Warm Dust in the First Few Billion Years

Karina Caputi

Kapteyn Astronomical Institute

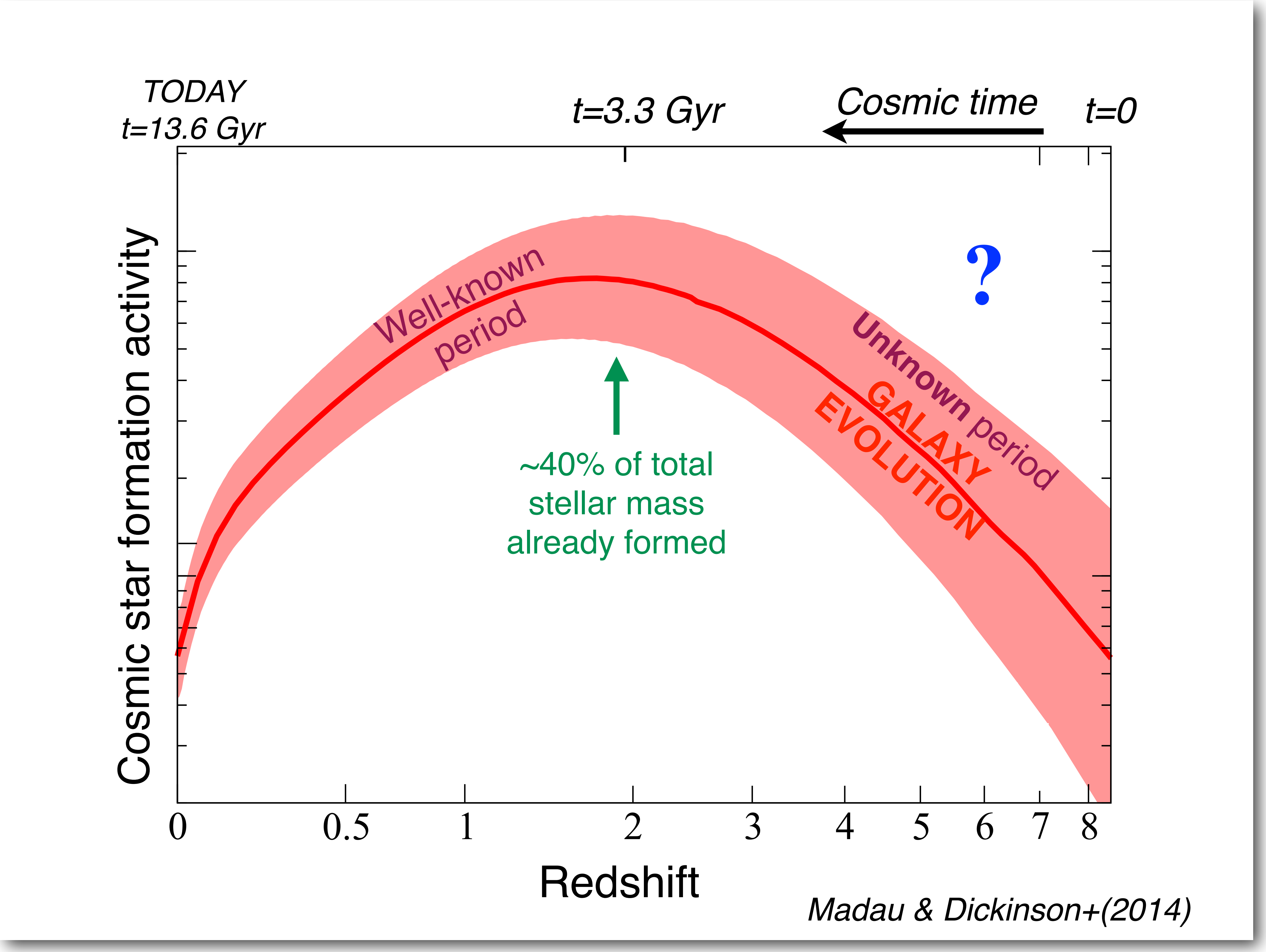
Credit: STScI

PRIMA Conference
Marseille
2 April 2025

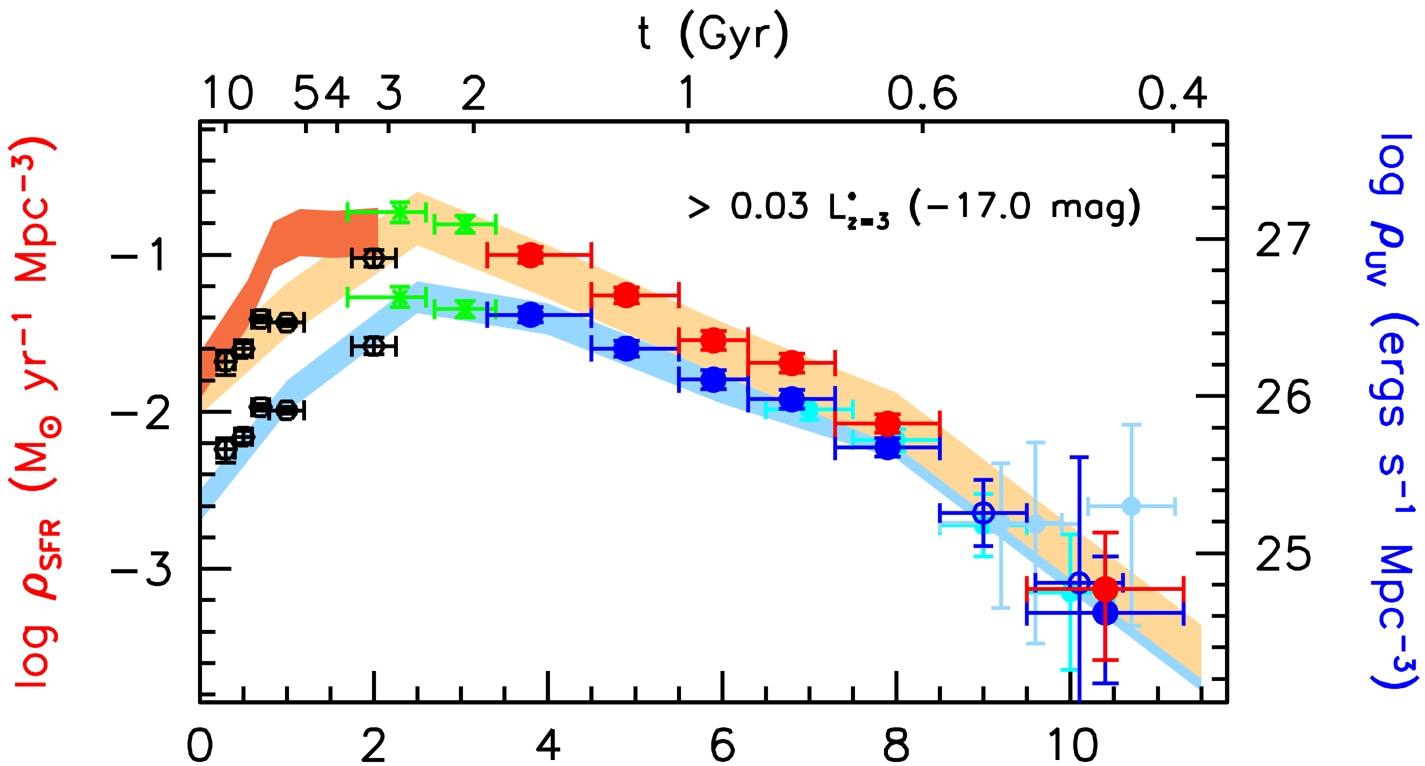
university of groningen

Netherlands Organisation for Scientific Research

The activity history of the Universe linked to star formation



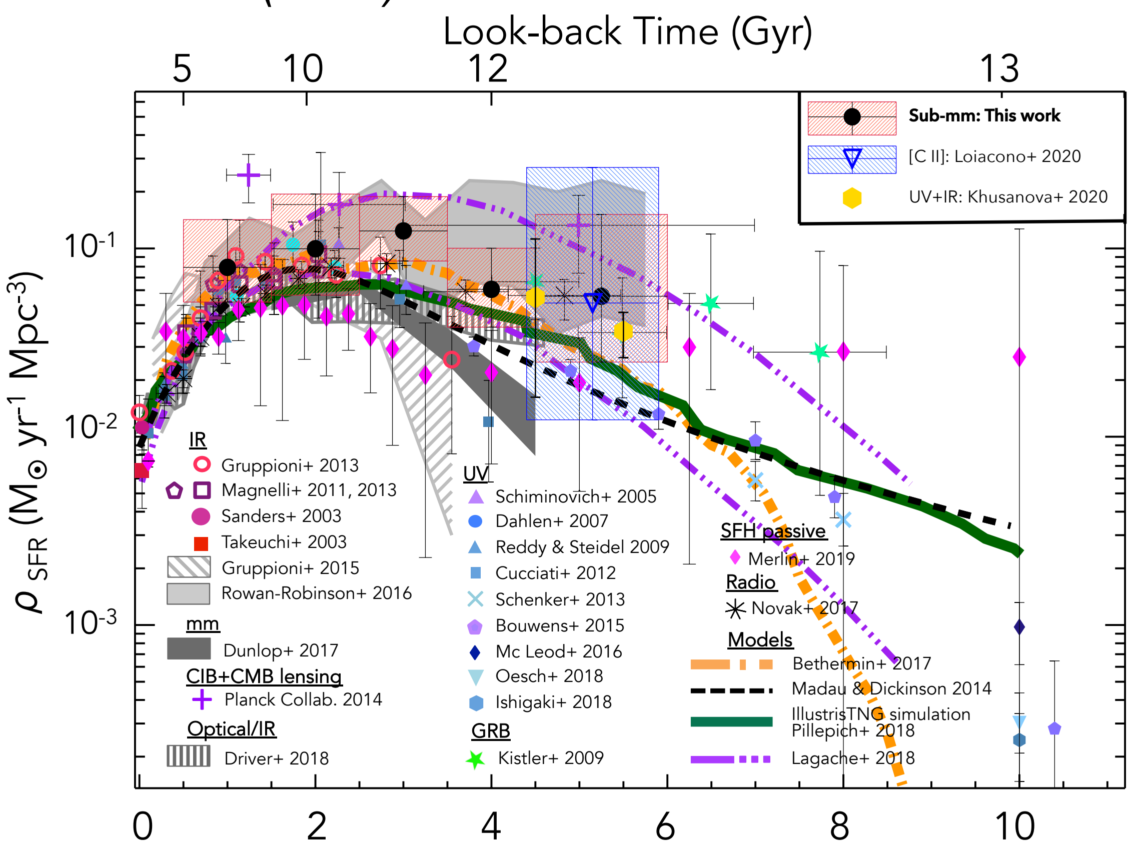
The activity history of the Universe linked to star formation



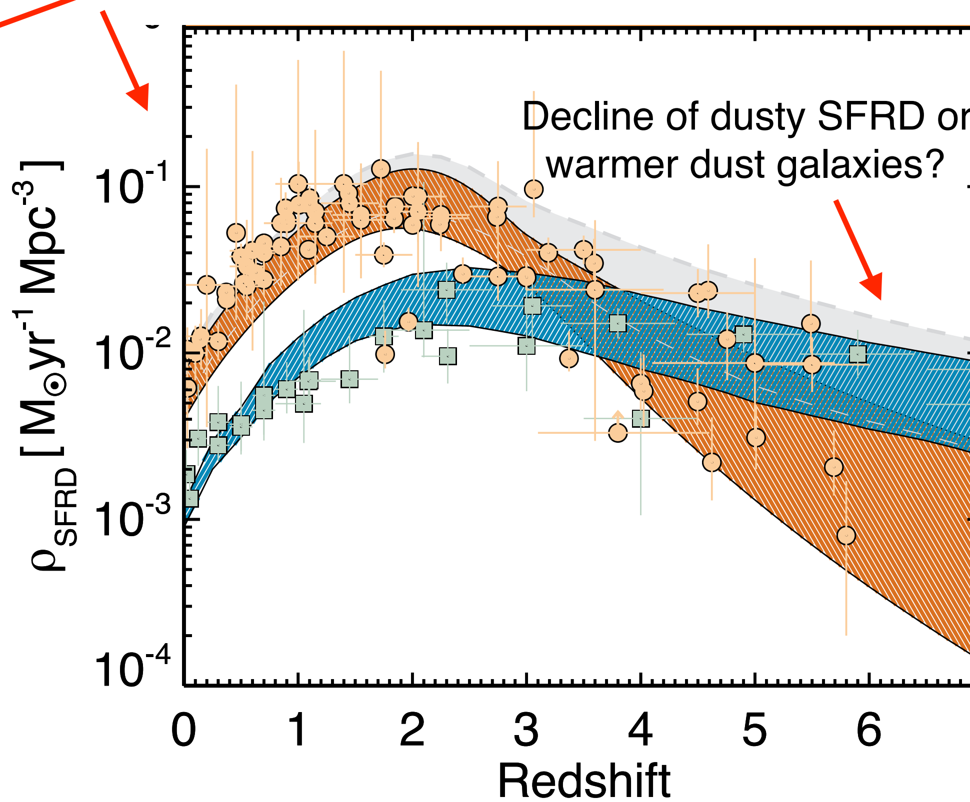
Bouwens+(2015)

From UV luminosity function

From far-IR luminosity function

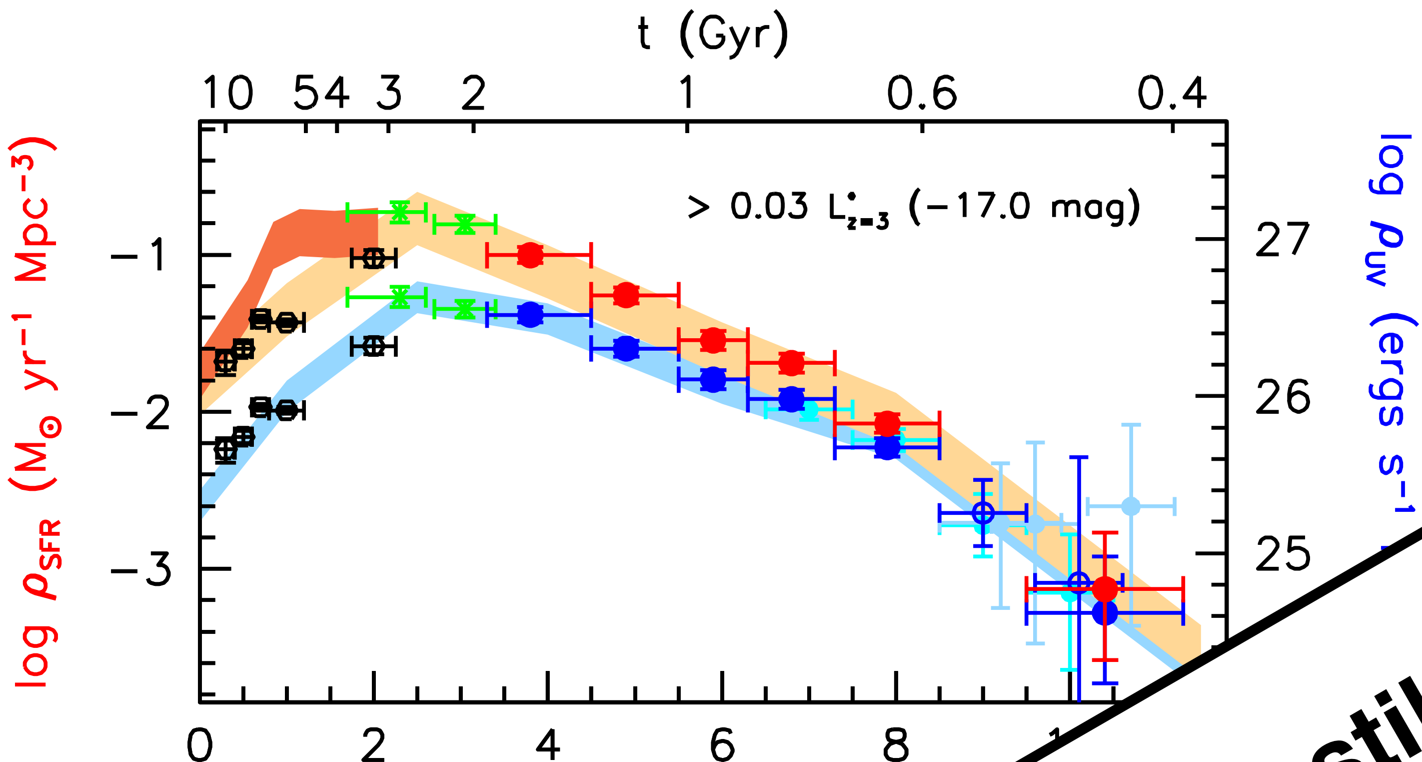


Gruppioni+(2020)



Zavala et al. (incl. KC, 2021)

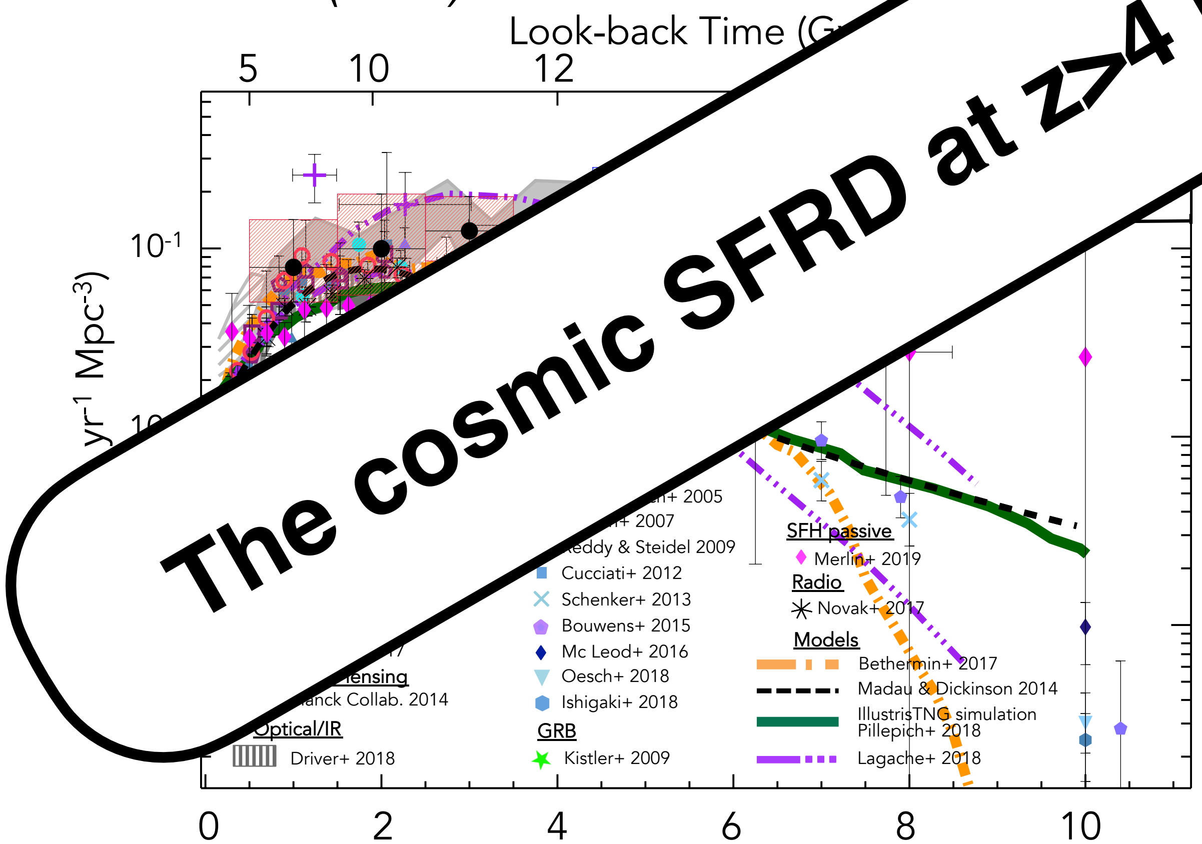
The activity history of the Universe linked to star formation



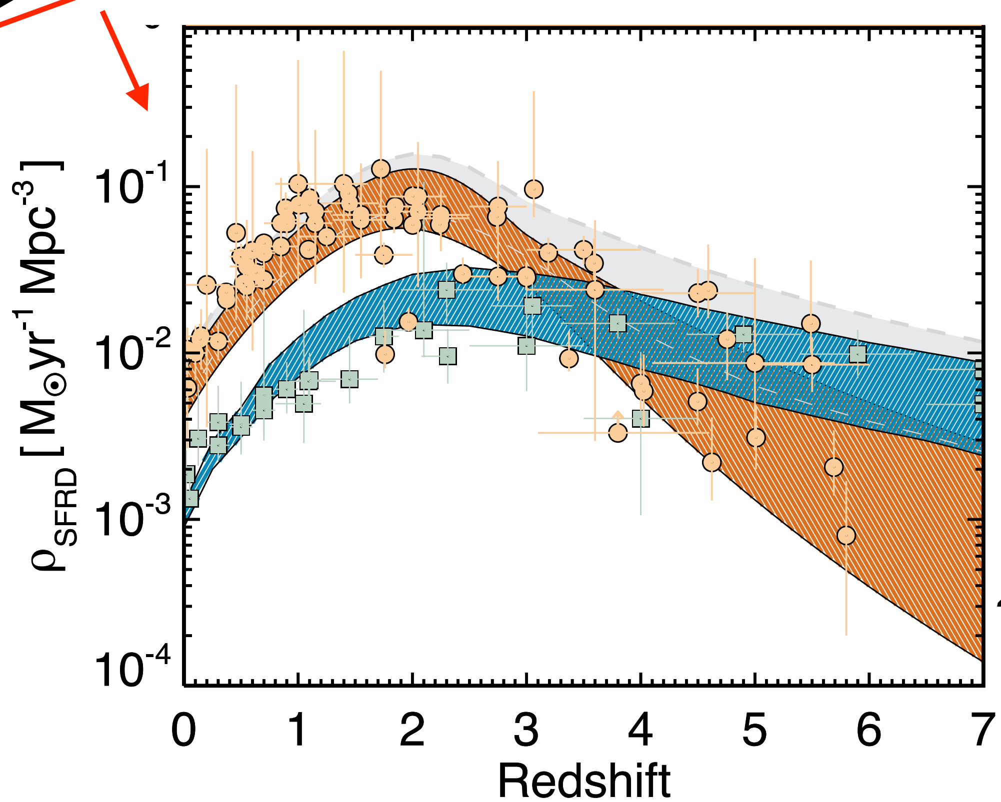
Bouwens+(2015)

The cosmic SFRD at z>4 is still uncertain in ~ 1 dex

From far-IR luminosity function

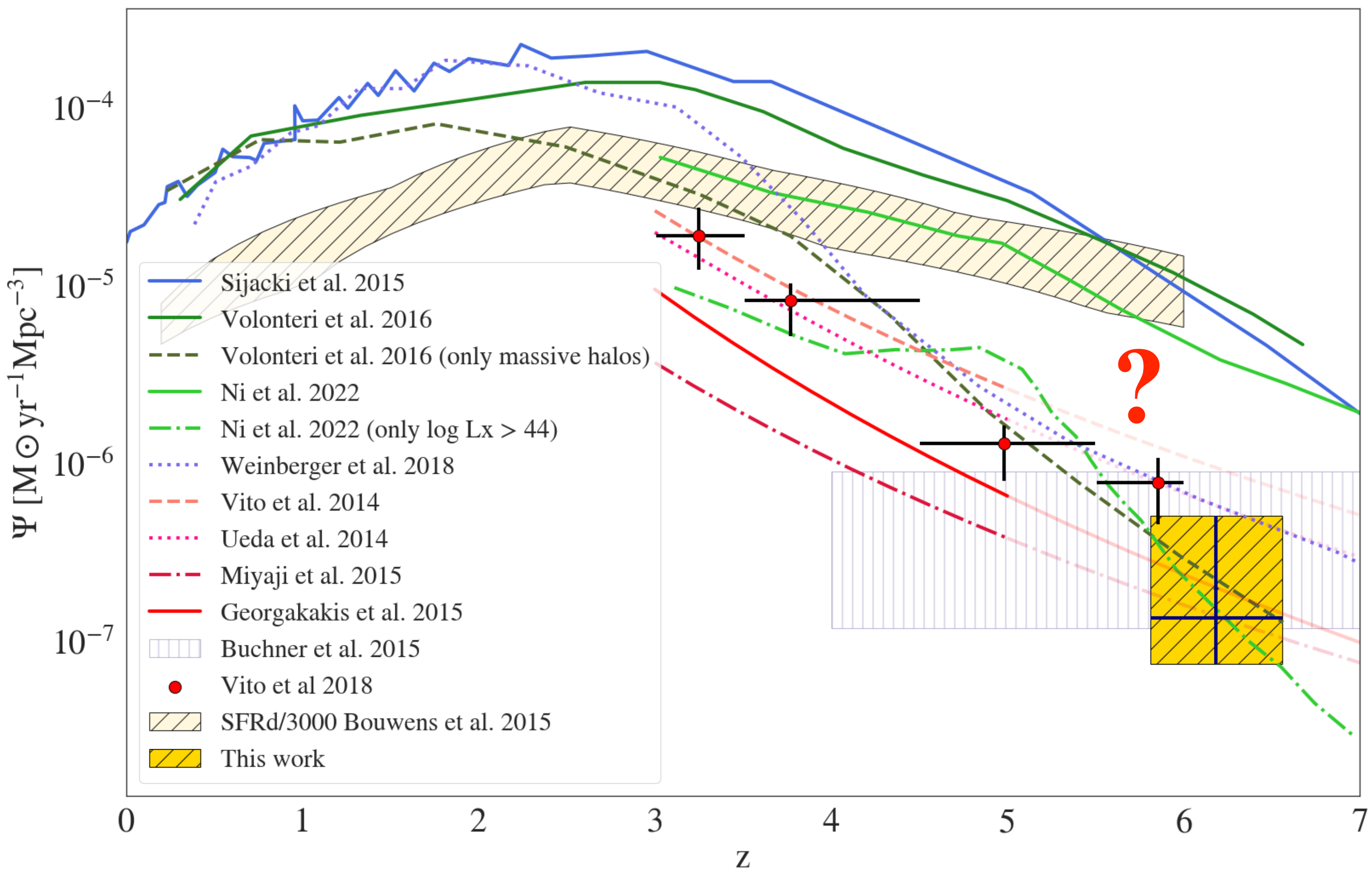


Gruppioni+(2020)



Zavala et al. (incl. KC, 2021)

The activity history of the Universe linked to nuclear activity



Wolf+(2023)

Discrepancies are even larger for the cosmic BHAD at z>3

In contrast to the SFRD, theoretical models predict more activity than observed

Main questions

✦ Are we accounting for all the SF and BH activity at high z?

✦ How much of this activity is hidden behind the dust?

✦ What are the relative contributions of SF and BH activity to dusty galaxies?

✦ What are the roles of dust-obscured SF and BH activity in the general context of galaxy evolution?

Talk Outline

- **The need of PRIMA to study the dusty Universe at high z**

- **Warm dust at high z: hints from ALMA and JWST results**

- **Potential of the PRIMAger to study the high-z Universe**

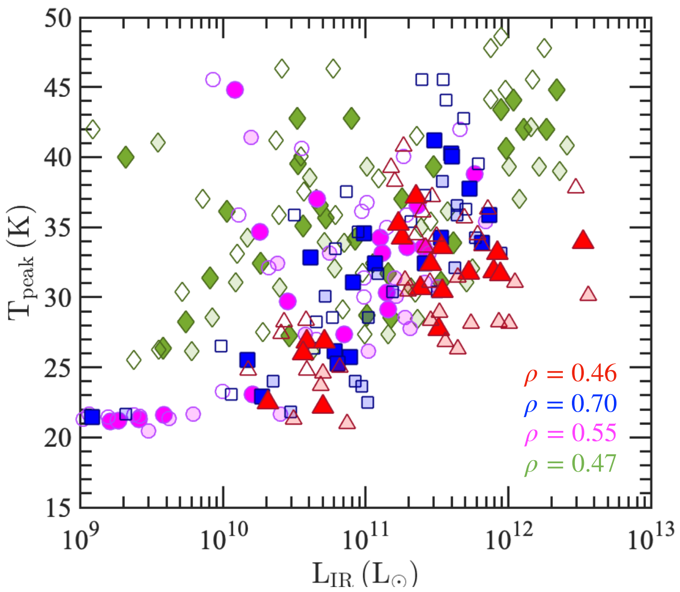
  Predictions from existing observations

Talk Outline

- The need of PRIMA to study the dusty Universe at high z

Warm dust from SF at high redshifts

Simulated galaxies z=2-6



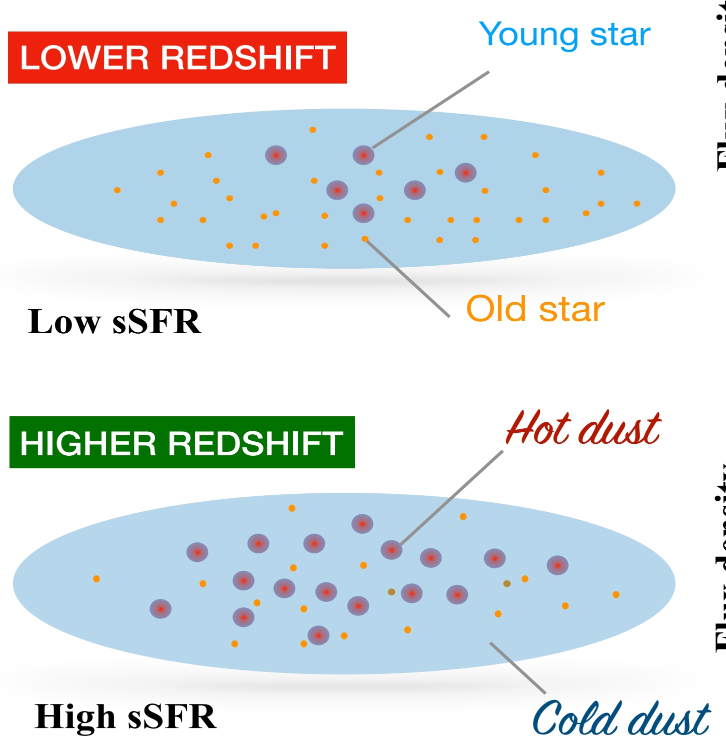
Liang+(2019)

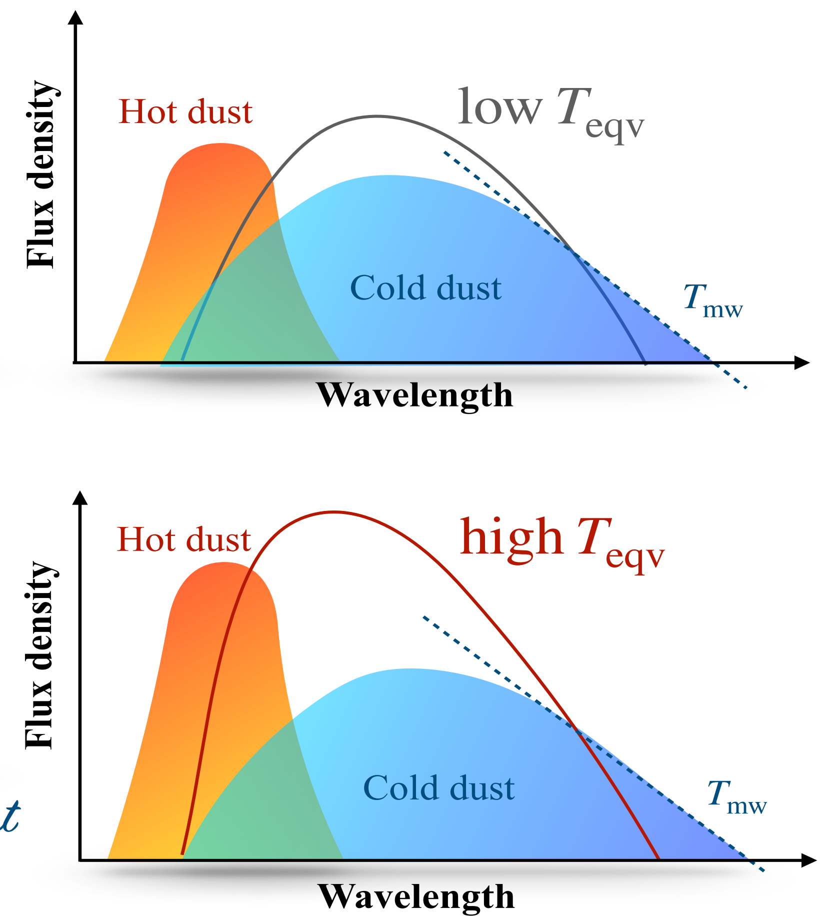
Dust in galaxies is expected to get warmer with increasing redshift

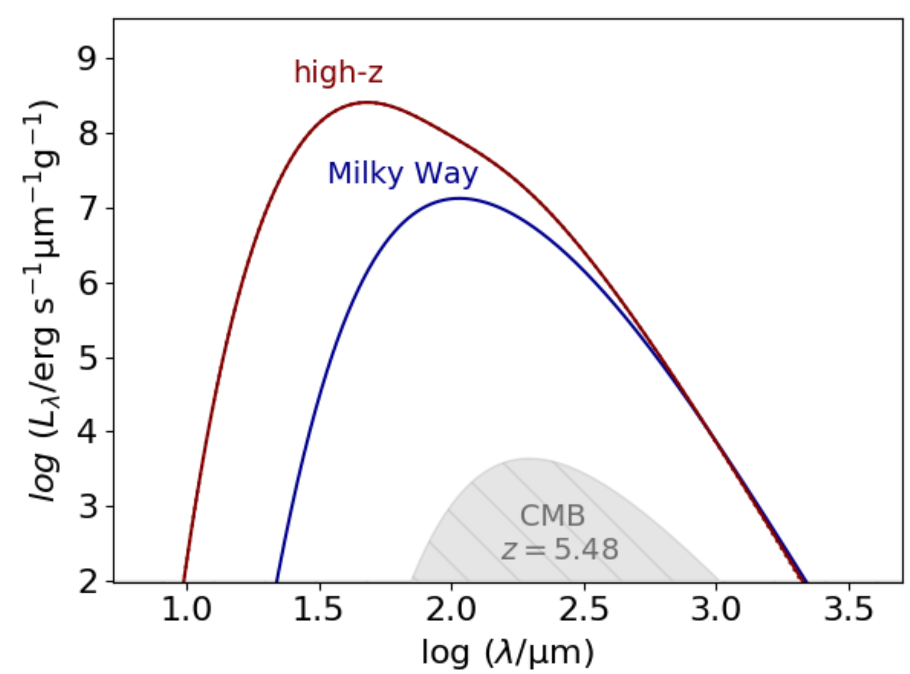
mainly due to increasing cosmological accretion rates

$$T_d \approx (1+z)^{0.42}$$

(Sommovigo+2022)





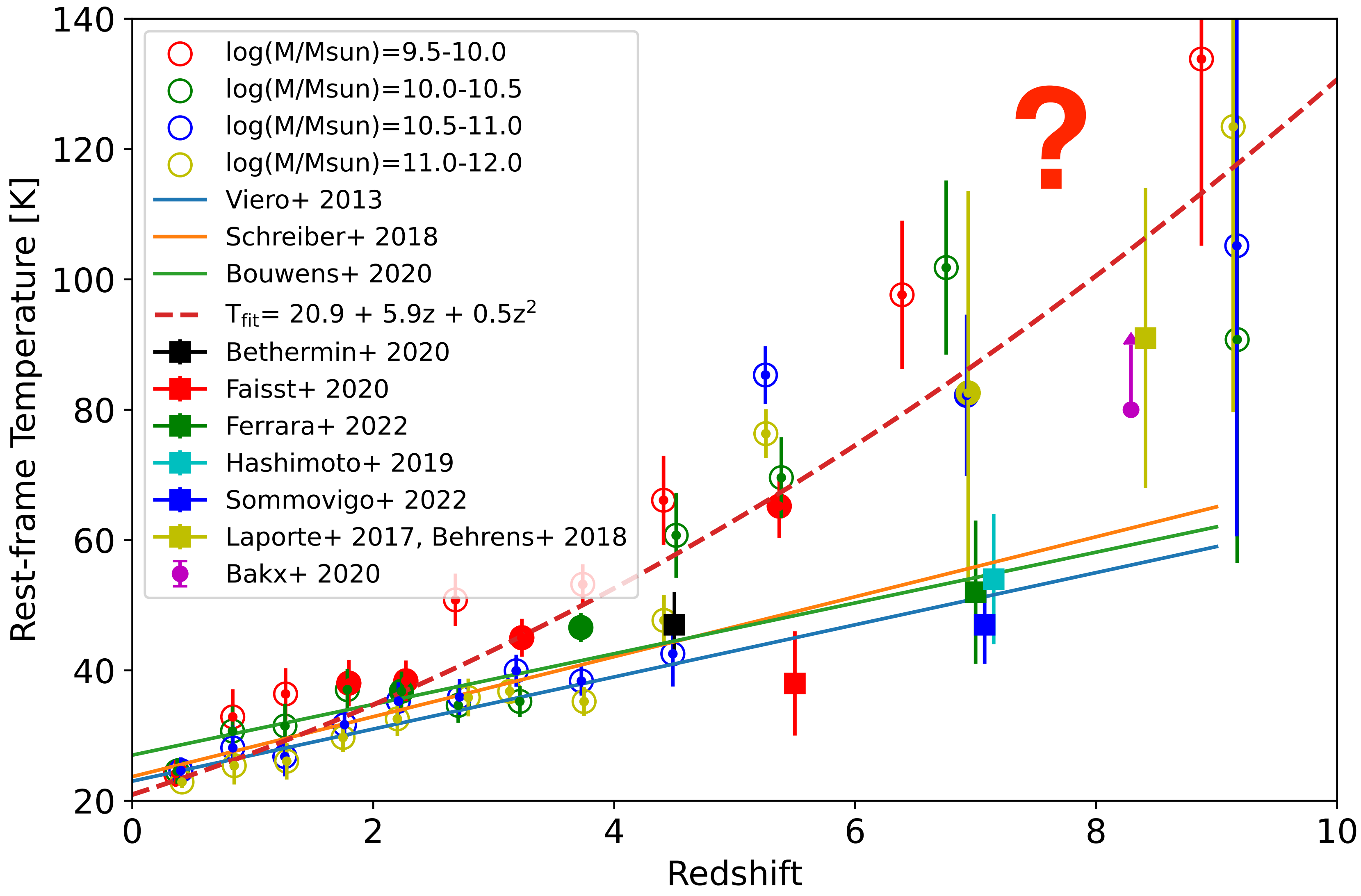


Sommovigo+(2020)

Rising dust temperature with redshift

some observational constraints suggest that dust temperatures could be even higher

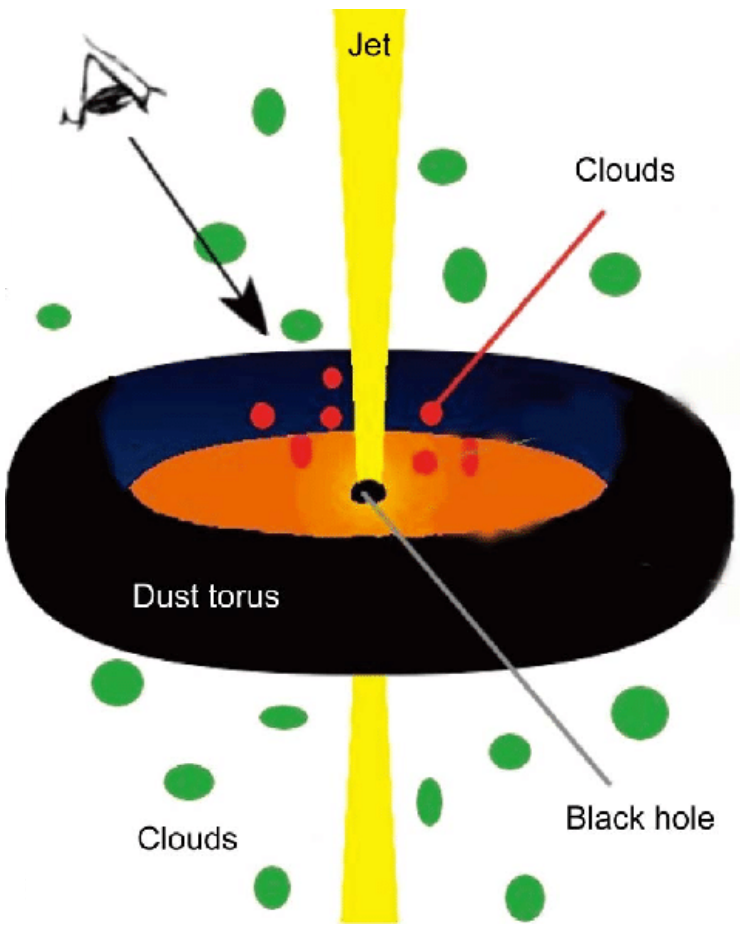
simple extrapolations from known sub-millimetre galaxies may underestimate Td

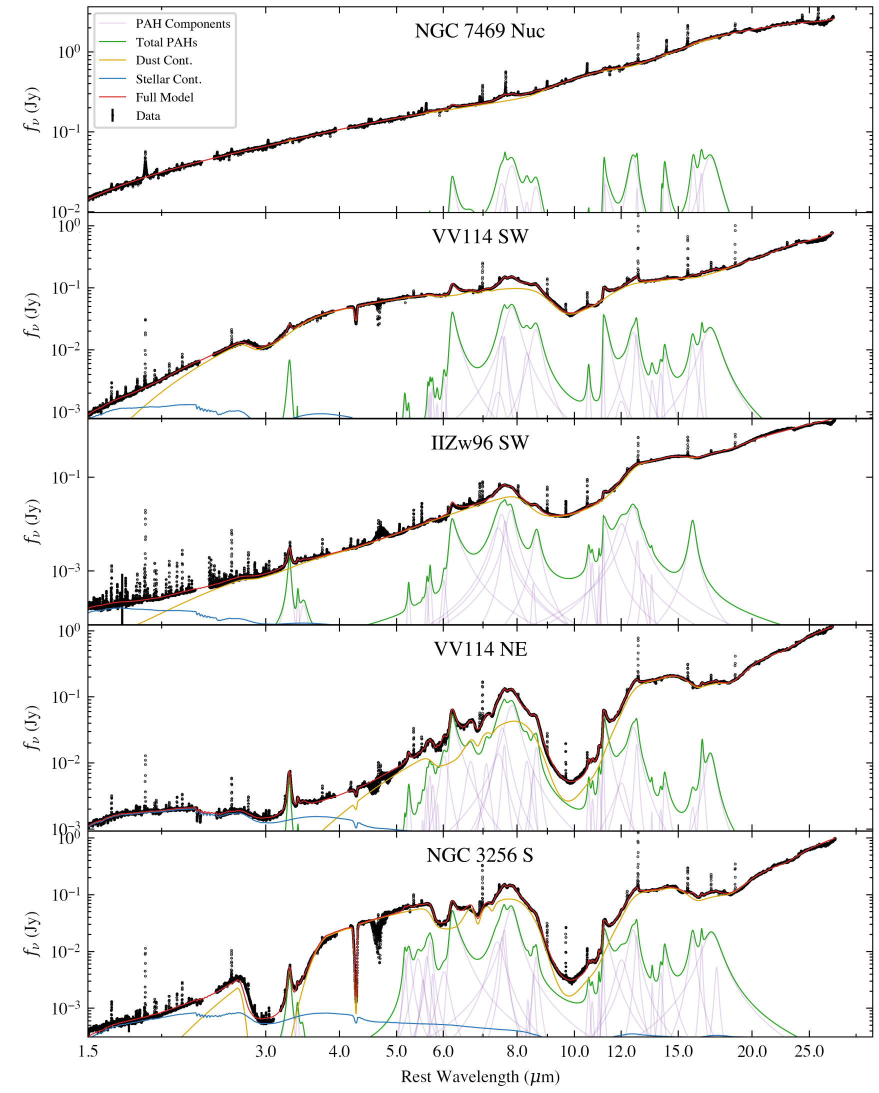


Viero+(2022)

Hot dust from AGN

a proper characterisation of the AGN dusty torus requires studying λem ~1-15 μm



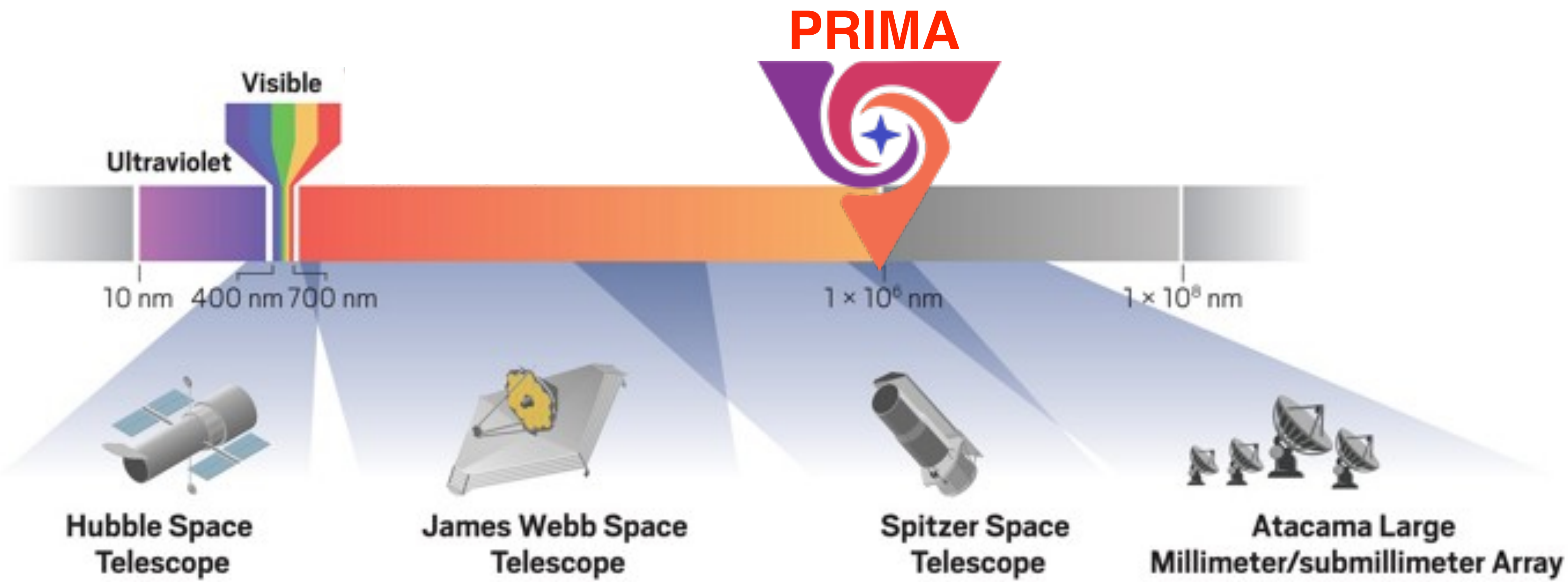


Donnan+(2024)

but this regime comes out of the MIRI bands at high z

The missing observing window: 24-250 microns

PRIMA will be the first *competitive* IR telescope operating between the wavelength domains of JWST & ALMA



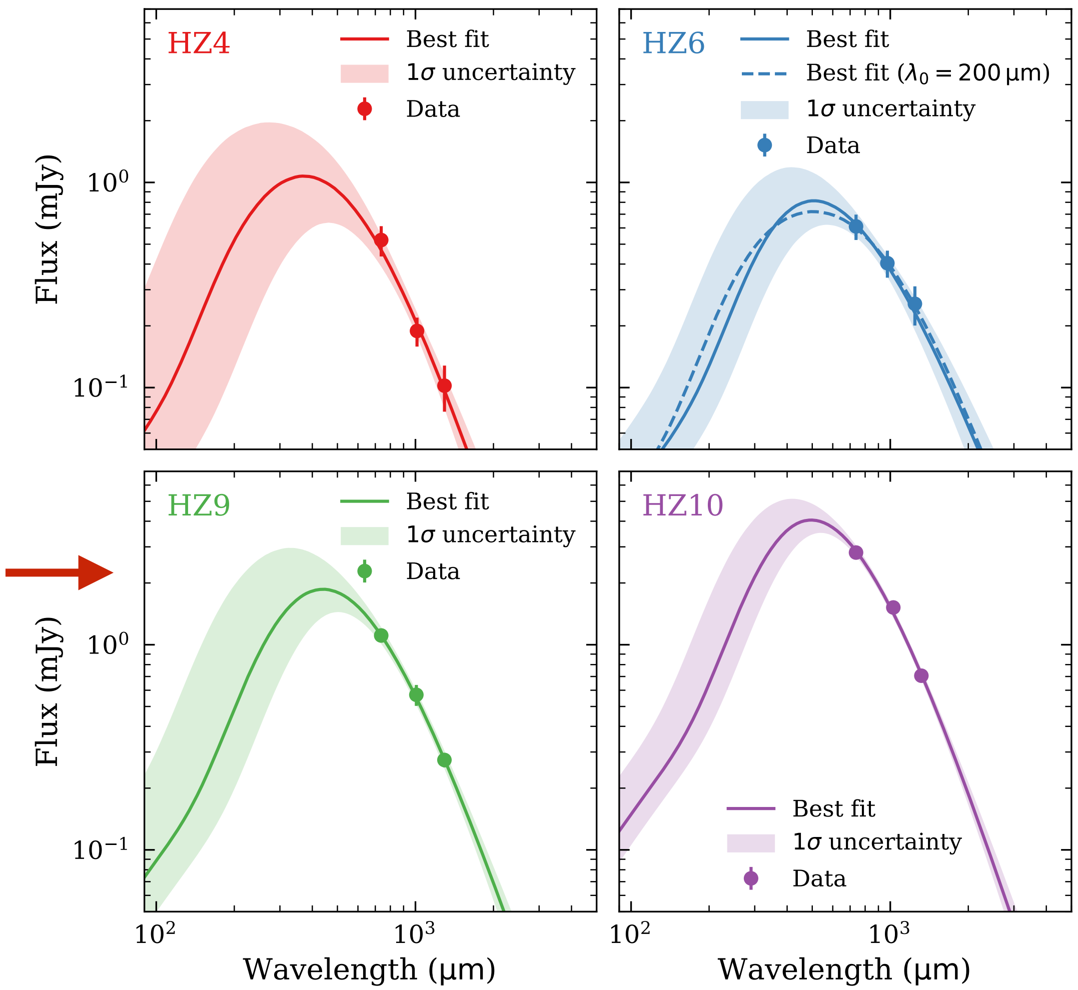
based on fig. credit: cen.acs.org

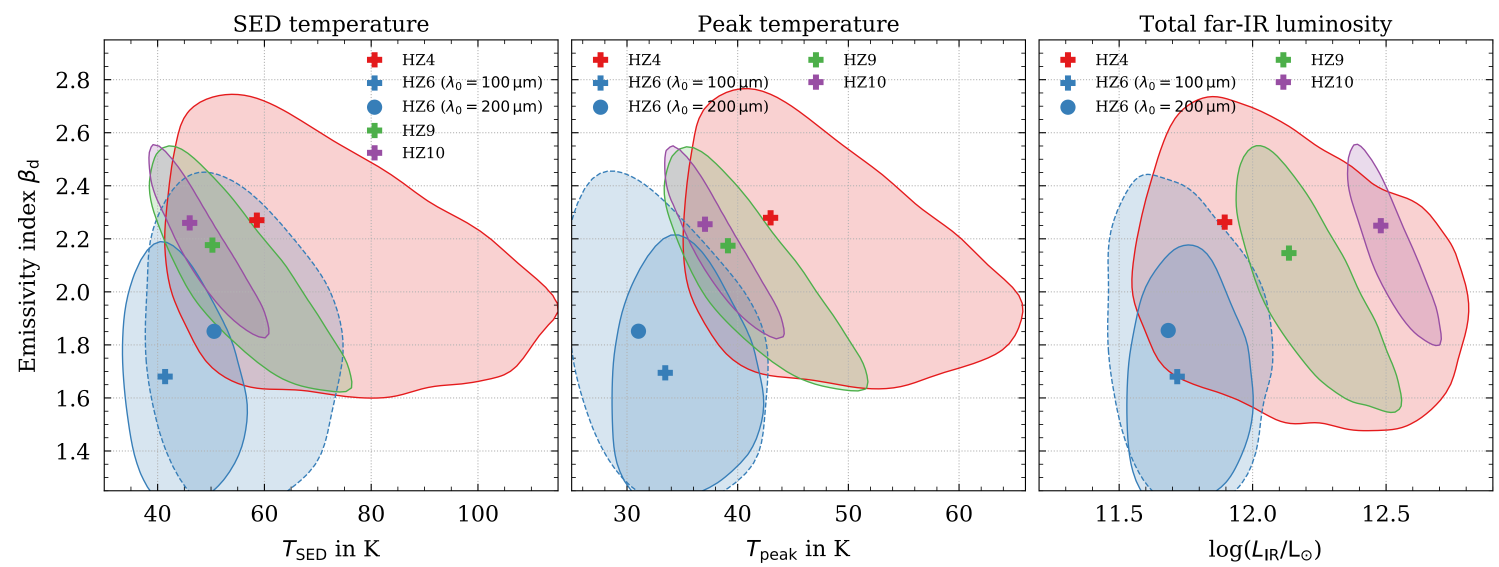
With PRIMA we will obtain the first representative census of warm-dust sources up to the EoR

Talk Outline

- Warm dust at high z: hints from ALMA and JWST results

Star-forming galaxies at z~5.5



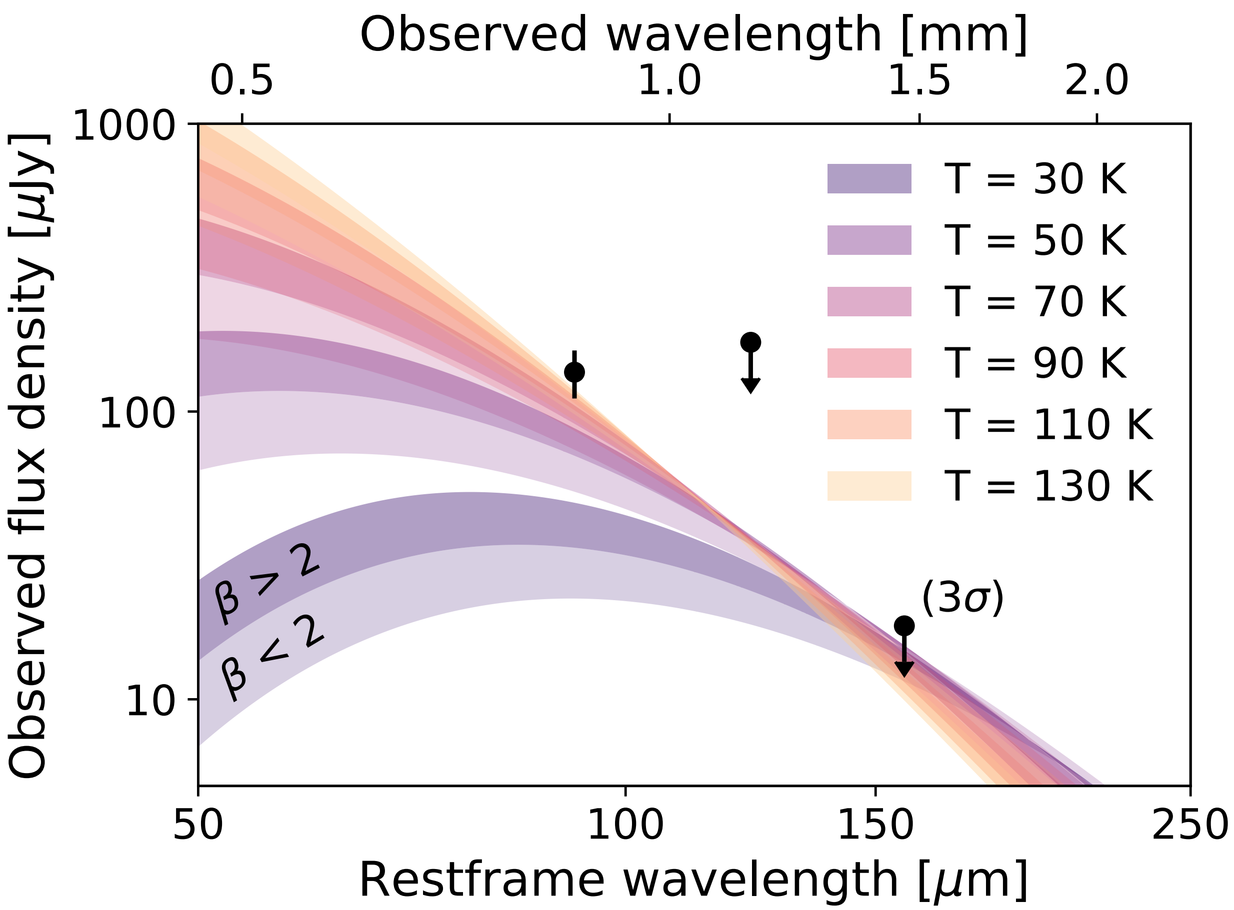


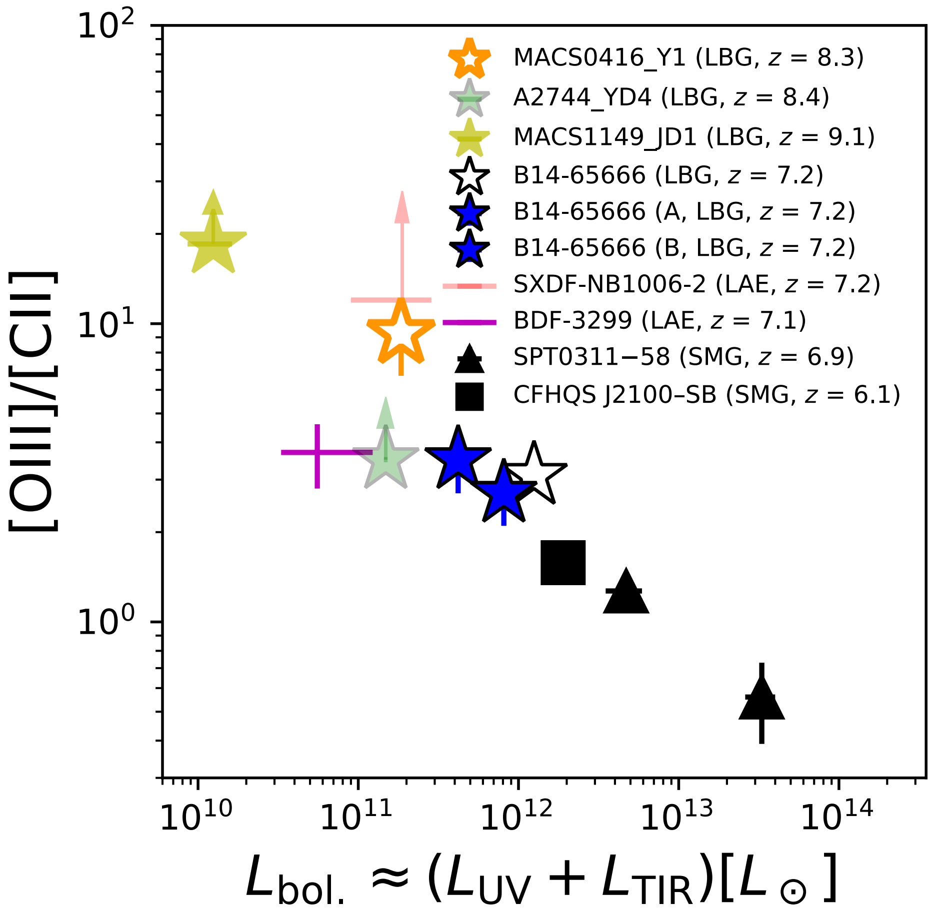
Faisst+(2020)

ALMA (Band 8) constrains the red-side of the IR dust emission SED

The inferred dust temperatures are still uncertain,
but suggest Td higher than local value

Warm dust in LBGs at z~7-9





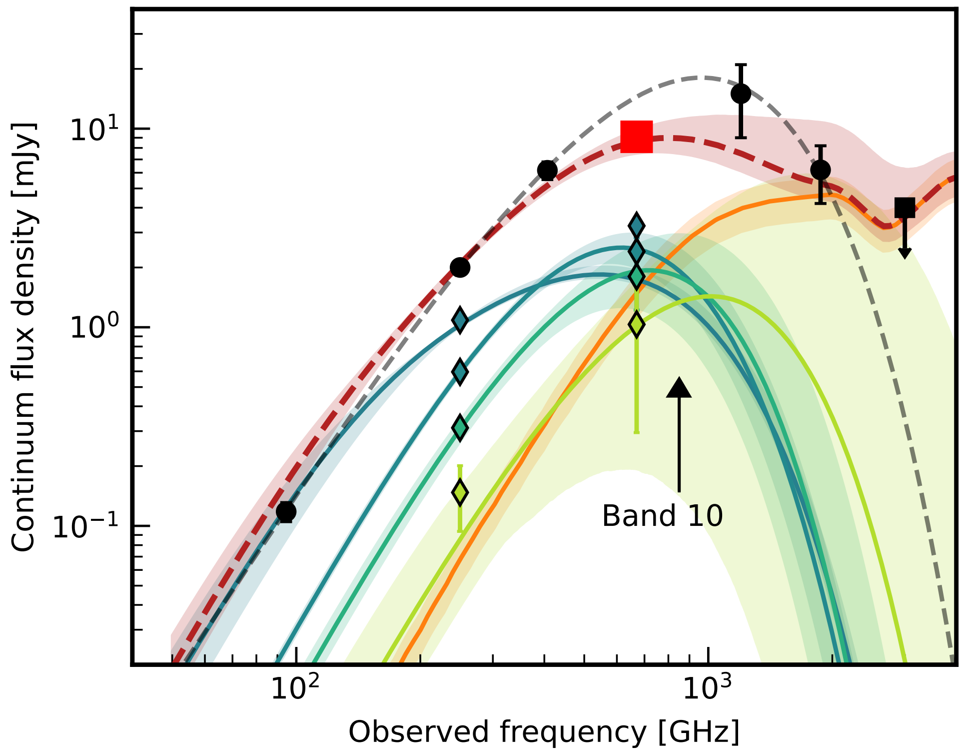
Bakx+(2020)

see also e.g. Walter et al. (2018); Tamura+(2019)

Why detections at shorter IR wavelengths are important

Having insufficient IR SED coverage can lead to
wrong (underestimated) T_{dust} and (overestimated) L_{IR}

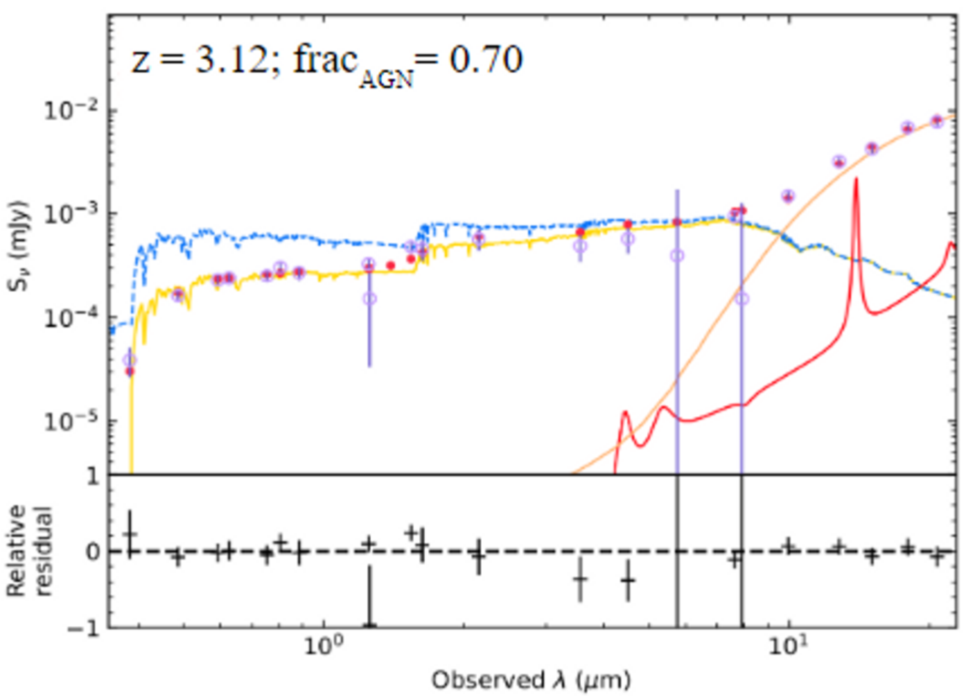
QSO host galaxy at z=6.9



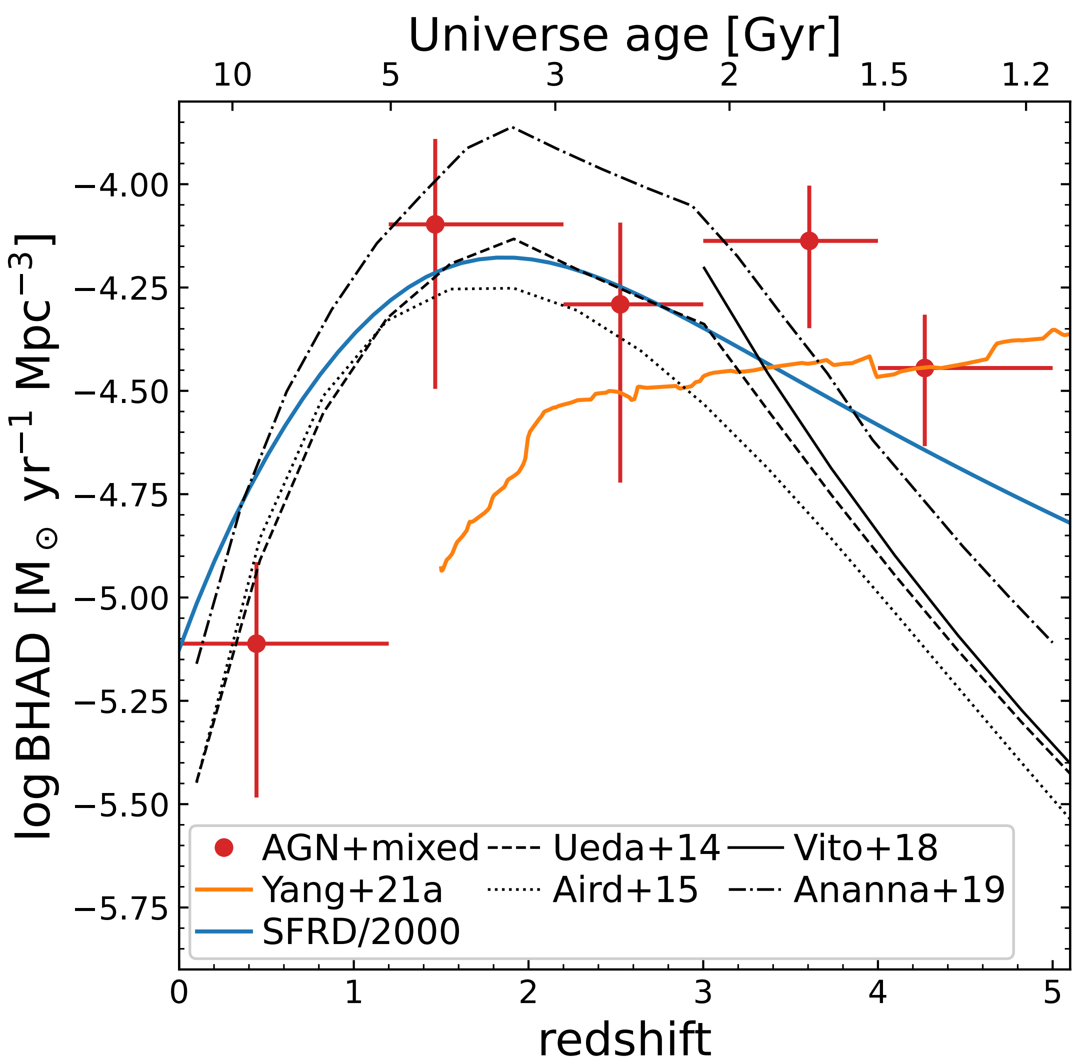
IR detections are shorter wavelengths give us information on warm dust
corresponds to an AGN dusty torus and/or central ISM heated by nuclear activity

Meyer+(2025)

JWST/MIRI: the importance of dust-obscured AGN



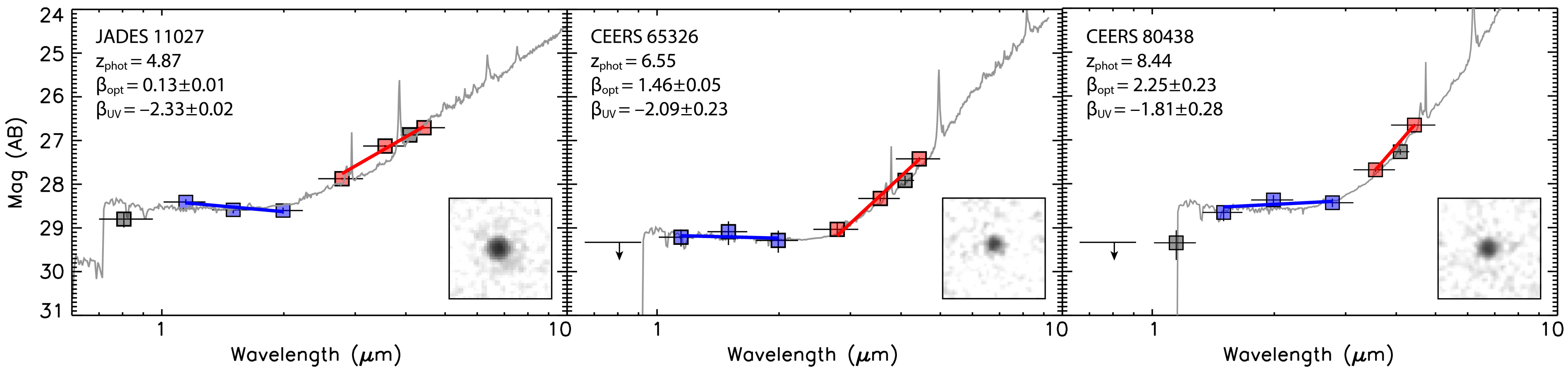
Yang, KC +(2023)



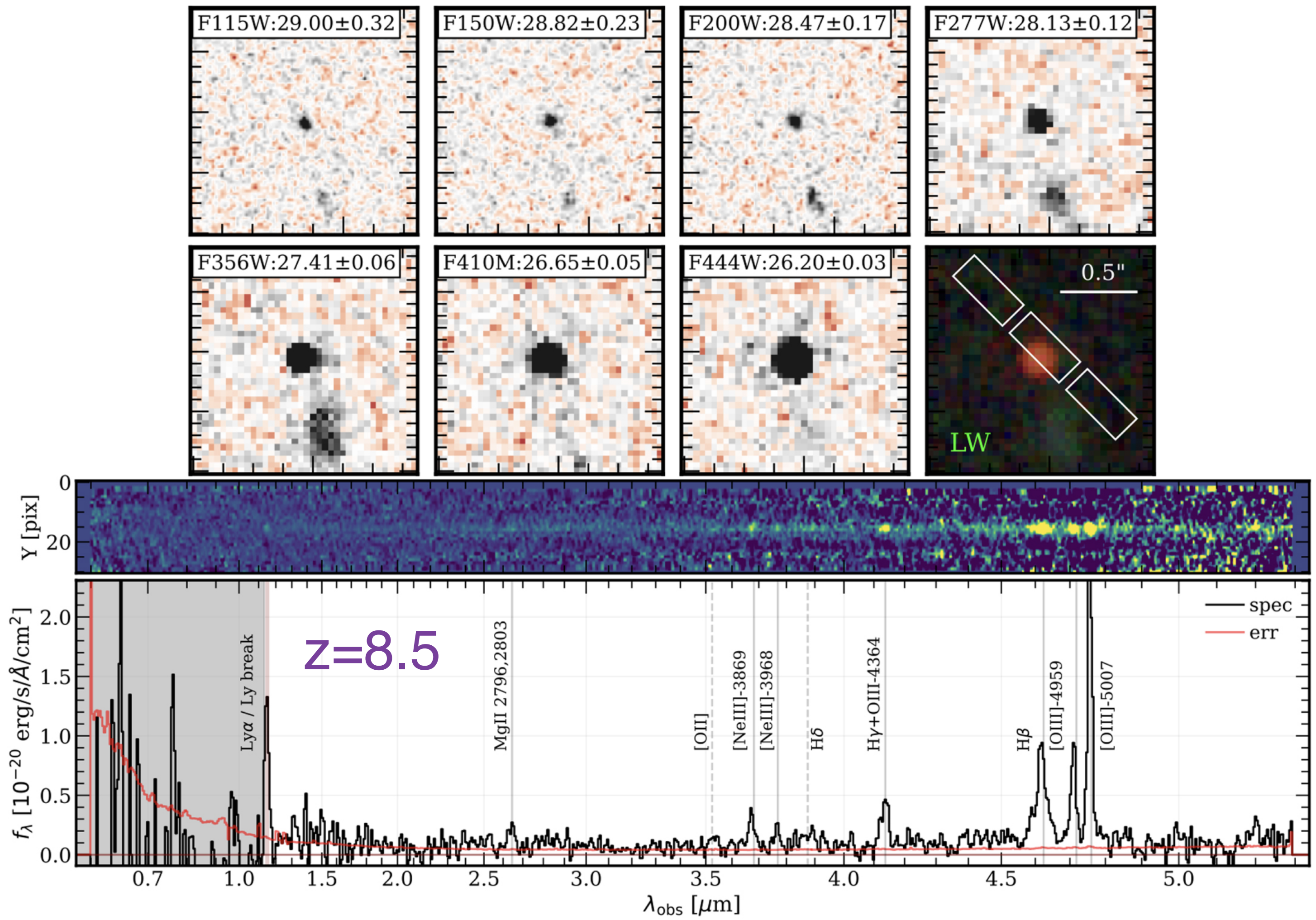
?

Indicates that BHAD is higher than thought at z=3-5 (includes contribution from composite systems)

Little Red Dots (LRDs)



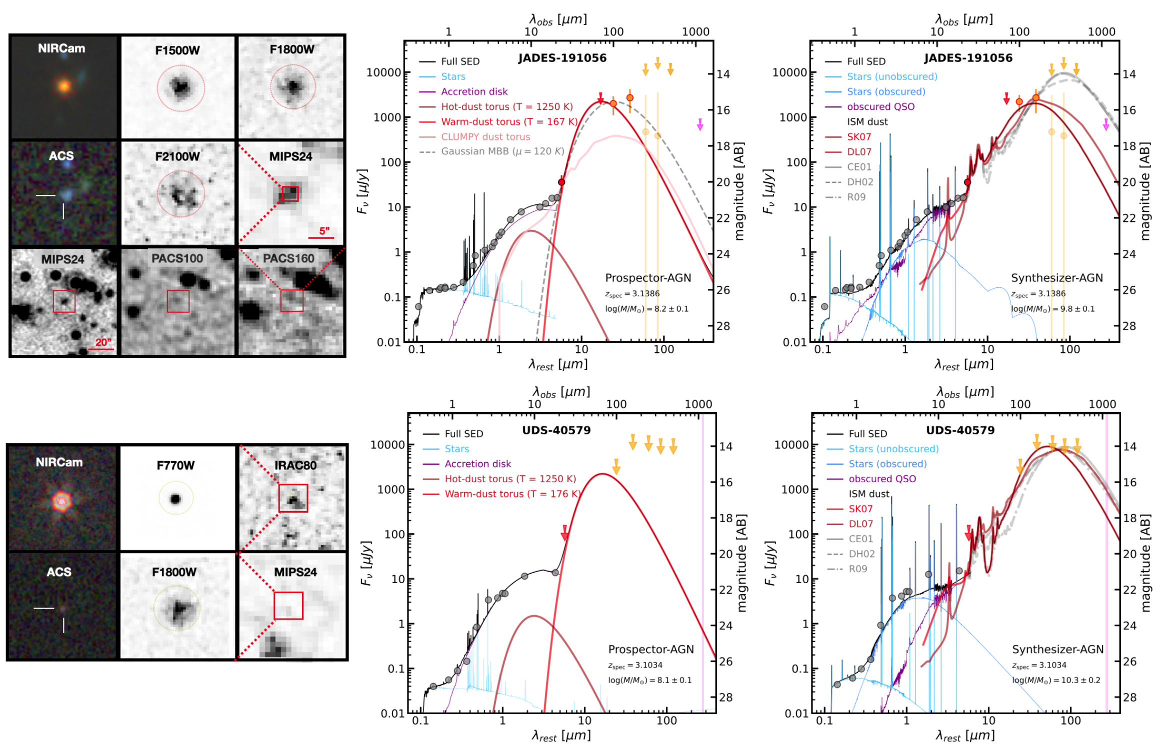
Kocevski +(2024)



Kokorev,…, KC +(2023)

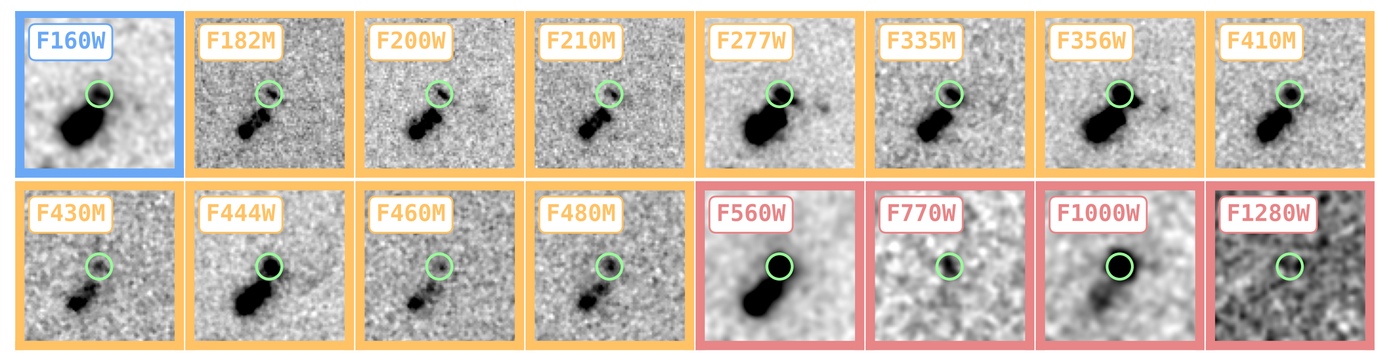
Little Red Dots (LRDs) and similar sources in MIRI

Not all LRDs are detected in MIRI, especially not at the longest wavelengths

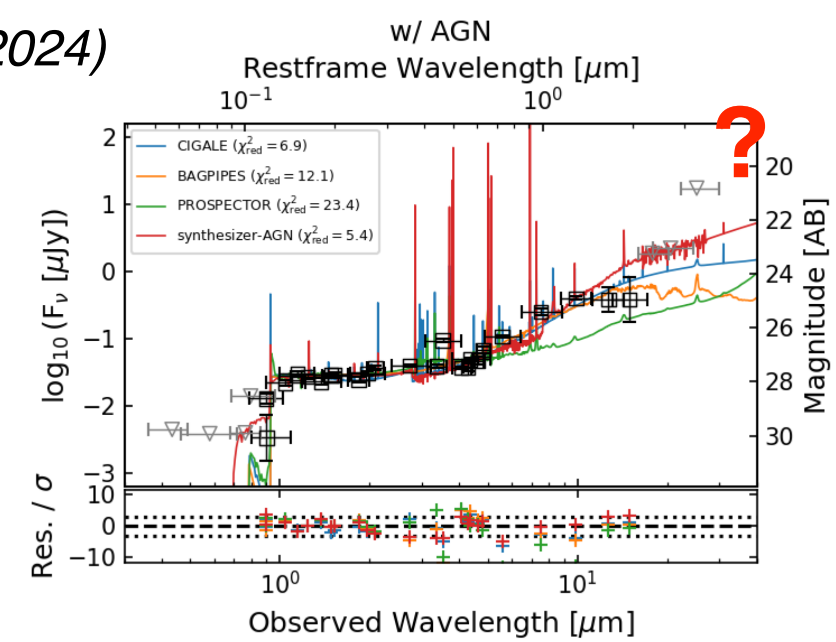


Barro +(2025)

Virgil = LRD + host (z=6.6)



Iani, Rinaldi, KC +(2024)



A PRIMA galaxy census could help disentangle the nature of the IR brightest cases

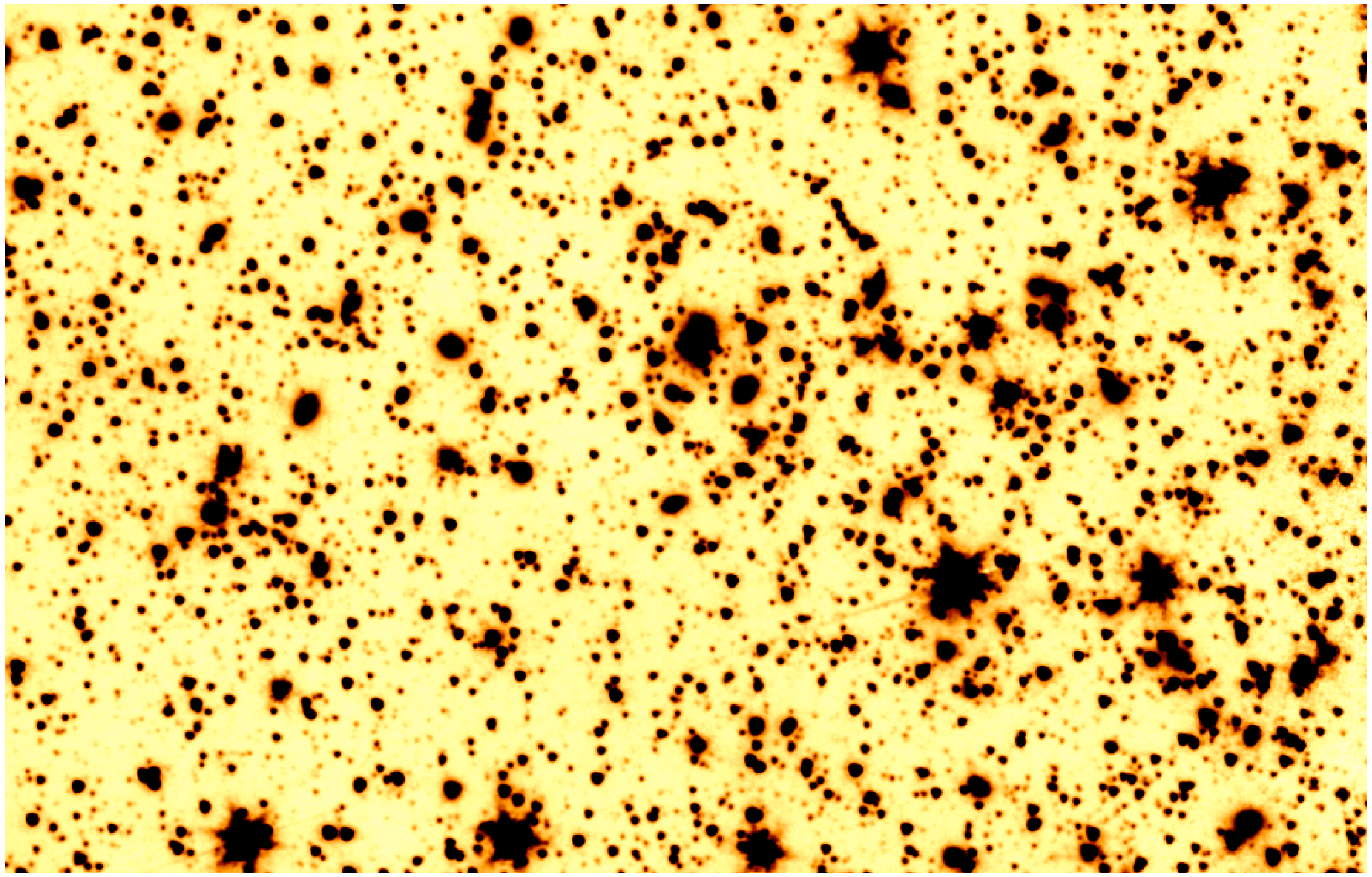
Talk Outline

- **Potential of the PRIMAger to study the high-z Universe**

Predictions from existing observations

Lessons from Spitzer galaxy surveys

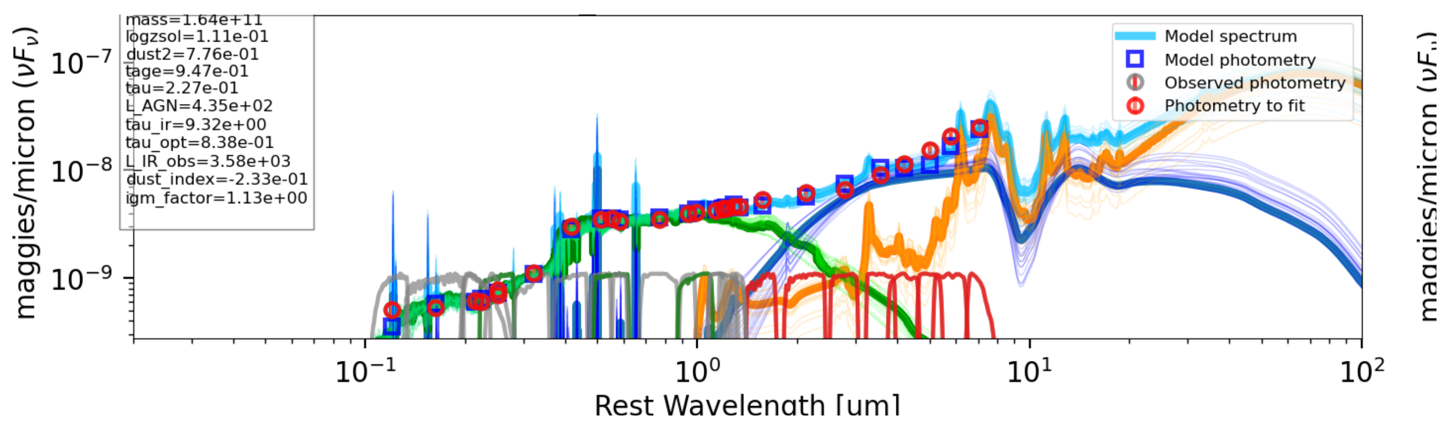
Spitzer (IRAC+MIPS) maps in COSMOS



There are ~90 galaxies at z>3 with Snu(24um) > 150 microJy
(over ~1.5 sq.deg)

Tier 1: PRIMA blank survey over ~10 sq. deg.

A PRIMAger blank survey down to ~ 150µJy (30µm) over ~10 sq. deg. would detect at least 600 (200) galaxies at z>3 (z>4)



Lyu +(2024)

Critical role to separate SF galaxies and AGN in most luminous sources at z>3

Synergies with Euclid/Roman

e.g., EDFN particularly advantageous (IRAC data)

Integration time (PRIMA ETC): ~1000 h (5σ over two 'bands')

Tier 2: PRIMA blank ultra-deep survey over ~1 sq. deg.

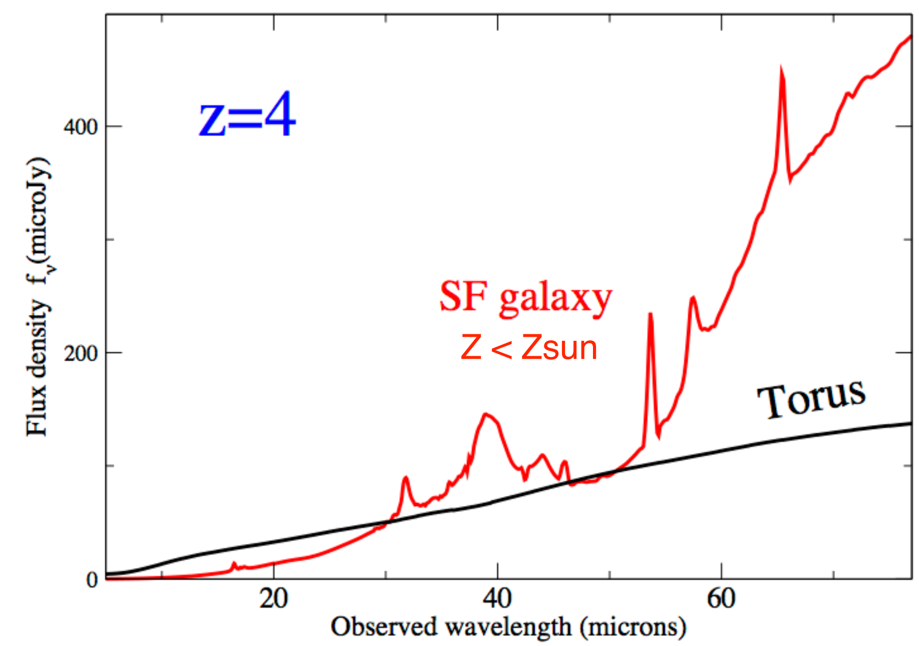
Try to push PRIMA towards the confusion limit

A PRIMAger blank survey down to ~ 60 µJy (30µm) over
~1 sq. deg. would detect **at least** 400 (150) galaxies at z>3 (z>4)

…but due to k-corrections, there will be many more at 60-70 µm

Detect warm dust in the ISM of low-metallicity galaxies

Understand their contribution to cosmic SFRD



Integration time (PRIMA ETC): ~1000 h (for 2 bands at 5σ)

May be a challenge to separate these galaxies in the PRIMA beam

Take home messages

- ✤ **Dust was warmer in the first few billion years (ISM dust + AGN)**

  expected from theory + observational evidence

- ✤ **Lack of constraints on warm dust leads to wrong LIR and Td - PRIMA**

- ✤ **Deep PRIMAger (10 sq.deg.) survey in areas w/Euclid/Roman + IRAC**

  systematic study of dust-obscured nuclear activity in most luminous IR galaxies

  study contribution to the cosmic BHAD

- ✤ **PRIMAger galaxy surveys down to confusion limit should detect warm dust in hundreds of z>4 galaxies with low metallicities**

  trace early chemical enrichment and (w/shorter wavelength IR data) disentangle dusty nuclear activity

  study contribution to the cosmic SFRD