

THE HERO'S JOURNEY OF RELIC GALAXIES

BIRTH & ESCAPE

Billions of years ago, massive red nuggets formed in massive starbursts.



They remained ultra-compact and old.

QUEST FOR THE FIRST

The rare fossils are finally identifiable. A unique window to the early universe!



THE REVOLUTION BEGINS (XIDS@VST)

Local relics found! Our contribution: KIDS@VST survey identifies new candidates.



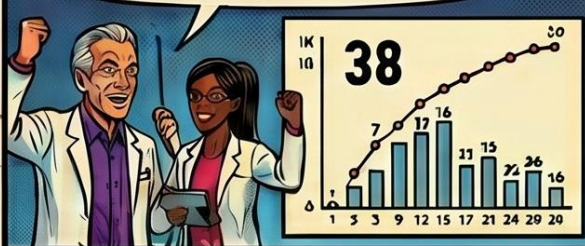
INTO THE CAVE (XShooter@VLT)

VENTURED INTO THE INNERMOST CAVE: Inspire ESO Large Program with XShooter



CONFIRMING THE HOARD

SEIZED THE SWORD: 38 relics confirmed! ($0.16 < z < 0.4$)



THE PROBLEM: RESOLUTION

JOURNEY'S END NOT OVER. Limited by $0.7''$ KIDS resolution.



THE EUCLID EYE

Euclid expands our sample. Thousands of candidates!



ELT & MORFEO: THE TWINS

MORFEO & ELT are the twin tools for extreme high-resolution imaging and spectral!



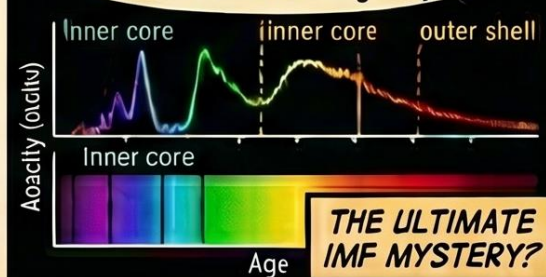
INNER SECRETS REVEALED

Tracing kinematics and dark matter from the centers to the outskirts.



STELLAR POPULATIONS & IMF

...Revealing age, metallicity, and the IMF across the galaxy!



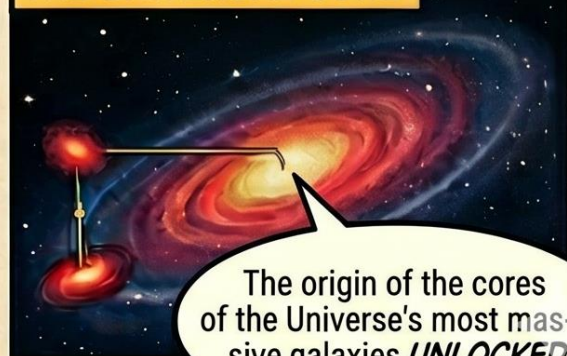
THE QUEST COMPLETE

...Observations bring back the ultimate prize: definitive formation insight!



THE UNIVERSAL CORE

The origin of the cores of the Universe's most massive galaxies UNLOCKED!



COMPLETING THE RELICS' REVOLUTION WITH ELT

The hero's journey of massive, compact, and old galaxies

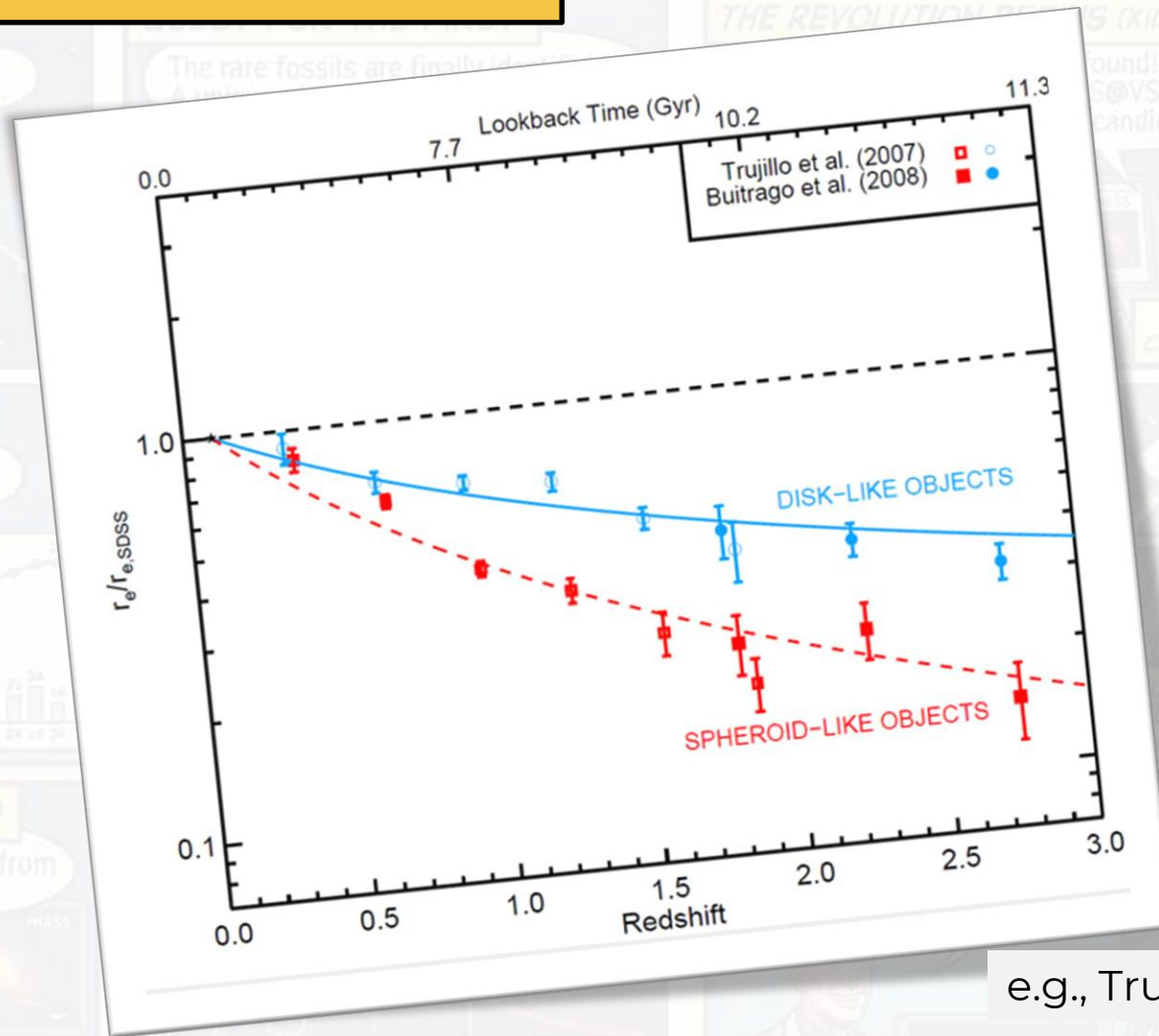


Crescenzo Tortora

In collaboration with C. Spiniello, N. R. Napolitano, F. La Barbera, G. D'Ago, M. Radovich, D. Scognamiglio, L. Coccato, M. Spavone, I. Martin-Navarro, A. Ferré-Mateu, M. Arnaboldi, L. K. Hunt, A. Gallazzi, S. Zibetti, C. Pulsoni, J. Hartke, M. Maksymowicz-Maciata, M. Cappellari, P. Saracco, D. Bevacqua, J. Mills, F. Getman, N. Roy, S. Cavauoti, M. Brescia, G. Longo, K. H. Kuijken, etc.



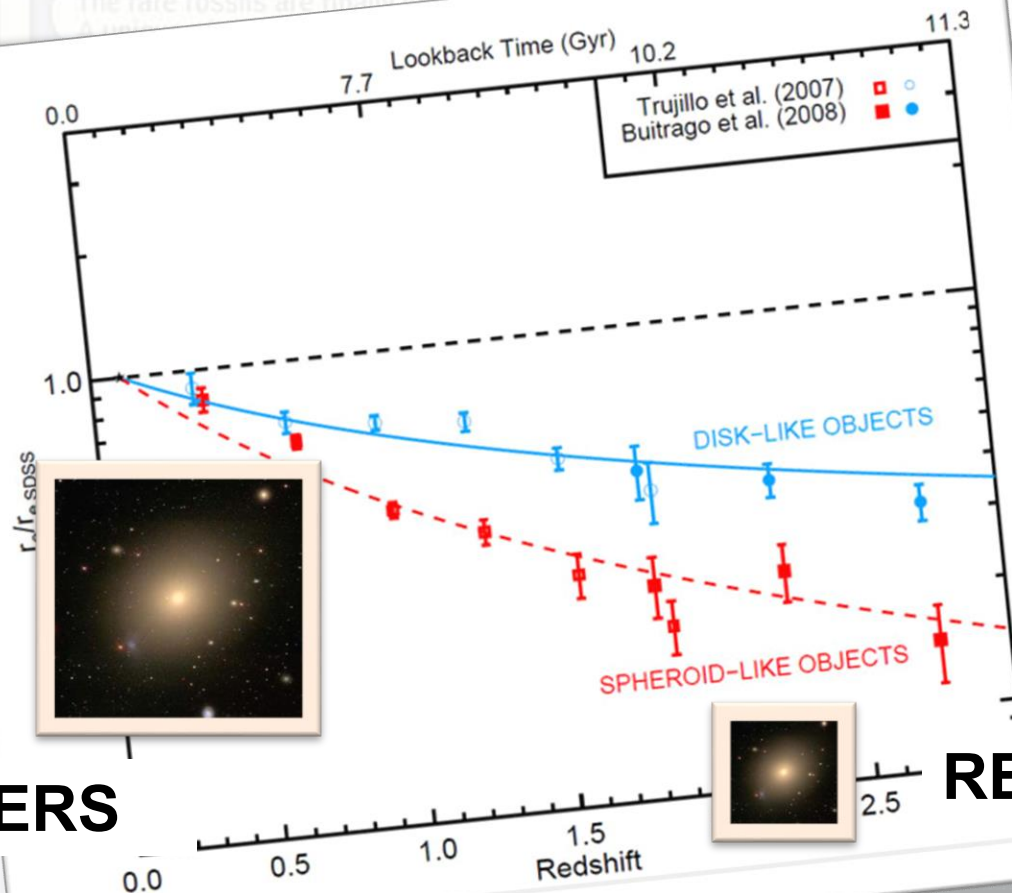
THE STATE OF THE ART



e.g., Trujillo et al. 2007

Size, morphological and dark matter evolution

THE STATE OF THE ART



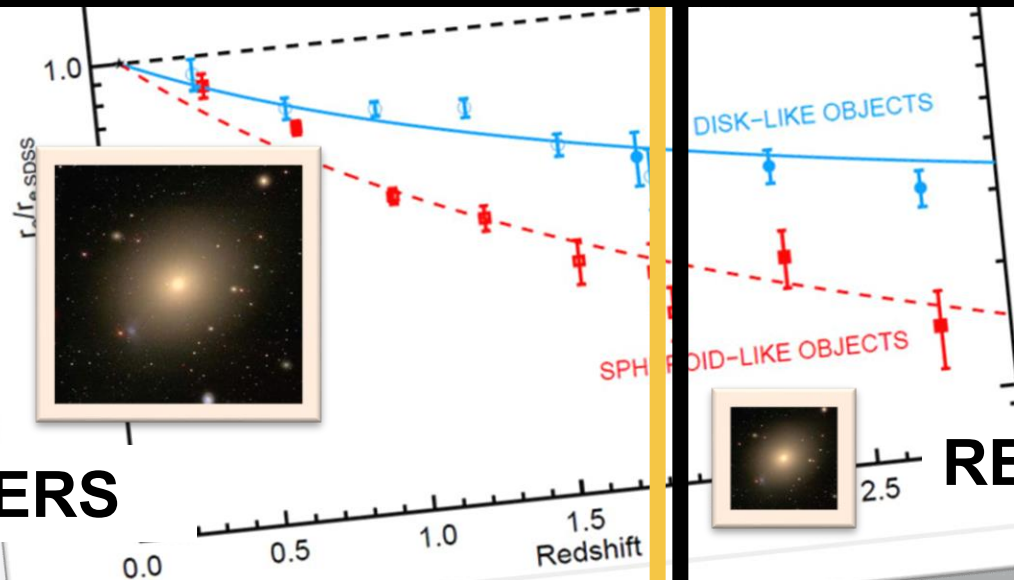
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Size, morphological and dark matter evolution

THE STATE OF THE ART

Two-phase scenario (Oser et al. 2010)

BIG MONSTERS



RED NUGGETS

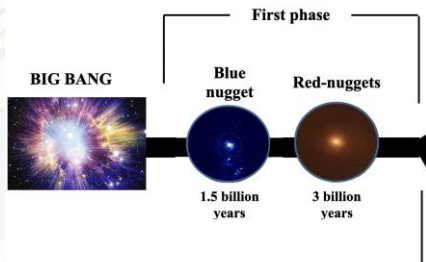
e.g., Trujillo et al. 2007

Size, morphological and dark matter evolution

OPEN QUESTIONS

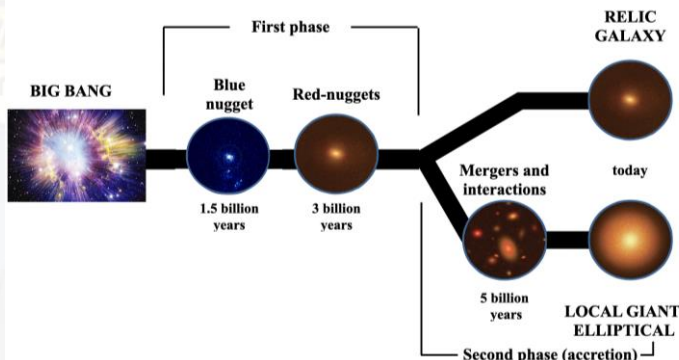
How do red nuggets form?

In what physical conditions?



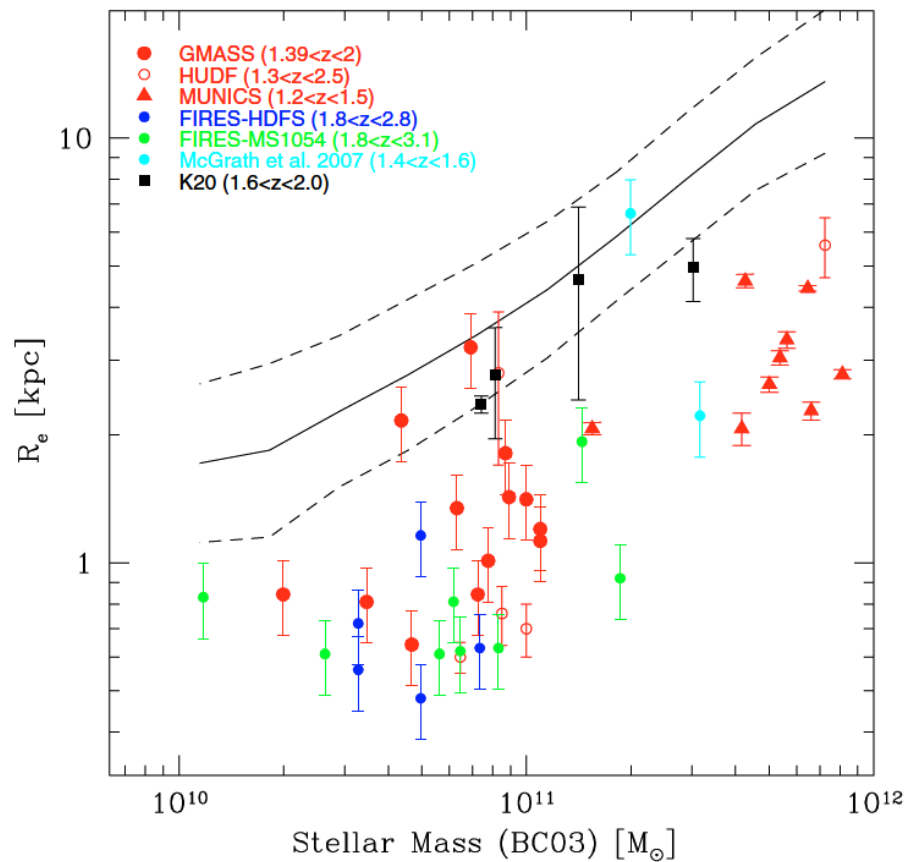
- In-situ stellar populations
- Blue to red nuggets transformation
- Initial conditions and IMF

What kind of transformations?



- Ex-situ stellar populations
- Structural evolution and mass assembly
- Environment

RED NUGGETS-LIKE AT LOW-Z?



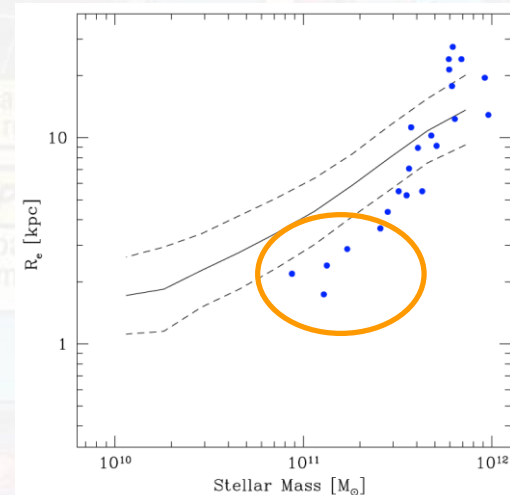
Bernardi et al. 2006,2007, Cimatti et al. 2008

Relics

10. Are there superdense relics at $z \approx 0$?

The superdense ETGs identified at $z > 1$ seem to disappear in the present-day Universe (e.g. Shen et al. 2003). However, recent works based on SDSS data showed that there is a population of very massive ETGs with $\sigma_V > 350 \text{ km s}^{-1}$ which, compared to ETGs of the same luminosity, are characterized by very small sizes (Bernardi et al. 2006, 2007). Thus, we investigated whether some of these local galaxies have properties similar to those observed in passive galaxies at $z > 1$.

Cimatti et al. 2008



WHY RELIC GALAXIES?

JOURNEY OF RELIC GALAXIES

Bricks accreted around
the central relic brick

BIG MONSTERS

RELIC

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JOURNEY OF RELIC GALAXIES

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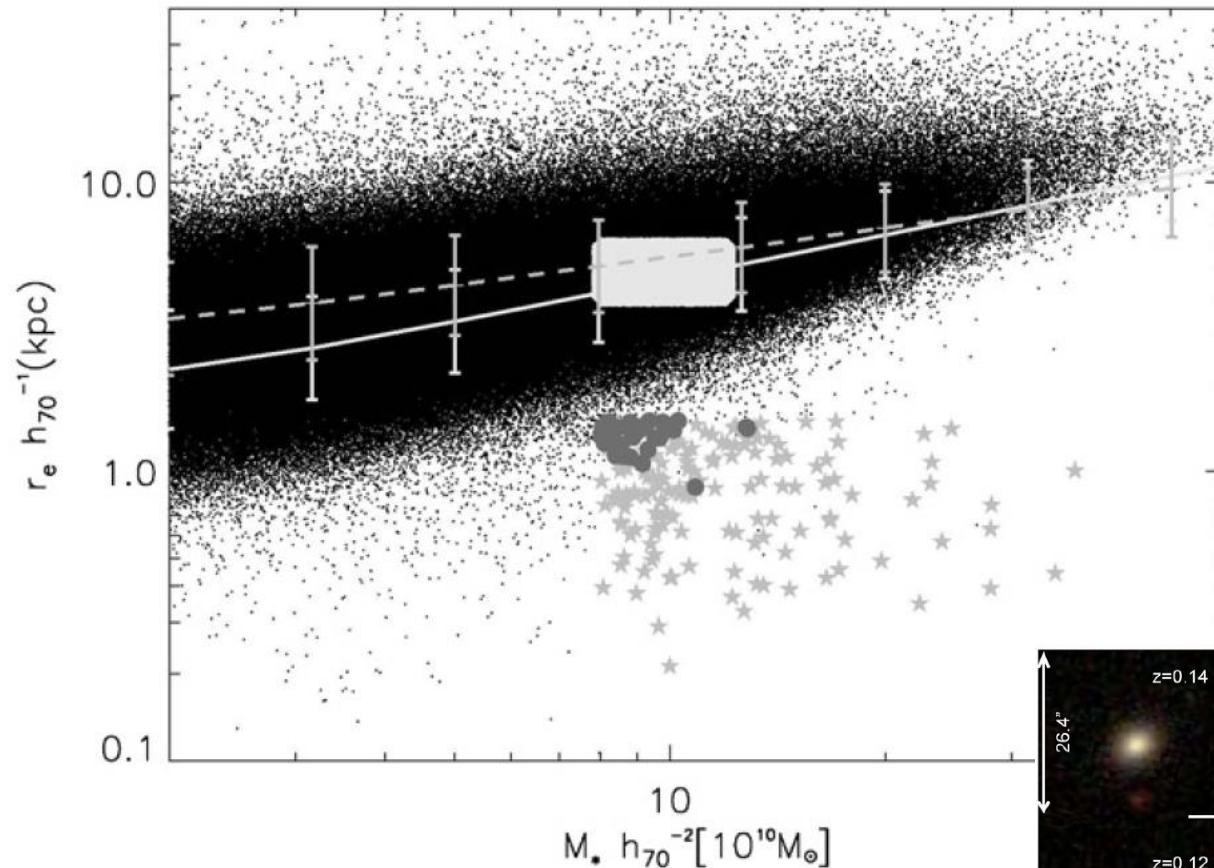
BIG MONSTERS

RELIC

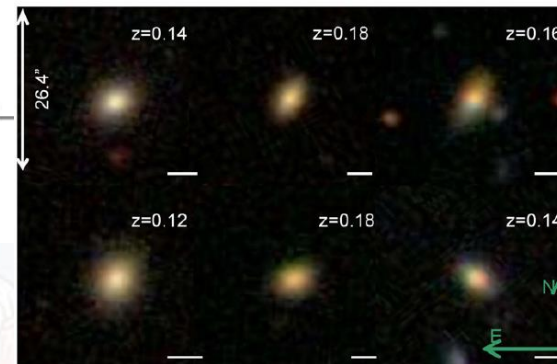
Isolate accretion and high-z red nuggets

Ex-situ vs In-situ
(Two-phase scenario)

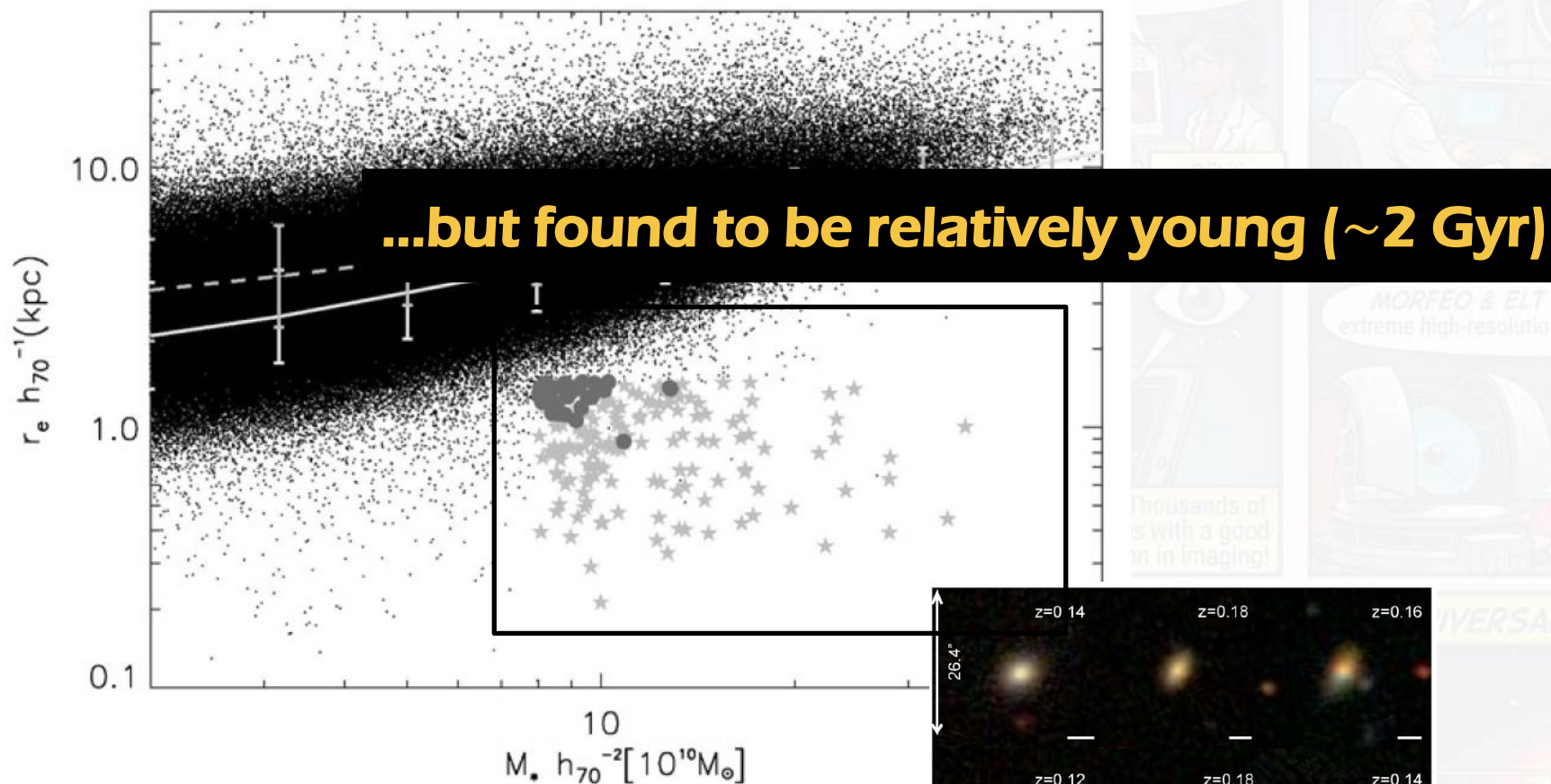
THE FIRST SYSTEMATIC SEARCHES FAILED



Trujillo et al. 2009 (see also Taylor et al. 2010)



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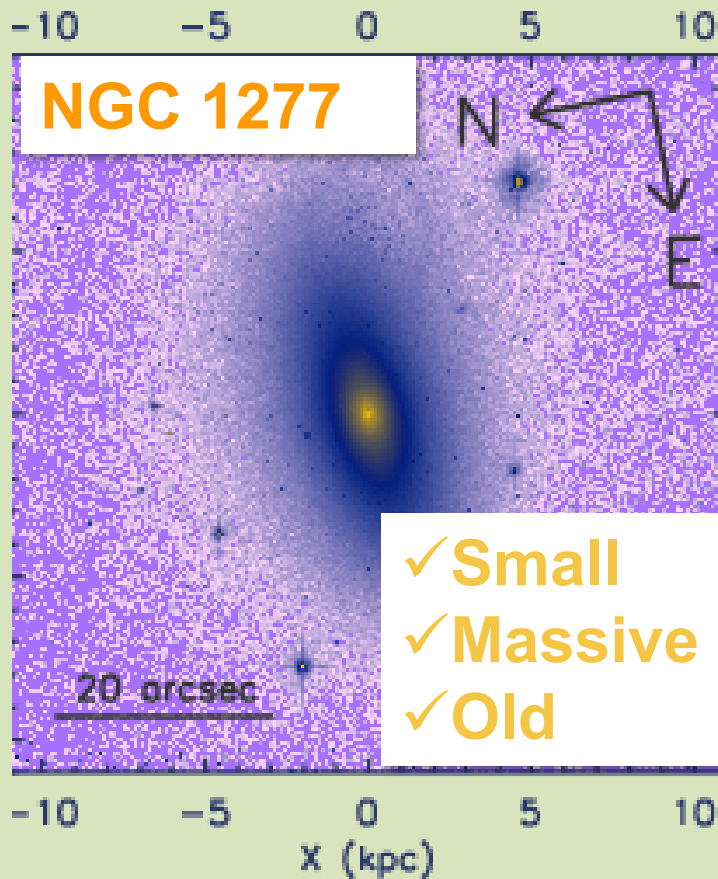


Trujillo et al. 2009 (see also Taylor et al. 2010)

THE DISCOVERY OF RELIC GALAXIES

“LOCAL RED NUGGET”

NGC 1277



- ✓ Small
- ✓ Massive
- ✓ Old

Trujillo et al. 2014

DISCOVERY BEGINS (KIDS@VST)

Local relics found! Our contribution: KIDS@VST survey identifies new candidates.

RELIC CANDIDATES

VENTURING INTO THE CAVE (XShooter@VLT)

VENTURED INTO THE INNERMOST CAVE: Inspire ESO Large Program with XShooter

XShooter

THE EUCLID EYE

Euclid expands our sample. Thousands of candidates!

Thousands of candidates with a good resolution in imaging!

ELT & MORFEO: THE TWINS

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MORFEO

THE QUEST COMPLETE

Observations bring back the ultimate prize: definitive formation insight!

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The origin of the cores of the Universe's most massive galaxies



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"LOCAL RED NUGGET"

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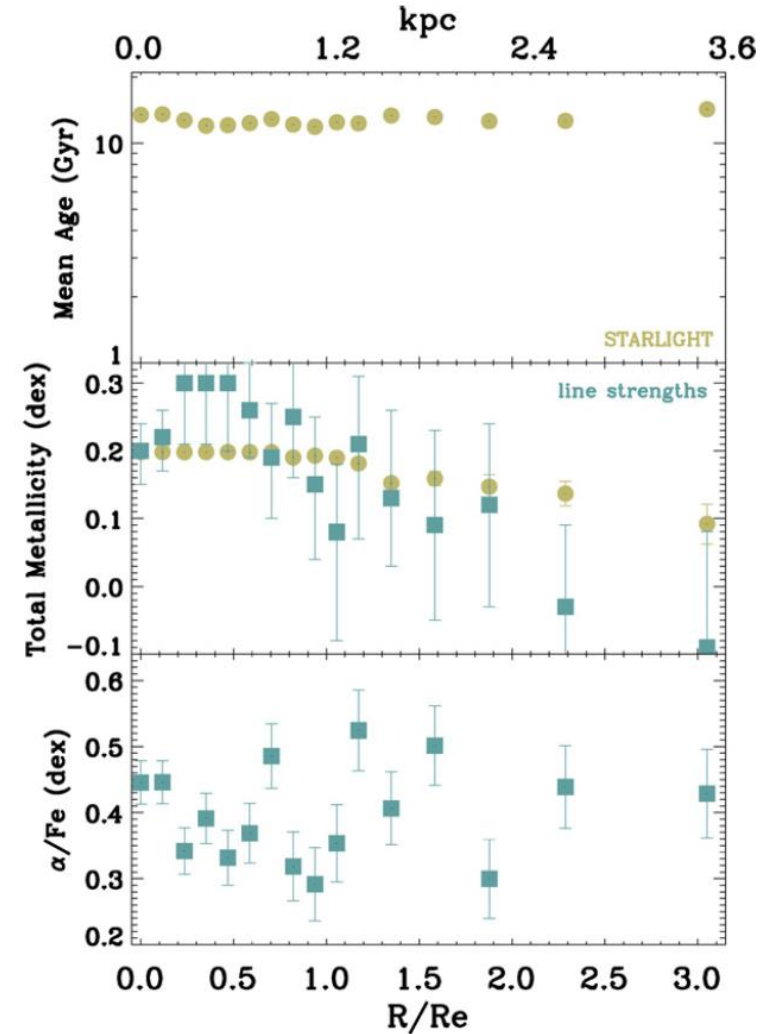
Formed at high redshift and in a unique fast event

- ✓ Small
- ✓ Massive
- ✓ Old

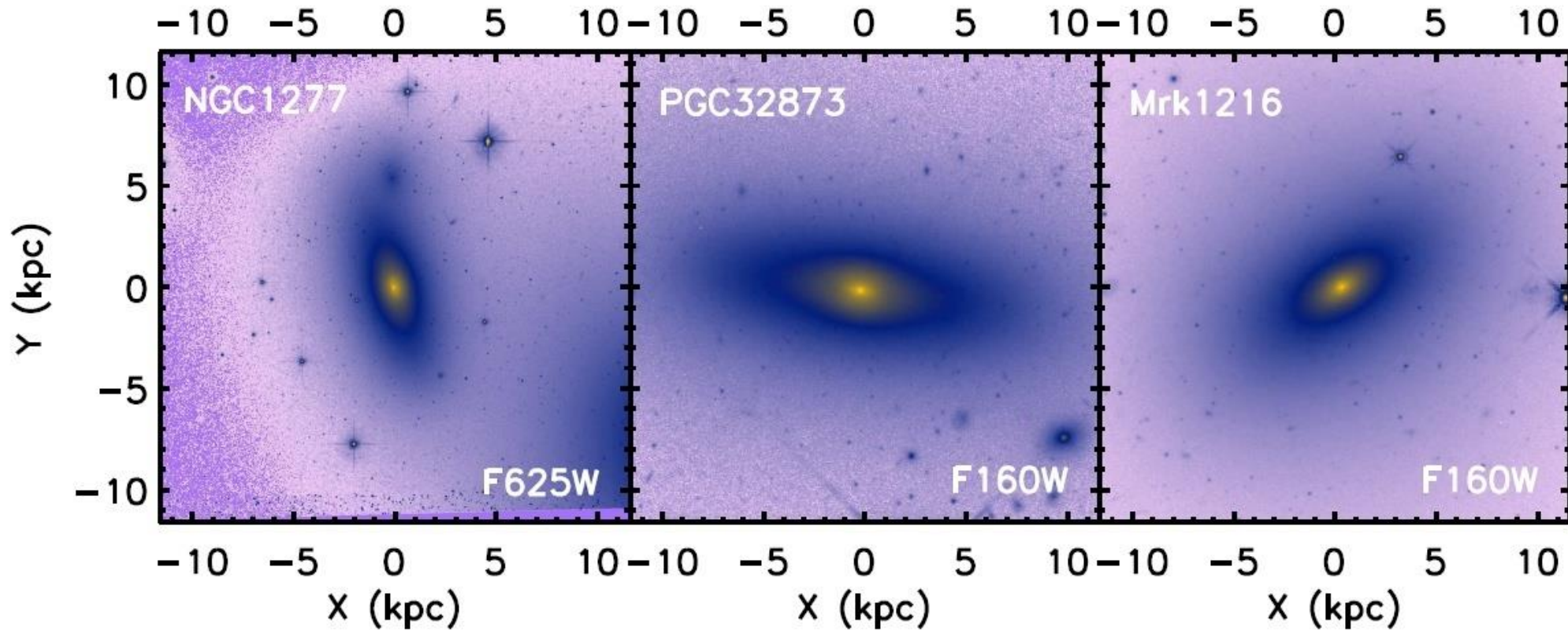
20 arcsec

x (kpc)

Trujillo et al. 2014

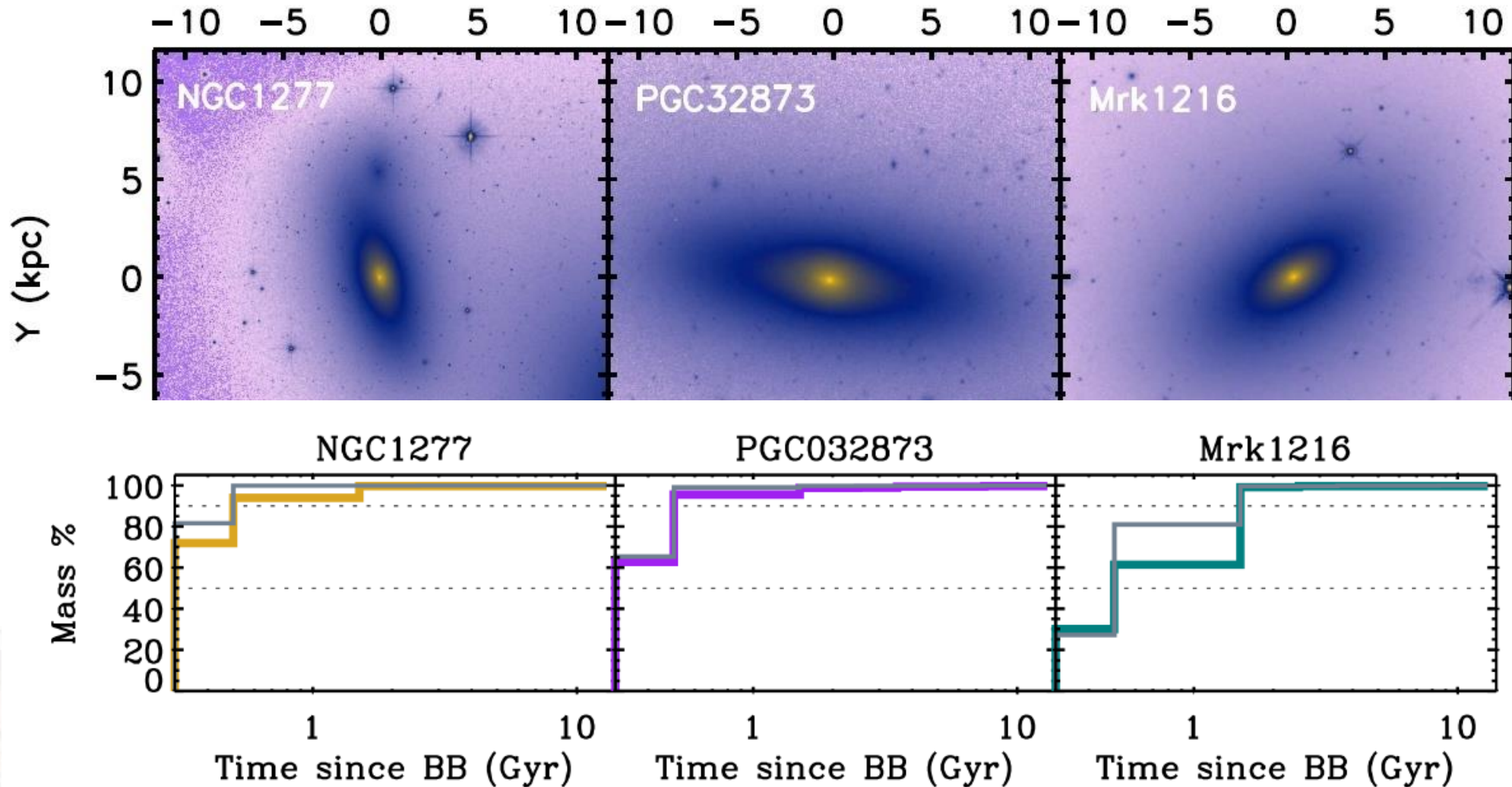


THE DISCOVERY OF RELIC GALAXIES



Ferré-Mateu et al. 2017

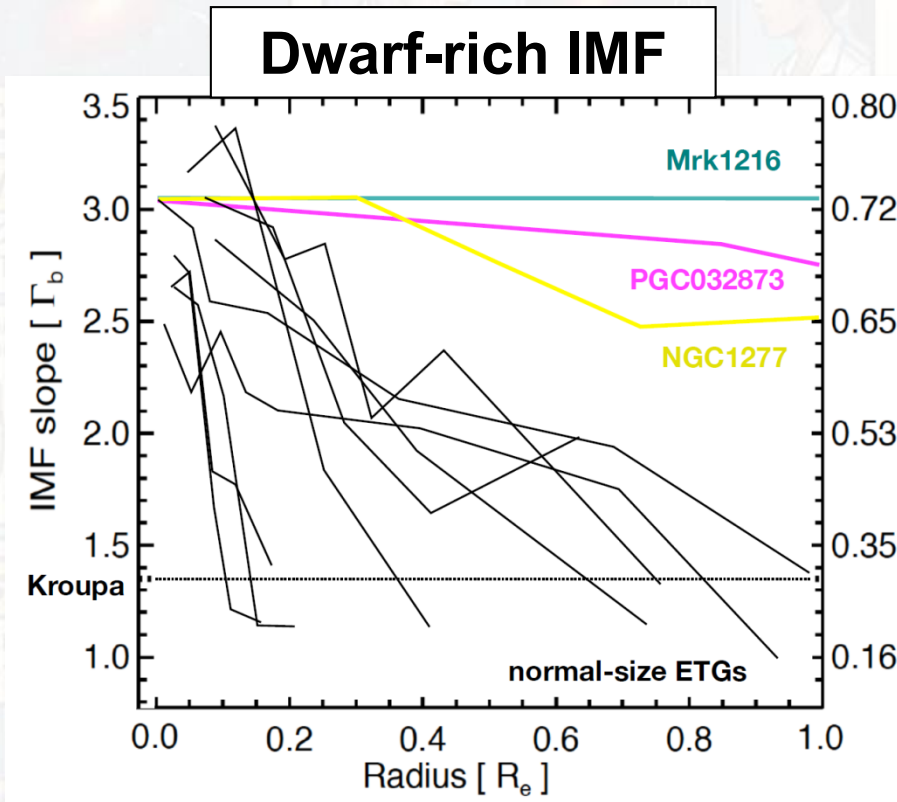
THE DISCOVERY OF RELIC GALAXIES



Ferré-Mateu et al. 2017

THE DISCOVERY OF RELIC GALAXIES

A first interesting property

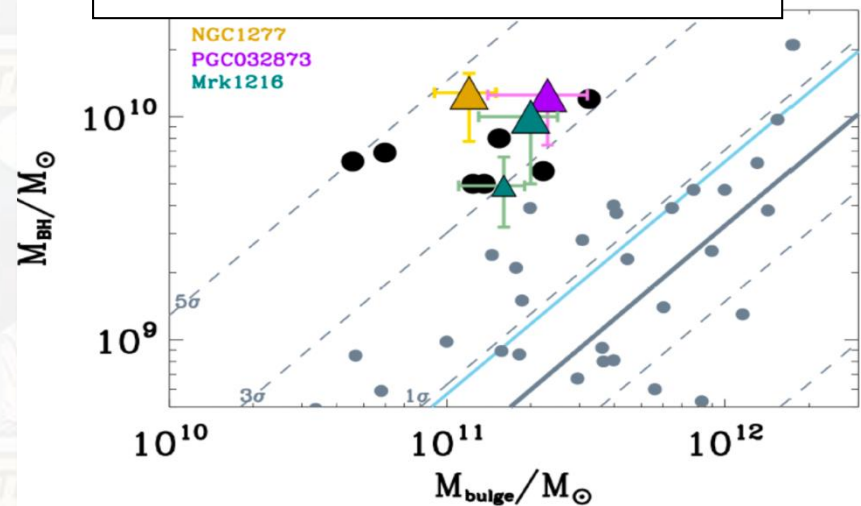


Ferré-Mateu et al. 2015, 2017

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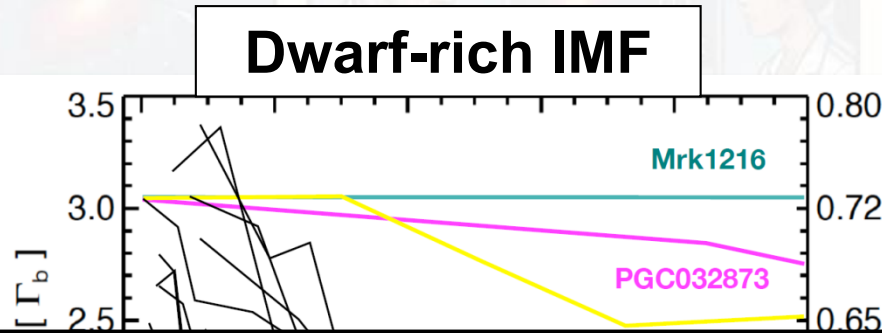
A second interesting property

Über-massive BHs

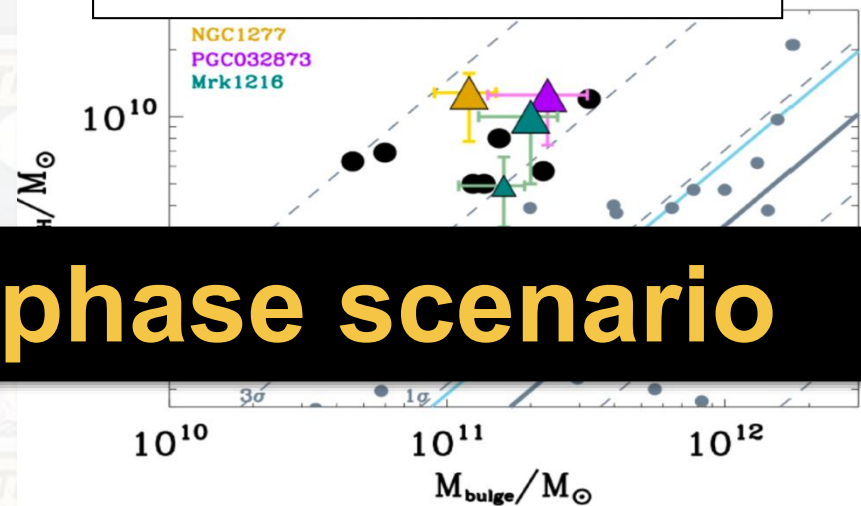


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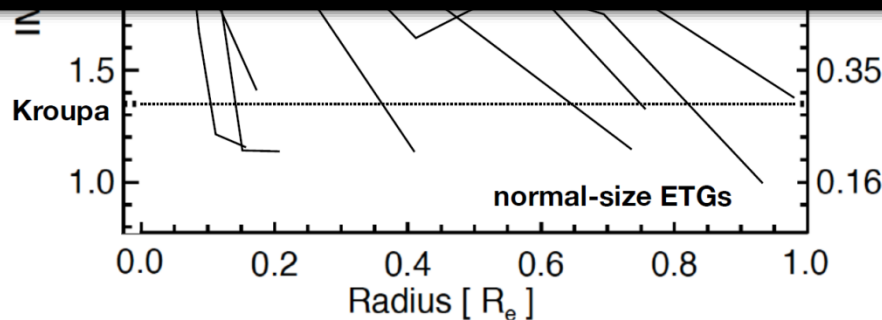
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Über-massive BHs



Confirm the Two-phase scenario



Ferré-Mateu et al. 2015, 2017

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Euclid expands our sample.

ELT & MORFEO: THE TWINS

MORFEO & ELT are the twin tools for the next spectral!

NO SIGNIFICANT STATISTICAL ANALYSIS CAN BE DONE

INNER SECRETS REVEALED

Tracing kinematics and dark matter from the centers to the outskirts.

STELLAR POPULATIONS & IMF

—Revealing age, metallicity, and the IMF across the galaxy!

THE QUEST COMPLETE

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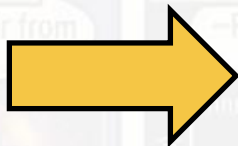
STELLAR POPULATIONS & IMF

Revealing the IMF of the inner core

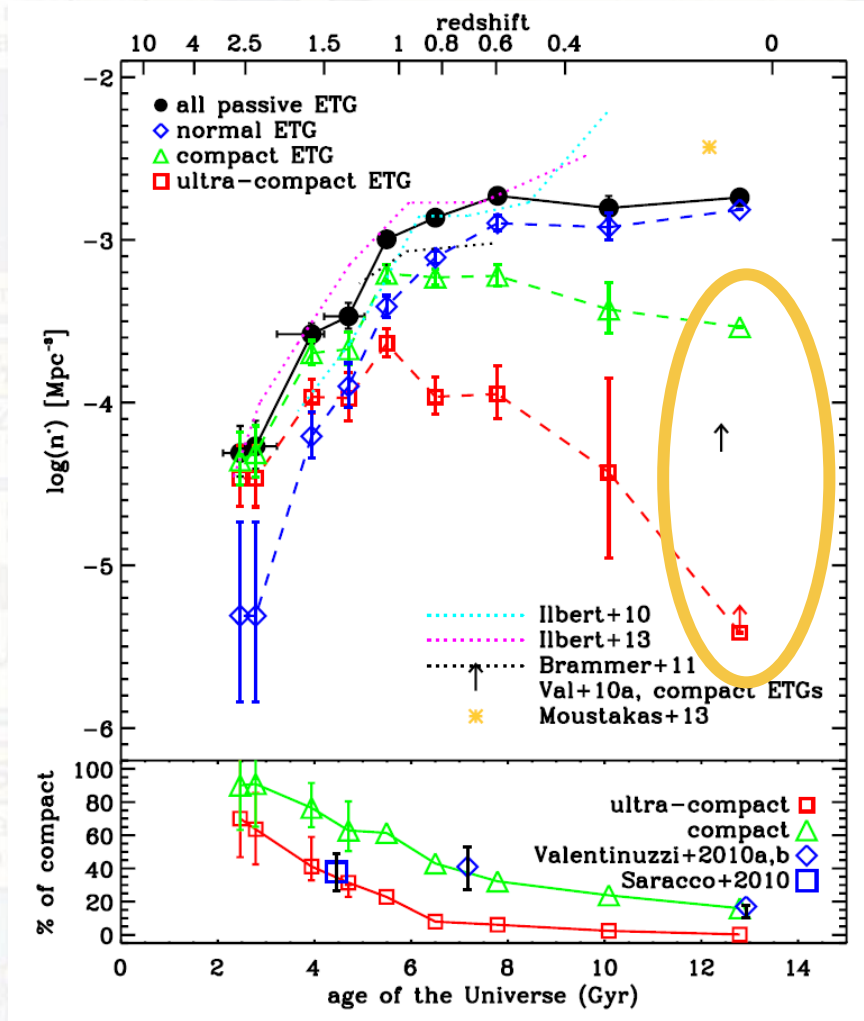
THE QUEST COMPLETE

THE UNIVERSAL CORE

LET'S MOVE TO HIGHER REDSHIFT



FIRST CENSUS AS A FUNCTION OF REDSHIFT



Cassata et al. 2013

LAXIES

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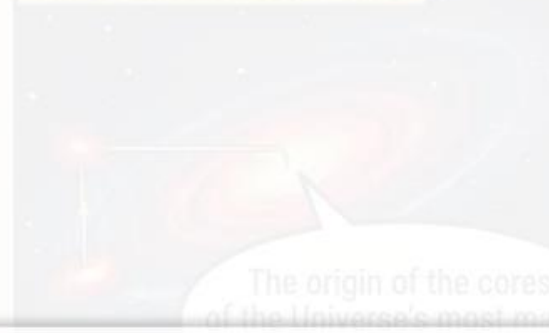


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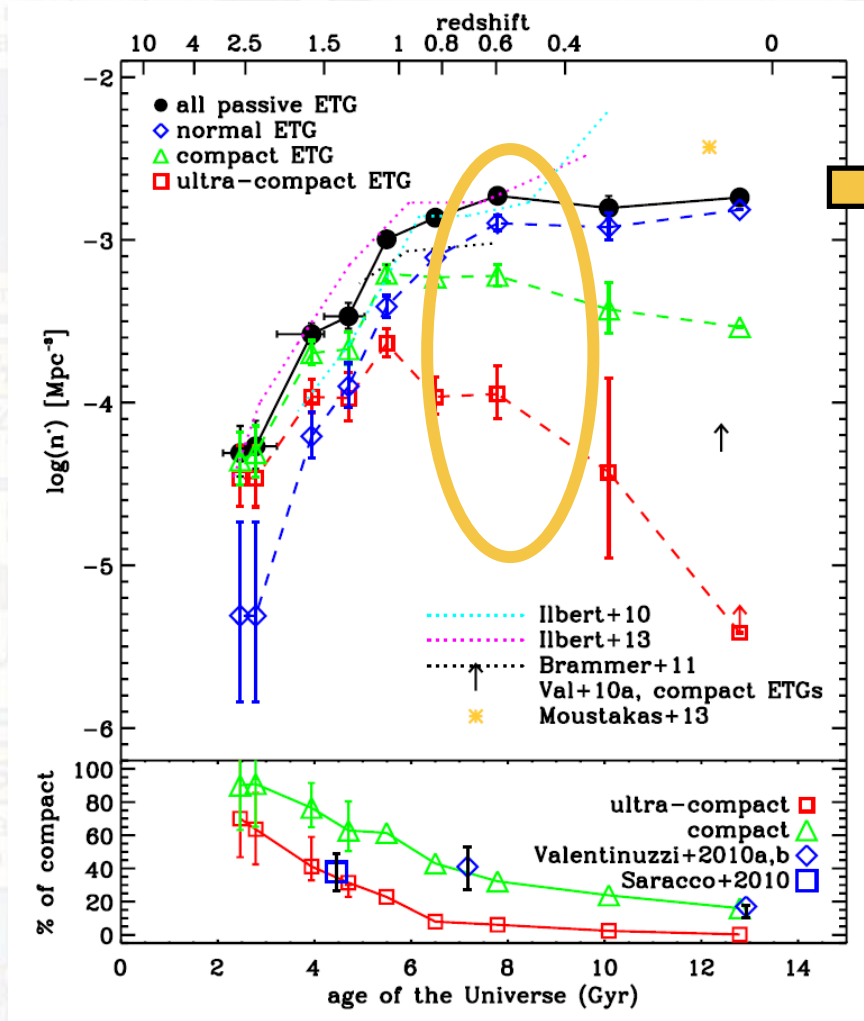
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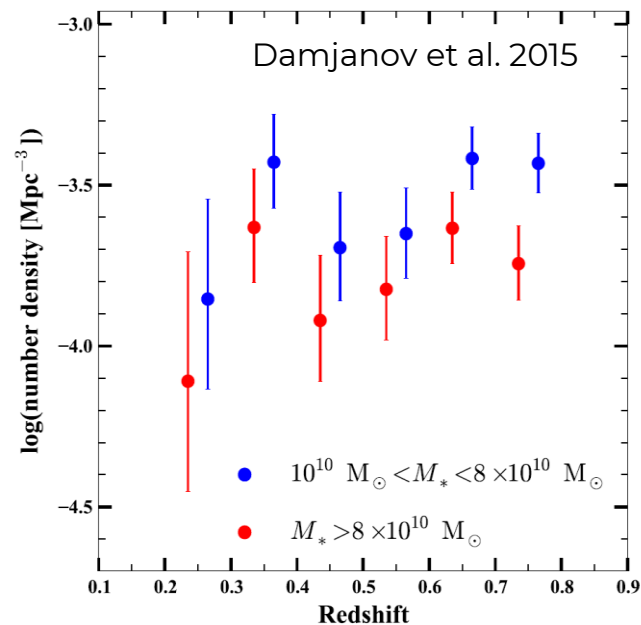
FIRST CENSUS AS A FUNCTION OF REDSHIFT



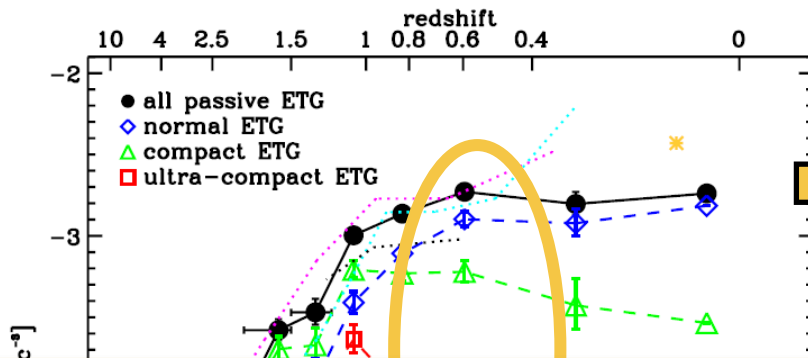
Cassata et al. 2013

Compact galaxies and relics more common at intermediate redshifts

COSMOS



FIRST CENSUS AS A FUNCTION OF REDSHIFT



Compact galaxies and relics more common at intermediate redshifts

COSMOS

But the statistics of these compact systems was still very low

Wide-field sky surveys (with good resolution) needed!

Cassata et al. 2013

age of the Universe (Gyr)

Redshift



OUR SYSTEMATIC SEARCH WITH KIDS

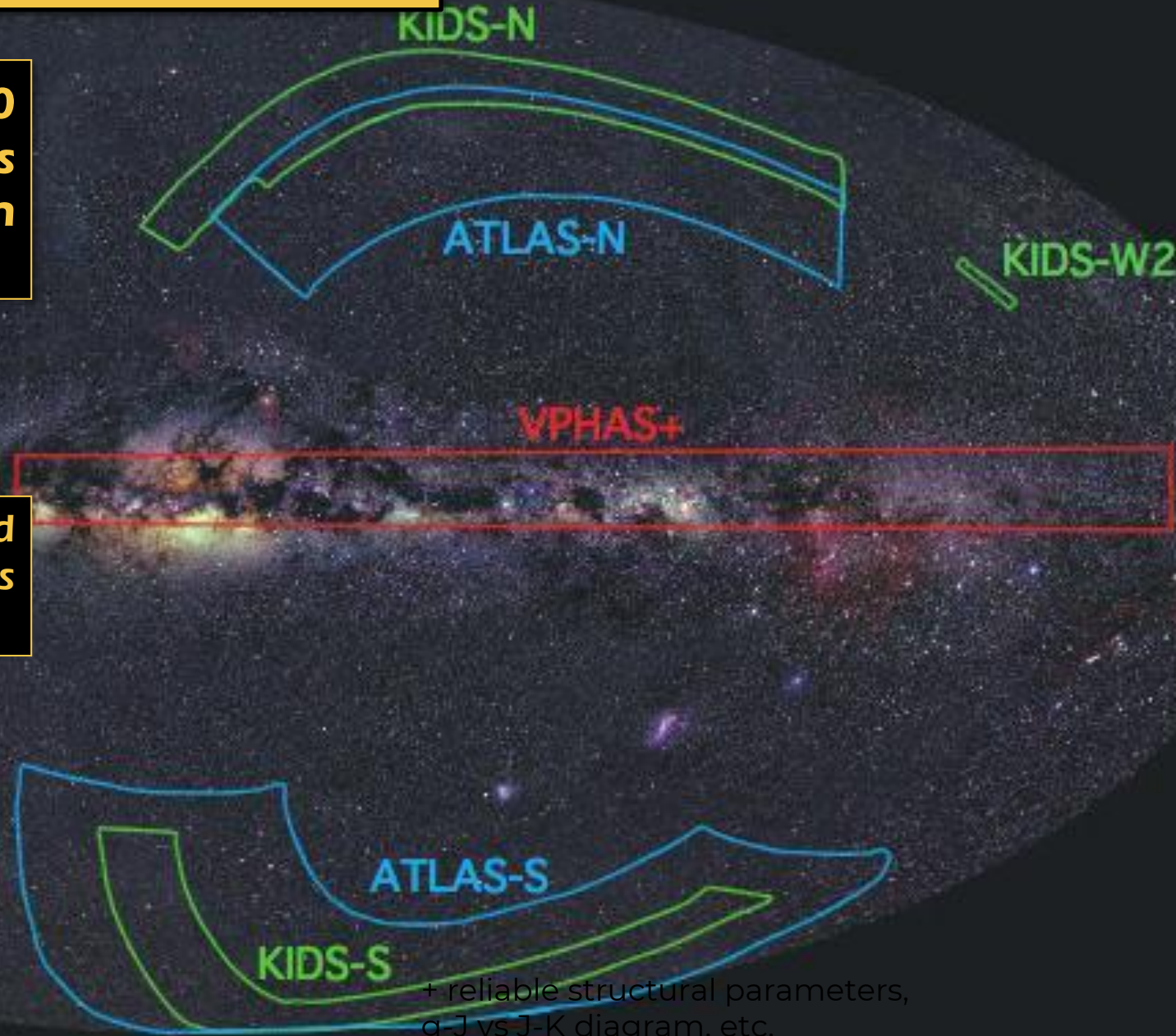
KIDS@VST has imaged 1350 square degrees in 4 optical bands (complemented in the NIR with **VIKING@VISTA**)

Deeper and with better quality and higher spatial resolution than previous surveys.

Pixel scale **0.2"/pxl**

Seeing **0.7" (r-band)**

Depth **r = 25 (r-band)**



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DR1/2/3 (333 sq. deg.)

Sources: ~ 60 millions

Galaxies: ~ 22 millions with photo-z
> 3 millions with high-quality photo-z
~ 1 million with structural parameters

NGC 1277 - type

Ultra-compact massive galaxies (UCMGs)

$$R_e < 1.5 \text{ kpc} \quad (R_e < 0.4'')$$

$$M_{\star} > 8 \times 10^{10} M_{\odot}$$

+ reliable structural parameters,
q-J vs J-K diagram, etc.

CENSUS AND SPECTROSCOPIC FOLLOW-UP

Towards a census of supercompact massive galaxies in the Kilo Degree Survey

C. Tortora,^{1*} F. La Barbera,¹ N. R. Napolitano,¹ N. Roy,^{1,2} M. Radovich,³ S. Cavuoti,¹ M. Brescia,¹ G. Longo,² F. Getman,¹ M. Capaccioli,² A. Grado,¹ K. H. Kuijken,⁴ J. T. A. de Jong,⁴ J. P. McFarland⁵ and E. Puddu¹

The first sample of spectroscopically confirmed ultra-compact massive galaxies in the Kilo Degree Survey

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Building the Largest Spectroscopic Sample of Ultracompact Massive Galaxies with the Kilo Degree Survey

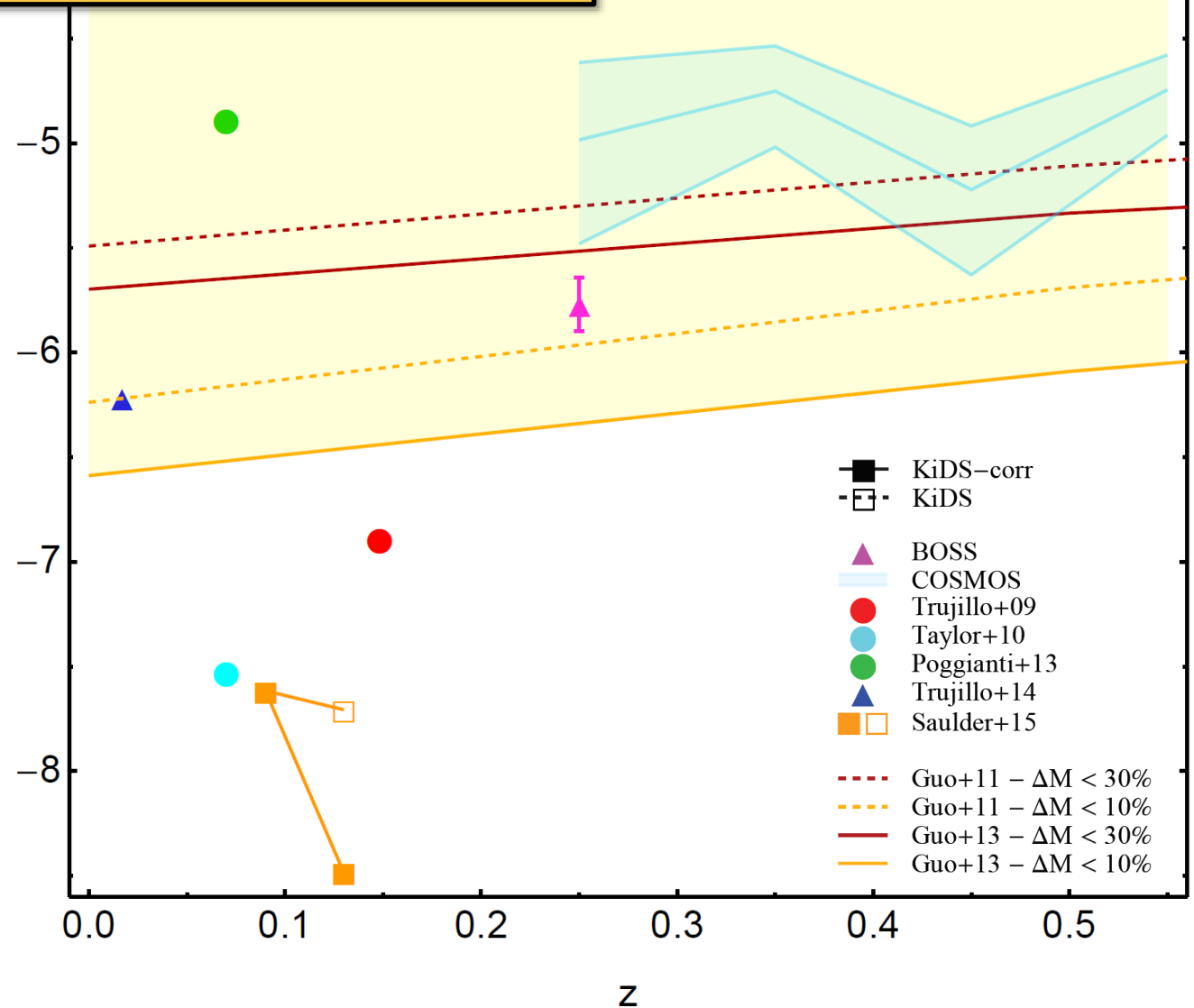
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LETTER TO THE EDITOR

Nature versus nurture: relic nature and environment of the most massive passive galaxies at $z < 0.5$

C. Tortora¹, N. R. Napolitano^{2,3}, M. Radovich⁴, C. Spiniello^{3,5}, L. Hunt¹, N. Roy², L. Moscardini^{6,7,8}, D. Scognamiglio⁹, M. Spavone³, M. Brescia³, S. Cavuoti^{3,10}, G. D'Ago¹¹, G. Longo¹⁰, F. Bellagamba^{6,7}, M. Maturi^{12,13}, and M. Roncarelli^{6,7}

log density [$1/\text{Mpc}^3$]



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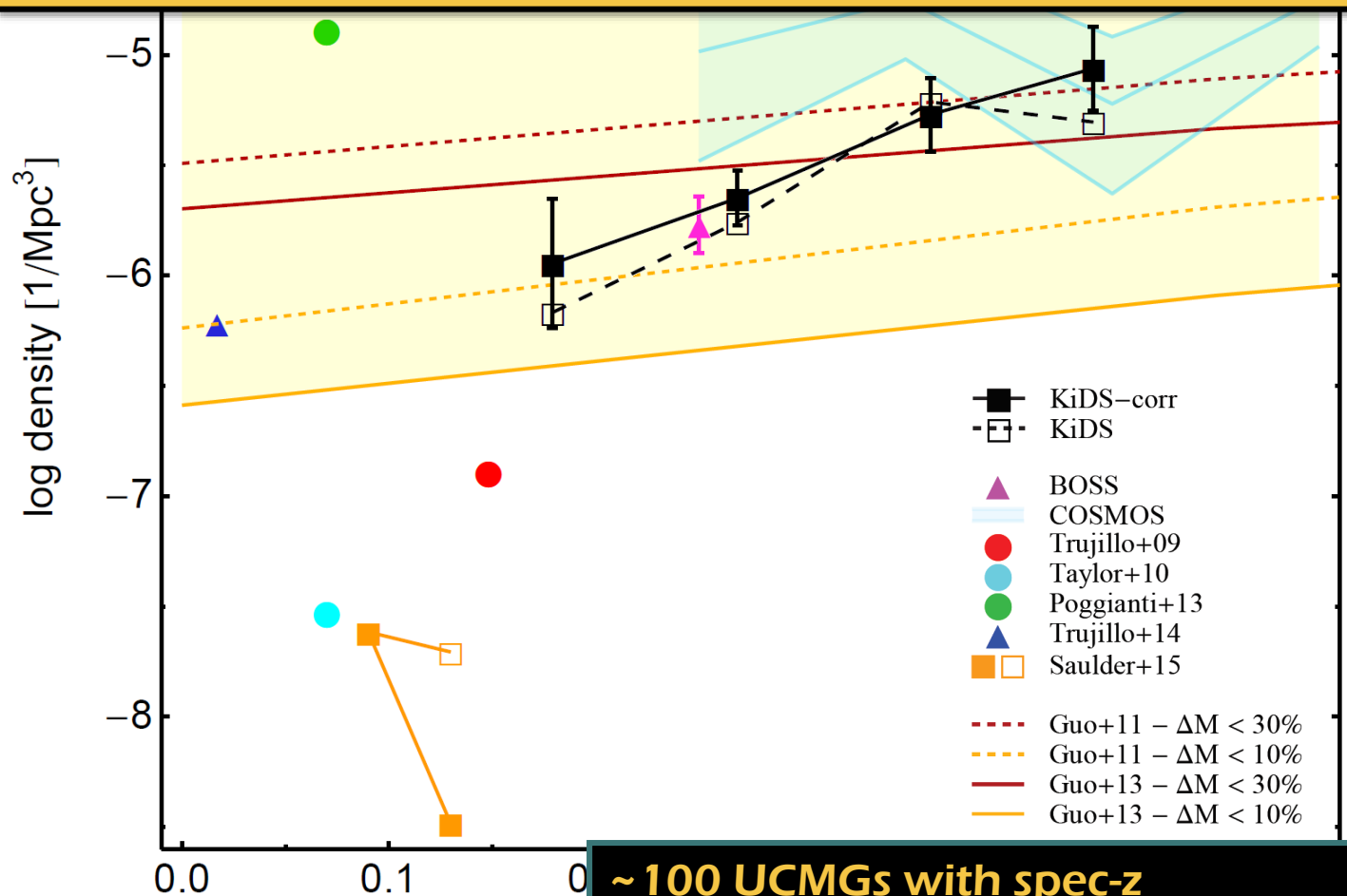
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~1000 UCMG candidates at $z < 0.5$ over 330 sq. deg.



~100 UCMGs with spec- z
(150h of observations + literature)



CENSUS AND SPECTROSCOPIC FOLLOW-UP



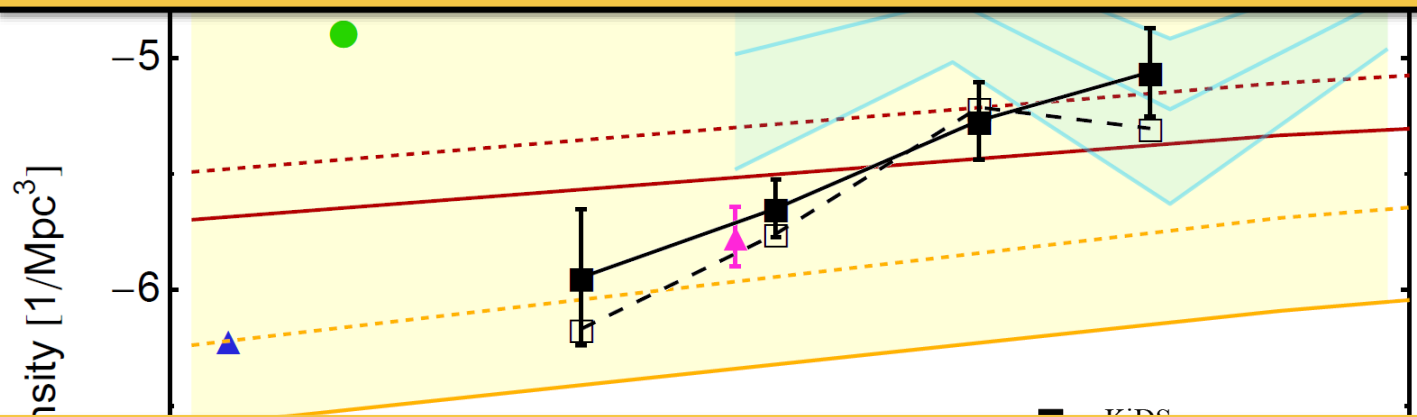
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The largest sample over the largest sky area

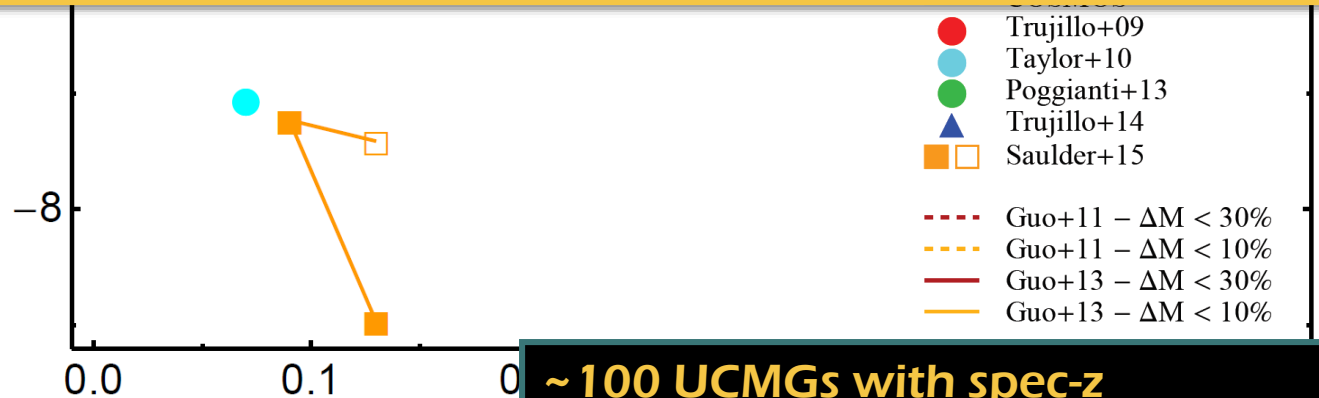
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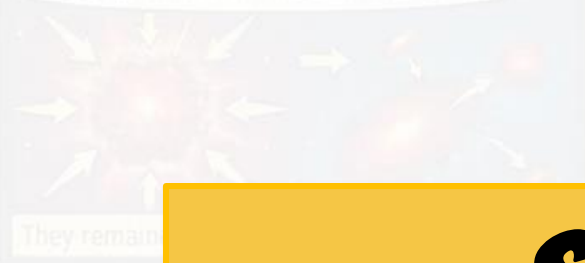
~100 UCMGs with spec-z
(150h of observations + literature)



THE HERO'S JOURNEY OF RELIC GALAXIES

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Billions of years ago, massive red nuggets formed in massive starbursts.



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**SIZE AND MASS MEASURED,
BUT WHAT ABOUT AGES, METALLICITIES
AND SFH (AND IMF!)?**

INNER SECRETS REVEALED

Tracing kinematics and dark matter from the centers to the outskirts.



STELLAR POPULATIONS & IMF

Revealing age, metallicity, and the IMF across the galaxy!



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Observations bring back the ultimate prize: definitive formation insight!



THE UNIVERSAL CORE

The origin of the cores of the Universe's most massive galaxies



INSPIRE (INVESTIGATING STELLAR POPULATION IN RELICS)

Sample: 52 UCMGs - from ~100 relic candidates (with z_{spec})

Aims: Characterize these galaxies by constraining their stellar populations and velocity dispersions

Results:

- **3 ESO data releases;**
- **9 papers published** (Spiniello et al. 2021a,b,2024, 2025; D'ago et al. 2023; Martin-Navarro et al. 2023, Maksymowicz-Maciata et al. 2024, Scognamiglio et al. 2024, Tortora et al. 2025);
- **1 ESO messenger** (Spiniello, Tortora et al. 2021)
- **Various press-releases and talks**

INvestigate
Stellar
Population
In
RElics



PI: Chiara Spiniello; Crescenzo Tortora

Total time awarded: 154h at XSHOOTER@VLT

INSPIRE PRODUCTION

The Investigate Stellar Population In Relics (INSPIRE) Project — Scientific Goals and Survey Design



INSPIRE: Investigating Stellar Population In Relics

I. Survey presentation and pilot study

C. Spiniello^{1,2}, C. Tortora³, G. D'Agostino⁴, L. Coccaro⁵, F. La Barbera⁶, A. Ferré-Mateu⁷, N. R. Napolitano^{2,8}, M. Spavone⁹, D. Scognamiglio¹⁰, M. Arnaboldi¹¹, A. Gallazzi¹², L. Hunt¹³, N. R. Napolitano^{2,8}, M. Radovich¹⁴, and S. Zibetti¹⁵

INSPIRE: Investigating Stellar Population In Relics

II. First data release (DR1)

C. Spiniello^{1,2}, C. Tortora³, G. D'Agostino⁴, L. Coccaro⁵, F. La Barbera⁶, A. Ferré-Mateu⁷, C. Pulsoni¹⁶, M. Arnaboldi¹¹, A. Gallazzi¹², L. Hunt¹³, N. R. Napolitano^{2,8}, M. Radovich¹⁴, D. Scognamiglio¹⁰, M. Spavone⁹, and S. Zibetti¹⁵

INSPIRE: Investigating Stellar Population In Relics

III. Second data release (DR2): testing the systematics on the stellar velocity dispersion*

G. D'Agostino⁴, C. Spiniello^{1,2}, L. Coccaro⁵, C. Tortora³, F. La Barbera⁶, M. Arnaboldi¹¹, D. Bevacqua¹⁷, A. Ferré-Mateu⁷, A. Gallazzi¹², J. Hartke¹⁸, L. K. Hunt¹³, I. Martin-Navarro¹⁹, N. R. Napolitano^{2,8}, C. Pulsoni¹⁶, M. Radovich¹⁴, P. Saracco²⁰, D. Scognamiglio¹⁰, and S. Zibetti¹⁵

INSPIRE: Investigating Stellar Population In Relics – IV. The initial mass function slope in relics

Ignacio Martín-Navarro^{1,24}, C. Spiniello^{1,24}, C. Tortora³, L. Coccaro⁵, G. D'Agostino⁴, A. Ferré-Mateu⁷, C. Pulsoni¹⁶, J. Hartke¹⁸, M. Arnaboldi¹¹, L. Hunt¹³, N. R. Napolitano^{2,8}, D. Scognamiglio¹⁰ and M. Spavone⁹

INSPIRE: Investigating Stellar Population In Relics – V. A catalogue of ultra-compact massive galaxies outside the local Universe and their degree of relicness

C. Spiniello^{1,24}, G. D'Agostino⁴, L. Coccaro⁵, J. Hartke¹⁸, C. Tortora³, A. Ferré-Mateu⁷, C. Pulsoni¹⁶, M. Cappellari²⁵, M. Maksymowicz-Maciata²⁶, M. Arnaboldi¹¹, D. Bevacqua¹⁷, A. Gallazzi¹², L. K. Hunt¹³, F. La Barbera⁶, I. Martin-Navarro¹⁹, N. R. Napolitano^{2,8}, M. Radovich¹⁴, P. Saracco²⁰, D. Scognamiglio¹⁰, M. Spavone⁹ and S. Zibetti¹⁵

INSPIRE: Investigating Stellar Population In Relics – VI. The low-mass end slope of the stellar initial mass function and chemical composition

Michalina Maksymowicz-Maciata^{1,9}, Chiara Spiniello^{1,24}, Ignacio Martín-Navarro^{1,24}, Anna Ferré-Mateu⁷, Davide Bevacqua¹⁷, Michele Cappellari²⁵, Giuseppe D'Agostino⁴, Crescenzo Tortora³, Magda Arnaboldi¹¹, Johanna Hartke¹⁸, Nicola R. Napolitano^{2,8}, Paolo Saracco²⁰ and Diana Scognamiglio¹⁰

INSPIRE: Investigating Stellar Population In Relics – VII. The local environment of ultra-compact massive galaxies

Diana Scognamiglio^{1,9}, Chiara Spiniello^{1,24}, Mario Radovich¹⁴, Crescenzo Tortora³, Nicola R. Napolitano^{2,8}, Rui Li²⁷, Matteo Maturi²⁸, Michalina Maksymowicz-Maciata²⁶, Michele Cappellari²⁵, Magda Arnaboldi¹¹, Davide Bevacqua¹⁷, Ludovico Coccaro⁵, Giuseppe D'Agostino⁴, Hui-Cheng Feng¹², Anna Ferré-Mateu⁷, Johanna Hartke¹⁸, Ignacio Martín-Navarro^{1,24} and Claudia Pulsoni¹⁶

INSPIRE: Investigating Stellar Population In Relics VIII. Emission lines and UV colours in ultracompact massive galaxies

Chiara Spiniello^{1,9}, Mario Radovich¹⁴, Anna Ferré-Mateu⁷, Roberto De Propriis²⁹, Magda Arnaboldi¹¹, Francesco La Barbera⁶, Johanna Hartke¹⁸, Giuseppe D'Agostino⁴, Crescenzo Tortora³, Davide Bevacqua¹⁷, Michalina Maksymowicz-Maciata²⁶, John Mills³⁰, Nicola R. Napolitano^{2,8}, Claudia Pulsoni¹⁶, Paolo Saracco²⁰ and Diana Scognamiglio¹⁰

INSPIRE: Investigating Stellar Populations In Relics – IX. KIDS J0842 + 0059: the first fully confirmed relic beyond the local Universe

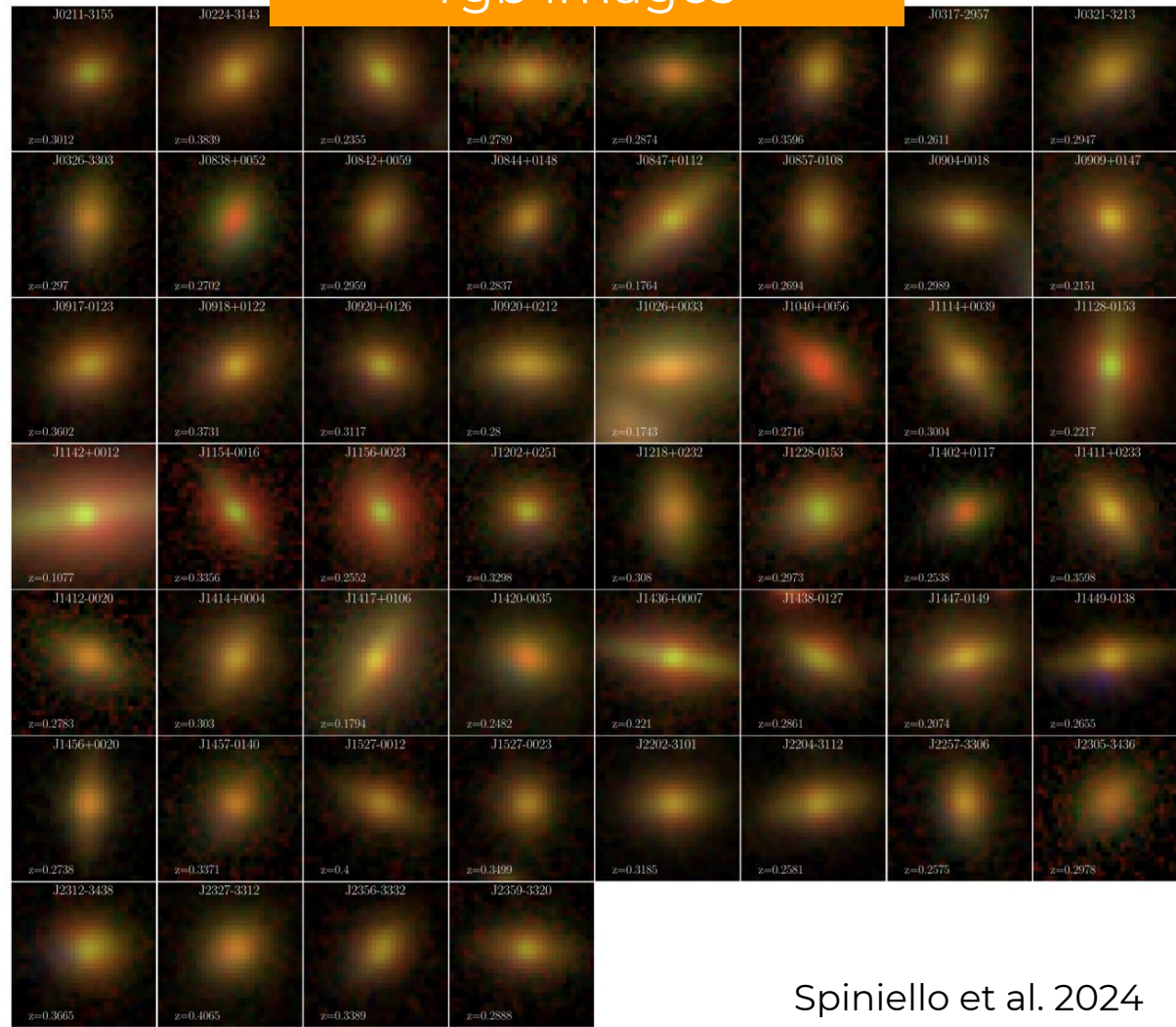
C. Tortora³, G. Tozzi³¹, G. Agapito³², F. La Barbera⁶, C. Spiniello^{1,24}, R. Li²⁷, G. Carlà³³, G. D'Agostino⁴, E. Ghose³⁴, F. Mannucci³⁵, N. R. Napolitano^{2,8}, E. Pinna³⁶, M. Arnaboldi¹¹, D. Bevacqua¹⁷, A. Ferré-Mateu⁷, A. Gallazzi¹², J. Hartke¹⁸, L. K. Hunt¹³, M. Maksymowicz-Maciata²⁶, C. Pulsoni¹⁶, P. Saracco²⁰, D. Scognamiglio¹⁰ and M. Spavone⁹



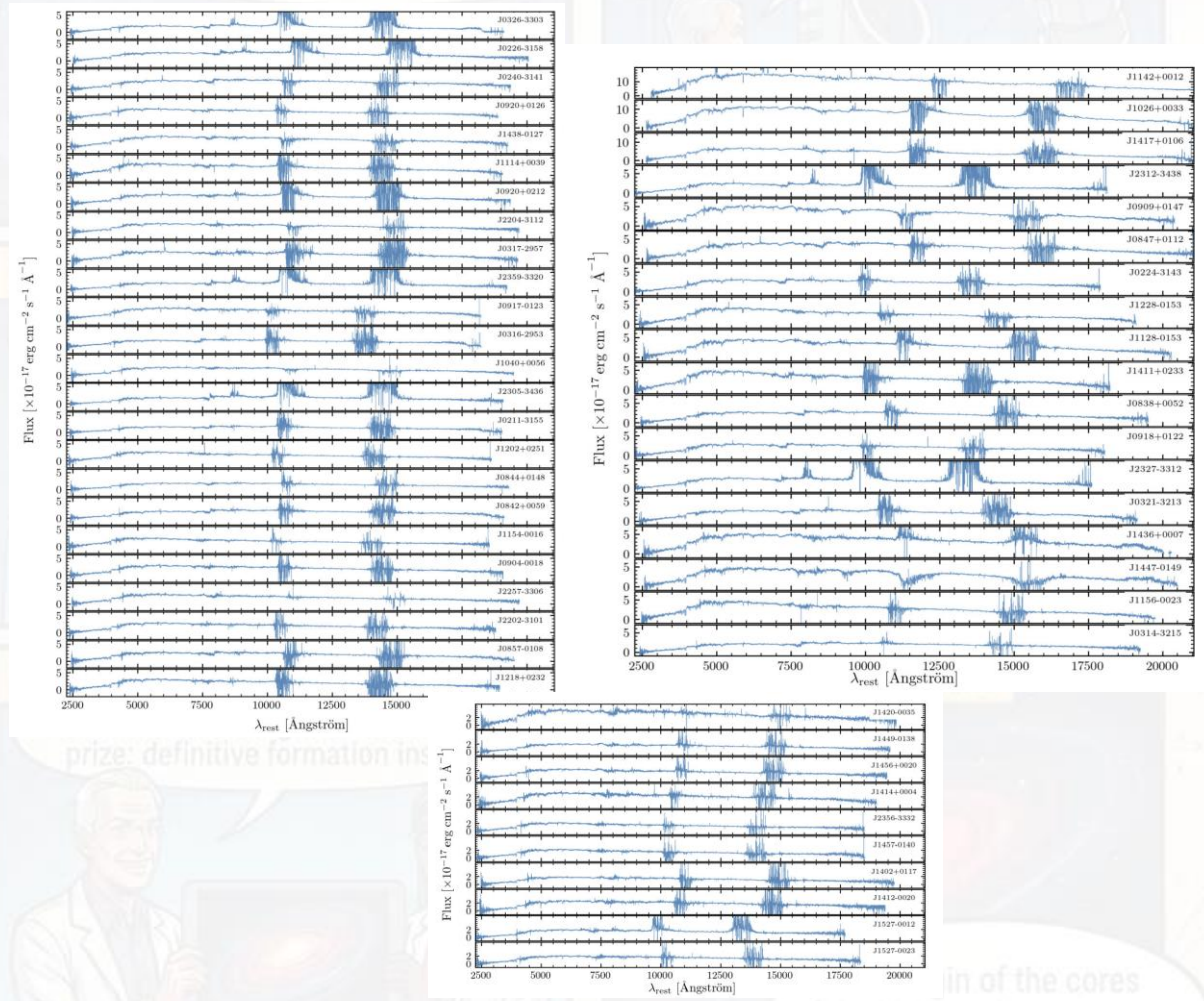
INSPIRE DATA RELEASE

INSPIRE: INvestigating Stellar Population In RELics - V.
Final Data Release: the first catalogue of relics outside the local Universe
C. Spiniello^{1,2*}, G. D'Ag^{3,2}, L. Coccat⁴, J. Hartke^{5,6}, C. Tortora², A. Ferré-Mateu⁷, C. Pulsoni⁸,
M. Cappellari¹, M. Makymowicz-Maciata¹, M. Arnaboldi⁴, D. Bevacqua^{9,10}, A. Gallazzi¹¹, L. K. Hunt¹¹,
F. La Barbera², I. Martín-Navarro⁷, N.R. Napolitano¹², M. Radovich¹³, D. Scognamiglio¹⁴, M. Spavone²,
S. Zibetti¹¹

rgb images



XShooter spectra



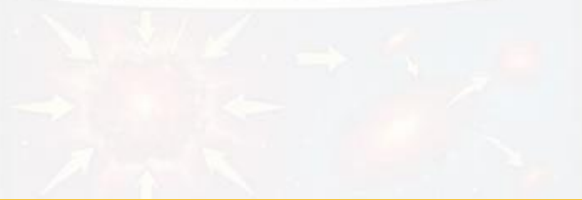
Spiniello et al. 2024



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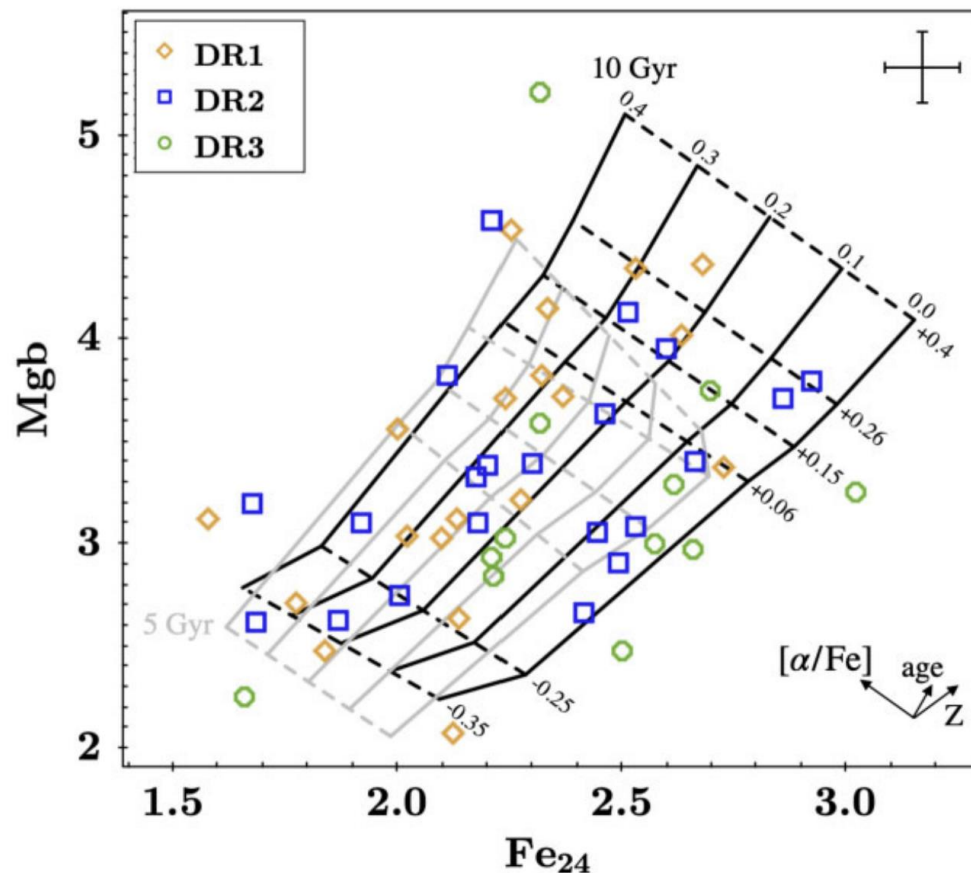
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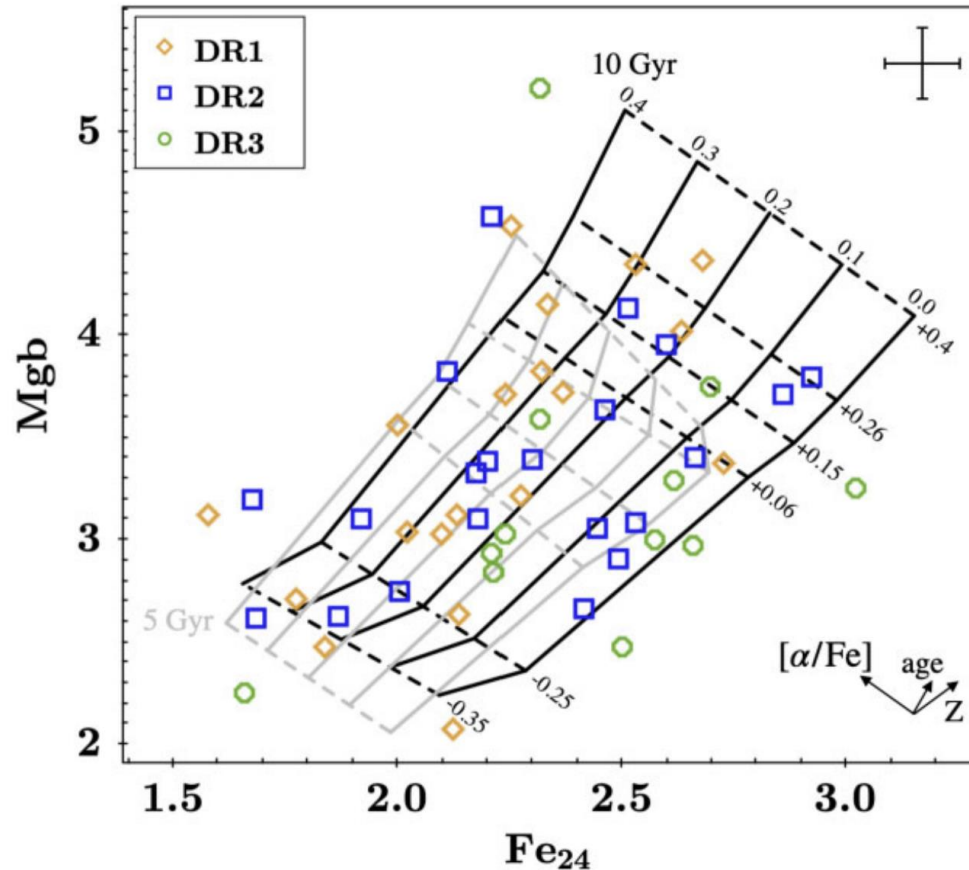
CONSTRAINING STELLAR POPULATIONS

Constraining $[\alpha/\text{Fe}]$

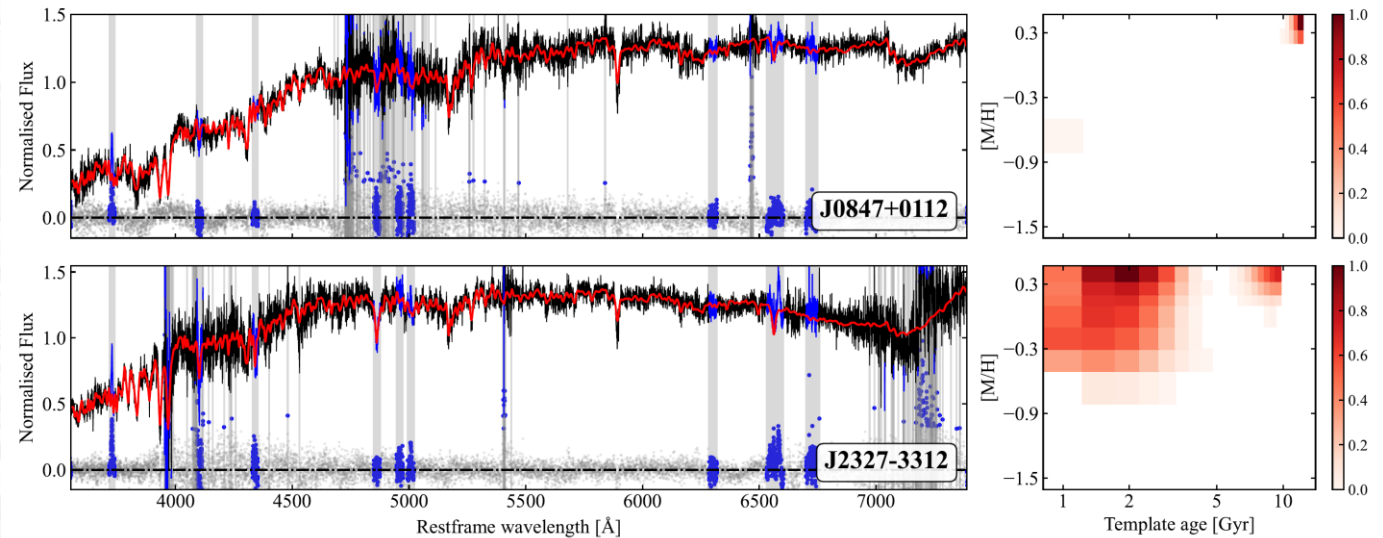


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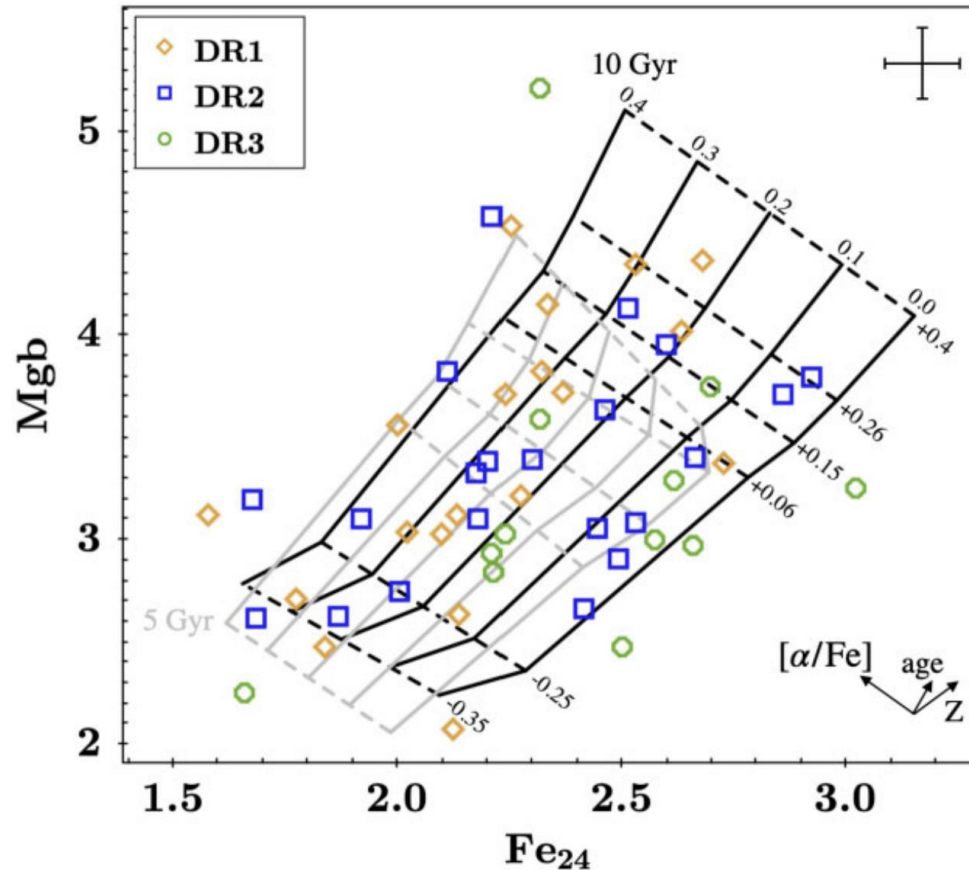


Constraining age and metallicity with *ppxf*

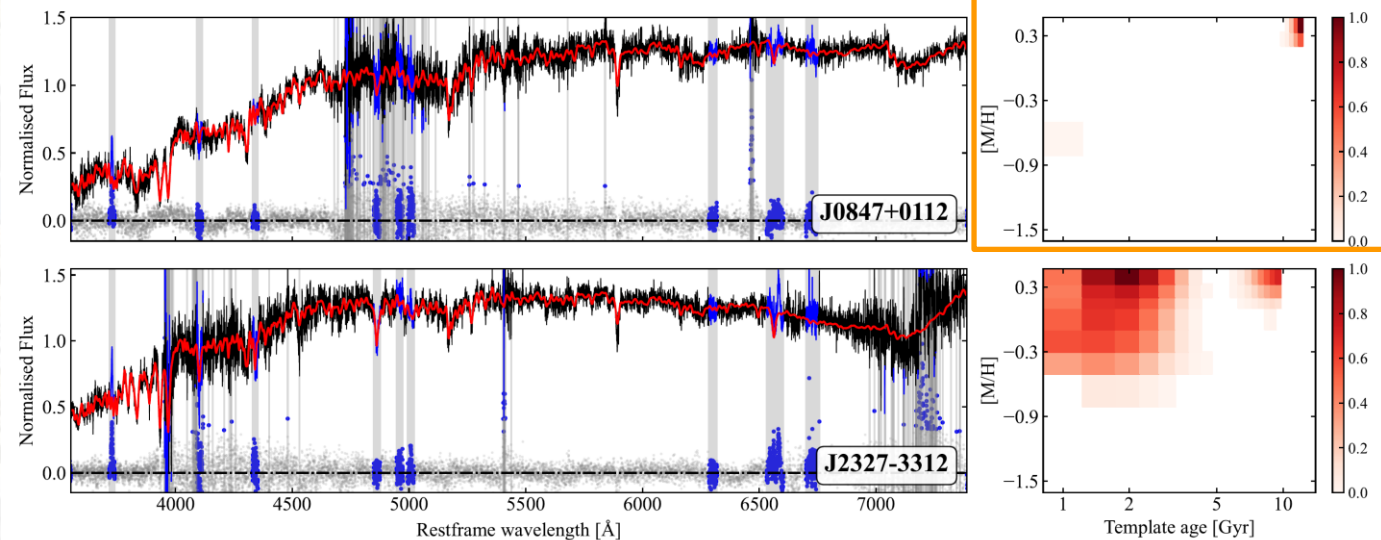


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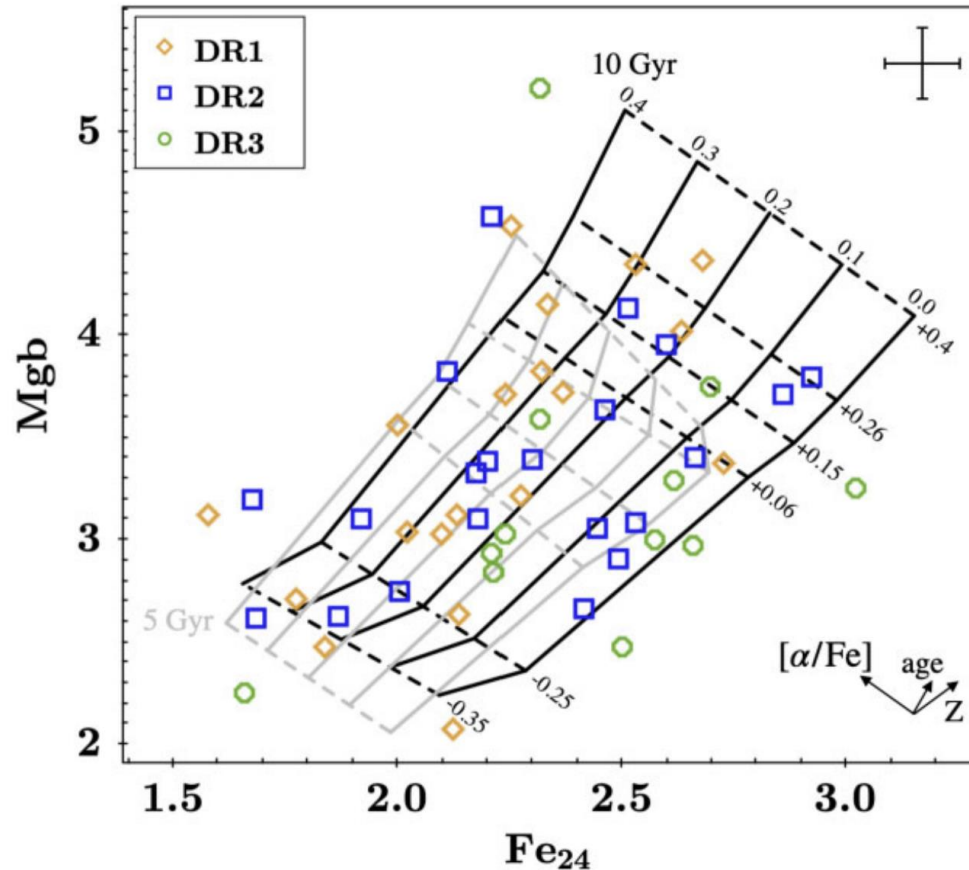
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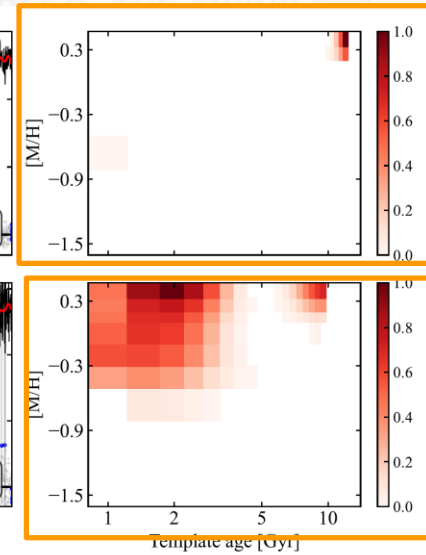
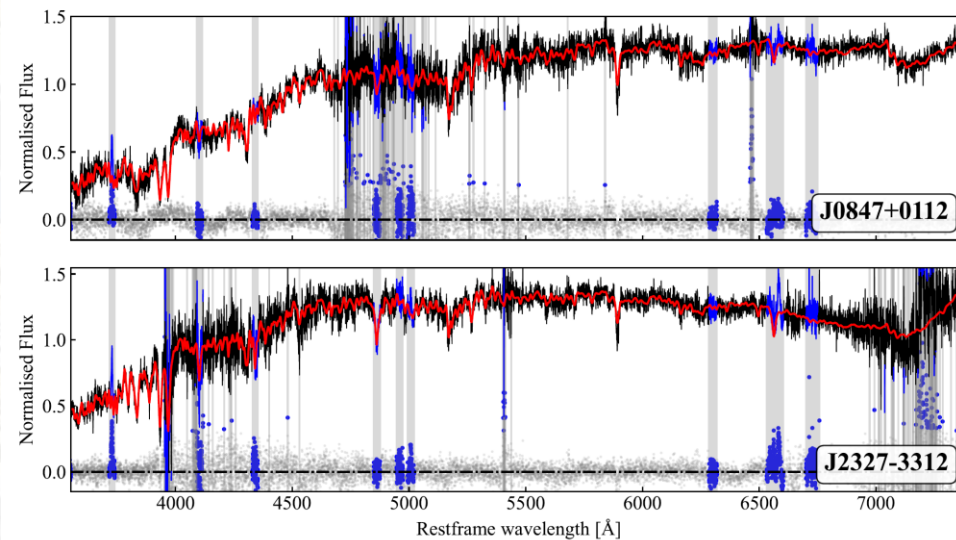
Relic

CONSTRAINING STELLAR POPULATIONS

Constraining $[\alpha/\text{Fe}]$



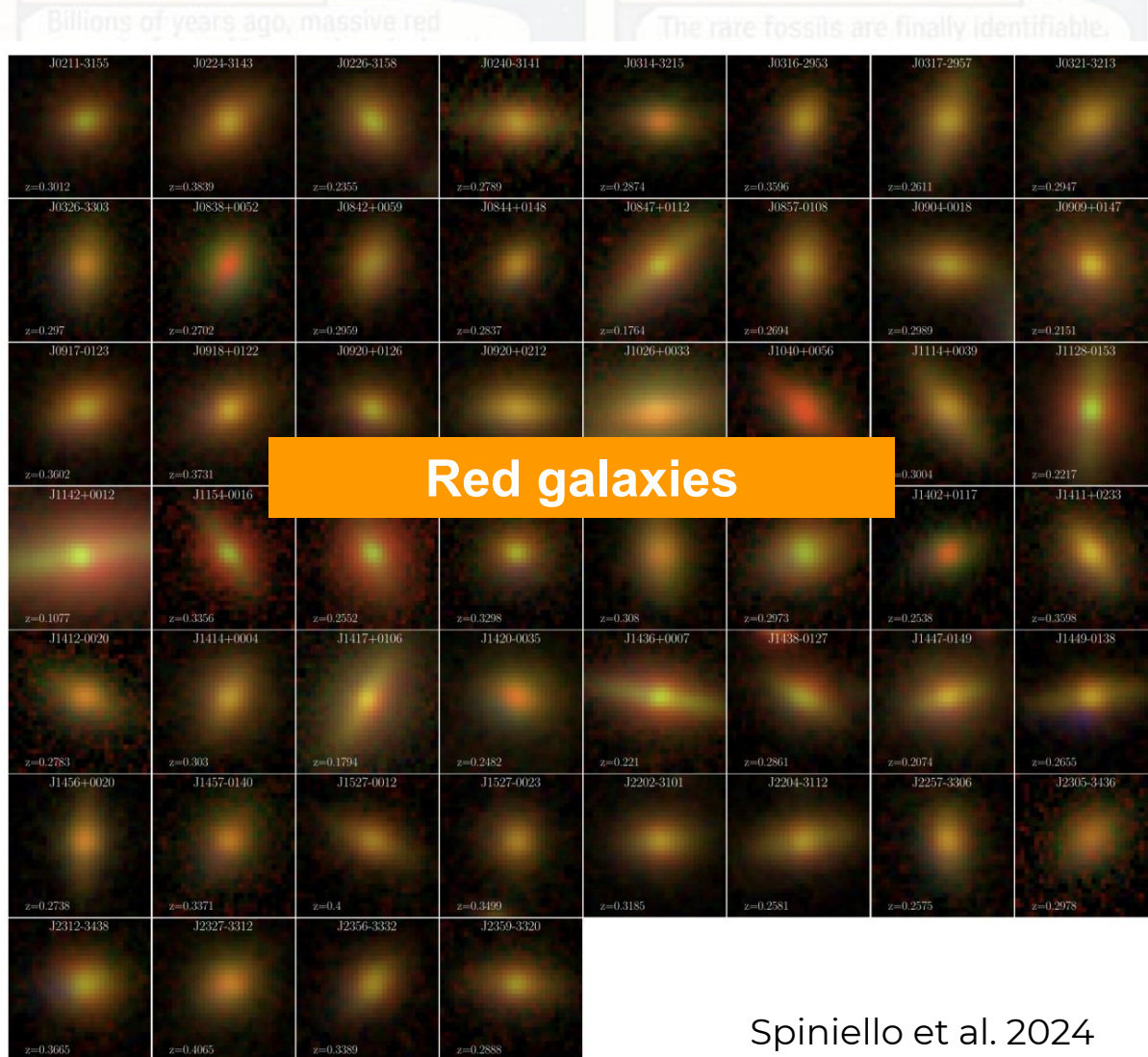
Constraining age and metallicity with *ppxf*



Relic

Non-relic

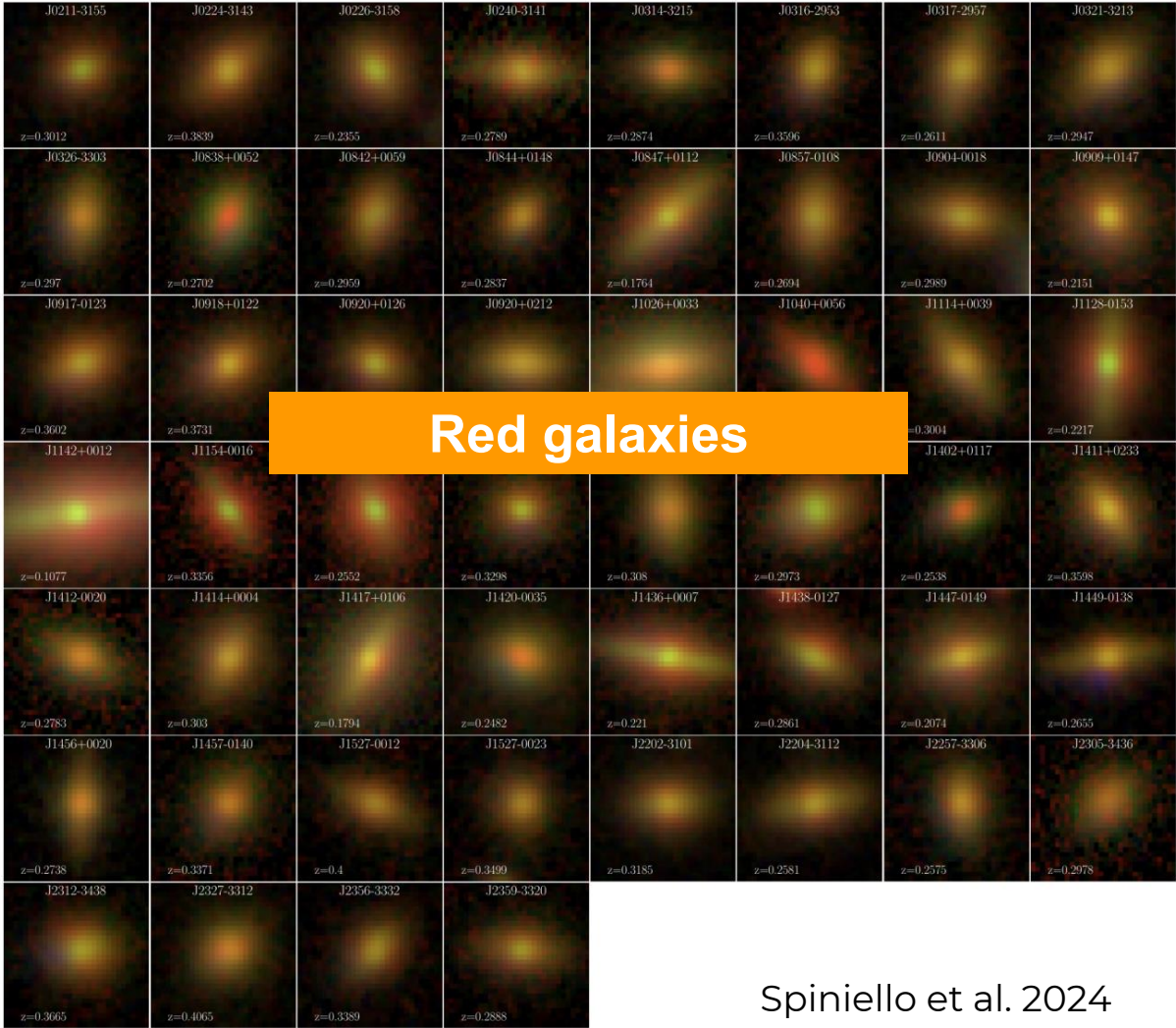
HOMOGENEOUS IN COLOR, HETEROGENEOUS IN SFH



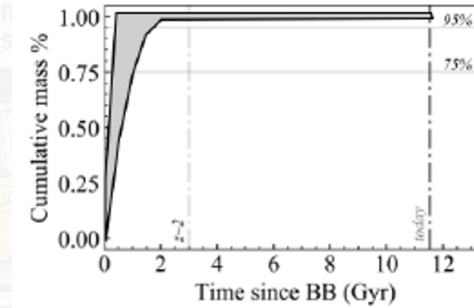
Spiniello et al. 2024



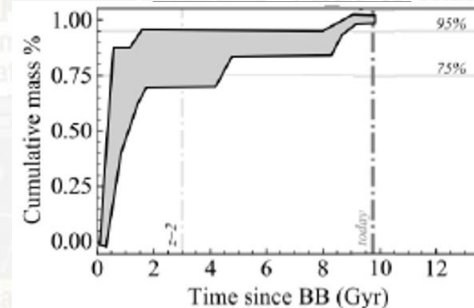
HOMOGENEOUS IN COLOR, HETEROGENEOUS IN SFH



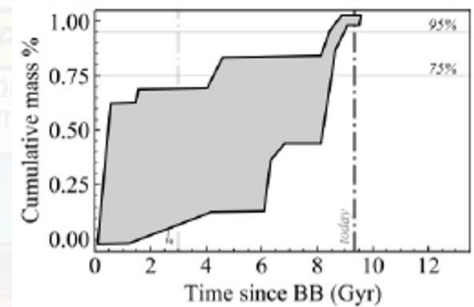
A range of SFHs



Extreme relic



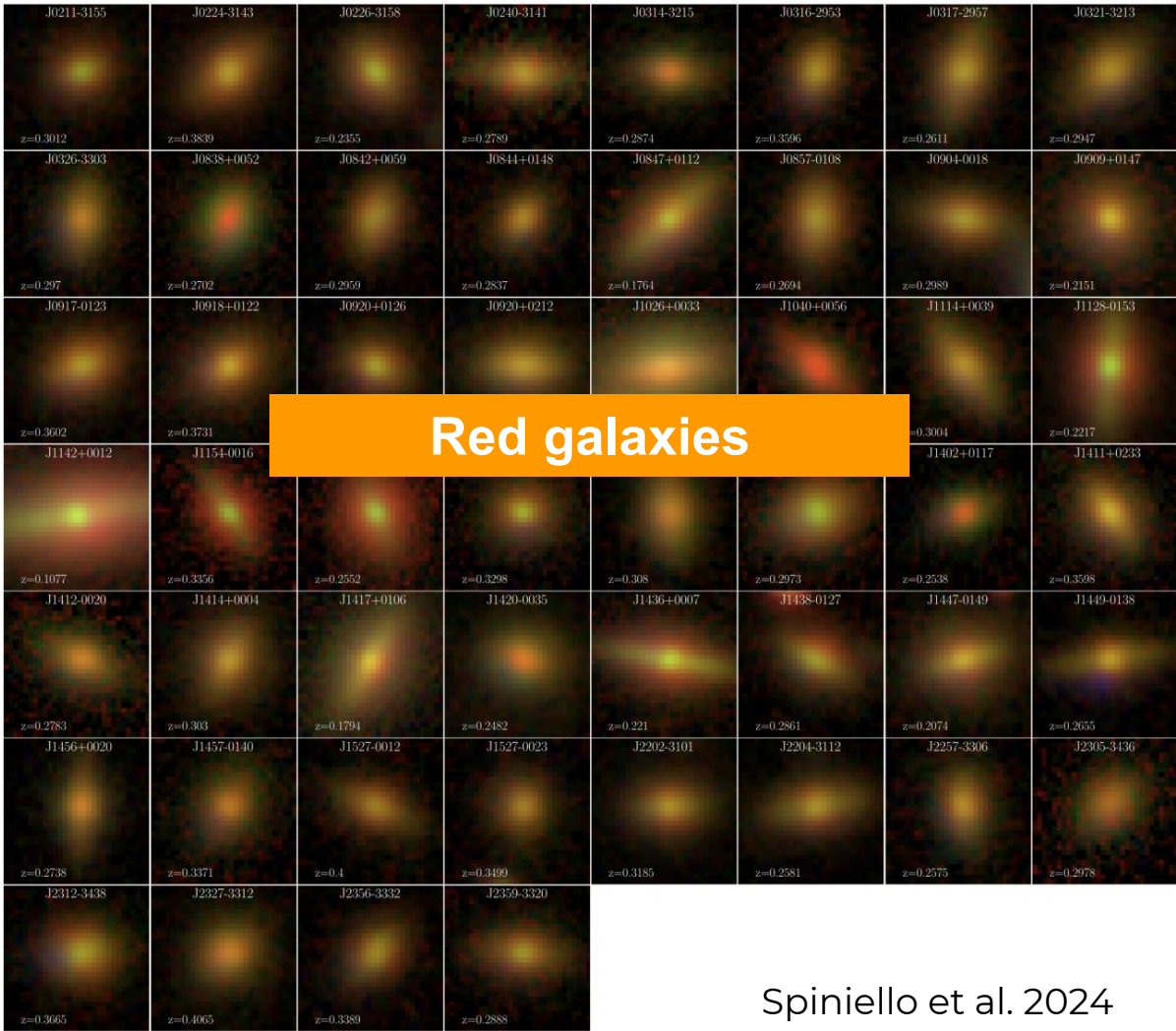
Relic



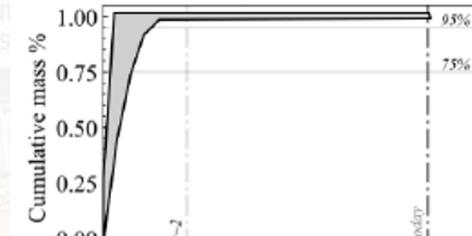
Non-Relic



HOMOGENEOUS IN COLOR, HETEROGENEOUS IN SFH

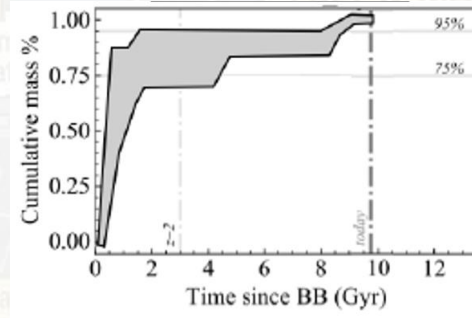


A range of SFHs

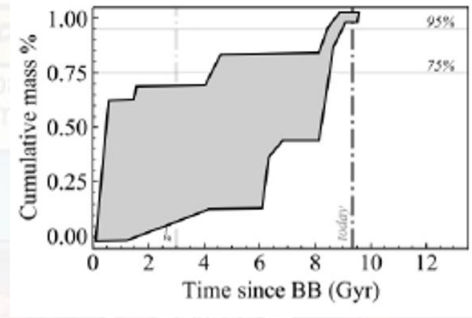


Extreme relic

7 have formed > 99% of their mass by $z=2$



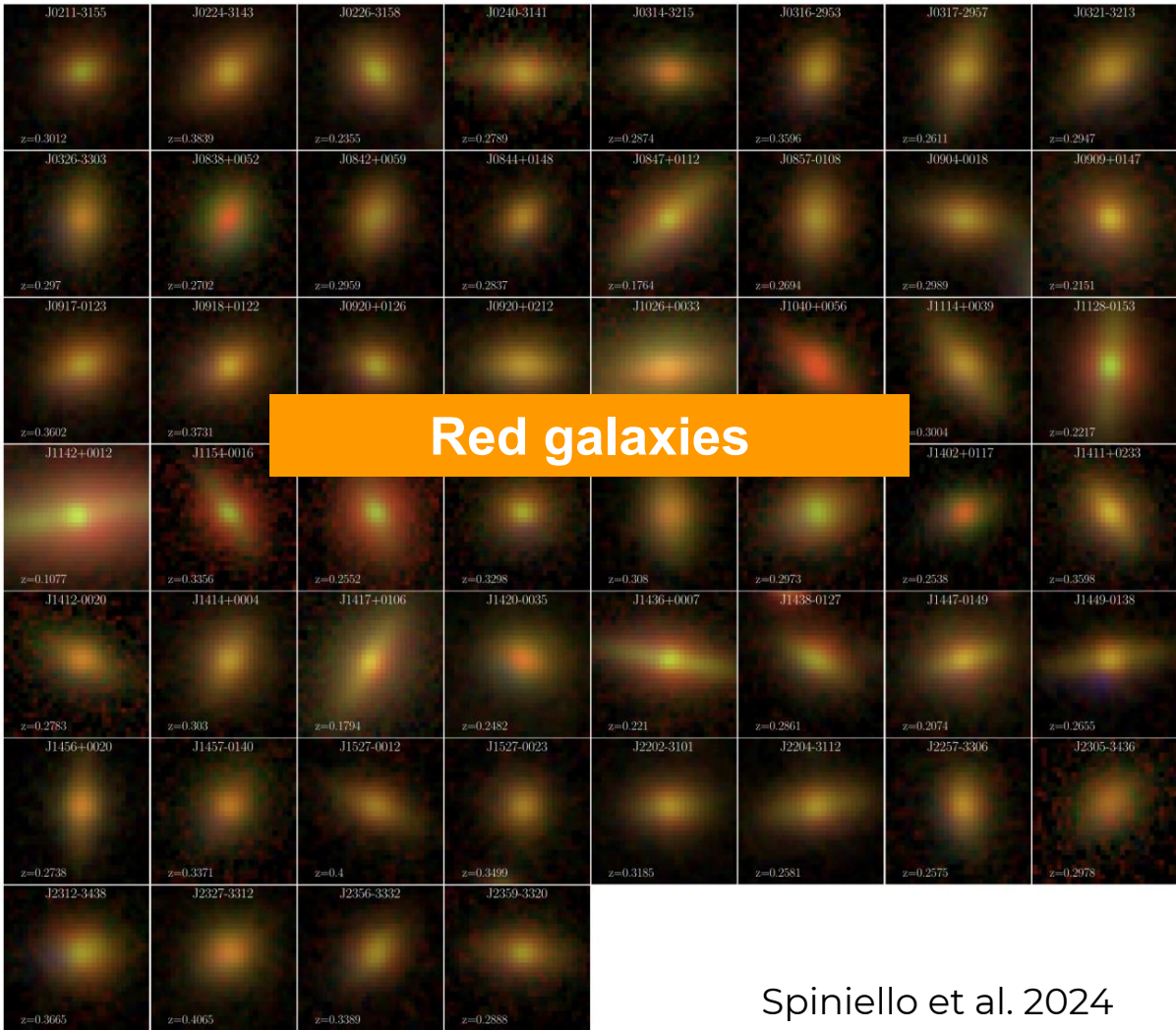
Relic



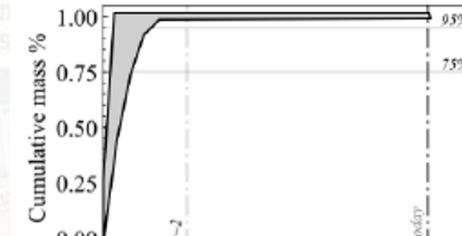
Non-Relic



HOMOGENEOUS IN COLOR, HETEROGENEOUS IN SFH

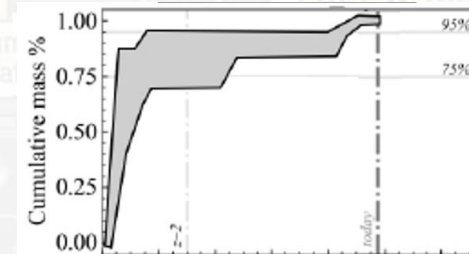


A range of SFHs



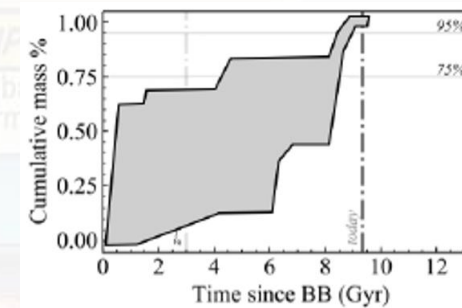
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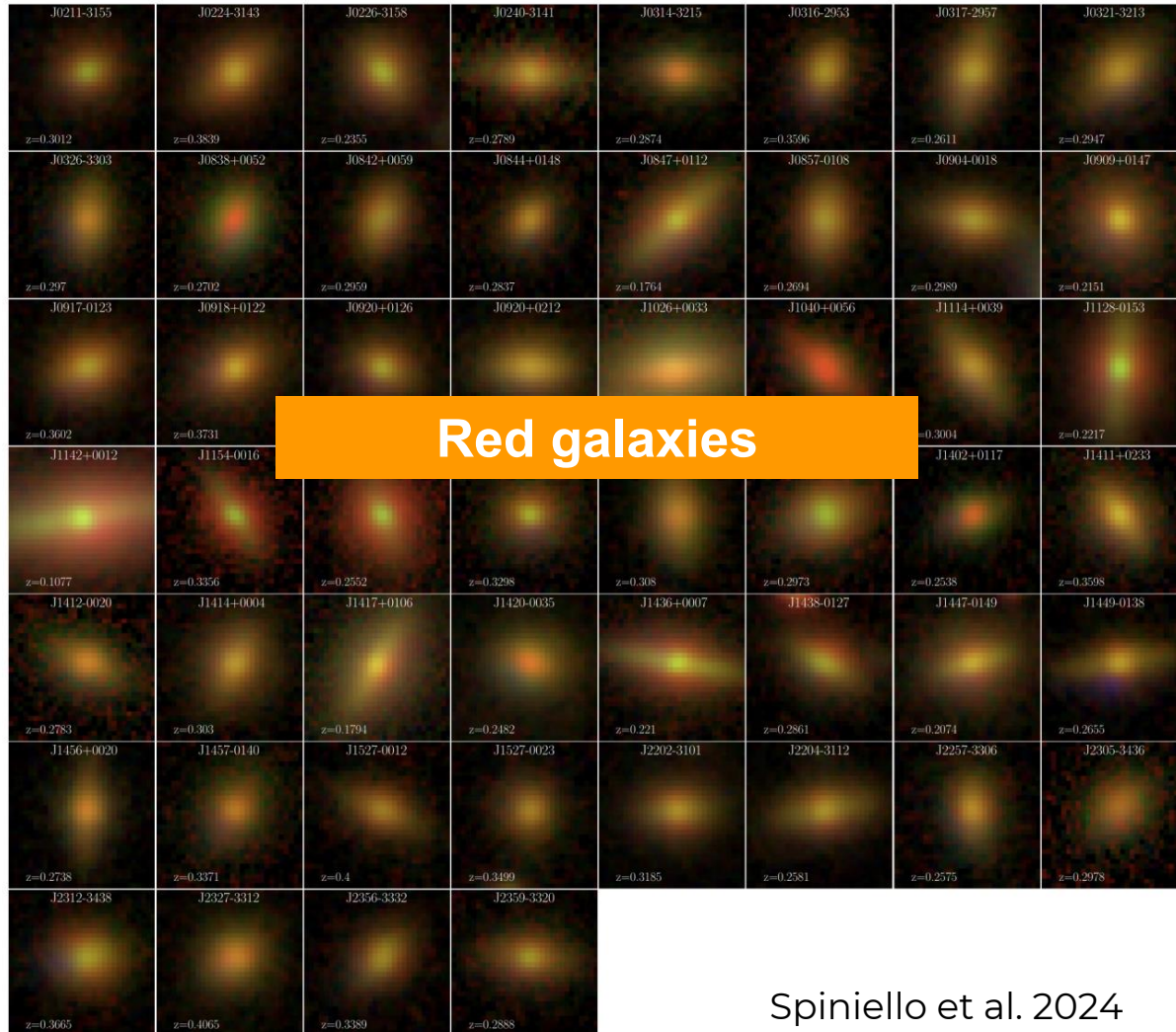
Relic

38/52 have formed > 75% of their mass by $z=2$

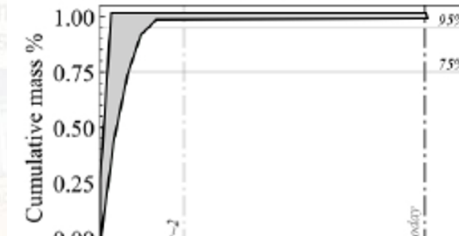


Non-Relic

HOMOGENEOUS IN COLOR, HETEROGENEOUS IN SFH

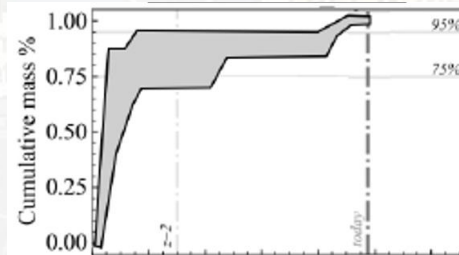


A range of SFHs



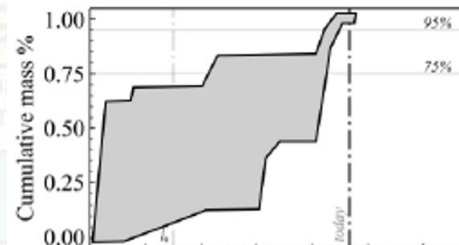
Extreme relic

7 have formed > 99% of their mass by $z=2$



Relic

38/52 have formed > 75% of their mass by $z=2$



Non-Relic

14/52 have more prolonged SFH, they are non-relic

CLASSIFICATION BASED ON "RELICNESS"

GALAXIES

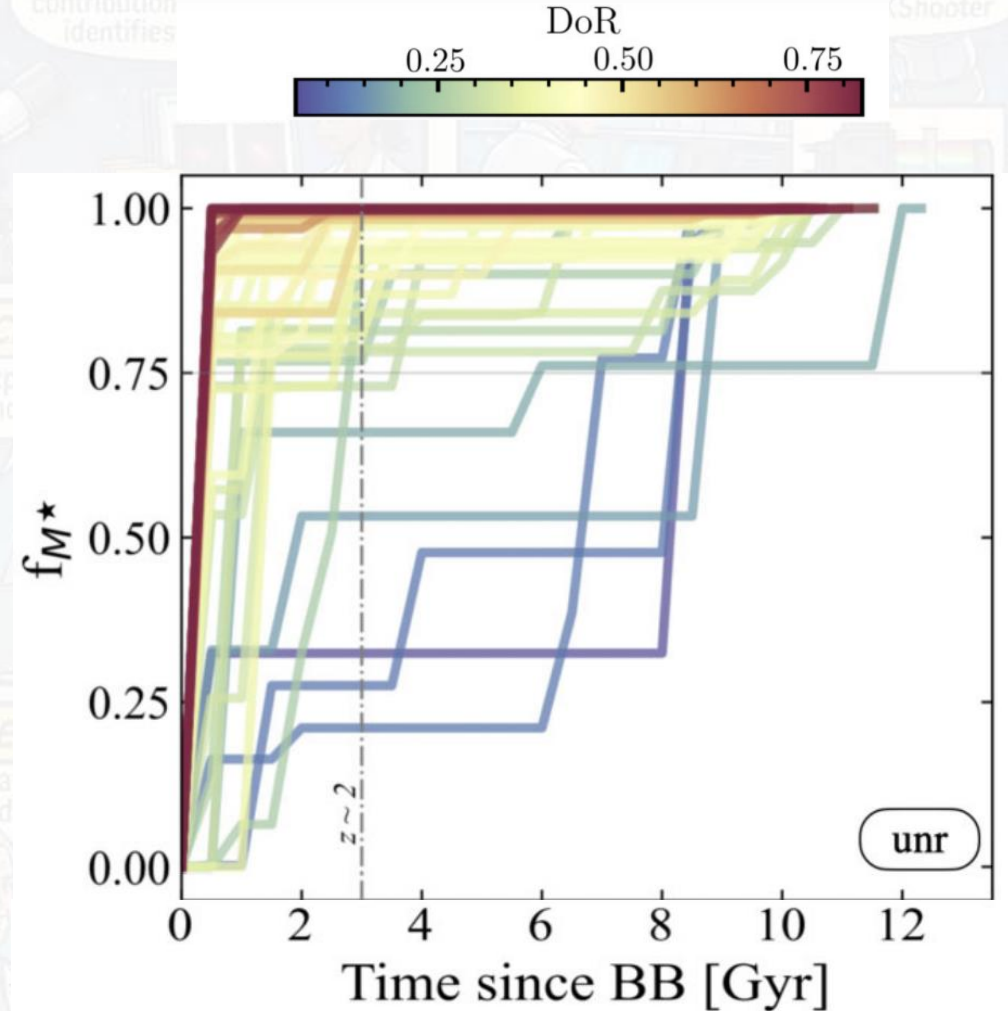
Degree of Relicness (DoR)

$$\text{DoR} = \left[f_{M_{t_{\text{BB}=3}}^*} + \frac{0.5\text{Gyr}}{t_{75}} + \frac{0.7\text{Gyr} + (t_{\text{Uni}} - t_{\text{fin}})}{t_{\text{Uni}}} \right] \times \frac{1}{3}$$

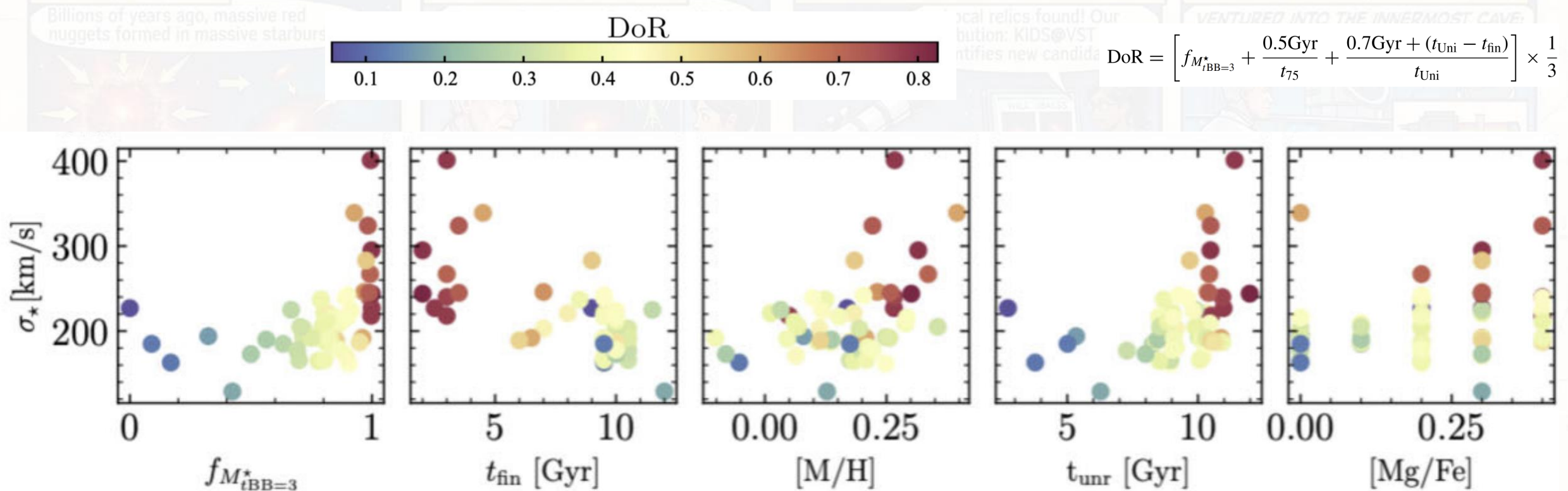
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A SUMMARY OF THE STELLAR POPULATION PROPERTIES



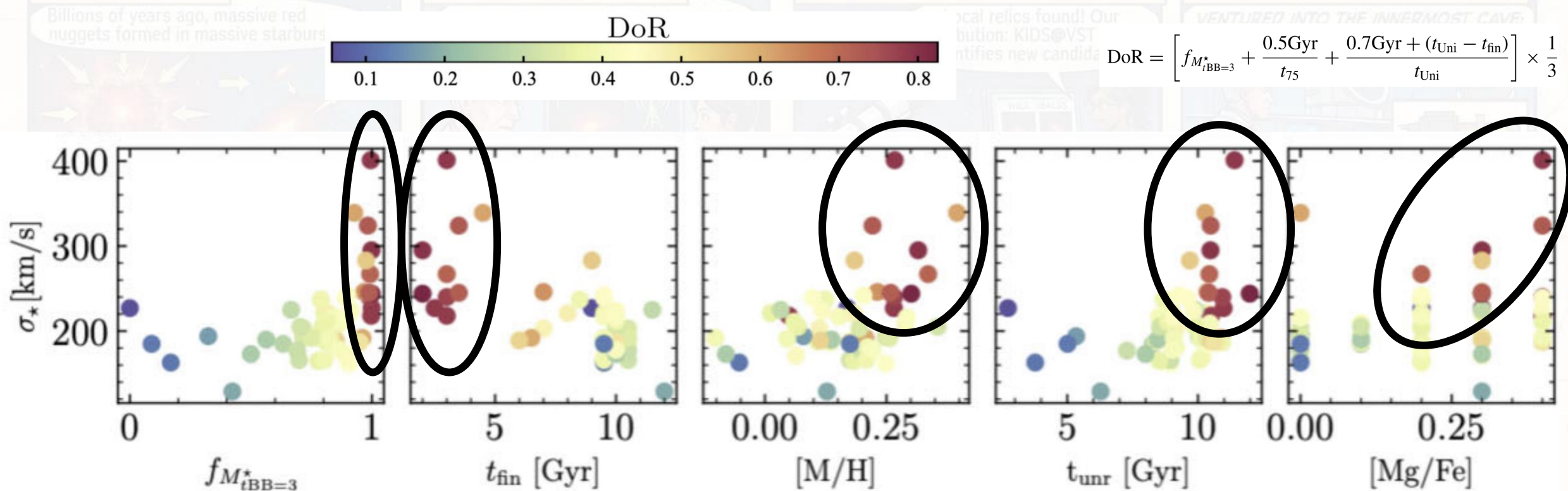
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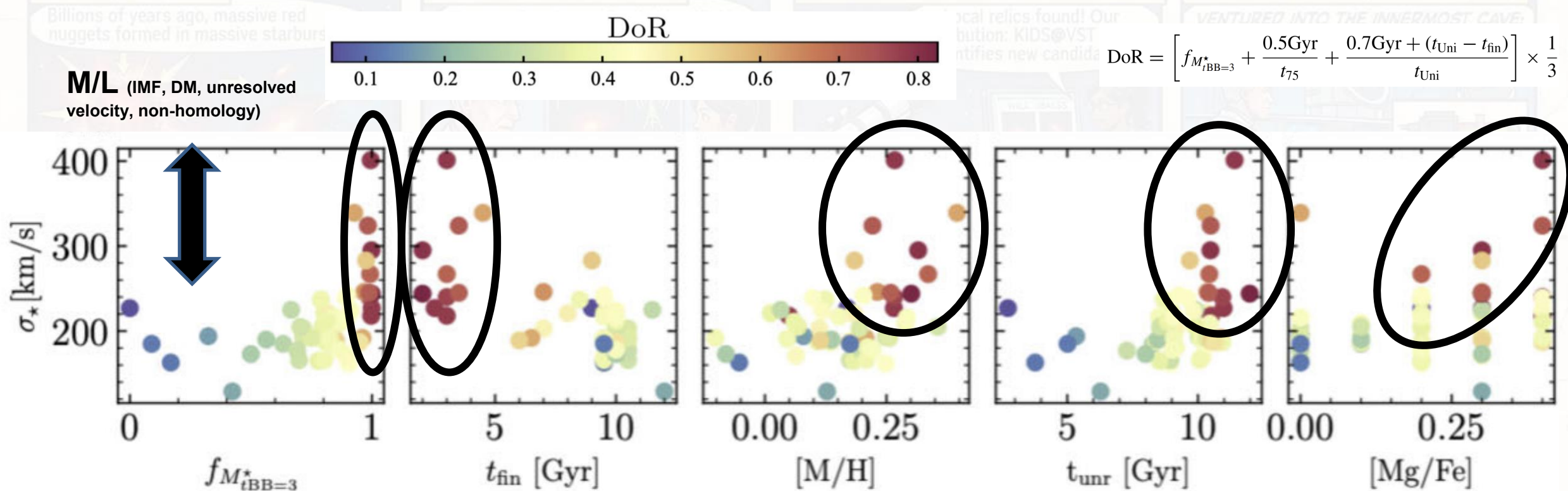


Extreme Relics

They form stars in a short time and are old (by definition)

They have larger velocity dispersions, are metal-rich, with high alpha enhancement

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INITIAL MASS FUNCTION



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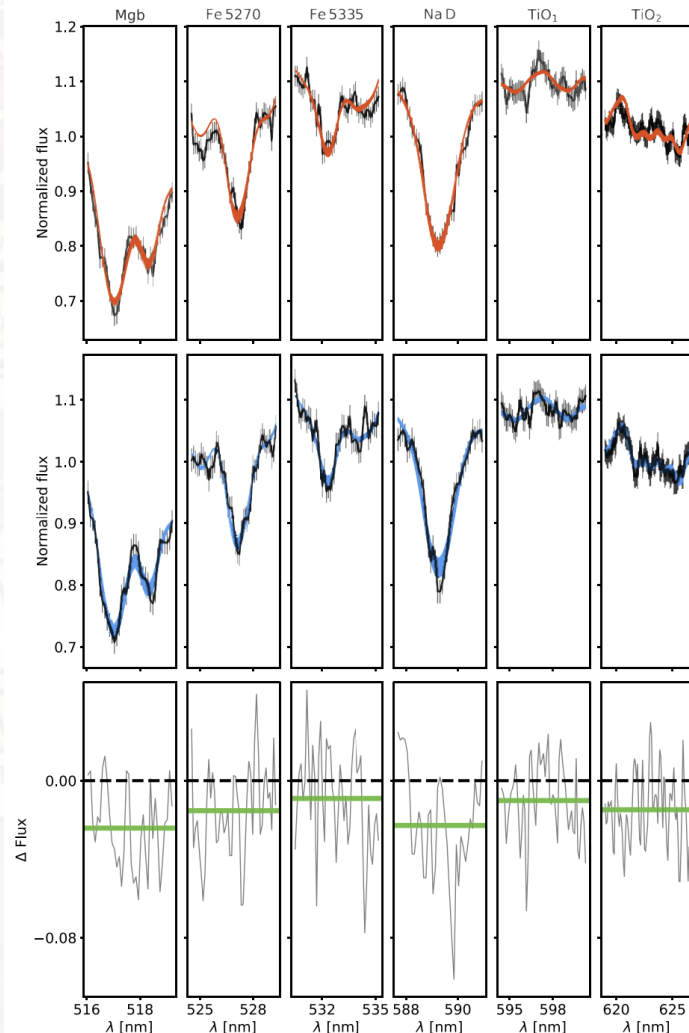
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WHAT ABOUT IMF?

On the stacked spectra of 5 relics and 5 non-relics

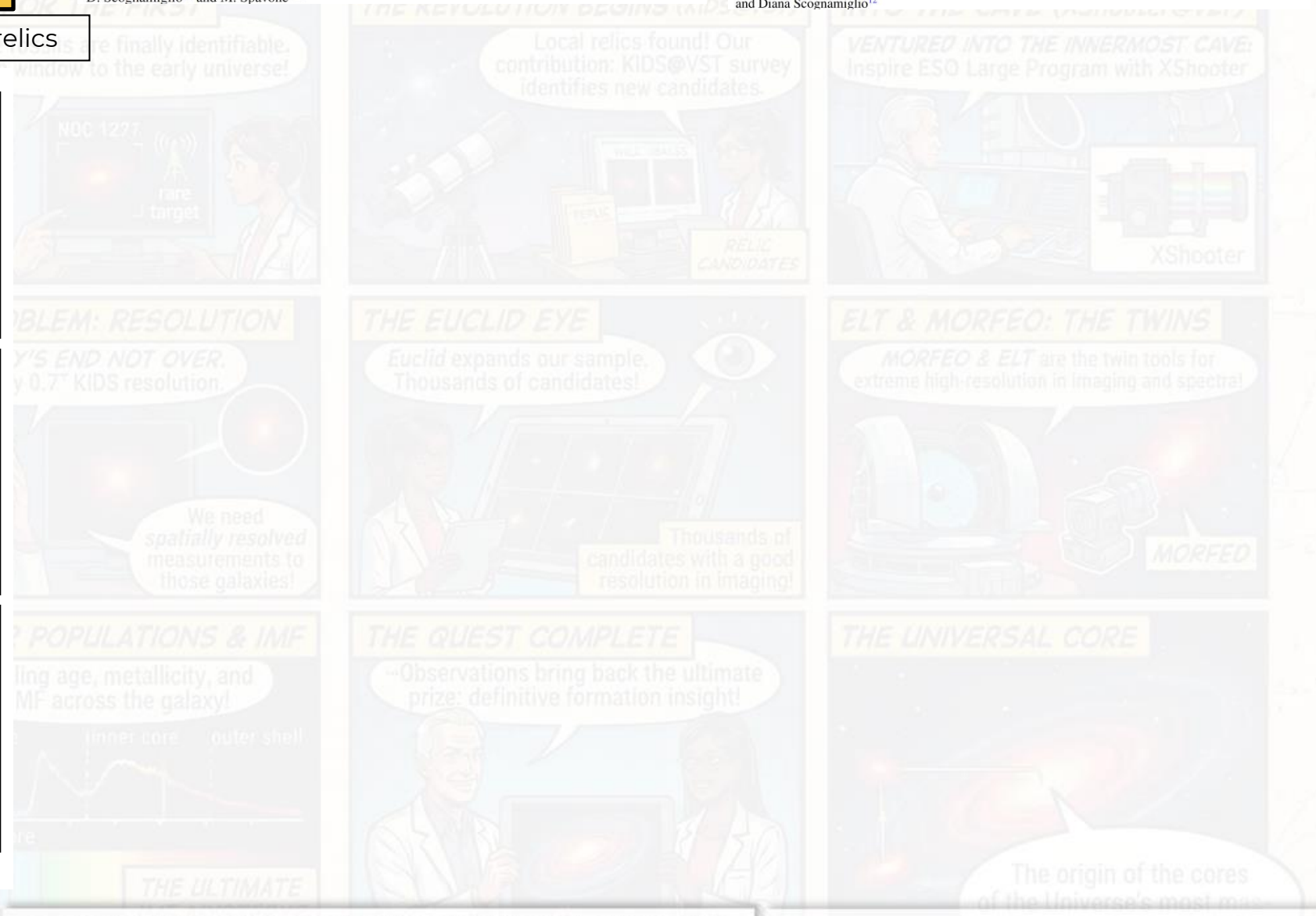


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A. Ferré-Mateu,^{1,2} C. Pulsoni,⁷ J. Hartke,^{8,3,5,8} M. Arnaboldi,⁵ L. Hunt,⁹ N. R. Napolitano,¹⁰
D. Scognamiglio¹¹ and M. Spavone⁴

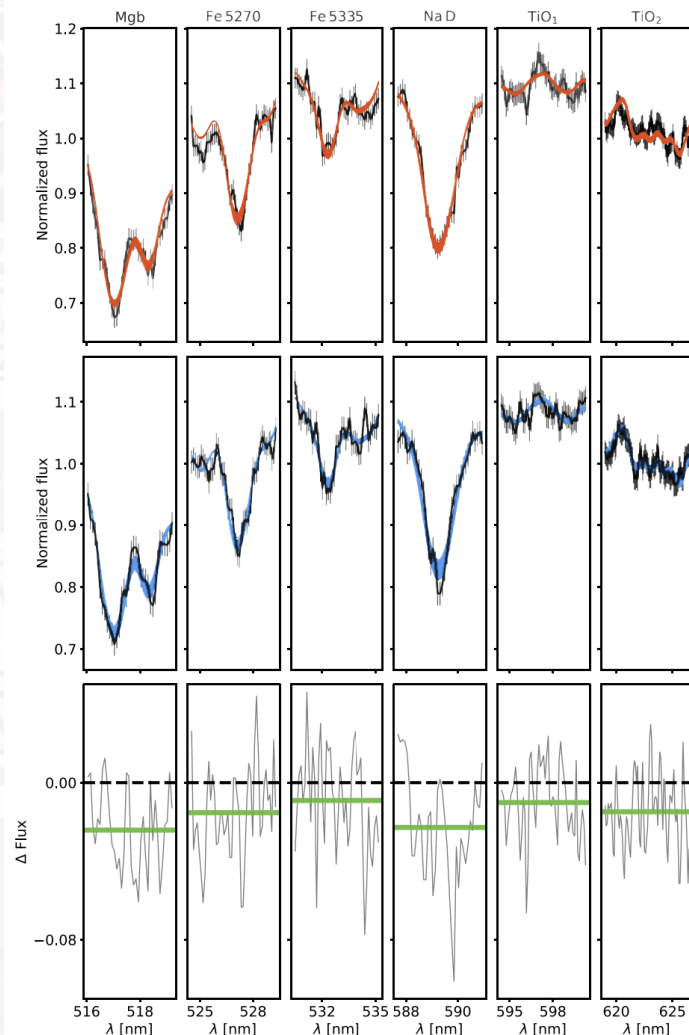
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and Diana Scognamiglio¹²



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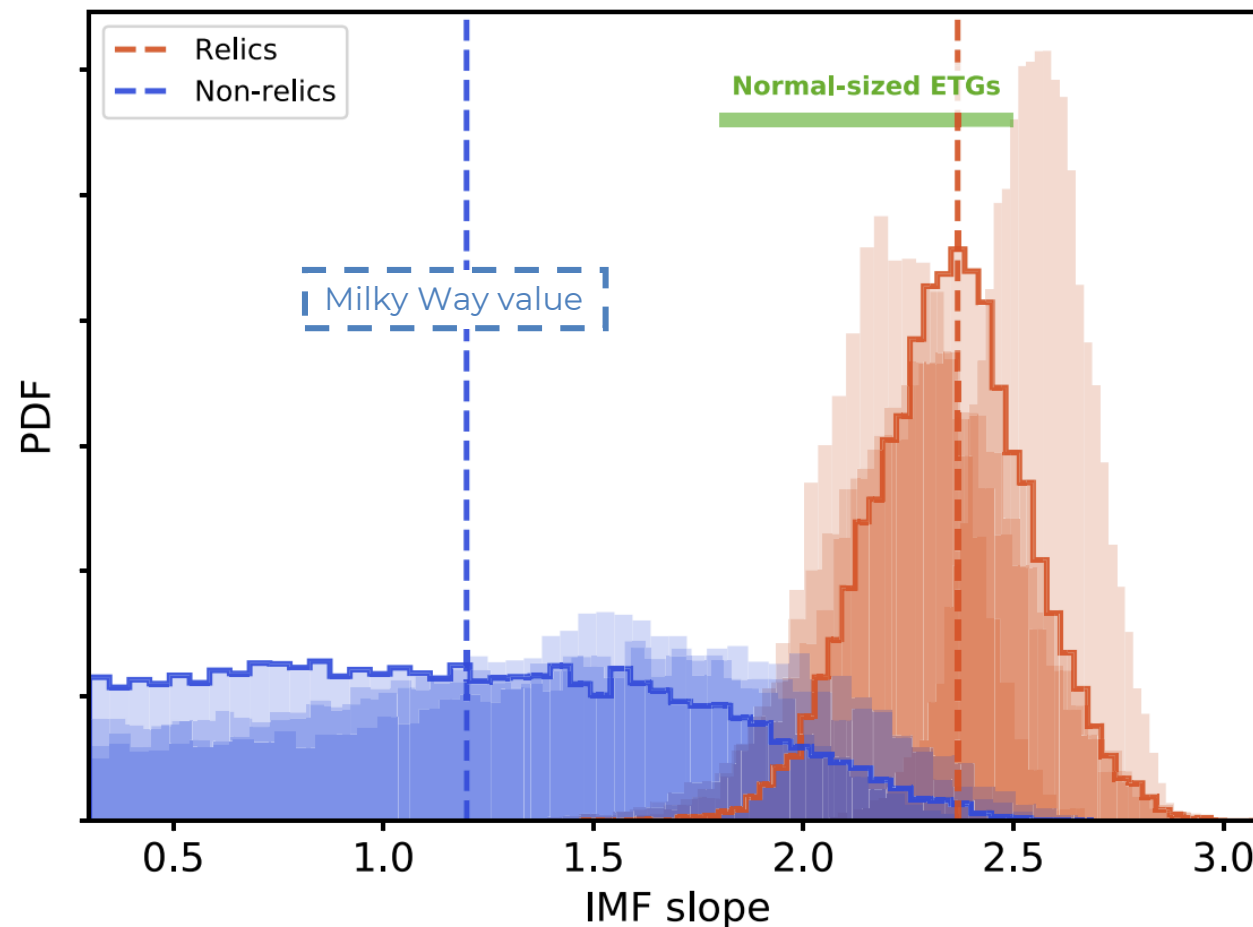
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MILES models are parametrized through the slope of the high-mass end



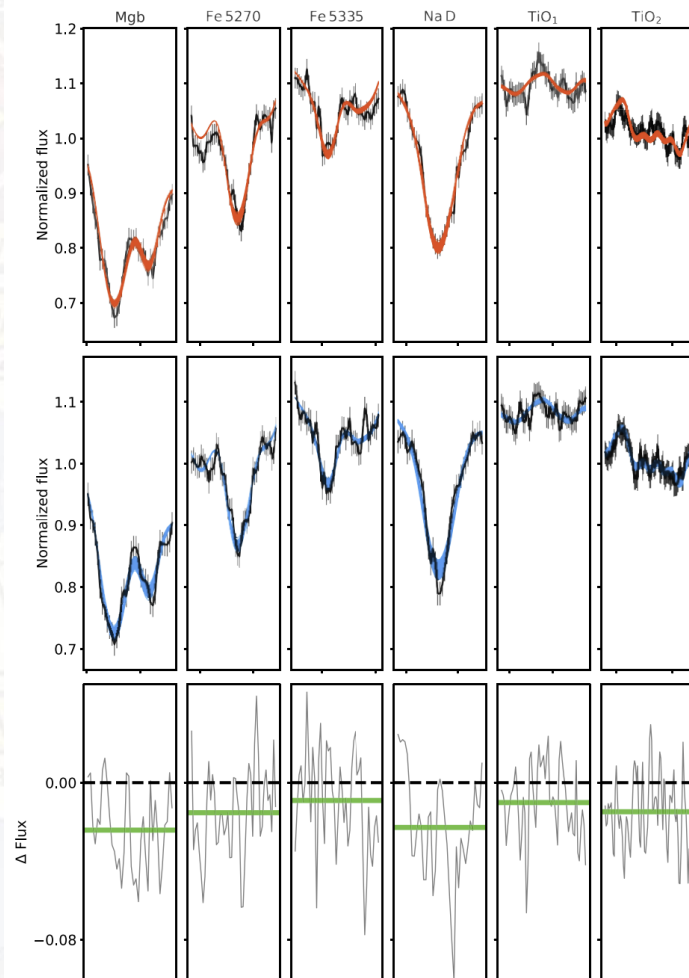
$$\alpha_{\text{non-relics}} = 1.10 \pm 0.10.$$

$$\alpha_{\text{relics}} = 1.59 \pm 0.18,$$



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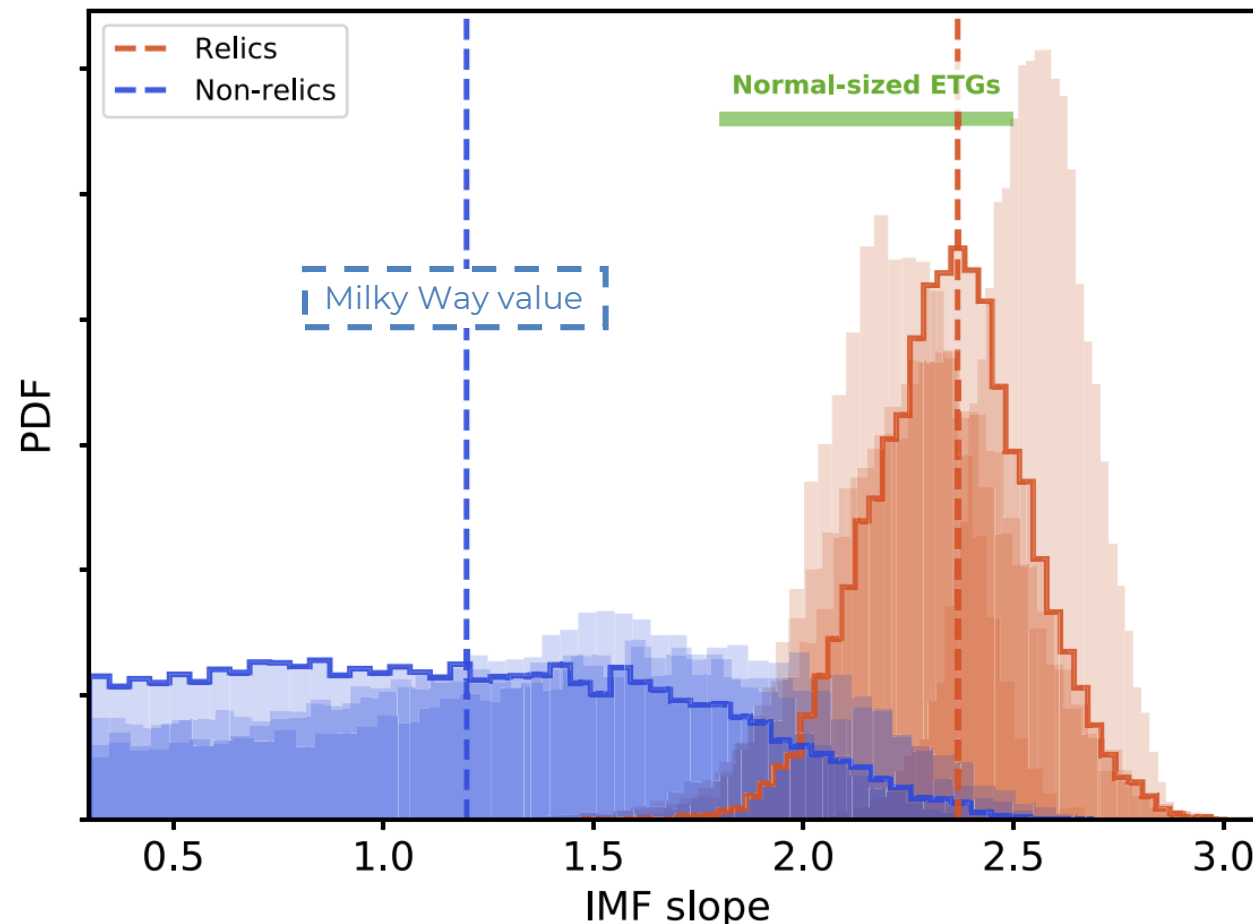
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A. Ferré-Mateu,^{1,2} C. Pulsoni,⁷ J. Hartke,^{8,9,10} M. Arnaboldi,⁵ L. Hunt,⁹ N. R. Napolitano,¹⁰
D. Scognamiglio¹¹ and M. Spavone⁴

INSPIRE: INvestigating Stellar Population In RELics – VI. The low-mass end slope of the stellar initial mass function and chemical composition

Michalina Maksymowicz-Maciata,^{1*} Chiara Spiniello,^{1,2*} Ignacio Martín-Navarro,^{3,4}
Anna Ferré-Mateu,^{3,4} Davide Bevacqua,^{5,6} Michele Cappellari,¹ Giuseppe D'Ago,^{7,2}
Crescenzo Tortora,² Magda Arnaboldi,⁸ Johanna Hartke,^{9,10} Nicola R. Napolitano,¹¹ Paolo Saracco⁵
and Diana Scognamiglio¹²

MILES models are parametrized through the slope of the high-mass end



Stellar M/L normalized to the Milky Way value

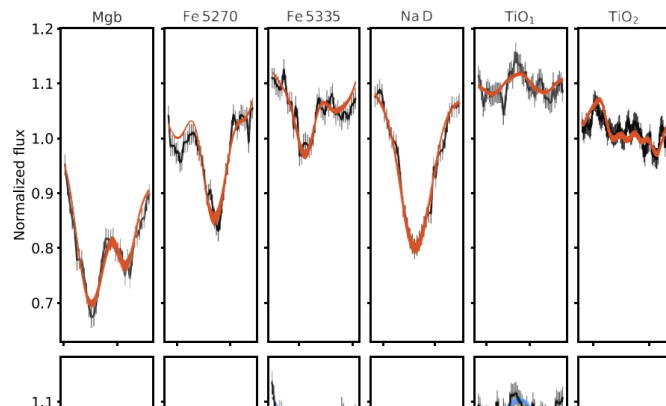
$$\alpha_{\text{non-relics}} = 1.10 \pm 0.10.$$

$$\alpha_{\text{relics}} = 1.59 \pm 0.18,$$

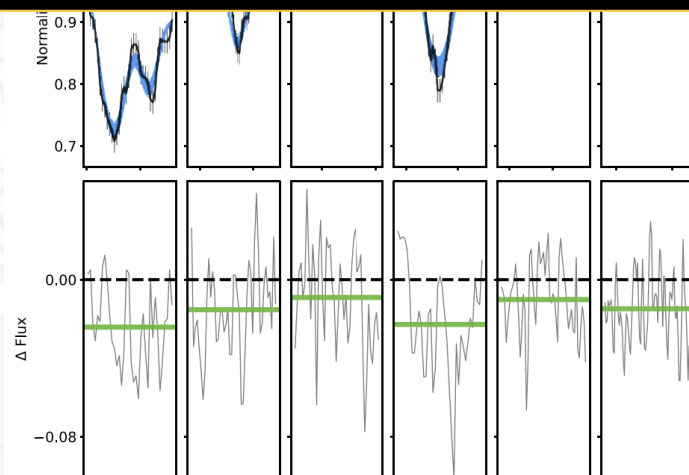


WHAT ABOUT IMF?

On the stacked spectra of 5 relics and 5 non-relics



Dwarf-rich in the cores of normal-size galaxies and in local relics



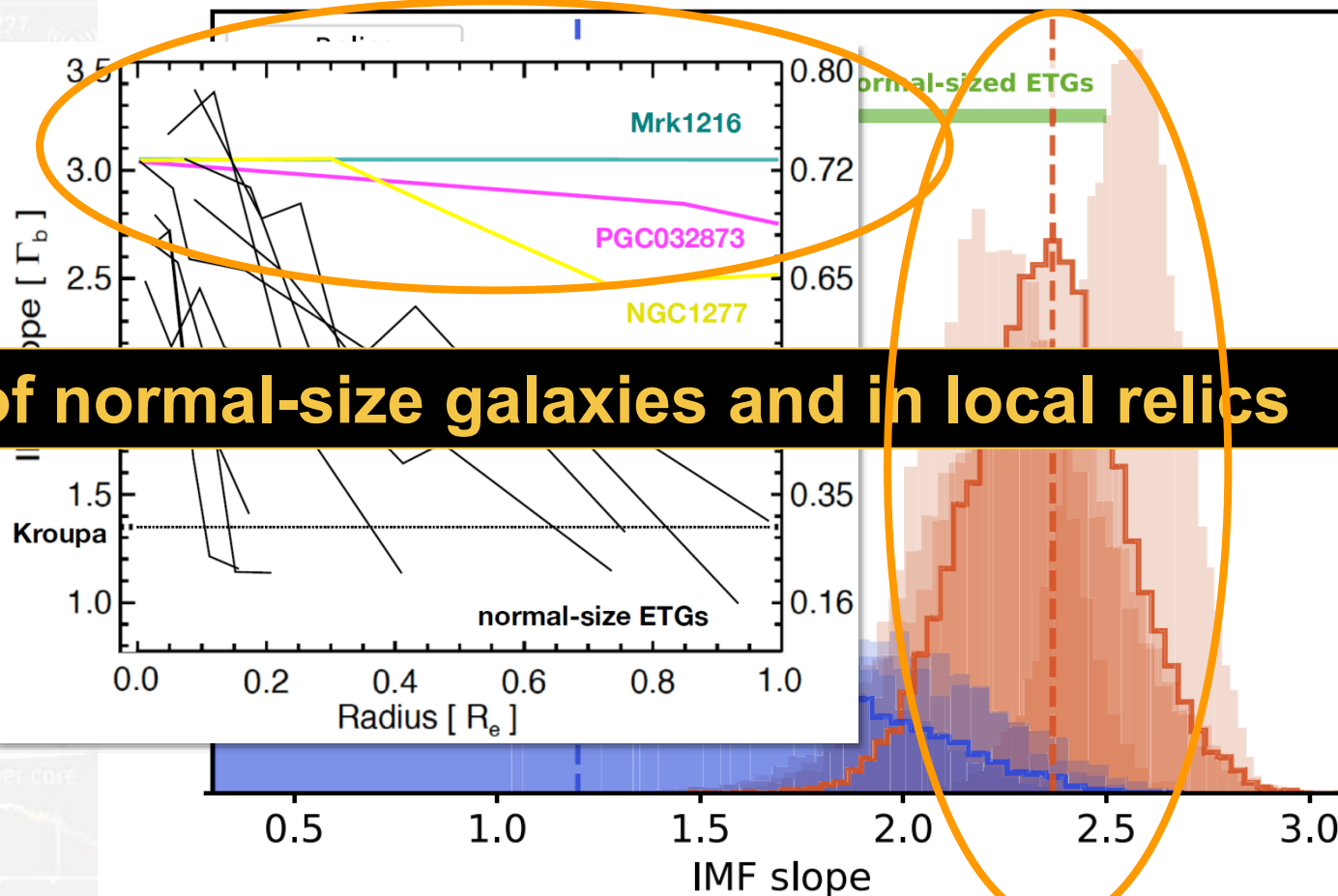
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THE HERO'S JOURNEY OF RELIC GALAXIES

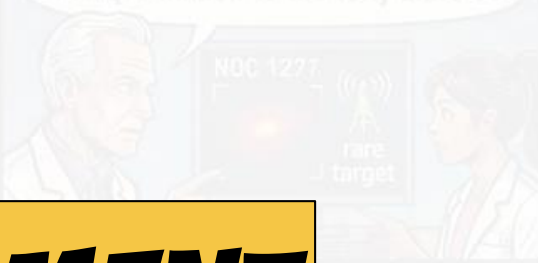
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IT OVER. resolution.



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WHERE DO UCMGS LIVE?

With INSPIRE

INSPIRE: Investigating Stellar Population In RElics – VII. The local environment of ultra-compact massive galaxies

Diana Scognamiglio^{1,*}, Chiara Spiniello^{2,3}, Mario Radovich⁴, Crescenzo Tortora^{5,3}, Nicola R. Napolitano⁵, Rui Li⁶, Matteo Maturi⁷, Michalina Maksymowicz-Maciata², Michele Cappellari^{8,2}, Magda Arnaboldi⁸, Davide Bevacqua^{9,10}, Lodovico Coccato⁸, Giuseppe D'Ago^{3,11}, Hai-Cheng Feng¹², Anna Ferré-Mateu^{13,14}, Johanna Hartke^{15,16}, Ignacio Martín-Navarro^{13,14} and Claudia Pulsoni¹⁷

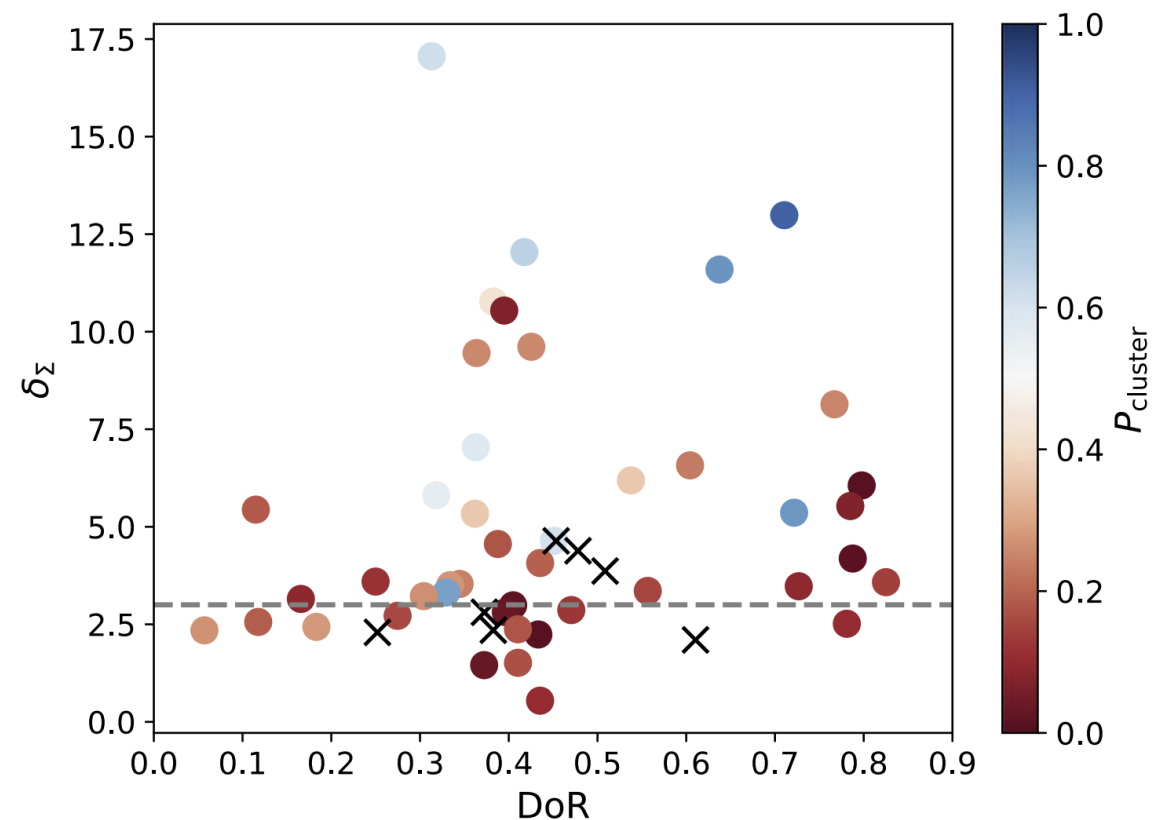
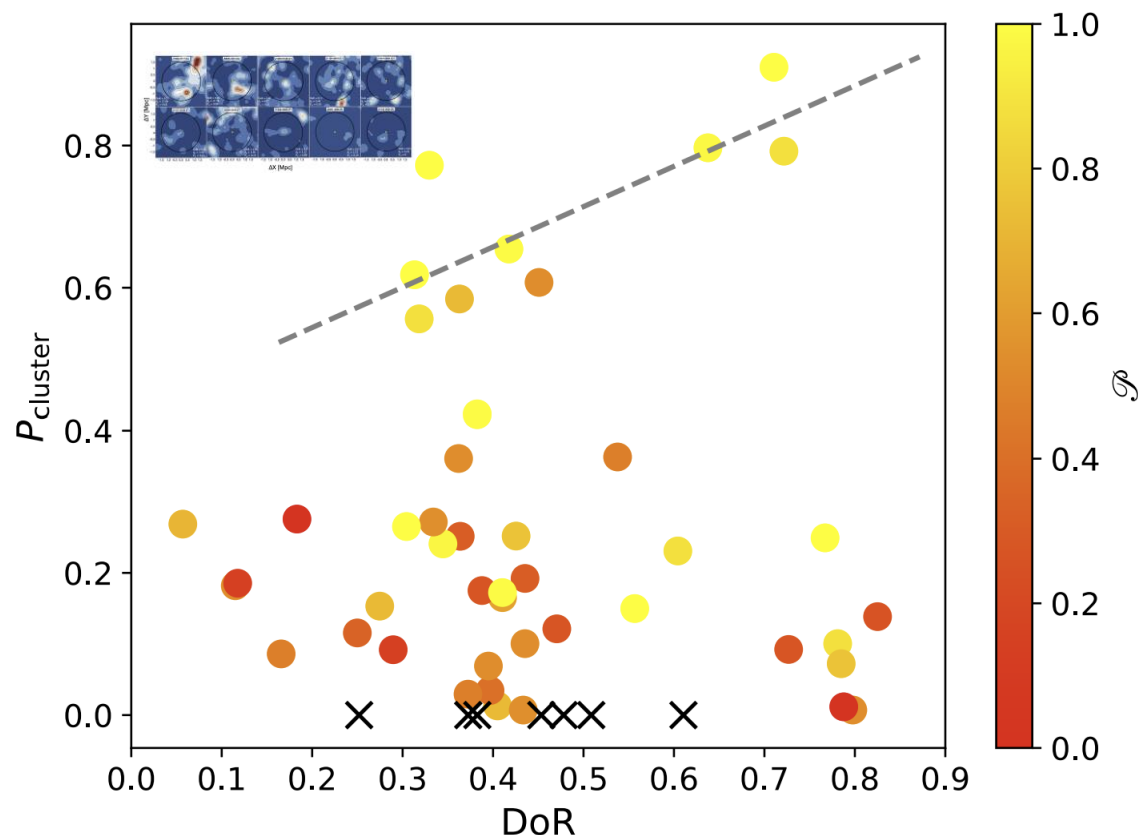
LETTER TO THE EDITOR

Nature versus nurture: relic nature and environment of the most massive passive galaxies at $z < 0.5$

C. Tortora¹, N. R. Napolitano^{2,3}, M. Radovich⁴, C. Spiniello^{2,3}, L. Hunt¹, N. Roy², L. Moscardini^{6,7,8}, D. Scognamiglio⁹, M. Spavone⁵, M. Brescia², S. Cavuoti^{3,10}, G. D'Ago¹¹, G. Longo¹⁰, F. Bellagamba^{4,7}, M. Maturi^{12,13}, and M. Roscarelli^{16,7}

Environmental characterization through

- a) AMICO cluster detection (Bellagamba et al. 2018) and
- b) overdensities through photo-z distribution



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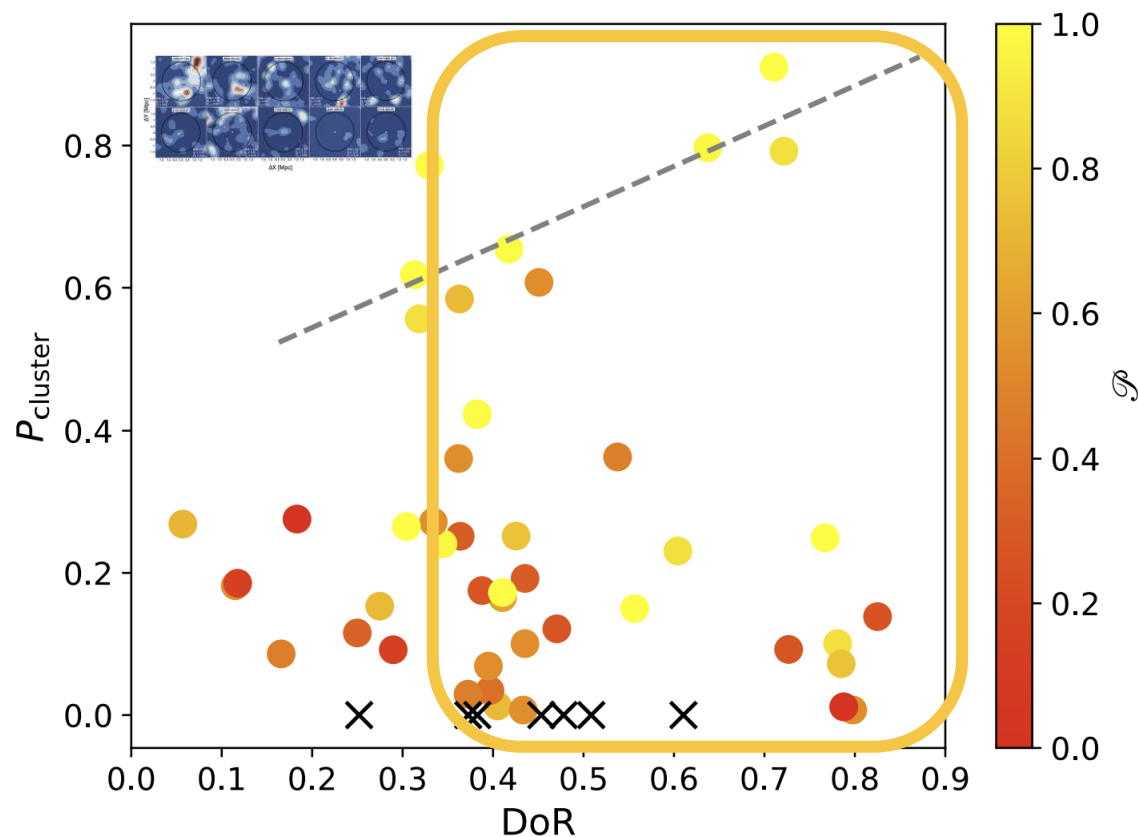
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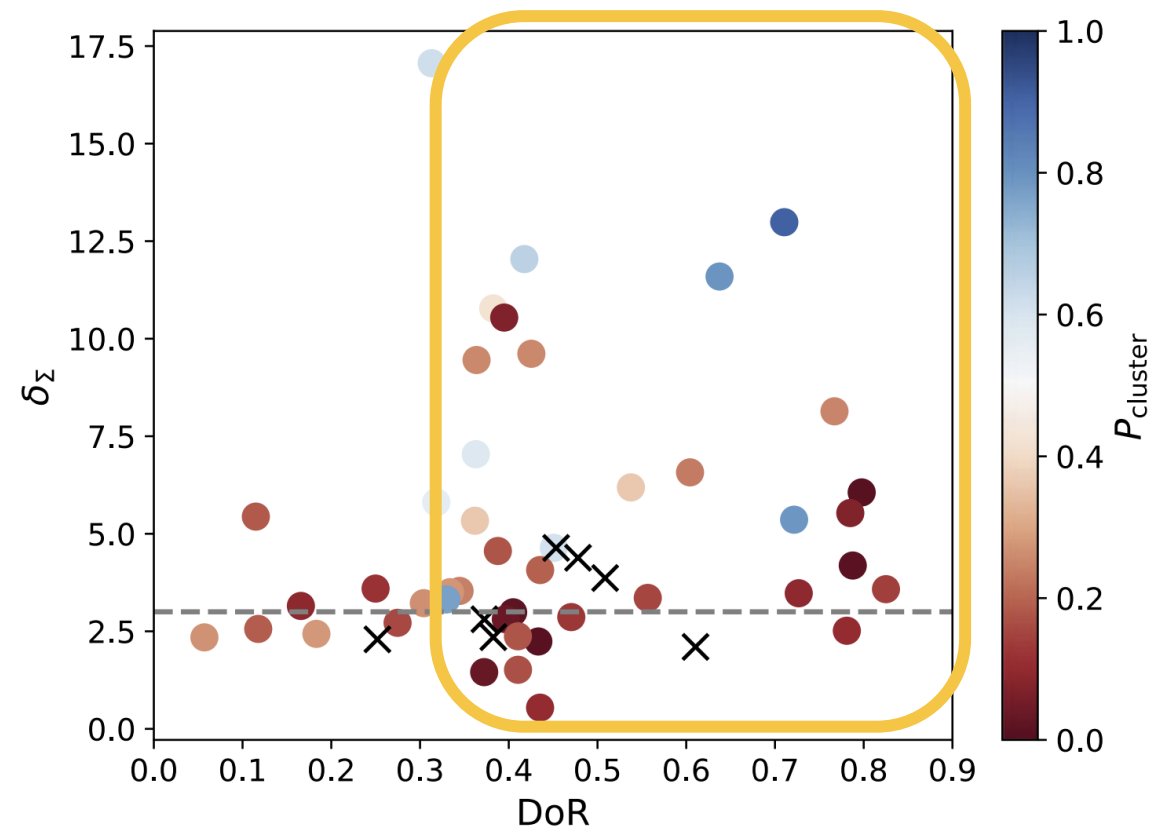
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UCMGs live everywhere!



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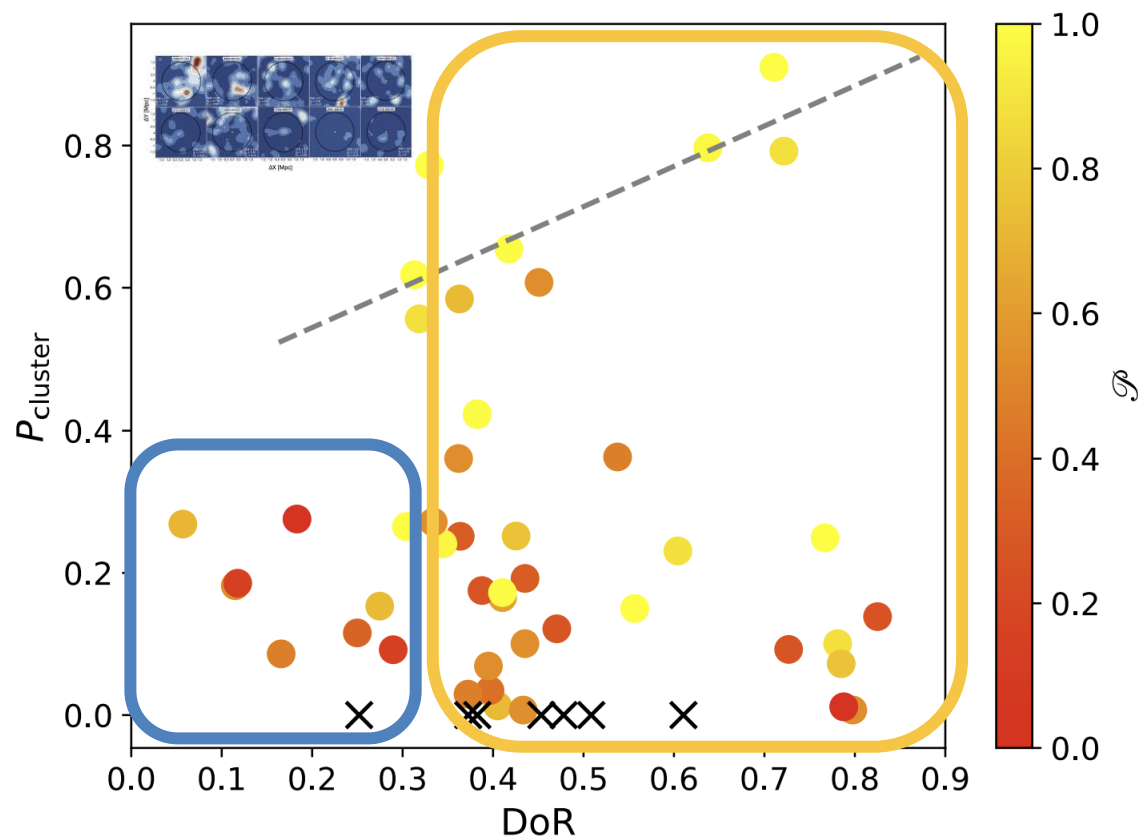
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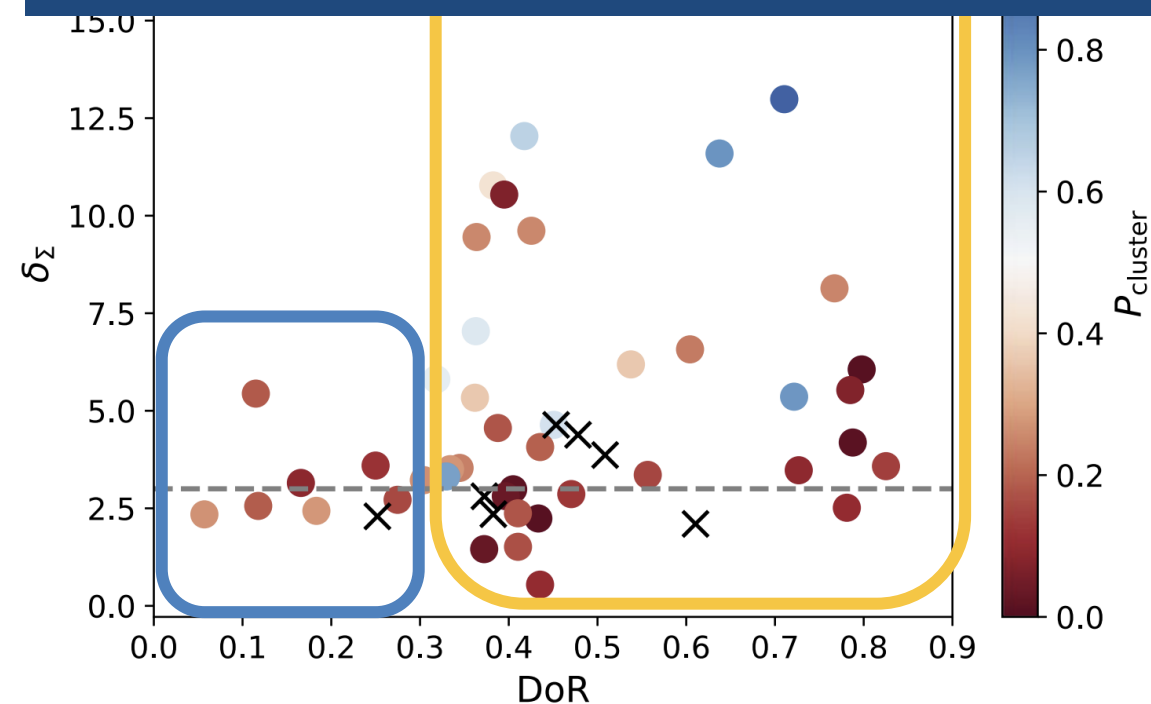
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UCMGs live everywhere!

UCMGs with low DoR prefer underdense environments



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WHAT IS MISSING?

Euclid: a golden mine

~30k candidates at $z < 0.5$ ("wide survey", 14k sq. deg.)

~70 at $z < 0.1$ >> 3 local relics

FWHM ~0.15" << KiDS survey FWHM



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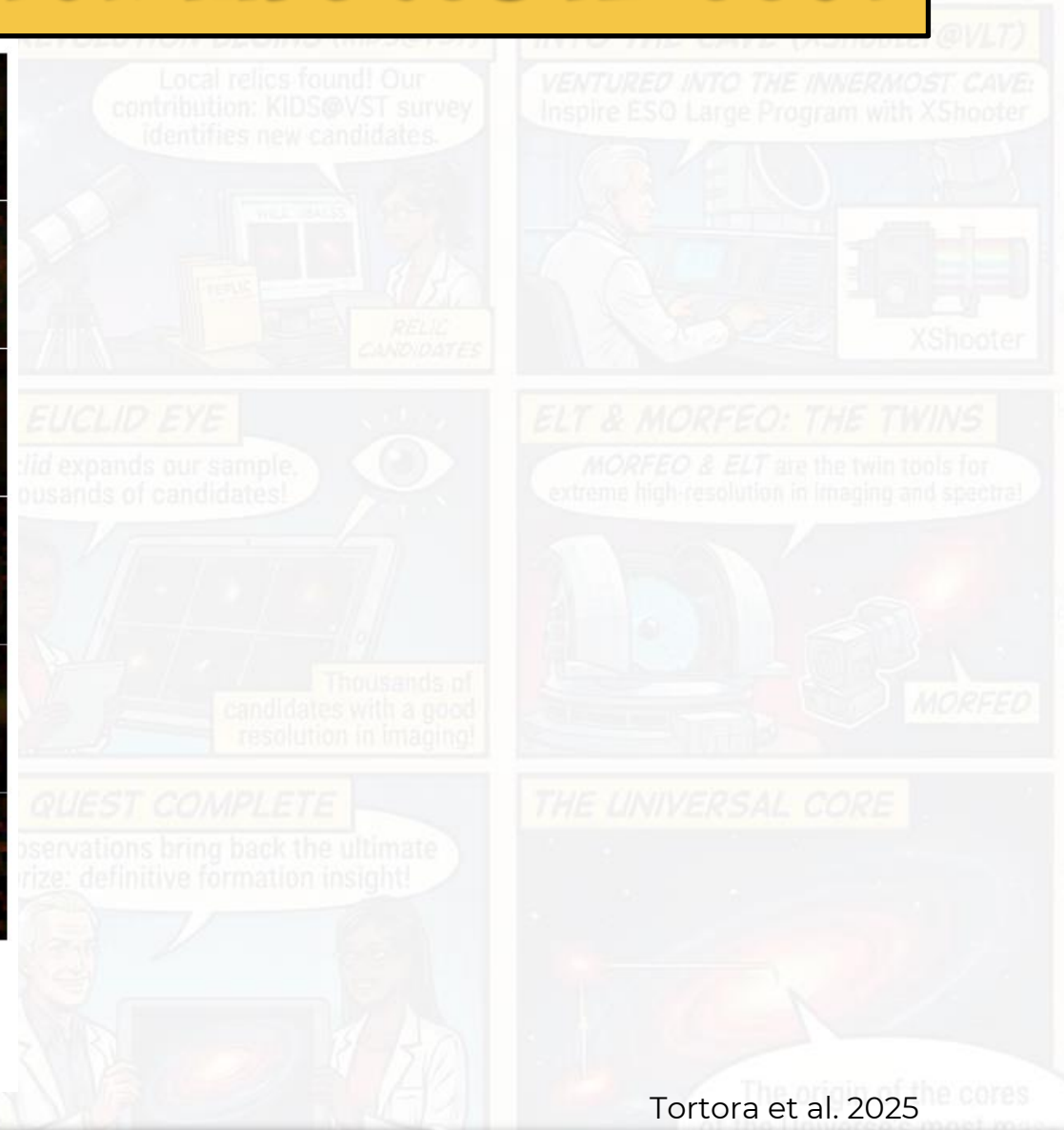
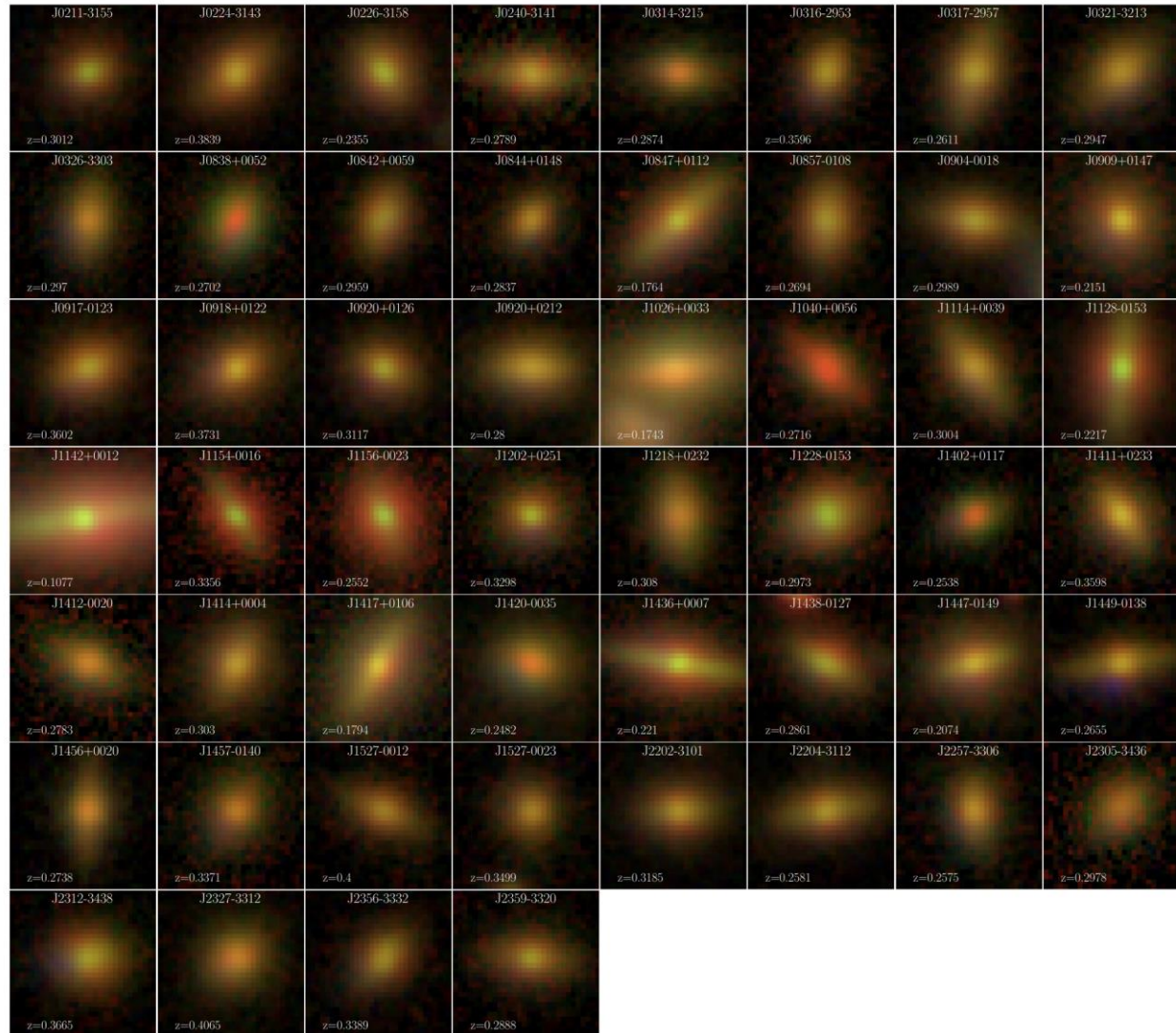
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FWHM $\sim 0.15''$ $\ll$ KiDS survey FWHM



AO-ASSISTED INSTRUMENTS
(SOUL@LBT, MAVIS@VLT MORFEO@ELT, ...)

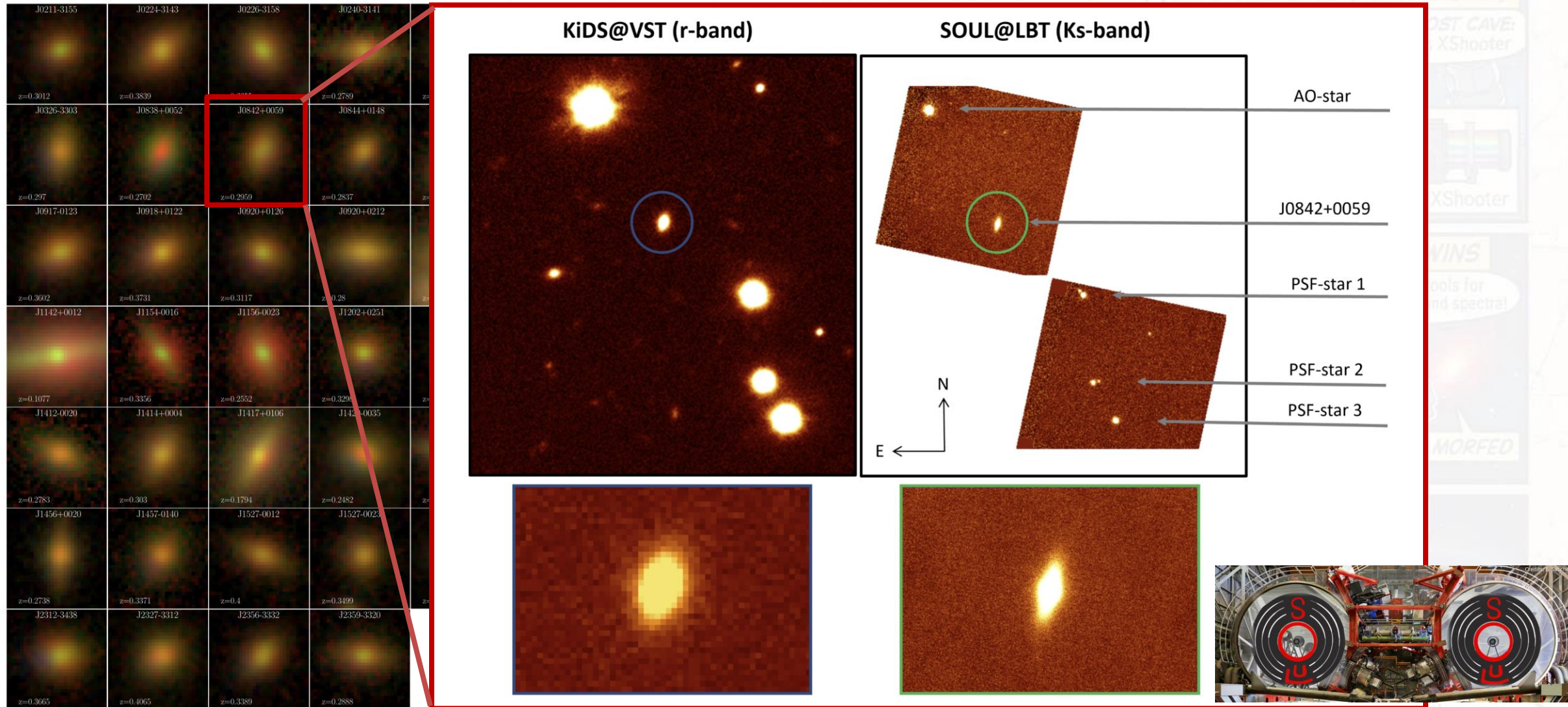
LBT HIGH-RESOLUTION IMAGING FOR KIDS J0842+0059



Tortora et al. 2025



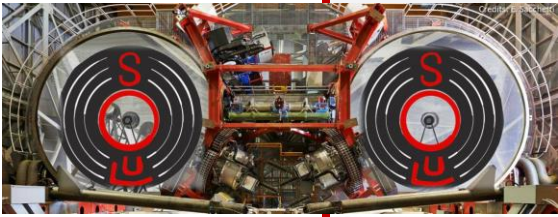
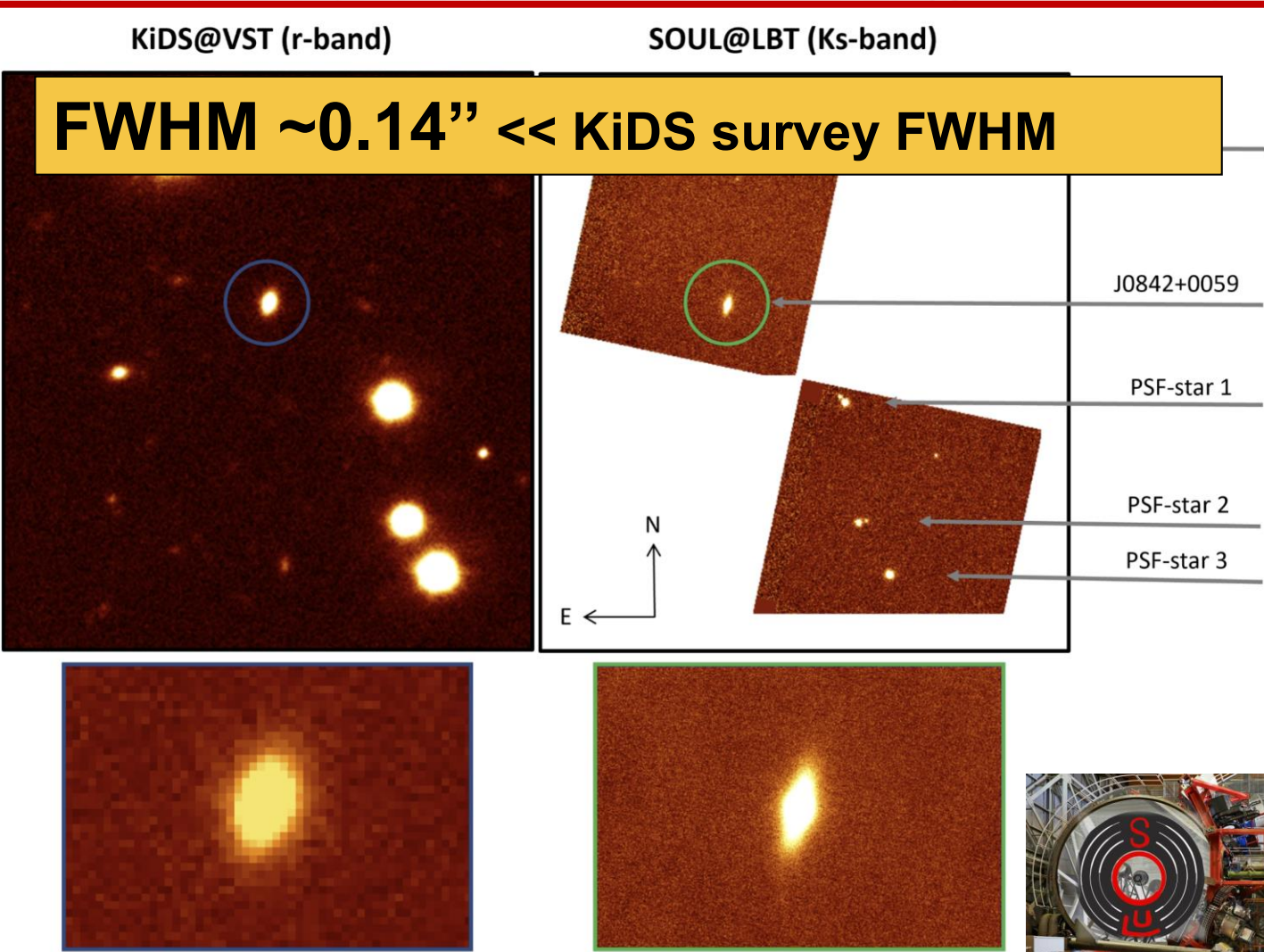
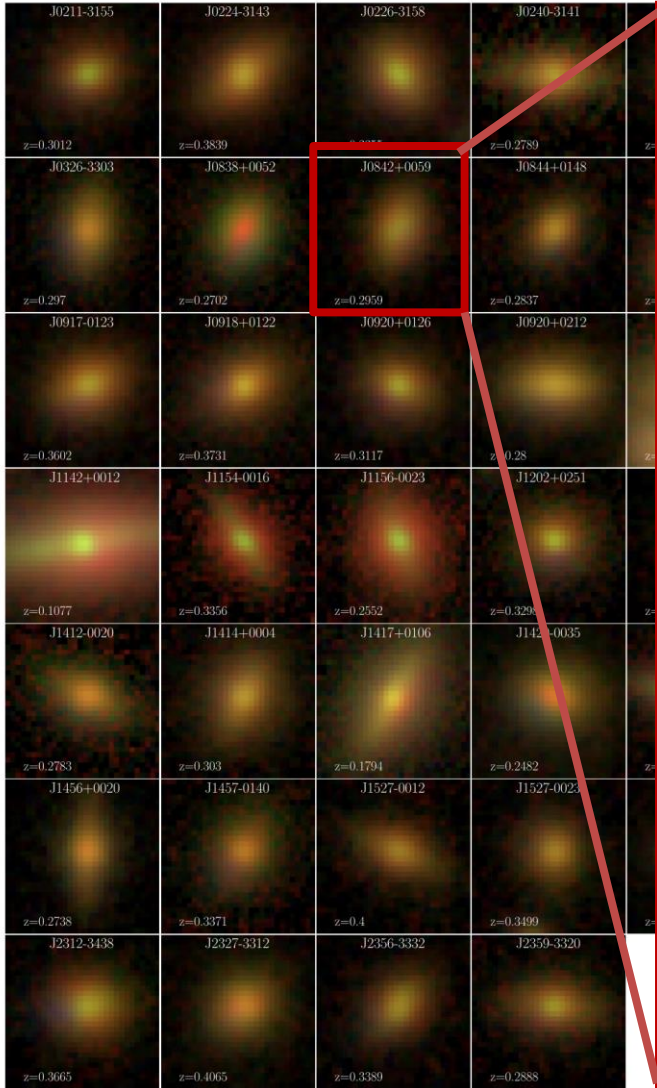
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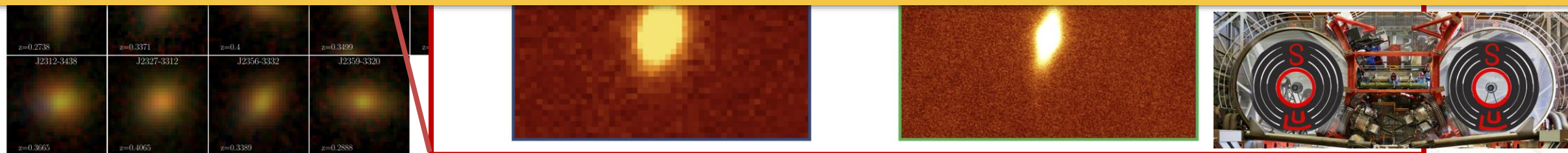
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LBT HIGH-RESOLUTION IMAGING FOR KIDS J0842+0059



Compactness confirmed - $R_e = 0.21''$ (~ 1 kpc)
Disky isophotes (resembling local relics and red-nuggets)

**The first fully confirmed relic
beyond the local universe**



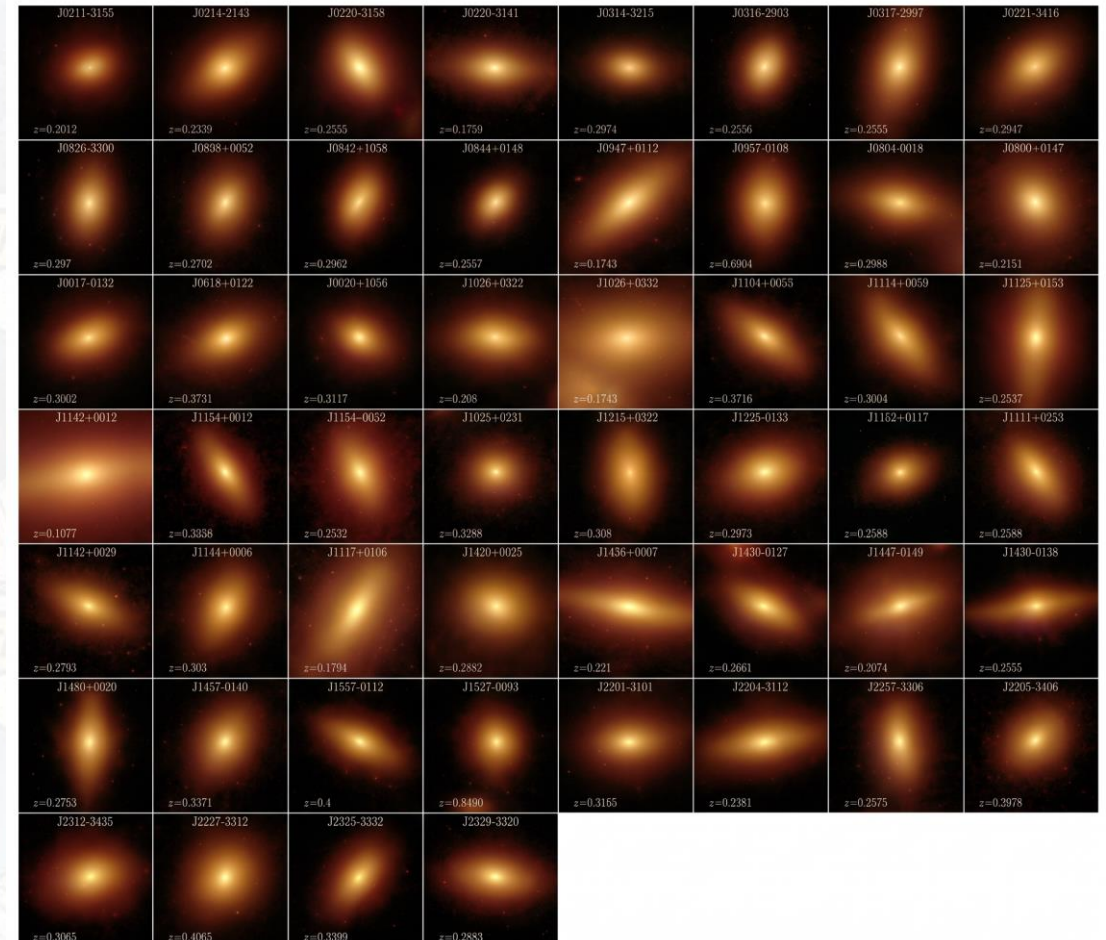
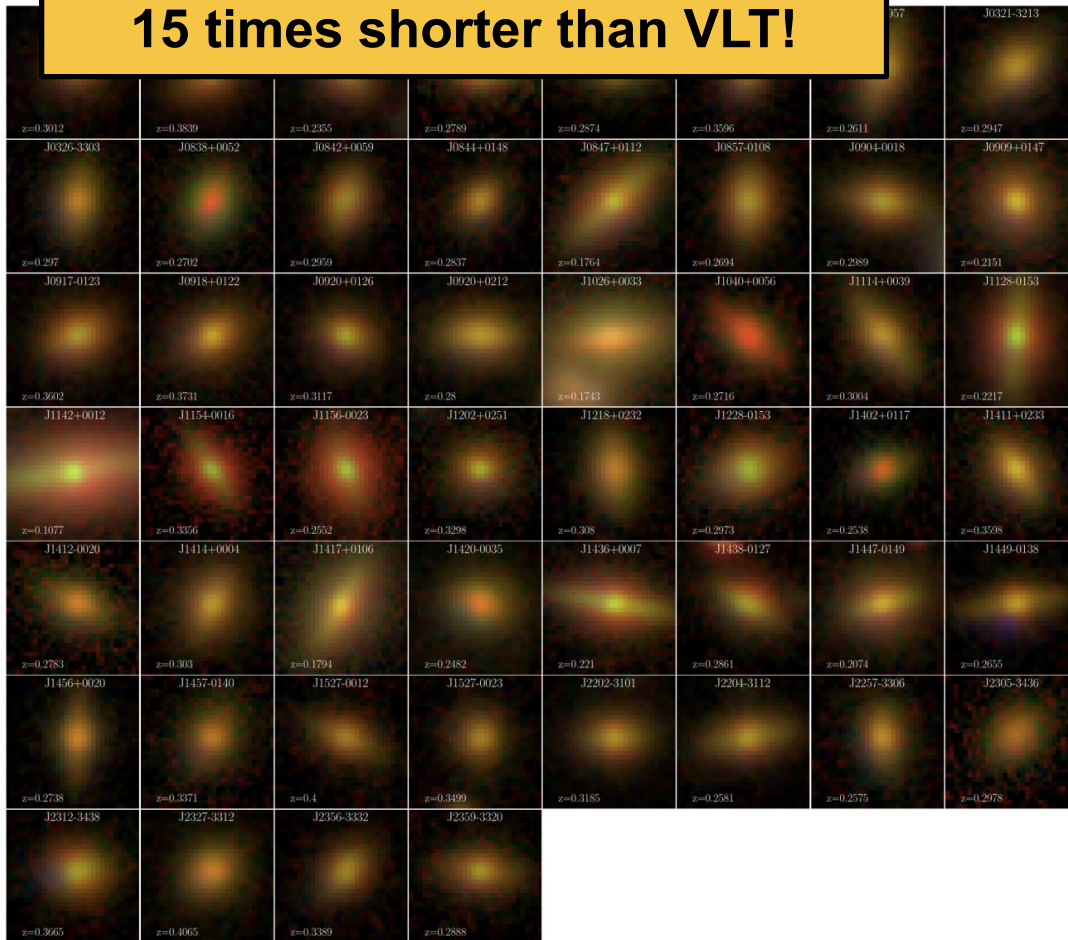
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HIGH-RESOLUTION IMAGING WITH MORFEO@ELT

1h of integration time → all the MICADO bands with high S/N

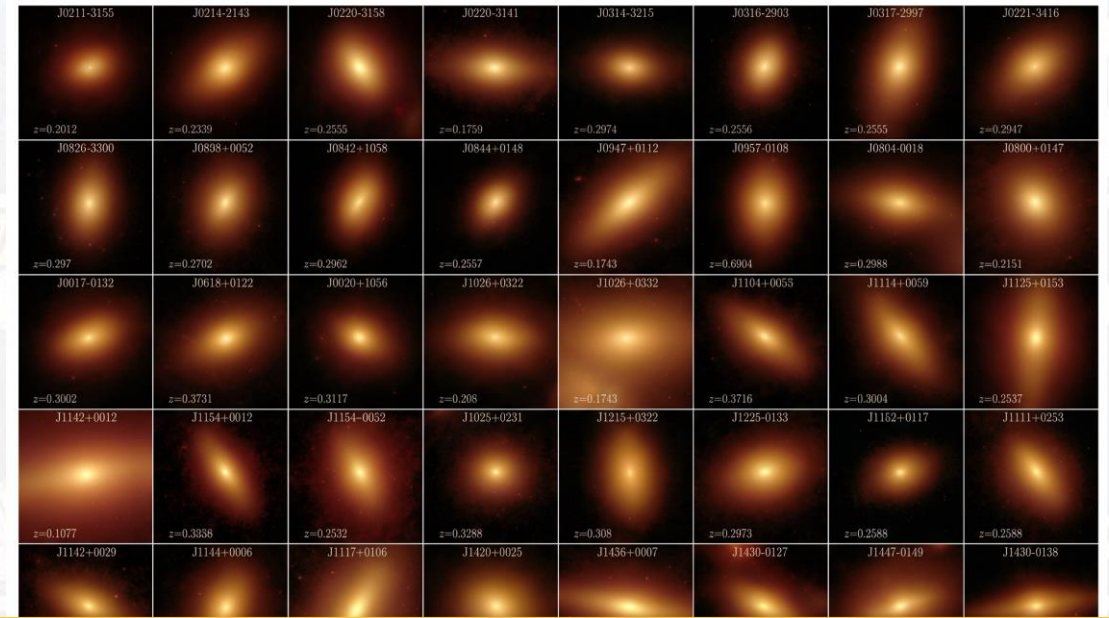
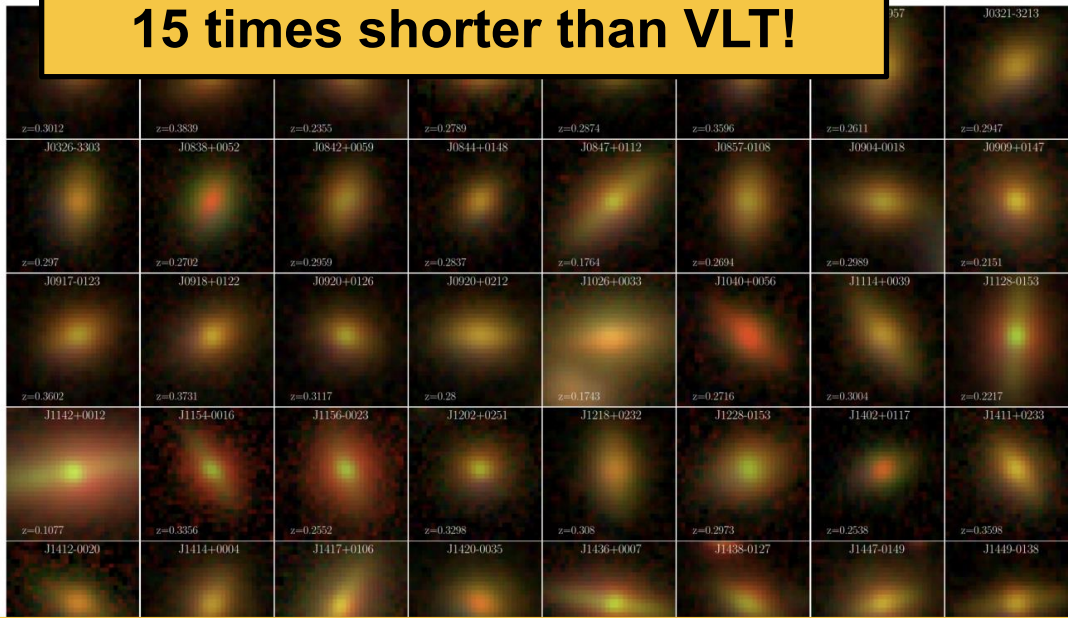
15 times shorter than VLT!



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1h of integration time → all the MICADO bands with high S/N

15 times shorter than VLT!



We will resolve the internal structure of the INSPIRE galaxies, constrain very precisely the size, the shape, and possibly unveil multiple components

z=0.3065 z=0.4065 z=0.3389 z=0.2888

z=0.3065 z=0.4065 z=0.3399 z=0.2883



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MARE: MAVis for RELics

ELT & MORFEO: THE TWINS

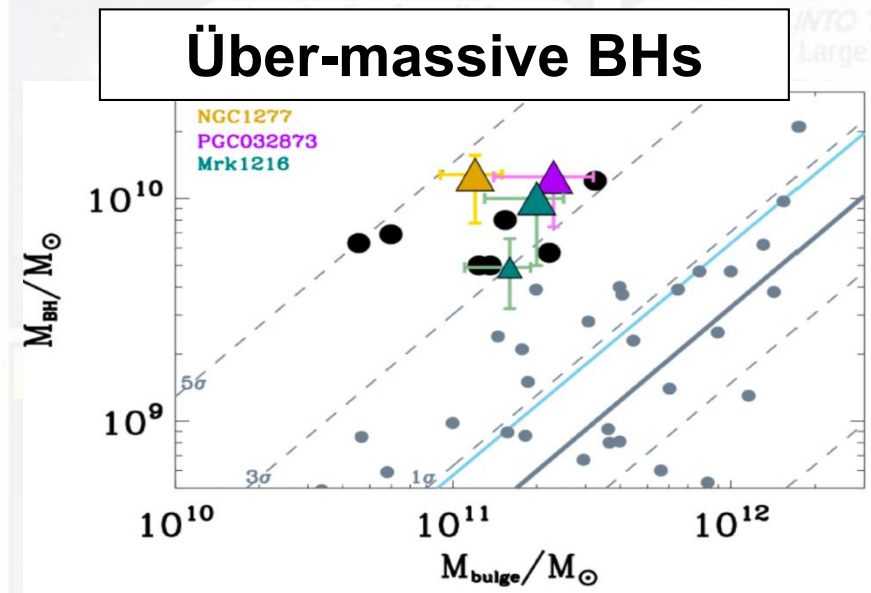
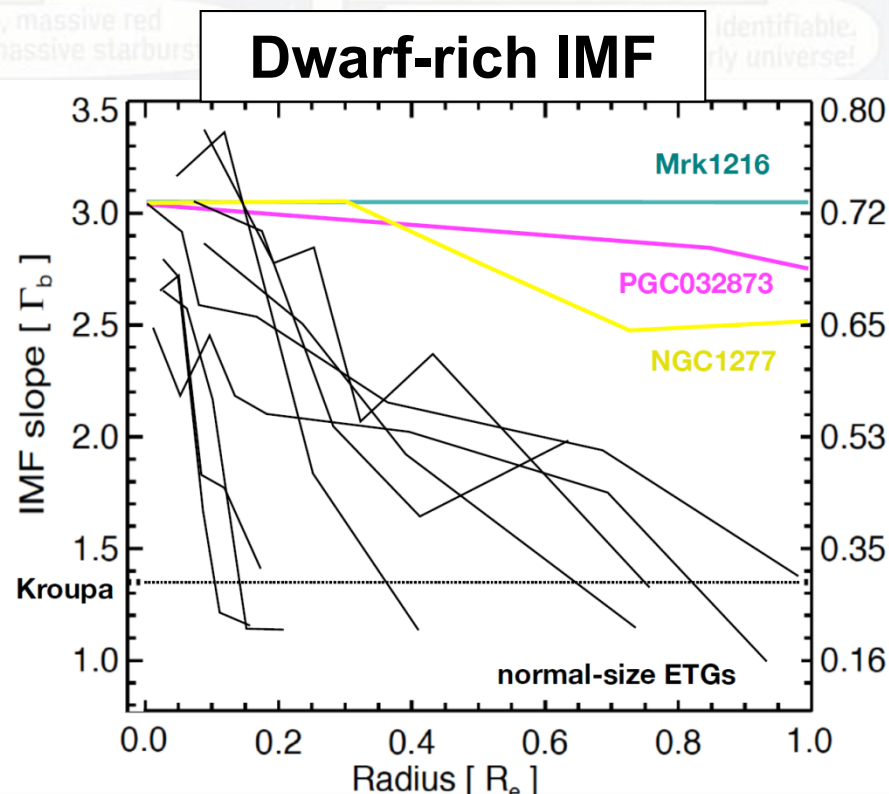
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SPATIALLY-RESOLVED SPECTRA WITH MORFEO@ELT



Missing the spatially-resolved counterparts of the Xshooter spectra, this is providing more constraining power

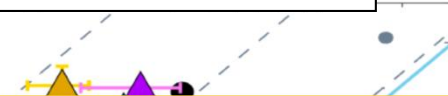
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Dwarf-rich IMF



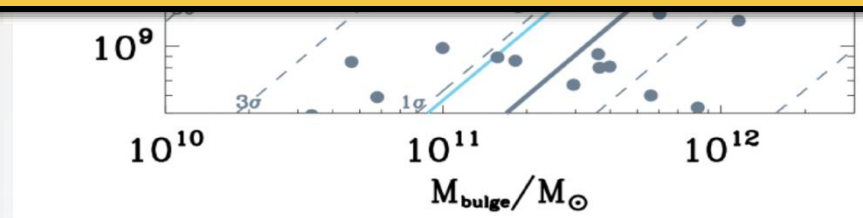
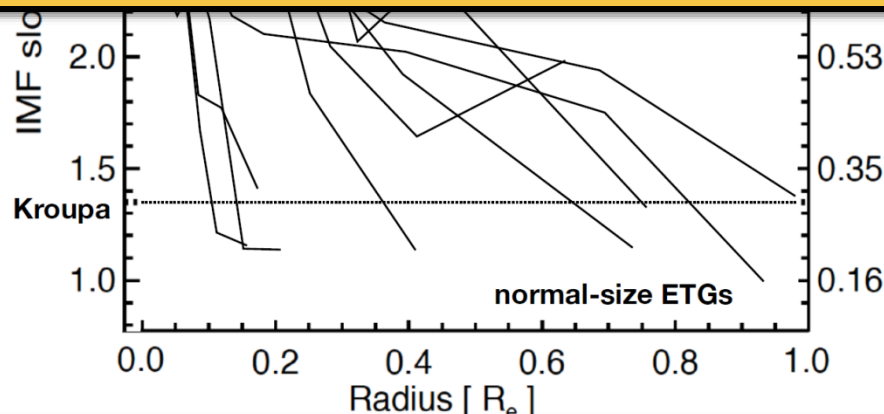
Über-massive BHs

NGC1277
PGC032873
Mrk1216



2h of integration time $\Rightarrow$ S/N (< 0.2 arcsec) = 30-200

Absorption lines: Ca II triplet, Na I doublet, Wing-Ford FeH band, etc.



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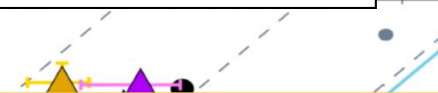
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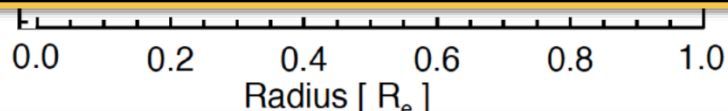
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Constrain stellar population, IMF, and dark matter density profiles (from kinematic), as well as BH mass



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TAKE-HOME MESSAGES

UCMGs and relics are rare,
but found in wide-field surveys

JOURNEY OF RELIC GALAXIES

Billions of years ago, massive red

The rare fossils are finally identifiable.

They remained ultra-compact and old!

CONFIRMING THE HOARD

SEIZED THE SWORD: 38 relics confirmed! ($0.15 < z < 0.4$)



THE PROBLEM: RESOLUTION

JOURNEY'S END NOT OVER.
Limited by $0.7''$ KIDS resolution.



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THE ULTIMATE



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They are metal-rich, have large velocity dispersions, dwarf-rich IMF, disk-like isophotes.
They do not prefer any particular environment.

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Relics are the litmus paper of the galaxy evolution,
probing the cores of massive galaxies and their size evolution

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Contact me if you are interested in joining the WG and contributing to a specific science case



THE ULTIMATE IMF MYSTERY?



The origin of the cores of the Universe's most massive galaxies **UNLOCKED!**