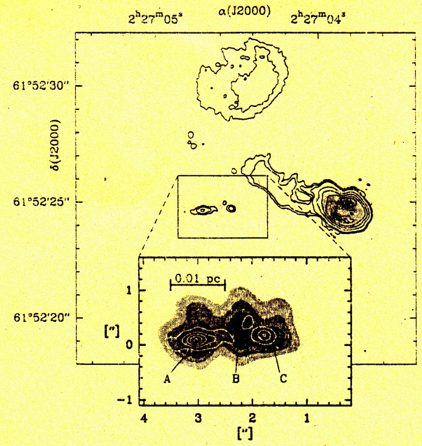

Workshop sull'Astronomia Millimetrica e Submillimetrica in Italia

28-29 ottobre 1998
Sala Verde – Palazzo Incontri
Via dei Pucci, 1
Firenze

Osservatorio Astrofisico di Arcetri

Images courtesy of Fabrizio Massi

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of Fabrizio Massi

More history …

PRIN-INAF 2005: PI M. Walmsley
Preparazione per ALMA (PALMA), approvato per 55k€

Included in this proposal were:

✓Interferometric CO studies of local starbursts and AGN (then NUGA-North, see NUGA-South talk by Casasola)

✓Metal-poor dwarf starbursts as templates for high-redshift star formation (this talk)

The ALMA view of the cool dust in an extreme metal-poor starburst

Leslie Hunt (INAF-OAA) with S. Garcia-Burillo (Madrid), V. Casasola (INAF-IRA), P. Caselli (Leeds), F. Combes (Paris), C. Henkel (Bonn), R. Maiolino (Cambridge), K. Menten (Bonn), L. Testi (ESO), A. Weiss (Bonn)

ALMA Cycle 0 proposal "highest priority" for observations in Band 7 (~800 μm), extended configuration (0.45 arcsec resolution): not yet observed

Timeline for extended configuration is the last part of Cycle 0, now extended to the end of 2012.

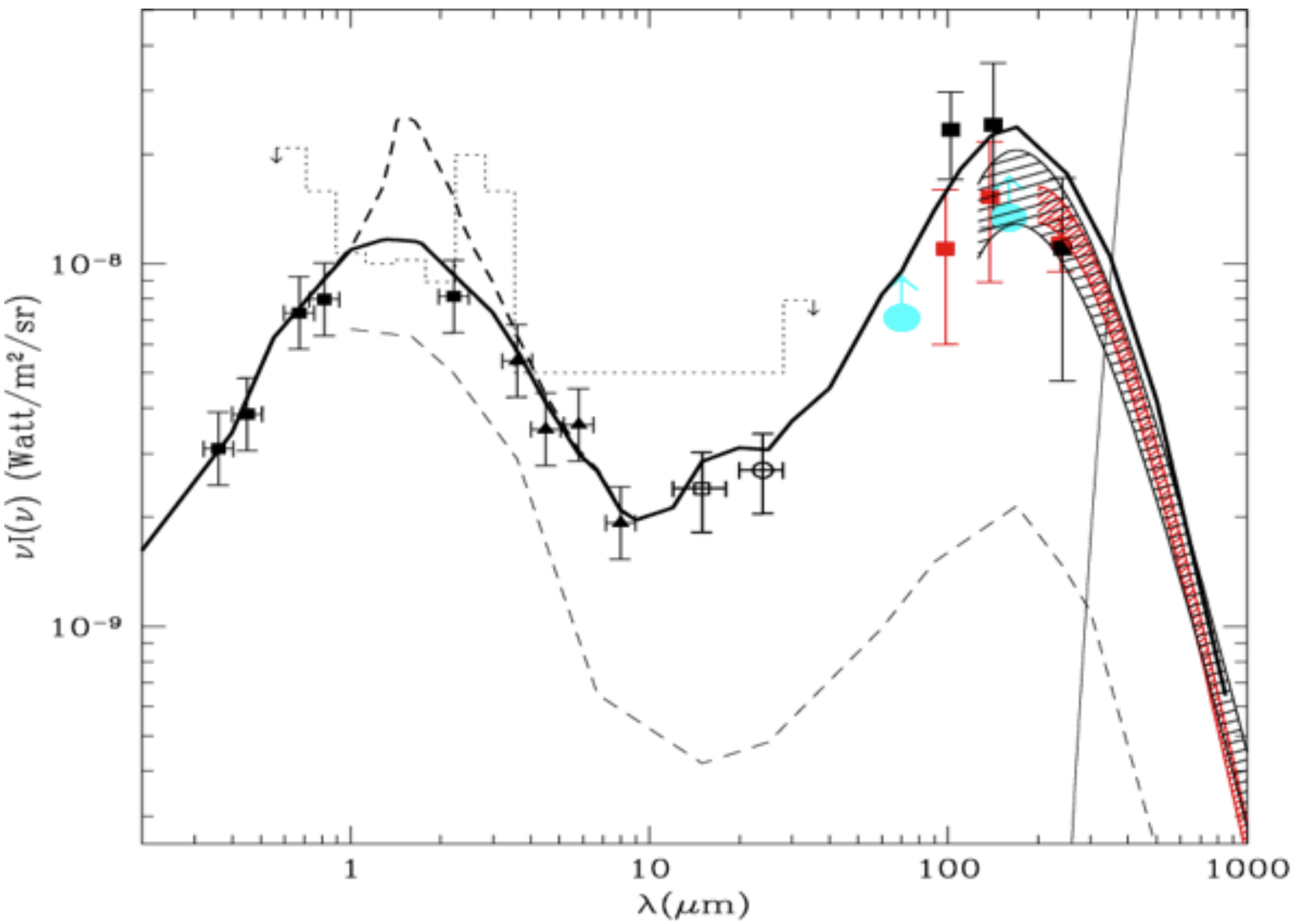
Why do we want to observe this low-metallicity dwarf galaxy with ALMA?

The context

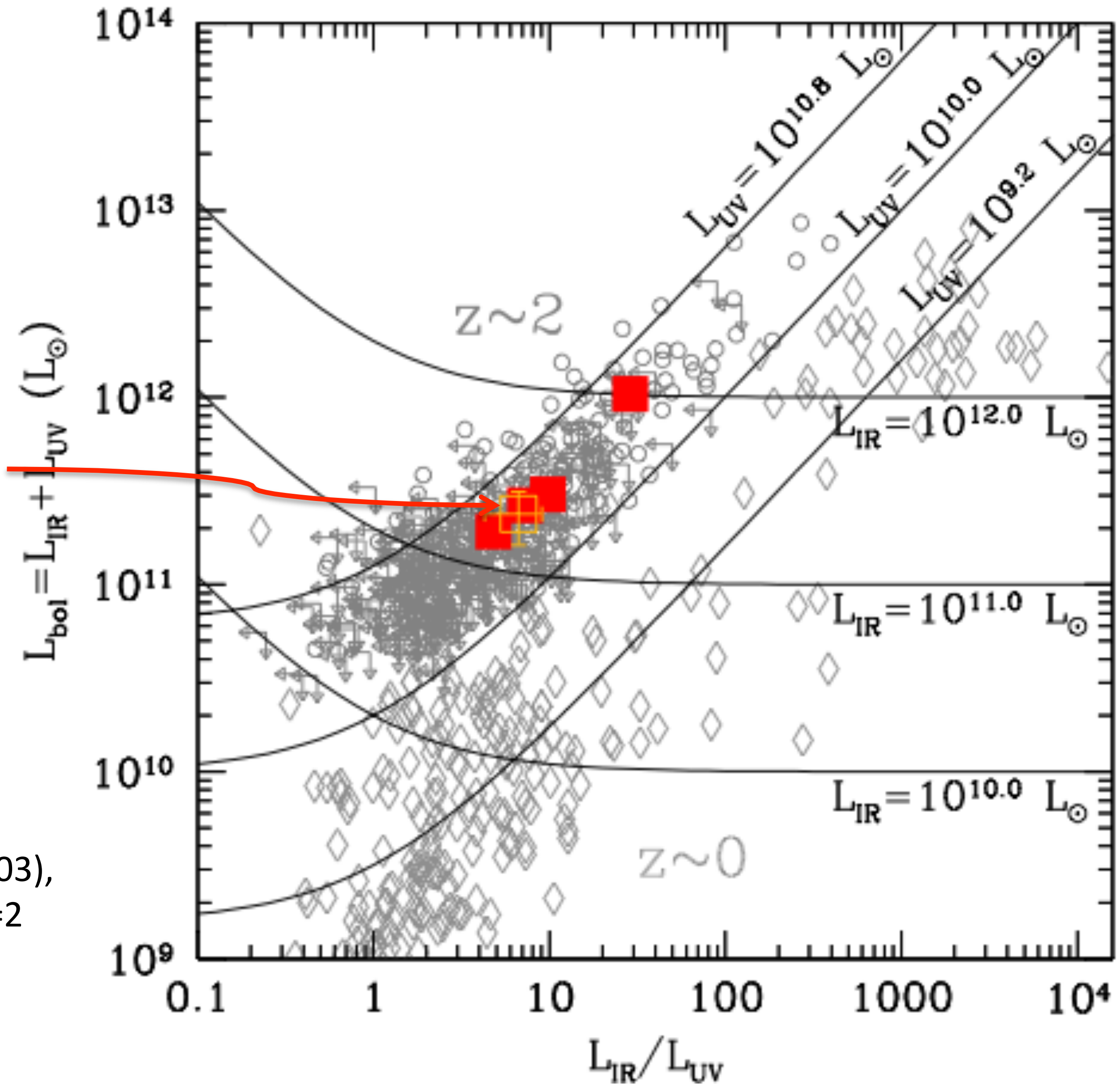
Much of the universe is obscured by dust

IRAS, ISO, SCUBA, COBE, Spitzer, Herschel, Planck have convincingly shown that half the photons and most of the energy in the universe come from infrared (IR) photons…

Cosmic extragalactic IR background as measured by COBE and optical from ultradeep HST fields, taken from Franceschini + (2008): unresolved infrared-bright galaxies

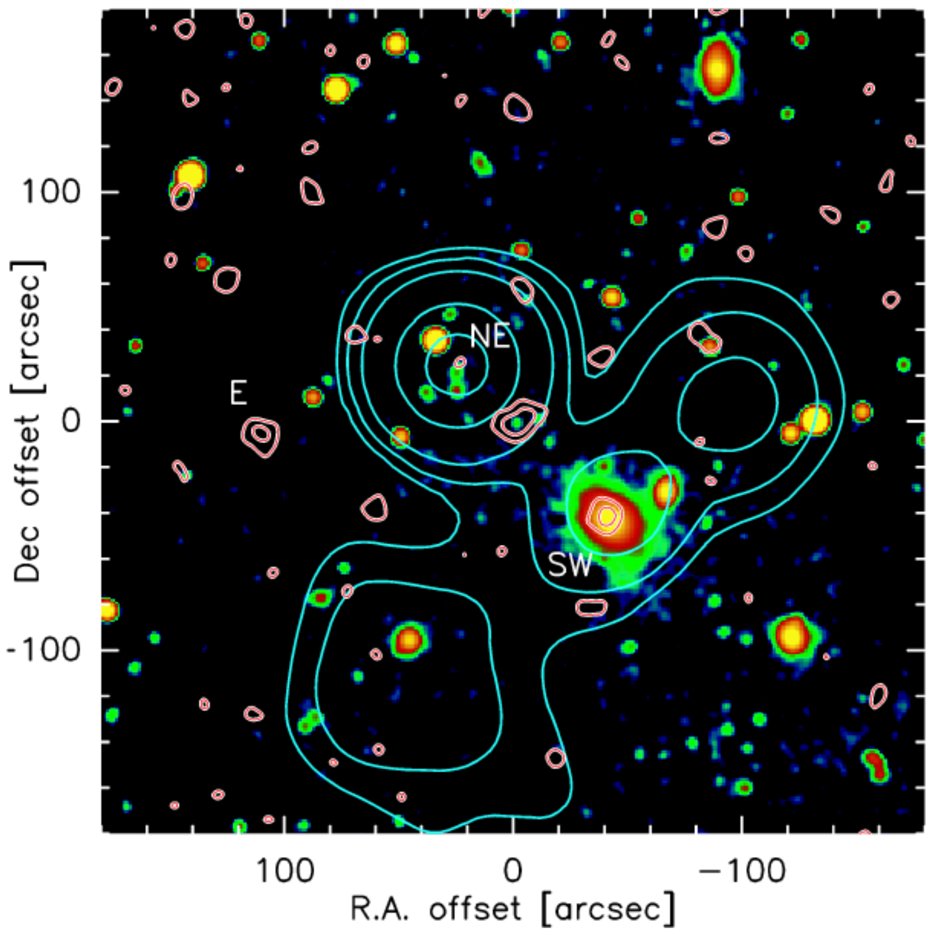


… and the most luminous galaxies in the universe are also the most obscured. Typical L*galaxies at z ~ 2 have 80% of their SF obscured by dust (Reddy+ 2006, 2012)



z=0 (diamonds) from Bell+ (2003), Huang+ (2009); UV-selected z=2 (circles) from Reddy+ (2010); stacked IR data (squares) from Reddy+ (2012)

Dust is present at very early times



Field of QSO SDSS J114816.64+525150.3 at z=6.42. Red-white contours 1.2mm MAMBO; blue contours 21cm VLA NVSS. Taken from Bertoldi+ (2003).

2-6 x 10^8 $M_\odot$ of dust in a quasar when the universe was <~ 1 Gyr of age means that the dust production and starburst episode must be very rapid.

Theoretical models of this quasar suggest that AGB and SNe dust yields are roughly consistent with the observed dust mass, but grain formation within GMCs must also play a role (Valiante+ 2009, 2011).

But how can dust be present in the primordial, metal-free environments prevalent in the early universe?

Exactly how massive starbursts such as that responsible for J1148+5251 occur and evolve is not yet clear.

The short interval in which star formation and the ensuing chemical enrichment and dust formation convert a dust-free metal-free environment to a dusty metal-rich one by redshift ~6 is as yet unobserved, and studies of such transitions remain a major observational challenge.

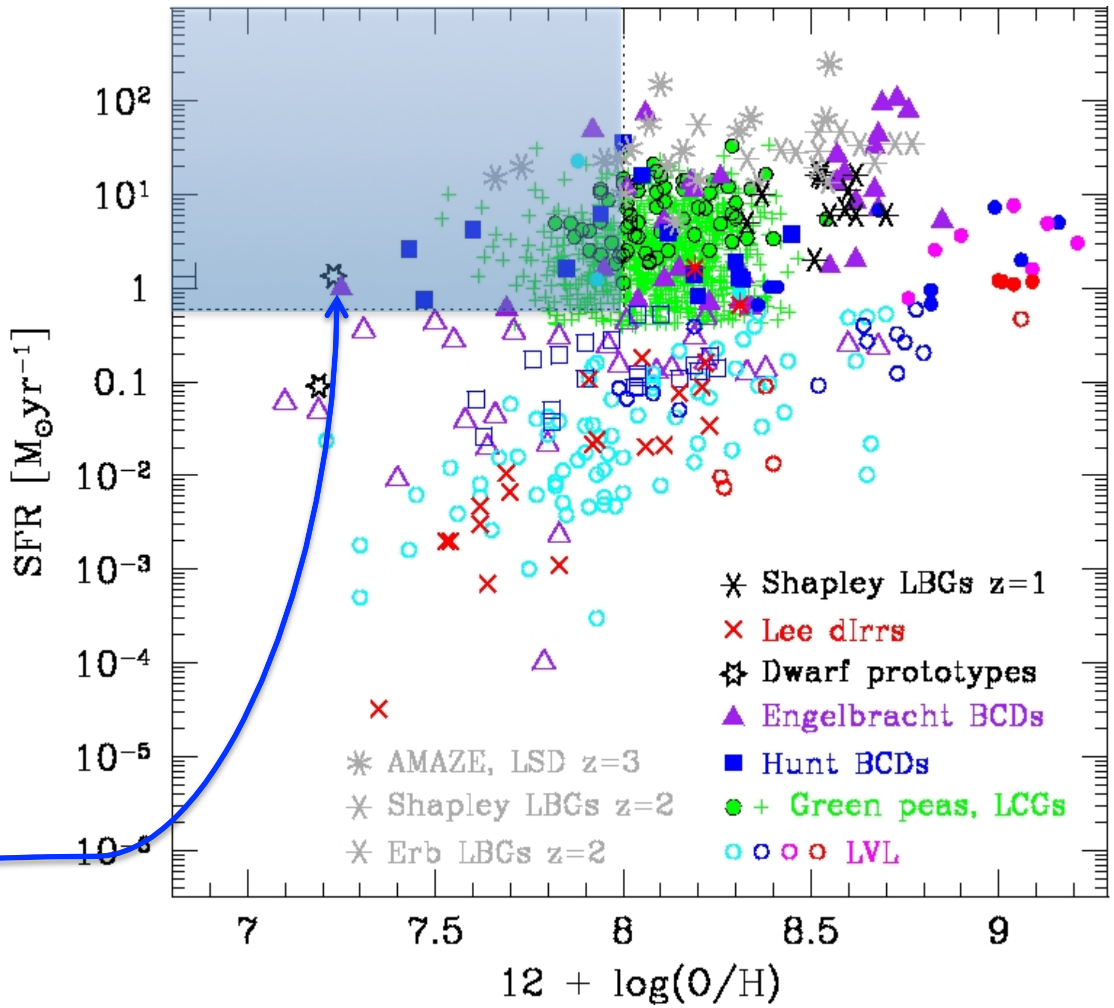
A “local” approach to a cosmological problem

If we can study the properties of a metal-poor ISM and its constituents locally, we may be able to better understand the high-redshift transition from metal-free Population III stars to the chemically evolved massive galaxies typical of the current epoch.

Metal-poor starbursts in the Local Universe

Locally, star-forming dwarf galaxies are much more metal poor than galaxies observed so far at high redshift. Hence, they can provide a unique window on the transition from a metal-free ISM to a metal-rich one.

But metallicity is generally correlated with SFR so we need to choose carefully in order to optimize the analogy with high-redshift starbursts.



SBS 0335-052, the most metal-poor starburst known

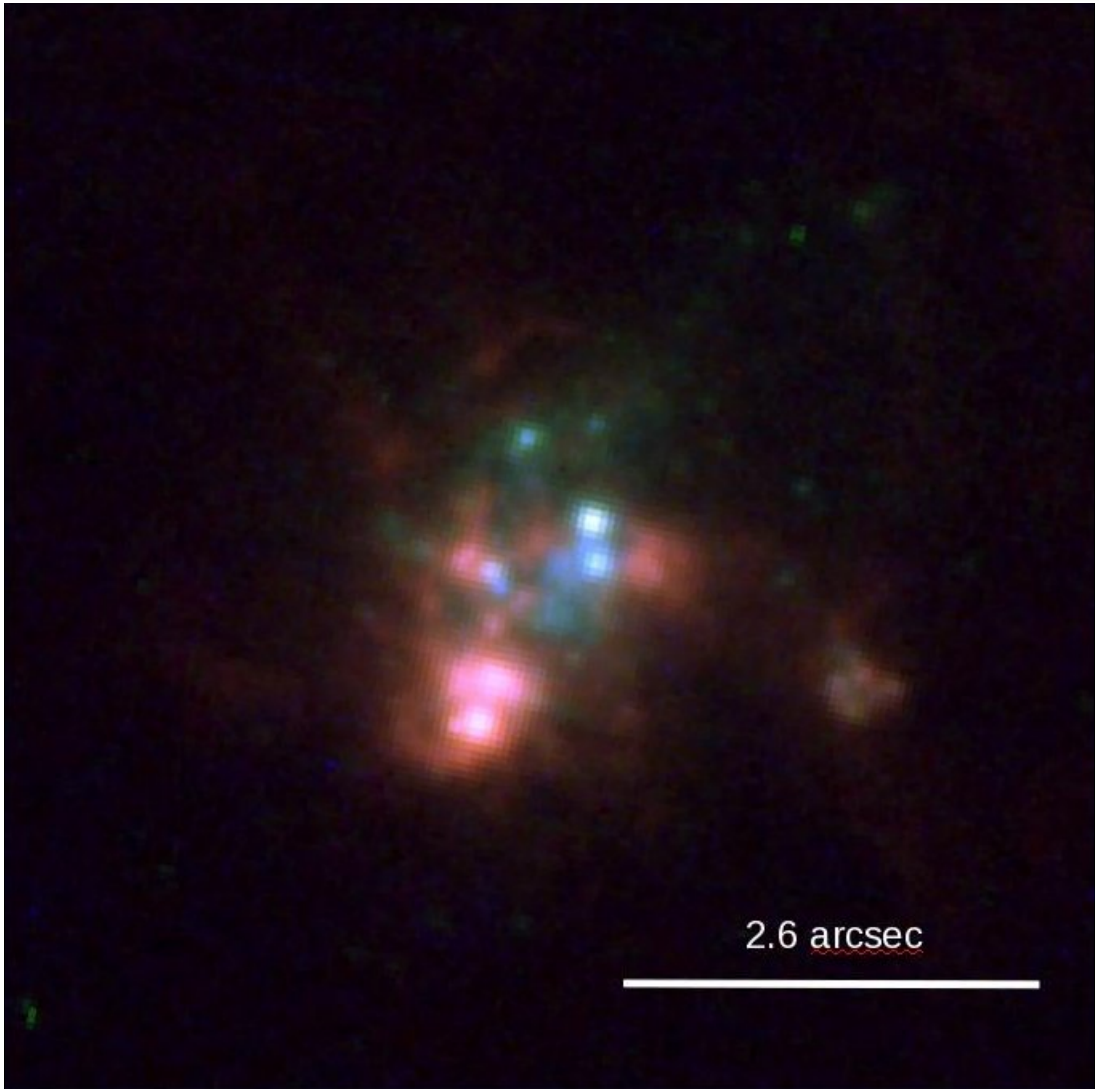


Figure from Reines, Johnson, Hunt (2008).

This blue compact dwarf (BCD) hosts six Super Star Clusters (SSCs), distributed over ~700 pc (2.6”).

Most of the SF takes place in the two southernmost SSCs, which together host ~10000 O stars. SSCs unresolved at HST/ACS resolution (<~ 30 pc).

12+log(O/H) = 7.2, ~1/30 $Z_{\odot}$
SFR = 1 $M_{\odot}$ /yr

Appropriate size (~10^7 $M_{\odot}$) and O/H for exploration of galaxy assembly in the early universe (e.g., Dekel & Silk 1986, Somerville+ 2001).

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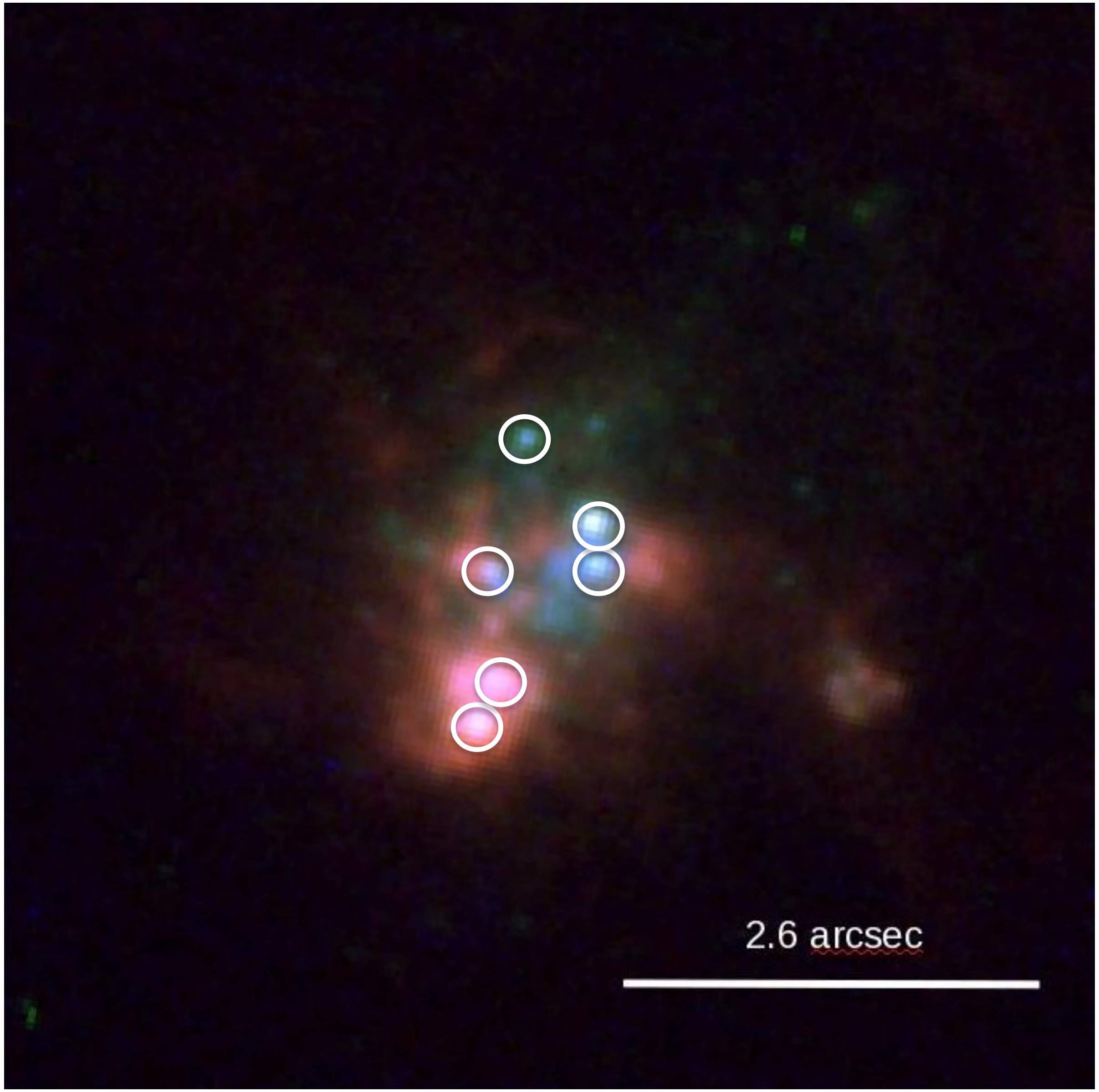

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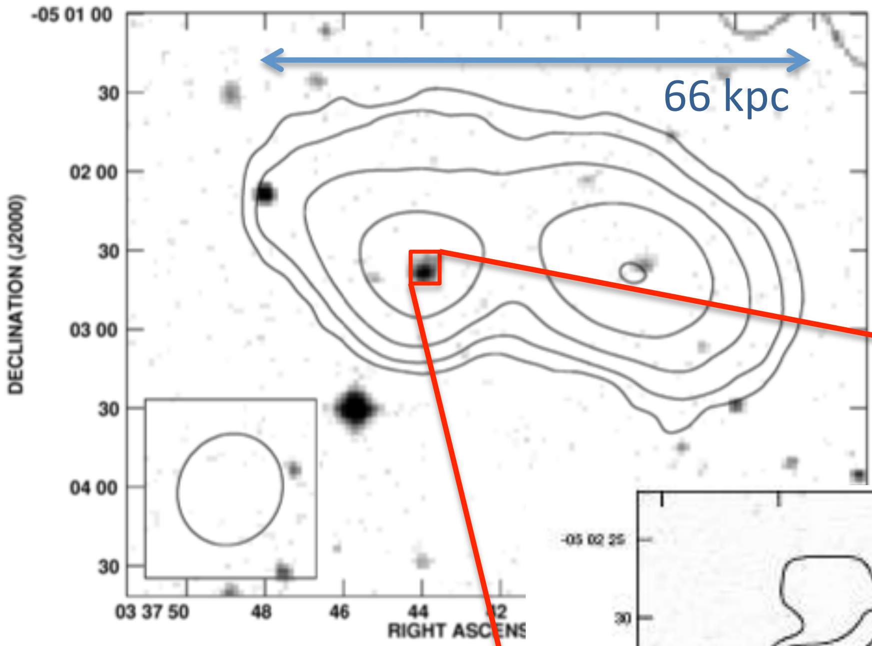
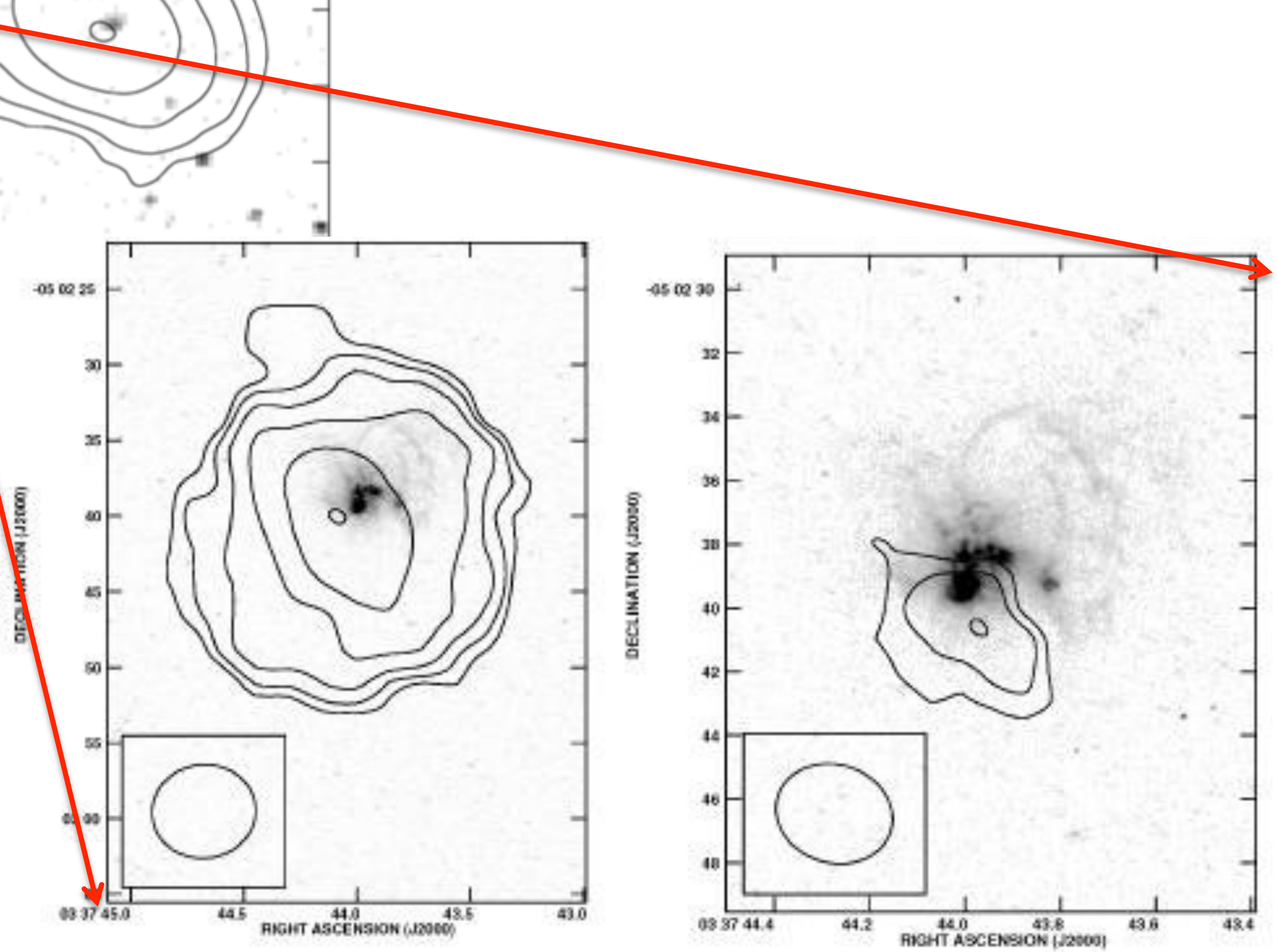
SBS 0335-052E embedded in a huge HI cloud …



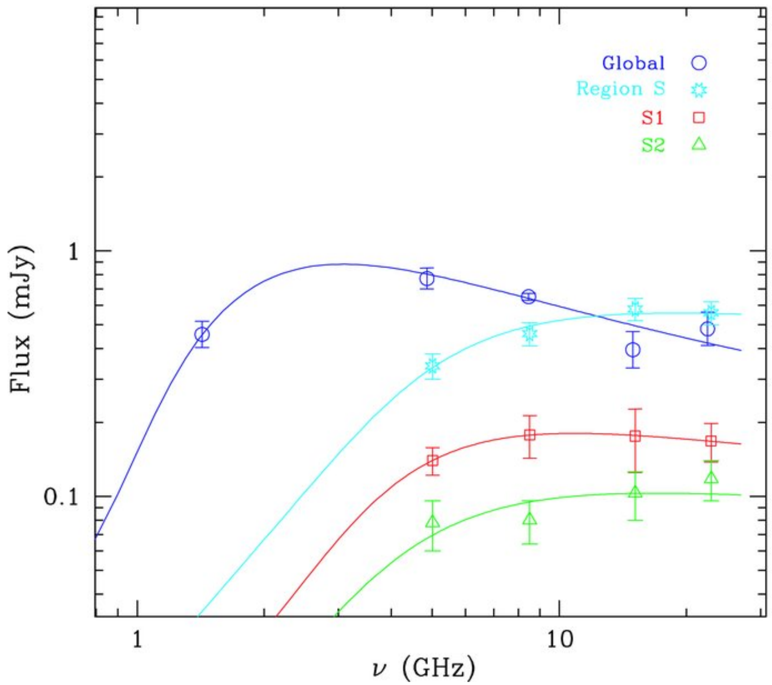
… together with SBS 0335-052W



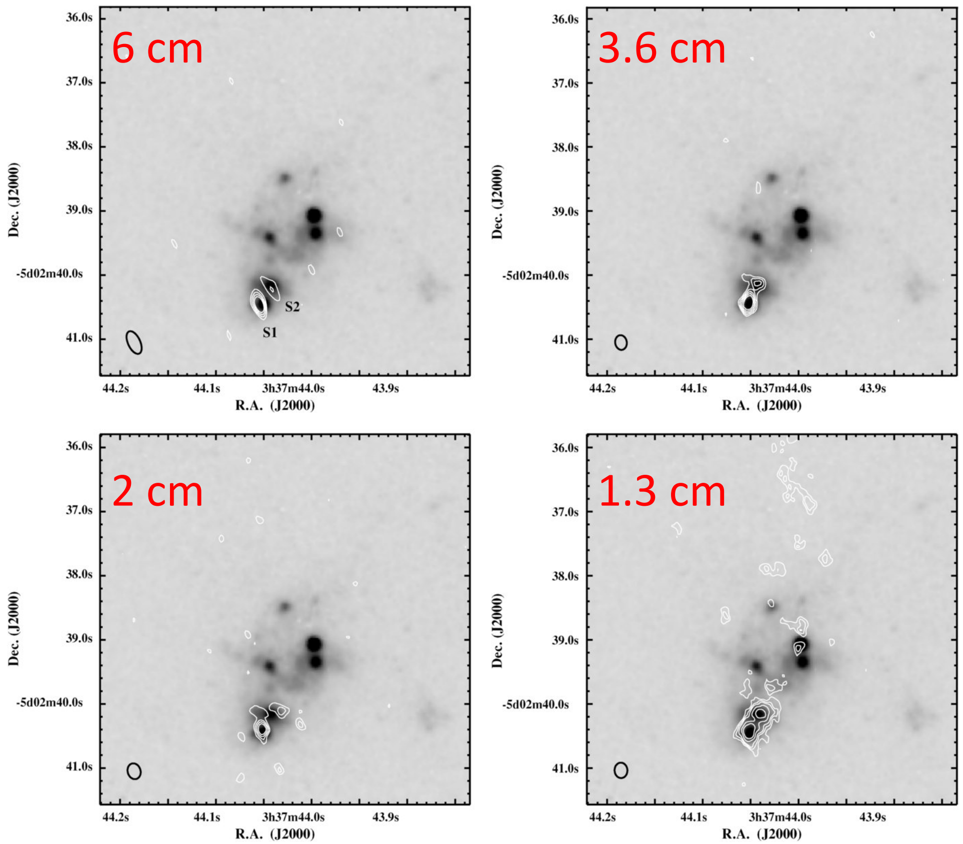
SBS 0335-052E has an HI mass of ~4.2 x 10^8 $M_{\odot}$, and a stellar mass of ~6 x 10^6 $M_{\odot}$, so very gas rich (not even considering the molecular component).

Figures from Ekta+ (2009).

Radio signature of dense gas in SBS 0335-052

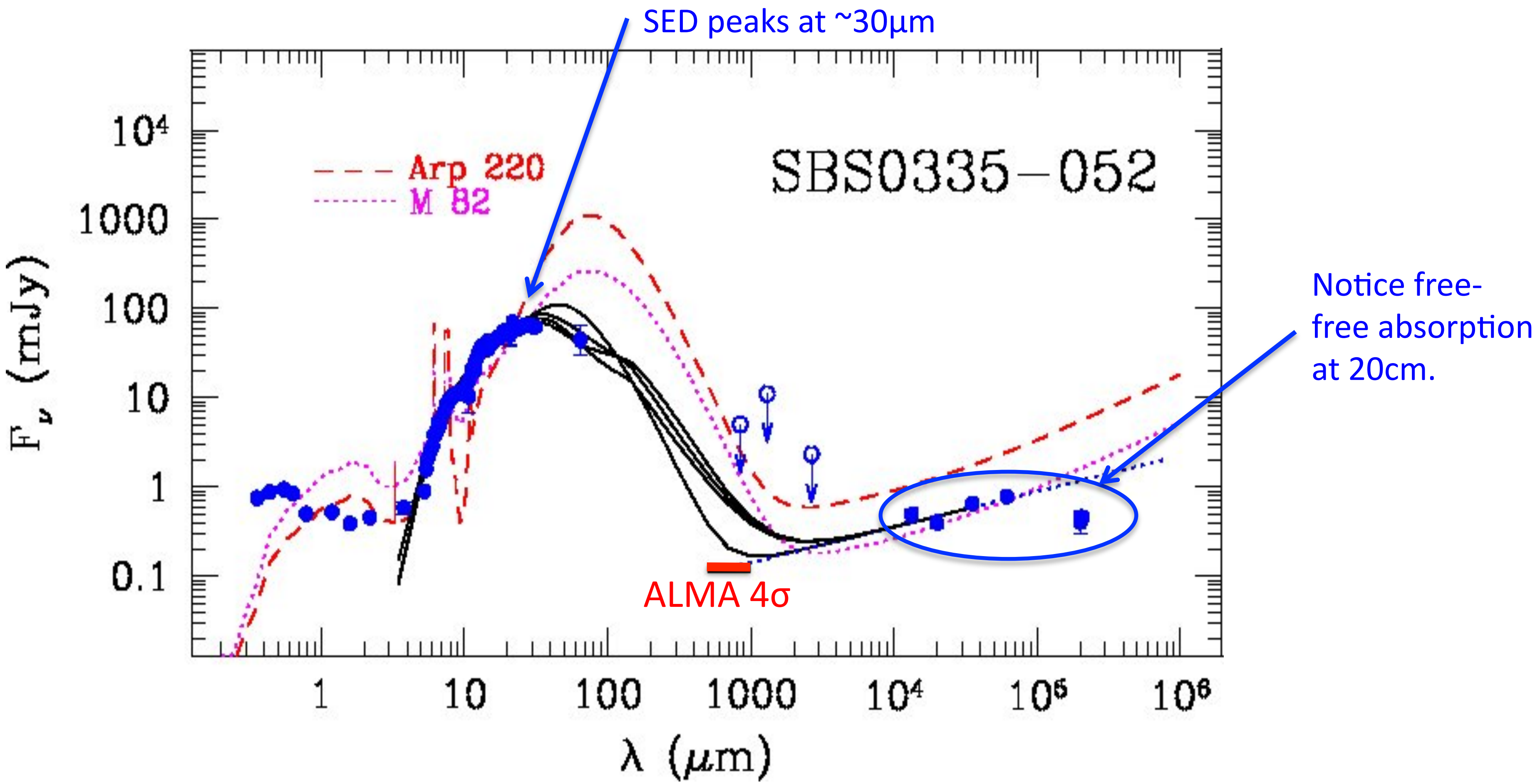


SED fitting of the radio continuum gives SSC sizes of 3-6 pc at high-resl'n, and 8-15 pc at low resl'n (Hunt+ 2004). Inferred electron densities are high, ~5000 cm^{-3}, about 10 times higher than estimated from the optical spectrum (Johnson+ 2009).



High-resolution VLA images of SBS0335-052E show that only the two brightest clusters have high-ν free-free emission (Johnson, Reines, Hunt 2009).

High dust extinction measured from SED



A_V ~ 15 mag from silicate absorption feature at 9.7µm (Houck+ 2004).

SED adapted from Hunt, Bianchi, Maiolino (2005).

ALMA can measure the cool dust morphology

A_V ~ 12 mag from near-infrared recombination line ratio (Br α/Br γ) (Hunt+ 2001), but A_V ~ 0.3-0.6 mag from optical and optical/NIR lines (Thuan+ 1997, Vanzi+ 2000).

Hence, dust must be clumpy (i.e., small filling factor) in order that SBS 0335-052 can be blue in the optical but also highly extinguished in the IR (Reines+ 2009).

✓ Our ALMA Band 7 continuum maps will probe the cool dust at a resolution of ~100 pc.

✓We will look for feedback effects of SNe and massive stellar winds on dust morphology.

✓We will also obtain a dust-to-gas mass ratio and compare with expectations from $Z/Z_\odot$. (High-resolution radio images will constrain non-dust contamination, e.g., synchrotron, free-free.)

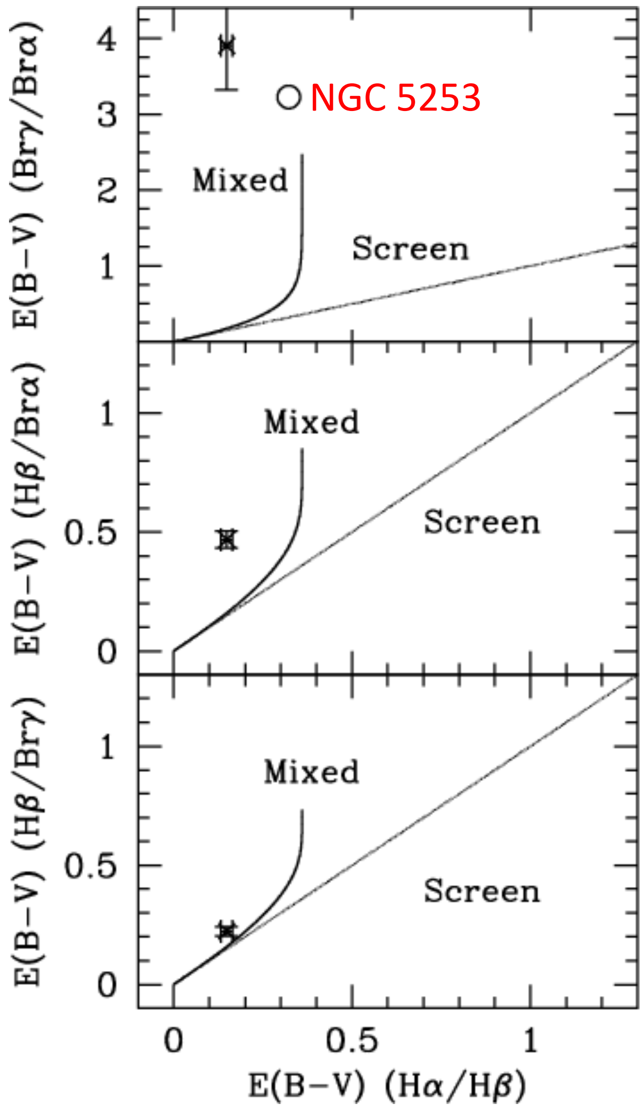


Figure from Hunt, Thuan, Vanzi (2001).

Looks similar to a ULIRG in gas scaling relations

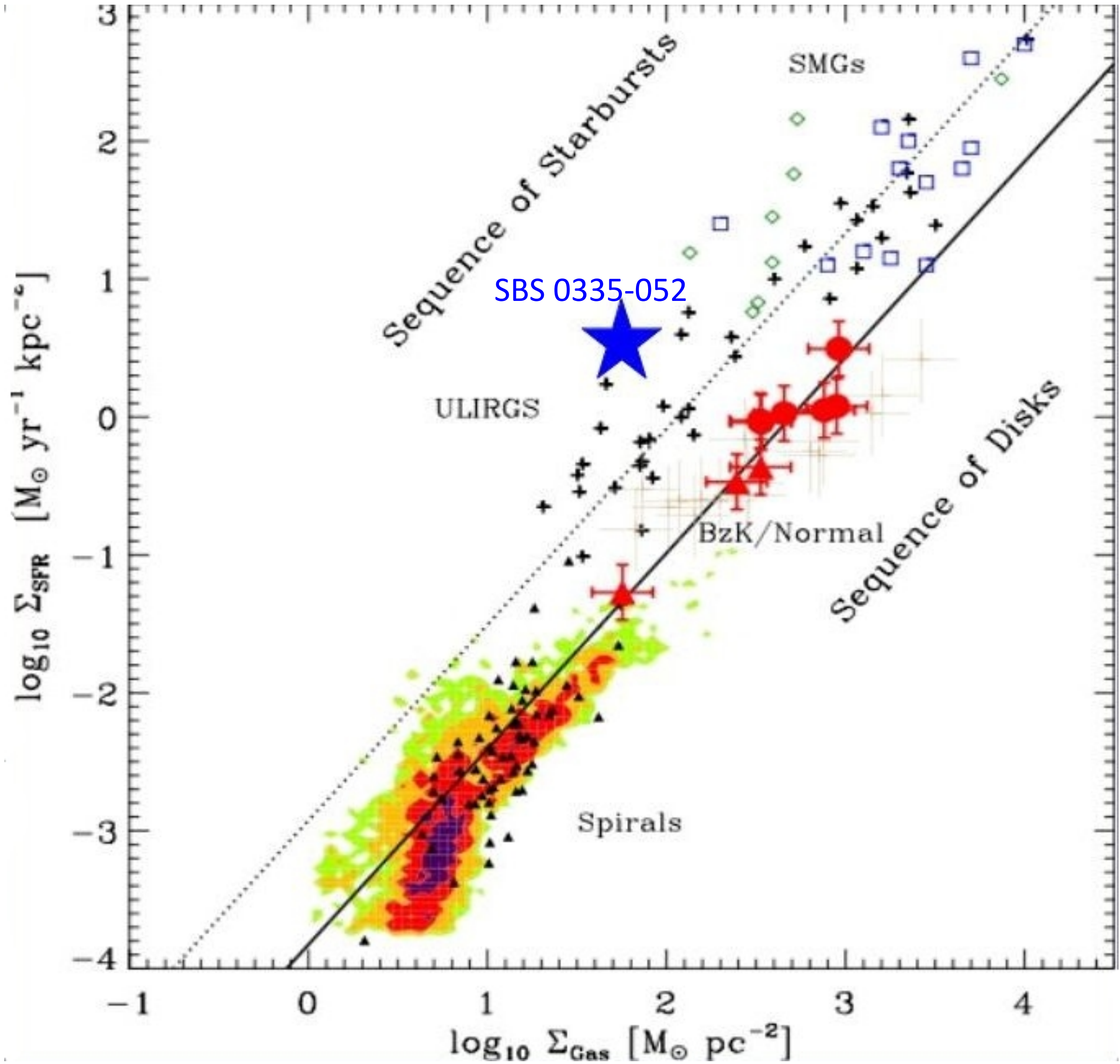


Figure adapted from Daddi+ (2010).

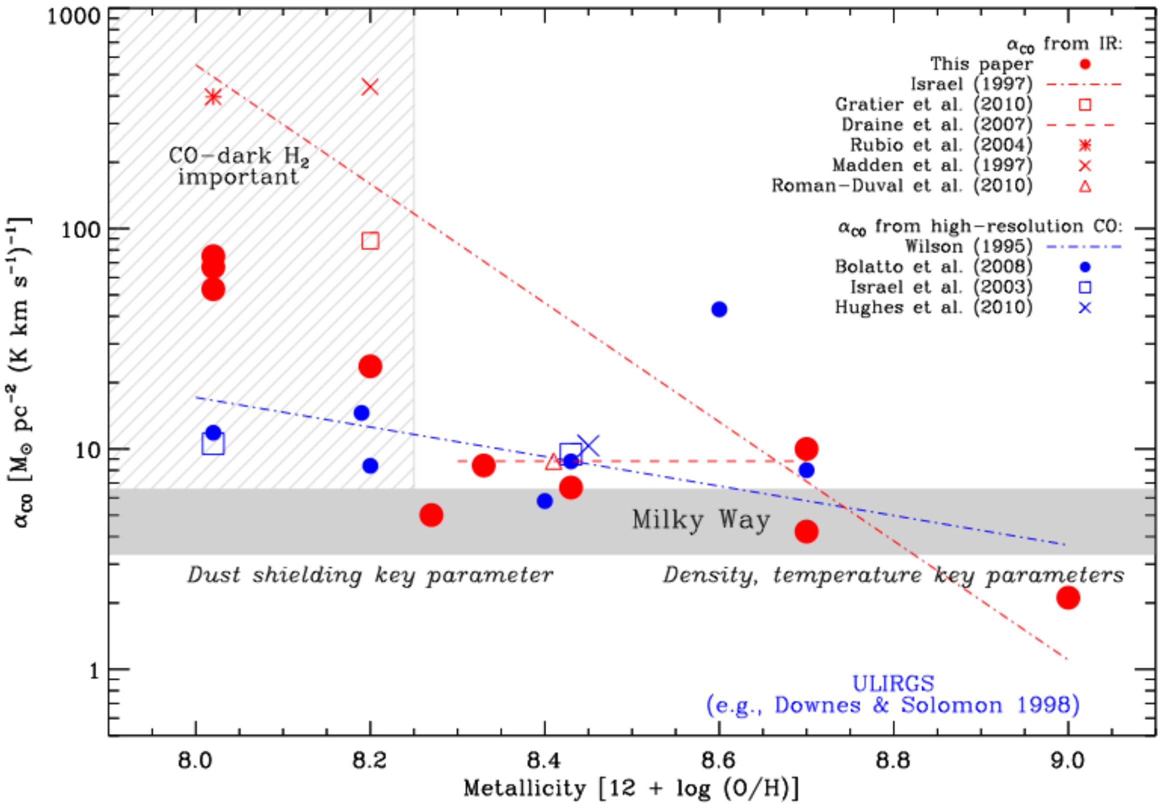
The star formation of 1 $M_{\odot}$/yr in SBS 0335-052 occurs in a very compact region (< 200 pc in diameter). Hence the SFR surface density Σ_{SFR} is very high.

Together with its high gas column density (here only Σ_{HI}) these parameters put this galaxy on the starburst sequence of the Kennicutt-Schmidt relation between Σ_{SFR} and Σ_{HI} .

CO(3-2) as ALMA "added value"

Much of the H_2 gas at low metallicities is thought to be "CO-dark", because in intense UV radiation fields CO is photodissociated.

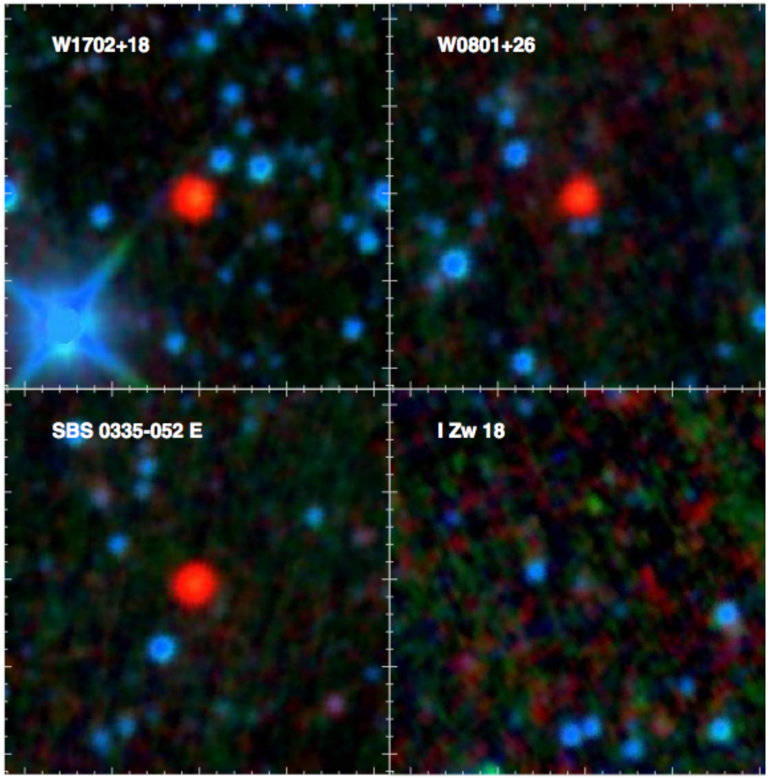
Only [CI] and [CII] will remain in the outer regions of the molecular clouds (e.g., Maloney & Black 1988, Bolatto+ 1999, Papadopoulos+ 2004, Wolfire + 2011, Leroy+ 2011).



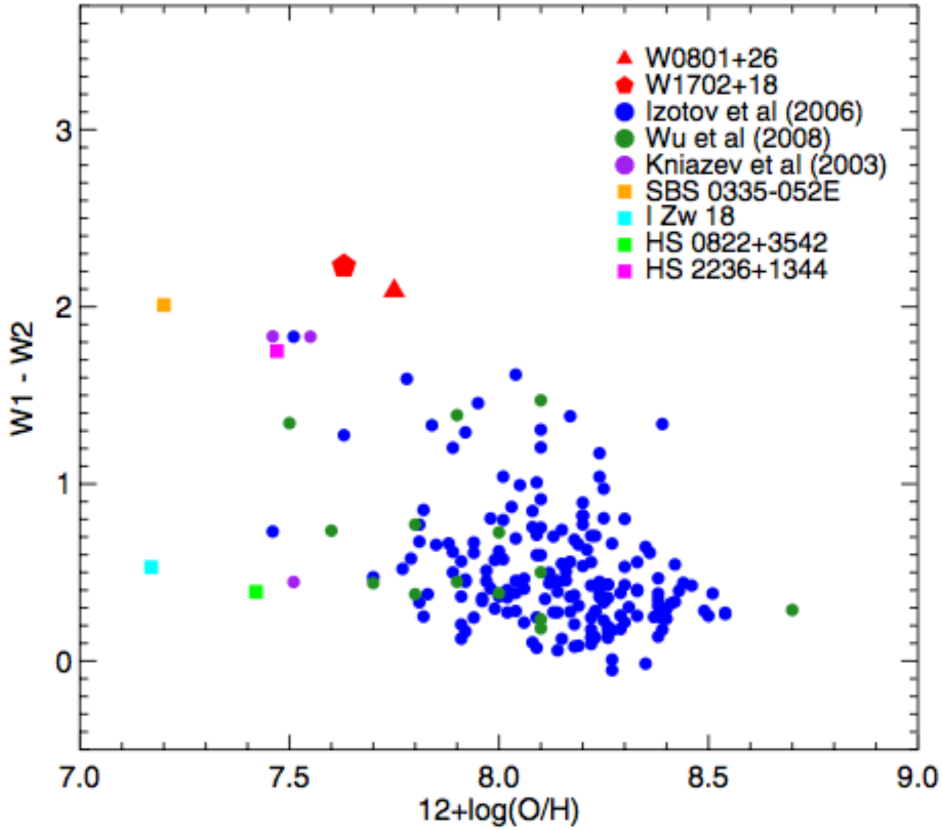
But in warm, dense SF complexes, higher-order CO transitions are better molecular tracers than $^{12}CO(1\text{-}0)$ or $^{12}CO(2\text{-}1)$, and may be as effective as neutral C. $^{12}CO(1\text{-}0)$ emission was not detected in SBS 0335-052 in 27 hrs with OVRO (Dale+ 2001), but we hope to detect $^{12}CO(3\text{-}2)$ emission with ALMA (a gratis).

Figure from Leroy+ (2011).

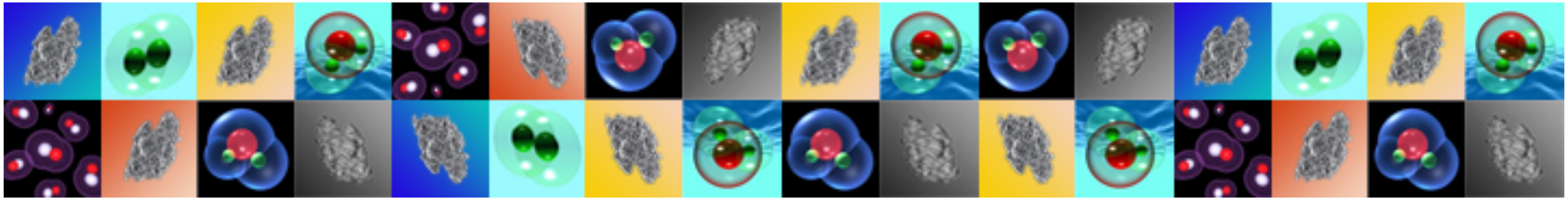
SBS 0335-052 E unusual, but not unique



W1-W2-W3 composite of newly discovered BCDs.



In the Local Universe, metal-poor BCDs with 12+log(O/H) ≤ 7.75 are extremely rare: ~0.004 deg^{-2} for $r \leq 17.8$ mag (Kniazev+ 2003). But the *Wide-field Infrared Survey Explorer* (*WISE*, Wright+ 2010) with 3.4, 4.6, 12, 22 μm detectors (W1, W2, W3, W4) is finding objects similar to SBS 0335-052E (see Griffith+ 2011).



Molecules and Dust at LOw metallicity (MODULO)

This proposal is part of an ongoing collaboration, MODULO, sponsored by ISSI, Bern http://www.issibern.ch/teams/modulo . We have been investigating various submm transitions to establish which is the best molecular tracer of star formation in metal-poor ISM. We hope to continue this with ALMA.


Thank you!