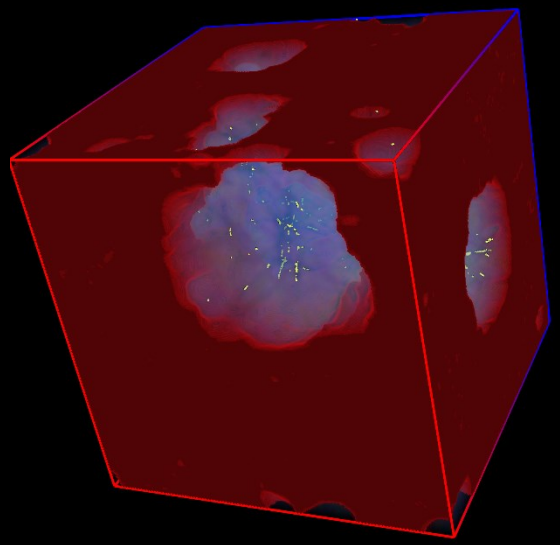
# SKA as a Probe of Dark Matter on Subgalactic Scales and the Galaxies that Reionized the Universe

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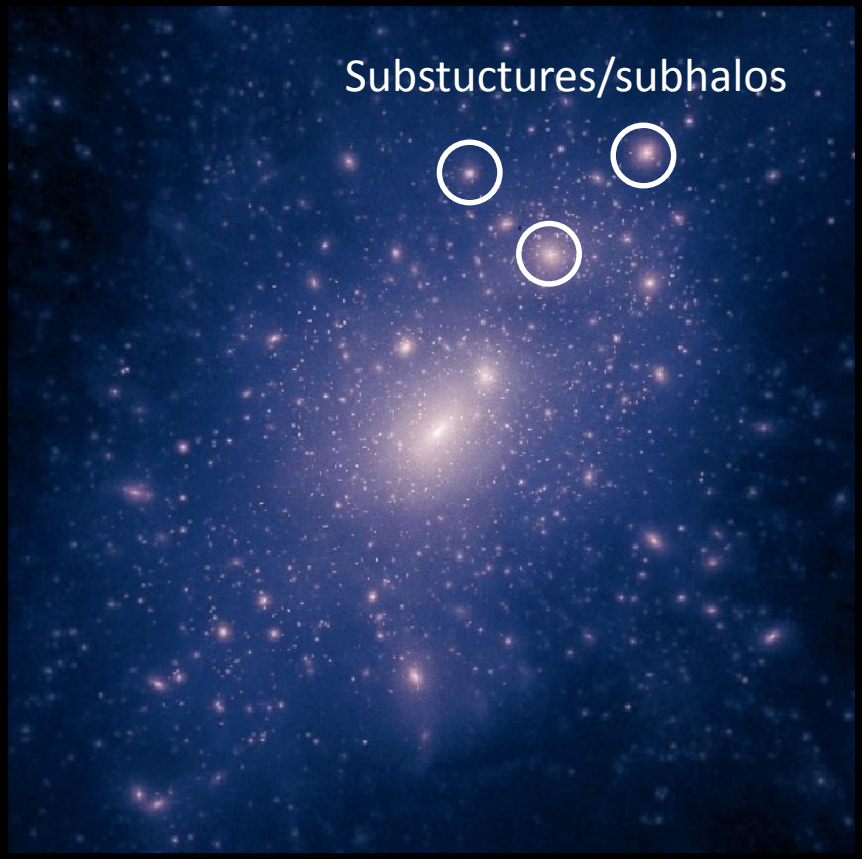
Erik Zackrisson

Saghar Asadi, Emily Freeland, John Conway, Hannes Jensen, Kaj Wiik, Garrelt Mellema

Oskar Klein centre

# Cold Dark Matter halos




N-body simulation of dark halo

Problems:

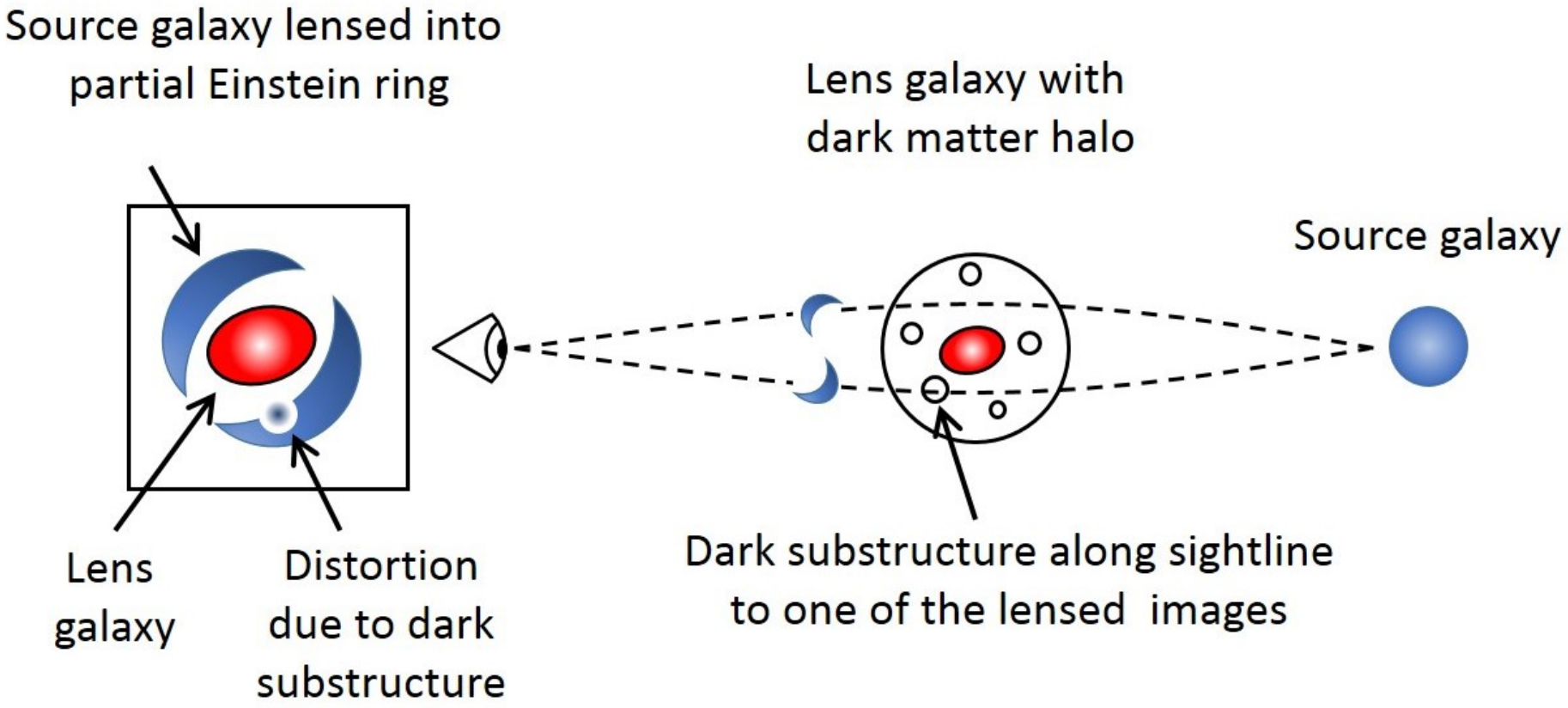
- ”Missing satellites”

Too many CDM subhalos compared to luminous satellite galaxies

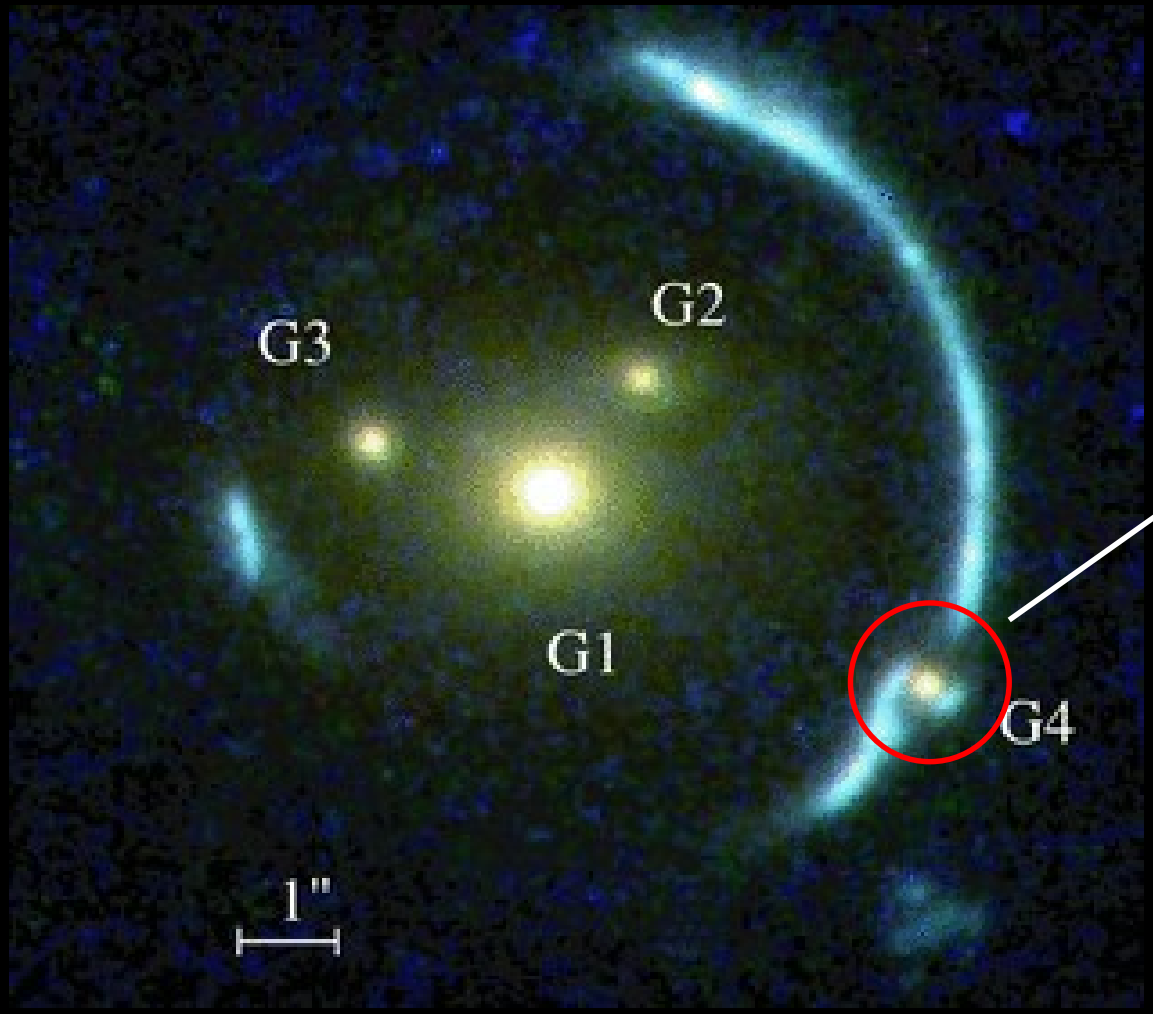
- ”Too big to fail”

The most massive subhalos predicted by CDM seem to have no counterparts among Milky Way satellite galaxies

# Gravitational lensing as a probe of dark halo substructures

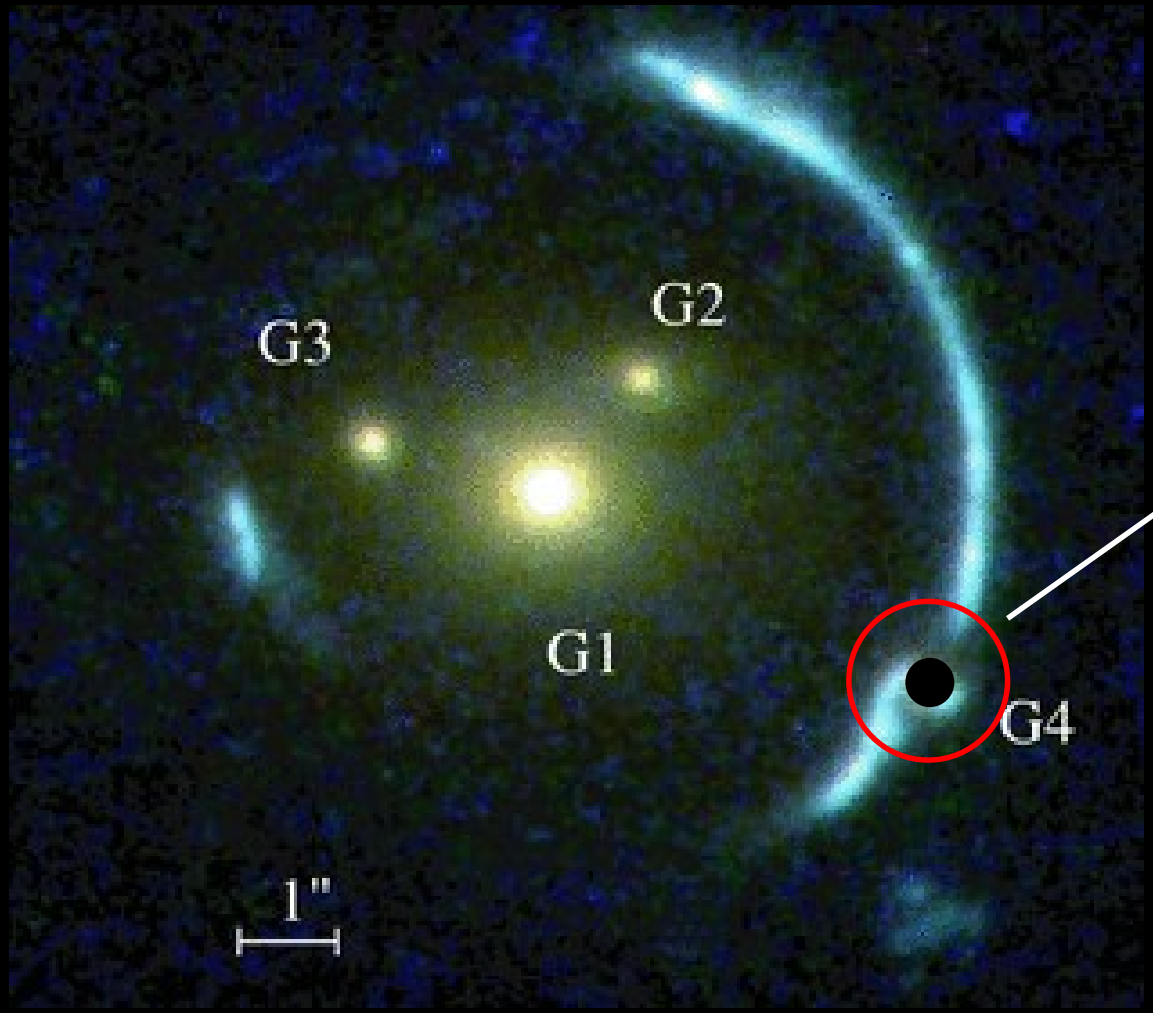



See Zackrisson & Riehm (2010) for a review




Luminous dwarf galaxy distorting Einstein ring

Vegetti et al. (2010)



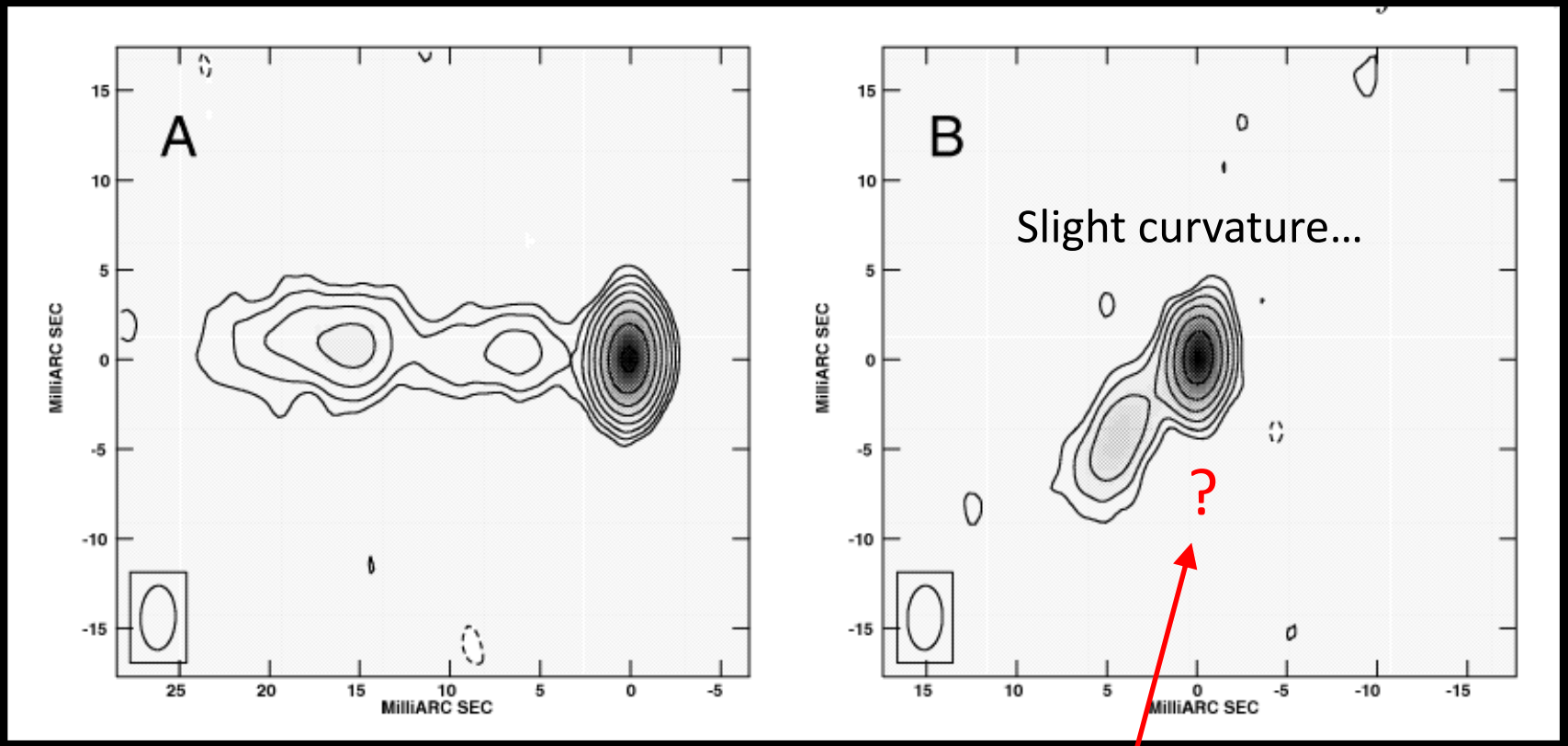

What you really want!

Two such cases already detected with HST and ground-based AO (Vegetti et al. 2010, 2012)

Higher angular resolution → Substructures of lower mass detectable.
ALMA with the longest baselines (~0.01”) is the next step (Zackrisson et al. 2013, Asadi et al. in prep)

# Lensed AGN jets at cm wavelengths

(Sub-)milliarcsecond resolution with VLBI →
Less massive substructures detectable




B1152+199 @ 5 GHz
(Rusin et al. 2002)

Metcalf (2002):
A ~$10^5$-$10^7$ Msolar object at approximately this position

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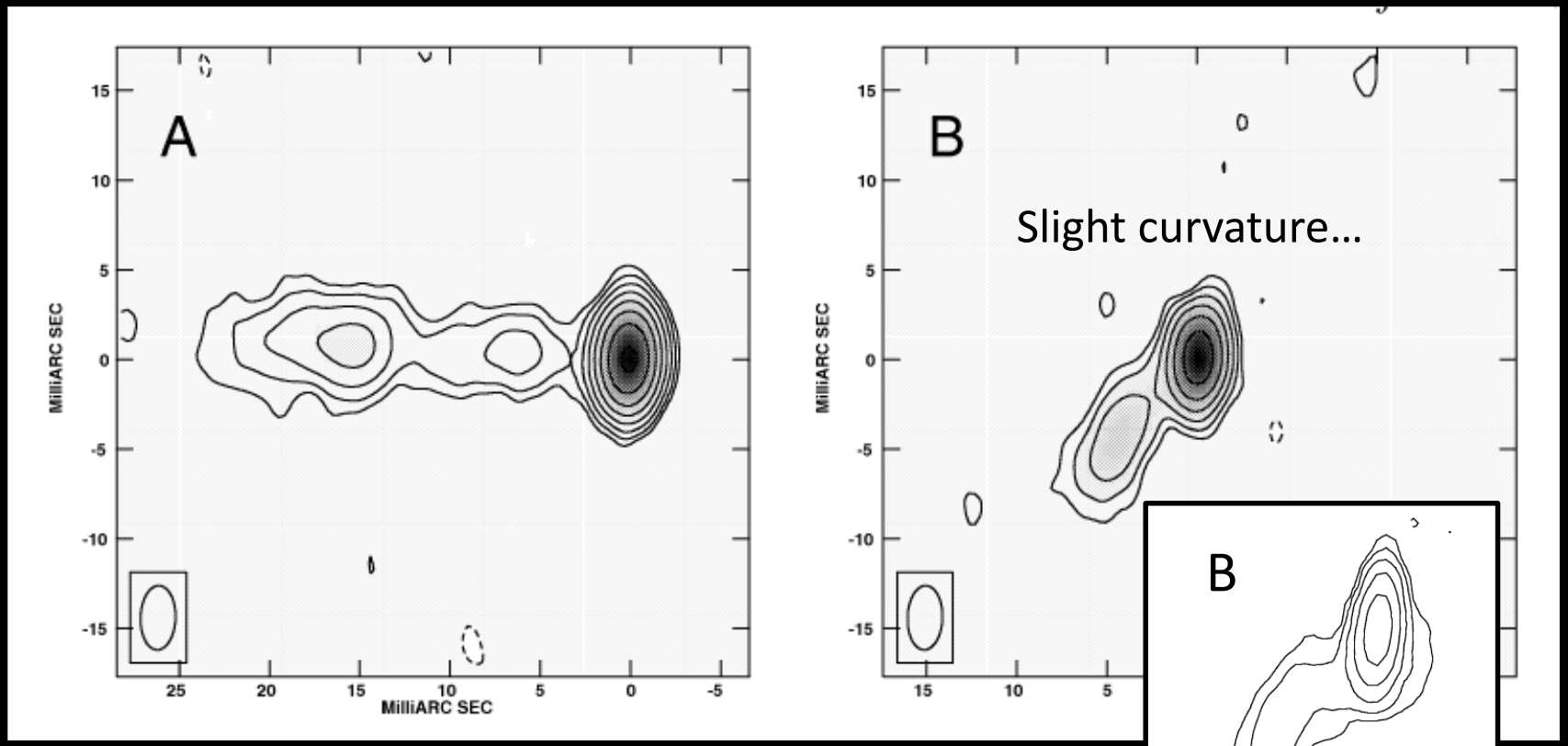
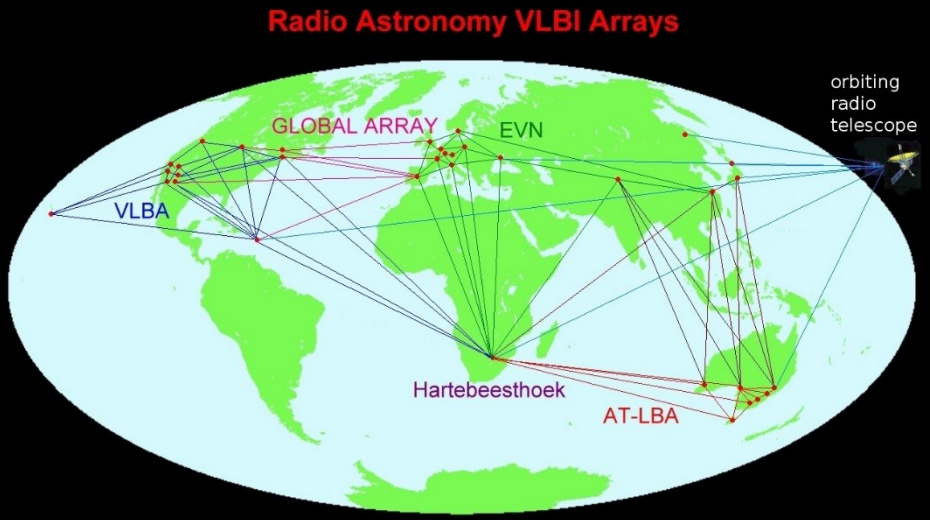



B1152+199 @ 5 GHz
(Rusin et al. 2002)

2nd epoch EVN data
(E. Freeland)

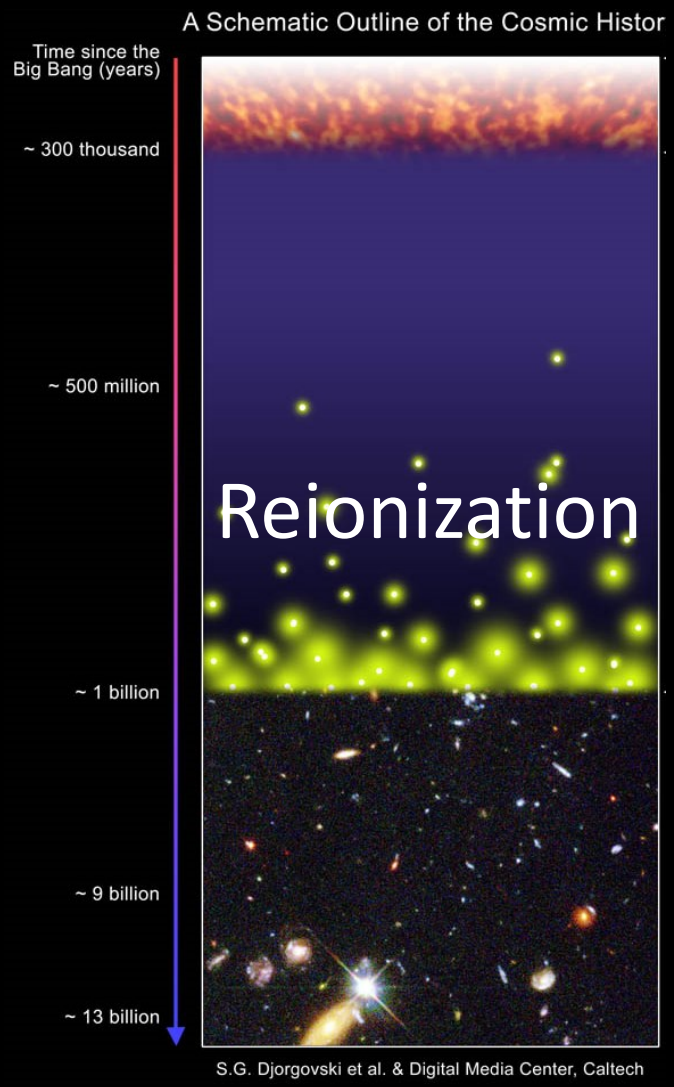
# SKA1 + African VLBI network + other VLBI arrays


Large antennas in Africa

Better resolution at low frequencies → Increased probability for detection of dark halo substructures (due to $\nu$-dependent jet sizes)

# Did galaxies reionize the Universe?



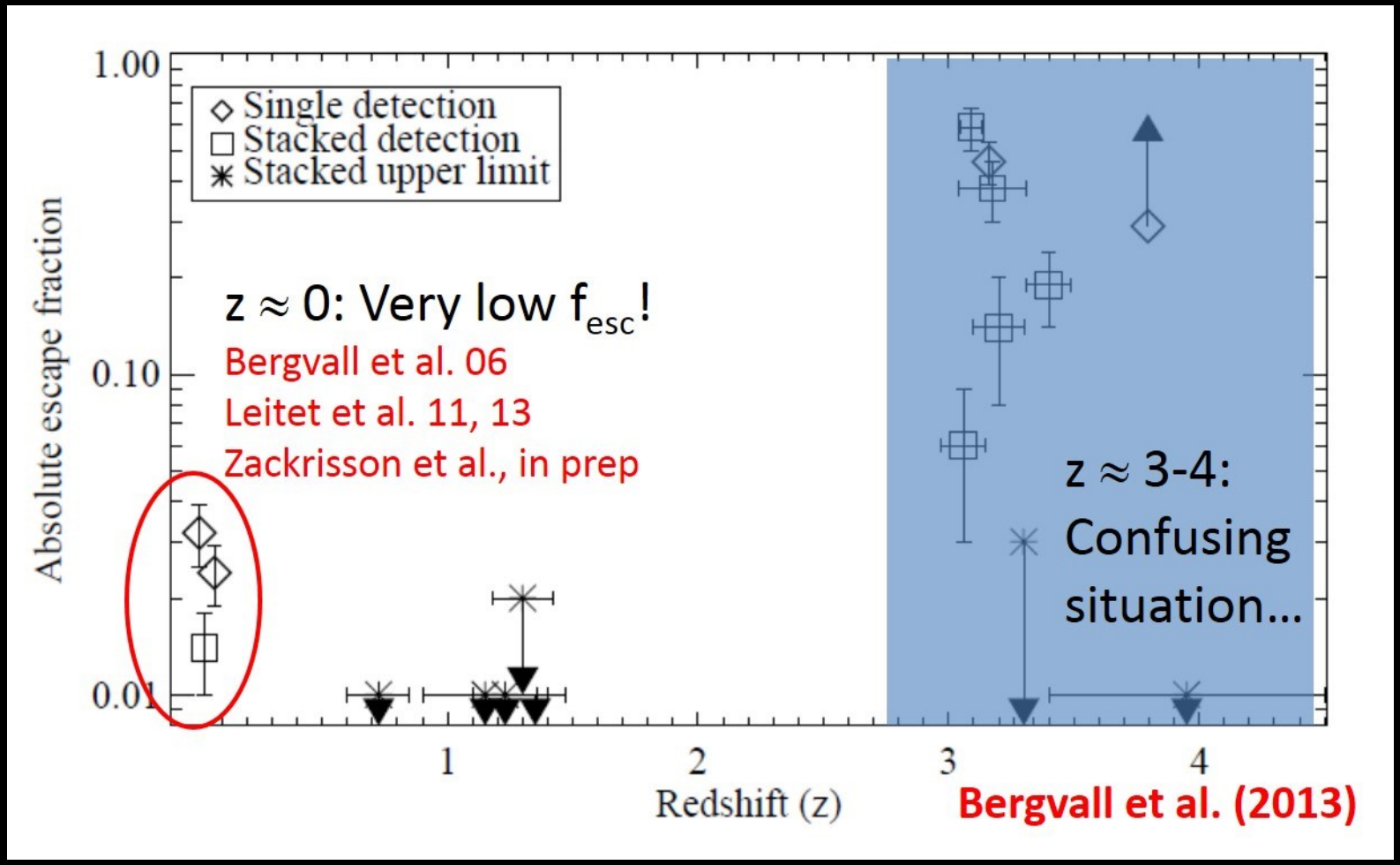

Ionizing photon budget relevant for reionization:

$$\dot{N}_{\mathrm{ion}} \propto \rho_{\mathrm{UV}} f_{\mathrm{esc}}$$

From observed galaxy luminosity function at z>6

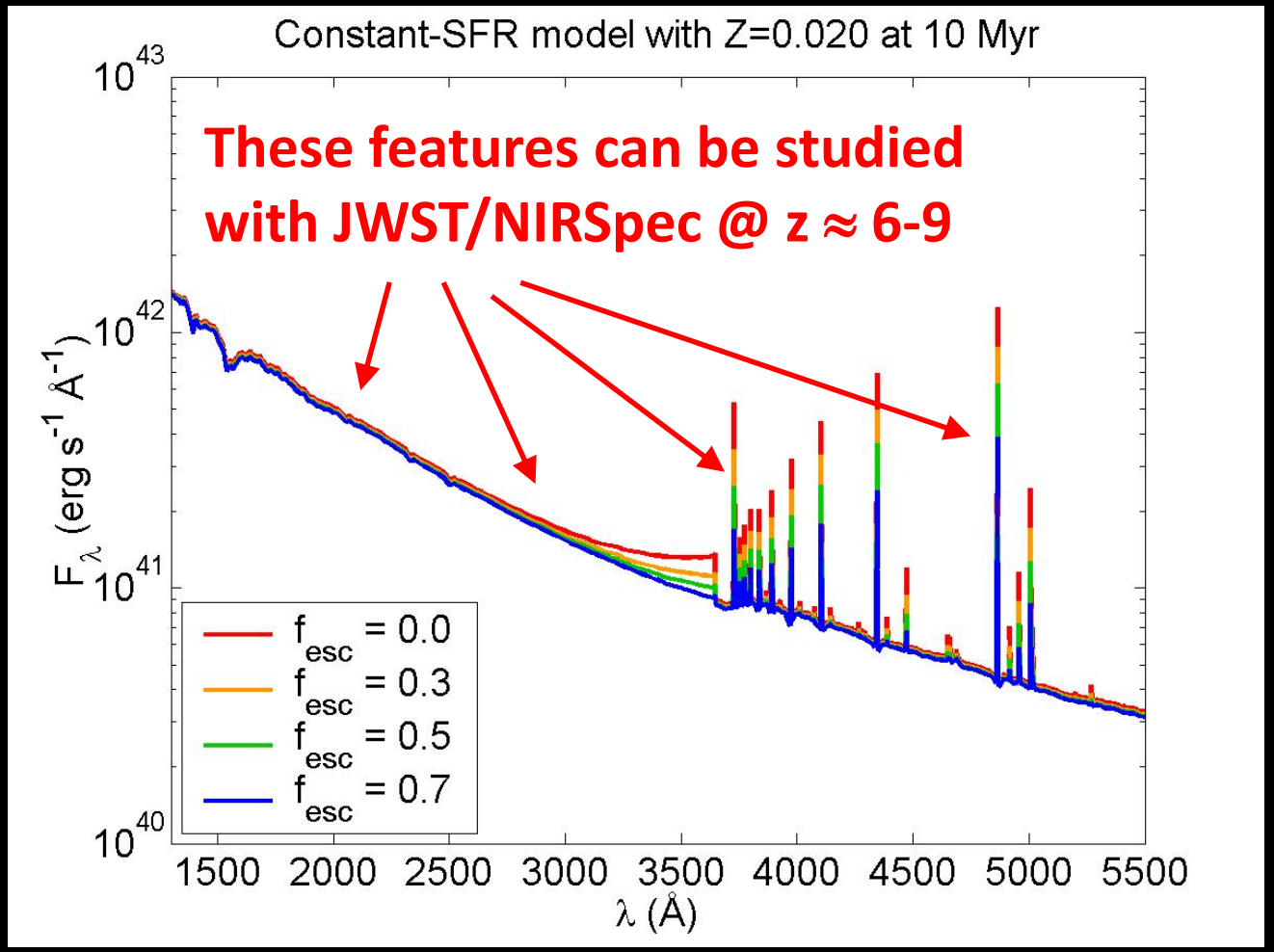
Escape fraction of ionizing photons (Lyman continuum)

# The Lyman Continuum Escape Fraction




At z > 4-5, the IGM opacity prevents direct detections of escaping Lyman continuum (Inoue & Iwata 2008) – Indirect methods needed!

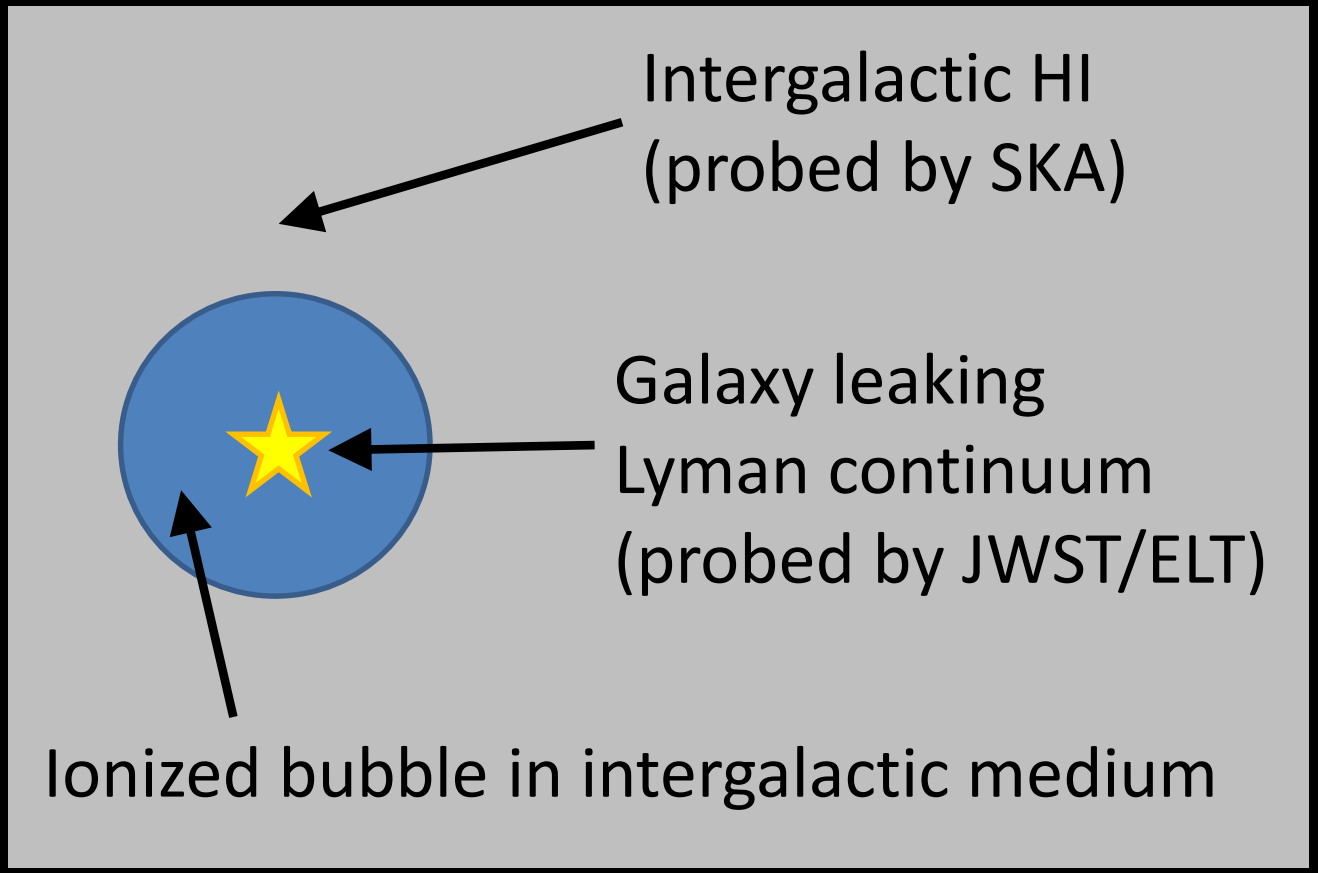
# Method I: Leakage signatures in JWST galaxy spectra



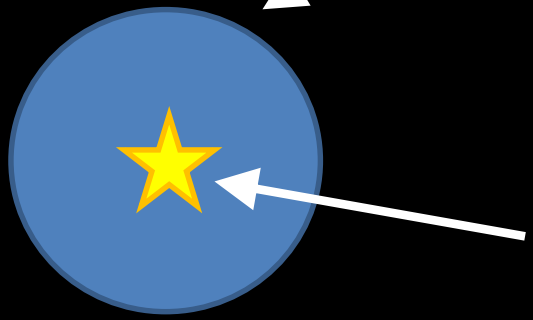

Zackrisson, Inoue & Jensen 2013, ApJ, 777, 39

# Method II: 21 cm tomography

Slice of the Universe during early reionization



# Method II: 21 cm tomography



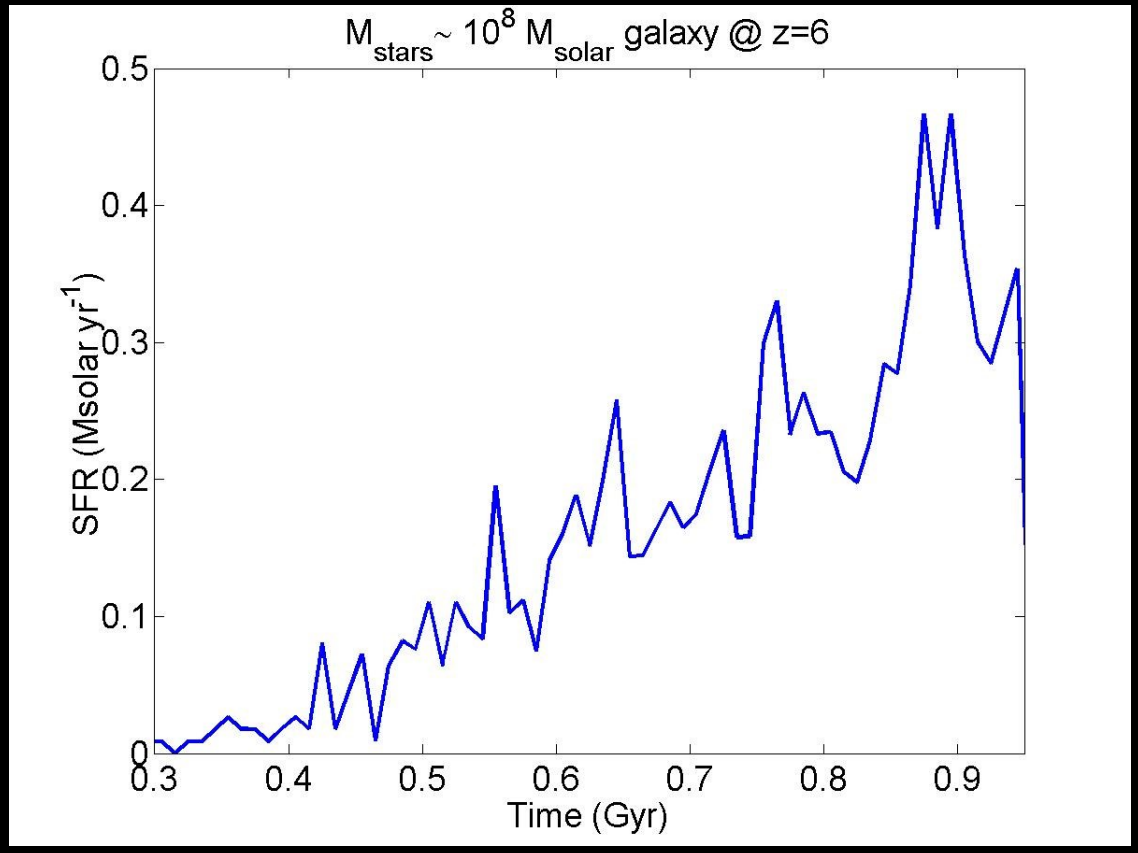
SKA → Size of ionized region
~ Number of LyC photons absorbed by IGM (i.e. escaping from galaxy)

JWST/ELT spectroscopy →
Number of LyC photons produced throughout star formation history

Combine the two → Time-integrated LyC escape fraction!

# Potential complications I

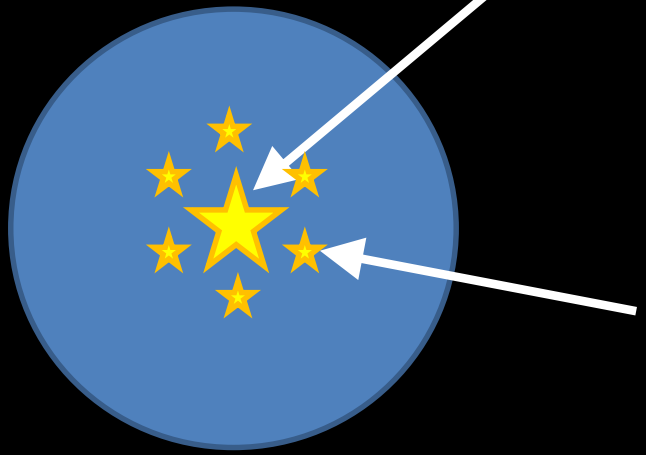
## Problems in reconstructing SFR(t)?




Simulations predict increasing SFR(t) → Most LyC photons produced recently → Not a serious problem?

# Potential complications II

## Least luminous objects dominate escape fraction?



Large galaxy → Sufficiently bright for JWST/ELT spectroscopy, but has $f_{esc} \approx 0$

Small galaxies → Not sufficiently bright for JWST/ELT spectroscopy, but have $f_{esc} \approx 1$

Objects that dominate bubble growth are out of reach…
Problematic!

# Lyman Continuum Leakage and Cosmic Reionization

**13-15 August 2014** | **AlbaNova University Center, Stockholm University, Stockholm, Sweden**

Home


The contribution from star-forming galaxies to the reionization of the Universe depends on the galaxy luminosity function *and* on the Lyman continuum (LyC) escape fraction of galaxies at redshifts greater than z~6. While most activity in this field has so far focused on quantifying the luminosity function, this 3-day workshop focuses on current and future efforts to constrain the LyC escape fraction of galaxies at both low and high redshift, and the impact that this is likely to have on our understanding of cosmic reionization.

**Topics to be explored include:**

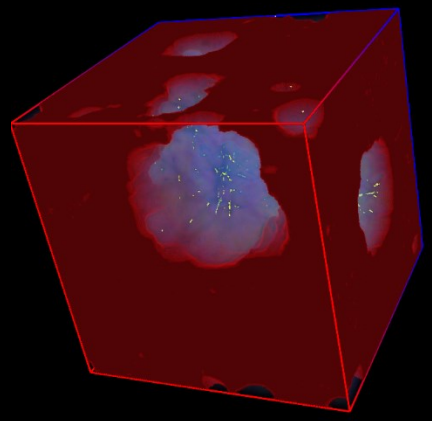
- Direct and indirect methods to constrain LyC leakage (from the local to the high-redshift Universe)
- Observations of LyC leakage
- Theoretical perspectives on LyC leakage mechanisms
- Simulations and observational probes of reionization: How can empirical data on LyC escape fractions help? Is it necessary to know the galaxy LyC escape fraction to prove that galaxies reionized the Universe?
- Complications: Anisotropic leakage, IGM clumping factors, gravitational lensing etc.

Stockholm, Sweden, August 13-15, 2014

# Summary

- SKA connected to African VLBI network and other VLBI arrays → Lensing probe of dark matter on subgalactic scales
- 21 cm tomography with SKA + JWST/ELT imaging spectroscopy → Contribution of individual galaxies to reionization at z~10

SKA
SQUARE KILOMETRE ARRAY



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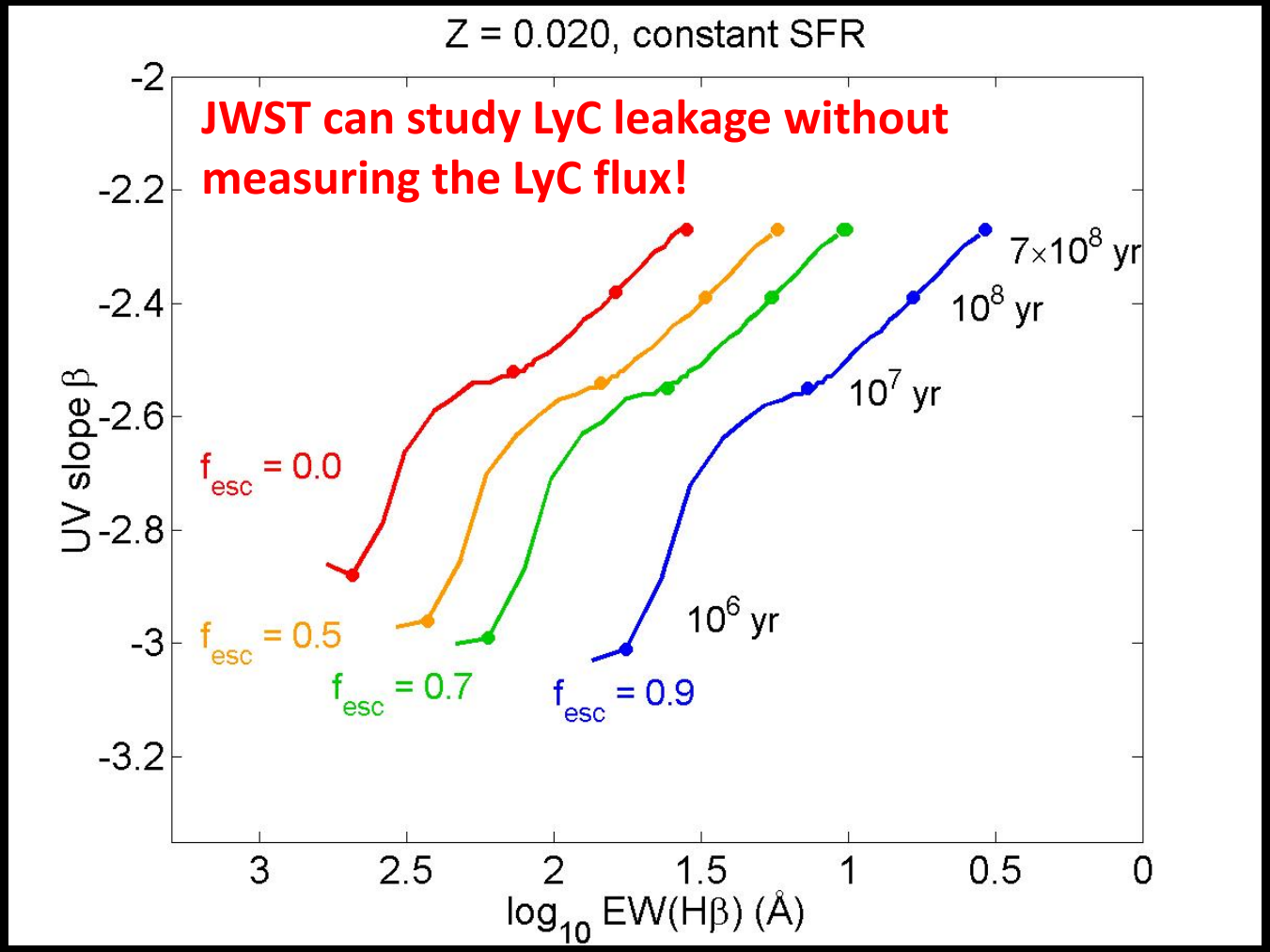


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