Planetesimal Formation in the Warm Inner Disk

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Abstract. In laboratory experiments we find that changes in composition of dust aggregates with increasing temperature are correlated to a strong increase in cohesive forces within the dust aggregates. We tempered samples of palagonite (JSC Mars-1a) for 1 hour at different temperatures and measured the tensile strength to the grains, where above 500 K the force per mass necessary to break contacts increase steadily.

Motivation. It is still unknown how elevated temperatures in the inner parts of protoplanetary disks influence the formation of planetesimals and no studies have been carried out concerning the analysis on the cohesive properties of a dust sample if the temperatures are varied between room temperature and melting of the high temperature minerals. Important to note is that particles in the inner disk most likely consist of a mix of different minerals due to mixing mechanisms like turbulence, photophoretic forces [1] and pressure driven inward drift [2]. So the key question about planetesimal formation within the inner 1 AU is:

Does the temperature change the sticking properties in a mix of different materials?

Cohesion Measurement. The dust samples consisting of palagonite (JSC Mars-1a) were heated at different temperatures (273 K - 1600 K, see Fig. 1) and studied at room temperature after cooling. The tensile strength was measured by inducing a dust flow through the dust bed, resulting in a force pulling at the surface grains. This flow is based on light induced temperature and pressure gradients within the dust bed [3]. The removal of dust (particle ejection rate) is critically depending on cohesive forces as follows [4]

$$N(g) = \frac{\Delta m}{\Delta t} = \frac{\omega_3}{g + \frac{F_C}{\Delta m}}$$

Hence, this effect can be used to measure the cohesive forces. As seen in Fig. 1 the erosion rate decreases strongly with higher temperature they were tempered at.

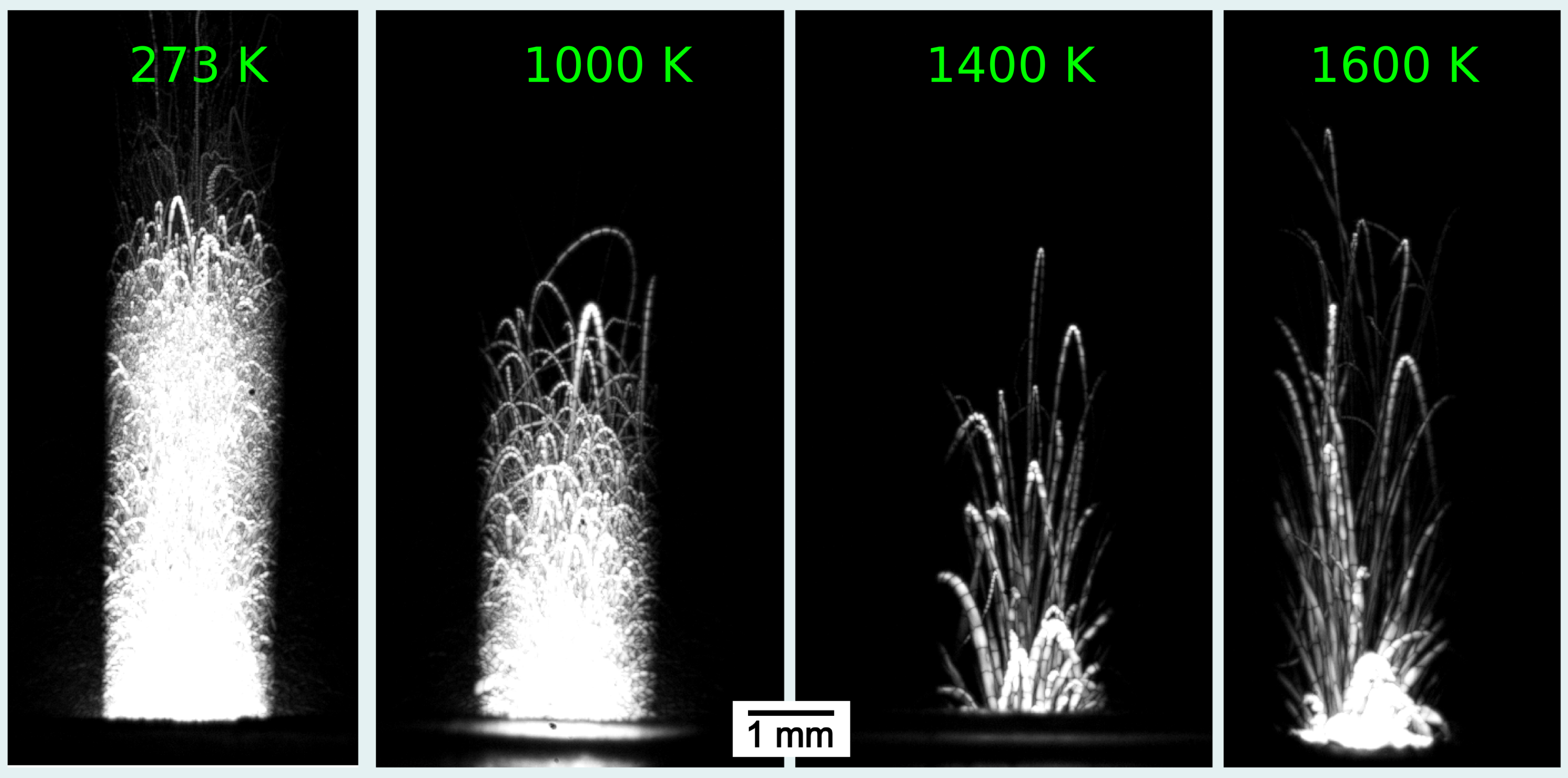

Fig 1: Strength of light induced dust removal (particle ejection rate), which is a measure of the cohesive force [4]. Here, Mars analog dust (JSC Mars-1a) was tempered at different temperatures for 1 hour; experiments are carried out at room temperature afterwards.

Dust Sample. The dust sample JSC Mars-1a consits of palagonitic tephra from regions near the Mauna Kea volcano (Hawaii). It contains a mixture of plagioclase feldspar, magnetite, olivine and pyroxene [5].

Structual Analyses. The mechanical properties of the dust particles in protoplanetary disks may depend on parameters like the degree of crystallization and homogeneity of its constituents, its composition and porosity.

Analyzing the variation of spectral areas versus heating temperatue, we find that iron-silicates (olivine and pyroxene) are present up to 1000-1200 K, while signs of increasing grain size and phase transitions to hematite starts at similar temperatures.

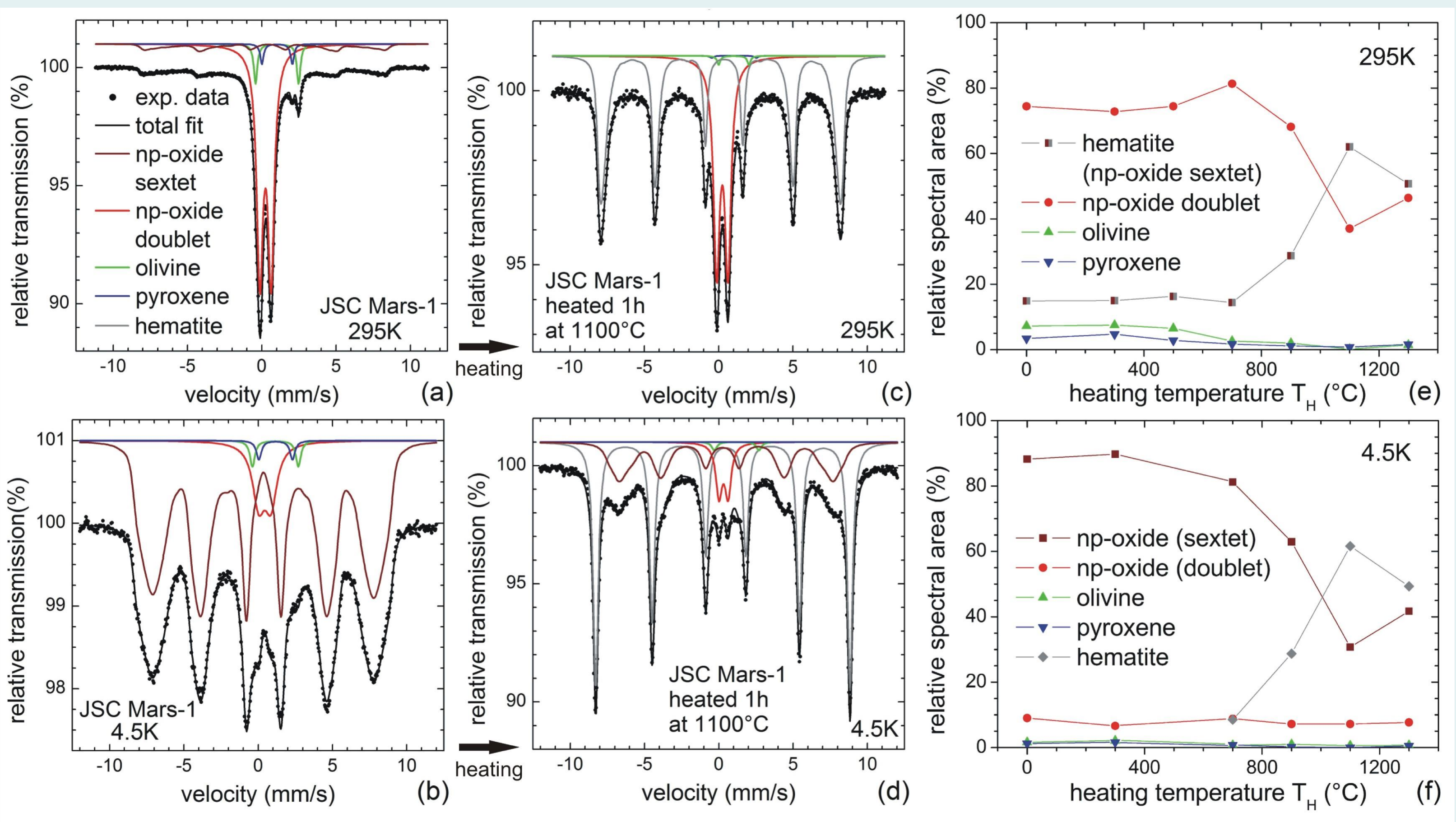

Fig 2: Mössbauer spectra before (a,b) and after heating at ~1400K (1100°C) (c,d) measured 295K and 4.5K and variation of relative spectral areas vs heating temperature TH (e,f). Upon heating poorly crystallized nanophase ferric oxide (np-oxide) undergoes a phase transition in well-ordered hematite.

Conclusion and Outlook. The internal changes are correlated to changes in cohesive forces at the different temperatures. In the process of planet formation, the balance between growth, bouncing, fragmentation and maximum size of particles at the bouncing barrier strongly depends on the cohesion between the dust grains.

The results show hat elevated temperatures might change the formation of planetesimals as the basic properties of coagulation models are changed.

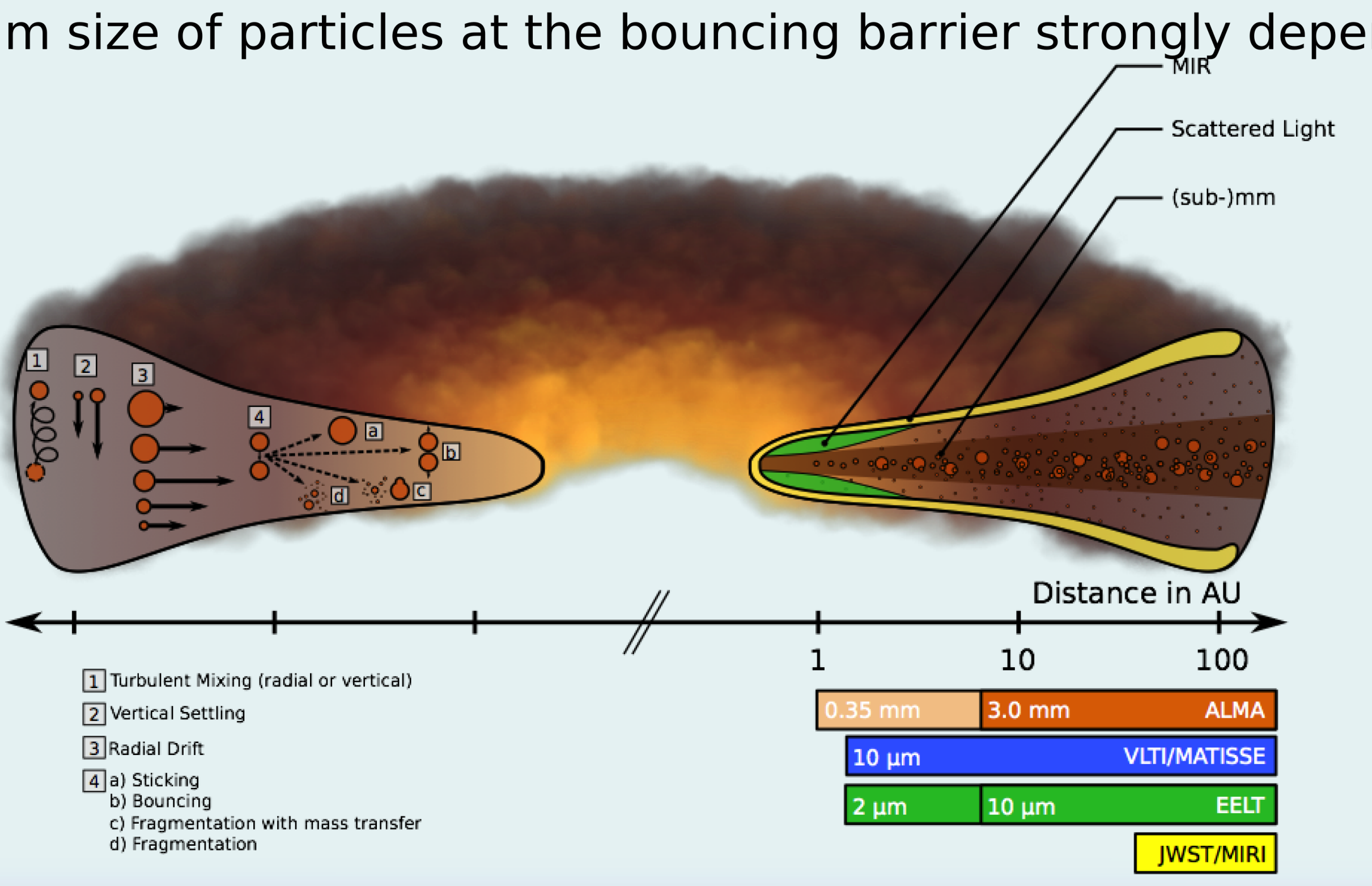

Fig 3: Sketch of processes and observables in protoplanetary disks from [6]. Important in the context of this work is the radial inward drift and the different collisional outcomes with increasing temperature closer to the star.

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