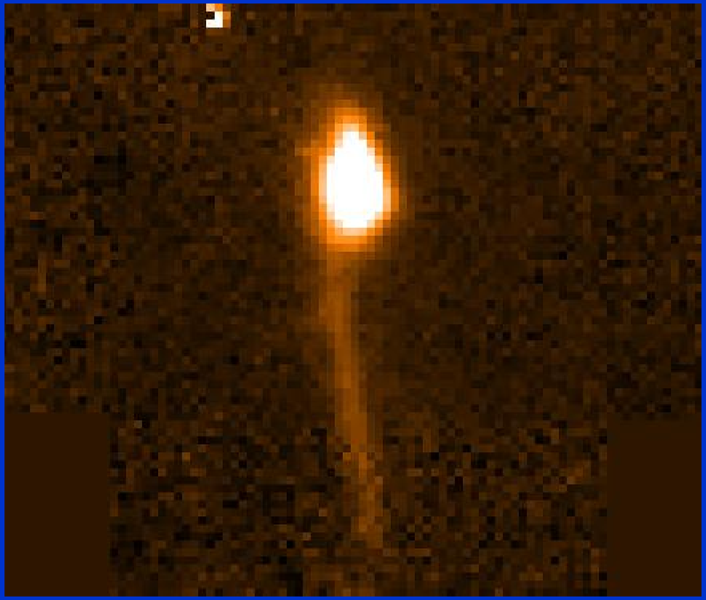
 

Nearby Galaxies with UKIRT

Phil James (Liverpool JMU)

Outline

- Try to review everything from mid-80s to present day and beyond
- Personal view, many omissions
- I will leave AGN, and very nearby galaxies with resolved stellar populations, to others
- Celebrate past achievements of UKIRT, look for pointers to future

IR-luminous galaxies

- AKA ‘IRAS galaxies’, LIRGs, ULIRGs, etc
- Discovered as a significant population by IRAS in early 1980s
- SEDs dominated by thermal emission from dust
- ‘Starbursts’ or ‘monsters’?

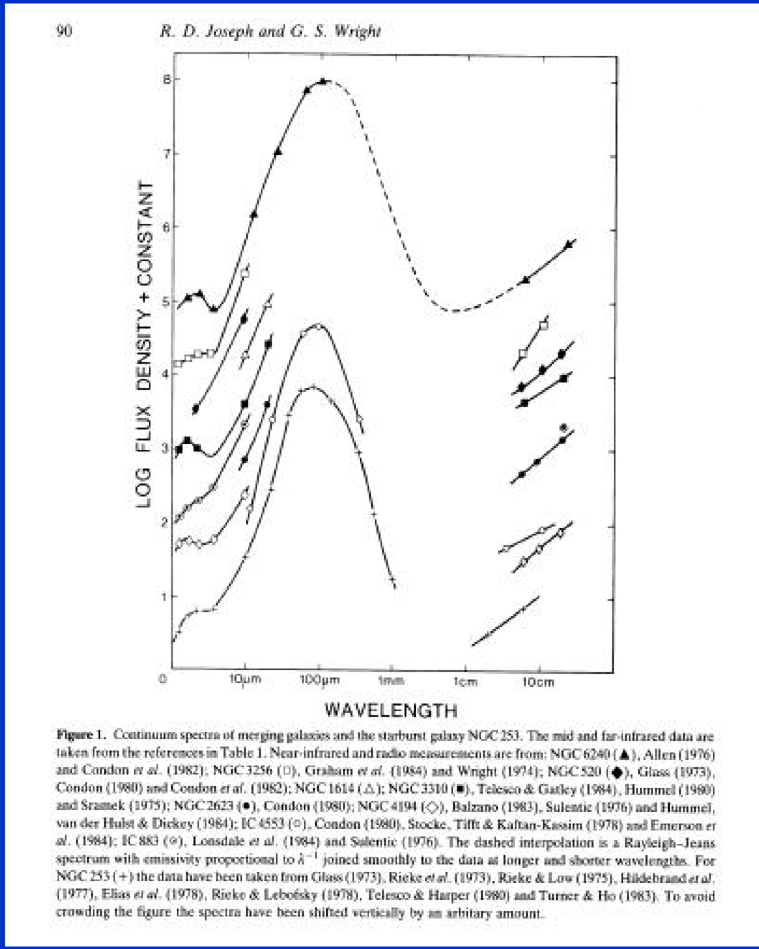


Figure 1. Continuum spectra of merging galaxies and the starburst galaxy NGC 253. The mid and far-infrared data are taken from the references in Table 1. Near-infrared and radio measurements are from: NGC 6240 (▲), Allen (1976) and Condon *et al.* (1982); NGC 3256 (□), Graham *et al.* (1984) and Wright (1974); NGC 520 (◆), Glass (1973), Condon (1980) and Condon *et al.* (1982); NGC 1614 (△); NGC 3310 (■), Telesco & Gatley (1984), Hummel (1980) and Sramek (1975); NGC 2623 (●), Condon (1980); NGC 4194 (◇), Balzano (1983), Sulentic (1976) and Hummel, van der Hulst & Dickey (1984); IC 4553 (○), Condon (1980), Stocke, Tifft & Kaftan-Kassim (1978) and Emerson *et al.* (1984); IC 883 (⊙), Lonsdale *et al.* (1984) and Sulentic (1976). The dashed interpolation is a Rayleigh–Jeans spectrum with emissivity proportional to λ^{-1} joined smoothly to the data at longer and shorter wavelengths. For NGC 253 (+) the data have been taken from Glass (1973), Rieke *et al.* (1973), Rieke & Low (1975), Hildebrand *et al.* (1977), Elias *et al.* (1978), Rieke & Lebofsky (1978), Telesco & Harper (1980) and Turner & Ho (1983). To avoid crowding the figure the spectra have been shifted vertically by an arbitary amount.

Joseph & Wright 1985

Optically disturbed - mergers

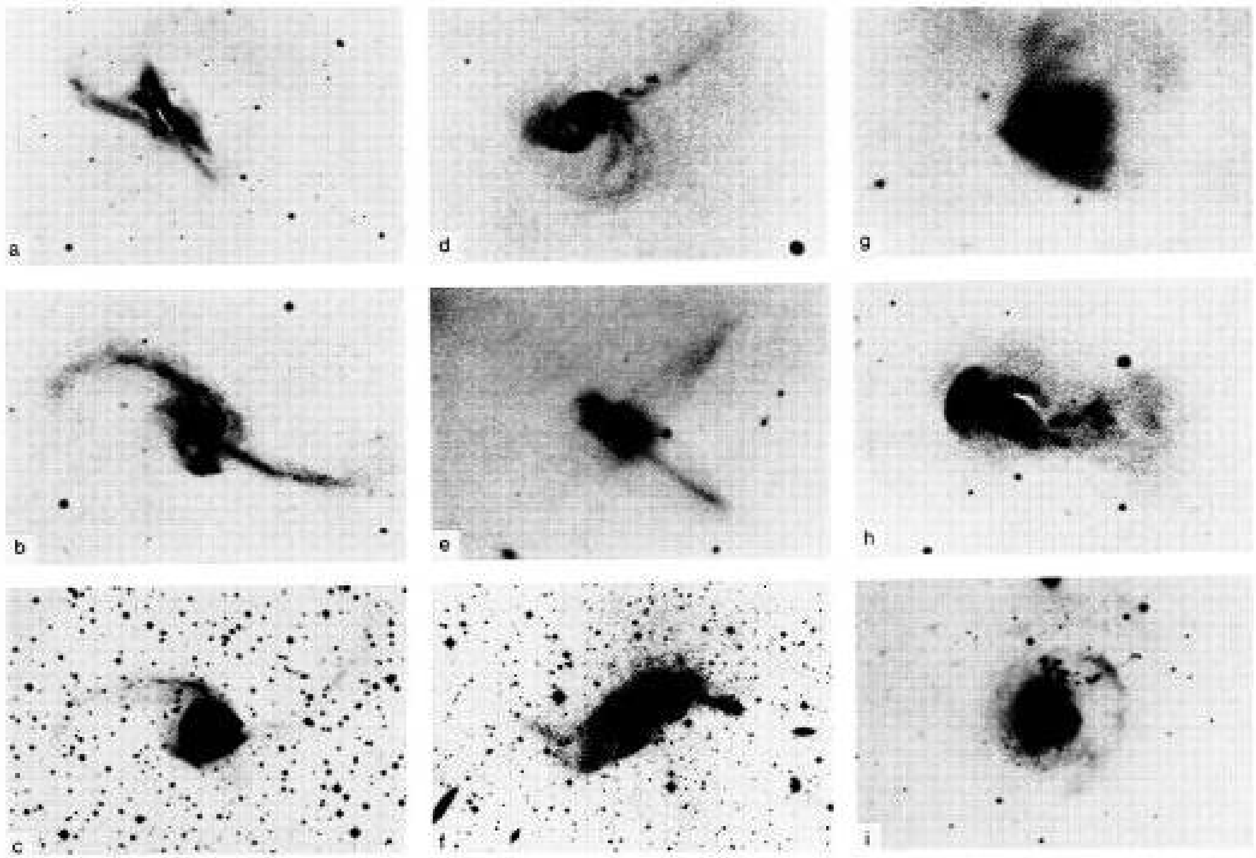


Plate 1. Pictures of the nine merging galaxies in our sample. The photographs have been reproduced from the Arp (1966) Atlas, except for NGC 3256, which is reproduced from the ESO/SERC Southern Sky Survey IIIaJ plate taken with the UK Schmidt Telescope, and for NGC 6240, which is reproduced from a plate published by Fosbury & Wall (1979). Ordered approximately according to relative merger age, the galaxies are (a) NGC 520, (b) NGC 2623, (c) NGC 3256, (d) NGC 1614, (e) IC 883, (f) NGC 6240, (g) IC 4553, (h) NGC 4194, (i) NGC 3310.

Joseph & Wright 1985

Joseph and Wright 1985:

Summary. The subset of galaxy–galaxy interactions which have resulted in a merger are, as a class, ultraluminous IR galaxies. Their IR luminosities span a narrow range which overlaps with the most luminous Seyfert galaxies. However, in contrast with Seyfert galaxies, the available optical, IR, and radio properties of mergers show no evidence for a compact non-thermal central source, and are easily understood in terms of a burst of star formation of extraordinary intensity and spatial extent: they are 'super starbursts.' We argue that super starbursts occur in the evolution of most mergers, and discuss the implications of super starbursts for the suggestion that mergers evolve into elliptical galaxies. Finally, we note that merger-induced shocks are likely to leave the gas from both galaxies in dense molecular form which will rapidly cool, collapse, and fragment. Thus a merger might in fact be expected to result in a burst of star formation of exceptional intensity and spatial extent, i.e. a super starburst.

UKIRT and IR-luminous galaxies

- Mergers and interactions efficient at triggering SF

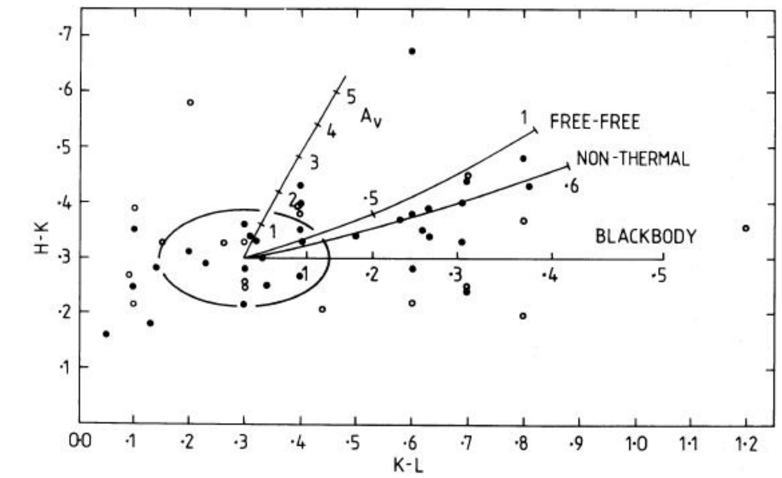
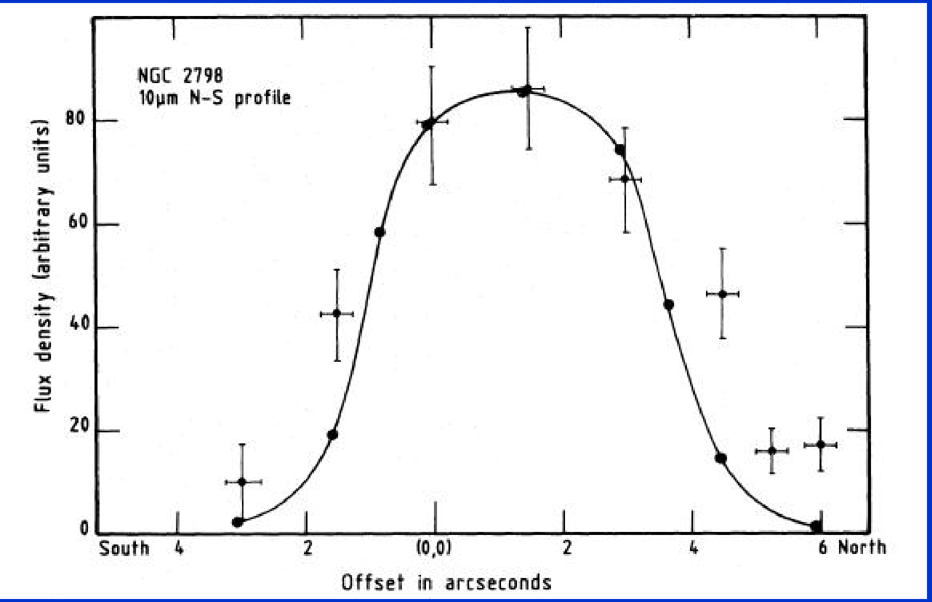


Figure 1. *HKL* colour–colour diagram for all the galaxies listed in Table 1. Normal galaxy colours lie within the ellipse. Tick marks on the reddening line indicate magnitudes of extinction at V. Tick marks on the free–free, non-thermal and blackbody lines correspond to the fraction of the total flux at *L* contributed by these components. The blackbody line corresponds to any temperature $\lesssim 300$ K. An open circle is used to indicate data with errors in $K-L > 0.1$.

Joseph et al. 1984

UKIRT and IR-luminous galaxies

- Mergers and interactions efficient at triggering SF
- Powered substantially by SF



Wright et al. 1988

(Extended emission also reported by Wright et al. 1984, Cutri et al. 1984.)

UKIRT and IR-luminous galaxies

- Mergers and interactions efficient at triggering SF
- Powered substantially by SF
- NIR profiles can resemble those of elliptical galaxies

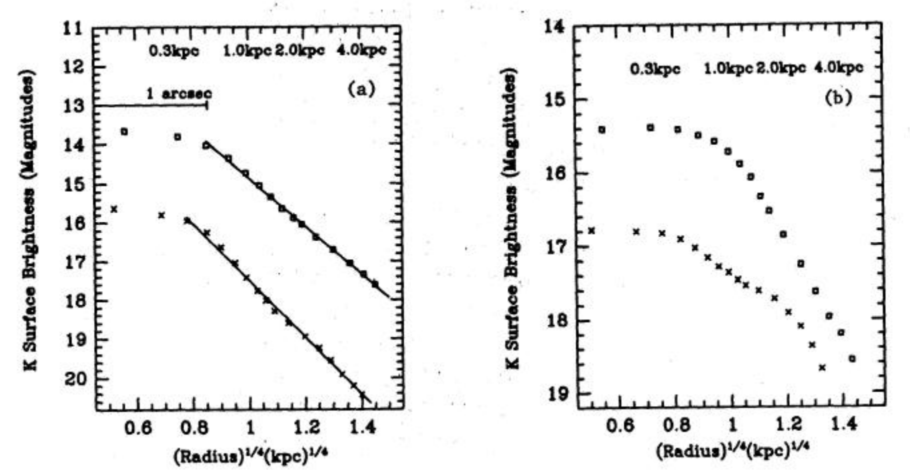
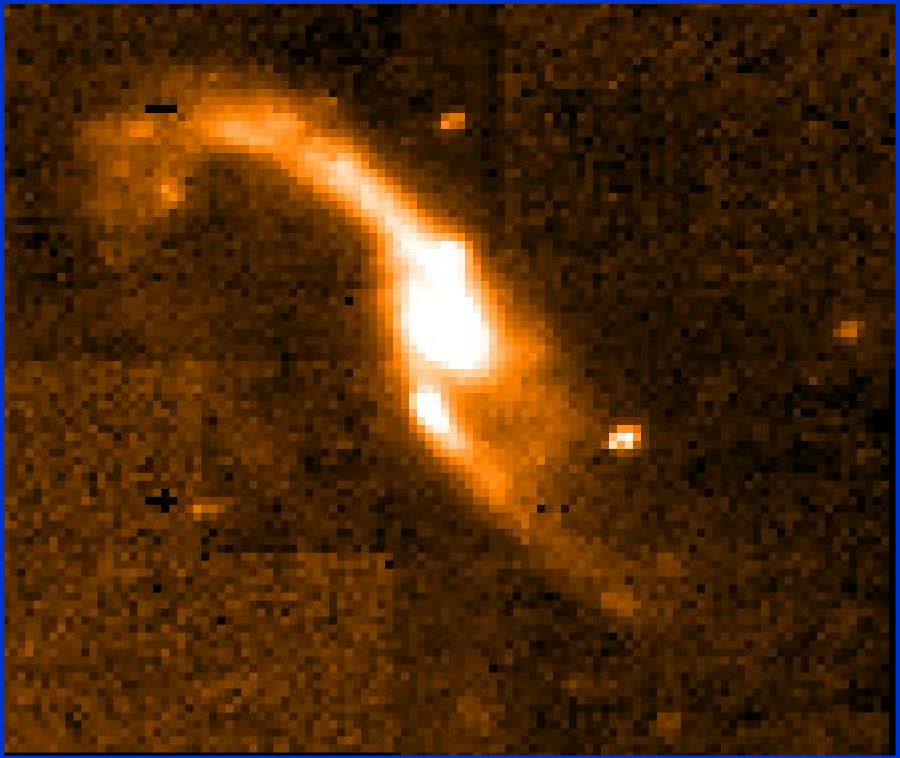


Figure 1 K surface brightness (mag/arcsec^2) plotted vs. the fourth root of the radius for **a)** Arp220 (□) and NGC2623 (×) and **b)** IC883 (□) and NGC6052 (×). The plot for NGC2623 has been offset by +2 magnitudes for clarity. The scale along the top of both plots is radius in kpc, assuming H_0 = 50 km s^{-1} Mpc^{-1}.

Wright et al. 1990

UKIRT and IR-luminous galaxies

- Mergers and interactions efficient at triggering SF
- Powered substantially by SF
- NIR profiles can resemble those of elliptical galaxies
- PAJ not great at near-IR imaging reduction…



UKIRT and IR-luminous galaxies

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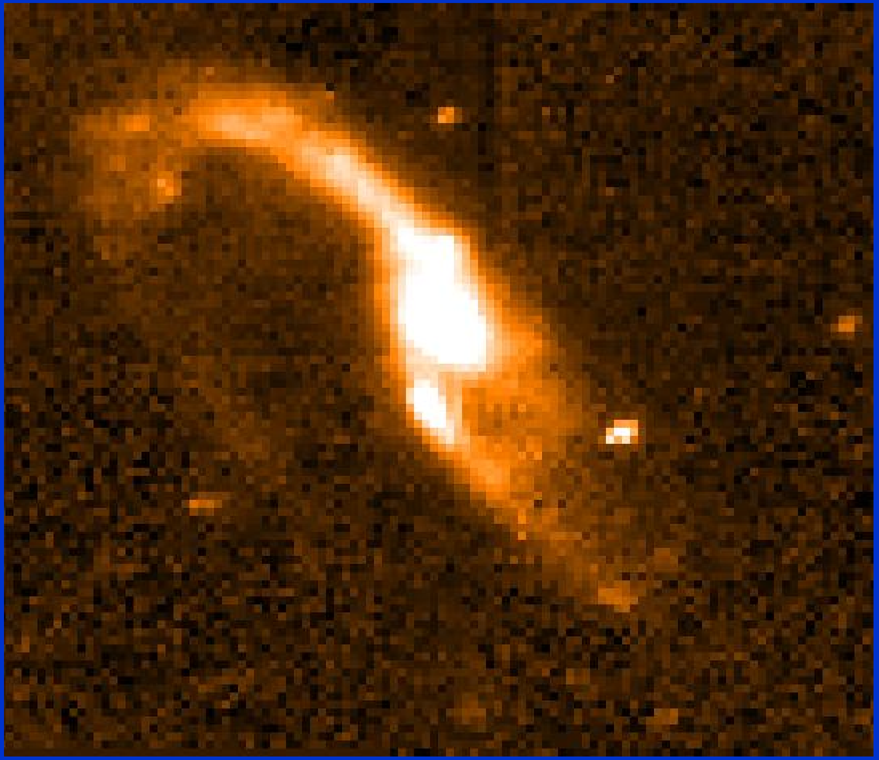

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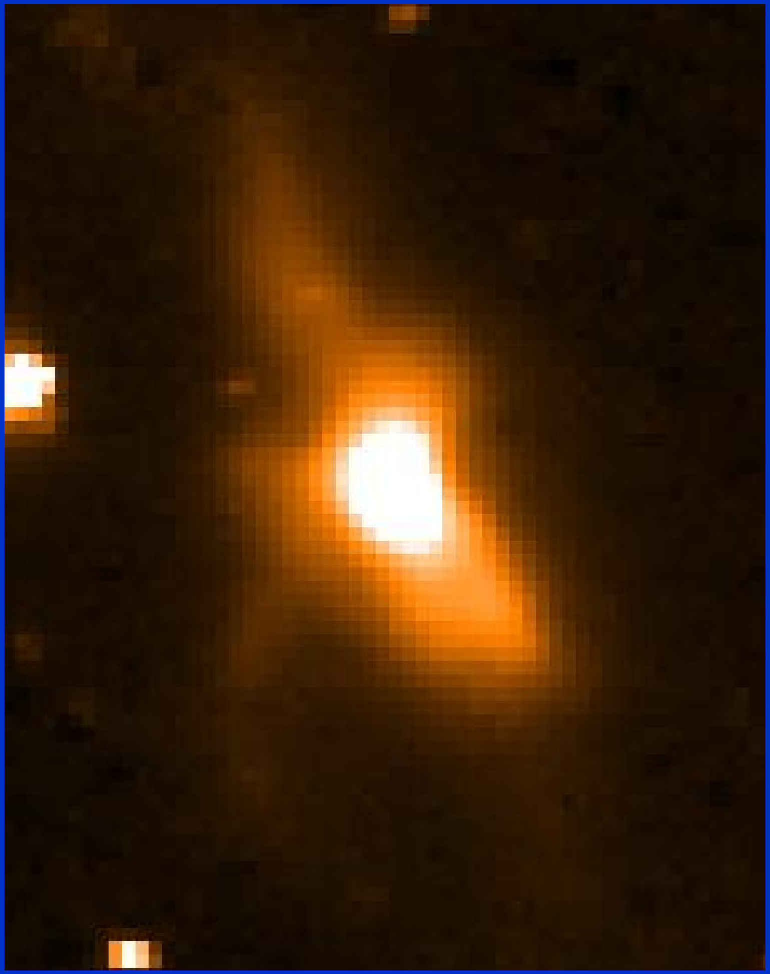

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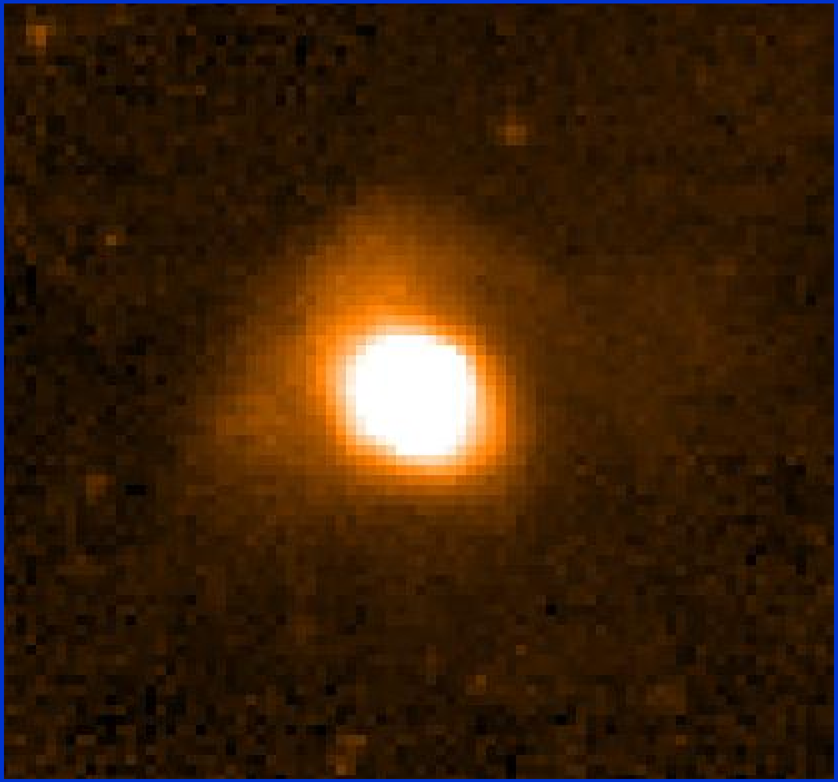

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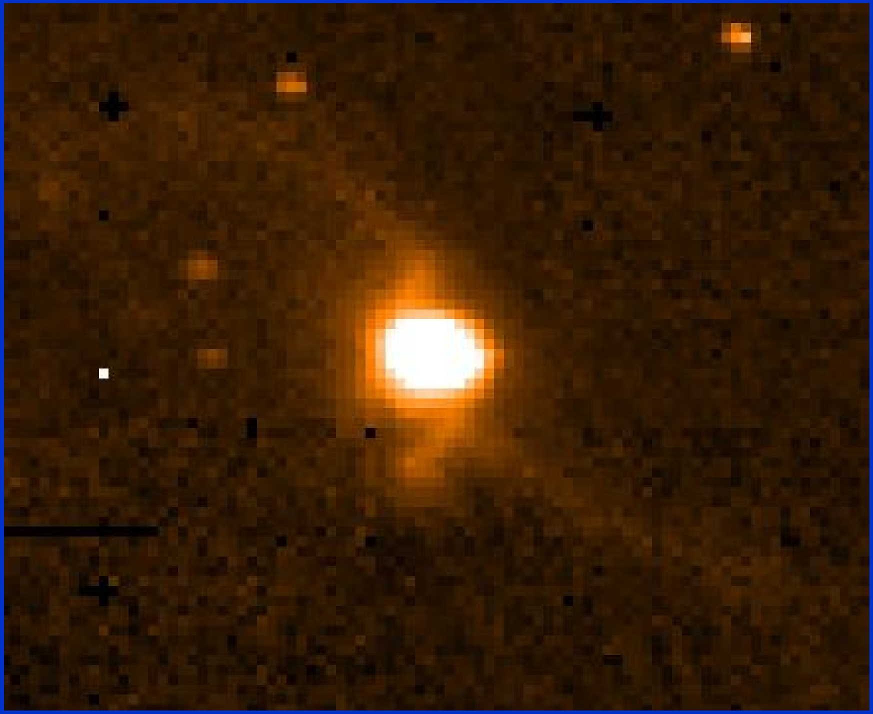

UKIRT and IR-luminous galaxies

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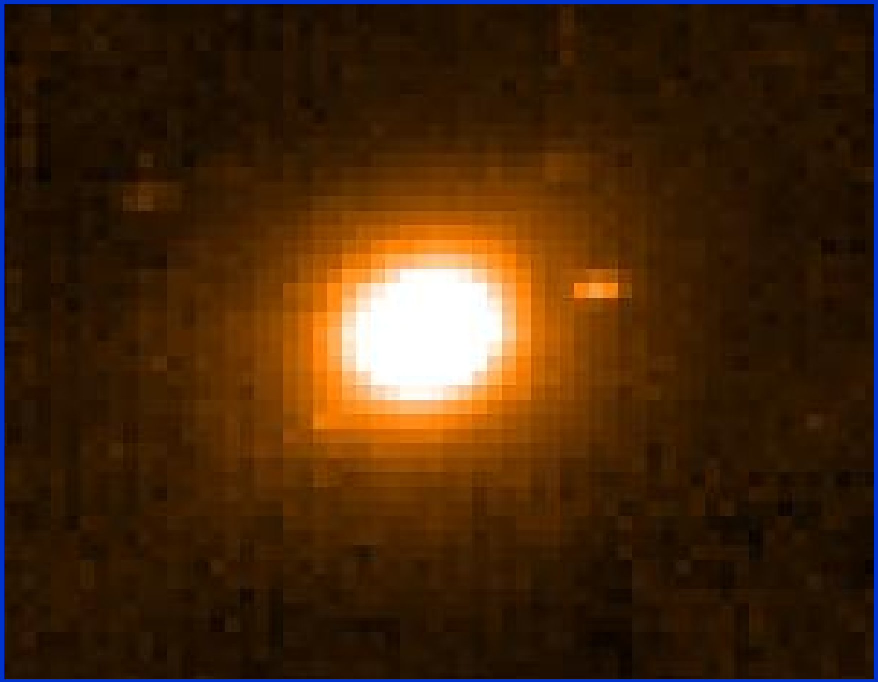


UKIRT and IR-luminous galaxies

- Mergers and interactions efficient at triggering SF
- Powered substantially by SF
- NIR profiles can resemble those of elliptical galaxies
- Some have kinematics of elliptical galaxies

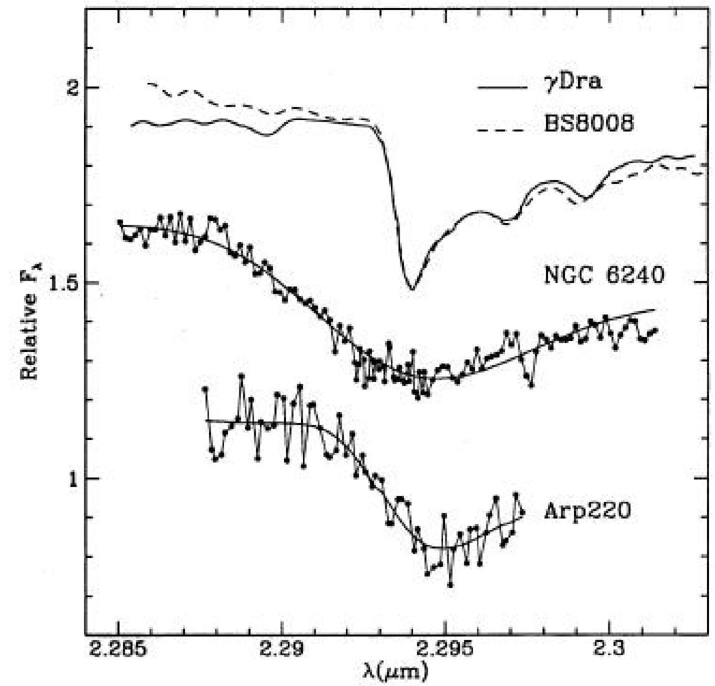


FIG. 1.—Spectra of the CO bandhead at 2.2935 μm. The spectra of Arp 220 and NGC 6240 are shown in the rest frame. The thick solid line superposed on each spectrum is the best fit obtained. The solid spectrum at the top is that of the giant star γ Dra taken from the Kleinmann & Hall (1986) atlas. The dashed spectrum is that of the star BS 8008 (K4 III) obtained with CGS4 after convolution with an instrumental velocity dispersion of 42 km s^{-1} (see text).

Doyon et al. 1994

UKIRT and IR-luminous galaxies

- Mergers and interactions efficient at triggering SF
- Powered substantially by SF
- NIR profiles can resemble those of elliptical galaxies
- Some have kinematics of elliptical galaxies

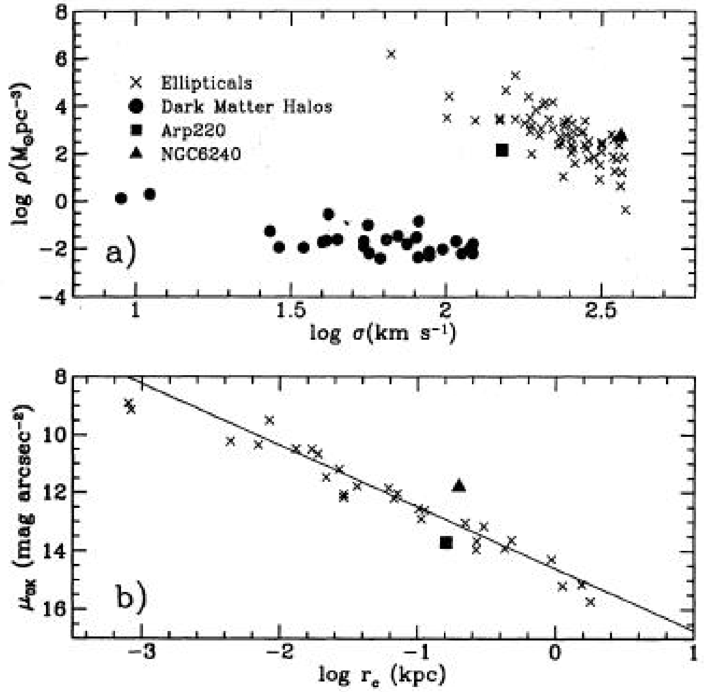


FIG. 3.—(*a*) Mass density vs. velocity dispersion for cores of elliptical galaxies and dark matter halos, adapted from Kormendy & Sanders (1992). (*b*) Central *K*-band surface brightness vs. core radius for bulges and elliptical galaxies, adapted from Kormendy (1985). The symbols have the same meanings as in (*a*). The solid line is a least-squares fit to the elliptical galaxy data.

Doyon et al. 1994

UKIRT and IR-luminous galaxies

- Mergers and interactions efficient at triggering SF
- Powered substantially by SF
- NIR profiles can resemble those of elliptical galaxies
- Some have kinematics of elliptical galaxies
- Many contain large masses of excited molecular hydrogen

UKIRT and the structures of normal galaxies

- Spiral galaxies – bars and their effects
- Spiral galaxies – spiral arms and SF
- Spiral galaxies – disk/bulge structure
- Spiral galaxies – haloes
- Dwarf galaxies
- Elliptical galaxies

Near-IR studies of bars

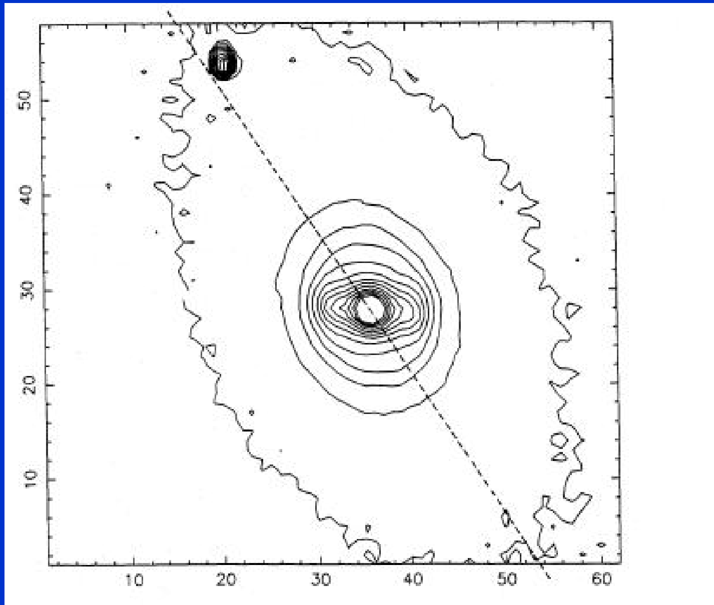
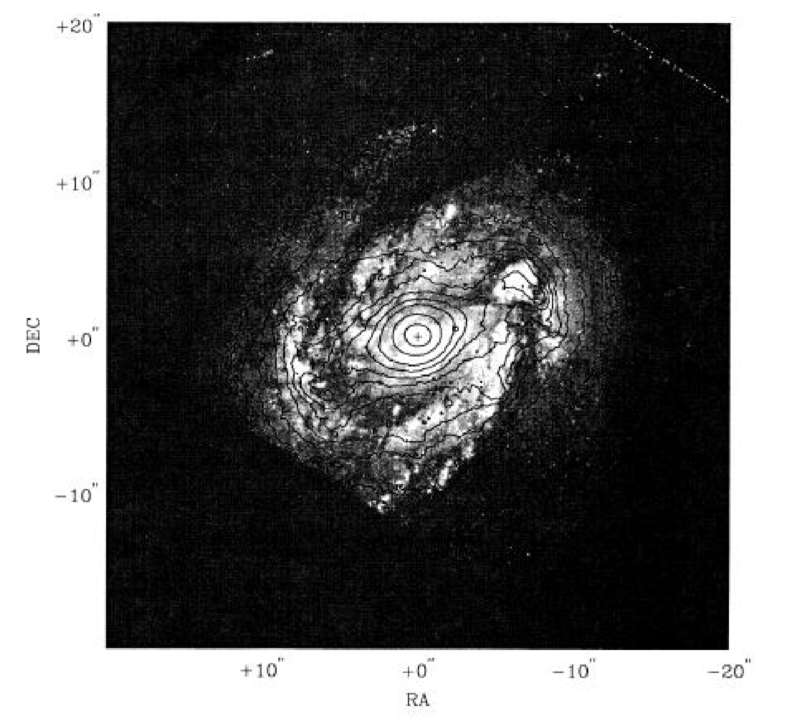
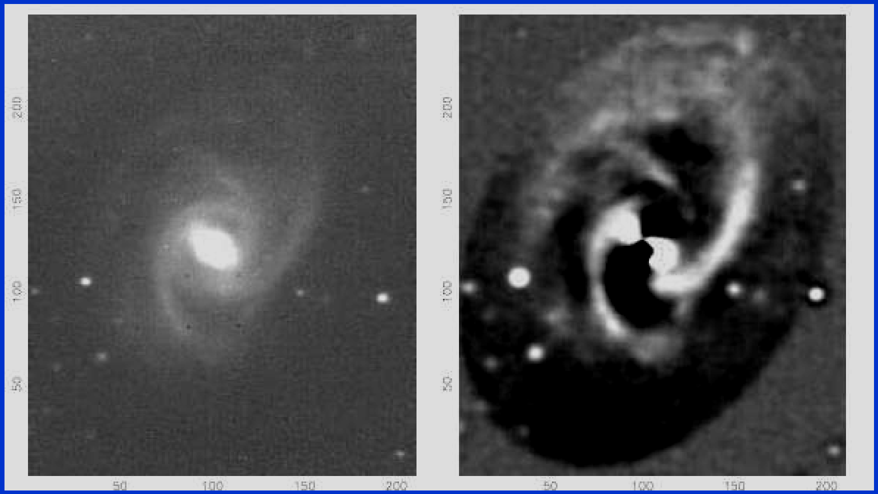


Fig. 1d. NGC5728 at 0.62 arcsec/pixel. For a distance of 3.5 Mpc and an H_0 of 100km/s/Mpc (Buta 1988), 1 arcsec corresponds to 17 pc. Contour increments correspond to 3.2 % of the sky background



IRCAM imaging of central bar structures used to investigate the effect of the stellar potential in funnelling gas into nuclear regions (Shaw et al. 1993, NGC 5728 on left; Knapen et al. 1995, M 100 on right)

Near-IR studies of spiral arms



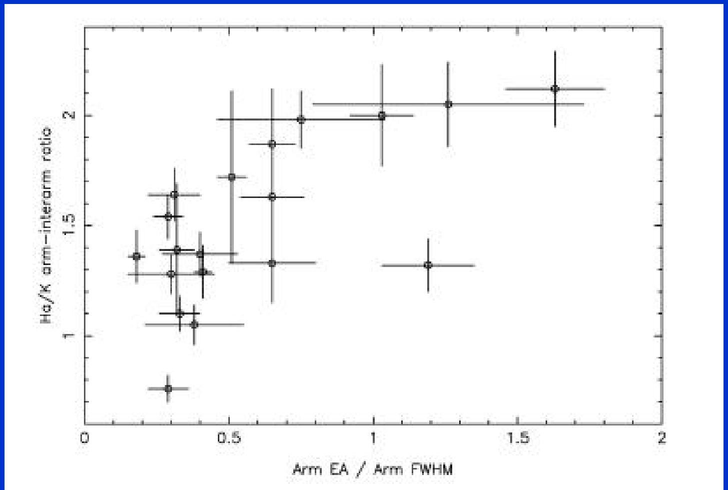
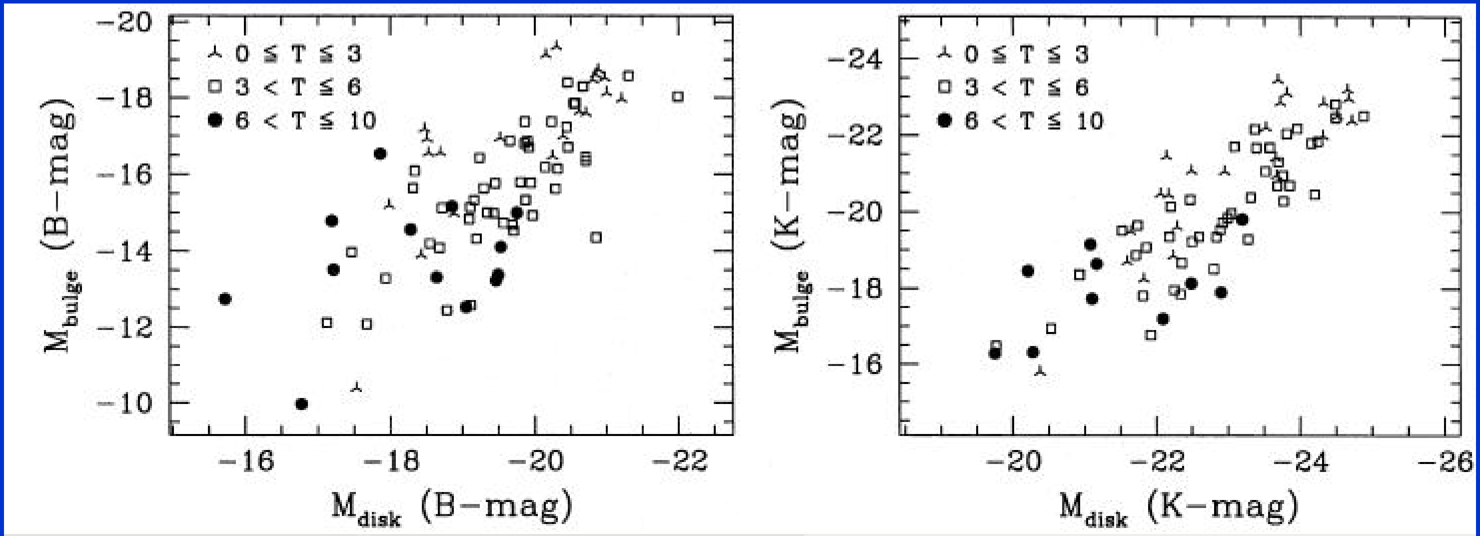


Figure 1. Hα/*K* ratio versus arm EA/FWHM ratio.

IRCAM3 imaging of spiral arms, looking at winding angles, arm strength and the triggering of star formation within arms (Seigar & James 1998, 2002)

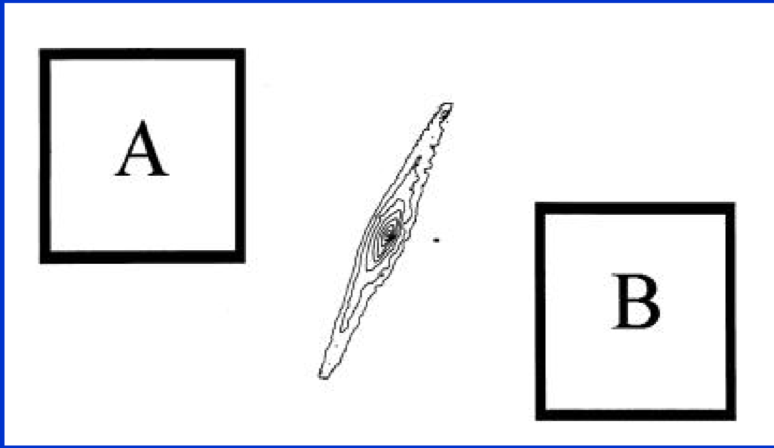
Near-IR studies of bulge-to-disk ratios

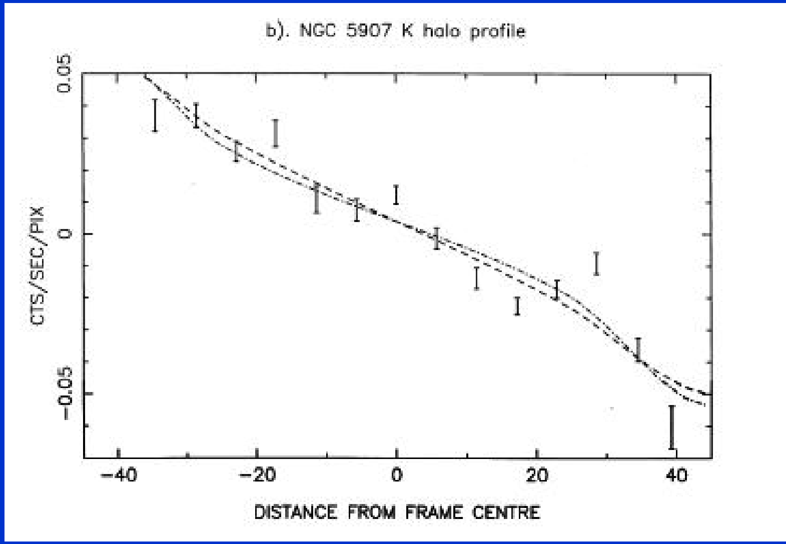
de Jong 1996



Detailed optical-near IR study by de Jong and collaborators of disk/bulge structures of nearby spirals, using the K-band to probe the dominant stellar mass component and its distribution.

Near-IR search for halo light





Search by James & Casali (1996, 1998) for extended near-IR emission from halo regions of edge-on galaxies. We found something (figure on right), but our choice of galaxy may have been poor…

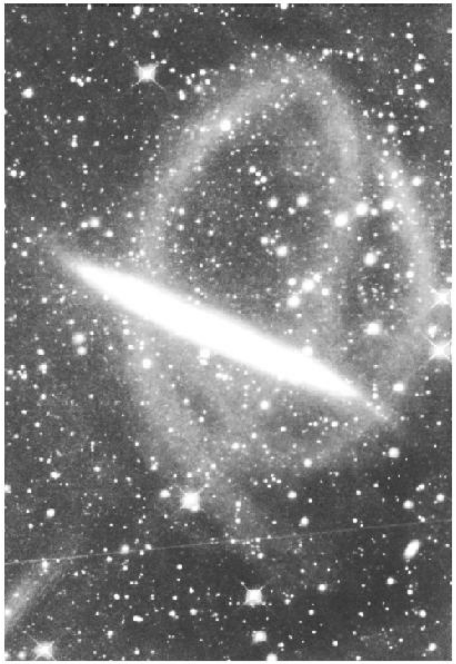
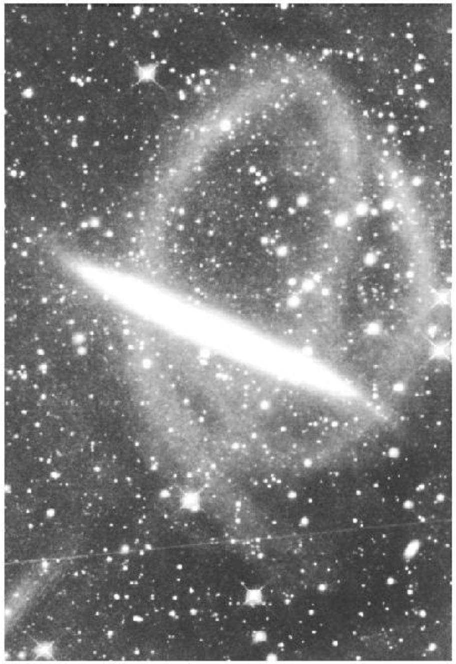


Fig. 1.— Image of NGC 5907 obtained with the BBRO 0.5-meter telescope. The total exposure time of this image is 11.35 hours, co-adding all images obtained in this project (see Table 1). The image has dimensions of 18.2 × 27.7 arcmins, which, at the distance of NGC 5907 is ∼ 75 × 115 kpc. For a better comparison with the N-body simulations given in Fig. 4, this image is shown east up and north to the right. The linear diagonal feature in the lower left corner of the image is spurious light from deflection of a bright star off of the edge of the CCD chip. The faint halos surrounding the field stars are due to the pass of the blur Gaussian filter mentioned in Sec. 2.2.

Recent optical image of NGC 5907 by Martinez-Delgado et al. (2009). Oops! However…



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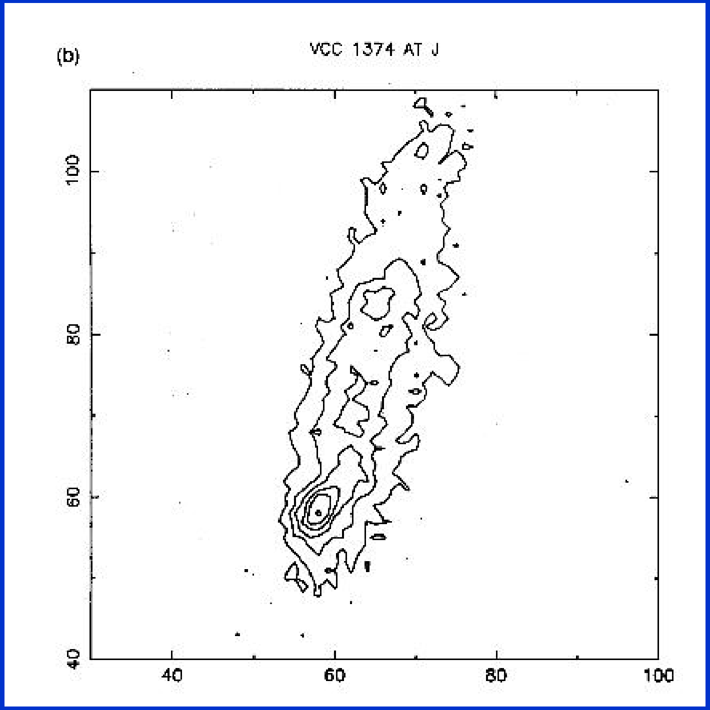
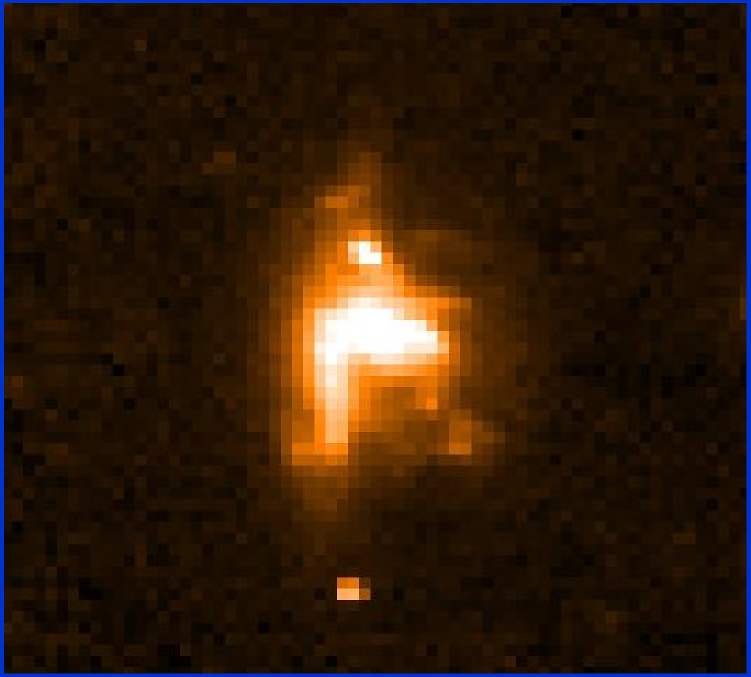
Recent optical image of NGC 5907 by Martinez-Delgado et al. (2009). Oops! However…

plane of a disk galaxy. Several studies of the evolution of disk galaxies have concluded that continuing infall of gas-rich dwarf galaxies may be required. We tentatively suggest that the light we detect could be due to the tidally disrupted remnants of such semi-digested dwarfs, in the process of accretion onto the disk of NGC 5907. The total luminosity required, assuming the light we detect to be spherically distributed with an approximately power-law distribution, gives a total K-band absolute magnitude of ∼ −19, less than 5% of the combined luminosity of the disk and bulge of NGC 5907. This model would also predict that the "halo" light would be clumpy and unrelaxed, which would certainly not be the case for an old massive halo. There is some evidence for such clumpiness, both from the visual appearance of the halo in Figure 2 of Sackett et al. (1994), and from the excess scatter seen in our profiles in Figure 2.

James & Casali 1998

UKIRT and the structure of dwarf galaxies





Study of dwarf irregulars and dwarf ellipticals (James 1991, 1994) – not similar in underlying structures, irregulars really are irregular

UKIRT and early-type galaxies

- Study of colour-mag relation of early type galaxies in Virgo and Coma by Bower, Lucey & Ellis (1992)
- UKIRT (UKT9!) and INT UVJK photometry
- Consistency of properties between Coma and Virgo used to argue for universality of C-M relation
- Small scatter implied similar SF histories between galaxies
- Standard comparison sample for high-z studies

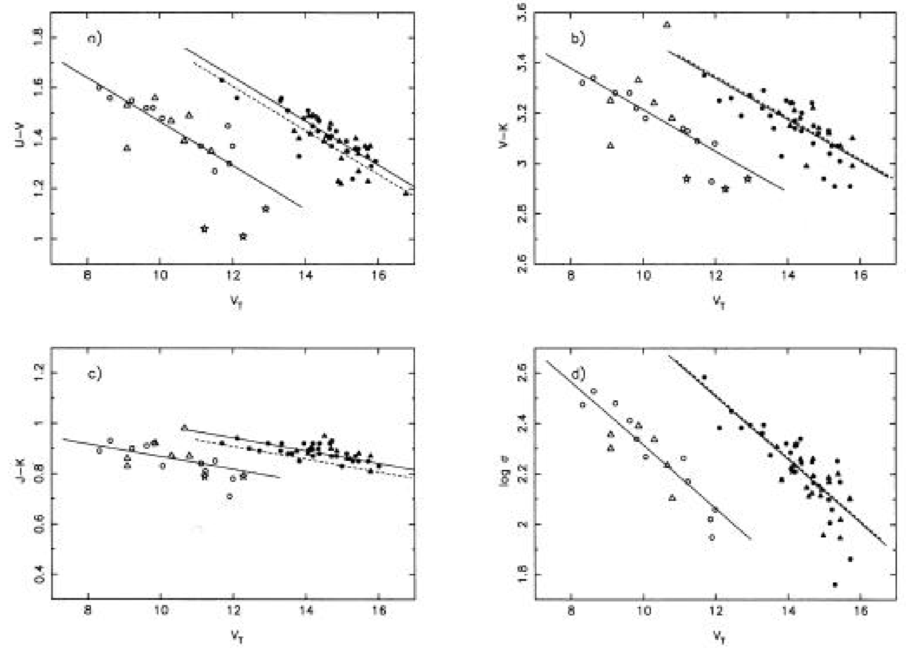


Figure 1. The colour–magnitude and Faber–Jackson relations for early-type galaxies in the Virgo and Coma clusters: (a) $U-V$ colour–magnitude; (b) $V-K$ colour–magnitude; (c) $J-K$ colour–magnitude; (d) the Faber–Jackson relation. The data are taken from tables 11 and 12 of Paper I. Open symbols denote galaxies in the Virgo cluster; filled symbols, galaxies in the Coma cluster. The symbols used denote galaxies of different morphological types – circles, elliptical; triangles, S0; stars, S0/a or $S0_3$. The solid lines show the median fit of a line with slope given in Table 2 (fitting to the full data set). The slope adopted is a compromise between the gradients of the separate best-fit lines of each cluster. The dashed lines show the expected relations in the Coma cluster predicted from the Virgo cluster zero-point plus an adopted relative distance modulus of 3.60.

Recent nearby galaxies research with UKIRT: UKIDSS

- K-band LF of 40,000 galaxies by Smith, Loveday & Cross (2009)– insensitivity of M/L ratio to SFH results in ~ stellar mass limited samples
- La Barbera et al. (2009), near-IR Fundamental Plane study using 1430 galaxies, UKIDSS photometry and SDSS velocity dispersions

K-band galaxies from UKIDSS LAS 11

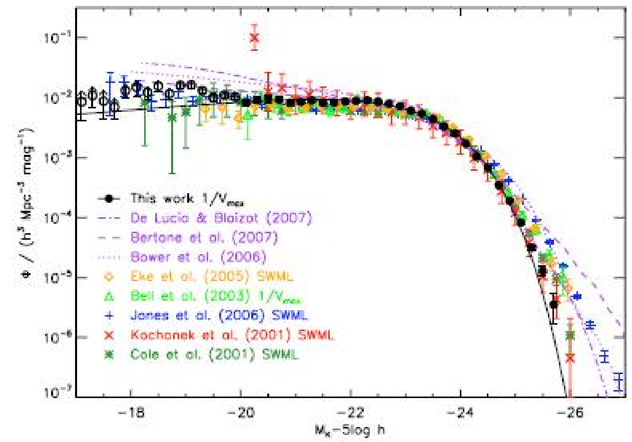


Figure 14. K-band LF for the whole sample, with a compendium of published results from observations or semi-analytic models. Only the filled points are used in the Schechter function fit, i.e., $M_K - 5\log h < -20$; the unfilled points are likely to suffer from some incompleteness of low-surface brightness or red, low-luminosity galaxies. Schechter function parameters are $M^* - 5\log h = -23.19 \pm 0.04$, $\alpha = -0.81 \pm 0.04$ and $\phi^* = (0.0166 \pm 0.0008)h^3\,\mathrm{Mpc}^{-3}$, although, as noted in the main text, the Schechter function provides a poor fit to the LF at both high and low luminosity.

Recent nearby galaxies research with UKIRT

- Search for low-redshift super-dense early type galaxies by Valentinuzzi et al. (2009), analogues of the high-z objects found by e.g. van Dokkum et al.
- Used the WFCAM WINGS-NIR survey of nearby clusters
- High-density objects are found locally, but less extreme than the high-z counterparts

T. Valentinuzzi et al.: WINGS III: Near-infrared catalogs

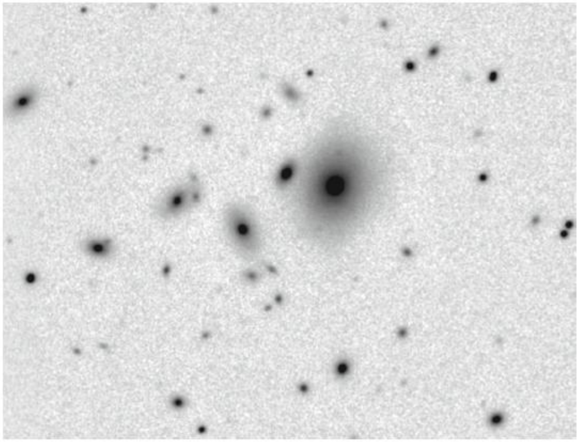


Fig. 2. The central region (2.5′ × 2.2′, north is up, east is left) of the cluster A2124 *K*-band mosaic.

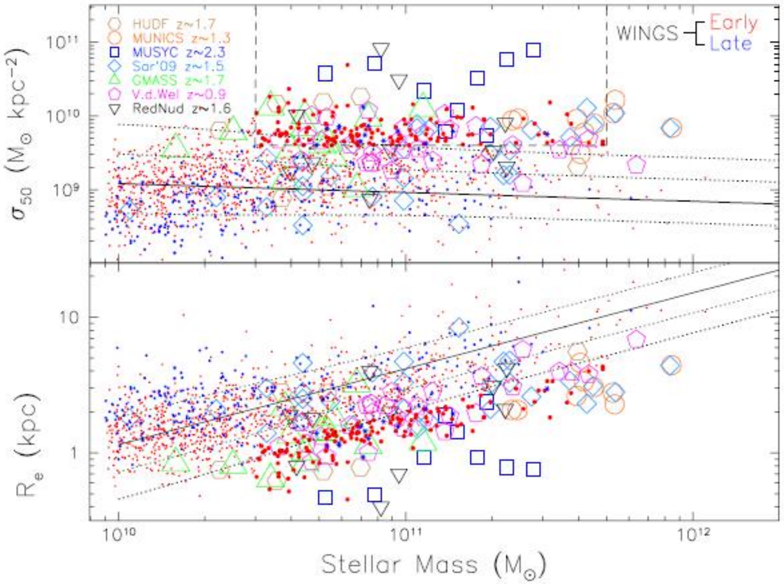


FIG. 1.— The circularized effective radius R_e and the mass-density inside R_e as a function of stellar mass for all WINGS galaxies with $M_* \geq 10^{10} M_\odot$, for the subsample of 21 clusters considered (see text). Blue and red tiny dots are late- (later than S0) and early-type (ellipticals and S0s) WINGS cluster galaxies, respectively. The region corresponding to our SDGs definition is delimited by the dashed lines in the top panel. The corresponding larger blue and red dots mark the WINGS SDGs. The black solid line is the SDSS-DR4 Shen et al. (2003) relation with dotted 1σ and 2σ lines. Open symbols are SDGs from high-z studies, see text for references.

Recent nearby galaxies research with UKIRT

- Modelling of optical – NIR colours of 2377 SF and 3438 non-SF galaxies by Eminian et al. (2009)
- Potential of optical-NIR colours to break age-metallicity degeneracy

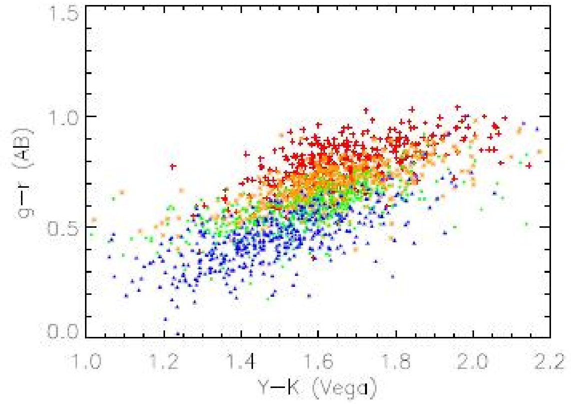


Figure 10. Distribution of galaxies with different mean stellar ages in the $g-r$ versus $Y-K$ colour-colour plane. The galaxies are divided in four equal classes according to their stellar age. Blue (triangles), green (filled circles), orange (stars) and red (crosses) indicate galaxies of increasing age.

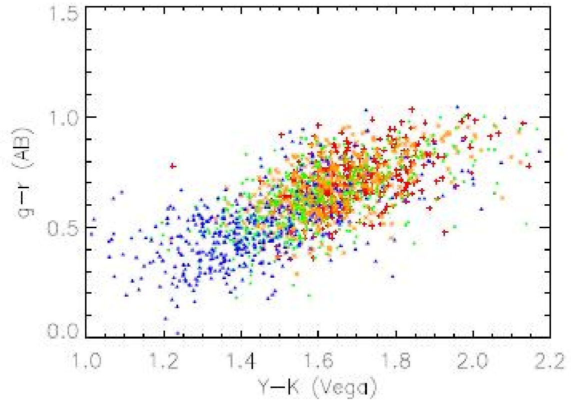


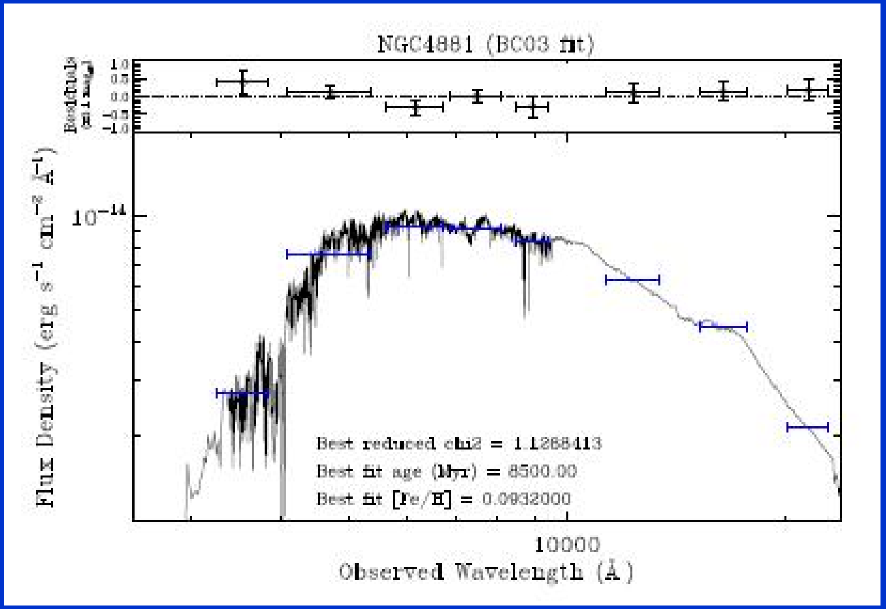
Figure 11. As in Fig. 8, except galaxies are divided according to metallicity.

What is left to do?

- All of the above! Studies of unresolved stellar populations and structures in galaxies in the near-IR tend to rely on assumptions like:
- ‘Near-IR traces old stellar populations’
- ‘Near-IR traces stellar mass’
- ‘Optical / near-IR colours can break age – metallicity degeneracy’
- The latest models enable us to test these assumptions

Near-IR population synthesis

- Only now getting to the stage where models can reliably predict colours and line indices over the near-UV to near-IR range
- Full spectral range necessary to break age-metallicity degeneracy
- Need models incorporating TP-AGB, α-enhanced abundance ratios, different mass-loss prescriptions…
- Advances in both theoretical models and empirical databases



Carter, Smith et al. 2009

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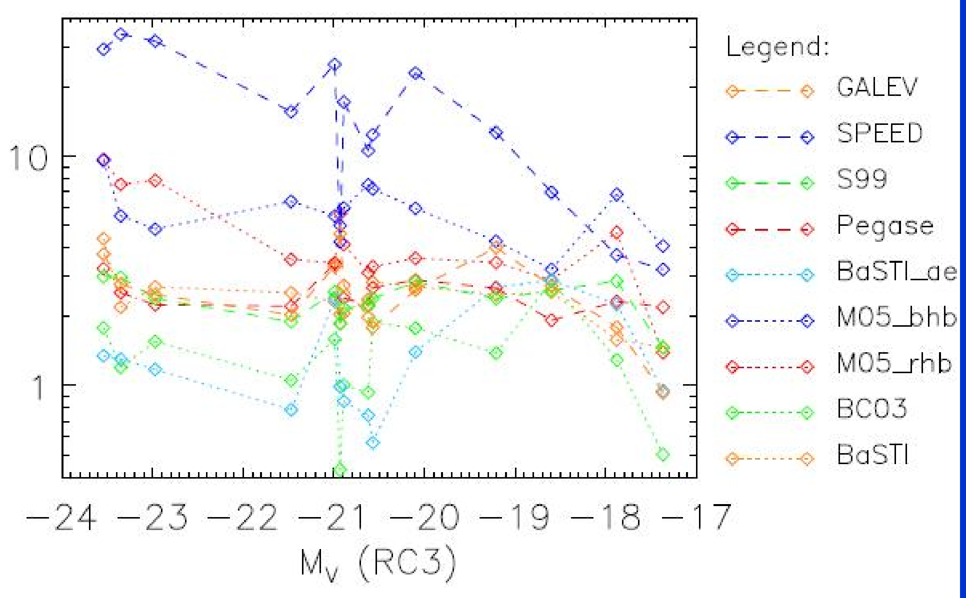
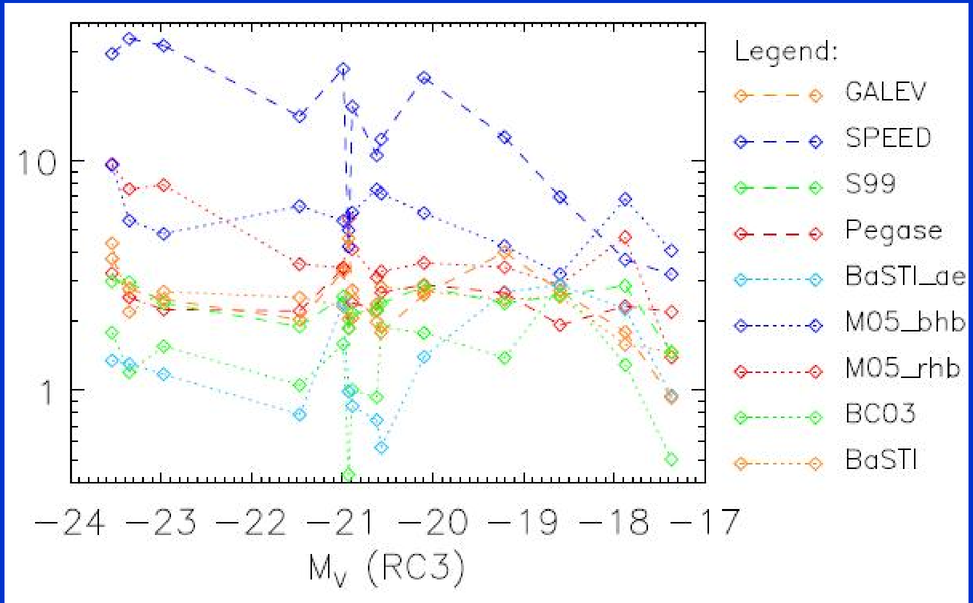


Figure 2. Best fit χ^2_ν against absolute magnitude for each model set.

Carter, Smith et al. 2009

Near-IR population synthesis

- Need excellent data quality (e.g. accurate photometric zero points) and up-to-date, well understood models
- Large numbers of galaxies not a substitute for the above…



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Carter, Smith et al. 2009

Image A. Bauer