PRINT-93-0064
Fermilab Library
0 1160 0021446 2

DEEP GALAXY COUNT PREDICTIONS IN THE RADIO, INFRARED AND X-RAY SPECTRAL BANDS[1]

Marie-Agnes Treyer
Astronomy Department and Center for Particle Astrophysics
University of California, Berkeley

Joseph Silk
Astronomy and Physics Departments
and
Center for Particle Astrophysics
University of California, Berkeley

ABSTRACT

The existence of a dominant population of strongly evolving starburst sources at moderate redshift is a plausible explanation for the excess number of faint blue galaxies detected in deep sky surveys. Multi-wavelength observations at faint magnitudes would allow the existence of such a population to be confirmed. We use observed luminosity correlations and physical properties of known starburst galaxies to predict their contribution to the deep radio, infrared and X-ray counts, as well as to the diffuse extragalactic background radiation in these various spectral bands.

1 INTRODUCTION

The steep slope of the optical counts at faint magnitudes (Tyson 1988, Lilly et al. 1991) implies that the blue light density of galaxies was significantly larger in the past than today. On the other hand, both the redshift distribution of $b_J \lesssim 22.5$ galaxies (Colless et al. 1990, 1992) and the deep K-band counts (Cowie et al. 1991, 1992) are consistent with non-evolving models of the local galaxy population. These latter observations strongly constrain the recent past of present-day bright galaxies, but may be reconciled with the excess blue counts (to $m_B \sim 27$) if evolution occurred at the faint end of the luminosity function. Broadhurst et al. (1988) first outlined a scenario in which strong starbursts in the early past of lower luminosity galaxies would boost the blue light at small enough redshift, without producing excessive light in the near infrared. Many of the very faint ($b_J > 23$) objects do have unusually blue colors with near-flat continuum spectra, revealing enhanced star-forming activity (Guhathakurta et al. 1990, Cowie et al. 1991, Broadhurst et al. 1992), characteristic of the nearby irregular galaxies that may account (Koo & Kron 1992) for the apparent "excess" at brighter magnitudes ($b_J < 22$) relative to non-evolving models (Maddox et al. 1990).

The suggestion that we may be seeing a new, actively star-forming population of low-redshift galaxies at the faintest magnitudes carries significant cosmological implications. Cole et al. (1992) have shown that the existence of starburst dwarf galaxies at moderate redshifts, which would have faded, self-destructed, or merged to larger galaxies so as to be undetected today, could simultaneously account for all of the above-mentioned observational constraints. Such a population may have once involved a substantial fraction of the baryonic matter and be responsible for most of the metals now present in the Universe. In this Letter, we extend the models of Cole et al. to make multi-wavelength predictions of the signature of the star-forming dwarf population in various deep counts and background measurements, that are within the reach of current or next-generation telescopes. The next section briefly describes our two basic blue dwarf models. We then consider in turn their possible contribution to the far-infrared, radio and X-ray source counts as well as to the diffuse extragalactic background radiation, using empirical luminosity correlations and observed physical properties of starburst galaxies. Our conclusions are discussed in the final section.

[1] Submitted to *Ap. J. Letters*, December 1992

2. THE FAINT BLUE GALAXY POPULATION

We summarize here the two simple models by Cole et al. (1992), aimed at reproducing simultaneously the observed B and K-band galaxy counts and redshift distribution. The deep K-band counts and the redshift distribution of moderately faint galaxies allow little recent evolution in the known populations of bright galaxies. Thus the luminosity function of local galaxies is assumed constant with time. On the other hand, the excess number of faint ($b_J \gtrsim 22$) blue sources seen in deep optical surveys requires the existence of an extra population of very blue objects at moderate redshift ($z \lesssim 1$), that is rapidly evolving so as to have disappeared from view by the present time. The light output of these galaxies is assumed to be dominated by newly formed, short-lived massive stars, thus producing the observed increase in the blue light density while not affecting the near-infrared luminosity (contributed by older populations of stars). They are assigned flat spectra in f_ν.

Our first model is described by a time-dependent Schechter luminosity function, with characteristic magnitude $M^*_{B_J} = -18$, slope $\alpha = -1.1$ and density $\Phi^*(z) = 6\times10^{-2}\,(1+(0.7/z))^{-1}\,h^3\mathrm{Mpc}^{-3}$. These parameters were fixed to meet the above observational constraints. The time dependence of the density parameter Φ^* mimics the gradual vanishing of the sources below $z \approx 0.7$. Rapid fading, merging or self-disruption can be advocated as plausible physical processes for this disappearance. The second model is based on the number density evolution of dark matter haloes in the cold dark matter scenario, using the formalism of Press & Schechter (1974). This derivation predicts a large abundance of low-mass halos, in accord with current numerical simulations (Bond et al. 1991). For each dark matter halo, the following mass-to-light ratio is assumed, again constrained by the observed optical counts : $M/L = 120\ \exp[t(z)/3\ \mathrm{Gyr}]\ (\mathrm{M}_\odot/\mathrm{L}_\odot)$ (assuming a Hubble constant of 50 km/s/Mpc). A physical motivation for this light decay would include the above processes as well as a top-heavy initial stellar mass function (Silk 1992). In the following section, we will refer to these two models as the blue dwarf (BD) and Press & Schechter (PS) models respectively. We assume $\Omega = 1$ and $H_0 = 50$ km/s/Mpc, although the BD model may also apply in various cosmologies. An open universe or a non-zero cosmological constant only allows us to weaken the evolution parameters, but cannot account for the observed steep slopes of the counts in the various wavebands that we consider.

3. MULTI-WAVELENGTH PREDICTIONS

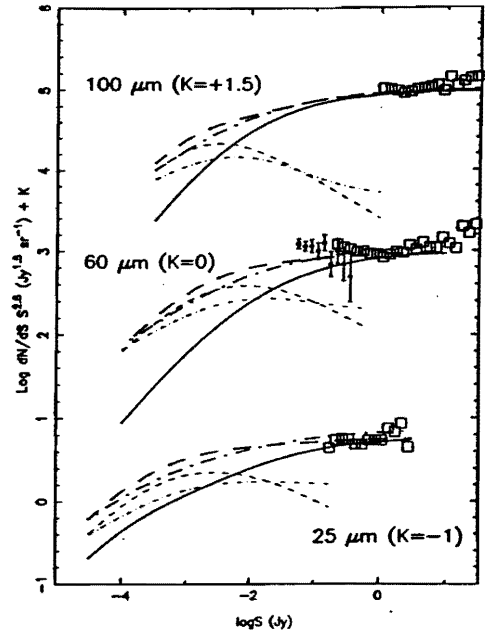
A realistic model of stellar population evolution would be necessary to predict the detailed physical properties of the faint blue galaxies. The aim of this work is to outline a possible scenario, and make a variety of predictions which may suggest further observations. We use observed correlations to relate the blue luminosity of the model populations to the far-infrared, radio and X-ray emissions. All of these are physically connected to starburst activity. With assumptions for the galaxy spectrum in these various bands, we derive the contribution of the faint blue galaxies to the deep counts, and compute the intensity and spectrum of the integrated radiation fields.

3.1 Far-Infrared

The far-infrared (FIR) emission originates from several dust components, of different grain sizes and temperatures, reprocessing the stellar radiation (Désert et al. 1990). Rowan-Robinson & Crawford (1989, hereafter RRC) showed that the FIR spectrum of IRAS galaxies is well fitted by the combination of two components: cool disk emission from interstellar dust ('cirrus component') and warm, starburst induced emission, from optically thick dust clouds heated by OB stars. The cirrus spectrum peaks at $\sim$ 30 K (i.e. $\sim$ 100 μm), whereas the starburst emission ranges from $\sim$ 50 K up to a few 100 K, and thus becomes dominant shortward of 60 μm. The starburst contribution to the total FIR flux increases towards later morphological types, reaching almost 100% for Sdm galaxies (Sauvage & Thuan 1992). Thus we can assume a single starburst component for the hot star-dominated, dwarf population, with optical depth τ defined so that $L_{fir} = (e^\tau - 1)L_B$. We model the FIR emission of local galaxies using RRC's two components, to which we attribute the 60μm luminosity functions derived by Saunders et al. (1990) for the cool (disk-dominated) and warm (starburst-dominated) IRAS sources respectively. These are assumed non-evolving according to our basic hypothesis.

Figure 1 shows the predicted differential counts (normalized to the Euclidian distribution) at 100, 60 and 25 μm for $\tau = 1$, i.e. assuming the dwarf FIR emission is entirely contributed by optically thick warm dust. In this and all subsequent figures, all thin dashed (or dot-dashed) curves represent the BD (or PS respectively) contribution alone. All thick dashed or dot-dashed lines represent the total contribution from both the model population and the assumed non-evolving local galaxies. The observed deep counts at 60μm derived from the

Figure 1 **The predicted differential number counts per steradian at a) 100, b) 60 and c) 25 μm, compared with the IRAS PSC, FSC, and north ecliptic pole survey (Hacking, Condon & Houck 1987). The thin solid lines are the no-evolution model predictions. The thin dashed lines (dot-dashed) show the BD (PS) population contribution, and the thick dashed lines (dot-dashed) are the corresponding model predictions, including the blue dwarfs and the non-evolving IRAS galaxies. K is the logarithmic scaling of the counts.**



IRAS *Point Source Catalogue* and north ecliptic pole survey and more recently from the Faint Source Survey (Lonsdale et al. 1990 and references therein), depart unambiguously from the no-evolution predictions (thin solid line). The starburst dwarf contribution below $\sim$ 0.1 Jy can account for this observed excess. It is clear that this contribution varies as a function of dust temperature and optical depth. At 60 μm, it increases with increasing τ and peaks at fainter fluxes at higher temperature. A similar effect will be observed to a lesser extent at 100 μm since this wavelength is dominated by cool disk emission. The existence of an extra population of faint starburst galaxies, with FIR properties similar to those of known local star-forming galaxies, is so far consistent with all observed IRAS band counts.

Contributions, plotted as νi_ν, to the diffuse extragalactic FIR background spectra resulting from the integrated emission of the assumed non-evolving IRAS galaxies, and from the two dwarf models, are shown in Fig. 2. The data points are the DIRBE measurements of the south ecliptic pole brightness (Wright 1991). The foregrounds have not yet been subtracted, and therefore these data represent upper limits to the extragalactic diffuse background. The dwarf populations produce significant radiation around their emission peak ($\lambda_{peak} \approx 50\mu$m), which may not be detectable by COBE, but will be within the reach of ISO and SIRTF. This prediction is consistent with that of Hacking & Soifer (1991), who inferred limits to the evolution of bright IRAS galaxies from their redshift distribution, and concluded that the detection of a strong background will require a source of radiation not accounted for by presently observed galaxies. We have provided a specific prediction of such a background from our physical model for the new evolving population of dwarfs required by the deep counts.

Another important effect of having so many dusty sources spread out all over the sky is obscuration. Depending on their angular diameter, which varies with redshift, these galaxies may cover up a significant area of the sky and obscure the background universe. More detailed modeling for the size and dust content of these objects is needed to make meaningful predictions, but given their space density, we can anticipate quite a dramatic covering factor.

3.2 Radio

The radio luminosity of spiral galaxies is a combination of thermal bremsstrahlung emission, originating from ionized HII regions, and non-thermal emission from cosmic-ray electrons associated with supernova remnants. A quasilinear correlation is observed between the galaxy FIR and radio luminosities, which is explained by their common starburst origin : the same populations of young massive stars heat the dust, ionize the HII regions, and eventually explode as supernovae, releasing the non-thermal fraction of the radio energy via accelerated cosmic ray electrons that emit synchrotron radiation. For bright, infrared selected galaxy samples and late type spirals, the $L_{1.4\mathrm{GHz}}/L_{fir}$ relation is tight and very linear, whereas a larger scatter and slope are observed for

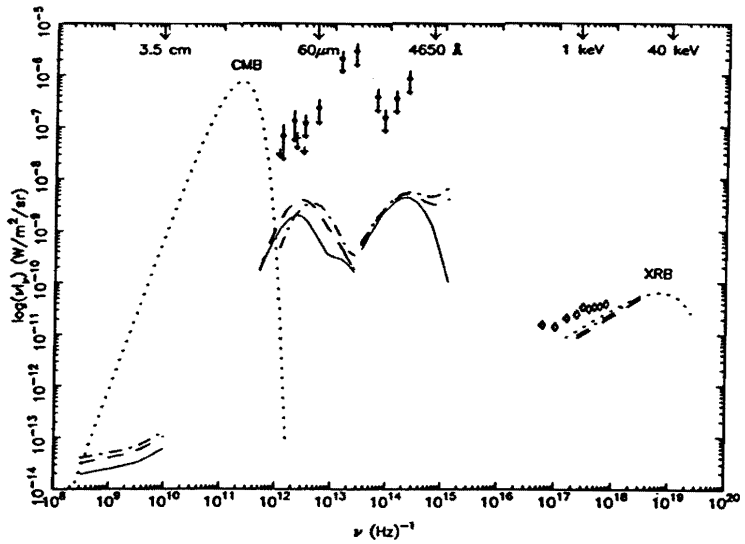


Figure 2 The integrated background radiation predicted by the no-evolution models (thin solid lines) and by the two models including the extra population of blue dwarf galaxies (thick dashed and dot-dashed lines). The dotted line in the high energy part of the spectrum fits the XRB measured with *HEAO-A2* (Marshall et al. 1980). The diamonds are the data by Wu et al. (1991) for the soft XRB. The far-infrared data points are the preliminary results from DIRBE at the south ecliptic pole (Wright 1991). The foregrounds have not been subtracted.

infrared faint sources and optically bright, early type spirals (Fabbiano et al. 1988, Condon et al. 1991). These are 'disk dominated' galaxies whose low mass star content is thought to be radio quiet (producing no Type II supernovae and negligible ionization). Although nonlinear, the correlation nevertheless exists for these cooler galaxies, suggesting that massive stars can also contribute significantly to the cirrus component luminosity (Condon et al. 1991). Allowing for these observations, we have made the following assumptions :

$L_{1.4\mathrm{GHz}} \propto L_{fir}$ for the starburst-dominated galaxy populations, i.e. 'warm' IRAS and dwarfs,

$L_{1.4\mathrm{GHz}} \propto L_{fir}{}^{\beta}$ for disk-dominated IRAS galaxies.

We use the mean spectral indices of the micro-Jansky radio source population observed in the VLA deep surveys below the flux range of quasars and luminous gE radio galaxies (Fomalont et al. 1991, Windhorst et al. 1991) :

$\nu < 5$ GHz, $n \sim 0.75$ (mostly nonthermal emission),

$\nu \gtrsim 5$ GHz, $n \sim 0.3$ (thermal bremsstrahlung dominated radiation).

We have predicted the contribution to the counts at 1.41 and 8.44 GHz from the non-evolving 'warm' and 'cool' IRAS galaxies and from the starburst dwarf model populations. For old disk dominated galaxies, the best fit is found for a high value of β. We adopted $\beta = 1.3$ as derived by Devereux & Eales (1989) and Condon et al. (1991) for optically bright, early type spirals. For the starburst sources, $L_{1.4\mathrm{GHz}}(\mathrm{erg/s/Hz}) = 10^{-15} L_{fir}(\mathrm{erg/s})$ (Fabbiano et al. 1988, Condon et al. 1991). Results are shown in Fig. 3. The same features are observed at low and high frequencies : the counts of bright radio sources (quasars and gE radio galaxies) rapidly converge at the mJy level, suggesting that they must have been practically all detected. Below 3 mJy, the slope clearly flattens (i.e. approaches again the Euclidean value), with no sign of weakening down to the survey flux limits of a few μJy. There is no observed change in the count slope, the spectral properties, and even the angular size of the sources over this ~ 3 dex range of flux (Fomalont et al. 1991). The simple starburst model we have described can account for these properties observed in the deep radio surveys. The dwarf population only appears at the micro-Jansky level, and keeps the count slope steep as observed, down to $\sim 1\mu$Jy. Preliminary optical identifications do indicate a significant fraction of star-forming galaxies among the micro-Jansky sources, most of which have been identified with faint blue galaxies with $22 \lesssim V \lesssim 27$ (Kristian et al. 1992). The observed angular diameter of these numerous starburst sources (~ 1 arcmin) supports the contention that they may play an important role in obscuration, as well as in absorption towards high redshift quasars.

3.3 X-Rays

Many very bright X-ray binaries, emitting well in excess of the Eddington limit for a $1 M_{\odot}$ accreting object, have been discovered with the Einstein satellite in apparent association with active star formation (Fabbiano 1992), suggesting that starburst galaxies could be orders of magnitude brighter in X-rays than normal galaxies with respect to optical luminosity. IRAS-selected, starburst candidates reveal hard energy flat spectra down to a few tens of keV (Rephaeli et al. 1991), as well as soft X-ray excesses around $\sim$ 1-2 keV that may be contributed by high and low mass X-ray binary populations respectively (Meurs & Boller 1992). These properties suggest

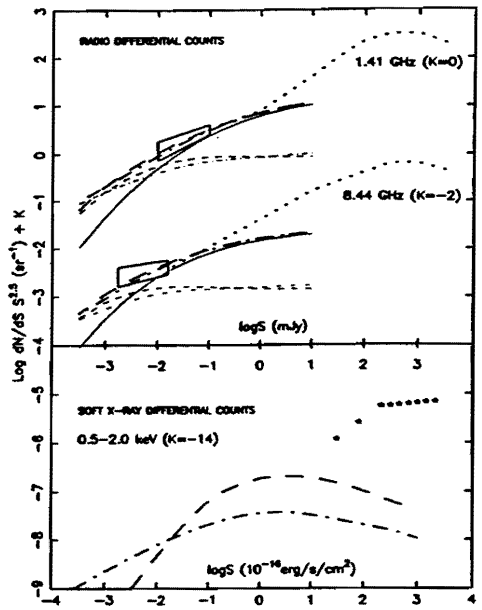


Figure 3 **Top panel: The predicted differential number counts at a) 21 and b) 3.5 cm, compared with the VLA and WSRT surveys (dotted lines) (Windhorst et al. 1992 and refs therein). The boxes are an extrapolation of the logN-logS curve using statistical analyses. The thin solid line is the 'cool' IRAS galaxy contribution, assuming no evolution of the local IRAS luminosity function. The thin dashed lines (dot-dashed respectively) are the 'warm' galaxy contribution, including the non-evolving 'warm' IRAS galaxies and the starburst dwarfs. The thick lines are the total counts.**

Bottom panel: The predicted differential number counts per steradian in the energy band 0.5-2 keV, contributed by the BD (dashed line) and PS (dot-dashed line) populations. The fluxes are in units of 10^{-16}erg/s/cm^2. The star symbols fit the X-ray counts derived from ROSAT (Hasinger 1992). All counts are normalized to the Euclidean number-flux relation $S^{-2.5}$, and rescaled as indicated on the figure.

that starburst galaxies could partly or even predominantly explain the still puzzling origin of the cosmic X-ray background (XRB). The observed correlations between the FIR and soft X-ray luminosities of local IRAS galaxies yield negligible X-ray emissivity however (less than 5% of the $\sim$ 3 keV XRB), unless strong evolution in the IRAS luminosity function is assumed (Griffiths & Padovani 1990, Treyer et al. 1992). Such evolution is accounted for by our model population of faint starburst galaxies which consequently could be responsible for a significant fraction of the XRB, mainly at high energies where most of the flux originates.

Assuming a simple power-law spectrum with energy index 0.3 in the range $\sim$ 3-30 keV, we have determined the X-ray to optical luminosity ratio of the dwarfs required to produce 50 to 100% of the observed flux in this energy range : $\log(L_X/L_B) = 31.5 - 31.7$ for the BD model, and $31.0 - 31.3$ for the PS model in which the number density of sources is larger. L_X refers to the 3 keV luminosity in erg/s and L_B to the B-band luminosity in units of $L_\odot$. Late type galaxies have $\log(L_X/L_B) \sim 27 - 31$ (Fabbiano et al. 1988). Thus the starburst dwarfs need not be much brighter in X-rays than ordinary spirals to produce the bulk of the XRB intensity. The assumed power-law cannot account for the observed thermal spectrum above $\sim$ 30-40 keV (Fig. 2). Other emission processes must be important at high energies, such as inverse Compton scattering of the FIR radiation field (Schaaf et al. 1989). We have computed the soft X-ray counts contributed by the blue dwarf galaxies, by assuming that they produce 100% of the hard XRB and extrapolating their flat spectra to the ROSAT energy band of 0.5-2 keV. The first of these assumptions is undoubtedly an overestimate, whereas the second one may underestimate a possible soft X-ray component, e.g. from low-mass X-ray binaries. The faint blue galaxies however are supposed to be populated by young massive stars, and are therefore not expected to show soft X-ray excesses. On the other hand, the observed XRB spectrum does become steeper below 3 keV (Wu et al. 1991, Hasinger et al. 1991). The measurement of the soft background intensity is still subject to some uncertainties, mainly due to galactic contamination. Assuming $I_{(0.9-2.4keV)} \approx 2.0\times10^{-8}$erg/s/cm^2/sr (Hasinger 1992), our models make up $\sim$ 30-40% of the soft XRB. The remaining emission and the steep spectrum can be accounted for by active galactic nuclei (e.g. Maccacaro et al. 1991) and a small contribution from galaxy clusters. The predicted differential counts are shown in Fig. 3, with the ROSAT deep survey data (Hasinger 1992). Most resolved sources are QSOs, which account directly for $\sim$ 30% of the 1 keV XRB (Shanks et al. 1991). The dwarf contribution becomes significant below the survey flux limit. Indeed a few star-forming galaxies at redshift $z \sim 0.4$ have been discovered among the resolved faint X-ray sources, via optical and FIR identifications

(Fruscione & Griffiths 1991, Griffiths et al. 1992), in agreement with our prediction. The algorithms used in these detections would have missed a population of sources fainter than 10^{-14} erg/s/cm^2 with angular diameter larger than one arcminute, as may be the case for the faint galaxies detected in the deep radio surveys.

4. DISCUSSION AND CONCLUSIONS

We have shown that the existence of a numerous population of dwarf starburst galaxies at moderate redshifts, locally undetected, can account for the faint source number counts observed at optical, far-infrared and radio wavelengths and possibly produce the bulk of the cosmic hard X-ray background. The existence of such a population was first suggested by optical data (Cowie et al. 1991), and is further motivated by multiwavelength observations. Various scenarios have been proposed for the formation of such dwarf galaxies (Lacey & Silk 1991; Babul & Rees 1992; Lacey et al. 1992)

Both of our schematic dwarf models can reproduce the available data in the various wavelength bands we have examined. Distinctive features of the different evolution modes show up at magnitudes $\sim$ one order of magnitude fainter than currently reached. The X-ray and radio source counts are predicted to be similar, with the bright counts being dominated by superluminous sources (mostly quasars) and the faint end by starburst galaxies (Fig. 3). Deeper counts over a wider spectral range, as well as multiwavelength identifications of faint blue galaxies are necessary to understand their physical properties and trace their evolution. The next generation of infrared and X-ray space telescopes (e.g. *ISO*, *ASTRO-D*, *AXAF* and *XMM*) is expected to allow this hypothesis to be tested.

Diffuse background analyses provide additional constraints on the emissivity and clustering properties of the faint unresolved galaxies. The contribution of the starburst dwarf population to the optical extragalactic light, and to the sky brightness fluctuations due to their assumed clustering has been studied by Cole et al. (1992). The auto-correlation function of the diffuse background fluctuations strongly depends on the source clustering and evolution and is thus important to measure. Such an analysis has been made possible at soft X-rays with the imaging capabilities of the ROSAT satellite reaching a few tens of arcsecond resolution (Hasinger et al. 1991), and exploited to constrain the contribution and clustering properties of the XRB sources (Treyer et al. 1992, Danese et al. 1992). The isotropy of the soft XRB on arcminute scales requires that any significant new population be weakly clustered, as indeed seems to be the case for the faint blue galaxies (Efstathiou et al. 1991, Neuschaefer et al. 1991). Models for the correlated component of the diffuse infrared, radio and X-ray extragalactic background light will be studied in a subsequent paper.

We conclude that a population of dwarf galaxies, undergoing bursts of star-formation at medium redshifts and rapidly vanishing via merging, fading or self-destruction, could be responsible for the excess counts seen in deep optical, FIR and radio observations, and for a dominant fraction of the FIR and X-ray backgrounds. This population may directly trace baryonic mass, and is therefore of crucial interest for our understanding of galaxy formation and evolution. Deeper counts and spectroscopic surveys, and more sensitive background measurements, over a wide range of wavelengths will be essential in order to understand the true nature of these faint objects.

Acknowledgements : this research has been supported in part by NASA and NSF. MAT acknowledges support from Ecole Polytechnique (France).

REFERENCES

Babul, A. & Rees, M. 1992, MNRAS, 255, 346

Bond, J., Cole, S., Efstathiou, G. and Kaiser, N. 1991, ApJ, 379, 440

Broadhurst, T., Ellis, R. and Shanks, T. 1988, MNRAS, 235, 235

Broadhurst, T., Ellis, R. and Glazebrook, K. 1992, Nature, 355, 55

Cole, S., Treyer, M.A. and Silk, J. 1992, ApJ, 385, 9

Colless, M., Ellis, R., Taylor, K. and Hook, R. 1990, MNRAS, 244, 408

Colless, M., Ellis, R., Broadhurst, T., Taylor, K. and Peterson, B. 1992, MNRAS, in press

Condon, J., Anderson, M. and Helou, G. 1991, ApJ, 376, 95

Cowie, L., Songaila, A. & Hu, E. 1991, Nature, 354, 460

Cowie, L., Gardner, J., Hu, E.M., Wainscoat, R. and Hodapp, K. 1992, ApJ, submitted
Danese, L., Toffolati, L., Franceschini, A., Martin-Mirones, J.M., and De Zotti, G. 1992, preprint
Désert, F.X., Boulanger, F. and Puget, J.L. 1990, A&A, 237, 215
Devereux, N. & Eales, S. 1989, ApJ, 340, 708
Efstathiou, G., Bernstein, G., Katz, N., Tyson, J. and Guhathakurta, P. 1991, ApJ, 380, L47
Fabbiano, G., Gioia, I. and Trinchieri, G. 1988, ApJ 324, 749
Fabbiano, G. 1992, in X-Ray Binaries, ed. W. Lewin et al. (Cambridge University Press), in press
Fomalont, E.B., Windhorst, R.A., Kristian, J.A. and Kellerman, K.I. 1991, AJ, 102, 1258
Fruscione, A. & Griffiths, R. 1991, ApJ, 380, L13
Griffiths, R. & Padovani, P. 1990, ApJ, 360, 483
Griffiths, R.E., Tuohy, I.R., Brissenden, R.J. and Ward M.J. 1992, MNRAS, 255, 545
Guhathakurta, P., Tyson, J. & Majewski, SR. 1990, ApJ, 357, L9
Hacking, P. & Soifer, B. 1991, ApJ, 367, L49
Hasinger, G., Schmidt, M., Trümper, J. 1991, A&A, 246, L2
Hasinger, G. 1992, in The X-Ray Background, ed. X. Barcons & A. Fabian (Cambridge University Press)
Koo, D. C. & Kron, R. G. 1992, ARAA, 30, 613
Kristian, J., Windhorst, R. and Fomalont, E. 1992, in preparation
Lacey, C. & Silk, J. 1991, ApJ, 381, 14
Lacey, C., Guiderdoni, B., Rocca-Volmerange, B. & Silk, J. 1993, AJ, in press
Lilly, S., Cowie, L. and Gardner, J. 1991, ApJ, 369, 79
Lonsdale, C., Hacking, P., Conrow, T. and Rowan-Robinson, M. 1990, ApJ, 358, 60
Maccacaro, T., Della Ceca, R., Gioia, I.M., Morris, S., Stocke, J. and Wolter, A. 1991, ApJ, 374, 117
Maddox, S. J., Sutherland, W. J., Efstathiou, G., Loveday, J. and Peterson, B. A. 1990, MNRAS, 247, 1P
Marshall, F. et al. 1980, ApJ, 235, 4
Meurs, E. & Boller, T. 1992, in X-ray Emission from Active Galactic Nuclei and the Cosmic X-ray Background, ed. W. Brinkmann & J. Trümper, MPE Report 235, 338
Neuschaefer, L., Windhorst, R. and Dressler, A. 1991, ApJ, 382, 32
Press, W.H. & Schechter, P. 1974, ApJ, 187, 425
Rephaeli, Y., Gruber, D., Persic, M. and MacDonald, D. 1991, ApJ, 380, L59
Rowan-Robinson, M. & Crawford, J. 1989, MNRAS, 238, 523
Saunders, W., Rowan-Robinson, M., Lawrence, A., Efstathiou, G., Kaiser, N., Ellis, R.S. and Frenk, C.S. 1990, MNRAS, 242, 318
Sauvage, M. & Thuan, T.X. 1992, ApJ, 396, L69
Schaaf, R., Pietsch, W., Biermann, P., Kronberg, P. and Schmutzler, T. 1989, ApJ, 336, 722
Shanks, T., Georgantopoulos, I., Steward, G., Pounds, K., Boyle, B. and Griffiths, R. 1991, Nature, 353, 315
Silk, J. 1992, in The Feedback of Chemical Evolution on the Stellar Content of Galaxies, ed. D. Alloin & G. Stasińska (Obs. de Paris), in press
Treyer, M.A., Mouchet, M., Blanchard, A. & Silk, J. 1992, A&A, 264, 11
Tyson, J.A, 1988, AJ, 96, 1
Windhorst, R.A., Fomalont, E.B., Partridge and Lowenthal, J. 1992, preprint
Wright 1991, in The Infrared and Submillimetre Sky after COBE, ed. M. Signore & C. Dupraz (Kluwer Academic Publishers)
Wu, X., Hamilton. T.T., Helfand, D.J. and Wang, Q. 1991, ApJ, 379, 564