|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **b/R** | **p**  **(mbar)** | **T**  **(K)** | **Size**  **(mm)** | Shape | **v**  **(m/s)** | **Phase** | **Porosity** | **Surface** | **Sticking**  **Probability** | **Threshold**  **Velocity** | **Threshold**  **Size** |
|  | 2016 Musiolik: free-falling aggregates (vertically, 1g), mix of vapour deposition & grain sticking | | | | | | | | | | | |
|  | 0 | ≈ 1 | 80 | 0.09 ± 0.02 | irregular | ≤ 1 | crystalline | high | irregular | ≈ 65 % at all v | blurry |  |
|  | 2016 Deckers: projectile fired by launcher (horizontally, 1g), solid ice frozen in moulds at 255.8 K | | | | | | | | | | | |
|  | 0 | 1013 | 256 | < 2 (p)  120 x 129 (t) | irregular (p)  cylindrical (t) | 0.2 - 50 | crystalline | low | rough | few cases | < 1 m/s  blurry | < 0.5 mm |
|  | 2015 Gundlach: particle impact on target (gas flow driven, horizontally, 1g), freezing μm-sized droplets in cold N2 atmosphere | | | | | | | | | | | |
|  | 0 | 1013  (production)  50 – 200  (path)  0.1 – 50  (collision) | 110 – 198  (p – production)  114 – 260  (p – collision)  80 – 133  (t – collision) | (2.9 ± 1.3) x 10-3 | spherical | 1 - 150 | probably  crystalline | 50 %  (aggregates)  0 %  (particles) | diffuse | threshold  velocity | below  210 K:  9.6 m/s  above:  increasing  with T |  |
|  | 2014 Hill: microgravity collisions (particles frozen in liquid nitrogen) | | | | | | | | | | | |
|  | 0 – 1 | 10-5  (collision)  1013  (production) | 130 – 160  (collision)  77  (freezing) | 5  4.7 – 10.8 | spherical  fragments | 0.26 – 0.51 | hexagonal  polycrystalline | low | rough  unfrosted | 0 |  |  |
|  | 2012 Shimaki: microgravity-like collisions (projectile + target free-falling), μm-sized droplets frozen in liquid N2, pressed into moulds, sintered (15 min – 2 days) | | | | | | | | | | | |
|  | ≤ 0.12 | 1013 | 263  (collision)  77  (freezing) | 10 – 100 (p/t)  (21 ± 15) x 10-3  (ice particles) | spherical (p/t)  cylindrical (t) | 0.44 – 4.12 | crystalline | 40 – 80 % | rough  frosted  “smooth” | dominant  for porosity  > 70 % |  |  |
|  | 2012 Shimaki: μg-like collisions (projectile free-falling or fired (gas/spring gun), target free-falling), μm-sized droplets frozen in LN2, pressed into moulds, sintered (1 h – 1 month) | | | | | | | | | | | |
|  | 0 | 1013  (v < 300 m/s)  < 100  (v > 300 m/s)  ≤ 104 (pressing) | 258  (collision)  77  (freezing) | 10 – 15 (p)  60 (t)  (28 ± 12) x 10-3  (ice particles) | cylindrical (p)  spherical (p/t) | 2.4 - 489 | crystalline | 0 – 30 % (p)  40 – 70 % (t) | rough  frosted  “smooth” | 0 |  |  |
|  | 2010 Heißelmann: microgravity collisions (particles frozen in moulds in kitchen freezer) | | | | | | | | | | | |
|  | 0 – 0.5 | 10-5  (collision)  1013  (production) | 130 – 180  (collision)  255  (freezing) | 15 | spherical | 0.06 – 0.22 | hexagonal | low | rough  unfrosted | 0 |  |  |
|  | 1995 – early 2000’s Arakawa, Kato, Ryan: various cratering and disruption studies | | | | | | | | | | | |
|  |  |  |  |  |  | ≈ 100 |  |  |  | 0 |  |  |
|  | 1998 Higa: free-fall into larger target (particles frozen then melted into spheres in moulds or composed of sub-mm spheres), multiple collisions | | | | | | | | | | | |
|  | 0 | 1013 | 261  (collision/storage)  77 / 288 - 298  (production) | 2.8 – 72 (p)  100 – 280 (t) | spherical (p)  cubic (t) | 0.01 - 10 | polycrystalline |  | unfrosted  “smooth”  rough | 0 |  |  |
|  | 1996 Bridges: disk-pendulum (1D-motion) and flat target | | | | | | | | | | | |
|  | 0 | 1013  (collision)  195  (frost deposition) | 110 – 150  (collision)  100 – 110  (frost deposition) | 50 | spherical (p)  flat block (t) | (0.2 – 5) x 10-3 | crystalline | low | frosted  300 μm thick | decreasing  with  increasing  velocity | 0.003 m/s |  |
|  | 1996 Higa: free-fall into larger target (particles frozen then melted into spheres in moulds), multiple collisions | | | | | | | | | | | |
|  | 0 | 10 | 113 – 269  (collision)  263  (storage)  288 - 298  (production) | 30 (p)  90 – 100 (t) | spherical (p)  block (t) | 0.01 - 7 | crystalline | low | smooth  (polished)  unfrosted  & frosted | 0 |  |  |
|  | 1996 Dilley: 2 pendula (long lines) (particles frozen in moulds) | | | | | | | | | | | |
|  | 0 | 1013 | 255 | 40, 48, 60, 101 | spherical | 0.01 | crystalline | low | “smooth”/  variety of frost  conditions | 0 |  |  |
|  | 1995 Supulver: disk-pendulum (2D-motion) and flat target (particles frozen in moulds) | | | | | | | | | | | |
|  | 0 / 1 | 1013 | 100  (collision)  255 / 270  (production) | 50 | spherical (p)  block (t) | (0.5 – 14) x 10-3 | crystalline | low | “smooth”  (> 200 μm)  unfrosted | 0 |  |  |
|  | 1991 Hatzes:disk-pendulum (1D-motion) and flat target (particles frozen in moulds, some frosted) | | | | | | | | | | | |
|  | 0 | 1013  (collision)  few  (frosting) | 130  (collision)  90 – 150  (frosting) | 50 | spherical (p)  block (t) | (0.1 – 20) x 10-3 | crystalline | low | “smooth”/  frosted  10 – 75 μm  thick | 1  below  threshold  0  above | 0.001 m/s |  |
|  | 1989 McDonald: disk-pendulum (1D-motion) and flat target | | | | | | | | | | | |
|  | 0 | 988 | 100 - 150 | 50 | spherical (p)  block (t) | (5 – 20) x 10-3 | crystalline | low | “smooth”/  very rough  (0.1 – 0.4 mm) | 0 |  |  |
|  | 1988 Hatzes: disk-pendulum (1D-motion) and flat target (particles frozen in moulds, some frosted, some roughened by sublimation) | | | | | | | | | | | |
|  |
|  | 0 | 1.3 x 10-5 - 1013 | 85 – 140  (collision)  200 – 220  (sublimation)  130 – 150  (frost deposition) | 50  (and different  radii of curvature:  25, 50, 100, 200) | spherical (p)  block (t) | (0.15 – 20) x 10-3 | crystalline  cubic frost | low | “smooth”/  rough/  frosted | 0 |  |  |
|  |
|  | 1984 Bridges: disk-pendulum (1D-motion) and flat target | | | | | | | | | | | |
|  | 0 | 1013 | 150 - 175 | 55 (p) | spherical (p)  block (t) | (0.15 – 51) x 10-3 | crystalline | low | minimal frost  “smooth”  rough | 0 |  |  |
|  | 1983 Kawakami: various cratering and disruption studies | | | | | | | | | | | |
|  |  |  |  |  |  | ≈ 100 |  |  |  | 0 |  |  |

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sticking | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Size** | **Velocity** | | | **Threshold** | | | | **Sticking** | | **COR** | | | **Shape** | | | | | | **p** | **T** | **Method** | | | **Gravity** | | | **Paper** | | | |
| **(μm)** | **(m/s)** | | | **(m/s)** | | | | **Probability** | |  | | |  | | | | | | **(mbar)** | **(K)** |  | | |  | | |  | | | |
| < 500 (stick)  < 2000 (exp) | 0.2 – 50 | | | 1 | | | blurry | 60 %  (3 of 5) | | scatter: ± 0.05  range: 0.05 – 0.45  size ↑ => ε ↑  v ↑ => ε ↓ | | | irregular fragment  cylindrical target | | | | | | 1013 | 256 | projectile launched horizontally  ice frozen in moulds (256 K) | | | 1 g | | | Deckers | | | 2016 |
| ≈ 90 | ≤ 1 | | | none | | | blurry | 65 % (all v) | | range: 0 – 0.4  uniform distribution | | | irregular aggregate | | | | | | ≈ 1 | 80 | free-falling aggregates  mix of vapour deposition & grain sticking | | | 1 g | | | Musiolik | | | 2016 |
| ≈ 2.9 | 1 – 150 | | | 9.6  -> 50 | | | blurry | ≈ 60 – 70 % | | not measured | | | spherical projectile  flat target | | | | | | 0.1 - 50 | ≤ 210  > 210 | particle driven by gas flow (horizontally)  droplets frozen in liquid Nitrogen | | | 1 g | | | Gundlach | | | 2015 |
| ≈ 21  1 – 10 cm | 0.44 – 4.12 | | | none | | | blurry | dominant for porosity > 70 % | | scatter: ± 0.05  range: 0 – 0.25  poros. ↑ => ε ↓  v ↑ => ε → (?)  b/R ↑ => ε → | | | spherical projectile  spherical / cylindrical target | | | | | | 1013 | 263 | projectile (first) + target free-falling  droplets frozen in LN2, aggregates (mould-pressed) | | | 0 g | | | Shimaki | | | 2012 |
| 300 thick (frost)  5 cm | 0.0002 – 0.005 | | | 0.003 | | | blurry | ≈ 20 %  (8 of 38) | | scatter: ± 0.1  range: 0.5 – 0.9  T ↑ => ε →  p ↑ => ε →  v ↑ => ε ↓ | | | spherical projectile  flat target | | | | | | 1013 | 110 - 150 | 1D disk pendulum + flat target  frosted surfaces | | | 1 g | | | Bridges | | | 1996 |
| 10 – 75  thick (frost)  5 cm | 0.0001 – 0.02 | | | 0.001 | | | clear | 100 % | | frost reduces ε by ≈ 25 % w.r.t smooth surface | | | spherical projectile  flat target | | | | | | 1013 | 130 | 1D disk pendulum + flat target  particles frozen in moulds  frosted surfaces | | | 1 g | | | Hatzes | | | 1991 |
|  |  | | |  | | |  |  | |  | | |  | | | | | |  |  |  | | |  | | |  | | |  |
| No Sticking (but rough/frosted surfaces) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Size** | | | **Velocity** | | **COR** | | | | **Shape** | | | **p** | | | **T** | | **Method** | | | | | **Gravity** | | | **Paper** | | | | | |
| **(cm)** | | | **(m/s)** | |  | | | |  | | | **(mbar)** | | | **(K)** | |  | | | | |  | | |  | | | | | |
| 4 – 10.1 | | | 0.01 | | scatter: ± 0.1  range: 0.2 – 0.9  mass ↑ => ε ↑  velocity ↑ => ε ↓ | | | | spherical | | | 1013 | | | 255 | | 2 pendula (long lines)  particles frozen in moulds  frosted (various unknown conditions) | | | | | 1 g | | | Dilley | | | 1996 | | |
| 3 | | | 0.3 – 2.8 | | scatter: ± 0.15  range: 0.3 – 0.9  T ↑ => ε →  v ↑ => ε ↑ (bounce)  v ↑ => ε ↓ (fragm.) | | | | spherical  block target | | | 10 | | | 113 – 215 | | free-fall into flat target, multiple impacts  p. frozen as cubes -> melted in moulds  frosted surface (unknown thickness) | | | | | 1 g | | | Higa | | | 1996 | | |
| 5  (radii of curvature: 2.5 – 20) | | | 0.00015 – 0.02 | | scatter: ± 0.2  range: 0.3 – 1  frost ↑ => ε ↓  roughness ↑ => ε ↓  (frost effect stronger) | | | | spherical  block target | | | 10-5 – 1013 | | | 85 – 140 | | 1D disk pendulum + flat target  particles frozen in moulds  frosted (unknown thickness) /  roughened by sublimation | | | | | 1 g | | | Hatzes | | | 1988 | | |
| 5 | | | 0.005 – 0.02 | | not measured  (mass transfer exp.) | | | | spherical  block target | | | 988 | | | 100 – 150 | | 1D disk pendulum + flat target  roughened by wire brush (100 – 400 µm) | | | | | 1 g | | | McDonald | | | 1989 | | |
|  |  | | |  | | |  |  | |  | | |  | | | | | |  |  |  | | |  | | |  | | |  |
| No Sticking | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Size** | | **Velocity** | | | | **COR** | | | | | **Shape** | | | **p** | | **T** | | **Method** | | | | | **Gravity** | | | **Paper** | | | | |
| **(cm)** | | **(m/s)** | | | |  | | | | |  | | | **(mbar)** | | **(K)** | |  | | | | |  | | |  | | | | |
| 0.5  0.47 – 1.08 | | 0.26 – 0.51 | | | | range: 0.08 – 0.87  uniform distribution  T ↑ => ε →  v ↑ => ε →  b/R ↑ => ε → | | | | | spherical /  irregular fragment | | | 10-5 | | 130 – 160 | | parabolic flight  particles frozen in liquid Nitrogen | | | | | 0 g | | | Hill | | | 2014 | |
| 1.5 | | 0.06 – 0.22 | | | | range: 0.06 – 0.84  uniform distribution  v ↑ => ε →  b/R ↑ => ε → | | | | | spherical | | | 10-5 | | 130 – 180 | | parabolic flight  particles frozen in moulds (2555 K) | | | | | 0 g | | | Heißelmann | | | 2010 | |
| 1 – 1.5 | | 2.4 – 300 | | | | range: 0.014 – 0.08  poros. ↑ => ε ↓ | | | | | cylindrical projectile  spherical target | | | 1013 | | 263 | | target free-falling, projectile f.f. or fired  droplets frozen in LN2, pressed in moulds | | | | | 0 g | | | Shimaki | | | 2012 | |
| 0.28 – 7.2 | | 0.01 – 10 | | | | scatter: ± 0.15  range: 0 – 1  size ↑ => ε ↑  v ↑ => ε → (bounce)  v ↑ => ε ↓ (fragm.) | | | | | spherical  cubic target | | | 1013 | | 261 | | free-fall into flat target, multiple impacts  p. frozen as cubes -> melted in moulds | | | | | 1 g | | | Higa | | | 1998 | |
| 3 | | 0.01 – 7 | | | | scatter: ± 0.1  range: 0 – 1  T ↑ => ε →  v ↑ => ε → (bounce)  v ↑ => ε ↓ (fragm.) | | | | | spherical  block target | | | 10 | | 245 – 269 | | free-fall into flat target, multiple impacts  p. frozen as cubes -> melted in moulds | | | | | 1 g | | | Higa | | | 1996 | |
| 5 | | 0.0005 – 0.014 | | | | scatter: ± 0.1  range: 0.5 – 0.95  v ↑ => ε ↓ | | | | | spherical  block target | | | 1013 | | 100 | | 2D disk pendulum + flat target  particles frozen in moulds | | | | | 1 g | | | Supulver | | | 1995 | |
| 5  (radii of curvature: 2.5 – 20) | | 0.00015 – 0.02 | | | | scatter: ± 0.1  range: 0.3 – 1  T ↑ => ε →  p ↑ => ε →  radius o. cur. ↑ => ε →  v ↑ => ε ↓ | | | | | spherical  block target | | | 10-5 – 1013 | | 85 – 140 | | 1D disk pendulum + flat target  particles frozen in moulds | | | | | 1 g | | | Hatzes | | | 1988 | |
| 5.5 | | 0.00015 – 0.051 | | | | scatter: ± 0.1  range: 0.25 – 0.9  v ↑ => ε ↓ (≤ 1 m/s)  v ↑ => ε → (> 1 m/s) | | | | | spherical  block target | | | 1013 | | 150 – 175 | | 1D disk pendulum + flat target | | | | | 1 g | | | Bridges | | | 1984 | |