Lucia Marchetti

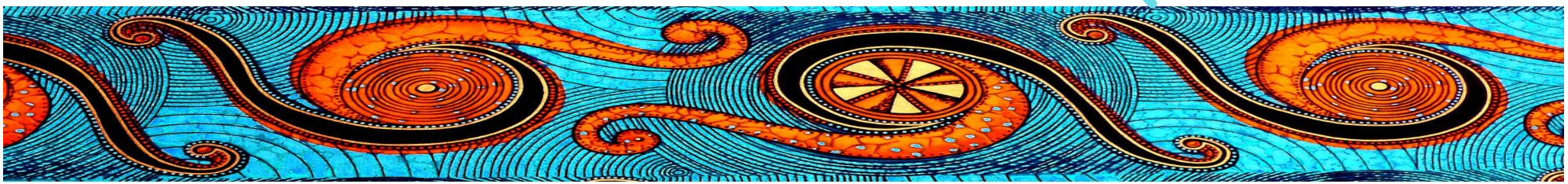
SARChi research fellow

@Luci_aMarchetti

UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

UNIVERSITY of the WESTERN CAPE

Thanks to Mattia Negrello (Cardiff) Stephen Serjeant (OU), Steve Crawford (SAAO), Mattia Vaccari (UWC)…



Strong Gravitational Lensing Studies with Herschel and Multi-Wavelength Follow-up Observations: synergies with KiDS

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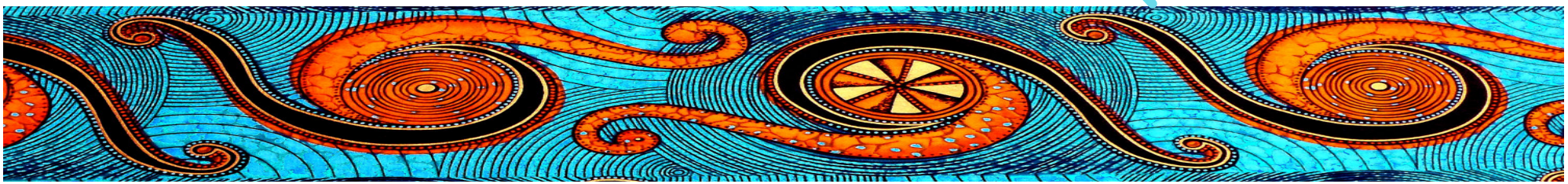
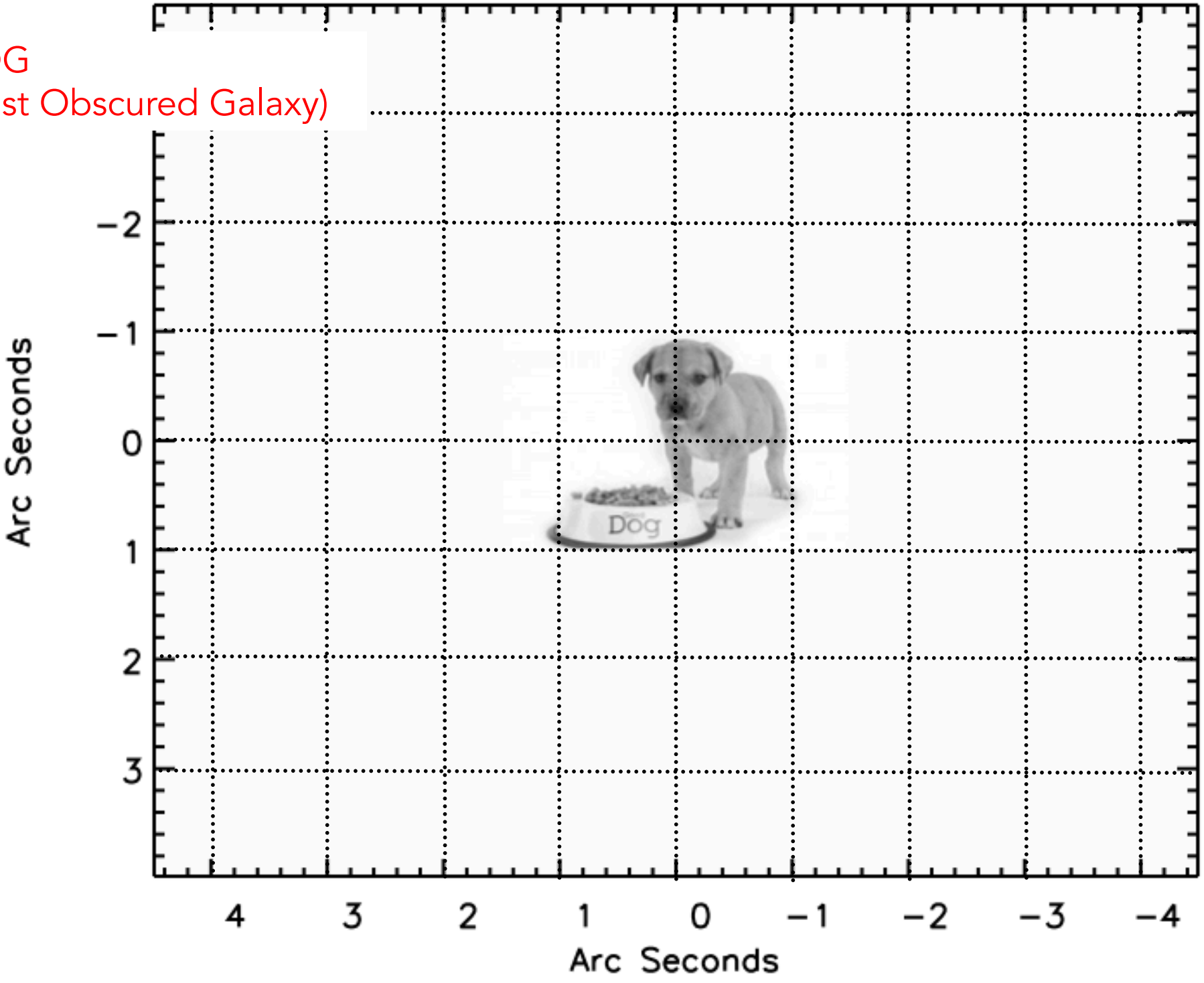
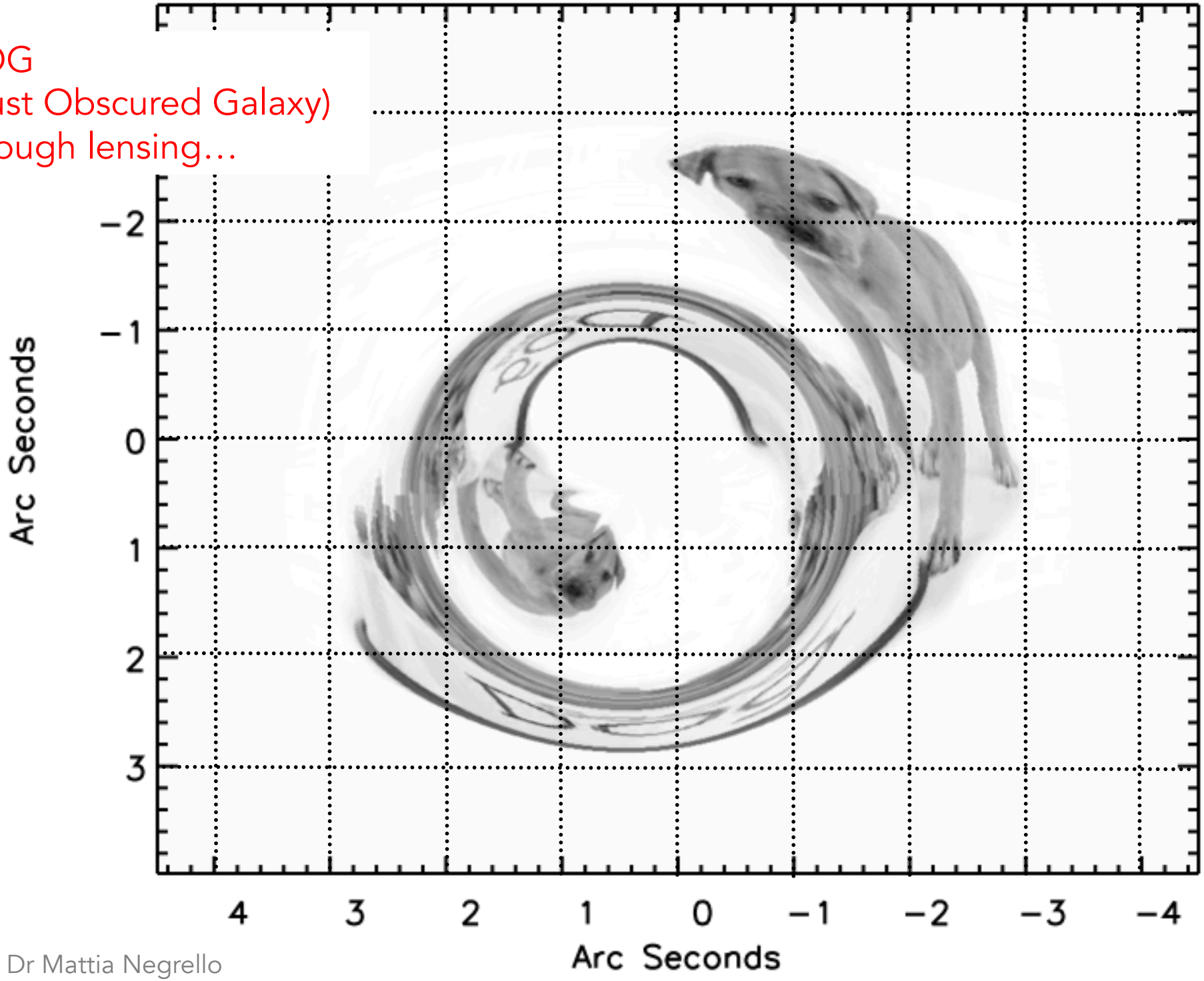


Strong Gravitational Lensing Studies with Herschel and Multi-Wavelength Follow-up Observations: synergies with KiDS

DOG
(Dust Obscured Galaxy)



DOG
(Dust Obscured Galaxy)
through lensing…



Credits: Dr Mattia Negrello

What is gravitational lensing?

- Gravitational lensing conserves surface brightness
- Angular magnification means flux magnification
- Multiple images and “Einstein ring” are possible

How to find lenses (before Herschel)

Gravitational lensing is a rare phenomenon.

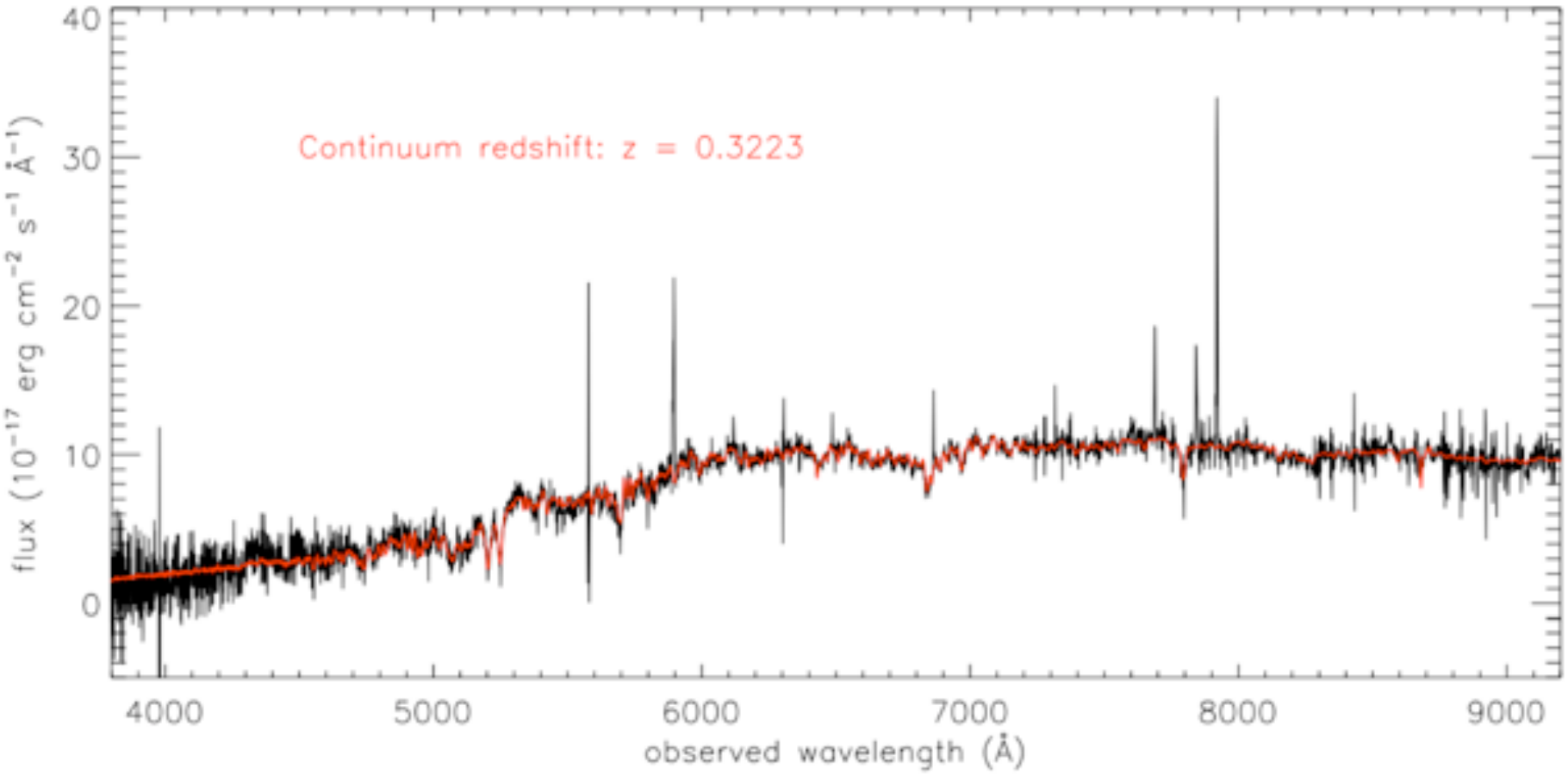
A number of different strategies:

- Look for potential lenses or potential deflectors and use additional information to identify the (small) subset of strong gravitational lensing events.

- Searching for gravitational lensing morphologies in high-resolution data (e.g. HST, Marshall et al. 2009)

How to find lenses - Optical

SLACS



www.slacs.org

How to find lenses - Optical

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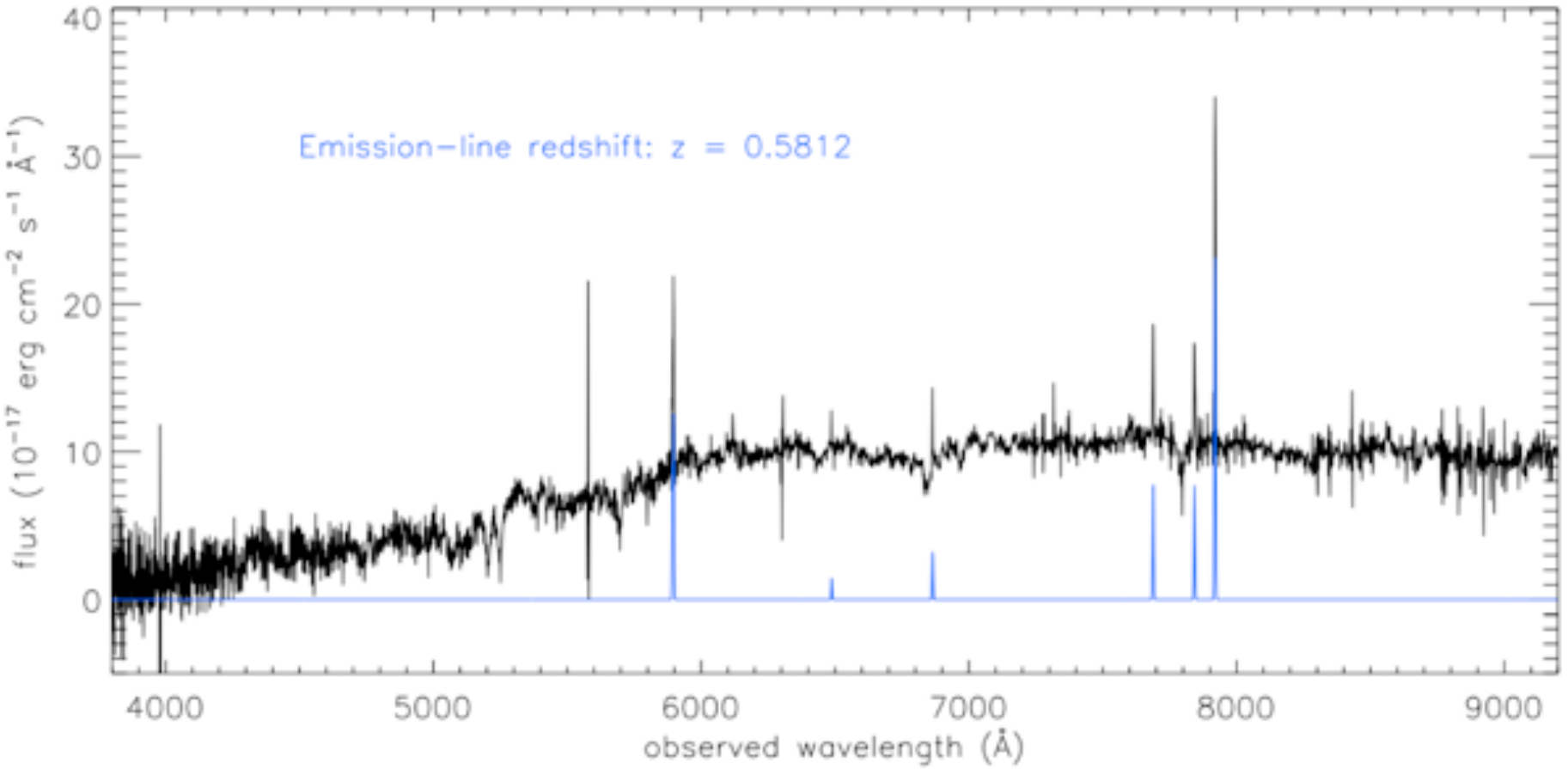

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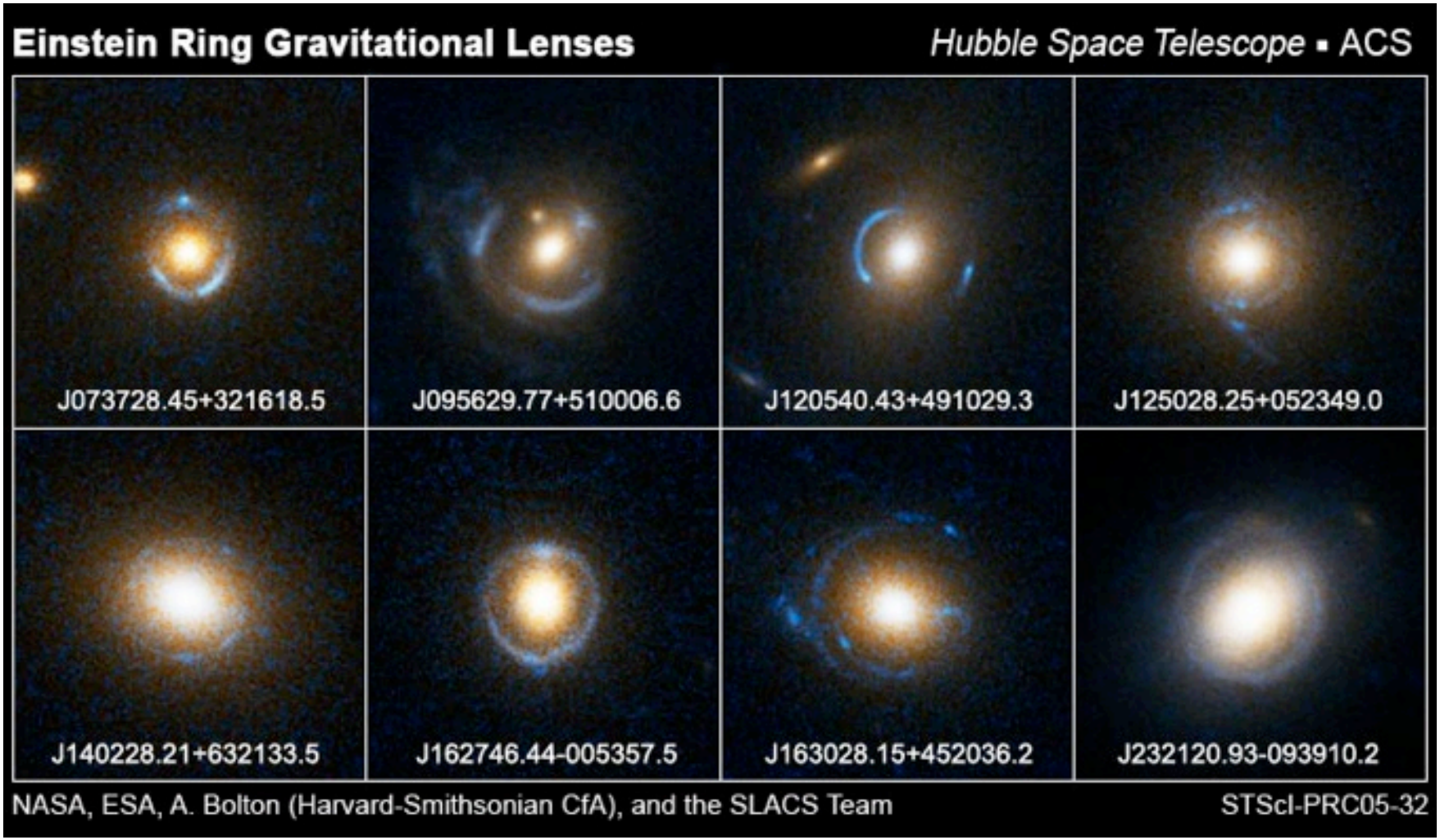
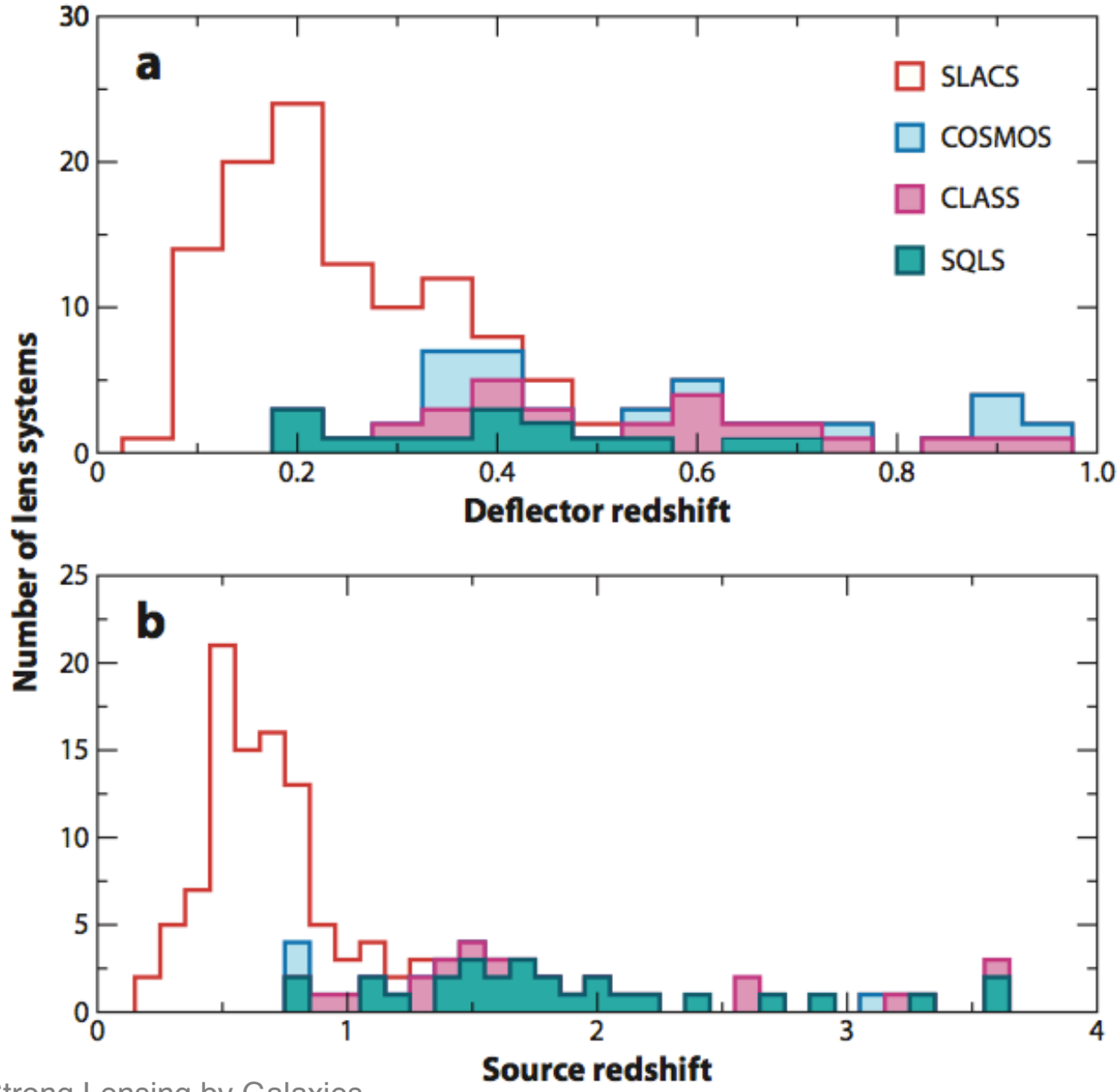


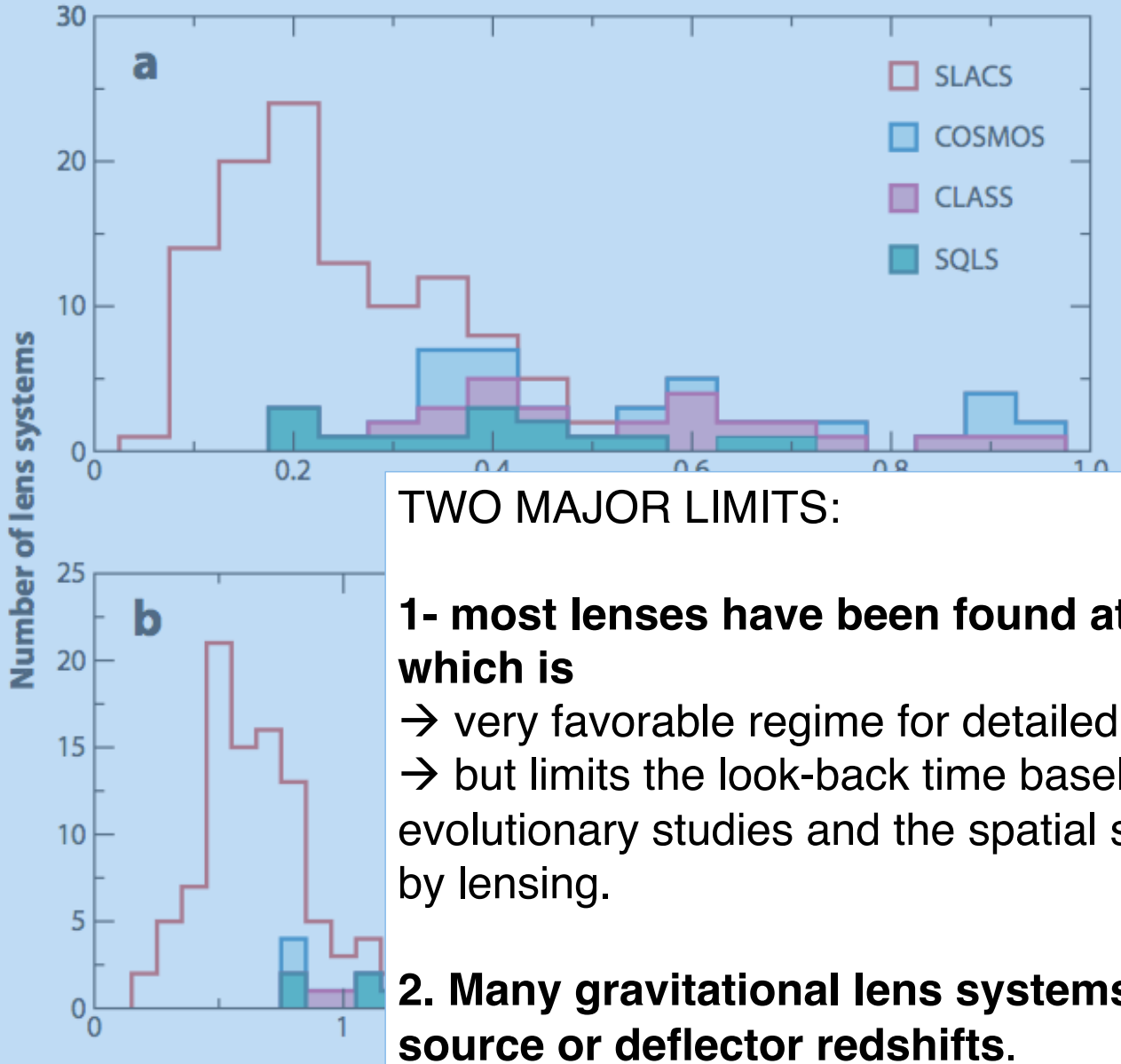
www.slacs.org

How to find lenses - Optical



Treu 2010 – Strong Lensing by Galaxies

How to find lenses (before Herschel)



TWO MAJOR LIMITS:

1- most lenses have been found at z < 0.4, which is

→ very favorable regime for detailed follow-up

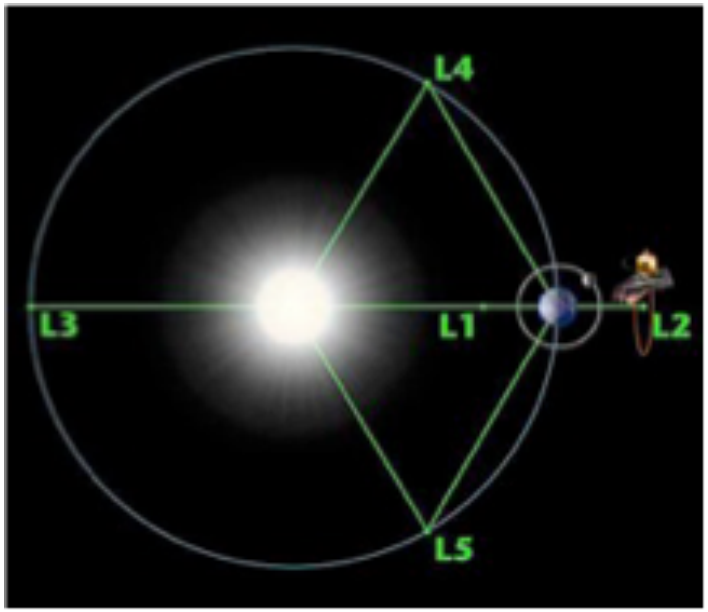
→ but limits the look-back time baseline for evolutionary studies and the spatial scales probed by lensing.

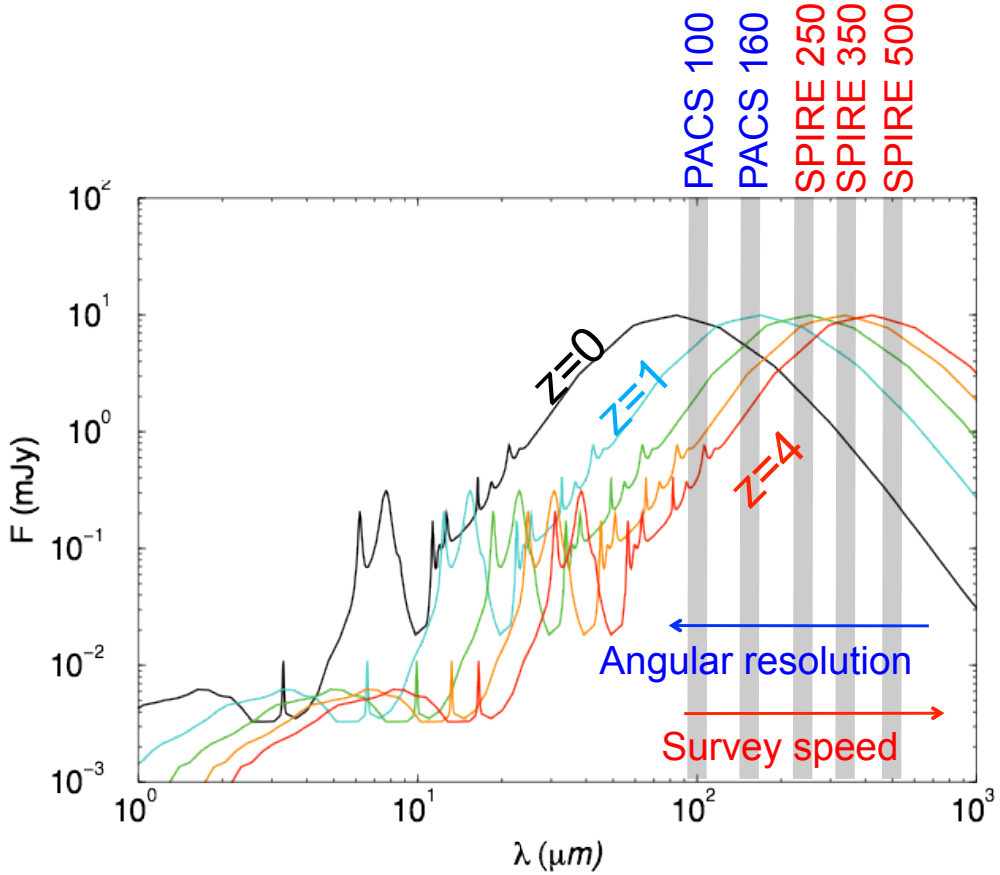
2. Many gravitational lens systems still lack source or deflector redshifts.

Treu 2010 – Strong Lensing by Galaxies

A breakthrough: Herschel

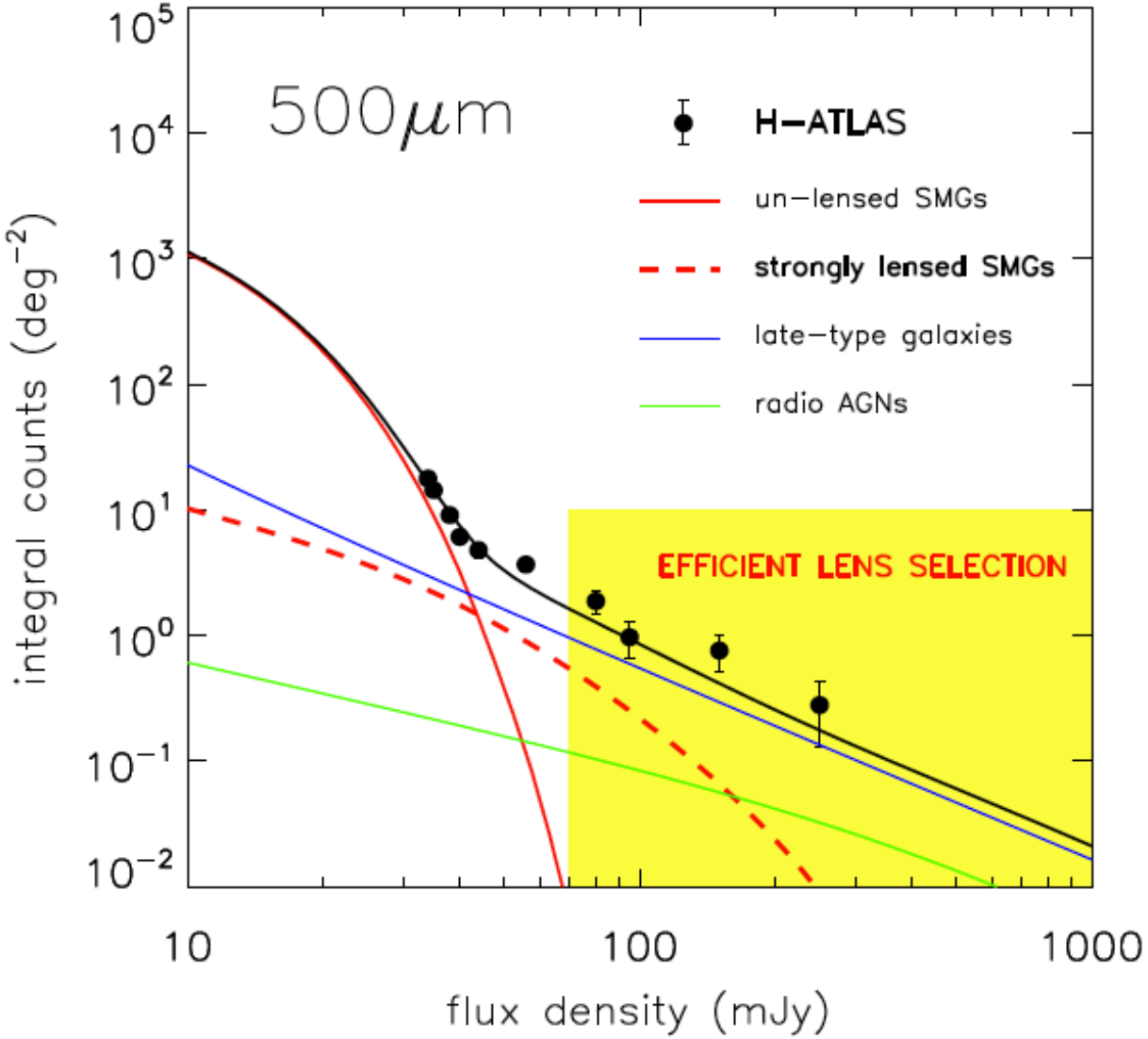
Herschel is an ESA cornerstone mission (2009-2013)
- large (3.5 m) aperture, low emissivity (~5%), passively cooled (70-90 K)
- cryogenically cooled focal plane science instruments

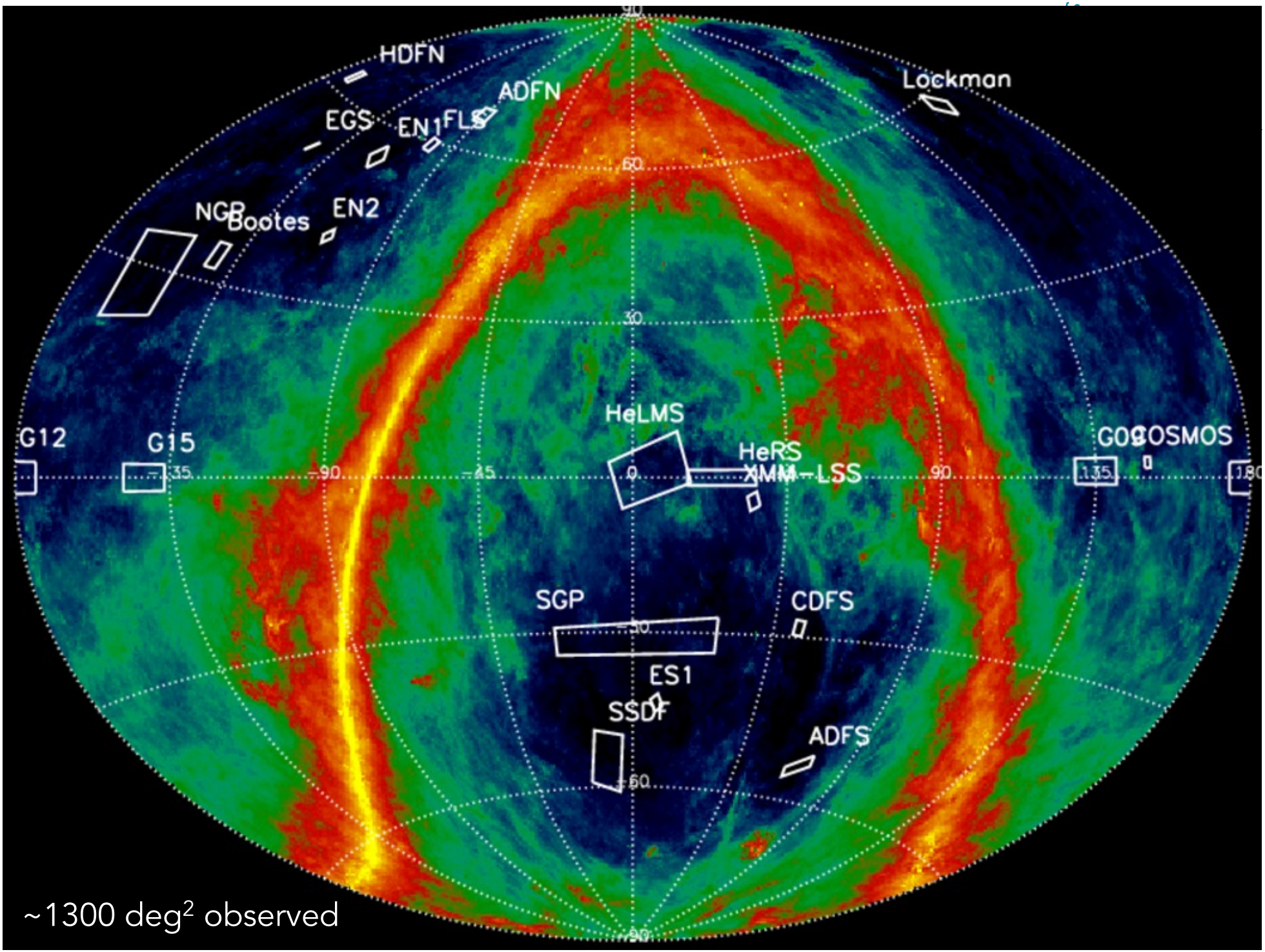


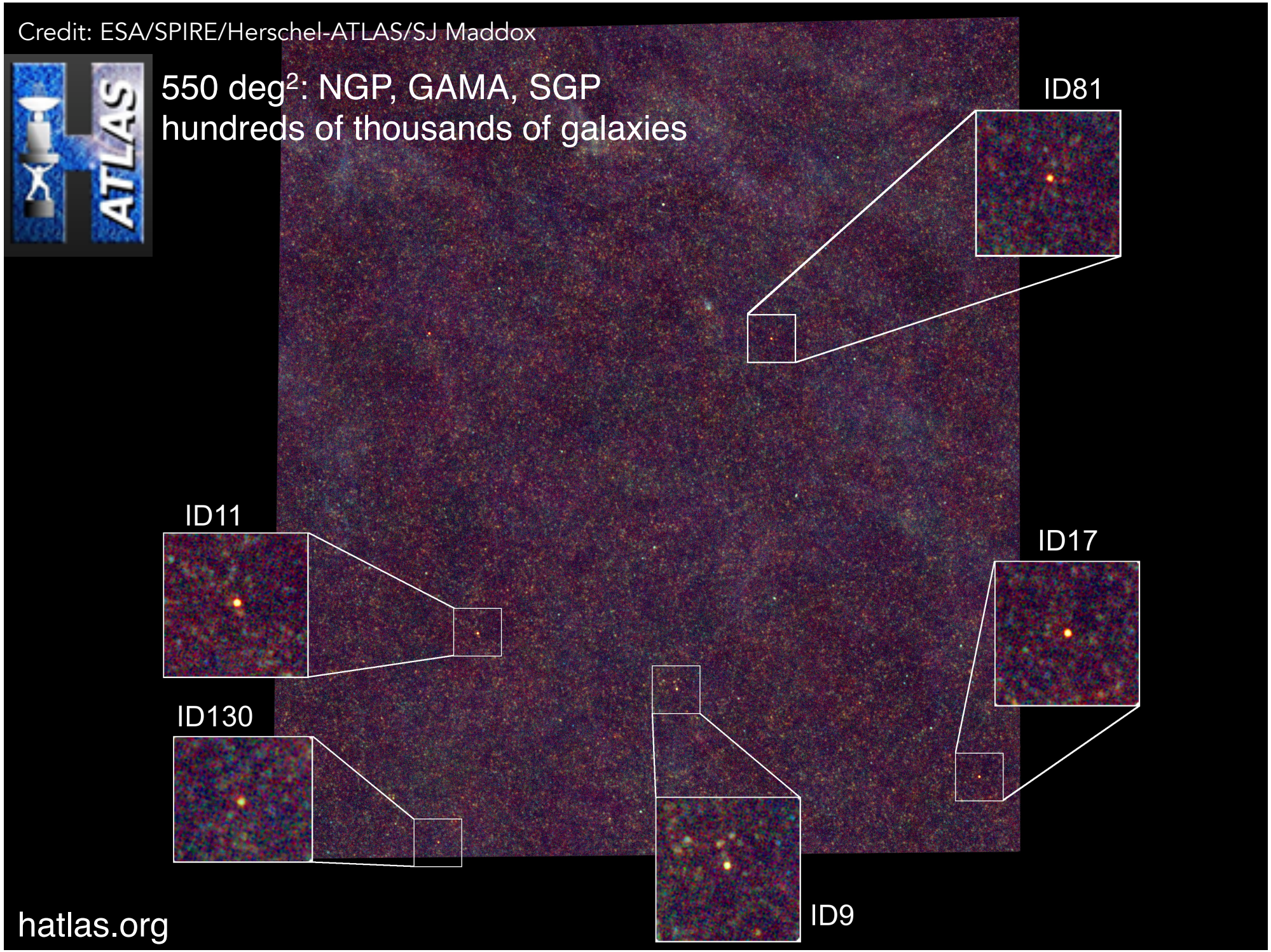


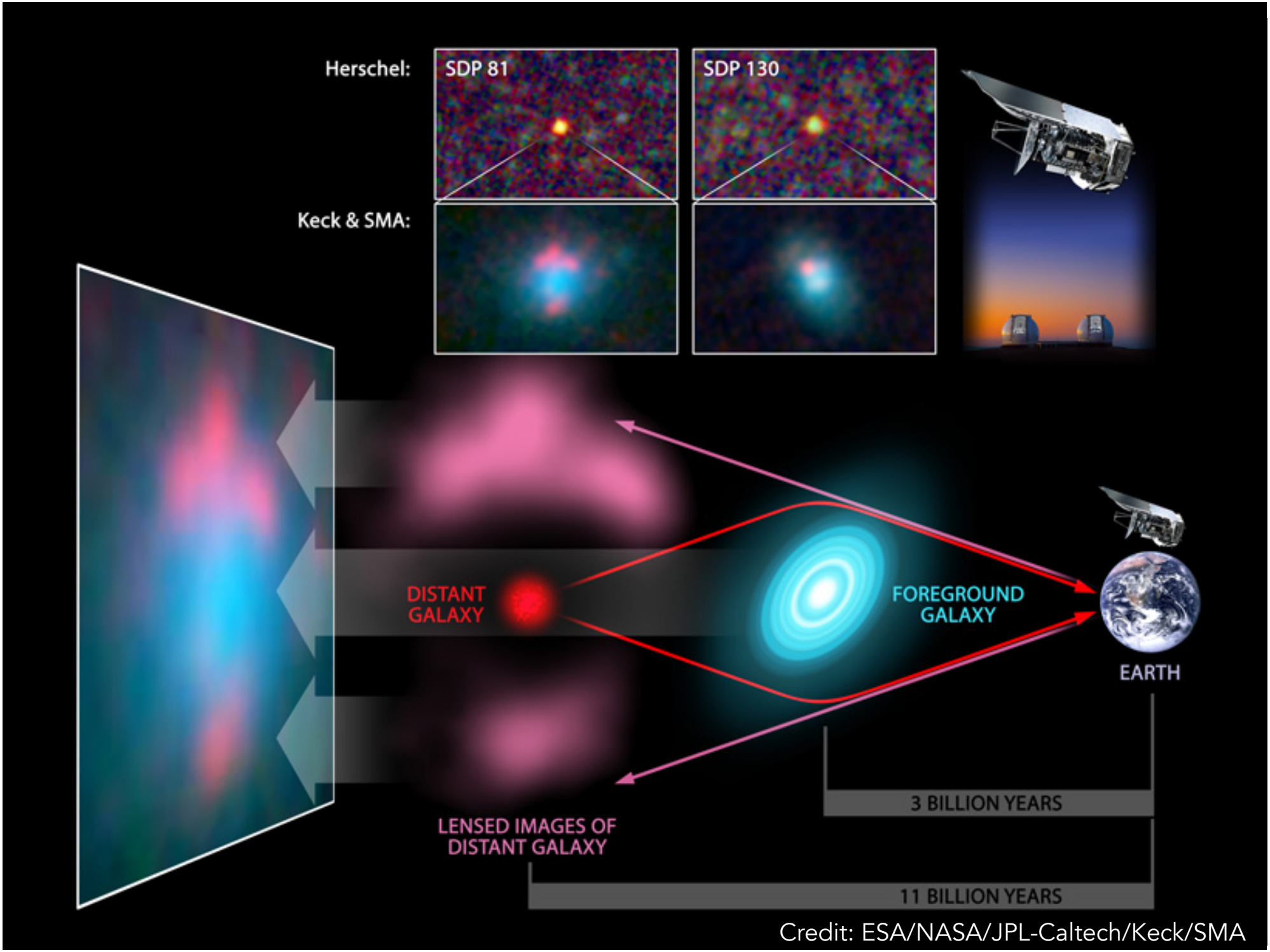
A breakthrough: Herschel

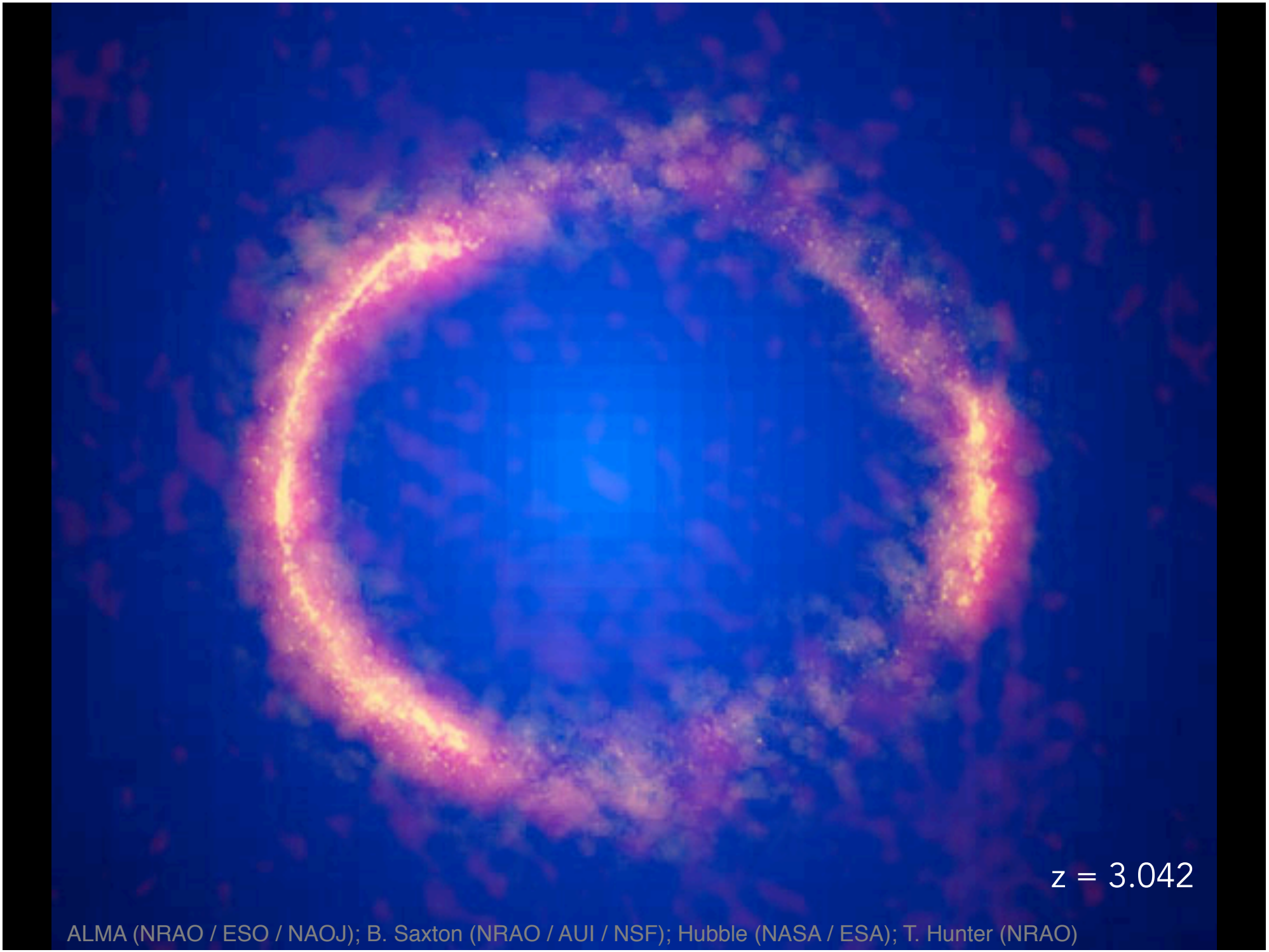
Negrello et al. 2010 Science 330, 800




HDFN
EGS
EN1
FLS
ADFN
Lockman
NGB
Bootes
EN2
HeLMS
HeRS
XMM-LSS
G12
G15
COSMOS
SGP
CDFS
ES1
SSDF
ADFS
~1300 deg² observed


Credit: ESA/SPIRE/Herschel-ATLAS/SJ Maddox
ATLAS
550 deg²: NGP, GAMA, SGP
hundreds of thousands of galaxies
ID81
ID11
ID17
ID130
ID9
hatlas.org


Herschel:
SDP 81
SDP 130
Keck & SMA:
DISTANT GALAXY
FOREGROUND GALAXY
EARTH
3 BILLION YEARS
LENSED IMAGES OF DISTANT GALAXY
11 BILLION YEARS
Credit: ESA/NASA/JPL-Caltech/Keck/SMA



ALMA (NRAO / ESO / NAOJ); B. Saxton (NRAO / AUI / NSF); Hubble (NASA / ESA); T. Hunter (NRAO)

A breakthrough: Herschel

Negrello et al. 2010 Science 330, 800

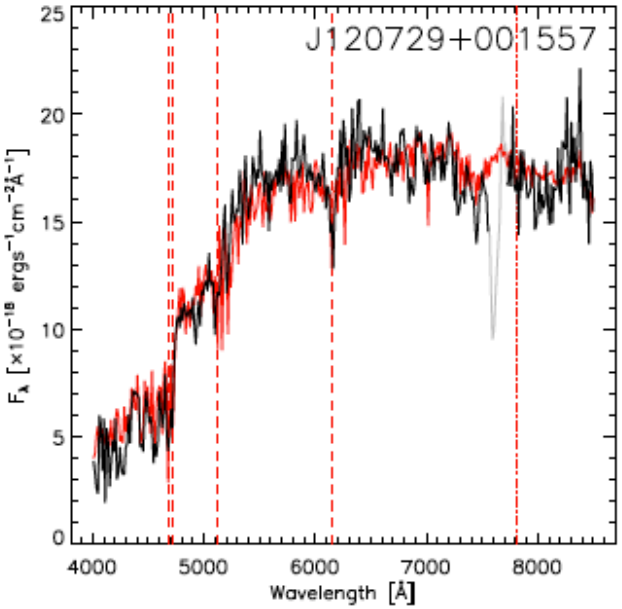
- ~100% lens selection efficiency
- ~1/deg^2 strong gravitational lenses in Herschel ATLAS
- Can find lenses at much higher redshifts

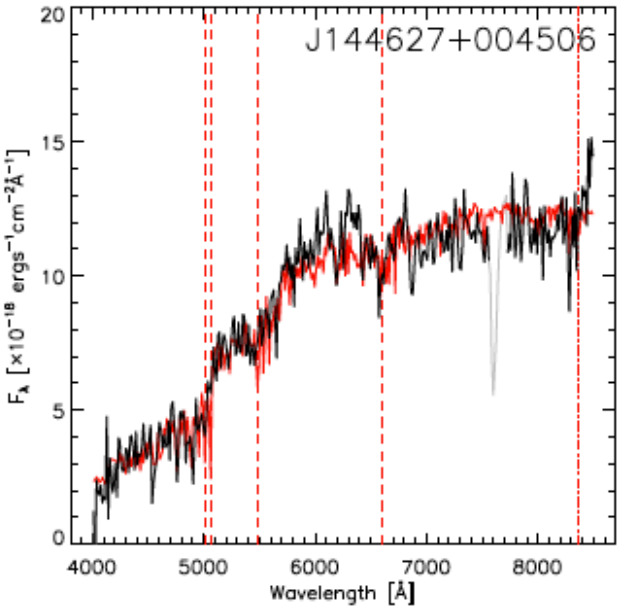
A breakthrough: Herschel

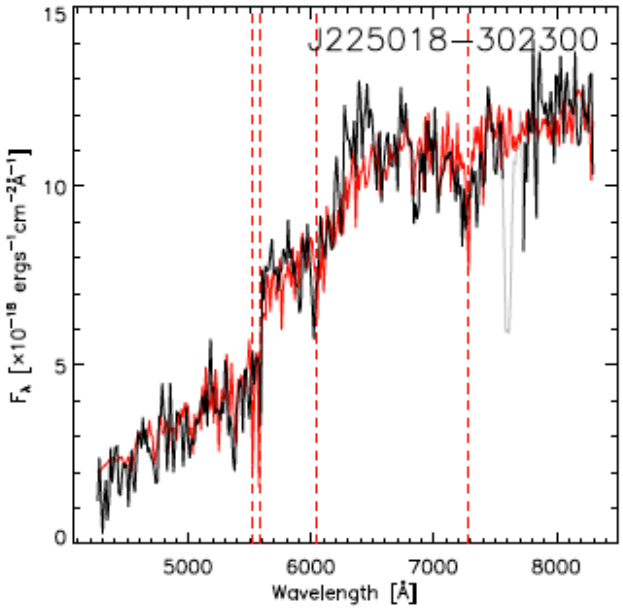
Negrello et al. 2010 Science 330, 800

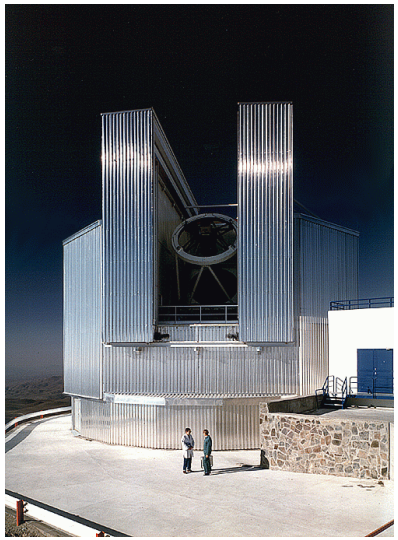
- ~100% lens selection efficiency
- ~1/deg^2 strong gravitational lenses in Herschel ATLAS
- Can find lenses at much higher redshifts than the optical selection
- Purely magnification-based selection
- Need to follow up: optical spectroscopy for foreground redshifts, CO for background redshifts

Multi-λ follow-ups: NTT spec-z









3.58 m telescope

BUT not great success:

- Bad weather conditions
- Need more time per target

Amber, 2015, PhD thesis

Multi-λ follow-ups: The SALT Strong Gravitational Lensing Legacy Project

Southern African Large Telescope

10-m class optical telescope

Based on HET (Texas, USA)
With significant improvements

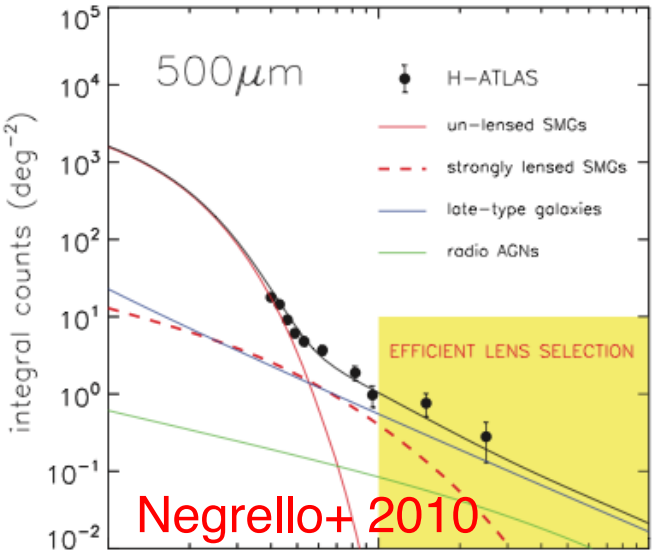
Funded by international consortium
Managed and operated by SAAO

Commissioned in 2011

Multi-λ follow-ups: The SALT Strong Gravitational Lensing Legacy Project

Grating Name	Wavelength Coverage (nm)	Usable Angles (deg)	Bandpass per tilt (nm)	Resolving Power (1.25" slit)
PG0300	370–900		390/440	250–600
PG0900	320–900	12–20	~300	600–2000
PG1300	390–900	19–32	~200	1000–3200
PG1800	450–900	28.5–50	150–100	2000–5500
PG2300	380–700	30.5–50	100–80	2200–5500
PG3000	320–540	32–50	80–60	2200–5500

Multi-λ follow-ups: The SALT Strong Gravitational Lensing Legacy Project

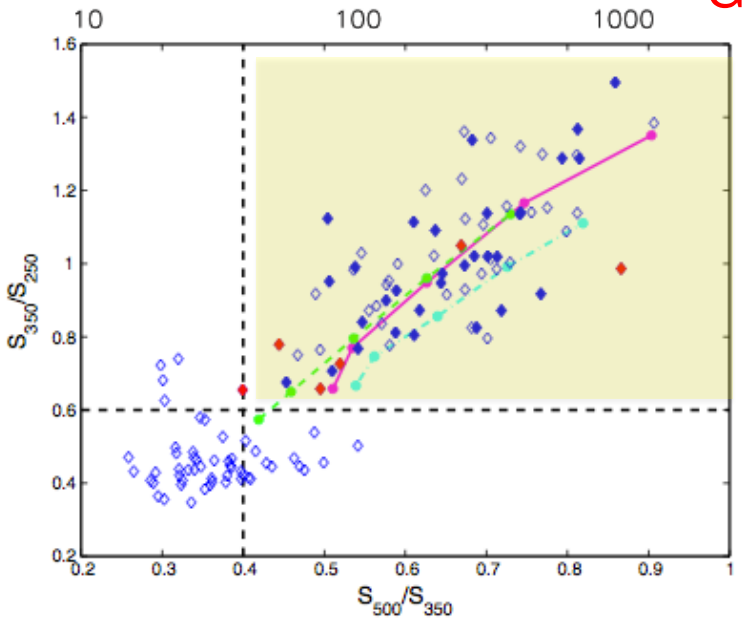


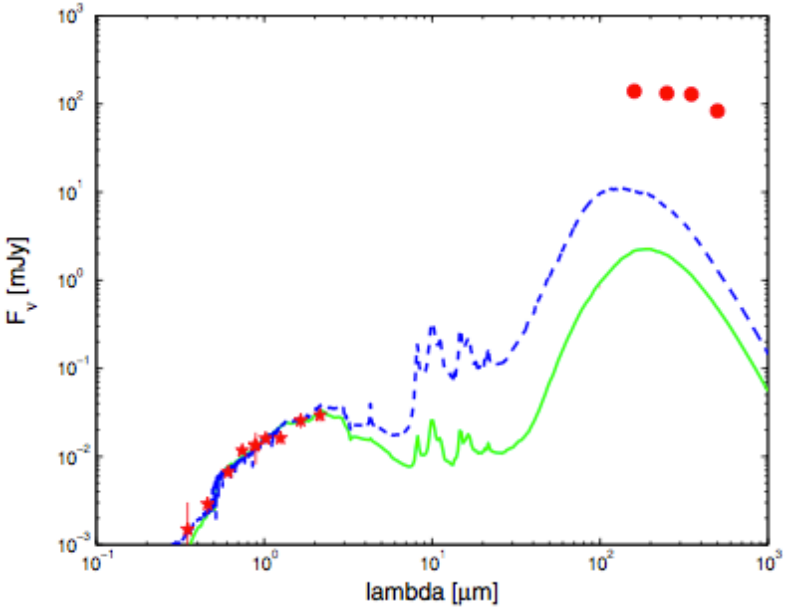
~100% lens selection efficiency
S500 > 100mJy

+

~80% lens selection efficiency
Combining Submm + NIR (+ Optical)
S500 > 80mJy

Gonzalez-Nuevo + 2012





Multi-λ follow-ups: The SALT Strong Gravitational Lensing Legacy Project

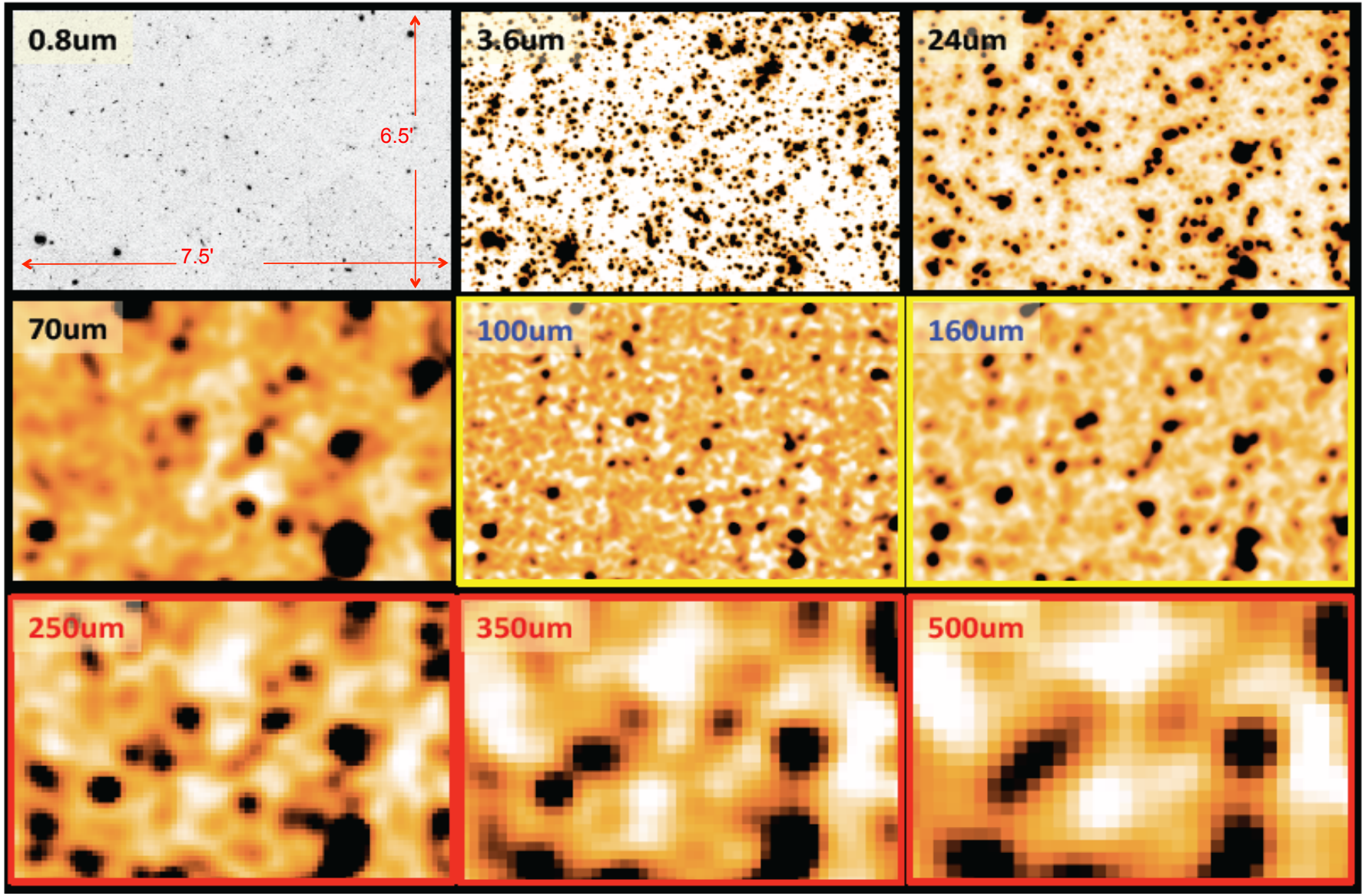
- ~1000 deg^2 Herschel surveys at all RAs
- ~500 Southern strong lens candidates

Multi-λ follow-ups: The SALT Strong Gravitational Lensing Legacy Project

- ~1000 deg^2 Herschel surveys at all RAs
- ~500 Southern strong lens candidates

- ~2 lenses per hour / long-slit RSS spec.
- 300hrs grey nights, 3-yr long term program
- ~1.5" seeing, poor transparency

How to identify the right counterpart?

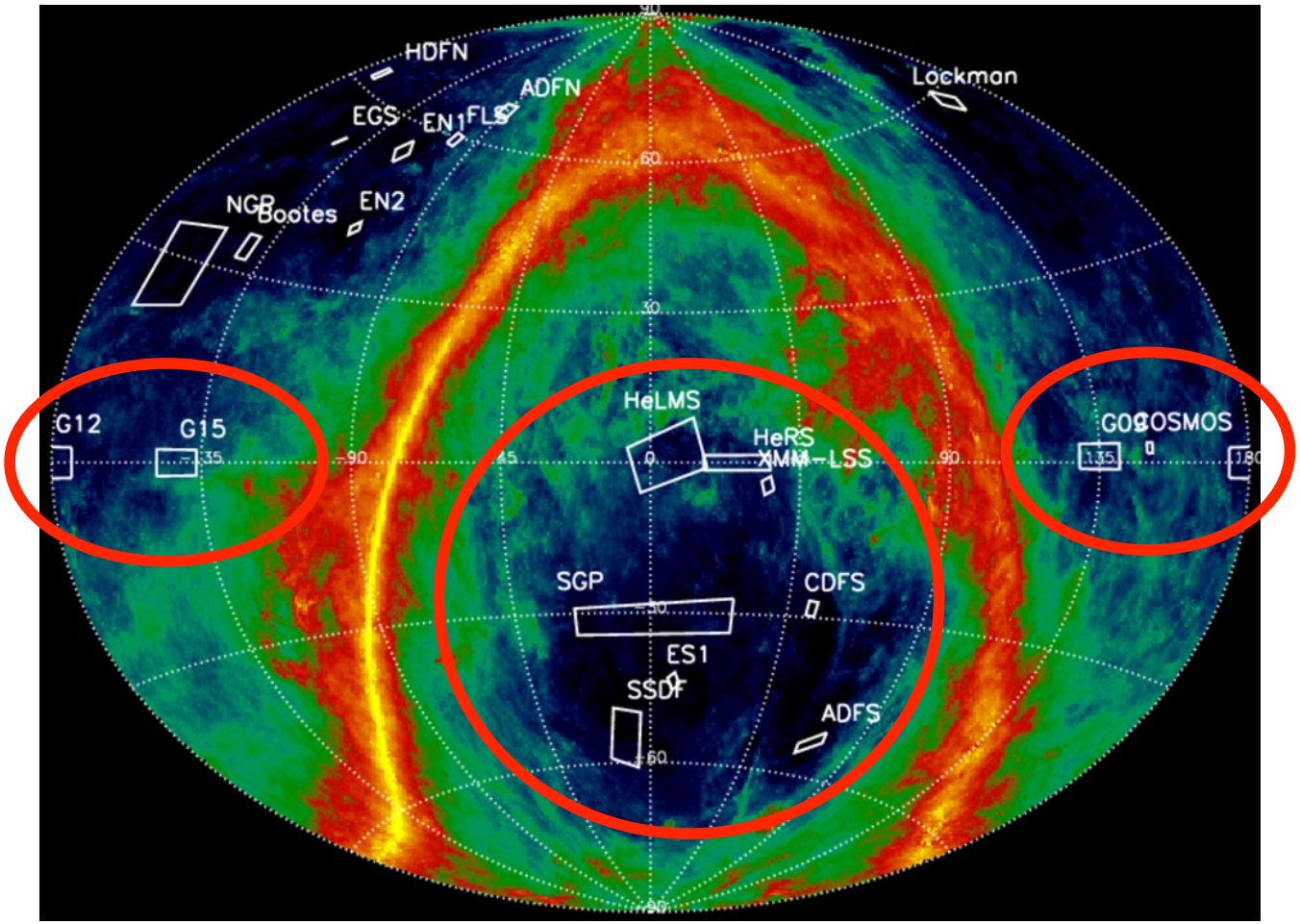


GOODS-N - D. Elbaz

From Herschel to the SALT Strong Gravitational Lensing Legacy Project

- 2.5 MEuros EC-REA FP7-SPACE Project co-funded by South African DST
- Bringing together Multi-Wavelength Data Over Herschel Extragalactic Fields
- Releasing Data Products and Software Tools to the Astronomical Community
- PI : Seb Oliver (Sussex)
- Project Scientists : Peter Hurley (Sussex) & Mattia Vaccari (UWC)

Multi-λ follow-ups: The SALT Strong Gravitational Lensing Legacy Project



- GALEX (UV)
- VST (ugriz)
- DES (grizy)
- VISTA (ZYJHK)
- IRAC & MIPS
- PACS & SPIRE
- GMRT/JVLA/ LOFAR/WSRT
- ASKAP/MeerKAT

See also Spitzer Data Fusion @ http://mattiavaccari.net/df/

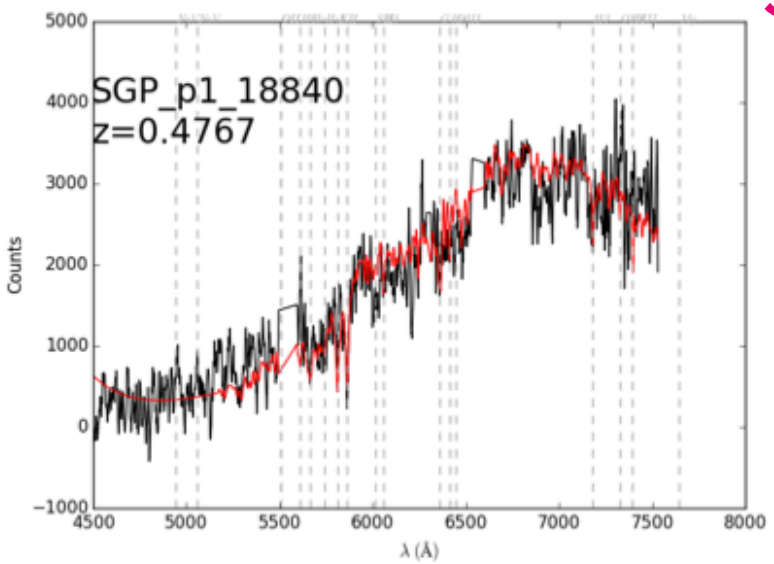
Vaccari 2015, Marchetti PhD thesis & Marchetti et al. 2016

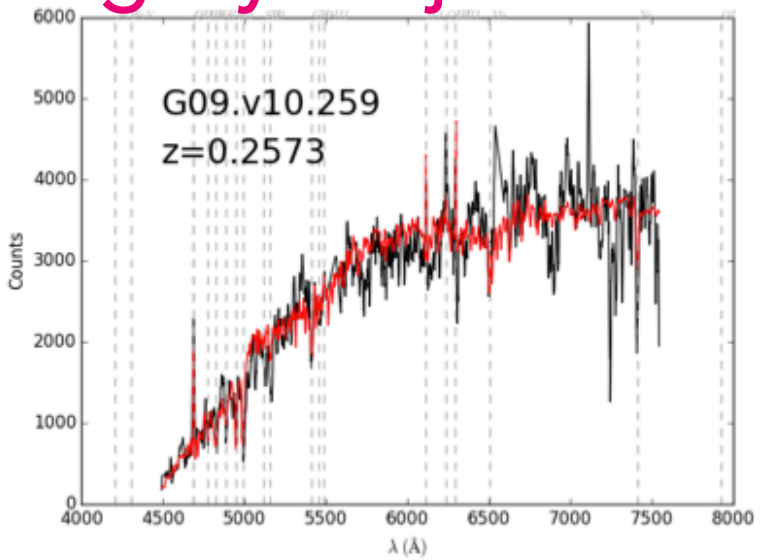
Multi-λ follow-ups: The SALT Strong Gravitational Lensing Legacy Project

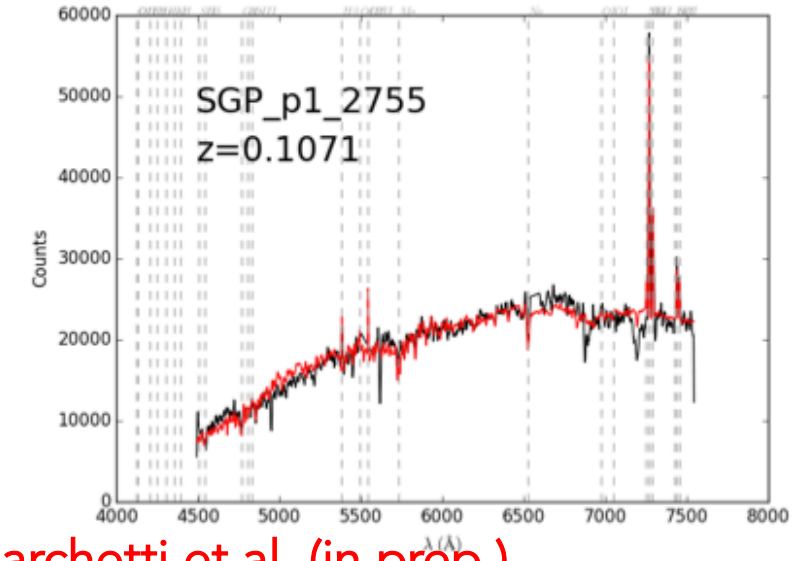
- PI : Stephen Serjeant (OU)
- Project Scientist : Lucia Marchetti (UCT/UWC)
- SALT Data Manager: Steve Crawford (SAAO)
- Data Fusion Manager : Mattia Vaccari (UWC)

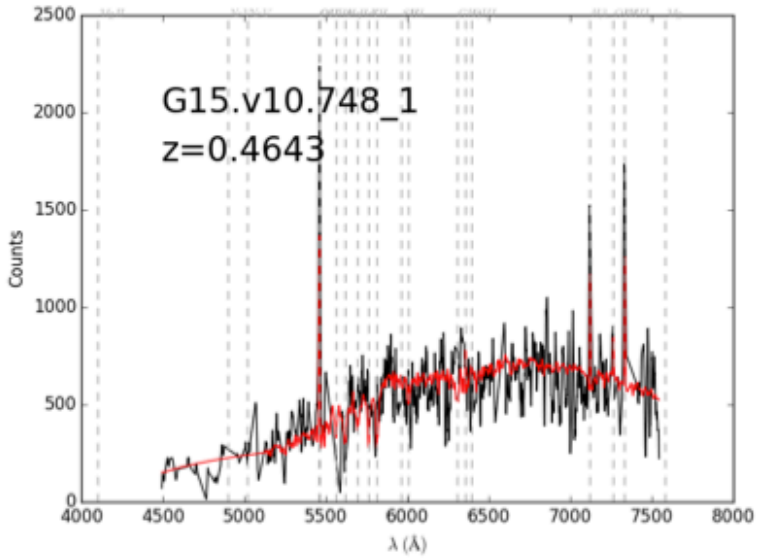
- 2015-2: 25.7hrs P1 + 9.6hrs P3
- 2016-1: 17.5hrs P2 + 48hrs P3
- 2016-2: 2.9hrs P1 + 5.5hrs P2 + 92.2hrs P3
- 2017-1: 9.1hrs P1 + 12.64hrs P2 + 34.38hrs P3
- 2017-2: 20.21hrs P2 + 18.8 hrs P3
- 2018-1 (current)

Multi-λ follow-ups: The SALT Strong Gravitational Lensing Legacy Project



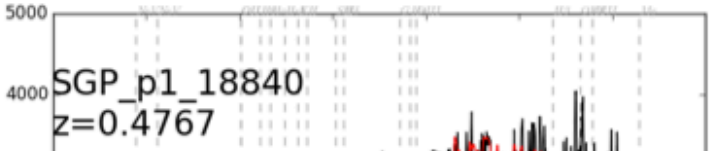






Marchetti et al. (in prep.)

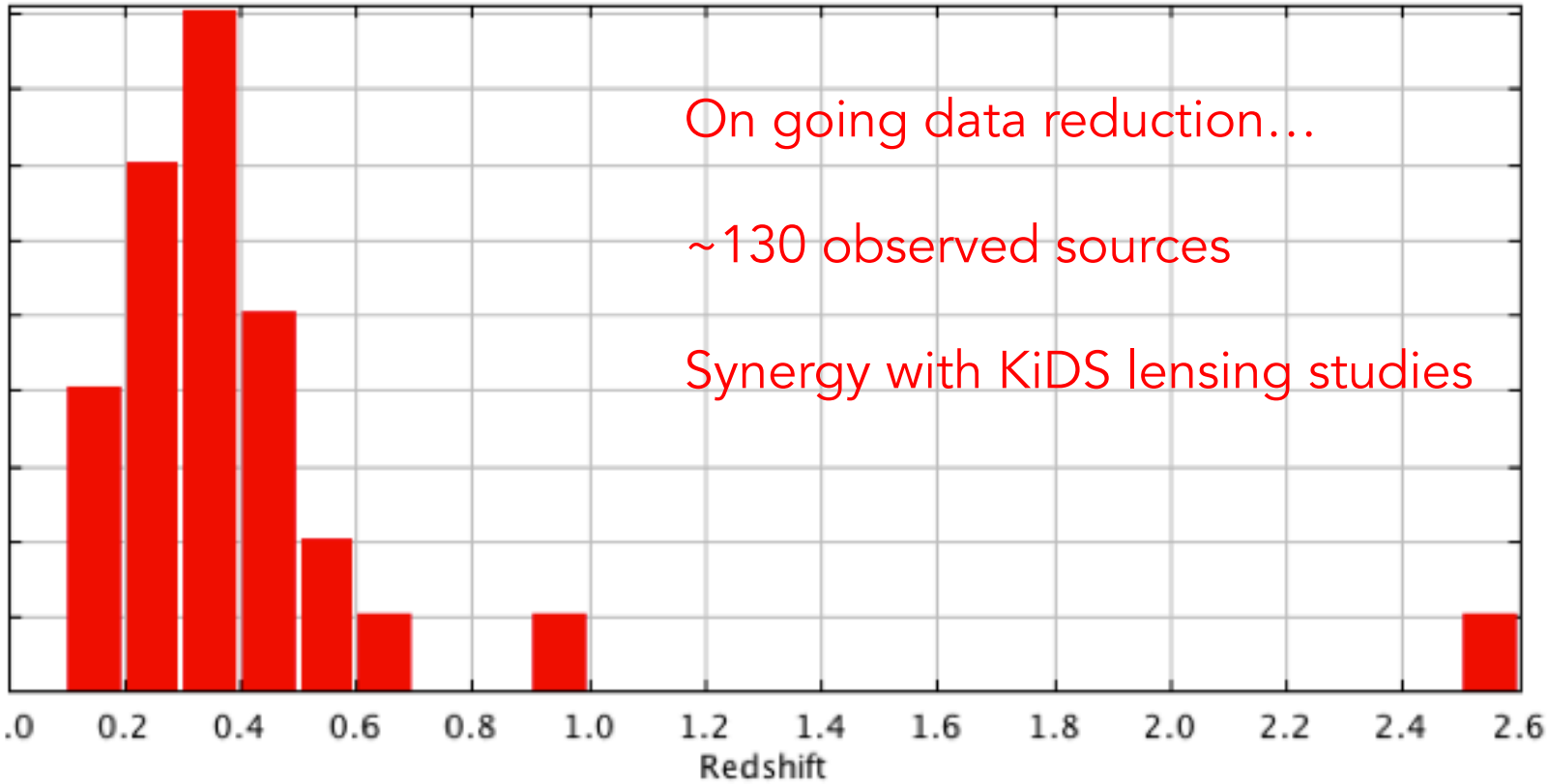
Multi-λ follow-ups: The SALT Strong Gravitational Lensing Legacy Project

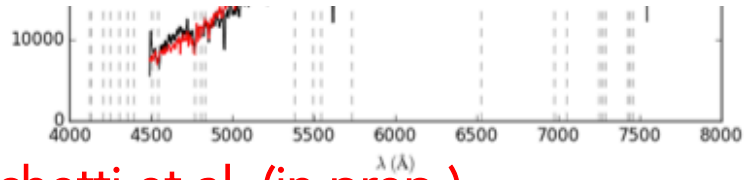


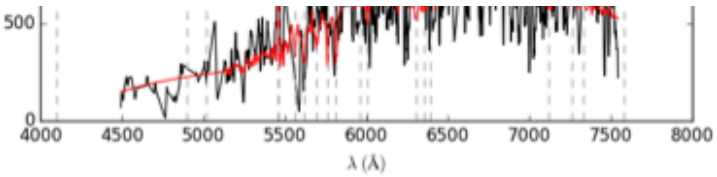
On going data reduction…

~130 observed sources

Synergy with KiDS lensing studies







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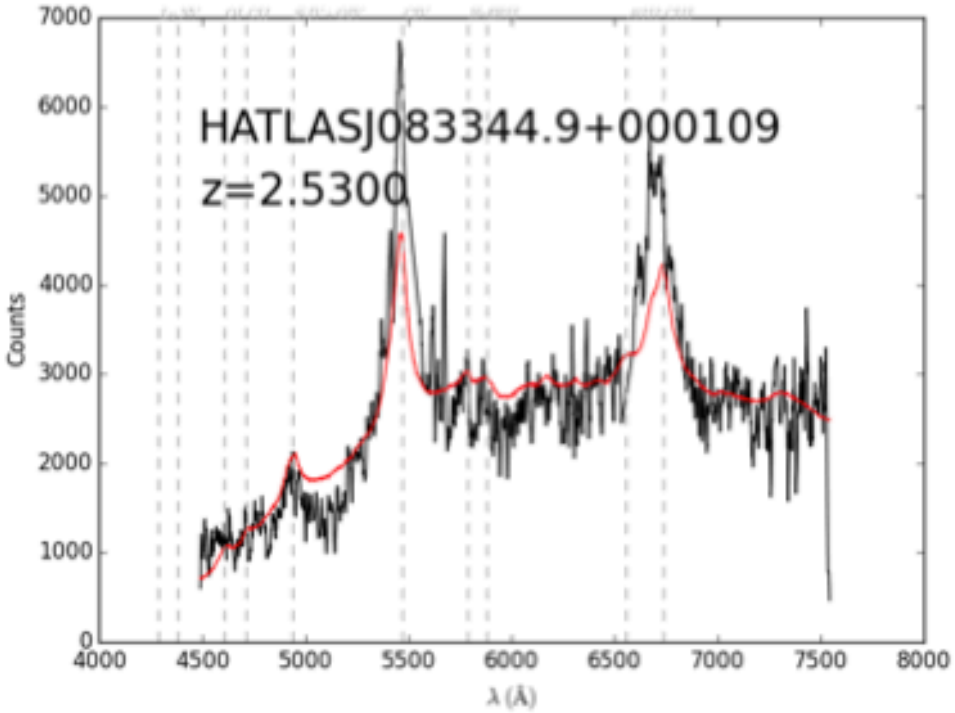
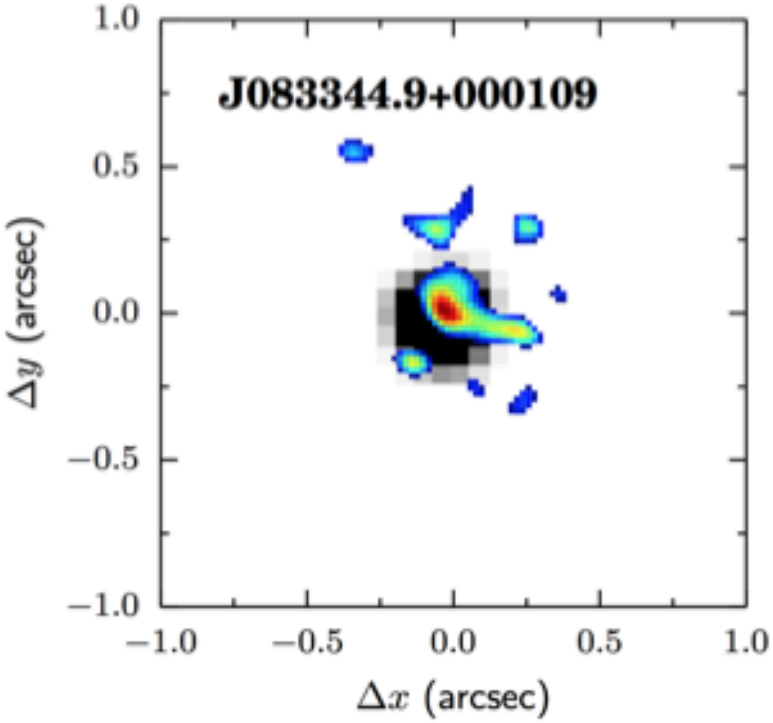
Multi-λ follow-ups: The SALT Strong Gravitational Lensing Legacy Project



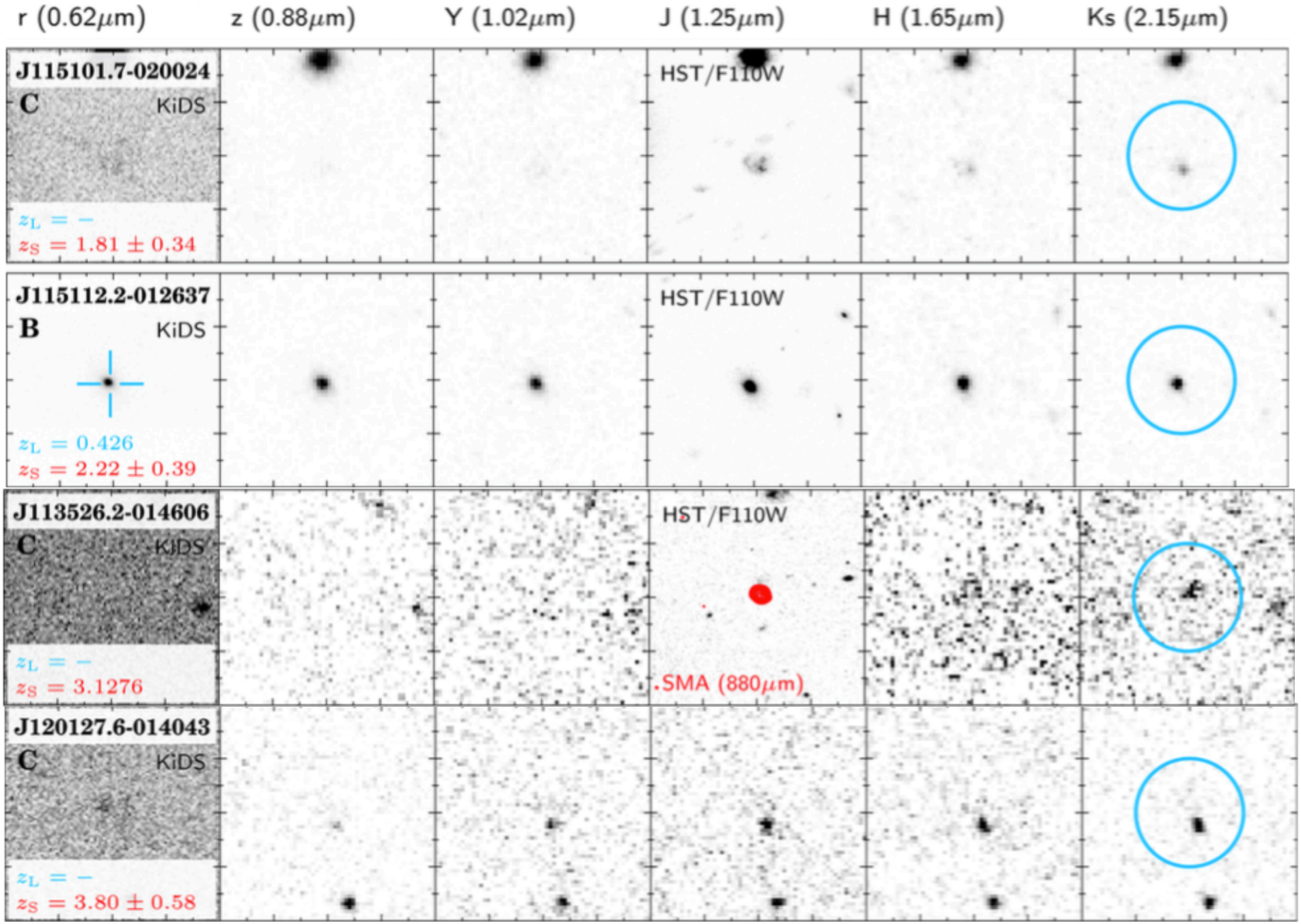
SALT



HST + ALMA

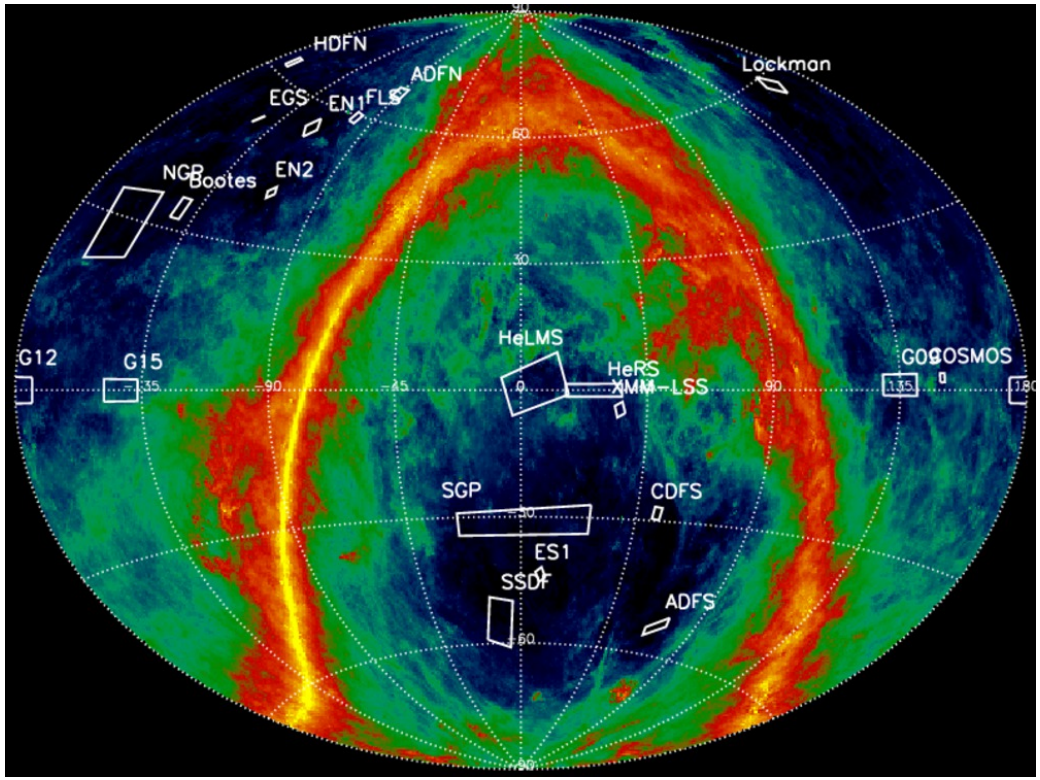
Marchetti el al. (in prep.)

Multi-λ follow-ups (Negrello et al. 2017)

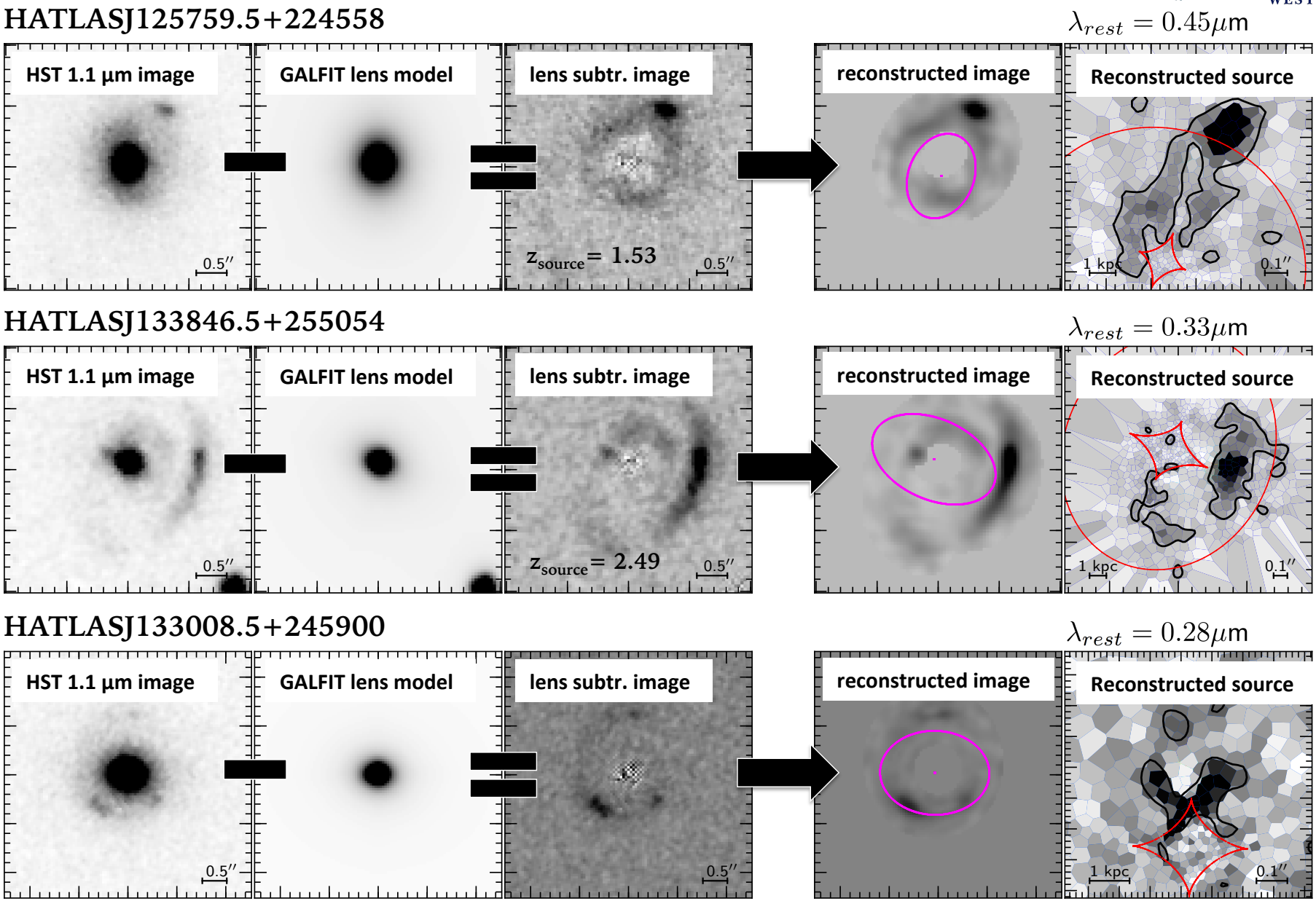


Multi-λ follow-ups: HST

→ Cycle-18 – 5 HATLAS SDP sources (PI: Negrello)
→ Cycle-19 – 200 F110W snapshots (PI: Negrello) – ~85% completed
Negrello et al. in prep Enia et al. in prep
[Etc..]
→ Cycle-25 – 200 F110W Snapshots (PI: Marchetti) – Observing

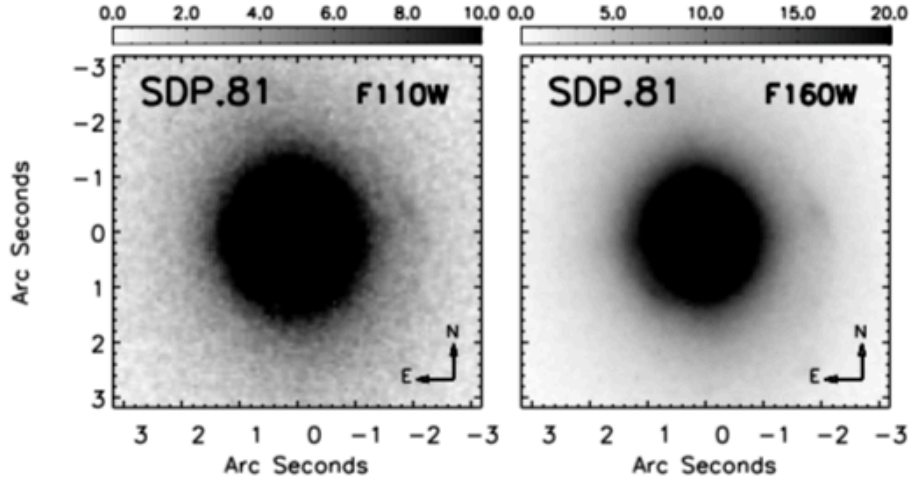


Multi-λ follow-ups & modeling



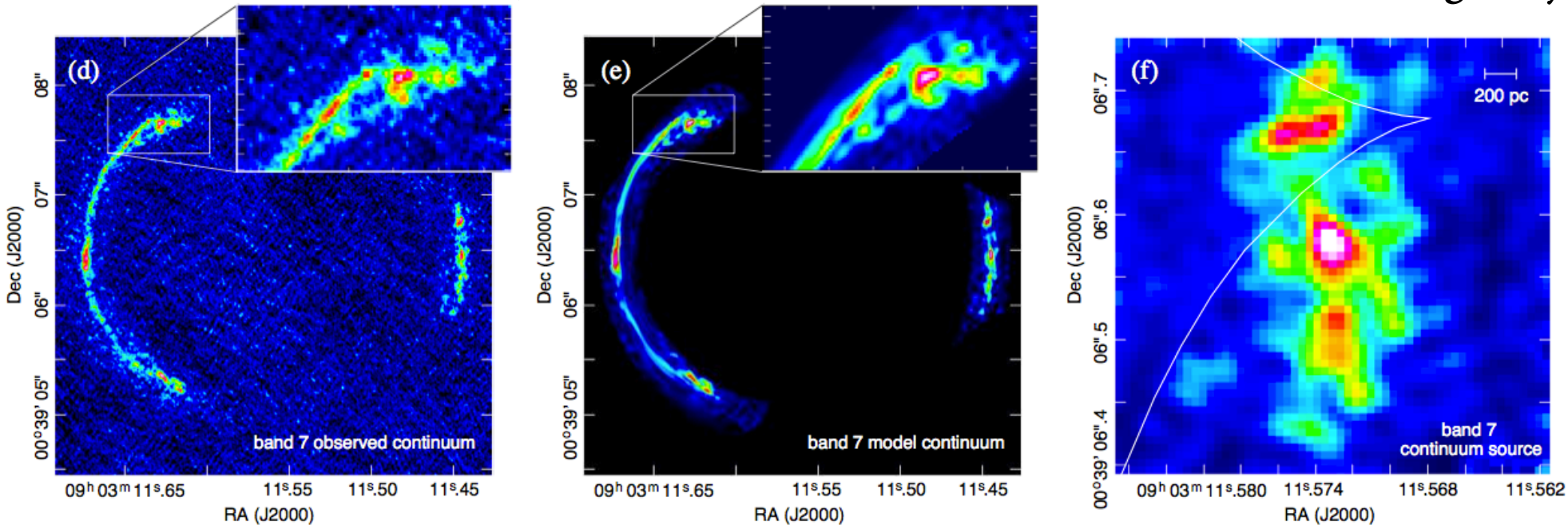
Negrello, Enia et al.(in prep.)

Multi-λ follow-ups: HST + ALMA



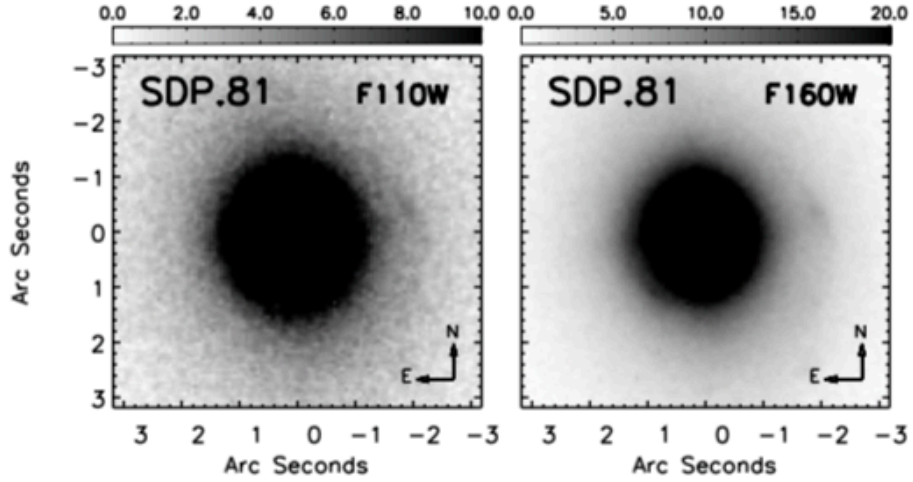
Negrello et al. 2013

Observations (Band 7) Best-fit model Reconstructed galaxy



Dye et al. 2015

Multi-λ follow-ups: HST + ALMA

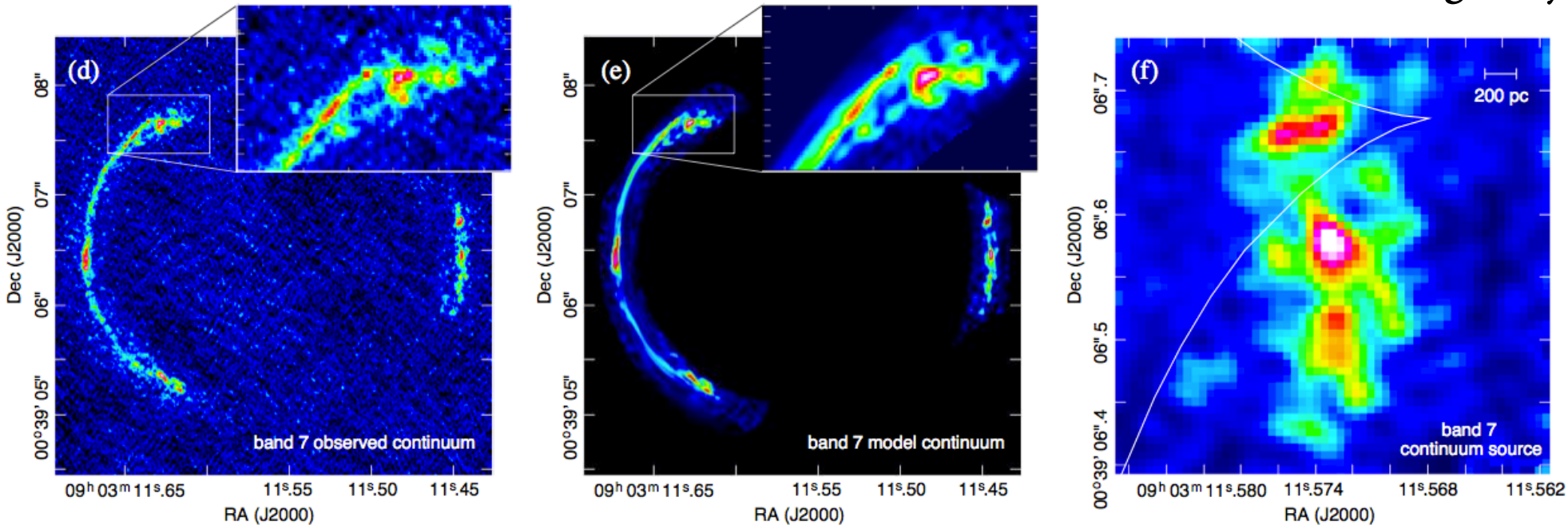


Negrello et al. 2013

Magnification due to lensing: **~6-30**

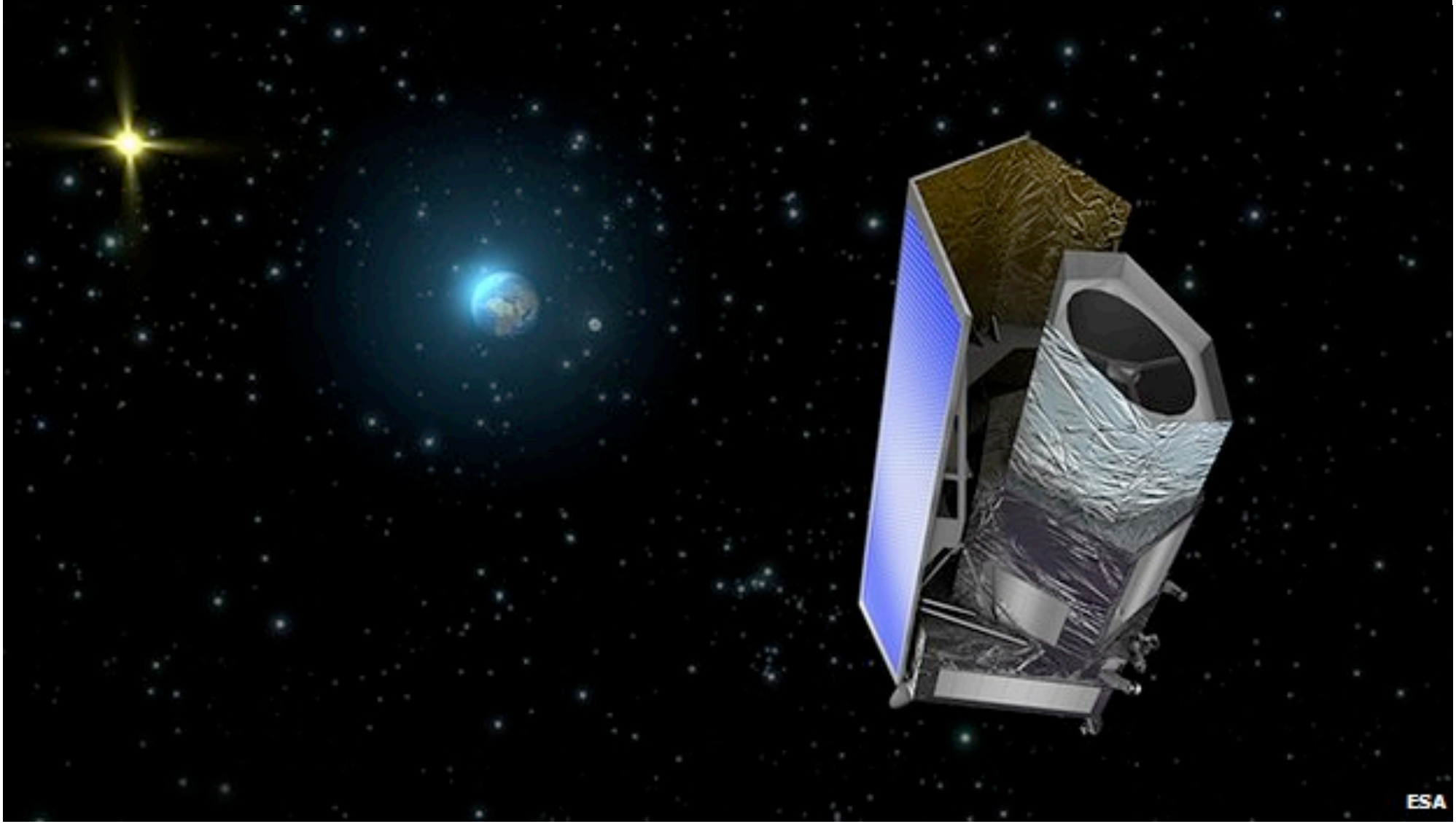
⇒ **resolution of** 180pc/√(6-30) = **30-70 pc !!**

Observations (Band 7) **Best-fit model** **Reconstructed galaxy**



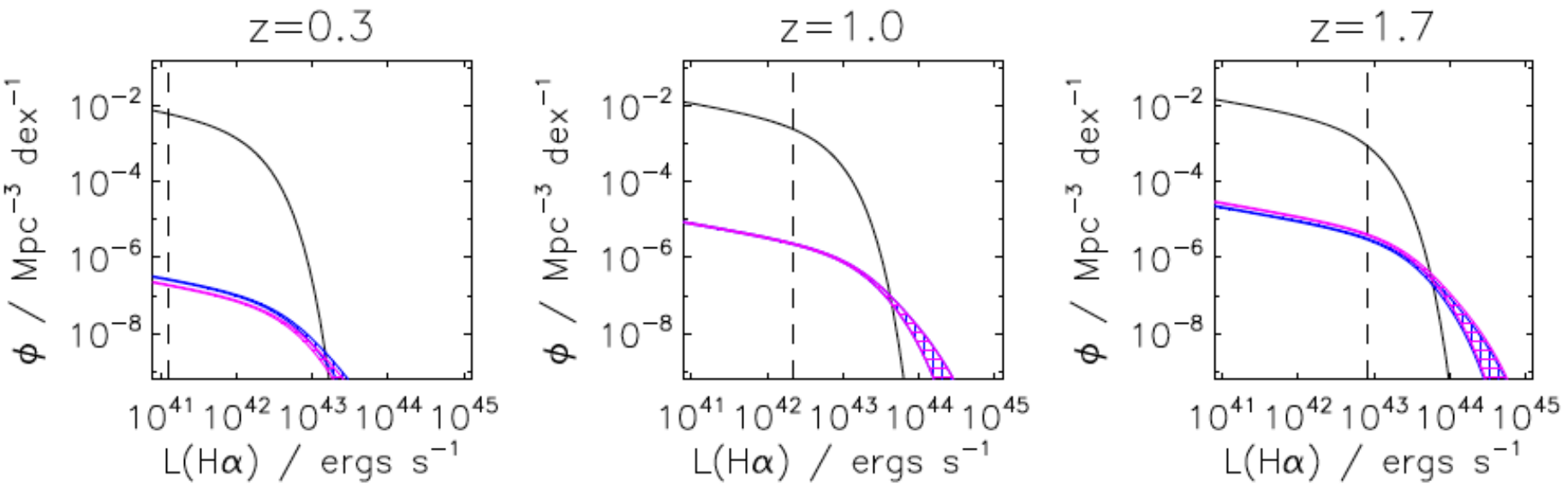
Dye et al. 2015

A golden future: Euclid



Euclid lenses – Hα LF

~1000 Hα lenses (97% pure), and ~10^5 arcs (needs arcfinders)

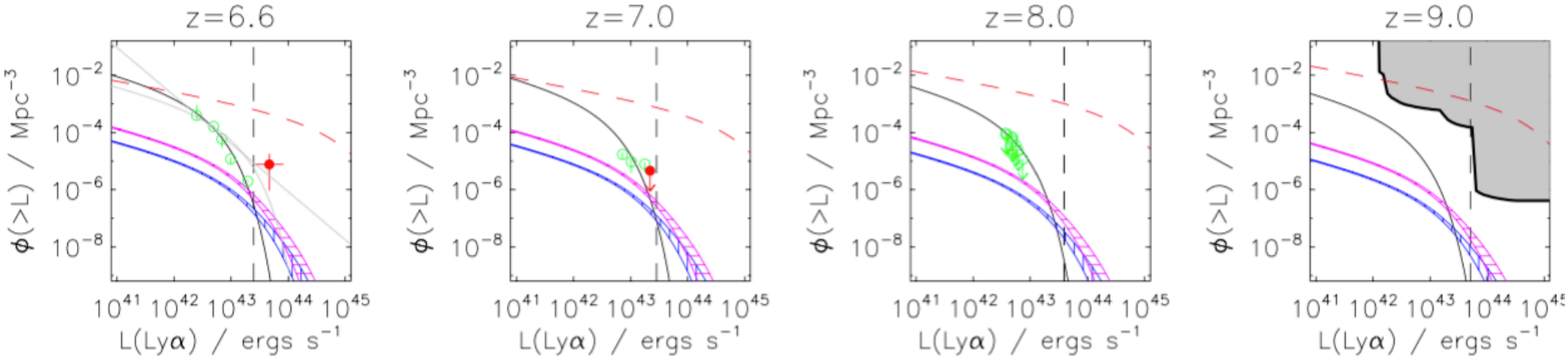


Serjeant 2014 ApJL 793, 10

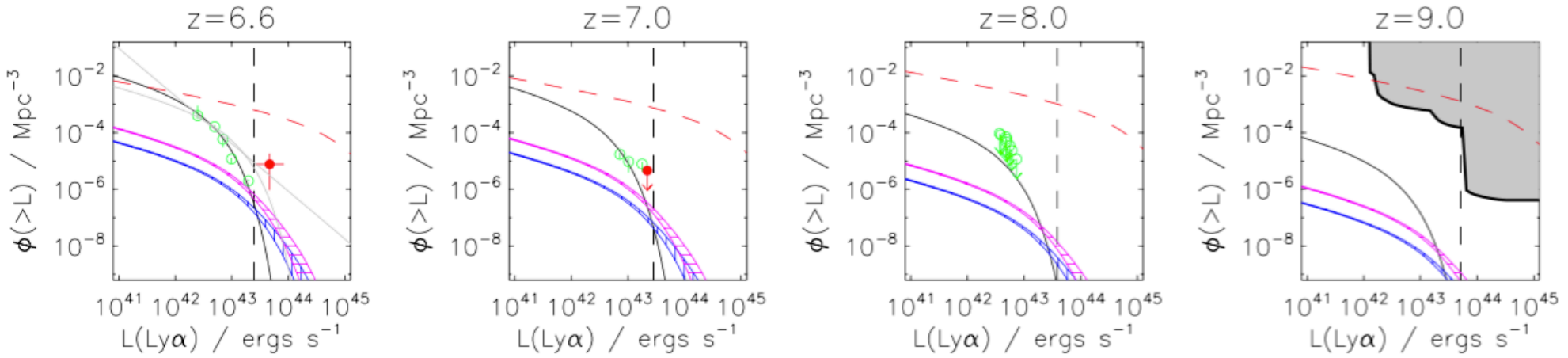
Euclid lenses – Lyman α LF

Marchetti, Serjeant, Vaccari 2017

Using LF from Ouchi et al. 2010

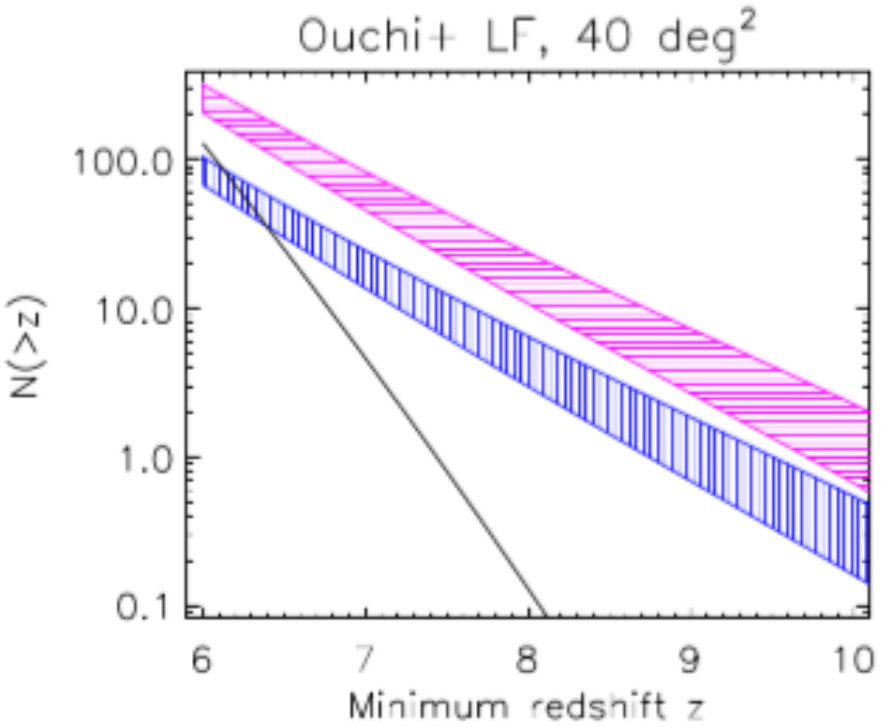


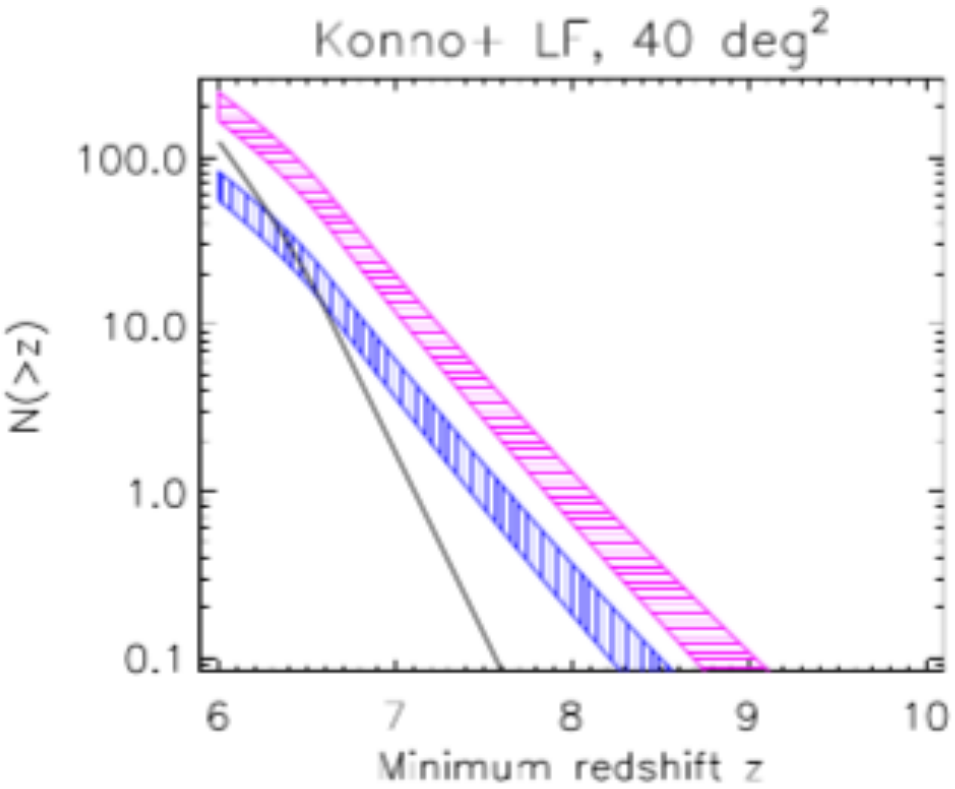
Using LF from Konno et al. 2014



Euclid lenses – Lyman α LF

Strong lensing roughly doubles the numbers of z>6 galaxies with Euclid-Deep surveys!



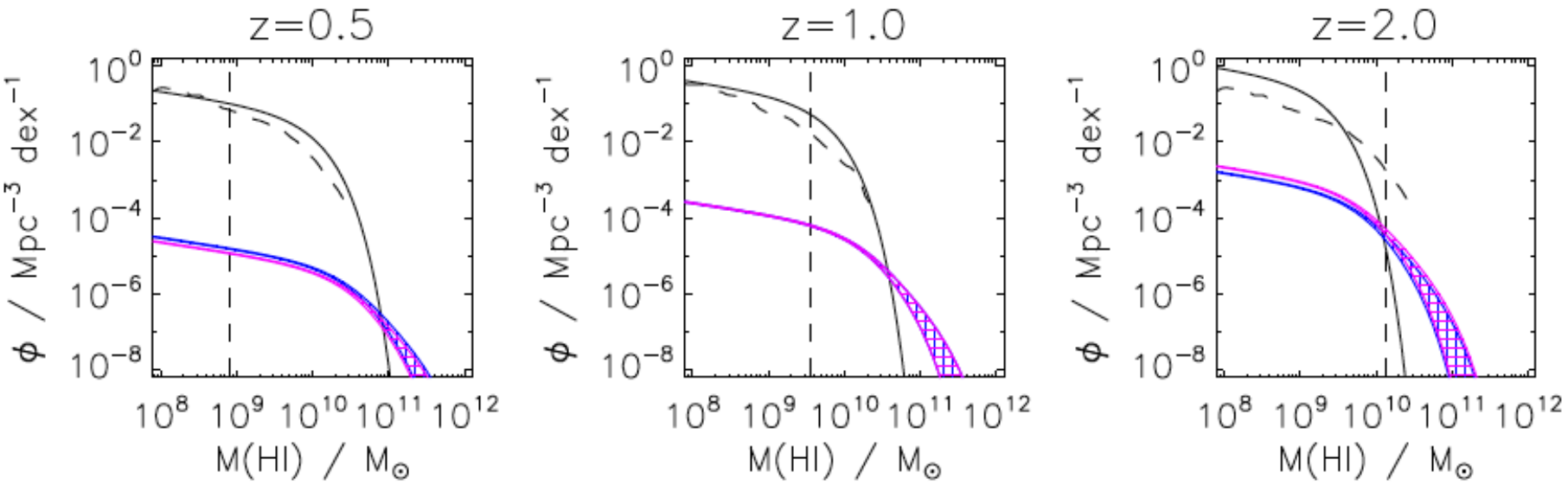


~0.85 and ~1.82 deg^{-2} lensed Ly α emitters at z>6.6

Marchetti, Serjeant, Vaccari 2017

SKA lenses – HI Mass function

~10^4 to ~10^5 strong lenses in SKA-2 dark energy survey!

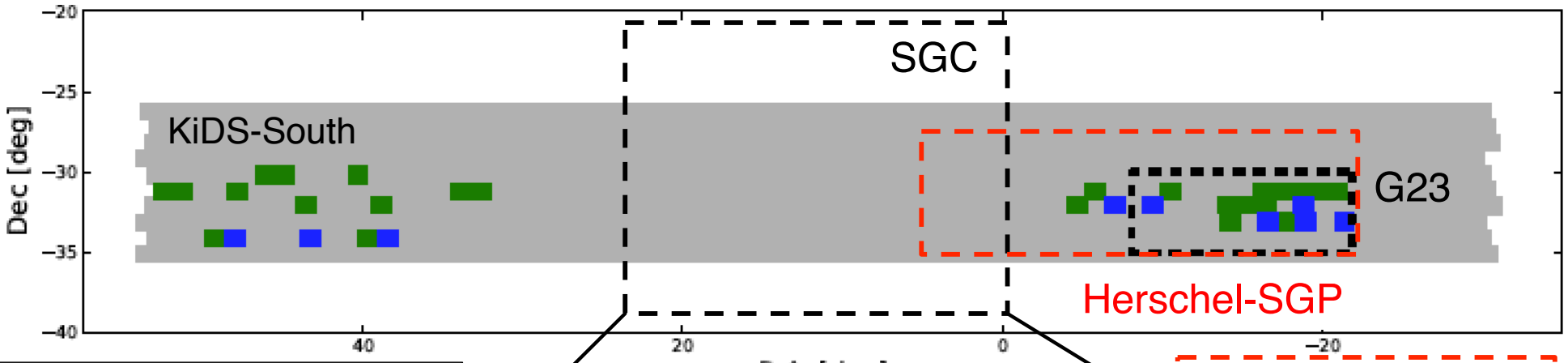


Serjeant 2014 ApJL 793, 10

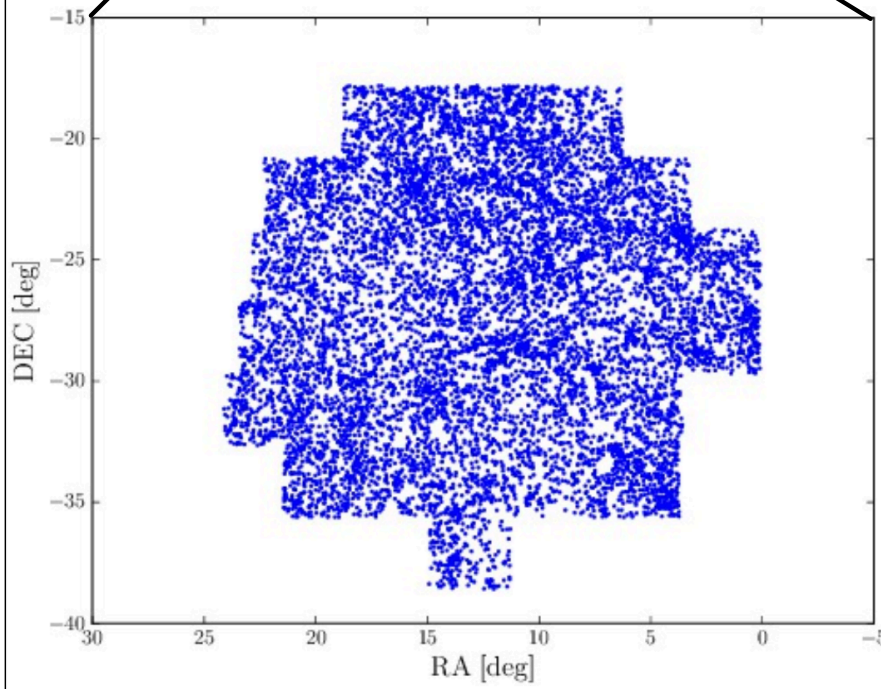
Summary

- Gravitational lensing is a powerful tool for cosmology
- Herschel has opened the door to a new strong lensing selection criterion – mostly complementary to Optical/ KiDS selection
- Redshifts and a multi-wavelengths observations are crucial to identify and characterise the lensing phenomena
- Euclid, SKA… will provide many more lensing systems enabling to put stronger constraints on cosmological parameters

EXTRAS: NEW WISE G23 & South Galactic Cap Project



Based on the example of G12 (Jarrett et al. 2017)
We aim to characterise the
WISE & Multi-λ properties of these sources to prepare the ground for Radio surveys.
e.g. KIDS is crucial for photo-z …



Available surverys:

- WISE
- GALEX (UV)
- VST (ugriz)
- DES (grizy)
- VISTA (ZYJHK)
- IRAC & MIPS
- PACS & SPIRE
- GMRT/JVLA/ LOFAR/WSRT
- ASKAP/MeerKAT

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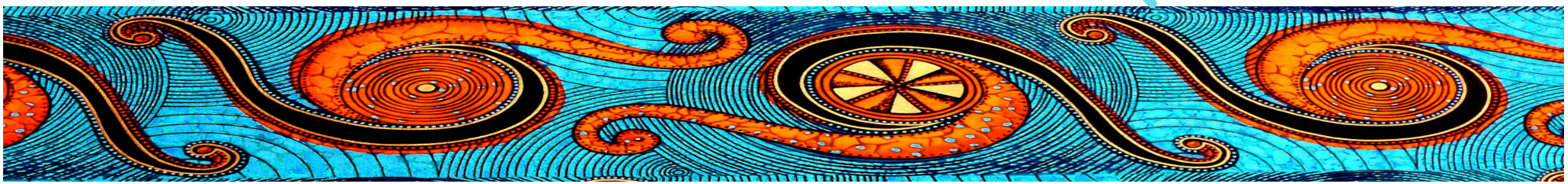

THANKS!