CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

NAM 2016

The Herschel view of galaxies throughout cosmic time

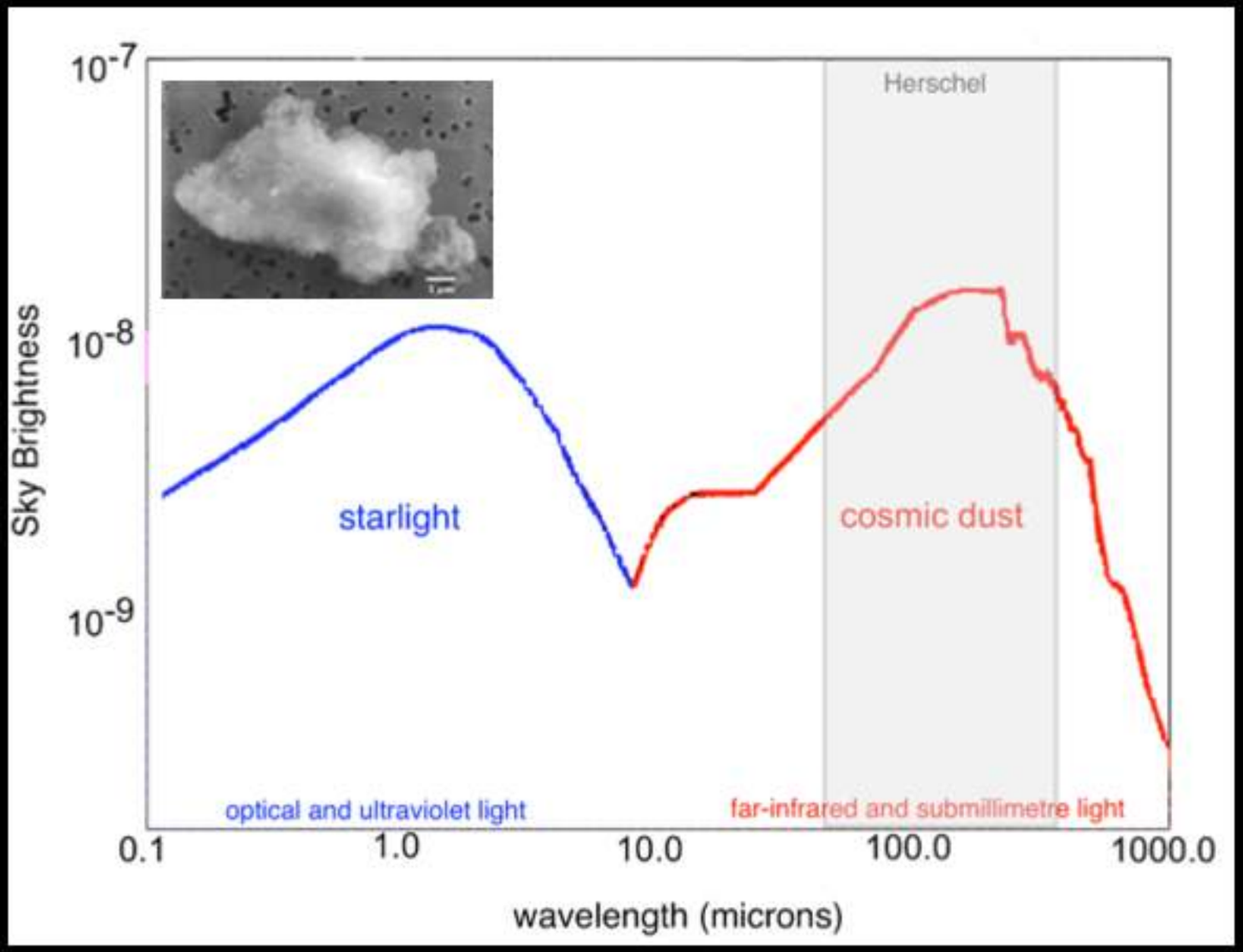
Haley Gomez

Photo credit: Babak Tafreshi

COSMIC DUST

erc
European Research Council
Established by the European Commission
Supporting top researchers from anywhere in the world

THE STOLEN STARLIGHT



adapted from Dole et al 2006

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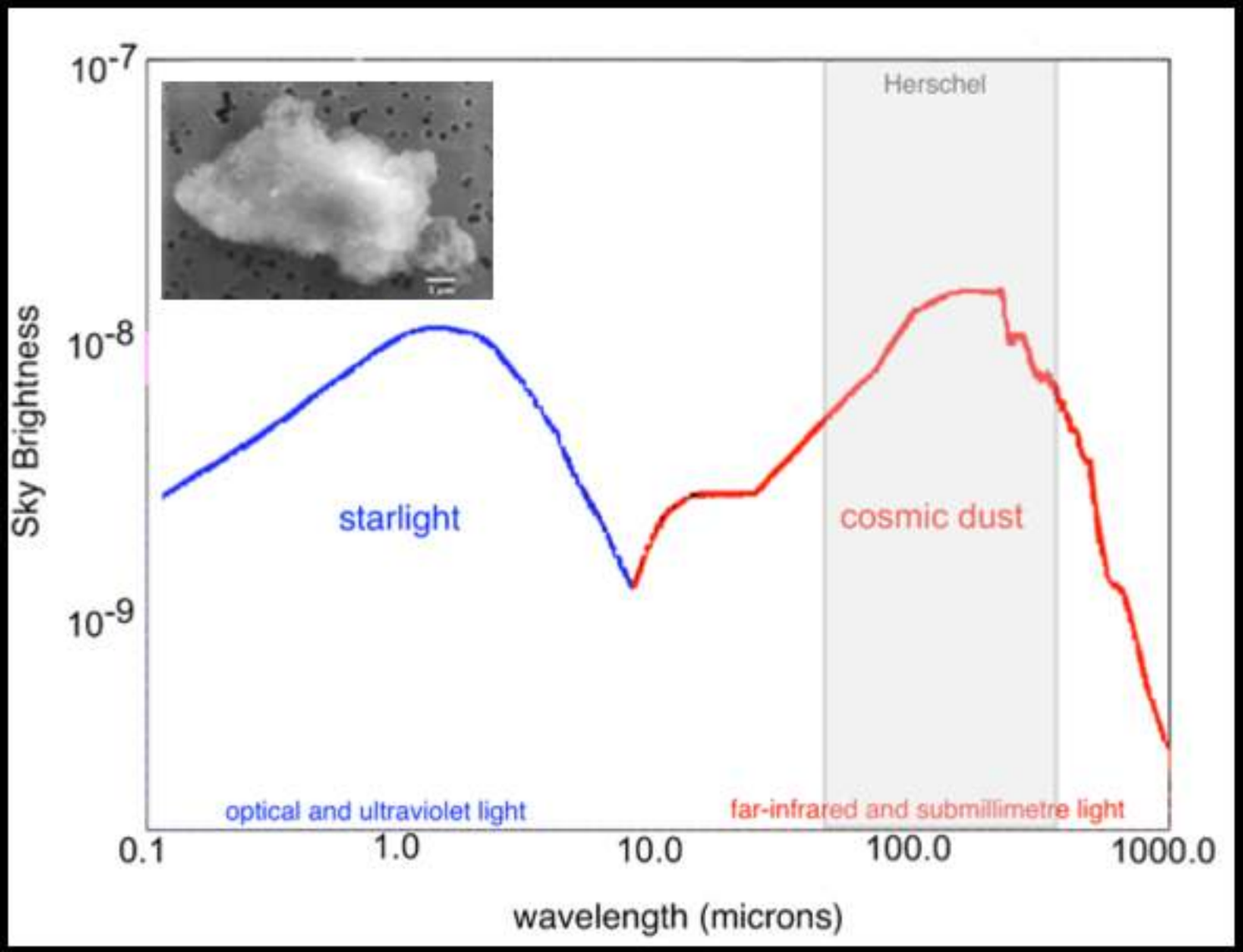

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Dust traces obscured star formation and interstellar content of galaxies

Building blocks of planets and site for water formation in the universe

Contains half of the heavy elements in the universe

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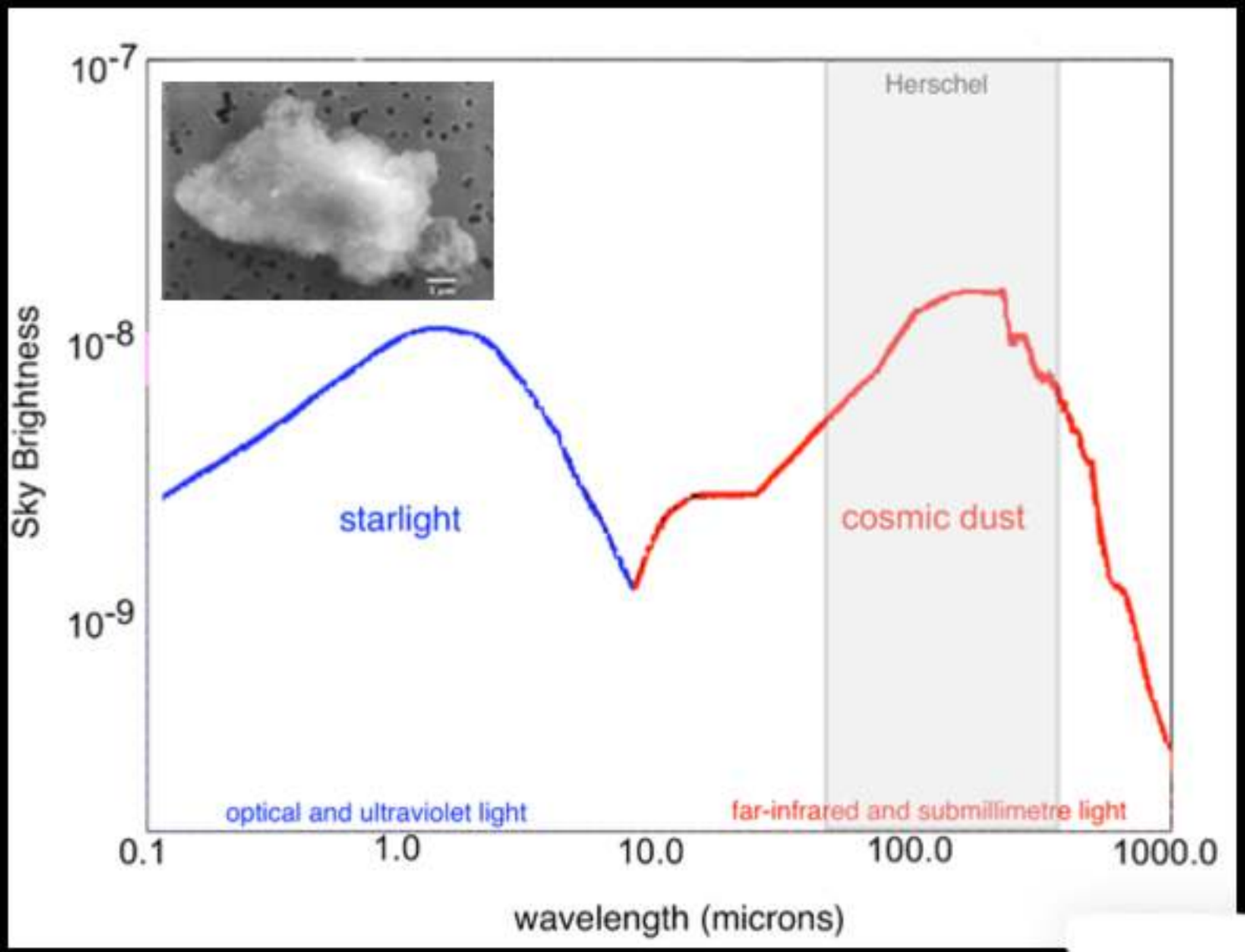

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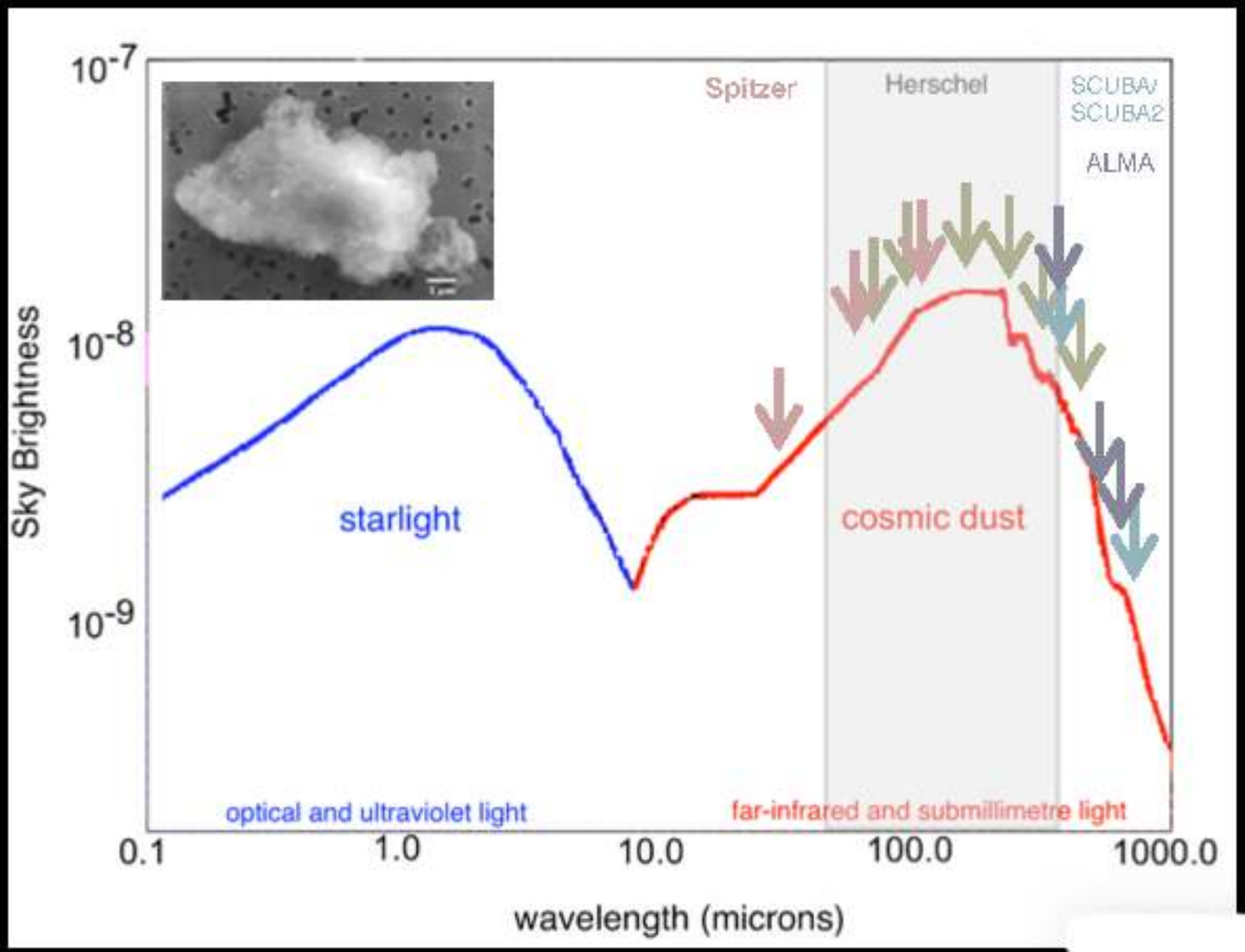

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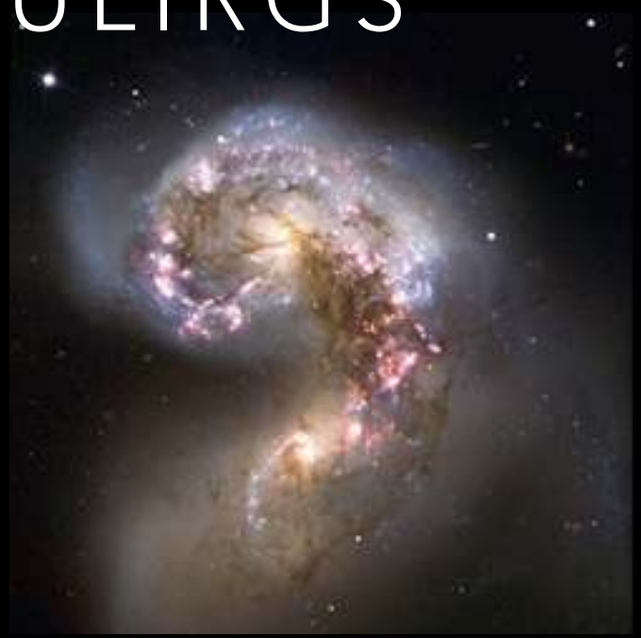
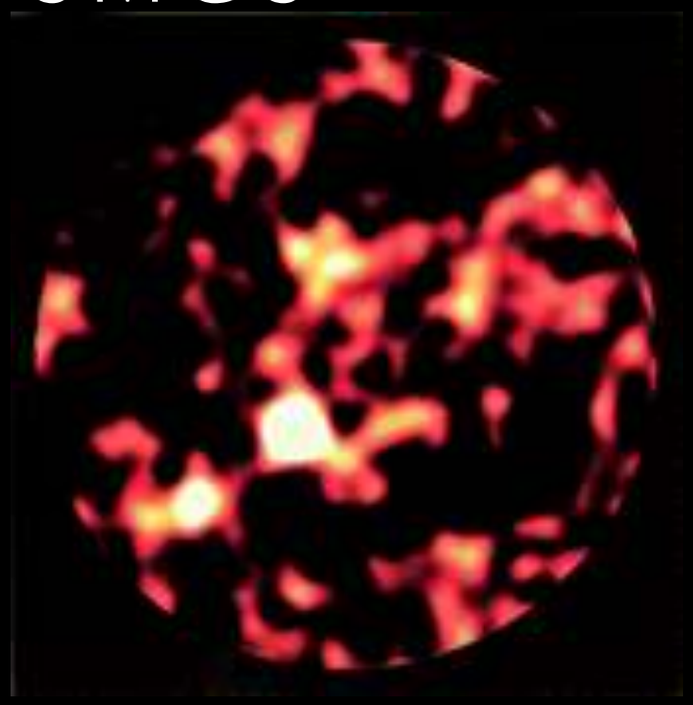
PRE-HERSCHEL DUSTY GALAXIES

ULIRGS



Most luminous IR galaxies at z~0 are ULIRGS
SFRs~100Msun/yr
Gas rich, merging systems

SMGS



850um/1mm selected
extreme SFRs~ **1000Msun/yr**
redshifts > 2

eg Hughes+ 1998, Smail+ 1997, Blain+ 2002, Chapman+ 2005

see reviews in Blain+ 2002, Casey, Narayan & Cooray 2014

THE HERSCHEL SPACE OBSERVATORY

New window on dusty universe - 55 to 672um

Three novel instruments SPIRE, PACS, HIFI

Photometers and Spectrometers

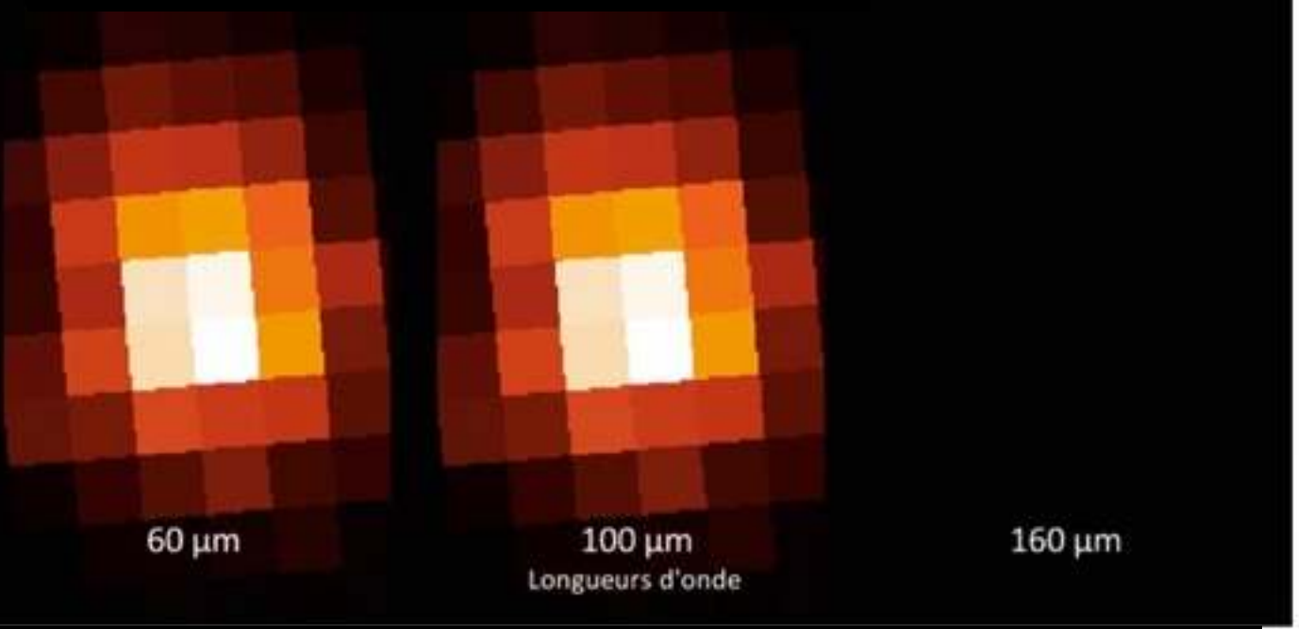
Superior sensitivity

3.5m mirror

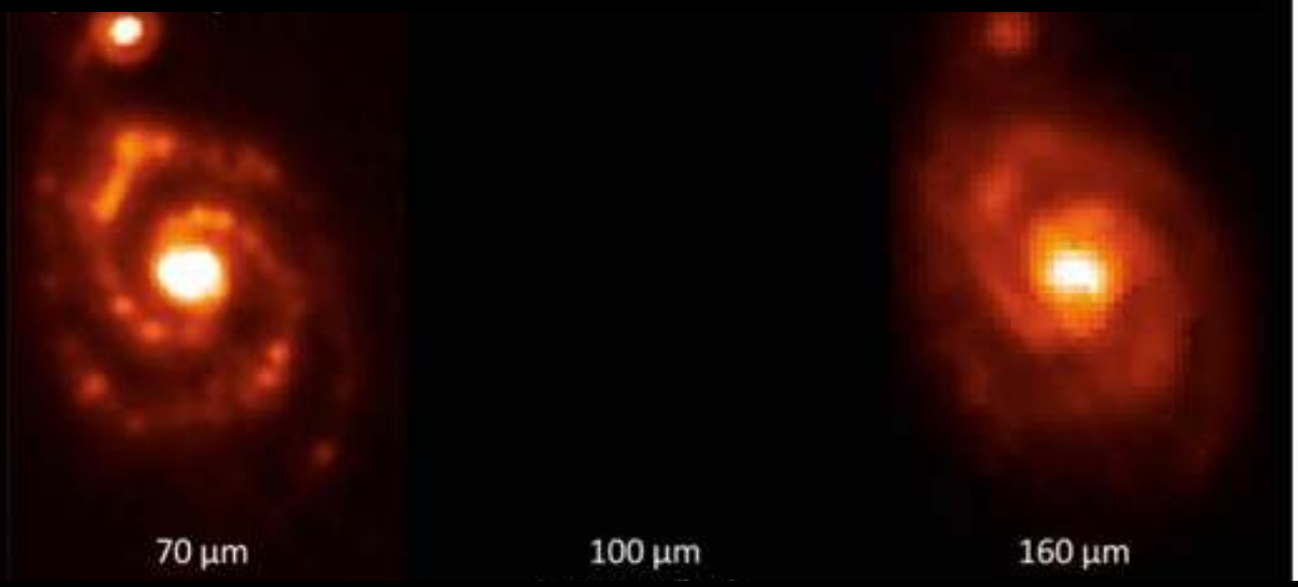
Pilbratt+ 2010, Griffin+ 2010, Poglitsch+ 2010

HERSCHEL: IMPROVED RESOLUTION

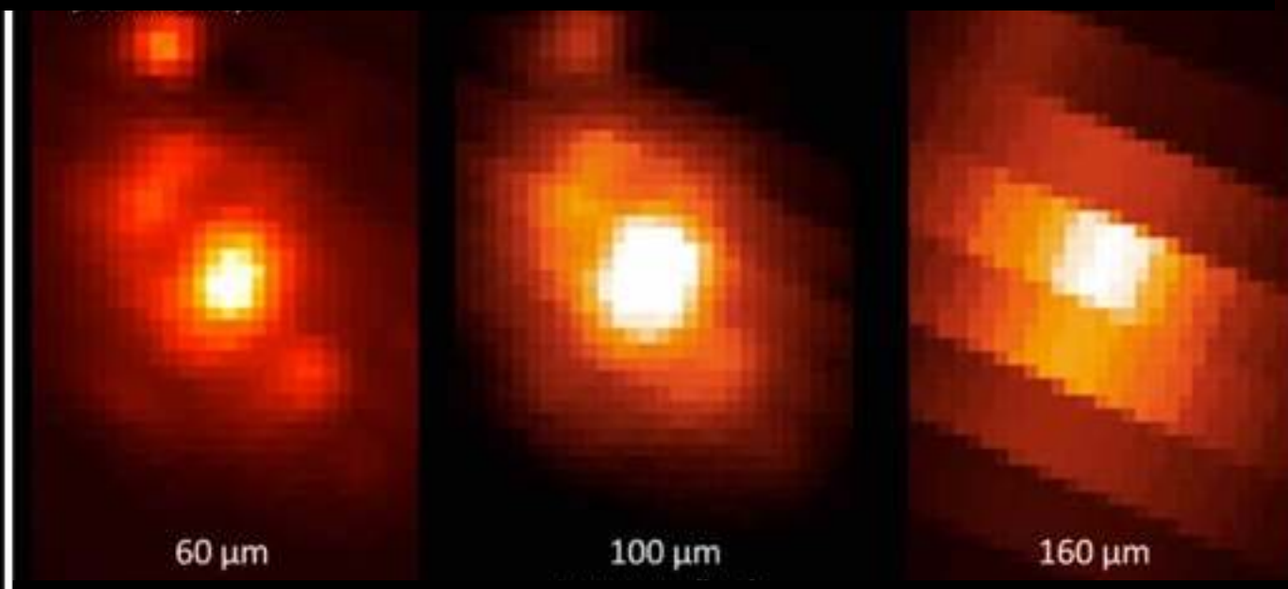
1983 - IRAS Satellite — 0.5m



2003 - Spitzer telescope — 0.8m



1995 - ISO Satellite — 0.6m



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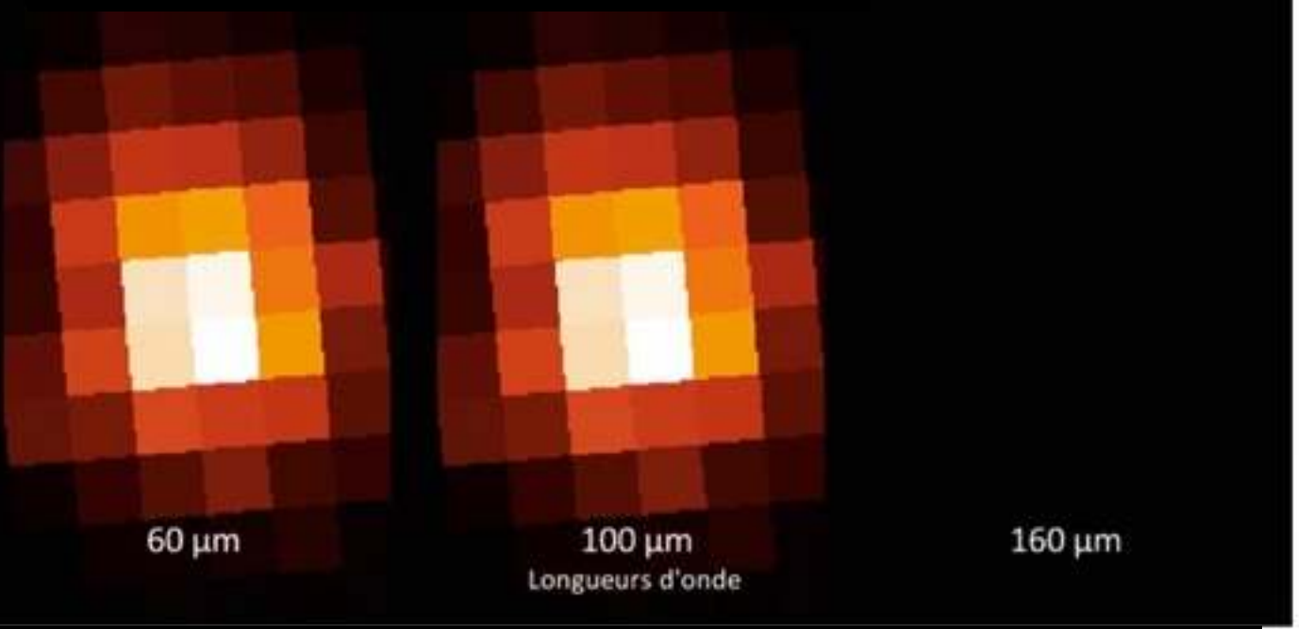

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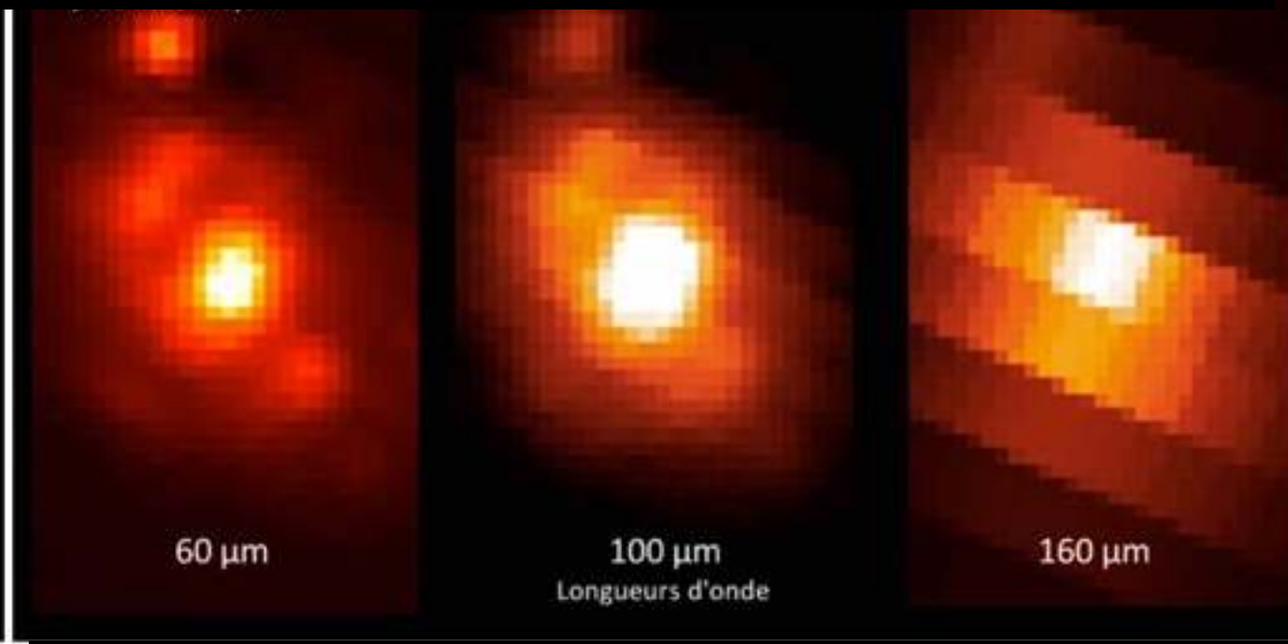

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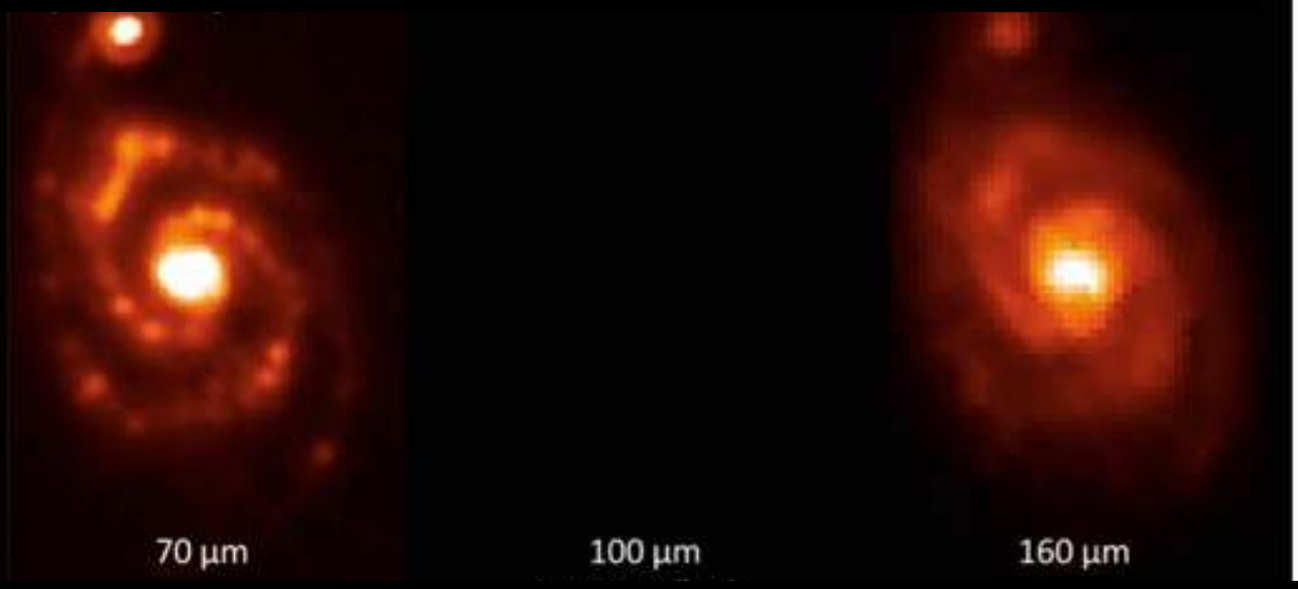
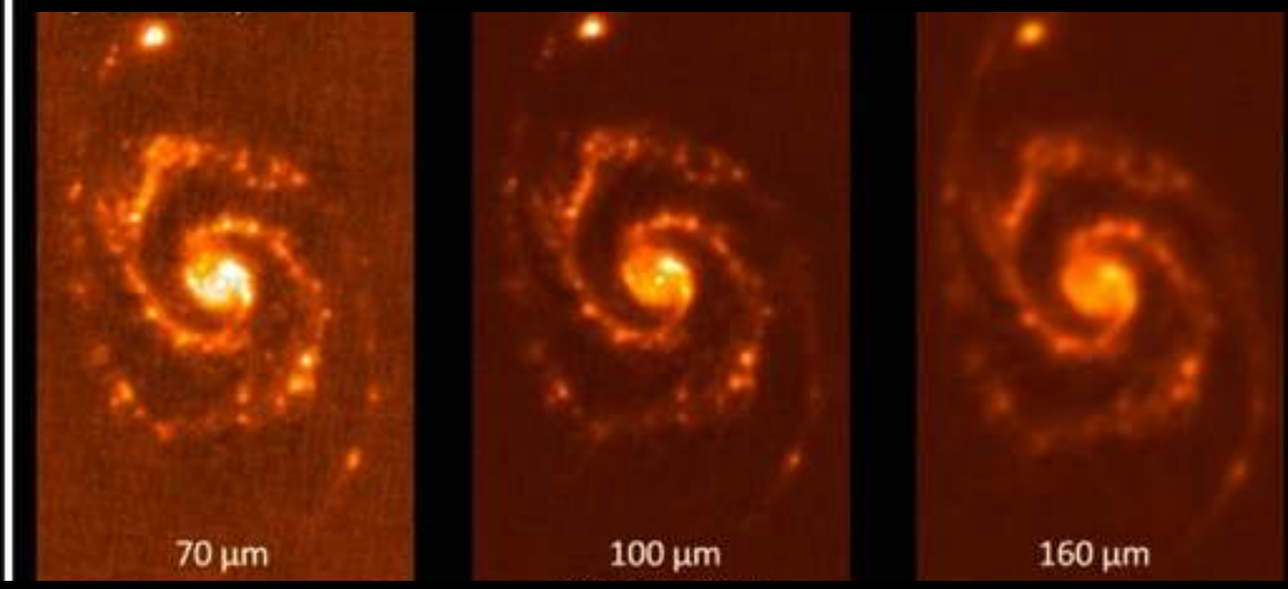
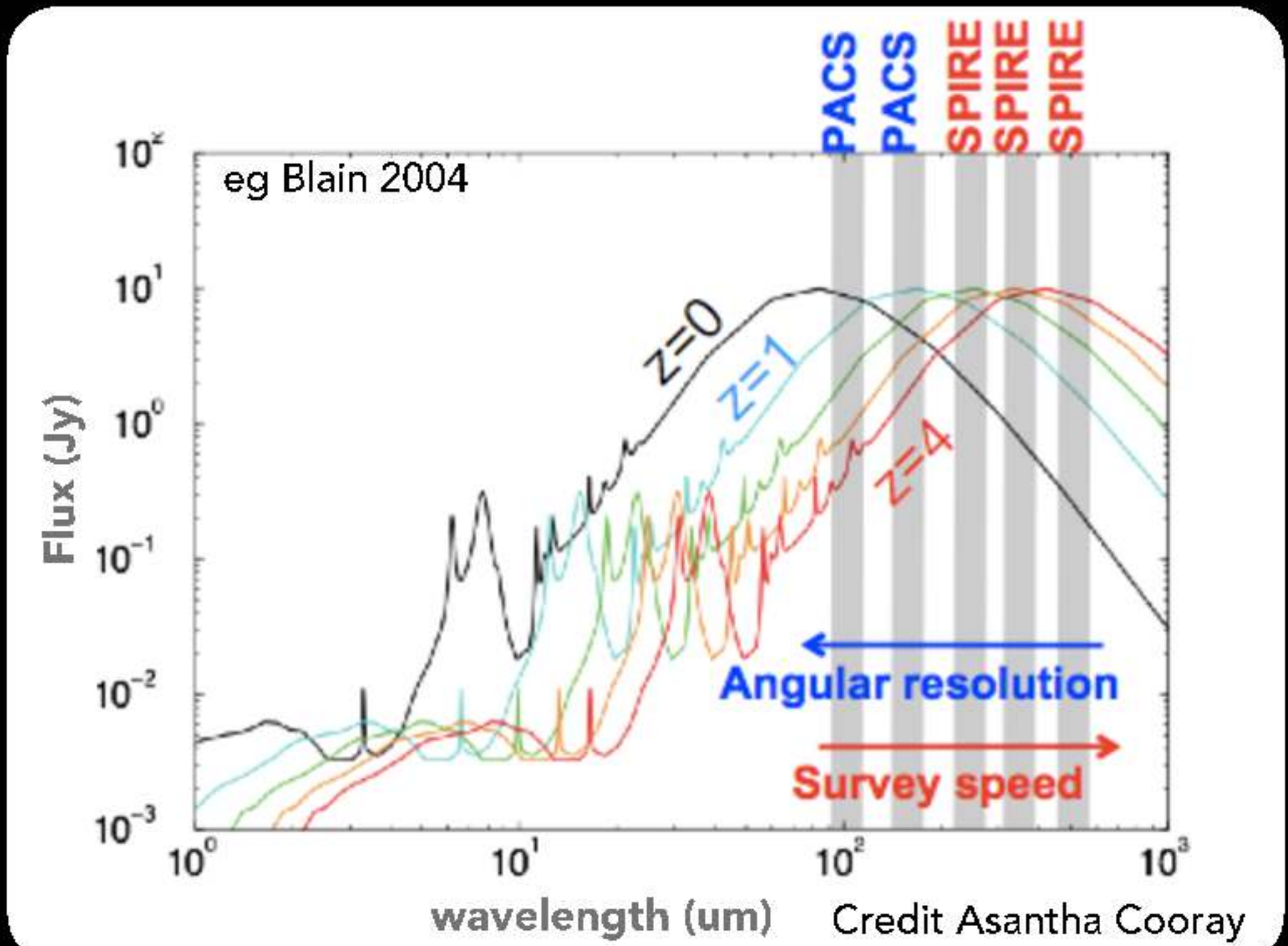
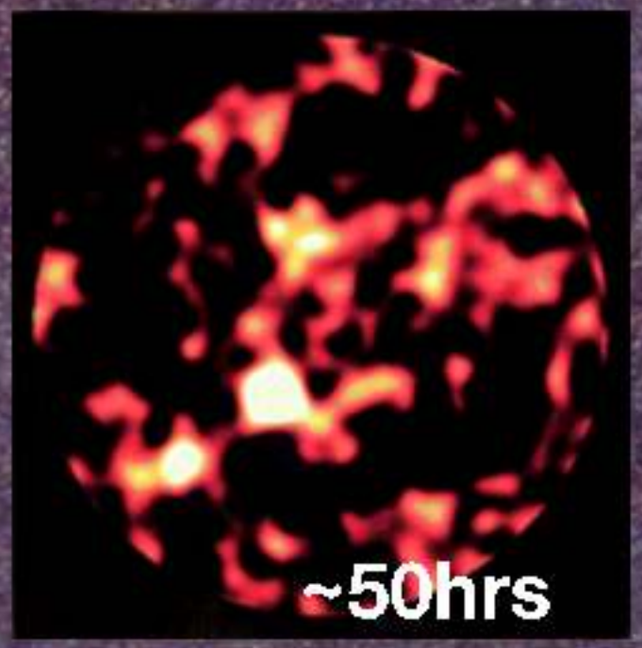


2009 - Herschel — 3.5m



HERSCHEL: IMPROVED TECHNICOLOUR





HERSCHEL: IMPROVED SENSITIVITY & MAPPING

***H**erschel* **A**strophysical **T**erahertz **L**arge-**A**rea **S**urvey

Credit: ESA/Herschel/H-ATLAS/Steve Maddox, Chris Clark, Haley Gomez

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Thousands of sources

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Thousands of sources
5s per galaxy!

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HERSCHEL EXTRAGALACTIC STUDIES

Resolved studies
Temperature and beta
Dusty disks
Hubble Sequence
Dusty ETGs
Blind Surveys
Dust Heating and SFRs
Dust to gas ratio
Dust to metals metals
Spectroscopy, CII and CO Ladder
AGN
Outflows

Luminosity functions
dust mass functions
AGN
Outflows
ULIRGS
Herschel SEDs
Dust as a gas tracer
Lenses
High z starbursts
Source of dust in early universe
Large scale structure
Cosmic Infrared background

NEARBY DUSTY GALAXIES WITH HERSCHEL

optical credit: R Gendler

NEARBY DUSTY GALAXIES WITH HERSCHEL

optical credit: R Gendler

Herschel 250 + Xray

Groves+ 2014
Draine+ 2013
Smith, HLG+ 2012a
Smith, Eales, HLG+ 2012b
Mattsson, HLG+ 2014
Kirk+ 2015
Viaene+ 2015

RESOLVED STUDIES

Smith, MWL+ 2012

Groves+2014, Draine+2013, Planck Collab XXV 2014,Galametz+ 2012

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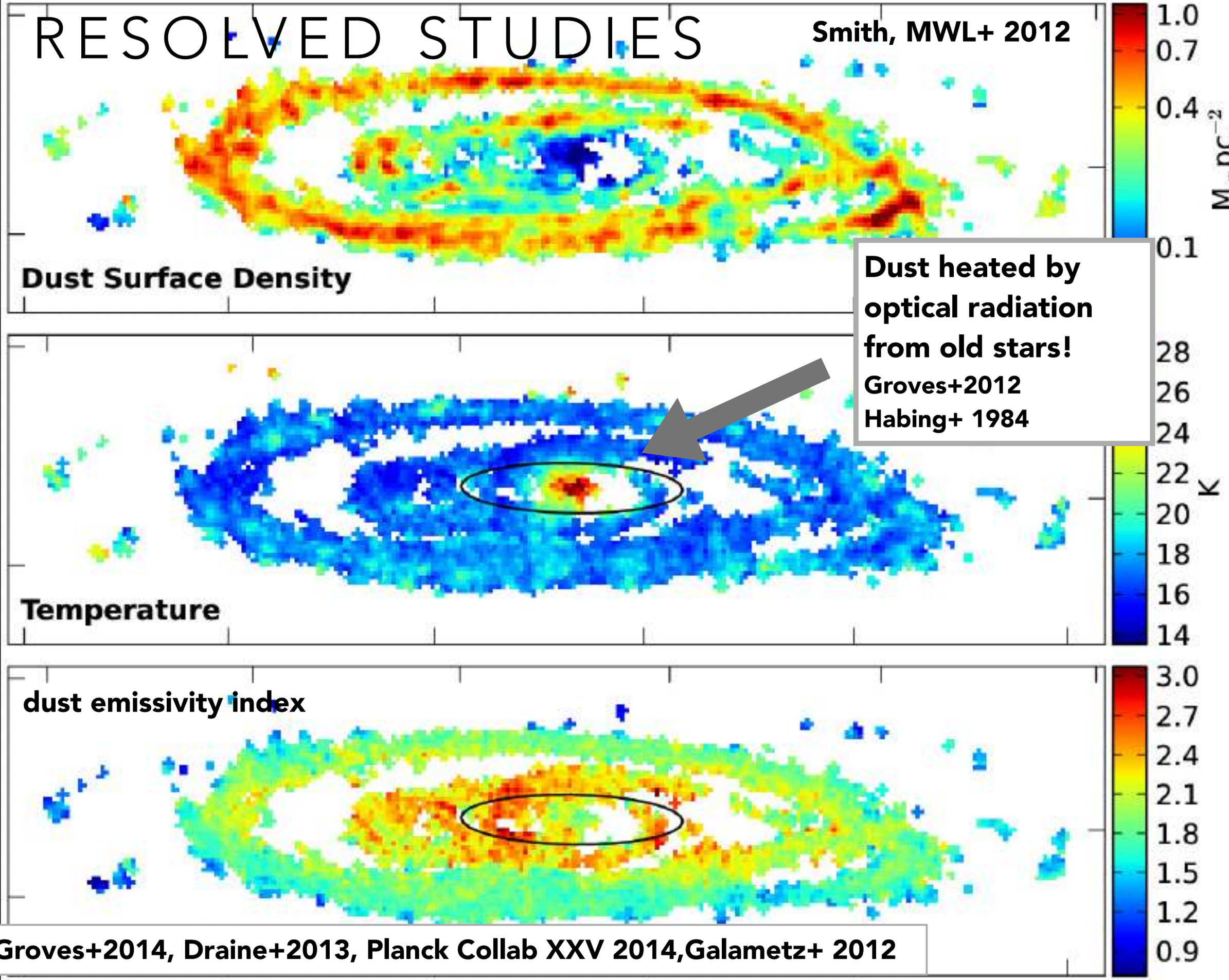


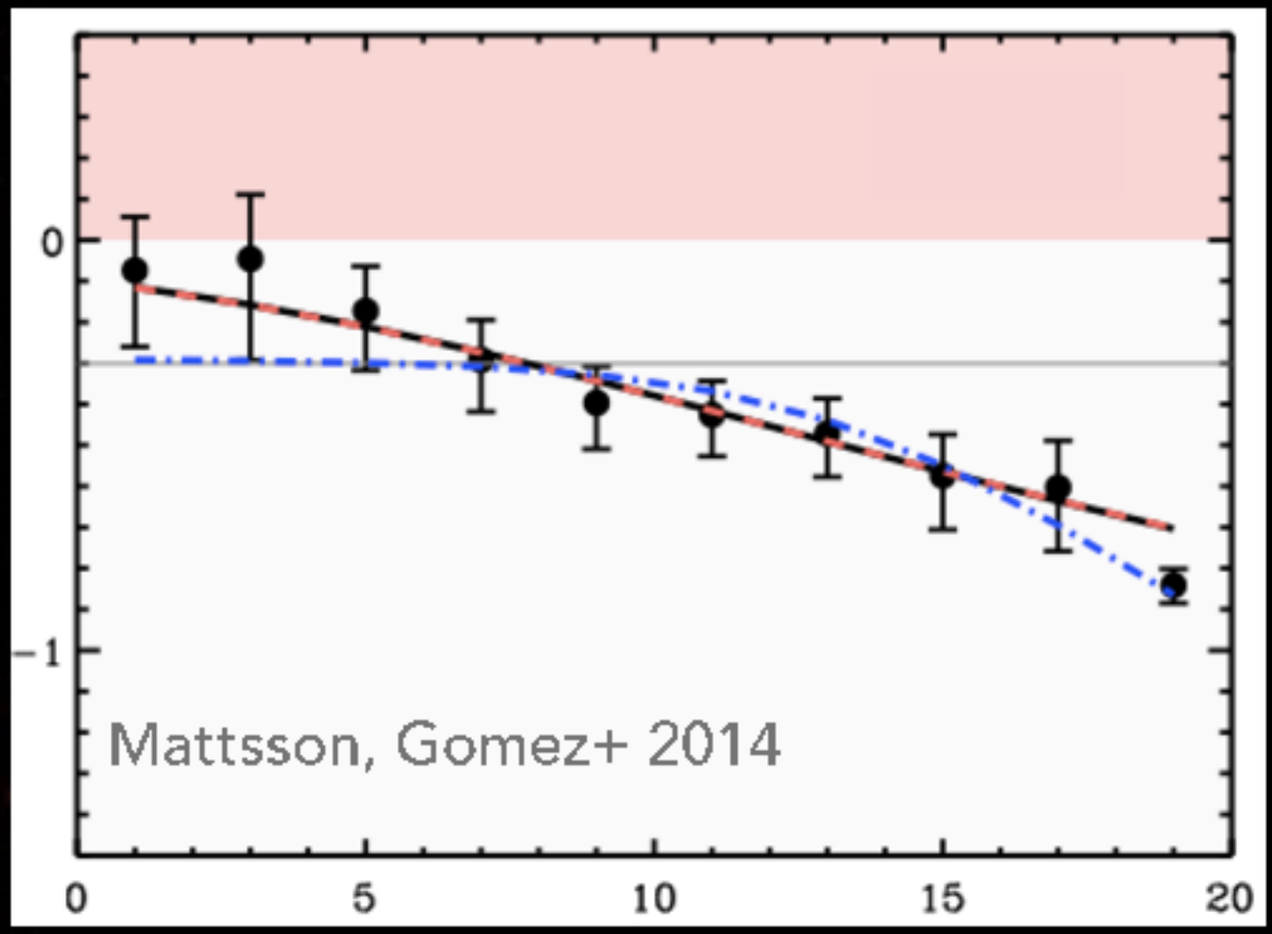
Dust heated by optical radiation from old stars!

Groves+2012

Habing+ 1984

Groves+2014, Draine+2013, Planck Collab XXV 2014,Galametz+ 2012

DUST SOURCES PROBED BY DUST GRADIENTS



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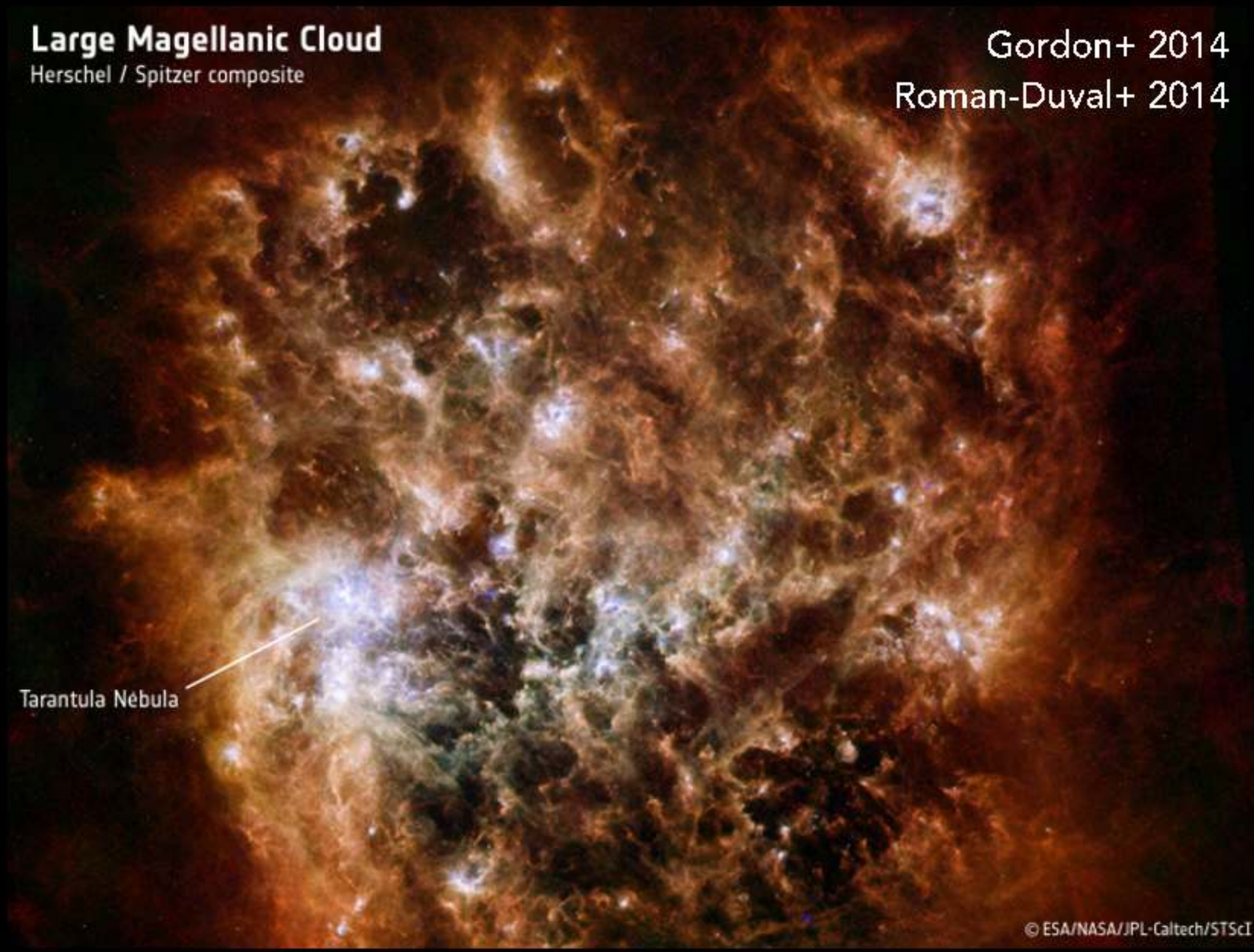
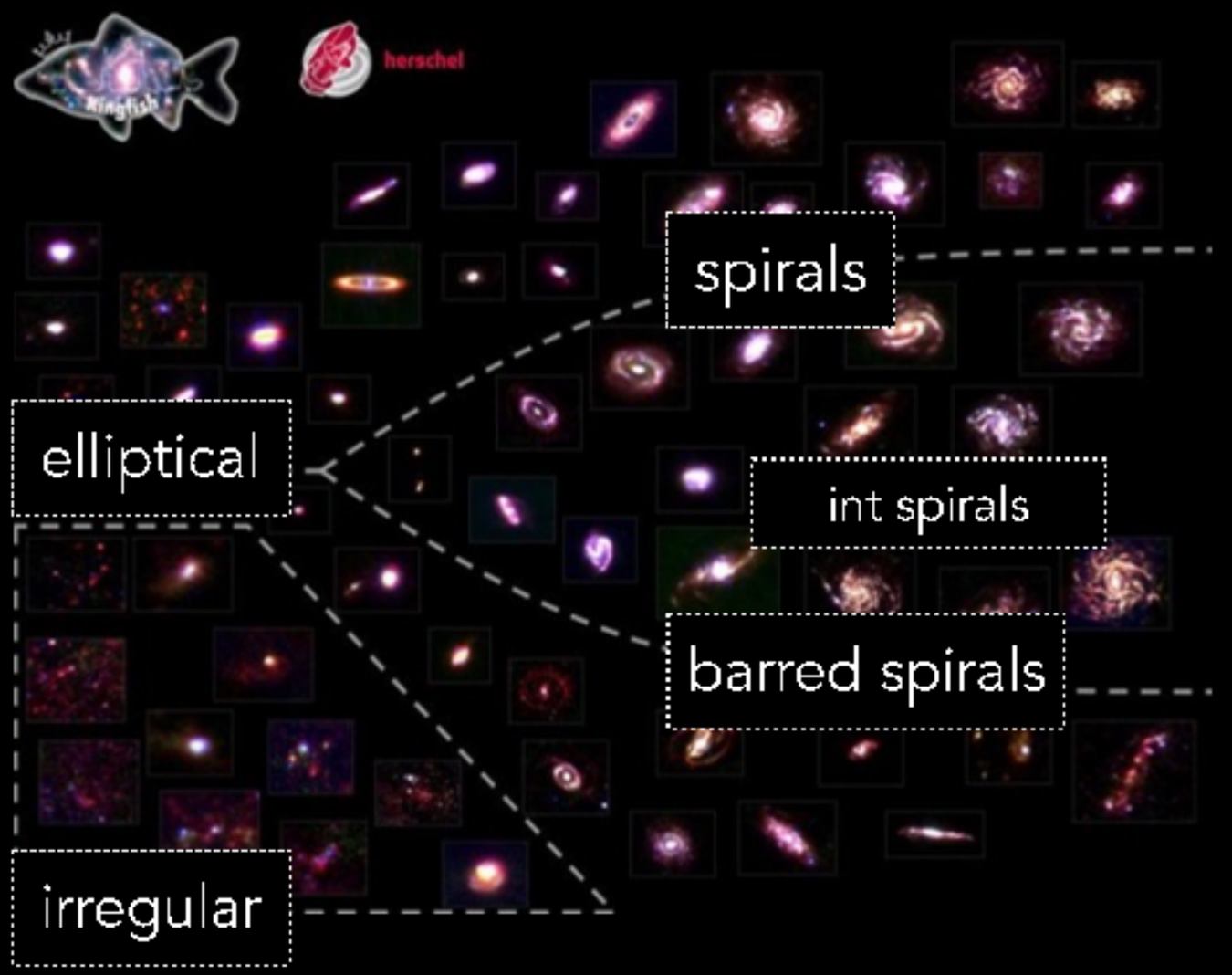


DUST SOURCES PROBED BY DUST GRADIENTS

HERSCHEL: UNPRECEDENTED NUMBERS OF NEARBY GALAXIES

Credit: ESA/Herschel/KINGFISH



Credit: ESA/Herschel/HRS-SAG2 and HeViCS Key Programmes/Sloan Digital Sky Survey/ L. Cortese (Swinburne University).

ARE EARLY TYPE GALAXIES DUSTY?

ETGs, especially ellipticals thought of as red and dead

M60

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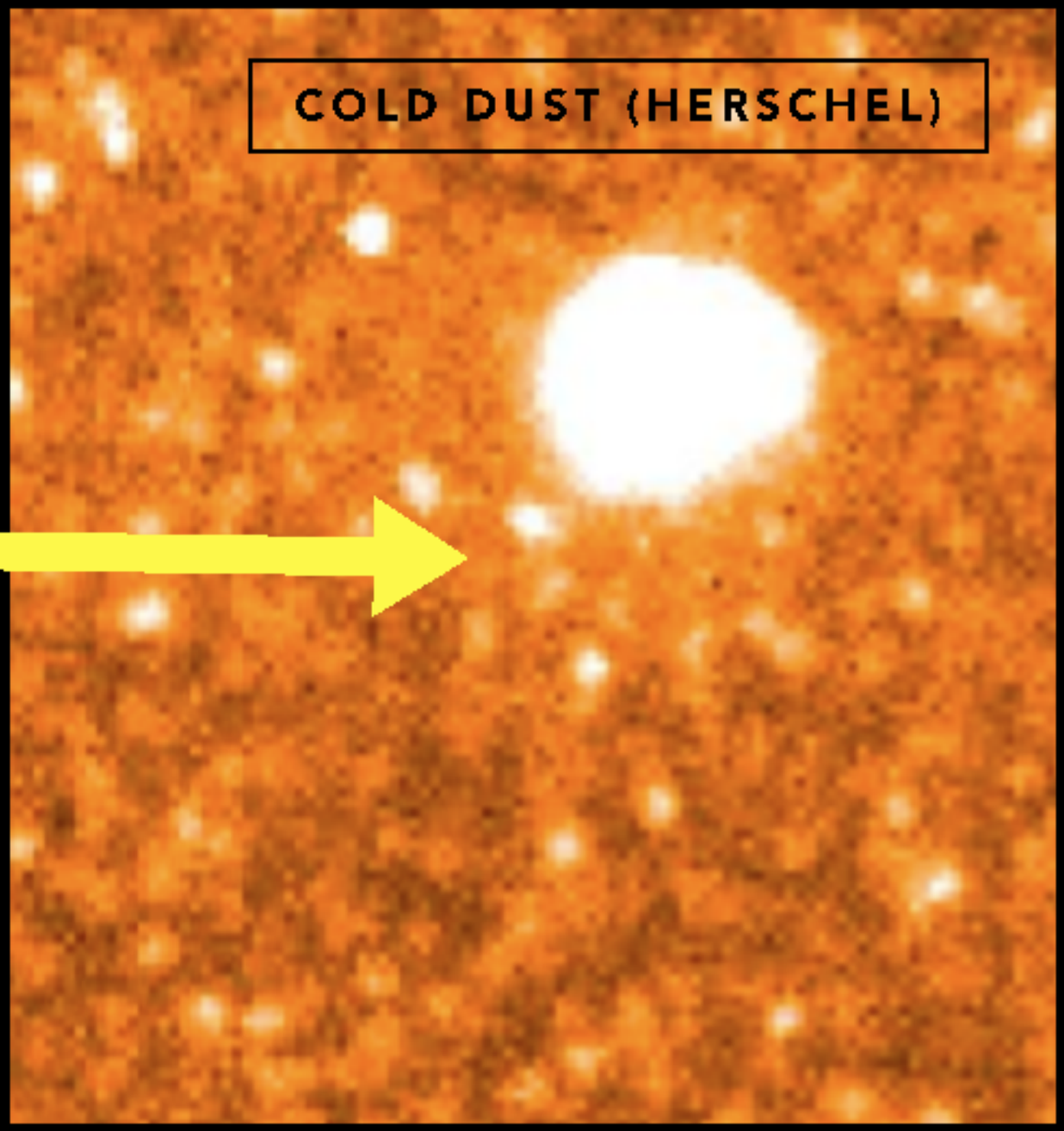
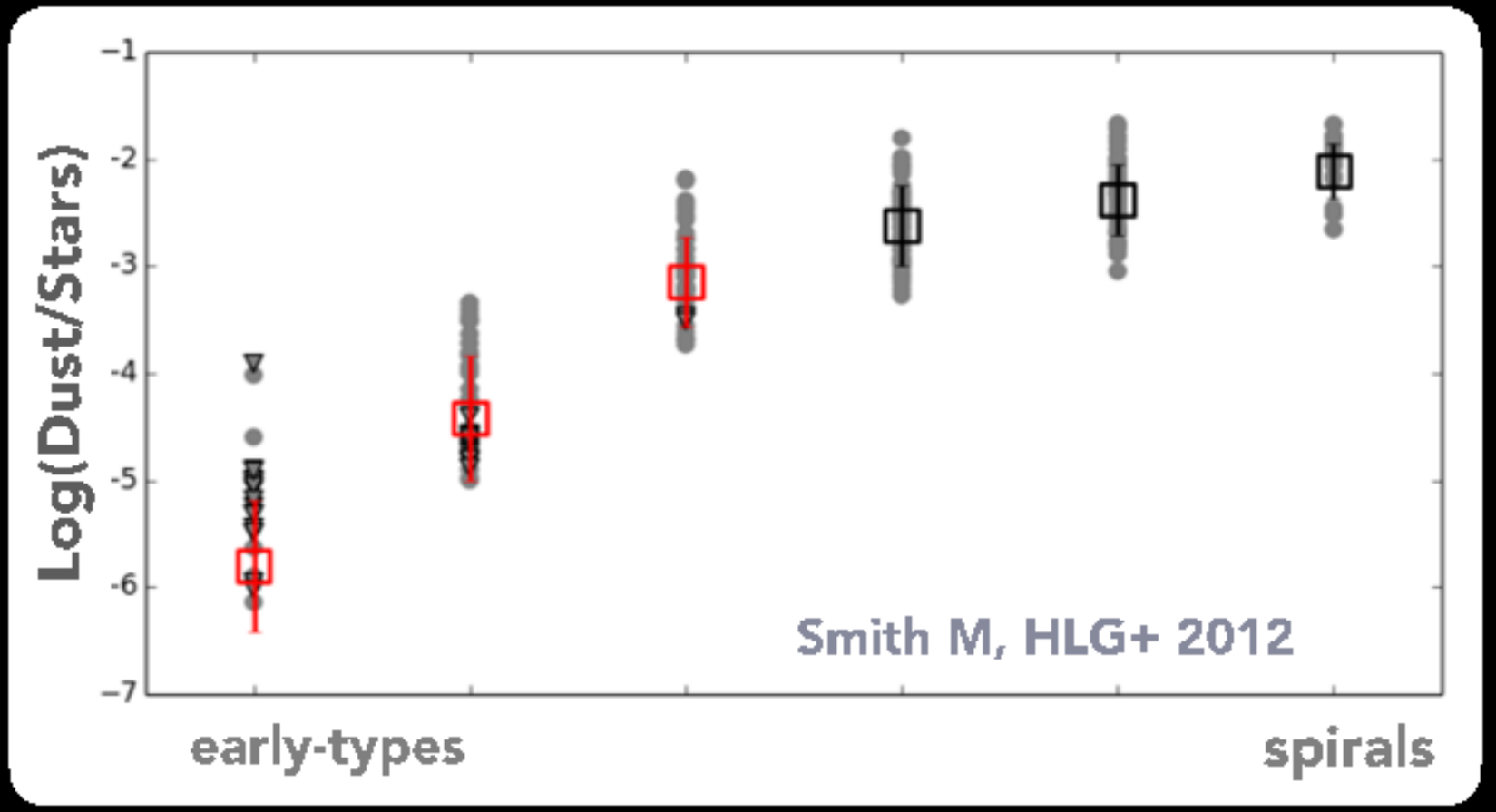


DUST ALONG THE HUBBLE SEQUENCE

50% ETGS detected with Herschel

Dust in ETGS 100x lower than spirals and more scatter



See also Draine+2007, Skibba+ 2011, Amblard+ 2014, Grossi+ 2014

DUST ALONG THE HUBBLE SEQUENCE

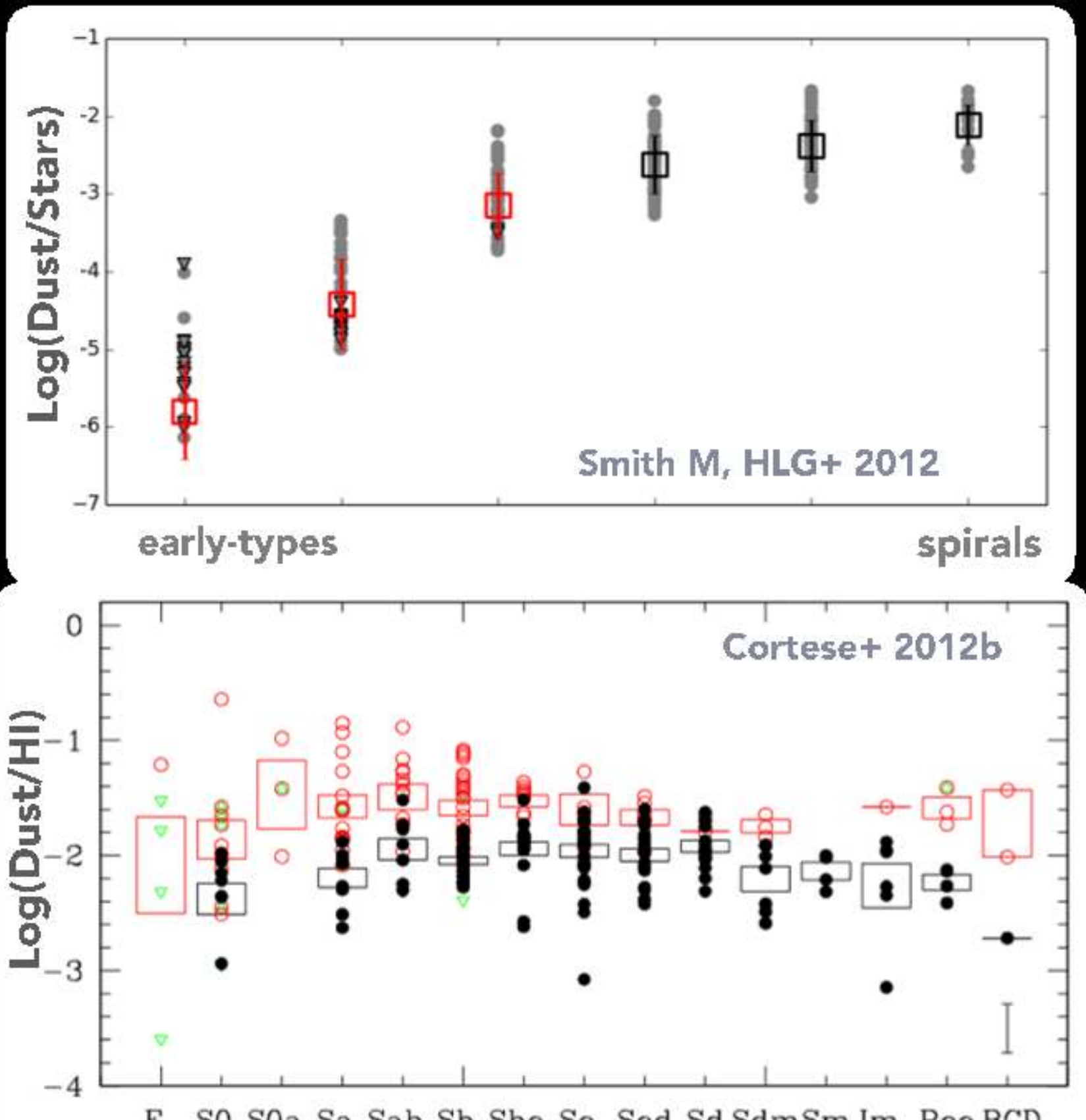
50% ETGS detected with Herschel

Dust in ETGS 100x lower than spirals and more scatter

Dust-to-gas ratio not a function of Hubble Type

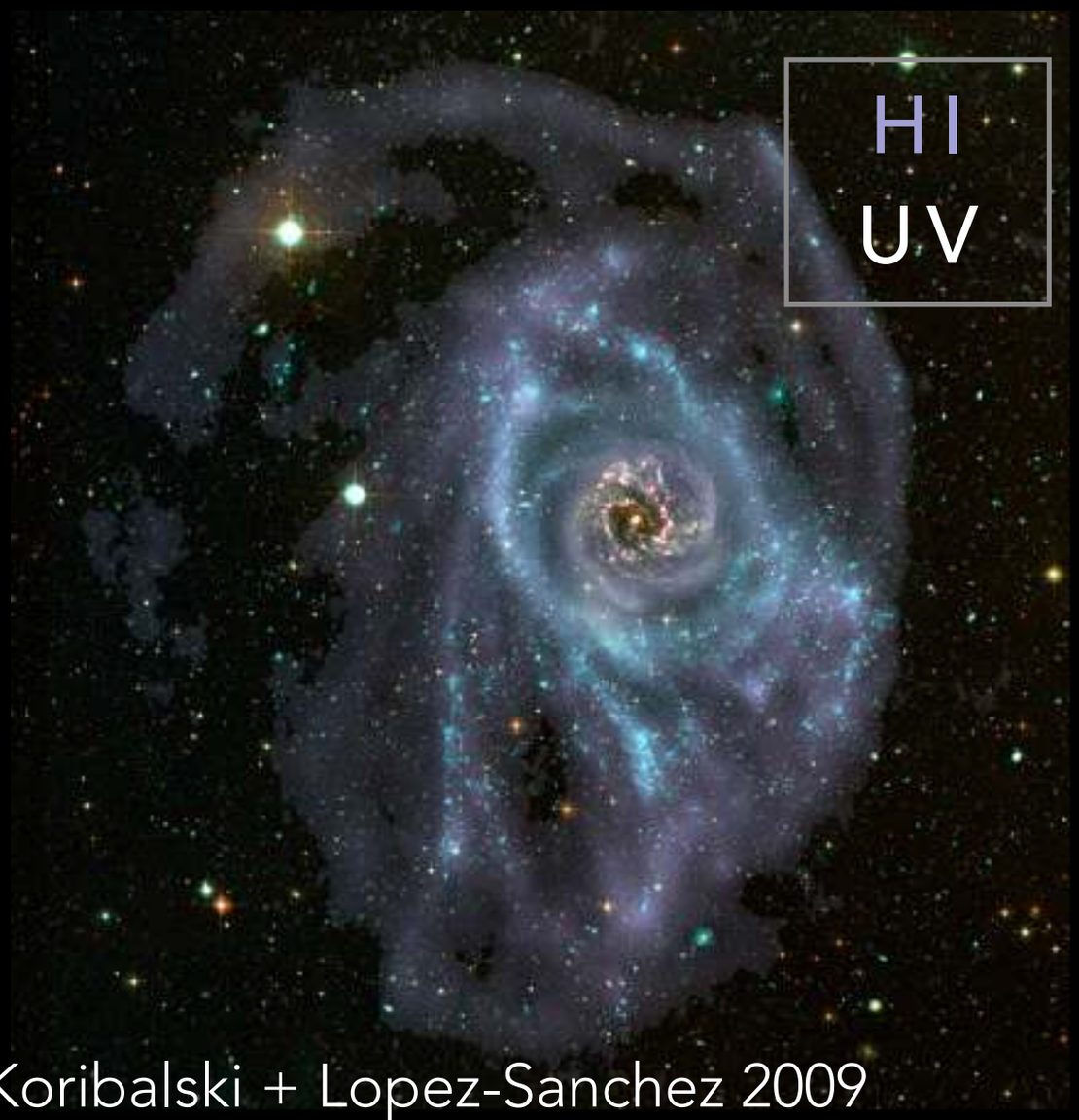
Environment matters

See also Draine+2007, Skibba+ 2011, Amblard+ 2014, Grossi+ 2014



HOW FAR DOES THE DUST GO?

HI disks larger than optical
10-30% galaxies have extended UV disks (Thilker+ 2007)
Reddening studies suggest half dust outside galaxies (Menard+ 2010)



Koribalski + Lopez-Sanchez 2009
Credit: Angel Lopez-Sanchez

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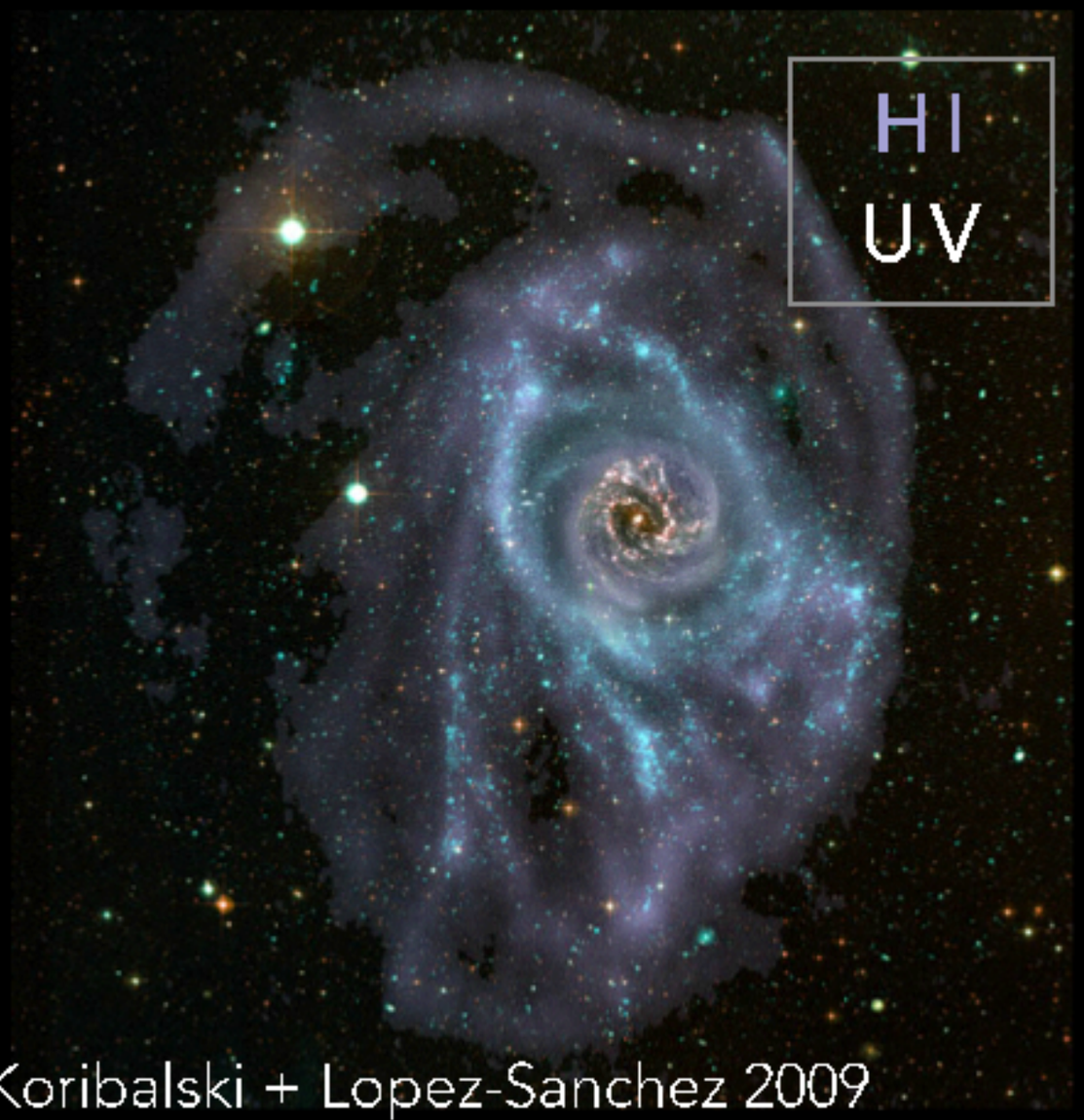

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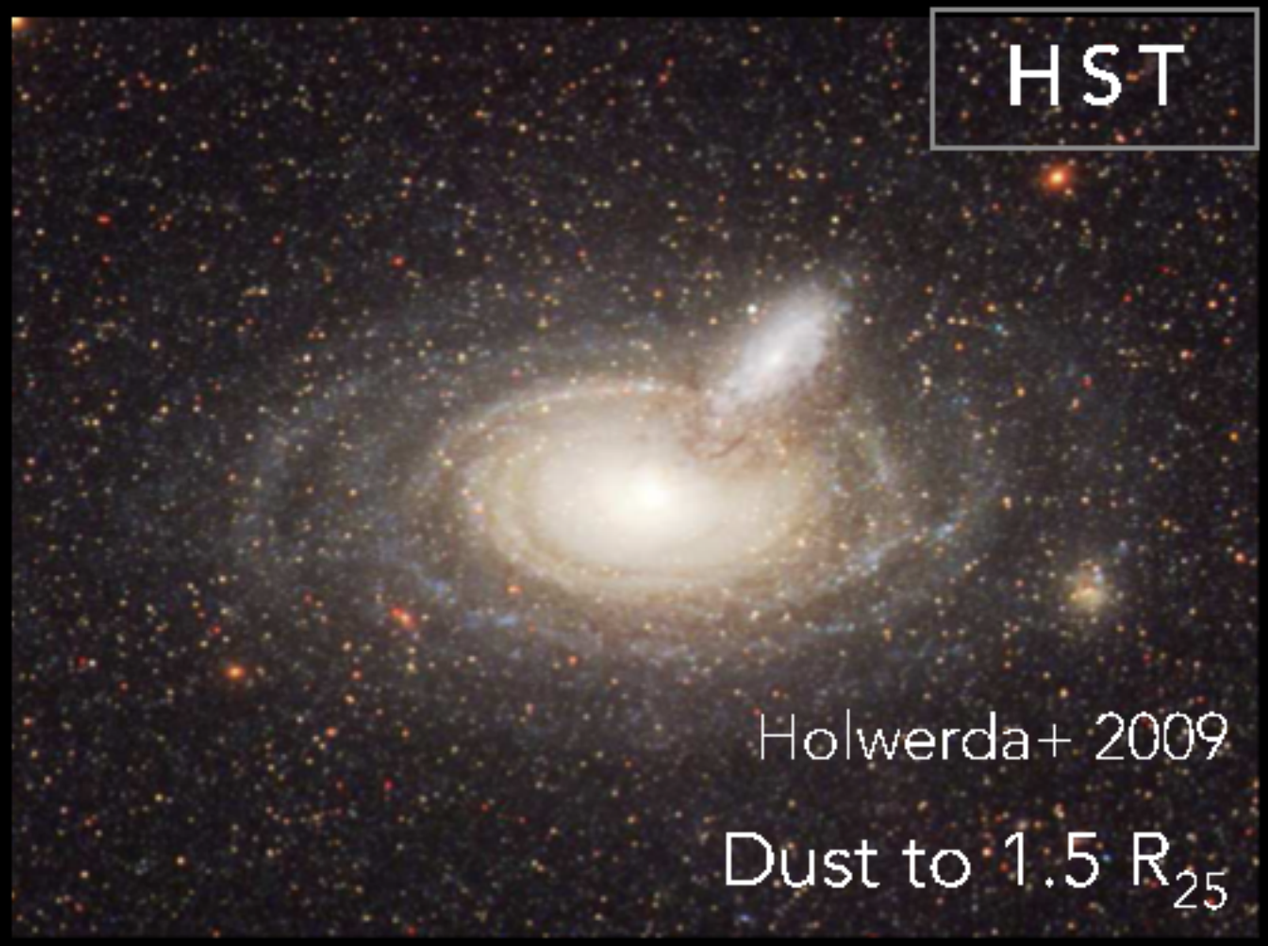
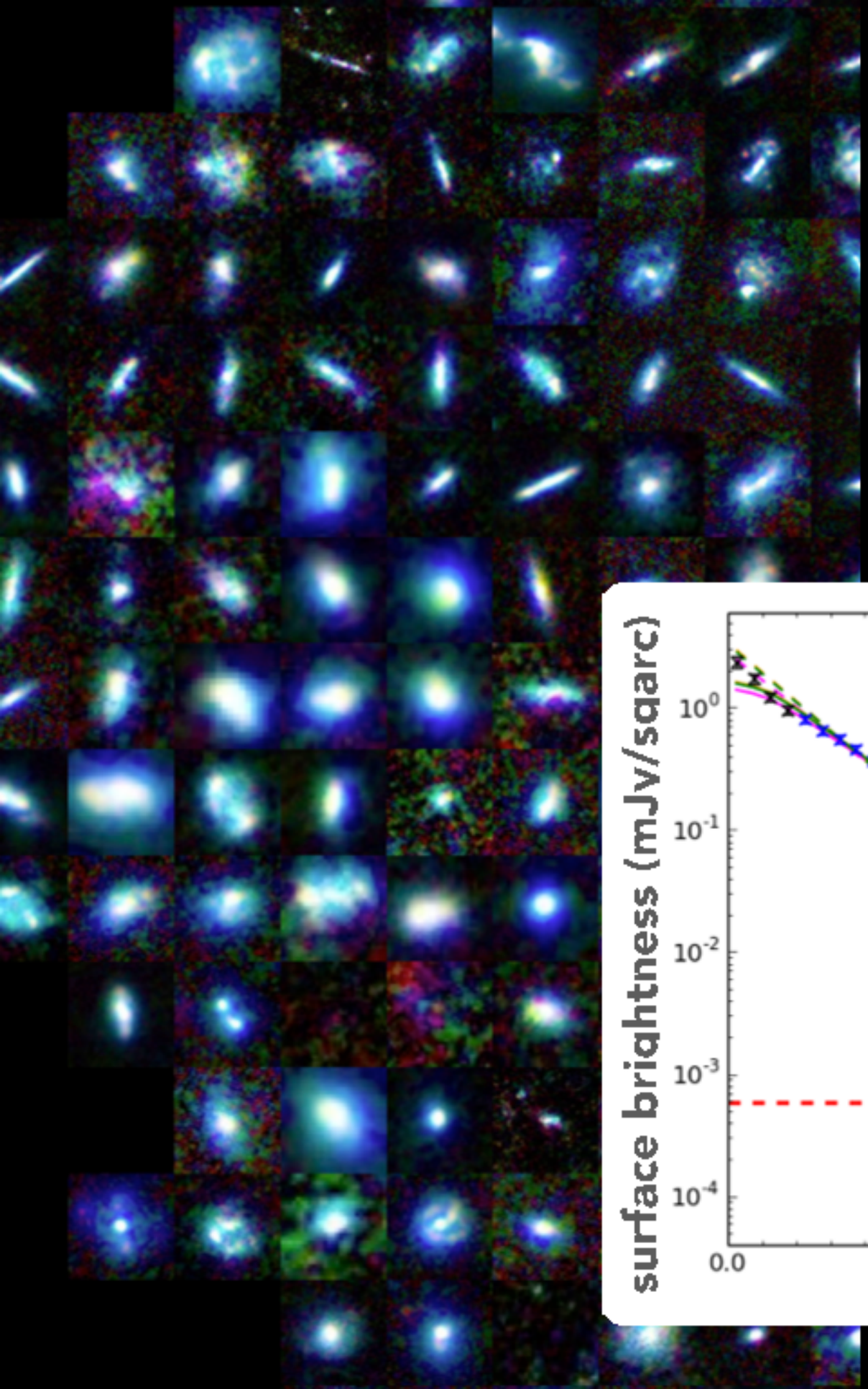
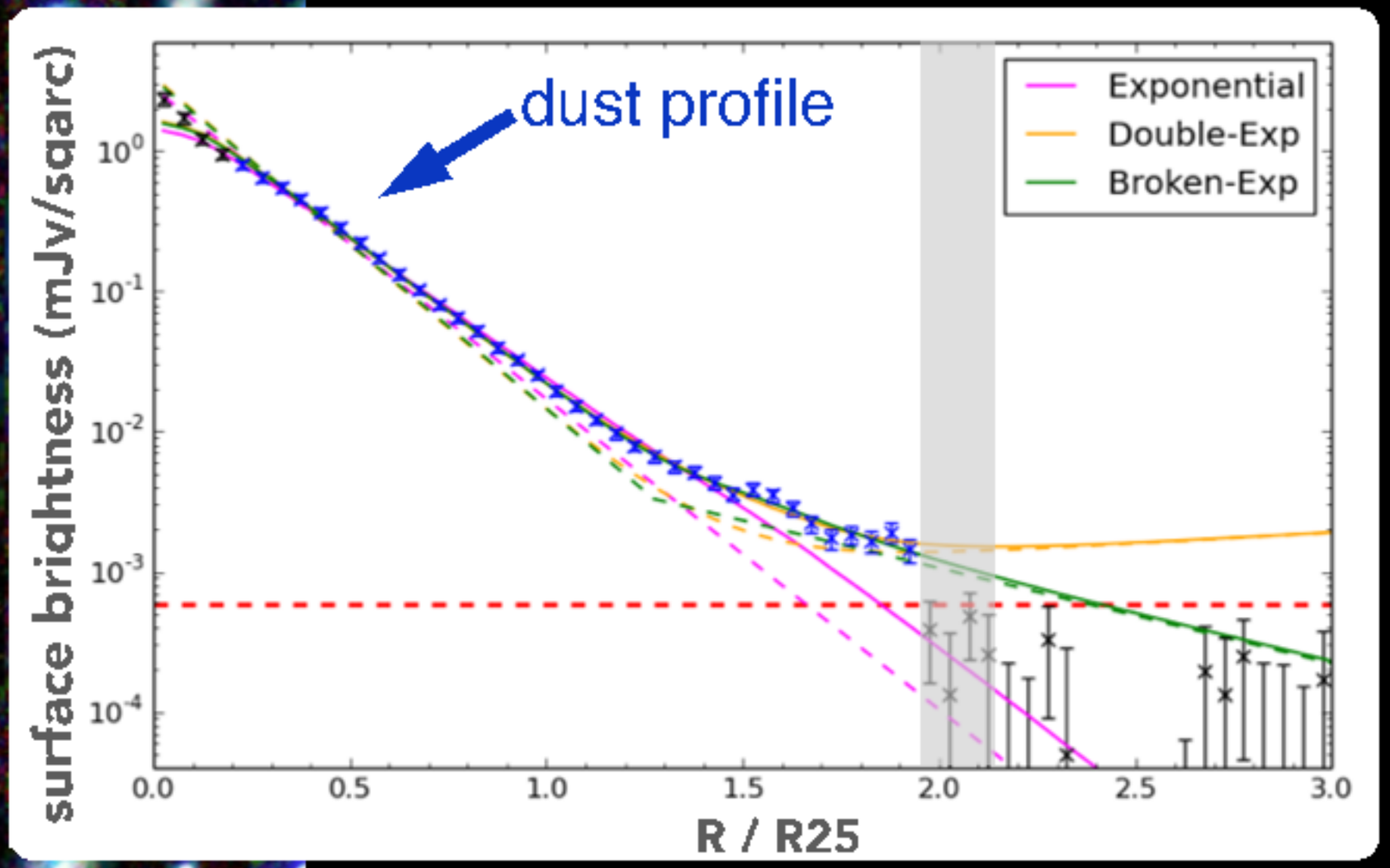




Stacked 117 late type galaxies in nearby Universe

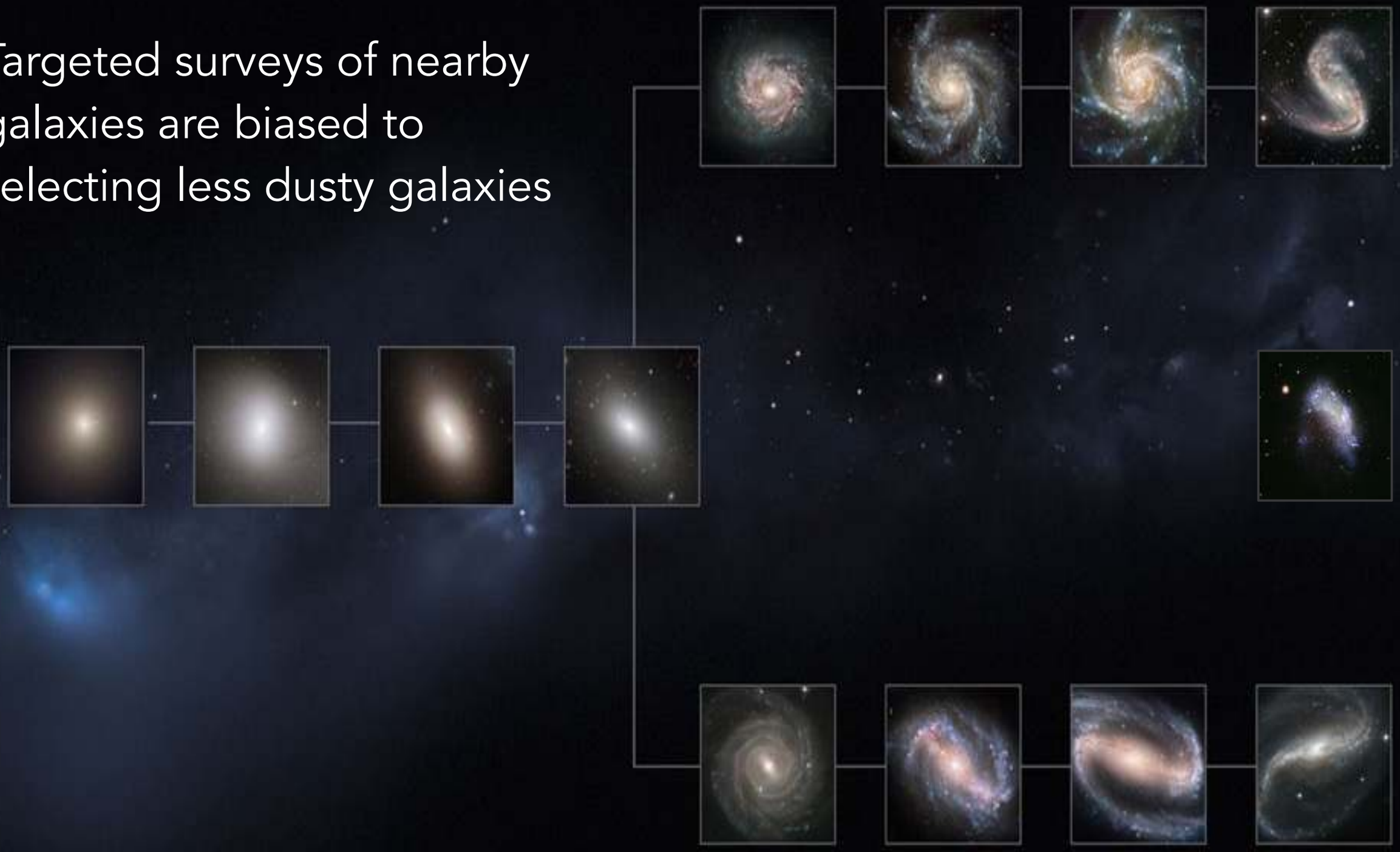
Dust extends out to ~1.9 R25

Smith, MWL+ in press



THE ELEPHANT IN THE ROOM

Targeted surveys of nearby galaxies are biased to selecting less dusty galaxies

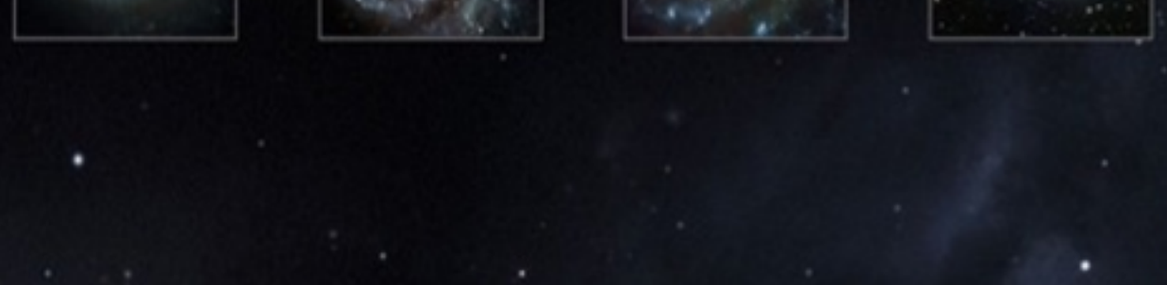


Credit: Adapted from NASA/ESA/M Kornmesser

THE ELEPHANT IN THE ROOM

Targeted surveys of nearby galaxies are biased to selecting less dusty galaxies

biased by high density environment and dust-poor systems



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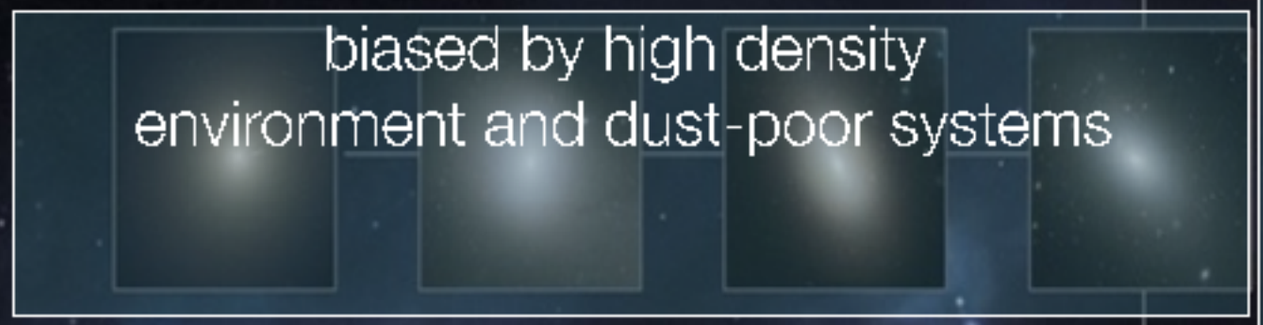

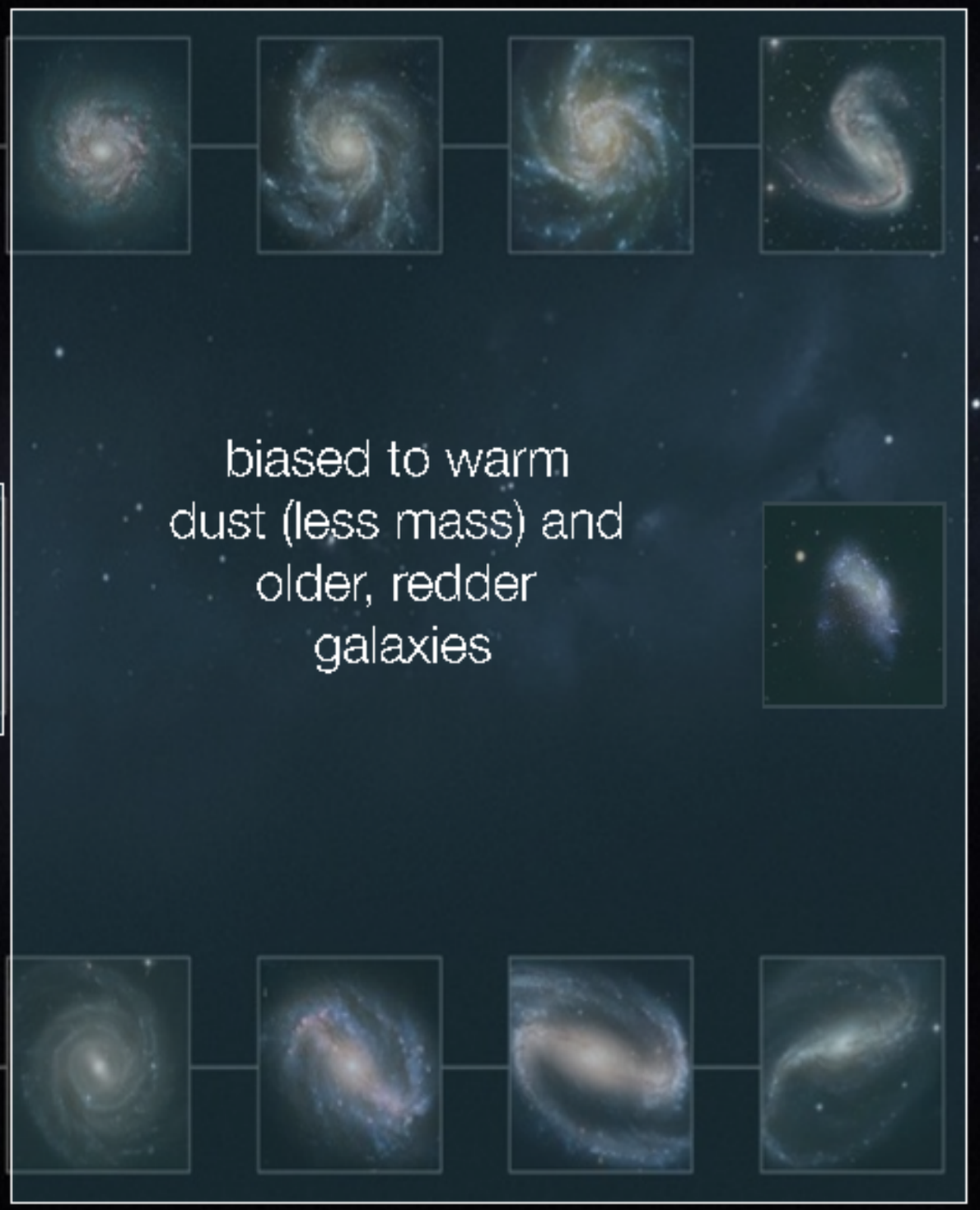

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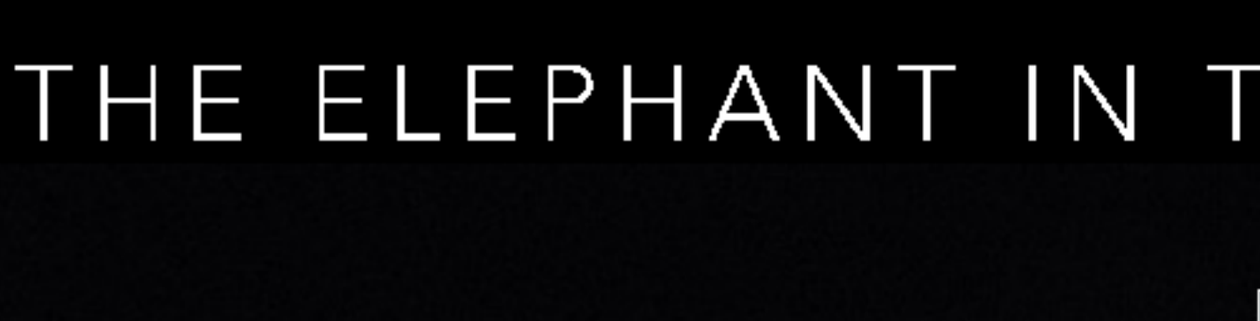

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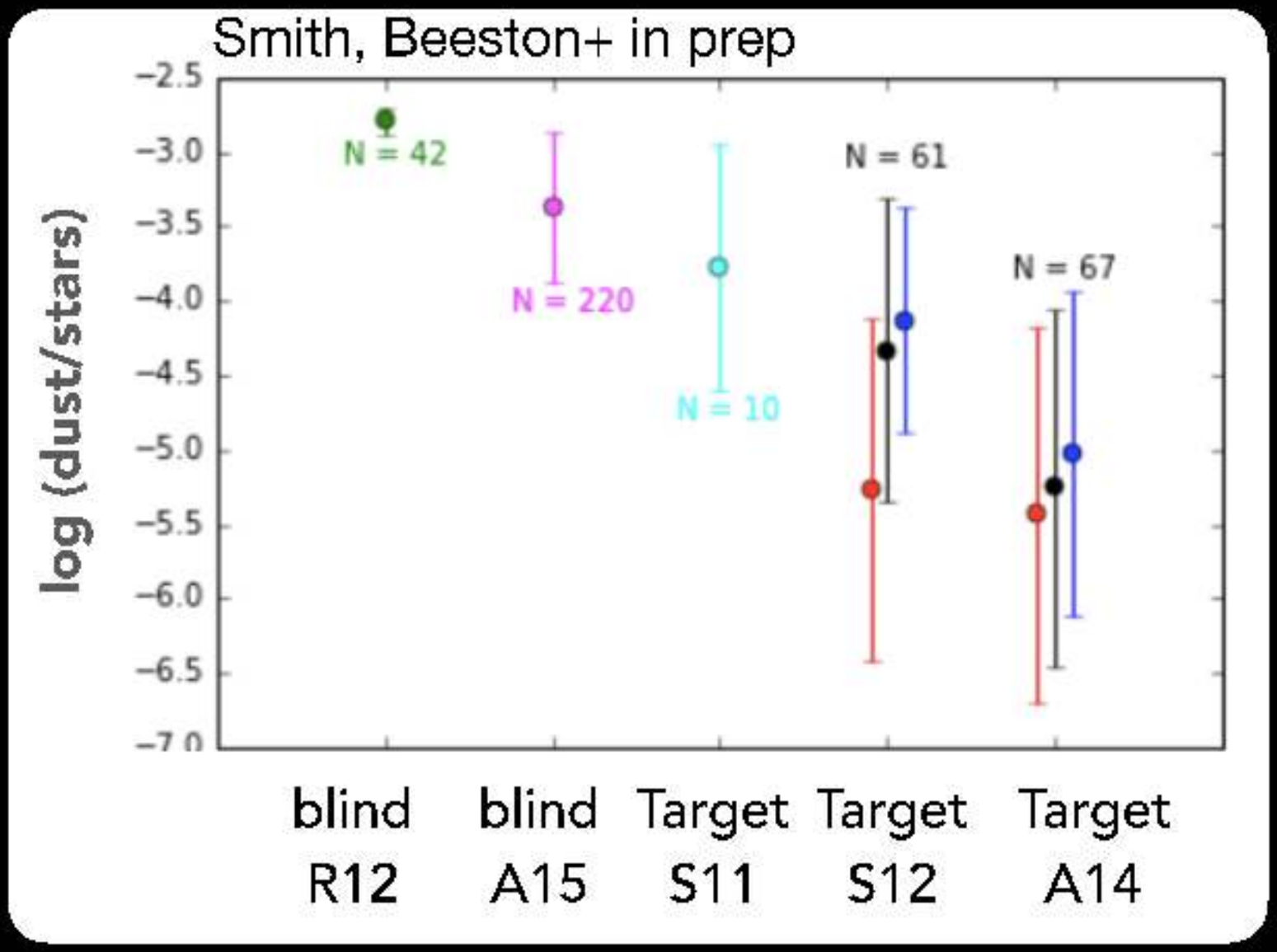
ETGS EVEN MORE DUSTY

ETGs found in large area blind dust surveys are dustier and bluer than those in targeted surveys



Rowlands+2012,Agius+2013,2015,Skibba+2011,Amblard+2014,Davis+ 2015, Dariush+ 2016

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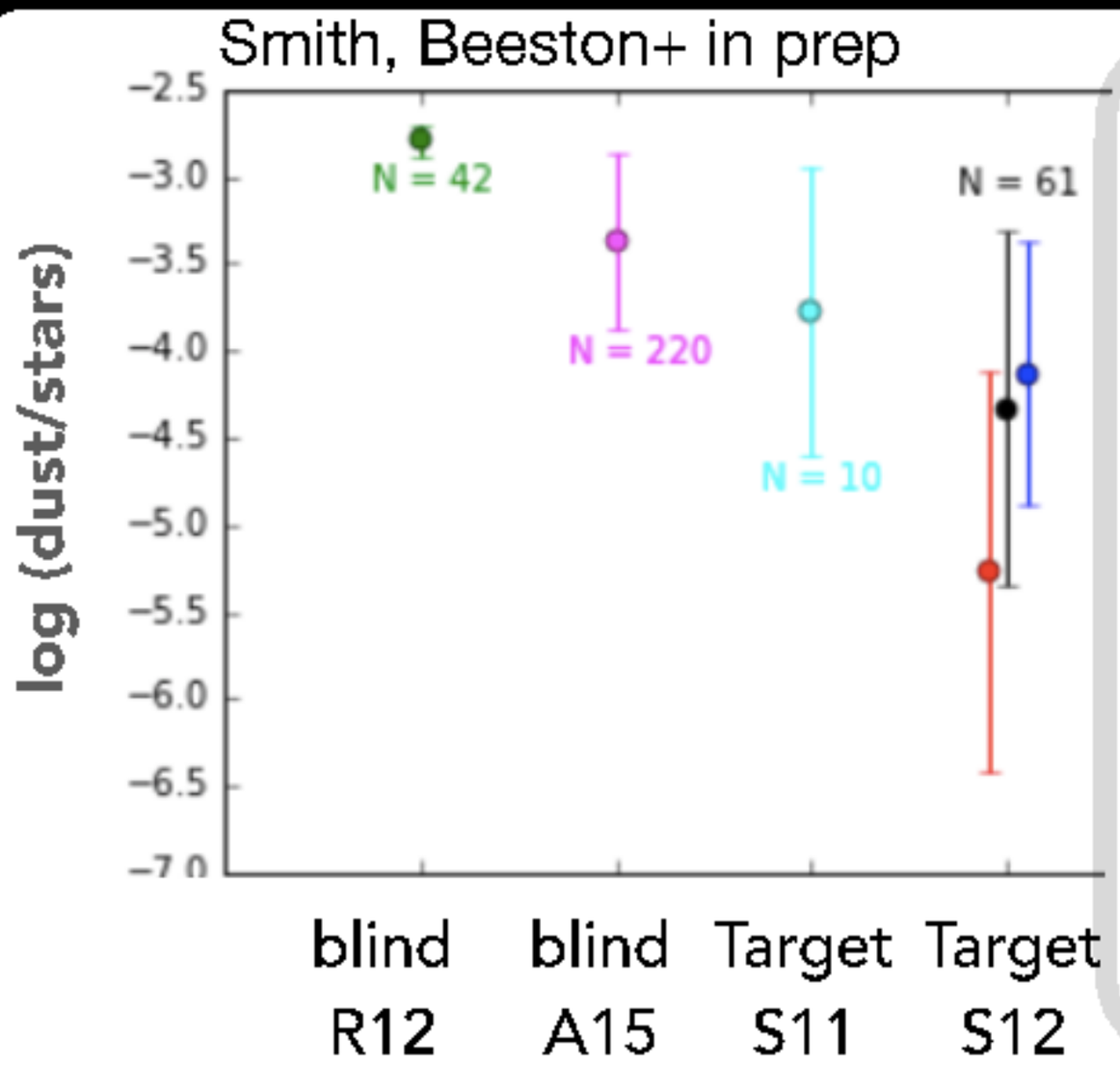

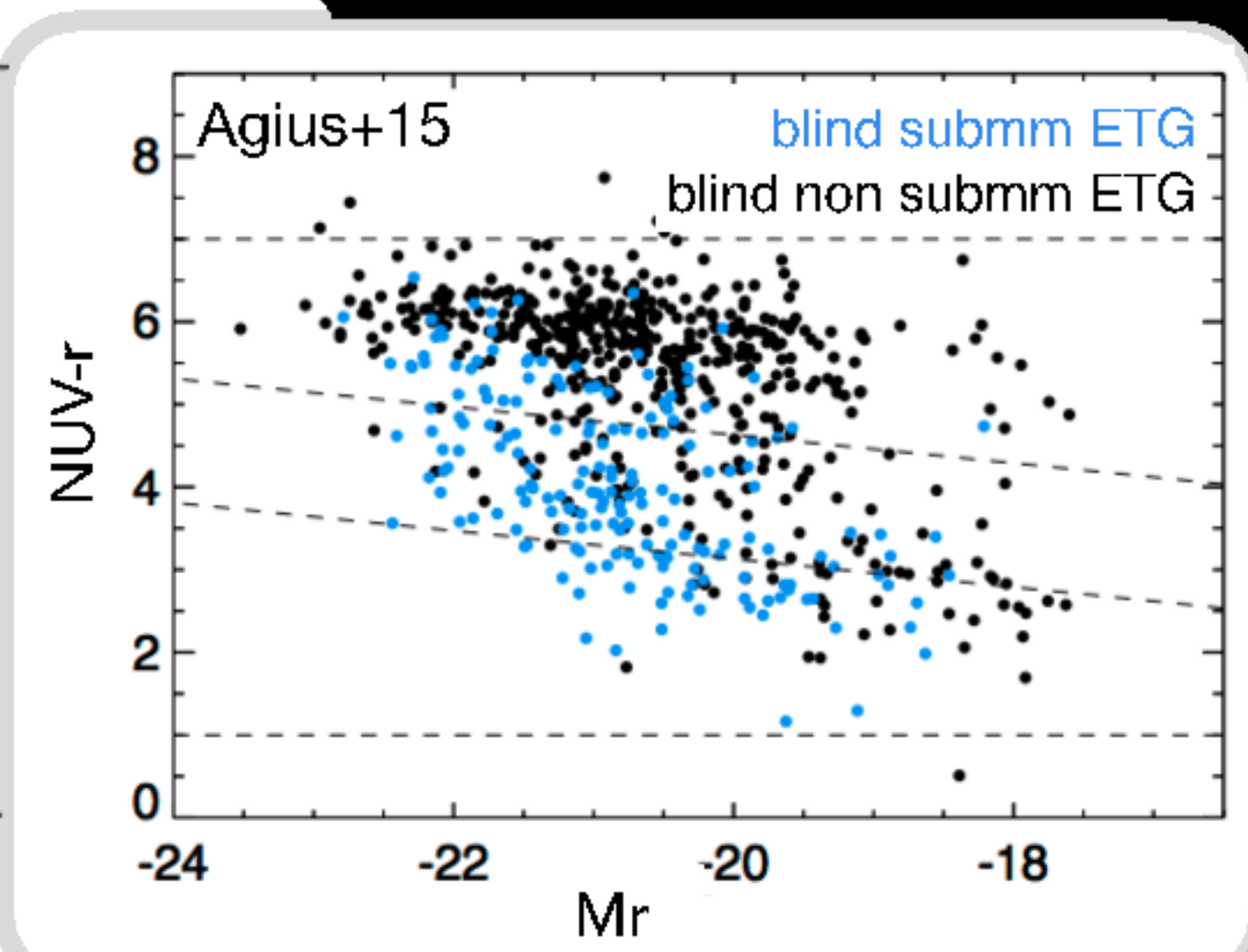

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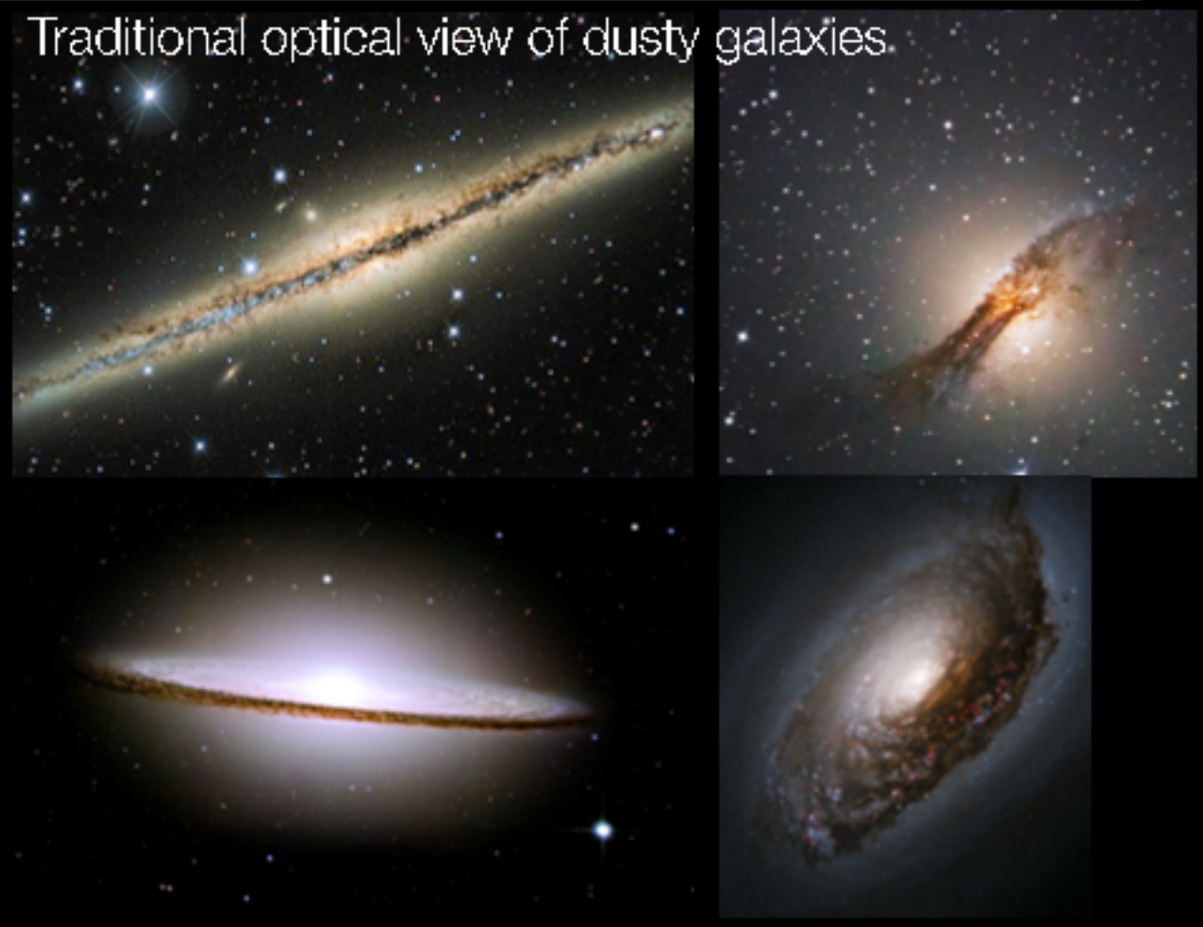

Clark C+ 2015, Bourne+ 2012, see also Santini+ 2012

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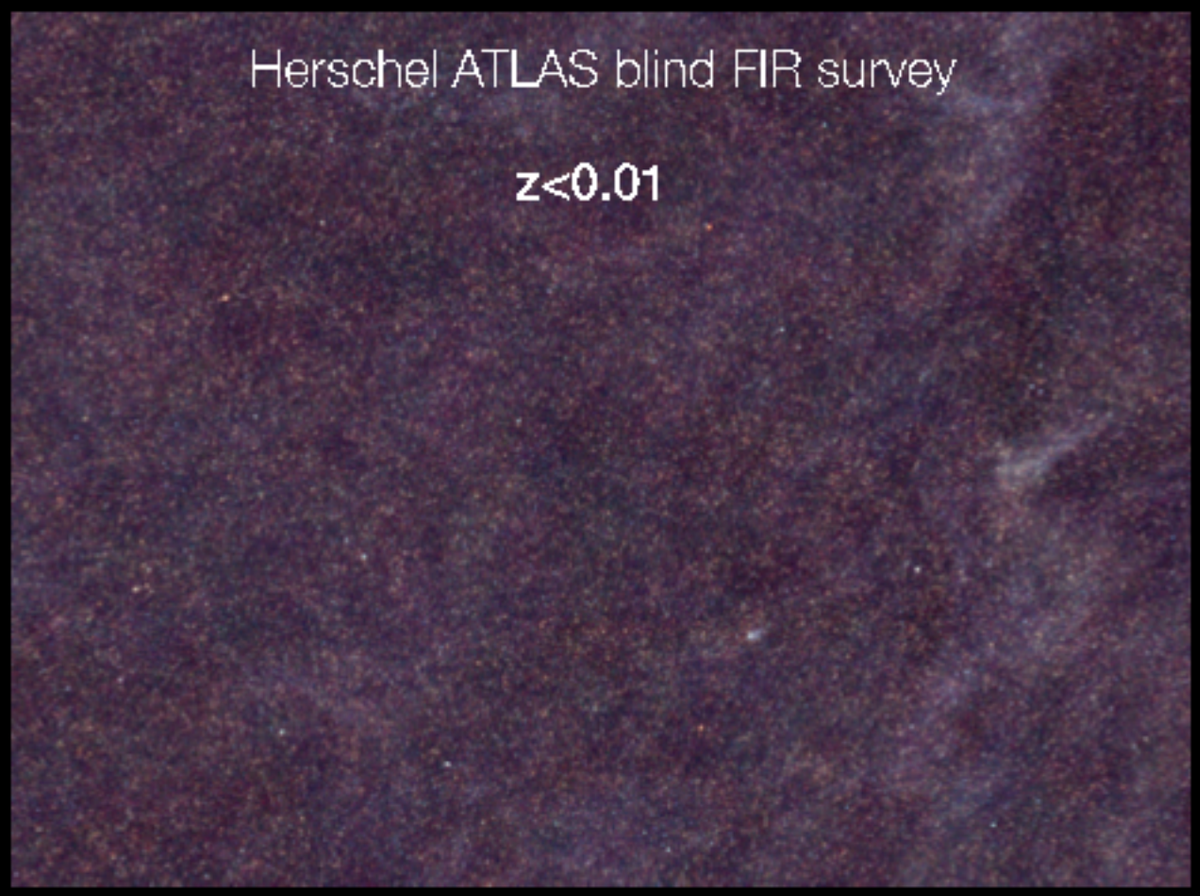

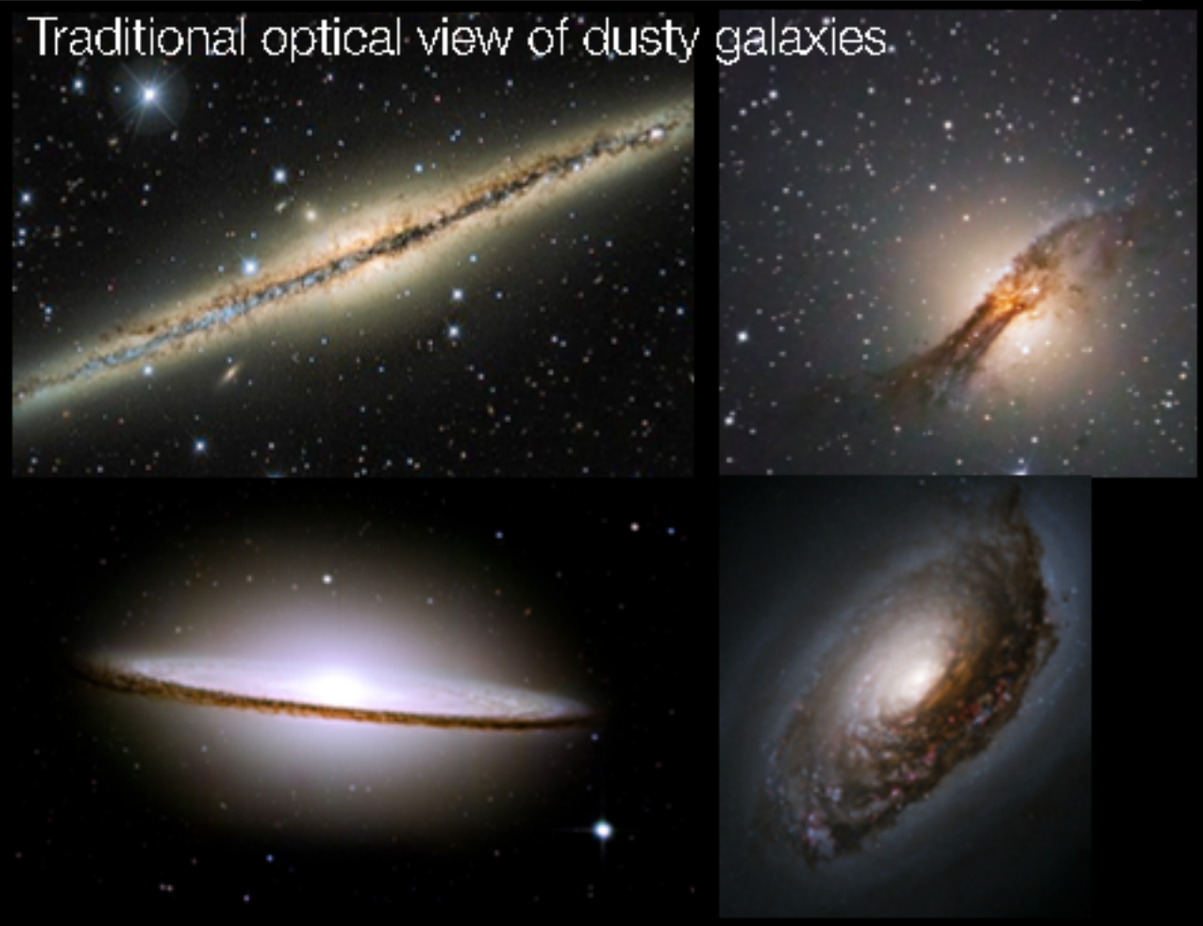

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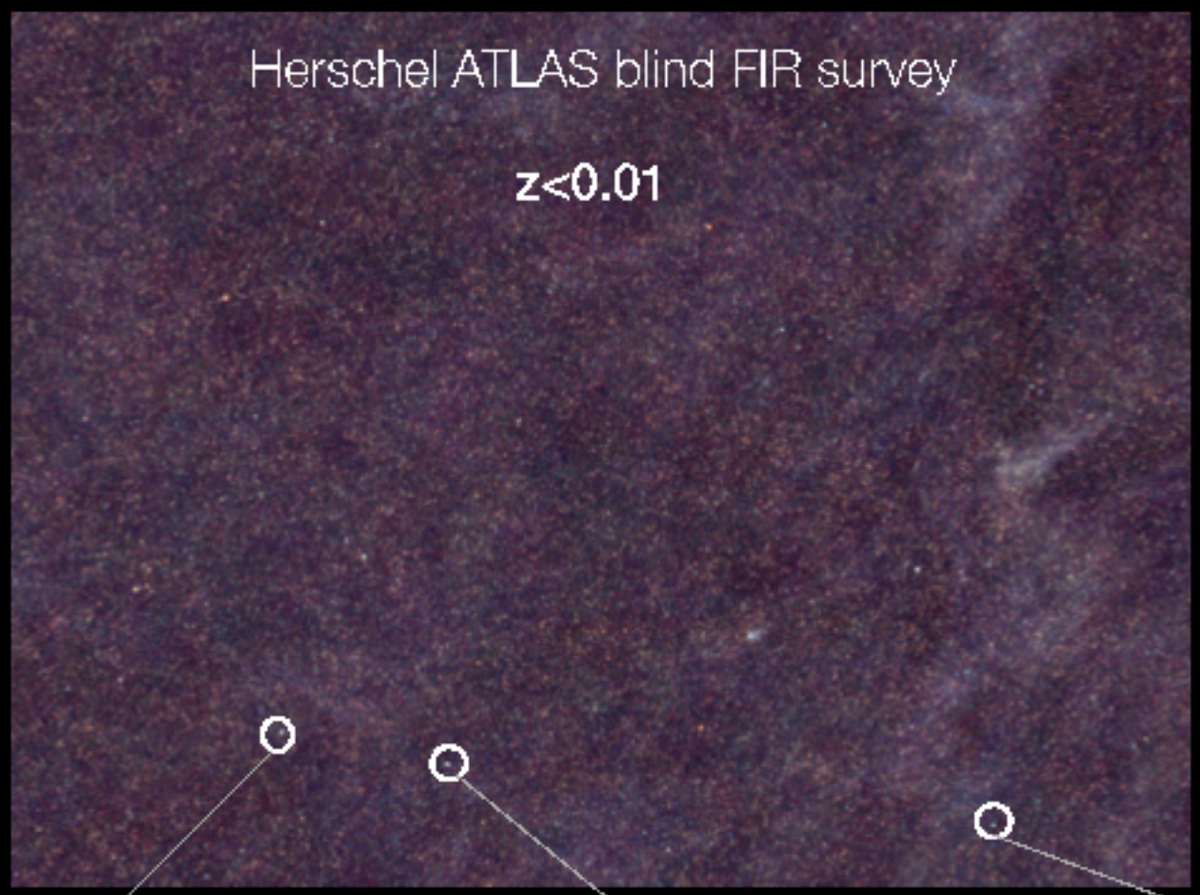
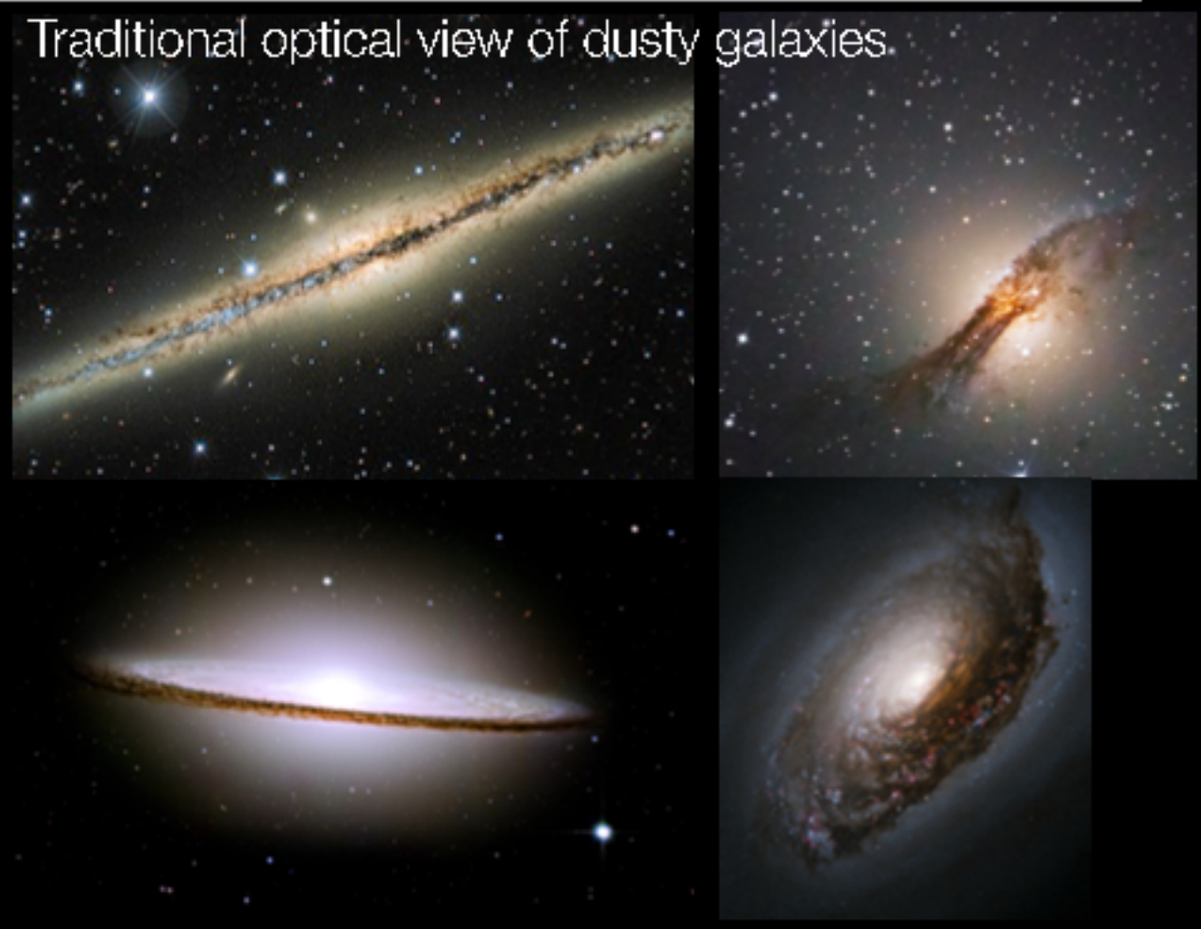
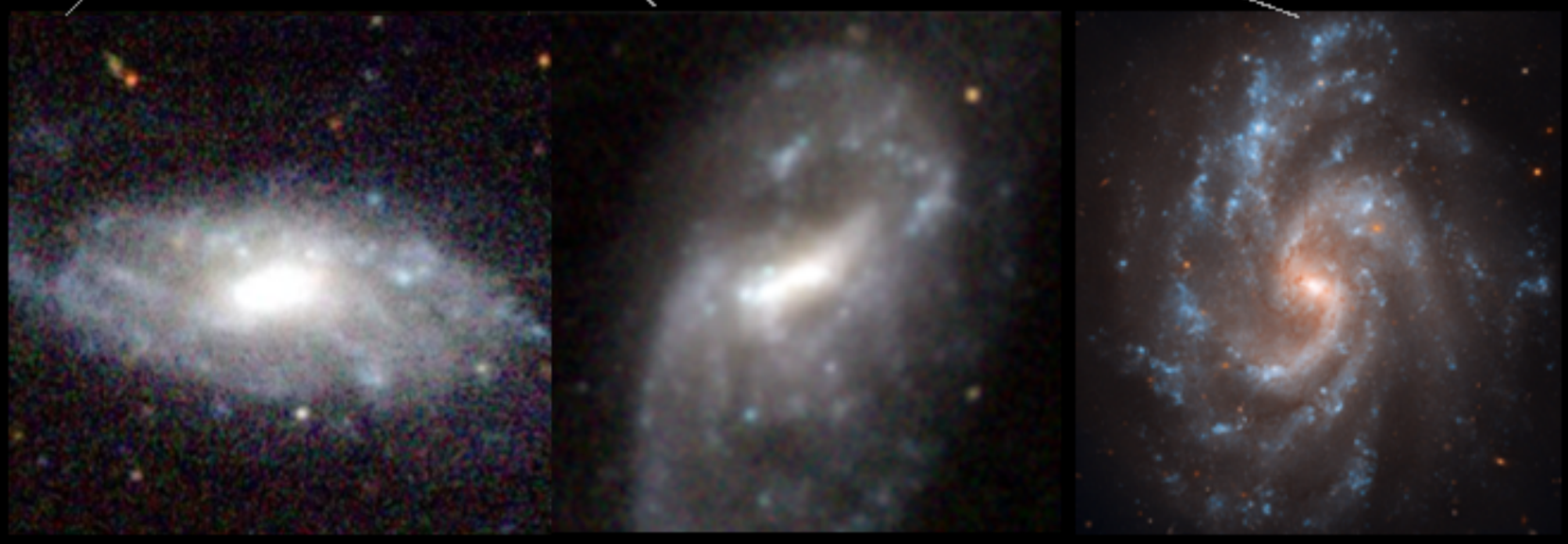


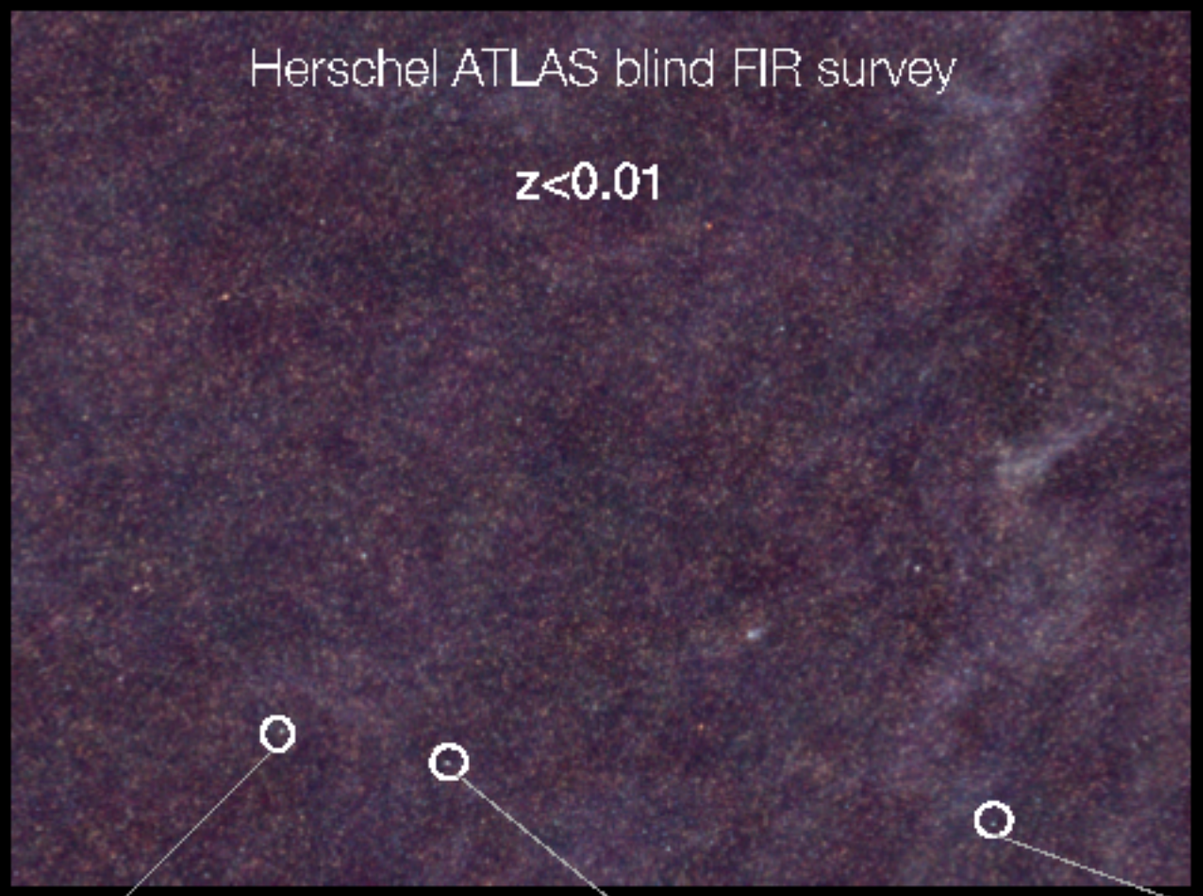


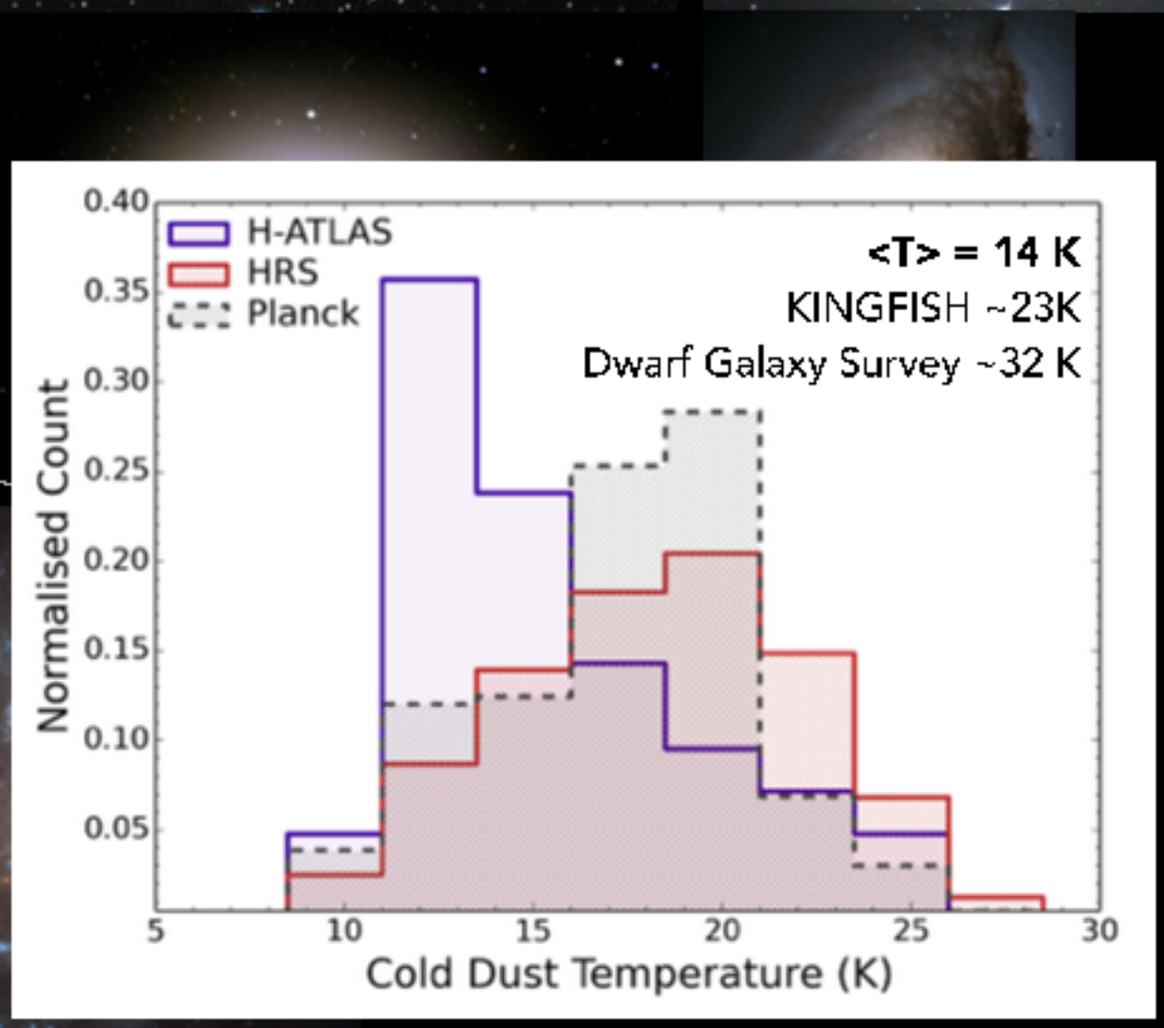


dust-rich galaxies in
nearby universe
actually look like this
smaller, and bluer

Clark C+ 2015, Bourne+ 2012, see also Santini+ 2012

WHAT DO THE DUSTIEST GALAXIES LOOK LIKE





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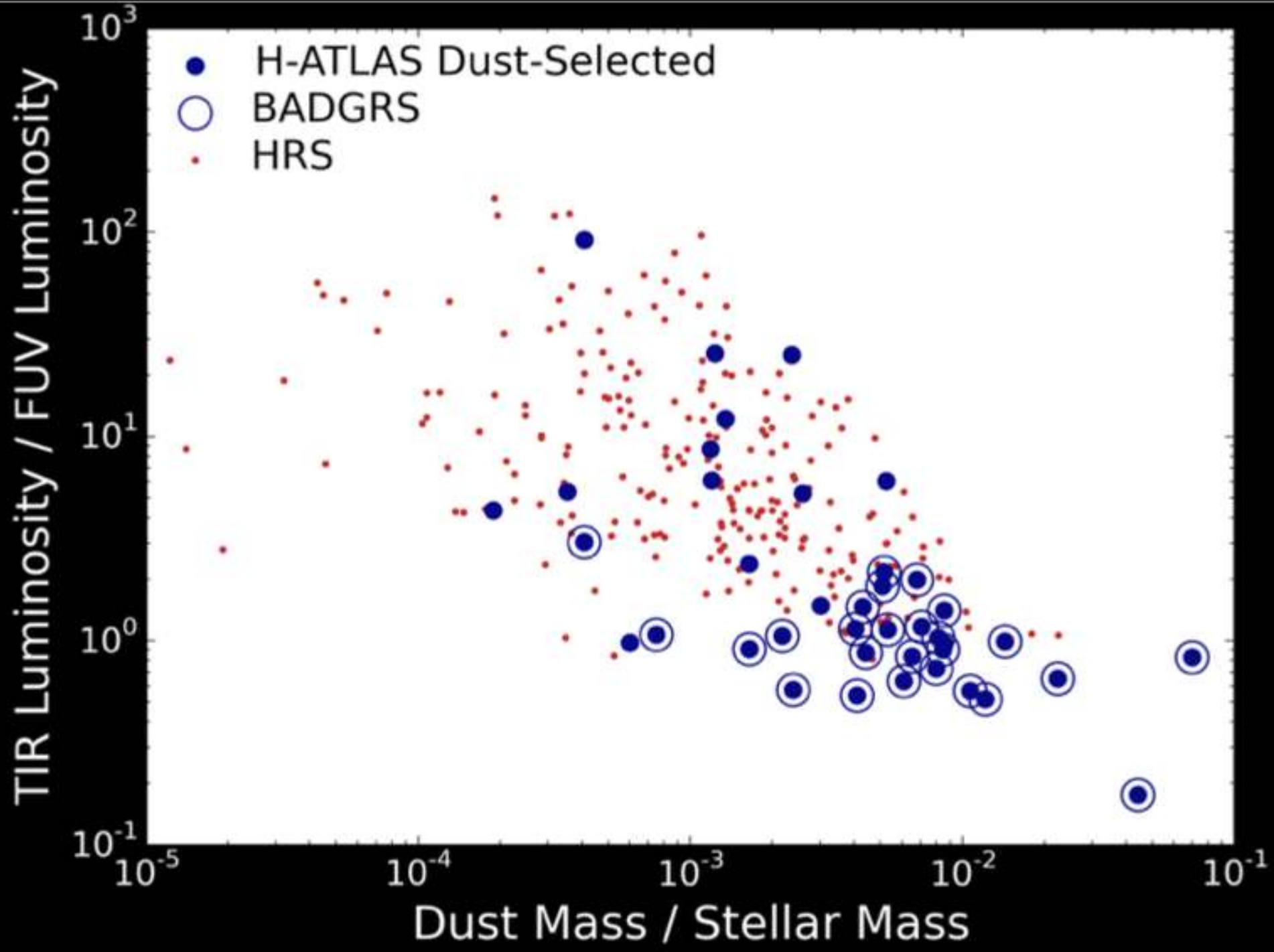
UNUSUAL PROPERTIES

Clark C, et al 2015

De Vis+ subm



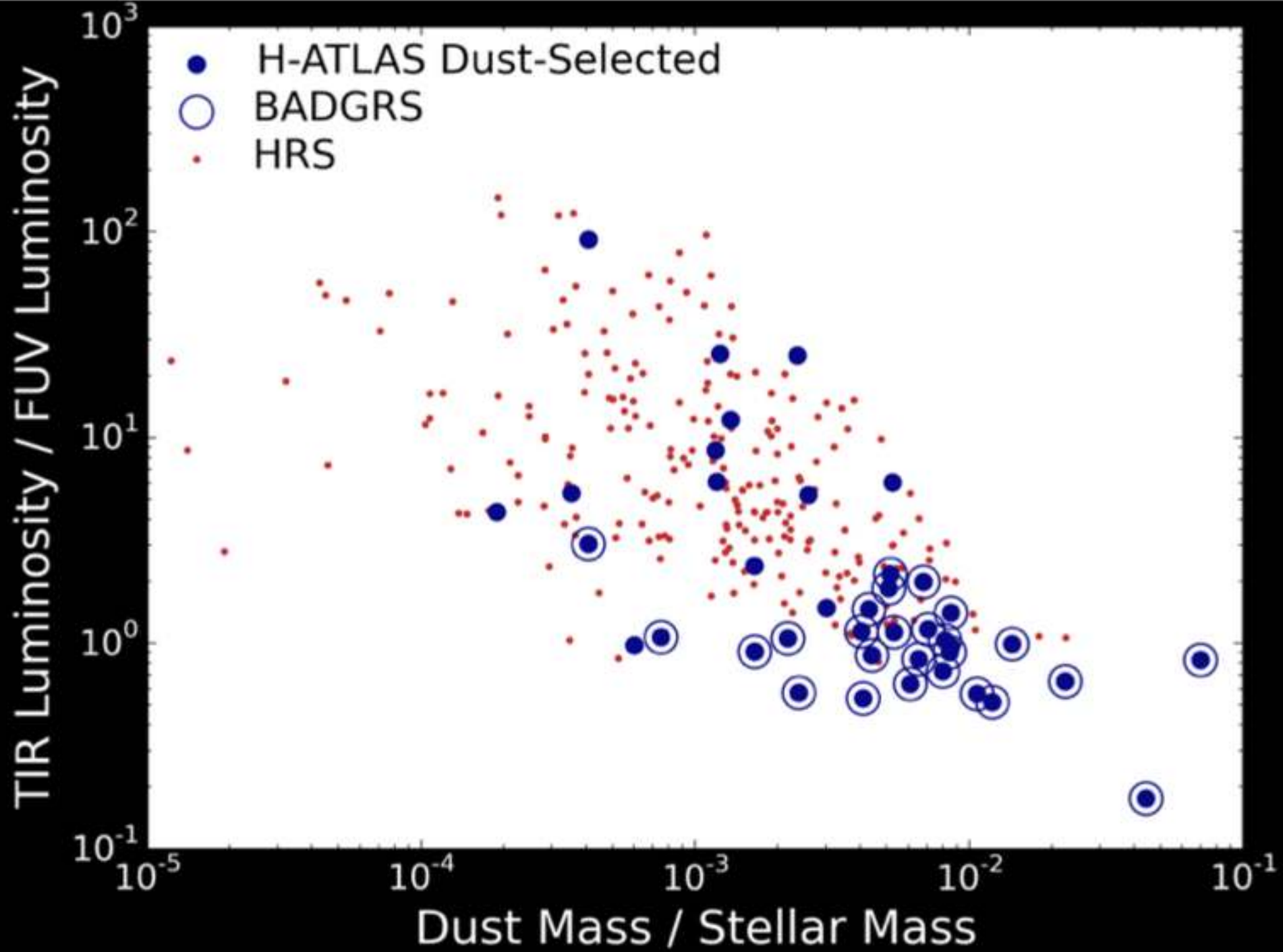
UNUSUAL PROPERTIES

Clark C, et al 2015

De Vis+ subm

More Extinction

Less Extinction



UNUSUAL PROPERTIES

Clark C, et al 2015

De Vis+ subm

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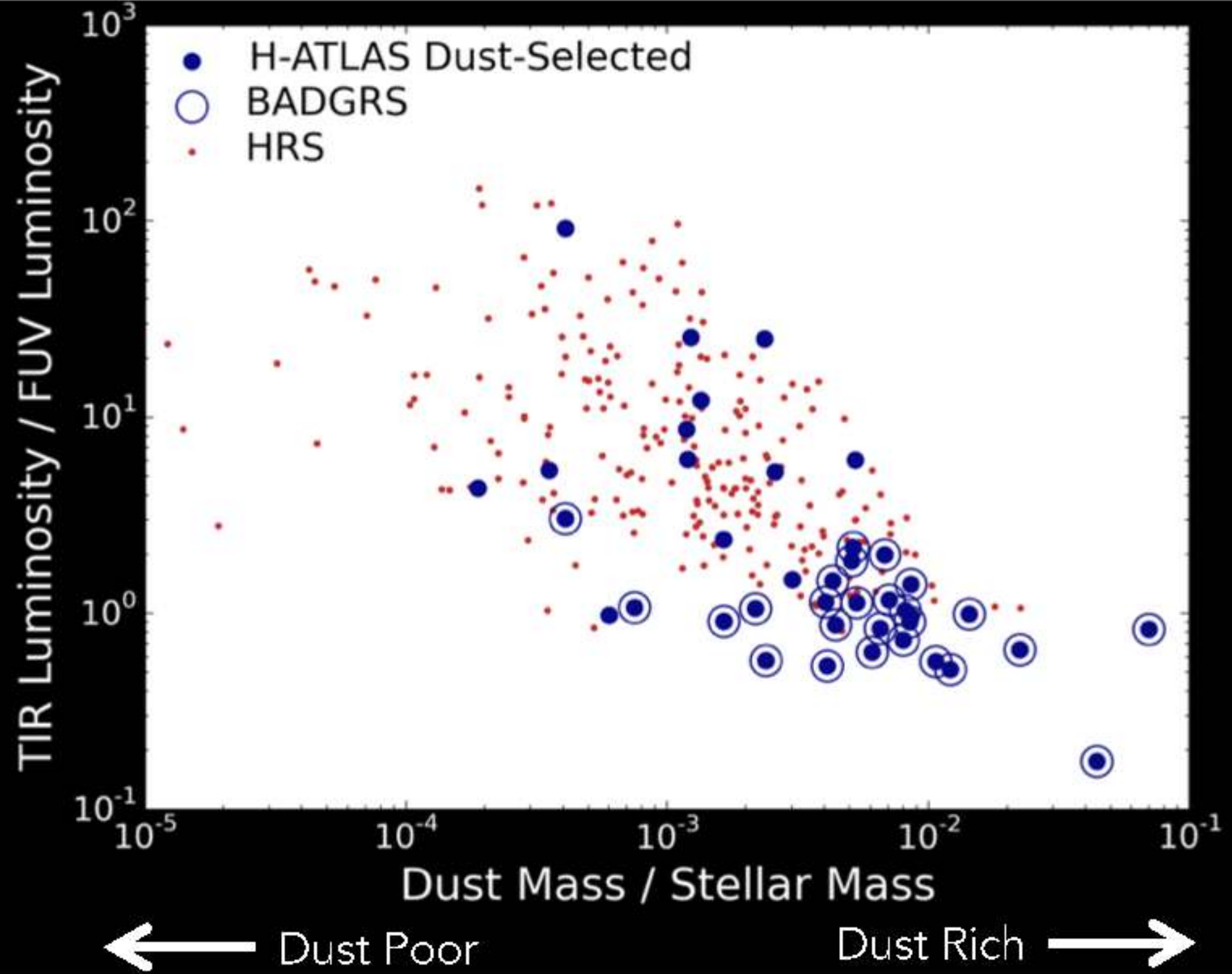
Less Extinction



Dust Poor

Dust Rich

UNUSUAL PROPERTIES

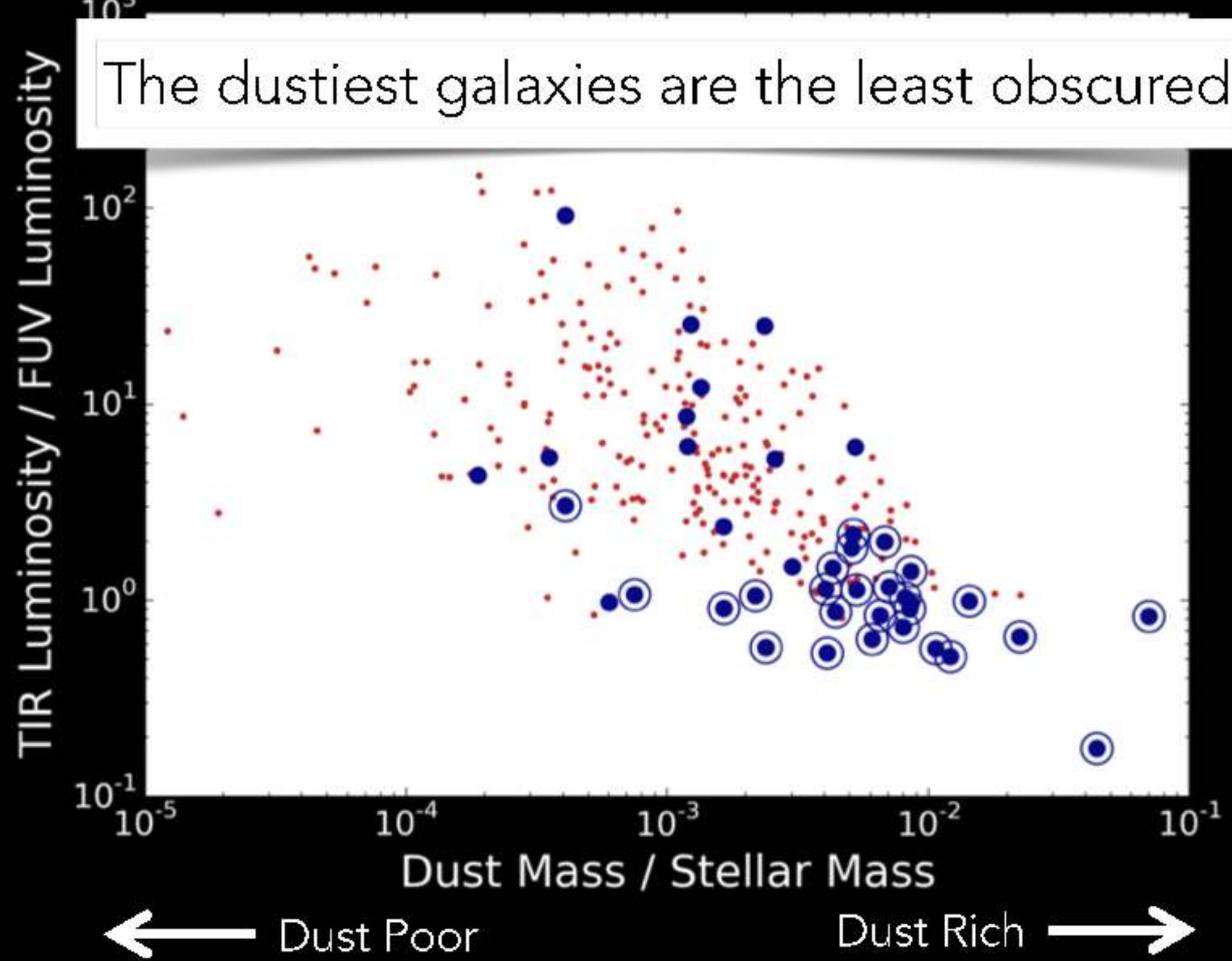
Clark C, et al 2015

De Vis+ subm

The dustiest galaxies are the least obscured

More Extinction

Less Extinction



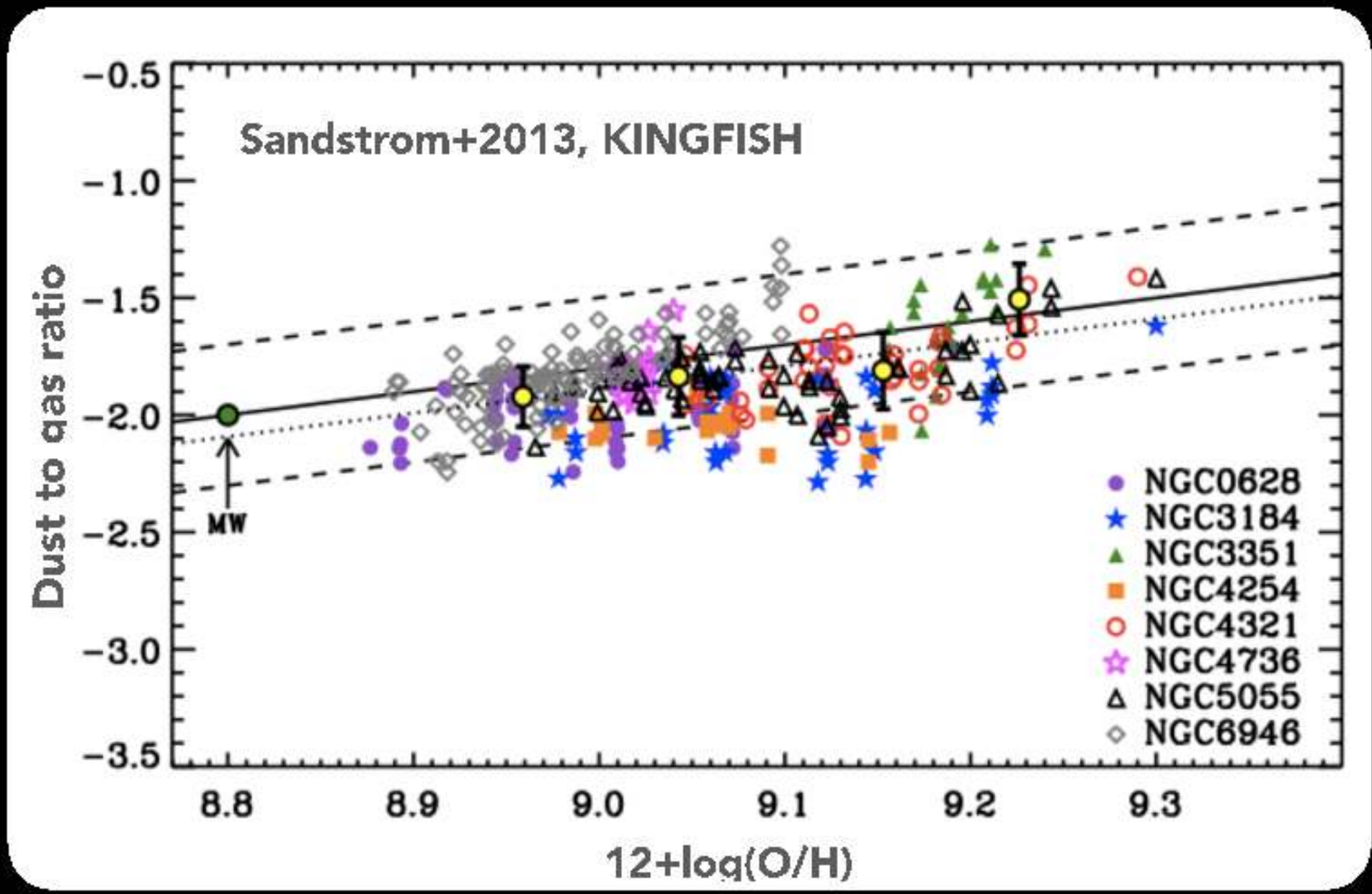
Dust Poor

Dust Rich

DUST, GAS AND METALLICITY

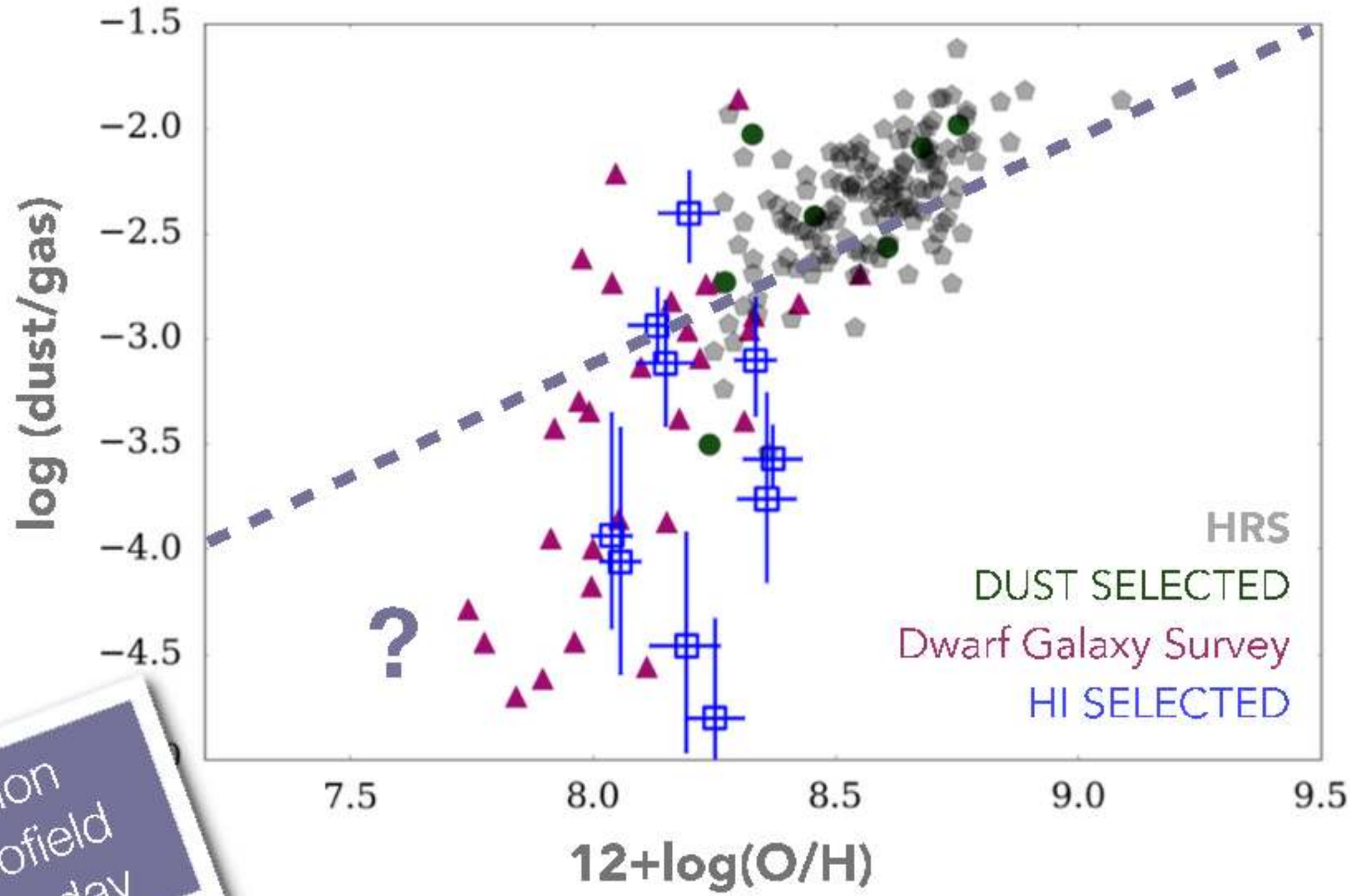
Dust potential tracer for total gas

Eales+2012,
Genzel+2010
Magnelli+2012
Bethermin+2014
Scoville+ 2014



Lisenfeld+Ferrara 1998, Hirashita 2002, Galametz+ 2011, Roman-Duval 2014

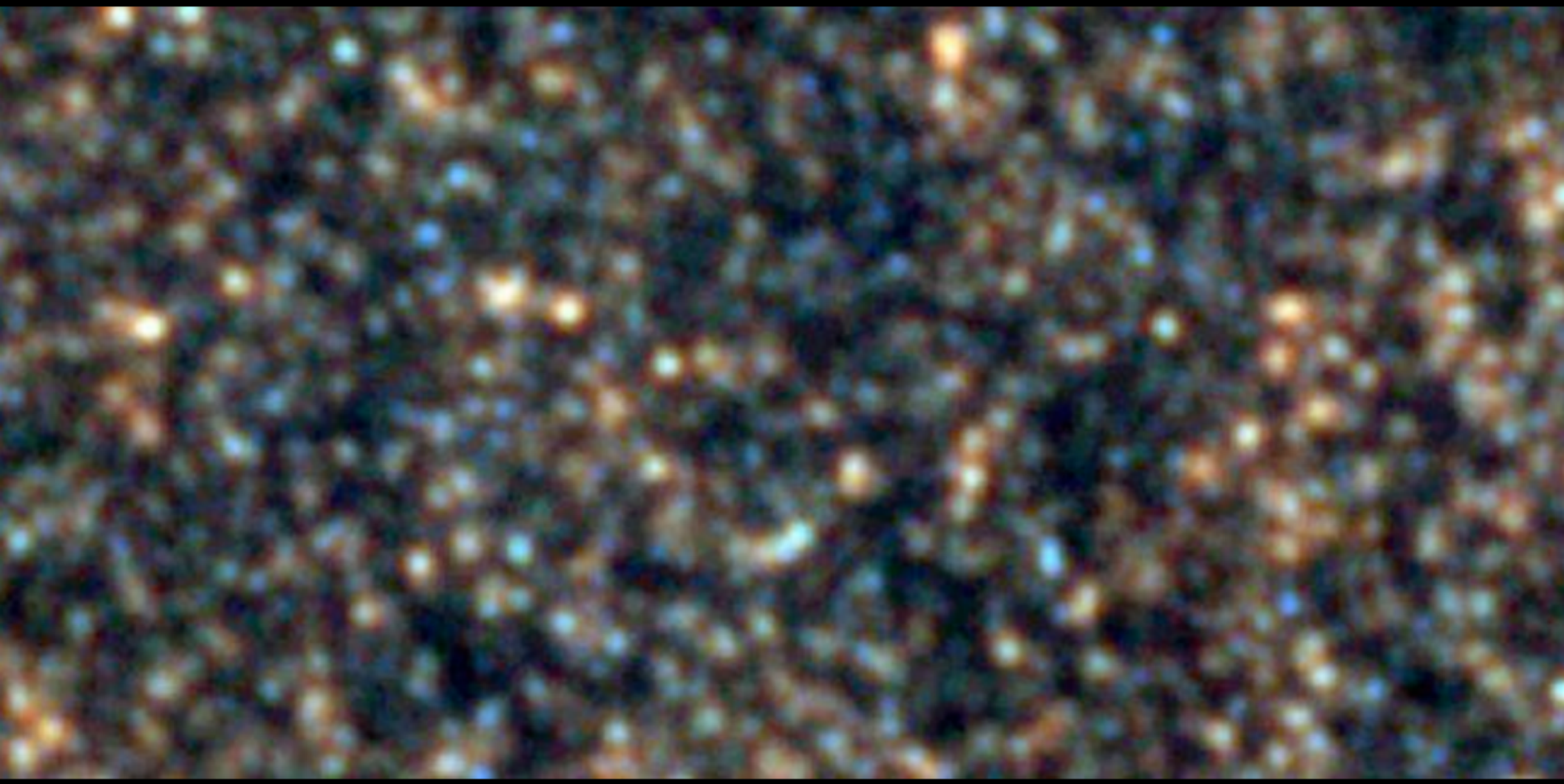
DUST, GAS AND METALLICITY



Simon Schofield Thursday

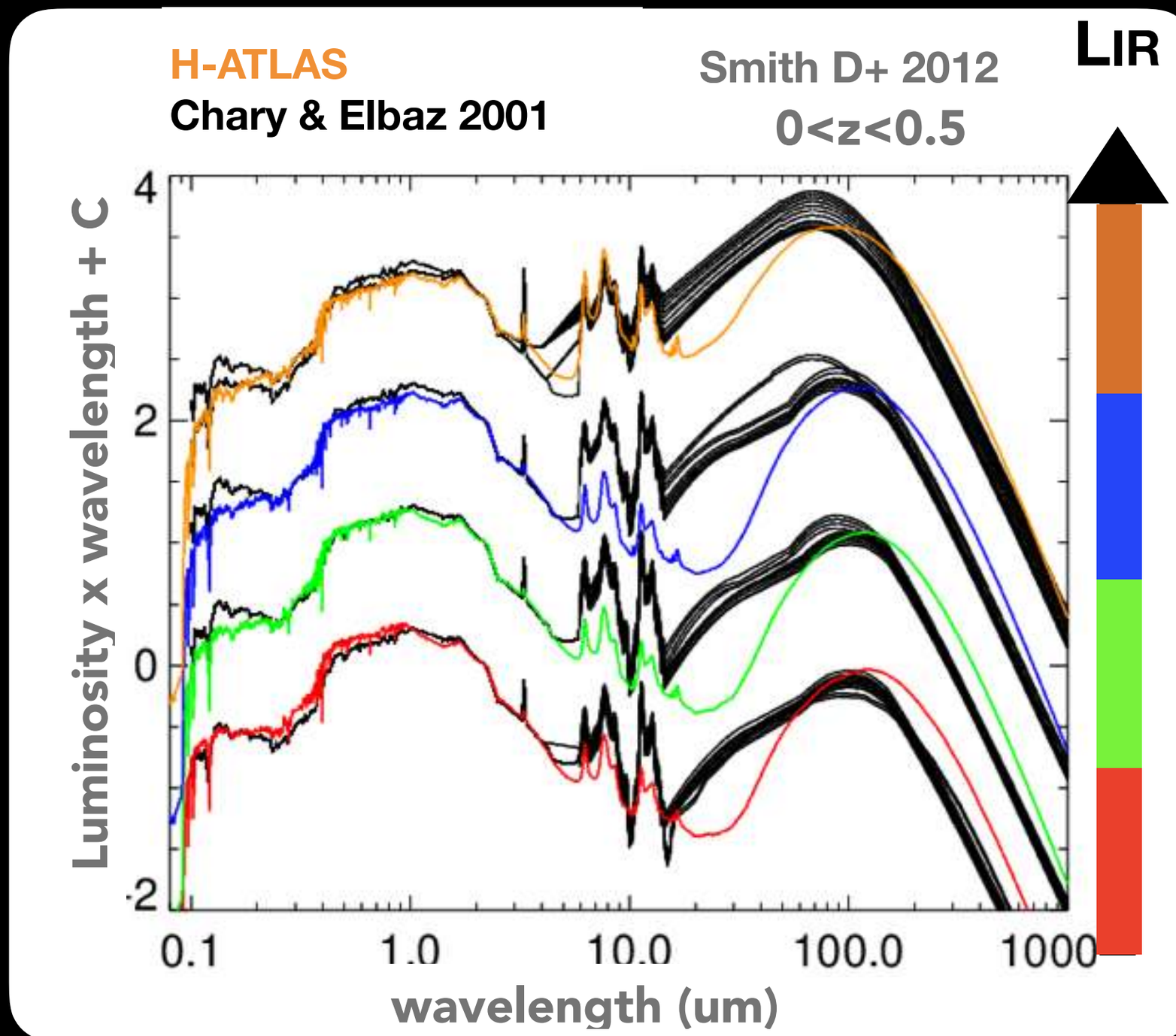
De Vis,Schofield+ in prep, Zhukovska 2013, Remy-Ruyer+ 2013, 2014

BLOBOLOGY (OR REDSHIFTS > 0.01)



Credit: ESA/HERSCHEL/HerMES

A COLDER DUST SED THAN BEFORE



see also Rowan-Robinson+ 2012, Symeonidis+ 2013, Wang+ 2014, Magdis+2012, Gruppioni +2013, Berta+2013

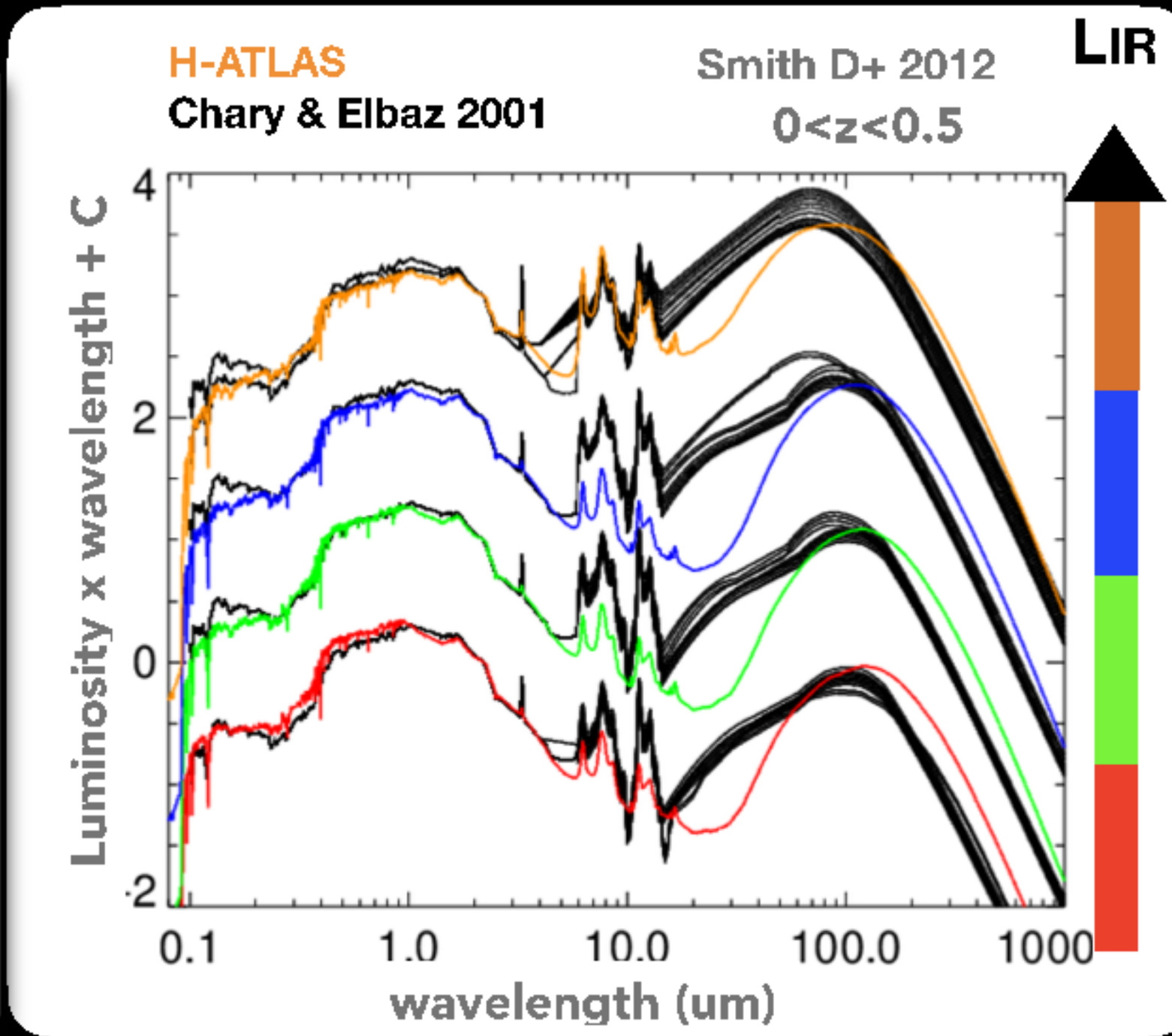
A COLDER DUST SED THAN BEFORE

z < 0.5 Herschel galaxies:

Normal galaxies : SFRs ~ few Msun/yr

Dust ~ 5x IRAS/ galaxies

Fleuren+ 2012, Smith D+ 2013, Rowlands+ 2014a



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RAPID EVOLUTION IN DUST CONTENT IN RECENT COSMIC HISTORY

Dunne, Gomez+ MNRAS, 2011
Beeston, Maddox, Gomez+ in prep
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Symeonidis+ 2013

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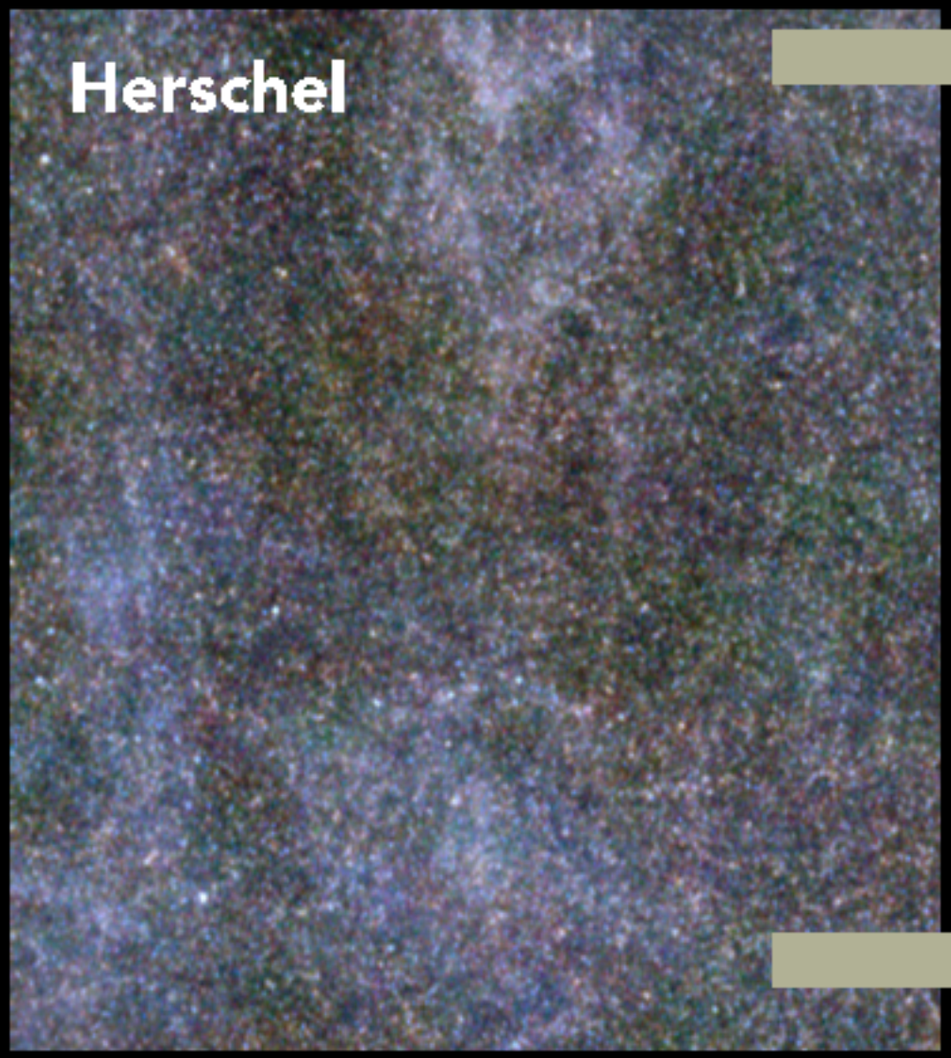

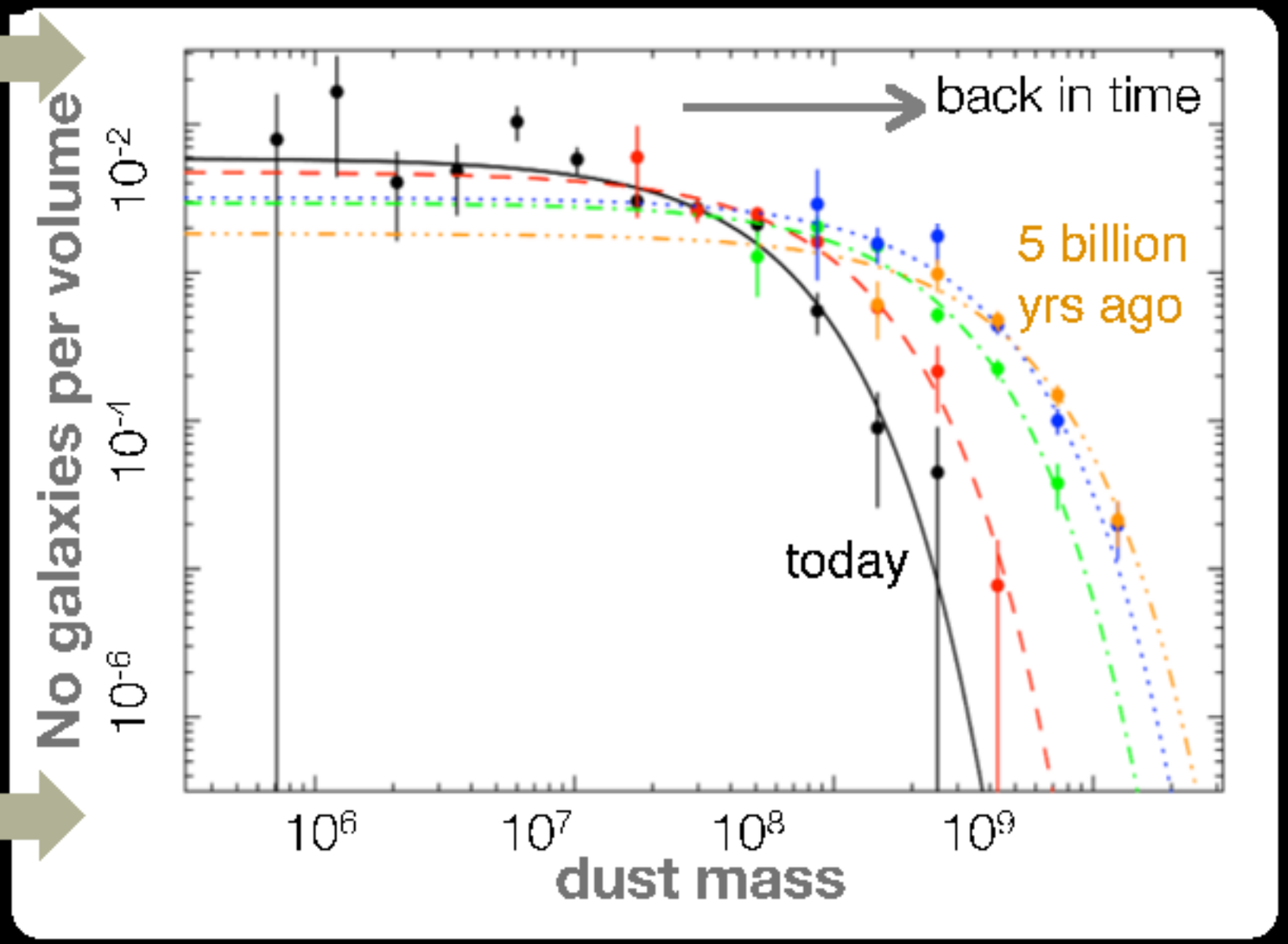

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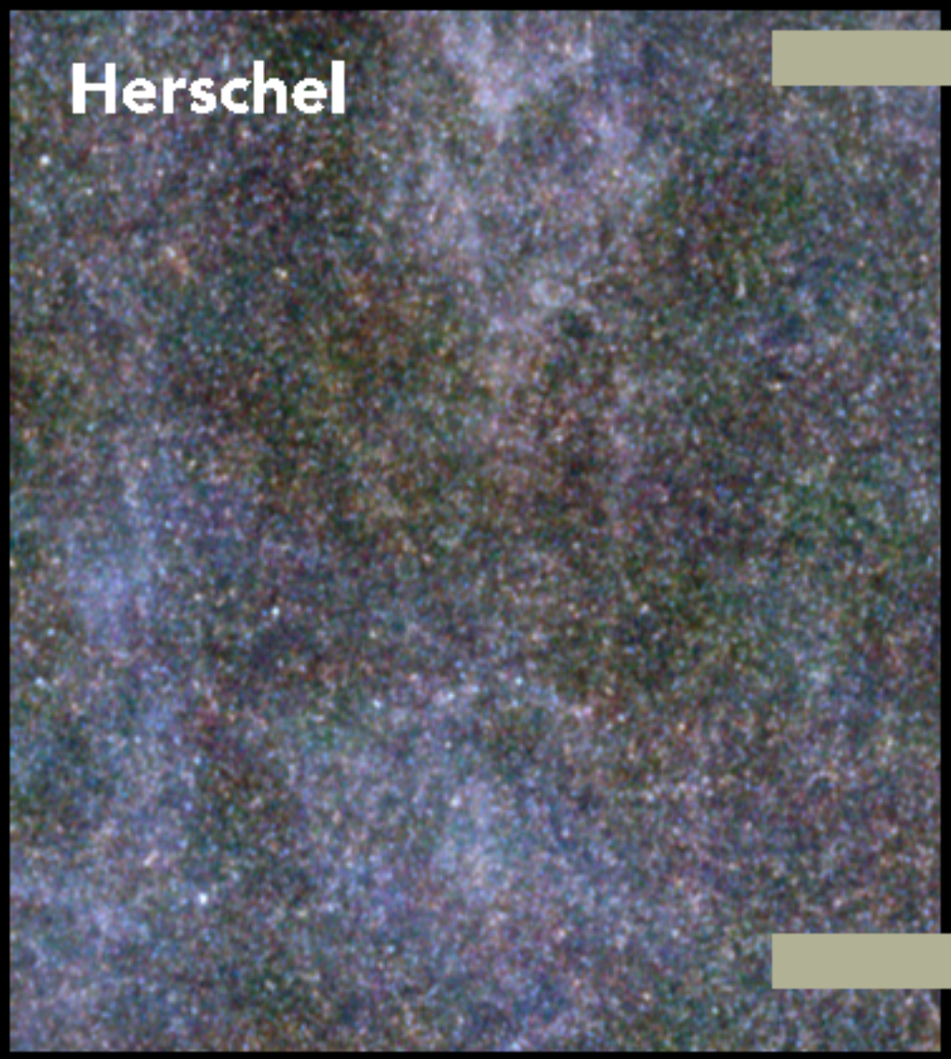
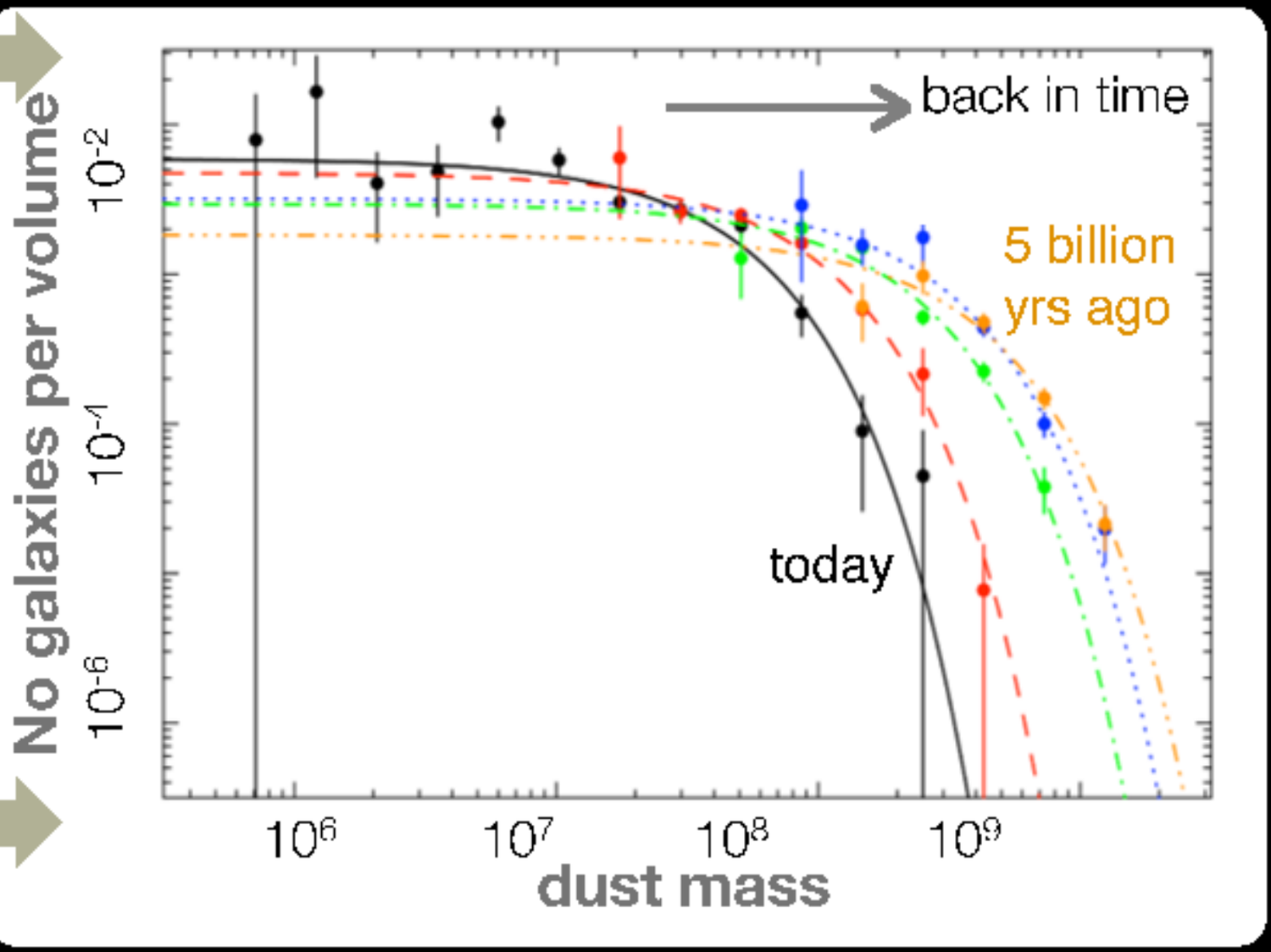
OR... THE UNIVERSE IS GRADUALLY GETTING CLEANER





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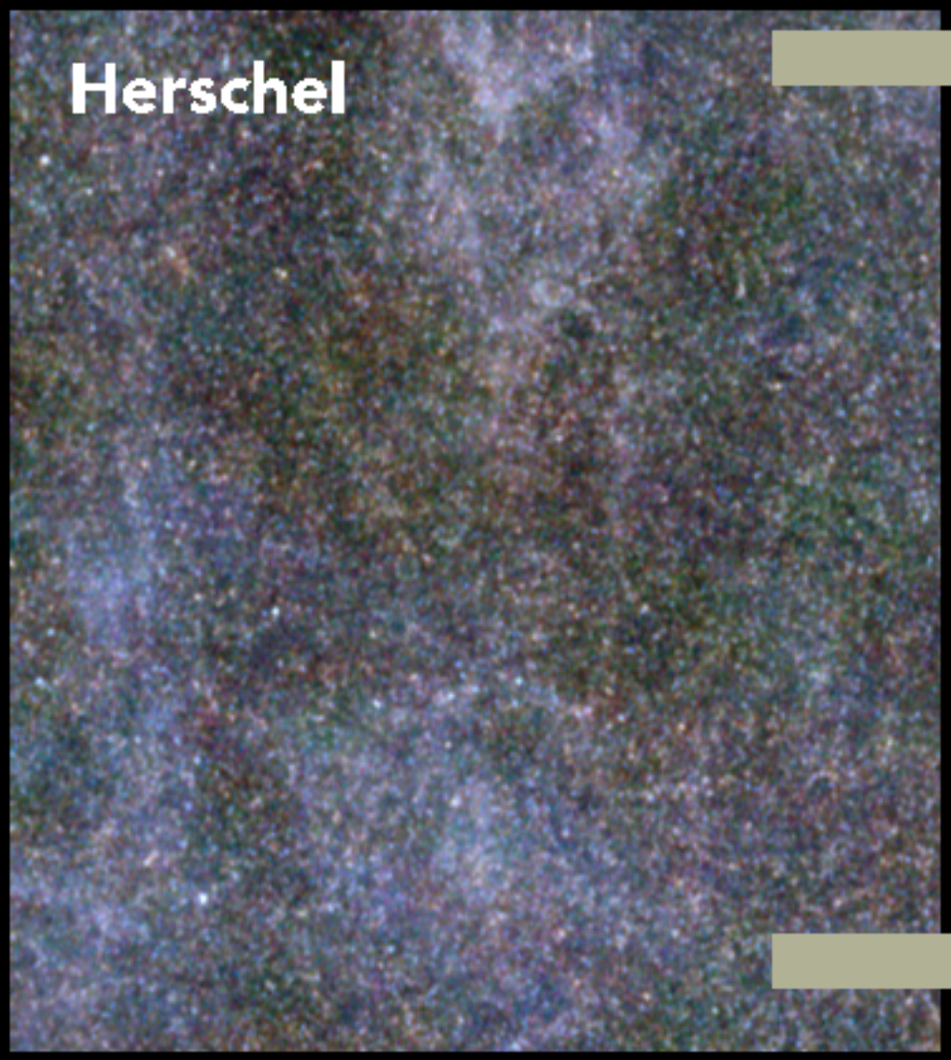

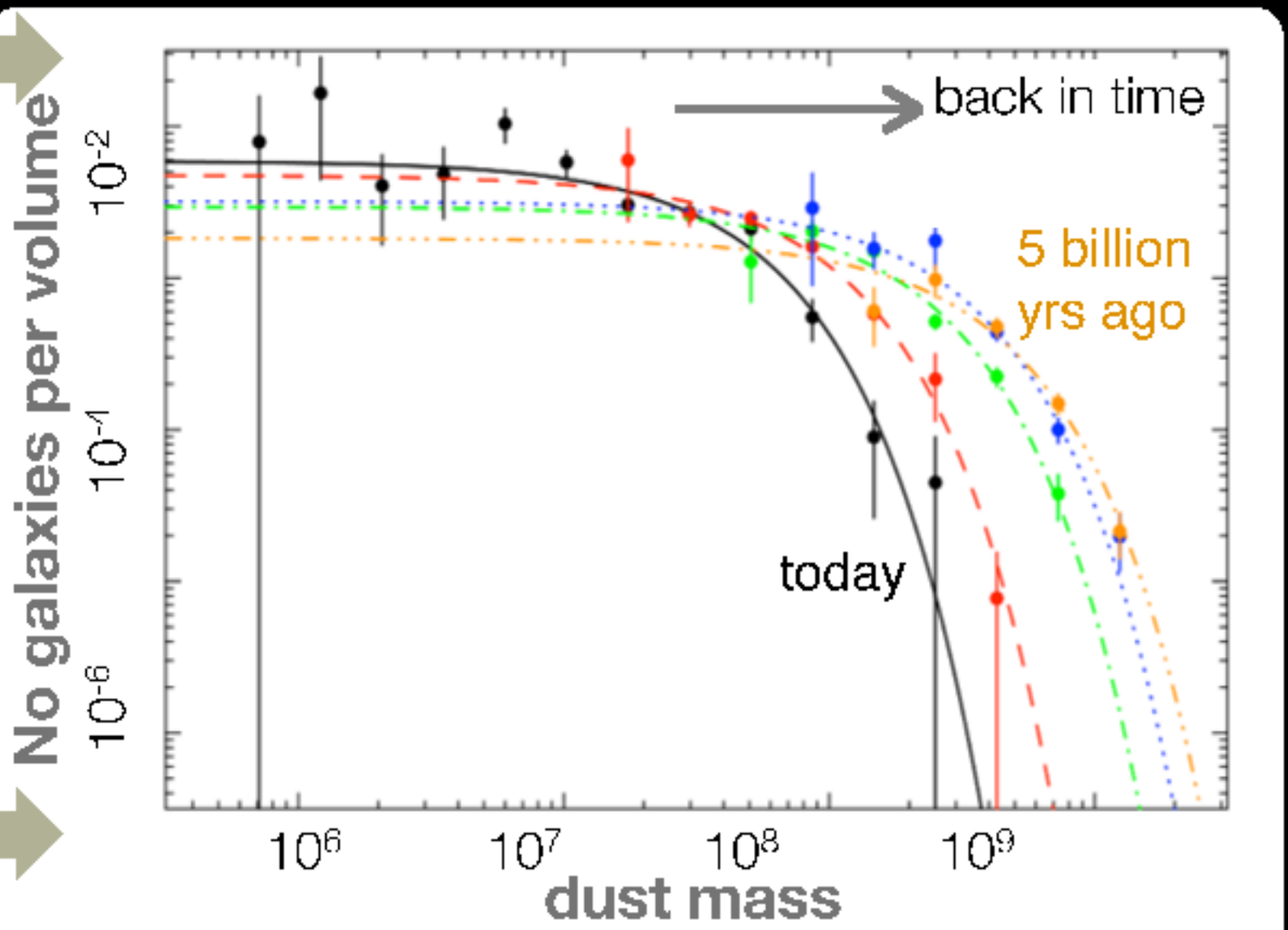

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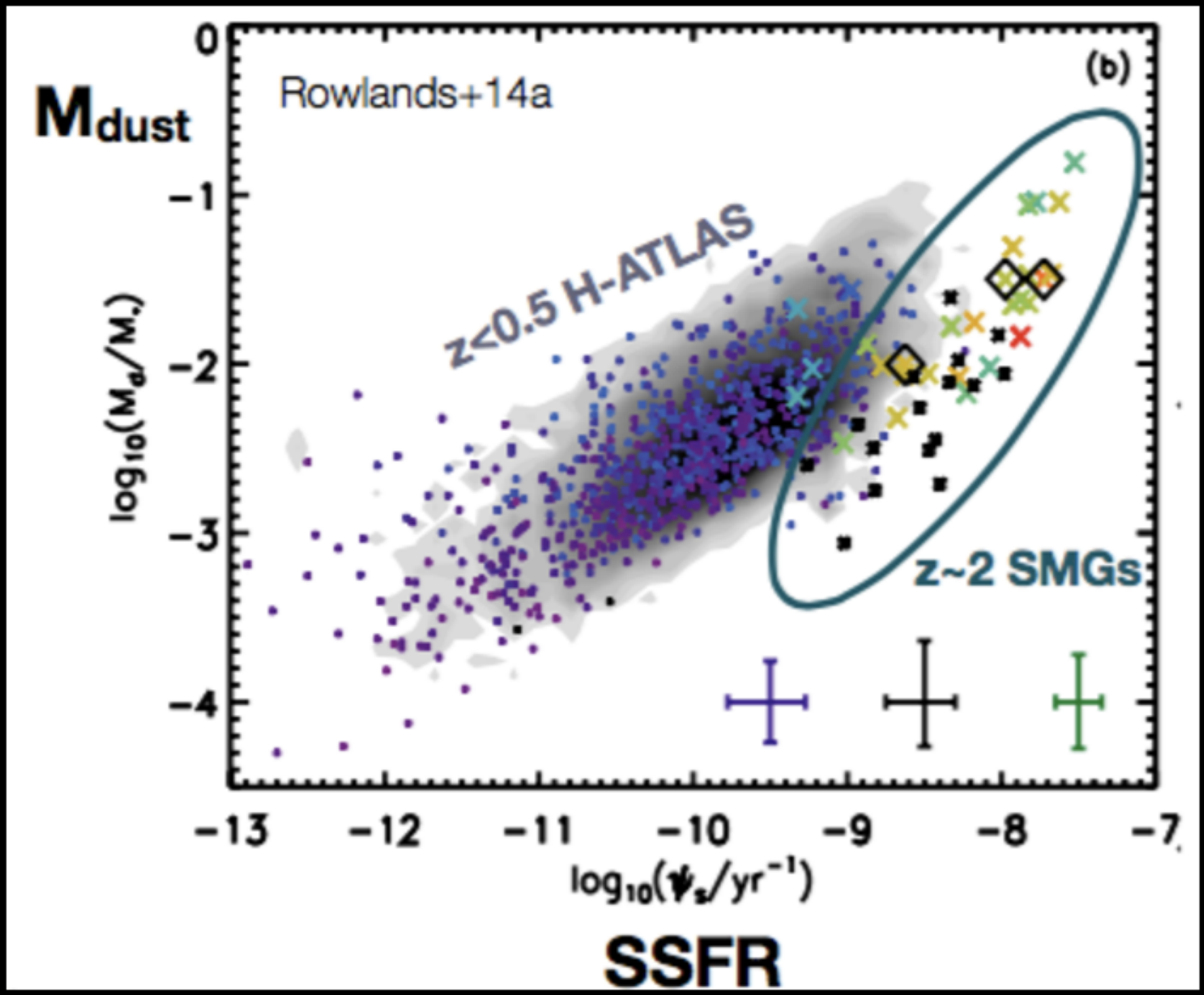
why does the dust content evolve so quickly?

LOCAL VS HIGH REDSHIFT DUSTY GALAXIES



Symeonidis+ 2013, Lee+2013, Greve+2004, Chapman+ 2005, Swinbank+2006, 2013, Hainline +2009, Lapi+ 2011, Wardlow+ 2011, Magnelli+2012, Michalowski+2010

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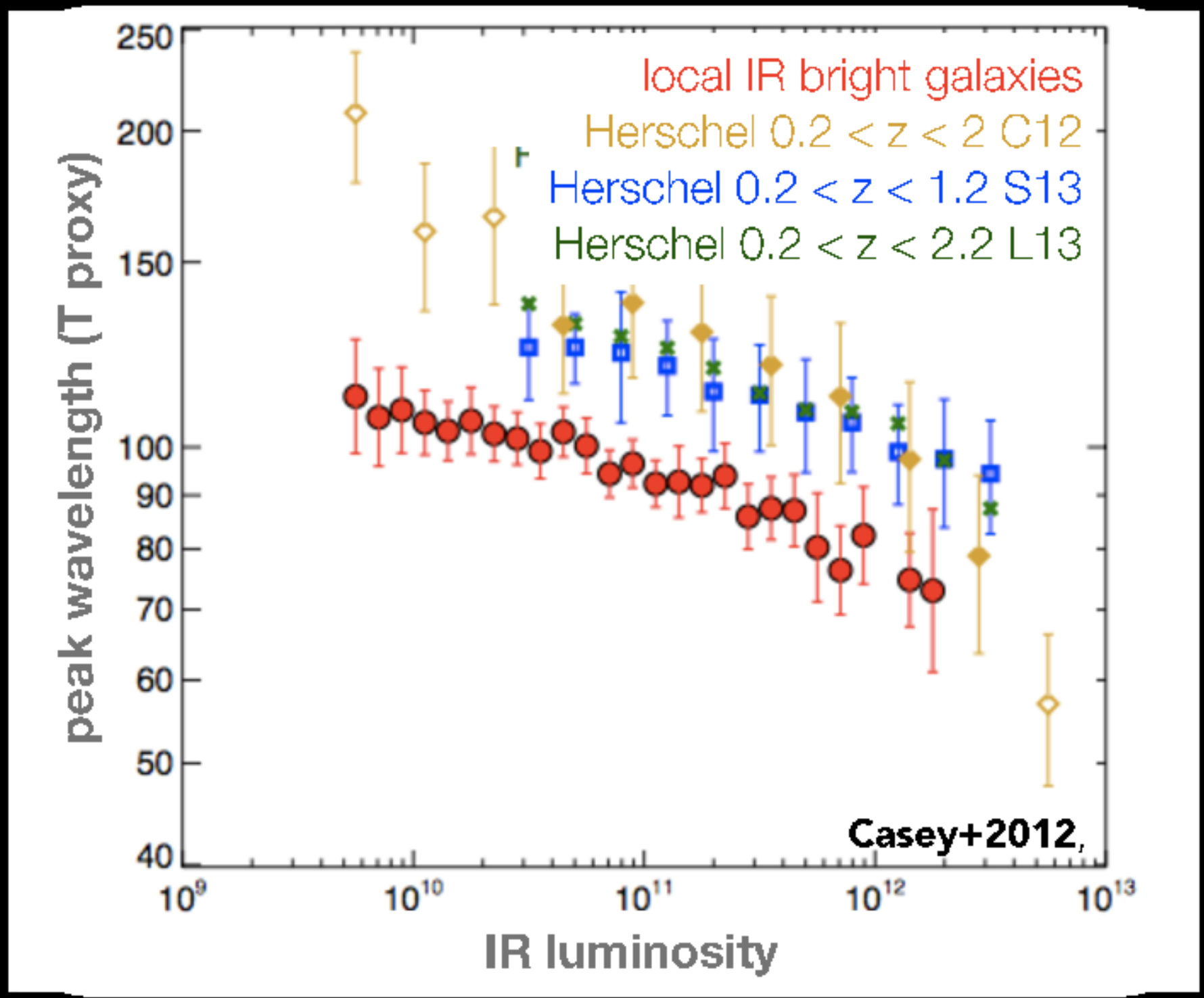

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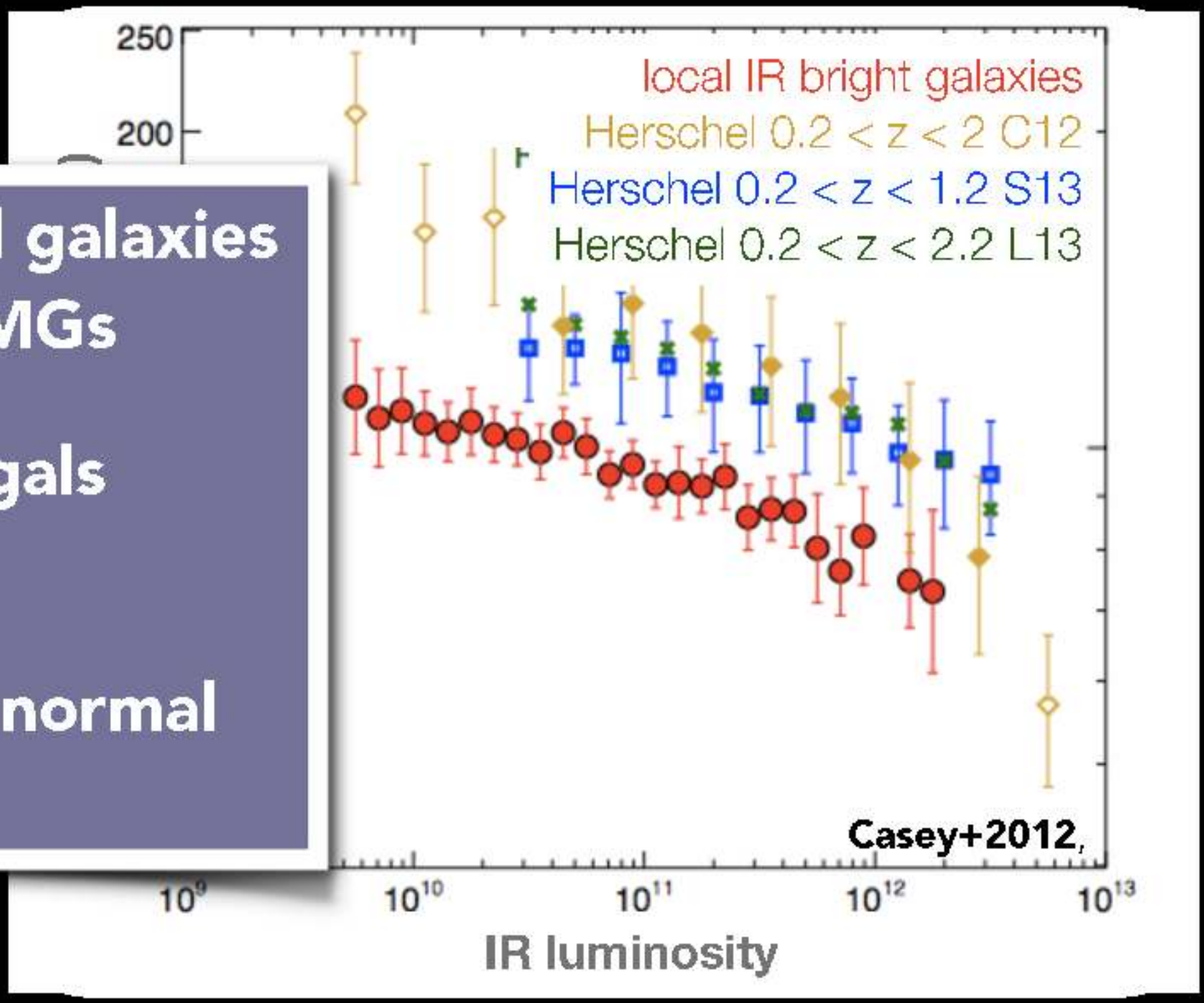
LOCAL VS HIGH REDSHIFT DUSTY GALAXIES

Local Herschel galaxies different to SMGs

z~2 Herschel gals cooler

no longer see normal sources z>1



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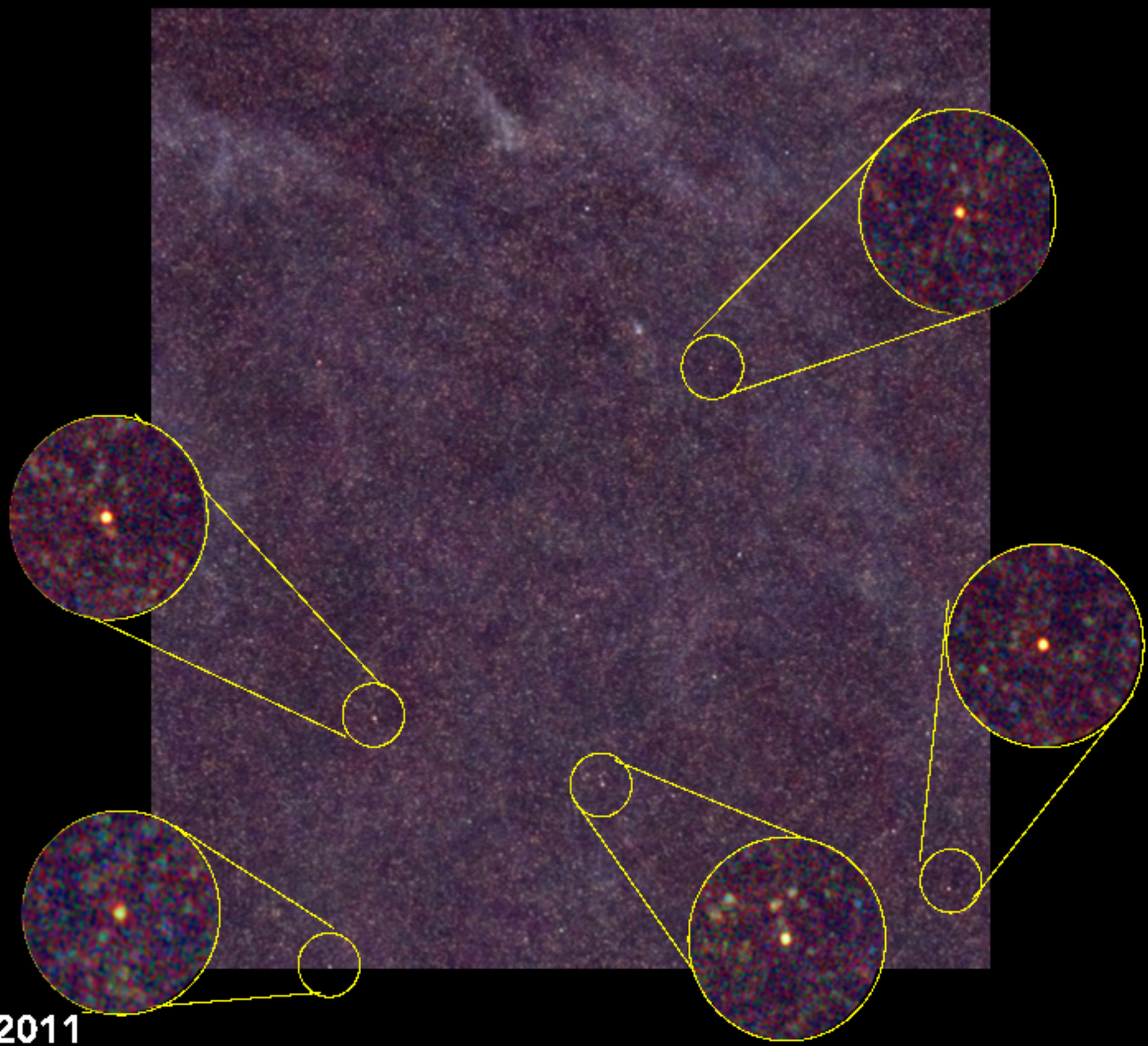
HERSCHEL EFFICIENT AT FINDING LENSES



Negrello+ 2011

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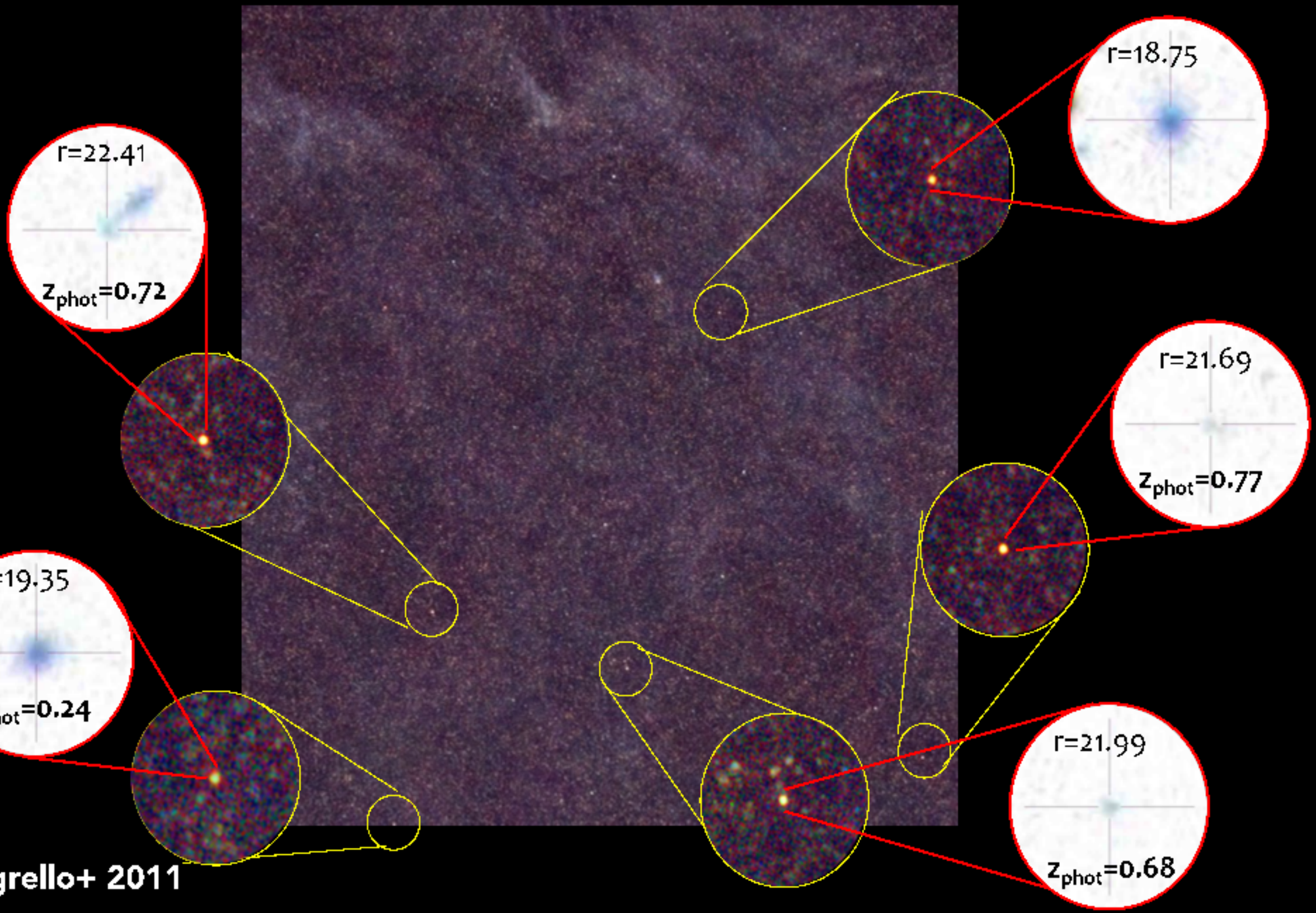
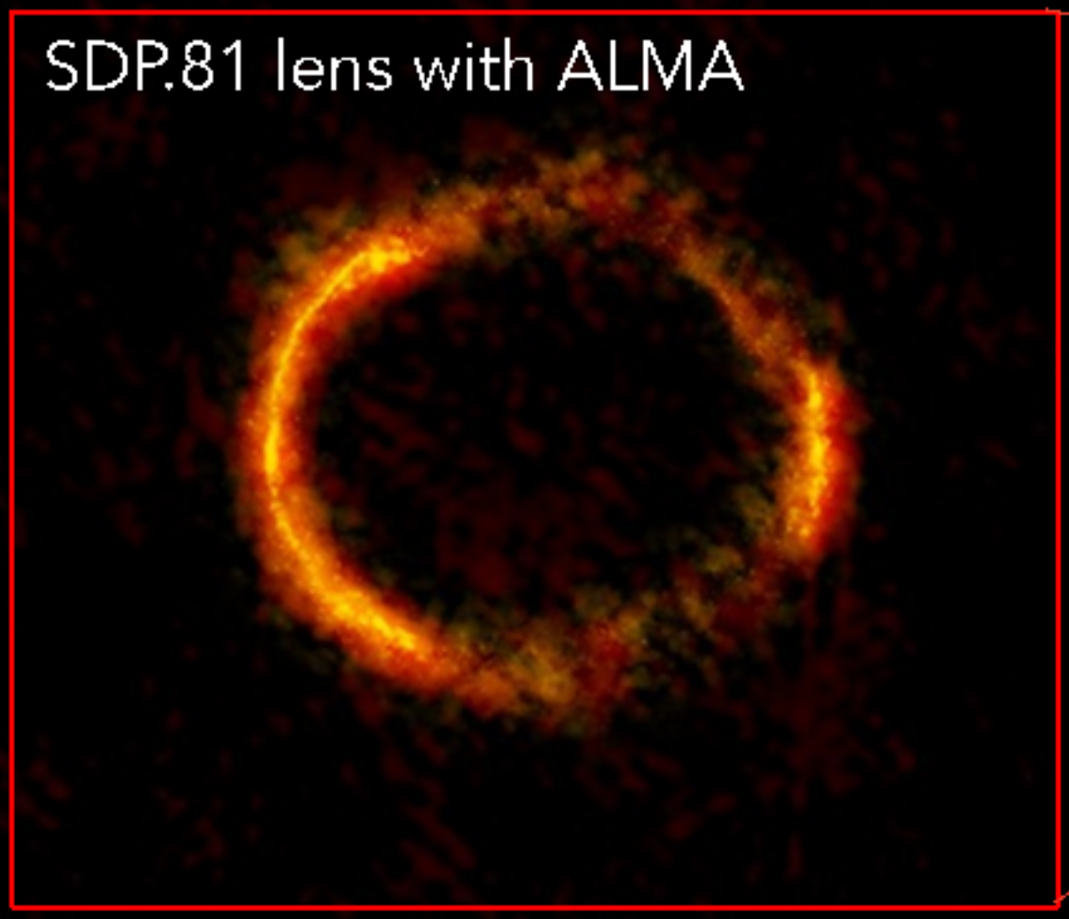


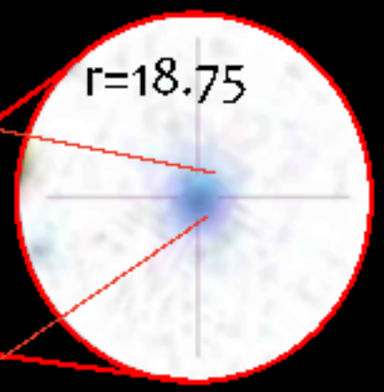
Negrello+ 2011

Swinbank+2015, Tamura+ 2015, Hatsukade+ 2015, Wang+2015, Vlahakis+2015

LENSES

SDP.81 lens with ALMA





Credit: ALMA (NRAO/ESO/NAOJ); B. Saxton NRAO/ AUI/NSF

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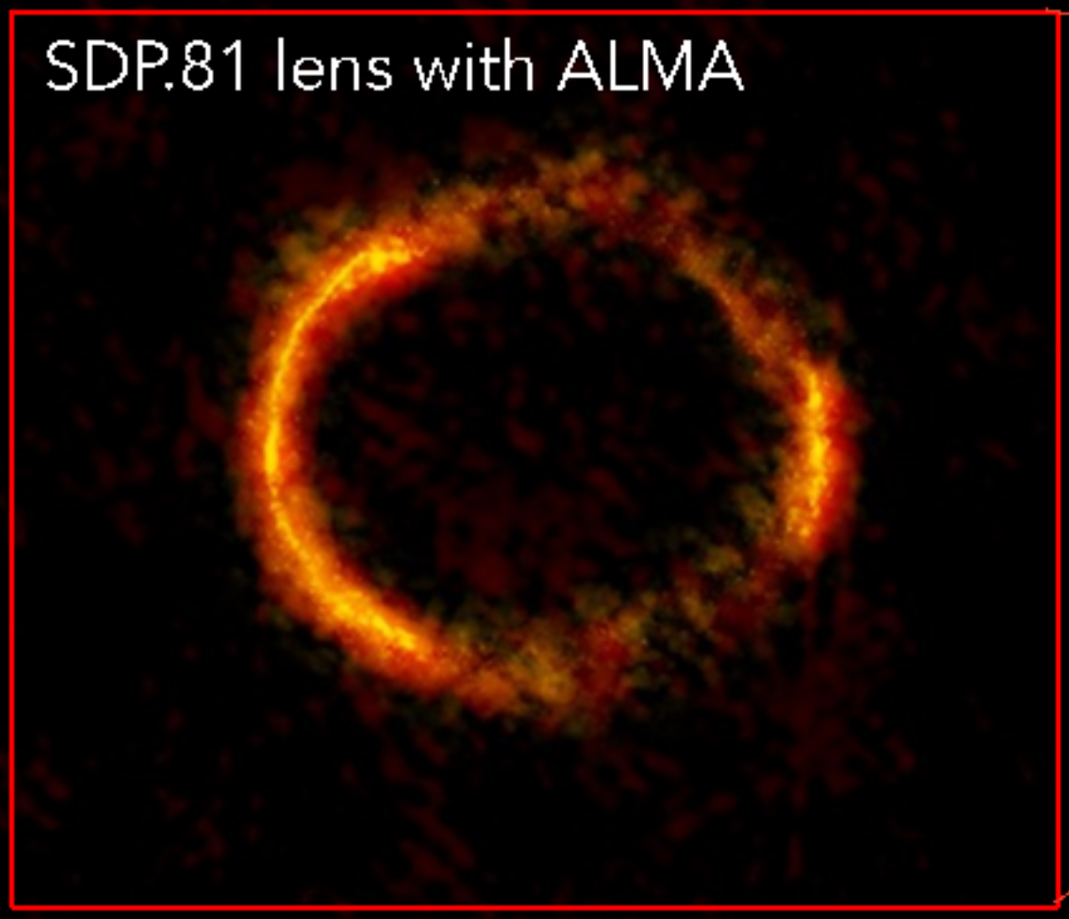

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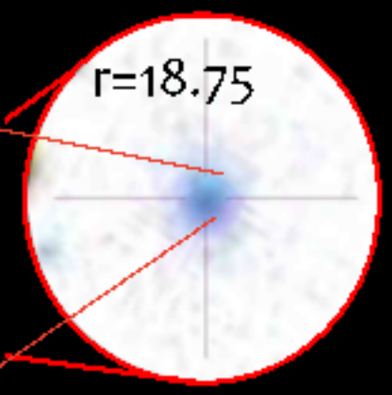
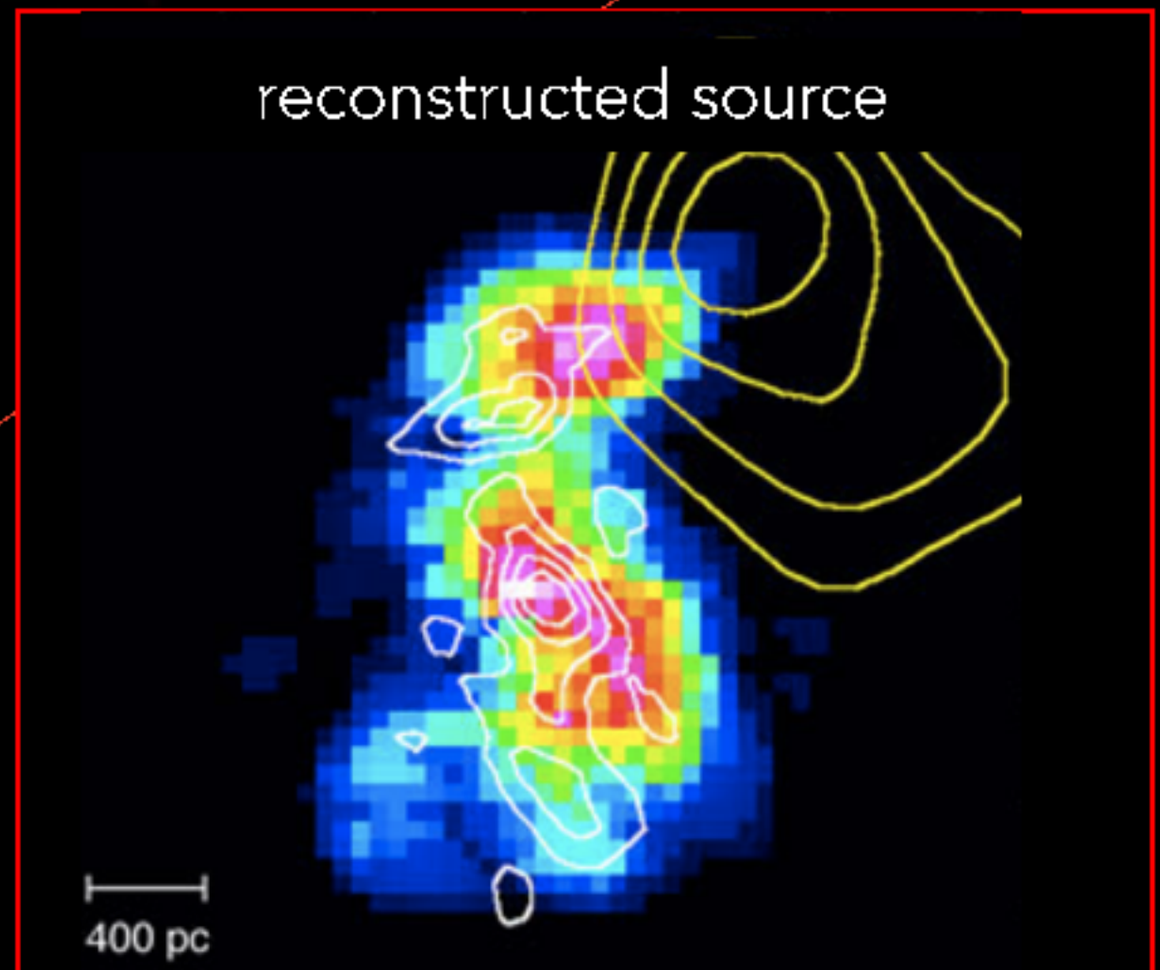


reconstructed source



Credit: Simon Dye + M Swinbank

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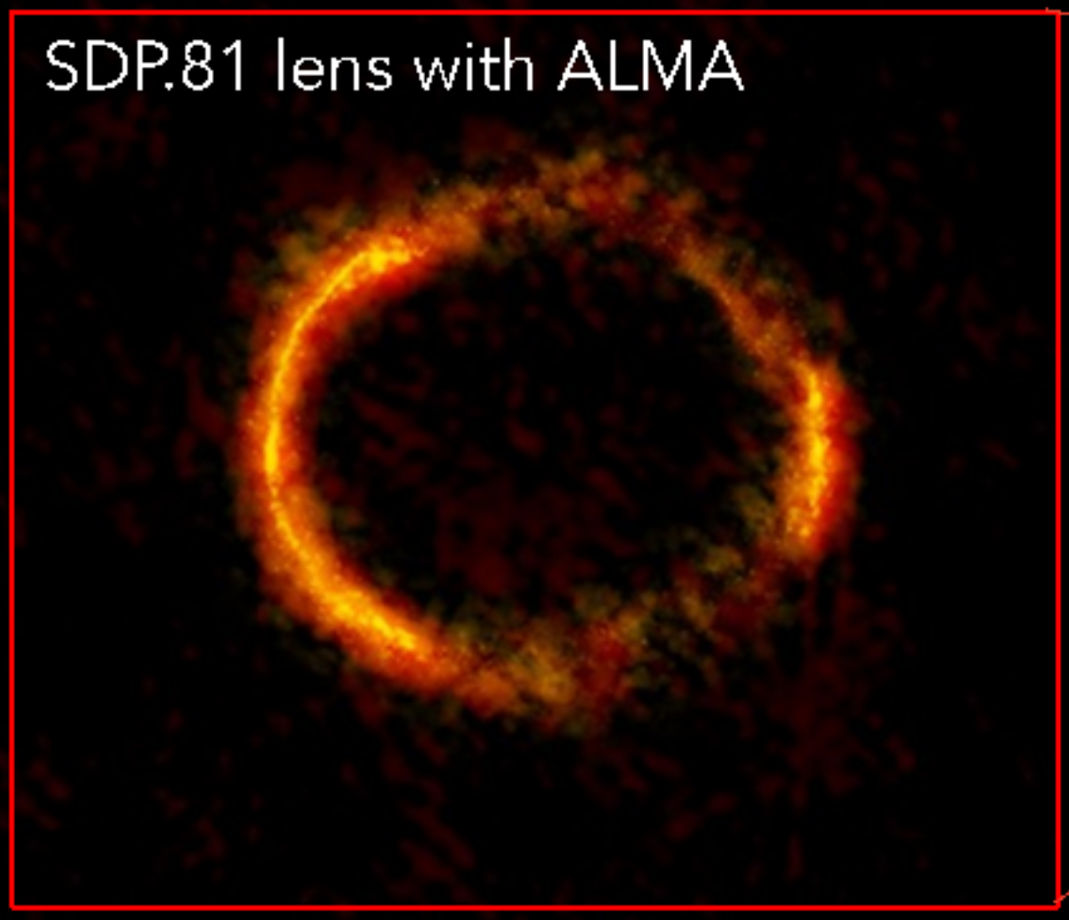

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Tom Bakx Thursday

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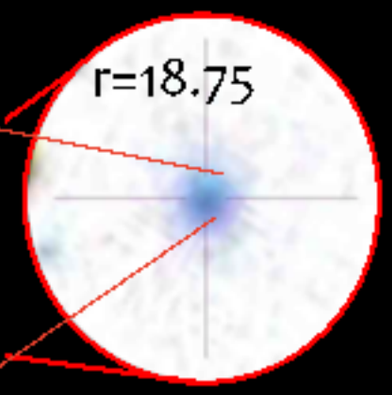

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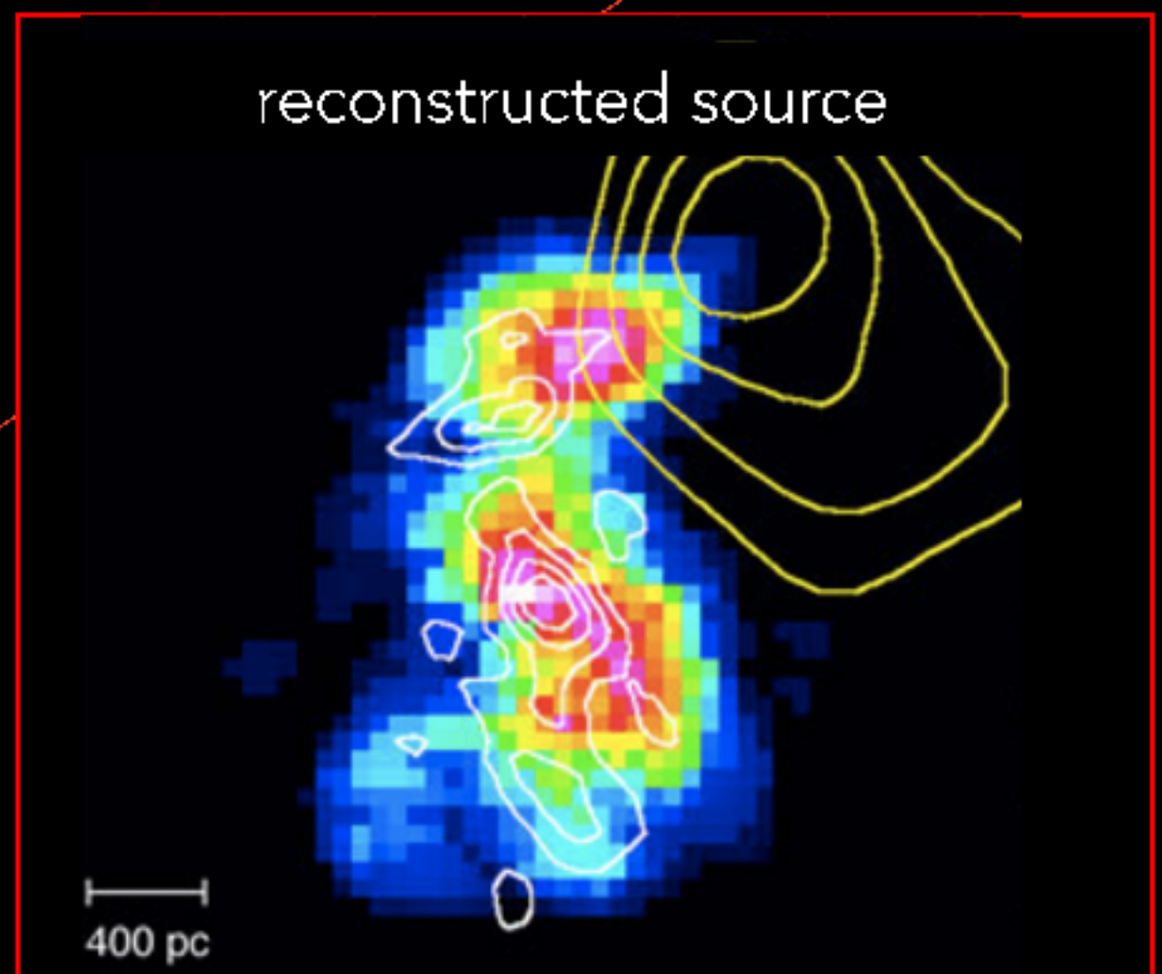

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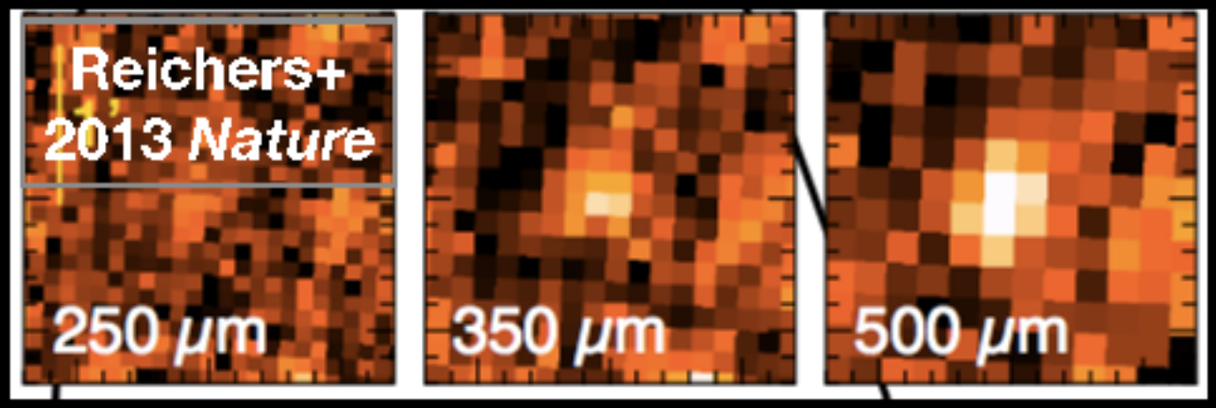
THE 500UM RISERS

SMGs at z >1 are forming stars at tremendous rates Chapman +2002,Blain+2002,Geach+2013,Casey+2013



Progenitors of massive ellipticals?

Herschel provides a sample of high-z starbursts

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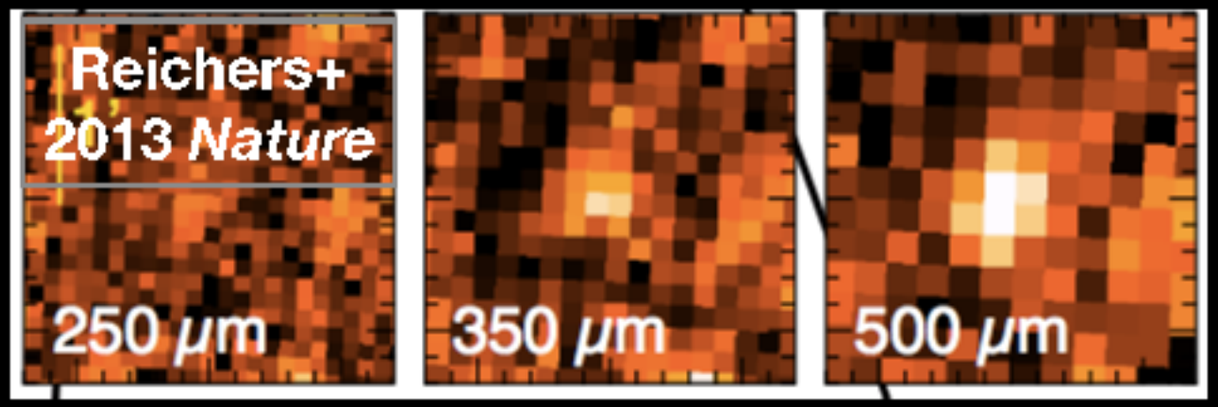

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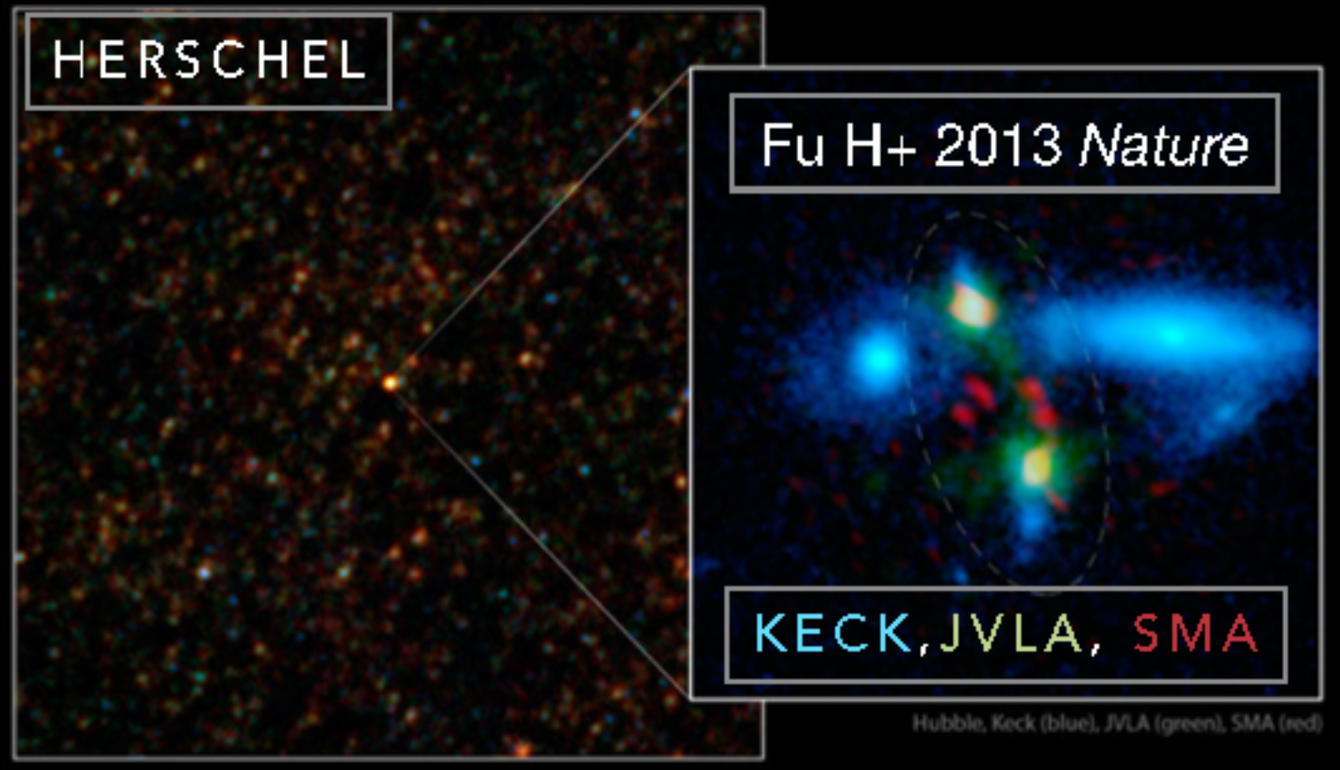
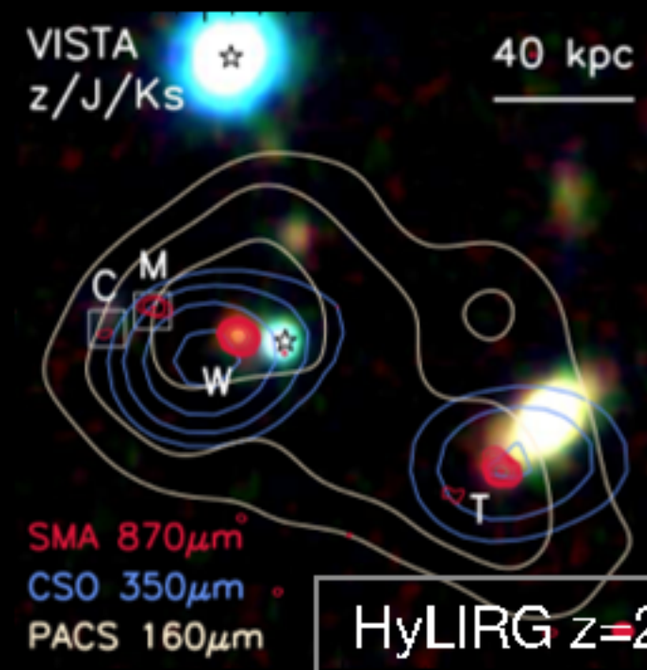
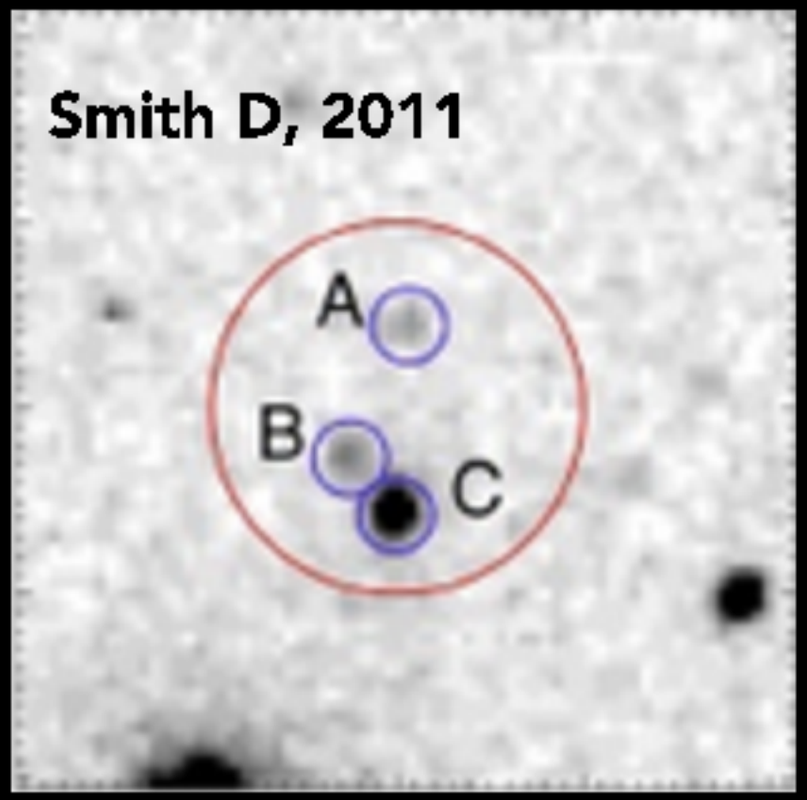




HyLIRG z=2.4 **Ivison+2016** Interacting starbursts
z=4.4 progenitor E galaxy **Oteo+ 2016**

see also Magdis+2011, Wardlow +2013, Dowell+2013, Swinbank +2014, Cooray+2014, Toft+ 2014, Nayeri+ 2016, Dowell+ 2013

CHALLENGE: WHAT ARE THE BLOBS?



Which optical source(s) is responsible for the Herschel flux? Hurley+ 2016, XID+

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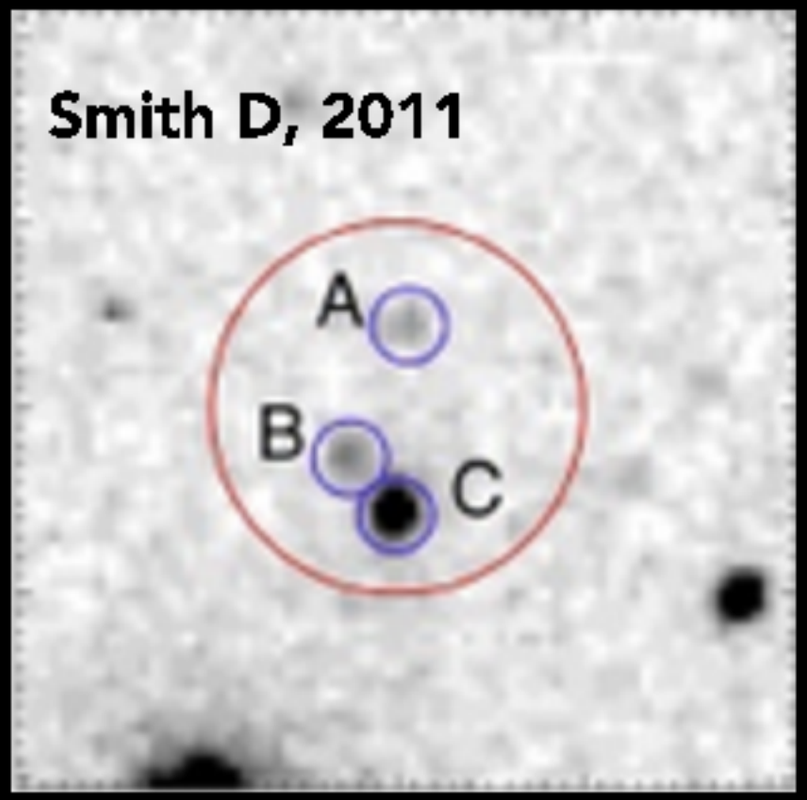

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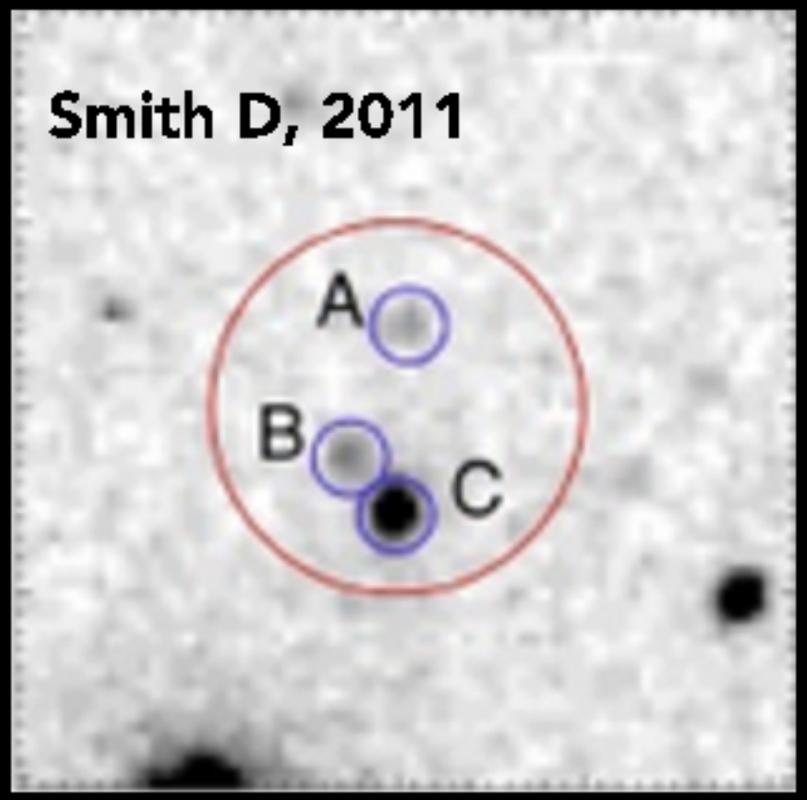

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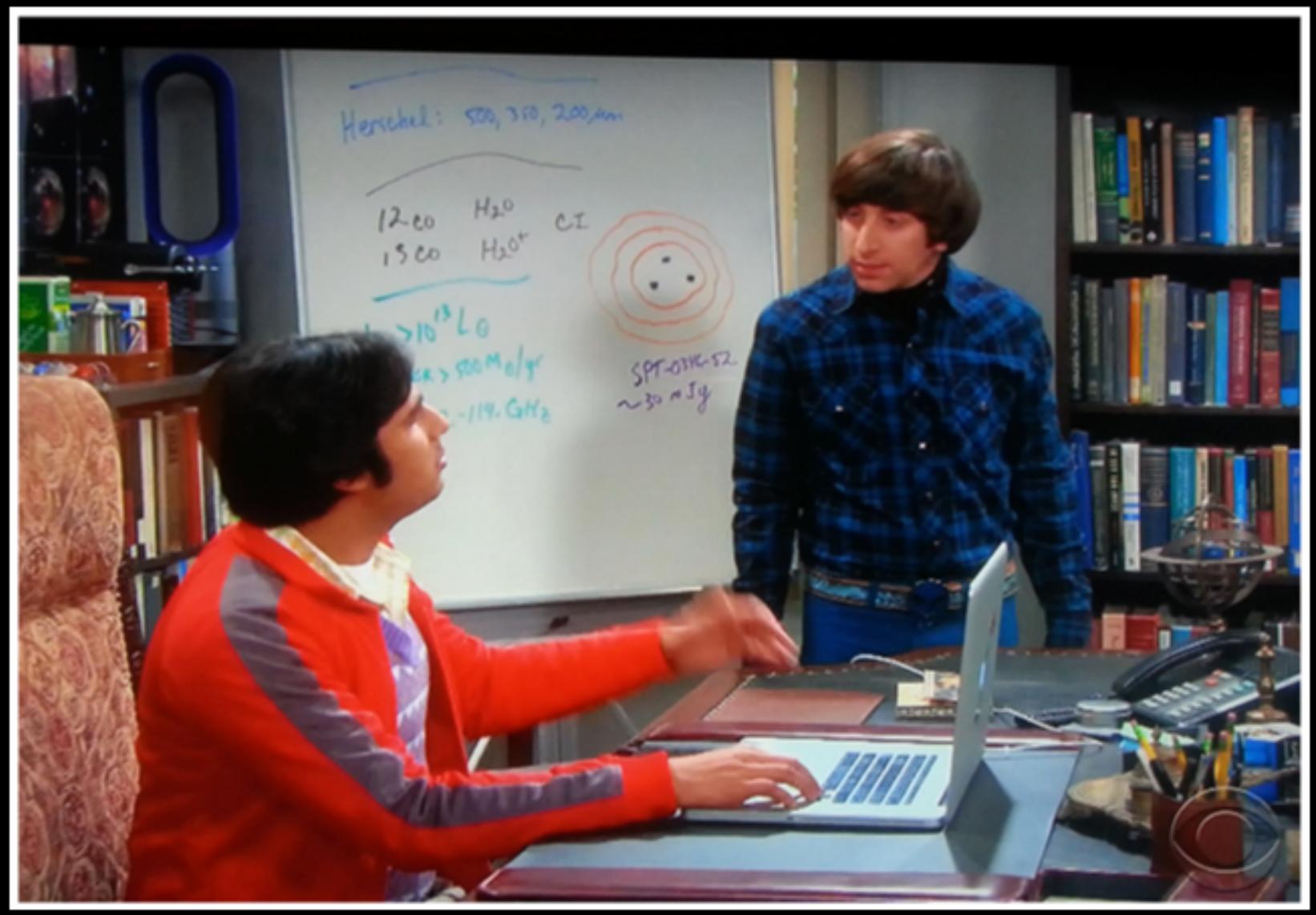
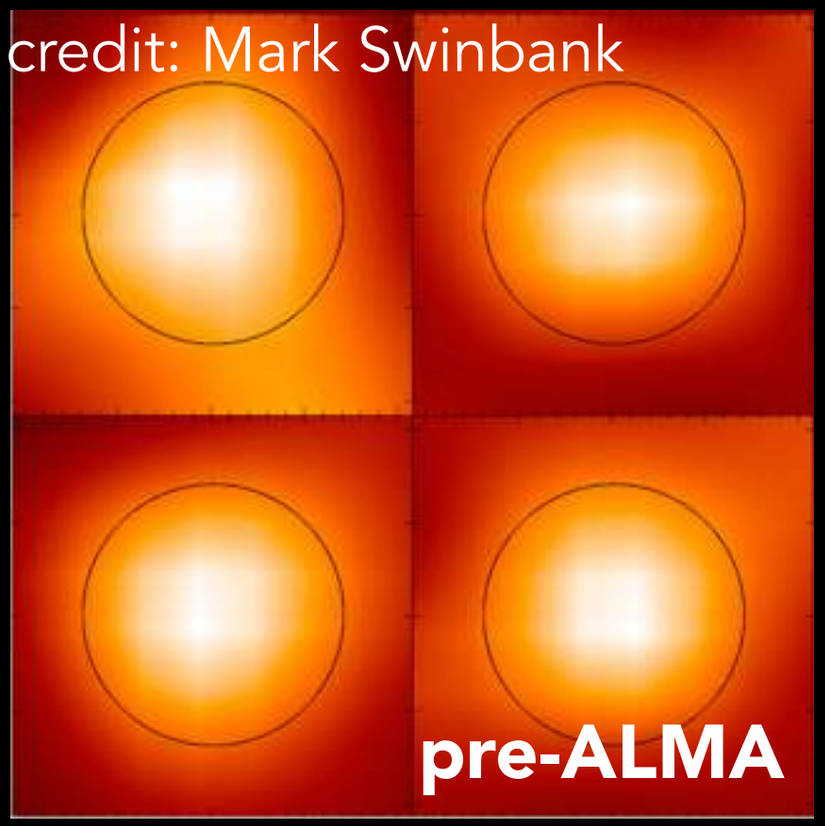


CHALLENGE: MULTIPLICITY



Hayward+2012, Barger+2012, Karim+ 2013, Chen+ 2013

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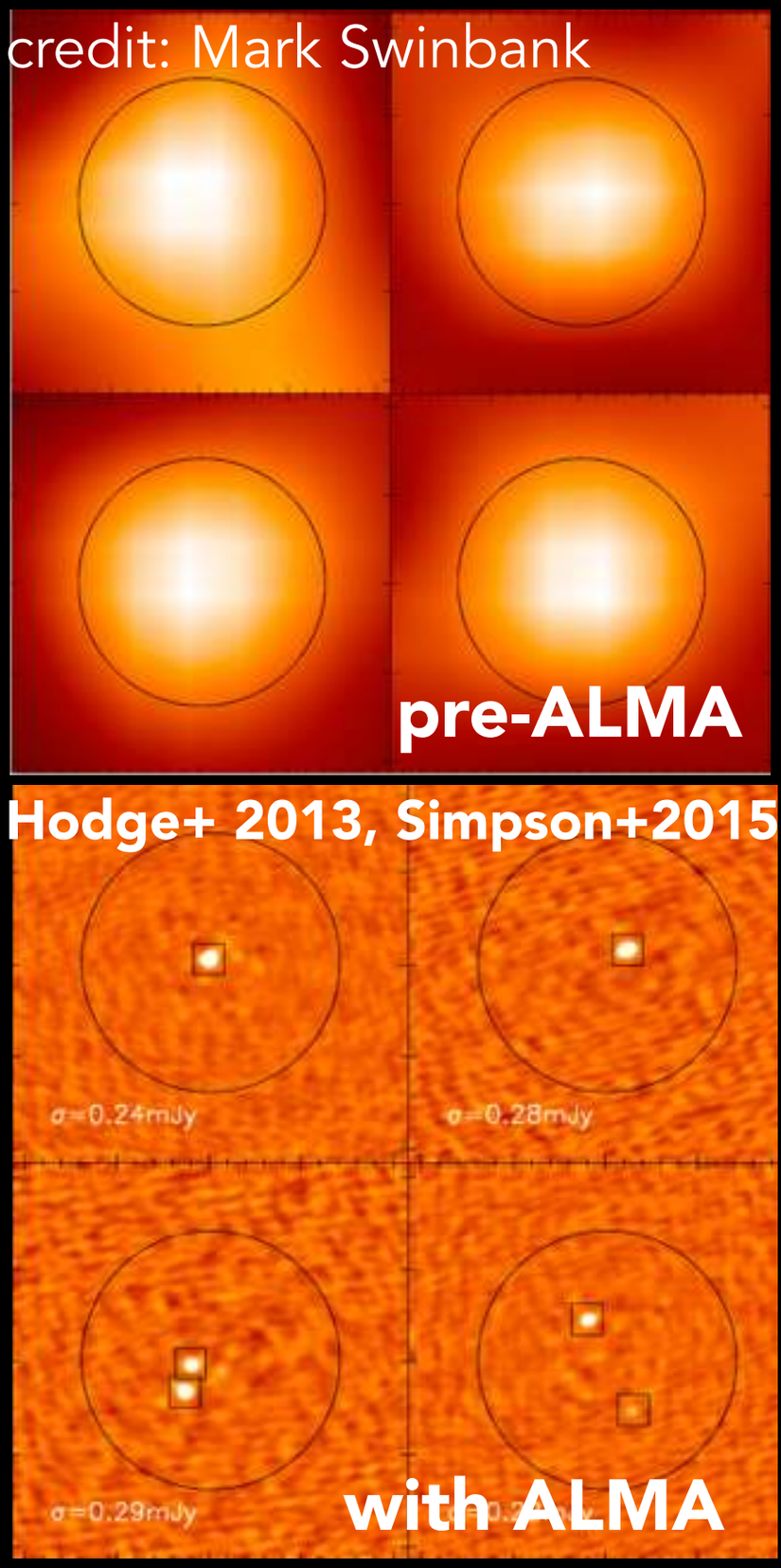

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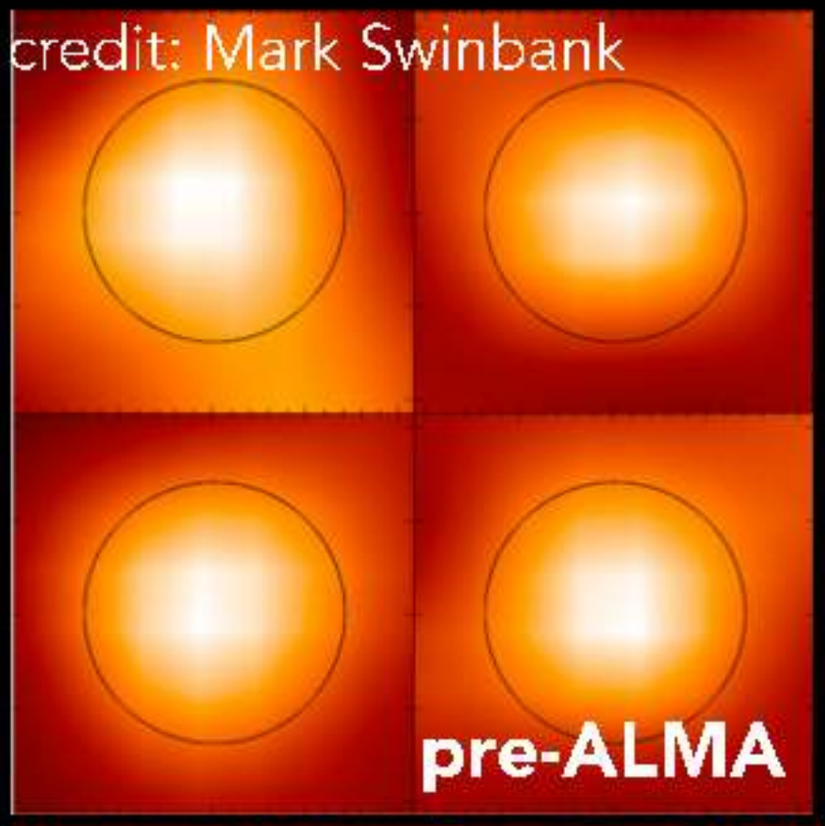
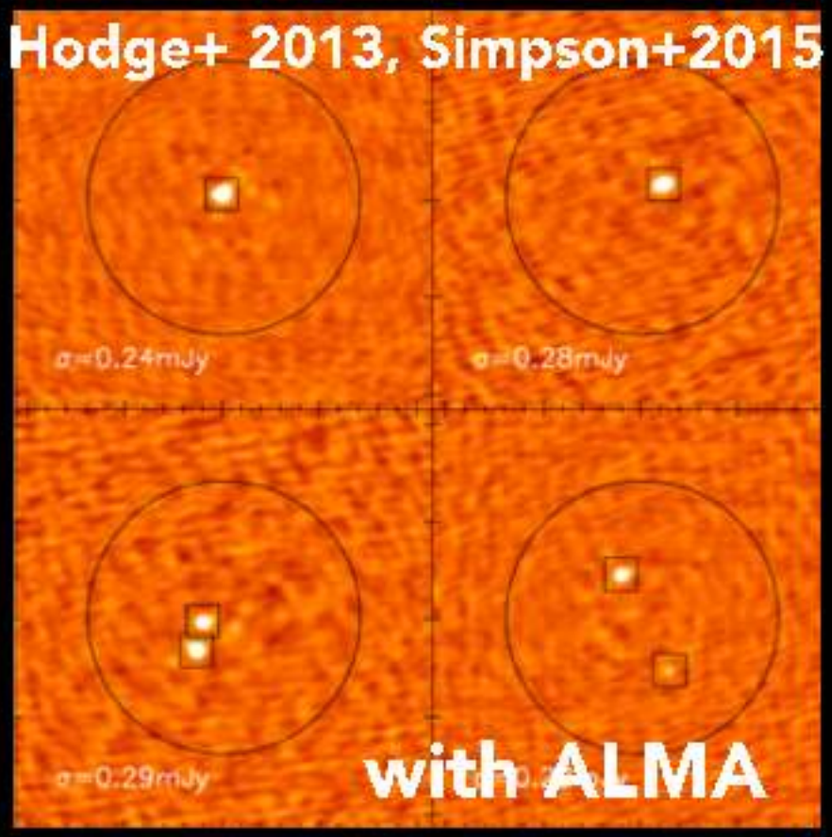
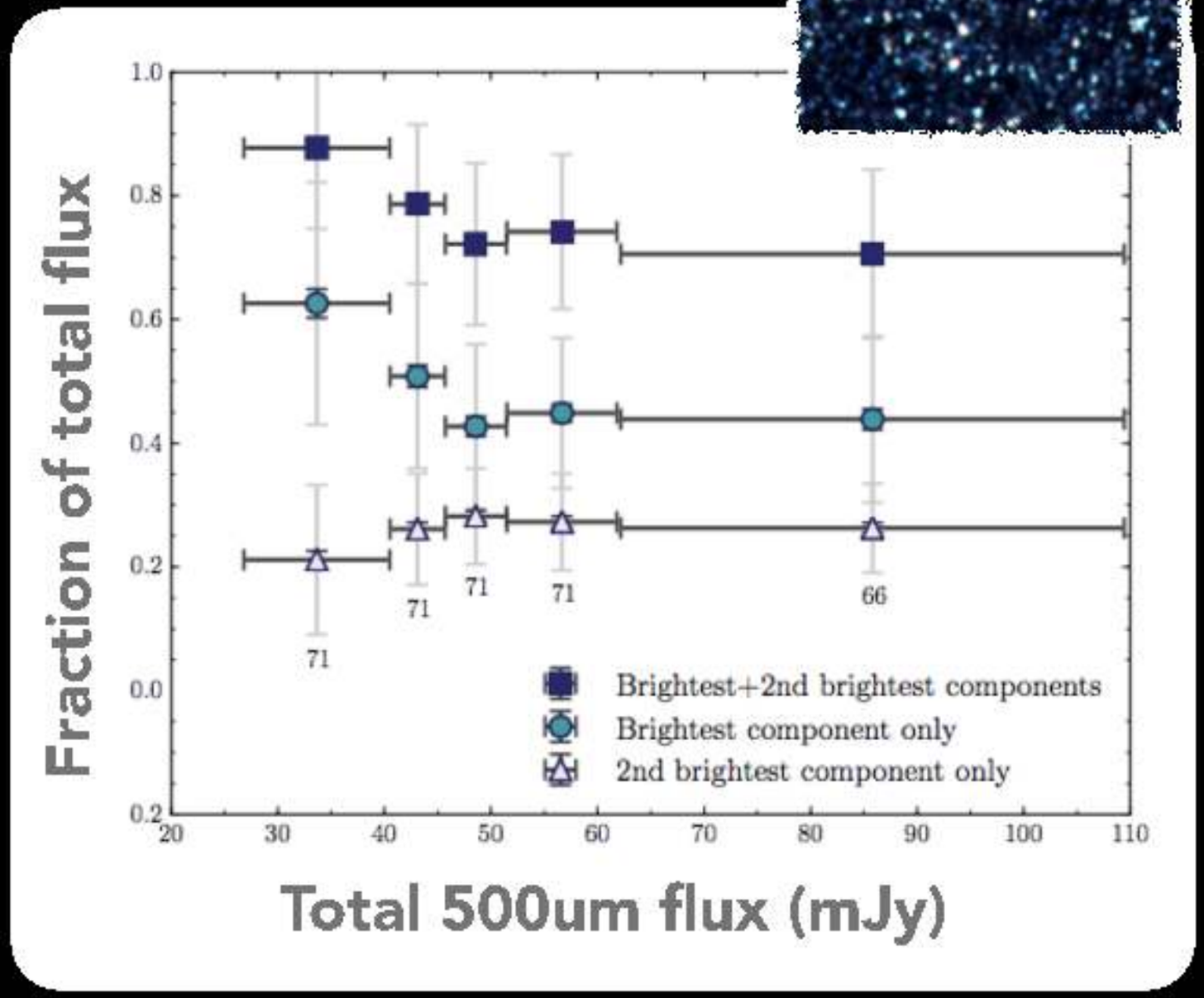




60%-70% of bright submm sources are blends of more than on SMG



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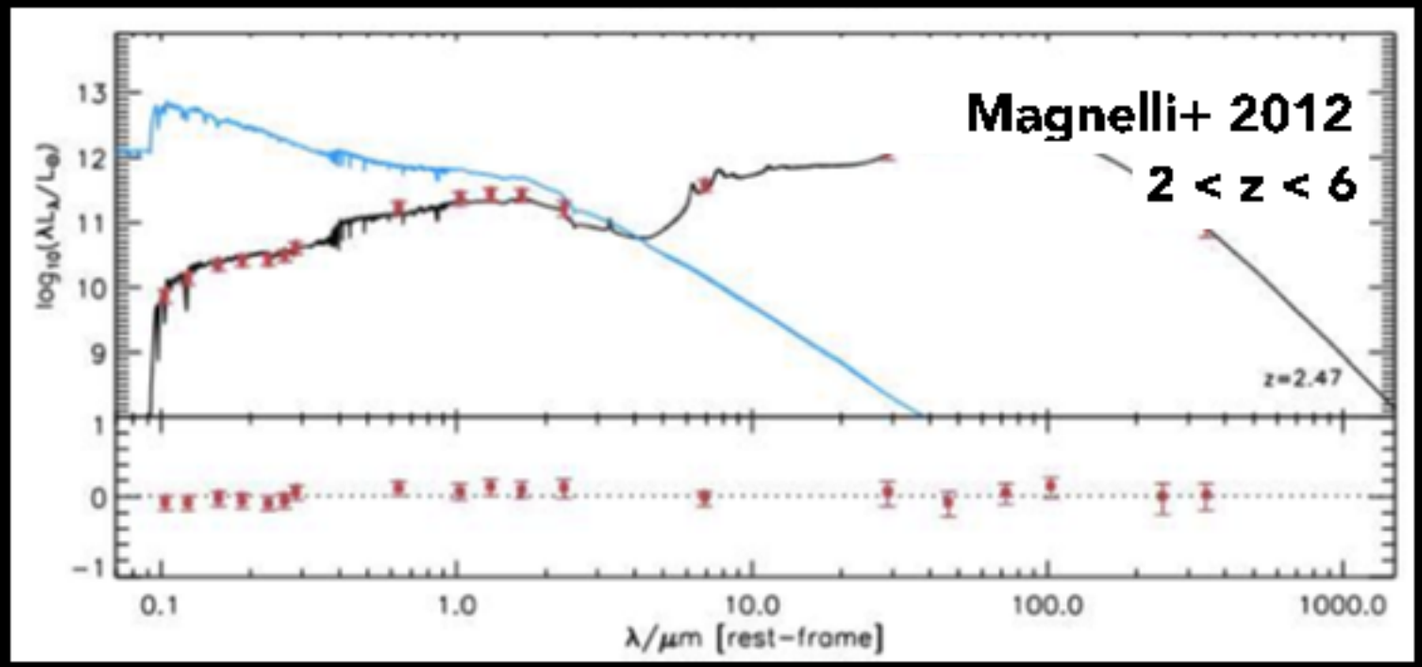
WHY IS THE UNIVERSE SO DUSTY?

MAKING DUST IN THE EARLY UNIVERSE IS HARD: **DUST BUDGET CRISIS**

Morgan (Gomez) +2003
Rowlands, Gomez+ 2014b
Rowlands+ 2014a
Using consistent SFHs



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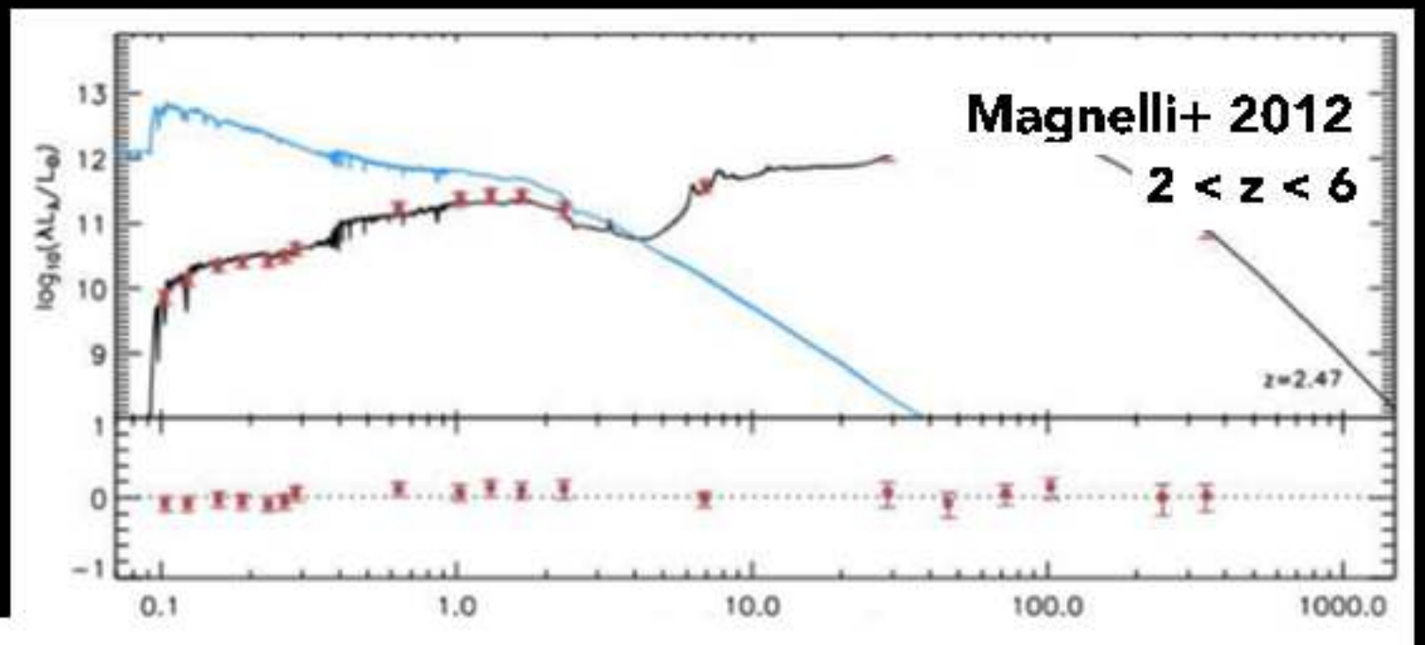

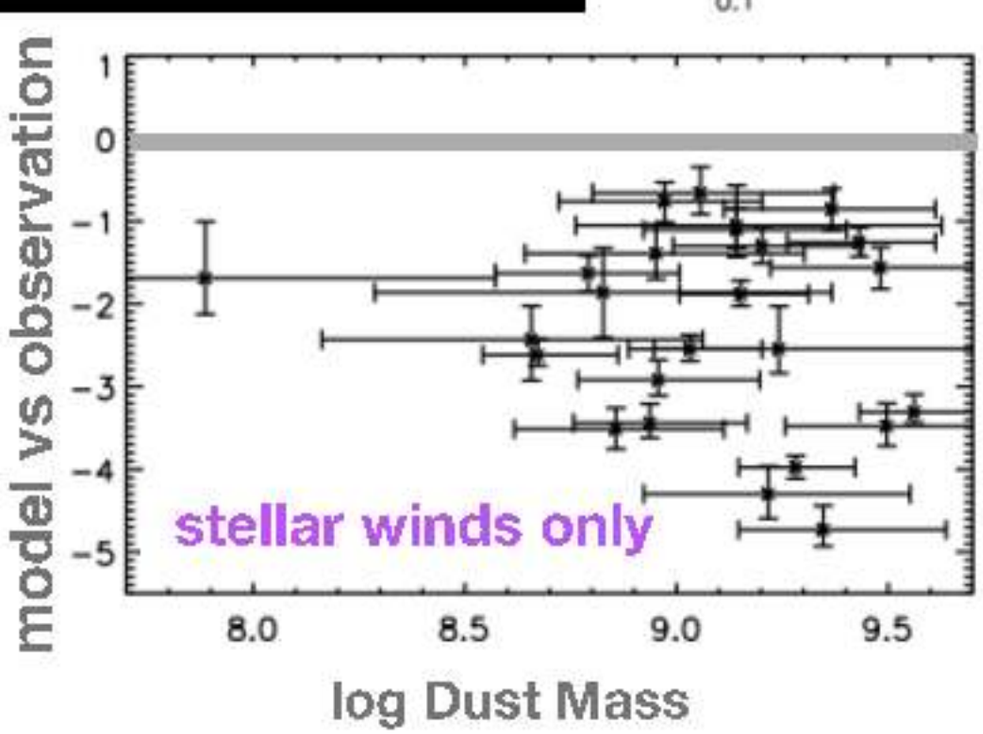

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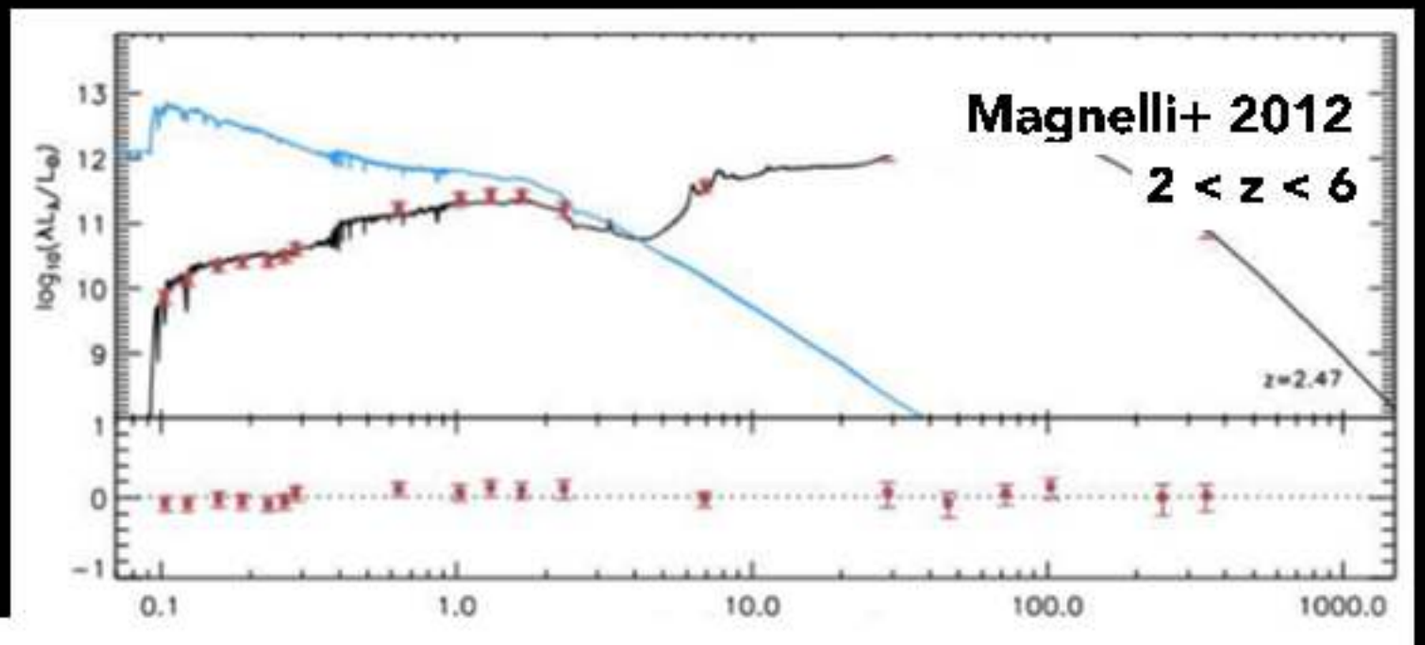

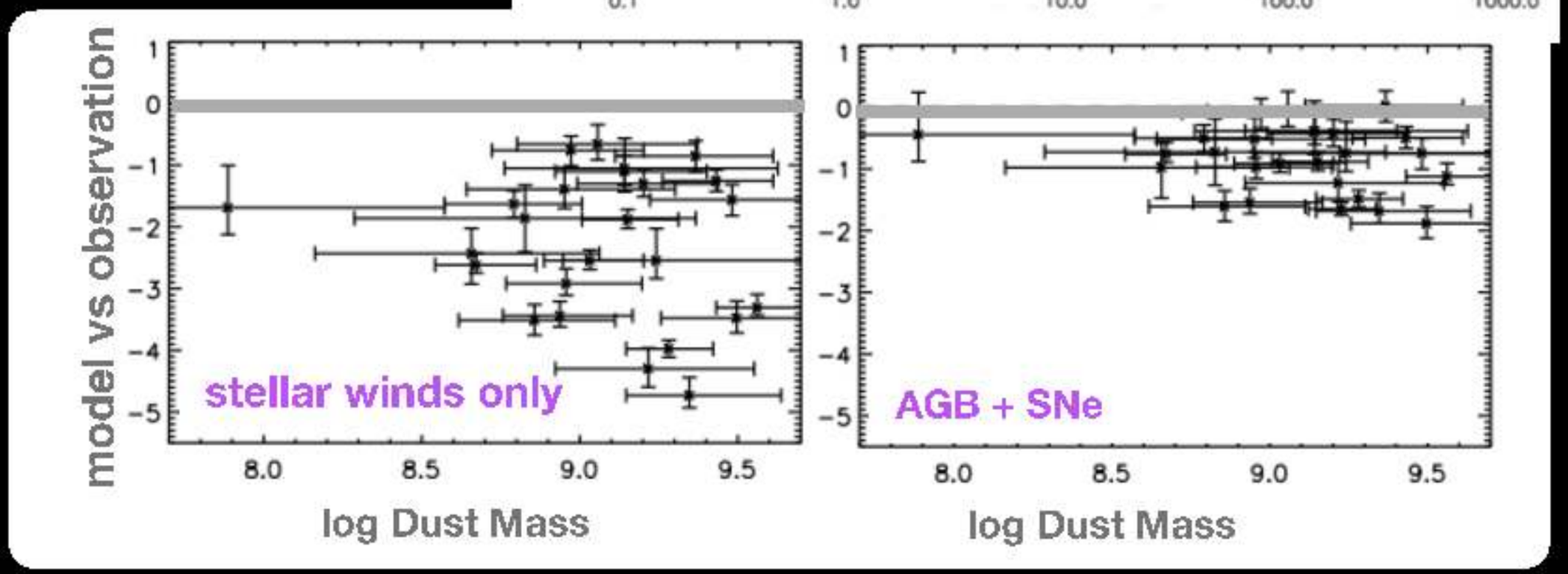

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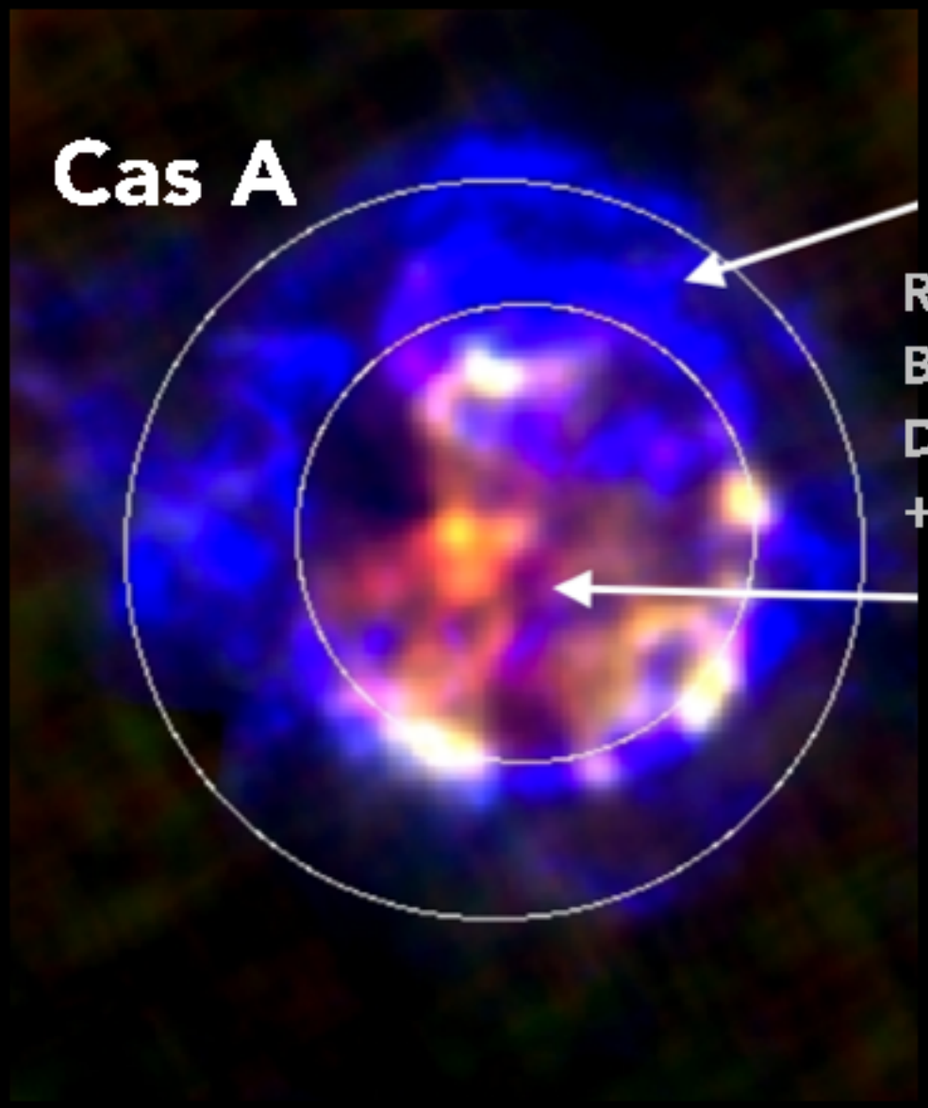
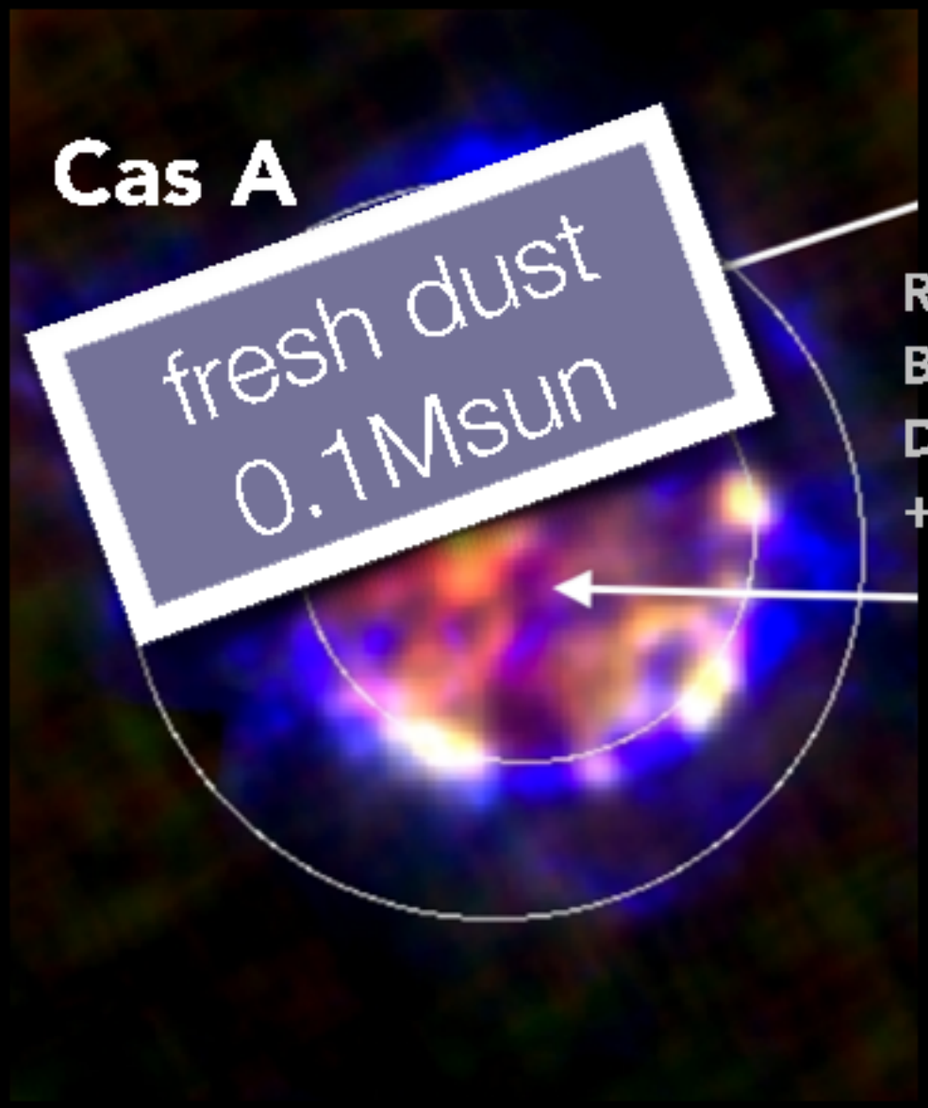
ARE SUPERNOVAE MAKING ALL THE DUST?



Rho+ 2009,
Barlow+ 2010
Dunne
+2003,2009

ARE SUPERNOVAE MAKING ALL THE DUST?



Rho+ 2009,
Barlow+ 2010
Dunne
+2003,2009

ARE SUPERNOVAE MAKING ALL THE DUST?

Rho+ 2009,
Barlow+ 2010
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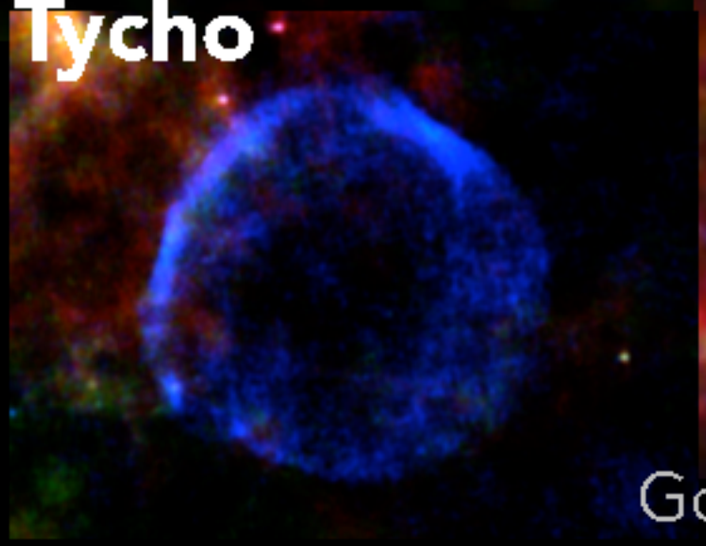
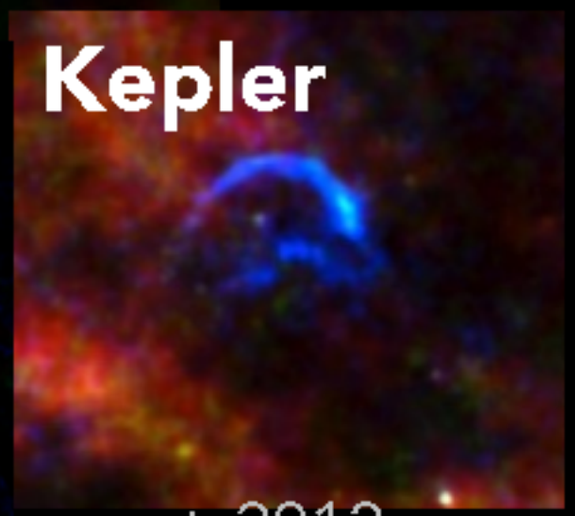
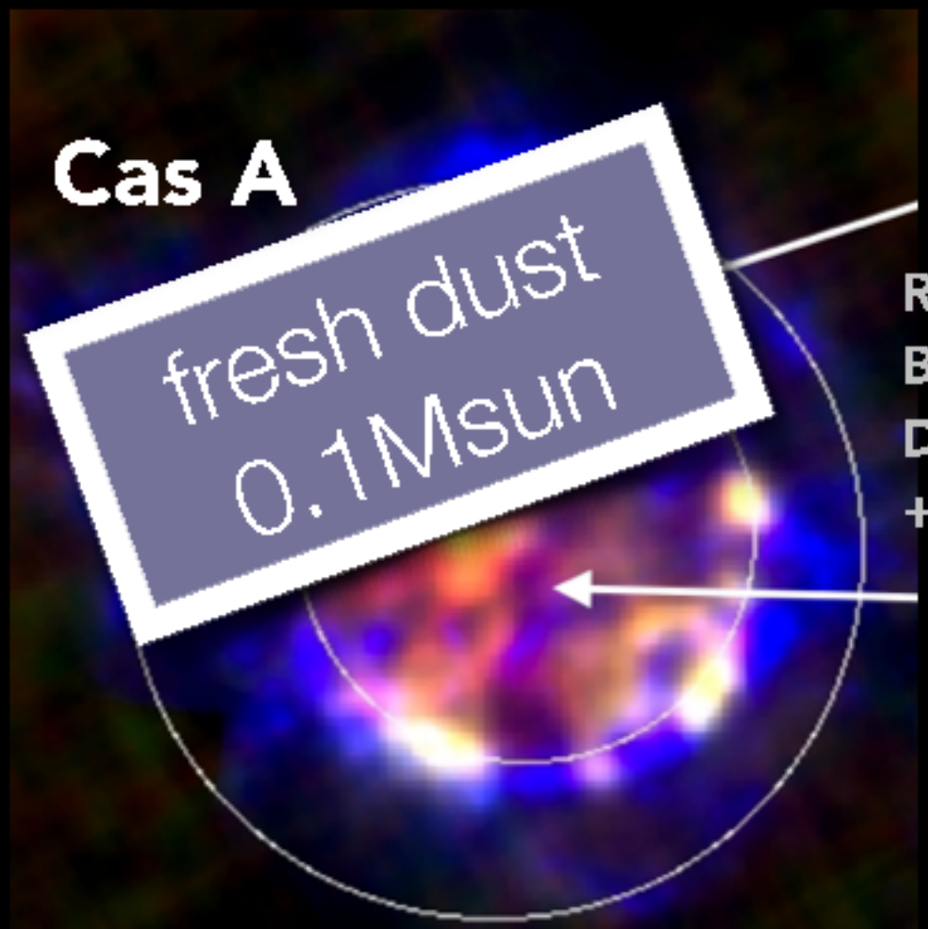
+2003,2009





Gomez+ 2012a

ARE SUPERNOVAE MAKING ALL THE DUST?



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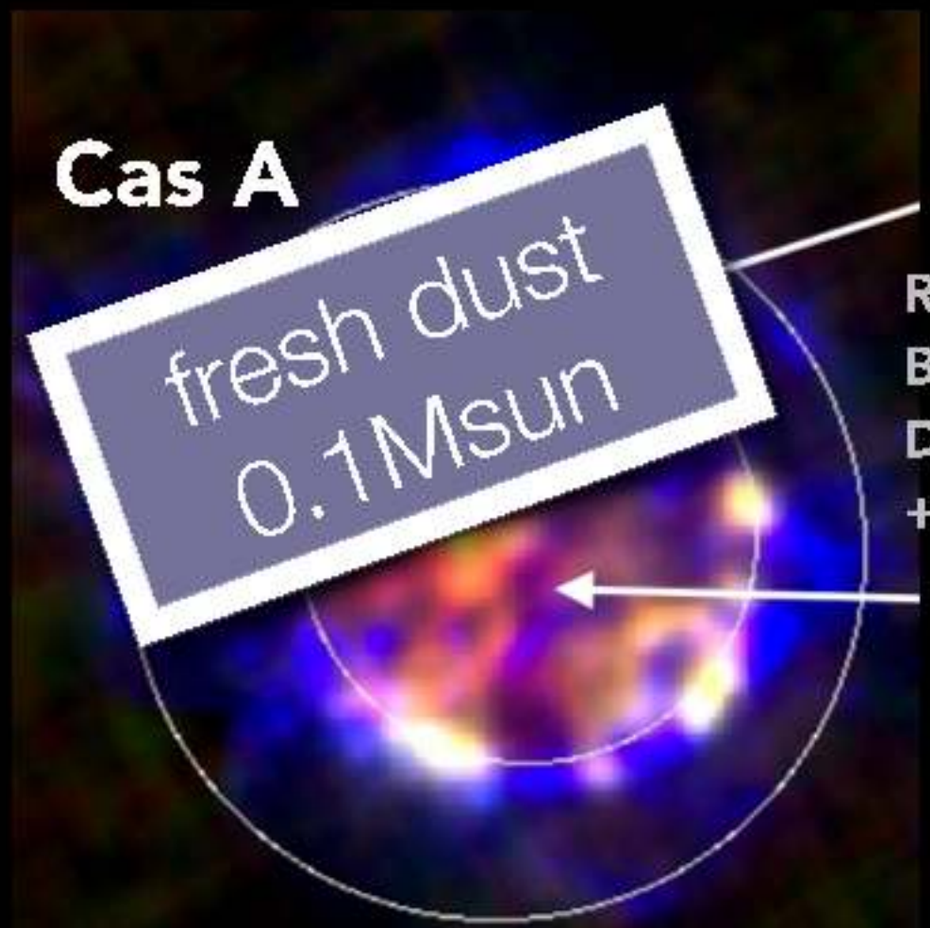

Rho+ 2009,
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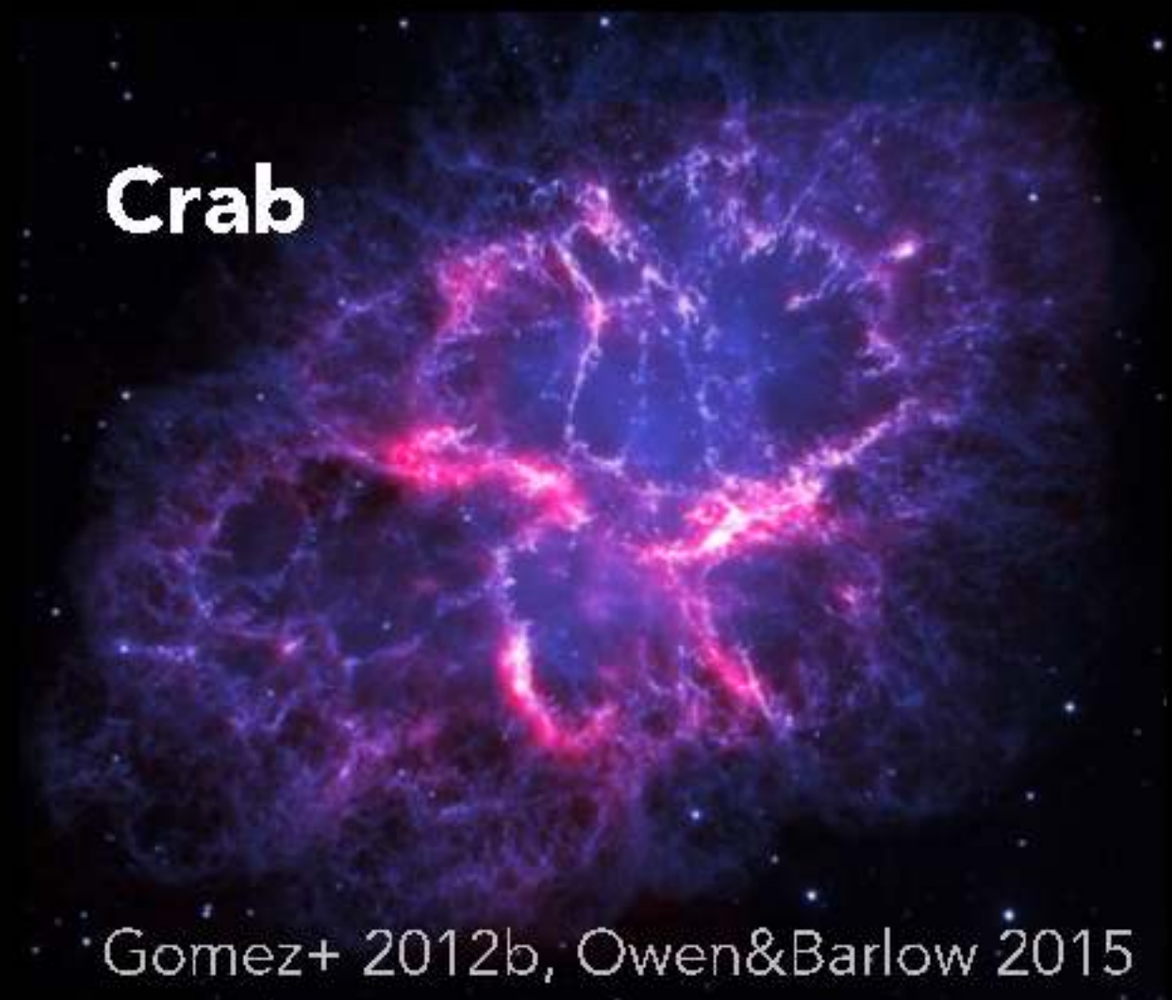
+2003,2009

Gomez+ 2012a



Gomez+ 2012b, Owen&Barlow 2015

ARE SUPERNOVAE MAKING ALL THE DUST?

Rho+ 2009,
Barlow+ 2010
Dunne
+2003,2009

Gomez+ 2012a

Gomez+ 2012b, Owen&Barlow 2015

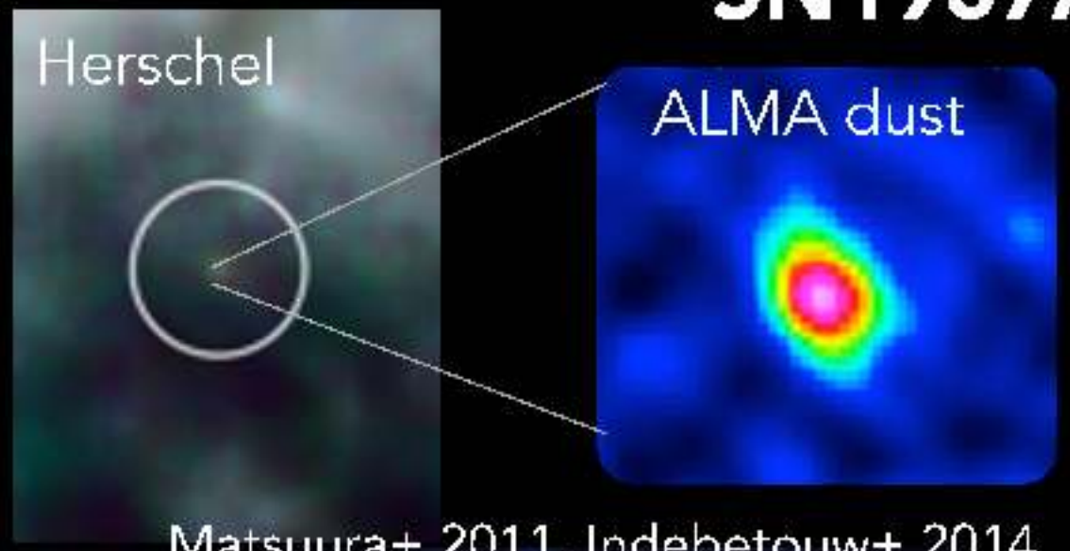
ARE SUPERNOVAE MAKING ALL THE DUST?

Cas A

fresh dust
0.1Msun

Rho+ 2009,
Barlow+ 2010
Dunne
+2003,2009

SN1987A



Matsuura+ 2011, Indebetouw+ 2014

Tycho

Kepler

swept up dust

Gomez+ 2012a

Crab

fresh dust
0.1-0.7Msun

Gomez+ 2012b, Owen&Barlow 2015

ARE SUPERNOVAE MAKING ALL THE DUST?

Cas A

fresh dust
0.1Msun

Rho+ 2009,
Barlow+ 2010
Dunne
+2003,2009

SN1987A

Herschel

ALMA dust

fresh dust
0.4-0.7Msun

Matsuura+ 2011, Indebetouw+ 2014

Crab

fresh dust
0.1-0.7Msun

Gomez+ 2012b, Owen&Barlow 2015

Tycho

Kepler

swept up dust

Gomez+ 2012a

WHAT HAVE WE LEARNT

Herschel reveals population of "more normal" dusty star forming galaxies

Blind Herschel surveys reveal more diversity in local galaxies

Dust masses measured with Herschel ~**5x higher**

Ability to find lensed systems and high redshifts

Herschel reveals supernovae form dust

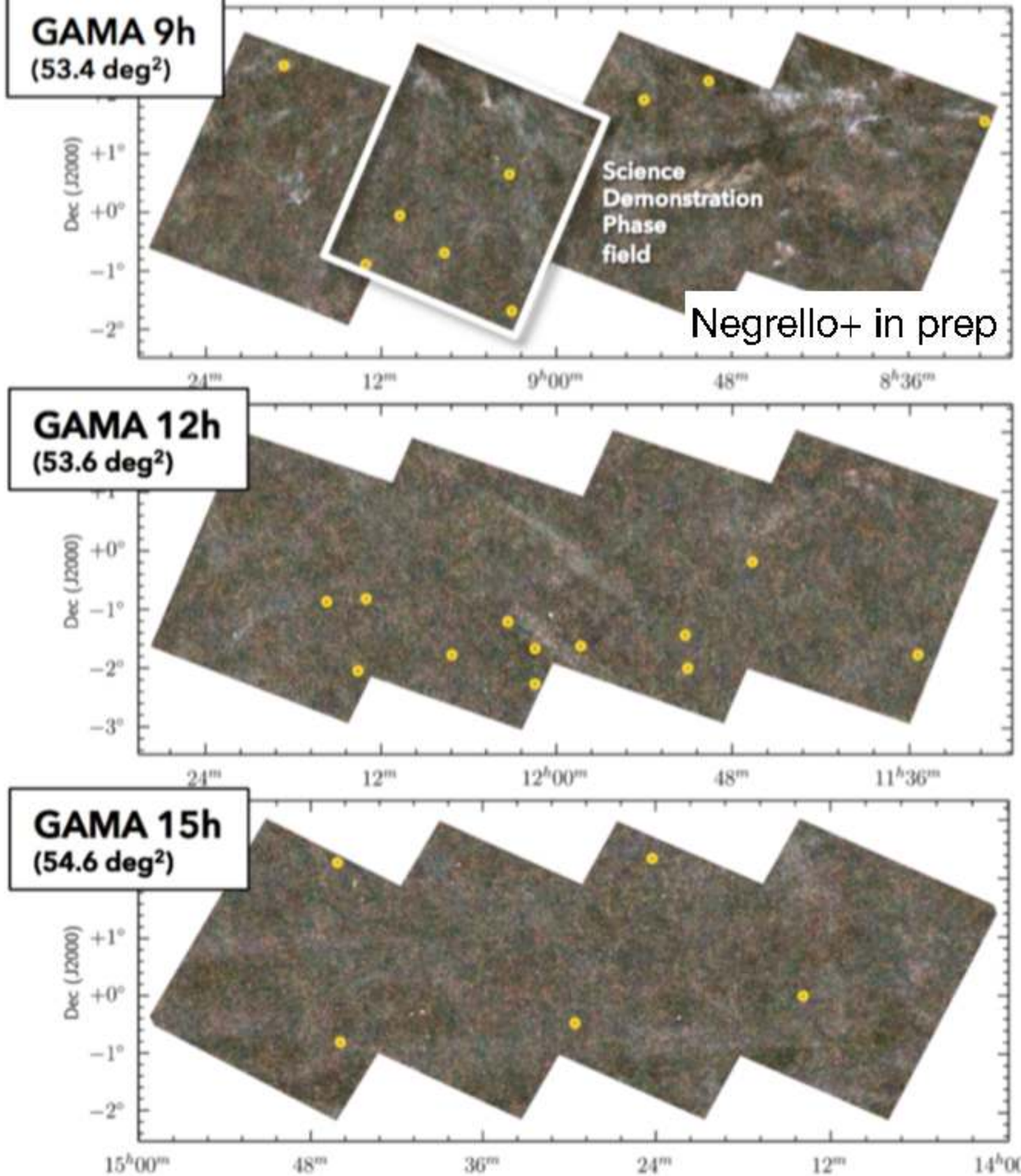
Blobology is a challenge - but Herschel great feeder for ALMA

Herschel ATLAS

PI L Dunne & S Eales

www.hatlas.org

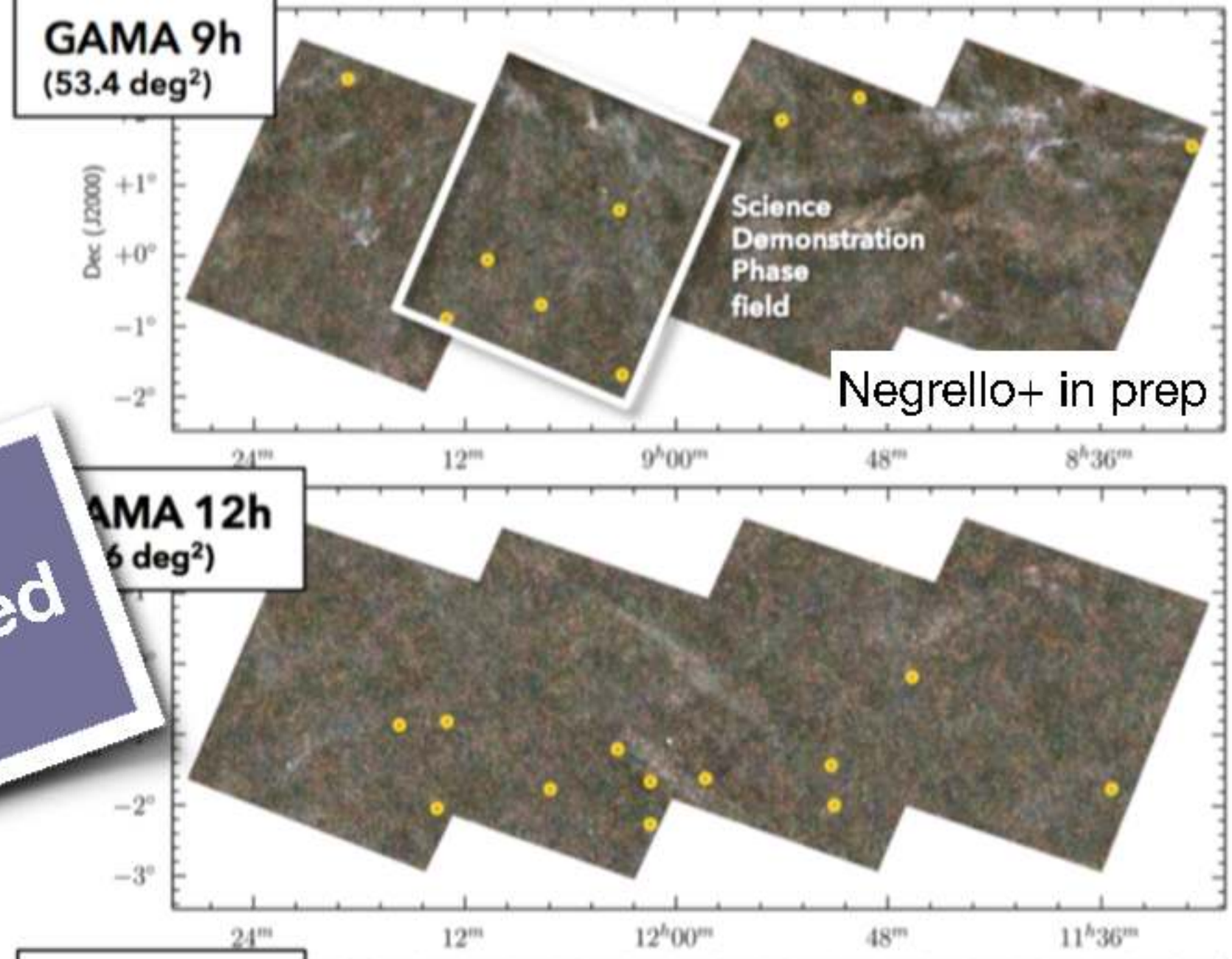
Bourne+ 2016, Valiante+ 2016



Herschel
ATLAS

PI L Dunne & S Eales

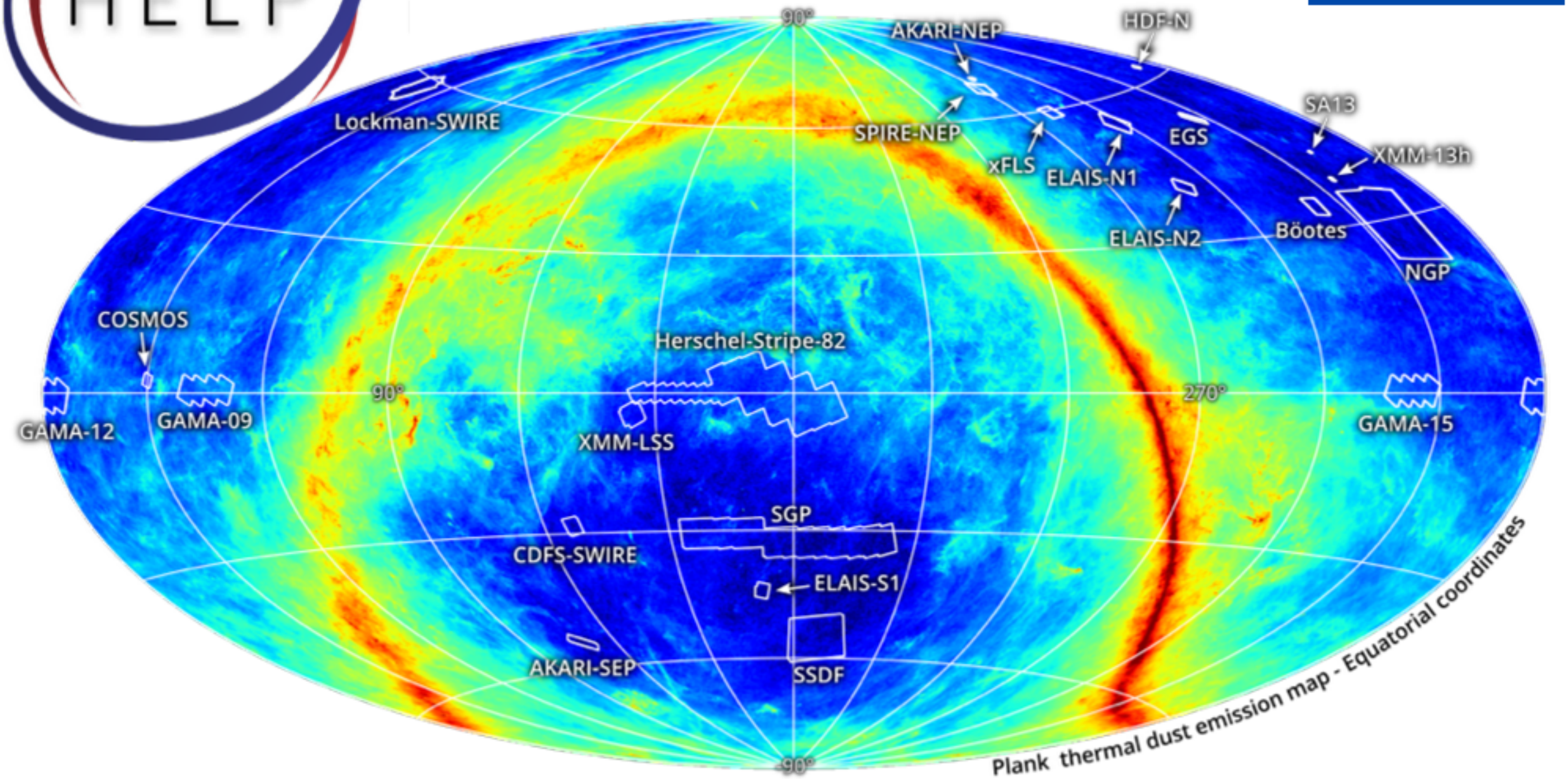
160 square degrees released today



www.hatlas.org

Bourne+ 2016, Valiante+ 2016

HELP

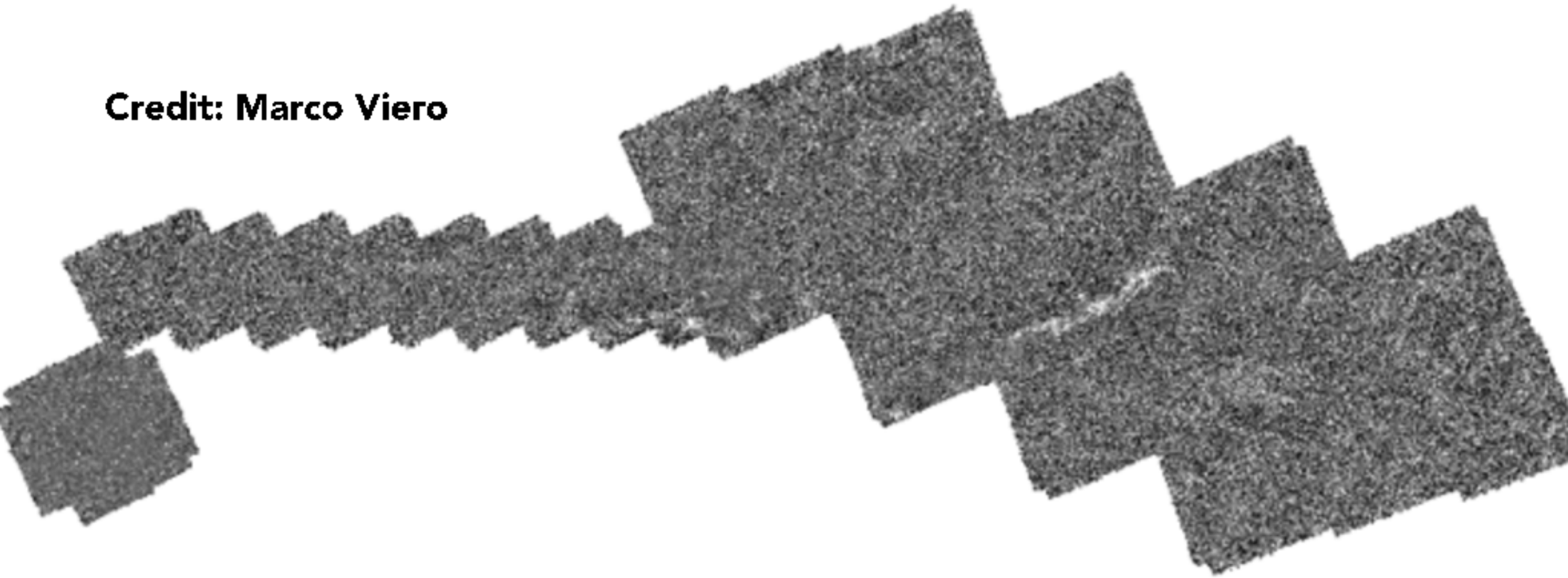


PI Seb Oliver

Scudder+ 2016, Hurley+2016,
Duivenvoorden+ 2016

THE LARGEST HERSCHEL XGAL MAP

Credit: Marco Viero



384 sq degree map released today

PI Seb Oliver
Scudder+ 2016, Hurley+2016,
Duivenvoorden+ 2016

THANKS TO ALL THE HERSCHEL TEAM!

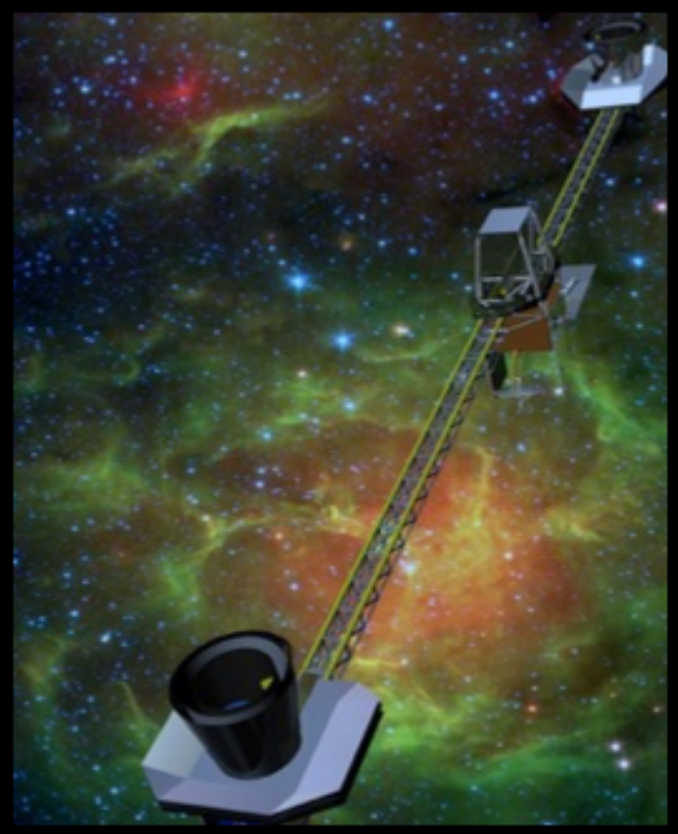
WHAT'S NEXT FOR FIR ASTRONOMY?

ALMA

SOFIA

SPICA

Space Infrared Telescope for Cosmology and Astrophysics



COLDER : MORE SENSITIVE
WILL REVOLUTIONISE SPECTROSCOPY

"ALMA AT PEAK DUST EMISSION" -
FIR INTERFEROMETRY (FIRI/SPIRIT)