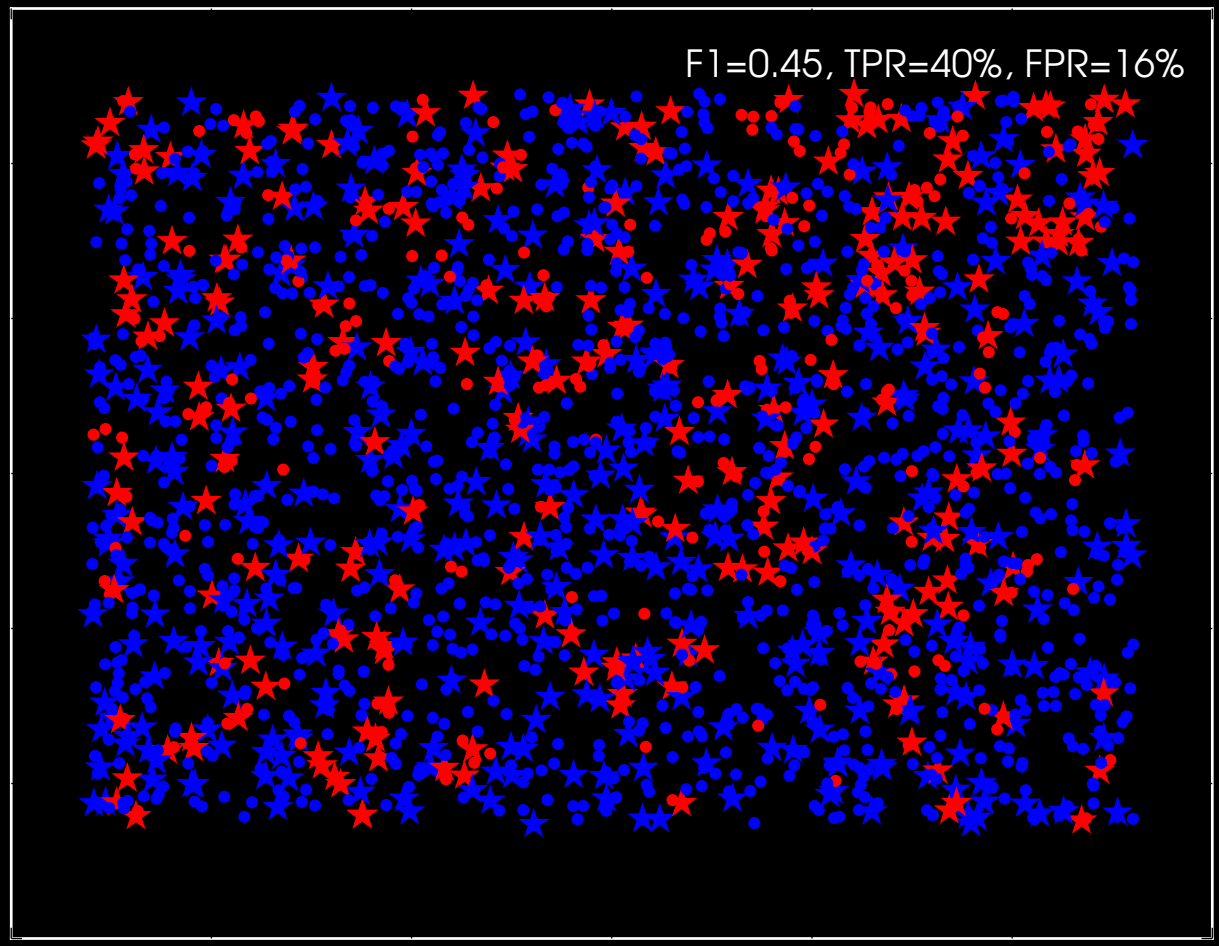

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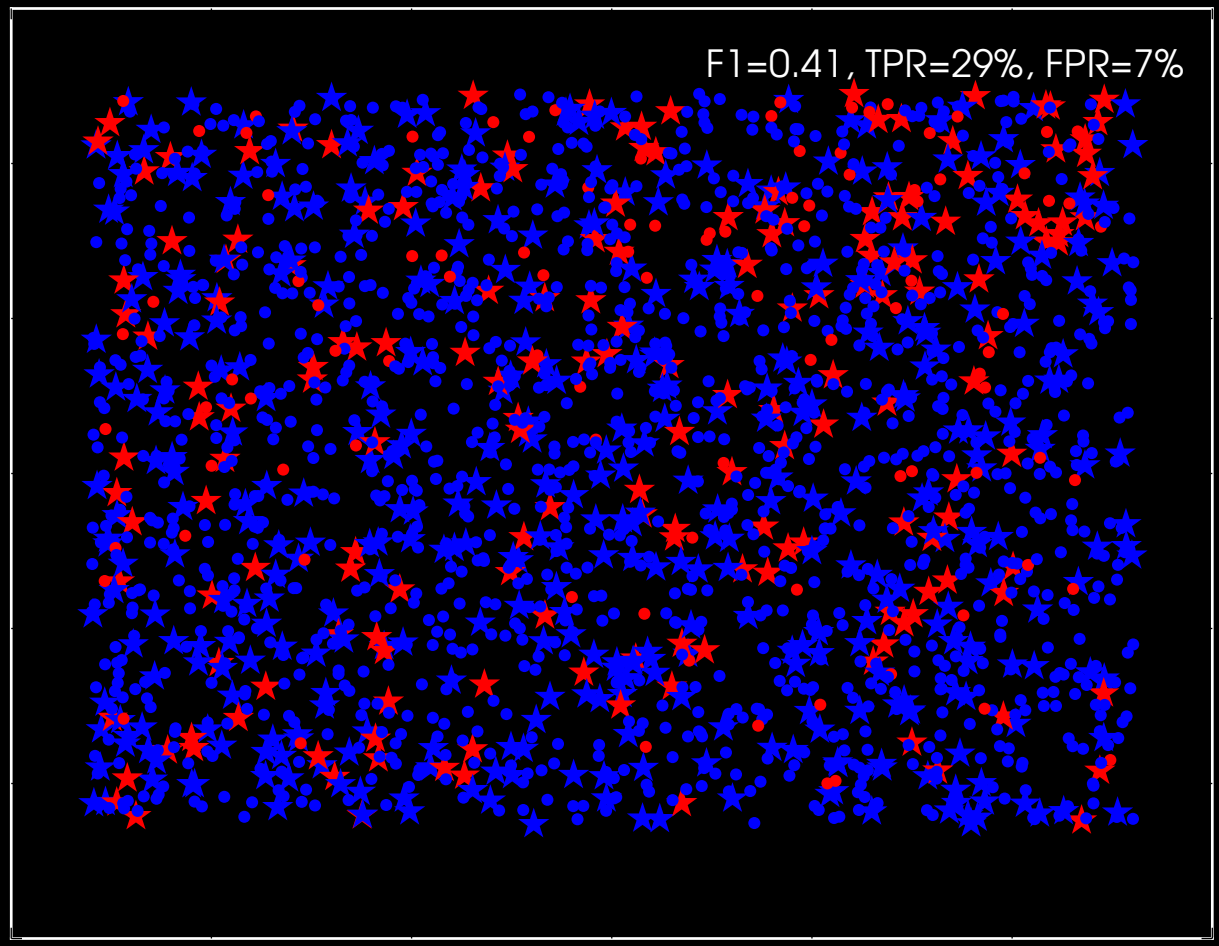

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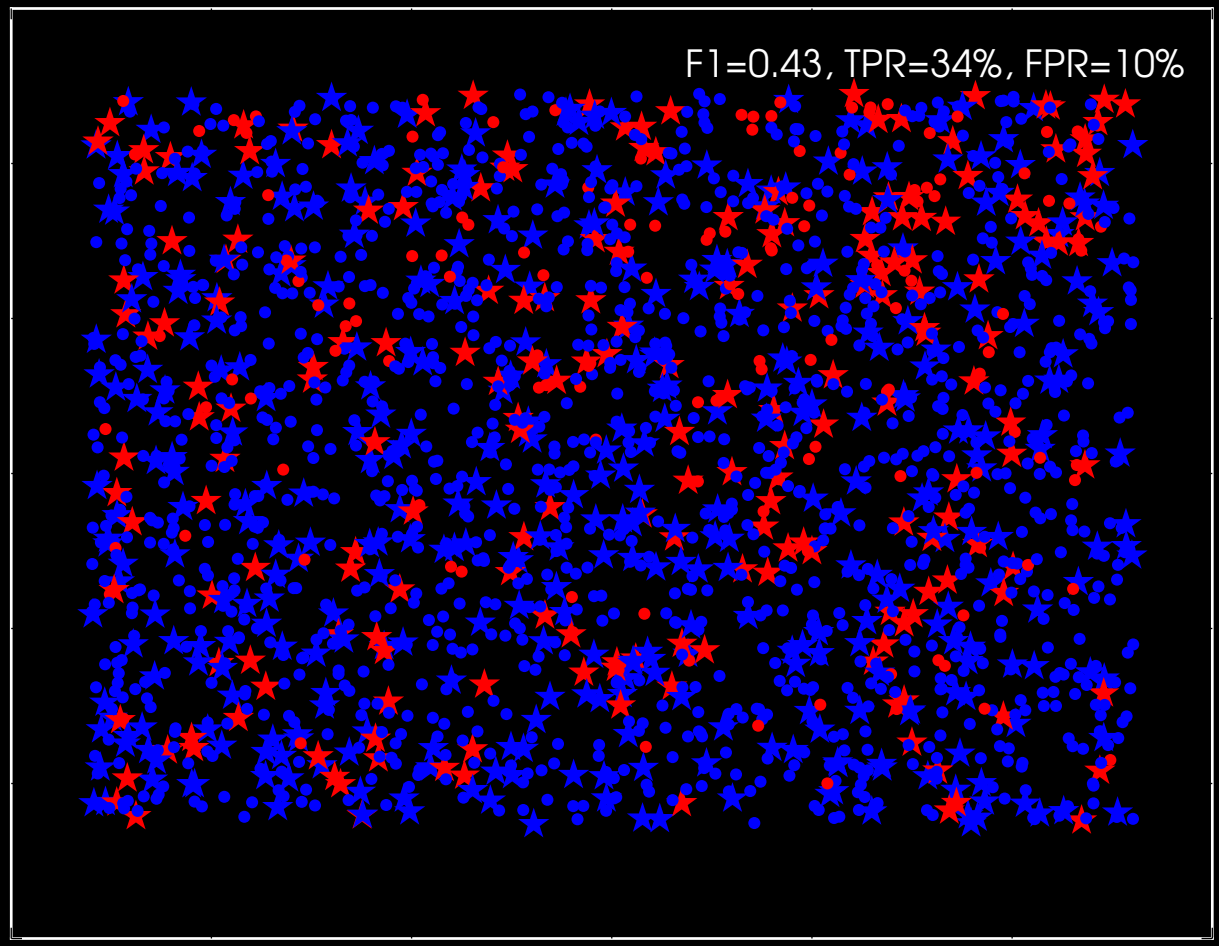

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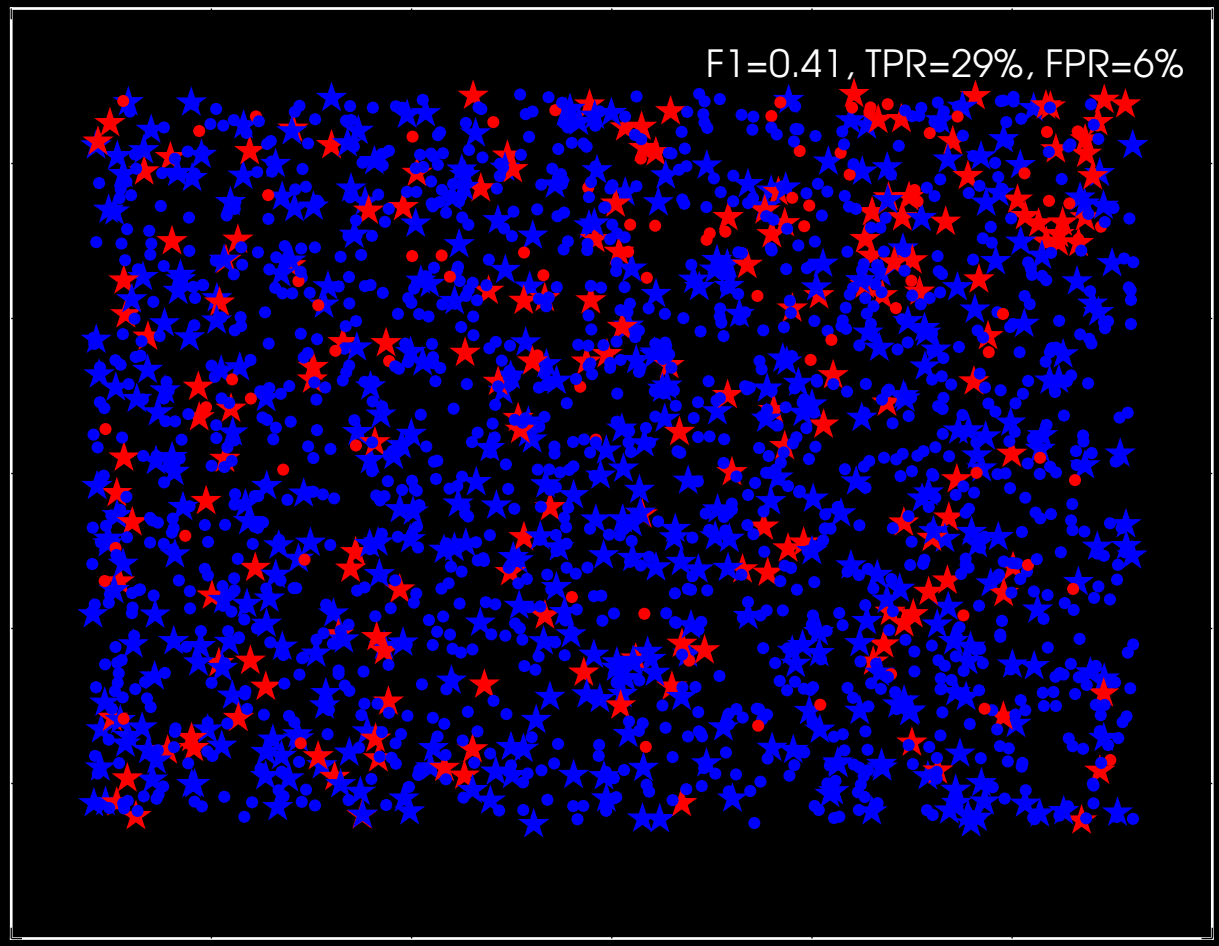

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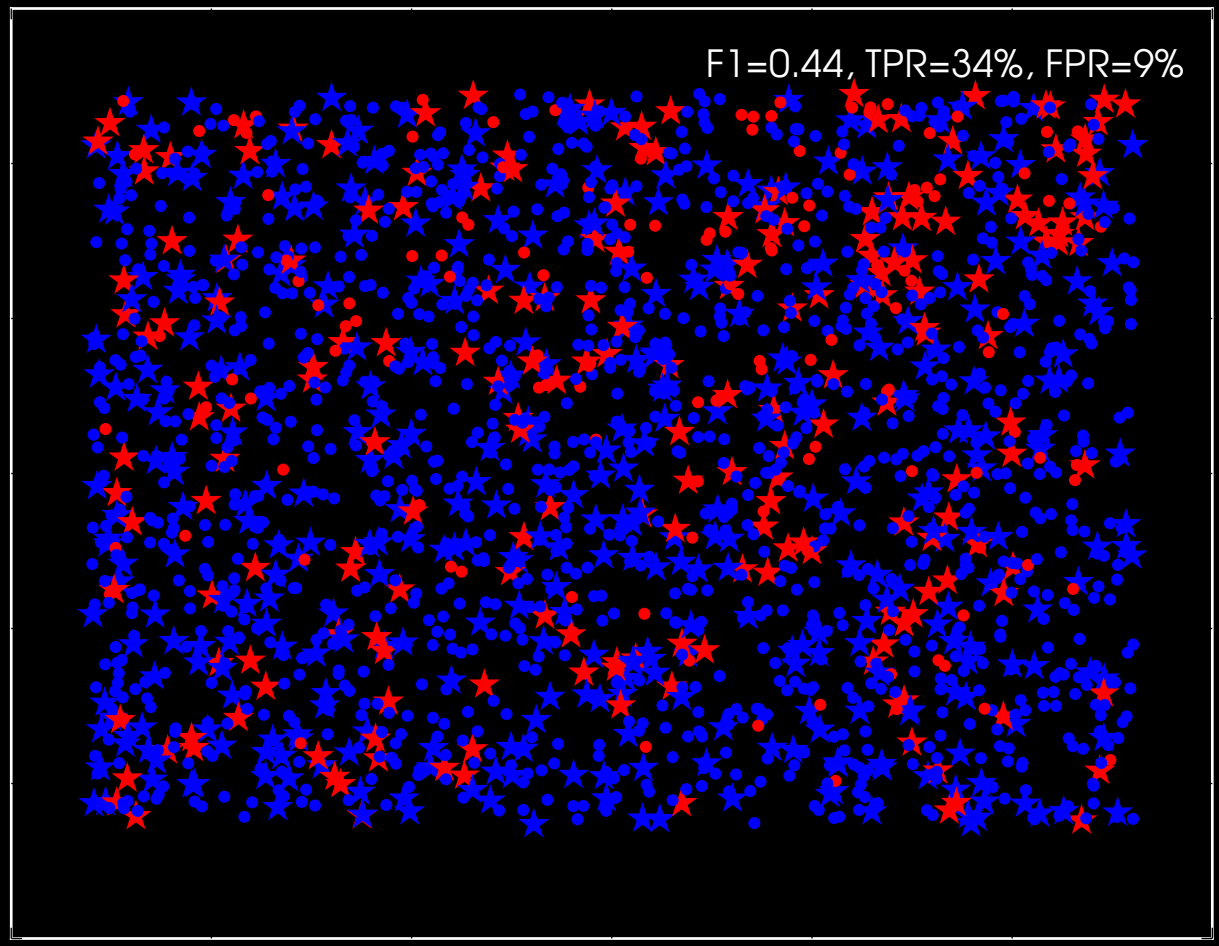

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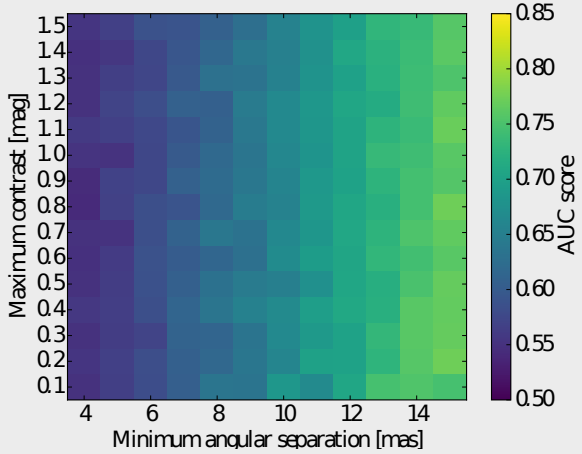
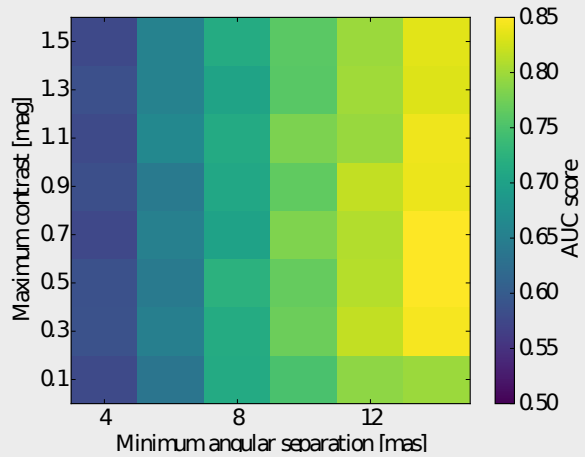
AUC metrics

ACF/Naive

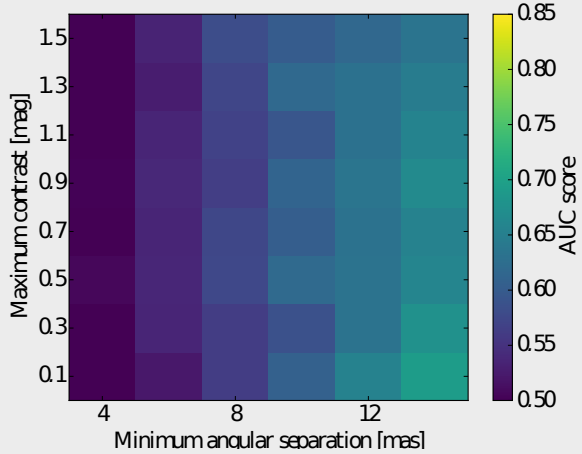
Random Forest

Known PSF

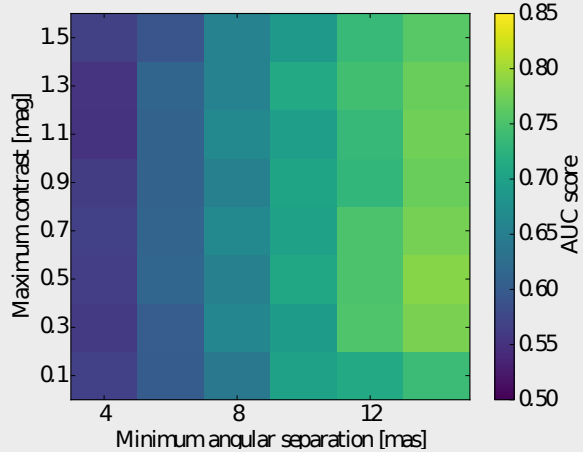




Unknown PSF



False positive: ~20%



False positive: ~5-10%

Summary: finding binaries

- Most of Euclid's binaries have small angular separations
- Effects on PSF measurement is $\mathcal{O}(10^{-4})$
- Identify harmful binaries (check Kuntzer+16a) using only VIS 4 exposures
- Looking for systematic biases in measured PSF parameters
- ✓ "Naive:" auto-correlation analysis, works, but high FPR (data-driven)
- ✓ "Machine learning:" promising, with low FPR (depends on model)
- Work in progress:
  - More simulations for healthier metrics evaluations
  - Bayesian approach
  - Inclusion of realistic issues ? (Stars not present in all exposures, dithering, ...)

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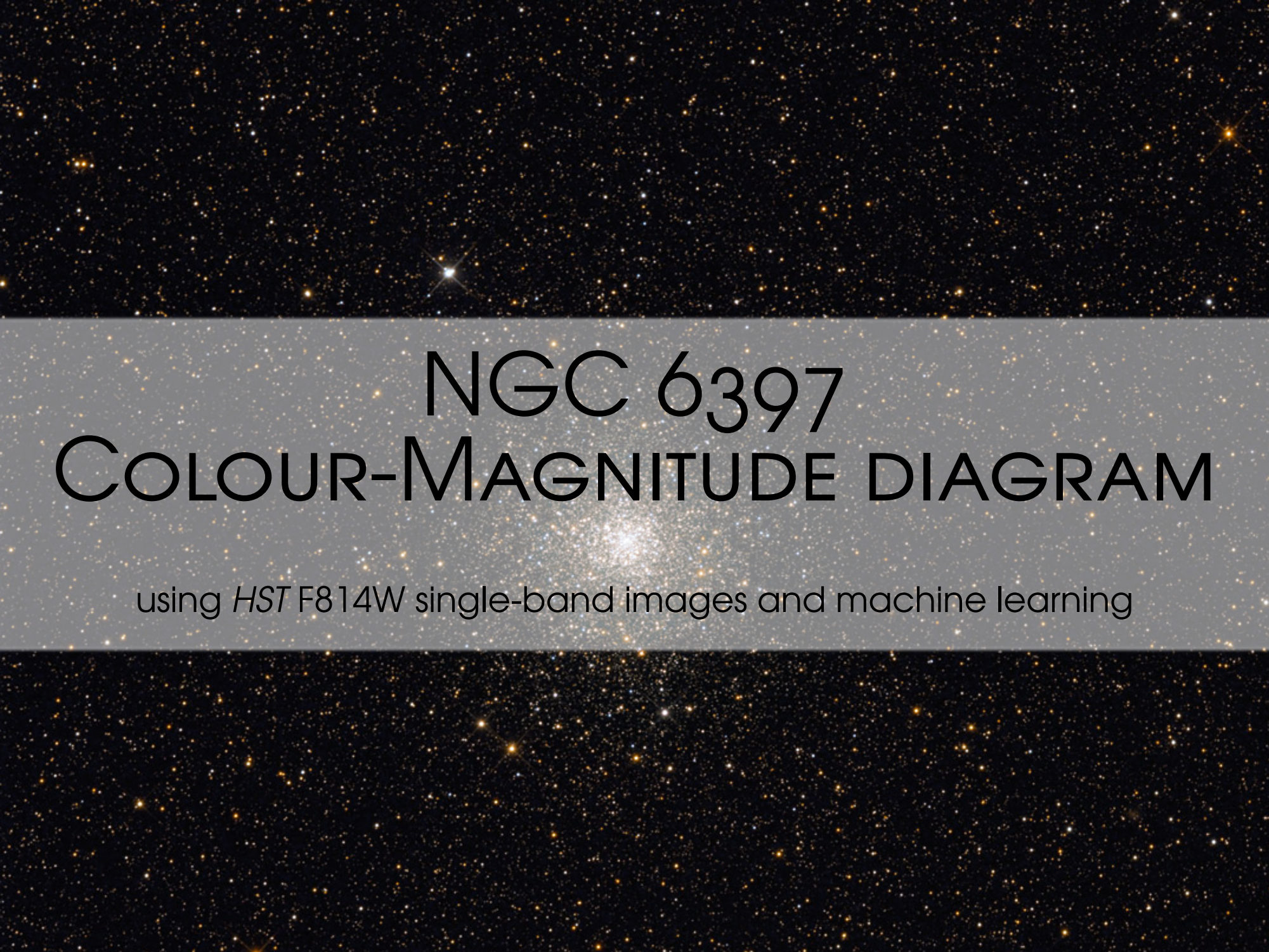
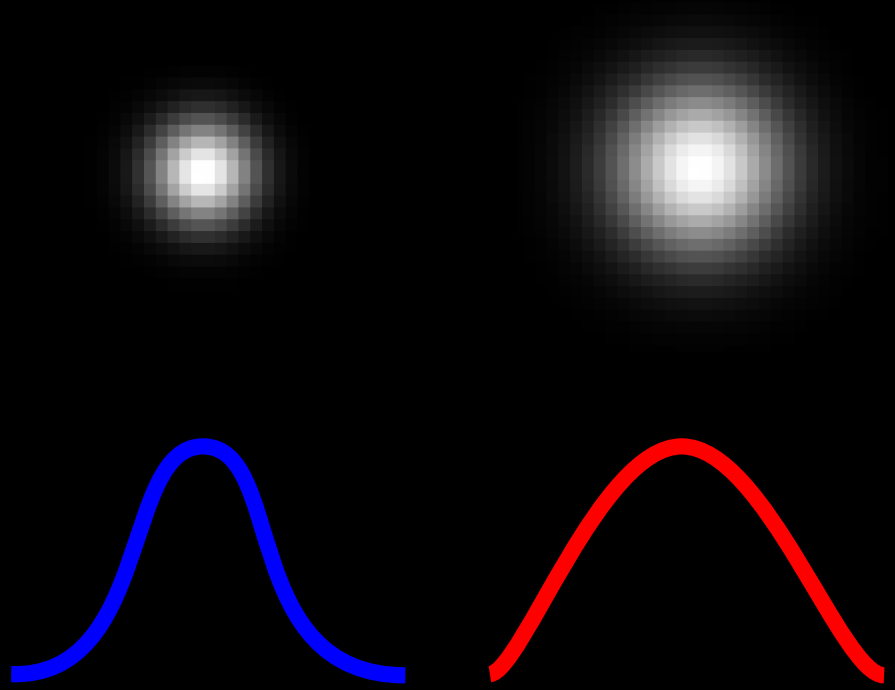

NGC 6397
Colour-Magnitude diagram
using *HST* F814W single-band images and machine learning

Stars in a wide band



- Stellar mass correlate with effective surface temperature
  $\Longrightarrow$ spectra $\sim T_{\text{eff}}$
- Different slope $\Longrightarrow$ different PSF (chromaticity!)

Angular resolution: $\theta \sim \frac{\lambda}{D}$

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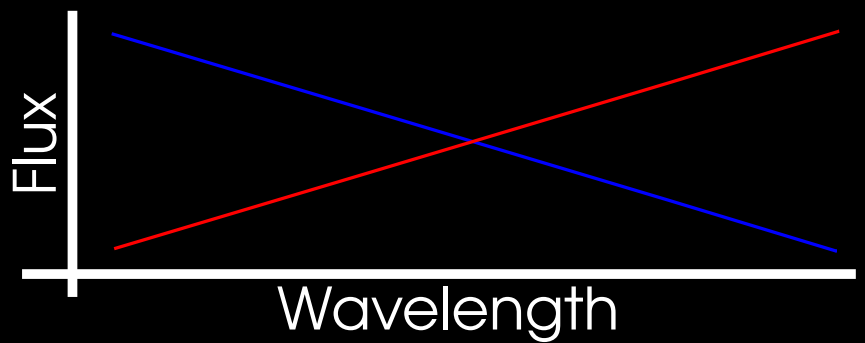

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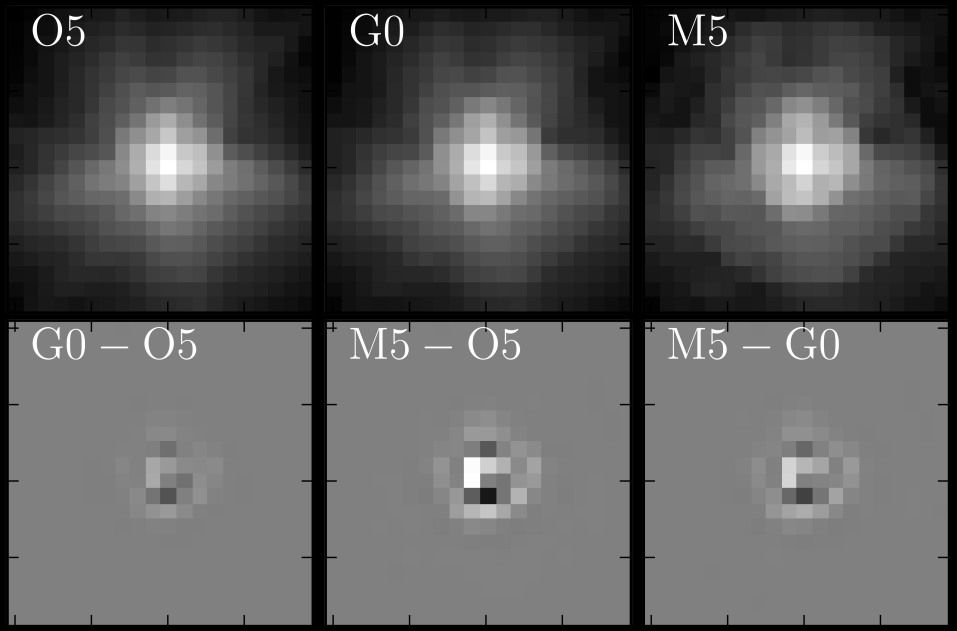

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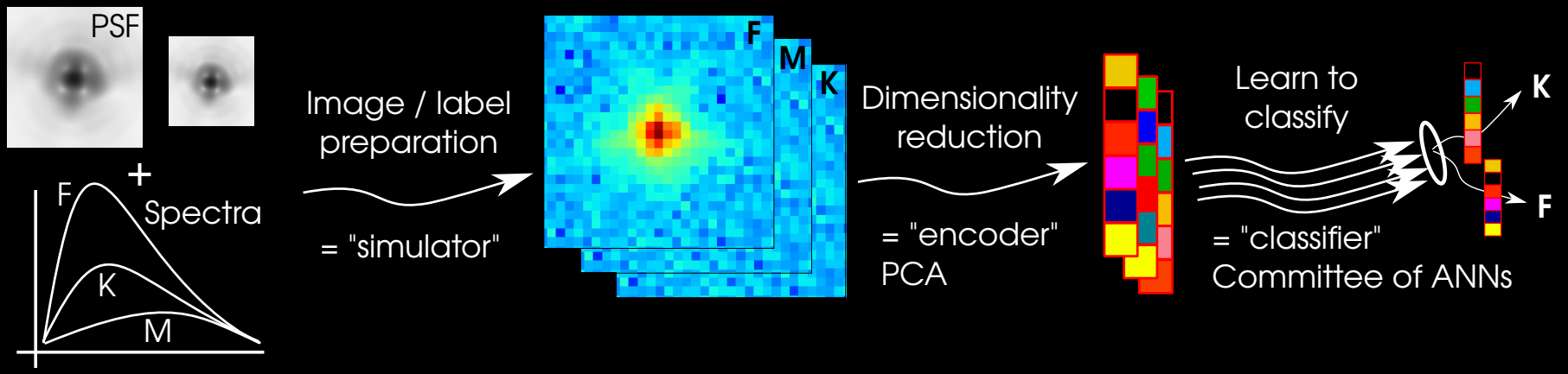
Classifying stars

Training Phase



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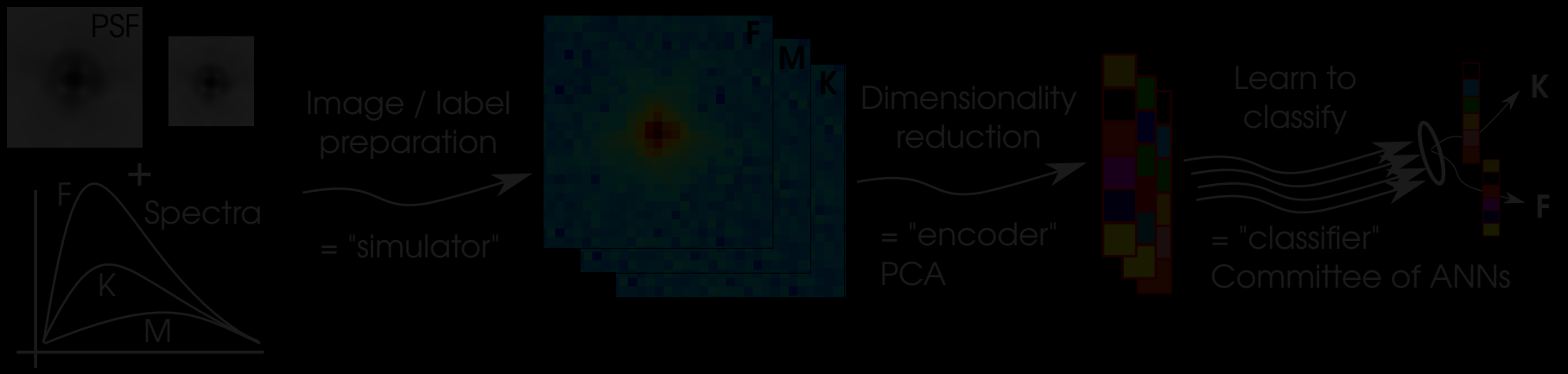
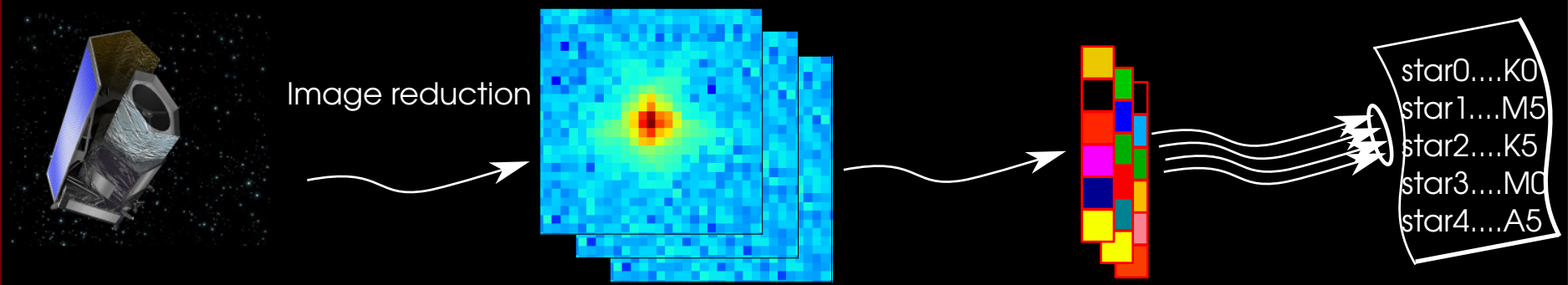


Predicting / Testing phase



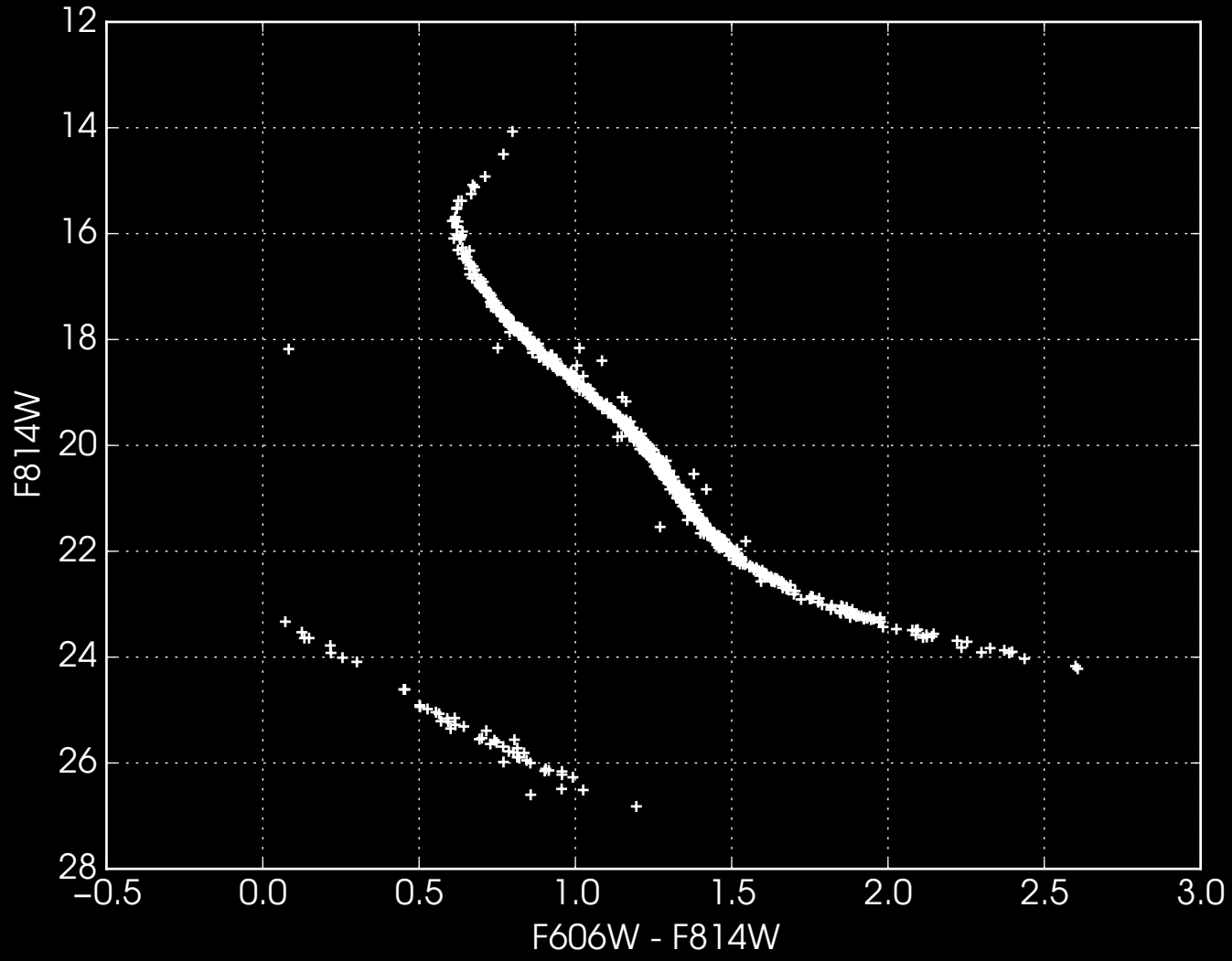
Data acquisition / preparation

Observations / Simulations

Compressed data

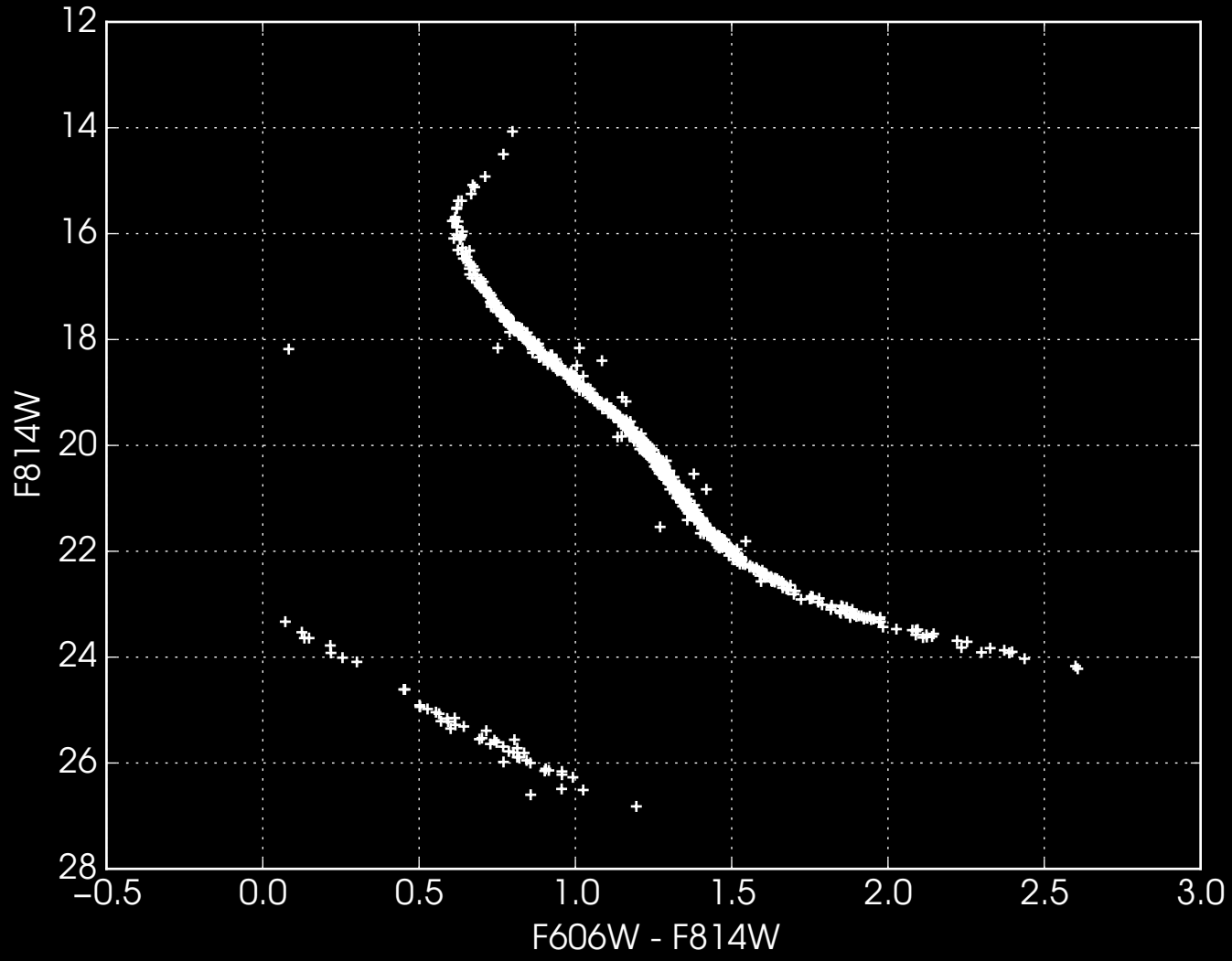
Classification

Colour-Magnitude Diagram



- Globular cluster, age 12.0 ± 0.8 Gyr, 2nd closest to $\odot$
- Richer+08: *HST* ACS for 126 orbits, F814W, F606W
- Goal: Reproduce colour from {F814W image + magnitude} or {image}

Colour-Magnitude Diagram



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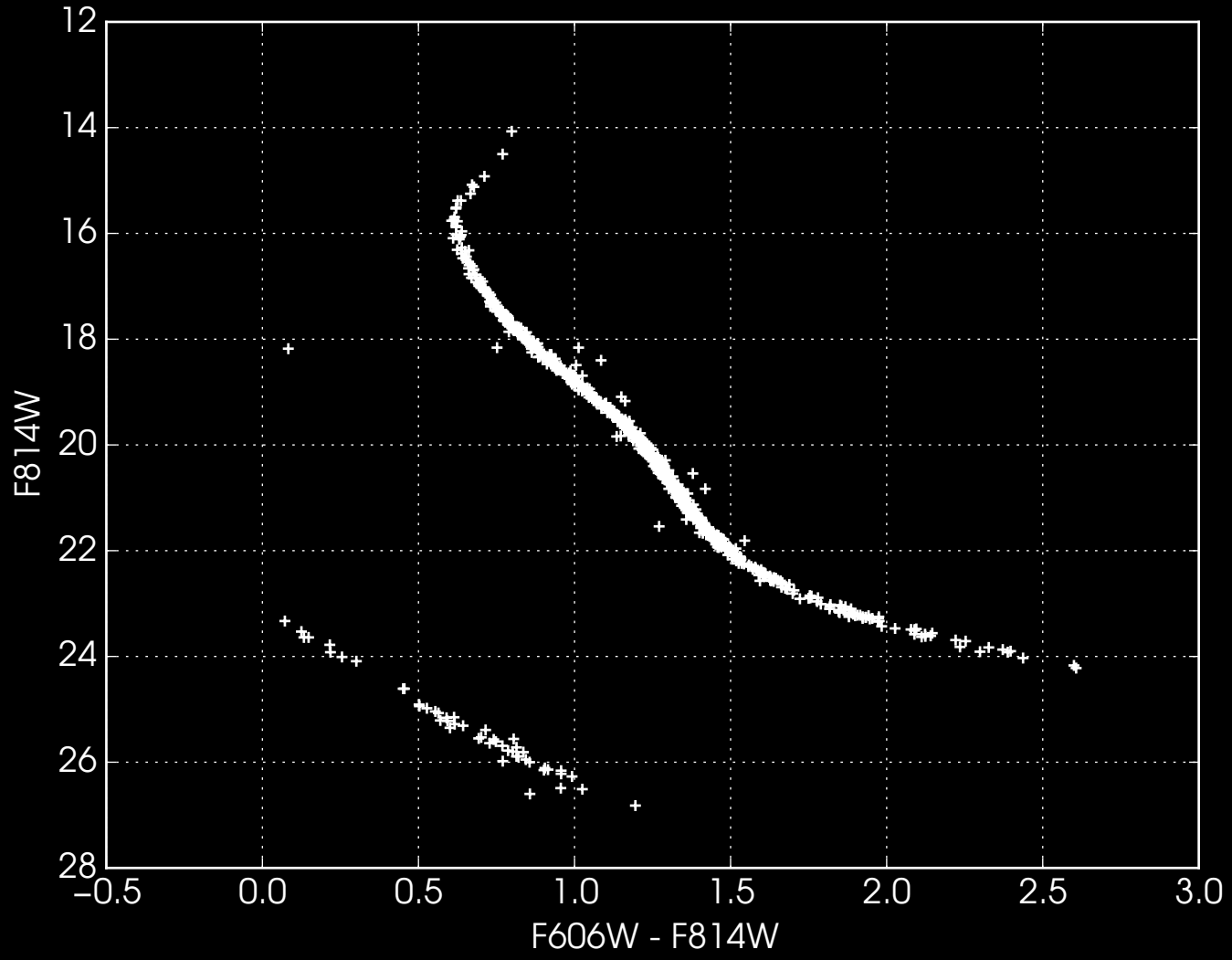
Colour-Magnitude Diagram



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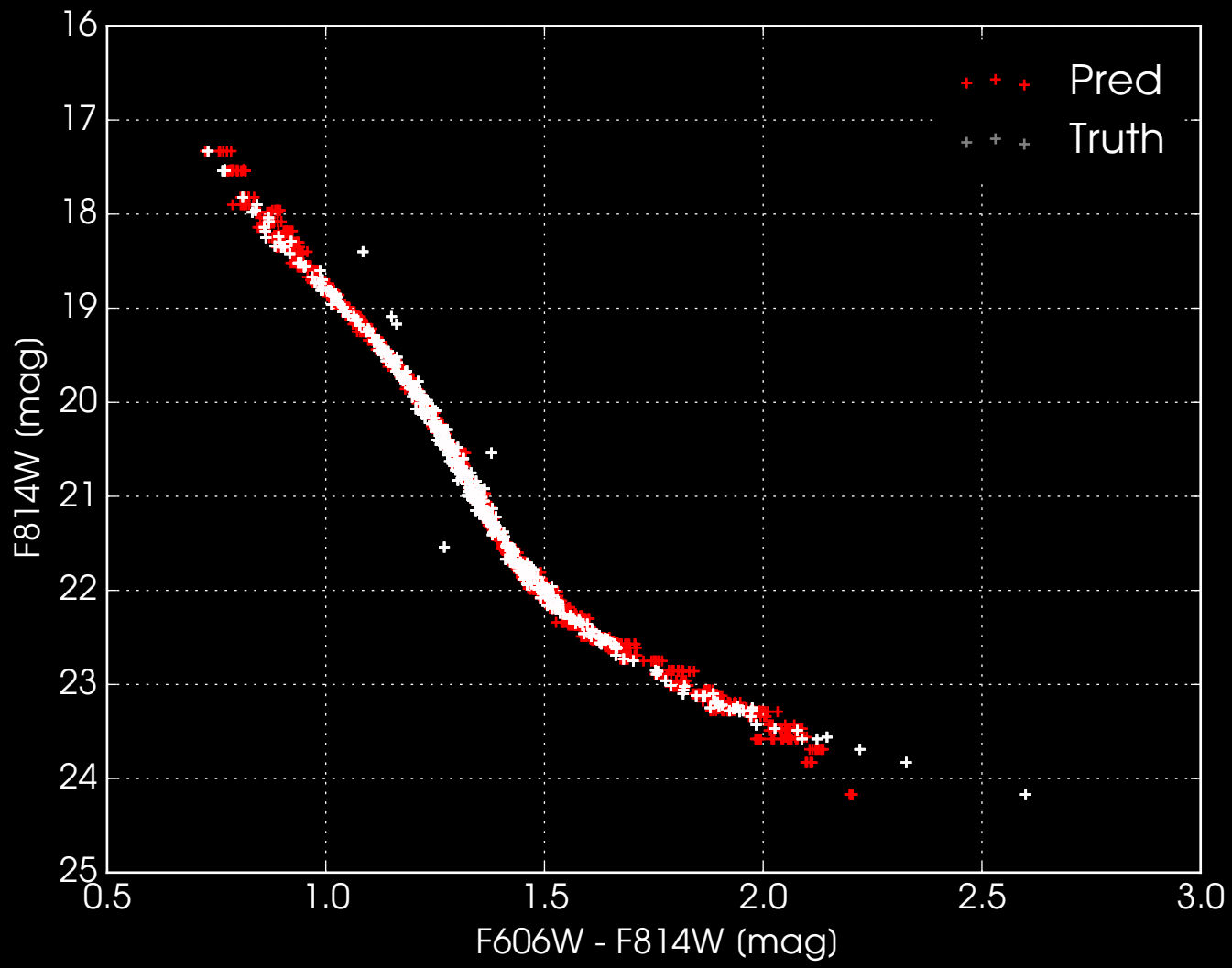

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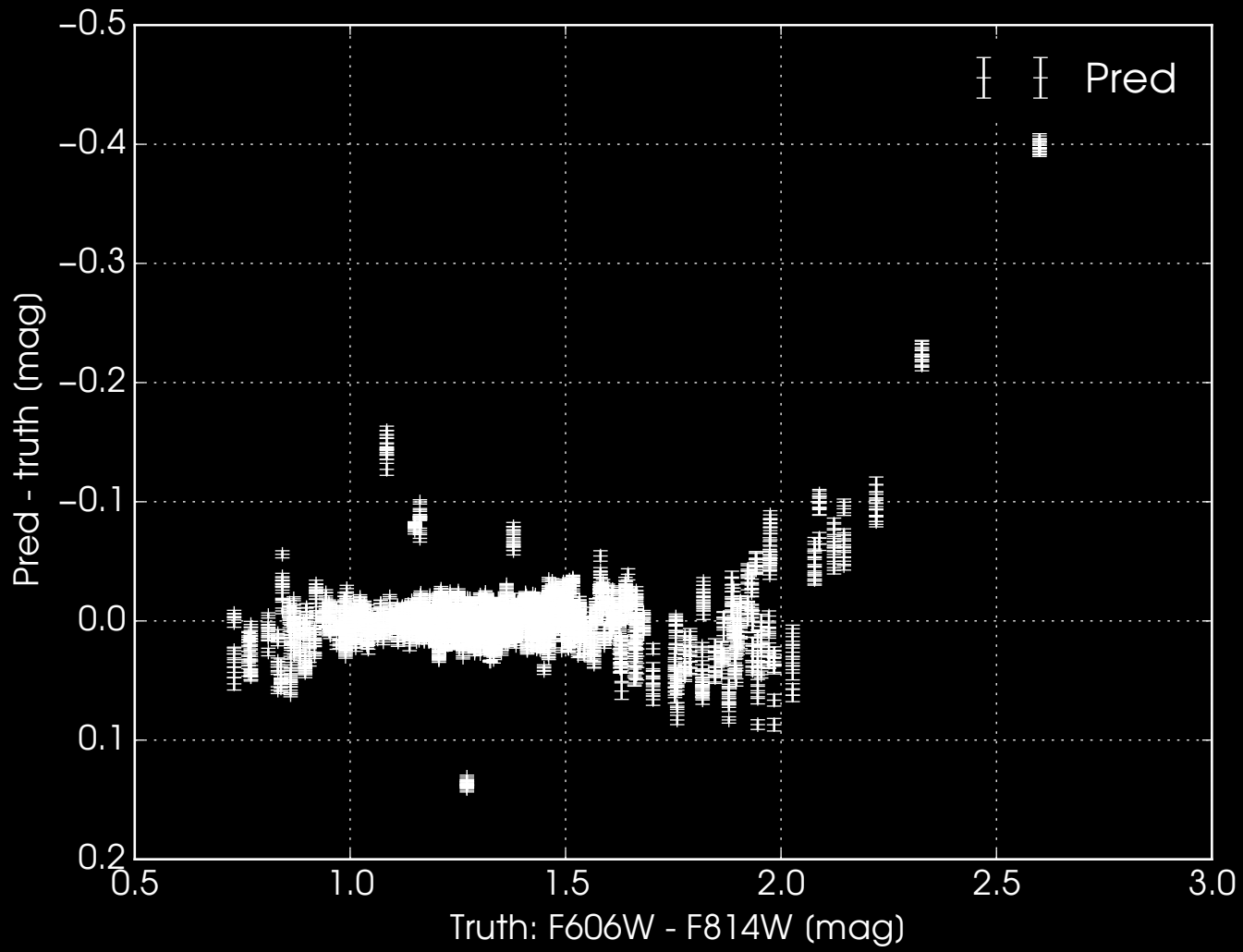

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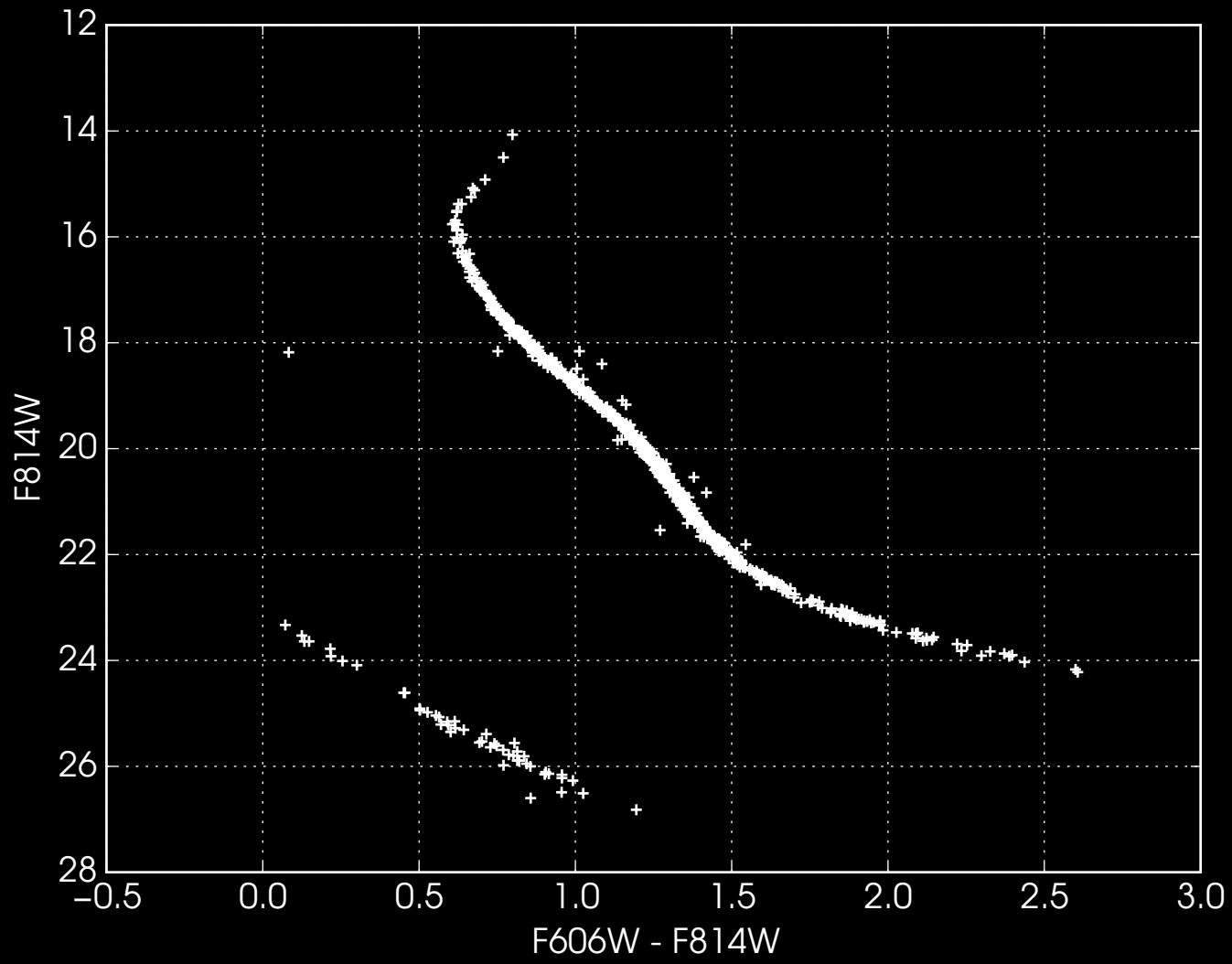
Dealing with non-MS stars



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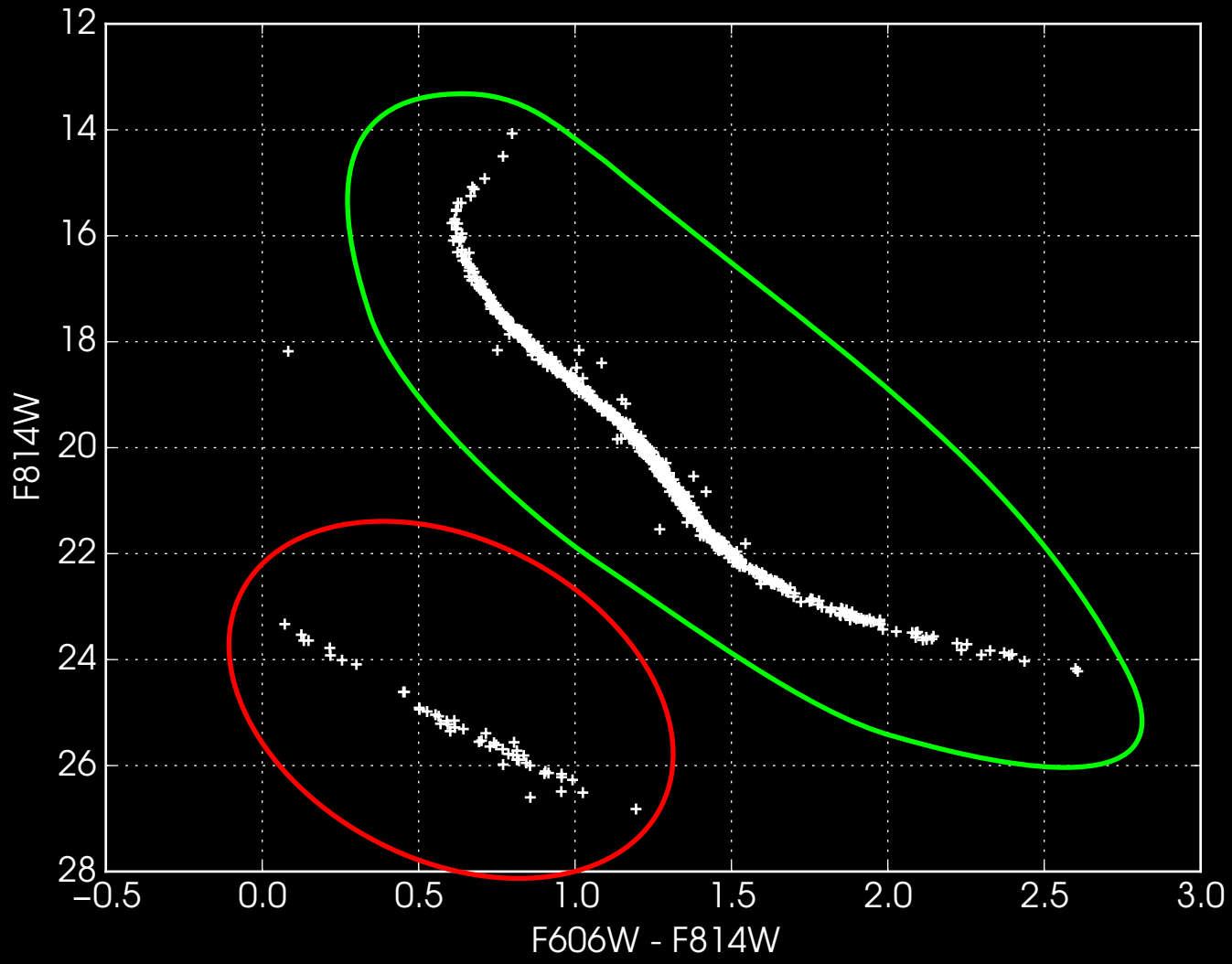

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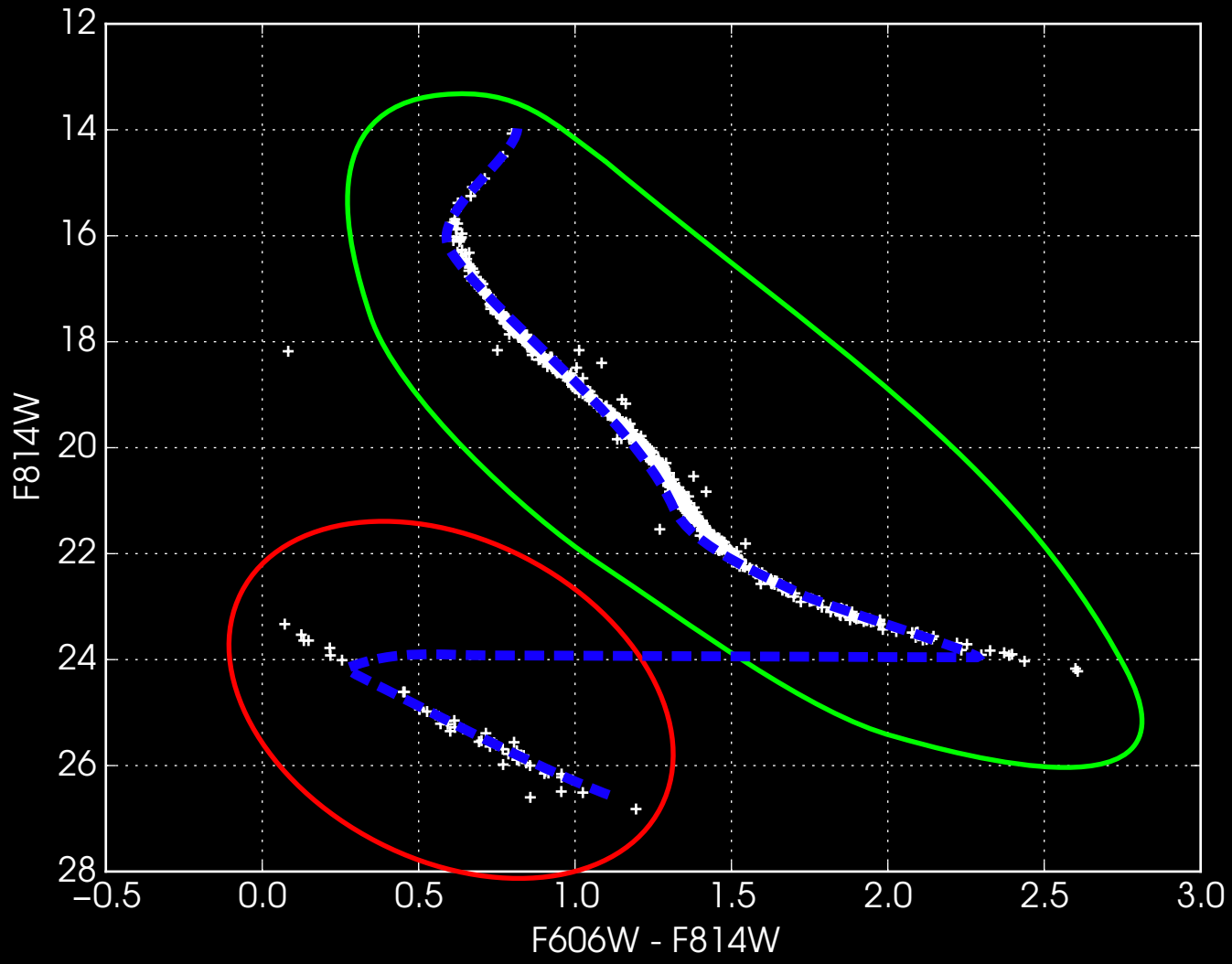

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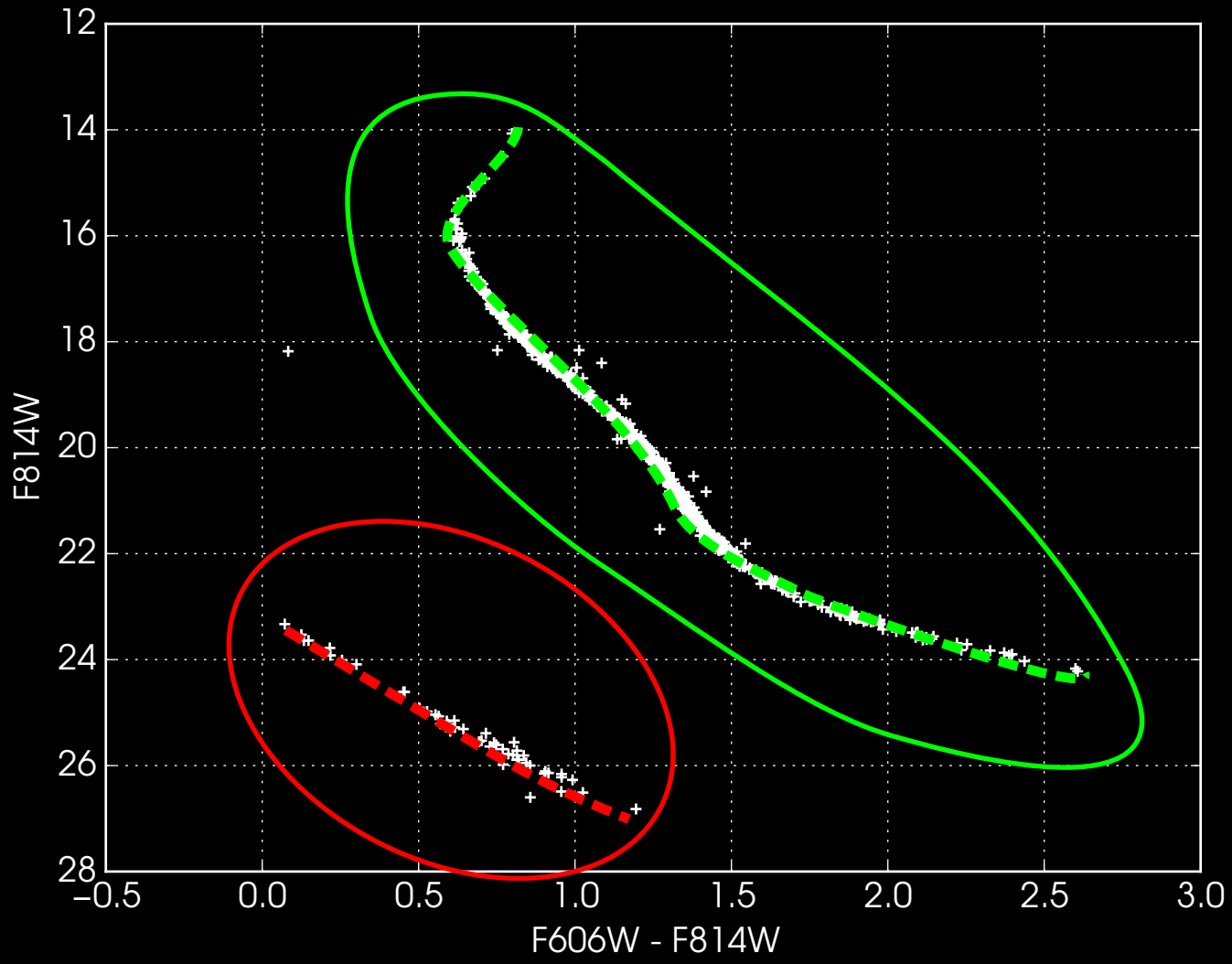

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Summary NGC 6397

- Creating a CMD for NGC 697 using *HST* F814W data
- ✓ Removing WD by hand creates great fit to the actual CMD
- ✓ Inputs: {imagette of star} and {imagette of star + magnitude}
- Work in progress:
  - Removal of WD using shape of PSF $\longrightarrow$ concept proven in Kuntzer+16b
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PSF Interpolation

using Auto-Encoders and manifold learning

SDSS

PSF requirements and measurement

- Measured shear power spectrum

$$\hat{C} \approx (1 + \mathcal{M})C + \mathcal{A}, \qquad \mathcal{M}, \mathcal{A} \sim \langle |\delta e_{\rm PSF}|^2 \rangle, \langle \delta R^2_{\rm PSF} \rangle$$

- Science requirement for the PSF shape:

size rms (relative)	$\frac{\sigma(R^2)}{\langle R^2 \rangle} \leq 10^{-3}$
ellipticity rms	$\sigma(e_i) \leq 10^{-4}$
ellipticity	$e_i < 0.15$

From Paulin-Henriksson+2008

- Performance needed for measurement

size	$\sim 5\%$
ellipticity	$\sim 1\%$

Auto-Encoders

1. Encode the PSF into a few coefficients

2. Interpolate the coefficients

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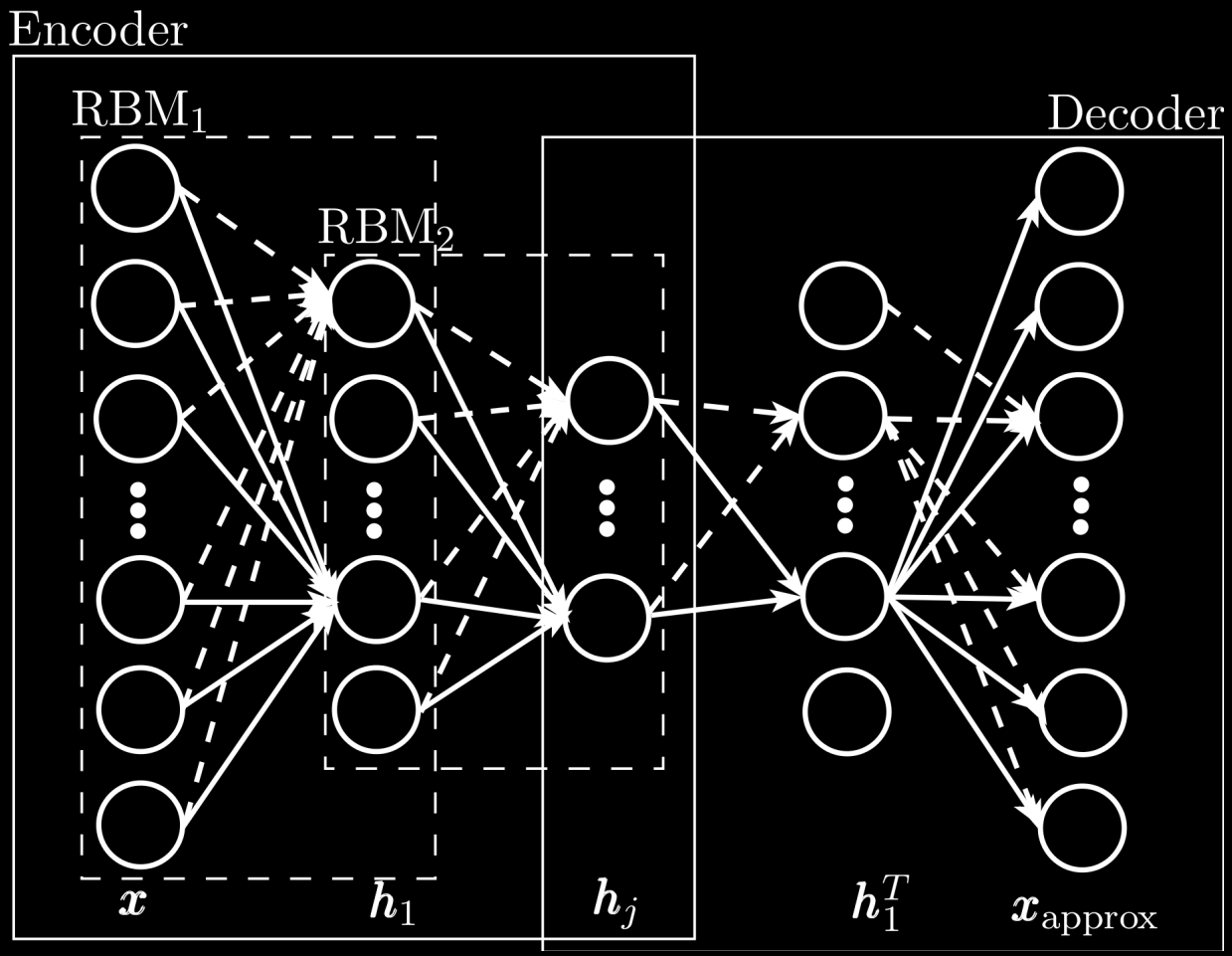
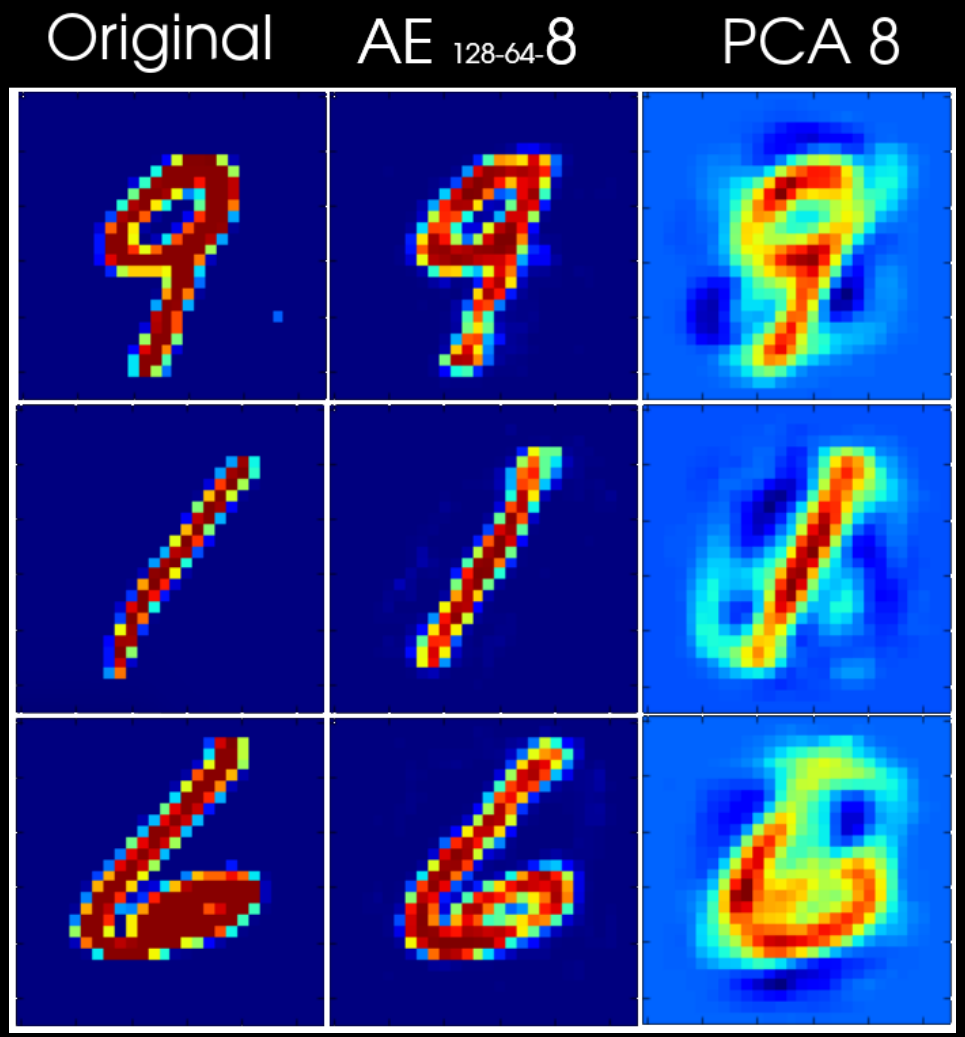
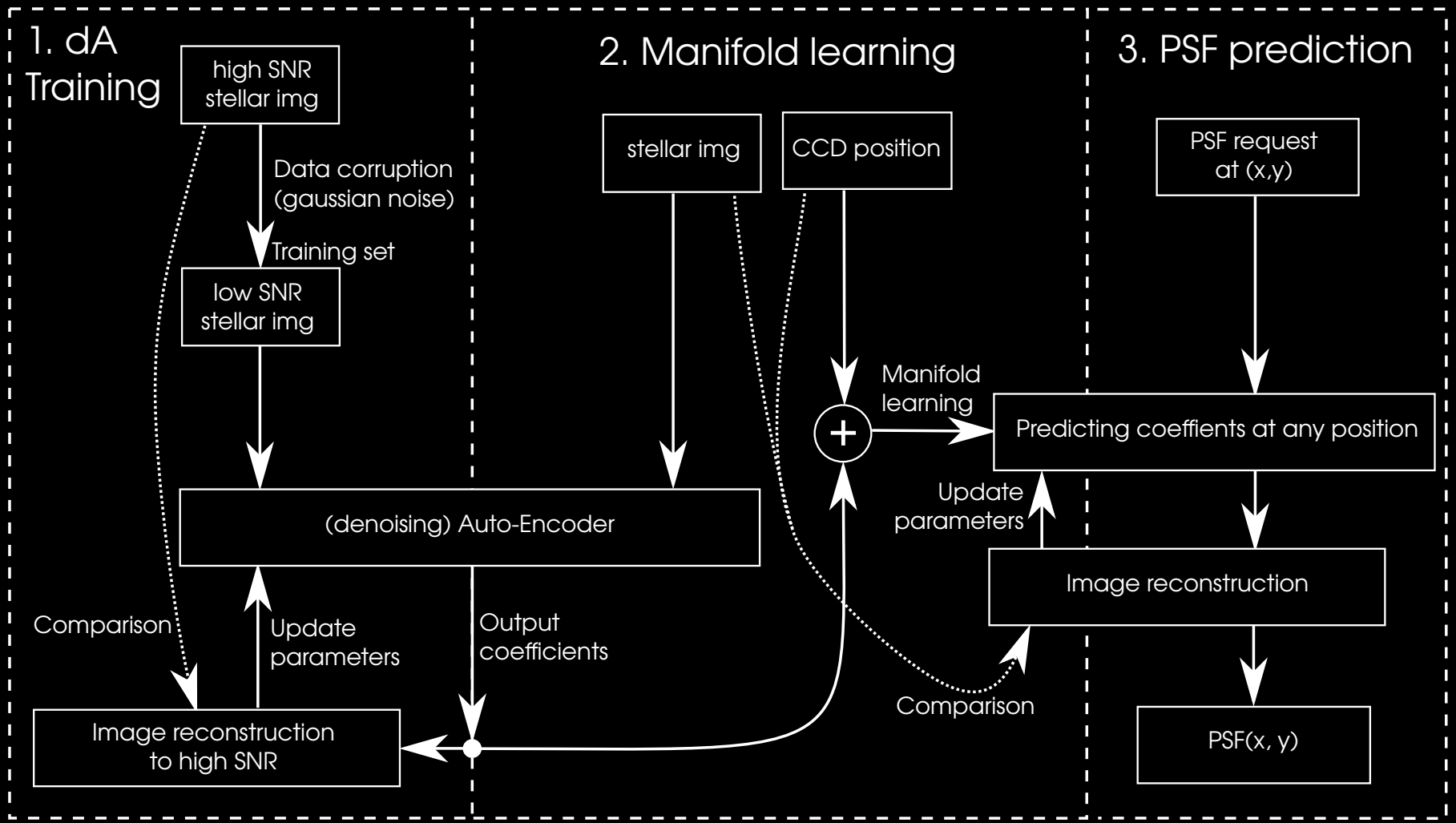


Auto-Encoder performance



Interpolating PSFs



Summary

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  - Most of Euclid's binaries have small angular separations
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  - Auto-correlation, random forests and Bayesian approach (?)

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MS stars and filters