

A Multiwavelength View of Galaxy Evolution

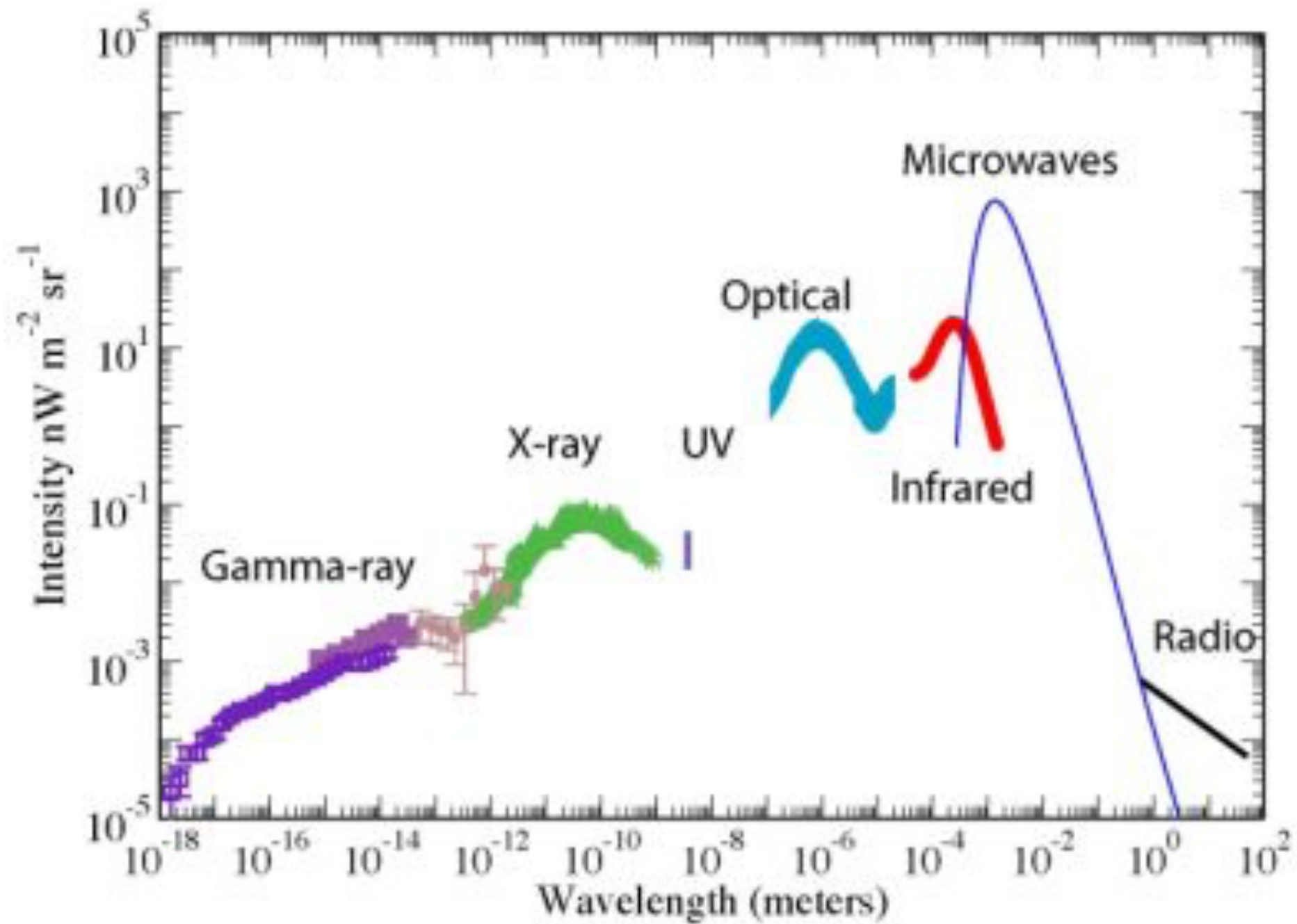
Karina Caputi

***Formation and Evolution of Galaxies 2023-2024 Q1
Rijksuniversiteit Groningen***



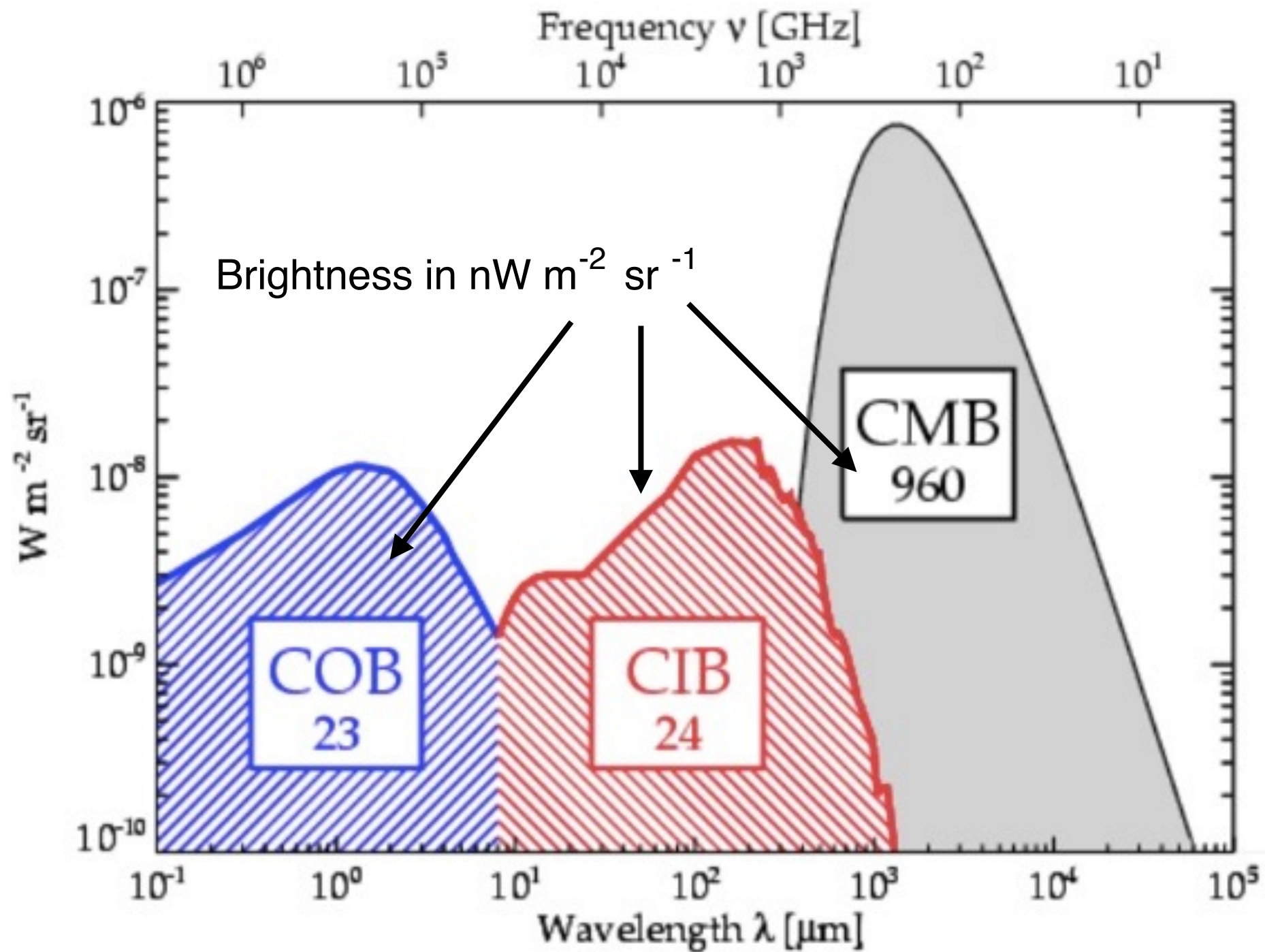
Picture Credit: <http://ecuip.lib.uchicago.edu/multiwavelength-astronomy/astrophysics/05.html>

The extragalactic background light



Picture Credit: <https://ned.ipac.caltech.edu/level5/March17/Cooray/Cooray1.html>

The extragalactic background light (cont.)



Dole et al. (2006)

Infrared Wavelengths

The IR wavelength range

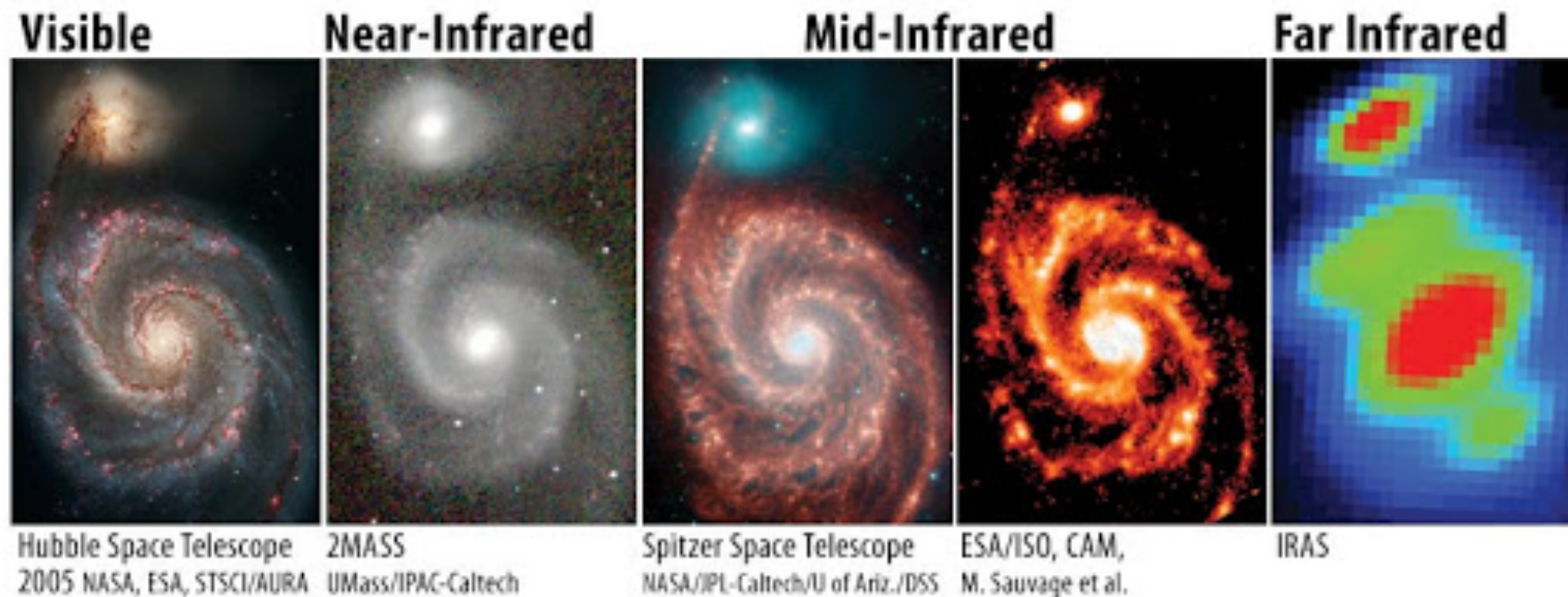
Corresponds to **different physical processes**:

1-3 microns (near-IR): mostly stellar emission - light of old/red giant stars

3-5 microns (mid-IR): RJ tail of stellar emission + hot dust + free-free

5-50 microns (mid-IR): hot/warm dust (AGN dusty torus; warm dust from SF)

50-3000 microns (far-IR/submm): cold dust (only related to SF)



The importance of dust through cosmic time

Dust in galaxies was very important at $z=1-5$

Total IR means $\sim(3-3000)$ microns, i.e., 3 microns through 3 mm

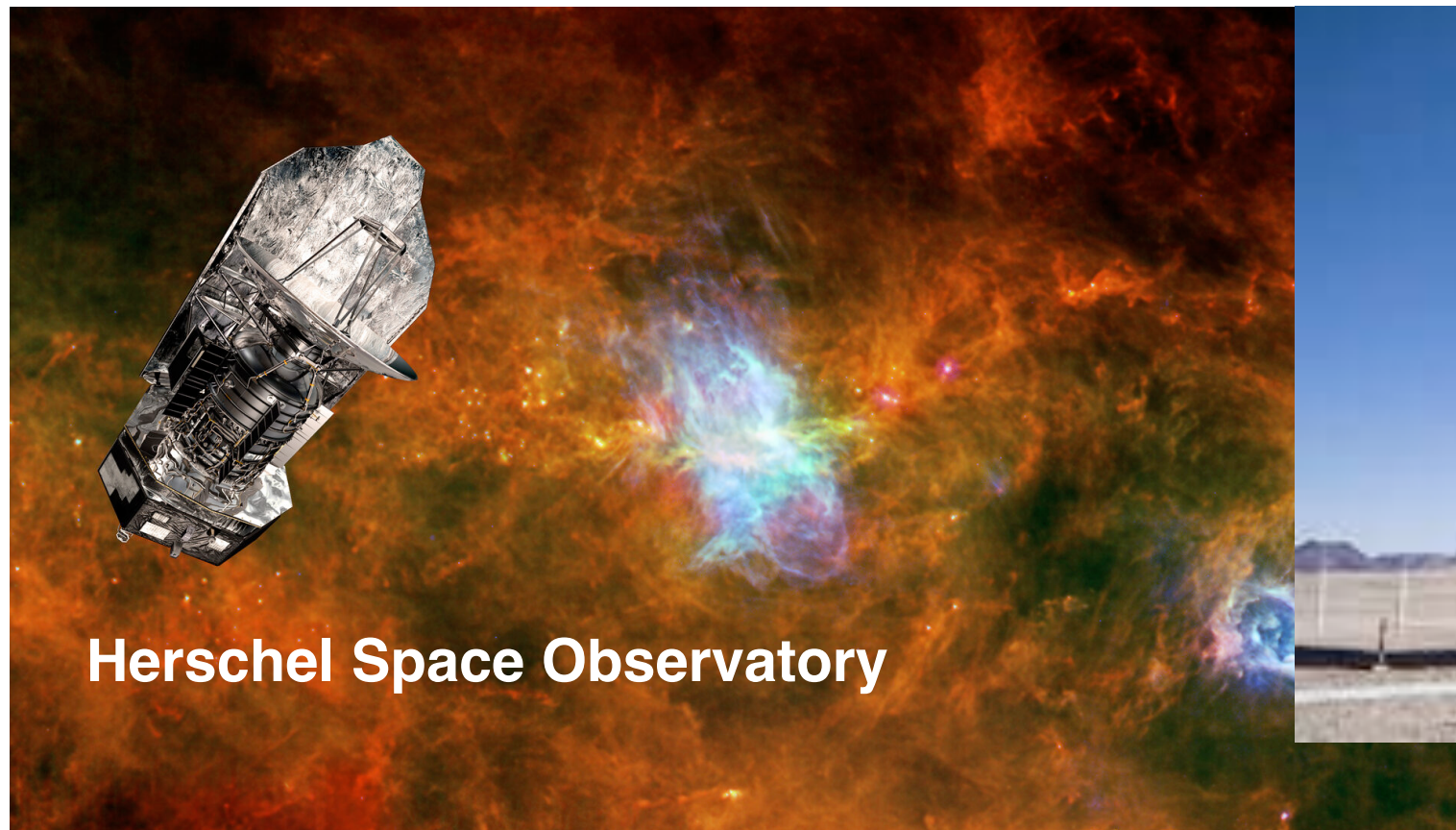
Mostly produced in the envelopes of red giant (AGB) stars

**It was less relevant at earlier cosmic times (higher z),
except for the most massive galaxies**

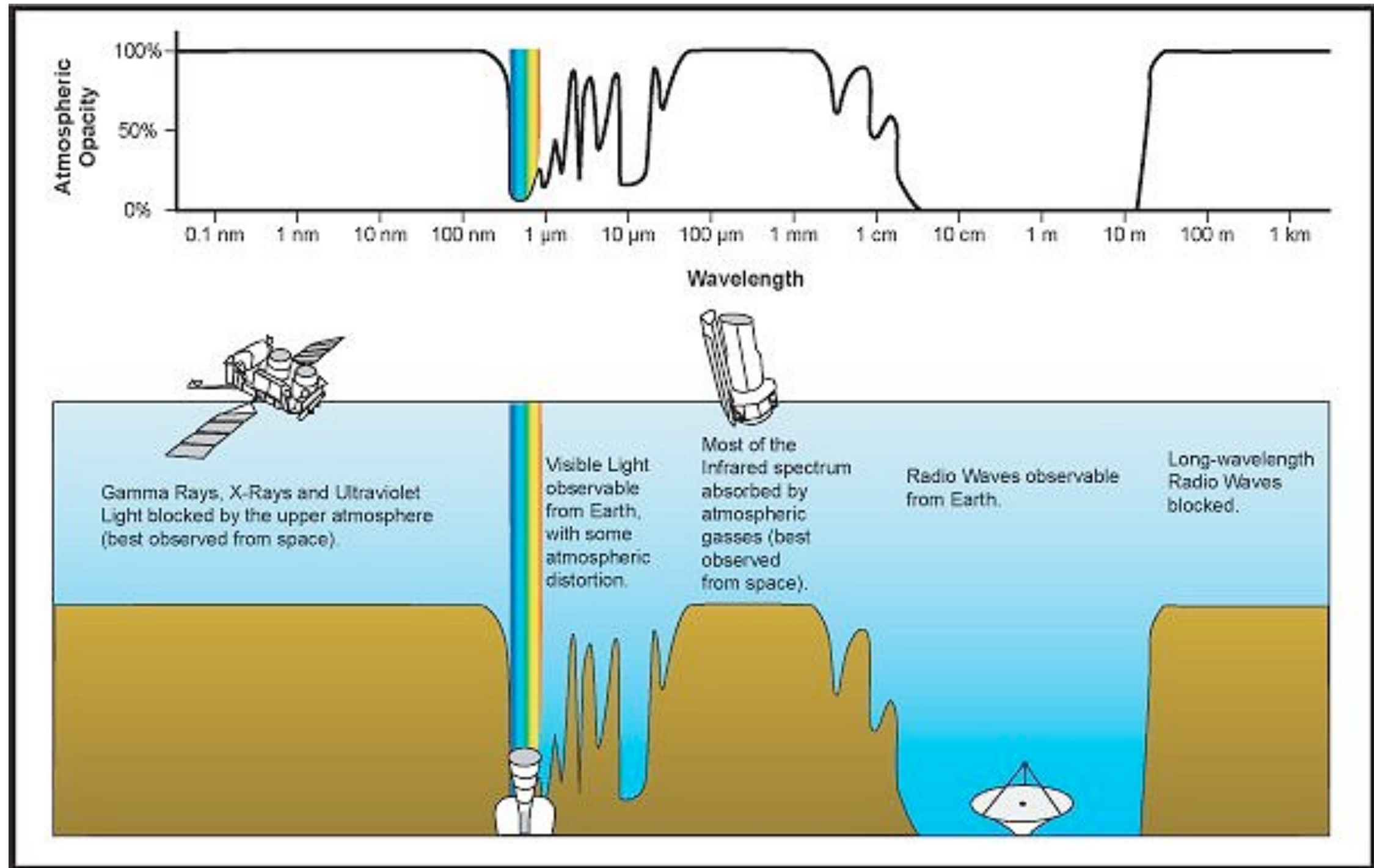
Origin of dust observed at $z>6$ is still under debate

Instruments to study of the dusty Universe

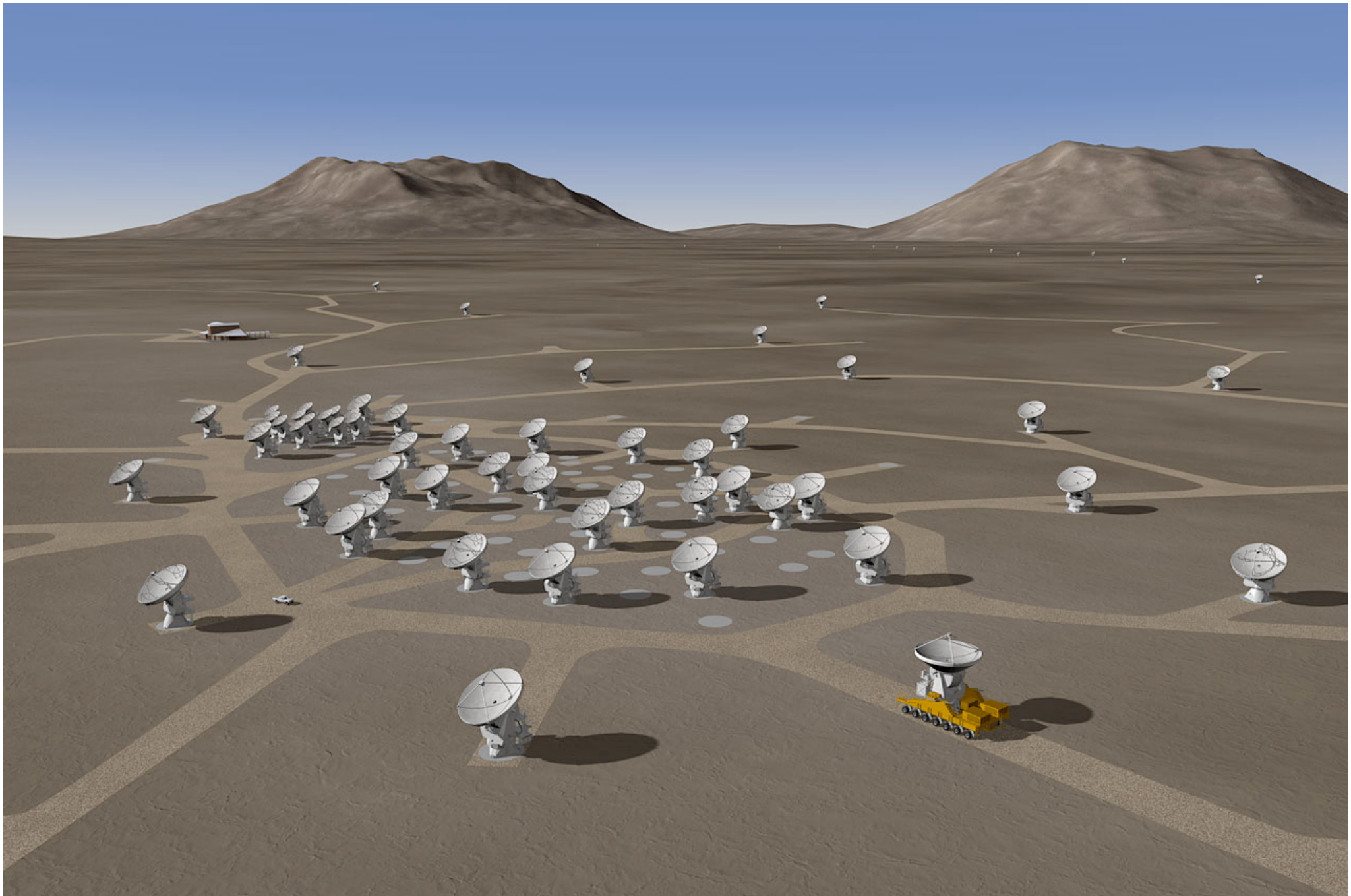
in space and ground-based



Atmospheric Transmission



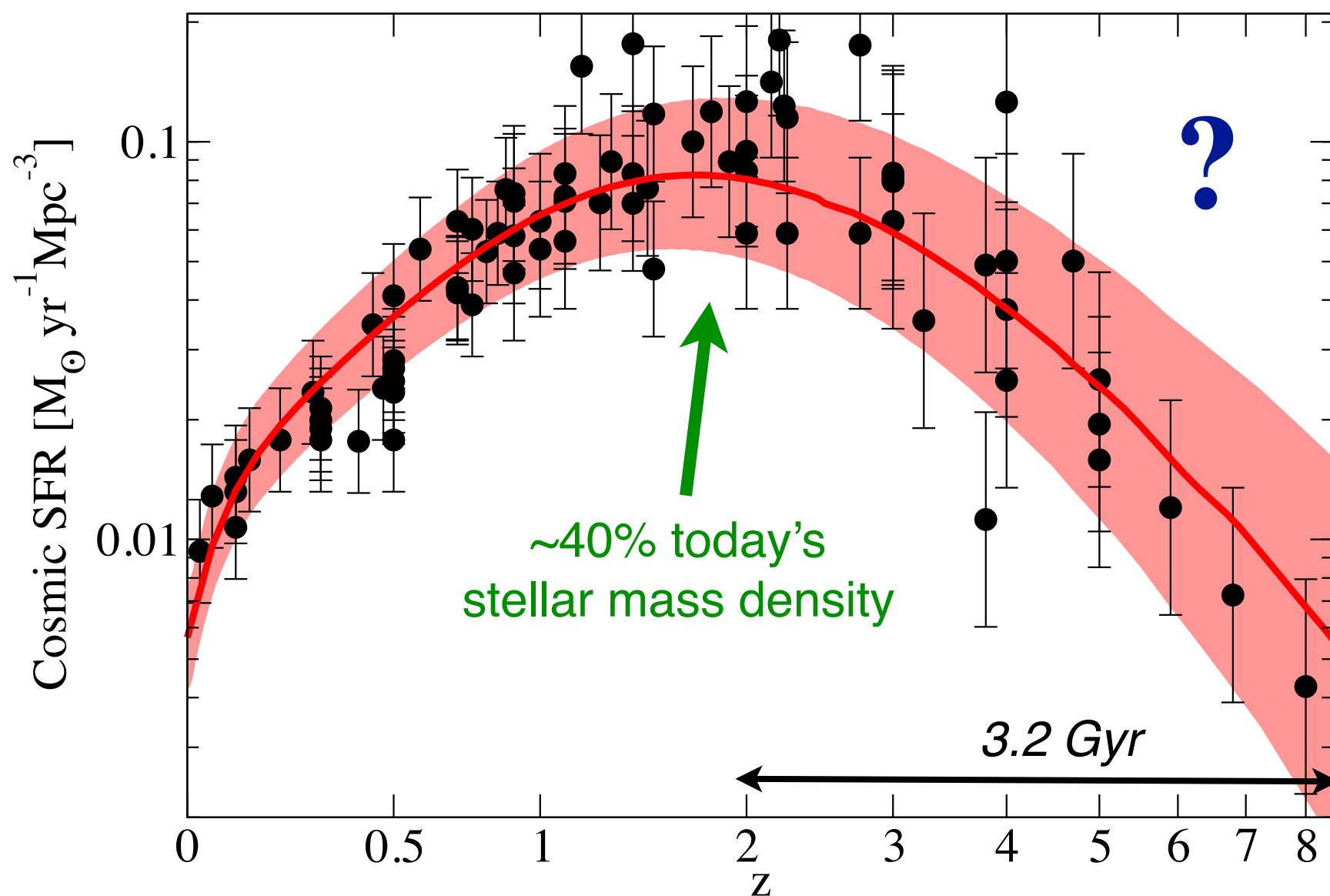
ALMA



Credit: ALMA (ESO/NAOJ/NRAO)/H. Zodet (ESO)

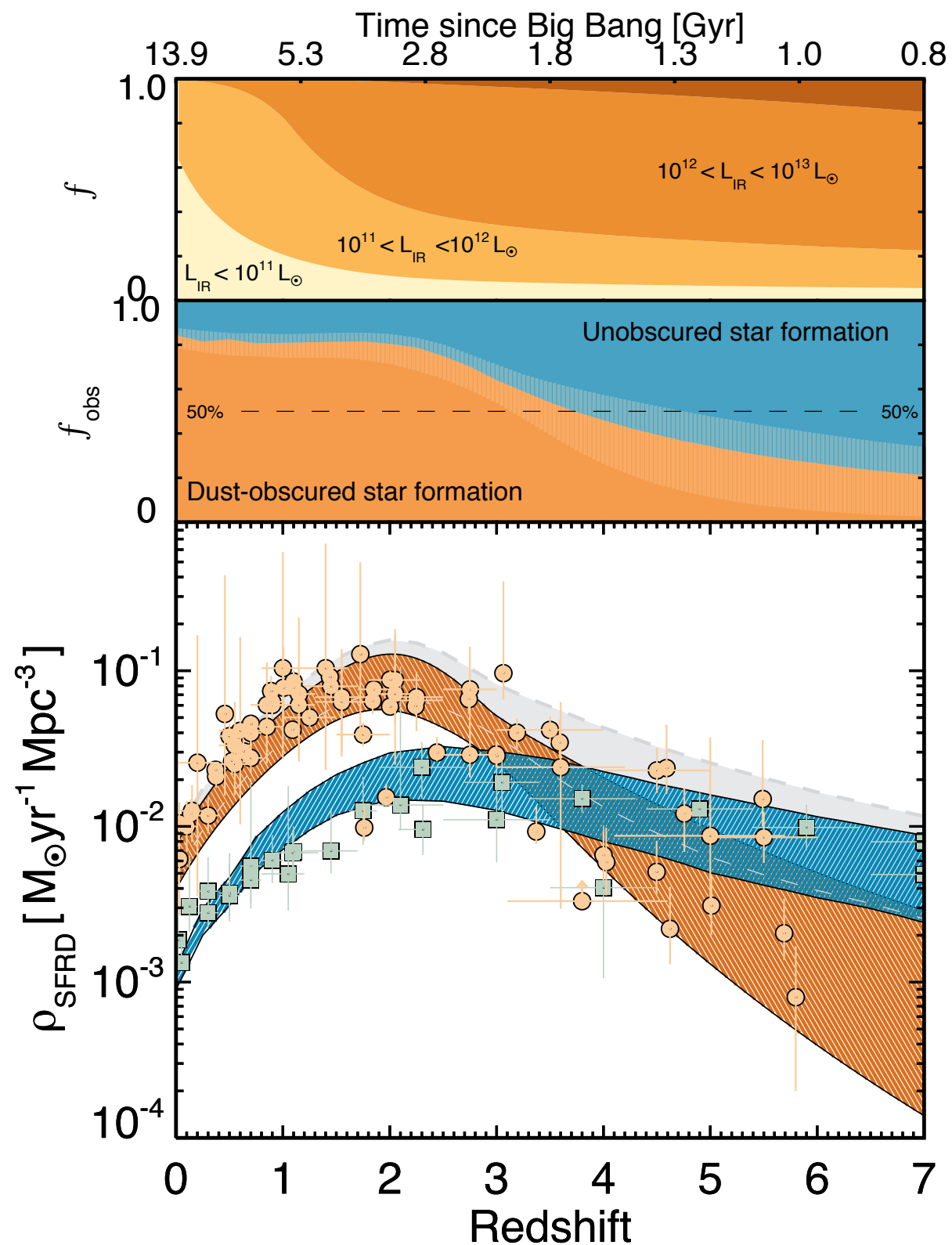
The cosmic SFR density

This was our best knowledge about ten years ago...



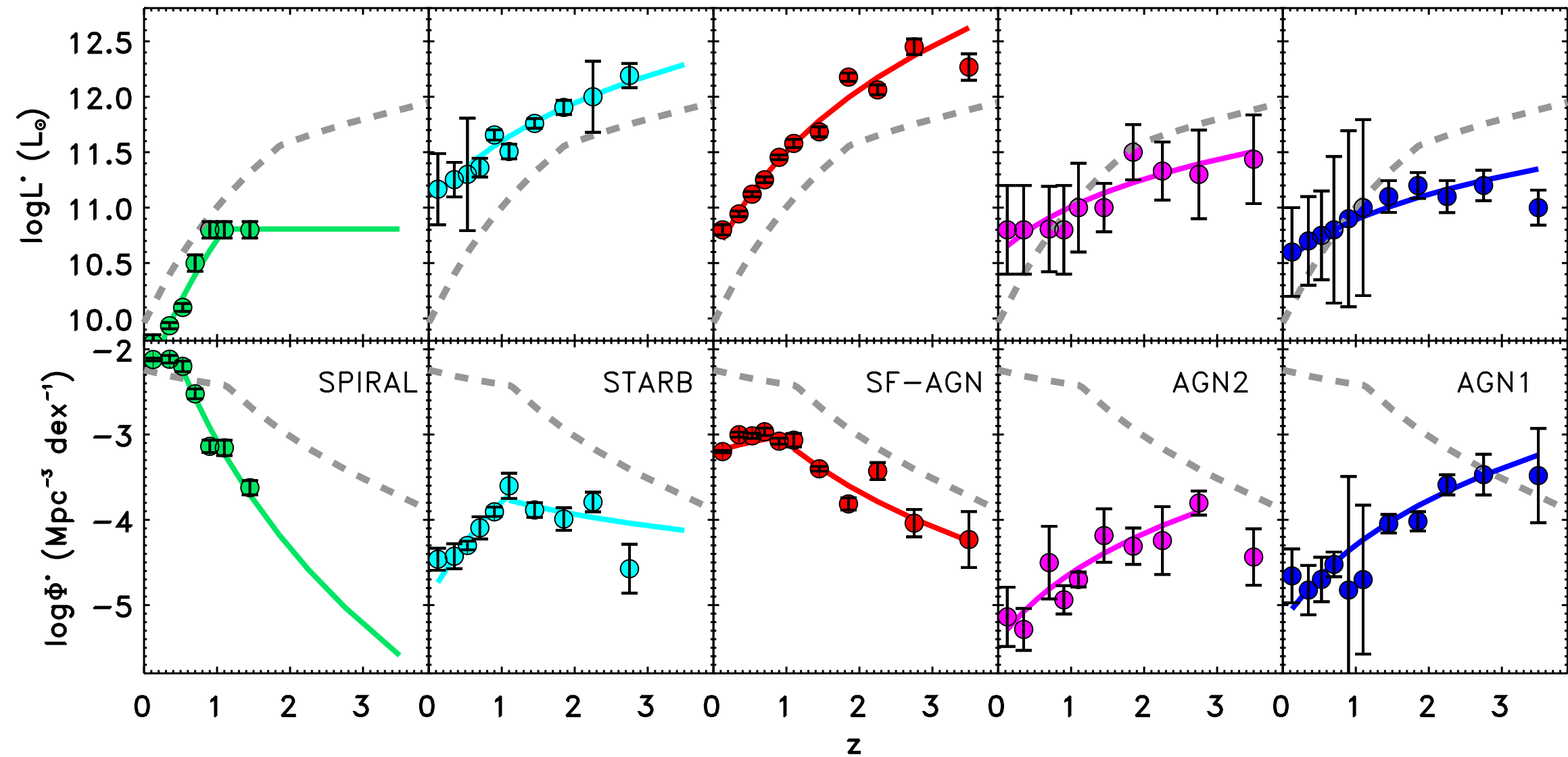
Behroozi et al. (2013); Madau & Dickinson (2014)

The contribution of dusty galaxies to the CSFRD



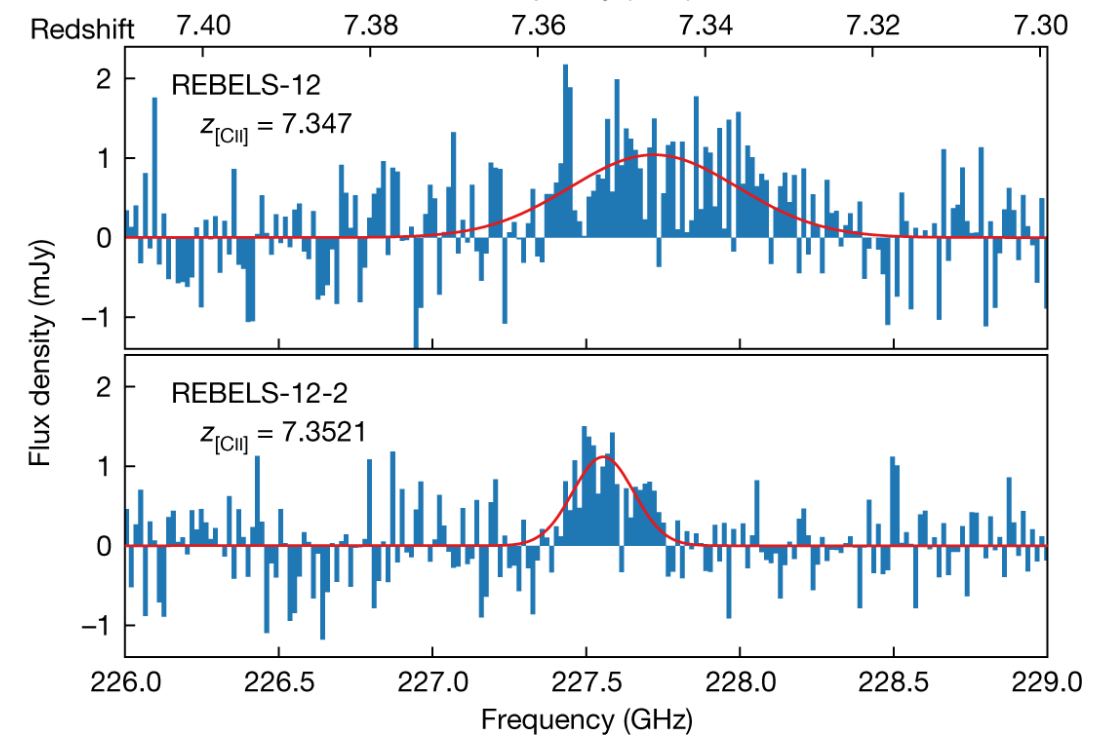
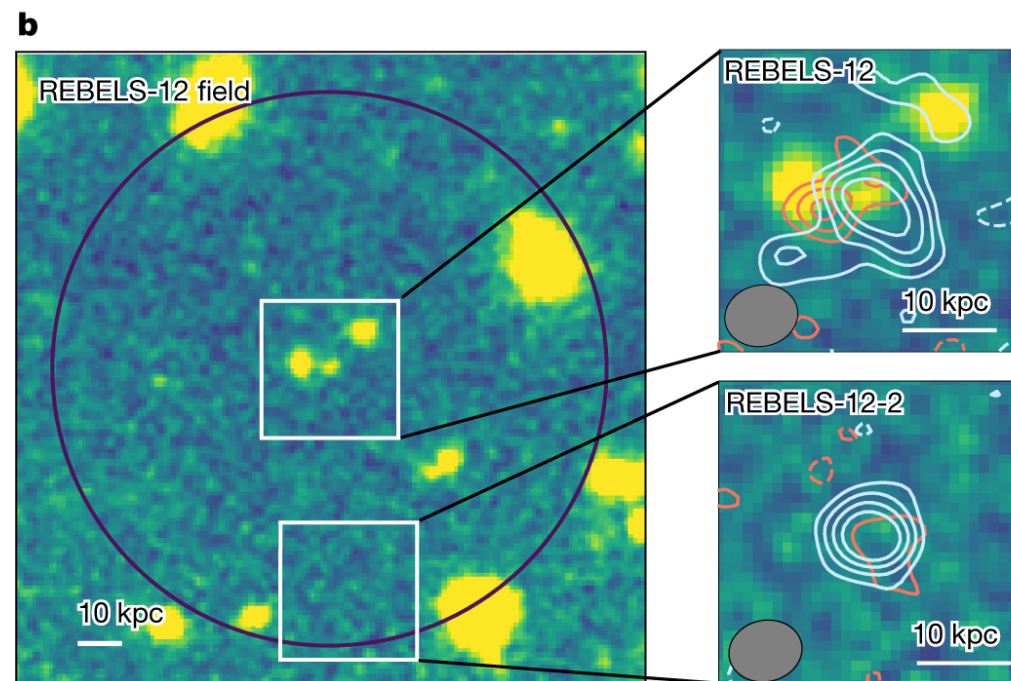
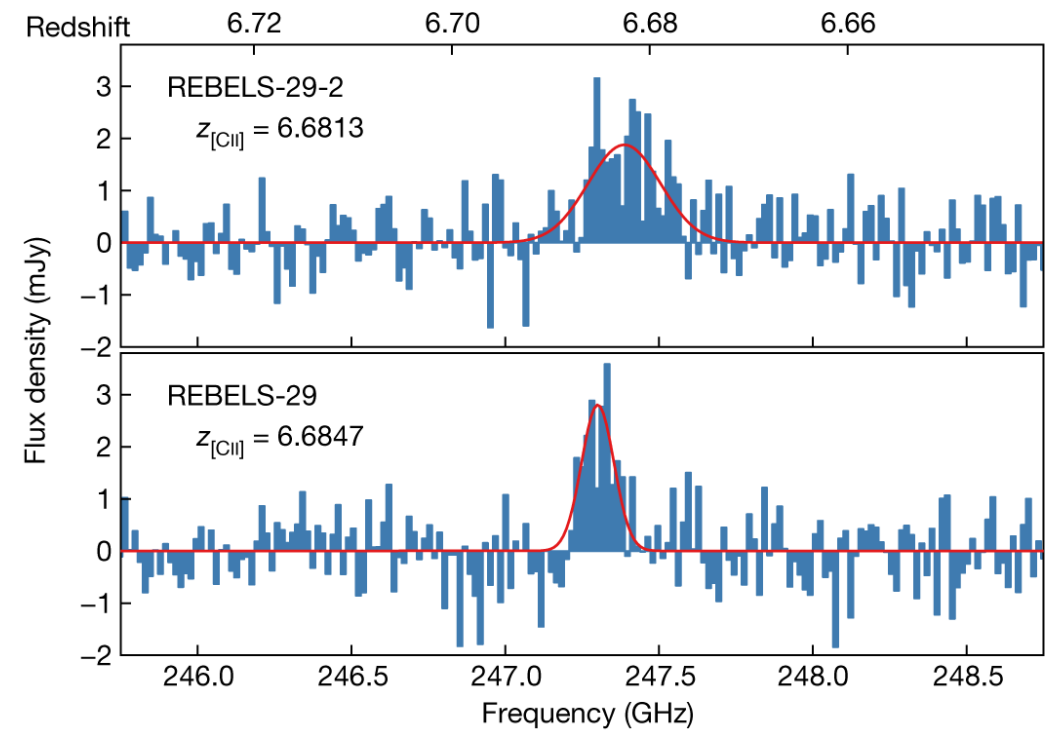
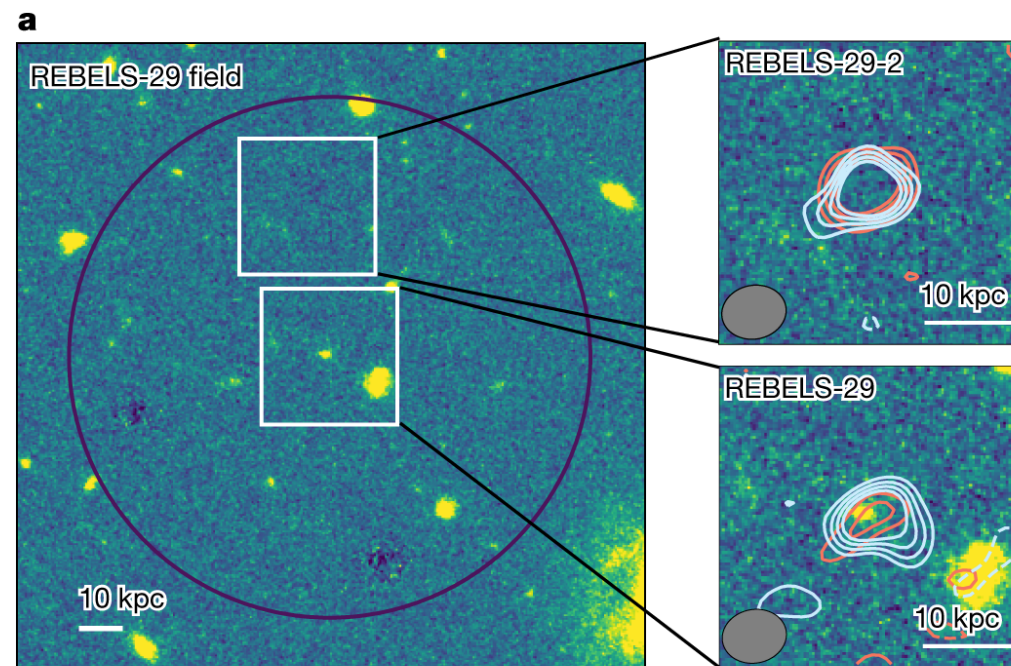
Up to $z \sim 4$, most star formation in the Universe is obscured by dust.

The total-IR LF



Gruppioni et al. (2013)

Dusty galaxies in the Early Universe

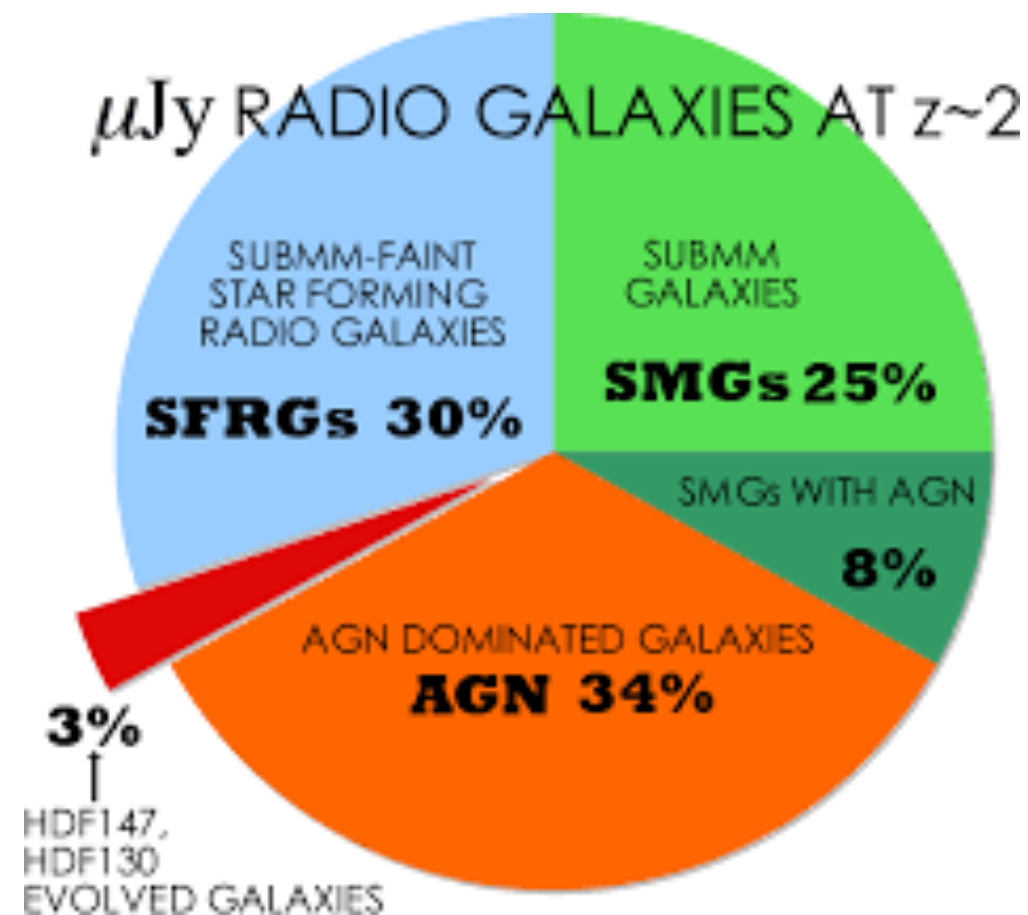


Radio Wavelengths

Radio sources

Brightest radio sources are mostly AGN

At fainter radio fluxes, the radio galaxy population is mixed in nature



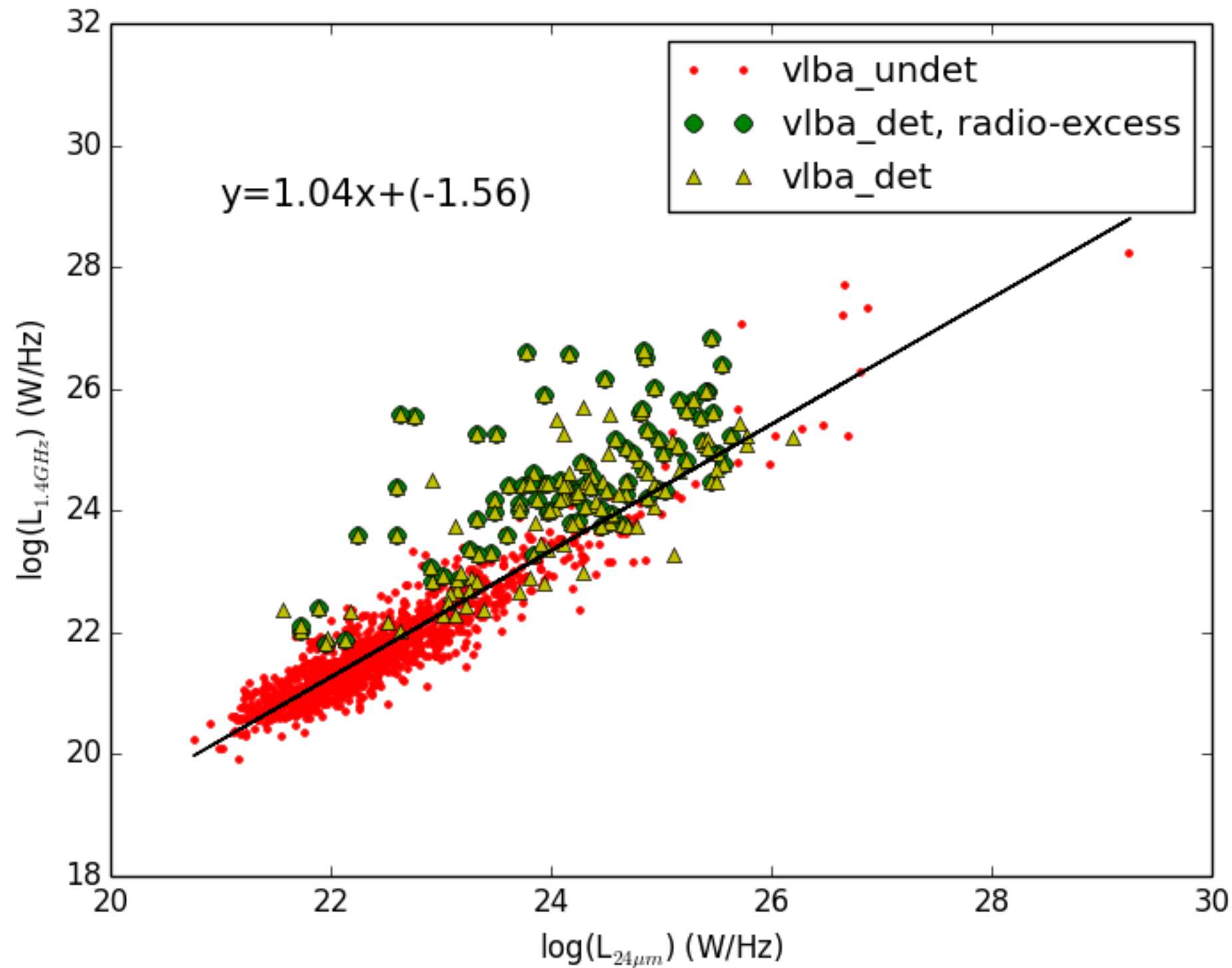
Casey et al. (2009)

The VLA

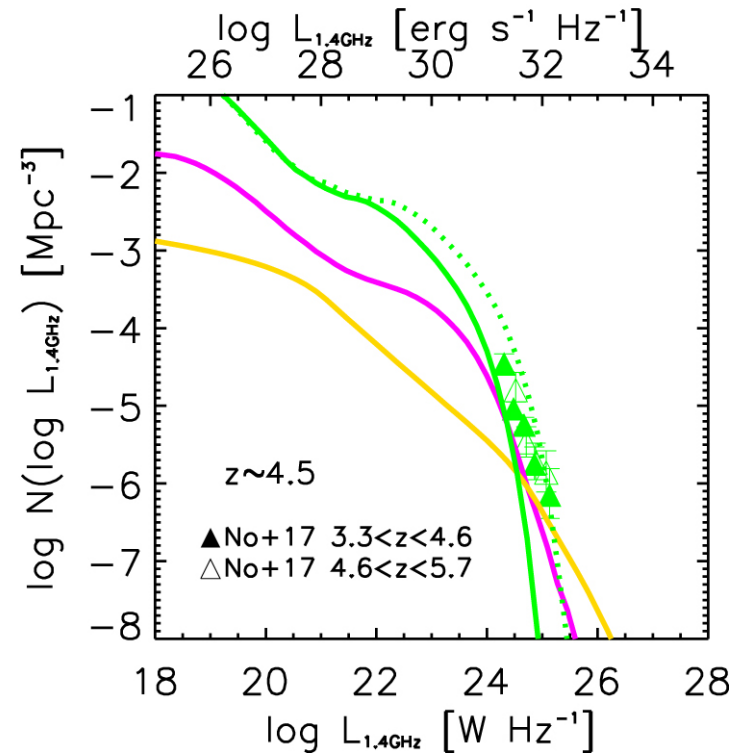
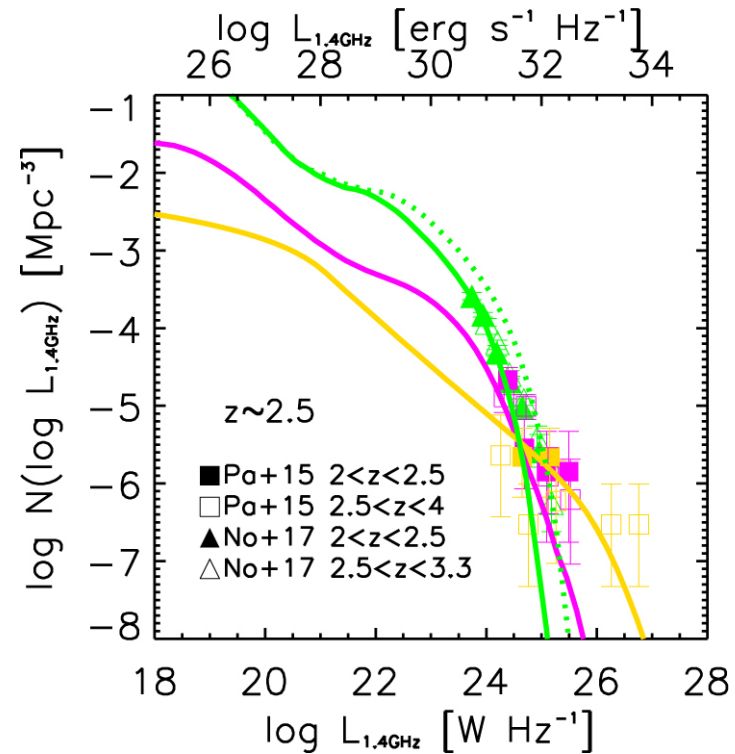
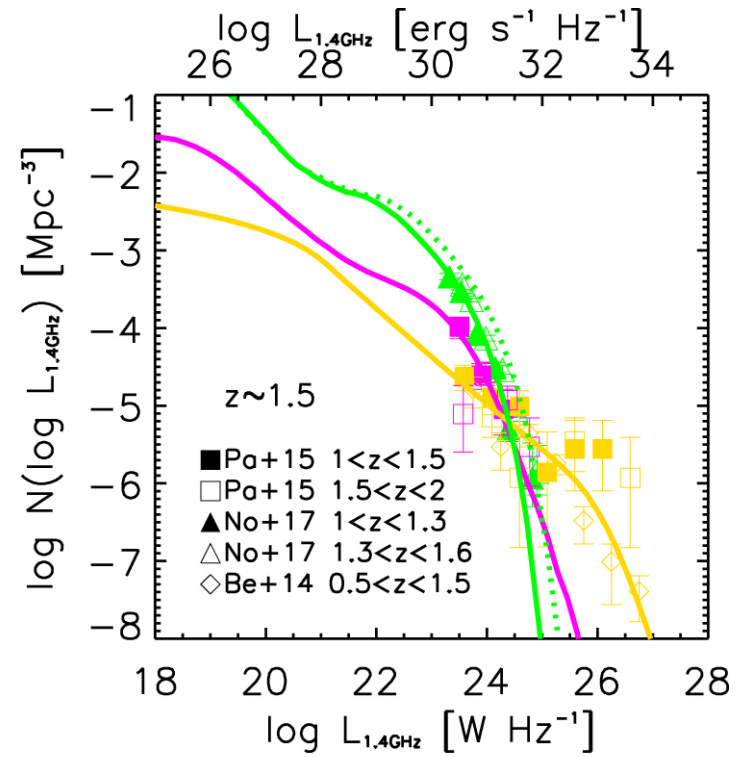
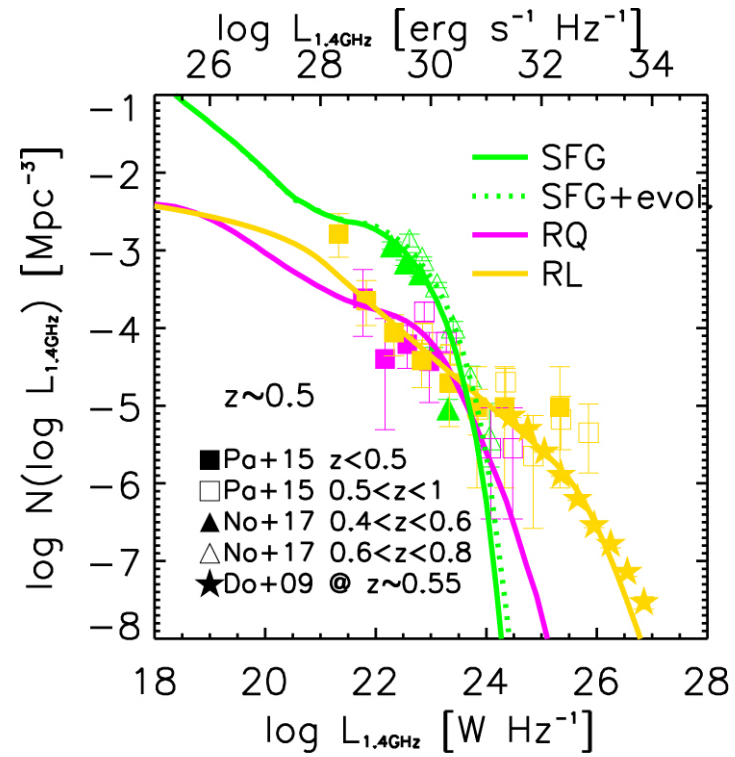


Credit: NRAO/AUI/NSF

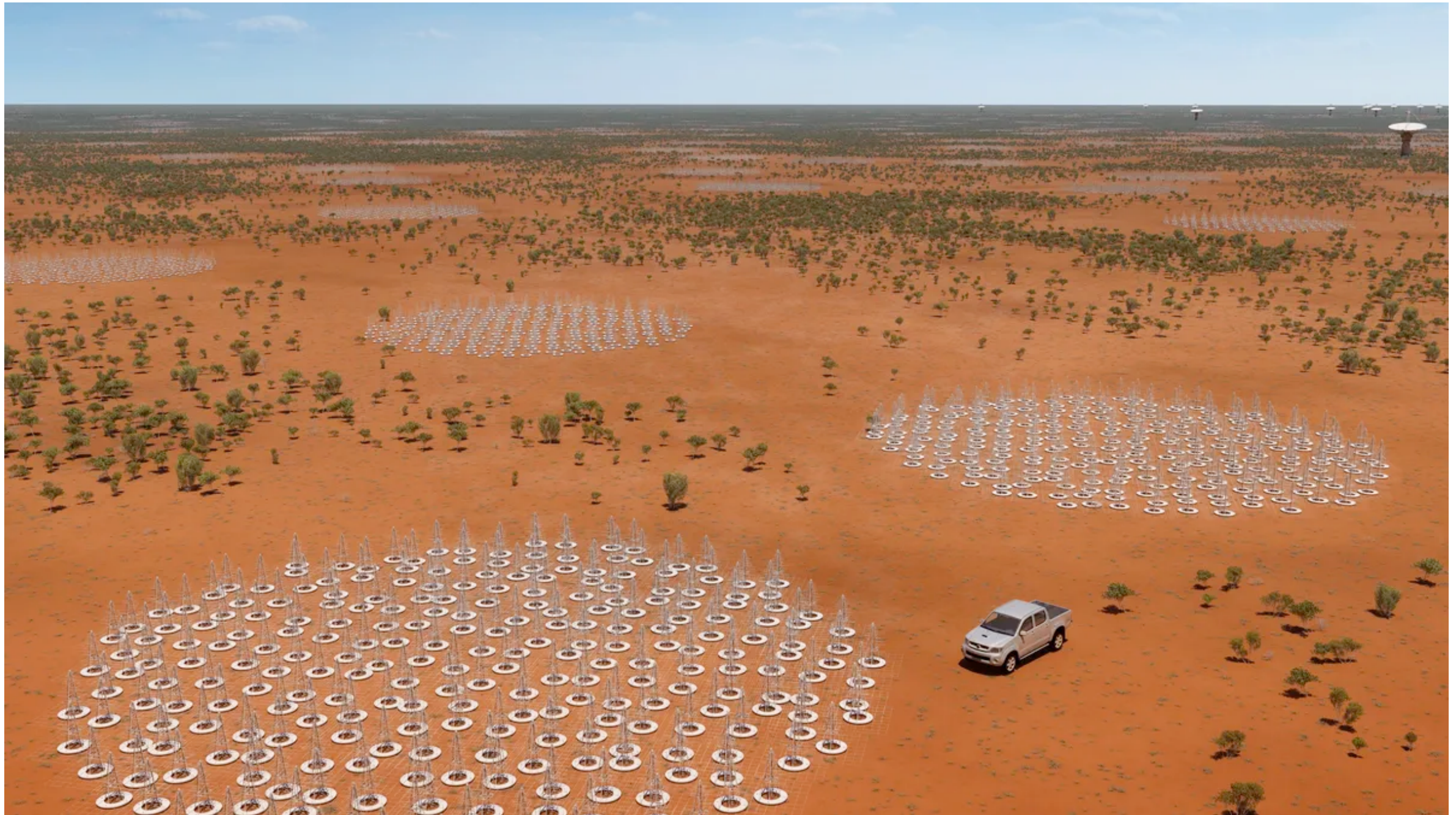
IR-radio correlation



Evolution of radio galaxies



Future Facilities: SKA



X rays

X-ray sources

Both AGN and star-forming are emitters in X rays

To disentangle nature:

- * **X-ray colours: $f_{\nu}(2-8\text{keV}) / f_{\nu}(0.5-8\text{ keV})$**

Sources bright at 2-8 keV (hard X rays) are almost all AGN

- * **use of complementarity tracers at other wavelengths**

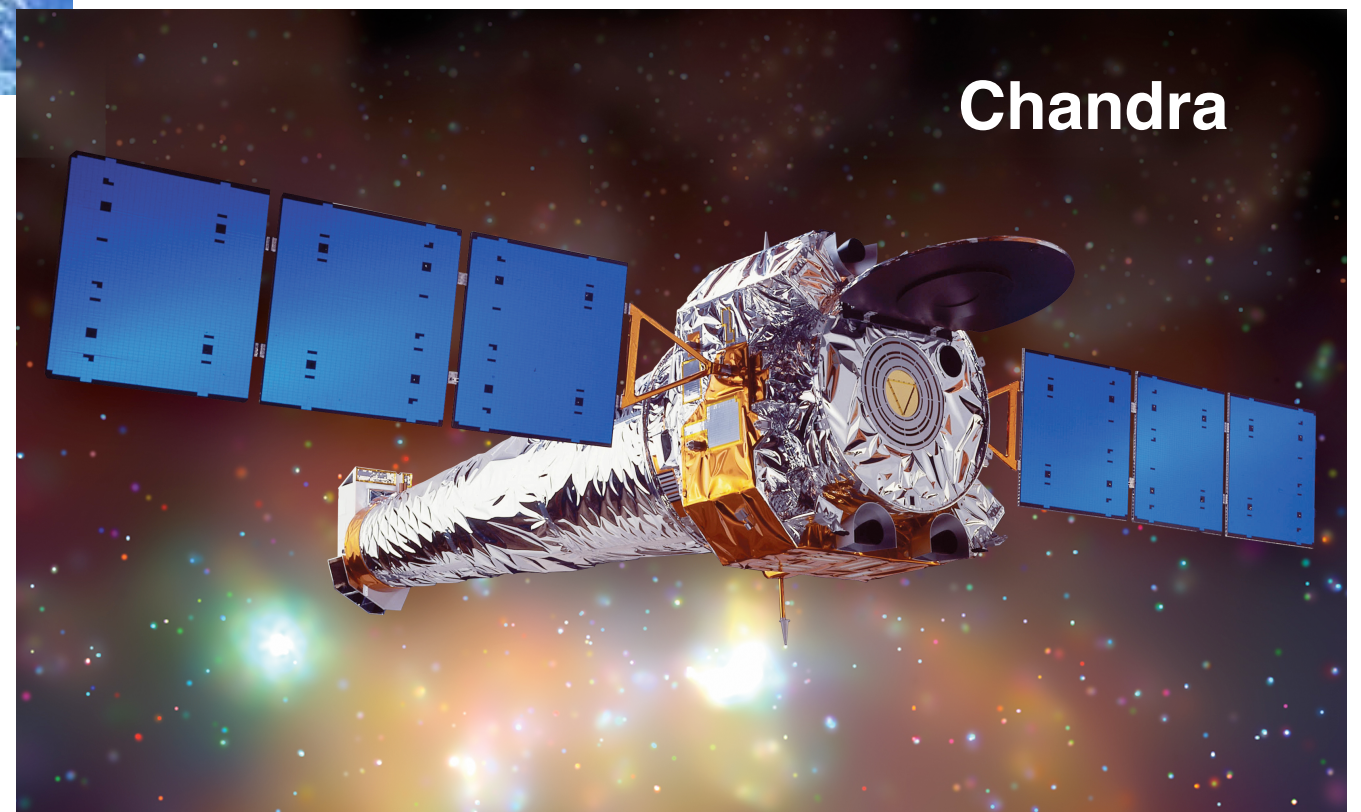
e.g. optical fluxes/colours - near-/mid-IR colours (none is perfect)

X-ray telescopes



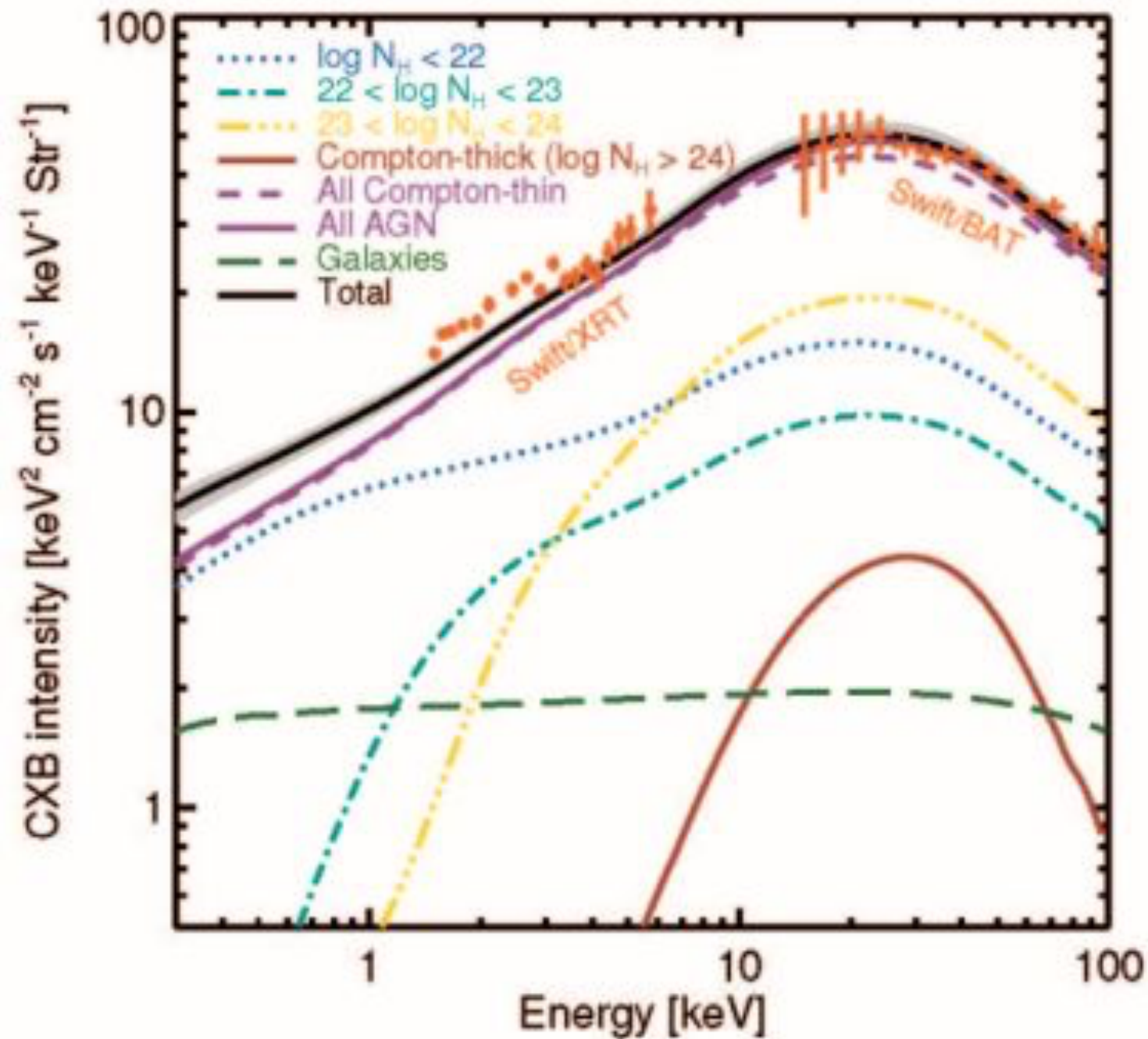
XMM Newton

**in operation for more than 20
years...**

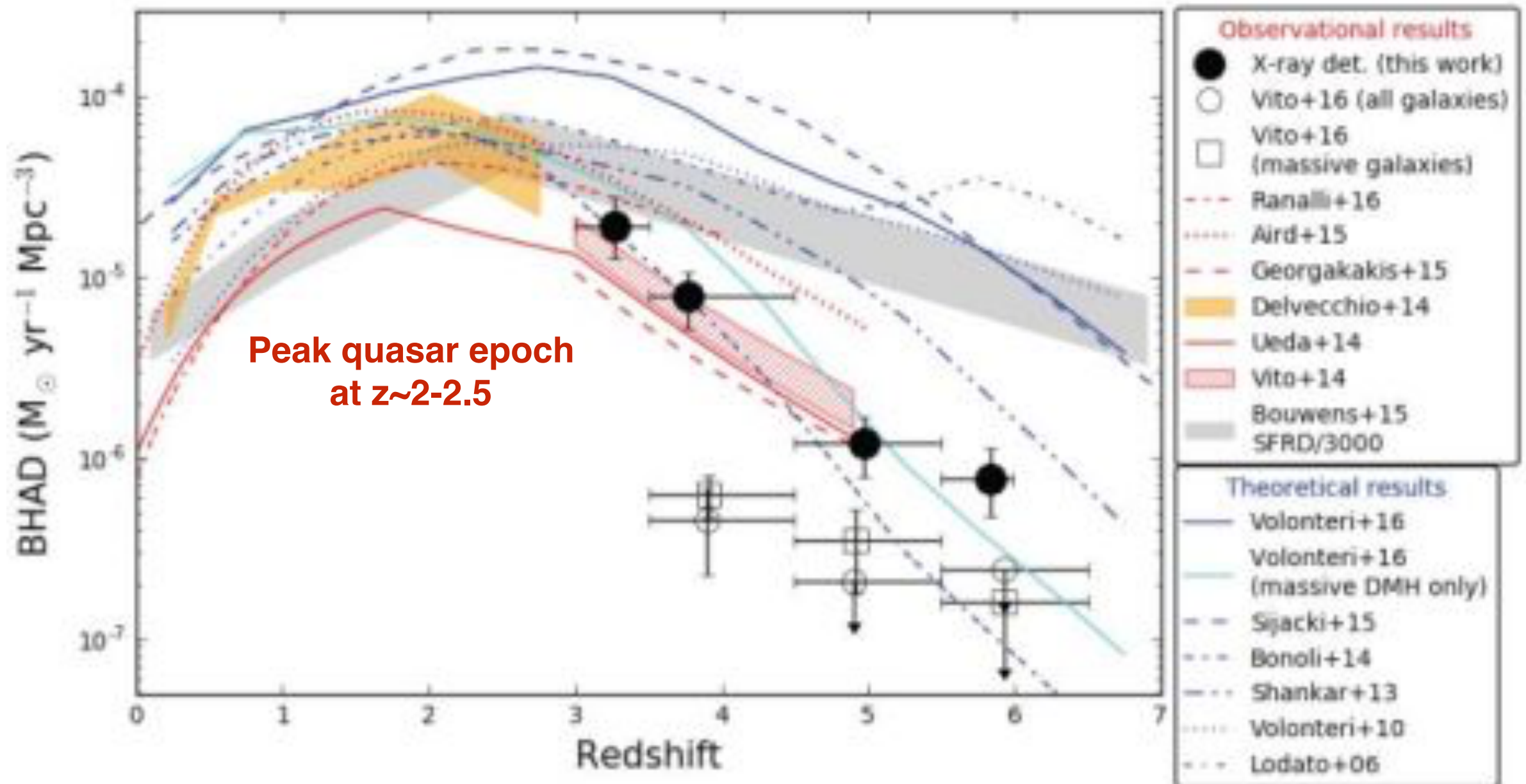


Chandra

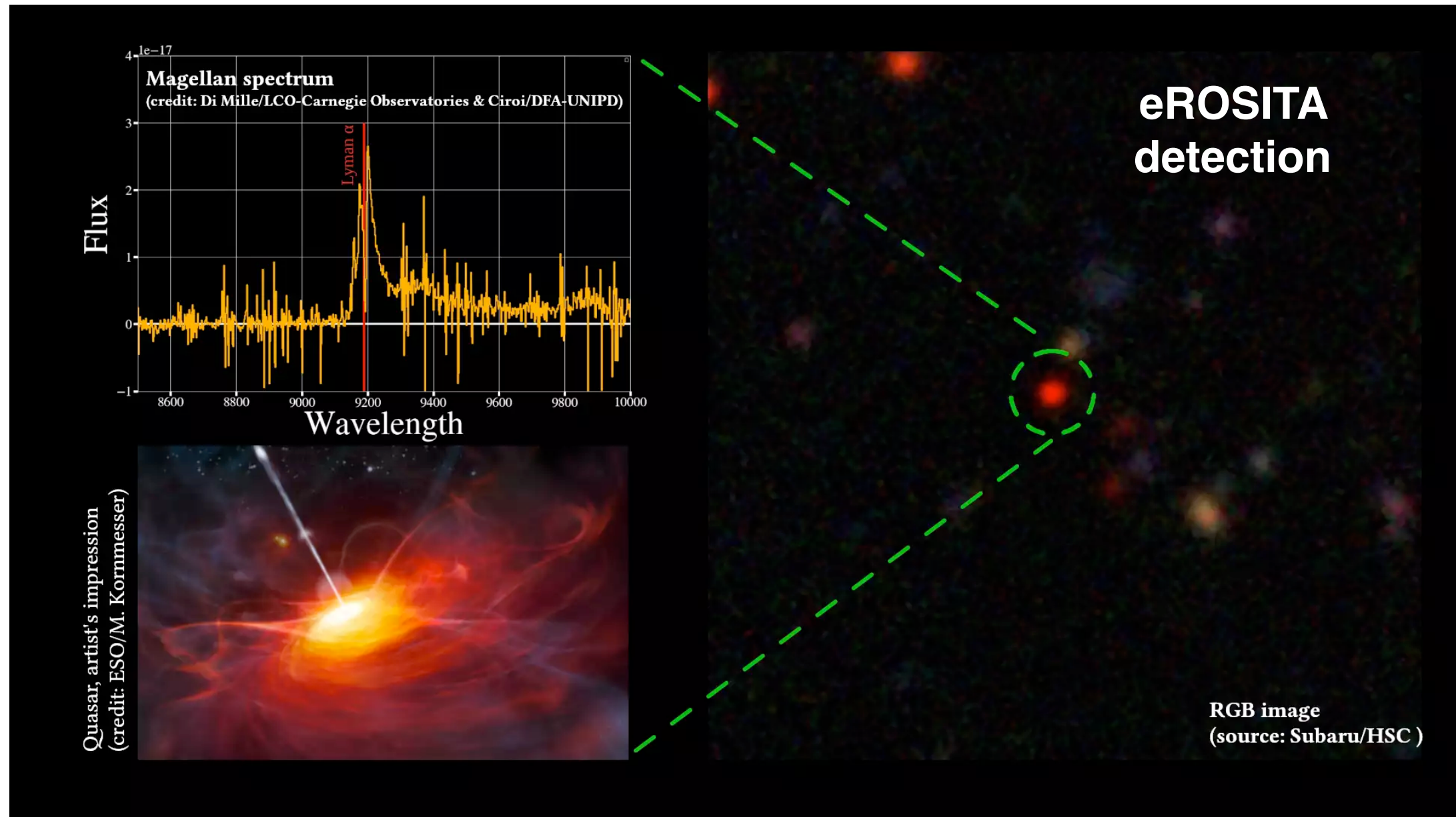
Sources of the X-ray background



AGN X-ray luminosity density



Rare X-ray detected AGN/QSO in early Universe



Wolf et al. (2023)