Wide-Field Imaging Surveys at CFHT: Past, Present and Future

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National Research Council, Victoria, British Columbia, Canada

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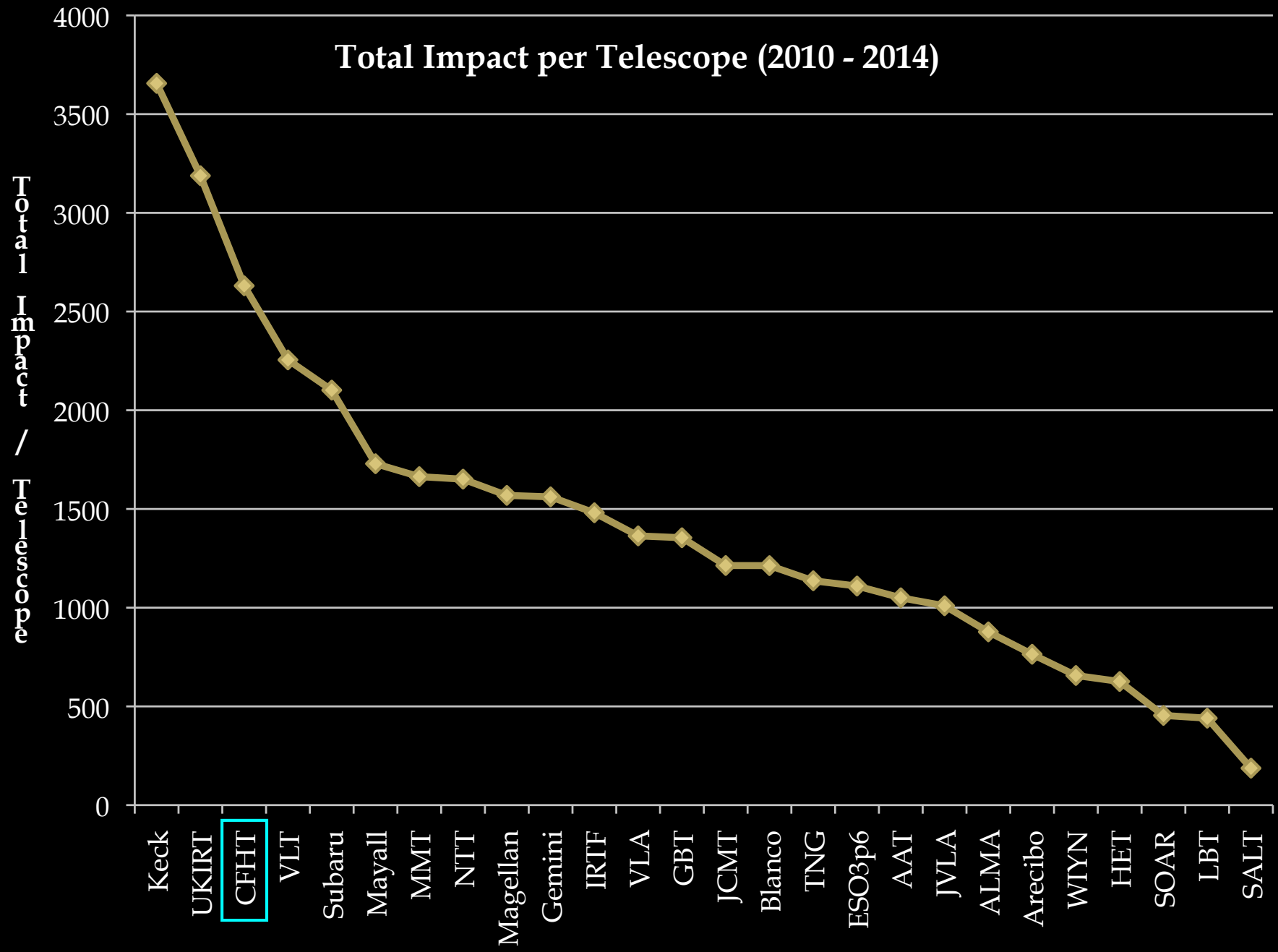
CFHT Large Programs

	Period	PI	Instrument	Allocation	Program
1st Call	**2008-2013**	**A. McConnachie**	**MegaCam**	**226 hrs**	**PandAS**
	2008-2013	**L. Ferrarese**	**MegaCam**	**771 hrs**	**NGVS** ★
	2008-2013	J.-F. Donati	ESPaDOnS	690 hrs	MaPP
	2008-2013	G. Wade	ESPaDOnS	640 hrs	MiMeS
2nd Call	**2013-2016**	**B. Gladman**	**MegaCam**	**560 hrs**	**OSSOS**
	2013-2016	**R. Ibata A. McConnachie**	**MegaCam**	**350 hrs**	**LUAU** ★
	2013-2016	**P.-A. Duc**	**MegaCam**	**300 hrs**	**MATLAS**
	2013-2016	Alecian/Wade	ESPaDOnS	604 hrs	BinaMIcS
	2013-2016	J.-F. Donati	ESPaDOnS	478 hrs	MaTYSSE
	2013-2016	P. Petit	ESPaDOnS	216 hrs	History of the Magnetic Sun
3rd Call	**2017-2019**	**J.-C. Cuillandre A. McConnachie**	**MegaCam**	**271 nights**	**CFIS** ★
	2017-2019	**A. Boselli**	**MegaCam**	**50 nights**	**VESTIGE** ★
	2017-2019	M. Liu	WIRCam	60 nights	CFHT IR Parallax Program

CFHT: Venerable and Productive



- courtesy D. Crabtree

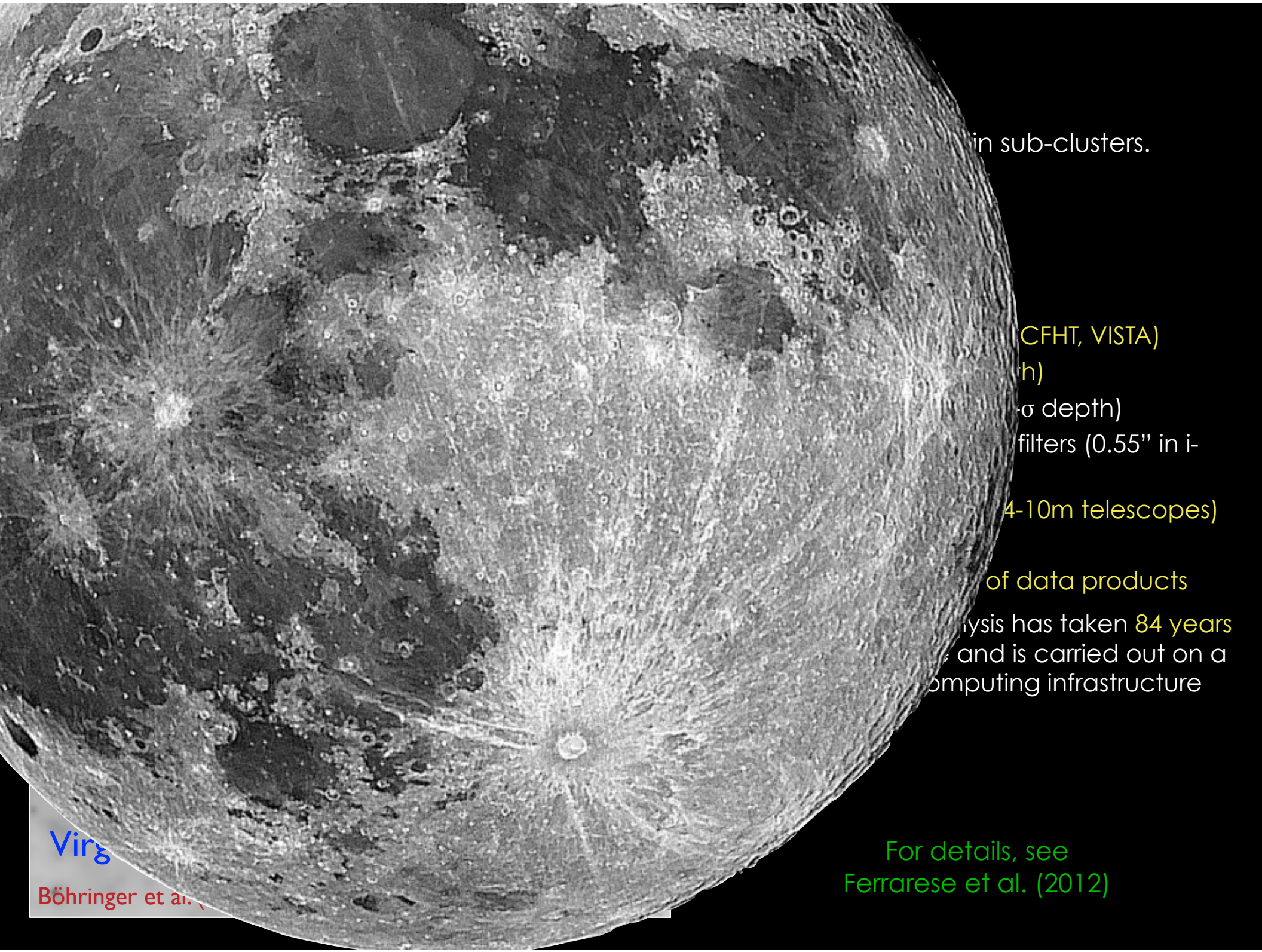
Near Field Cosmology

- Two Environments
  1. The Virgo Cluster: NGVS + VESTIGE
  2. The Milky Way: Pristine + LUAU/CFIS

- Key Questions
  - The low-mass end of the galaxy luminosity function.
  - What is the role of accretion vs secular evolution?
  - Galaxy transformative processes.
  - What was the particular history of our Galaxy?
  - What was the role of our galactic environment?
  - What is the distribution of dark matter on galaxy scales?
  - Is dark matter a dynamically cold particle?
  - Constraints on alternative gravity theories.

NGVS

*(The **N**ext **G**eneration **V**irgo Cluster **S**urvey)*



in sub-clusters.

CFHT, VISTA)

h)

σ depth)

filters (0.55" in i-

4-10m telescopes)

of data products

ysis has taken 84 years
and is carried out on a
mputing infrastructure

Virg

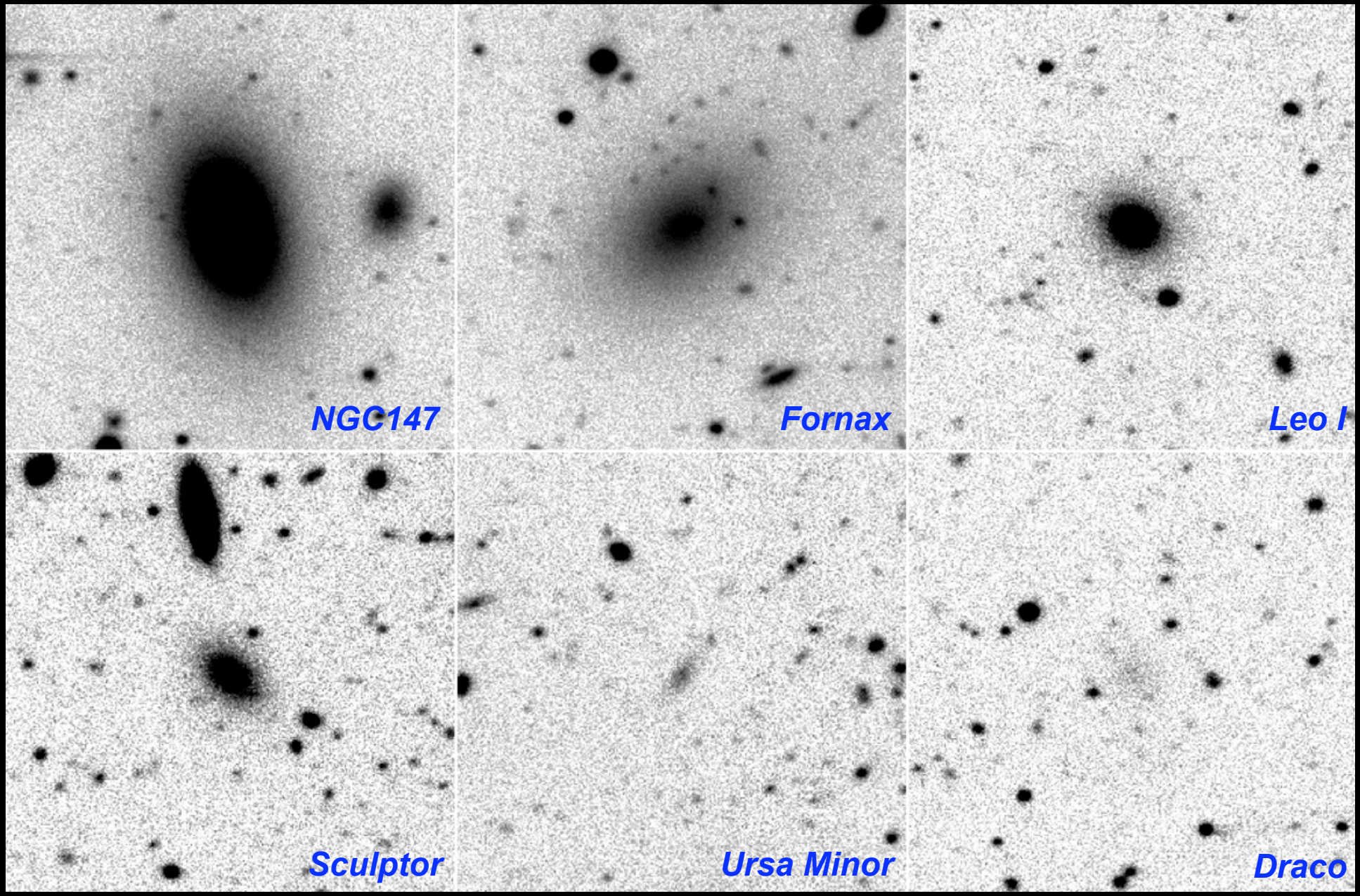
Böhringer et al.

For details, see
Ferrarese et al. (2012)

NGVS - Publications

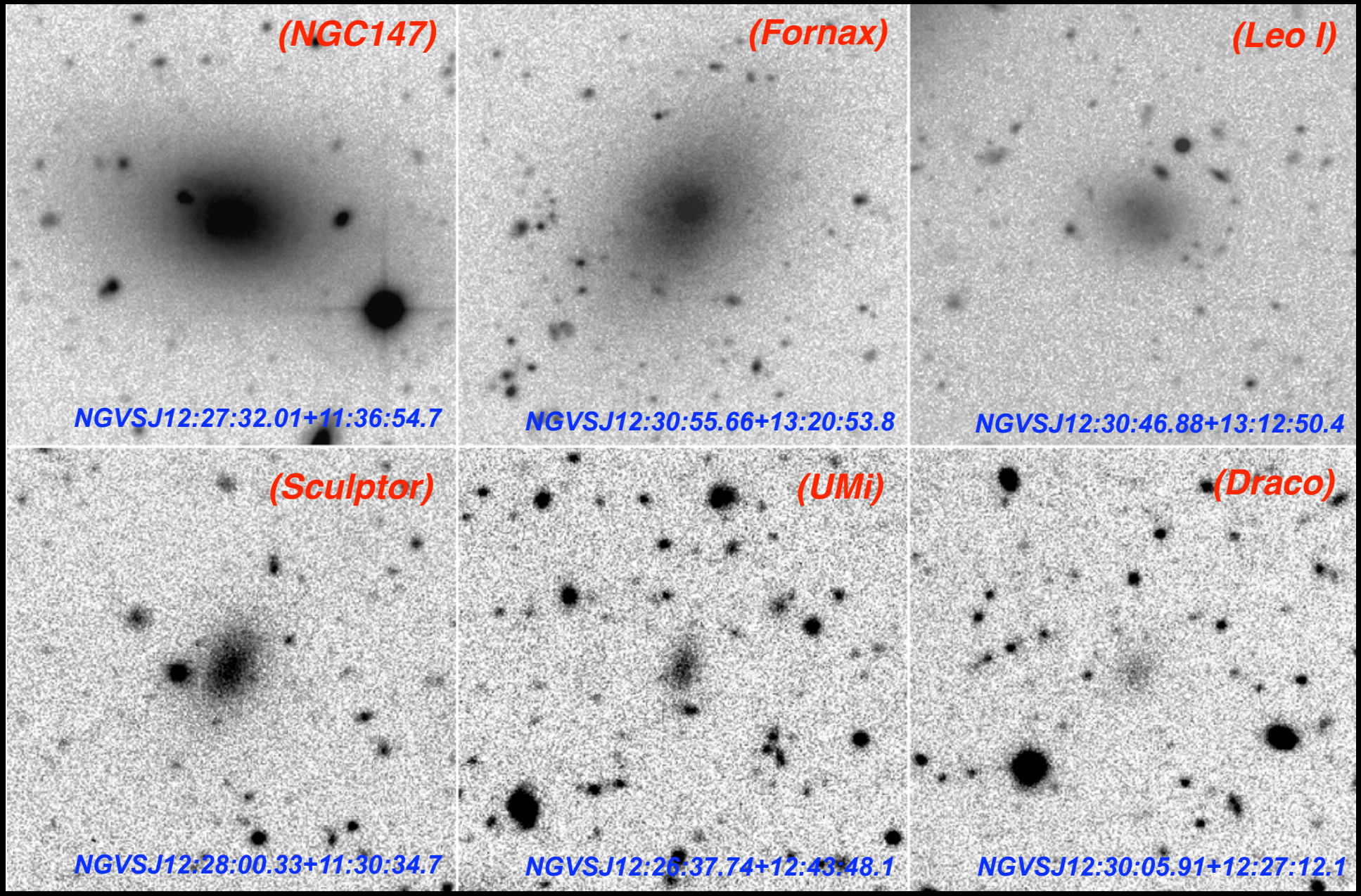
- ★ **"The GALEX Ultraviolet Virgo Cluster Survey (GUViCS). I. The UV Luminosity Function of the Central 12 Sq. Deg."** – Boselli et al. 2011
- ★ **"The GALEX Ultraviolet Virgo Cluster Survey (GUViCS). II. Constraints on star Formation in Ram-Pressure Stripped Gas"** – Boissier et al. 2012
- ★ **"Stripped Gas as Fuel for Newly Formed HII Regions in the Encounter Between VCC 1249 & M 49: A Unified Picture from NGVS & GUViCS"** – Arrigoni Battaia et al. 2012
- ★ **"Introduction to the Survey"** – Ferrarese et al. 2012
- ★ **"NGC 4216: A Bombarded Spiral in the Virgo Cluster"** – Paudel et al. 2013
- ★ **"Discovery of a New Member of the Inner Oort Cloud from the Next Generation Virgo Cluster Survey"** – Chen et al. 2013
- ★ **"The Next Generation Virgo Cluster Survey-Infrared (NGVS-IR). I. A New Near-Ultraviolet, Optical, and Near-Infrared Globular Cluster Selection Tool"** – Muñoz et al. 2014
- ★ **"The GALEX Ultraviolet Virgo Cluster Survey (GUViCS) III. The Ultraviolet Source Catalogs"** – Voyer et al. 2014
- ★ **"Modelling the Dynamics of M87 with the Made-to-Measure Method"** – Zhu et al. 2014
- ★ **"Intergactic Globular Clusters in Virgo"** – Durrell et al. 2014
- ★ **"Estimation of Photometric Redshifts for Background Sources"** – Raichoor et al. 2014
- ★ **"NGC4370: A Case Study for Testing our Ability to Infer Dust Distribution and Mass in Nearby Galaxies"** – Viaene et al. 2015
- ★ **"Galaxies at the Extremes: Ultra Diffuse Galaxies in the Virgo Cluster"** – Mihos et al. 2015
- ★ **"The Most Massive Ultra-Compact Dwarf Galaxy in the Virgo Cluster"** – Liu et al. 2015
- ★ **"The Efficiency of Galaxy Formation on Small Scales from Abundance Matching in the Virgo Cluster"** – Grossauer et al. 2015
- ★ **"The Kinematics of Ultra-Compact Dwarfs and Globular Clusters in M87"** – Zhang et al. 2015
- ★ **"Stellar Populations and Internal Kinematics of Compact, Low-Mass Galaxies from Gemini Spectroscopy"** – Guerou et al. 2015
- ★ **"Properties of UCDs in the M87, M49 and M60 Regions"** – Liu et al. 2015

NGVS - Virgo Galaxies



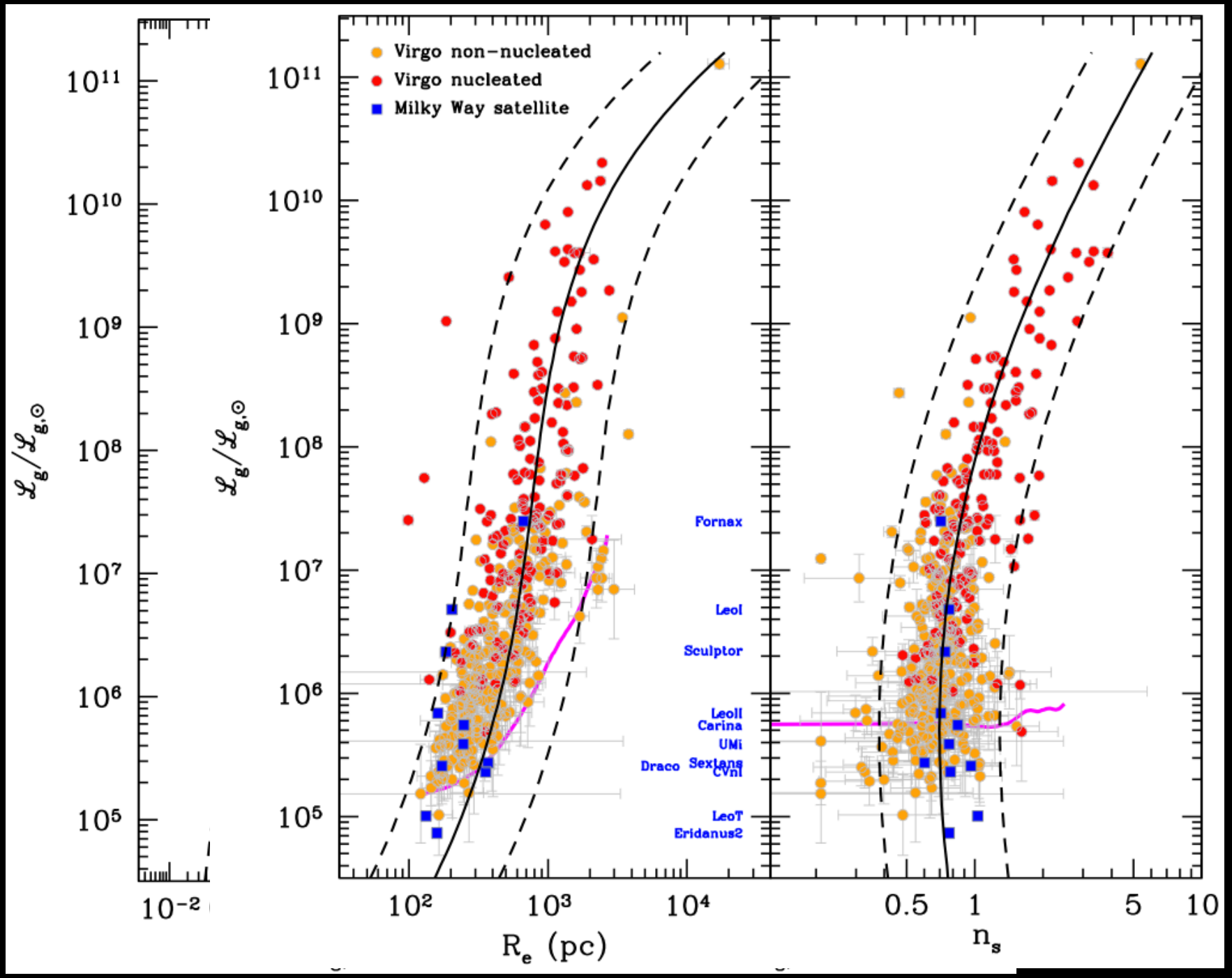
Simulated

NGVS - Virgo Galaxies

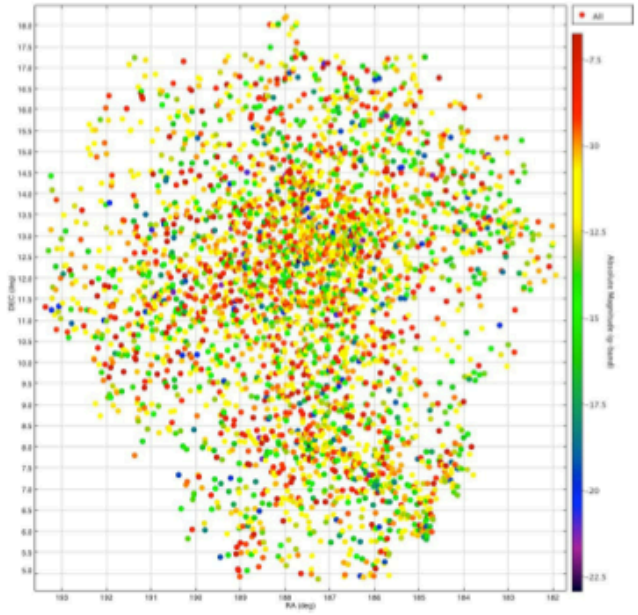


Observed

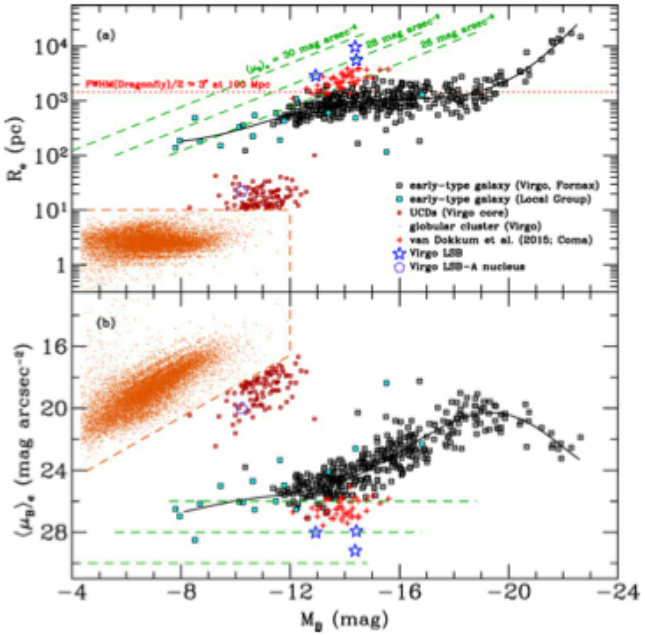
NGVS - Scaling Relations



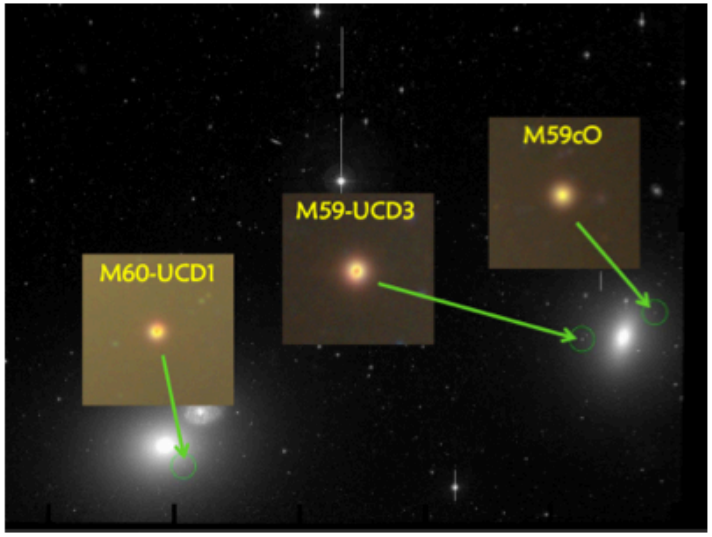
NGVS - Baryonic Structures



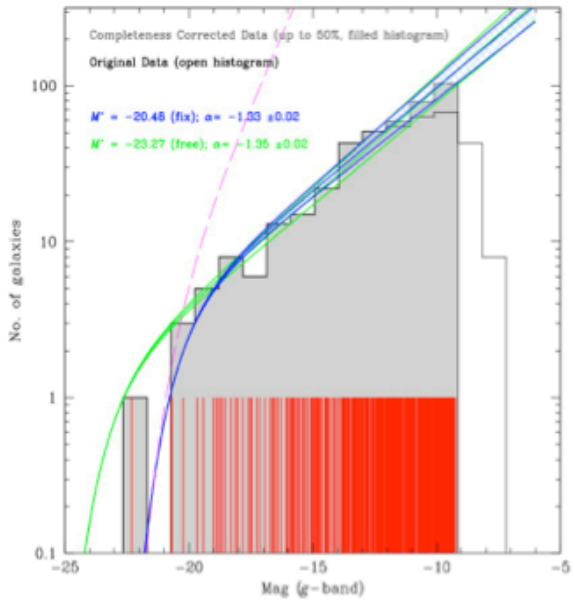
Virgo Galaxy Catalogue



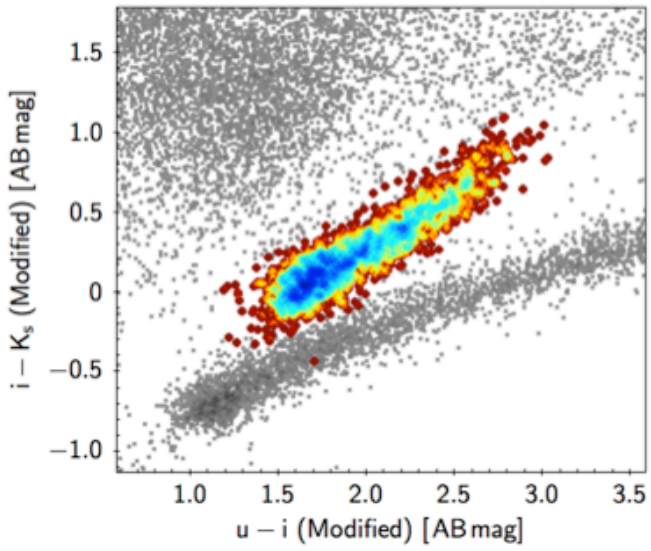
Extreme LSB Galaxies
(Mihos et al. 2015)



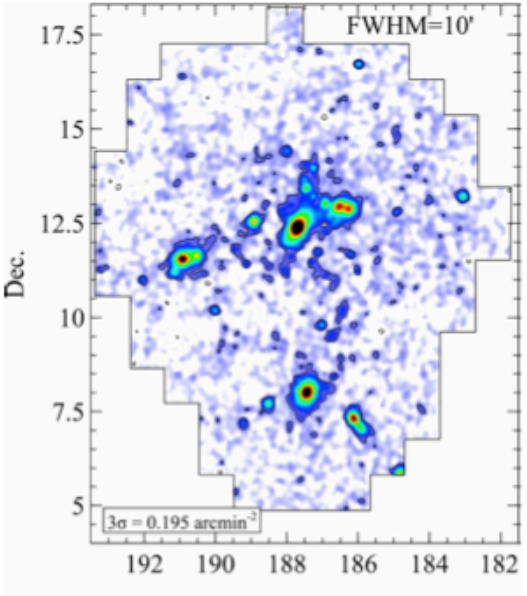
Extreme HSB Galaxies
(Liu et al. 2015)



Luminosity Function
(Ferrarese et al. 2016)



Stellar Populations
(Powalka et al. 2016)



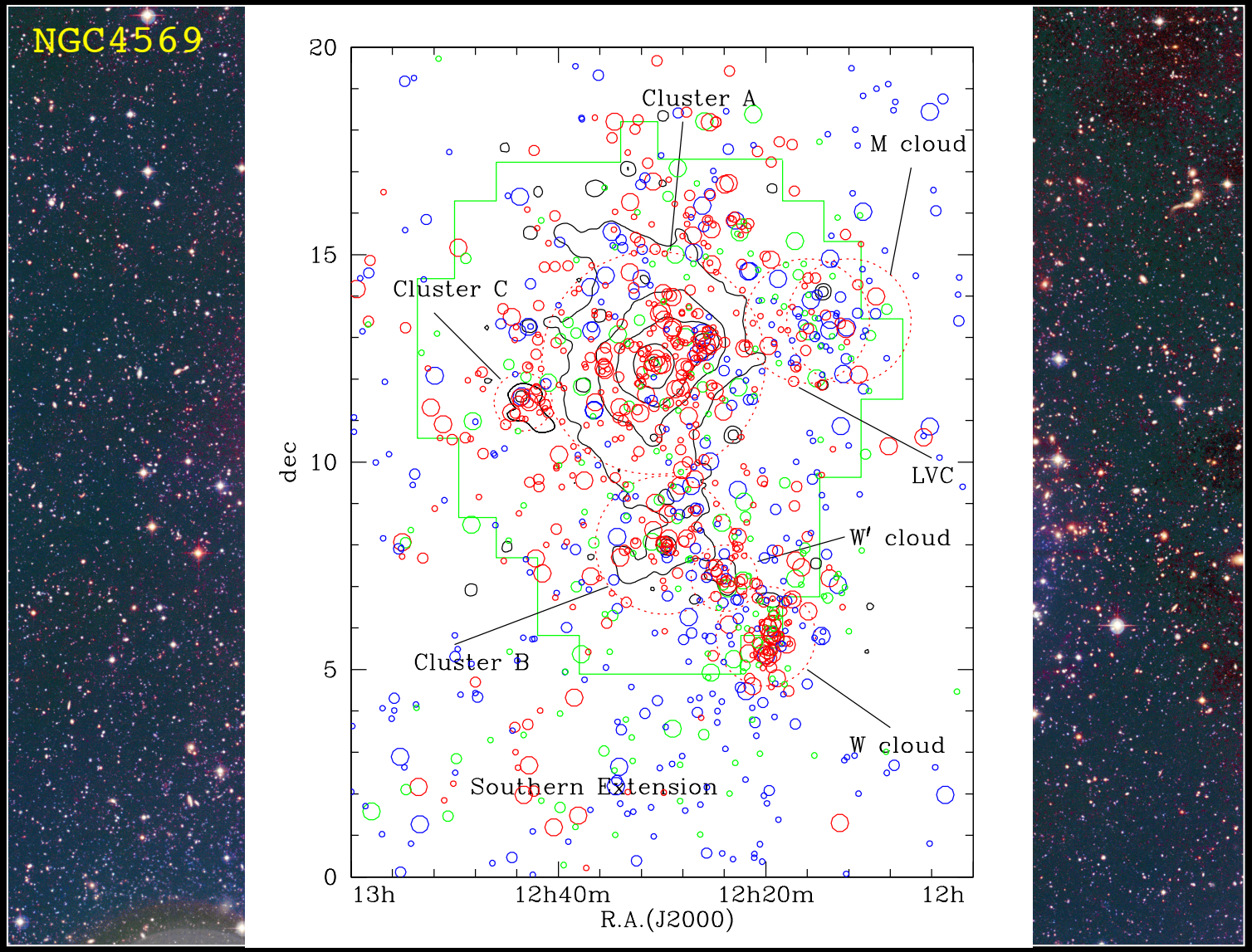
Globular Clusters and the ICM
(Durrell et al. 2014)

VESTIGE

*(A **V**irgo **E**nvironmental **S**urvey **T**racing **I**onized **G**as **E**mission)*

VESTIGE

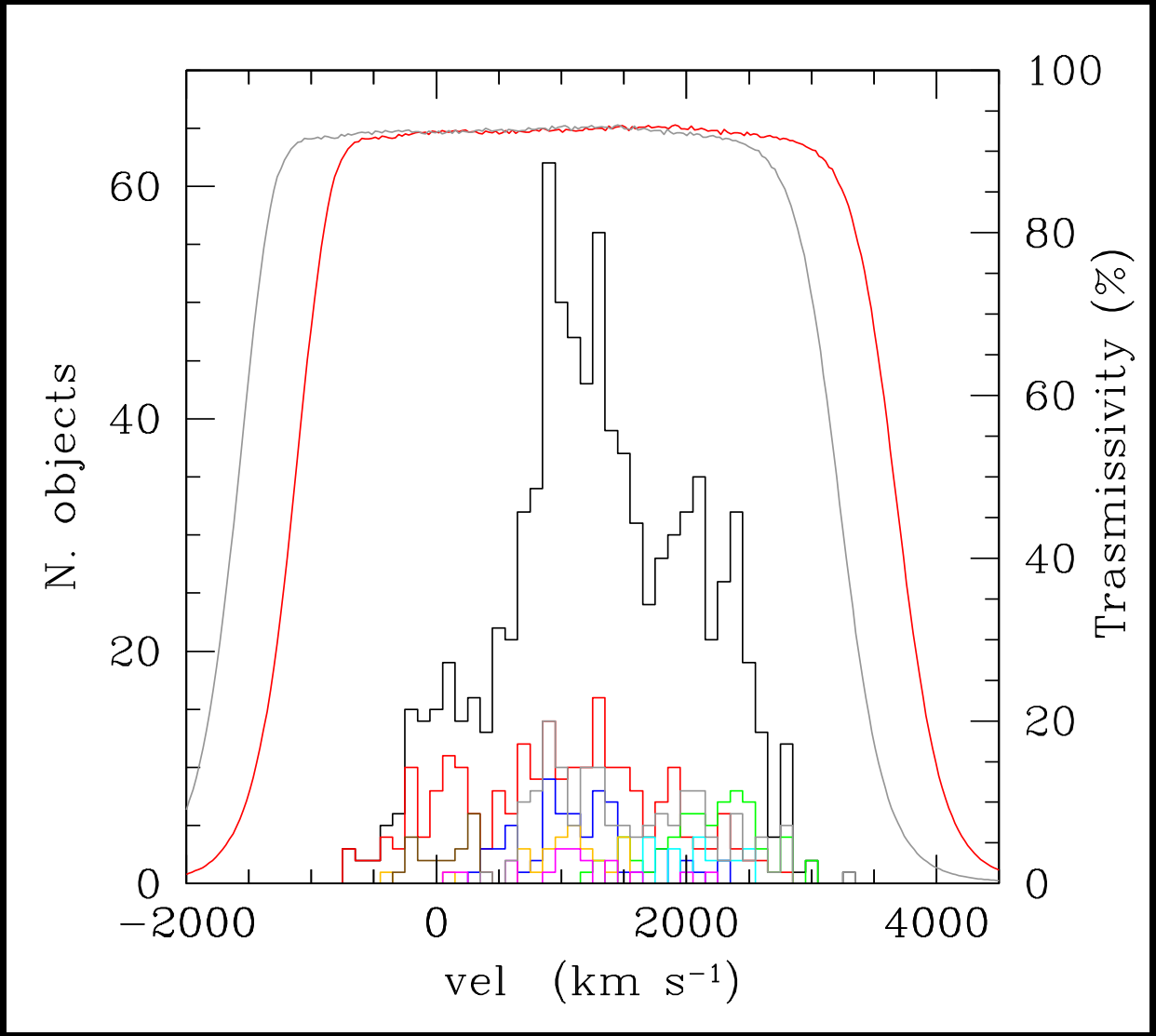
- Large Program to image the Virgo cluster region (≈100 deg^2) with MegaCam and a 106 Å narrowband filter centered on H-alpha (6591 Å).
- awarded 50 nights (2017-2019).
- PI = Alessandro Boselli (LAM)



VESTIGE

- H-alpha filter transmission optimized to observe galaxies within the Virgo cluster.

- Spiral rich
- $M_{200} = 4.2 \times 10^{14}\ M_{\odot}$
- $\Sigma(\mathrm{vel}) = 800$ km s^{-1}
- $\varrho(\mathrm{ICM}) = 2 \times 10^{-3}$ cm^{-3}
- ~3700 cluster members (from NGVS)

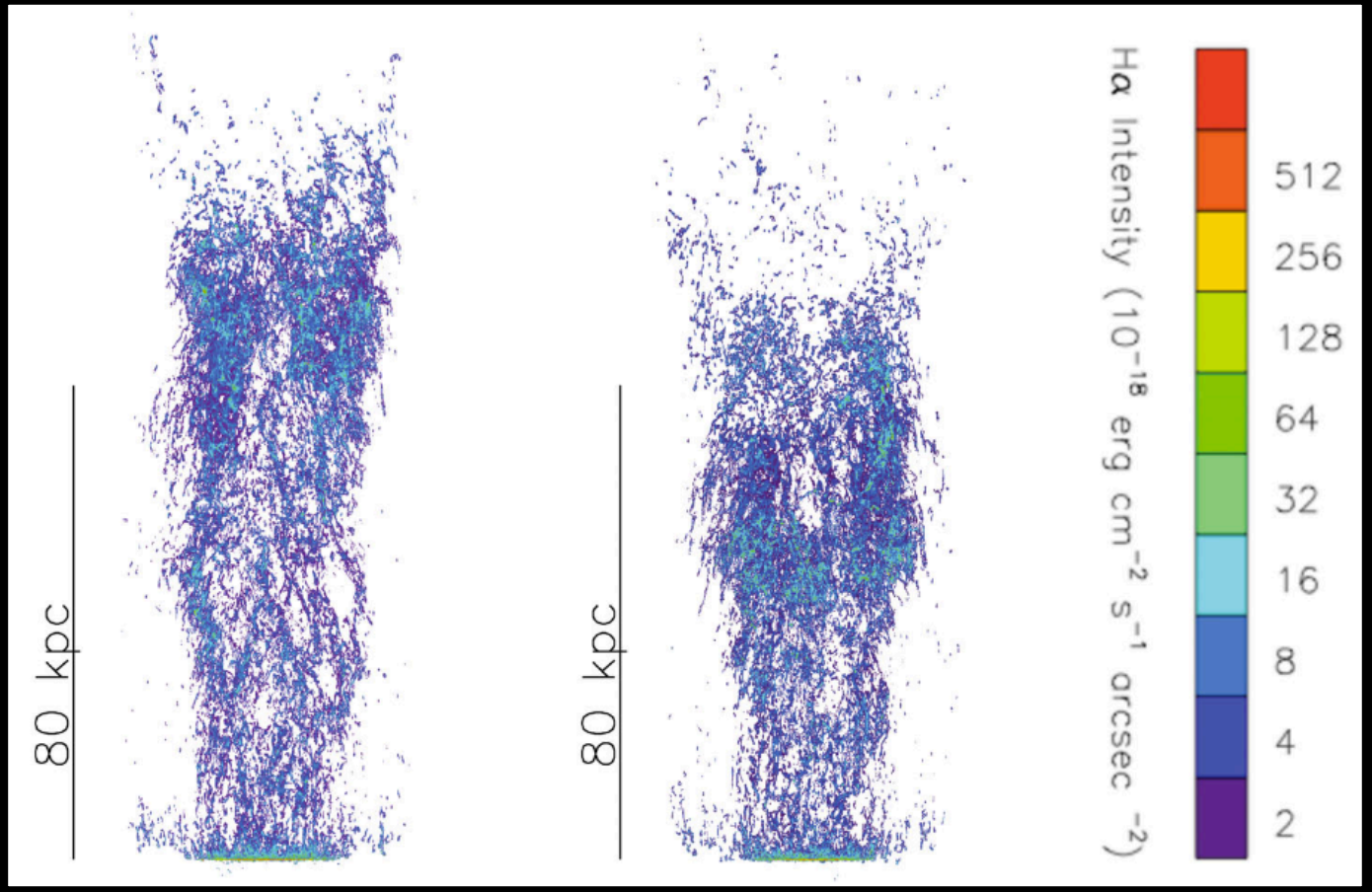


Boselli et al. (2017, in preparation)

VESTIGE

- Integration time:
  - 2h integration in the narrowband H-alpha filter (24.4 AB mag).
  - 720 sec in the r-band filter.

- Sensitivity:
  - $\Sigma(H_\alpha) = 2 \times 10^{-18}$ erg s^{-1} cm^{-2} arcsec^{-2} (2σ extended sources).
  - $F(H_\alpha) = 2 \times 10^{-17}$ erg s^{-1} cm^{-2} (5σ point sources).

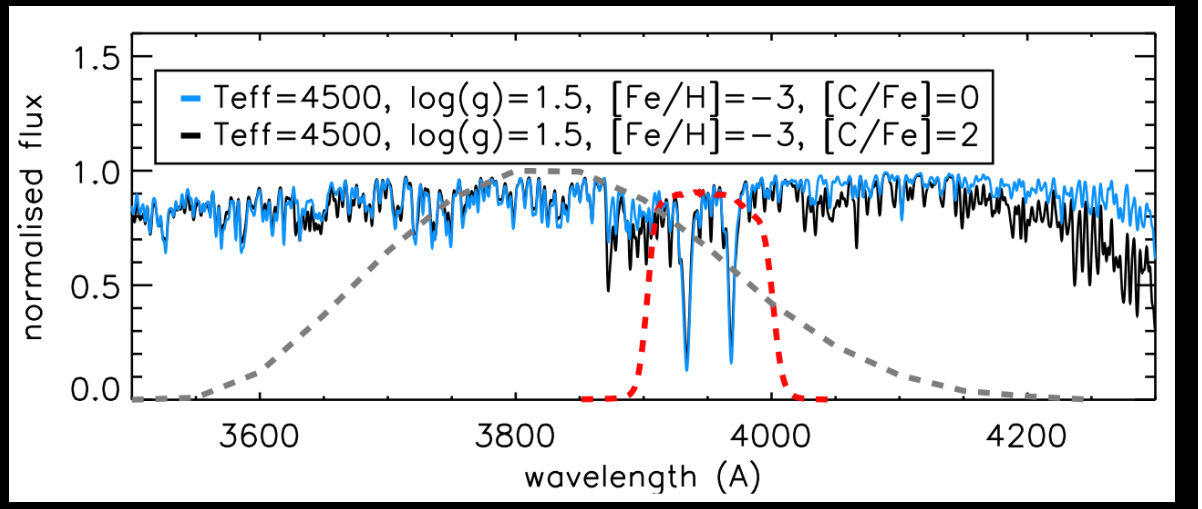


Pristine

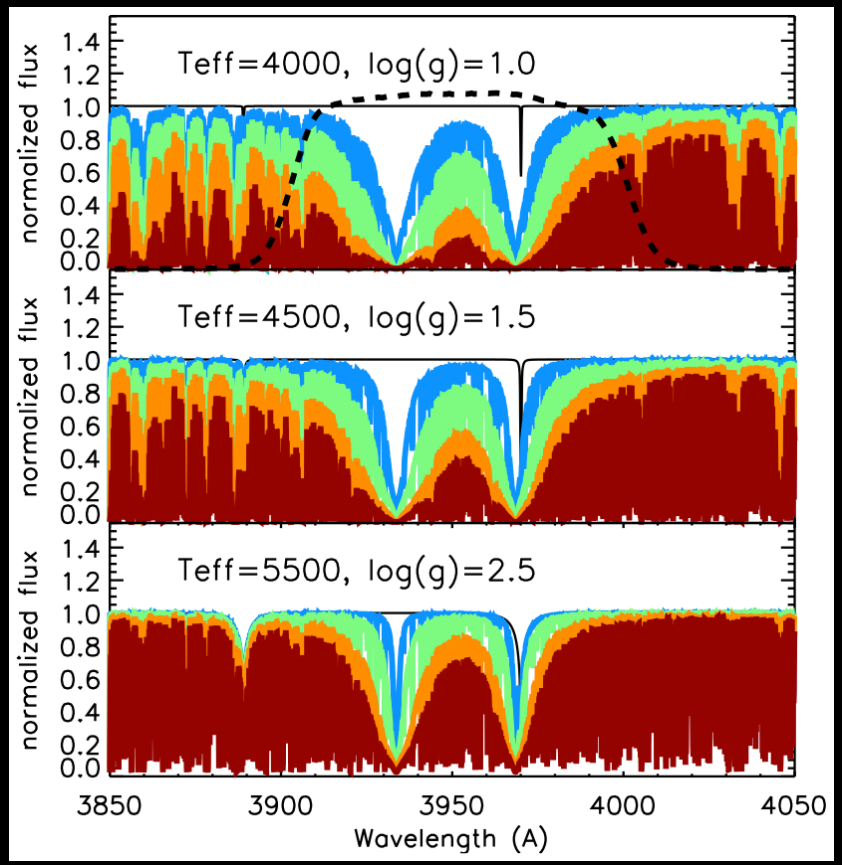
(Searching the Most Metal-Poor Stars in the Galaxy)

Pristine

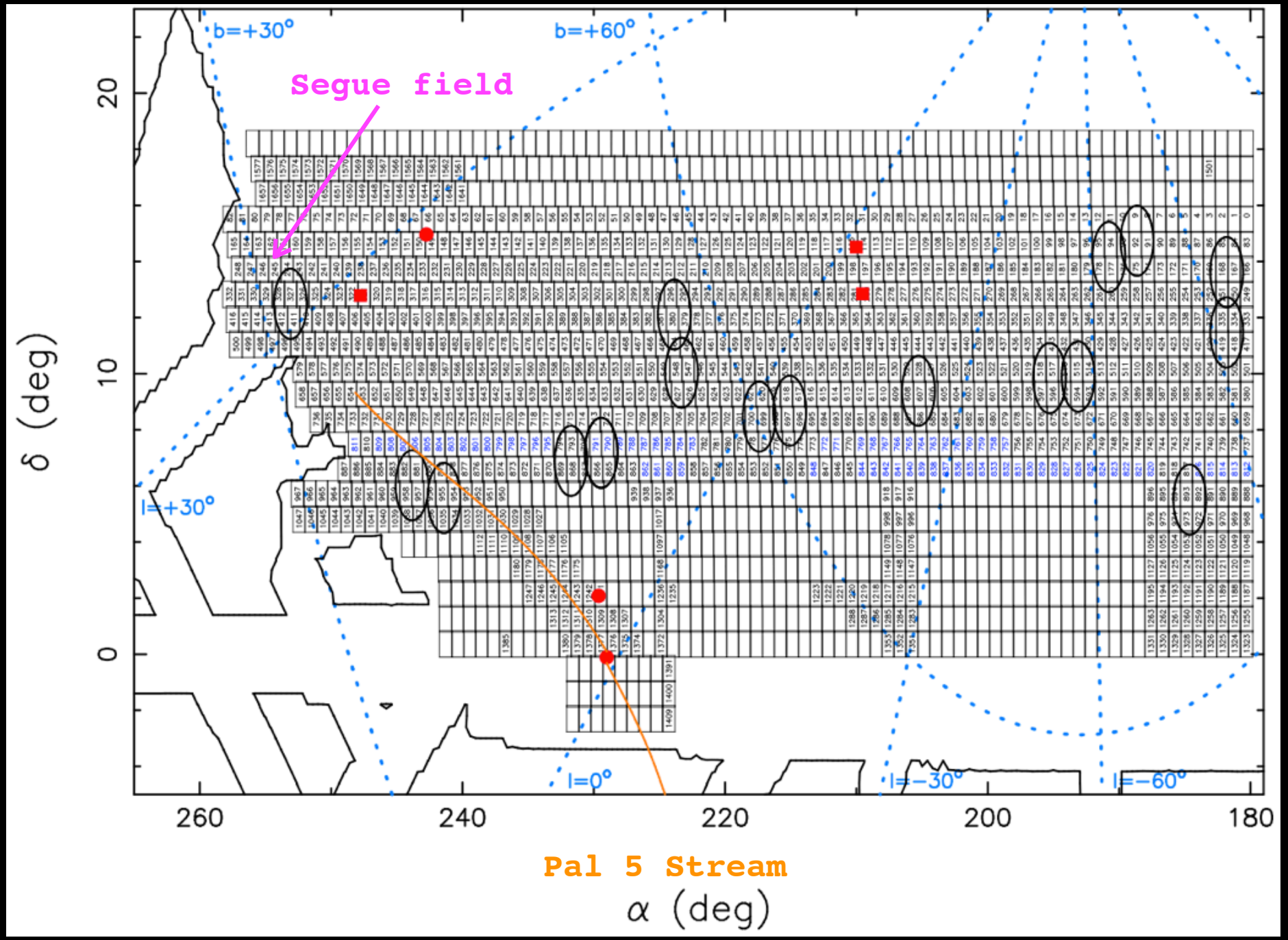
- PI program to image ≈1000 deg^2 during 2015/2016 with MegaCam and a 98 Å narrowband filter centered on CaHK (3952 Å).
  - Goal is to identify efficiently the most metal-poor stars in the Milky Way (similar to the *Skymapper* project).
  - Survey area lies within the SDSS and Pan-STARRS1 footprints.
- 50 hours awarded during 2015 and 2016.
  - Program to continue through 2018. Final goal = 3000 deg^2.
- PIs = Else Starkenburg (UVic, Postdam), Nicolas Martin (Strasbourg).



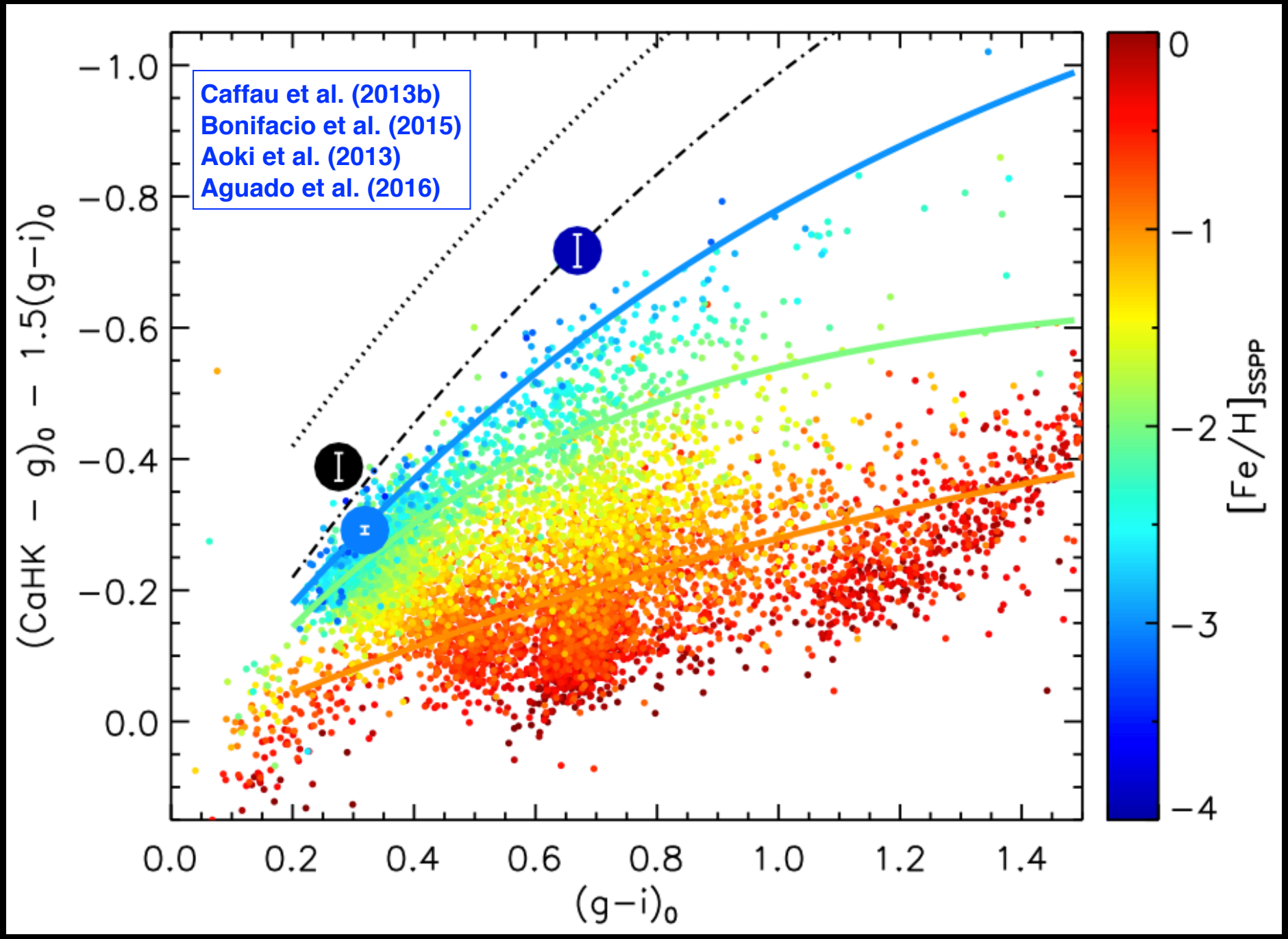
Starkenburg et al. (2017), submitted



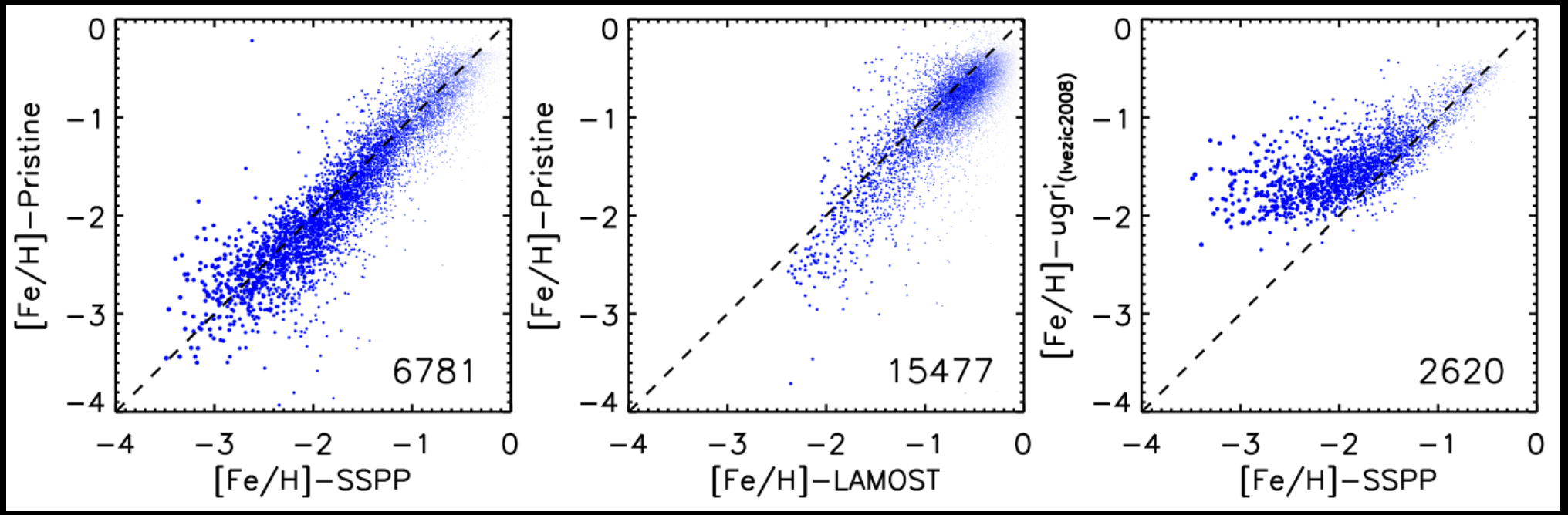
Pristine


b=+30°
b=+60°
Segue field
l=+30°
l=0°
l=−30°
l=−60°
δ (deg)
α (deg)
Pal 5 Stream
20
10
0
260
240
220
200
180

Pristine


Caffau et al. (2013b)
Bonifacio et al. (2015)
Aoki et al. (2013)
Aguado et al. (2016)
(CaHK − g)₀ − 1.5(g−i)₀
(g−i)₀
[Fe/H]SSPP
−1.0
−0.8
−0.6
−0.4
−0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0
−1
−2
−3
−4

Pristine



- 40+ nights approved follow-up at INT, WHT, DAO, NTT, etc, for V < 18.5. Negotiations with WEAVE project ongoing.
- Pristine metallicities accurate to ~0.2 dex in the range -0.5 < [Fe/H] < -3.0 dex.
- Success rate of uncovering $[Fe/H]_{Segue}$ < -3 dex among $[Fe/H]_{Pristine}$ < -3 dex is 26%, and 80% of stars have [Fe/H] < -2 dex.
- Several complementary Pristine programs are now underway: (1) the Galactic bulge; (2) M31; and (3) Galactic ultra-faint dwarfs.

LUAU

*(CFHT **L**egacy for the **u**-band **A**ll-sky **U**niverse)*

CFIS

*(**C**anada **F**rance **I**maging **S**urvey)*

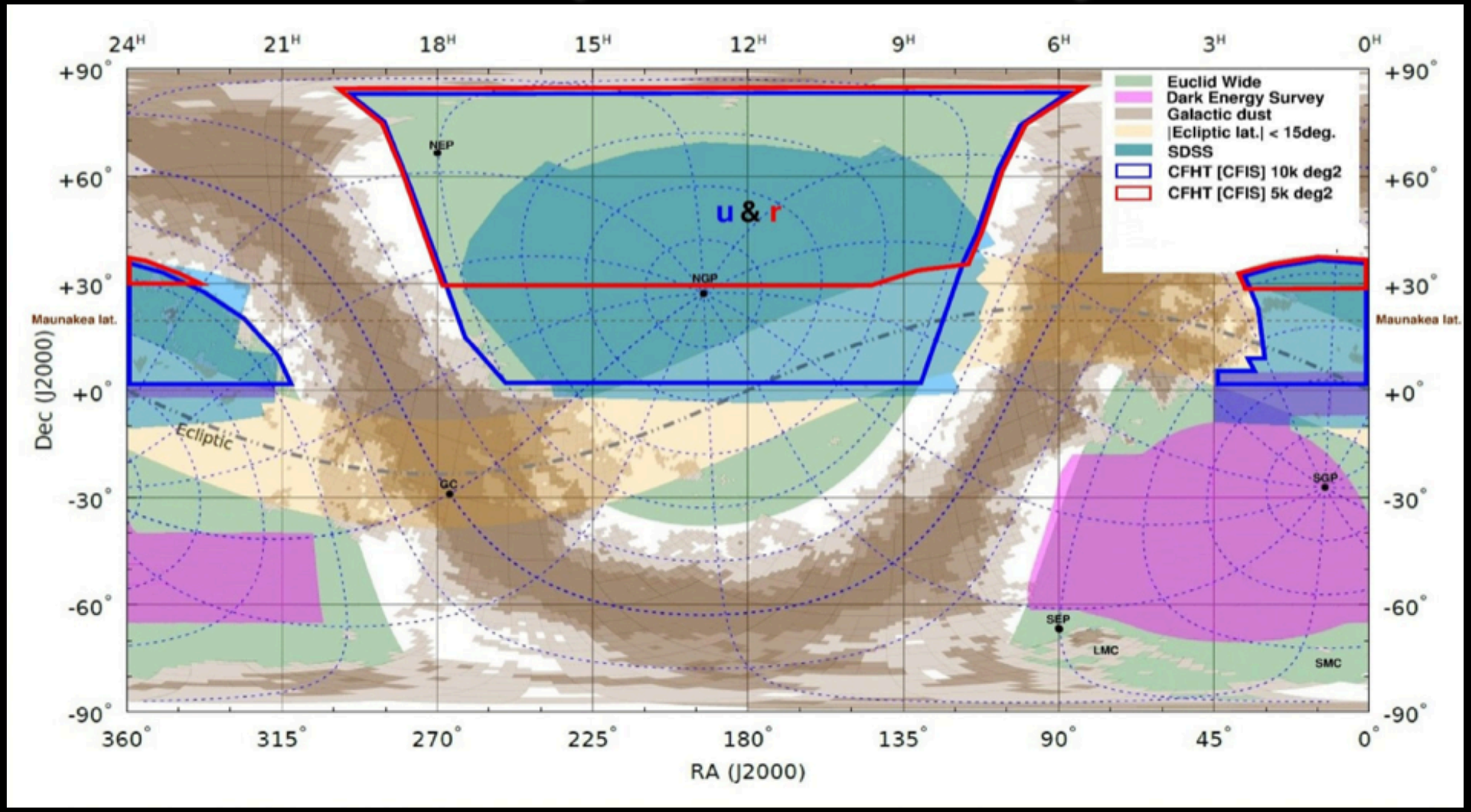
CFIS (LUAU+WIQD)

- CFIS: CFHT Large Program with numerous standalone science drivers, plus broad support for the Euclid mission.
  - PIs = J.-C. Cuillandre (LAM) + A. McConnachie (NRC) and > 100 cols.
  - Combination of two programs:

✳ CFIS-LUAU
  - u-band imaging over 10,000 deg^2 to u=23.6 (S/N=10 point source).
  - 117 nights (~640 hours)
  - complementary to SDSS and Pan-STARRS.
  - Galactic structure (metallicities to 0.2 dex, photometric distances to ~10%), halo tomography, white dwarfs, blue HB stars, extremely metal-poor stars, star-forming galaxies.

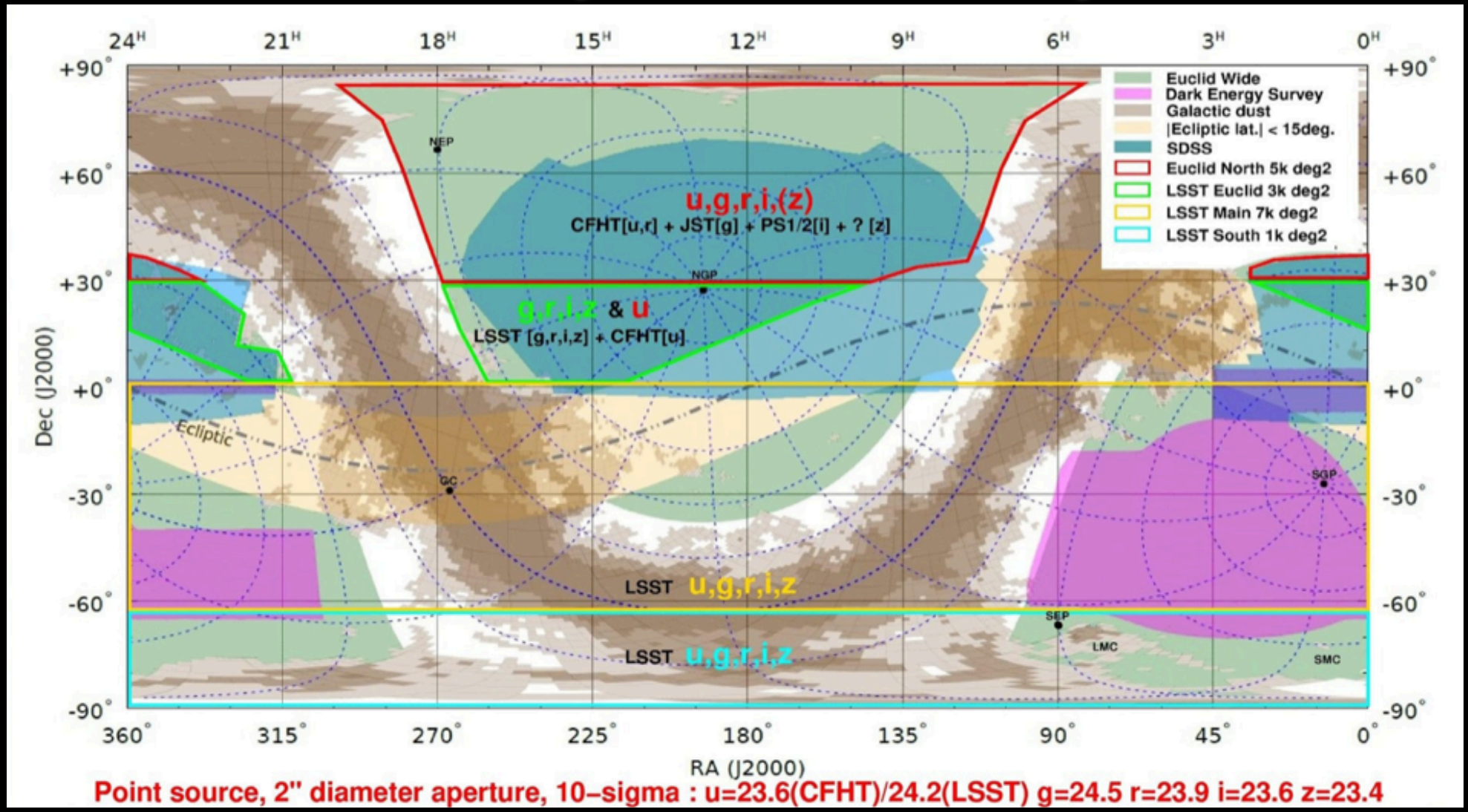
✳ CFIS- WIQD (Wide + Image Quality + Deep)
  - r-band imaging over 5,000 deg^2 to r=24.1 (S/N=10 point source).
  - 154 nights (~840 hours)
  - weak lensing science: DM filaments, stripping of satellite DM halos, DM halo shapes, test of General Relativity.

CFIS (LUAU+WIQD)



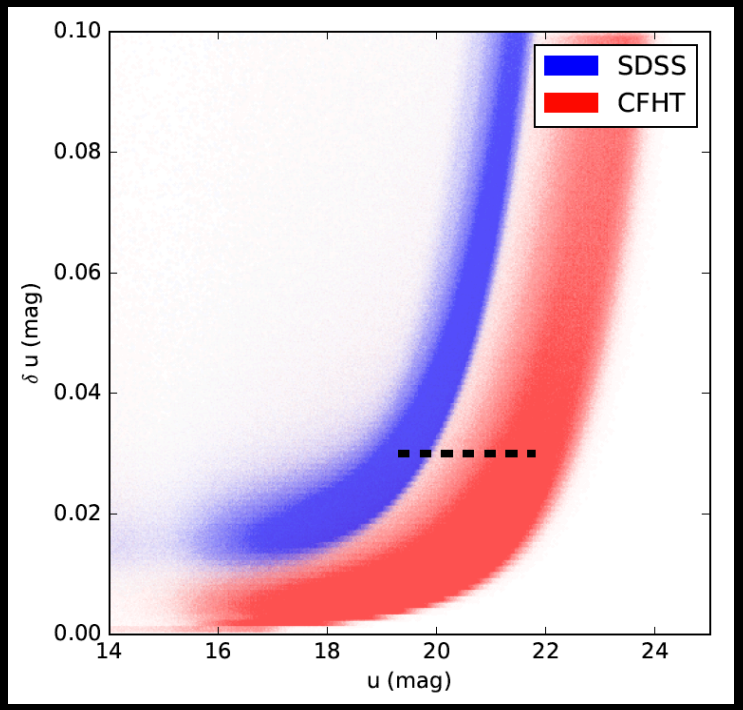
- CFIS-LUAU: 10,000 deg^2 in u-band above the galactic plane, 3 mag. deper than SDSS-u
- CFIS- WIQD: 5,000 most northern Euclid Wide deg^2 in r-band at the nominal Euclid depth.

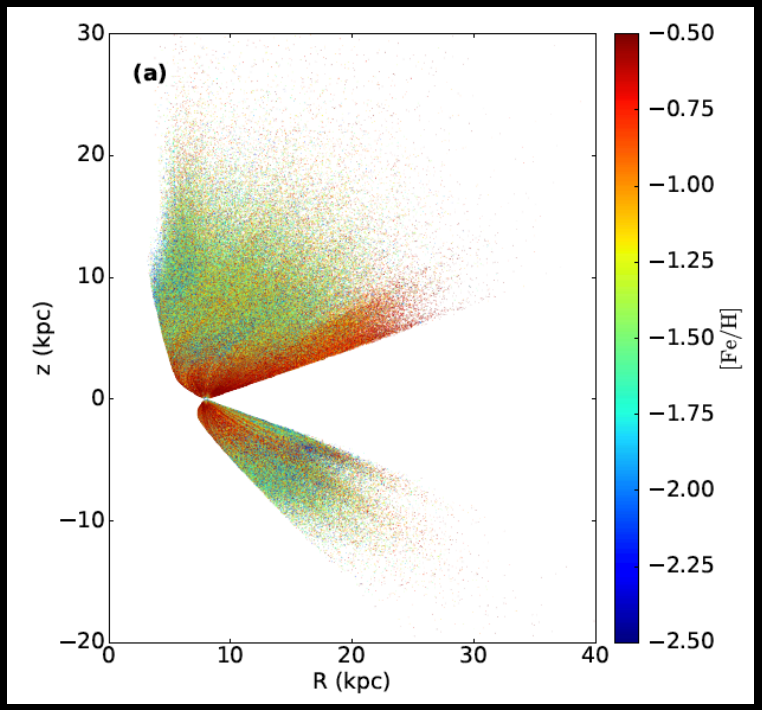
CFIS (LUAU+WIQD)

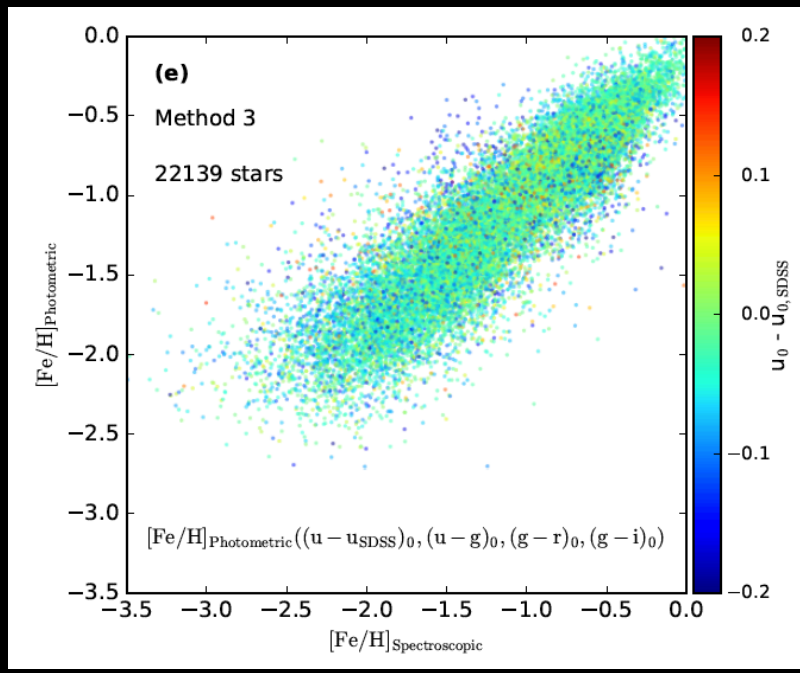


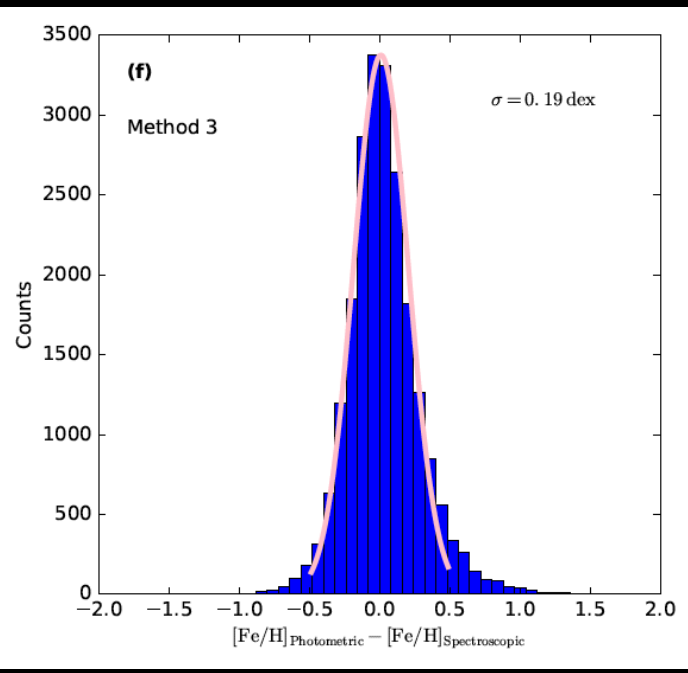
- Five different WFI telescopes to cover ~15,000 deg^2 in five broad SLOAN photometric bands (u,g,r,i,z)
- The Euclid North campaign (1/3 Euclid sky) starts in 2017 with CFIS, spread over 5 years.
- Nearly 1.3 of the Euclid sky coverage relies on LSST, which will be contemporary with Euclid (2021).

CFIS (LUAU+WIQD)



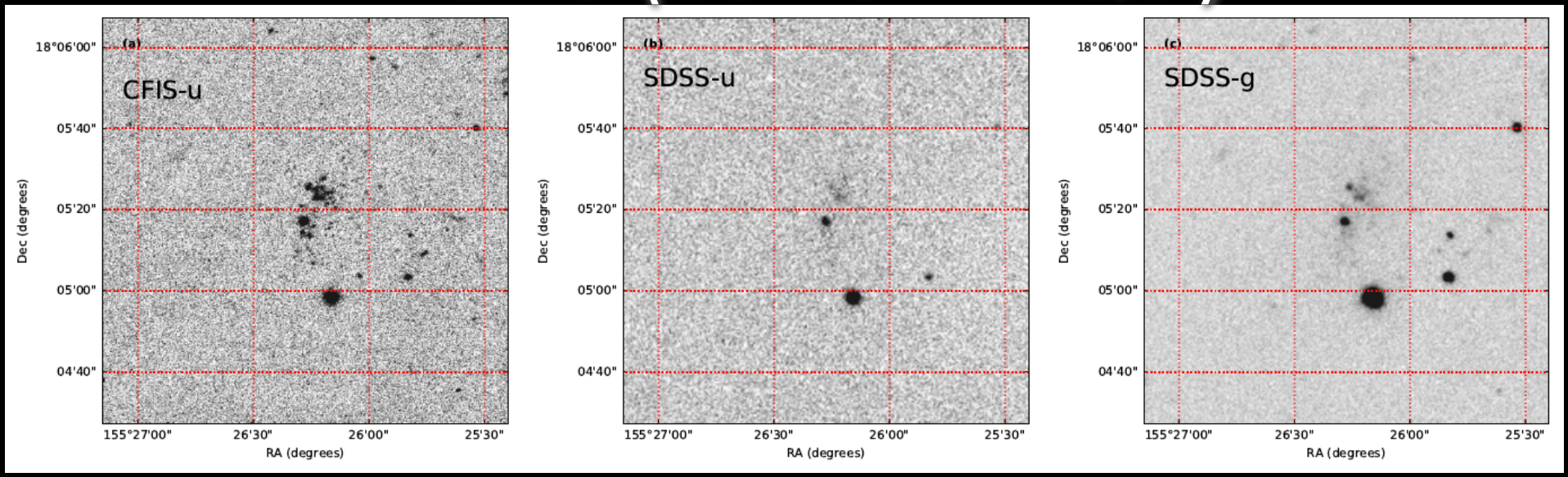


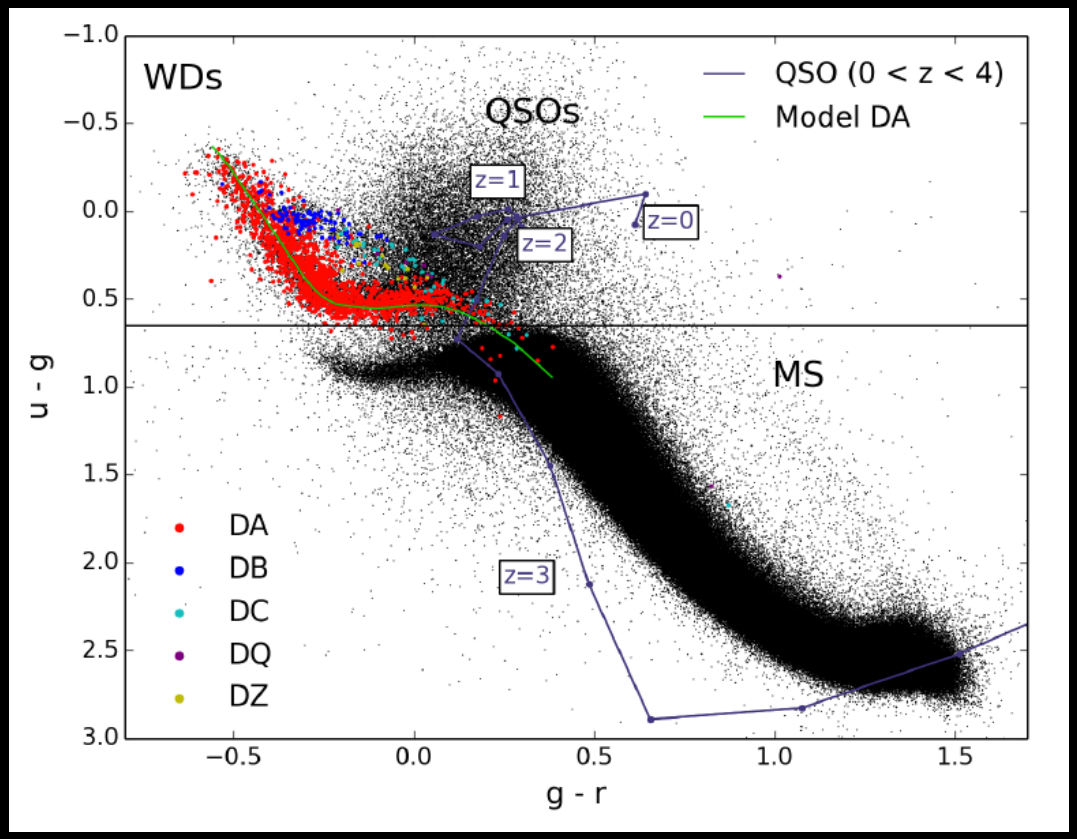


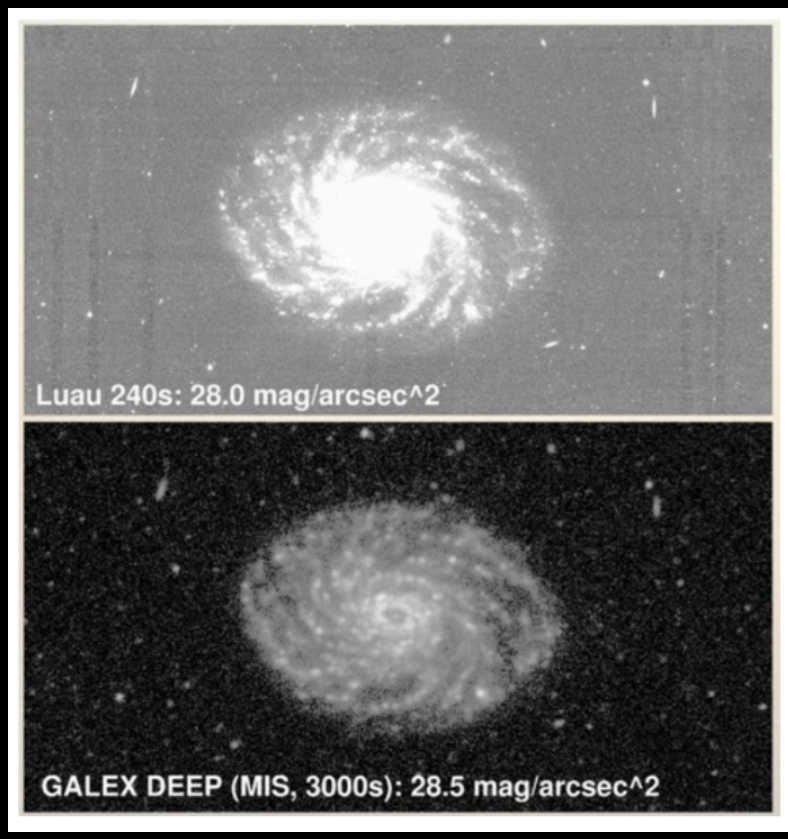


Ibata et al. (2017), in preparation

CFIS (LUAU+WIQD)







Ibata et al. (2017), in preparation

CFHT

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SUBARU

- NGVS + VESTIGE
  1. chemical enrichment and star formation histories of galaxies, nuclei, star clusters and ultra-compact galaxies
     - Subaru/PFS (R ~ 2000)
  2. dark matter distribution on galaxy scales
     - Subaru/PFS (R ~ 4000) ⇒ MSE
  3. coexistence of galactic nuclei and supermassive black holes
     - Subaru/IRCS

- PRISTINE
  1. follow-up of faint extremely metal-poor candidates
     - Subaru/PFS (R ~ 4000) ⇒ MSE
  2. element abundance analyses for most extreme stars
     - Subaru/HDS (R ~ 40000+) ⇒ MSE

- CFIS/LUAU
  1. Star formation histories of thin disk, thick disk and halo from white dwarf luminosity functions
     - masses and ages from Subaru/PFS (R ~ 2000)
  2. confirmation of new substructures
     - Subaru/PFS (R ~ 4000) ⇒ MSE
  3. dark matter vs. tides vs. alternate gravity
     - Subaru/PFS (R ~ 6000) ⇒ MSE