The intensity of cosmic rays on the evolving Earth and young exoplanets

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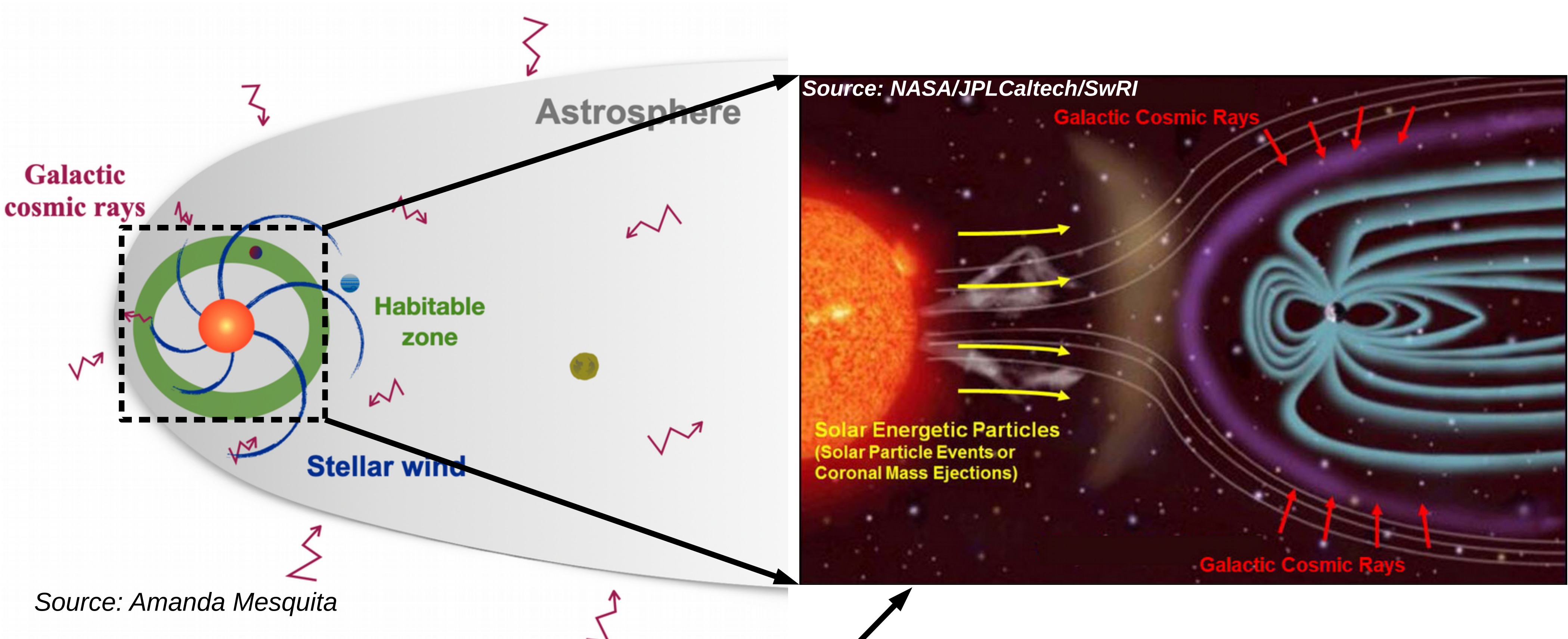
Galactic and stellar cosmic rays differ in flux and energy



Stellar cosmic rays for other stars

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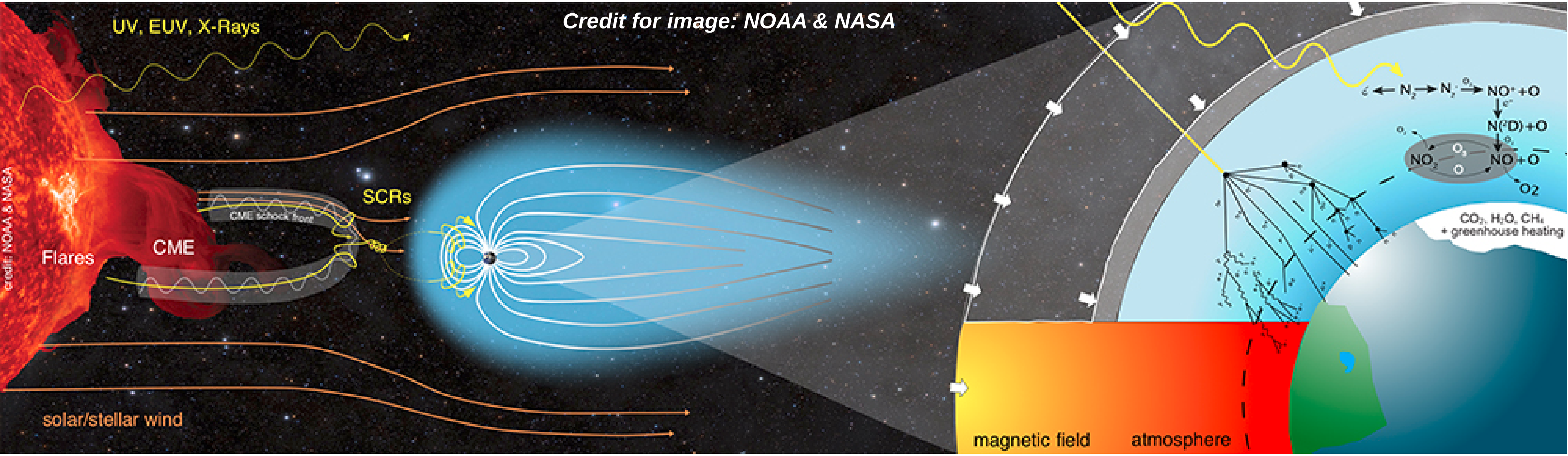
Cosmic rays are important for the origin of life & JWST observations



Cosmic rays can:

- Lead to prebiotic molecules and fingerprint ions (Airapetian et al. 2016; Dong et al. 2019; Helling & Rimmer 2019; Barth et al. 2020)
- Produce fake biosignatures (Grenfell et al. 2012)
- Affect life-forms by damaging DNA (Herbst et al. 2019, Atri 2020)

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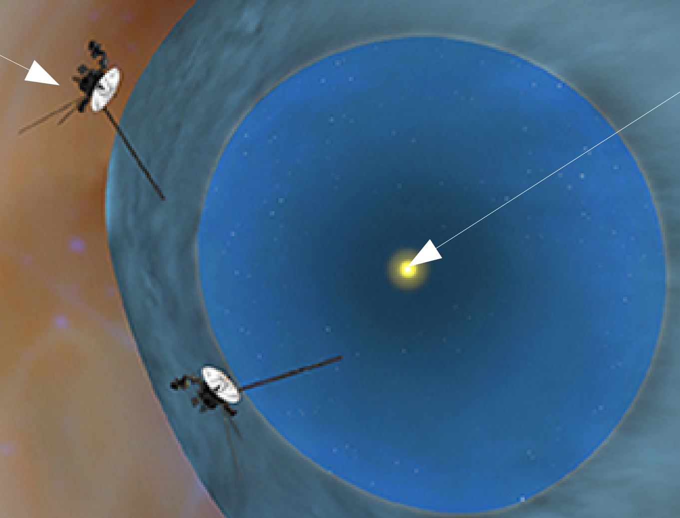
Galactic cosmic rays in time

Galactic cosmic rays
(GCRs, known from *Voyager 1&2*)
Stone et al. (2013, 2019)

GCRs on Earth
(known from PAMELA)
Parker (1965),Vos & Potgieter (2015)



Change solar wind properties
Johnstone et al. (2015), Vidotto et al. (2014)

GCRs at earlier
times in the solar system
Rodgers-Lee et al. (2020, 2021)

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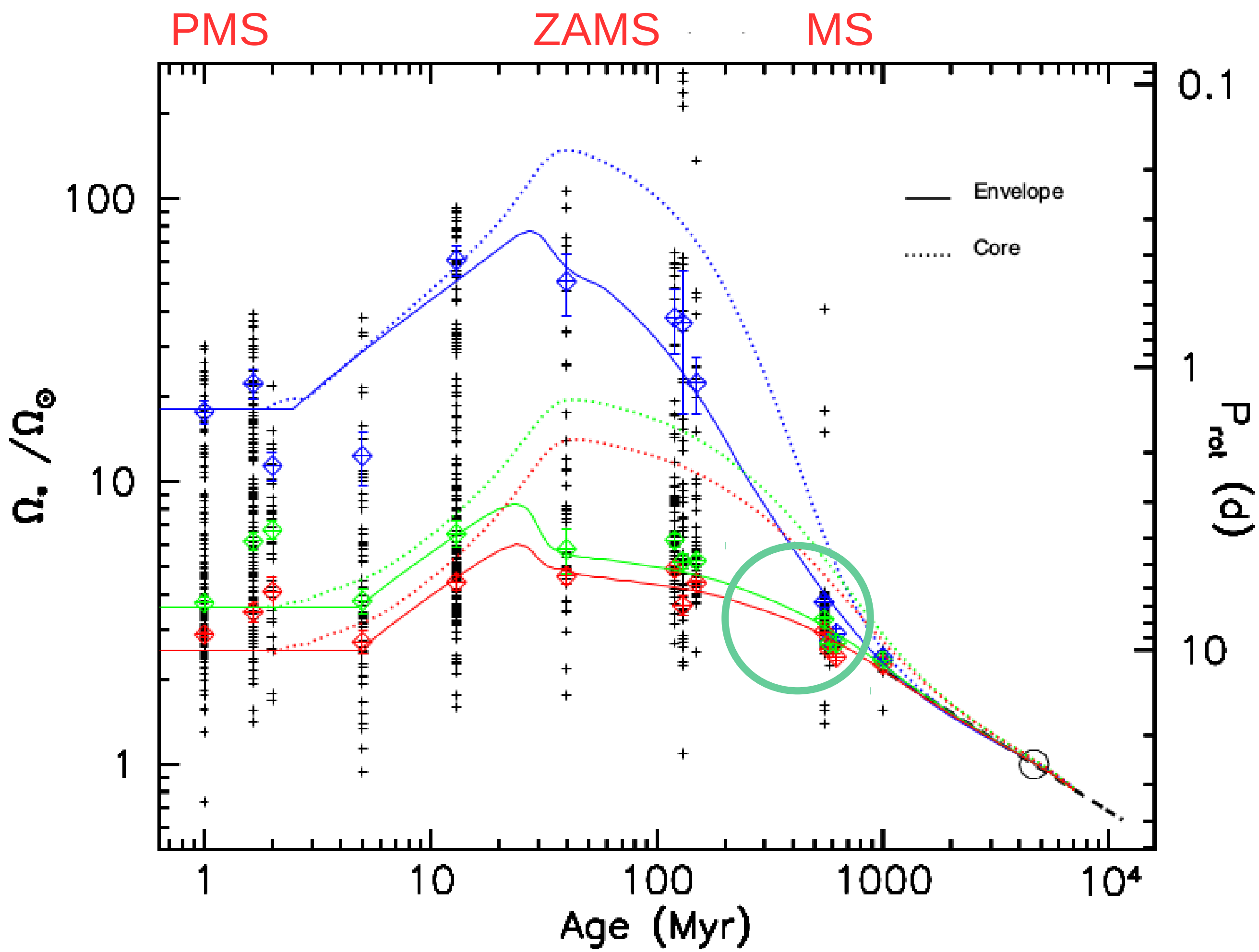
Image credit: NASA

Stellar rotation rate as a function of time



Gallet & Bouvier (2013)

$B_\star(\Omega),\ T_{\rm base}(\Omega),\ \rho_\star(\Omega)$ → 1.5D stellar wind model

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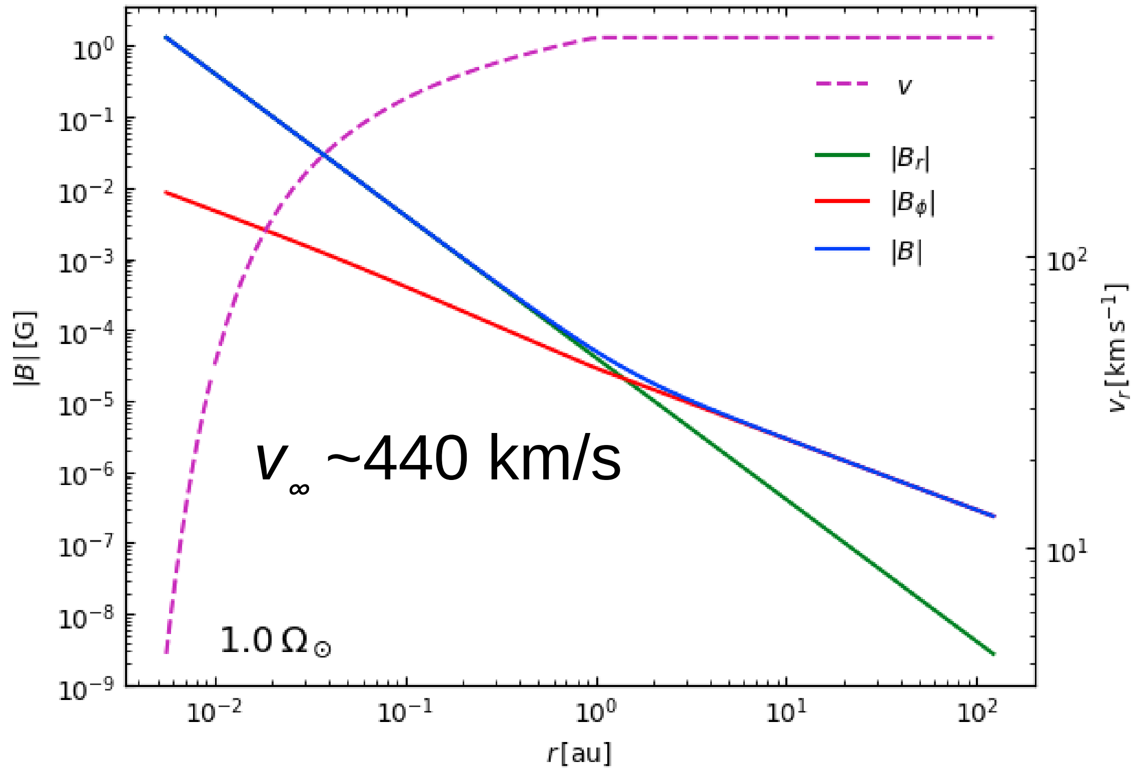
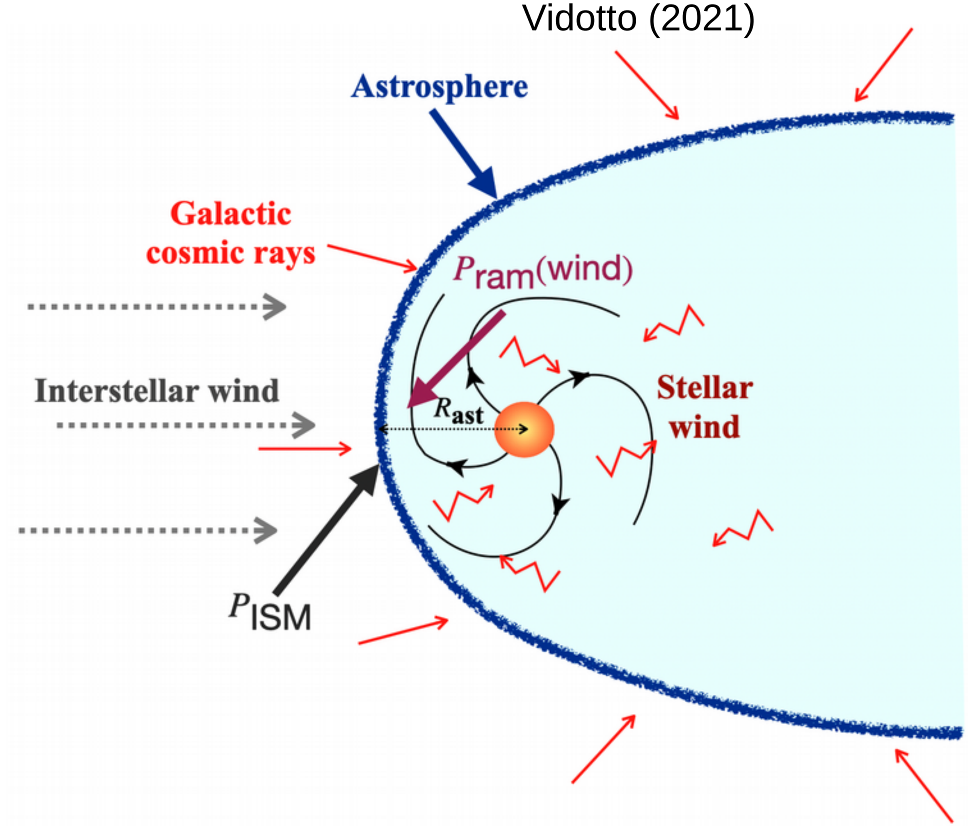
Carolan et al. (2019)
Johnstone et al. (2015)

Stellar wind velocity, magnetic field and astrospheric size are important for CRs

Mesquita, Rodgers-Lee & Vidotto (2021)





At younger ages:

v_∞ ~800 km/s and B ~7G

R_{ast} = 47 – 1725 au

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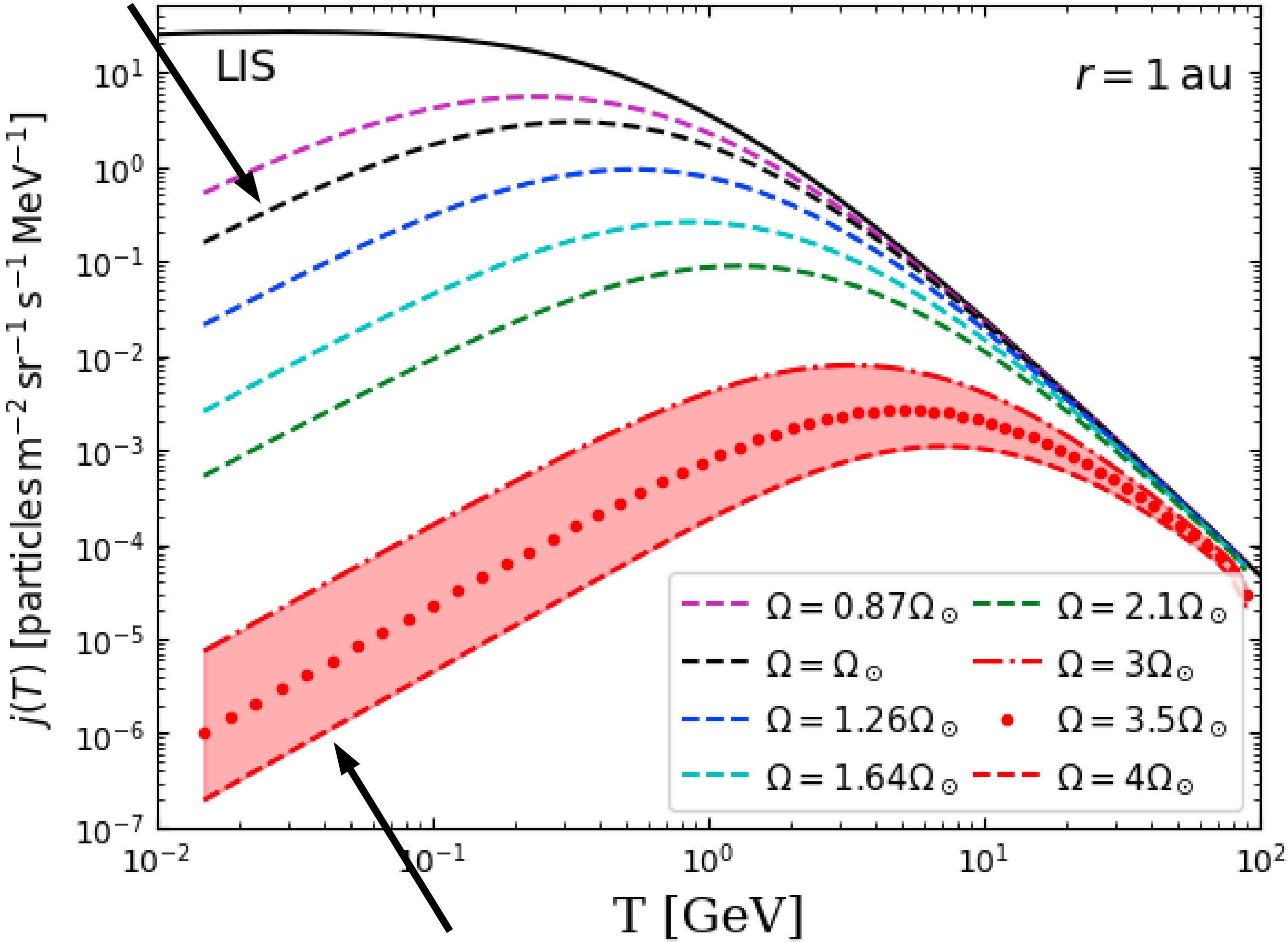
Galactic cosmic ray intensities @Earth decrease with decreasing stellar age

Present day values

Rodgers-Lee et al. (2020)



Slow or fast rotator scenarios for Sun at 600Myr

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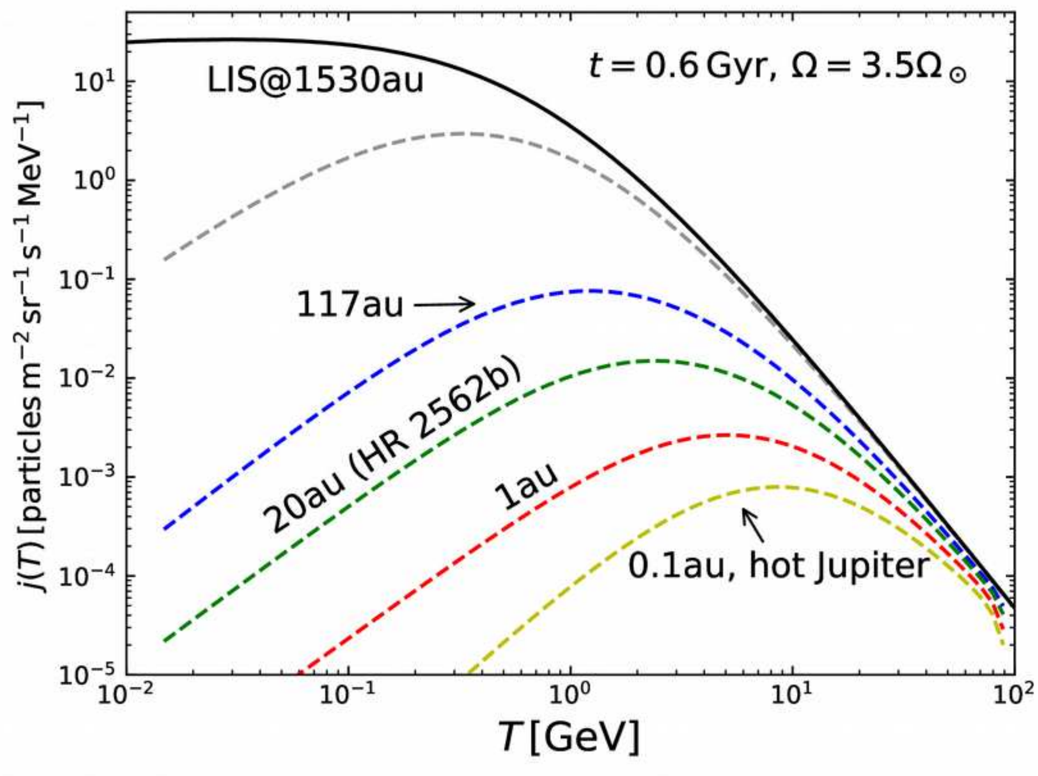
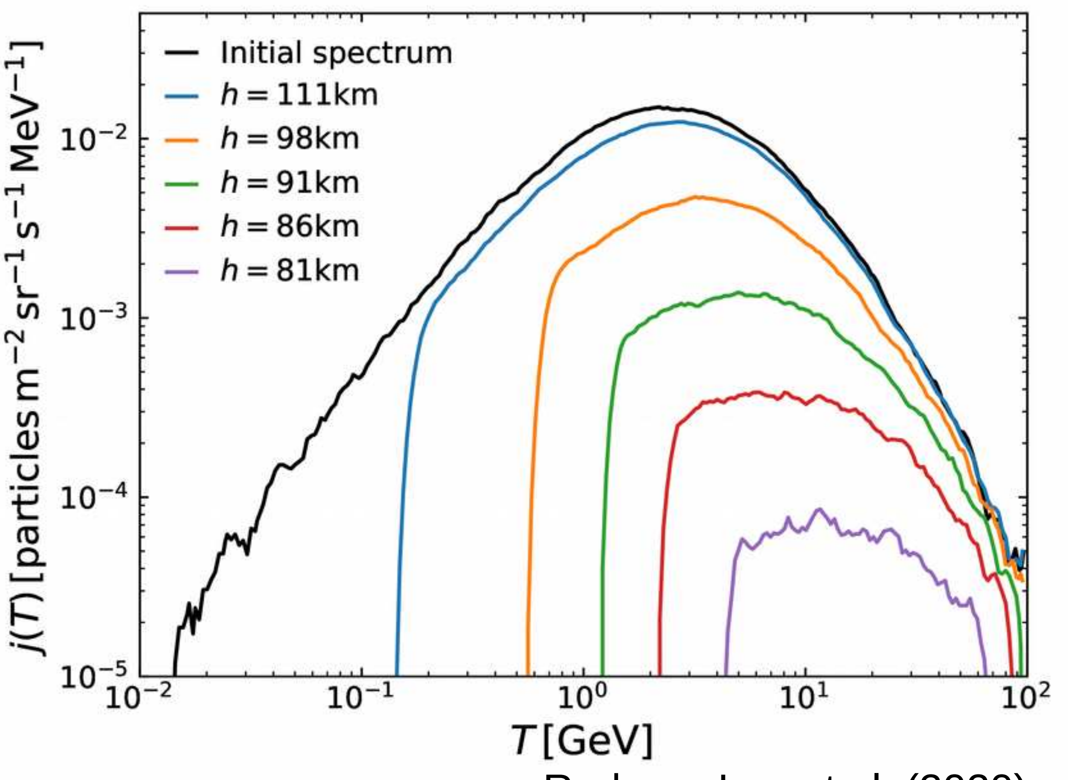
Galactic cosmic ray fluxes in HR 2562b's atmosphere

Chemical signatures for JWST observations:

H_3^+, H_3O^+, NH_4^+ Helling & Rimmer (2019), Barth et al. (2020)

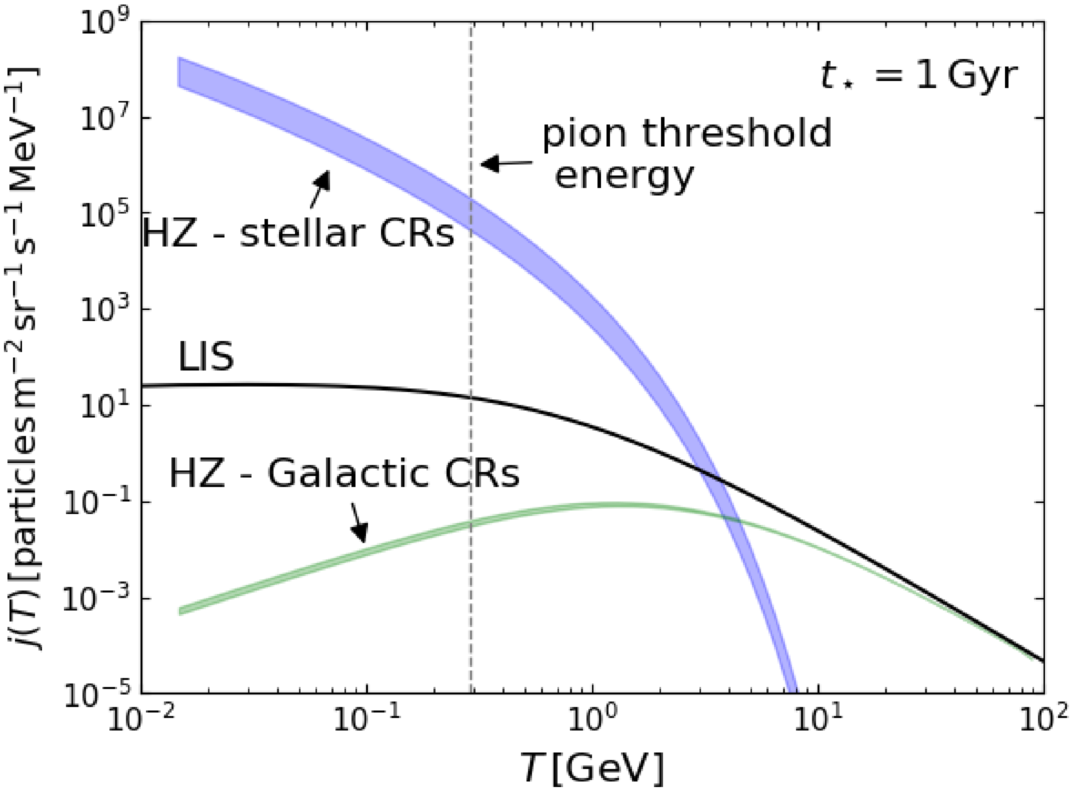


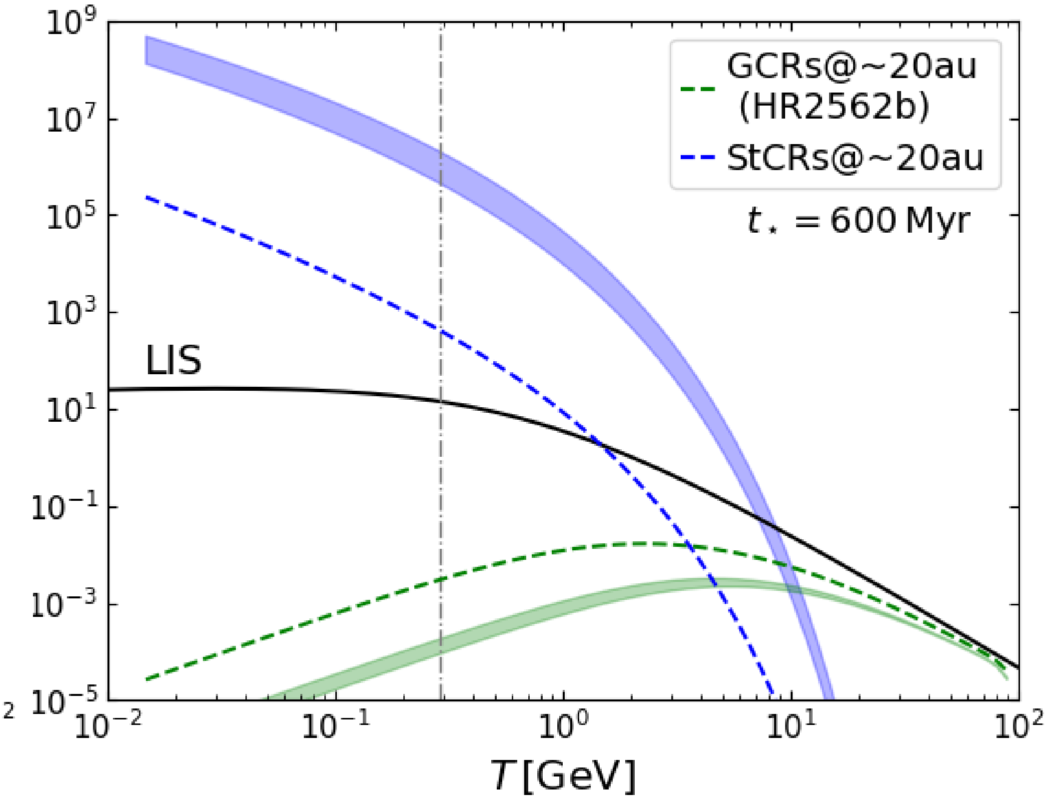


Rodgers-Lee et al. (2020)

HR2562 is a 600 Myr solar-like star with a planet located at 20au

Stellar cosmic rays dominate over Galactic cosmic rays up to ~GeV energies





Rodgers-Lee et al. (2021)

~when life began on Earth

HR 2562b, young Jupiter-like planet

Conclusions

JWST observations:

- HR2562b is an interesting target due to its large orbital distance

Stellar energetic particles:

- For stellar ages <1Gyr stellar energetic particles dominated over Galactic cosmic rays at GeV energies @1au

Future work

What type of behaviour can we expect for M dwarf and other Sun-like star systems?

arxiv.org/abs/2009.02173

Thank you!

arxiv.org/abs/2103.15460

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