

# Future Prospects of Simulating Emission Lines

What is becoming possible with simulations?

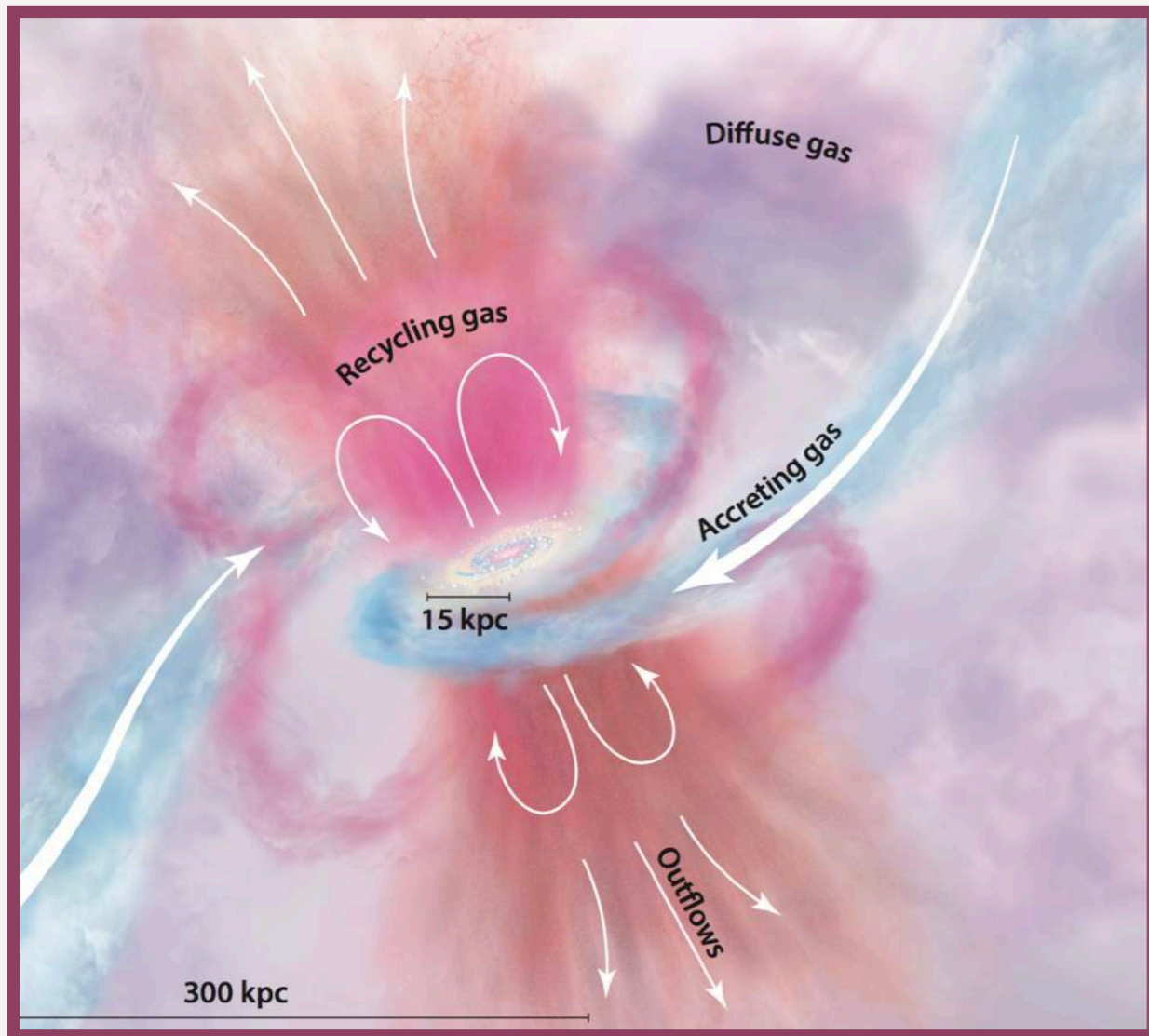
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in collaboration with

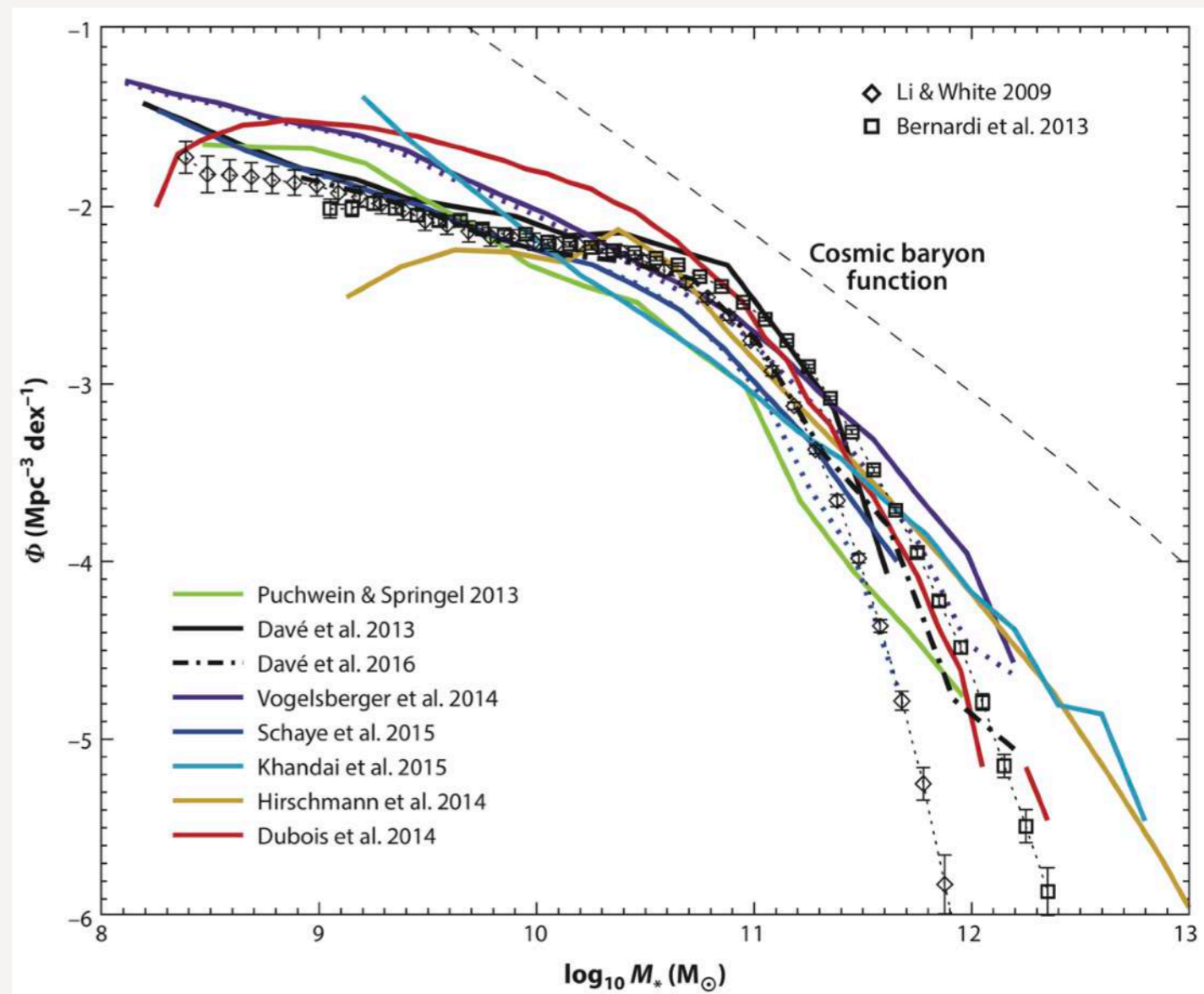
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**The 9th Survey Science Group Workshop, 2020/02/12, High1**

# Galaxy formation in a nutshell



Tumlinson+(17, ARAA)



Naab & Ostriker (17, ARAA)

“Strong outflows are not easily generated in simulations with SN feedback”  
We need stronger outflows, but how?

# Early feedback before SNe

Westerlund 2 (HST)

**~20'**

**RADIATION  
FEEDBACK**

**~10'**

**AGN FEEDBACK  
COLD FLOWS**

**~00'**

**SN FEEDBACK**

# New Observables with Radiation

Luminosities

Masses

Sizes

Morphologies

Metallicity

SFR

Kinematics

Thermal  
properties

Gas content

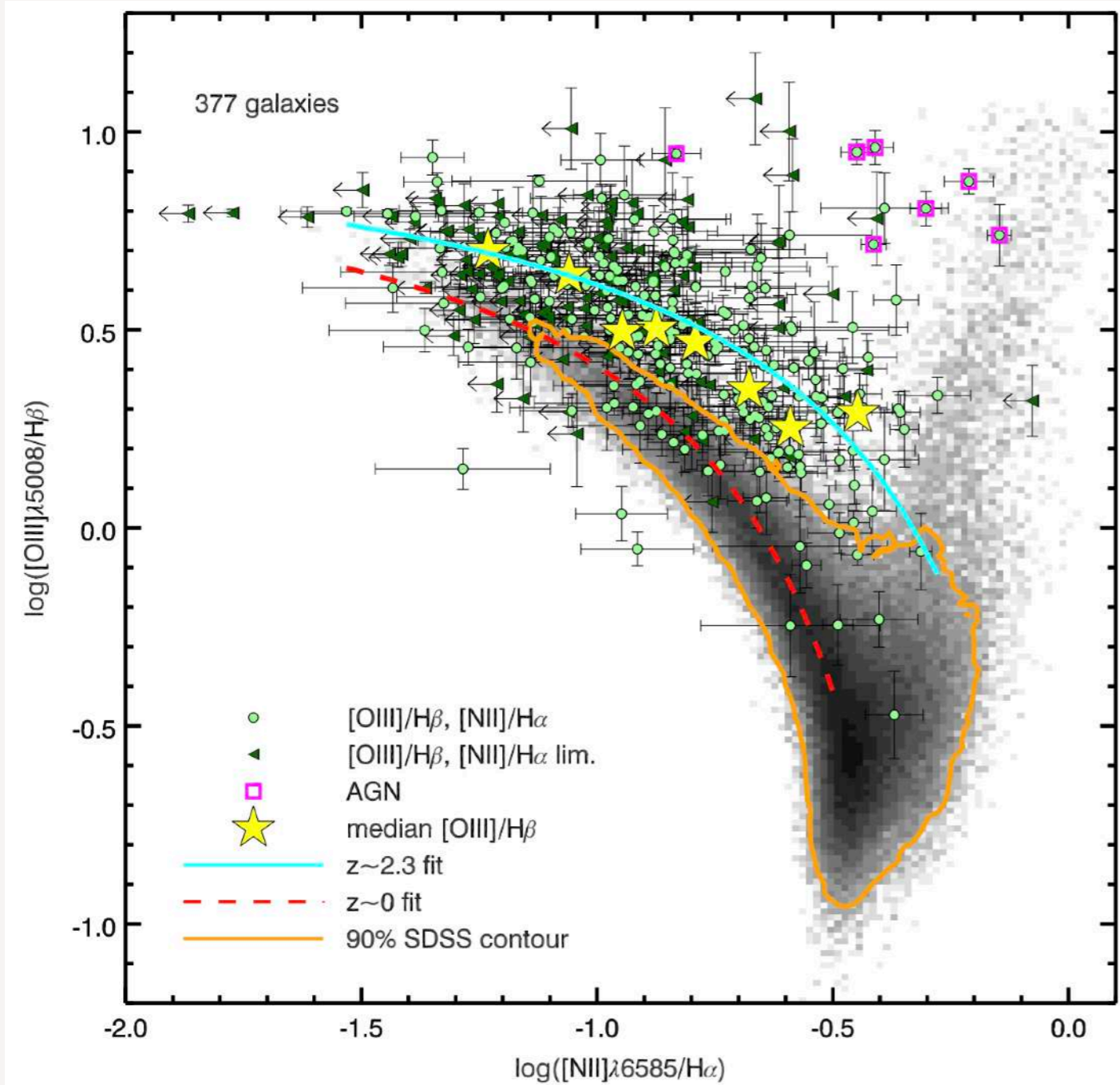
ISM

CGM

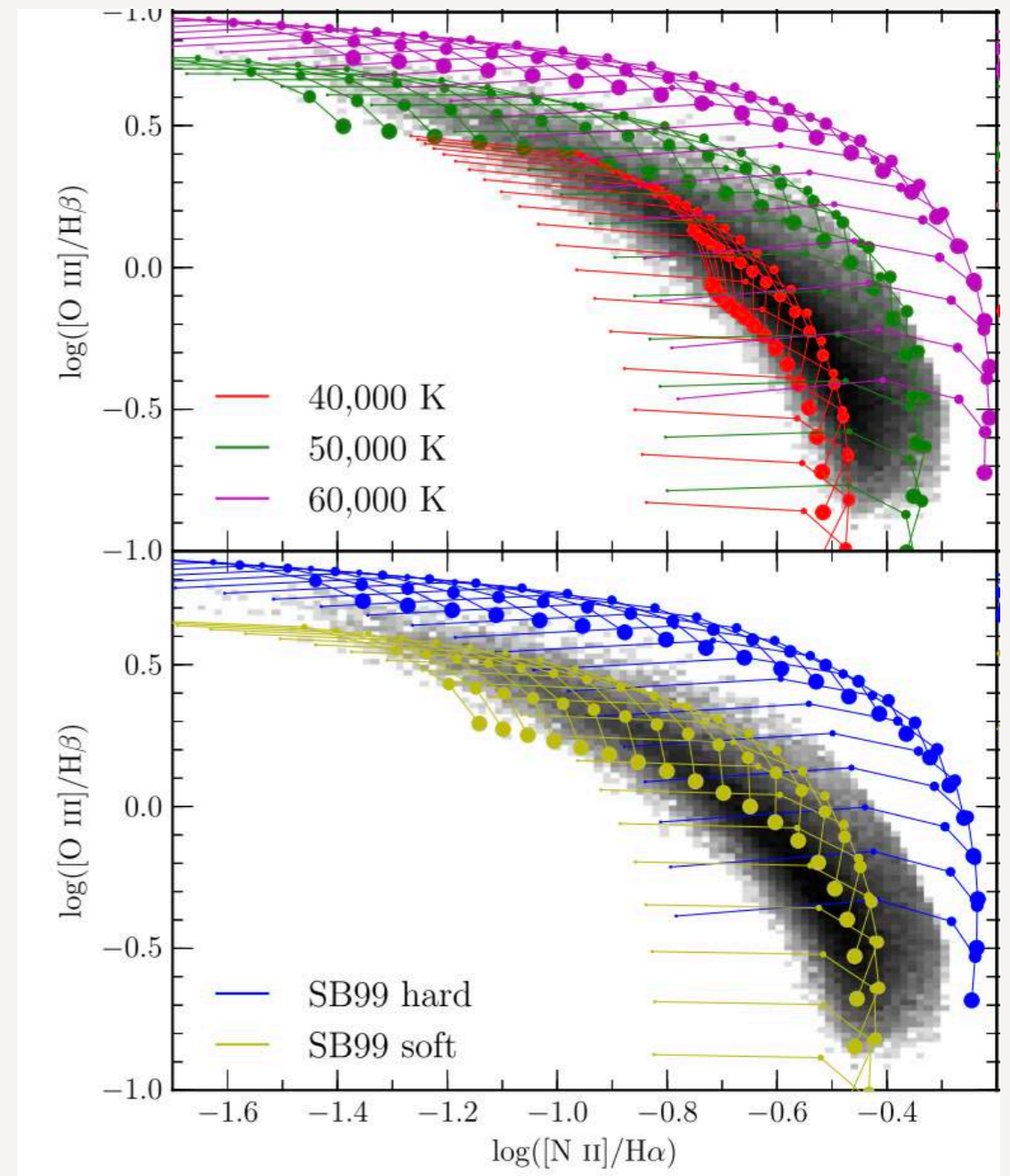
IGM

Two examples: Lyman alpha, metal lines

# Strong metal emission lines - BPT diagram



Strom+(17)

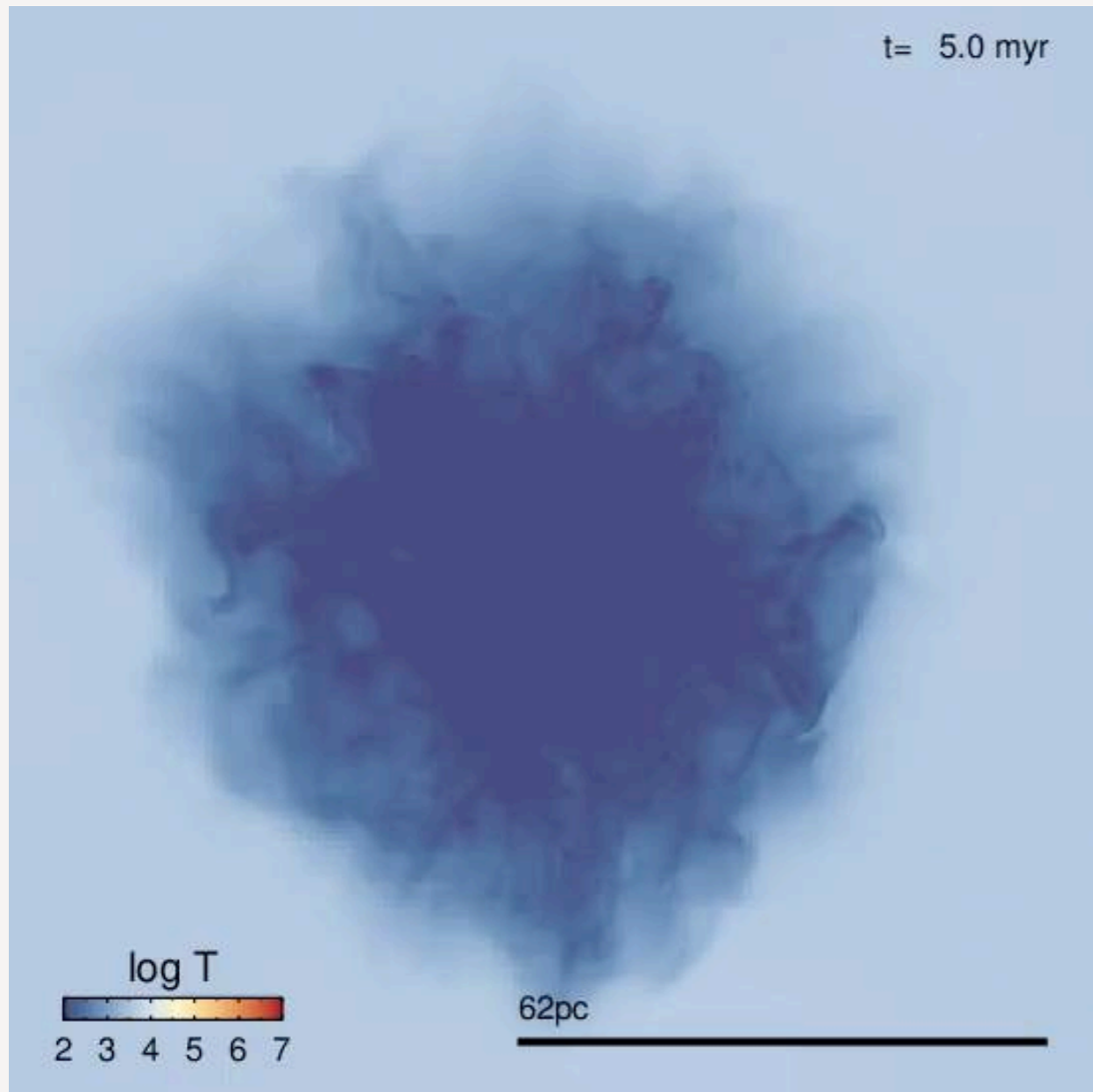


Sanders+(16)

Line ratios: useful probe of (electron) densities, temperature, and SEDs

Offset in BPTs may be attributed to the harder spectra of stellar populations: Binaries?

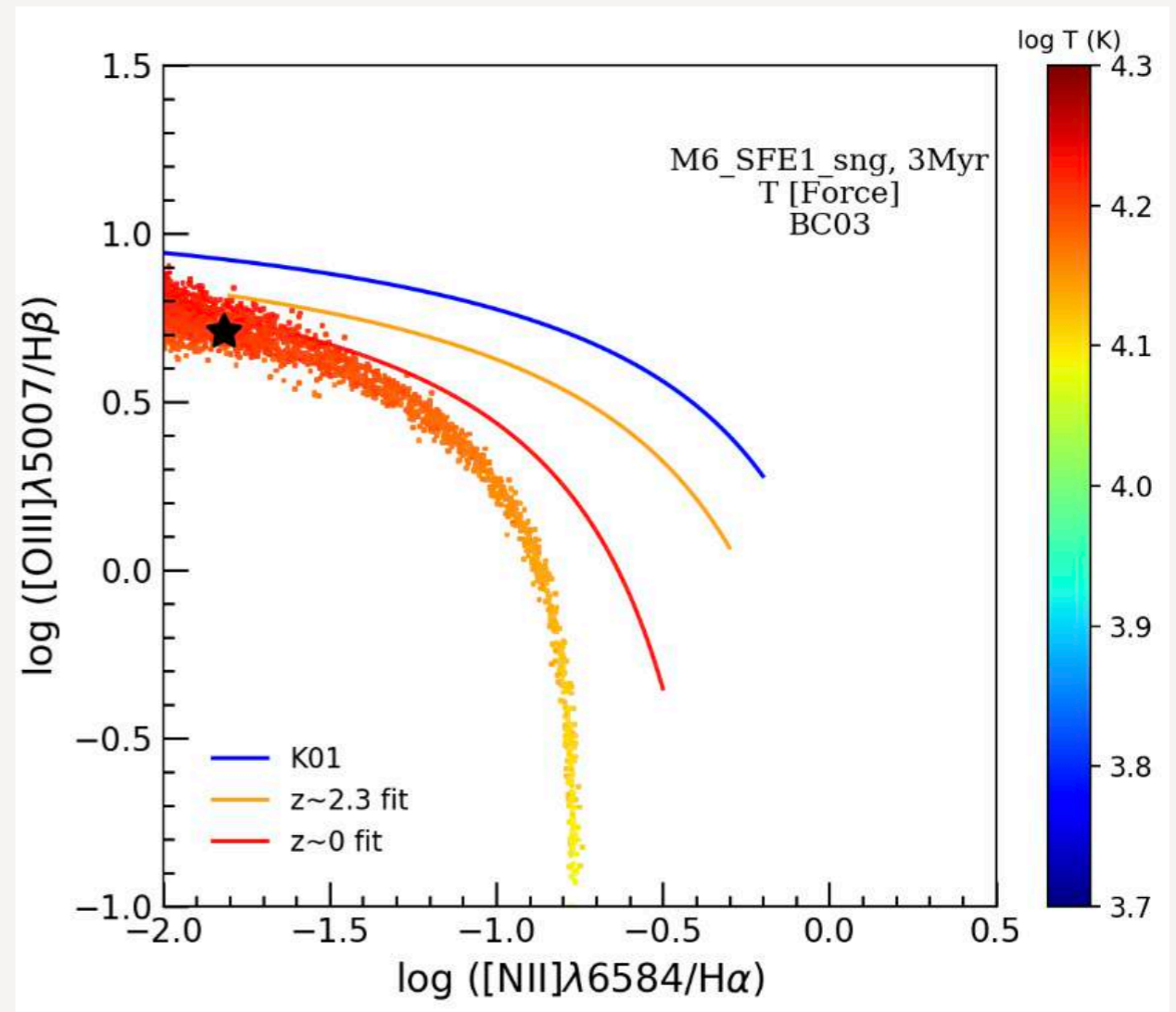
# Predicting metal emission lines from simulations



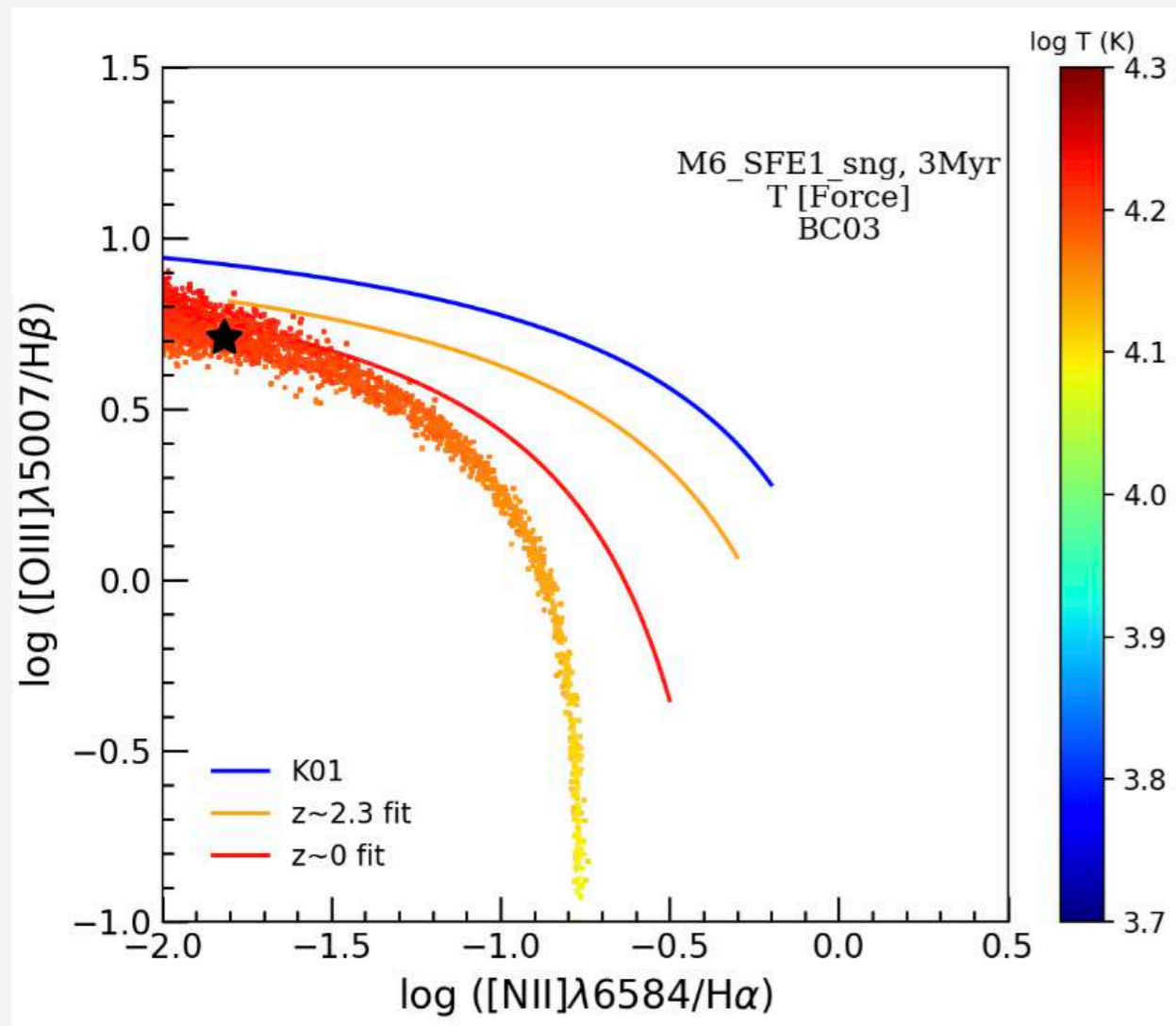
Radiation-hydrodynamic simulation of a star-forming cloud

Kimm+(19,MNRAS)

Radiation field,  $n_H$ ,  $T$  in each cell  
+  
Cloudy

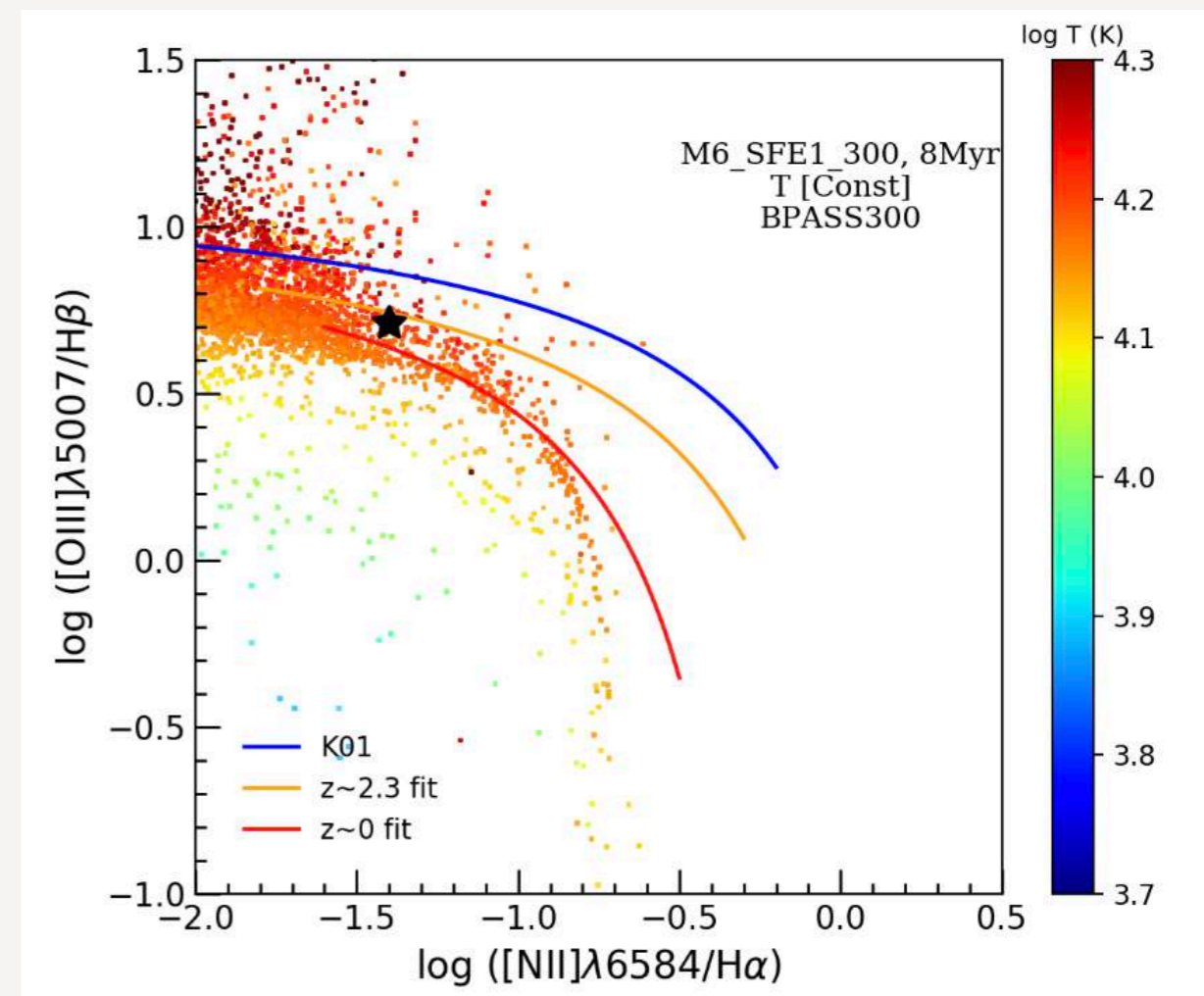


# Predicting metal emission lines from simulations



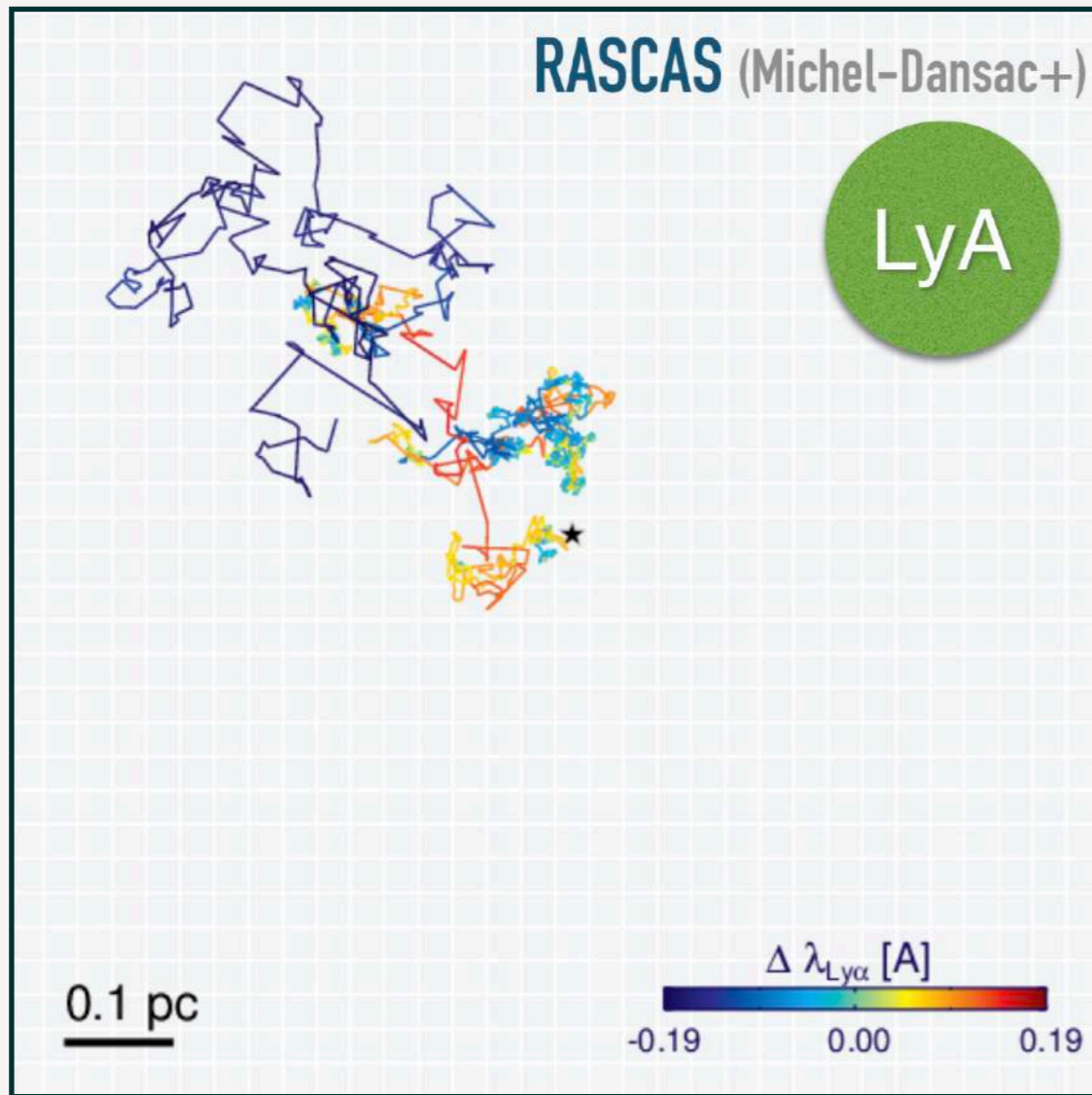
SEDs w/o binaries (0.1-100  $M_{\text{sun}}$ )

The offset in BPT diagram is due to strong/harder spectra



SEDs with binaries (0.1-300  $M_{\text{sun}}$ )

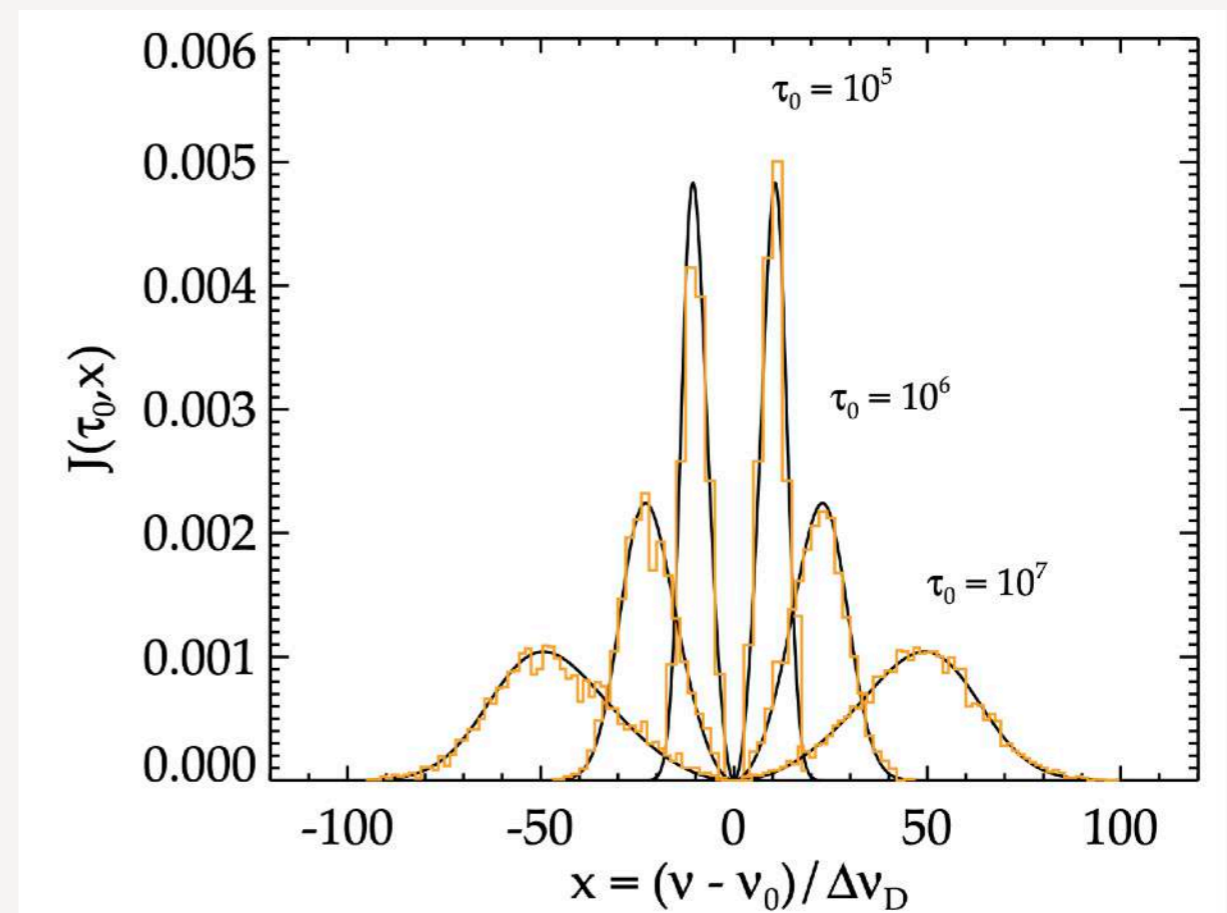
# Lyman alpha emission line: useful probe of kinematics



How optically thick?  
expanding or infalling?

Advantage

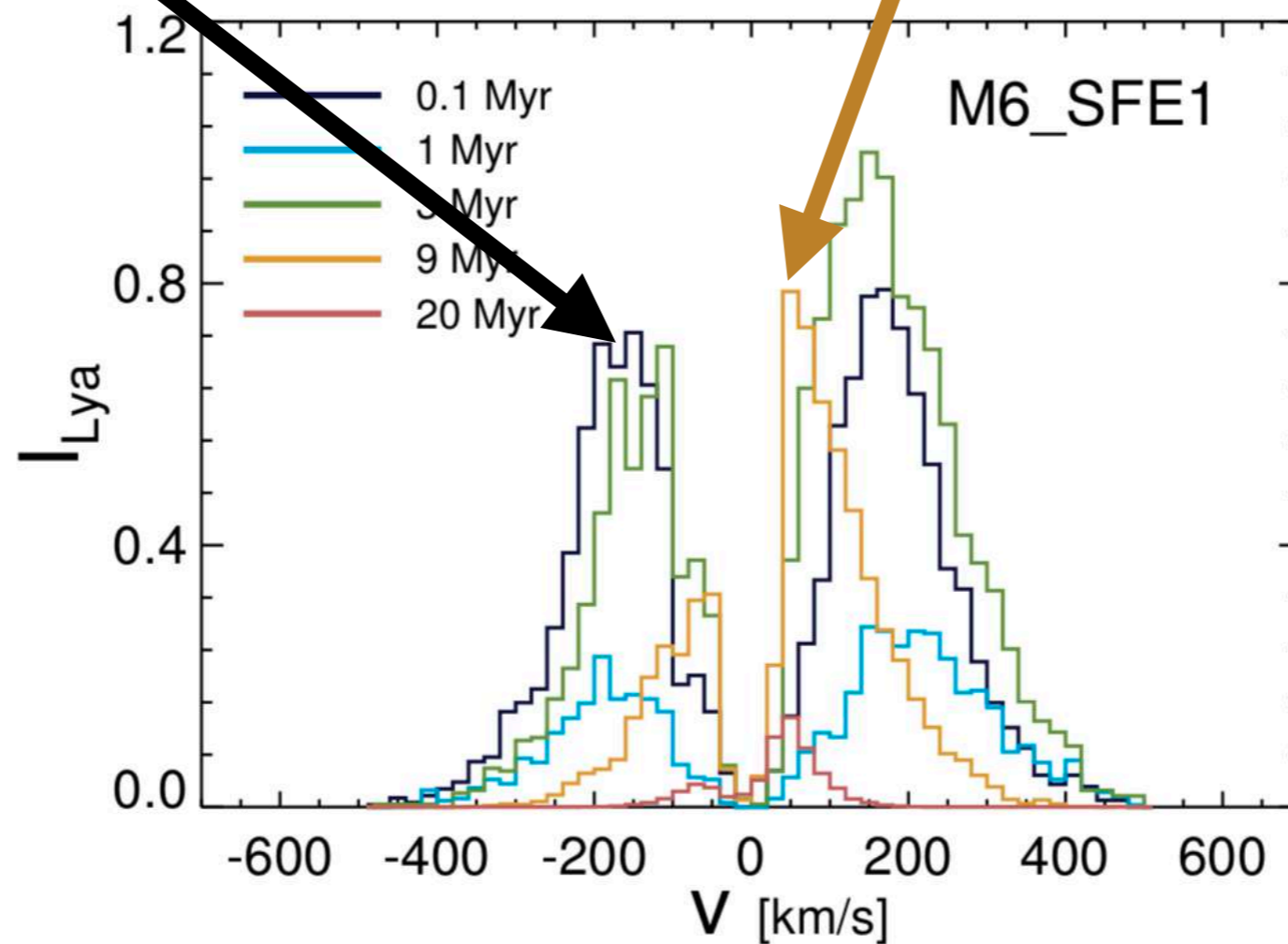
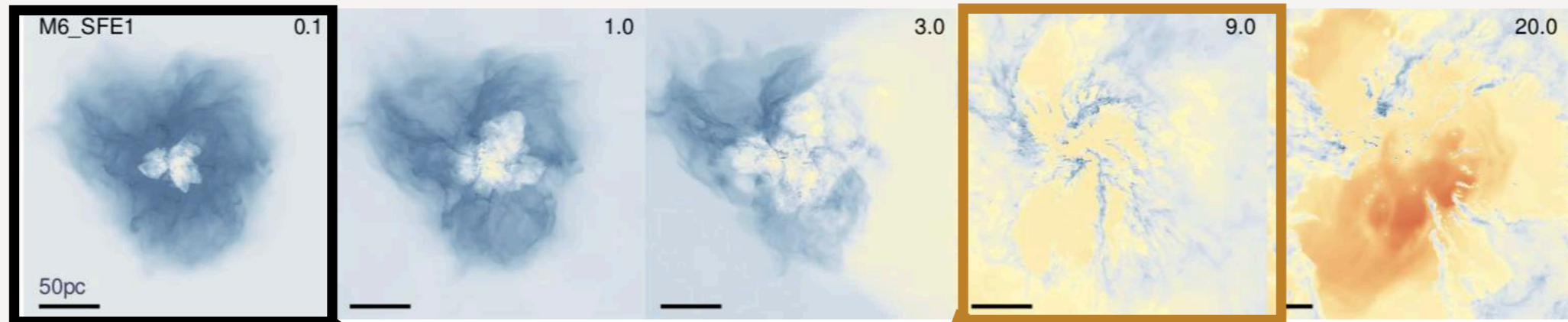
- 1) one of the strongest lines
- 2) carries kinematic information



Dijkstra (14)



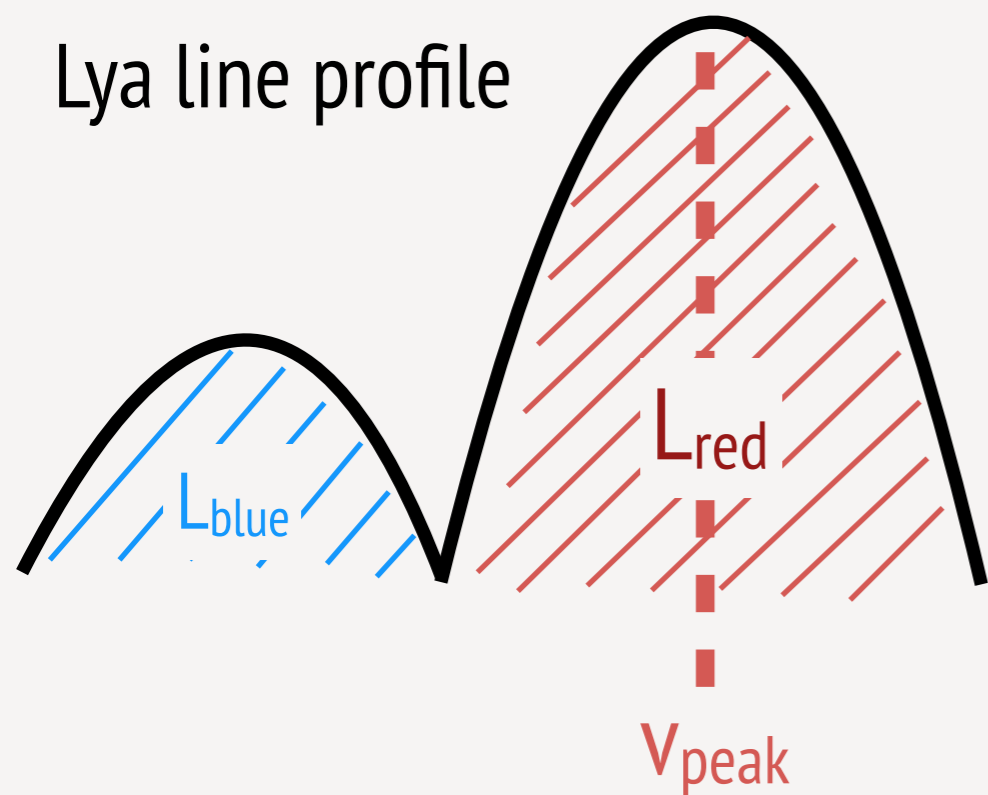
# Lyman alpha emission line: useful probe of kinematics



Blue peak

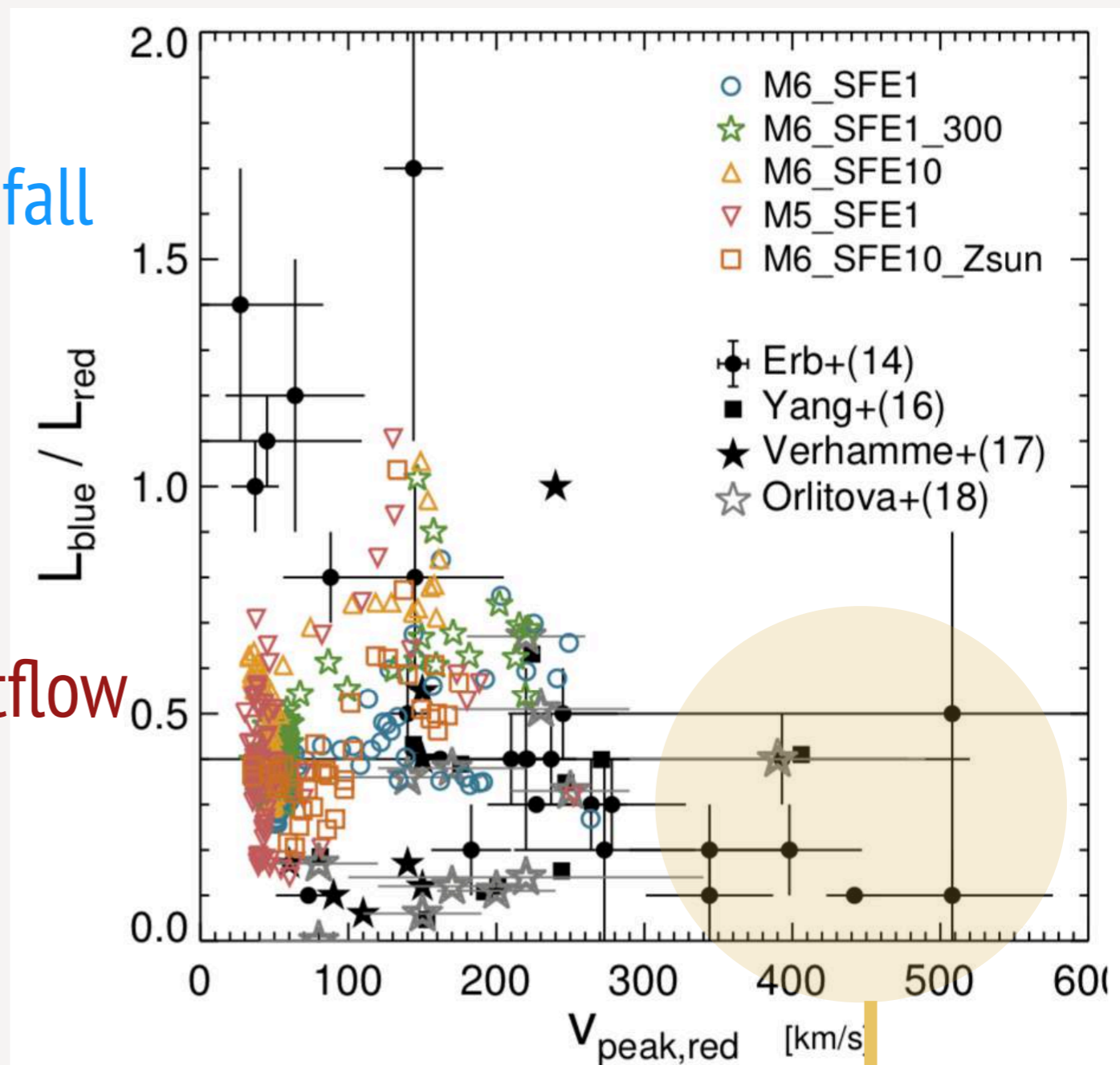
Red peak

# Lyman alpha emission lines: useful probe of kinematics



infall

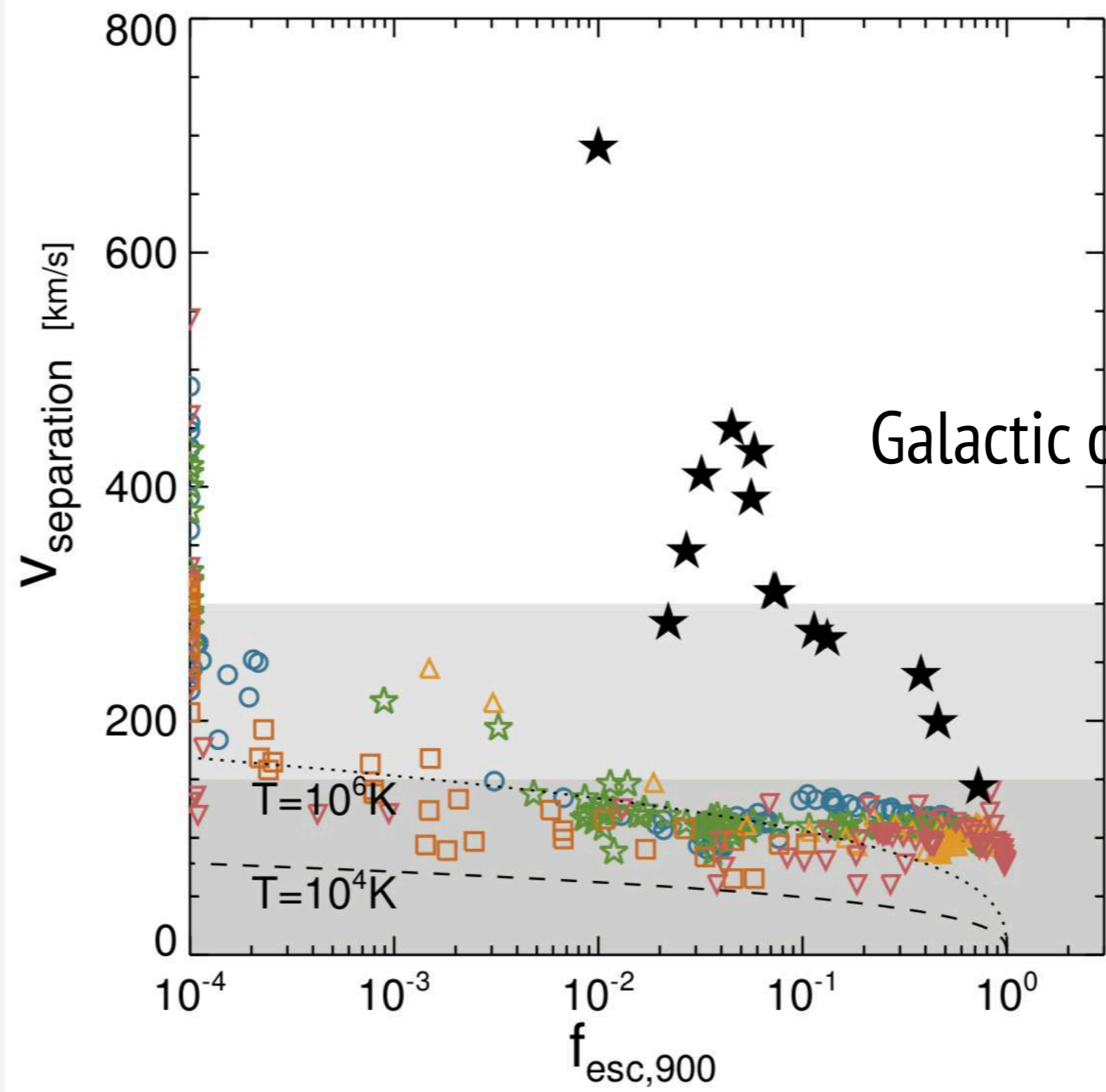
outflow



**optically thick outflow?**

# LyA-LyC connection - distribution of neutral hydrogen

more scattering  $\uparrow$

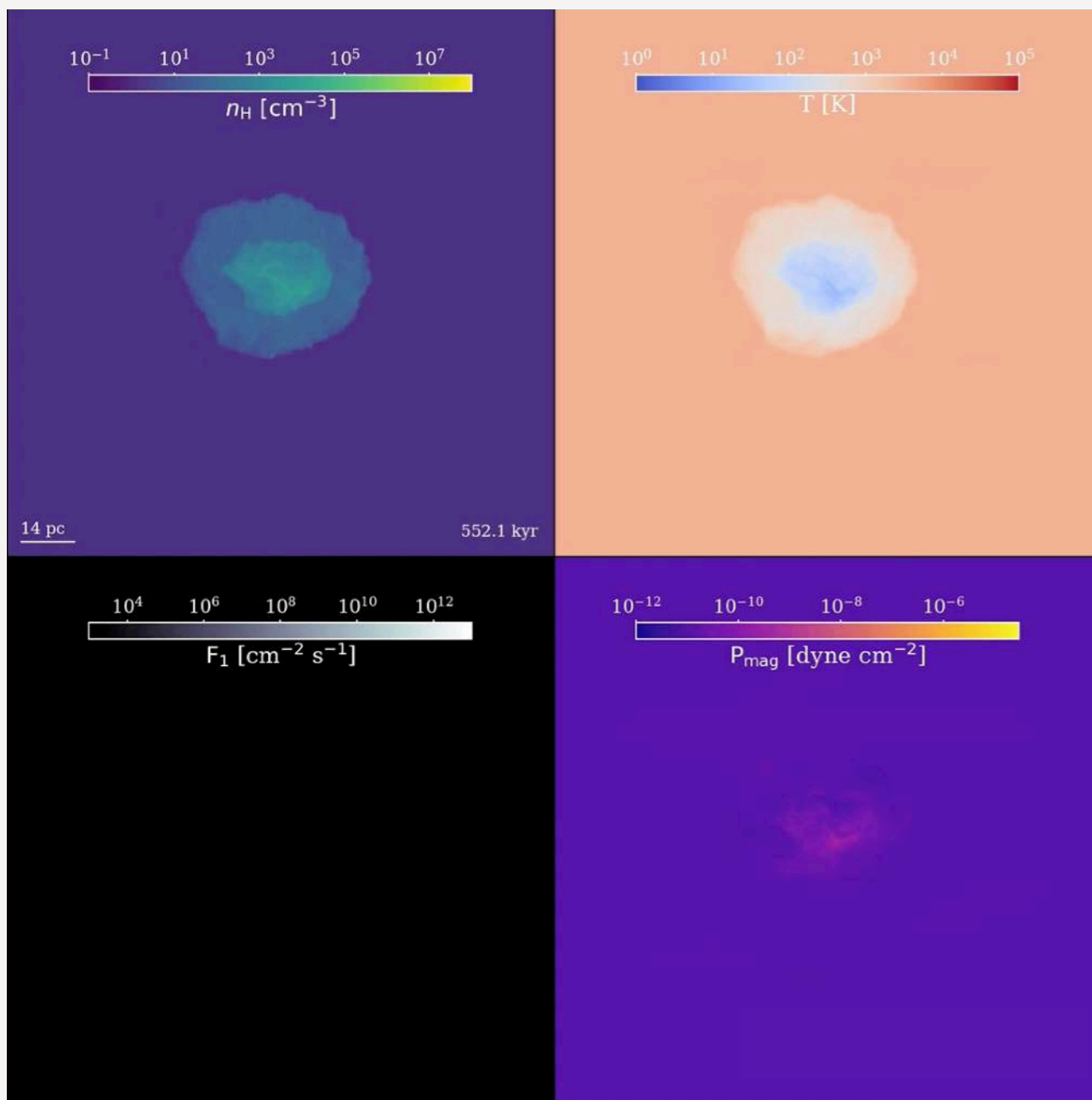


more optically thin  $\rightarrow$

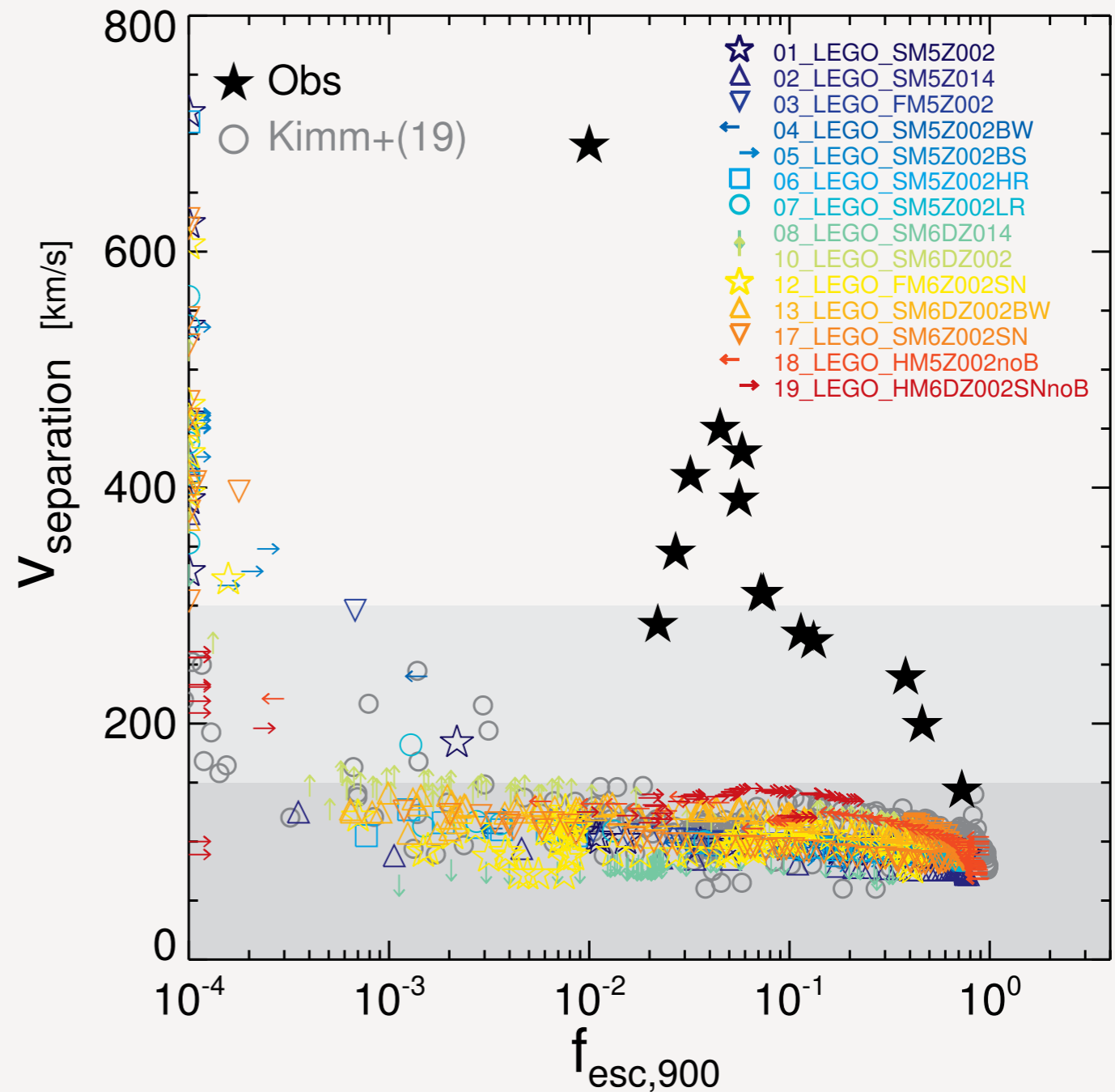
# LyA-LyC connection - distribution of neutral hydrogen

Adding magnetic fields, various morphologies

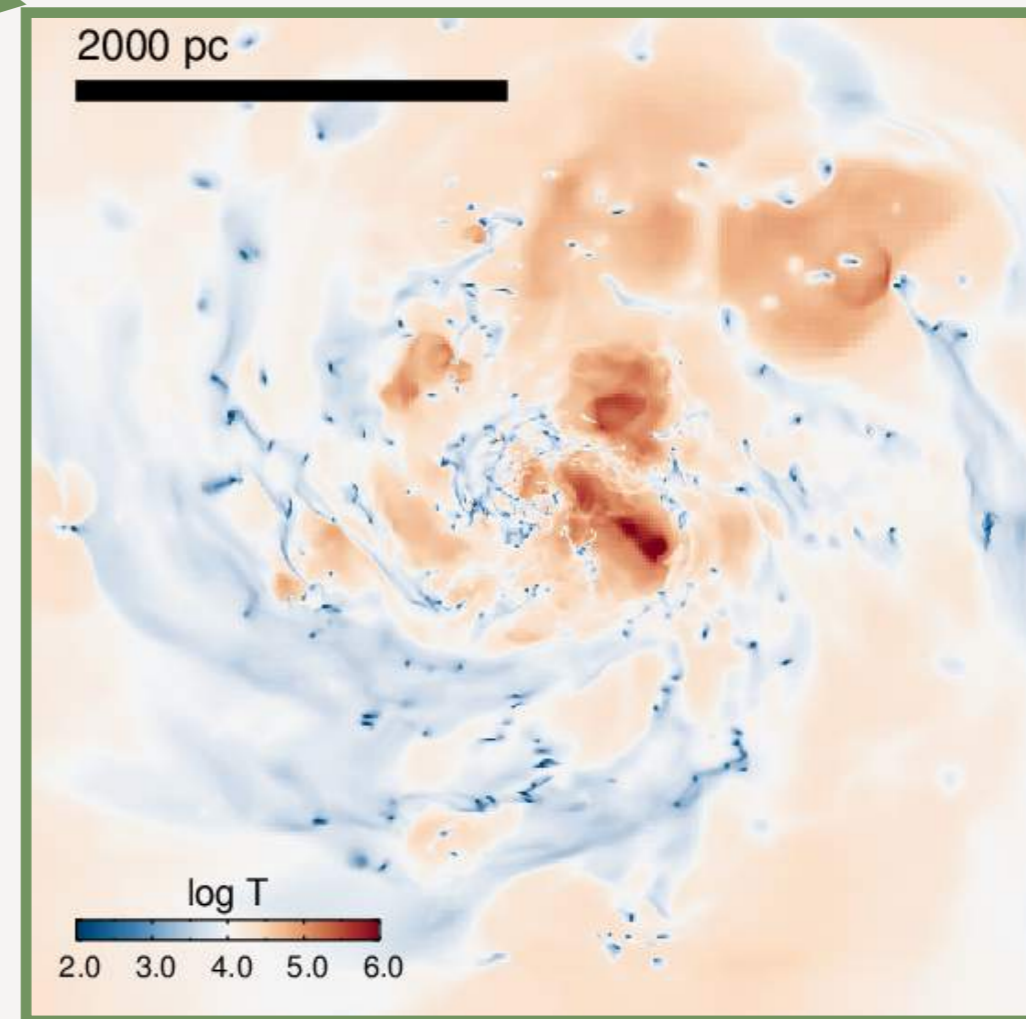
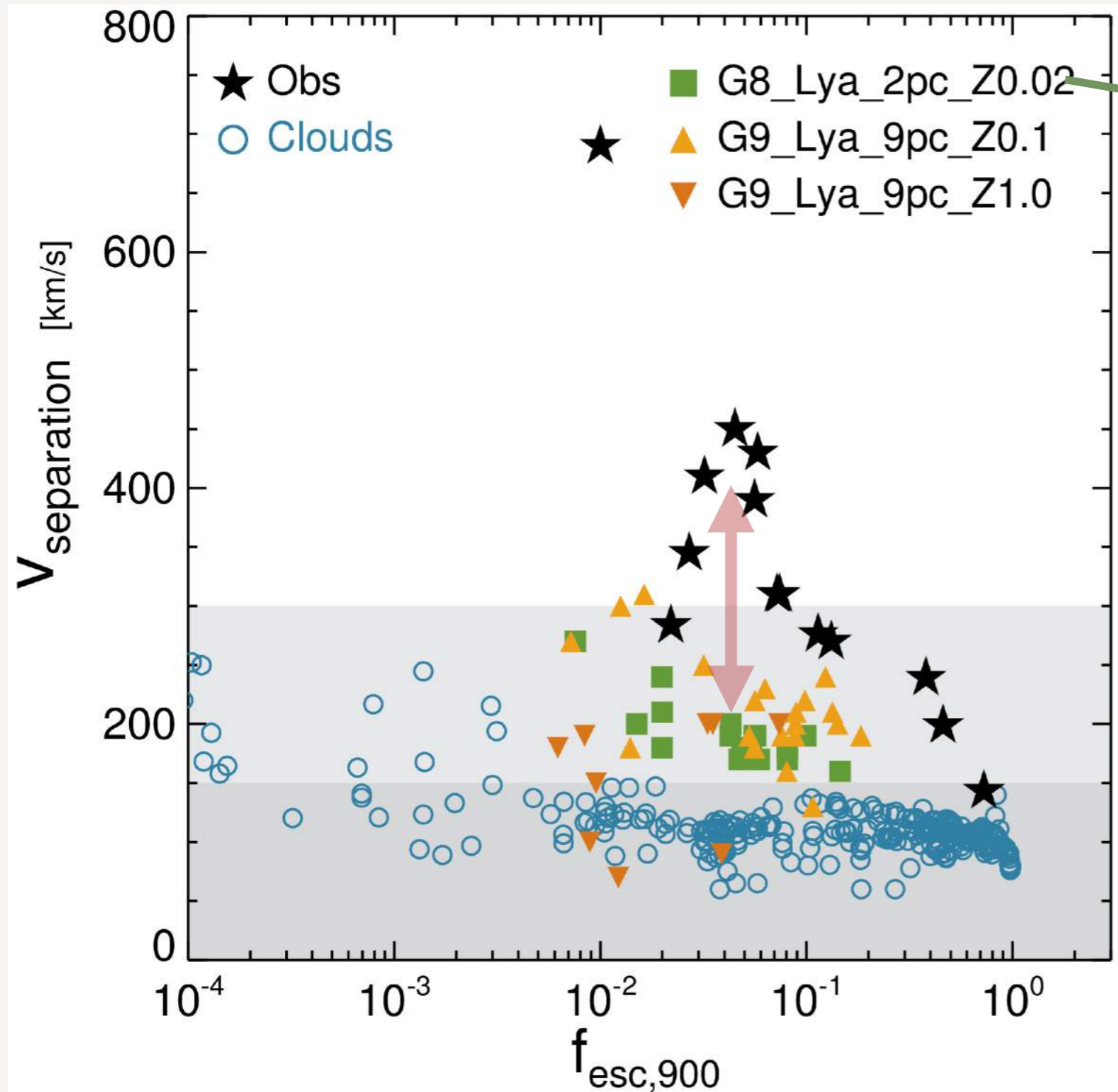
Spherical, Filamentary, Uniform etc...



RMHD simulations of a GMC



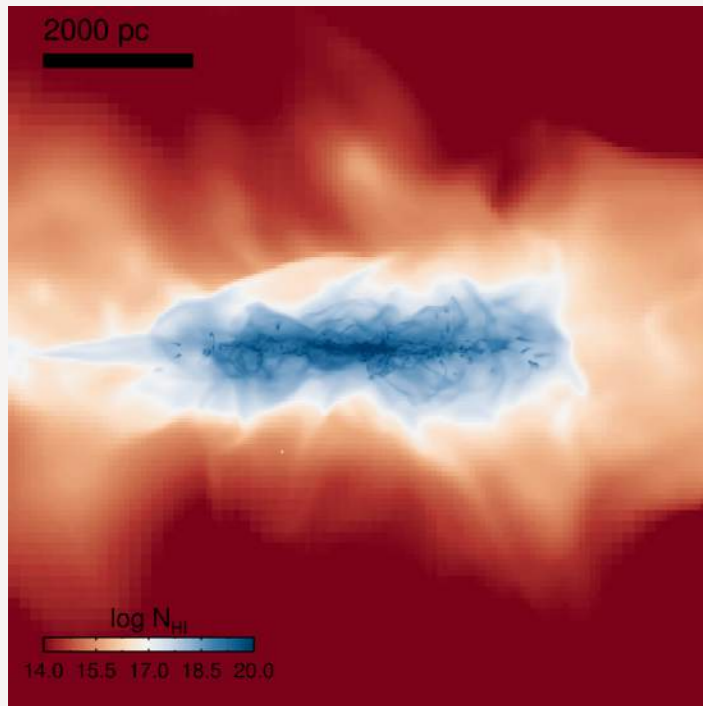
# LyA-LyC connection on galactic scales?



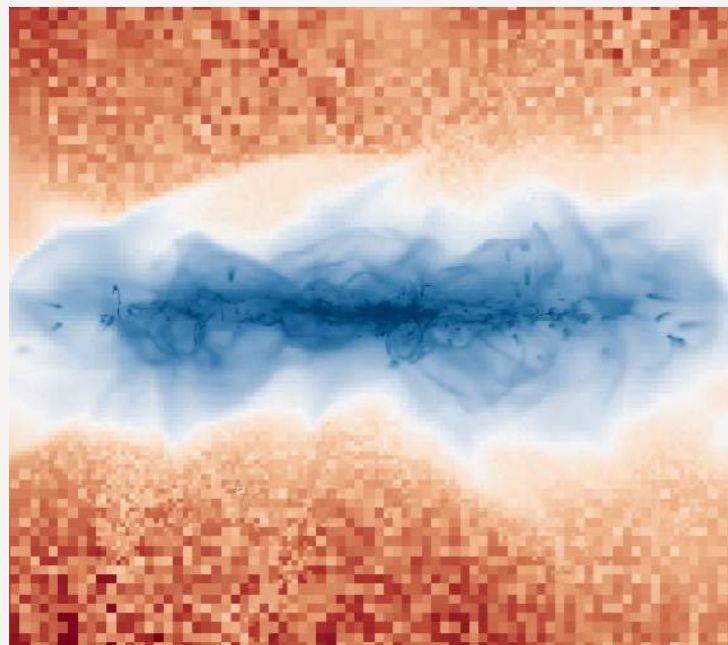
**G8:**  $M_{\text{star}} \sim 10^8 M_{\text{sun}}$   
**G9:**  $M_{\text{star}} \sim 10^9 M_{\text{sun}}$

# A possible scenario: foggy circum-galactic medium

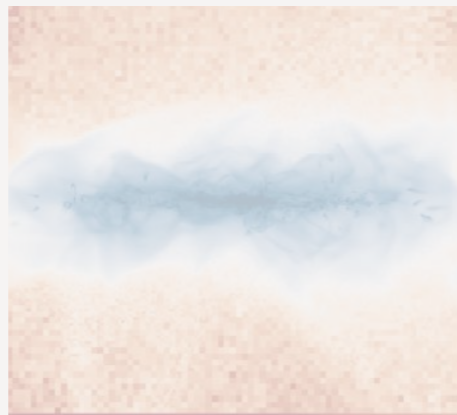
what we get from the latest RHD sim



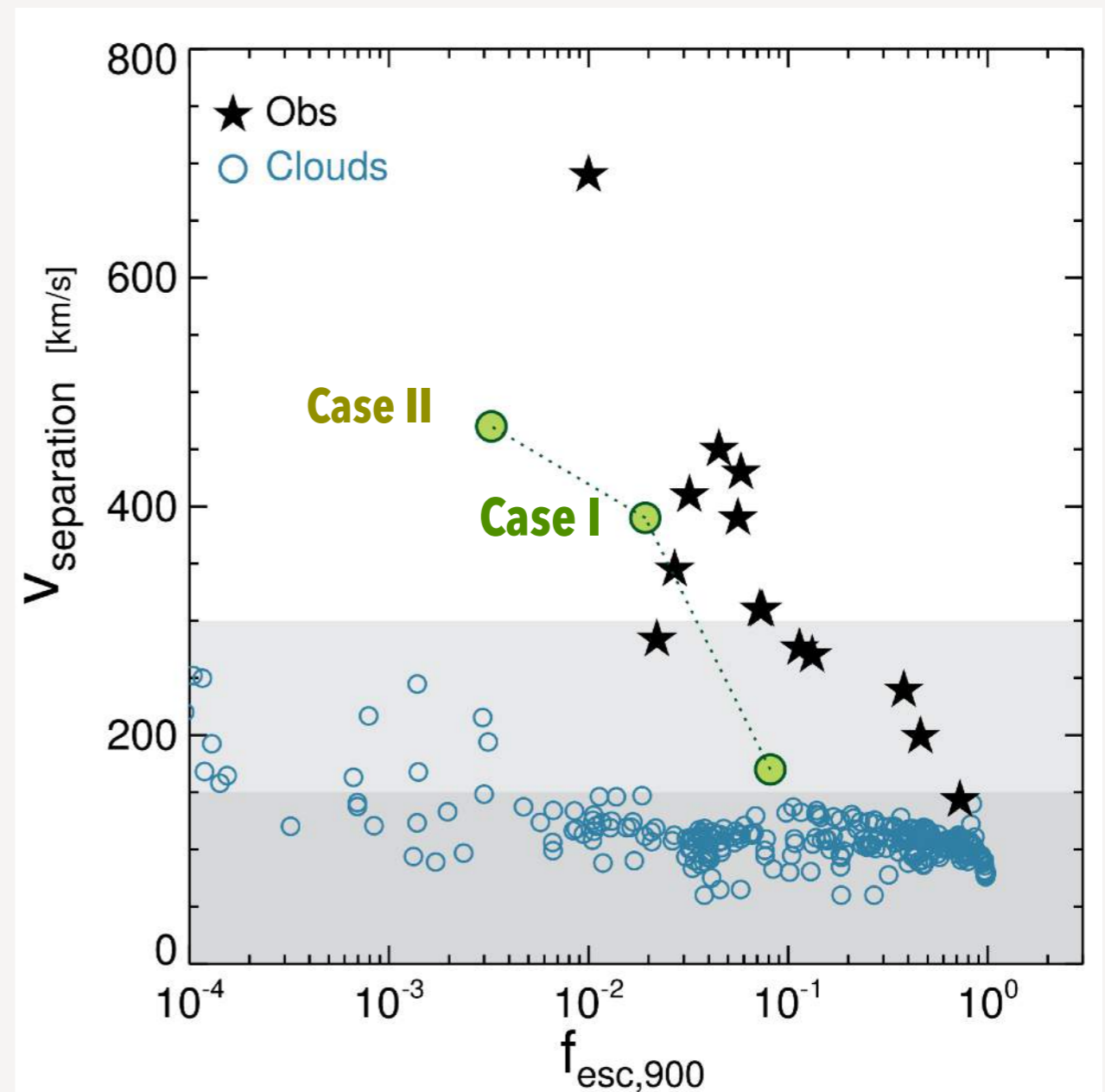
Case I



Case II



Suppose that we have **foggy** but still **diffuse** ( $N_{\text{HI}} \sim 10^{17} \text{ cm}^{-2}$ )  
**circum-galactic medium,**  
(also responsible for the extended Lyman alpha halo)



if the cloudlets in the CGM are more neutral, yes!

# Summary

High-resolution simulations with radiation can now make predictions about strong emission lines, including BPT lines, Lyman alpha etc

These lines will be useful to understand the thermal status and kinematics of the star-forming regions, ISM, CGM, and possibly even providing some useful info about the SEDs

Of course, **long way to go**, but it will also provide **exciting new possibilities**

- Lyman alpha source distribution at high  $z$  (HETDEX, MUSE, JWST..)
- Formation of globular clusters