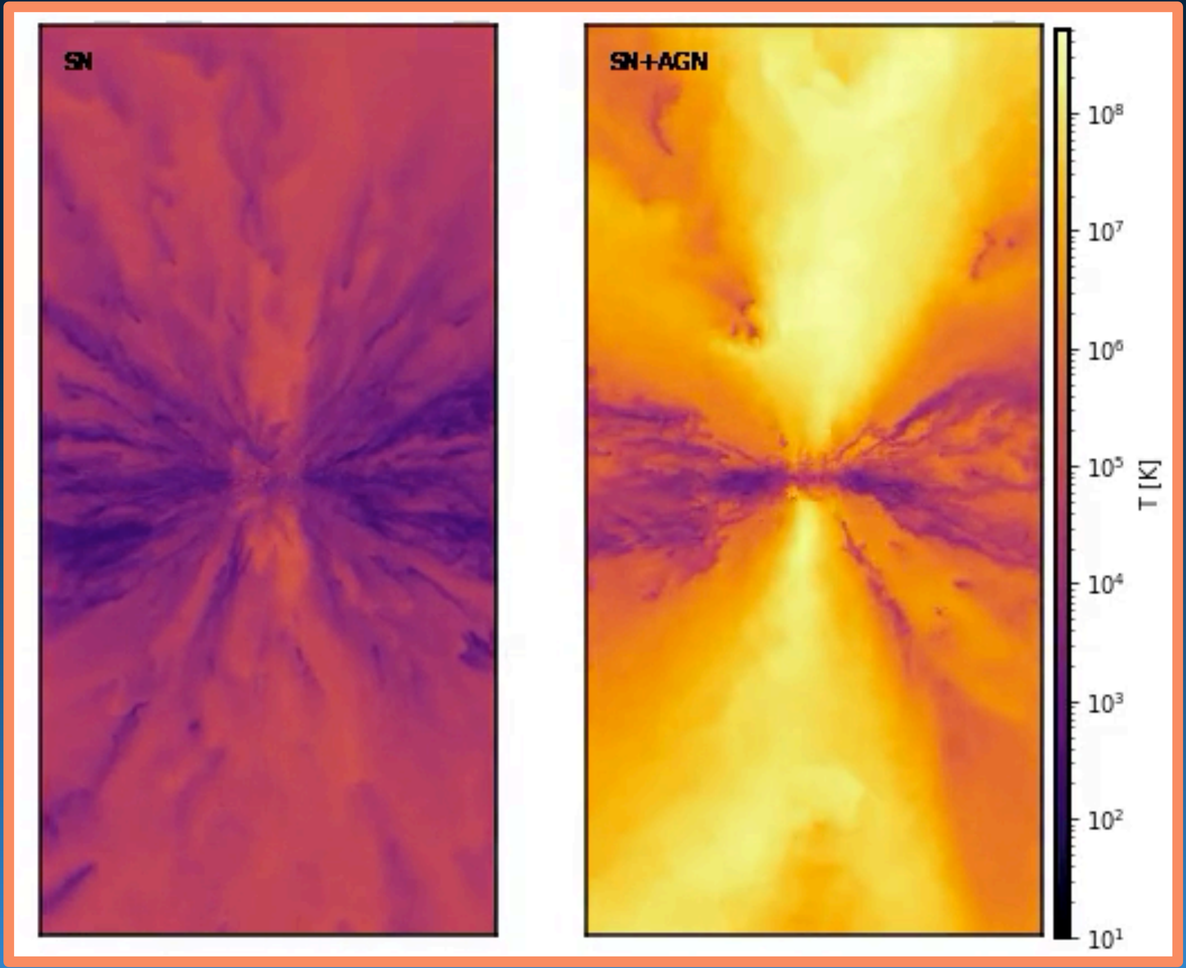
AGN-DRIVEN OUTFLOWS IN SIMULATED DWARF GALAXIES



Small Galaxies, Cosmic Questions

Durham, 30/07/19

Sophie Koudmani

with Debora Sijacki, Martin Bourne, and Matthew Smith

Koudmani+2019: MNRAS, 484, 2, 2047

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DWARF GALAXIES & THE ΛCDM MODEL: A TESTBED FOR SIMULATIONS

(Apparent) Discrepancies:

Missing satellites

(e.g. Kauffmann+1993, Klypin+1999, Moore+1999)

Too-big-to-fail

(e.g. Boylan-Kolchin+2011)

Cusp vs. core

(e.g. Moore 1994)

Modify dark matter model:

Warm dark matter

(e.g. Lovell+2012)

Self-interacting dark matter

(e.g. Vogelsberger+2014)

Fuzzy dark matter

(e.g. Marsh & Silk 2014)

Improve baryonic physics:

Reionization

(e.g. Efstathiou 1992, Okamoto+2008, Fitts+2016)

Supernovae (may need additional stellar feedback mechanisms)

(e.g. Navarro+1996, Governato+2010, Parry+2012, Garrison-Kimmel+2014, Hopkins+2014, Vogelsberger+2014, Kimm+2015, Emerick+2018, Smith+2018)

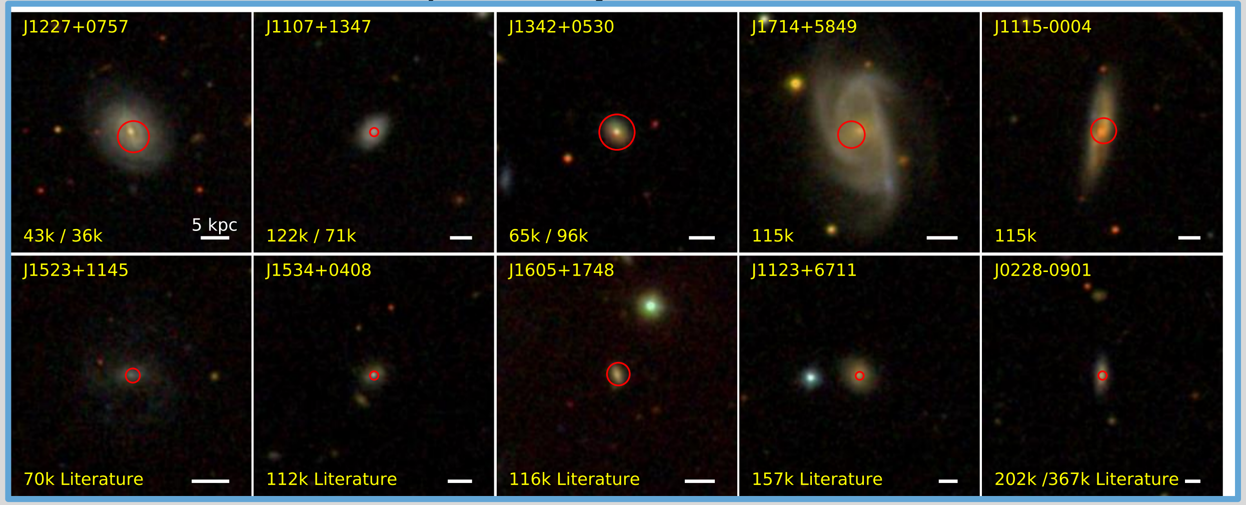
AGN?

(e.g. Wadepuhl & Springel 2011, Habouzit+2017, Silk 2017, Barai+2018, Bellovary+2018, Dashyan+2018, Trebitsch+2018)

OBSERVATIONAL EVIDENCE

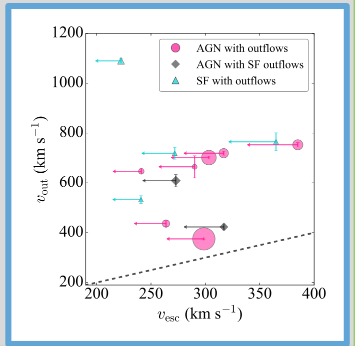
SDSS search + X-ray follow-up (Chilingarian+2018):

305 IMBH candidates, 10 X-ray confirmed



Keck follow-up observations:

- **16 out of 20 isolated, quiescent dwarfs** host central **AGN-like line** ratios (Dickey+2019)
- **9 out of 29 dwarfs with AGN signatures** have high velocity **ionized gas outflows** (Manzano-King+2019)

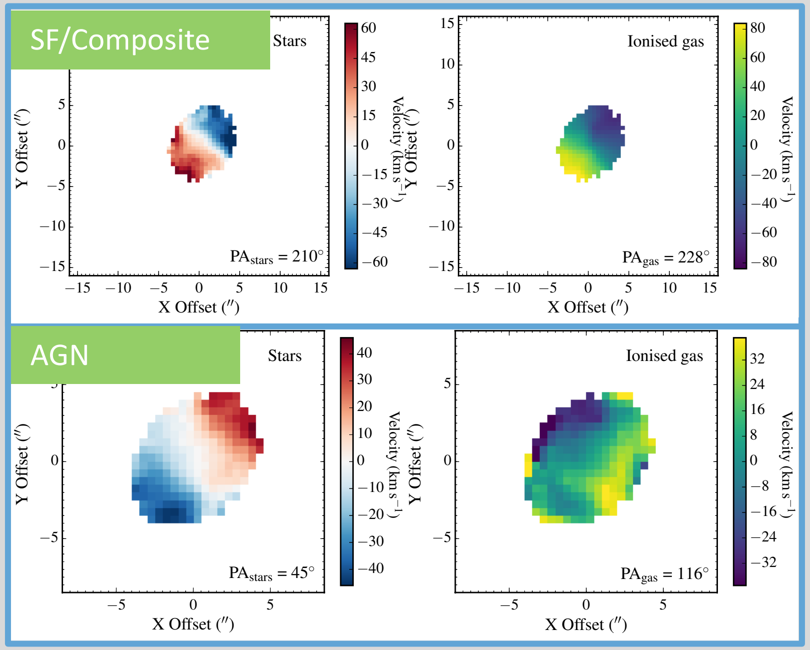


Systematic searches in the COSMOS field:

- **40** dwarf galaxies with **X-ray AGN** out to **z∼2.4** (Mezcua+2018)
- **35** dwarf galaxies with **radio AGN** out to **z∼3.4** (Mezcua+2019)

MaNGA (Penny+2018):

5 out of 6 quenched low-mass galaxies with BPT classification 'AGN' have kinematically offset gas



See also: Greene & Ho 2004, 2007; Satyapal+2007, 2008, 2014; Desroches+2009; Dong+2012; Marleau+2013; Reines+2013; Moran+2014; Lemons+2015; Sartori+2015; Baldassare+2016,2017,2018; Pardo+2016; Mezcua+2016; Cann+2019; Graham & Soria 2019; Graham+2019; Kaviraj+2019

INTERMEDIATE-MASS AGN LUMINOSITIES

- Analytical models of intermediate-mass AGN in dwarfs look promising (Dashyan+2018)

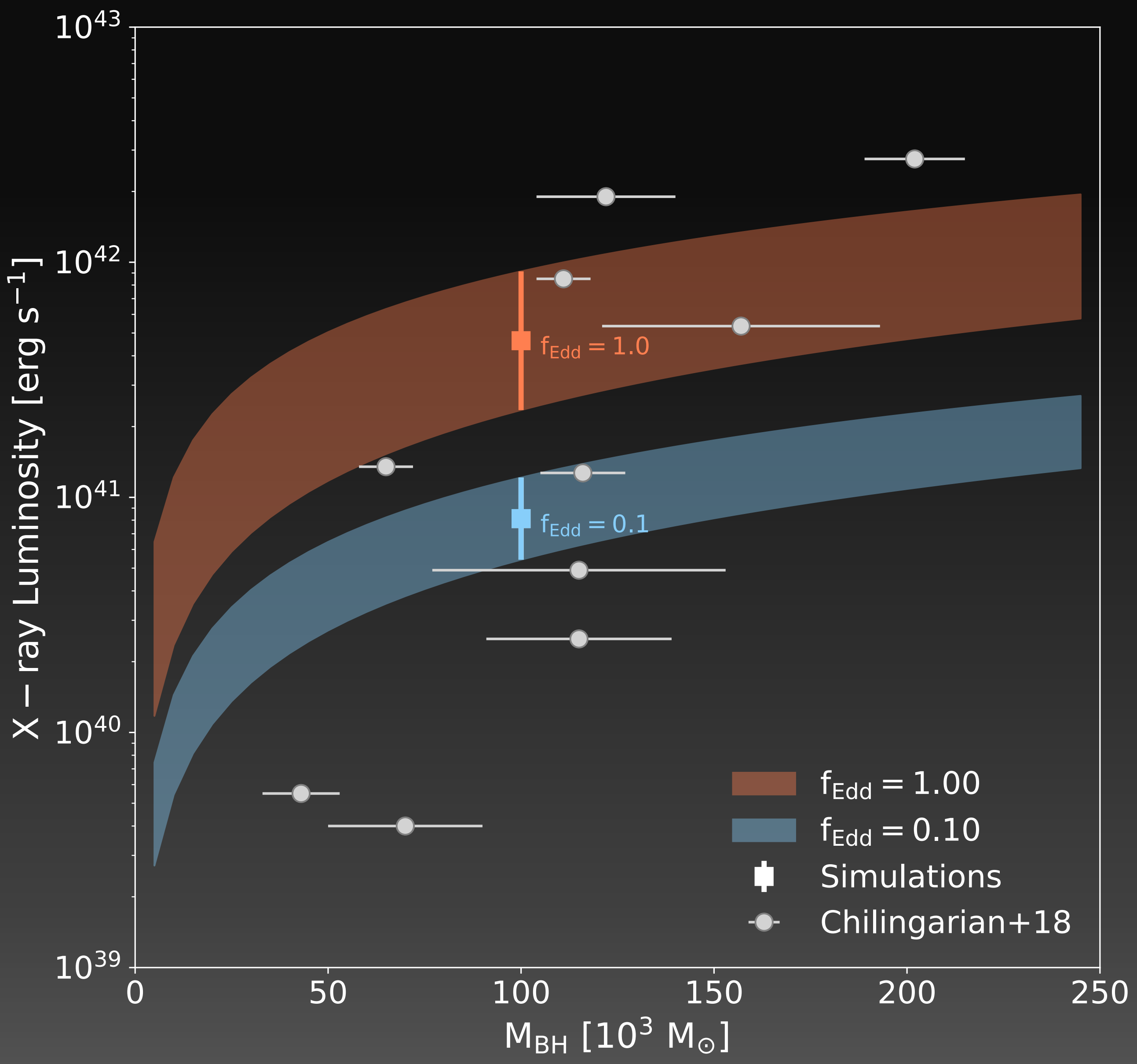
- Previous numerical simulations mostly used Bondi accretion model (Wadepuhl & Springel 2011, Habouzit+2017, Barai+2018, Bellovary+2018, Trebitsch+2018)

$$\dot{M}_{\rm acc} = \dot{M}_{\rm Bondi} \propto M_{\rm BH}^2$$

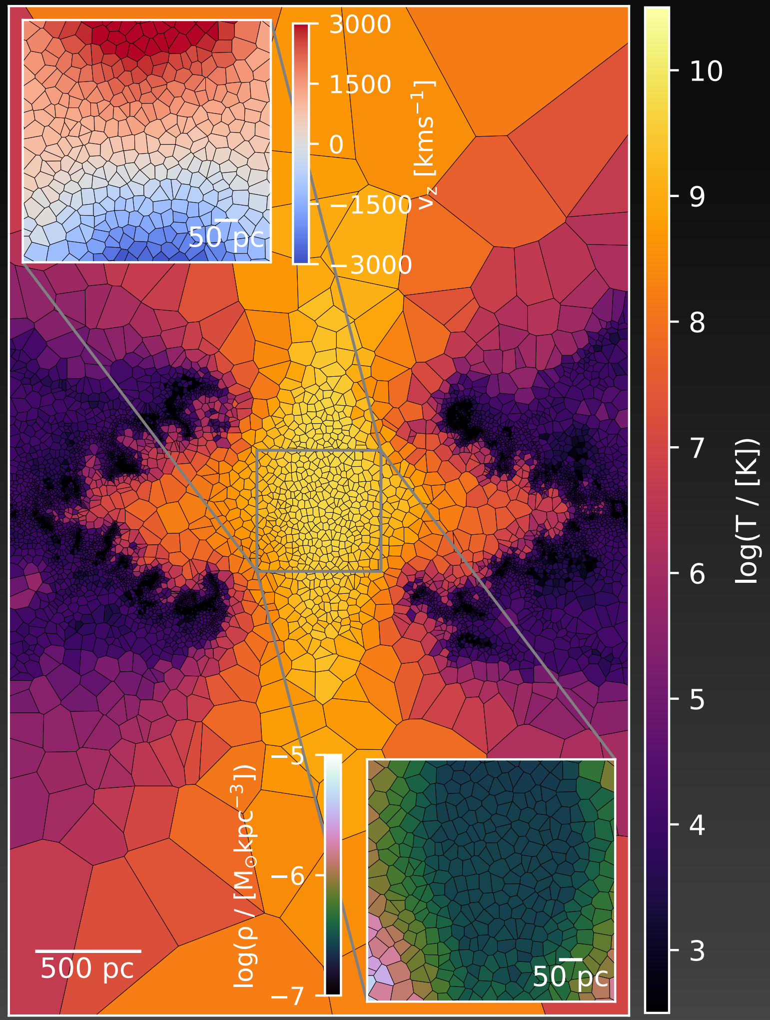
➔ for IMBHs get low Eddington ratios

$$f_{\rm Edd} = \dot{M}_{\rm acc}/\dot{M}_{\rm Edd}$$

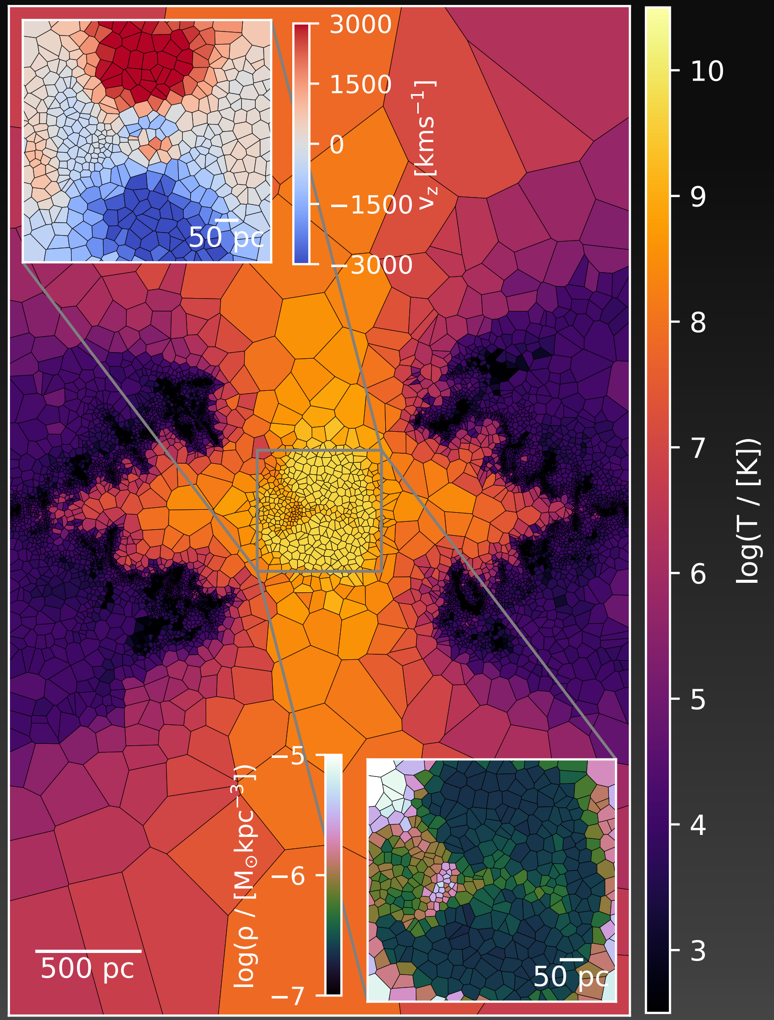
We set constant high Eddington ratio to test maximum impact!



SIMULATION SET-UP



Isotropic, thermal winds



Mass-loaded, bipolar outflows

- Hydrodynamical simulations using the moving-mesh code **AREPO** (Springel, 2010)
- **Super-Lagrangian** refinement (Curtis & Sijacki, 2015)
- **AGN activity** (Curtis & Sijacki, 2015)
- **Star formation & supernova feedback** (Smith+2018)

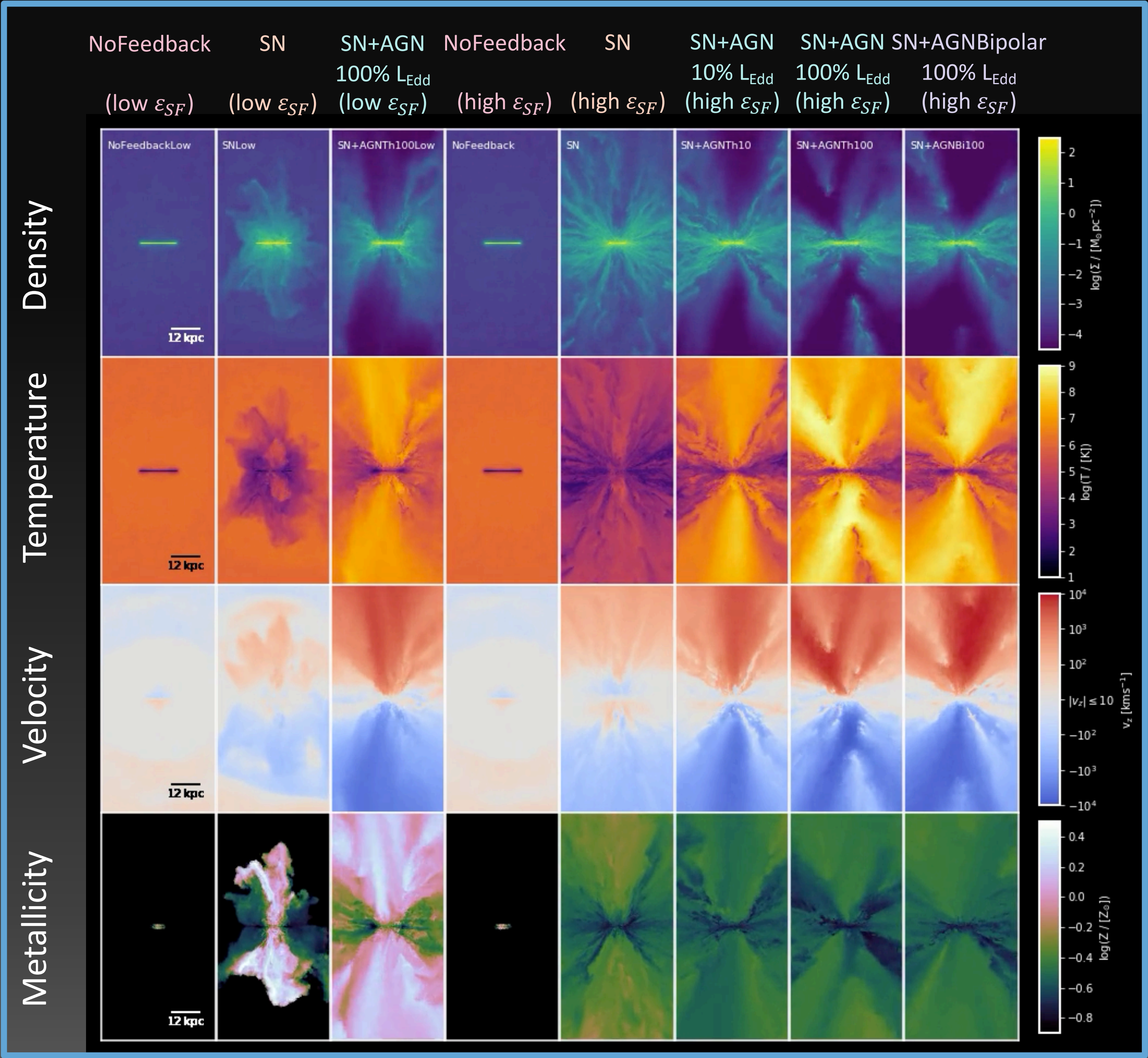
‘Fast and energetic AGN-driven outflows in simulated dwarf galaxies’, Koudmani et al. (2019), MNRAS, 484, 2, 2047

SIMULATION SUITE

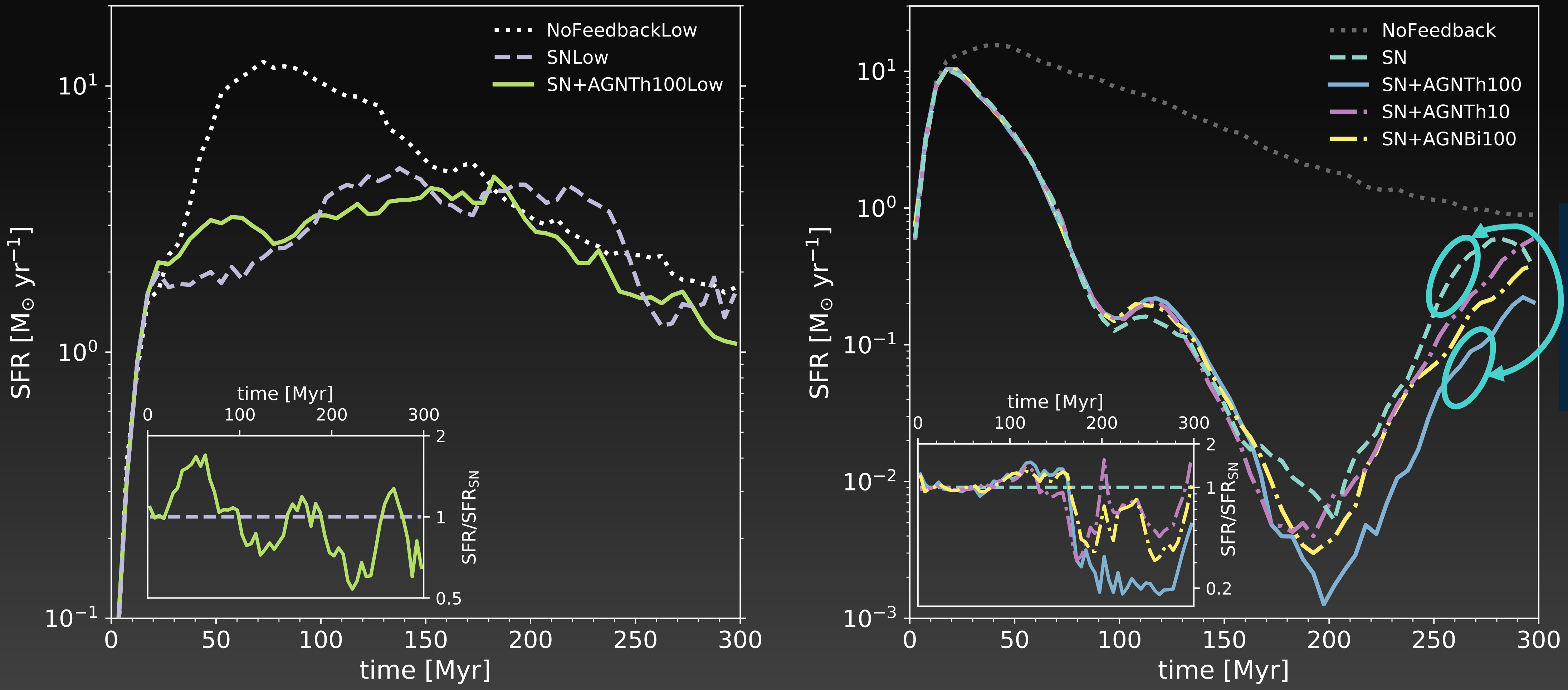
Isolated disc galaxies (non-cosmological) with $M_{stars} = 2.1 \times 10^9\ M_\odot$ and a central black hole ($M_{BH} = 10^5\ M_\odot$)

Star formation efficiency $\varepsilon_{SF} = 0.015$ or $\varepsilon_{SF} = 0.15$

With added AGN feedback outflows are significantly faster and reach higher temperatures.



STAR FORMATION PROPERTIES

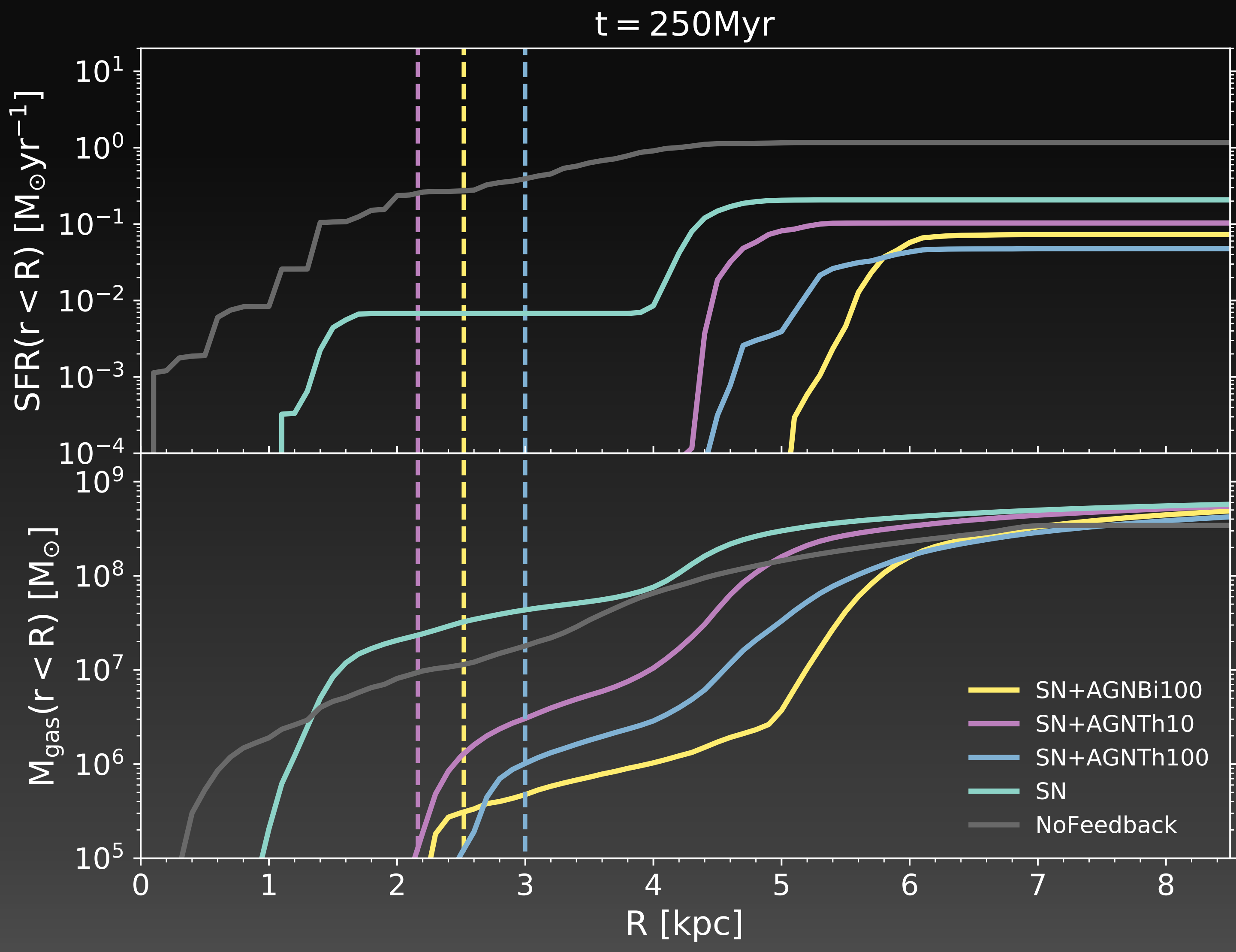


Significant offset only for high-luminosity, isotropic AGN winds

AGN activity only has a **small** effect on **overall** star formation rates. But no cosmological inflows!

‘Fast and energetic AGN-driven outflows in simulated dwarf galaxies’, Koudmani et al. (2019), MNRAS, 484, 2, 2047

STAR FORMATION PROPERTIES



AGN activity has a **significant** effect on **central** star formation rates.

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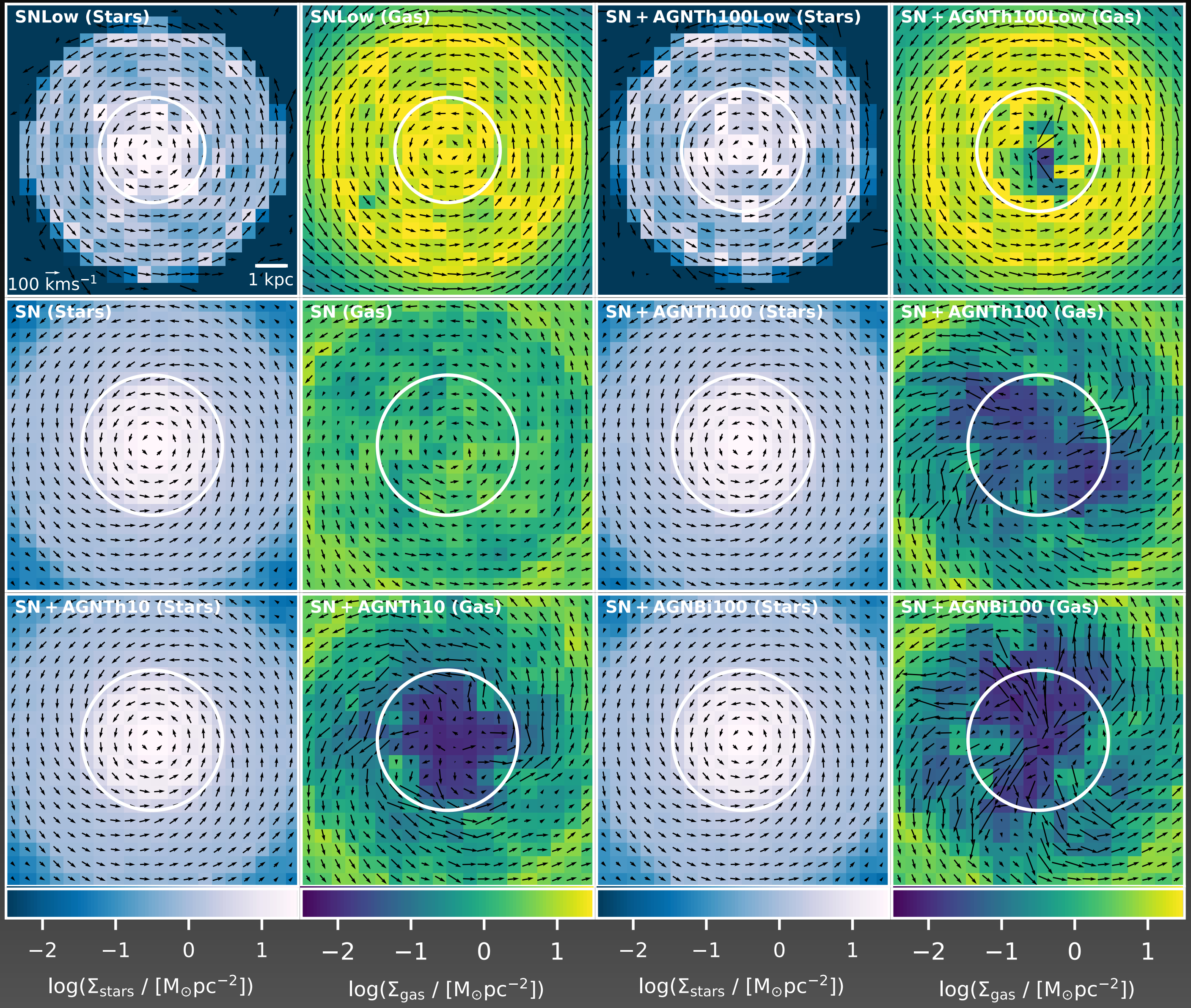
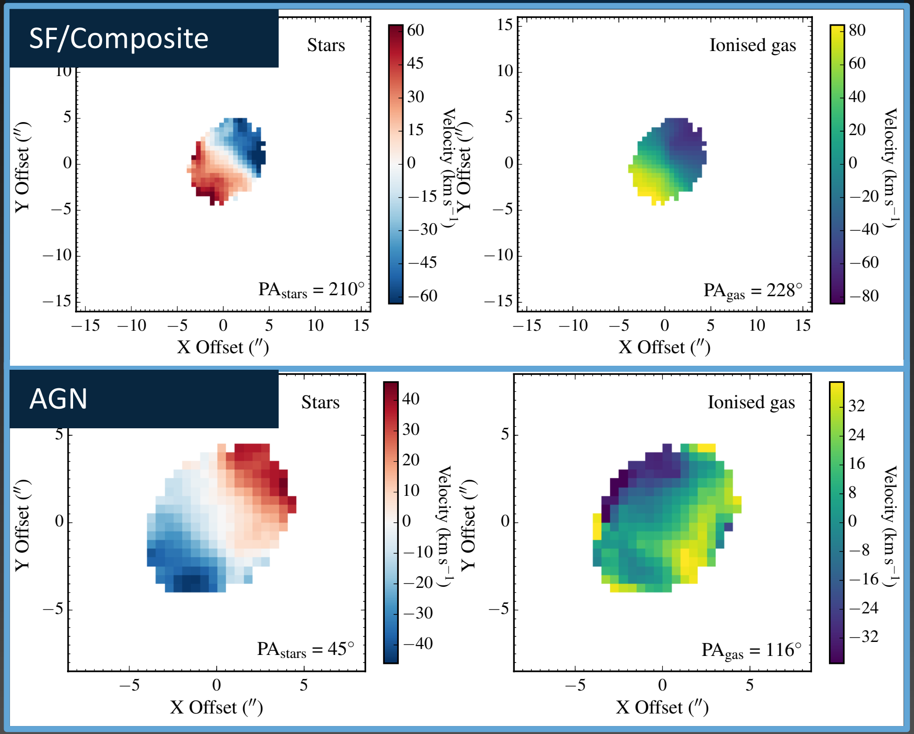
COMPARISON TO MANGA OBSERVATIONS



- Stellar motions unaffected by feedback
- Supernova-driven outflows too slow to affect gas kinematics
- AGN-driven outflows disturb gas motions



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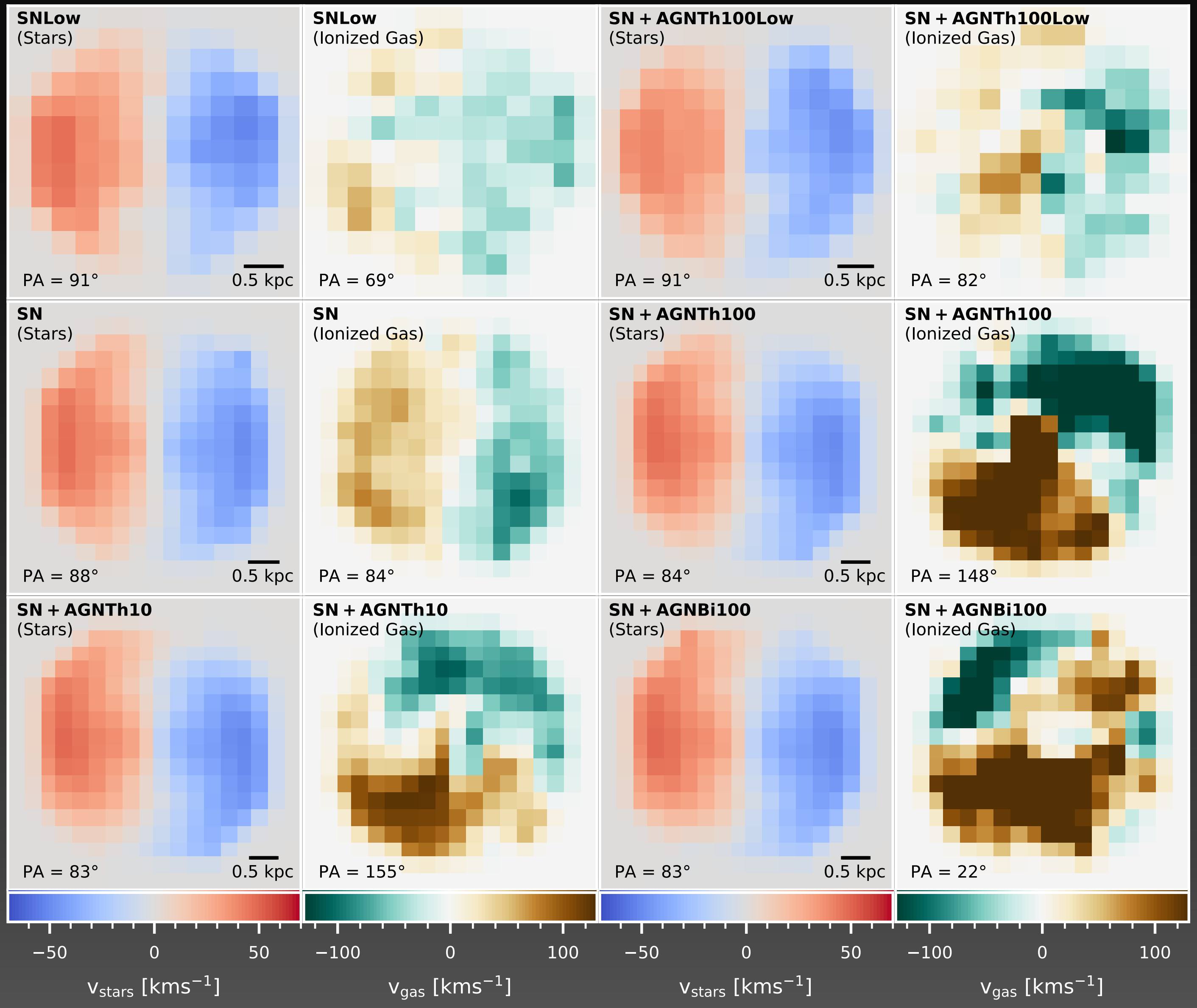

- Stellar motions unaffected by feedback
- Supernova-driven outflows too slow to affect gas kinematics
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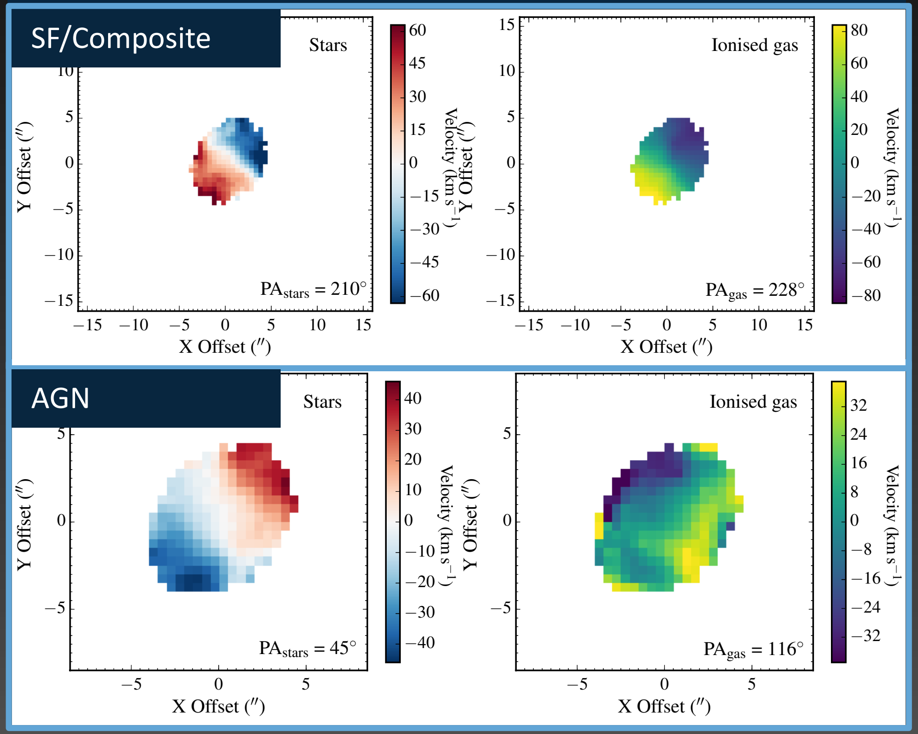
→ inferred angular momentum vectors are misaligned by kinematic offset **ΔPA**



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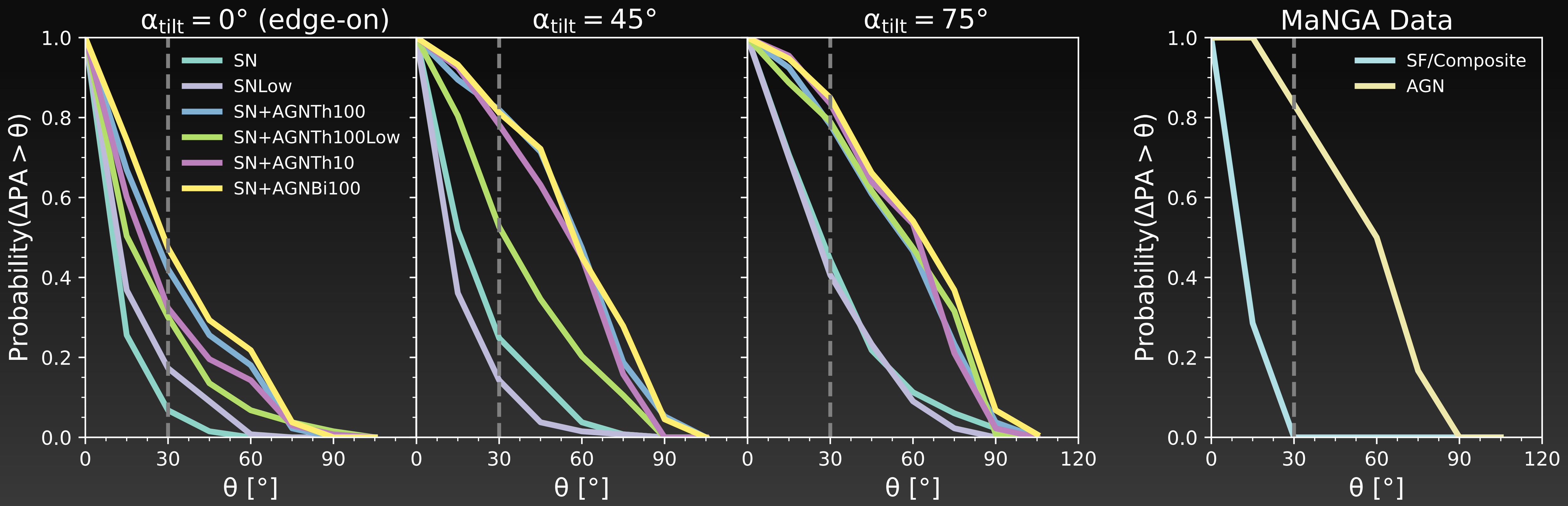

- Galaxies with AGN activity significantly more likely to be 'offset'.

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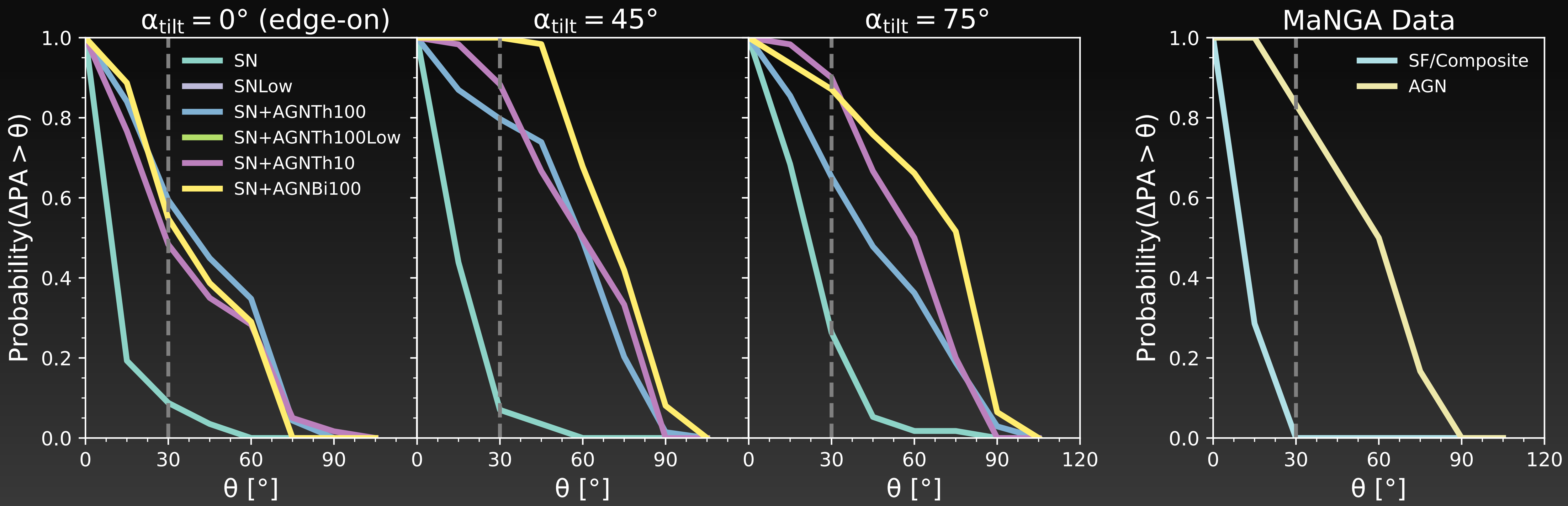
COMPARISON TO MANGA OBSERVATIONS



- Galaxies with AGN activity significantly more likely to be 'offset'.
- Star formation rate cut brings supernova only run into agreement with MaNGA.

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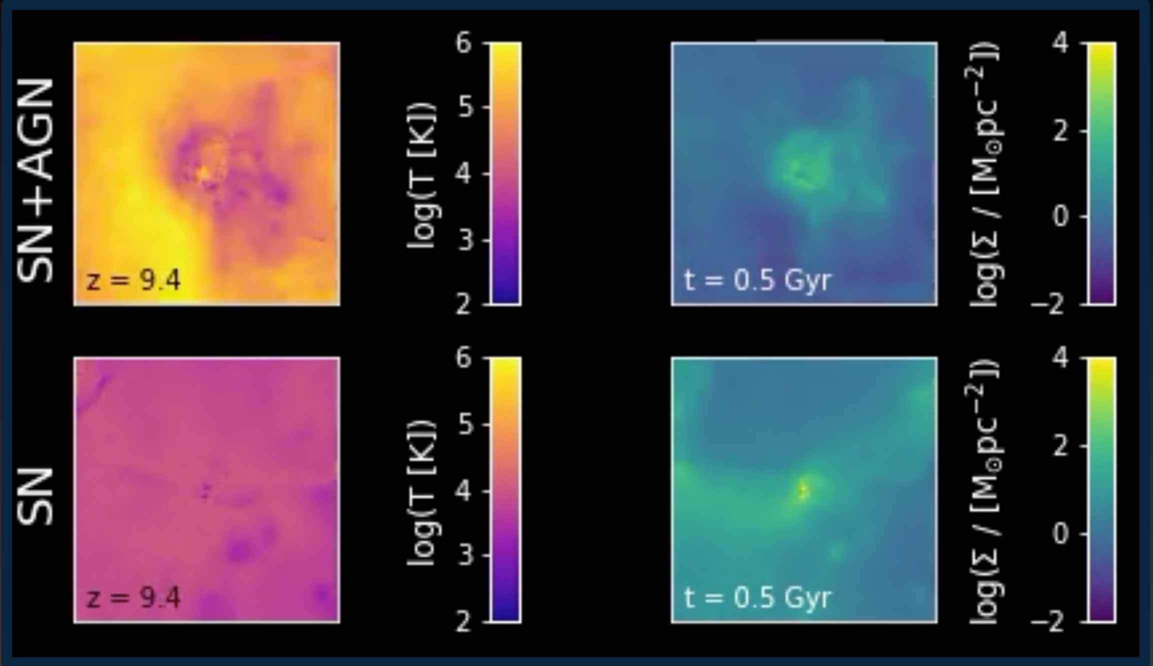
CURRENT WORK

Isolated simulations: Fast and energetic outflows, but no significant effect on SFRs

Next step: fully self-consistent cosmological zoom-in simulations of high-redshift dwarfs

- Can AGN regulate star formation via hindering cosmic gas inflows?
- Build-up of dense gas from inflows and mergers renders SNe on their own too inefficient to expel gas (Smith+2019).
- Add AGN to this set-up: try different accretion/feedback models.



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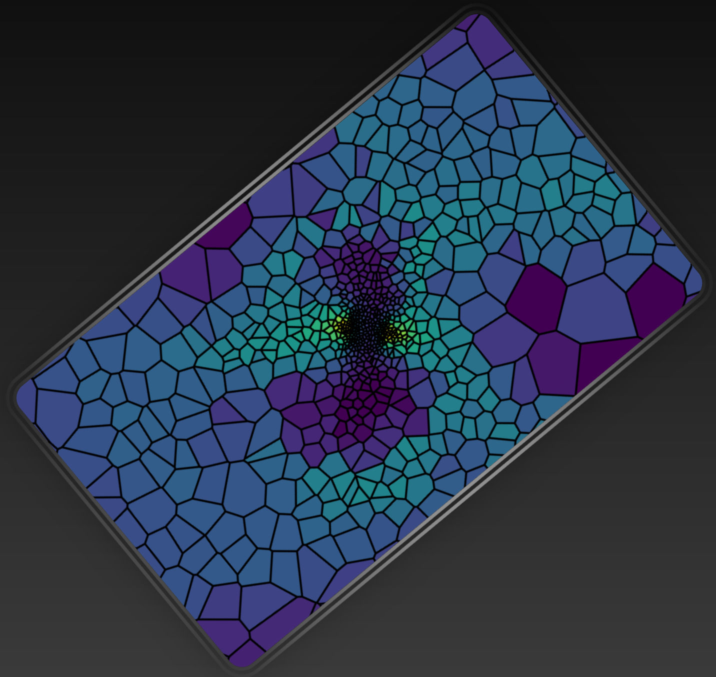
CONCLUSIONS & OUTLOOK

- AGN may be an important ingredient in dwarf galaxy models.
- We find that AGN activity
  - has a small effect on overall star formation rates.
  - has a significant effect on central star formation rates.
  - enhances outflows to much higher temperatures and much higher velocities, in agreement with observations from MaNGA.
- Current and future work
  - fully self-consistent cosmological zoom-in simulations
  - Test different environments and different black hole feedback prescriptions.



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