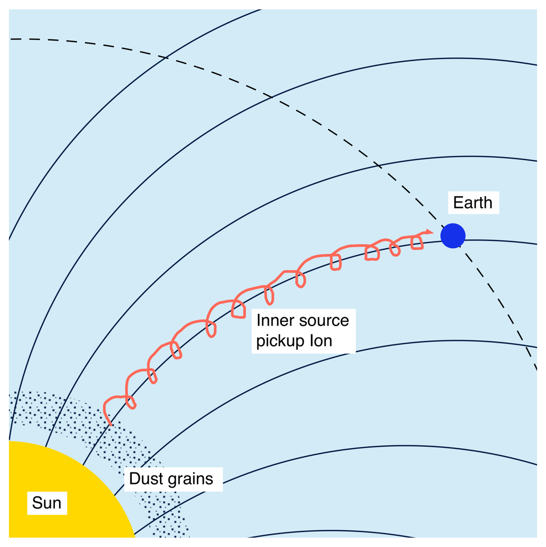
Profile of C^+/O^+ and C^+/He^+ from Solar Wind Recycling

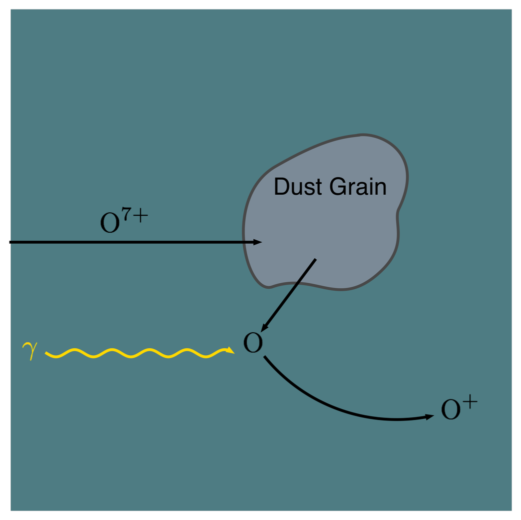
P. R. Quinn, N. A. Schwadron, E. Möbius
Space Science Center and Department of Physics, University of New Hampshire, Durham, NH, USA

Motivation



- The mechanism behind the production of inner source pickup ions is not well understood
- Possible production mechanisms include
  - **Solar wind recycling** – absorption and desorption of solar wind ions
  - **Solar wind neutralization** – charge exchange through carbon foil-like dust grain population
  - Sputtering from grains
  - Dust-dust collisions
  - Sun-grazing comets
  - Energetic neutral atoms
- Question - How does C^+/O^+ and C^+/He^+ produced from solar wind recycling (and interstellar sources) change with distance and longitude?
- Question - How does C^+/O^+ and C^+/He^+ change with solar wind speed?
- Question - How does C^+/O^+ and C^+/He^+ change with solar activity?
- Question - Is solar wind recycling the sole production mechanism of inner source pickup ions?

Solar Wind Recycling Model



- Mechanical process:
  - Solar wind ions penetrate about 10-30 nm per keV and nucleon into the outer mineral layer of dust grains
  - Electron capture neutralizes the solar wind ion within the dust grain
  - Dust grains become saturated with neutralized solar wind atoms
  - Due to saturation, the solar wind atoms diffuse to the surface and desorb from the dust grain
  - Once desorbed, the neutrals are ionized by photoionization, charge exchange, or electron impact
  - Due to the very close proximity to the sun, ionization occurs almost immediately
  - After ionization, the ions are picked up and convected out with the solar wind
- Formalism
  - Assumes a density profile that peaks near the sun and falls off as $r^{1.3}$

$$n_d(r) = n_d(1\text{AU}) \left(\frac{1\text{AU}}{r}\right)^{1.3} \exp\left[-\frac{L}{1\text{AU}}\left(\frac{1\text{AU}}{r} - 1\right)\right] \quad (1)$$

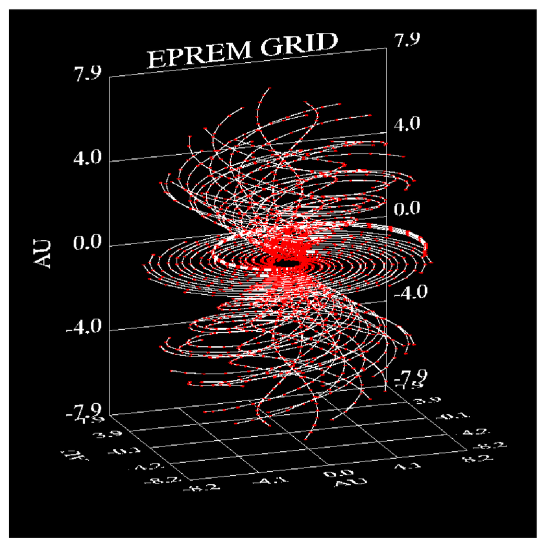
L = radial distance to peak of dust distribution

- – Absorption, desorption, and ionization are assumed to be in steady state, therefore the production of pickup ions is:

$$\beta = \frac{X}{H}\frac{un\Gamma}{n_d(1\text{AU})} \quad (2)$$

X/H = fractional abundance of solar wind ion
u = solar wind speed
n = solar wind density at 1 AU
Γ = geometric cross section of dust
$n_d(1\text{AU})$ = density of dust at 1 AU

EPREM and Hot Gas Model

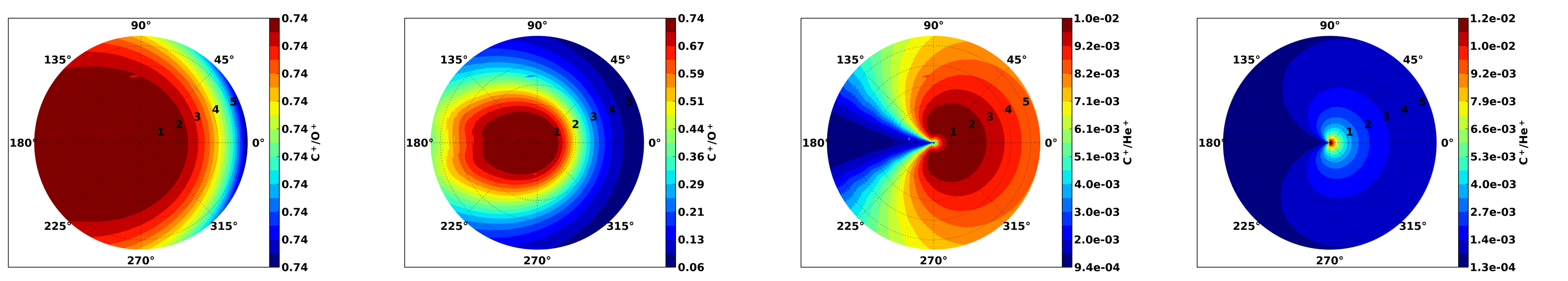


- Energetic Particle Radiation Environment Module (EPREM)
  - Models particle transport throughout the heliosphere
  - Solves the focused transport equation and convection-diffusion equation
  - Takes into account: convection, streaming, adiabatic cooling, adiabatic focusing, pitch-angle scattering, perpendicular diffusion, and drift
- Hot Gas Model
  - Spatial distribution of interstellar neutral atoms within the heliosphere
  - Based on temperature, velocity, and density of neutral atoms in the local interstellar medium

Procedure

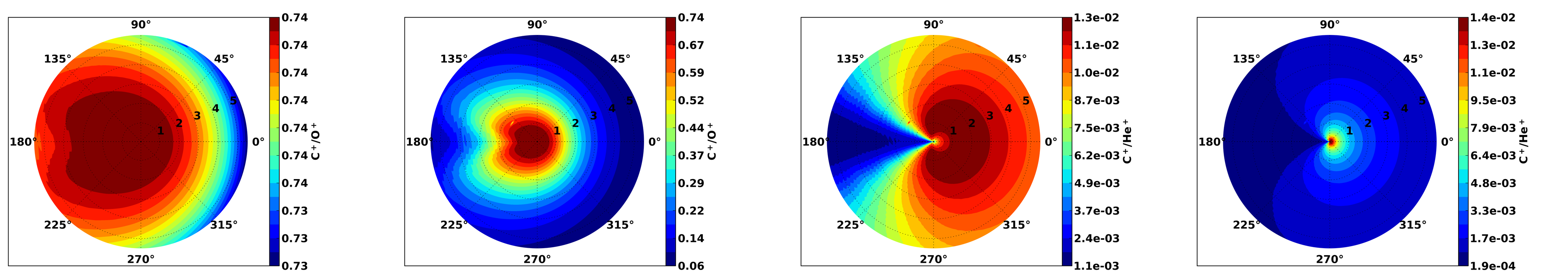
- Simulate inner source C^+, O^+, and interstellar He^+, O^+ from the sun out to 5.5 AU
- Integrate the velocity distribution function over two energy ranges to get the number density
  - inner source dominated energy range: $0.08 \le w \le 0.2$
  - interstellar dominated energy range (for C^+/O^+): $0.5 \le w \le 1.0$
- Repeat for solar wind speeds of u = 325, 425, and 525 km/s
- Repeat for solar minimum and solar maximum

Solar Minimum, $u = 325$ km/s



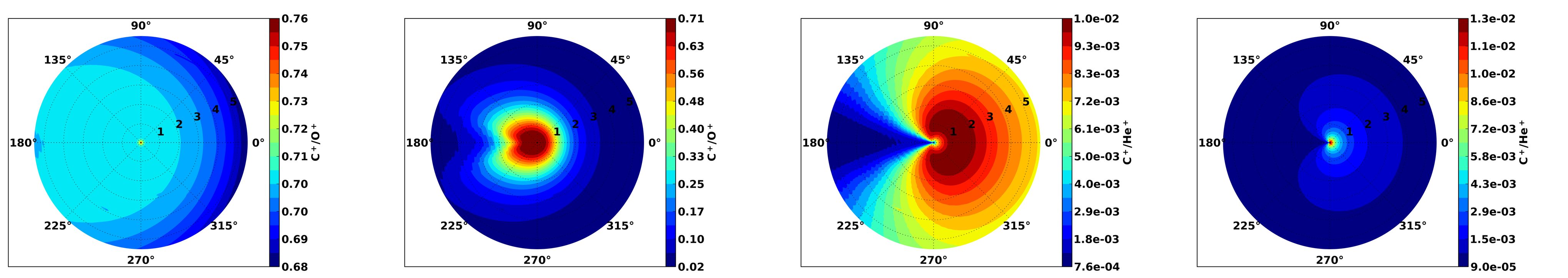
$0.08 \le w \le 0.2$ | $0.5 \le w \le 1.0$ | $0.08 \le w \le 0.2$ | $0.5 \le w \le 1.0$

Solar Minimum, $u = 425$ km/s



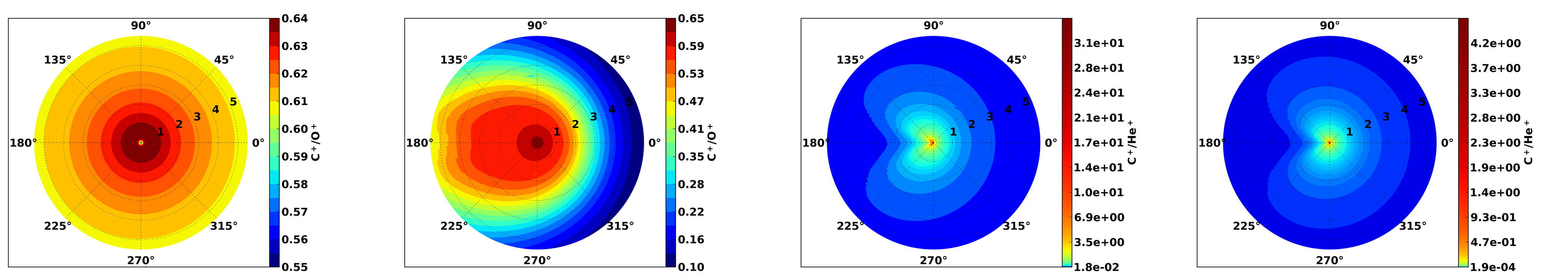
$0.08 \le w \le 0.2$ | $0.5 \le w \le 1.0$ | $0.08 \le w \le 0.2$ | $0.5 \le w \le 1.0$

Solar Minimum, $u = 525$ km/s



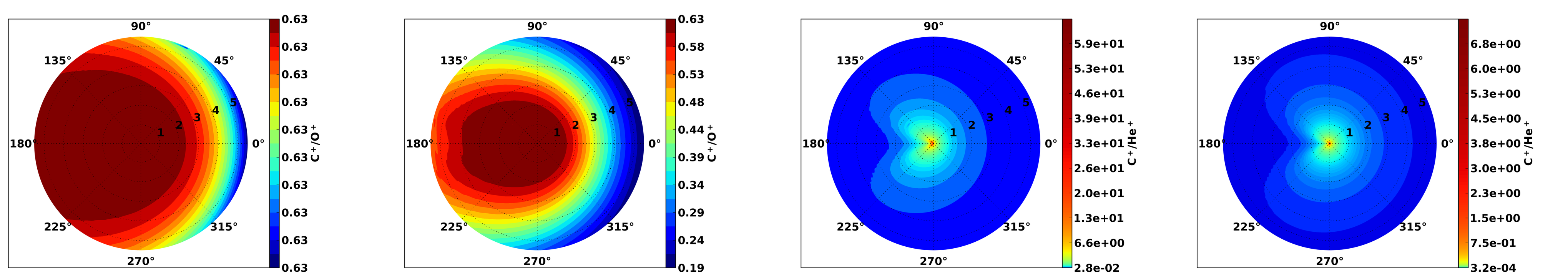
$0.08 \le w \le 0.2$ | $0.5 \le w \le 1.0$ | $0.08 \le w \le 0.2$ | $0.5 \le w \le 1.0$

Solar Maximum, $u = 325$ km/s



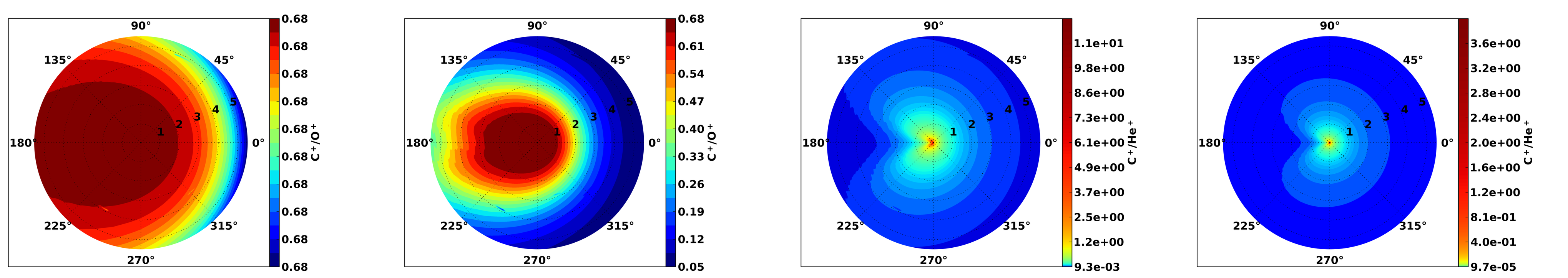
$0.08 \le w \le 0.2$ | $0.5 \le w \le 1.0$ | $0.08 \le w \le 0.2$ | $0.5 \le w \le 1.0$

Solar Maximum, $u = 425$ km/s



$0.08 \le w \le 0.2$ | $0.5 \le w \le 1.0$ | $0.08 \le w \le 0.2$ | $0.5 \le w \le 1.0$

Solar Maximum, $u = 525$ km/s



$0.08 \le w \le 0.2$ | $0.5 \le w \le 1.0$ | $0.08 \le w \le 0.2$ | $0.5 \le w \le 1.0$

Summary Thus Far

- More O^+ than C^+ is produced by solar wind recycling
- Solar wind recycling cannot be the sole mechanism behind inner source pickup ion production
- Must factor in the contributions of sputtering and solar wind neutralization
- Must factor in other dissociation processes that lead to additional O^+ and C^+