The Power of High Precision Photometry on Near-Field Cosmology with DECam

Ting Li
University of Toronto

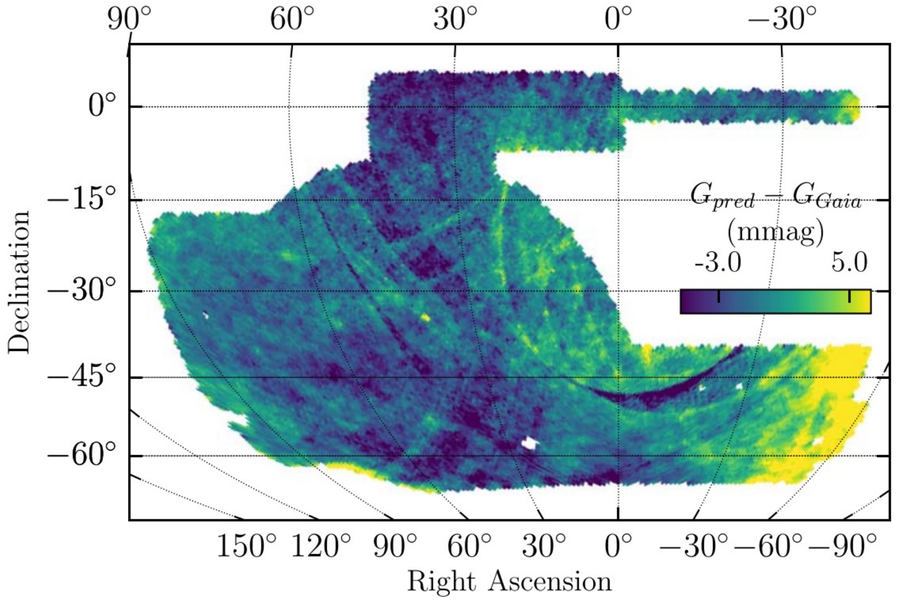
Collaborators: **Charlie Hughes**, **Grace Yu**, **Nora Shipp**, Josh Speagle
S5 Collaboration & DES Collaboration

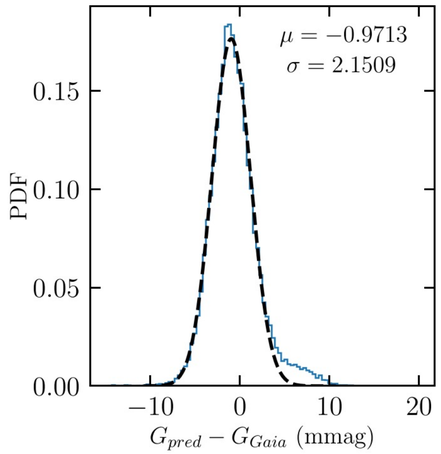
Sept. 12, 2022
DECam at 10 Years Workshop, Tucson

Image Credit: Reidar Hahn

The Unprecedented High Precision Photometry Achieved by DES

The Dark Energy Survey Data Release 2



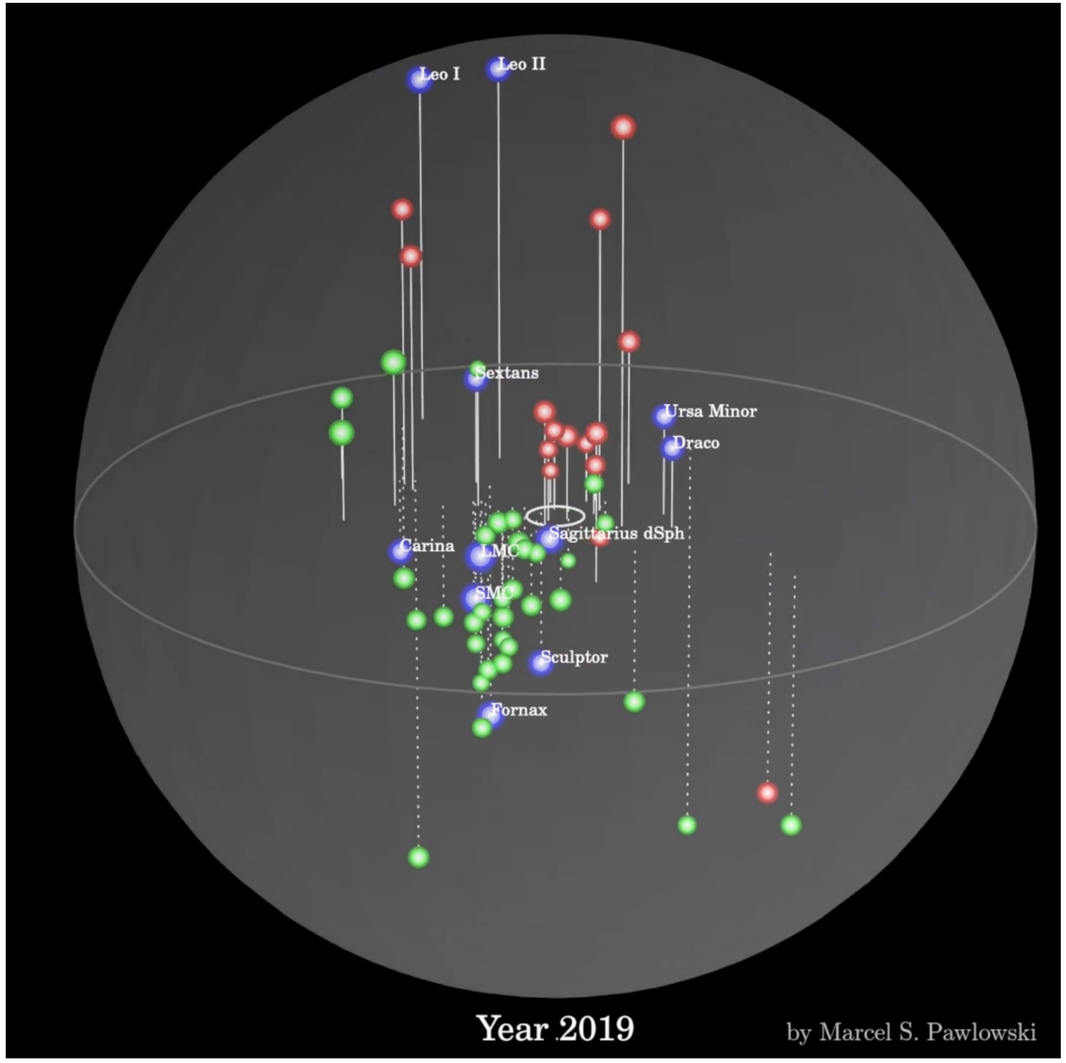


- Photometric Uniformity vs. Gaia: 2.15 mmag
- Single-epoch Photometric Repeatability: 2-3 mmag
- Achieved with efforts from many aspects
  - Auxiliary Calibration Systems: DECaLS, aTmCam, GPS Monitor
  - Forward Global Calibration Method (FGCM, Burke, Rykoff+2018) for photometric zeropoint
  - Chromatic Correction and Interstellar Reddening Task Force

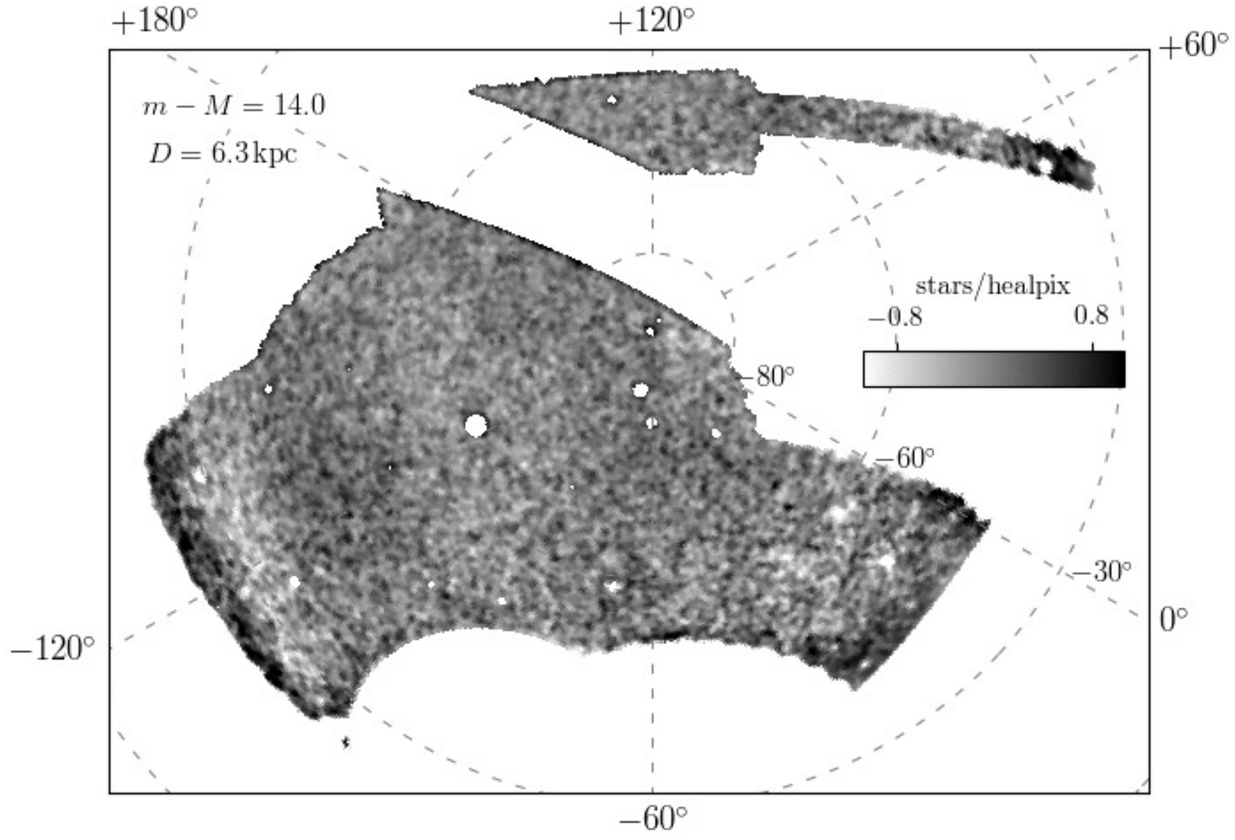
Abbott et al. 2021 (DES Collaboration)

DES/DECam's Contribution in Near-Field Cosmology

Discovery of Dwarf Galaxies



Discovery of Stellar Streams



Shipp, Drlica-Wagner et al. 2018
(DES Collaboration)

S^5: Southern Stellar Stream Spectroscopic Survey

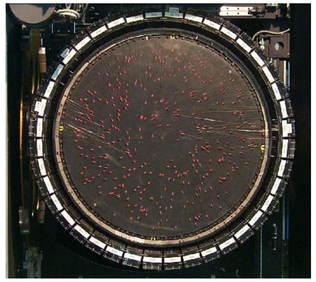
Since Summer 2018

s5collab.github.io

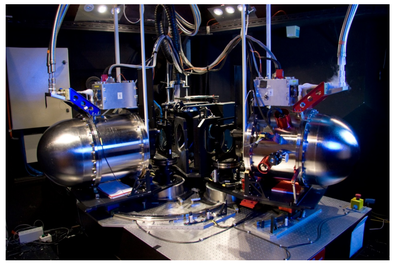
S^5: DES+Gaia+AAT

Since Summer 2018

3.9-m Anglo-Australian Telescope (AAT)



2-degree-Field (2df) fibre positioned



AAOmega spectrograph

Efficient Target Selection w/

DES DR1 photometry Gaia DR2 proper motions

DARK ENERGY SURVEY

gaia

s5collab.github.io

The Southern Stellar Stream Spectroscopic Survey (S5): Overview, Target Selection, Data Reduction, Validation, and Early Science
TSL et al. 2019, arXiv:1907.09481

S^5: DES+Gaia+AAT

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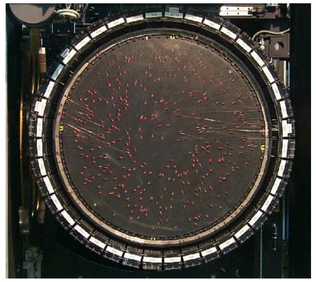

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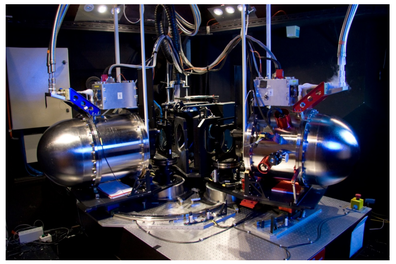

AAOmega spectrograph

Efficient Target Selection w/

DES DR1 photometry Gaia DR2 proper motions

DARK ENERGY SURVEY

gaia

Since Summer 2018

s5collab.github.io

- 80+ AAT nights
- ~700 sq deg.
- Mapped 20 streams
- Collected 70,000+ stellar spectra between 16 < r < 20 mag
- 13 publications and 3 press releases (NYTimes, CBS, etc.)
- First public data release

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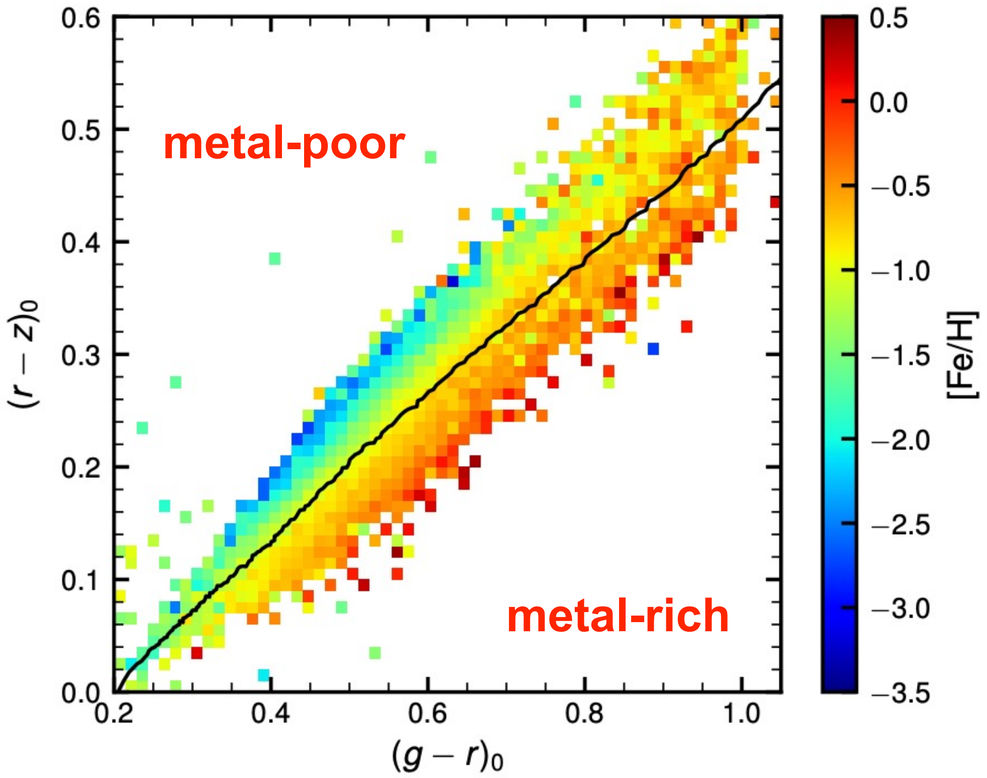
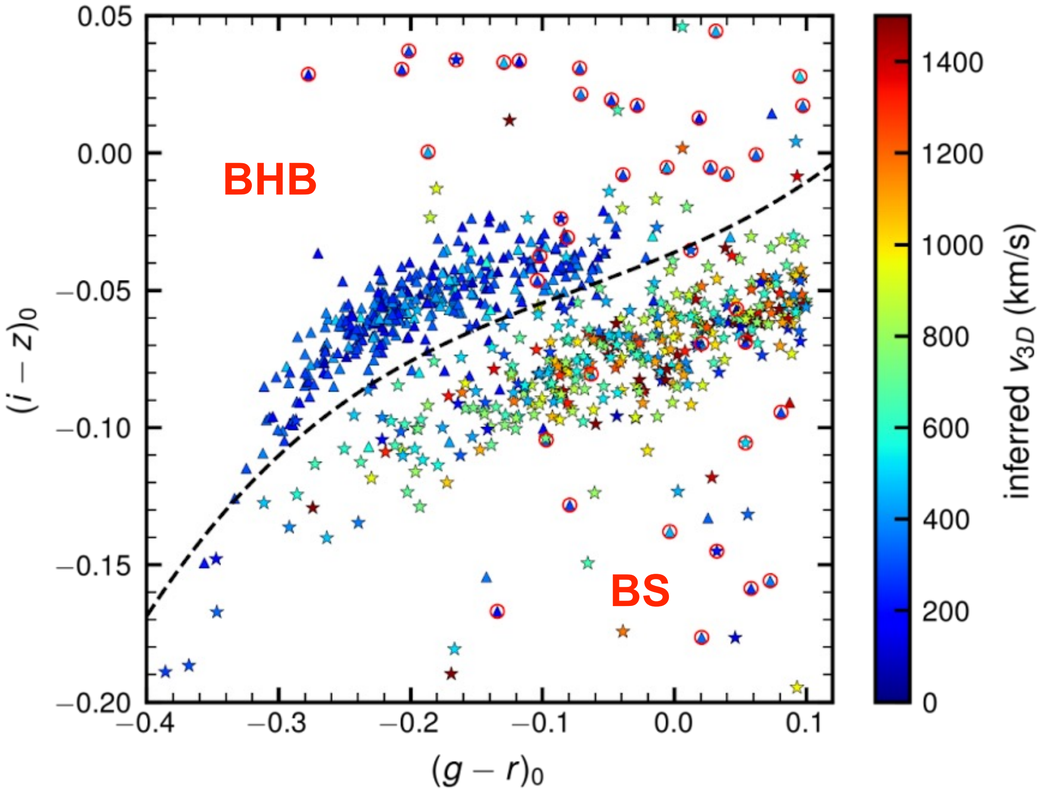
The Power of High Precision Photometry on Near-Field Cosmology with DECam



Photometric metallicity of stars w/ DES photometry

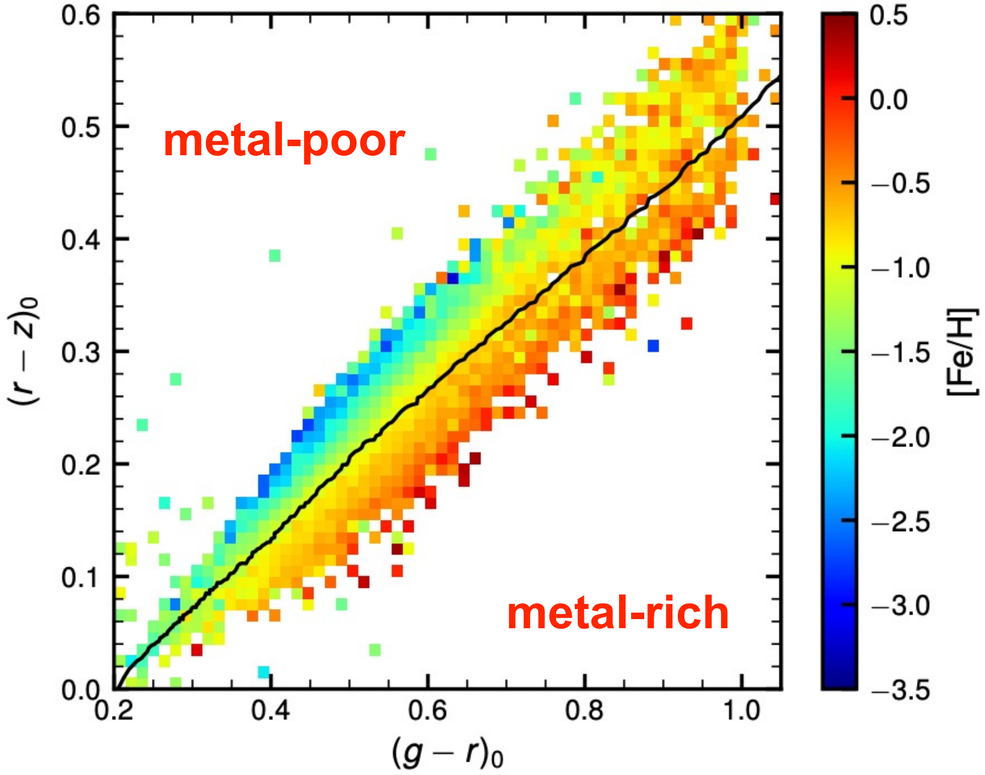


- BHB: Blue horizontal branch stars
- BS: Blue straggler stars

Separating giant and dwarf stars in blue w/ DES photometry

TSL et al. (2019)
(S5 Collaboration)

The Power of High Precision Photometry on Near-Field Cosmology with DECam



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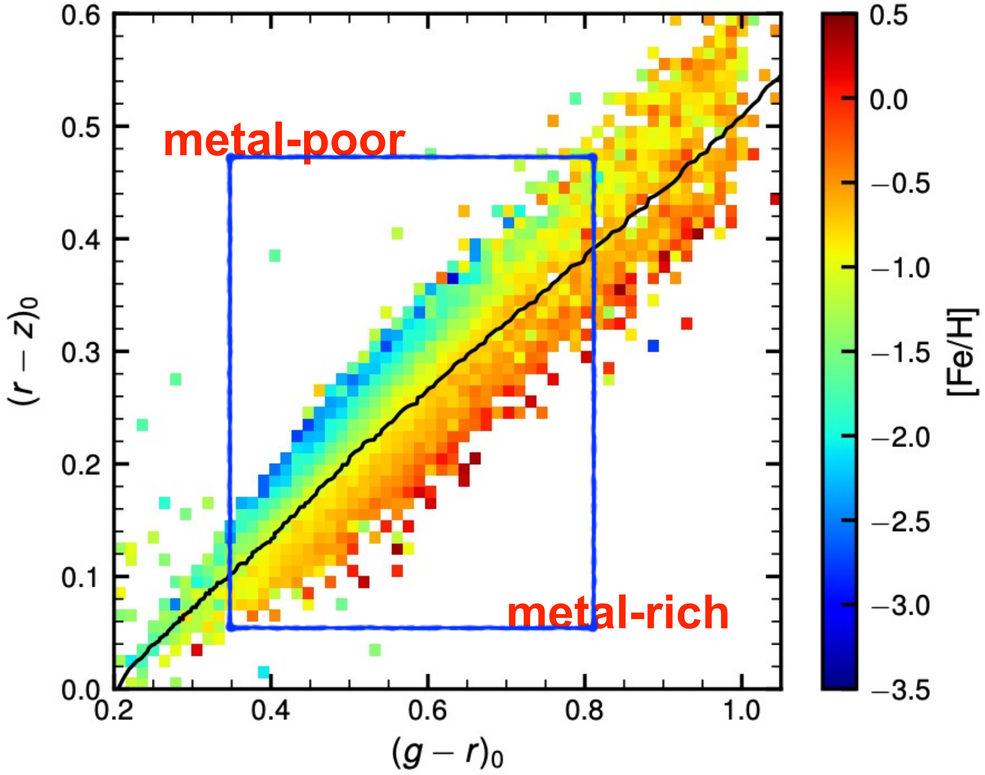


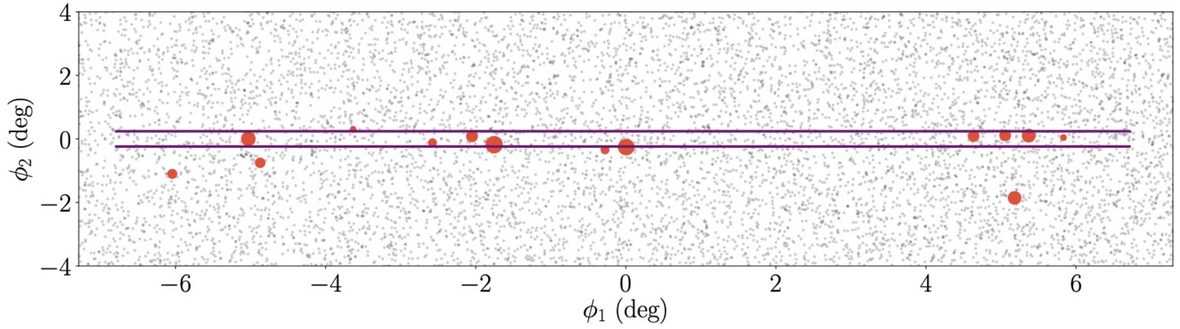
Photometric metallicity of stars w/ DES photometry

TSL et al. (2019)
(S5 Collaboration)

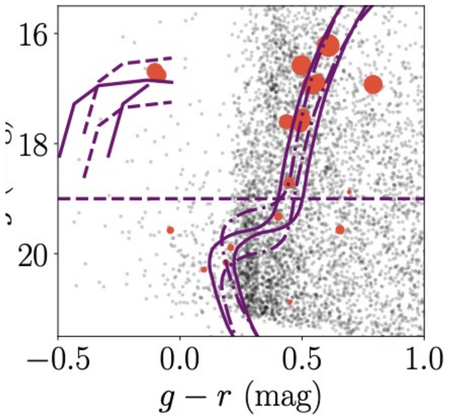
Application 1:
Determine the Proper Motions of Stellar Streams

Nora Shipp

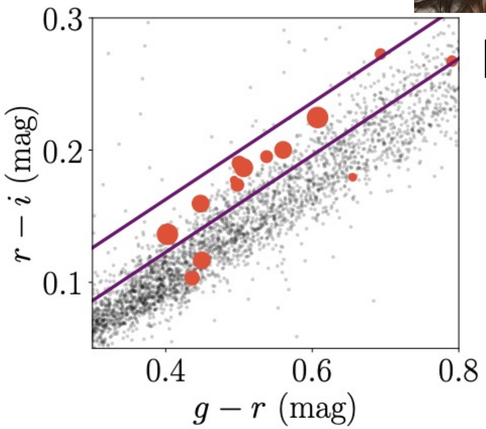
Spatial Cut



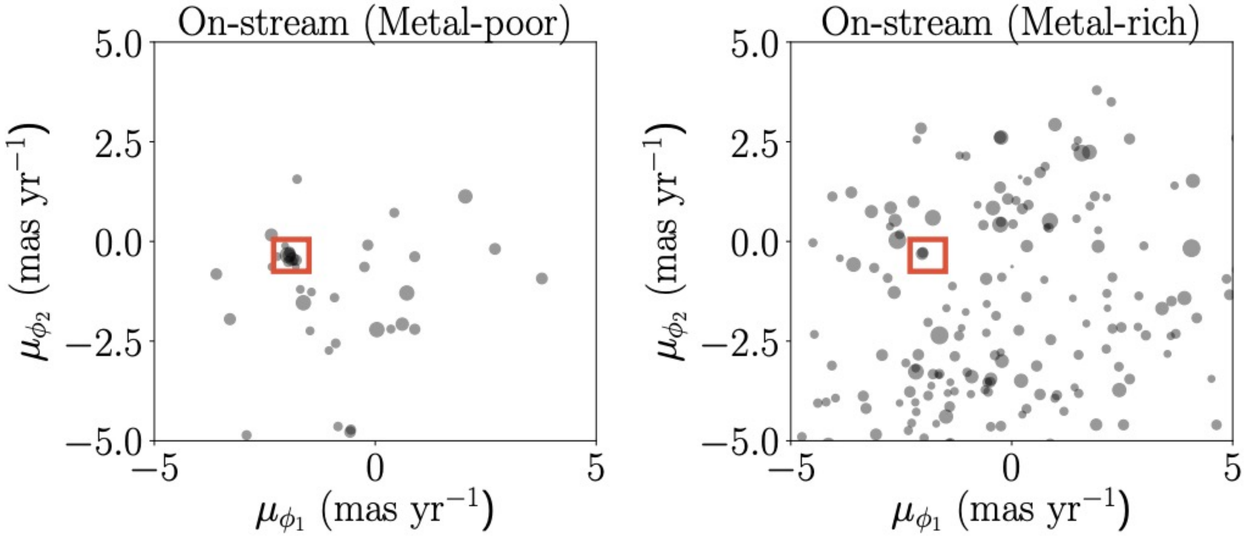
color-magnitude



color-color



Proper Motion Space



Shipp, Li et al. 2019

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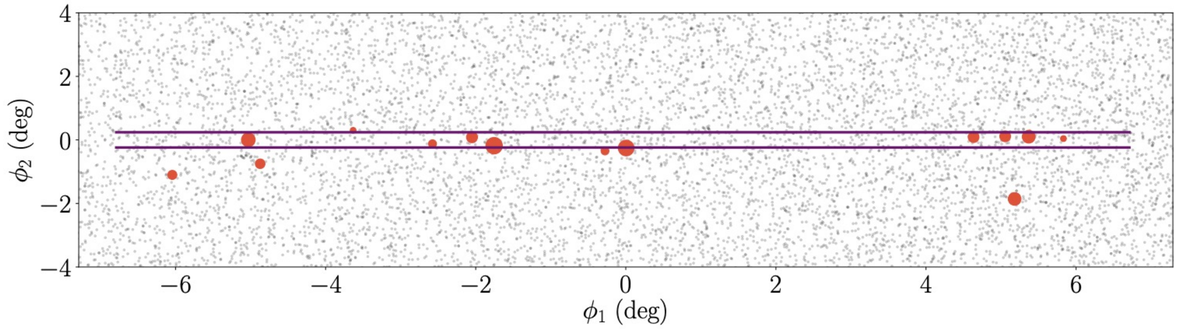

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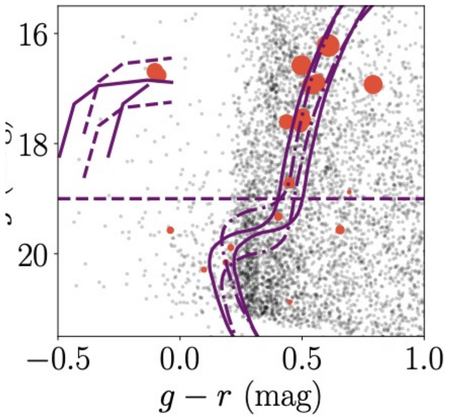

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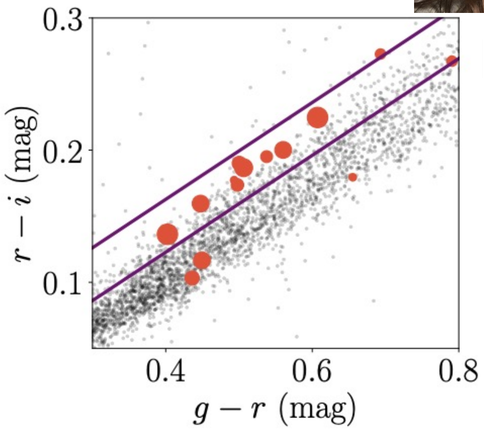

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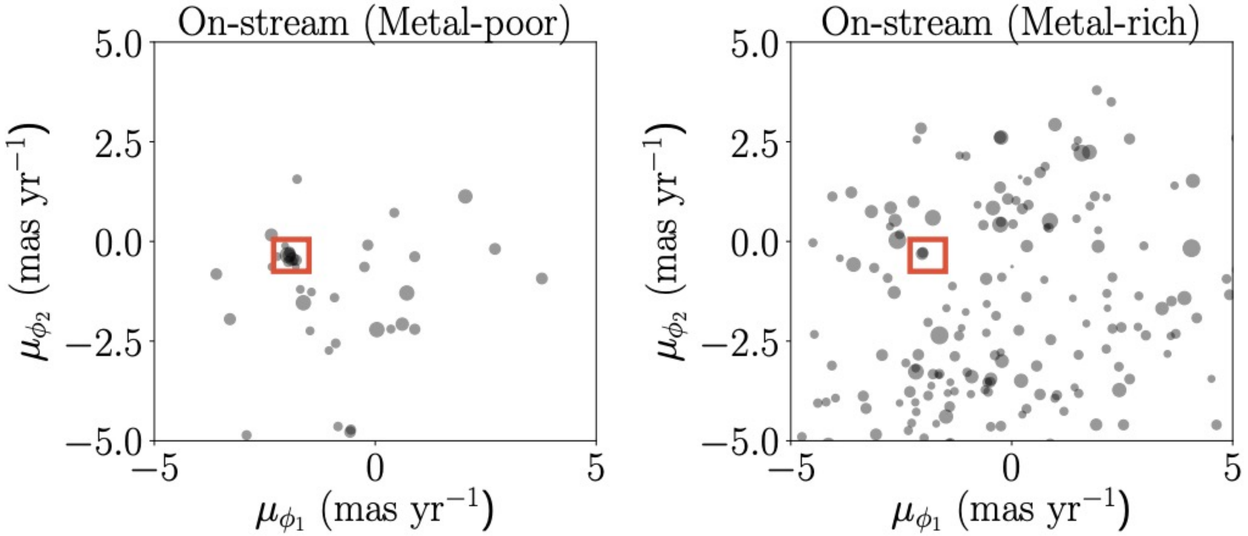


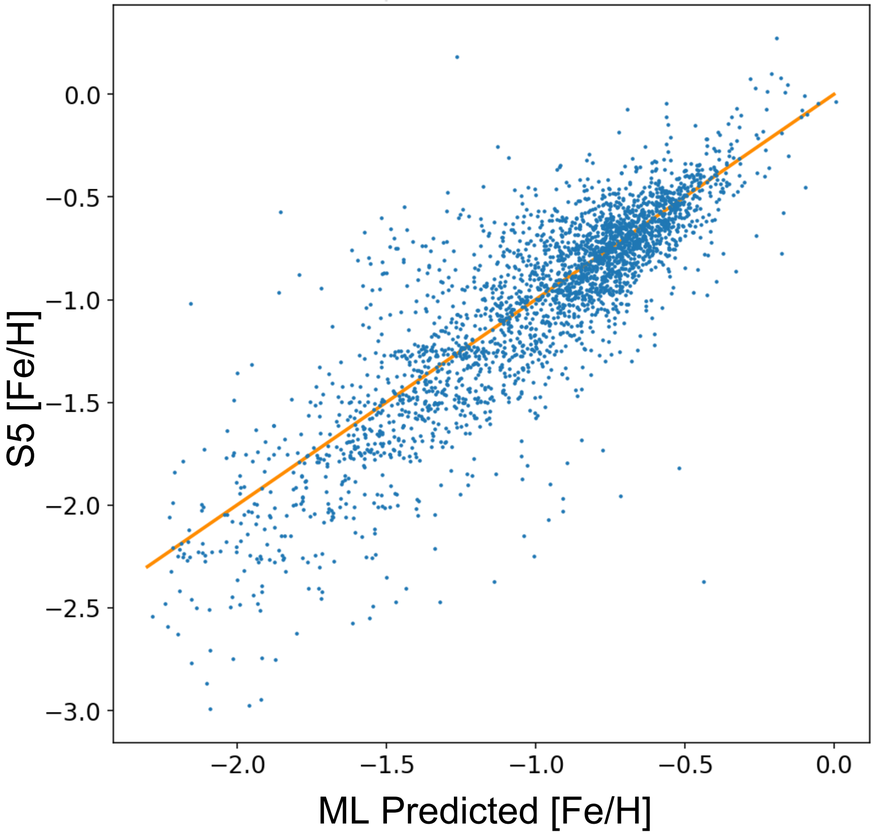
High precision photometry

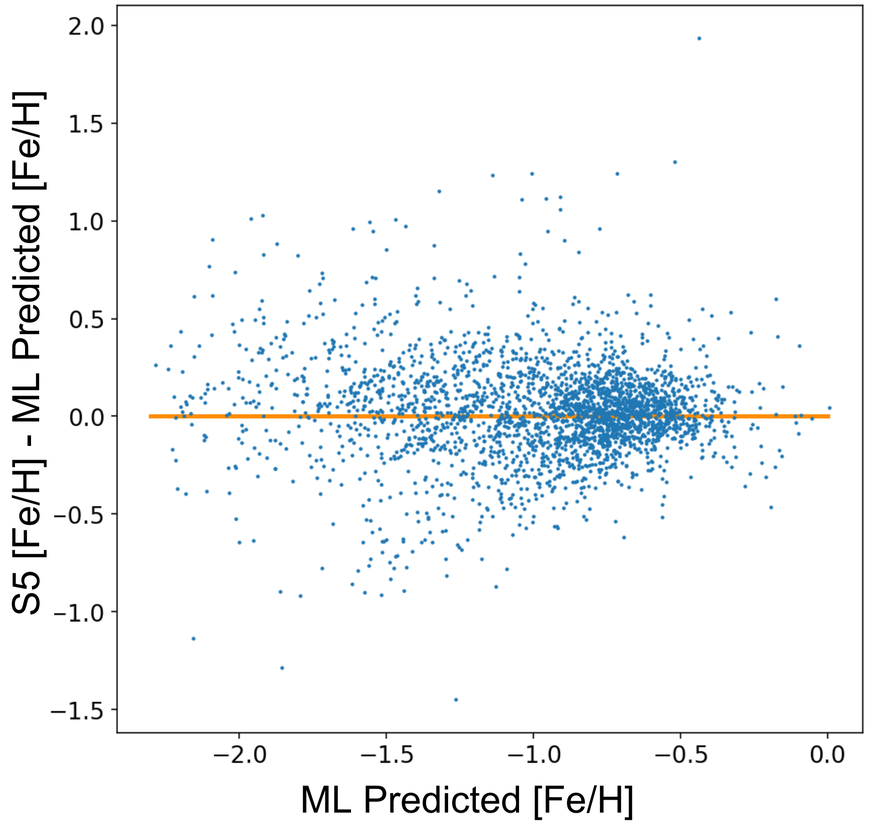
- **help detection of proper motion of streams**
- **largely improve target selection efficiency**

Shipp, Li et al. 2019

Application 2: Predicting Stellar Metallicity w/ DES Photometry + Machine Learning (ML)

Charles Hughes





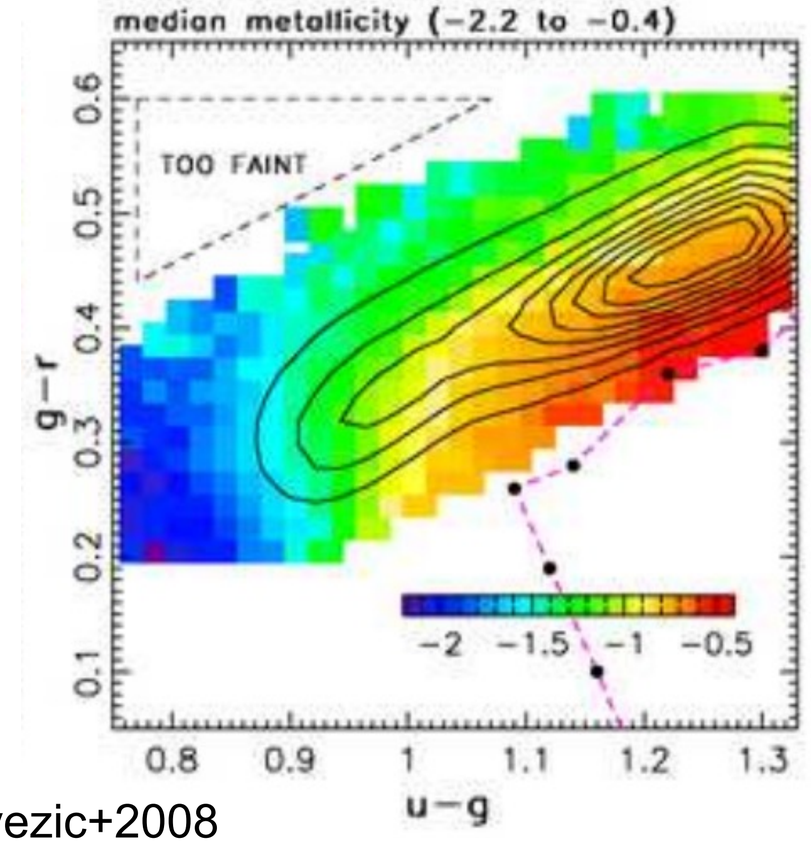
Training Set:
~ 10,000 stars at 16 < r < 19
Photometry: DES griz
Spectroscopic Metallicity: S5

Uncertainty:
RMSE in Test Set: 0.25 dex

Hughes, Li, Speagle, in prep.

Metallicity w/ Broadband Photometry

SDSS ugr-band photometry
metal-poor —> UV excess



Ivezic+2008

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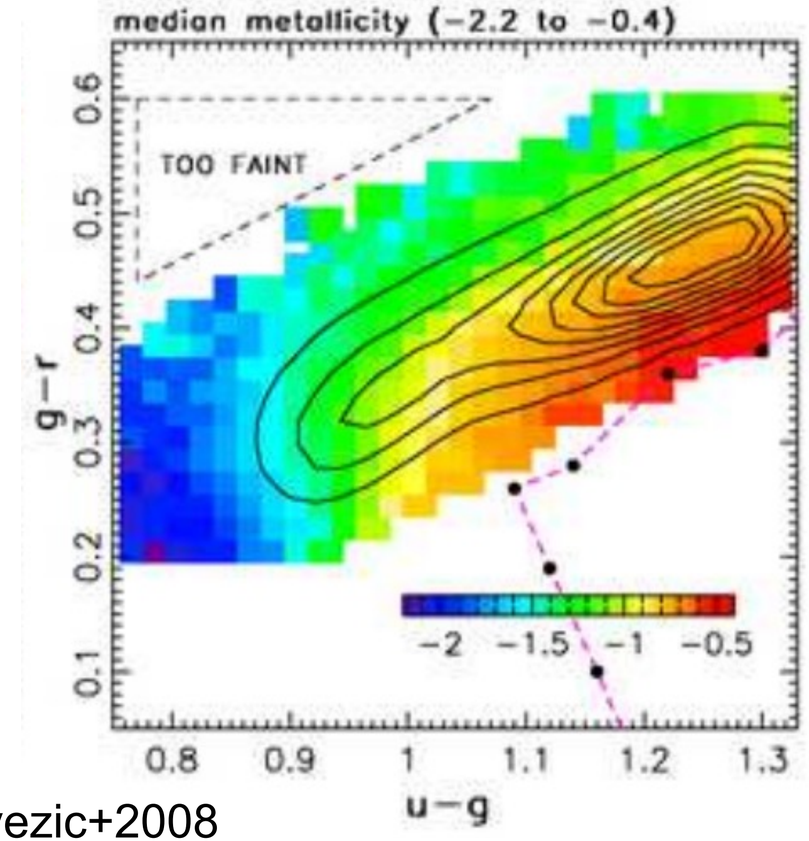
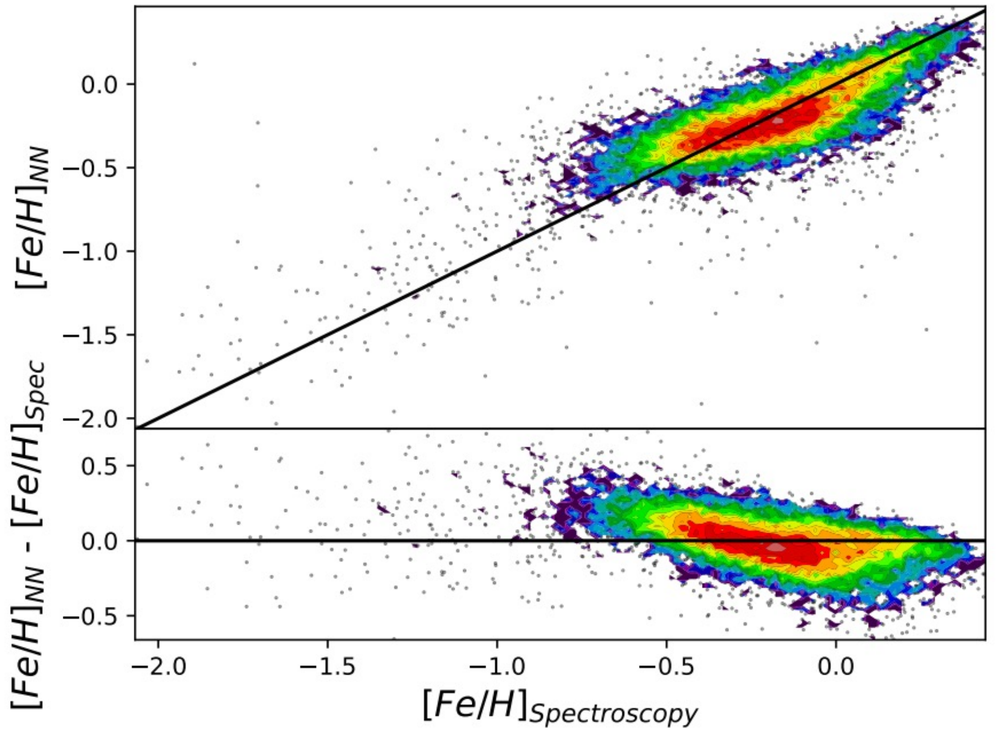


Ivezic+2008

ML approach w/ 8-band from
Gaia + 2MASS + WISE

Uncertainty: 0.19 dex



Fallows & Sanders (2022)

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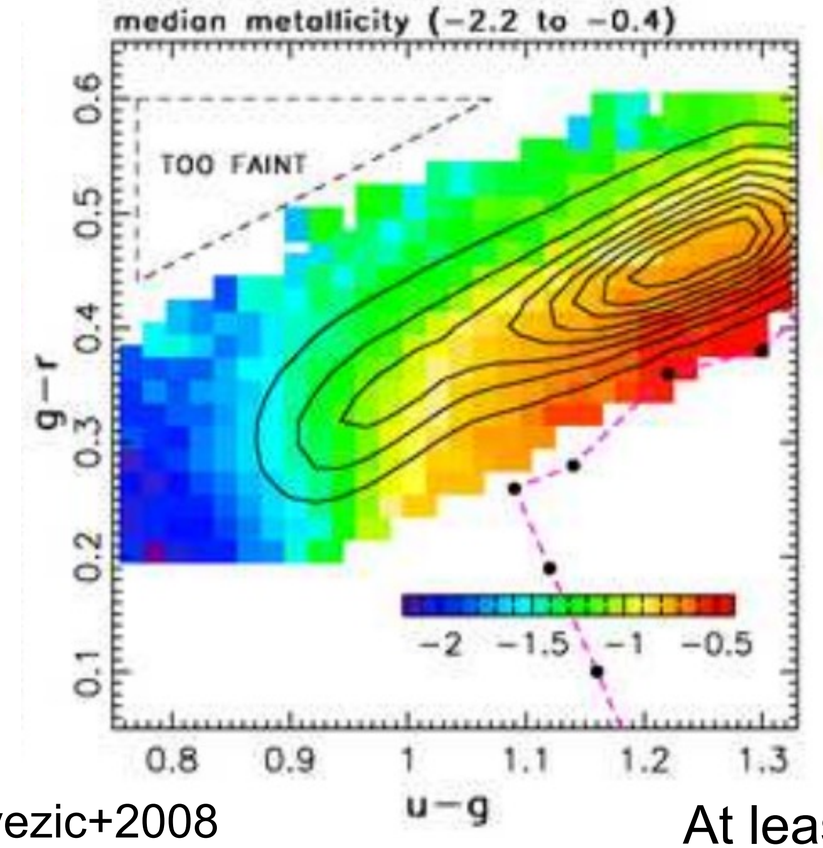

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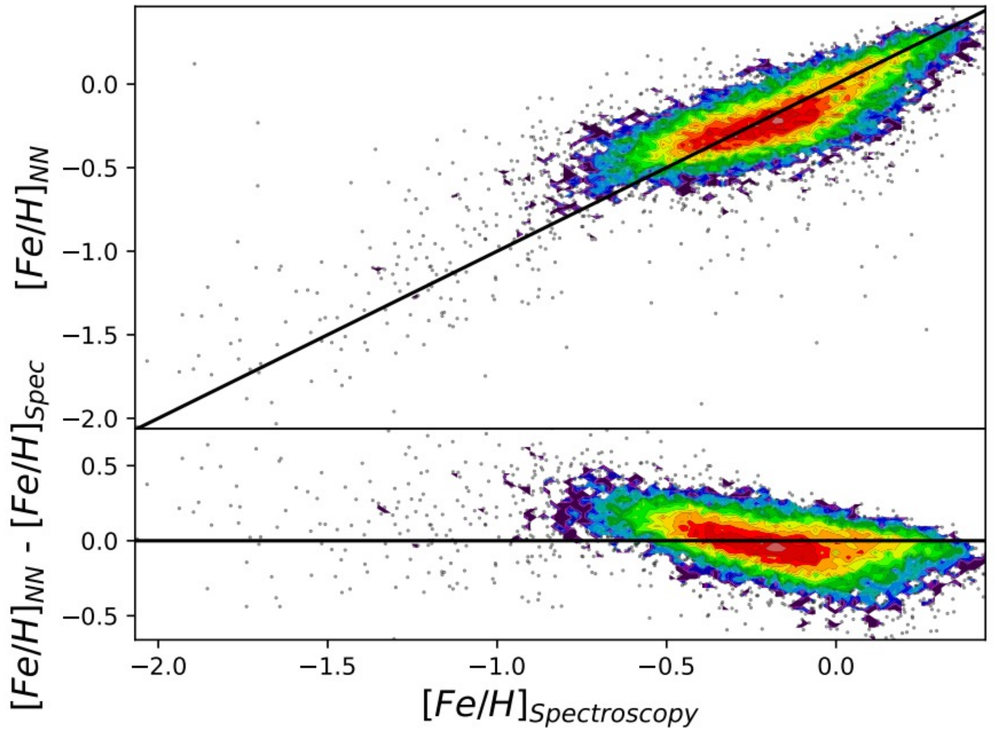


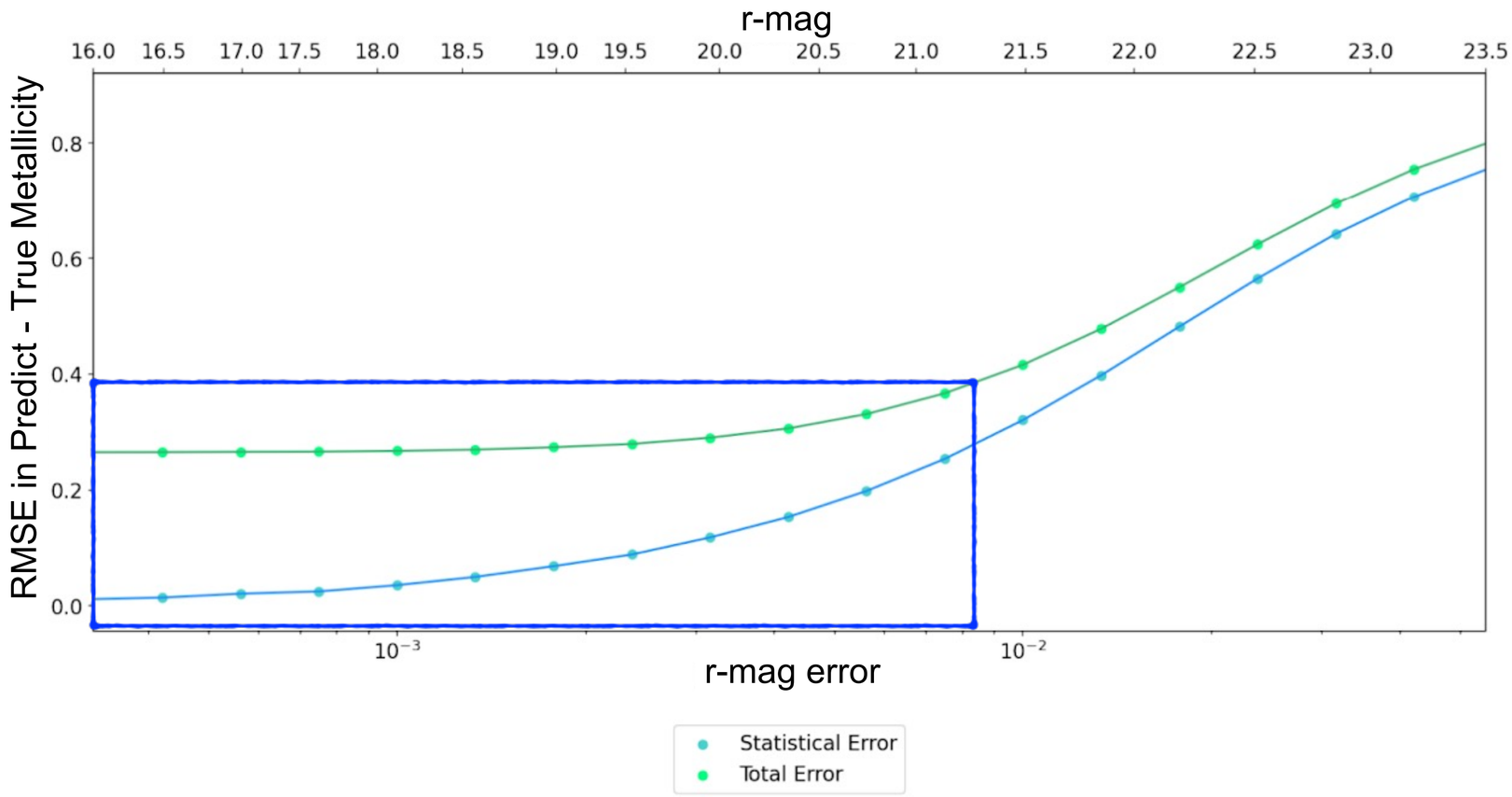
At least 3 independent groups working on
Gaia XP coefficients —> metallicity ! (G<17)

Fallows & Sanders (2022)

Metallicity Uncertainty at the faint end

Charles Hughes

Gaia XP



[Fe/H] uncertainty < 0.4 dex
at r < 21 mag

Hughes, Li, Speagle, in prep.

Metallicity Uncertainty at the faint end

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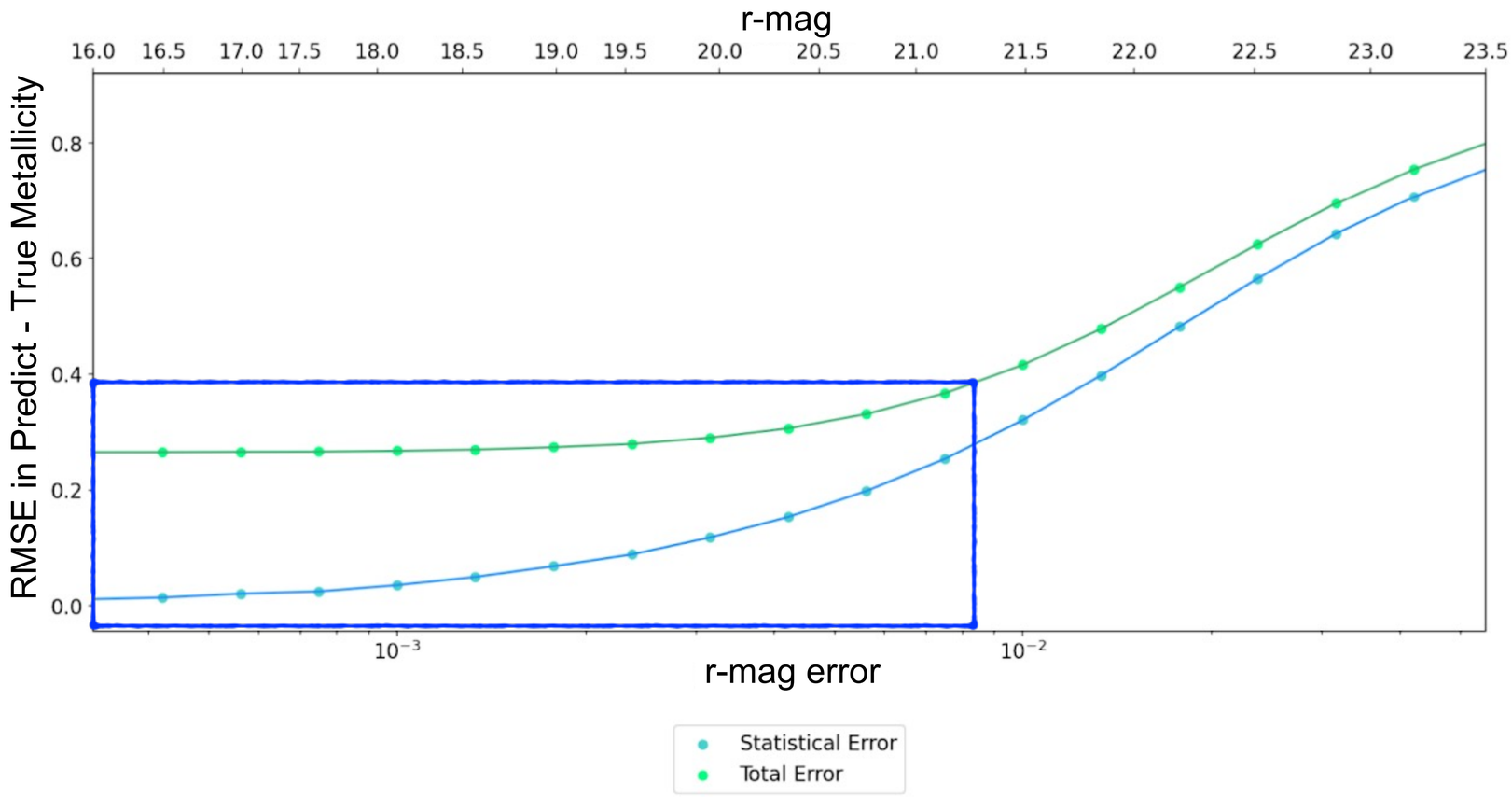

[Fe/H] uncertainty < 0.4 dex at r < 21 mag

and Rubin will do 2-3 mag deeper!

Hughes, Li, Speagle, in prep.

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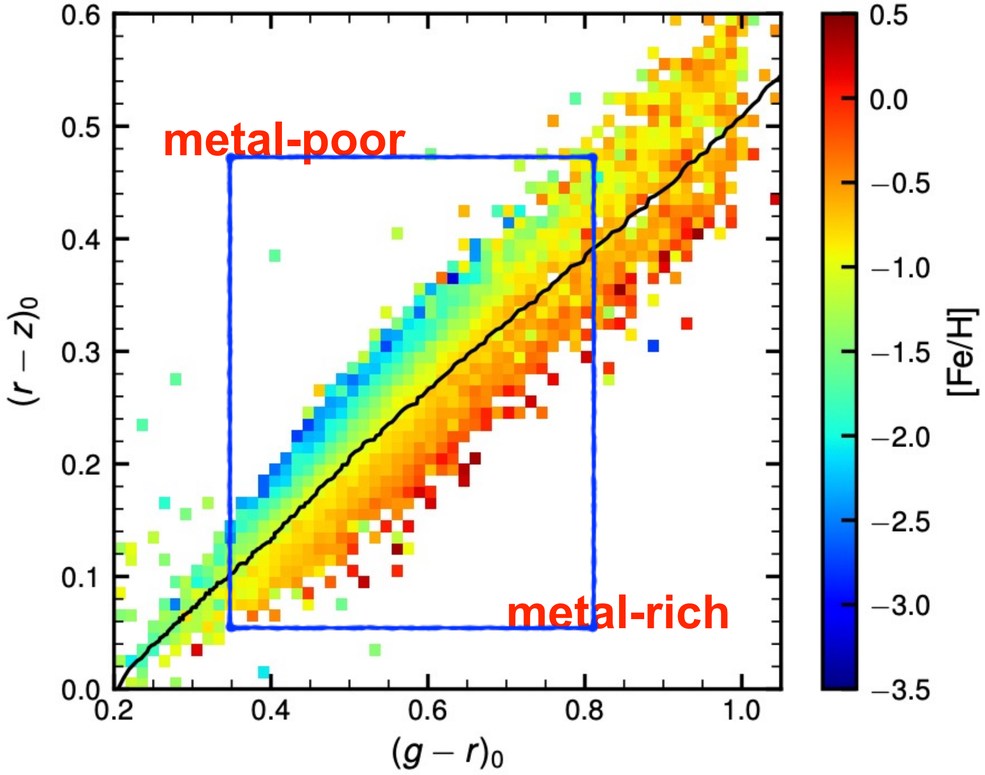

Photometric metallicity of stars w/ DES photometry

TSL et al. (2019)
(S5 Collaboration)

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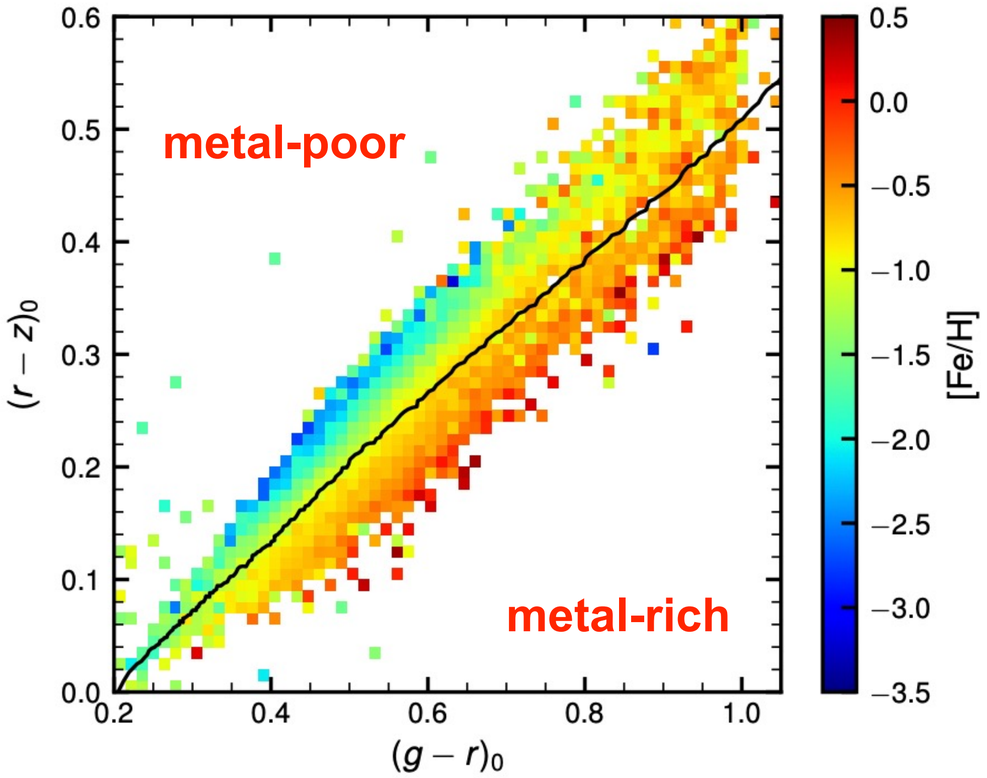

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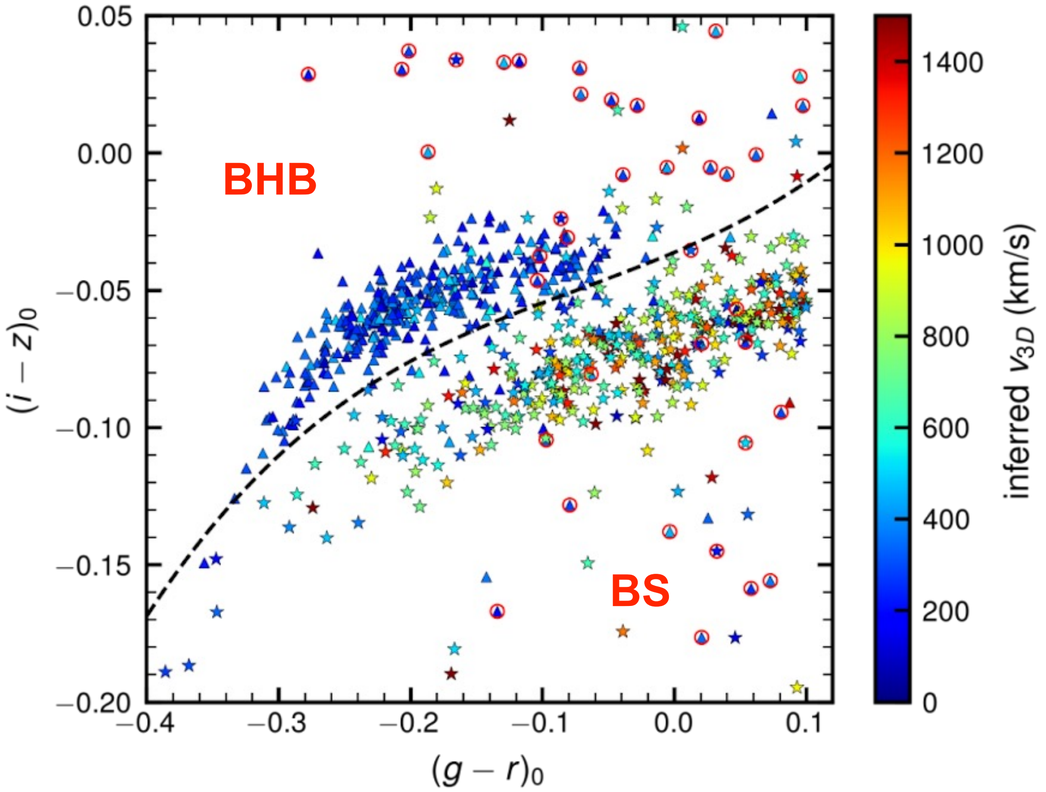

- BHB: Blue horizontal branch stars
- BS: Blue straggler stars

Separating giant and dwarf stars in blue w/ DES photometry

TSL et al. (2019)
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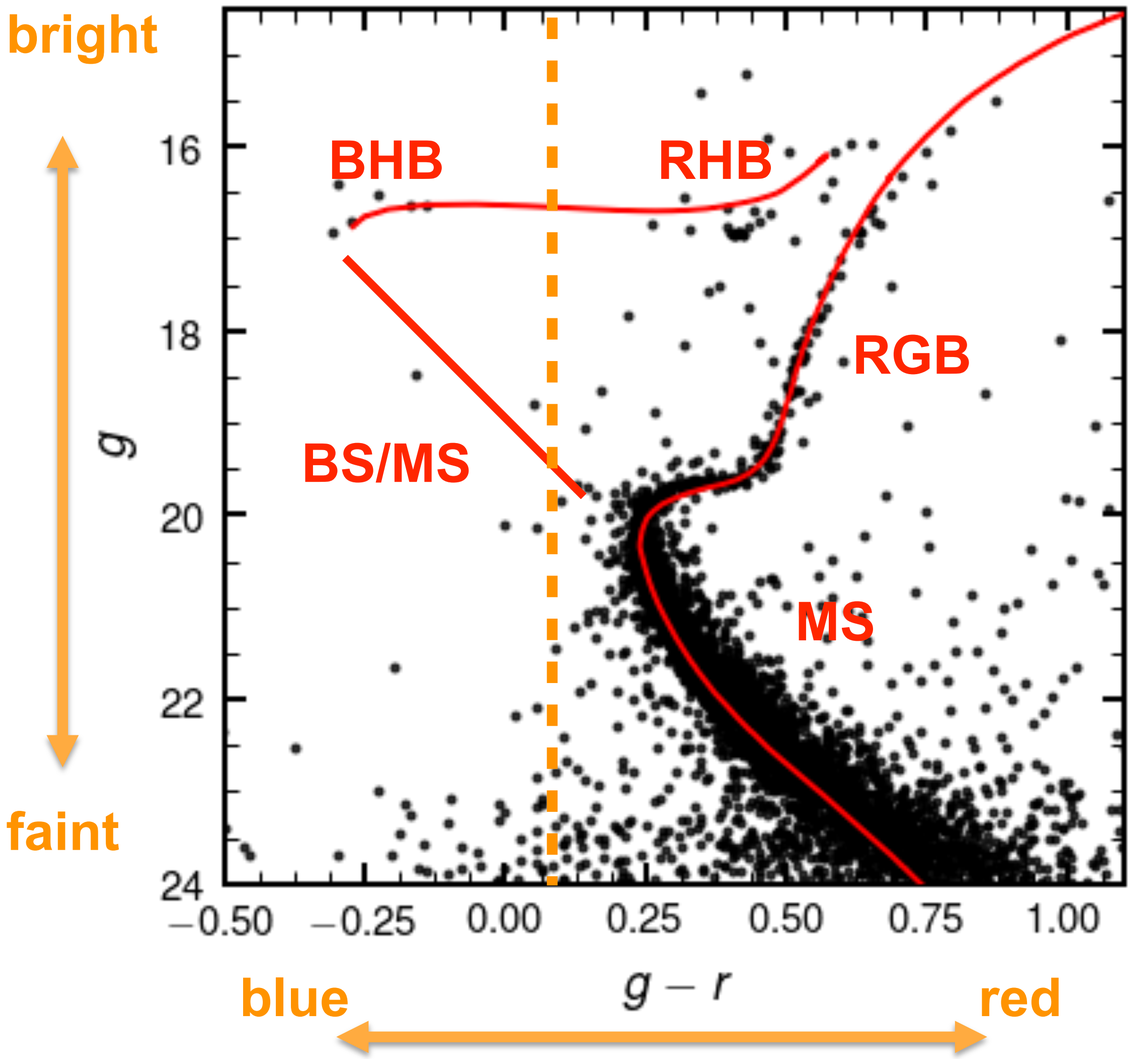
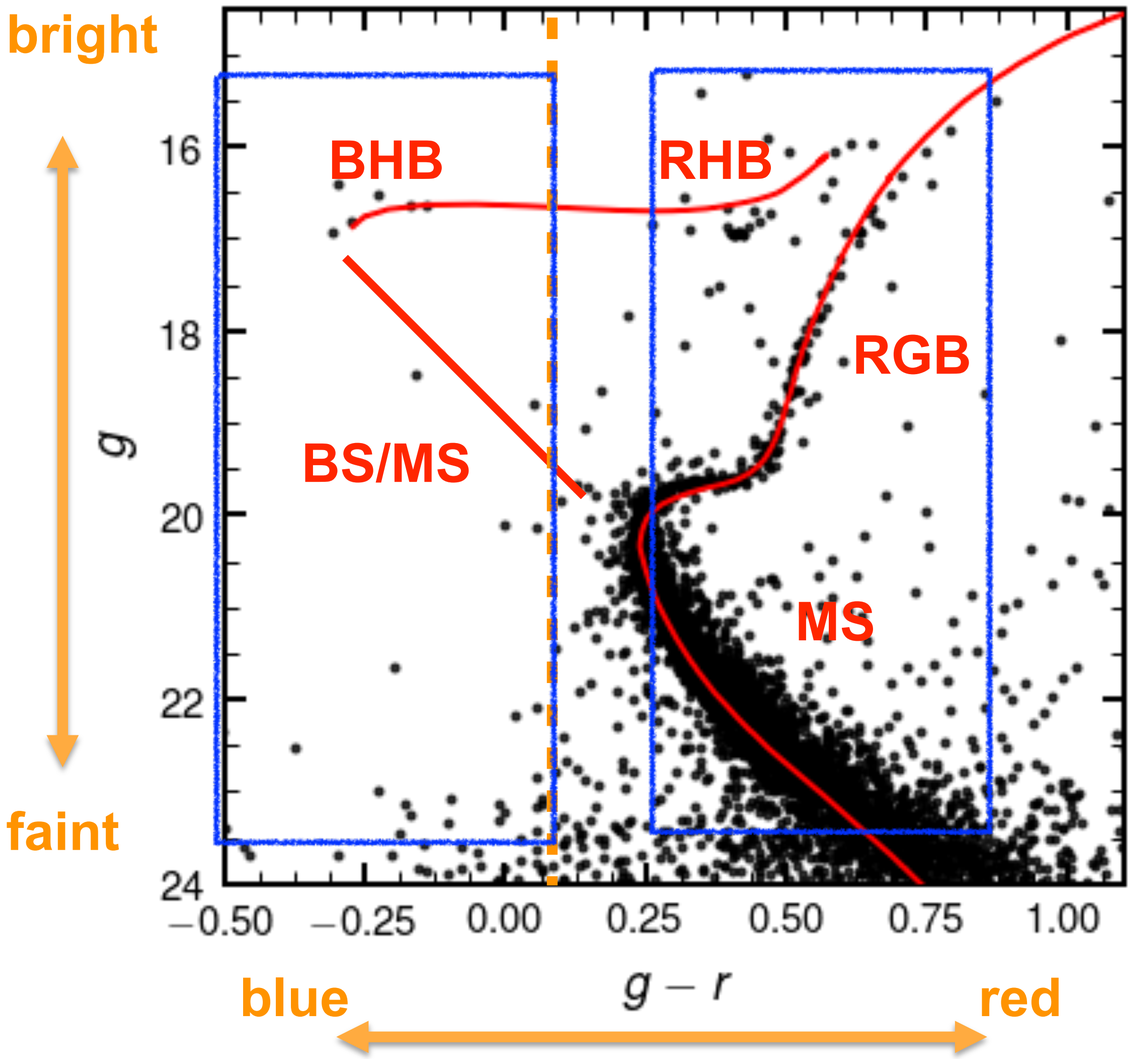
Stellar Population — NGC 1261



MS: main sequence
RGB: red-giant branch
BHB: blue horizontal branch
RHB: red horizontal branch
BS: blue stragglers

select all blue stars
with g-r < 0.1

Stellar Population — NGC 1261



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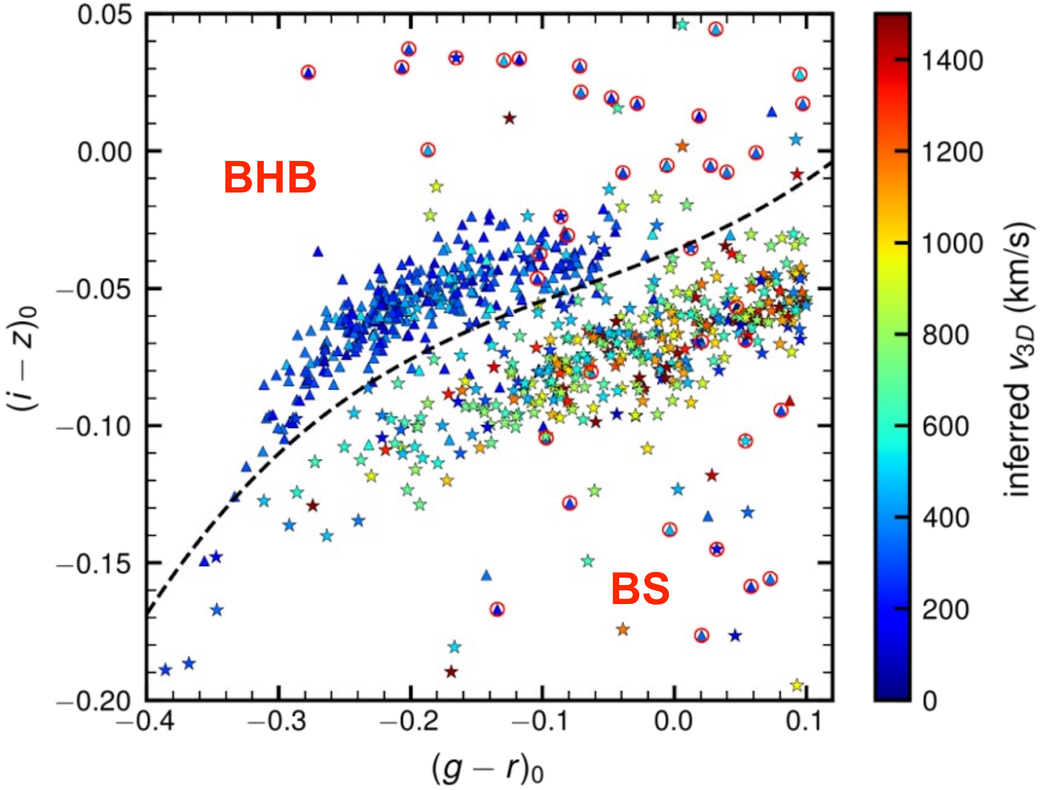

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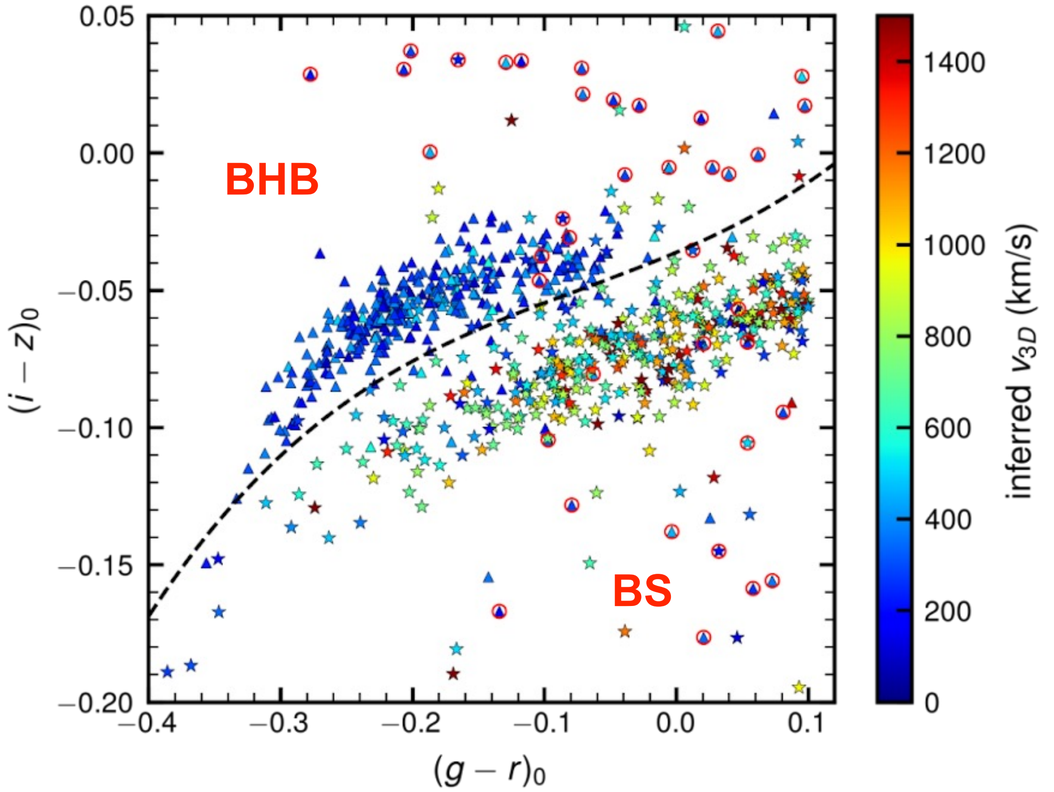
The Power of High Precision Photometry on Near-Field Cosmology with DECam

DES DR1



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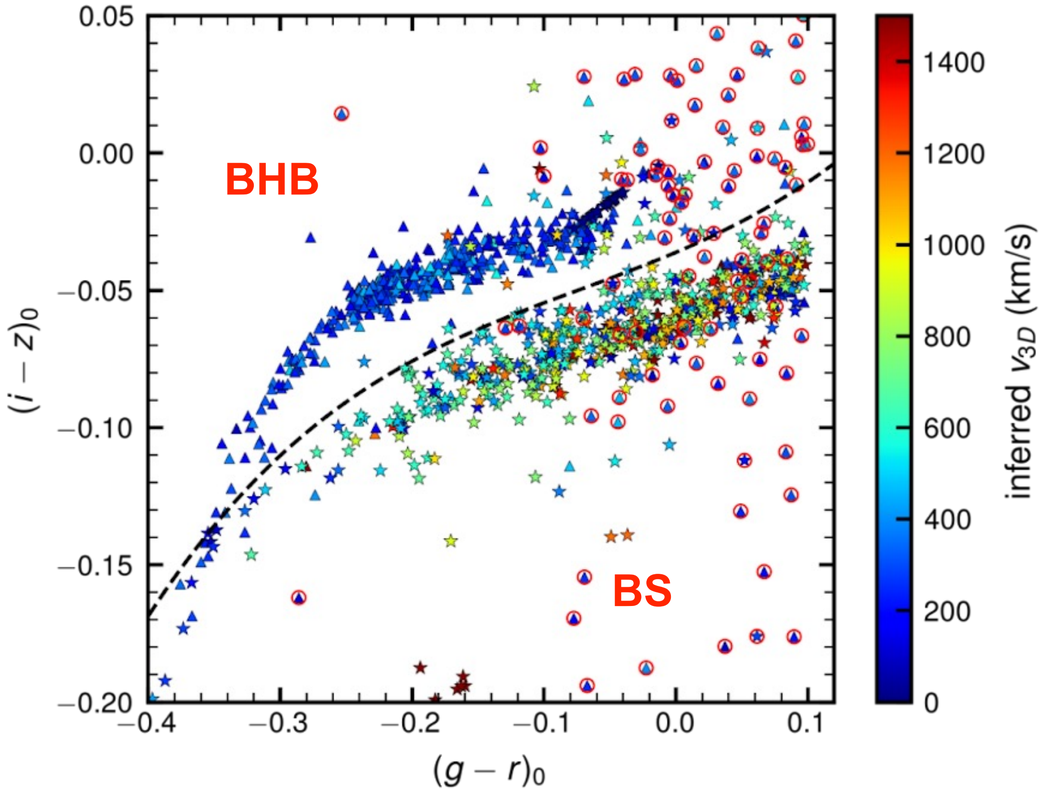
The Power of High Precision Photometry on Near-Field Cosmology with DECam

DES DR2



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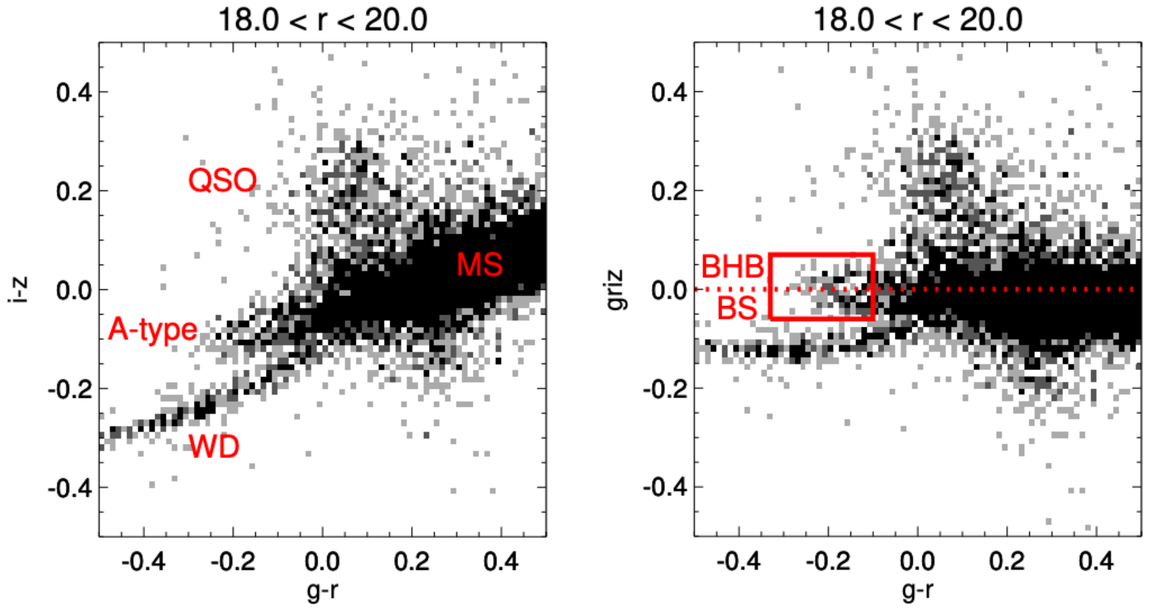
Separating giant and dwarf stars in blue w/ DES photometry

TSL et al. (2019)
(S5 Collaboration)

BHB/BS Separation w/ Broadband Photometry

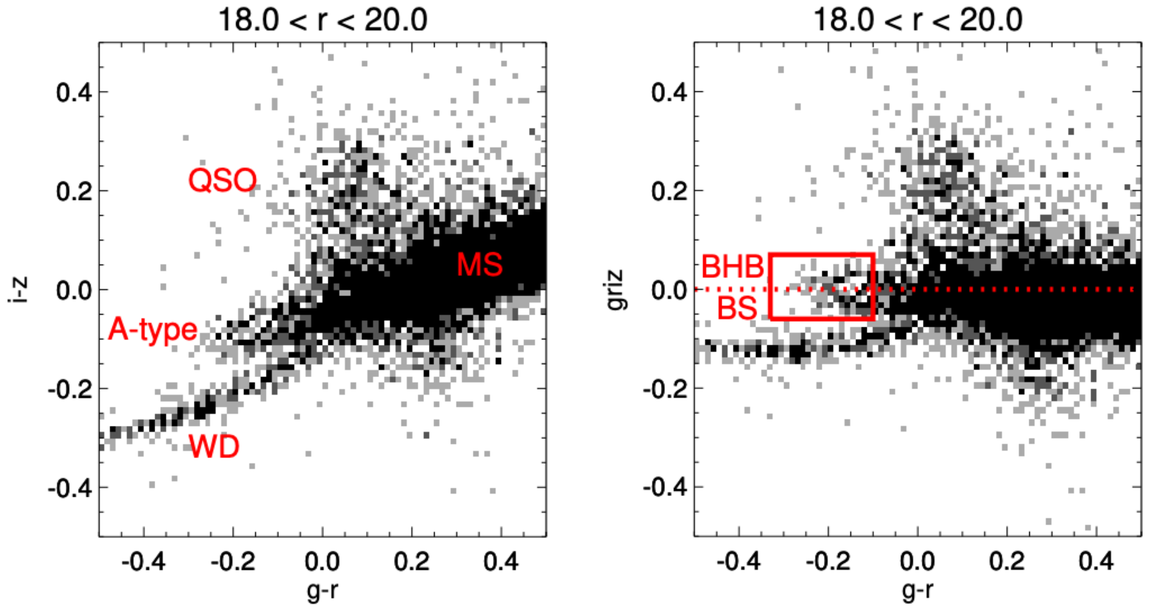
Subaru/Hyper-Supreme Cam

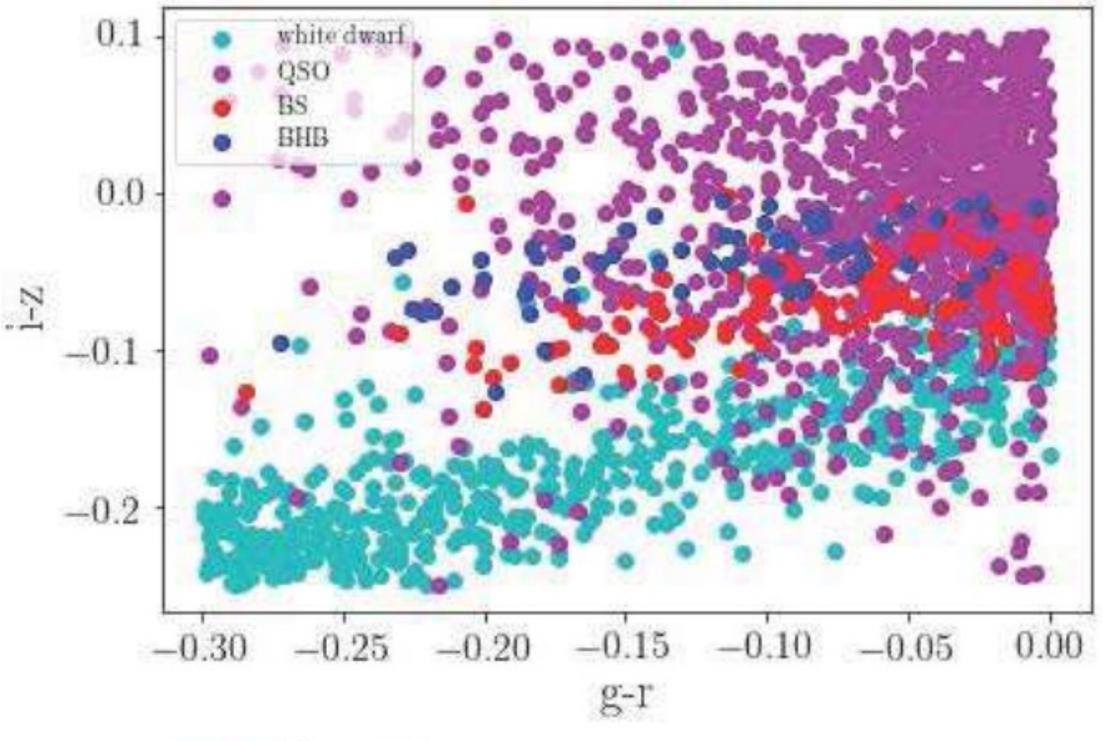


Deason+2018

BHB/BS Separation w/ Broadband Photometry

Subaru/Hyper-Supreme Cam



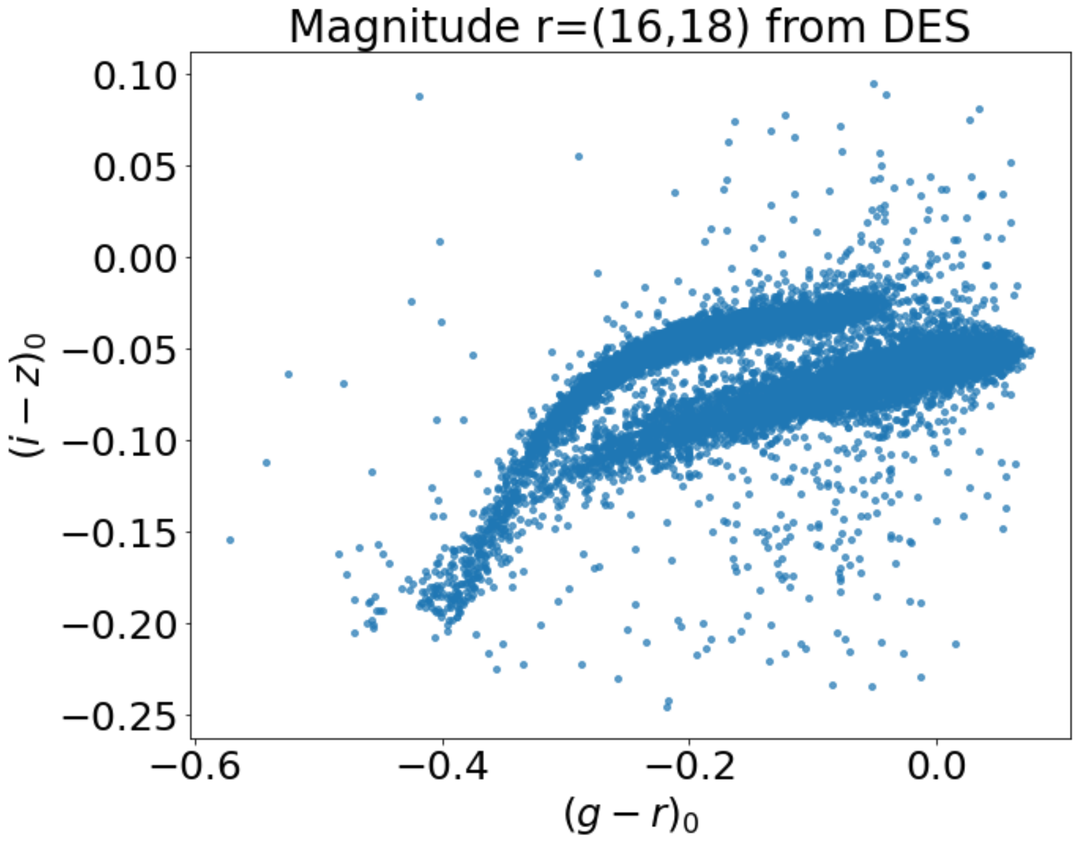


Deason+2018

Fukushima+2019

BHB/BS Separation w/ DES Photometry

Grace Yu



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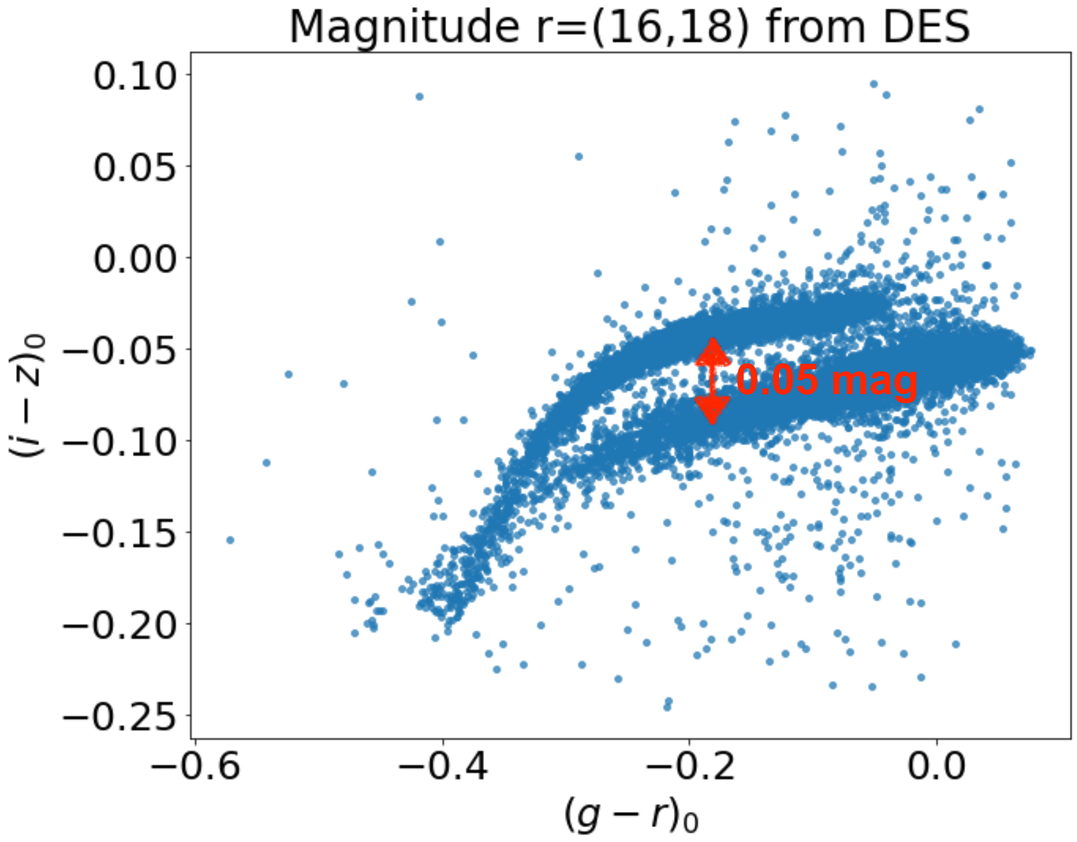
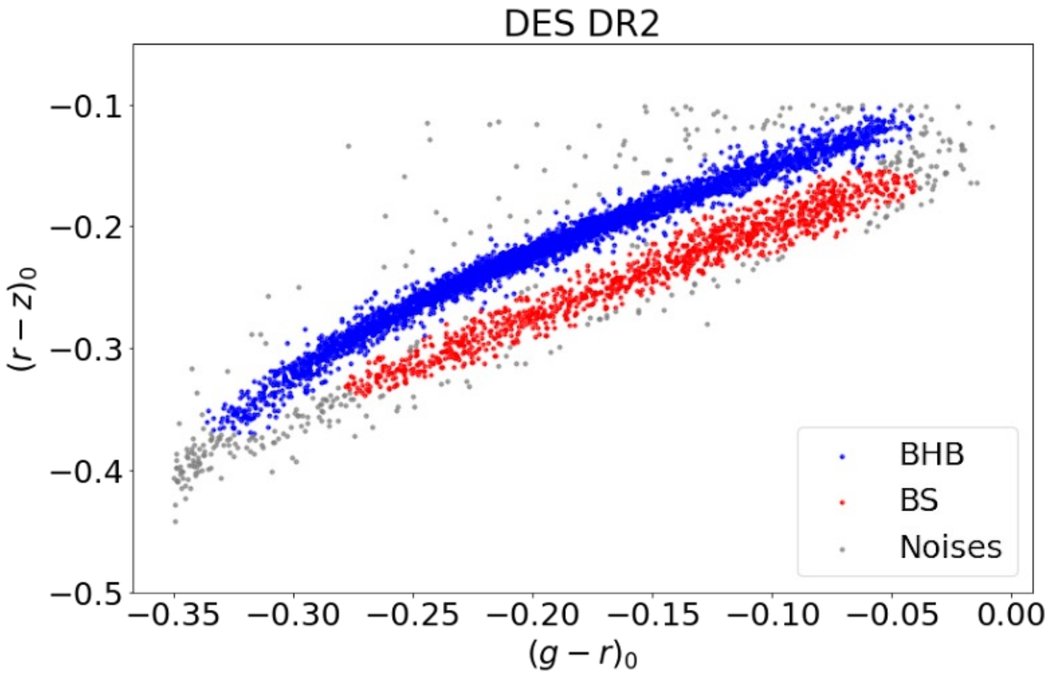


BHB/BS Separation w/ DECam Photometry: DES vs DECaLS

Grace Yu

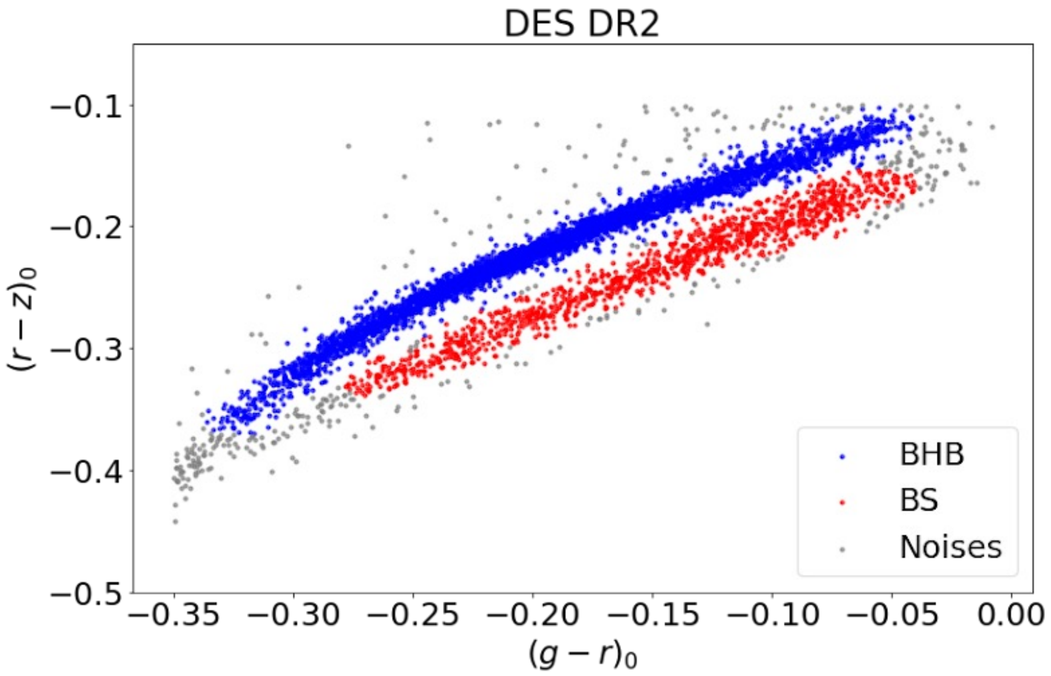


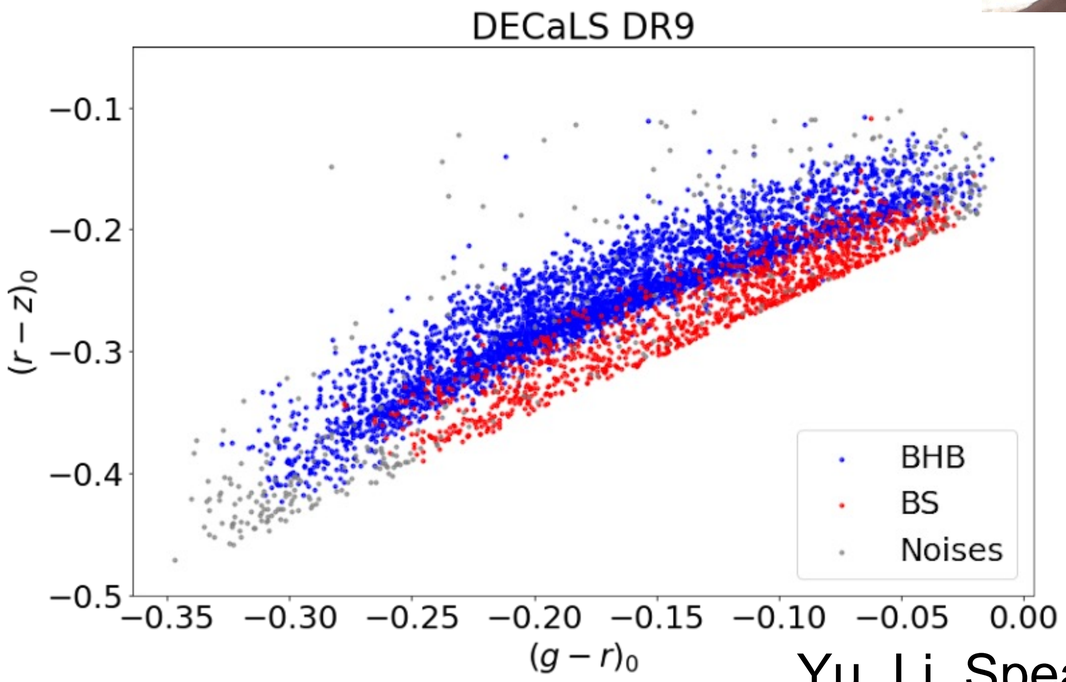
Yu, Li, Speagle, in prep.

BHB/BS Separation w/ DECam Photometry: DES vs DECaLS

Grace Yu

Same stars in DES footprint

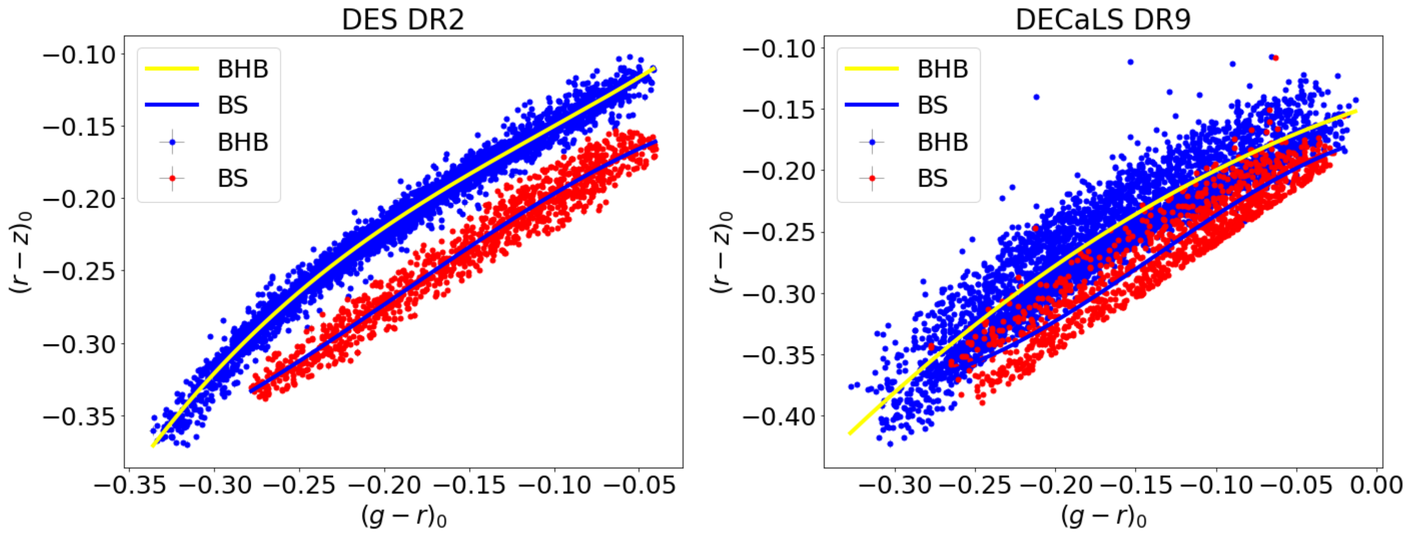




Yu, Li, Speagle, in prep.

Note that DECaLS DR9 is shallower than DES DR2

BHB/BS Separation w/ DECam Photometry



Grace Yu

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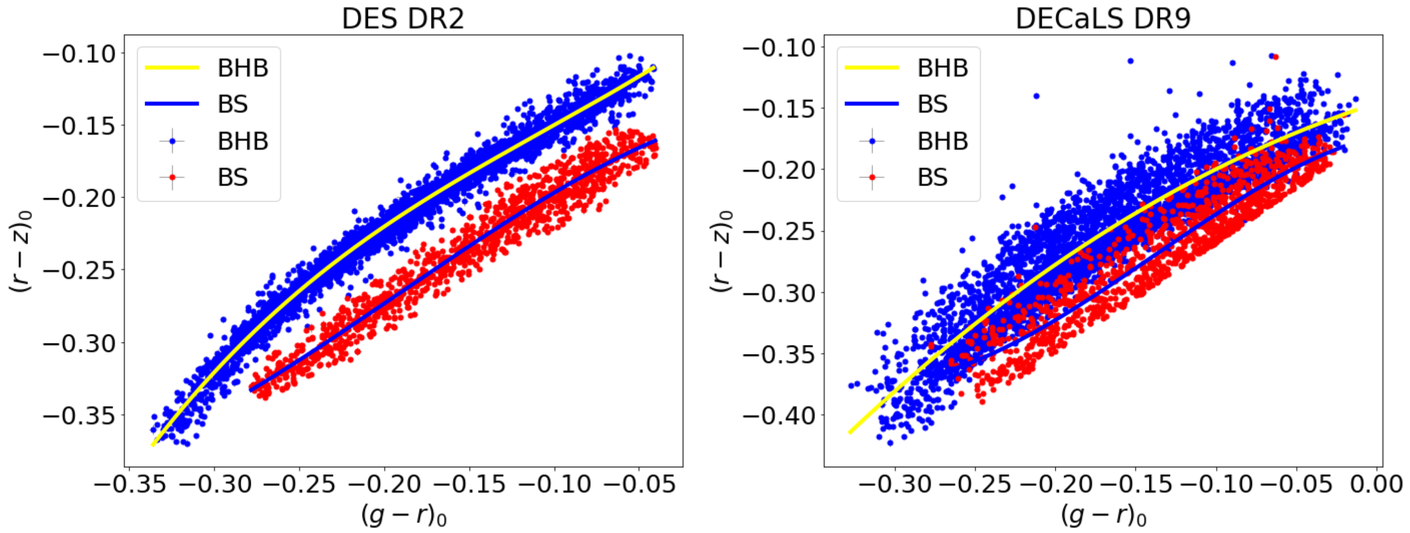
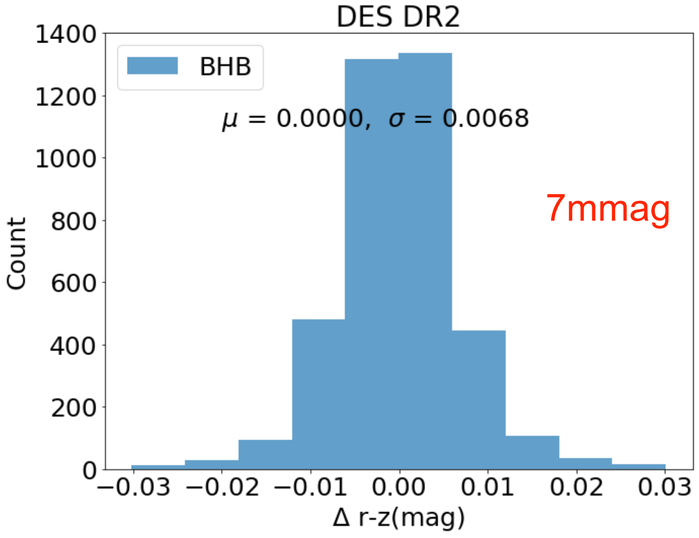
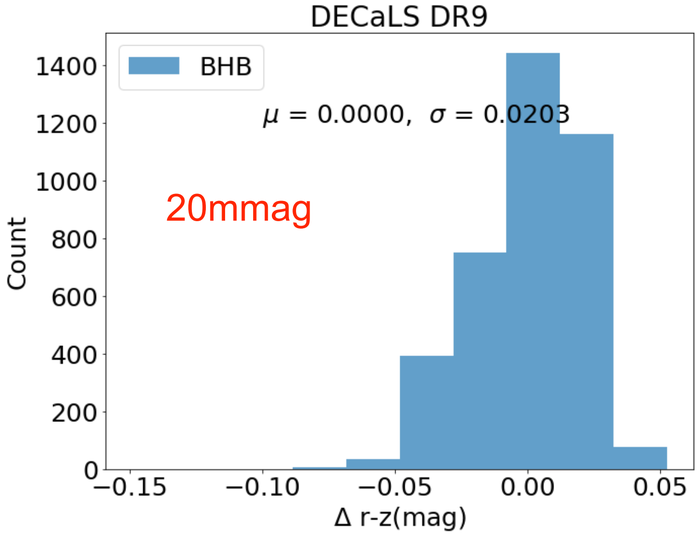
Grace Yu



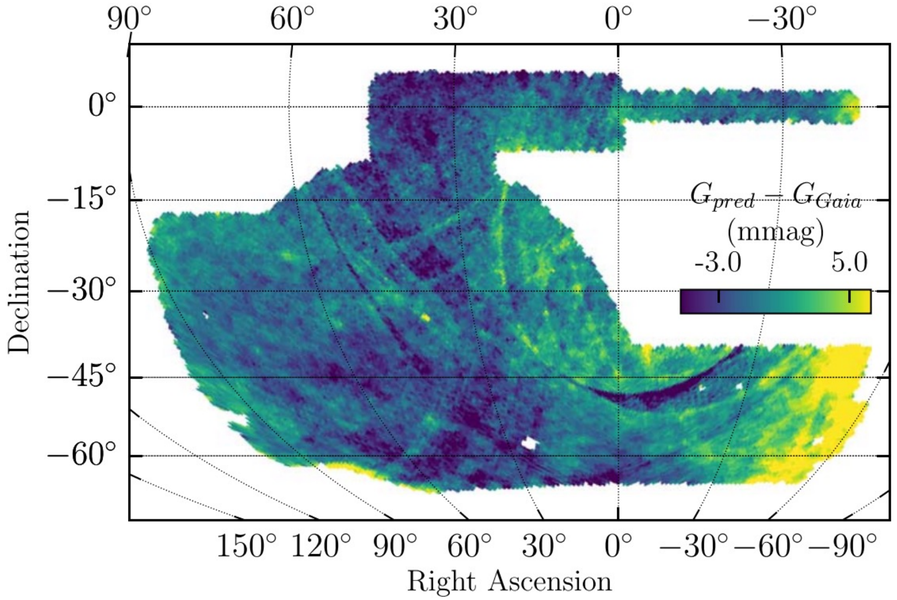


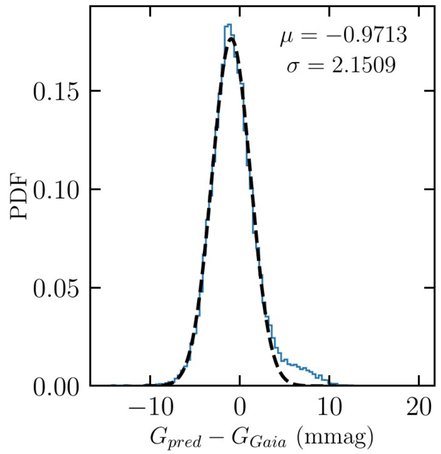


Yu, Li, Speagle, in prep.

The Unprecedented High Precision Photometry Achieved by DES

The Dark Energy Survey Data Release 2



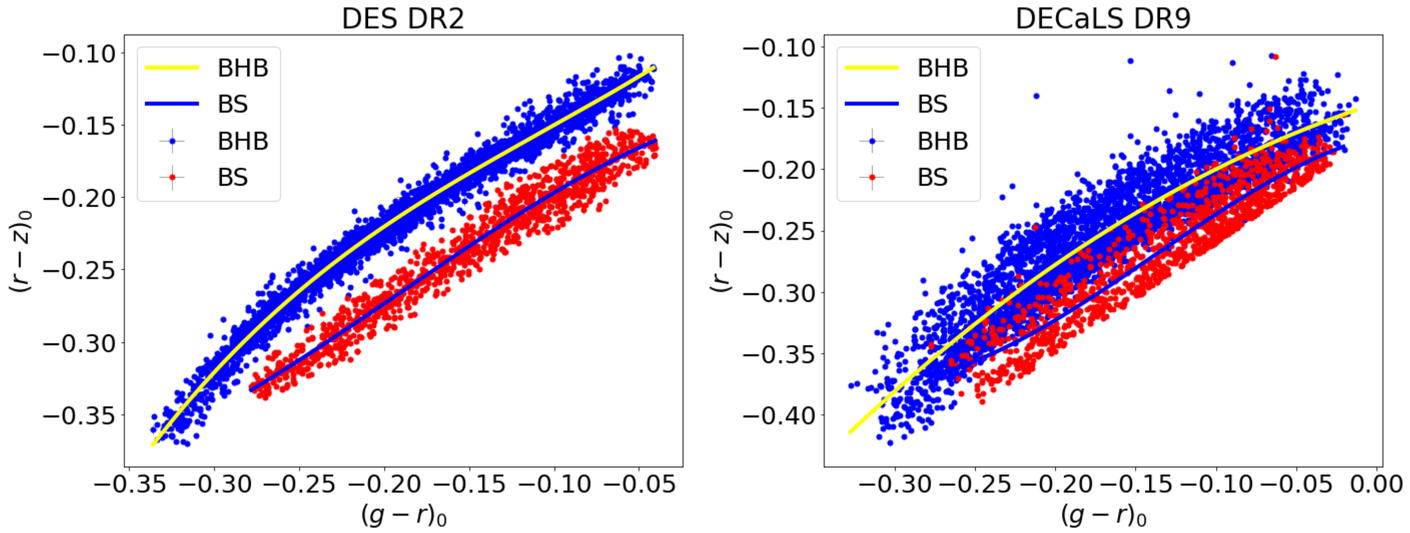


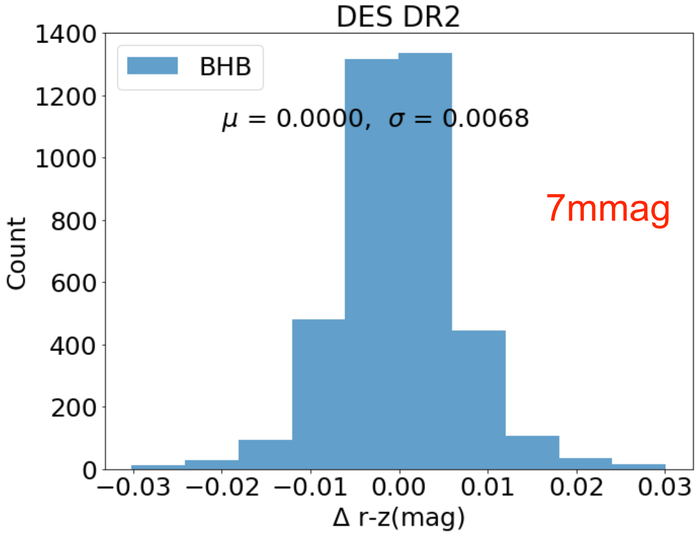
- Photometric Uniformity vs. Gaia: 2.15 mmag
- Single-epoch Photometric Repeatability: 2-3 mmag
- Achieved with efforts from many aspects
  - Auxiliary Calibration Systems: DECaLS, aTmCam, GPS Monitor
  - Forward Global Calibration Method (FGCM, Burke, Rykoff+2018) for photometric zeropoint
  - Chromatic Correction and Interstellar Reddening Task Force

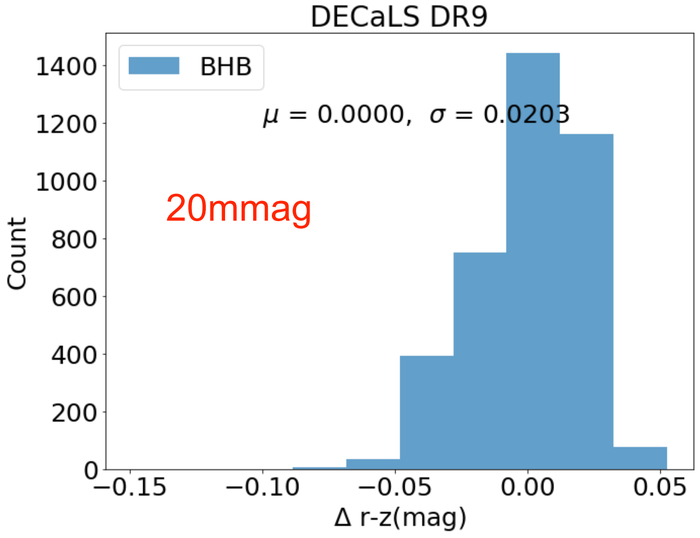
Abbott et al. 2021 (DES Collaboration)

BHB/BS Separation w/ DECam Photometry

Grace Yu





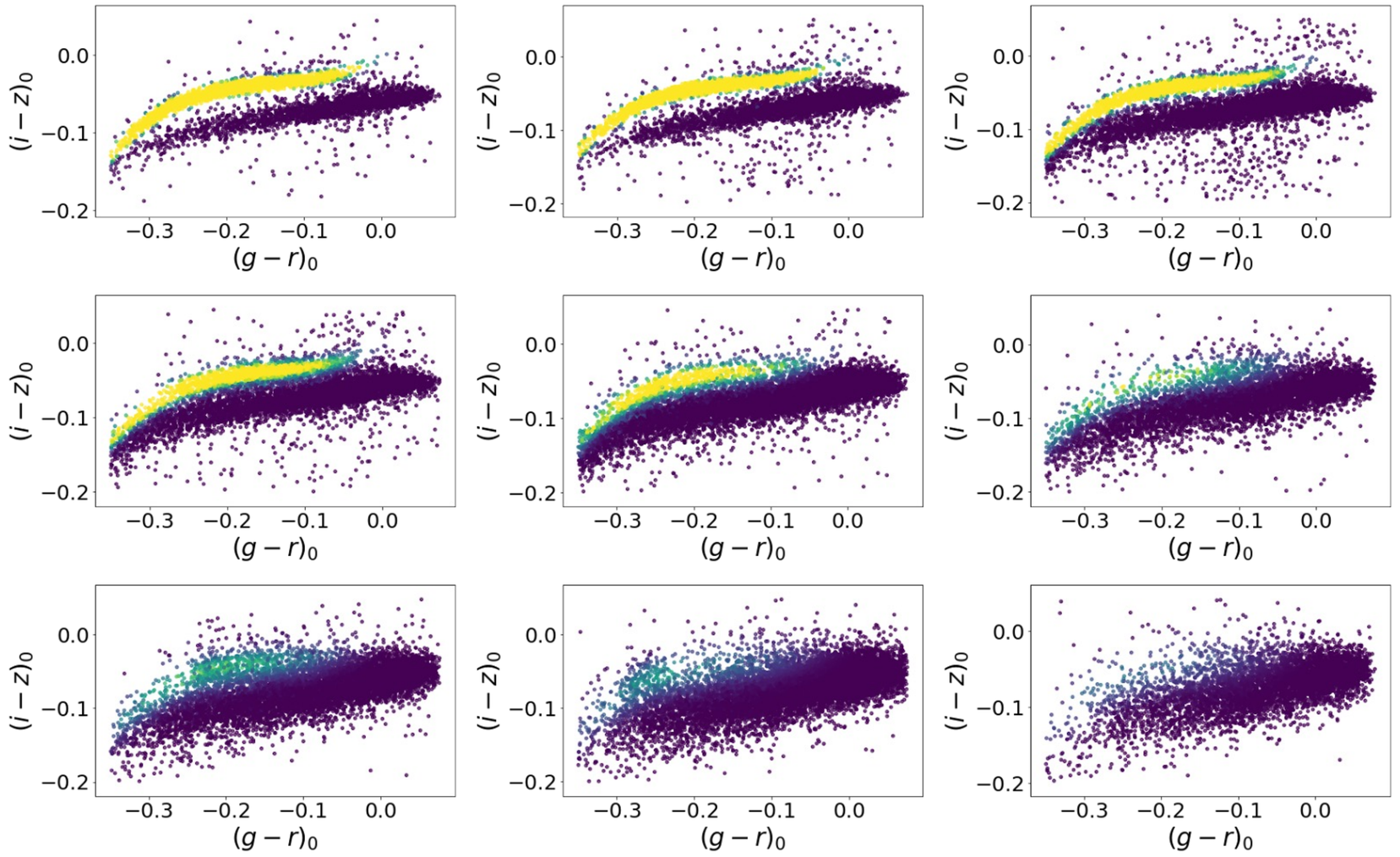


Yu, Li, Speagle, in prep.

Milky Way Density Profile w/ BHB stars

Grace Yu

r=16



r=22

Yu, Li, Speagle, in prep.

Summary

- DES provides the unprecedented high precision photometry (~2mmag).
- With DES photometry + S5 metallicity, we show that DES photometry can provide photometric metallicity at a precision of ~0.25 dex.
- The high precision photometry from DES also allows us to separate BHB from BS; the former could be used to map the density profile of the Milky Way.
- The high-precision photometry from DES largely improved the target selection of spectroscopic follow up program on metal-poor giant stars in the Milky Way halo.
- Rubin/LSST will be able to reach similar precision and go 2-3 mag deeper!