X-ray properties of normal galaxies in the local universe

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Thanks to: M. Bauer, N. Brassington, D. Breitschwerdt, G. Fabbiano, D.-W. Kim, E. Memola, S. Pellegrini, F. Pizzolato, W. Pietsch, A. Wolter….. and many others

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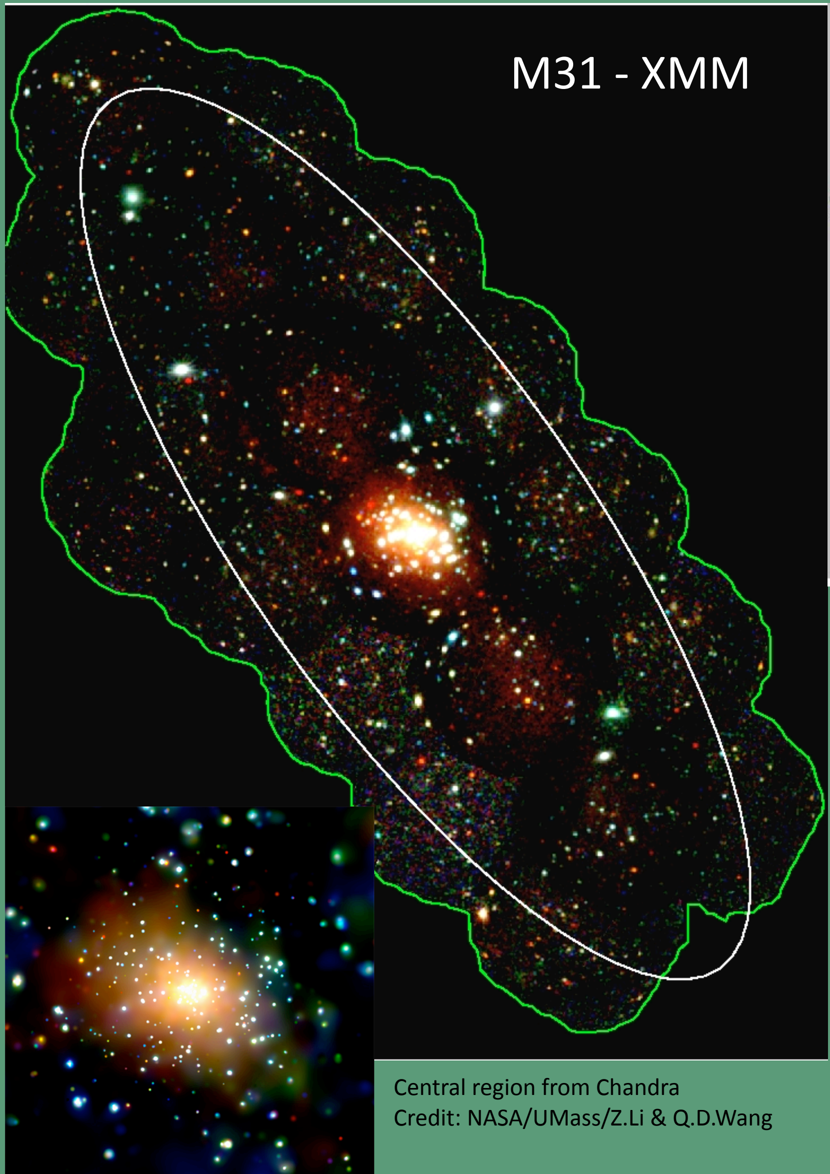
Galaxies are

- ***Faint*** X-ray sources : L_x ~10^{39} – 10^{41} erg/s
  → low flux sources!
- ***Complex*** systems: at least 3 main components, with different relative importance
  - ✓Individual sources
    - ✓ Binaries : LMXB - HMXB – ULX in BH/NS/WD
    - ✓ SN - SNR
    - ✓ Stars
  - ✓Gas from normal stellar evolution/starformation activity
  - ✓Low luminosity AGN
- ***In different*** environments : isolated - interacting – in groups – in clusters

Normal late-type Galaxies in the local universe



Central region from Chandra
Credit: NASA/UMass/Z.Li & Q.D.Wang

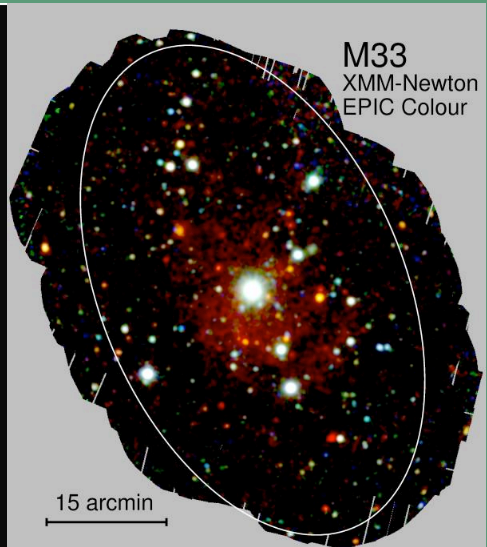
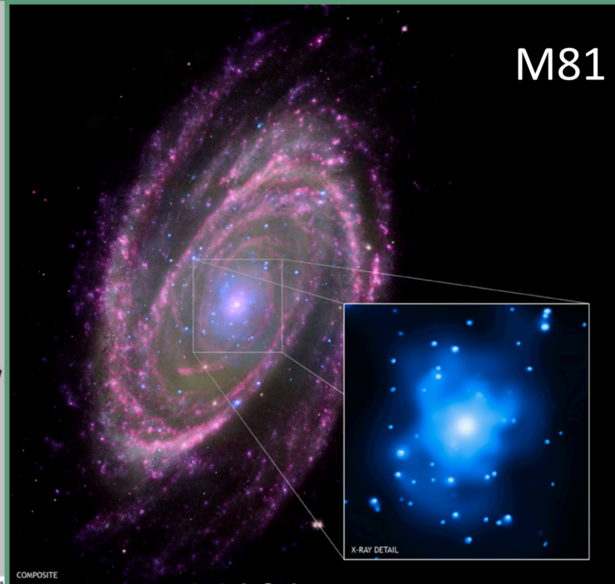
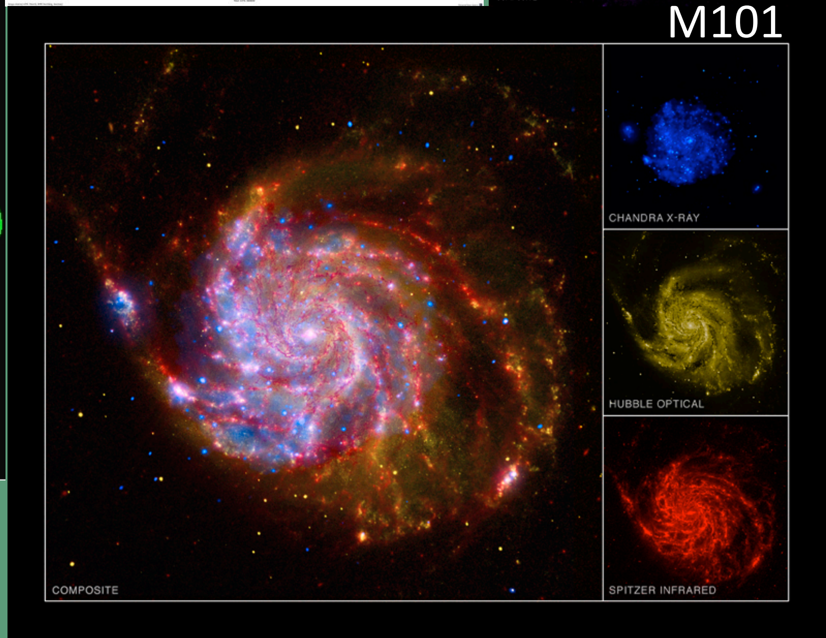


Image courtesy of W. Pietsch, MPE Garching, Germany and ESA.





Chandra
image
gallery

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Normal late-type Galaxies in the local universe

→Hot ISM a minor component : compact sources dominate (but energy dependent)

→Gas - contributes at <1.5 keV

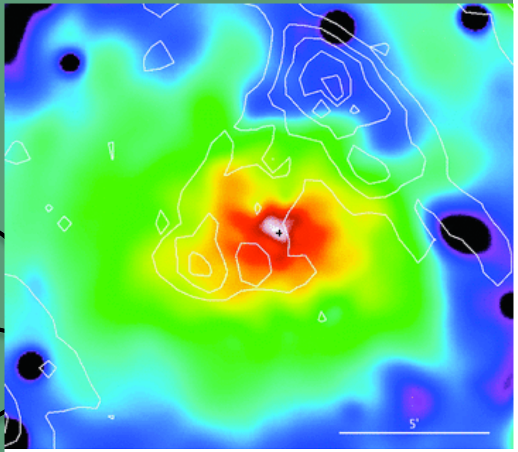
- in disks e.g. Ehle et al 1998, Read & Pietsch 2001; Kuntz et al. 2003; Tyler et al. 2004, Warwick et al 2007; Bauer et al 2007; Owen & Warwick 2009 ….

  2T (0.2;0.7 keV);

  L_X≈0.1-6 10^{39} erg/s;

  M_{gas}≈ 10^8 $M_\odot$

  Relation with local SFR



Gas distribution in the center of M31 Fig. 8 in Bogdan & Gilfanov 2008

- in bulges e.g. M31 (Bogdan & Gilfanov 2008):
  kT ≈ 0.3 keV; M_{gas}≈ 2 10^6 $M_\odot$

- in halo : so far associated with Hα/SF activity

Normal late-type Galaxies in the local universe

→Individual sources concentrated towards the bulge/center/plane/arms as in MW

Studies of populations of X-ray sources:

Posters on SMC M31

→**Variability**

→**Spectral properties and HR diagrams**

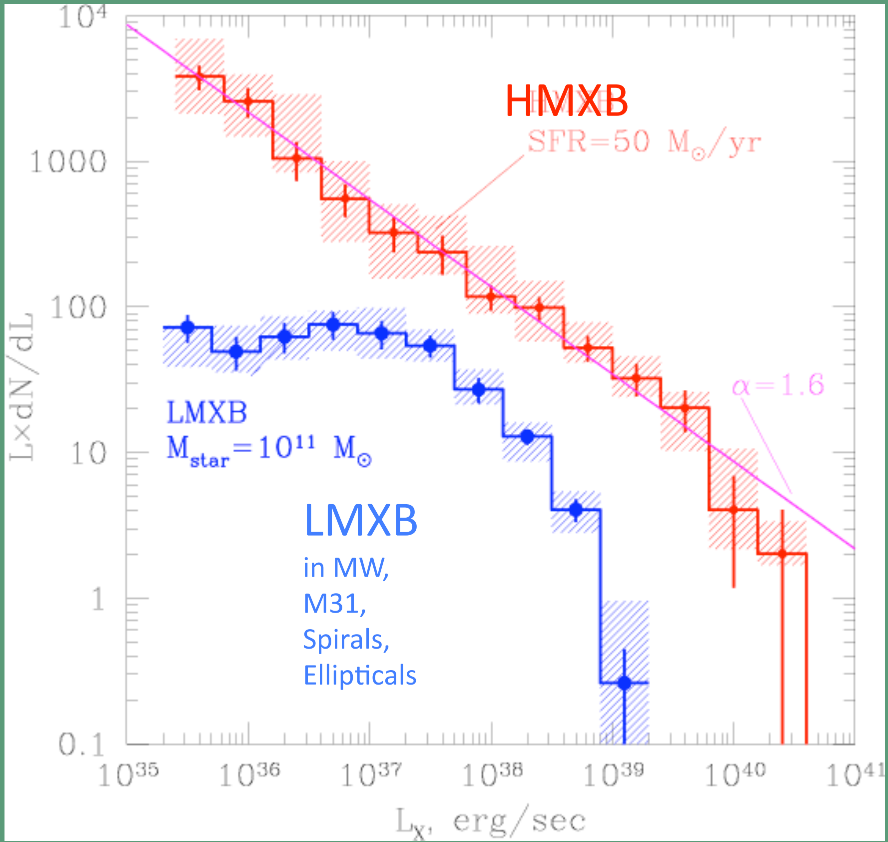
→**Source classification**

→**XLF : "universal" shape. Normalization:**
LMXB as stellar mass indicator
HMXB as SF activity indicator

Too many refs: latest Prestwich et al. 2009 Friday astro-ph!

"Universal" luminosity functions

Poster on HMXB XLF

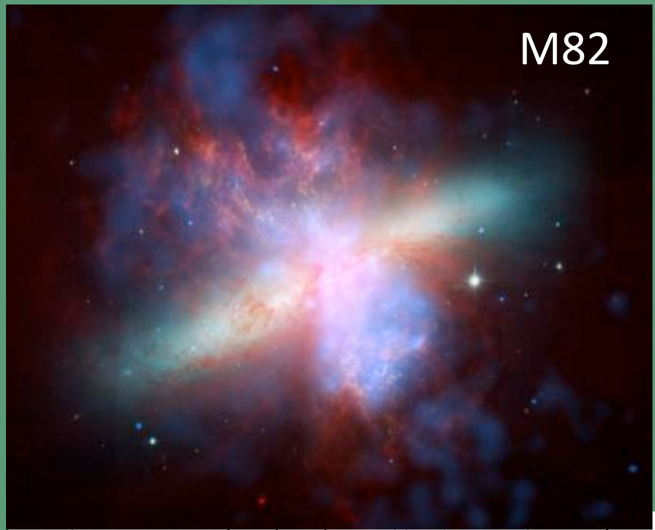


* HMXB: Single power law.
Normalization is SFR
S arms/disks and starbursts

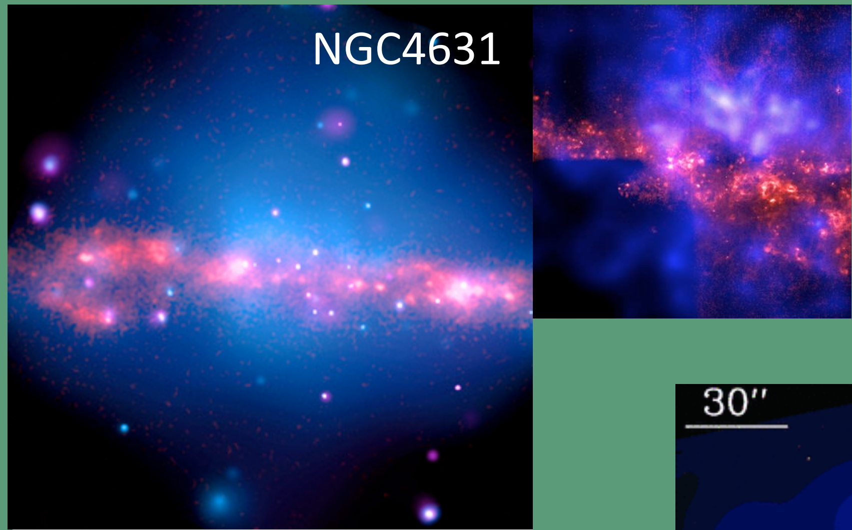
* LMXB: Broken power law.
Normalization is Stellar Mass.
Spirals + Ellipticals

see Grimm et al 2003, Ranalli et al 2003, Gilfanov et al 2004, Mineo this conf.

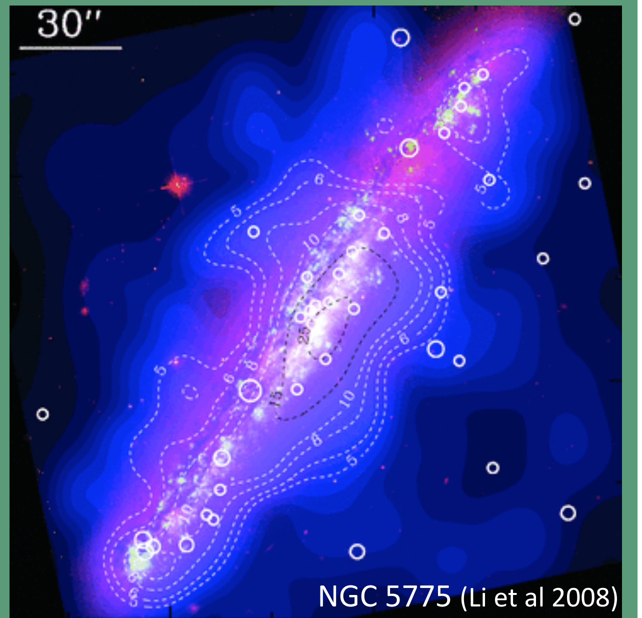
Starburst Galaxies in the local universe



Credit: X-ray: NASA/CXC/JHU/D.Strickland; Optical: NASA/ESA/STScI/AURA/The Hubble Heritage Team; IR: NASA/JPL-Caltech/Univ. of AZ/C. Engelbracht

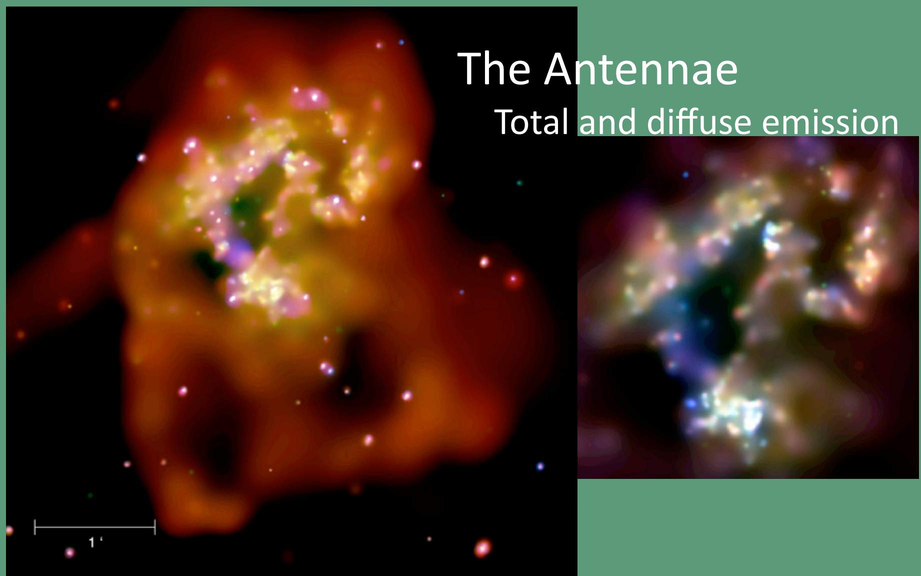


Credit: X-ray: NASA/CXC/UMass/D.Wang et al., Optical: NASA/HST/D.Wang et al.



NGC 5775 (Li et al 2008)
R band (red), Hα (green) and 0.3–1.5 keV (blue)

The Antennae
Total and diffuse emission



(Credit: NASA/CXC/SAO/G.Fabbiano et al.)

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Starburst Galaxies in the local universe

Large fraction of soft emission is from *hot gas*: >20% NGC3256 Moran et al. 1999, Lira et al 2002, ~50% Antennae Fabbiano et al. 2001 ~80% M82 Zezas et al 2001

Gas is

- multi-T: kT 0.2–1 keV
- different metal abundance in different regions (Antennae, Ngc253)
- associated with Ha emission/SF activity indicators (Antennae, N253, N3079, Arp220, Cartwheel), both in the plane and in the halo.
- Halos are softer than disks, possible multi-T (N253, Bauer et al 2008)

Gas extent correlates with SF activity and disk size

Compact source population correlates with SF activity

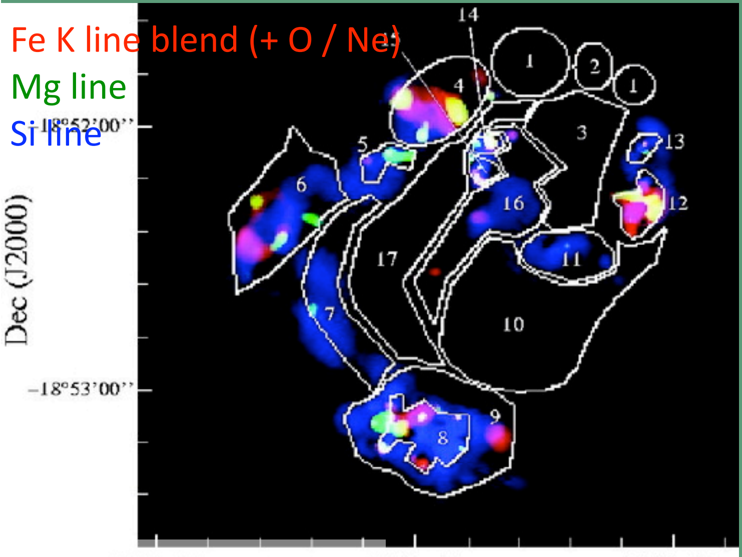
Talk later

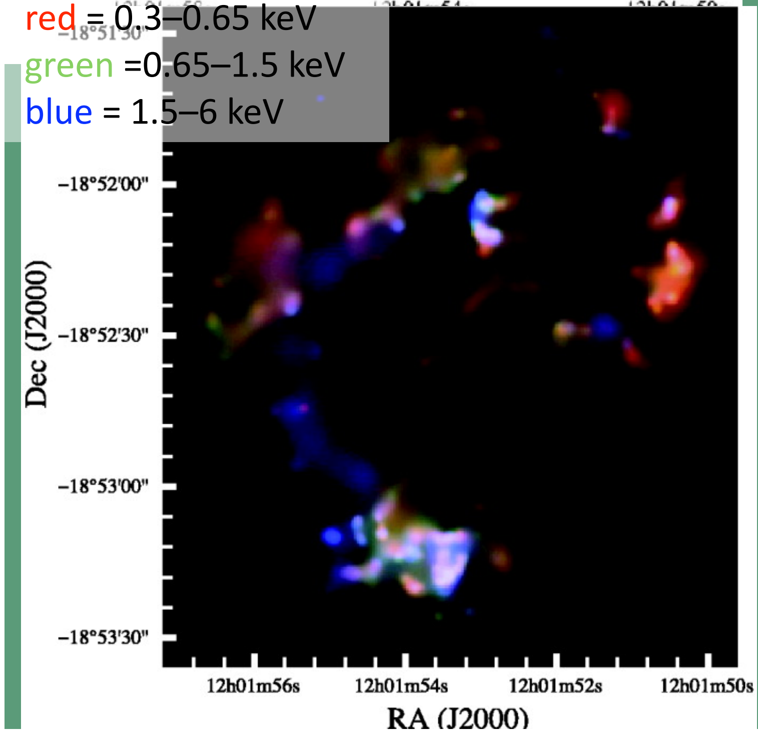
from Cecil et al. 03, Strickland et al. 02-04, Baldi et al. 06 Tüllmann et al. 2006, Bauer et al 2007-2008,

The Antennae

Baldi et al. 2006, Fabbiano et al 2002-3-4

Talk on M82

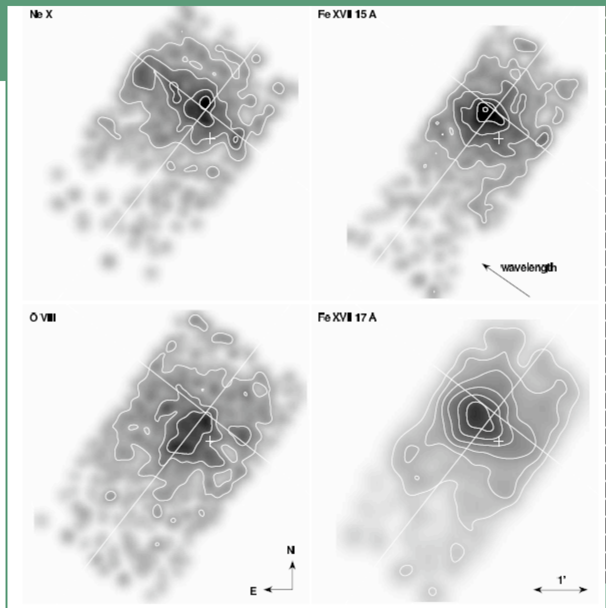




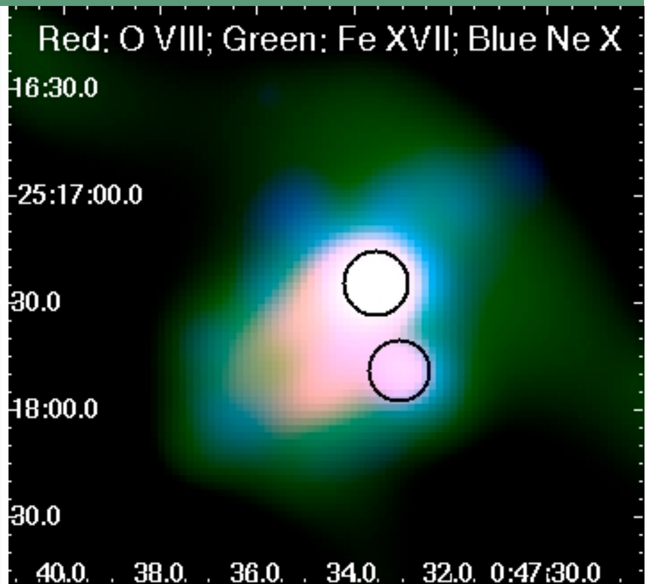
- Emission in many different lines
- Different spatial distribution / temperature for different elements

Nuclear outflow in NGC253

Bauer et al, 2007



“monocromatic” RGS

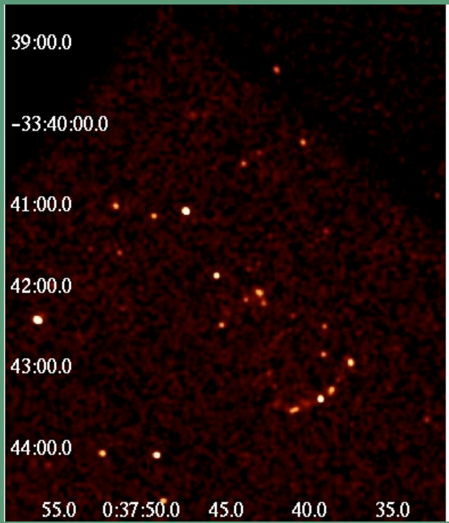


narrow-band EPIC-pn images

The Cartwheel galaxy

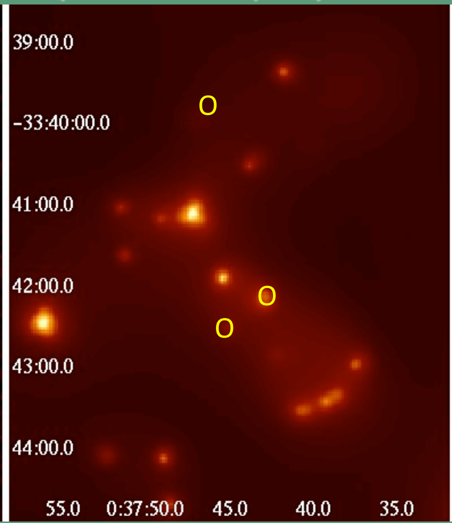
(Wolter et al 1999, 2004, 2006, Crivellari et al 2009, Pizzolato et al in prep)

Chandra (May 2001)



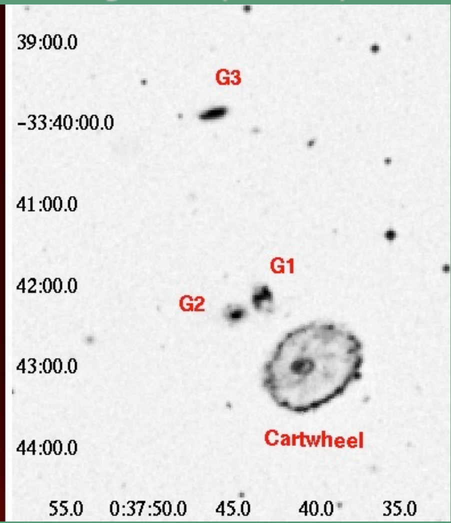
ACIS-S data smoothed with a 3″ Gaussian

XMM-Newton (Dec 04 – May 05)

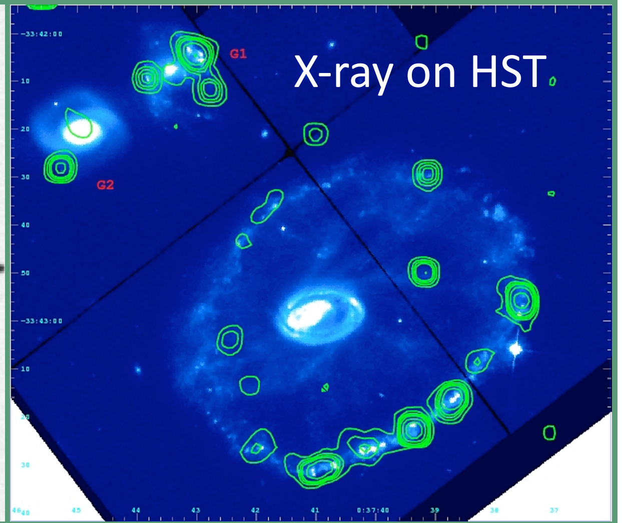


Sum of 2 pn datasets smoothed with a 3″ Gaussian

Digital Sky Survey



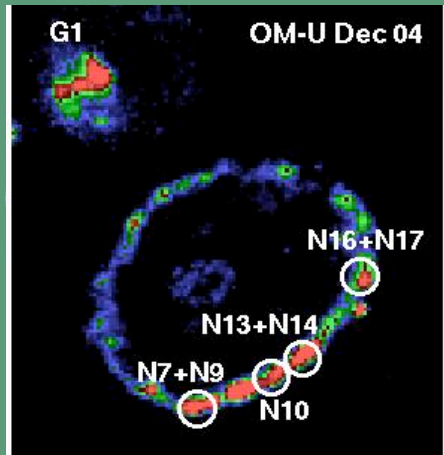
Cartwheel group as defined by Higdon (1995)

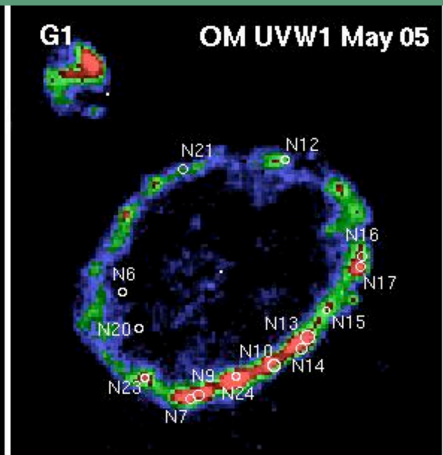


- ~20 sources in ring, ~15 ULX ➔ N10 @ 10^{41} erg/s
- G1/ G2/ G3 and group gas also detected @ ~10^{40} erg/s each
- Gas: Total $L_x \approx 6\ 10^{40}$ erg/s

~50% of unresolved emission in ring

$M_{gas} \approx 5\ 10^8\ M_{\odot}$ in ring





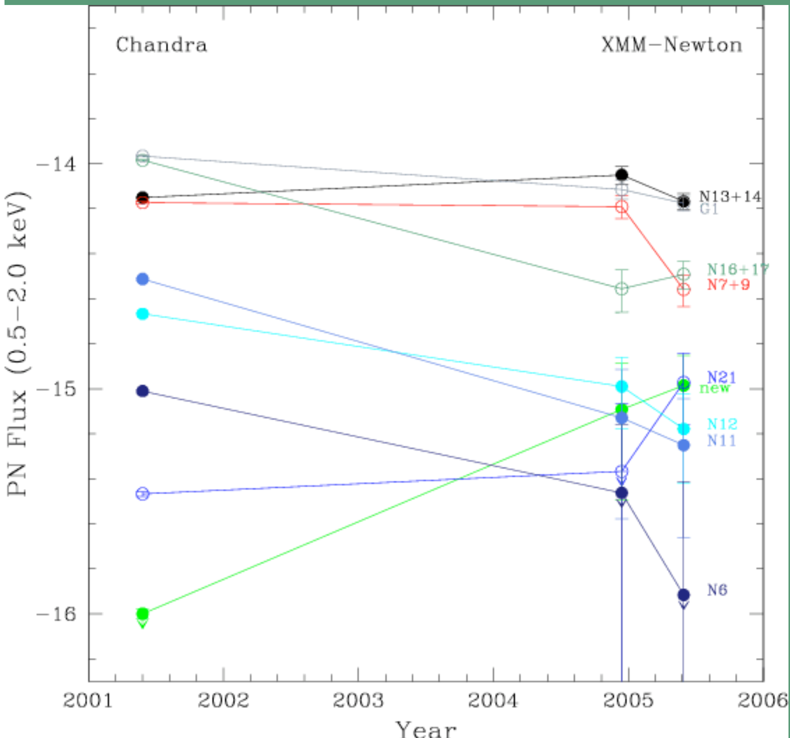
The Cartwheel galaxy

(Wolter et al 1999, 2004, 2006, Crivellari et al 2009, Pizzolato et al in prep)

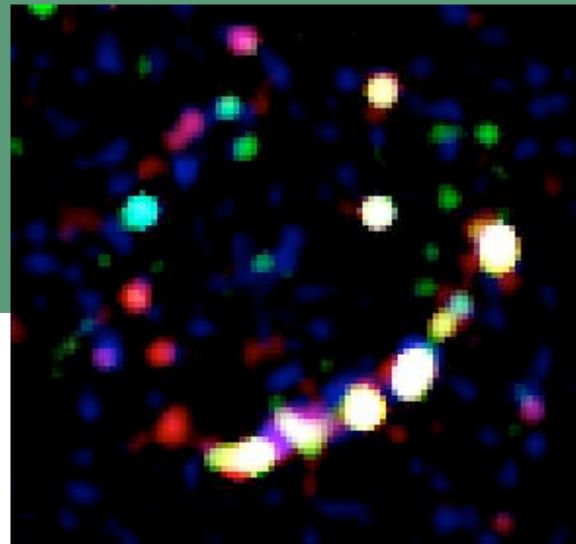
variability

Chandra - XMM

XMM - XMM



Ch-Ch-Ch



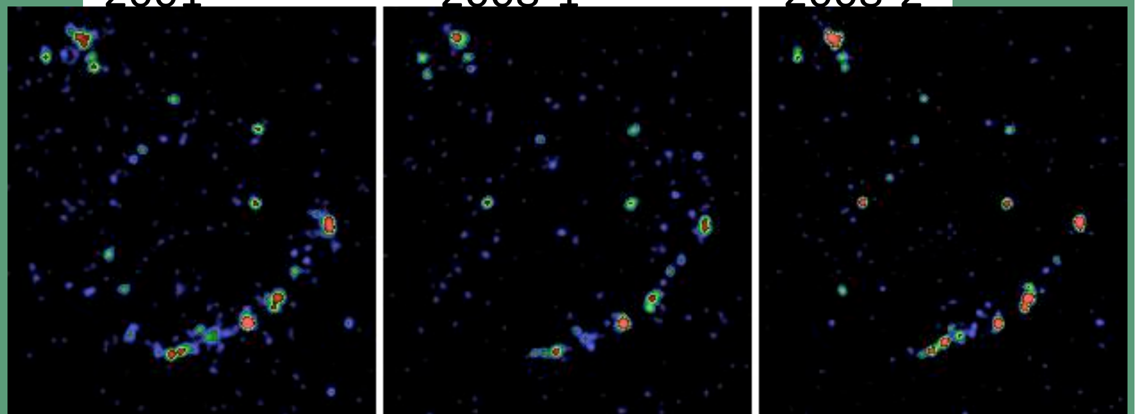
3 epoch Chandra

2001: red

2008-1 : green

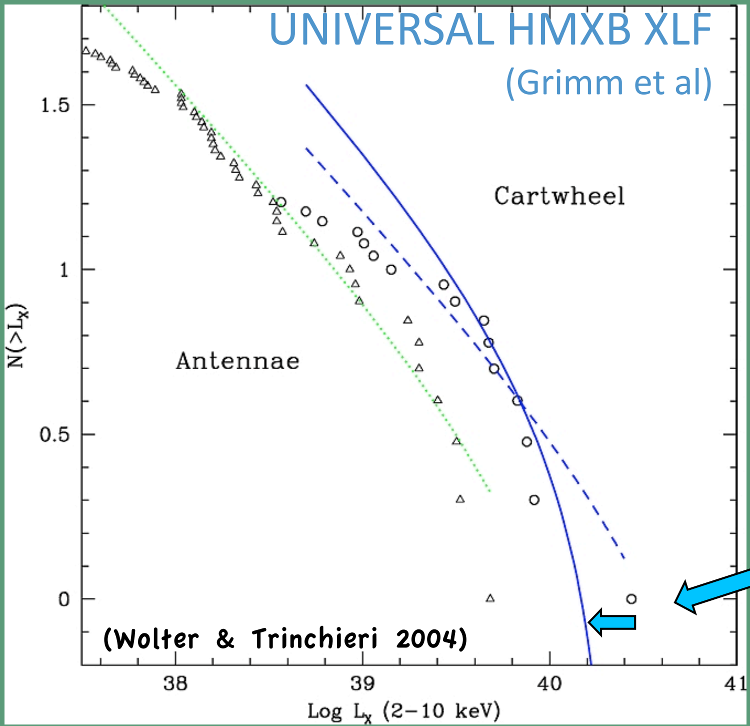
2008-2 : blue

2001 2008-1 2008-2

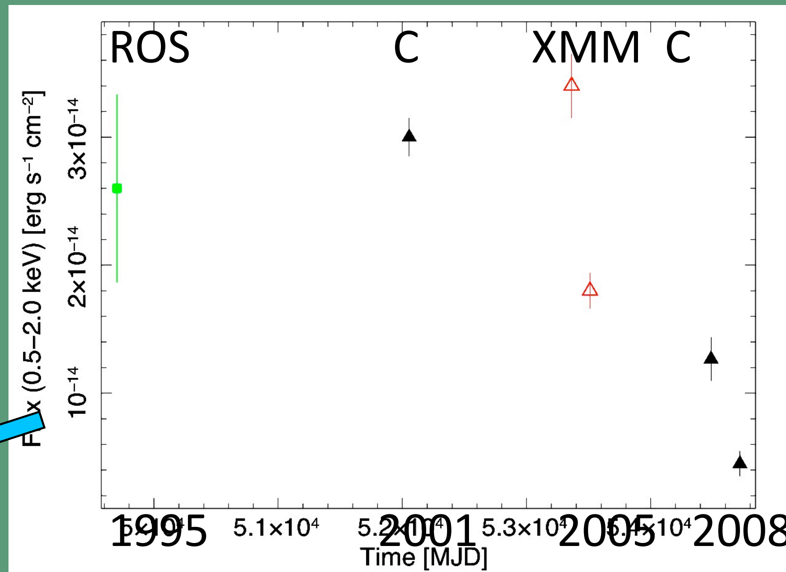


The Cartwheel galaxy

(Wolter et al 1999, 2004, 2006, Crivellari et al 2009, Pizzolato et al in prep)



Light curve of ULX n. 10



Antennae: SFR = 7 Msun/yr

Cartwheel: SFR = 20 Msun/yr

(see Mayya et al 2005)

Accreting Compact source or SN?

If accreting source: ~100 Msun BH

SN hypothesis cannot be rejected

Talk by Zampieri

Early type Galaxies in the local universe

- ✓ hot gas: Extended and highly disturbed @ center
- ✓ binaries: brightest are individually detected

Credit: NASA/CXC/UFRGS/R.Nemmen et al.

Which are "normal"?

Best studied/brightest are central group objects!

Are they special cases?

Relatively little info on "normal" systems ➔ fainter

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What I will not cover

[among others]

- **Metallicity:** better agreement with stellar metallicities, around solar. Possibly non-solar ratios. Where do "low-luminosity" objects fit?
- **AGN feedback:** spectacular images of cavities / rims and [anti]correlation with radio lobes
- **XLF of LMXB:** similar in different objects, normalization linked to stellar mass AND GC relative freq. Extended down to ~$10^{36\text{-}37}$ erg/s. "Universal" break?
- **Field vs GC XLF:** clear deficit of low luminosity sources in GC - implication for LMXB formation

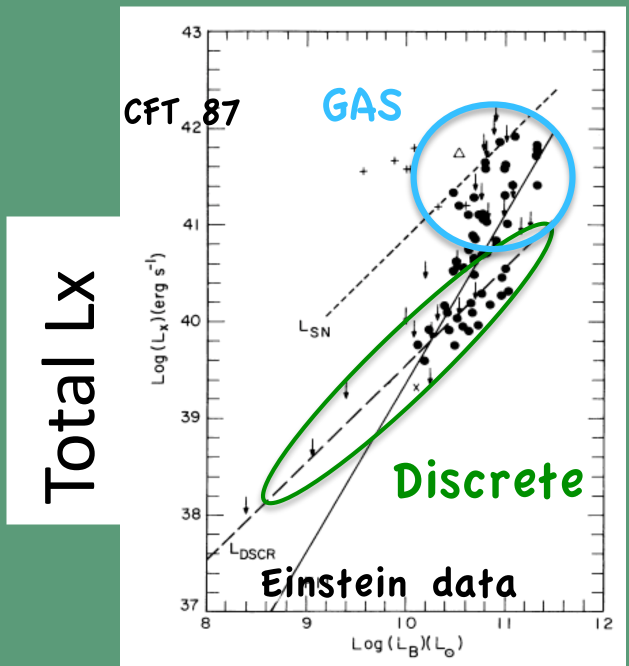
Talk on ISM/IGM

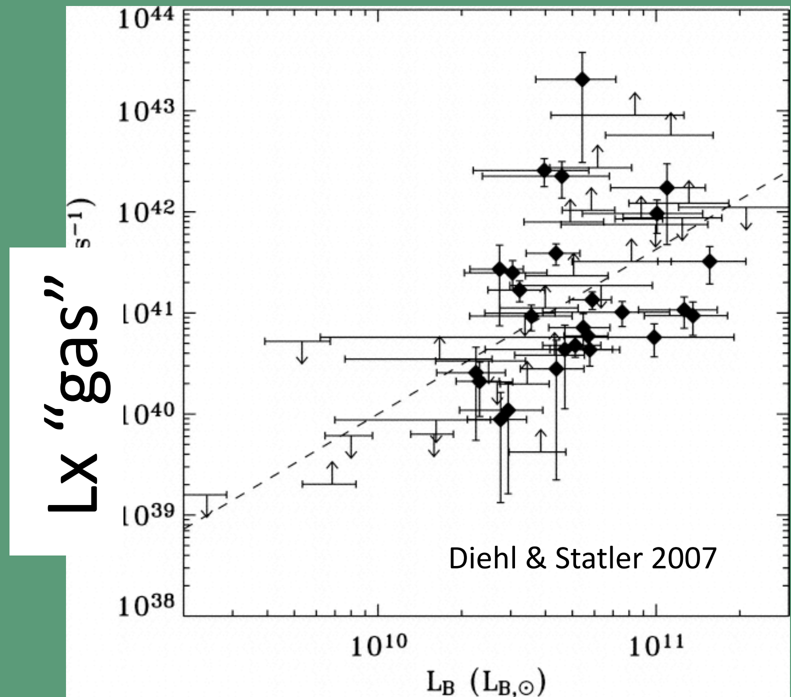
Posters on GC-LMXB connection

How much gas is in “normal” galaxies

- **Discrete sources** @ low Lx --- Now clearly observed in images
  ~ proportional to mass/GCs → Predictable when not measured!

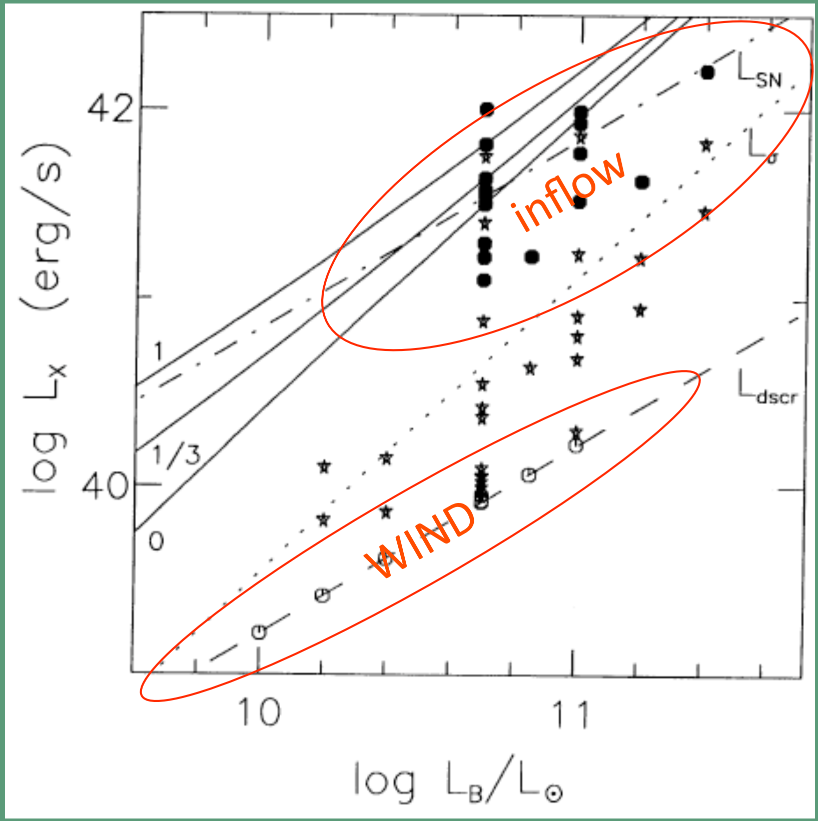
- **Hot gas** @ high Lx large scatter
  (>100x @ L_B~10^{11}) → correlation with galactic properties?





How do we interpret the scatter?

Modeling for gas component. For ex:



Inflow/outflow (winds) (Ciotti et al '91)

Inflow→ keep gas in system
→ high Lx

Outflow→ clean out the gas
→ low Lx

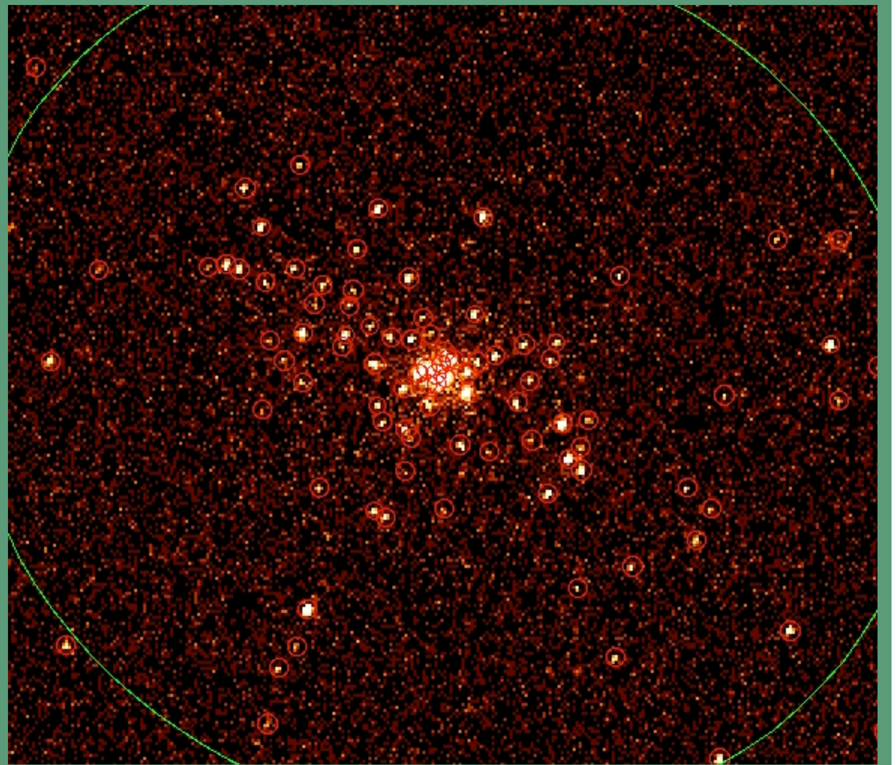
Note : Assumed to work in low luminosity systems (e.g. David et al. 2006) **, winds are hard/impossible to detect!**

1 case so far: NGC3379

Trinchieri with Pellegrini Brassington Fabbiano Fu Kim Zezas Gallagher DavisKalogera Angiolini Davies King Zepf 2008

NGC 3379 (Trinchieri et al 2008)

- "Prototypical" E at D=10.8 Well studied at many ν
  Age = 9.0±2.3 Gyr;
  Little/no DM
- Deep Chandra obs:
  98 sources in D_{25}
  down to $L_X \sim 10^{36}$ erg s^{-1}
  Brassington et al 2008
- residual unresolved
  emission @ $L_X \sim 10^{38}$ erg s^{-1}
  ➔ gas or stellar sources?
  Min. L_X ~3-5 10^{39} $M/10^{12} M_\odot$ erg s^{-1}
  expected from stellar-type
  XS – coronae, RS CVn, SSS
  (see M 32, NGC 891, MW ridge Revnivtsev et al. 2007, Pellegrini et al. 2007)



ACIS-S merge of 5 observations
raw data & detected sources within D_{25}

NGC 3379 (Trinchieri et al 2008)

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- residual unresolved emission @ $L_X \sim 10^{38}$ erg s^{-1}
  → gas or stellar sources?
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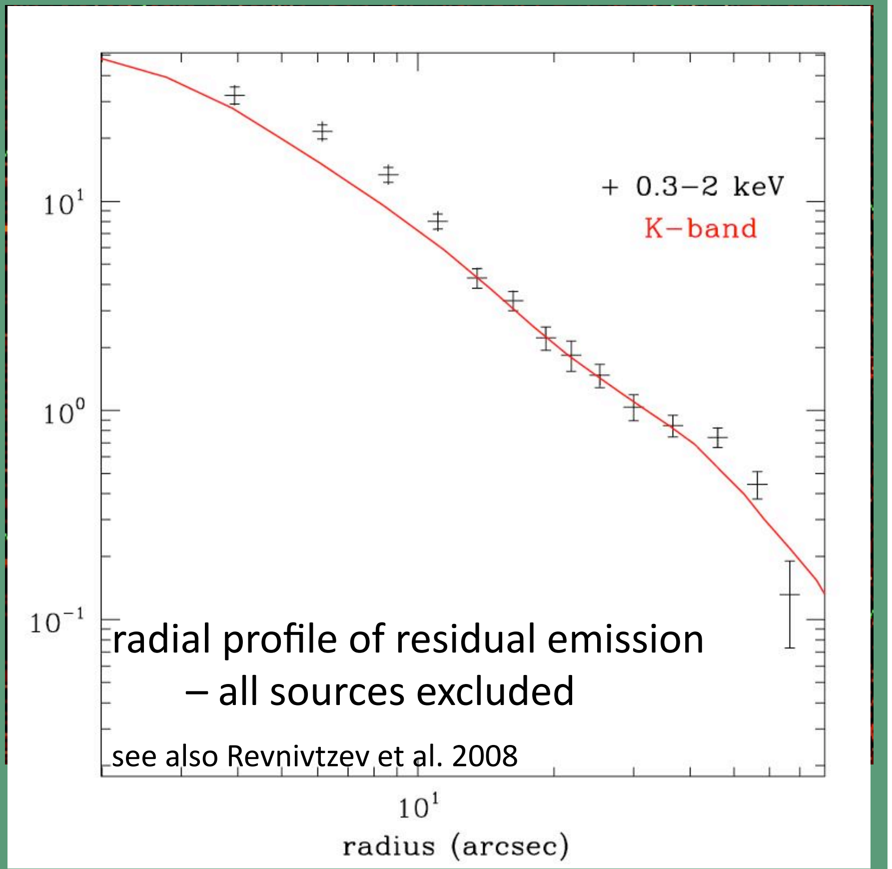
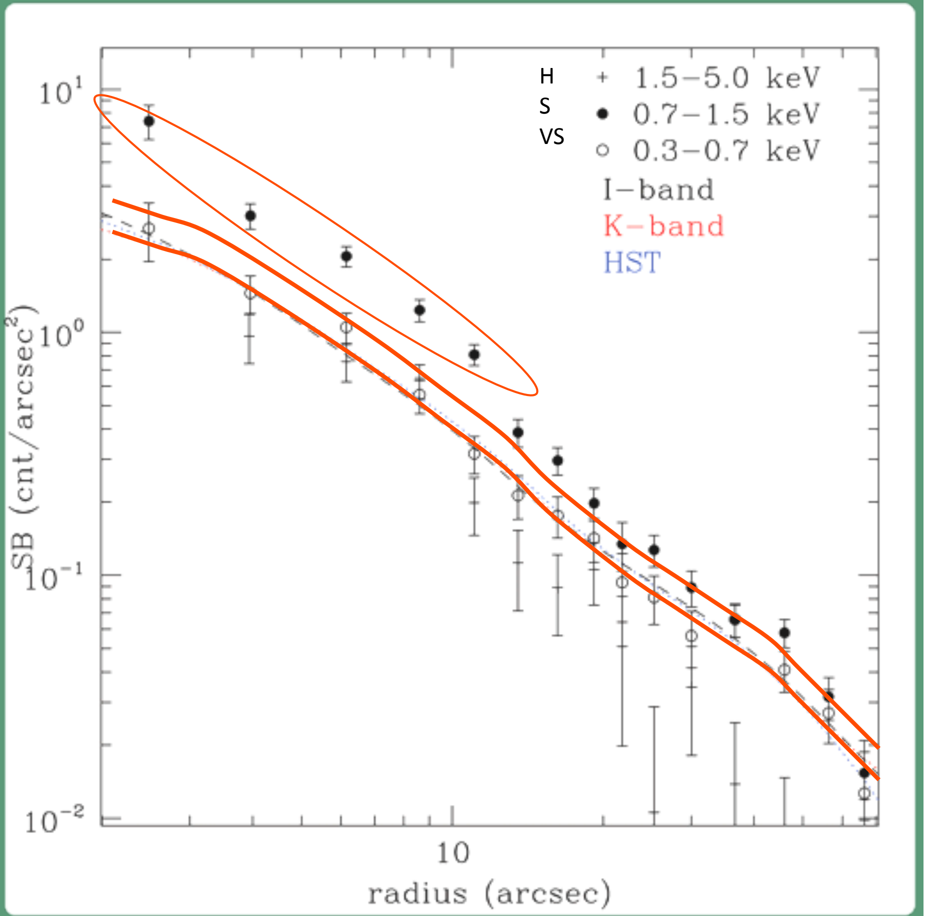


Radial Distribution

- Radial profile in “suitable” bands dictated by spectrum
  - Very soft 0.3-0.7 keV
  - Soft 0.7-1.5 keV
  - Hard 1.5-5.0 keV
- Compare one another and with optical/IR
  - Very soft ~ hard ~ opt/IR
  - Soft STEEPER than
    Very soft
    hard
    opt/IR

  ➔ but comparable outside 15”



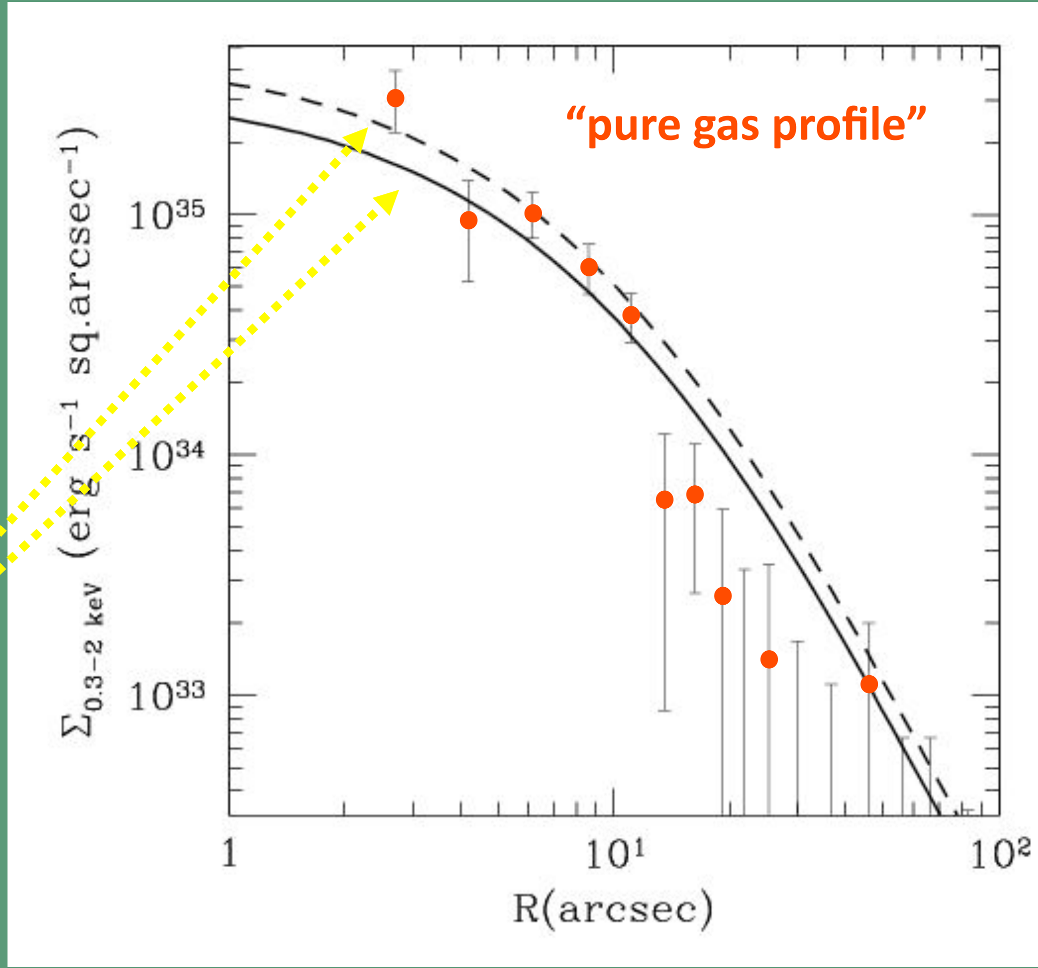
- Soft emission has clear excess at r<15´´

➔ L_x~4x10^{37} erg s^{-1} (0.5-2.0 keV)

Gas in an outflow phase? ✓YES

- Hydrodynamical simulations tailored to NGC 3379
- Assume passive evolution and age=9 Gyr
- Use: observed L_B, velocity dispersion, total stellar mass
- Time evolving inputs:
  - stellar mass loss
  - SNIa heating

→ Predicted profiles for 2 SNIa decay rates



- Gas in **outflow** phase:

L_X~4×10^{37} erg s^{-1} (0.5-2.0 keV) (vs 2) M_{gas}~ 3×10^5 $M_\odot$ (vs 5)

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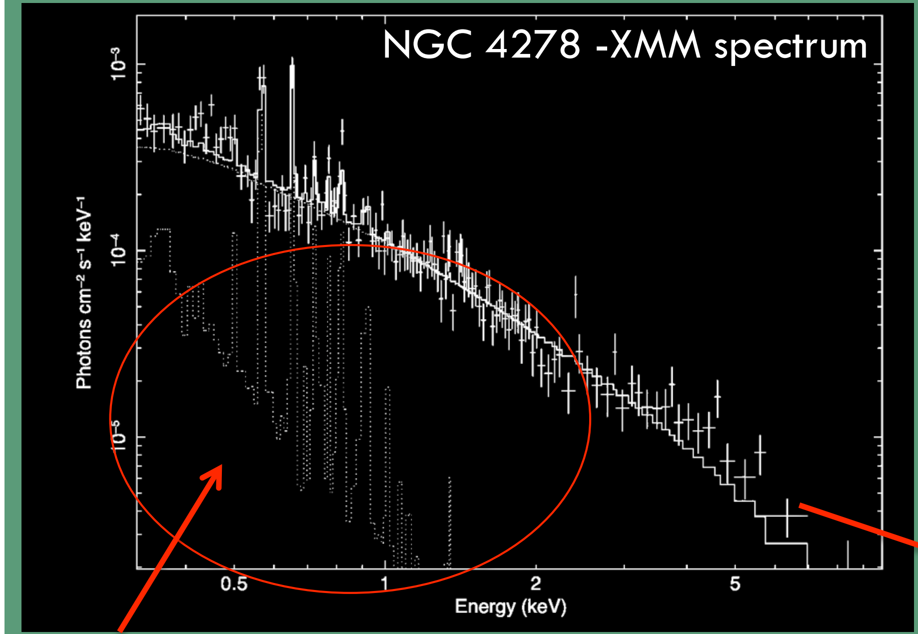
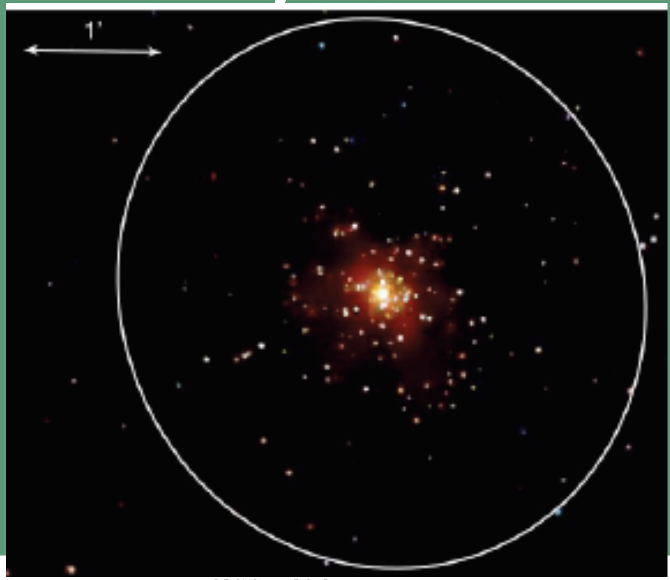
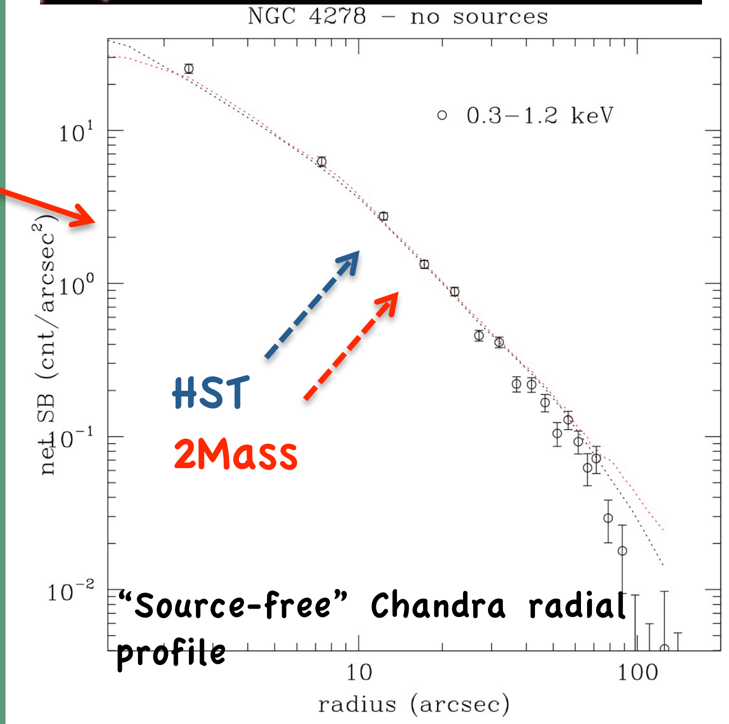
However : how many can we actually find?

e.g. NGC 4278 - same quality Chandra data







"Source-free" Chandra radial profile

"plasma" component - but

How much is hot ISM/how much is "stars"? No spatial/spectral signature to help us!

Can we understand the Lx/Lb[k] plane?

Select sample "appropriately"

➔ Morphology [E/S0] eg. Eskridge et al. '95

➔Shape [Bender et al '89, Pellegrini '94, Ellis & O'Sullivan '06 Kormendy et al '09]

* Boxy-core : X-ray gas and powerful AGNs
* Disky-coreless : no X-ray gas no strong RS

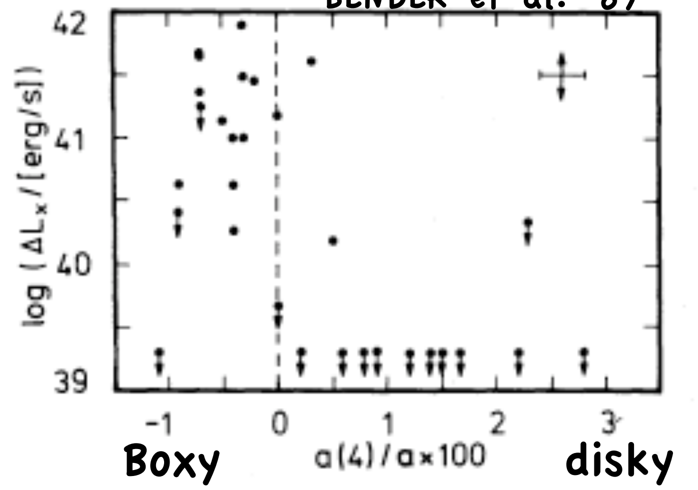
➔ Total / luminous Mass Central velocity dispersion

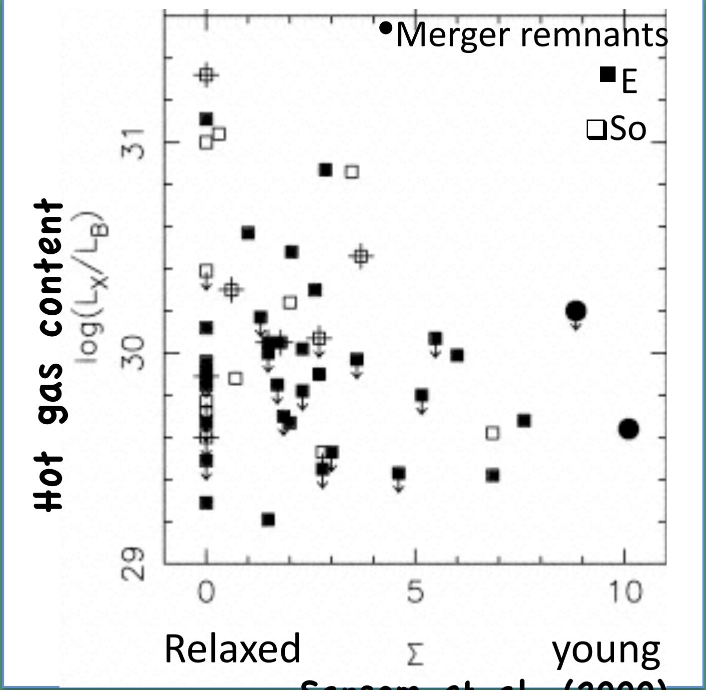
➔ Evolutionary history (Fabbiano & Schweitzer 1995, Samson et al 2000, Nolan et al. 2004, Brassington et al 2007):

* young galaxies are fainter

How many are central group galaxies?

BENDER et al. '89





Sansom et al. (2000)

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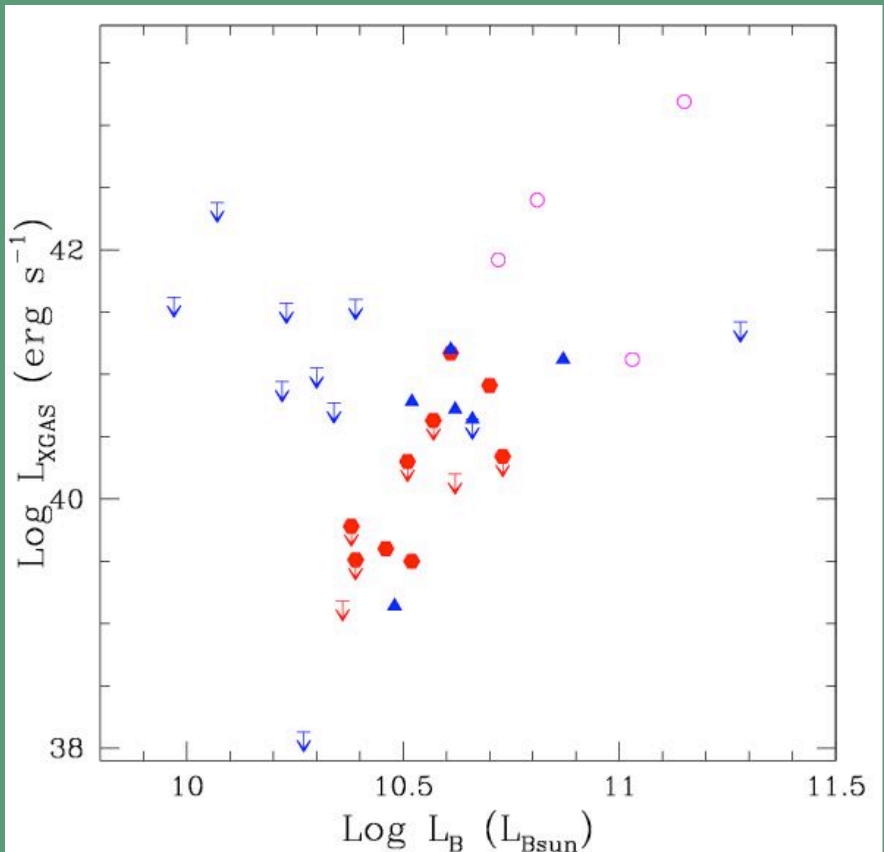
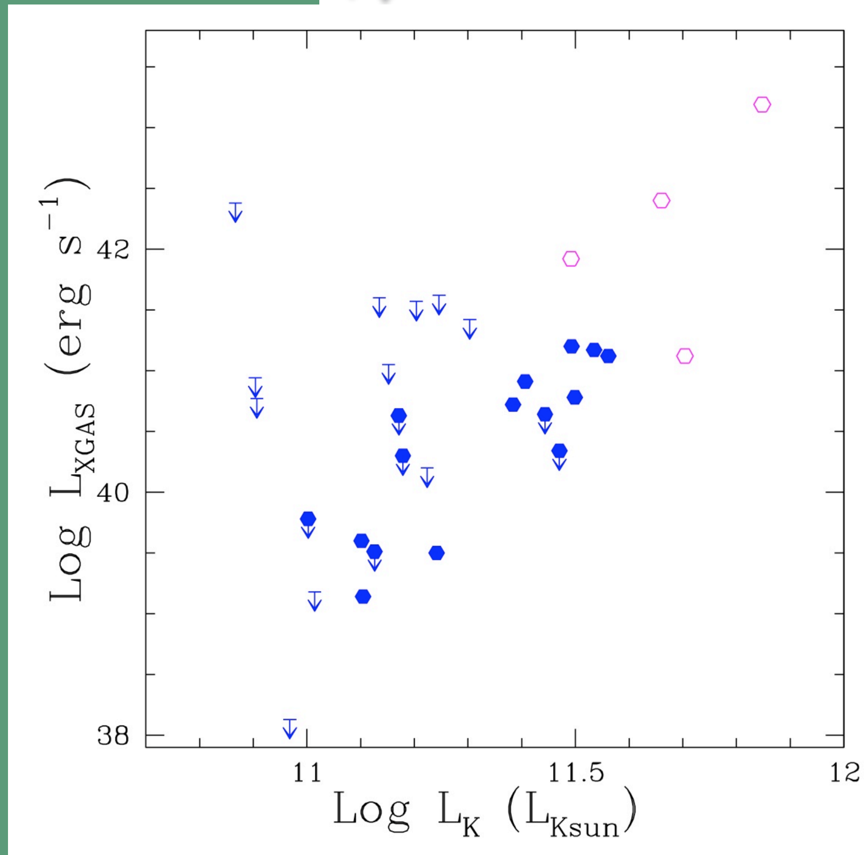
"truly isolated" early-types:

is this a guarantee of a more homogeneous behaviour?

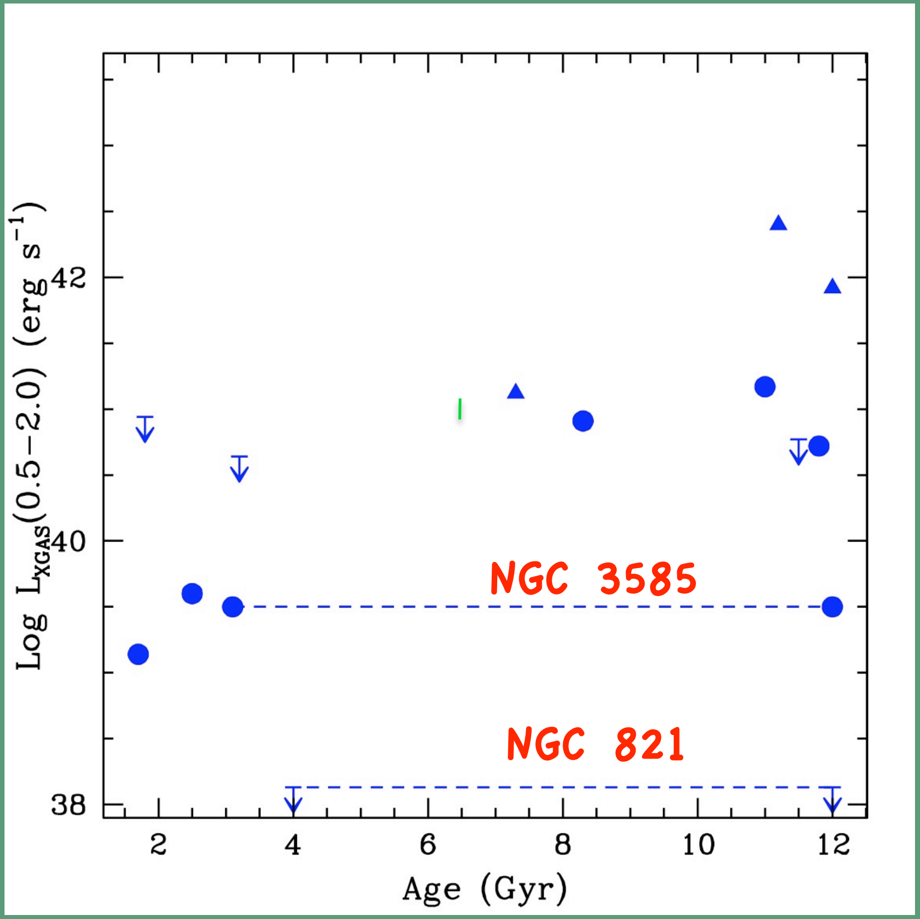
Isolation defined as "no companions" within Δmag~2-3, Δv~500-1000, Δrad~0.4-1 Mpc as in Smith et al '04, Reda et al '04, AMIGA, Memola et al. 2009

- ▲ literature
- ● archival/proprietary
- ○ fossil groups (X-ray evidence)
- gas u.l. ↓ Total u.l.

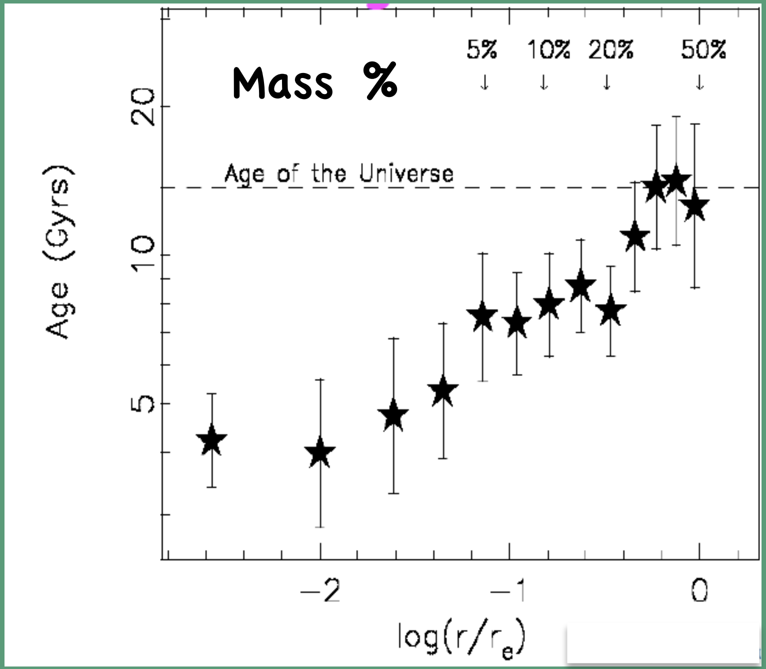




What about age?



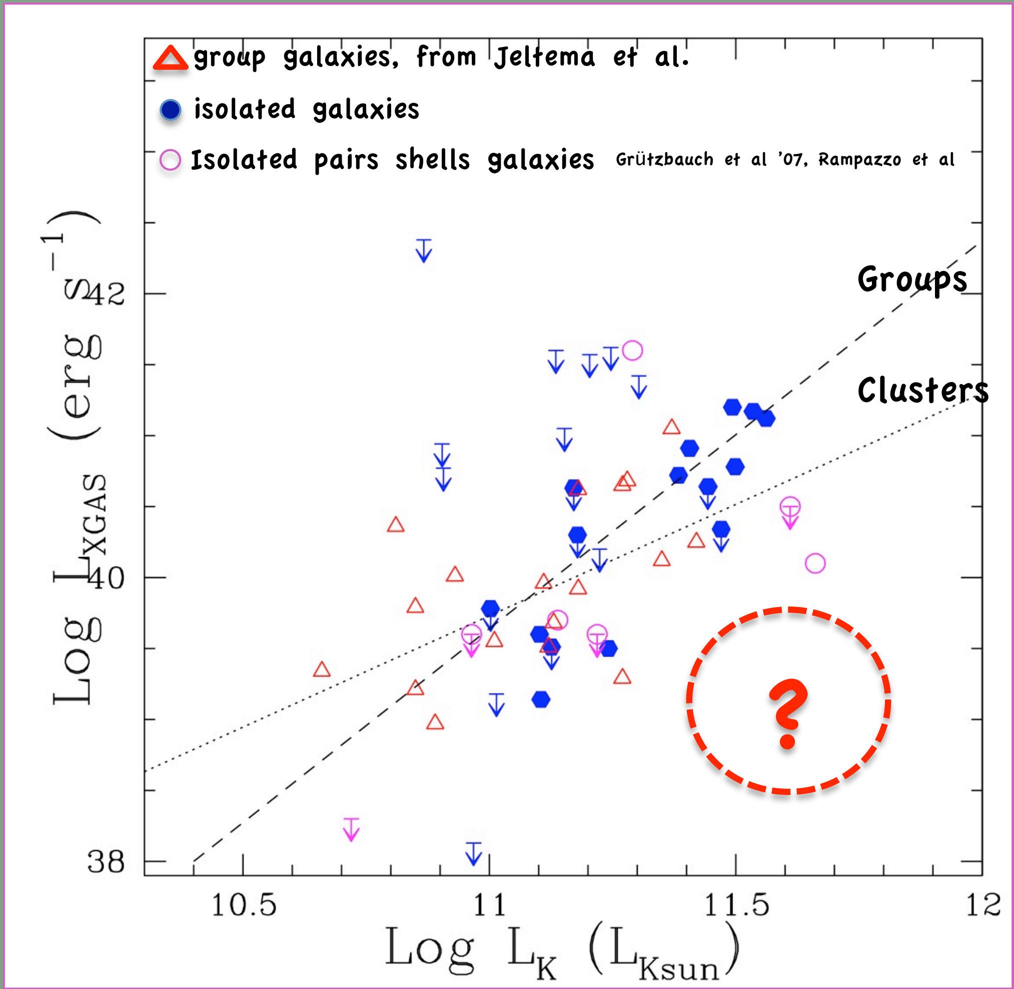
NGC 821: Proctor et al. 2005
[Adapted from talk by D. Forbes, Granada 2009]



luminosity-weighted age vs radius

burst of star formation fuelled by in situ gas from the galaxy itself

“Less extreme” yet “poor” environments



Excluding central bright galaxies is not the answer

Mass/Lum issue?
Galaxies “can” loose the hot gas produced only for “low” L/M?

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The future

Since galaxies are

- *Faint*
- *Complex*
- *In complex* environments

→ high spatial [spectral] resolution
→ large FoV
→ large throughput

Poster

Thank you