Hubble Frontier Fields:
"A New Era for Gravitational Lensing & Cosmology"

DEX XIII - Edinburgh
10th January 2017

Durham University

Mathilde Jauzac

Dominique Eckert, Johan Richard, Richard Massey, Johannes Schwinn, Carlton Baugh, Eric Jullo, Marceau Limousin, Jean-Paul Kneib, Harald Ebeling & the CATS team

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"The Extraordinary Abell 2744"

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Outlines

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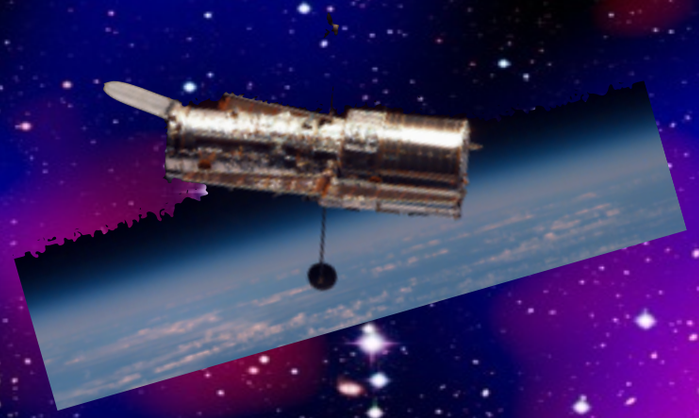

2. A ‘Super’ Strong Lens

3. Distribution of substructures : A possible conflict with LCDM ?

4. A proper Node of the Cosmic Web

5. Conclusions & Perspectives

COSMOLOGICAL CONTEXT : THE HFF

COSMIC WEB

Large-Scale Filaments
Funnelling matter in Clusters

125 Mpc/h

Node
Massive Galaxy Clusters

HST

Void

Millenium simulation

THE *HST FRONTIER FIELDS* INITIATIVE

WHY THE *HUBBLE FRONTIER FIELDS* ?

(http://www.stsci.edu/hst/campaigns/frontier-fields)

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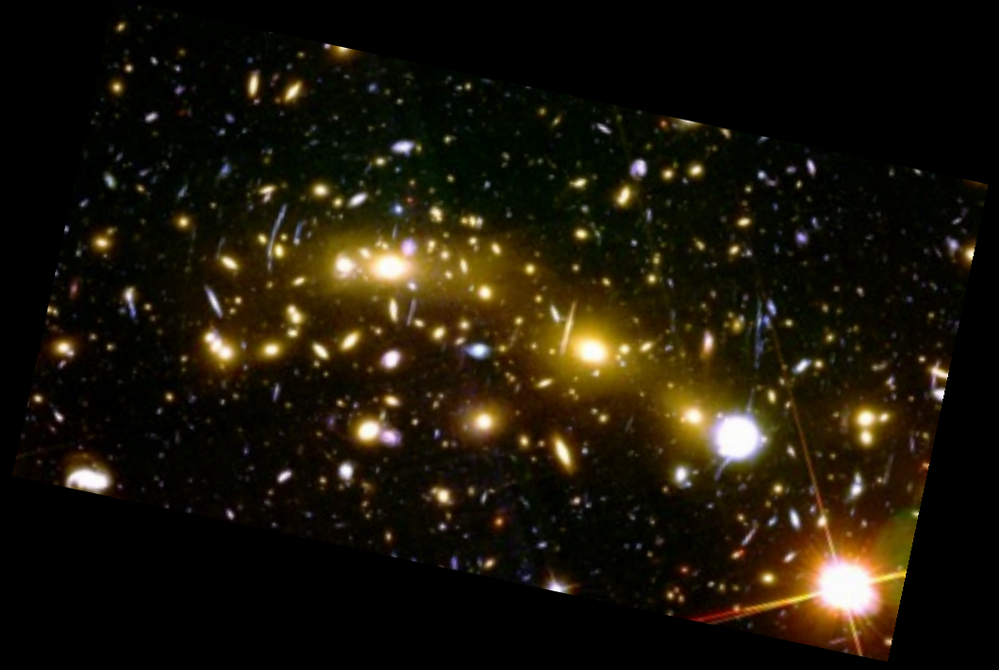

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THE MOST POWERFUL TELESCOPE TO OBSERVE THE DISTANT UNIVERSE

- Highly-constrained Gravitational Lensing mass models
- Highly-precise Magnification estimates

1. THE DISTANT UNIVERSE
2. CLUSTER PHYSICS : STUDYING THE COSMIC WEB
3. GALAXY EVOLUTION, …

THE *HST FRONTIER FIELDS* INITIATIVE

WHAT ARE THE *HUBBLE FRONTIER FIELDS* ?

(http://www.stsci.edu/hst/campaigns/frontier-fields)

- 6 strong lenses & 6 blank fields
- 140 HST orbits (> 3days of observations) – ACS & WFC3
- mag ~ 29 in the optical and near-IR

THE DEEPEST DATA EVER OBTAINED FOR LENSING GALAXY CLUSTERS !!!

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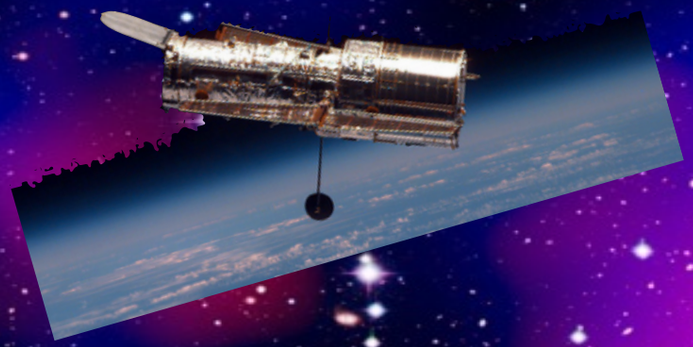

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ABELL 2744 : BEFORE HFF ...

Past Lensing History

Smail et al. 1997, *APJ, 479, 70*
Allen 1998, *MNRAS, 296, 392*

2011

Merten et al. 2011, *MNRAS, 417, 333*

34 SL multiple images

2014 : PreHFF GL analysis

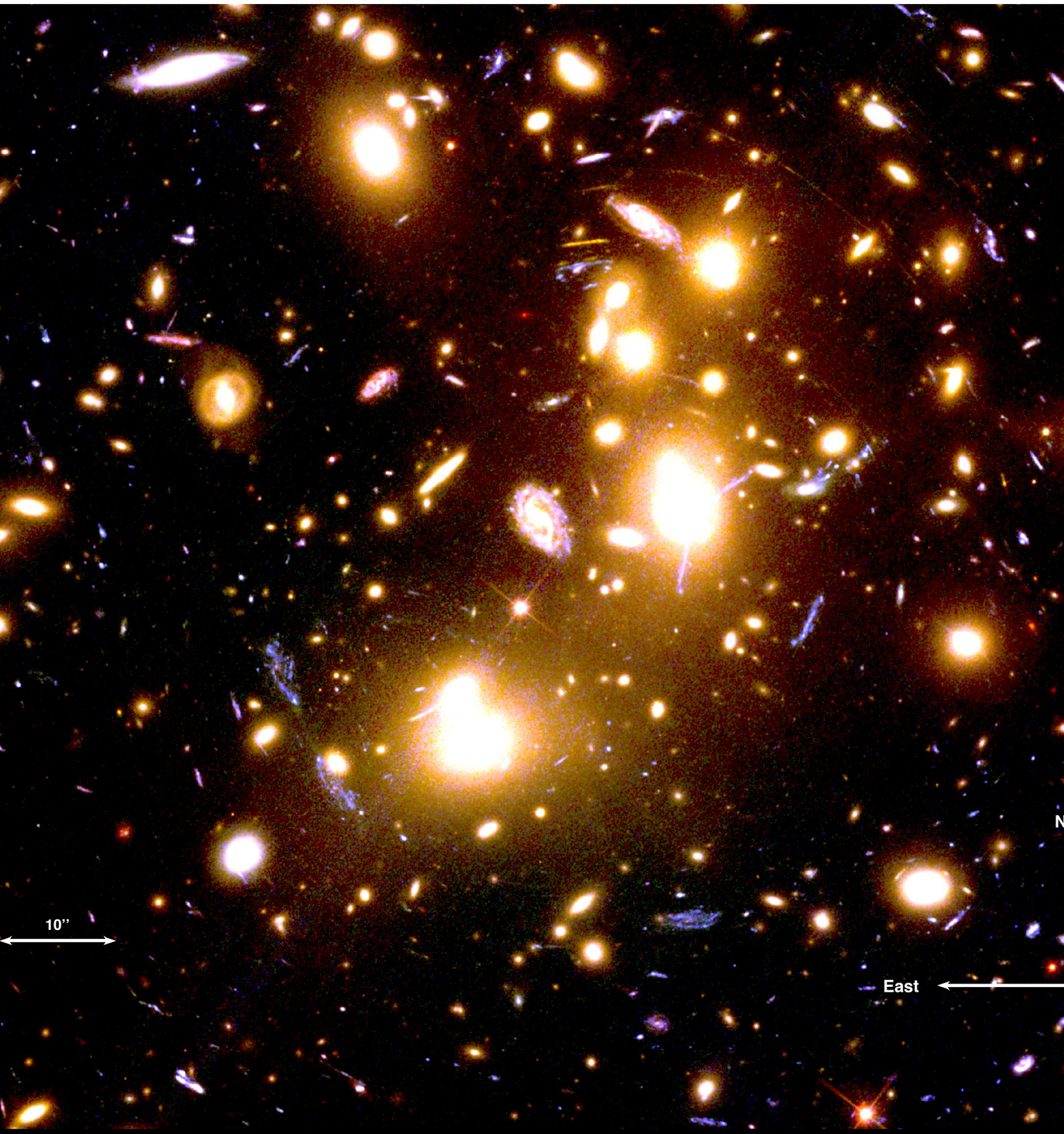
Johnson et al. 2014, *ApJ*, 797, 48
Coe et al. 2015, *ApJ*, 800, 84
Richard et al. 2014, MNRAS, 444, 268

55 SL multiple images

~50 WL gal.arcmin^{-2}

HST/ACS imaging - Merten et al. 2011

ABELL 2744 : … AFTER HFF !!!



TODAY Lensing Picture

2014 - 2015 : HFF GL analysis

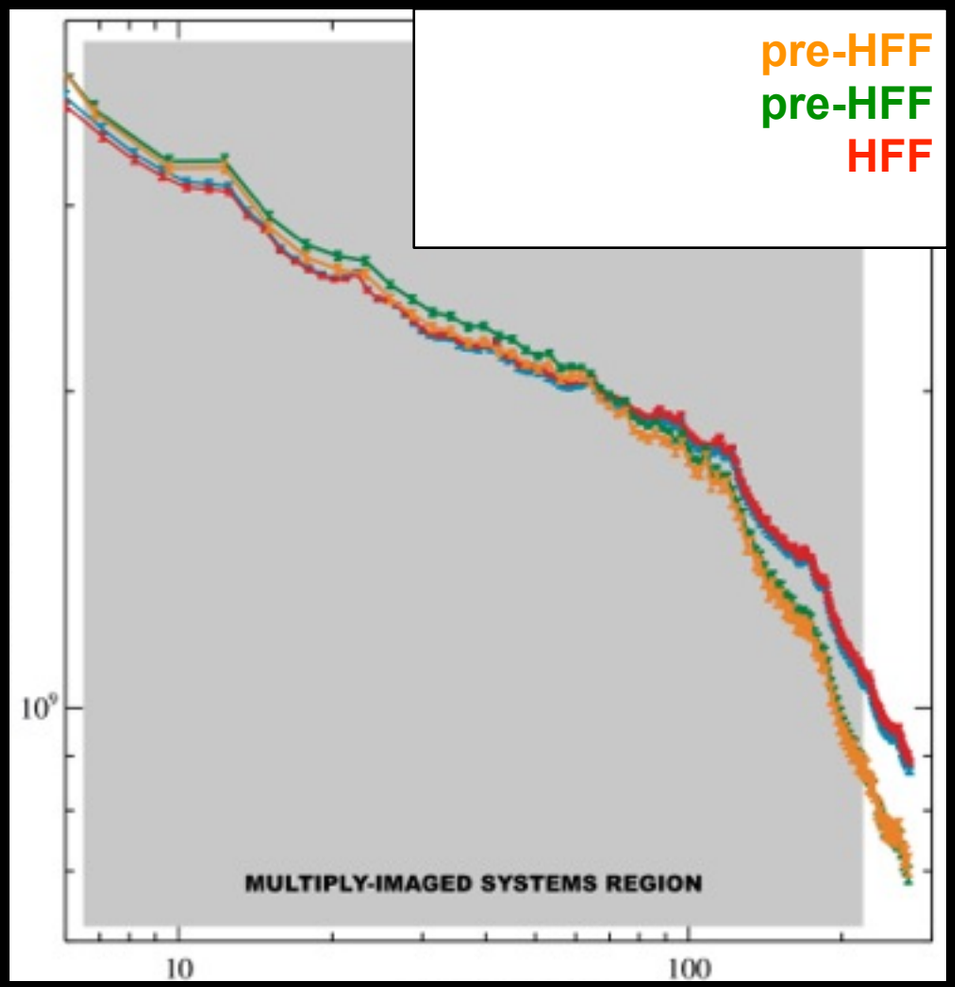
Jauzac et al. 2015b, MNRAS, 452, 437
Lam et al. 2014, ApJ, 797, 98
Wang et al. 2015, arXiv1504.0240
Medezinski et al. 2016, arXiv1507.03992
Eckert et al. 2015, *Nature*
Jauzac et al. 2016b, *sub. to MNRAS*

181 SL multiple images

~100 WL gal.arcmin^{-2}

Another HIGHLY constrained cluster !!!

ABELL 2744 : INNER MASS & MAGNIFICATION

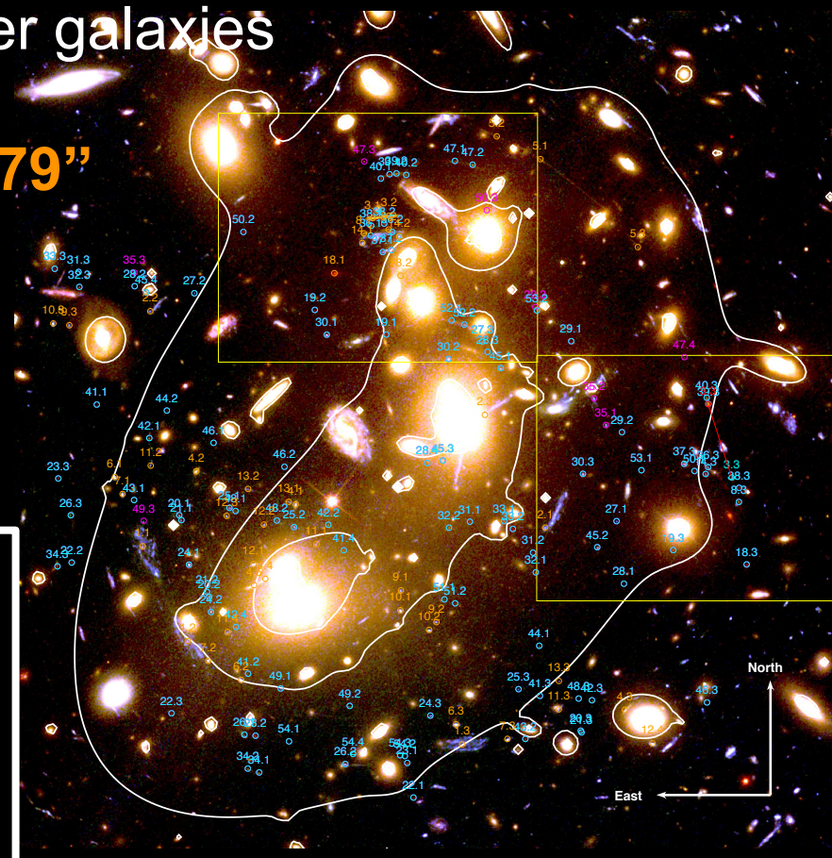


SL-only analysis

Jauzac et al. 2015b, *MNRAS, 452, 437*

Best-fit parametric mass model - LENSTOOL :

- 154 SL constraints
- 2 DM clumps
- 733 cluster galaxies
- **RMS = 0.79”**



Mass estimation to ***the <1% level :***
M(R<250kpc) = 2.765 ± 0.008 (stat) 10^{14} M_{sun}

Magnification to ***the 2% level :***
μ = 5.61 ± 0.10 (stat) ± 0.57 (sys)

pre-HFF (Richard et al. 2014, MNRAS, 444, 268) :
μ = 4.69 ± 0.32 (stat)

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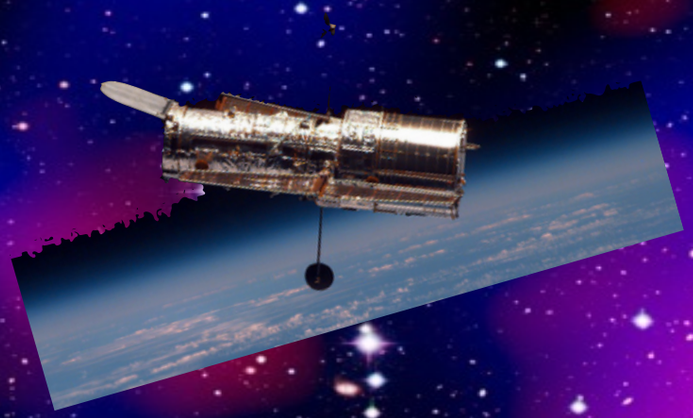

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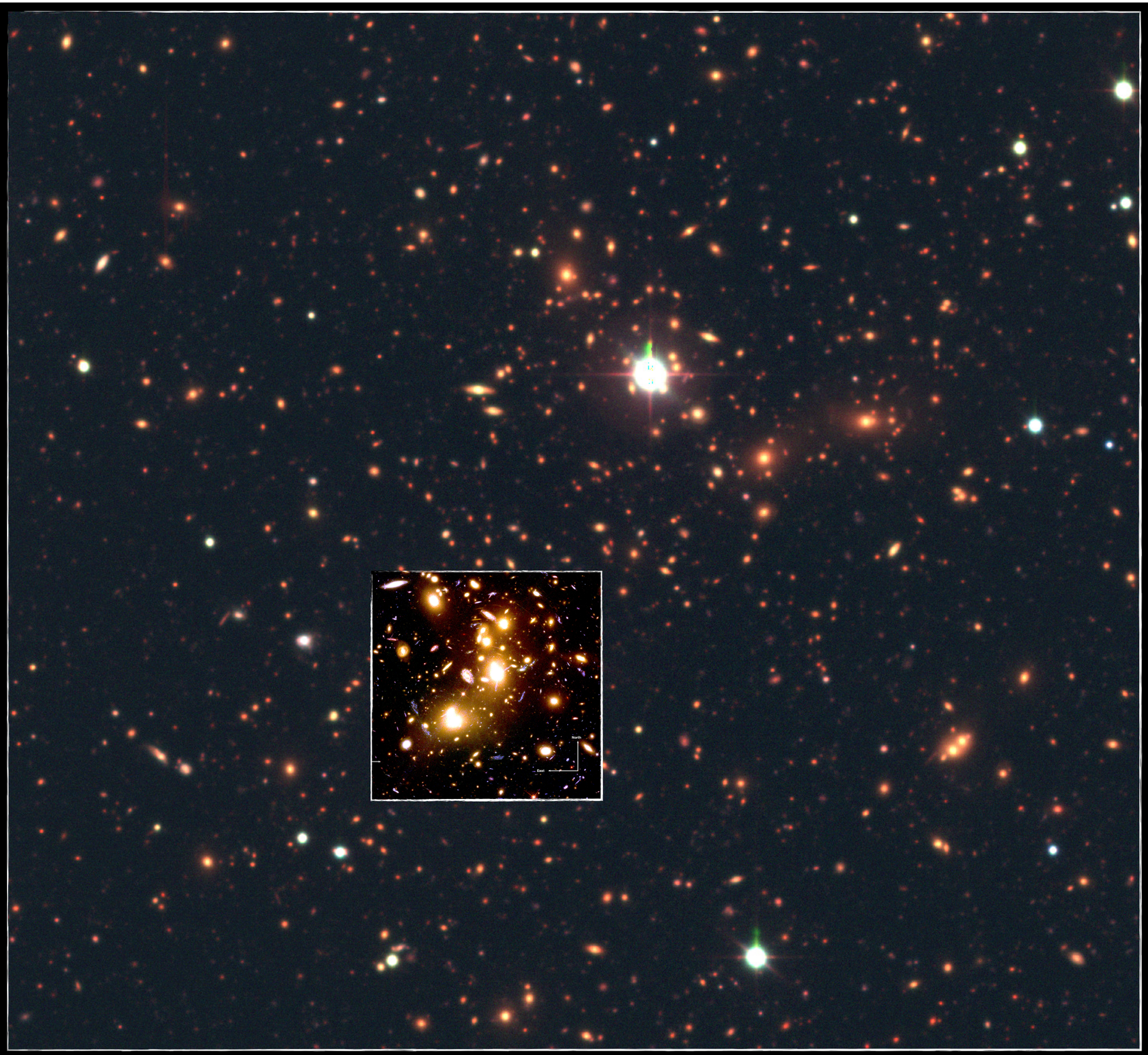
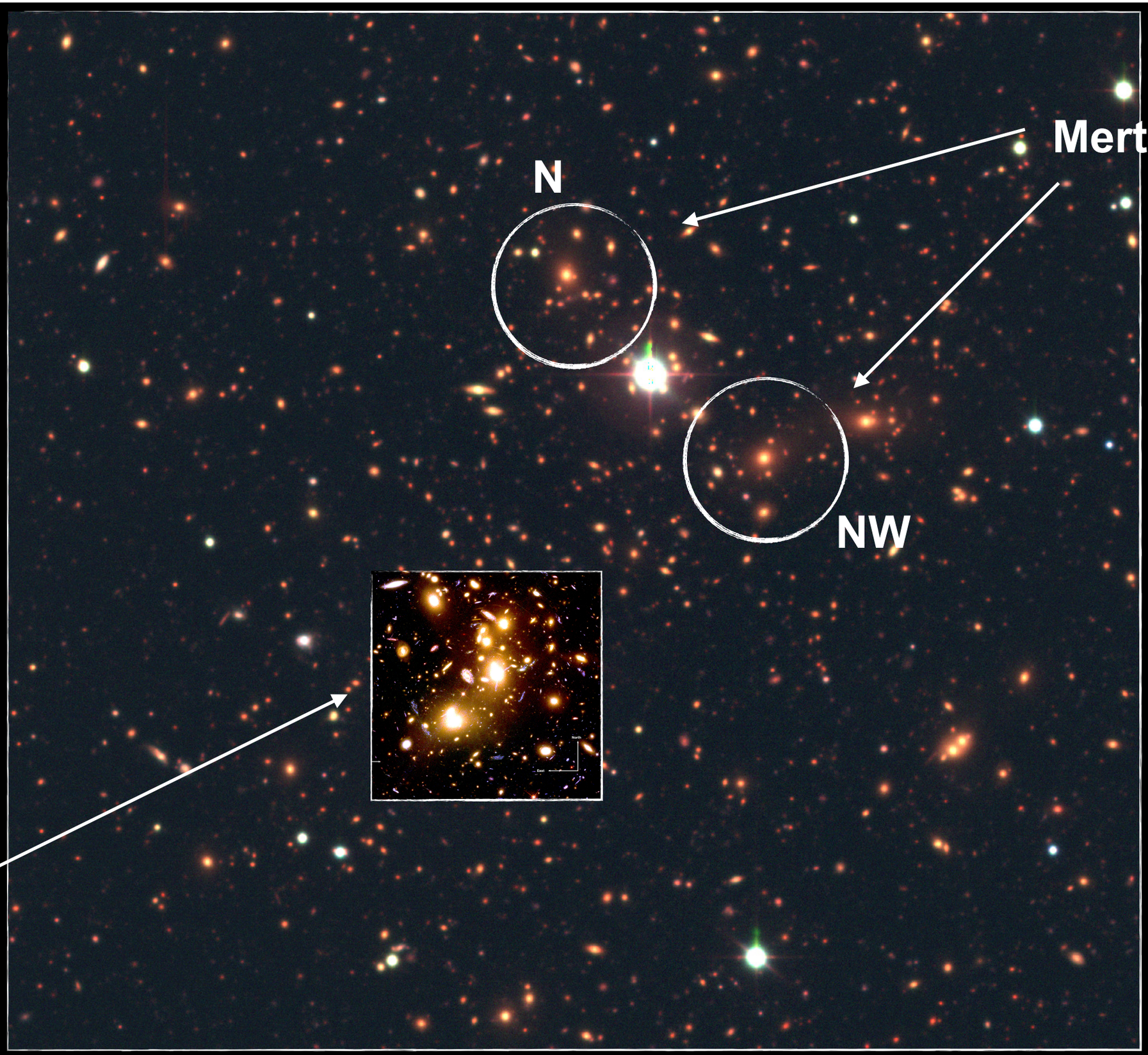
Abell 2744 : The Substructure Distribution



ABELL 2744 : THE SUBSTRUCTURE DISTRIBUTION



ABELL 2744 : DM DISTRIBUTION

SL+WL Analysis within R < 2 Mpc

Jauzac et al. 2016b, *MNRAS, in press*

WL : HST + CFHT

HYBRID-LENSTOOL : SL potentials + Uniform grid

ABELL 2744 : DM DISTRIBUTION

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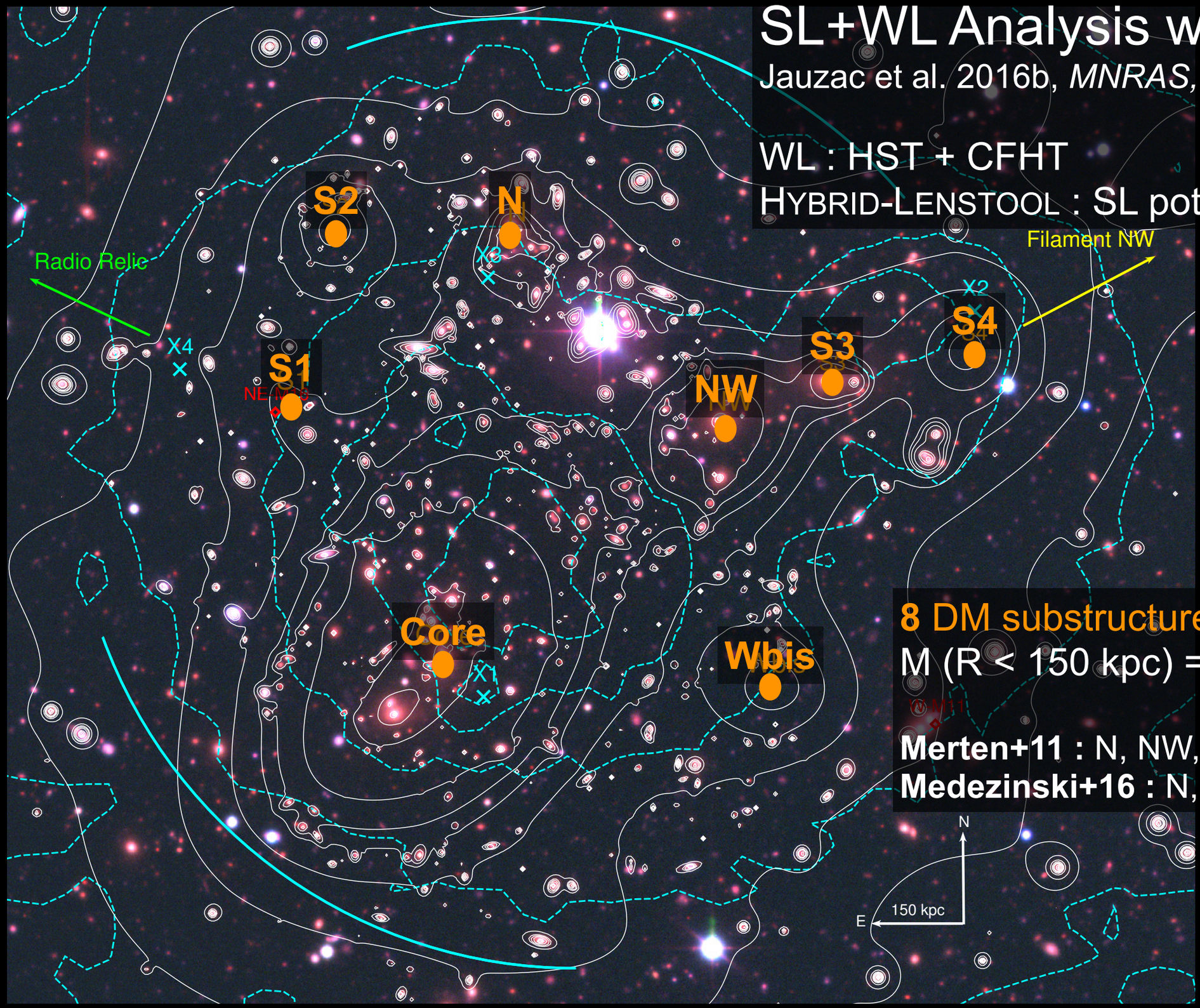
8 DM substructures with SN > 5

M (R < 150 kpc) = 0.5 -1.4 10^{14} M_{sun}

ABELL 2744 : DM DISTRIBUTION



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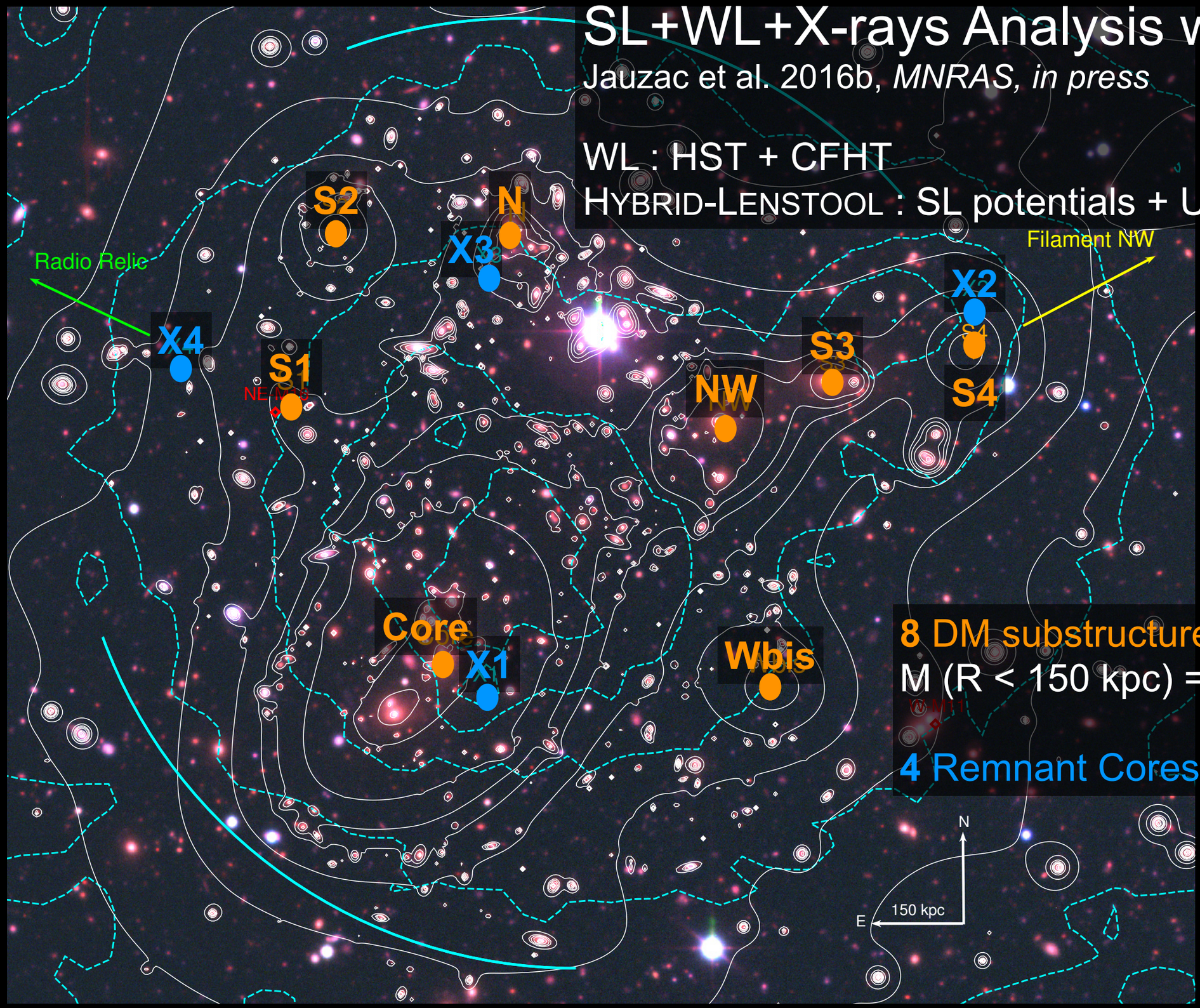
M (R < 150 kpc) = 0.5 -1.4 10^{14} M_{sun}

Merten+11 : N, NW, W

Medezinski+16 : N, NW, Wbis, NE

ABELL 2744 : DYNAMICAL SCENARIO ?



SL+WL+X-rays Analysis within R < 2 Mpc

Jauzac et al. 2016b, *MNRAS, in press*

WL : HST + CFHT

HYBRID-LENSTOOL : SL potentials + Uniform grid

8 DM substructures with SN > 5

M (R < 150 kpc) = 0.5 -1.4 10^{14} M_{sun}

4 Remnant Cores

Merger DM Remnants

Putative Shock

Radio Relic

Eckert et al. 2016

S2

X3

N

Gas Plum

Advanced-stage Merger

X4

S1

Main Merger Axis

NW

S3

X2

S4

Cool gas trail

Early-stage Merger

Bullet close to LOS

Core

X1

W_{bis}

Shocks

Owers et al. 2011

ABELL 2744 : CONFLICT WITH ΛCDM ?

Comparison with MXXL

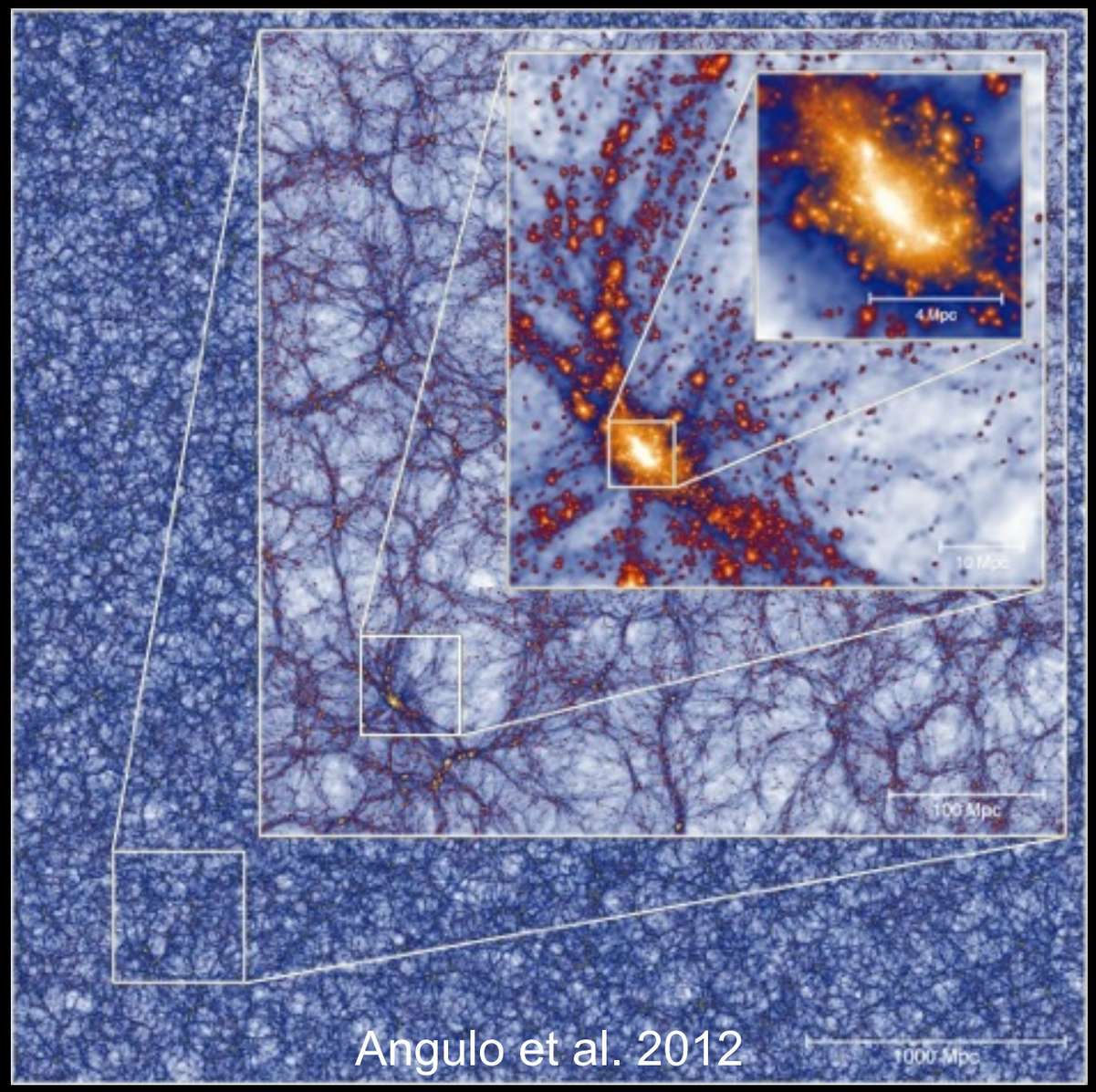
Jauzac et al. 2016b, *MNRAS, 463, 3876* &
Swchinn, Jauzac et al. 2016, *sub. MNRAS*

Total Mass : **~70 clusters** 0.28 < z < 0.32

★ **Cluster as massive as A2744 are common**

Number of Substructures : 2 clusters with max of 4 substructures within 1 Mpc

★ **A2744 substructure distribution is not observed in MXXL**



Angulo et al. 2012

Numerical & observational caveats

- Lack of resolution for subhalo finder algorithms
- LOS substructures from 2D mass measurements (see Gioccoli+16)

POSSIBLE CONFLICT to be investigated over more clusters !

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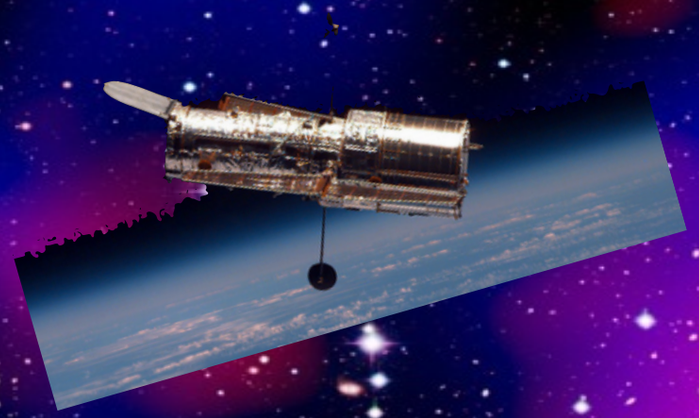

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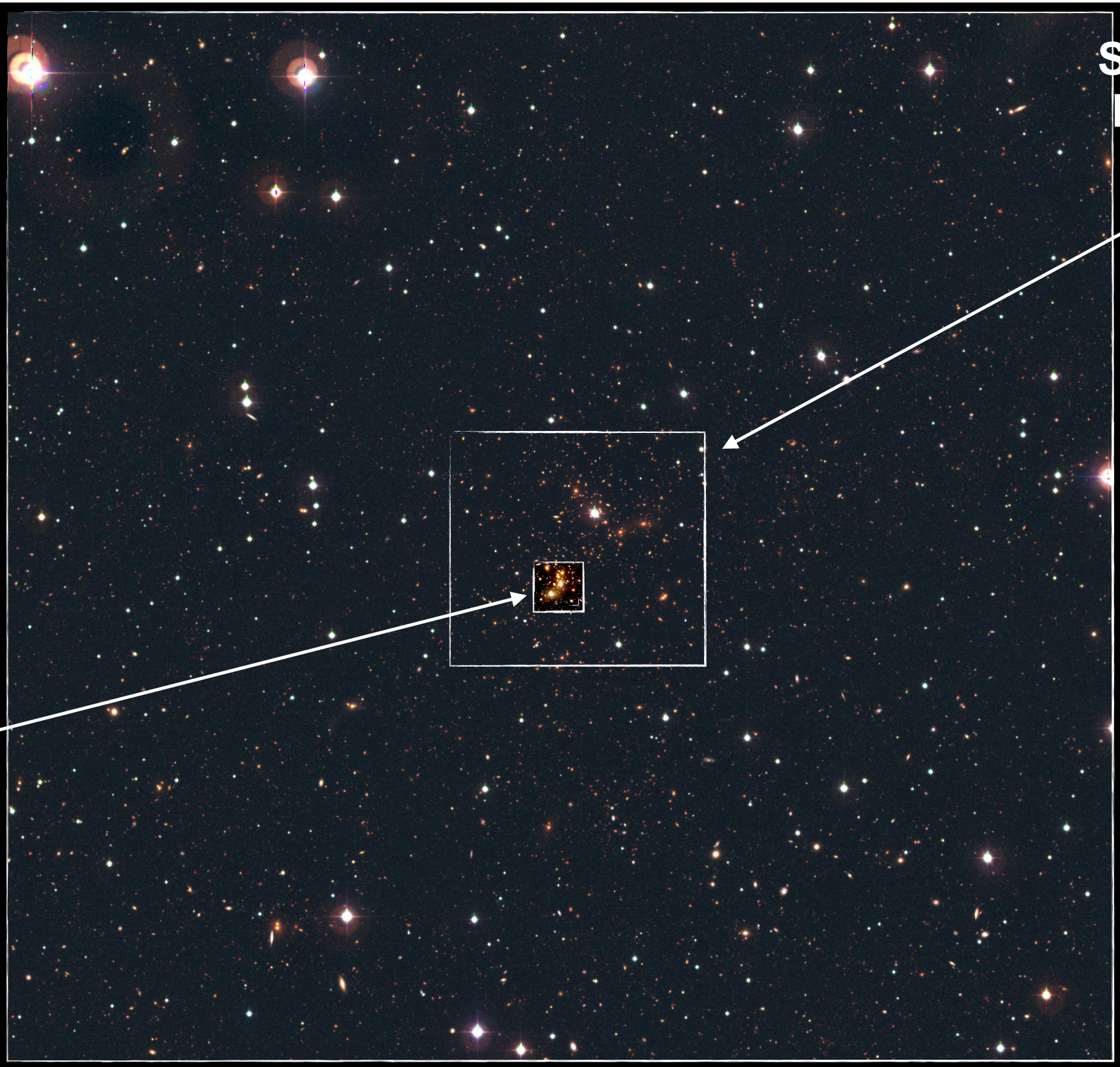
ABELL 2744 : THE LARGE-SCALE FILAMENTS

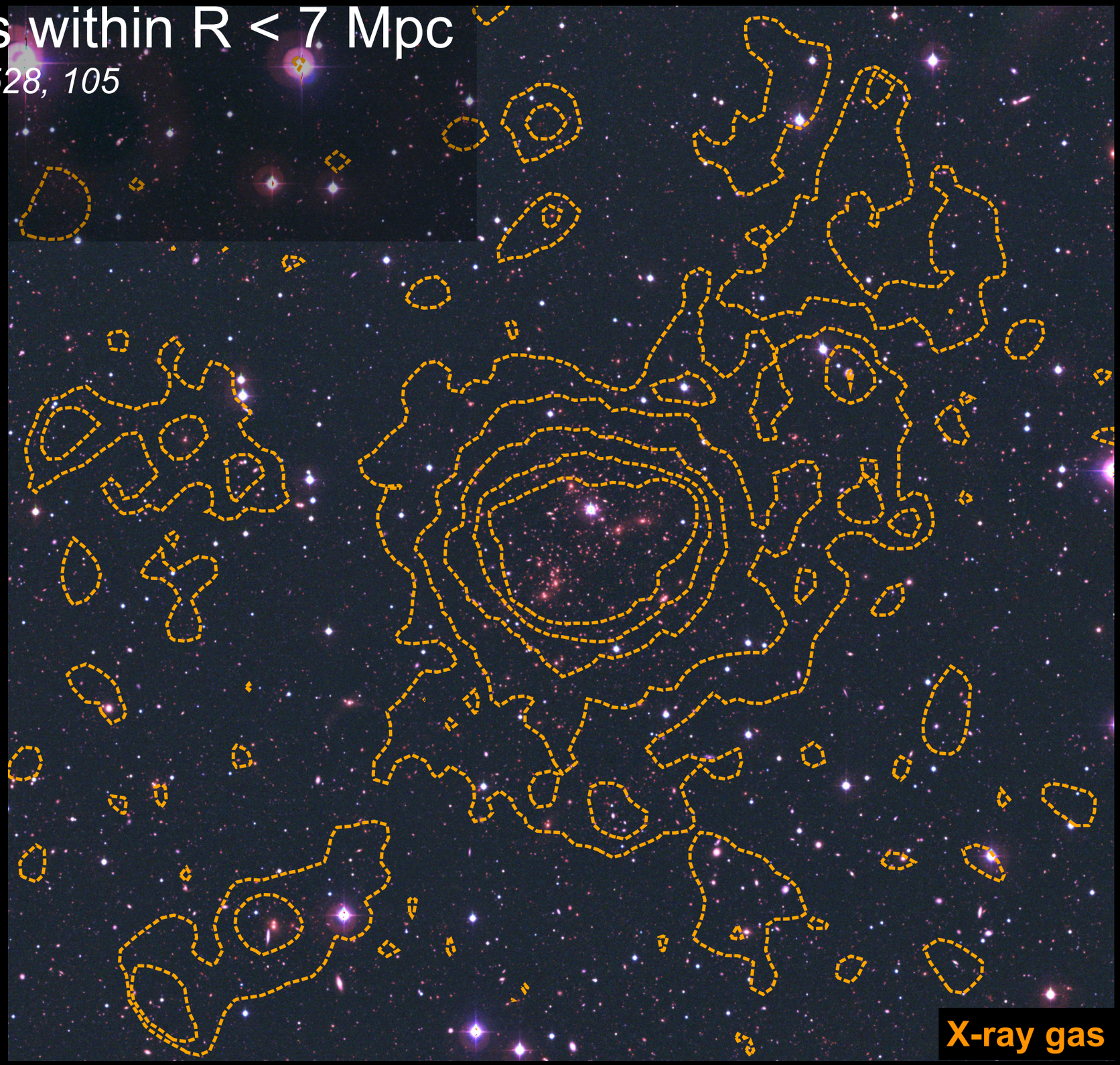


6. Abell 2744 : A Node of the Cosmic Web

X-ray+SL+WL Analysis within R < 7 Mpc

Eckert, Jauzac et al. 2015, *Nature, 528, 105*

Deep XMM Observations



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Deep XMM Observations
WL : HST + CFHT
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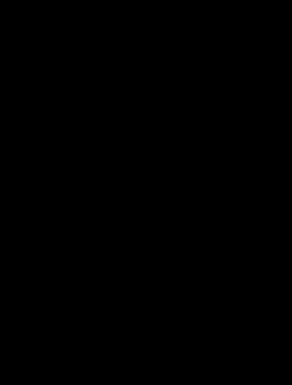
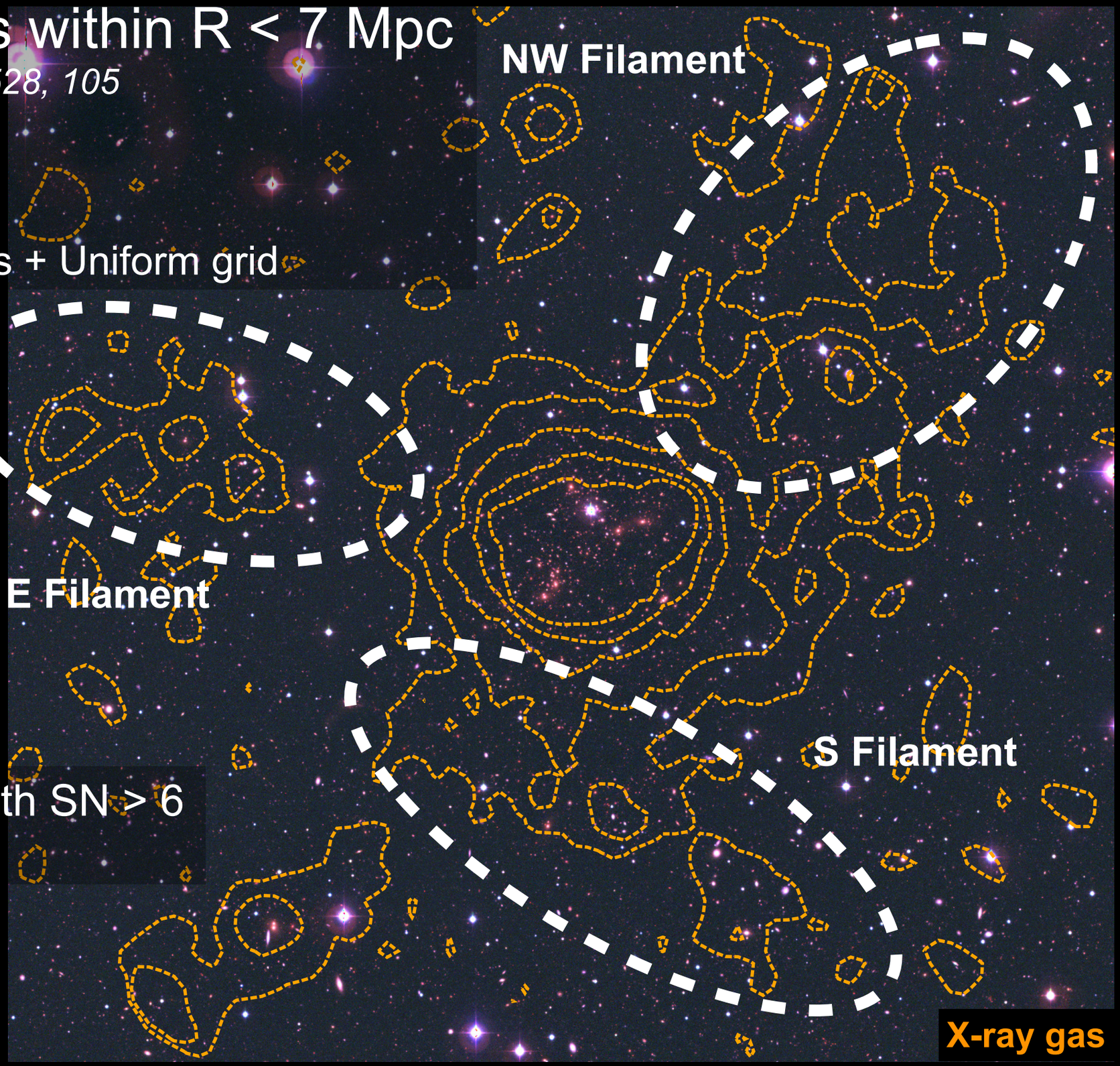
3 large-scale filaments with SN > 6
T ~ 15-20 10^6 K





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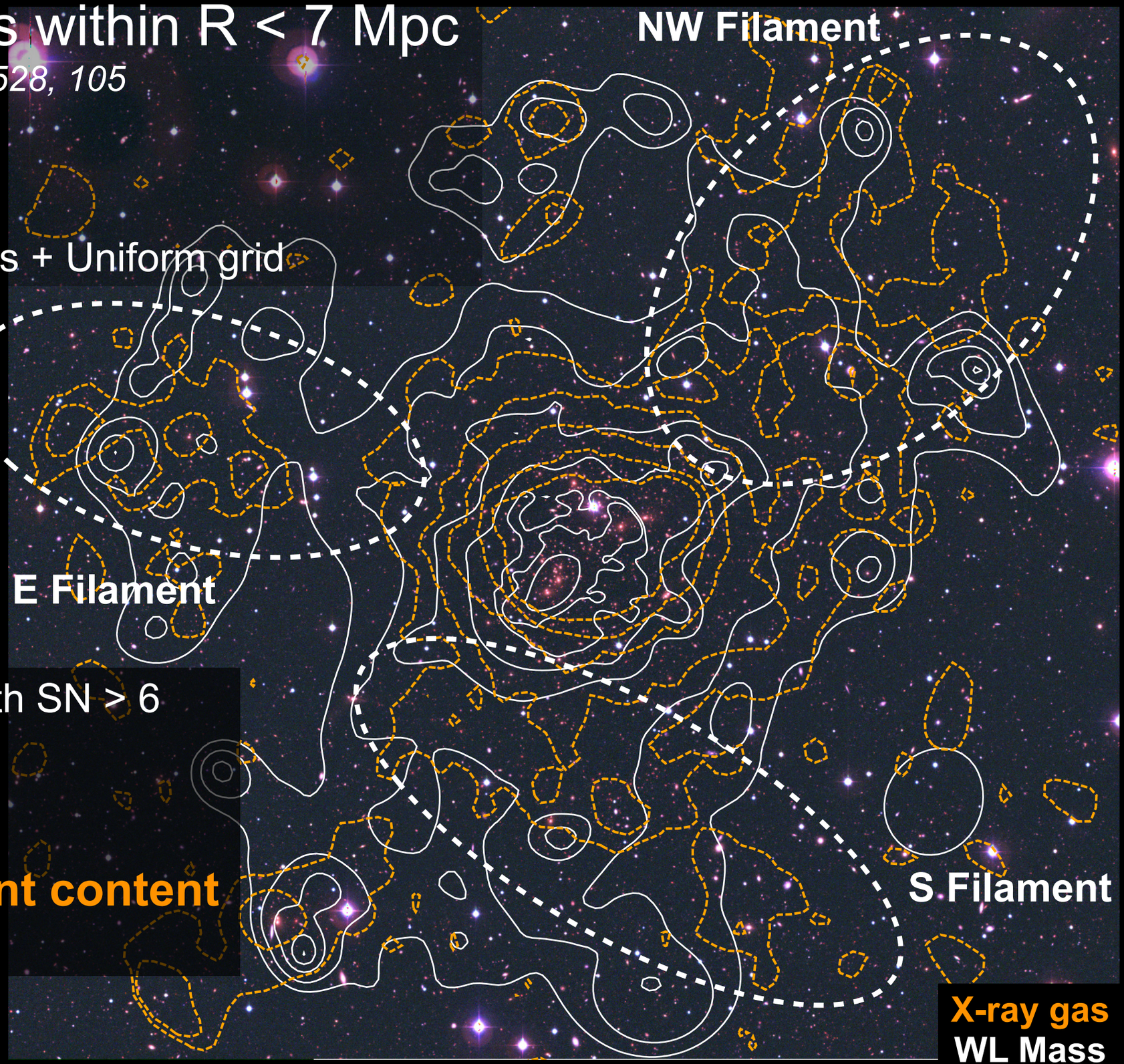

3 large-scale filaments with SN > 6
T ~ 15-20 10^6 K
DM counterparts for all 3

Gaz ~ 5-10% of filament content

X-ray gas
WL Mass

Outlines

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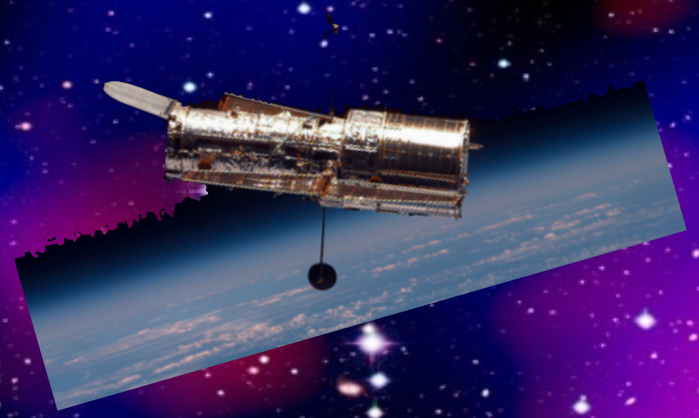

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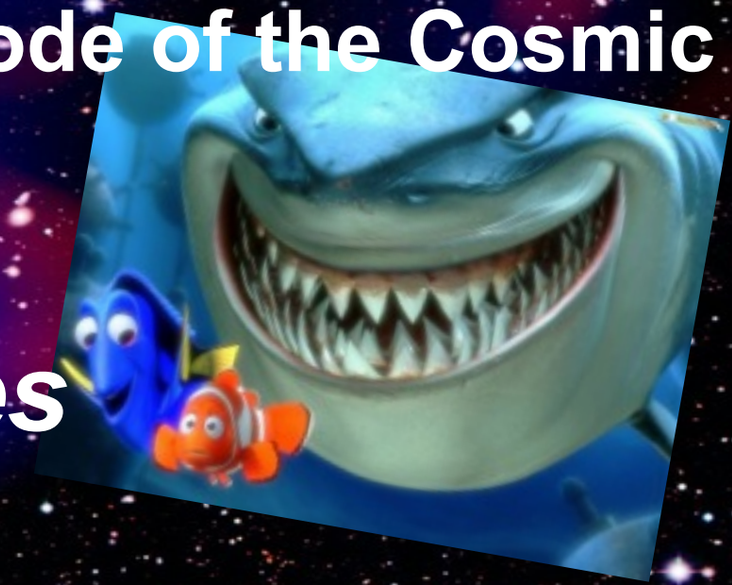

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CONCLUSIONS/SUMMARY

HFF : TONS of multi-wavelength datasets

- **Highest precision mass models for cluster cores & outskirts**
  - ★ ***MACSJ1149*** **: First cluster to demonstrate the predictive power of Lens Modelling ! (Jauzac et al. 2016b)**

- **Multi-wavelength analysis**
  - ★ ***Abell 2744*** **: One of the most complicated cluster known**
    (Eckert et al. 2015, 2016 ; Medezinski et al. 2016 ; Jauzac et al. 2015b, 2016b ; Schwinn, Jauzac et al. 2016, *sub. MNRAS*)
    - » **Probable conflict with LCDM**

  - ★ ***MACSJ0416*** **: An active double-merger**
    (Jauzac et al. 2014, 2015a, b ; Ogrean et al. 2015)
    - » **Deeper *Chandra*/ACIS-I observations confirmed our first putative scenario (Ogrean et al. 2015)**

WHAT'S NEXT ?

- **More clusters needed to constrain substructure evolution**
  - ★ **All HFF clusters = Nodes of the Cosmic Web …**

My last safari :)

Thank you for your attention

Future Prospects

- ***MACSJ0717 : Another Node of the Cosmic Web***

(Jauzac et al., in prep.)

- **2 X-ray detected filaments**
- **1 DM detected filament (Jauzac et al. 2012)**
- ***WORK in PROGRESS ...***

XMM contours
HST WL mass

Filament 1
Jauzac et al. 2012

Filament 2
...

Ma et al. 2008, 2009
Zitrin et al. 2010
Jauzac et al. 2012
Medezinski et al. 2013
Diego et al. 2015
Limousin et al. 2012, 2016

Future Prospects