# *Observing the Formation of Dense Stellar Nuclei at Low and High Redshift (?)*


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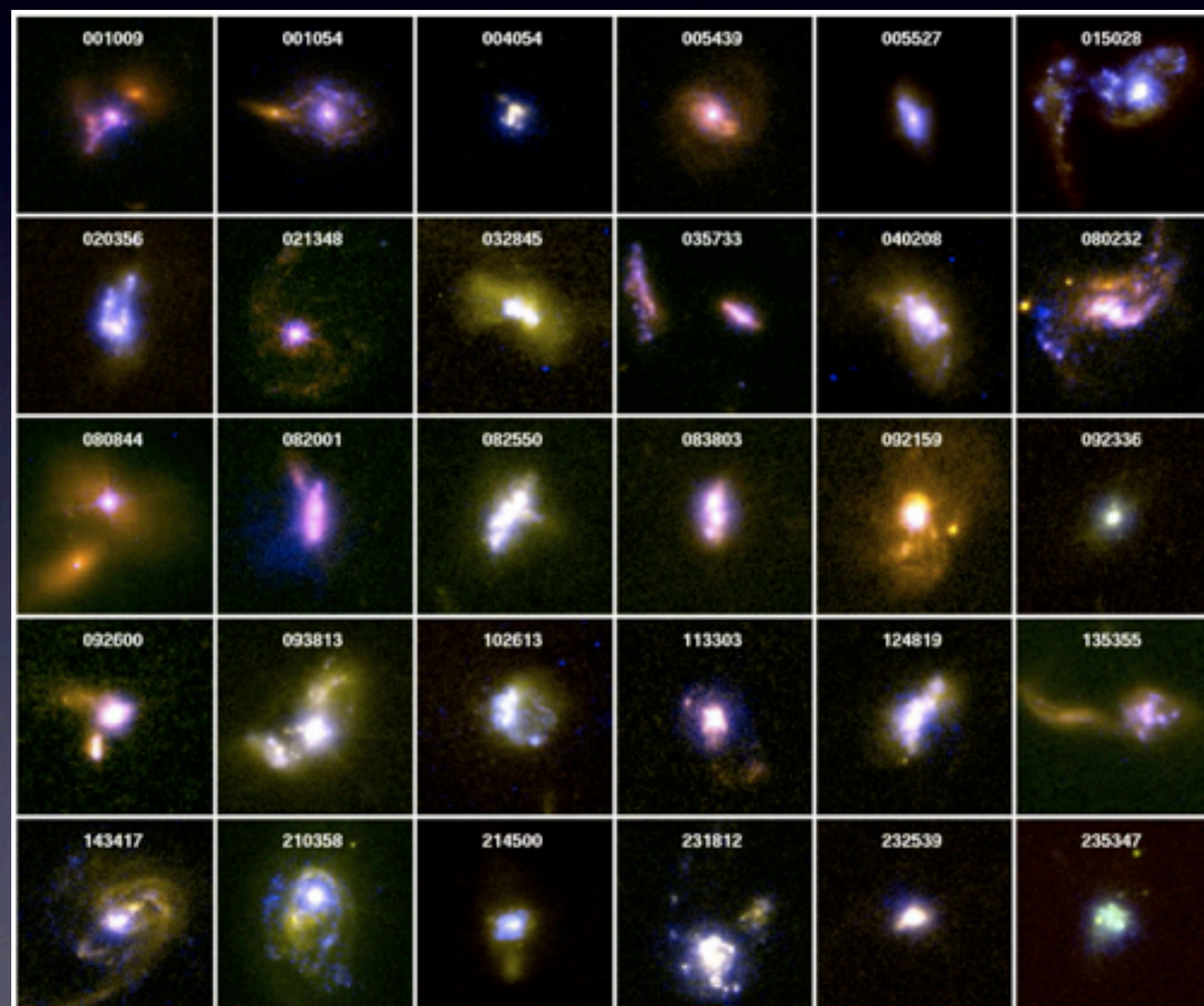
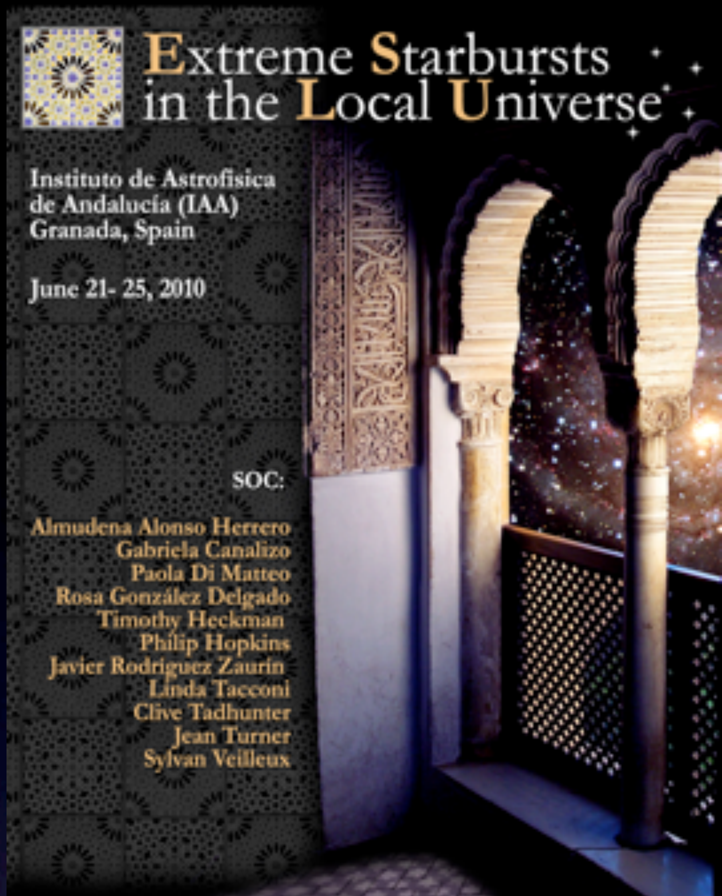




WITH: TIM HECKMAN (JHU)

GALEX SCIENCE TEAM (PI: CHRIS MARTIN), LEE ARMUS, AND MANY OTHERS



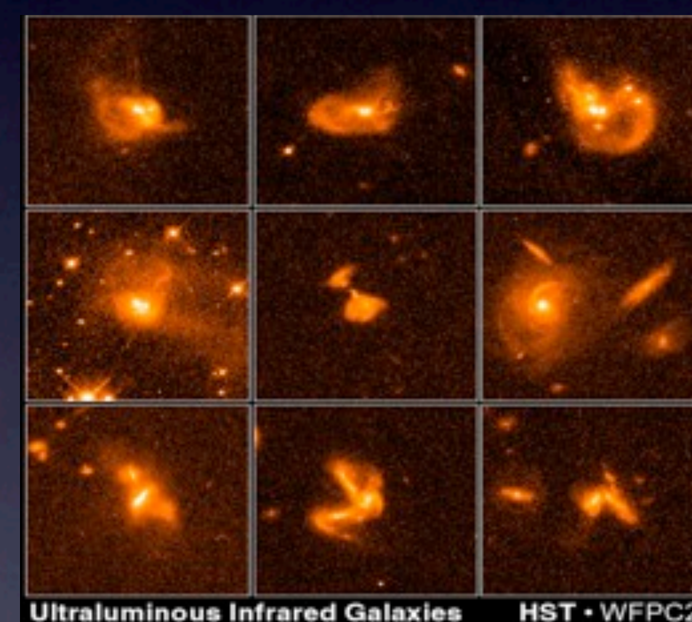

✳ *How are extreme starbursts triggered ?*

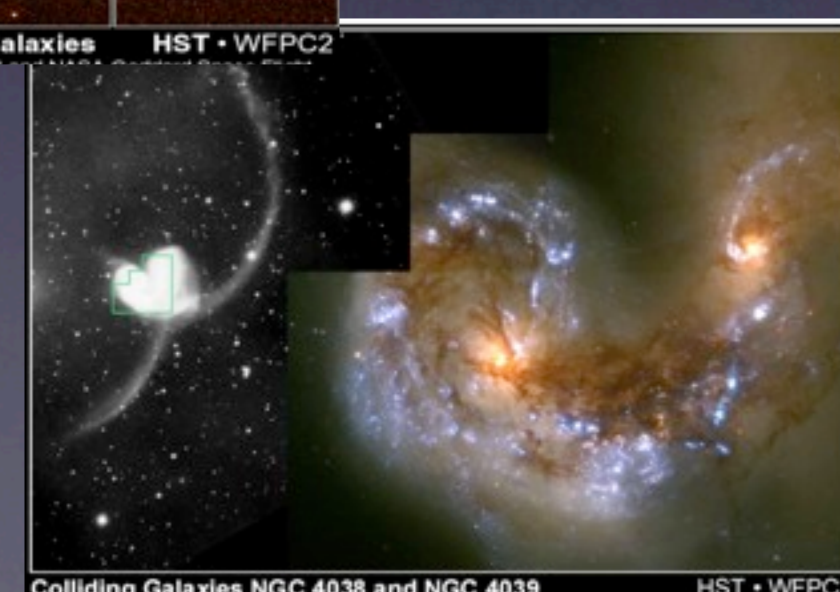
✳ *How efficiently are stars formed in extreme starbursts ?*

✳ *How important is the role of extreme starbursts in the hierarchical assembly of galaxies?*

✳ *How are extreme starbursts related to the triggering of AGN in the nuclei of galaxies?*

✳ *What can we learn about starbursts in the distant Universe through studies of their local counterparts?*




**Some Important Issues:**

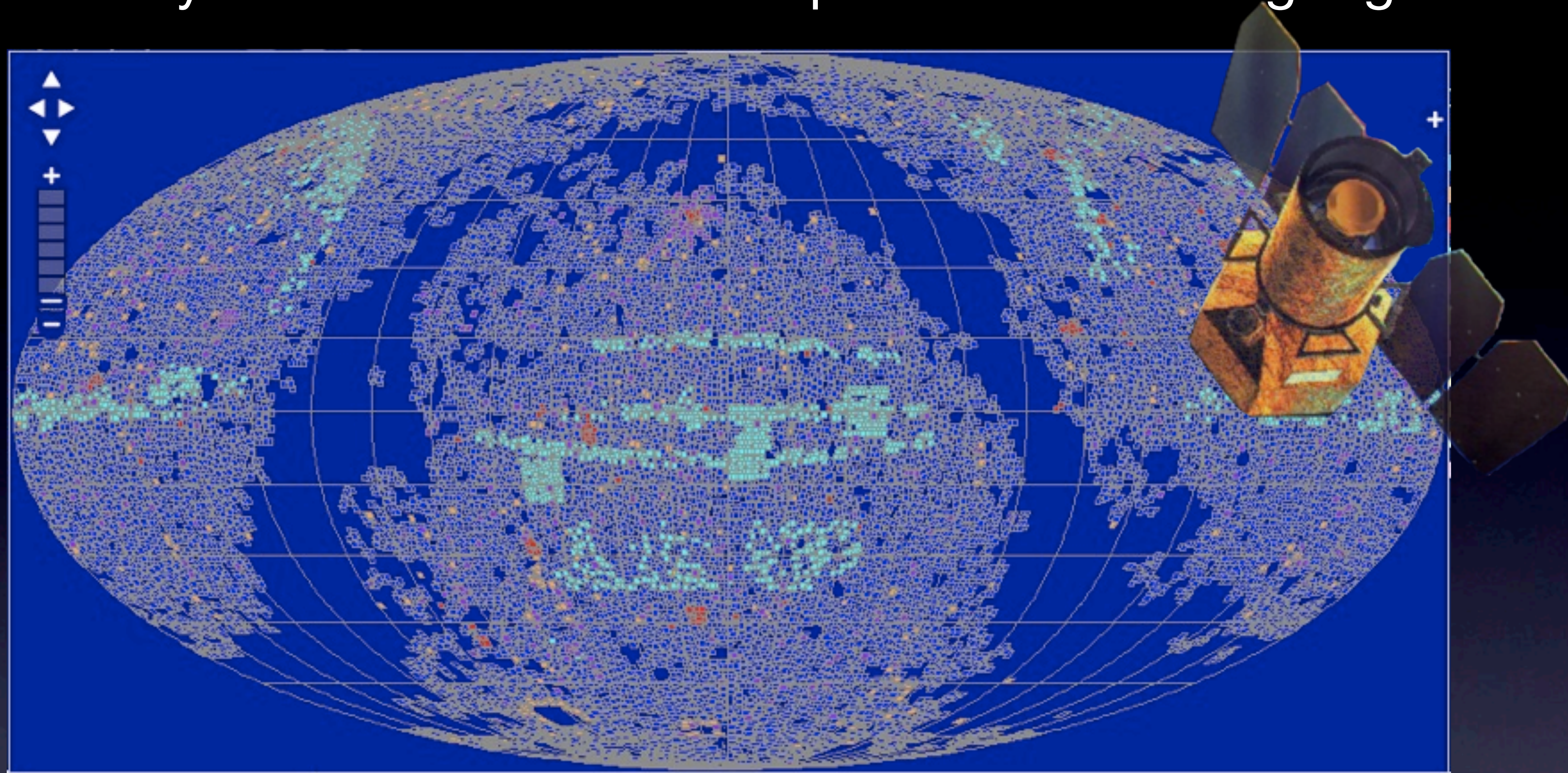
- Starbursts take place behind a thick screen of obscuring material
- Emission of AGN often dominates nuclear emission
- Causality between mergers/interactions, starbursts, and AGN not always straightforward
- Progenitors/Descendants ?


- *CMOs as end-products of starbursts*
- *What is the evolutionary connection between host galaxy, bulge, (nuclear) SCs and BH ?*
- *Do we understand the formation of SCs ?*
- *Do intermediate mass black holes form in SCs ?*
- *How do we feed the BH in the central pc ?*

**Some Important Issues:**

- Formation of GCs, SCs, bulges, disks and SMBHs happened very long ago
- High redshift starbursts were probably not the same as low redshift ones
- BH feeding difficult to observe directly
- IMBHs difficult to detect

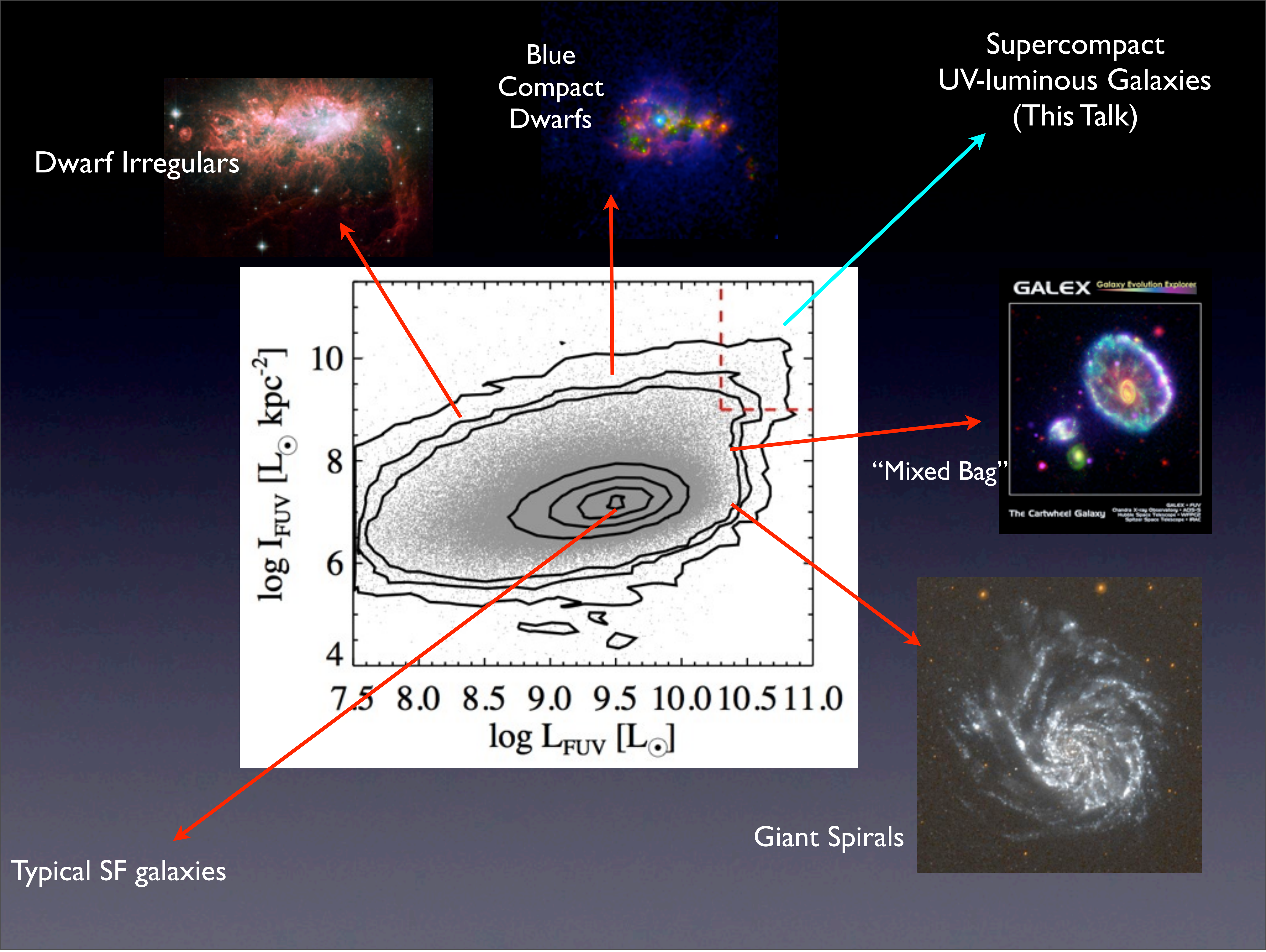
# Discovery of a GALEX/SDSS sample of local UV-bright galaxies



GALEX UV survey + SDSS spectroscopic survey (now 700,000 objects) allows us to search for highly rare outliers <0.1%

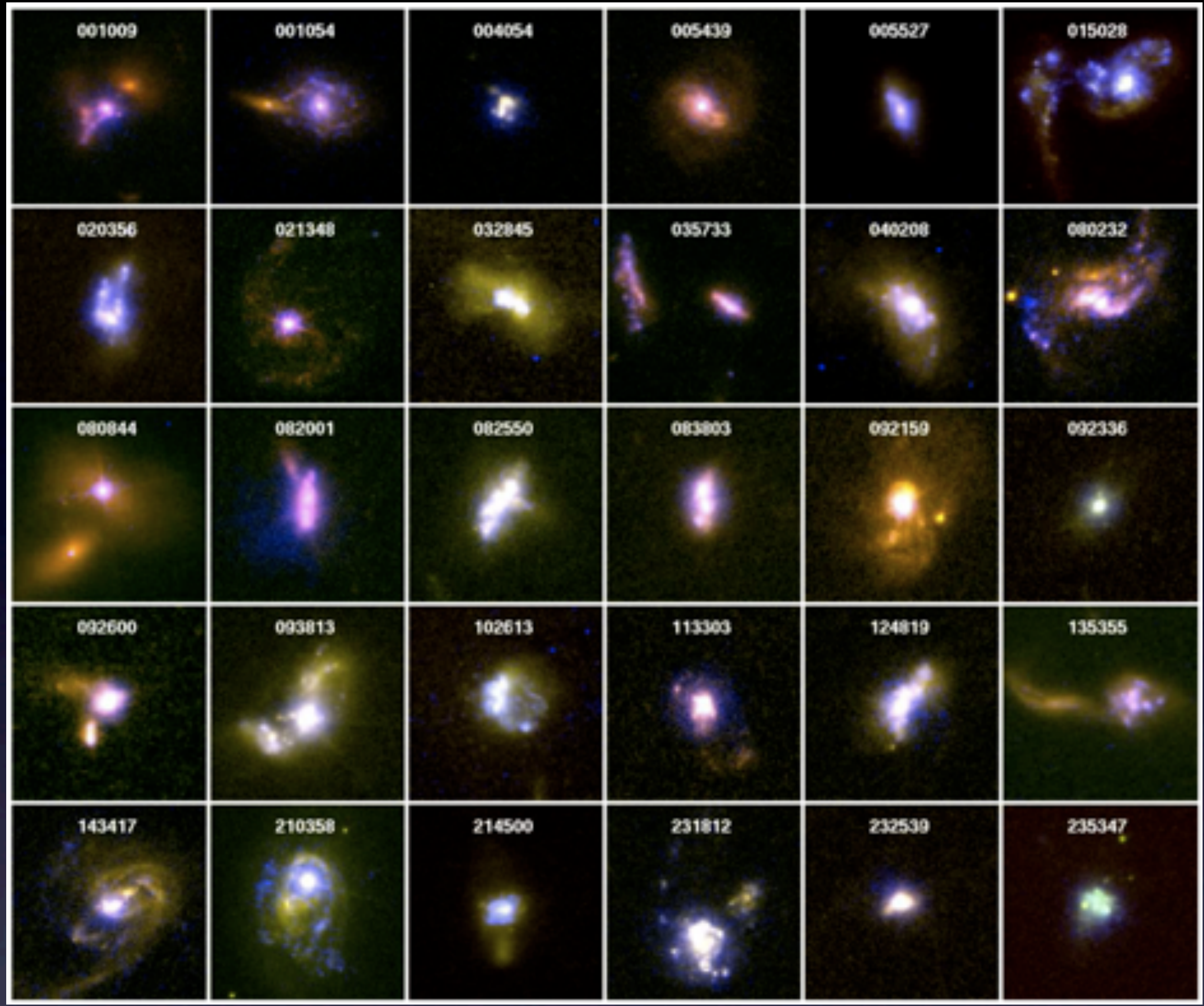
***Matching typical characteristics of UV-selected starbursts at high redshift:***

a large *far-UV luminosity* (high SFR, little dust) AND
a large *far-UV surface brightness* (compactness)


Dwarf Irregulars
Blue
Compact
Dwarfs
Supercompact
UV-luminous Galaxies
(This Talk)
GALEX Galaxy Evolution Explorer
The Cartwheel Galaxy
"Mixed Bag"
Giant Spirals
Typical SF galaxies
log $I_{FUV}$ [$L_\odot$ kpc$^{-2}$]
10
8
6
4
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
log $L_{FUV}$ [$L_\odot$]

# UV Starburst Sample Characteristics

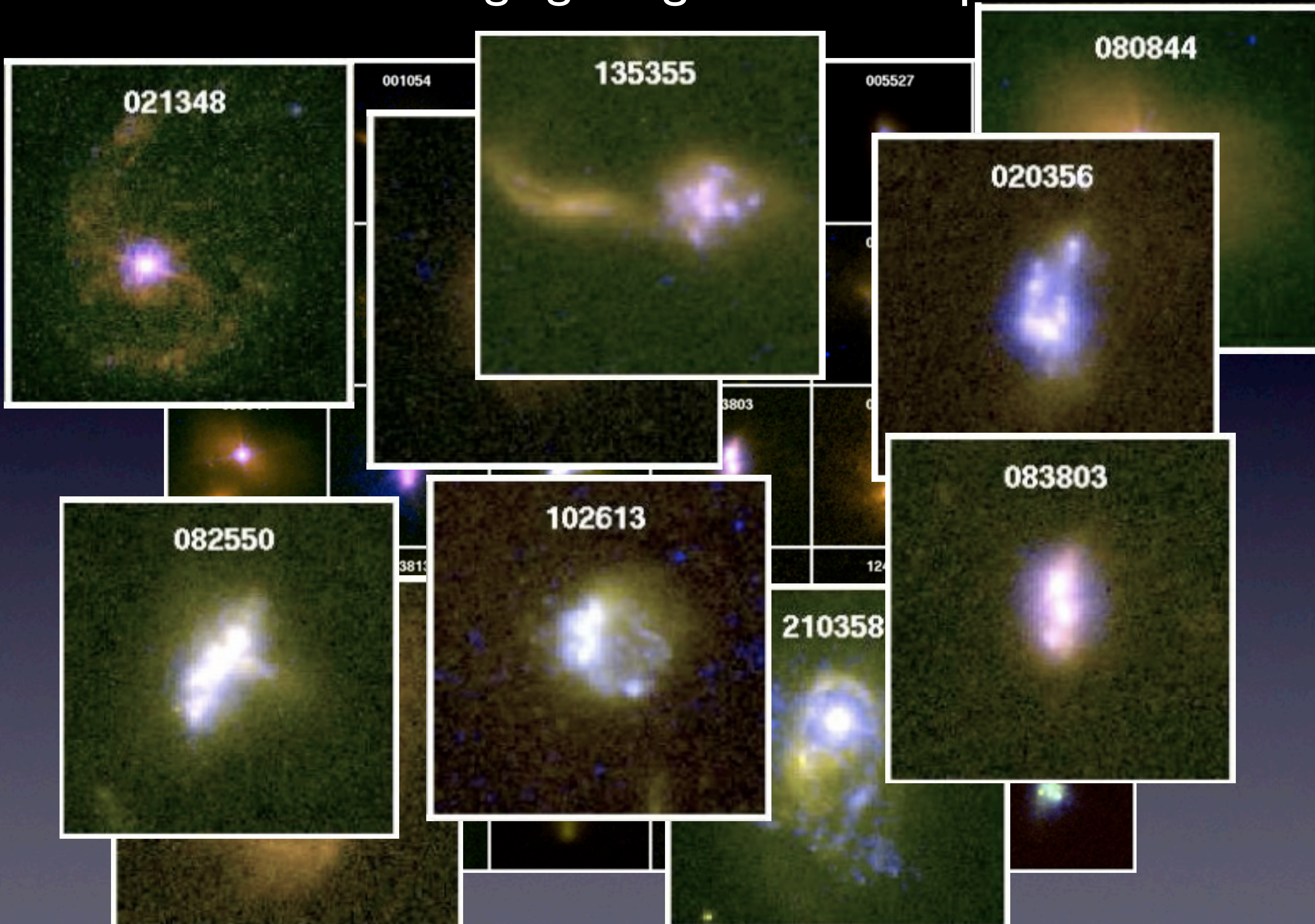
★ UV-selected Starburst galaxies
★ $0.1 < z < 0.3$
★ no QSOs
★ UV half-light radius of 1 - 2 kpc
★ FUV - R colour < 2
★ metallicity $0.2Z_o$ - $Z_o$
★ attenuation E(B-V) = 0 - 0.3 mag
★ stellar masses of $10^{9.5}$ -$10^{11}$ $M_o$
★ SFRs of 10-100 $M_o$ $yr^{-1}$
★ gas velocity disp. of 60-130 km $s^{-1}$



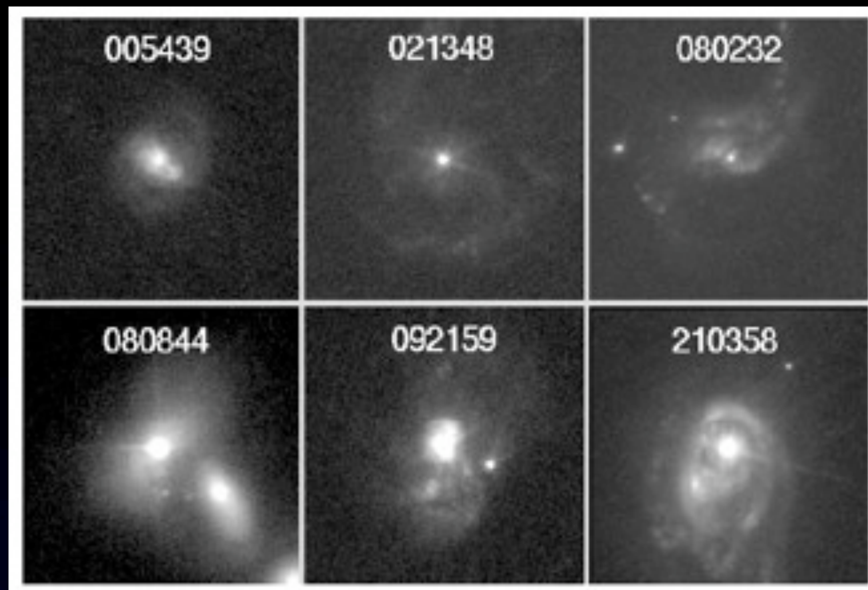

**• Spectral, photometric, morphological and kinematic properties very similar to those of star-forming galaxies that were very common only in the early Universe (z ~ 3)** [Heckman et al. 2005, Hoopes et al. 2007, Overzier et al. 2008,2009,2010]

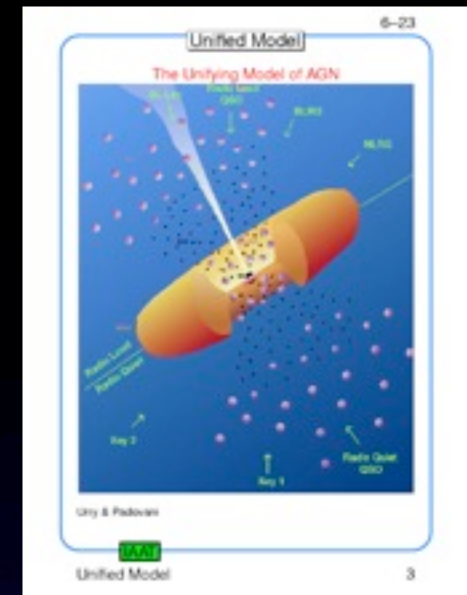
→ ***Can we use these to study the formation of (clumpy) disks, spheroids, CMOs, or BHs in action?***

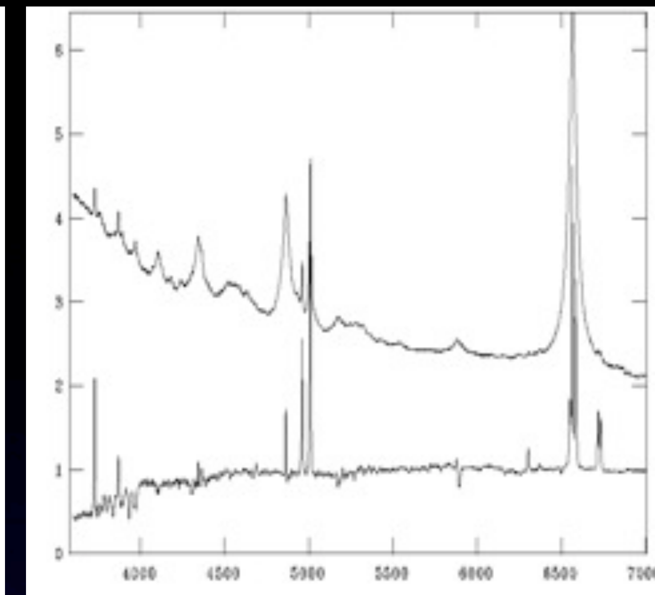
# HST Imaging Program in UV/optical



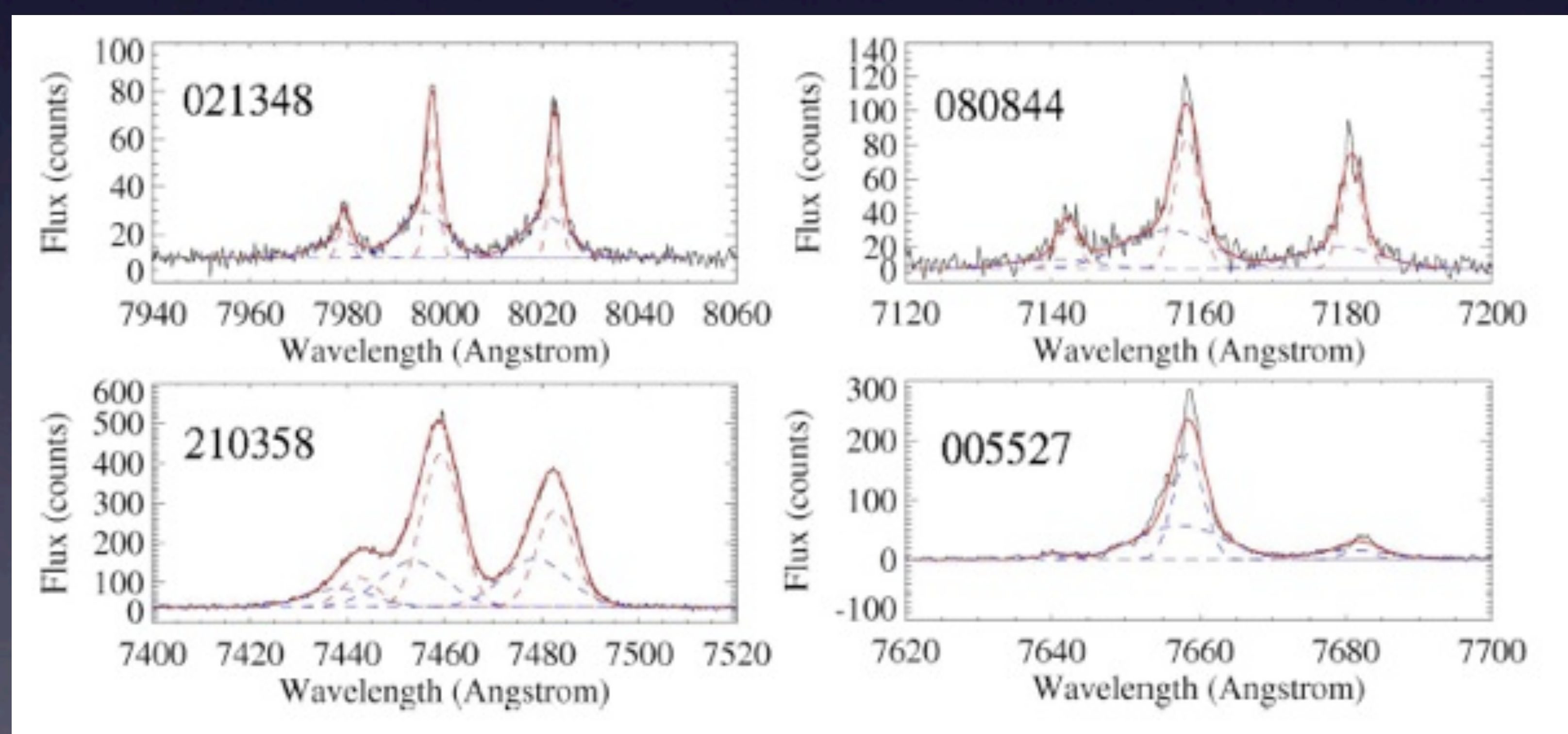
# These bright unresolved cores are not Type 1 AGN!



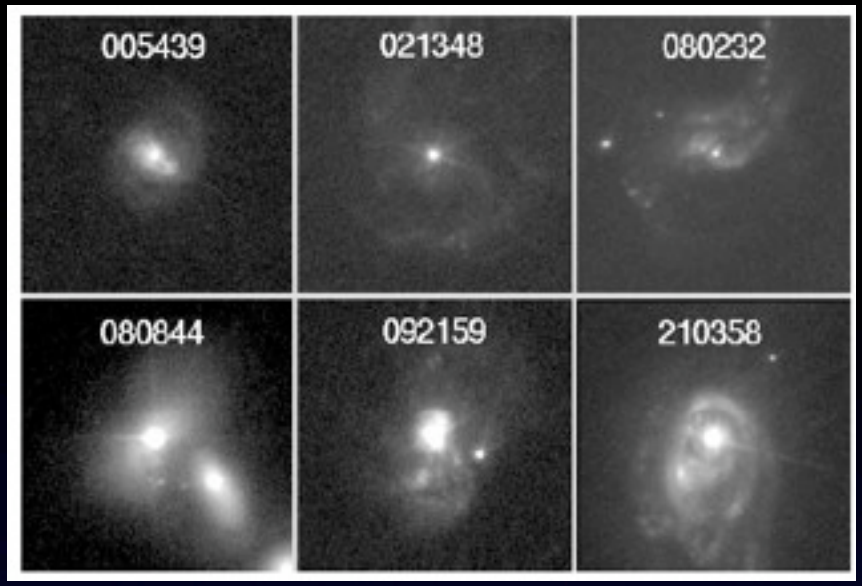



- VLT spectra: no detectable BLR characteristic of Type 1 Seyfert
- Blue-asymmetric Hα,[NII] lines: dusty outflows at few hundred km/s



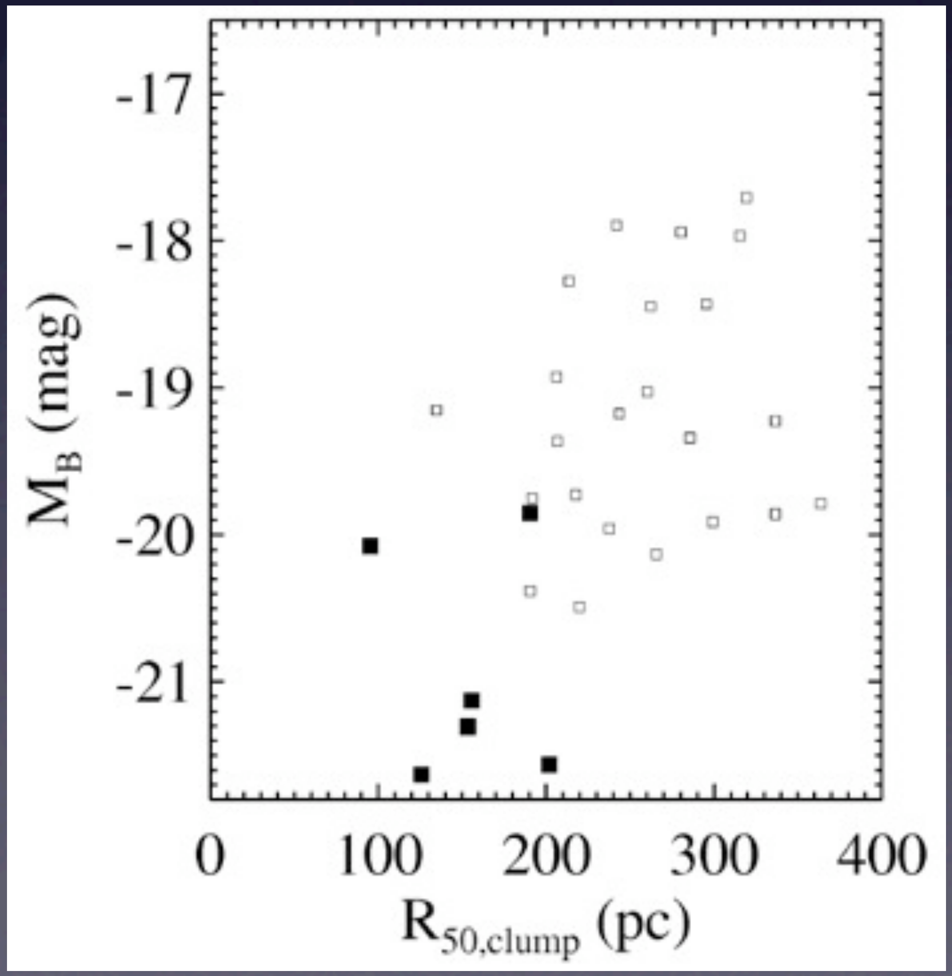

High SN rates in very compact regions lead to high pressures/densities that drive large-scale Galactic winds
(common in low and high-z SBs; Lehnert & Heckman 1996, Lehnert et al. 2009)

# Stellar "Dominant Compact Objects" (DCOs)

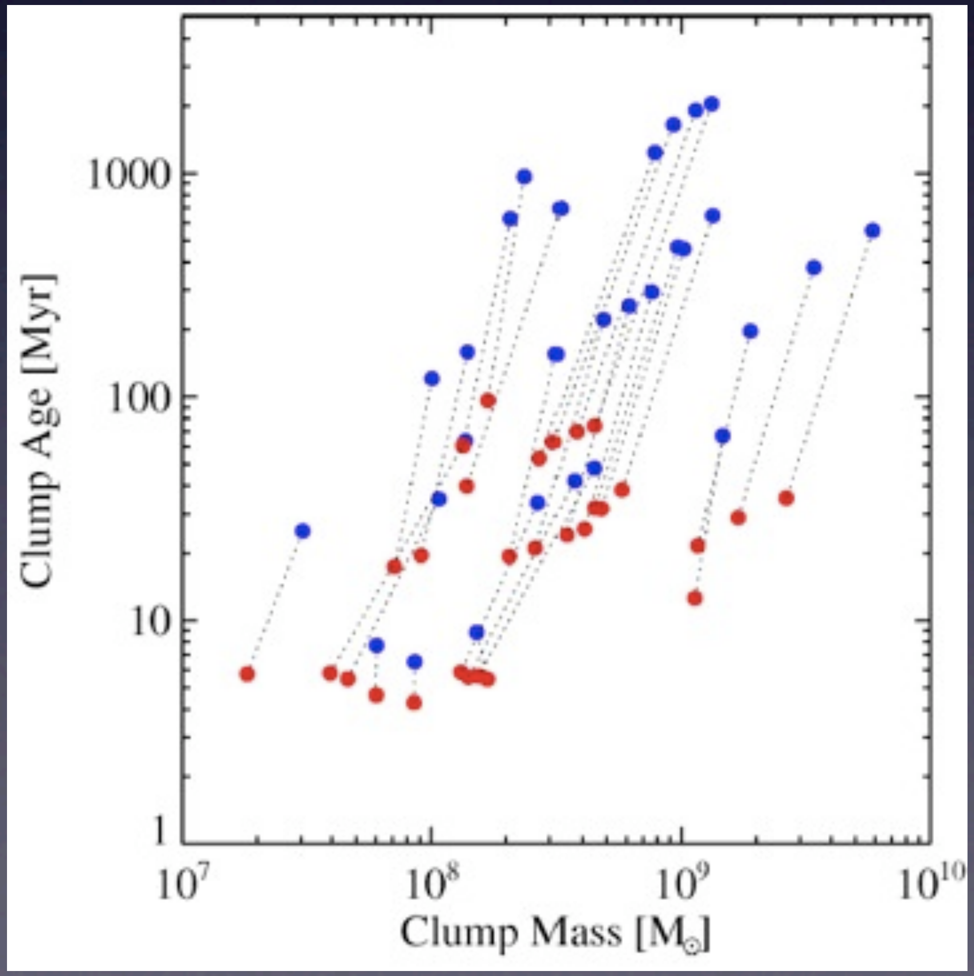



- ★ Radius <100-200 pc
- ★ Stellar Mass ~$10^9$ $M_o$
- ★ Ages ~10-50 Myr
- ★ $t_{dyn}$ <5 Myr

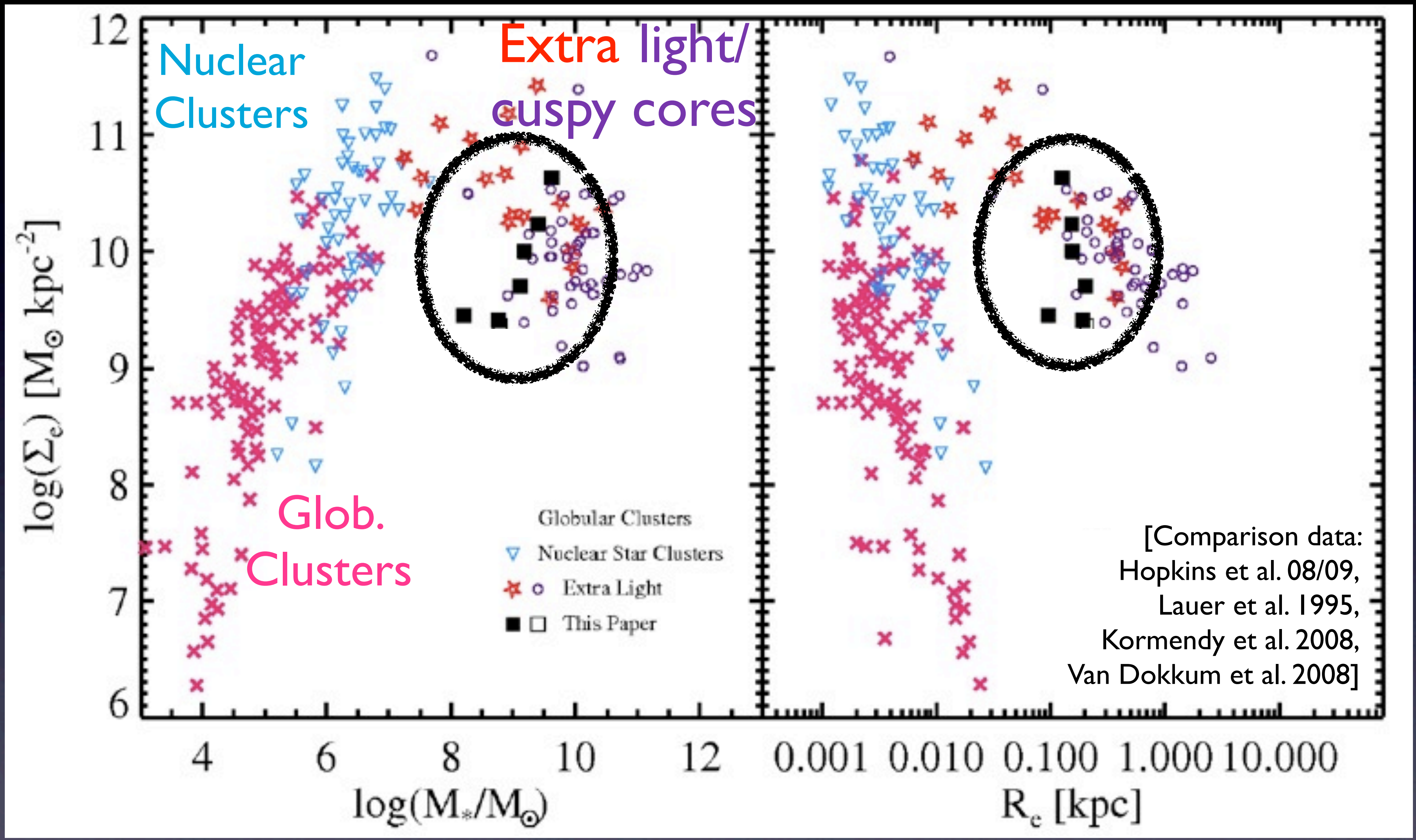
Size vs. Magnitude



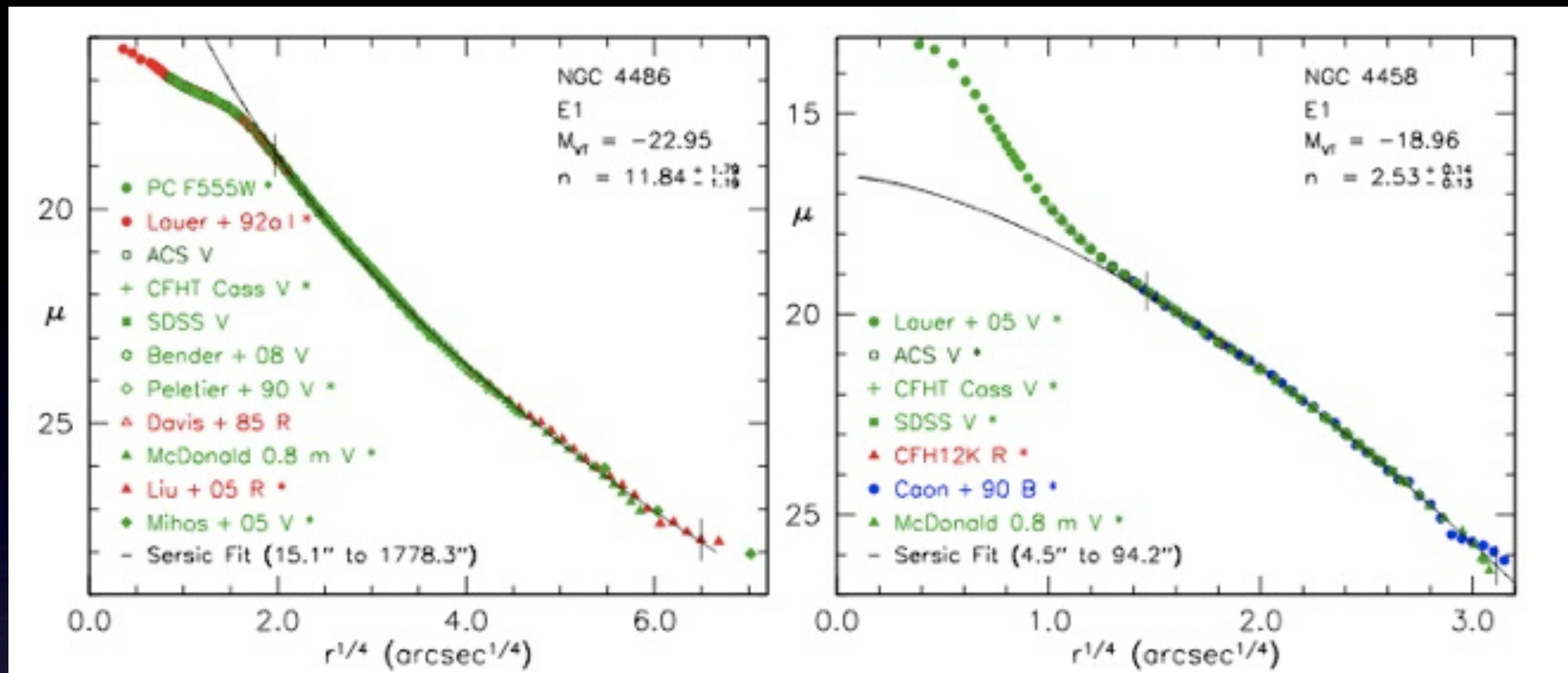

Mass vs. Age



# *Witnessing the Forming Nuclei of Galaxies (?)*



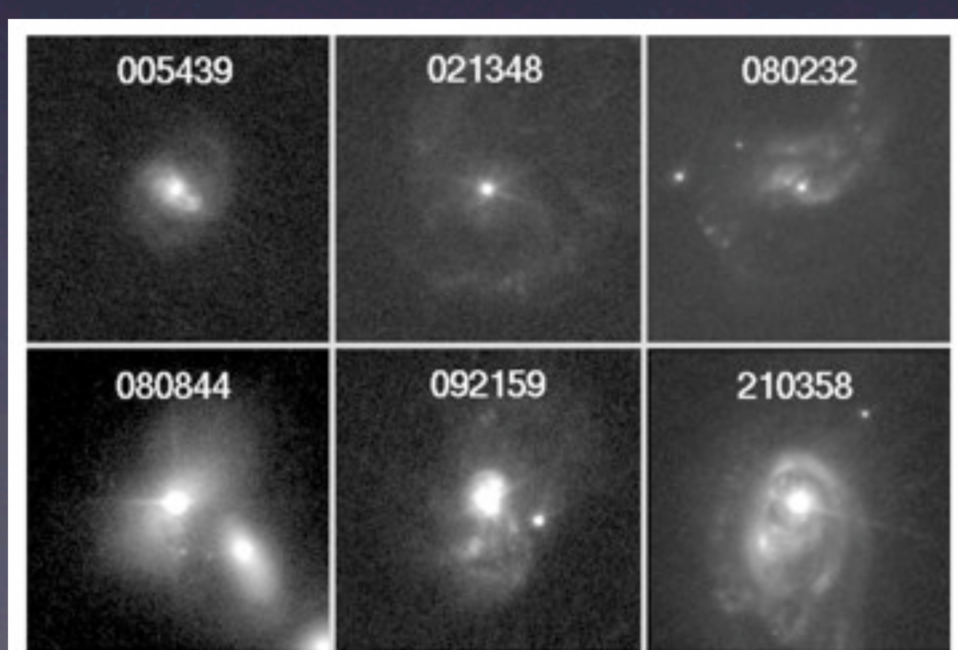
# *The Forming nuclei of low-mass early-type galaxies (?)*




[Kormendy et al. 2008, Hopkins et al. 2009]

***High mass ellipticals have core "deficiencies" > dry mergers***

***Low mass ellipticals have core "excess" or "cusps" > wet mergers***

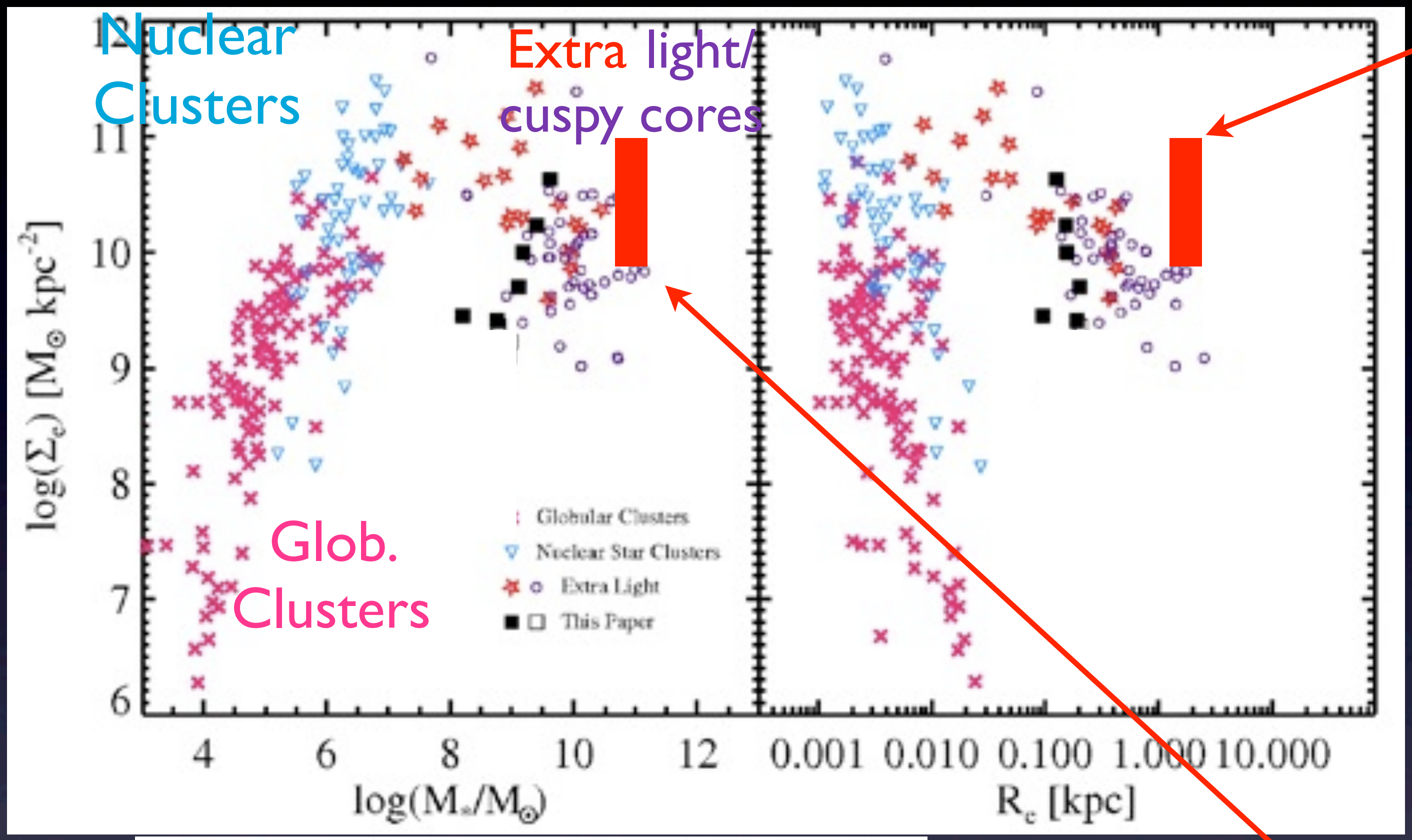



Consistent with Wet Merger Formation Scenario:

- ✓ Galaxy mass <$10^{11}$ $M_{sun}$
- ✓ High Core Stellar Mass Densities
- ✓ Core/Total Mass ratio ~2-20%
- ✓ Gaseous merger-driven nuclear SBs

# *"Down-sizing" of CMO formation since z=2*

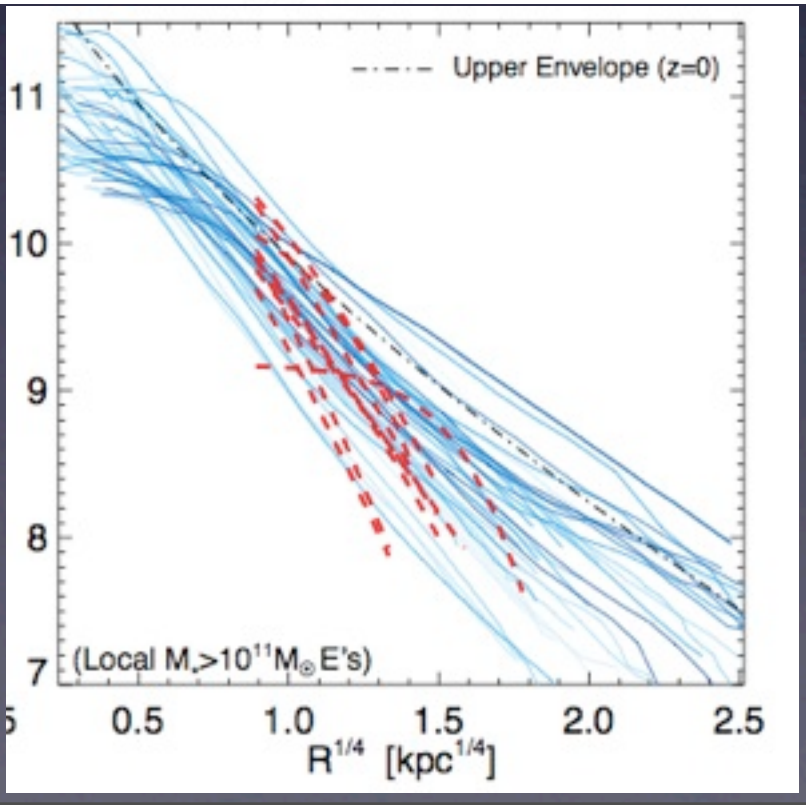
*Massive Compact Galaxies at z=2*





[van Dokkum et al., Toft et al., Zirm et al.]

$\Sigma_e$

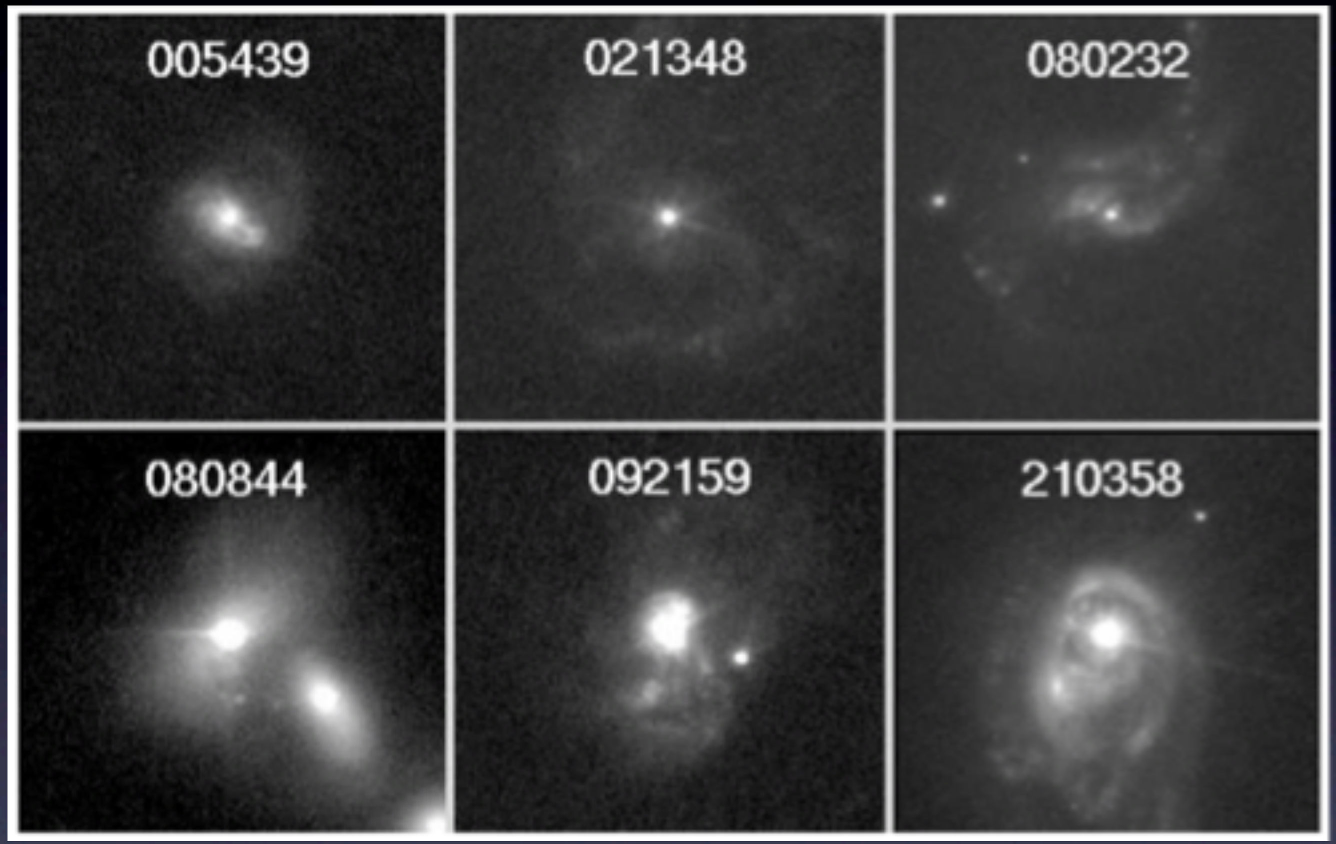



*Mass density profiles of local ellipticals*

[Hopkins et al. 2009]

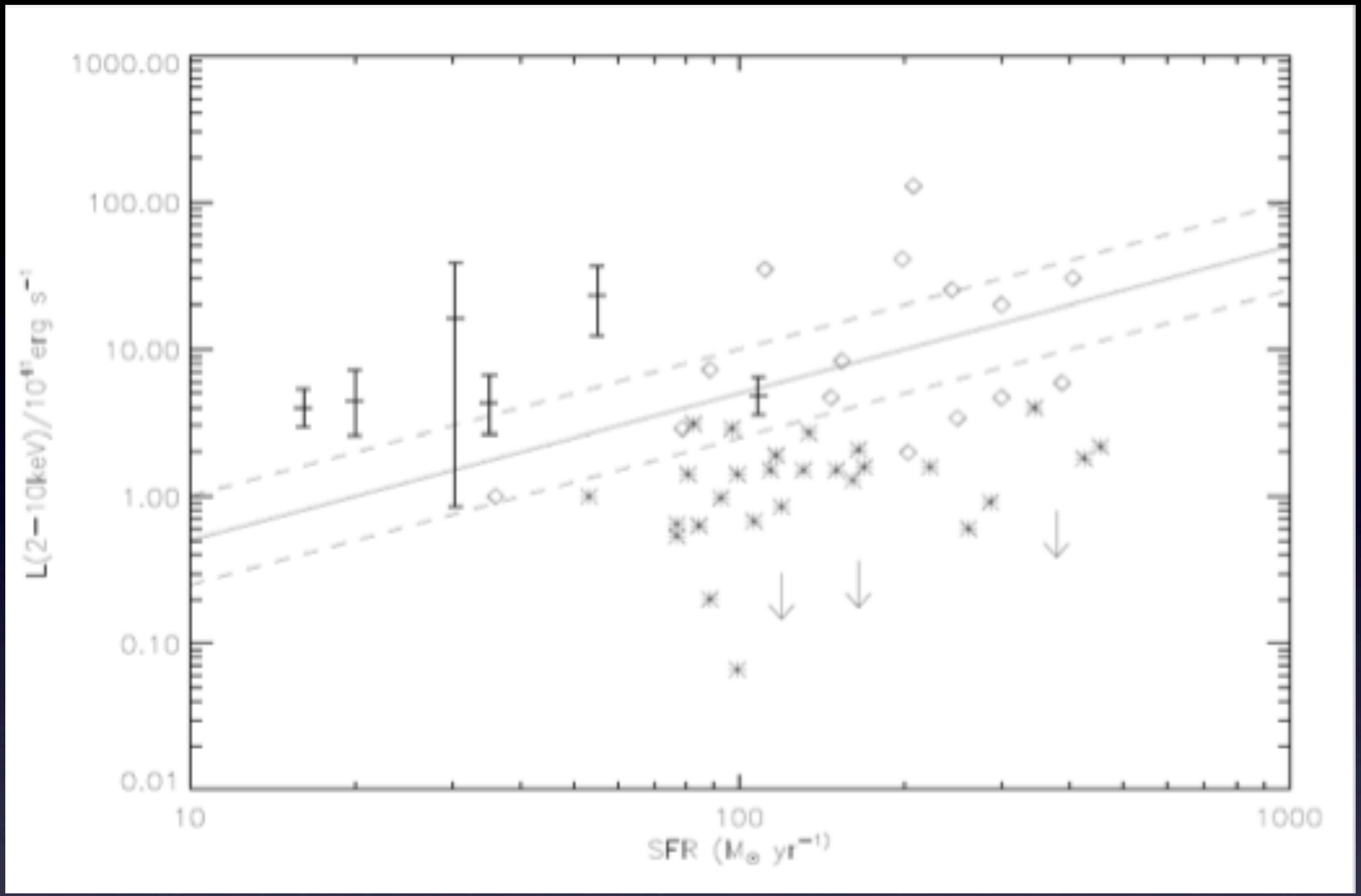
# THE FORMATION OF SUPERMASSIVE BLACK HOLES ?

The Dominant Compact Objects




- Sizes ~100 pc, masses of several billion solar masses, young (association with cold dense gas)
- Should be ideal sites for the formation/growth of supermassive BHs

# The View from XMM




Lx

SFR

[Jha, Ptak et al., in prep.]

- The DCOs are over-luminous in the 2-10 keV band compared to starbursts by factors ~2 to 10
- Spectra are harder than typical SBs: $(L_{2\text{-}10}/L_{0.5\text{-}2})$ ~ 2 vs. ~1

# 1) Low-Luminosity AGN?

- If these are Compton-thin, the implied $L_{Bol,agn}$ ~ $10^9$ to $10^{10}$ $L_{sun}$
- A few % of $L_{Bol,tot}$ (consistent with optical and mid-IR spectroscopy)
- For $L/L_{Edd}$ ~ 0.3, the implied BH masses would be one to a few $10^5$ $M_{sun}$

# 2) Powerful Compton-Thick AGN?

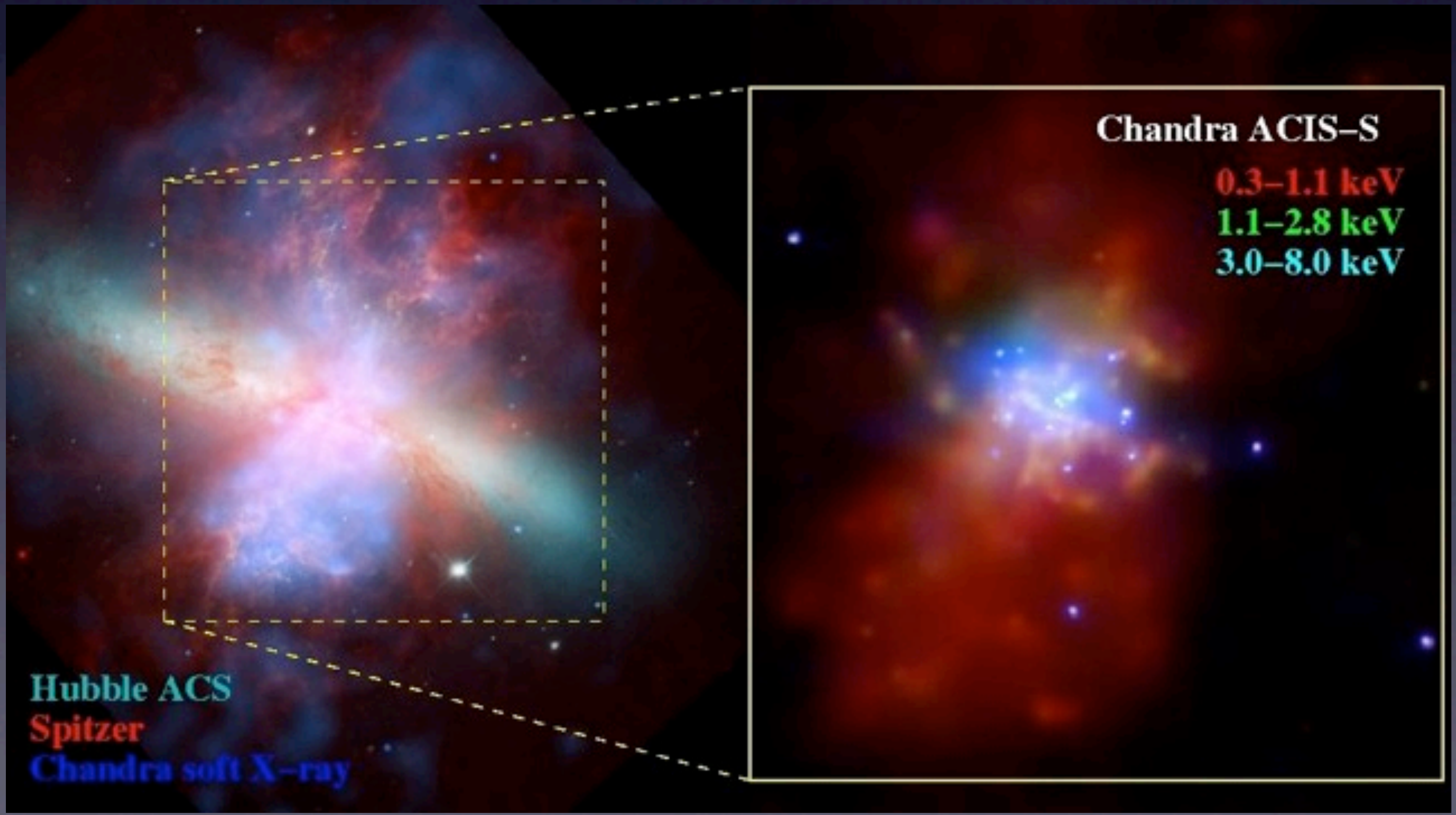
- Heavily absorbed in the hard X-ray band and are more powerful AGN?
- This seems inconsistent with the Mid-IR and UV spectroscopy data which imply starburst-dominated objects
- The Fe K-alpha emission-line is an important constraint

(in Compton-thick AGN this line has an EQW ~ 1 keV and E = 6.4 keV from the cold obscuring material)

# 3) Exotic Starbursts?

- Simple analytic arguments imply that hard X-ray emission from ~$10^8$ K gas can be boosted for sufficiently compact starbursts
- A "smoking gun" would be strong Fe K-alpha emission-line with E ~ 6.7 keV (He-like) or 6.9 keV (H-like) iron

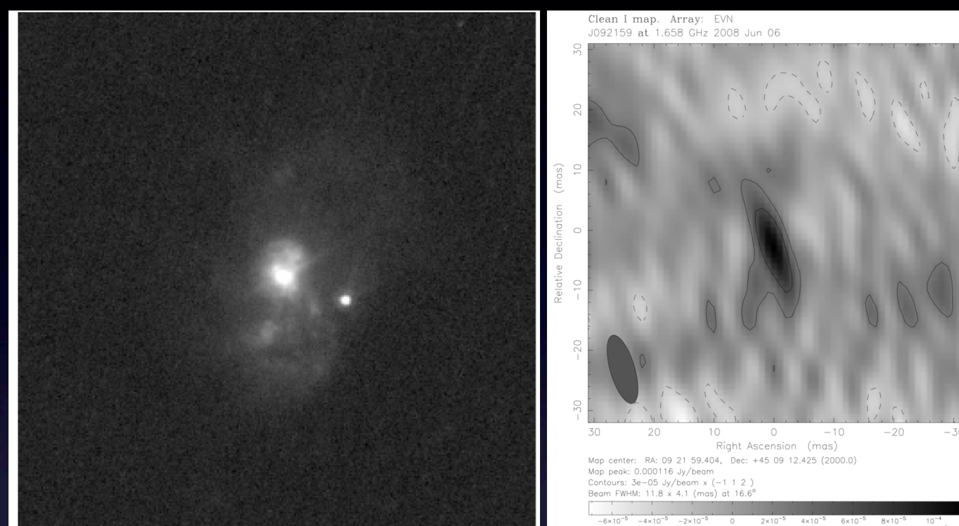
This hot gas is observed in the central starburst of M82…



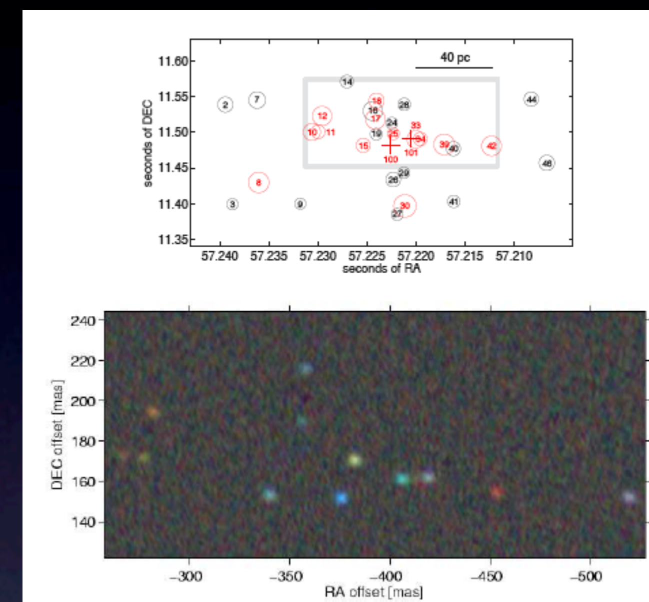
# Do we see any ***Direct*** Evidence of low luminosity black holes?

## Looking for "compact cores" at 18 cm with the European VLBI (EVN)

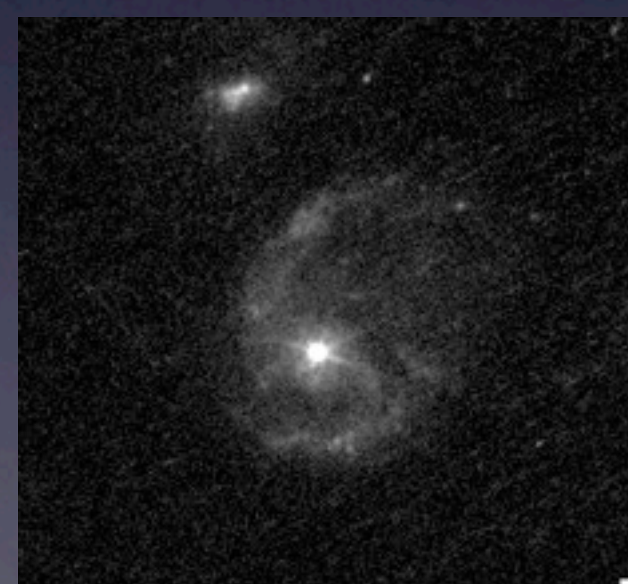
Compact source detected!

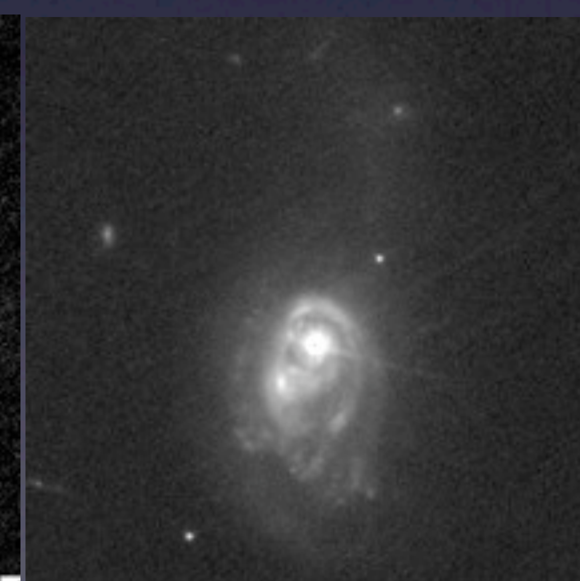



10x more luminous then central region of Arp 220 containing ~10 Radio-SN and SN Remnants:




However two other obvious candidates remained undetected:

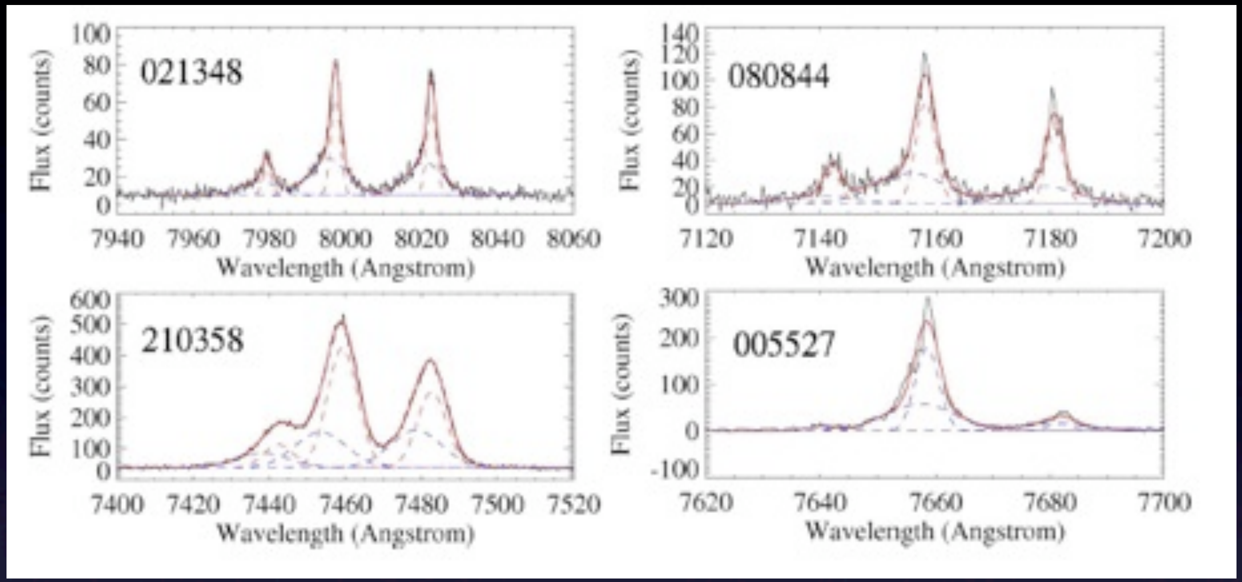




Deeper and multi-band observations allocated...

# Summary: Triggered CMO formation and Delayed Central Black hole feeding (?)

- Young, triggered starburst galaxies in the nearby universe
- Massive, dense stellar nuclei consistent with being proto-bulges
- No radiatively dominant AGN
- <50 Myr: central gas flow dominated by massive stars & SNIIs




- ~100 Myr: dominated by low-velocity outflows from post-AGB stars
- low-velocity gas will not be able to escape a central black hole
- delay time between onset of starburst and BH growth (~100 Myr, e.g. Davies et al. 2007)
- next phase is perhaps a dusty SB + luminous AGN

Consistent with high redshift:
AGN fraction is 3% in LBGs vs. 50% in, e.g., sub-mm galaxies
(Steidel et al. 2002, Ouchi et al. 2008, Alexander et al. 2005)