# $^{26}$Al AND THE FORMATION OF INNER DISK ATMOSPHERE CONDENSATES.

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**Introduction:** Equilibrium condensation calculations [1] indicate that an alloy of the most refractory metals: W, Re, Os, Ir, Mo, Ru, Pt, and Rh would probably be the first condensate from a solar gas [2]. Concentrated levels of these elements with relative abundances consistent with equilibrium condensation were found in five submicron-sized refractory metal nuggets (RMNs) enclosed in spinel grains [3]. Berg et al. [4] isolated 458 RMNs from the Murchison meteorite and chemically analyzed 88 RMNs. All the RMNs were submicron in size, seemingly pristine, and had compositions consistent with equilibrium condensation. For an assumed pressure of 10 Pa, Berg et al. deduced maximum cooling rates of around 1 K/year between the condensation temperature range of 1620K and 1450K, thereby suggesting formation timescales of order one hundred years. As RMNs have, so far, only been found within CAIs, it is possible that RMNs may have acted as nucleation particles for CAI-like materials.

**The Inner Solar Accretion Disk:**

Given these constraints, the challenge is to find a region of the Solar Nebula (SN) where such cooling rates and gas pressures could be achieved. A schematic summary of the structure of the inner SN is given in Figure 1. Material from the inner disk accretes onto the star via stellar magnetic field lines [5]. Here, $R_t$ is the distance of the inner edge of the disk from the center of a star, where the stellar magnetosphere truncates the accretion disk [6].

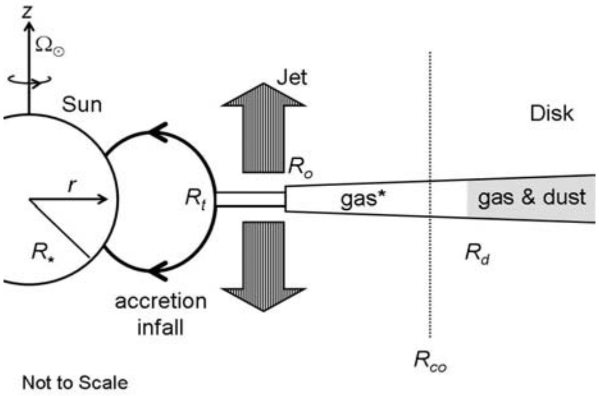

Figure 1: Length scales of the inner SN: $R_t$ - disk truncation radius, $R_*$- radius of a star/Sun, $R_o$ – outer radius of the jet flow, $R_{co}$ - co-rotation radius, $R_d$ - dust sublimation radius and $\Omega_\odot$ - angular rotational frequency of the Sun, $r$ and $z$ are the standard cylindrical coordinates. Silicate dust particles are destroyed for $R < R_d$. The "gas*" refers to gas and refractory particles. The case of $R_t < R_{co}$ is shown, where material accretes along stellar magnetic field lines.

**Infalling Gas – A source of condensate material:**

We can obtain an approximate expression for the pressure, $P_a$, of the infalling accreting gas in the near neighbourhood of the disk as a function of time, where it can be shown [7] that $P_a$ is proportional to $\dot{M}_a$, the mass accretion rate of the SN onto the Sun, where the average mass accretion rate is given by [8]

$$\dot{M}_a(t) \approx \dot{M}_a(t_0)\left(\frac{t}{t_0}\right)^{-\eta}, \qquad (1)$$

with $t > 10^4$ year, $t_0 = 10^6$ year, $\dot{M}_a(t_0) \approx 4\times10^{-8}\ \mathrm{M}_\odot\mathrm{yr}^{-1}$ and $\eta = 1.5$. Thus, for high accretion rates, we should expect relatively high average pressures that will decrease over time. This behaviour is shown in Figure 2.

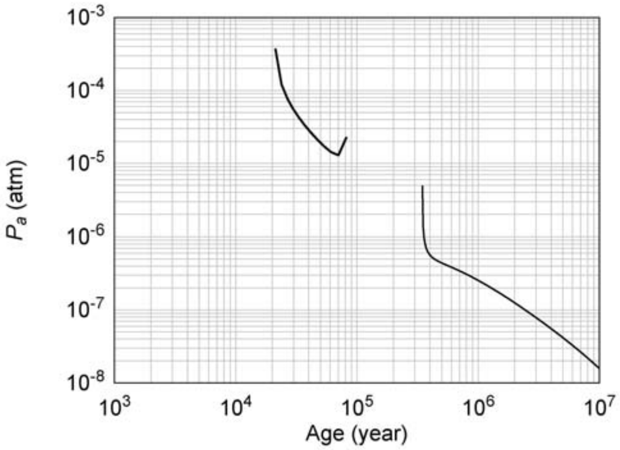

Figure 2: The pressure, $P_a$, of the infalling accreting gas as it leaves the inner radius of the accretion disk as a function of the age of the SN. The gaps in the pressure distribution are due to $R_t/R_{co} > 1$ (when accretion is less likely). The pressures obtained between 20,000 and 80,000 years are compatible with CAI and AOA formation.

There are gaps in the pressure record due to times when $R_t > R_{co}$, a condition that makes accretion less likely. The pressures obtained in the accreting gas around the 20,000 to 30,000 year mark are similar to the $10^{-4}$ atmospheres (10 Pa) suggested for CAI/RMN formation ([4], [9]).

### The Atmosphere of the Inner Accretion Disk:

The infalling gas from the inner SN moved along the solar magnetosphere to accrete onto the proto-Sun. However, the expansion of the solar magnetosphere coupled with the production of a toroidal field in the inner SN could have produced a high temperature, rarefied atmosphere above the inner SN [7].

The solar radiation and the inner SN geometry produced a range of effective particle temperatures around the inner SN which are shown in Figure 3. Using these temperatures as surrogate gas temperatures, and the deduced atmospheric gas densities, gives a pressure range of 1 to 7 Pa above the inner SN (Figure 4) .

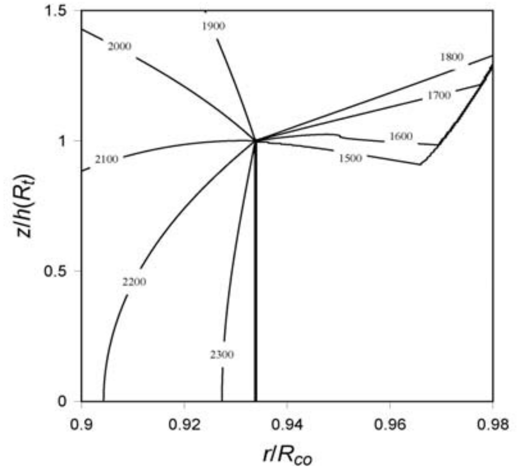

Figure 3: Contour plot of the effective particle temperature (K) around the inner accretion disk. The $z$ coordinate has been normalized to the isothermal scale height at the inner SN radius. The $r$ coordinate has been normalized to the co-rotation radius. The inner truncation radius is located at ~ $r/R_{co} = 0.934$.

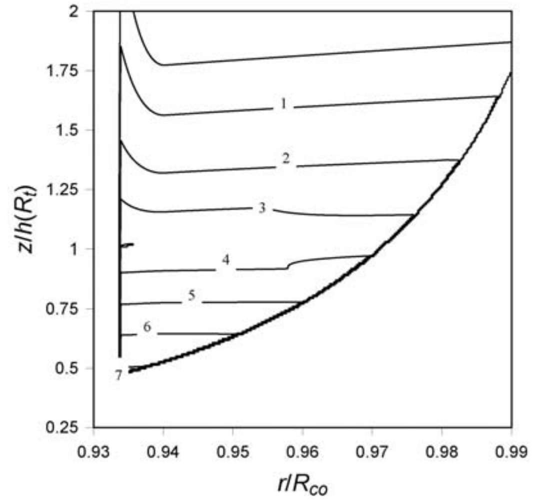

Figure 4: Estimated pressure in Pa above the inner accretion disk due to radial leakage of gas accreting onto the star.

### Temperature vs Time:

Radiation pressure from the proto-Sun (Figure 5) forced the submicron RMN away from the Sun. The interaction between the solar magnetosphere and the inner SN produced disk currents and toroidal magnetic fields which compressed the inner SN [10]. At the truncation radius, $R_t$, the compressive forces are released and the disk can increase in height, thereby producing a shadow region of decreased temperature (Figure 3). The resulting movement of the RMNs through the shadow region produces a decrease in temperature in a range of temperatures that can be consistent with observation [7].

**Conclusions**:

Between 20,000 and 30,000 years after the SN was formed, the pressures and temperatures near or at the base of the accretion column, that extended from the SN to the proto-Sun, were comparable with the canonical conditions for the formation of RMN and CAI. Such a short formation timescale can only imply that the, now extinct, $^{26}$Al found in some, but not all, CAIs was injected into the SN during this brief formation period. Some CAIs formed prior to and some after $^{26}$Al injection, thereby explaining the dichotomy of observed $^{26}$Al in CAIs.

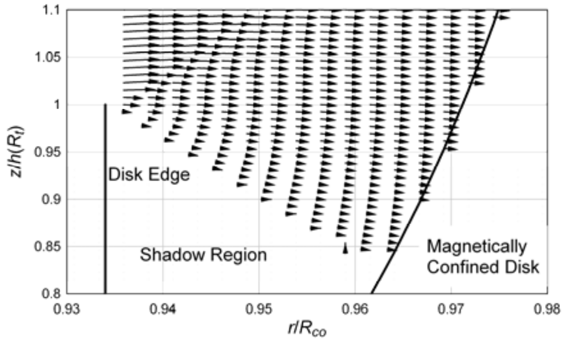

Figure 5: Radiation pressure vectors for radiation from the protoSun.

### References:

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