Cosmic ray driven winds in disk galaxies

Rüdiger Pakmor, Ringberg, May 11th, 2016
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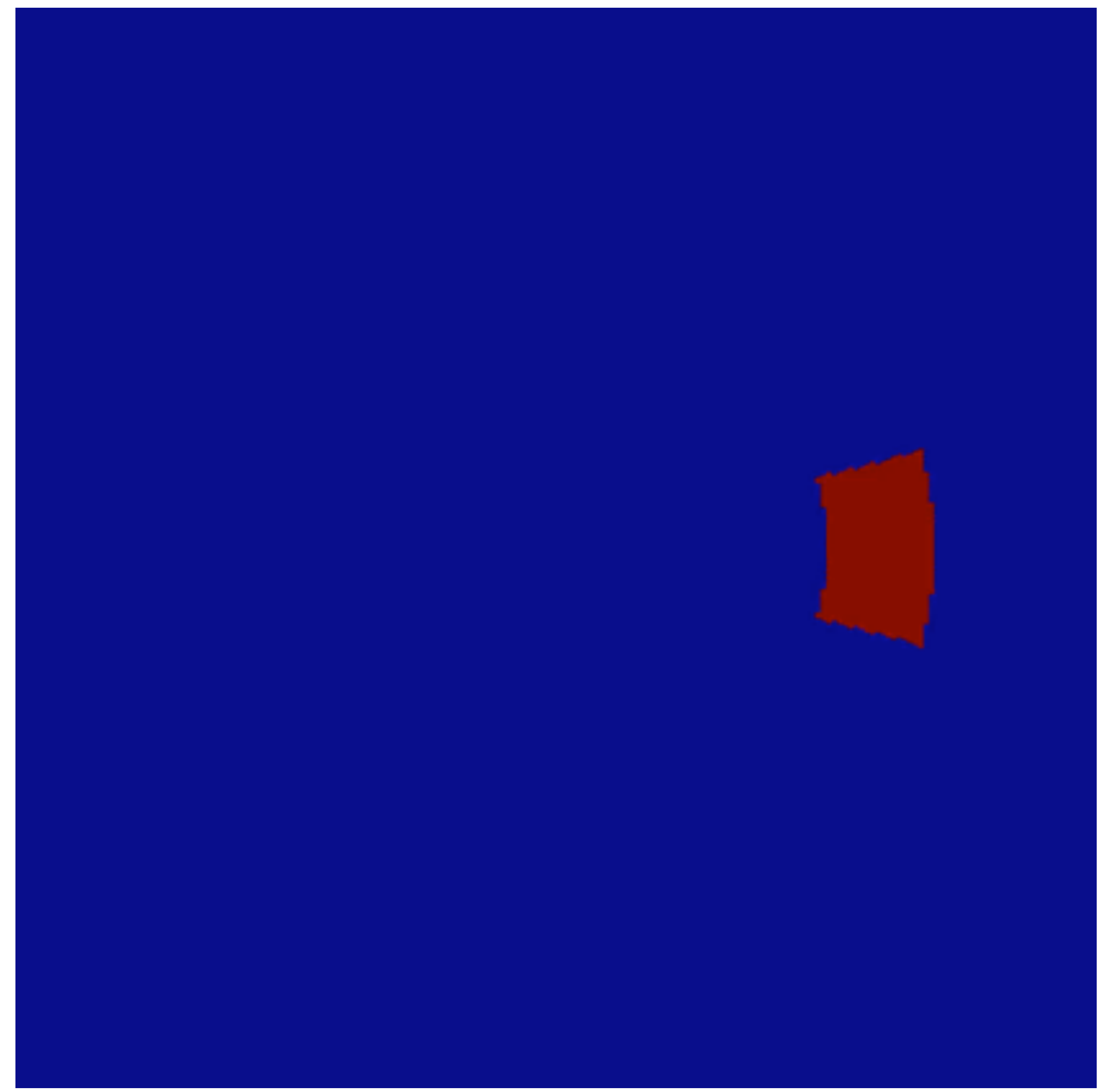
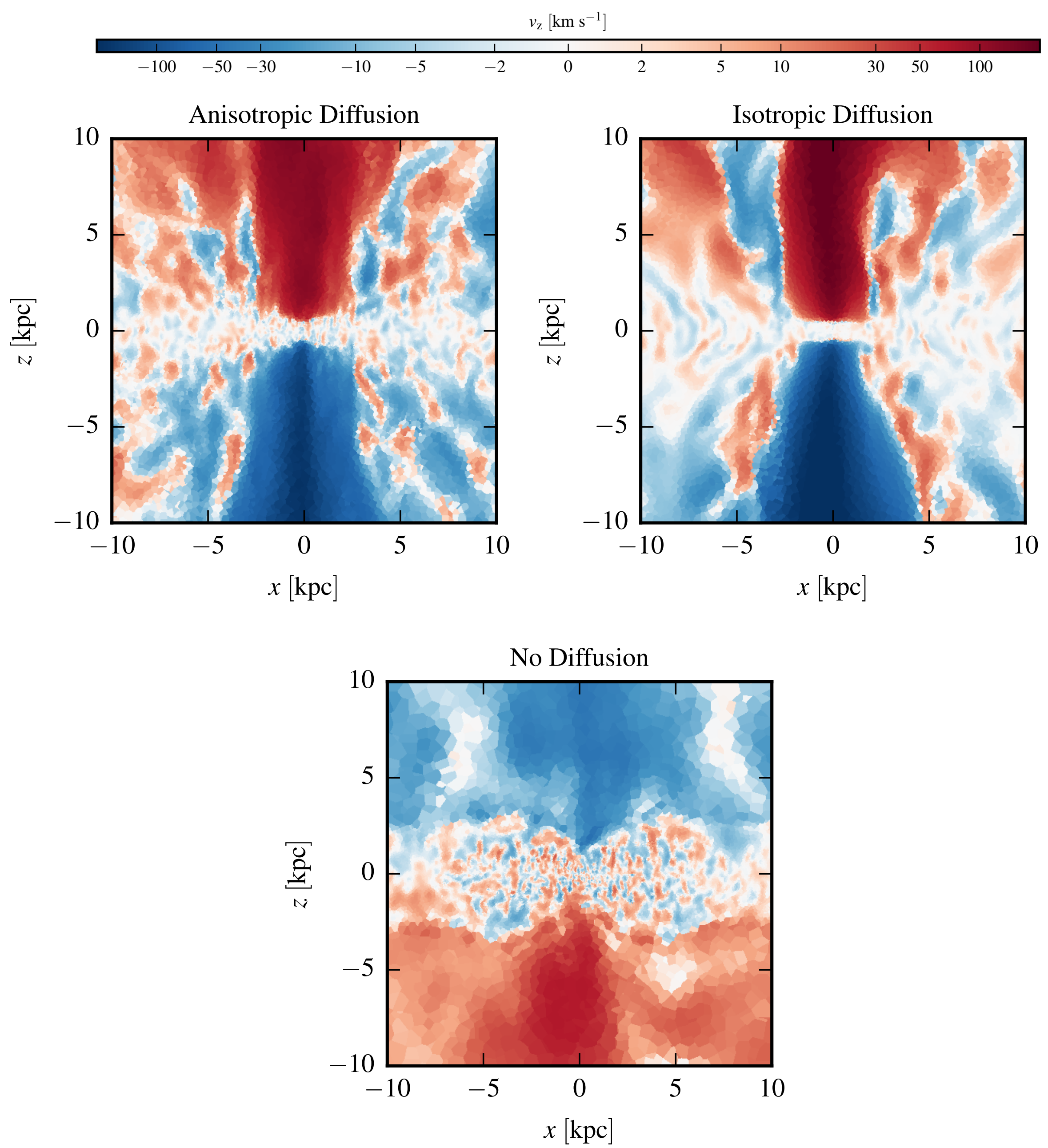
Isolated disk galaxies

- Isolated halo 10^{11} $M_\odot$
- Cooling + Star formation, Springel & Hernquest ISM model
- Magnetic seed field
- New stars inject 4×10^{48} erg per $M_\odot$, CRs cool
- CRs are advected and diffuse along B with $\kappa=10^{28}$ cm^2 s^{-1}
- Implicit solver with local time stepping, energy conservation, no entropy violation



Anisotropic vs. isotropic diffusion: CR driven galactic wind

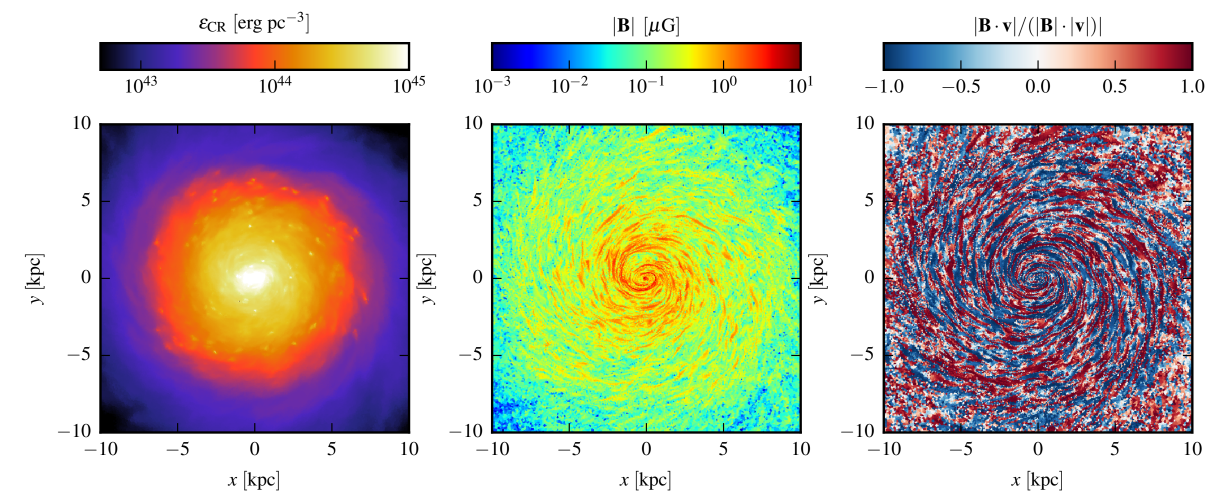
- Diffusion causes CR driven central outflow
- Velocities up to 300 km/s, don not change significantly with height
- No diffusion shows only fountain flow
- No qualitative difference between isotropic and anisotropic diffusion for wind properties



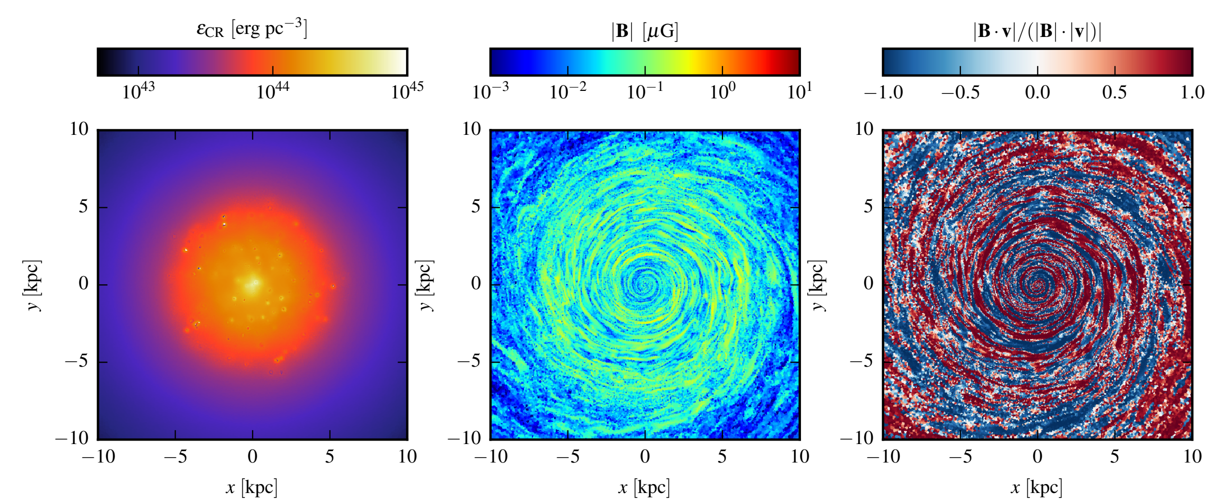
Anisotropic vs. isotropic diffusion

- Magnetic field dominated by azimuthal component
- CRs more centrally concentrated with anisotropic diffusion (confined to disk by B-field)
- Magnetic field strength 10 times larger for anisotropic run

Anisotropic

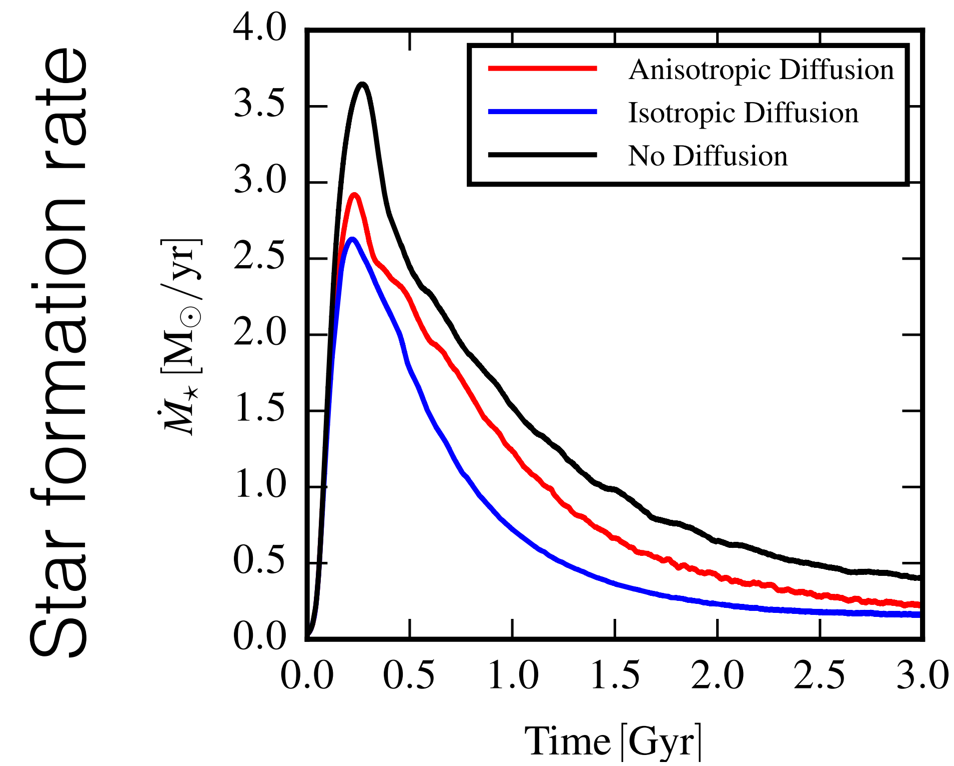


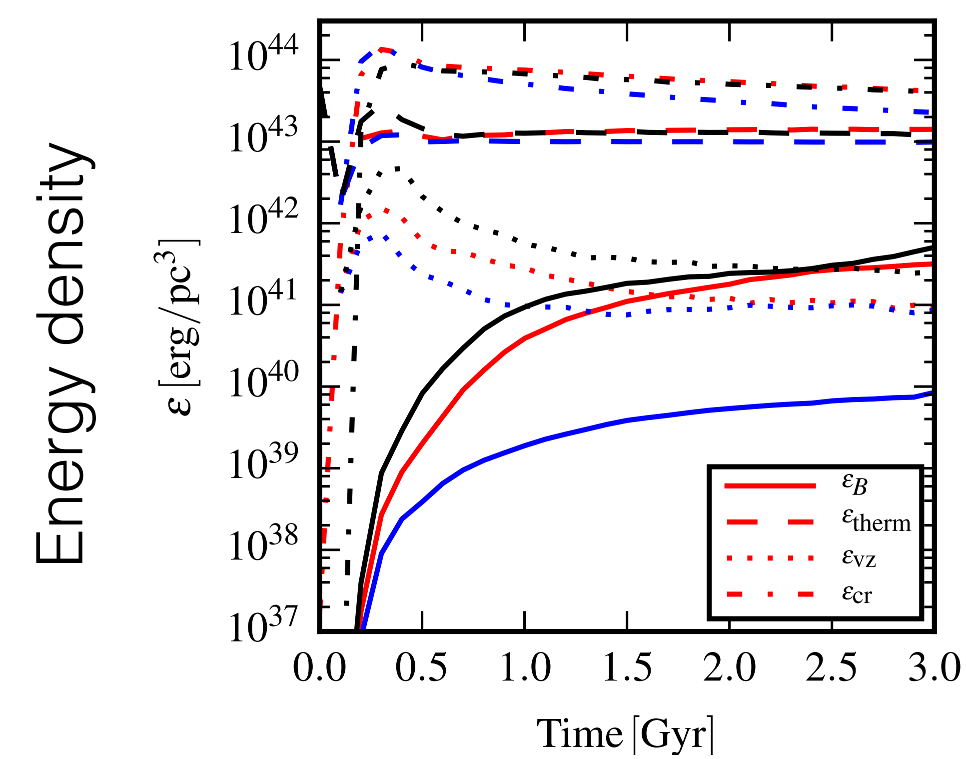
Isotropic



Anisotropic vs. isotropic diffusion

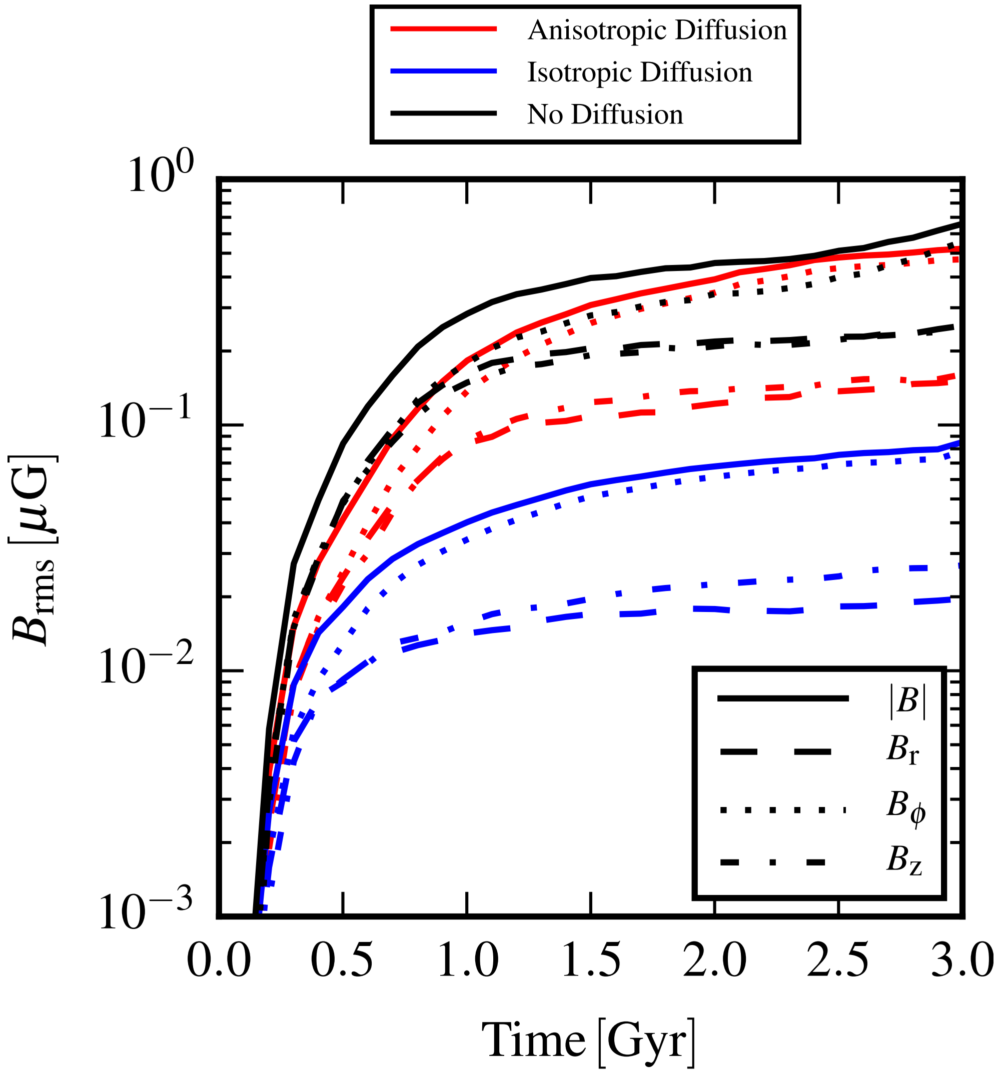
- Star formation slightly suppressed in diffusion runs compared to purely advective runs after ~300Myrs
- CR energy dominates after ~300Myrs in disk
- Magnetic energy dynamically irrelevant





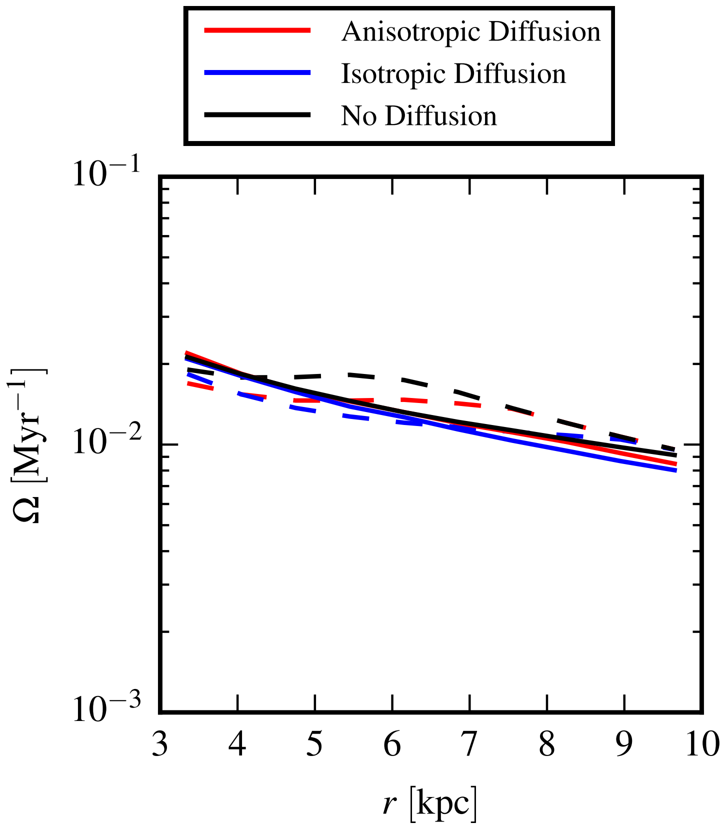
Magnetic field amplification

- Initial turbulent dynamo leads to unstructured B-field
- After ~300Myrs ordering, large-scale amplification dominates



Magnetic field amplification

- Initial turbulent dynamo leads to unstructured B-field
- After ~300Myrs ordering, large-scale amplification dominates
- Azimuthal velocity field identical for all runs



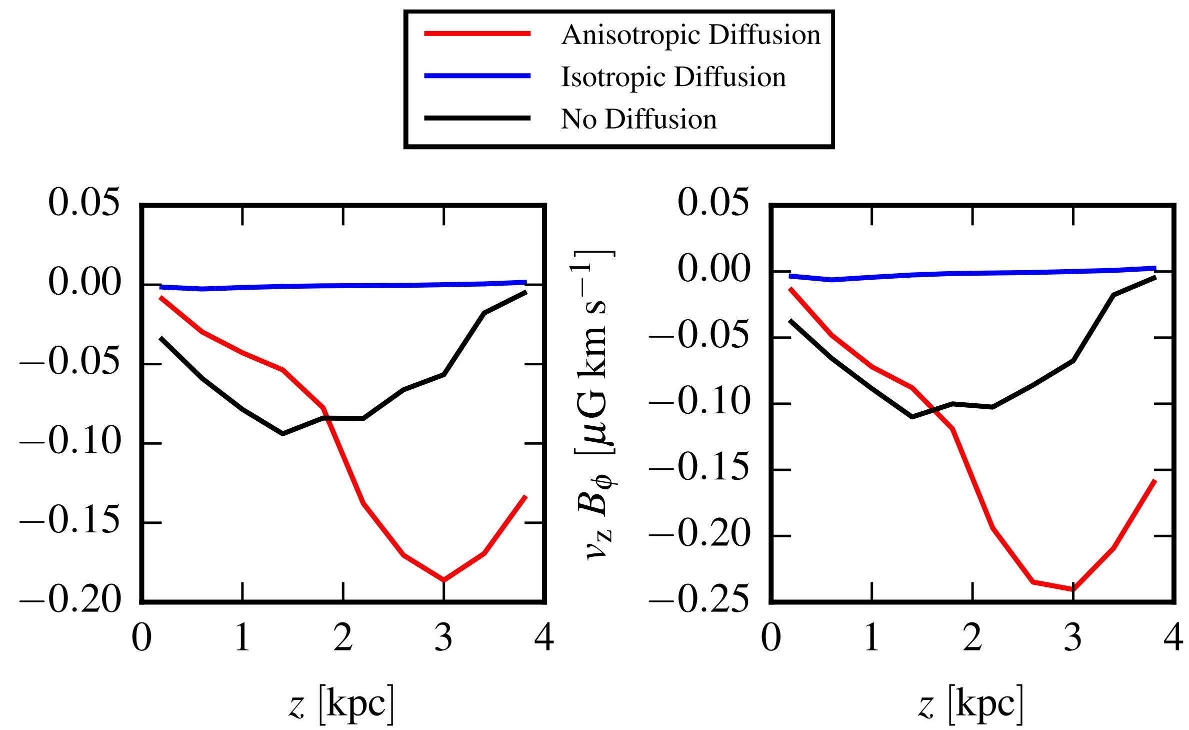
$$\frac{\partial \bar{B}_r}{\partial t} = -\frac{\partial}{\partial z}\left(\bar{v}_z \bar{B}_r + \mathcal{E}_\phi\right)$$

$$\frac{\partial \bar{B}_\phi}{\partial t} = -\frac{\partial}{\partial z}\left(\bar{v}_z \bar{B}_\phi + \mathcal{E}_r\right) + q\Omega_0 \bar{B}_r$$

Galactic dynamo
(Shukurov et al. 2006)

Magnetic field amplification

- Initial turbulent dynamo leads to unstructured B-field
- After ~300Myrs ordering, large-scale amplification dominates
- Azimuthal velocity field identical for all runs
- Vertical velocity and B-field gradients erased by isotropic diffusion



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Galactic dynamo
(Shukurov et al. 2006)

Anisotropic vs. isotropic diffusion: summary

- CRs suppress star formation, isotropic diffusion > anisotropic diffusion > advective CRs

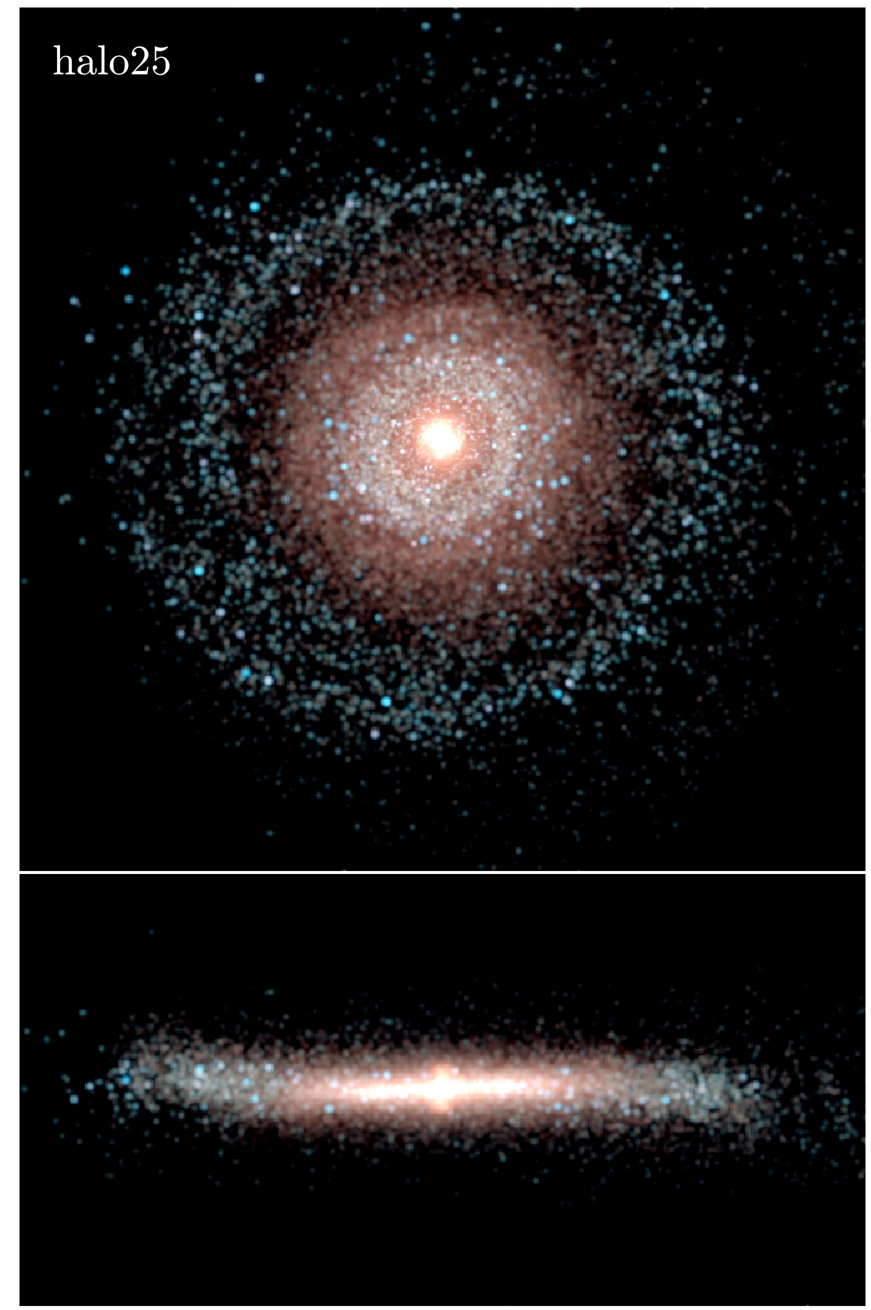
- CR energy density in disk higher and more centrally concentrated for anisotropic diffusion compared to isotropic diffusion

- Magnetic field amplification significantly suppressed by isotropic diffusion, as vertical pressure gradient is washed out

- -> Need to model **anisotropic** diffusion…

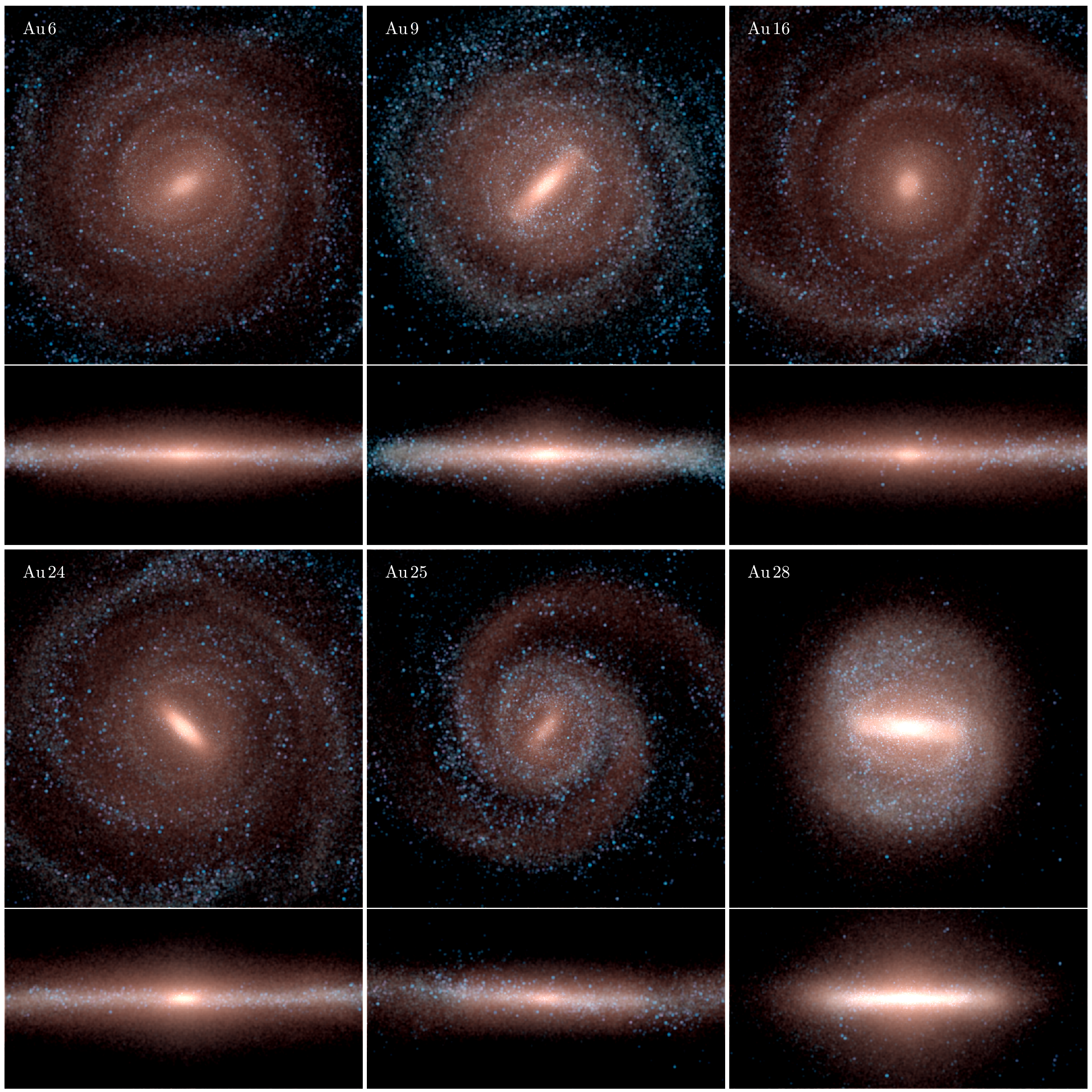
Cosmological Milky Way zooms with anisotropic CR diffusion

- Rerun a set of Auriga halos (Rob's talk next) 10^{12} halos @ lvl5 $M_{Gas}=4\times10^5\ M_\odot$
- no wind feedback
- no BHs (no AGN feedback)
- Cooling + Star formation, Springel & Hernquest ISM model
- Magnetic seed field
- New stars inject 4×10^{48} erg per $M_\odot$, CRs cool
- CRs are advected and diffuse along B with $\kappa=10^{28}$ cm^2 s^{-1} along magnetic field lines

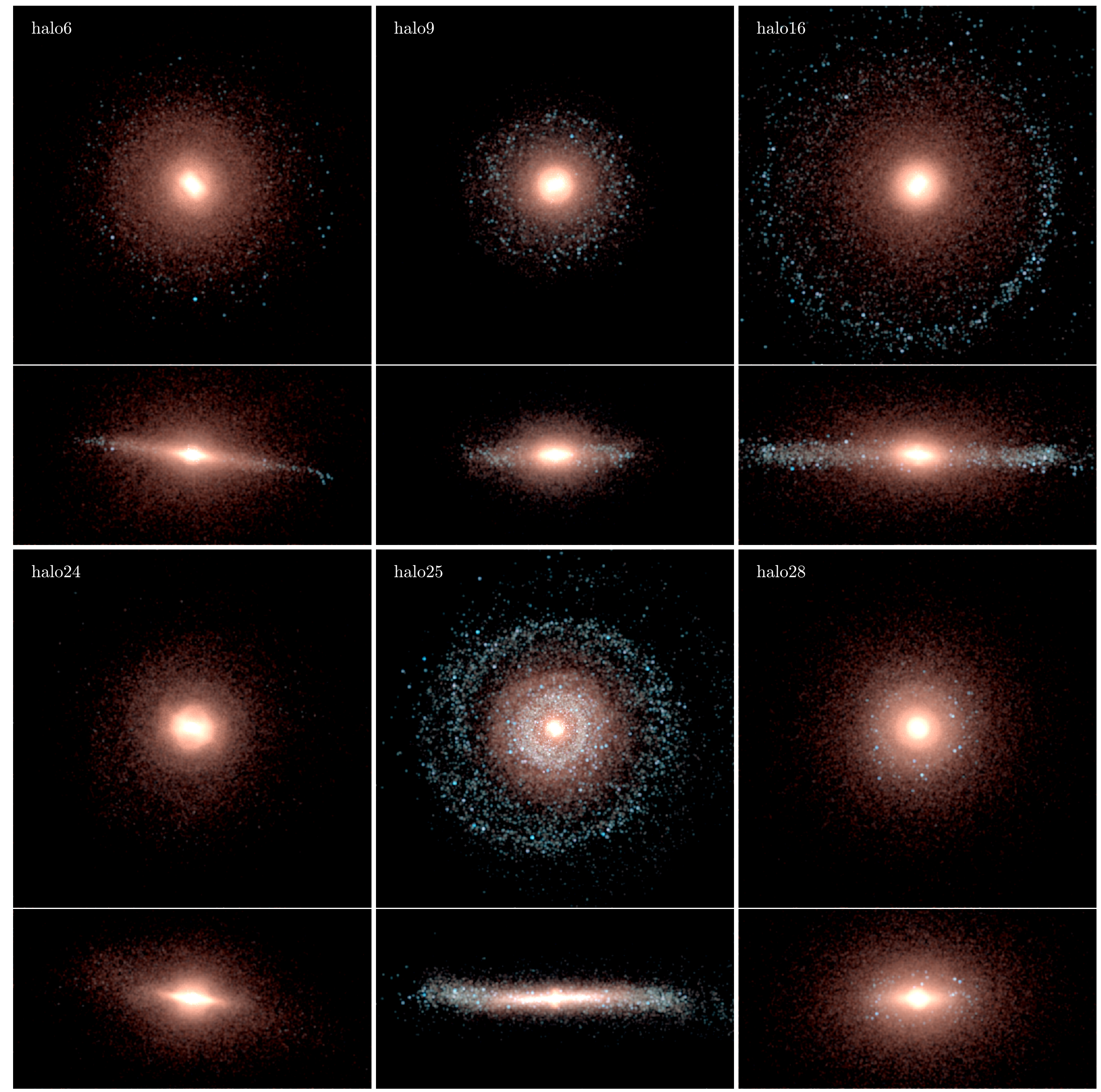


Stellar projections

Auriga model (see Robs talk next)

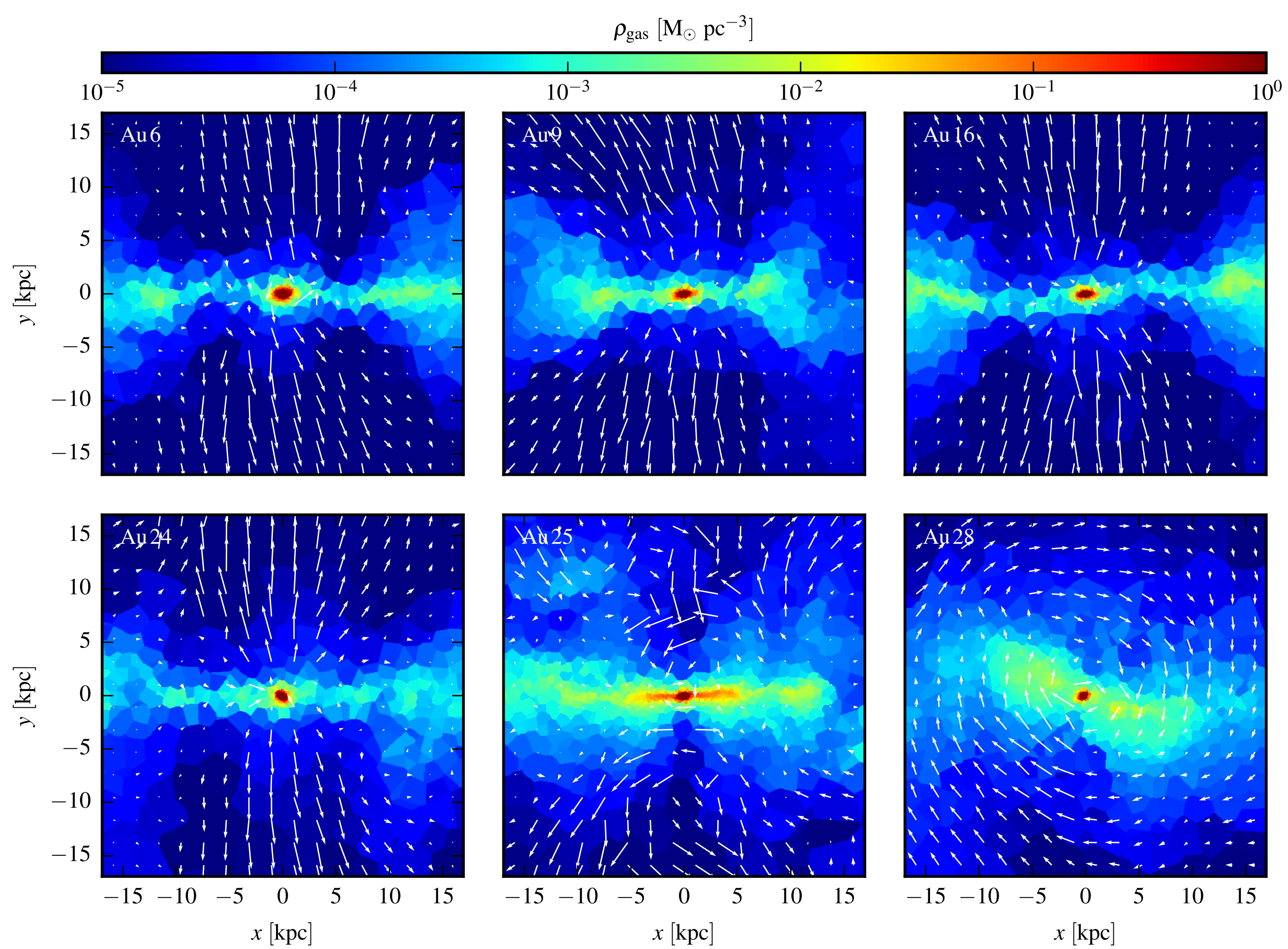


Cosmic rays



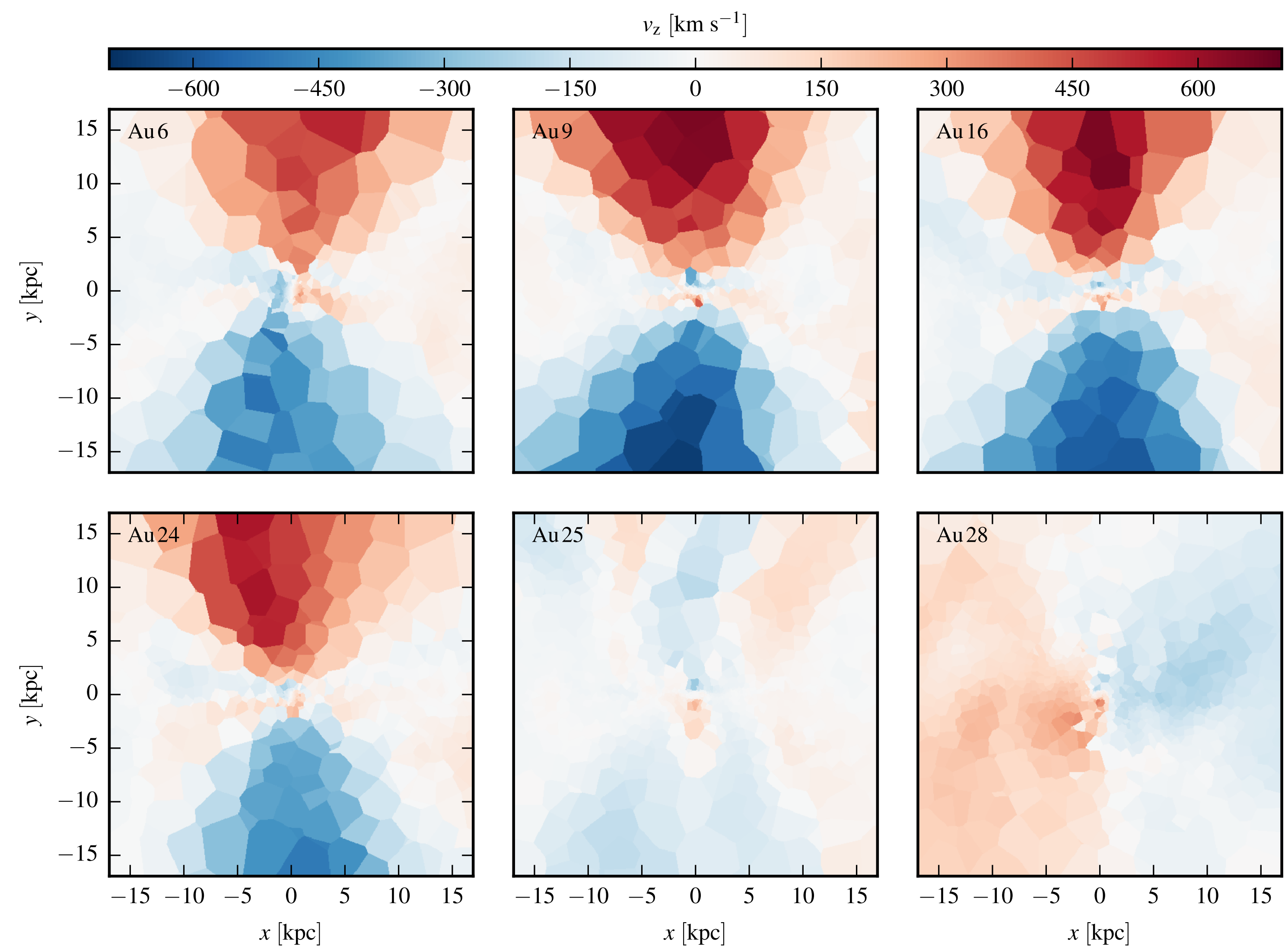
Gas disks

- 5 gas disk, 1 spheroidal
- very dense central bulge
- 4 disks show strong bipolar outflows
- one disk shows an unstructured outflow and has much more gas left
- no outflow in the spheroidal galaxy



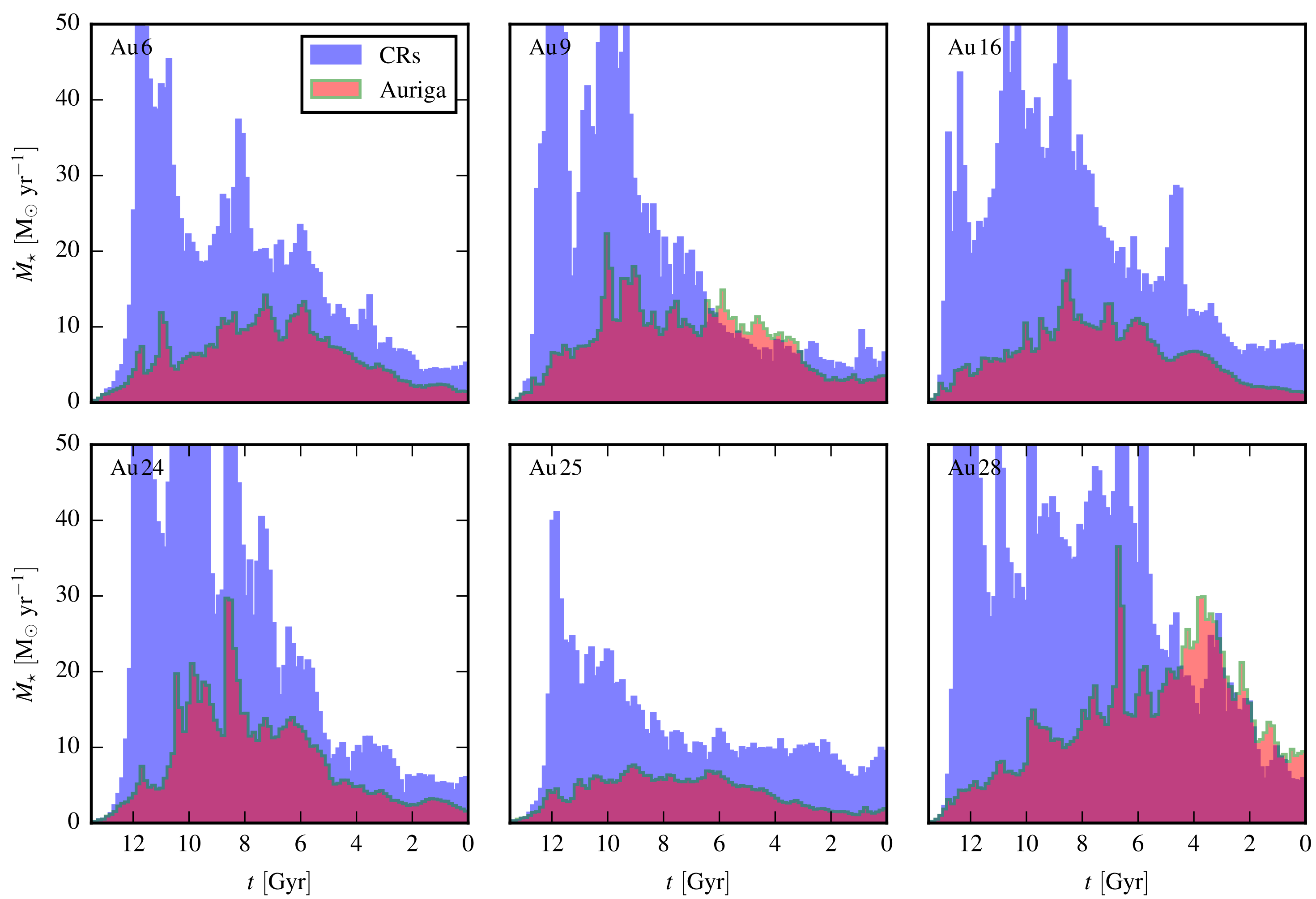
Outflow velocities

- Outflow velocities up to 700km/s
- Outflows can become unbound
- Mass-loading factors (z=10kpc, instantaneous SFR) ~5 for the 4 disks with strong outflows



Star formation history

- Star formation rate significantly higher in CR runs compared to Auriga (and observations)
- Additional (SN, AGN) feedback needed to reduce stellar mass



Summary

- CR diffusion alone can blow strong bipolar winds in full cosmological Milky Ways
- Wind velocities up to 700km/s
- Mass loading factor ~5
- Does not prevent bulge formation
- Needs to be combined with additional feedback components
- Streaming!