The Influence of Cluster Mergers on Galaxy Formation

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Eiichi Egami, Pablo Perez Gonzalez, Bruno Altieri
and the Herschel Lensing Survey collaboration

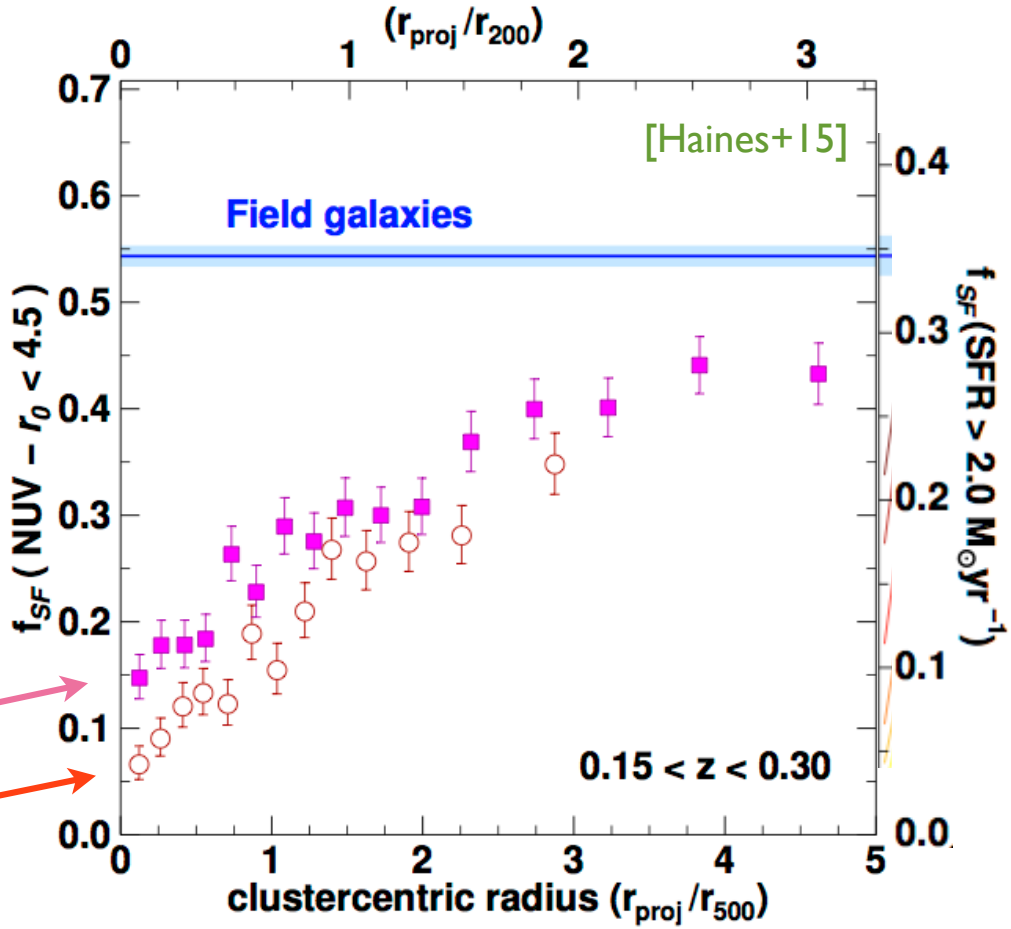
Star formation in galaxy clusters

In the local Universe, star formation is suppressed (quenched) in clusters compared to the field

[e.g. Kennicutt83, Gómez+03]

The fraction of star-forming galaxies forms a systematic radial trend, decreasing towards the core, which suggests a mechanism involving in-fall

[e.g. Ellington+01, Wake+05, Haines+09]



For the LoCuSS sample of 30 clusters at 0.1<z<0.3:

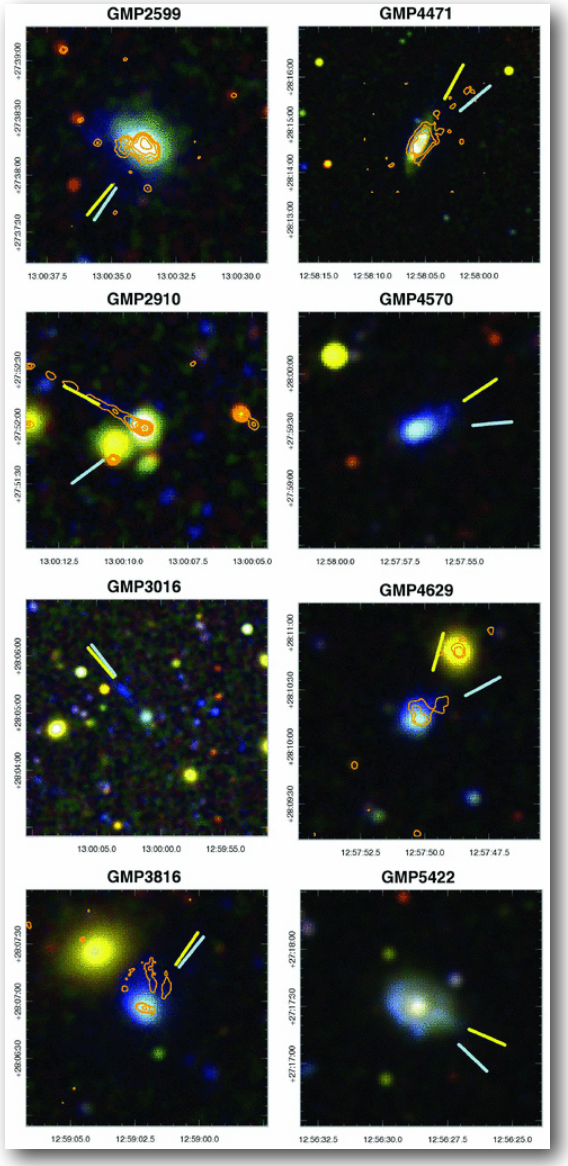
NUV−r < 4.5

or $SFR_{24\mu m}$ > 2.0 $M_\odot$/yr

Star formation in galaxy clusters

ESO137-001 (in A3627) [NASA, ESA, CXC]

Coma cluster "infall" galaxies



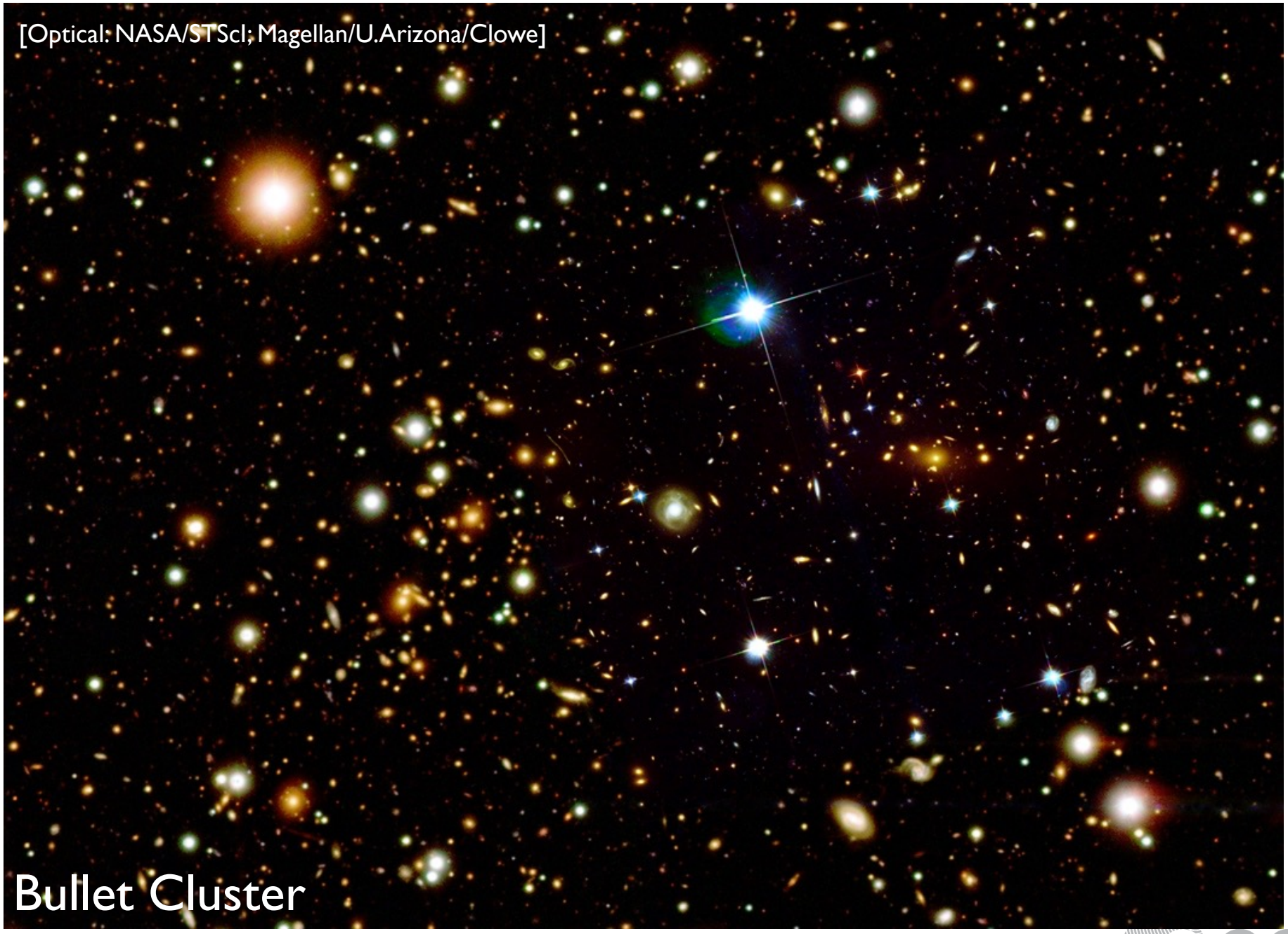
[R.J.Smith+10]

Galex (FUV,NUV) + MegaCam (g,u,i) + INT Hα

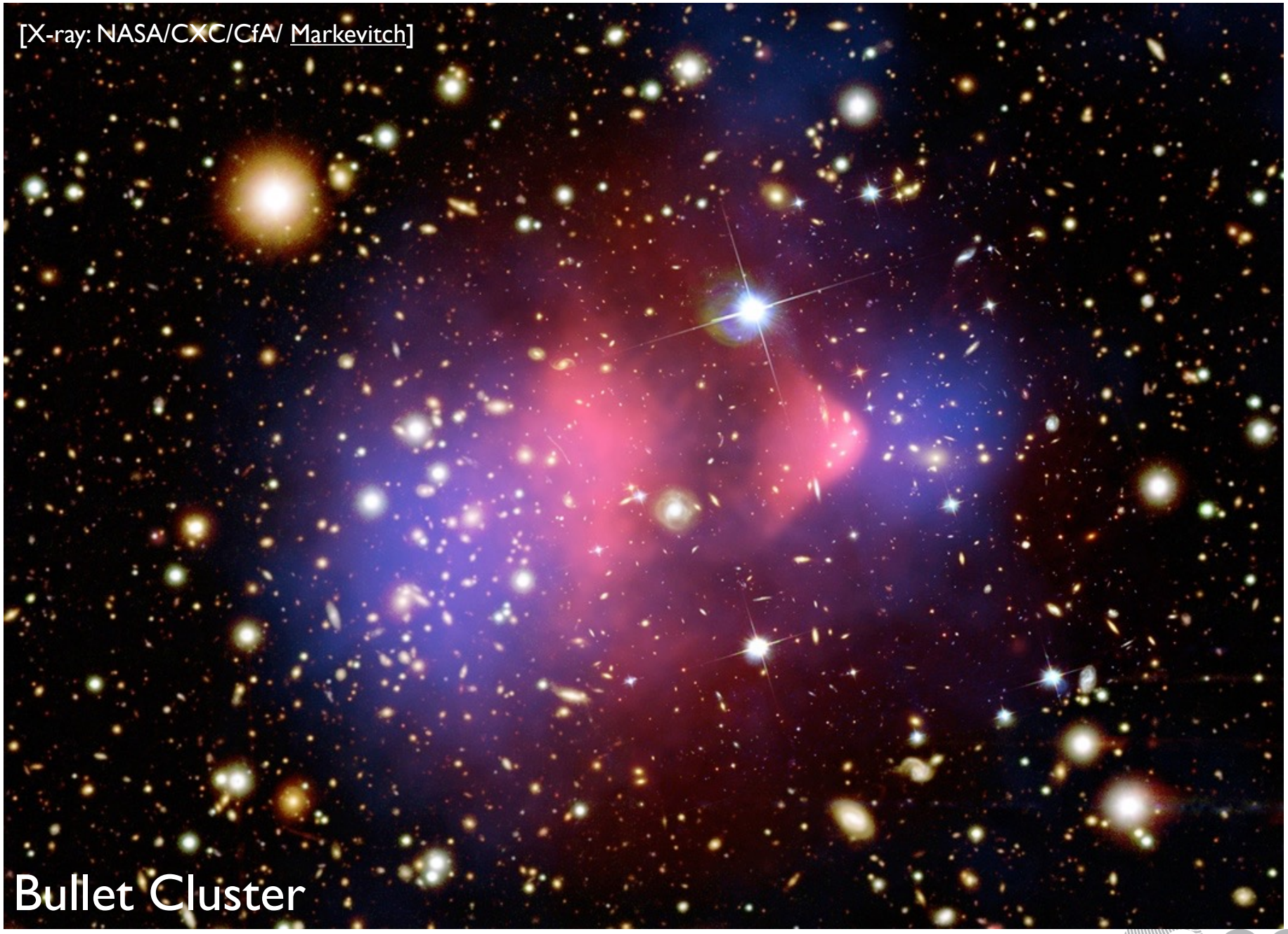
Yellow line: points along the identified trail

Blue line: points away from the cluster centre

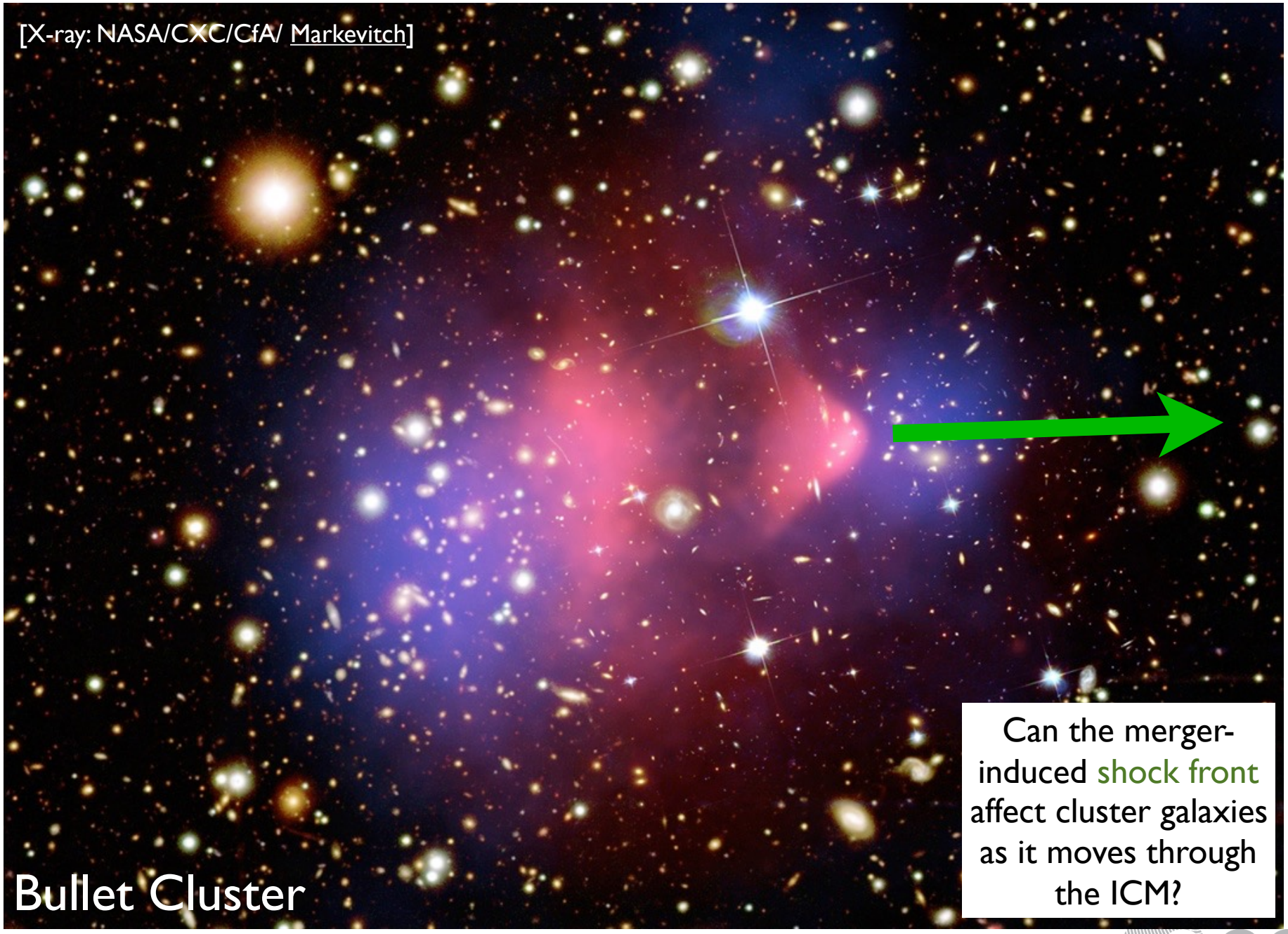
Star formation in merging galaxy clusters



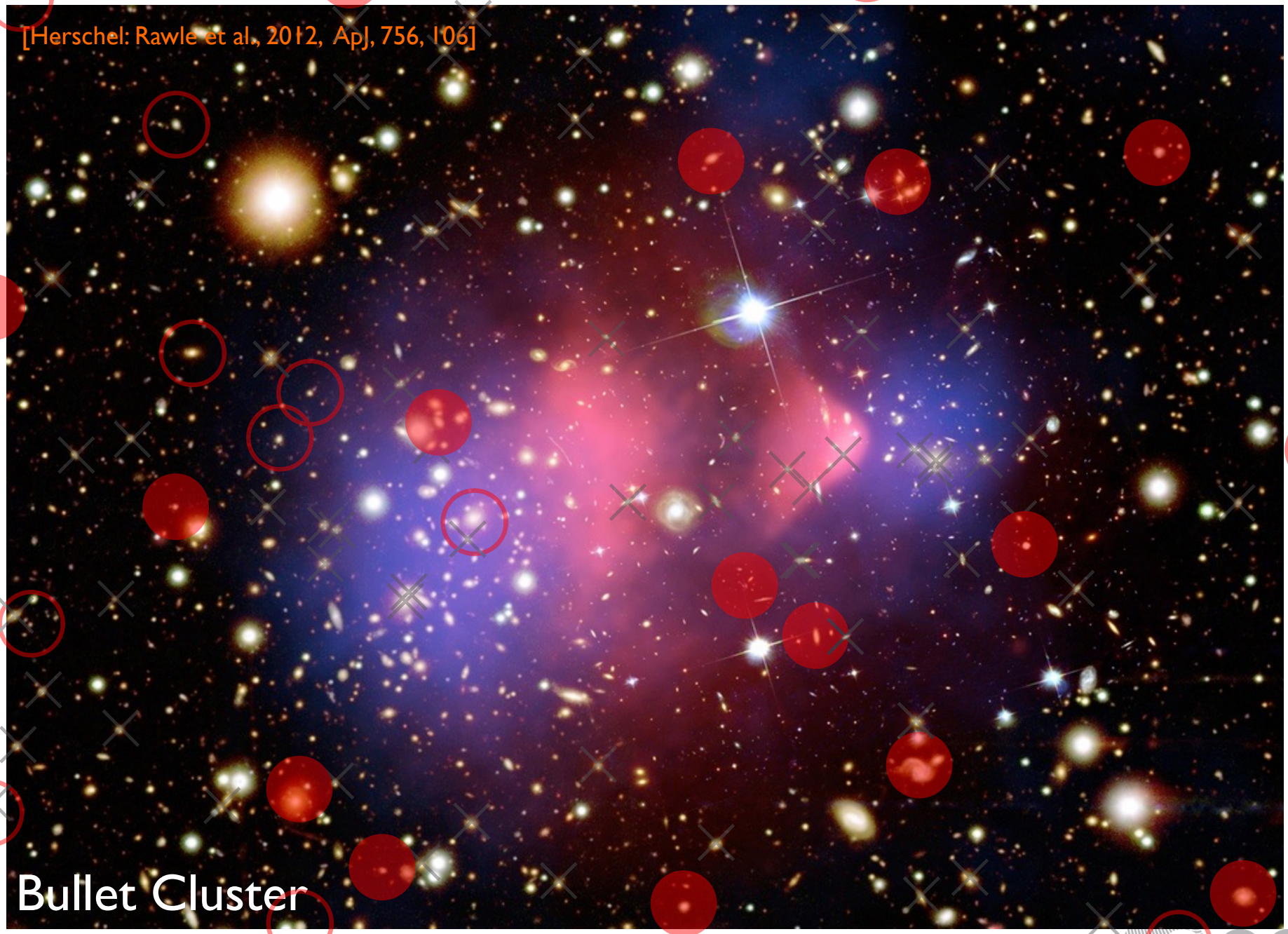
Star formation in merging galaxy clusters



Star formation in merging galaxy clusters



Star formation in merging galaxy clusters



Star formation in merging galaxy clusters

...but Herschel FIR only detects dusty activity.
Ram pressure stripping could remove much of the dust, leaving unobscured (UV-bright) star formation

We need a multi-wavelength approach to view ALL star formation

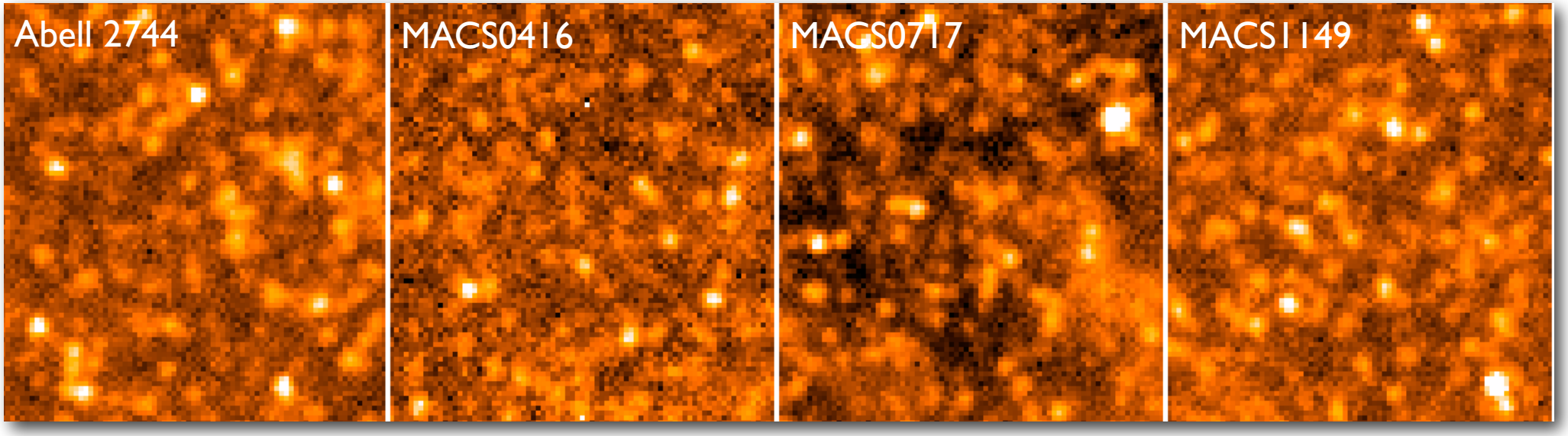
The Herschel Lensing Survey (HLS)

(Egami+10, Egami+prep)

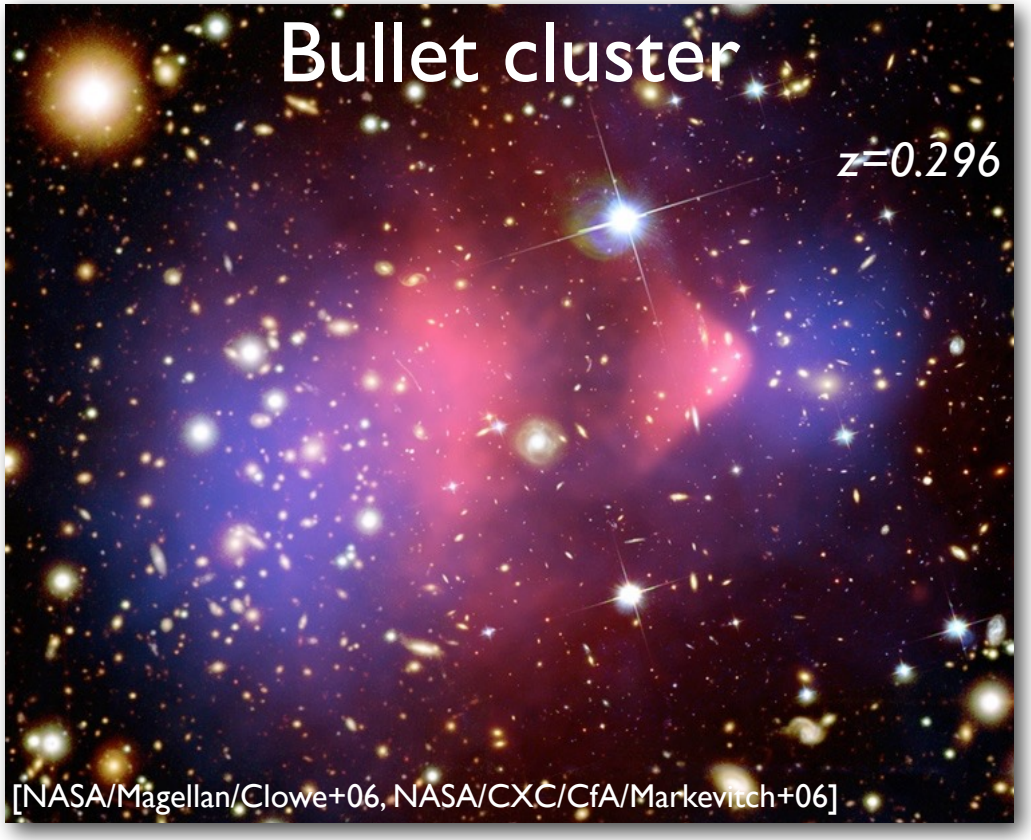
- 65 well-studied massive (lensing) galaxy clusters (0.1<z<1.0)

- Deep 100−500μm PACS+SPIRE imaging (~5 deg^2)
- IRAC observations for ALL clusters, ~75% have MIPS 24μm
- Complete multi-band wide-field optical and near-infrared coverage
- 90% GALEX UV coverage (unfortunately not Bullet Cluster)

- Sample includes all 25 CLASH clusters
- Sample includes all 6 HST Frontier Fields → **Rawle+16** for full Herschel catalogues



HLS SPIRE 250μm imaging of first 4 HFF clusters



- Chandra **X-ray** (500ks)

- Magellan IMACS **B, V, R**
- HST optical
- VLT HAWK-I **Y, J, H**
- Spitzer IRAC 4 channel (**3.6, 4.5, 5.8, 8μm**)
- WISE 4 band (**3.6, 4.6, 12, 22μm**)
- Spitzer MIPS **24μm**
- Herschel PACS **70, 100, 160μm**
- Herschel SPIRE **250, 350, 500μm**

- **371** cluster spec-zs

- Chandra **X-ray** (120ks)
- GALEX **UV**
- ESO2.2m WFI **U-band**
- HST optical (including HFF ultra-deep)
- CTIO NEWFIRM **J** and **K_s**
- Spitzer IRAC 4 channel (**3.6, 4.5, 5.8, 8μm**)
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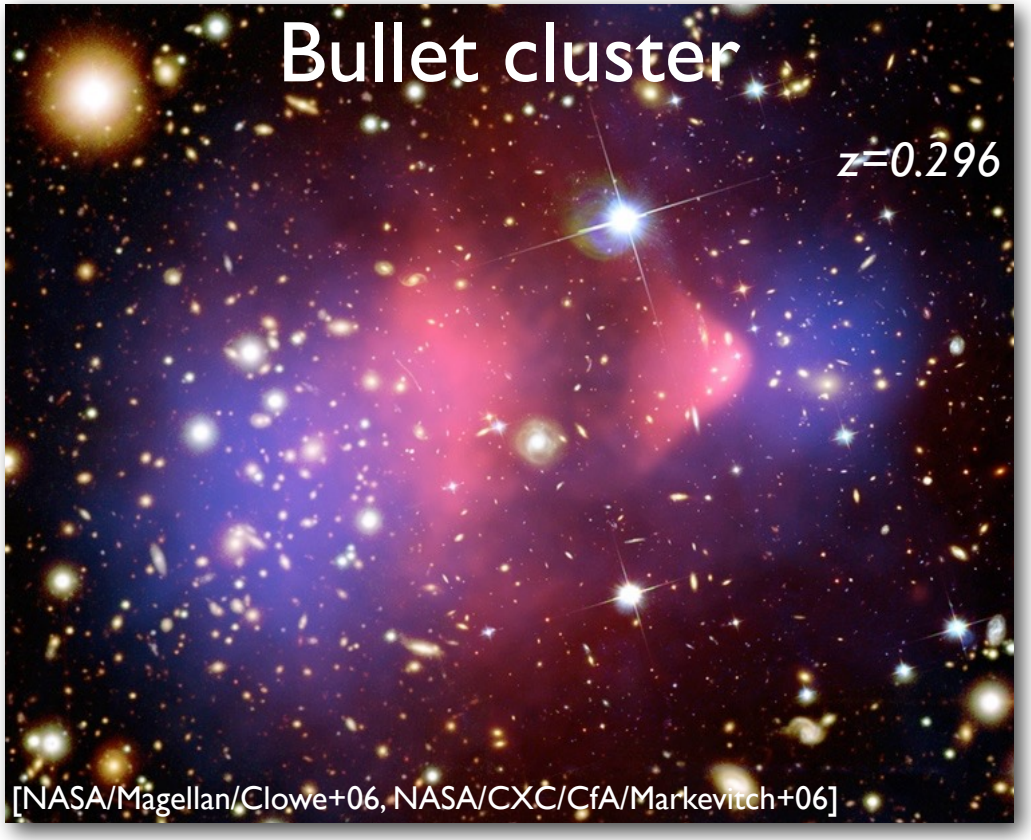

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SFR_{UV}

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- Herschel PACS **70, 100, 160μm**
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SFR_{IR}

- **371** cluster spec-zs

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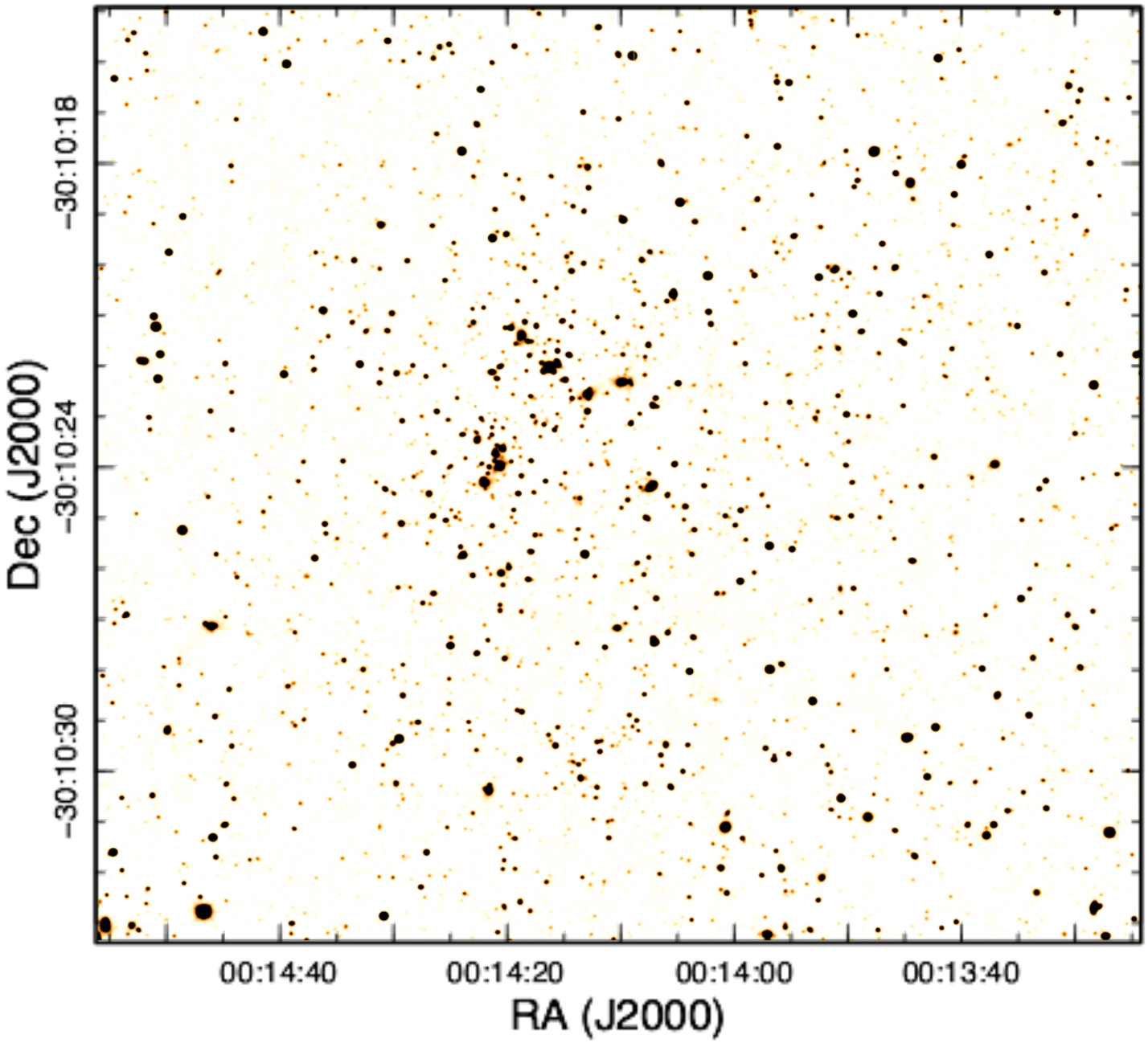
- **447** cluster spec-zs

esa

A2744 (Pandora's cluster)



CTIO/NEWFIRM
K band

[Rawle+14]

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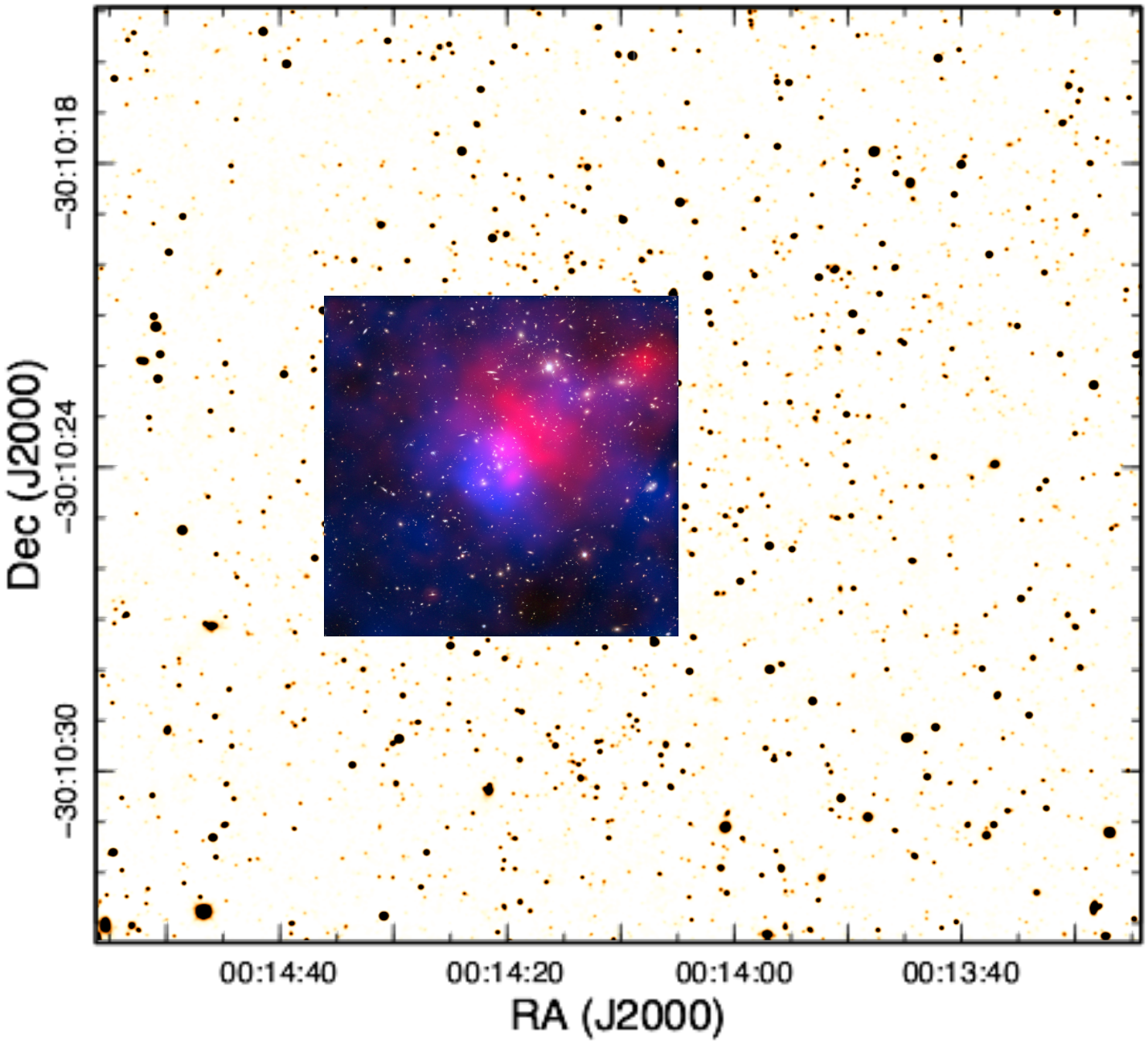

CTIO/NEWFIRM
K band

[Rawle+14]

Optical+lensing+
X-ray

[NASA/ESA/ESO
Merten+11]

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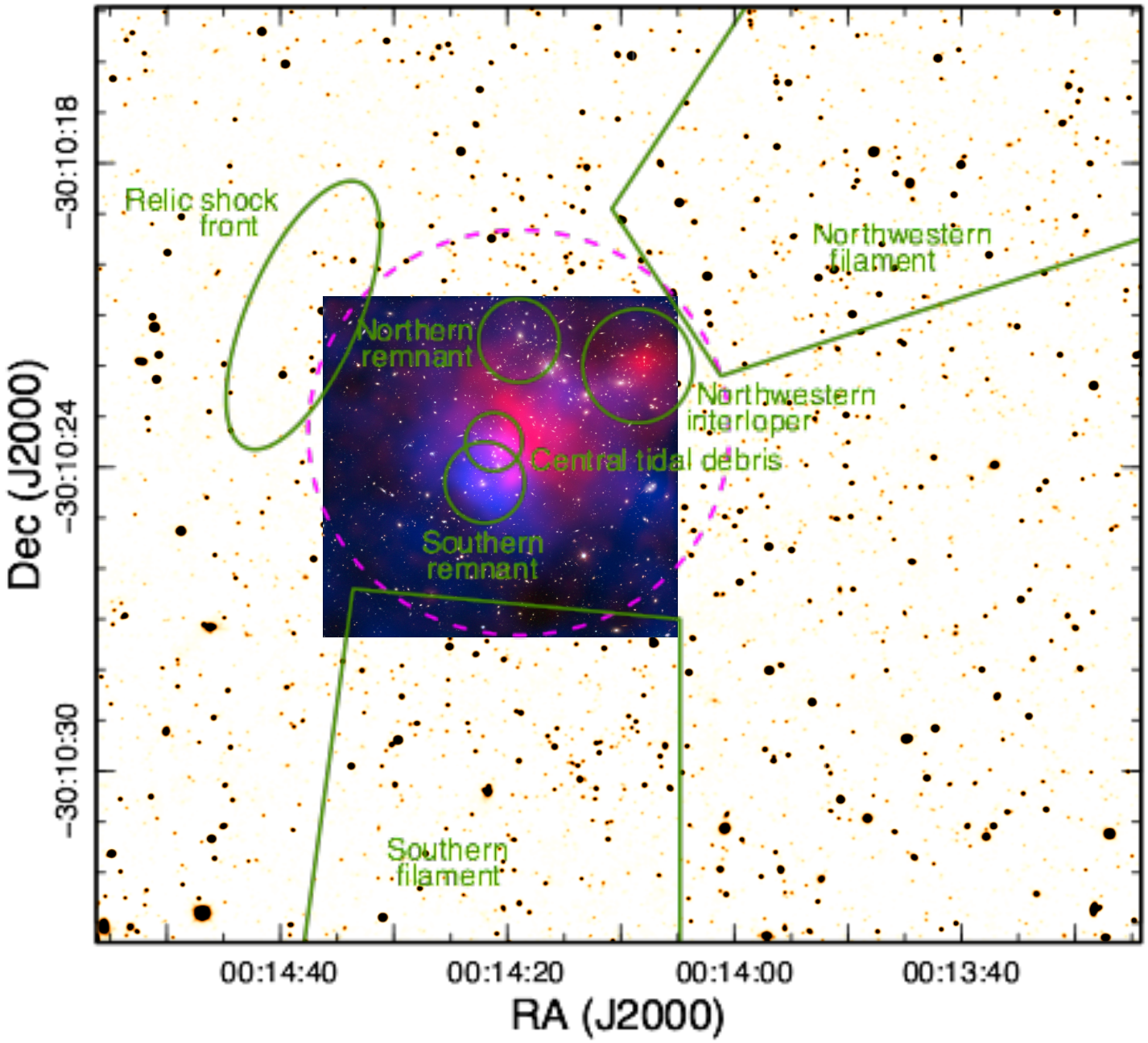

Primary cluster substructure

[Kempner & David 2004, Boschin+2006, Braglia+09, Owers+2011, Merten+11]

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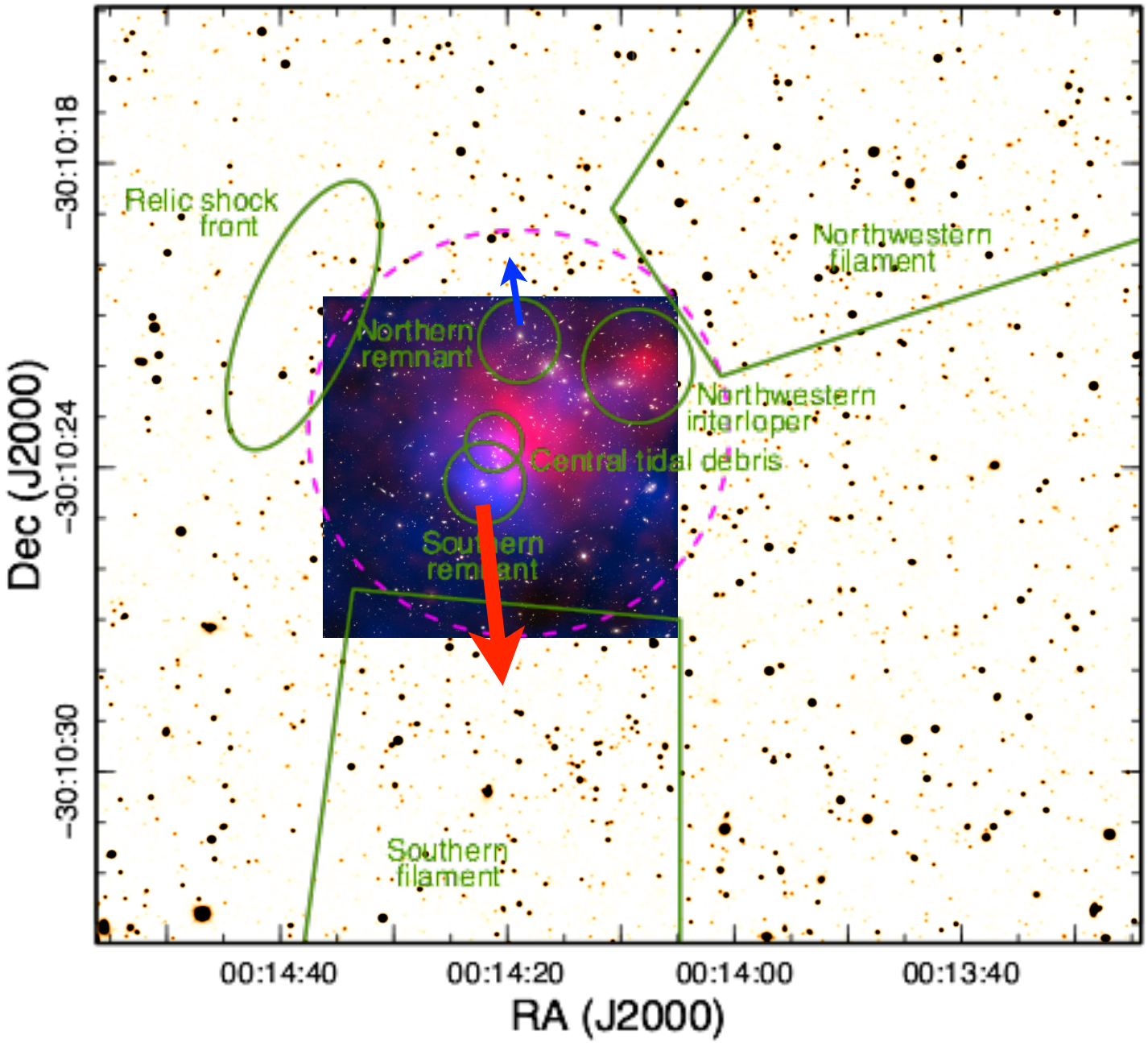

Central merger:
~3:1 mass ratio
~Mach 3 shock front

Southern remnant (bullet-like):
Moving southwards & away from observer

Northern remnant (main cluster):
Moving northwards and towards observer

[e.g. Kempner & David 2004, Boschin+2006, Owers+2011]

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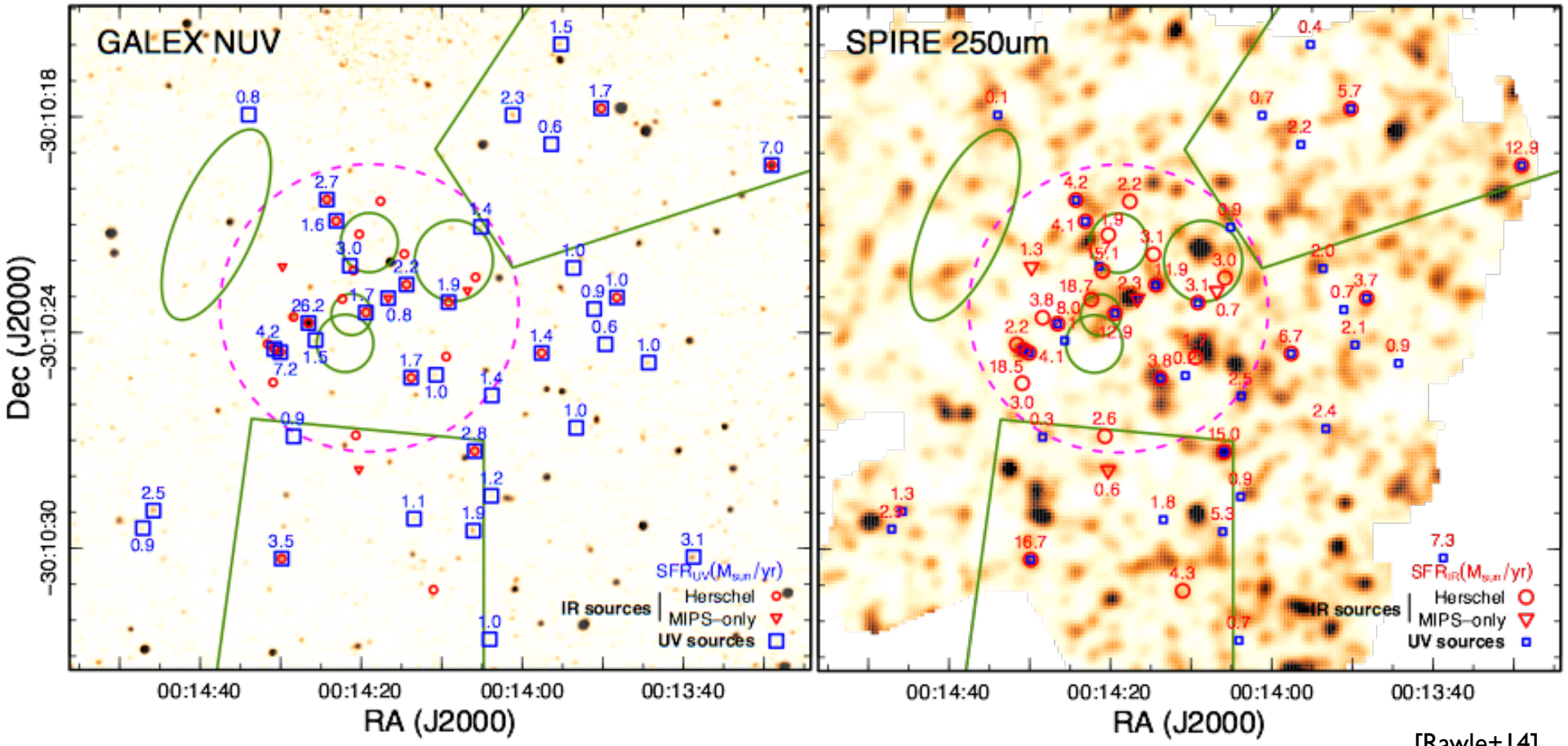


[Rawle+14]

53 star-forming cluster galaxies:

16 UV+IR

15 IR only

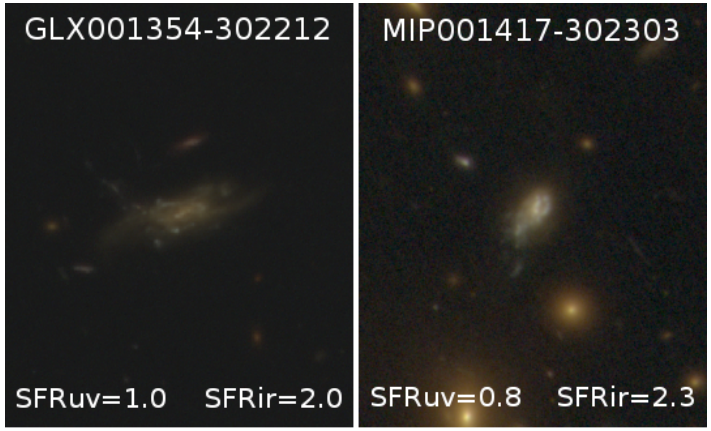
22 UV only

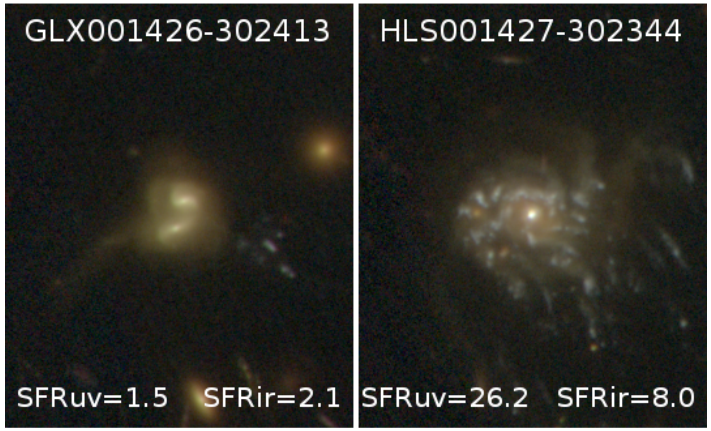
$SFR_{IR} = 138 \pm 8\ M_\odot\ yr^{-1}$

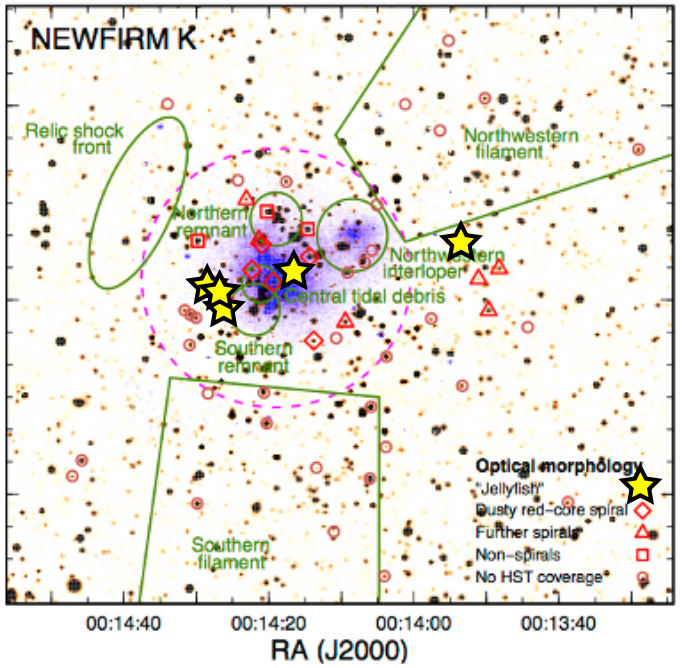
$SFR_{IR} = 63 \pm 3\ M_\odot\ yr^{-1}$

$SFR_{UV+IR} = 201 \pm 9\ M_\odot\ yr^{-1}$

Jellyfish in A2744







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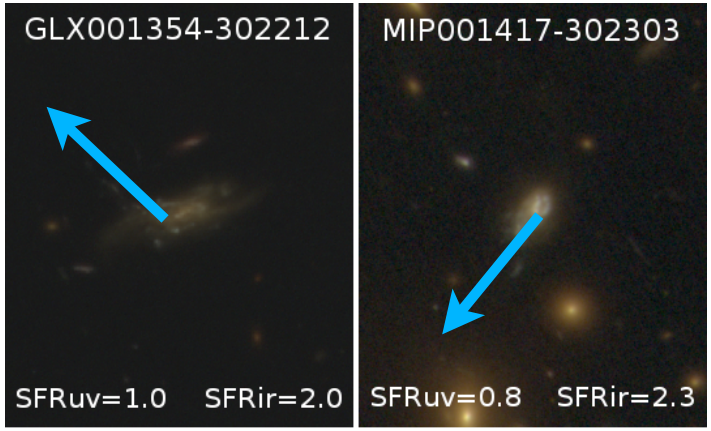
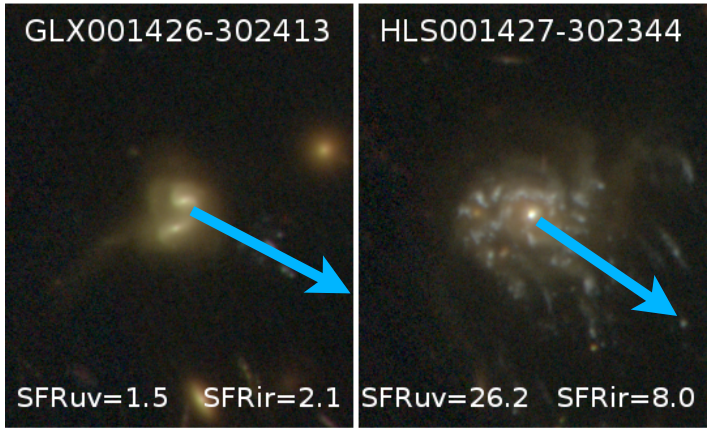
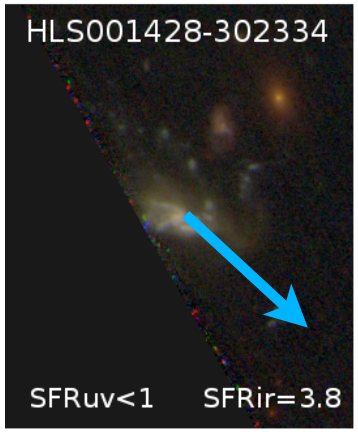
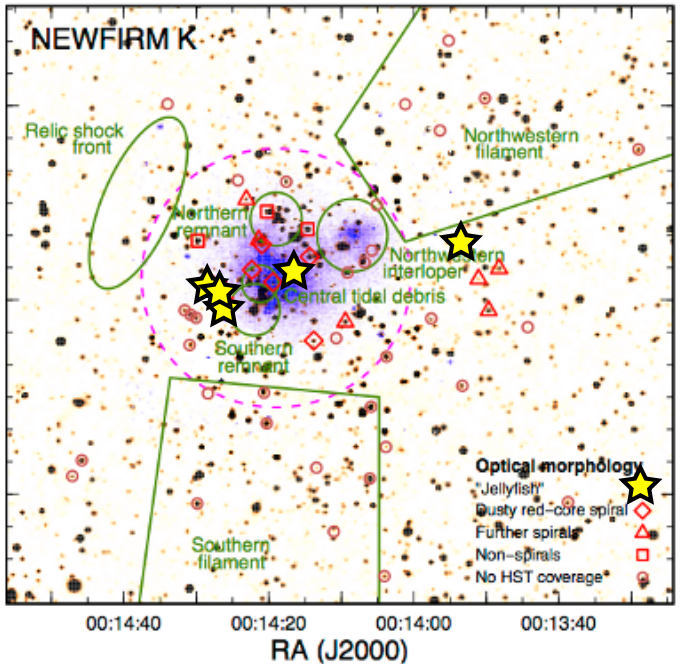


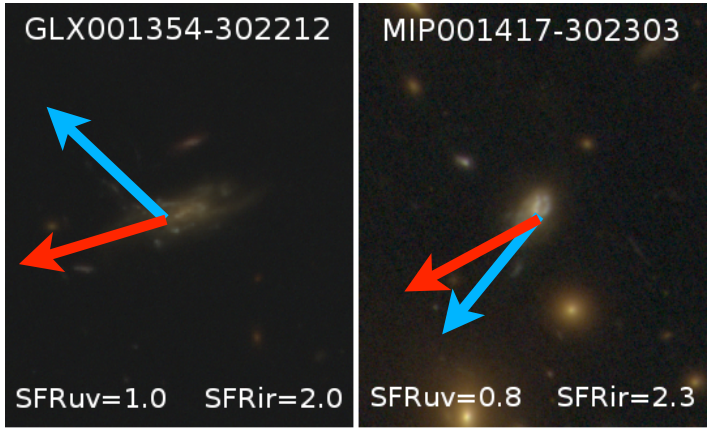


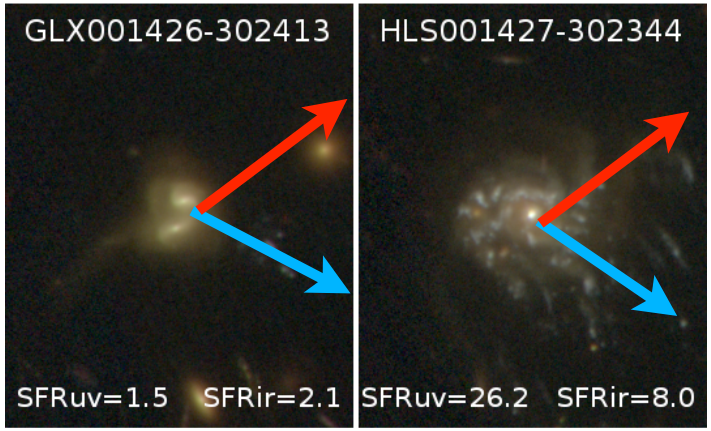


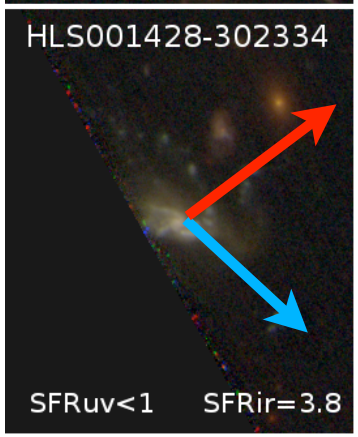


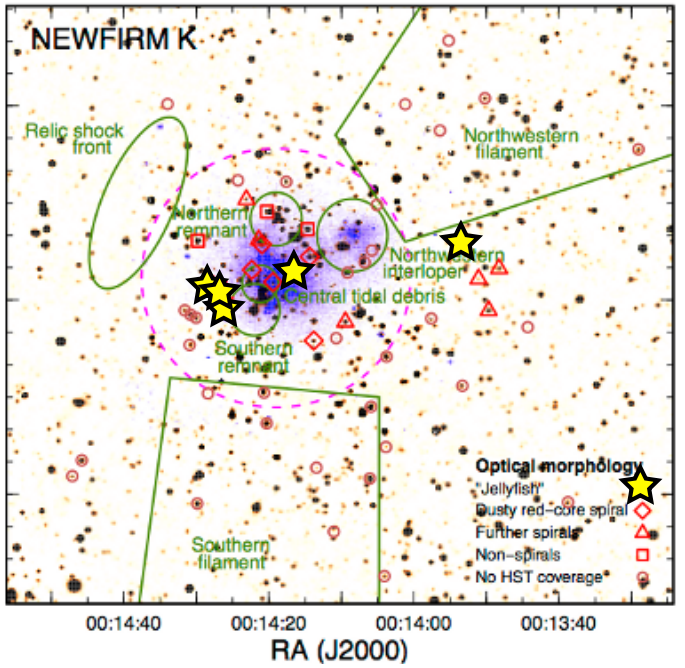
Trail direction

Jellyfish in A2744





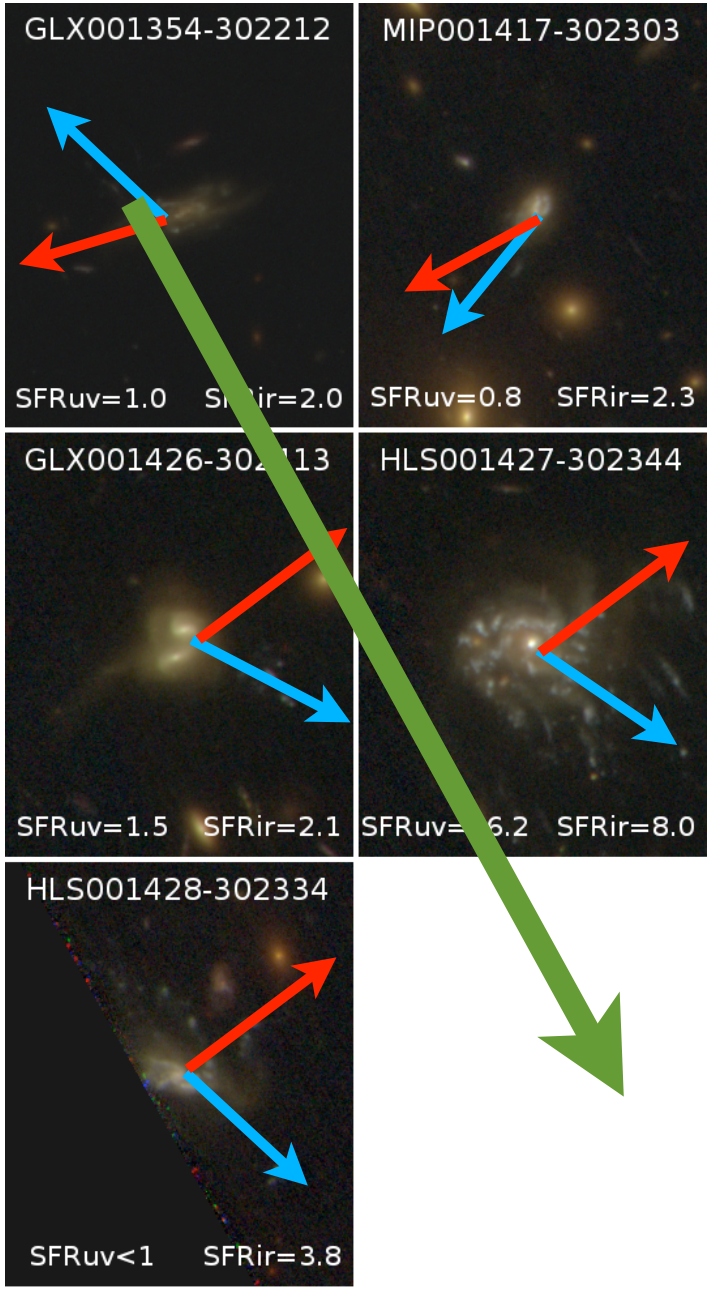


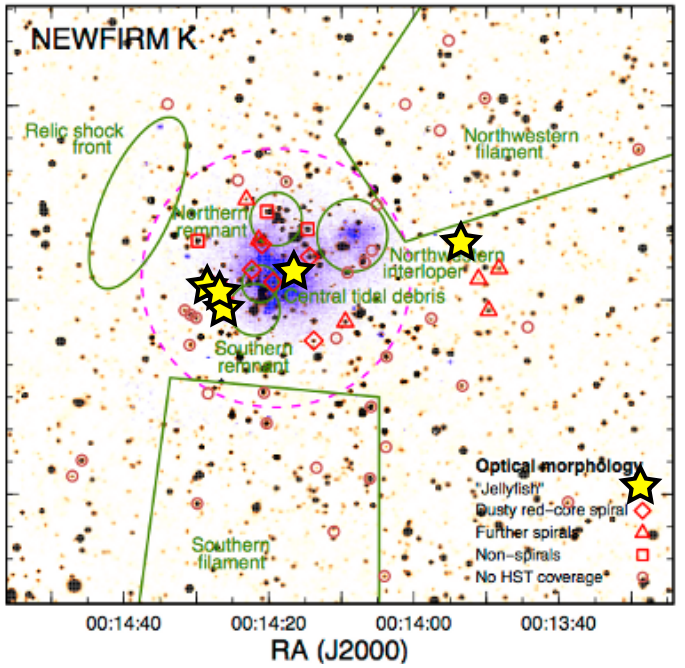


Trail direction

Direction TO cluster centre

Jellyfish in A2744



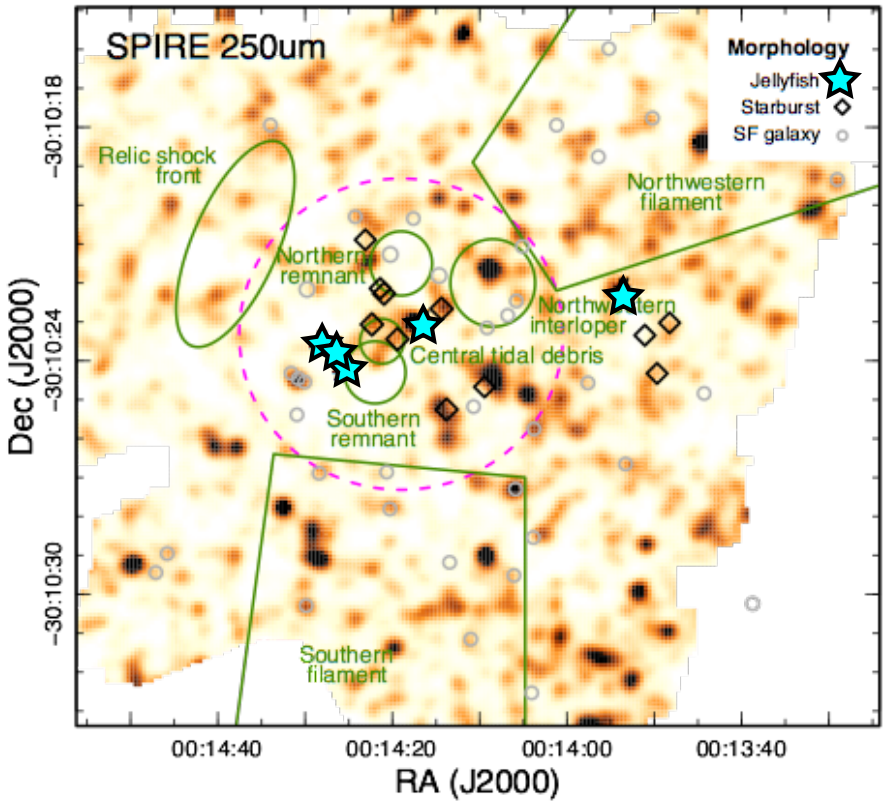


Trail direction

Direction TO cluster centre

Dynamic axis of the merger

A trail of transformation in A2744



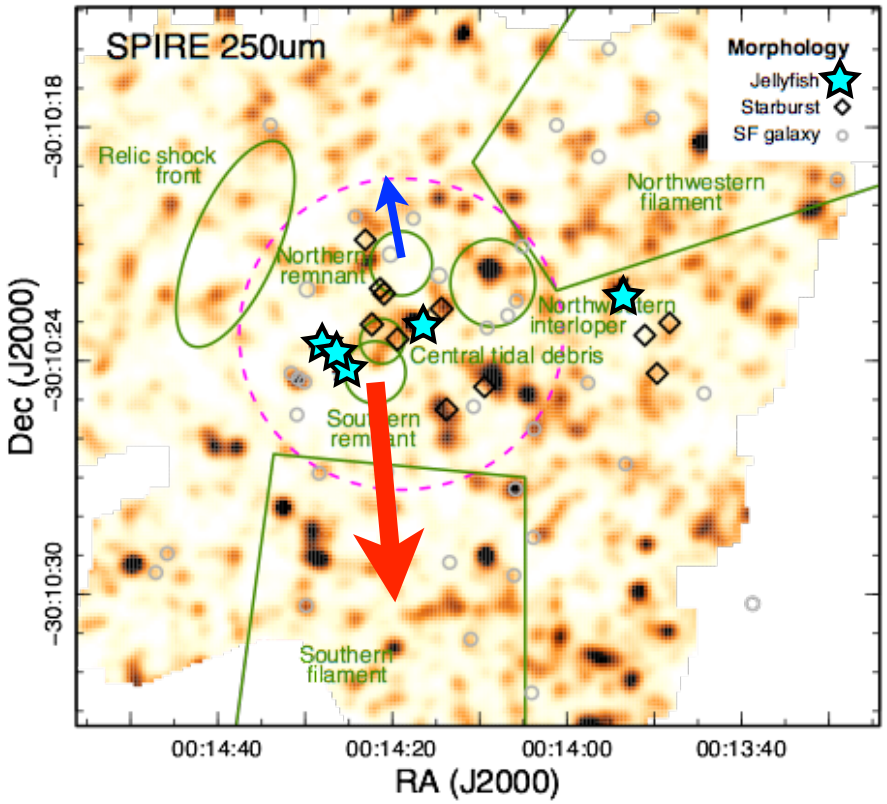
[Rawle+14]

A trail of transformation in A2744

Southern remnant (bullet-like):
Moving southwards & away from observer

Northern remnant (main cluster):
Moving northwards and towards observer

[e.g. Kempner & David 2004, Boschin+2006, Owers+2011]



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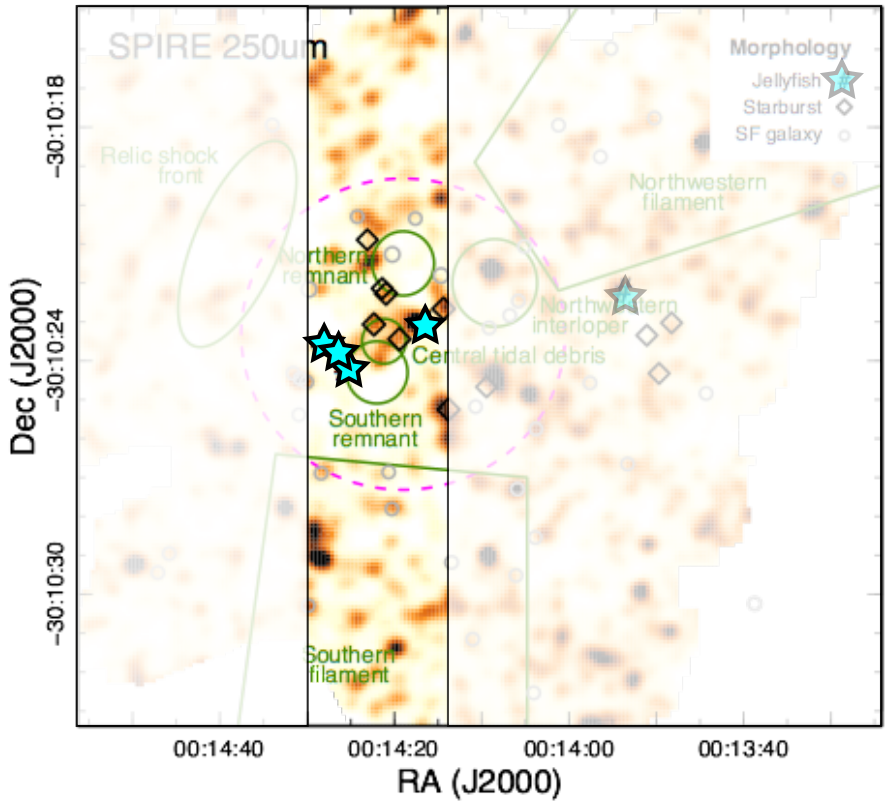

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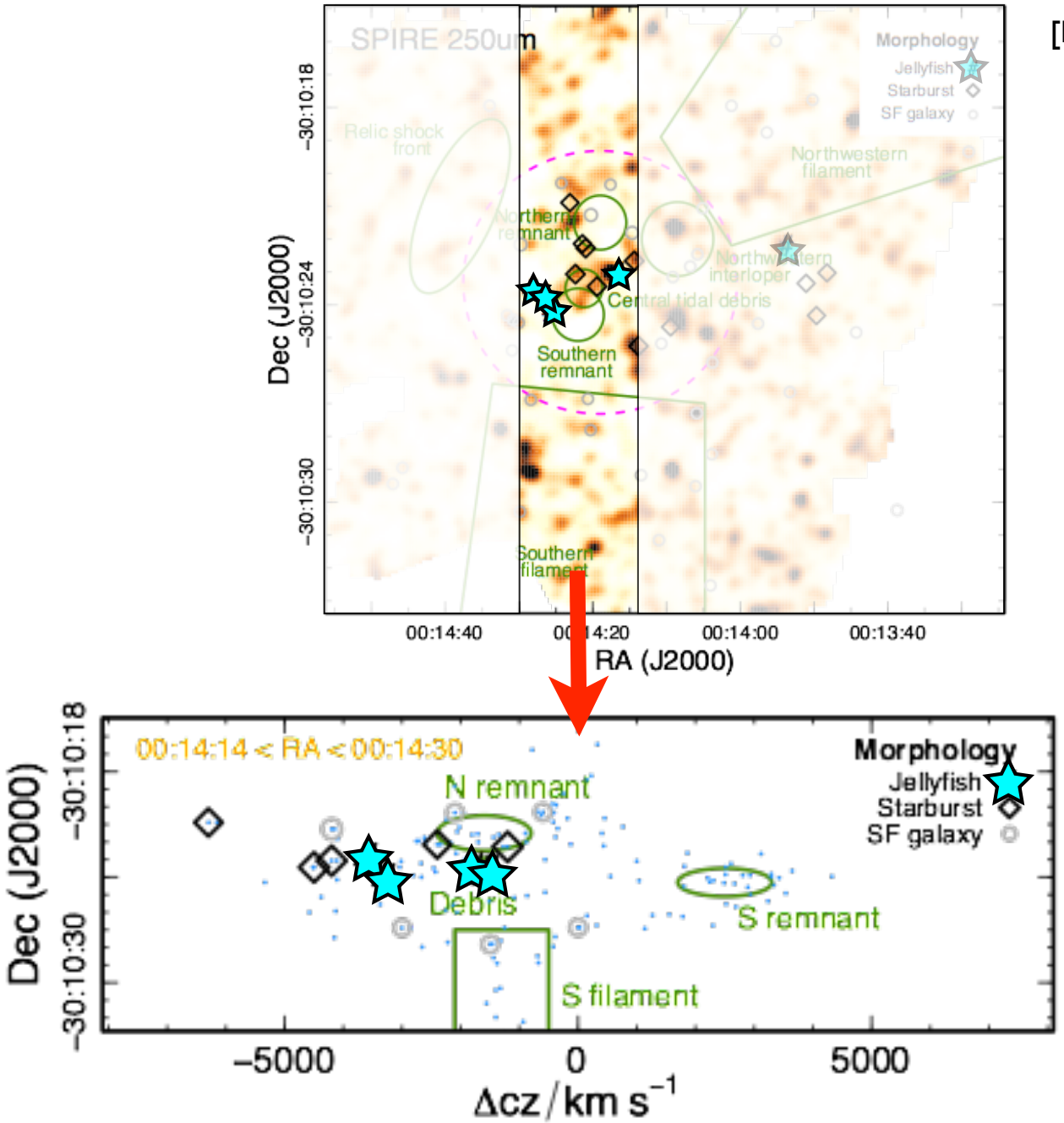

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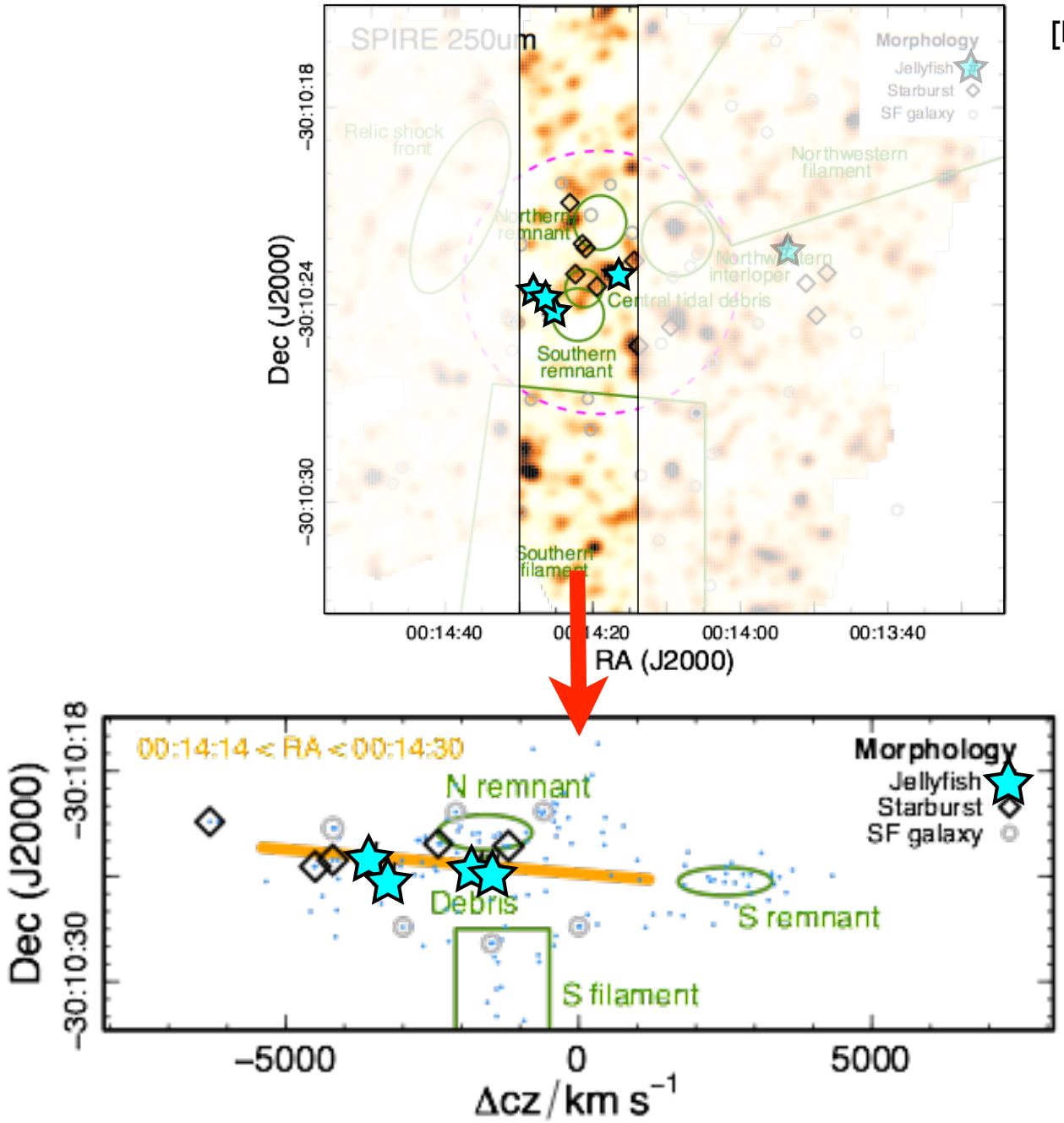
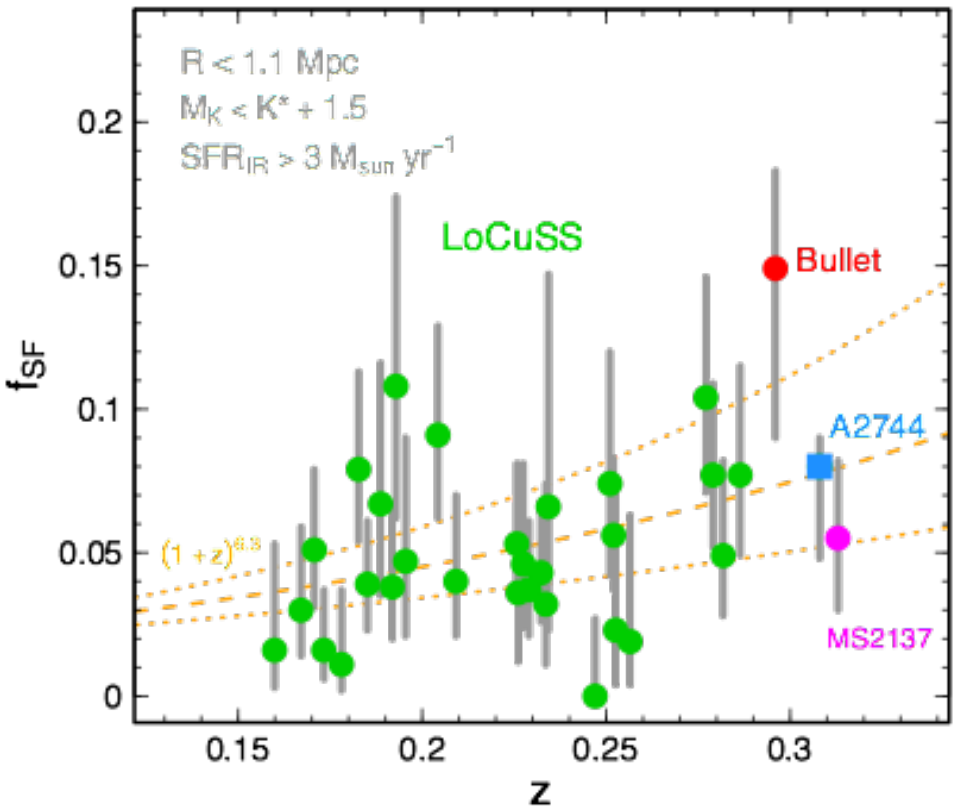
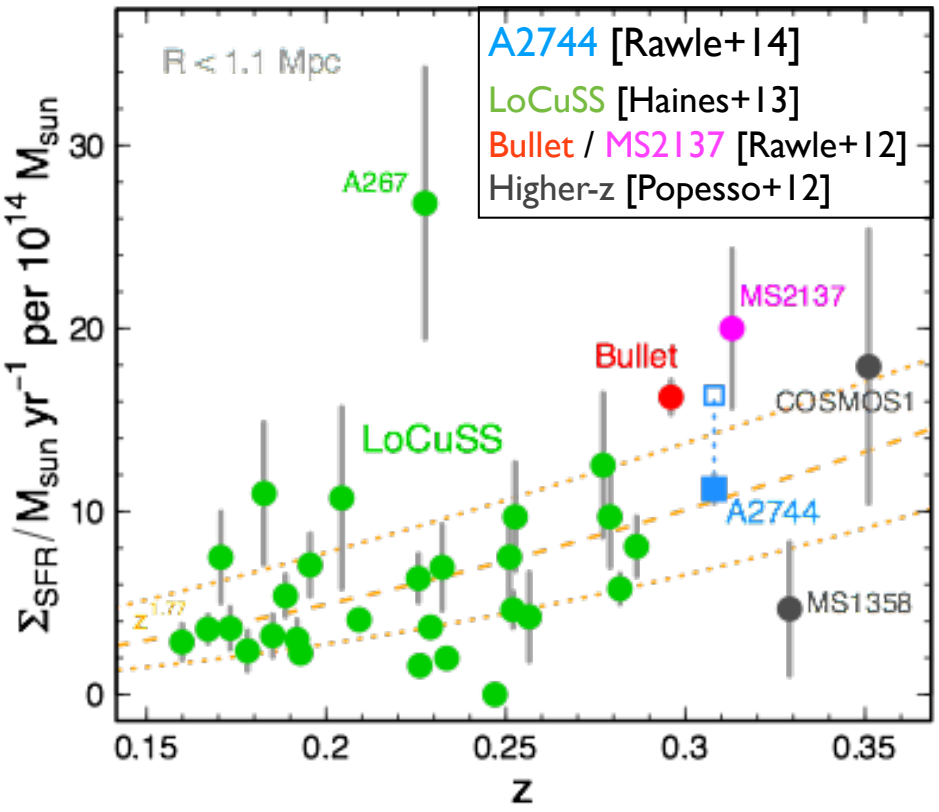


[Rawle+14]

Passage of "bullet" leaves behind a trail of galaxy transformation, including both triggered star formation AND significant stripping

Total cluster obscured star formation





In A2744, the merger has a net-zero effect on the bulk obscured star formation properties. In the Bullet, they are only marginally enhanced.

The IR properties are not systematically correlated with the existence of a recent merger (A2744, Bullet, MS1358).

The possible enhancement of unobscured SF properties in A2744 (e.g. by Jellyfish) needs confirmation via similar UV+IR analysis in other clusters

Summary

SFR_{IR} Not systematically correlated with the existence of a recent merger

Starbursts behind the shock front in A2744 - balanced by stripping elsewhere?

SFR_{UV} Possible enhancement of unobscured SF properties in A2744 needs confirmation via UV+IR analysis of more clusters (63 remaining HLS clusters).

Both obscured and unobscured SF is crucial to understand the galaxy evolution within the densest environments

- **Environmental effects not a simple function of local density, but dynamics too**

- **Clusters of same density at different redshifts may have different dynamics**

Rawle et al., 2010, A&A, 518, 14 *"Deep Herschel view of obscured star formation in the Bullet cluster"*

Rawle et al., 2012, ApJ, 756, 106 *"Discovery of 'Warm Dust' Galaxies: Evidence for Stripping of Cool Dust in the Dense Environment?"*

Rawle et al., 2014, MNRAS, 442, 196 ***"Star formation in the massive cluster merger Abell 2744"***

Rawle et al., 2016, MNRAS, accepted (arXiv:1508.00586) *"Complete census of Herschel-detected sources within the HFF"*

Tim Rawle

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http://astro.rawle.org/

…briefly wearing my JWST/NIRSpec hat

- JWST on schedule for launch in Oct 2018
- Cycle 1 GO call will be Nov 2017 (Early Release Science call Mar 2017)
- NIRSpec = Near-Infrared Spectrograph (provided by ESA)

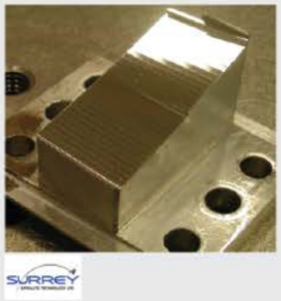
MOS

Multi-object spectroscopy with 0.2″-wide mini-slits.

~250,000 configurable shutters
~100 simultaneous targets

- 9 square arcmin. field of view
- Low spectral resolution (30 to 300), prism-based mode covering the 0.6-5.0 micron range in one exposure.
- Medium spectral resolution (500 to 1300), grating-based mode covering the 0.7-5.0 range

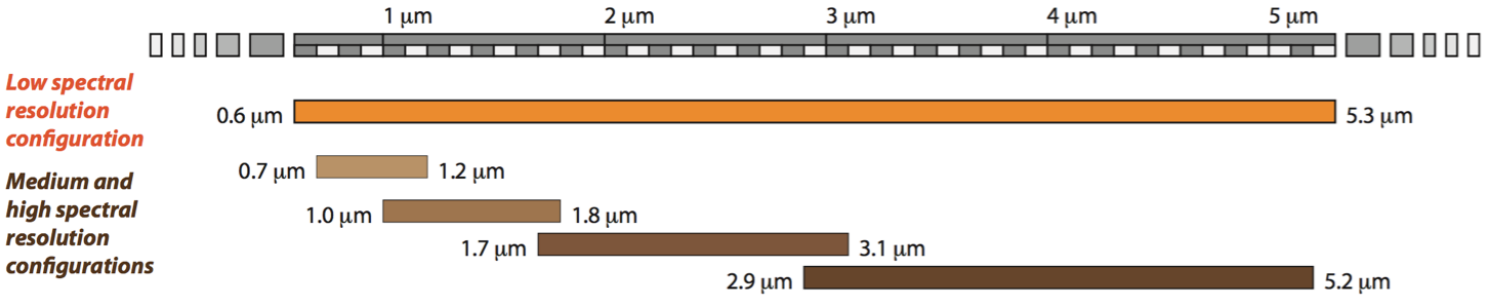
IFU



IFU spectroscopy with a 0.1″ sampling.

(IFU made of 30 slices for a total of 900 "spaxels")

- 3″x3″ field of view
- Low spectral resolution (30 to 300), prism-based mode covering the 0.6-5.0 micron range in one exposure.
- Medium (500 to 1300) and high (1400-3600) spectral resolution modes, covering the 0.7-5.0 range in 4 exposures.
- IFU and MOS cannot be used at the same time.



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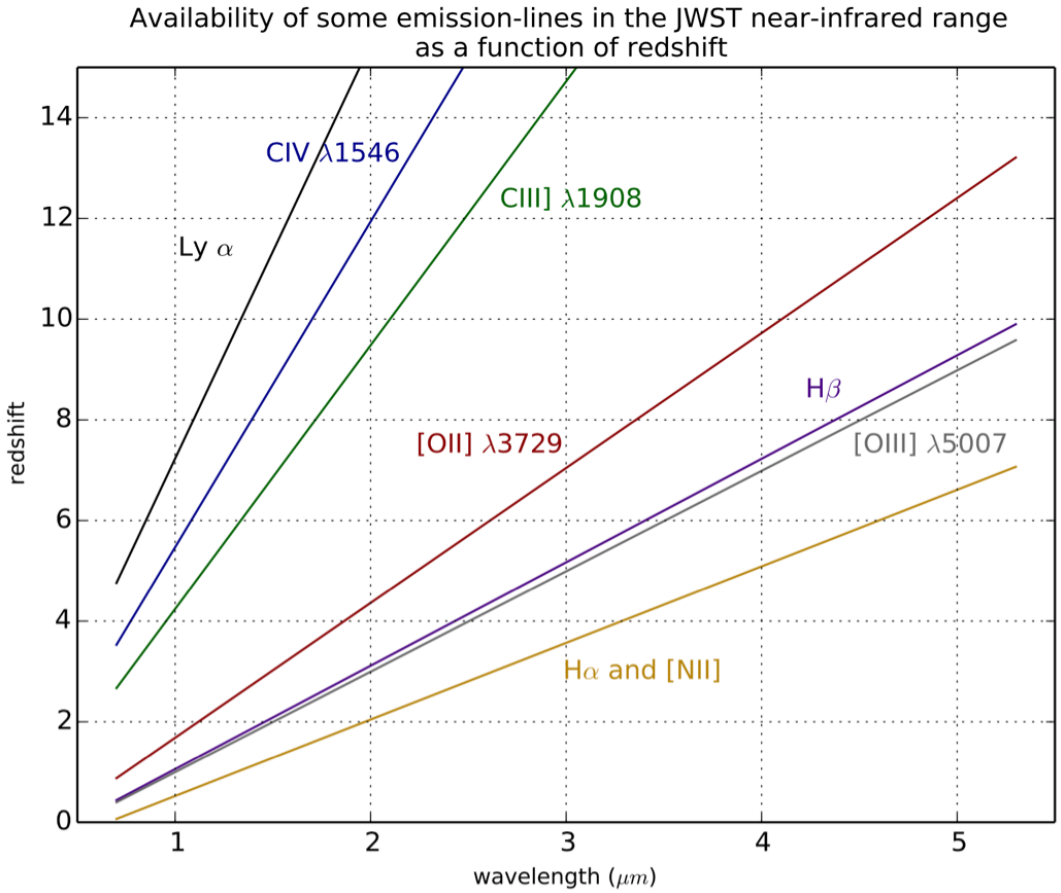
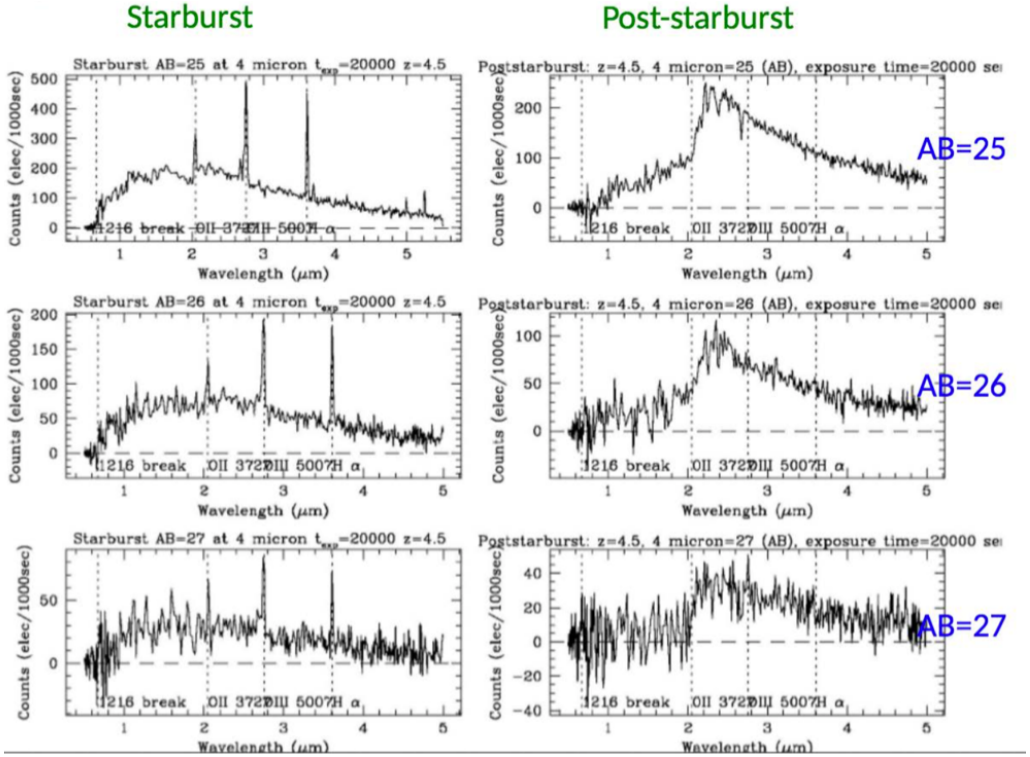


NIRSpec MSA simulations: T_{exp}=20,000s; z=4.5; R100



Summary

- **Environmental effects not a simple function of local density, but of cluster-scale dynamics too**

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