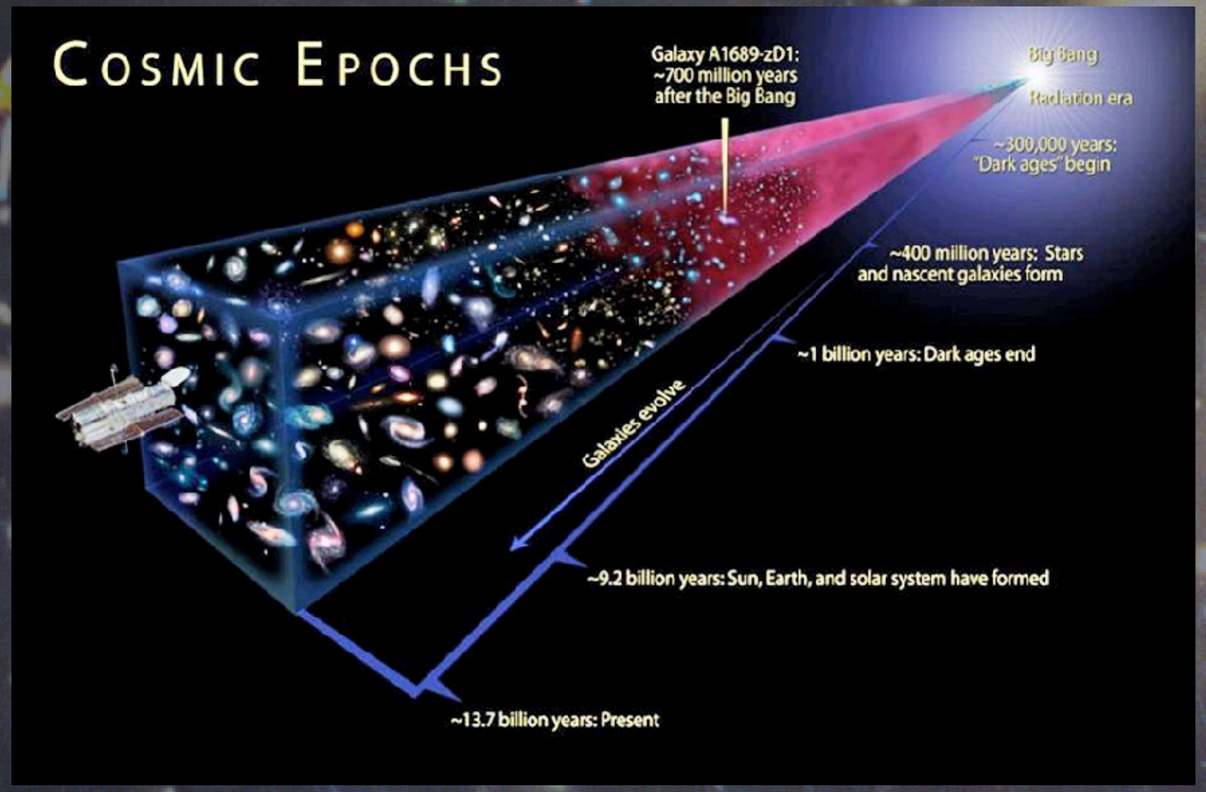
High redshift galaxies under the microscope with future adaptive optics facilities



Outline

High-z galaxies and cosmic reionization

Unveiling star-forming complexes and star clusters at high redshift

Extreme Adaptive Optics and cosmic telescopes
VLT/MAVIS: European and Australian participation

Eros Vanzella (INAF - OAS/Bologna)

INAF OAS BOLOGNA

Collaborators: M. Meneghetti, F. Calura, P. Rosati, A. Zanella, M. Castellano, U. Mestric, P. Bergamini, A. Mercurio, G.B. Caminha, M. Nonino, E. Sani, G. Cupani, G. Brammer et al.

Motivation I: cosmic hydrogen (re)ionization

A major phase transition in the history of the Universe

Impact on galaxy formation and evolution

Robertson 2021, ARAA (arxiv: 211013160R)

Motivation II: proto-GCs

Progenitors of the ancient and dense Globular Clusters

UV lum. funct. (N/mag/Mpc3)

ioniz. luminosity (phot/s)

(ξ_{ion} underlying spectrum)

escape fraction ion. photons: transmission

$$\dot{n}_{\rm ion}^{\rm com} = \int_{M_{\rm lim}}^{\infty} dM_{\rm UV}\, \phi(M_{\rm UV}) \gamma_{\rm ion}(M_{\rm UV})\, f_{\rm esc}$$

Volume filling factor:

Volume(HII) / Volume Universe

$Q_{HII}=1$ z<6

$Q_{HII}(z)<1$ z>6

$$\frac{dQ_{\rm H\,II}}{dt} = \frac{\dot{n}_{\rm ion}}{\bar{n}_{\rm H}} - \frac{Q_{\rm H\,II}}{\bar{t}_{\rm rec}}$$

mean comoving hydrogen number density

$$\bar{t}_{\rm rec} = \frac{1}{C_{\rm H\,II}\alpha_B(T_0)\bar{n}_{\rm H}(1+Y/4X)(1+z)^3}$$

$$\approx 0.93\ {\rm Gyr} \left(\frac{C_{\rm H\,II}}{3}\right)^{-1} \left(\frac{T_0}{2\times10^4\ {\rm K}}\right)^{0.7} \left(\frac{1+z}{7}\right)^{-3}$$

Hui (2012)

$$C_{\rm HII} \equiv \langle n_{\rm HII}^2 \rangle / \langle n_{\rm HII} \rangle^2$$

$$C_{\rm H}(z) = (2.9)\left[\frac{(1+z)}{6}\right]^{-1.1}$$

Shull et al. (2012)

IGM Physics

Did reionization occurred at z~6-8(10)?

What's its topology?

What sources caused reionization?

Galaxies(AGNs) at z>5(z<5)

(e.g., Villasenor et al 2021)

Are SF mode and fesc evolving with redshift?

(bursty SF seems more frequent with increasing z, e.g., Boyett+21)

Push analysis to unprecedented **low luminosities** and **small spatial scales** at any cosmic epoch...

Cosmic Dawn II (Ocvirk et al. 2018)

z=150

z=5.8

Extreme Adaptive optics facilities at the focus of "cosmic telescopes"

Multi-conjugate-adaptive-optics-Assisted Visible Imager and Spectrograph @ VLT (MAVIS)
Sky coverage > 50% in the South (see McDermid talk)

will open a new window to small angular scales and faint luminosities

Imager: ugriz bands, 7.4 mas/pixel, 30"x30" FoV, mag>29 (5sig) 1h integration
Spectrograph IFU: 2.5" x 3.6" 25mas/spaxel; (5"x7.2" 50 mas/spaxel)

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

Australian National University

AAO

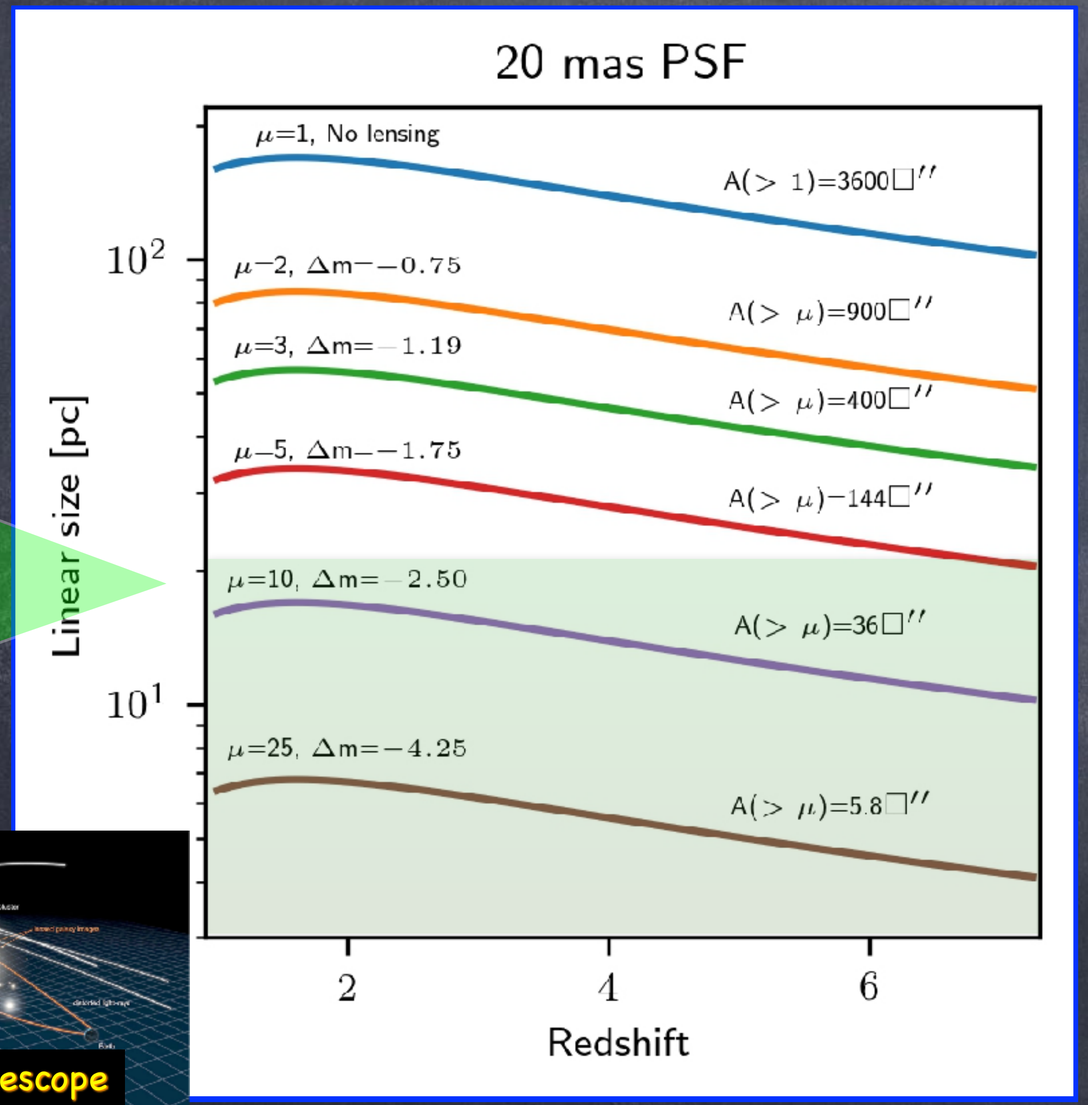
LAM
LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

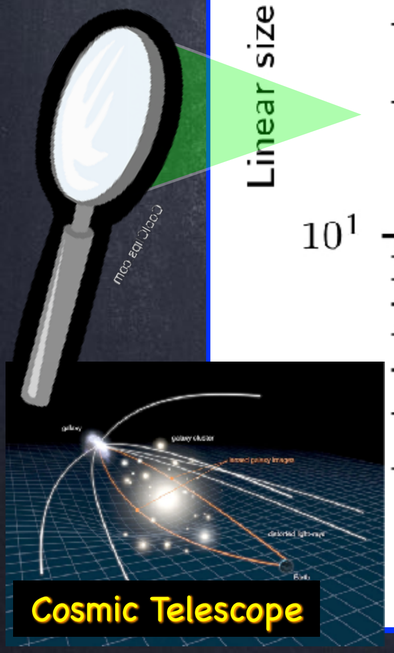
MACQUARIE University
SYDNEY·AUSTRALIA

ESO

Unveiling tiny star-forming complexes up to EoR (z<7.2) with VLT/MAVIS

MAVIS + strong gravitational lensing





SF complex

Star clusters

Looking for grav. bound YMCs at high-z

The dynamical age Π

Age/Tcr = Π , if Π>1 grav. bound

$$T_{cr} \equiv 10 \left(\frac{R_{eff}^3}{GM} \right)^{1/2}$$

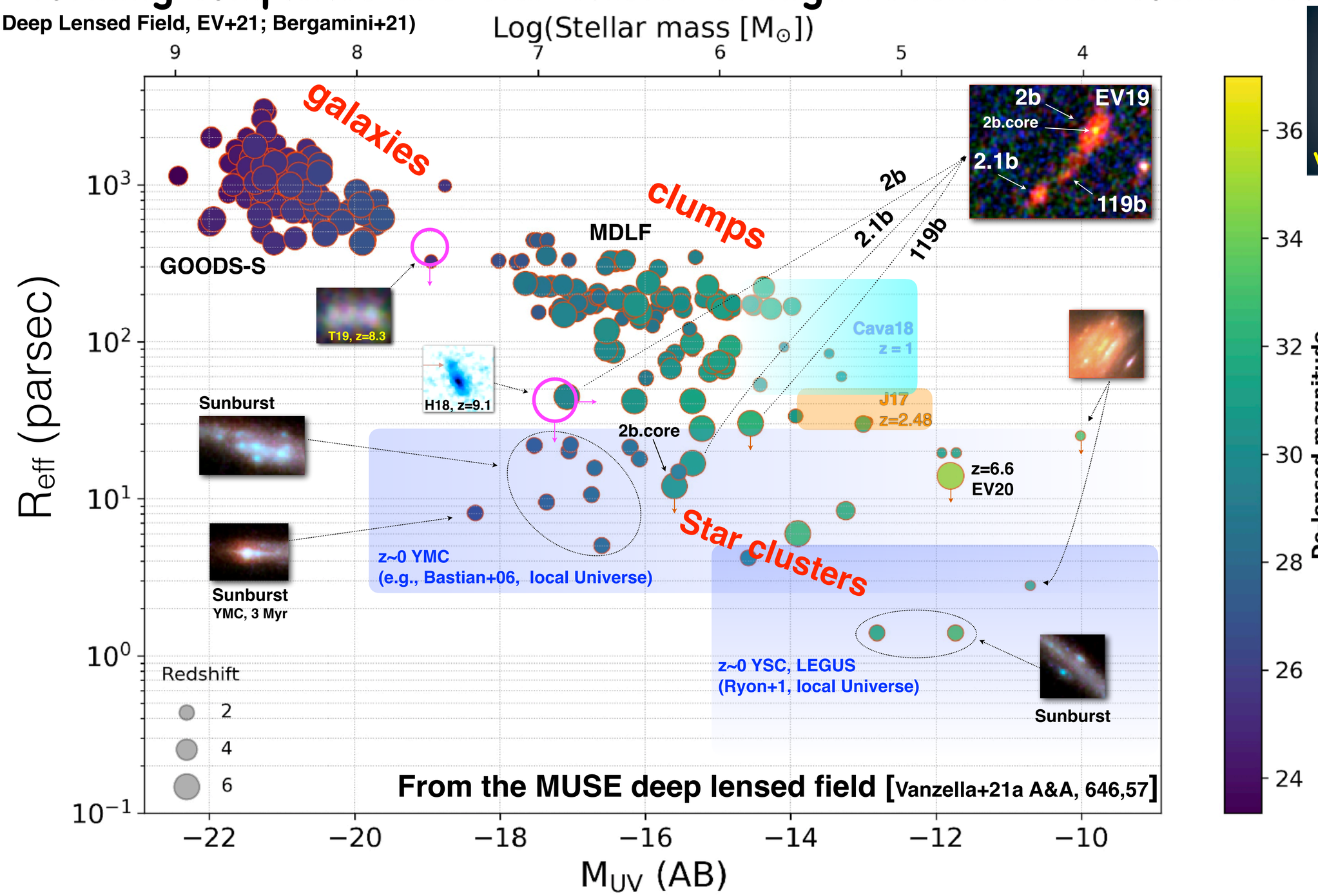
Gieles+11, Ryon+17

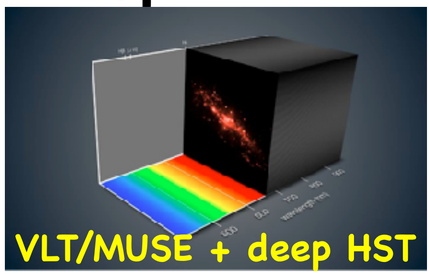
Stellar agglomerates for which the age of the stars exceeds the crossing time are bound

VLT/MAVIS + ELT: will probe tiny scales (Reff)
JWST will provide Age/Masses

Star-forming complexes and star cluster at high redshift with cosmic telescopes

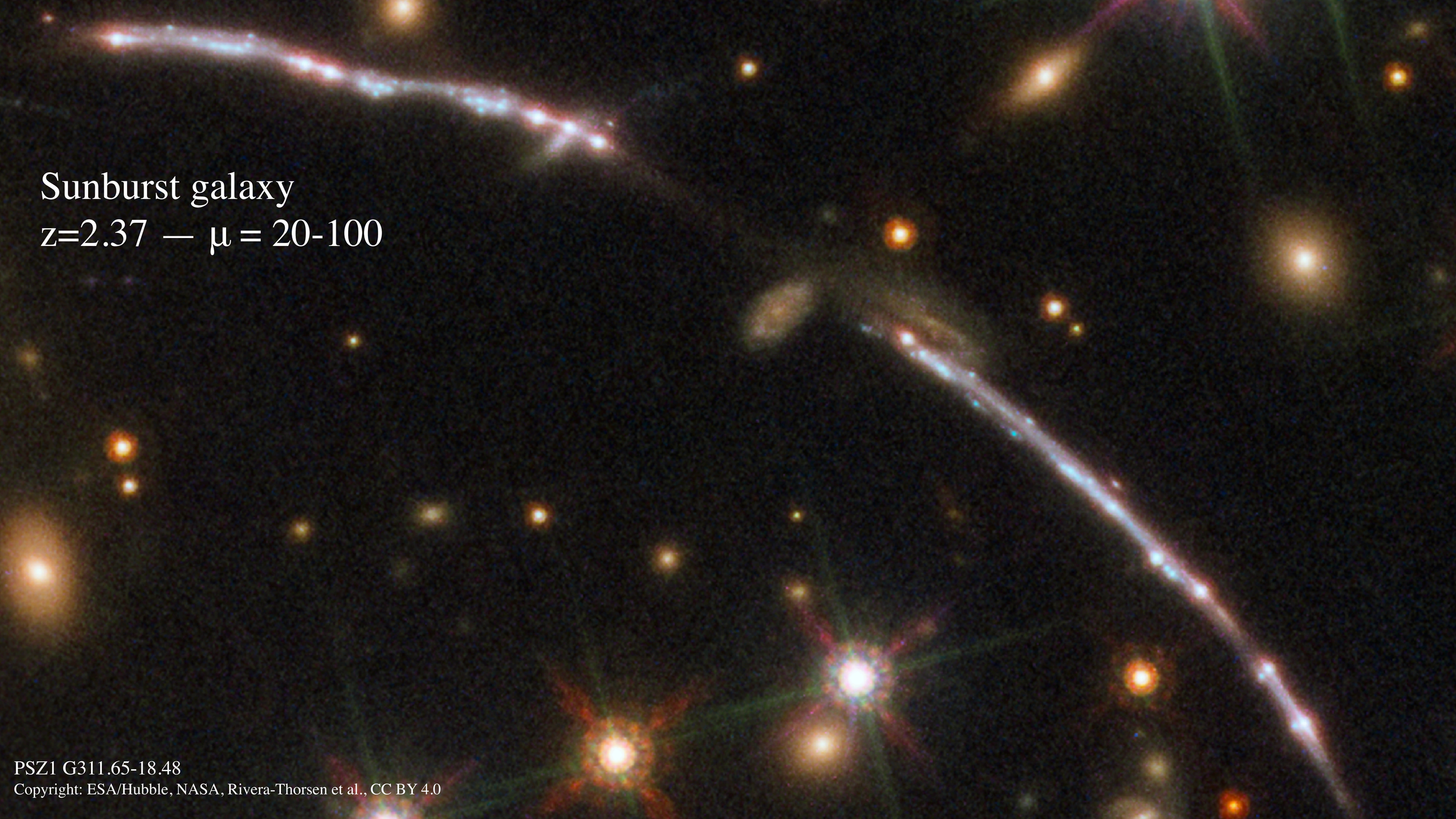
(MUSE Deep Lensed Field, EV+21; Bergamini+21)





Whenever the angular resolution increases, compact SF clumps emerge in high-z SF galaxies …

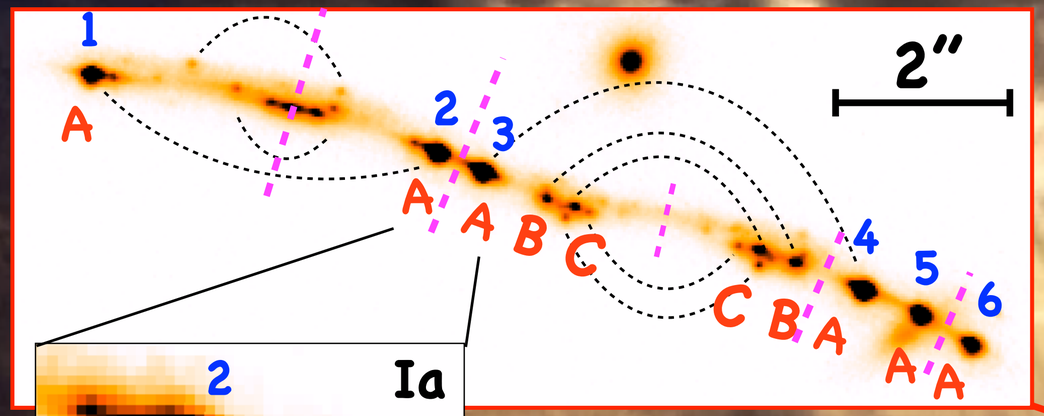
Analysis ongoing
> 120 SF clumps
2 < z < 6.5
Mestric+ in prep.

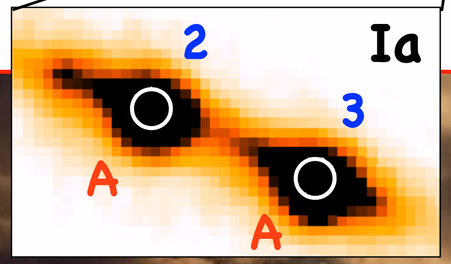


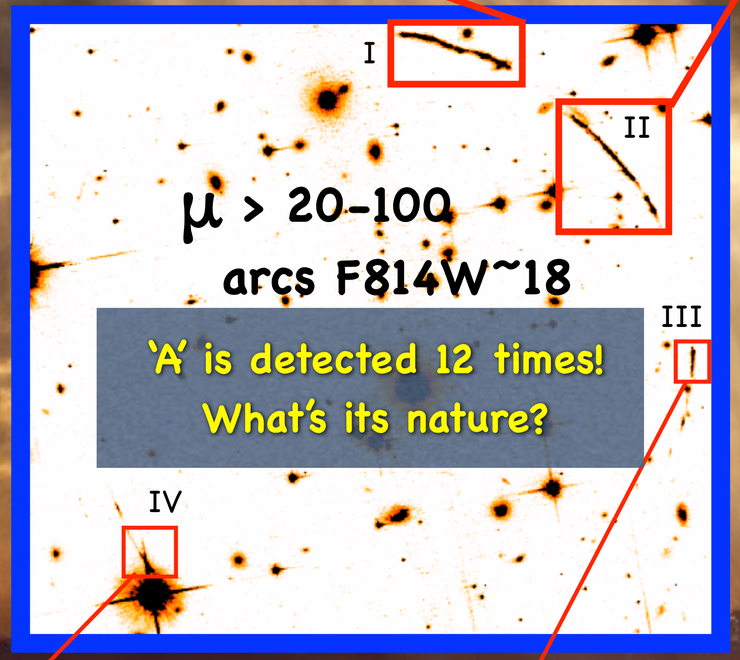
PSZ1 G311.65-18.48

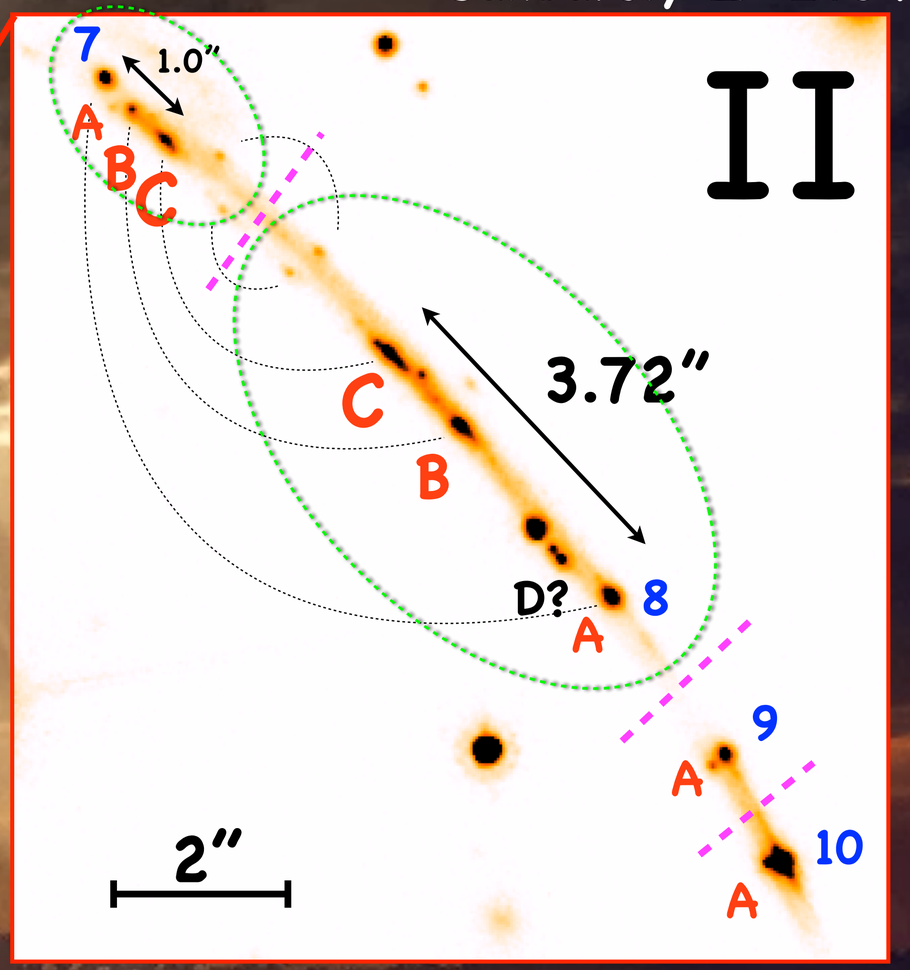
Superlensed system

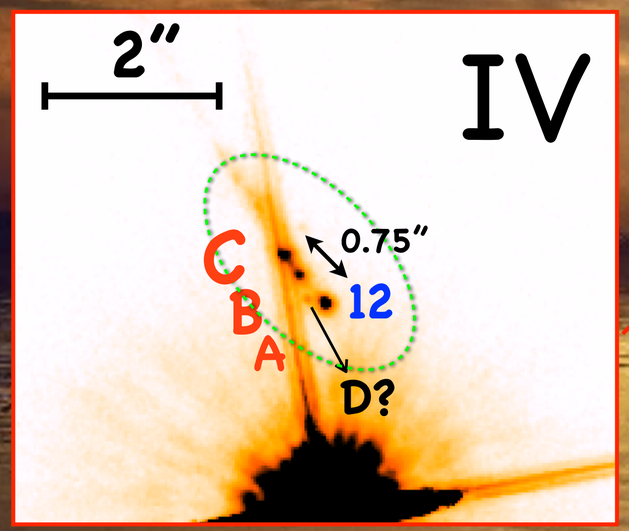
Sunburst, z=2.37

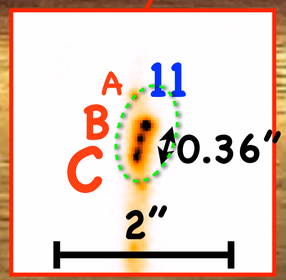












Vanzella+20 MNRAS 491, 1093 (LyC & YMC)

Vanzella+21 arXiv/210610280 (CFE)

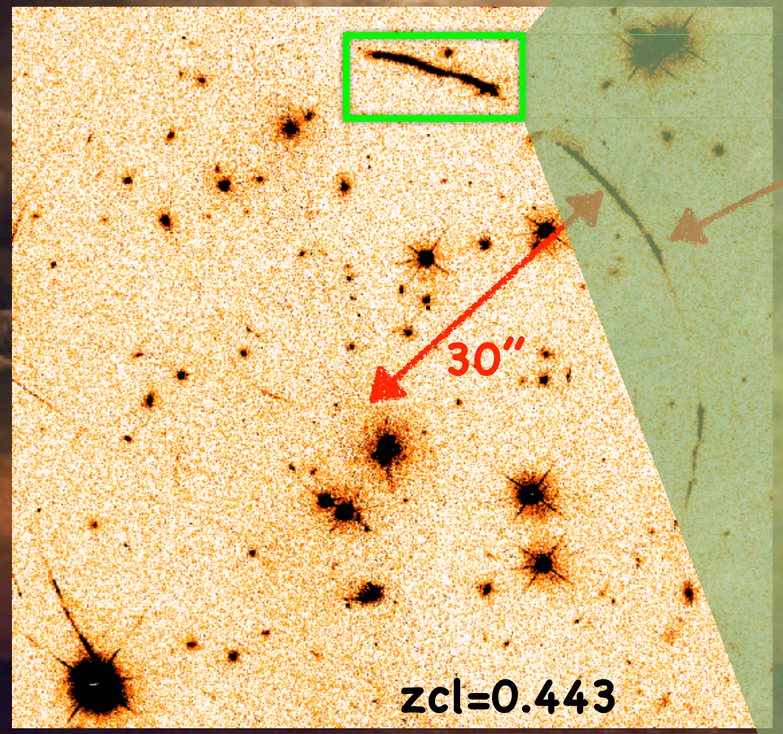
Pignataro+21 arXiv:210610286 (lens model)

Chisholm+19 ApJ, 882, 182

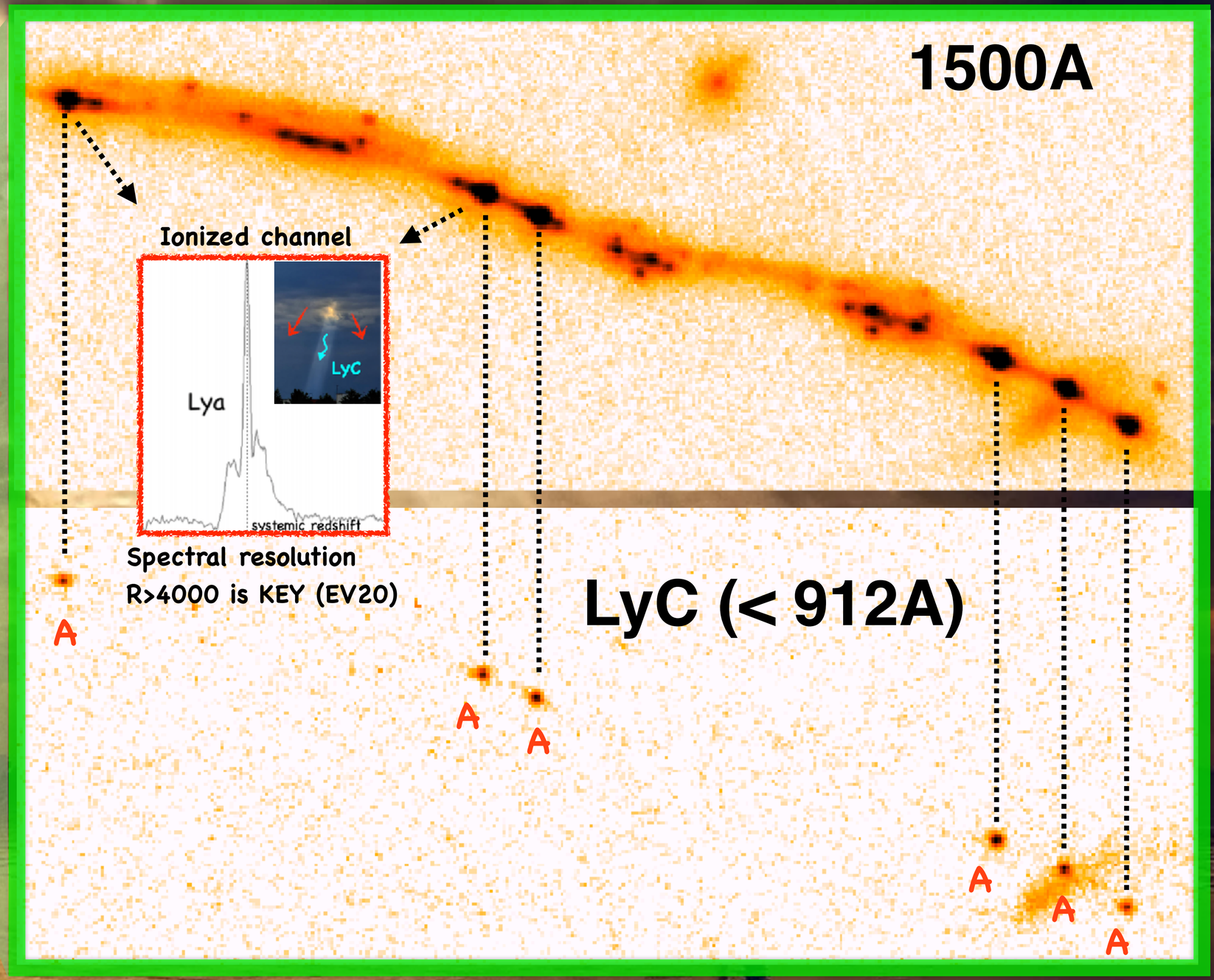
Rivera-Thorsen+19, 366, 738 SCIENCE

Superlensed LyC galaxy: Sunburst z=2.4

(54 multiple images of SF knots)



Knot 'A' is a YMC with Reff~**8pc**; **10^7** $M_\odot$; **3 Myr** old, and powerful ionizer



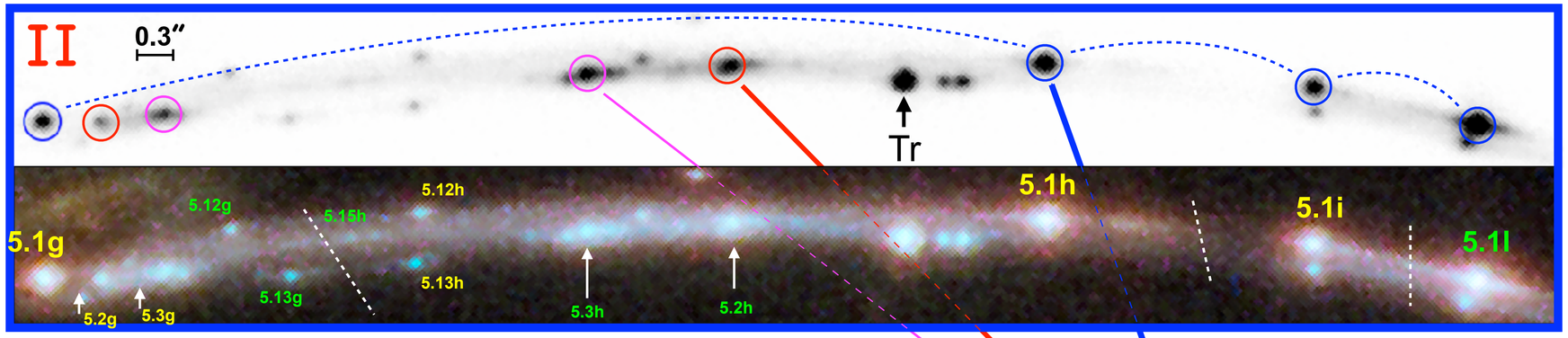
HST progs ID: 15101, 15949, 15377

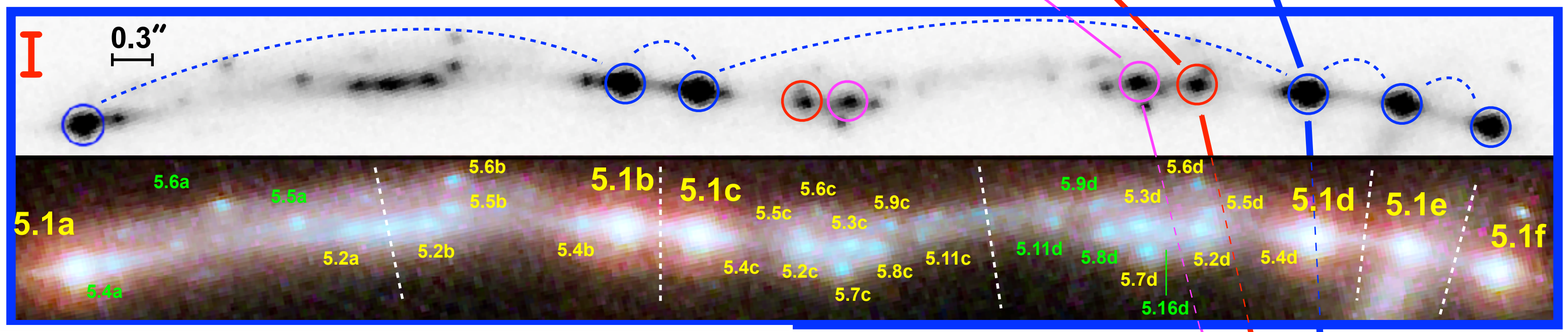
ANATOMY of the Sunburst galaxy, z=2.37

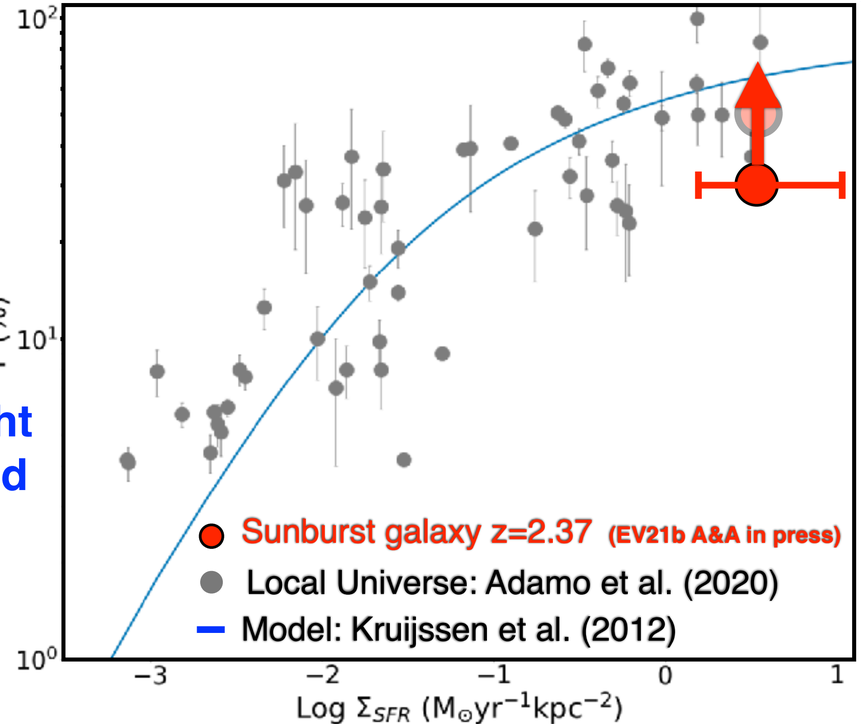
Many unresolved knots (HST)

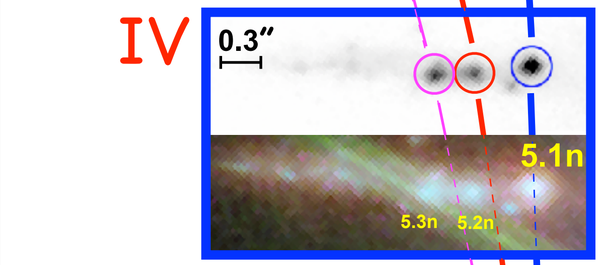
The first attempt to measure the cluster formation efficiency at cosmological distance (Vanzella+21b A&A sub. arXiv:210610280)
Likely hosts > 13 gravit. bound young star clusters

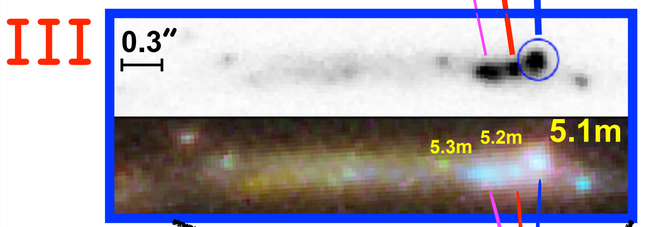
40-60% of total UV light of the galaxy is located In star clusters [T_L(UV) parameter]

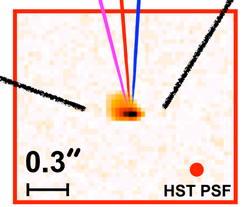












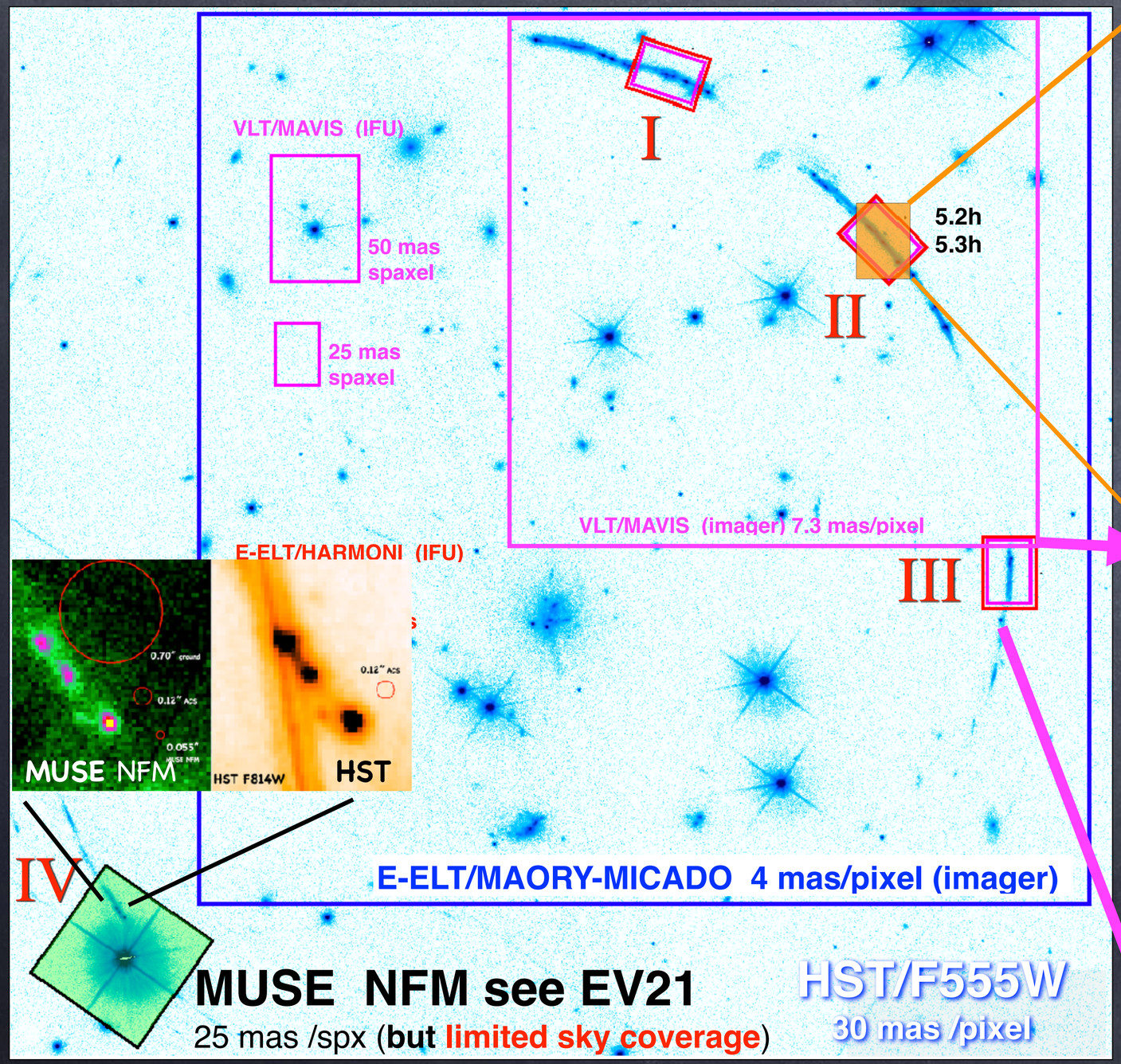
Source plane Reconstruction

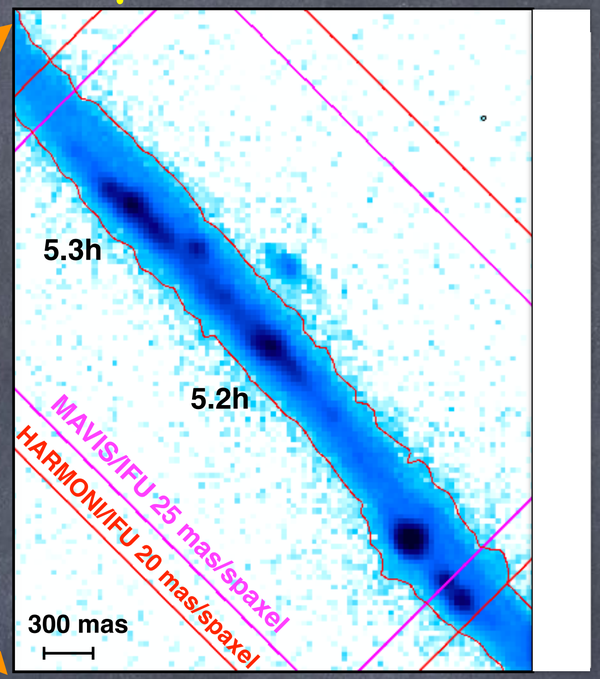
5.1 ↔ 5.3
3.70″
~2 (1)
5.1 ↔ 5.3
1.27″
~4 (2)
5.1 ↔ 5.3
0.71″
~7 (4)
5.1 ↔ 5.3
0.36″
~14 (7)
5.1 ↔ 5.3
0.03″
~164 (80)
FWHM ~ 20 pc
μ=1

μ<50
Increasing μ
μ<50

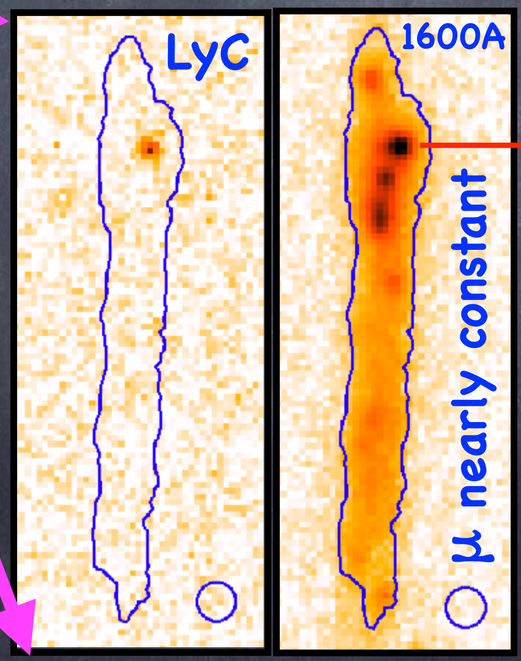
MAVIS IMAGING UV
ELT MAORY-MICADO optical

Star-clusters at high-z: the Sunburst example with extreme AO (V21 A&A)

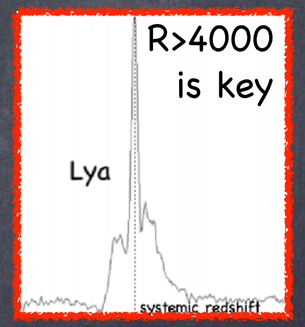




MAVIS:
- will sample the light profiles of HST-unresolved knots
- will find additional (clustered) star clusters
- will perform spatial maps of emission lines @ 20pc/spx



MAVIS: will perform 2D map of Lya and UV lines at 20 pc /spx



ELT will map the rest-optical at 10 pc (MAORY-MICADO, HARMONI)

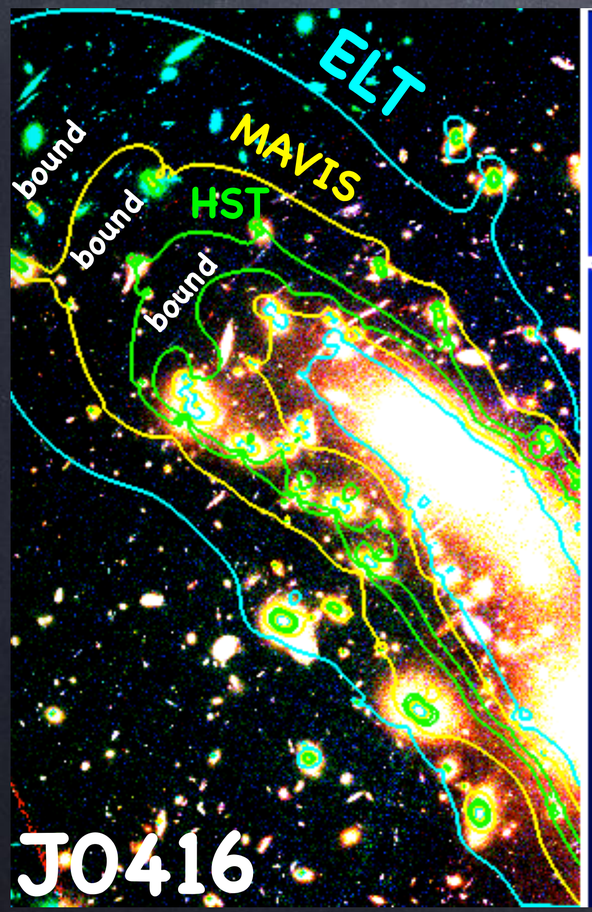
RT Lya, Lyman continuum, stellar feedback, massive stars ionized channels

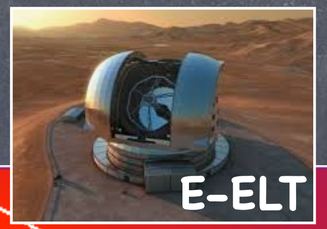
Extreme AO will allow to relax the required lensing amplification

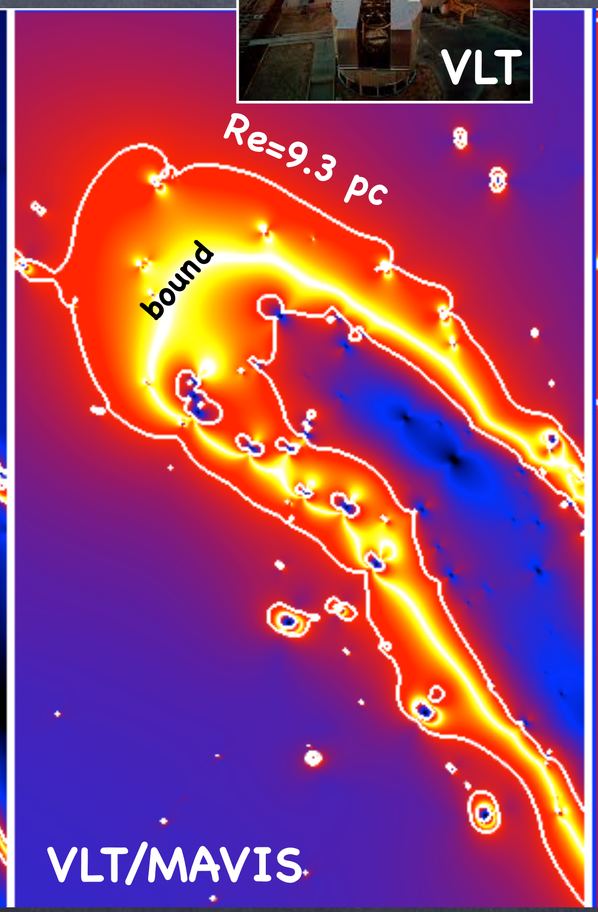
Assumed star cluster properties (YMC):

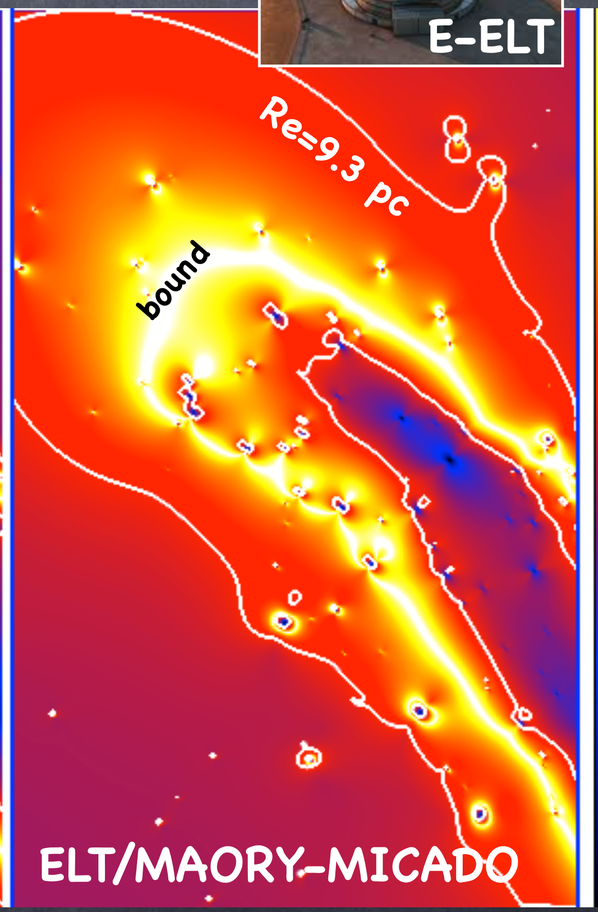
$M=2\times10^6$ Msun
Age=3×10^6 Myr
M_{1500} = −17 (29.7)

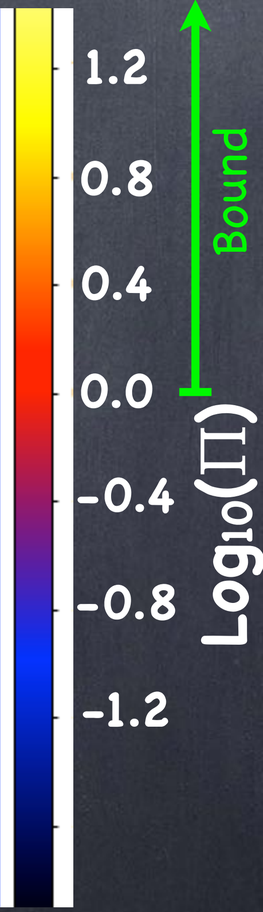
Π > 1 requires Re < **9.3** pc









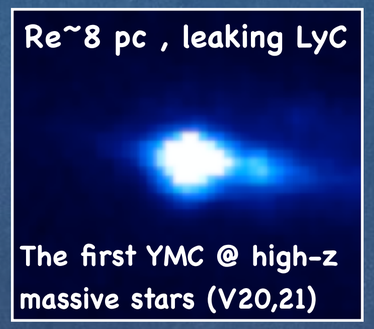


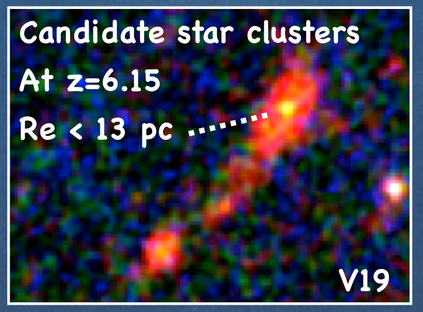
Take-Home messages

➜ VLT/MAVIS will probe ultraviolet star-forming complexes (<200pc scale) at any cosmic time up to z<7.2 (ELT will do @ z>7)

➜ VLT/MAVIS + Strong Lensing will open a new window to unprecedented small spatial scales (< 20 pc) at 0.3um < λ < 1um: star clusters

JWST + MAVIS + ELT will (routinely) probe stellar clusters up to EoR





Current studies need large μ (>30-50)

Star formation and stellar mass located in star clusters were substantial at high-z (z>5, e.g., Renzini+17)

➜ Is the CFE & cluster mass function evolving with redshift ?
[SF modes in high-z galaxies]

➜ Star clusters & the host galaxy: ionization ?
[feedback, massive stars ξ_{ION}, ionized channels, fesc]

➜ How/when globular clusters formed ?
[proto-GC, extending UV LFs to faintest limits]

➜ How high-z star clusters: connection with high-z SF "clumps" ?
[galaxy evolution]