Interstellar dust growth: near and far

Lars Mattsson, Anja C. Andersen & Stefano Zibetti

Niels Bohr Institute, University of Copenhagen, Juliane Maries Vej 30, DK-2100, Copenhagen Ø, Denmark

e-mail: mattsson@dark-cosmology.dk

Dark Cosmology Centre

We present evidence for dust-grain growth in the ISM based on simple theoretical models. Dust-to-metals gradients derived for a subsample of galaxies selected from the SINGS suggest there has to be net-growth of dust (growth rate larger than destruction rate) in the ISM. The gradients are typically negative, which is only consistent with a significant net-growth rate, according to our model. Furthermore, we argue that dust in high-redshift galaxies must also be dominated by grain growth, since there is no possibility that stars alone can produce the dust masses seen in these objects when all observational constraints are taken into account. This suggests the time scale for grain-growth is short, which is in fact consistent with our results for the SINGS galaxies.

Dust-to-metals gradients in SINGS galaxies

We have constructed an analytical model (assuming "instantaneous recycling") of the evolution of the dust-to-gas ratio $Z_{\rm d}$ and the metallicity Z including dust destruction (as prescribed by McKee 1989, IAUS, 135, 431) and dust growth in the ISM (see, e.g., Dwek 1989, ApJ, 501, 643). The dust-growth rate turns out to be

$$\left(\frac{dZ_{\rm d}}{dt}\right)_{\rm gr} = \left(1-\frac{Z_{\rm d}}{Z}\right)\frac{Z_{\rm d}}{\tau_{\rm gr}}, \quad \tau_{\rm gr}^{-1} = \epsilon Z\frac{d\Sigma_{\rm s}}{dt}, \qquad (1)$$

where $\Sigma_{\rm s}$ is the stellar mass density $\tau_{\rm gr}$ is the growth-time scale and ϵ is considered an essentially free (fitting) parameter in our study.

Fitting the model to the dust-to-gas/metals gradients in 15 selected SINGS galaxies shows a preference for models with significant dust growth in the ISM of late-type galaxies (see Fig. 1), while models with only stellar dust production are inconsistent with the observations in most cases. Dust destruction by SN shocks is typically rejected by the model fitting.

For several galaxies the fraction of "grown" dust mass seems to be very large. This is an indication of a short grain-growth time scale, which is consistent with the results for high redshift.

Dust destruction by shocks from exploding SNe is believed to be a rather efficient process. We challenge this viewpoint, and suggest that SN shocks *shatter* interstellar dust rather than completely destroy it. **The effect of complete destruction of dust by SN-shock waves on the dust-to-metals gradients is not compatible with these gradients being negative in general, which is what observations tell us at this point.**

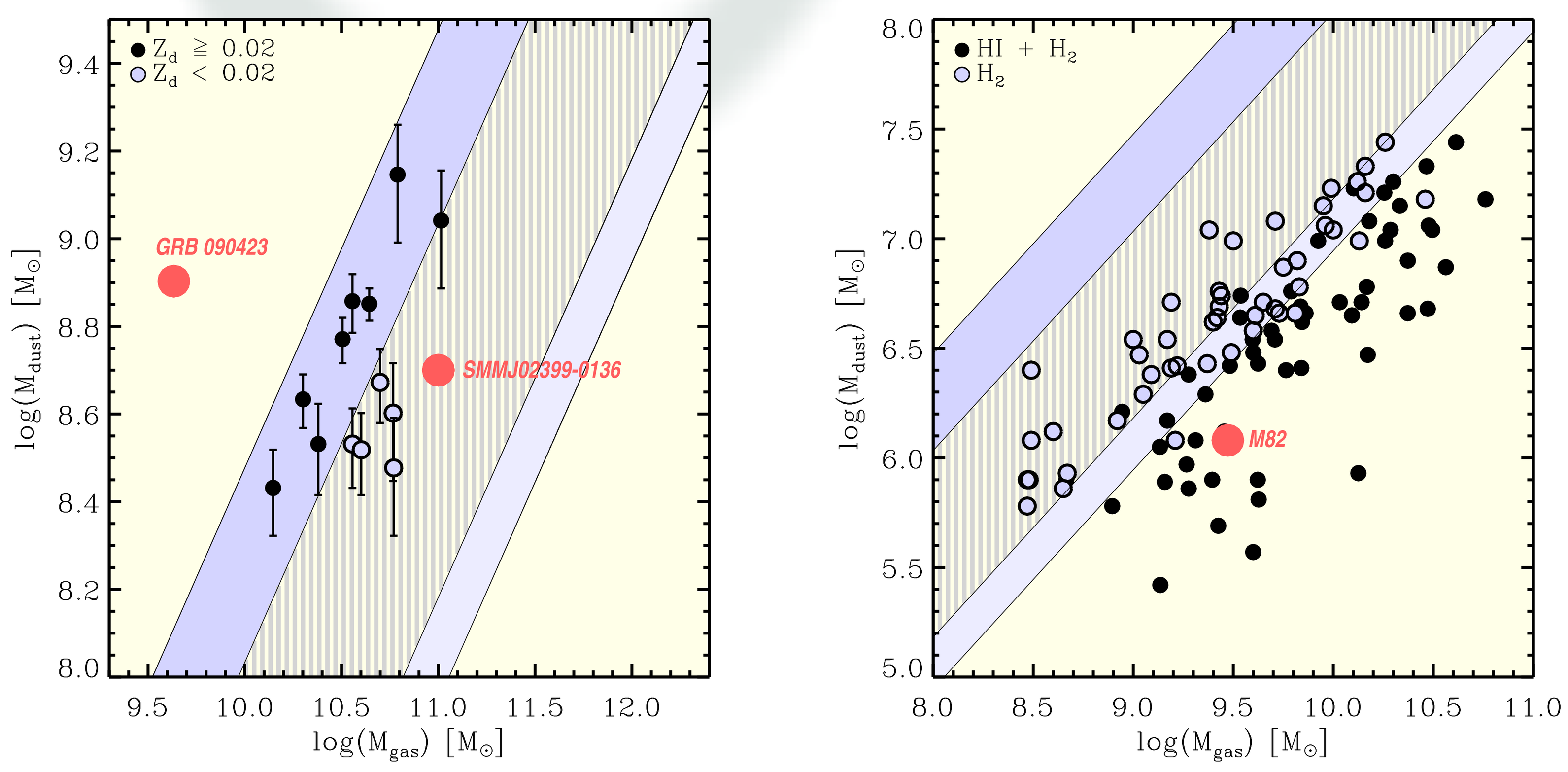

Fig. 2: *Left*: Comparison between models with 'secondary' dust production (but without dust destruction) and observationally inferred dust masses of high-z galaxies. The light-blue region is only accessible using 'observed' supernova (SN) dust yield (see Gall et al. 2011, A&A, 528, A13). The darker blue region can only be reached using a theoretical 'maximum' SN yield and the hatched area in the middle corresponds to the region accessible using a theoretical SN yield including some dust destruction due to reverse shocks (Bianchi & Schneider, 2007, MNRAS 378, 973). The plotted gas masses are twice the molecular hydrogen gas mass to account for neutral gas. For comparison, upper limits of the dust and gas masses of the host/surroundings of GRB 090423 are overplotted, as well as the derived dust and gas masses for the less distant sub-millimeter galaxy SMM J02399-0136. *Right*: Same models as in the left panel, but compared to local galaxies, with and without the inclusion of neutral hydrogen in the gas mass. For further details, see Mattsson (2011, MNRAS, 414, 781).

Dust at high redshifts

Observations have revealed unexpectedly large amounts of dust in high-redshift galaxies and its origin is still much debated. The dust-to-gas ratios for these high-redshift galaxies are remarkably high and stellar dust production is likely insufficient. A model including non-stellar dust formation (likely grain growth in the ISM on a very short time scale) is therefore required (see Fig. 2). Actually, the contribution from this non-stellar dust component needs to be larger than what appears realistic.

Are the large dust-to-gas ratios at high-redshifts due to uncertainties and/or systematic errors in the determination of gas and dust masses?

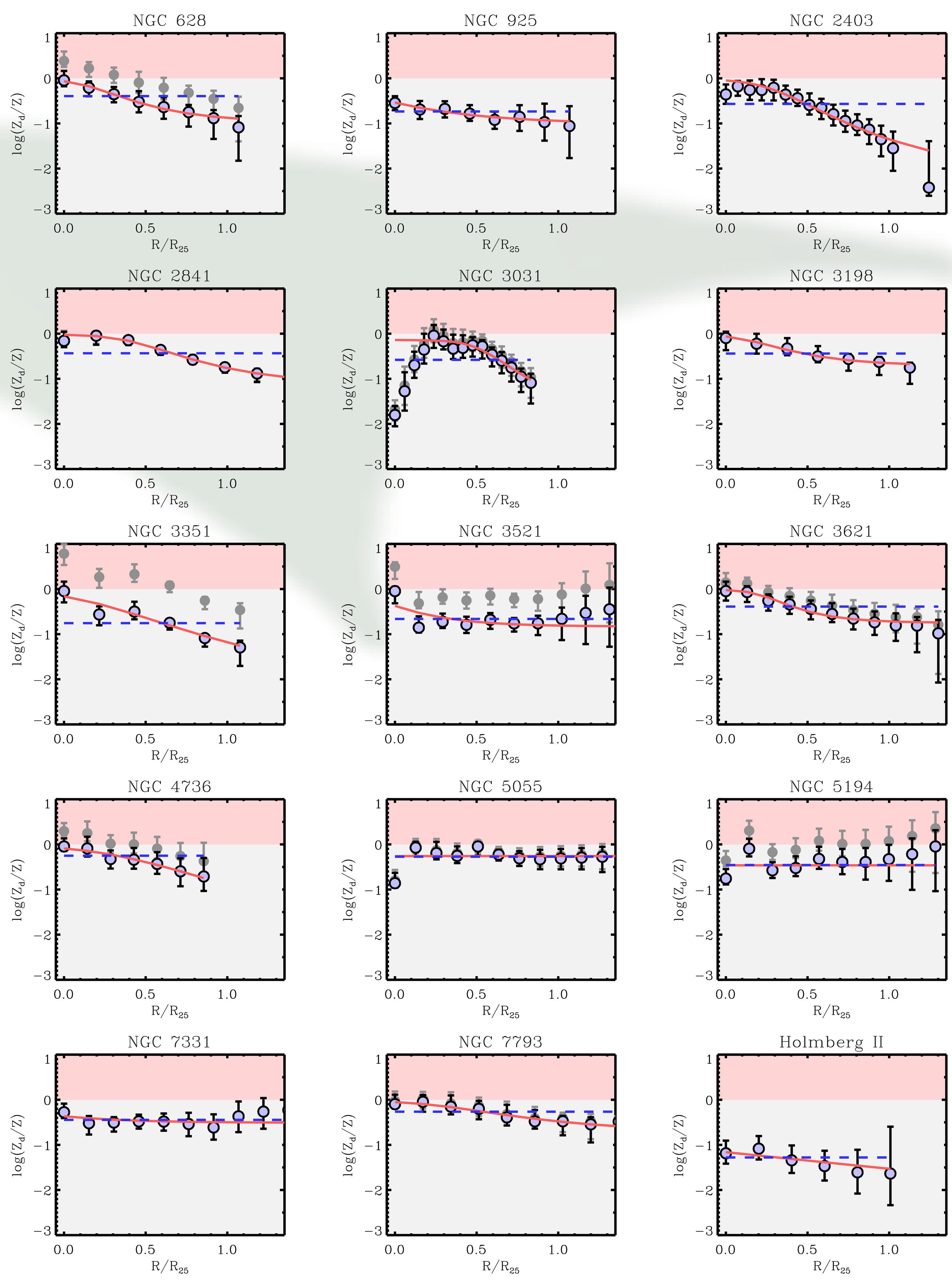

Fig. 1: Dust-to-metals gradients for our sample of SINGS galaxies as obtained from Muñoz-Mateos et al. (2009, ApJ, 701, 1965) and Moustakas et al (2010, ApJS, 190, 233). In several cases the dust abundance has been scaled down to avoid dust-to-metals ratios above unity (grey circles in the background represents original data). The red full-drawn lines show our model fits including dust growth in the ISM (but no explicit dust destruction), while the blue dashed lines show the case of stellar dust production only, which always leads to flat (zero) gradients. Negative gradients can be obtains only by adding dust growth. Dust destruction in the ISM due to supernova shocks has the opposite effect.