

Status of the 2MASS Red AGN Survey

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What Fraction of all AGN are Red/Obscured?

- Far-IR and Radio Surveys suggest 50-80% of AGN in the local universe missed by earlier optical/UV surveys due to dust obscuration (Low et al. 1987; Webster et al. 1995; Francis et al. 1999; Gregg et al. 2002; Cutri et al. 2002)
- But recent optical/UV color-selected surveys are deeper and use *i*-color selection so should detect more of extinguished population. Some claim to be **80-90%** complete
 - 2dF complete spectroscopic survey - $16.5 < b_j < 19.7$ (Meyer *et al.* 2001)
 - SDSS QSO survey (Ivezic *et al.* 2002; Richards et al. 2003)
- Utilize 2MASS to conduct a large-scale, uniform IR survey for reddened AGN

2MASS Red AGN Search Criteria

- “Hit ‘em where they ain’t” (‘Wee’ Willy Keeler)

- Candidate selection:

- $|b| > 30^\circ$, exclude LMC/SMC

- **J-K_s > 2 mag**,

- 3-band detection

- No morphology constraint

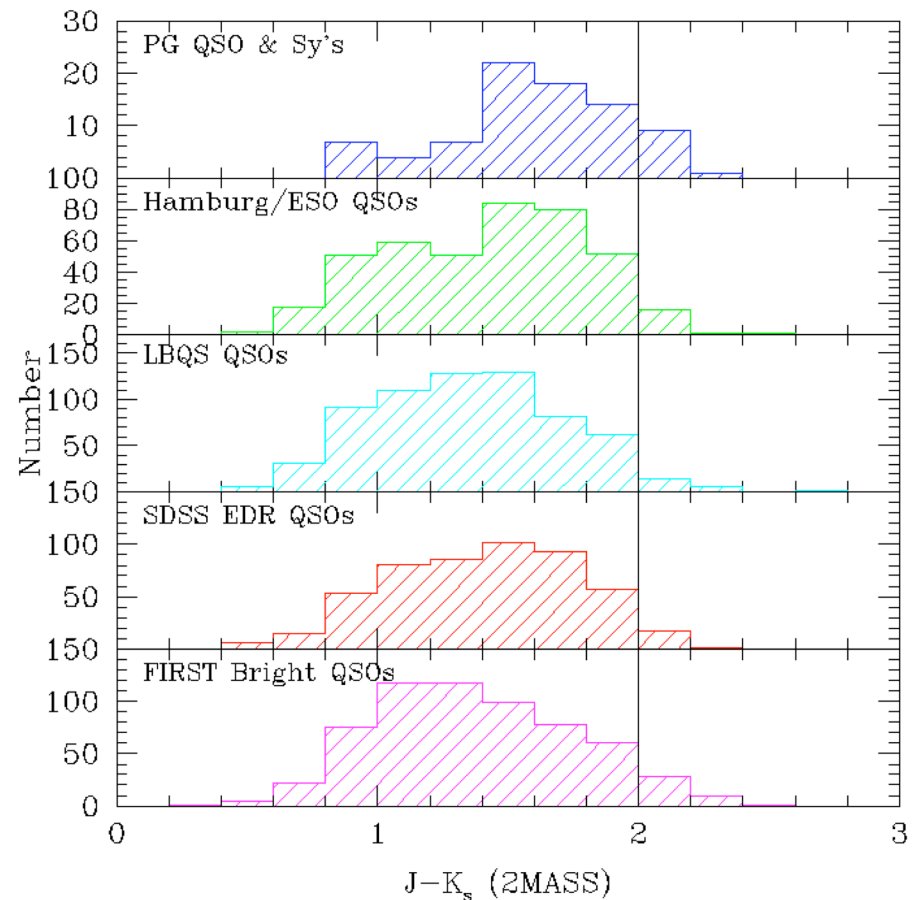
- **12,408** candidates in **20,402 deg²**

- 2.2% are previously known AGN

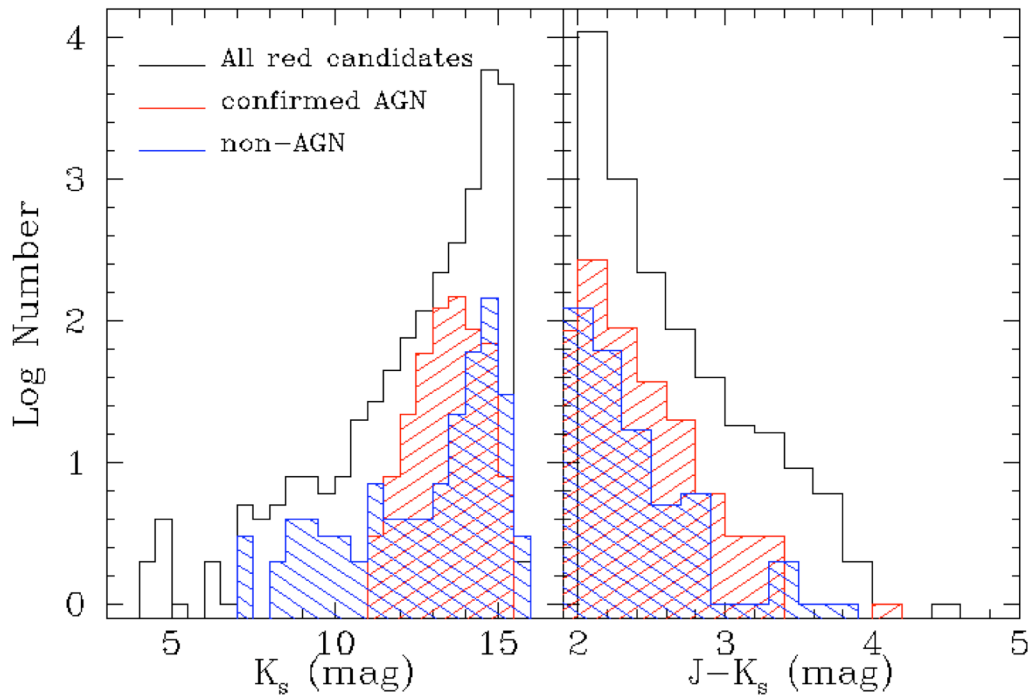
- 6dF Ancillary target subset:

- $dec < 0^\circ$, $r_F < 17.9$

- **2,132** candidates in **10,090 deg²**



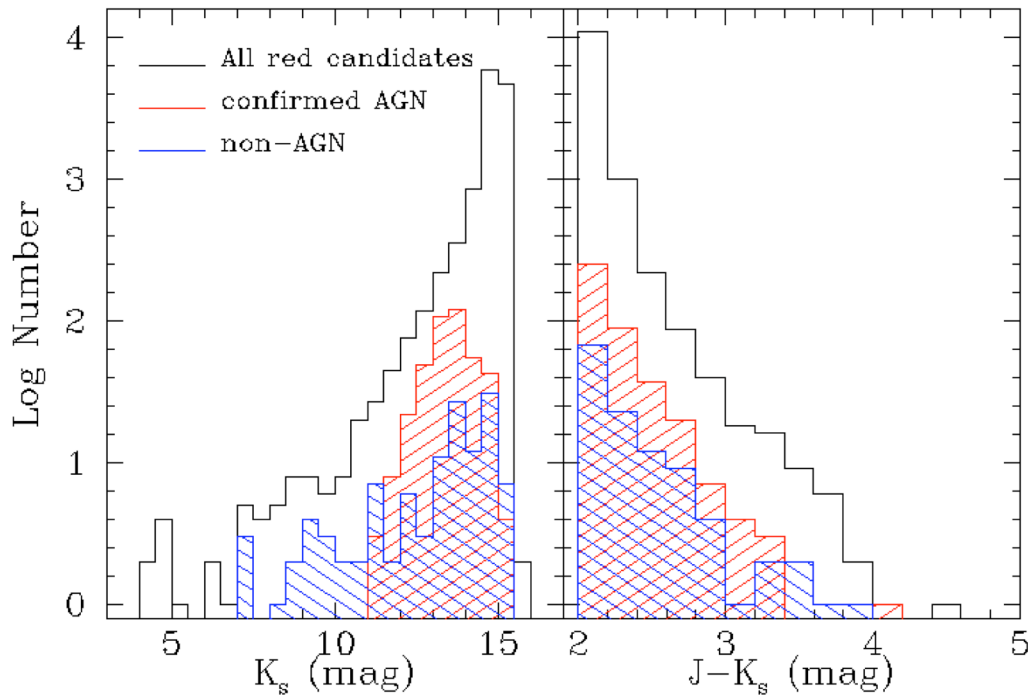
Results of Spectroscopic Follow-up



Total	6dF	Class
395	35	Type 1 AGN (Sy1/QSO)
96	17	Type 2 AGN (Sy2/LINER)
232	193	Normal & Starburst Galaxies
33		Stars (M,L,C,AGB,etc)
26	10	Unidentifiable

- Spectroscopic follow-up of **782** candidates (6.3%) so far
 - **255/2132** (12%) of 6dF targets
- Brightest candidates are Galactic sources (C*, PN, etc)
- **63%** of all observed candidates in full sample are Type 1 or Type 2 AGN
 - **20-25%** of 6dF sample are AGN (assuming all non-classified spectra are normal galaxies)
 - 6dF samples fainter K_s-band
- N(type 1)/N(type 2):
 - **~4** full sample (like ISO & X-ray)
 - **~2** 6dF (like radio-selected)

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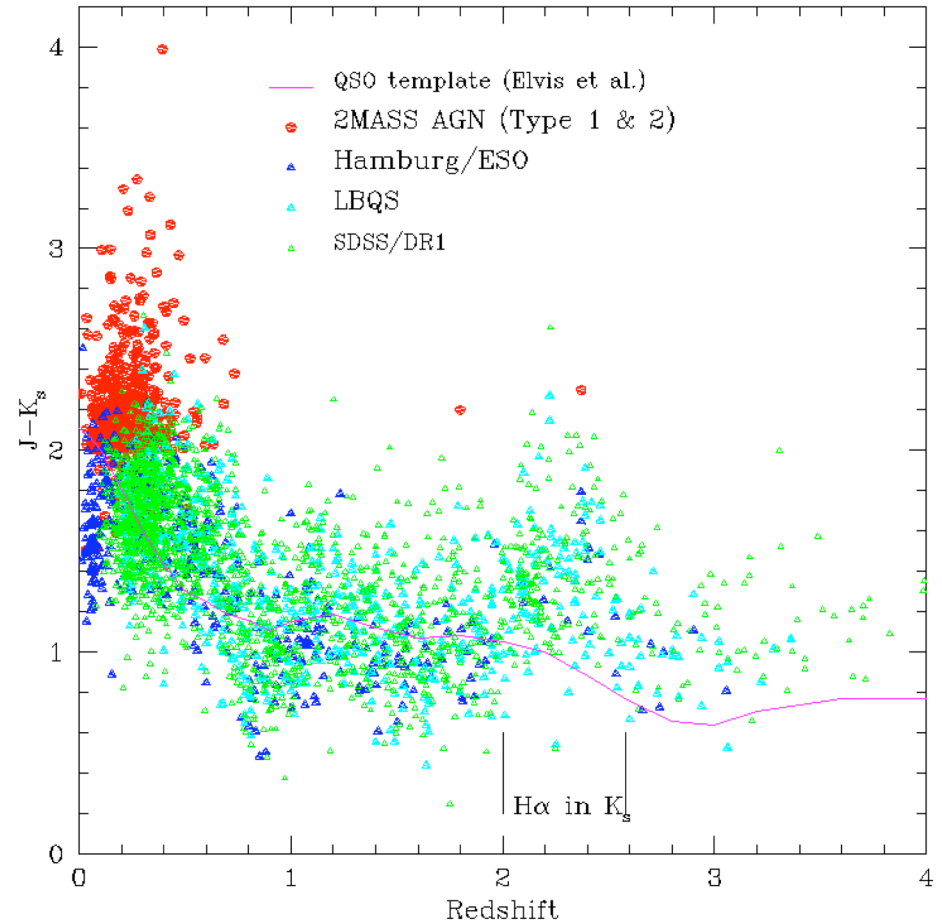


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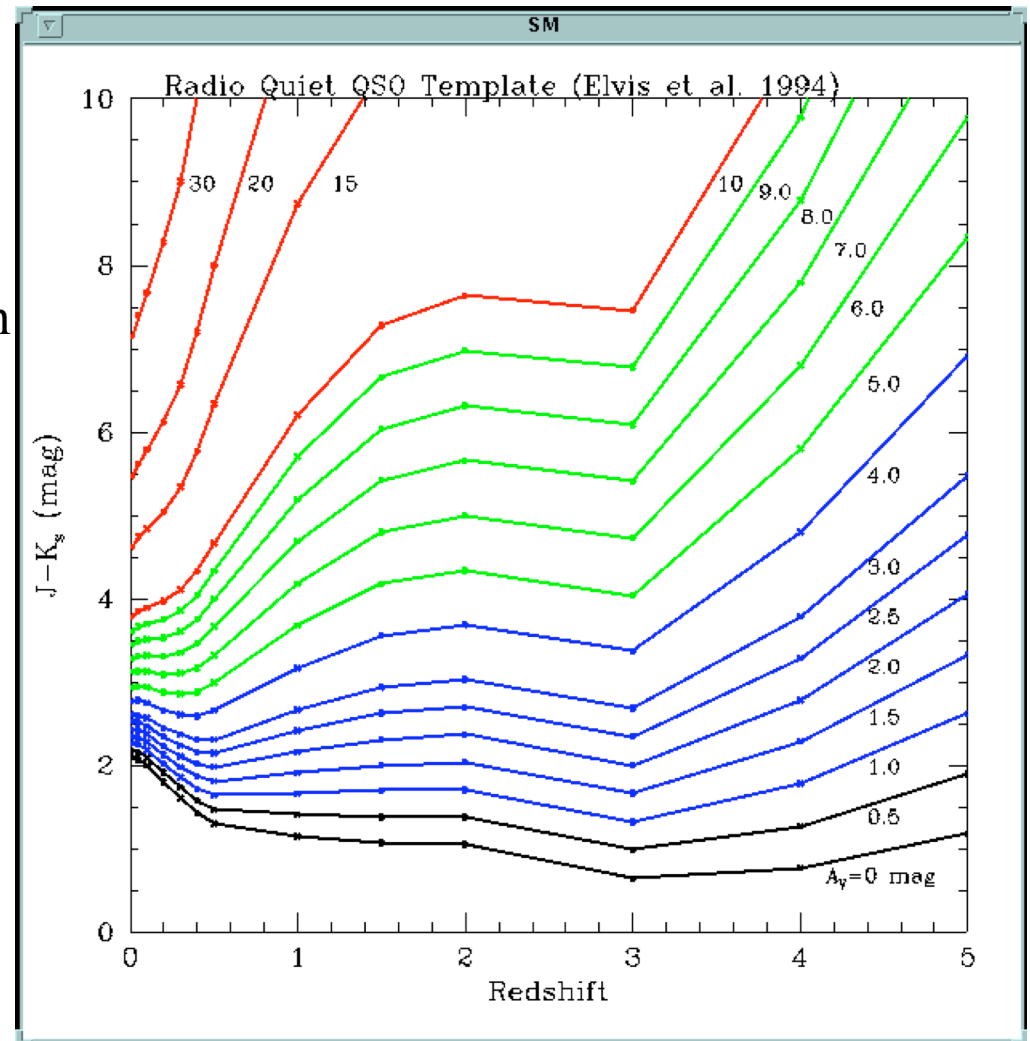
Basic Properties

- Predominantly low redshift
 - Median $z = 0.22$
 - k-correction bias
- J-Ks colors of local AGN population span $\sim 2-3$ mags
- No evidence for luminous, distant red population
- L_{K_s} comparable to optical/UV-selected AGN
- 2MASS sample is biased against finding most distant and luminous objects



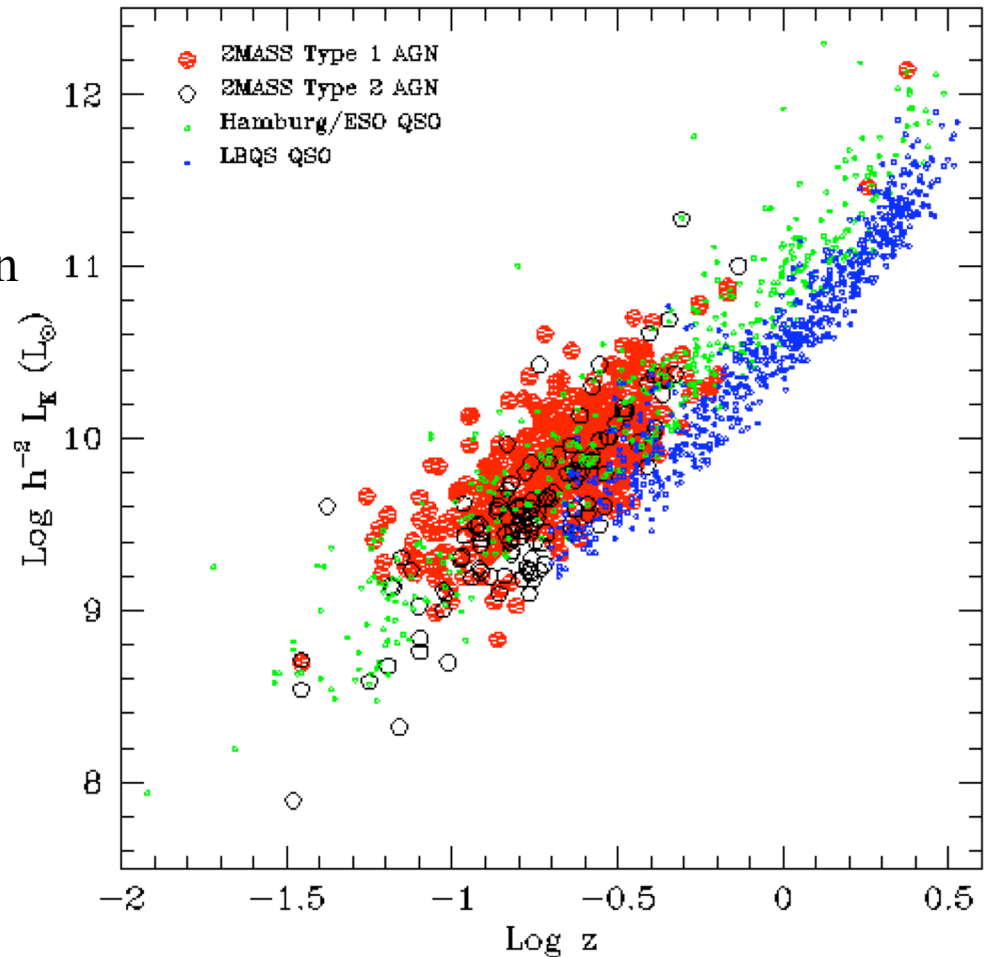
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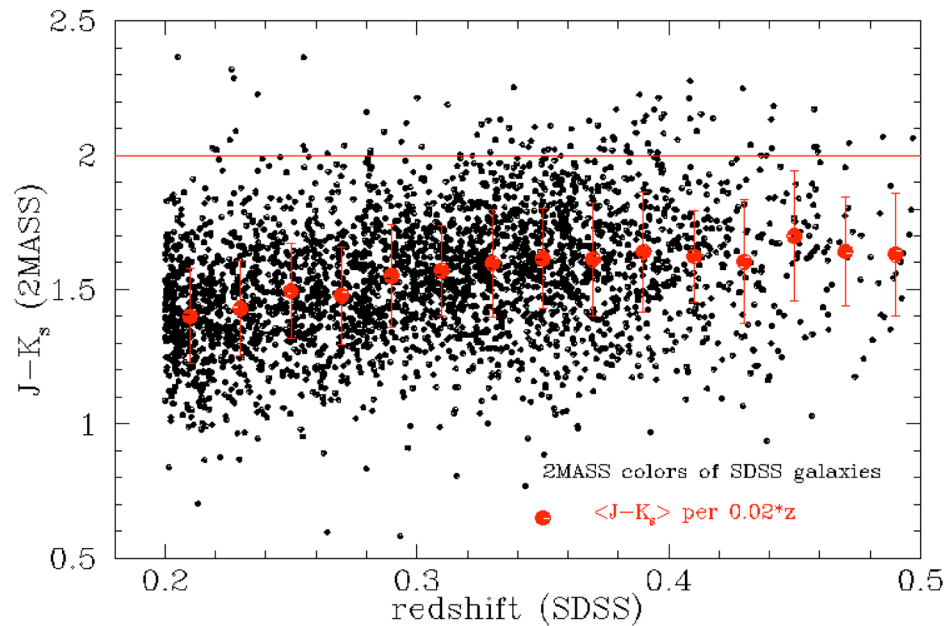


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Contamination from Normal Galaxies

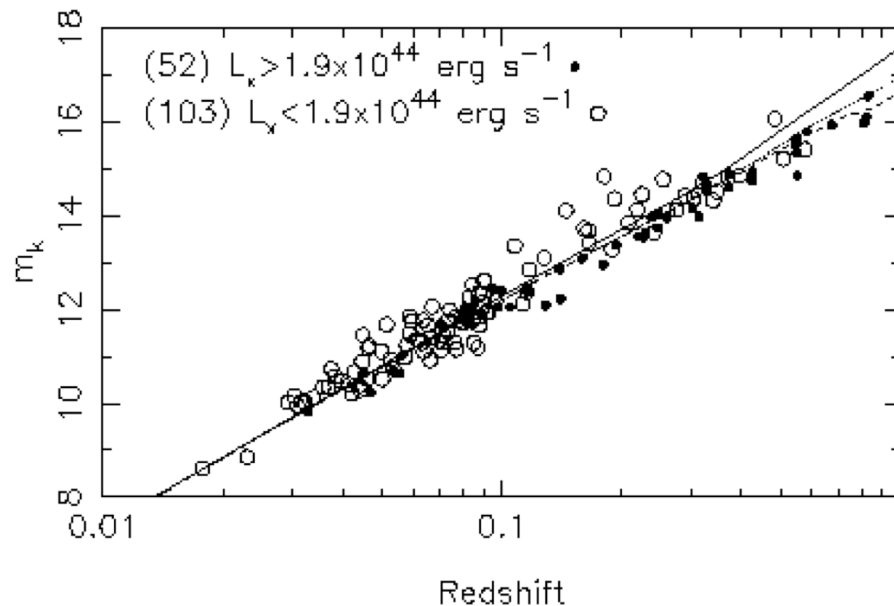


- K-correction for normal galaxies shifts $J-K_s$ color to the **red** with increasing z (opposite from QSOs)

- E/S0 $J-K_s=2$ mag @ $z=1$, but contamination begins earlier due to spread in intrinsic galaxy colors and measurement uncertainties

- Greater contamination by normal galaxies in 6dF sample because fainter objects included ($K_s > 14.5$ mag)

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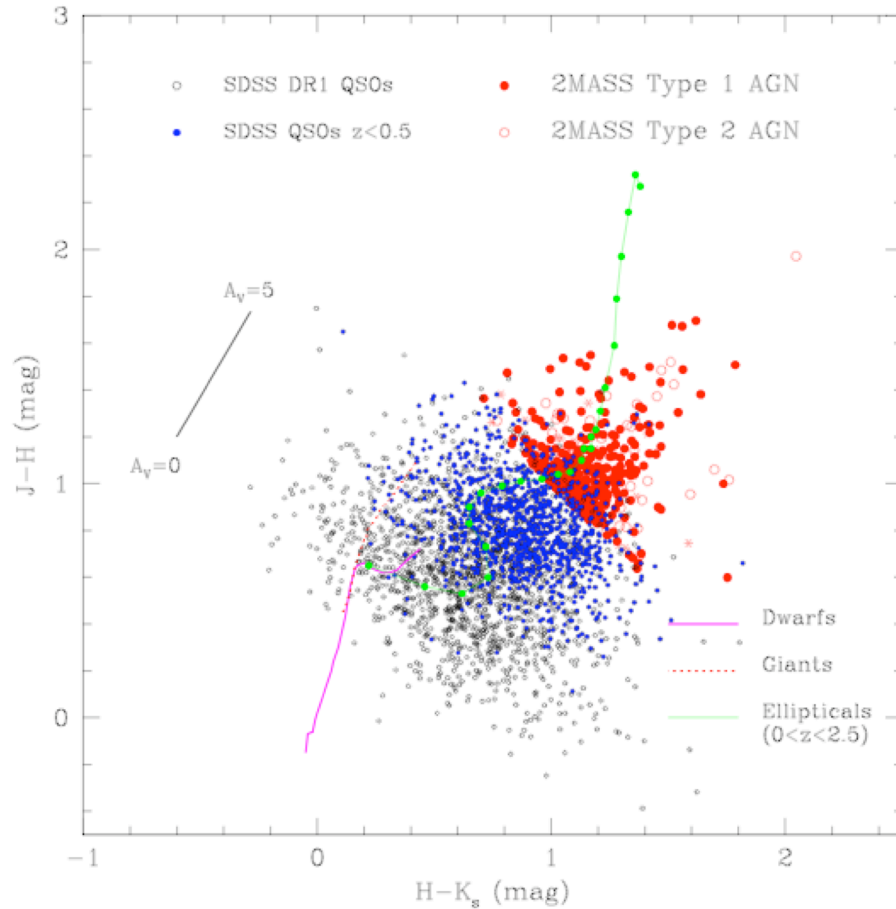
(e.g. brightest cluster galaxies; Brough et al. 2001, MNRAS, 329, L53)

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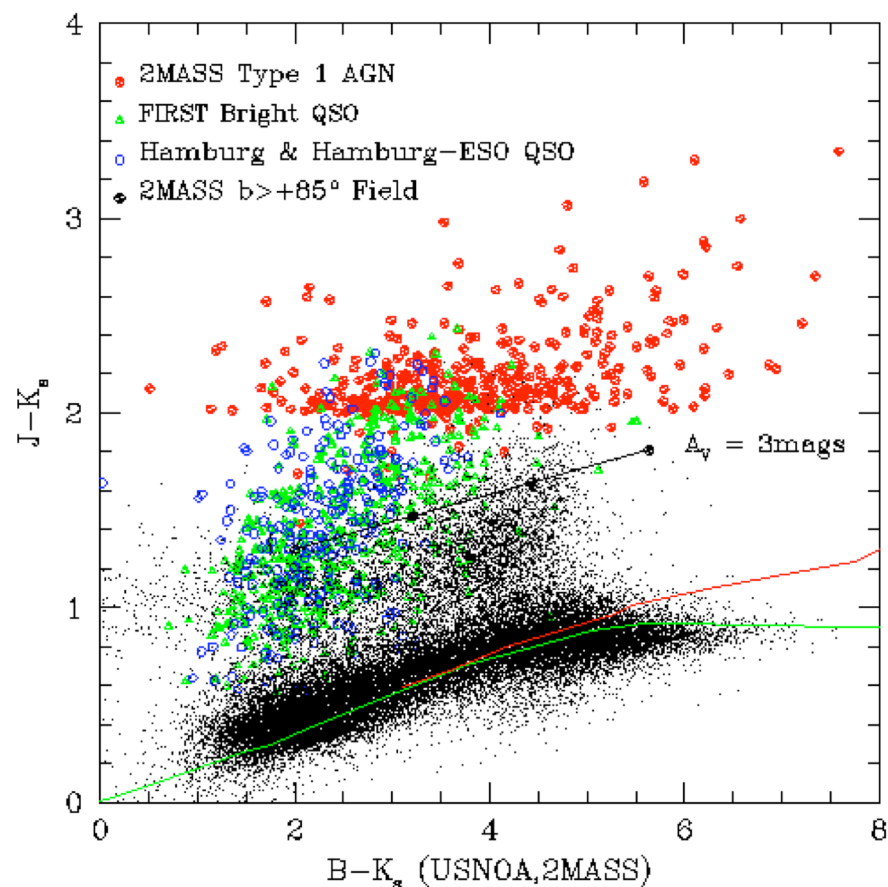
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Near-IR colors



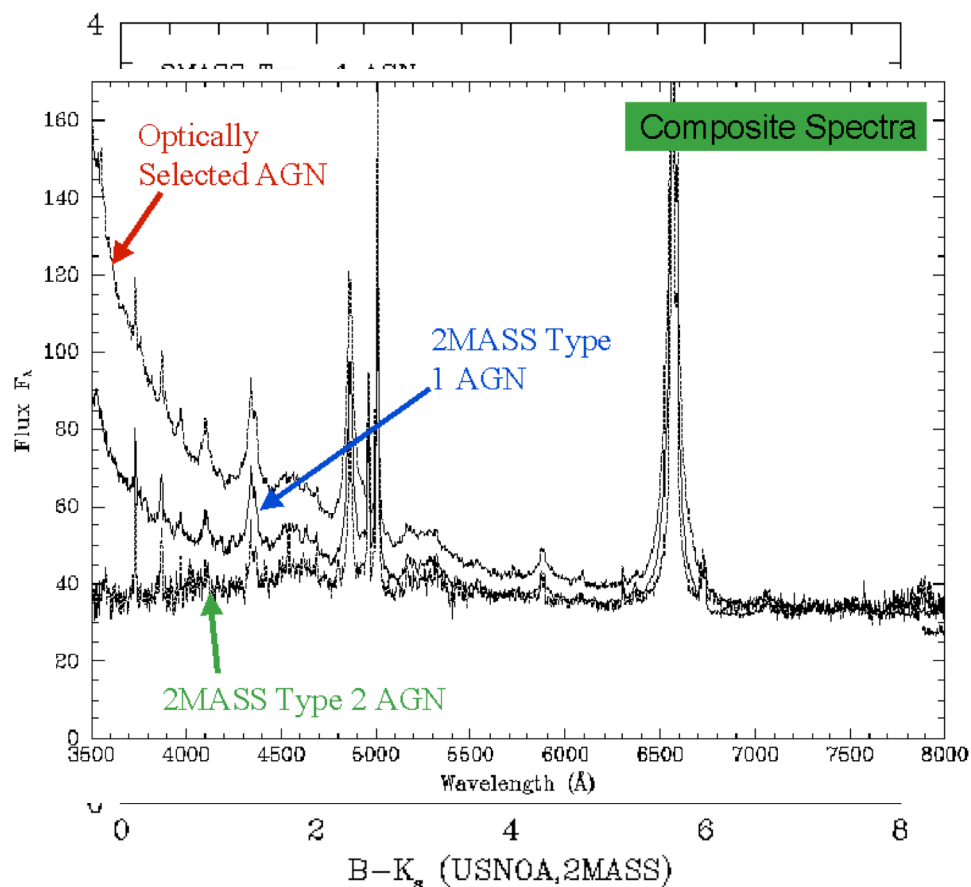
- Relative near-IR colors of 2MASS red AGN roughly consistent with **reddened** colors of optical/UV population
- Requires $A_V \sim 2 - 5$ mags

Optical/Near-IR Colors



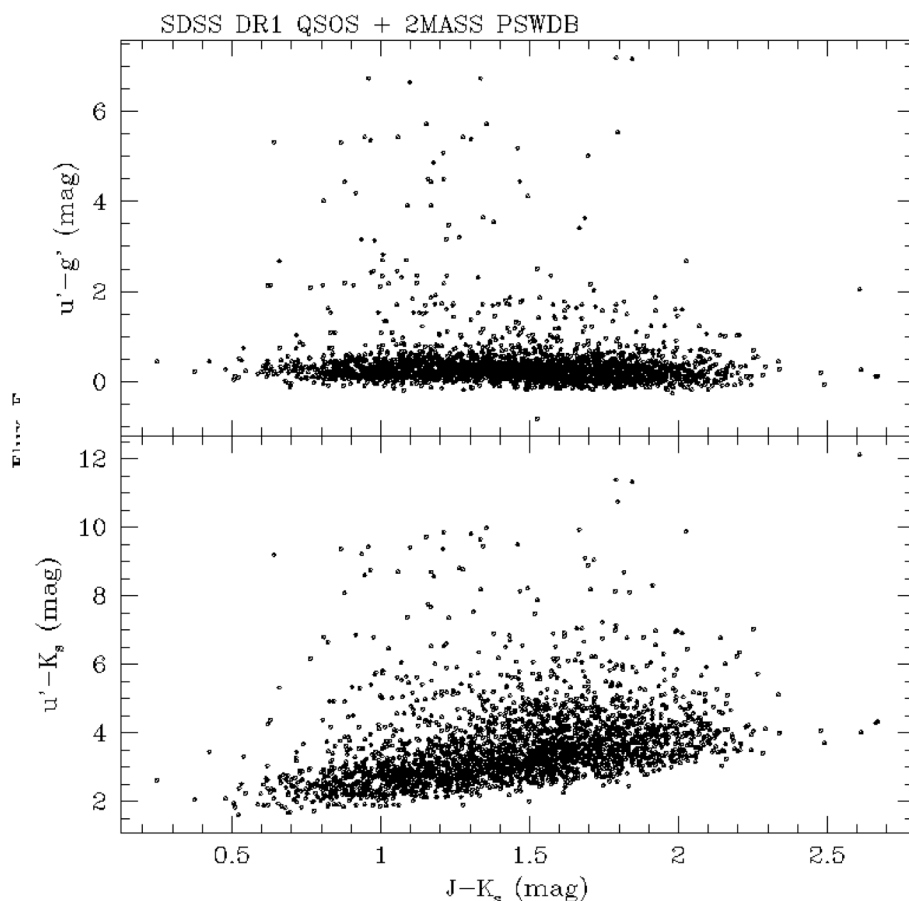
- B-Ks colors are **not consistent** with reddened optical/UV population, ruling out simple nuclear screen extinction model
- 2MASS red AGN span much larger range of B-Ks than optically-selected QSOs (similar to results from radio surveys - Webster et al. 1995; Francis et al. 1999)
- Extinction can account for redder **optical continuum** of 2MASS red AGN
- Unlike IR-selected AGN, reddest SDSS AGN are not necessarily red in visible, or in visible/IR colors

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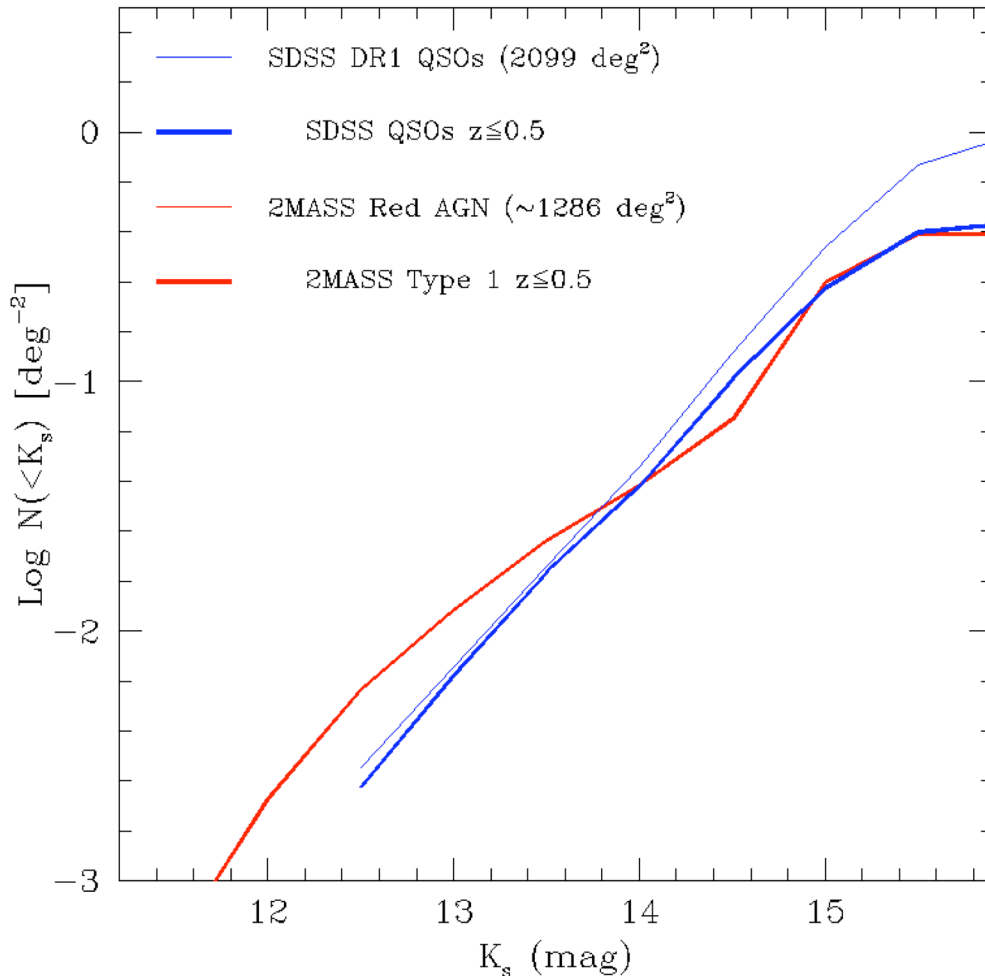
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Apparent Surface Densities



- 2MASS red AGN have K_s -band source counts per unit apparently similar to optical (SDSS) QSOs
- BUT:
 - Assumes IR discovery efficiency remains at 63% (6dF results suggests it probably won't)
 - SDSS incompleteness due to i^* , luminosity cuts, especially for low luminosity AGN

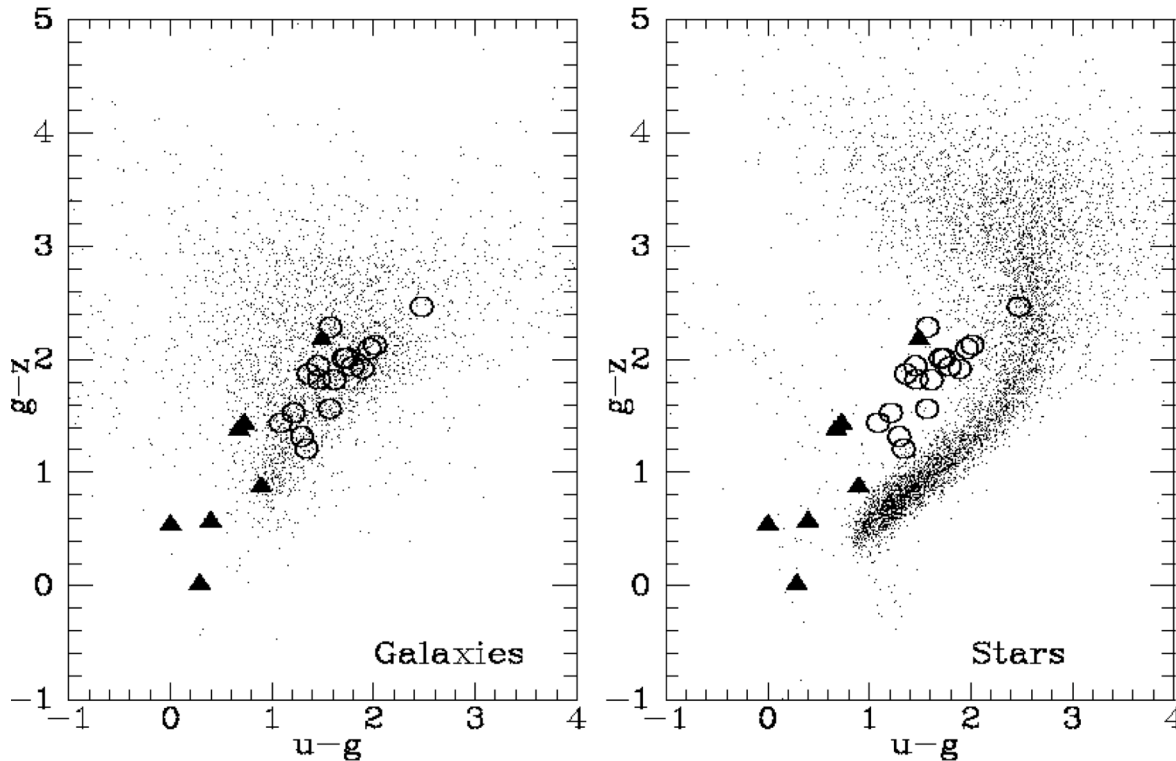
What Fraction of all AGN are Red/Obscured?

(with Z. Ivezić)

- Examine **357** $K_s < 14.8$ 2MASS red AGN candidates in SDSS DR1 area
 - 298 resolved, 59 unresolved
 - 145 were targeted for spectra
- Of 145 targeted objects with spectra: **99 QSO**, 44 GALAXY, 2 L Dwarfs
 - $\sim 30/44$ GALAXIES are AGN (16 pipeline, 14 visual inspection)
 - **129 total AGN** (115 auto-id, 14 visually id'd), $\langle z \rangle \sim 0.25$
- Of 212 objects not targeted for SDSS spectra:
 - 14 unresolved, 198 resolved
 - 1/3 QSO-like colors, but $i^* > 19$, 2/3 galaxy colors
- Fraction of $z < 0.5$ QSOs with $J - K_s > 2$: **0.1-0.2**
- SDSS correctly ID's **34% - 89%** of IR-selected red AGN

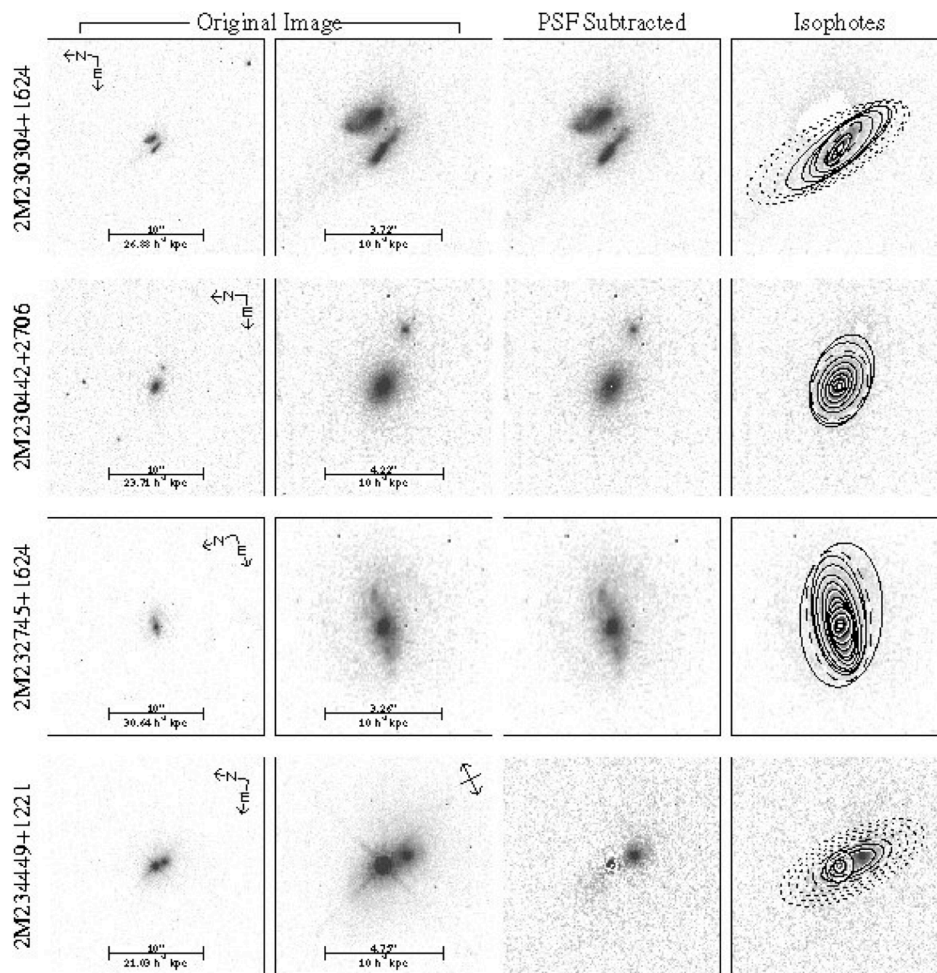
Host Galaxy Contamination

Complete, largely unbiased IR-selected sample of AGN using 2dF
(Francis, Nelson and Cutri 2004, AJ)



- Many of the Type 1&2 AGN have optical colors like normal galaxy
- IR-selected AGN not dramatically different from blue-selected AGN
- Number of AGN \sim constant with $J-K_s$ color

Optical Morphology



Marble, Hines, Schmidt, Smith, Surace, Armus, Cutri & Nelson 2003, ApJ & Hutchings, Maddox, Cutri and Nelson 2003, AJ

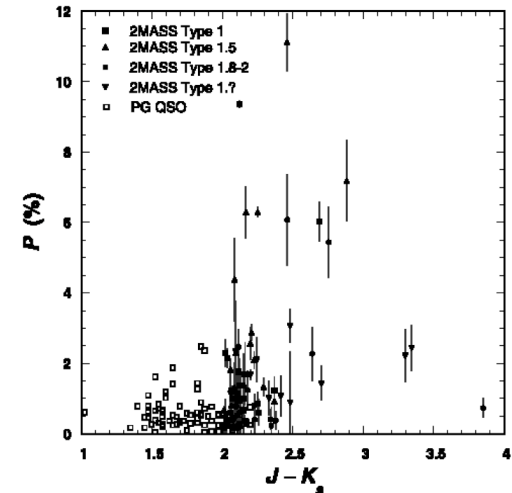
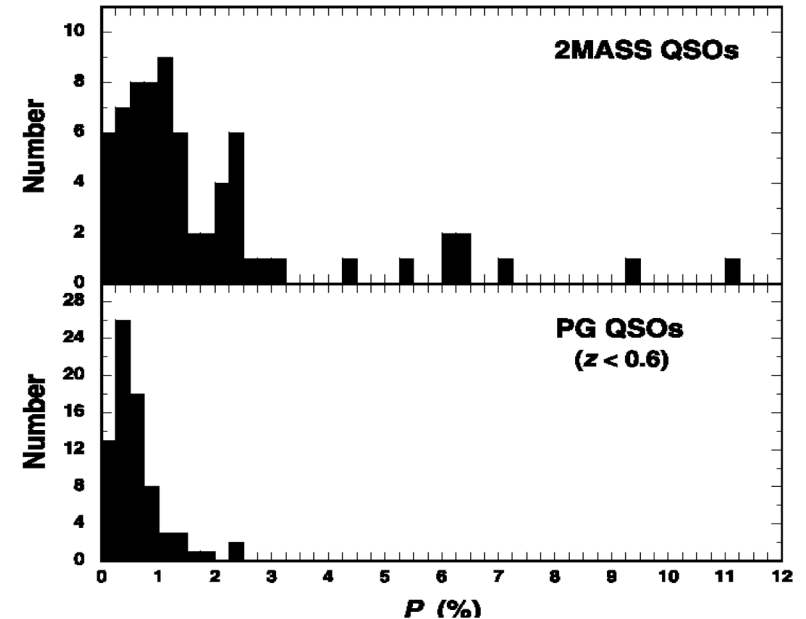
- HST/WFPC2 and CFHT R-band imaging of low redshift ($z < 0.3$) 2MASS AGN
- Host galaxies easily detected
- Red IR colors likely due to **dust in nucleus** rather than indication of new class of object
- Different conclusions on interaction:
 - WFPC2 imaging show range of host galaxy morphologies, environments and luminosities similar to PG QSO hosts, with no preference for interacting systems
 - CFHT imaging shows $>70\%$ in interacting systems compared with $\sim 39\%$ in optical AGN sample

Polarization of 2MASS AGN

Smith, Schmidt, Hines, Cutri, & Nelson
(2002 ApJ, 569, 23)

- 2MASS AGN **most strongly polarized sample** of radio quiet AGN
 - 11/89 2MASS red AGN have optical broadband $P > 3\%$, with max $P = 11\%$ (no PG QSOs have $P > 3\%$)
 - Host galaxy dilutes light in some, so %P lower limit
 - Intermediate types (1.5-1.9) highest polarized fraction (23%)
 - Highest degree of polarization seen in reddest objects, but not all of the reddest are highly polarized

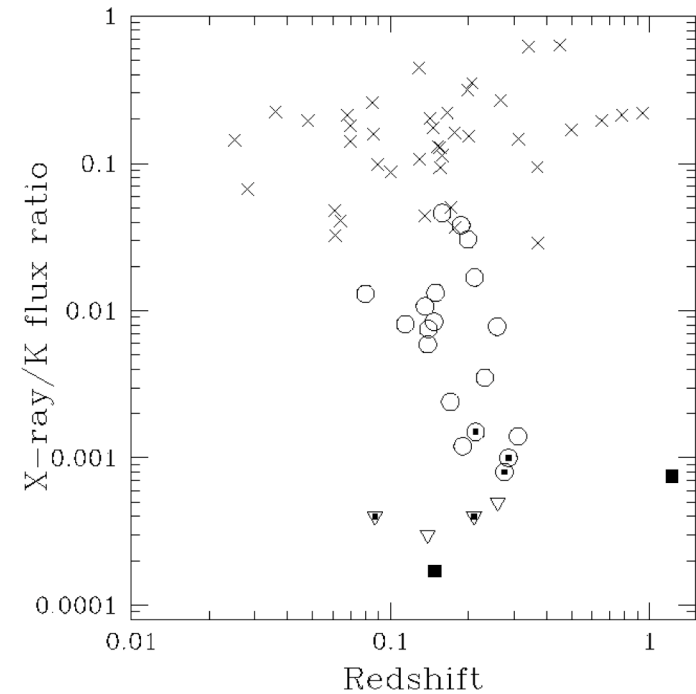
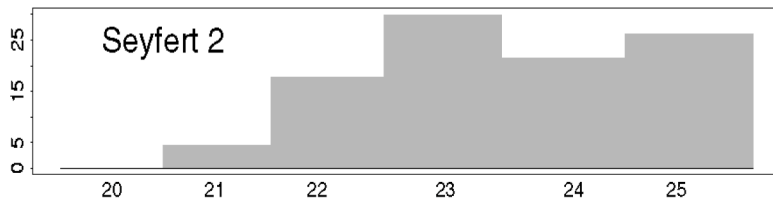
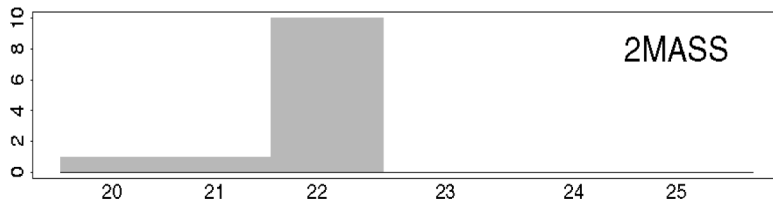
- Spectropolarimetry of two 2MASS AGN shows **highly polarized broad lines**
 - Viewing obscured BLR in scattered light



X-ray Properties of 2MASS Red AGN

Wilkes, Schmidt, Cutri, Ghosh, Hines, Nelson
& Smith (2001 ApJ, 564, L65)

- ACIS-I observations of 15 Type 1 & 2 AGN with $K_s < 13.8$ & $B - K_s > 4.3$
 - Exposures set to detect $1/800$ x prediction based on $\alpha_{KX} = 2.1$



- 2MASS red AGN are **absorbed** in X-rays
 - All are X-ray faint
 - Hardness ratios - $N_H \sim 10^{21}-10^{23}$
 - Even after correction for internal extinction, some are still underluminous in X-rays

Summary

- 2MASS $J-K_s > 2$ color selection is revealing large numbers of previously unknown, predominantly low redshift, red AGN
- 6dF sub-sample contains smaller fraction of AGN than previous results
 - More contamination from faint, distant galaxies
 - Optical brightness may de-select obscured AGN
- 2MASS red AGN population may comprise $\sim 20\%$ of all AGN
 - Many still missed in new, deeper optical surveys because optical colors are indistinguishable from normal galaxies
 - 2MASS selection biased against finding more distant and reddest objects, though
- NIR and optical colors, polarization properties and X-ray flux and slopes suggest that many 2MASS AGN are red because of obscuration
 - But geometry and distribution of dust, origin of continuum at different wavelengths complicates interpretation