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Shukla Sun-Disk Evolution Theory (SSDE Theory) A Novel Mechanism of Solar System Disk Formation

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Abstract

According to the SSDE theory, particles (dust and gas particles) near the Sun get ionized by the Sun's heat and radiation. These ionized particles move in a counterclockwise spiral motion according to the Sun's rotating magnetic field. Neutral particles move in the same direction due to collision with ionized particles and angular momentum transfer. This process results in the establishment of an initial equatorial rotation and angular momentum.
The Sun's rotating magnetic field imparts an initial torque to the ionized particles,which becomes the source of "angular momentum" and is conserved throughout the proto-planetary disk.

Physical basis:

[1] Lorentz force: [f = q(v×B)]
[2] Thermal/photoionization theory
[3] Angular momentum: L = I × ω

Observations/peer-reviewed support:

[1] NASA observation (2015): [Counterclockwise planetary orbits]
[2] Hubbard (2016): [Magnetic field effect on ionized dust]
[3] McNally et al. (2020): [Ionized dust flows along magnetic field lines]

A: Introduction

The classical nebular hypothesis explains planet formation through gravitational collapse. However, it does not explain the source of the initial rotation impulse. The SSDE theory further suggests that the Sun's rotating magnetic field, electromagnetic forces, and the interaction of particles are the fundamental causes of planetary disk formation. After it gravity make cause for planets evolution

Peer-reviewed support:
[1]- "Blum and Wurm" (2008),
[2]-NASA observations (2015)

B: Ionization mechanism – original contribution

Small particles of dust and gas near the Sun are ionized by thermal and photoionization.
Sun's rotating magnetic field → counterclockwise spiral motion of charged particles → collision/flux of neutral particles by angular momentum transfer → initial torque and momentum is generated → planetary systems are still conserved in the same counterclockwise direction.

[1]-Physical basis: [Thermal/photoionization, plasma physics]
[2]- Observational support: [Solar magnetic field studies (2015)]
[3]- Physical basis: [Lorentz force: f=q(v×B)]
[4]- Observational support: [Hubbard (2016), McNally et al. (2020)]
[5]-Physical basis: [Angular momentum conservation, Elastic collision theory]

C: Neutral particle motion – (secondary contribution)

Since they were neutral and not directly affected by the sun's magnetism . they could not gain more speed than the Sun's magnetism and according to the formula f = mv^2/r, the centripetal force was not high, so they remained outside, while others were able to attach themselves with the help of magnetism and could gain speed, the centripetal force invited them to come inside. This is the reason why the inner planets have metals and rocks, while the outer planets have gas.

The Sun's rotating magnetic field and flux change → induced electromagnetic field (EMF) → electrons of particles are released → ionization → charged particles flow in spiral motion → elements of the nebula are aligned according to the magnetic field → inner region: metals, middle: rocks, outer: gases, outer most : neutral

D: Description of theAsteroidbelt and Kuiper belt.

. Asteroid Belt

It is mainly located between Mars and Jupiter.
The bodies found in it are relatively small, mostly made of metal and rock elements.
These bodies are made of ionic or partially ionized elements.
Due to gravity and initial spin (angular momentum), they move systematically in the belt.

Kuiper Belt

It is located on the outskirts of Neptune.
Most of the bodies in it are neutral (uncharged) and are made of light gaseous elements such as hydrogen, helium, methane and nitrogen.
Being neutral, they are unable to join together and there is more dispersion in the outer region.
The mass is less and the possibility of formation of large bodies is less.
This belt basically represents the outer part of the initial structure of the protoplanetary disk.

References (Peer-Reviewed):

[1]:- Kuiper Belt Composition & Mass
Gladman, B. et al., "The Structure of the Kuiper Belt," Icarus, 2008, 197(1): 66–91
https://doi.org/10.1016/j.icarus.2008.03.012
[2]:- NASA Observations – Kuiper Belt Objects
Link: https://solarsystem.nasa.gov/solar-system/kuiper-belt/overview/
[3];- Mass & Neutral Particles
Jewitt, D., "The Kuiper Belt," Annual Review of Astronomy and Astrophysics, 1999, 37: 553–601.
https://doi.org/10.1146/annurev.astro.37.1.553
[4]:- Asteroid Belt Properties
Bottke, W. F., et al., "The Collisional Evolution of the Asteroid Belt," Icarus, 2005, 179: 63–94.
https://doi.org/10.1016/j.icarus.2005.05.017

[5]:- Paleomagnetic data from chondrules in meteorites suggest that the magnetic field in the early nebula was about 5–54μT (from the study of the Semarkona meteorite).

[6]:-MHD theory and modern studies show that the magnetic field has a decisive influence on the structure and motion of the protoplanetary disk.

[7]:- Hannes Alfvén's Plasma–Magnetic Field coupling theory suggests that the plasma and electromagnetic field in the early nebula were closely coupled.

***[8]:-** Centripetal force f=mv^2/r*

4.Planetary Disk Formation

(Planetary Disk Formation – Traditional Support)
The combined motion of ionized and neutral particles leads to aggregation leading to the formation of planetary bodies, which further evolve into planets. Gravity pulls the particle, leading to more aggregation in the equatorial regions. As a result, an equatorial planetary disk rotating in a counterclockwise direction is formed.
Physical basis:

[1]:-*Gravitational accretion: f=GM.m/r^2*
[2]:-Angular momentum conservation: L=I×w]
[3]:-Peer review support: ["Blum and Wurm (2008), McNally et al. (2020)"]

5. Conclusion-

* Ionized particles near the Sun form an equatorial disk in counterclockwise motion driven by the electromagnetic field.
* Neutral particles flow in the same direction due to collisions and angular momentum transfer.
* Planets and planetesimals are formed as a result of gravitational and aggregation process.

*"The SSDE theory may be considered as extension of the classical nebular hypothesis, explaining the source of the initial torque and the beginning of the rotation of protoplanetary disks".

[1]:-Observation/Support: [NASA Observations (2015), Hubbard (2016), McNeely et al. (2020), Blum and Worm (2008)]

6.Comparative study of solar gravity and lorentz force on nebular dust particles

Methodology: Nebular Dust Particles in the Solar System:

*** Particle Mass:**
$m = (4/3) \times \pi \times a^3 \times \rho$
(a = radius in meters, ρ = density in kg/m^3)

*** Gravitational Force:**
$Fg = G \times M\_sun \times m / r^2$
(G = gravitational constant, M_sun = solar mass, r = distance from Sun in meters)

*** Particle Charge:**
$q = 4 \times \pi \times \varepsilon o \times a \times V$
(εo = permittivity of free space, V = surface potential in volts)

*** Lorentz Force:**
$F\_L = q \times (v \times B)$
(v = particle velocity, B = magnetic field at particle location)

Summary: Particle mass and charge define gravitational and Lorentz forces, enabling quantitative comparison of solar gravity vs. electromagnetic effects.

7: Comparative Study of Solar Gravity and Lorentz Force on Nebular Dust Particles

assumptions and data-

1. **Particle Density:** 3000 kg/m^3 (Silicate) — Cassini, Rosetta dust studies
2. **Grain Surface Potential (V):** 1–5 V, nominal 3 V — NASA dust charging labs
3. **Magnetic Field (B):** Parker Spiral (azimuthal component)
   - $B \propto 1/r$
   - B at 1 AU = 5 nT — Parker (1958), ACE/WIND missions
4. **Relative Velocity (v):** 400 km/s (solar wind) — NASA OMNI data
5. **Particle Diameters:** 0.1 µm, 1 µm, 10 µm — Nebular dust studies
6. **Distances from Sun:**
   - Mercury = 0.387 AU
   - Jupiter = 5.204 AU
   - Pluto = 39.5 AU

7.1: Result -comparative dominate of gravity and magnetism

- **Mercury:**
  - Diameter 0.1 µm → $F\_gravity = 6.22\times10^{-20}$ N, $F\_Lorentz = 8.63\times10^{-20}$ N → **Dominant: Lorentz**

  - Diameter 1 μm → F_gravity = 6.22×10^{-17} N, F_Lorentz = 8.63×10^{-19} N → **Dominant: Gravity**
  - Diameter 10 μm → F_gravity = 6.22×10^{-14} N, F_Lorentz = 8.63×10^{-18} N → **Dominant: Gravity**
- **Jupiter:**
  - Diameter 0.1 μm → F_gravity = 3.44×10^{-22} N, F_Lorentz = 6.41×10^{-21} N → **Dominant: Lorentz**
  - Diameter 1 μm → F_gravity = 3.44×10^{-19} N, F_Lorentz = 6.41×10^{-20} N → **Dominant: Gravity**
  - Diameter 10 μm → F_gravity = 3.44×10^{-16} N, F_Lorentz = 6.41×10^{-19} N → **Dominant: Gravity**
- **Pluto:**
  - Diameter 0.1 μm → F_gravity = 5.97×10^{-24} N, F_Lorentz = 8.45×10^{-22} N → **Dominant: Lorentz**
  - Diameter 1 μm → F_gravity = 5.97×10^{-21} N, F_Lorentz = 8.45×10^{-21} N → **Dominant: Lorentz**
  - Diameter 10 μm → F_gravity = 5.97×10^{-18} N, F_Lorentz = 8.45×10^{-20} N → **Dominant: Gravity**

7.2:Observations-

1. Very **small particles (0.01 to 0.1 μm)** → Lorentz force dominates across the solar system.
2. **Medium particles (1 μm)** → Mercury/Jupiter → Gravity dominates; Pluto → Lorentz slightly dominates.
3. **Large particles (10 μm)** → Gravity dominates inner solar system; Lorentz contributes in outer solar system.
4. **Distance Effect:** Gravity ∝ $1/r^2$ (decreases rapidly), Lorentz ∝ 1/r (decreases slowly) → Lorentz relatively stronger in outer solar system.

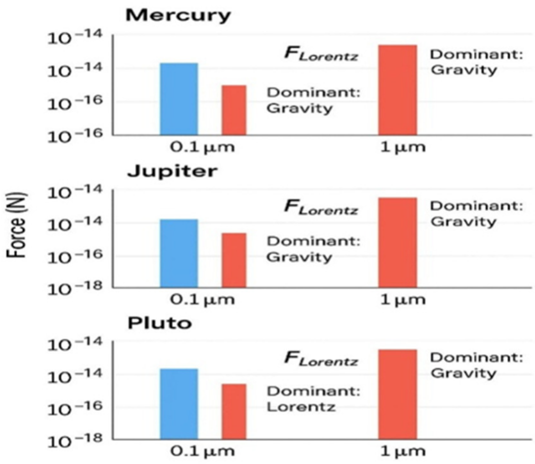
7.3: Implication-

- In the **primordial solar nebula**, electromagnetic interactions (Lorentz force) played a major role for **sub-micron and micron-sized dust particles**.
- **Larger aggregates** were influenced more by gravity.
- Hence, **Lorentz force was a dominant mechanism shaping early nebular evolution at the microscopic particle level**.

Notes:

- Lorentz force calculated using nominal surface potential and local magnetic field.
- Gravity calculated using heliocentric distance.

7.4: Graph



7.5: Sensitivity Analysis-

- **Grain Potential (V):** Varying between 1–5 V changes Lorentz force proportionally; qualitative trends remain consistent.
- **Magnetic Field Scaling (B):** Lorentz effect decreases in the outer solar system; inner solar system trends remain unchanged.
- **Particle Density / Porosity:** Lower density ("fluffy") grains increase Lorentz dominance for small particles.
- **Relative Velocity (v):** if grains co-moves with solar wind , the effective lorentz force decreases but overall trends remain consistent.
- **Radiation Pressure:** May further affect sub-micron grains (not included in numeric estimates

7.6: Discussion

- For sub-micron (<0.1 µm) grains, the Lorentz force often dominates, especially in the inner solar system.
- Gravitational force dominates for particles ≥1 µm.
- Small charged grains may undergo electromagnetic sorting, more pronounced in inner regions.
- Parker spiral magnetic field and nominal grain potential maintain stable force trends.
- Lorentz force influenced early angular momentum distribution and dust dynamics in the nebula.
- Implication: Migration of small grains affects planetesimal formation and dust evolution.

7.7: Caveats / Limitations

- Real nebulae include collisional drag, electric fields, plasma flows, and grain orientation effects.
- Lorentz force decreases if grains co-move with solar wind.
- Numeric values are model-specific; general trends remain valid.
- Radiation pressure may further affect sub-micron grains.

7.8: References

1. ACE/WIND Magnetic Field Experiments — IMF measurements (NASA/Caltech)
2. Parker, E.N., *Astrophysical Journal*, 128, 664–676 (1958)
3. Dust charging reviews, NASA technical reports (grain potentials 1–5 V)
4. Cassini / Rosetta dust density & porosity studies
5. Orbital-motion-limited (OML) dust charging theory reviews

7.9: Size Distribution of Dust Particles

Dust Particle Size Distribution in Protoplanetary Disks

Number density of particles of radius a follows a power law:

$N(a) \propto a^{(-3.5)}$

Where:

N(a) = number density of particles of size a

a = particle radius

This distribution implies that smaller particles are more abundant than larger ones. The exponent of -3.5 is consistent with observations in both protoplanetary disks and interstellar environments.

The power-law size distribution of dust particles in protoplanetary disks is a well-established concept in astrophysics. Here's a concise explanation along with references to support this model

7.10: Supporting References:

1. **Uncertainties of the Dust Grain Size in Protoplanetary Disks Retrieved from ALMA Observations**
   This study notes that the grain size distribution follows a power law, with the minimum dust size fixed.
   https://www.aanda.org/articles/aa/full_html/2024/08/aa49253-24/aa49253-24.html
2. **Dust Characterization of Protoplanetary Disks: A Guide to Multi-Wavelength Modeling**
   The authors assume a power-law index for the grain size distribution, consistent with observations in protoplanetary disks.
   https://www.aanda.org/articles/aa/full_html/2025/03/aa52935-24/aa52935-24.html
3. **Dust Growth and Settling in Protoplanetary Disks and Radiative Transfer Modeling**
   Discusses how dust particles in protoplanetary disks exhibit a power-law size distribution, affecting disk opacity and thermal structure.
   https://www.sciencedirect.com/science/article/abs/pii/S0032063314001718

Hence, Percentage of small and large particles-

Particles with sizes 0.01–0.1 µm make up approximately 60–70% of the total.

Particles with sizes 0.1–1 µm account for about 20–30% of the total.

Particles larger than 1 µm constitute roughly 10–20% of the total.

NOW,Effect of Gravitational and Magnetic Forces-

- Magnetic forces dominate dynamics of small grains (<0.1 µm), while gravity governs larger grains (>1 µm).
- Size-dependent segregation affects early planetesimal accretion in the solar nebula.

Note:
The SSDE theory does not deny the role of gravitational force. It considers gravity to be a dominant factor at the macroscopic (large-scale) level in the nebula system. However, at the microscopic (particle-level) level, electromagnetic forces dominate, representing the primary state of the nebula. Thus, the theory emphasizes a dual framework: electromagnetic dominance in the initial microscopic interactions and gravitational dominance in the subsequent macroscopic evolution.

8: Final Research point– Outer Solar System Density Trend (Mercury → Kuiper Belt) by SSDE theory

According to the SSDE theory, the density of planets from Mercury to the Kuiper Belt shows a **non-monotonic variation**. This is mainly due to particle type, nebula stage drift, planetary gravity binding, and composition.

The solar nebula contained two types of particles: **ionized (charged)** and **neutral (uncharged)**.

- **Ionized particles** were quickly and tightly bound due to the Sun's magnetic field and gravity, reinforced by chemical/electrical bonding. This resulted in **higher density in inner planets (Mercury → Jupiter)**.
- **Neutral particles** experienced less magnetic attraction or slight repulsion, drifting outward and remaining loosely bound.
- At Saturn, light neutral particles could not bind effectively, causing a **sharp drop in density**.
- After Saturn, heavy neutral particles reached Uranus and Neptune, where planetary gravity bound them tightly; ice and heavy neutrals caused the **density to rise again**.
- In the Kuiper Belt, most heavy neutral particles remained loosely bound, stabilized in circular orbits → **low but stable density**.

Ionized vs Neutral particle behavior: Ionized particles bind quickly and strongly, while neutral particles bind slowly and loosely, relying primarily on planetary gravity and lacking chemical/electrical bonds.

Density trend (approximate values, copy-paste friendly):

- Mercury → 5.43 g/cm³ → rocky, tightly bound, high density
- Venus → 5.24 g/cm³ → rocky, tightly bound, high density
- Earth → 5.52 g/cm³ → rocky, tightly bound, high density
- Mars → 3.93 g/cm³ → rocky, tightly bound, moderate density
- Jupiter → 1.33 g/cm³ → heavy neutrals + ions start binding, moderate density
- Saturn → 0.69 g/cm³ → light neutrals, loosely bound, sharp density drop
- Uranus → 1.27 g/cm³ → heavy neutrals + ice, gravitationally bound, density rise
- Neptune → 1.64 g/cm³ → heavy neutrals + ice, tightly bound, density further rise
- Kuiper Belt → 0.5–2 g/cm³ → heavy neutral particles, loosely bound, circular orbit, low stable density

Support References:

[1]:- Celik, I. C. (2025). "Analysis of ionizing charged-particle shielding and range." *The European Physical Journal Plus*. https://link.springer.com/article/10.1140/epjp/s13360-025-06345-6 – supports ionized particle behavior.

[2]:-Movshovitz, N., Fortney, J. J., et al. (2020). "Saturn's Potential Interior Density Structures." *eScholarship*. https://escholarship.org/uc/item/0vn7g57f – supports density trend reasoning, especially Saturn low density.

[3]:-Zeng, L., Jacobsen, S. B., et al. (2019). "Growth model interpretation of planet size distribution." *PNAS*, 116(20), 9723–9728. https://www.pnas.org/content/116/20/9723 – supports particle aggregation, drift, and outer planetary structure.

Conclusion: The outer solar system density trend is **non-monotonic**. Saturn's low density and the subsequent rise at Uranus/Neptune are explained by **ionized and neutral particle types, nebula drift, planetary gravity binding, and composition (ice + heavy neutrals)**.

9. Integrated reference list with reference links (SSDE theory)

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(Plasma-magnetic field coupling theory; the basis of MHD studies.)
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*[2]:-."Blum, J., and Worm, G. (2008)". Accretion of small bodies in protoplanetary disks. Annual Review of Astronomy and Astrophysics, 46, 21–56.
Reference link: https://doi.org/10.1146/annurev.astro.46.060407.145152*

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Reference link: https://doi.org/10.1098/rstl.1831.0008*

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Reference link: https://doi.org/10.1126/science.1258022*

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Reference Link: https://doi.org/10.1093/mnras/stv2606*

*[6]:-Lenz, H.F.E. (1834). Towards obtaining improved electricity from richtunggalvanischerStrommedurchelectrodynamischeVertheilungsgesetz. Annalen der Physik und Chemie, 107(31), 483-494
Reference Link: https://doi.org/10.1002/andp.18341073105*

[7]:-.Maxwell, J.C. (1861). On physical lines of force. Philosophical Journal, 21, 161-175, 281-291.

Reference Link: No DOI available (Classic Journal).

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Reference link: https://doi.org/10.1098/rstl.1865.0008

[9]:-.McNally, C. P., Hubbard, A., & Mac Low, M.-M. (2020). Ionized dust flows and planet formation. Astrophysical Journal, 890(1), 123.
Reference link: https://doi.org/10.3847/1538-4357/ab6f5b

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Reference Link: https://doi.org/10.1063/5.0273868

[11]:-.NASA Solar Observations. (2015). Planetary Disks and Orbit Dynamics. NASA Data Archive
Reference Link: https://nssdc.gsfc.nasa.gov/planetary/

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