Stellar cosmic ray driven chemistry in the terrestrial planet-forming region of protoplanetary disks

Donna Rodgers-Lee

Dublin Institute for Advanced Studies

SFI-IRC Pathway Fellow

COSMIC RAYS2: The salt of the star formation recipe, Florence, 8th November 2022

Collaborators: Kamber Schwarz (MPIA)

dlee@cp.dias.ie

DIAS Institiúid Ard-Léinn Bhaile Átha Cliath | Dublin Institute for Advanced Studies

sfi Fondúireacht Eolaíochta Éireann Dá bhfuil romhainn | Science Foundation Ireland For what's next

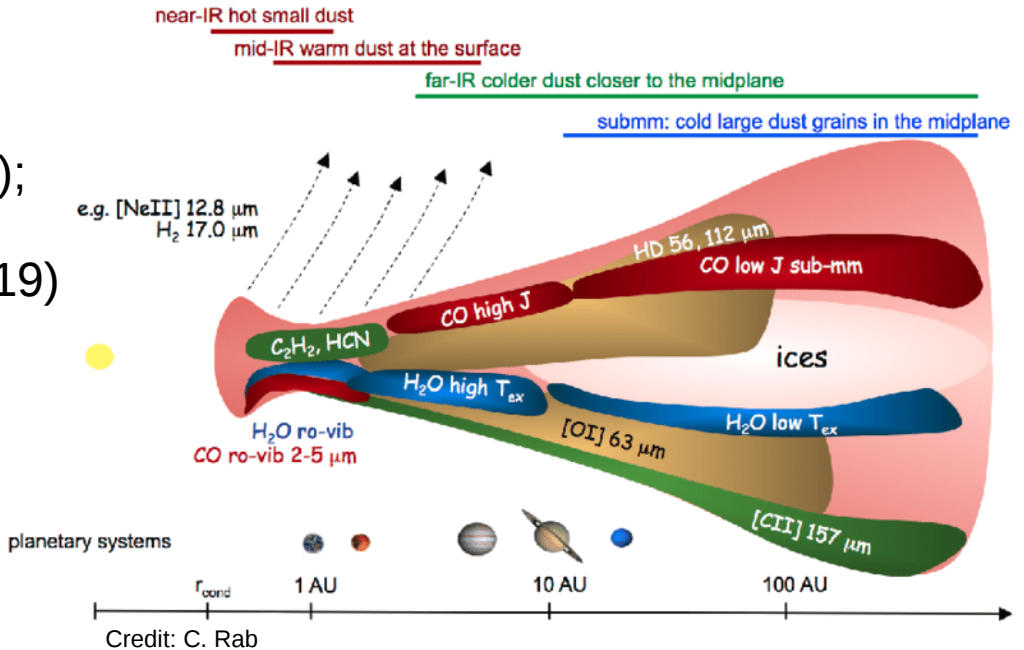
IRISH RESEARCH COUNCIL An Chomhairle um Thaighde in Éirinn

ICHEC Irish Centre for High-End Computing

Ionisation sources in protoplanetary disks

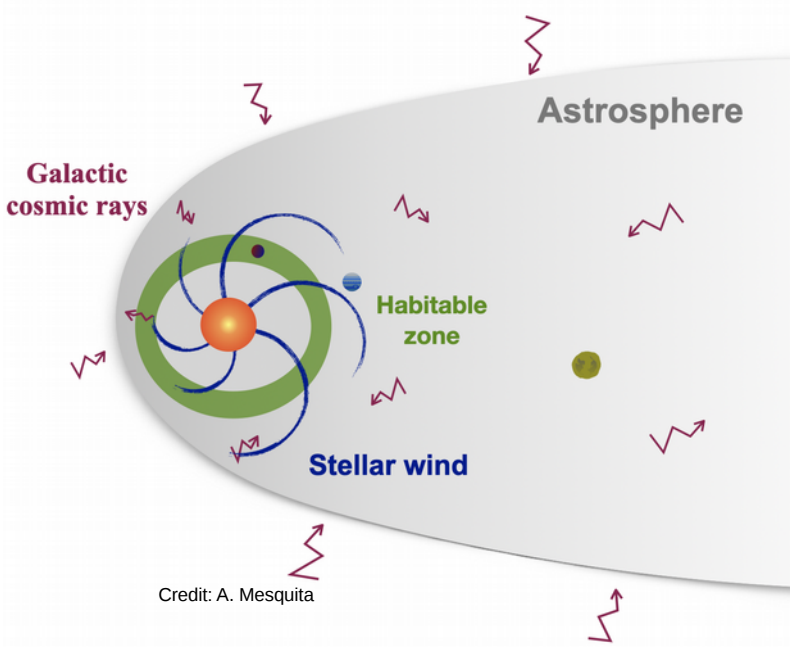
- **Stellar cosmic rays:**

  Turner & Drake (2009); Rab et al (2017); Rodgers-Lee et al (2017, 2020a); Fraschetti et al (2018), Offner et al. (2019)
- Galactic cosmic rays
- Stellar X-ray & FUV photons
- Radioactive nuclides (Brandt Gaches' talk!)



Credit: C. Rab

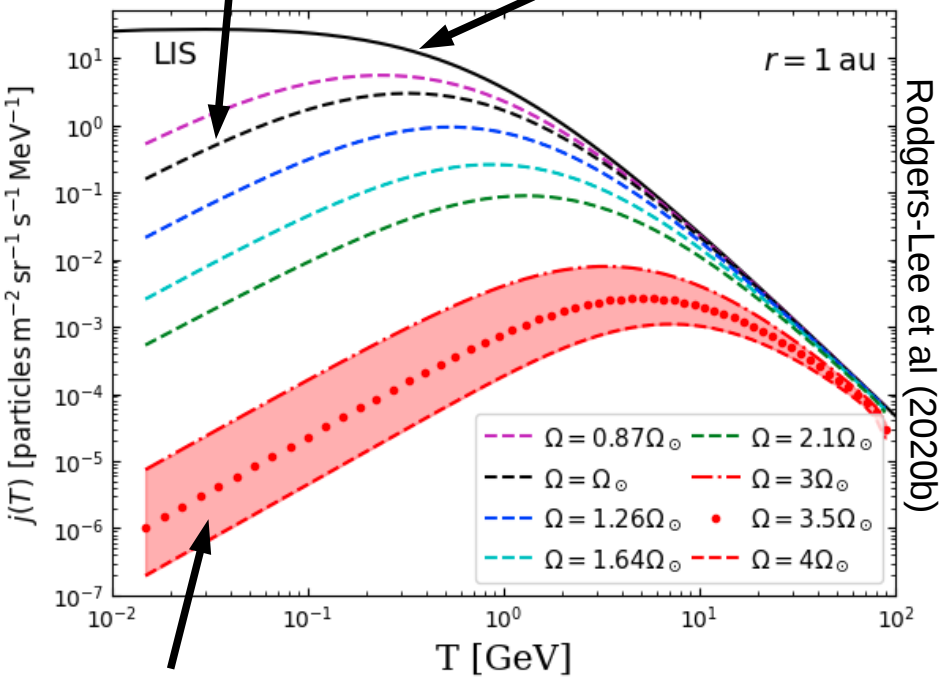
Galactic cosmic rays are suppressed by magnetised stellar winds



→ See Cleeves et al (2013); Padovani et al (2015)

Present day values

Local interstellar spectrum



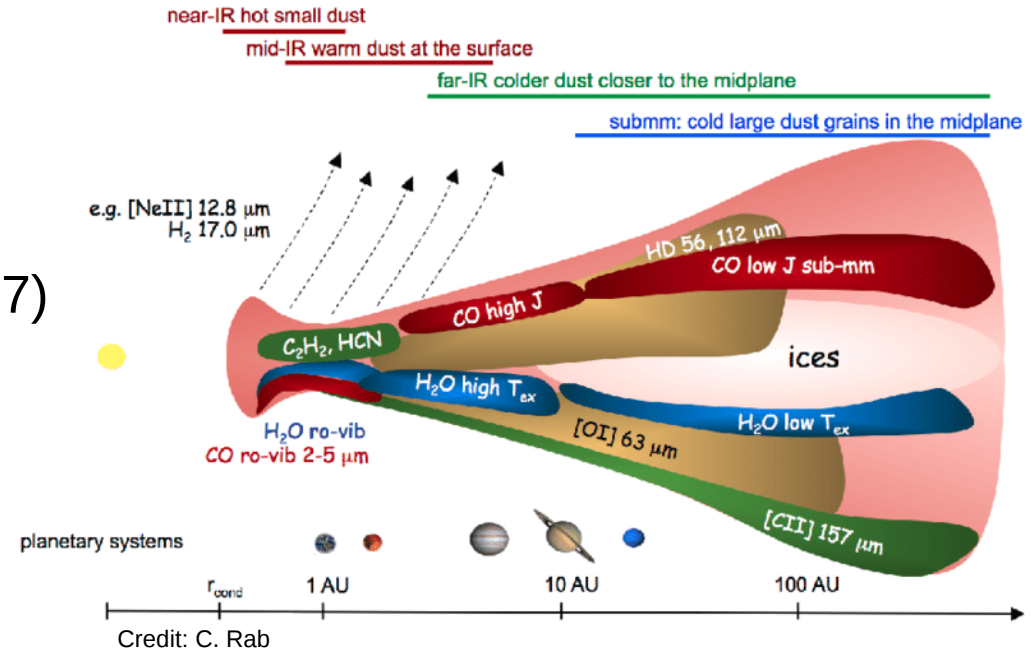
Rodgers-Lee et al (2020b)

Young Sun scenarios (600 Myr)

Can stellar cosmic rays explain low CO abundances observed by ALMA?

(probably not)

- Low CO abundances at large radii in protoplanetary disks (Miotello et al 2017)
- Schwarz et al (2018):
  Chemical processing not enough



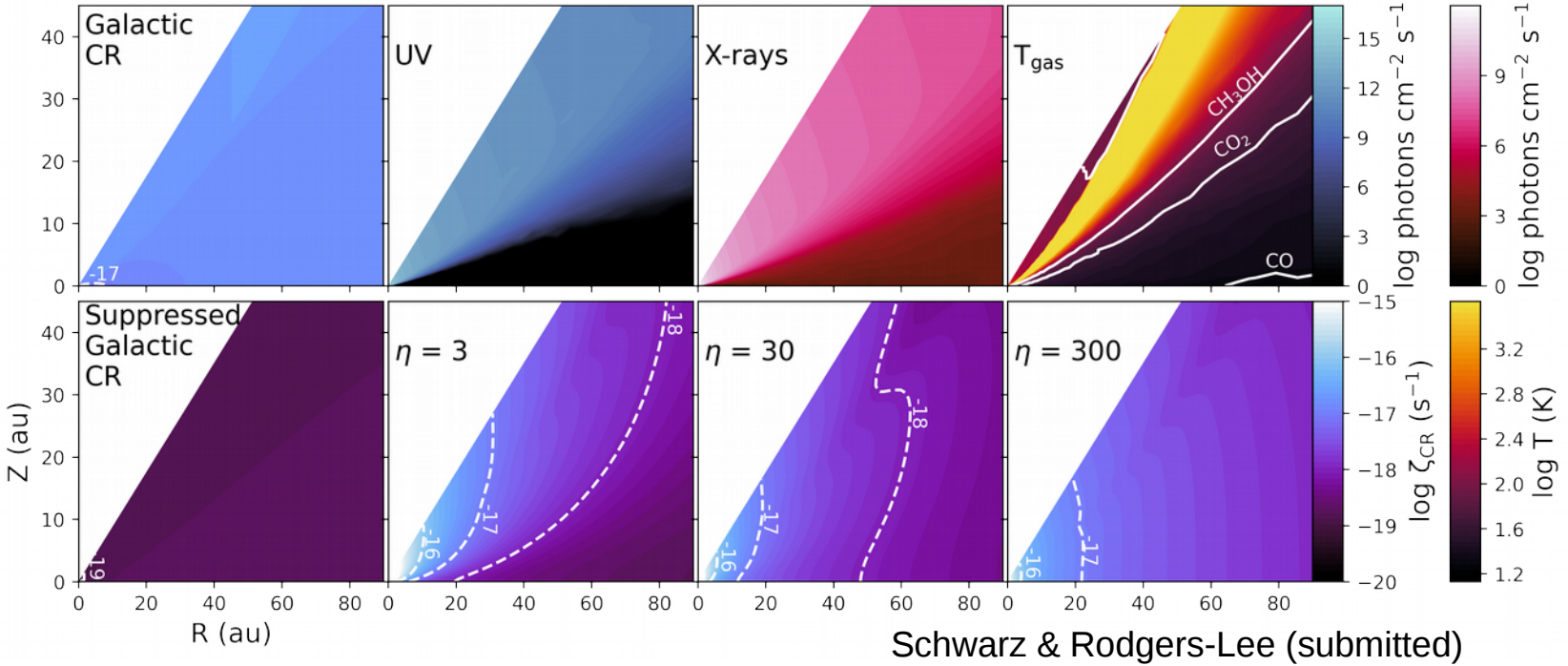
Credit: C. Rab

Alexandra Mulholland
(undergrad. research project)

Faster diffusion leads to higher ionisation rate at larger distances

DIAS
Institiúid Ard-Léinn Bhaile Átha Cliath | Dublin Institute for Advanced Studies

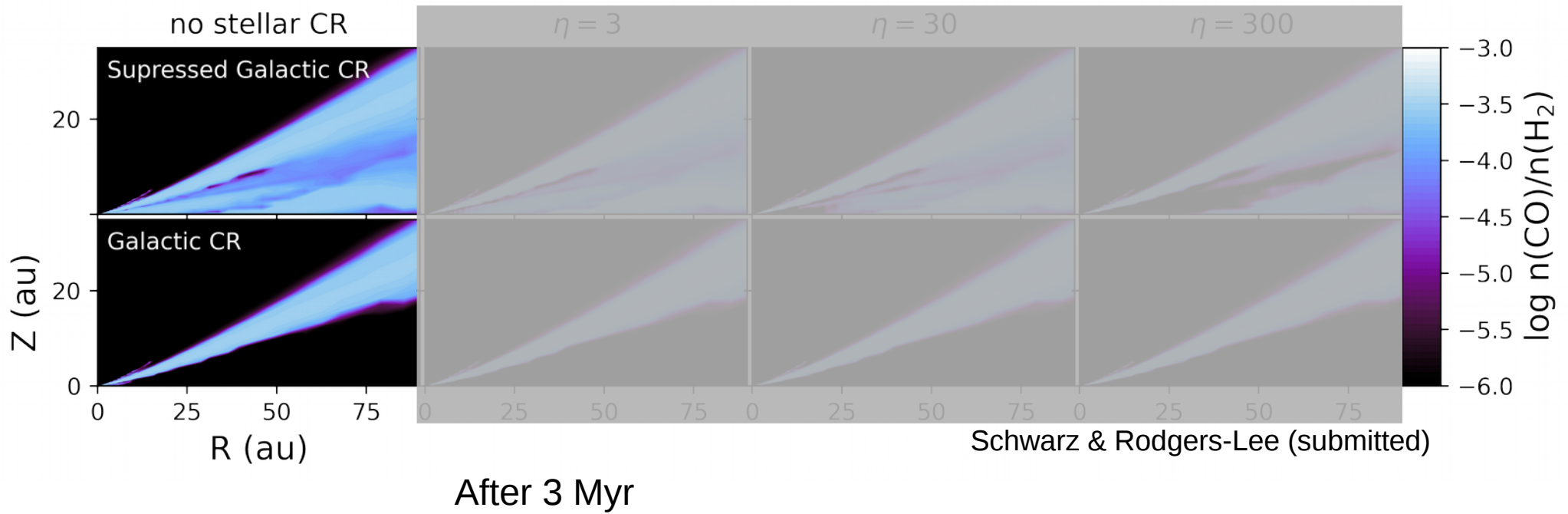
$$\frac{D}{\beta c} = \eta r_{\mathrm{L}}$$



Schwarz & Rodgers-Lee (submitted)

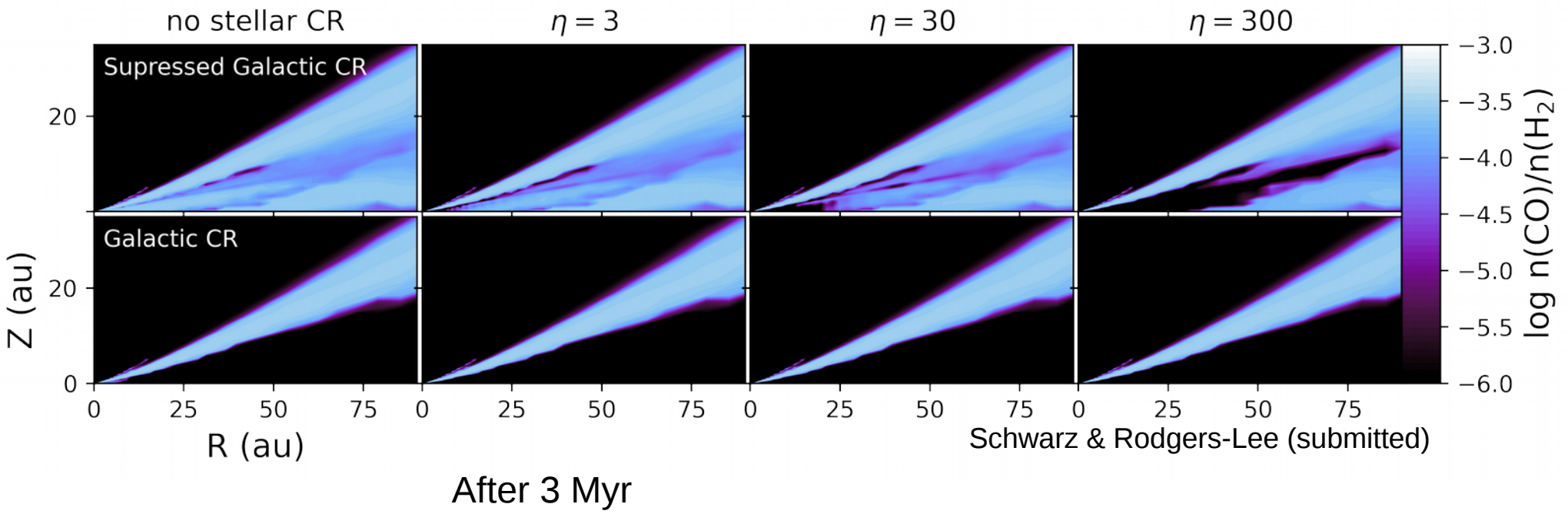
→ Considering GeV energy cosmic rays and diffusive transport

Stellar cosmic rays deplete CO in the inner terrestrial planet-forming region

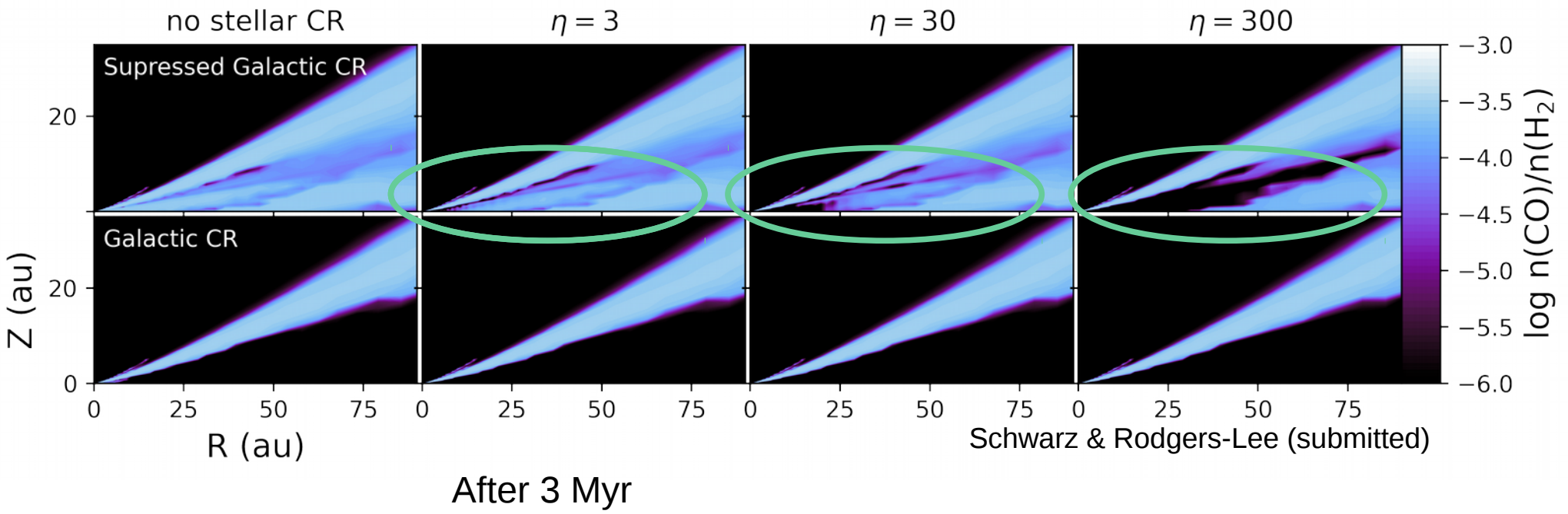


After 3 Myr

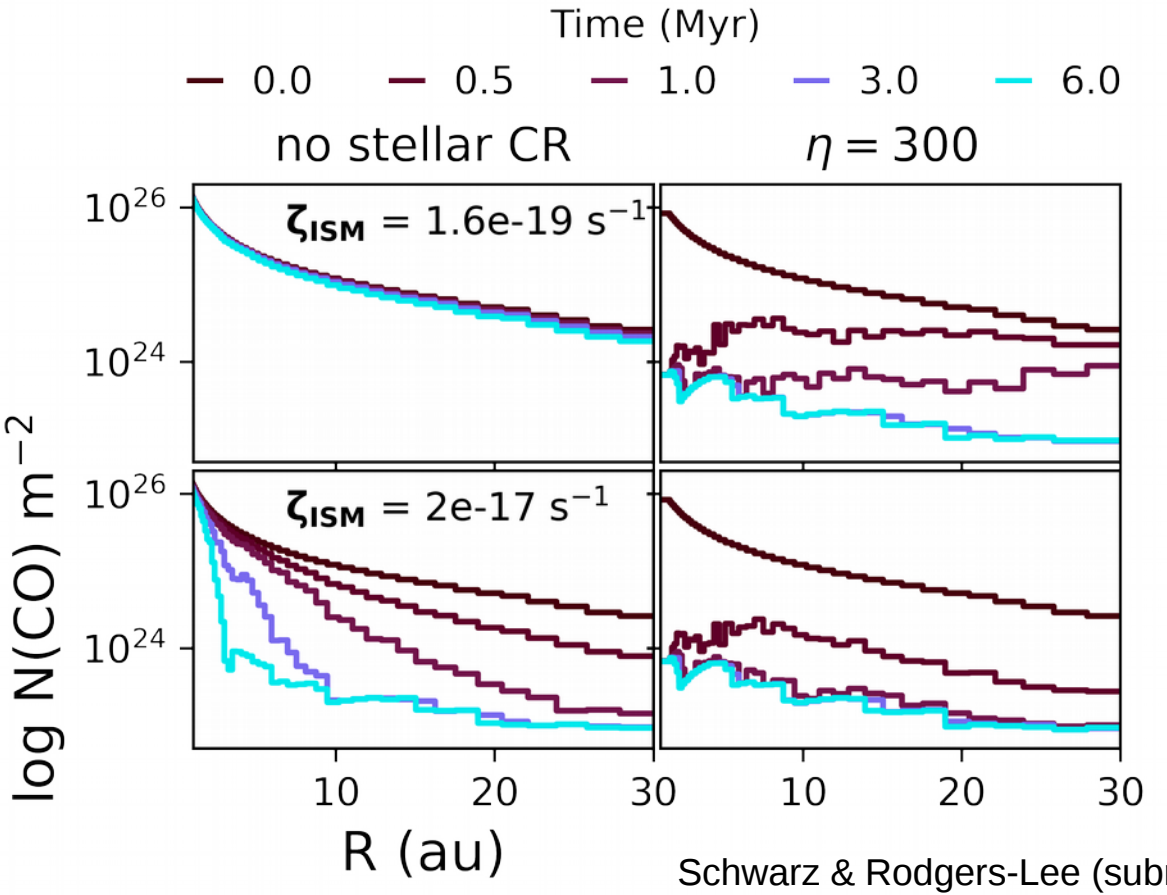
Stellar cosmic rays deplete CO in the inner terrestrial planet-forming region



Stellar cosmic rays deplete CO in the inner terrestrial planet-forming region

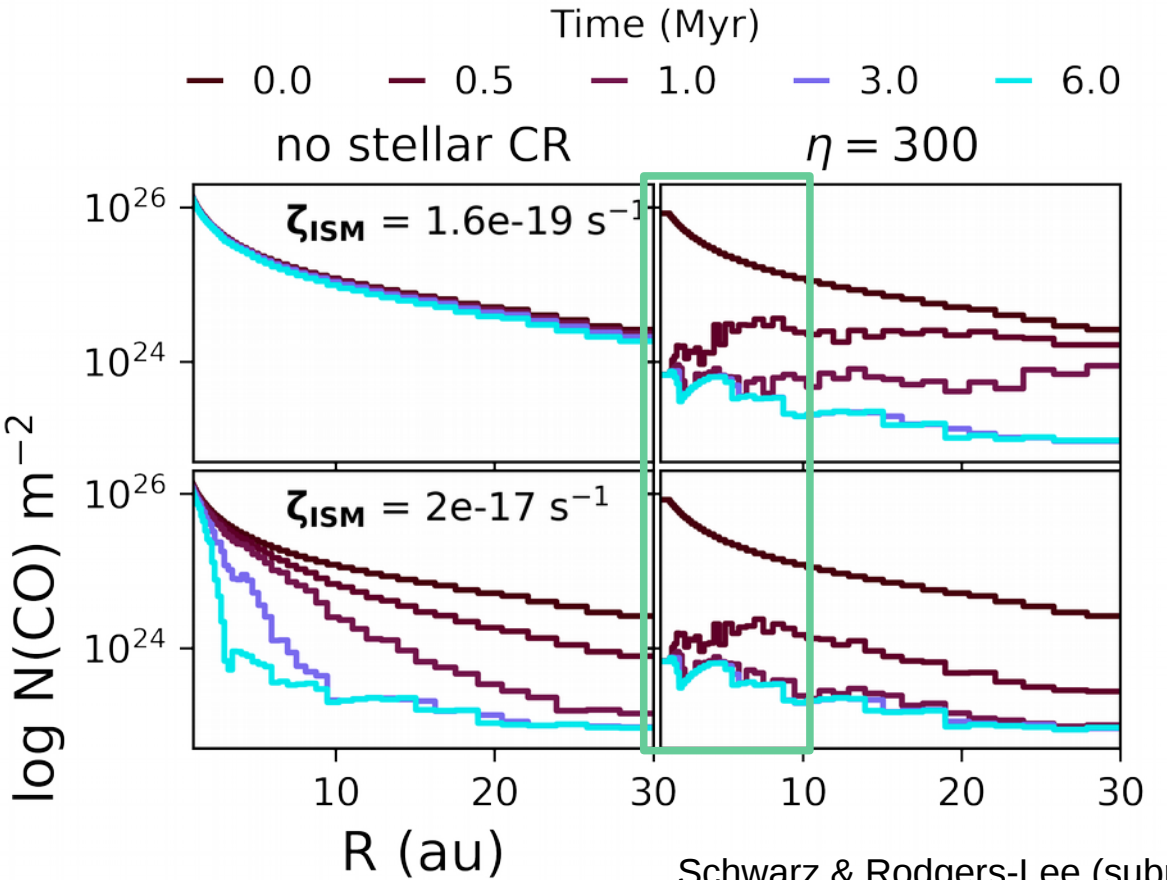


CO is significantly depleted within 1 Myr



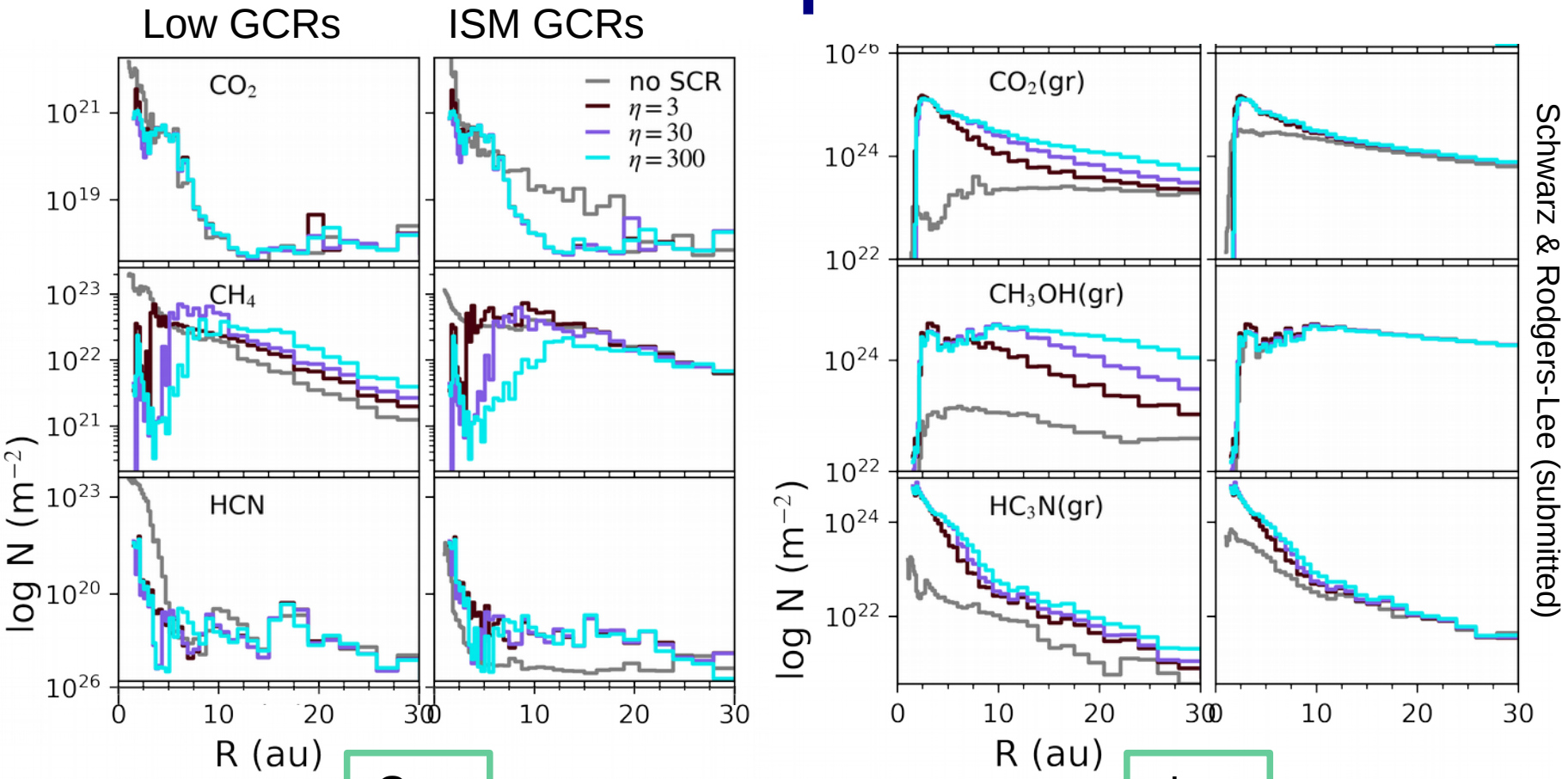
Schwarz & Rodgers-Lee (submitted)

CO is significantly depleted within 1 Myr

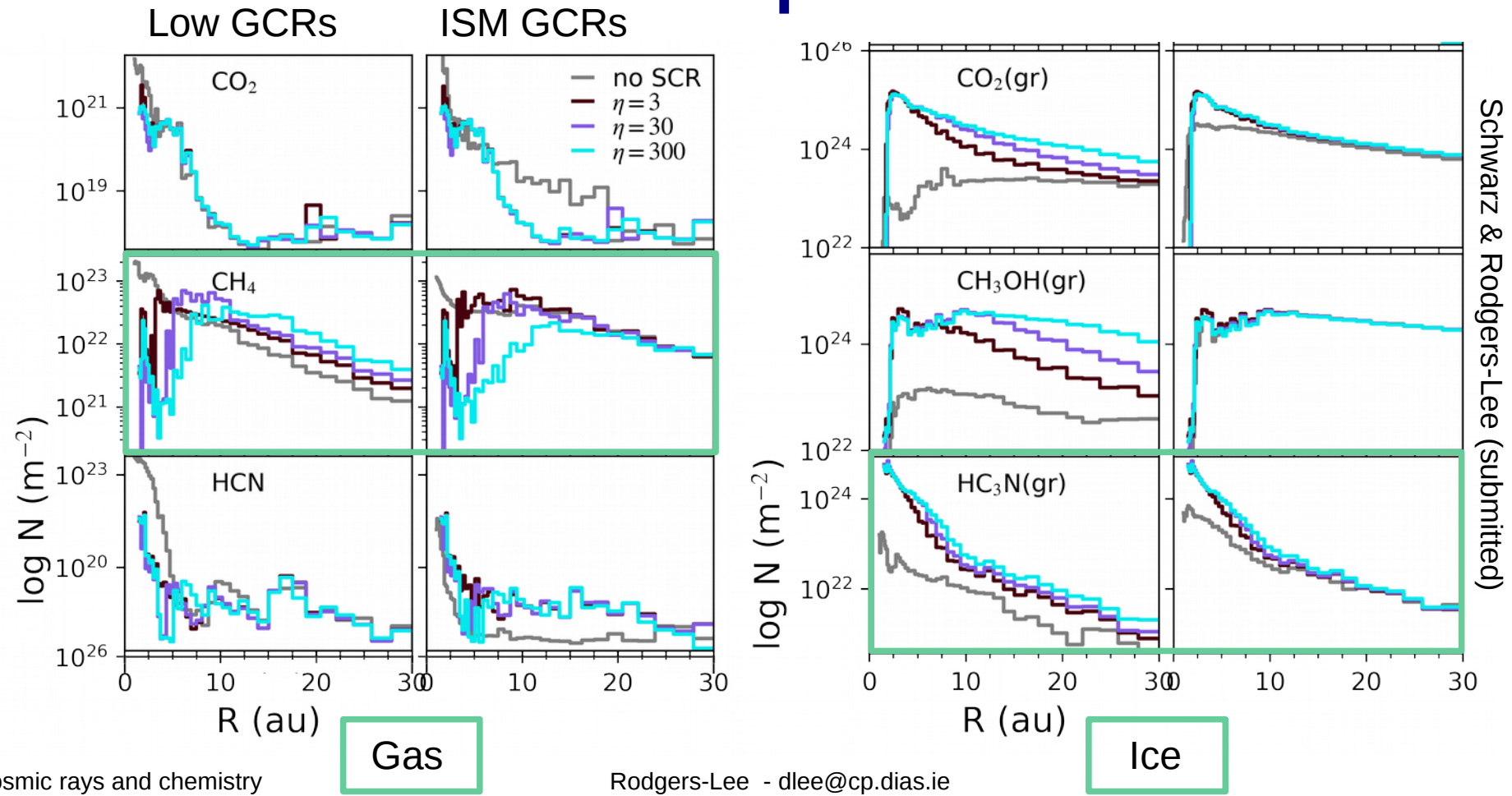


Schwarz & Rodgers-Lee (submitted)

Stellar cosmic ray effect on most abundant species

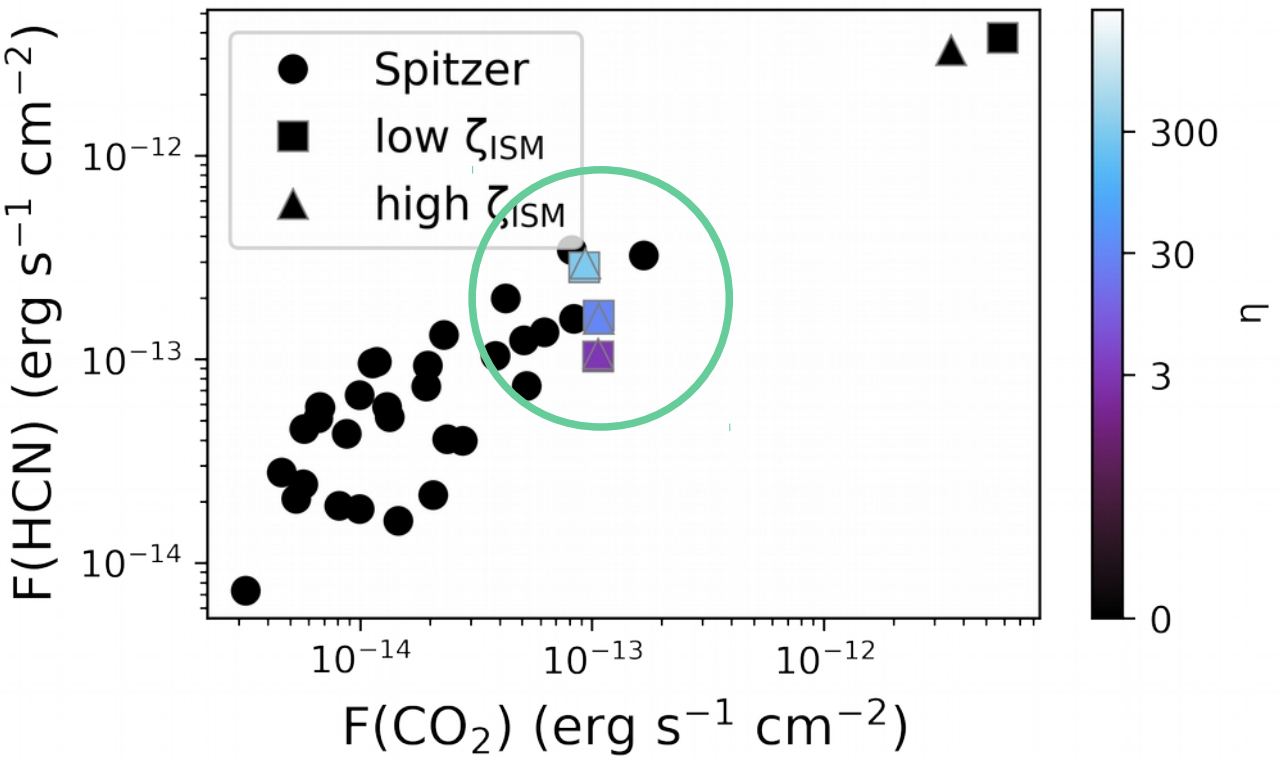


Stellar cosmic ray effect on most abundant species



Stellar cosmic ray ionisation rates agree better with Spitzer observations

- Spitzer fluxes (Banzatti et al 2020)
- Synthetic spectra using Slabspec (Salyk et al 2020)
- 15 micron HCN band and 14 micron CO_2 band



Schwarz & Rodgers-Lee (submitted)

Next steps

Can we explain radially varying ionisation rates? (Seifert et al 2021)

What is the radial dependence of the Galactic cosmic ray spectrum?

What about transition disks?

Conclusions

GeV energy stellar cosmic rays can significantly deplete CO in the terrestrial planet-forming region of protoplanetary disks within 3 Myr

Spitzer flux ratio measurements of HCN and CO_2 are better matched when stellar cosmic rays are included

JWST's MIRI may contribute to our understanding of stellar cosmic ray fluxes

Go raibh maith agaibh (Thank you!)

Any questions → dlee@cp.dias.ie