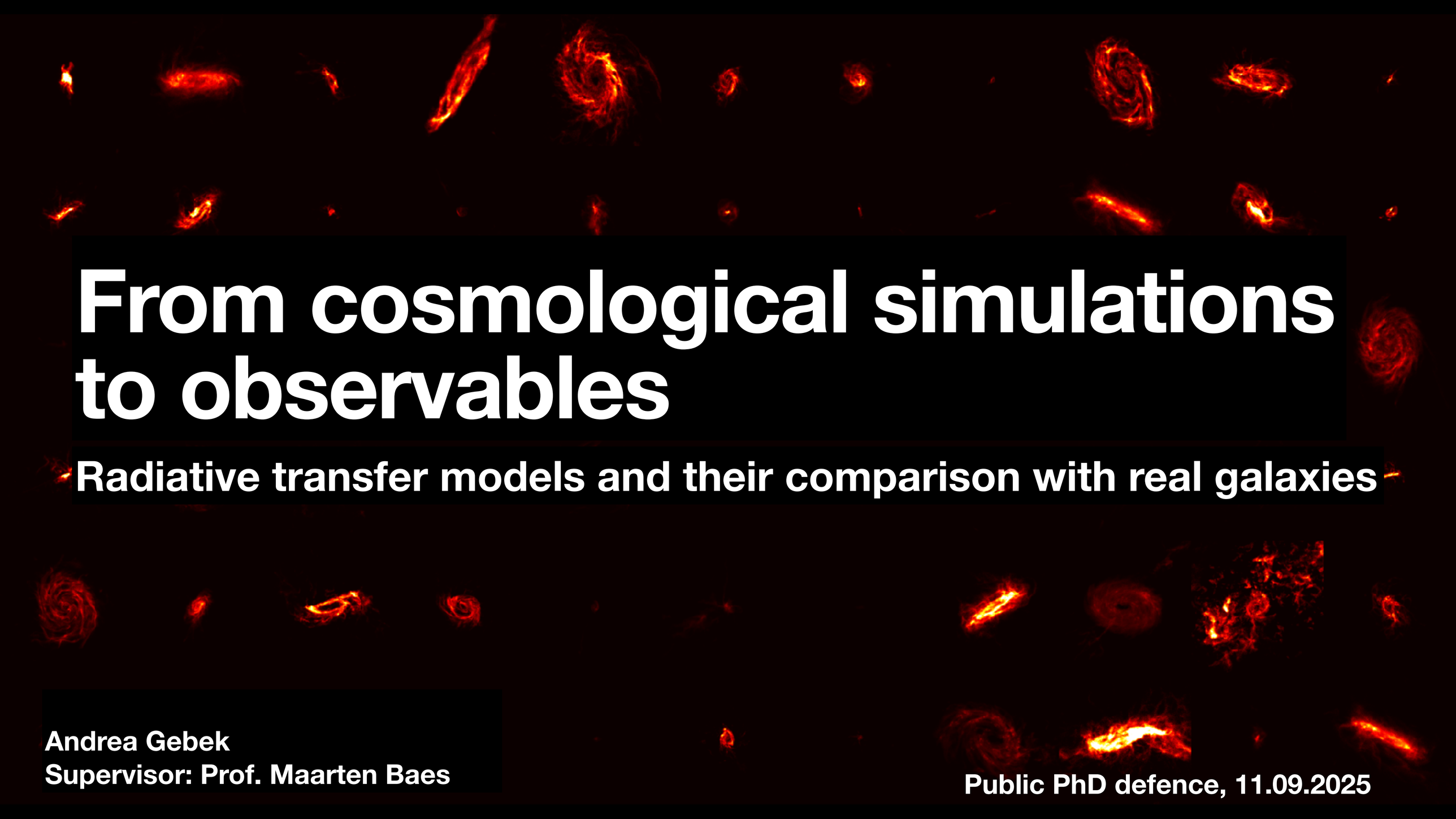
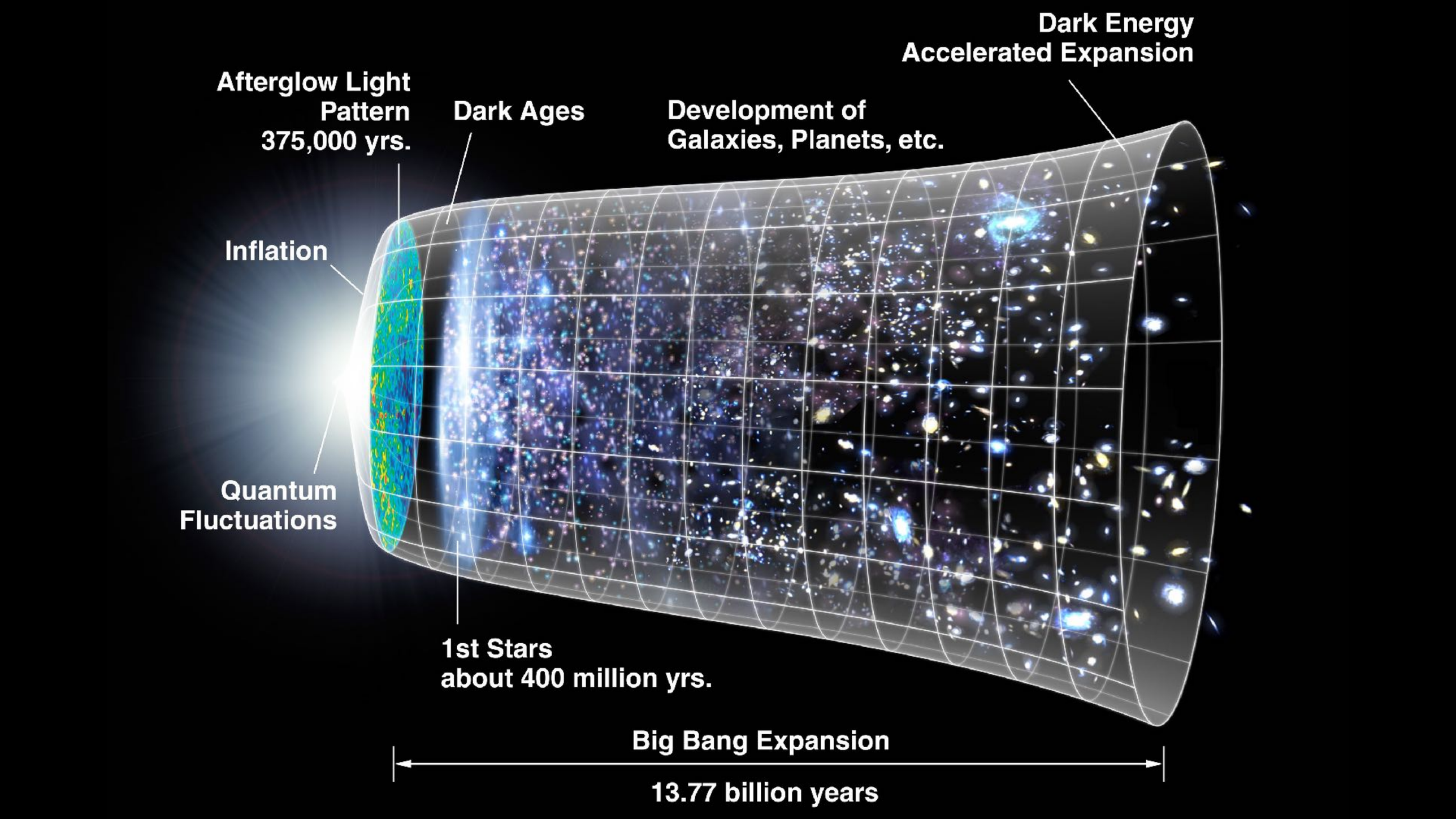


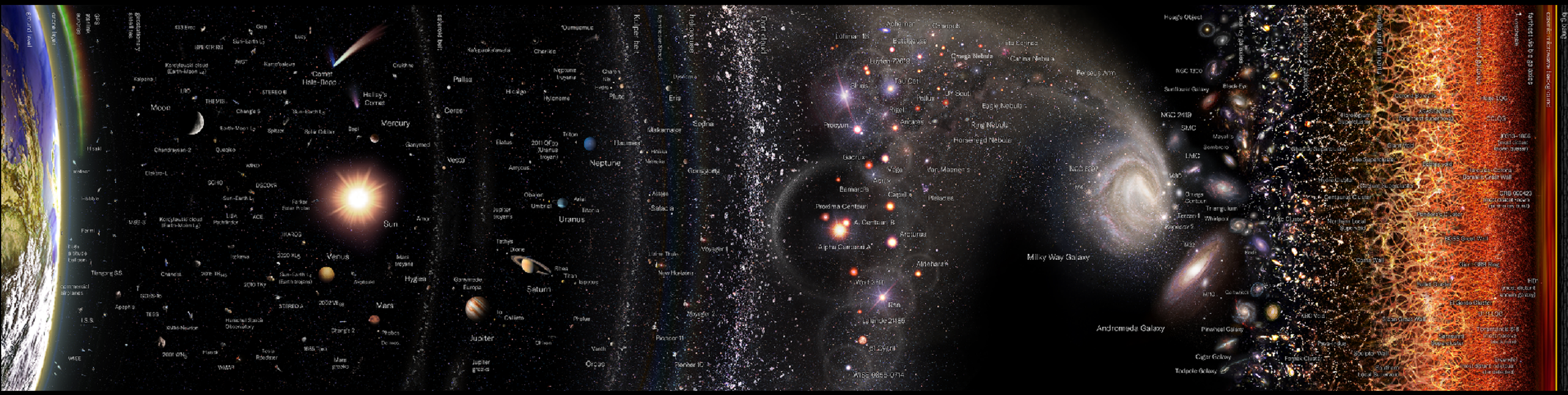
From cosmological simulations to observables

Radiative transfer models and their comparison with real galaxies

Andrea Gebek
Supervisor: Prof. Maarten Baes

Public PhD defence, 11.09.2025


Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
375,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.77 billion years



Extragalactic Astronomy

Galaxies in a nutshell

- Consist of dark matter, stars, and interstellar matter
- Bound by gravity
- Our Milky Way:
  - ~100’000’000’000 stars
  - Comparable mass in gas (mostly hydrogen & helium)
  - ~30 kpc disk diameter (~6’000’000’000 times Earth-Sun distance)



Andromeda, a nearby spiral galaxy



ESO 325-4, a nearby elliptical galaxy

Extragalactic Astronomy





- How do galaxies form and evolve?
- Problem: We cannot observe galaxy evolution “live”

?





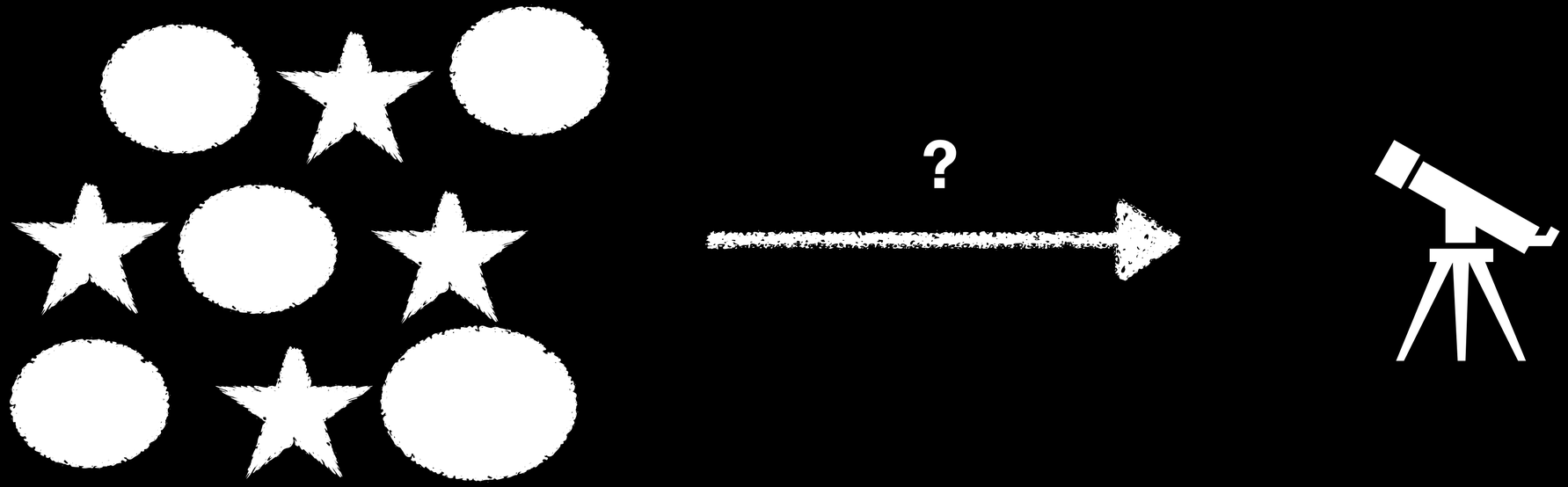
Computers to the rescue!

- Cosmological simulations: Model the “life” of a galaxy
- Large-volume: Simultaneously model thousands of galaxies
- Start from a large box with dark matter and gas 13.7 billion years ago
- Stars, black holes, and galaxies form until the present day

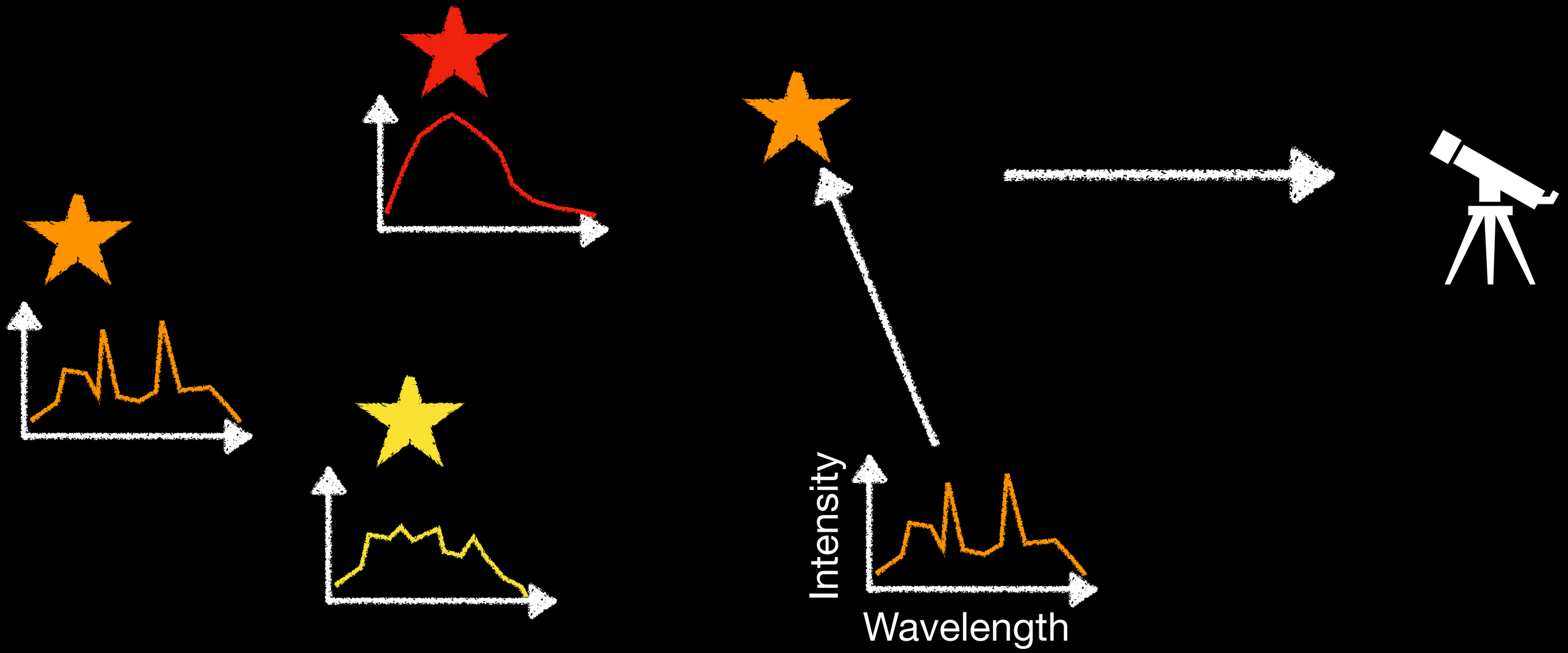


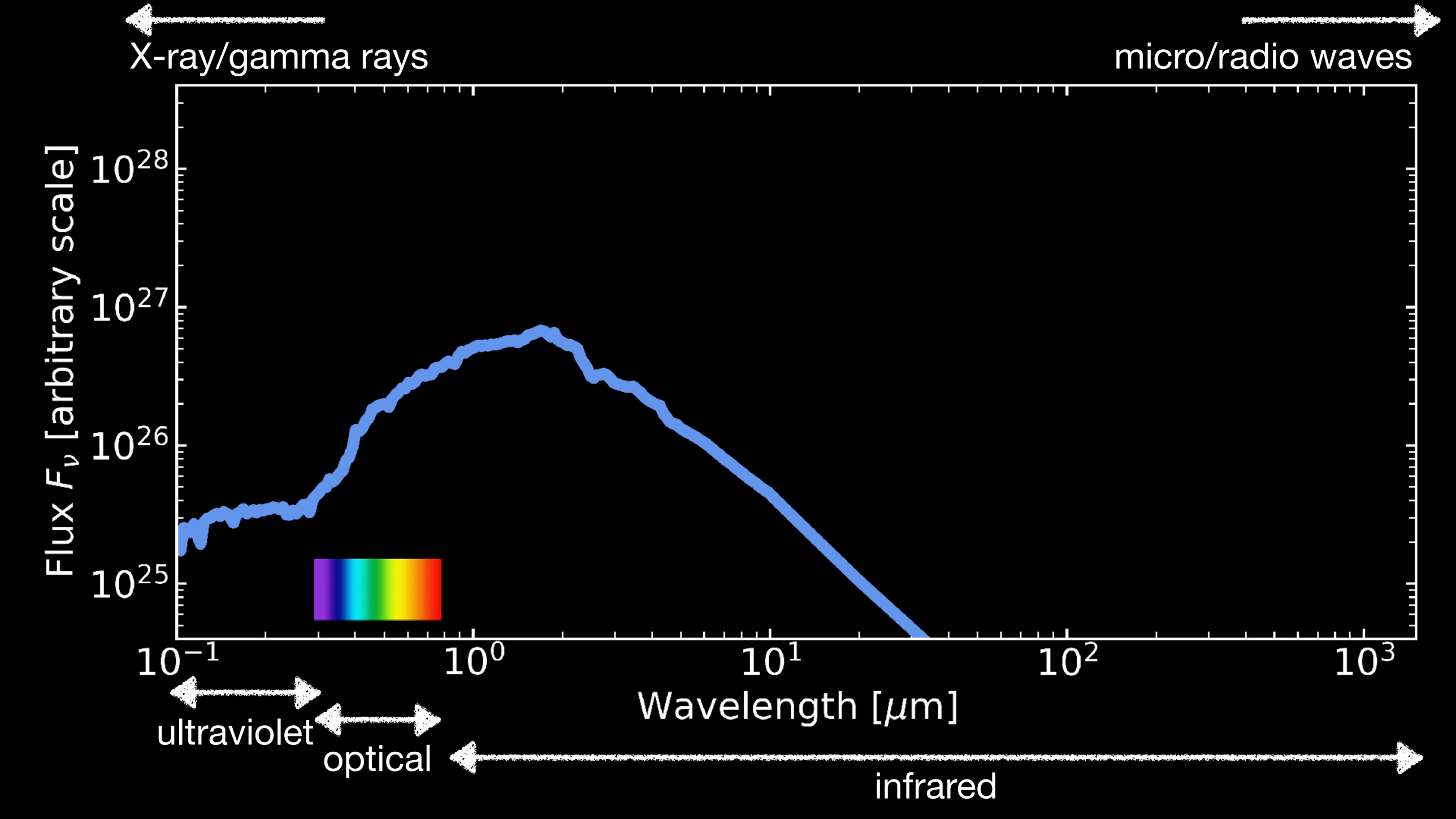
Are the simulations realistic?

- Problem: Simulations predict distribution of stars and gas (matter)
- Our telescopes observe light!
- How would simulated galaxies look like through a telescope?

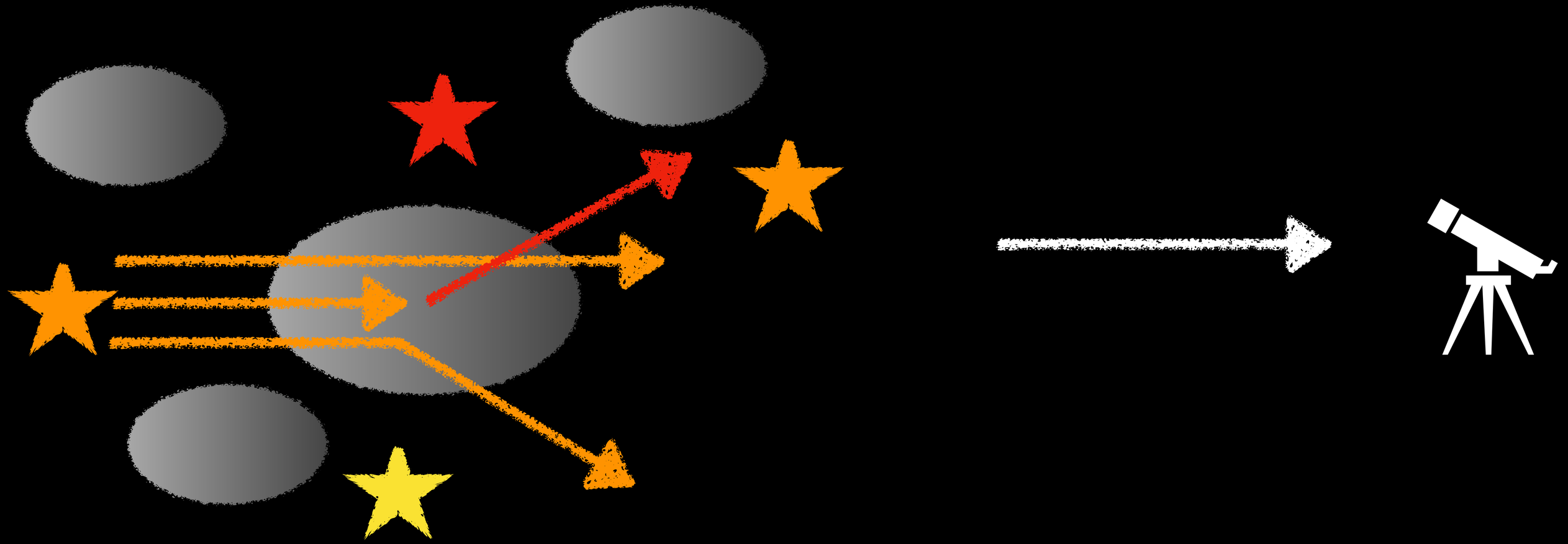


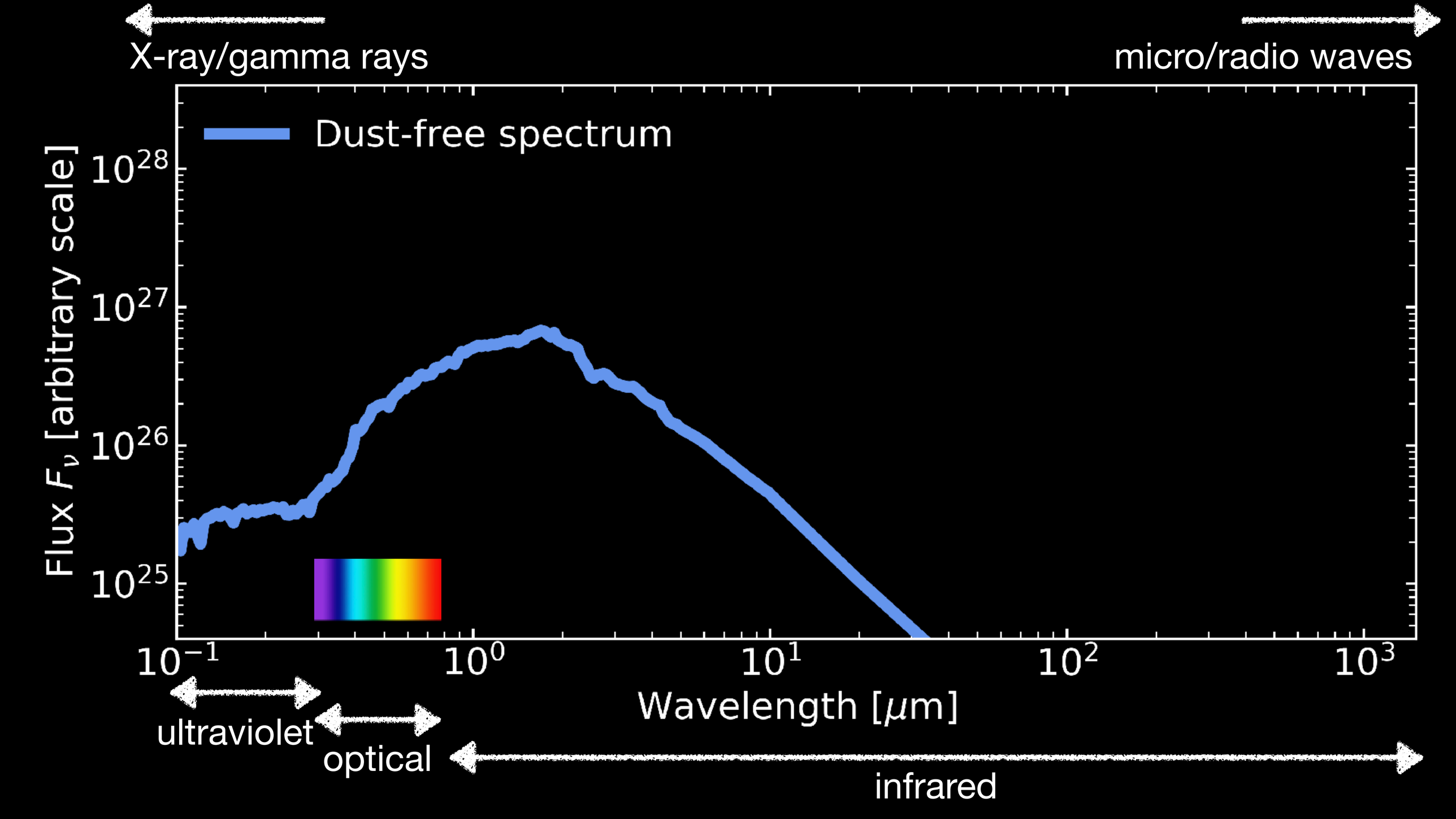
The art of dust radiative transfer

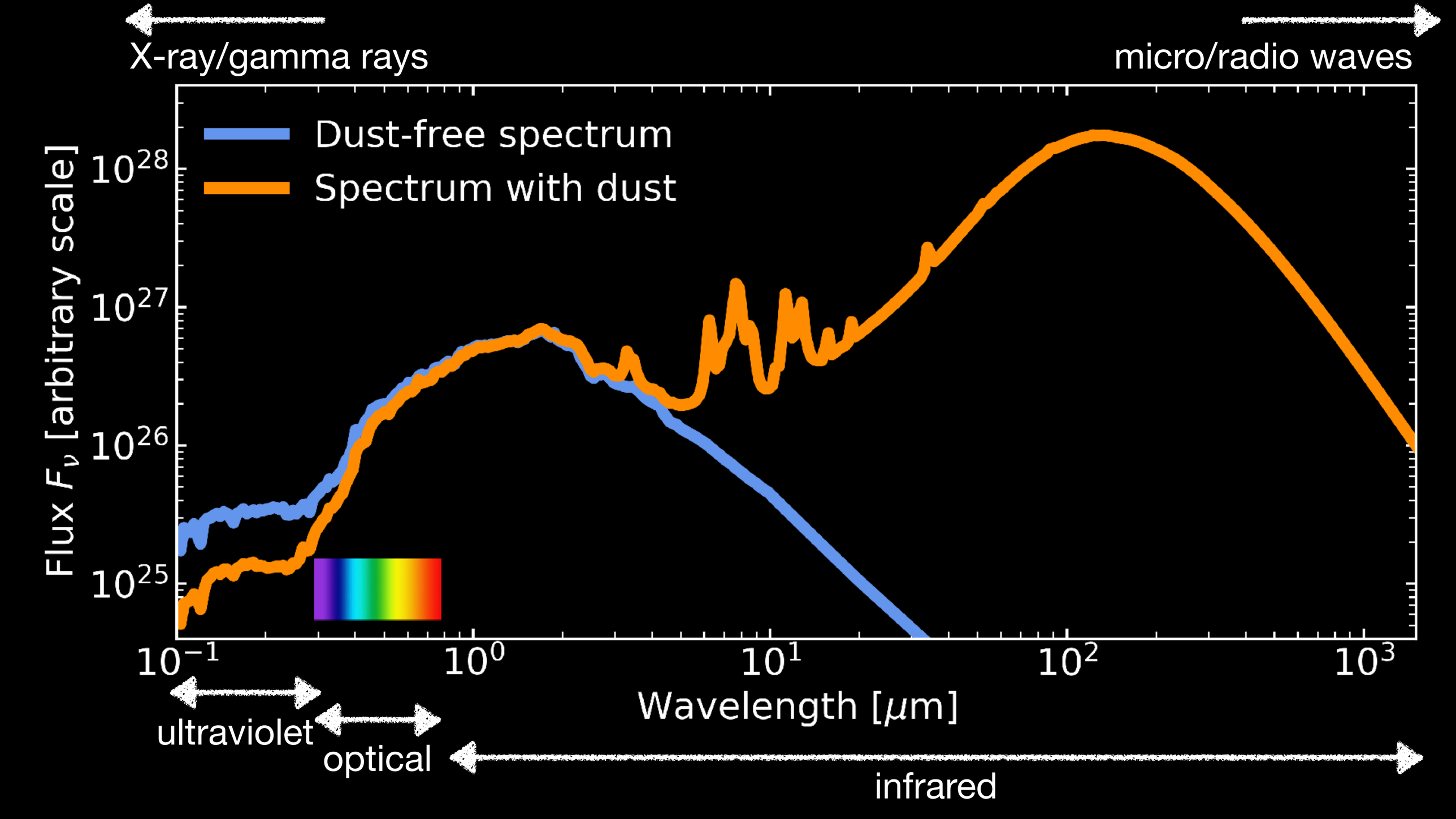



X-ray/gamma rays
micro/radio waves
Flux F_ν [arbitrary scale]
10^{28}
10^{27}
10^{26}
10^{25}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
Wavelength [μm]
ultraviolet
optical
infrared

The art of dust radiative transfer

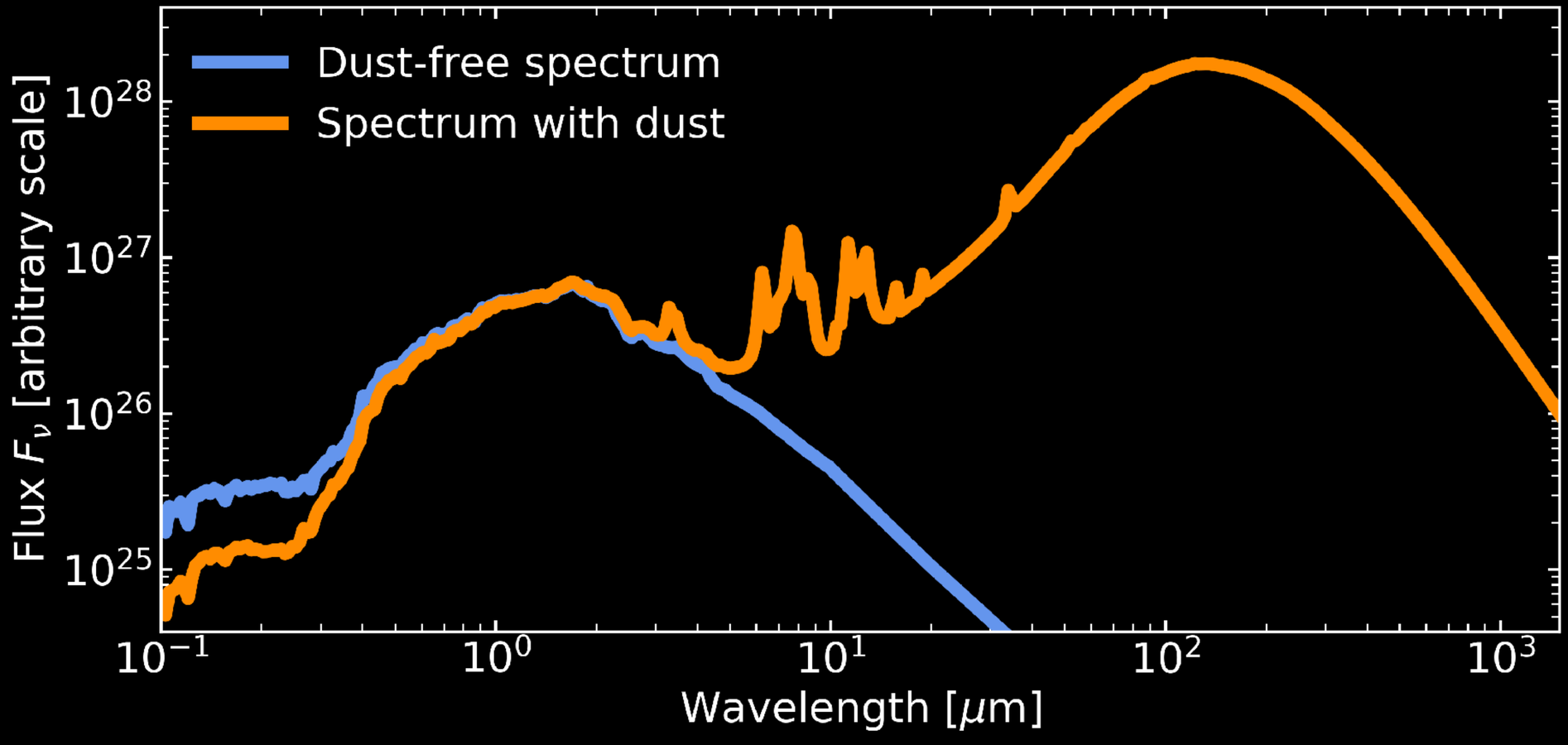


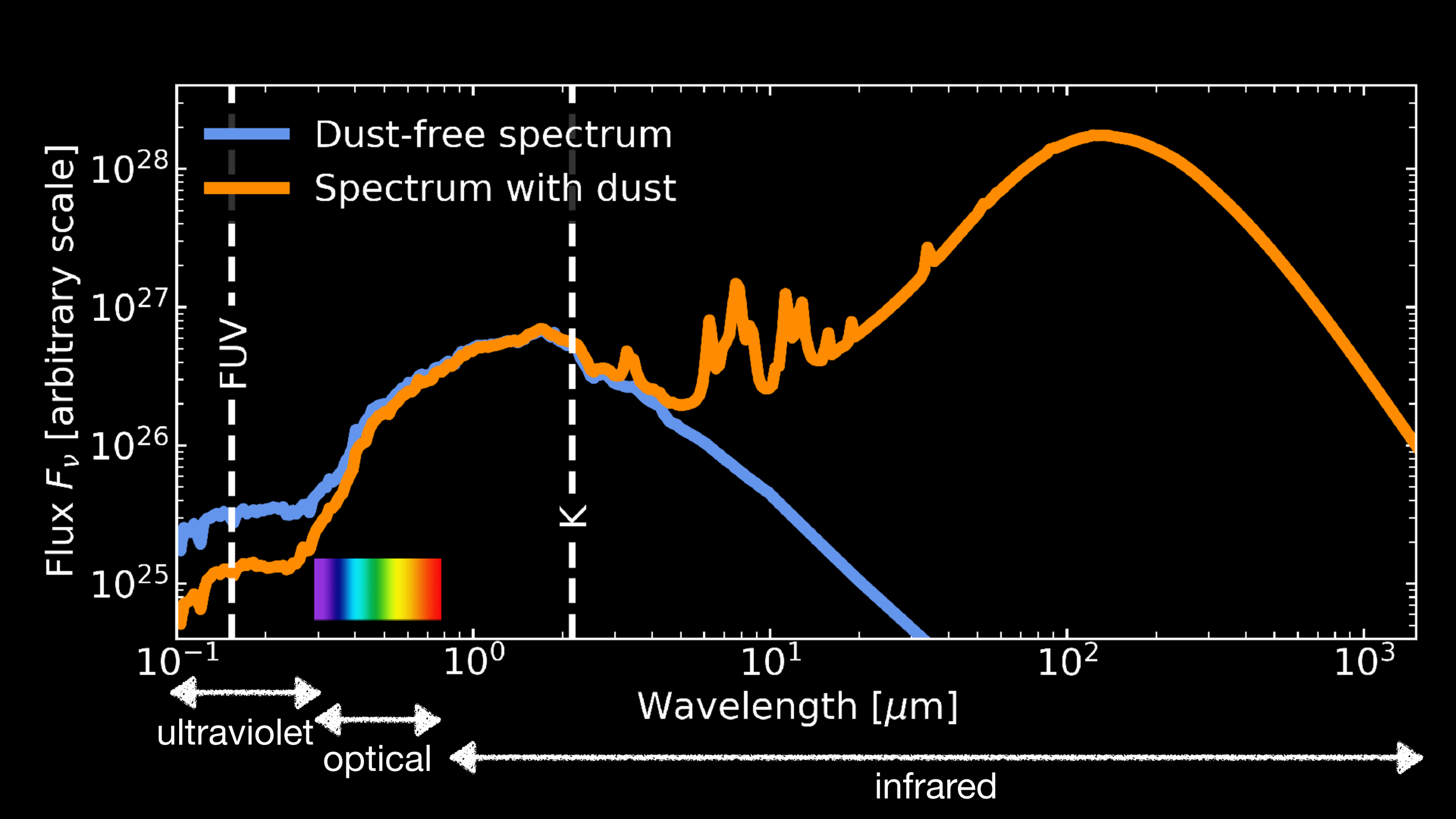

X-ray/gamma rays
micro/radio waves
Dust-free spectrum
Flux F_ν [arbitrary scale]
10^{28}
10^{27}
10^{26}
10^{25}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
Wavelength [μm]
ultraviolet
optical
infrared

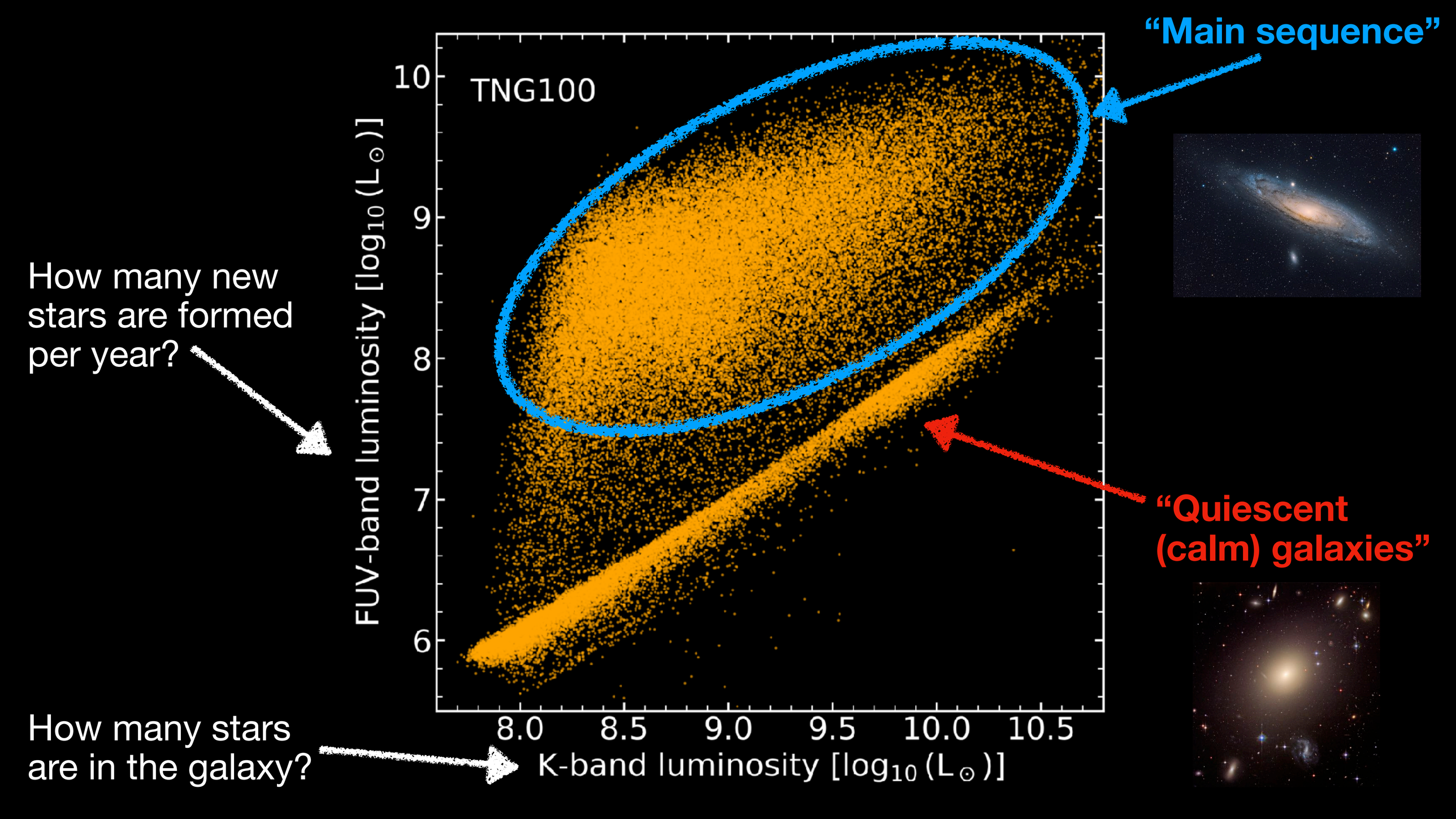

X-ray/gamma rays
micro/radio waves
Dust-free spectrum
Spectrum with dust
Flux F_ν [arbitrary scale]
10^{28}
10^{27}
10^{26}
10^{25}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
Wavelength [μm]
ultraviolet
optical
infrared

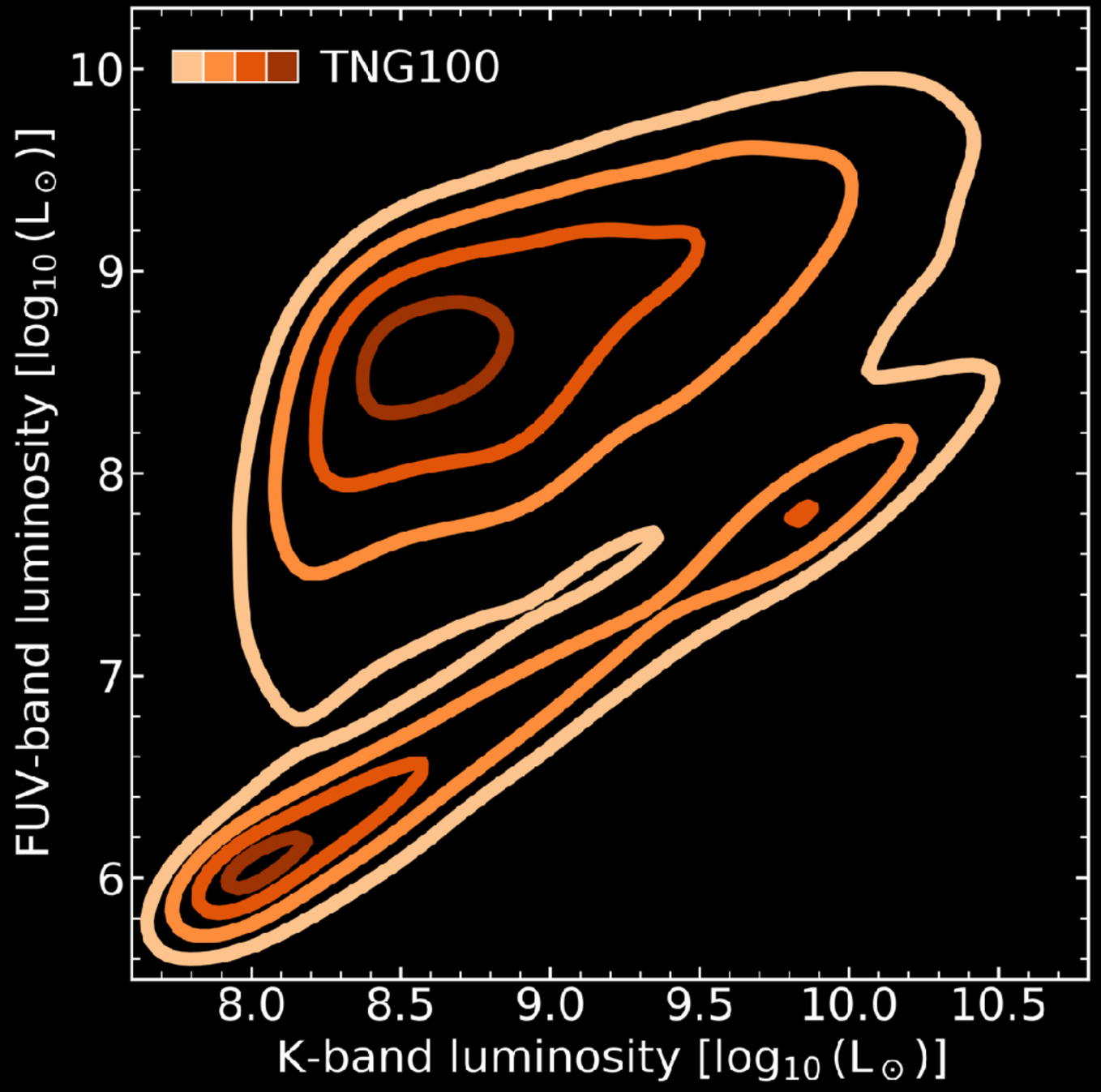
Let’s test a simulation!

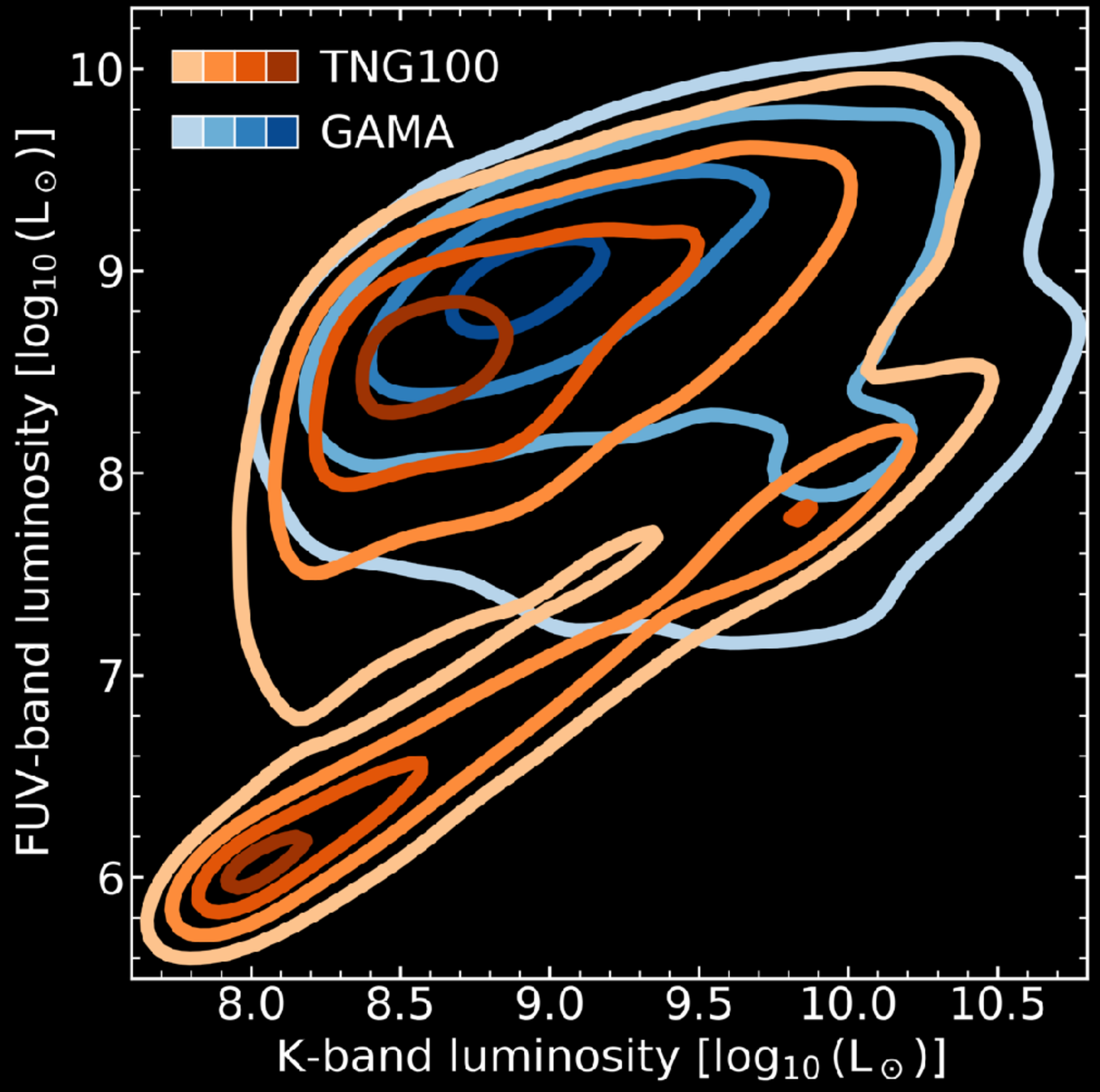
- TNG100 cosmological simulation (finished 2016)
- SKIRT code for dust radiative transfer

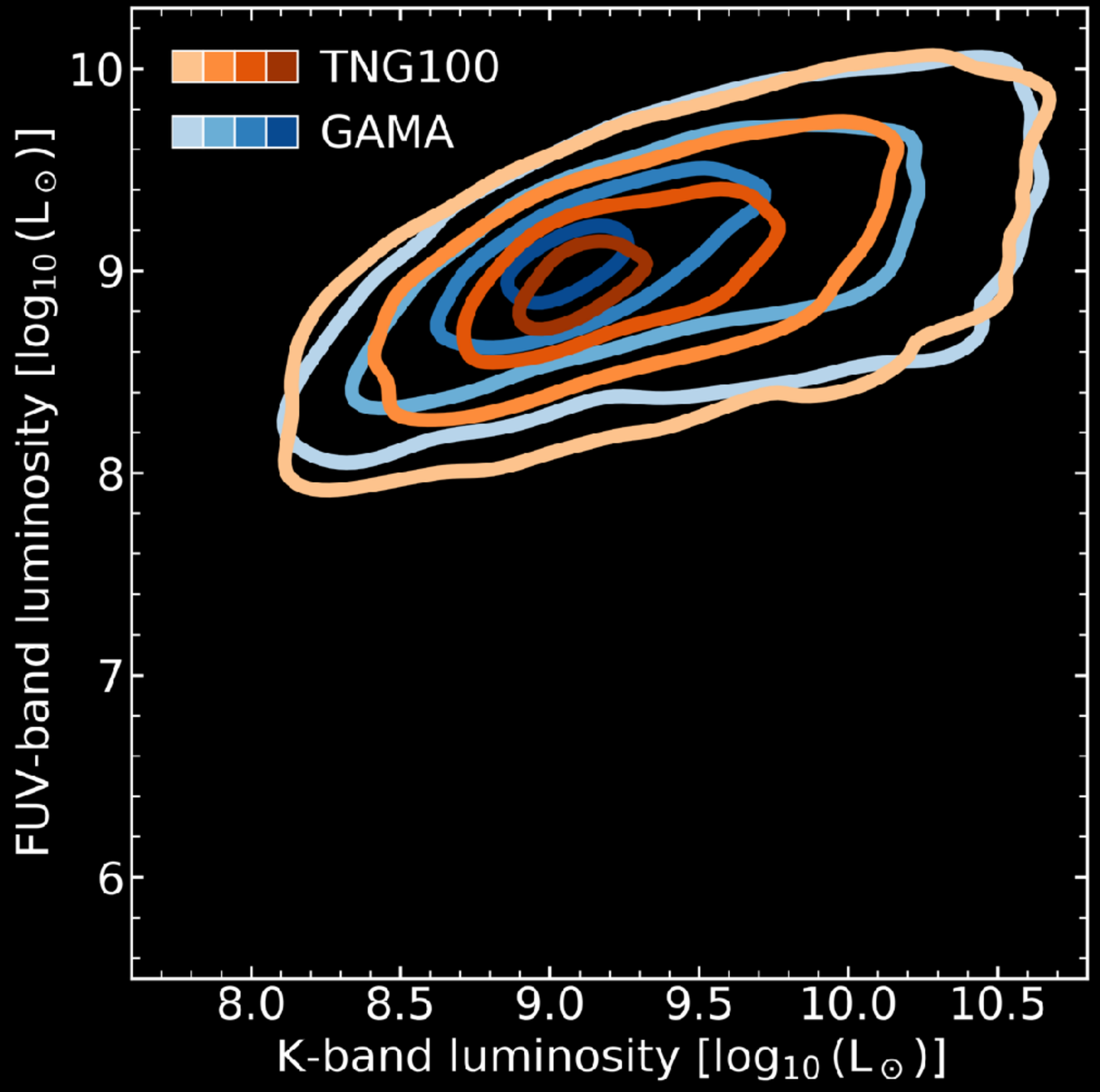


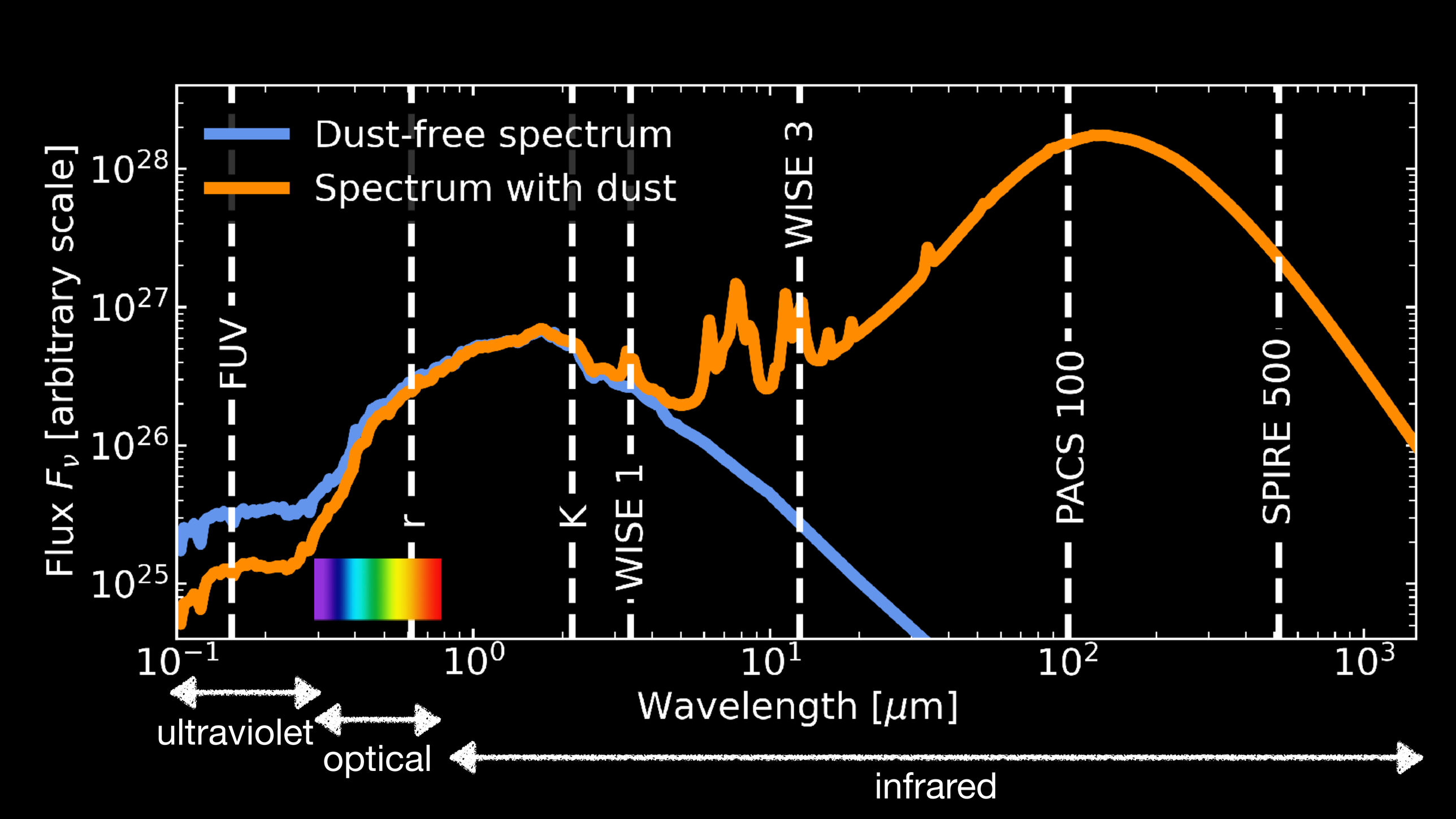

Dust-free spectrum
Spectrum with dust
FUV
K
Flux F_ν [arbitrary scale]
10^{28}
10^{27}
10^{26}
10^{25}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
Wavelength [μm]
ultraviolet
optical
infrared

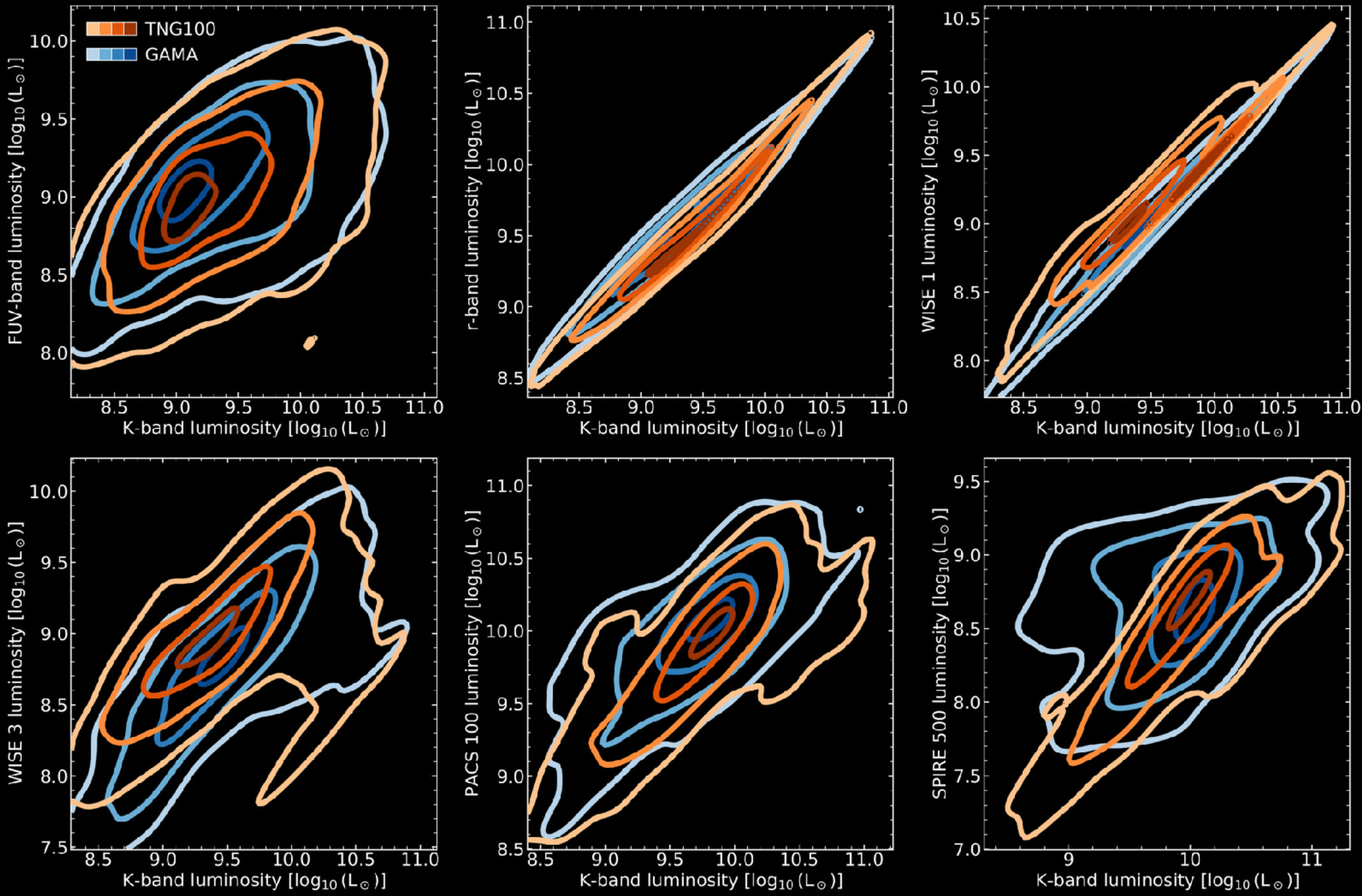

TNG100
FUV-band luminosity [log10(L⊙)]
K-band luminosity [log10(L⊙)]
10
9
8
7
6
8.0
8.5
9.0
9.5
10.0
10.5
How many new stars are formed per year?
How many stars are in the galaxy?
“Main sequence”
“Quiescent (calm) galaxies”


TNG100
10
9
8
7
6
FUV-band luminosity [log10 (L⊙)]
8.0
8.5
9.0
9.5
10.0
10.5
K-band luminosity [log10 (L⊙)]


TNG100
GAMA
10
9
8
7
6
FUV-band luminosity [log10 (L⊙)]
8.0
8.5
9.0
9.5
10.0
10.5
K-band luminosity [log10 (L⊙)]

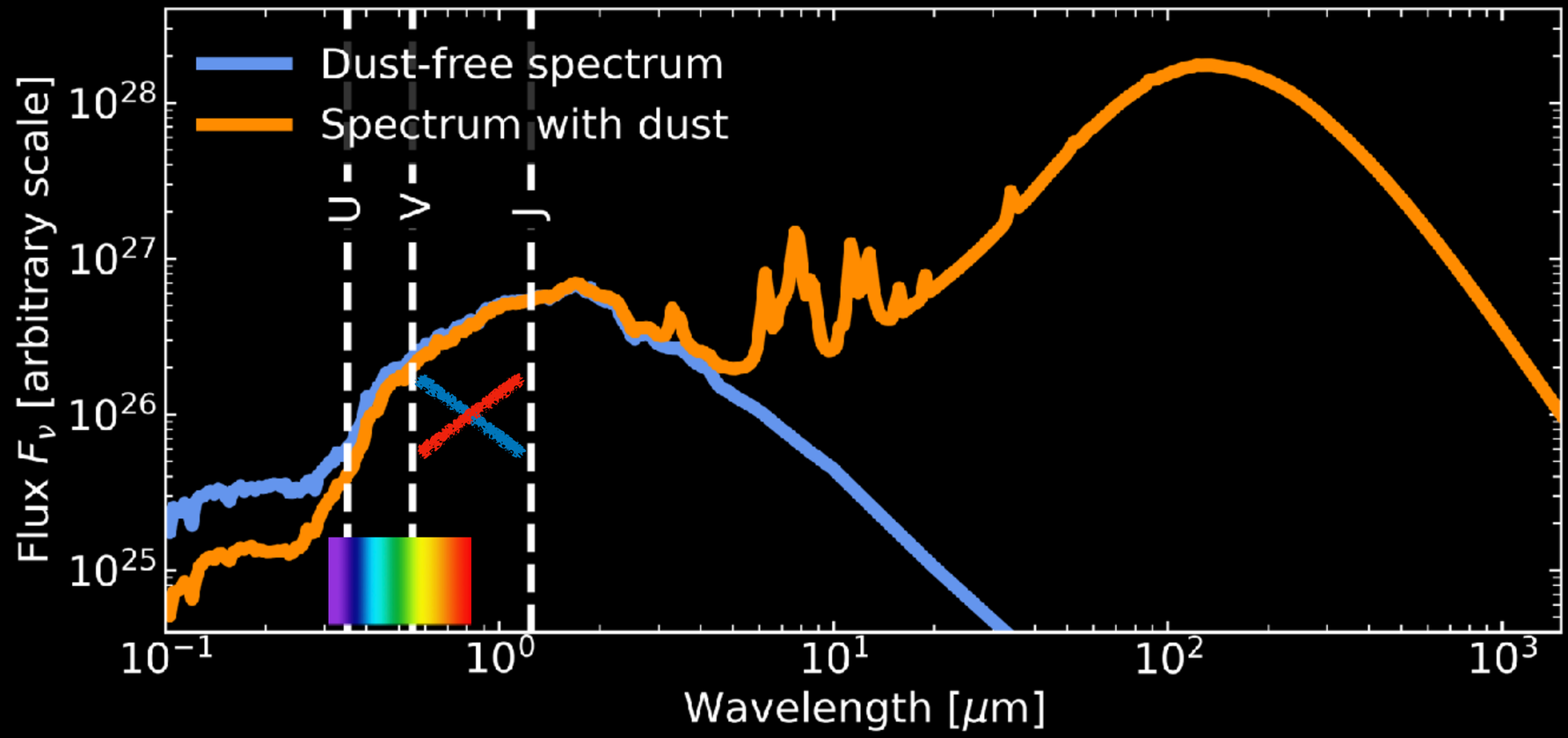

TNG100
GAMA
10
9
8
7
6
8.0
8.5
9.0
9.5
10.0
10.5
FUV-band luminosity [log10 (L⊙)]
K-band luminosity [log10 (L⊙)]

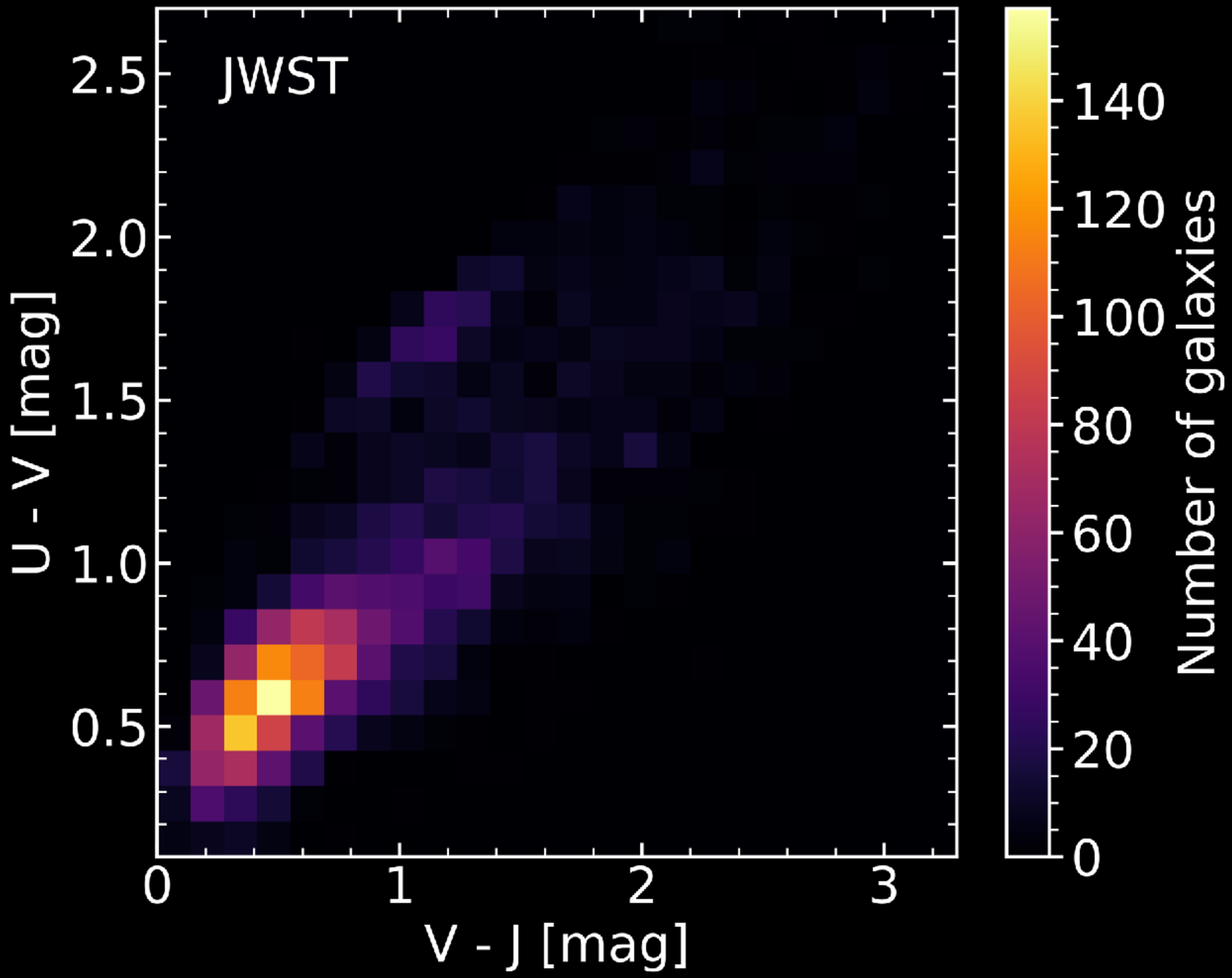

Dust-free spectrum
Spectrum with dust
Flux F_ν [arbitrary scale]
10^{28}
10^{27}
10^{26}
10^{25}
FUV
r
K
WISE 1
WISE 3
PACS 100
SPIRE 500
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
Wavelength [μm]
ultraviolet
optical
infrared

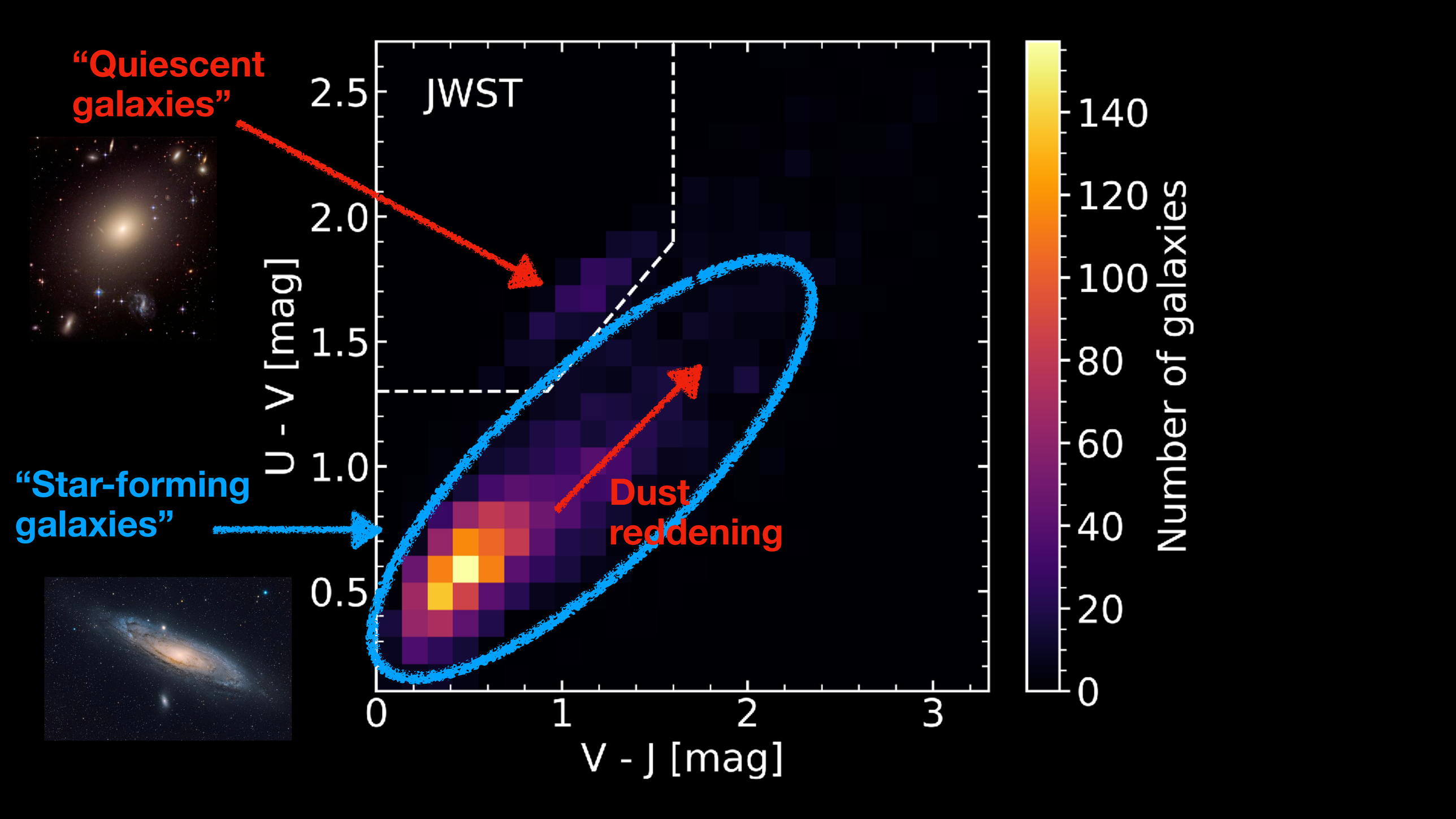

TNG100
GAMA
FUV-band luminosity [log10 (L⊙)]
r-band luminosity [log10 (L⊙)]
WISE 1 luminosity [log10 (L⊙)]
WISE 3 luminosity [log10 (L⊙)]
PACS 100 luminosity [log10 (L⊙)]
SPIRE 500 luminosity [log10 (L⊙)]
K-band luminosity [log10 (L⊙)]

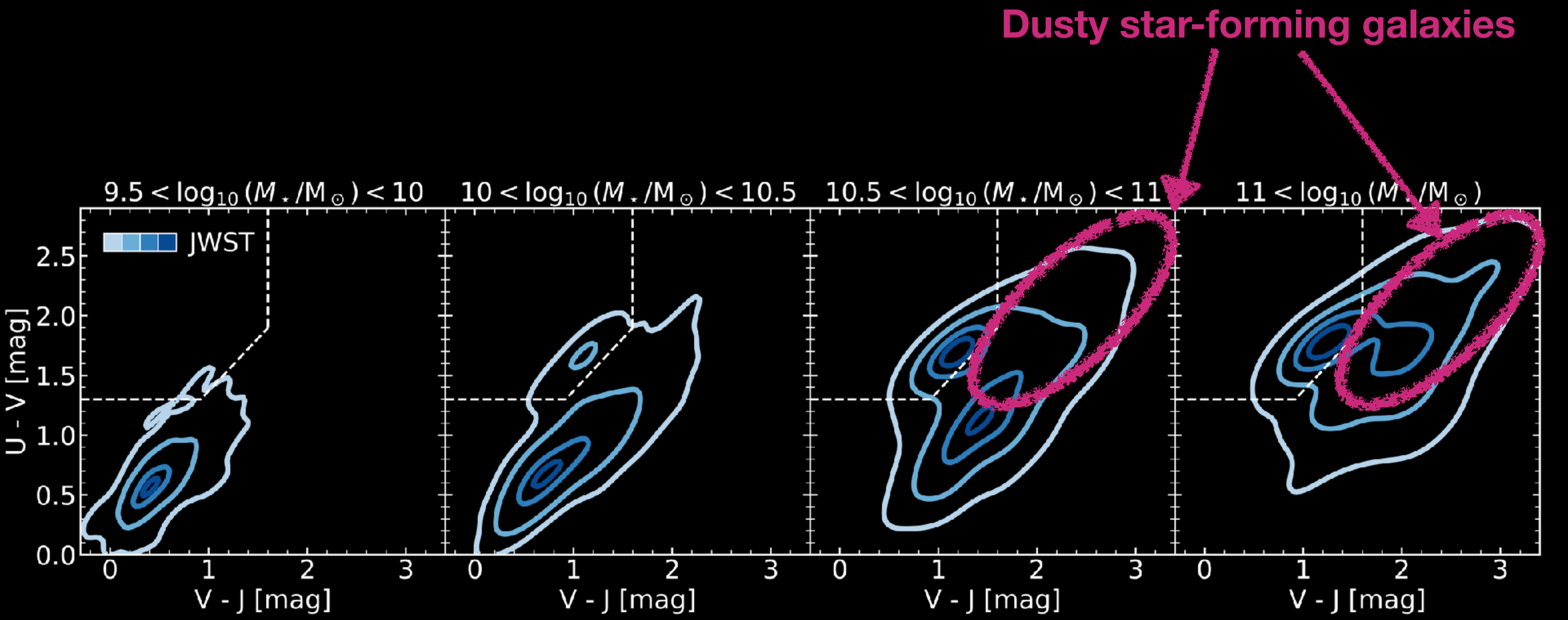
The reddest galaxies in the Universe

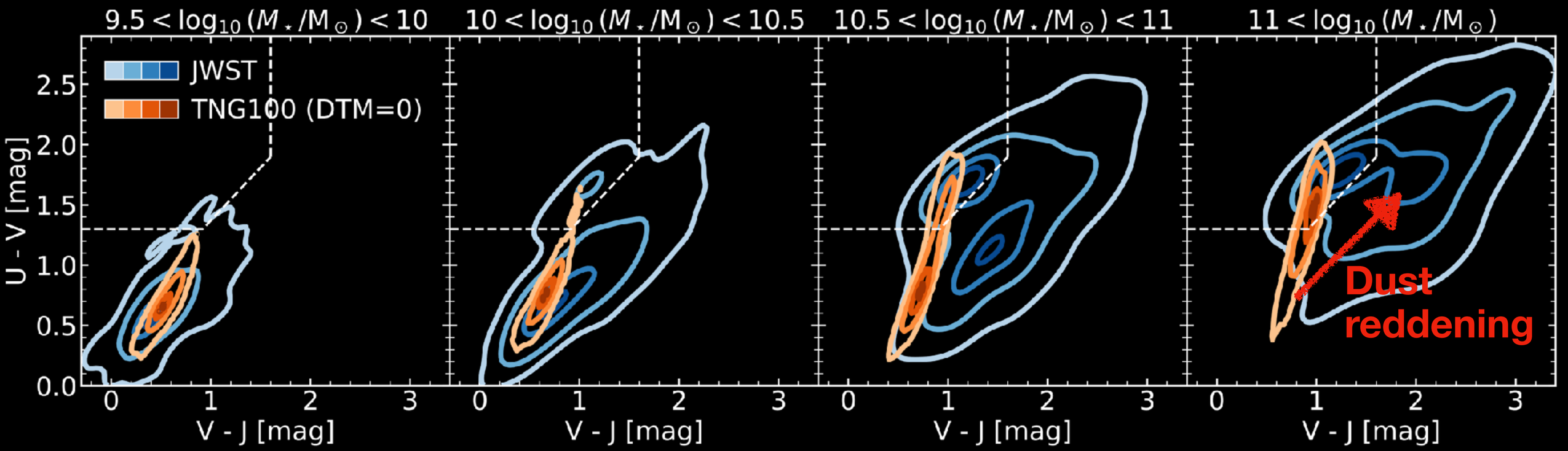
- Consider the UVJ diagram at redshift two
- Galaxy colors: slope of the spectrum

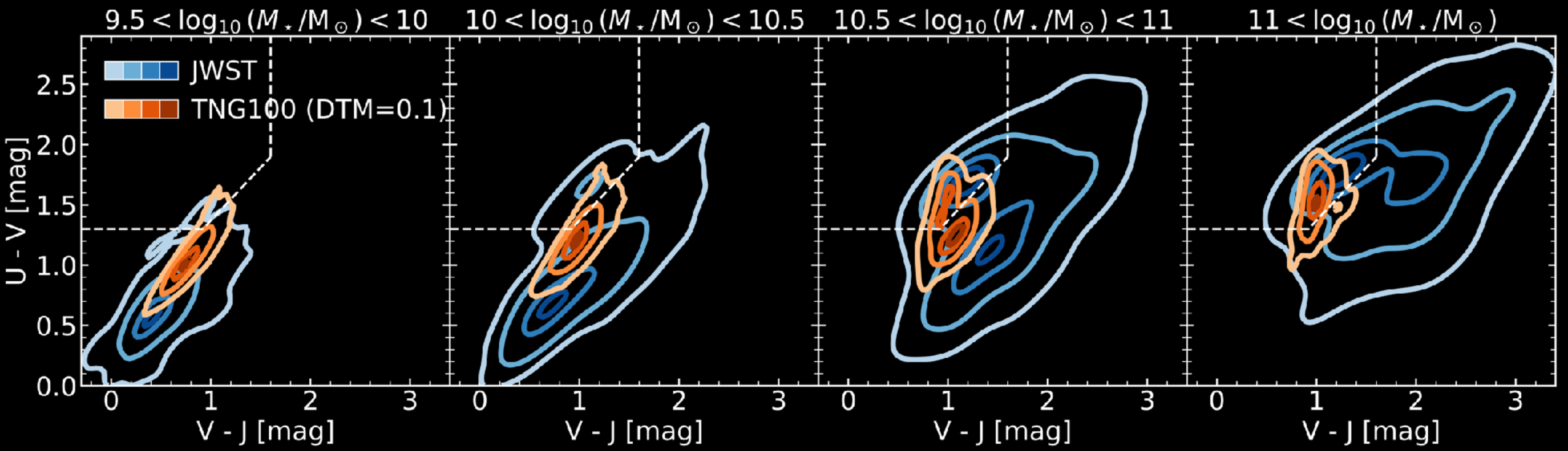


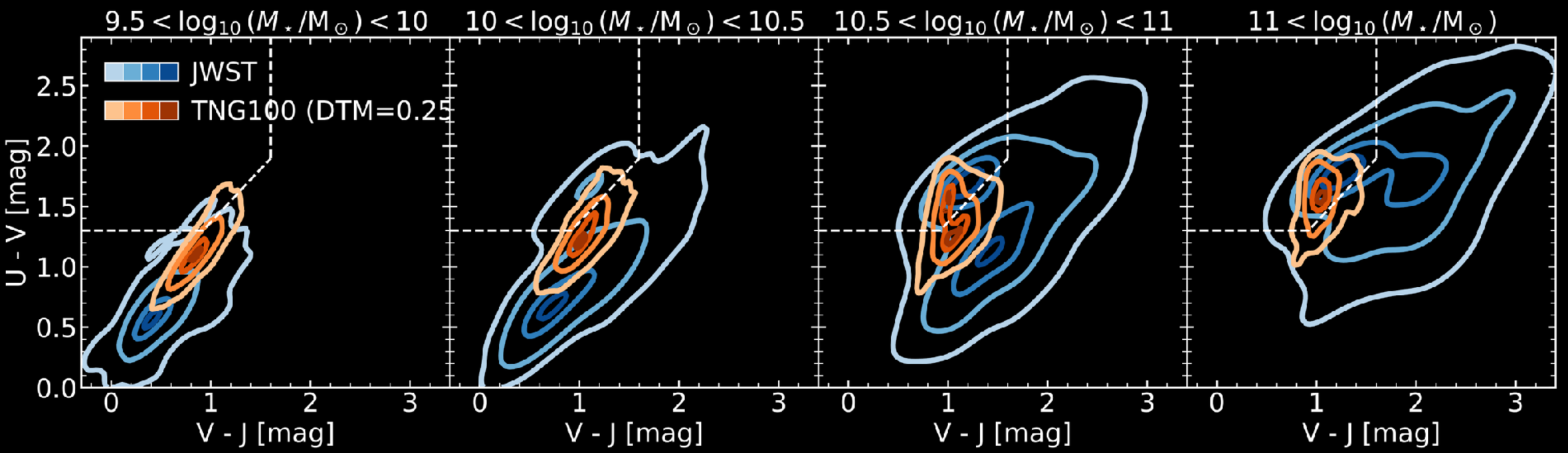

JWST
U - V [mag]
V - J [mag]
0
1
2
3
0.5
1.0
1.5
2.0
2.5
Number of galaxies
0
20
40
60
80
100
120
140

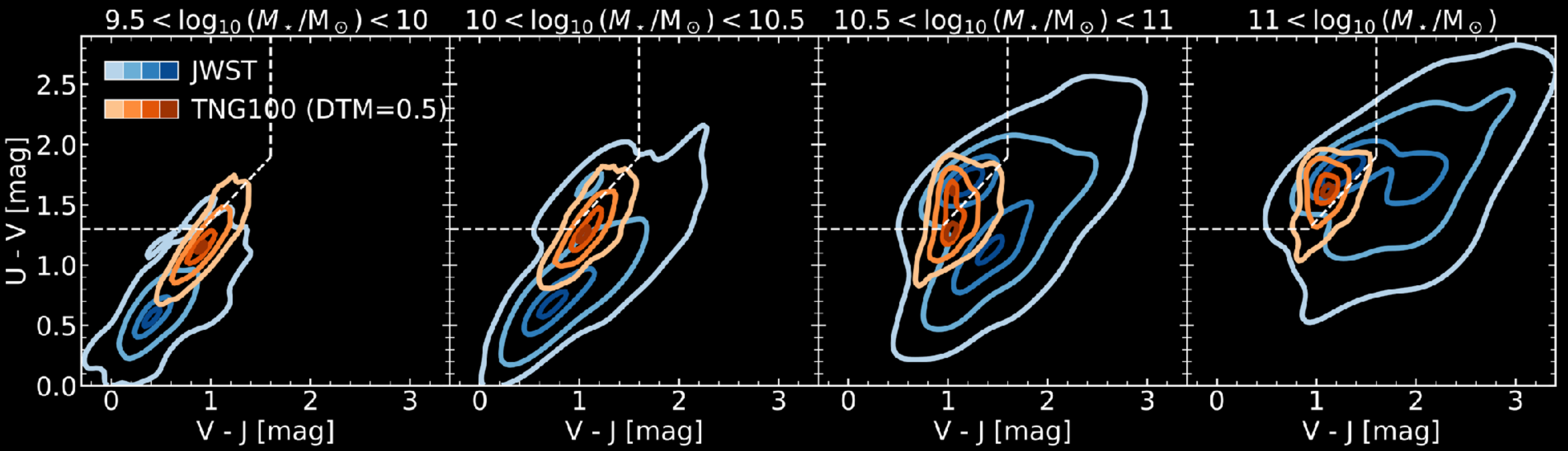

“Quiescent galaxies”
“Star-forming galaxies”
JWST
Dust reddening
U - V [mag]
V - J [mag]
Number of galaxies
0
0.5
1.0
1.5
2.0
2.5
0
1
2
3
0
20
40
60
80
100
120
140

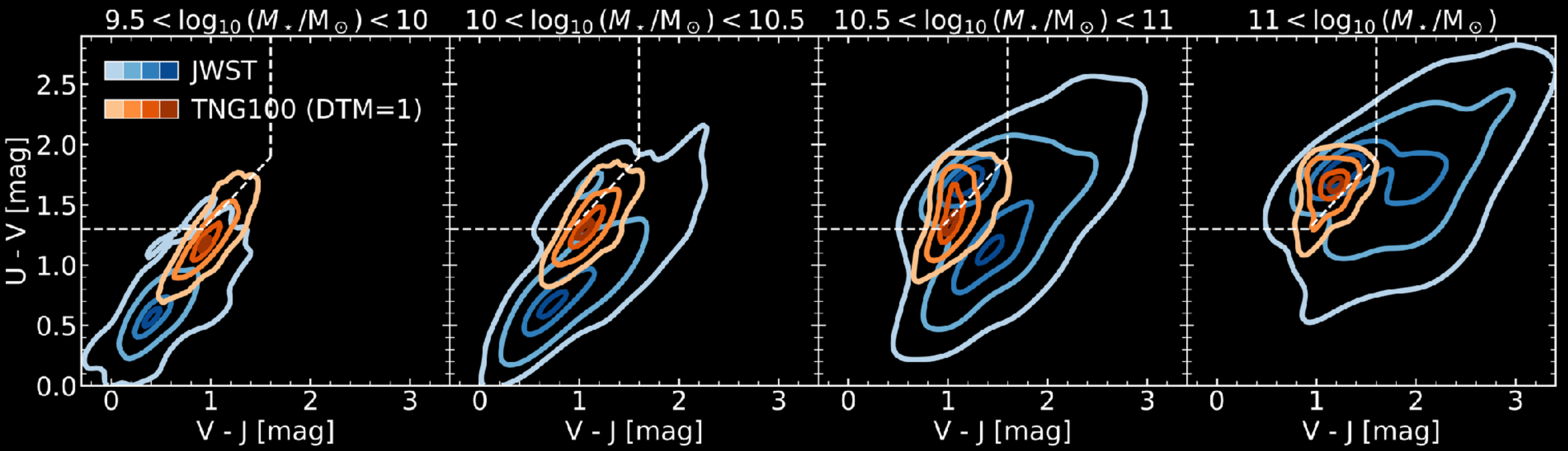

Dusty star-forming galaxies
$9.5 < \log_{10}(M_\star/\mathrm{M}_\odot) < 10$
$10 < \log_{10}(M_\star/\mathrm{M}_\odot) < 10.5$
$10.5 < \log_{10}(M_\star/\mathrm{M}_\odot) < 11$
$11 < \log_{10}(M_\star/\mathrm{M}_\odot)$
JWST
U - V [mag]
V - J [mag]
0.0
0.5
1.0
1.5
2.0
2.5
0
1
2
3


$9.5 < \log_{10}(M_\star/\mathrm{M}_\odot) < 10$
$10 < \log_{10}(M_\star/\mathrm{M}_\odot) < 10.5$
$10.5 < \log_{10}(M_\star/\mathrm{M}_\odot) < 11$
$11 < \log_{10}(M_\star/\mathrm{M}_\odot)$
JWST
TNG100 (DTM=0)
U - V [mag]
V - J [mag]
Dust reddening

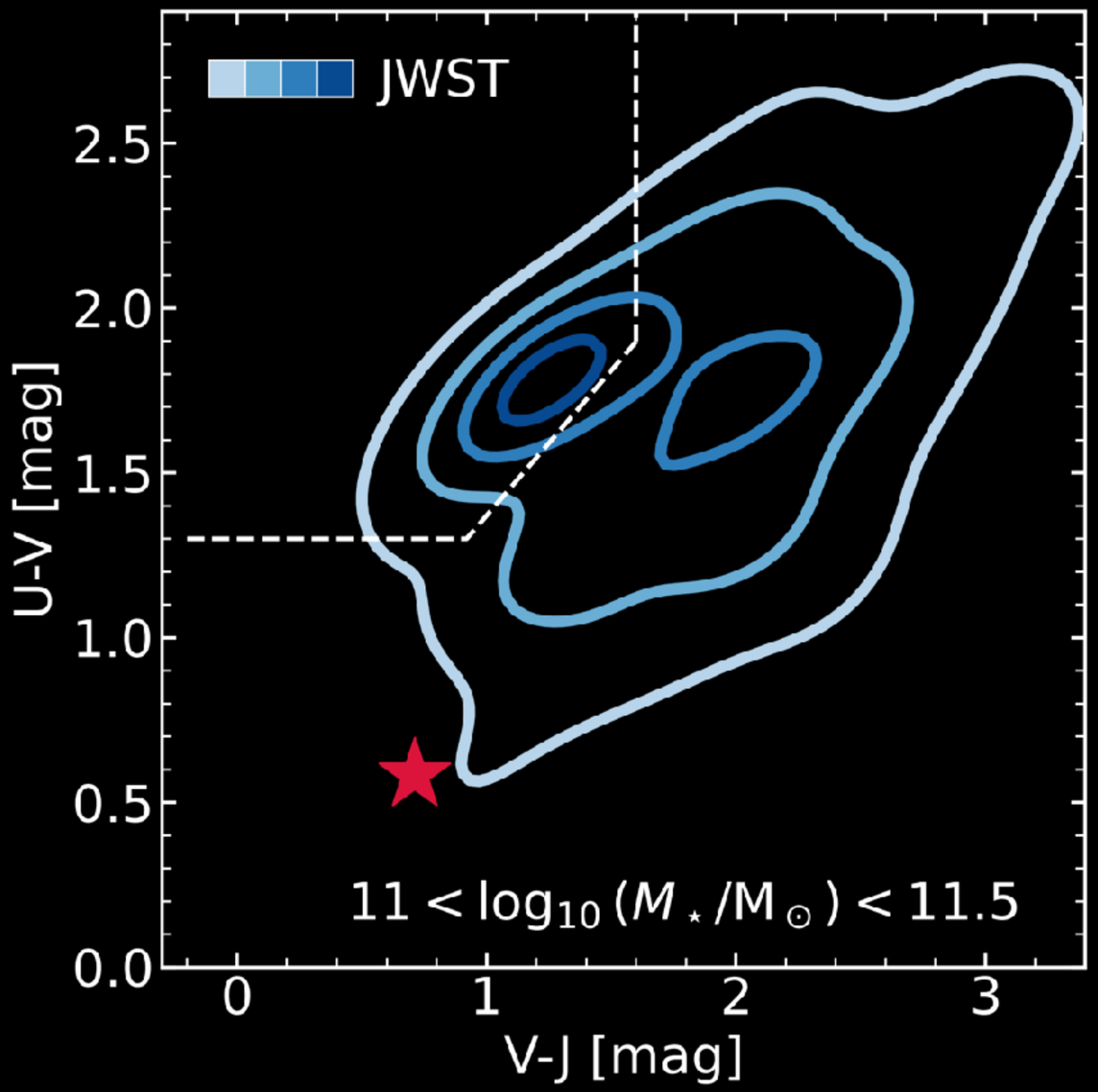

$9.5 < \log_{10}(M_\star/\mathrm{M}_\odot) < 10$
$10 < \log_{10}(M_\star/\mathrm{M}_\odot) < 10.5$
$10.5 < \log_{10}(M_\star/\mathrm{M}_\odot) < 11$
$11 < \log_{10}(M_\star/\mathrm{M}_\odot)$
JWST
TNG100 (DTM=0.1)
U - V [mag]
V - J [mag]
0.0
0.5
1.0
1.5
2.0
2.5
0
1
2
3


$9.5 < \log_{10}(M_\star/\mathrm{M}_\odot) < 10$
$10 < \log_{10}(M_\star/\mathrm{M}_\odot) < 10.5$
$10.5 < \log_{10}(M_\star/\mathrm{M}_\odot) < 11$
$11 < \log_{10}(M_\star/\mathrm{M}_\odot)$
JWST
TNG100 (DTM=0.25
U - V [mag]
V - J [mag]
0.0
0.5
1.0
1.5
2.0
2.5
0
1
2
3

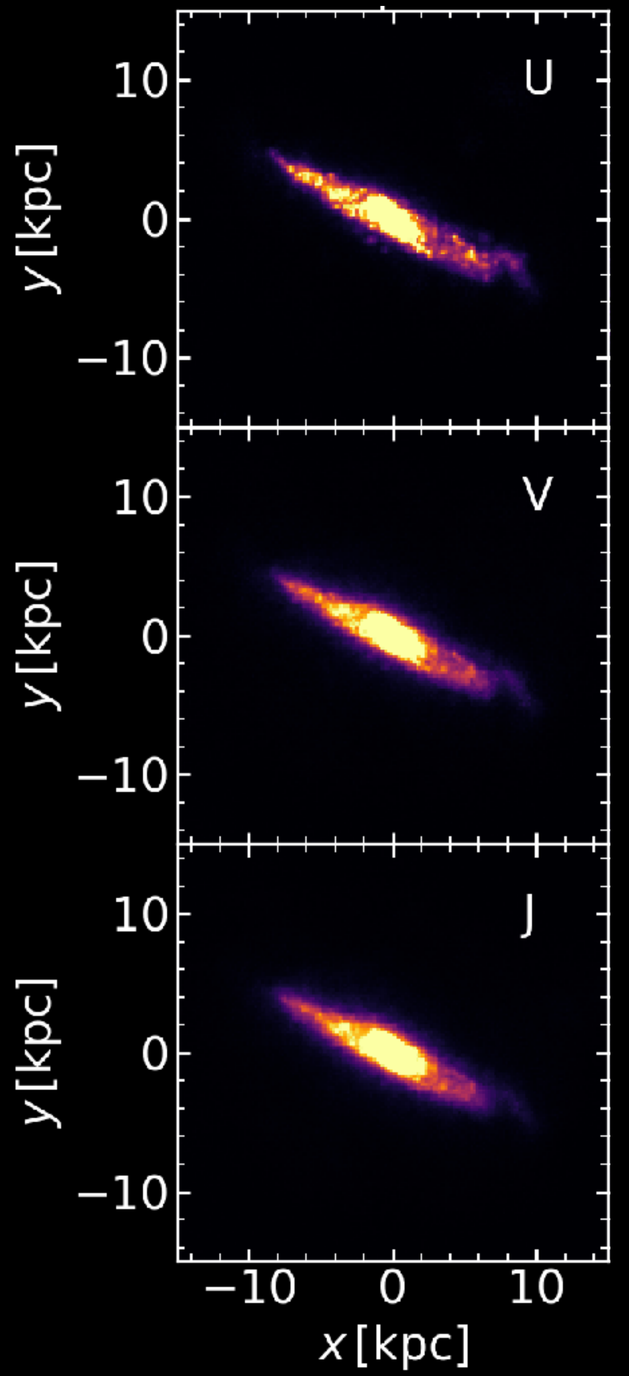

$9.5 < \log_{10}(M_\star/\mathrm{M}_\odot) < 10$
$10 < \log_{10}(M_\star/\mathrm{M}_\odot) < 10.5$
$10.5 < \log_{10}(M_\star/\mathrm{M}_\odot) < 11$
$11 < \log_{10}(M_\star/\mathrm{M}_\odot)$
JWST
TNG100 (DTM=0.5)
U - V [mag]
V - J [mag]
0.0
0.5
1.0
1.5
2.0
2.5
0
1
2
3


$9.5 < \log_{10}(M_\star/\mathrm{M}_\odot) < 10$
$10 < \log_{10}(M_\star/\mathrm{M}_\odot) < 10.5$
$10.5 < \log_{10}(M_\star/\mathrm{M}_\odot) < 11$
$11 < \log_{10}(M_\star/\mathrm{M}_\odot)$
JWST
TNG100 (DTM=1)
U - V [mag]
V - J [mag]
0.0
0.5
1.0
1.5
2.0
2.5
0
1
2
3

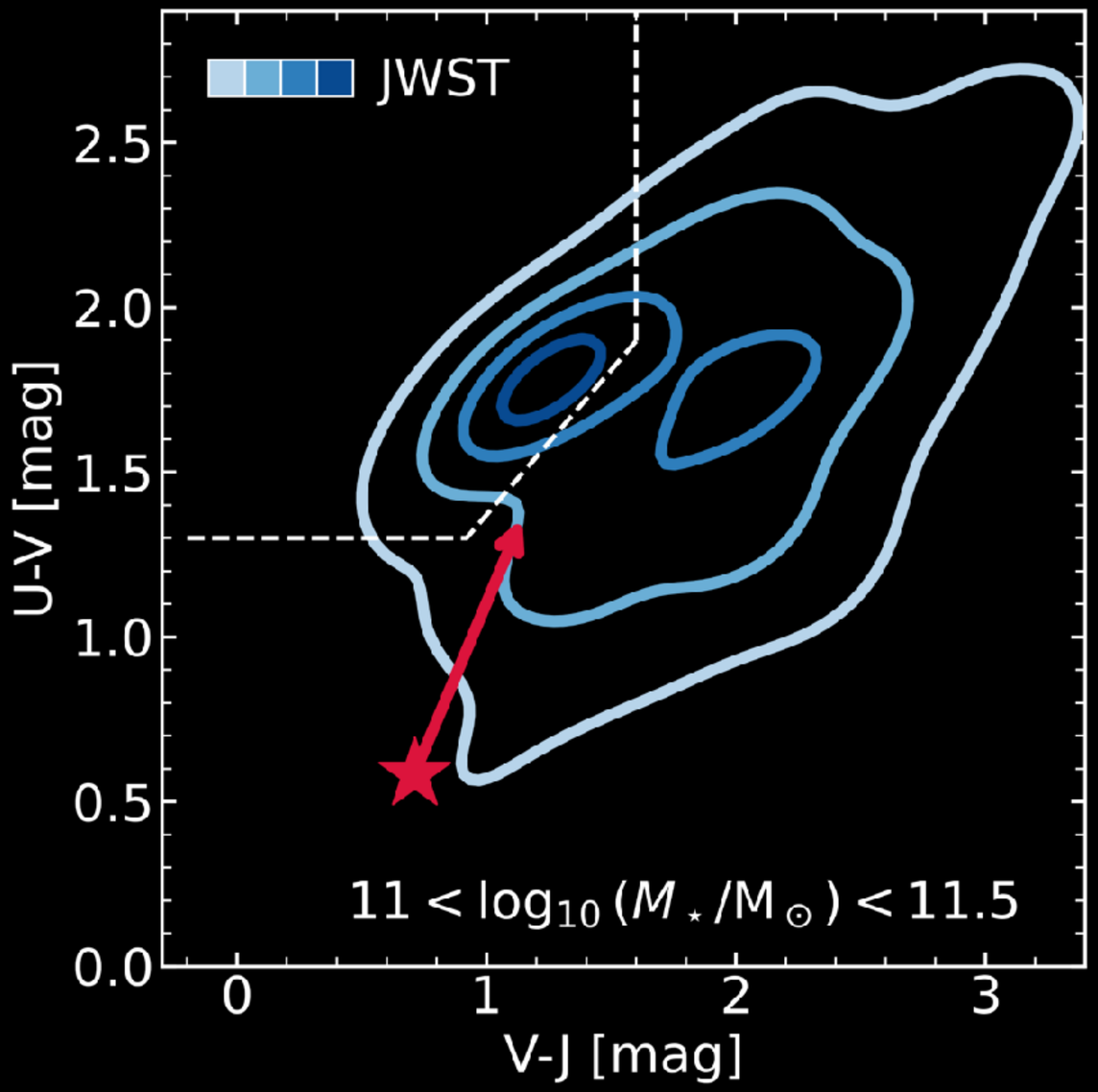
No dust

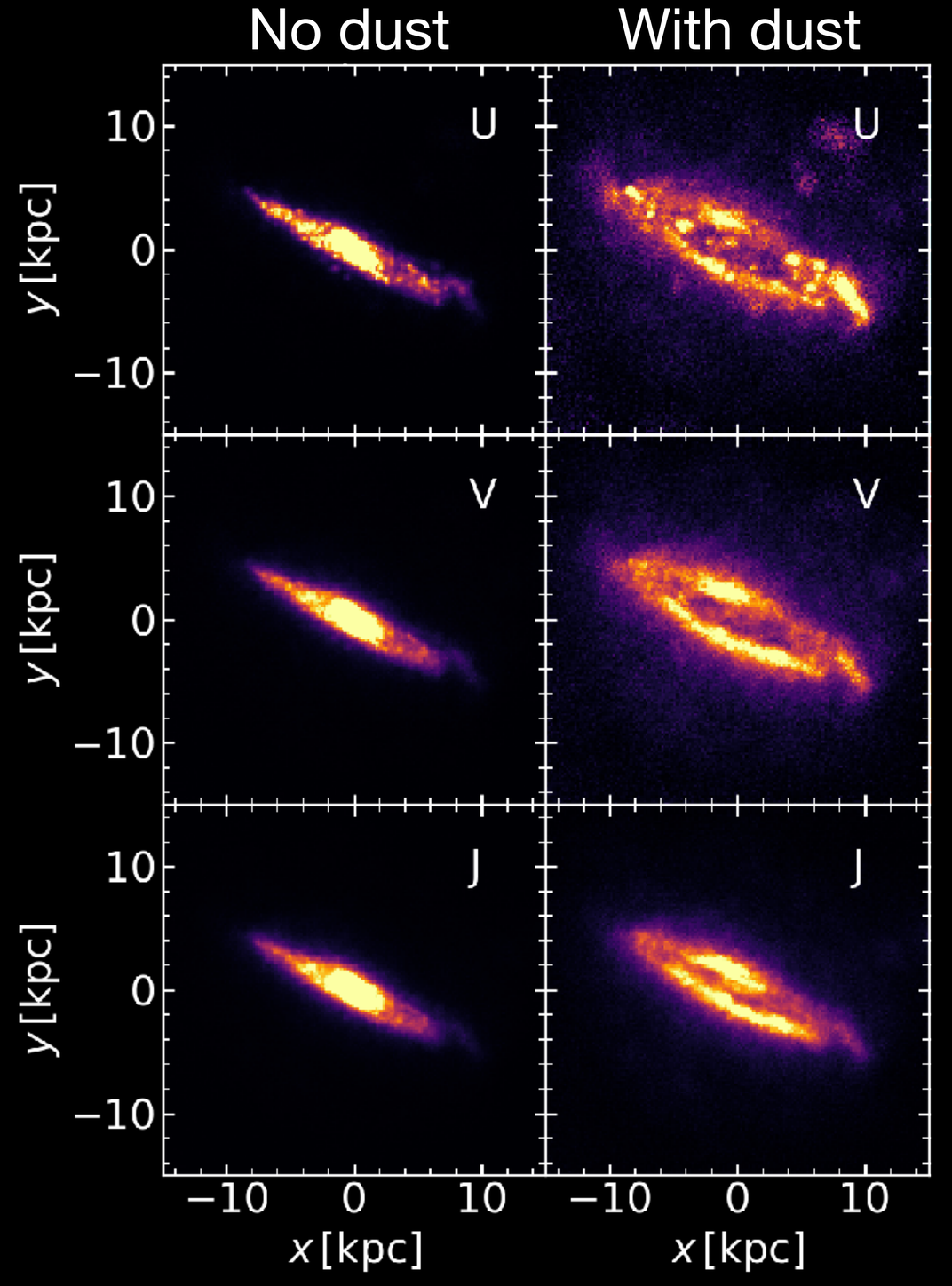


No dust

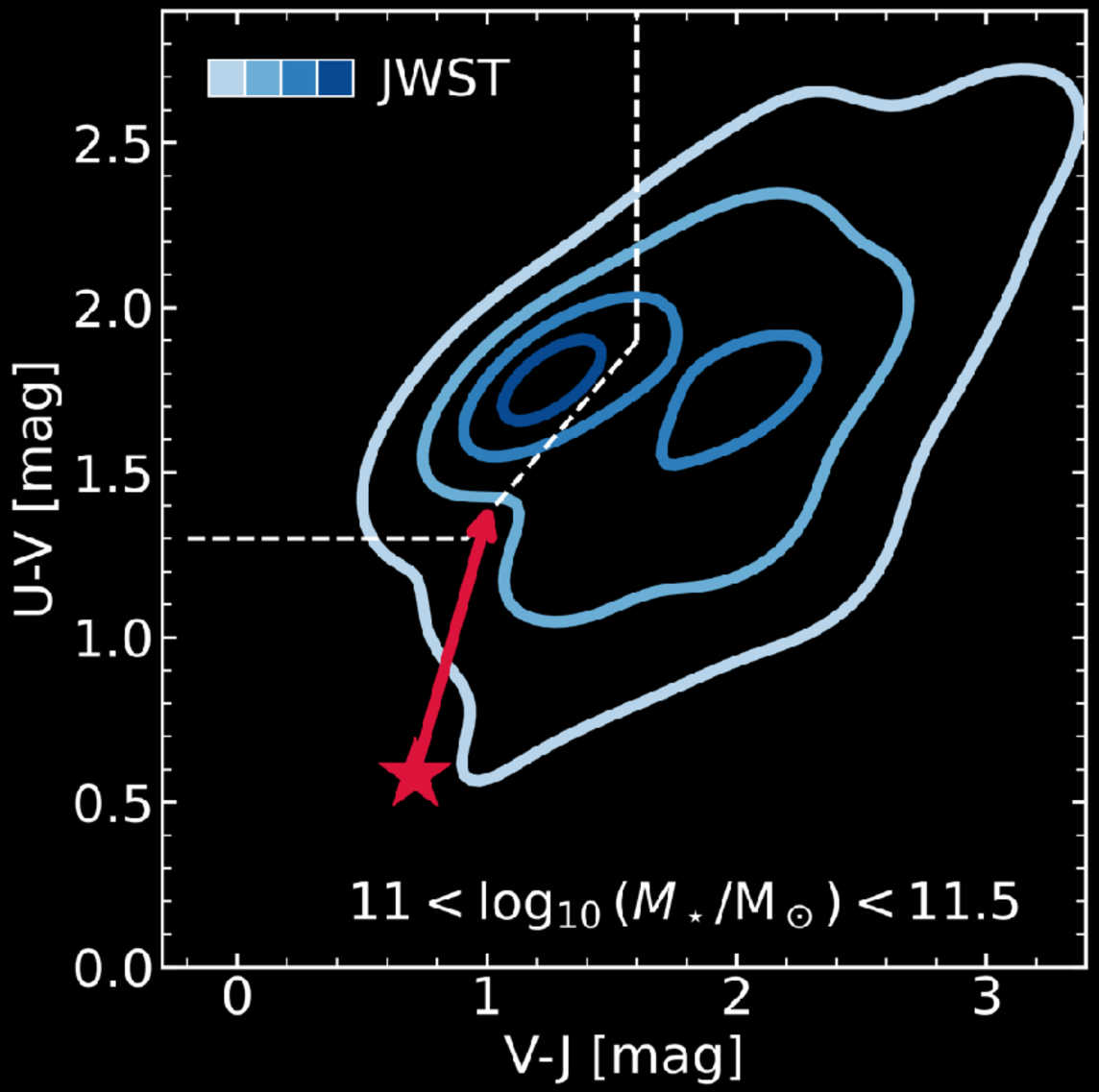


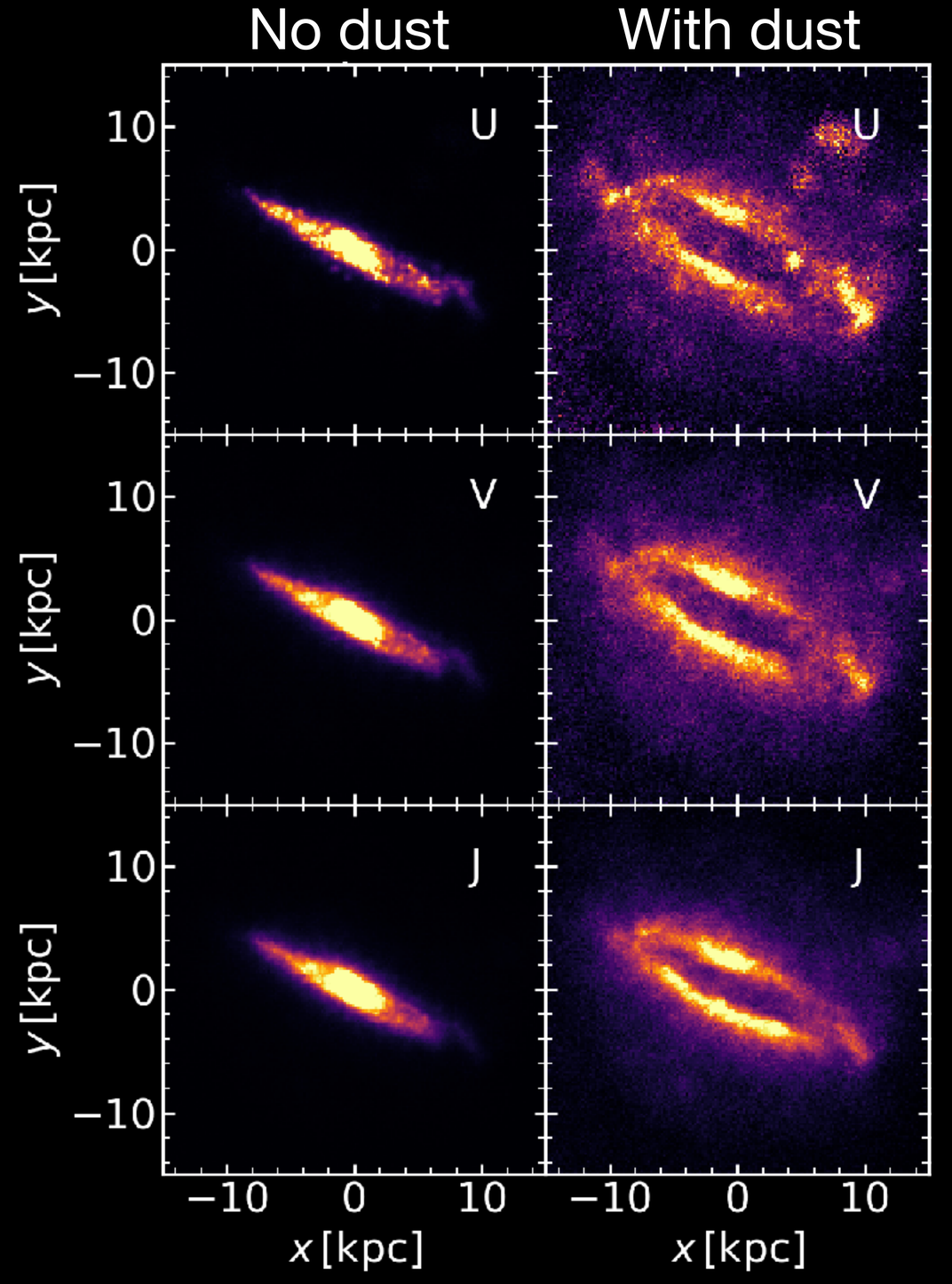
Dust-to-metal ratio 10%

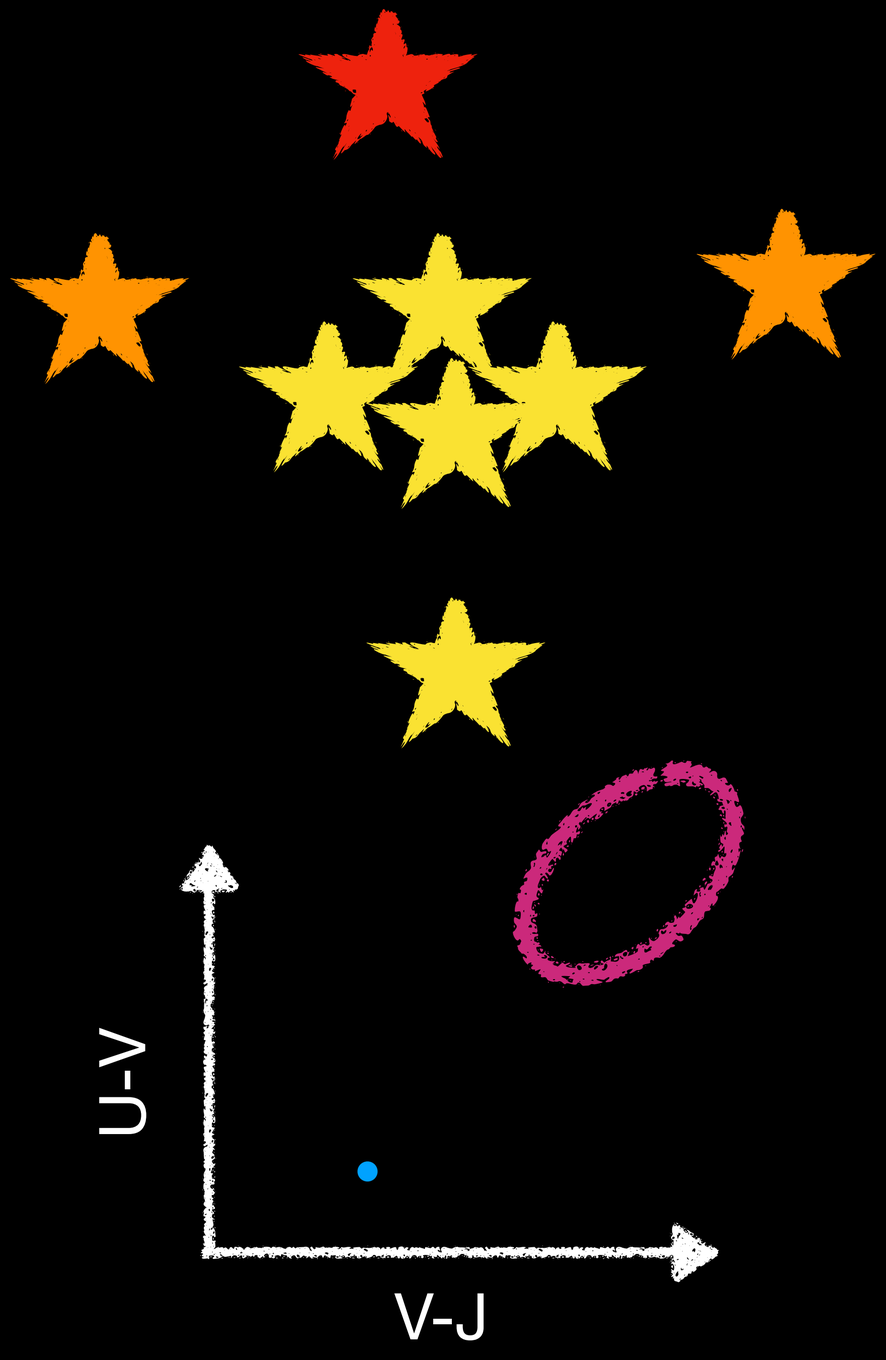




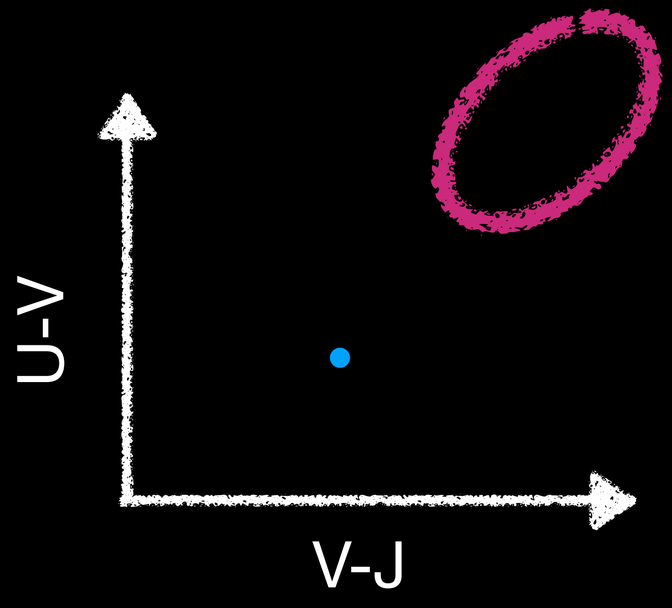
Dust-to-metal ratio 50%



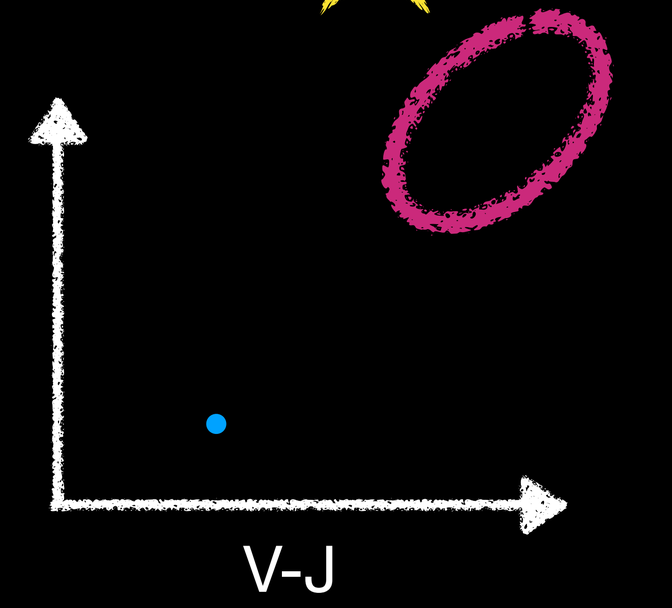


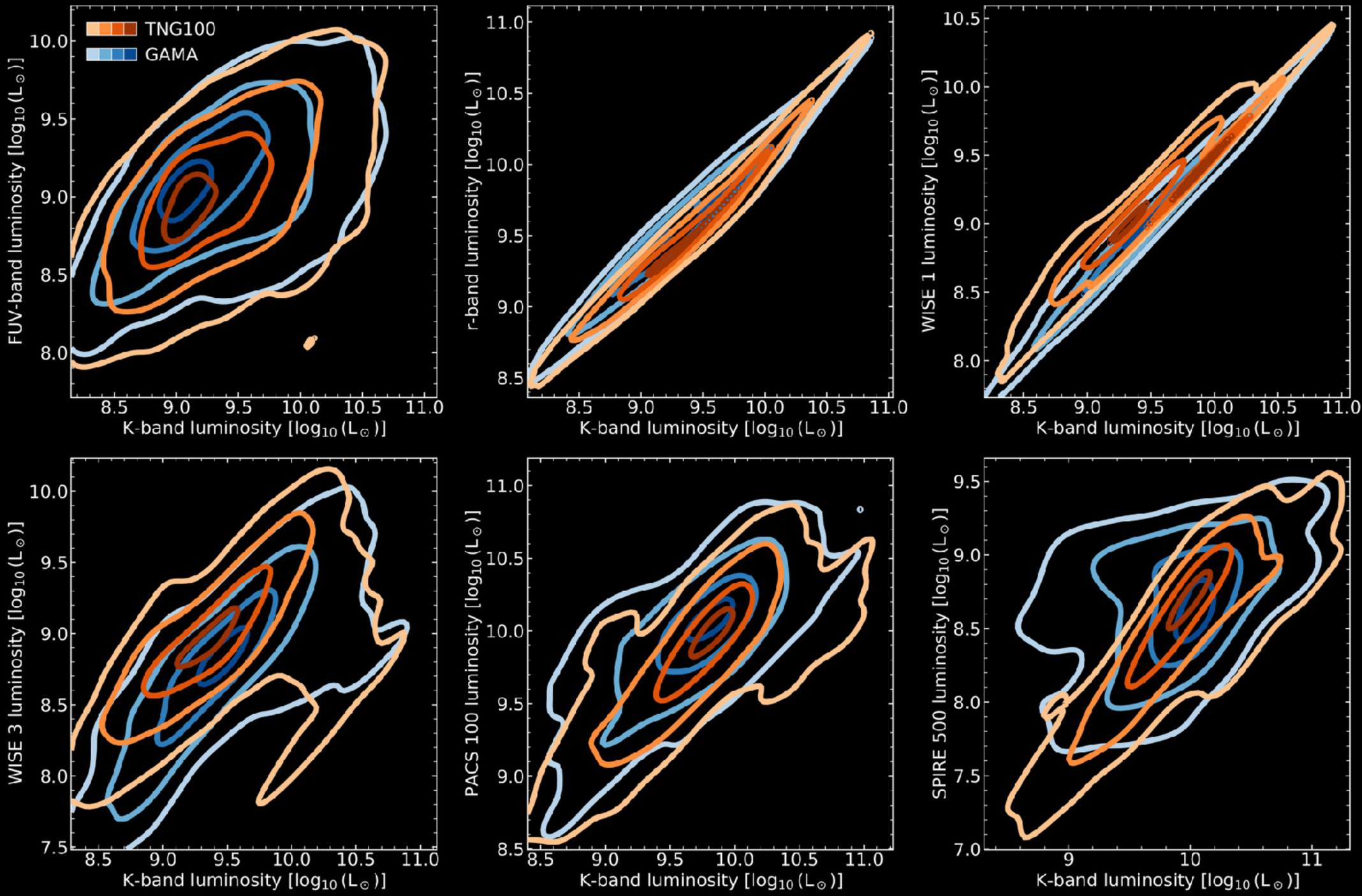

U-V
V-J



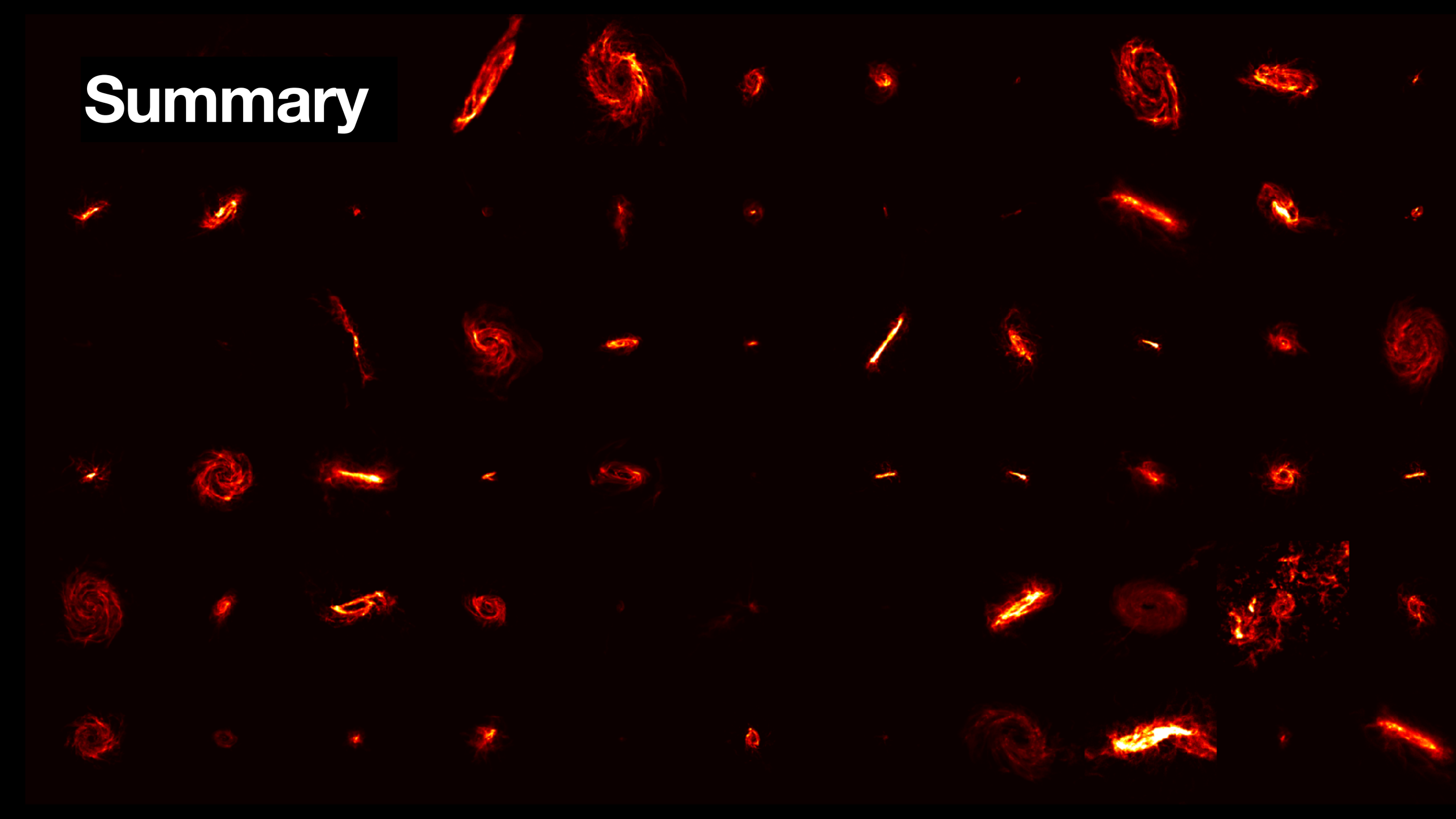

U-V
V-J



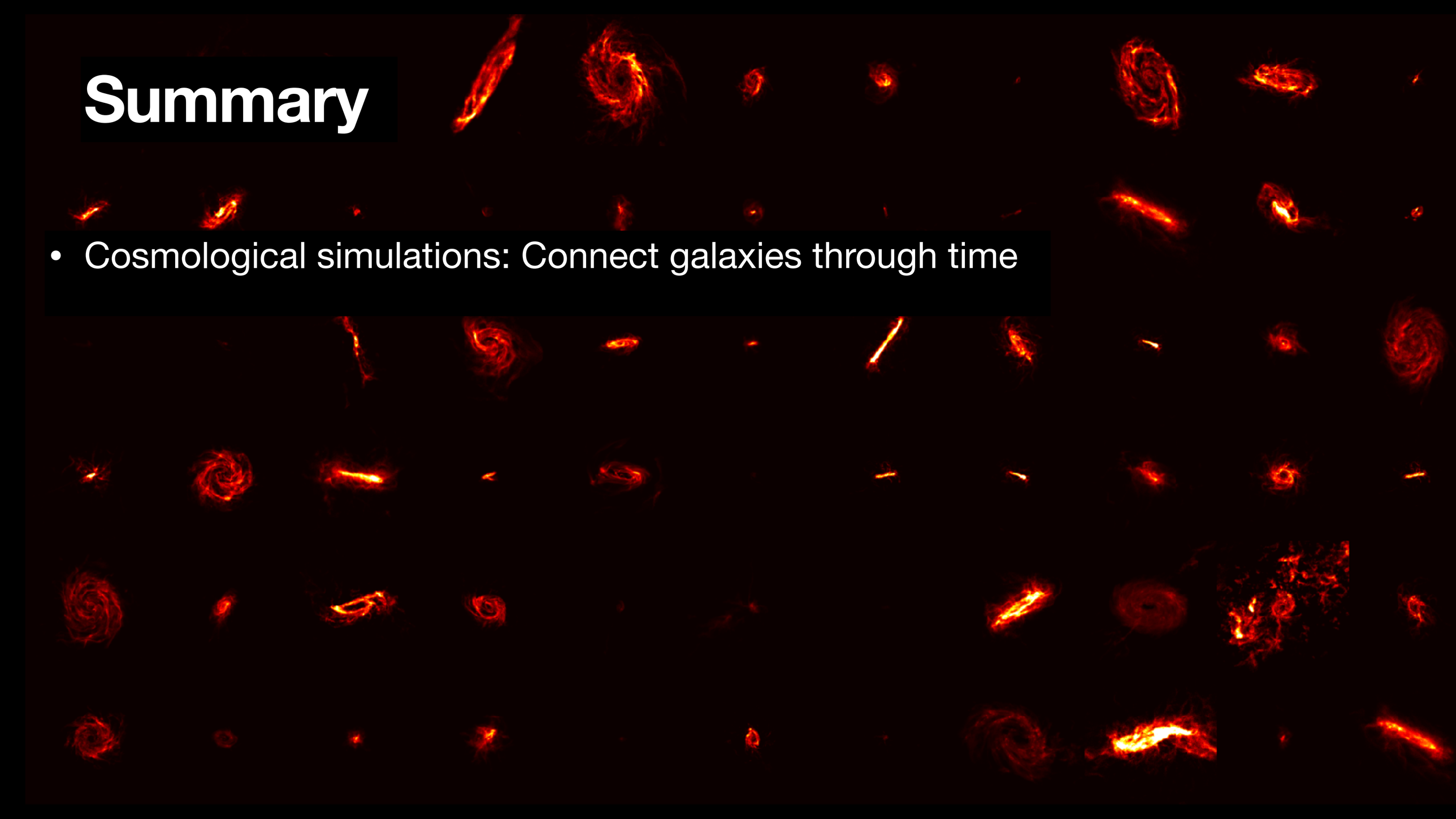

U-V
V-J


TNG100
GAMA
FUV-band luminosity [log10 (L⊙)]
r-band luminosity [log10 (L⊙)]
WISE 1 luminosity [log10 (L⊙)]
WISE 3 luminosity [log10 (L⊙)]
PACS 100 luminosity [log10 (L⊙)]
SPIRE 500 luminosity [log10 (L⊙)]
K-band luminosity [log10 (L⊙)]

Summary



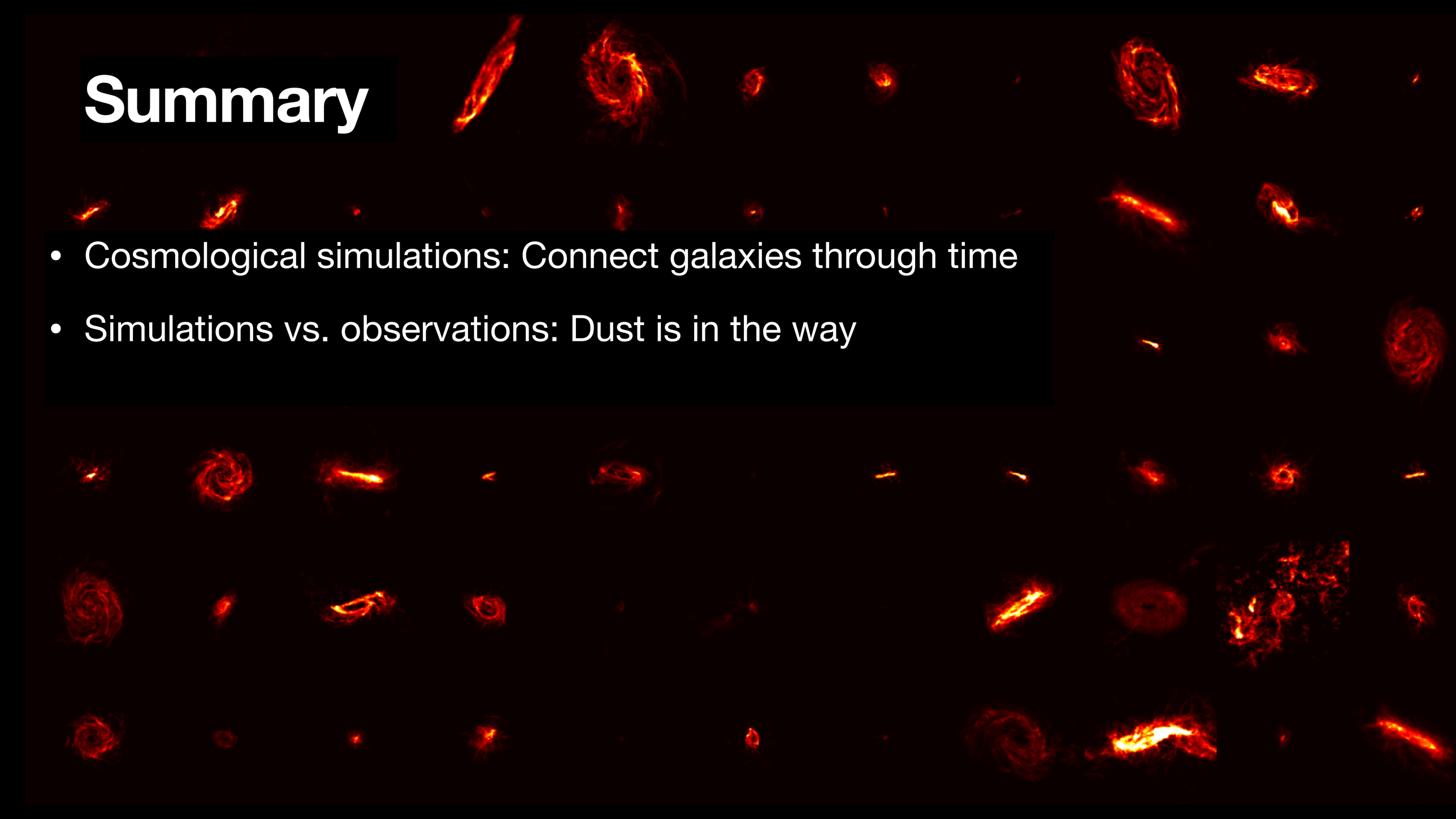
Summary



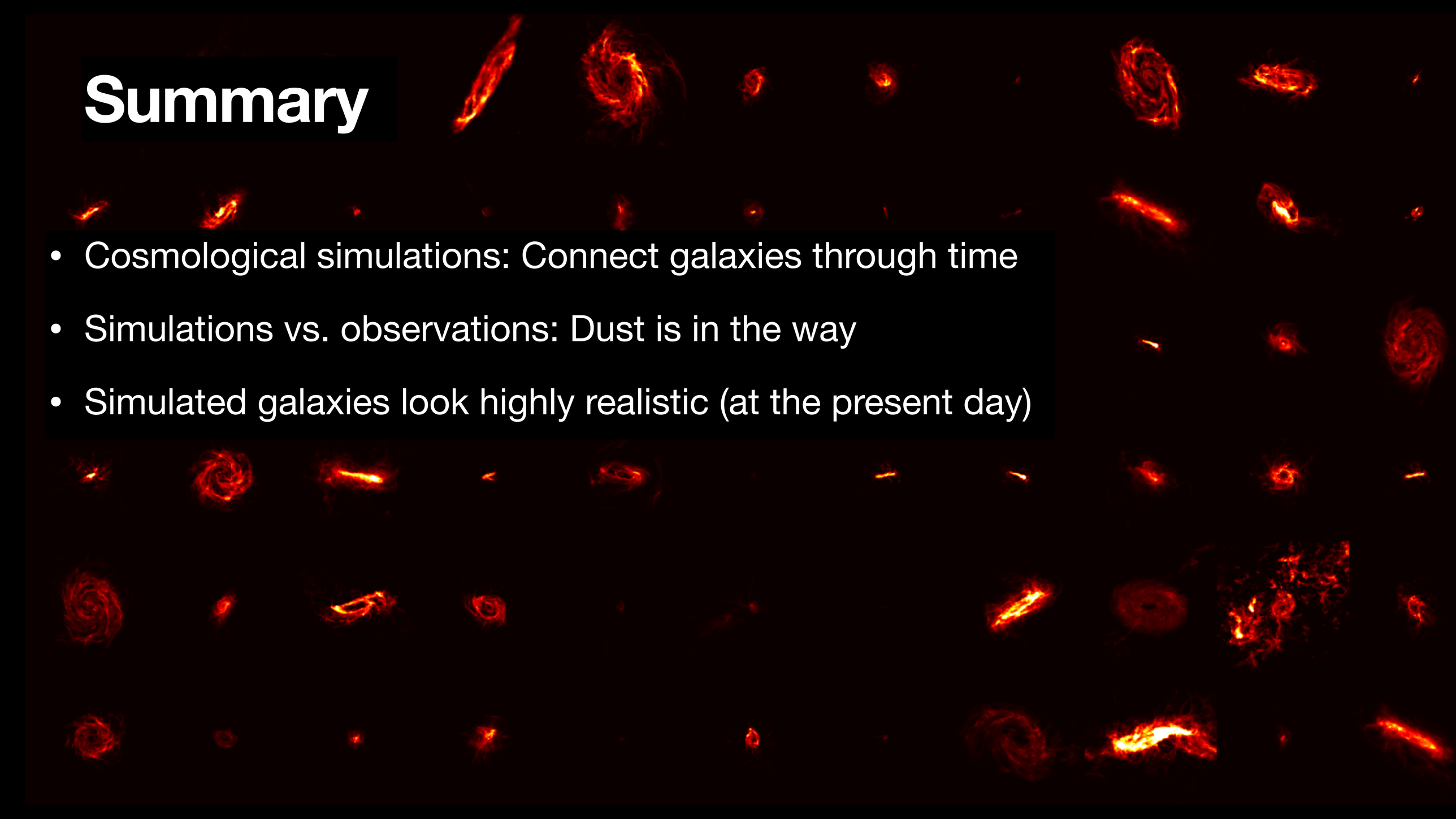
- Cosmological simulations: Connect galaxies through time

Summary

- Cosmological simulations: Connect galaxies through time
- Simulations vs. observations: Dust is in the way

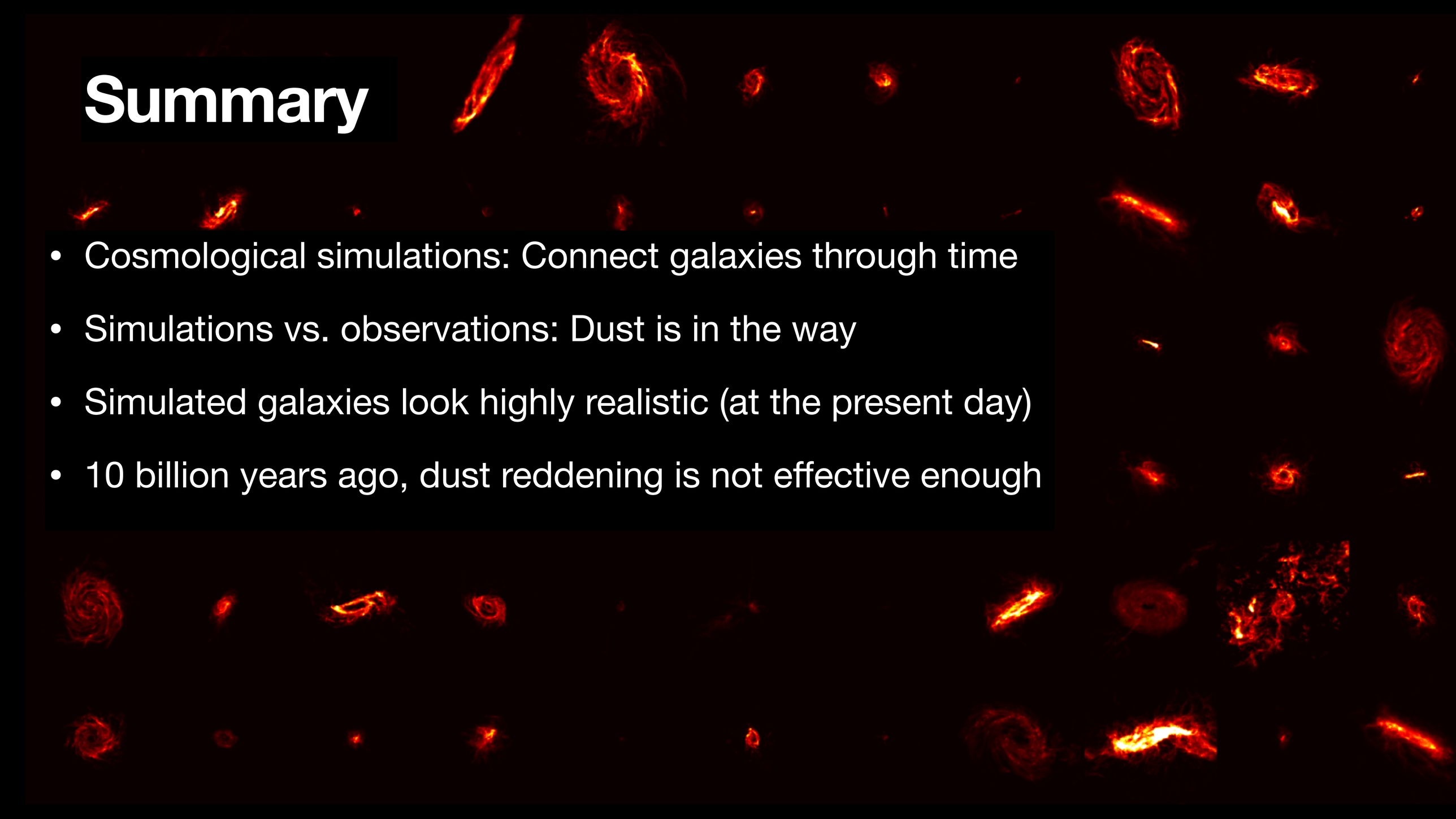


Summary



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- 10 billion years ago, dust reddening is not effective enough