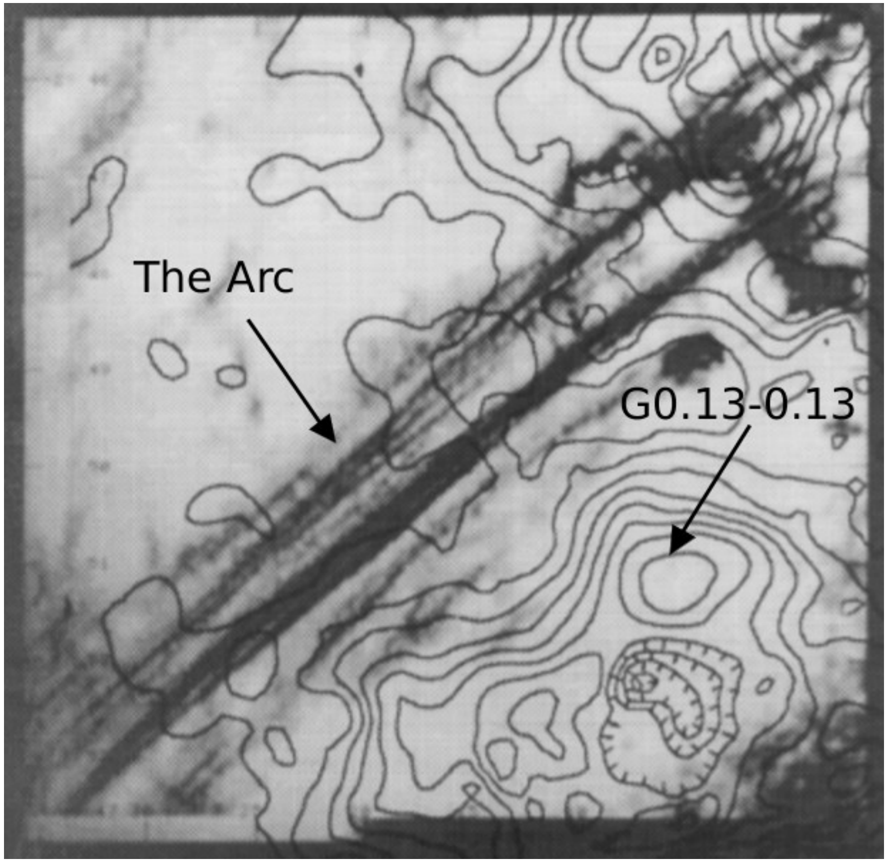
The GC molecular cloud G0.13-0.13: A Laboratory for Understanding Cosmic Ray Acceleration and Interactions

Andrew Lehmann (Macquarie University). Supervisor: Mark Wardle



Tsuboi et al. (1997)

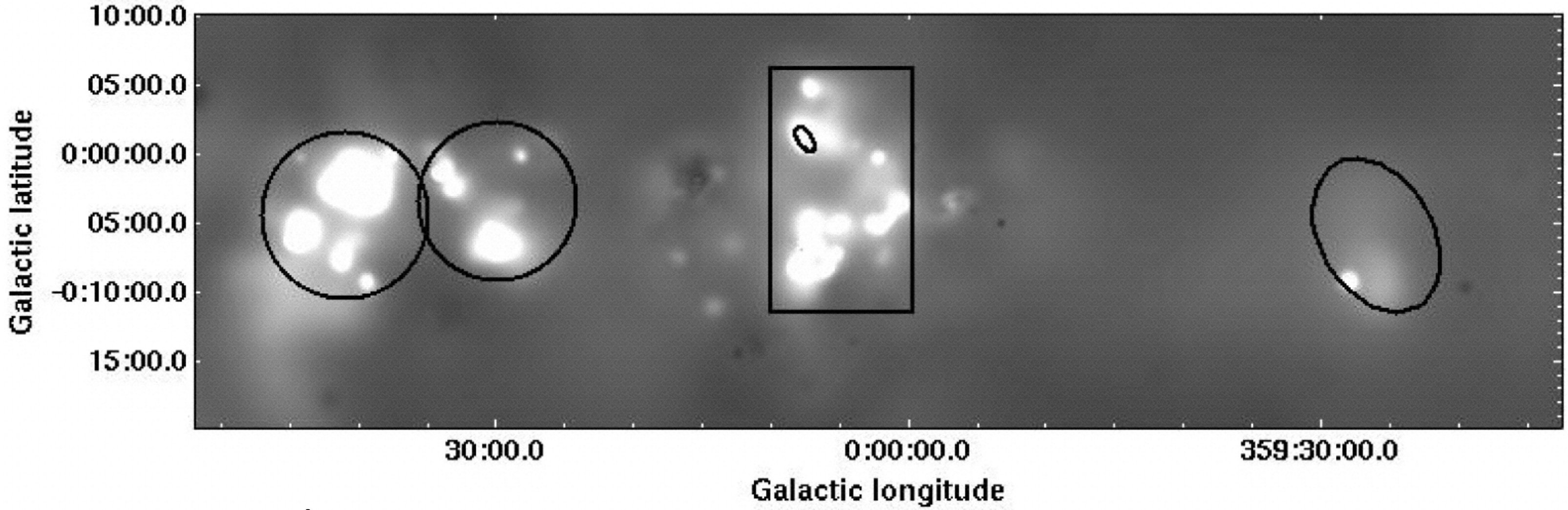
Overview:

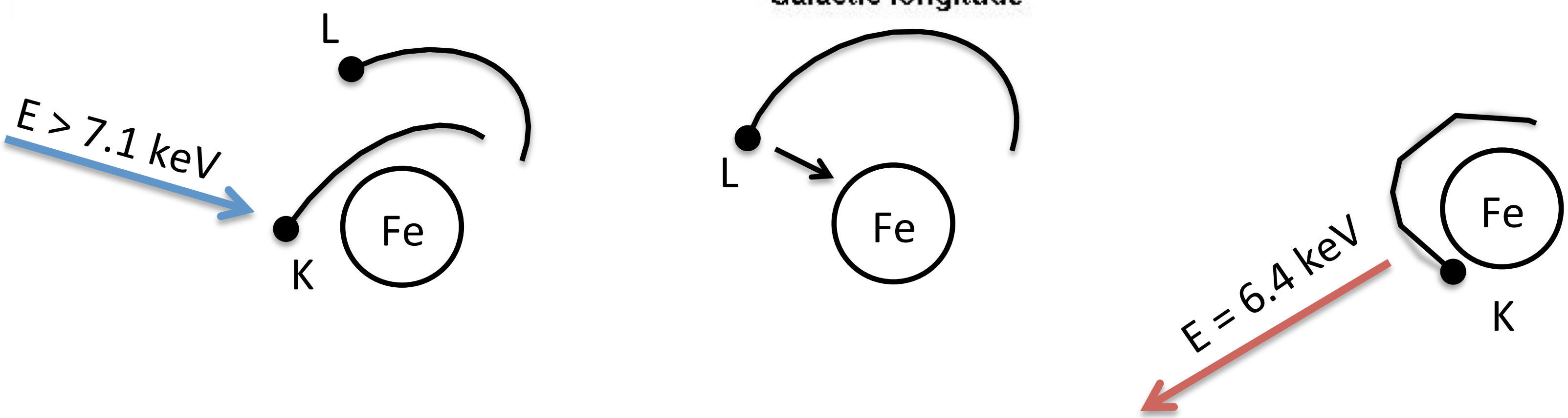
- Context
- G0.13-0.13: Properties
- Cosmic Ray Diffusion
- Implications
- Future Work/Summary

MACQUARIE UNIVERSITY
ASTRONOMY, ASTROPHYSICS AND ASTROPHOTONICS RESEARCH CENTRE

Background: Diffuse 6.4 keV Fe Kα emission

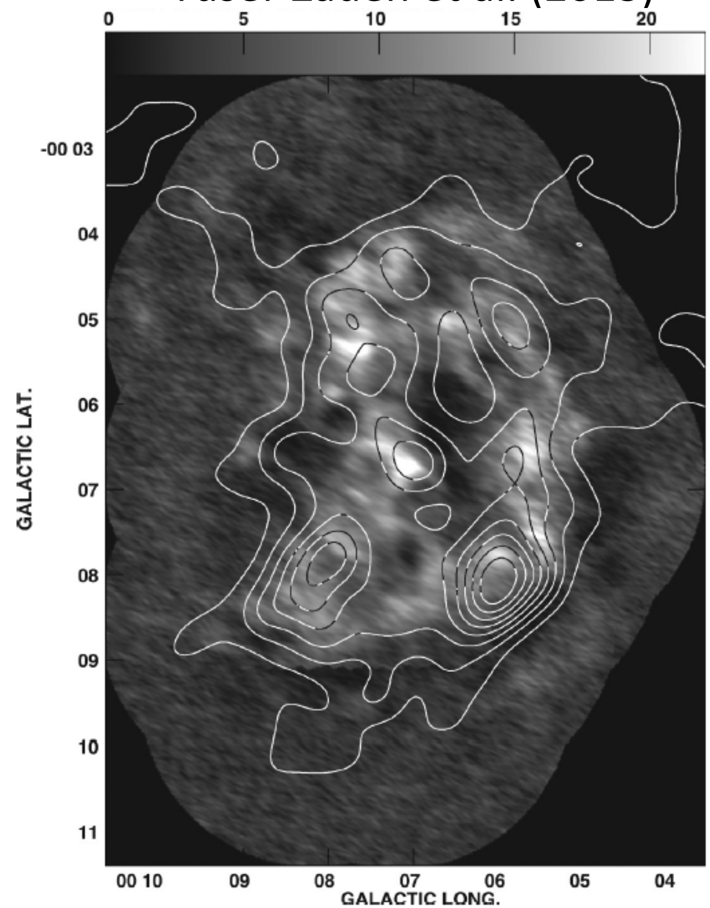
Yusef-Zadeh et al. (2007)





G0.13-0.13: Properties

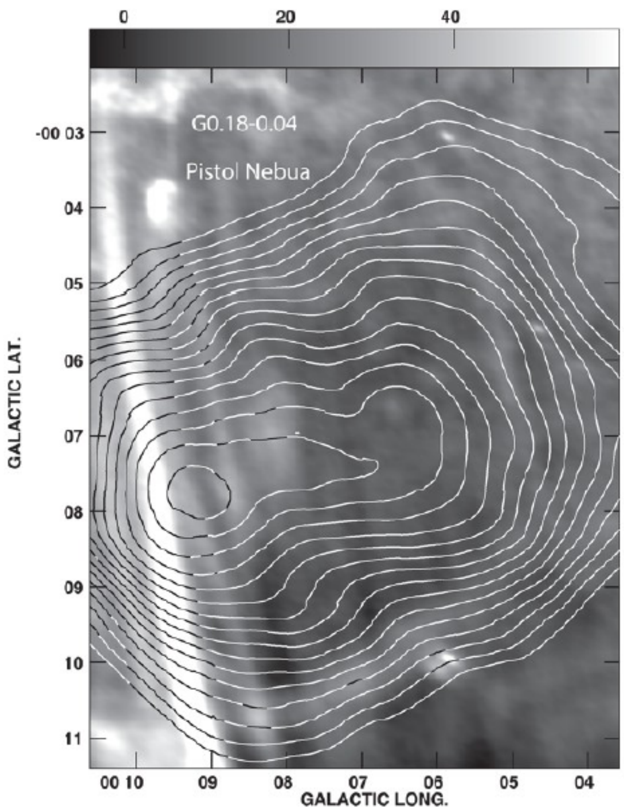
CS 2->1 contours over
6.4 keV Fe line emission
Yusef-Zadeh et al. (2013)



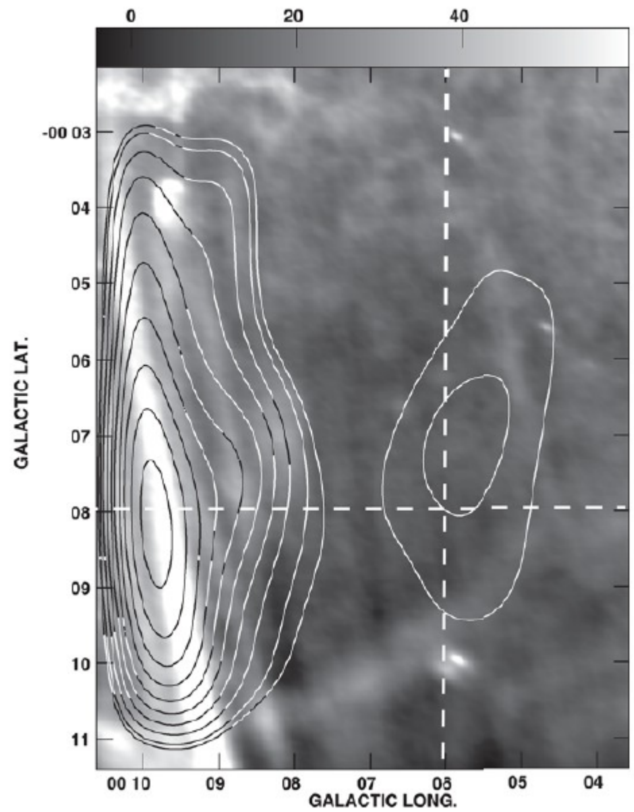
- Size: 7.5 pc (@ 8.5 kpc)
- $M = 6x10^5\ M_{sun}$
- $n(H_2) = 6x10^4\ cm^{-3}$
- $N(H_2) = (6\text{-}7)x10^{23}\ cm^{-3}$
- $\Delta v = 20$ km/s
- $(1/2)\rho(\Delta v)^2 \sim 10^{51}$ erg
- Possibly an expanding shell due to 10-100 supernovae.
- Possibly interacting with the Arc.

Low Energy Cosmic Ray Electrons

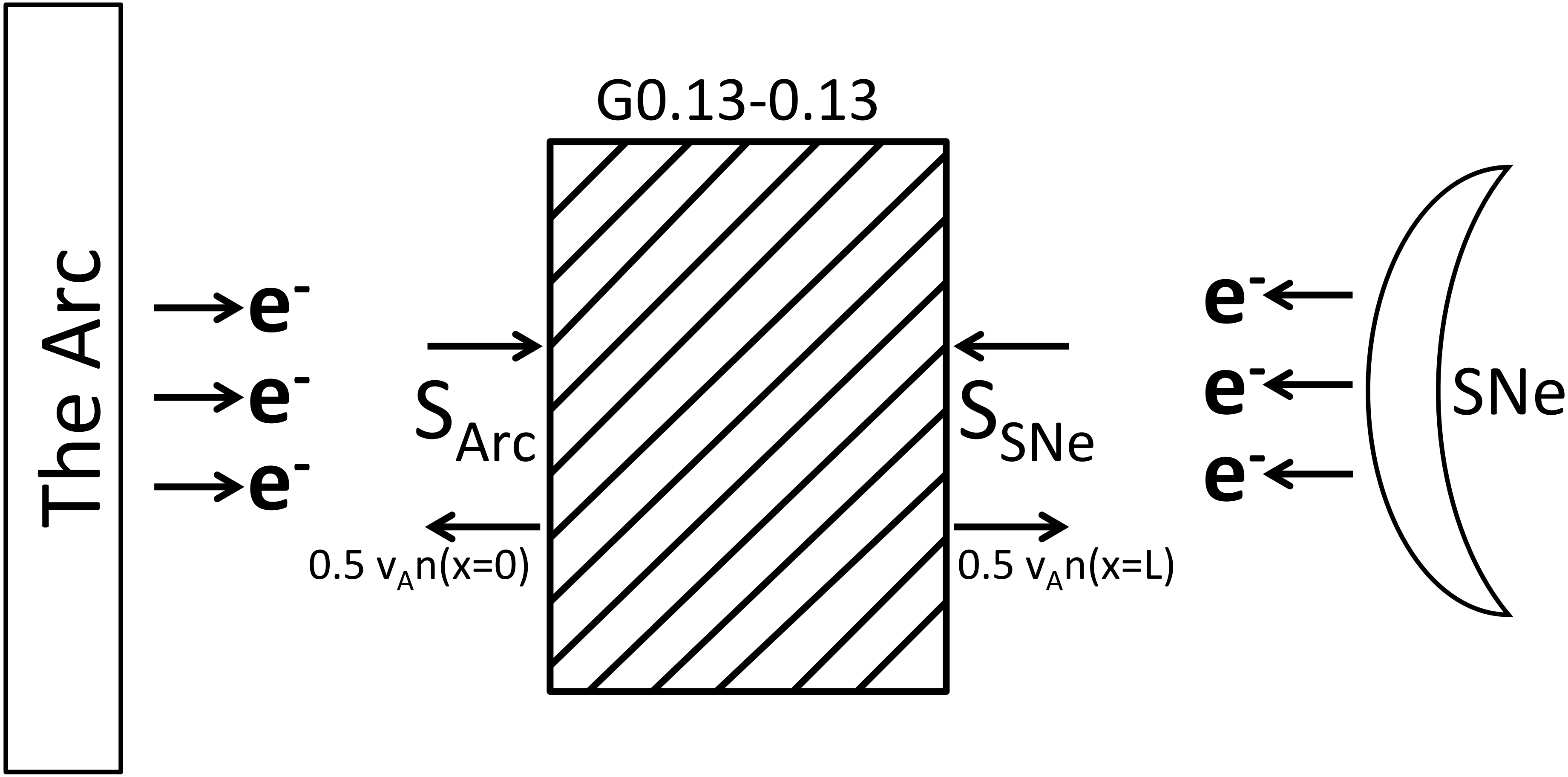
74 MHZ contours over
5 GHz continuum



327 MHZ contours over
5 GHz continuum



Synchrotron emission at these frequencies betrays the presence of low energy electrons.

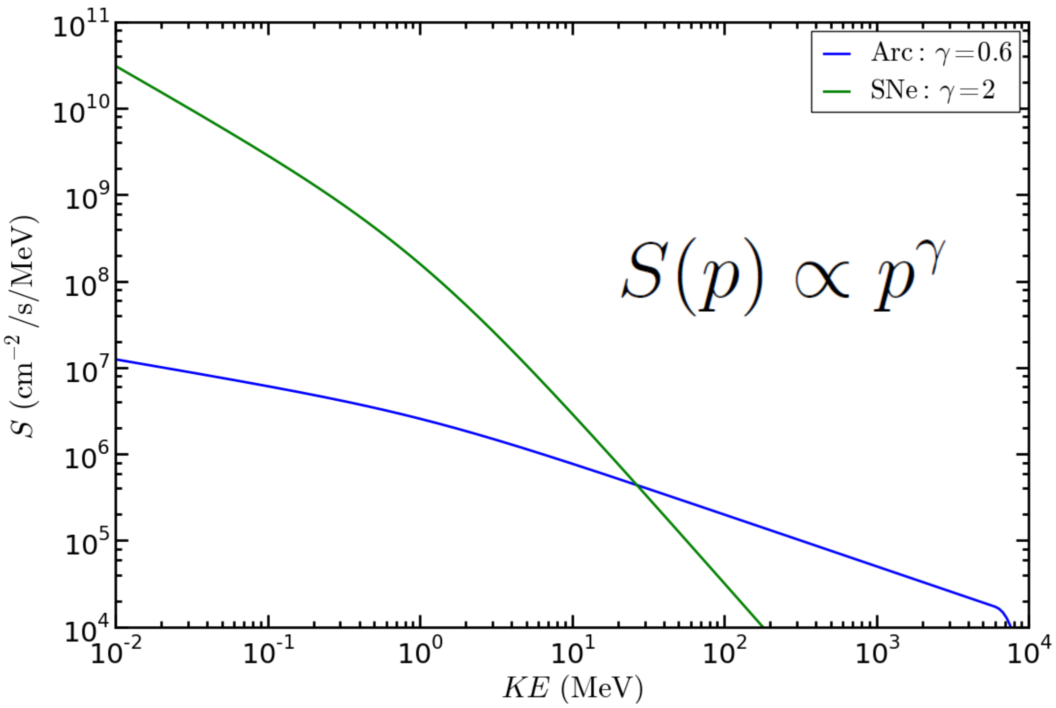


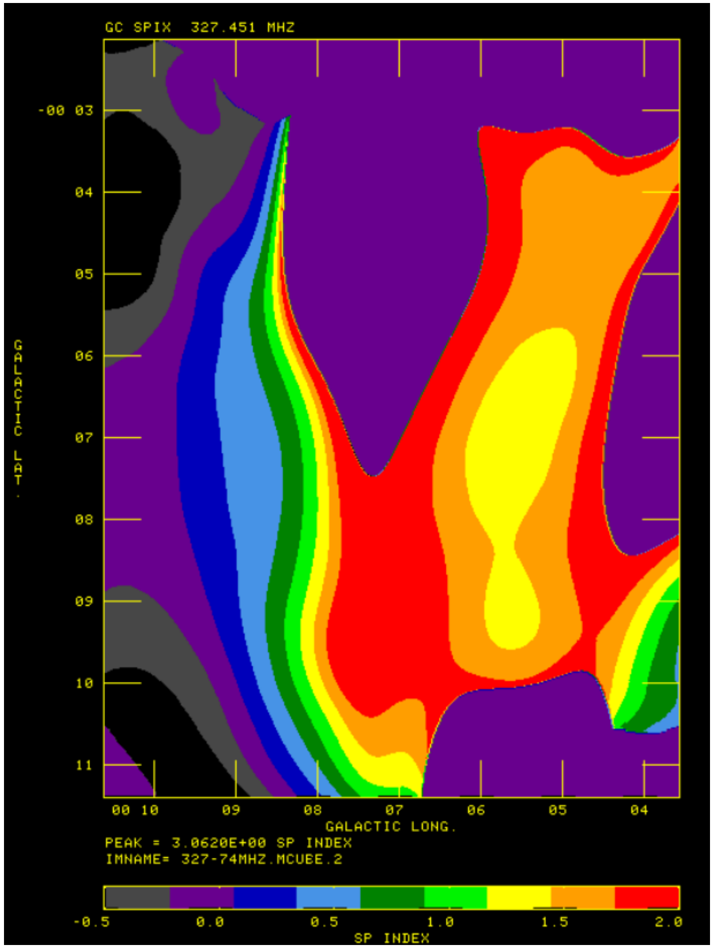
$$\partial_t n\left(x,p,t\right) = \kappa(p)\partial_x^2 n - \partial_p\left(\dot{p}n\right) + Q(x,p,t)$$

Source Flux

Yusef-Zadeh et al. (2013)

Observed spectral index used to create Arc source flux.

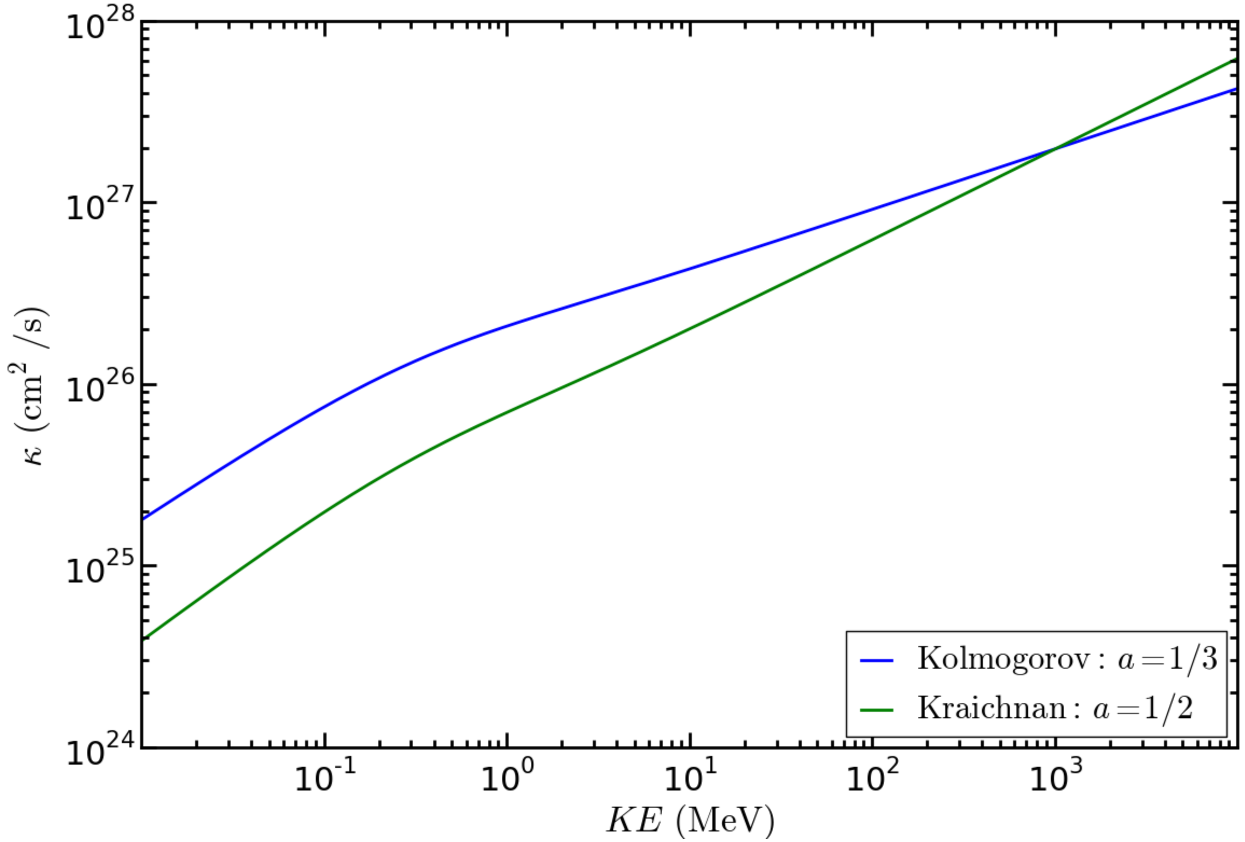




Diffusion Coefficient

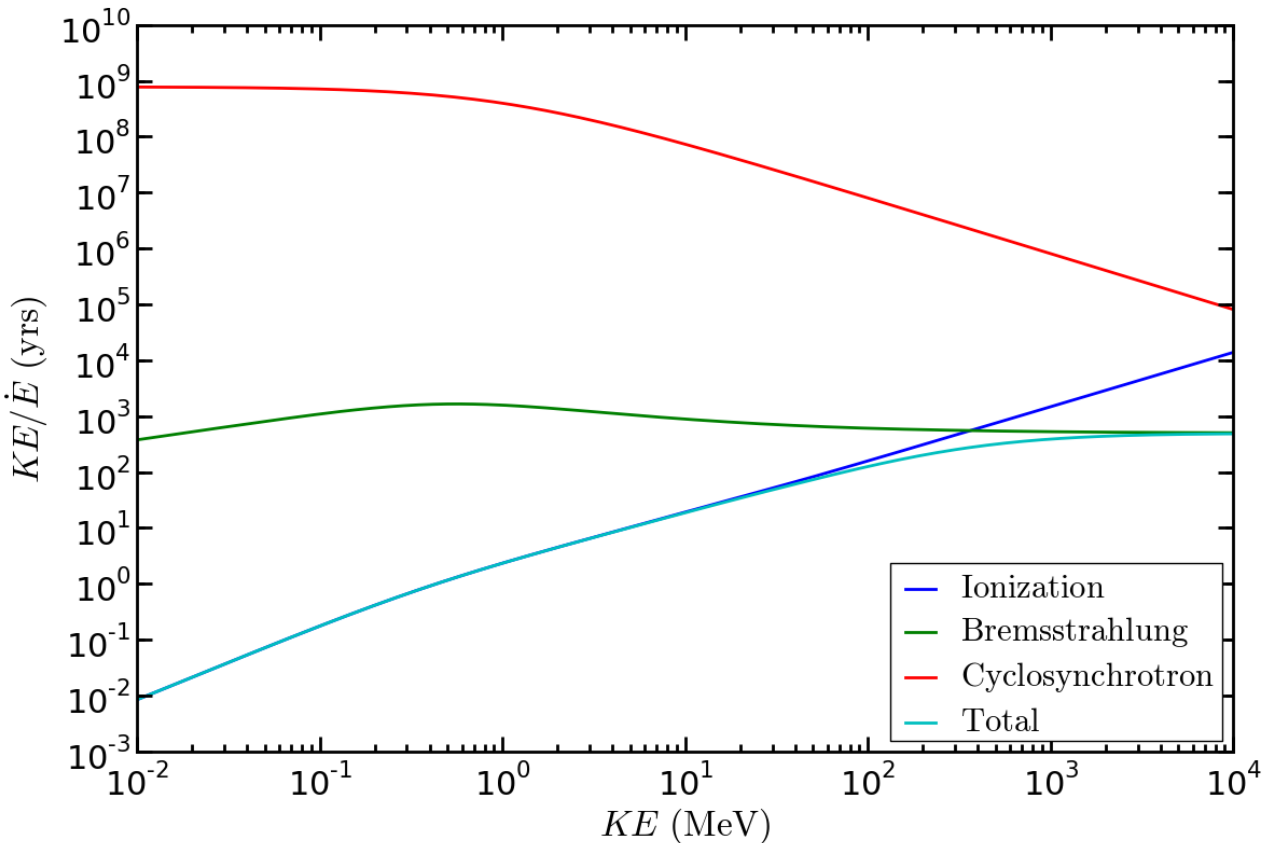
$$\kappa(p) = 2 \times 10^{27} \beta R_{GV}^{a} \, (\mathrm{cm}^2/\mathrm{s}) \qquad R = \frac{pc}{e}$$

Strong et al. (2007)

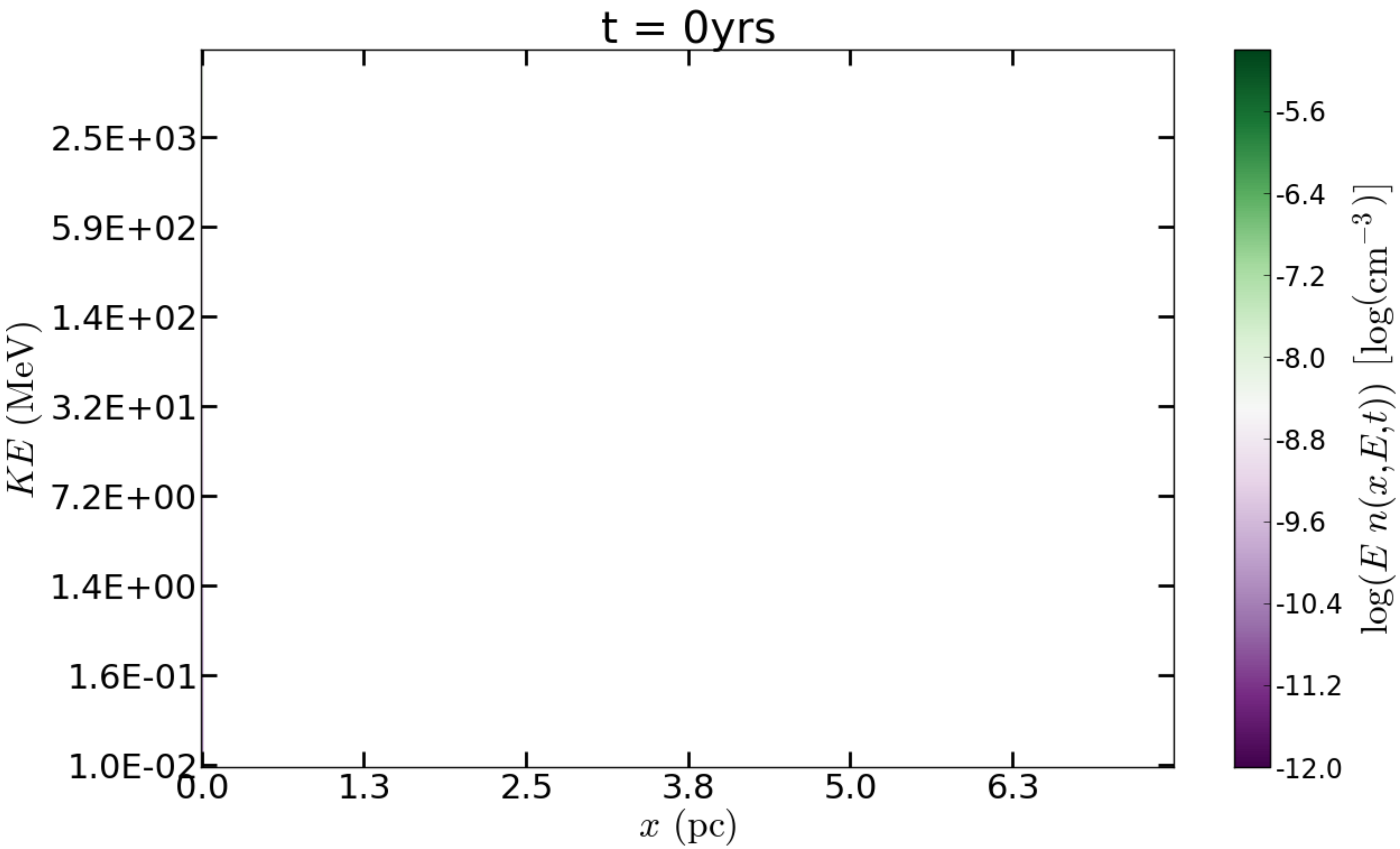


Losses

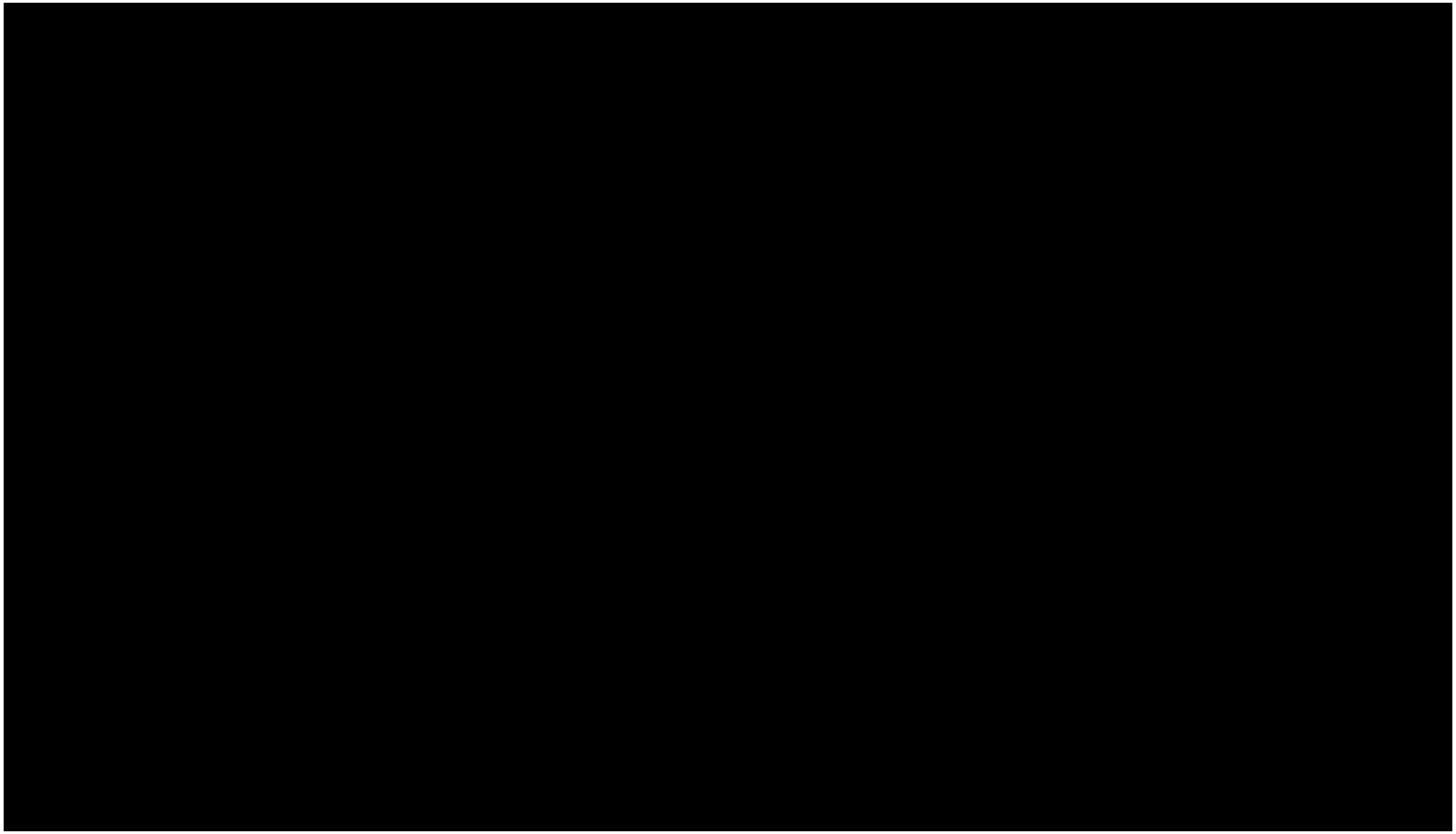
NIST Database for Stopping Power + Schlickeiser (2002)

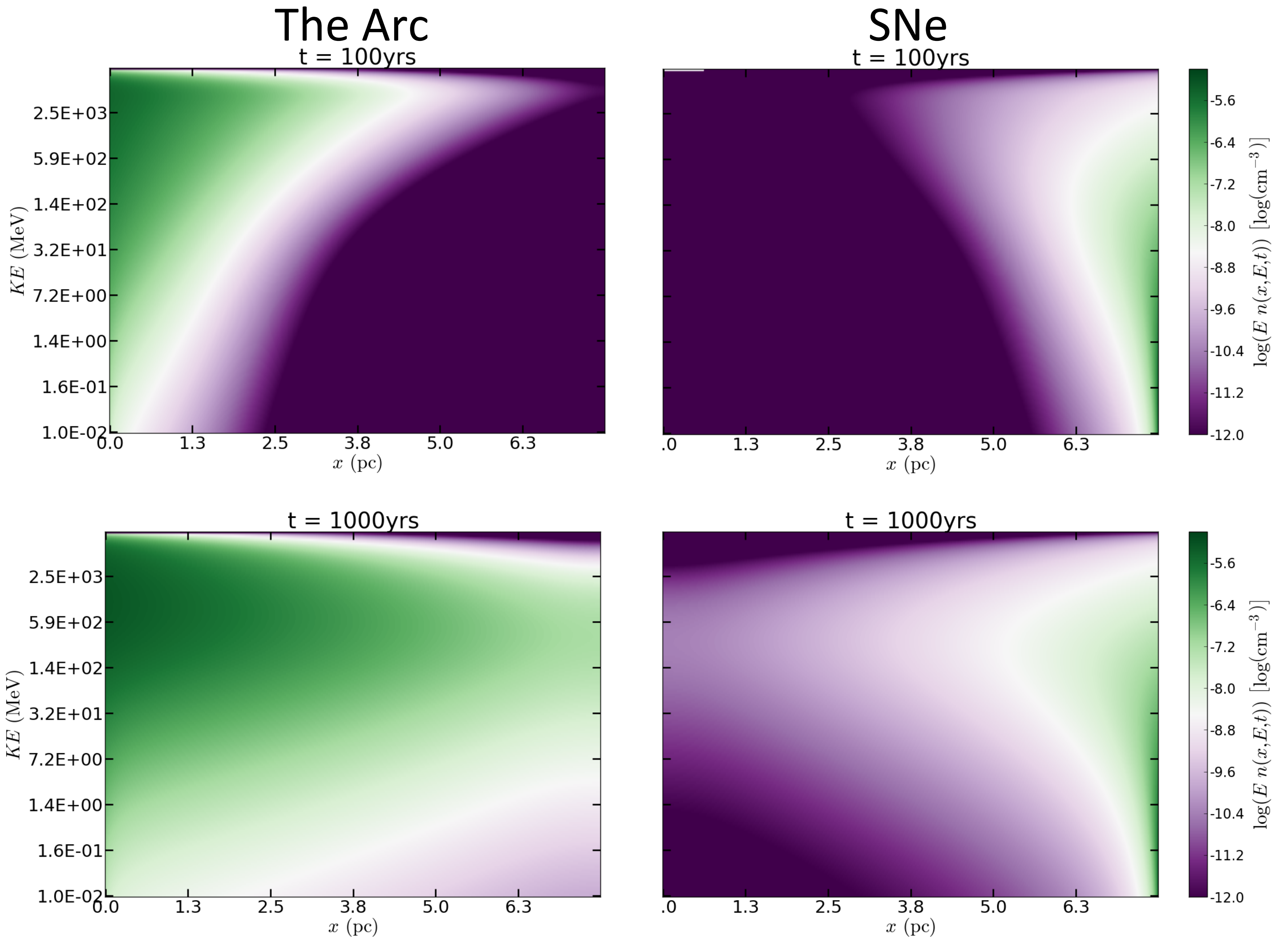


Results: Propagation



Results: Propagation





The Arc
SNe
t = 100yrs
t = 100yrs
t = 1000yrs
t = 1000yrs
KE (MeV)
x (pc)
2.5E+03
5.9E+02
1.4E+02
3.2E+01
7.2E+00
1.4E+00
1.6E-01
1.0E-02
0.0
1.3
2.5
3.8
5.0
6.3
$\log(E\, n(x,E,t))$ $[\log(\mathrm{cm}^{-3})]$
-5.6
-6.4
-7.2
-8.0
-8.8
-9.6
-10.4
-11.2
-12.0

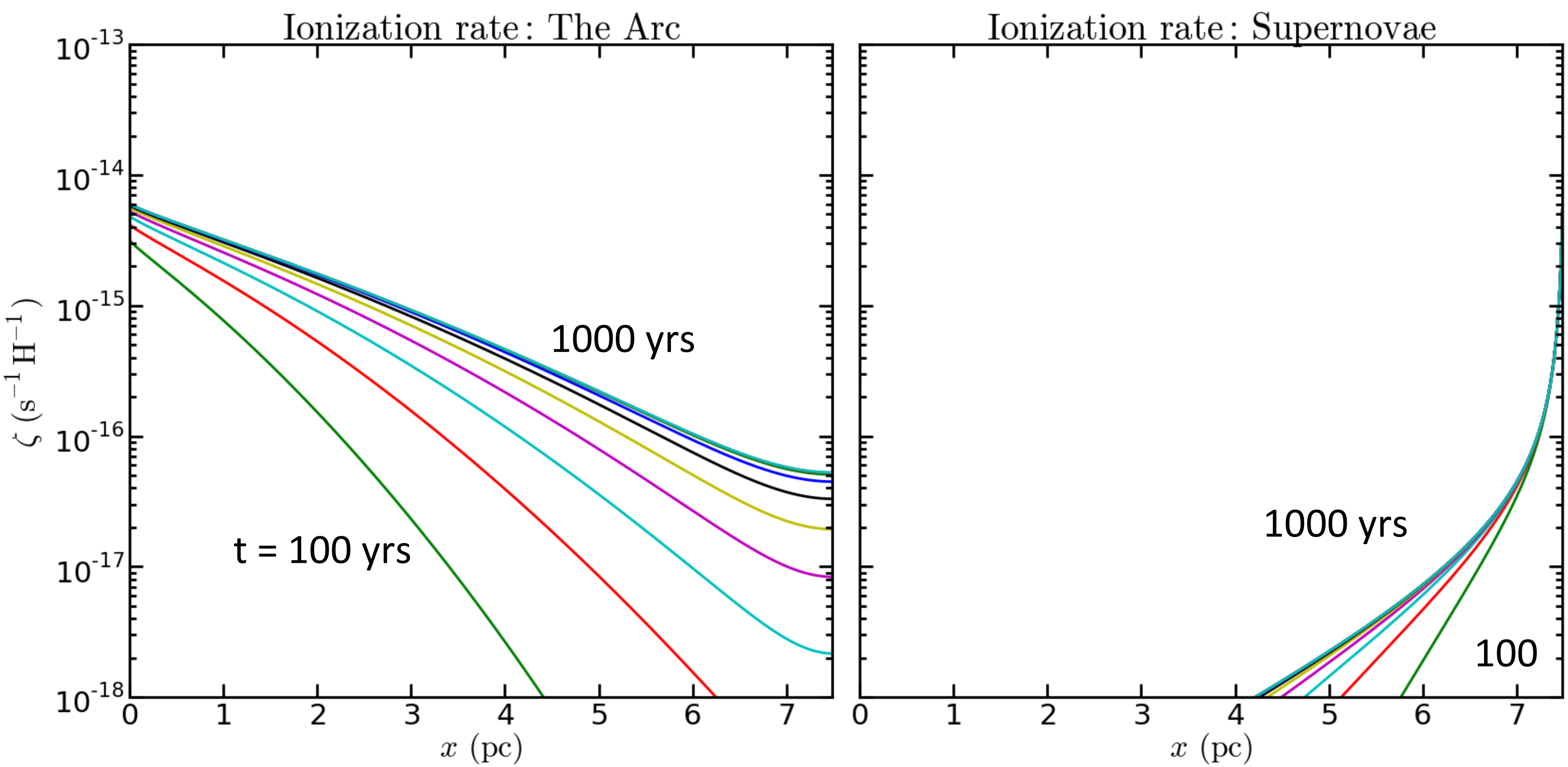
Applications

Ionization: $$\zeta_{CRe} = \frac{1}{(40.1\mathrm{eV})\, n_H} \int n(E)\dot{E} dE \quad (\mathrm{s}^{-1}\mathrm{H}^{-1})$$

Synchrotron: $$j_\nu \sim \frac{\sqrt{3}}{4\pi} \frac{e^3 B \sin\theta}{m_e c^2} E_\nu n(E_\nu) \quad (\mathrm{erg/s/Hz/sr/cm^3})$$

Fe Kα: $$q_{K\alpha} = \frac{n(\mathrm{Fe})}{n(\mathrm{H})} \omega_K f_K \int c\beta\sigma_K(E) n(E) dE \quad (\mathrm{ph/s/H})$$

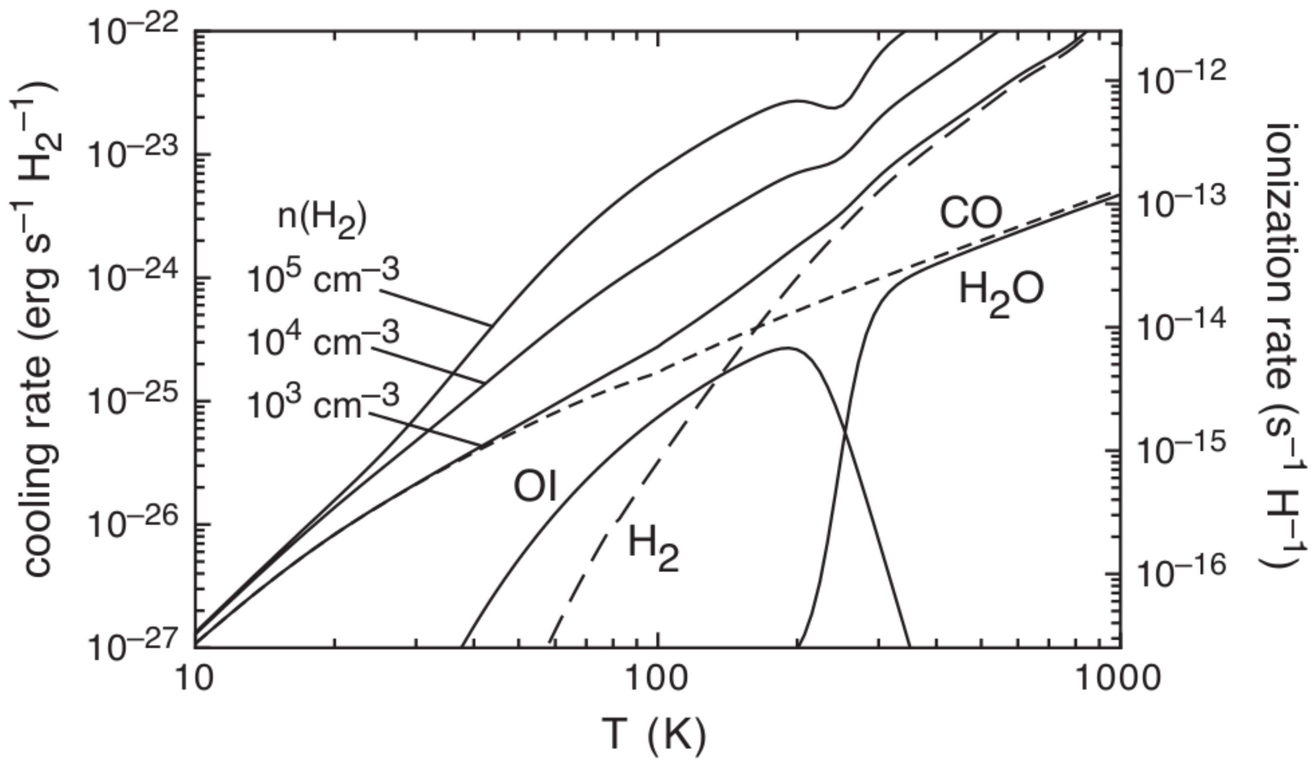
Ionization Rate



- The Arc electrons ionize the whole cloud
- SNe electrons do not penetrate very far

Heating Rate

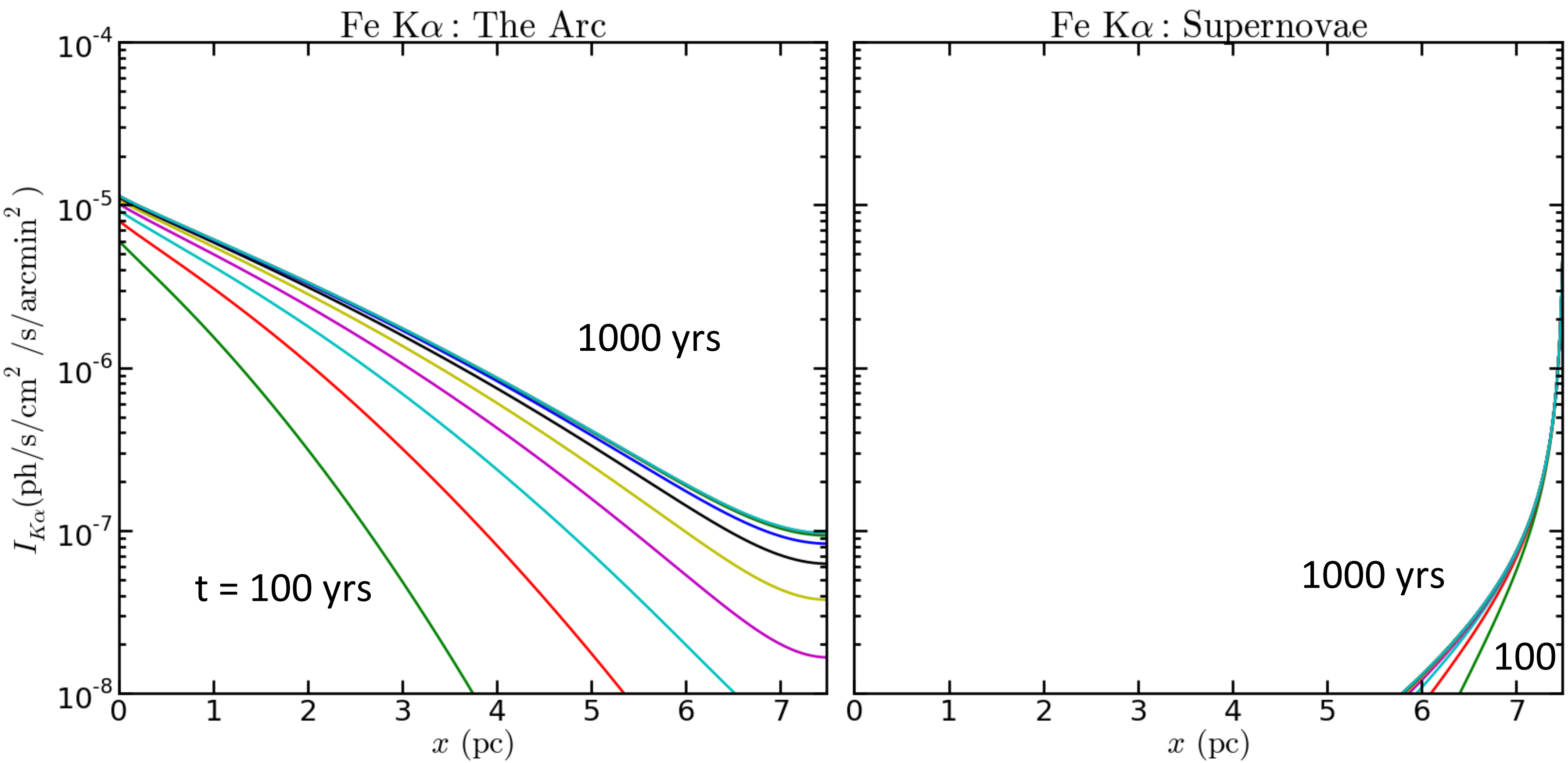
12.4 eV of energy goes into heat for each ionization event.



Yusef-Zadeh et al. (2013)

Ionization rate between 10^{-15} and 10^{-14} s^{-1} H^{-1} leads to temperatures between 30-60 K.

Fe Kα Emission



- The Arc: comparable Kα emission to observations
- SNe: Kα emission only from a small region

Future Work

Observables:
- Bremsstrahlung emission
- SiO abundances

Source:
- Time dependent source
- Source embedded in cloud

Realism:
- Clumpy density structure
- More dimensions

Extensions:
- Analyse other clouds in the CMZ

Summary

- Developed time dependent diffusion code that computes n(x,p,t) through a slab of molecular gas.

- n(x,p,t) can be used to compute the ionization rate, synchrotron emission and 6.4 keV Fe emission as functions of position and time.

- The ionization rate can be used to determine heating and is consistent with observed values.

- Flexible sources, diffusion coefficient, densities, magnetic field strengths.