CHALMERS
UNIVERSITY OF TECHNOLOGY

Probing normal starbursts at high-z: ALMA observations of lensed SMGs

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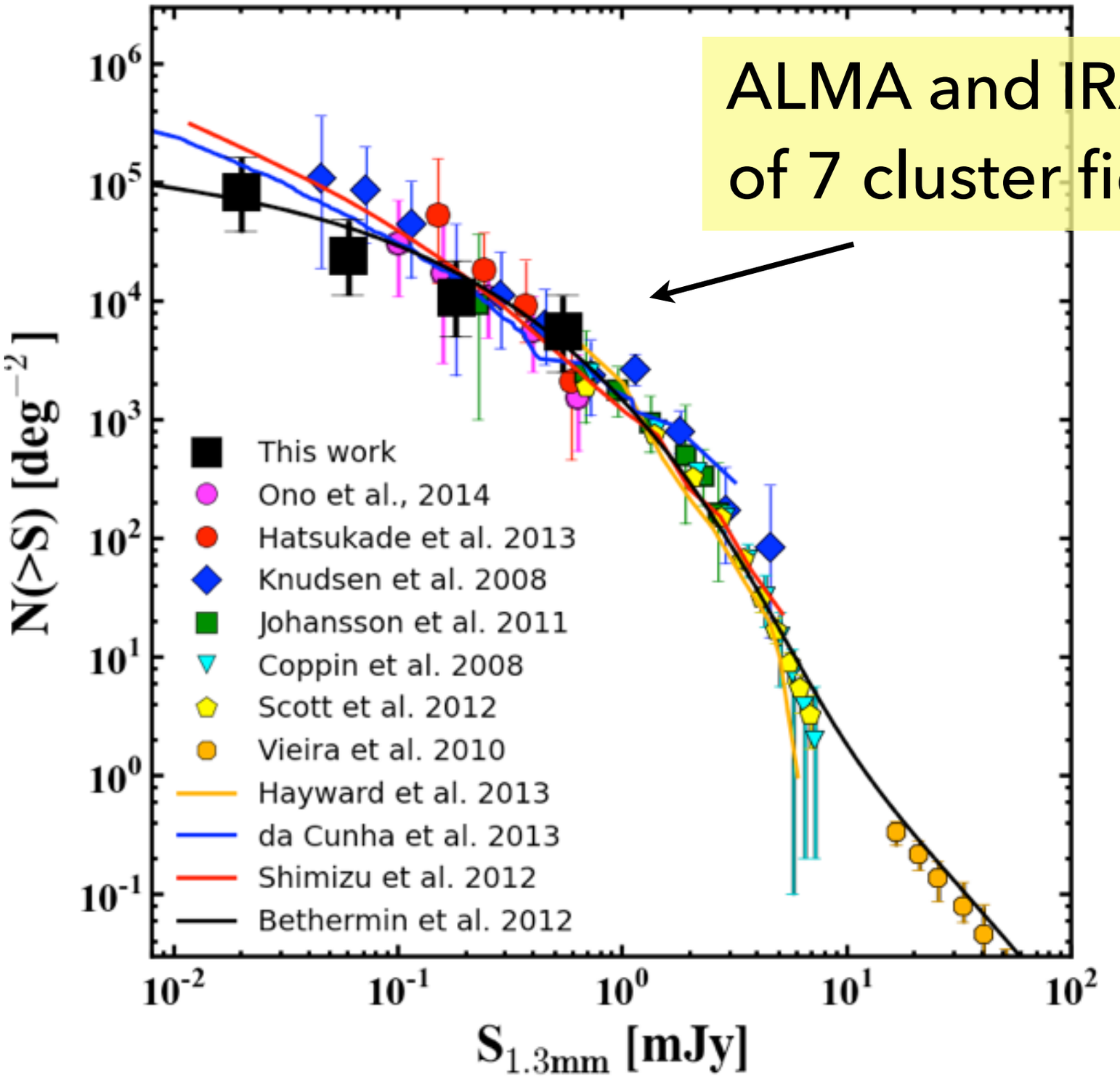
Collaborators: **Johan Richard, Jean-Paul Kneib, Lukas Lindroos, Guillaume Drouart**, Darach Watson, D Stark, B Altieri, R Neri, I Smail, et al. et al...

Vetenskapsrådet
WALLENBERG ACADEMY FELLOWS

Number counts - now with mm-interferometry



(Knudsen et al., Richard et al., Kneib et al. in prep)

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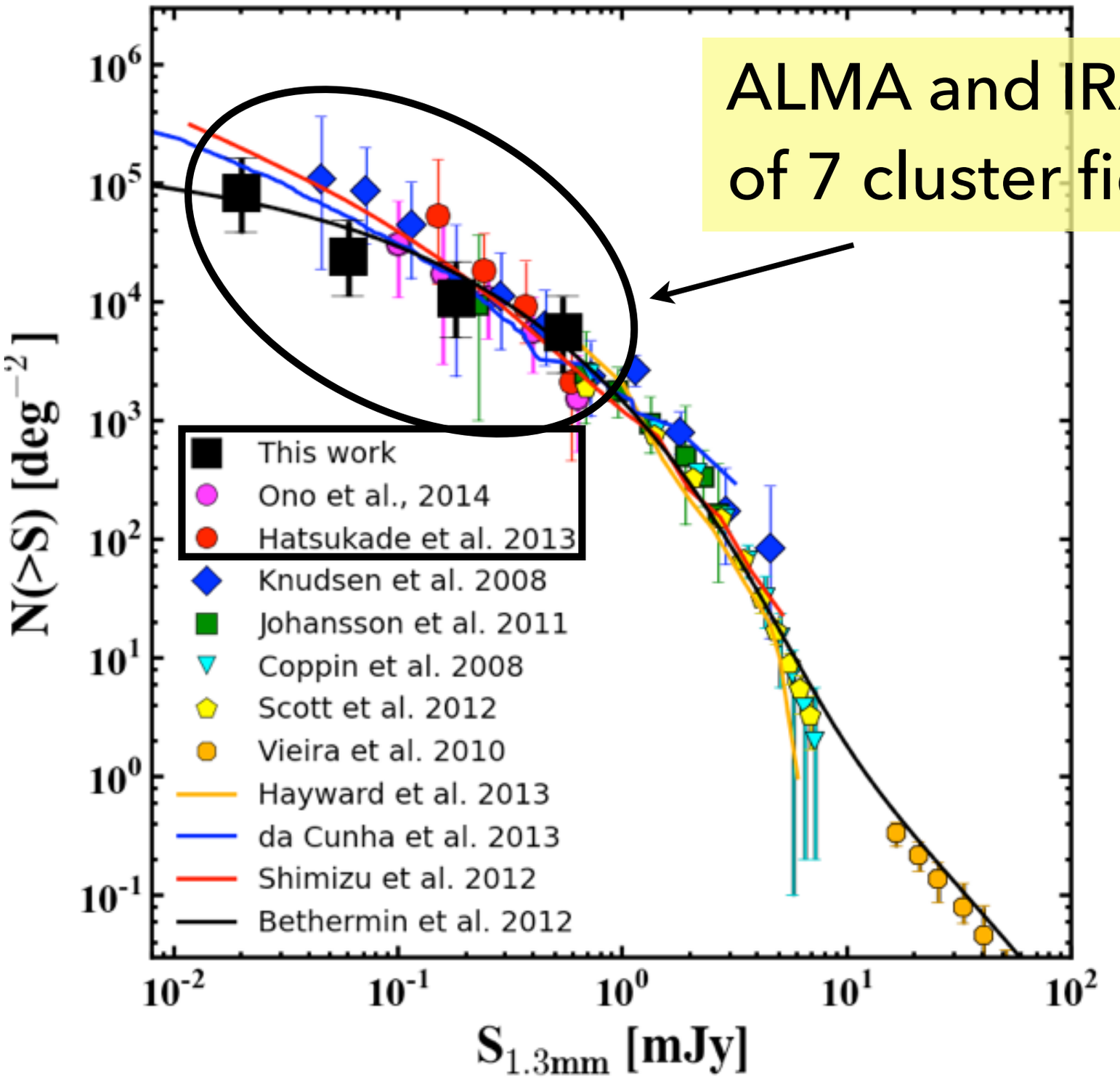

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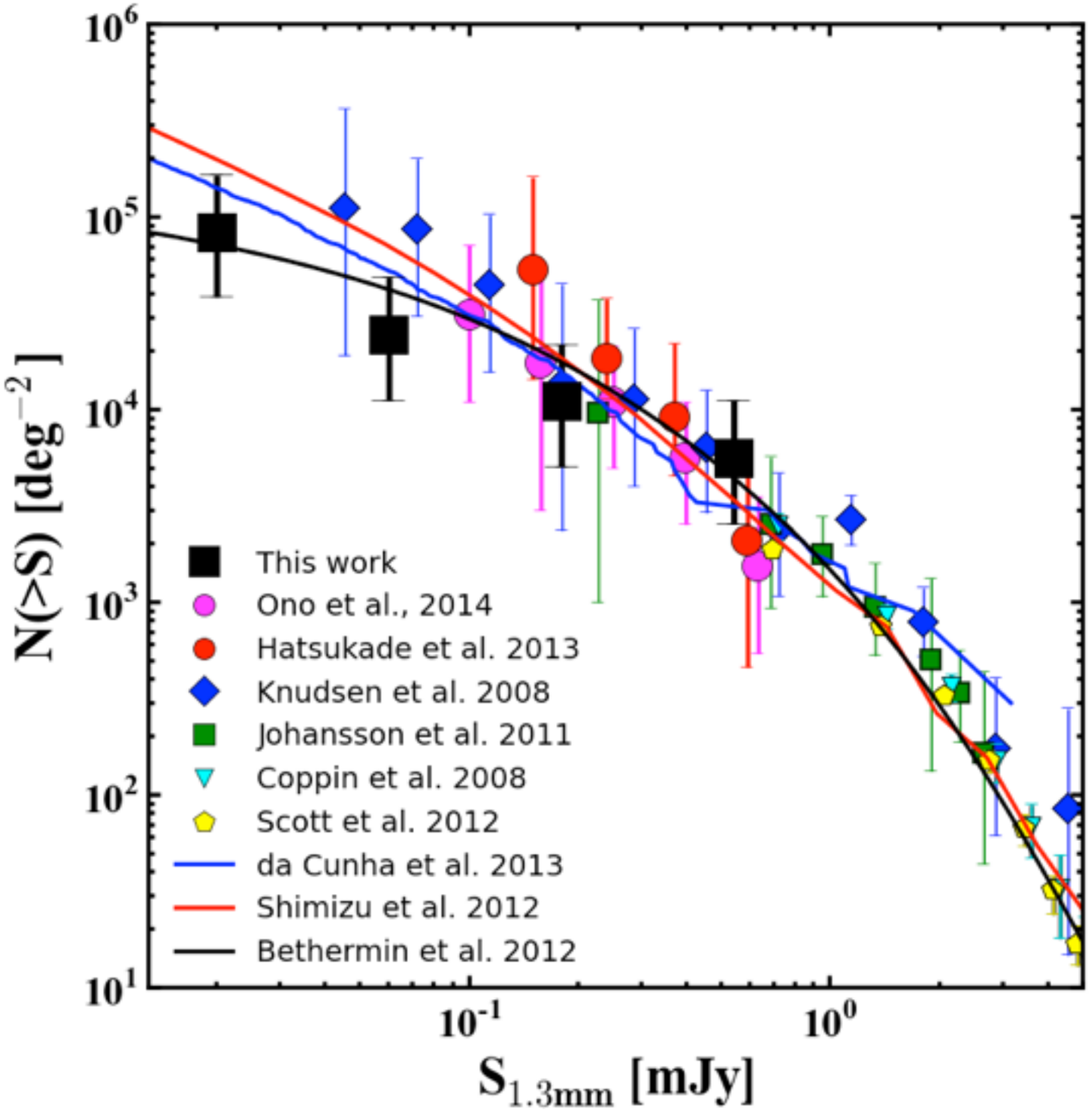
The faint end



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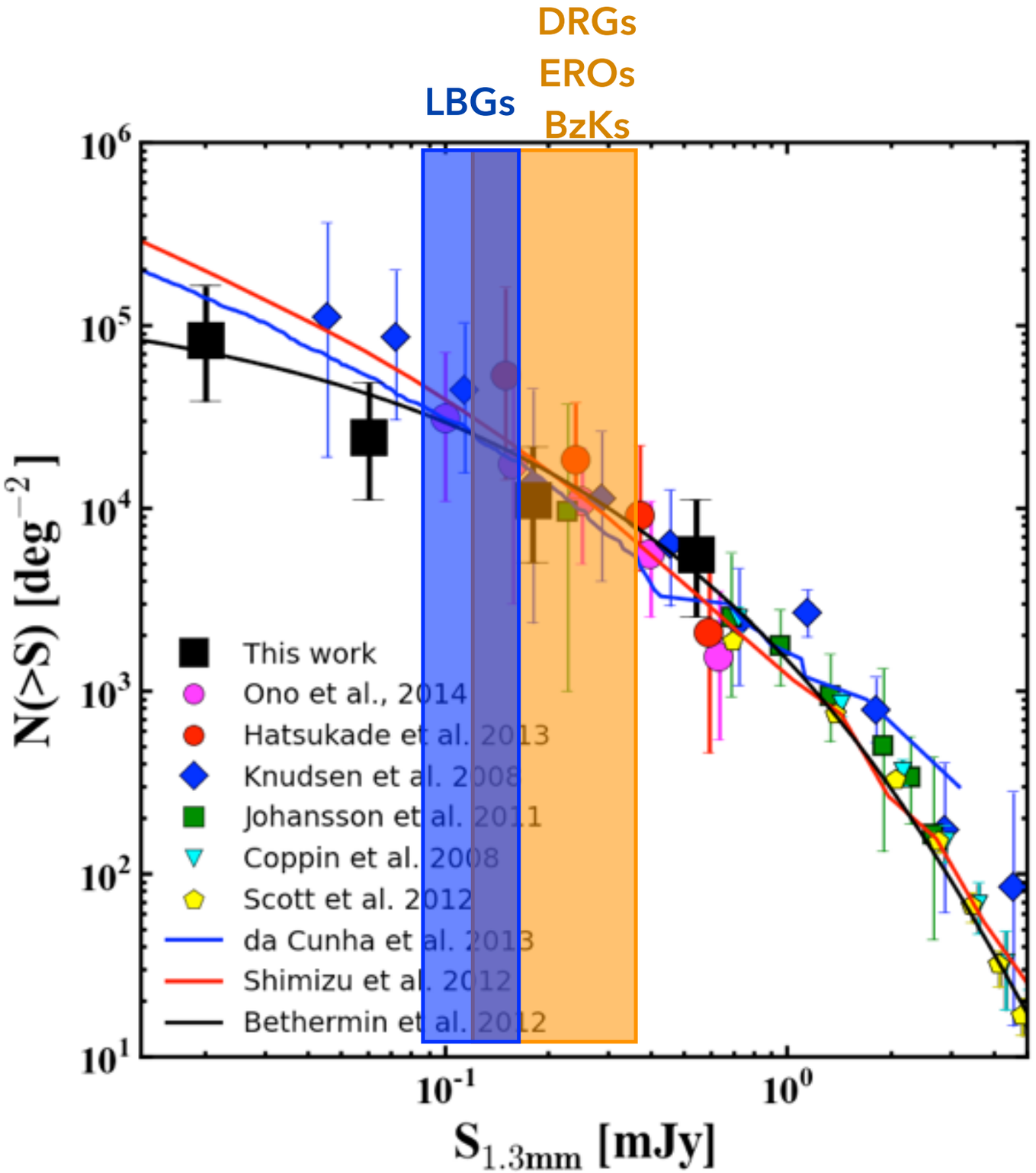
The faint end

Stacking results of LBGs, DRGs, EROs, BzKs:

e.g. Coppin et al. 2015, Decarli et al. 2014

However, stellar masses of $\langle M \rangle \sim 10^{10} - 10^{11}\ M_o$



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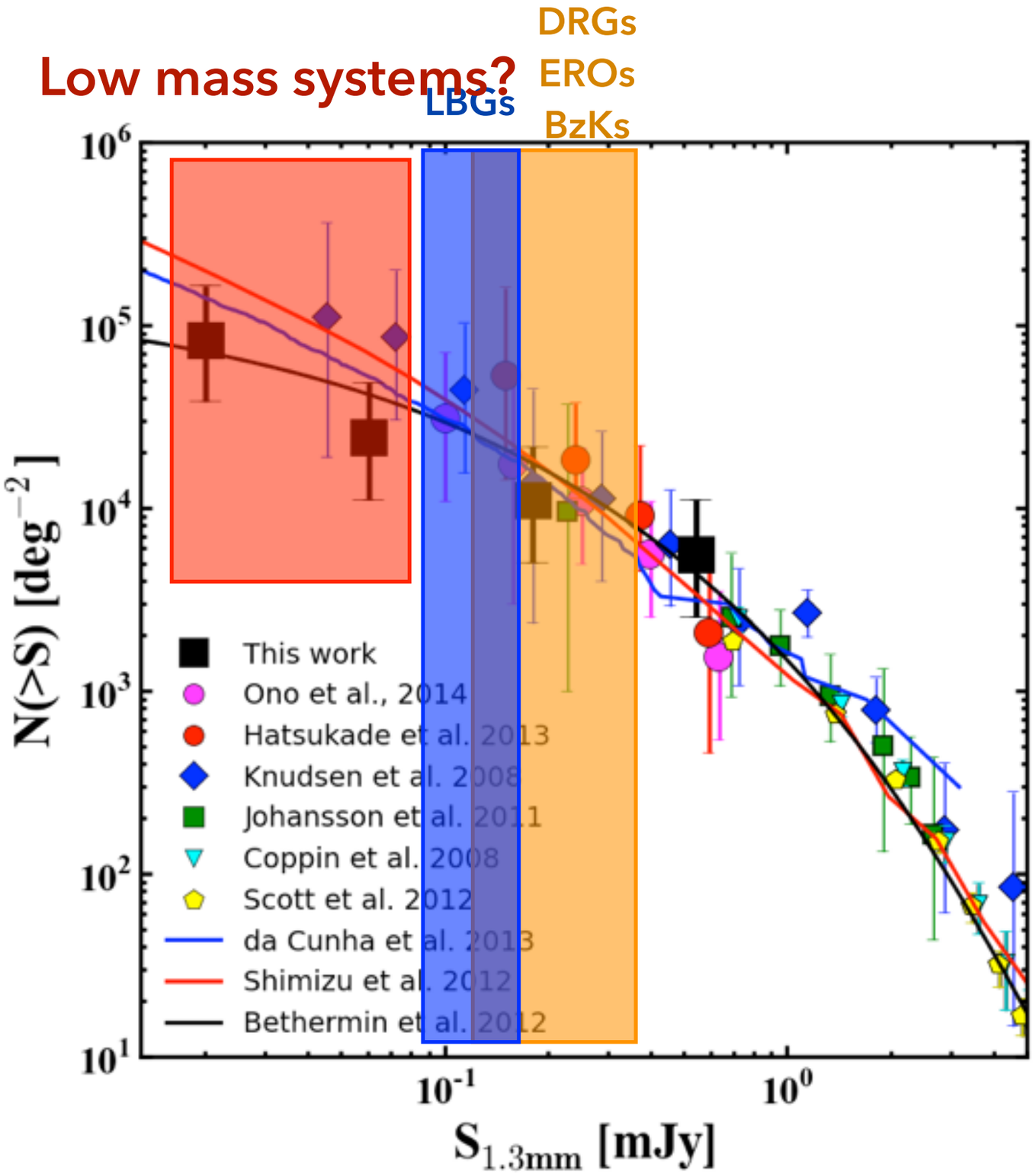

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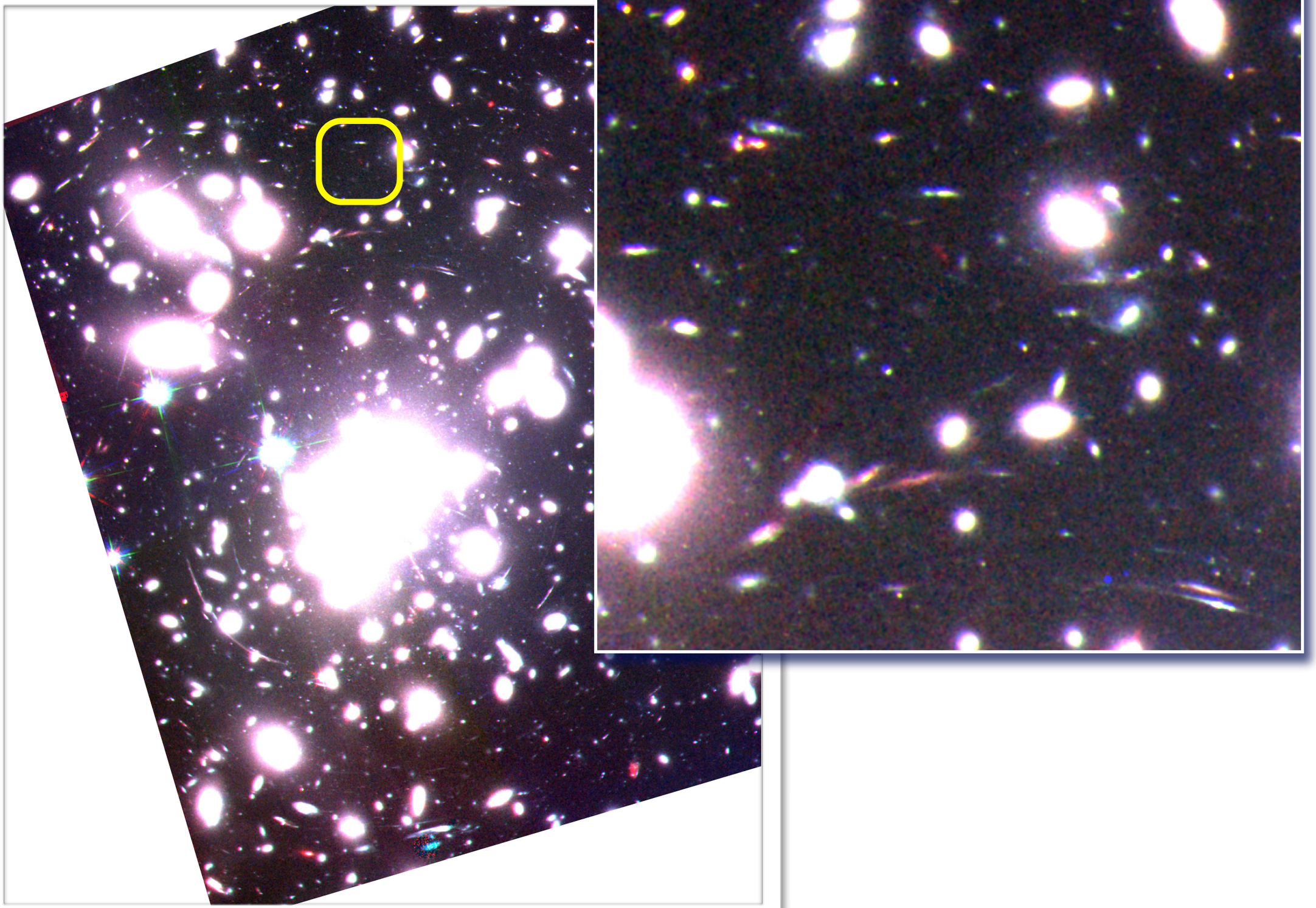
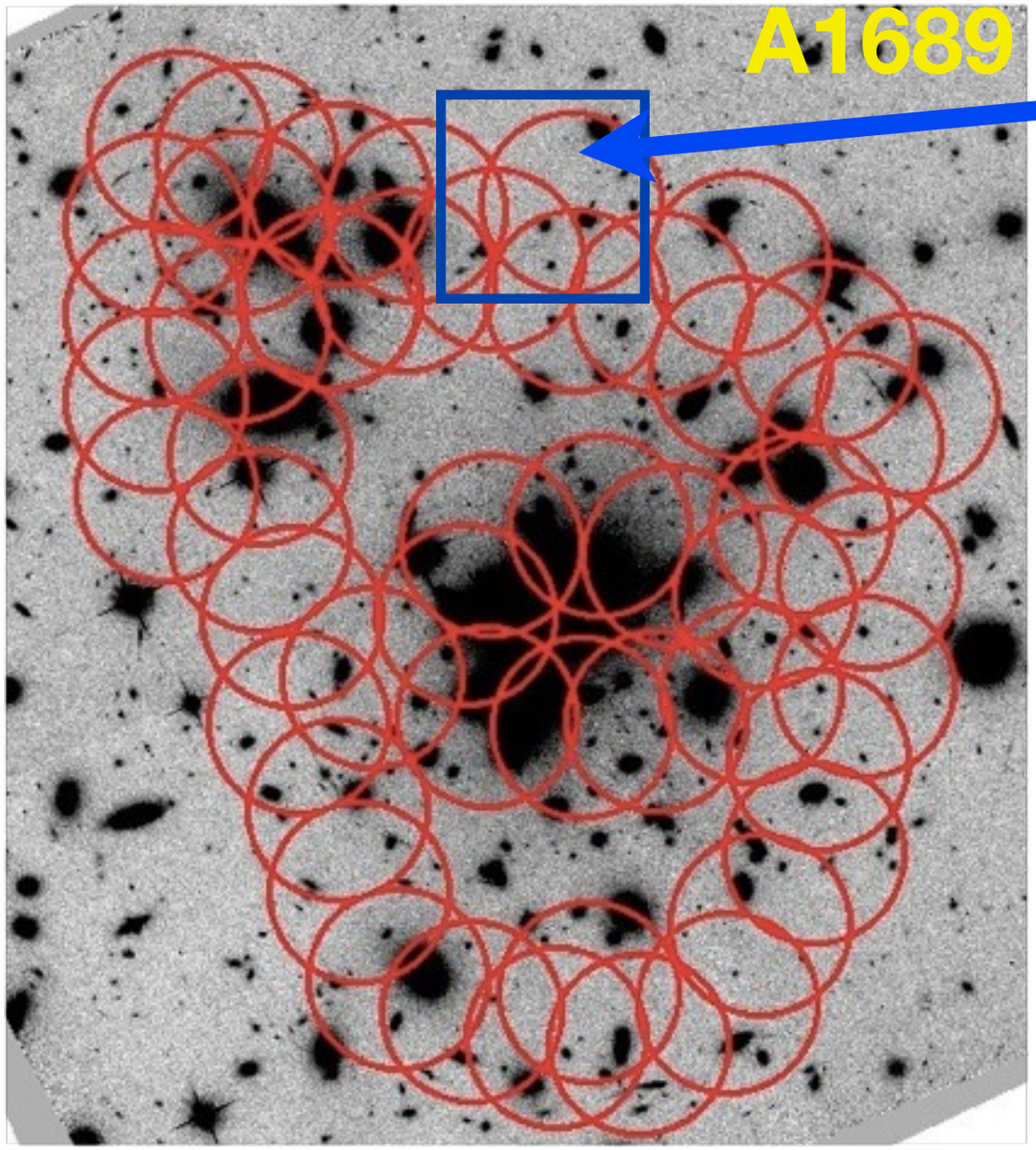
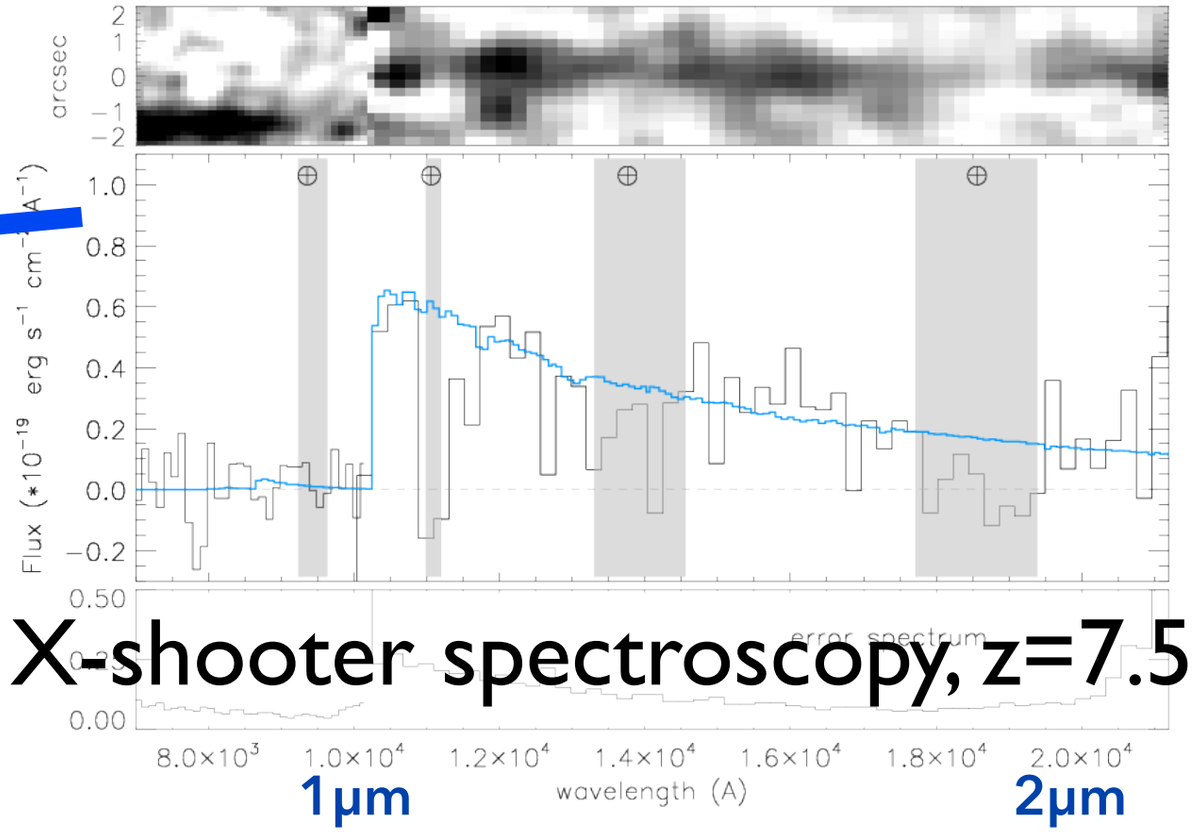
Galaxy cluster field A1689



Going beyond z=7 with ALMA

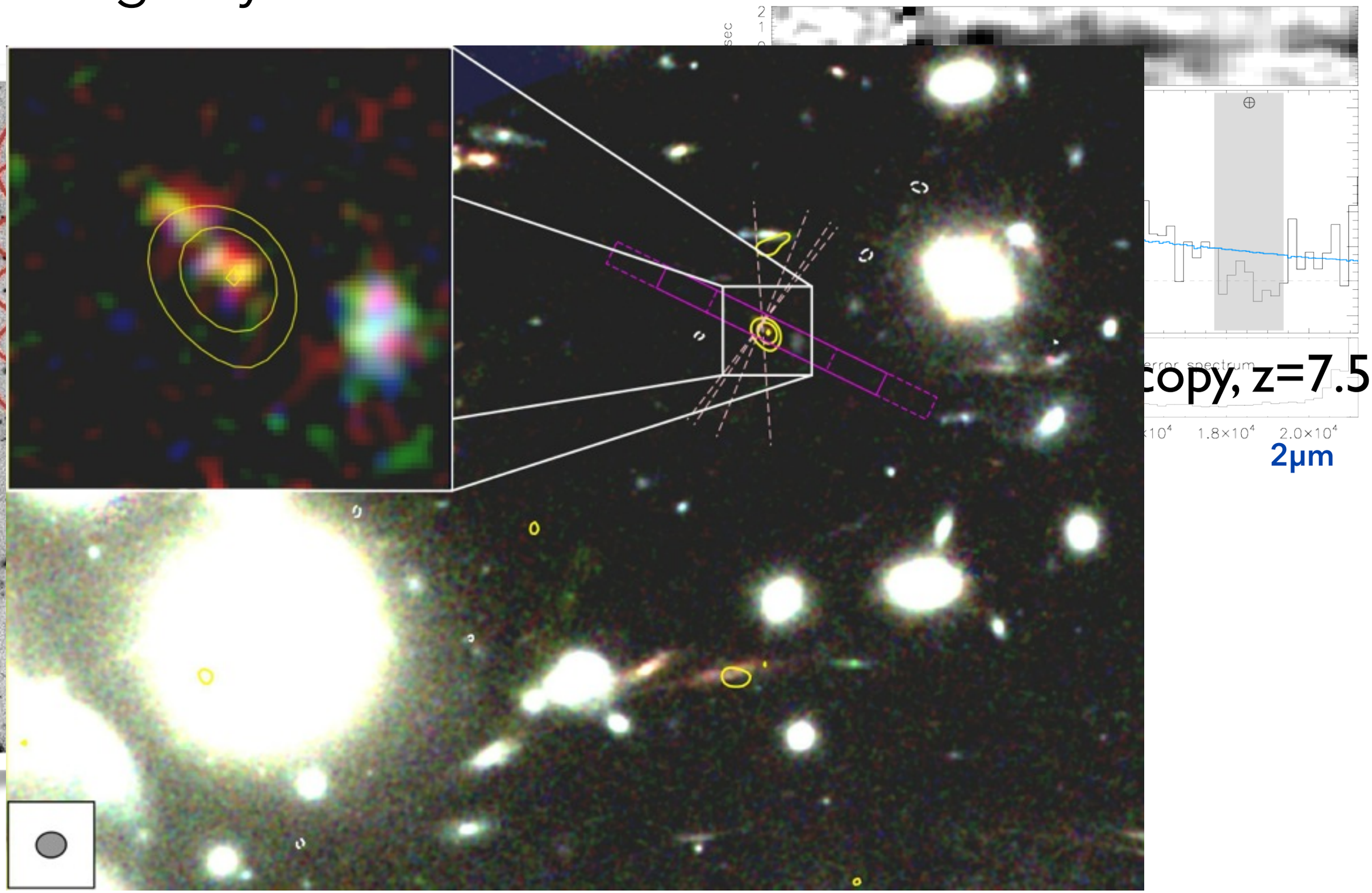




X-shooter spectroscopy, z=7.5

[Watson et al. 2014, Nature, resubmitted]

Going beyond z=7 with ALMA



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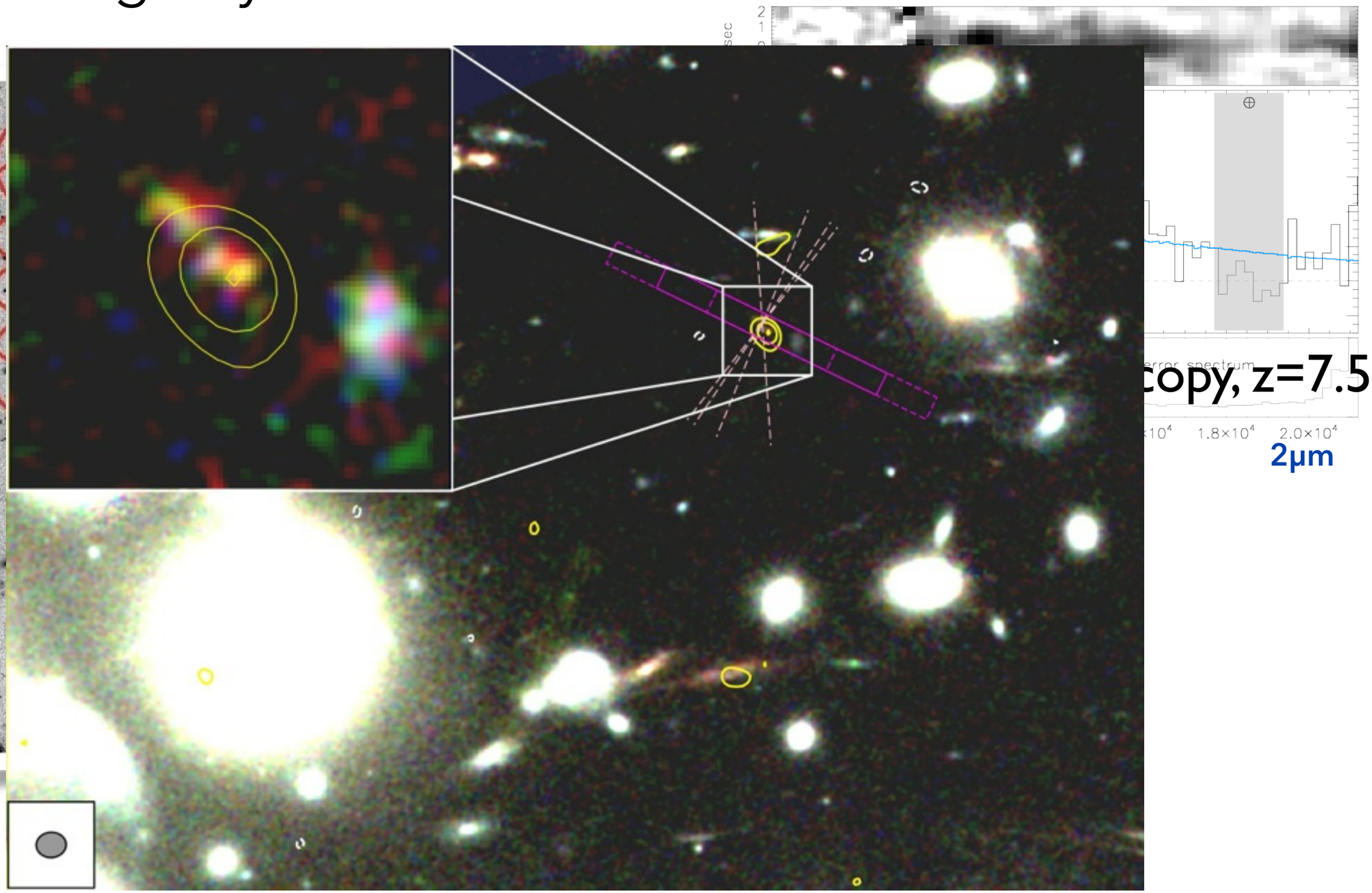

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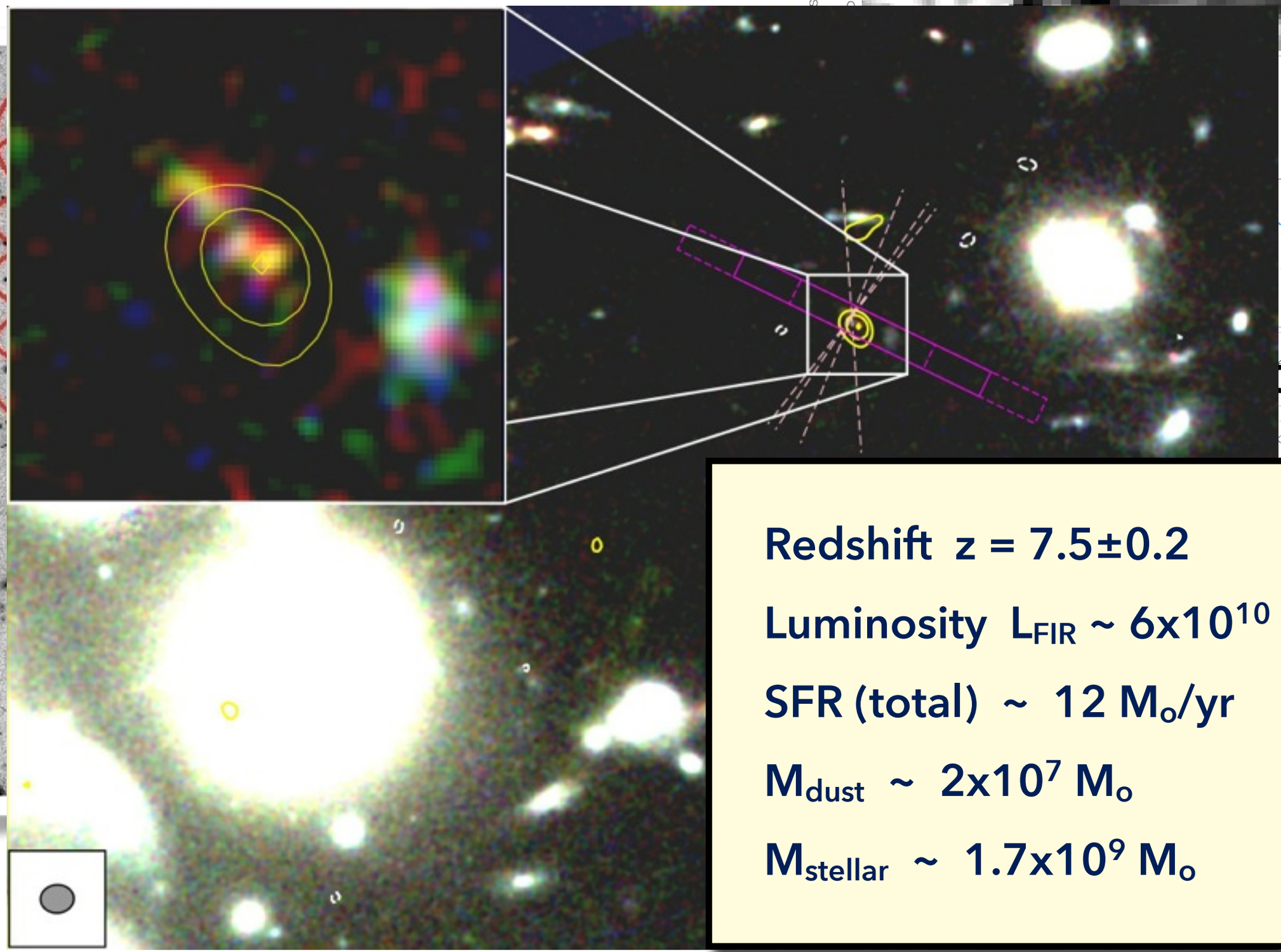


copy, z=7.5

2μm

Redshift z = 7.5±0.2

Luminosity L_{FIR} ~ 6x10^{10} L_o

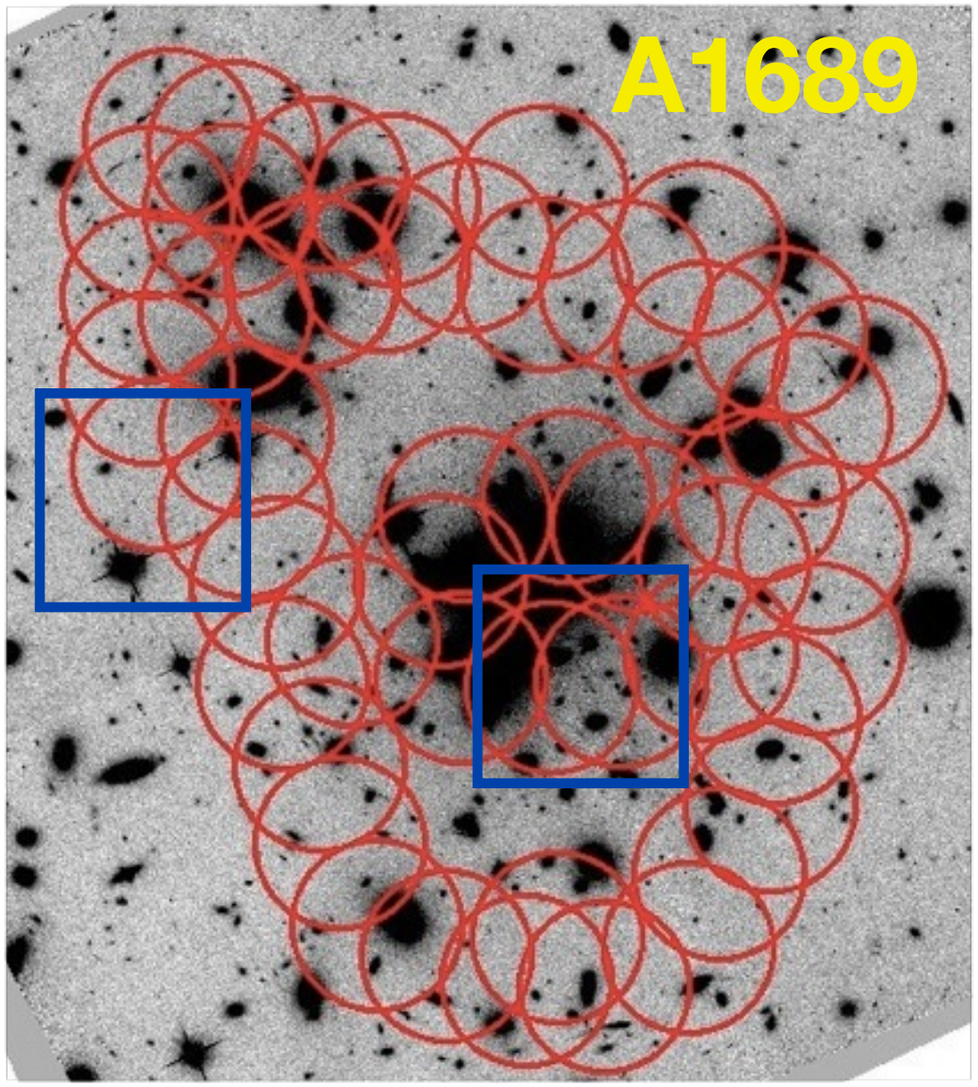
SFR (total) ~ 12 M_o/yr

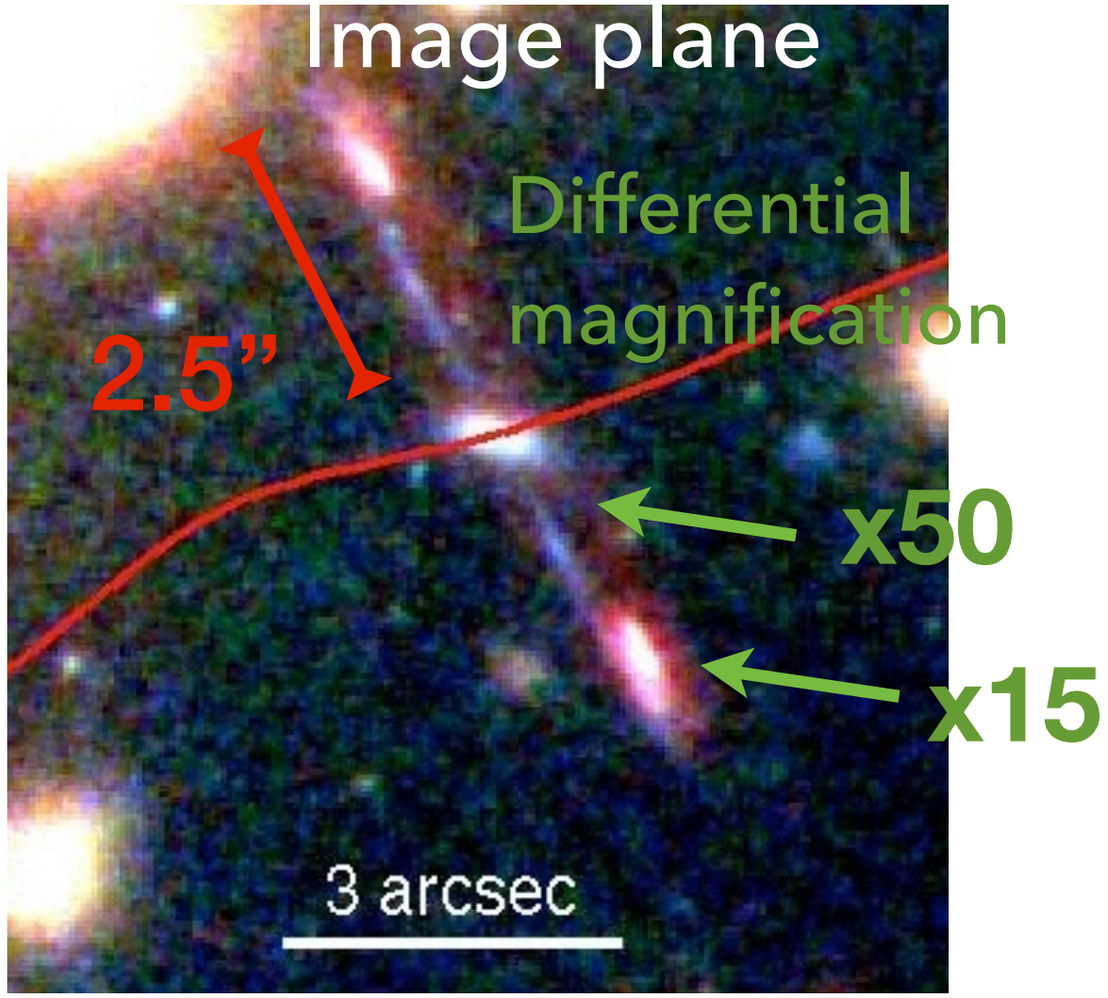
M_{dust} ~ 2x10^{7} M_o

$M_{stellar}$ ~ 1.7x10^{9} M_o

[Watson et al. 2014, Nature, resubmitted]

Less extreme starbursts, z=2.6





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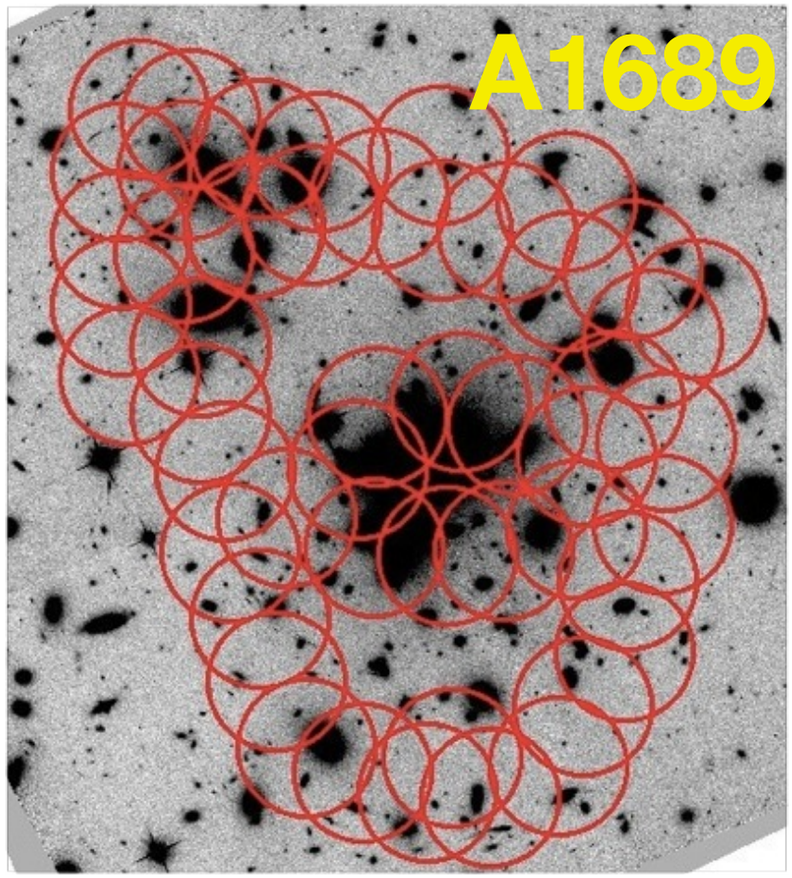

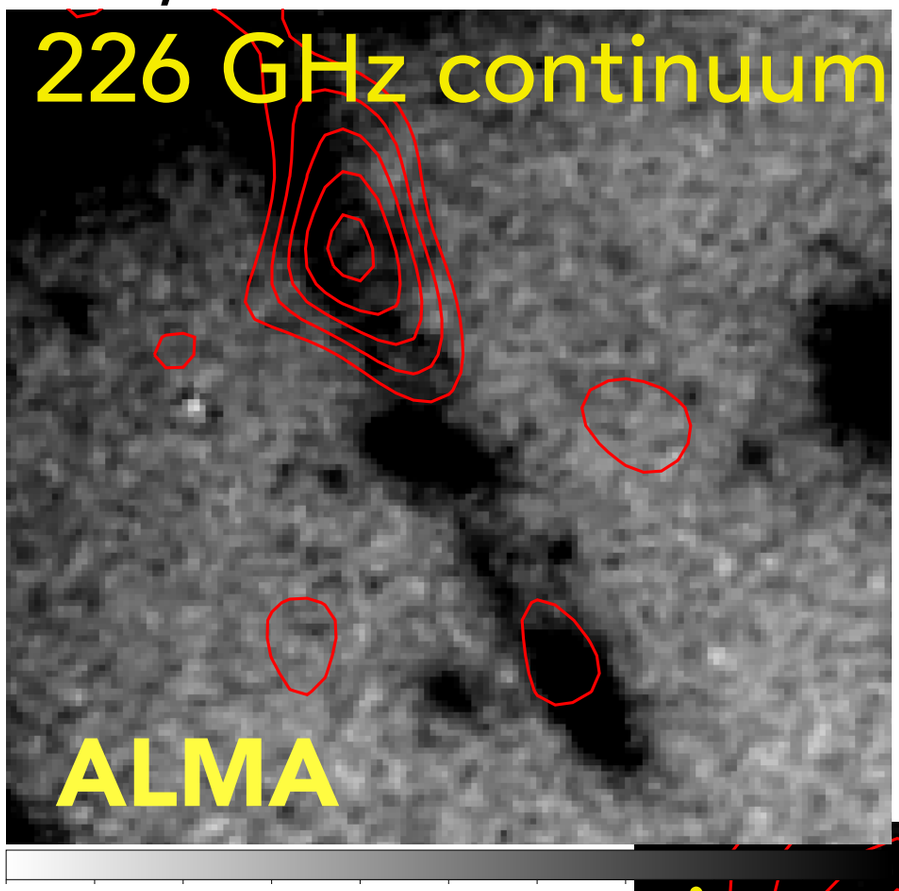

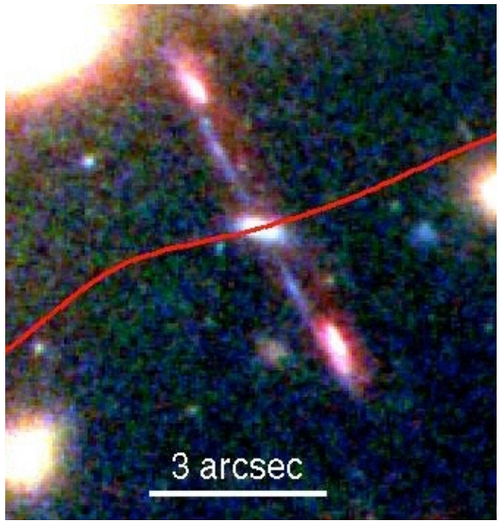

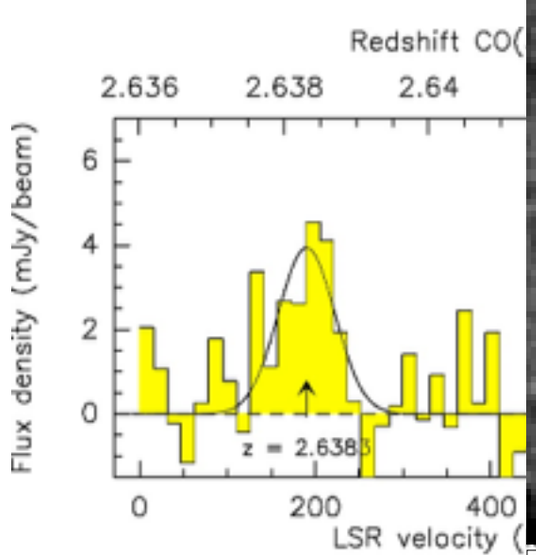

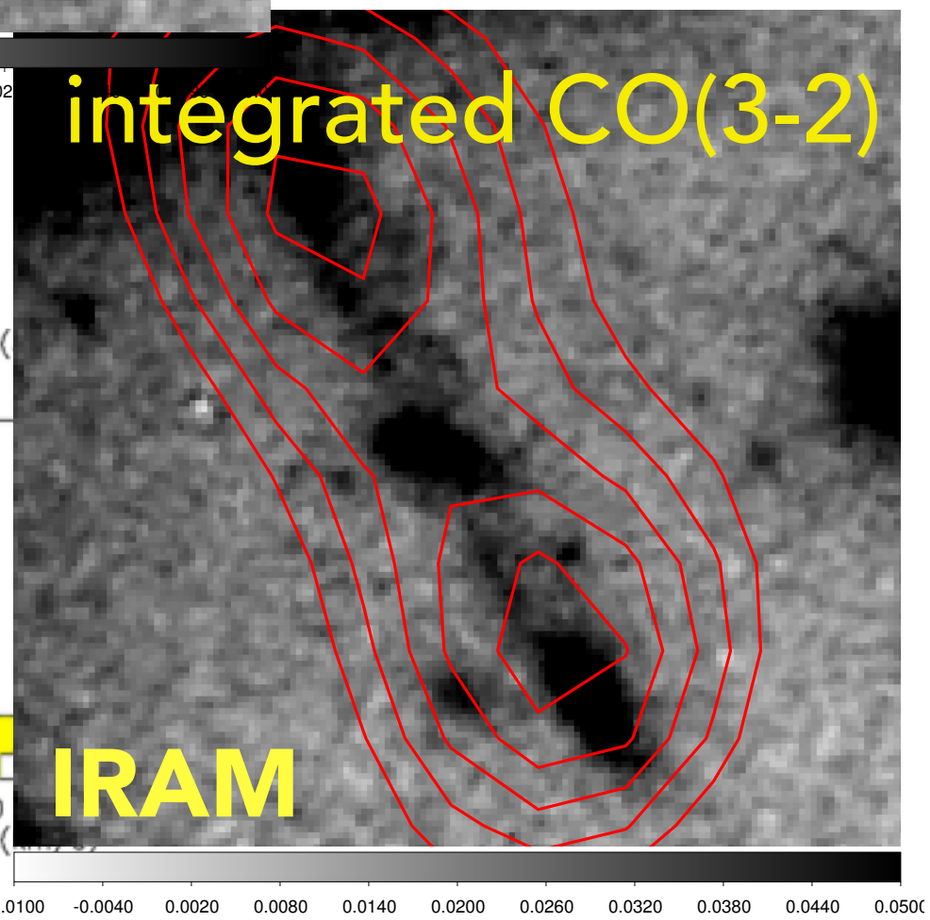

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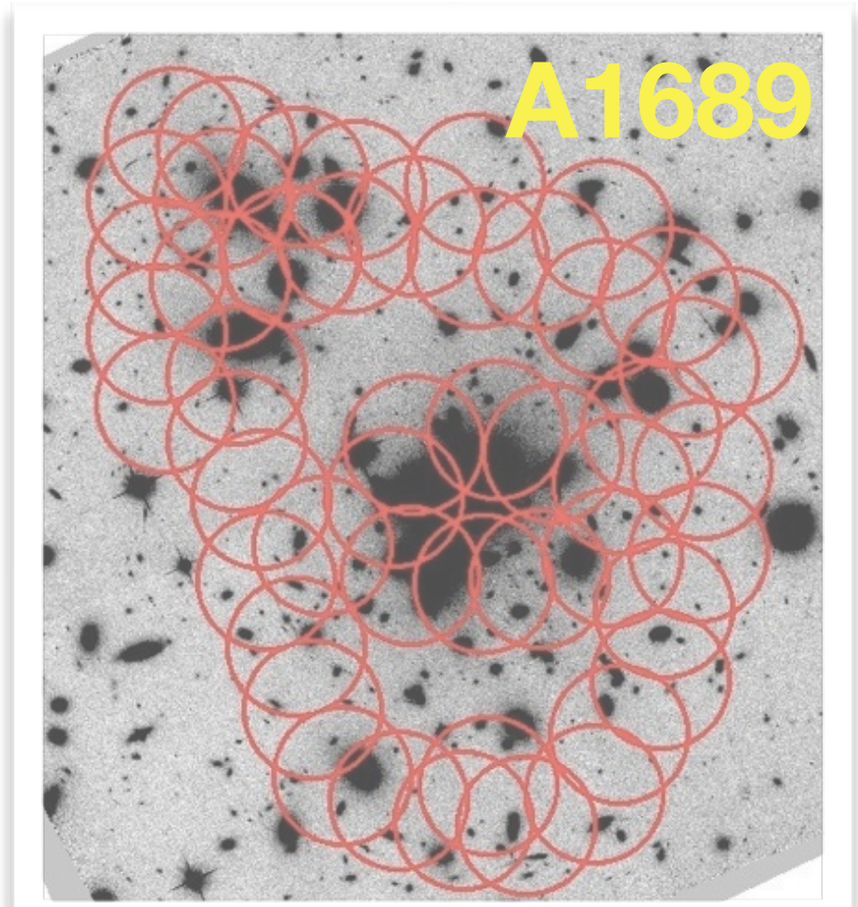

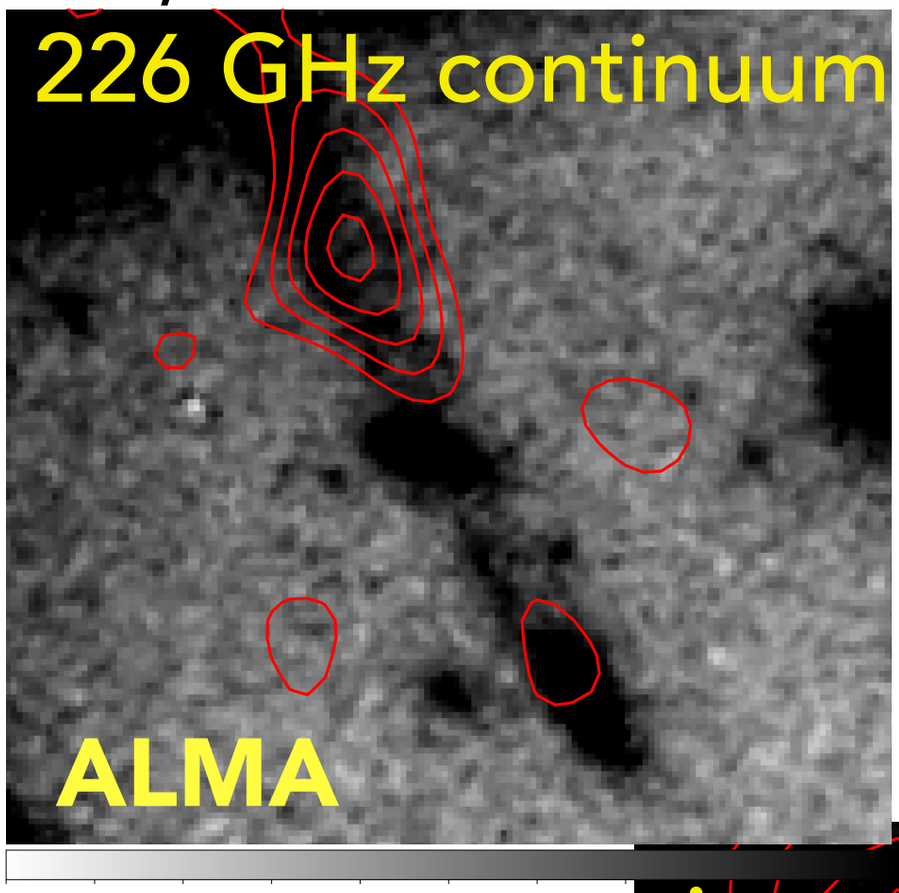

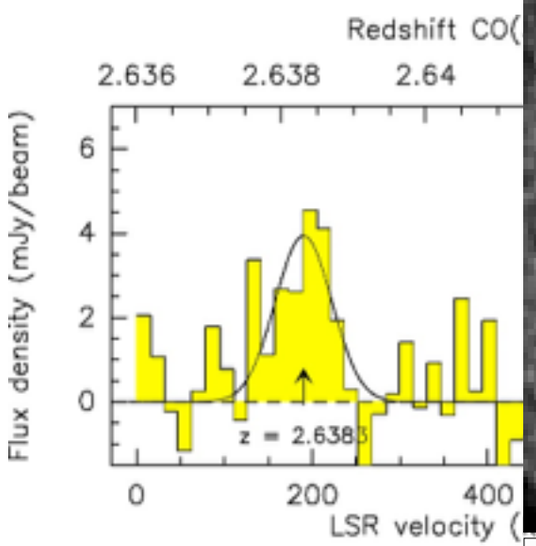

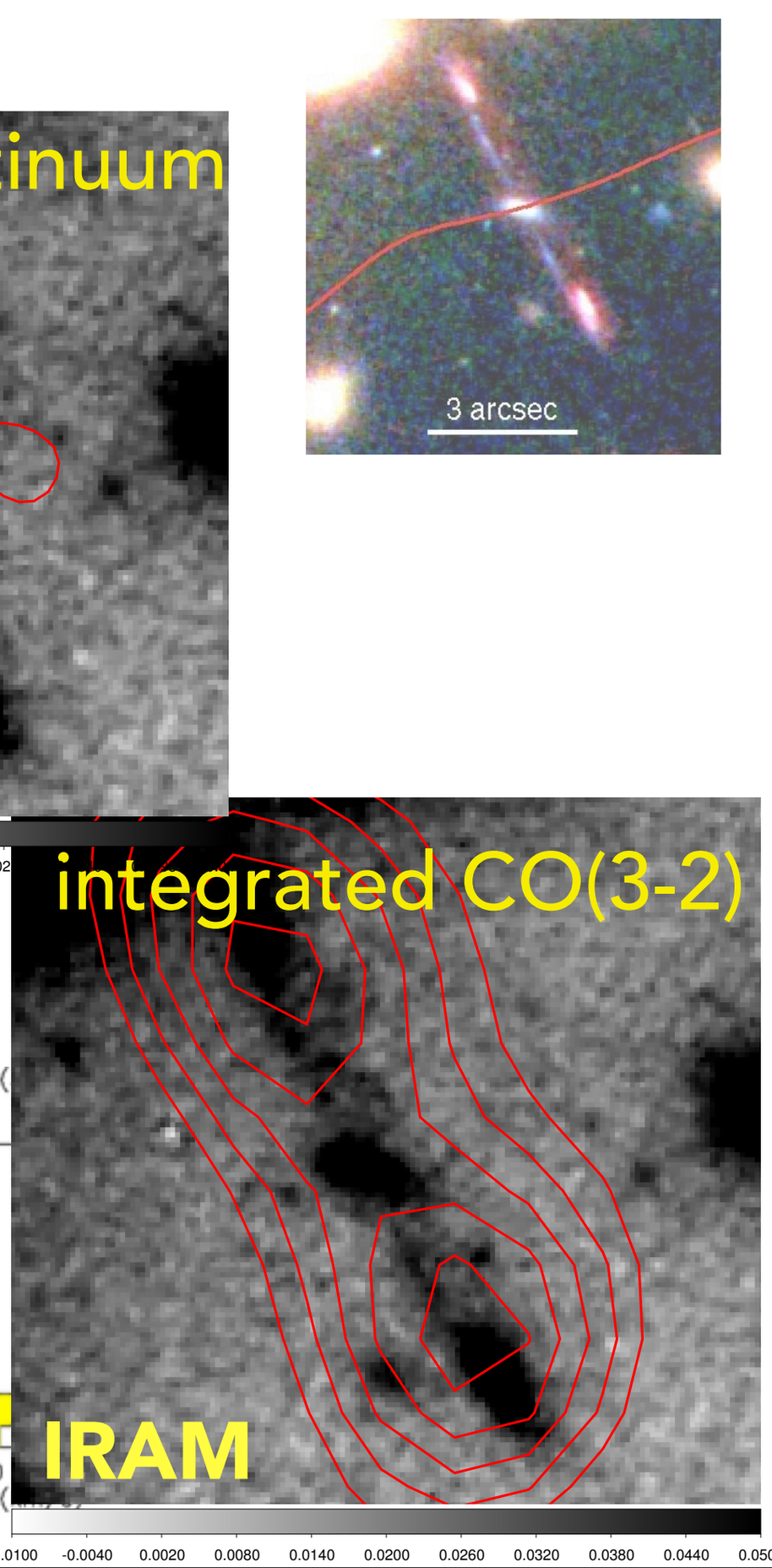

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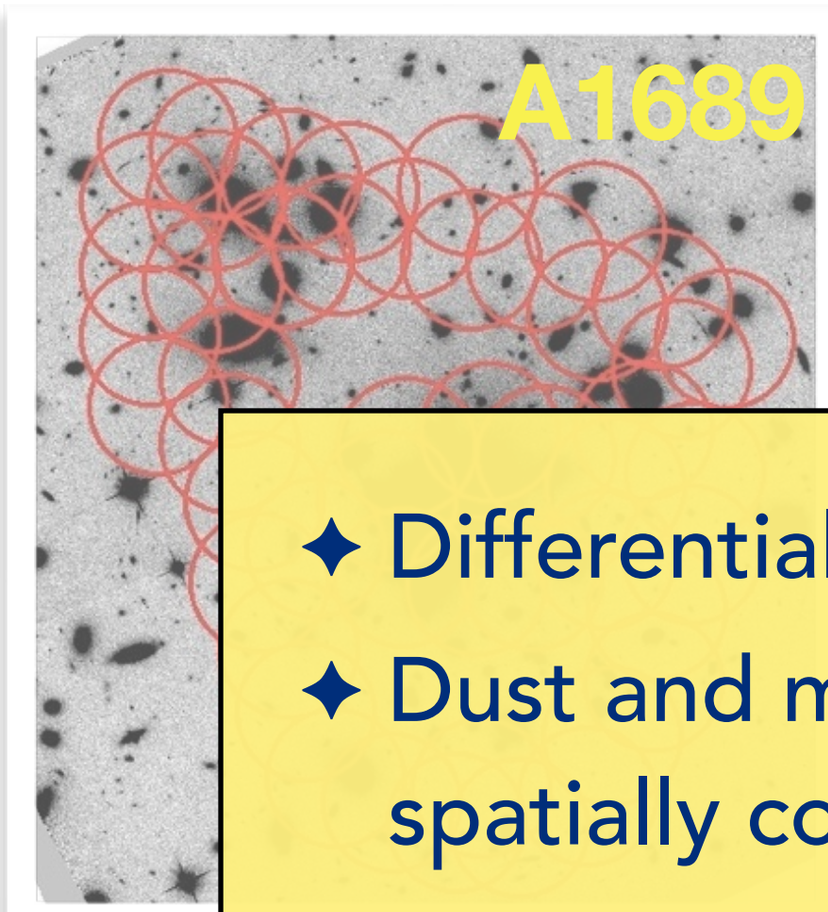
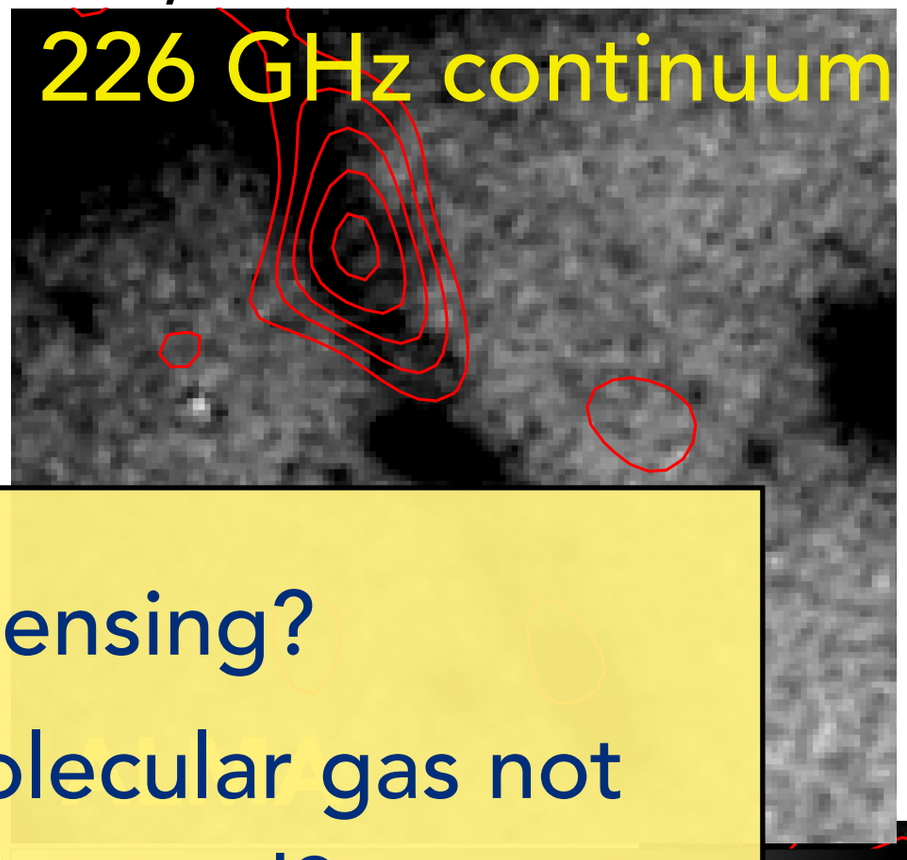
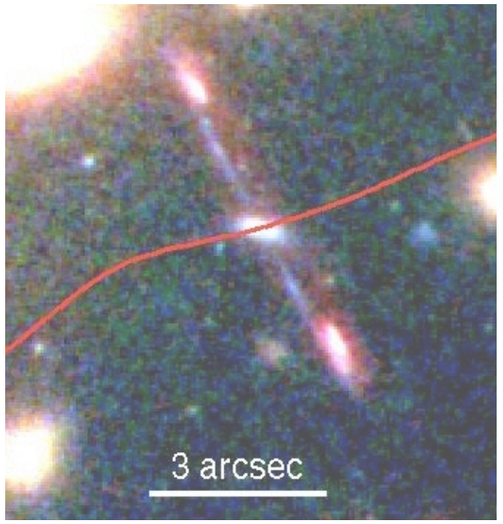
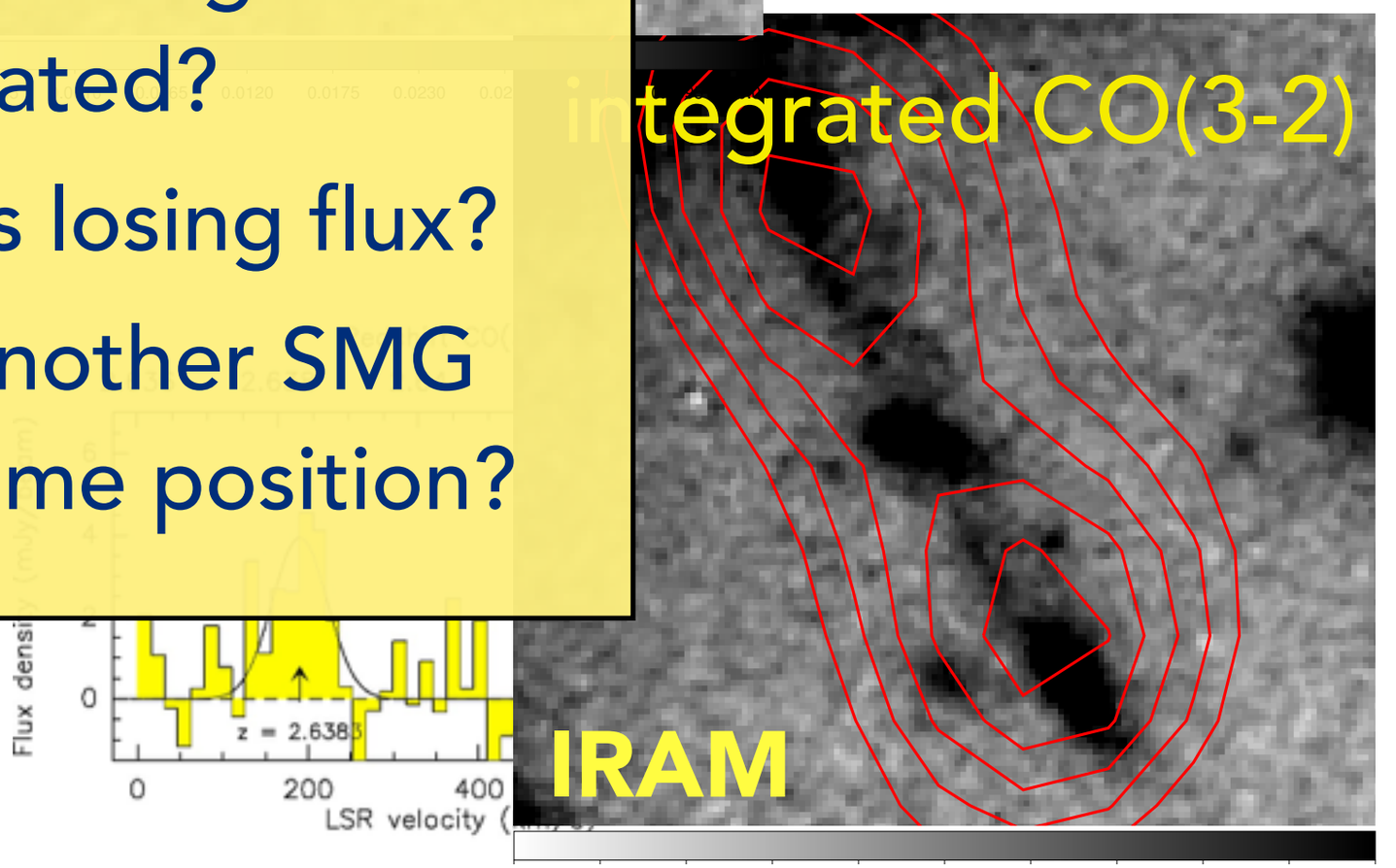






- ✦ Differential lensing?
- ✦ Dust and molecular gas not spatially co-located?
- ✦ Large size, thus losing flux?
- ✦ Coincidence, another SMG ‘blob’ at the same position?



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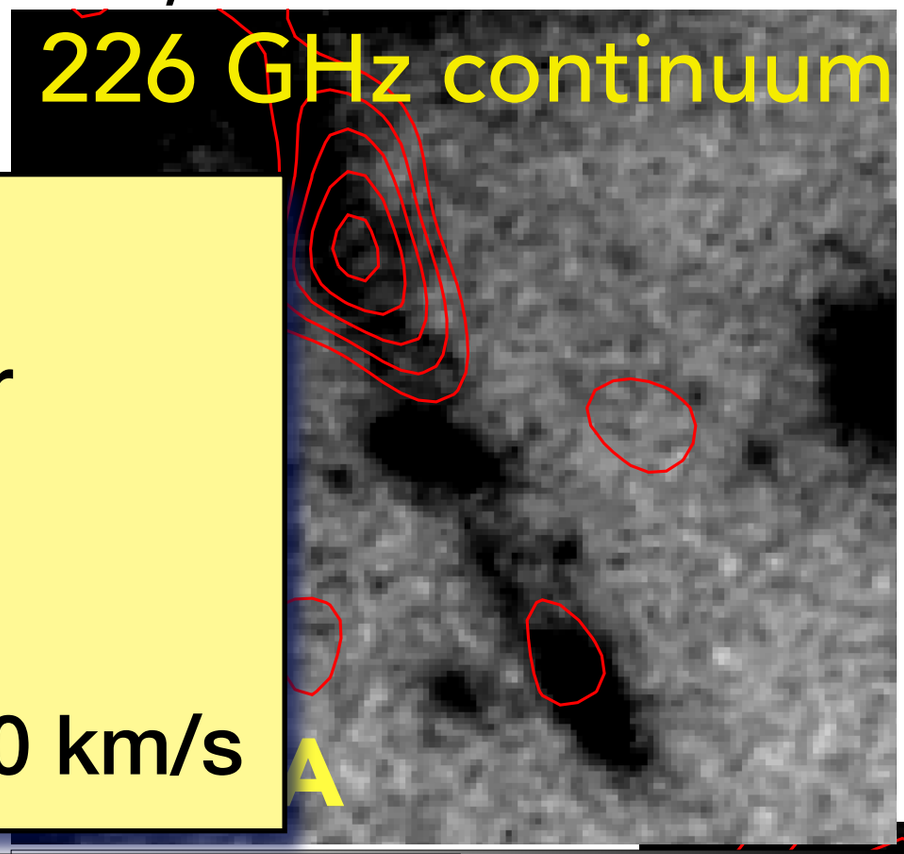
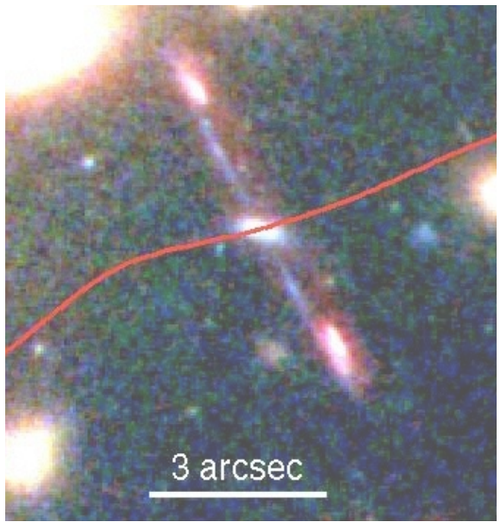




L_{FIR} ~ 1.0x10^{11} L_o

SFR ~ 10-20 M_o/yr

$M_{stellar}$ ~ 2x10^{9} M_o

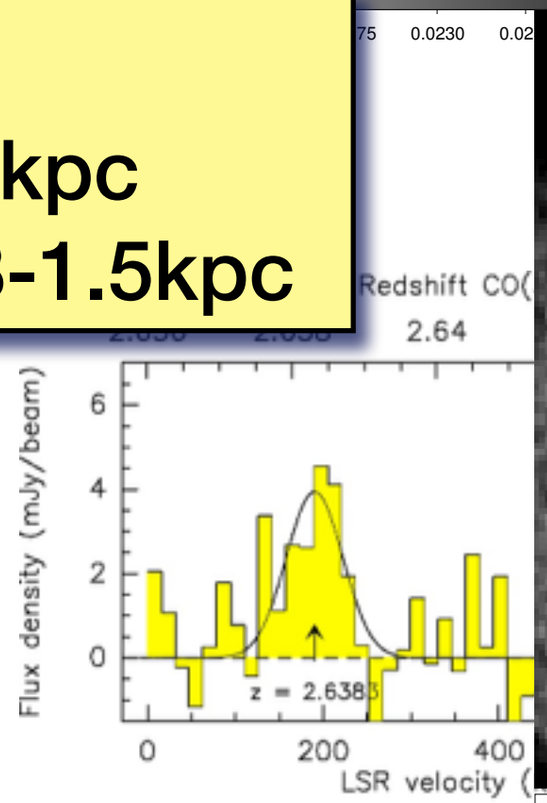
M_{gas} ~ 3x10^{8} M_o

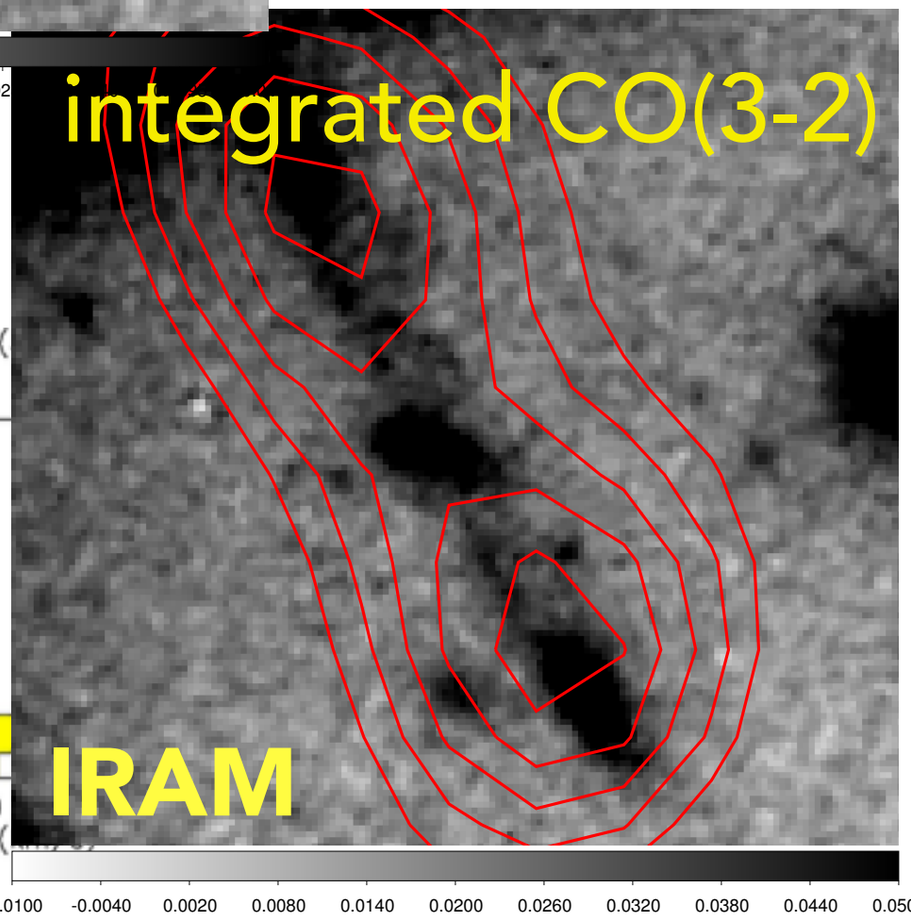
CO line width ~ 140 km/s

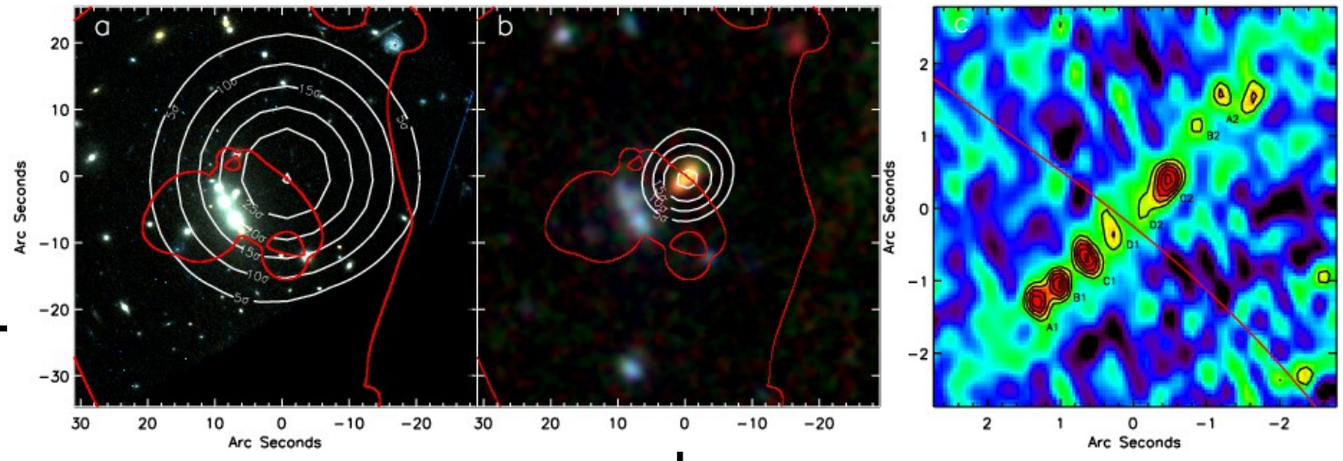
Reconstructed image:

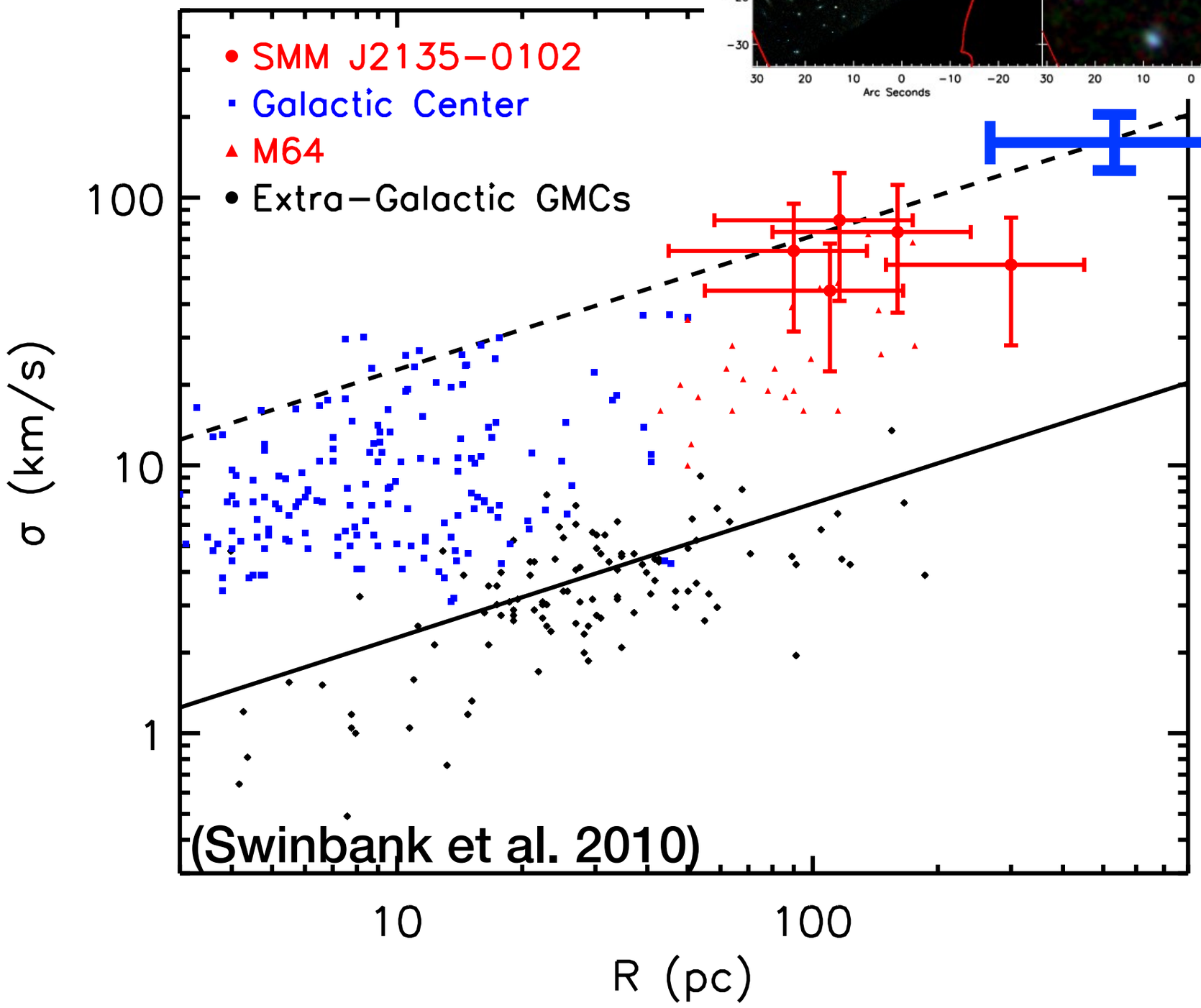
Size of galaxy ~ 1-1.5 kpc

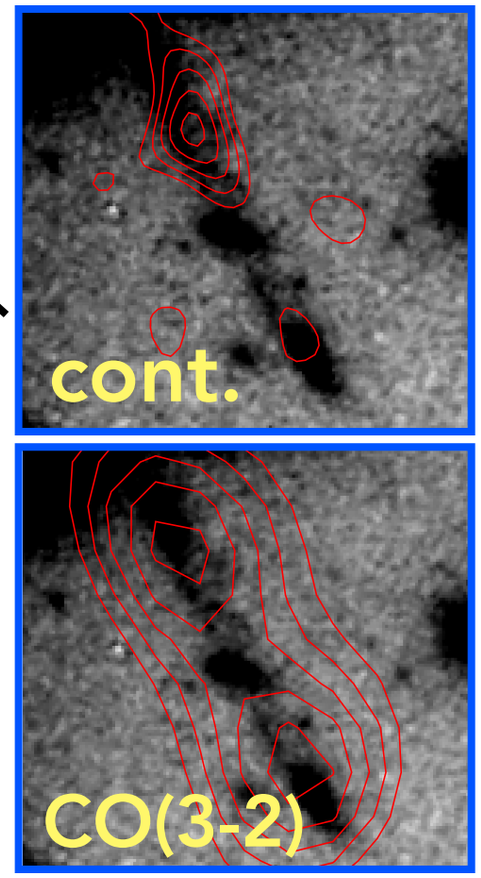
Starburst region ~ 0.3-1.5kpc

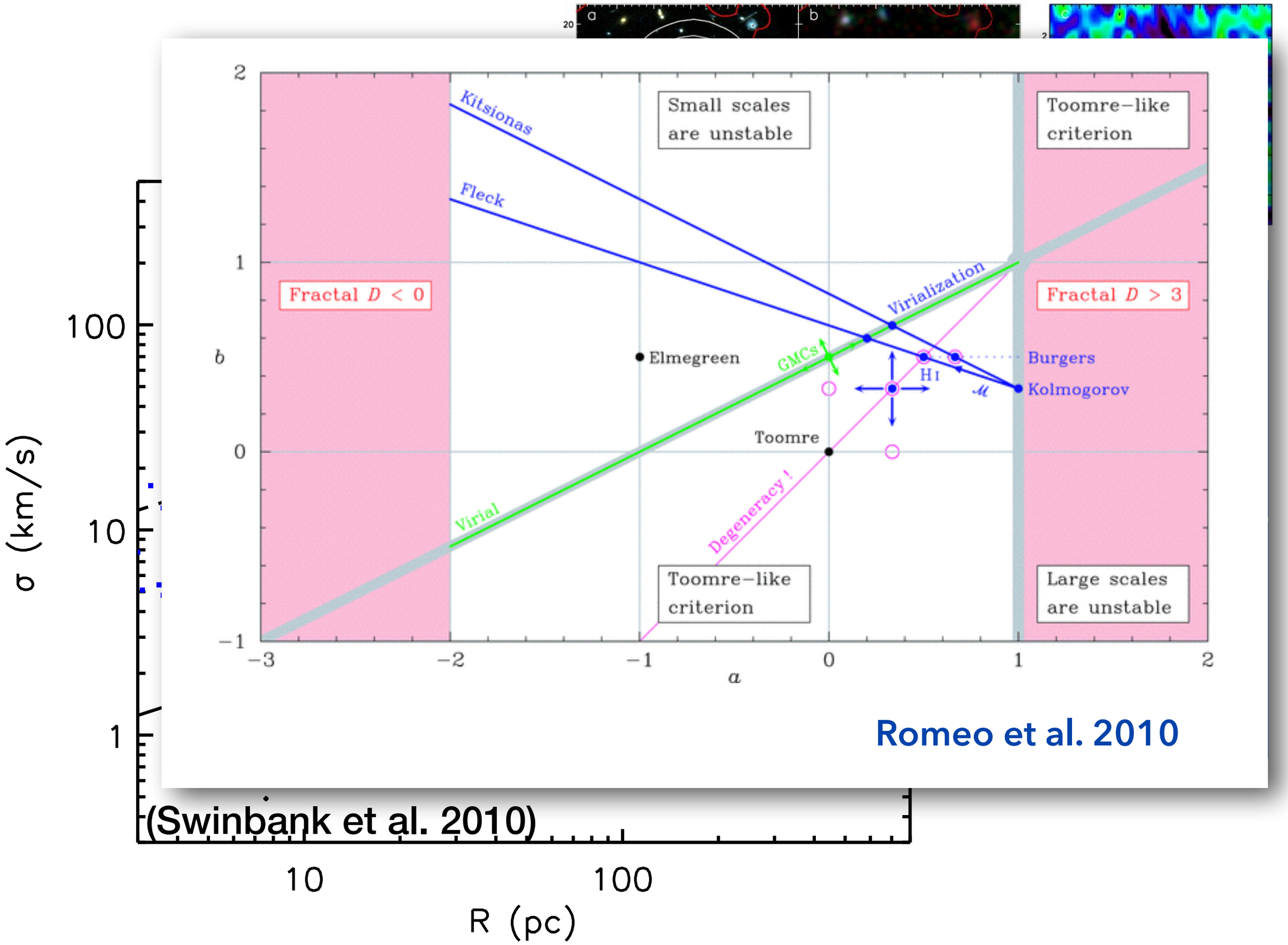





a
b
c
Arc Seconds
Arc Seconds
Arc Seconds
A1
B1
C1
D1
D2
C2
B2
A2

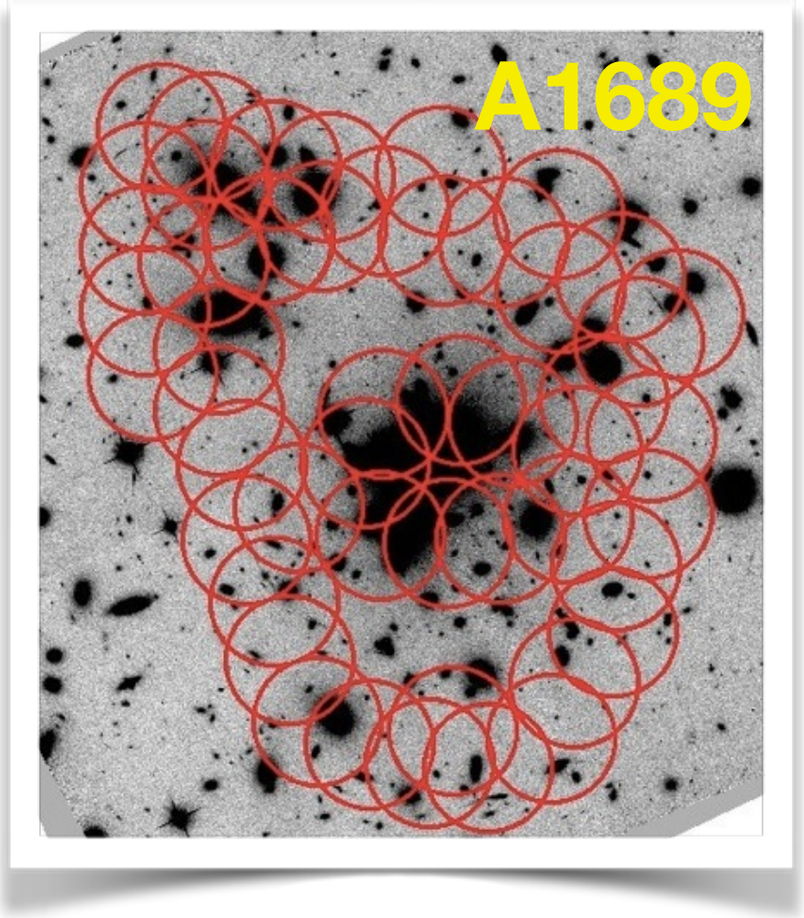

• SMM J2135−0102
▪ Galactic Center
▲ M64
• Extra−Galactic GMCs
100
10
1
σ (km/s)
10
100
R (pc)
(Swinbank et al. 2010)


cont.
CO(3-2)

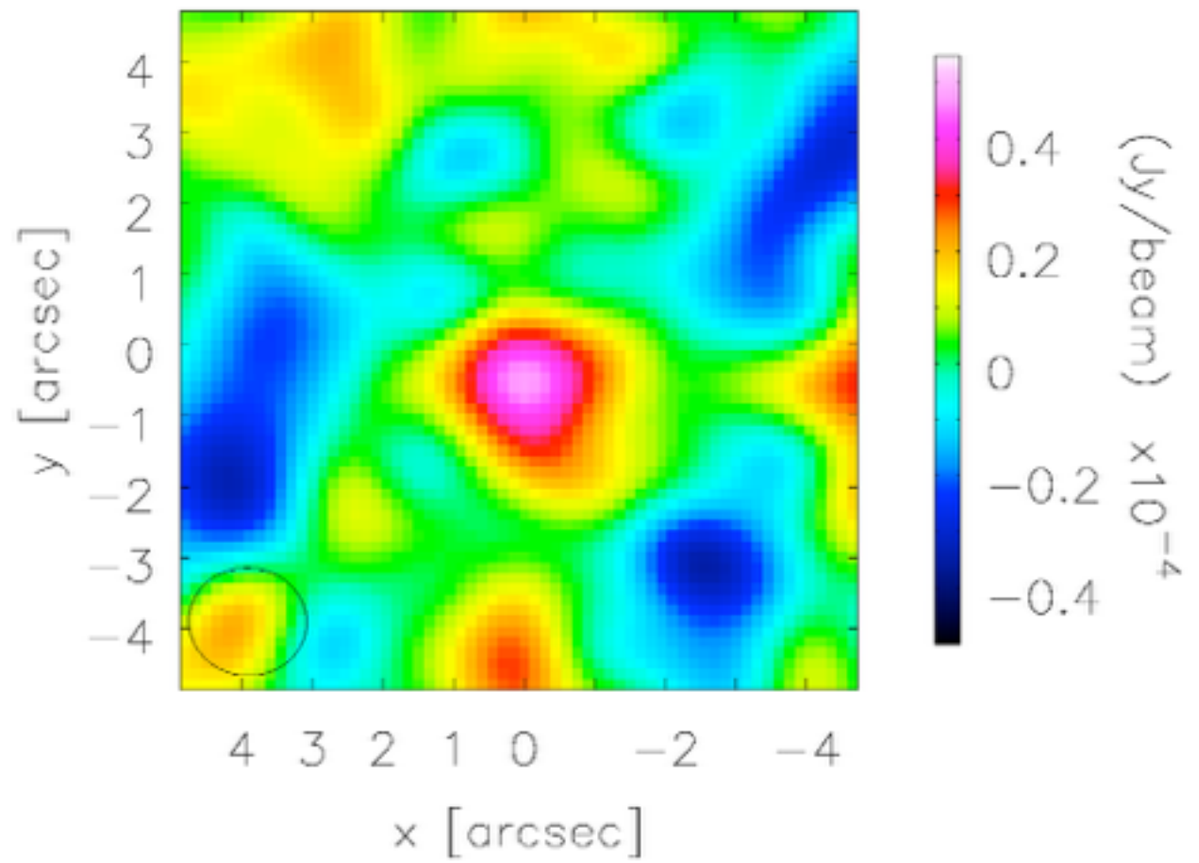

a
b
c
20
2
Kitsionas
Fleck
Small scales
are unstable
Toomre−like
criterion
Fractal D < 0
Fractal D > 3
Virialization
Elmegreen
GMCs
HI
Burgers
Kolmogorov
$\mathscr{M}$
Toomre
Virial
Degeneracy !
Toomre−like
criterion
Large scales
are unstable
b
a
1
0
−1
−3
−2
−1
0
1
2
Romeo et al. 2010
100
10
1
σ (km/s)
(Swinbank et al. 2010)
10
100
R (pc)

SMM J2135−0102
Galactic Center
M64
Extra−Galactic GMCs
With strong lensing
Without lensing
100
10
1
σ (km/s)
(Swinbank et al. 2010)
10
100
R (pc)

Looking below the noise:



ALMA 226GHz of A1689:



Stacking, 80 positions

$< S_{226GHz} >$ ~ 48±15 μJy

$M_{stellar}$ ~ 10^9 M_o

$< \mu >$ ~ 4

=> $< S_{226GHz} >$ ~ 10 μJy

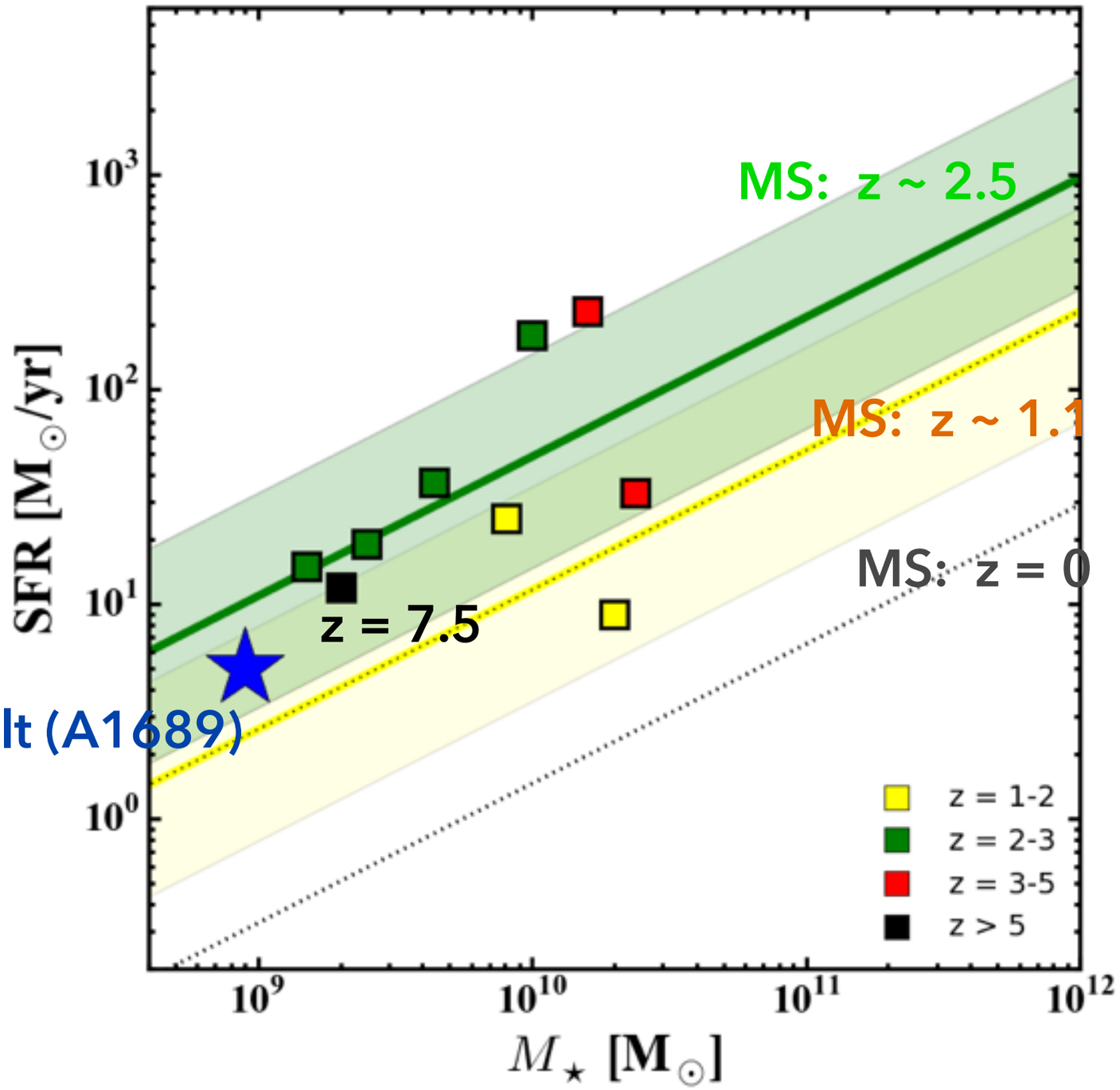
L_{FIR} ~ 10^{10} L_o

SFR ~ 1-4 M_o / yr

Stacking: using uv-stacking algorithm by Lindroos et al. 2014

[Knudsen, Richard et al. in prep]

Extreme or normal starbursts?



Stacked result (A1689)

Stacking: using uv-stacking algorithm by Lindroos et al. 2014

[Knudsen, et al. in prep]

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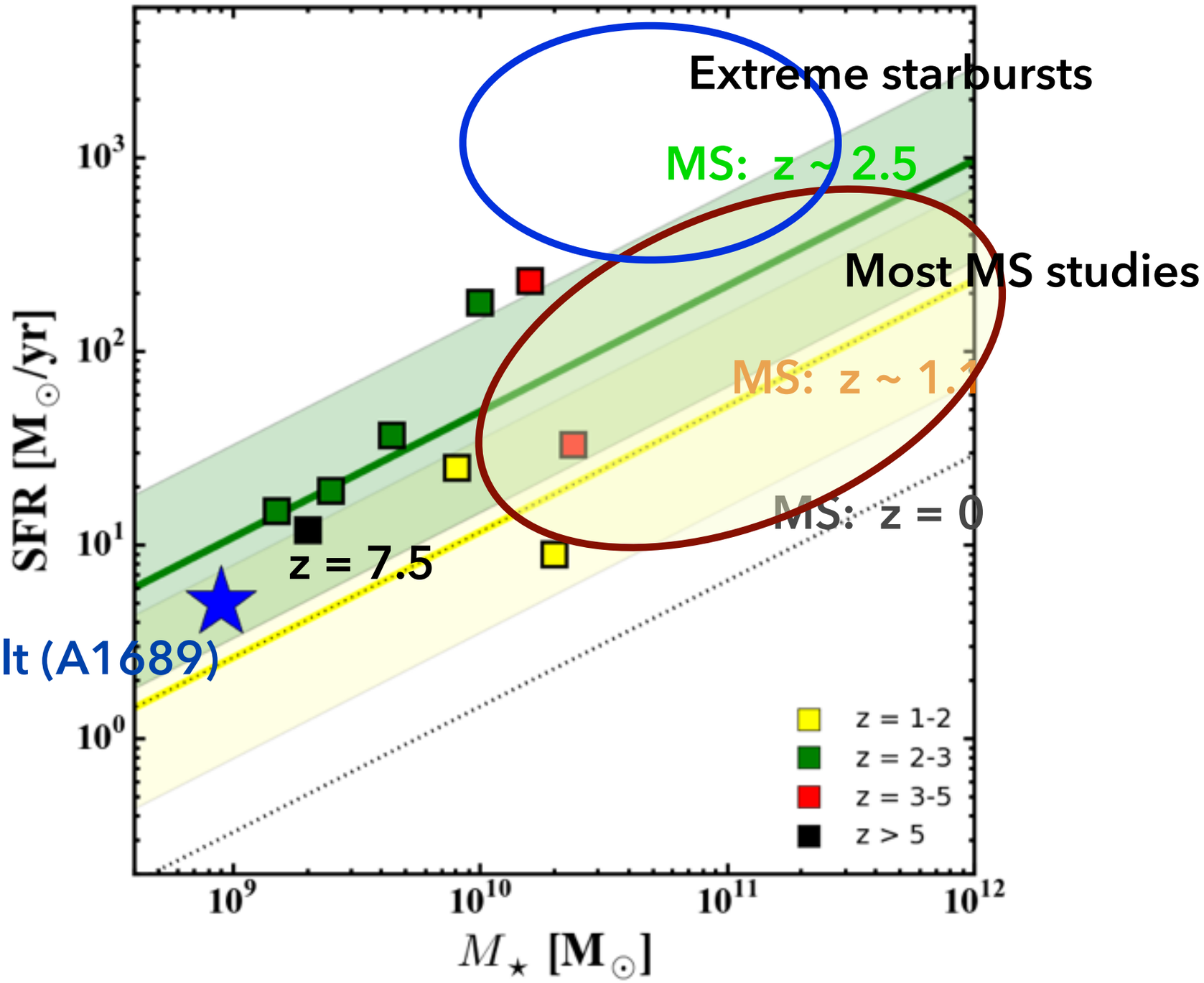

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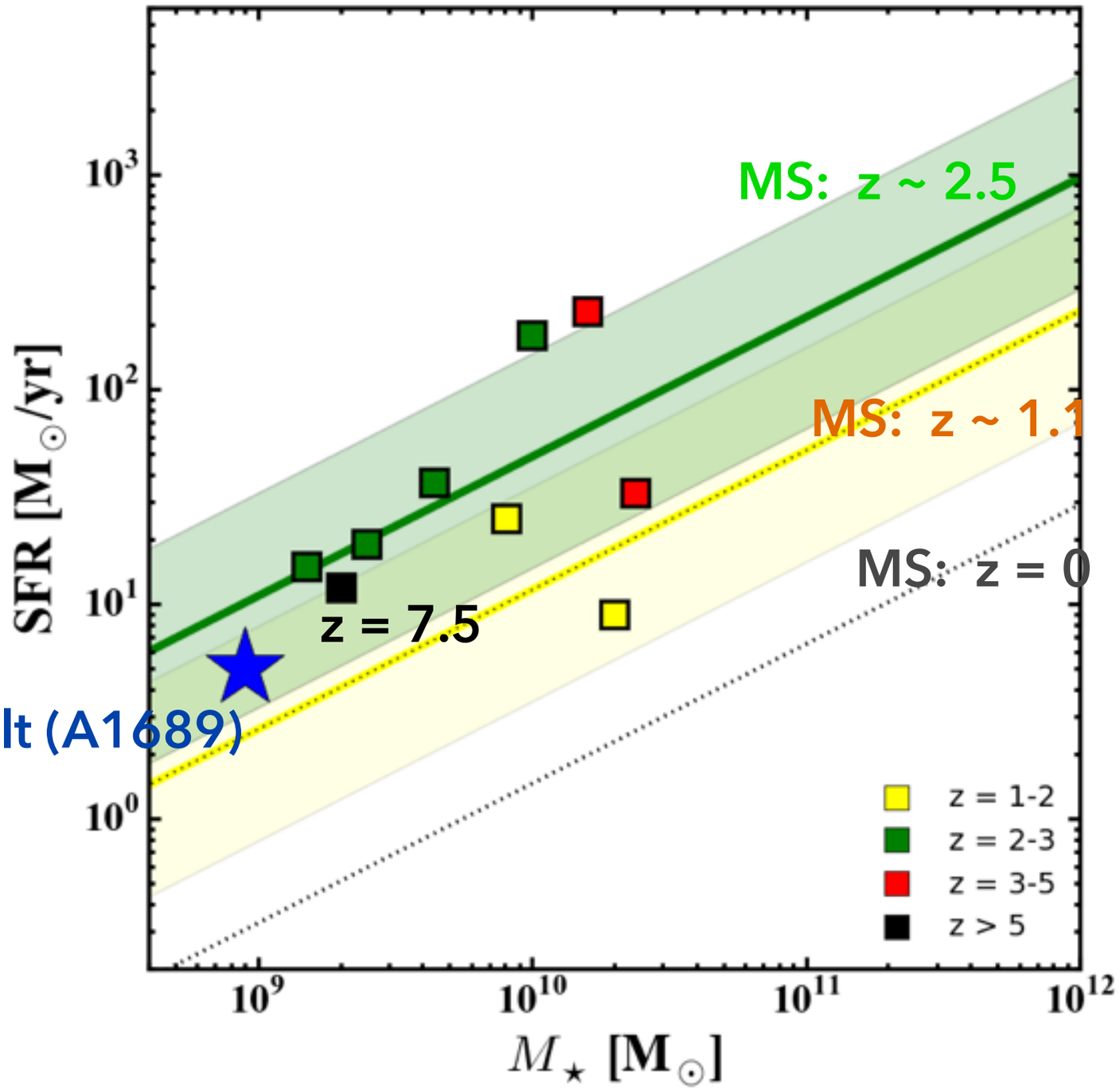

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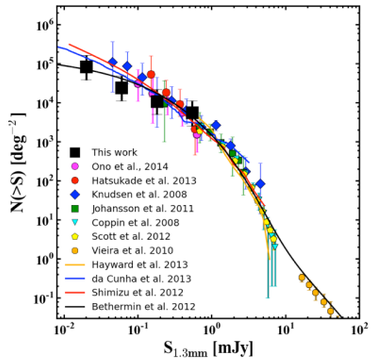
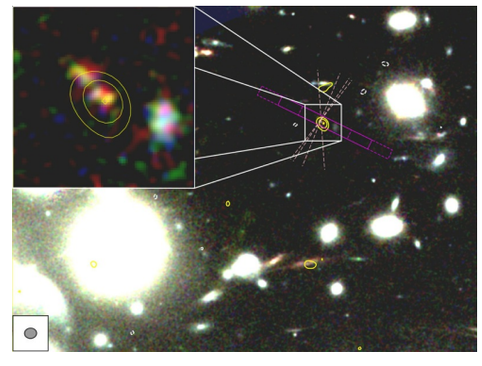
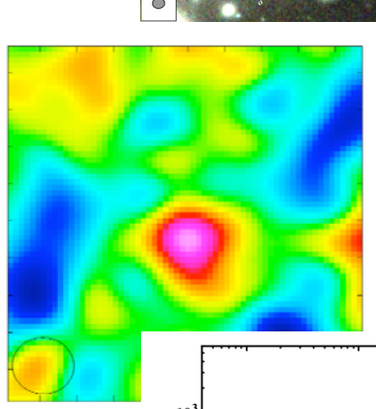
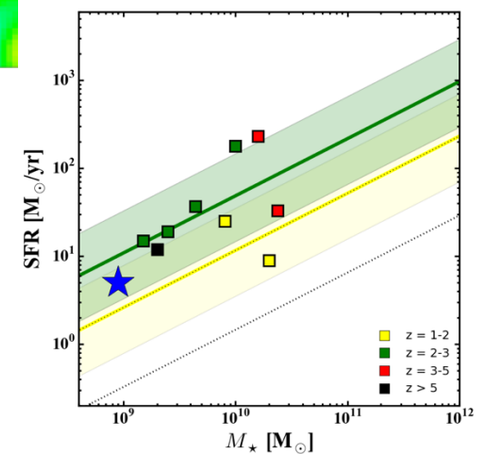
Summary and conclusions...

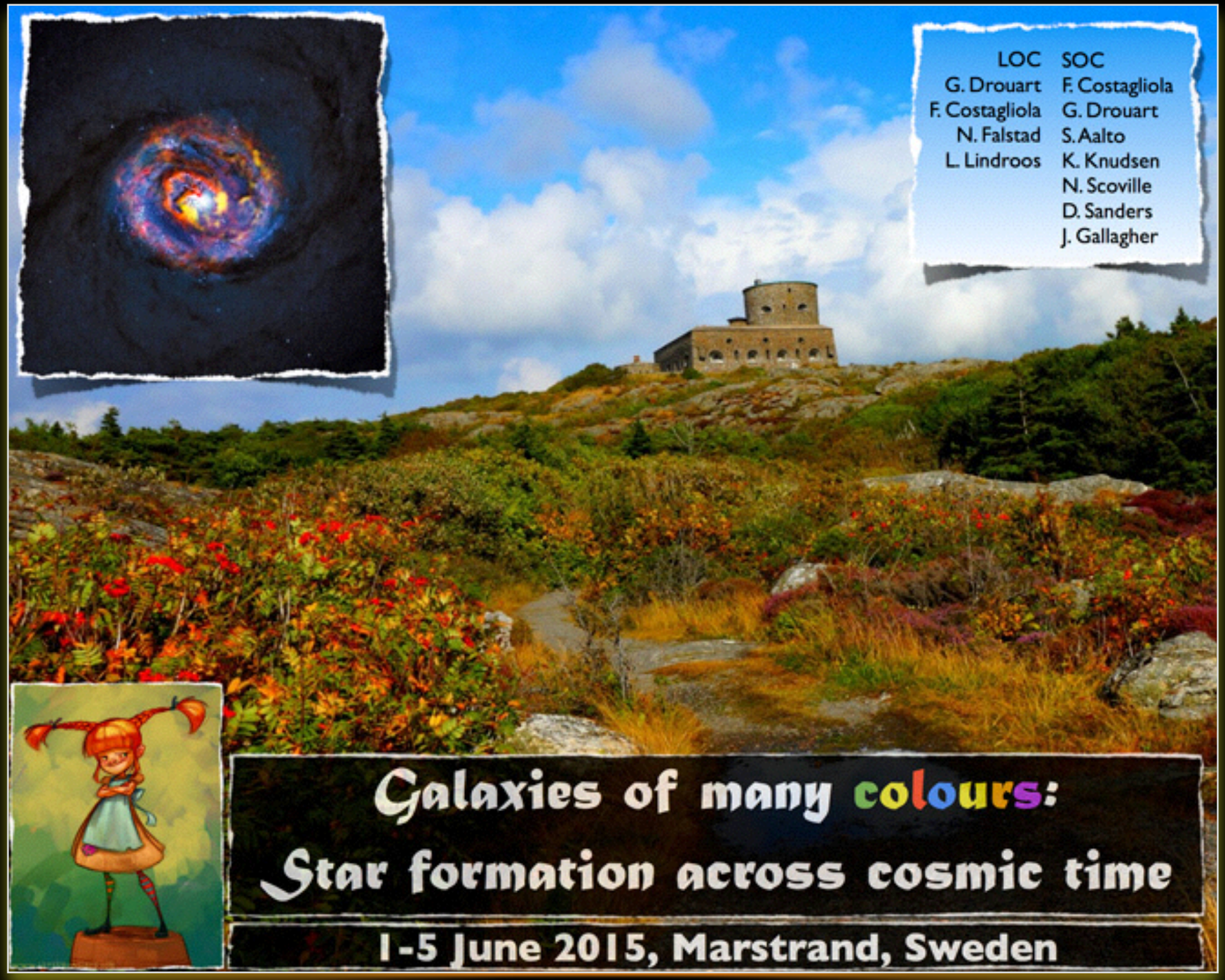




- ★ **Using nature's own telescopes we push to faint fluxes and 'low' SFRs**
- ★ **Finding dust emission at redshift z = 7.5**
- ★ **Finding "normal" starbursts at redshift z ~ 2**
- ★ **Statistical detection of SFR ~ 1-4 M_o/yr in $M_{stellar}$ ~ 10^9 M_o galaxies**
- ★ **Gravitational lensing essential to probe scales < few 100 pc in high-z galaxies**







Registration deadline: April 3rd
(Hotel block booking March 27th)