

A High Incidence of Mid-infrared Variability in Local Ultraluminous Infrared Galaxies

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超高光度赤外線銀河 (ULIRGs)

ULIRGs

- 赤外線で明るい ($L_{\text{IR}} > 10^{12} L_{\odot}$)
- 通説; 主にダストに埋もれた活動銀河核 (AGN)が熱源 (Nardini+10)

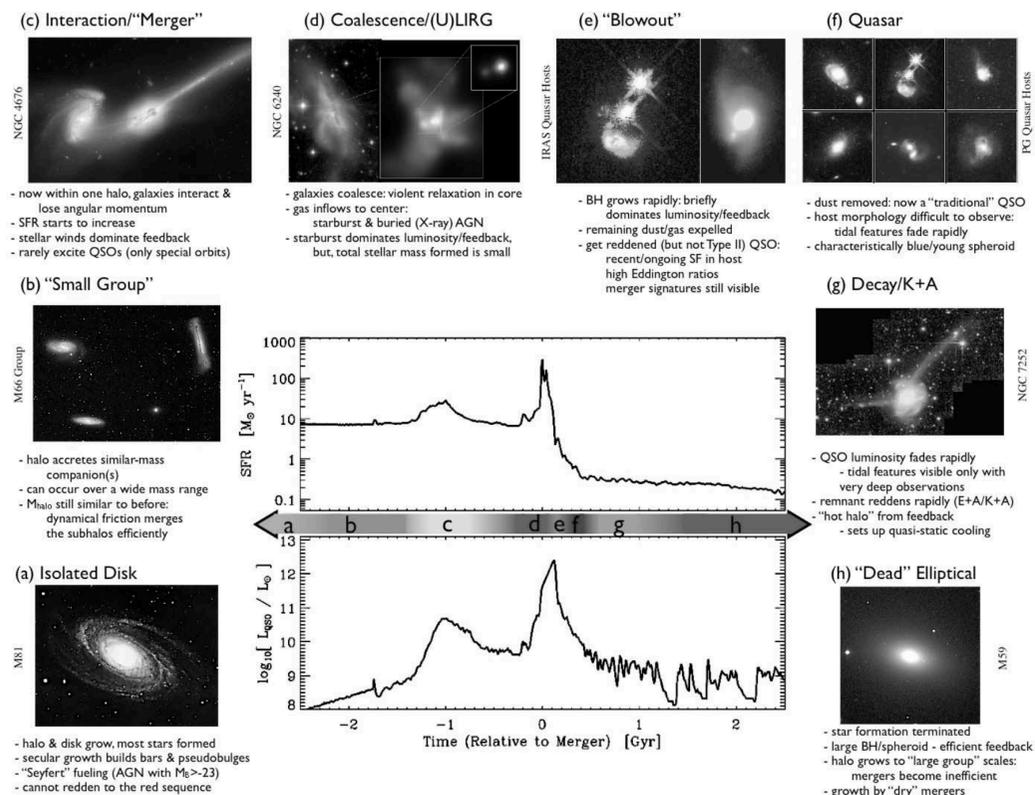
重要性

- 超大質量ブラックホールの成長現場 (Hopkins+08)

しかし、narrow line regionが隠され、輝線診断が使えない

過去の研究と課題

- 透過力のある波長: 硬X線観測, IR分光, ALMA分子輝線診断 (e.g., Oda+17; Nardini+10; Imanishi+23)
- 課題: (特にX線以外) 独立手法による検証必要 & よりelusiveなAGNが存在する可能性



Hopkins+08

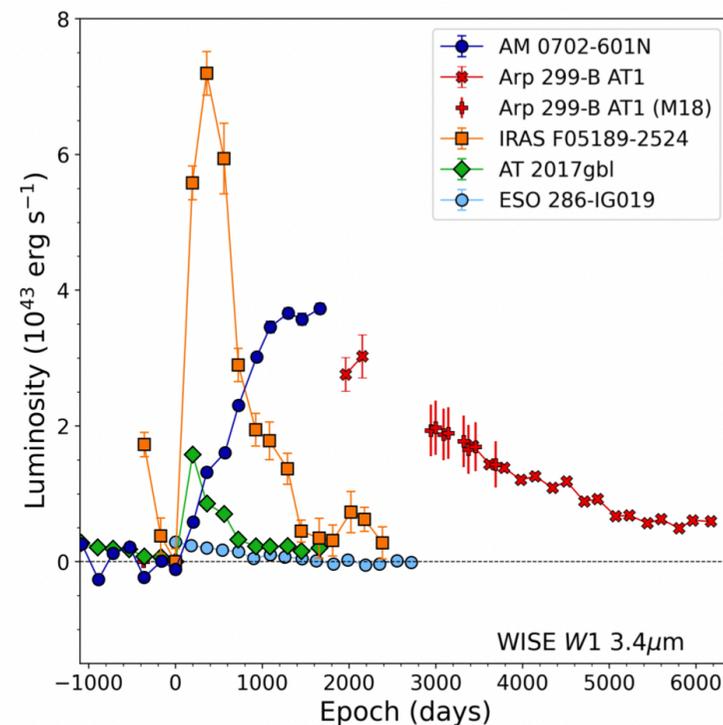
中間赤外線時間変動探査

WISE衛星のNEOWISEミッション

- 3-4 μm 全天をサーベイ
- 2013-2024まで2回/yr測光

過去のサイエンス

- LIRGsのTDE探索: Reynolds+22 (Sanders+03を探索)
- 矮小銀河: (e.g., Secrest&Satyapal 2020, Harish+23, Hatano+23, Aravindan+2024)



Reynolds+22

変動の検出手法: 相関係数を用いた検定

$$r > 0.65 \text{ and } \sigma_{W1} > 0.024 \text{ and } \sigma_{W2} > 0.028.$$

r : W1バンドとW2バンドの光度曲線の相関係数

σ_{W1} : W1測光値の分布の標準偏差

σ_{W2} : W2測光値の分布の標準偏差

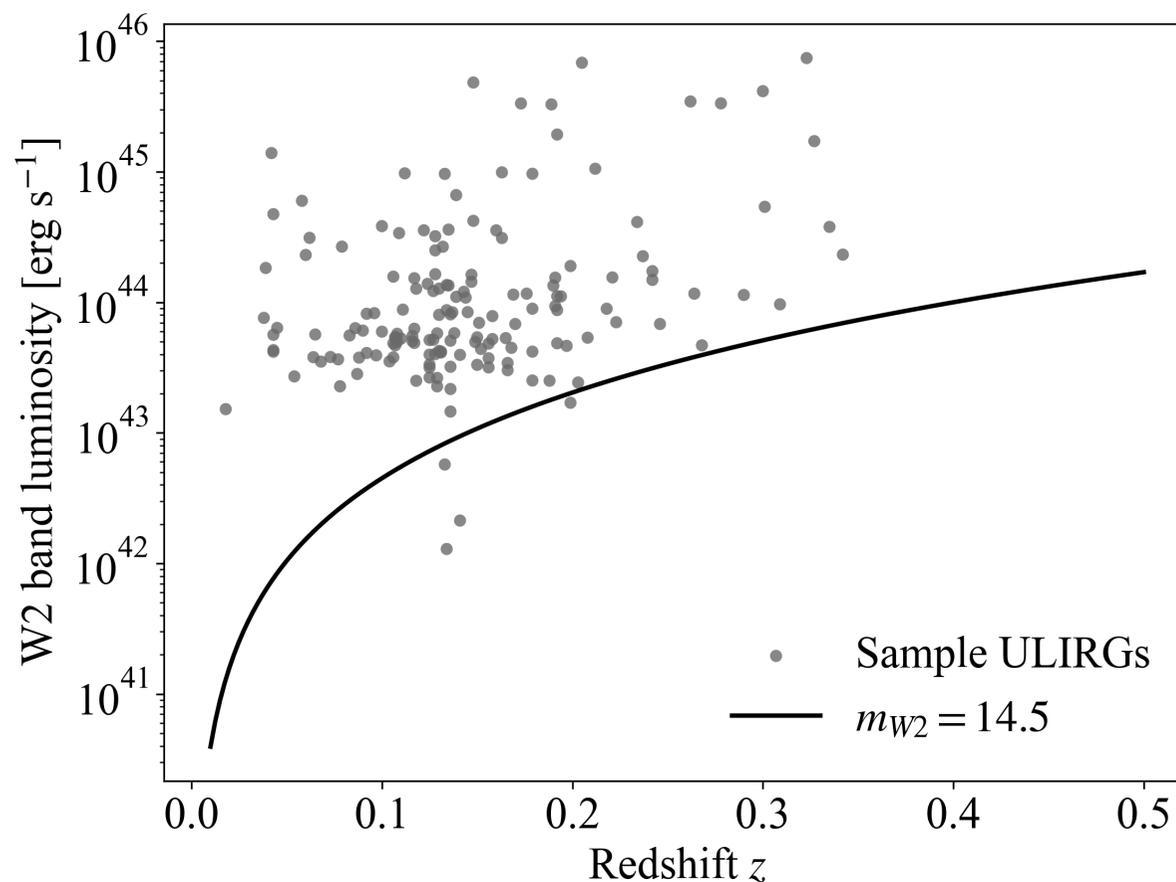
$$t = r \sqrt{\frac{N - 2}{1 - r^2}} \quad \text{は、}$$

- スチューデント化した相関係数 t は、帰無仮説のもと自由度 $N-2$ (N は r の計算に用いた点数)の t 分布に従う
- $r > 0.65$ が実現する可能性が $\sim 0.1\%$ (正規分布で $\sim 3\sigma$ 相当)
- 系統誤差があると、 r が相関する可能性
→ 変動の標準偏差が系統誤差 (Jarret+11)以上の変動を持つ天体に限る

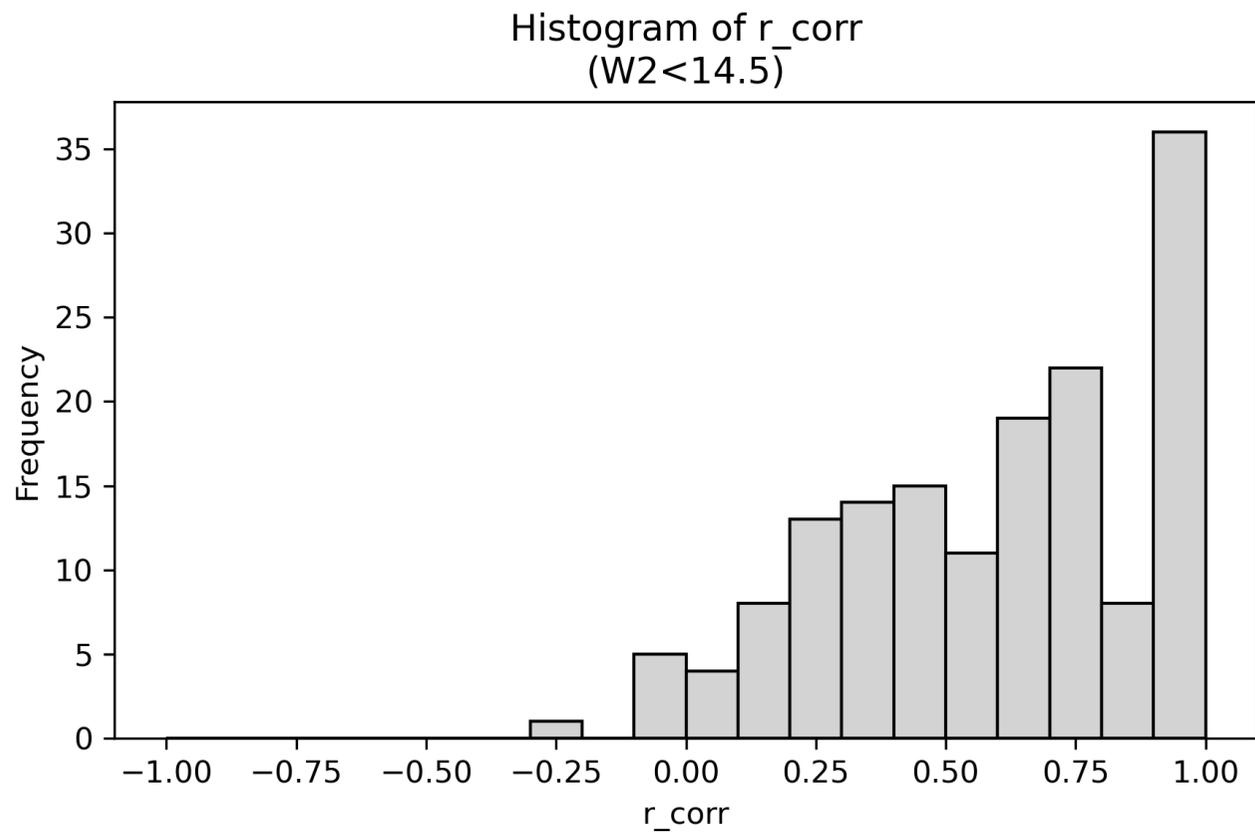
ULIRGsサンプル

Nardini et al. 2010

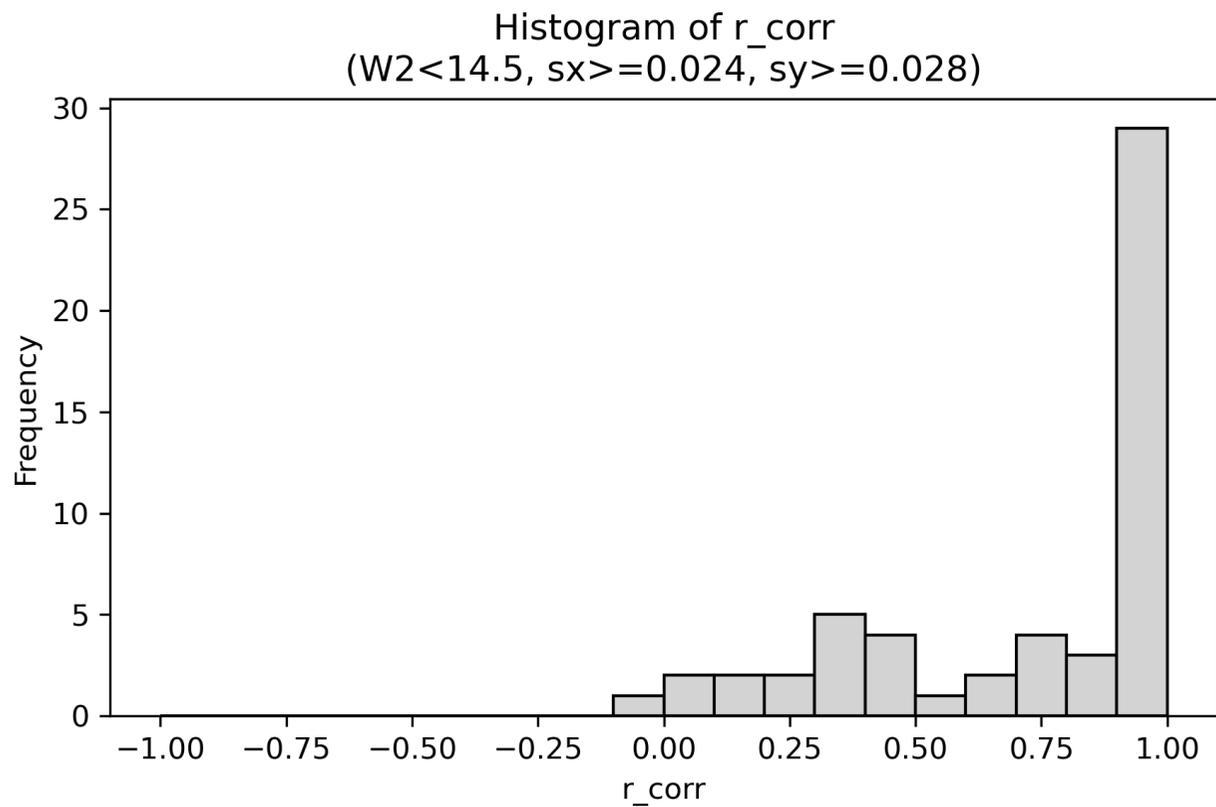
- IRAS天体をSpitzerで分光
著名なULIRGsカタログ
(Sanders+03と一部重複)
- 164天体
- 本手法では $m_{W2} < 14.5$ に限る
- データをIRSAデータベースから
取得



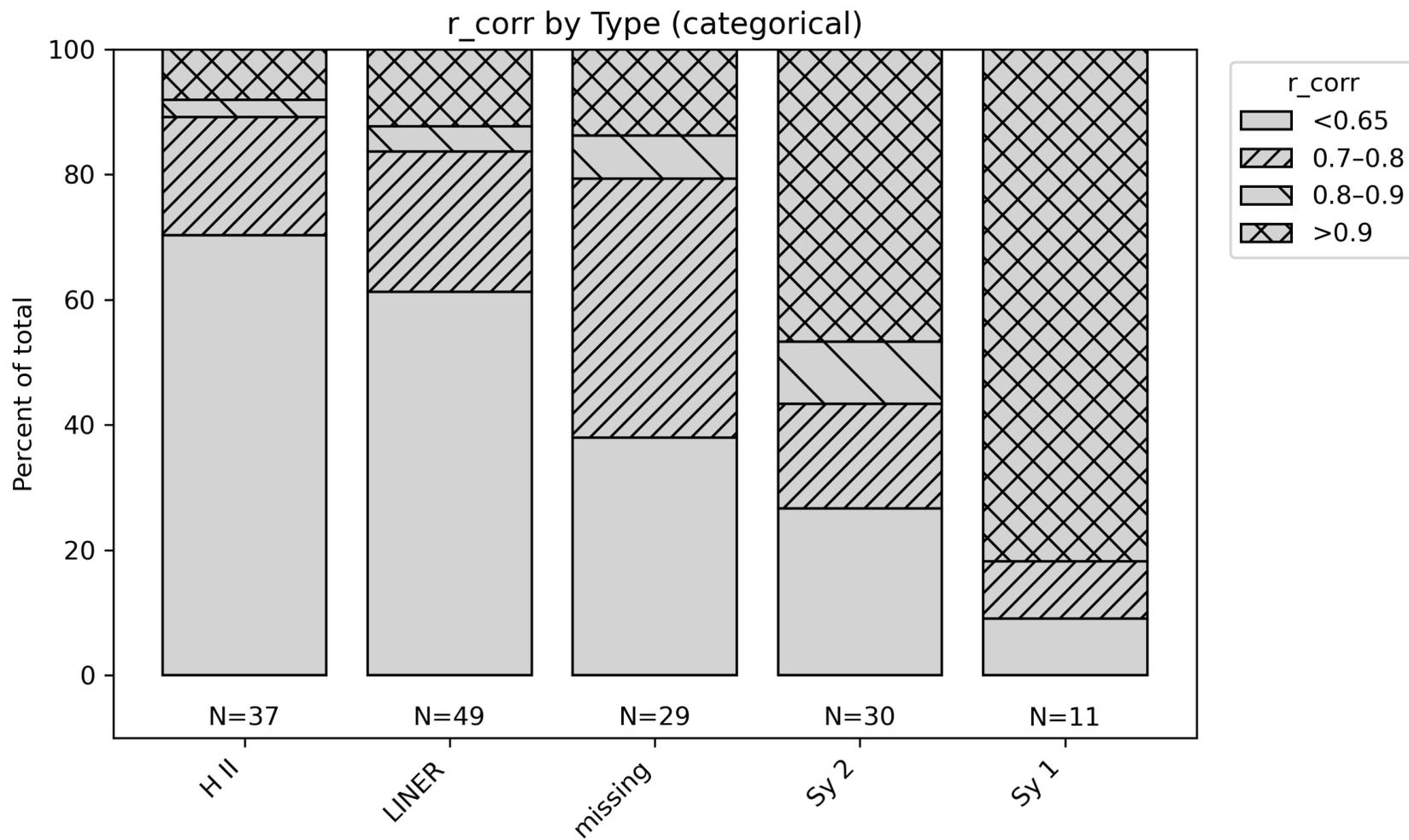
結果



結果



AGN Typeごとのr分布



変動幅が既知の超新星より大きい

→ 変動の起源は、AGNs or TDEsが候補

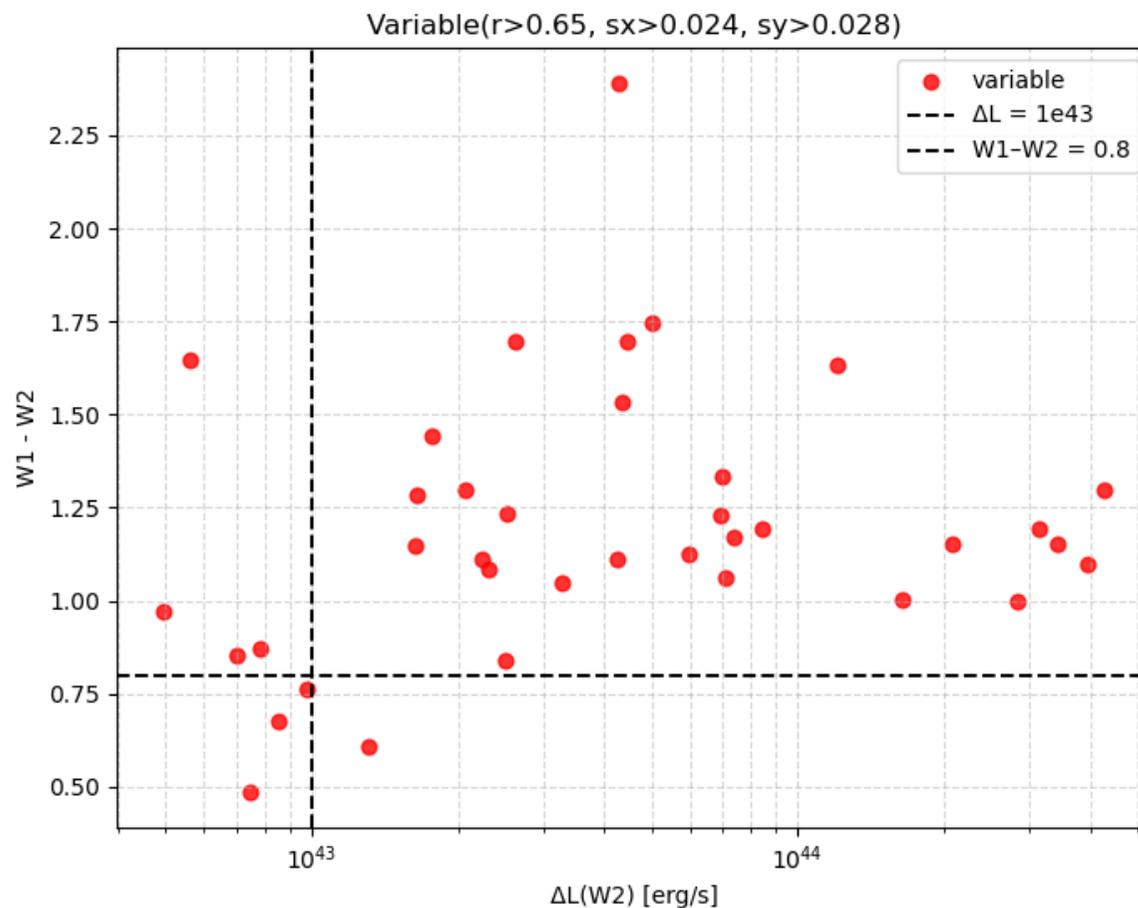
- 超新星

$$\Delta L_{W2} < 10^{42.3} \text{ erg/s}$$

(SN 2010jl; Szalai+19)

- 多くがStern+12の
AGN criteria

$W1-W2 > 0.8$ を満たす



既存のAGN？

- 変動していたULIRGsは少なくとも1つ以上のAGN signatureを持つ
- MIR時間変動は、elusive AGNを探る手法と言える

Table 1. Variable Sources.*

| IRAS | z | Type | r | s_x | s_y | Abol (%) | $W1 - W2$ | $\log_{10} \Delta L_{W2}$ (erg s ⁻¹) | AGN sign? (ref.) | Note |
|------------|-------|-------|-------|-------|-------|----------|-----------|--|------------------|--------------|
| 00275-0044 | 0.242 | nan | 0.763 | 0.039 | 0.079 | 3.2 | 1.046 | 43.515 | Y(1) | |
| 00275-2859 | 0.278 | Sy 1 | 0.911 | 0.037 | 0.031 | 78. | 1.153 | 44.534 | Y(1) | |
| 01003-2238 | 0.118 | H II | 0.952 | 0.207 | 0.140 | 50. | 1.631 | 44.083 | Y(1) | TDEs |
| 01388-4618 | 0.090 | H II | 0.954 | 0.028 | 0.067 | 1.6 | 0.609 | 43.117 | Y(1) | |
| 01572+0009 | 0.163 | Sy 1 | 0.974 | 0.143 | 0.108 | 27. | 0.998 | 44.453 | Y(1) | Mrk 1014 |
| 04103-2838 | 0.117 | LINER | 0.950 | 0.037 | 0.034 | 5.4 | 1.286 | 43.216 | Y(1) | |
| 04394-3740 | 0.237 | Sy 2 | 0.900 | 0.029 | 0.033 | 21. | 1.298 | 43.316 | Y(1) | |
| 05189-2524 | 0.043 | Sy 2 | 0.979 | 0.055 | 0.036 | 30. | 1.125 | 43.777 | Y(1) | TDE |
| 06361-6217 | 0.160 | nan | 0.986 | 0.071 | 0.042 | 18. | 1.748 | 43.701 | Y(1) | |
| 07246+6125 | 0.137 | Sy 2 | 0.932 | 0.064 | 0.050 | 19. | 1.150 | 43.212 | Y(1) | |
| 07572+0533 | 0.190 | LINER | 0.784 | 0.099 | 0.100 | 25. | 1.112 | 43.627 | Y(1) | |
| 08559+1053 | 0.148 | Sy 2 | 0.873 | 0.048 | 0.038 | 7.6 | 1.061 | 43.853 | Y(1) | |
| 09320+6134 | 0.039 | LINER | 0.979 | 0.042 | 0.049 | 14. | 1.697 | 43.419 | Y(1) | UGC 05101 |
| 11223-1244 | 0.199 | Sy 2 | 0.884 | 0.044 | 0.038 | 5.6 | 1.085 | 43.362 | Y(1) | |
| 12071-0444 | 0.128 | Sy 2 | 0.988 | 0.100 | 0.085 | 41. | 1.335 | 43.844 | Y(1) | |
| 12514+1027 | 0.300 | nan | 0.975 | 0.034 | 0.035 | 96. | 1.297 | 44.630 | Y(1) | |
| 12540+5708 | 0.042 | Sy 1 | 0.908 | 0.117 | 0.075 | 34. | 1.097 | 44.598 | Y(1) | Mrk 231 |
| 15130-1958 | 0.109 | Sy 2 | 0.992 | 0.109 | 0.088 | 30. | 1.231 | 43.842 | Y(1) | |
| 15176+5216 | 0.139 | Sy 2 | 0.960 | 0.071 | 0.041 | 37. | 1.194 | 43.926 | Y(1) | |
| 15462-0450 | 0.100 | Sy 1 | 0.957 | 0.091 | 0.061 | 26. | 1.170 | 43.870 | Y(1) | |
| 16155+0146 | 0.132 | Sy 2 | 0.988 | 0.062 | 0.070 | 40. | 2.390 | 43.632 | Y(1) | |
| 16334+4630 | 0.191 | LINER | 0.932 | 0.041 | 0.043 | 1.0 | 1.112 | 43.349 | Y(1) | |
| 16541+5301 | 0.194 | Sy 2 | 0.938 | 0.064 | 0.065 | 6.0 | 0.839 | 43.399 | Y(1) | |
| 17044+6720 | 0.135 | LINER | 0.983 | 0.043 | 0.044 | 27. | 1.533 | 43.638 | Y(1) | |
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| 20037-1547 | 0.192 | Sy 1 | 0.977 | 0.035 | 0.032 | 26. | 1.002 | 44.216 | Y(1) | |
| 20087-0308 | 0.106 | LINER | 0.942 | 0.031 | 0.057 | 3.1 | 1.233 | 43.400 | Y(1) | |
| 20551-4250 | 0.043 | LINER | 0.952 | 0.033 | 0.109 | 26. | 1.441 | 43.247 | Y(1) | |
| 23060+0505 | 0.173 | Sy 2 | 0.933 | 0.043 | 0.034 | 78. | 1.195 | 44.497 | Y(1) | |
| 23498+2423 | 0.212 | Sy 2 | 0.957 | 0.080 | 0.072 | 26. | 1.153 | 44.319 | Y(1) | |
| 00456-2904 | 0.110 | H II | 0.951 | 0.037 | 0.056 | — | 0.677 | 42.932 | Y(2) | |
| 01298-0744 | 0.136 | H II | 0.656 | 0.030 | 0.030 | 75. | 1.645 | 42.751 | Y(1) | |
| 14197+0812 | 0.131 | nan | 0.843 | 0.035 | 0.057 | 11. | 0.486 | 42.874 | Y(1) | |
| 14378-3651 | 0.068 | Sy 2 | 0.920 | 0.039 | 0.060 | 1.0 | 0.871 | 42.894 | Y(1) | |
| 19542+1110 | 0.065 | nan | 0.981 | 0.060 | 0.060 | 3.8 | 0.762 | 42.991 | Y(1) | |
| 23233+0946 | 0.128 | LINER | 0.702 | 0.025 | 0.035 | 1.7 | 0.969 | 42.695 | Y(1) | |
| 23327+2913 | 0.107 | LINER | 0.716 | 0.031 | 0.040 | 9.6 | 0.852 | 42.845 | Y(1) | |

* General properties and statistics of our variable ULIRG sample. (1) IRAS name, (2) redshift, (3) optical class, (4) Pearson r value, (5) Standard variation of $W1$ photometric values, (6) Standard variation of $W2$ photometric values, (7) AGN bolometric contribution (in per cent), (8) WISE $W1 - W2$ color, (9) Difference between max and minimum $W2$ band luminosity, (10) Presence of AGN signatures and its reference, (11) references for optical type, and (12) Notes.

† (1) Nardini et al. (2010), (2) Imanishi et al. (2023).

まとめ

- ULIRGsは高い割合でMIR変動を示す ~20 %
- 多くが変動幅が既知の超新星より大きい → AGN or TDEs
- 時間変動がULIRGsの隠れたAGNの探索に有効

既存のAGN?

- 変動していたULIRGsは少なくとも1つ以上のAGN signatureを持つ
- MIR時間変動は、elusive AGNを探る手法と言える

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UFOのあるULIRGs (野田さんtalk)

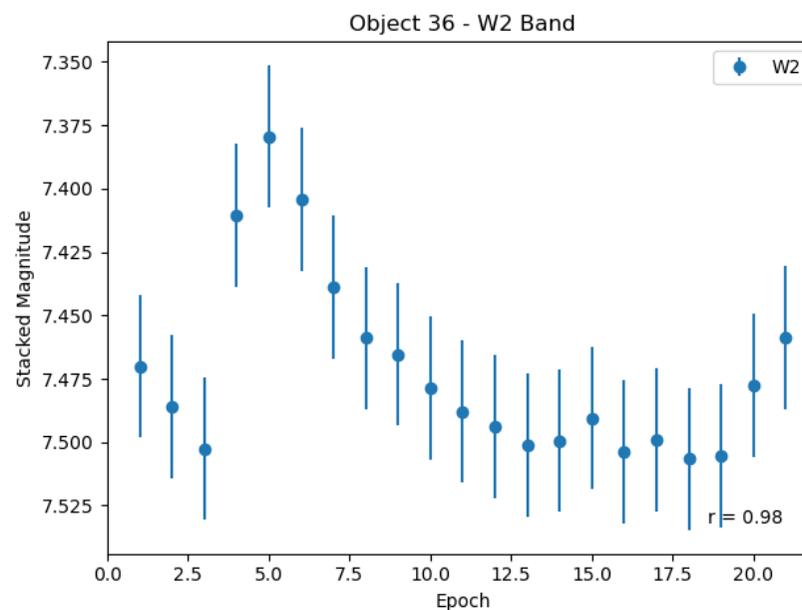
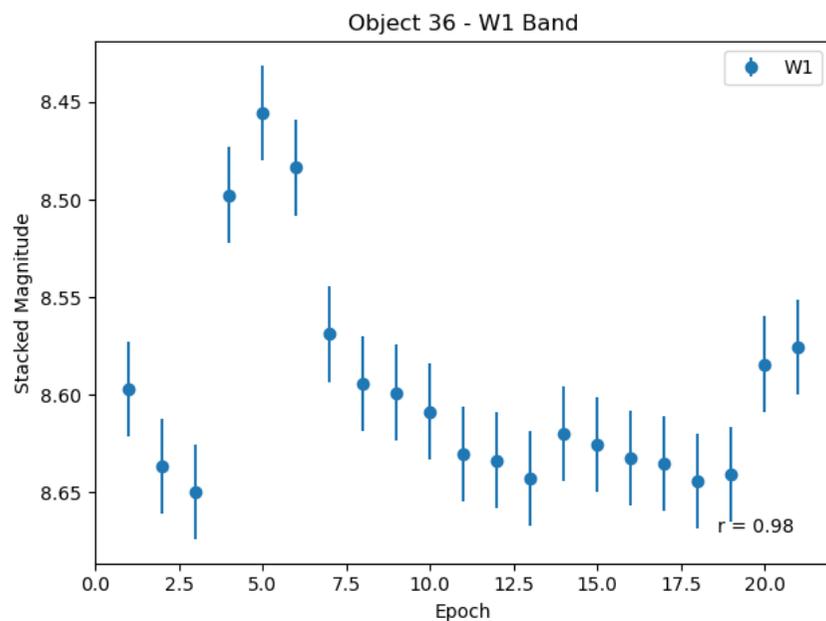
* General properties and statistics of our variable ULIRG sample. (1) IRAS name, (2) redshift, (3) optical class, (4) Pearson r value, (5) Standard variation of $W1$ photometric values, (6) Standard variation of $W2$ photometric values, (7) AGN bolometric contribution (in per cent), (8) WISE $W1 - W2$ color, (9) Difference between max and minimum $W2$ band luminosity, (10) Presence of AGN signatures and its reference, (11) references for optical type, and (12) Notes.

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IRAS 05189-2524

ULIRGs with Ultra Fast Outflow

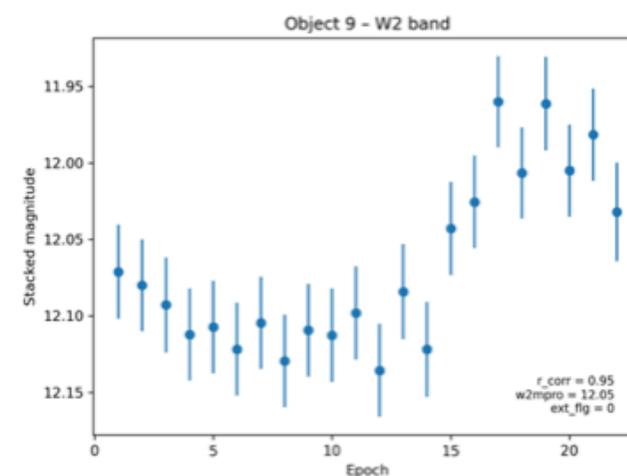
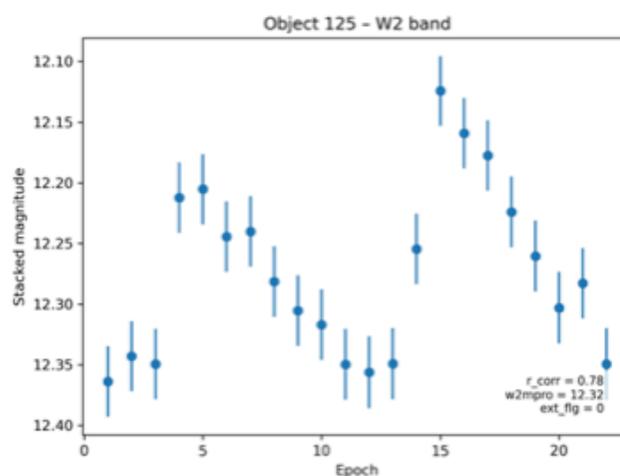
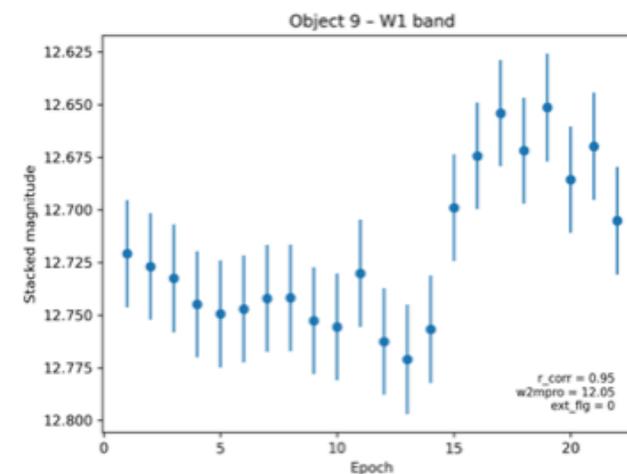
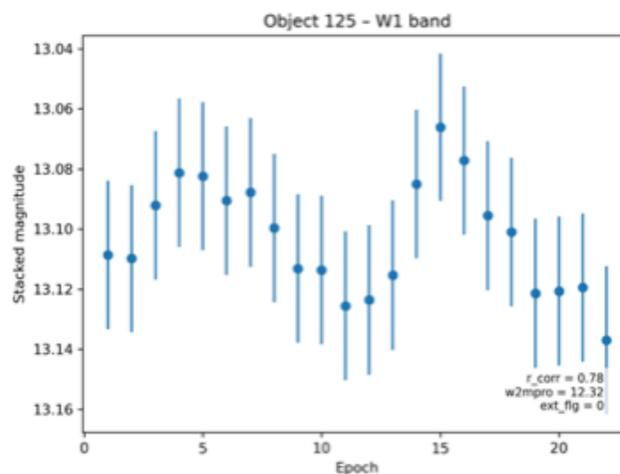
- $\Delta L_{W2} = 10^{43.77}$ erg/s (2010jlの~30倍; Reynolds+22が報告済)



IRAS 17028+5817, IRAS 00456-2904

- Nardini+10でAGNの寄与が認められなかった天体

- 左天体は変動なしと判定された (W1変動小)

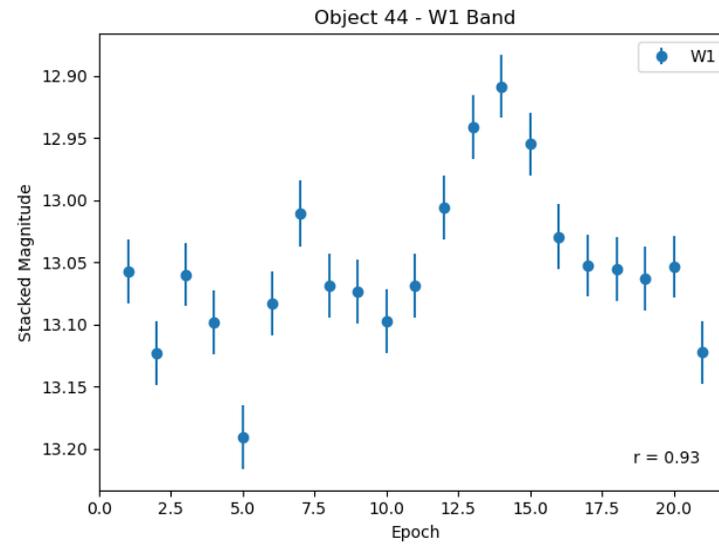


9.0e+42

8.5e+42

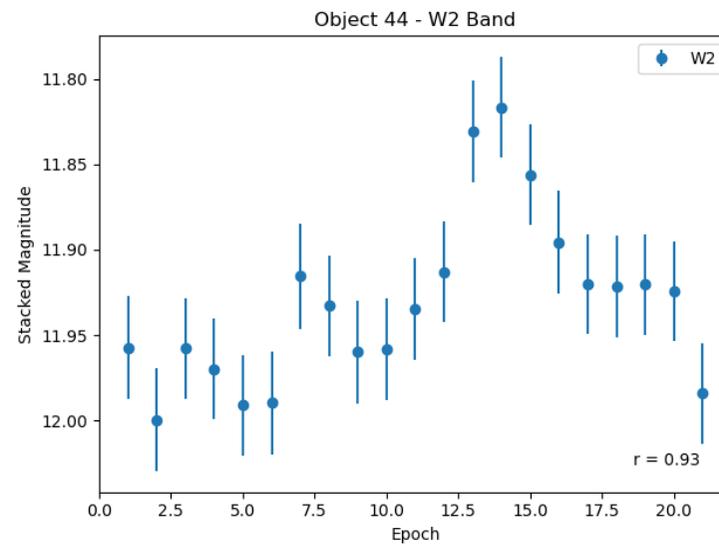
IRAS 07246+6125

43.212



IRAS 07246+6125

43.212



IRAS 06361-6217

43.701

