

Structure and Components of the Interstellar Medium

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*The role of Disk-Halo Interaction in Galaxy Evolution:
Outflow vs Infall*

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Outline

- 1 Introduction
- 2 Ordinary matter
 - Physical characteristics
 - Spatial distribution
 - In the Galactic Bulge
- 3 Cosmic rays
 - Observational properties
- 4 Magnetic fields
 - Observational properties
 - Near the Galactic Center
- 5 Conclusion

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The 3 basic constituents of the ISM

- Ordinary matter (gas & dust)

$$\begin{aligned} n &\simeq 0.003 \rightarrow > 100 \text{ cm}^{-3} & (\langle n \rangle_{\odot} \sim 1 \text{ cm}^{-3}) \\ T &\simeq 10^6 \rightarrow 10 - 20 \text{ K} \end{aligned}$$

- Cosmic rays

$$P_{\text{CR}} \sim P_{\text{g}}$$

- Magnetic fields

$$B \sim 5 \mu\text{G} \Rightarrow P_{\text{M}} \sim P_{\text{g}}$$

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Ordinary matter

- Mass

~ 10 – 15 % of the total mass of the Galactic disk

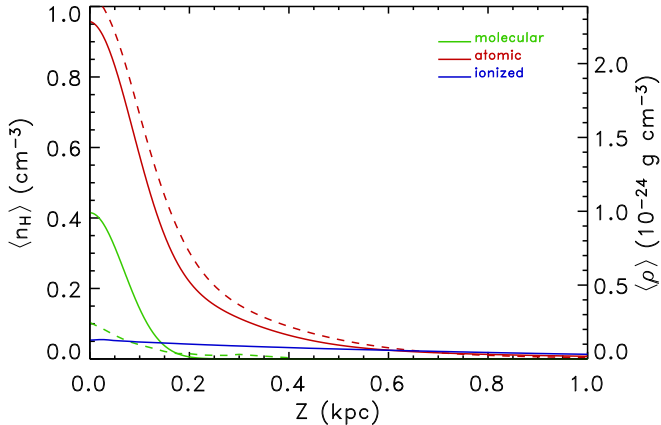
- Composition

Element	Fraction by number	Fraction by mass
Hydrogen	91 %	70.6 %
Helium	9 %	27.5 %
"Metals"	0.14 %	1.9 %

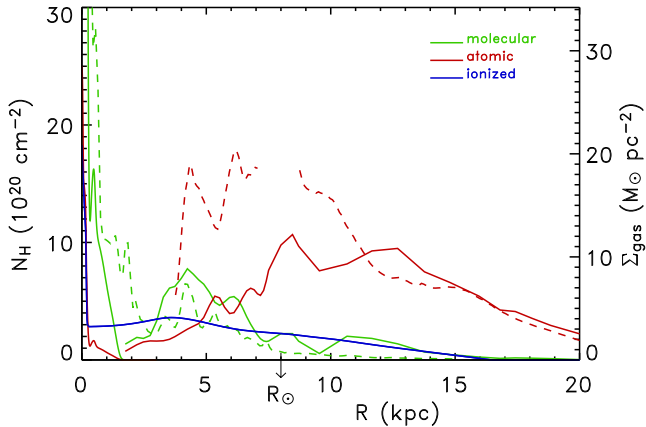
- Gas components

Component	T (K)	n_{H} (cm ⁻³)
Molecular	10 – 20	$10^2 - 10^6$
Cold atomic	50 – 100	20 – 50
Warm atomic	6 000 – 10 000	0.2 – 0.5
Warm ionized	~ 8 000	0.2 – 0.5
Hot ionized	~ 10^6	0.003 – 0.01

Space-averaged density near the Sun



Column density



In the Galactic Bulge

- **Neutral gas** (~ 91% molecular & ~ 9% atomic)

- * *Central molecular zone (CMZ)*

- Thin sheet of gas – ~ parallel to GP – displaced from GC
 - Projected radius ~ 200 pc
 - Thickness ~ 30 pc (molecular) & ~ 90 pc (atomic)

- * *Galactic Bulge (GB) disk*

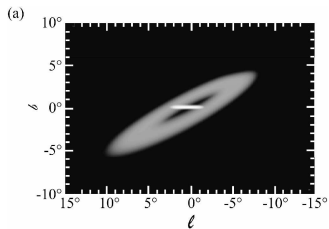
- Thicker layer of gas – tilted to GP & inclined to l.o.s.
 - Projected radius ~ 1.3 kpc
 - Thickness ~ 70 pc (molecular) & ~ 200 pc (atomic)
 - Hole around CMZ

- **Ionized gas** (~ 83% warm & ~ 17% hot)

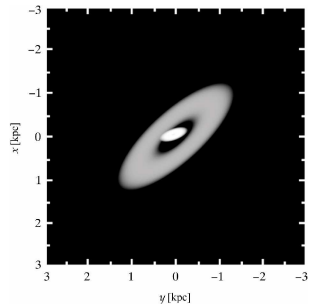
- Widespread distribution throughout GB
scale height ~ 1 kpc (warm) & ~ 2 kpc (hot)
 - Local concentration around GC
radius ~ 120 pc & thickness ~ 40 pc

CMZ & GB disk (molecular gas)

Projection onto p.o.s



Face-on view



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Cosmic rays

- Near the Sun
Voyager 1 CR data
 $e_{\text{CR}} \simeq 1.8 \text{ eV cm}^{-3}$
- Radial distribution
 γ -ray intensity maps
 $L_{\text{CR}} \sim 13 \text{ kpc}$
- Vertical distribution
CR propagation models + measured CR elemental composition
 $H_{\text{CR}} \lesssim 3 \text{ kpc}$
- Global distribution
Synchrotron emission measurements

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Magnetic fields

- Near the Sun

Measured polarization of starlight

\vec{B} is horizontal & nearly azimuthal (angle $\approx 7^\circ$)

- In neutral regions

Zeeman splitting measurements

- In atomic clouds : $B \sim$ a few μG

- In molecular clouds : $B \sim (10 - 3000) \mu\text{G}$

- In ionized regions

Faraday rotation measurements

- $B_{\text{reg}} \approx 1.5 \mu\text{G}$ & $B_{\text{turb}} \sim 5 \mu\text{G}$ near \odot

- \vec{B}_{reg} is nearly horizontal & predominantly azimuthal away from the GC

- Reversals in B_ϕ in the disk (\Rightarrow spiral structure ?)

- In general ISM

Synchrotron emission measurements

- $B_{\text{tot}} \sim 5 \mu\text{G}$ near $\odot \rightarrow B_{\text{tot}} \sim 7 \mu\text{G}$ in MR

- Global spatial distribution ($L_B \sim 12 \text{ kpc}$ & $H_B \sim 4.5 \text{ kpc}$)

Near the Galactic Center

- Non-thermal radio filaments

- * *Morphology & radio (synchrotron) polarization measurements*

- $\vec{B} \parallel \text{filaments} \Rightarrow \vec{B} \perp \text{GP}$

- * *Dynamical argument*

- No distortion $\Rightarrow B \gtrsim 1 \text{ mG}$

- * *Radio (synchrotron) intensity measurements*

- $B_{\text{equip}} \sim (50 - 200) \mu\text{G}$

- In general ISM

- Diffuse synchrotron intensity measurements*

- $B_{\text{equip}} \sim 10 \mu\text{G}$

- In dense molecular clouds

- FIR/submm (dust thermal emission) polarization measurements*

- \vec{B} is nearly $\parallel \text{GP}$

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Interstellar pressures near the Sun

