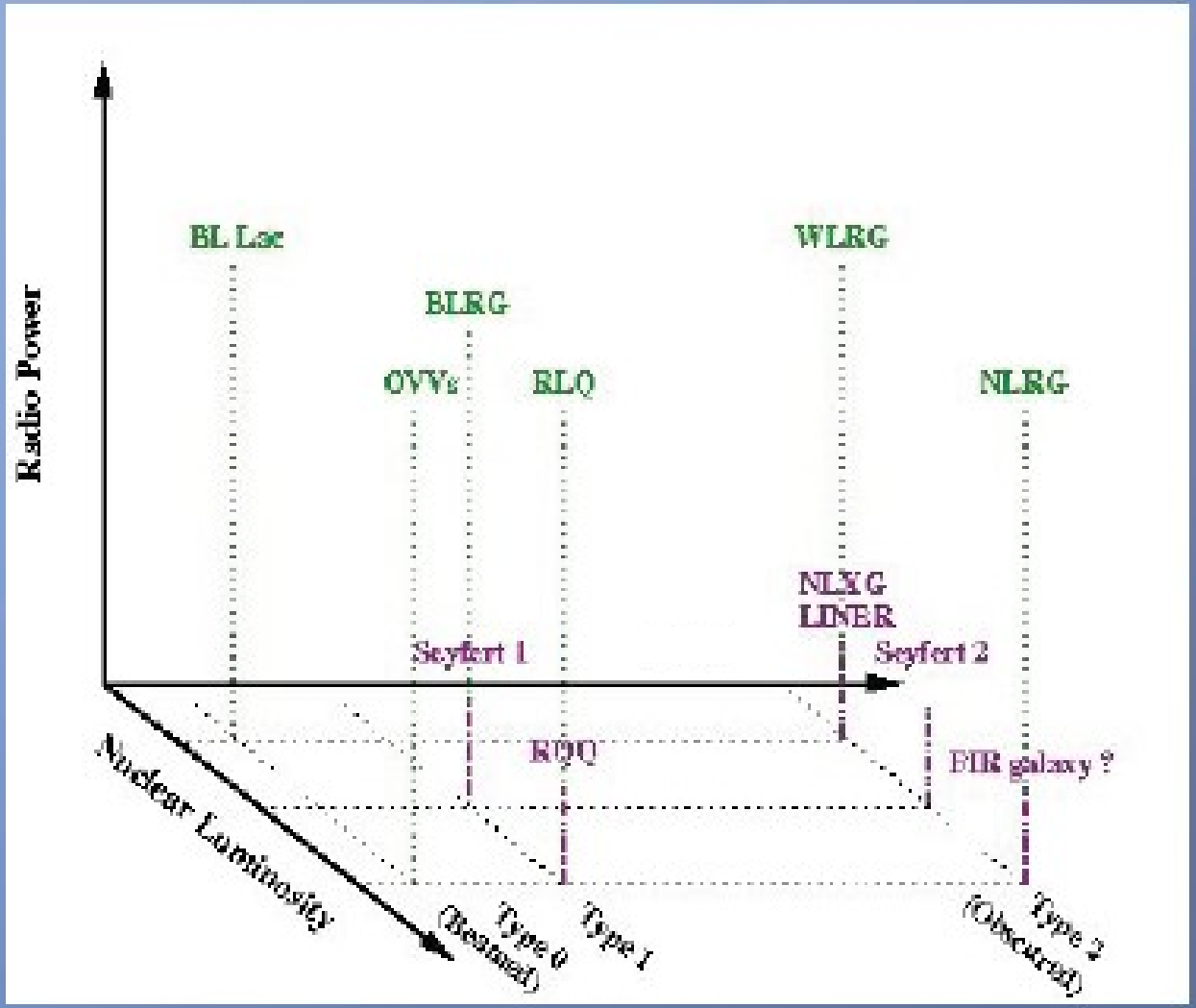
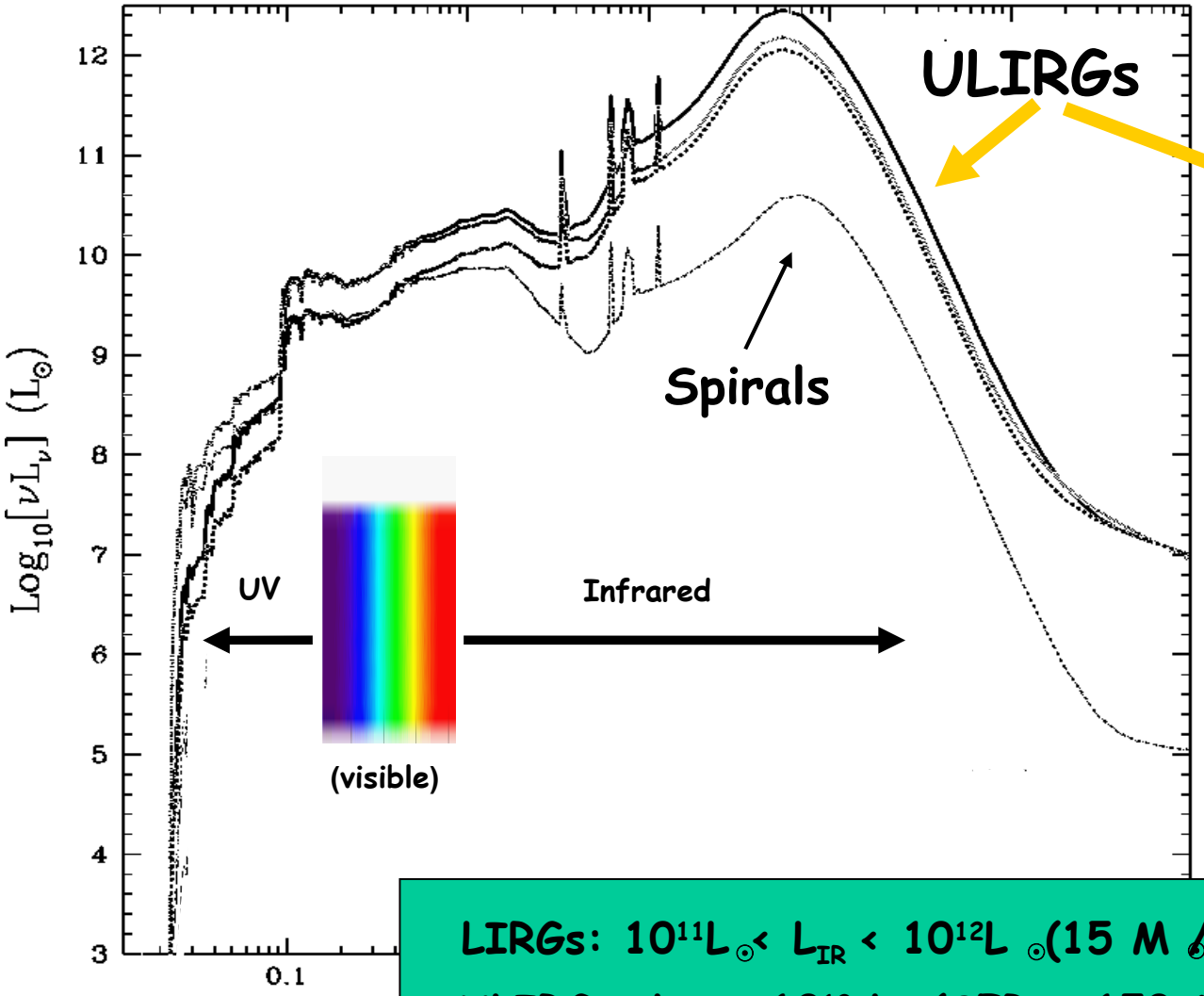
AGN Classification

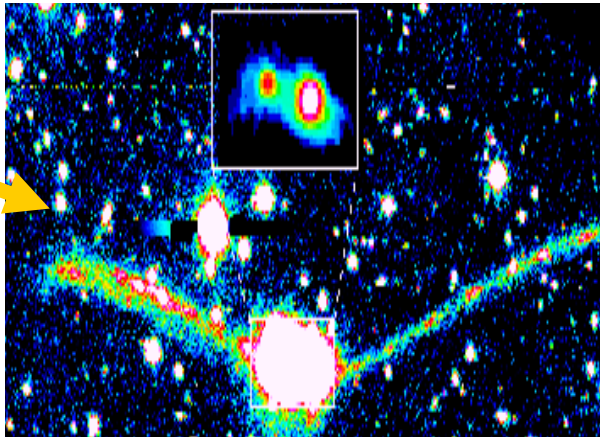


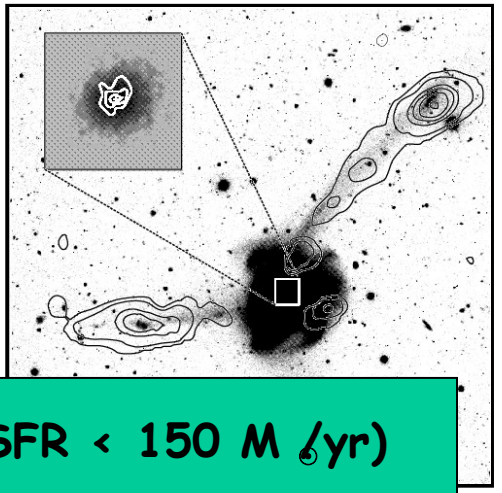
LINERs

- Low-Ionization Nuclear Emission Region
- Narrow low-excitation emission lines
- Weak nonthermal continuum
- Spiral host galaxies
- Observed emission could be due to AGN or shocks/winds from a *starburst*
- Some appear as unresolved compact sources in the UV
- Some have radio sources: AGN or supernovae remnant?

ULIRGs at low redshift







(Adapt. Devriendt et al. 1999)

LIRGs: $10^{11} L_\odot < L_{IR} < 10^{12} L_\odot$ (15 $M_\odot$/yr < SFR < 150 $M_\odot$/yr)

ULIRGs: $L_{IR} > 10^{12} L_\odot$ (SFR > 150 $M_\odot$/yr)

Mergers triggering SF/AGN

LIRGS

LIRGs: Luminous Infrared Galaxies; emit up to 90% of their bolometric luminosity ($L_{bol} \sim 10^{11} L_{\odot}$) in the IR. Most found in interacting/merging galaxies which are rich in molecular gas.

LIRGs either

- starburst galaxies where the starbursts occur in dense molecular clouds which heats dust which re-radiates the stellar flux in the IR
- or possibly a newly formed AGN which is swallowing lots of molecular gas, producing high IR luminosity
- ULIRGs: can have as much luminosity as a low-luminosity AGN

ULIRG's - Ultra Luminous IR Galaxies

- First detected in IRAS all-sky survey
- Galaxies that emit most of their light in IR - $L_{IR} > 10^{12} L_{sun}$
- Few in local universe; most beyond z > 1
- Nearly all are undergoing mergers - forming E's
- **IR light is likely a combination of dust reprocessed AGN emission and starbursts.**
- Some AGN may manifest as ULIRGs during different stages of evolution.

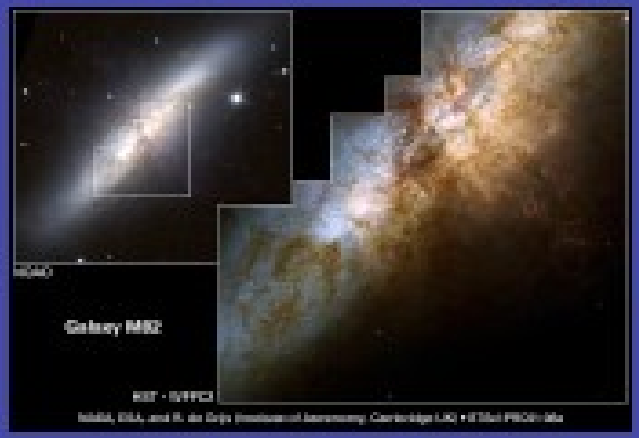
Nicmos Near-IR Image of IRAS selected ULIRG

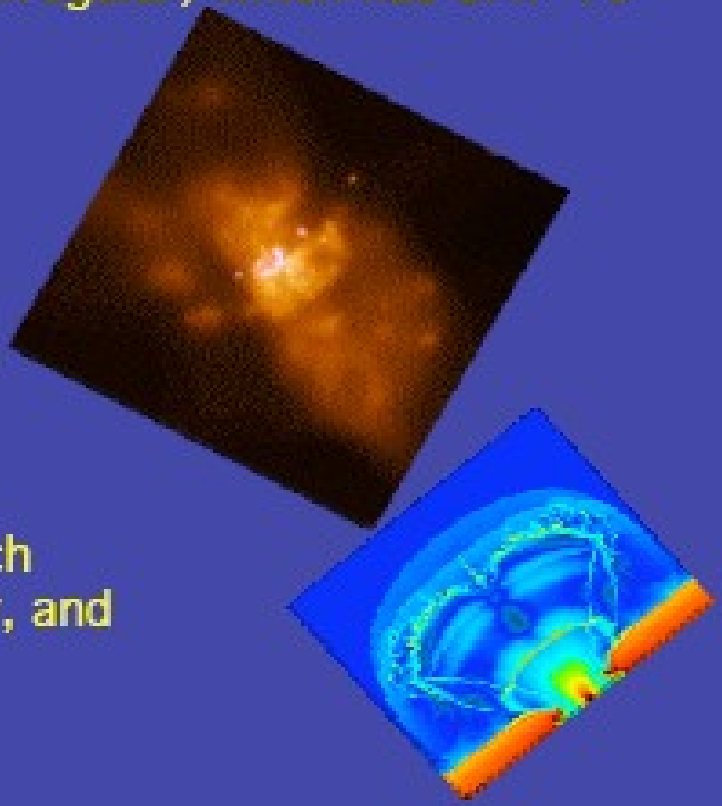
Starburst galaxies

- Stars are forming in our galaxy
  - Star formation rate: $R_* \sim 1$ star / year
- In some galaxies $R_* \sim 100$ stars / year
  - Known as starburst galaxies
- Often have double nuclei
- Likely explanation: A collision of two spiral galaxies
  - Why spirals?
    - Need gas / dust for star formation

M82: Canonical Starburst

M82 is an irregular galaxy (a "disk" irregular) which has SFR~10 SFR_{MW}.





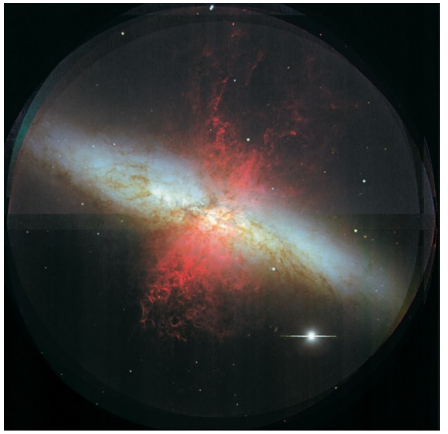
Rapid SF produces lots of SNe which can blow a hole through the galaxy, and feed the IGM.

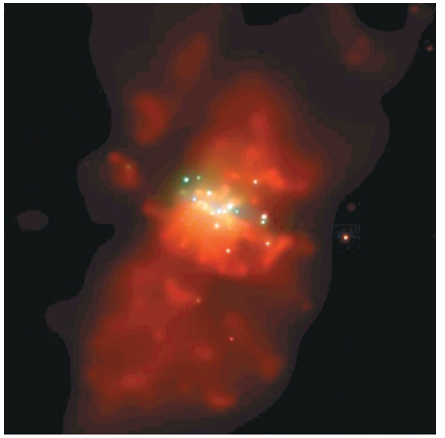
Astronomy 191 Space Astrophysics

exists in M82. A broad iron line emission was found, which is similar to other LLAGNs. ... adsabs.harvard.edu/abs/2001AIPC..599..758M

Starbursts Due to Galactic Collision

- Computer models suggest that galactic collision should ignite huge bursts of rapid star formation – so rapid that ***all the cool gas would be quickly transformed into stars, leaving little leftover to form a disk***.
- Some galaxies are observed to be in the midst of rapid star formation, **<u>at the rate of 100 star births per year or more –</u>** ***starburst galaxies.***
- The giant hot bubble formed by continuous supernovae can erupt into intergalactic space, forming a ***galactic wind***





AGN-Starburst connection

Concentrated nuclear starburst (cf. the Arches, Quintuplet clusters in the MW) might help form/feed SMBH:

- star formation produces stellar mass black holes which grow by collision/accretion
- explosions may trigger more star formation
- Galaxy mergers: drive gas towards the center of the galaxy, producing star formation and feeding BHs.
- Mergers more common in early Universe?

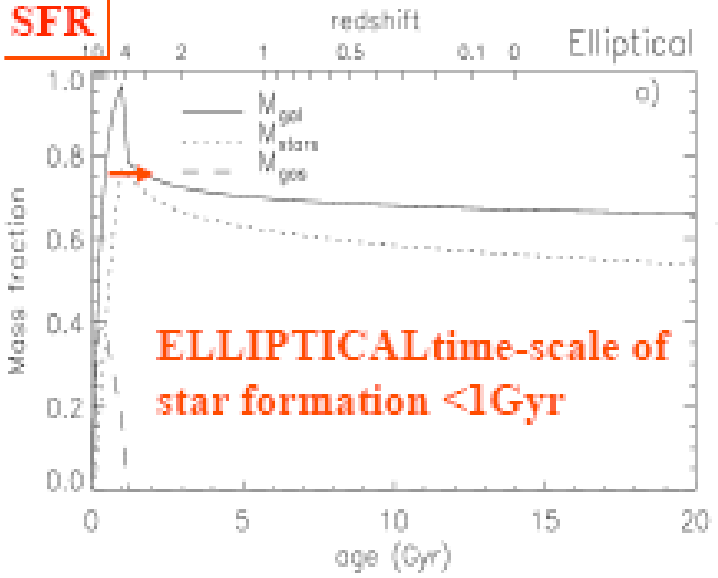
EVOLUTION SCENARIOS BY TYPE (SFR, winds, accretion)

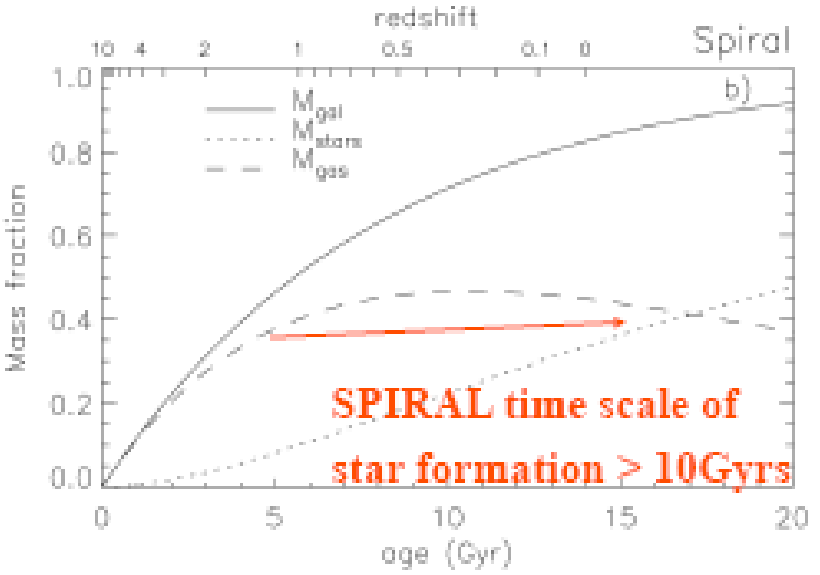
- Fioc & Rocca-Volmerange, 1997, 1999 (PEGASE code)
- Le Borgne, Rocca-Volmerange, Fioc, 2002 (phot z code Z-PEG)

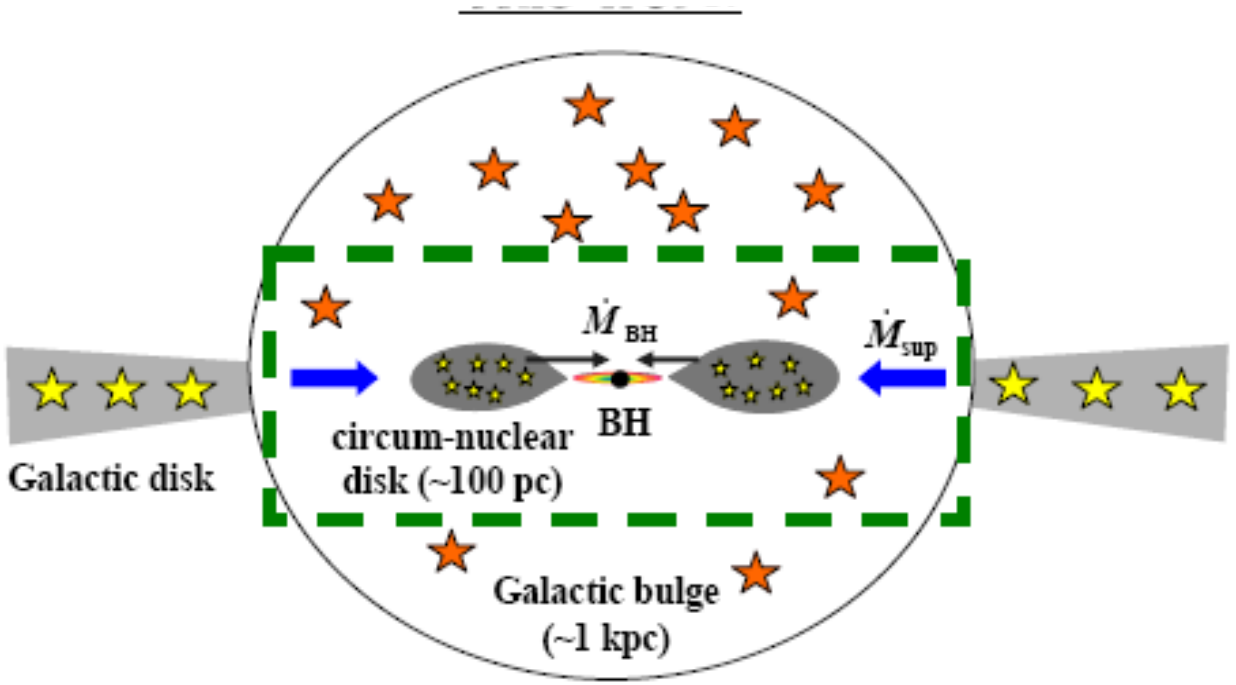
Elliptical galaxy

Spiral Galaxy

SFR

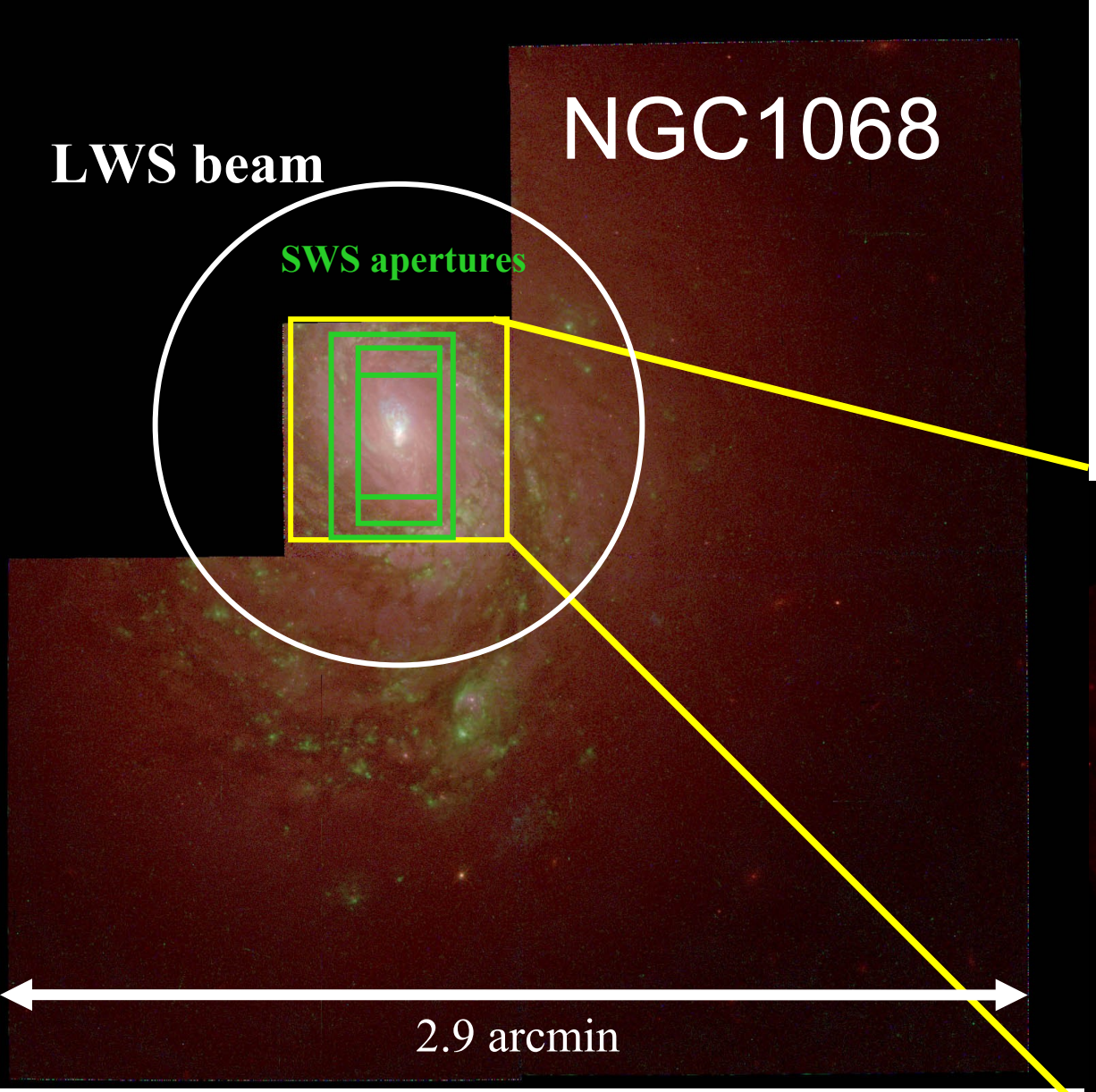






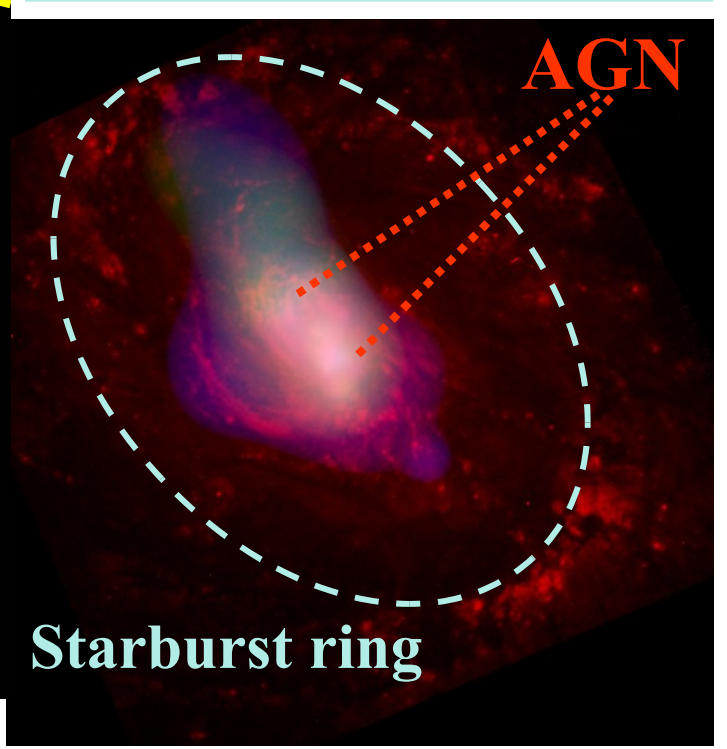
We focus on the mass accretion from the outskirts of a circum-nuclear disk into a SMBH, considering the mutual connection between the mass-supply from hosts and physical states of the disk accompanied with SF consistently.

http://www.astro.noa.gr/xray07/rodos-talks/Kawakatu_SMBHgrowth.pdf



CHANDRA image overlayed on a HST image (X-ray: green 0.4-0.8 keV, blue 0.8-1.3 keV; optical: red)

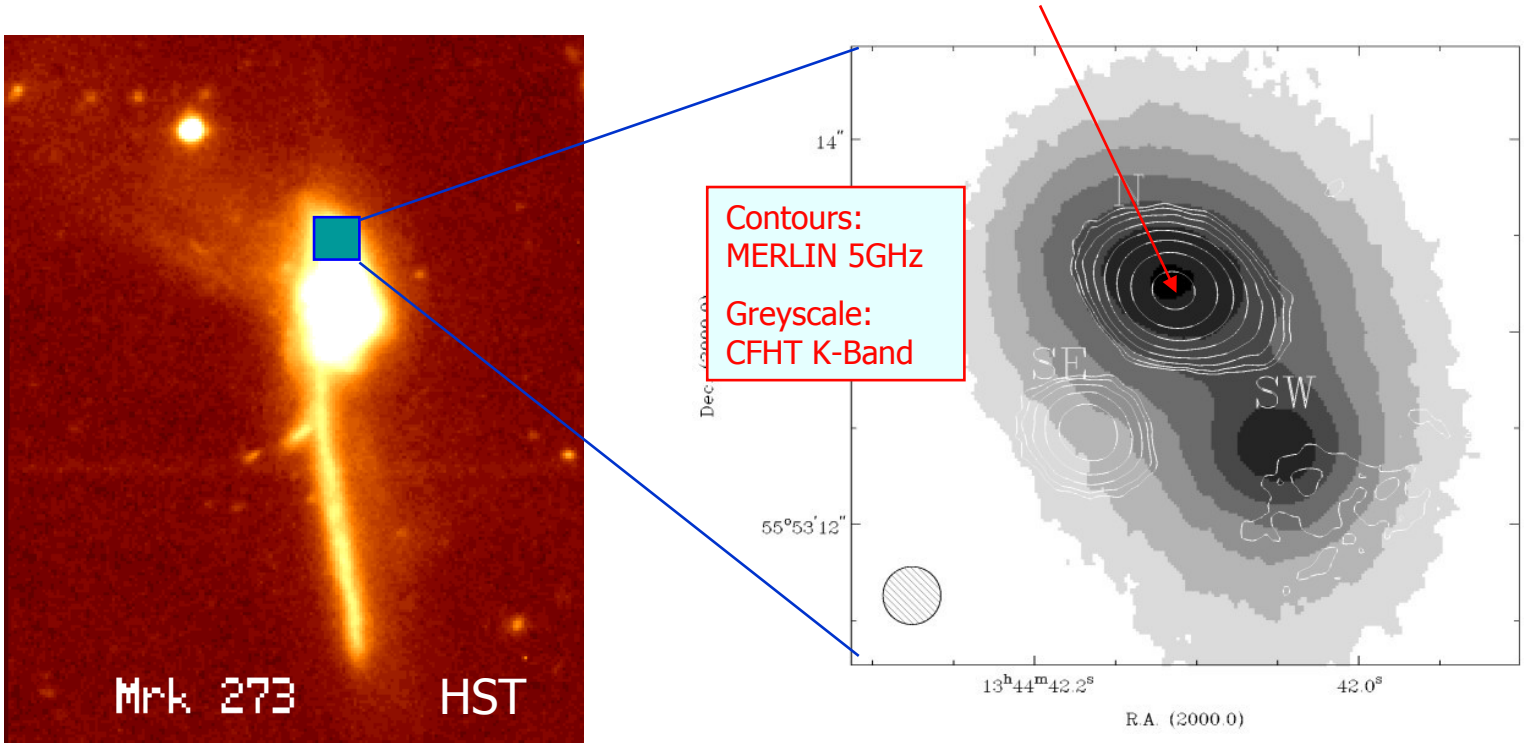
X-ray: P.Ogle et al.; Optical: A.Capetti et al.



HST three-colour image of the WFPC2 camera ([OIII], Hα+[NII], wide-band 791nm filter)

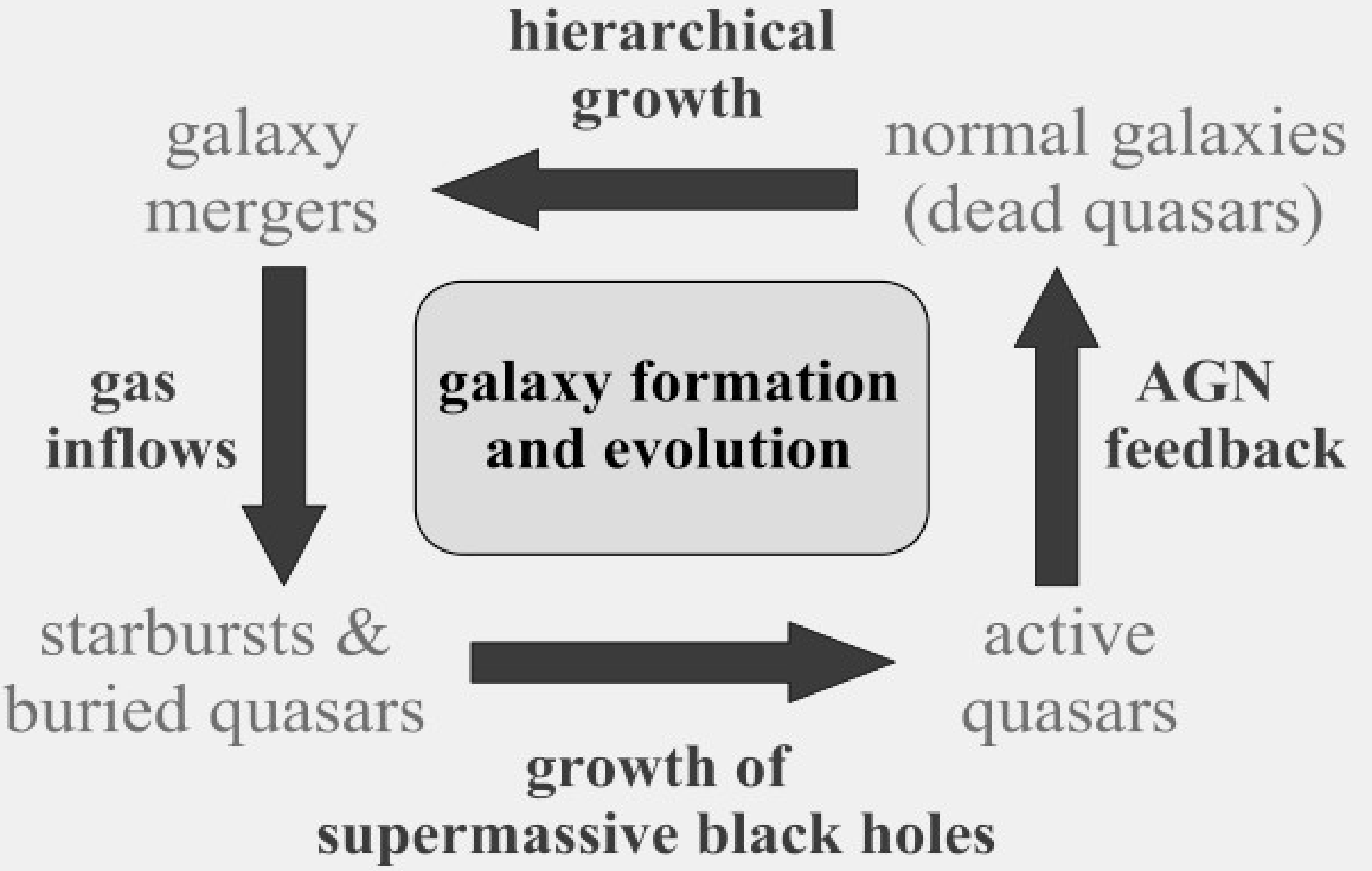
Starbursts can have embedded AGN

- Often the AGN is obscured and may only contribute a small proportion of the total flux density
  - eg ULIRG Mkn273 – twin merging nuclei Knapen et al 1997
    - Flat spectrum radio component detected

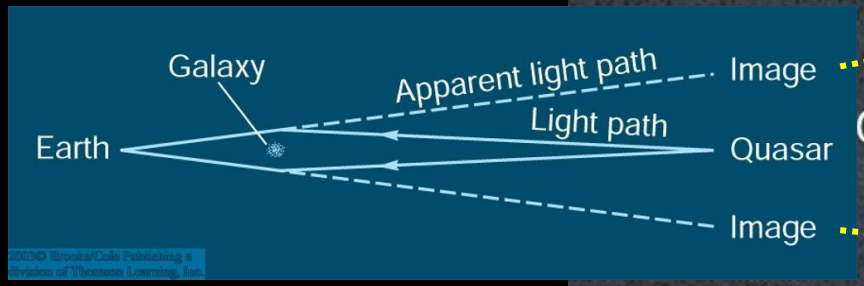


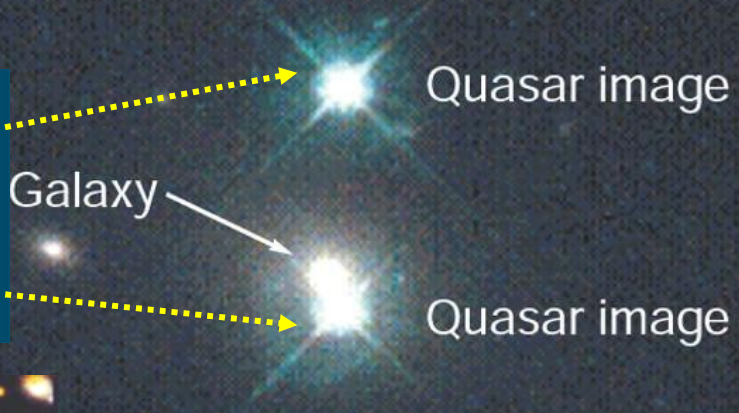
• First quasars forms together
with first galaxies.

• AGN activity is linked to the onset of
and quenching of the starformation
in merging systems.


hierarchical growth
galaxy mergers
normal galaxies (dead quasars)
gas inflows
galaxy formation and evolution
AGN feedback
starbursts & buried quasars
active quasars
growth of supermassive black holes

Probing Dark Matter with High-z Quasars:
Gravitational Lensing



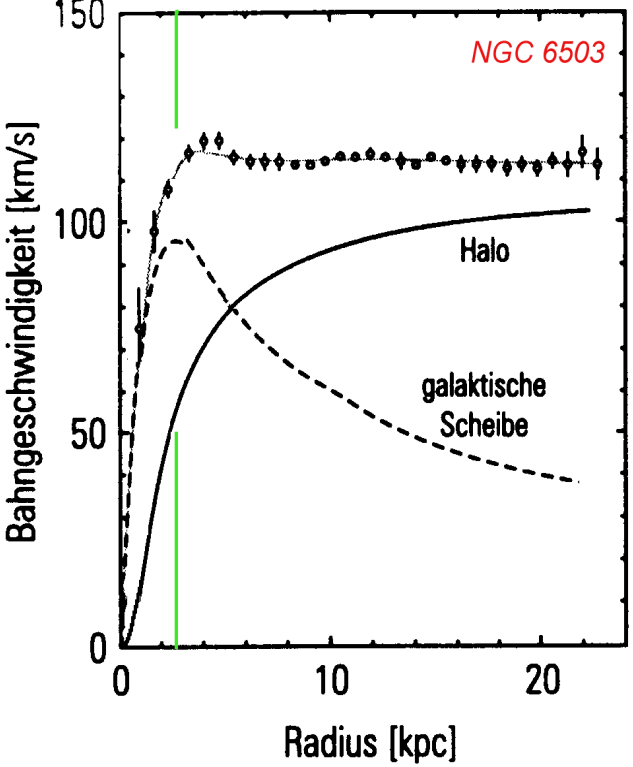


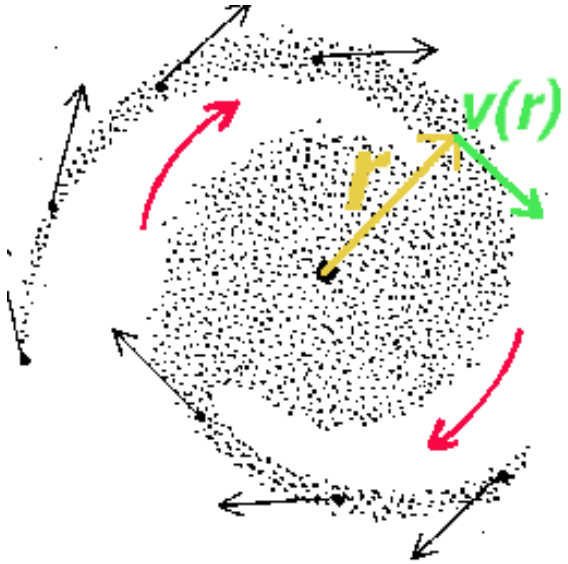
Light from a distant quasar is bent around a foreground galaxy

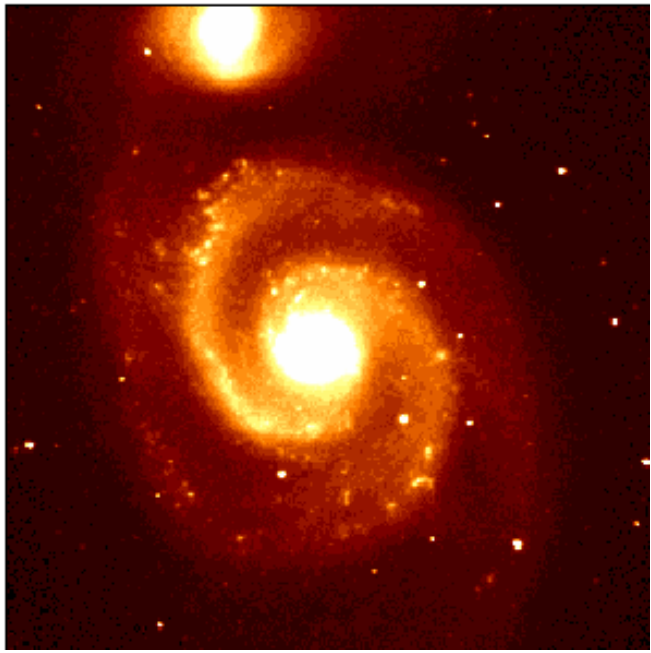
→ two images of the same quasar!

Light from a quasar behind a galaxy cluster is bent by the mass in the cluster.

Use to probe the distribution of matter in the cluster.

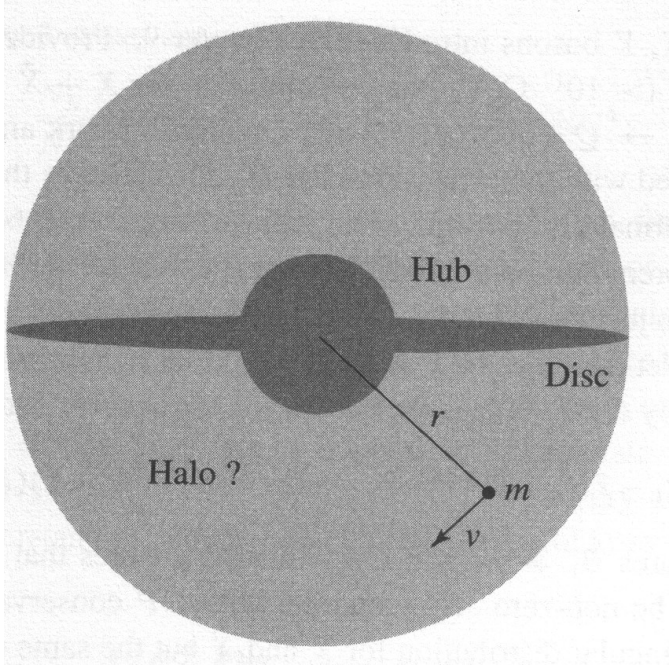


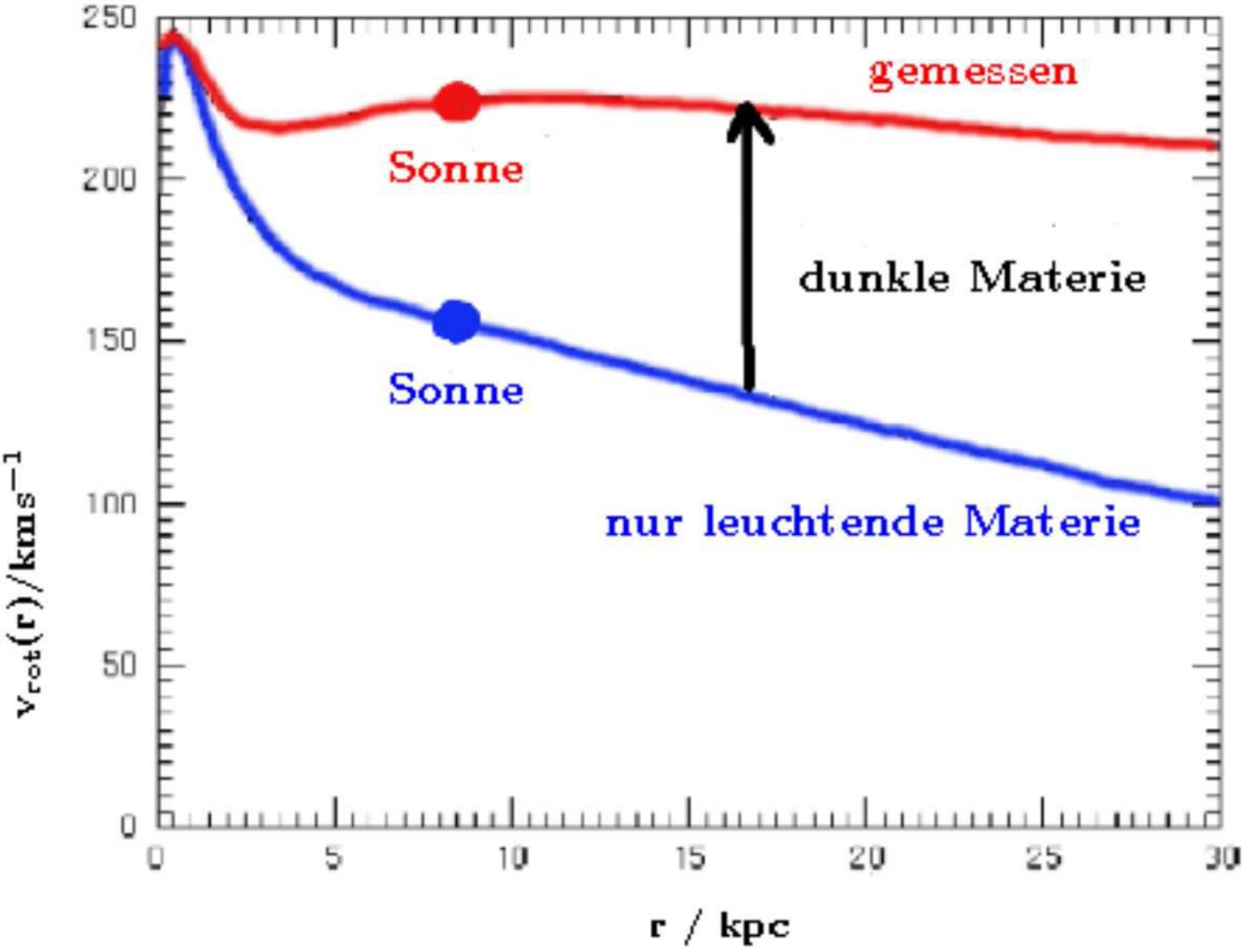




Dark matter: form of matter that is undetectable by its emitted radiation, but whose presence can be inferred from gravitational effects on visible matter.

Rotation curve of a typical spiral galaxy: If the motion was entirely Keplerian (i.e. classical circular orbits around a central mass) the rotational velocity would decrease with a R-½ dependence. The lack of decline with distance suggests that not all the mass is in the center of the Galaxy. Dark matter **halo** can explain the velocity curve having a 'flat' appearance out to a large radius

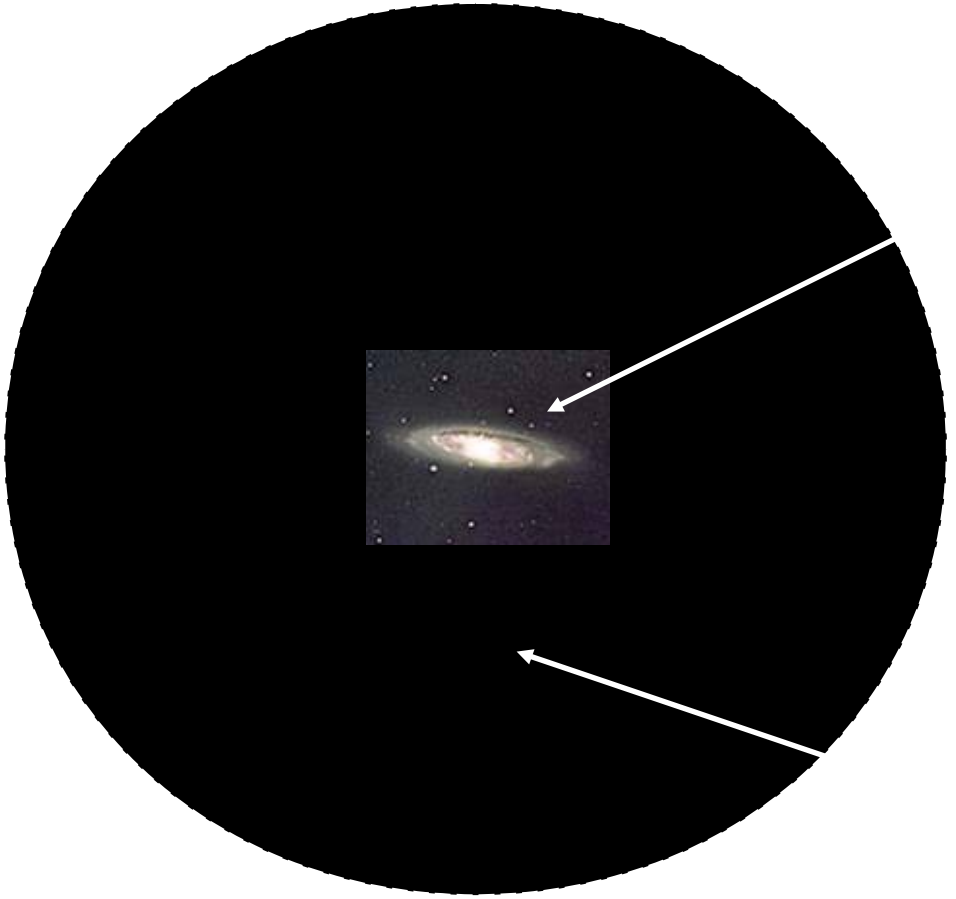



250
200
150
100
50
0
0
5
10
15
20
25
30
gemessen
Sonne
dunkle Materie
Sonne
nur leuchtende Materie
$v_{rot}(r)/kms^{-1}$
r / kpc

Dark Matter Halos I

Galaxy ≈ Stars + Gas + Dust +
Supermassive Black Hole + Dark Matter

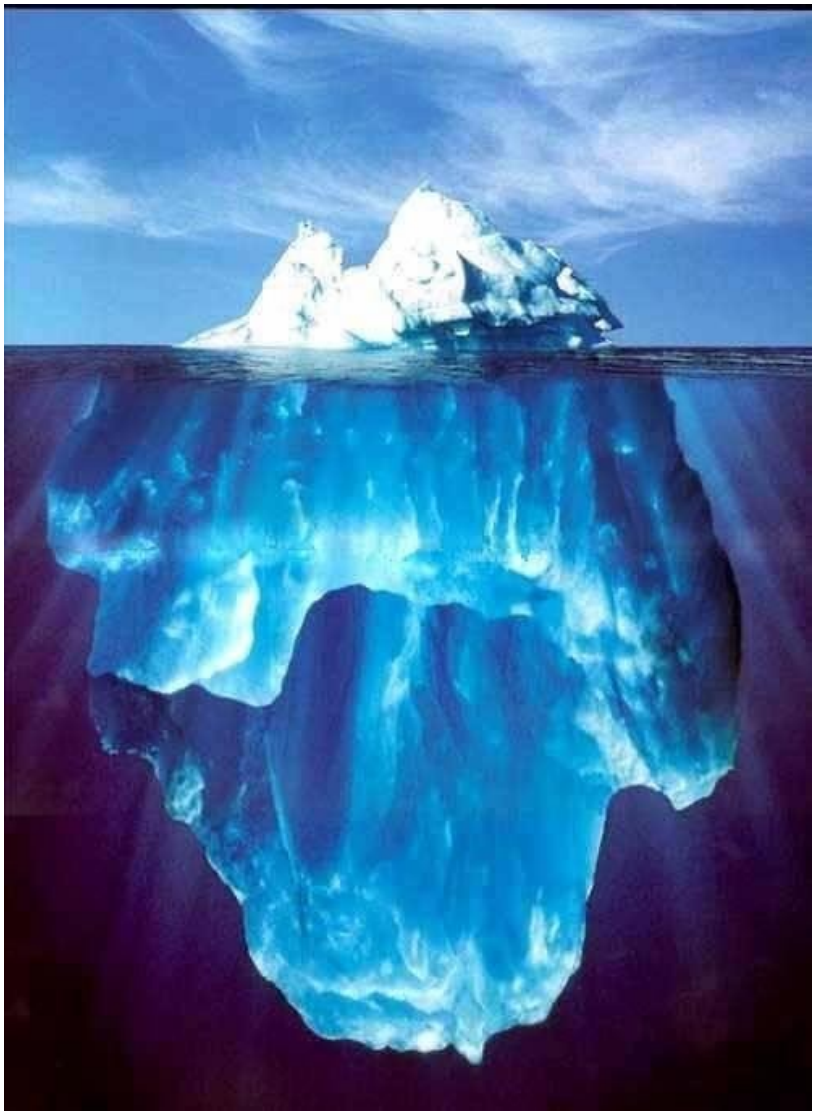
Dark Matter Halos II



Luminous galaxy

Dark halo

The Dark Matter Problem



~2%
(Luminous)

~98%
(Dark)

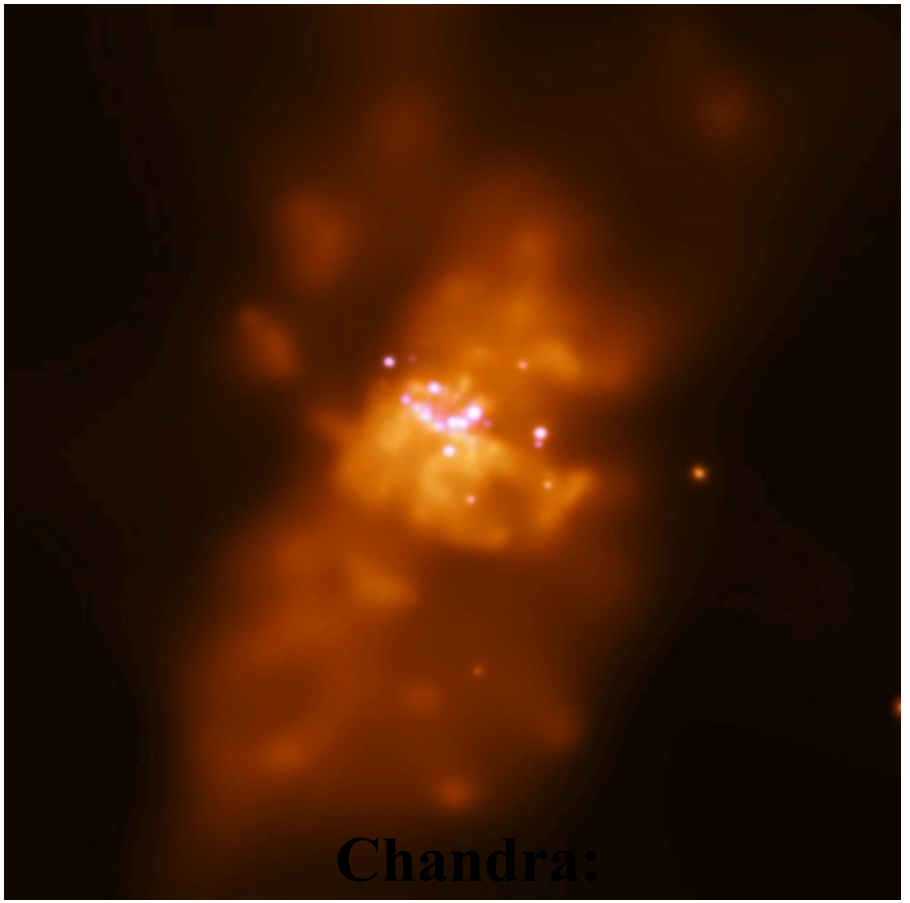
www.astro.isas.ac.jp/conference/bh2003/program/ppt/20031029am/KyotoBH2003_Falcke.ppt

Ultra-Luminous X-ray Sources
Are there microblazars?

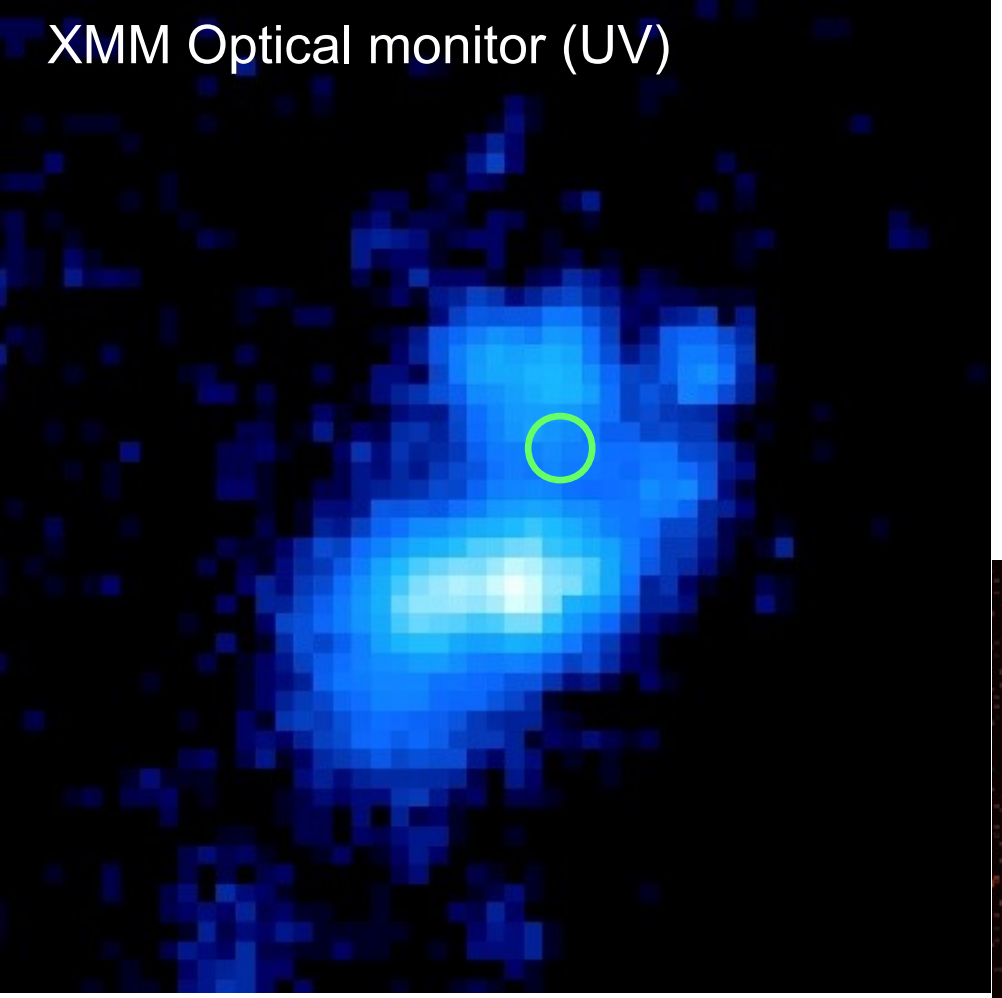
- Claim: jets in X-ray binaries produce X-rays

⇒Some X-ray binaries must be beamed microblazars (Mirabel & Rodriguez 1999)

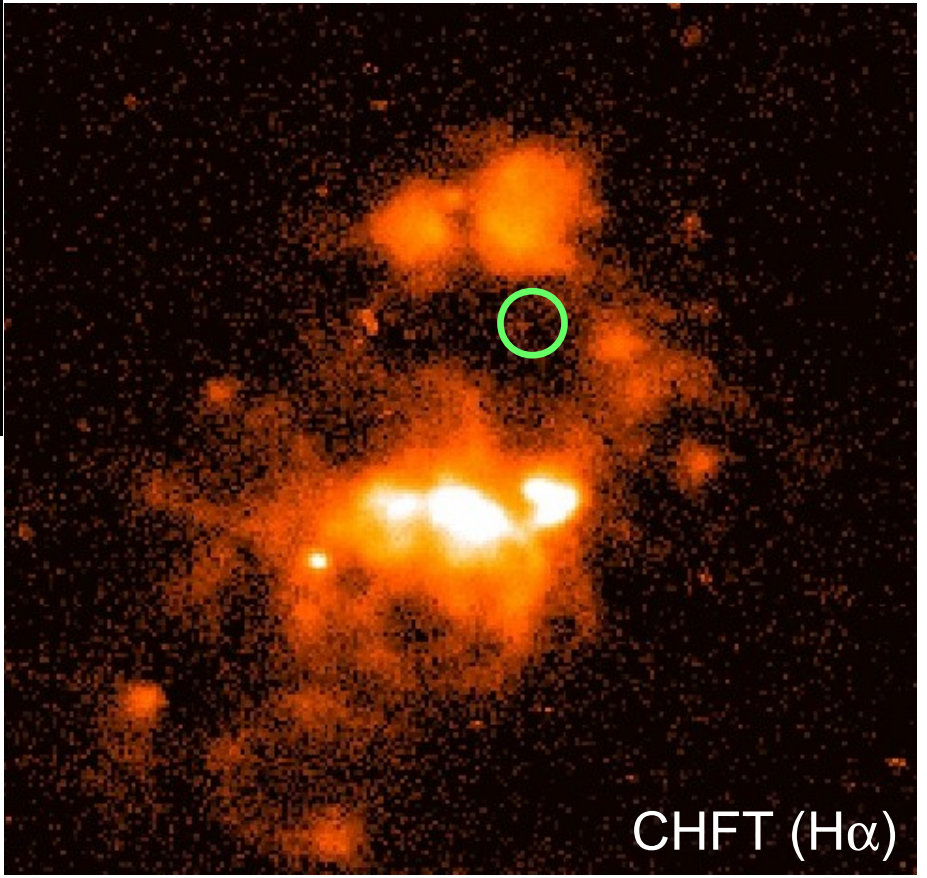
⇒Check with X-ray point sources in nearby galaxies (ULX)



M82

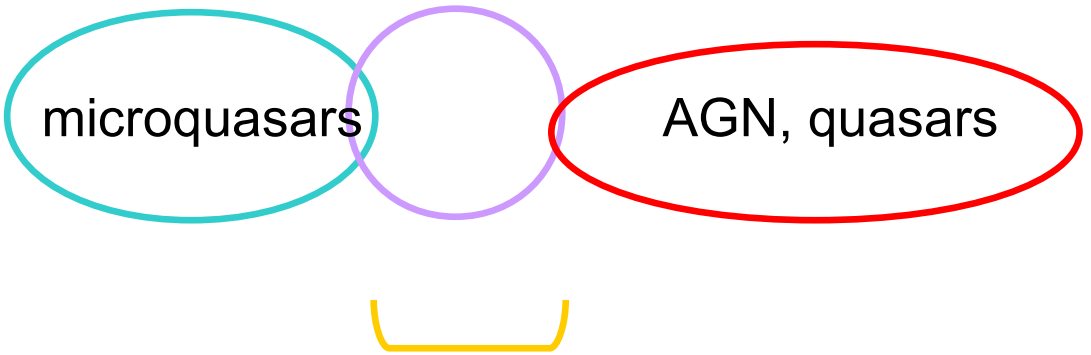


This ULX is in a large star-forming complex at the outer edge of the spiral galaxy



Brightest ULX in NGC 4559

$L_x \sim 3\ 10^{40}$ erg/s


microquasars
AGN, quasars
Intermediate-mass
BHs (“milliquasars”)?