INVESTIGATING THE IMPACT OF SMBHs ON THEIR HOST GALAXIES WITH THE ZFOURGE SURVEY

MICHAEL COWLEY

SUPERVISORS: DR. LEE SPITLER,
PROF. ANDREW HOPKINS, DR. RICHARD MCDERMID

University of Southern Queensland, October 12th 2016

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NGC 1097: Mazlin, Star Shadows Remote Observatory (SSRO)

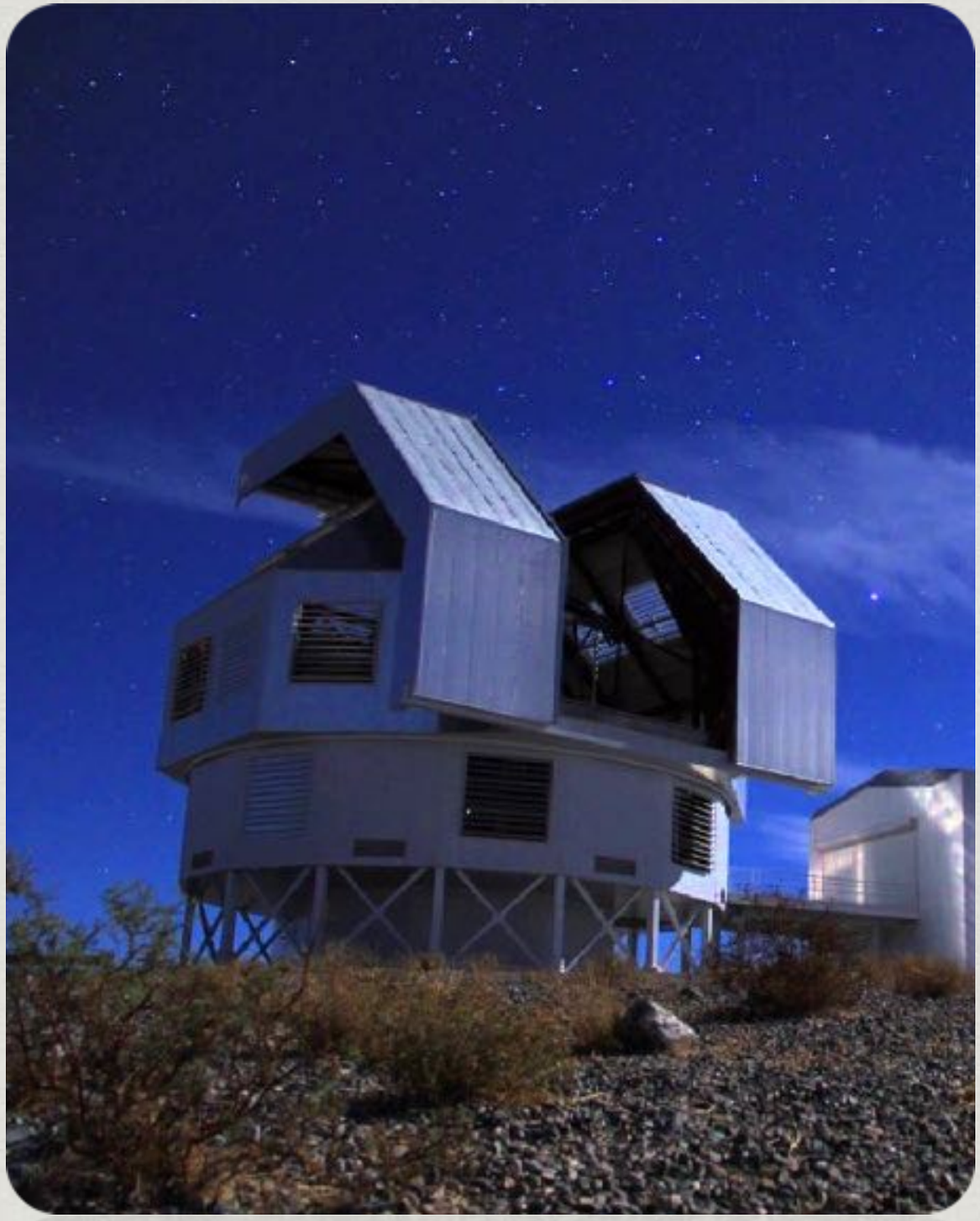
OUTLINE

The ZFOURGE Survey

- Survey overview
- Meet the team
- FourStar instrument
- Medium-band filters
- Survey highlights

AGN in ZFOURGE

- AGN 101
- Feedback
- Selecting AGN
- Properties of their hosts
- Evolutionary trends



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ZFOURGE

FourStar Galaxy Evolution Survey

What:

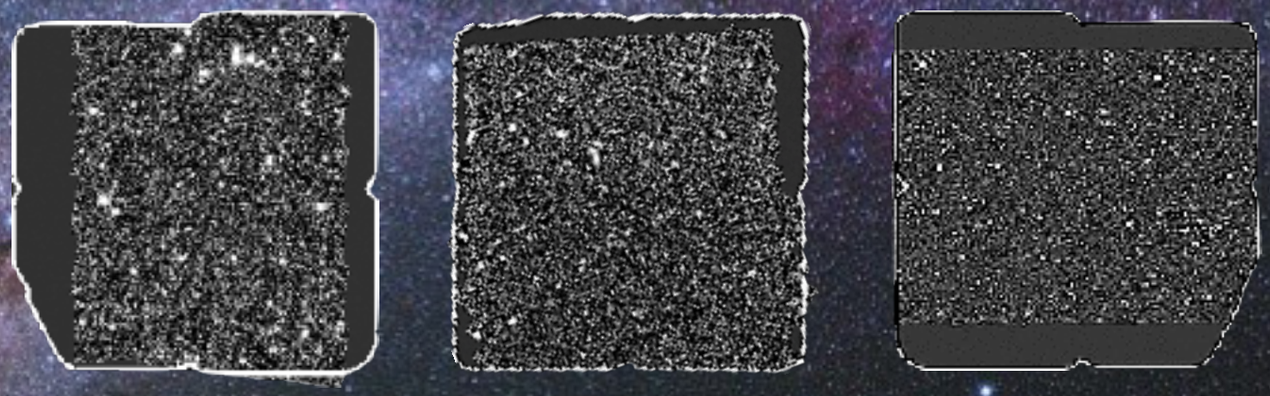
- ~50 nights on Magellan/
- FourStar near-IR camera
- 5 medium-band filters
- Ks broadband (NIR @ 2.2μm)

Primary goal:

- Accurate photometric redshift of ~70,000 galaxies
- Study galaxy formation and evolution at z > 1

3 legacy fields

- COSMOS, GOODS-S, UDS
- each 11’ x 11’ field of view



COSMOS GOODS-S UDS

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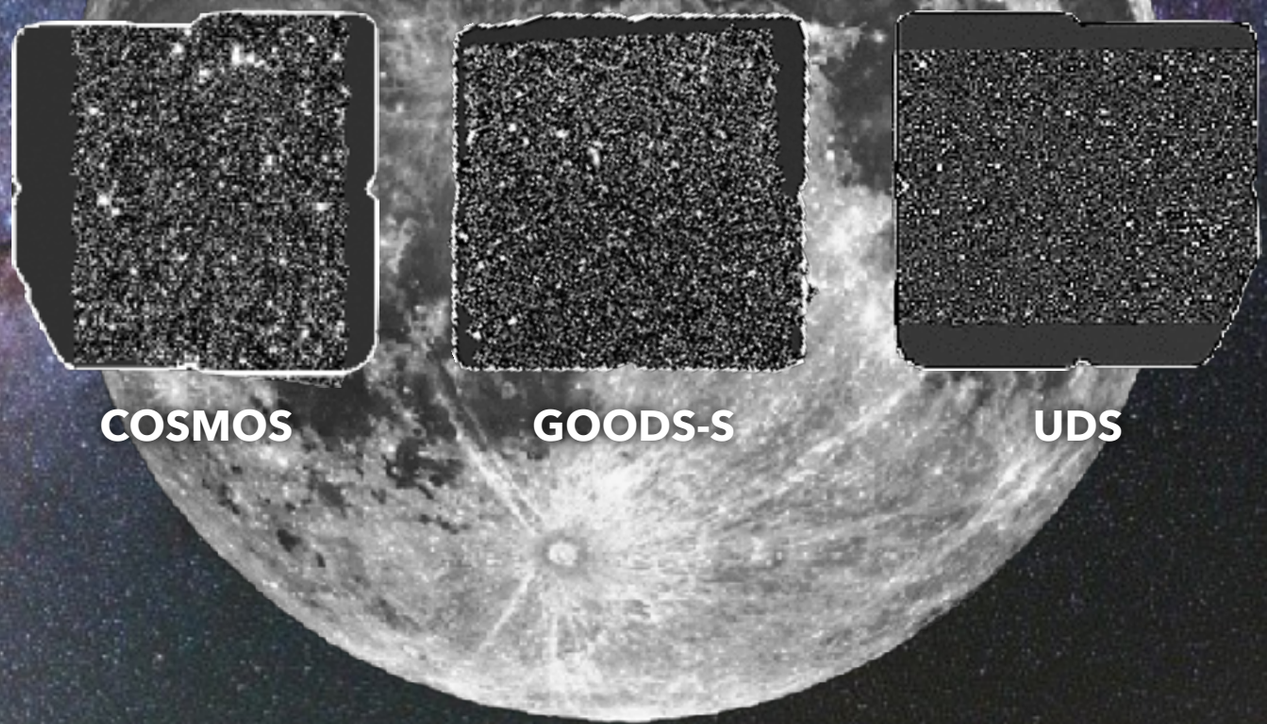

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IVO LABBÉ (PI)
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CASEY PAPOVICH
ERIC PERSSON
RYAN QUADRI
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Catalogues: arXiv 1608.07579

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ZFIRE

Catalogues: arXiv 1607.00013

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LISA KEWLEY
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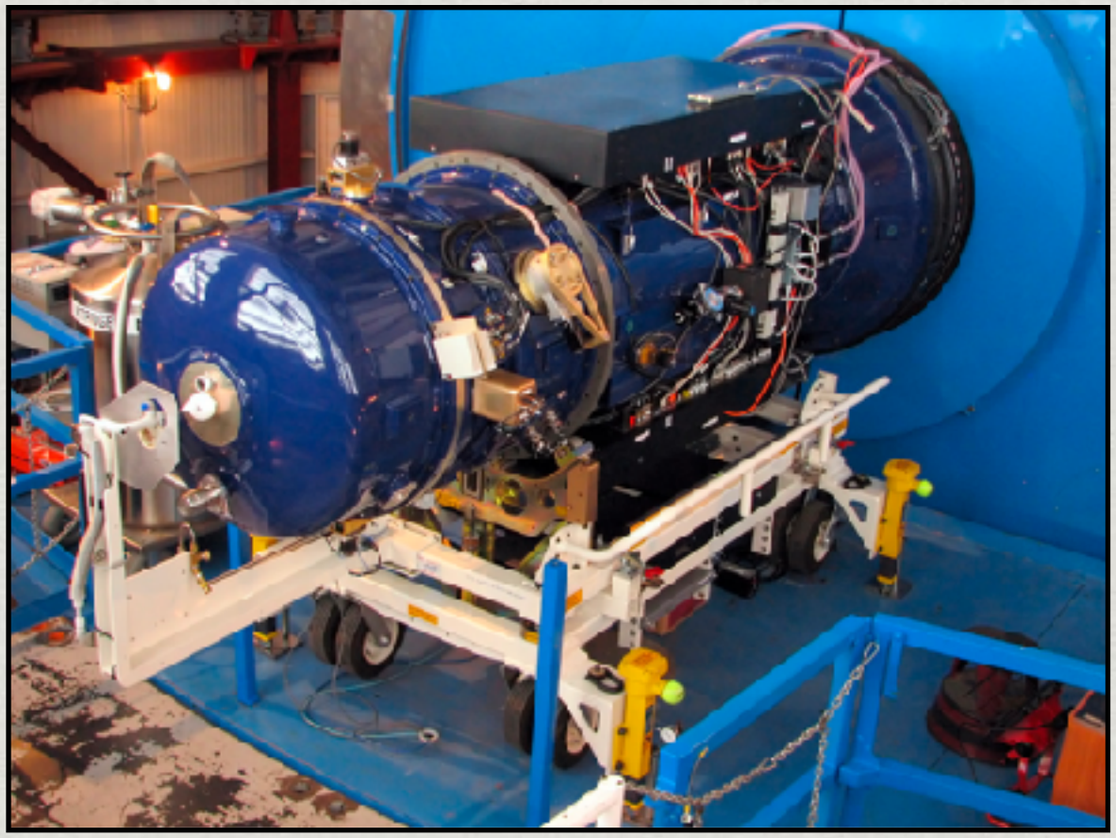
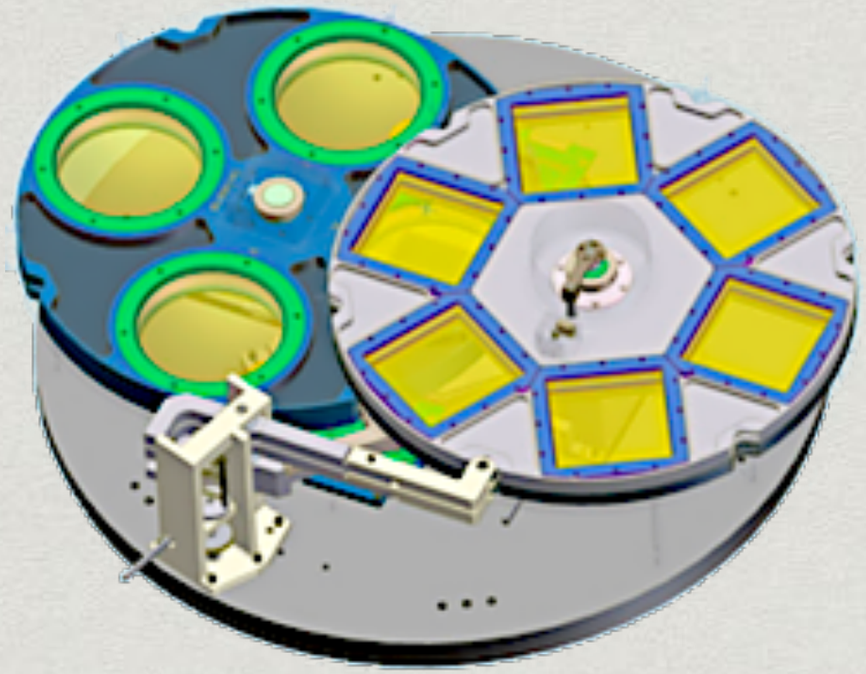
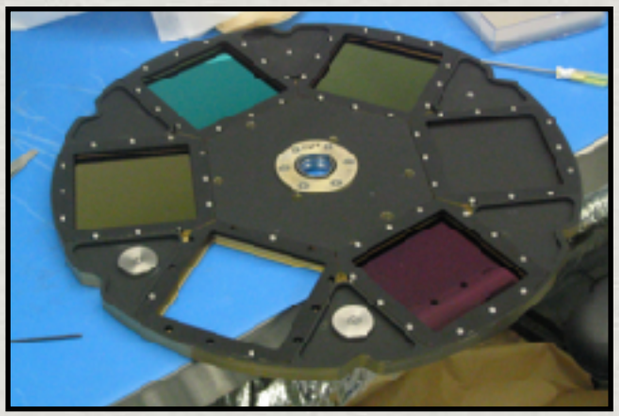
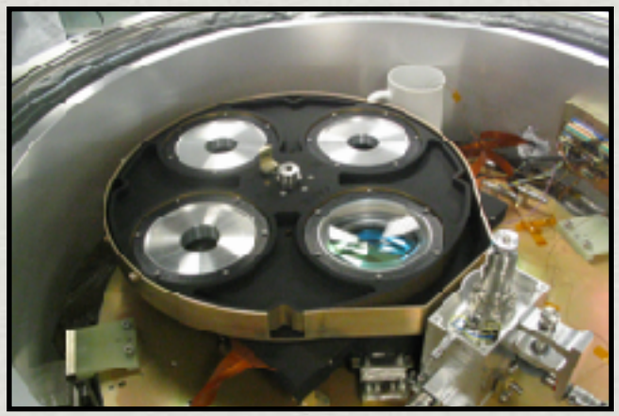
FOURSTAR









The Four Star infrared camera is a 1-2.5 micron near infrared camera for the Magellan Baade Telescope. The instrument utilises four imaging arrays in a close-packed arrangement to achieve a 4096 X 4096 equivalent pixel imaging area. The projected field size on the sky is 11' X 11'.

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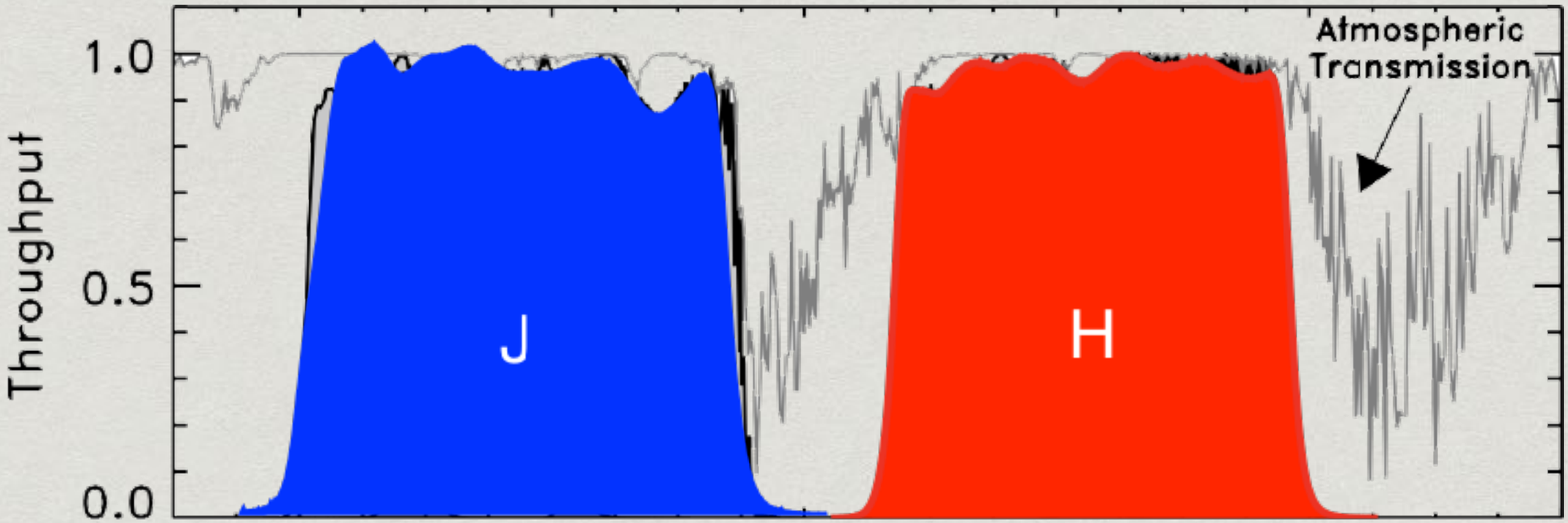
WITHOUT ZFOURGE

FourStar Galaxy Evolution Survey

Traditional Broad-band Filters



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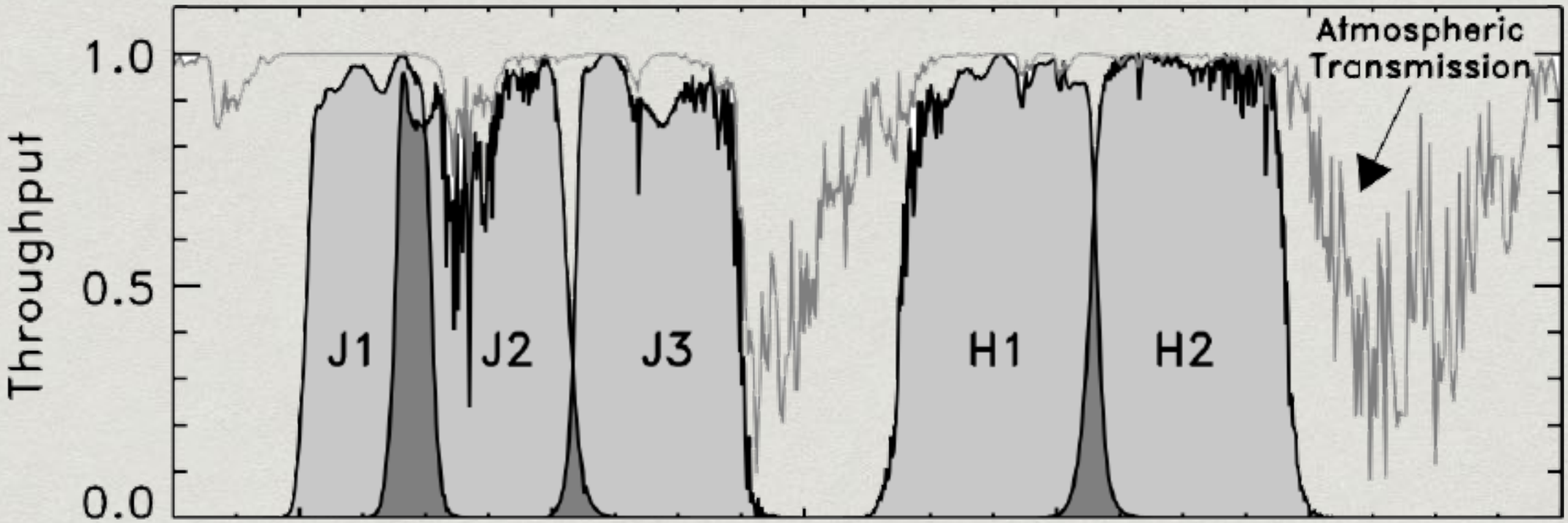
ZFOURGE

FourStar Galaxy Evolution Survey

ZFOURGE Medium-band Filters



Excellent agreement with publicly available spectroscopic redshifts, with $\sigma_z /(1 + z) \sim 1\%$

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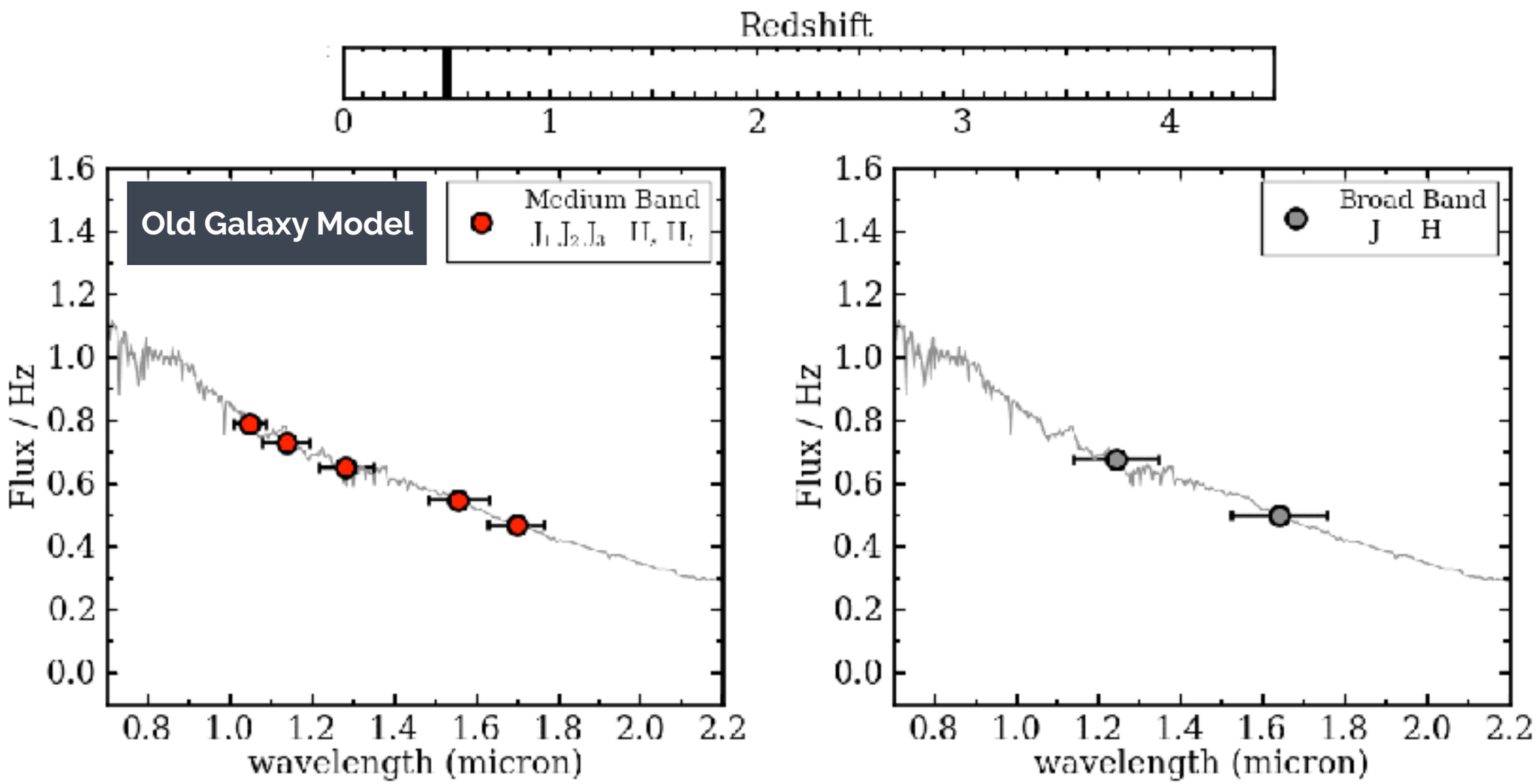
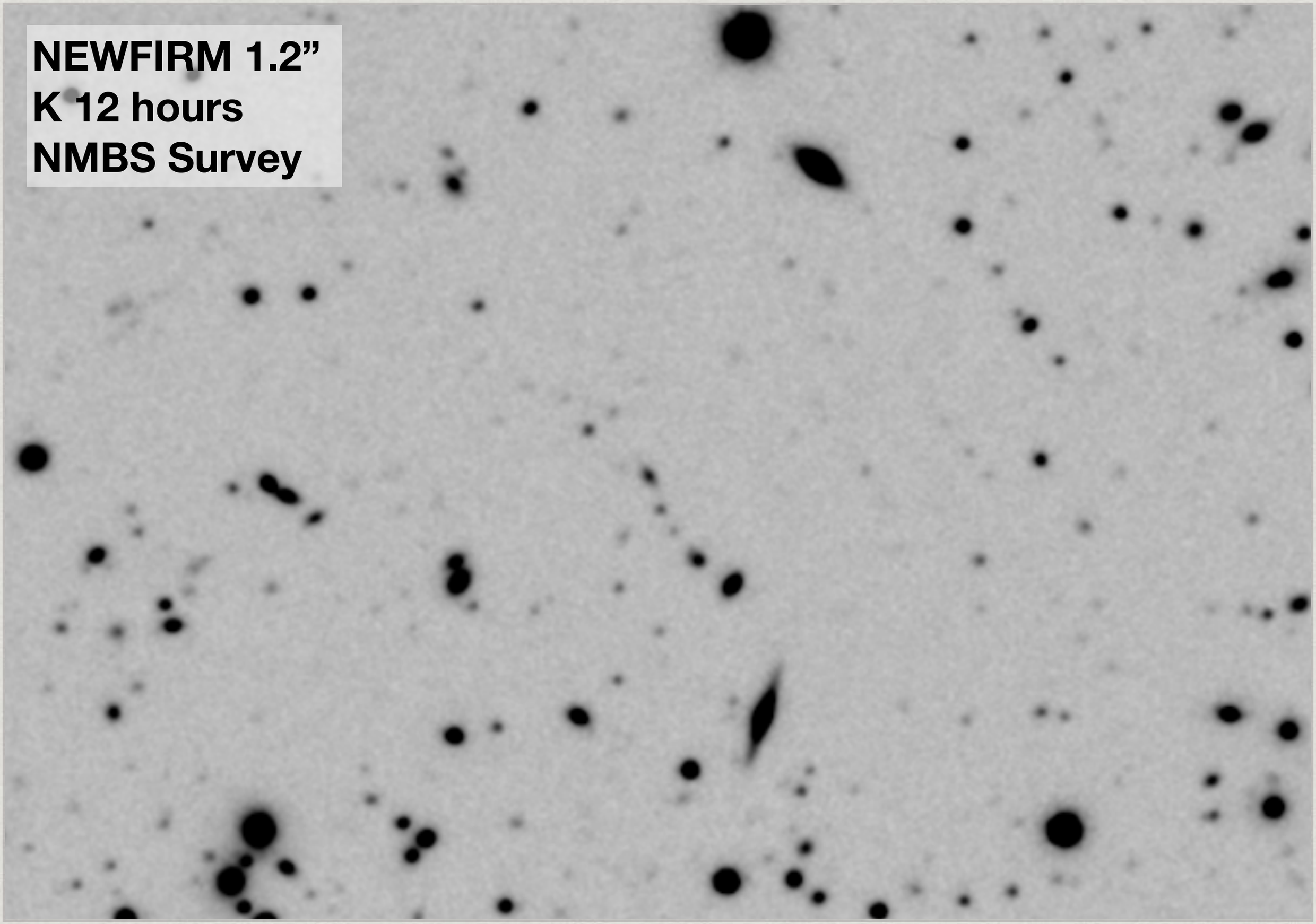
FourStar Galaxy Evolution Survey



ZFOURGE Filters

Traditional Filters



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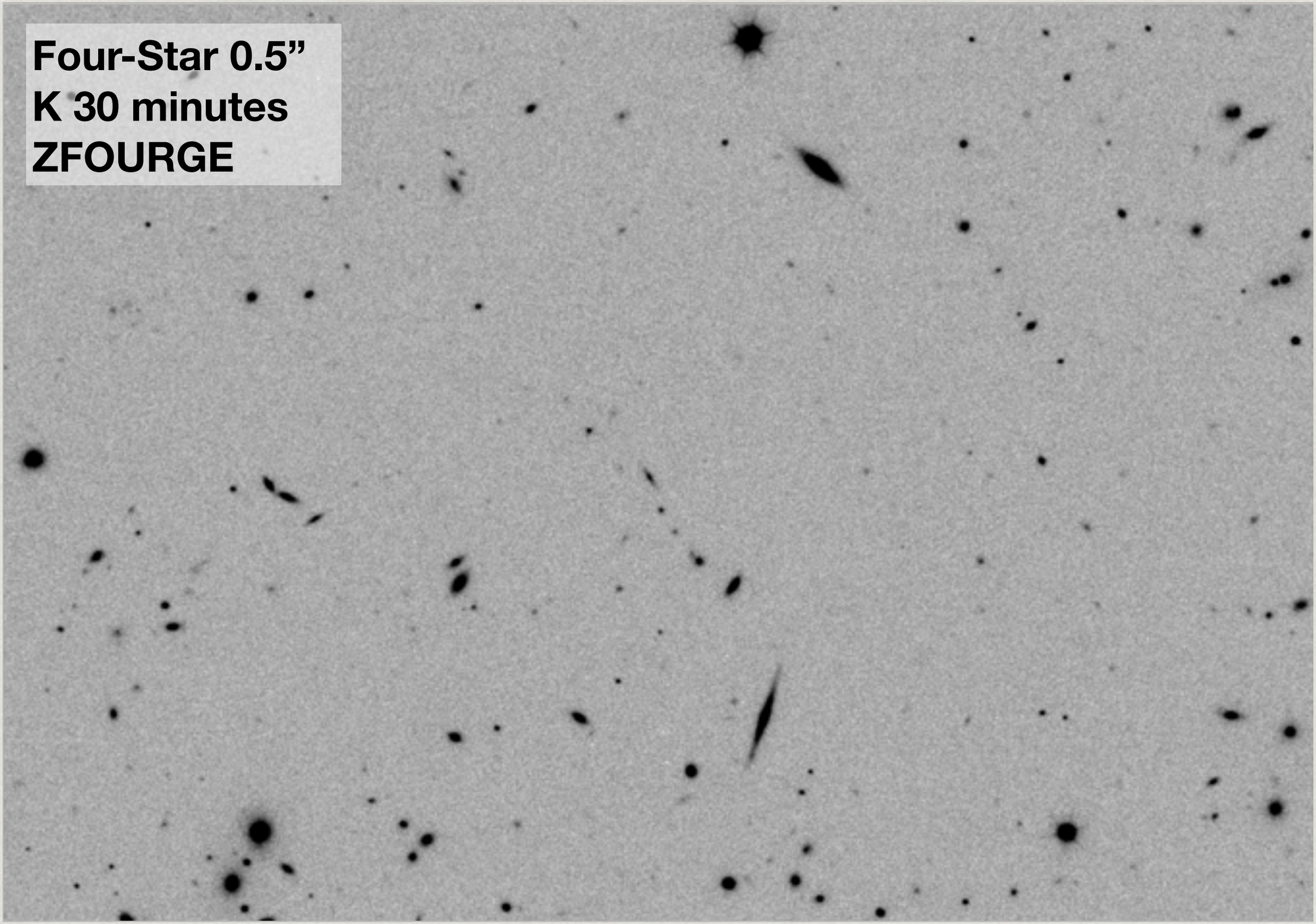
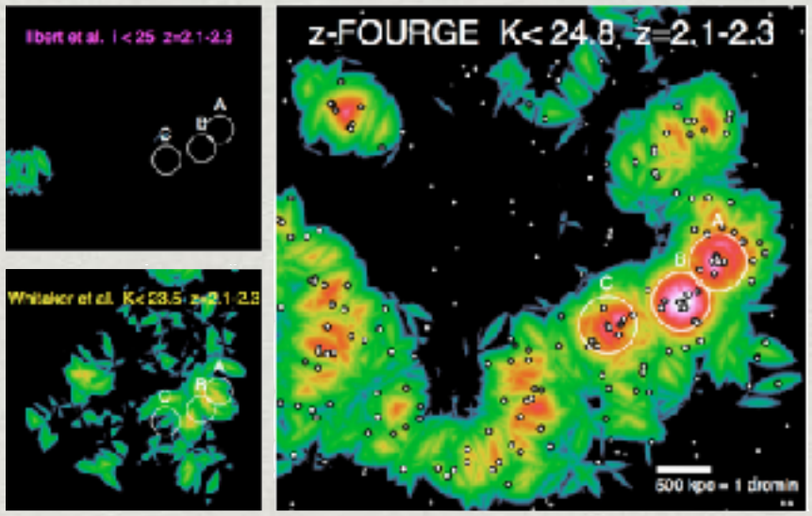
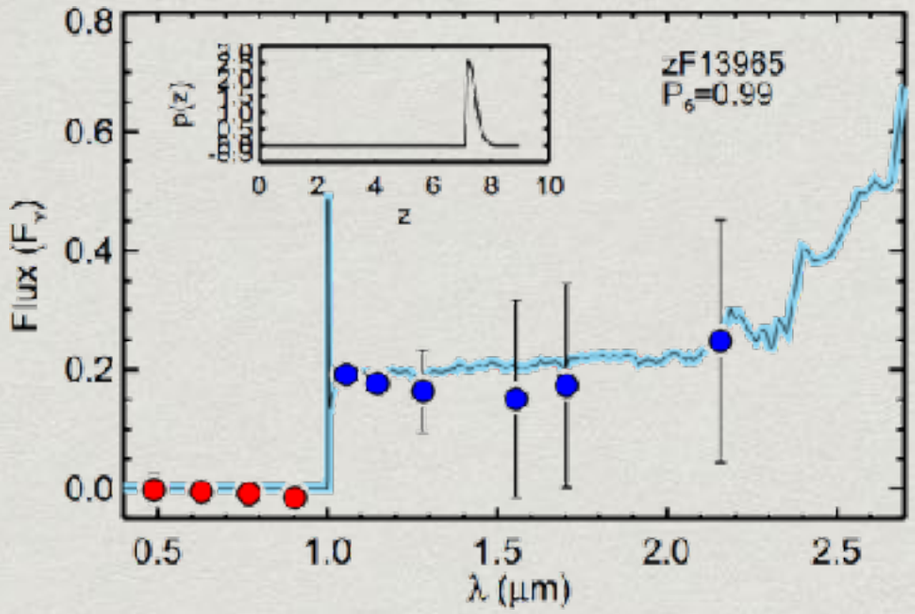

Four-Star 0.5”
K 30 minutes
ZFOURGE

HIGHLIGHTS FROM ZFOURGE



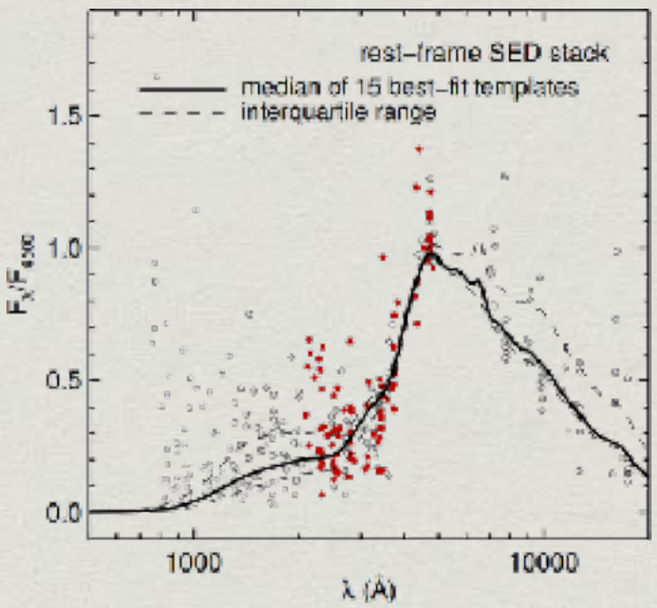
DISCOVERY OF A CANDIDATE CLUSTER AT z = 2.2 IN COSMOS

Spitler et al. 2012, *Astrophysical Journal Letters*



DISCOVERY OF LYMAN BREAK GALAXIES AT z~7 FROM THE ZFOURGE SURVEY

Tilvi et al. 2013, *Astrophysical Journal*



A SUBSTANTIAL POPULATION OF MASSIVE QUIESCENT GALAXIES AT z~4 FROM ZFOURGE

Straatman et al., 2014, *Astrophysical Journal Letters*

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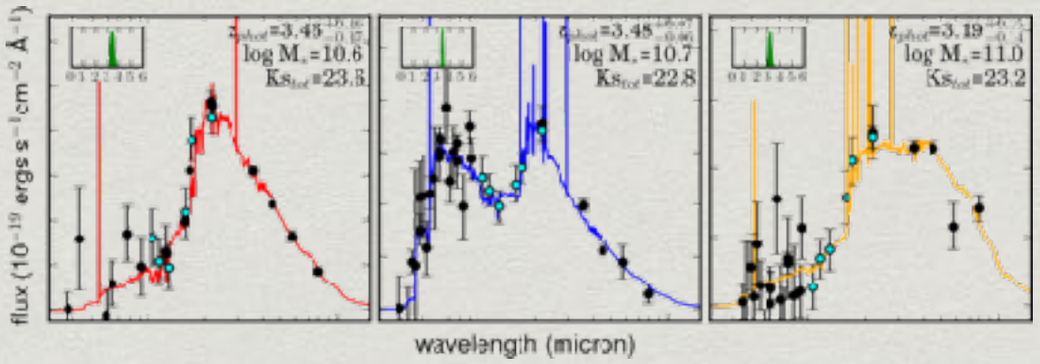
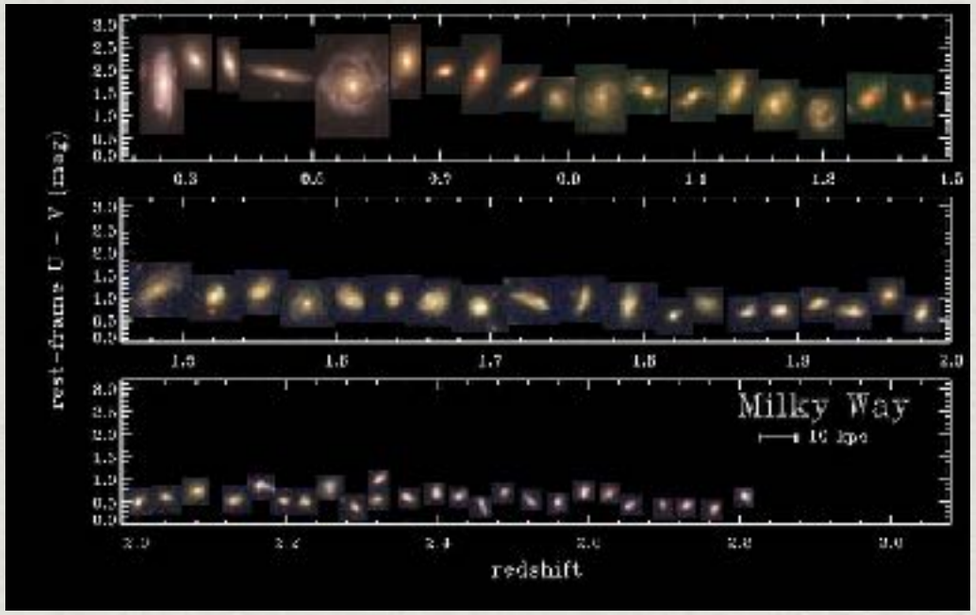
MORE HIGHLIGHTS FROM ZFOURGE



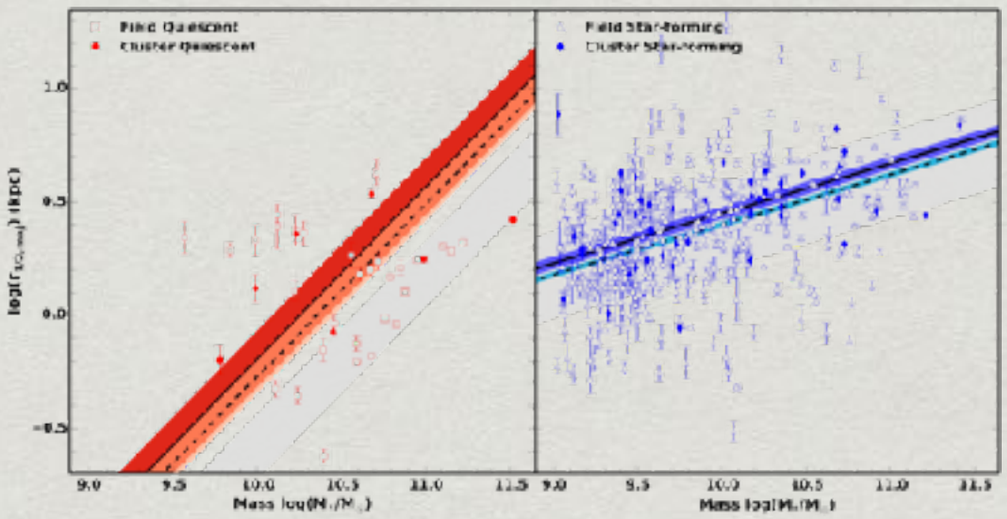
EXPLORING THE z=3-4 MASSIVE GALAXY POPULATION WITH ZFOURGE

Spitler et al. 2014, *Astrophysical Journal Letters*



ON THE EVOLUTION OF M* GALAXY PROGENITORS FROM z = 3 TO 0.5

Papovich et al. 2015, *Astrophysical Journal*



THE DIFFERENTIAL SIZE GROWTH OF FIELD AND CLUSTER GALAXIES AT z = 2.1 USING THE ZFOURGE SURVEY

Allen et al. 2015, *Astrophysical Journal*

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WELCOME TO AGN 101

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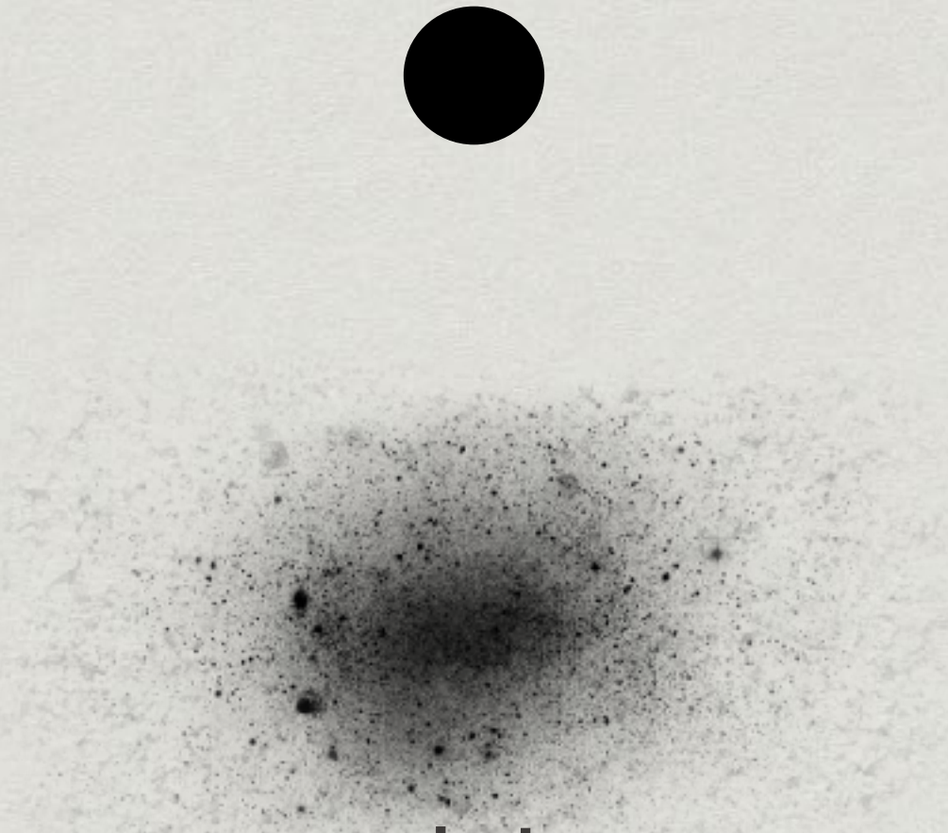
WHAT IS AN AGN?

- The term “active galactic nucleus” or AGN refers to the existence of energetic processes in the nuclei or central regions of some galaxies
- These energetic processes are not related to the normal evolution of stars

SUPERMASSIVE BLACK HOLE

FEEDING A SUPERMASSIVE BLACK HOLE

gas



dust

stars

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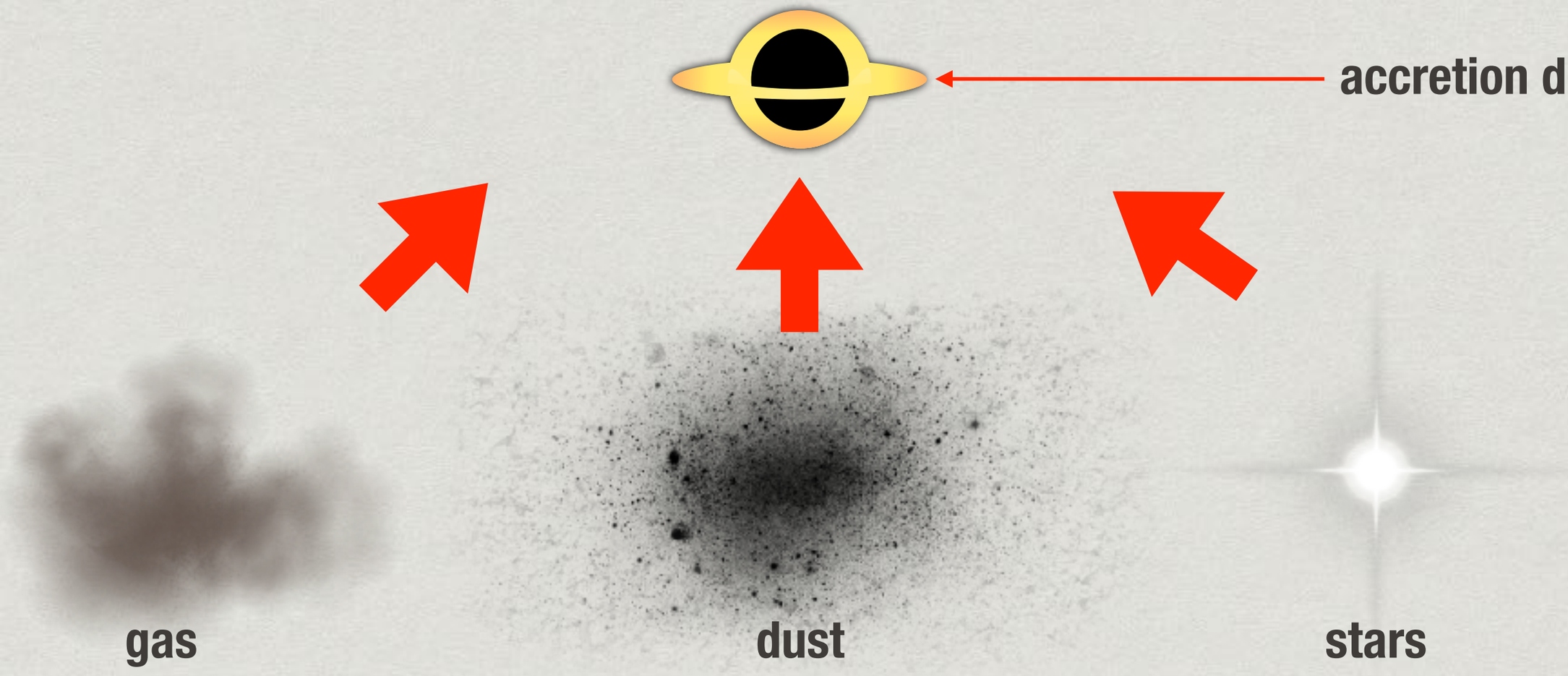
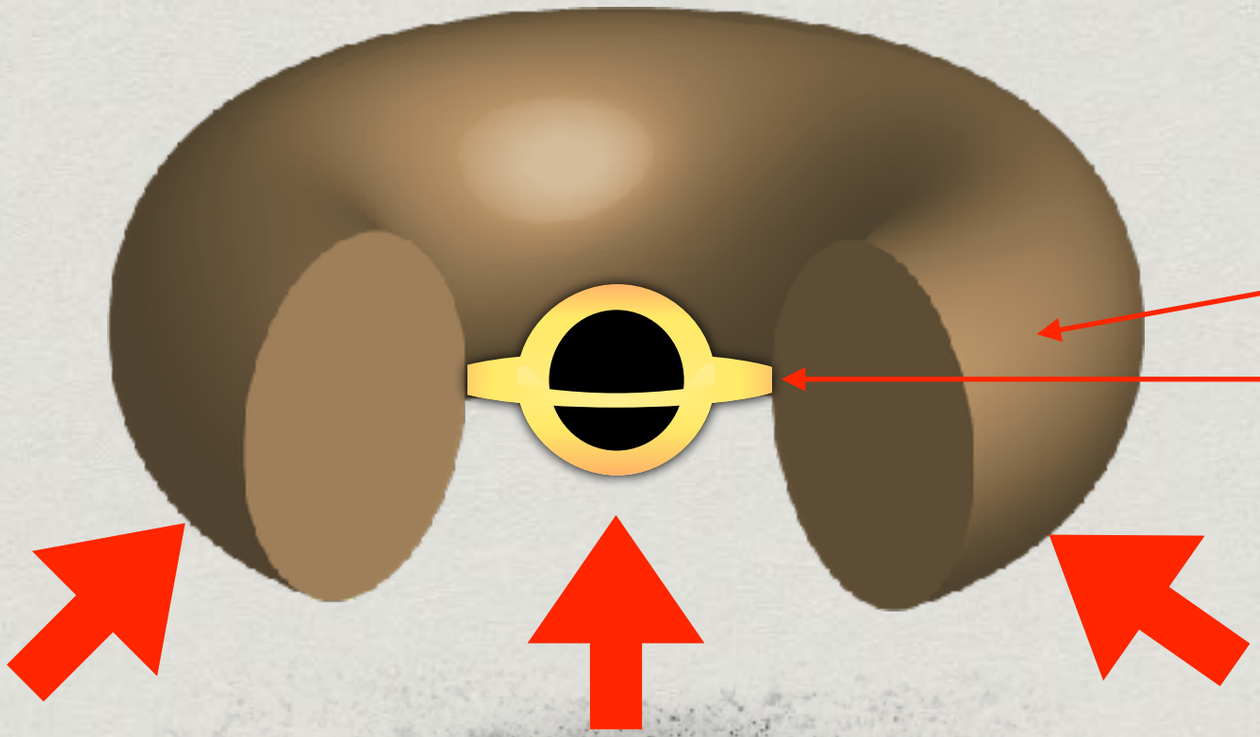
FEEDING A SUPERMASSIVE BLACK HOLE

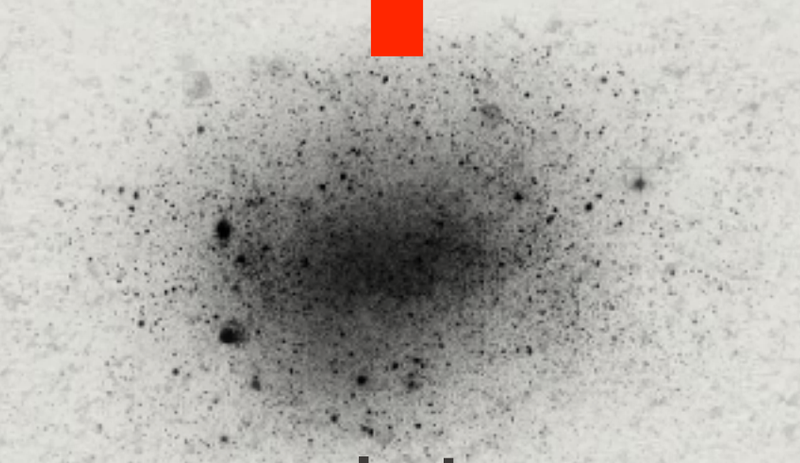
Conservation of angular momentum causes fuel to form a disk as it spirals in



FEEDING A SUPERMASSIVE BLACK HOLE



gas



dust

stars

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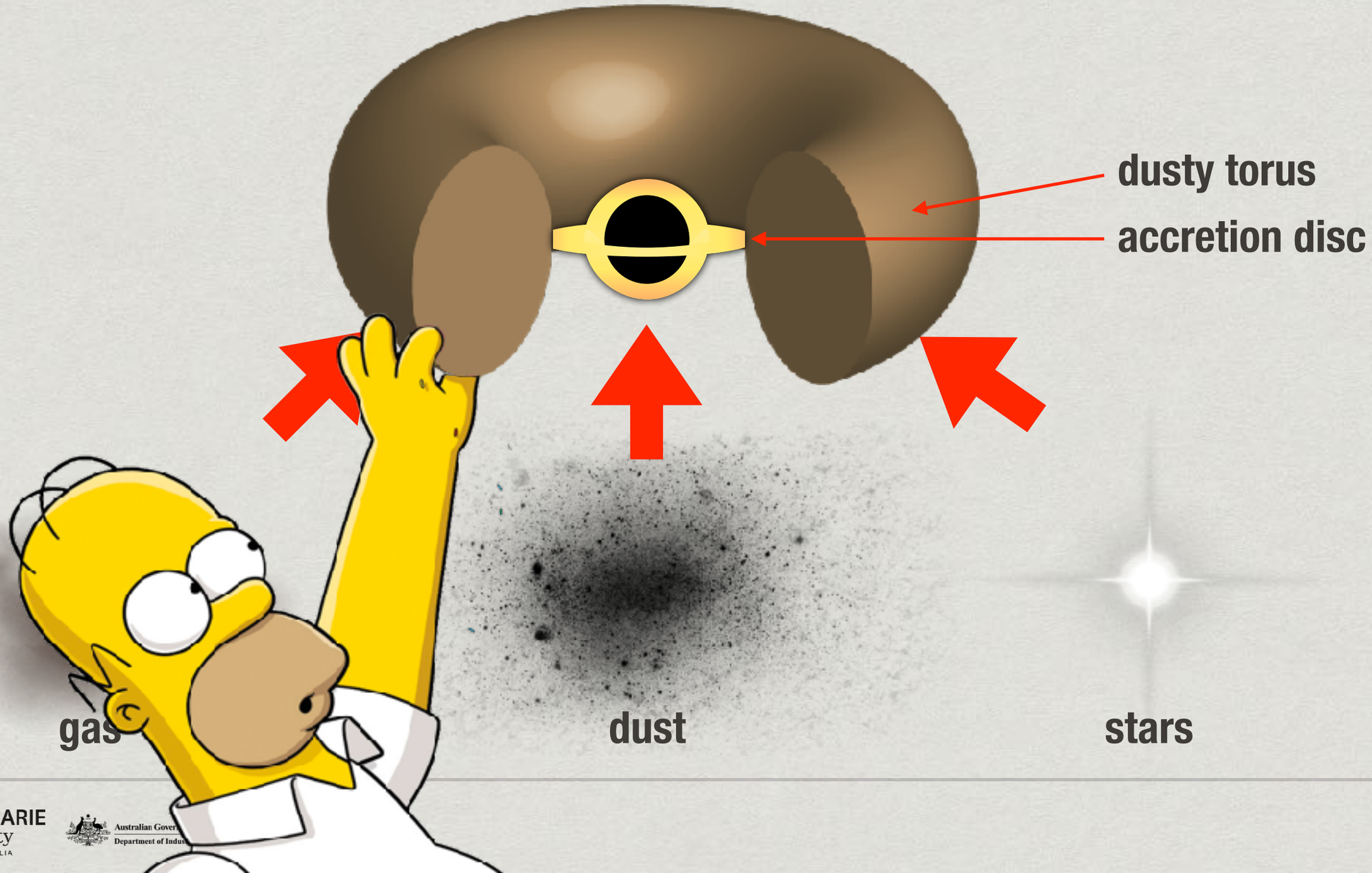

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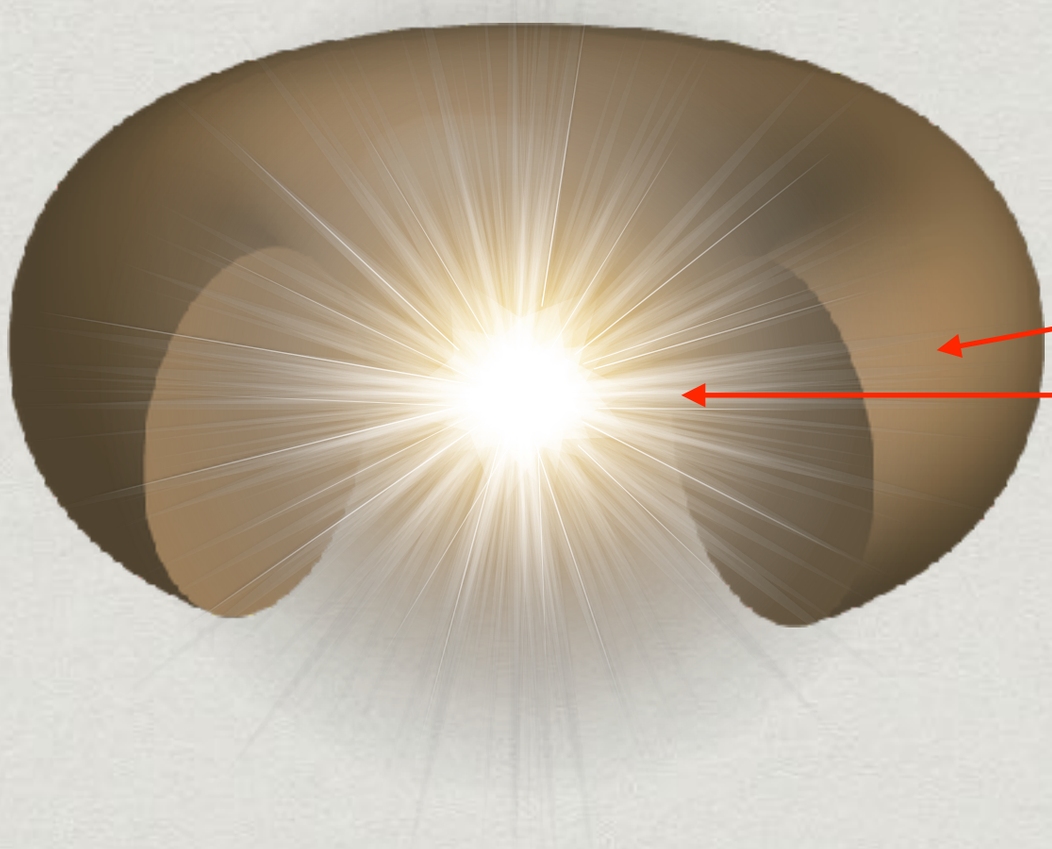
ACTIVE SUPERMASSIVE BLACK HOLE

$L \sim 10^{37\text{-}41}$W

(i.e. $\sim 10^{10\text{-}14} L_{\odot}$)



Within this disc, there are dissipative processes, e.g. collisions, shocks, etc. This dissipated energy emerges as radiation

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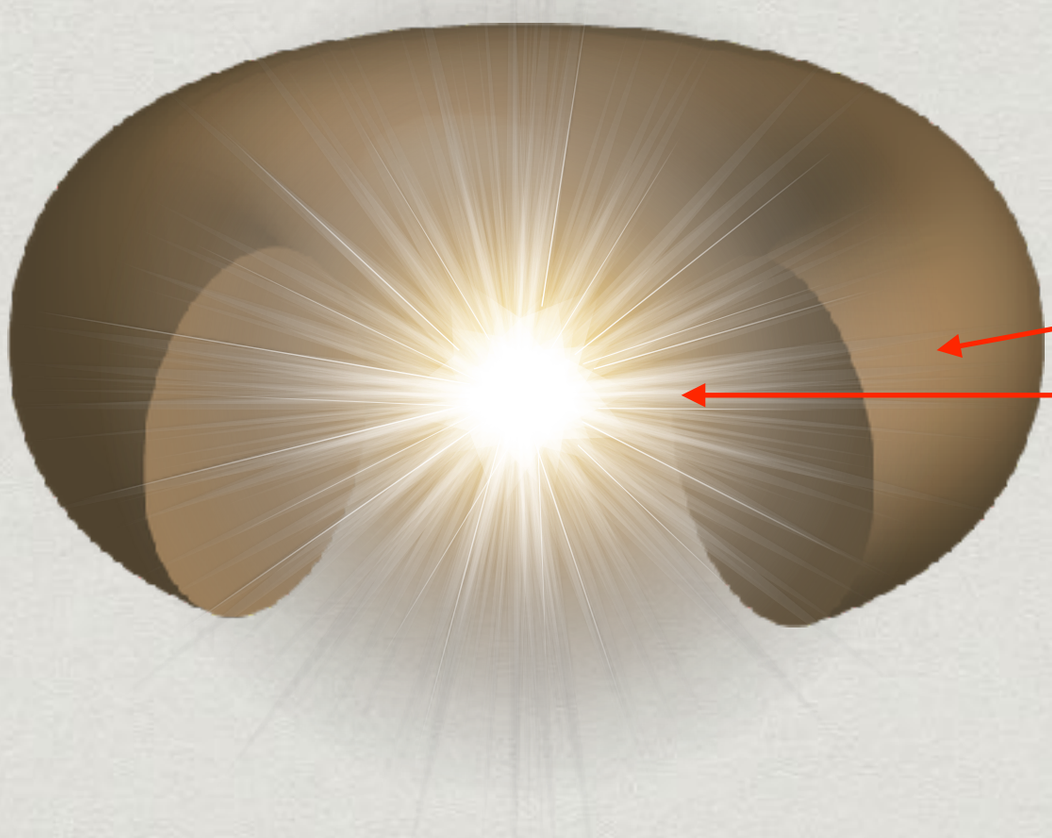
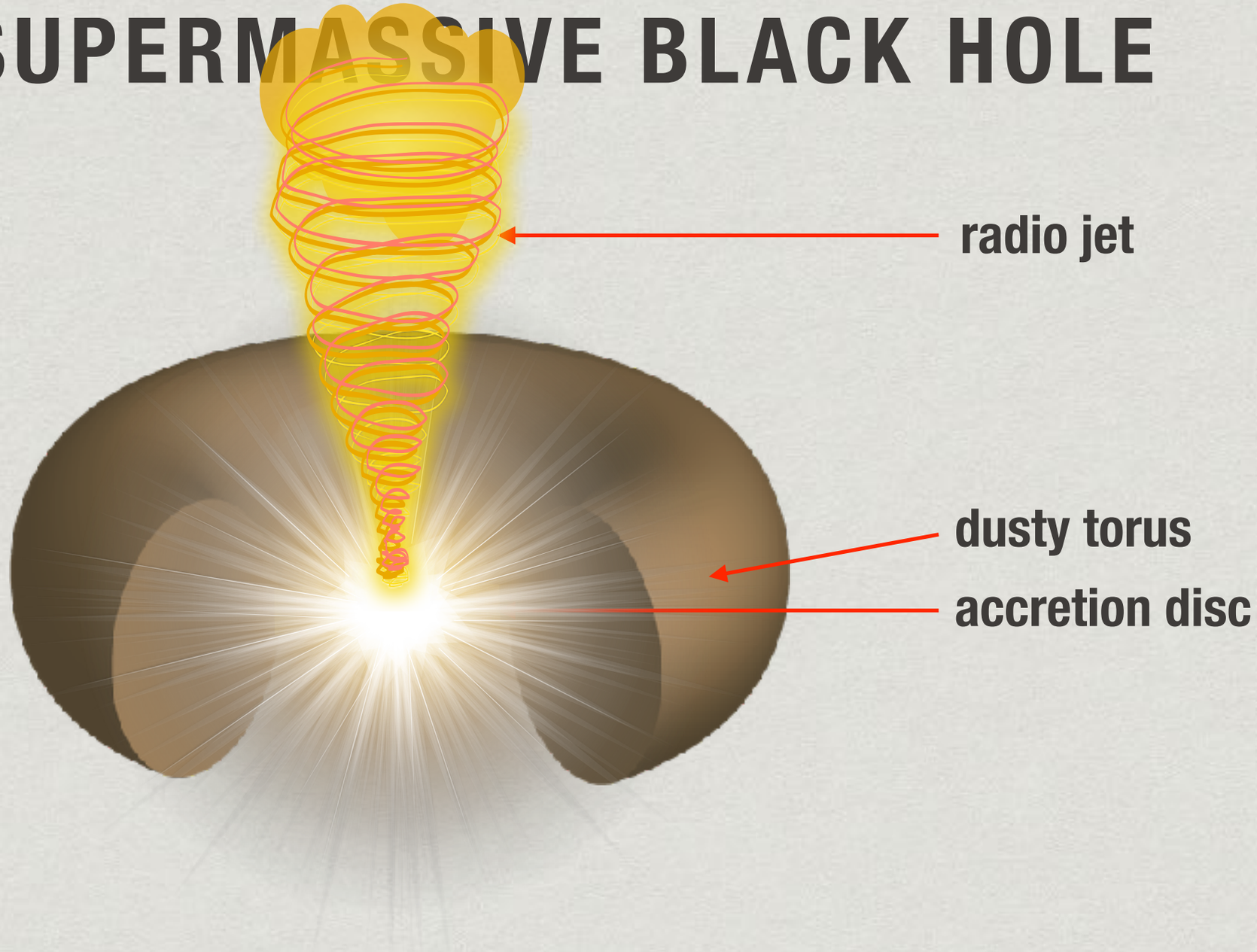


Accretion rate… $\dot{M} = \dfrac{L}{\eta c^2} = \dfrac{10^{10} L_\odot}{0.1 c^2} \approx 0.01 M_\odot \mathrm{yr}^{-1}$

ACTIVE SUPERMASSIVE BLACK HOLE



Jets of ionised gas that propagate perpendicular to the plane of the accretion disc emit radio emission

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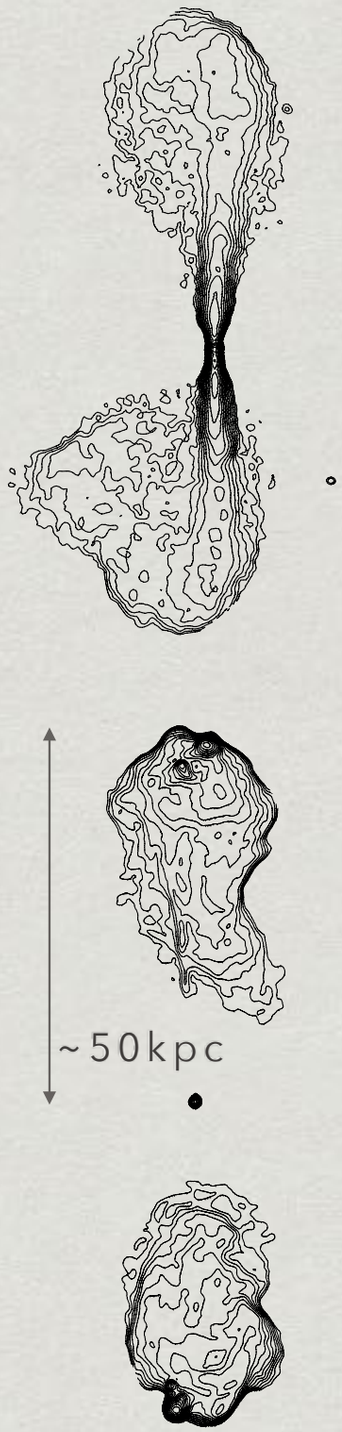
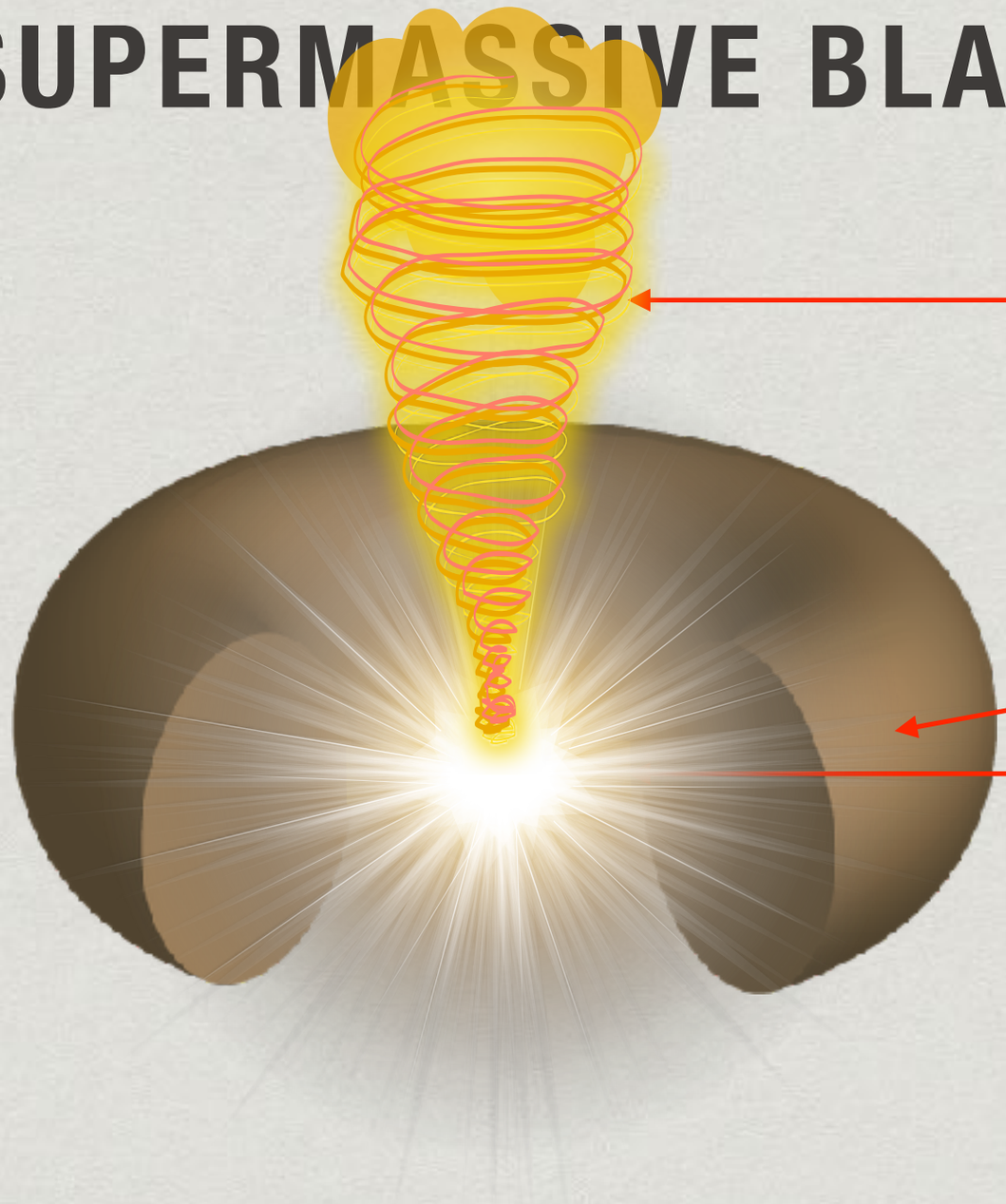
ACTIVE SUPERMASSIVE BLACK HOLE





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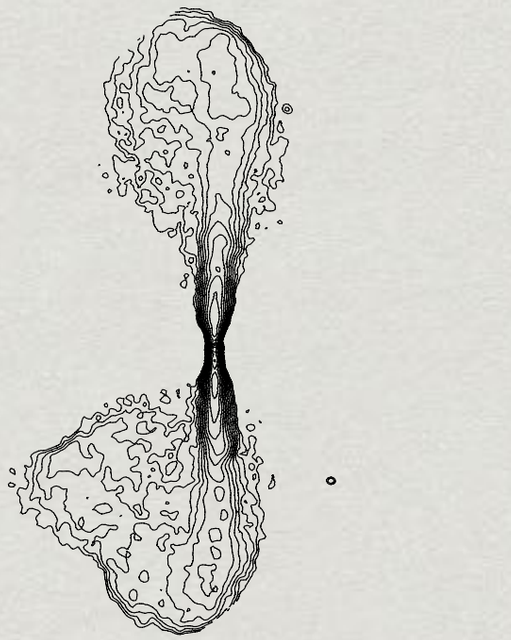

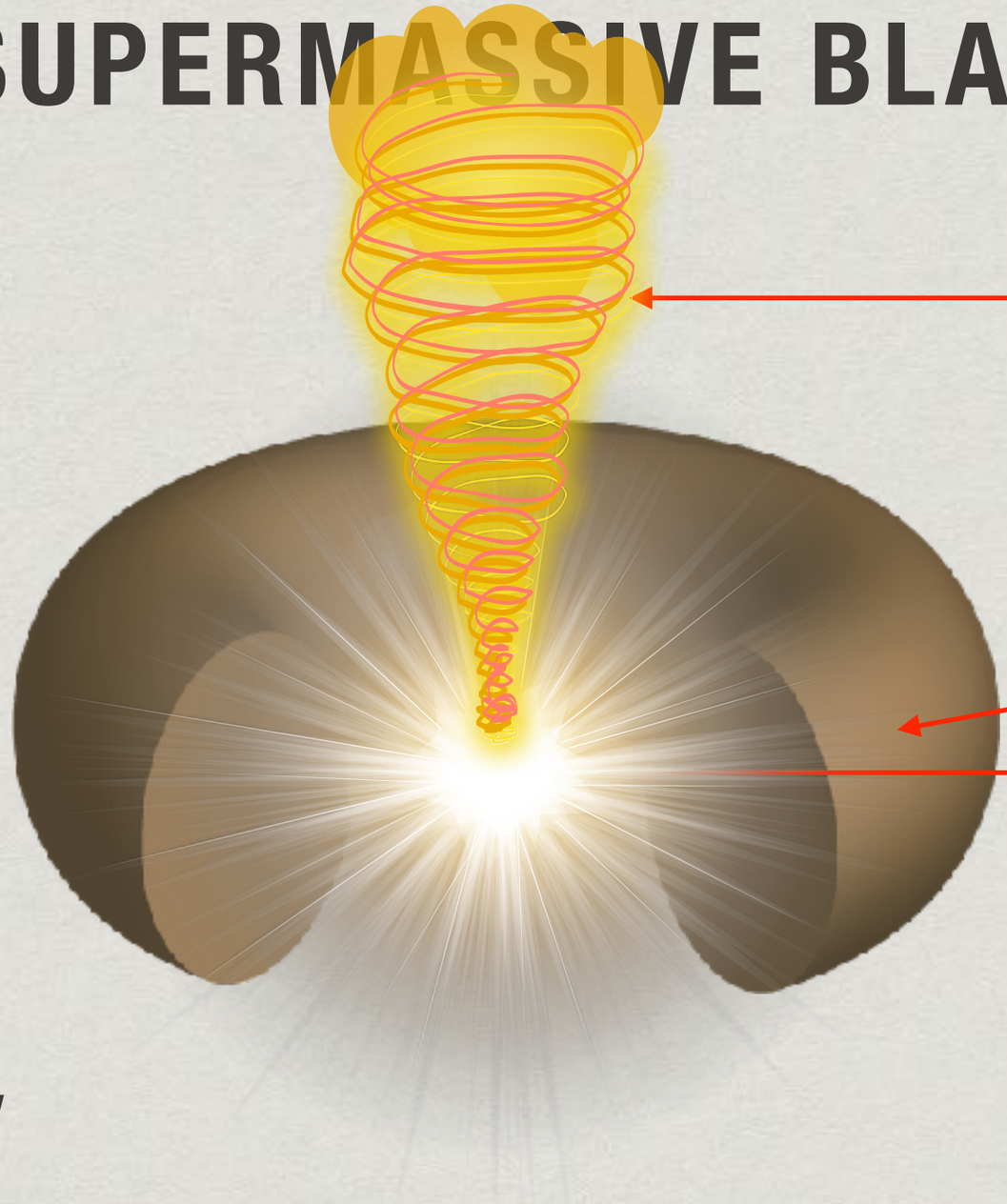

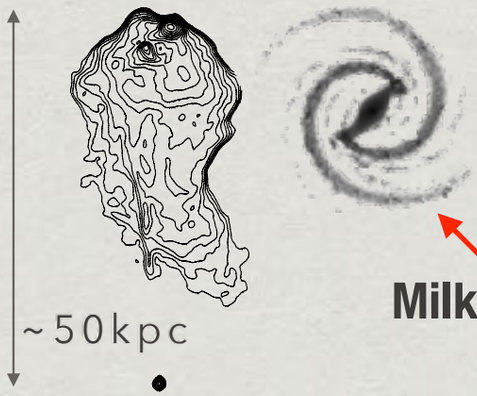

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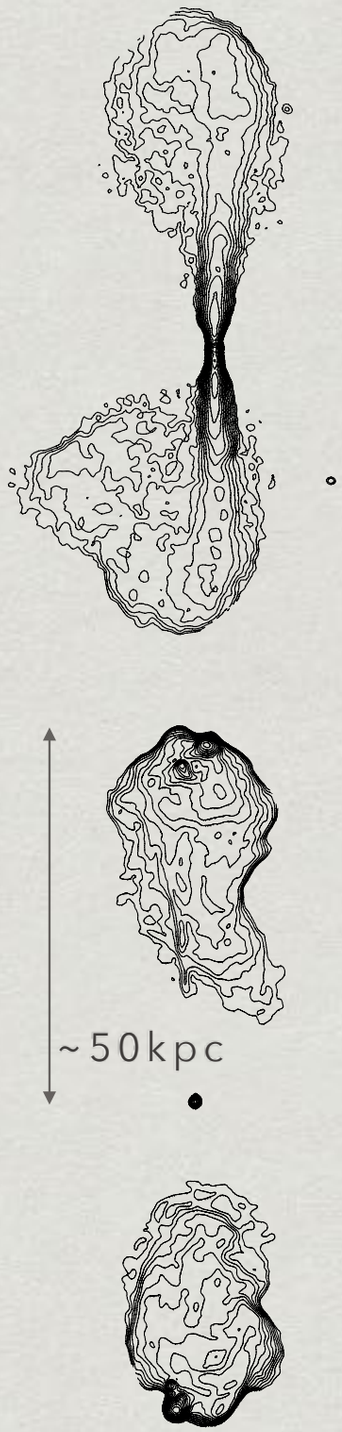

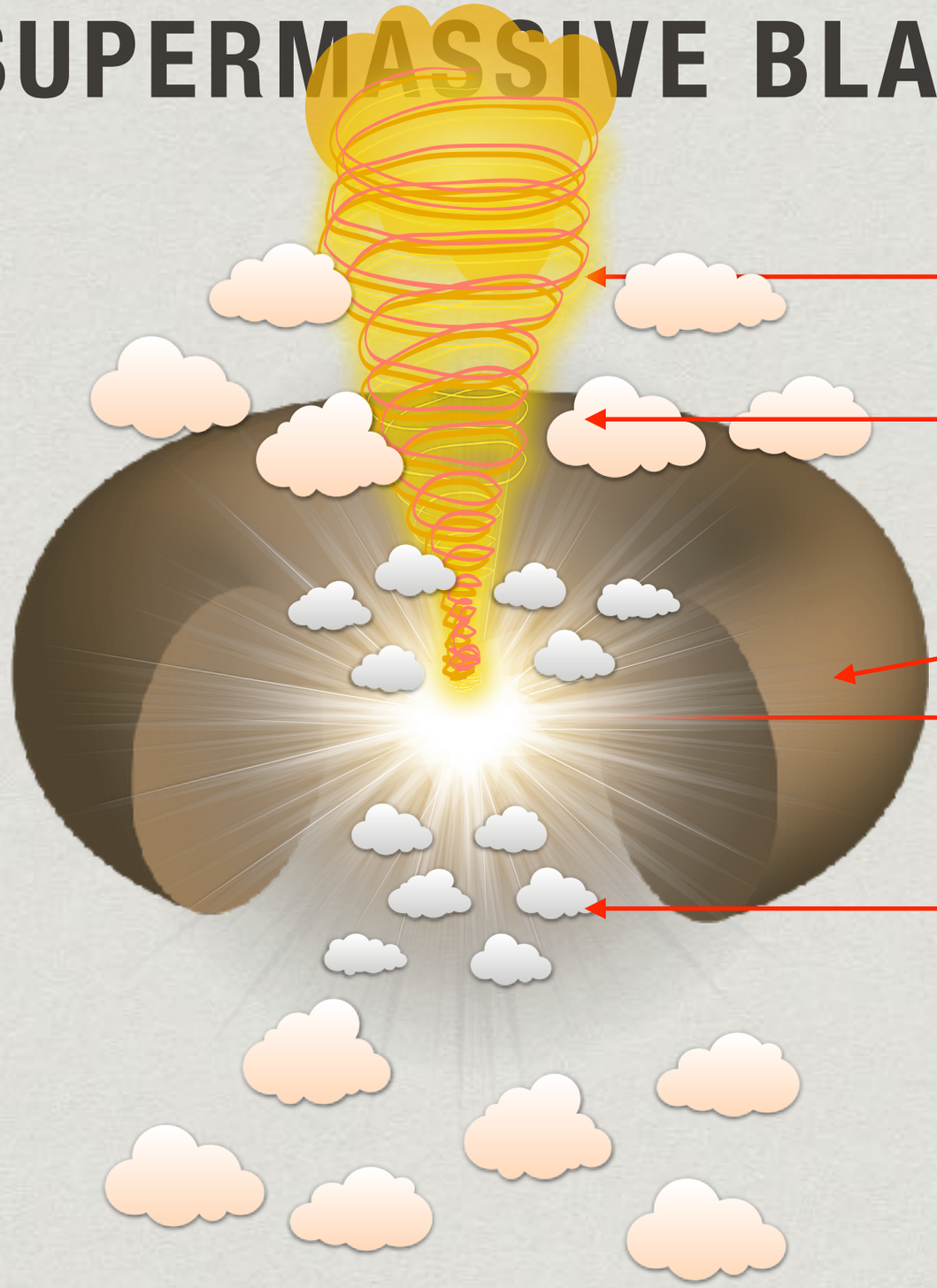

radio jet

narrow line region (~500-1000 km/s)

dusty torus

accretion disc

broad line region (~1000-5000 km/s)

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FR-I

Fanroff & Riley 1
Lower *L* and faint lobes

Quasar

Quasai-Stellar Radio Source

RL QSO

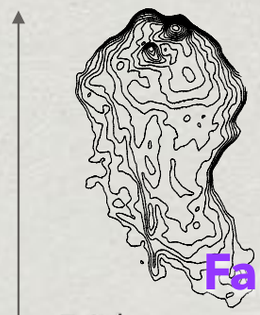
Radio Loud QSO

BLRG

Broad Line (+NLs) Radio Galaxy

NLRG

Narrow Line Radio Galaxy



~50kpc

FR-II

Fanroff & Riley 2
Higher *L* and bright lobes

Seyfert-2

Dust Obscured, Narrow Line

Seyfert-1.x

Weaker Broad Lines for numerically larger

Seyfert-1

Unobscured, Broad Lines & Narrow Lines

QSO

Quasai-Stellar Object

RQ QSO

Radio Quiet QSO

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Quasar

Quasai-Stellar Radio Source

RL QSO

Radio Loud QSO

BLRG

Broad Line (+NLs) Radio Galaxy

FR-I

Fanroff & Riley 1 Lower *L* and faint lobes

NLRG

Narrow Line Radio Galaxy

Other subclasses include: **NLSy1** (very narrow-line) Seyferts; **OVV** (Optically Violently Variable) quasars; **BAL** (Broad Absorption Line) quasars; **HPQ** (Highly Polarized Quasars); **LPQ** (Low Polarization Quasars); **SSRQ** (steep-spectrum radio quasars); **FSRQ** (flat-spectrum radio quasars); compact radio sources; superluminal sources; **blazars** etc., etc...

Seyfert-2

Dust Obscured, Narrow Line

yfert-1.x

ker Broad Lines merically larger

Seyfert-1

Unobscured, Broad Lines & Narrow Lines

QSO

Quasai-Stellar Object

RQ QSO

Radio Quiet QSO

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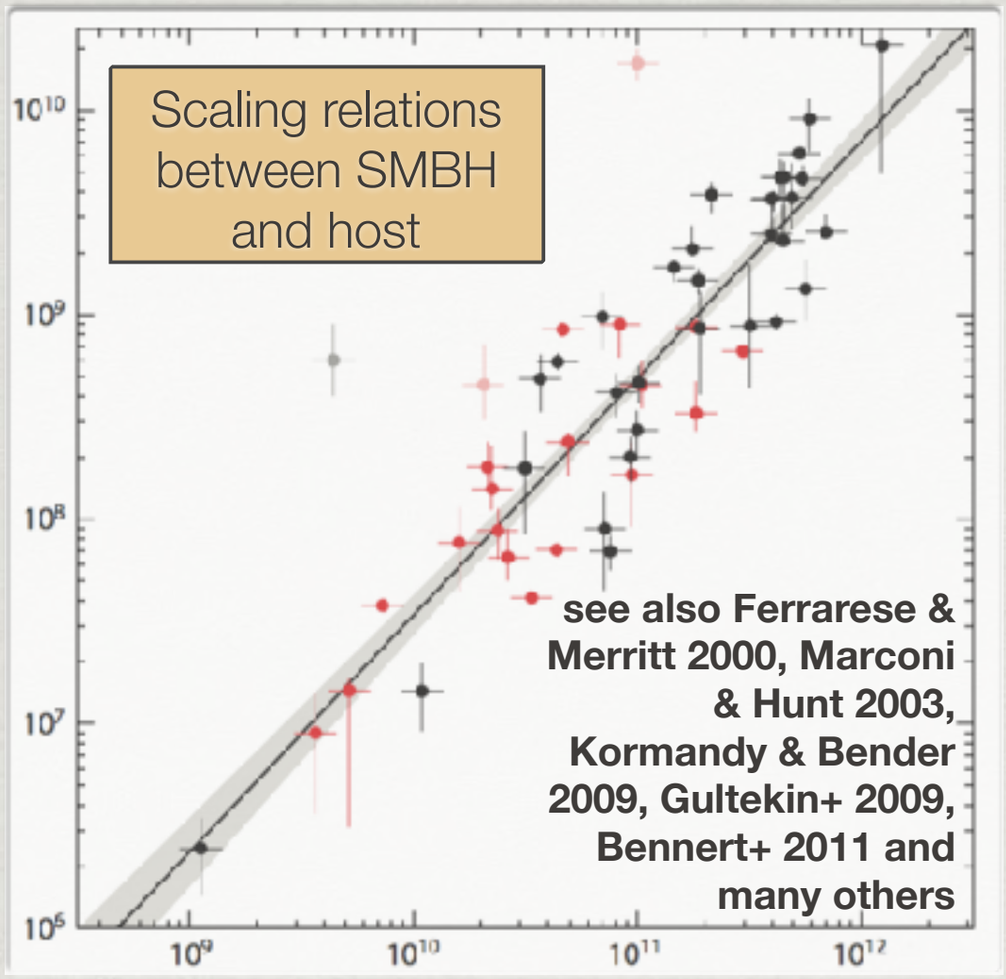
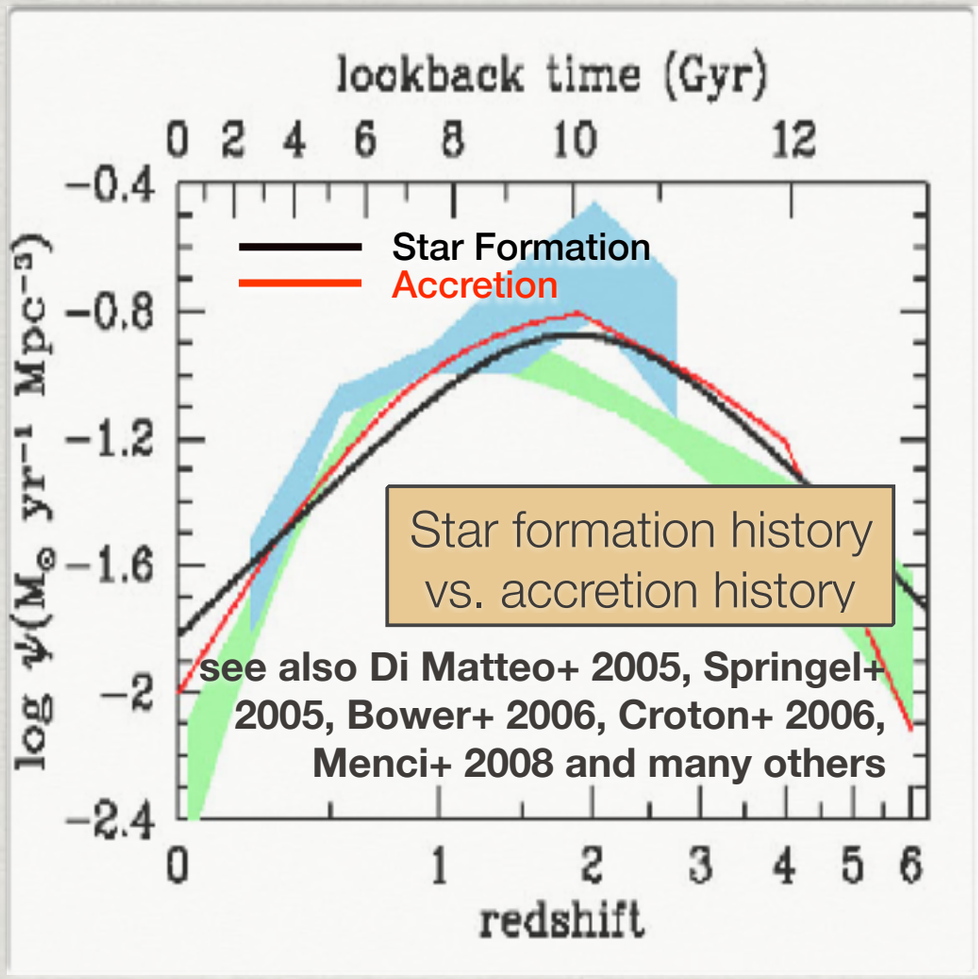
WHY SHOULD WE CARE ABOUT ACTIVE GALACTIC NUCLEI (AGN)?

There's a close connection between AGN and their hosts

Sani+ 2011



Madau & Dickinson 2014



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HOW DOES THE GALAXY KNOW THE SMBH IS THERE?

The mass of the SMBH…

$$\sim 10^8 M_\odot$$

…so its gravity only influences a region…

$$r_{\mathrm{inf}} = \frac{GM}{\sigma^2} \approx 11\mathrm{pc}\left(\frac{M_\odot}{10^8 M_\odot}\right)\left(\frac{\sigma}{200\mathrm{km\ s^{-1}}}\right)^{-2}$$

…which is far smaller than the bulge (MW ~ 5 kpc)

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SUPERMASSIVE BLACK HOLE FEEDBACK

The gravitational energy of material falling into the centre of a galaxy toward the central supermassive black hole is released in the form of

- **radiation in the IR/optical/UV/X-rays**
- **mildly relativistic accretion winds**
- **relativistic radio jets**

The radiation, winds and jets all "feed back" energy and momentum into the surrounding area of the galaxy

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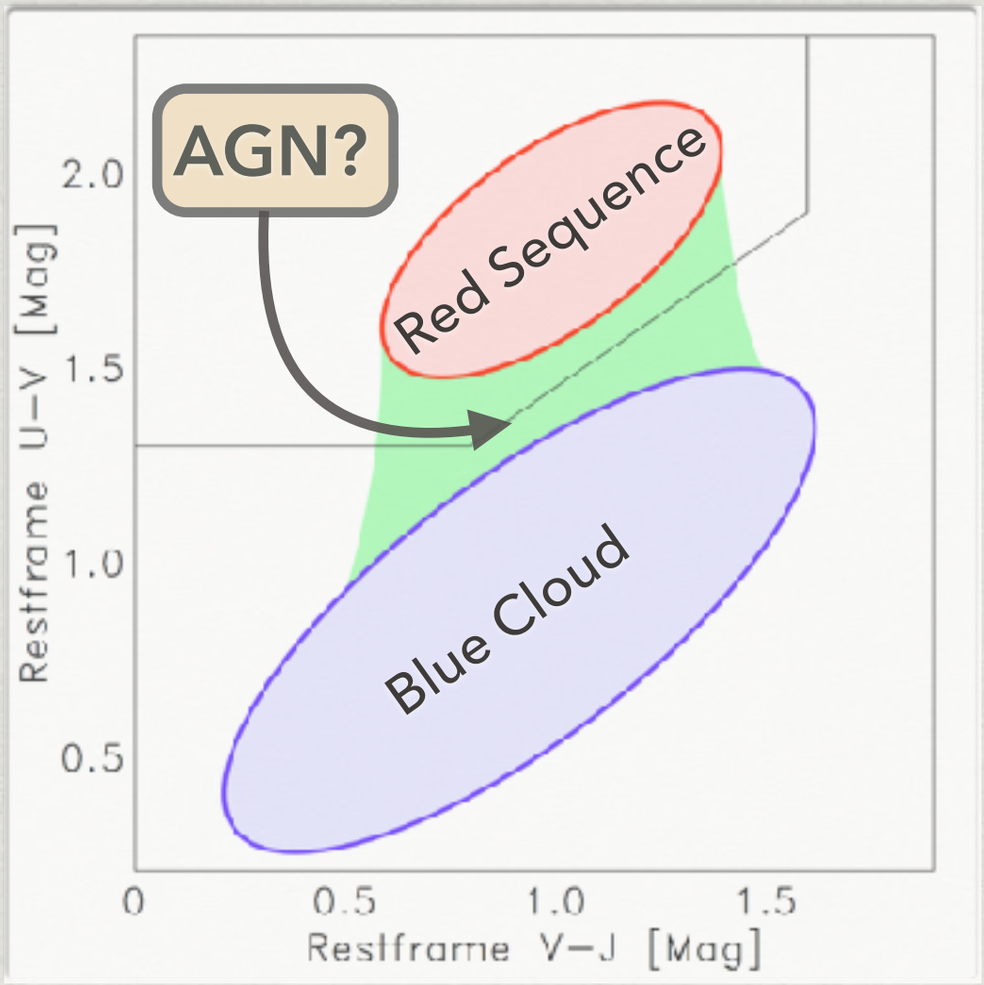
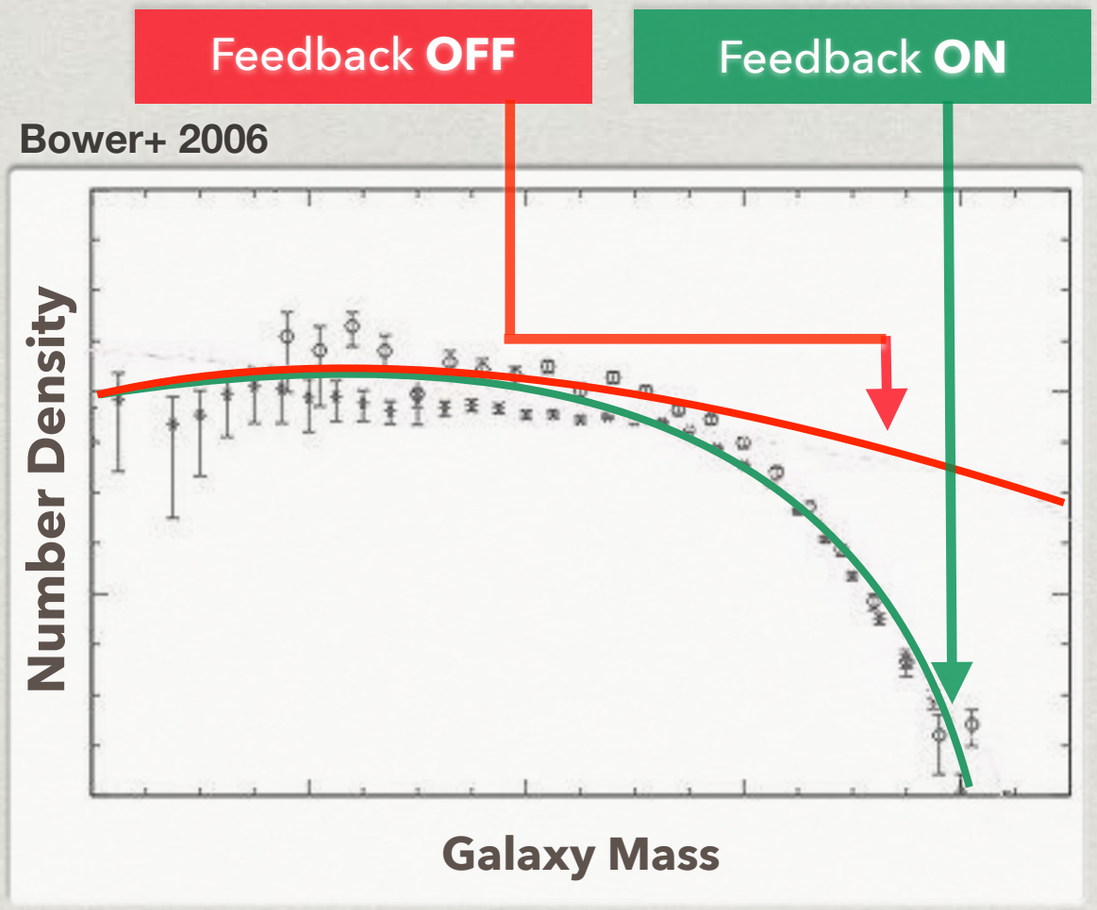
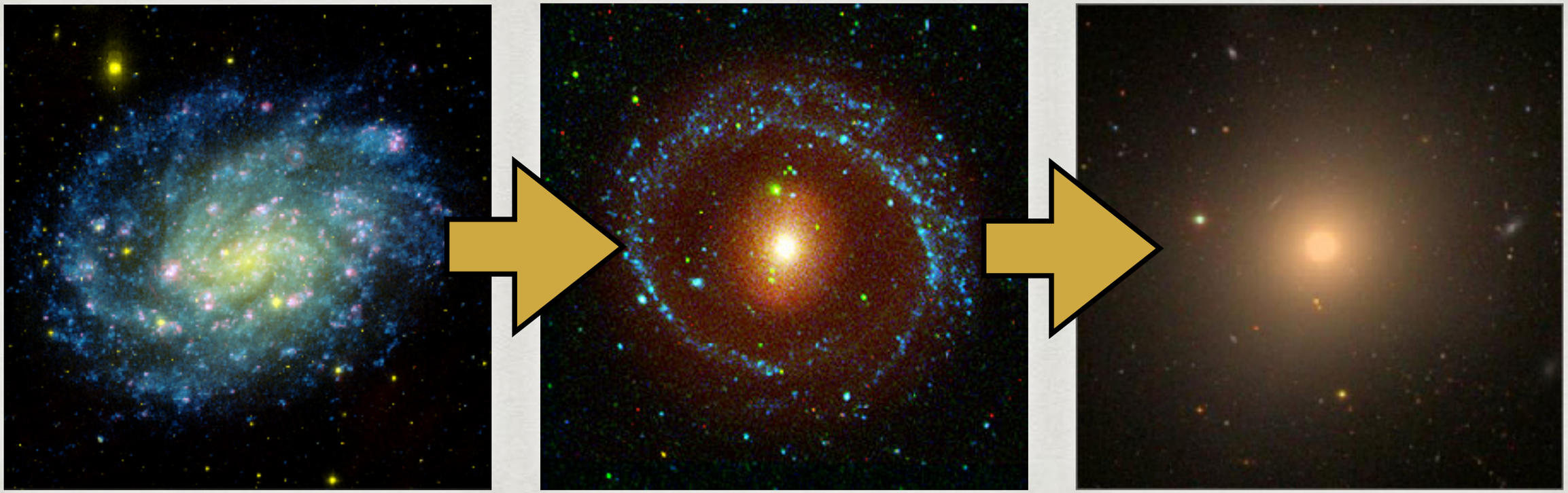
WHY IS FEEDBACK IMPORTANT?

Feedback may help suppress ongoing star formation and reduce the overproduction of massive galaxies seen in models





IS FEEDBACK THE PRIMARY MECHANISM TO QUENCH STAR-FORMATION OVER COSMIC TIMESCALES?



Younger Galaxies | Transitional | Older Galaxies

Understanding this is central to building a coherent picture of galaxy evolution

Image Credit: NASA/JPL-Caltech

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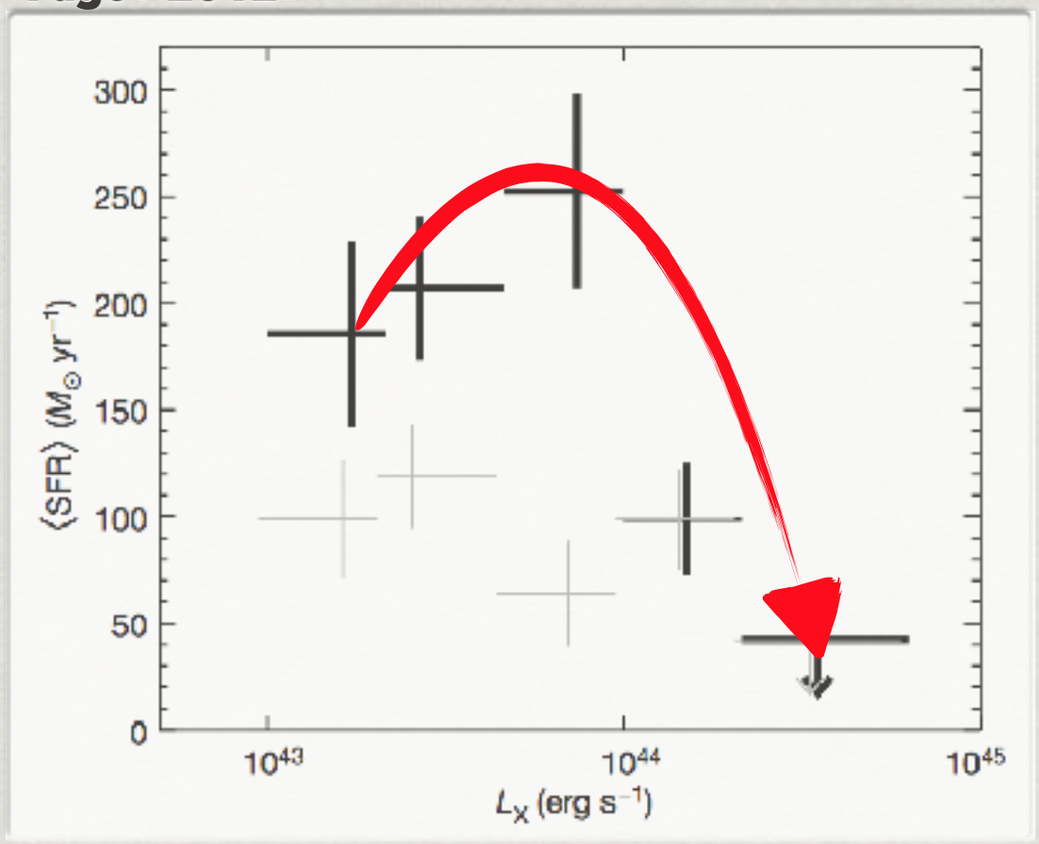
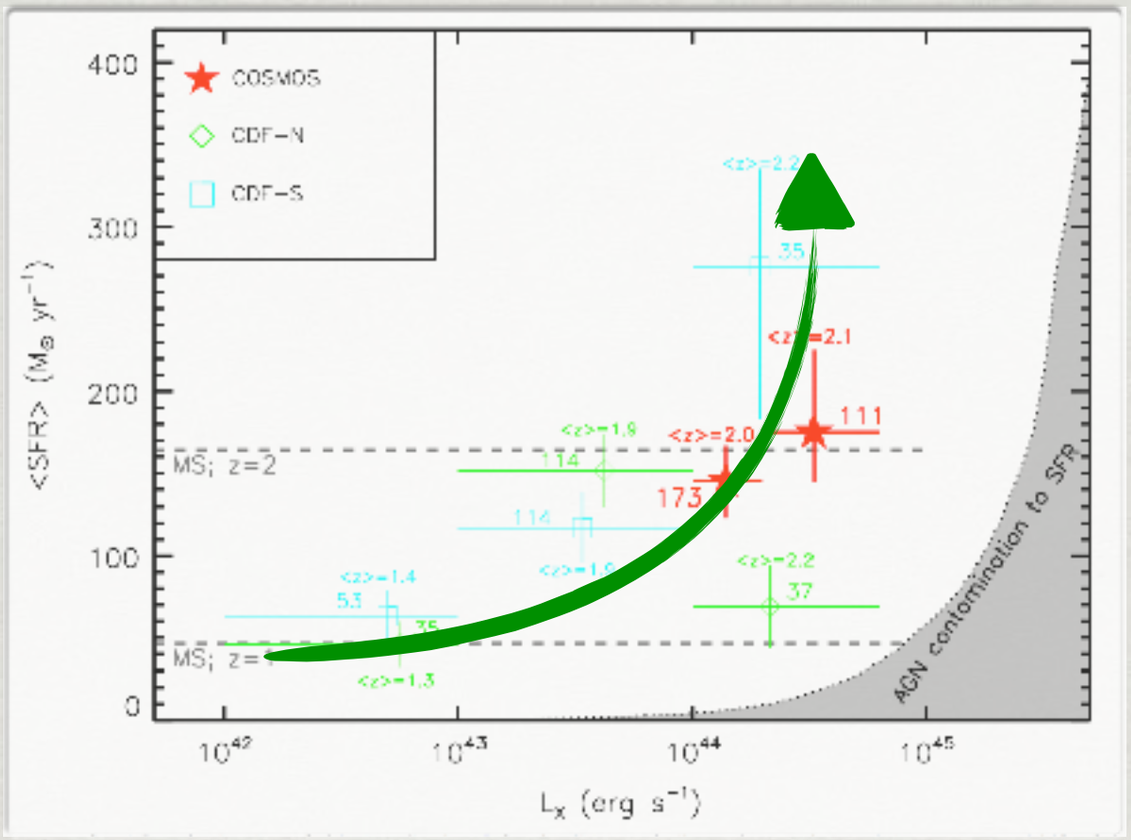
NEGATIVE FEEDBACK
OR POSITIVE FEEDBACK?

The details of this feedback are not well understood!

Page+ 2012



Harrison+ 2012a



GOAL:

1) IDENTIFY A DIVERSE POPULATION OF GALAXIES HOSTING AN ACTIVE SMBH OVER A LARGE CHUNK OF COSMIC TIME

2) COMPARE THE STAR-FORMATION ACTIVITY OF THIS POPULATION WITH THOSE LACKING AN ACTIVE SMBH

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GOAL:

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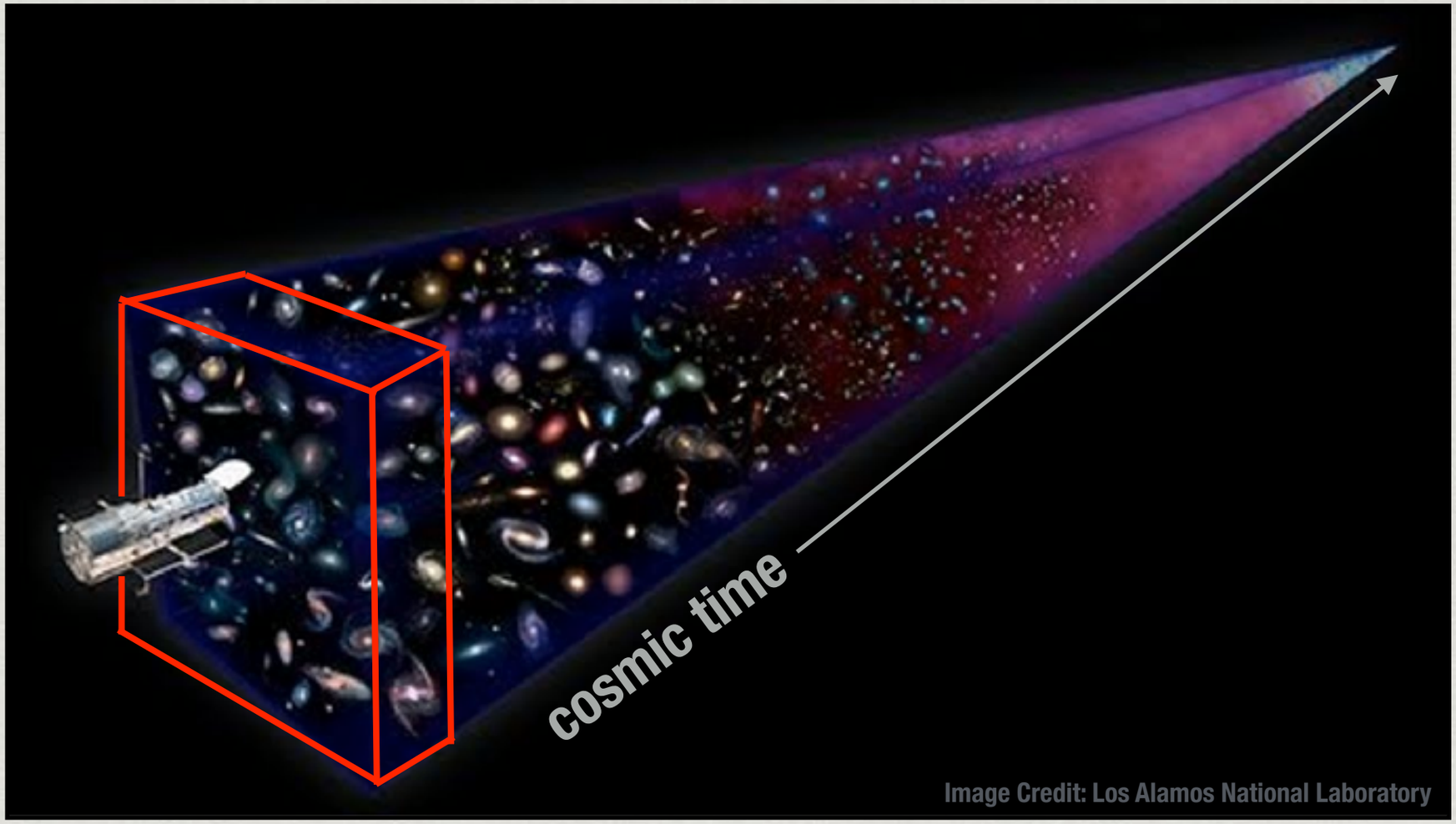

Image Credit: Los Alamos National Laboratory

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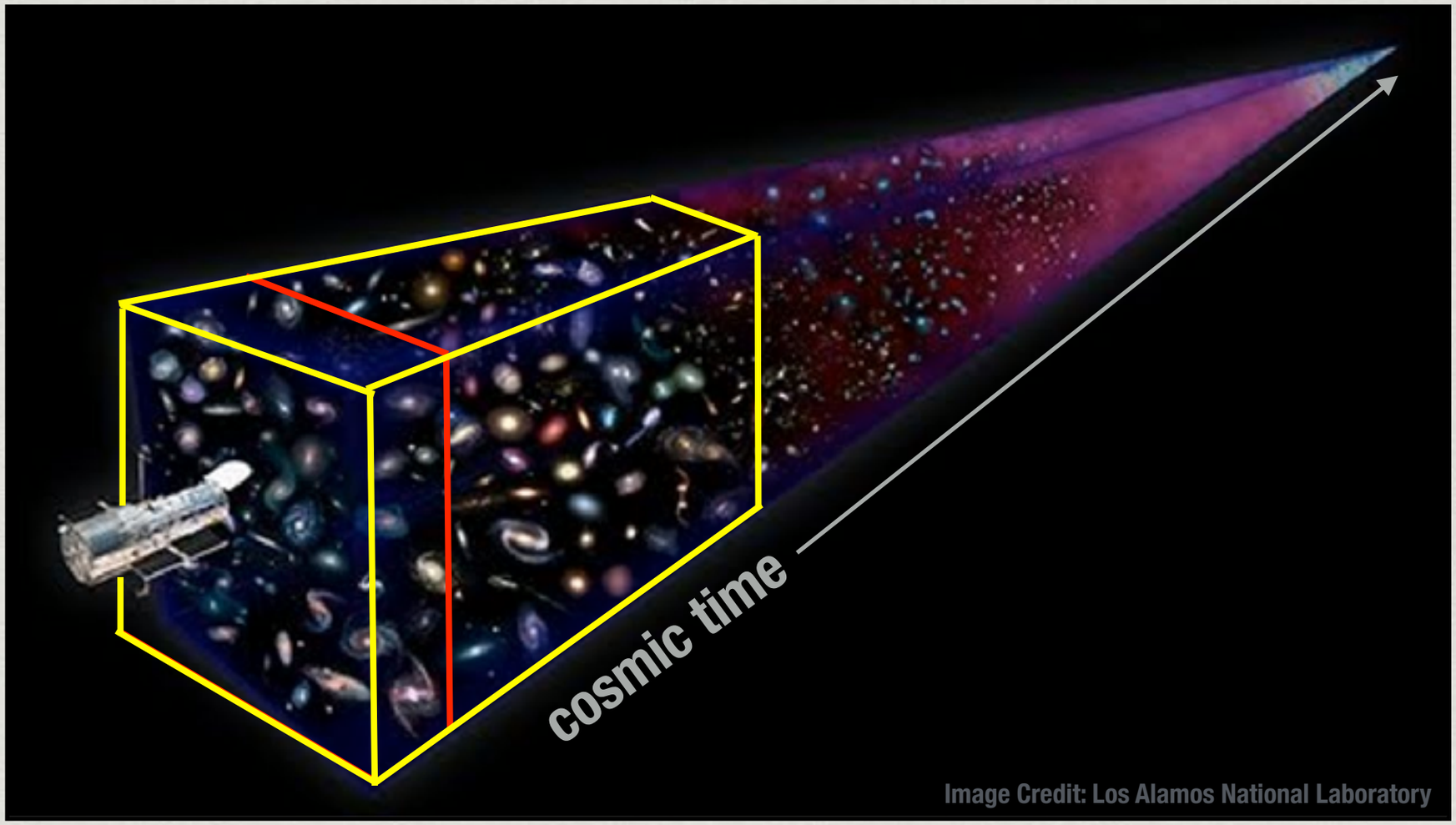

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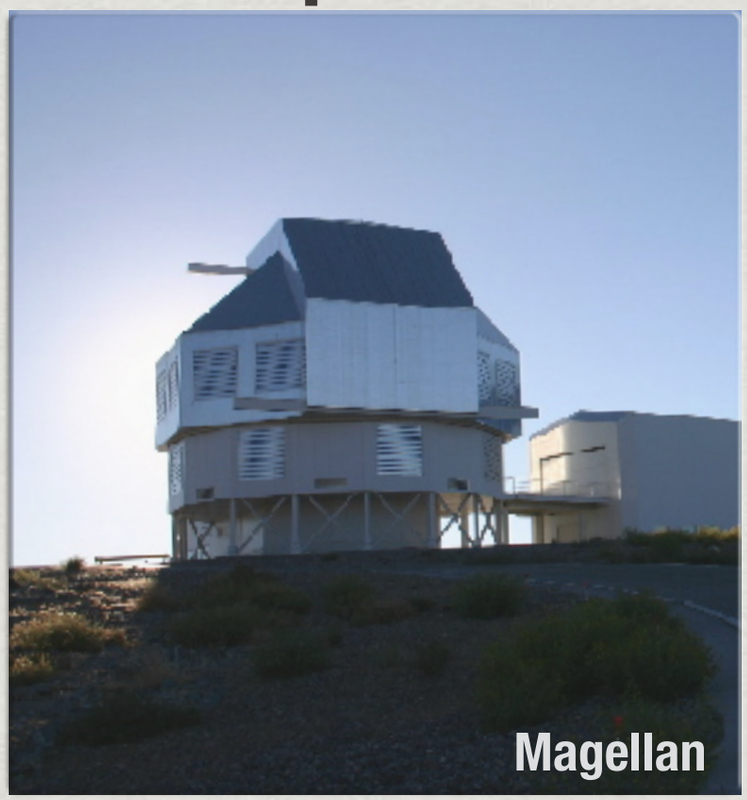
GOAL:

1) IDENTIFY A POPULATION OF GALAXIES HOSTING AN ACTIVE BLACK HOLE OVER A LARGE CHUNK OF COSMIC TIME

A multi-wavelength approach

Optical

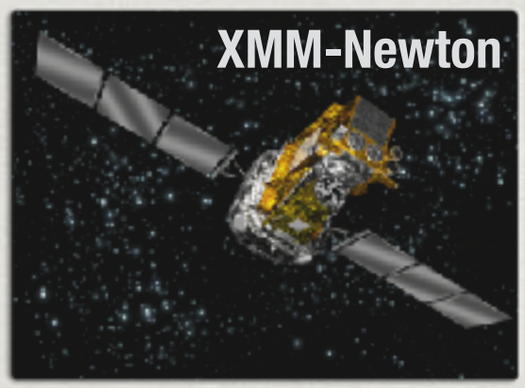


Radio

Optical/IR

Infrared

Infrared



X-Ray

X-Ray

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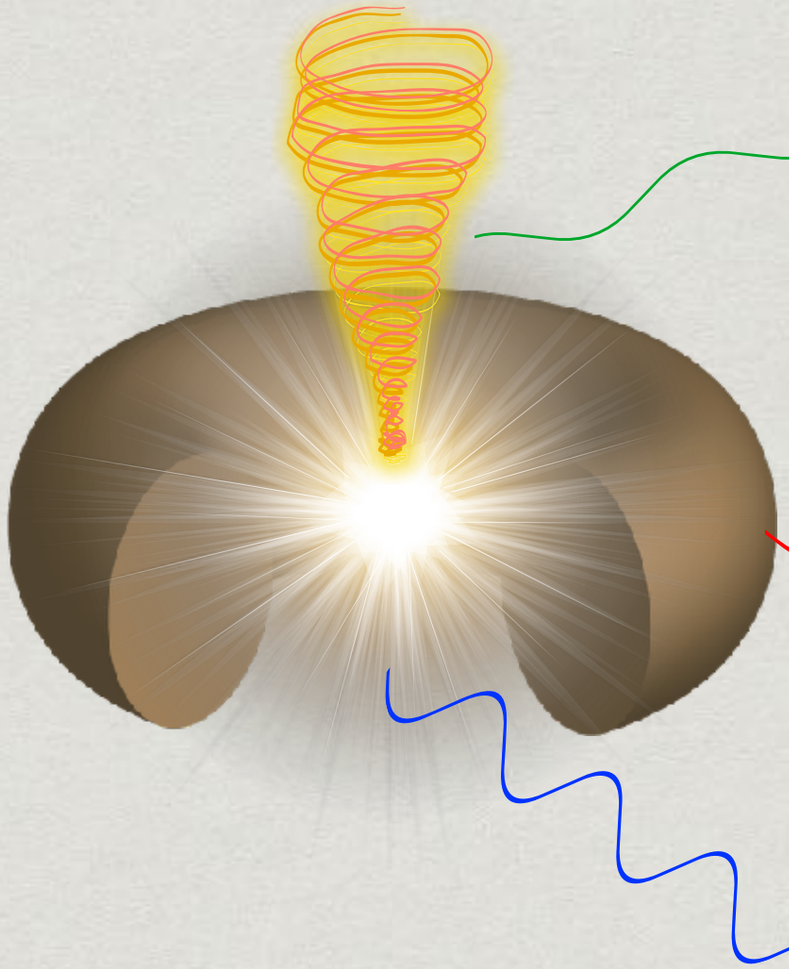

IDENTIFYING AGN IN ZFOURGE

Requires a multi-wavelength approach

A source with excess radio emission is identified as a radio AGN

A source with excess X-ray emission is identified as a X-ray AGN

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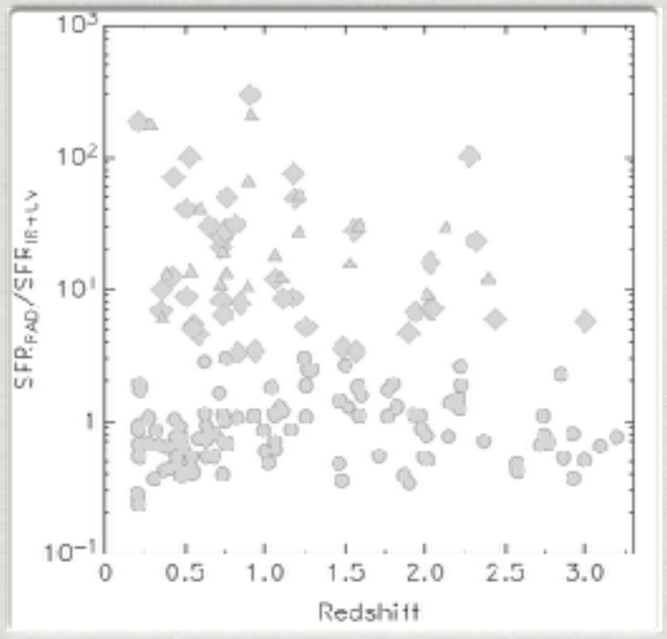
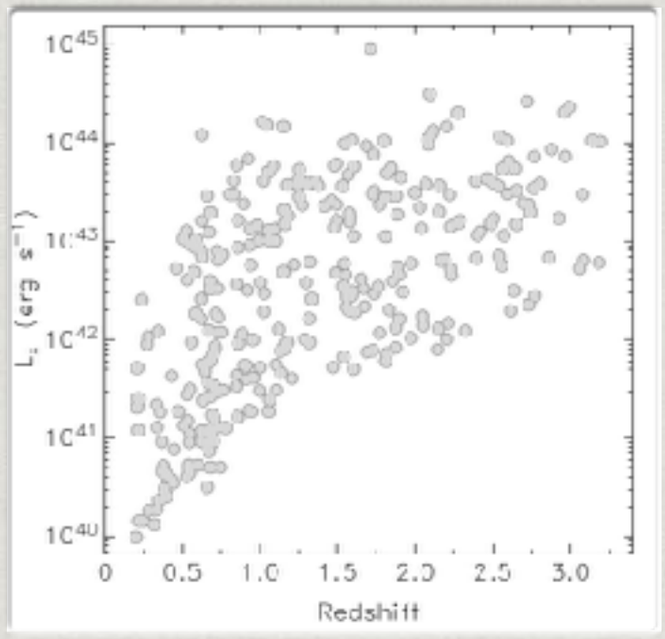
Radio SFR / IR+UV SFR



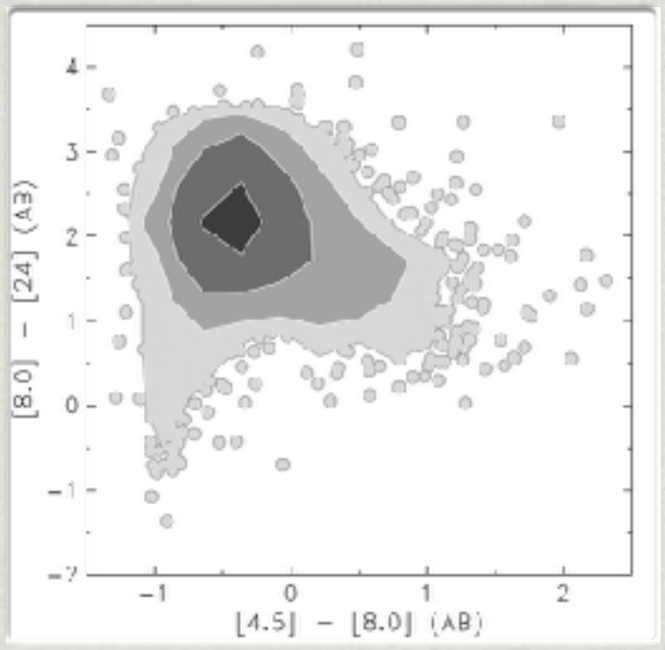
Redshift

X-Ray Luminosity



Redshift

IRAC CH4 - MIPS24



IRAC CH2-CH4

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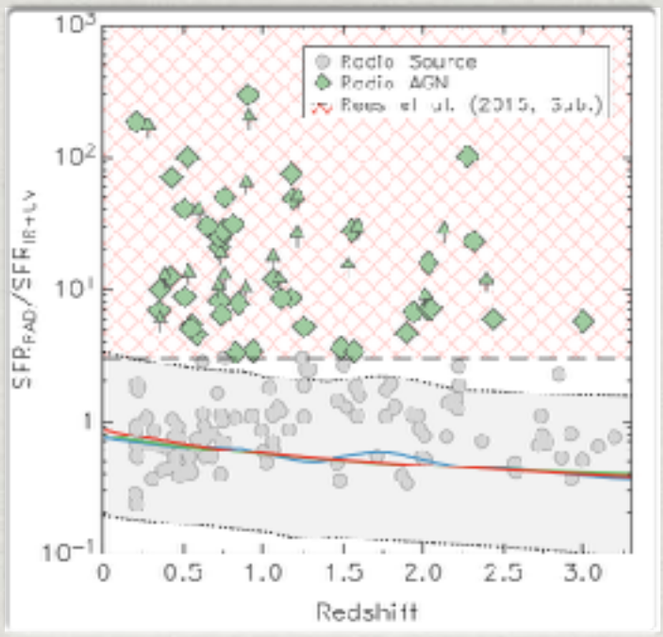

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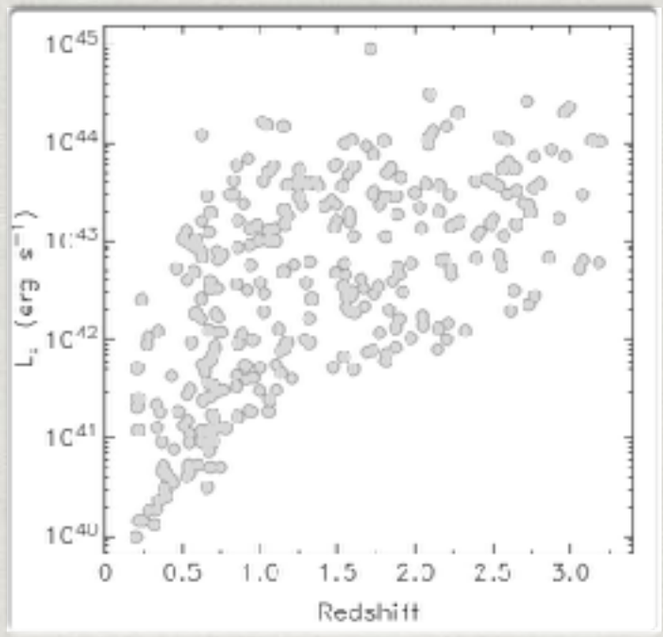

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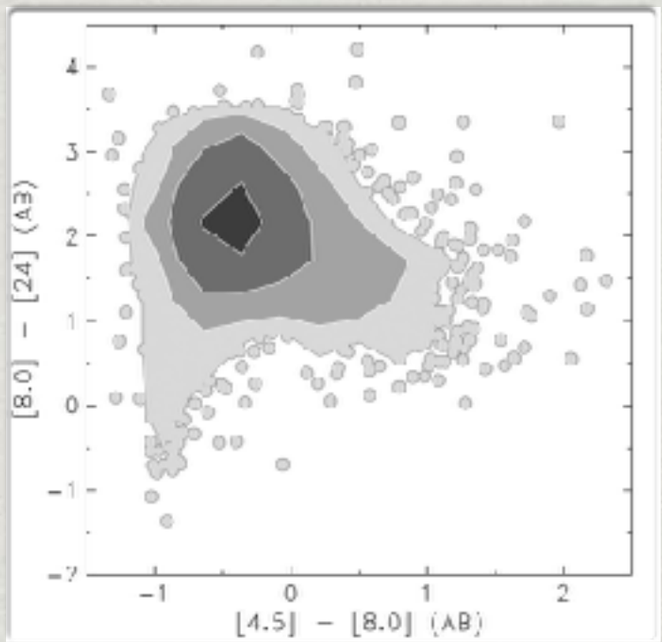

IRAC CH2-CH4

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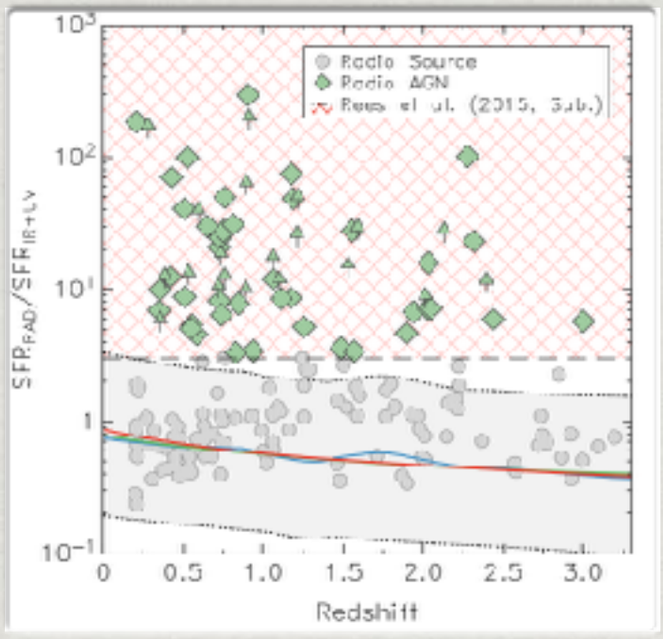

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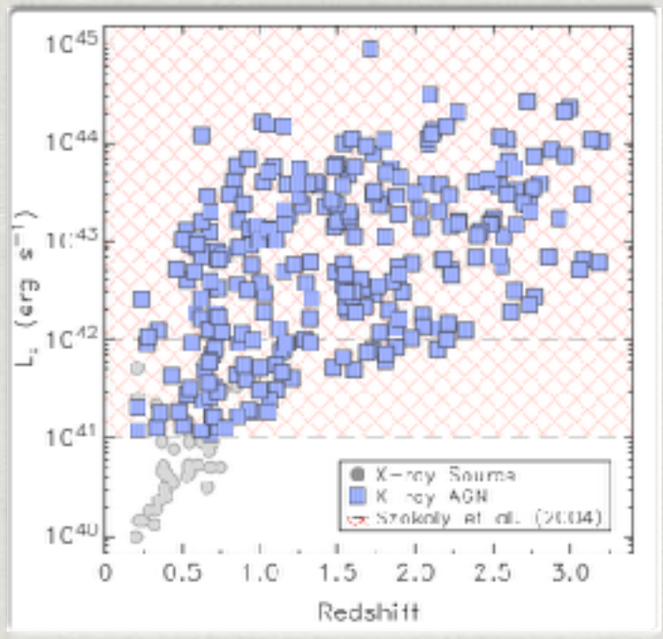

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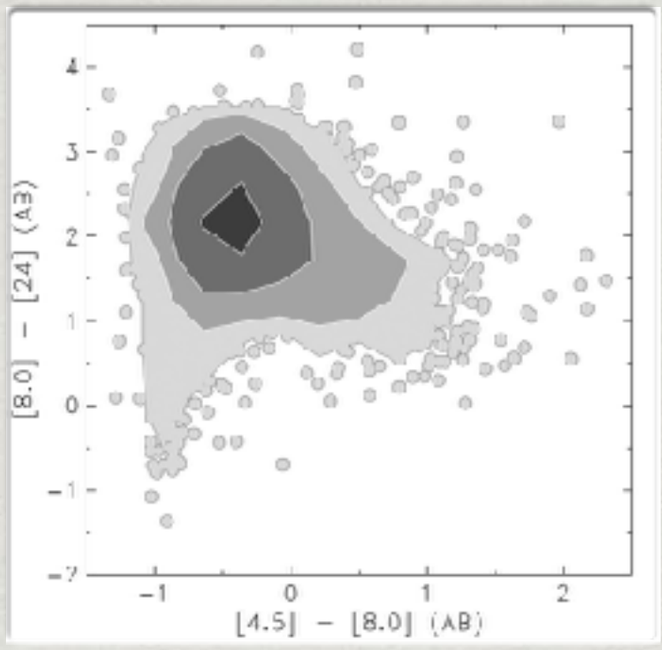

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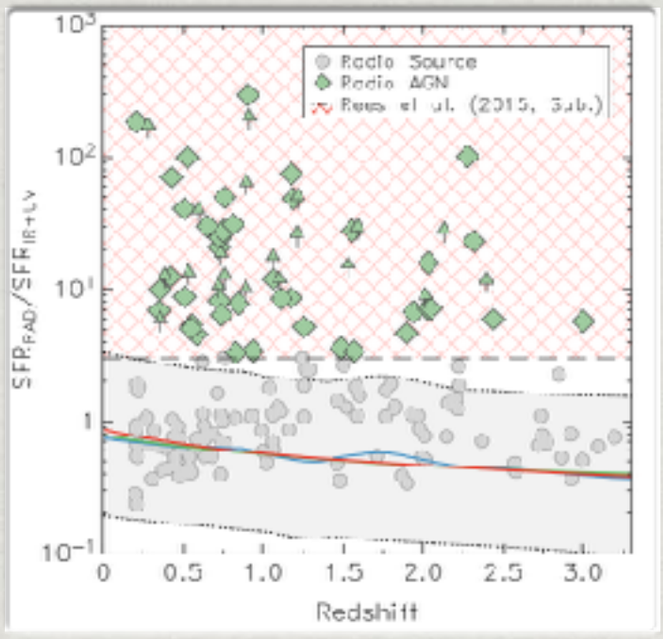

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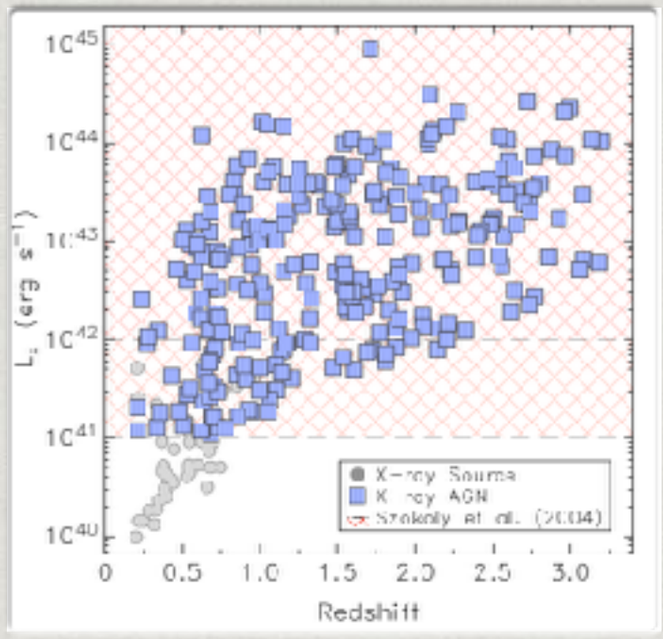
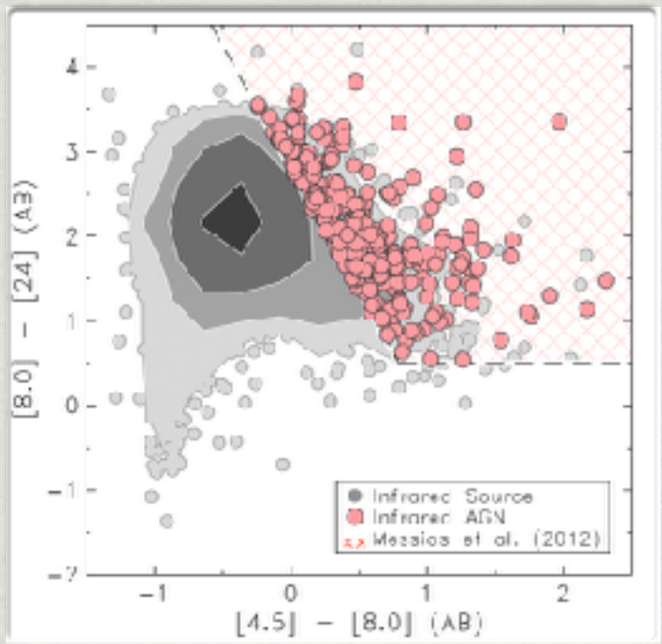


Redshift

IRAC CH4 - MIPS24



IRAC CH2-CH4

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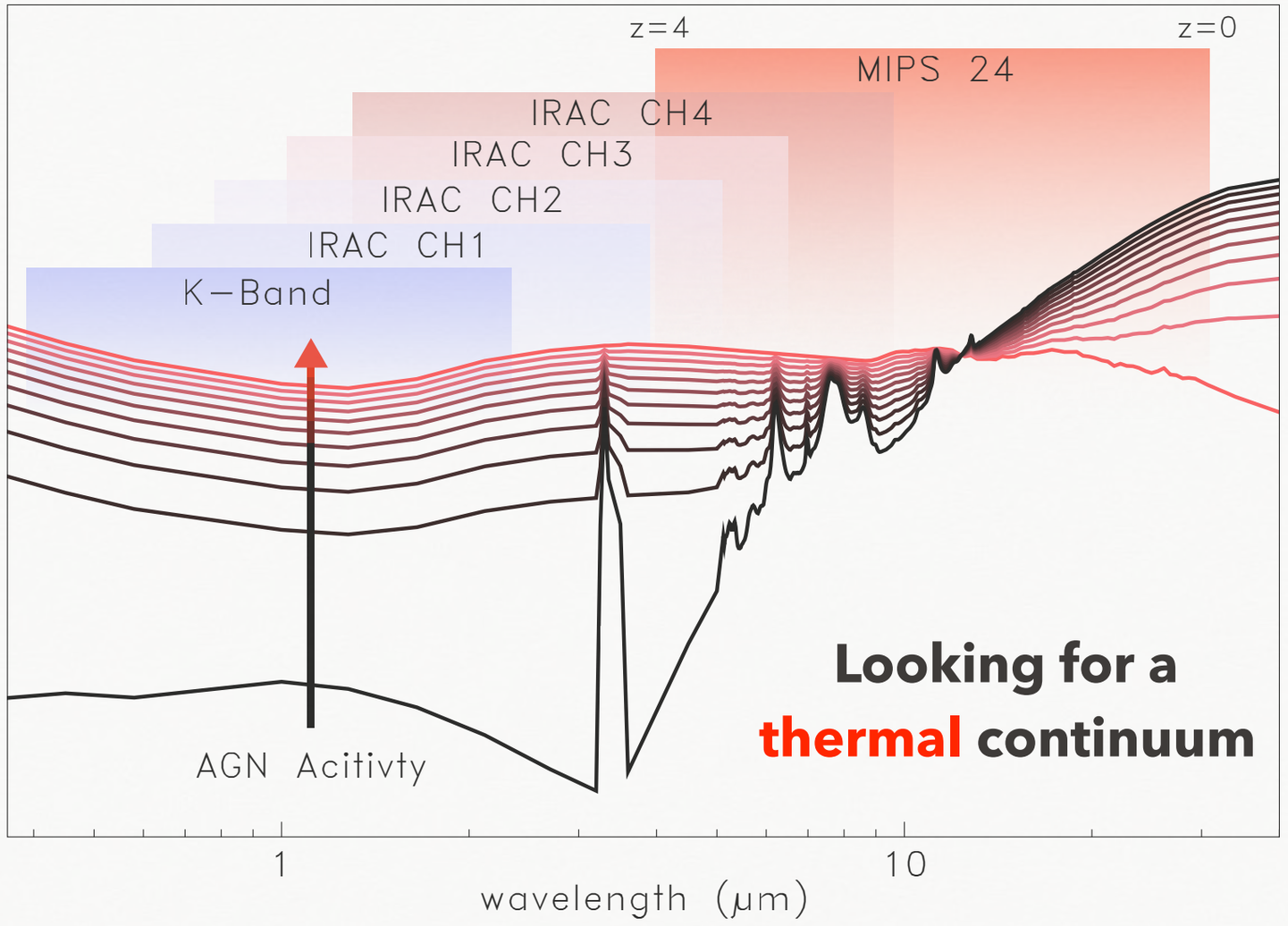
IDENTIFYING INFRARED AGN IN ZFOURGE



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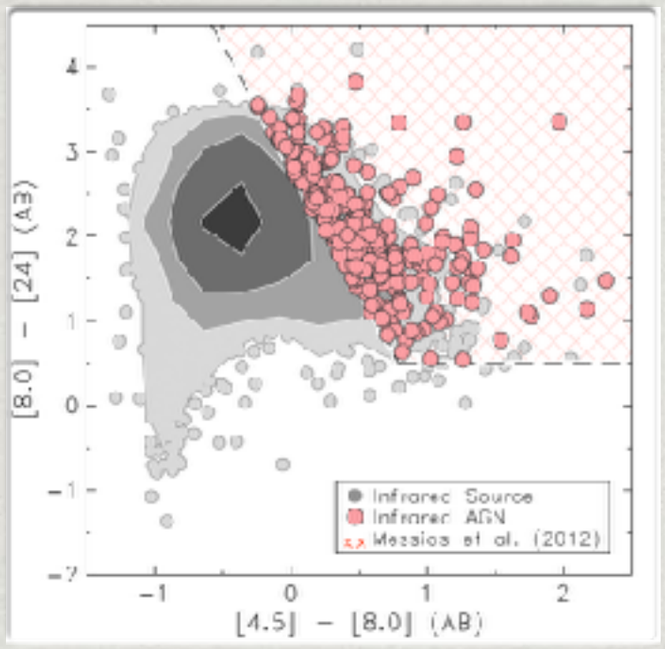

IRAC CH2-CH4

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GOAL:

1) IDENTIFY A POPULATION OF GALAXIES HOSTING AN ACTIVE BLACK HOLE OVER A LARGE CHUNK OF COSMIC TIME

2) COMPARE THE STAR-FORMATION ACTIVITY OF THIS POPULATION WITH THOSE LACKING AN ACTIVE BLACK HOLE

Control Sample

Image Credit: NASA/JPL-Caltech

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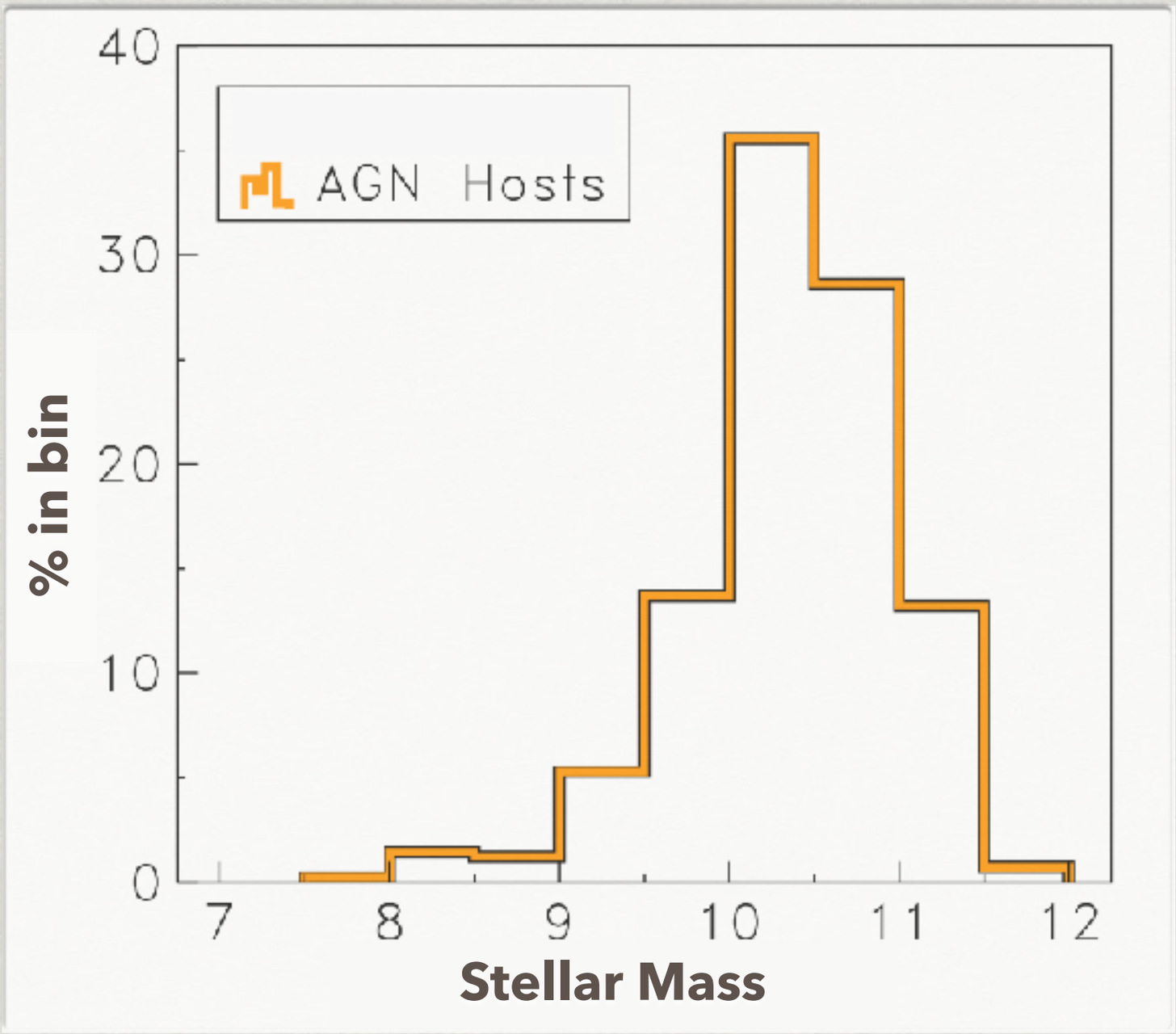
2) COMPARE THE STAR-FORMATION ACTIVITY OF ACTIVE AND NON-ACTIVE GALAXIES



AGN are preferentially hosted in galaxies with high stellar mass (e.g., Aird+12)

A galaxy's stellar mass is tightly correlated with its star-formation rate (e.g., Noeske+07)

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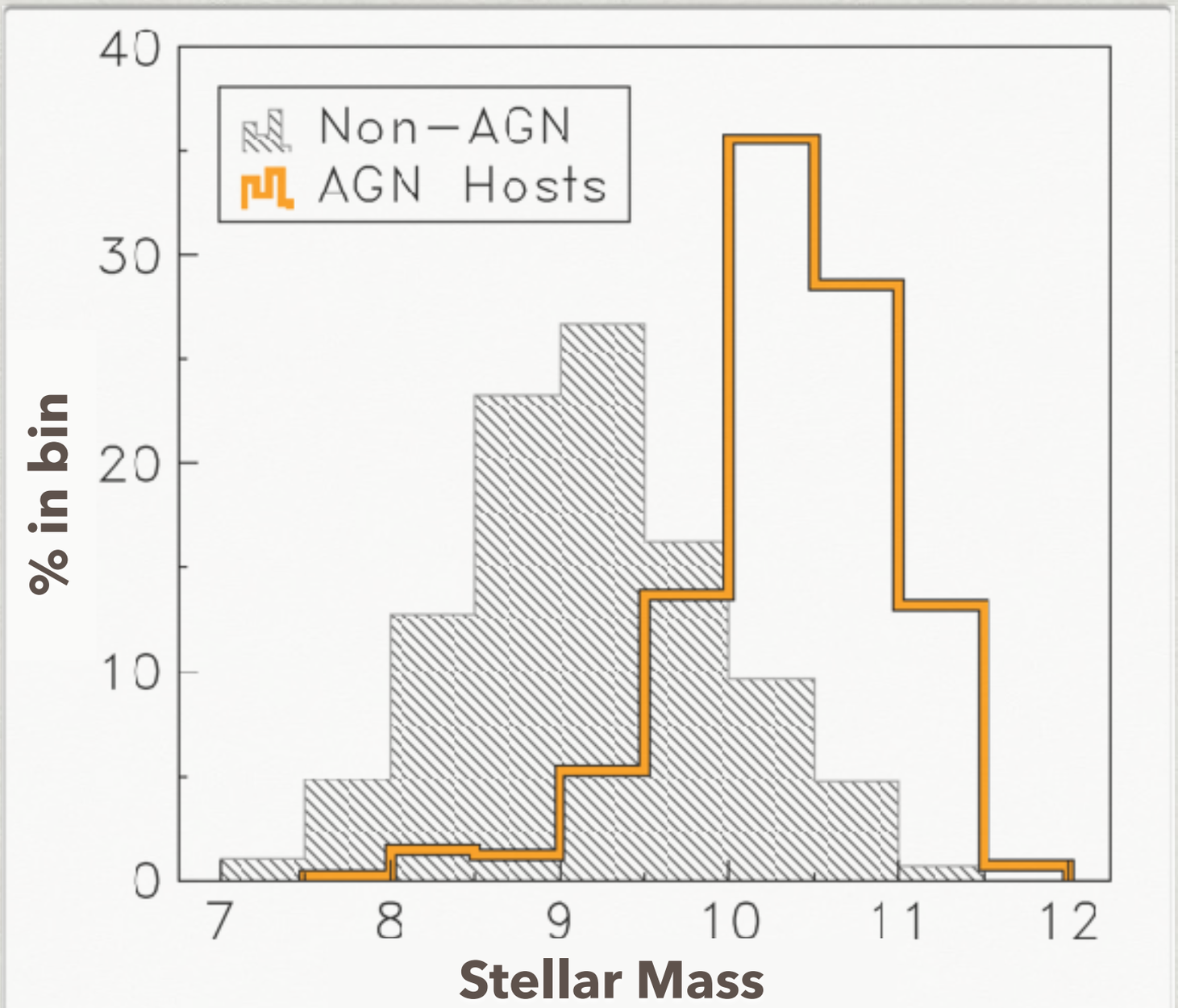

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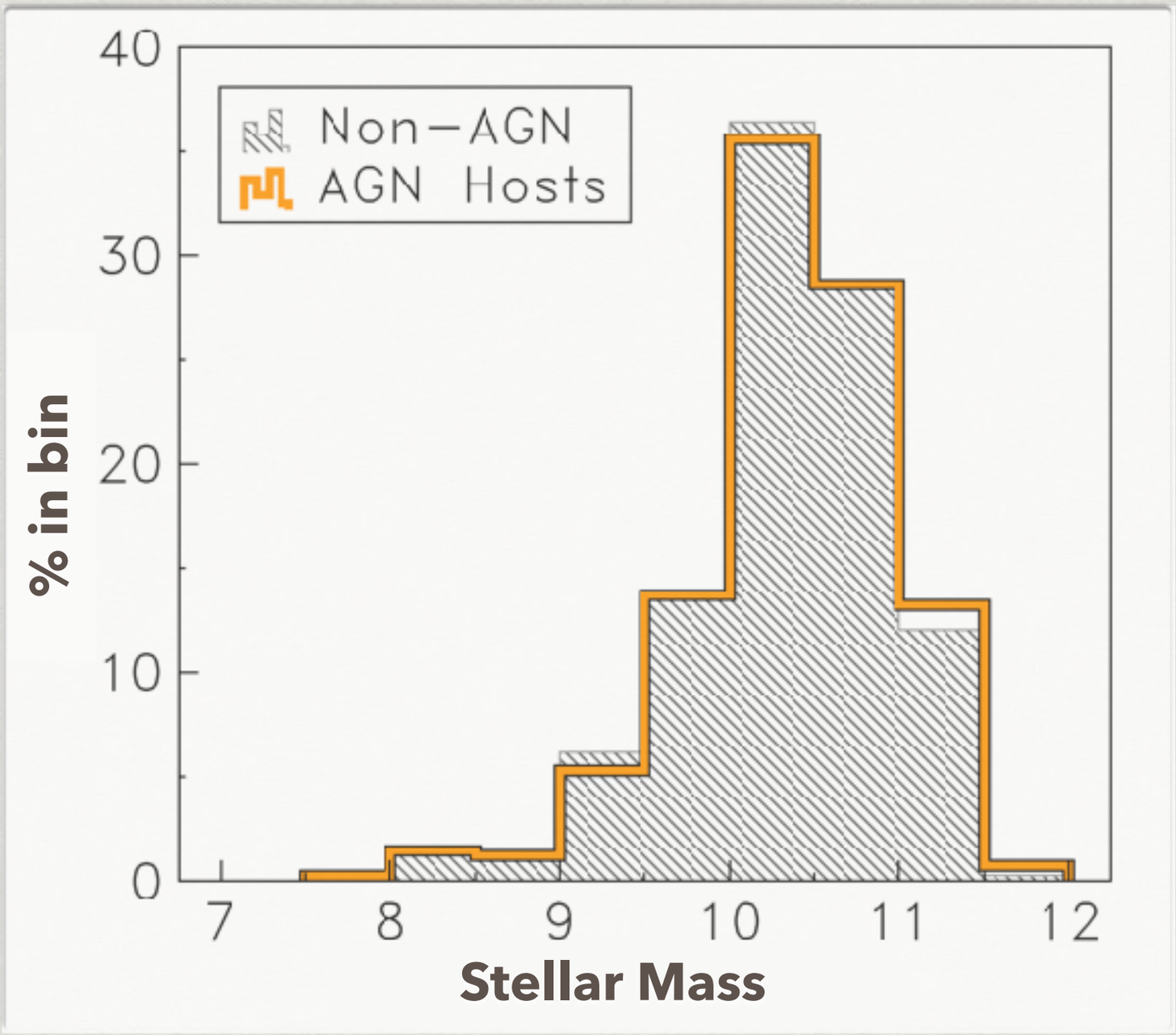
...OF SIMILAR MASS



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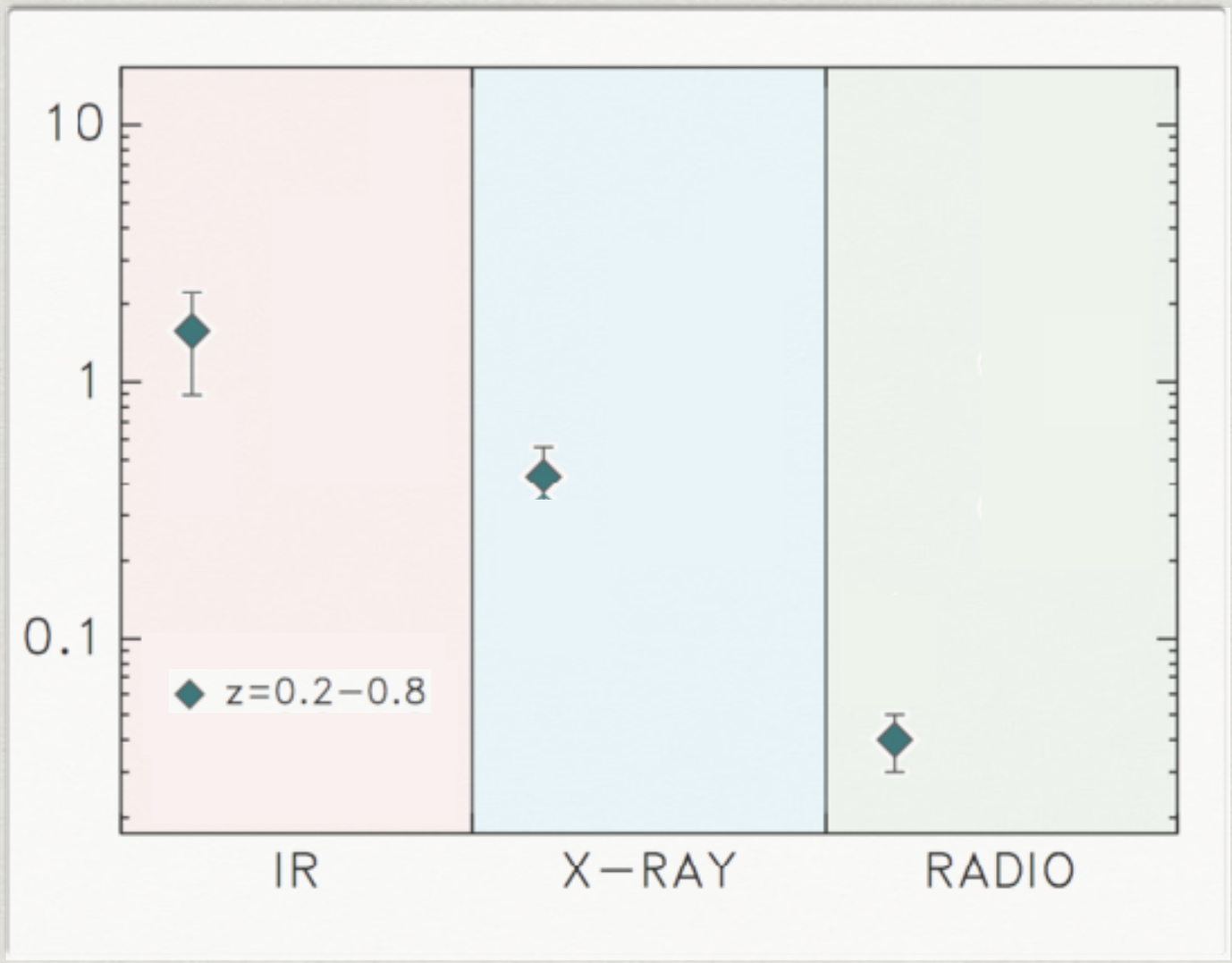
COMPARE THE STAR-FORMATION ACTIVITY OF GALAXIES HOSTING AN ACTIVE BLACK HOLE TO THOSE WITHOUT



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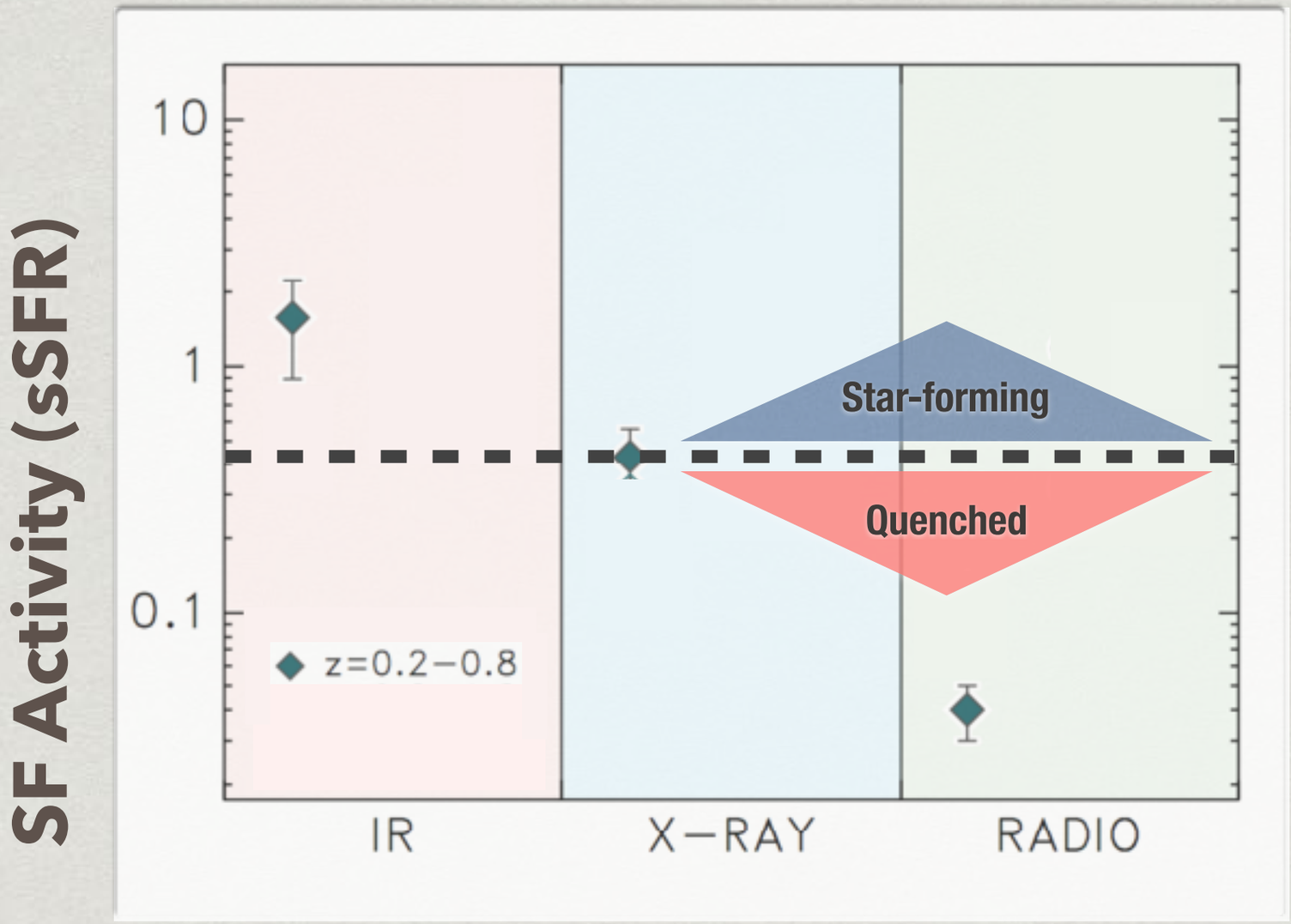

Infrared w/ Active Black Hole

Star forming hosts

X-ray w/ Active Black Hole

Straddles between star-forming and quiescent

Radio w/ Active Black Hole

Quenched hosts

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GOAL:

COMPARE THE STAR-FORMATION ACTIVITY OF GALAXIES HOSTING AN ACTIVE BLACK HOLE TO THOSE WITHOUT

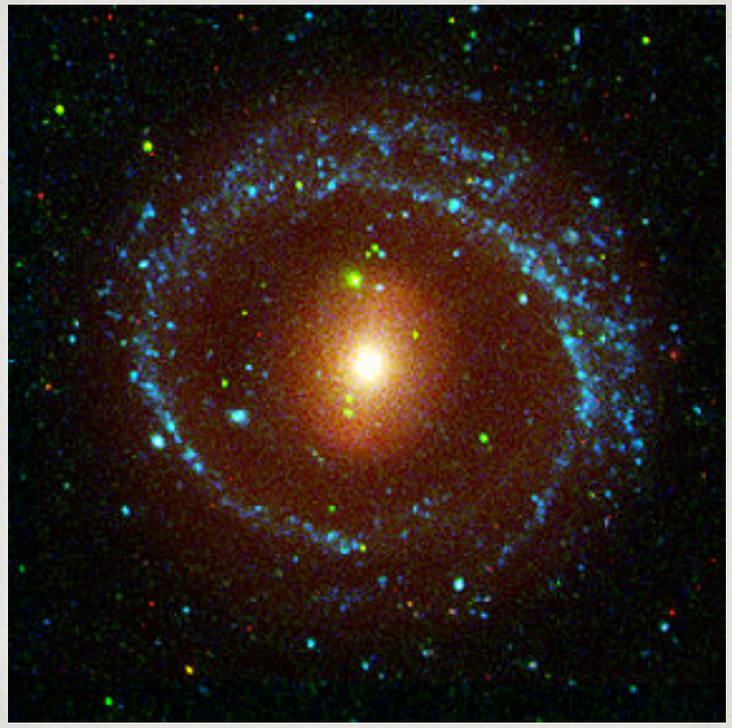
Infrared w/ Active Black Hole	X-Ray w/ Active Black Hole	Radio w/ Active Black Hole
		
Younger Galaxies	**Transitional**	**Older Galaxies**

Image Credit: NASA/JPL-Caltech

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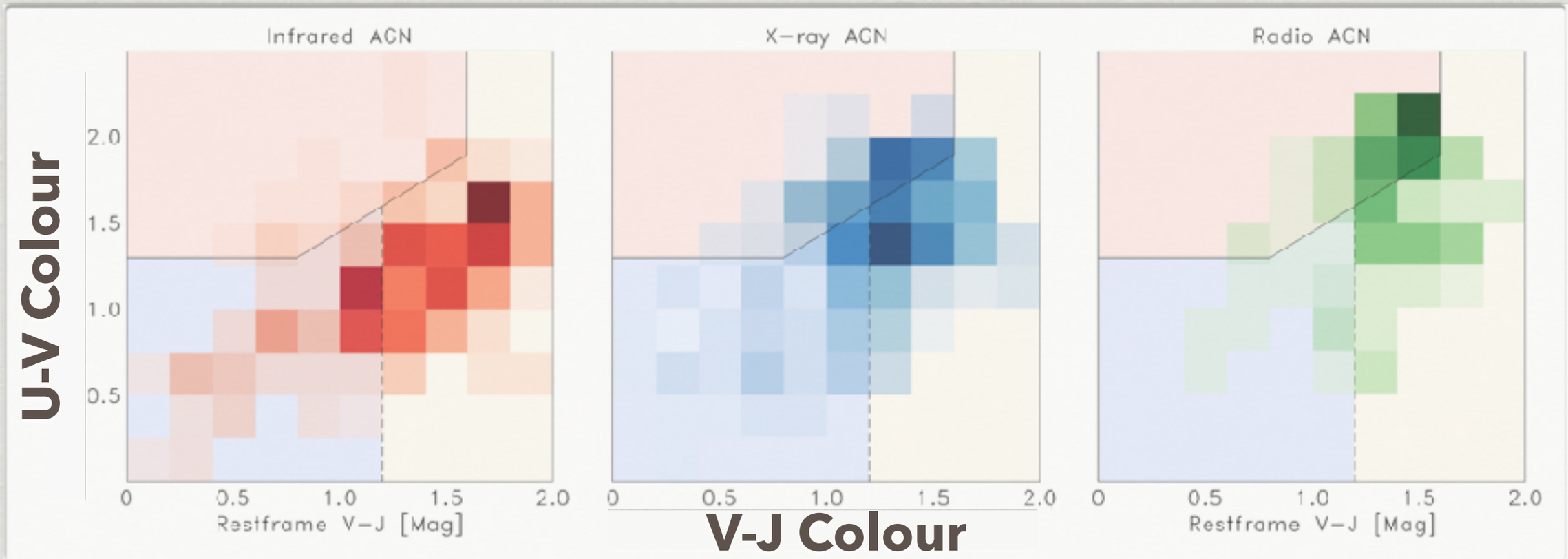
U-V vs V-J (UVJ) COLOURS OF AGN HOSTS

Infrared AGN

X-Ray AGN

Radio AGN



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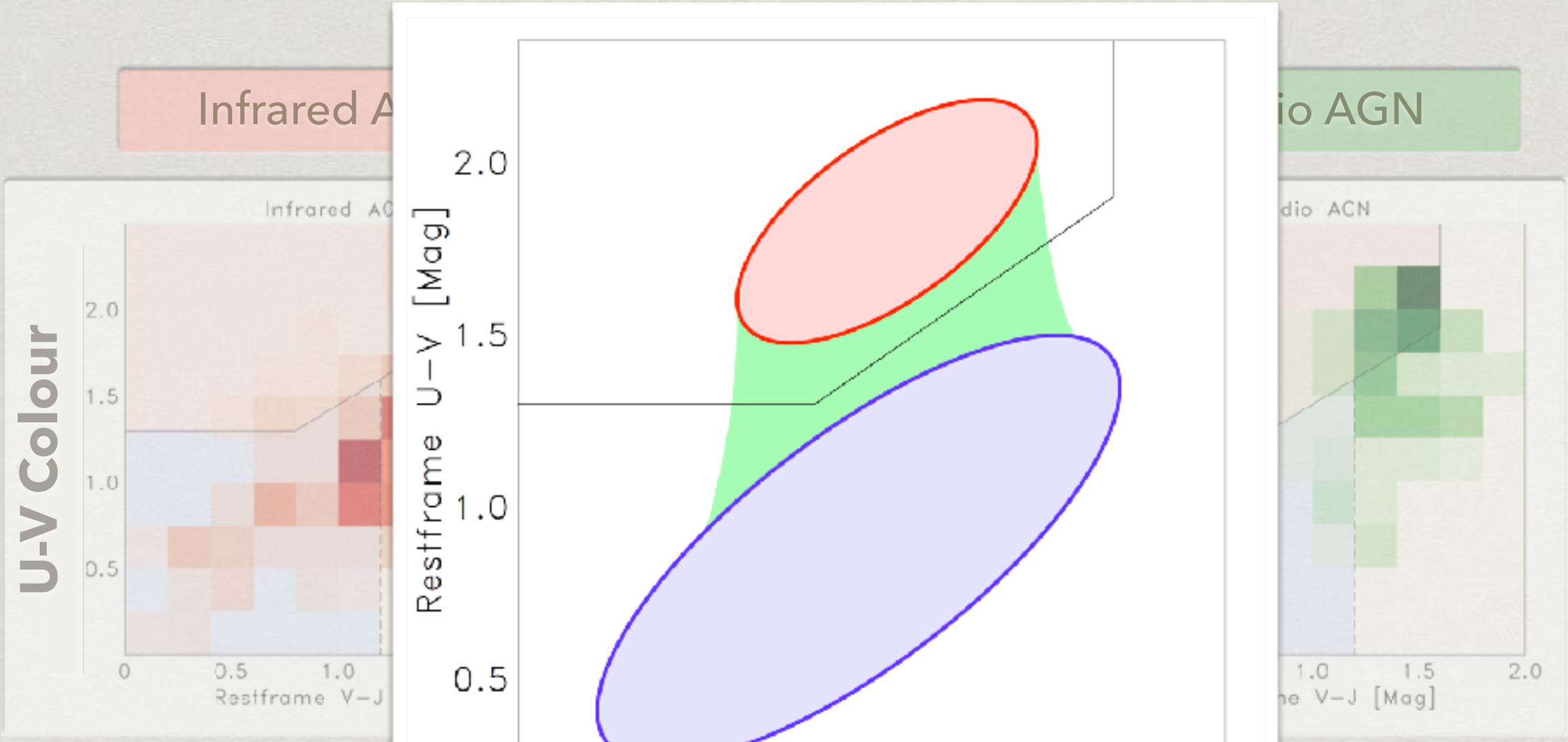

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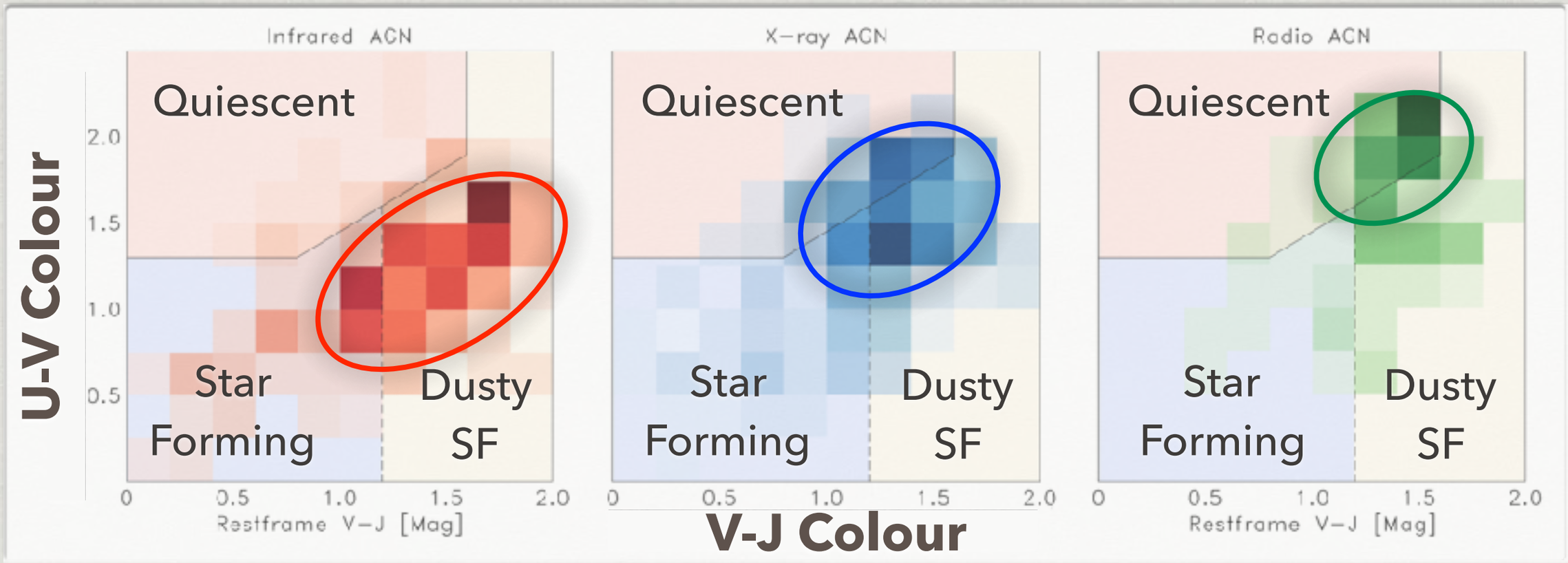


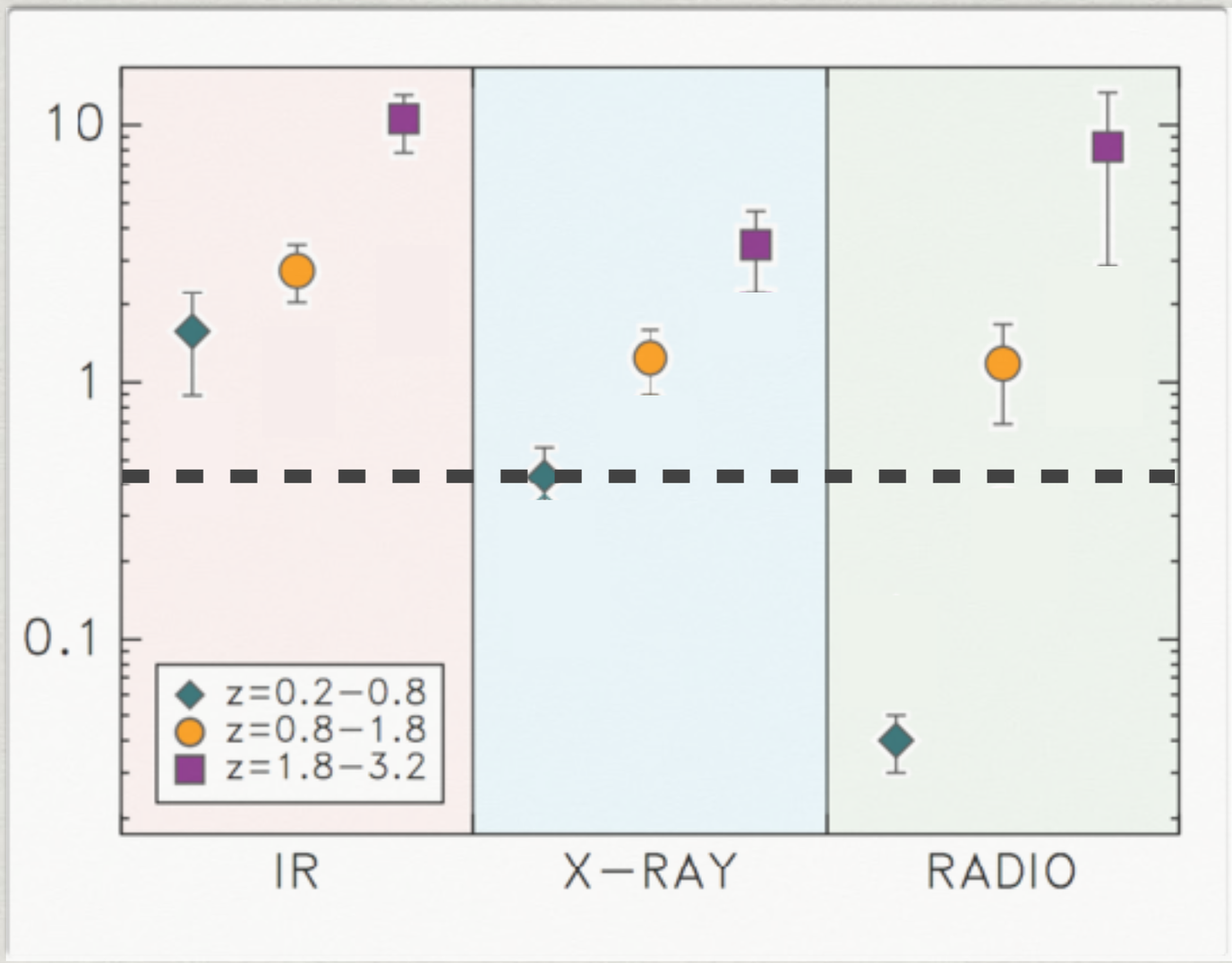
Star forming hosts

Straddles between star forming and quiescent

Quiescent hosts

GOAL:

COMPARE THE STAR-FORMATION ACTIVITY OF GALAXIES HOSTING AN ACTIVE BLACK HOLE TO THOSE WITHOUT



Infrared w/ Active Black Hole

Star forming hosts

X-ray w/ Active Black Hole

Star forming hosts

Radio w/ Active Black Hole

Star forming hosts

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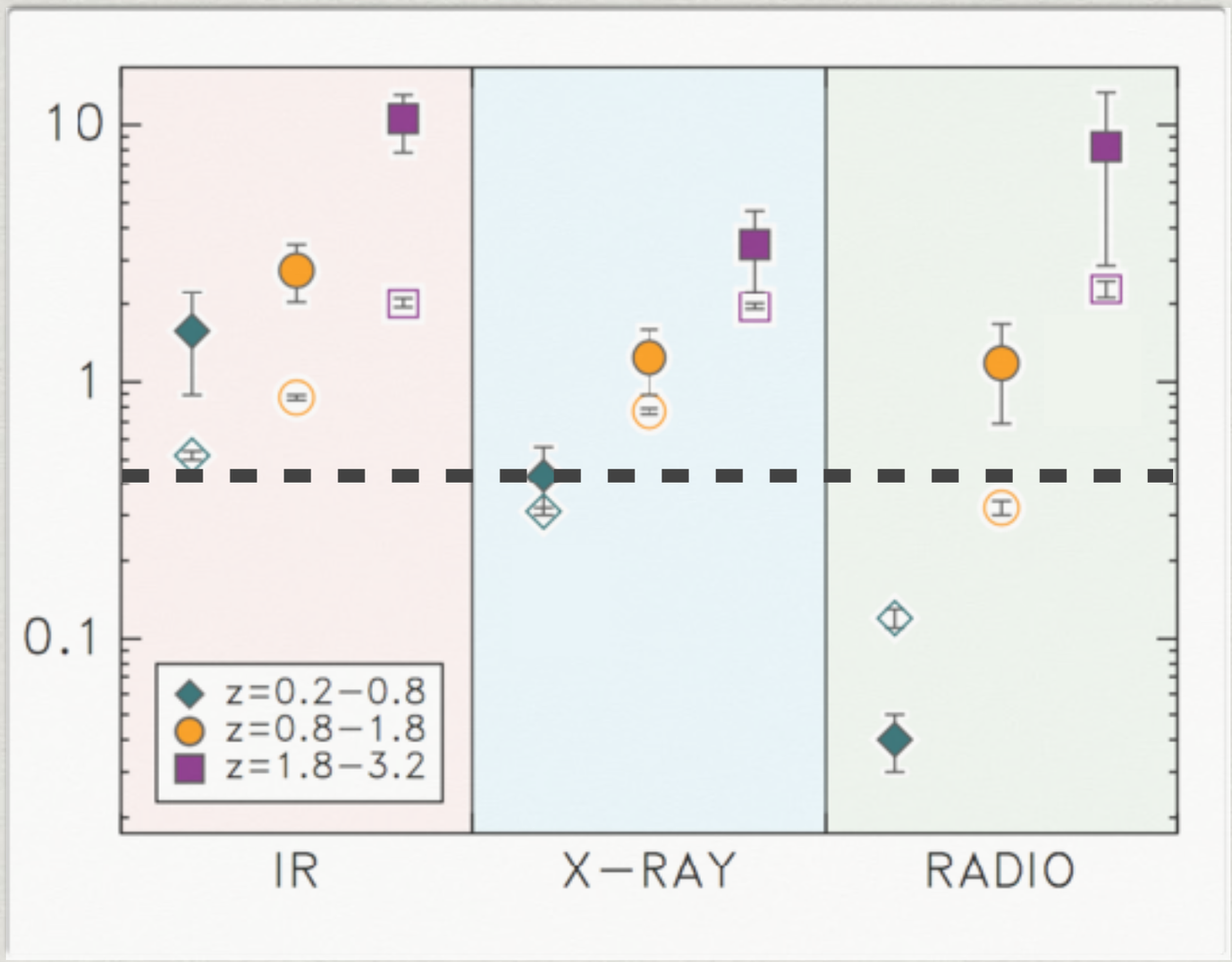

Infrared w/ Active Black Hole

Star forming hosts

X-ray w/ Active Black Hole

Star forming hosts

Radio w/ Active Black Hole

Star forming hosts

“Normal” Galaxies

Lower SF activity!

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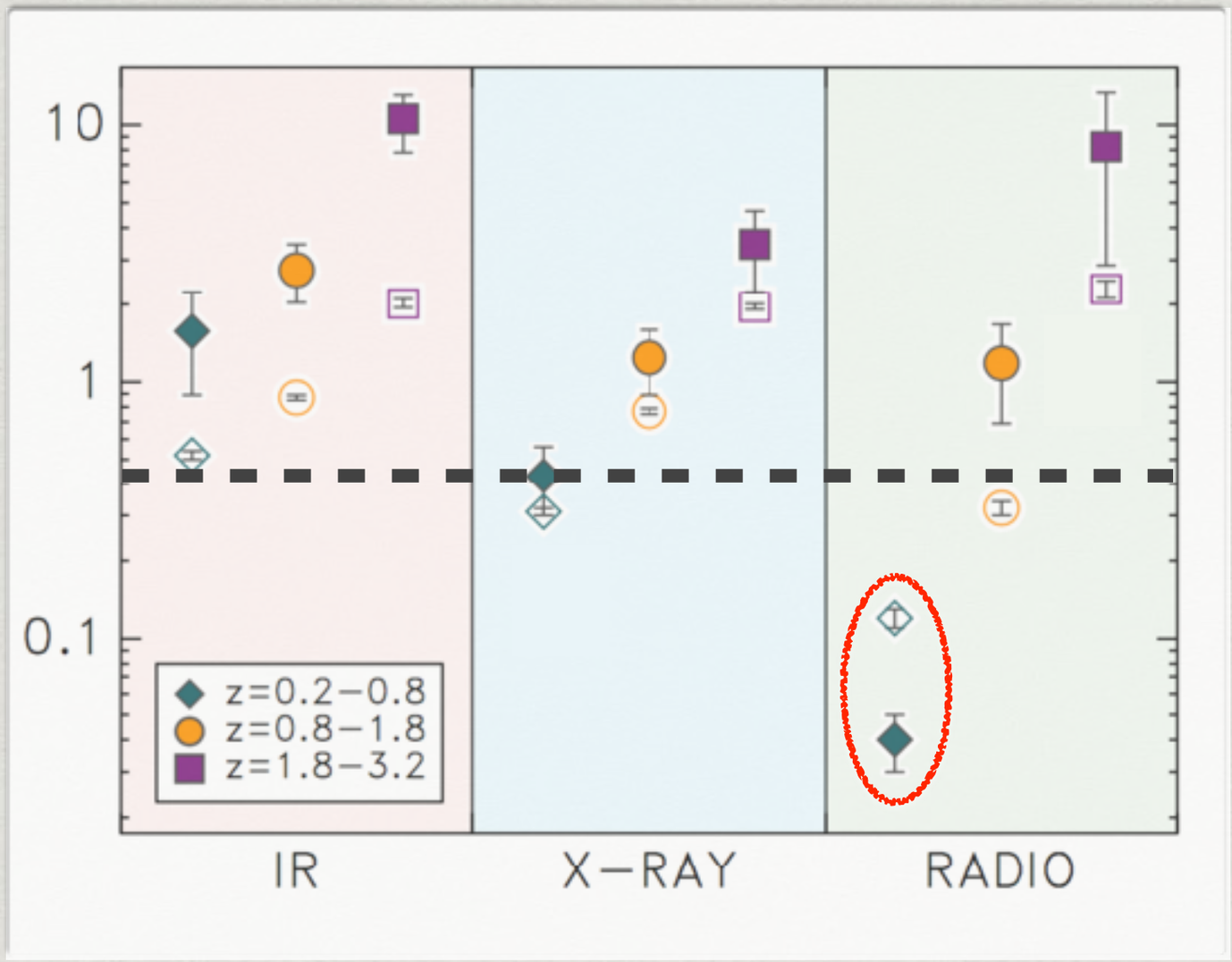

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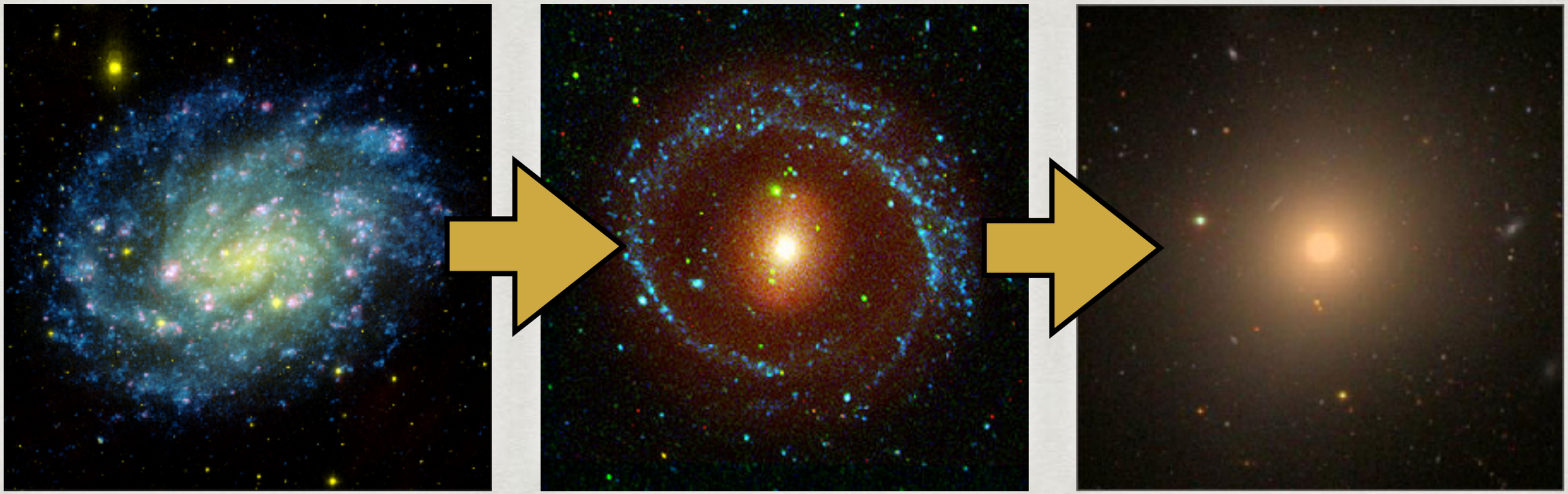
BEYOND THE NAÏVE UNIFIED MODEL

Galaxy colour diagrams and SF histories suggest AGN co-evolve with their host galaxy

Infrared AGN

X-ray AGN

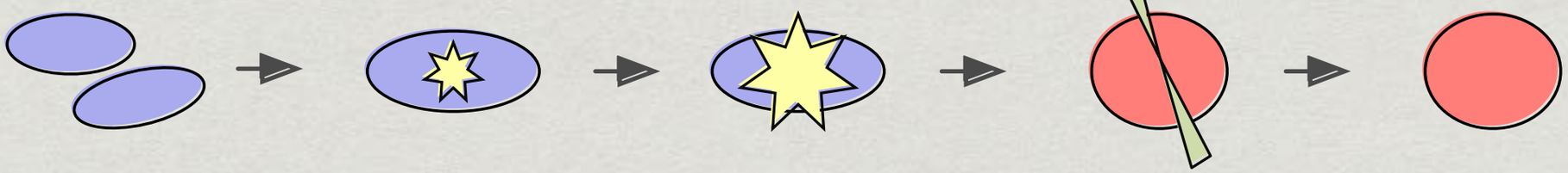
Radio AGN



Younger Galaxies

Transitional

Older Galaxies



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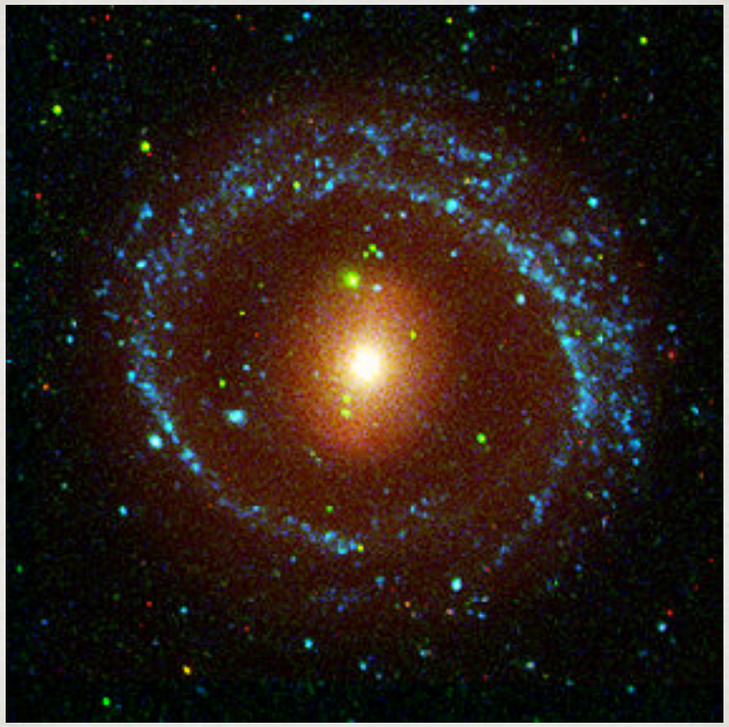
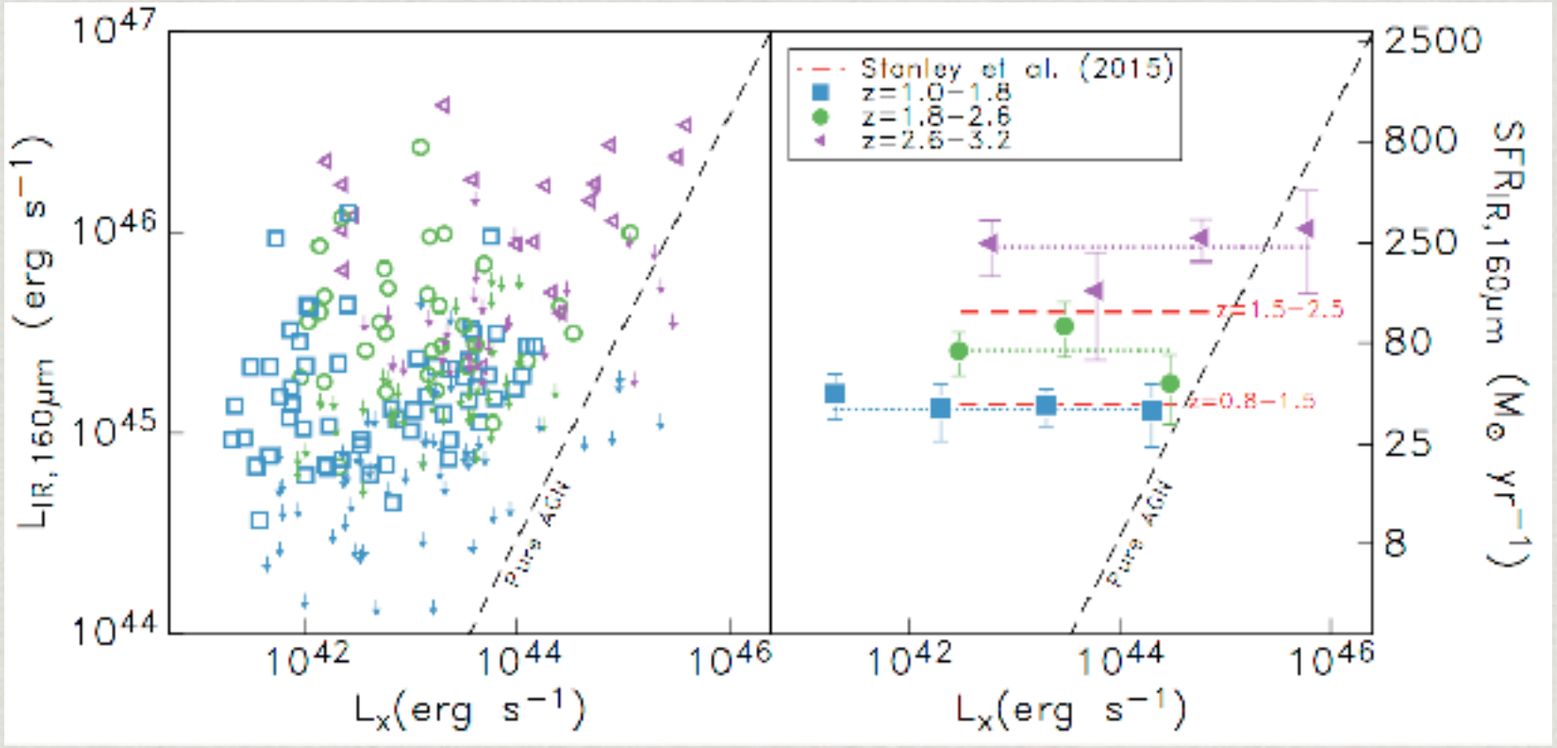
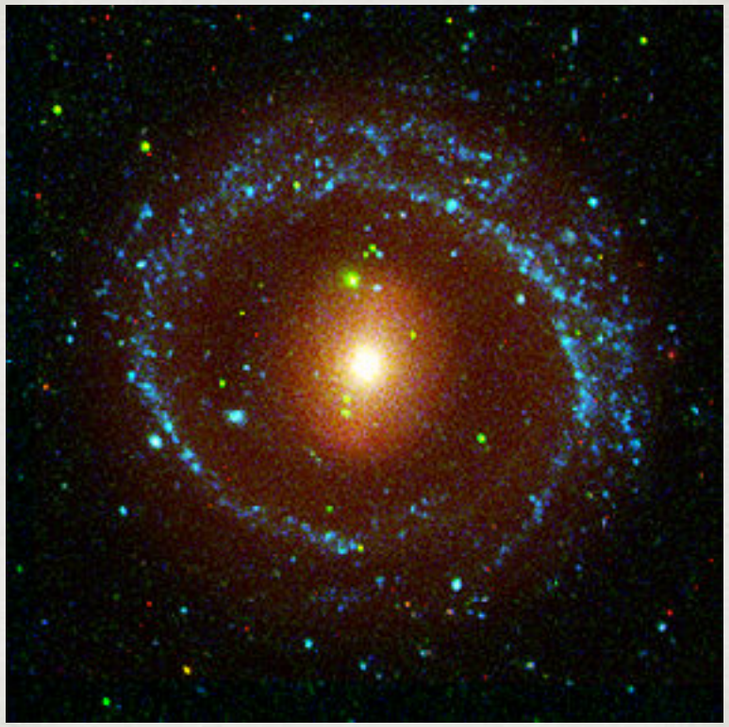
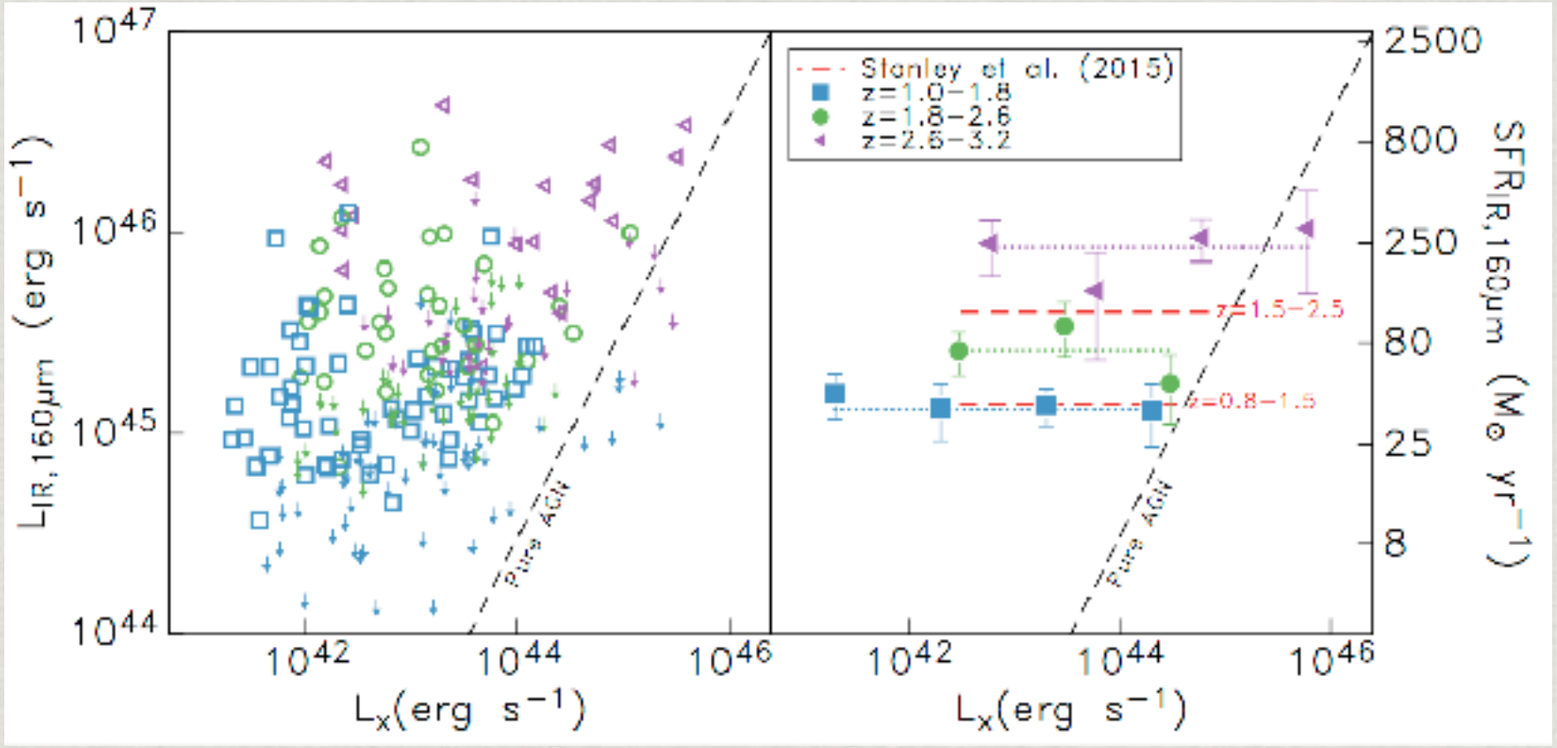
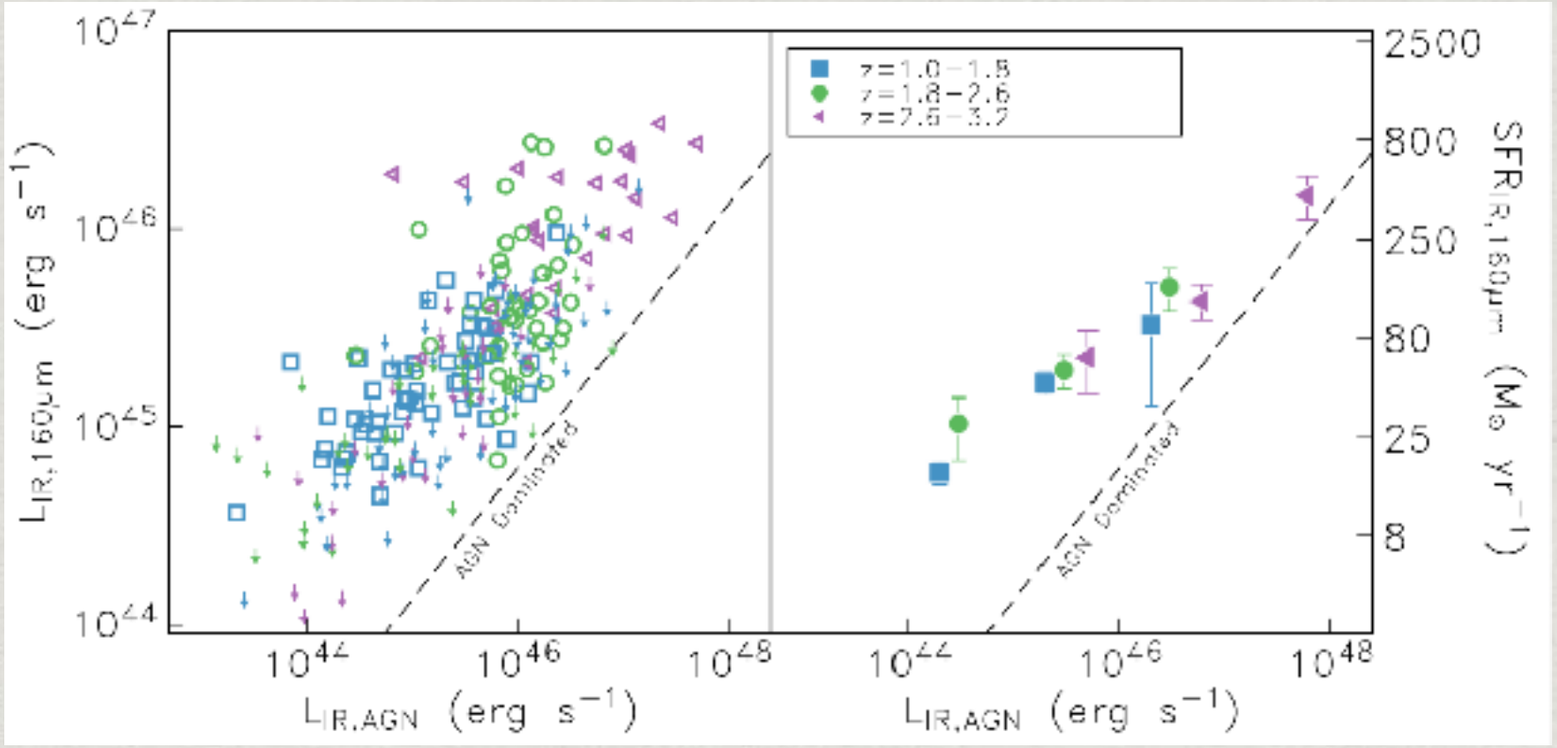



Stanley et al. (2015)
z=1.0−1.8
z=1.8−2.6
z=2.6−3.2
z=1.5−2.5
z=0.8−1.5
Pure AGN
Pure AGN
$L_{IR,160\mu m}$ (erg s^{-1})
$SFR_{IR,160\mu m}$ ($M_\odot$ yr^{-1})
L_x(erg s^{-1})
L_x(erg s^{-1})
10^{47}
10^{46}
10^{45}
10^{44}
10^{42}
10^{44}
10^{46}
2500
800
250
80
25
8







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SUMMARY

- IR, X-ray and radio-selected AGN hosts exhibit SF activity and colours consistent with distinct galaxy populations (at lower-z)
- SF enhancement in AGN hosts compared to mass–matched non–AGN (on average)
- This calls into question the significance of black hole feedback being a primary mechanism for the suppression of star-formation in galaxies over cosmic timescales
- The SF-AGN connection points to a likely connection between the fuelling mechanisms of both processes in dusty IR-selected AGN, but is washed out in the X-ray samples

THANK YOU!

QUESTIONS?

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NGC 1672: NASA, ESA and the Hubble Heritage Team