Thermal-Instability-Driven Turbulent Mixing in Galactic Disks

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Radial Metallicity Gradient

Nearby Disk Galaxies

Bresolin, Kennicutt, & Ryan-Weber 2012
Radial Metallicity Gradient

26 MASSIV Galaxies at $z \sim 1.2$

Queyrel et al. 2012
What Sets Radial Metallicity Gradients?
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• **Supernova-driven galactic fountains** (Spitoni, Recchi, & Matteucci 2008; Spitoni et al. 2009)

• **Gas radial inflows within the disk** (Mayor & Vigroux 1981; Lacey & Fall 1985; Pitts & Tayler 1989; Götzt & Köppen 1992; Portinari & Chiosi 2000; Spitoni & Matteucci 2011; Bilitewski & Schönrich 2012)


• **Merger/interaction history** (Perez et al. 2006, 2011; Kewley et al. 2010; Rupke, Kewley, & Barnes 2010; Rupke, Kewley, & Chien 2010; Torrey et al., in prep.)

• **Stellar radial migration** (Roškar et al. 2008a,b; Schönrich & Binney 2009)
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- **Turbulent mixing (?)**
Driving Turbulence in the Interstellar Medium

- Supernova explosions
- Rayleigh-Taylor instability
- Gravitational instability
- Magneto-rotational instability
- Thermal instability
Two-phase Model for the ISM

Heating rate $\sim n \Gamma(T)$

Cooling rate $\sim n^2 \Lambda(T)$
Two-phase Model for the ISM

- **Cooling Dominated**
- **Heating Dominated**

- **Warm Neutral Medium**
- **Cold Neutral Medium**

\[
\begin{align*}
\text{Cooling rate} & \sim n \Gamma(T) \\
\text{Heating rate} & \sim n^2 \Lambda(T)
\end{align*}
\]
Setup
Setup

- Thin gas disk (2D)
Setup

- Thin gas disk (2D)
- Local shearing sheet
- Goldreich & Lynden-Bell (1965)

\[ L_y = 2L_x \]

\[ L_x = \pi R_0 \sin \iota \]

Kim & Ostriker (2002)
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- Metals as passive scalar fields
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Turbulent Steady State

Spiral Forcing  Magnetic Fields

Surface Density

Isothermal  Thermally Unstable

3 kpc
Turbulent Steady State

Spiral Forcing

Magnetic Fields

Metal Tracer Field

Isothermal

Thermally Unstable

Metal Injection Layer
Turbulent Steady State

Spiral Forcing

Magnetic Fields

Surface Density

Isothermal

Thermally Unstable
Turbulent Steady State

Spiral Forcing  Magnetic Fields

Metal Tracer Field

 Isothermal  Thermally Unstable
Turbulent Steady State

- Isothermal
- Thermally Unstable
- Spiral Forcing
- Magnetic Fields
- Surface Density

Isothermal

Thermally Unstable
Turbulent Steady State

Spiral Forcing  Magnetic Fields

Metal Tracer Field

Isothermal

Thermally Unstable
Power Spectrum of Mixed Metals

Normalized Power Density

Thermal Instability
+Spiral Forcing
+Magnetic Fields

$2\pi R_0 k$
Following the Flow

Metal Tracer Field

Power in $k_y$

Space

$e_\phi$

Time
Following the Flow

Metal Tracer Field

Power in $k_y$

Space

Time

Thursday, August 16, 12
Conclusions

Turbulent mixing of metals is...

• efficient (timescale < orbital time).

• not the same as the viscous stress of the gas.

• important in setting metallicity gradients.