AGN feedback in ETGs: local or global accretion modes ?

Luca Ciotti
Dept. of Physics & Astronomy
University of Bologna - Italy

AGN11 – 23-26 September 2014 - Trieste

1. Empiric
2. 1D-models (hot-cold)
3. 2D-models (J)
4. Summary – open ?

1. EMPIRICAL FACTS ABOUT MASS & ENERGY BUDGETS of ETGs

ETGs ARE NOT “DEAD” OBJECTS EVEN WHEN ISOLATED

For Cosmologists: “ISOLATED” = NO MERGING

Suppose we start with a “dead” ETG …

stellar evolution ➔
INTERNAL MASS & ENERGY SOURCES

Mass

$$\dot{M}_*(t) \simeq 1.5 \times 10^{-11} L_{\rm B} t_{15}^{-1.3} \quad M_\odot {\rm yr}^{-1}$$

$$\Delta M_* \approx 0.1 - 0.3 M_*$$

- The rate in the past was HIGHER
- The total mass injection scales LINEARLY with M*

Energy

$$L_{\rm SN}(t) = 1.015 \times 10^{31} h^2 \vartheta_{\rm SN} \eta_{\rm SN} \frac{L_{\rm B}}{L_{\rm B\odot}} \left(\frac{t}{13.7\,{\rm Gyr}} \right)^{-s} \quad {\rm erg\,s^{-1}}$$

These 2 ingredients explain in detail X-ray observations of ETGs (cooling flow model and its improvements)

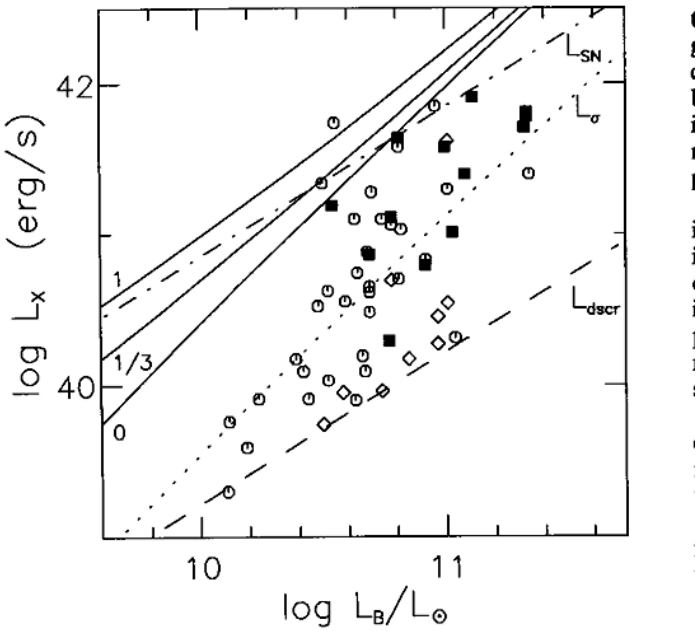


FIG. 1.—The X-ray vs. blue luminosity for early-type galaxies from Canizares, Fabbiano, & Trinchieri (1987). Filled squares and open diamonds refer to galaxies with boxy and disklike isophotal shapes, respectively. Open circles represent galaxies for which this morphological detail is unknown. The dot-dashed line shows the power L_{SN} generated by the SN I heating at the standard rate ($\vartheta_{SN} = 1$). The heating due to stellar motions L_σ is shown by the dotted line, while L_{dscr} represents the expected contribution from discrete stellar X-ray sources (*dashed line*). Finally, the solid lines represent the expected X-ray luminosity of steady state cooling flow models ($L_{inflow} = L_{SN} + L_\sigma + L^+_{grav}$), for the

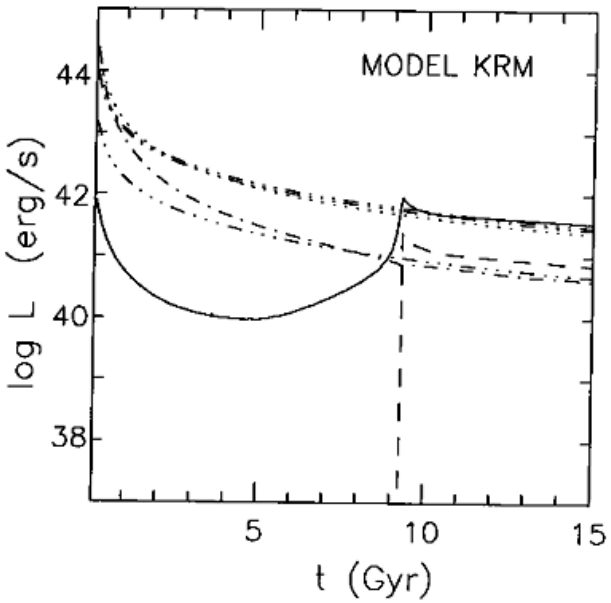


FIG. 5.—The time evolution of the energy budget of the gas flow of the KRM sequence. Displayed is the evolution of the X-ray luminosity L_X (*solid line*), together with L^+_{grav}, L^-_{grav}, and L_σ (*three-dot–dashed lines*, see text), and the enthalpy losses through the outer edge (L_{out}; *dot-dashed line*) and the central sink (L_{in}; *dashed line*).

PARTIAL WINDS
(cuspy systems)

(Pellegrini & Ciotti, 1998)

WIND-
OUTFLOW-
INFLOW

(Ciotti, D'Ercole, Pellegrini, Renzini, 1991)

DECOUPLED FLOWS
(flat & rotating galaxies)

(D'Ercole & Ciotti 1998)

DISCOVERY OF SMBHs

i) SMBHs of ~0.001 Mgal are found at the center of Es, a factor < 0.01 **SMALLER** than the gas made available from stellar evolution.

ii) Why QSOs are not seen in all medium/big ETGs?

MASS problem (not energy!)

i)+ii) MUST be solved together
(STEADY OBSCURED ACCRETION is NOT a SOLUTION)

THE ISSUE IS NOT THE ENERGETICS
THE ISSUE IS HOW and HOW MUCH
RADIATION/MECH. **INTERACTS** WITH THE ISM

Lbh ~ 10^46 erg/s [accretion of 1 solar mass/yr]
Lgrav ~ 10^41 erg/s [extraction of 1 solar mass/yr]

Long term project (started in ’91)
radiation-hydrodynamical numerical simulations of
PHYSICALLY BASED AGN FEEDBACK

Feedback modulated accretion flows

2. 1D-models

Hydrodynamical simulations of Radiative + Mechanical feedback

Ongoing study, Ciotti & Ostriker (1997), with improving physics and numerics (Sazonov, Sunyaev, Proga, Shin, Yang, Spitkovski, Pellegrini, Choi, Novak, Hansley, Gan, Yuan, Posacki, Negri, Volonteri)

CONS: SPHERICAL SYMMETRY

(J, B, conduction, viscosity: NOT included in 1D)

PRO: FUEL - BH ACCRETION SELF-DETERMINED

(Physically based feedback description)

Stellar component + DM halo + SMBH [Jeans modeling]

Self-consistent internal & projected dynamics + FP [etc]

Hydro equations with mass, momentum, energy sources

Old SSP+SNIa+Stellar winds

Star formation + SNII + Stellar winds

Dust formation & destruction

SMBH accretion + ADAF/ADIOS/RRIOS-modulation

ISM Heating & cooling photoionization, Compton, line and free-free mechanisms

Absorption & emission: equations of radiative transfer in spherical symmetry are solved for the X-ray, UV, IR radiation. In this way we compute

Radiation pressure: on the ISM (photoionization, electron scattering – Ledd, etc) + DUST (grain formation, destruction & mixing times taken into account).

Radiative feedback: radiation energy and momentum absorbed by the ISM & DUST added to the hydrodynamical equations.

Mechanical feedback: nuclear wind/jet [QUALITATIVE due to 1D-geometry]

Recurrent phases of a "dead" ETG

1. Stellar evolution produces gas

2. Cold shell ~ kpc (beginning of CF phase) GLOBAL

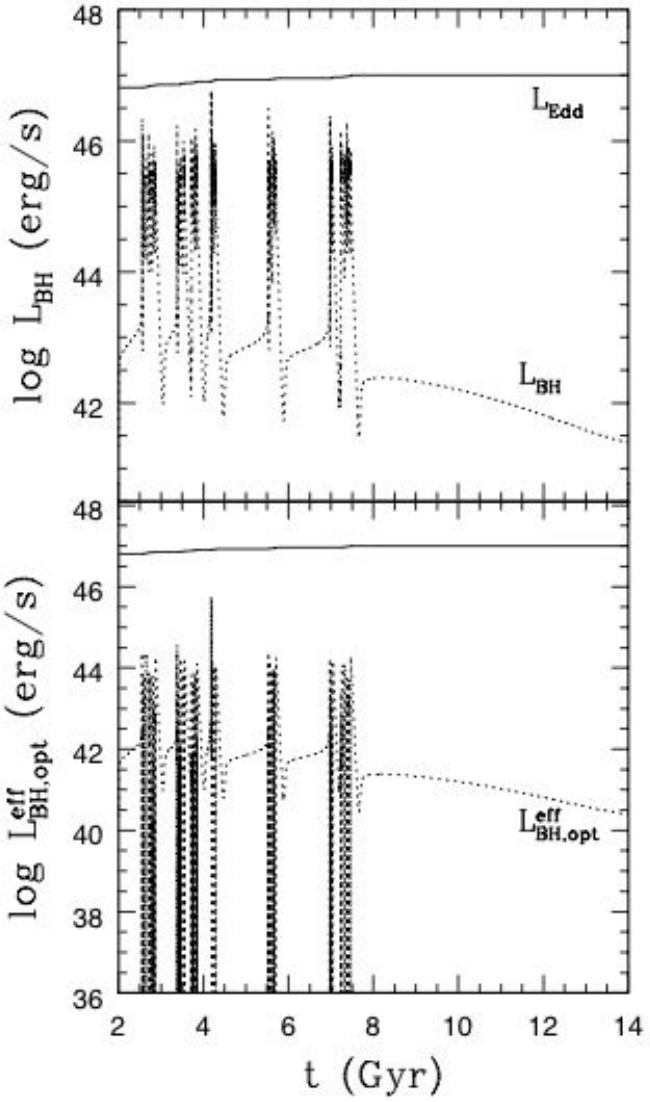
3. Accretion on SMBH ➔ feedback (& star formation: INDUCED & SUPPRESSED) ➔ Shock wave

4. Hot & low lumin. steady accretion LOCAL

5. Fresh gas accumulates over the galaxy body ➔ new cycle (more and more time needed)…. until SNIa take over

6. Final outflow phase, hot & low lumin. steady accretion

Luminosities



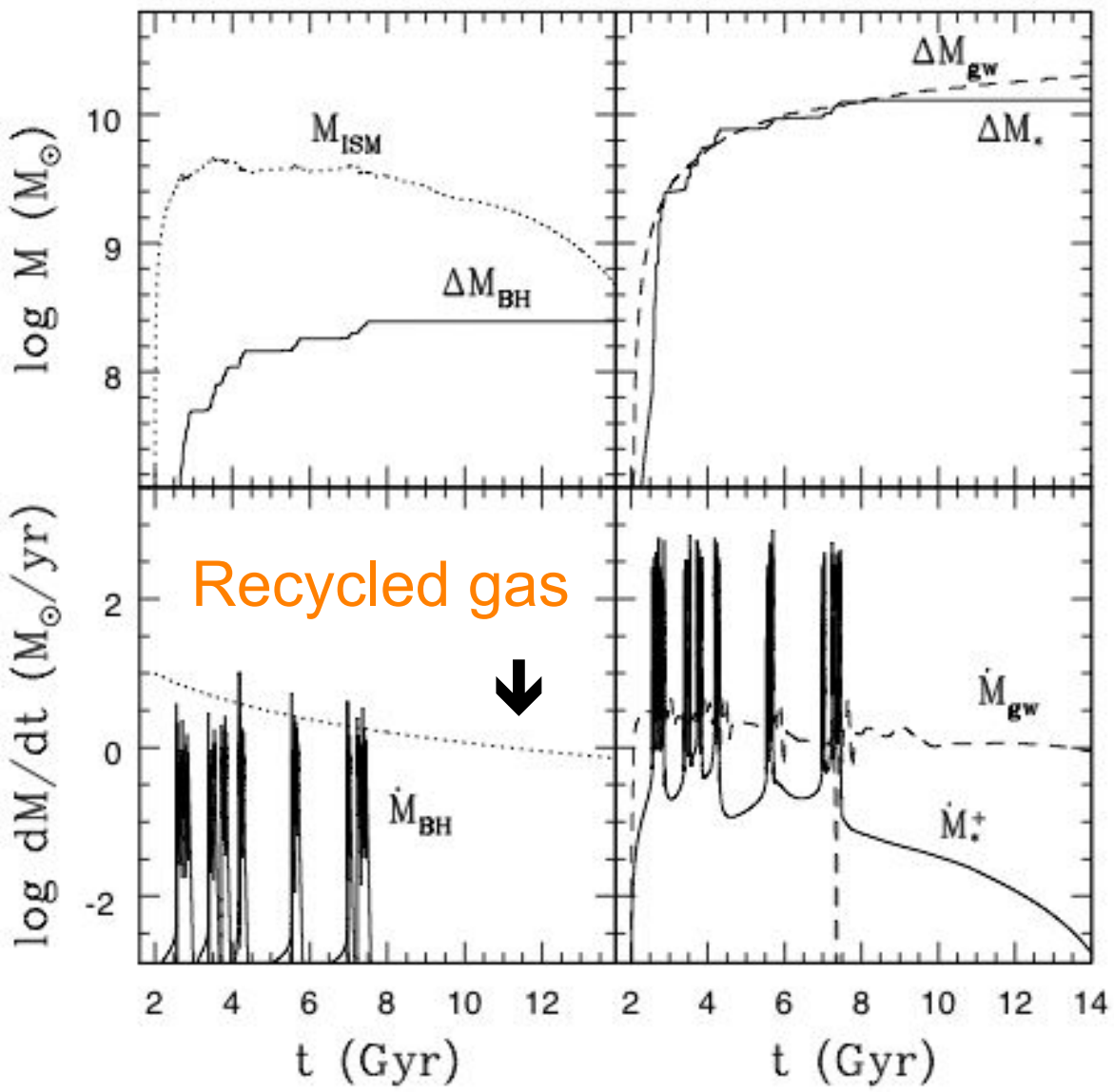
M*= 3 10^11 Msun
Lb= 5 10^10 Lsun
Re= 6.9 kpc
Central vel.disp. = 260 km/s

Bolometric accretion luminosity

AGN Duty ~ 1% or less

Optical (absorption corrected) BH accretion luminosity, peaks “obscured”

Mass Budget & Rates



C&O (2007)

INDUCED star formation + SUPPRESSED star formation

Positive & Negative AGN feedback described in

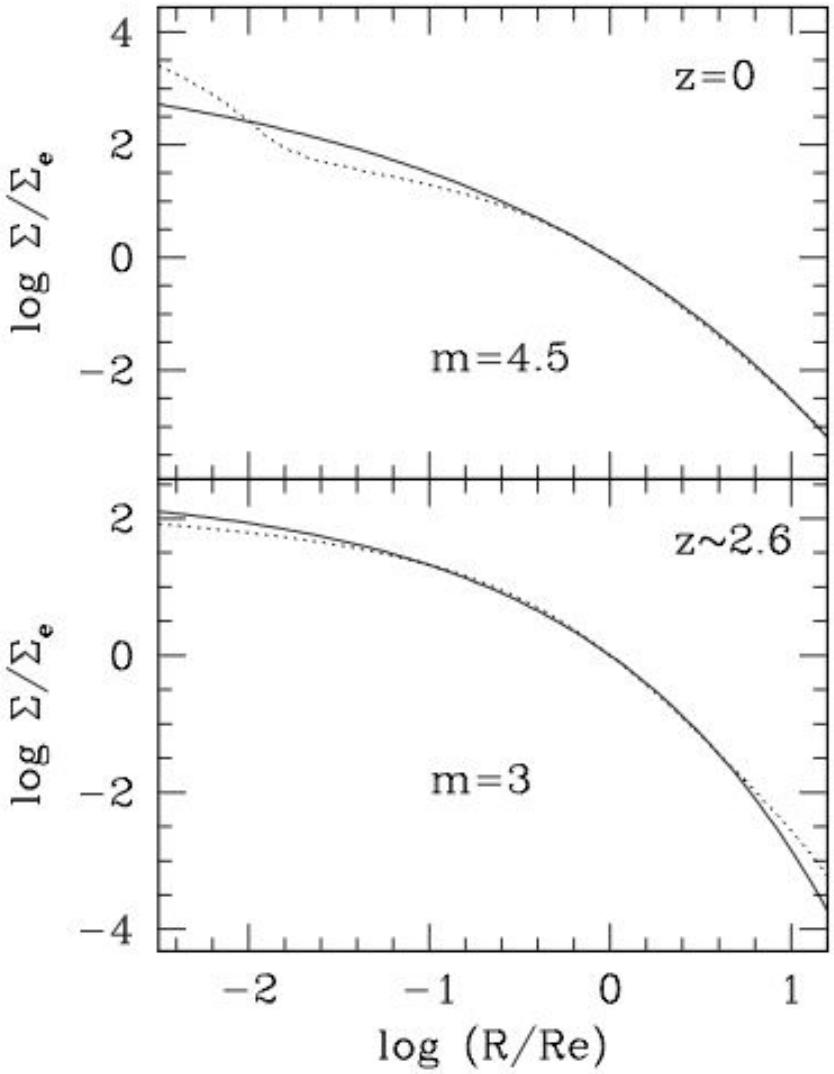
THE ASTROPHYSICAL JOURNAL, 665:1038–1056, 2007 August 20

RADIATIVE FEEDBACK FROM MASSIVE BLACK HOLES IN ELLIPTICAL GALAXIES: AGN FLARING AND CENTRAL STARBURST FUELED BY RECYCLED GAS

LUCA CIOTTI[1] AND JEREMIAH P. OSTRIKER[2,3]
Received 2007 March 2; accepted 2007 May 14

ABSTRACT

Sersic fit (solid: initial cond.)

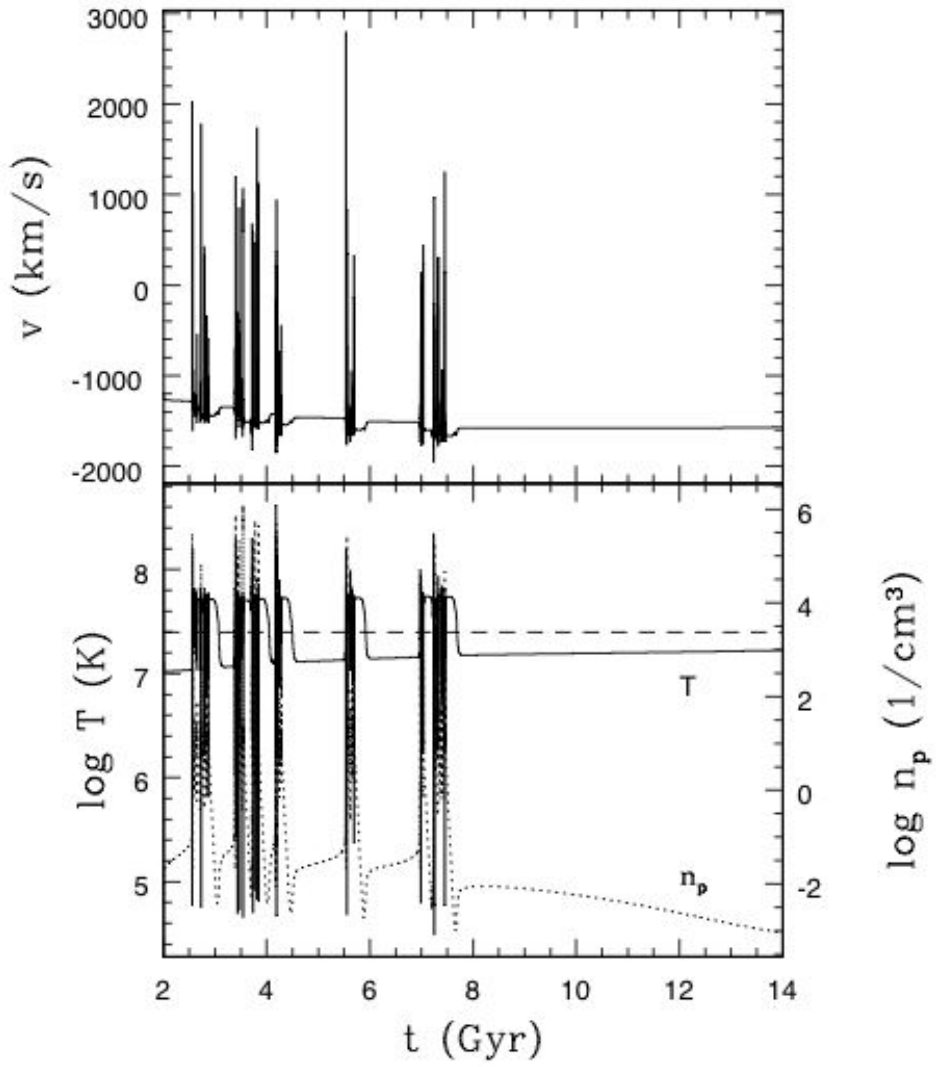


$$\Sigma(R) = \Sigma_0 e^{-b(m)(R/R_e)^{1/m}}$$

$$b(m) = 2m - 1/3 + 4/(405m)$$

Sersic index
increases
central extra-light
~300pc scale

Hydrodynamics

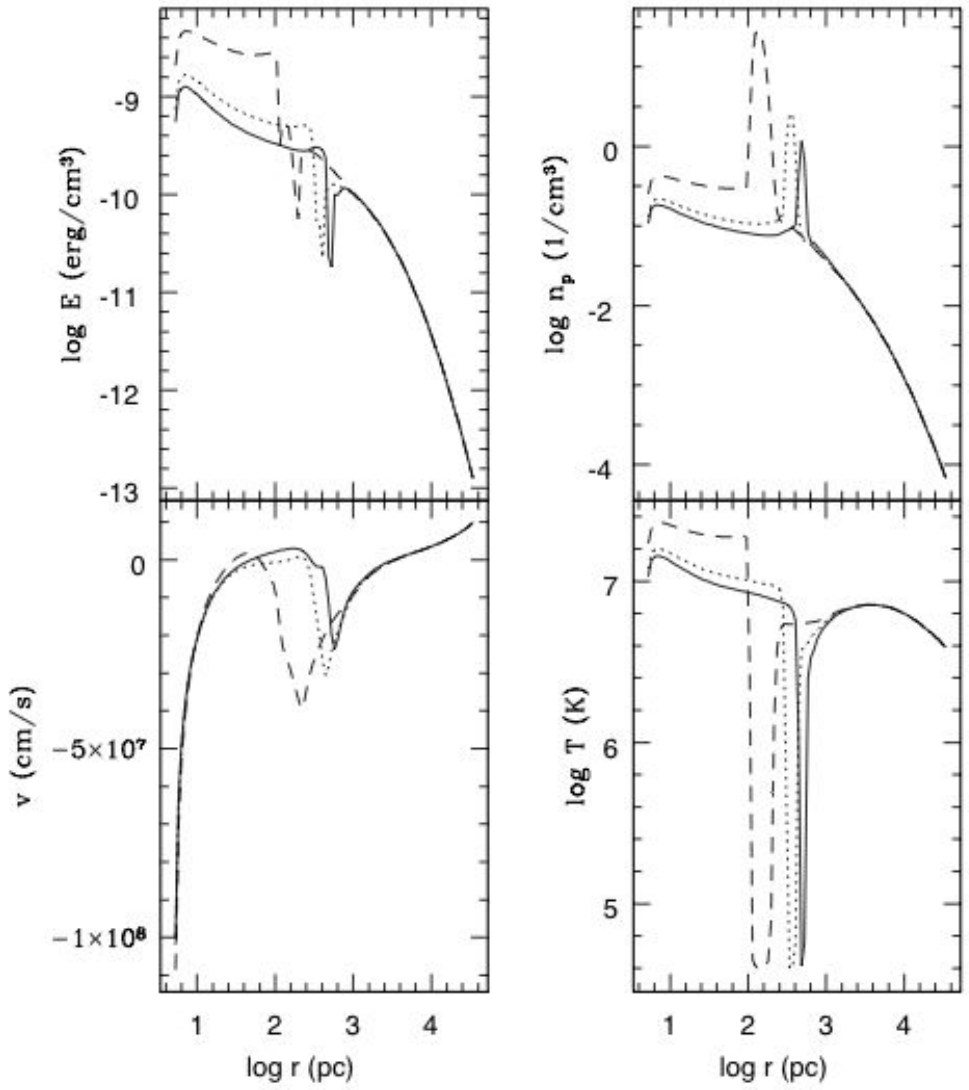


←ISM velocity

~ 1 pc from SMBH

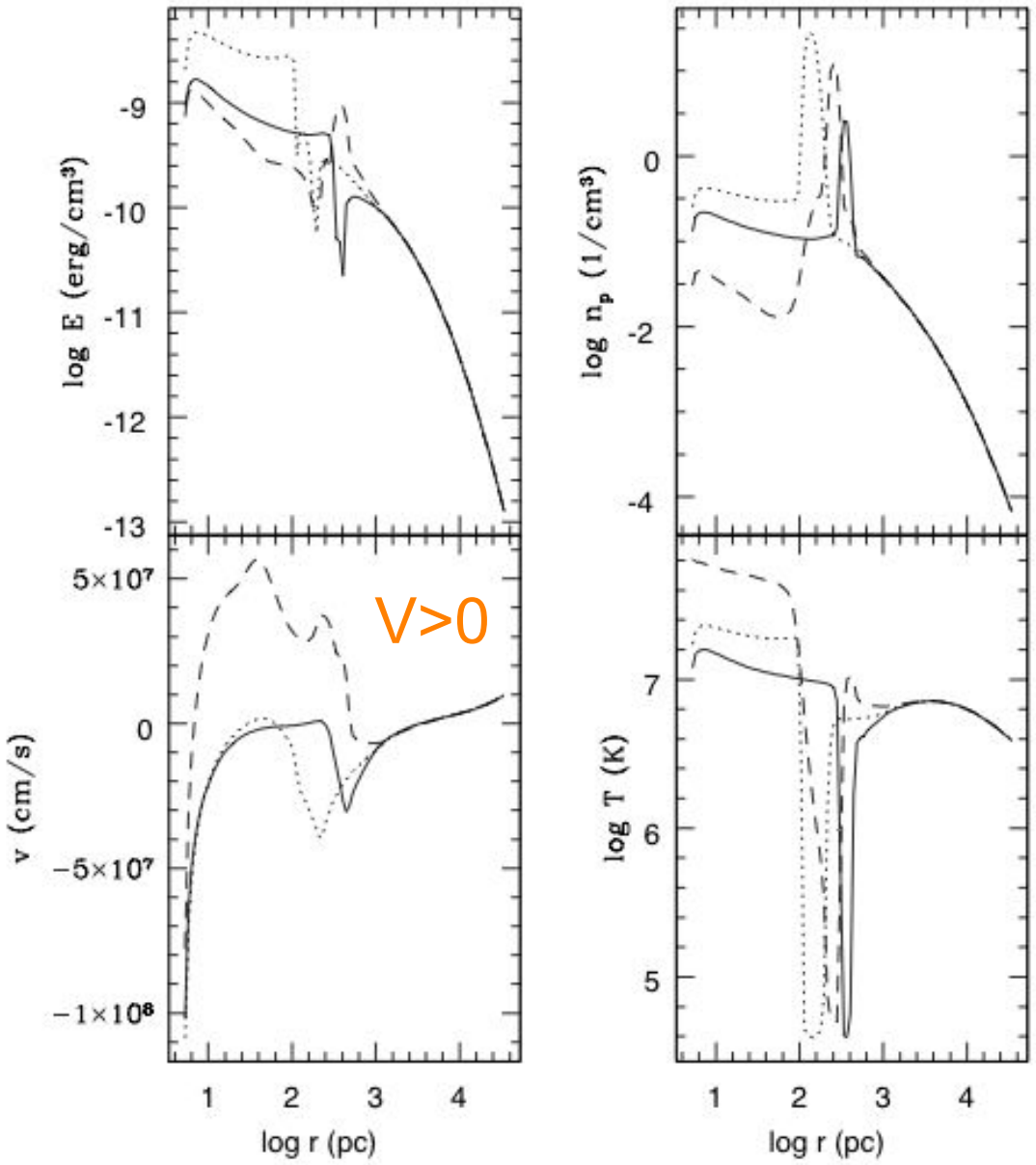
ISM density & Temperature

The cold shell is falling to the center

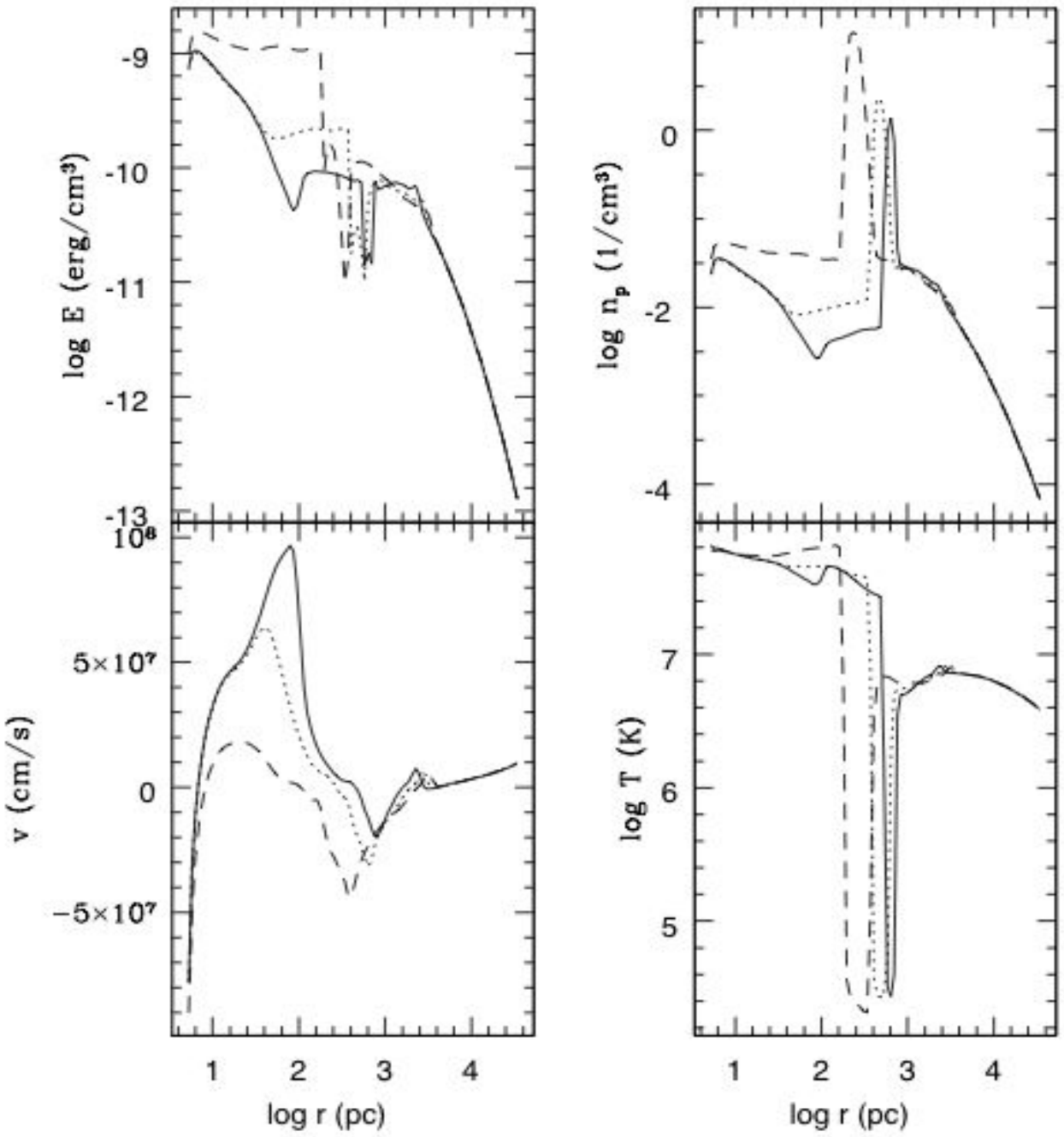


Time separation=1Myr

A shock is launched (dashed) & cooled



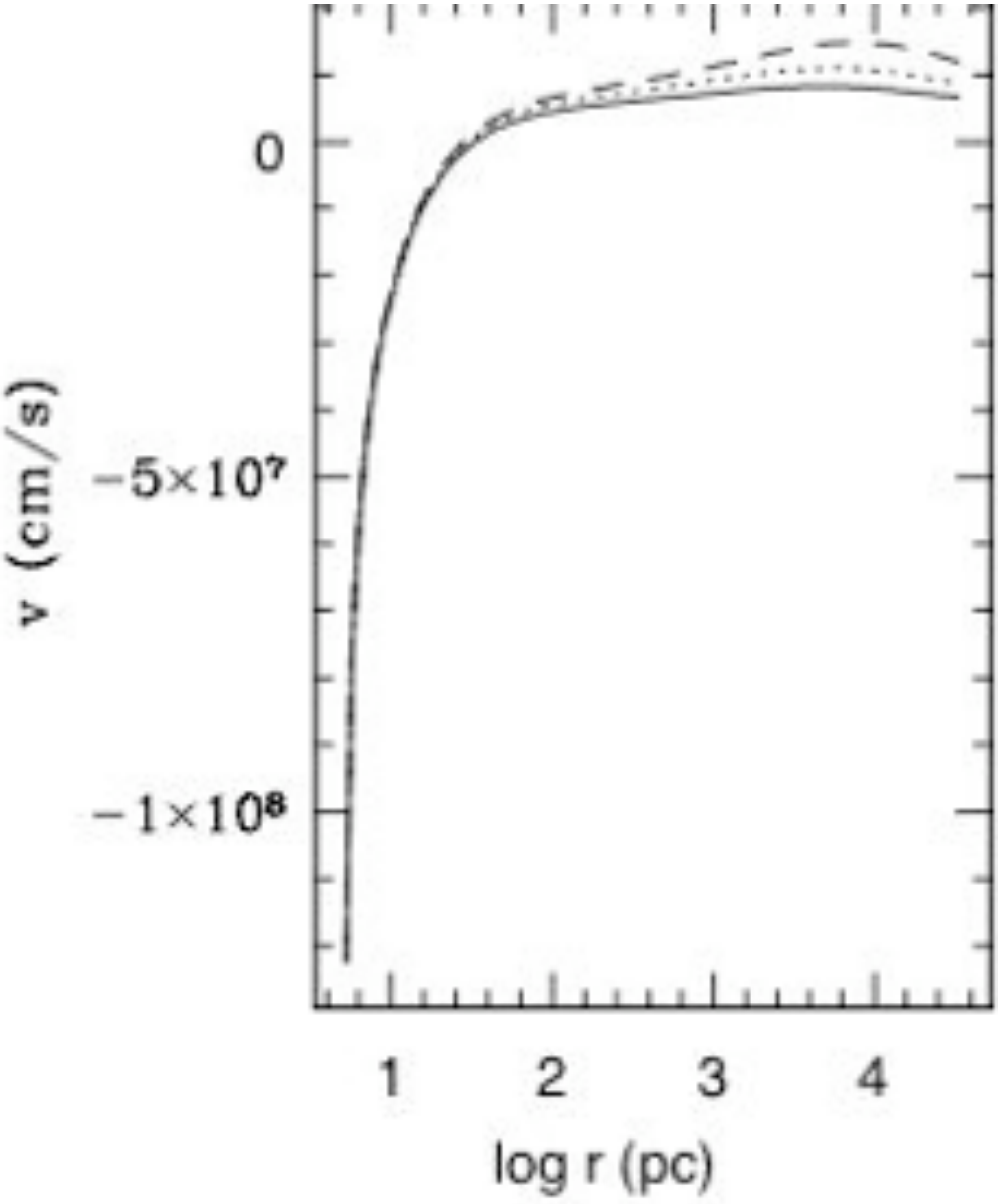
Compton cooling
PLUS
Adiabatic cooling
PLUS
Radiative cooling



Another cold shell is formed, and start to fall.

In the shell, vigorous star formation.

SNIa take over, a low-density partial wind with low-luminosity, hot accretion is established (ADAF state)



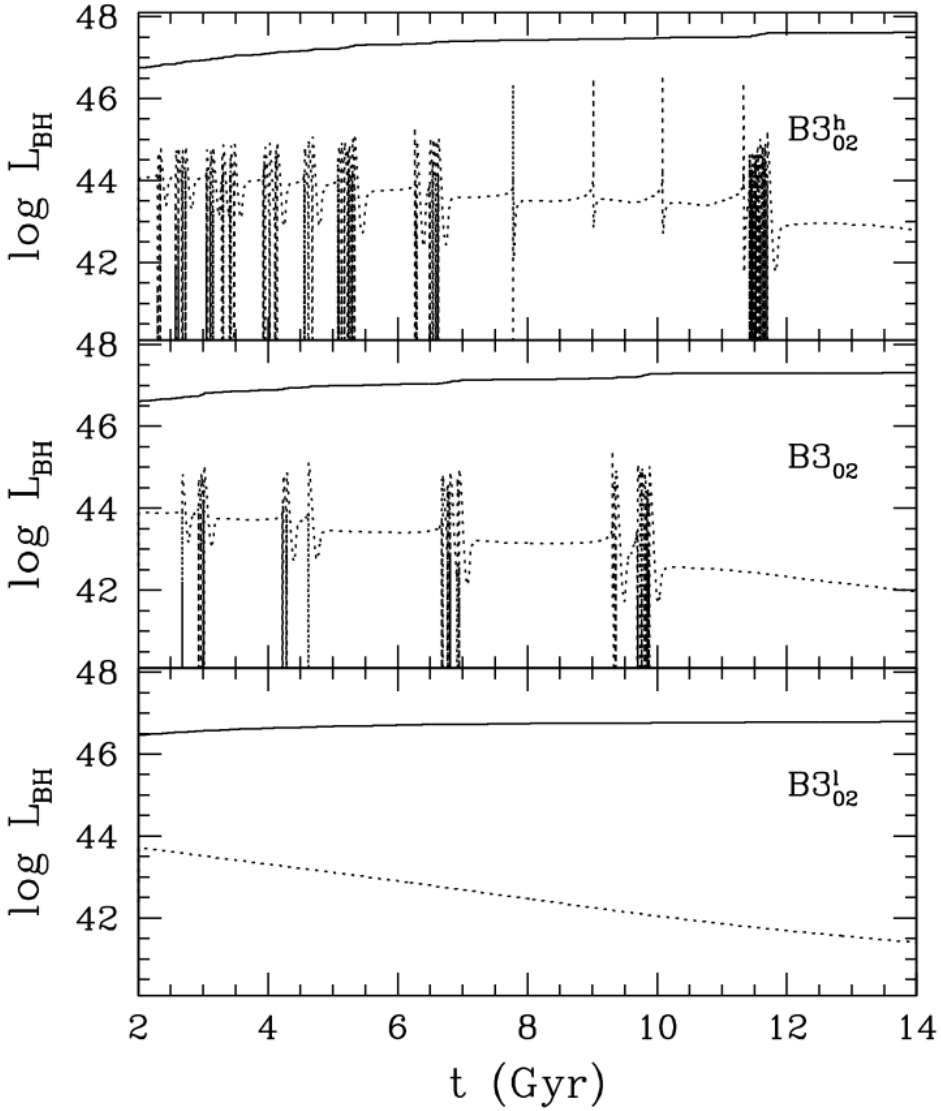
A caveat about "standard" Bondi accretion!

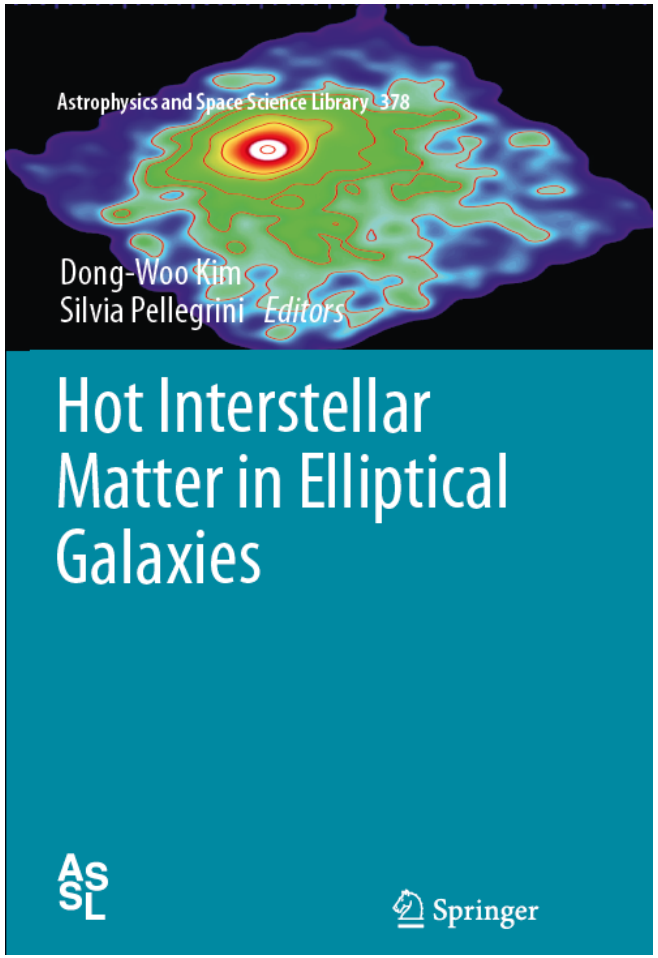
LOCAL

A full exploration of the parameter space is impossible

AGN feedback in elliptical galaxies: numerical simulations

Luca Ciotti and Jeremiah P. Ostriker

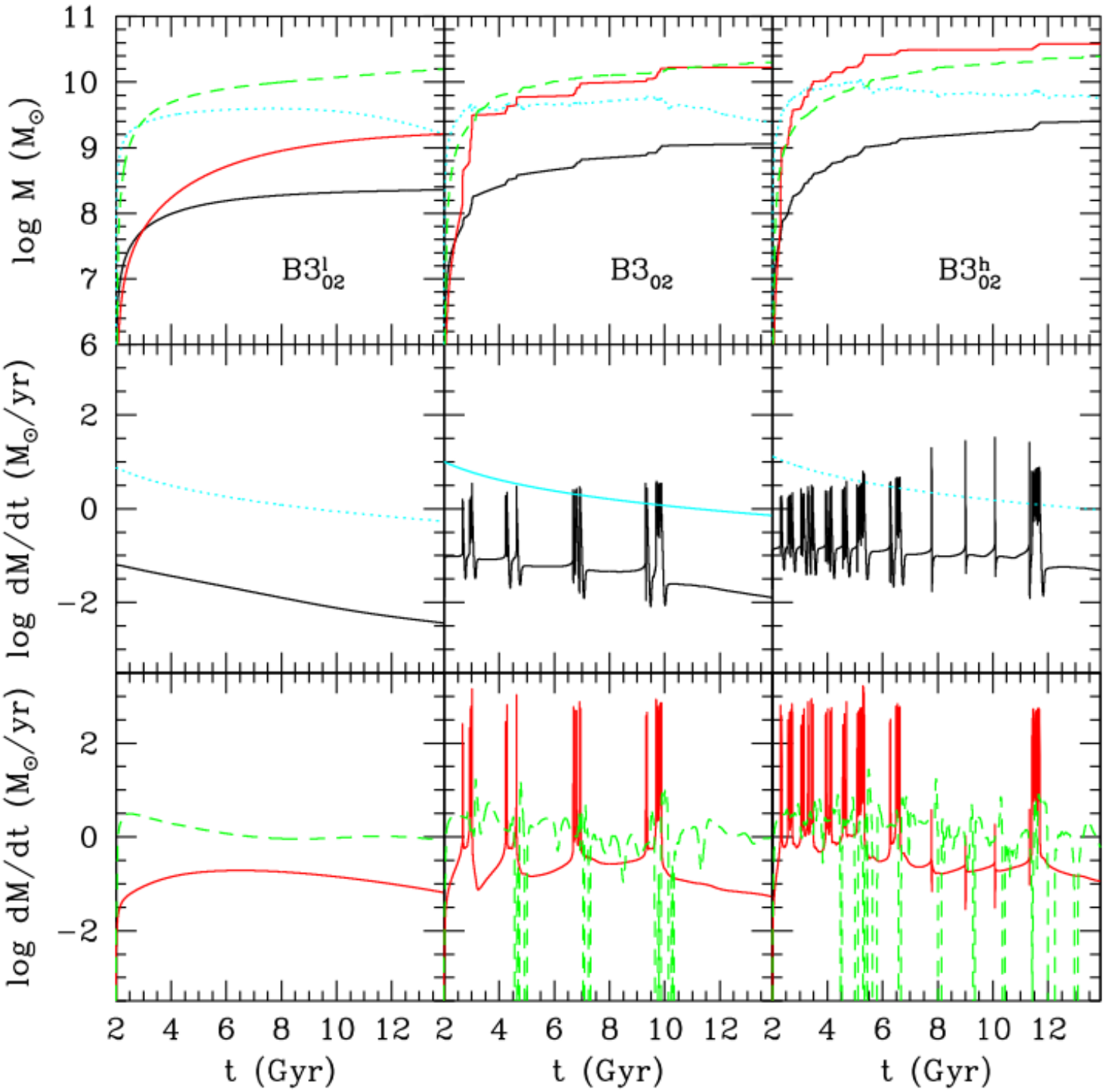




280 (top) – 260 (midle) – 240 (bottom) km/s

Mass budgets

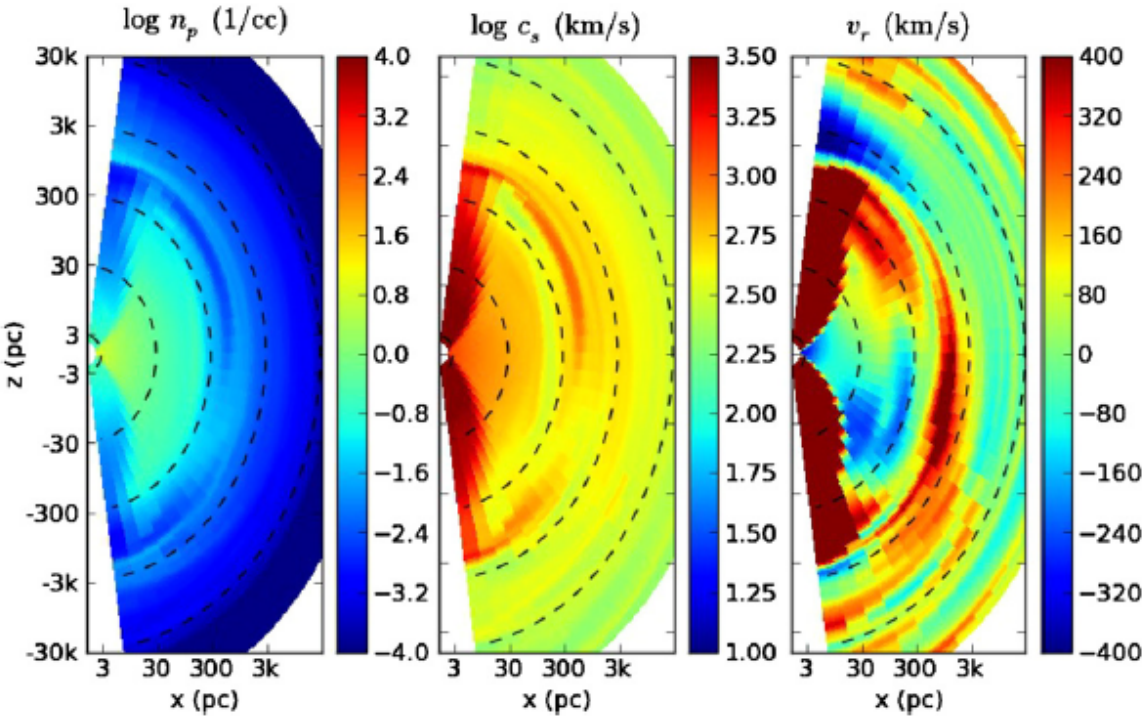
Red: stars
Black: BH
Cyan: SSP
Green: G.W.



3. 2D-models

Ciotti, Novak, Ostriker, et al., ongoing

State-of-the-art dynamical modeling of the galaxies
PLUS
2D-extension of feedback treatment



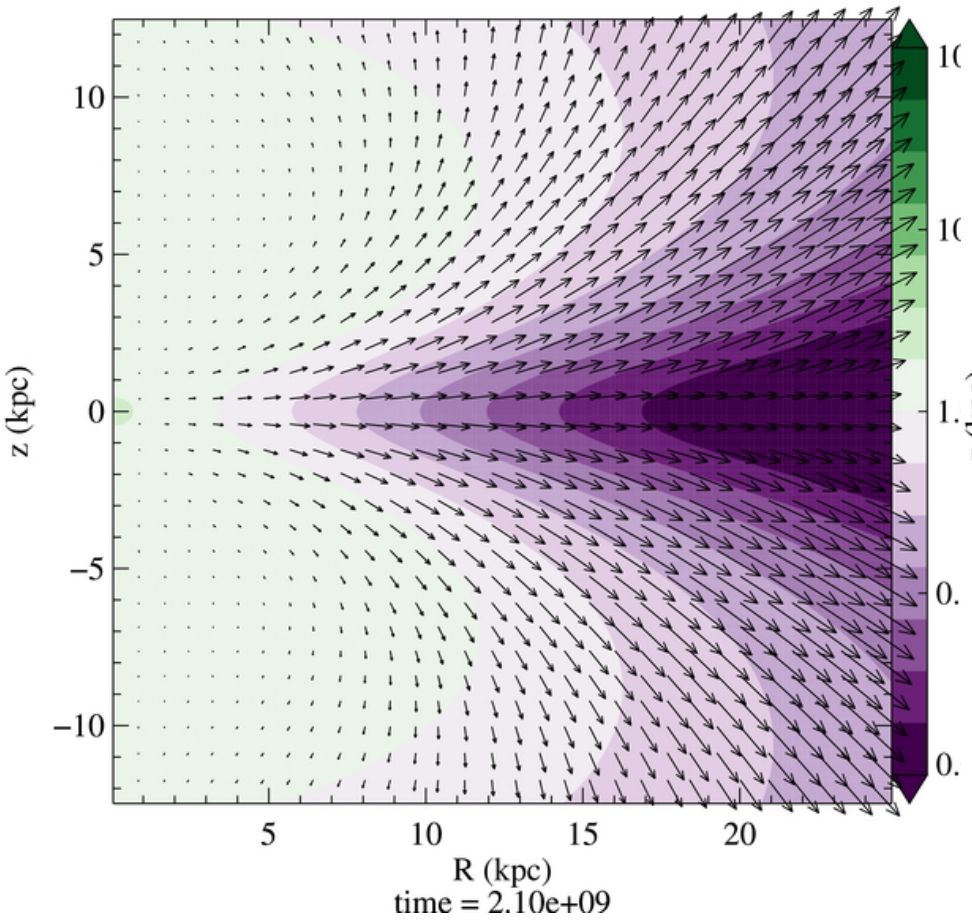
Novak, Ostriker, Ciotti
(2011,2012)

Examples of ISM evolution in a realistic S0/E4 galaxy with different internal dynamics
NO AGN feedback activated

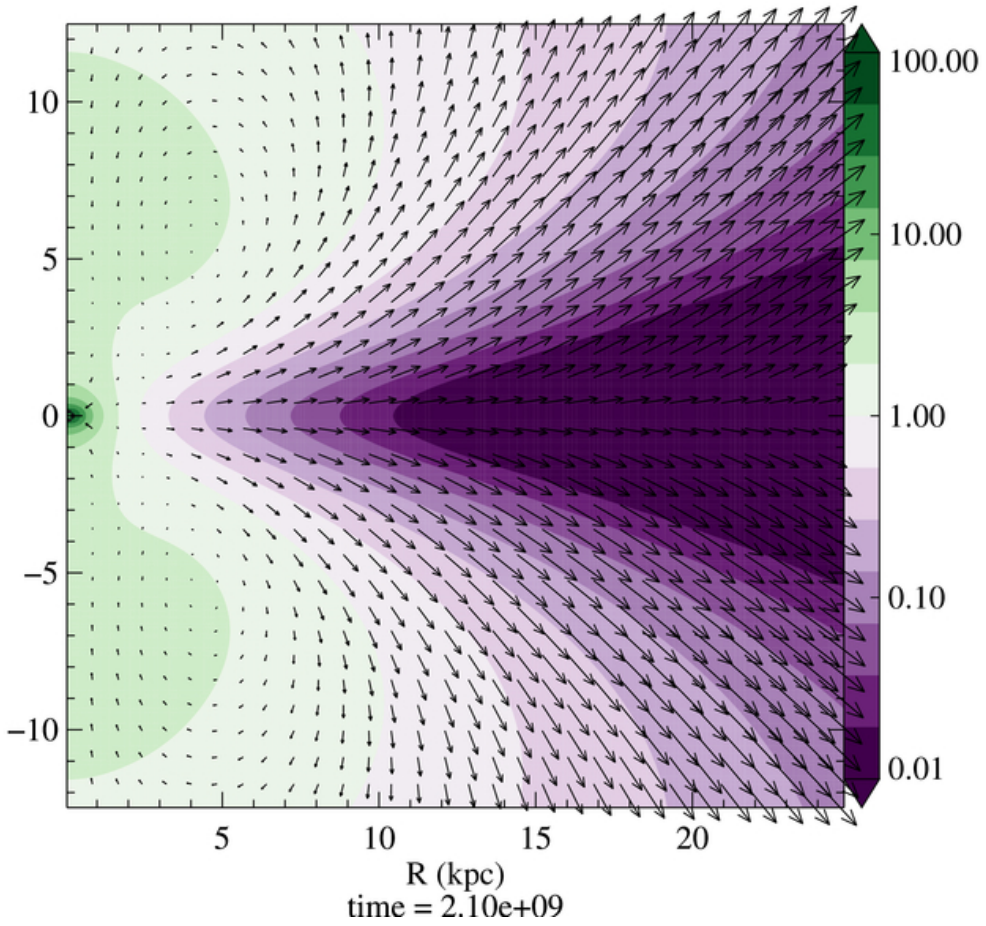
Posacki, Pellegrini, Ciotti (MNRAS, 2013),
Negri, Ciotti, Pellegrini (MNRAS, 2013),
Negri, Posacki, Pellegrini, Ciotti (MNRAS, 2014):

theoretical and 2D hydro models for the X-ray halos properties of ETGs as a function of their shape and internal kinematics

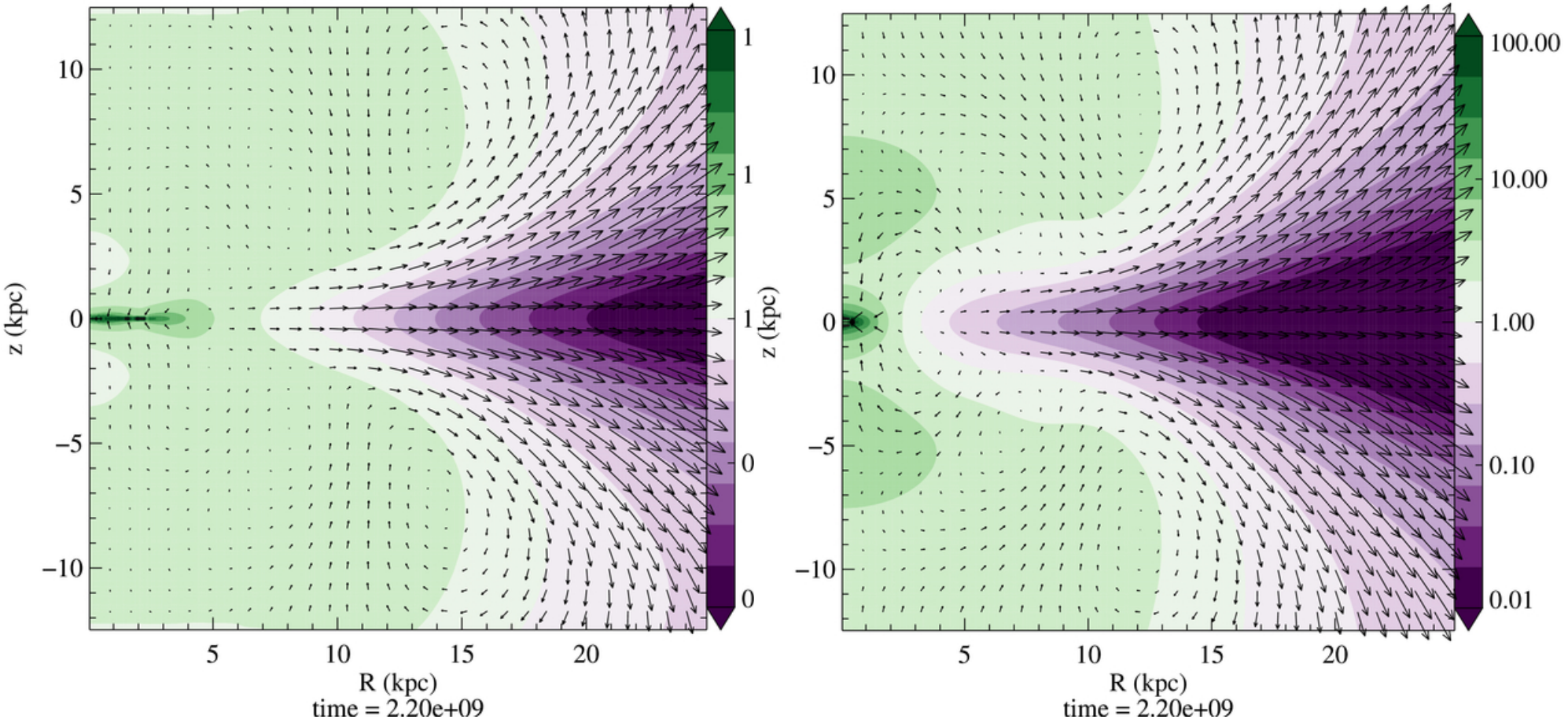
In the following, IDENTICAL galaxy models EXCEPT for the internal kinematics

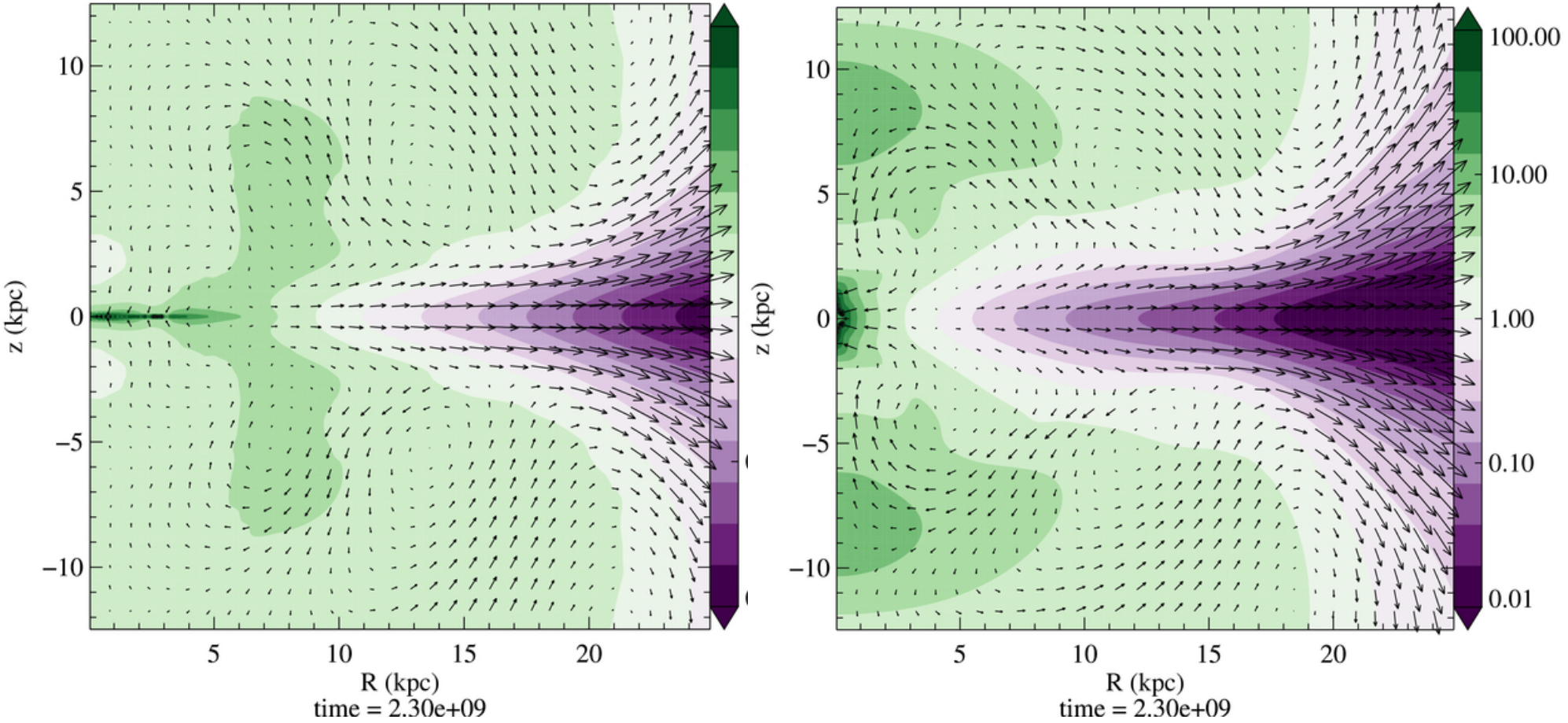


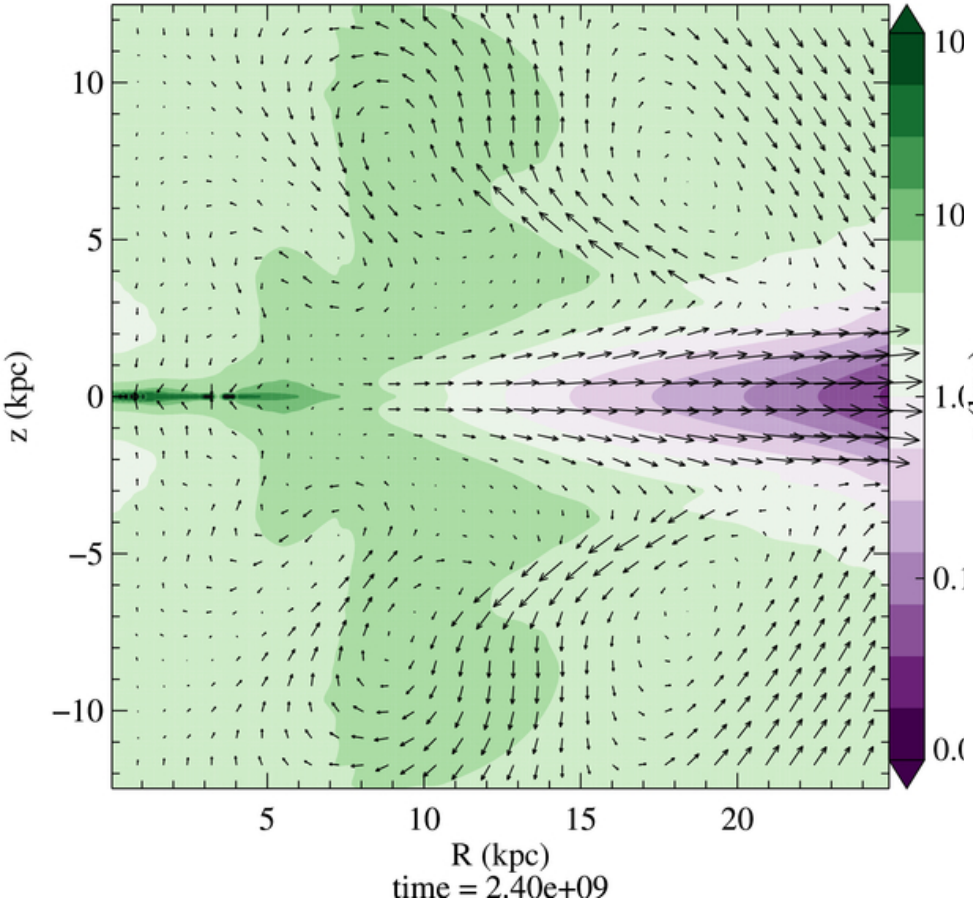
Isotropic rotator

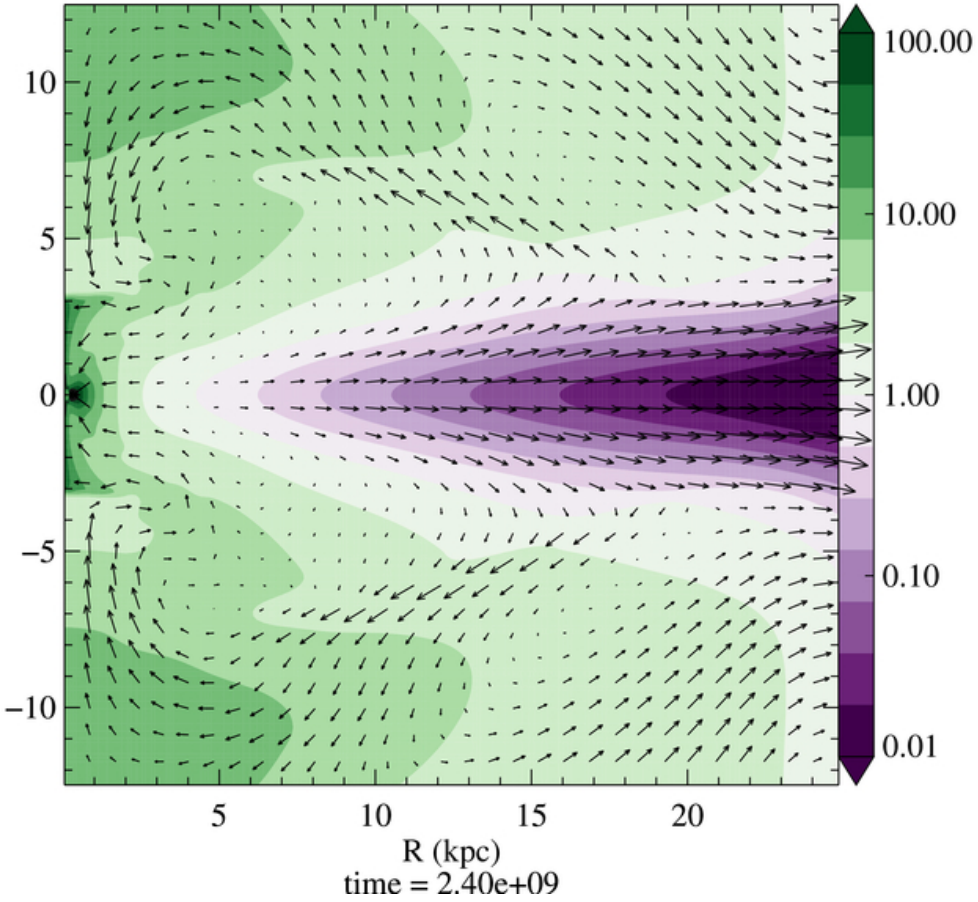


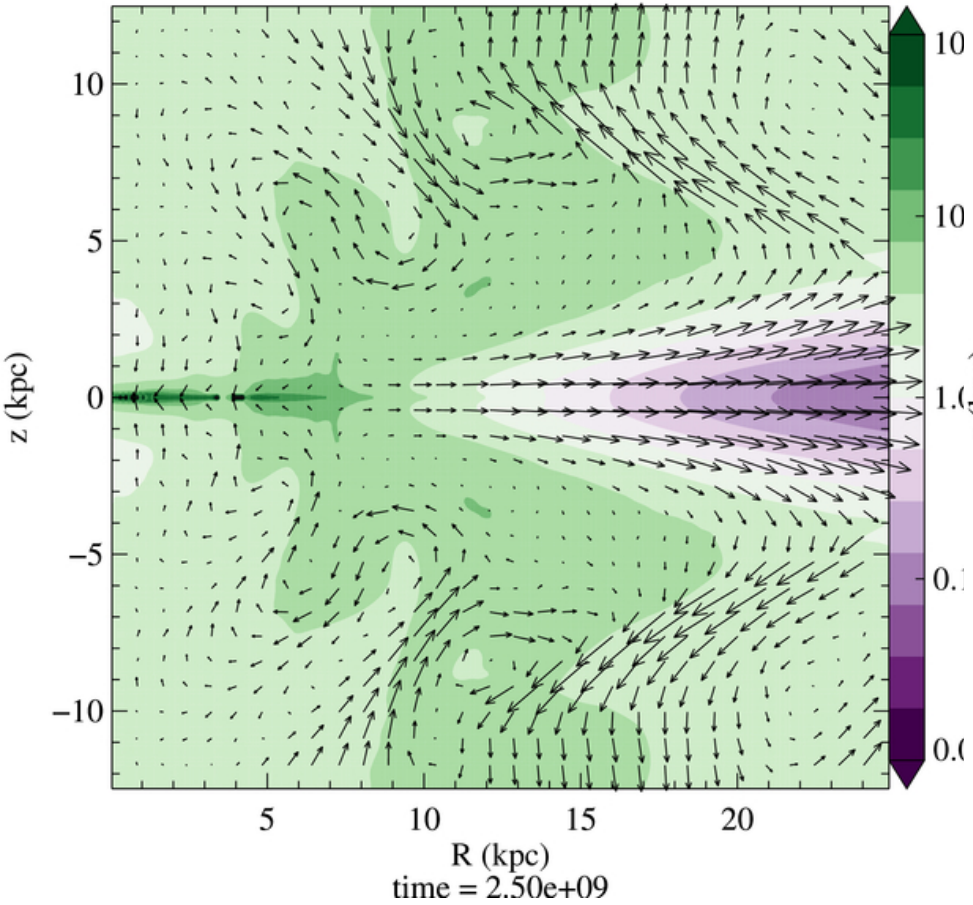
Velocity dispersion supported

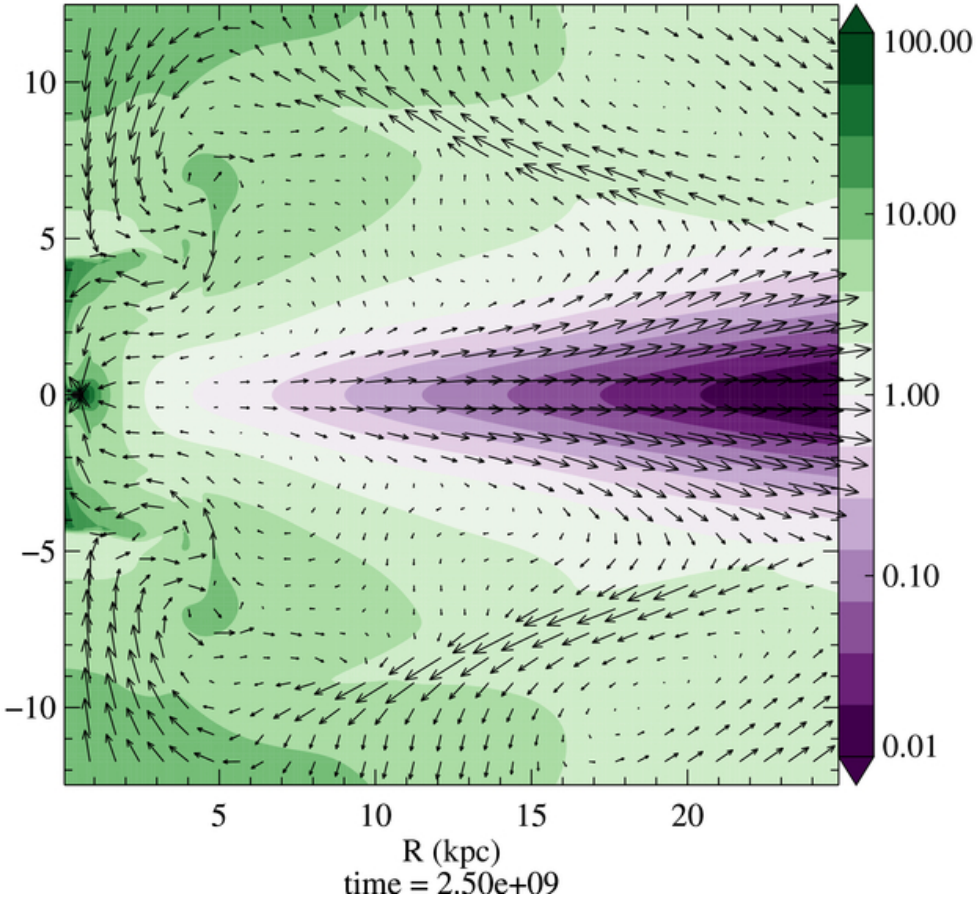

z (kpc)
R (kpc)
time = 2.20e+09
10
5
0
−5
−10
5
10
15
20
1
1
1
0
0
z (kpc)
R (kpc)
time = 2.20e+09
100.00
10.00
1.00
0.10
0.01

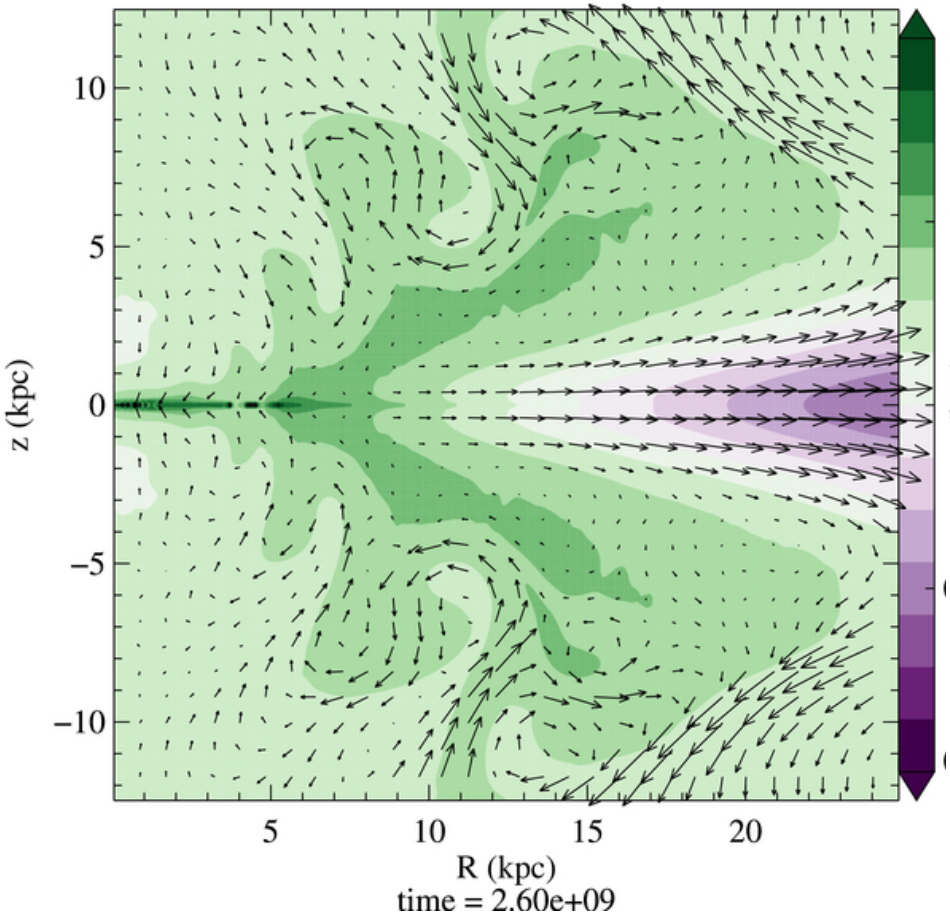

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 2.30e+09
z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 2.30e+09
100.00
10.00
1.00
0.10
0.01

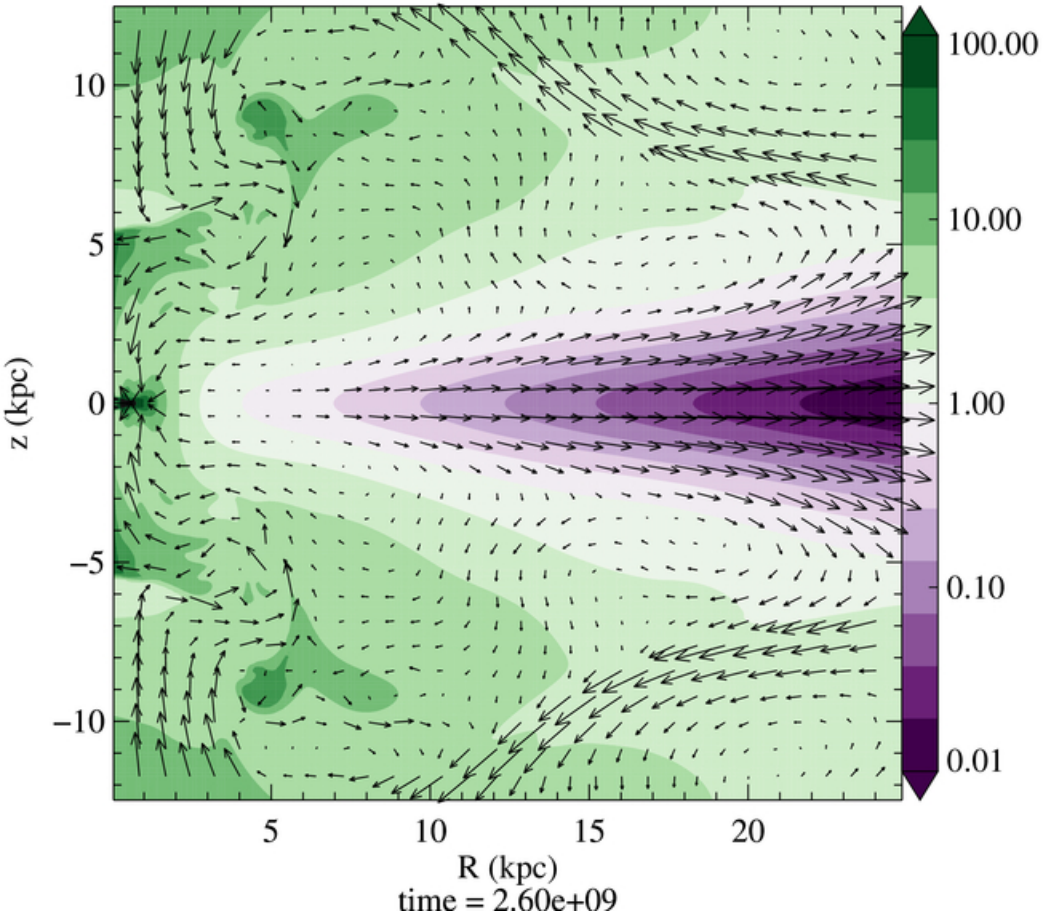

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 2.40e+09

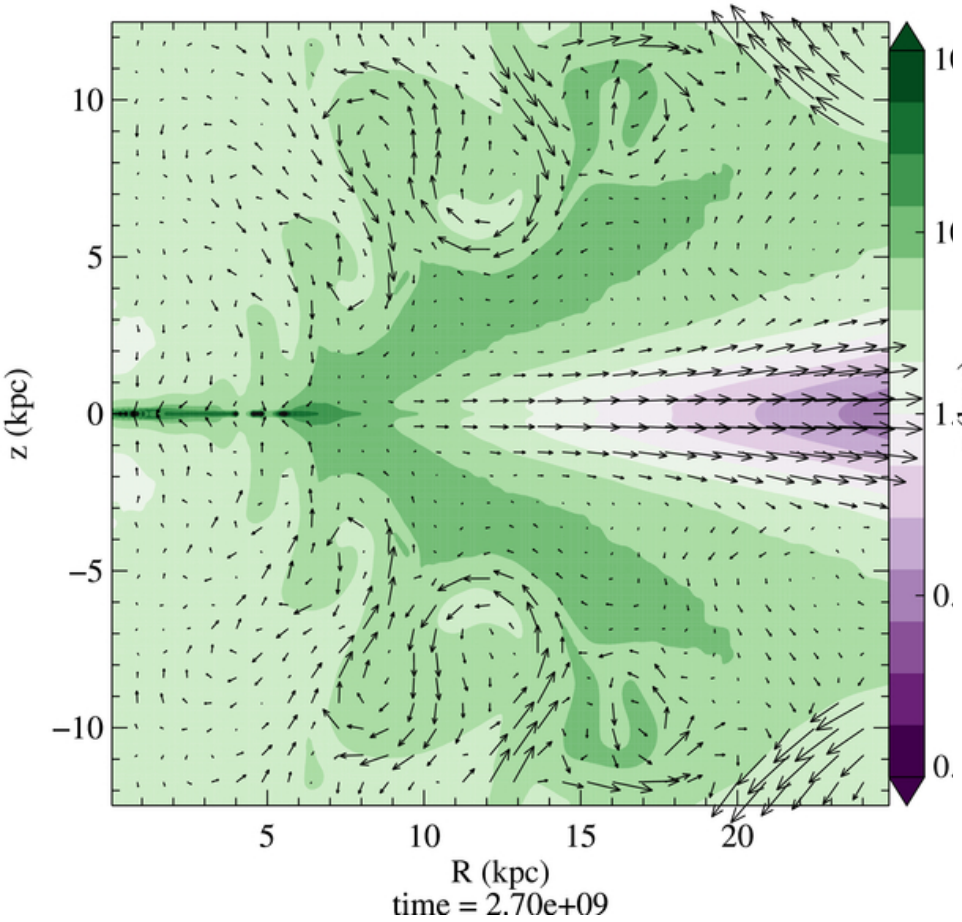

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 2.40e+09
100.00
10.00
1.00
0.10
0.01

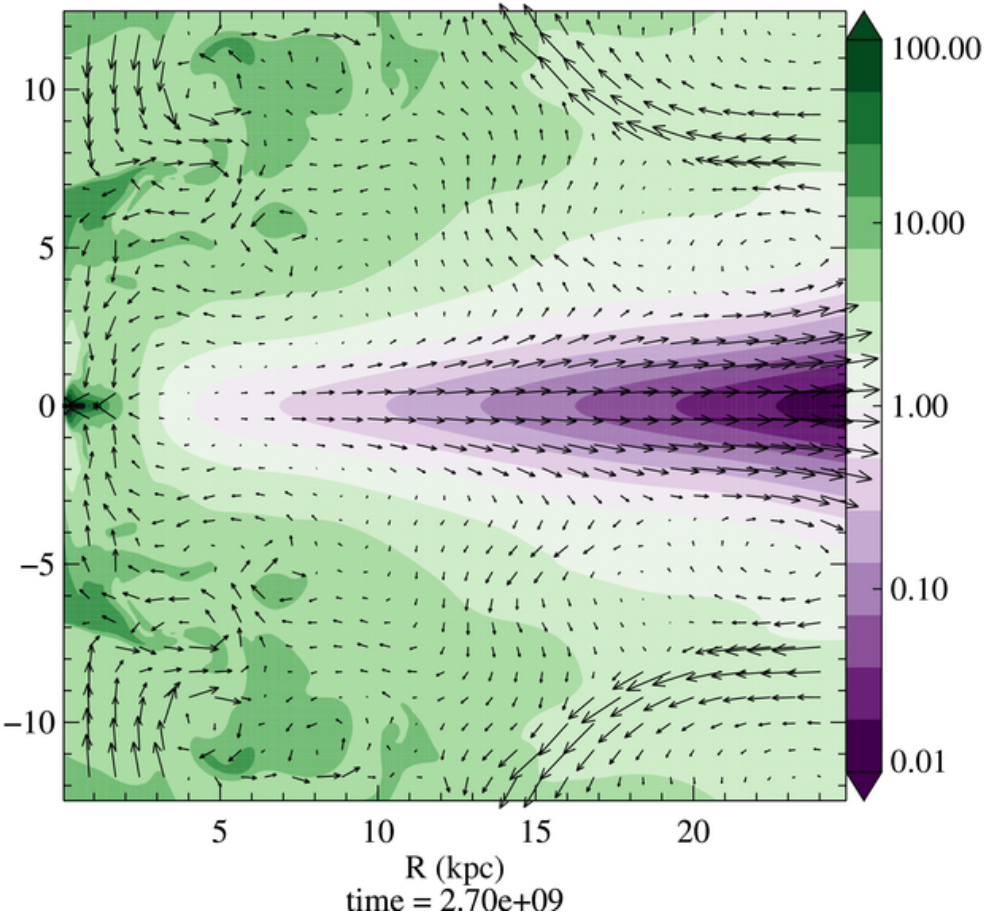

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 2.50e+09

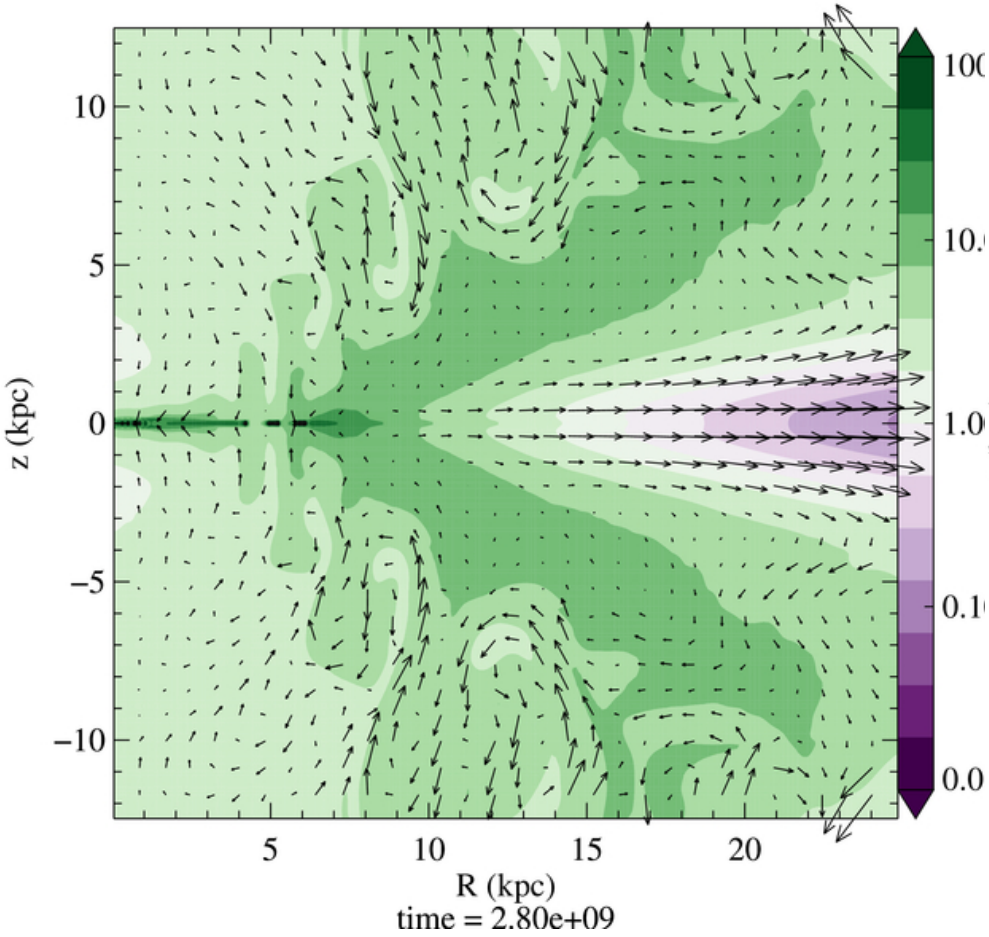

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 2.50e+09
100.00
10.00
1.00
0.10
0.01

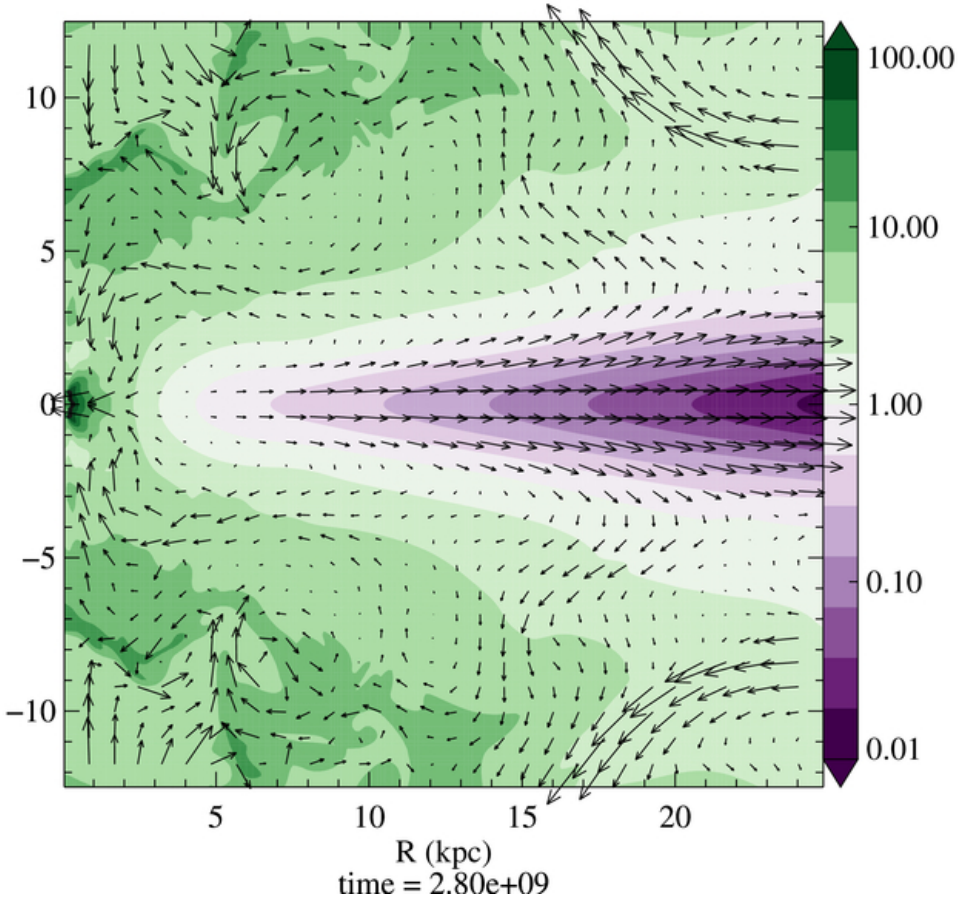

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 2.60e+09

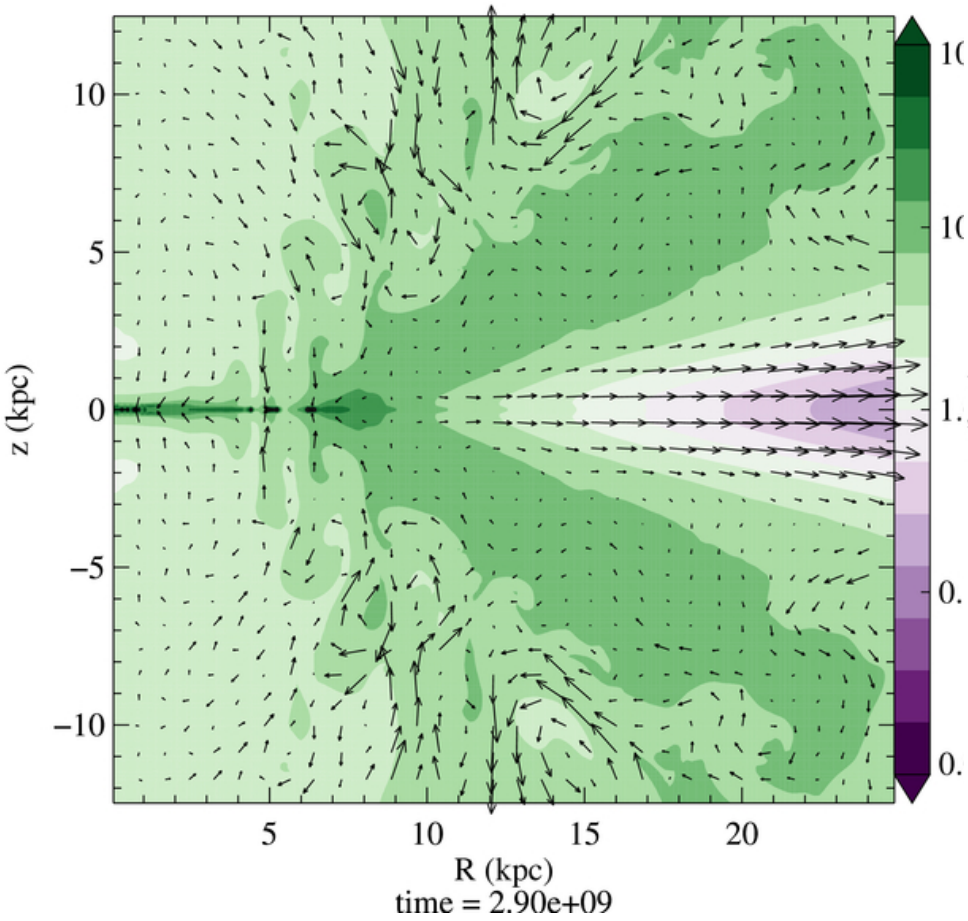

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 2.60e+09
100.00
10.00
1.00
0.10
0.01

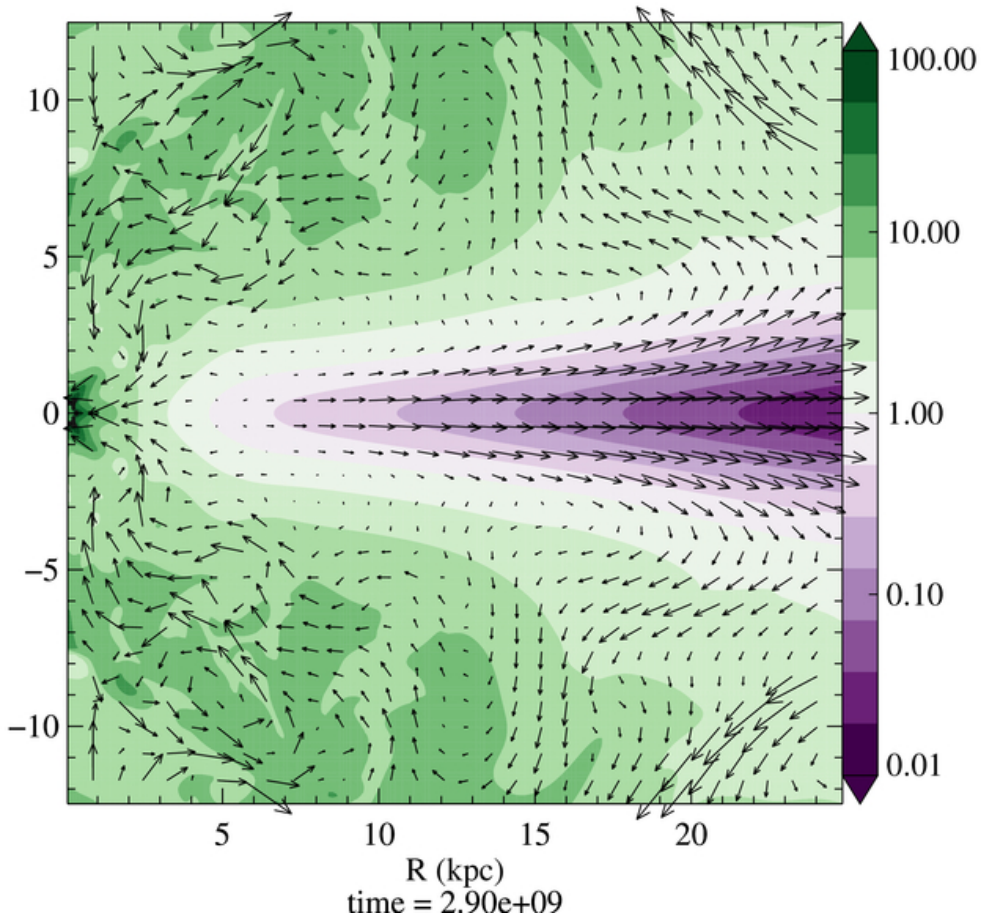

z (kpc)
R (kpc)
time = 2.70e+09

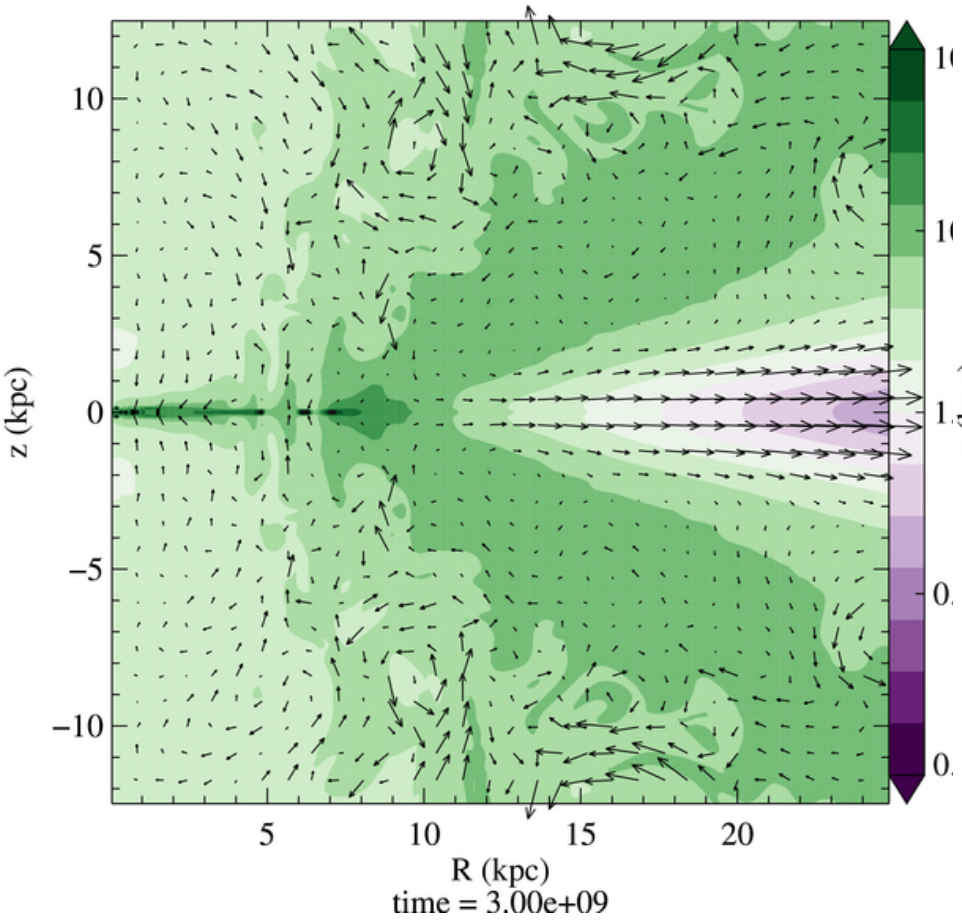

100.00
10.00
1.00
0.10
0.01
z (kpc)
R (kpc)
time = 2.70e+09

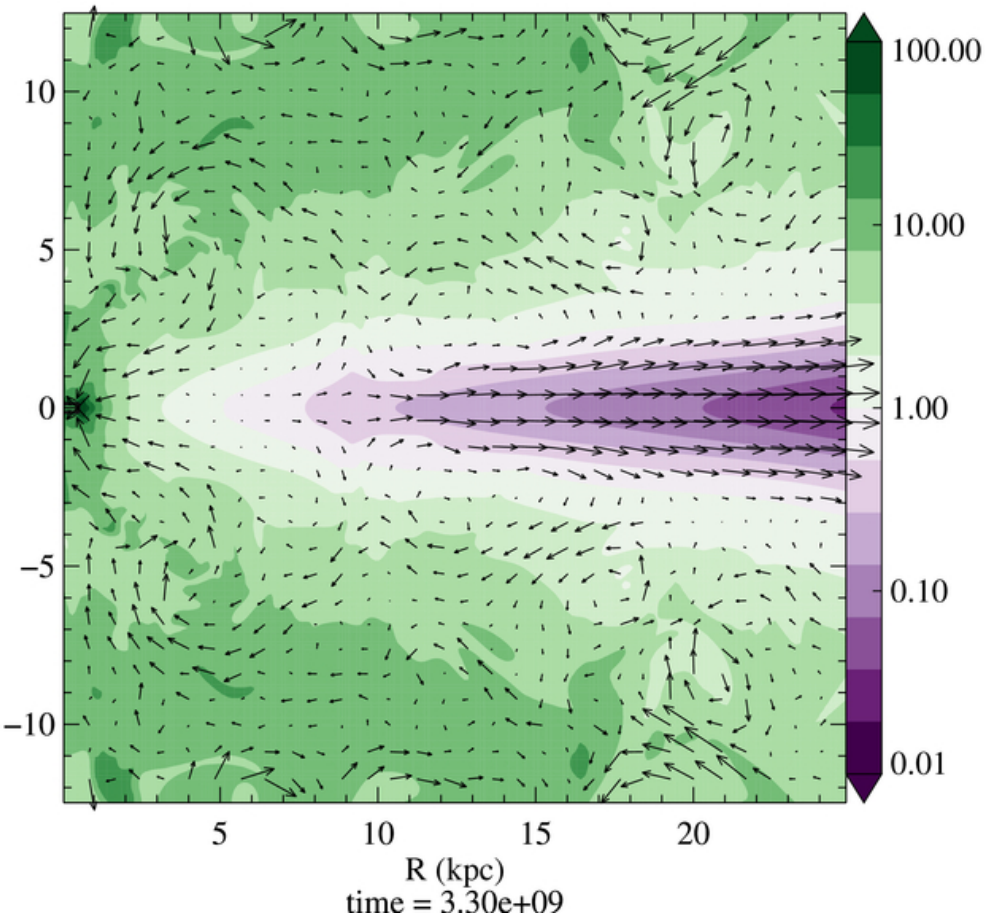

z (kpc)
R (kpc)
time = 2.80e+09

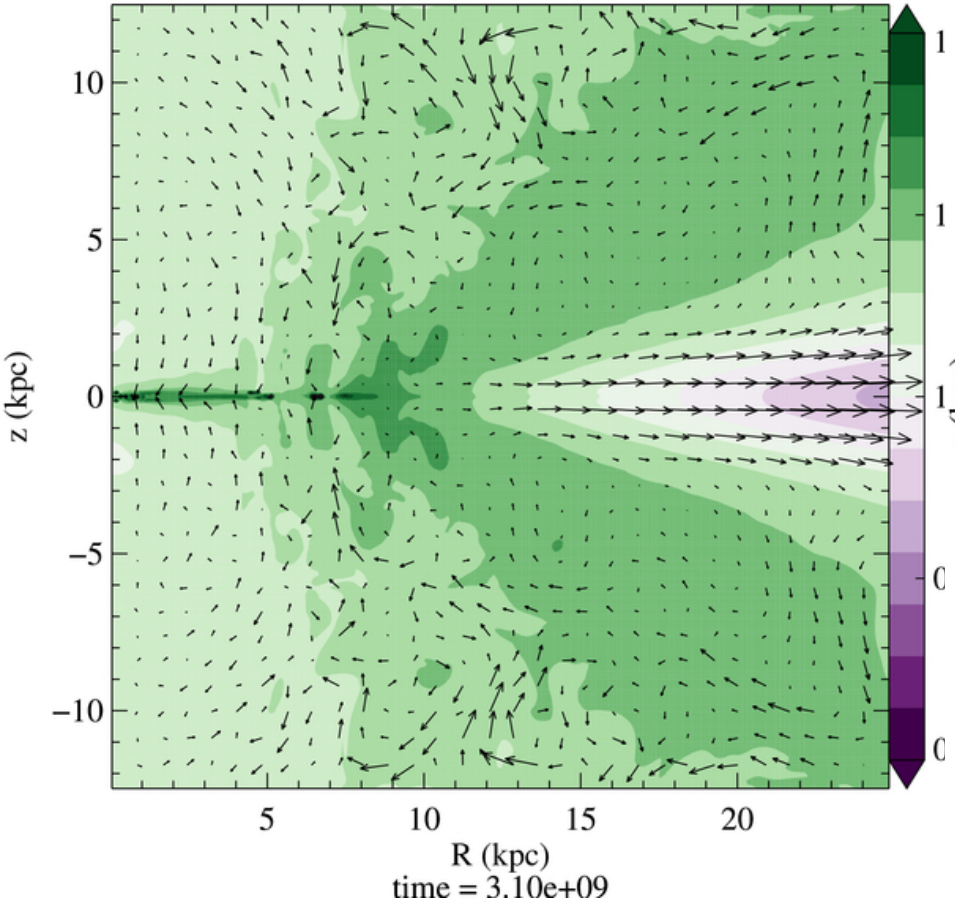

100.00
10.00
1.00
0.10
0.01
z (kpc)
R (kpc)
time = 2.80e+09

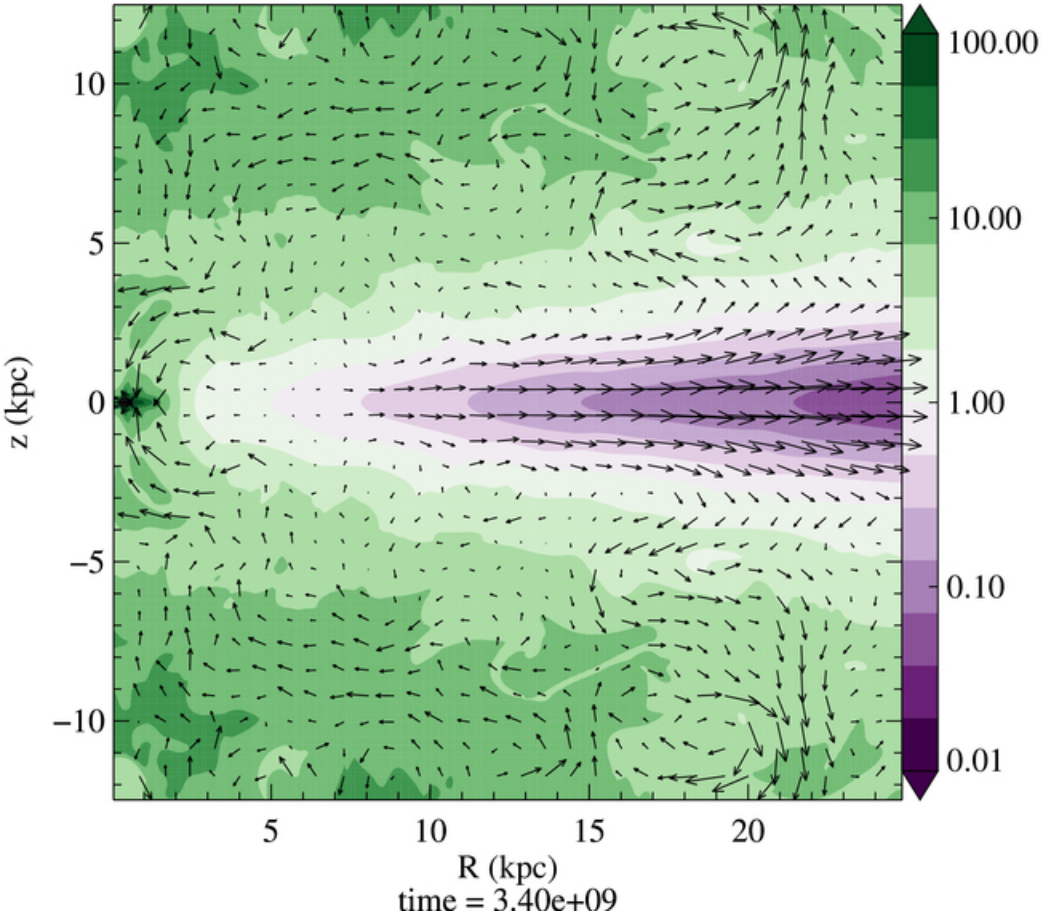

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 2.90e+09

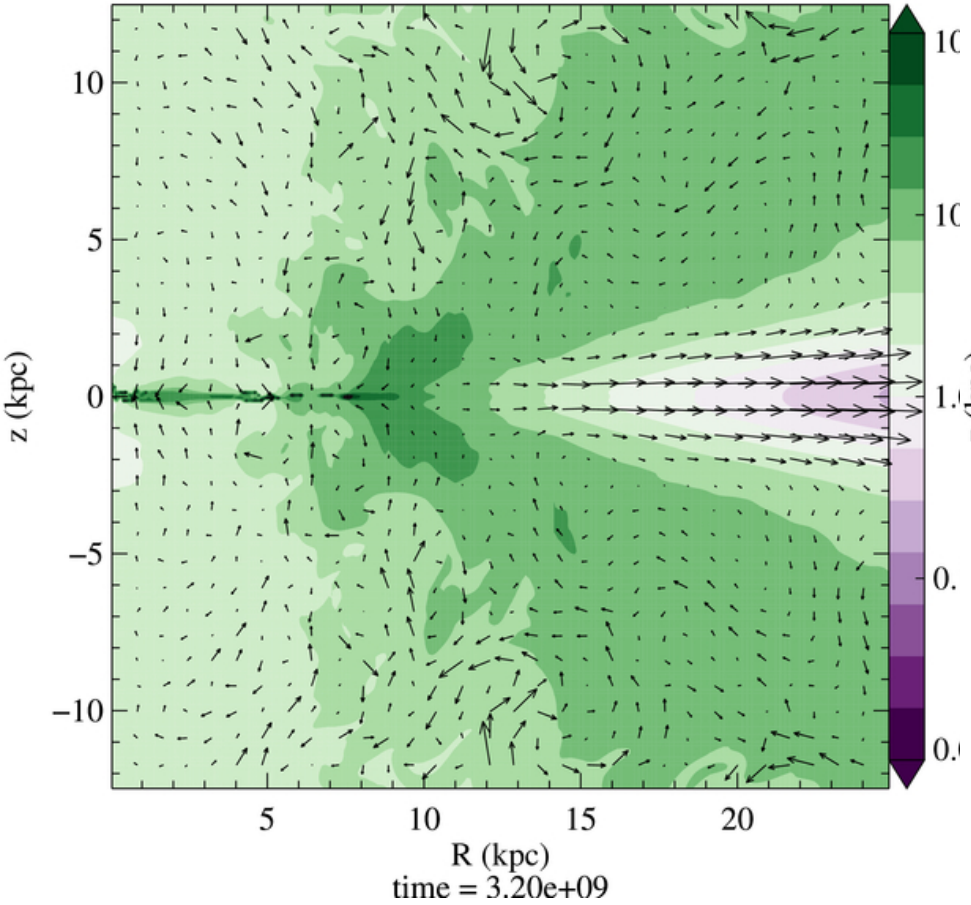

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 2.90e+09
100.00
10.00
1.00
0.10
0.01

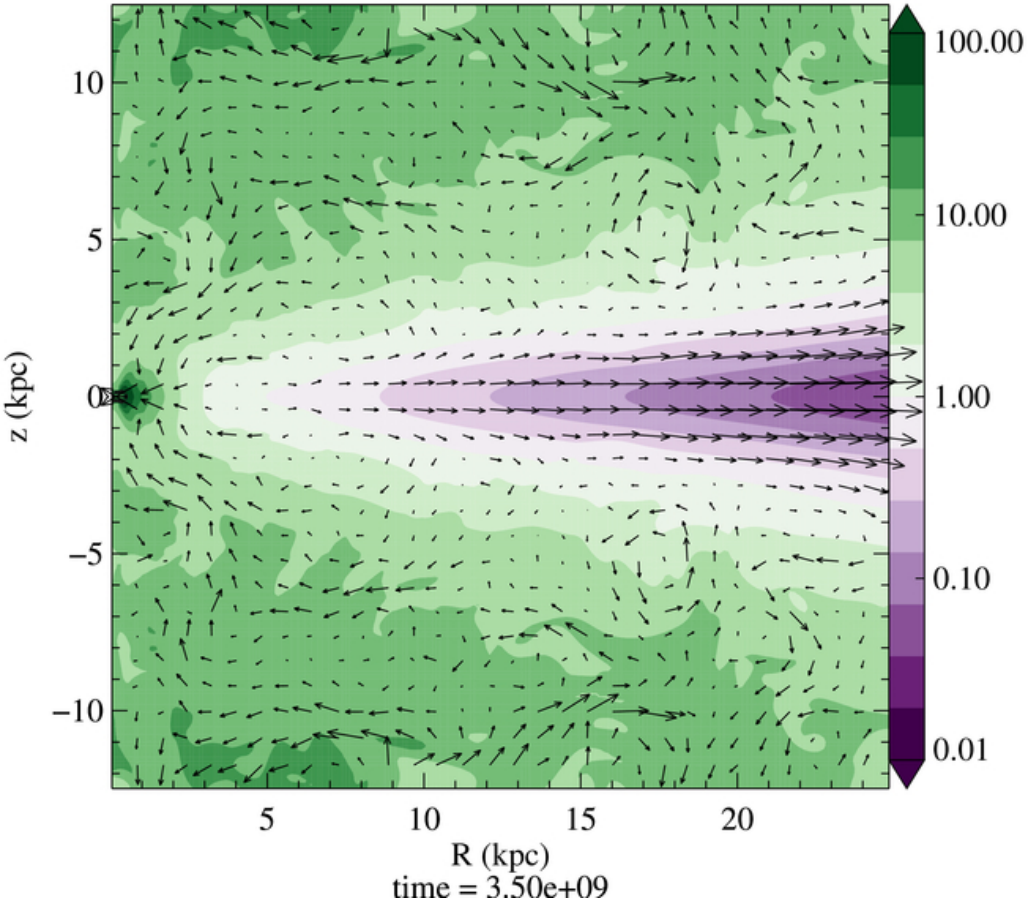

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 3.00e+09

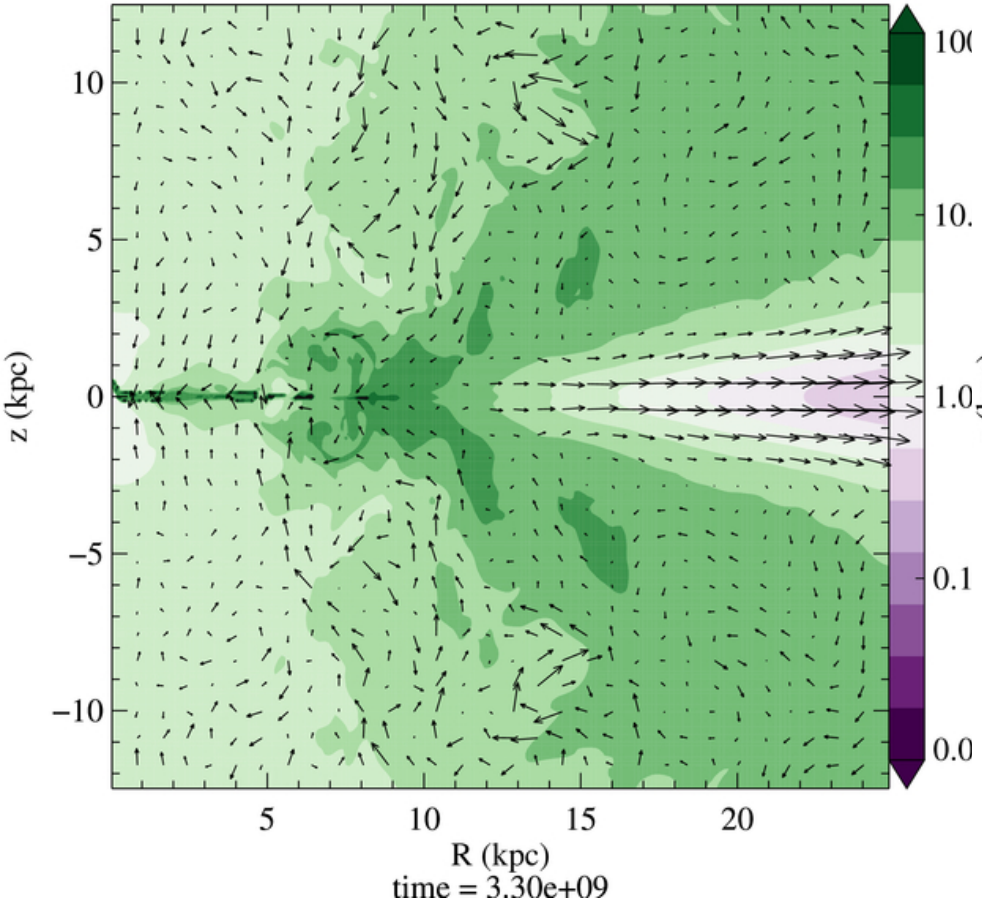

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 3.30e+09
100.00
10.00
1.00
0.10
0.01

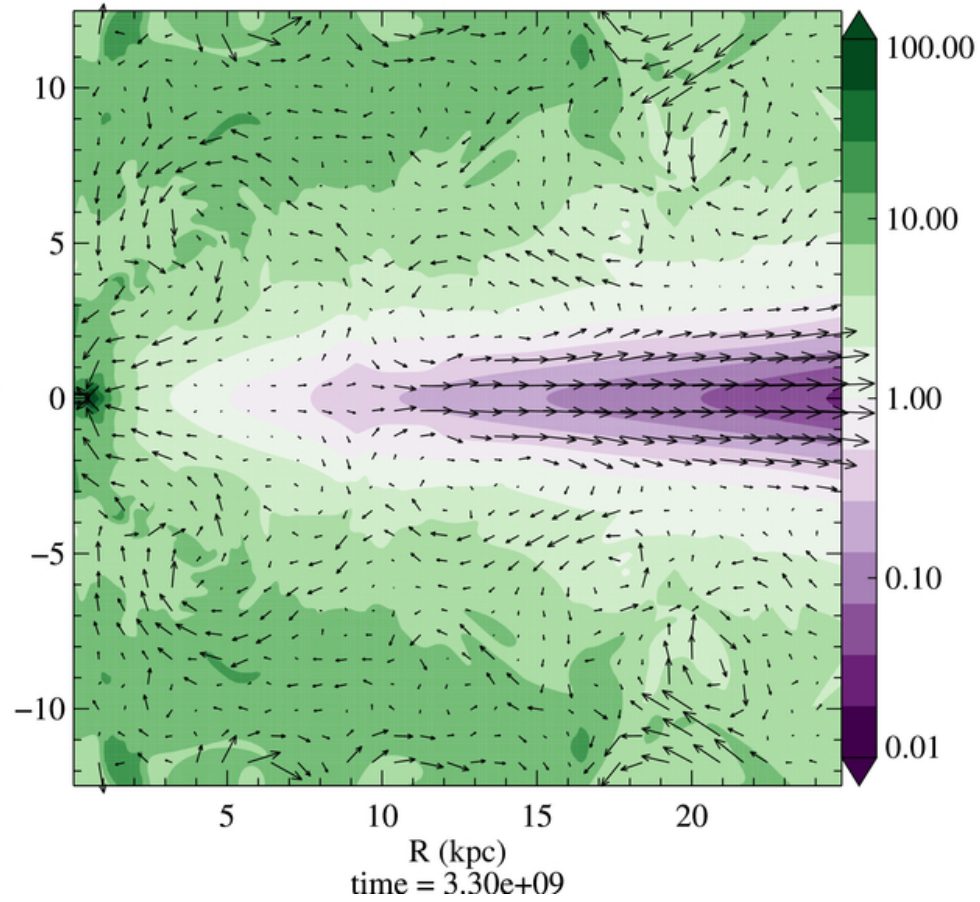

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 3.10e+09

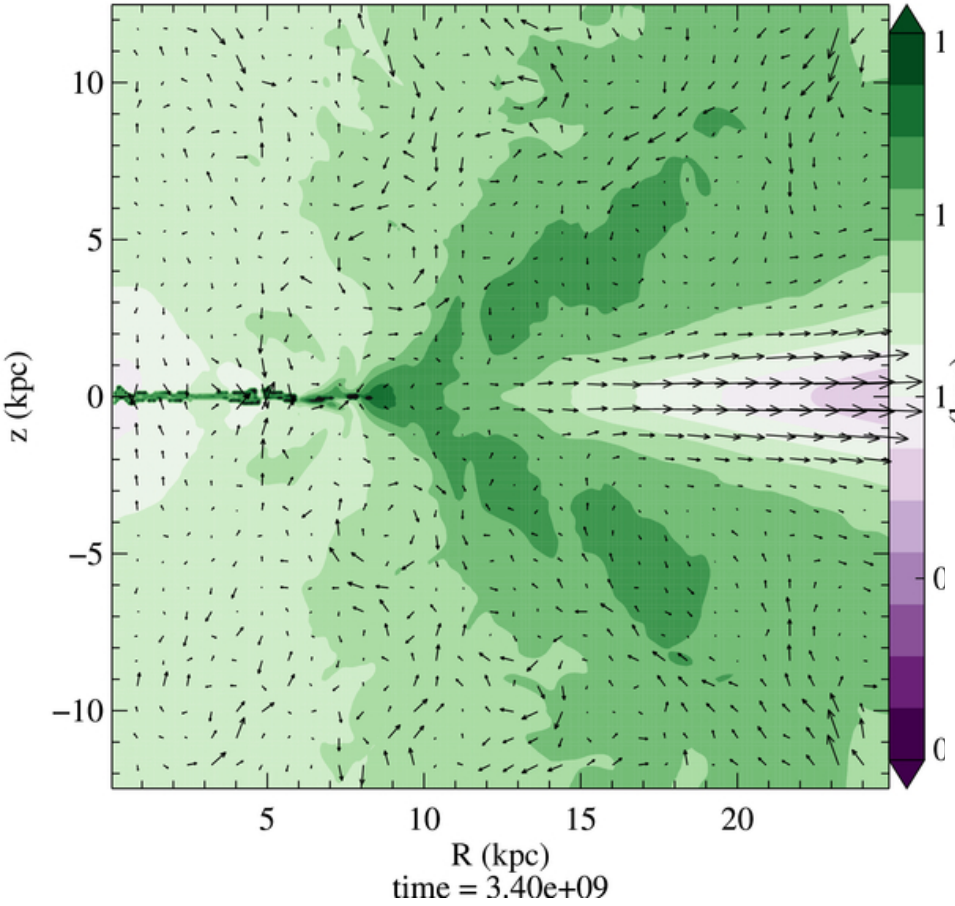

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 3.40e+09
100.00
10.00
1.00
0.10
0.01

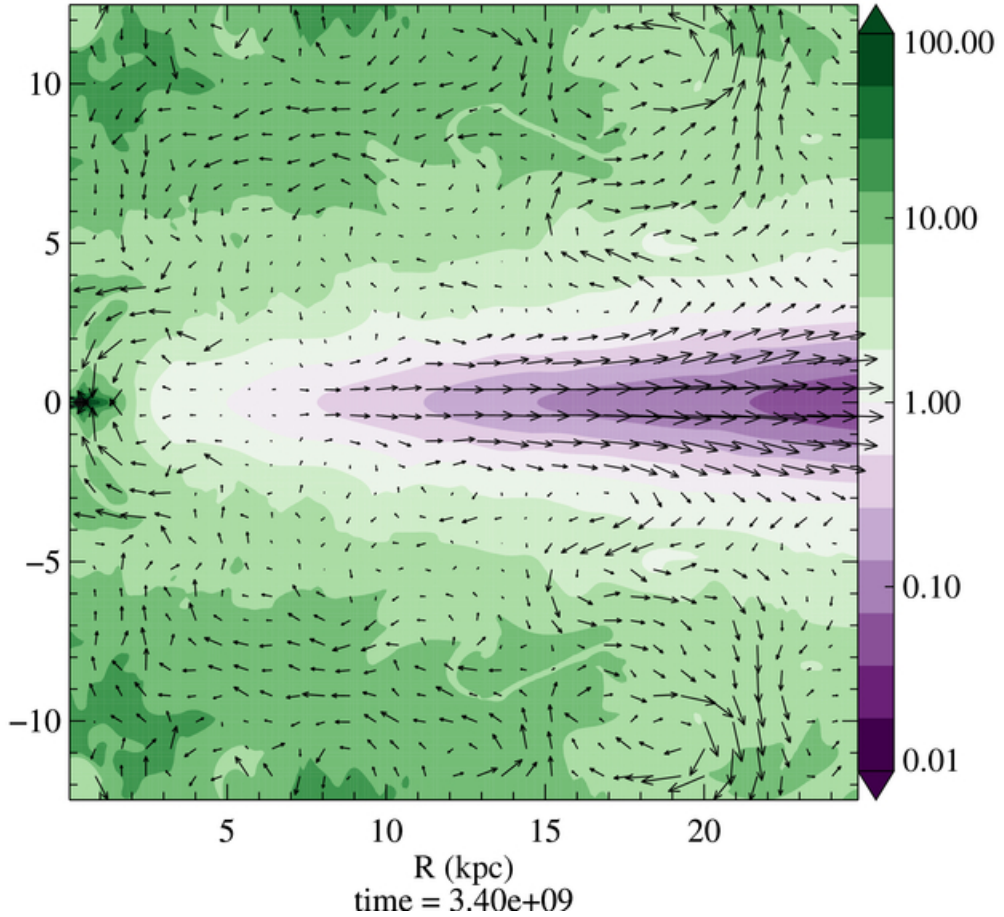

z (kpc)
R (kpc)
time = 3.20e+09

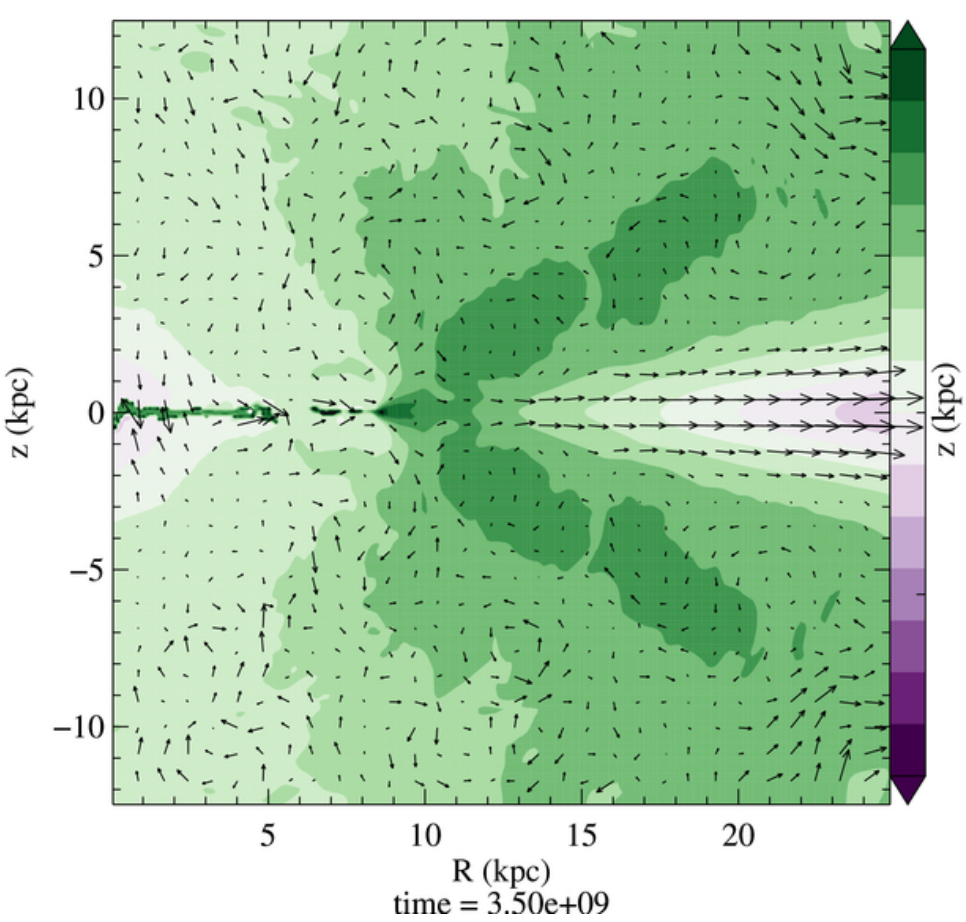

100.00
10.00
1.00
0.10
0.01
z (kpc)
R (kpc)
time = 3.50e+09

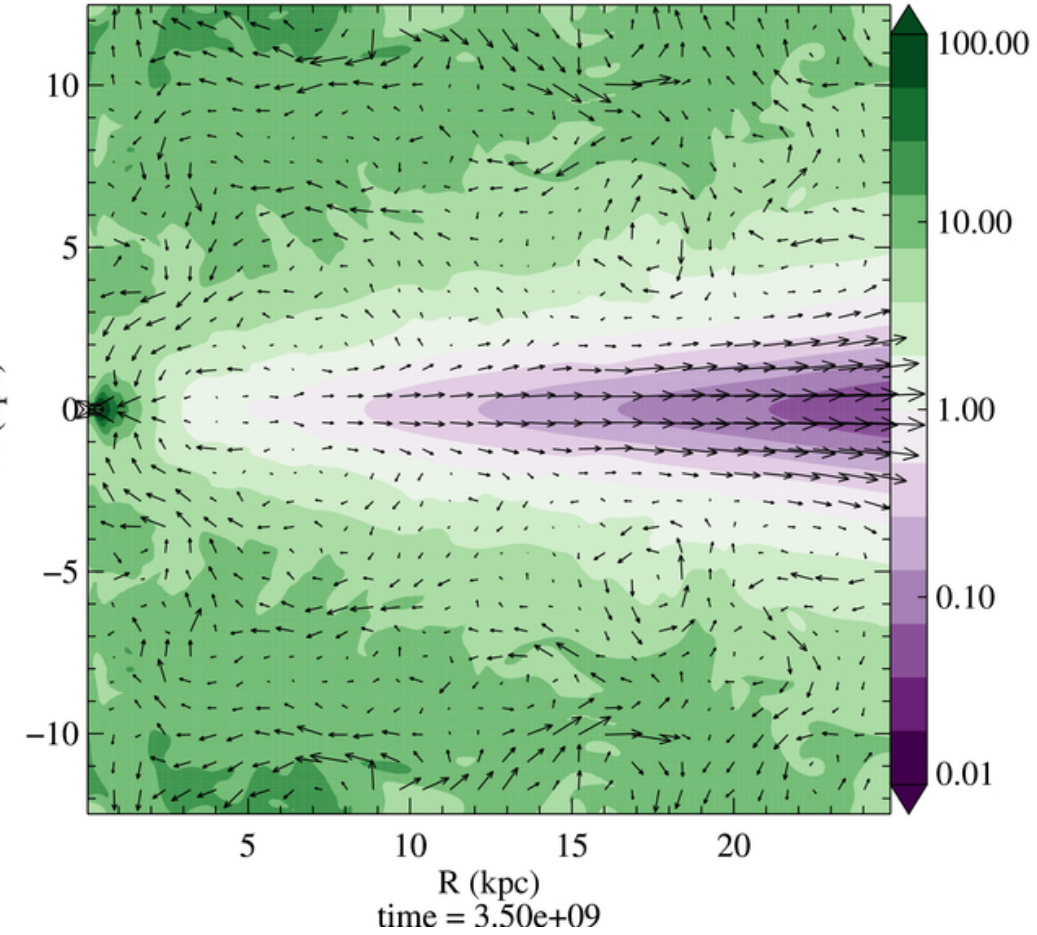

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 3.30e+09
10
10.
1.0
0.1
0.0

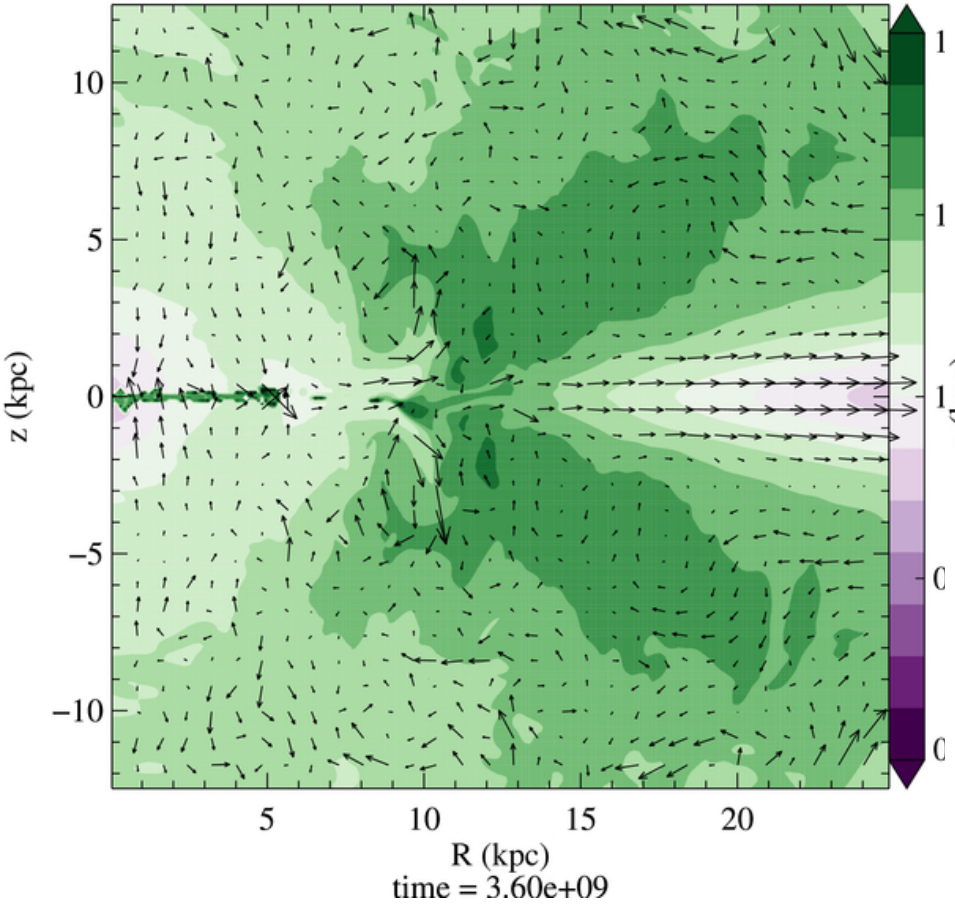

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 3.30e+09
100.00
10.00
1.00
0.10
0.01

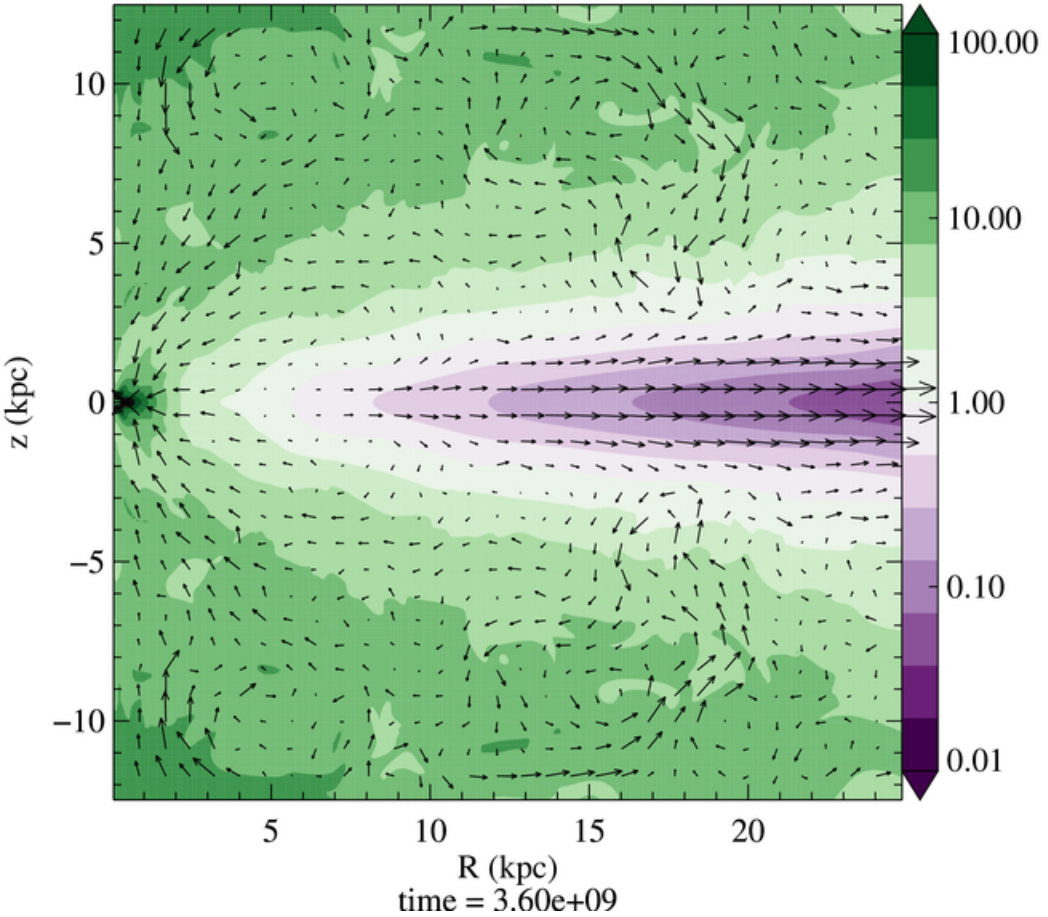

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 3.40e+09

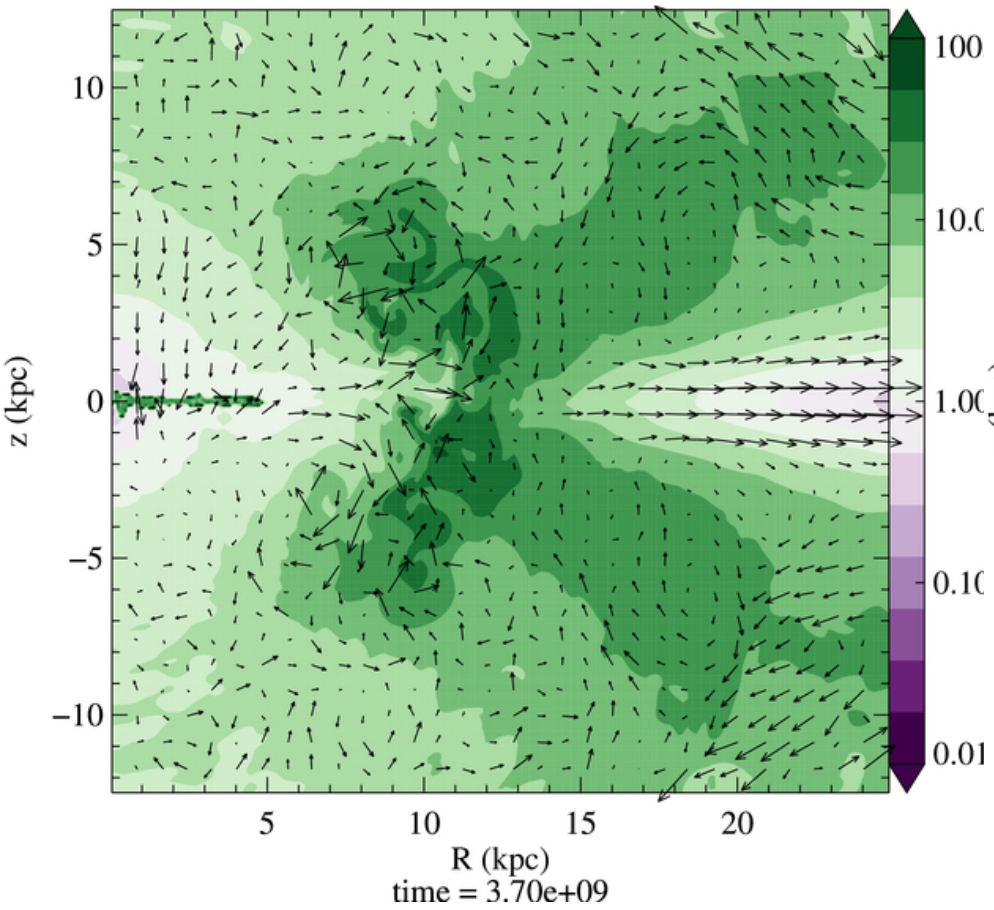

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 3.40e+09
100.00
10.00
1.00
0.10
0.01

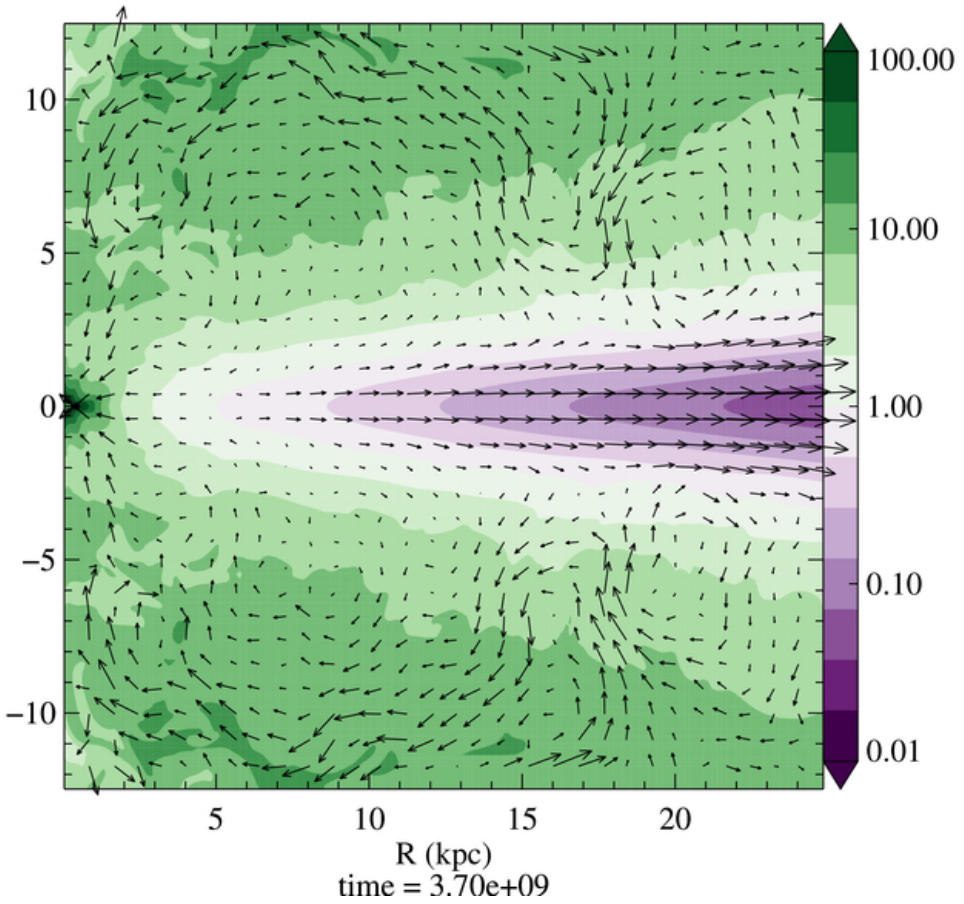

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 3.50e+09

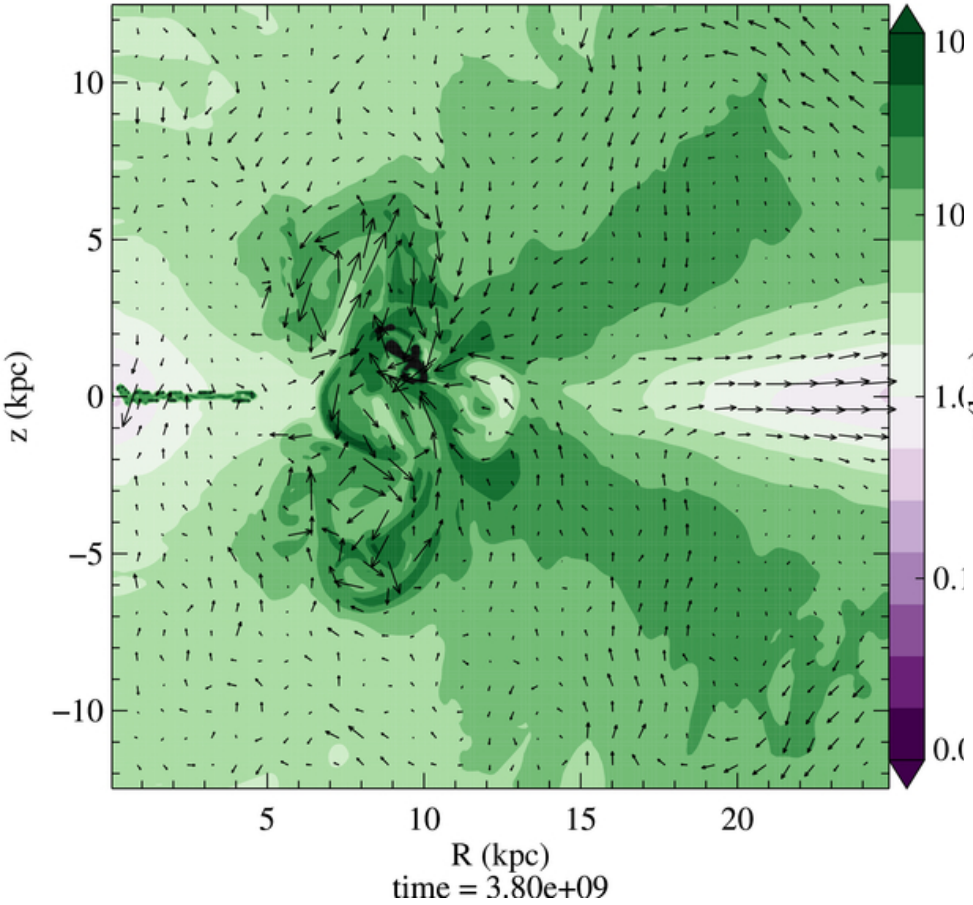

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 3.50e+09
100.00
10.00
1.00
0.10
0.01

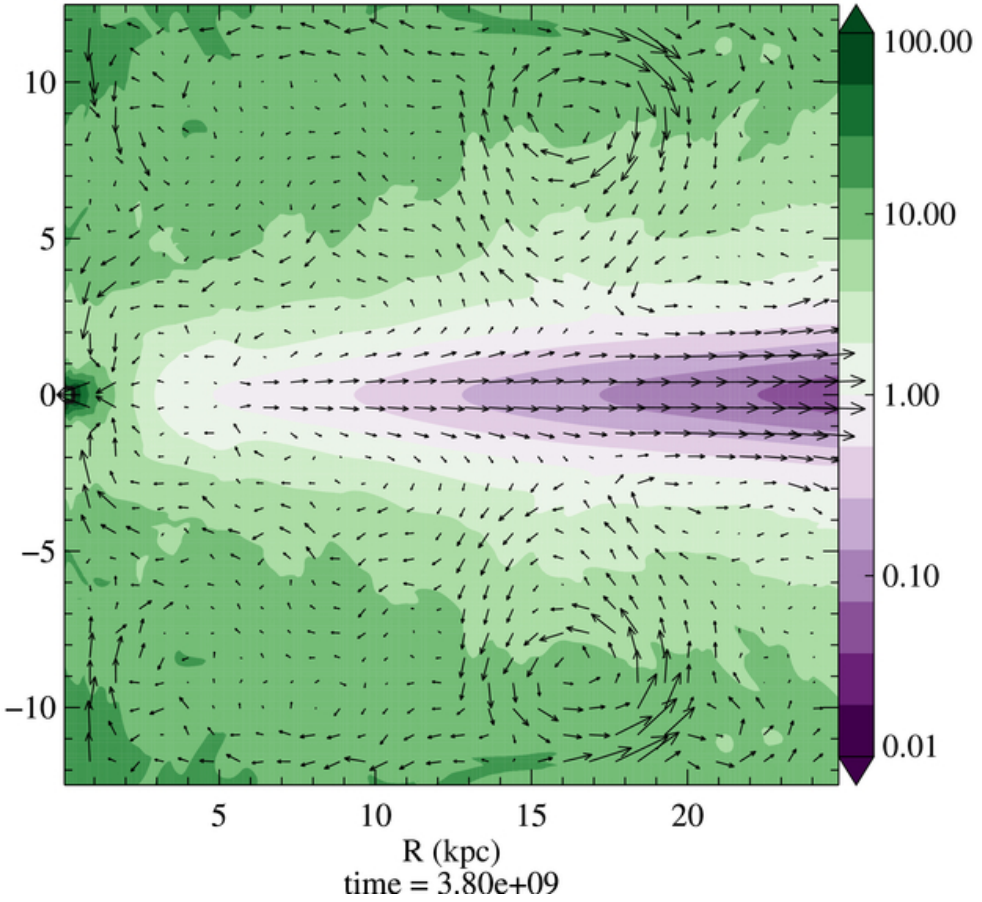

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 3.60e+09

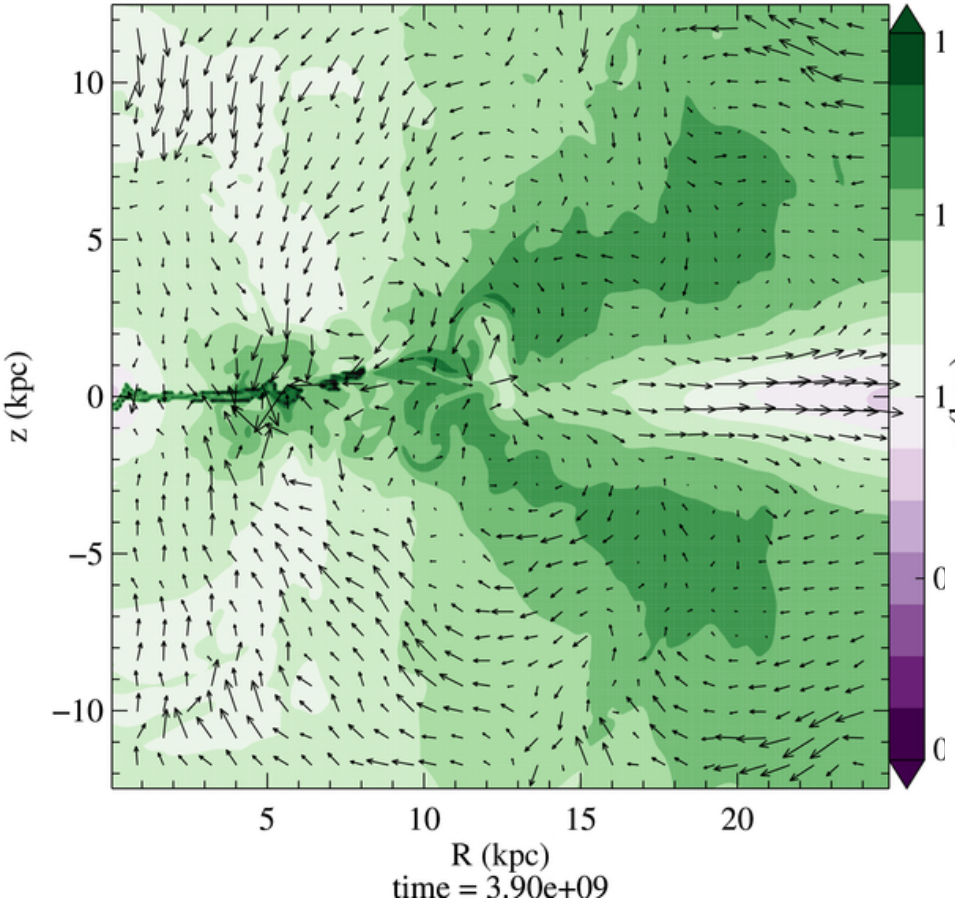

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 3.60e+09
100.00
10.00
1.00
0.10
0.01

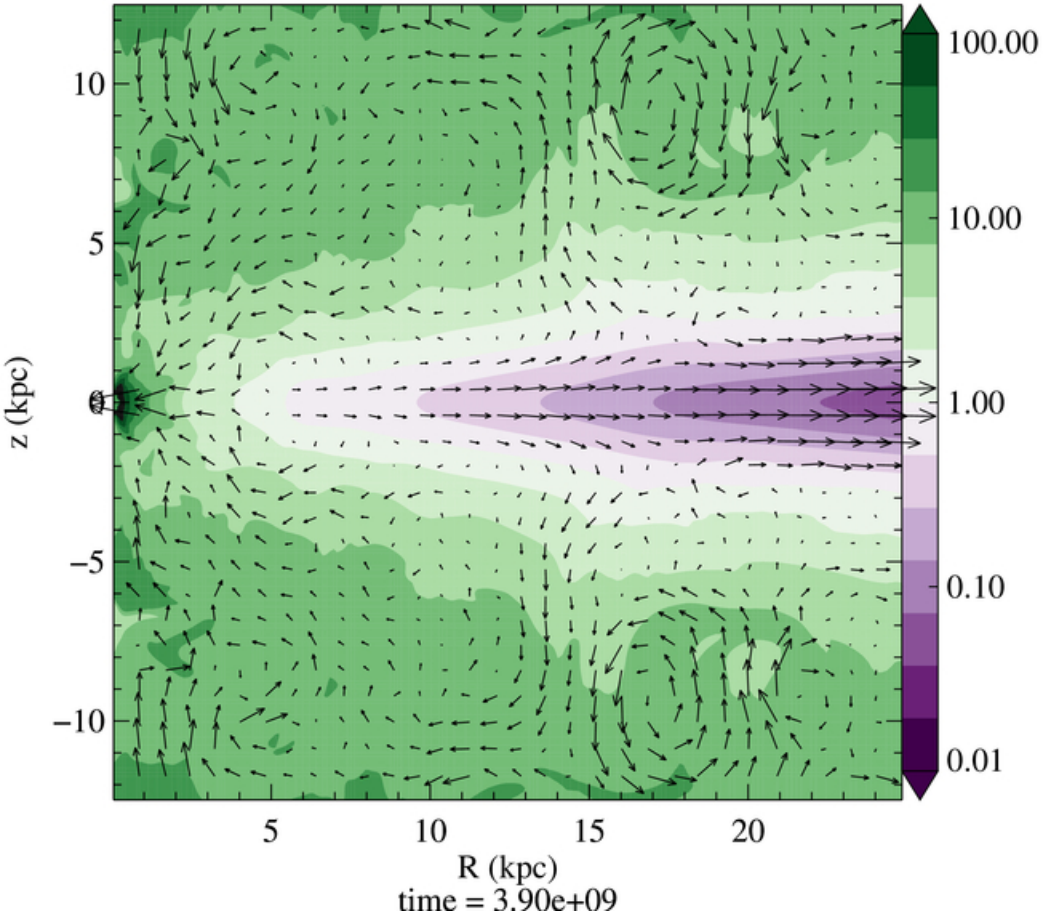

z (kpc)
R (kpc)
time = 3.70e+09

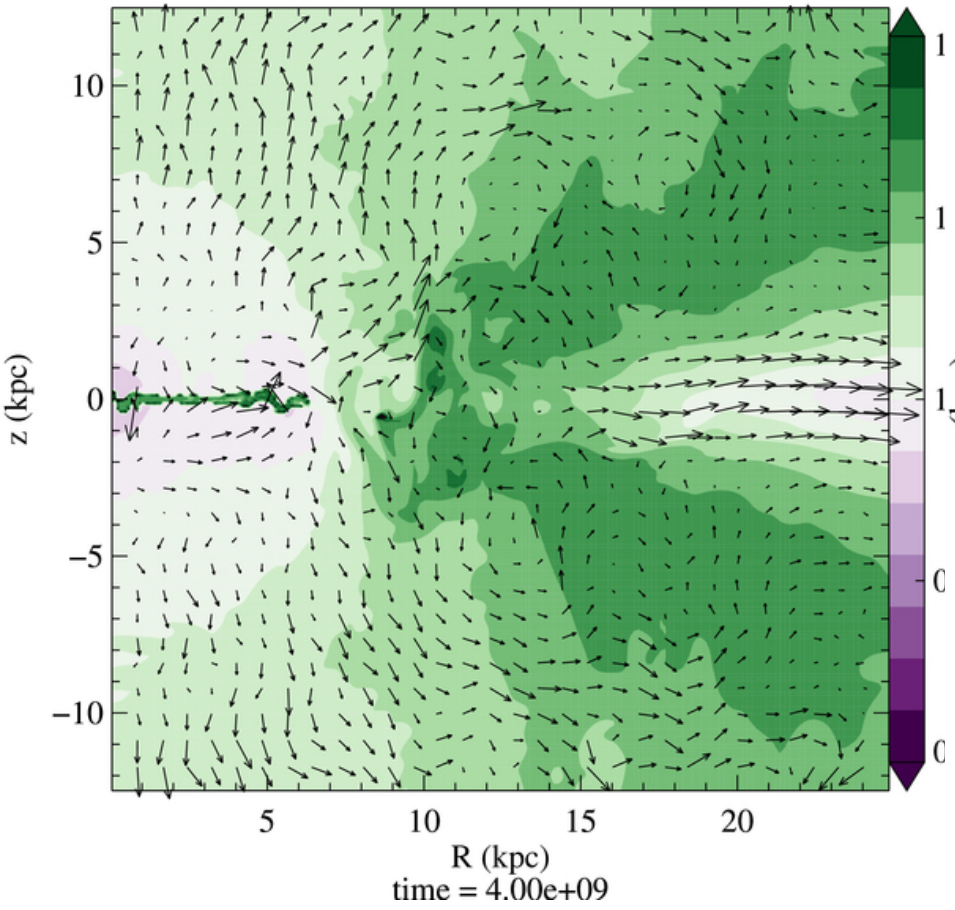

z (kpc)
R (kpc)
time = 3.70e+09

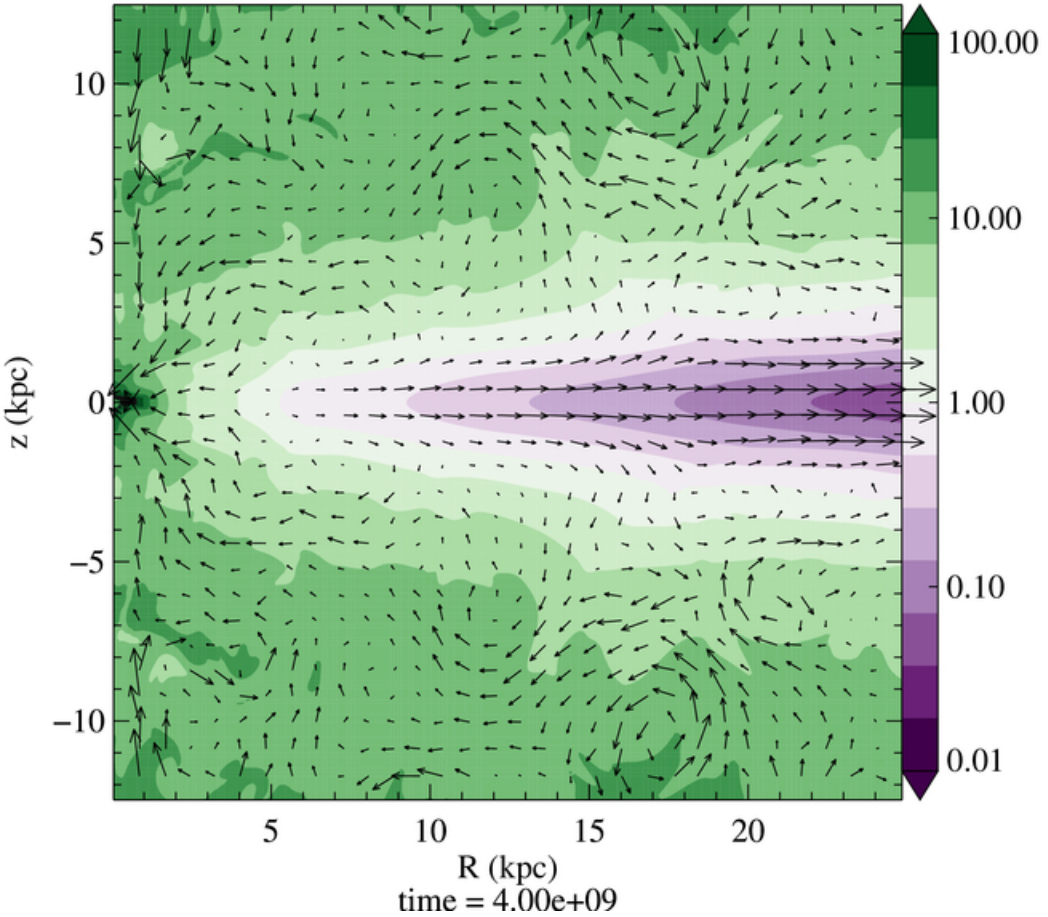

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 3.80e+09

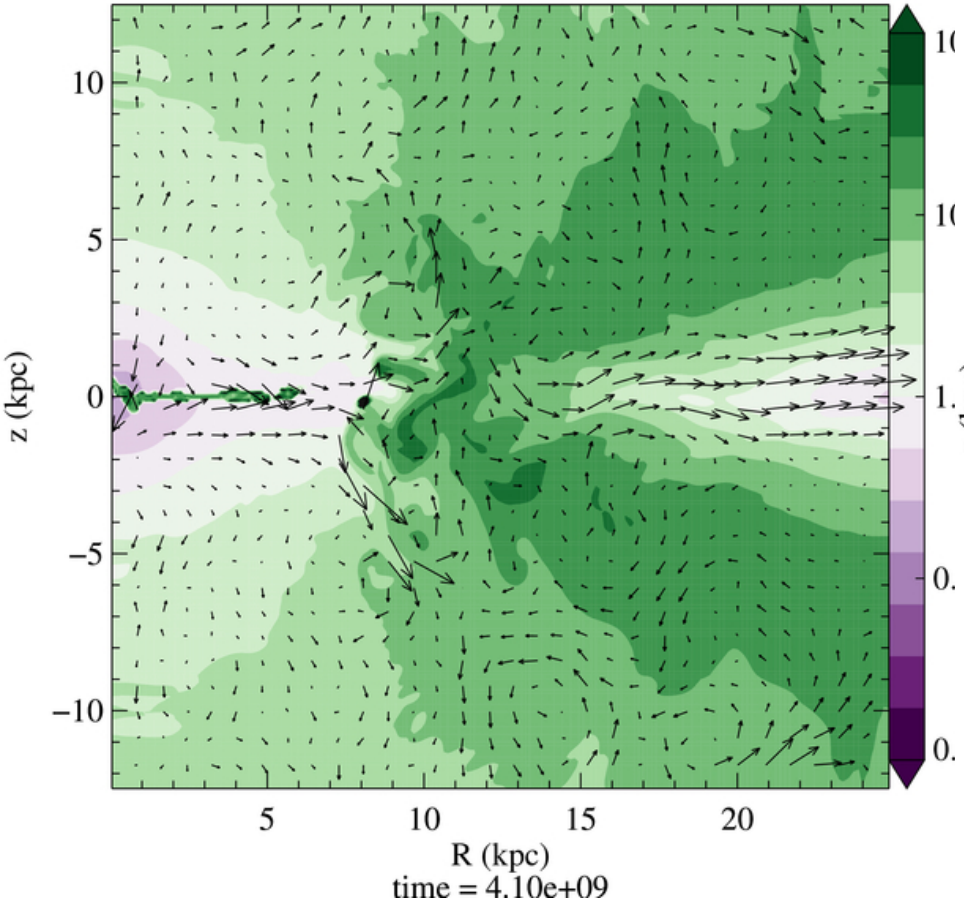

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 3.80e+09
100.00
10.00
1.00
0.10
0.01

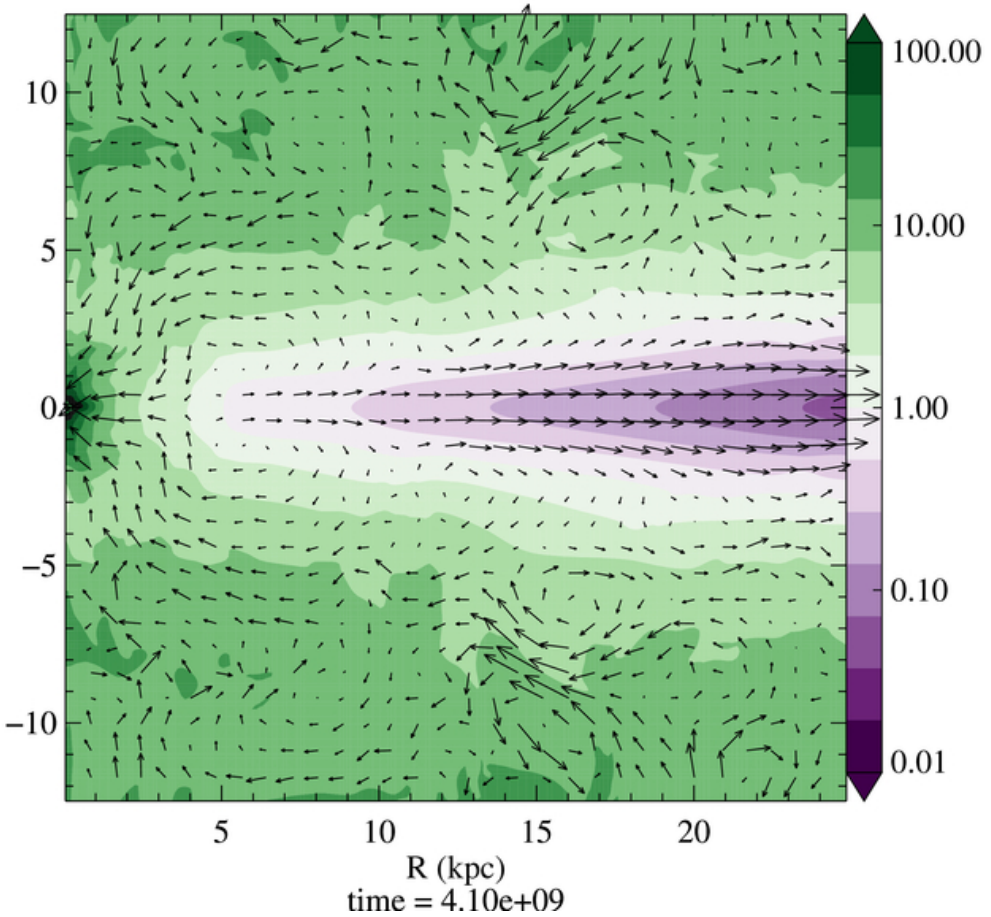

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 3.90e+09

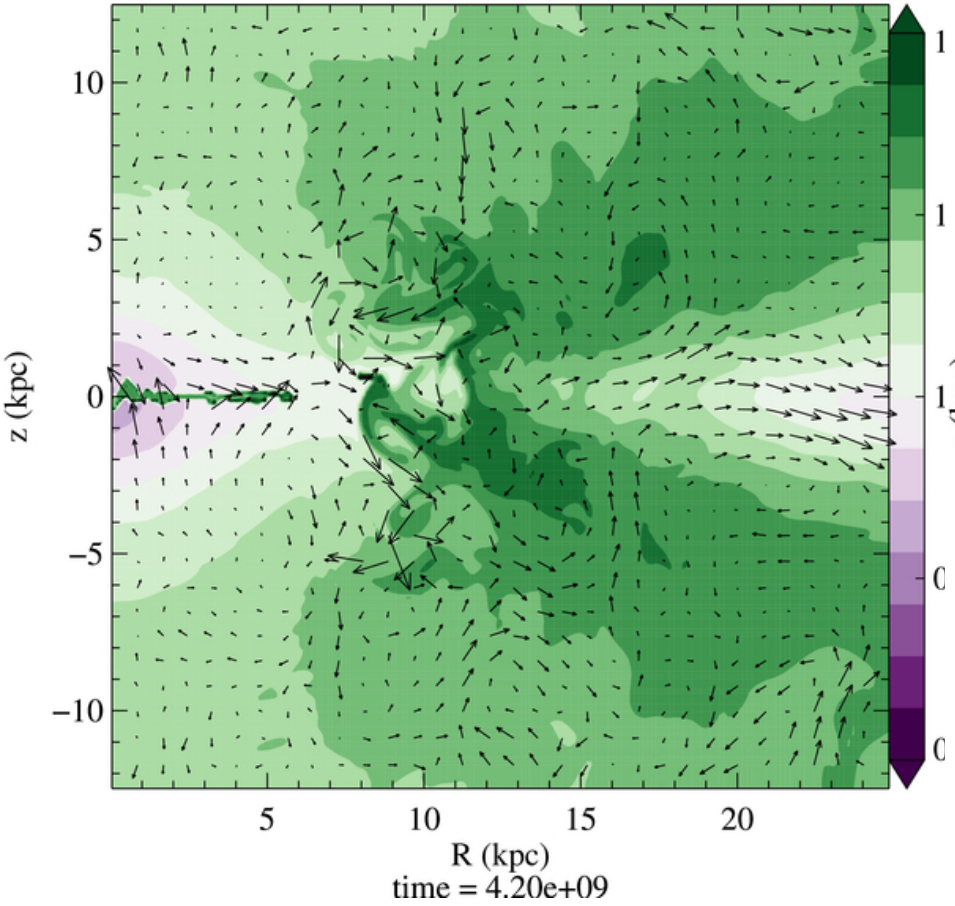

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 3.90e+09
100.00
10.00
1.00
0.10
0.01

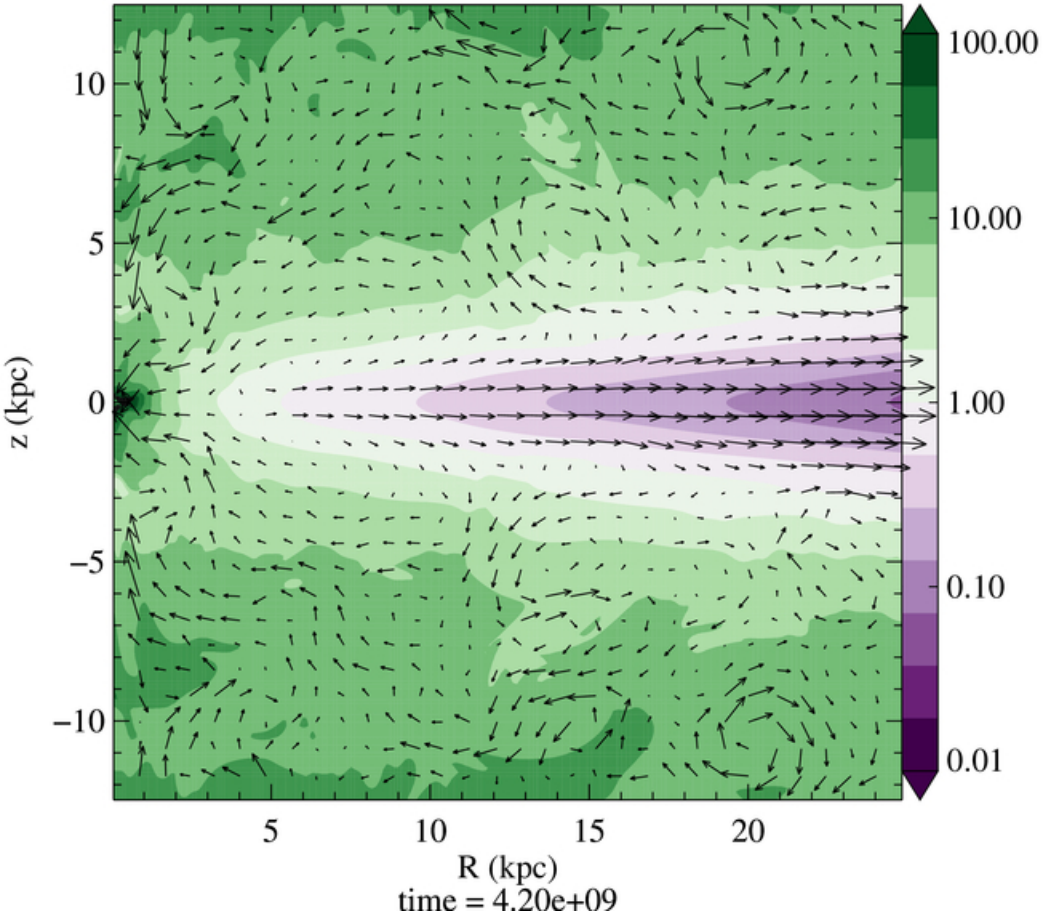

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 4.00e+09

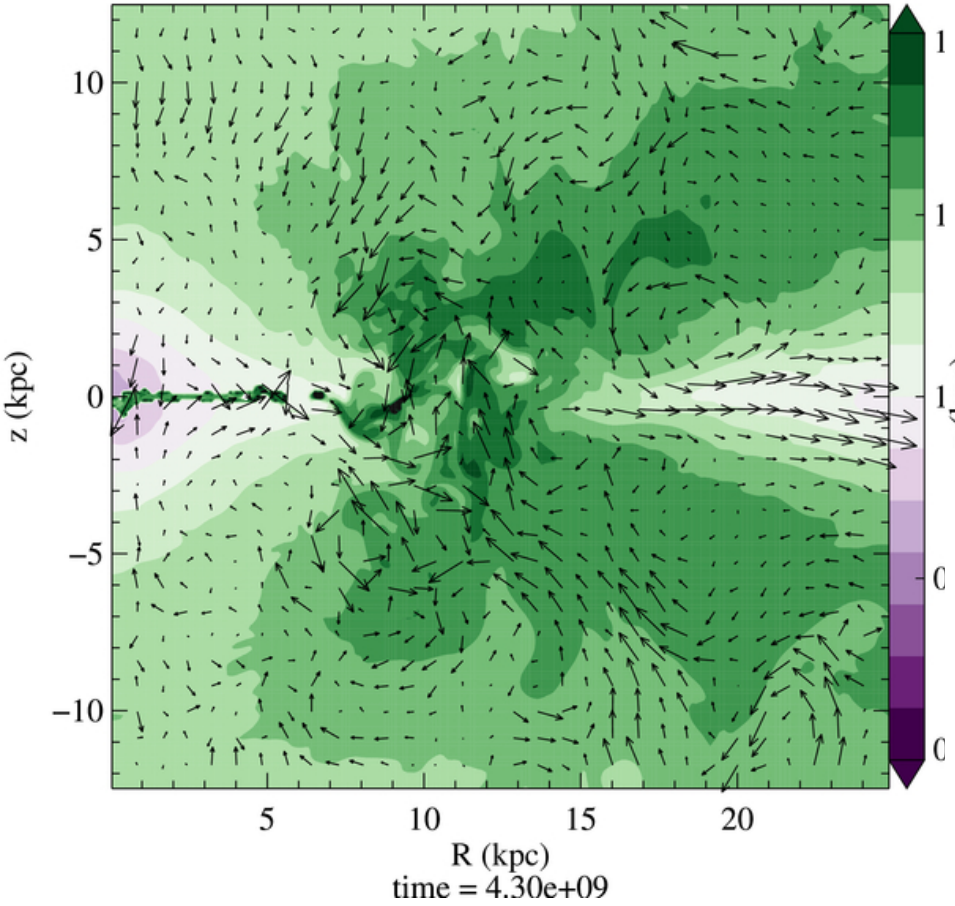

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 4.00e+09
100.00
10.00
1.00
0.10
0.01

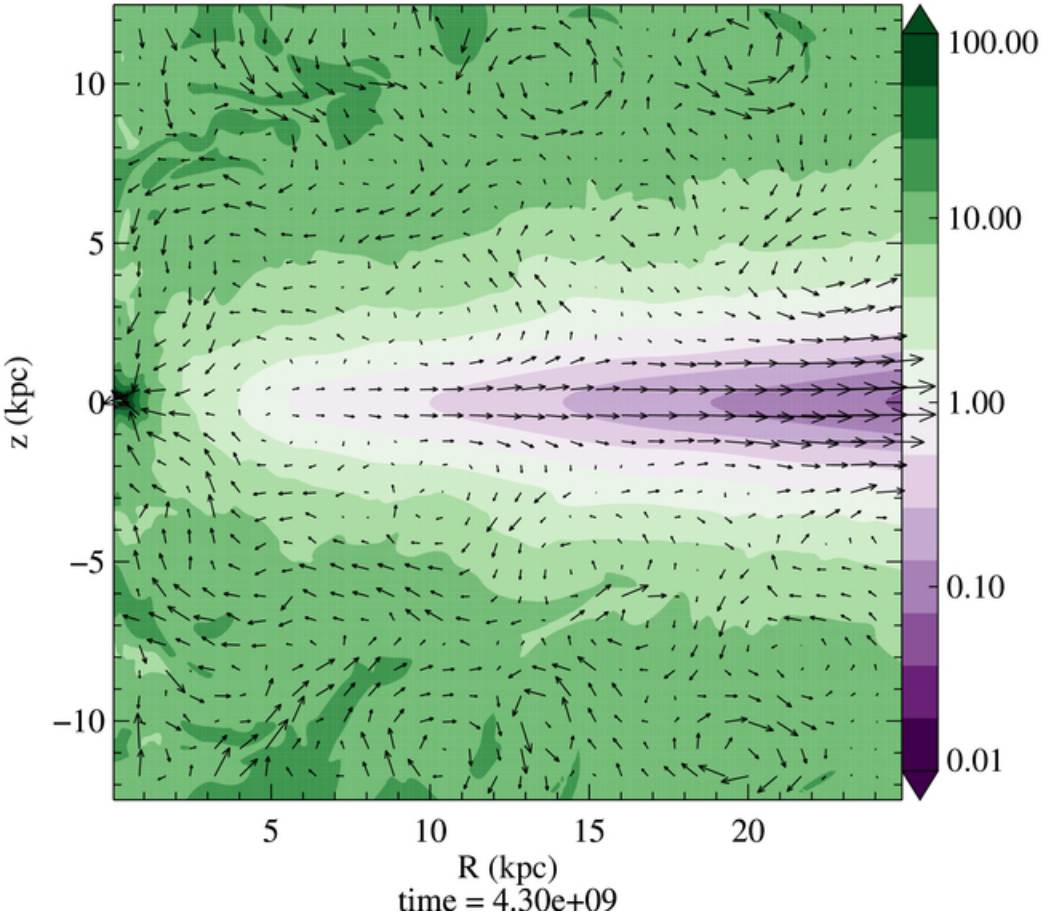

z (kpc)
R (kpc)
time = 4.10e+09

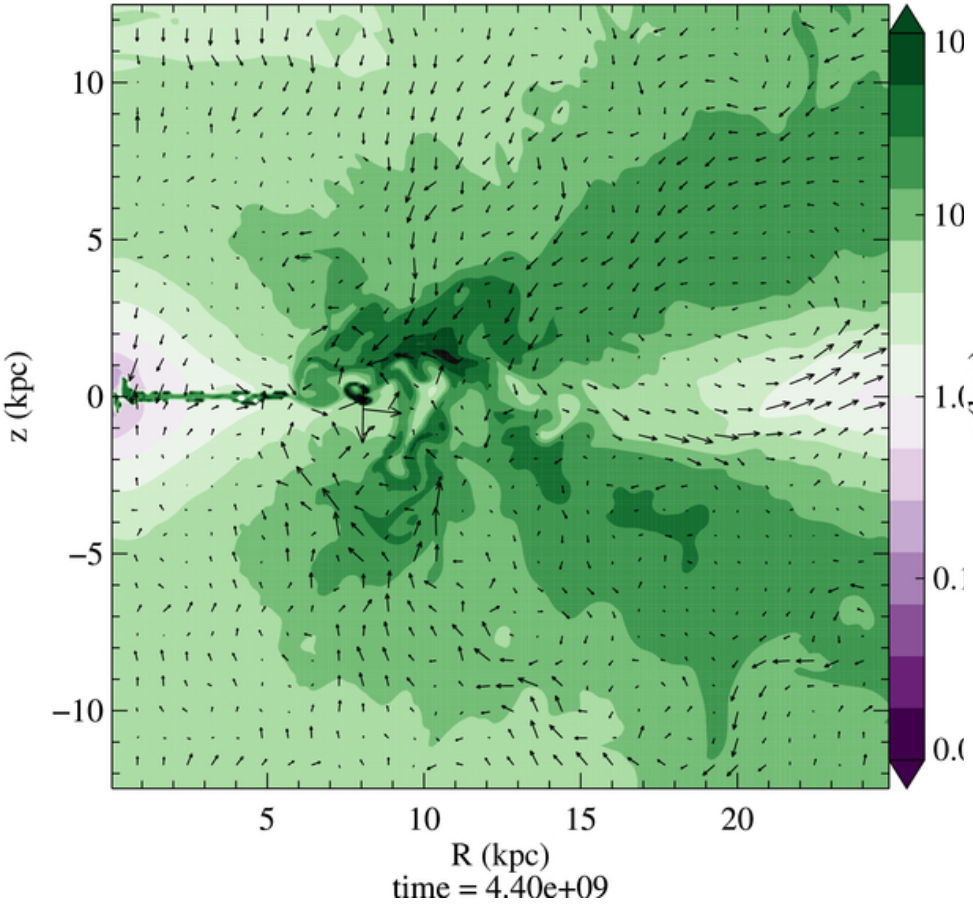

100.00
10.00
1.00
0.10
0.01
z (kpc)
R (kpc)
time = 4.10e+09

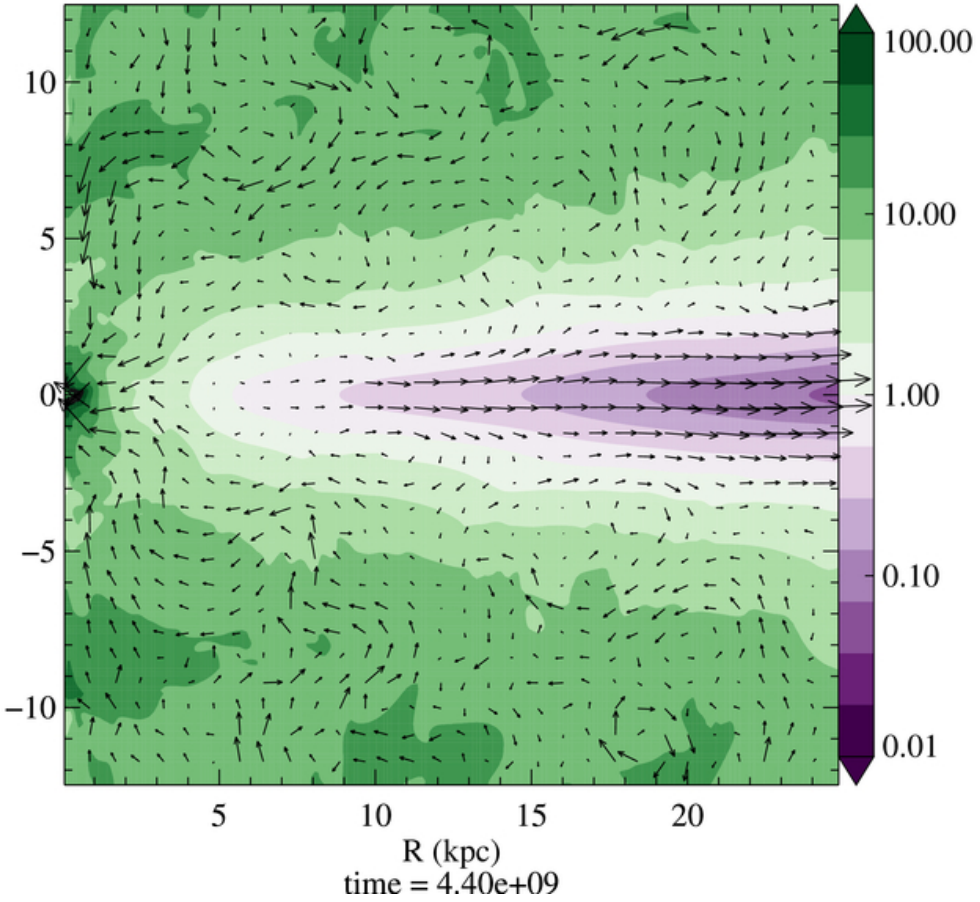

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 4.20e+09

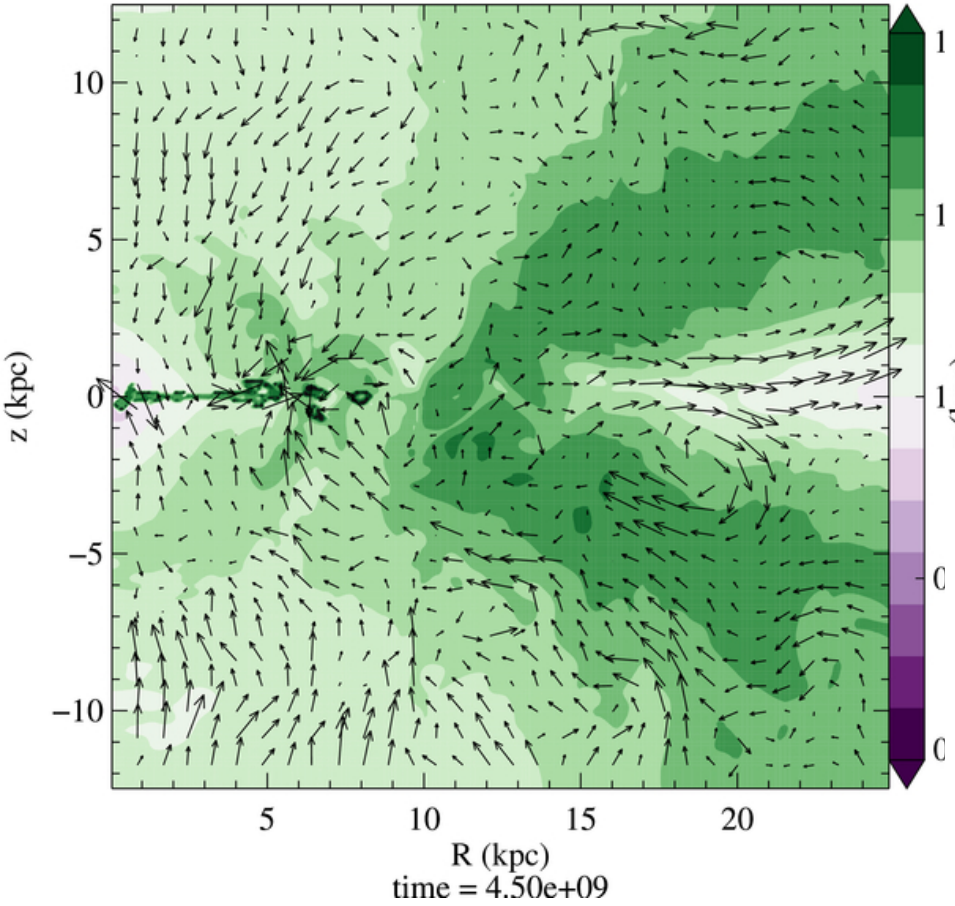

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 4.20e+09
100.00
10.00
1.00
0.10
0.01

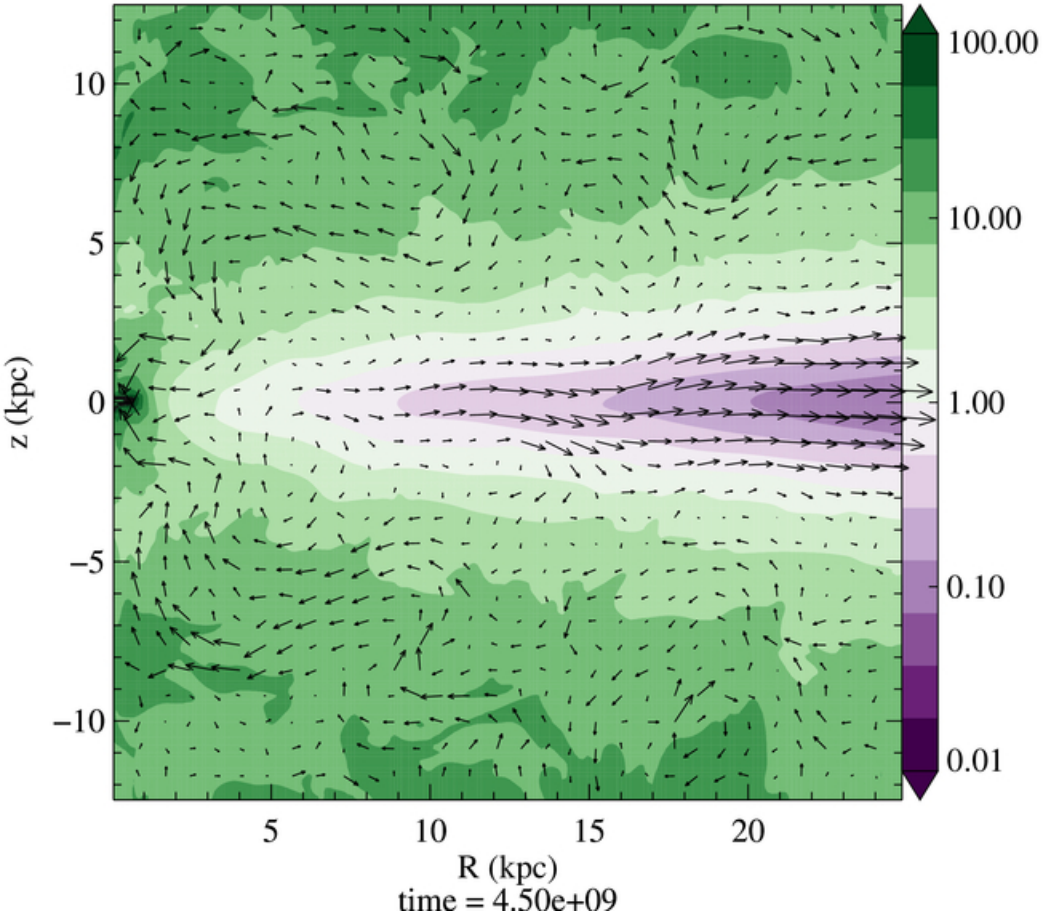

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 4.30e+09

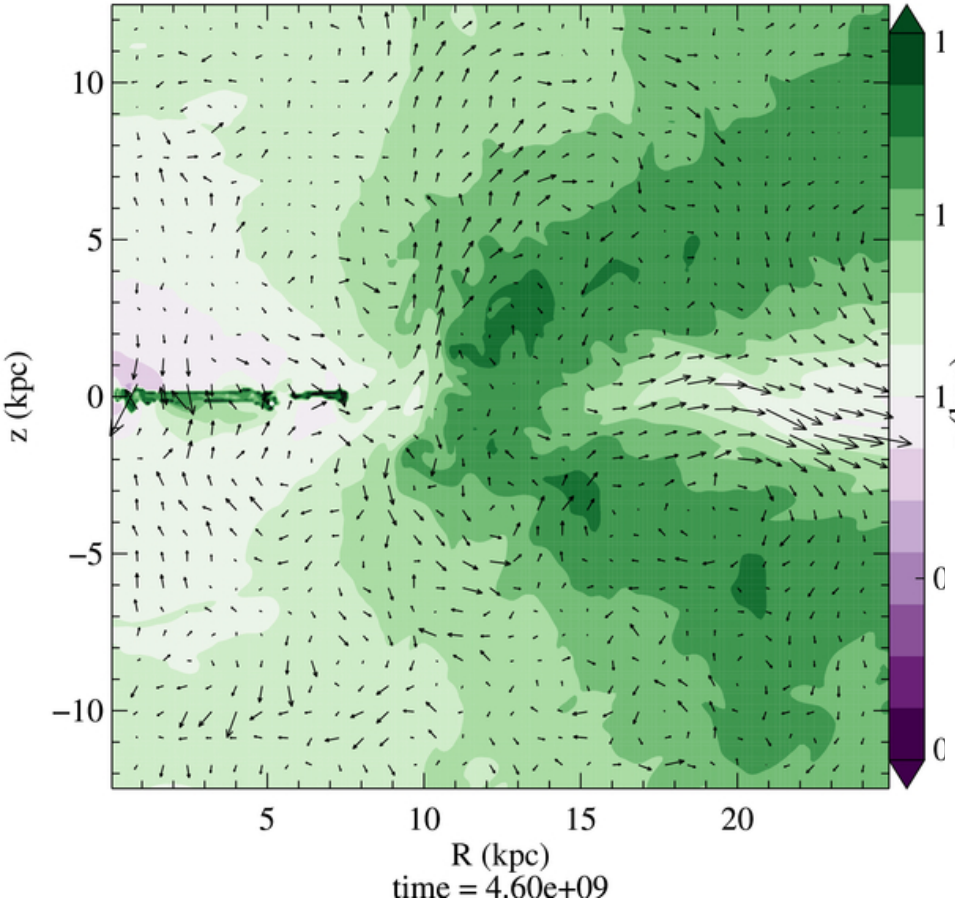

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 4.30e+09
100.00
10.00
1.00
0.10
0.01

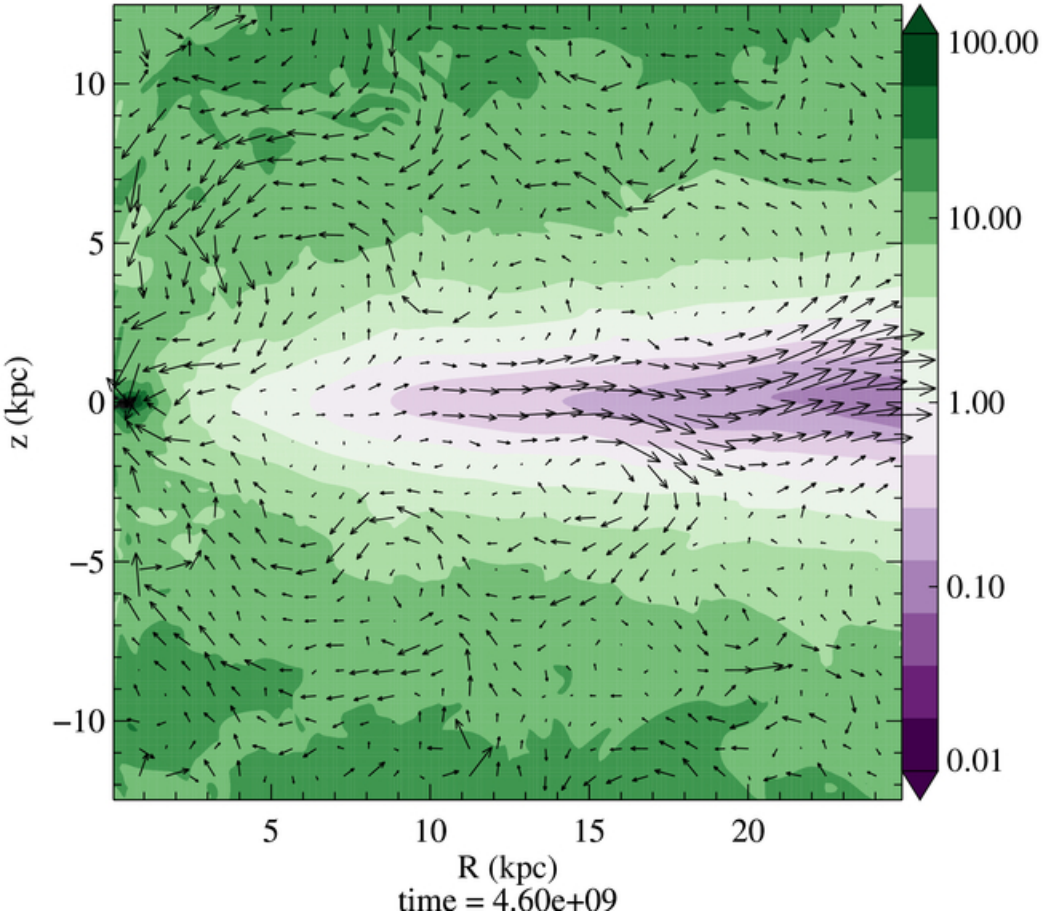

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 4.40e+09

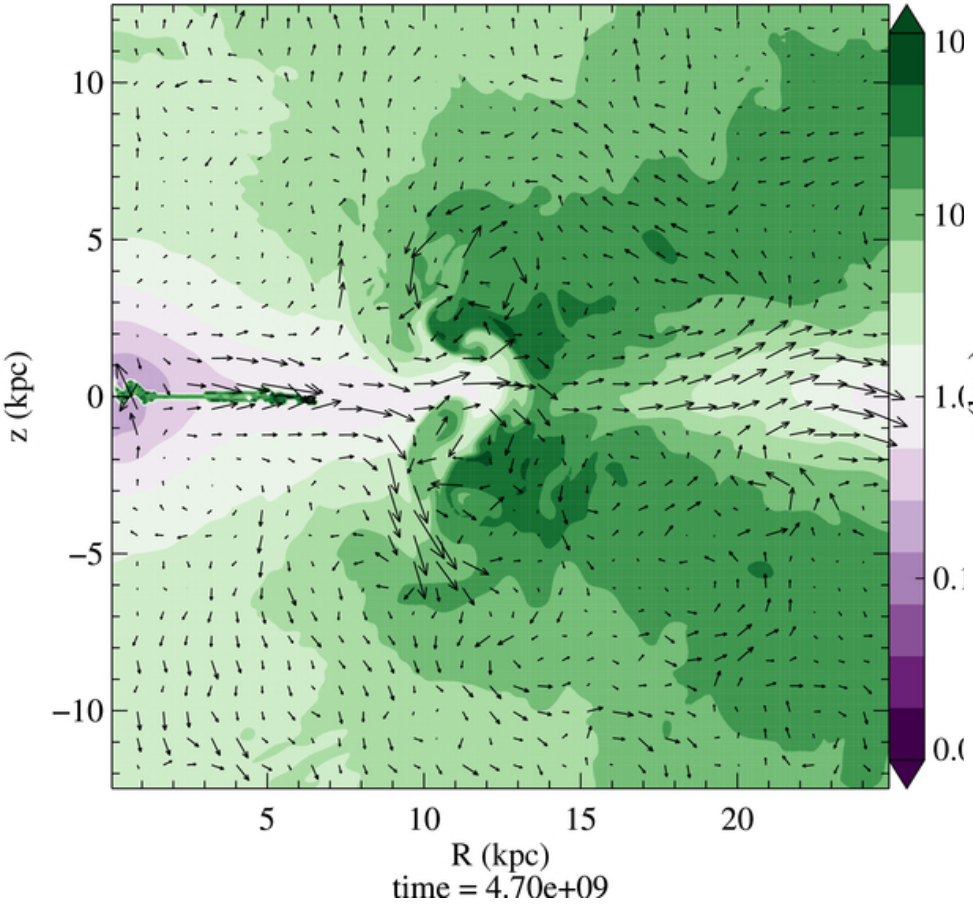

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 4.40e+09
100.00
10.00
1.00
0.10
0.01

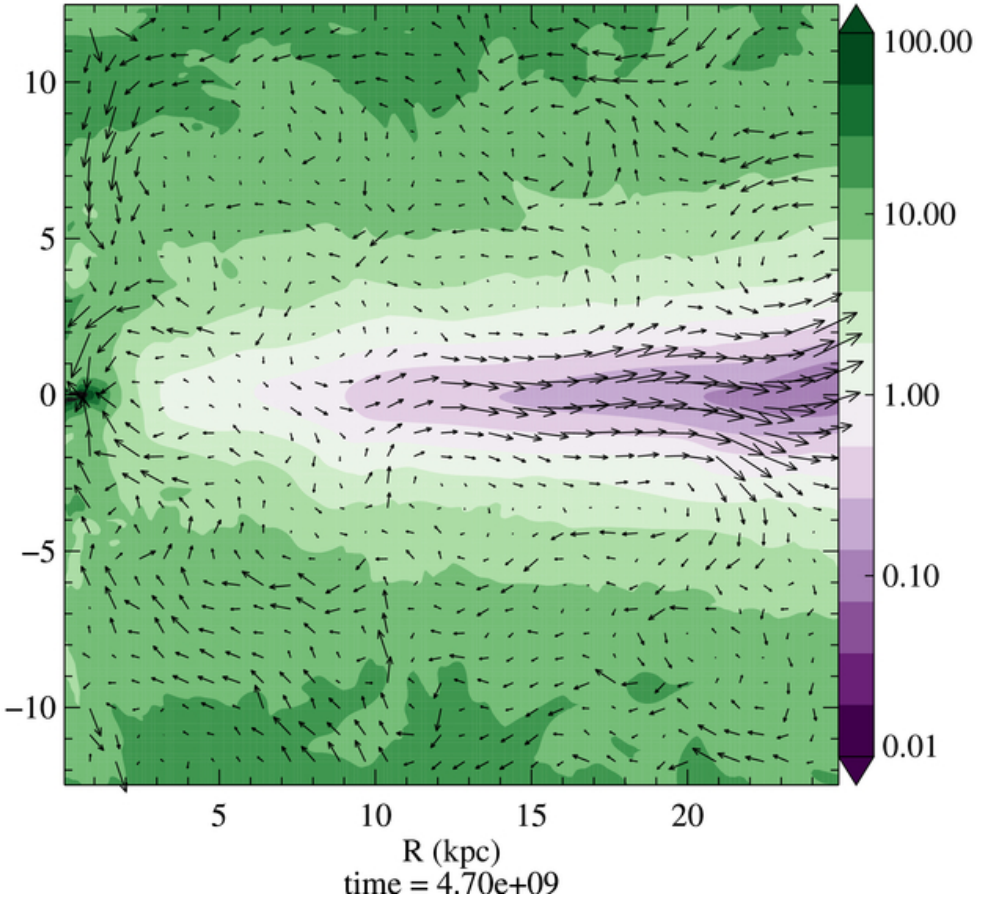

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 4.50e+09

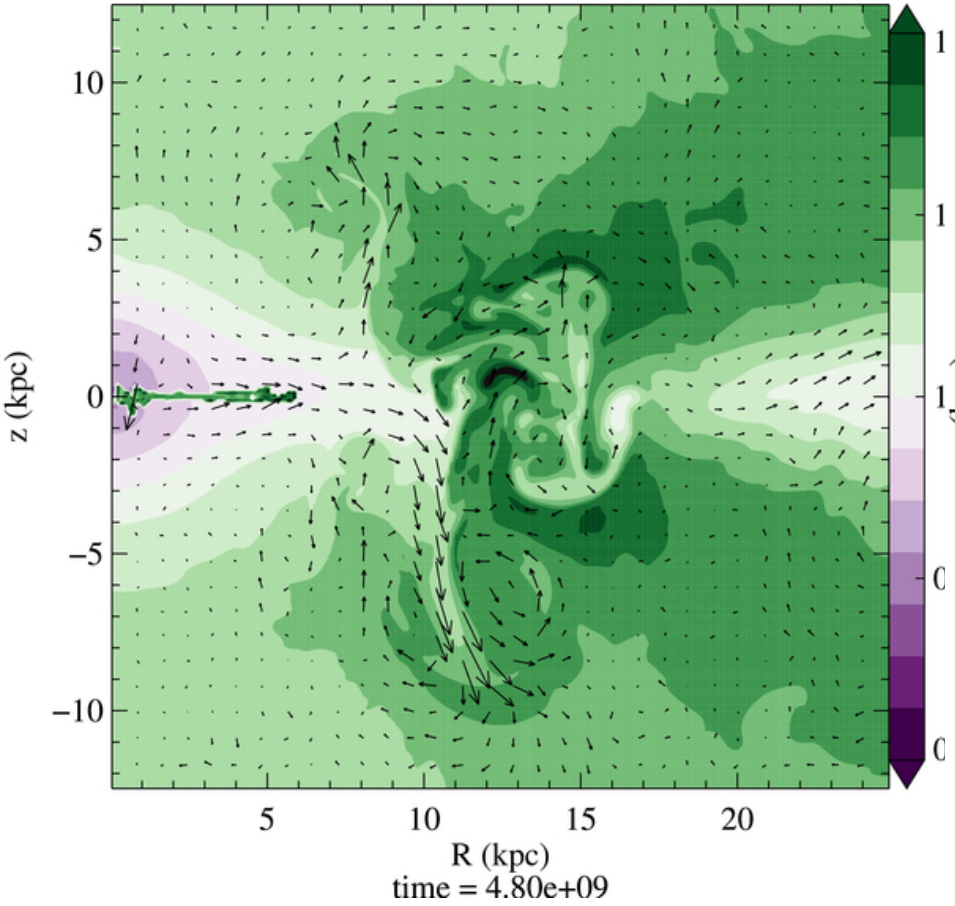

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 4.50e+09
100.00
10.00
1.00
0.10
0.01

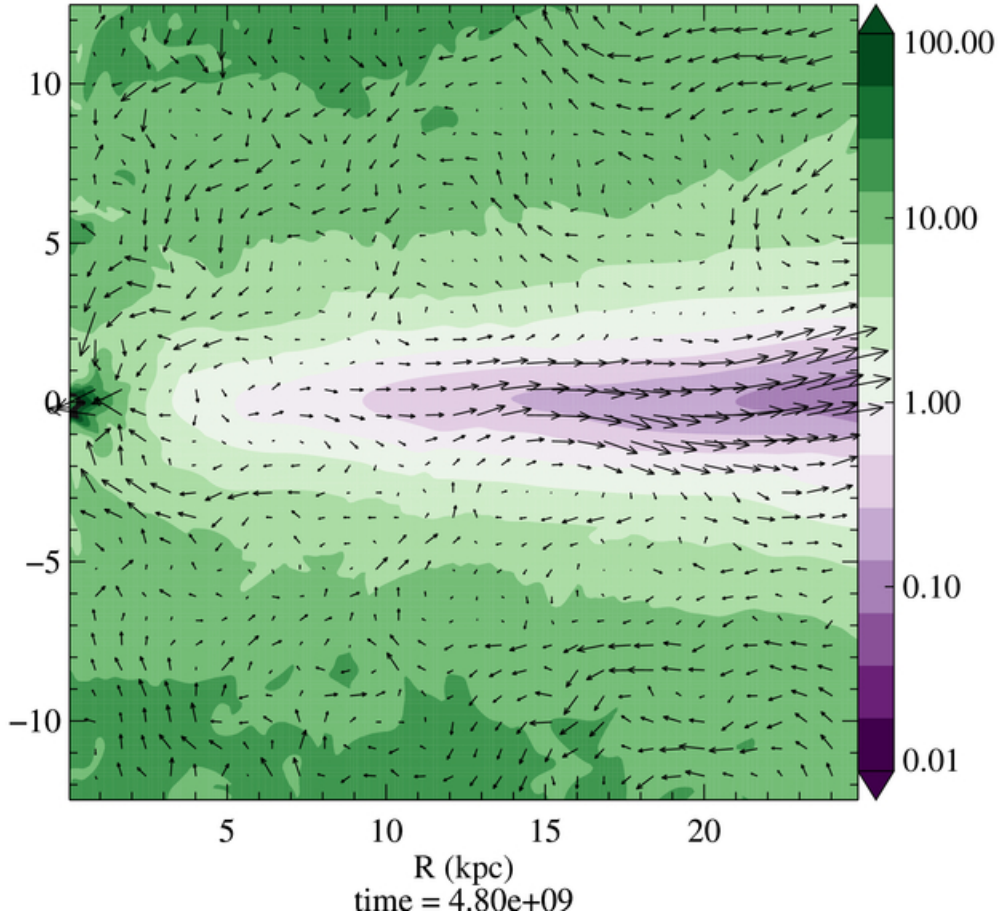

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 4.60e+09

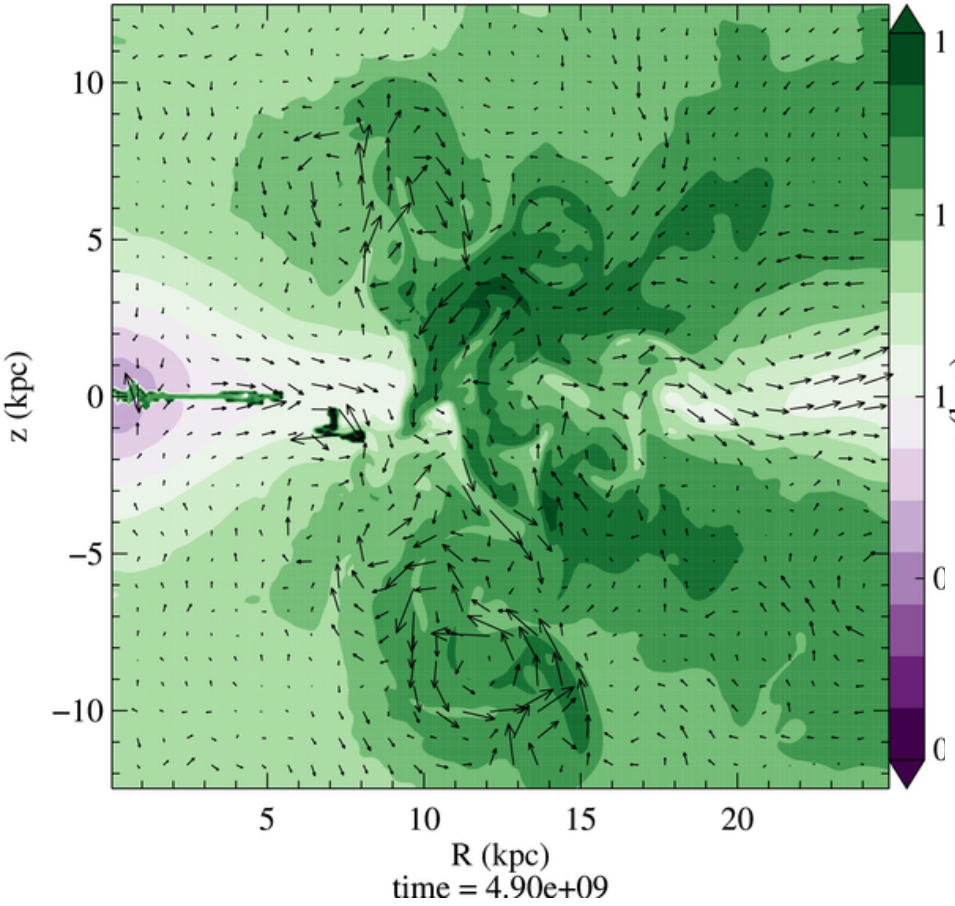

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 4.60e+09
100.00
10.00
1.00
0.10
0.01

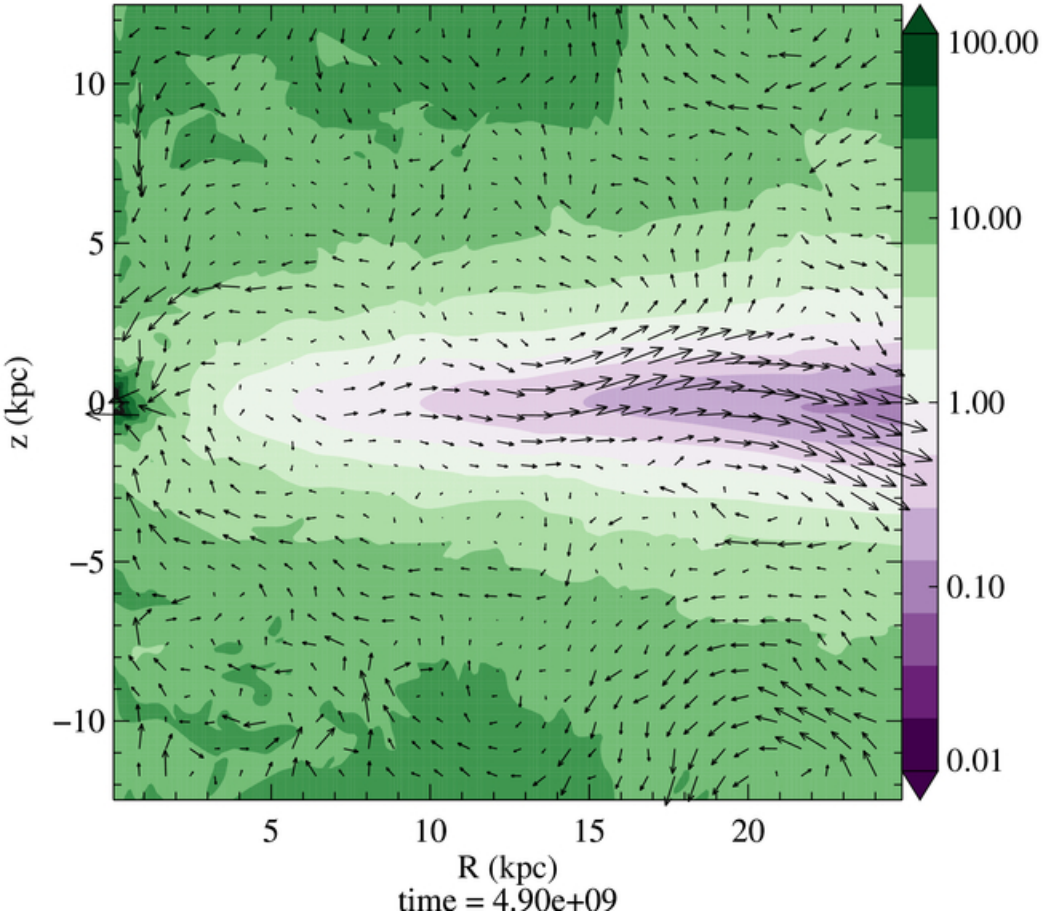

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 4.70e+09

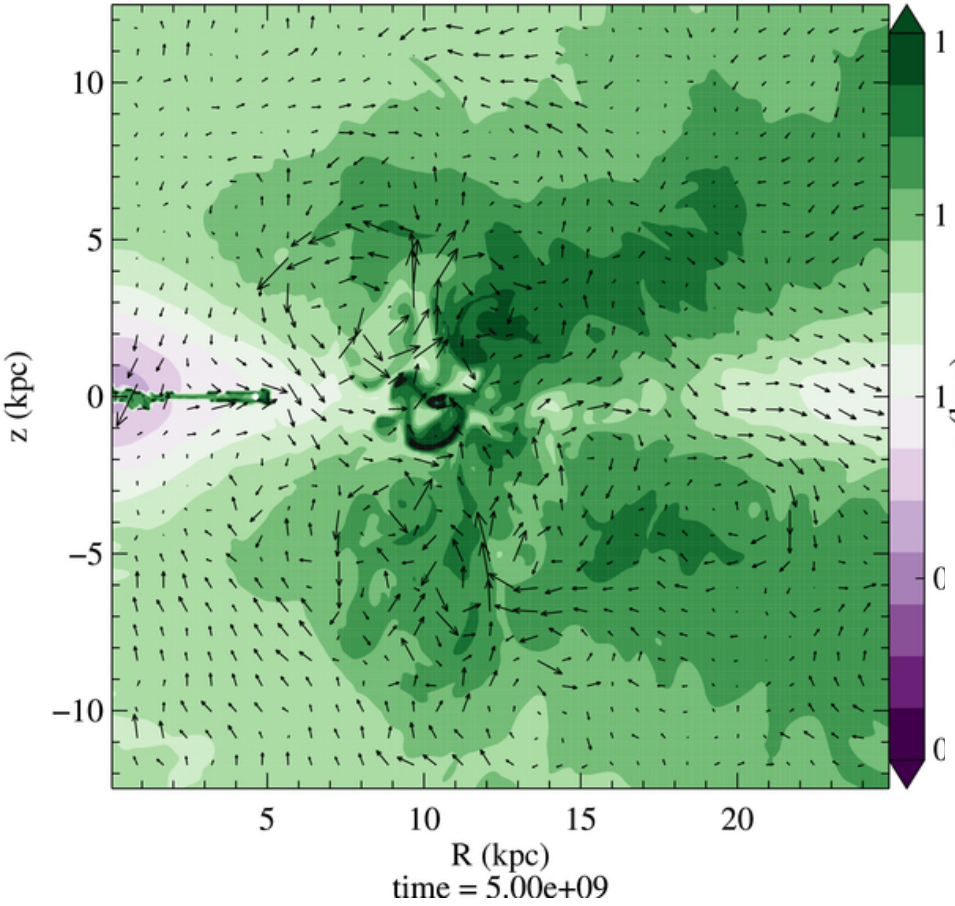

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 4.70e+09
100.00
10.00
1.00
0.10
0.01

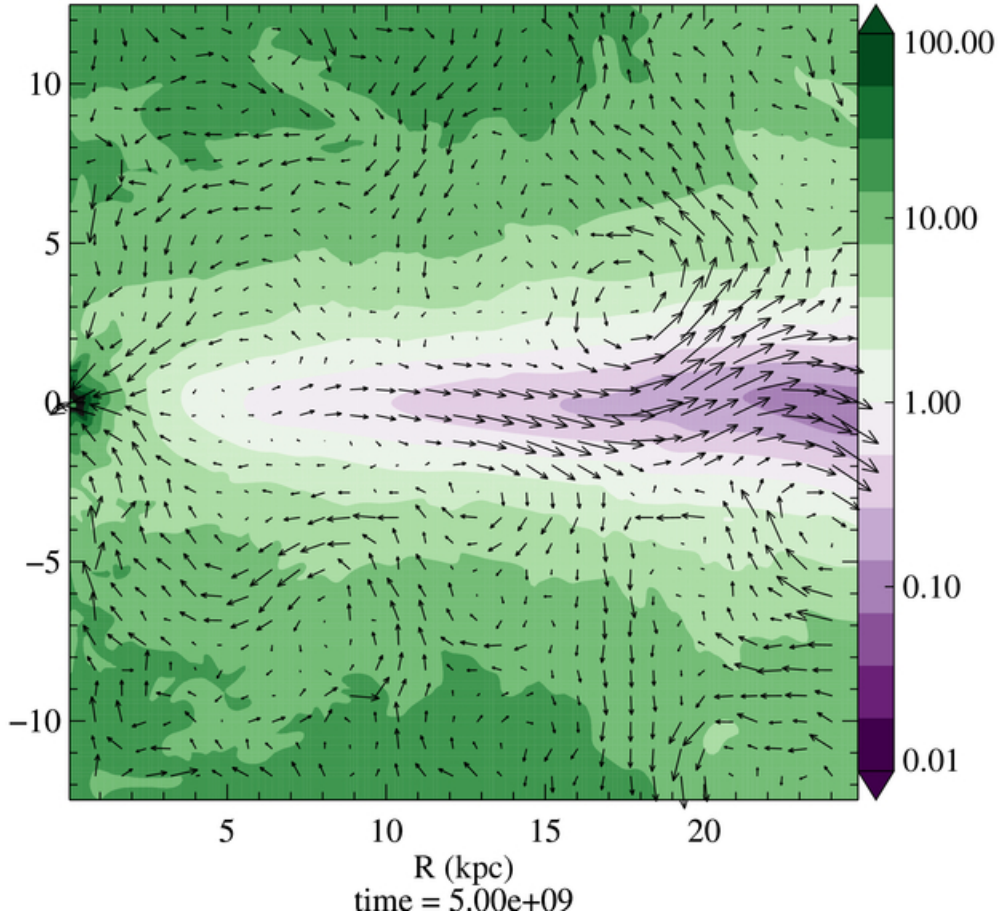

z (kpc)
R (kpc)
time = 4.80e+09

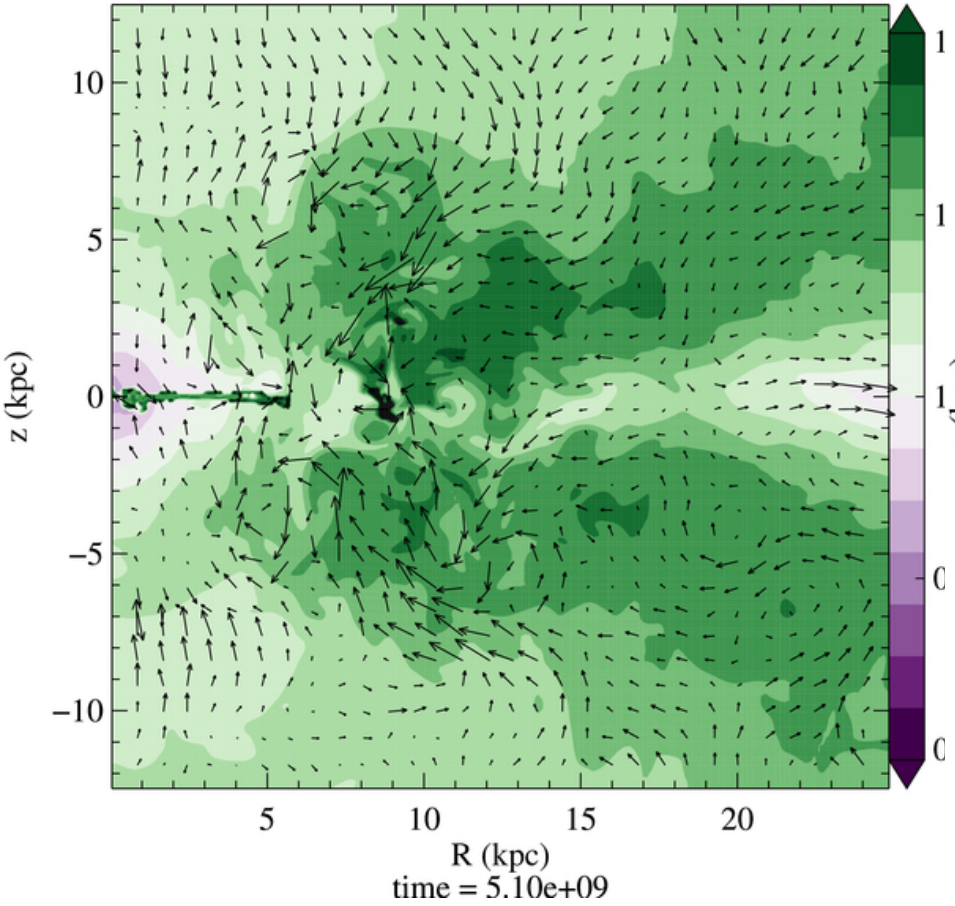

100.00
10.00
1.00
0.10
0.01
z (kpc)
R (kpc)
time = 4.80e+09

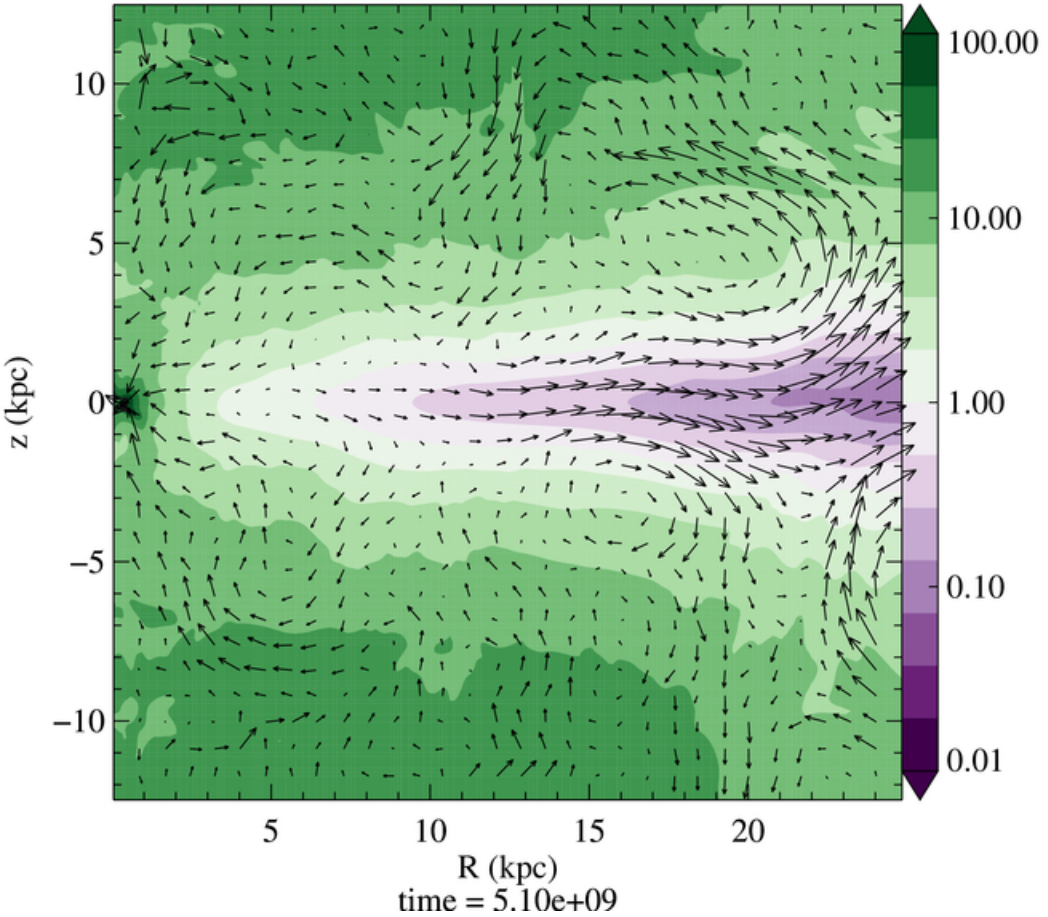

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 4.90e+09

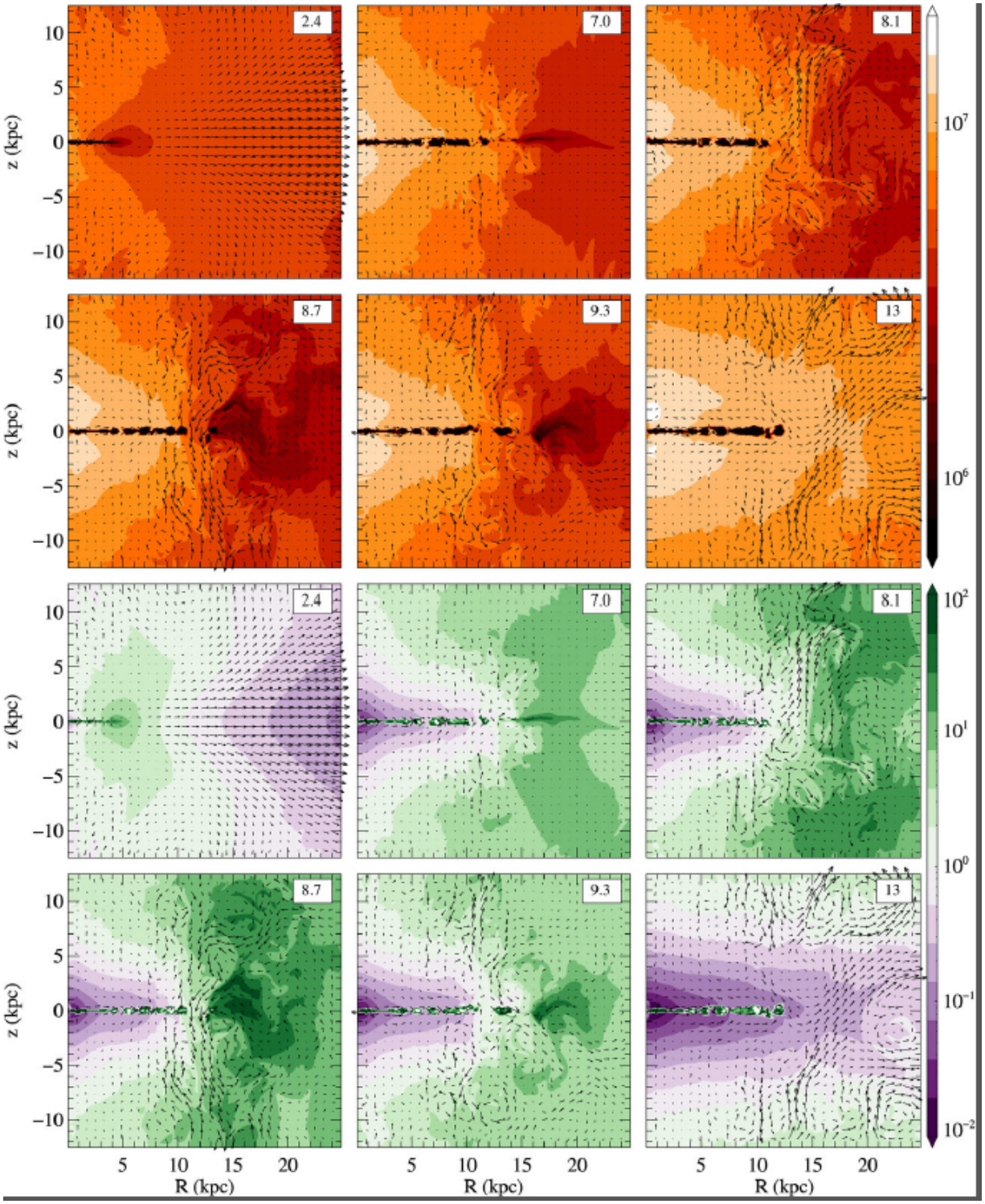

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 4.90e+09
100.00
10.00
1.00
0.10
0.01


z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 5.00e+09


z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 5.00e+09
100.00
10.00
1.00
0.10
0.01

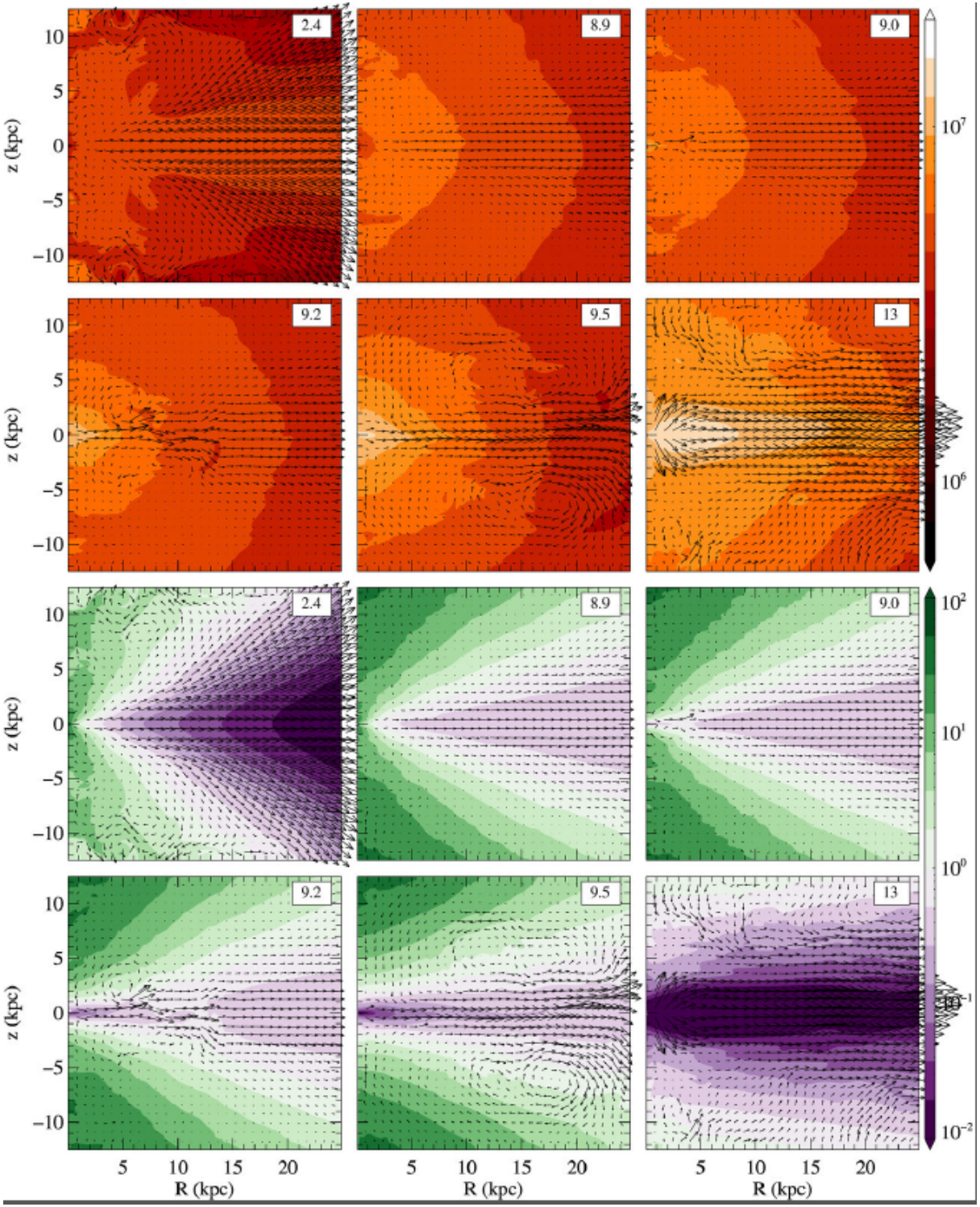

z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 5.10e+09


z (kpc)
10
5
0
−5
−10
5
10
15
20
R (kpc)
time = 5.10e+09
100.00
10.00
1.00
0.10
0.01



Negri et al. 2014

Isotropic rotator



Velocity dispersion supported galaxy

Large rotating gaseous disks:

1) J stored at large radii
2) Formation of cold, rotating disks

Star formation
Q-regulation in self-gravitating case
Viscosity

An additional possible (?) mechanism:
Secular angular momentum mixing produced by stellar mass losses in the disk plus asymmetric drift

(Posacki, Smet, Ciotti 2014, submitted)

4. SUMMARY

- Radiative + mechanical feedback is effective in maintaining “small” SMBH mass (increase <~2-3)
- Source of “fuel” proportional to M*, stellar mass losses decline with cosmic time, specific heating increases
- LITTLE impact on galaxy: bursting star formation (in shells, INDUCED & SUPPRESSED), production of nuclear cusps
- Accretion highly non-stationary (duty ~0.01 or less)
- Interplay between global & local scales, modulated by cosmological times vs accretion times
- Importance of detailed ETGs structure/internal kinematics on accretion (J problem)

- QSO activity can be independent of merging

- HIGH DANGER in the application of simple “back-to-the-envelope” arguments based on local/average galaxy properties, especially in semi-analytical models
- E.g.: Bondi formula in case of local mass sources: Mbh growth increases local stellar velocity dispersion -> increase of gas temperature -> reduction of Bondi rate (Mbh^1/2 instead of Mbh^2)
- Need of global, internal mechanism for the J problem in rotating ETGs