Is molecular gas necessary for star formation?

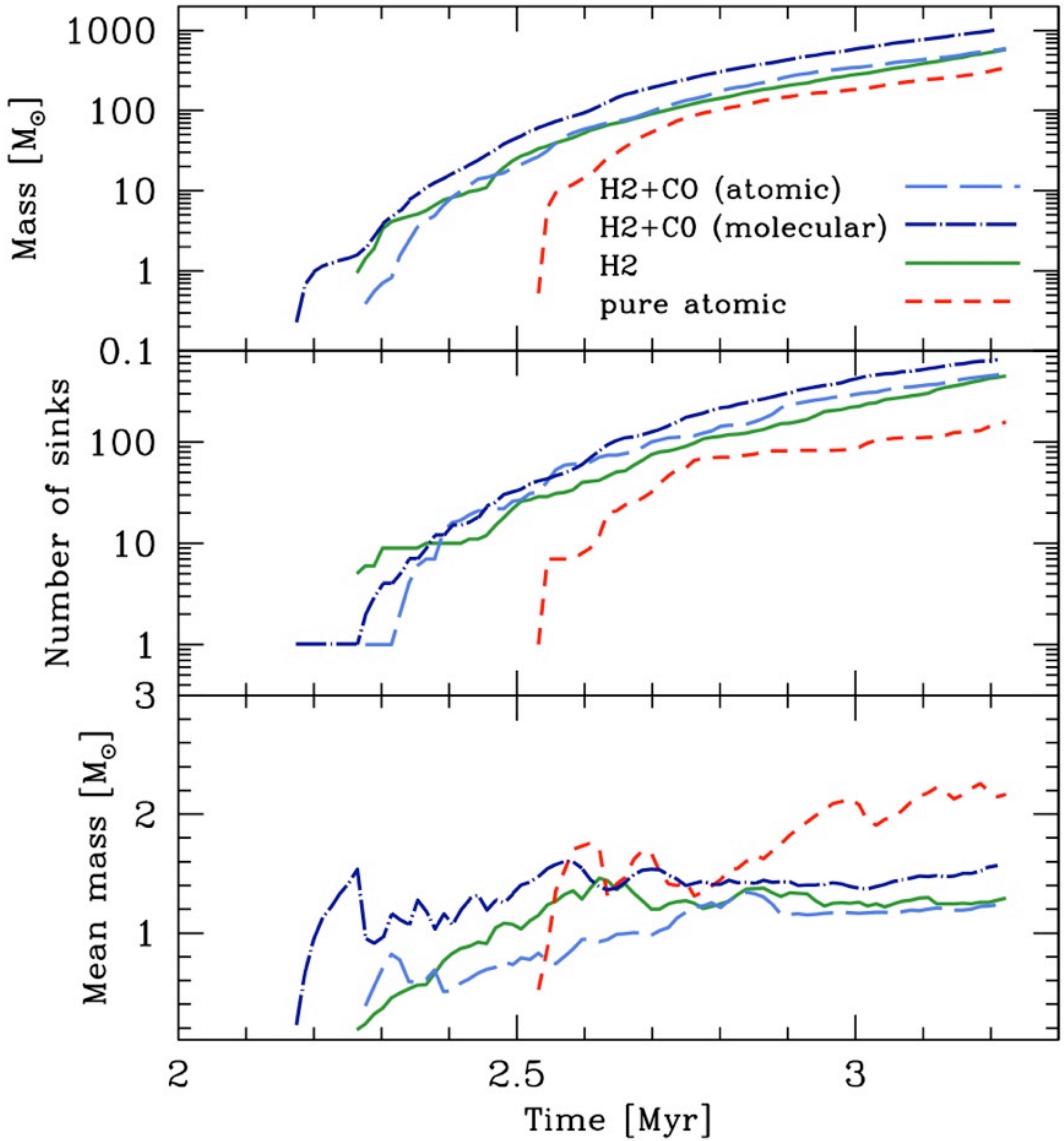
Simon Glover & Paul Clark

- Good evidence that molecular gas and star formation are correlated in local galaxies
- An obvious hypothesis is that you need molecular gas in order to form stars.
- But why should this be the case? At typical GMC temperatures, H_2 provides no cooling
- Perhaps CO cooling is the vital ingredient?
- Alternatively, perhaps the hypothesis is wrong...

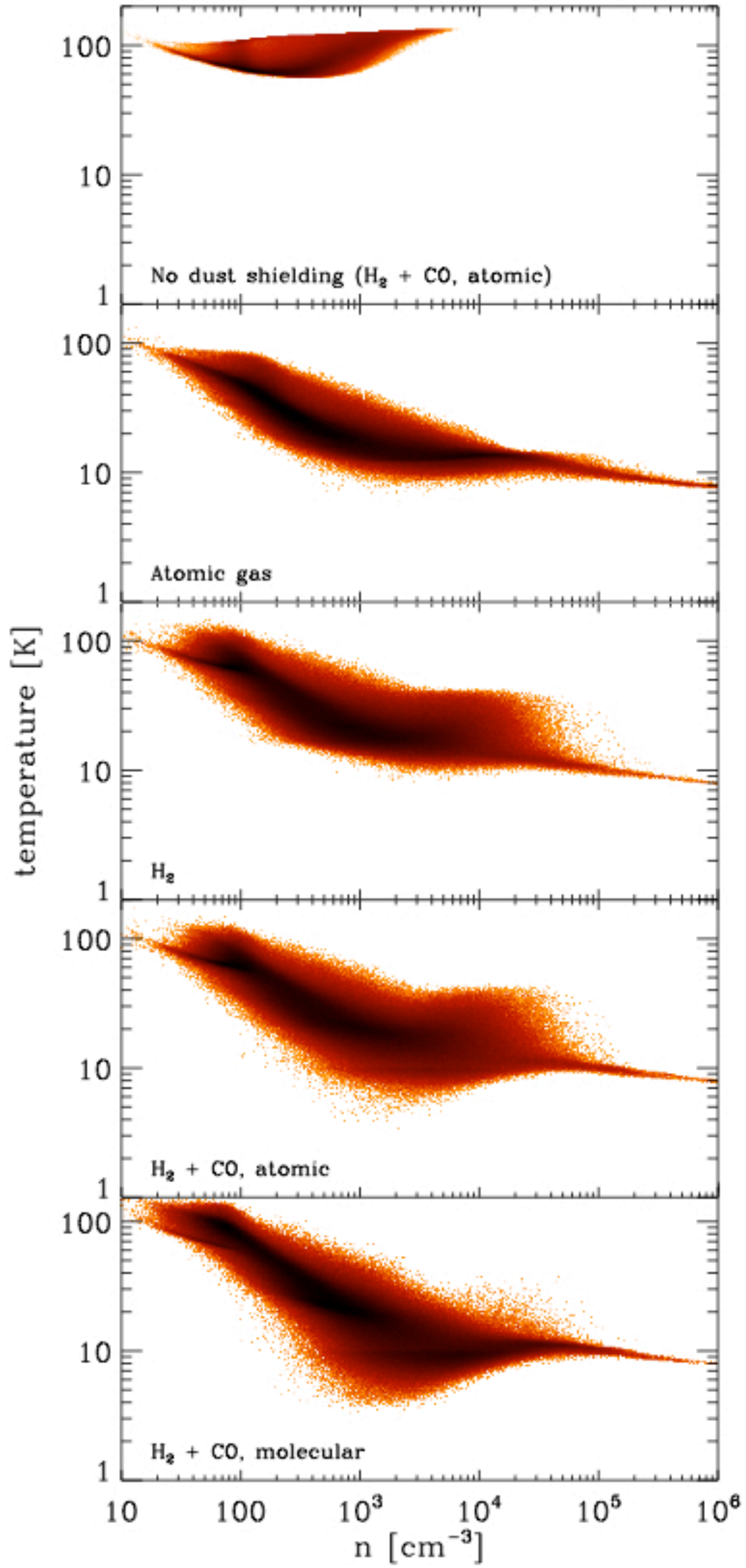
- In order to form stars, we need lots of cold, dense gas
- Clouds of cold, dense gas are also good places to form molecules
- This suggests that the correlation between molecular gas and star formation may be a coincidence
- We decided to test this idea with the help of numerical simulations

- Use detailed atomic/molecular cooling function, simplified chemistry
- Column densities for H_2 self-shielding, dust shielding determined using our new TreeCol algorithm (see Clark, Glover & Klessen 2012)
- Create sink particles at $n > 10^7$ cm^{-3}

- 5 different simulations:
  - no shielding
  - no chemistry, gas remains atomic
  - H_2 chemistry, but no CO
  - H_2 and CO chemistry, hydrogen initially atomic
  - H_2 and CO chemistry, hydrogen initially molecular



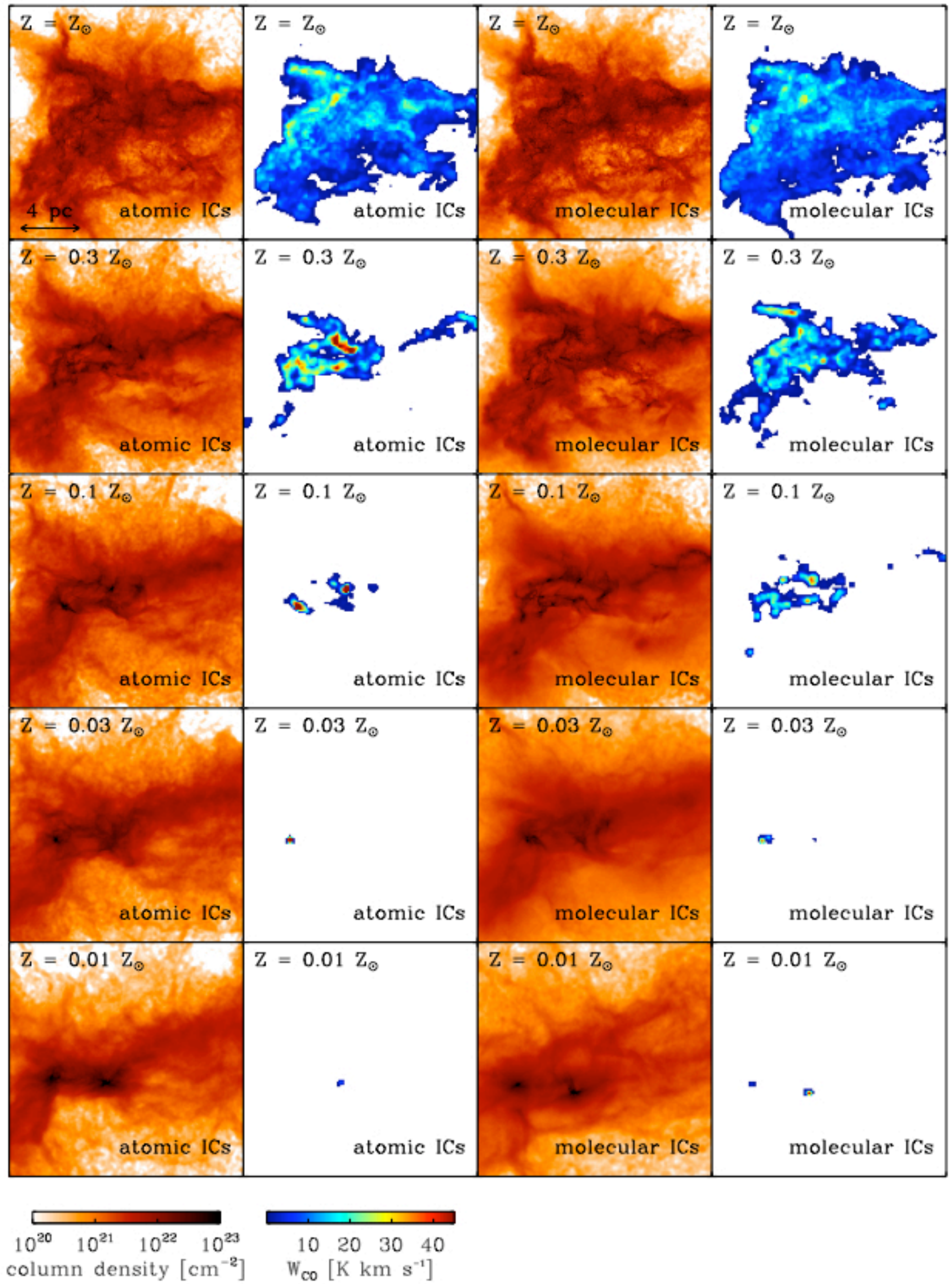
Glover & Clark (2012a, MNRAS, 421, 9)



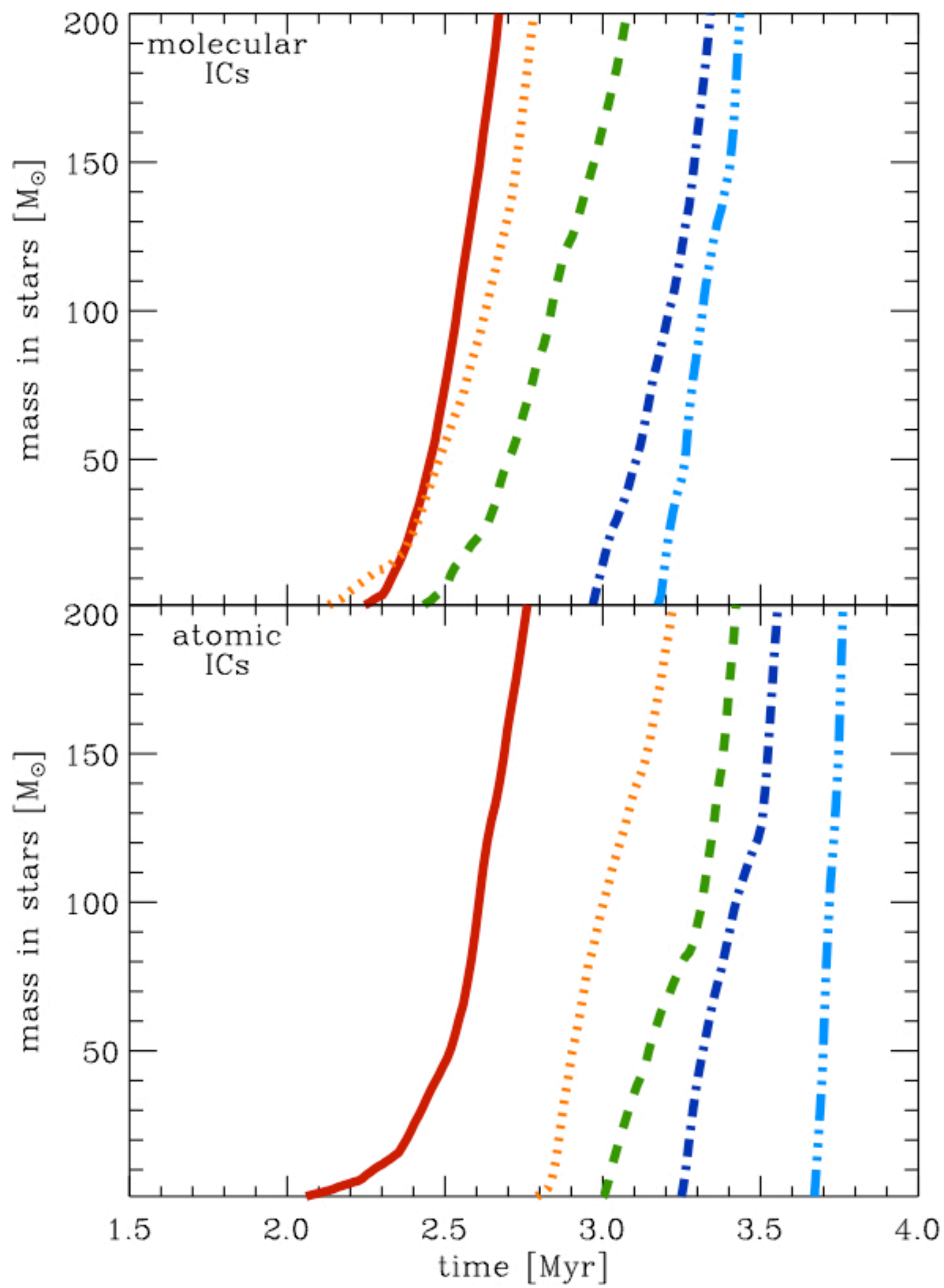
Glover & Clark 2012a

- Presence of molecular gas has only very minor influence on ability of cloud to form stars
- On the other hand, ability of cloud to shield itself from interstellar radiation field (ISRF) appears to be crucial
- But clouds that are big/dense enough to shield themselves will be molecular!
- Suggests that the correlation between H_2 and star formation in local galaxies is a coincidence

- This study artificially switched-off the molecules, which obvious doesn’t happen in reality
- Are there real systems where we might expect star formation without (much) molecular gas?
- Yes! We just need to look at low metallicity star forming regions...



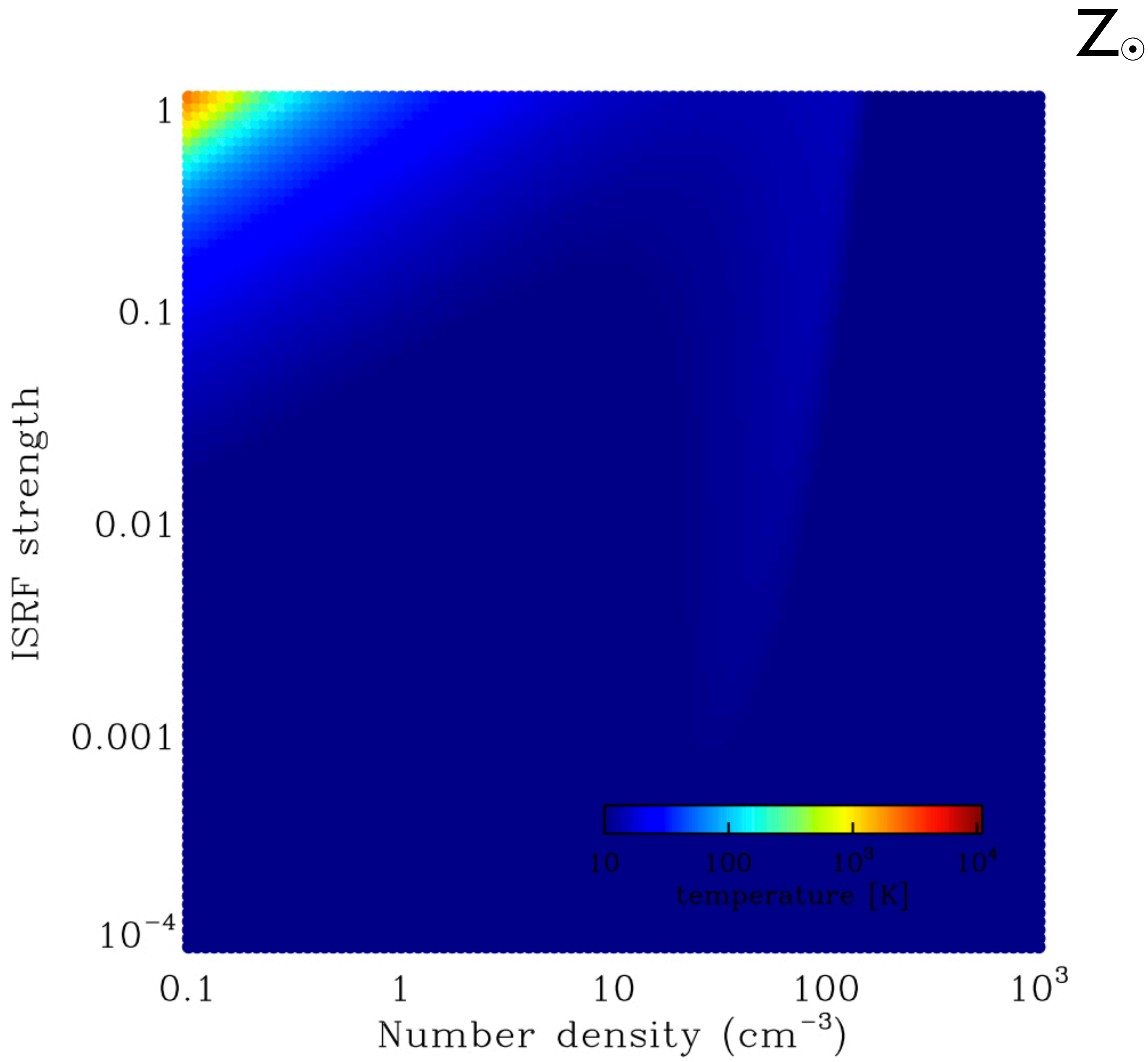
Glover & Clark (2012b, MNRAS, 426, 377)



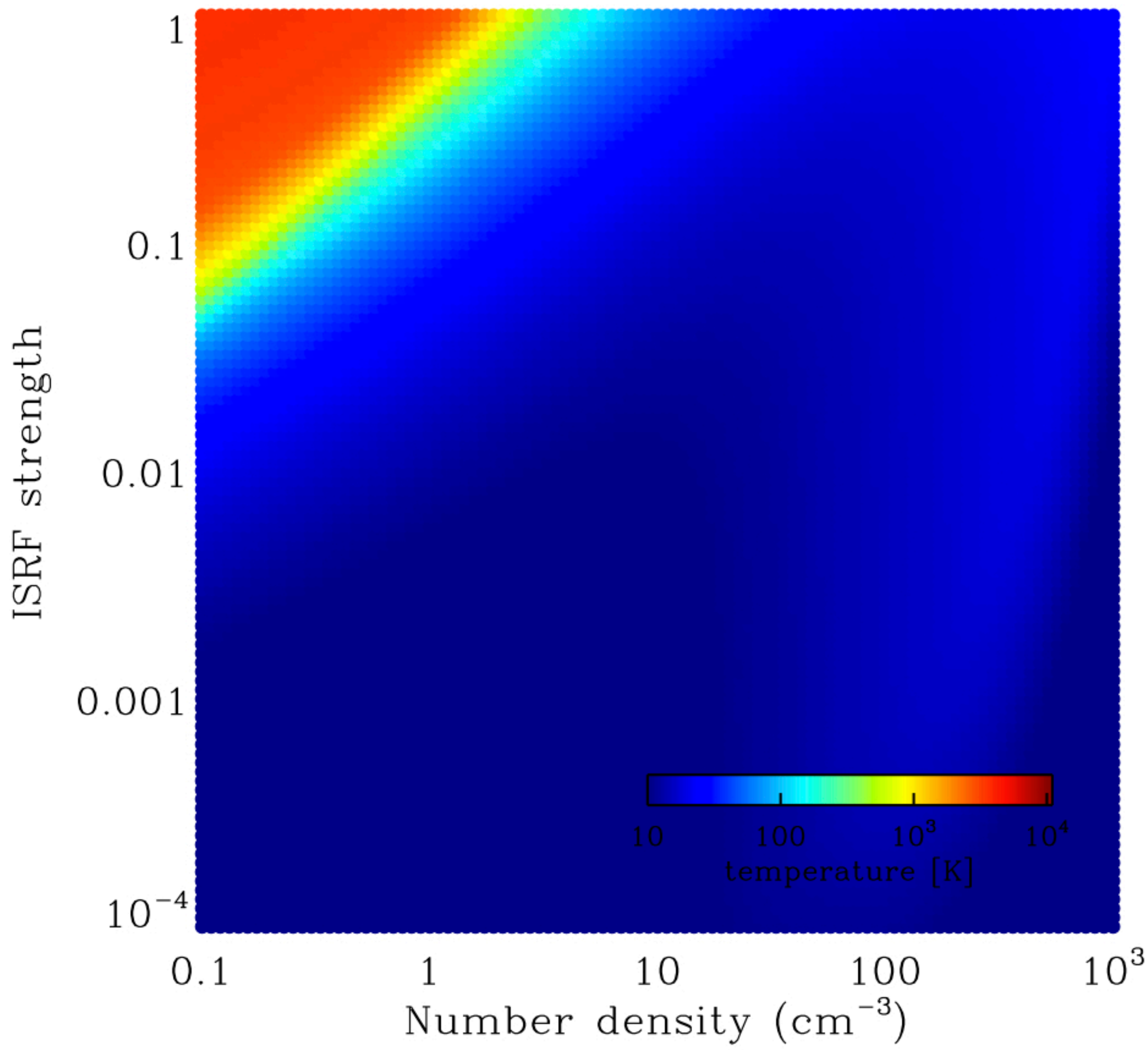
Glover & Clark 2012b

- So far, we've only been considering dense clouds. Perhaps we need H_2 in order to form these clouds?
- To test this idea, we perform some simple one-zone models.
- Gas initially fully ionized, T = 10000 K. Follow cooling for one free-fall time, determine final temperature.
- Models take very little time to run, so we can explore wide range of density, UV field strength, metallicity

No molecular hydrogen

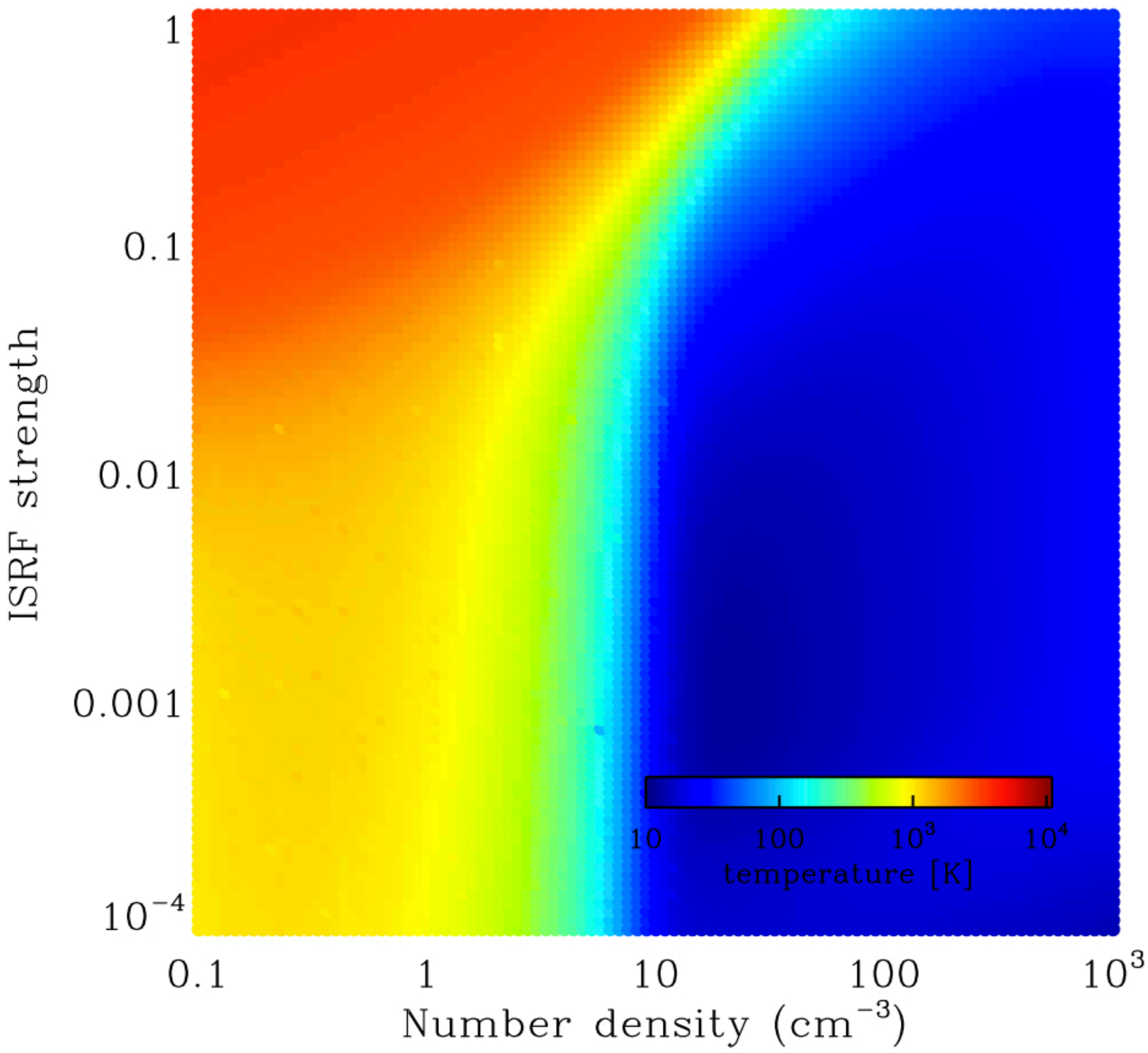

Z⊙
1
0.1
0.01
0.001
10^-4
ISRF strength
0.1
1
10
100
10^3
Number density (cm^-3)
10
100
10^3
10^4
temperature [K]

$0.1\ Z_\odot$

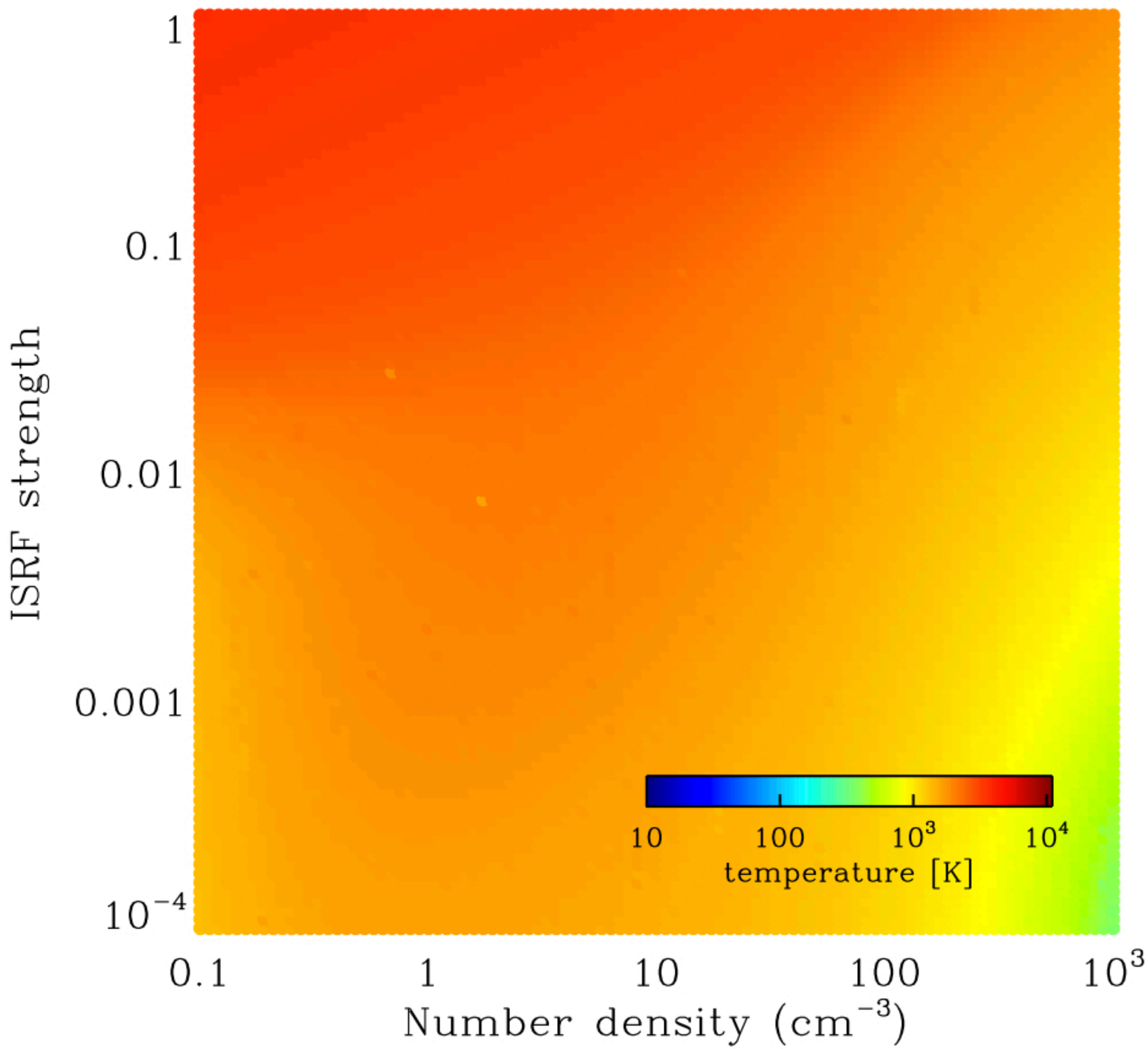


1
0.1
0.01
0.001
10^{-4}
ISRF strength
0.1
1
10
100
10^{3}
Number density (cm^{-3})
10
100
10^{3}
10^{4}
temperature [K]

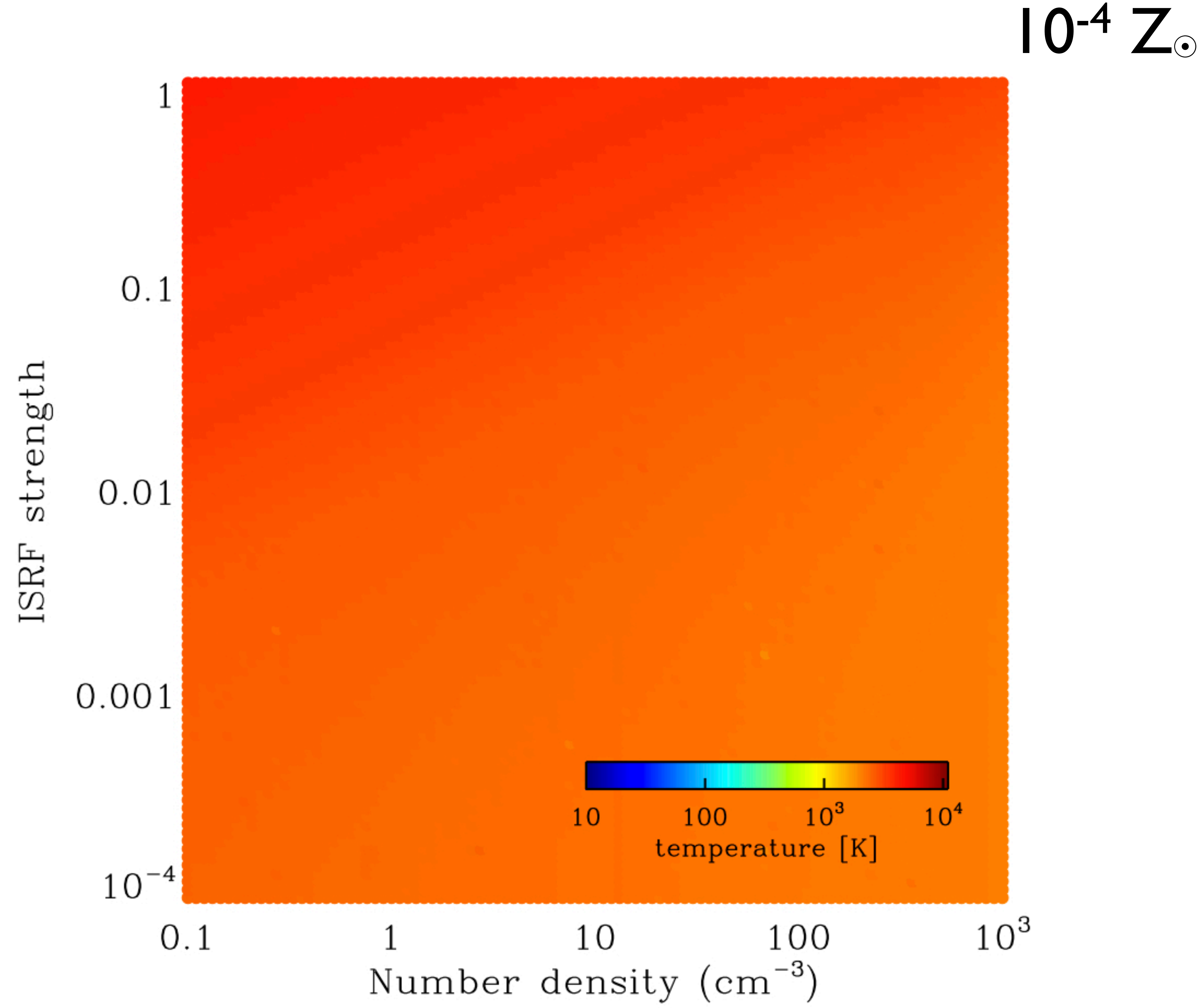
$10^{-2}\ Z_\odot$


ISRF strength
1
0.1
0.01
0.001
10^-4
0.1
1
10
100
10^3
Number density (cm^-3)
10
100
10^3
10^4
temperature [K]

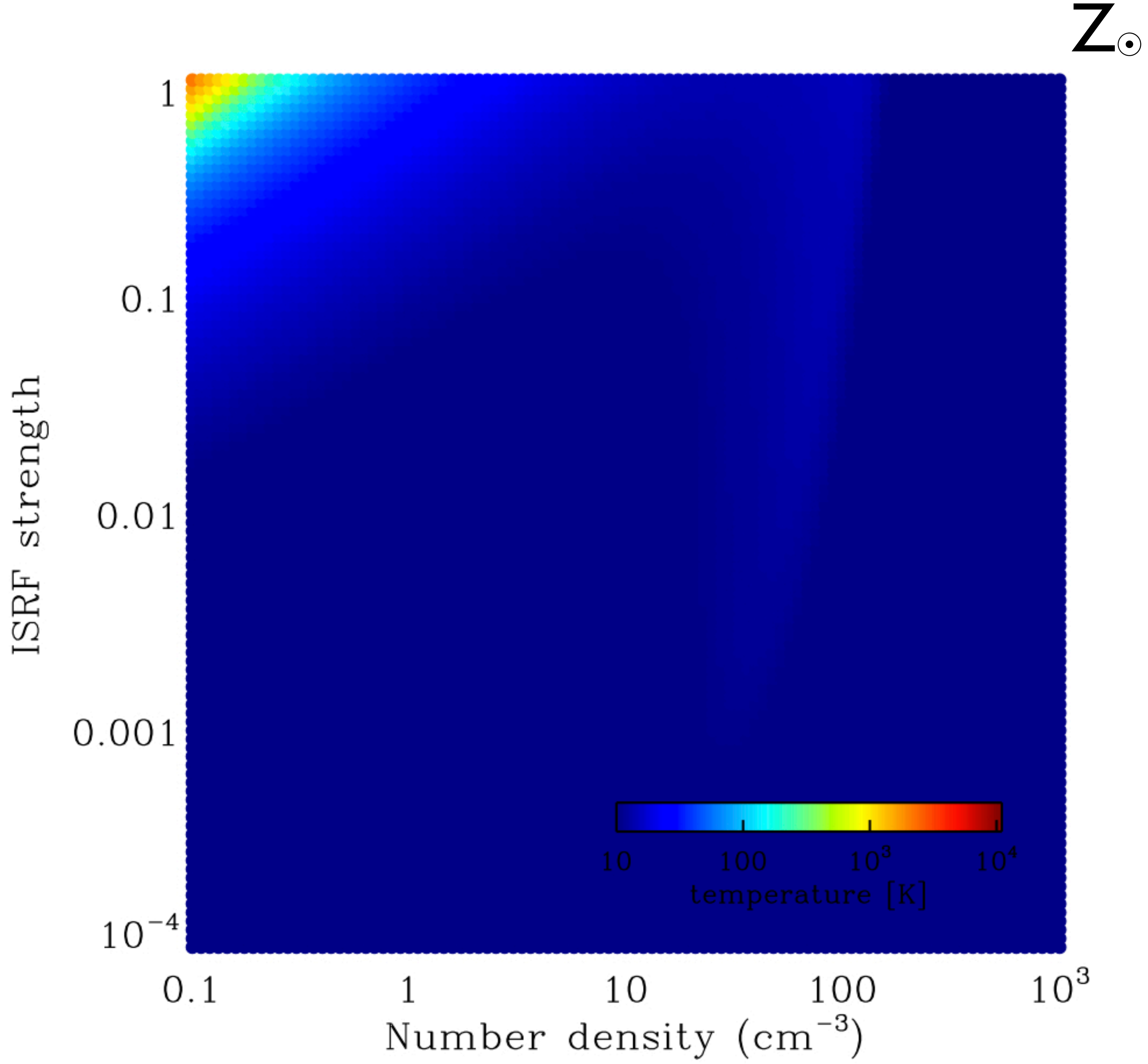
$10^{-3}\ Z_\odot$



1
0.1
0.01
0.001
10^−4
ISRF strength
0.1
1
10
100
10^3
Number density (cm^−3)
10
100
10^3
10^4
temperature [K]

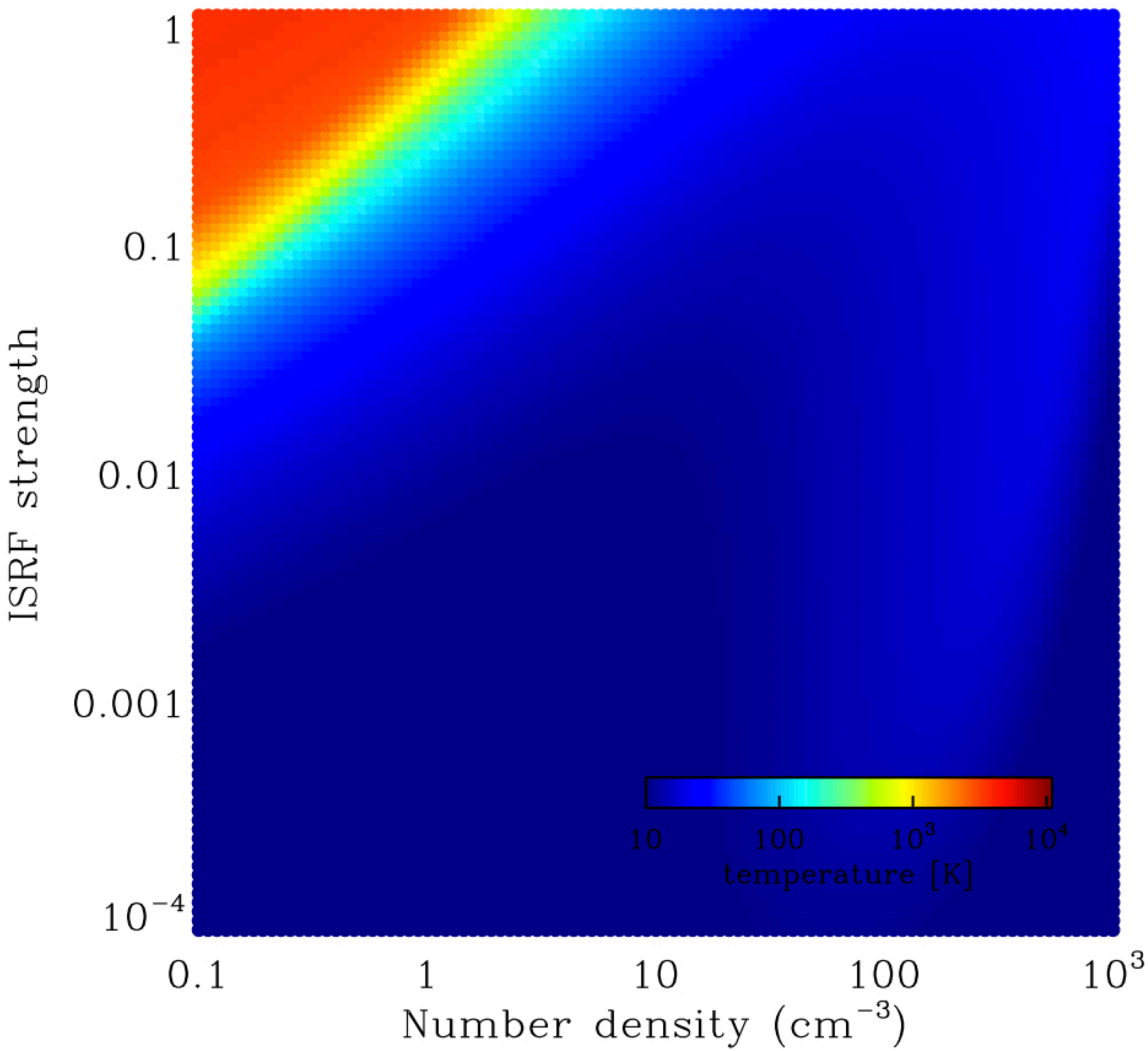

10-4 Z☉
1
0.1
0.01
0.001
10−4
ISRF strength
0.1
1
10
100
10³
Number density (cm−3)
10
100
10³
10⁴
temperature [K]

With molecular hydrogen



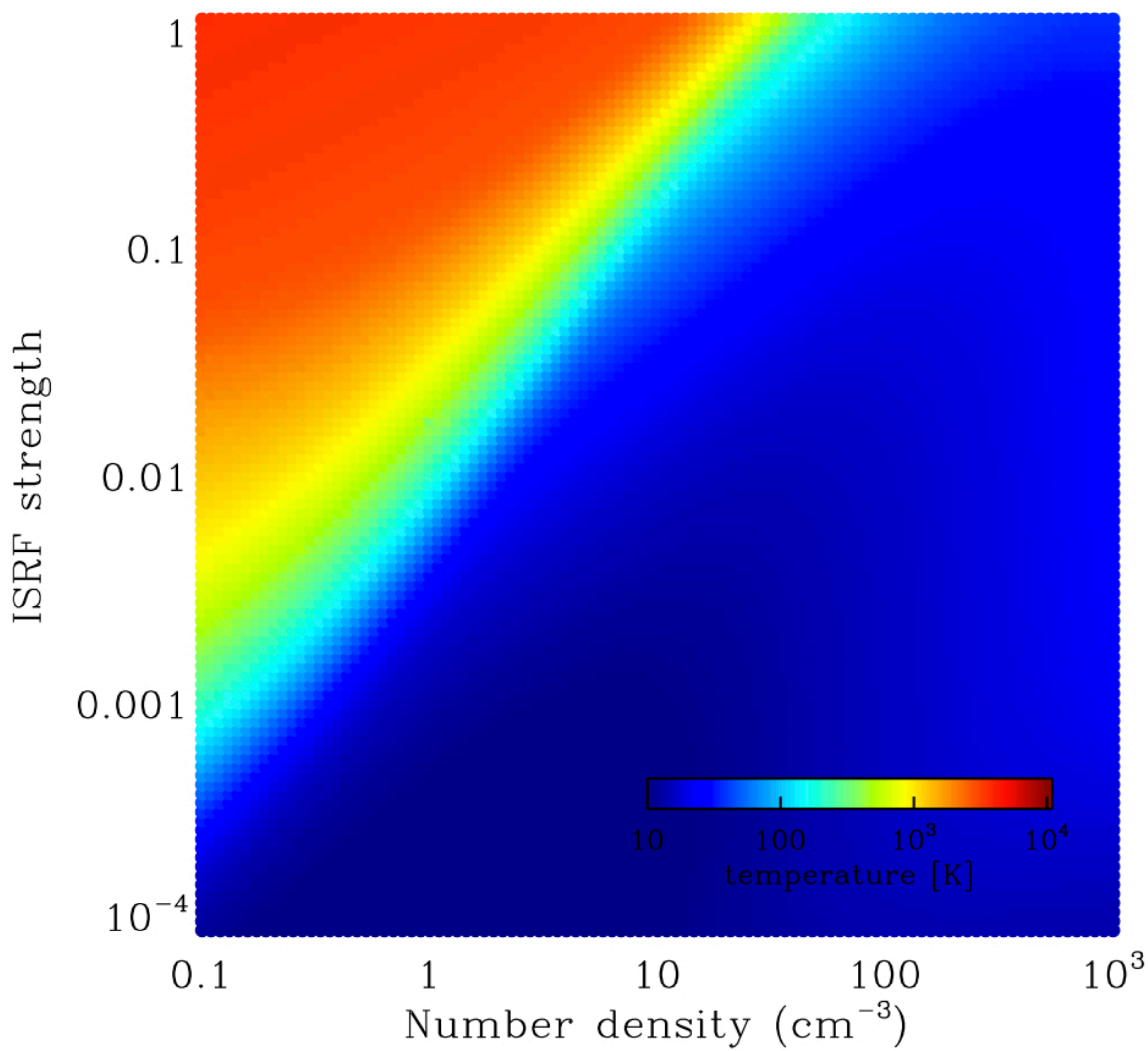
Z$_\odot$
1
0.1
0.01
0.001
10^{-4}
ISRF strength
0.1
1
10
100
10^3
Number density (cm^{-3})
10
100
10^3
10^4
temperature [K]

$0.1\ Z_\odot$

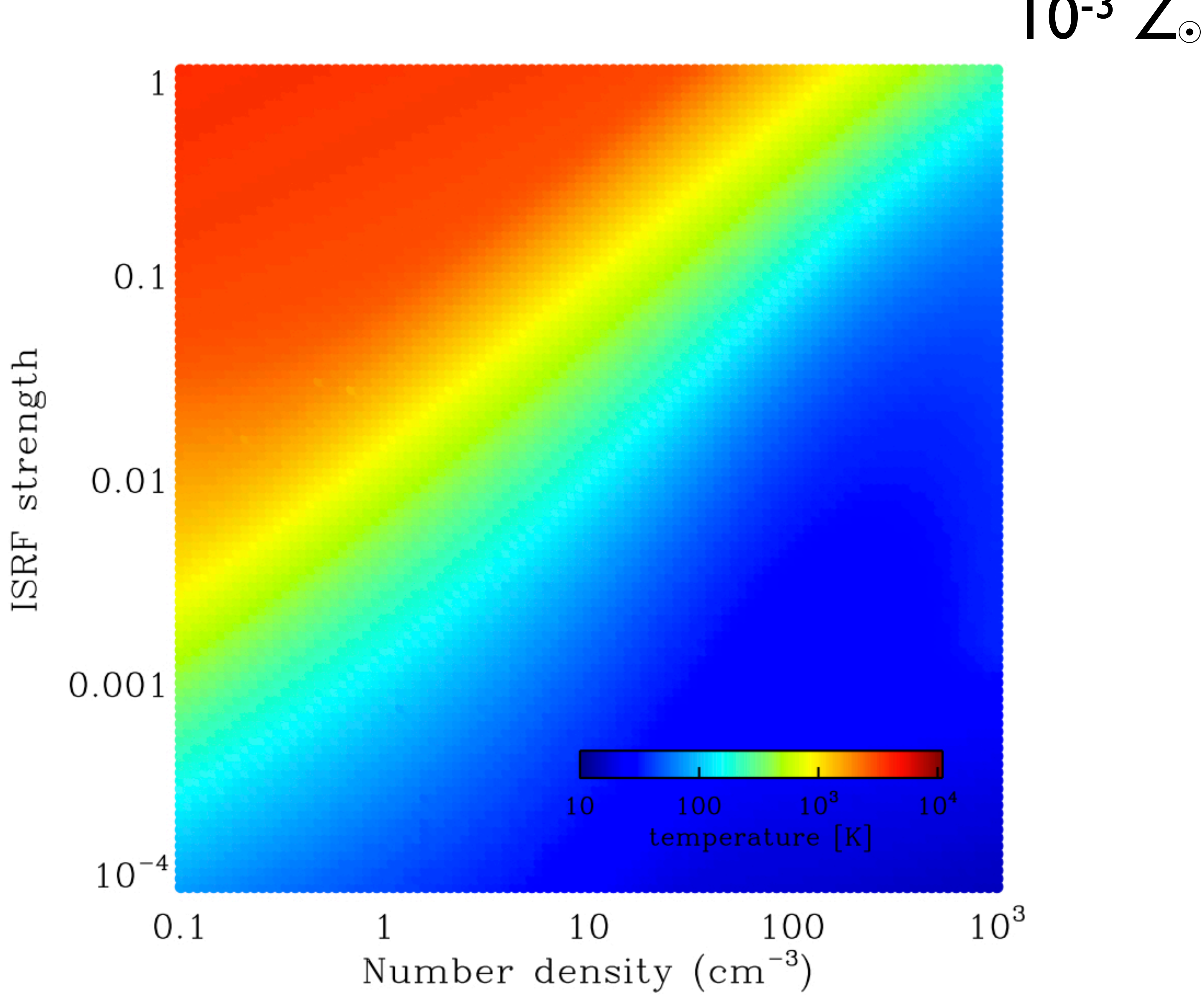


ISRF strength
1
0.1
0.01
0.001
10^-4
Number density (cm^-3)
0.1
1
10
100
10^3
10
100
10^3
10^4
temperature [K]

$10^{-2}\ Z_\odot$

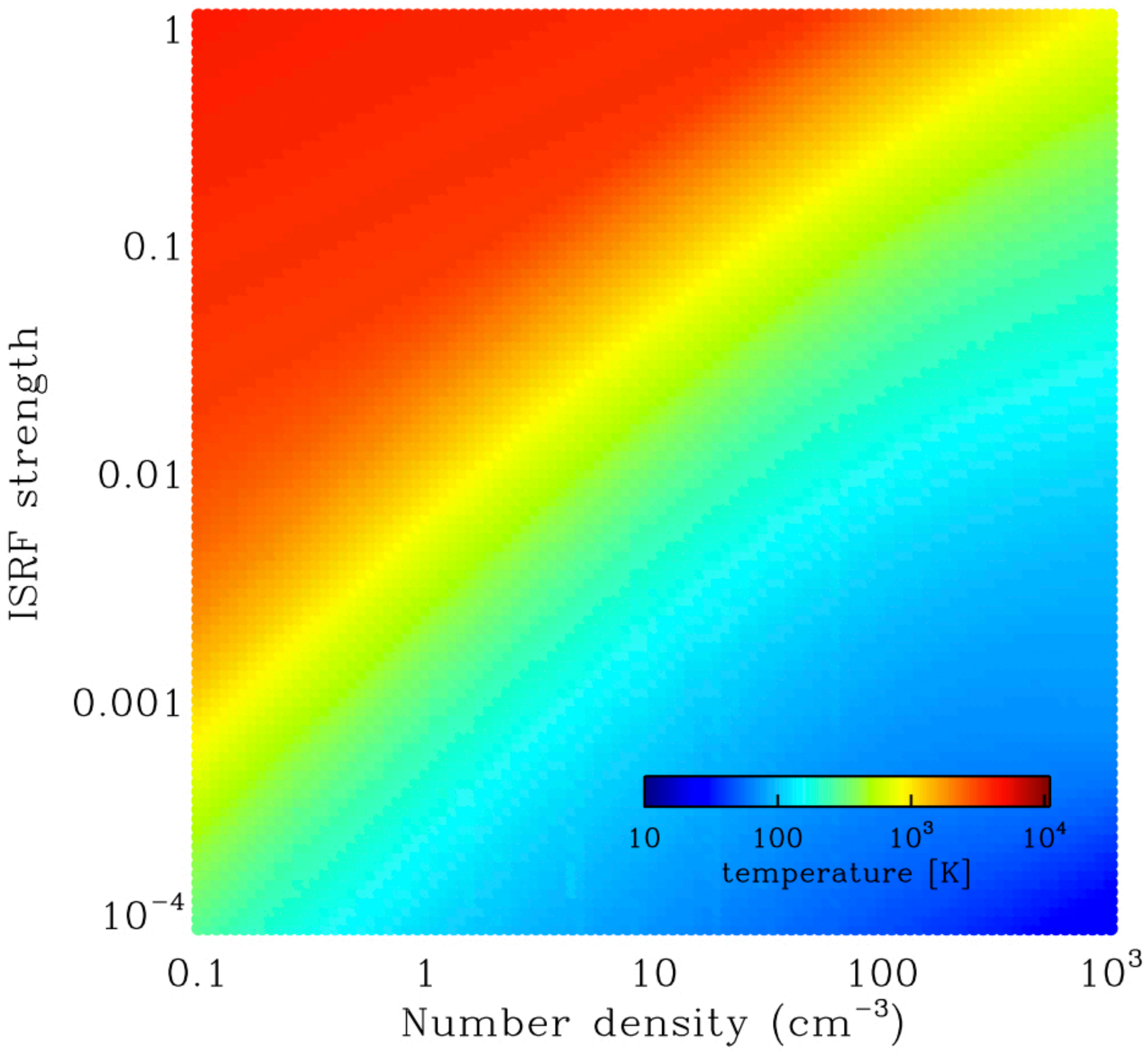


ISRF strength
1
0.1
0.01
0.001
10^-4
0.1
1
10
100
10^3
Number density (cm^-3)
10
100
10^3
10^4
temperature [K]



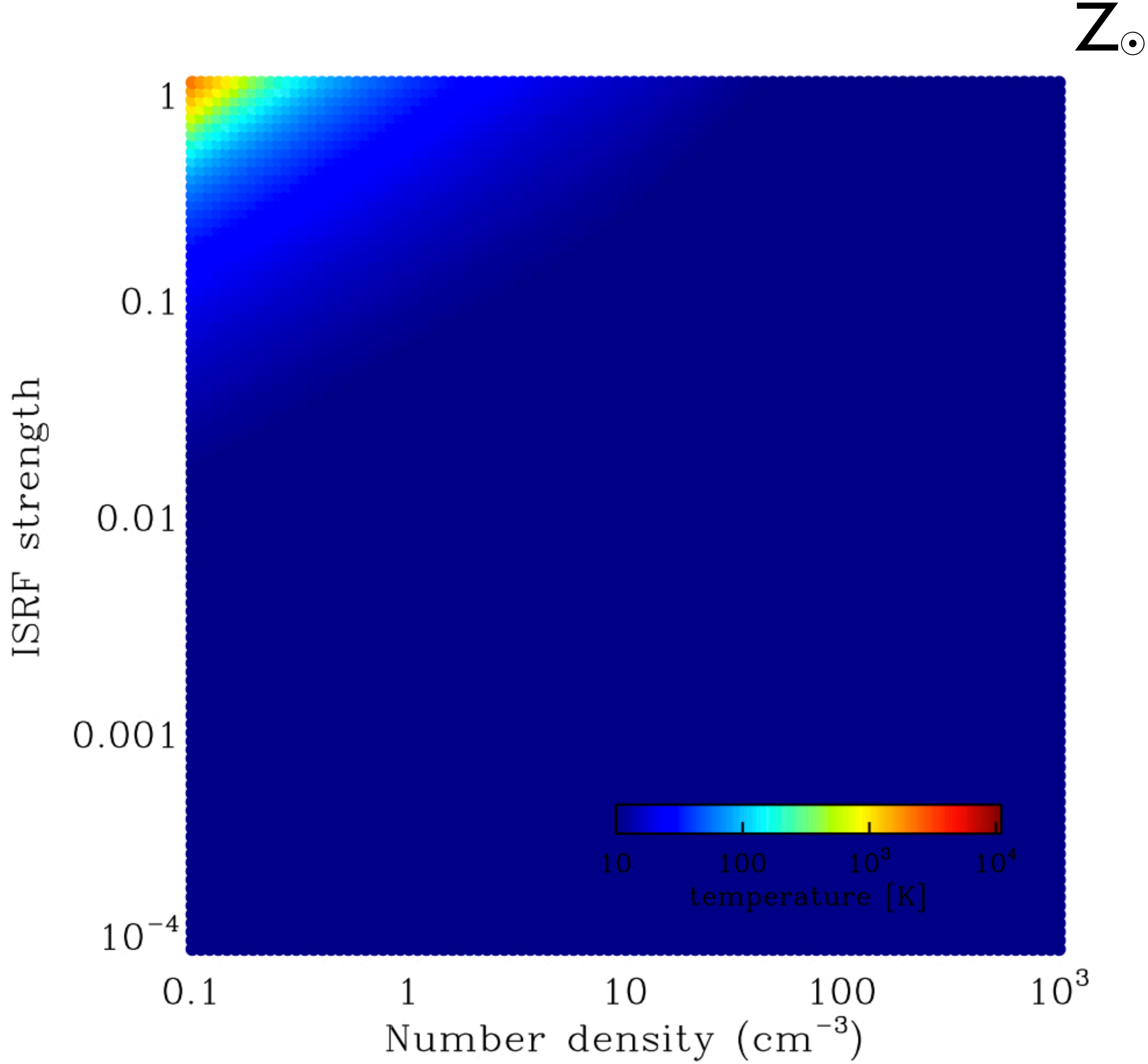
10-3 Z☉
ISRF strength
1
0.1
0.01
0.001
10−4
0.1
1
10
100
10³
Number density (cm−3)
10
100
10³
10⁴
temperature [K]

$10^{-4}\ Z_{\odot}$

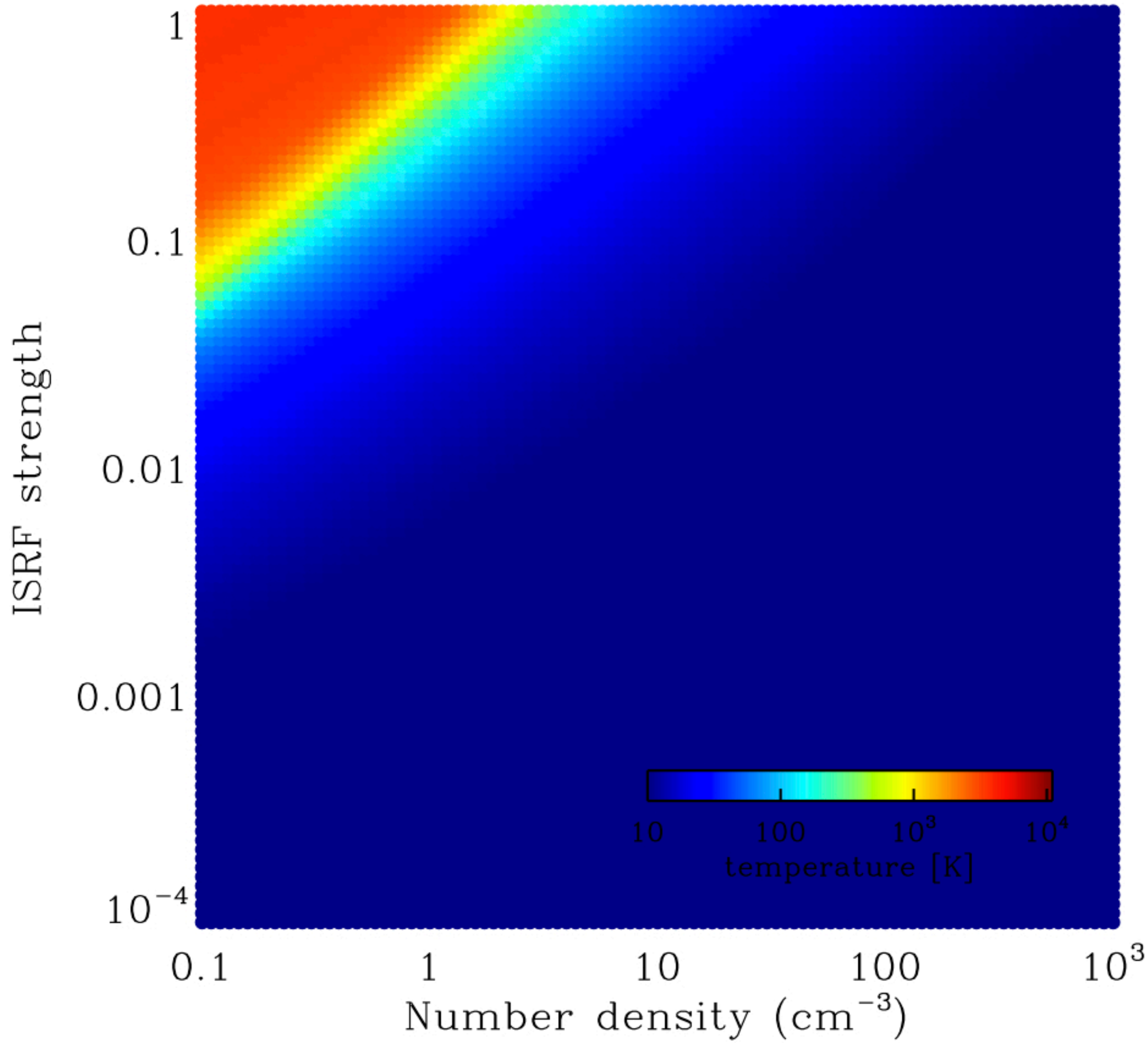


1
0.1
0.01
0.001
10^-4
ISRF strength
0.1
1
10
100
10^3
Number density (cm^-3)
10
100
10^3
10^4
temperature [K]

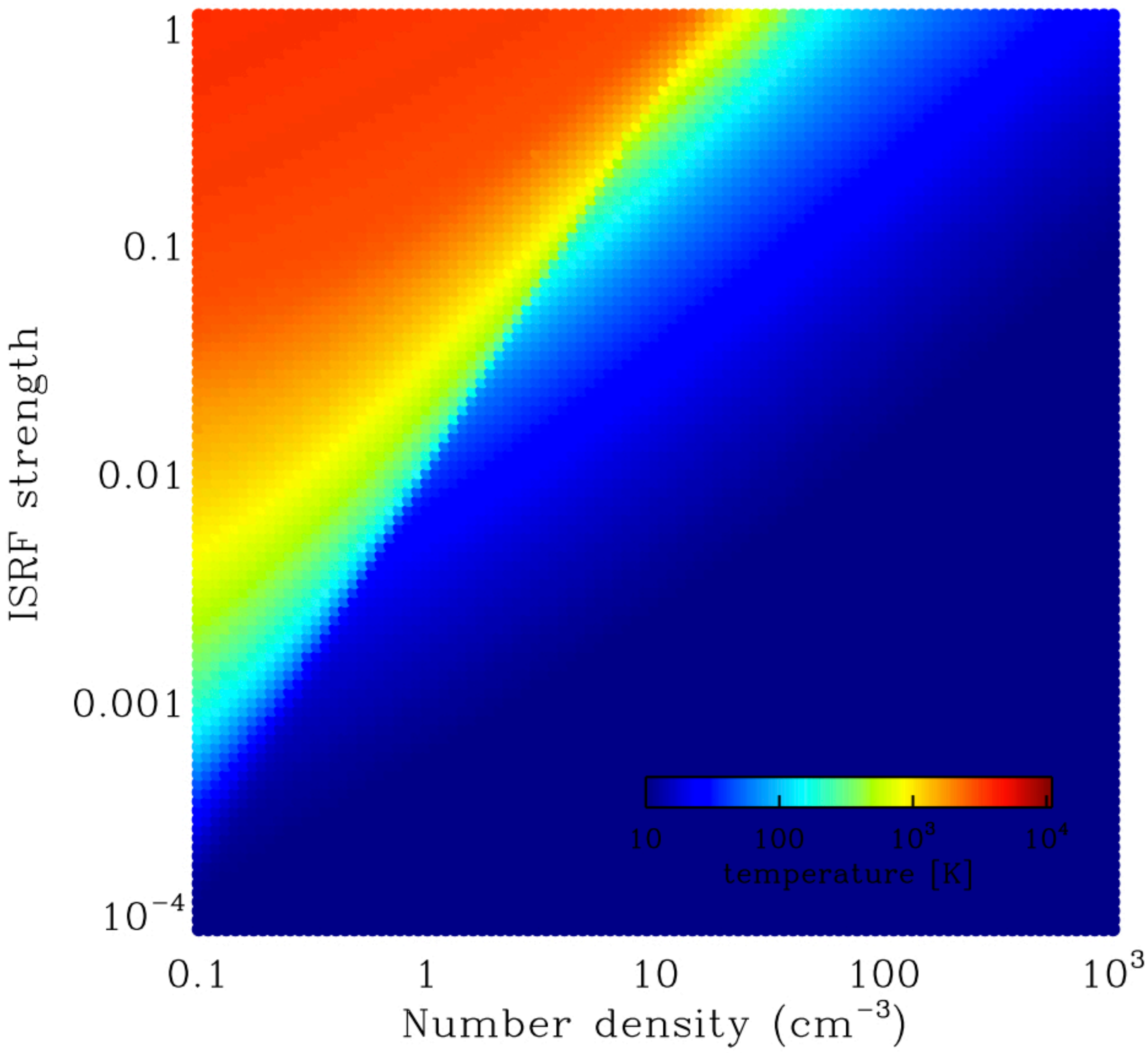
With H_2 and (approximate) self-shielding


Z⊙
1
0.1
0.01
0.001
10^{-4}
ISRF strength
0.1
1
10
100
10^3
Number density (cm^{-3})
10
100
10^3
10^4
temperature [K]

0.1 $Z_\odot$

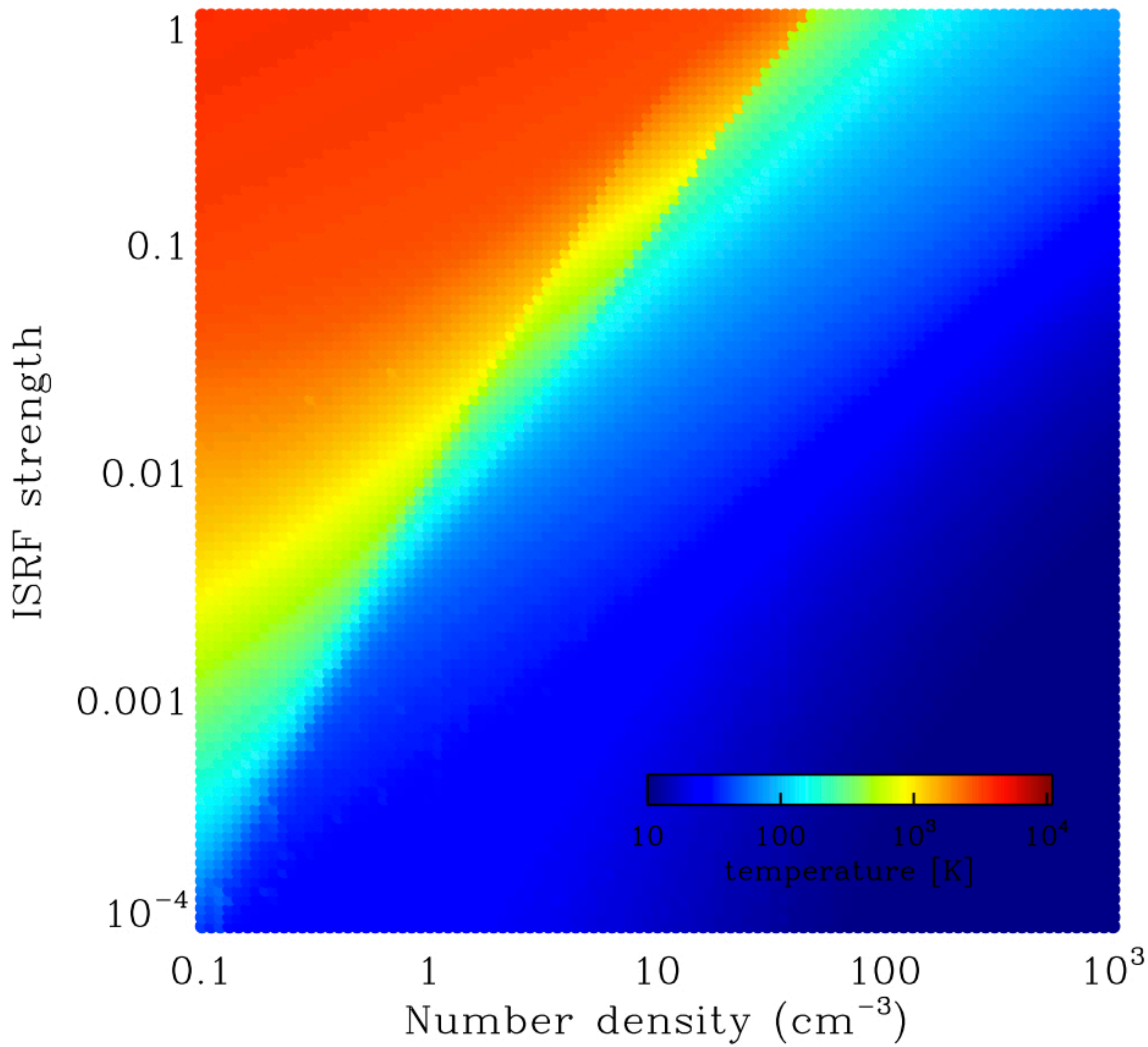

1
0.1
0.01
0.001
10^-4
ISRF strength
0.1
1
10
100
10^3
Number density (cm^-3)
10
100
10^3
10^4
temperature [K]

$10^{-2}\ Z_\odot$



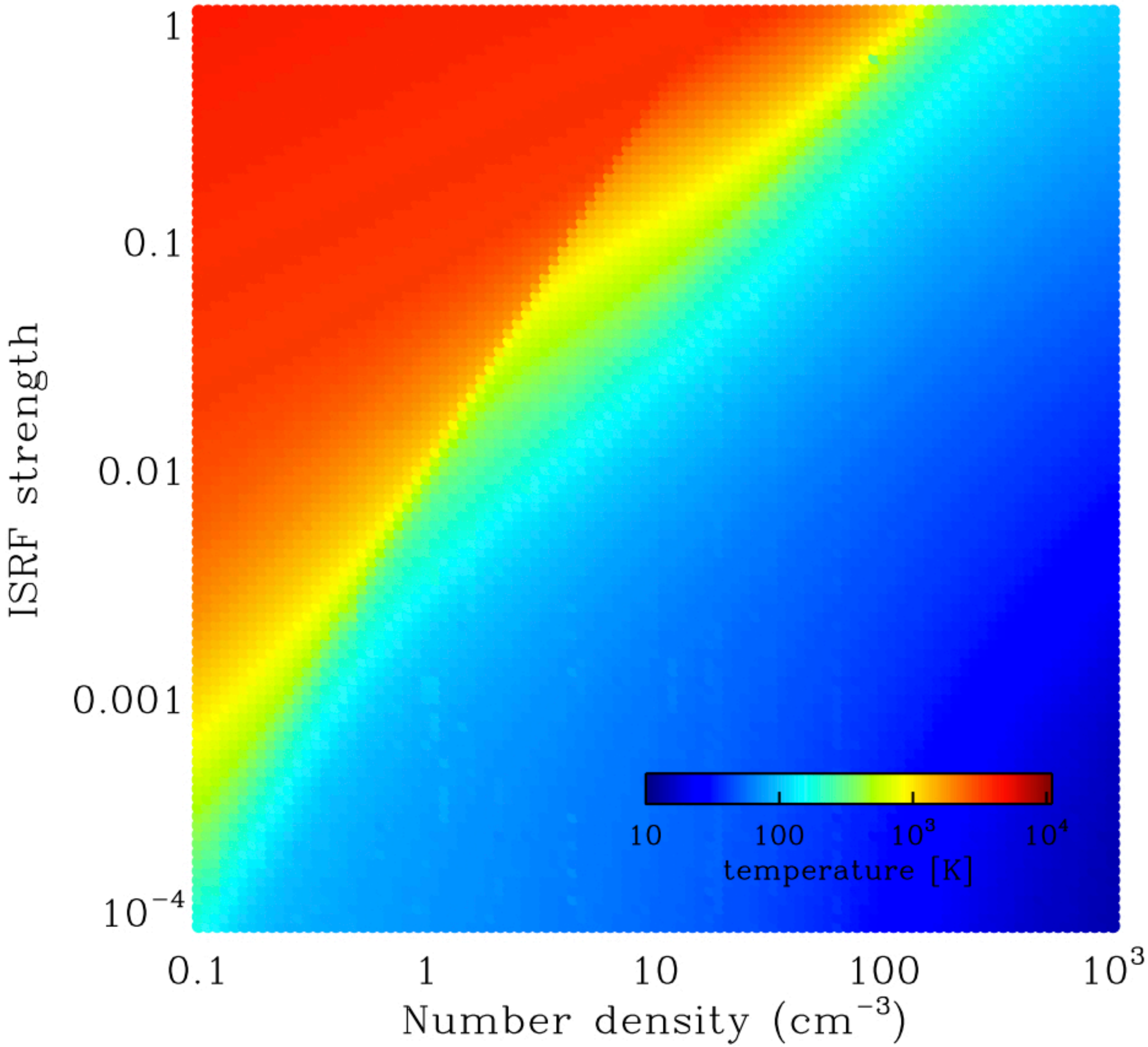
1
0.1
0.01
0.001
10^-4
ISRF strength
0.1
1
10
100
10^3
Number density (cm^-3)
10
100
10^3
10^4
temperature [K]

$10^{-3}\ Z_\odot$



1
0.1
0.01
0.001
10^{-4}
ISRF strength
0.1
1
10
100
10^3
Number density (cm^{-3})
10
100
10^3
10^4
temperature [K]

10^{-4} $Z_{\odot}$



1
0.1
0.01
0.001
10⁻⁴
ISRF strength
0.1
1
10
100
10³
Number density (cm⁻³)
10
100
10³
10⁴
temperature [K]

Summary

- At $Z > 0.01\ Z_{\odot}$, molecular gas is not necessary for star formation: fine structure cooling and dust cooling are sufficient
- At $Z < 0.01\ Z_{\odot}$, H_2 cooling drives star formation provided UV field is weak ($G_0/n < 0.01$). Otherwise, cooling is very inefficient unless the gas can be driven up to high densities by gravity and/or turbulence