INNER SOURCE C^+/O^+ PICKUP IONS PRODUCED BY SOLAR WIND RECYCLING, NEUTRALIZATION, BACKSCATTERING, SPUTTERING, AND SPUTTERING-INDUCED RECYCLING

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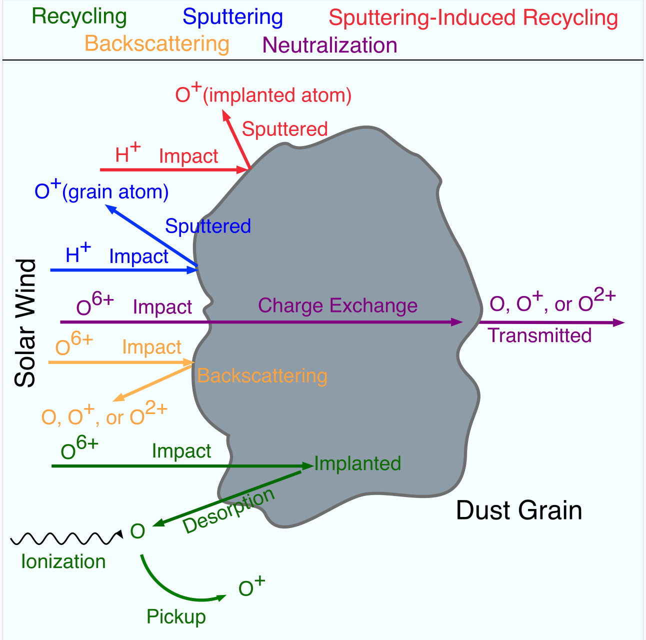
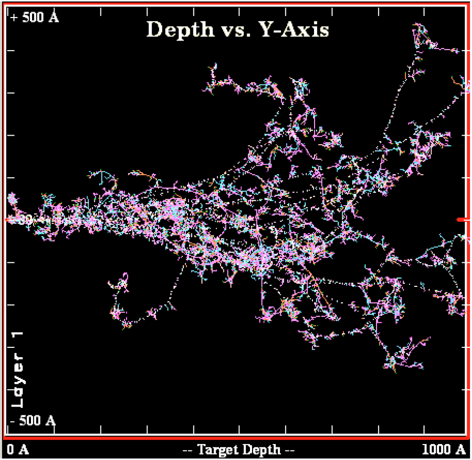
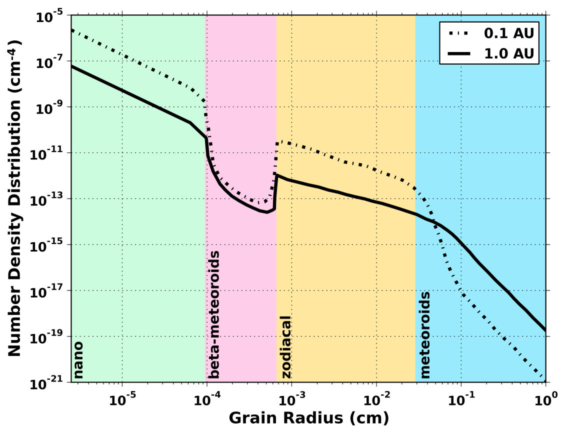


Recycling
Sputtering
Sputtering-Induced Recycling
Backscattering
Neutralization
O+(implanted atom)
Sputtered
H+ Impact
O+(grain atom)
Sputtered
H+ Impact
Solar Wind
O6+ Impact
Charge Exchange
O, O+, or O2+
Transmitted
O6+ Impact
Backscattering
O, O+, or O2+
O6+ Impact
Implanted
Desorption
O
Ionization
Pickup
O+
Dust Grain



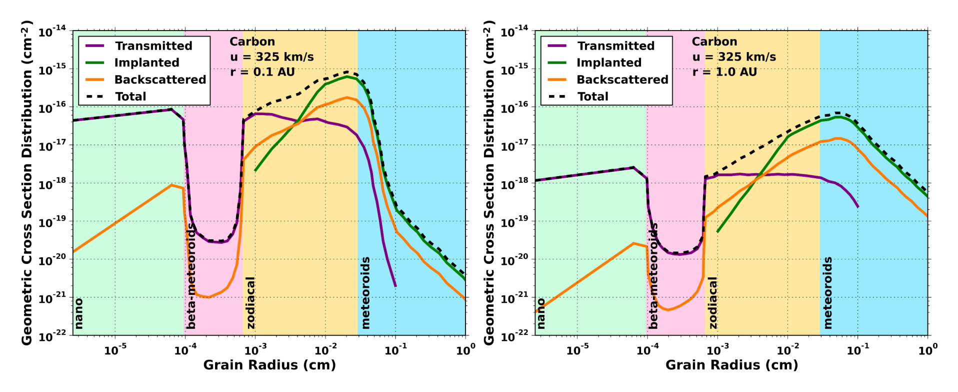
- C = 2.39
- O = 3.98
- Na = 0.056
- Mg = 1.015
- Al = 0.070
- S = 0.417
- Ca = 0.047
- Cr = 0.016
- Fe = 0.705
- Ni = 0.024

- Average chondritic IDP composition relative to Si.
- Consider fluffy IDPs with equivalent density of 0.001 g/cm^3.
- Use SRIM to simulate solar wind ions through grains of varying size to determine the percent of ions transmitted, implanted, backscattered, and the sputtering yield.



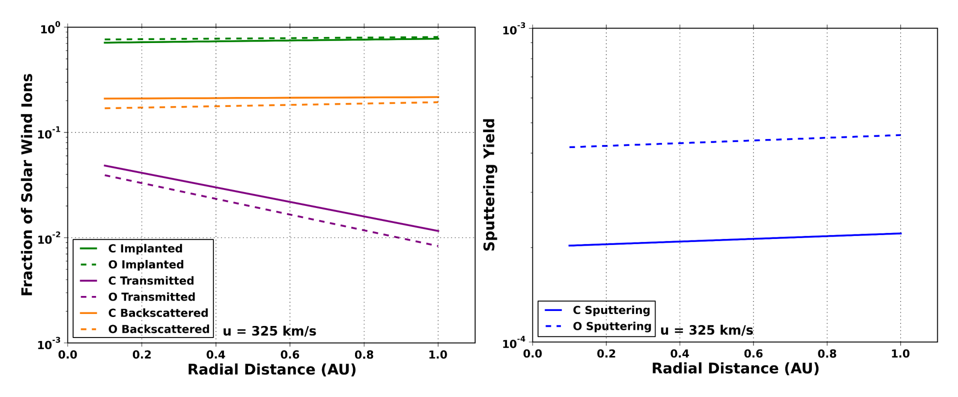
- Grains spiral toward the sun due to the Poynting-Robertson effect.
- Larger grains break apart into smaller grains due to dust-dust collisions.

SRIM RESULTS AND GRAIN GEOMETRIC CROSS SECTION DISTRIBUTION

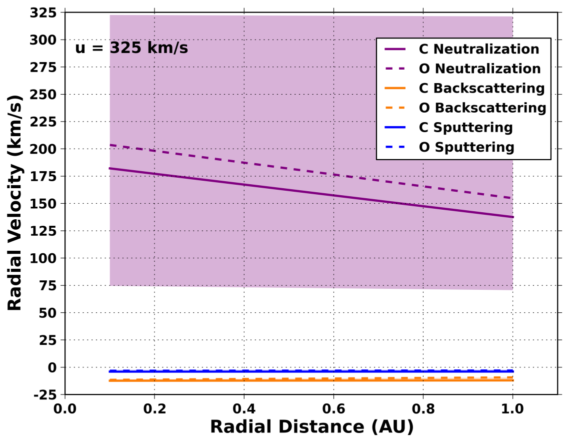


- $\Gamma(r, s) = n(r, s)\pi s^2$.

FRACTION OF PUIS PRODUCED - RADIAL DEPENDENCE

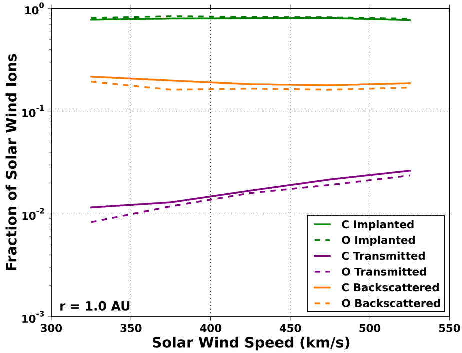


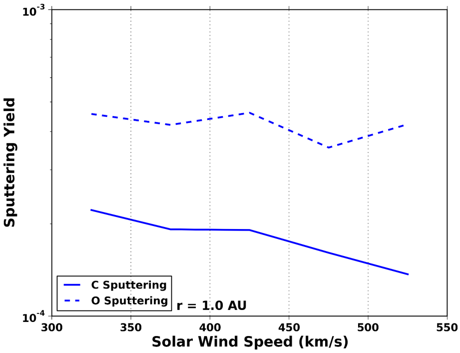
- Integrate over all grain sizes to get the total percent of PUIs produced for each mechanism.
  - $k_{\mathrm{N,R,B}}(r,u) = \int k_{\mathrm{N,R,B}}(r,s,u)n(r,s)\pi s^2 ds$
- Similarly for the sputtering yield.
  - $Y(r,u) = \int Y(r,s,u)n(r,s)\pi s^2 ds$



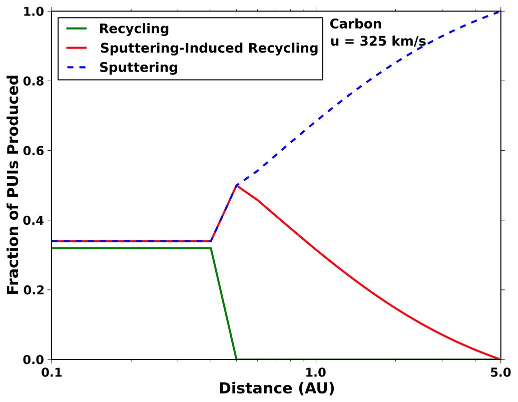
- Average radial velocity of PUIs weighted by $k_{\mathrm{N,B}}(r, u, s)$ or $Y(r, u)$ at each grain size.
- Shaded area is 1σ about the average radial velocity (very small for sputtering and backscattering).
- The velocity of recycled ions is that of the grain.

SOLAR WIND SPEED DEPENDENCE





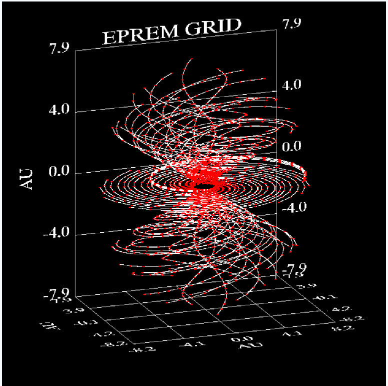
- Repeat entire process for solar wind speeds from 325 km/s to 525 km/s.
- Now we have the following as a function of distance from the sun and solar wind speed:
  - Fraction of PUIs transmitted (neutralization), implanted (recycling and sputtering-induced recycling), and backscattering, $k_{\mathrm{N,R,B}}(r, u)$
  - Sputtering yield, $Y(r, u)$.
  - Average radial velocity of ions after production, $v_{\mathrm{N,R,B,S}}(r, u)$.



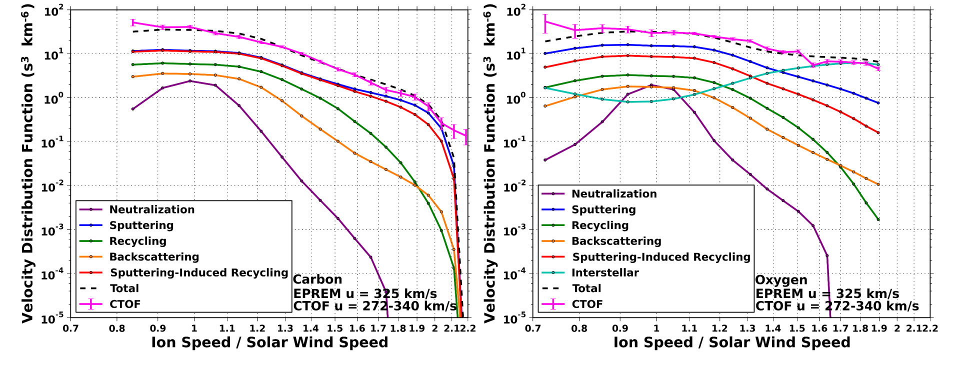
- Fraction of PUIs produced by recycling, sputtering, and sputtering-induced recycling, $\kappa_{\mathrm{R,S,SIR}}(r, u)$

- Saturation
  - Saturation occurs when a one-to-one correlation between implanted solar wind ions and dust grain atoms is reached.
  - Solar wind flux close to the sun is high enough to saturate grains during their Poynting-Robertson lifetime.
- Dissociation
  - Implanted C and O form compounds with implanted H.
  - Assume that C is desorbed as CH and O is desorbed as OH.
  - $CH \rightarrow C + H$ or $CH \rightarrow CH^+ + e^-$.
- Sputtering-Induced Recycling
  - Once ions are implanted, they have a chance of being sputtered.
  - Within the saturation zone, there's 50% of sputtering a grain atom or implanted ion.

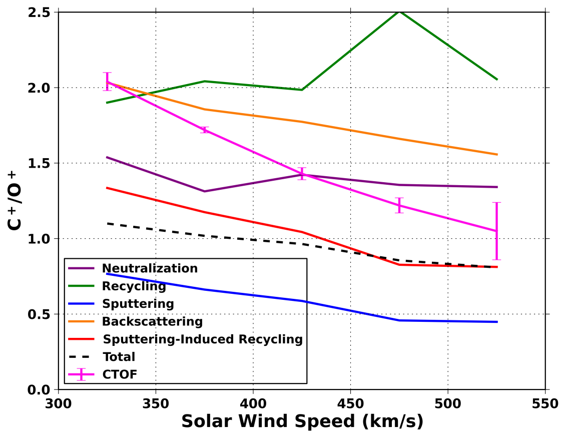
- $S_{\mathrm{R}}^{+}(r,u) = \kappa_{\mathrm{R}}(r,u) k_{\mathrm{R}}(r,u) S_{\mathrm{impact}}(r) P^{+}(r) \left[\left(\frac{\beta_{\mathrm{diss}}}{\beta_{\mathrm{diss}} + \beta_{\mathrm{ion}}} \right) \left(\frac{\beta_{\mathrm{ion}}^{0}}{\beta_{\mathrm{ion}}^{0} + \beta_{\mathrm{ion}}^{+}} \right) + \left(\frac{\beta_{\mathrm{ion}}}{\beta_{\mathrm{diss+ion}}} P_{\mathrm{diss}}(r) \right) \right]$
- $S_{\mathrm{N}}^{+}(r,u) = k_{\mathrm{N}}(r,u) S_{\mathrm{impact}}(r) \left[\eta^{+} P^{+}(r) + \eta^{0} P^{0}(r) \right]$
- $S_{\mathrm{B}}^{+}(r,u) = k_{\mathrm{B}}(r,u) S_{\mathrm{impact}}(r) \left[\eta^{+} P^{+}(r) + \eta^{0} P^{0}(r) \right]$
- $S_{\mathrm{S}}^{+}(r,u) = \kappa_{\mathrm{S}}(r,u) Y(r,u) S_{\mathrm{impact}} P^{+}(r)$
- $S_{\mathrm{SIR}}^{+}(r,u) = \kappa_{\mathrm{SIR}}(r,u) Y(r,u) S_{\mathrm{impact}} P^{+}(r) \left[\left(\frac{\beta_{\mathrm{diss}}}{\beta_{\mathrm{diss}} + \beta_{\mathrm{ion}}} \right) \left(\frac{\beta_{\mathrm{ion}}^{0}}{\beta_{\mathrm{ion}}^{0} + \beta_{\mathrm{ion}}^{+}} \right) + \left(\frac{\beta_{\mathrm{ion}}}{\beta_{\mathrm{diss+ion}}} P_{\mathrm{diss}}(r) \right) \right]$
- $S_{\mathrm{I}}^{+}(r,\theta) = \beta_{\mathrm{ion}}^{0} \left(\frac{r_1}{r} \right)^{2} n_{\mathrm{O}}(r,\theta) P^{+}(r)$



VDF COMPARISON TO CTOF



- Compare EPREM to SOHO/CTOF at 1 AU.
- Method from Taut et al. 2015 is used to derive normalized count rates of C^+ and O^+ as a function of $w = v/u$.
- **New constraint - broad VDF at 1 AU with possible cutoff near $w = 2$.** Implies PUIs near 1 AU are produced with near zero speed.



- Recycling $C^+/O^+ > 1$ due to dissociation rate of CH being much higher than OH.
- Sputtering-Induced Recycling $C^+/O^+ > 1$ for slow solar wind speeds but is just below 1 for higher speeds.
- Total $C^+/O^+ > 1$ for slow solar wind speeds and now decreases with speed.

CONSTRAINTS

Constraint	Recycling	Neutralization	Backscattering	Sputtering	Sputtering-Induced Recycling
Broad VDF at 1 AU with cutoff near $w = 2$	No	Possibly	Yes	Yes	Yes
$C^+/O^+ > 1$	Yes	Yes	Yes	No	Mostly
Decreasing C^+/O^+ with u	No	Yes	Yes	Yes	Yes
Solar wind-like composition	Yes	Yes	Yes	No	Yes
Stability over the solar cycle	Yes	Unlikely	Yes	Yes	Yes

- Backscattering and SIR satisfy the most constraints, but the total C^+/O^+ ratio does not match CTOF due to the over-production of O^+.
- Possibility that silicate IDPs break down. For example $MgSiO_3 \rightarrow MgO + SiO_2$ where MgO has higher survivability near the sun.
- We test the production of sputtering from MgO IDPs. Results show a 30-40% decrease in O^+ production – making the total C^+/O^+ ratio about 1.37-0.95 for 325-525 km/s solar wind speed. These results move toward better agreement with CTOF.
- This suggests that the IDP composition may indeed change inside 1 AU.

- Determined a new constraint on the inner source PUI production mechanism: a broad VDF at 1 AU with possible cutoff near $w = 2$ which implies PUIs near 1 AU are injected into the solar wind at near zero speeds.
- Introduced two new mechanisms for inner source PUI production: backscattering and sputtering-induced recycling.
- Backscattering and sputtering-induced recycling satisfy the most constraints.
- The dominant mechanisms (based on intensity) are sputtering and sputtering-induced recycling.
- The composition of our simulated PUIs does not perfectly agree with CTOF observations most likely due to the high production of sputtered O^+. We showed that a change in IDP composition may reduce the amount of sputtered O^+ and agrees better with CTOF. Observational evidence of PUI composition and dust grain composition inside 1 AU is necessary to investigate this idea further.