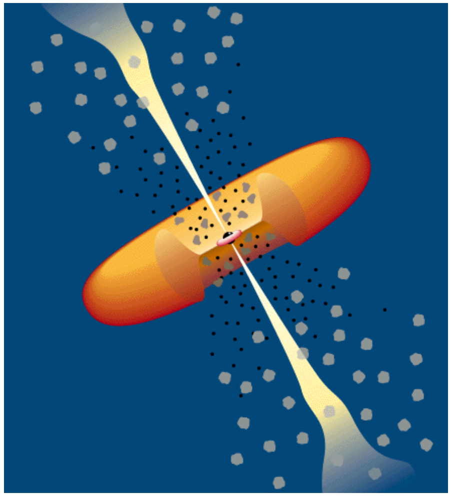
Evolution of ULIRGs and AGNs ~ through IRC spectroscopy ~

Takao Nakagawa
For ULIRG/AGN group

November 7, 2016

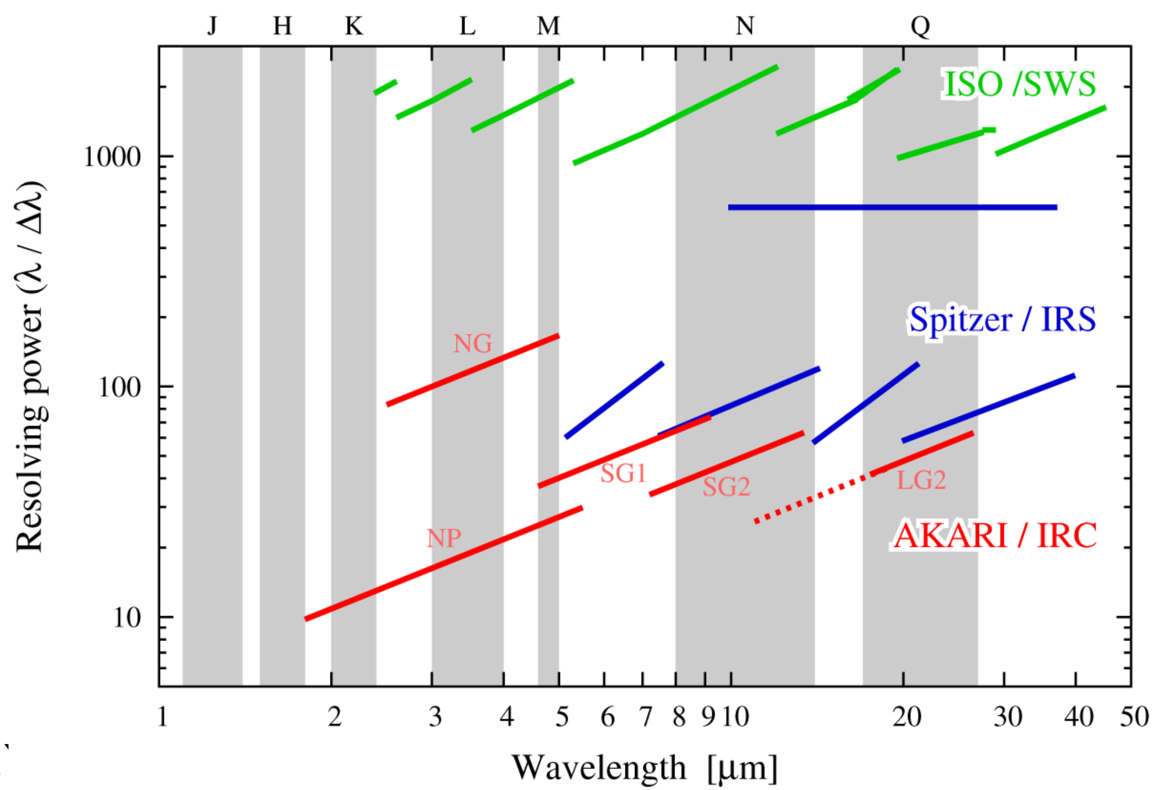
Questions
(what makes them so luminous?)

- What powers them ?
  - AGN vs Starburst
- What enhances them ?
  - Modes of Starburst, Main sequence ..
- What obscures them ?
  - Unified scheme of AGN
- How did they evolve ?



Tools

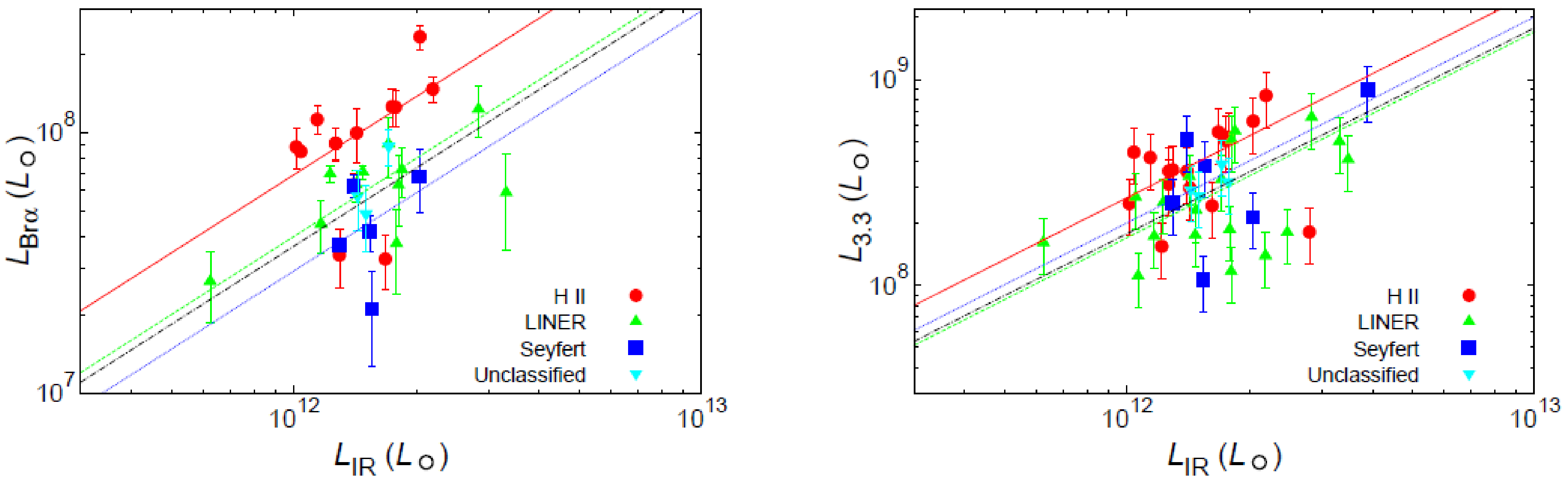
- Lines
  - Recombination Lines
  - H2 Lines
- Features
  - PAH
  - 3.4μm feature
  - H2O Ice
  - CO2 (gas and ice)
  - CO (gas and ice)



What powers them ?

AGN vs Starburst

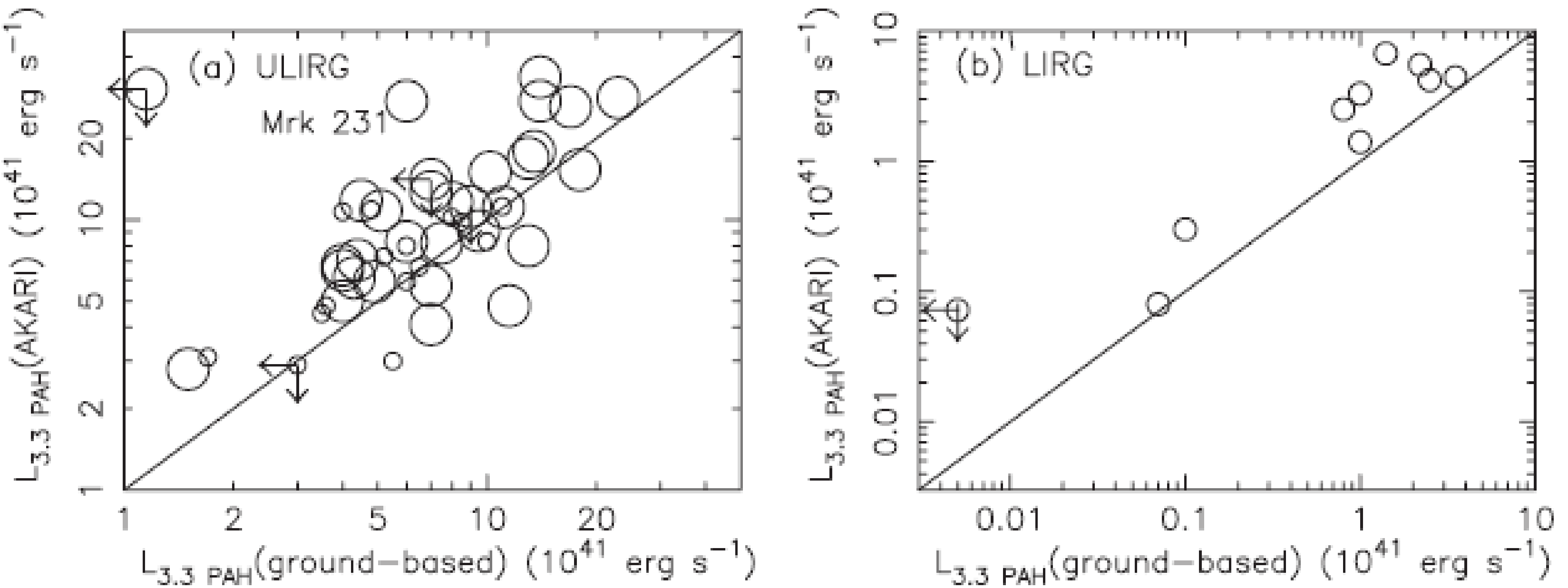
Starburst Indicators



Brα、PAH, FIR luminosity

Yano et al. (2016), ApJ, accepted

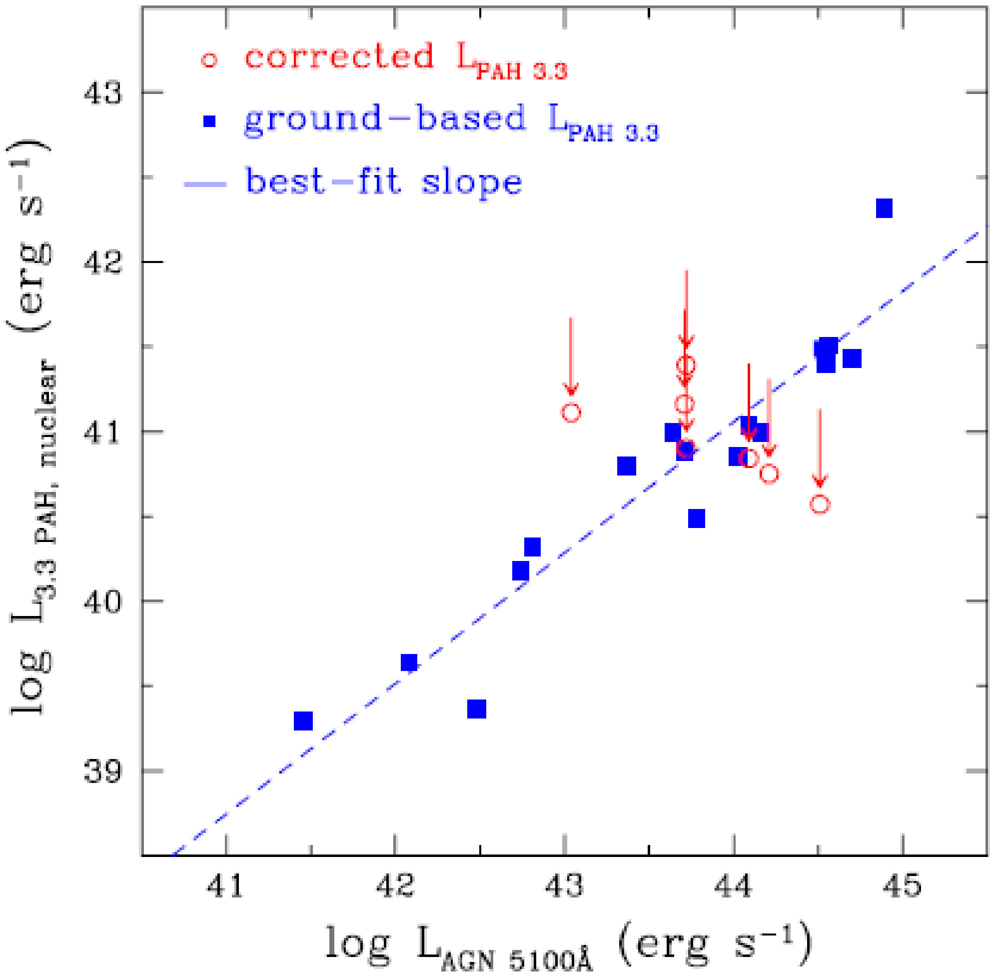
Nuclear Starburst is dominant



- Extended (several kpc), modestly obscured (AV < 15 mag) starburst activity is energetically unimportant in nearby ULIRGs.

Imanishi et al. (2008), PASJ, 60, S489
Imanishi et al. (2010), ApJ, 721, 1233

Global vs Nuclear starbursts



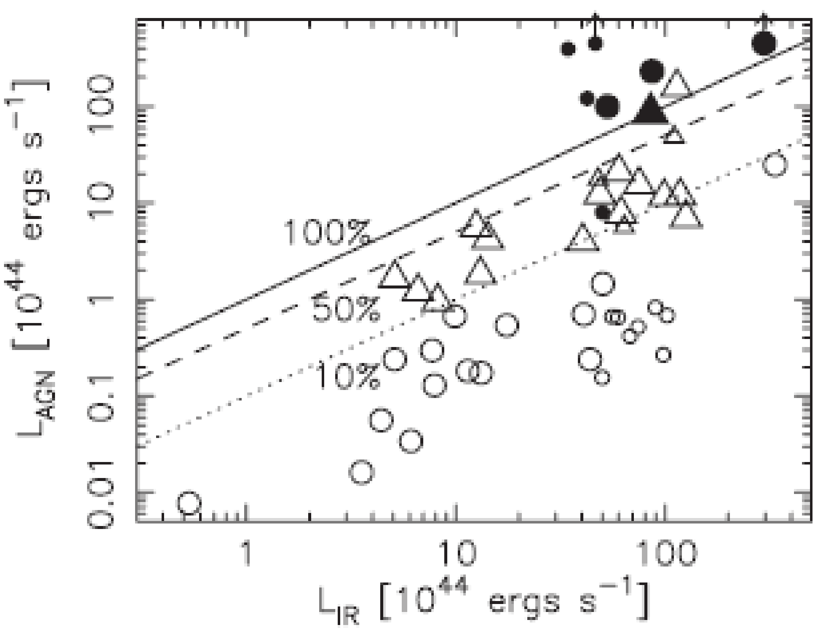
Wu et al. (2012), AJ, 143, 49

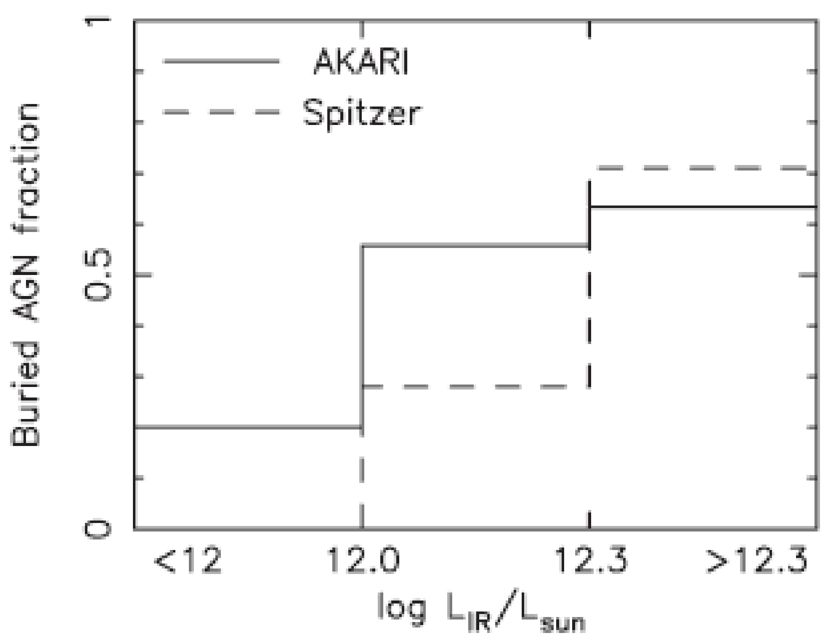
Global vs Nuclear starbursts

- No strong correlation between the 3.3μm PAH emission and AGN luminosity in the limited range of the observed AGN luminosity
  - Suggesting that global star formation may not be closely related to AGN activity.
- The 3.3μm PAH luminosity measured from the central part of galaxies correlates with AGN luminosity, implying that starburst activity and AGN activity are directly connected in the nuclear region.

Wu et al. (2012), AJ, 143, 49

Energy Sources





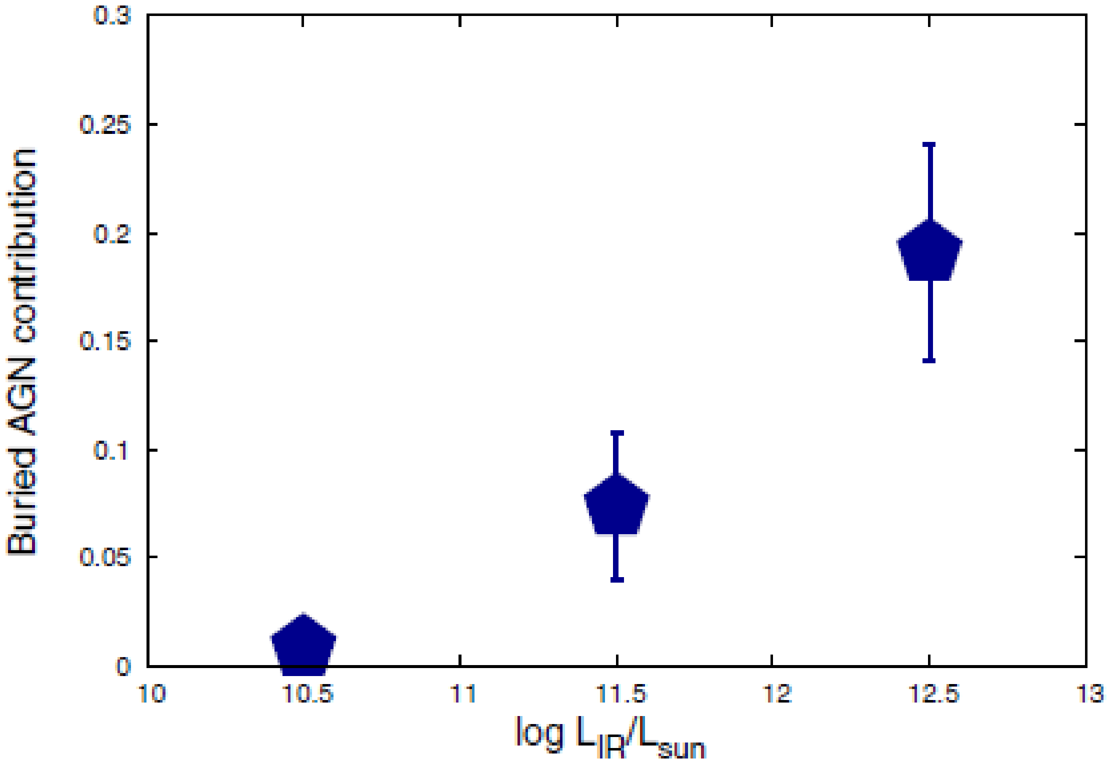
Imanishi et al. (2010), ApJ, 721, 1233

Energy Sources

- A significant fraction of the observed sources display signatures of obscured active galactic nuclei (AGNs).
- The energetic importance of optically elusive buried AGNs in optically non-Seyfert galaxies tends to increase with increasing galaxy infrared luminosity, from LIRGs to ULIRGs.

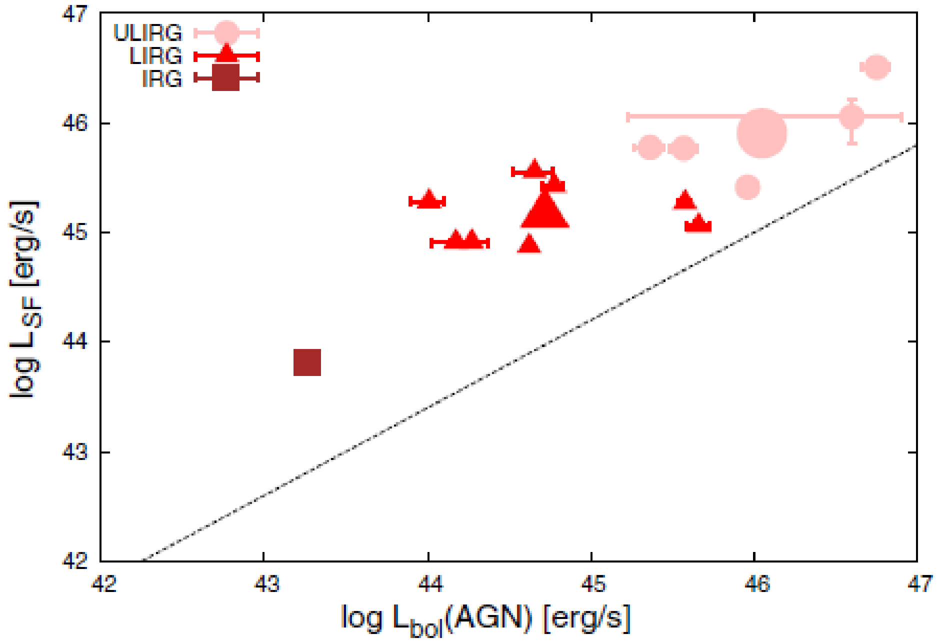
Imanishi et al. (2010), ApJ, 721, 1233

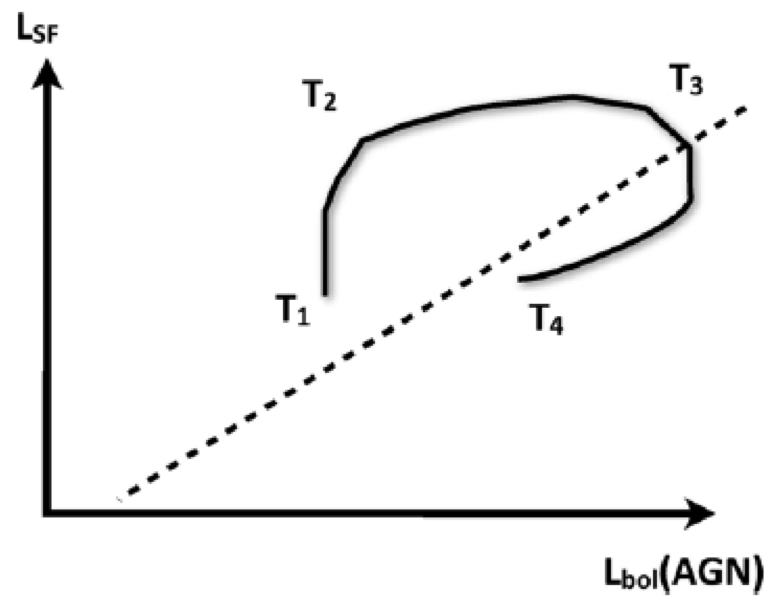
AGN Fraction



Ichikawa et al. (2014), ApJ, 794, 139

Early stage of evolution ?



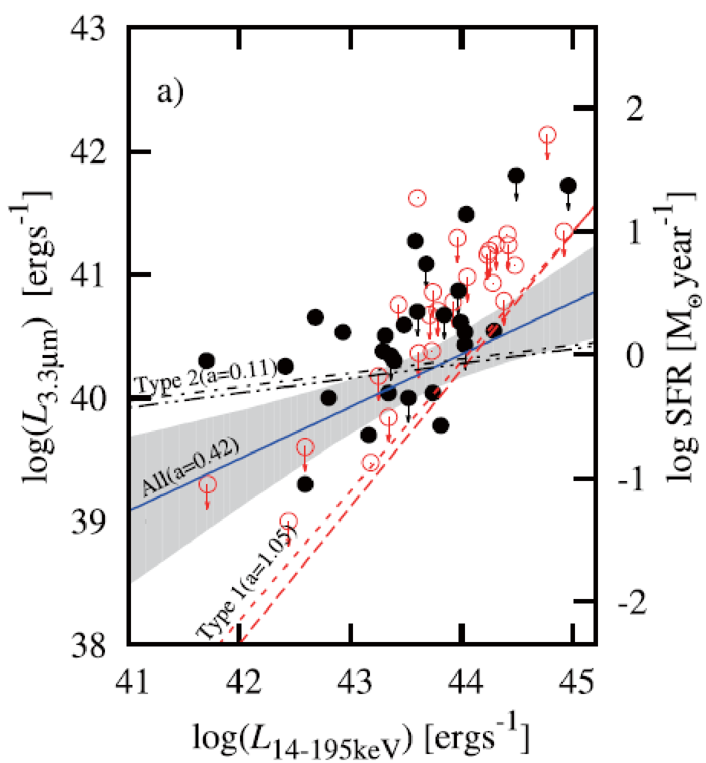


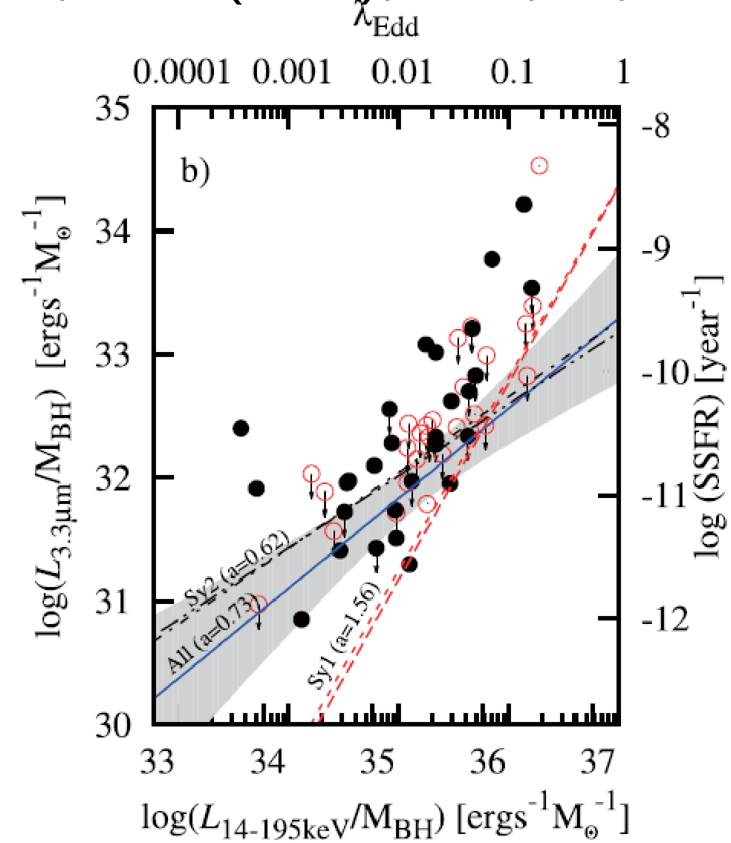
- Infrared galaxies exhibit higher star formation rates than optically selected Seyfert galaxies with the same AGN luminosities, implying that infrared galaxies could be an early evolutionary phase of AGN.

Ichikawa et al. (2014), ApJ, 794, 139

Relation with hard X-ray obs.

The slope for the type 1/unobscured AGNs is steeper than that of type 2/obscured AGNs (Castro, et al. (2014), PASJ, 66, 110)





Open: type 1, filled: type 2

See also Isobe's talk

What enhances them ?

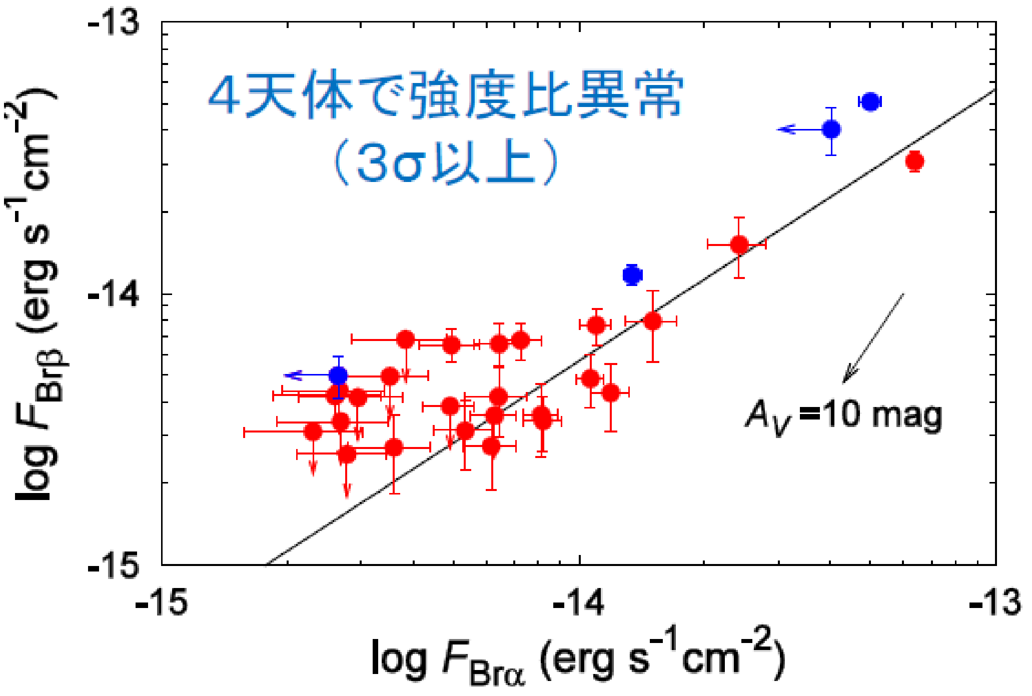
Tracing starbursts

- 非常に Luminous → 特別な star-formation mode にあるのか？
  - ダスト減光に影響されずに調べたい
- 赤外線の水素再結合輝線を利用
  - Brα (n=5-4), Brβ (n=6-4)
  - 電離光子の良いトレーサー
  - 観測強度比から減光量を推定できる
    - 輝線強度比を理論的に計算できる（Brβ/Brα～0.57）光電離、case B を仮定

Yano et al. (2016) in prep.

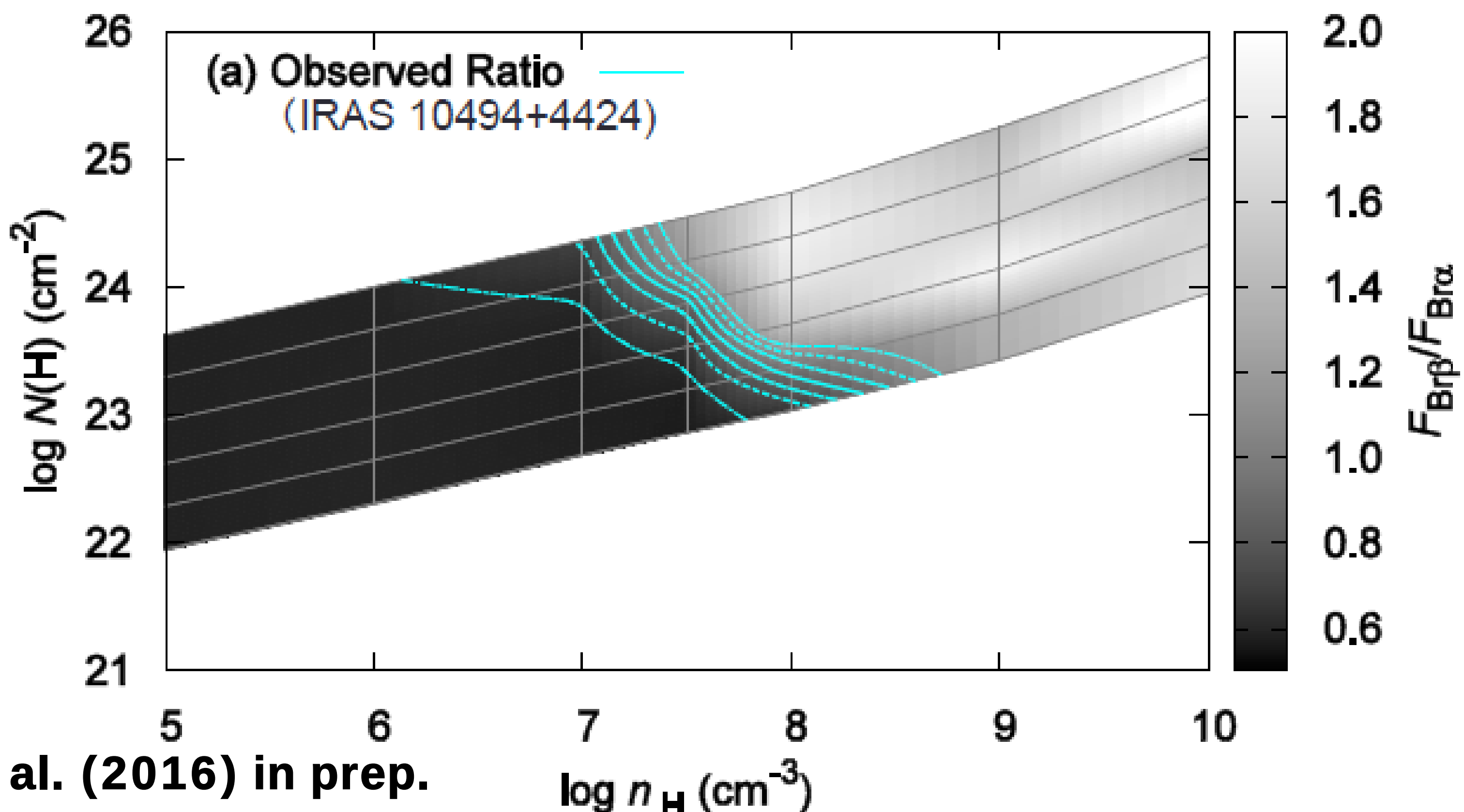
再結合線強度比異常

51個のULIRGを観測→29個でBrα, Brβを検出



Yano et al. (2016) in prep.

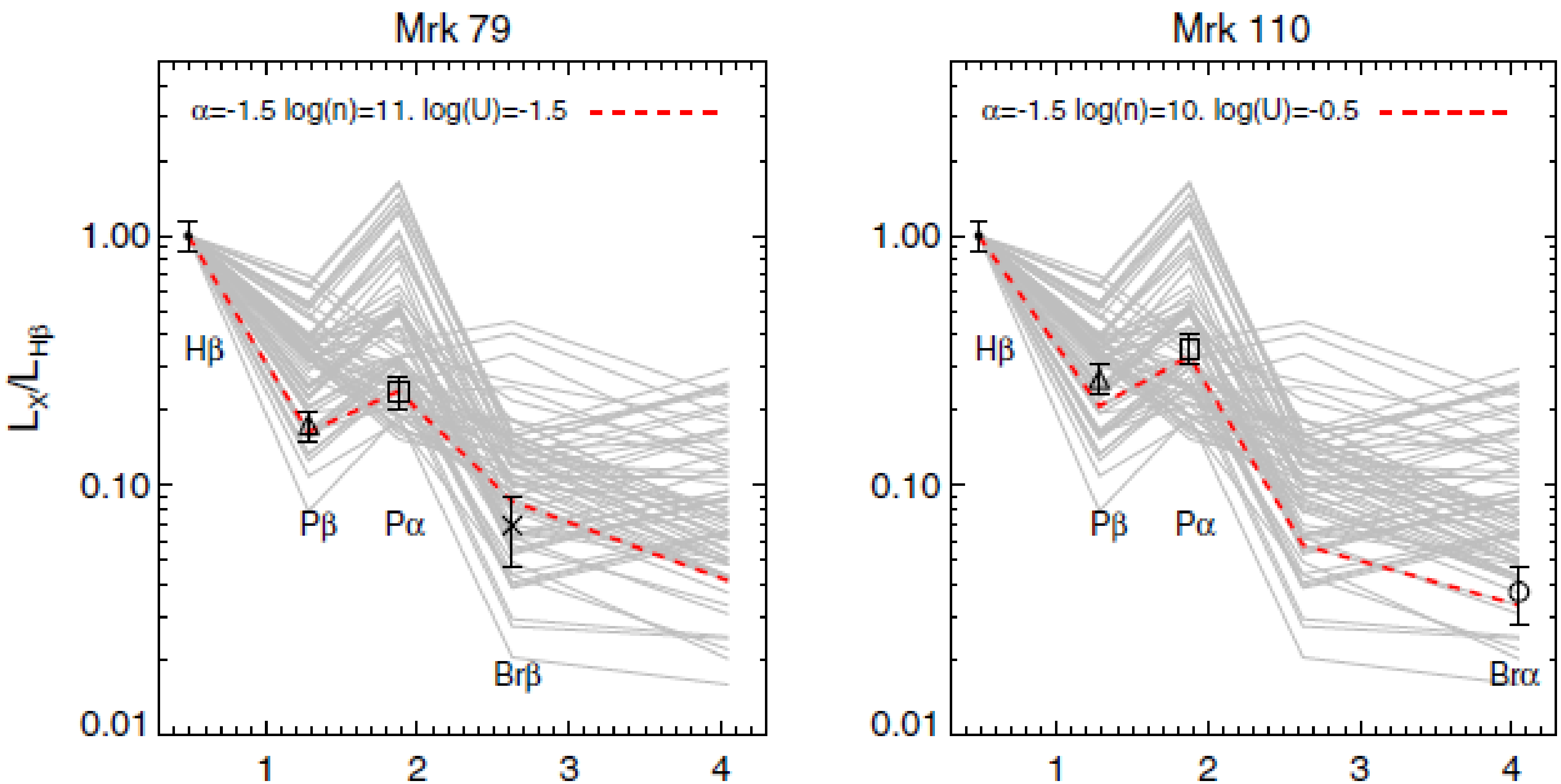
Very high-density gas in starbursts ?



Yano et al. (2016) in prep.

Very high-density gas in BLR

- High density (log n ~ 11) required

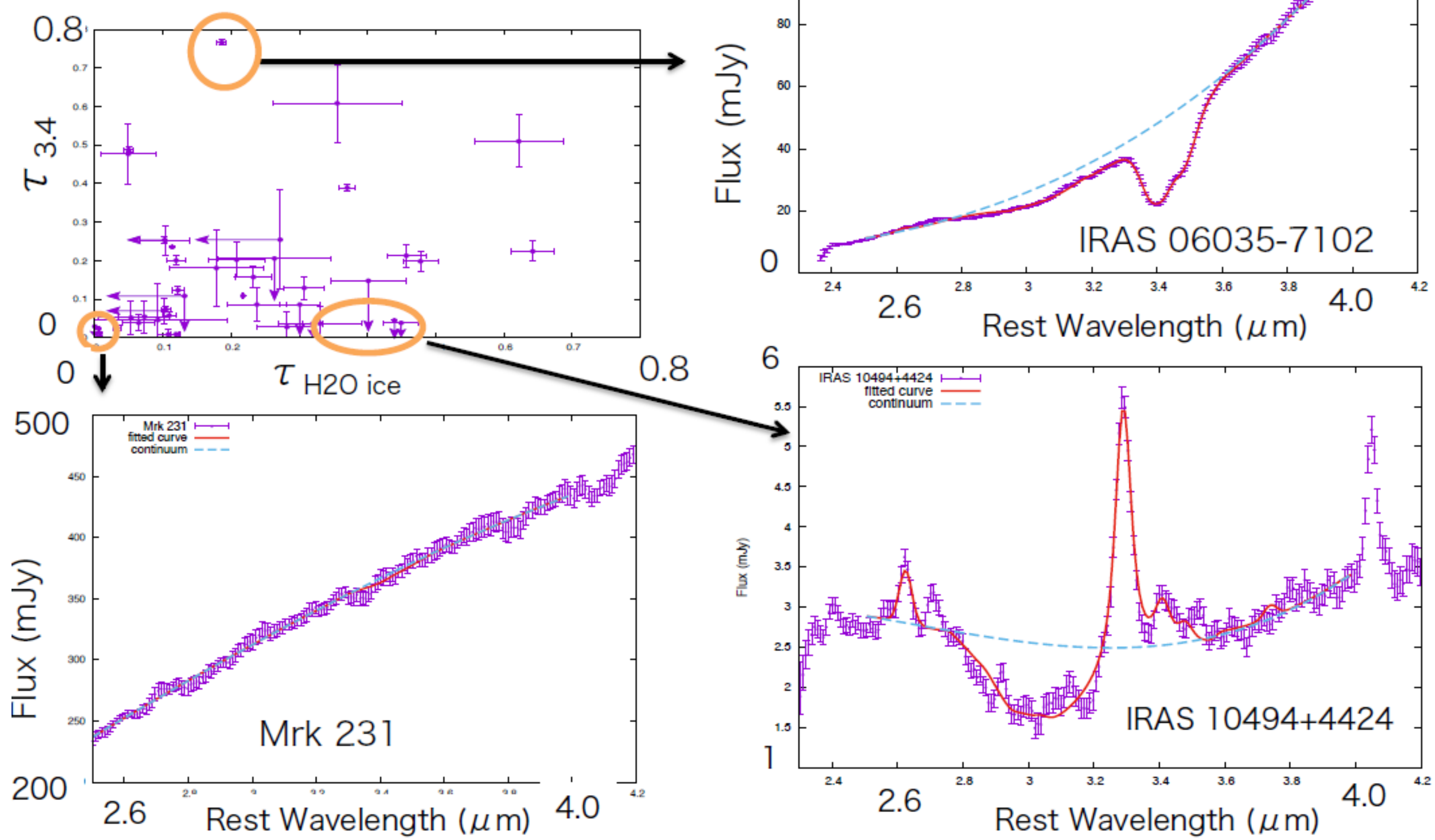


Kim et al. (2015), ApJS, 216, 17

Environment of star-formation

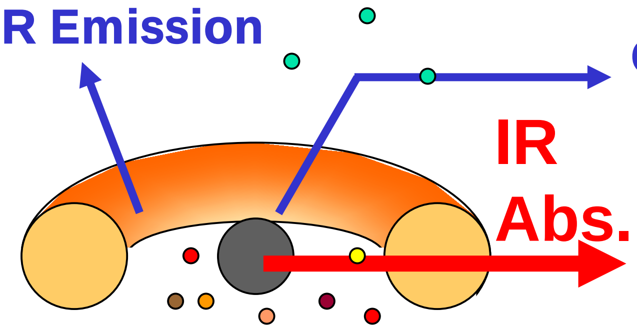
See also Doi's talk

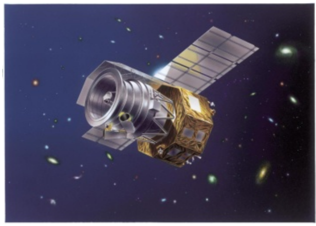
$\tau_{\mathrm{H2O\ ice}} - \tau_{3.4}$



What obscures them ?

Looking into obscuring Tori





- To prove physical characteristics of molecular tori
  - We propose absorption observations of CO ro-vibrational transition in molecular tori.
  - Emission-line observations can be contaminated by foreground star-formation activity

See Baba's talk

How did they evolve ?

Mass evolution of Super Massive Black Holes

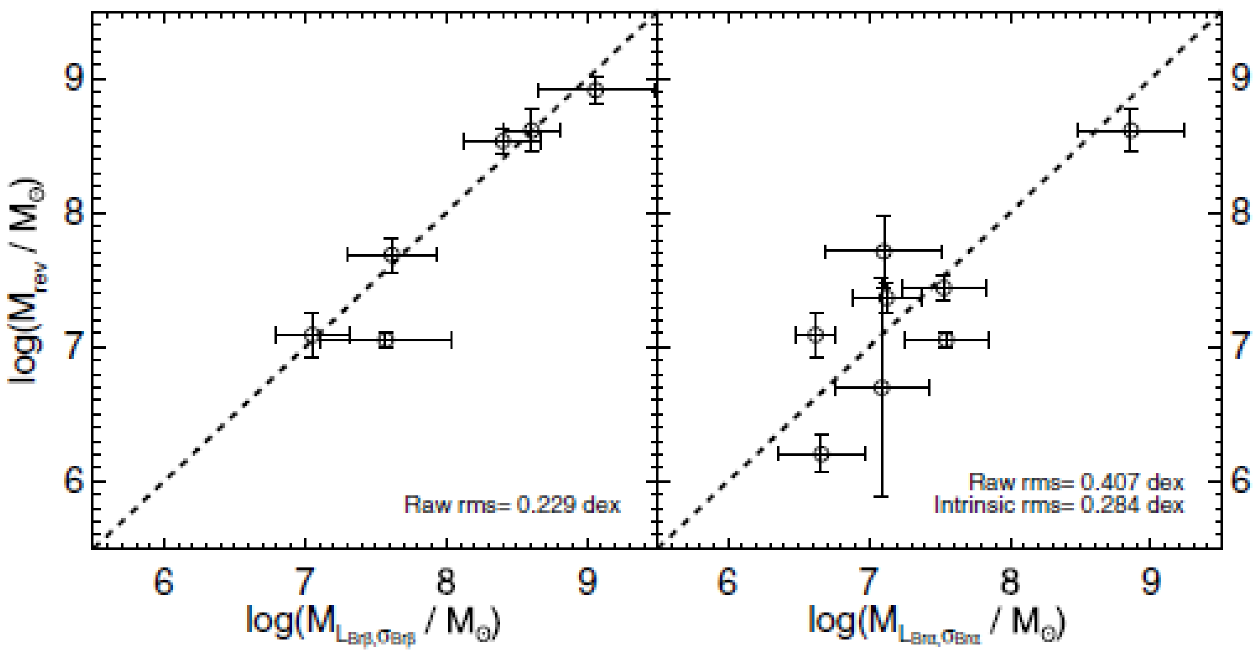
- *Accretion by Eddington-limited rate*

$$M(t) = M_0 \ \exp\left(\frac{1-\epsilon}{\epsilon}\frac{t-t_0}{t_{\mathrm{Edd}}}\right)$$

  - *M_0* : mass at *t*_0
  - ϵ: radiative efficiency
  - *T*_Edd: Eddington-limited timescale of 0.45 Gyr
- Example
  - With typical ϵ = 0.1, a BH can grow only by 2 × 10^4 times over the time span of 0.5 Gyr
  - Time span between z=11.5 (reionization) and z=6 (current observation) is 0.5 Gyr

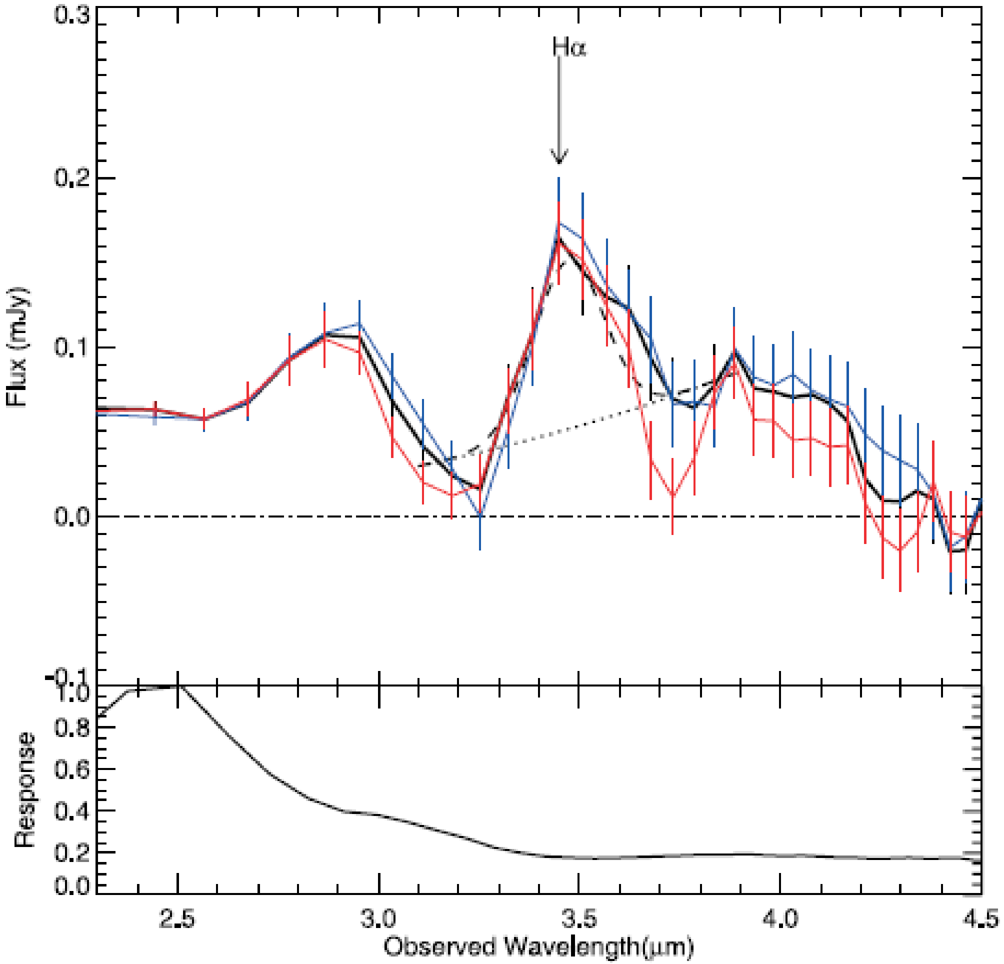
Near-by AGN

- Nearby (0.002 < *z* < 0.48) type-1 AGN
  - Bracket series



Kim et al. (2015), ApJS, 216, 17

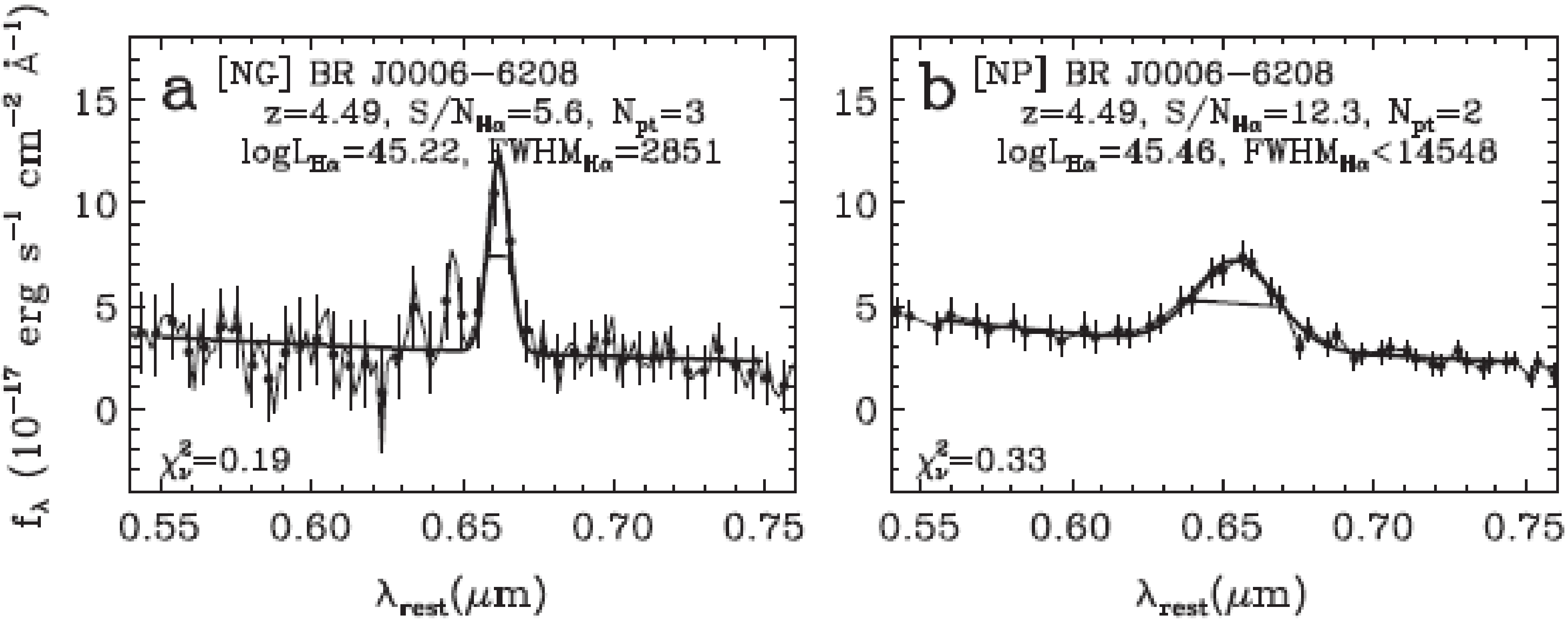
Toward high-z: Hα



RX J1759.4+6638 @ z=4.3

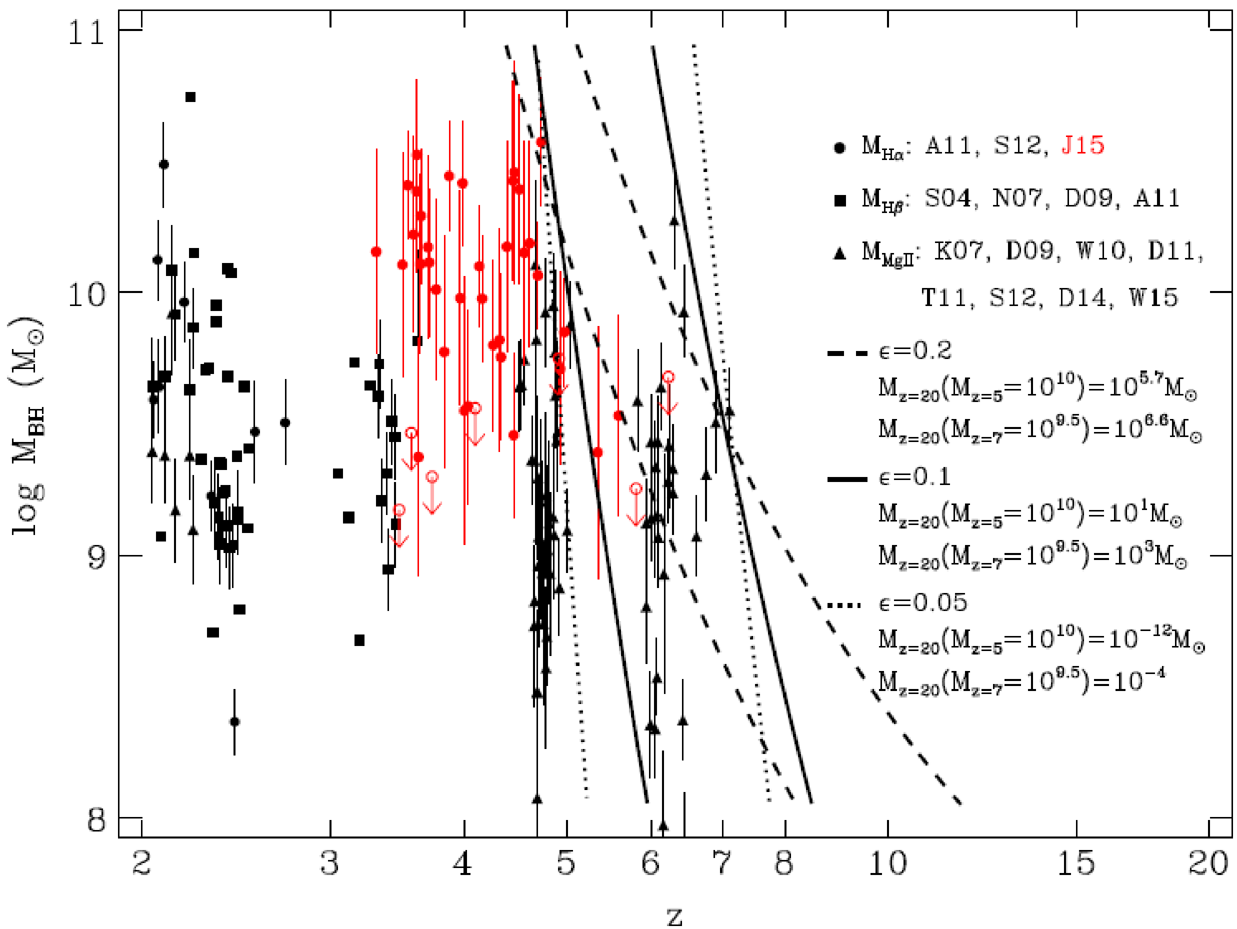
Oyabu et al. (2007), PASJ, 59, S497

Line width



Jun et al. (2015), ApJ, 806, 109

Evolution of SMBH Mass



Jun et al. (2015), ApJ, 806, 109

How did they evolve?

- 155 luminous quasars at $3.3 < z < 6.4$
  - The first detection of the Hα emission line as far out as $z \sim 6$.
- The existence of BHs as massive as $\sim 10^{10}\ M_{\odot}$ out to $z \sim 5$ shows that a rapid M_{BH} growth has occurred in the early universe.
  - E.g. the Eddington-limited accretion onto $\sim 10^{1\text{-}3}\ M_{\odot}$ seed masses at $z=20$.

Age of QSOs

- When and how were hosts of QSOs formed ?
- FeII/MgII Ratio
  - Indicator of Age
  - Mg: SN II (short life time, massive stars)
  - Fe: SN I (long life time, low mass stars)
    - Delay ～ 1Gyear
- AKARI/IRC Spectroscopy
  - Good sensitivity longer than L
  - NIR spectroscopy only by AKARI

To be done

Summary

- Nuclear Starburst is energetically important.
  - High-density star-forming regions ?
- AGN fraction increases with luminosity.
  - Rapid increase of SMBH required in the early universe.
- Future
  - JWST (low-z) and SPICA (high-z)