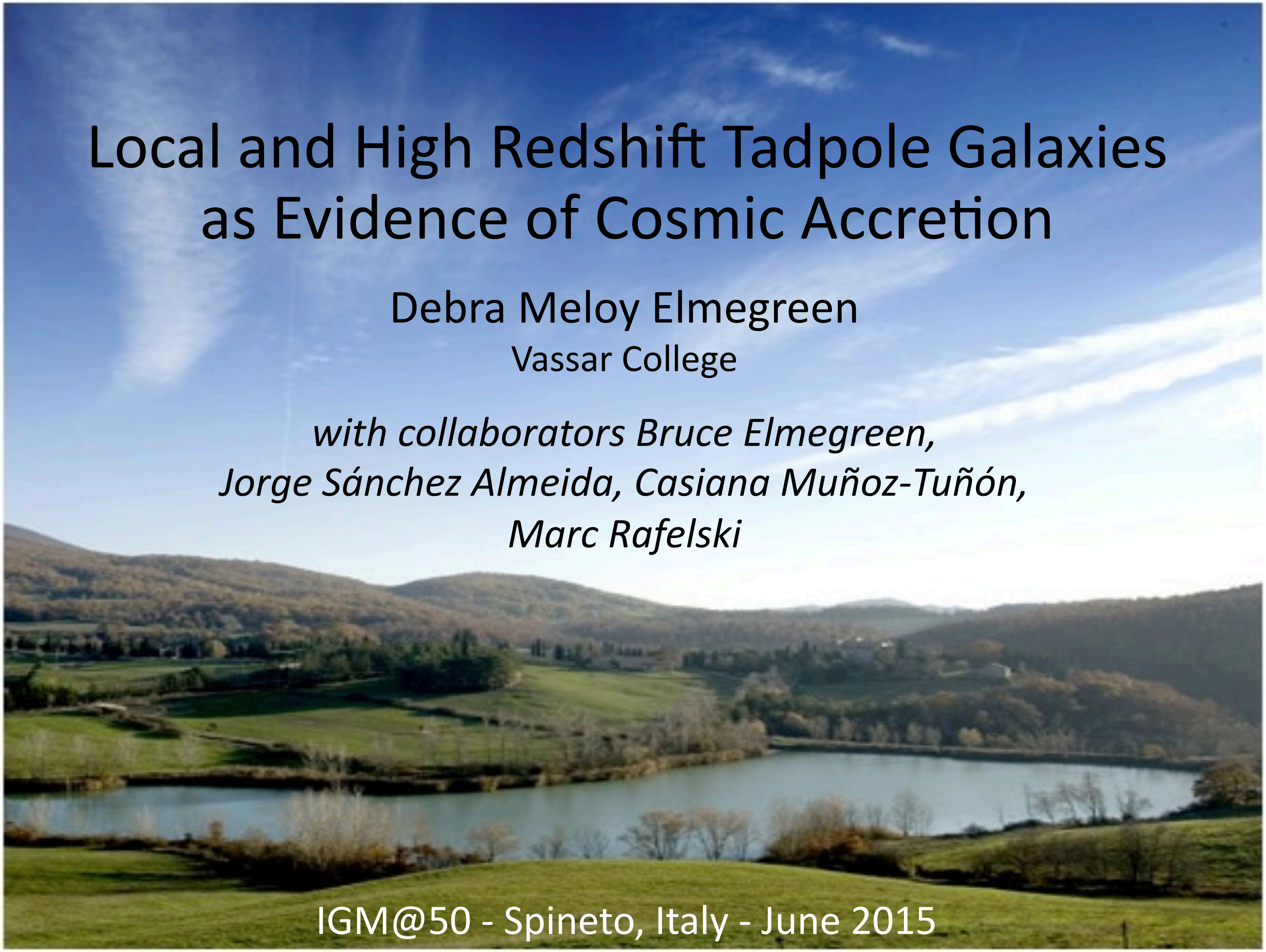

Local and High Redshift Tadpole Galaxies as Evidence of Cosmic Accretion

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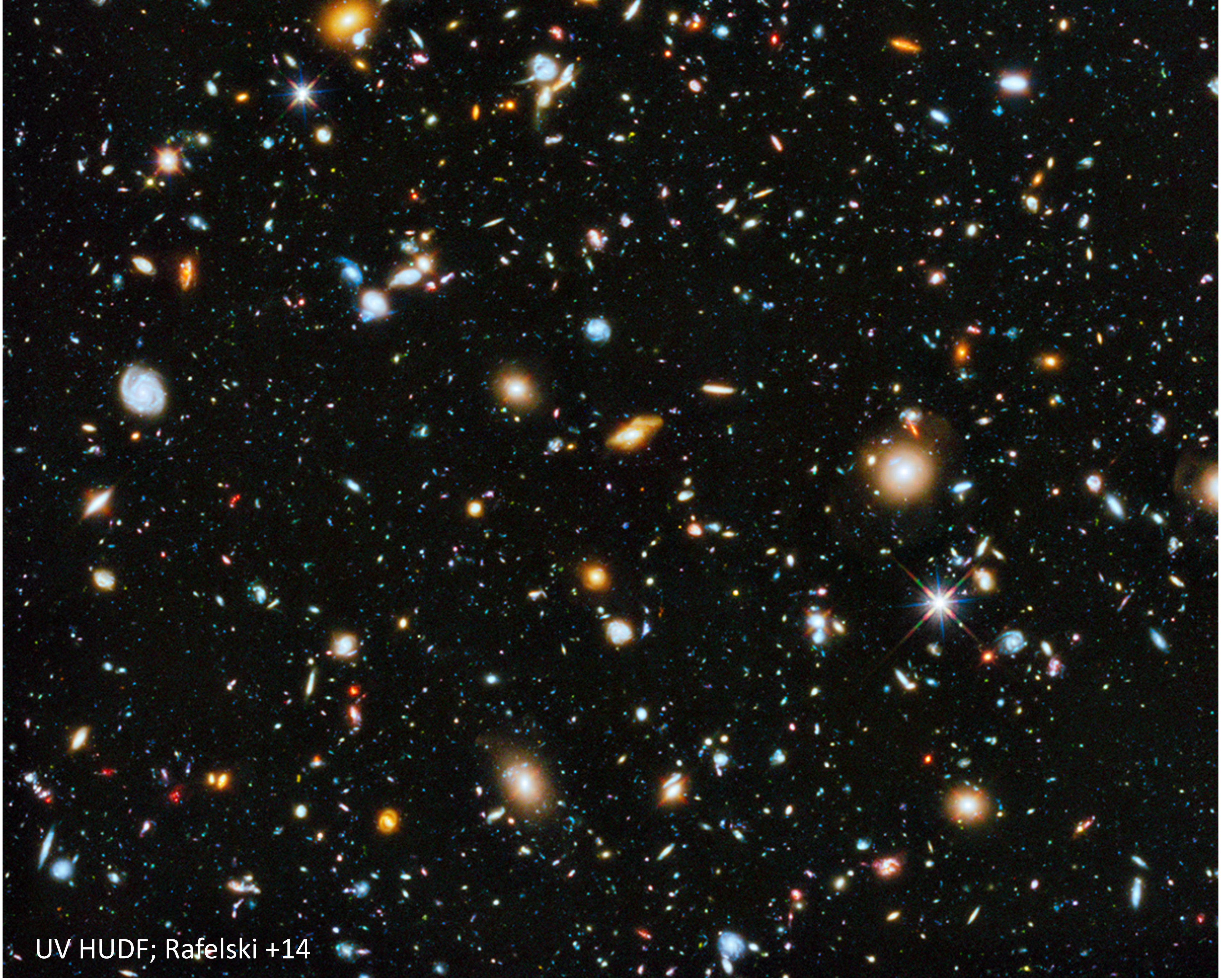
Vassar College

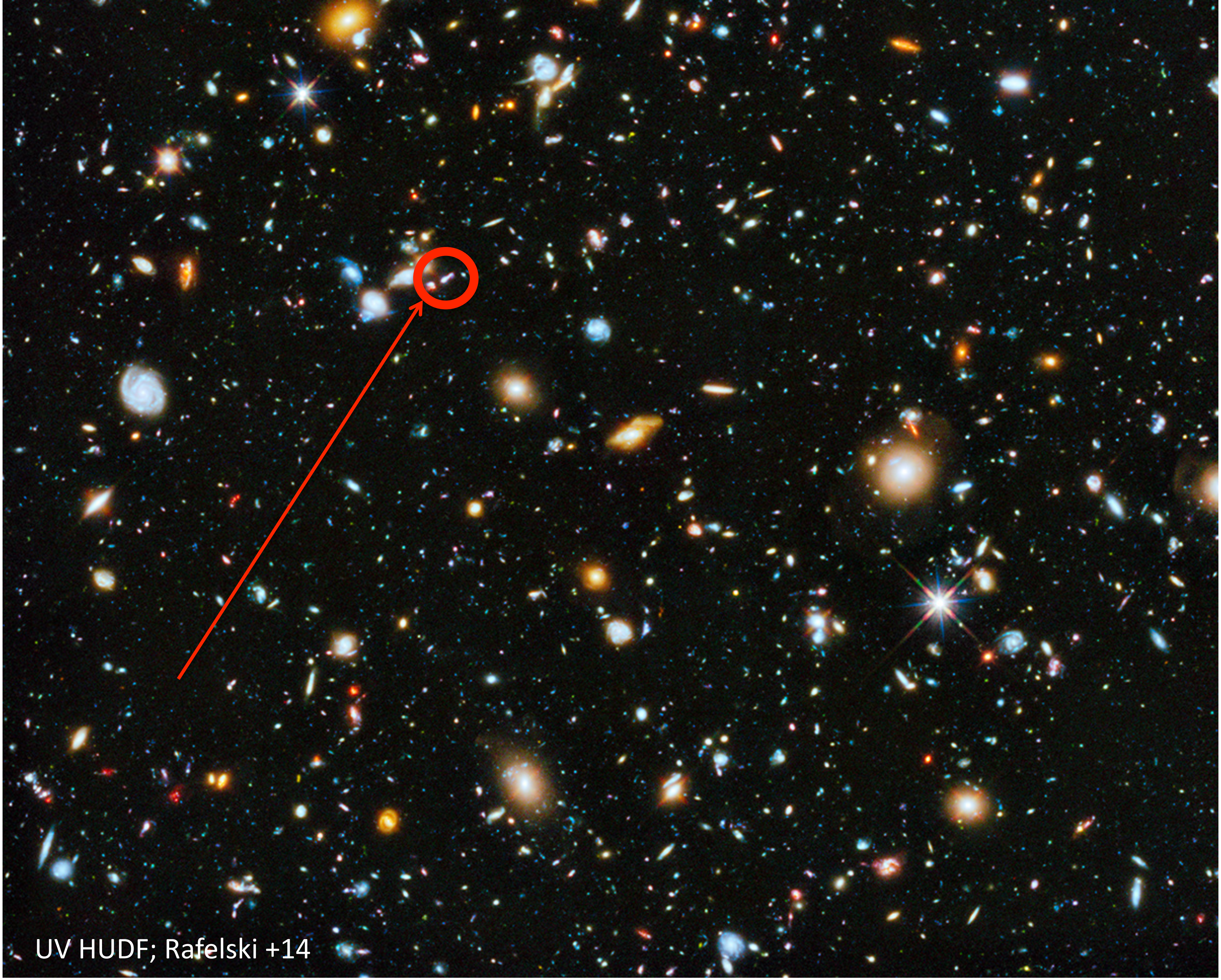
with collaborators Bruce Elmegreen, Jorge Sánchez Almeida, Casiana Muñoz-Tuñón, Marc Rafelski

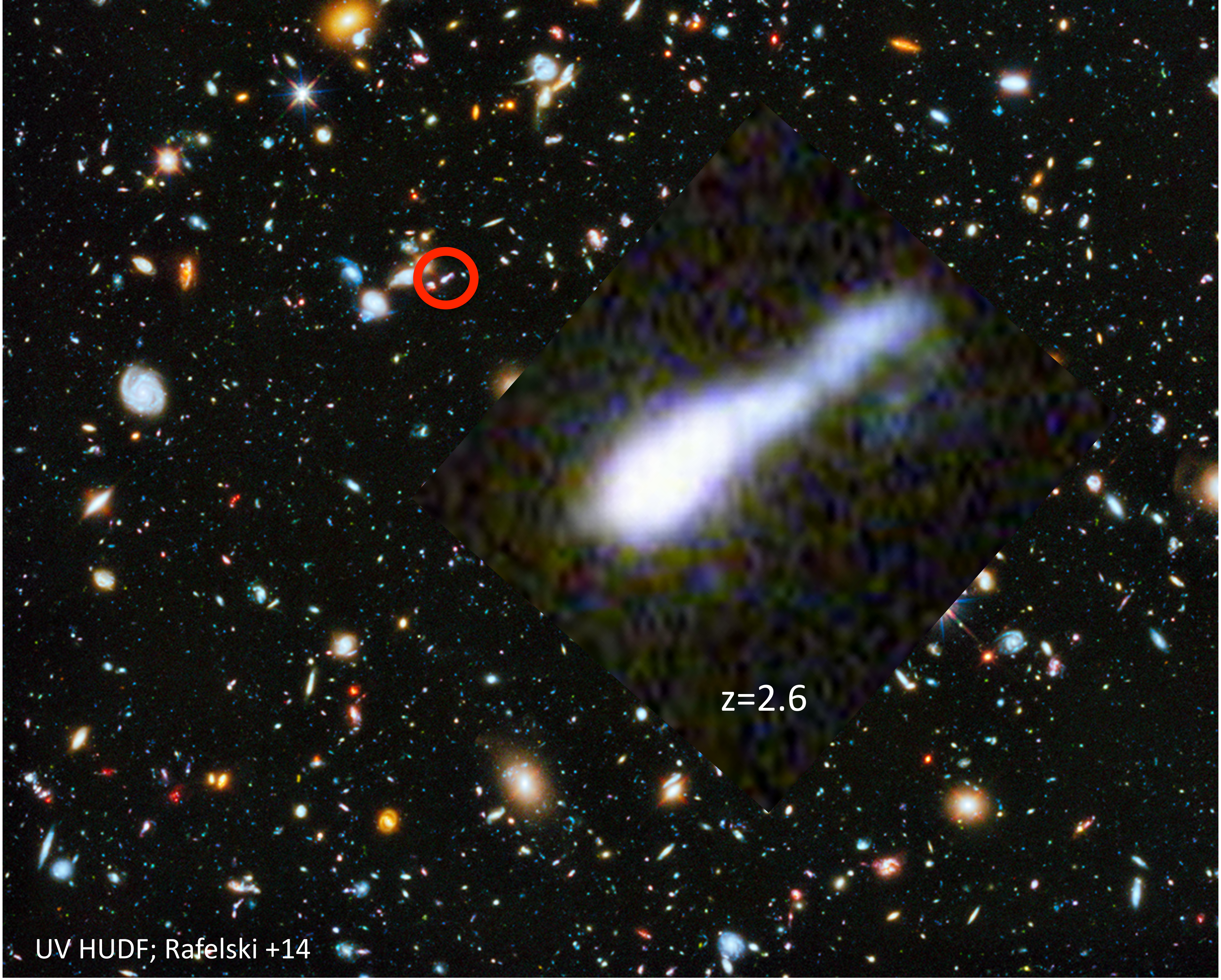
IGM@50 - Spineto, Italy - June 2015

Outline

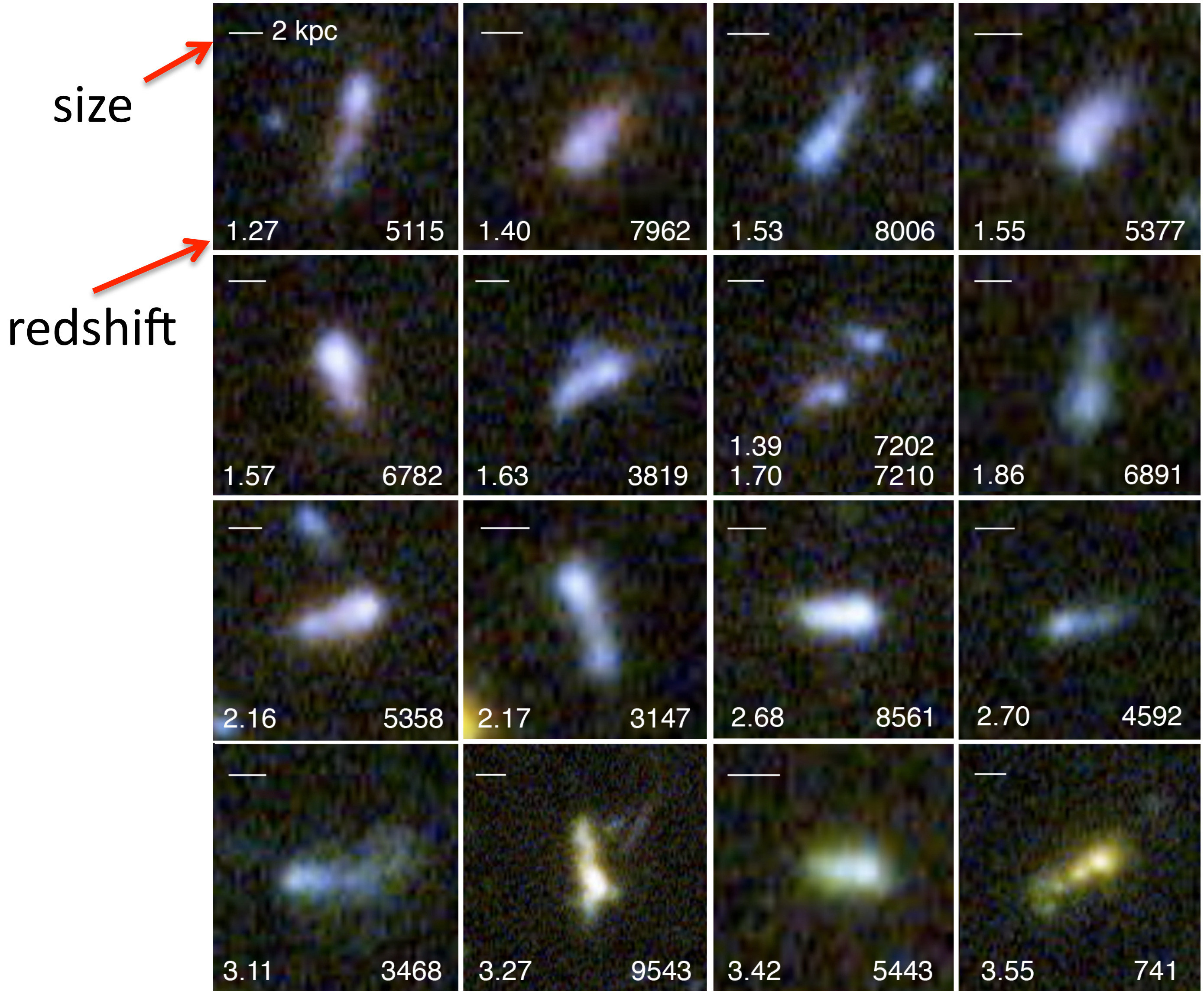
- Occurrence of high z and local tadpoles
- Mechanisms for tadpole formation
- Recent HST observations of a local tadpole
- Comparison of star formation rates in local and high z tadpoles


UV HUDF; Rafelski +14


UV HUDF; Rafelski +14


z=2.6
UV HUDF; Rafelski +14

Tadpole galaxies in the UDF

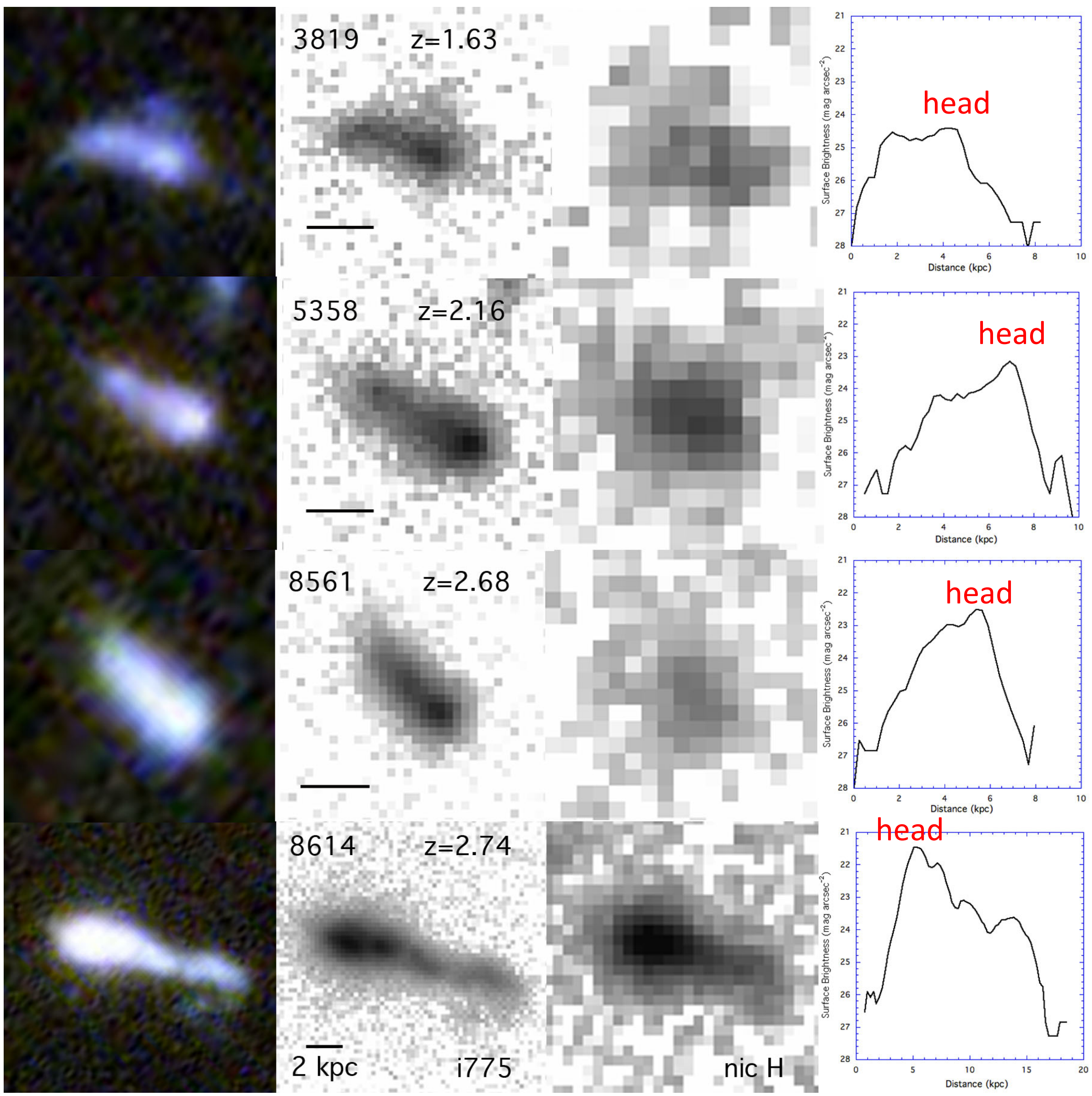


~10% of resolved UDF galaxies are tadpoles;

30% of clumpy galaxies are tadpoles

Elmegreen +07,10

(see van den Bergh+ 96, Abraham+ 96, Straughn+06,Windhorst+06, de Mello+06)

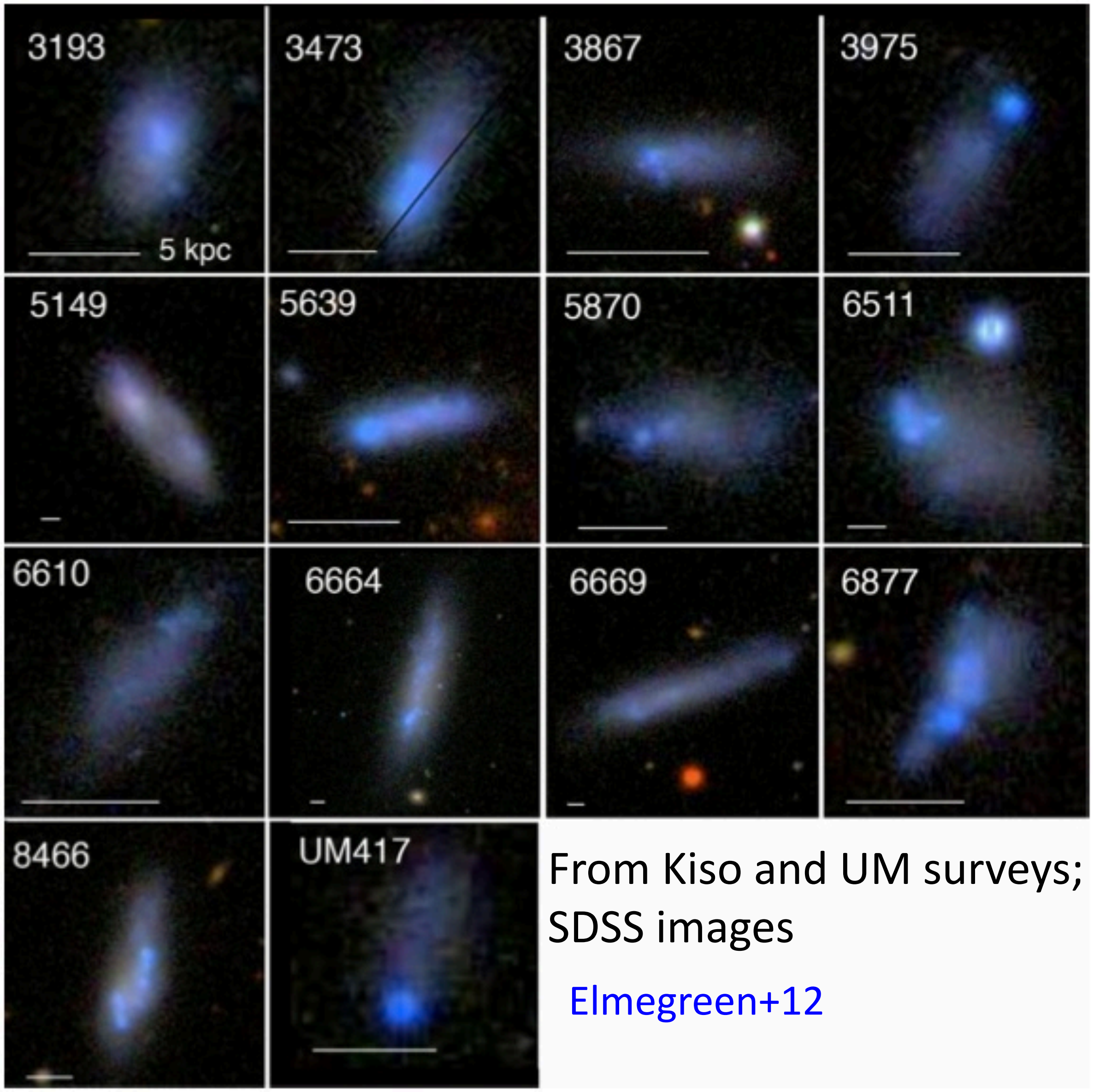


ACS i775 NICMOS H Surface brightness profile

Radial light profiles are dominated by the head

Elmegreen^2 2010

Local tadpoles



From Kiso and UM surveys; SDSS images

Elmegreen+12

Only 0.2% of the galaxies in the Kiso Survey of UV-bright local galaxies are tadpoles

But 70% of metal-poor BCDs are tadpoles, and tadpoles are often XMPs (Papaderos+08, Morales-Luis+11, Filho+13, Sánchez Almeida+13,14,15)

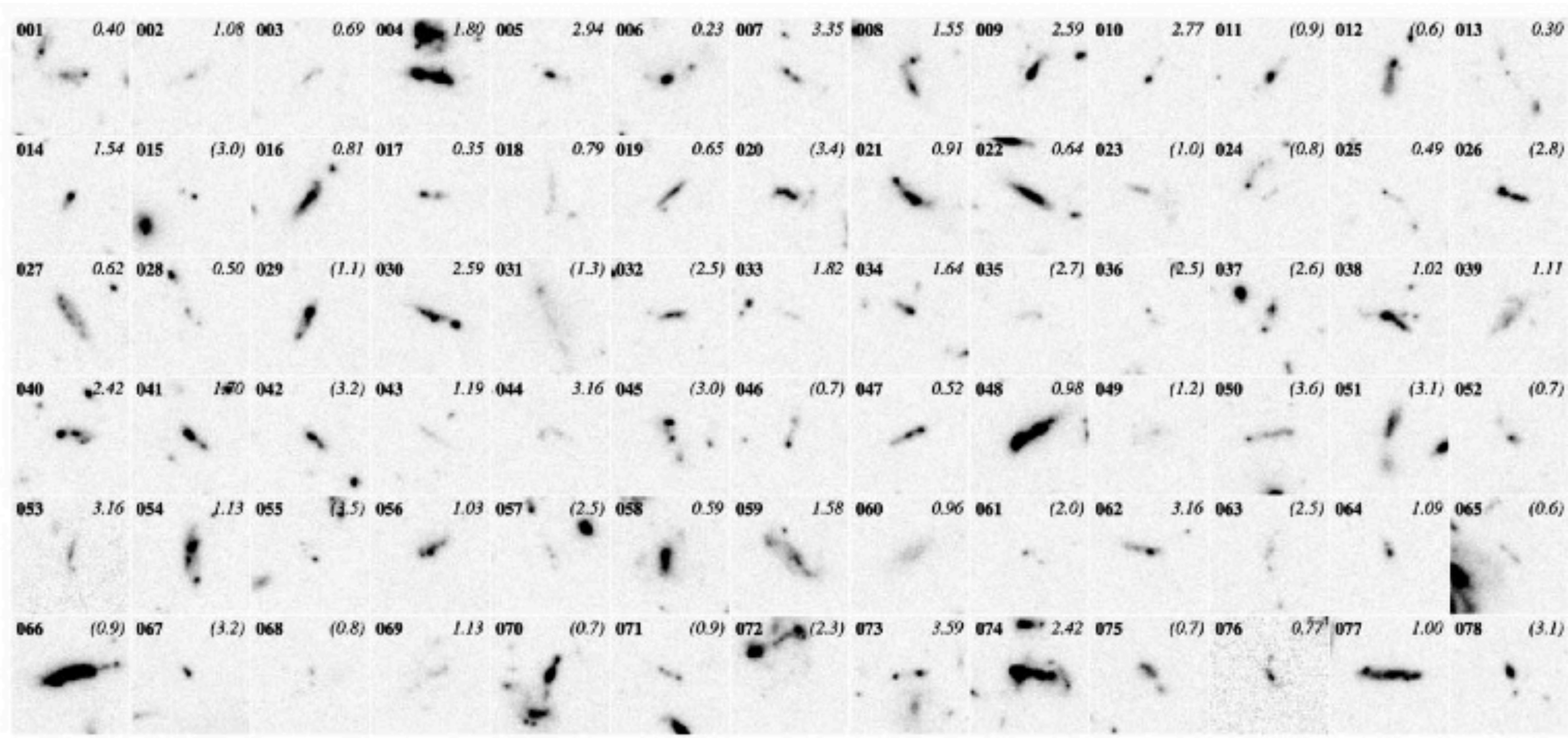
What makes tadpoles?

Possibilities

- Mergers
- Ram pressure stripping
- Cosmic web accretion
- Local random Jeans instability in disk

Mergers? SExtractor-selected “tadpoles” in UDF

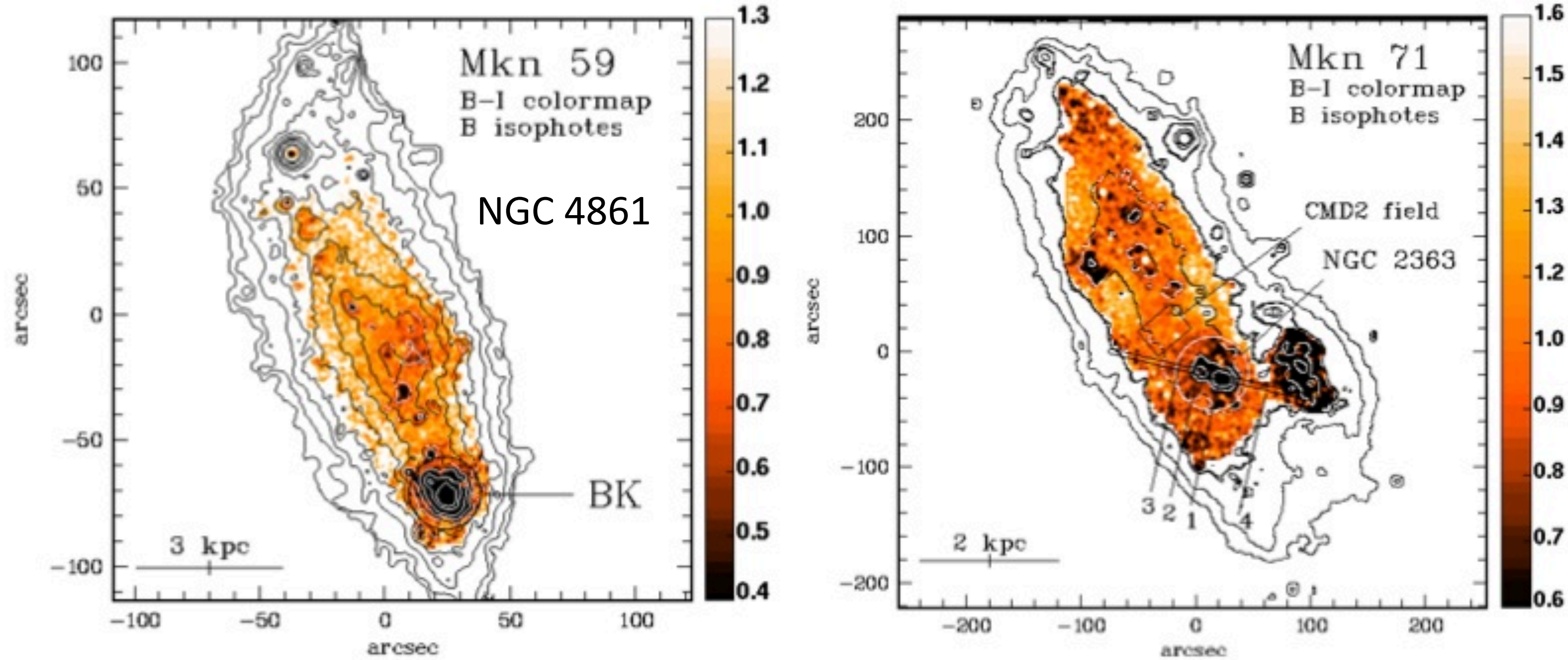
(many are not what we’d classify as tadpoles)



Straughn+06, Windhorst+06

- Straughn+ and Windhorst+ suggest mergers, but they note:
- Each galaxy would need to undergo 10-30 mergers to account for observed fraction of tadpoles, inconsistent with simulations and observations

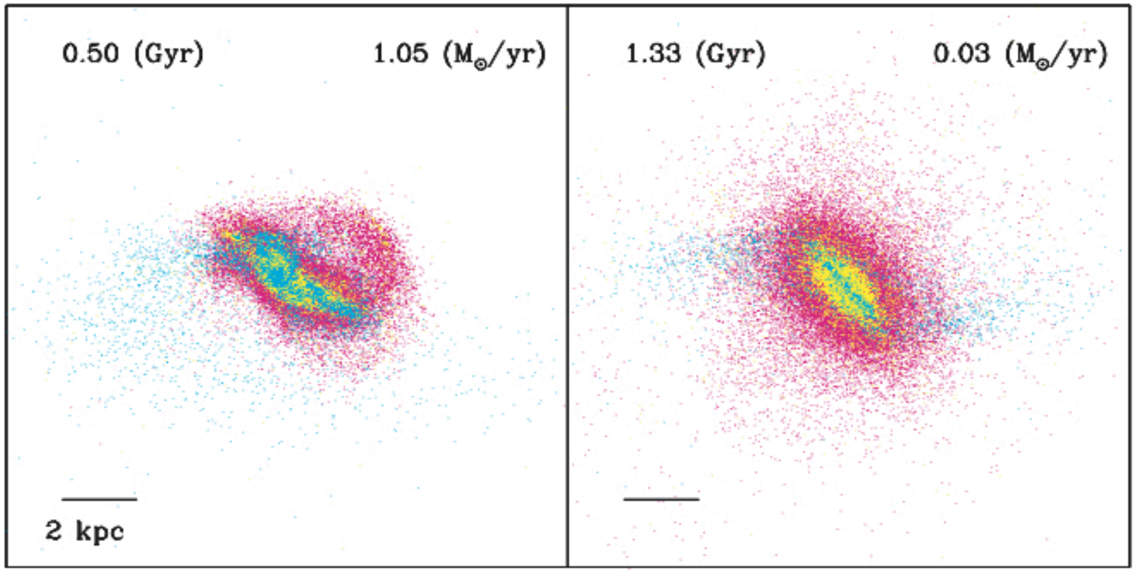
BCDs with off-center starbursts look like tadpoles



Noeske+2000

Noeske+ : cometary BCDs are relatively young, < few Gyr, and generally metal-poor

Simulations show BCDs can form from mergers of 2 dwarfs with large gas fractions…

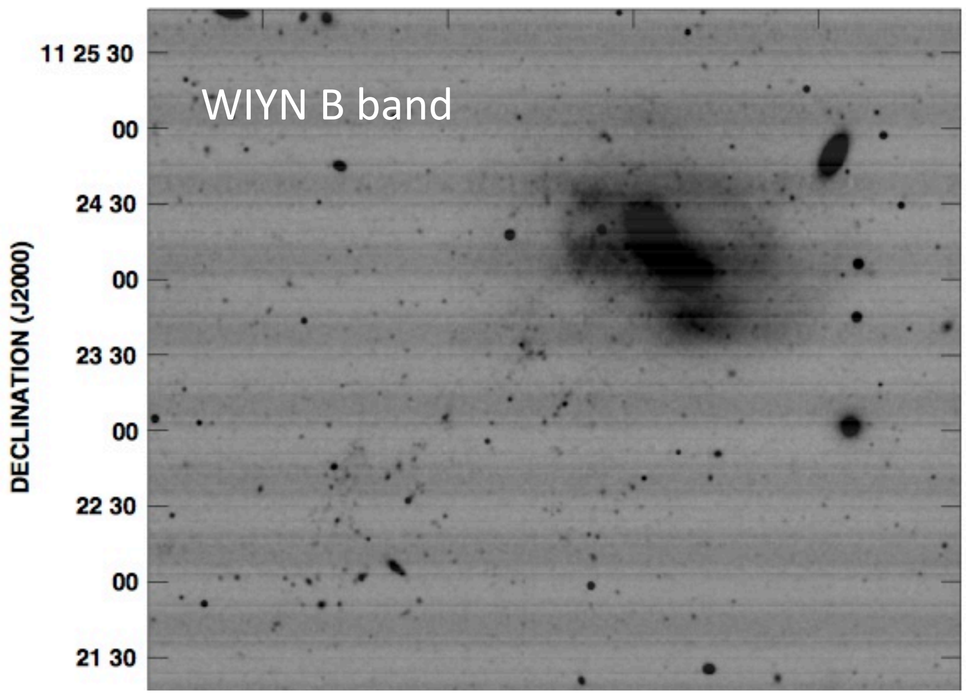


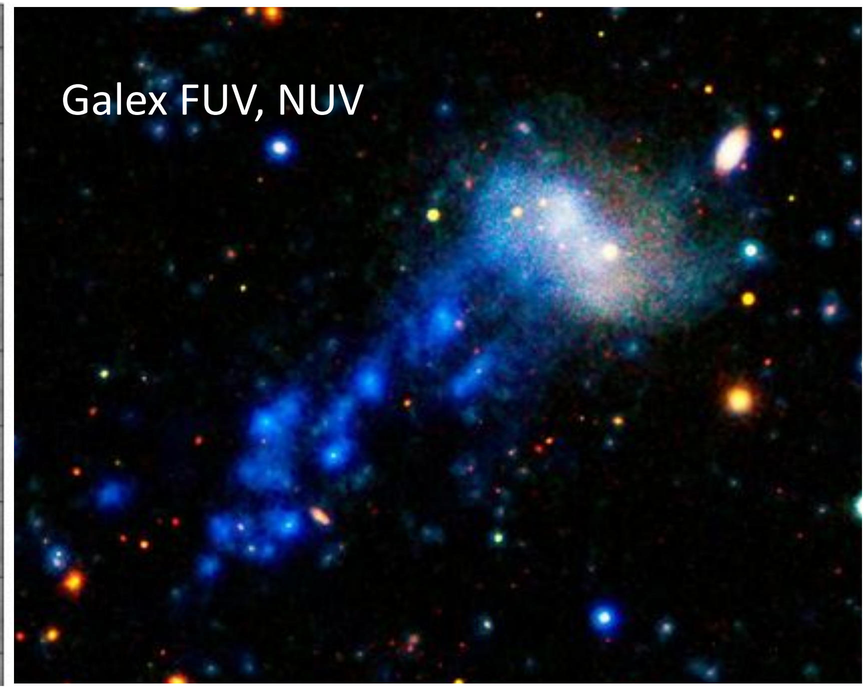
Yellow = new stars Red = old stars Green = gas Bekki08

…however, starburst is in center

Gil de Paz+03 suggested "iI C" BCDs (cometary shapes) could be ongoing mergers with long tidal tails - but they note other processes such as ram pressure stripping can cause them too

Ram pressure stripping: IC 3418 in Virgo, with star formation in tail



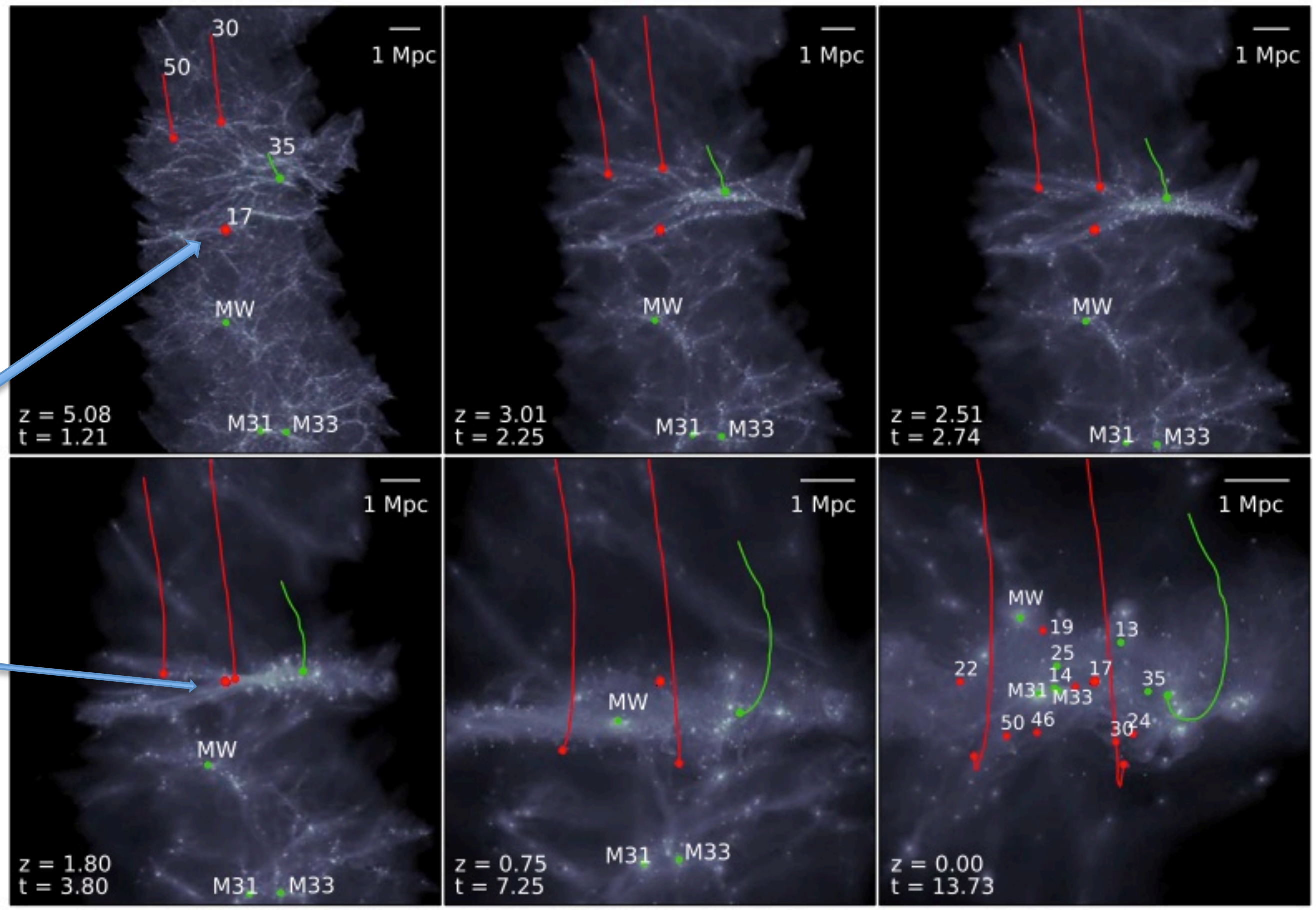


NASA/JPL

Kenney+10

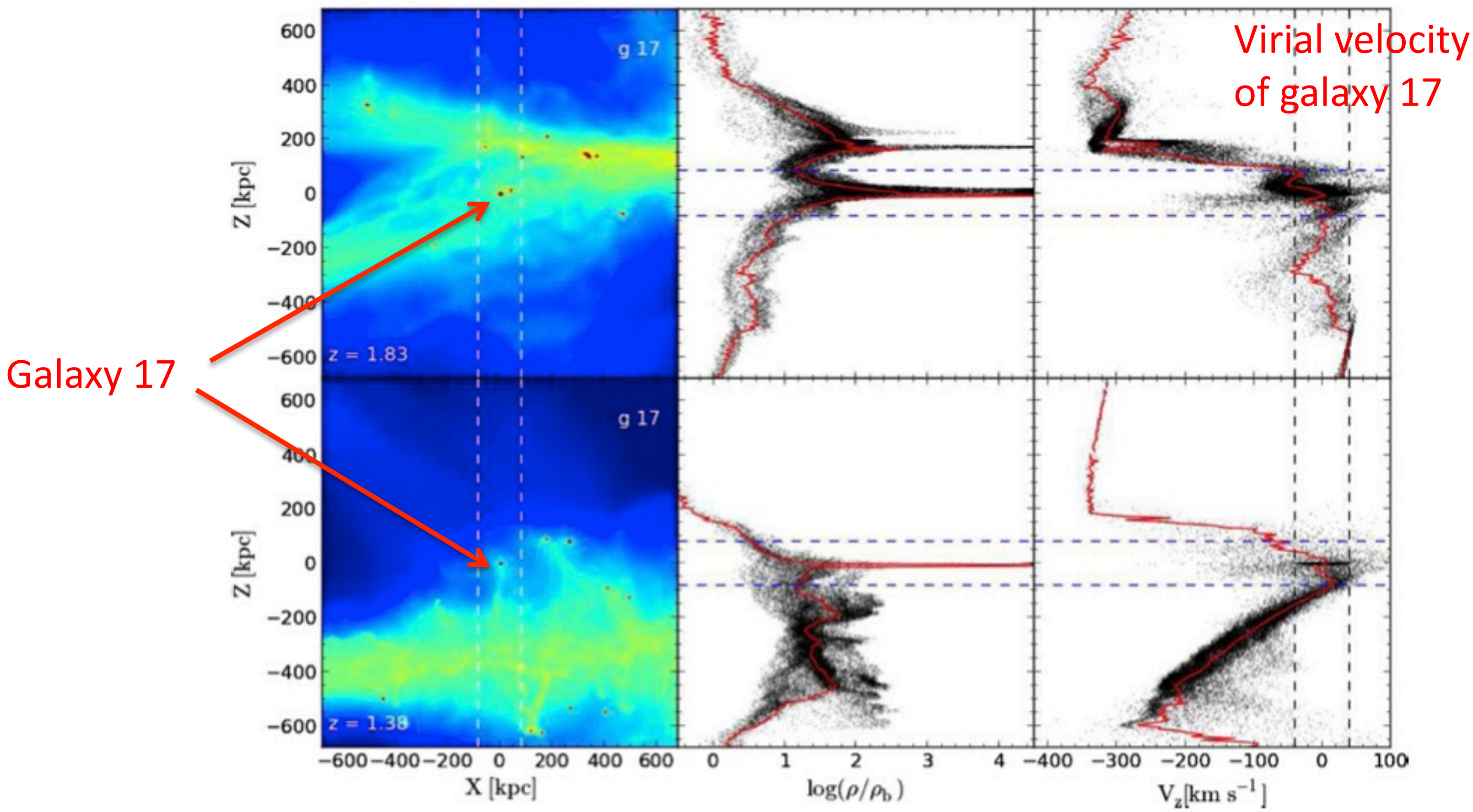
Simulation of gas and 10^{10} M_o galaxies vs redshift; pancake forms at z~2

Note
galaxy 17



Benítez-Llambay+13

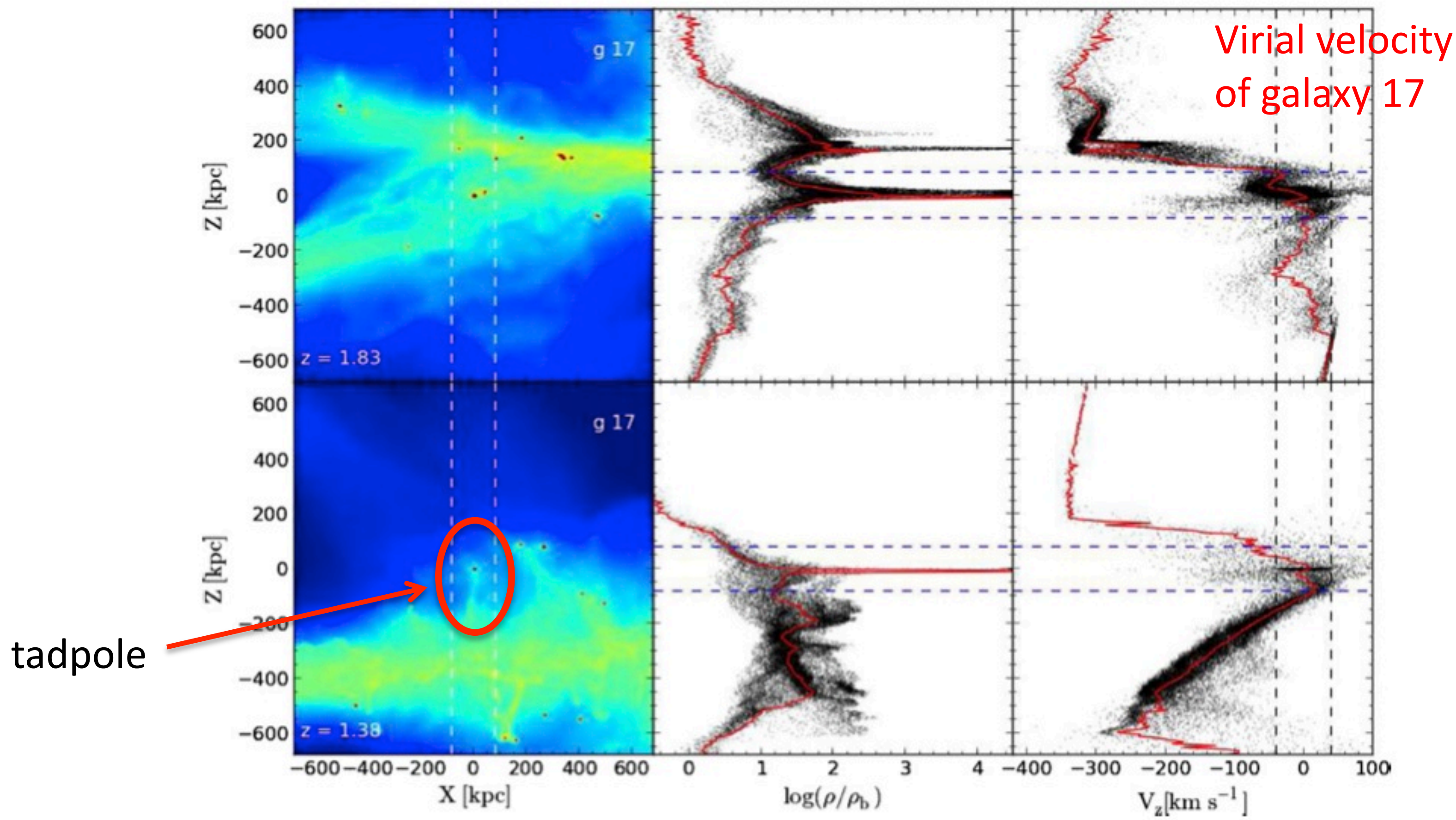
Ram pressure stripping makes tadpole as galaxy falls through cosmic web pancake



Benítez-Llambay+13

Galaxy is dense but weakly bound, so pancake strips it

Ram pressure stripping makes tadpole as galaxy falls through cosmic web pancake

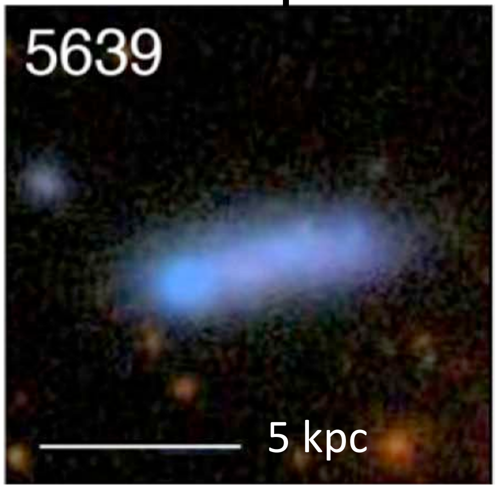


Benítez-Llambay+13

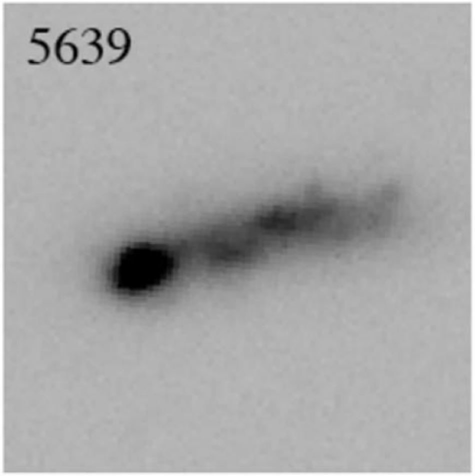
Galaxy is dense but weakly bound, so pancake strips it

But, we now observe tadpoles with rotating disks, so these are not stripped or tidal tails …

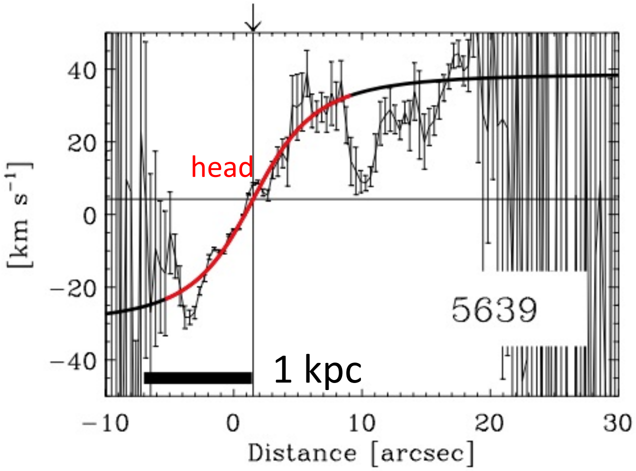
Local tadpole: Kiso 5639



SDSS



Elmegreen+12



Sánchez Almeida+13

- Distance 24.5 Mpc, M_g=-16.4
- Head diameter 830 pc
  - SED head mass = 5x10^6 M_o, age 300 Myr
  - Tail mass 4x10^7 M_o, age 1.3 Gyr
- Rotation velocity of 30-40 km/s

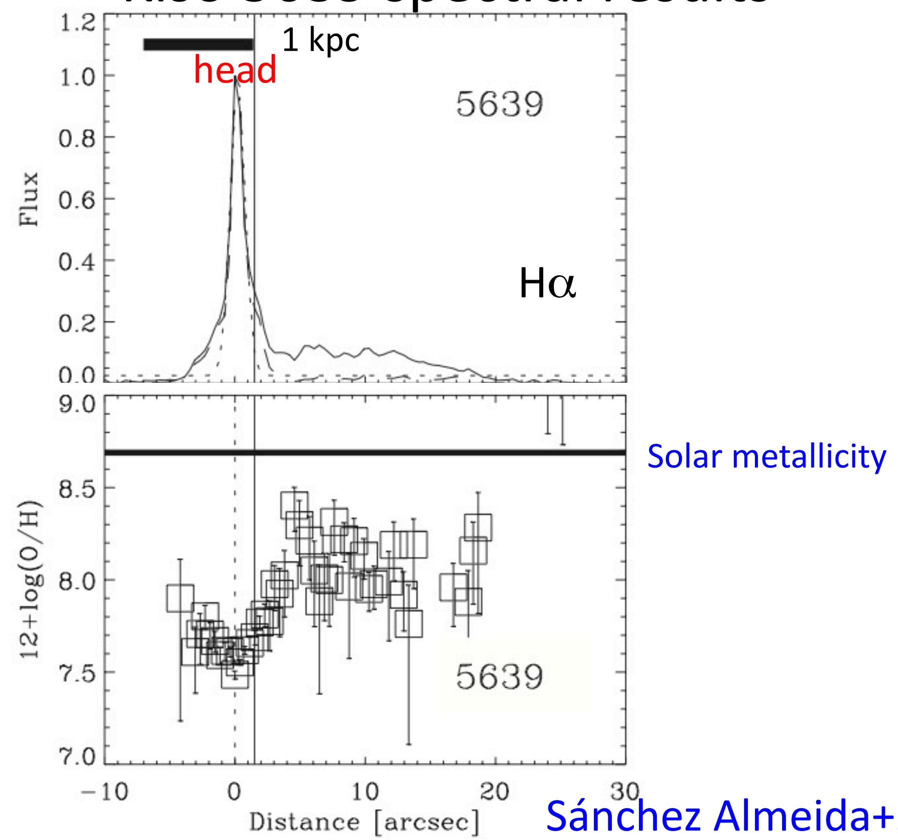
…and the tadpole head has low metallicity

- Strong Hα in head
- Low metallicity (XMP):

12+log(O/H)=7.6 head,

8.1 tail

Kiso 5639 spectral results



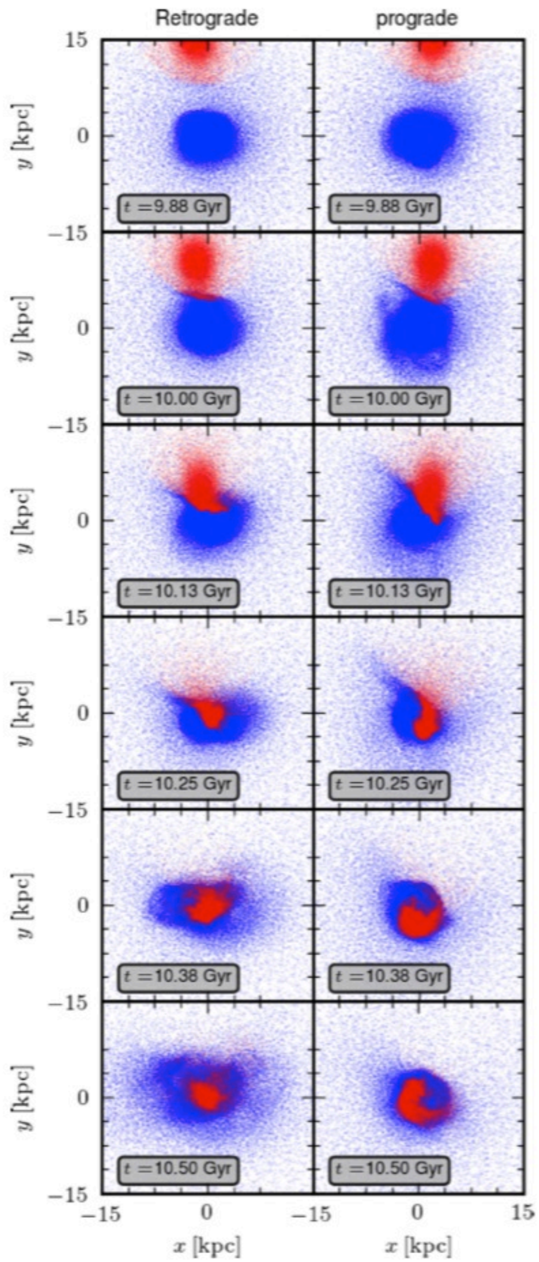
Sánchez Almeida+2013

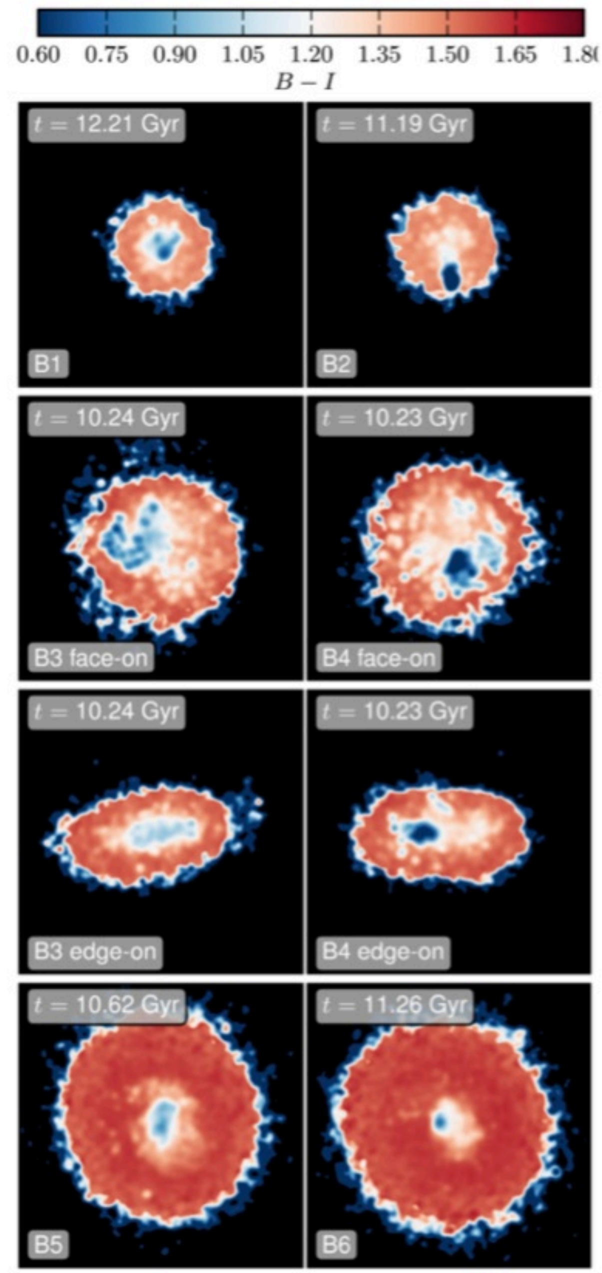
The metallicity drop at the region of strong star formation in the head implies accretion of metal-poor gas (and not just random star formation in disk)

Accretion:

Simulations of gas infall triggering starbursts in dwarf galaxies

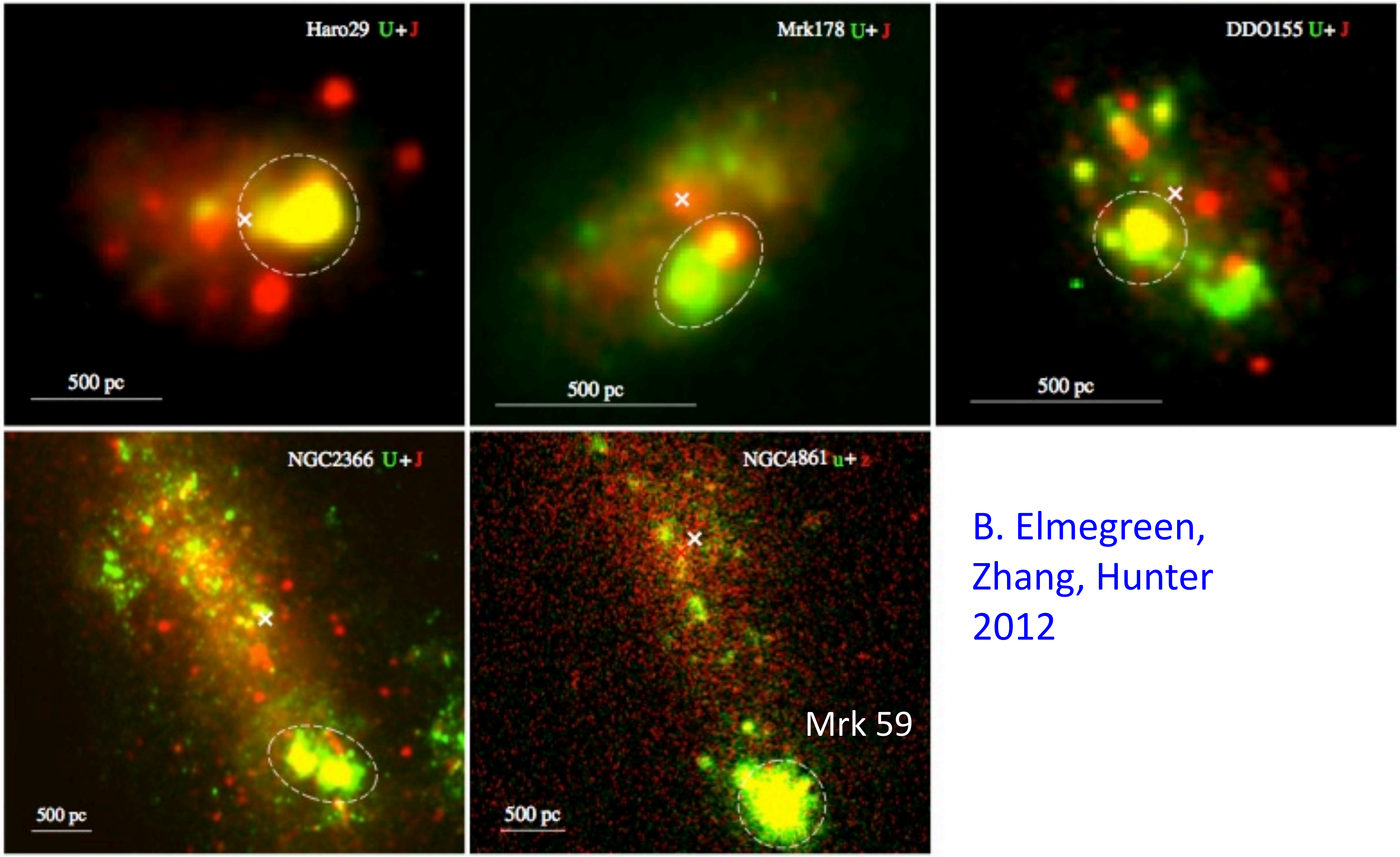
- Metallicities of starbursts are low if formed mostly from accreted metal-poor gas
- Prograde hit has offset SF like a tadpole





Verbeke+14

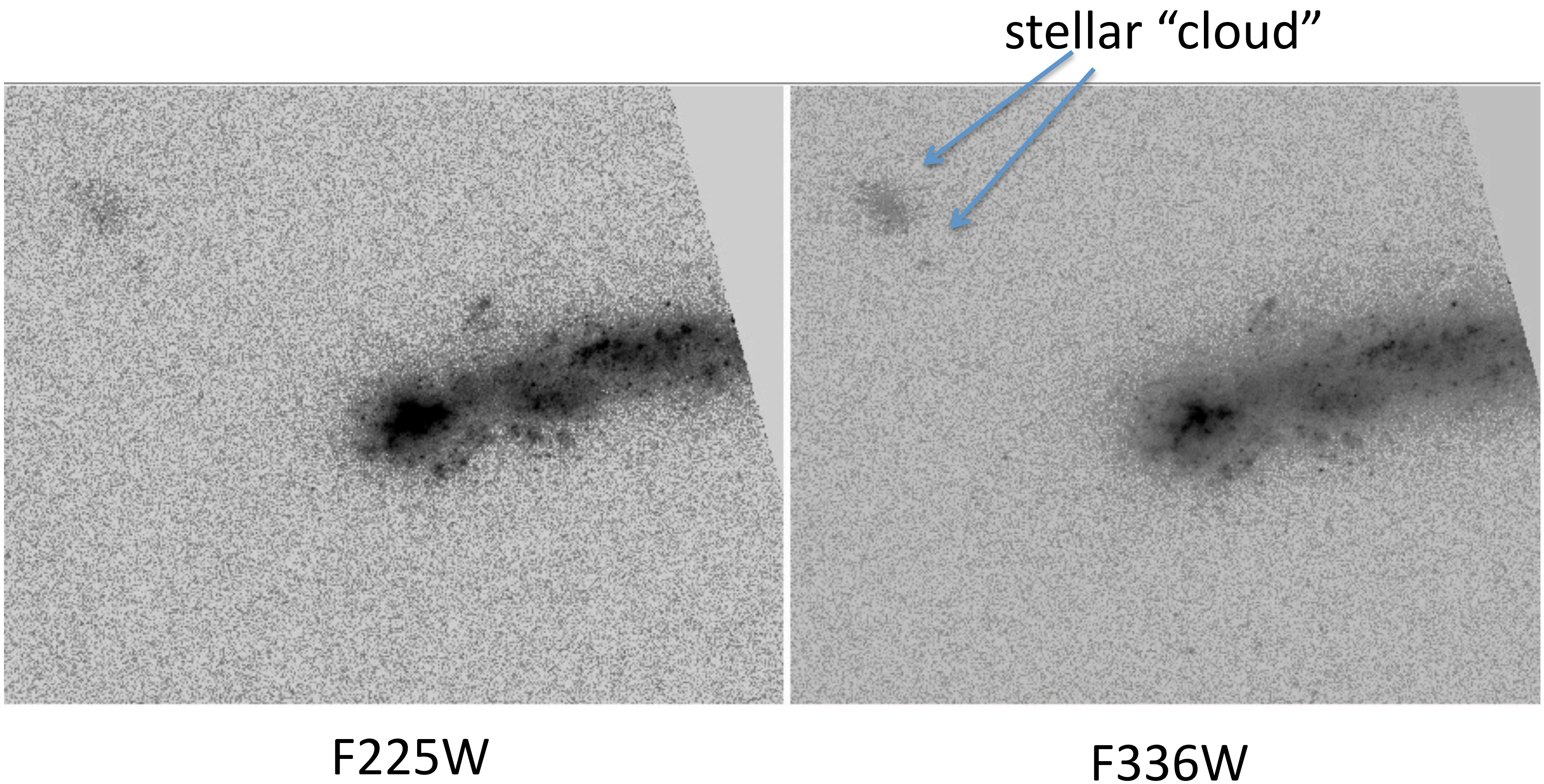
Local clumpy irregular galaxies



B. Elmegreen, Zhang, Hunter 2012

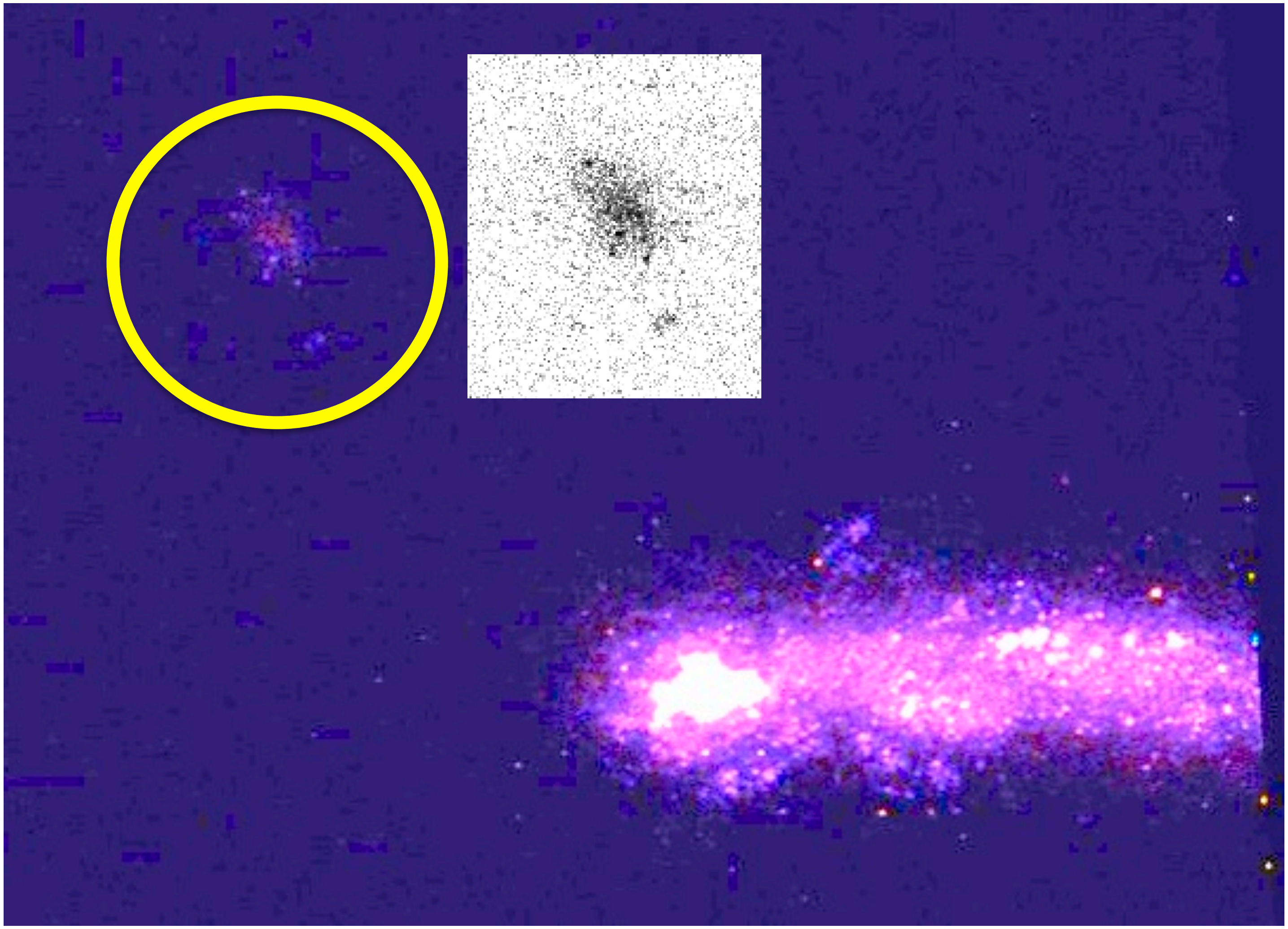
Clumpy BCD galaxies (top) could be face-on tadpoles

Focus on Kiso 5639: new HST observations



HST WFC3 logarithmic images

Kiso 5639 - F225W, F336W enhanced

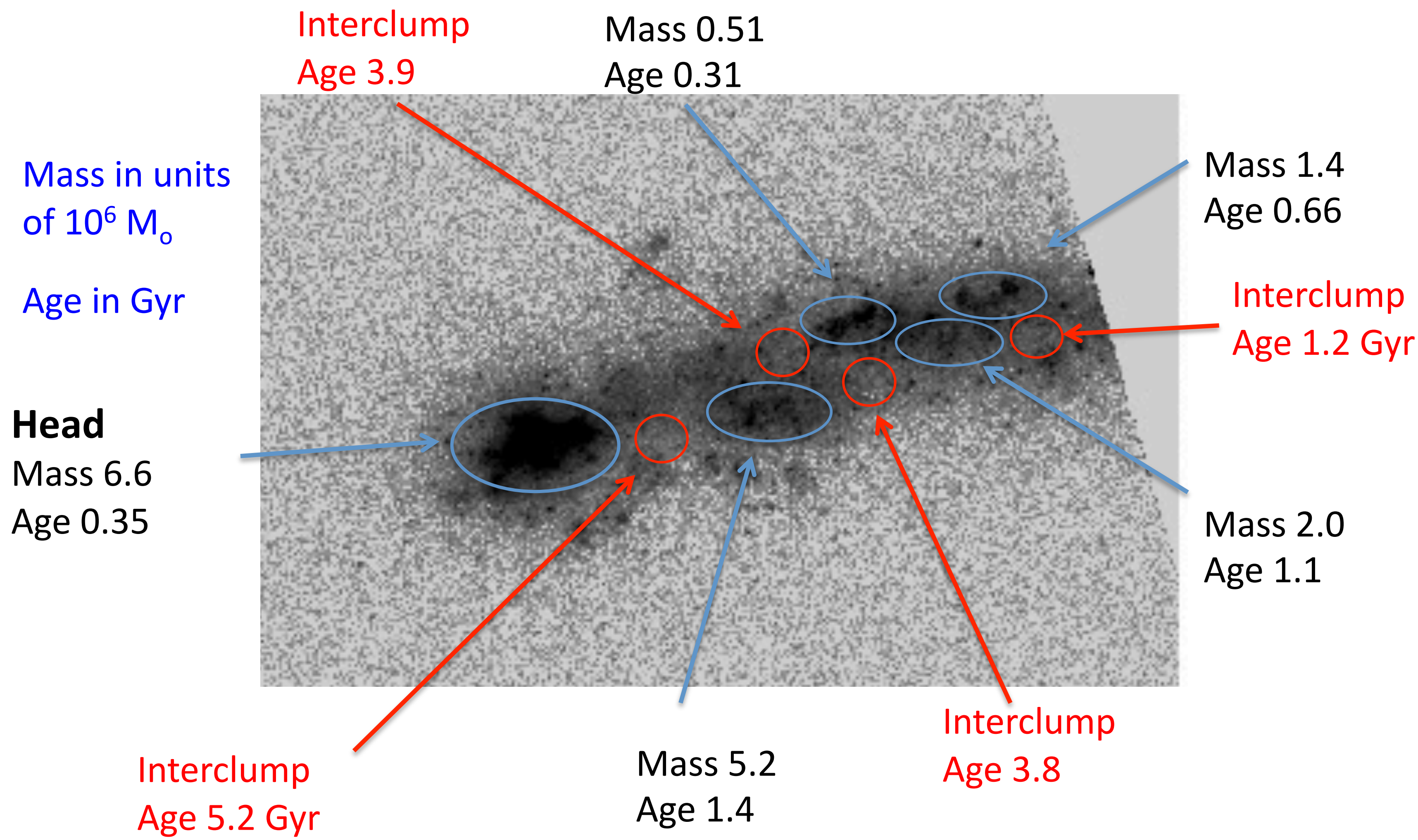


Stellar Cloud mass $6.2x10^6$ M_o, age $1.2x10^{10}$ yr

Total age, mass of each region*

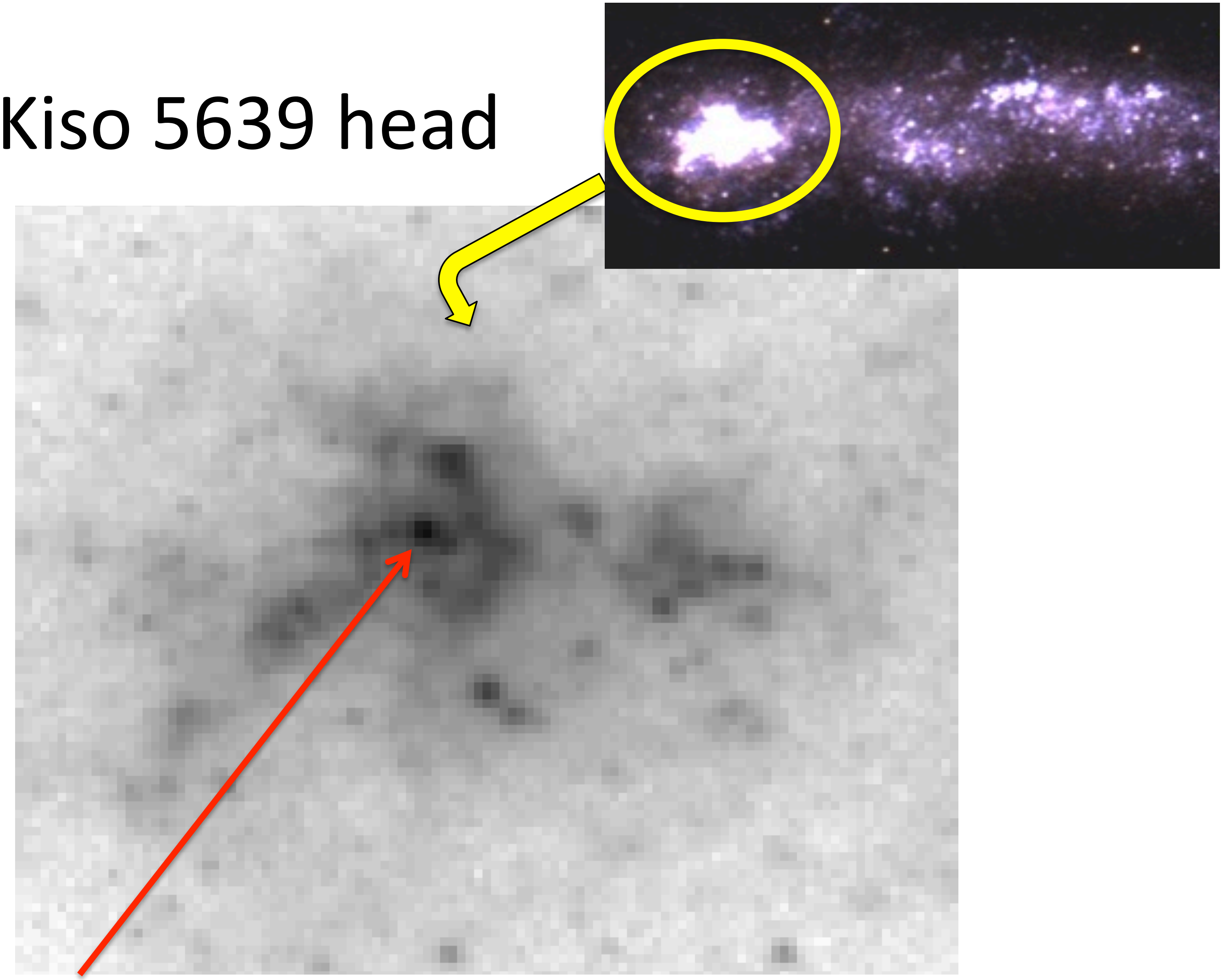
Mass in units of 10^6 M_o

Age in Gyr



*ignoring dust since just 2 filters; awaiting other WFC3 optical+Hα filters (F438W, F555W, F606W, F814W, F657N)

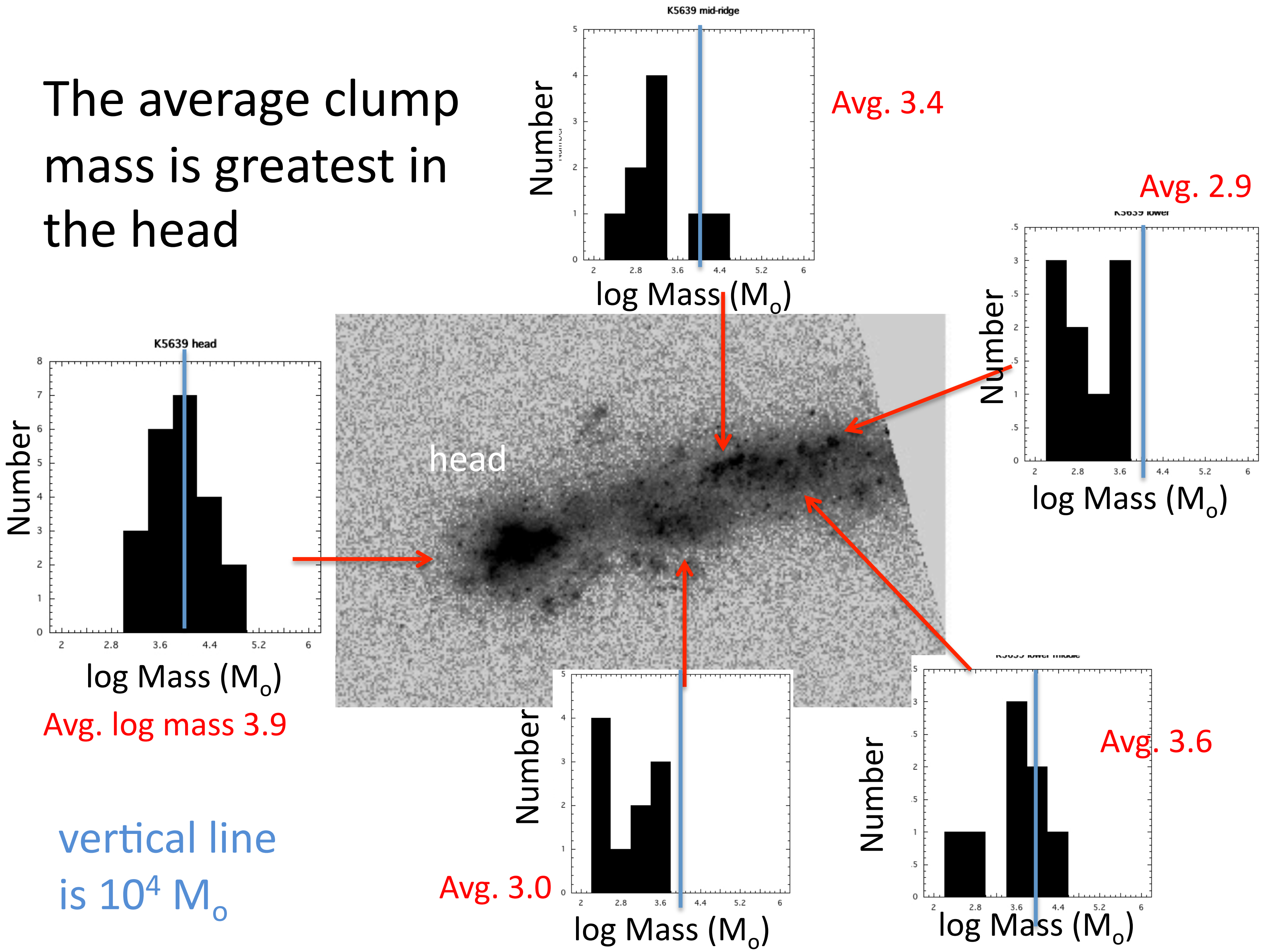
Kiso 5639 head



Main star-forming clump mass 1.4×10^{4} M_{o}, age 6.3×10^{6} yr

Comparison of clump masses in head, tail

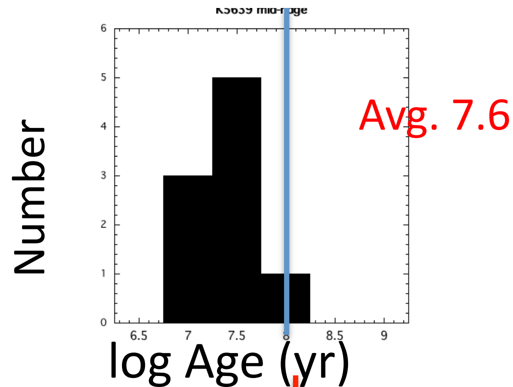
The average clump mass is greatest in the head

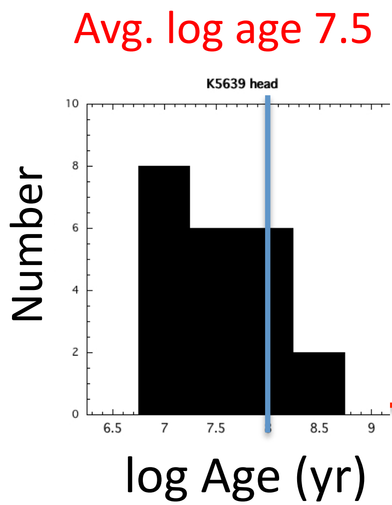


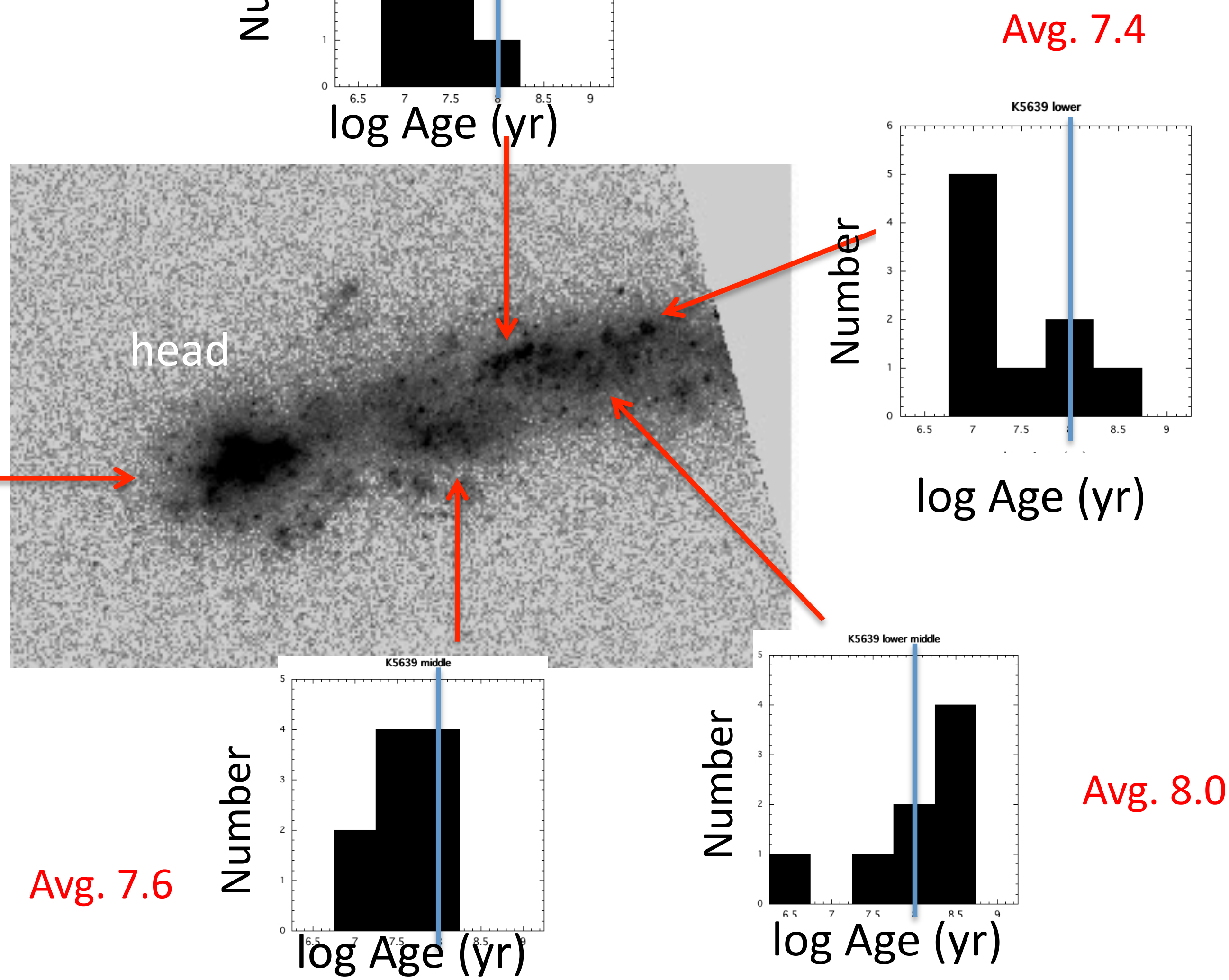
vertical line is 10^4 M_o

Comparison of clump ages in head, tail

The average clump ages are ~ the same



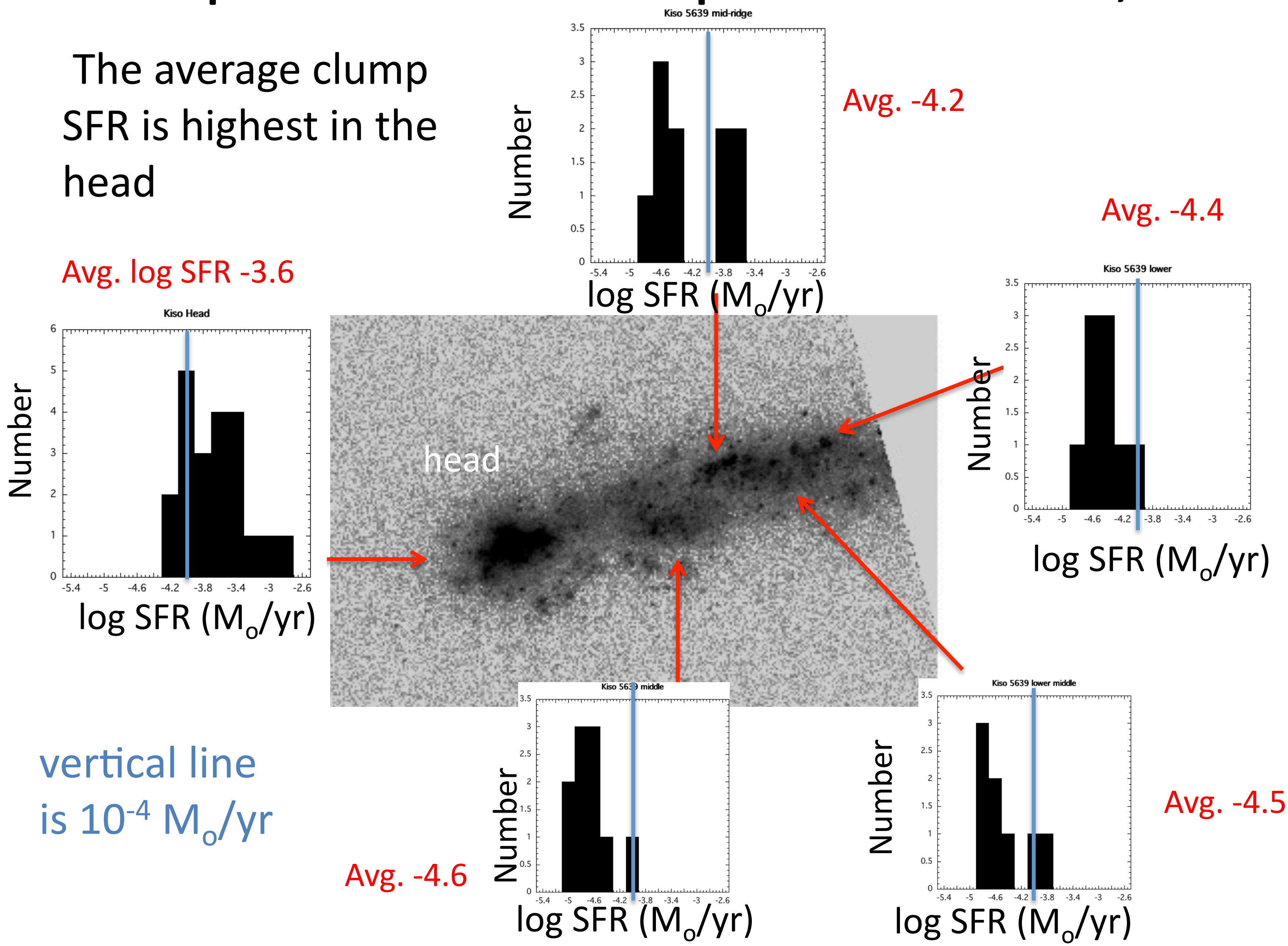




vertical line is 10^8 yr

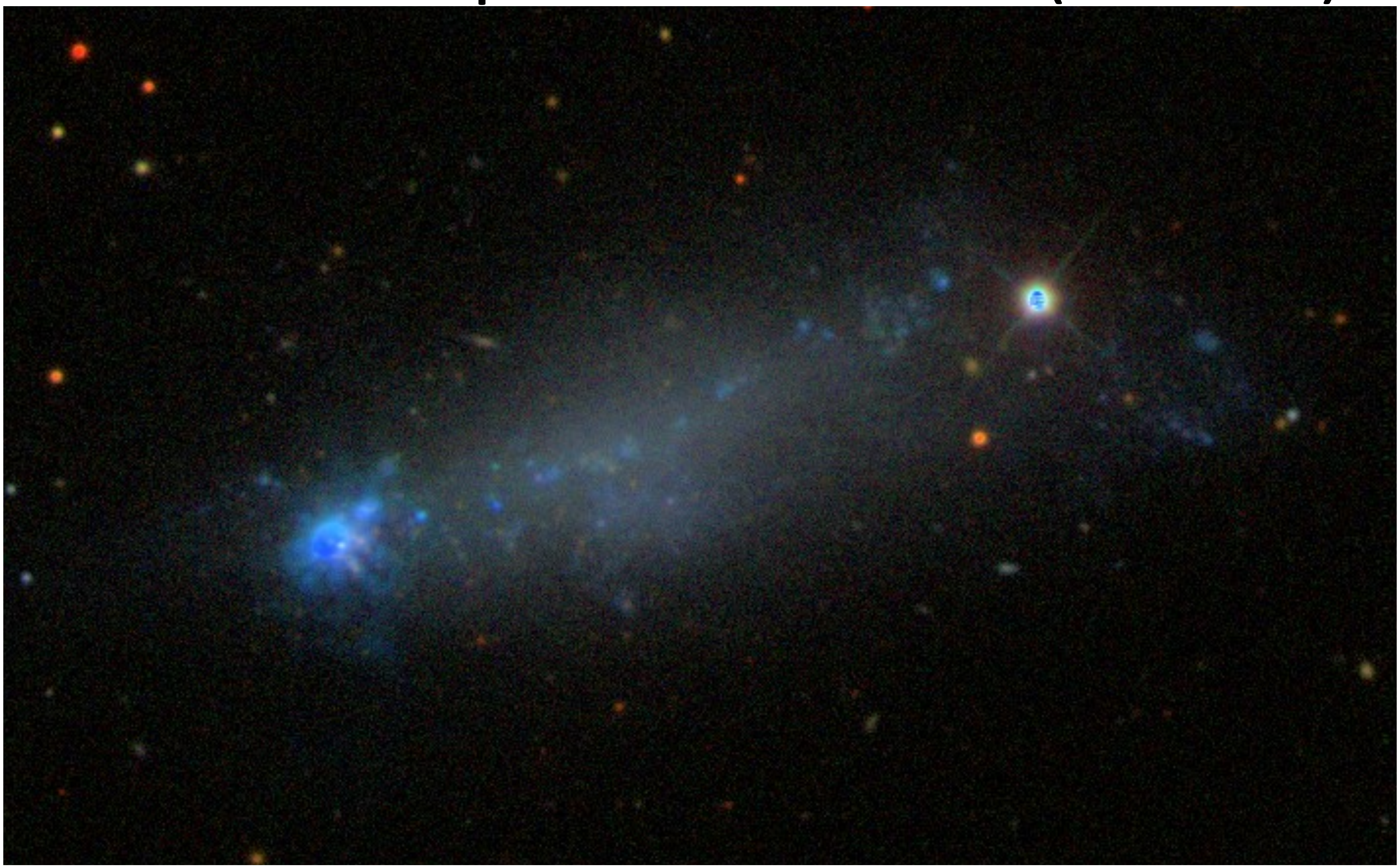
Comparison of clump SFR in head, tail

The average clump SFR is highest in the head

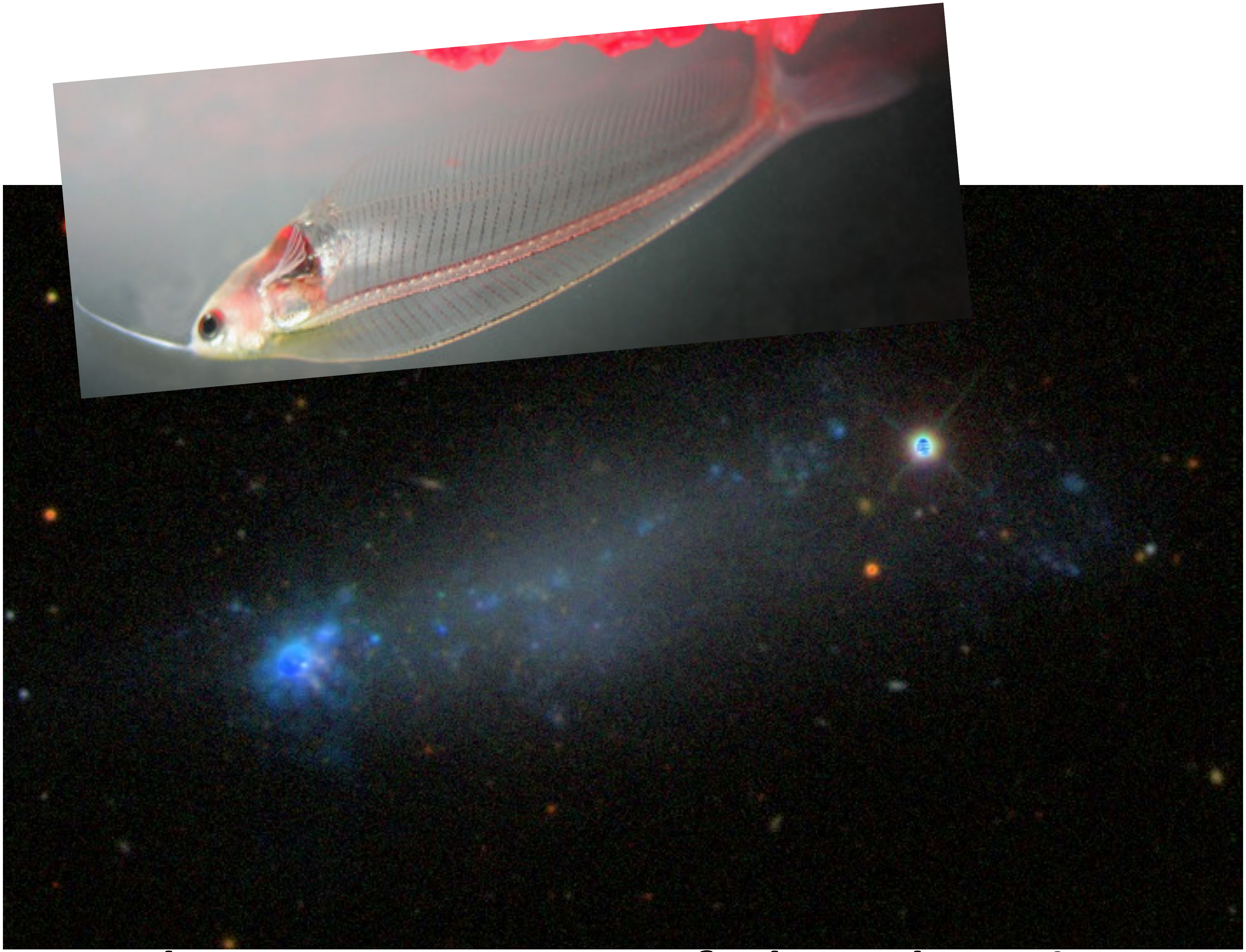


vertical line is 10^{-4} M_o/yr

Another tadpole: NGC 4861 (Mrk 59)



D=7.6 Mpc M_V = -17.5 SDSS

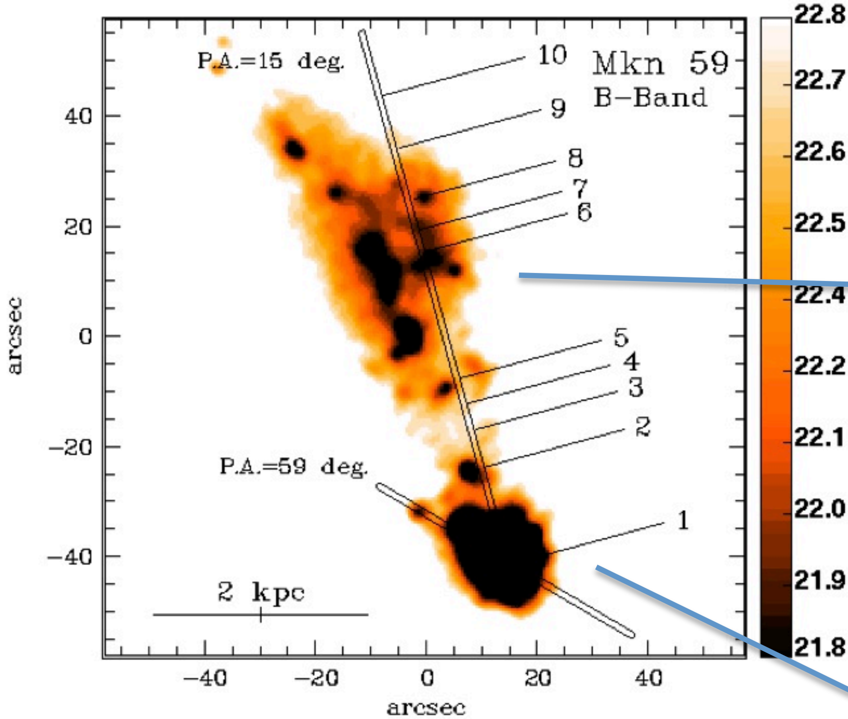


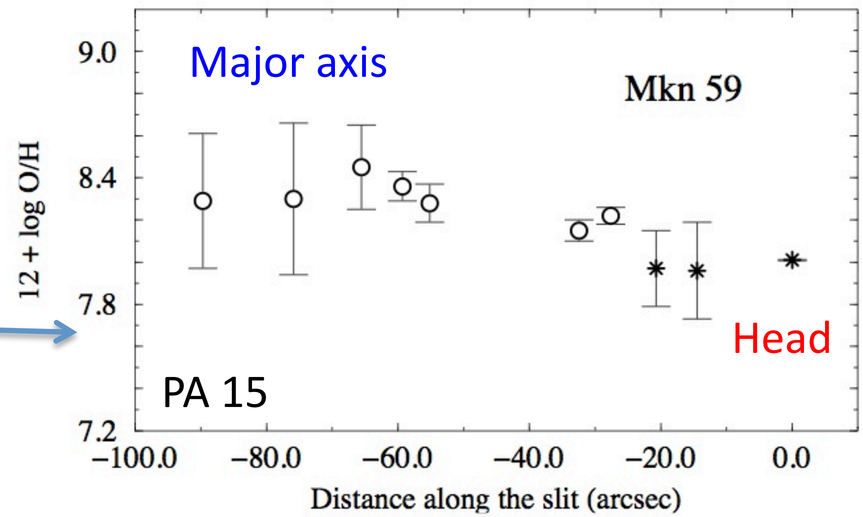
The transparent fish galaxy!

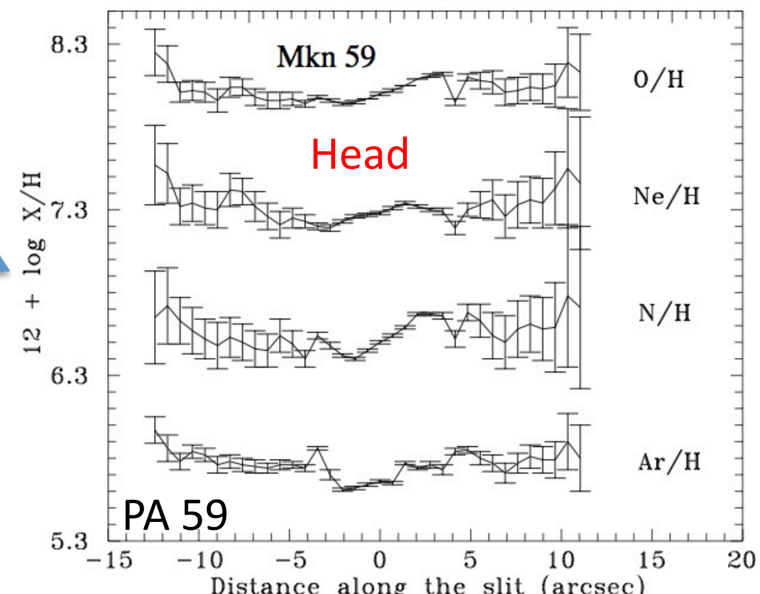
N4861 r, g, 3.6μ logarithmic scale

Overall 12+log(O/H)~8.0 (Dinerstein & Shields 86,Noeske+00, Esteban +09, Karthick+14)

NGC 4861 metallicity



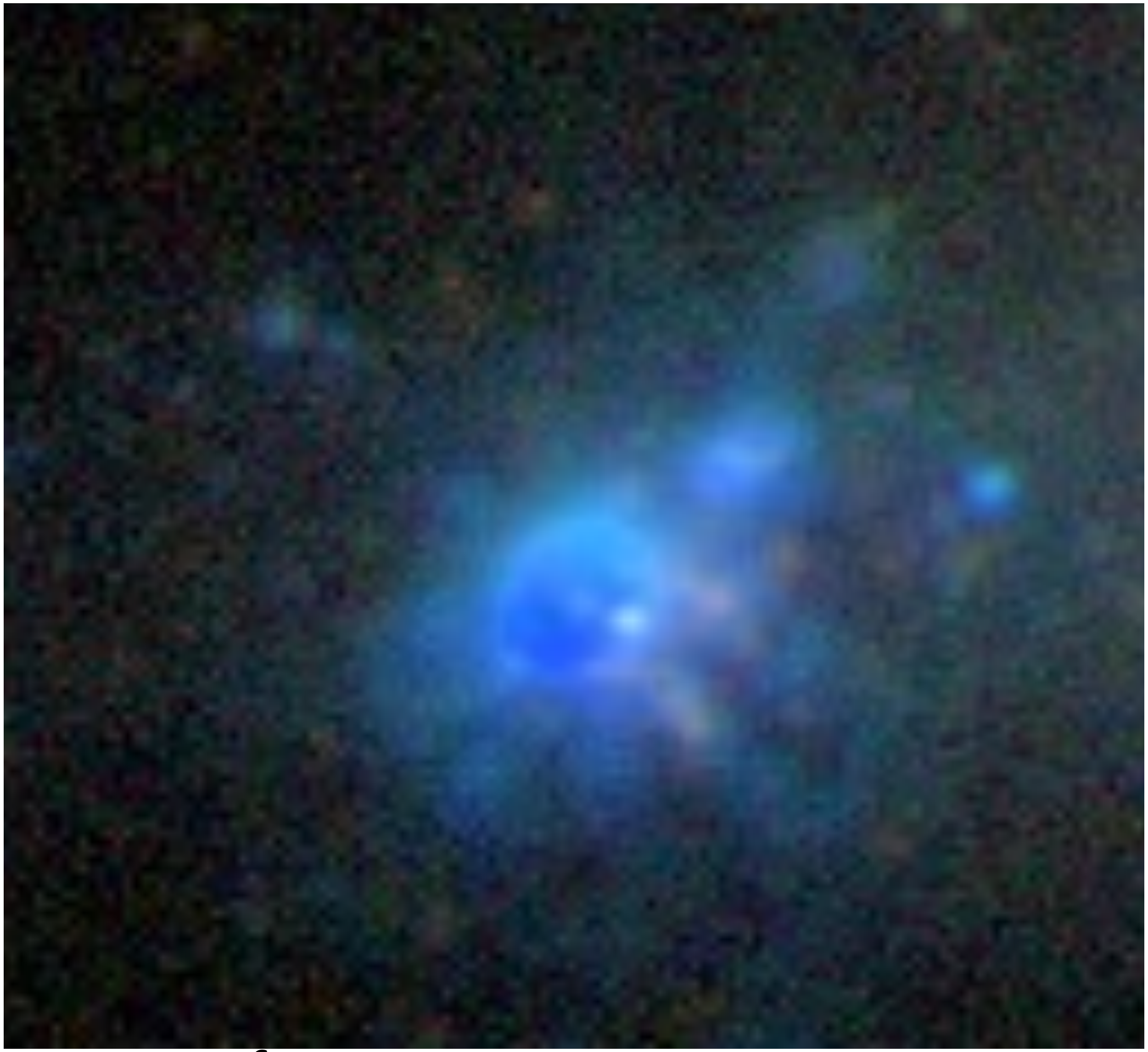




Noeske+2000

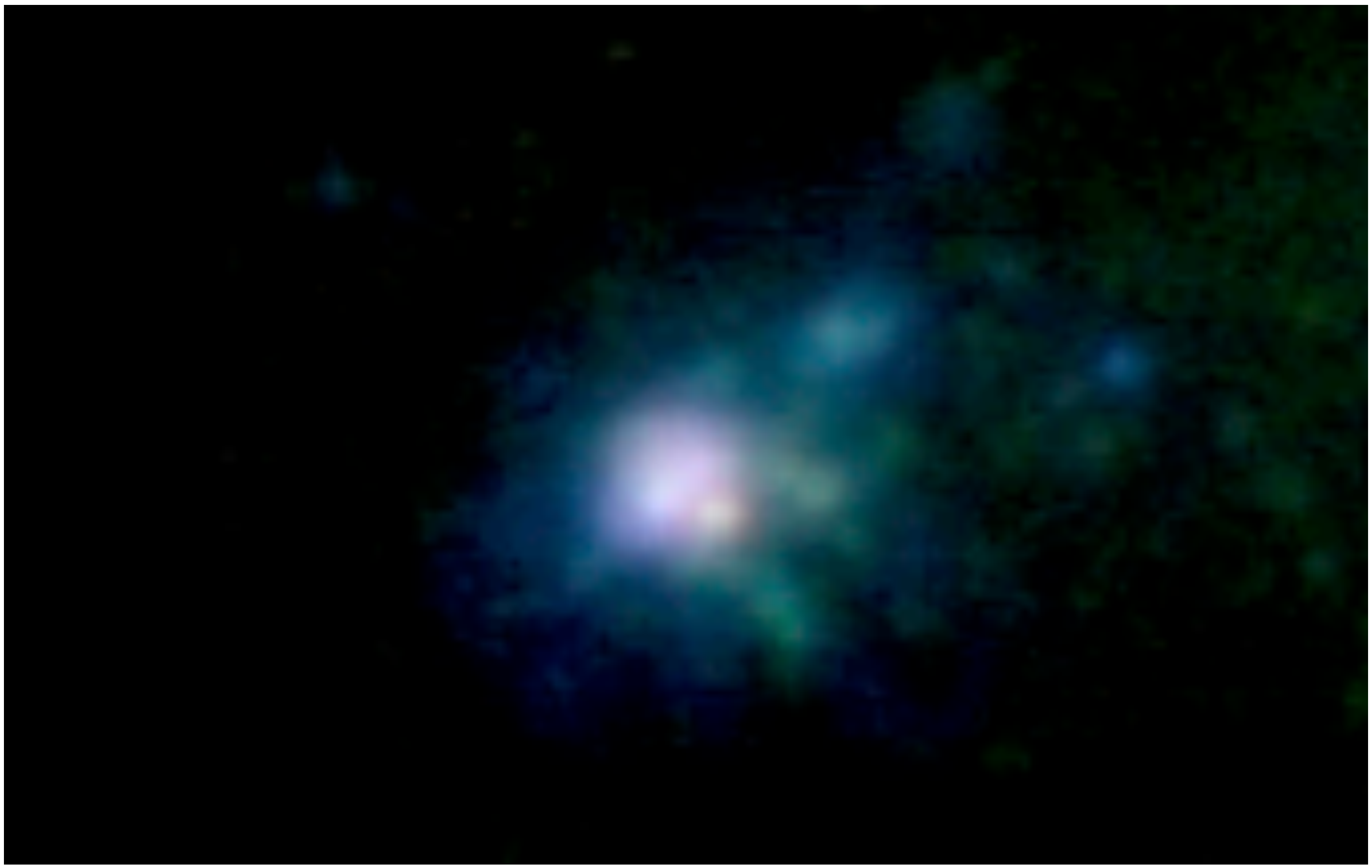
Although Noeske+2000 note overall 12+log(O/H)=7.95 and nearly constant, in fact metallicity is lower at the head than the tail (8.3)

NGC 4861 head - SDSS



Head mass 7.8×10^6 M_o, radius 2 kpc (B. Elmegreen, Zhang, Hunter 2012)

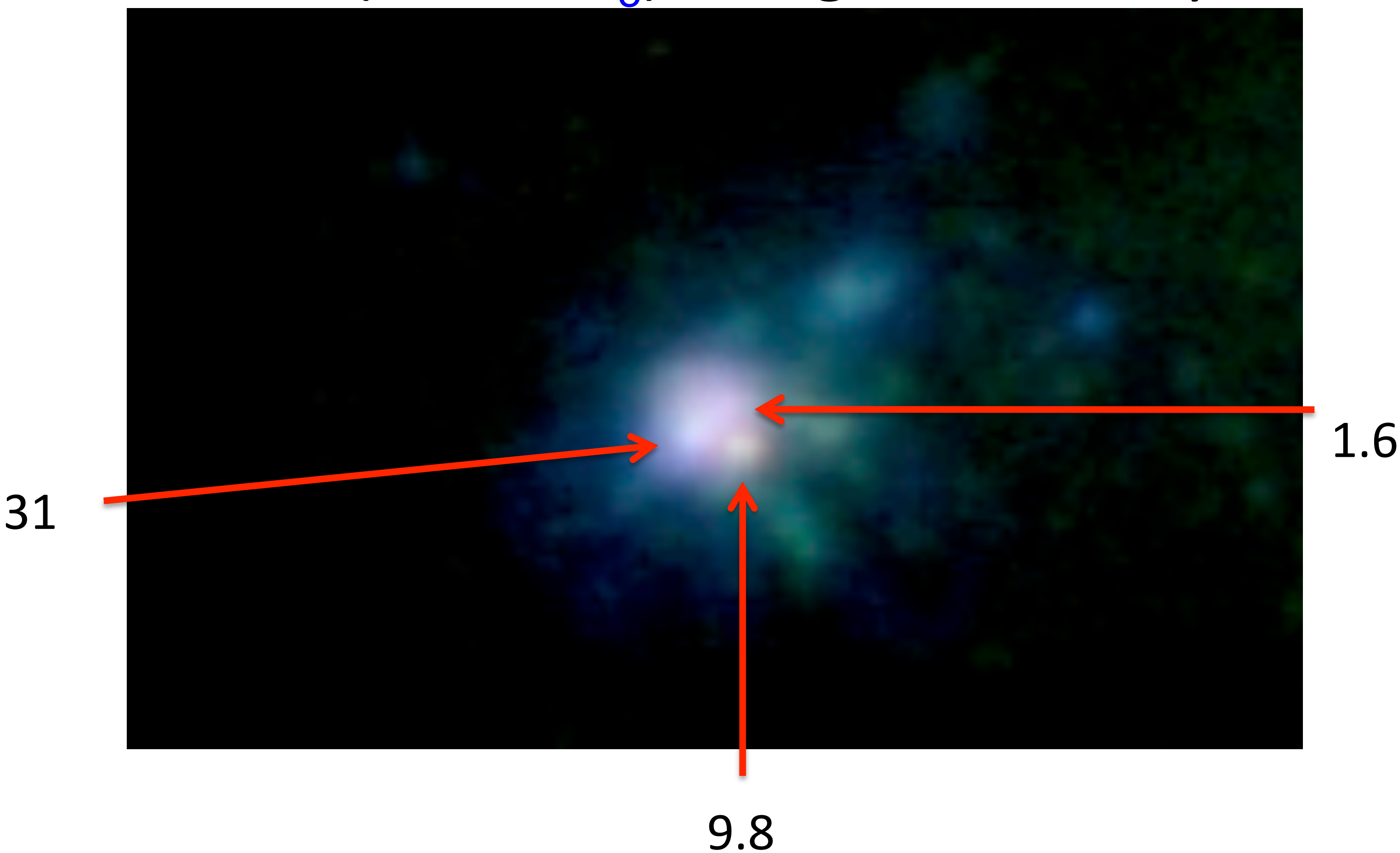
N4861 head r, g, 3.6μ



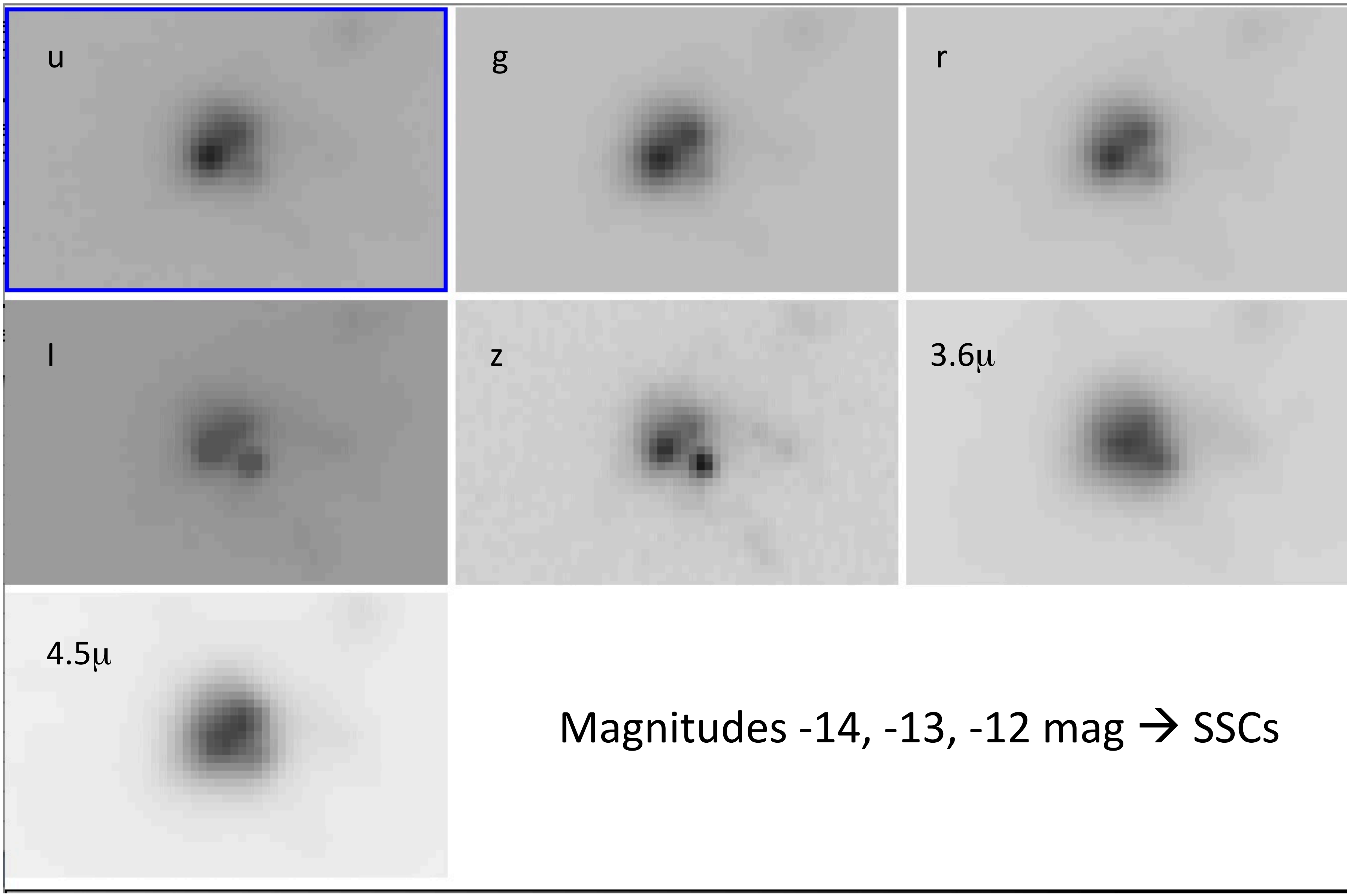
Spitzer data from S^4G survey Sheth+10

N4861 head

Masses (in 10^5 M_o) for ages of $4x10^6$ yr

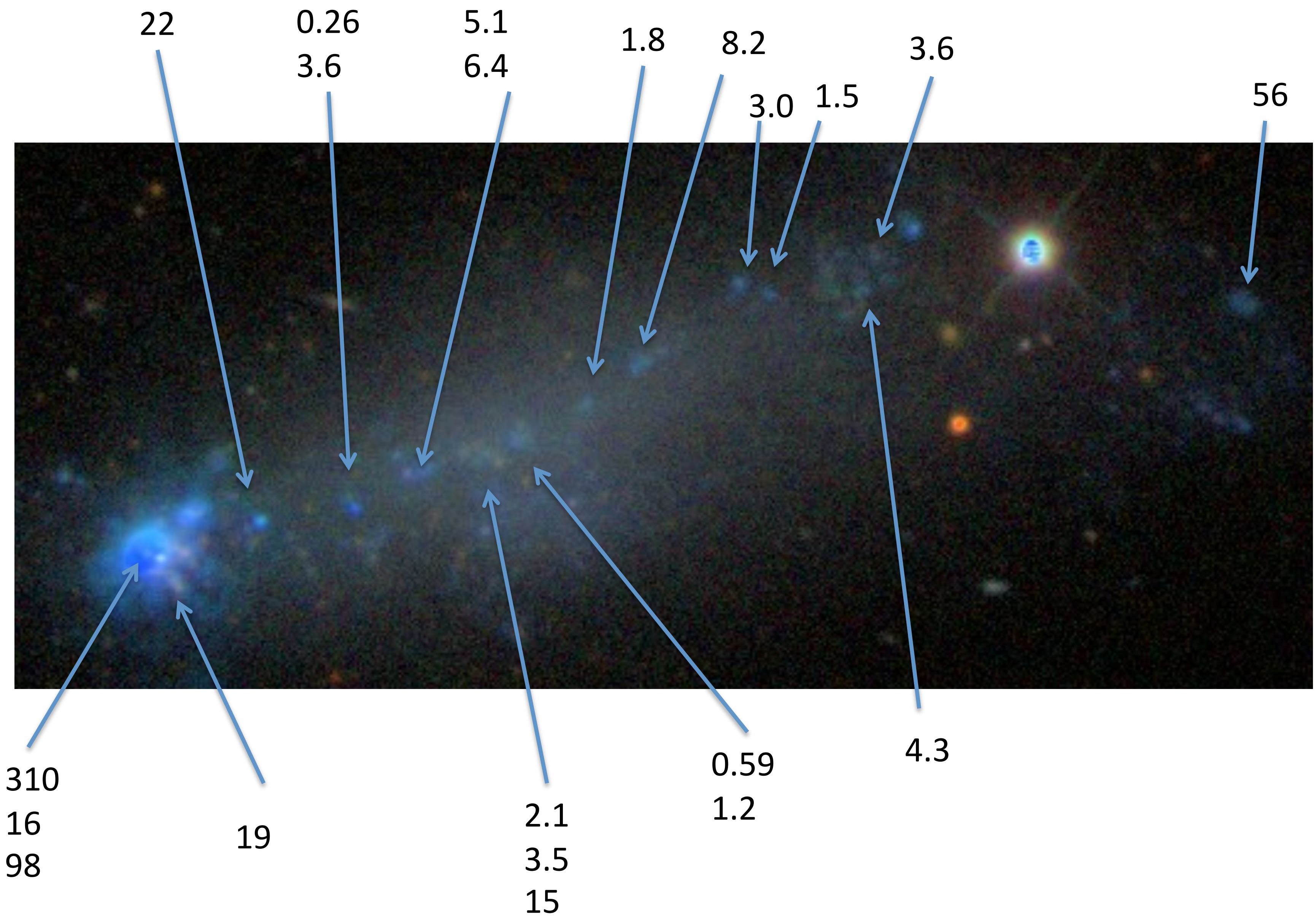


N4861 head

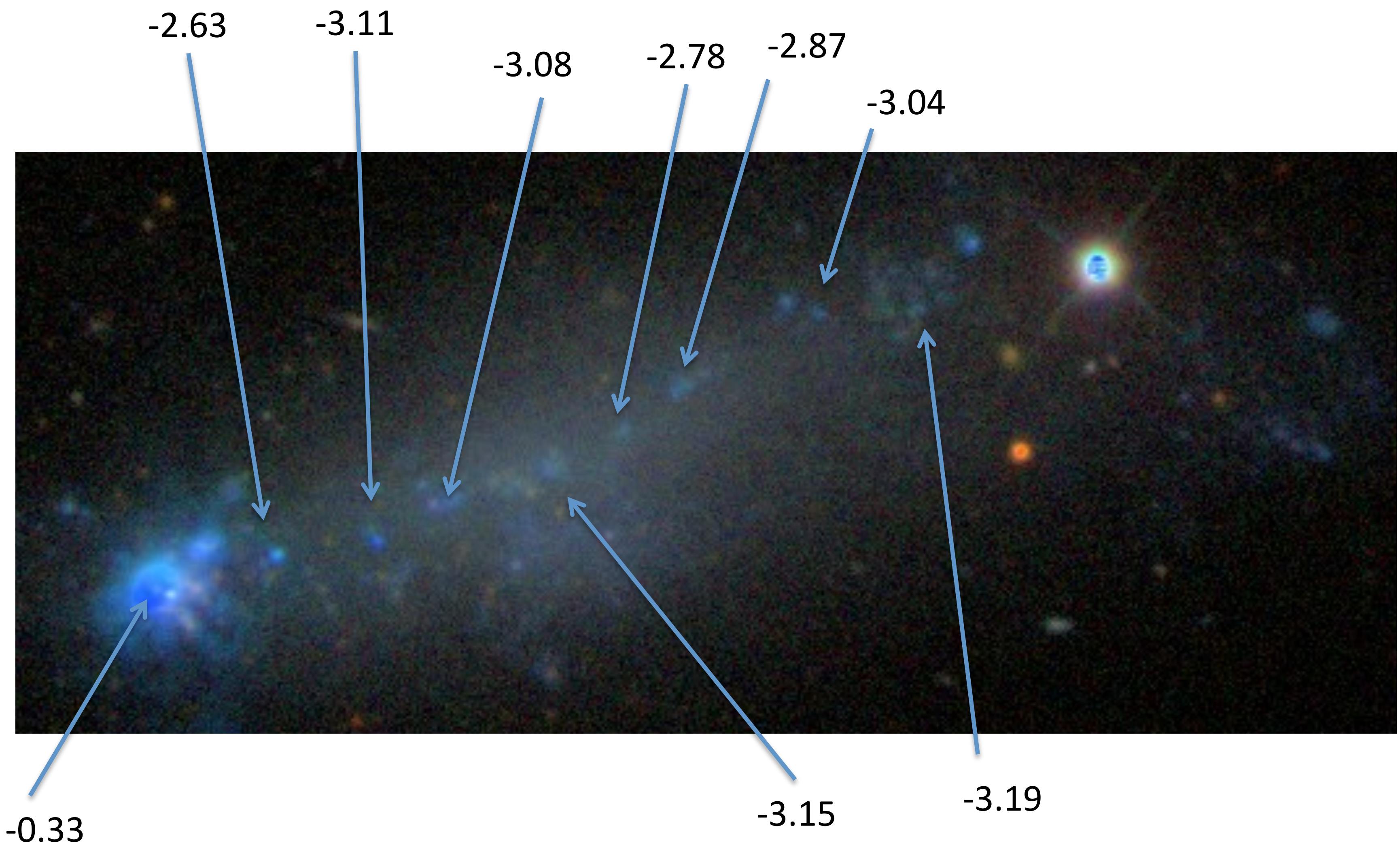


Magnitudes -14, -13, -12 mag → SSCs

Masses (in 10^4 M_o) along the spine for age = 4 Myr

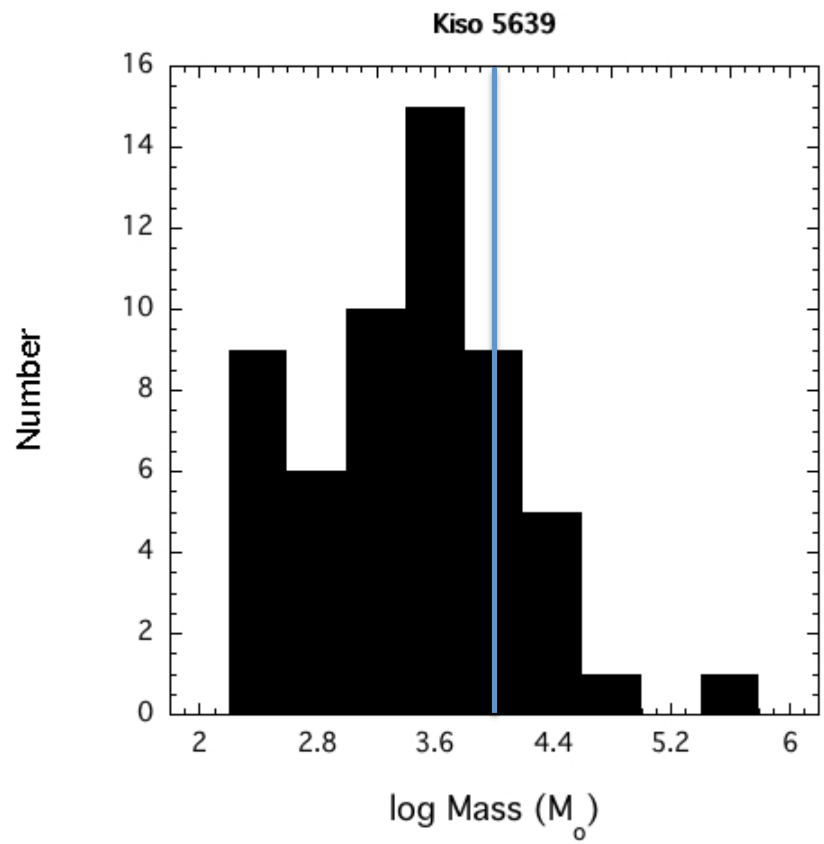


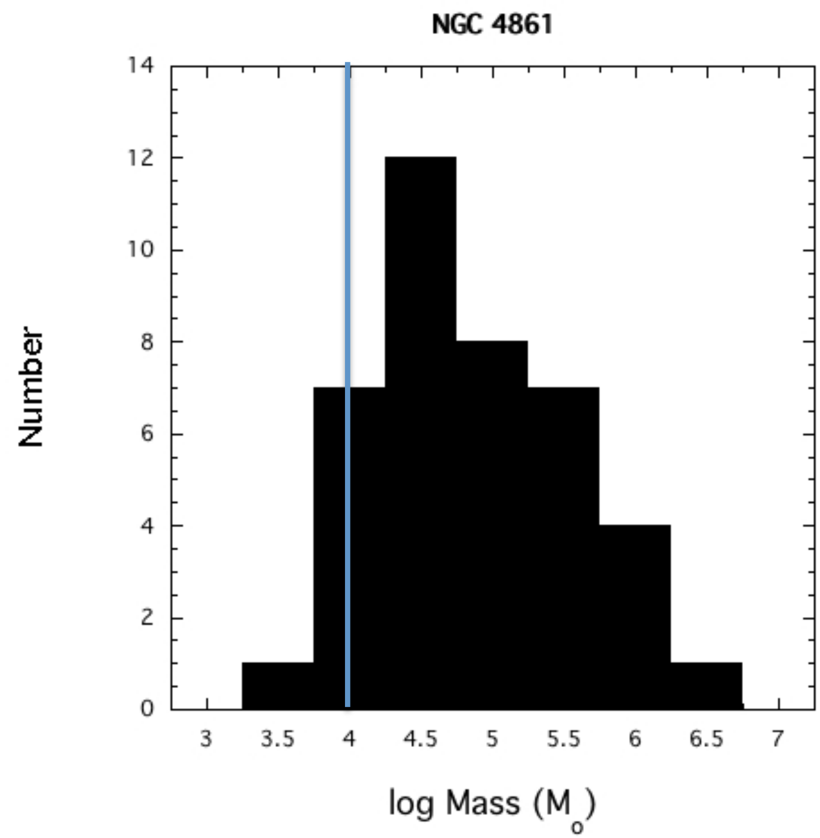
log SFR (M_o/yr) along the spine (from Karthick+2014)



log SFR/area=-1.02 $M_o/yr/kpc^2$ in head, -1.7 to -2.5 in tail

Comparison of Kiso 5639, NGC 4861 clumps

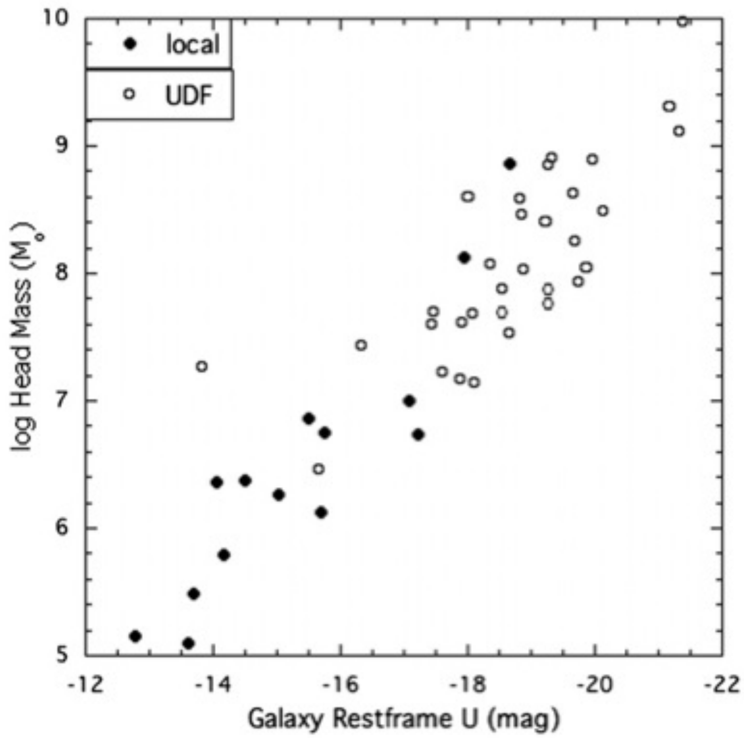




Vertical line at 10^4 M_o

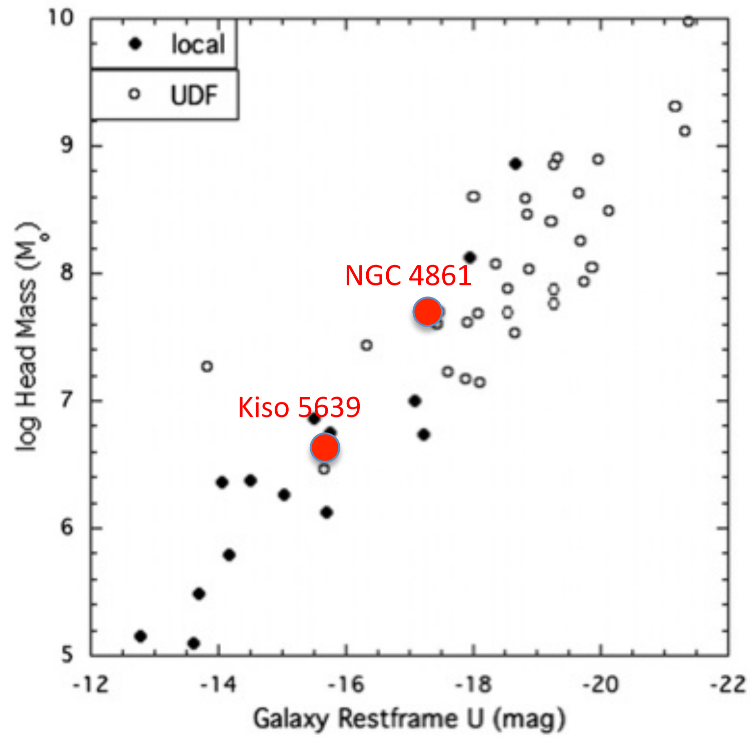
More massive clumps in NGC 4861, since it is 1 mag brighter

Head masses for local and high z tadpoles scale with galaxy brightness



Elmegreen+12

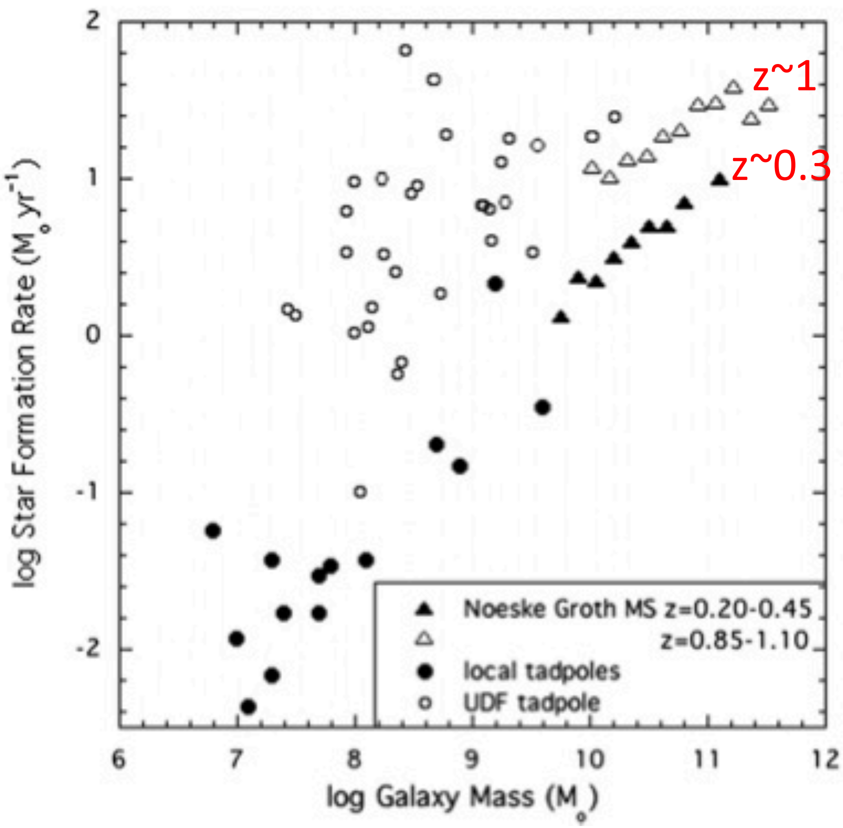
Head masses for local and high z tadpoles scale with galaxy brightness

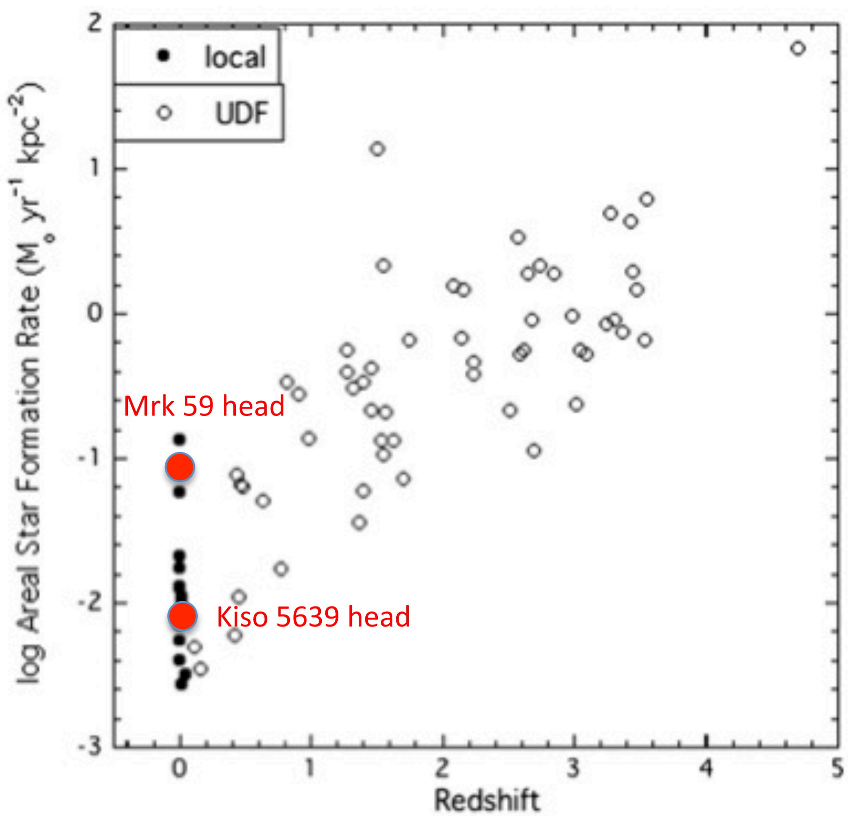


The clump mass distributions are consistent with the head masses scaling with galaxy brightness

Elmegreen+12

Comparison between local and high z tadpole SFR





Elmegreen+12

Higher redshift galaxies, including tadpoles, have higher star formation rates for a given mass

Conclusions

- Tadpoles with rotation and metallicity drops in the head likely result from accretion of cosmic gas
- Star formation is triggered in head from low metallicity gas infall
- Star formation rate scales with galaxy mass
- Local tadpoles have lower SFR and SFR/area than high z tadpoles, consistent with less accretion


Many thanks to
Edvige and Francesco !!!
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