The Fate of AGB Winds in Massive Galaxies and the ICM

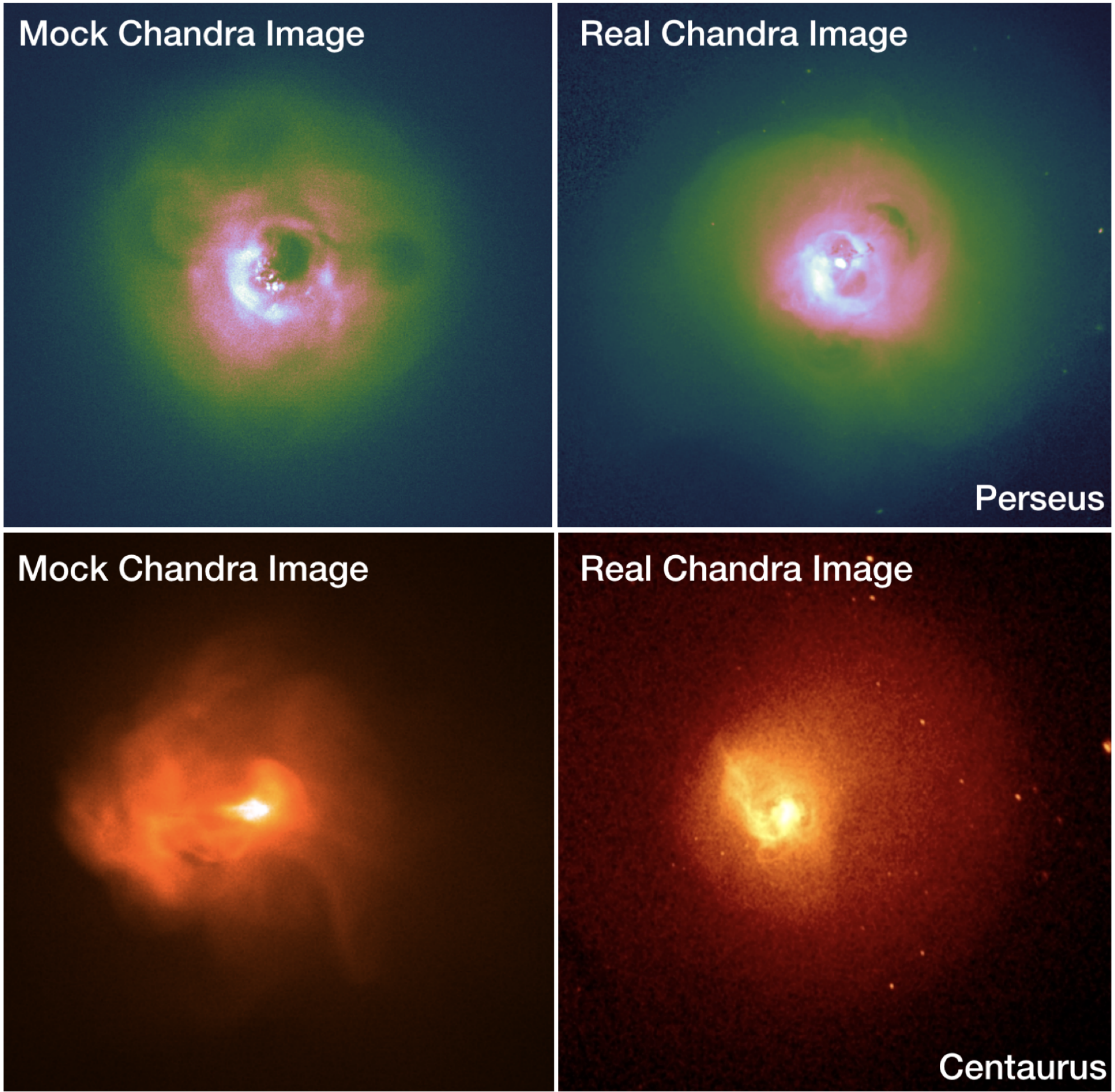
Yuan Li

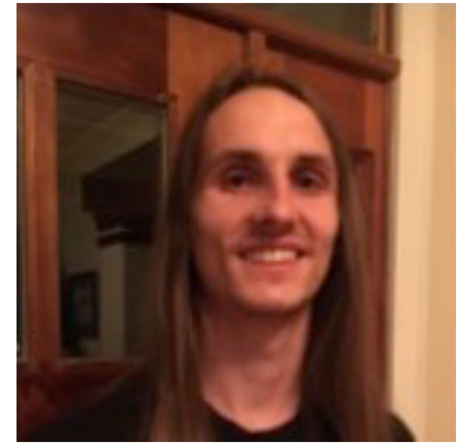
TAC Fellow

University of California, Berkeley

ICM 5th, March, 2019

Nature of Perturbations Driven by AGN Feedback

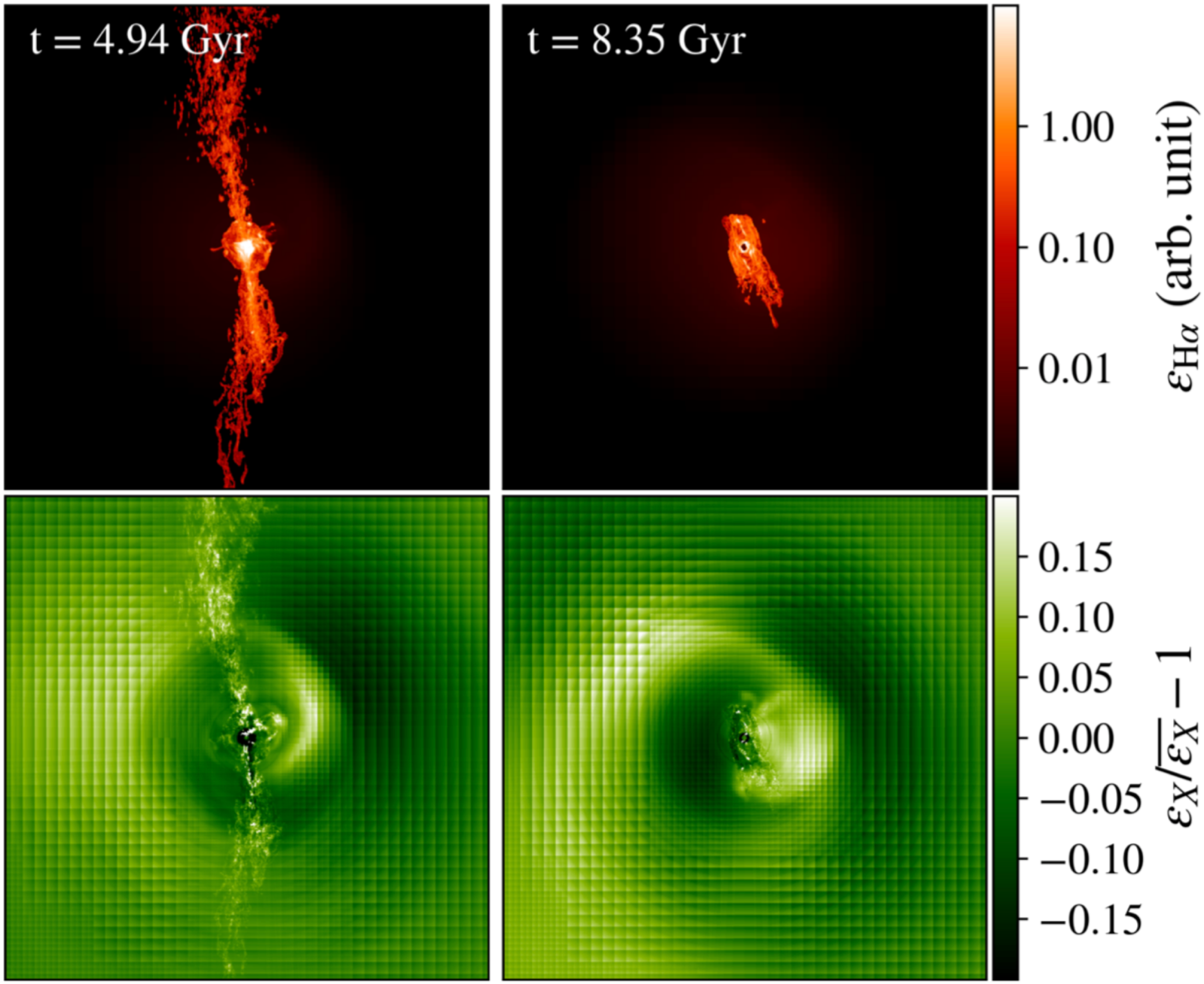


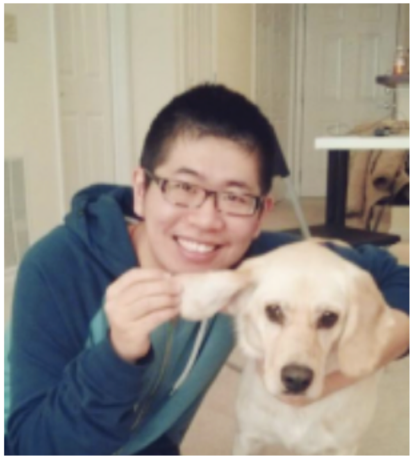


Corey Brummel-Smith
(Georgia tech)

With
Irina Zhuravleva
Daisuke Nagai
Mateusz Ruszkowski

Radiative Feedback in Galaxy Clusters





Qiu, Yu
(Georgia tech=> KIAA)

With
Tamara Bogdanovic
KwangHo Park
John H. Wise
Michael McDonald

arxiv:1810.01857
arxiv:1812.05247

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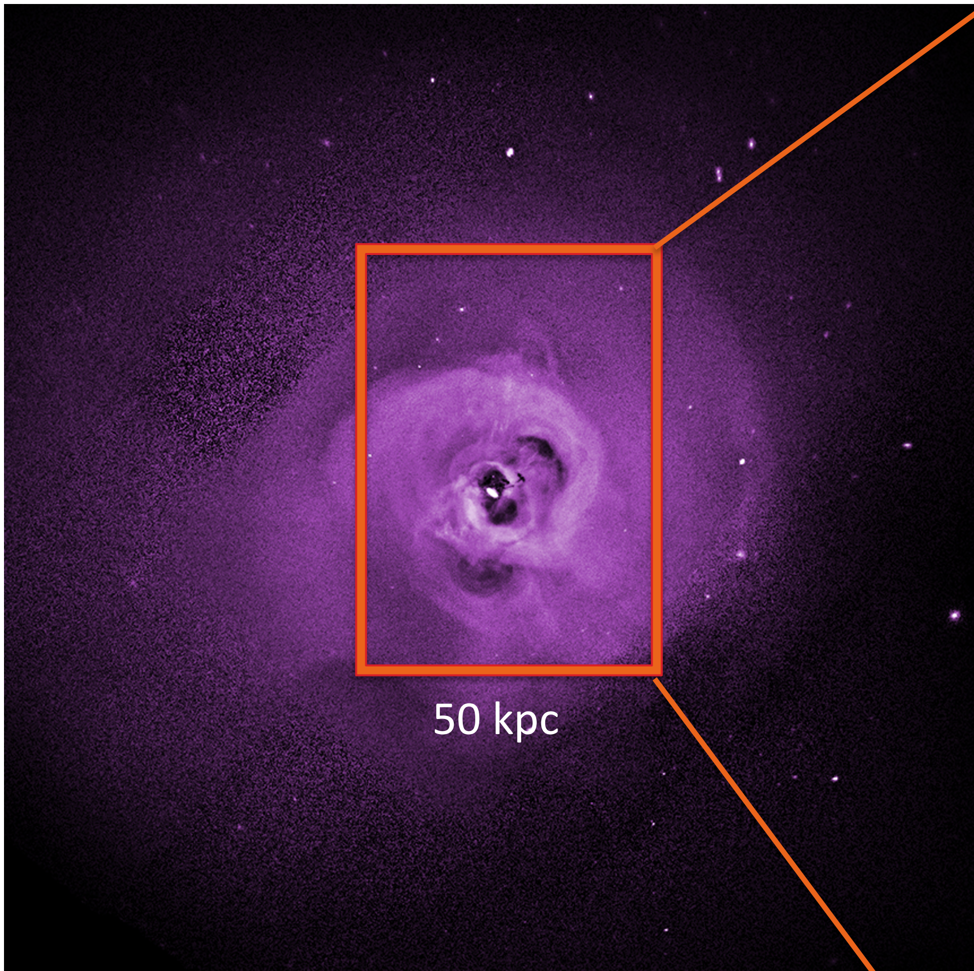
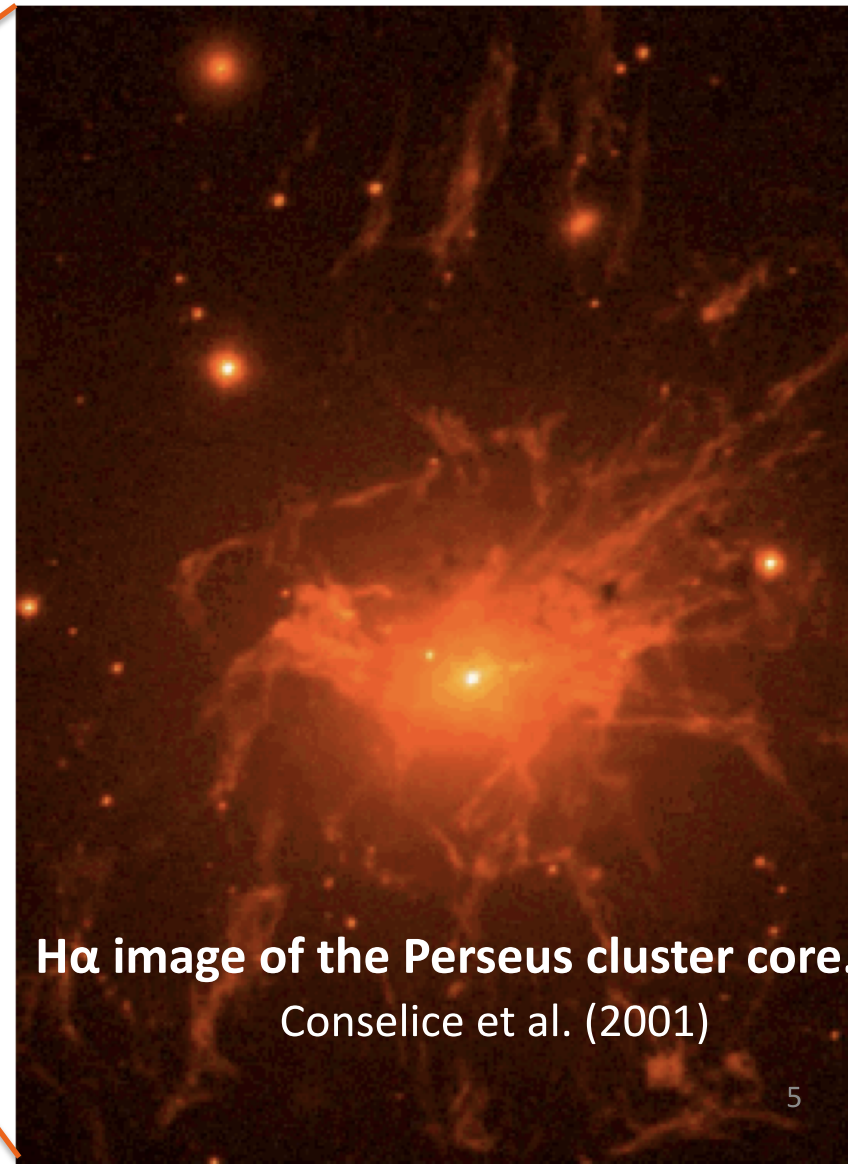
Hot Gas



Chandra X-ray image of Perseus Core

Cold Gas



Hα image of the Perseus cluster core.

Conselice et al. (2001)

Multiphase Gas in Elliptical Galaxies

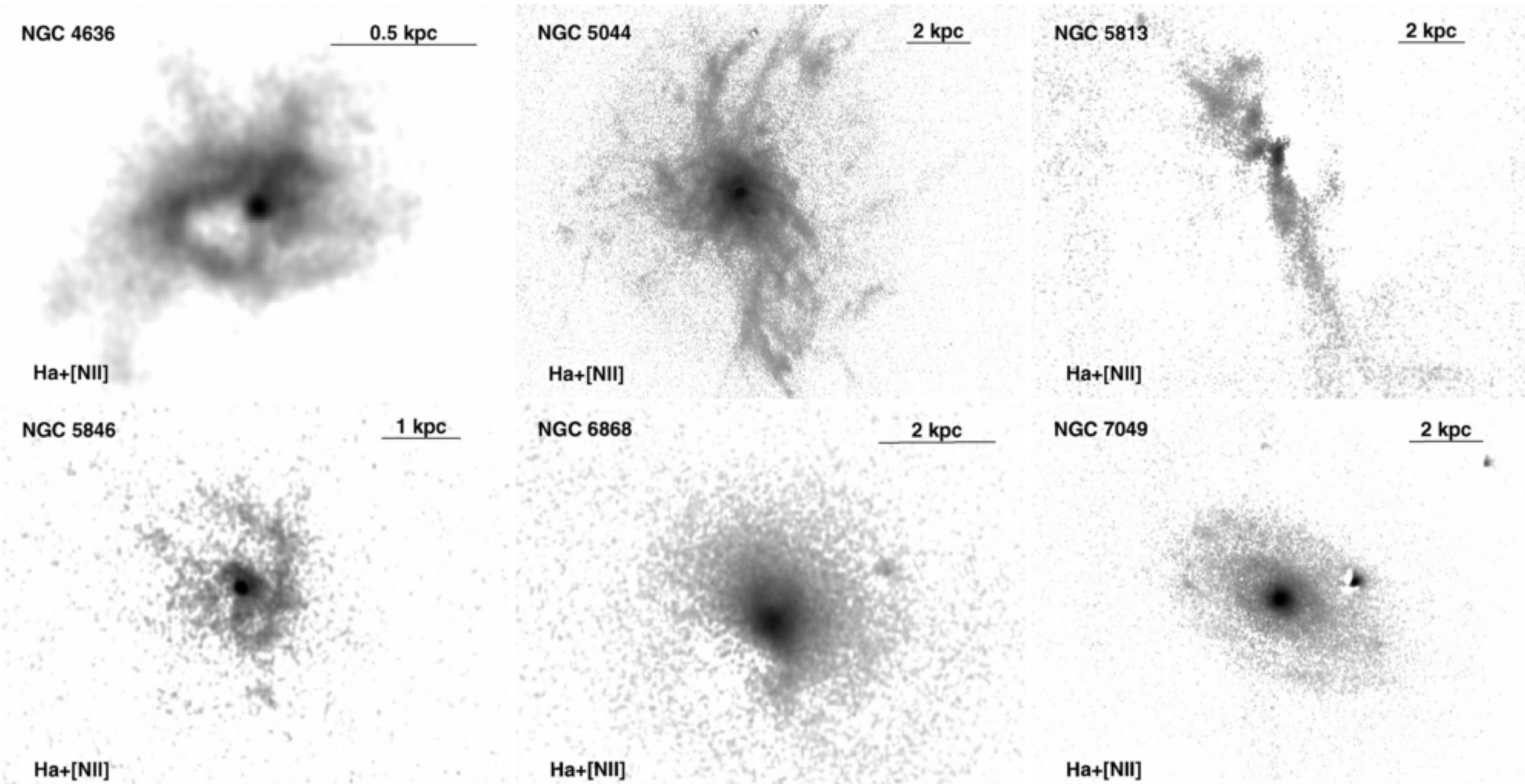


Figure 1. Hα+[N II] images of the galaxies with extended emission-line nebulae in our sample obtained with the 4.1 m SOAR telescope.

Werner+2014, see also ATLAS3D and MASSIVE surveys

The Origin of Multiphase Filaments

- Fountain/Fondue model

Pushed/dredged up

- Thermal Instability

In-situ formation

Thermal Instability Criterion

Idealized Simulations with Volumetric Heating

- Sharma+2011 (Spherical geometry): **t_{cool}/t_{ff} =10**
- McCourt+2012 (Cartesian geometry): **t_{cool}/t_{ff} =1**
- Meece+2015 (Cartesian & Spherical geometry): **t_{cool}/t_{ff} ~ 10**
- Choudhury & Sharma 2015 (Cartesian & Spherical geometry): **t_{cool}/t_{ff} ~ 10**
- Ji+2018: **t_{cool}/t_{ff} > 10 (B fields)**

Global Simulations with Feedback

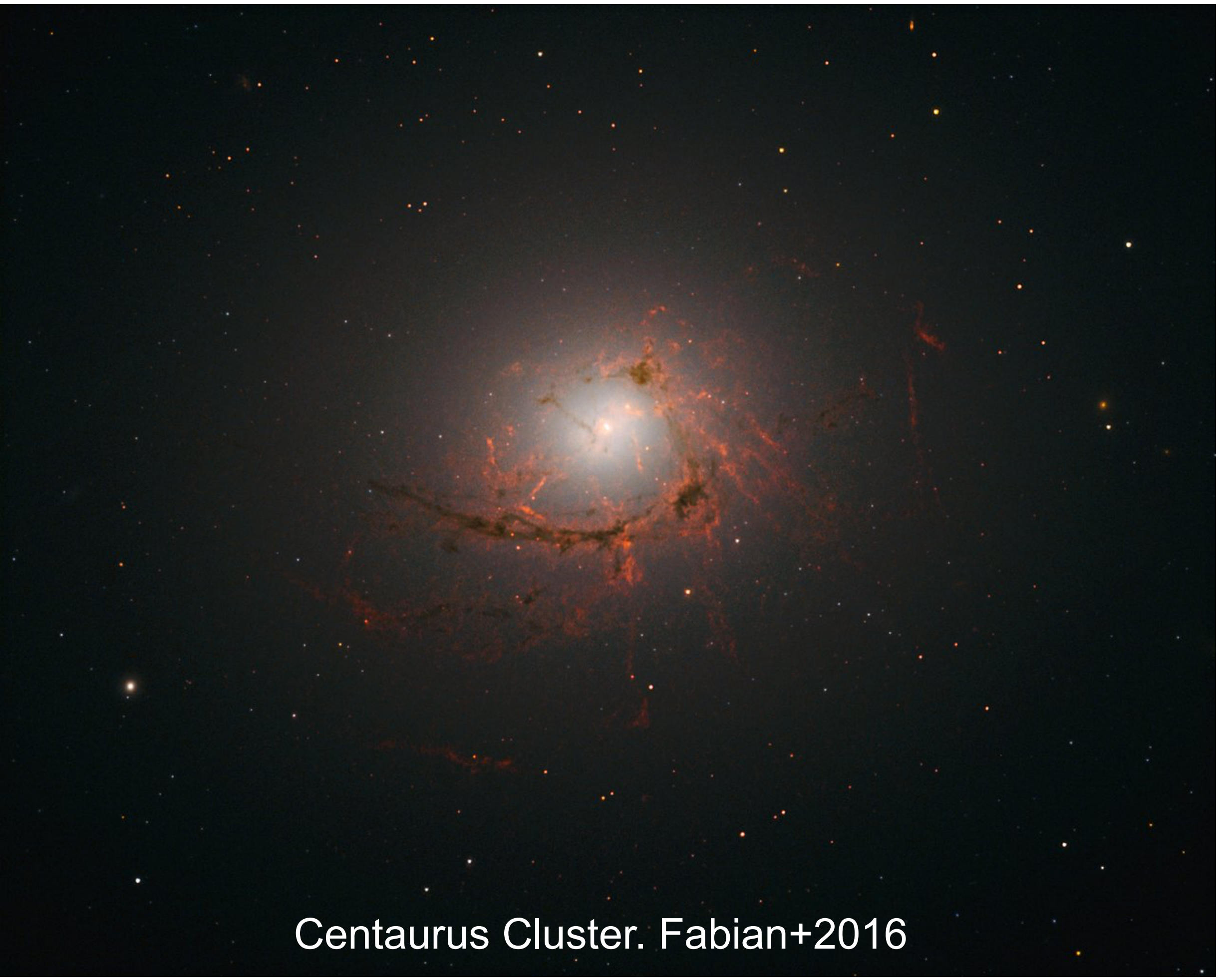
- Gaspari+2012: **t_{cool}/t_{ff} ~ a few to 20**
- Li & Bryan 2014 a & b, Li+2015: **t_{cool}/t_{ff} ~ a few to 10 (AGN uplifting)**
- Prasad+2015, Fielding+2017, Wang+2019: **t_{cool}/t_{ff} ~10**

And More

Not a complete list!

- Voit+2017, Choudhury+2019 **(background entropy)**
- Banerjee&Sharma2014, Gaspari+2018, Voit 2018 **(turbulence)**

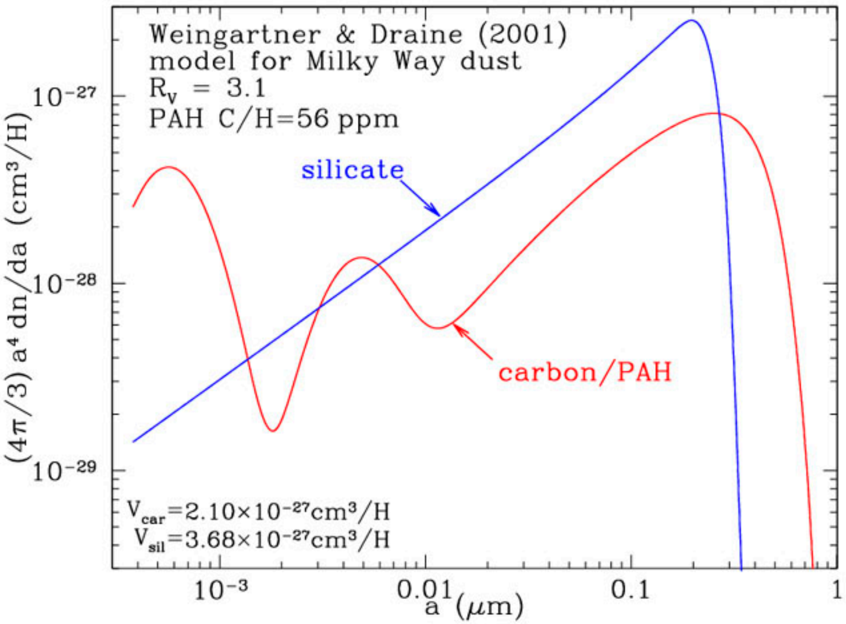
The Origin of Dust



Donahue+2011:

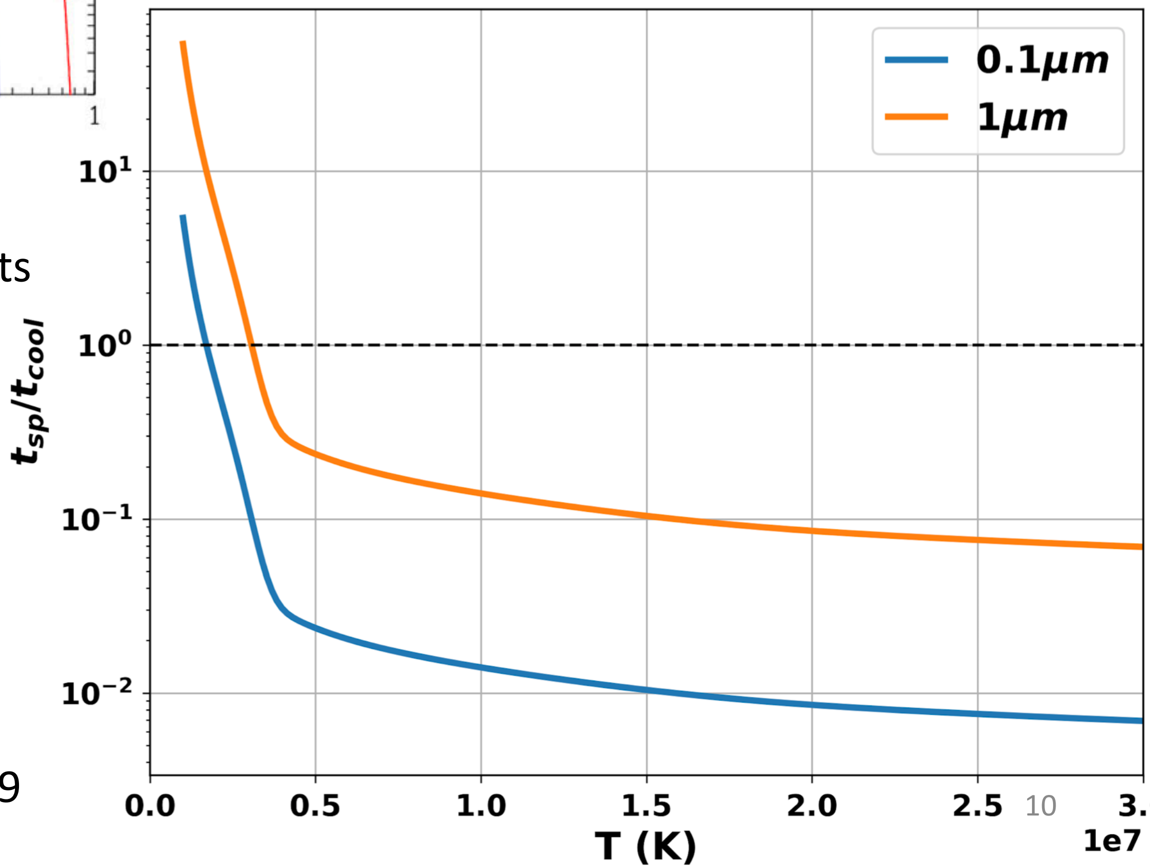
- Filaments are dusty
- dust grains similar to those of normal star forming galaxies
- polycyclic aromatic hydrocarbons (PAHs)

Dust Grain Size Distribution



Even the largest grains cannot survive longer than t_{cool} in massive galaxies!

Dust Sputtering:
Smaller grains in hotter environments are destroyed faster



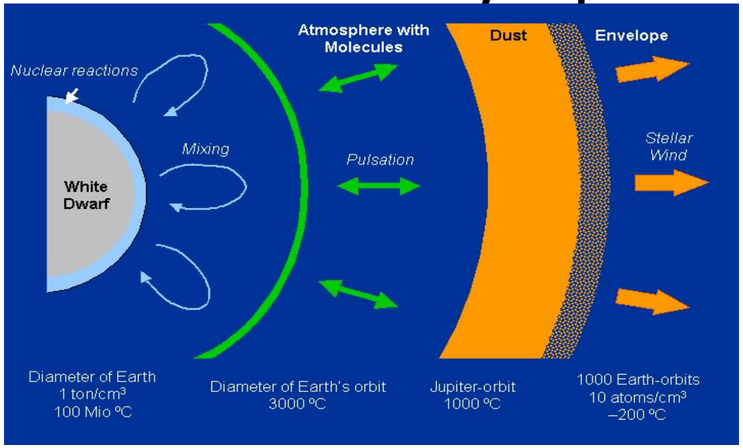
Li+2019

Yuan Li, Berkeley

How is dust made?

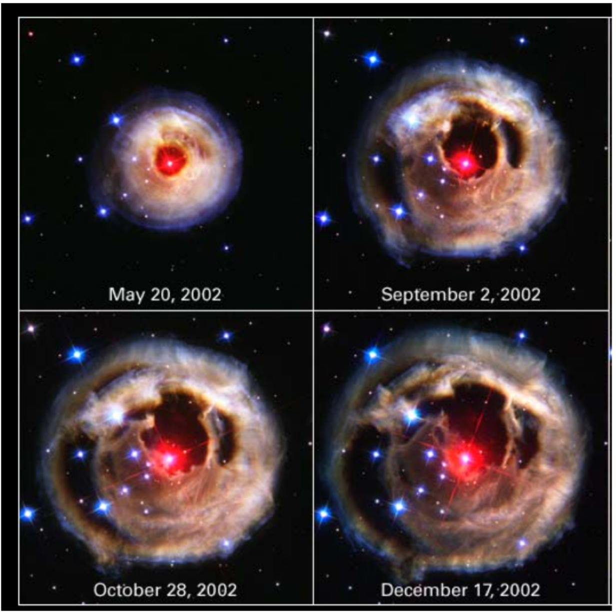
As far as we (read: Draine) know

- Winds from Asymptotic Giant Branch (AGB) stars



- Core-collapse SN: not enough in massive galaxies
- SN Ia: not enough & shocks destroy dust (Nozawa+2011)

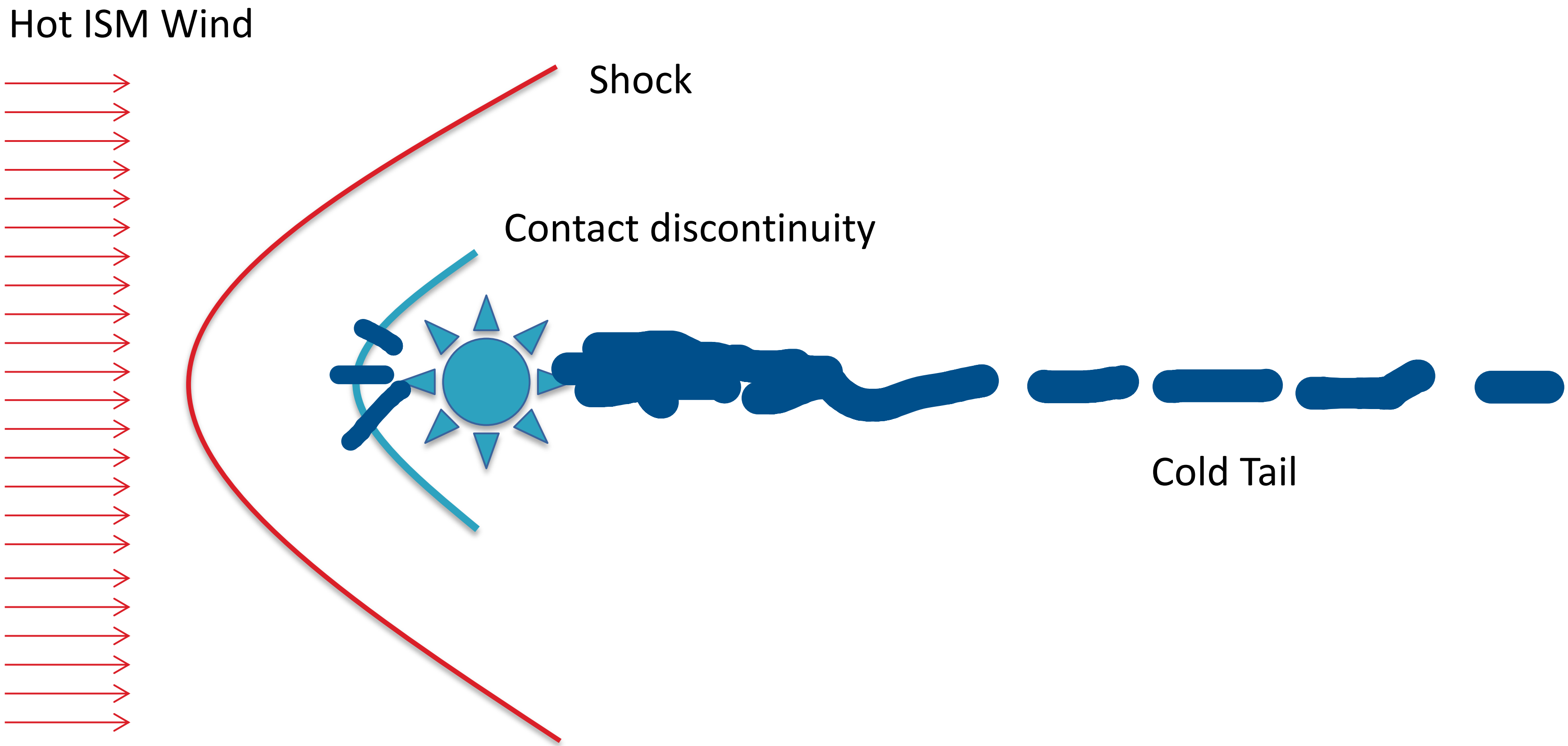
AGB Winds in Our Milky Way



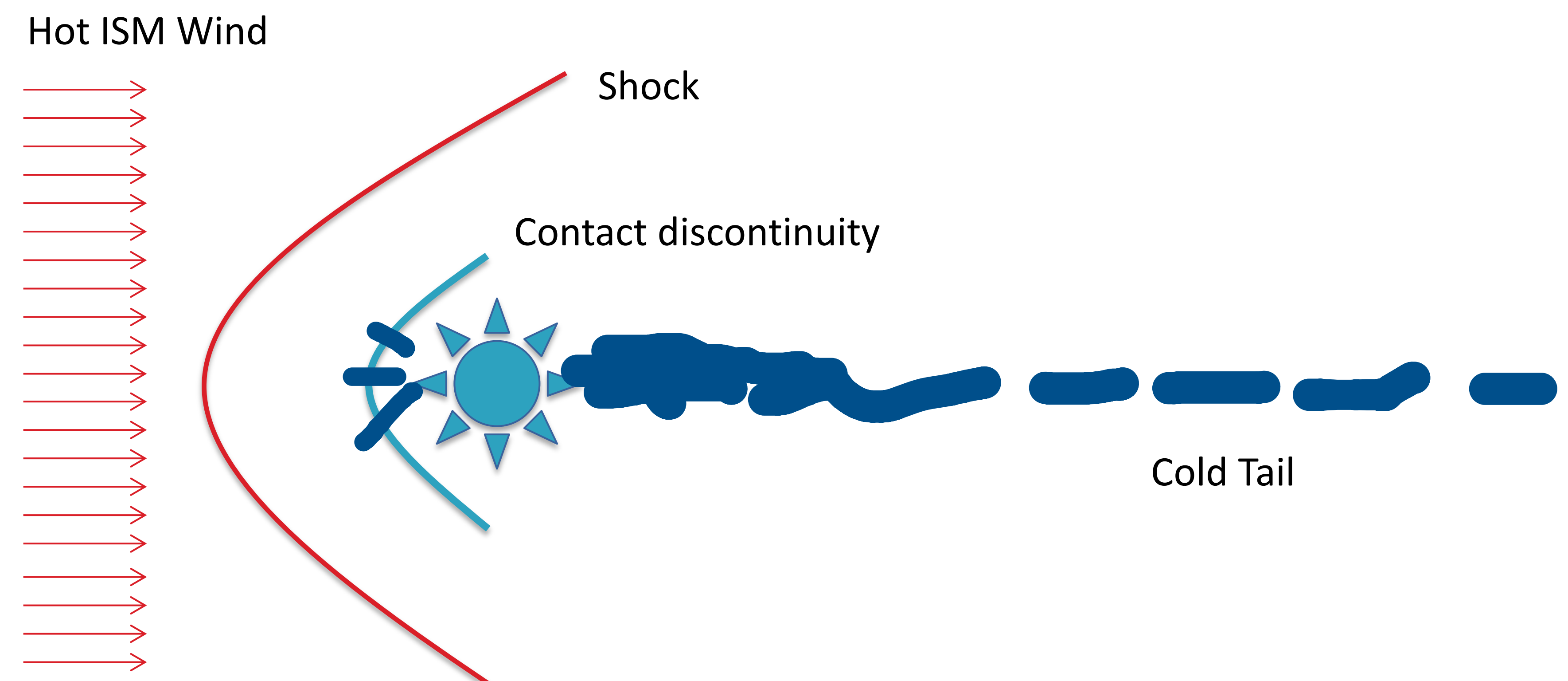
AGB star (maybe)
(V838 Monocerotis)
Seen by Hubble

planetary nebula (the Helix Nebula)

AGB Winds in Massive Galaxies


Hot ISM Wind
Shock
Contact discontinuity
Cold Tail


GALEX UV image of Mira the Wonderful Star
Location: Local Bubble. Tail Length: 4 pc


Hot ISM Wind
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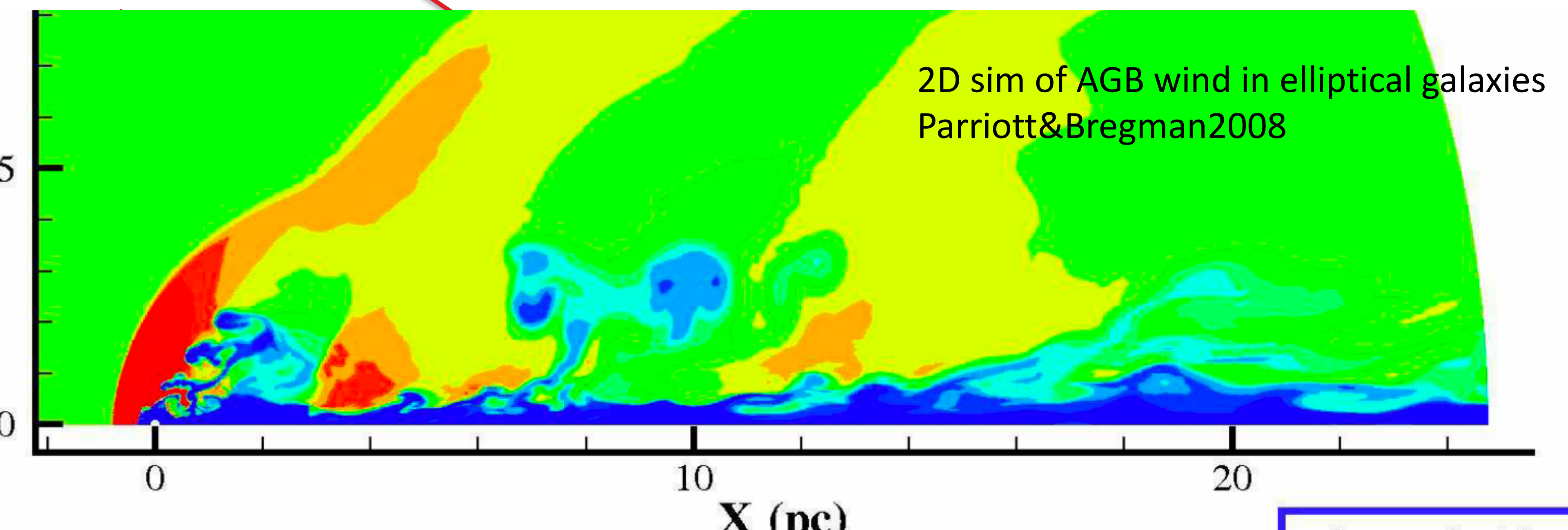
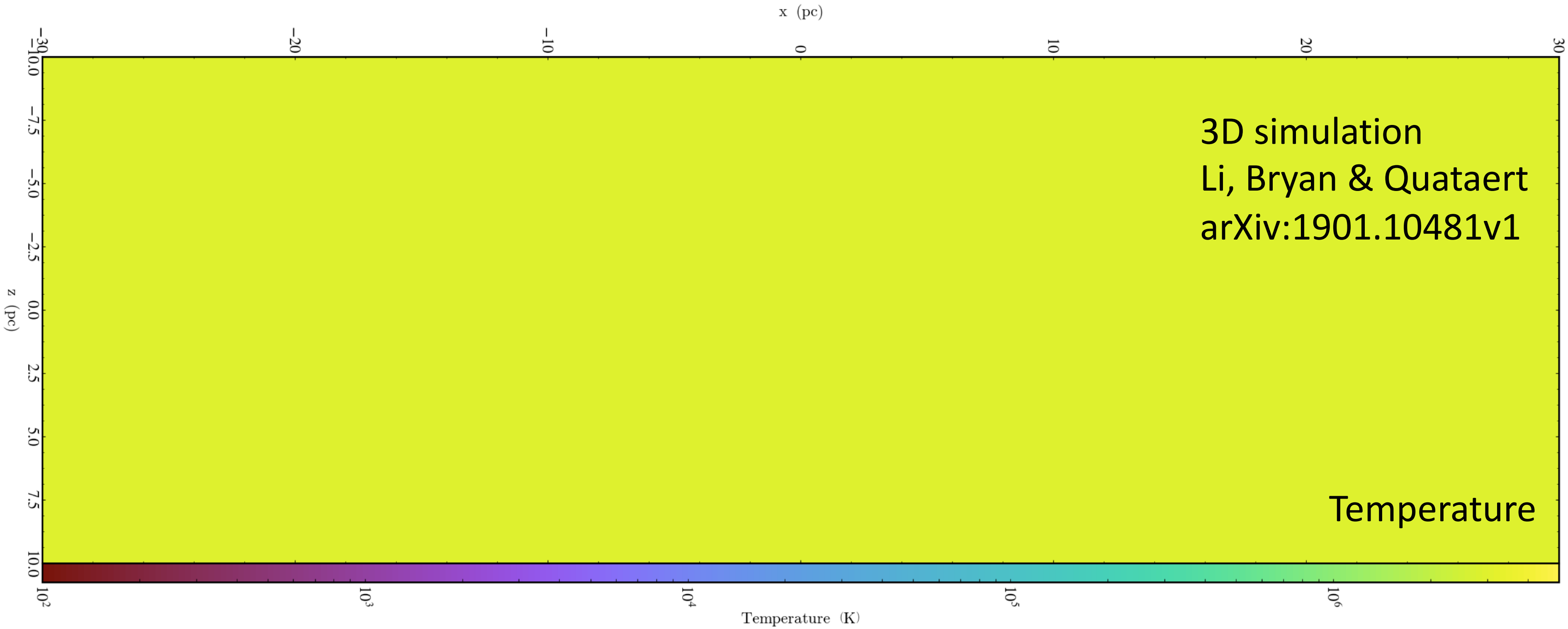
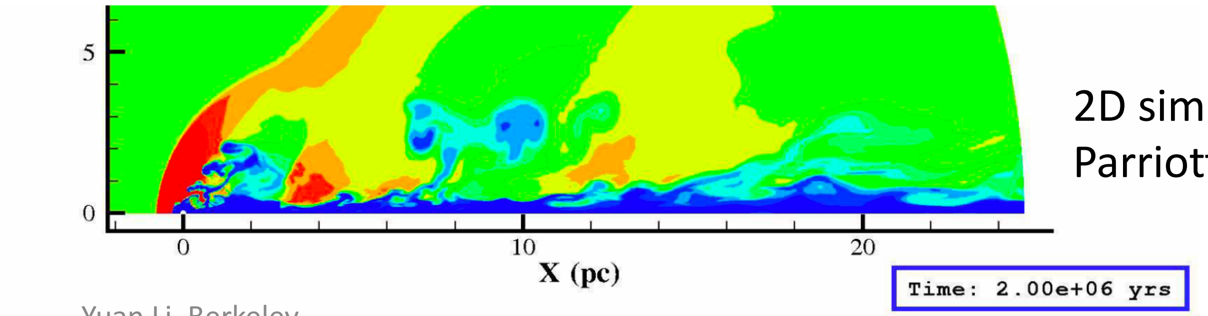

2D sim of AGB wind in elliptical galaxies
Parriott&Bregman2008
5
0
0
10
20
X (pc)

AGB Wind in Elliptical Outskirts



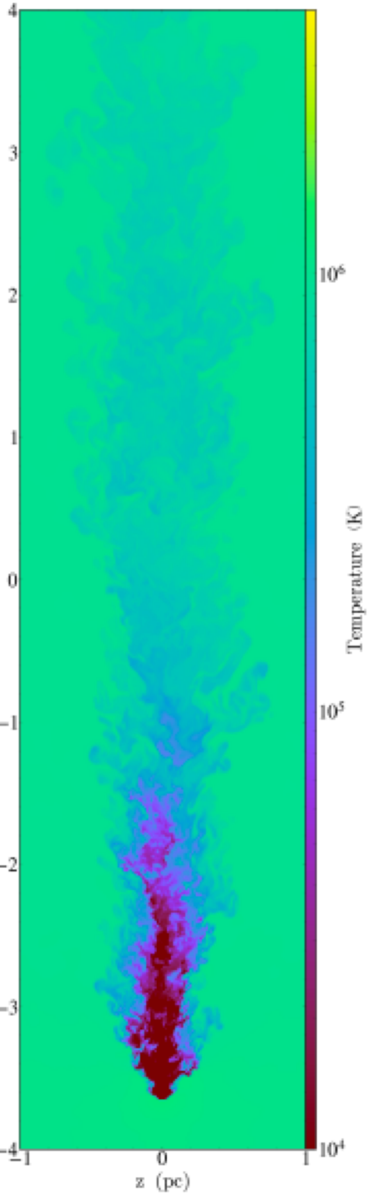
3D simulation
Li, Bryan & Quataert
arXiv:1901.10481v1



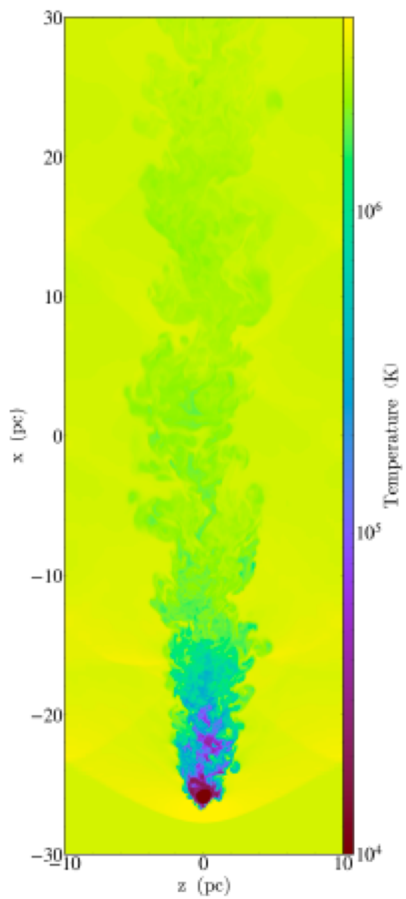
2D simulation
Parriott&Bregman2008

Mira

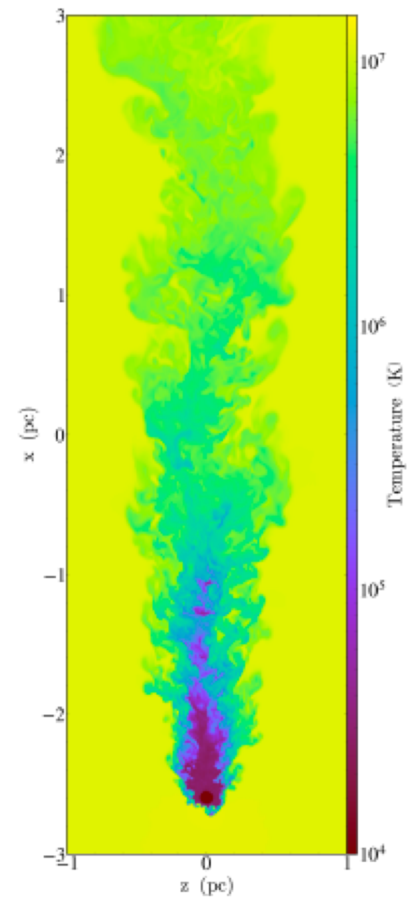
Analytically, all Mira-like stars should have the same tail-to-head ratio of ~4 in the absence of cooling.



AGB star in
outskirts of Elliptical galaxies

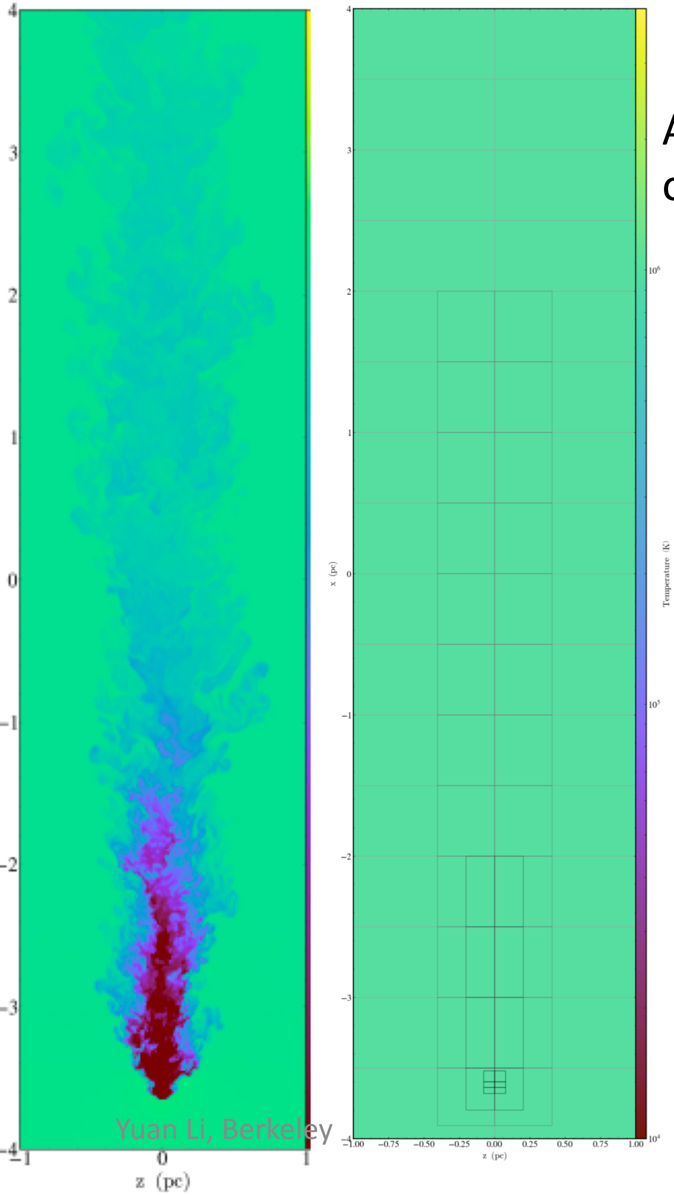


AGB star in
centers of Elliptical galaxies



Mira

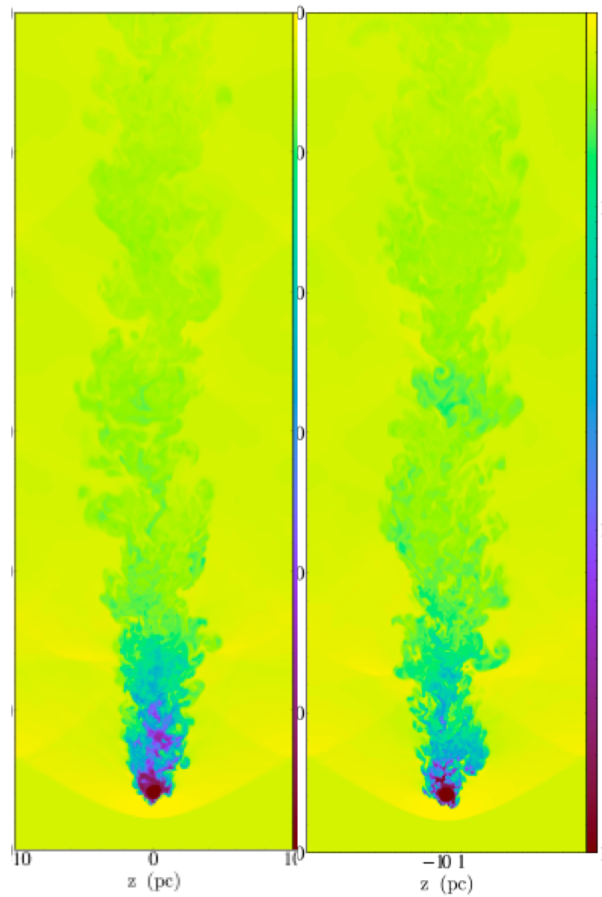
No Cooling Yes Cooling



Analytically, the cooling time of the tail is inversely proportional to the ambient pressure: $t_{cool} \propto 1/P_{ISM}$

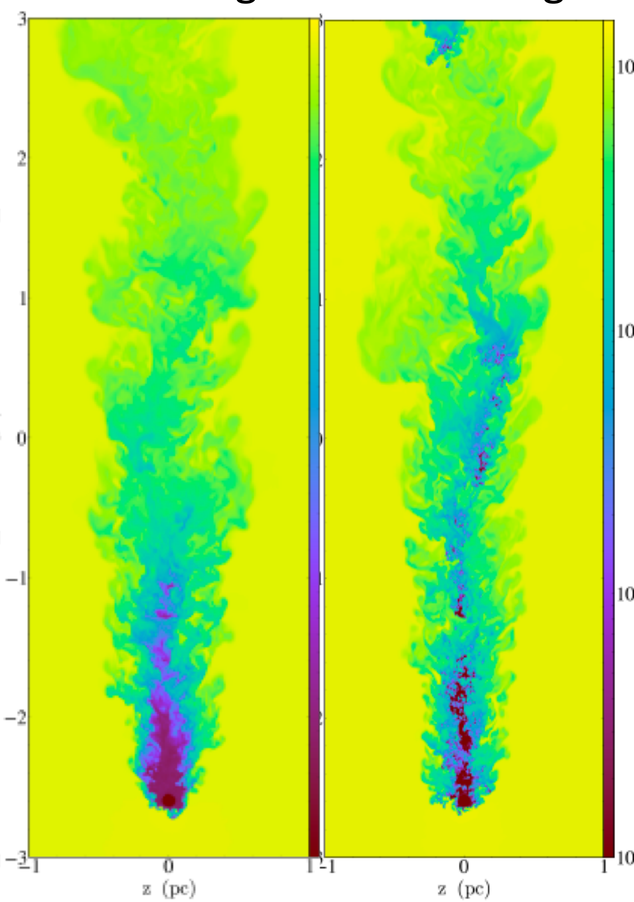
AGB star in outskirts of Elliptical galaxies

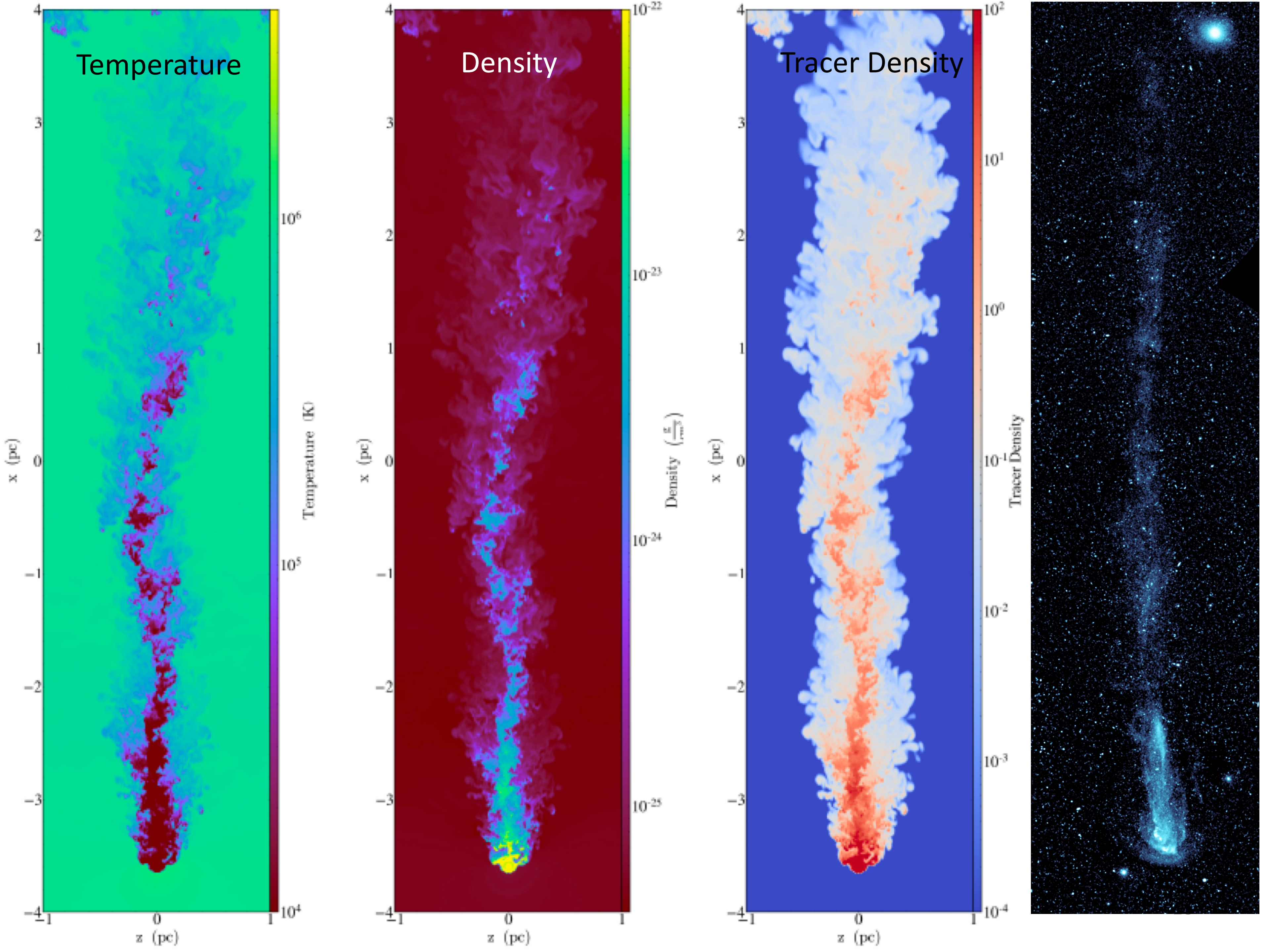
No Cooling Yes Cooling



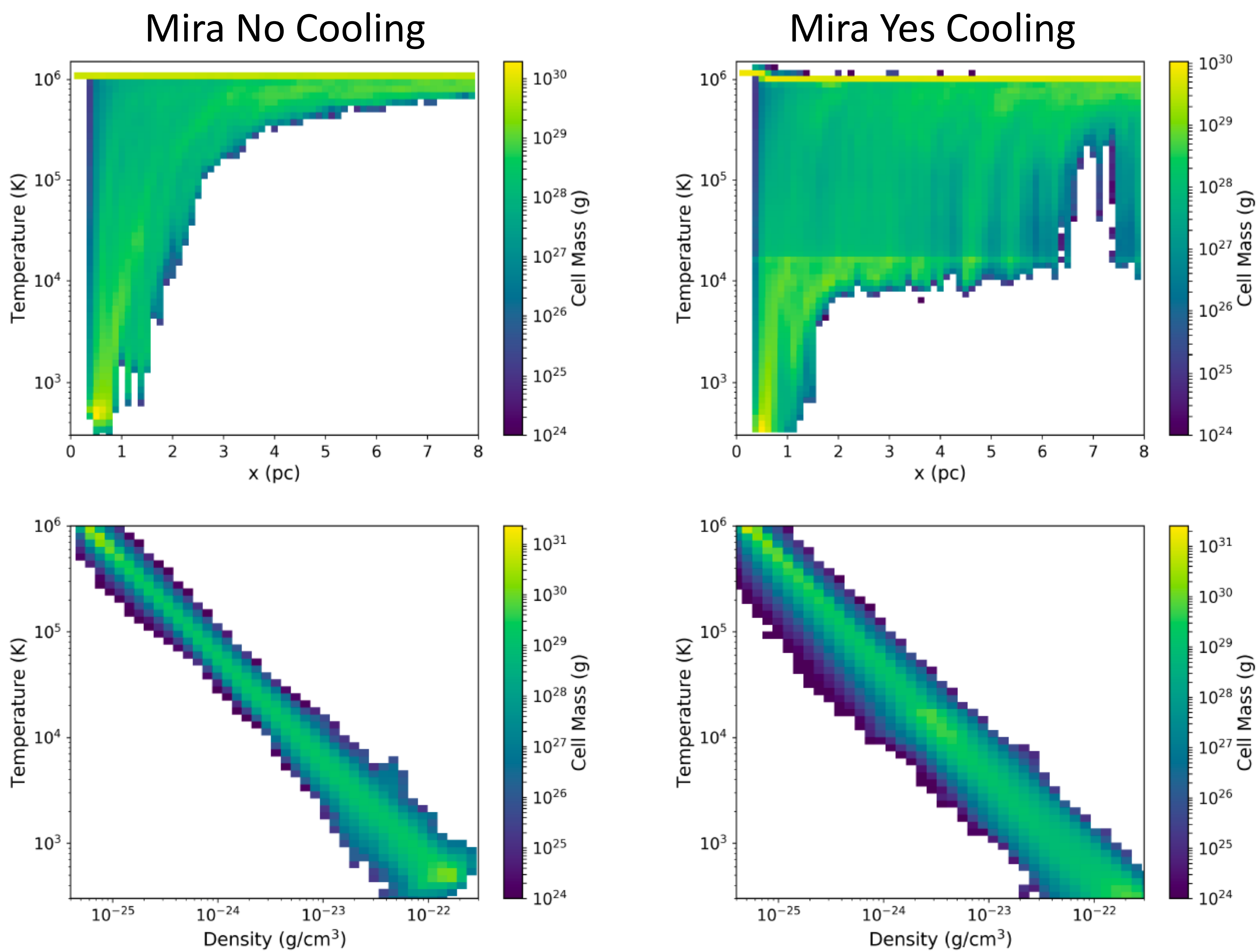
AGB star in centers of Elliptical galaxies

No Cooling Yes Cooling



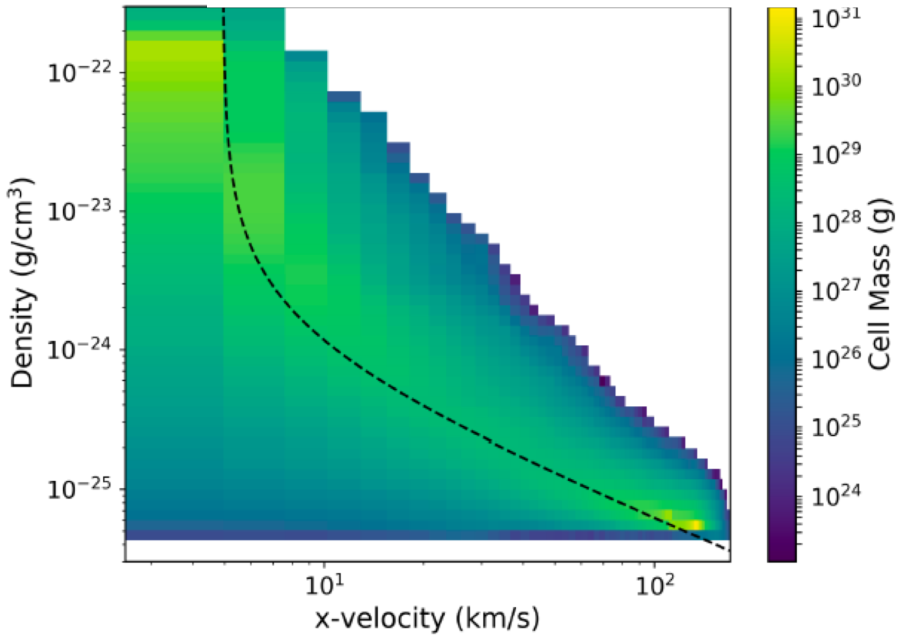


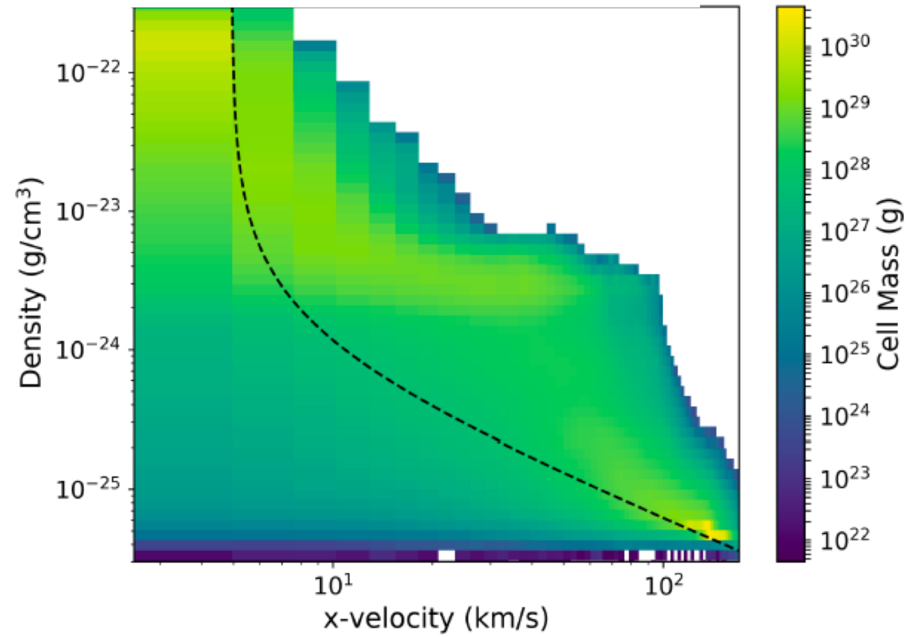
Temperature
Density
Tracer Density
Temperature (K)
Density ($\frac{g}{cm^3}$)
Tracer Density
x (pc)
z (pc)
10^{4}
10^{5}
10^{6}
10^{-25}
10^{-24}
10^{-23}
10^{-22}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}


Mira No Cooling
Mira Yes Cooling
Temperature (K)
x (pc)
Cell Mass (g)
Density (g/cm^3)

Mira No Cooling

Mira Yes Cooling

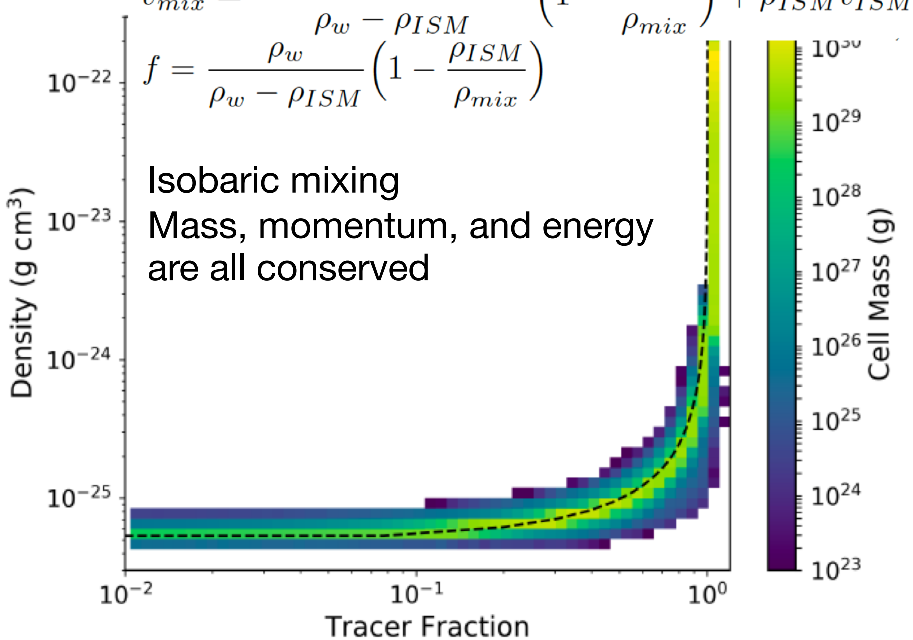


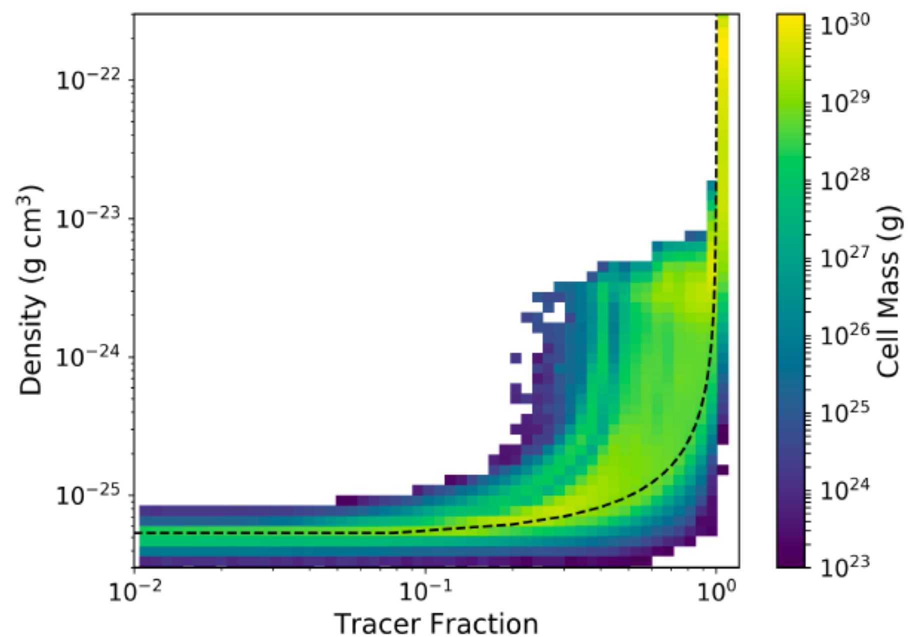


$$v_{mix} = \frac{\rho_w v_w - \rho_{ISM} v_{ISM}}{\rho_w - \rho_{ISM}} \left(1 - \frac{\rho_{ISM}}{\rho_{mix}}\right) + \rho_{ISM} v_{ISM}$$

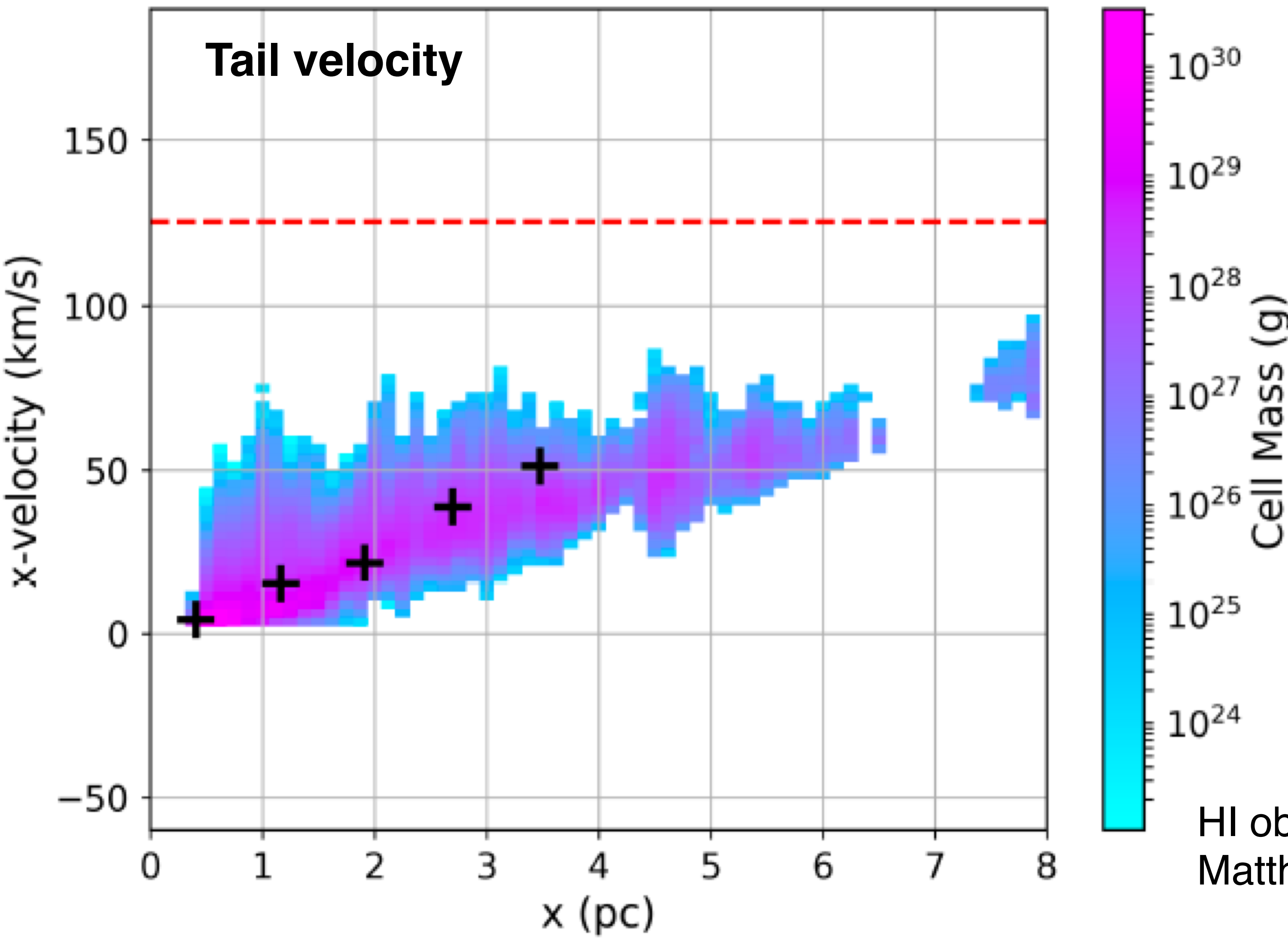
$$f = \frac{\rho_w}{\rho_w - \rho_{ISM}} \left(1 - \frac{\rho_{ISM}}{\rho_{mix}}\right)$$

Isobaric mixing
Mass, momentum, and energy are all conserved



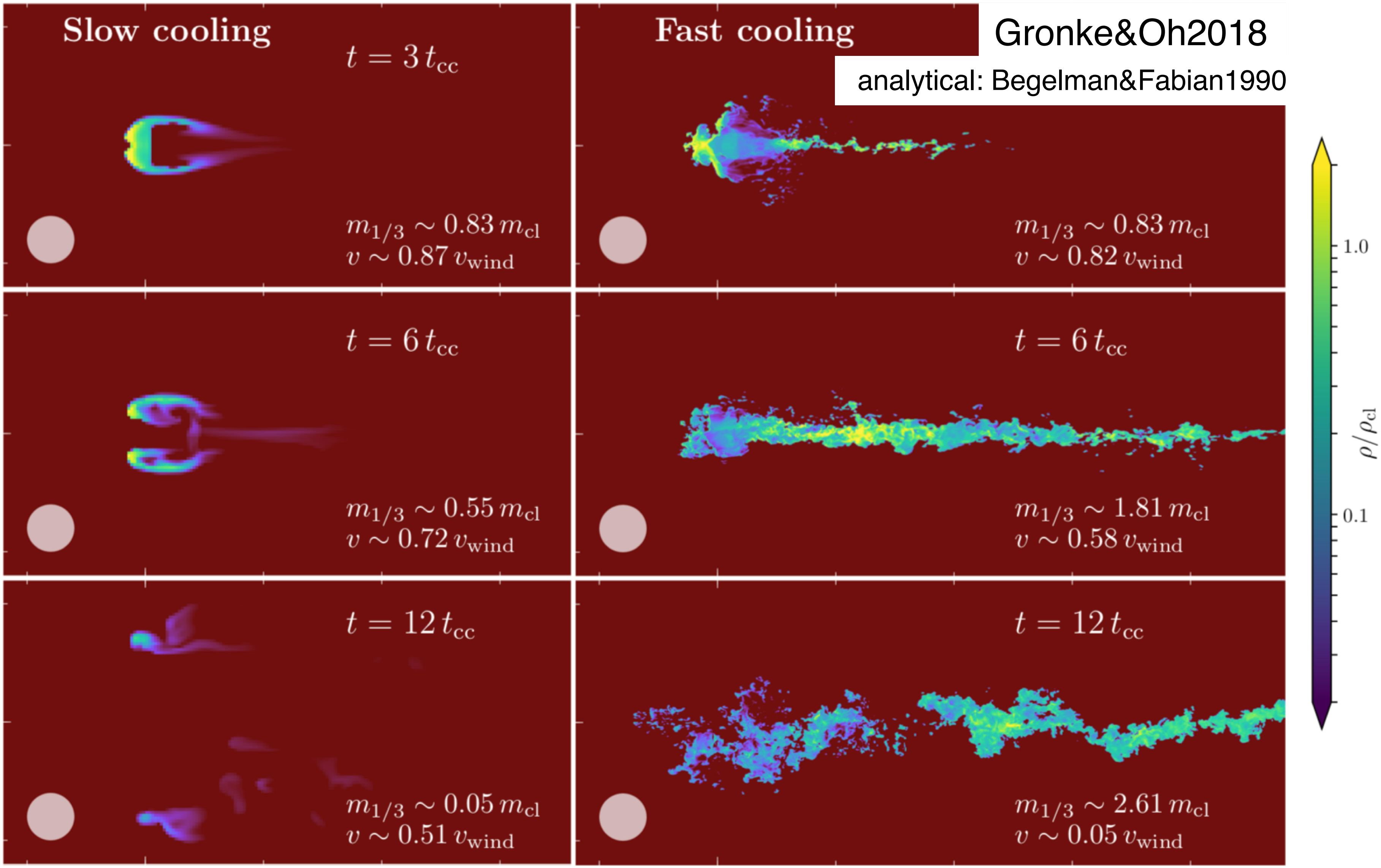


Comparison with Mira Observations

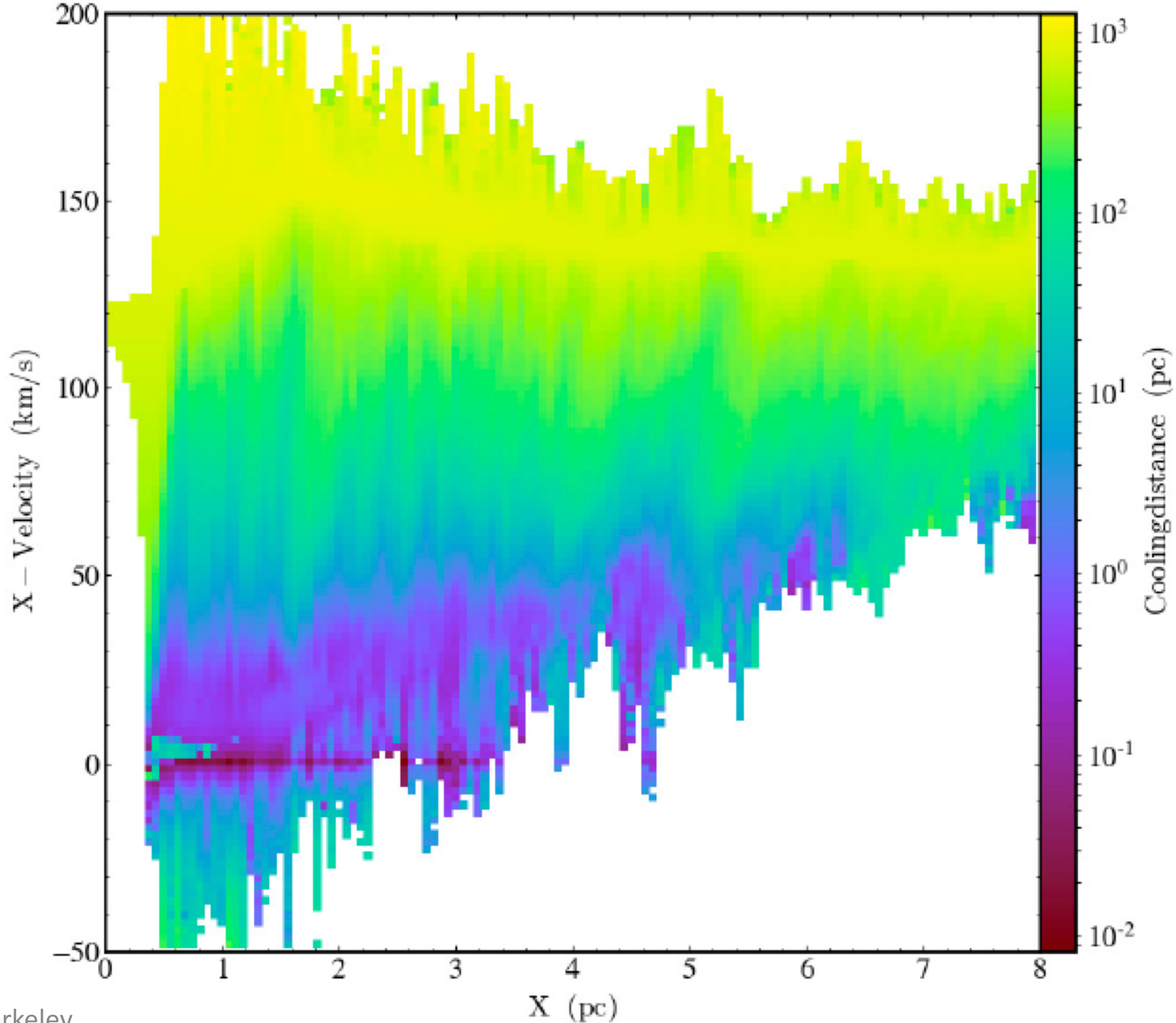


HI observations
Matthews+2008

More Gas May Cool Later



But my box is not long enough to see it



The Origin of Multiphase Filaments

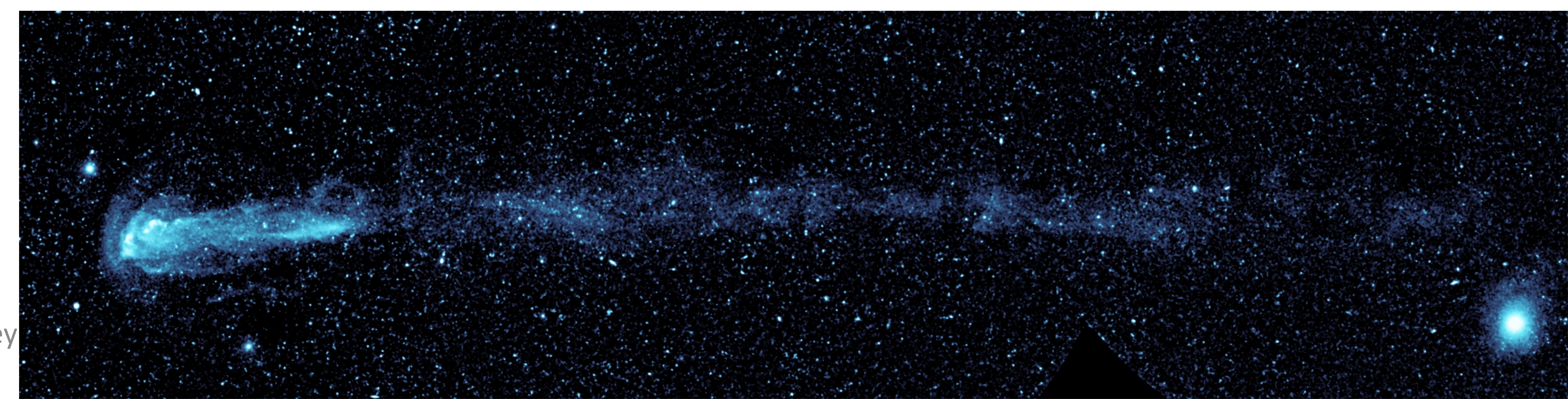
- Fountain/Fondue model

Pushed/dredged up

- Thermal Instability

In-situ formation

- Induced Cooling



The Origin of Dust in Filaments

- Fountain/Fondue model

Center of the Galaxy

Pushed/dredged up

- Thermal Instability

In-situ

?

- Induced Cooling

AGB Stars in the Halo

Next Steps
(in no particular order)

- Bigger boxes.
- AGB stars in centers of clusters.
- Planetary nebula phase - short duration but large mass loss (may be more important).
- More sophisticated Mira simulations (adding B fields, chemistry, realistic AGB winds).
- Adding dust to simulations.

Not a complete list!

Conclusions

- In the absence of cooling, all AGB tails look the same.
- Radiative cooling is important in high pressure environment, such as the Local Bubble, and centers of massive galaxies and clusters.
- Hot gas can cool onto AGB tails due to mixing in high pressure environments (e.g. Mira). This may explain the origin of dusty cold gas in massive systems.