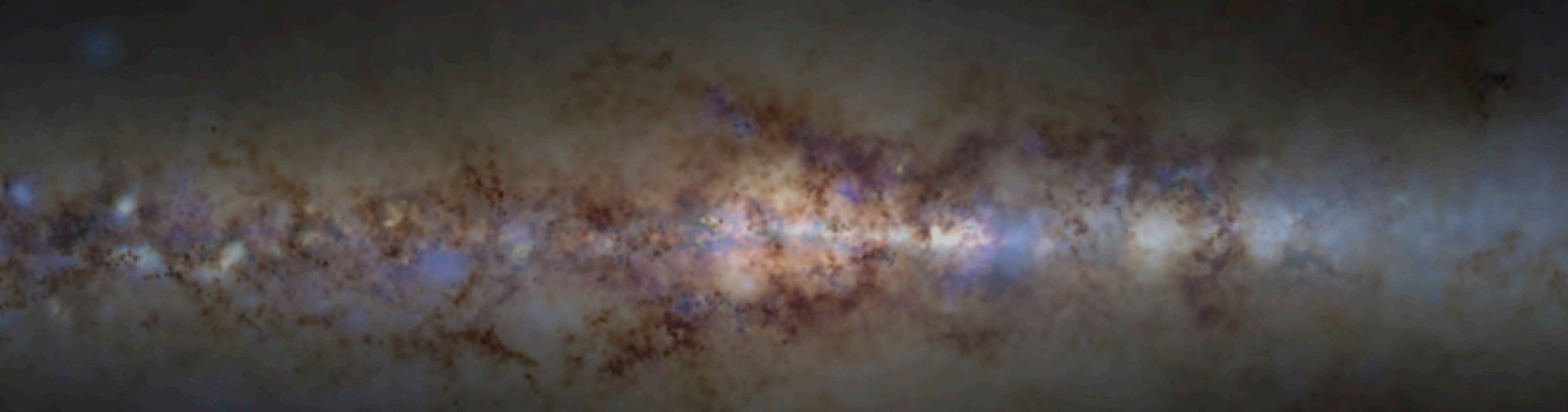
Simulating nuclear fueling in realistic environments

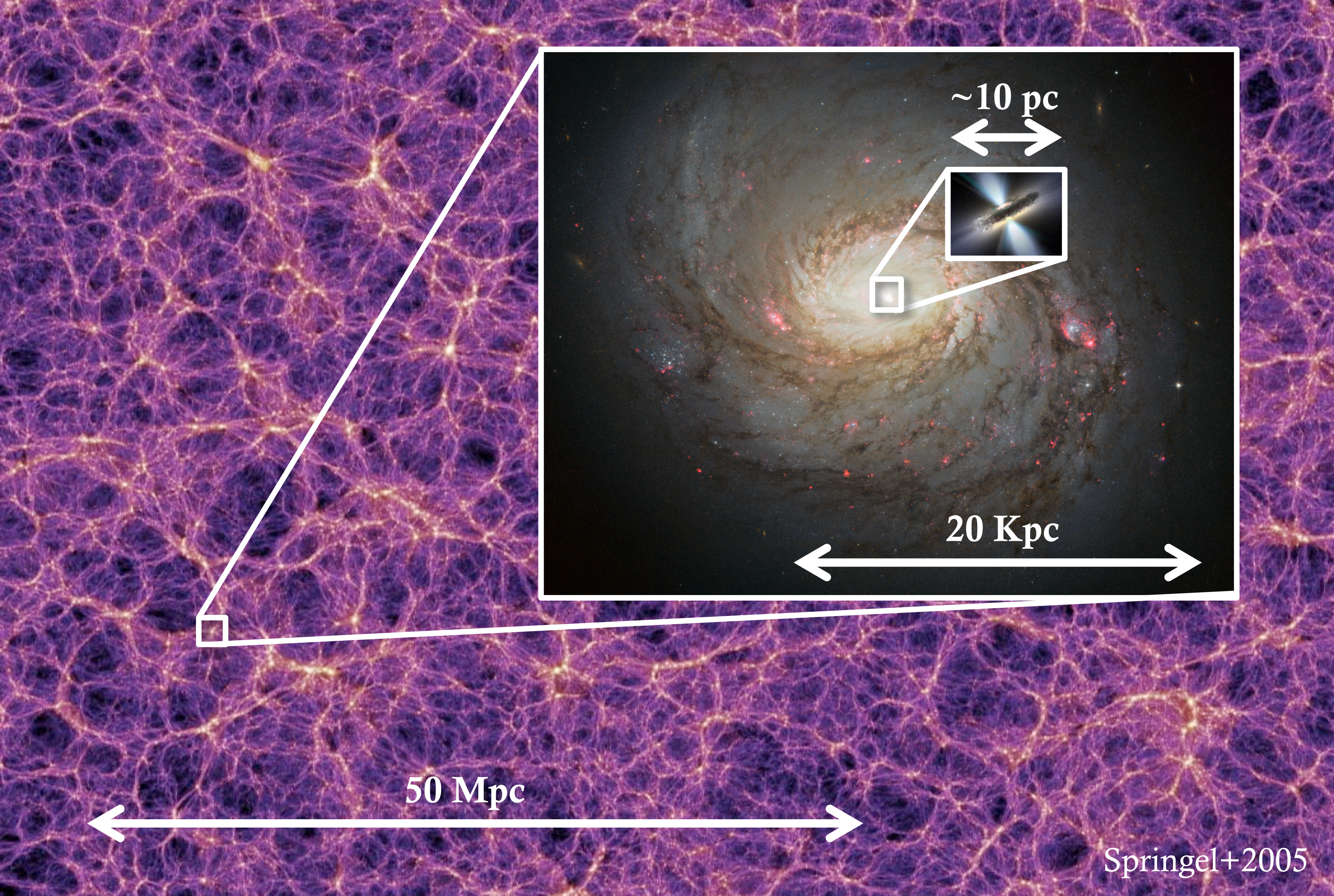


Daniel Anglés-Alcázar
Center for Computational Astrophysics
Flatiron Institute, New York City

G. Bryan, R. Davé, C.-A. Faucher-Giguère, R. Feldmann, C. Hayward, P. Hopkins,
D. Keres, N. Murray, E. Quataert, R. Somerville, P. Torrey, A. Wetzel, …

TORUS 2018: The many faces of the AGN obscuration, Puerto Varas, Chile, December 13th, 2018

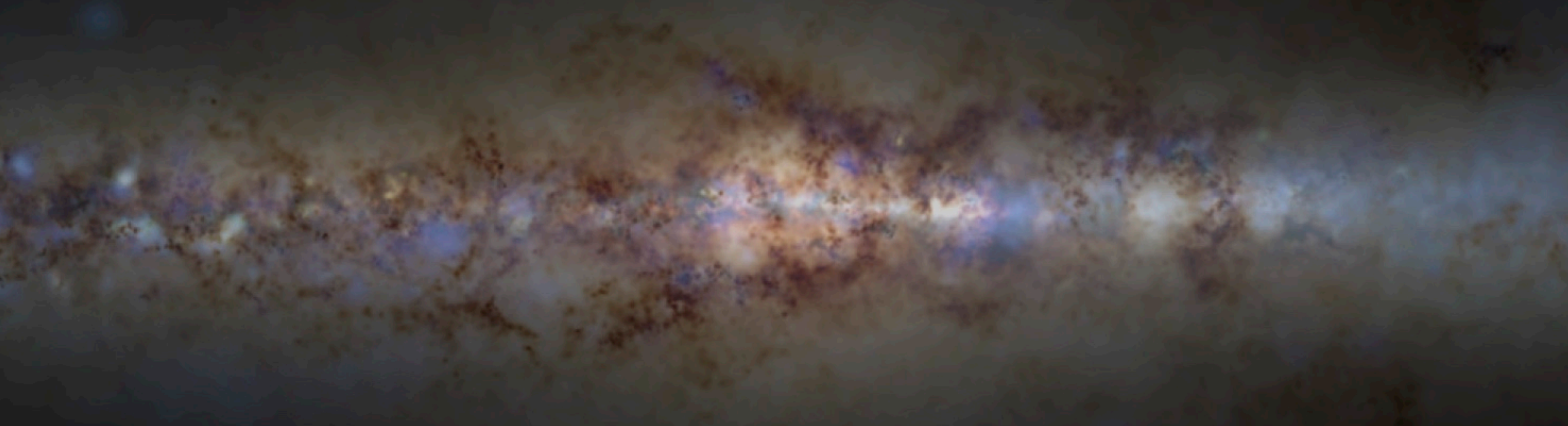
"Torus in its surrounding"



FIRE cosmological “zoom-in” simulations

Hopkins et al. 2018 (arXiv:1702.06148)

Mock galactic projection seen at 10 kpc from the center of MW-mass galaxy (Wetzel+16)



1) Stars form from high density (n > 1000 cm-3), molecular, locally self-gravitating gas

2) Mass, momentum, energy, and metal feedback from supernovae, stellar winds and radiation injected at the scale of star forming regions

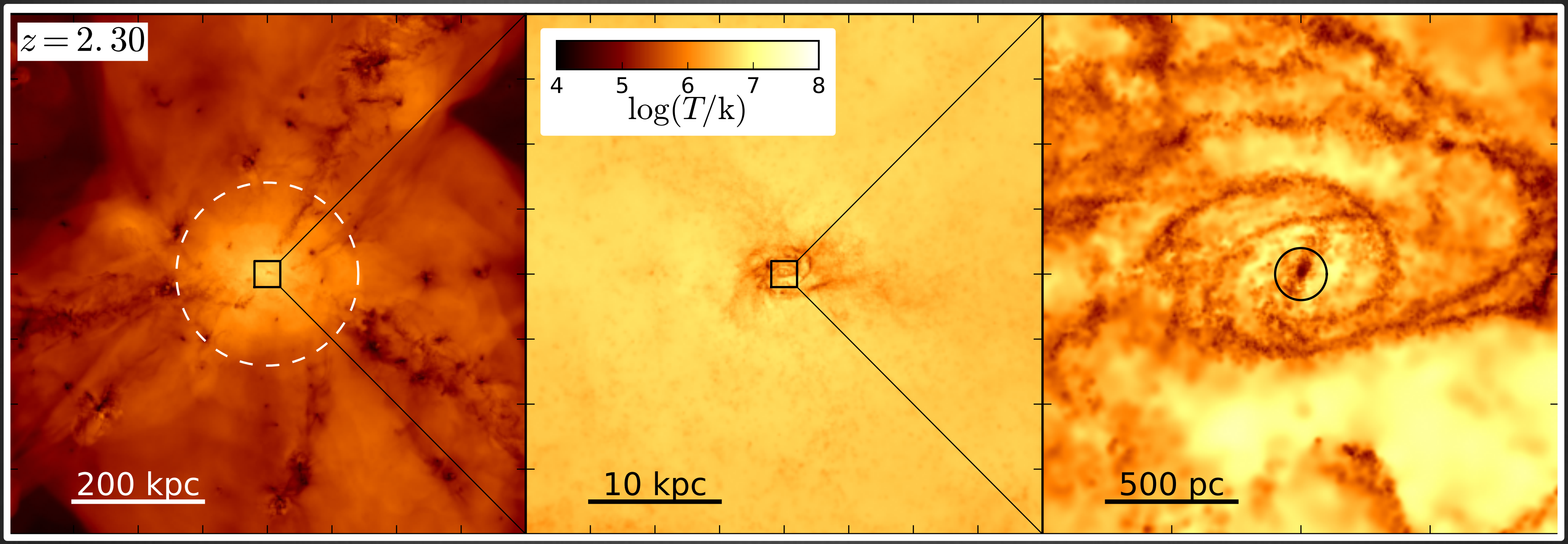
3) Reproduce many galaxy properties without tuning parameters

FIRE cosmological "zoom-in" simulations

Hopkins et al. 2018 (arXiv:1702.06148)

Ideal framework to investigate the evolution of SMBHs in a cosmological context

FIRE simulations with Black Hole Growth

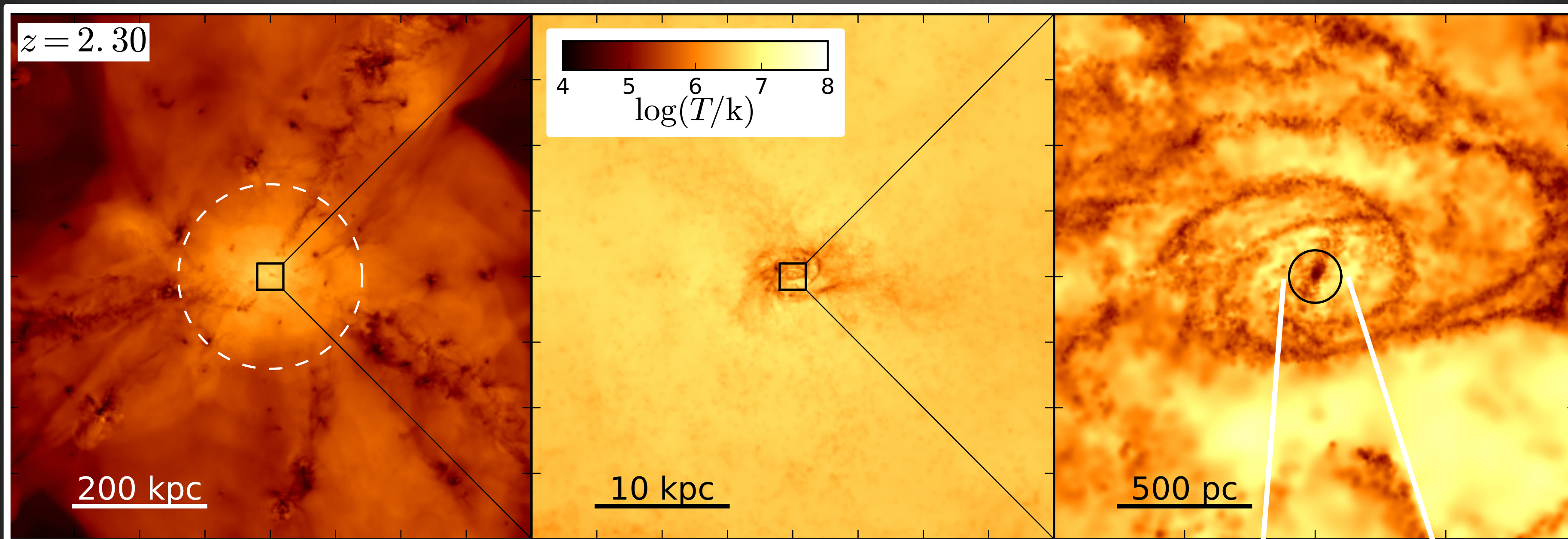


Anglés-Alcázar+2017c, MNRAS 472, L109 (arXiv:1707.03832)

→ QSO host halos $M_{vir} = 10^{12.5}$ - 10^{13} $M_{\odot}$ at z=1

- ICs from Feldmann+17
- baryonic particle mass = $3\text{x}10^4$ $M_{\odot}$
- minimum gas adaptive softening = 1 pc
- star formation at n > 1000 cm^{-3}

FIRE simulations with Black Hole Growth



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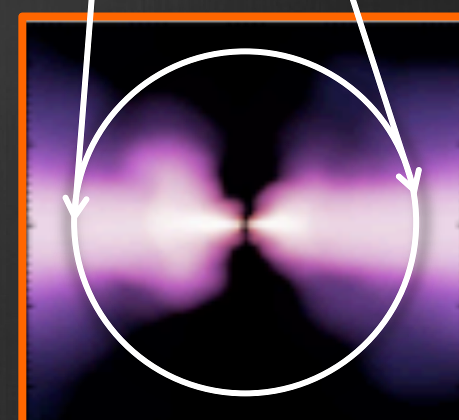
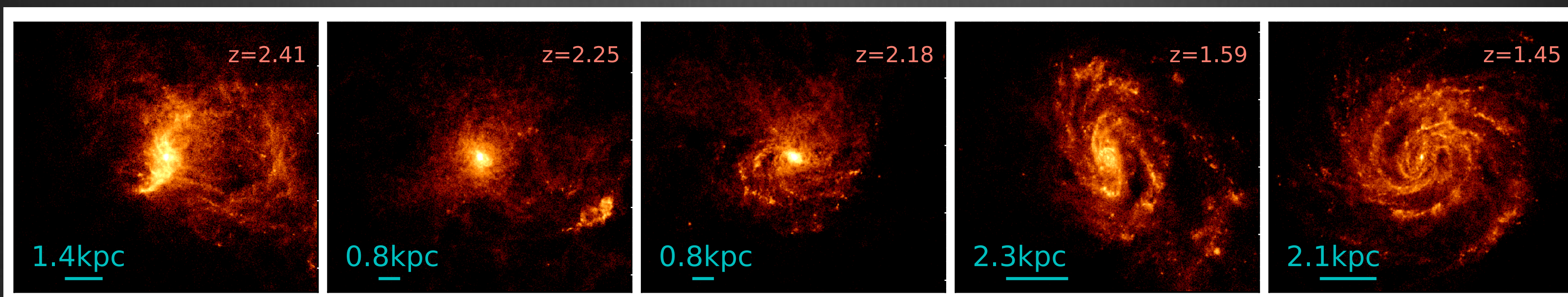
→ BH accretion based on nuclear scale simulations

Gravitational torques from non-axisymmetric perturbations in the stellar potential (Hopkins & Quataert 2010,2011)



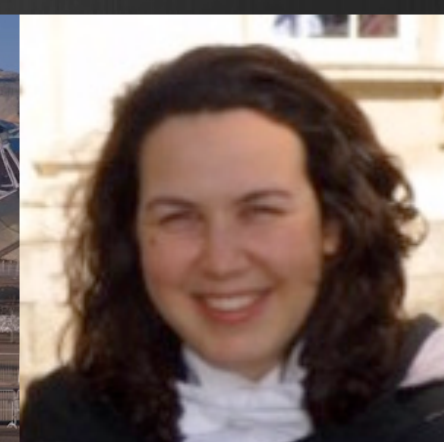
My contribution to "ALMA day"

3D continuum radiative transfer with

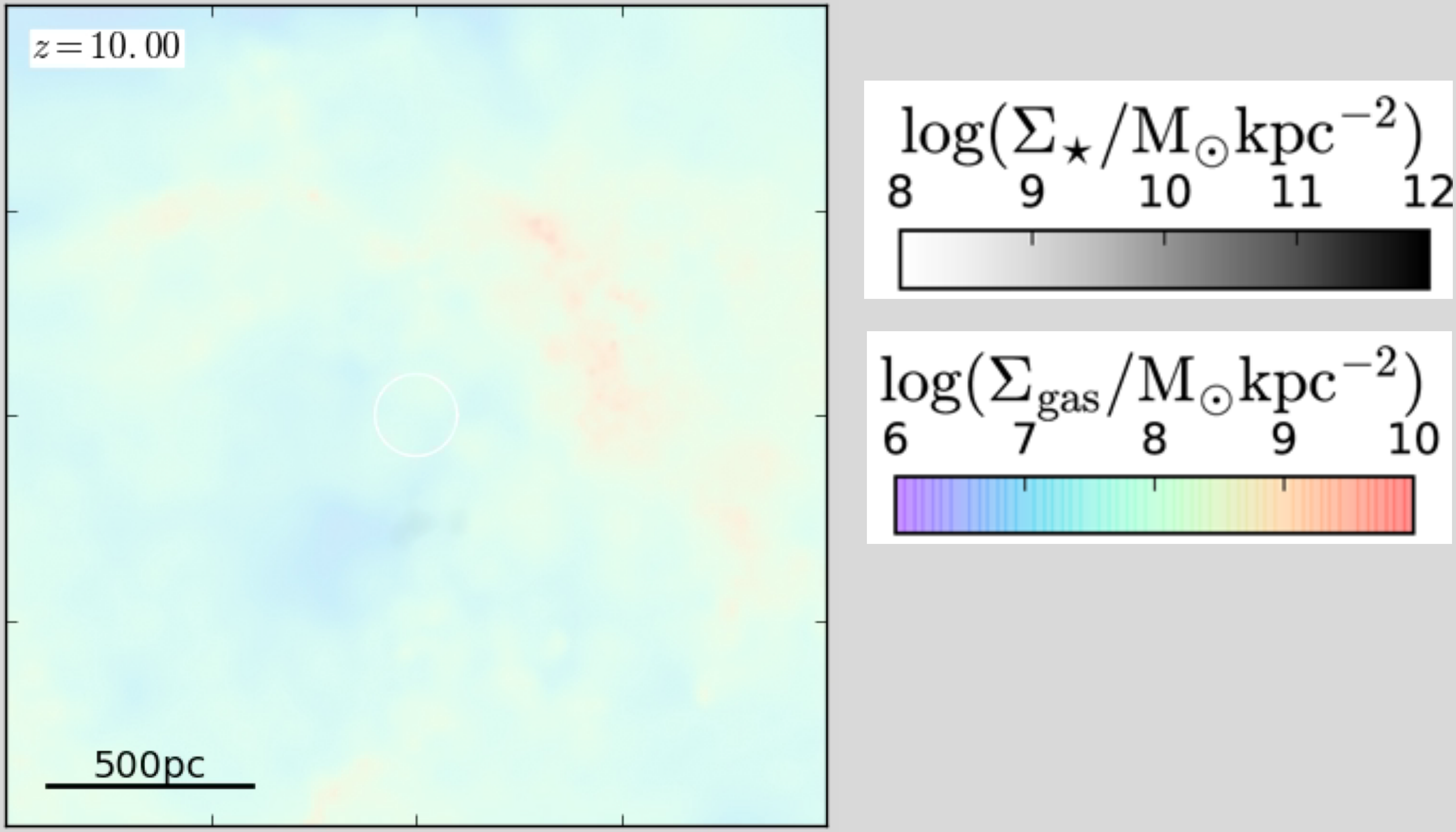


870-µm observed-frame flux maps

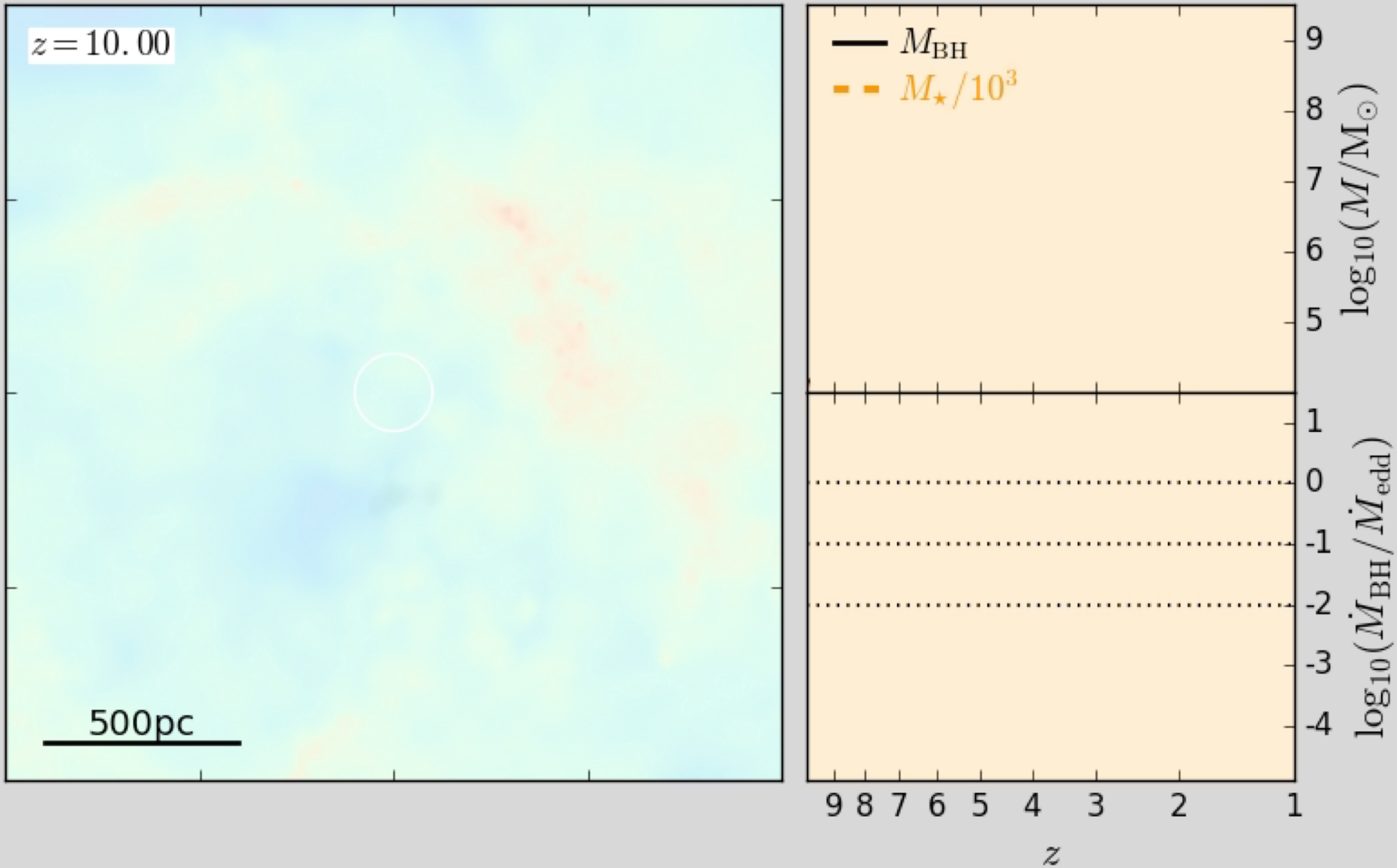
Rachel Cochrane
University of Edinburgh



FIRE simulations with Black Hole Growth



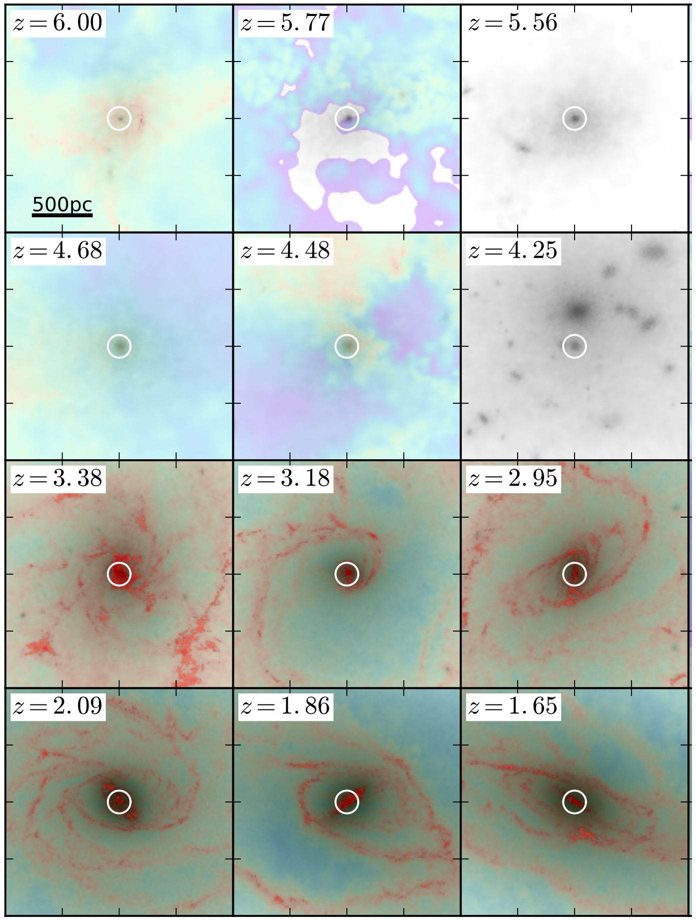
Effects of stellar feedback on Black Hole Growth

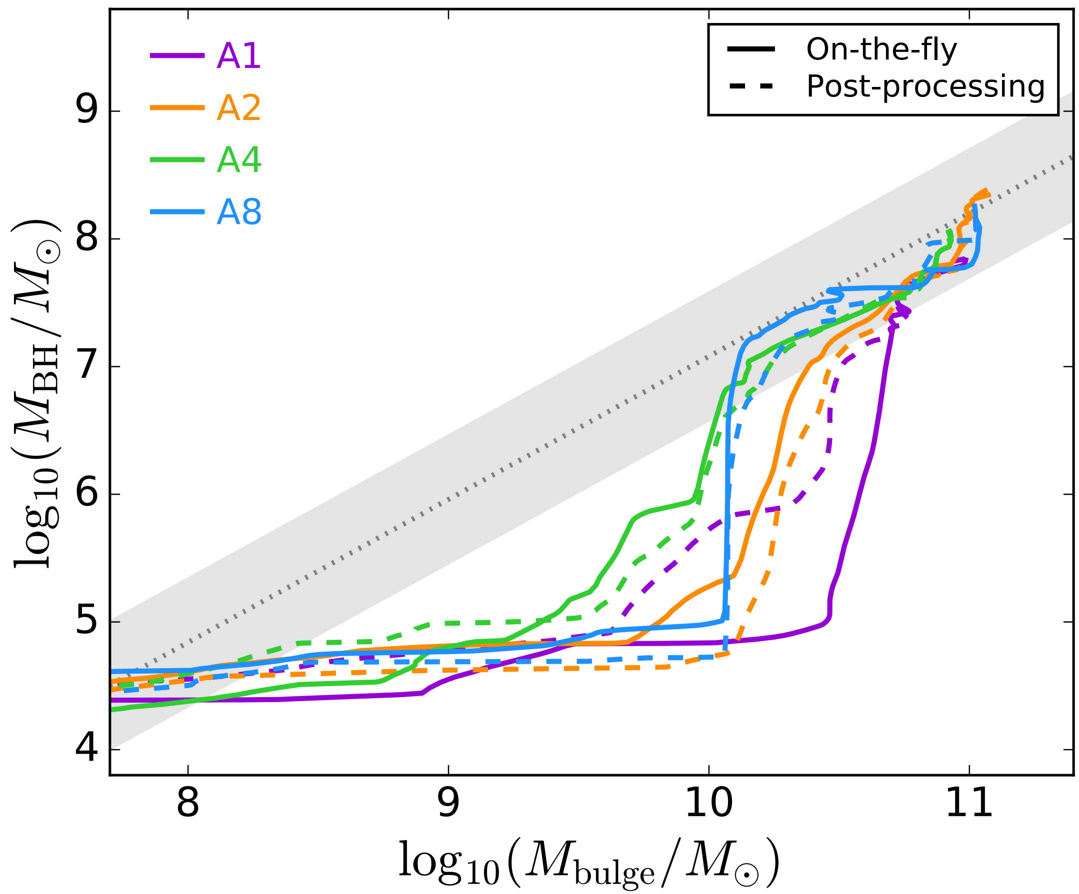


Anglés-Alcázar+2017c, MNRAS 472, L109 (arXiv:1707.03832)

Effects of stellar feedback on Black Hole Growth

Anglés-Alcázar+2017c, MNRAS 472, L109 (arXiv:1707.03832)



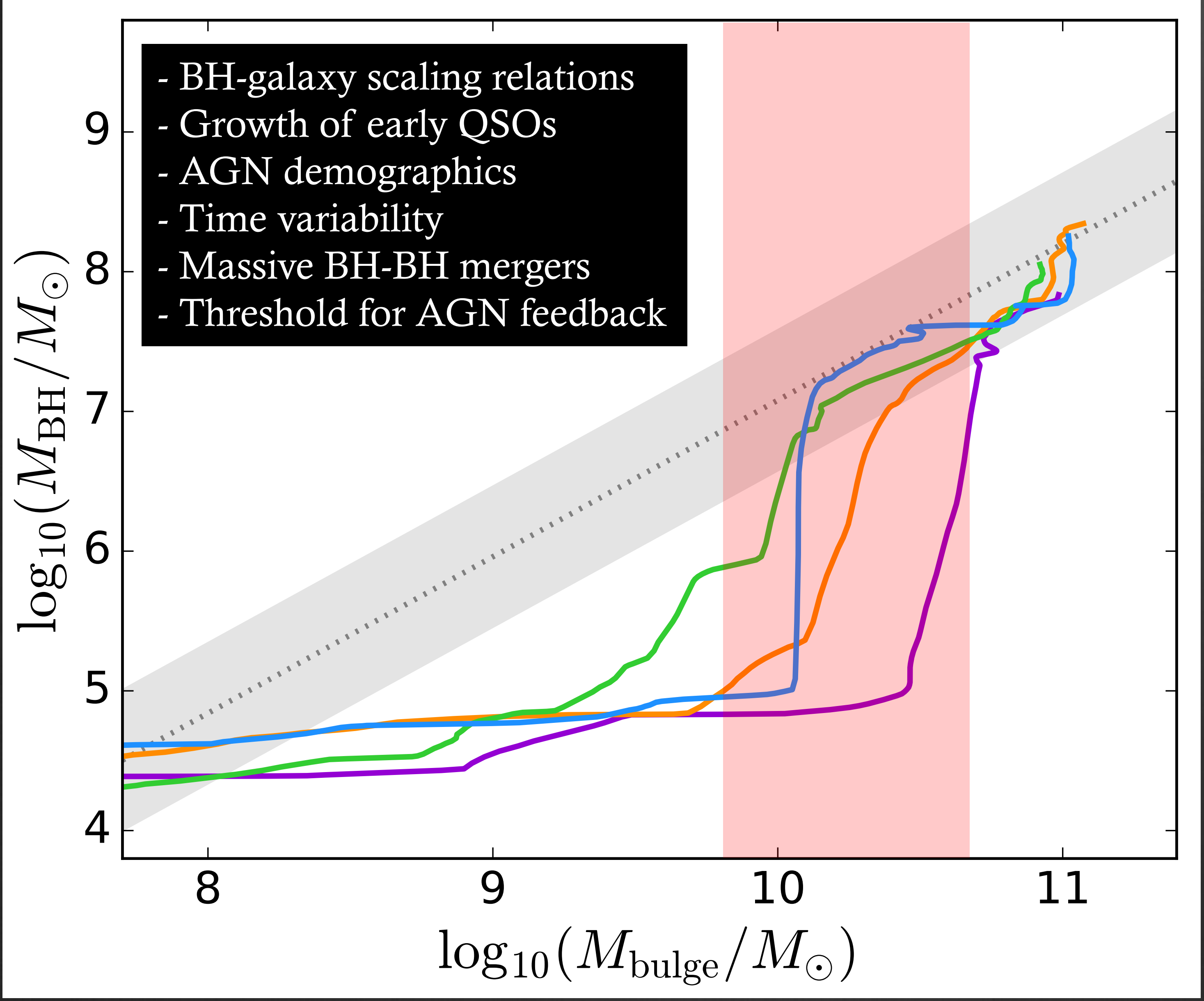


TRANSITION FROM

(1) Irregular morphology, bursty star formation, highly dynamic conditions TO

(2) Well-defined stellar potential, more steady star formation, and long-lived nuclear gas disk enabling efficient BH growth.

Important implications!

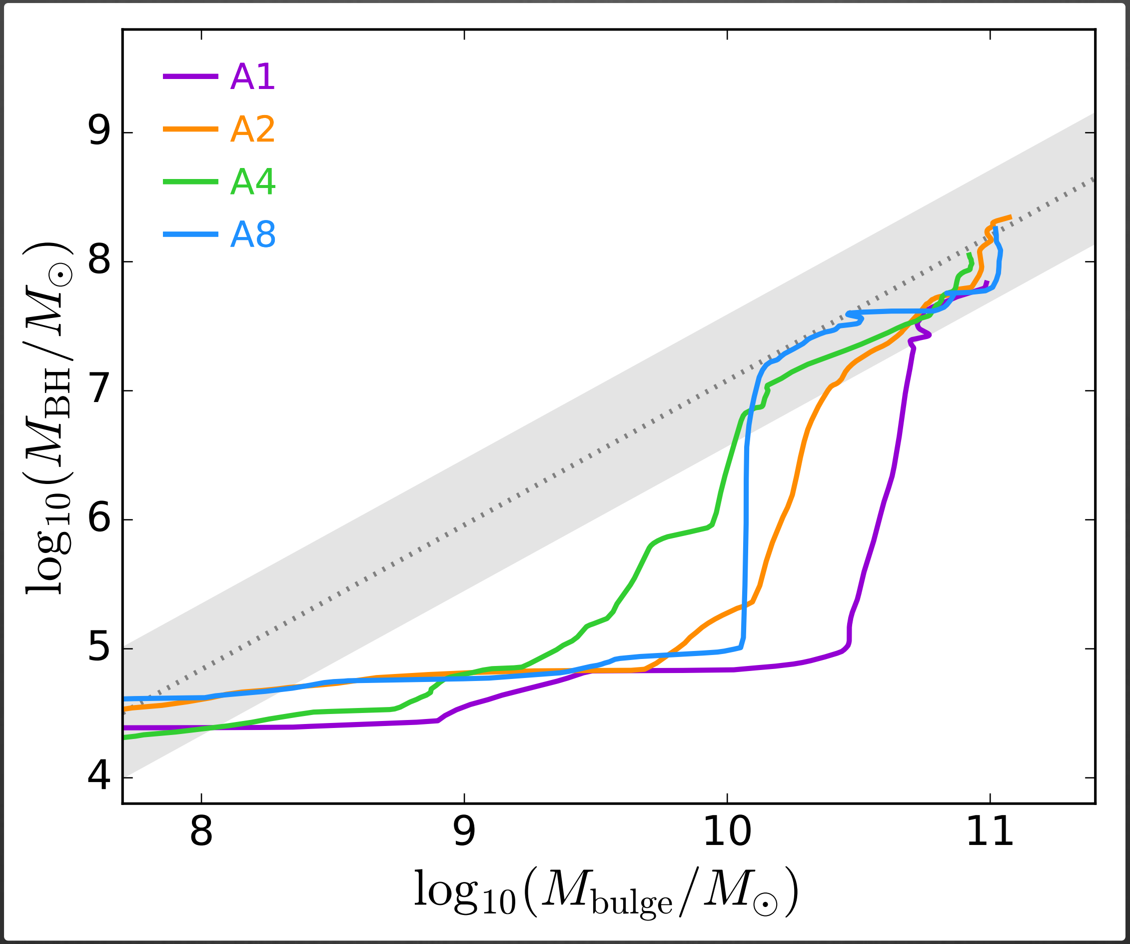


Many aspects explored in sims with different resolution/physics

Costa+2014
Dubois+2015
Bonoli+2016
Keller+2016
Biernacki+2017
Bower+2017
Fiacconi+2017
Habouzit+2017
Prieto+2017
Latif+2018

What about Black Hole Feedback?

Anglés-Alcázar+2017c (arXiv:1707.03832)



→ BH feedback *not* needed to reproduce BH-galaxy scaling relations

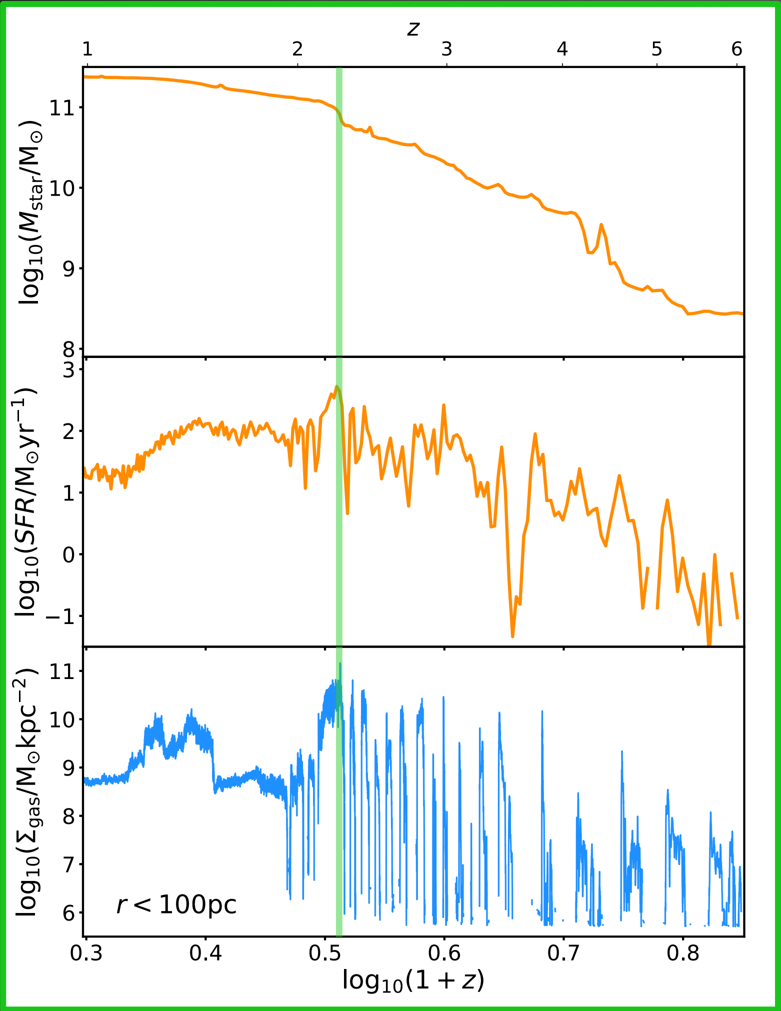
Anglés-Alcázar+2013, 2015, 2017a. → Common gas supply for Star Formation and BH growth!

… Work in progress …

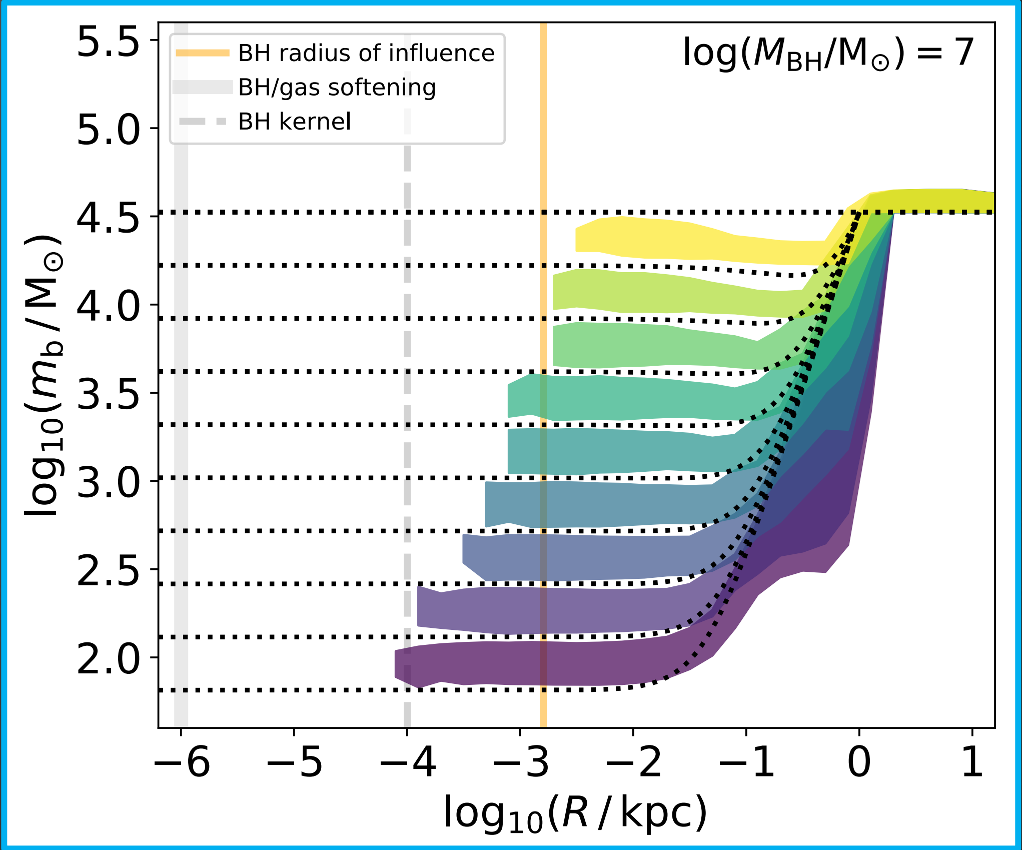
Cosmological hyper-refinement simulations

Anglés-Alcázar+ in prep.

→ Choose interesting redshift from full cosmological simulation
→ Re-start the simulation splitting gas resolution elements near the SMBH

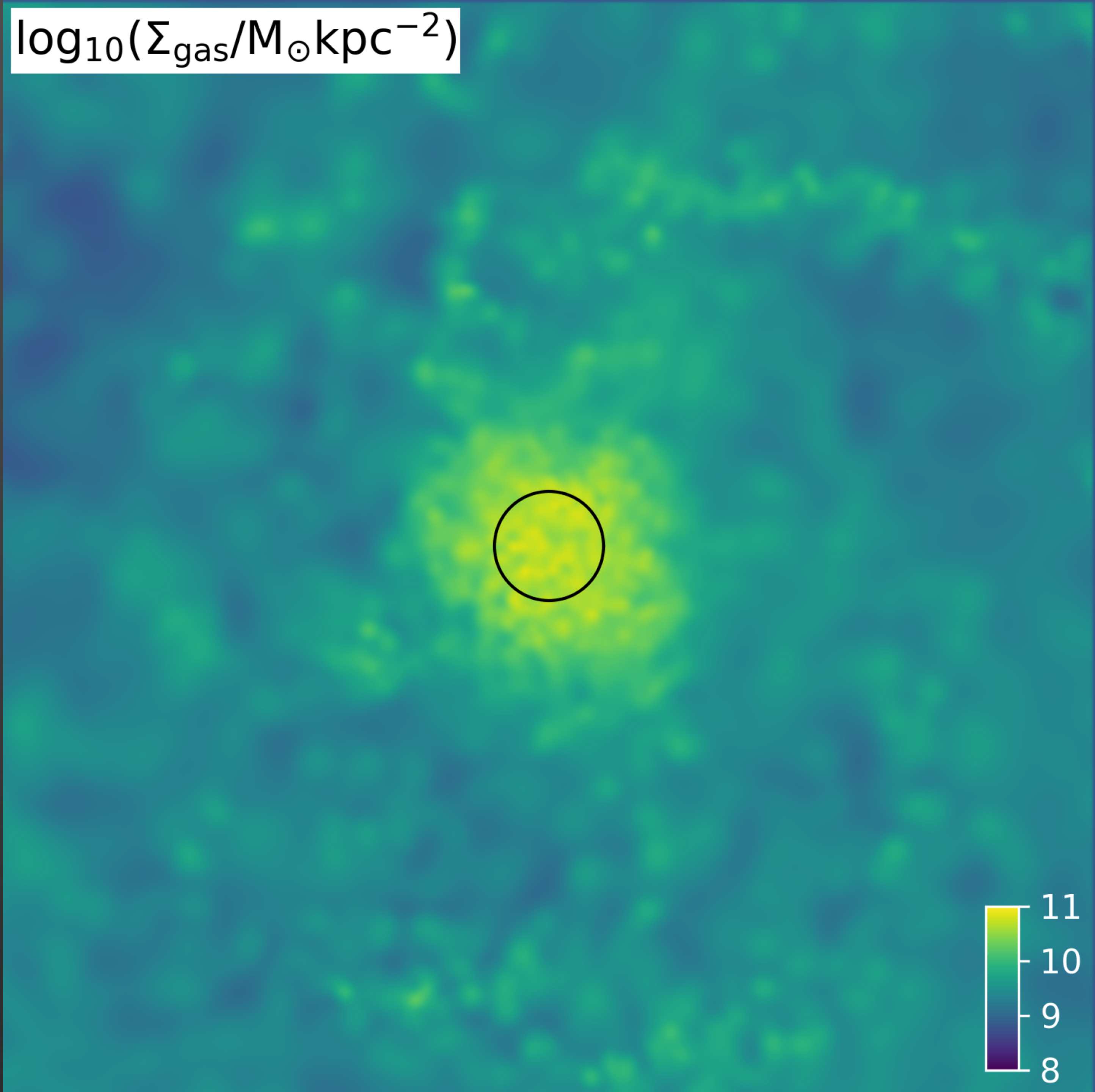


Imposed mass resolution profile



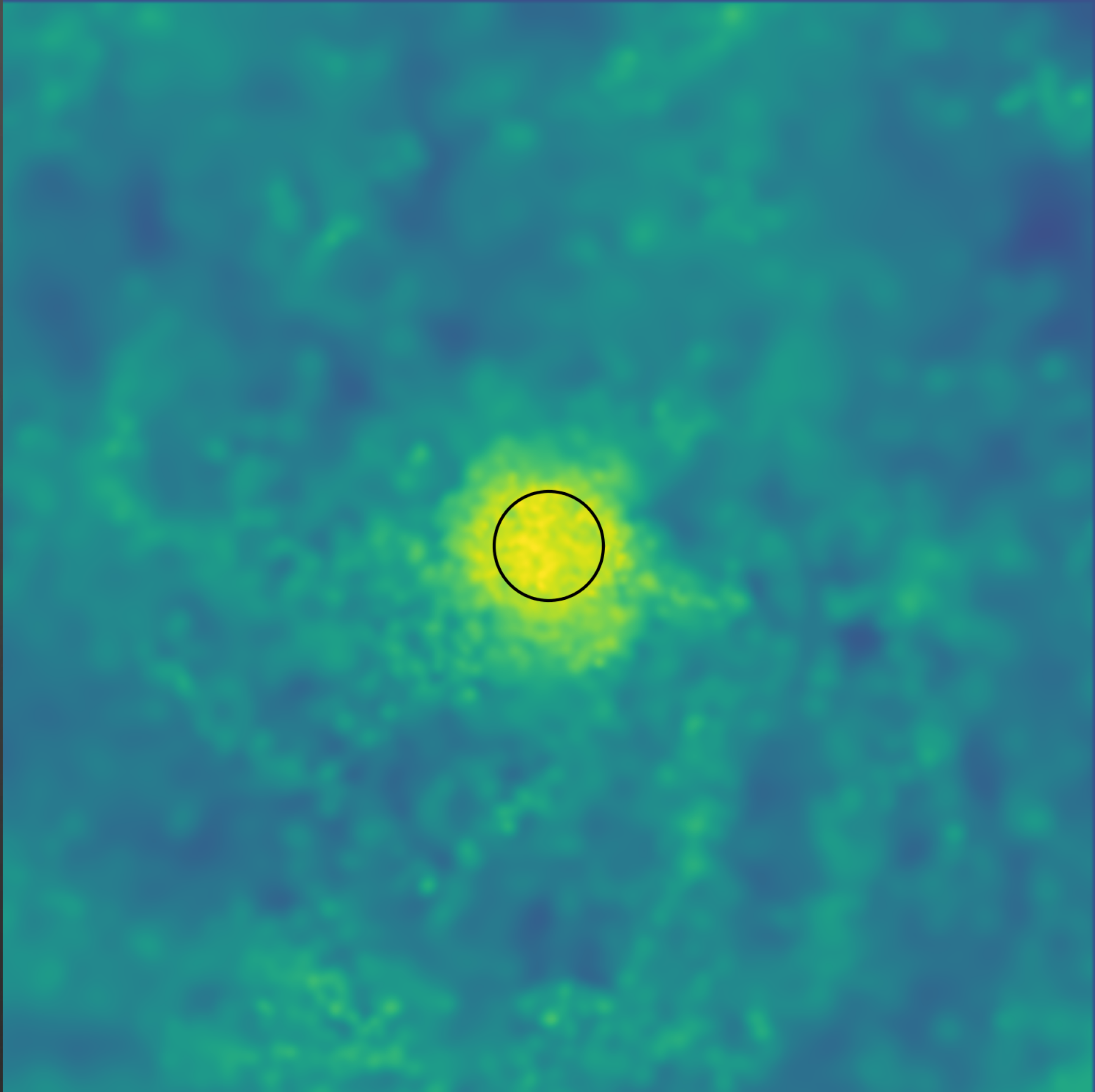
Central 100 pc

Increasing mass resolution by factors of 2

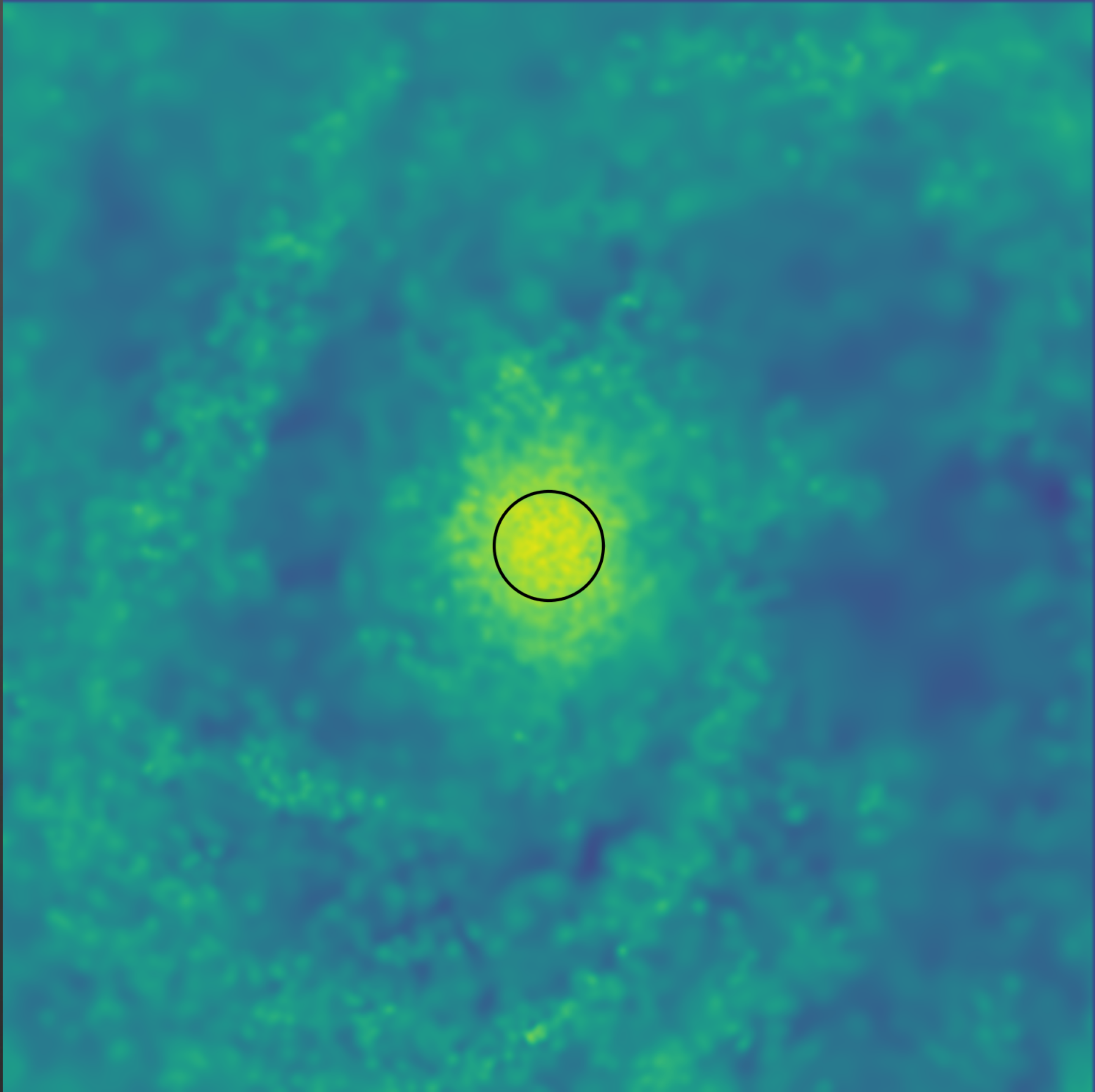


Central 100 pc

Increasing mass resolution by factors of 2



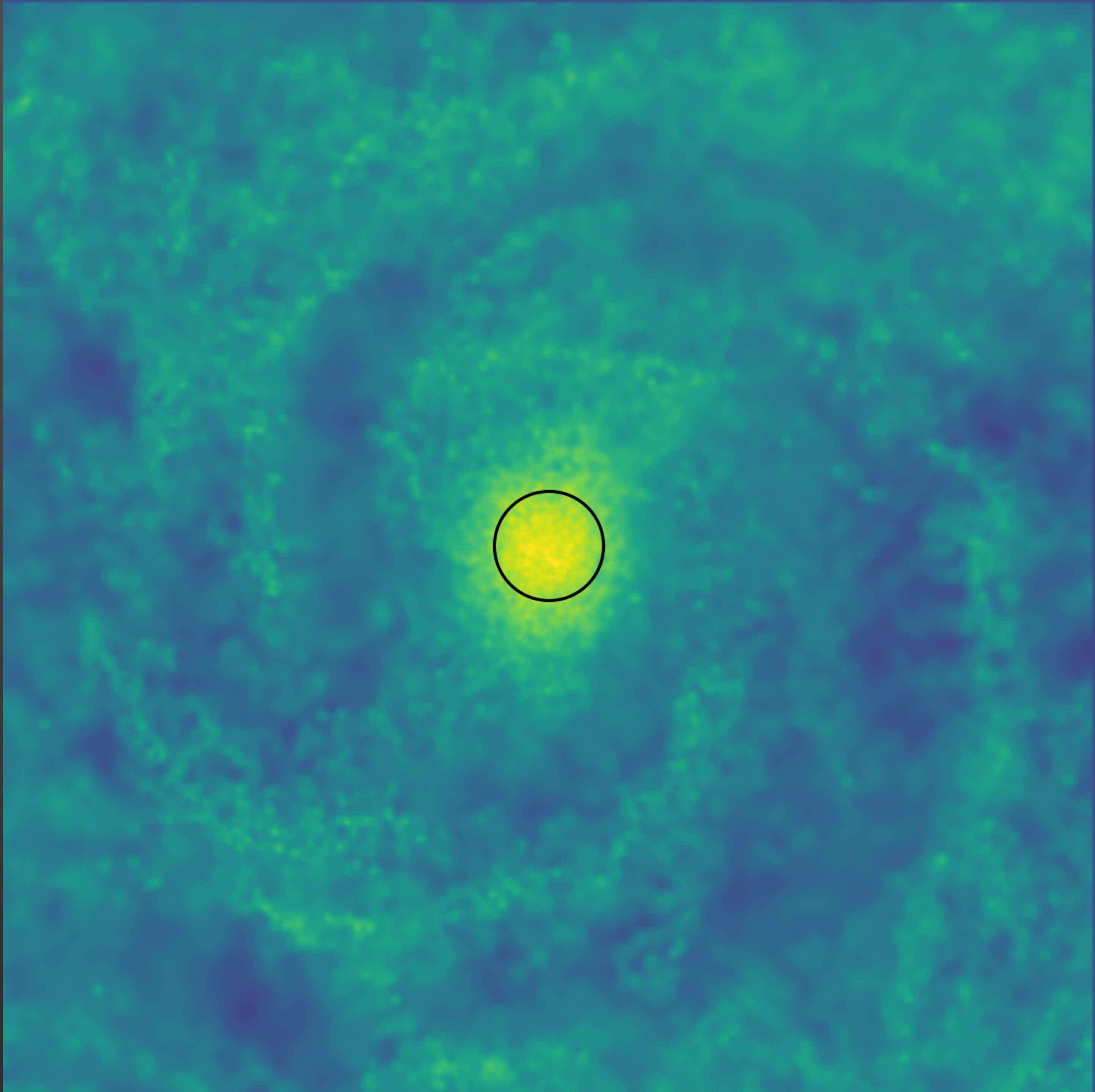
Central 100 pc



Increasing mass resolution by factors of 2

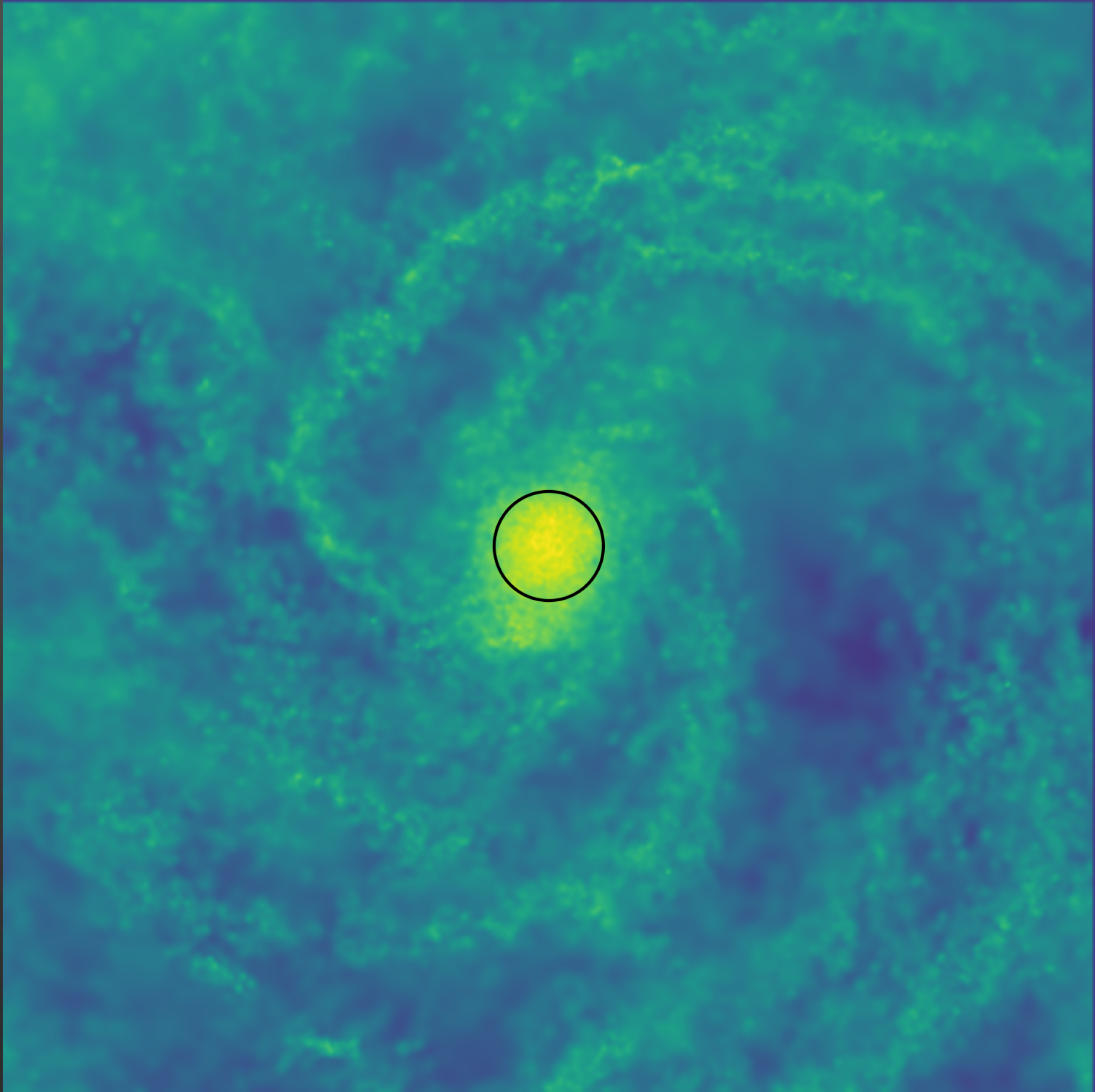
Central 100 pc

Increasing mass resolution by factors of 2



Central 100 pc

Increasing mass resolution by factors of 2



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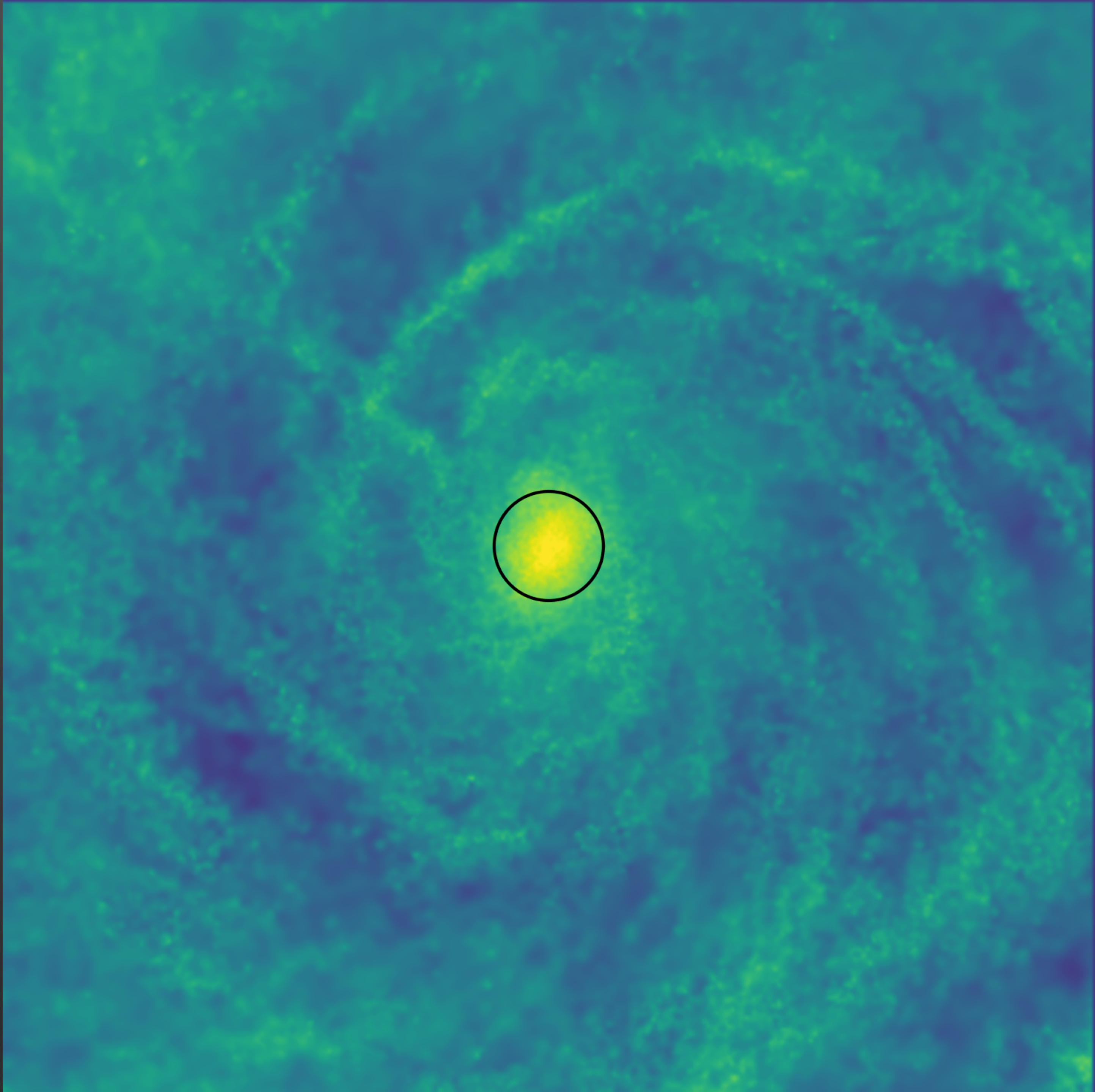

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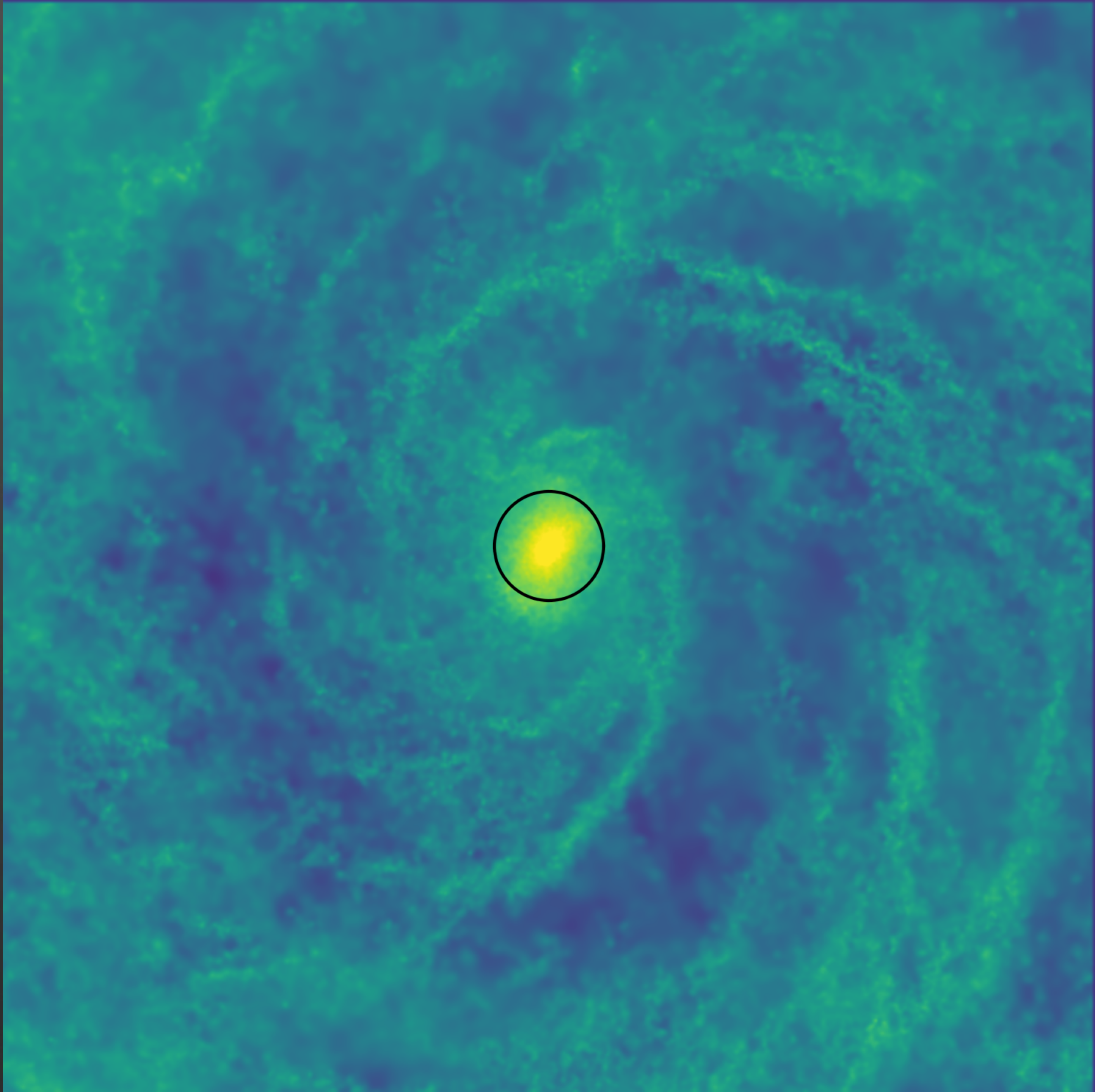

Central 100 pc

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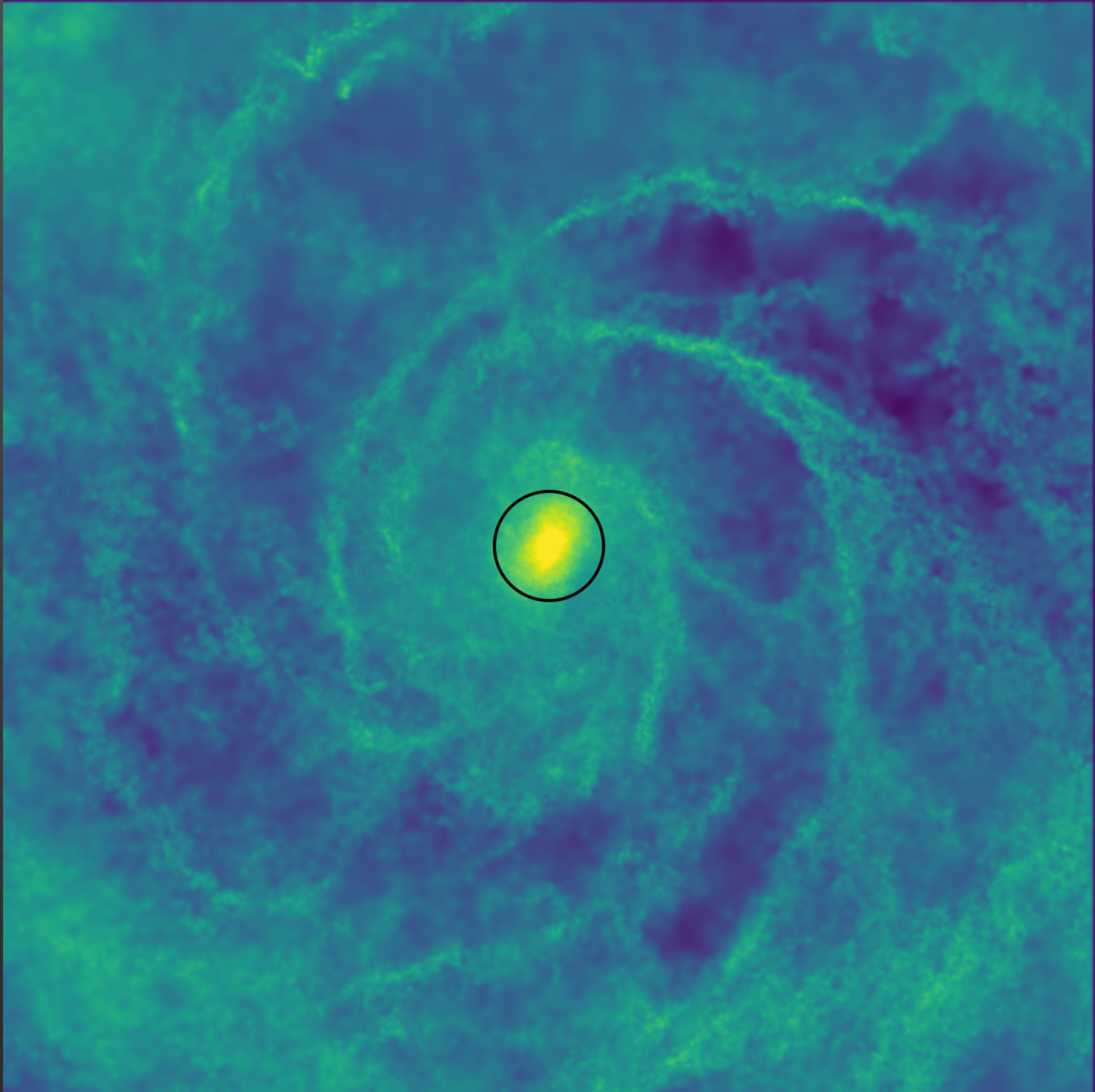

Central 100 pc

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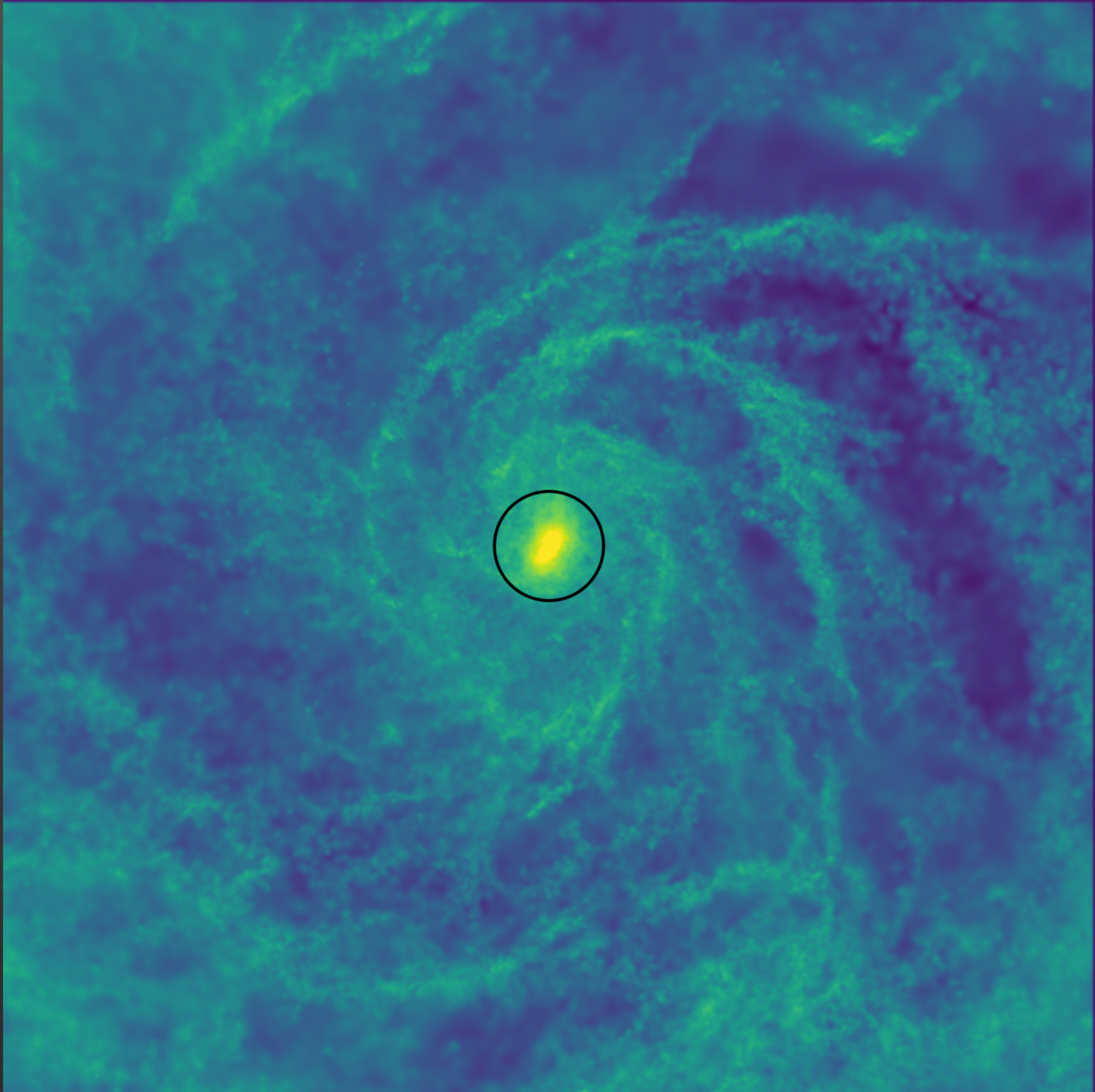

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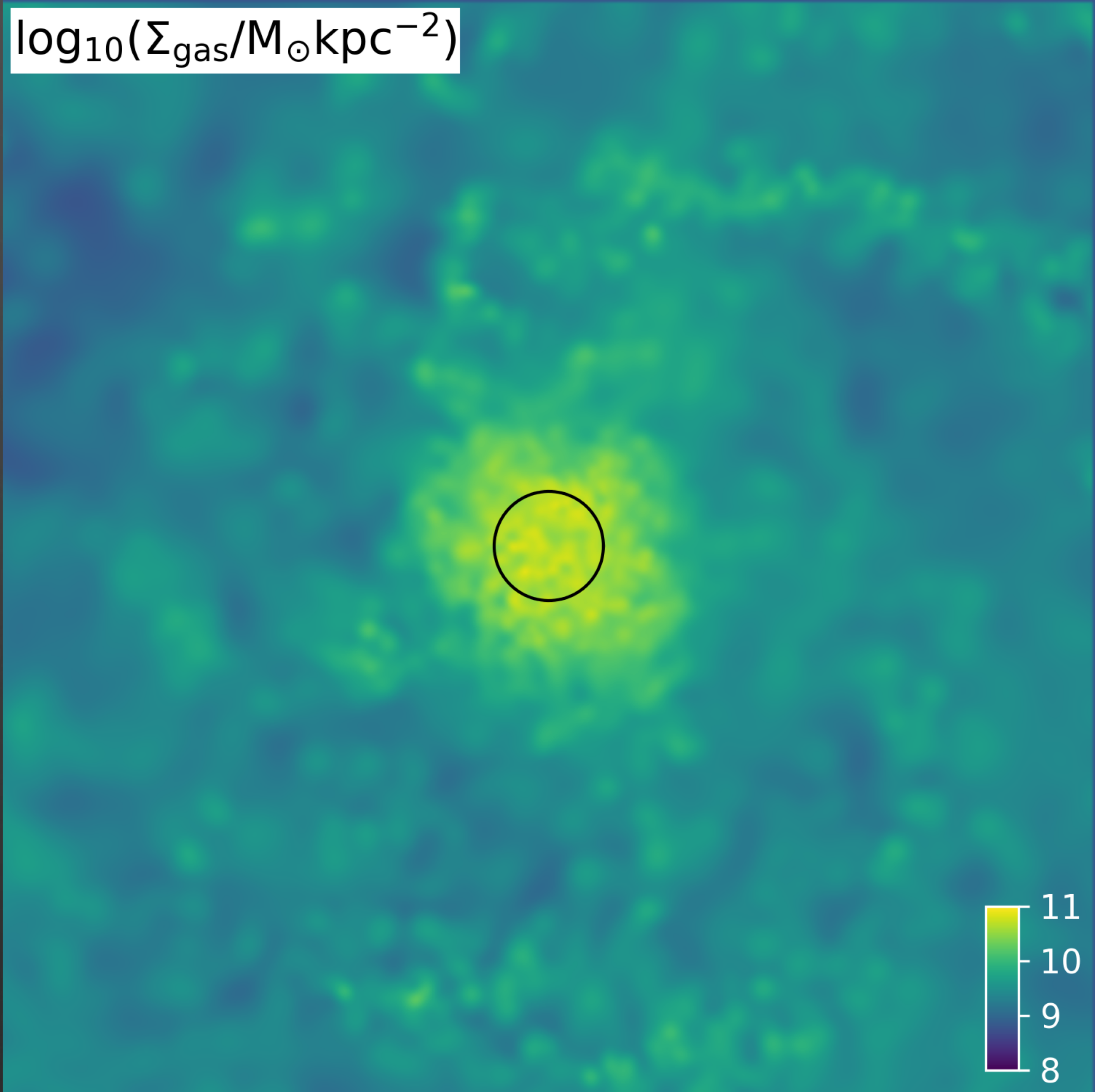
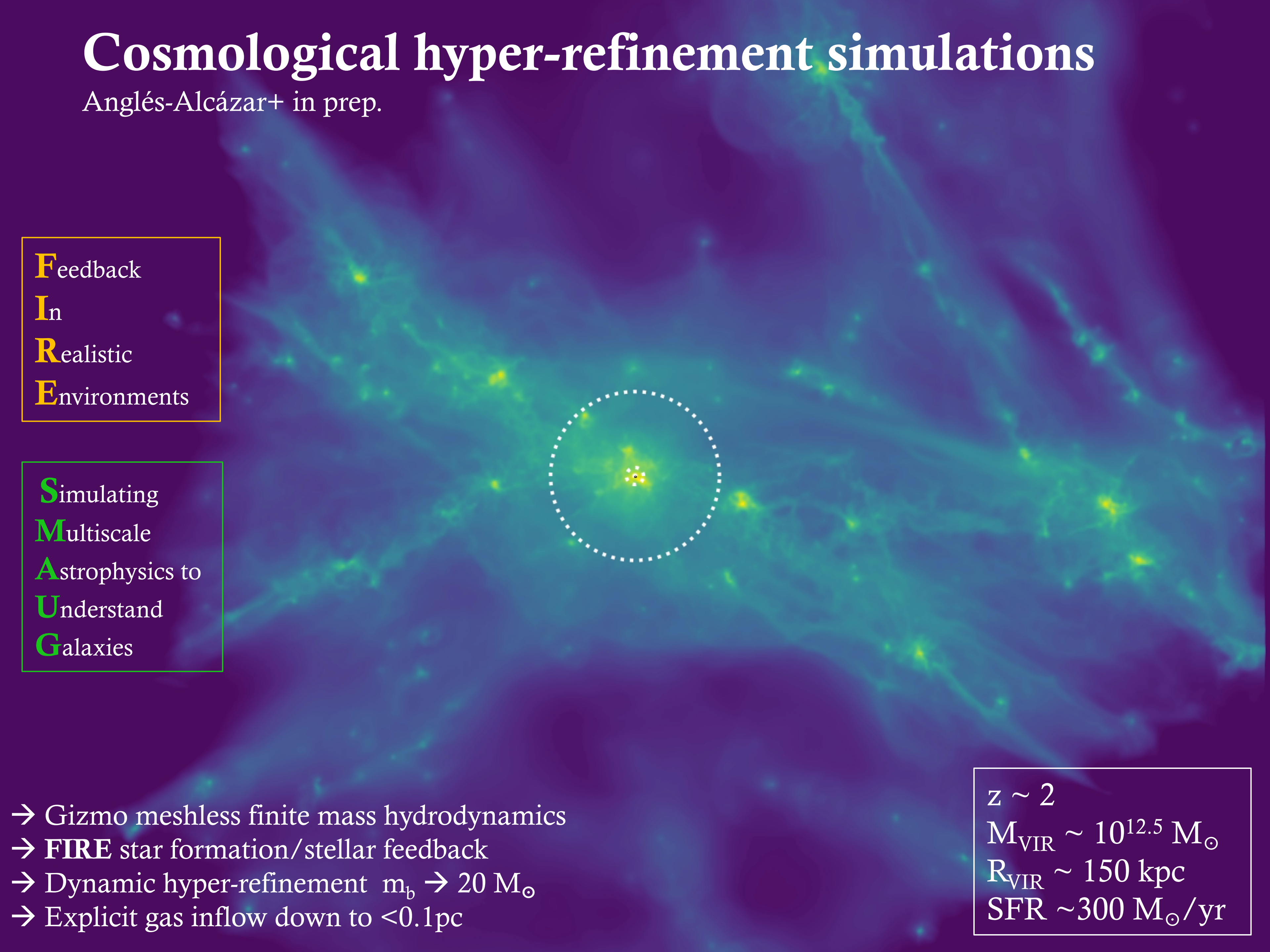


Cosmological hyper-refinement simulations

Anglés-Alcázar+ in prep.



Feedback
In
Realistic
Environments

Simulating
Multiscale
Astrophysics to
Understand
Galaxies

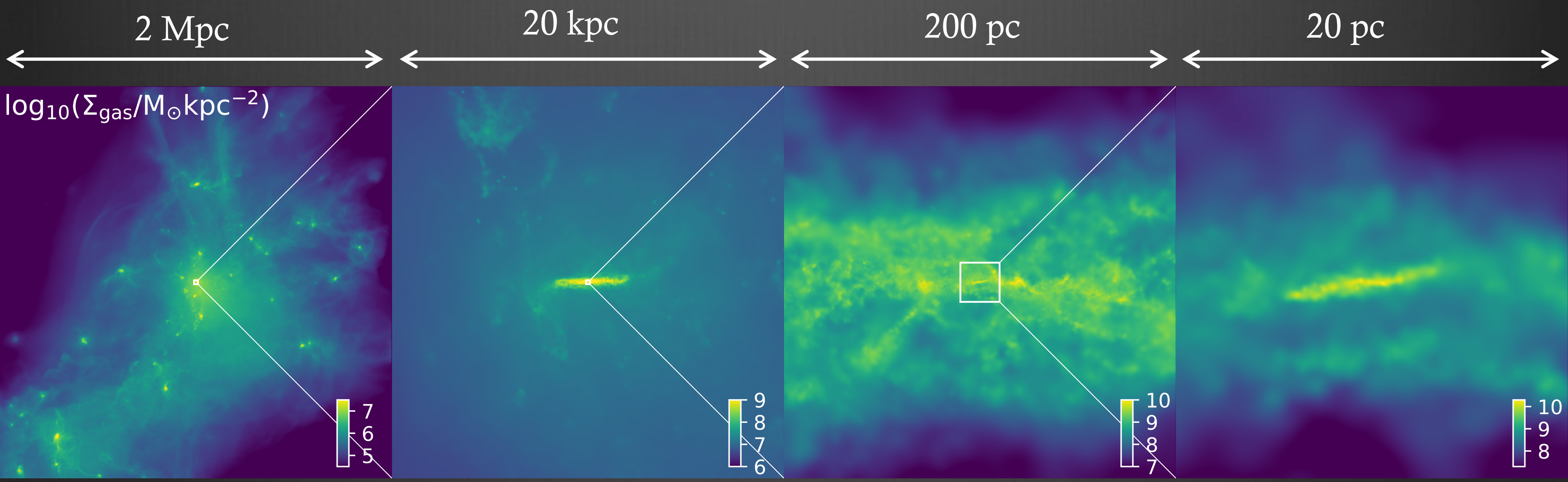
→ Gizmo meshless finite mass hydrodynamics
→ **FIRE** star formation/stellar feedback
→ Dynamic hyper-refinement $m_b \rightarrow 20\ M_\odot$
→ Explicit gas inflow down to <0.1pc

$z \sim 2$
$M_{VIR} \sim 10^{12.5}\ M_\odot$
$R_{VIR} \sim 150$ kpc
SFR $\sim 300\ M_\odot$/yr

Cosmological hyper-refinement simulations

Anglés-Alcázar+ in prep.

→ From Mpc to Torus scales in a single model!



- Very well defined initial conditions (the CMB!)
- No boundary issues, continuous inflow from larger scales → steady state
- Radial inflow/outflow/star formation from >10kpc to < 1pc
- Mechanisms responsible for angular momentum transport vs R?
- Nuclear vs galaxy-scale obscuration?
- Redshift evolution?

AGN winds in the FIRE simulations

From isolated galaxies (Torrey+ in prep.) to full cosmological simulations (Anglés-Alcázar+ in prep.)

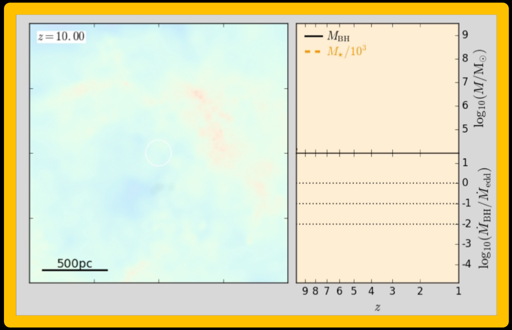
→ $M_{star} \sim 10^{11.5}\ M_\odot$, SFR ~20 $M_\odot$/yr, z = 1
→ $M_{BH} = 10^9\ M_\odot$ accreting at Eddington
→ V_{out} = 30,000 km/s
→ Outflow rate = BH accretion rate

} 5% L_{bol} injected isotropically at 0.1 pc

→ Early black holes are under FIRE!

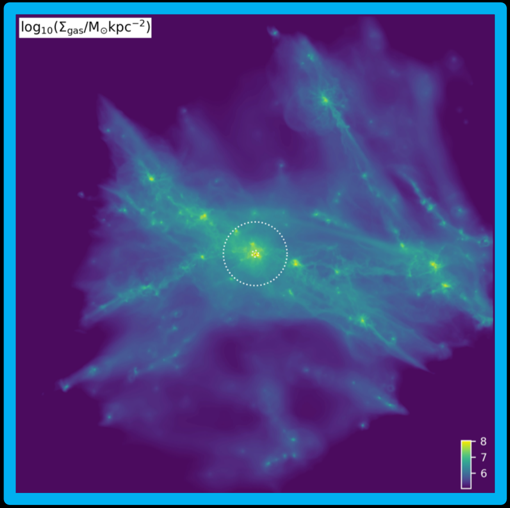
Nuclear star formation/stellar feedback critical to many aspects of SMBHs

Anglés-Alcázar+2017c (arXiv:1707.03832)



→ From the CGM down to the torus!

Hyper-refinement techniques predict explicit inflow rates down to ~0.1 pc scales



→ AGN winds in multi-phase ISM!

Impact from torus to CGM scales?