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The evolution of dust in the local and high-redshift universe

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Abstract. Dust is a ubiquities component of the interstellar medium (ISM) of galaxies, and manifests itself in many different ways. Yet, its origin, composition, and size distribution are still a matter of great debate. Most of the thermally condensed dust is produced in the explosively expelled ejecta of core collapse supernovae (CCSNe) and in the quiescent winds of AGB stars. Following its injection into the ISM it is destroyed by supernova (SN) shock waves. Knowing the relative rates of these processes is crucial for understanding the nature and evolution of dust in galaxies. In the following we will review three aspects of the evolution of dust in galaxies: the evolution of dust in the ejecta of SN1987A; the rates of dust production and destruction rates in the Magellanic Clouds (MCs), and the evolution of dust in CLASH 2882, a gravitationally-lensed galaxy at $z = 1$.

Keywords. Dust, supernovae, SN1987A, Magellanic Clouds, galaxies, CLASH 2882

1. The evolution of dust in SN1987A

SN1987A offers astronomers a unique opportunity to follow the evolution of dust in its ejecta from the epoch of its formation until about 25 years after the explosion. The most recent far-infrared (IR) observations, summarized in Matsuura *et al.* (2015), suggest the presence of about 0.5 $M_\odot$ in the ejecta. This mass is significantly larger than the $\sim 10^{-3}$ $M_\odot$ of dust inferred from early observations on day 615, close to the epoch of dust formation. This discrepancy, and the shape of the infrared spectrum, has been interpreted as evidence that the dust in the ejecta of SN1987A consists mostly of carbon, and that it grew from its initial mass to the currently observed one by cold accretion.

However, a new analysis of the infrared (IR) emission from the ejecta, covering days 615, 775, 1144, 8515, and 9090 after the explosion, showed that the observations are consistent with the rapid formation of about 0.4 $M_\odot$ of dust, consisting of mostly silicates of the form $MgSiO_3$, near day 615, and evolving to about 0.45 $M_\odot$ of composite dust grains consisting of ~ 0.4 $M_\odot$ of silicates and ~ 0.05 $M_\odot$ of amorphous carbon after day $\sim$ 8500 (Dwek & Arendt 2015). It alleviates several problems with previous interpretations of the data: (1) it reconciles the abundances of silicon, magnesium, and carbon with the upper limits imposed by nucleosynthesis calculations; (2) it eliminates the requirement that most of the dust observed around day 9000 grew by cold accretion onto the $\sim 10^{-3}$ $M_\odot$ of dust previously inferred for days 615 and 775 after the explosion; and (3) establishes the dominance of silicate over carbon dust in the SN ejecta.

2. Dust production and destruction rates in the Magellanic Clouds

Two major issues concerning the dust yield in CCSNe are whether the newly formed dust will survive the reverse shock that propagates through the ejecta, and if the yields of CCSNe and AGB dust are high enough to counter the effects of grain destruction by supernova remnant (SNR) shocks in the ISM. The latter was addressed by detailed analysis of the CCSN dust production rate in the MCs (Temim *et al.* 2015).

Because of their extensive wavelength coverage, proximity, and nearly face-on geometry, the MCs provide a unique opportunity to study these processes in great detail. The observed SNR form a complete sample of the SN that exploded during the last $\sim 20,000$ yr. Combining the SN rate inferred from the number of observed remnants with theoretical calculations of the efficiency of grain destruction in shocks, Temim *et al.* (2015) derived the current destruction rate of silicate and carbon grains in the MCs. They found that silicate and carbon dust lifetimes in the clouds are significantly shorter than those in the Milky Way. This is a direct consequence of the fact that the overall dust mass in the MCs is lower than that in the Milky Way, and that SNRs in the MCs expand in regions of higher than average dust-to-gas mass ratios. Comparing dust formation and destruction rates, the study showed that the dust injection rates are an order of magnitude lower than the dust destruction rates by SNRs. This supports the conclusion that, unless the dust destruction rates have been considerably overestimated, most of the dust must be reconstituted from surviving grains in dense molecular clouds.

3. The evolution of dust in CLASH 2882

Models for the evolution of dust in external galaxies have reached the same conclusion. Here we report on the recent analysis of the evolution of dust in a gravitationally lensed galaxy at redshift $z = 1$. Two millimeter observations of the MACS J1149.6+2223 cluster with the GISMO 2 mm camera (Staguhn *et al.* 2015) have detected a source that was consistent with the location of the lensed MACS1149-JD galaxy at $z = 9.6$ (Dwek *et al.* 2015). A positive identification would have rendered this galaxy as the youngest dust forming galaxy in the universe. Follow up observation with the AzTEC 1.1 mm camera and the IRAM NOrthern Extended Millimeter Array (NOEMA) at 1.3 mm have not confirmed this association showing that the 2 mm source is associated with source number 2882 in the *Hubble Space Telescope* (*HST*) Cluster Lensing and Supernova (CLASH) catalog of MACS J1149.6+2223. This source, hereafter referred to as CLASH 2882, is a gravitationally lensed spiral galaxy at $z = 0.99$. Combining the GISMO 2 mm and NOEMA 1.3 mm fluxes with other (rest frame) UV to far-IR observations, Dwek *et al.* (2015) derived the rest frame UV to far-IR spectral energy distribution (SED) of this galaxy, its star formation history, and its stellar and interstellar dust content. The results show that the inferred dust mass is higher than the maximum mass that can be produced by CCSNe and evolved AGB stars. As with many other star forming galaxies, most of the dust mass in CLASH 2882 must have been accreted in the dense phases of the ISM.

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