Massive Star Formation near Sgr A* and in the Nuclear Disk

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Outline

1. Small Scale ~ 0.5pc

- ☐ The stellar disk around Sgr A*

Consequence of the Motion of GMCs Engulfing Sgr A*

2. Large Scale ~ 200pc

- ☐ Elevated gas temperature
- ☐ Low star formation rate

Consequence of Cosmic-Ray Ionization and Heating

Conclusions

Star Formation near Sgr A*

- Majority of early type stars in one or two disks < 0.5pc
- Disks have moderate thickness (h/r~0.1)
- Stars have low-to-high eccentricities
- Coeval disks t=(6+/-2)x10^6 yrs
- Disk mass < 10^4 solar mass

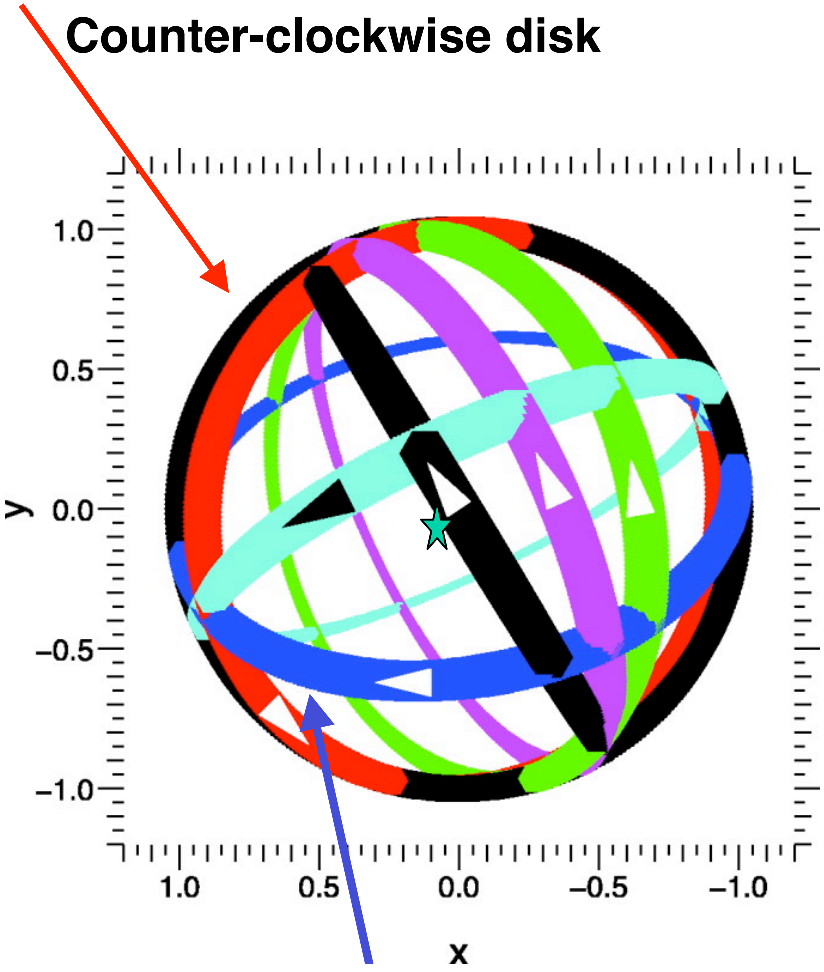
- Two scenarios of star formation:

1. Migration: massive clusters will undergo dynamical friction (Gerhard 2001)

- dynamical friction is too long
- no massive stars beyond 0.5pc

2. In-situ: massive disk becomes Jeans unstable

- preferred



Levin and Beloborodov 2003; Genzel et al. 2003; Lu et al. 2006; Paumard et al. 2006

Stellar Disk Formation

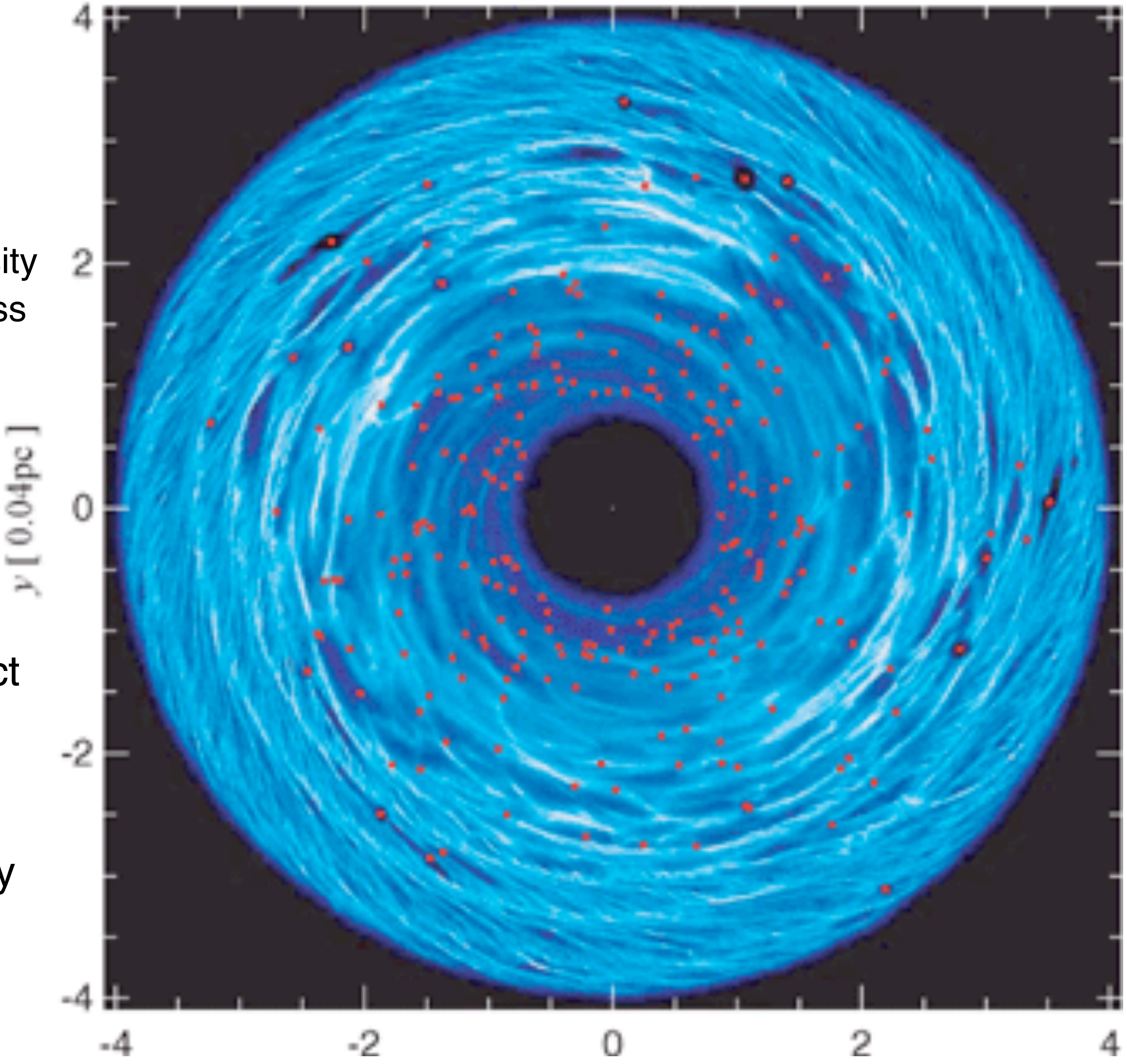
- In-situ star formation

☐ Simulation of star formation in an accretion disk
☐ Snapshot of disk column density
☐ Red spots: stars > 3 solar mass

- How do these disks get in there in the first place?
- What about eccentric orbits?

- The trajectory of a compact cloud less than 1pc at 100 km/s: Highly rare

- Compact cloud has no way of shedding its angular momentum



Nayakshin, Cuadra and Springel 2007

Molecular Cloud Engulfs Sgr A*

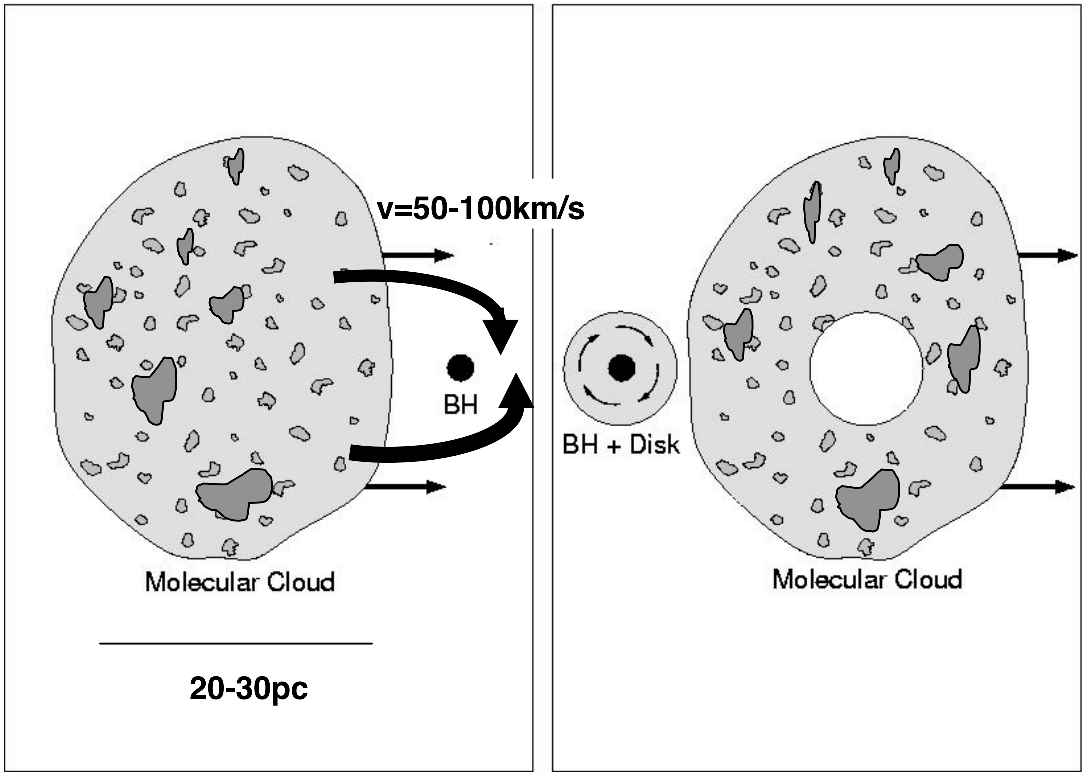
- Bondi-Hoyle: Inhomogeneous, extended cloud gravitationally focused

- Capture radius: 3pc
- 70% of angular momentum cancels out as r=3pc circularizes to 0.3pc

- Q<1 as the disk self-gravitates

$$Q = \frac{\Sigma_{\rm crit}}{\Sigma_d} = \frac{y\, c_s\, v^3}{\pi G^2 M\, w\, \Sigma_c} = 0.029\, \frac{y\, v_{50}^3}{w N_{24}}$$

- Cloud-cloud collisions:
- The circumnuclear ring (few pcs)

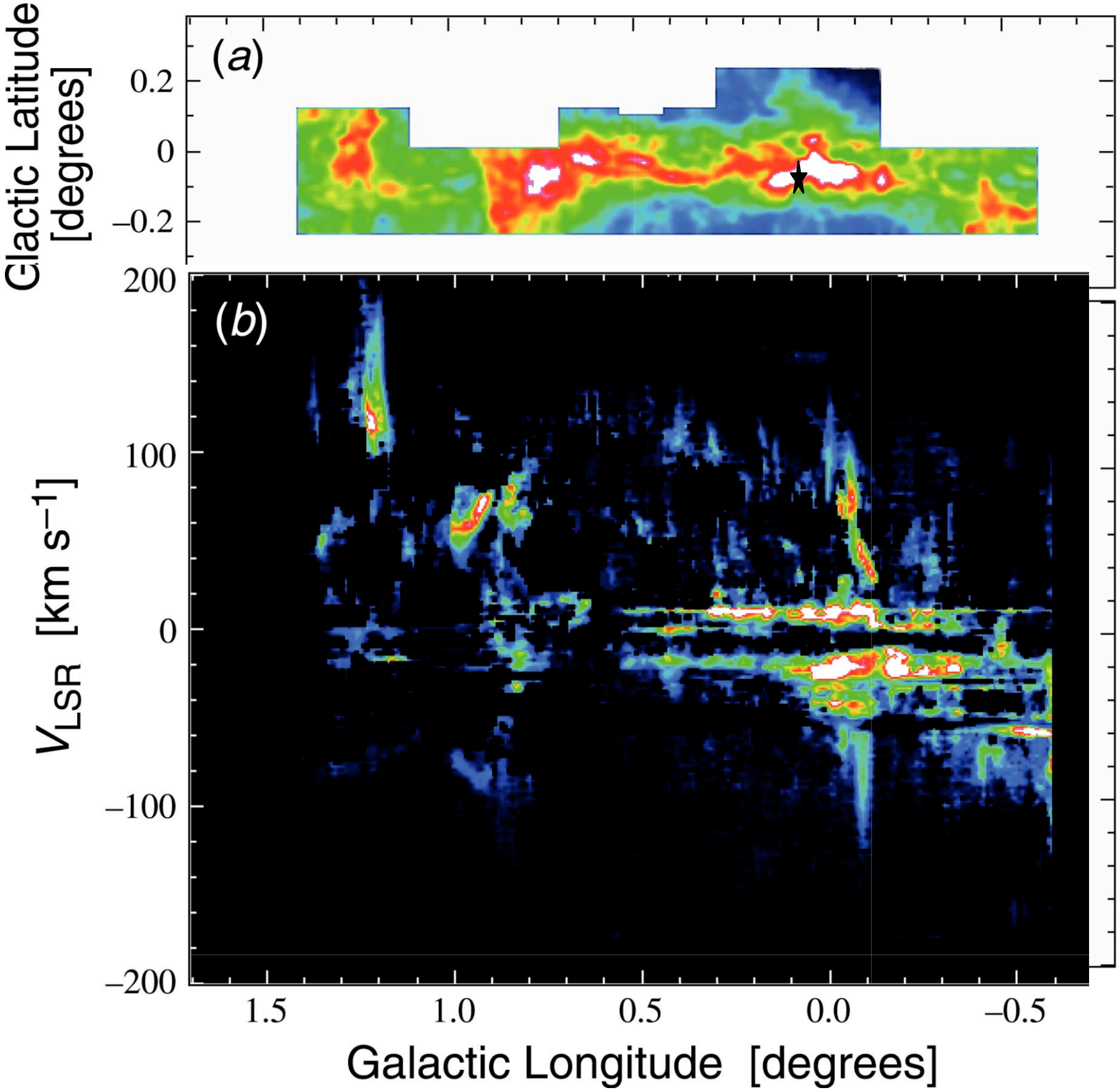


Wardle and FYZ (in prep)

Physical Conditions of the Molecular Nuclear Disk

- Molecular layer: 450 x 50 pcs
- 2×10^7 to 10^8 M_{sol}
- Size: 20-40 pcs
- Asymmetric (2/3 on oneside)
- Surface brightness: > 100 $M_{sun}pc^{-2}$
- Molecular density n ~ 10^4 cm^{-3}
- Non-circular motion

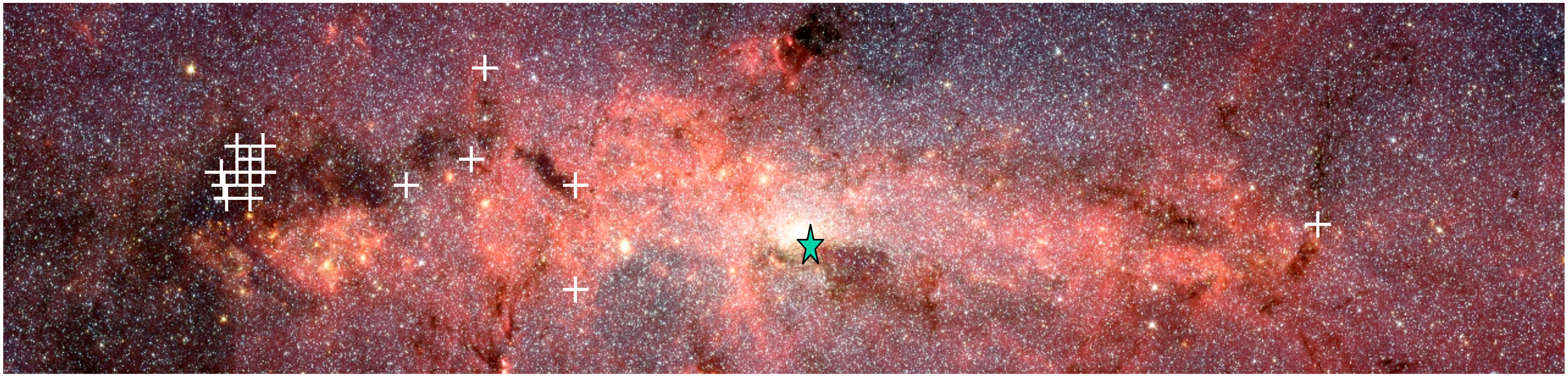
- Gas temperature T ~ 70K,
- Dust temperature T ~ 20K
- Velocity dispersion Δv ~15 km/s



CO (3-2))

Oka et al. 2007

IRAC image of the Nuclear Disk



IRAC
(Stolovy et al. 2007)

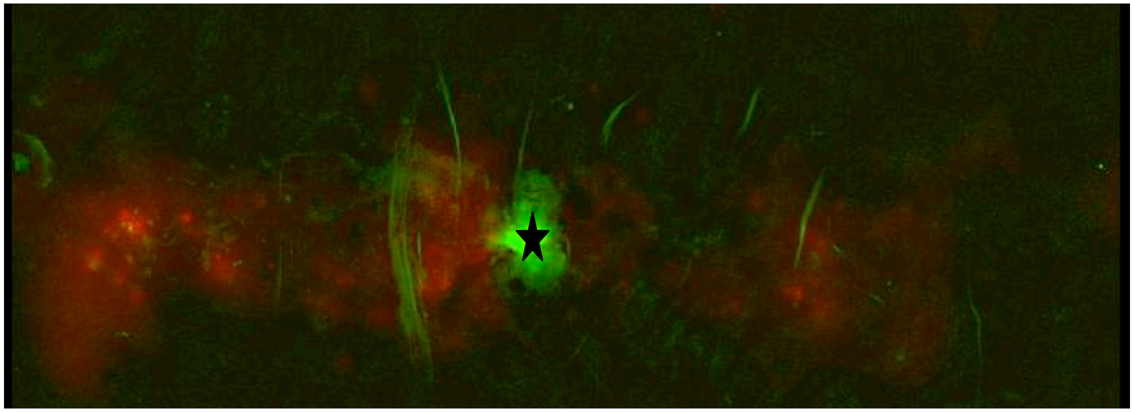
6.7 GHz Methanol Sources (Caswell 1996)	# Masers
Sgr B2	11
Sgr C	2
Dust Ridge	3-5
20-40 km/s clouds	0

⇒ Space density of masers:
Low massive star formation

- Quiescent IRDCs with no radio continuum but high kinetic temperature (Lis et al. 1994)

⇒ SF efficiency/mass< 0.1%

Nonthermal Processes in the Nuclear Disk

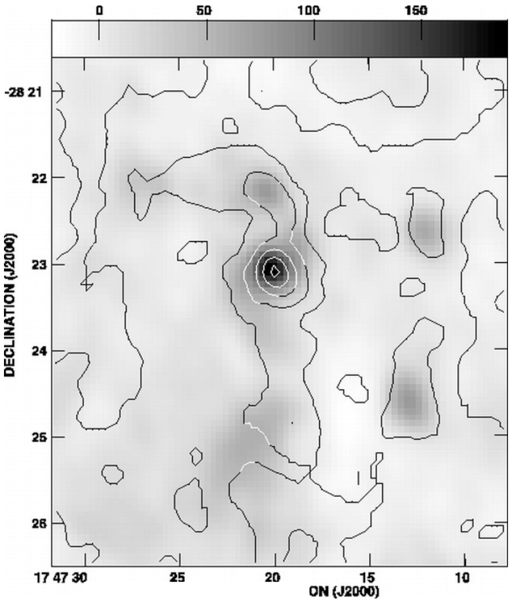


🟥 **6.4 keV line**

🟩 **90cm**

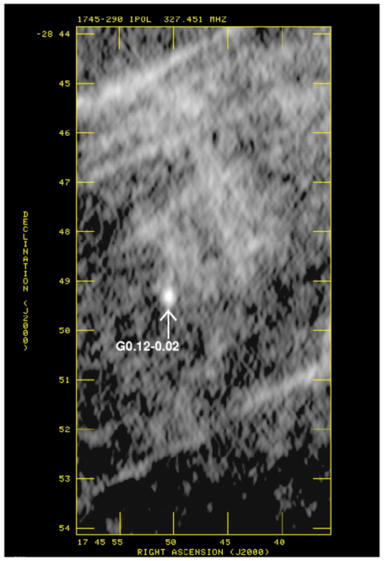
90cm
(Nord et al. 2004)

6.4keV: FYZ, Muno,
Wardle and Lis 2007



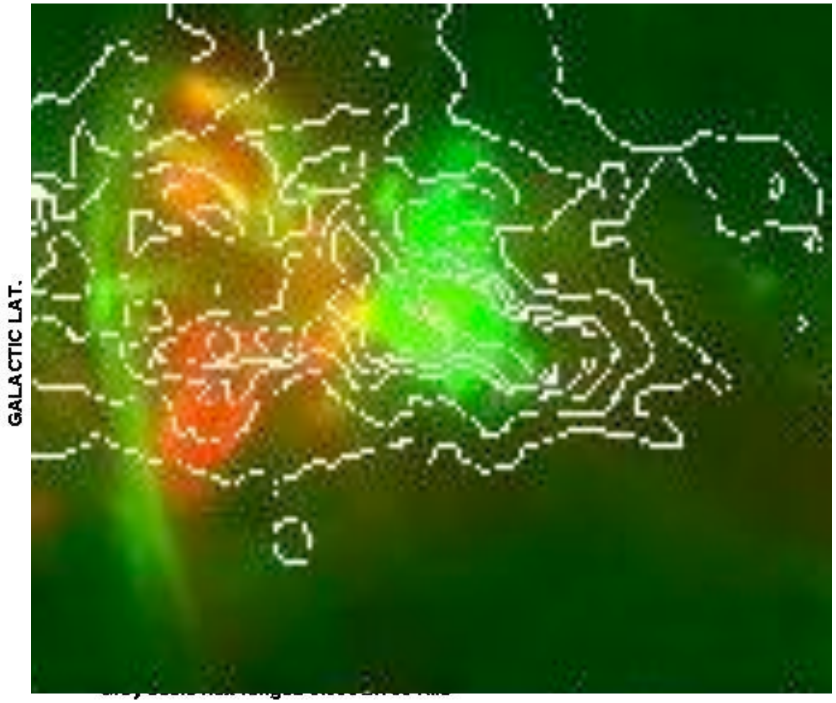
Sgr B2

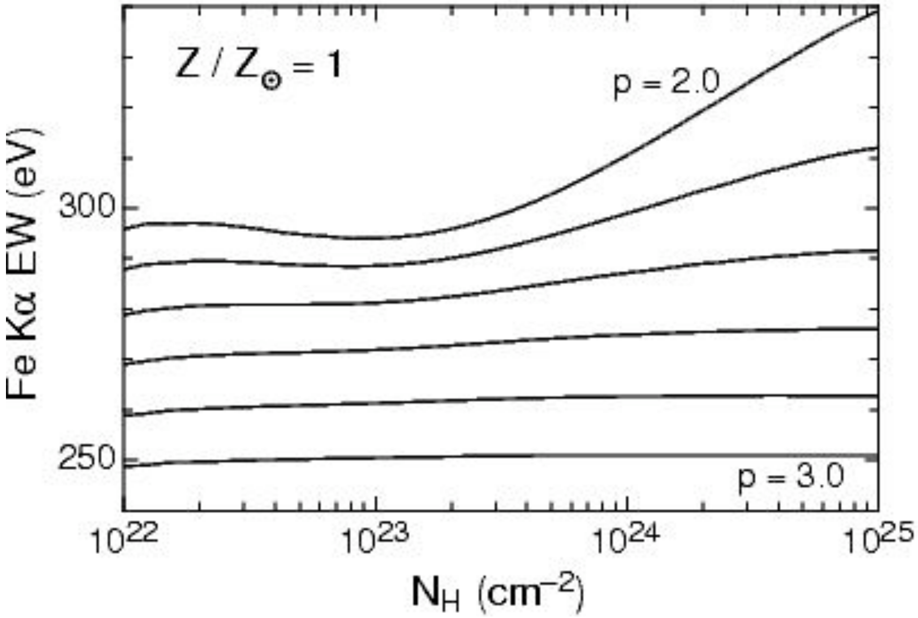
Hollis et al. 2007;
Crocker et al. 2007
FYZ et al. 2007



Arches Cluster: 327 MHz
(FYZ et al. 2003)

Enhanced Cosmic Ray Emission





1. 6.4 KeV Kα line emission from Fe
2. Non-thermal radio Emission (Sgr B2, Arches cluster)
3. H^+_3 measurements (Oka et al. 2005)
4. H_3O^+ measurements (van der Tak et al. 2006)

$\varepsilon \sim 7-1000$ eV cm^{-3}

⟹

- Cosmic ray bombardment of molecular gas
- The needed ionization rate is $\zeta \sim 10^{-15}$ s^{-1}
- Two orders of magnitude higher than in the Galactic disk
- Elevation of gas temperature (Gusten et al. 1985)

Star Formation in the Nuclear Disk

- Jeans Mass

$$M_J \approx 0.53 \left(\frac{T}{10\,\mathrm{K}}\right)^{3/2} \left(\frac{n_{\mathrm{H}}}{10^6\,\mathrm{cm}^{-3}}\right)^{-1/2} M_\odot$$

- $M_J \sim 11\ M_{solar}$ when T~75K : consistent with massive stellar clusters

- Ambipolar diffusion time scale

$$t_{\mathrm{AD}} = \frac{R}{v_d} \approx 0.8\left(\frac{x_e}{10^{-8}}\right)\ \mathrm{Myr}$$

- High ionization fraction: x_e $\Longrightarrow$ Suppression of star formation

- Implication: Trigger of star formation by expanding SNRs (Fatuzzo et al. 2007)

Conclusions

- The Origin of Stellar Disks near Sgr A*
  - In situ star formation preferred
  - Non-circular moving clouds pass through strong gravitational potential

- The Role of Cosmic Rays:
  - Higher T_{gas} than T_{dust}
  - Increases Jeans Mass: massive star formation
  - Slows down star formation