

Starburst-AGN connection in
forming early-type galaxies.

Growth of binary massive black holes in
gas-rich mergers.

Kenji Bekki (UNSW)

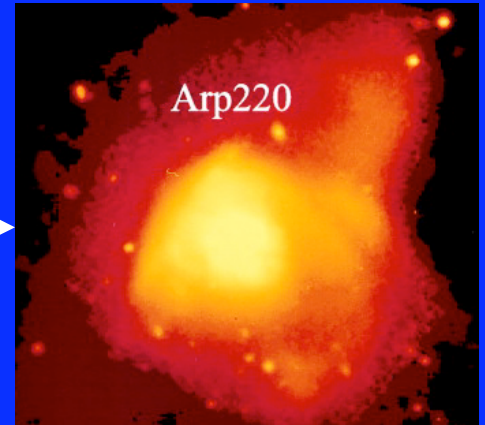
Evolutionary links between different galaxy populations ?



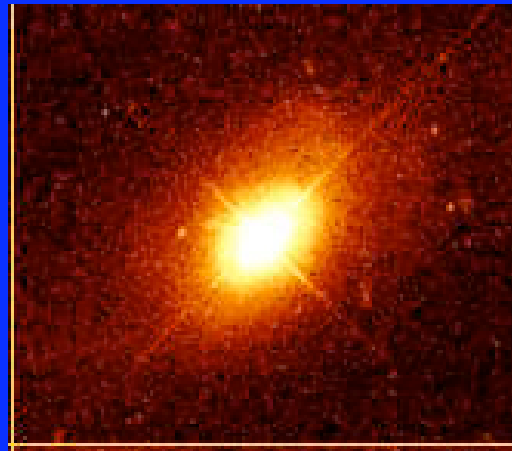
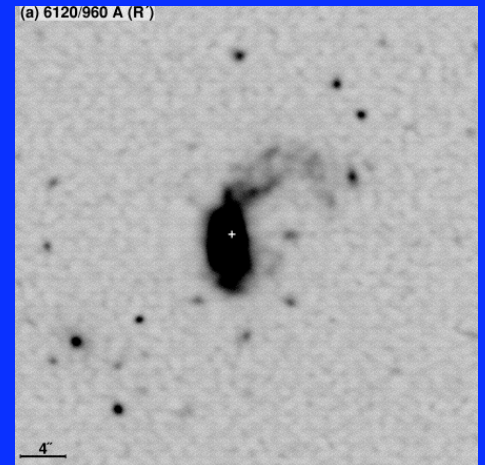
Spiral



Merger



ULIRG



QS

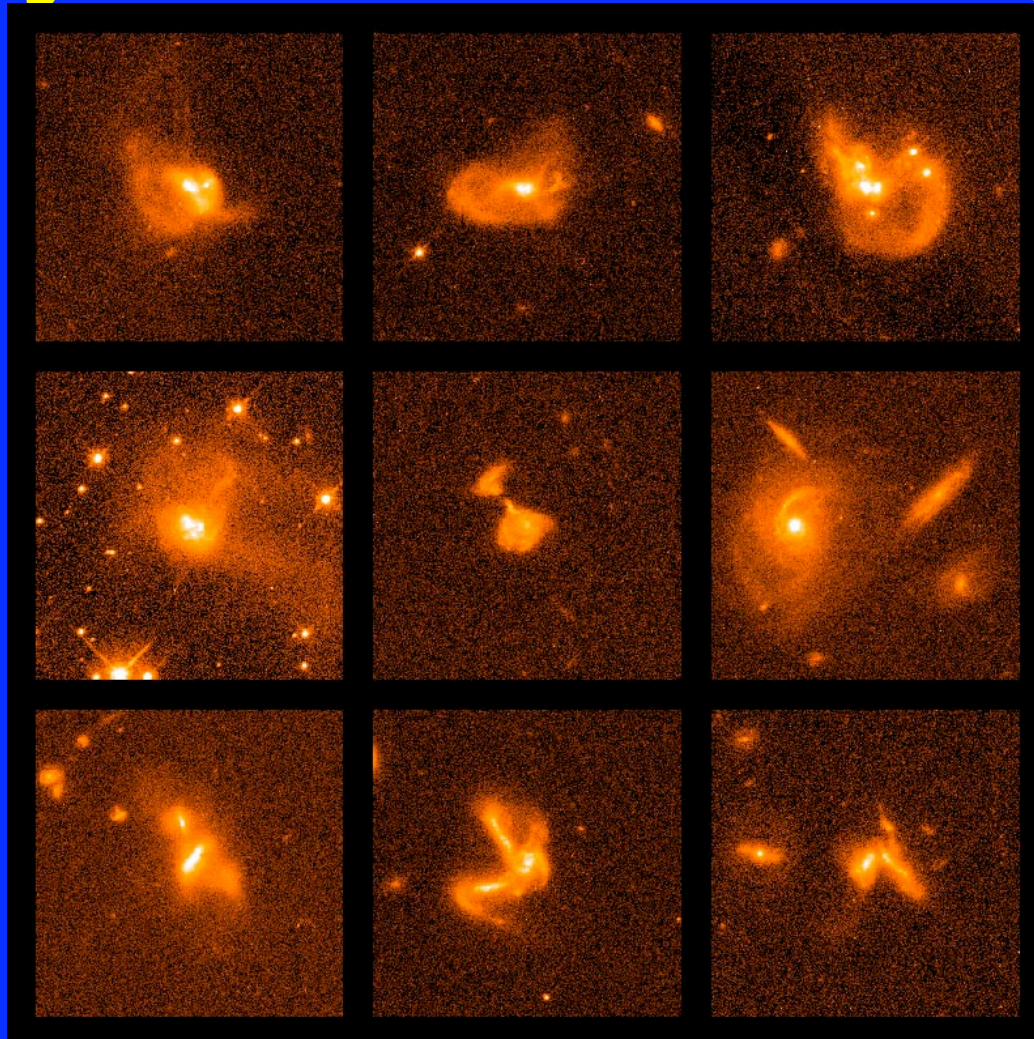


Elliptical

Today's topic

- Key questions on starburst-AGN connection in gas-rich galaxy mergers.
- Numerical simulations of starburst, growth of super massive black holes, and AGN formation.
- Implications on the latest observations.
- Conclusions.

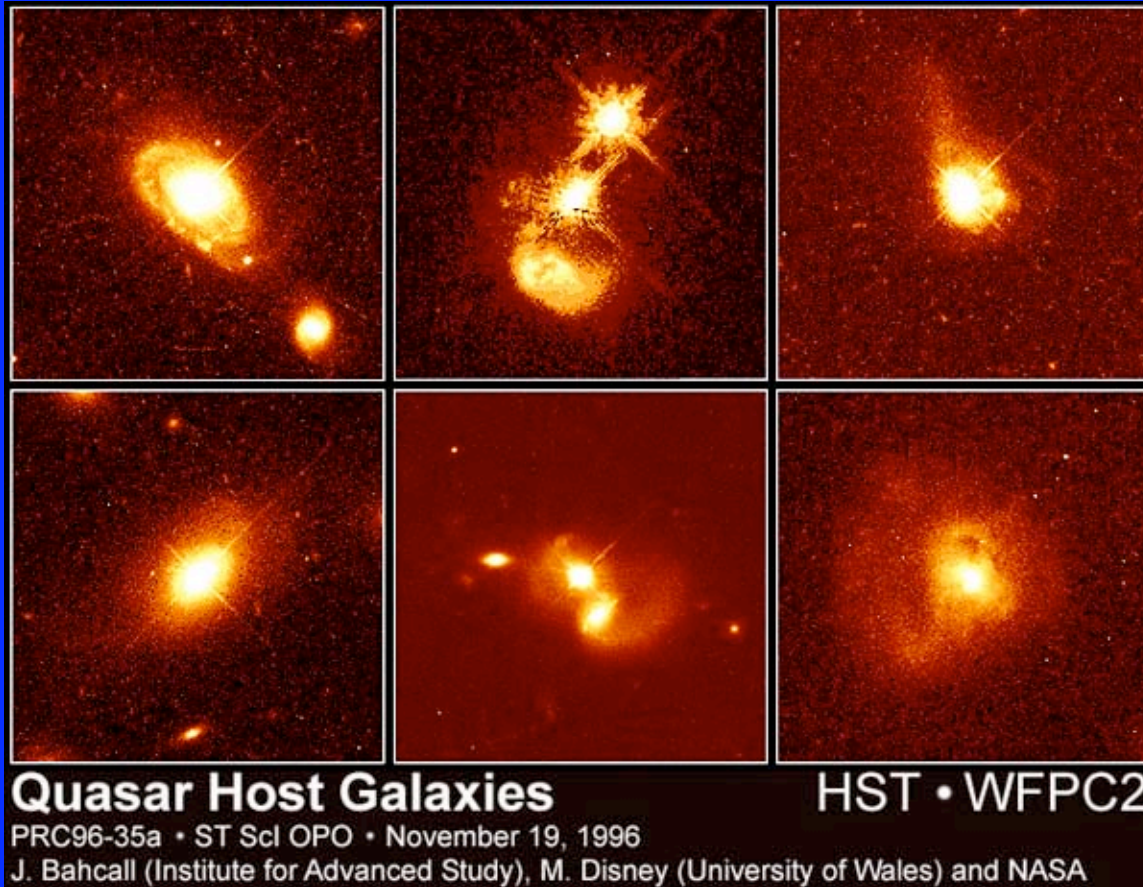
Formation of Ultra-luminous infrared galaxies (ULIRGs) by galaxy interaction and merging.



HST images
of ULIRGs

(Borne et al. 2000)

QSO formation by galaxy interaction and merging.



HST images
of QSOs

(Bahcall et al. 1995)

Three key questions.

- What controls star formation rates and gas accretion rates onto massive black holes in gas-rich mergers ?
- How can massive black holes grow during galaxy merging ?
- Evolution from ULIRGs into QSOs ?

Bolometric luminosity from Starburst
(SB) and AGN

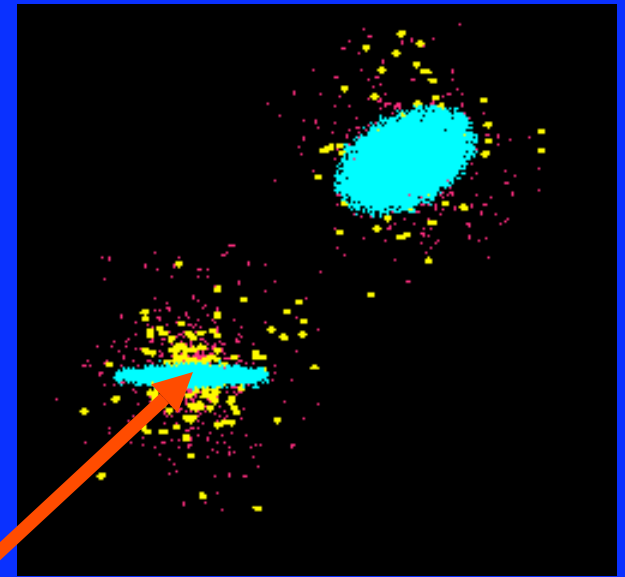
$$\begin{aligned} L_{\text{sb}} &= \eta_{\text{sb}} f_{\text{ys}} \dot{m}_{\text{sb}} c^2 \\ &= 10^{12} L_{\odot} \left(\frac{\dot{m}_{\text{sb}}}{140 M_{\odot} \text{yr}^{-1}} \right) \left(\frac{\eta_{\text{sb}}}{0.01} \right) \left(\frac{f_{\text{ys}}}{0.05} \right) \\ &\quad \text{(Kennicutt 1998)} \end{aligned} \tag{1}$$

$$\begin{aligned} L_{\text{acc}} &= \eta_{\text{acc}} \dot{m}_{\text{acc}} c^2 \\ &= 10^{12} L_{\odot} \left(\frac{\dot{m}_{\text{acc}}}{0.7 M_{\odot} \text{yr}^{-1}} \right) \left(\frac{\eta_{\text{acc}}}{0.1} \right) \\ &\quad \text{(e.g., Shapiro \& Teukolsky 1983)} \end{aligned} \tag{2}$$

**The
fueling
problem.**

Merger models: **GRAPE5** chemodynamical simulations

- Fully self-consistent approaches (Star formation, SNIi feedback, evolution of SMBHs, AGN feedback, chemical evolution etc)
- Star formation: **Schmidt law**.
- Accretion rates onto SMBHs: **Bondi accretion**.

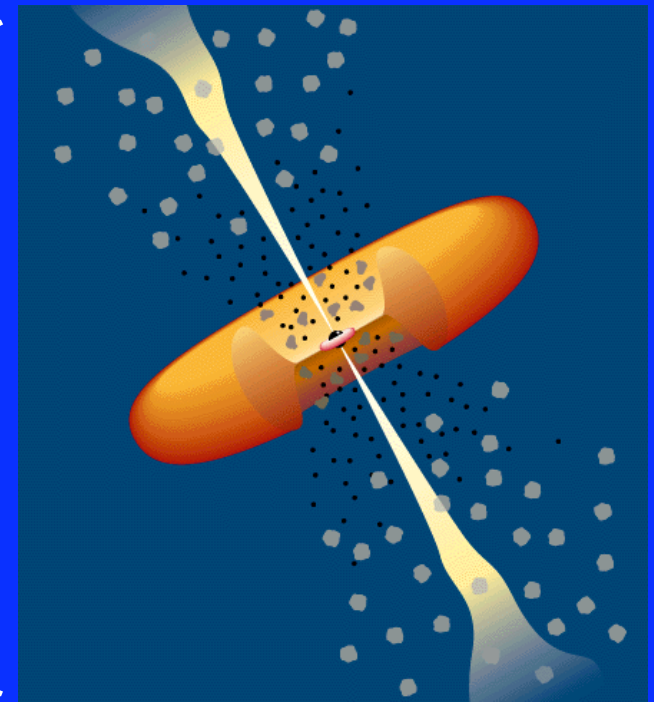


Each contains a
SMBH.

Gas transfer from ~ 10 kpc to 0.01 pc



~ 10 kpc

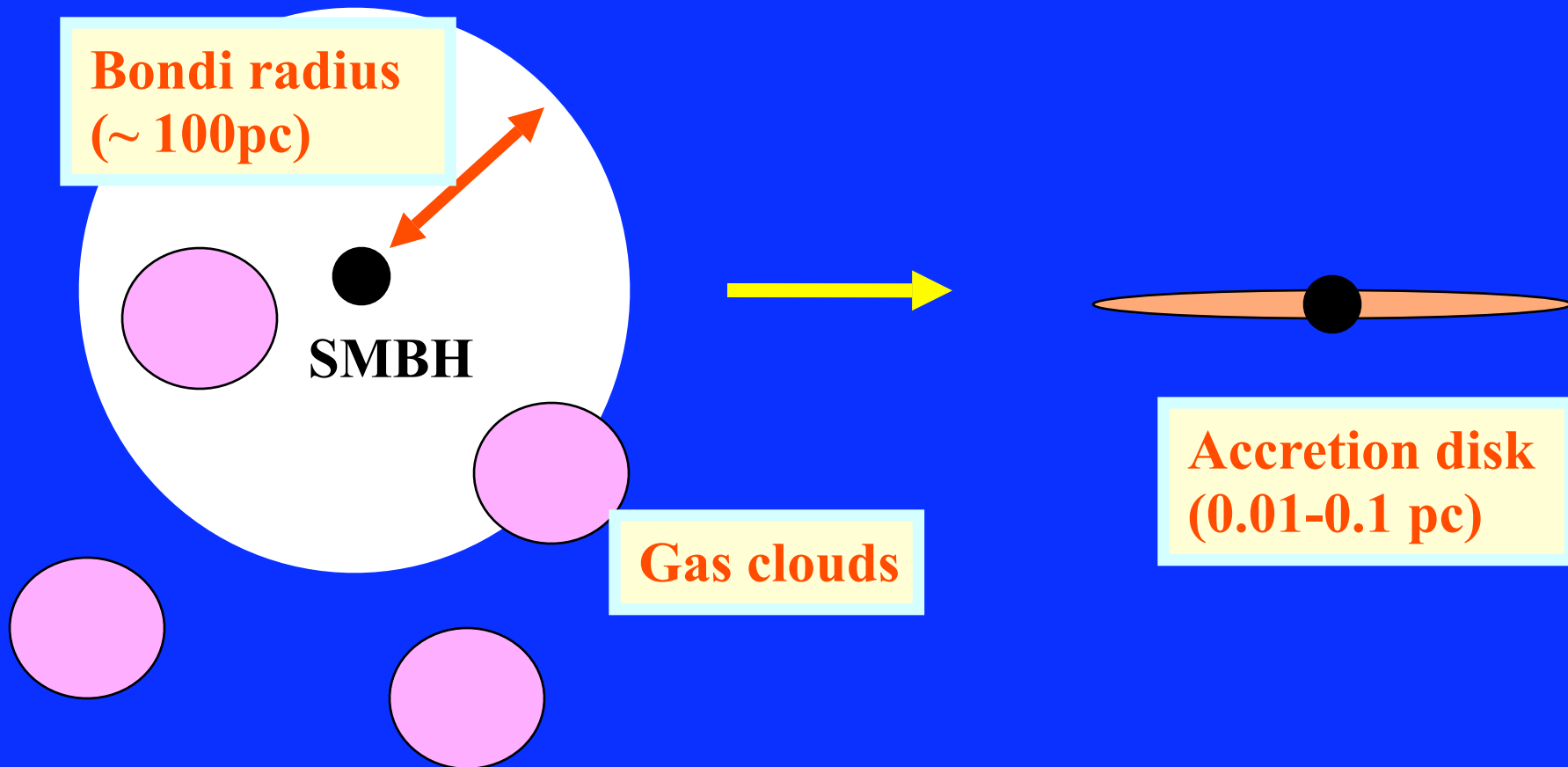


~ 0.01 pc

A two-hold model for BH accretion.

(1) Estimation of Bondi accretion rates.

(2) Estimation of accretion rates onto SMBHs.



From Bondi rate to accretion rate.

Bondi radius (Hoyle & Lyttleton 1939;
Bondi & Hoyle 1952)

$$r_{\text{bon}} = \frac{2GM_{\text{BH}}}{v_{\infty}^2} = 86 \left(\frac{M_{\text{BH}}}{10^8 M_{\odot}} \right) \left(\frac{100 \text{ km s}^{-1}}{v_{\infty}} \right)^2 \text{ pc}$$

$$\dot{m}_{\text{bon}} = \pi r_{\text{bon}}^2 G M_{\text{BH}} \rho_{\infty} v_{\infty}$$

From \dot{m}_{bon} to \dot{m}_{acc}

$$\dot{m}_{\text{ad}} = \dot{m}_{\text{bon}} - \dot{m}_{\text{acc}}$$

$$\dot{m}_{\text{acc}} = F(m_{\text{ad}})$$

m_{ad} = accretion disk mass

$$F(m_{\text{ad}}) \propto m_{\text{ad}}^{5/3}$$

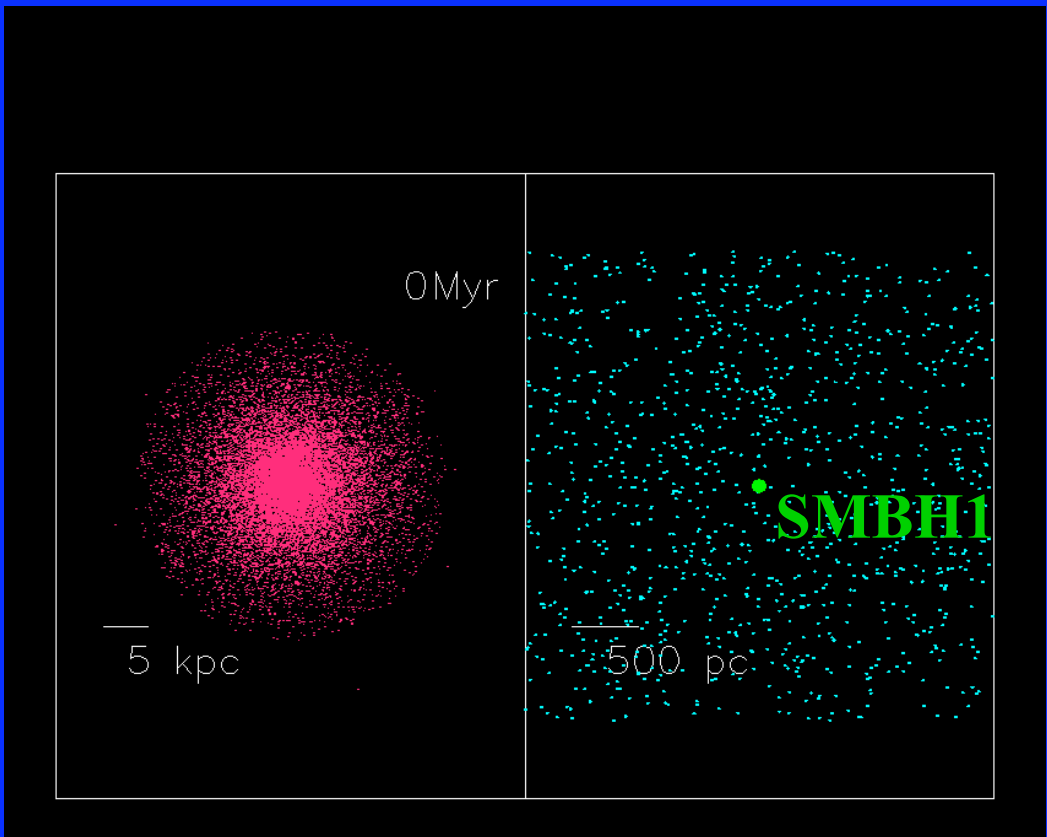
(Colin & Huré 2001; Liu 2004)

Results.

- The standard model.
- Parameter dependences (on B/D ratio, gas mass fraction, initial disk mass etc).

Evolution of binary SMBHs.

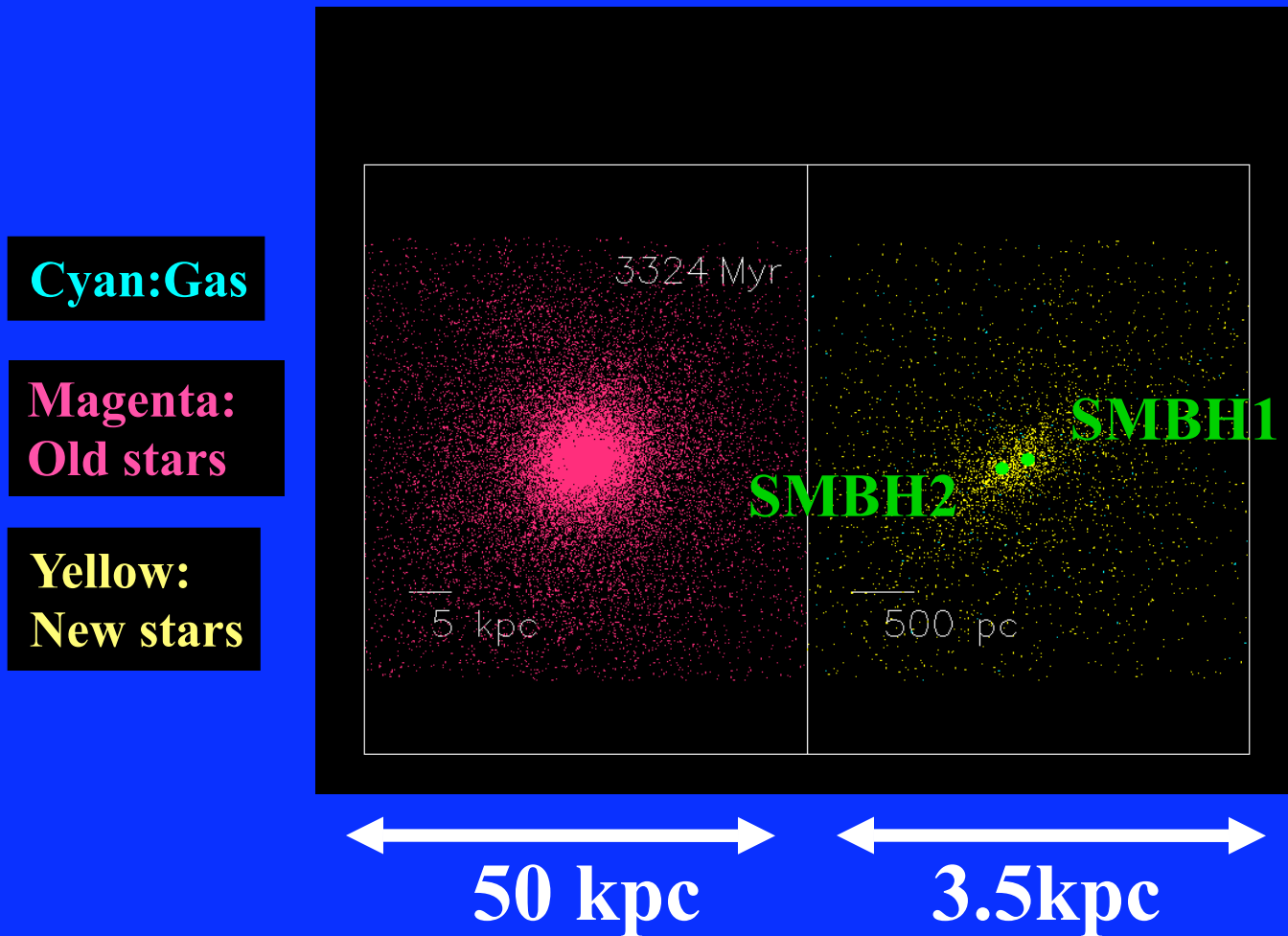
- Cyan: Gas**
- Magenta: Old stars**
- Yellow: New stars**



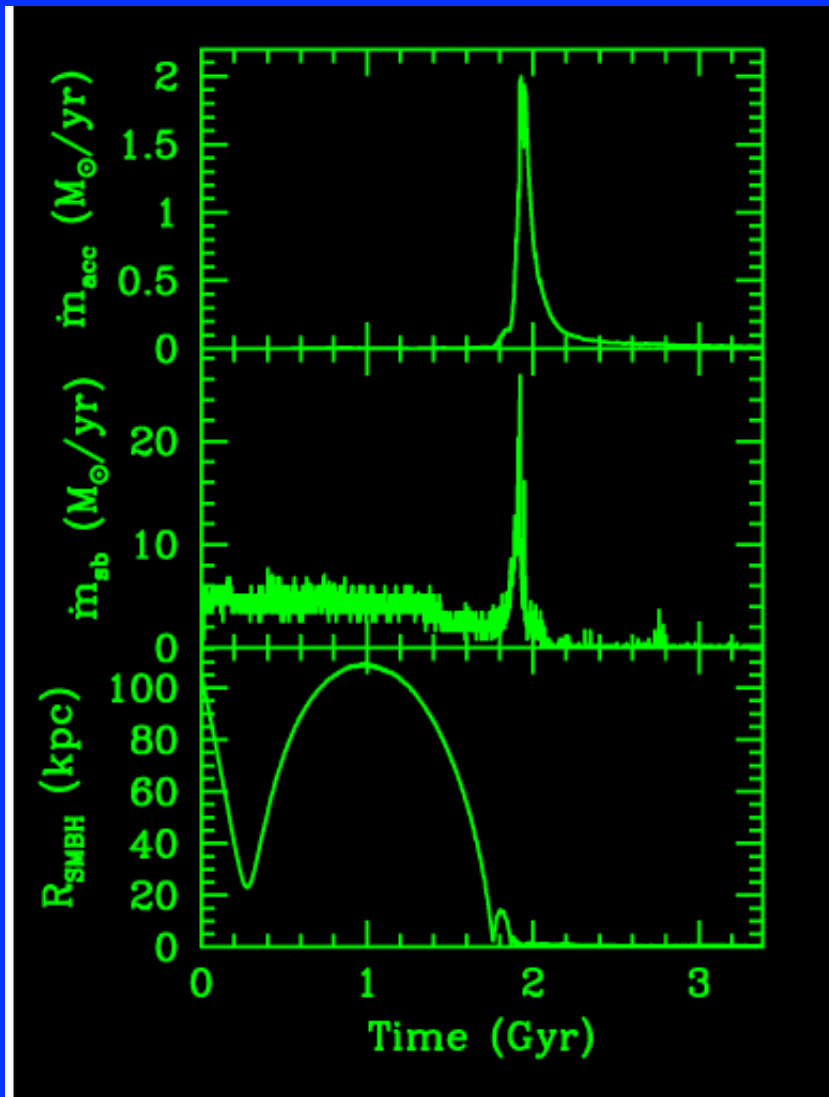
50 kpc

3.5 kpc

Binary SMBHs and poststarburst populations.



Evolution of SFR and ACR. (B/D ratio=0.5, gas fraction=0.2)

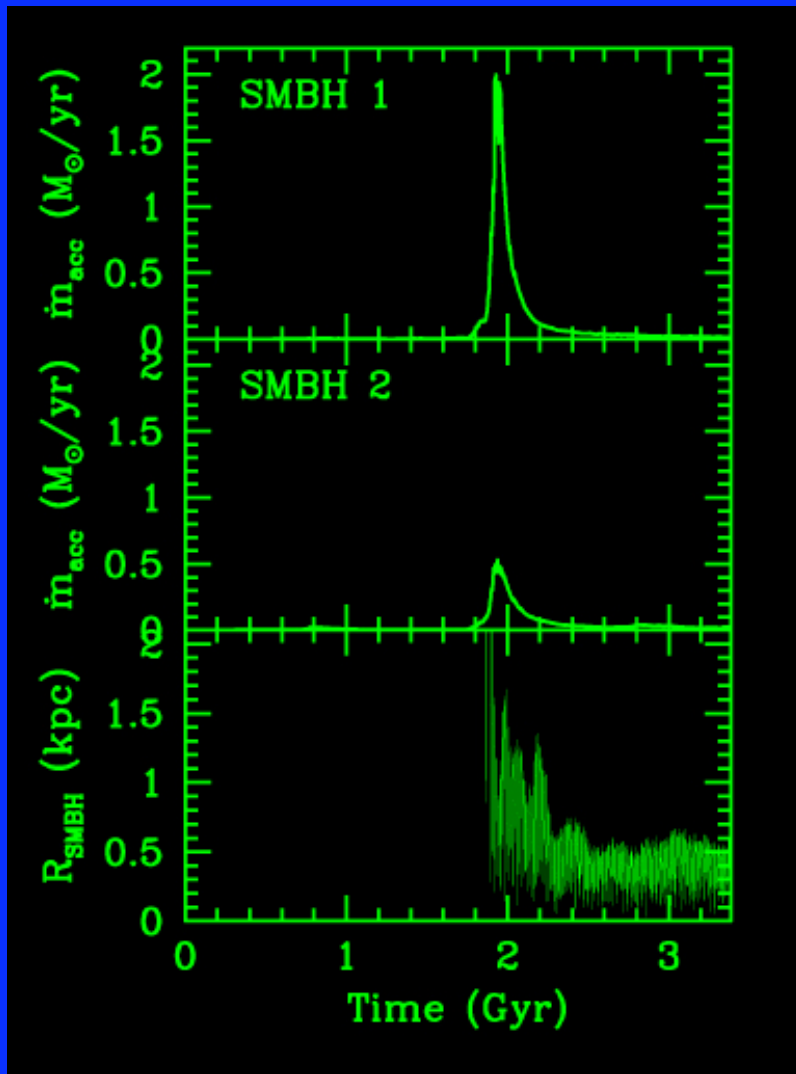


Accretion rate

Star formation rate

Separation between
two SMBHs.

Binary formation & Gas fueling

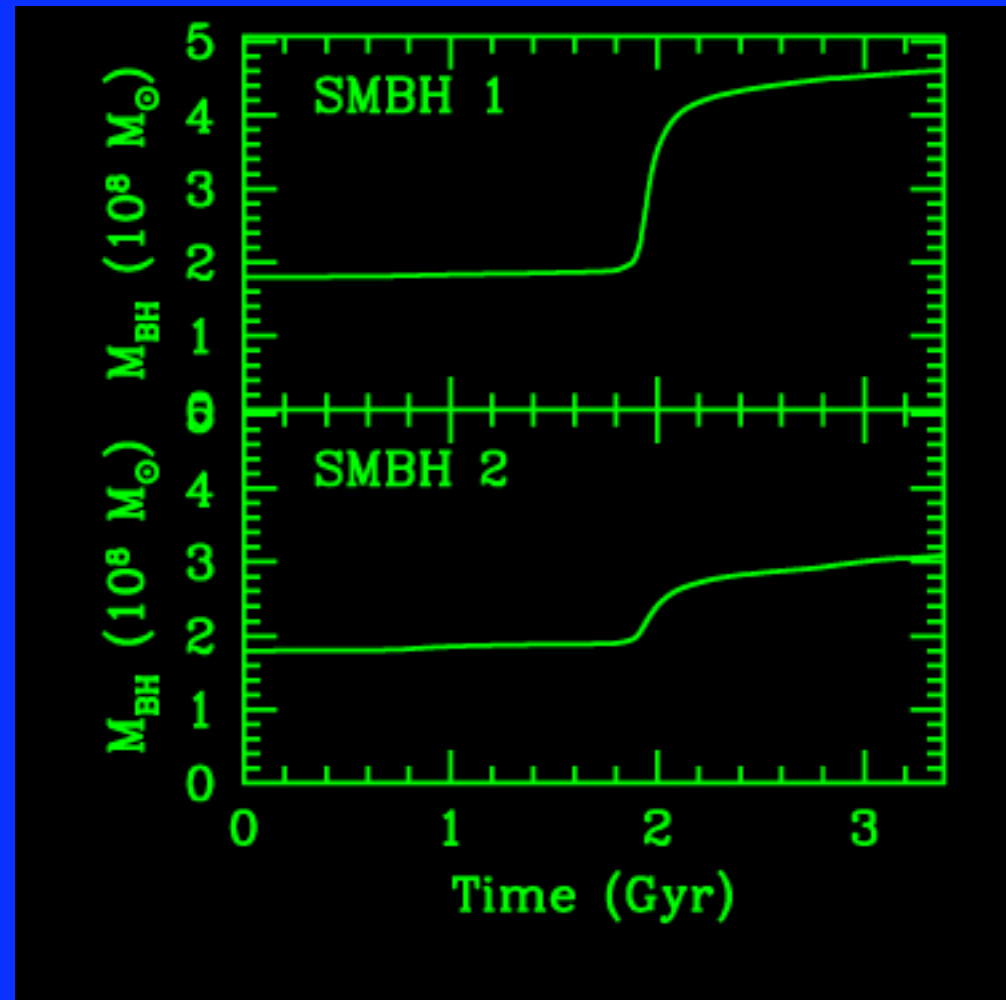
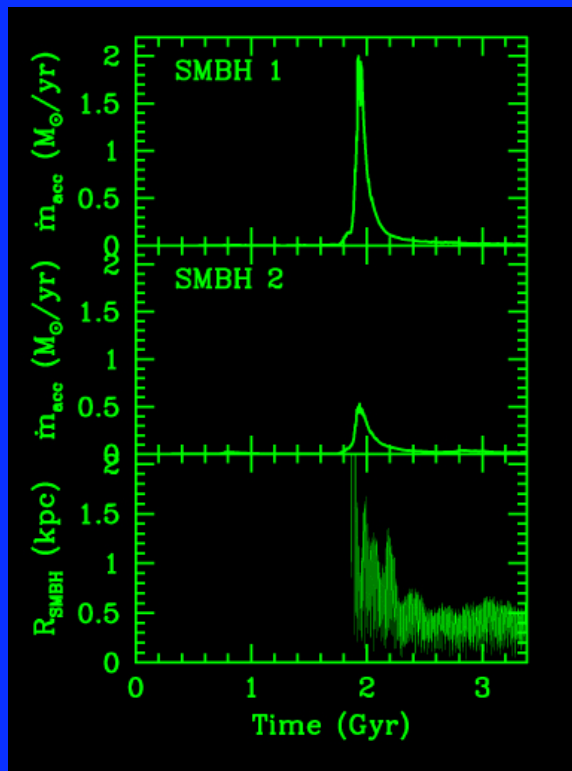


Accretion rate (SMBH1)

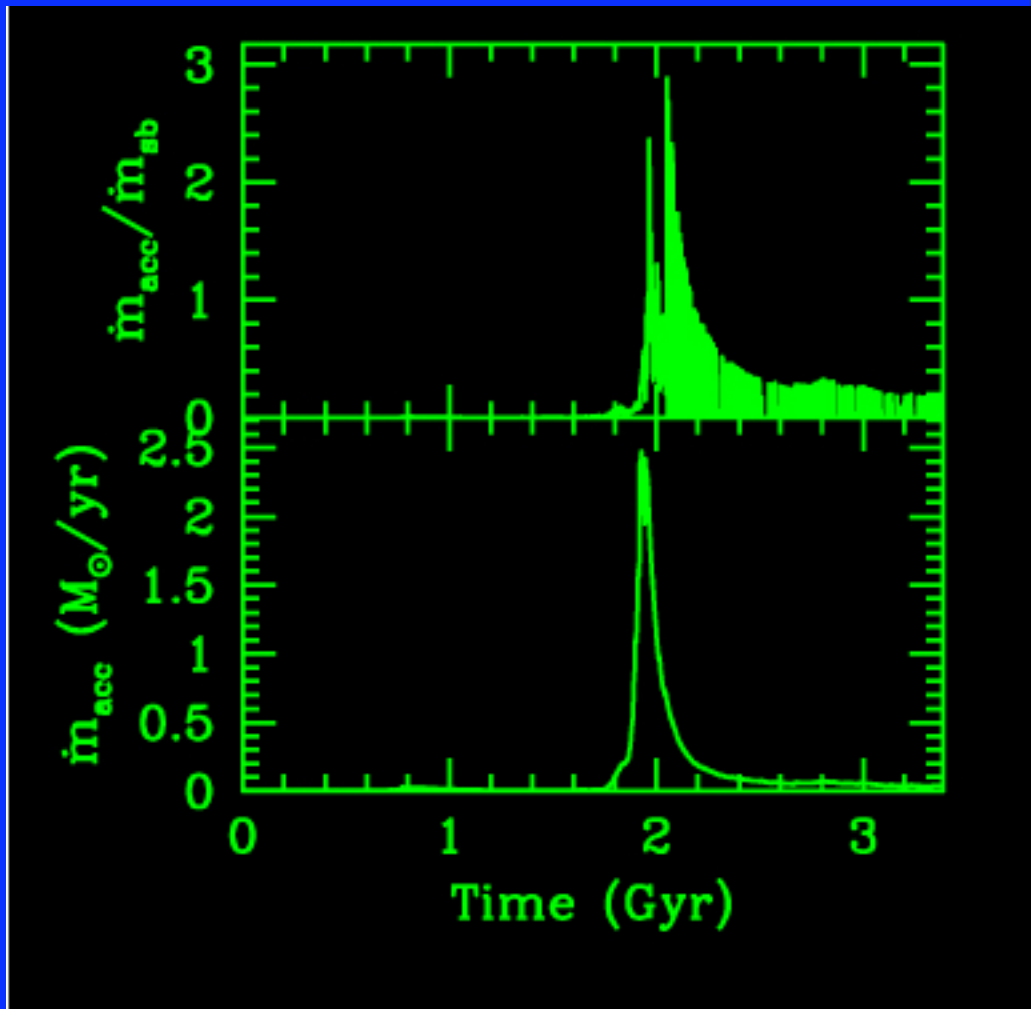
Accretion rate (SMBH2)

Separation of binary SMBHs

Time evolution of the masses of SMBHs.



AGN-dominated mergers.



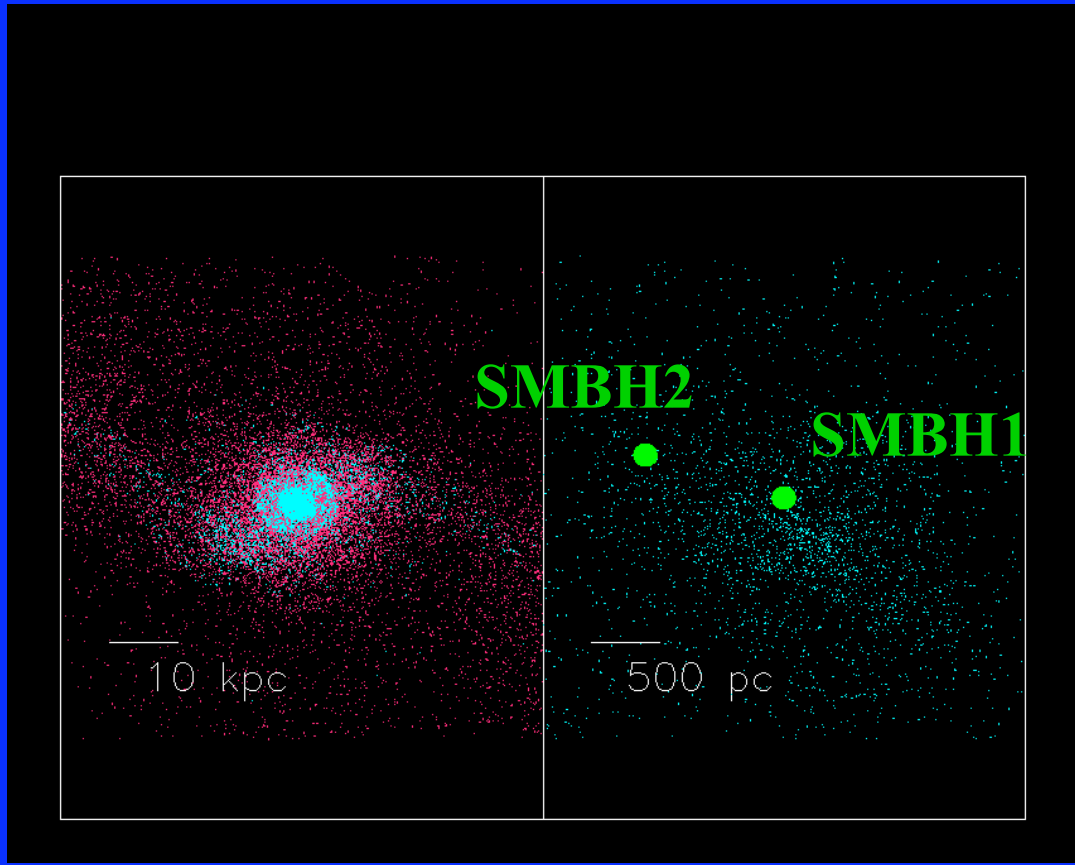
ACR/SFR

ACR

Morphologies of AGN-dominated mergers.

Cyan:
Young stars

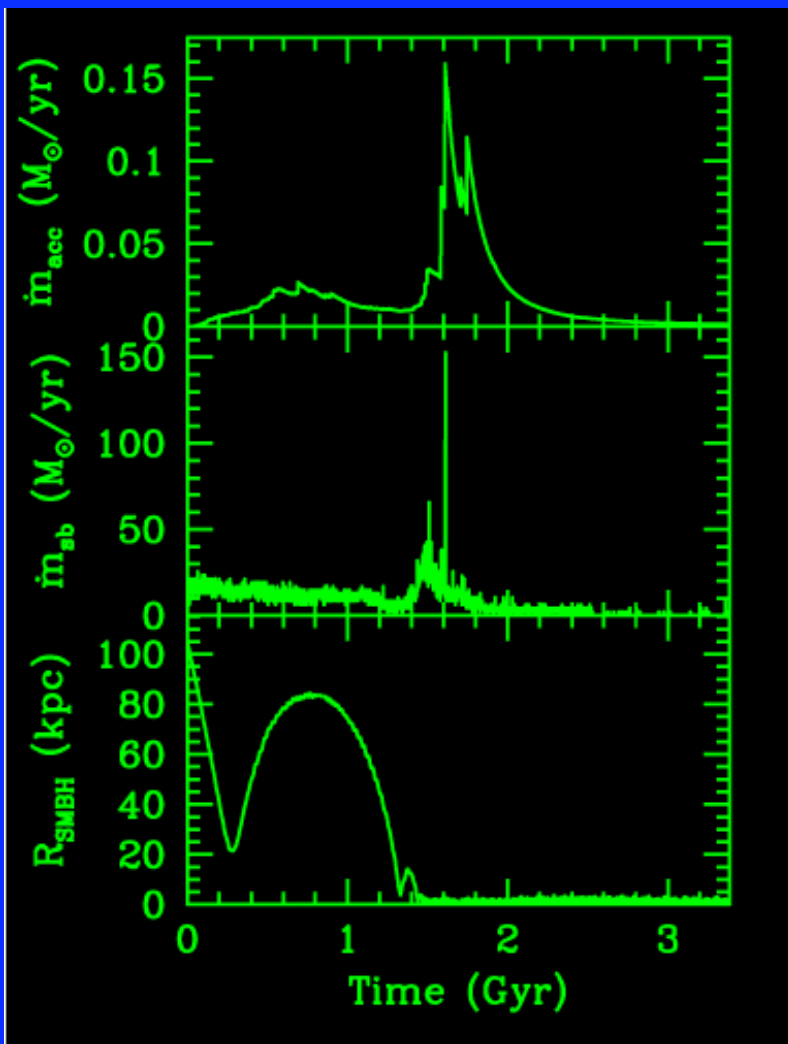
Magenta:
Old stars



70kpc

3.5kpc

SB-dominated mergers. (B/D ratio=0.1, gas fraction=0.5)



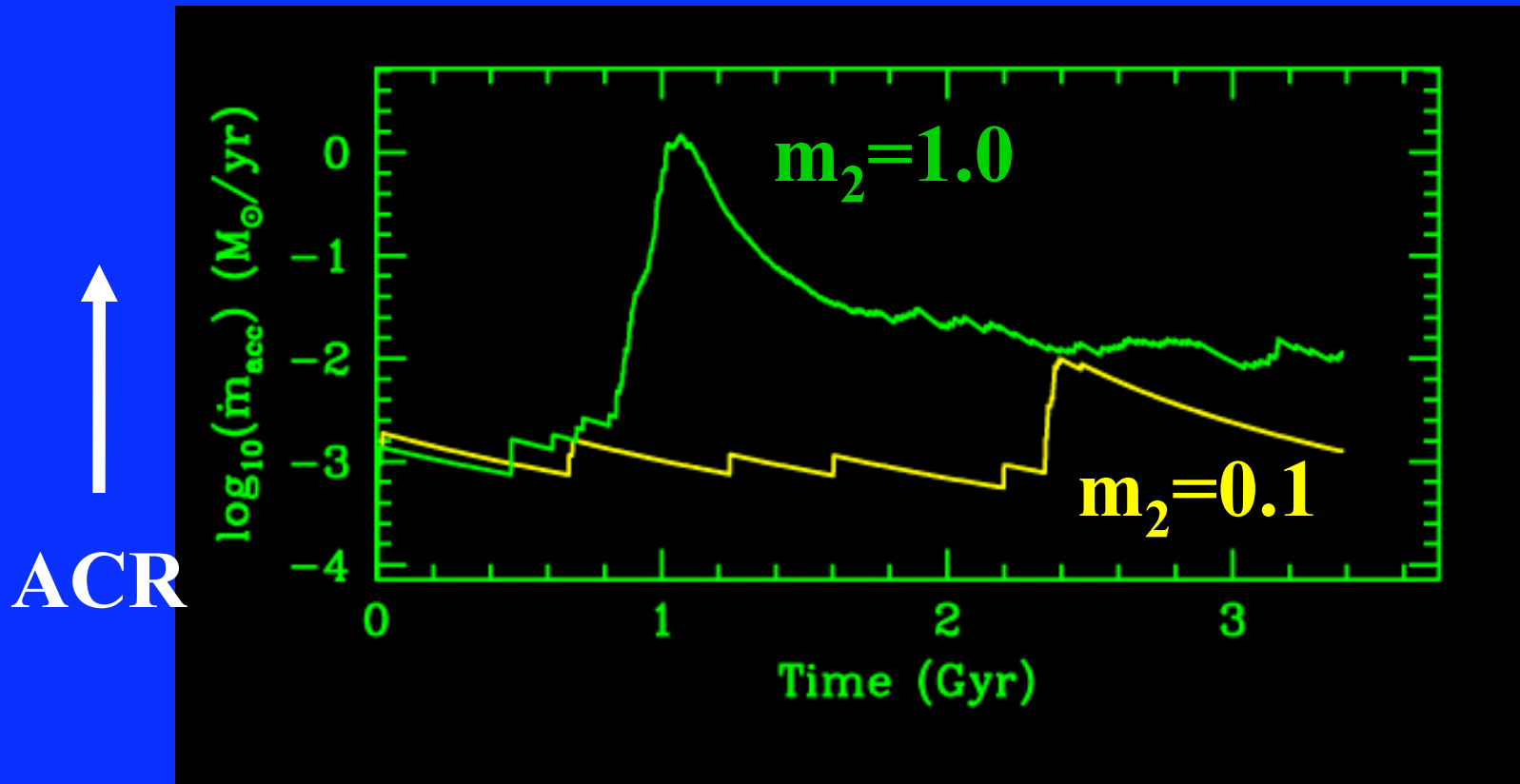
ACR

SFR

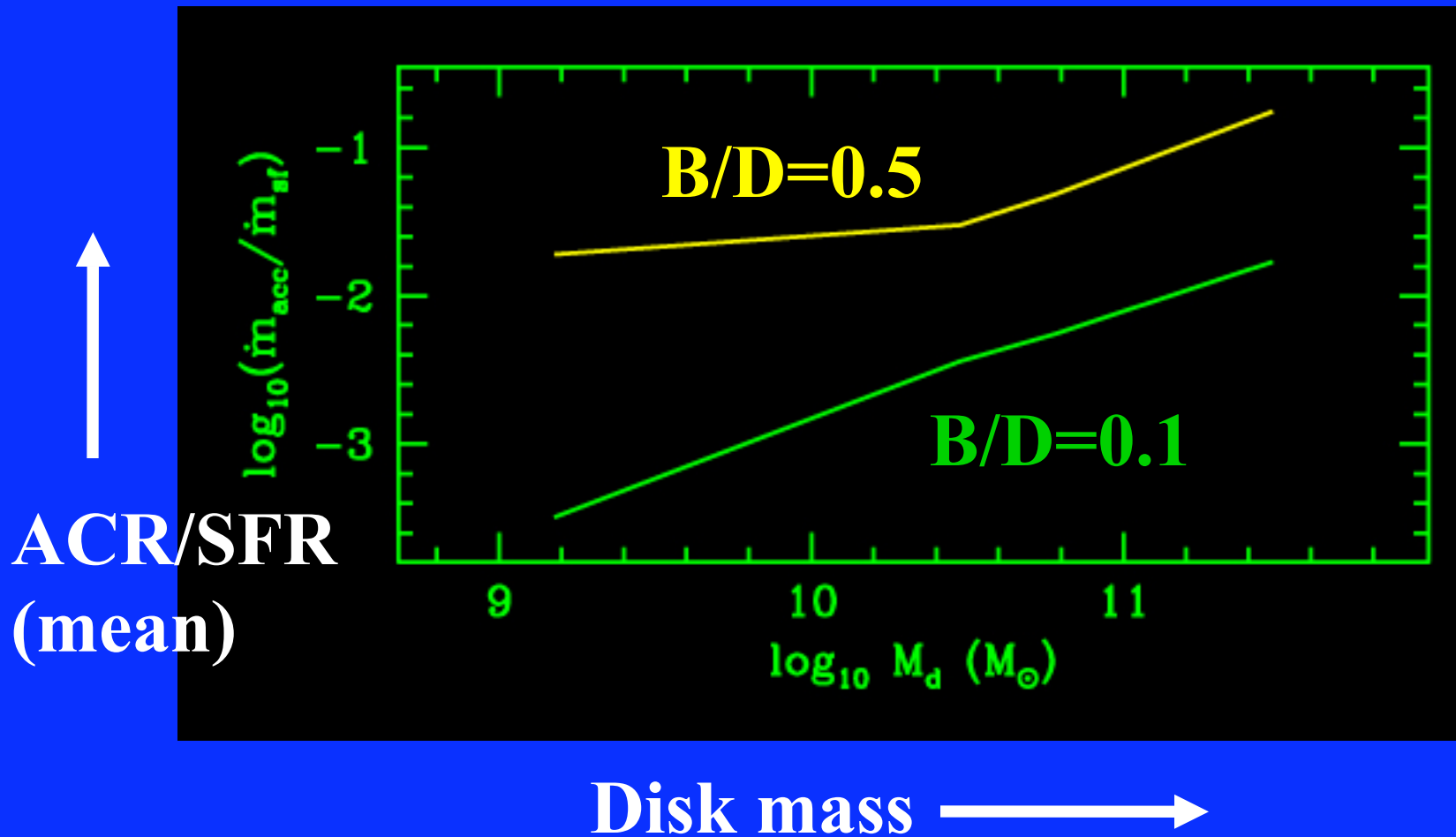
Separation of
two SMBHs

Minor mergers and weak AGNs

Dependence of ACR on m_2 (mass ratio of two spirals).



AGN-dominated in more luminous mergers.



AGN-dominated in more luminous mergers (Why?)

The origin of the dependence of $\dot{m}_{\text{acc}}/\dot{m}_{\text{sb}}$ ($L_{\text{acc}}/L_{\text{sb}}$) on M_{d} .

$$\dot{m}_{\text{acc}} \propto \dot{m}_{\text{Edd}} \propto M_{\text{BH}} \propto M_{\text{bul}} \propto M_{\text{d}}, \quad (1)$$

where \dot{m}_{Edd} is the Eddington accretion rate.

$$\dot{m}_{\text{sb}} \propto \mu_{\text{g}}^{1.5} \propto M_{\text{d}}^{0.75}, \quad (2)$$

for $\mu_{\text{g}} \propto \mu_{\text{s}} \propto M_{\text{d}}^{0.5}$ (Kauffmann et al. 2003).

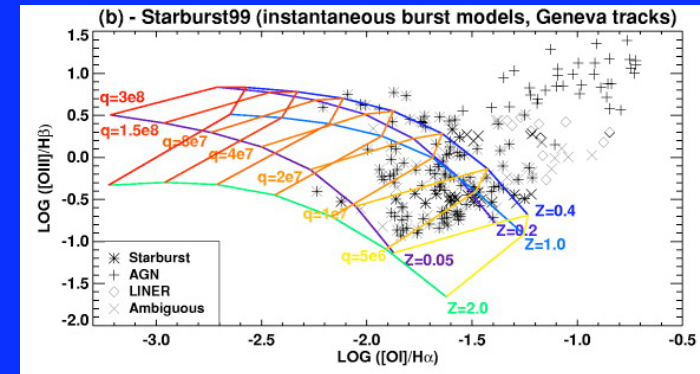
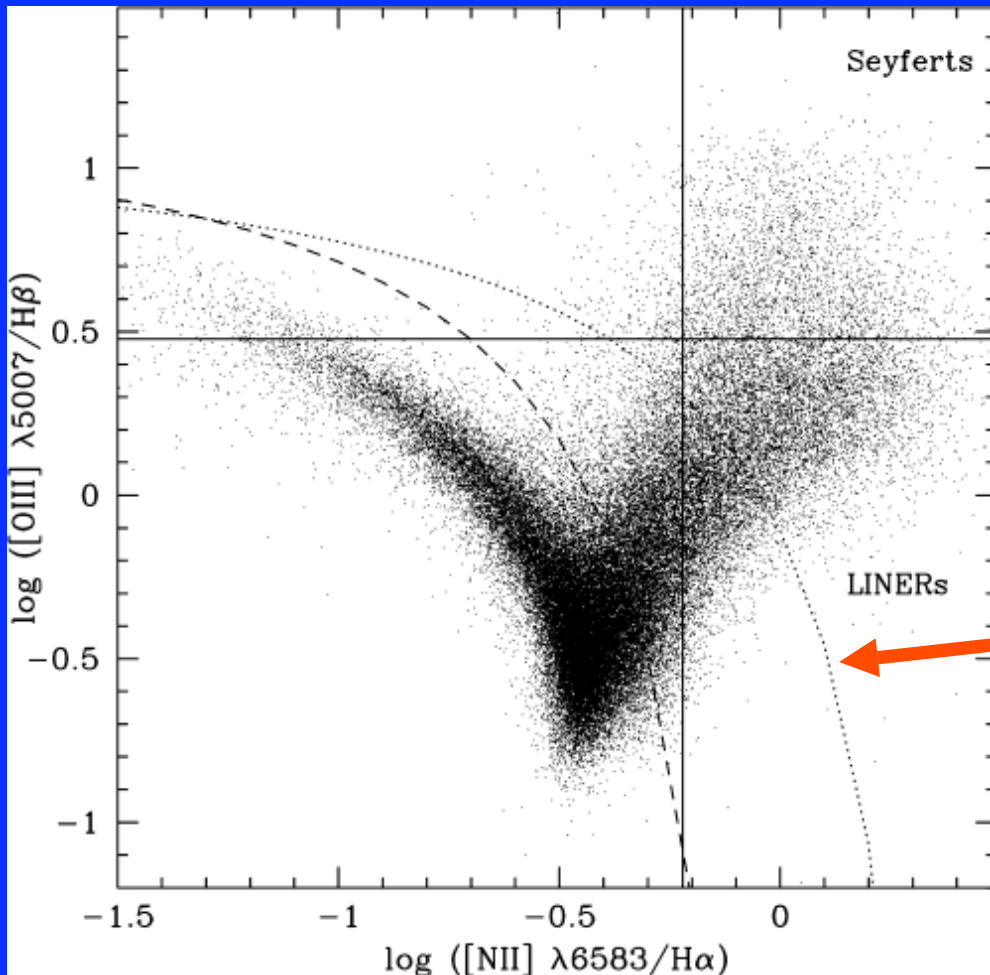
From (1) and (2),

$$\frac{L_{\text{acc}}}{L_{\text{sb}}} \propto \frac{\dot{m}_{\text{acc}}}{\dot{m}_{\text{sb}}} \propto M_{\text{d}}^{0.25} \quad (3)$$

Parameter dependences.

- (1) Mergers between spirals with big bulges are more likely to become AGN-dominated.
- (2) ACR/SFR are both smaller for mergers with smaller gas mass fraction and smaller mass ratios of merging two spirals.
- (3) Less luminous mergers are likely to become SB-dominated.

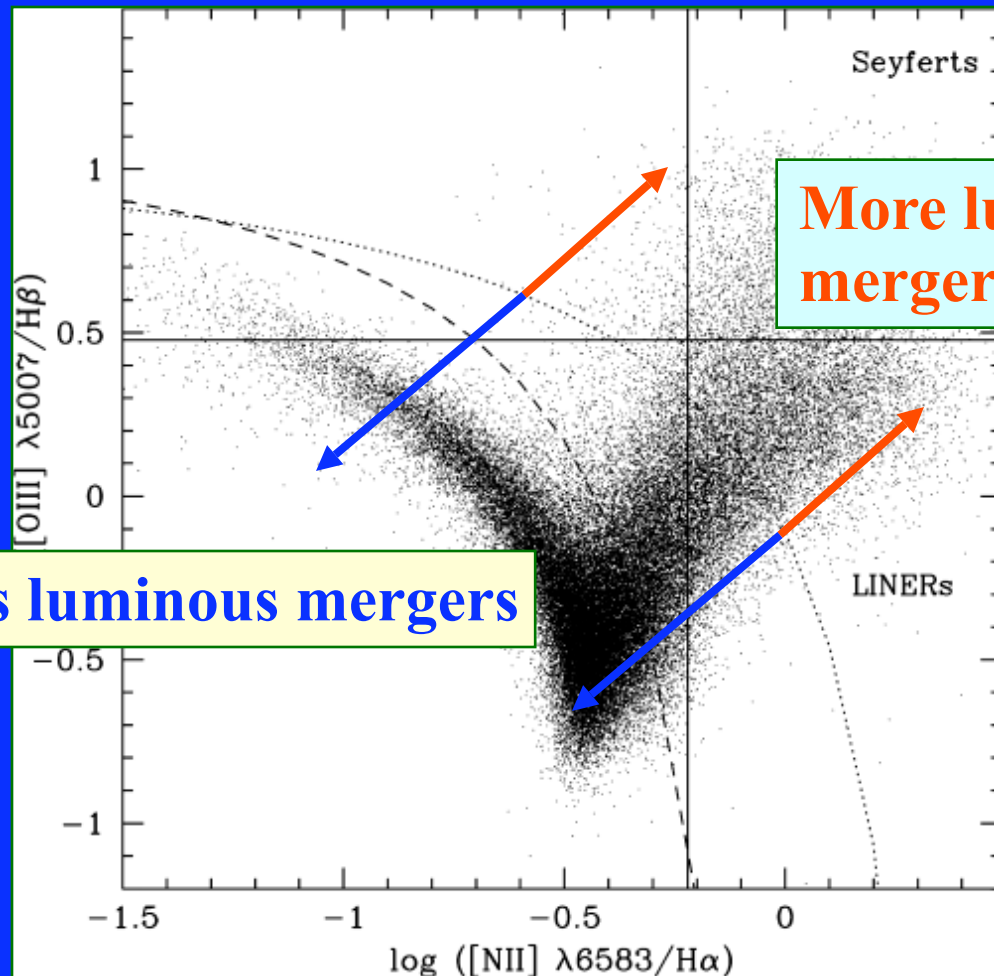
Discussions: Implications on recent observational results.



(Kewley, Dopita,
Sutherland, Heisler 2001)

SDSS AGN survey (Kauffmann et al. 2003)

AGN-dominated in more luminous mergers ?



Less luminous mergers

More luminous mergers

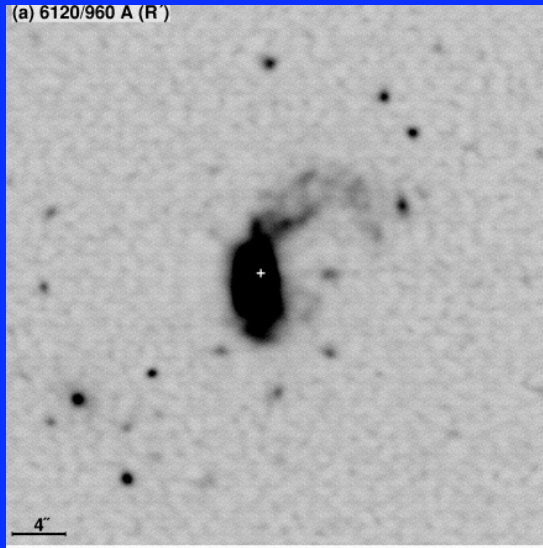
SDSS AGN survey (Kauffmann et al. 2003)

Evolution from ULIRGs to QSOs ?

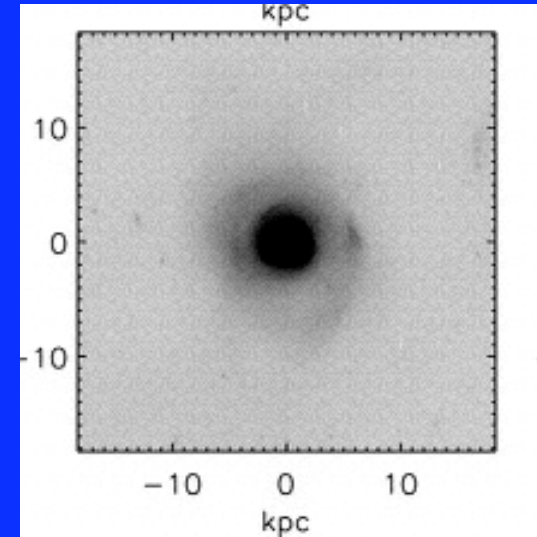
If structural parameters of ULIRGs are consistent with those of L_* ellipticals (Tacconi et al. 2002), then

- ULIRGs are more likely to be dominated by starbursts.
- Most of them are less likely to evolve into QSOs.

From Q+A to E+A ?



“Q+A” (Canalizo & Stockton 2000)



“E+A” (Yang et al .2004)

- Are there any differences in host properties (e.g., core structures and radial gradients of Balmer absorption lines) between the two ?

Conclusions.

- Coexistence of SB and AGN in forming elliptical galaxies.
- Relative fraction of AGN to SB emission depends on galaxy parameters.
- Not all of ULIRGs can evolve into QSOs.