The Onset of Grand Design Spiral Structure in the Universe

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Disk galaxies in the early universe are dominated by clumpy structure rather than spiral arms, as seen in the Hubble Ultra Deep Field (UDF) and other deep extended surveys. The large scale star-forming regions in clumpy galaxies are 100x more massive than in local spiral galaxies. Clumpy galaxies are thought to transition to today's spirals as the massive clumps disperse in the disks or merge in the centers. Here we examine spiral structure and large-scale star formation in resolved galaxies in the UDF and GEMS and GOODS fields. We find that spirals at redshift z~1 have morphologies ranging from flocculent arms to massive and regular clumpy arms to grand design arms. We compare the structure in these intermediate redshift galaxies with that in local galaxies in order to understand when grand design spirals start to occur in the universe.