

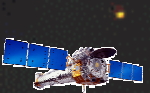
First Results from the Extended Chandra Deep Field South (E-CDF-S)

Anton Koekemoer

(Space Telescope Science Institute)

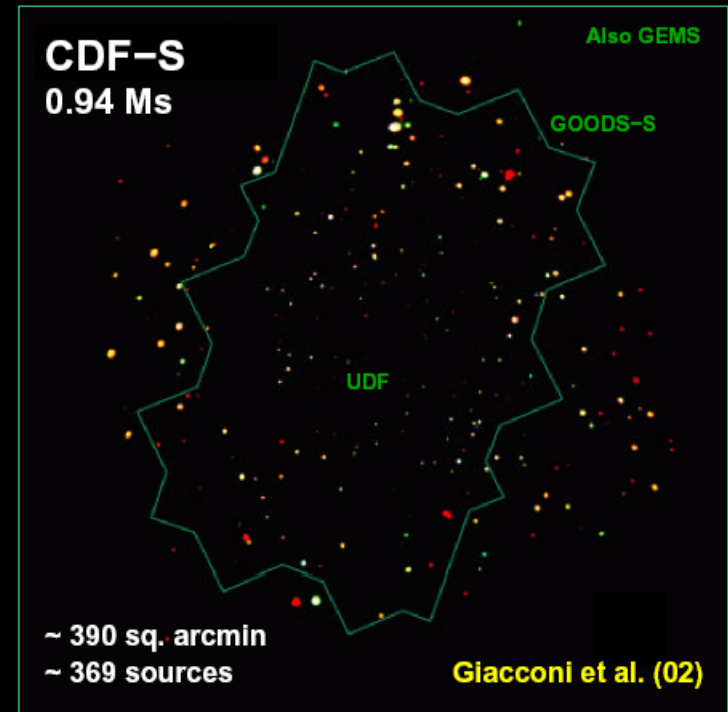
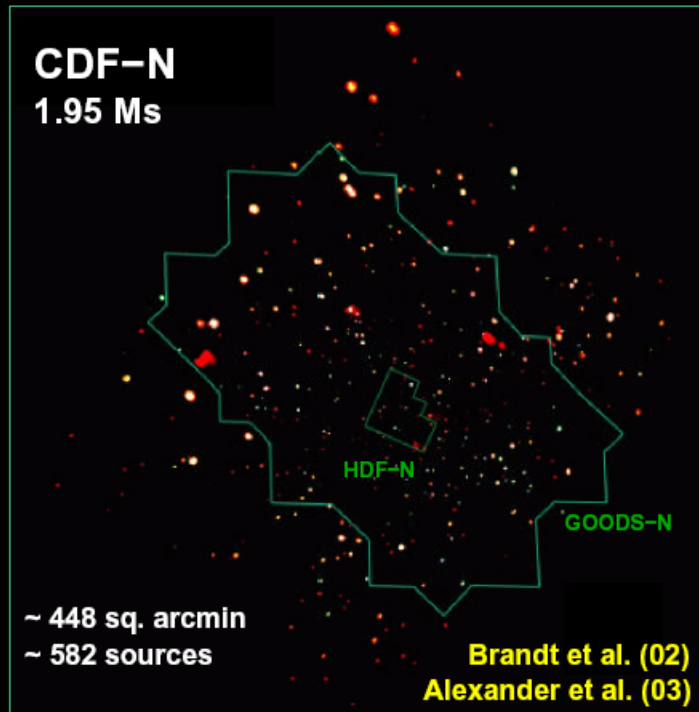
on behalf of the E-CDF-S Team:

Niel Brandt (PI), Bret Lehmer, Dave Alexander, Franz Bauer, Don Schneider, Paolo Tozzi, Jacqueline Bergeron, Gordon Garmire, Riccardo Giacconi, Roberto Gilli, Günther Hasinger, Ann Hornschemeier, Anton Koekemoer, Vincenzo Mainieri, Takamitsu Miyaji, Mario Nonino, Piero Rosati, John Silverman, Aaron Steffen, Guyla Szokoly, Christian Vignali



Original Chandra Deep Fields

*Chandra Deep Fields Overview: Anton Koekemoer
6 Years of Science with Chandra - Nov 2005*



Multi-wavelength follow-up - "GOODS":

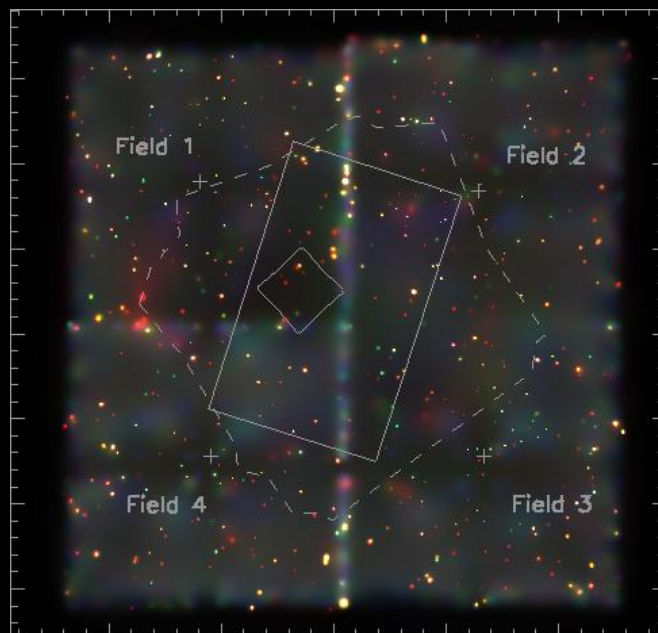
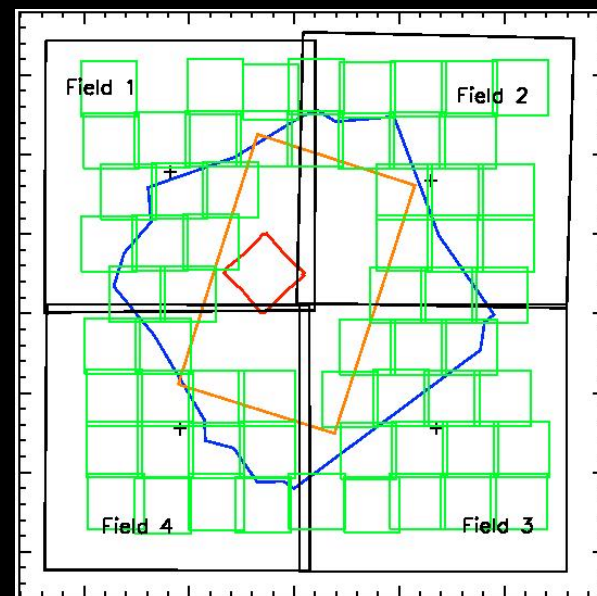
- **HST/ACS:** BViz (Giavalisco et al. 2004)
- **SPITZER:** 3.6 - 24 μm (Dickinson et al. 2004)
- **VLT,CTIO,KPNO,Subaru:** uBVRizJHK
- **VLA,ATCA,...** (Afonso et al. 2005, Koekemoer et al. 2005,...)



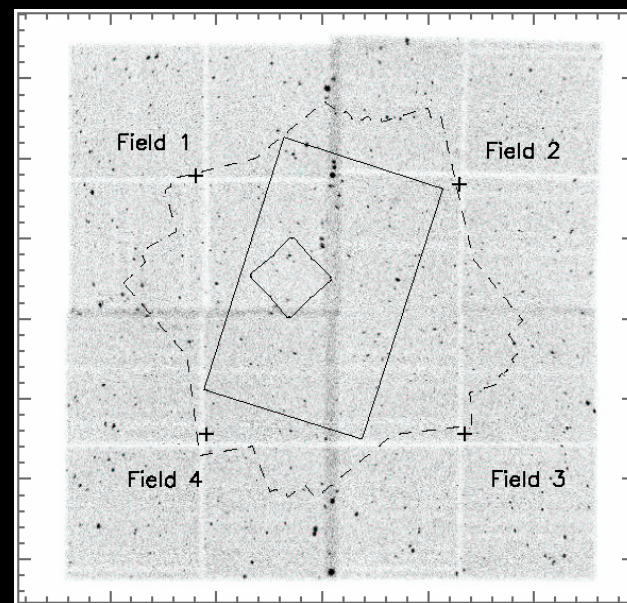
Extended CDF-S (E-CDF-S)

*E-CDF-S Overview: Anton Koekemoer
6 Years of Science with Chandra - Nov 2005*

- Large-scale structure & angular correlation
- Better statistics for rare sources:
 - growth of AGN at high z
 - nature of Type 2 QSOs
 - evolution of star forming galaxies
 - off-nuclear ULX's in normal galaxies



0.5-2.0 keV (red)
2-4 keV (green)
4-8 keV (blue)

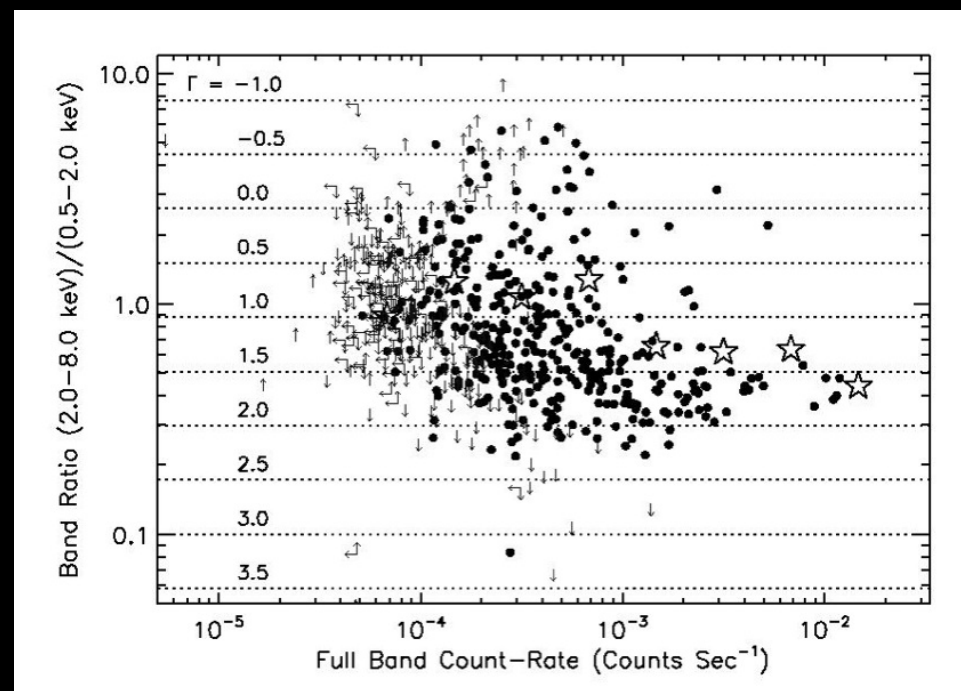
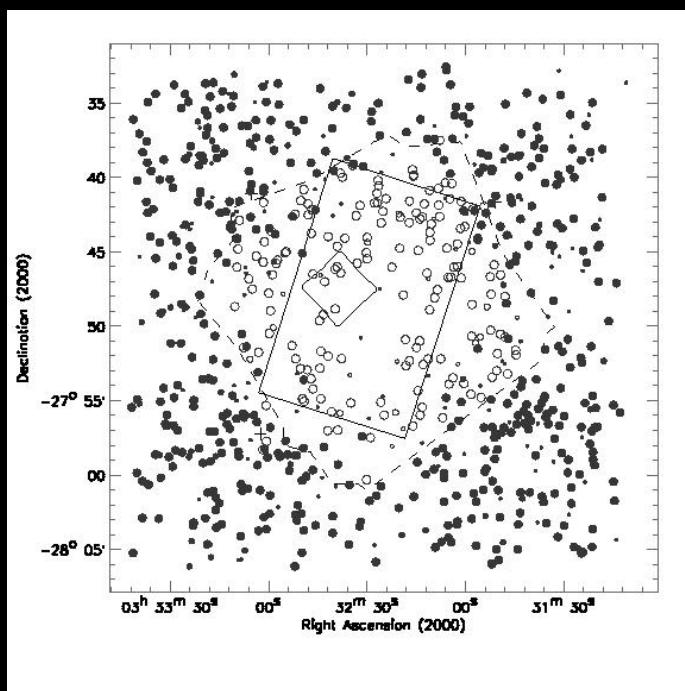


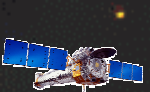


E-CDF-S: Observations

*E-CDF-S Overview: Anton Koekemoer
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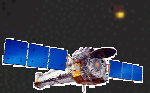
- ACIS-I, 9 observations, Feb 29 - Nov 20, 2004
- Centered on CDF-S: R.A.=03^h32^m28.0^s, Dec=-27°48'30"
- 4 fields, 250 ks each: total 33' x 33' (0.3 sq deg)
- 1.1×10^{-16} & 6.7×10^{-16} erg s⁻¹cm⁻² (0.2-2 keV, & 2-8 keV)
- Full catalog 915 sources: Lehmer et al. 2005, ApJS 161, 21





First Science Results

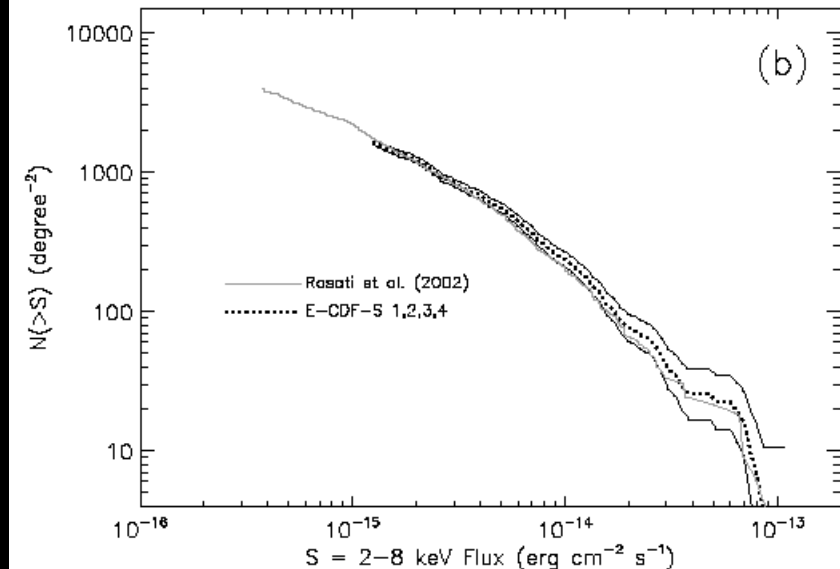
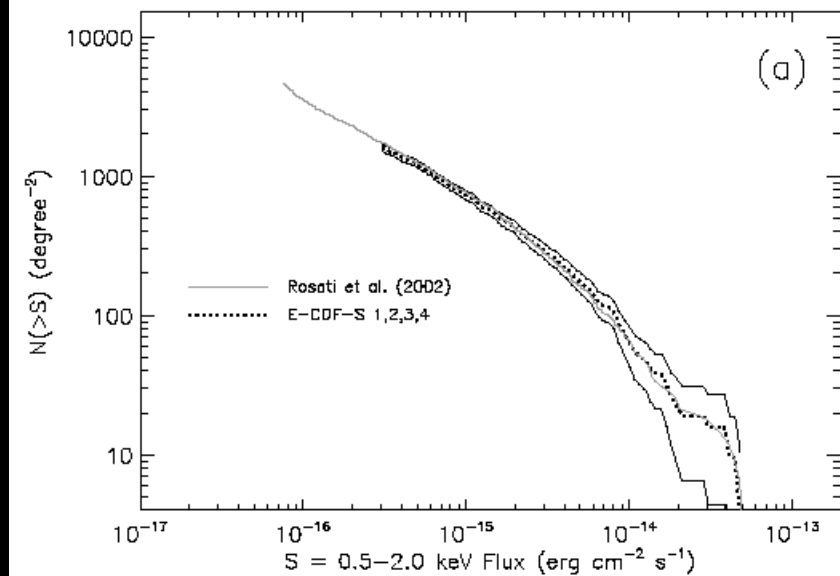
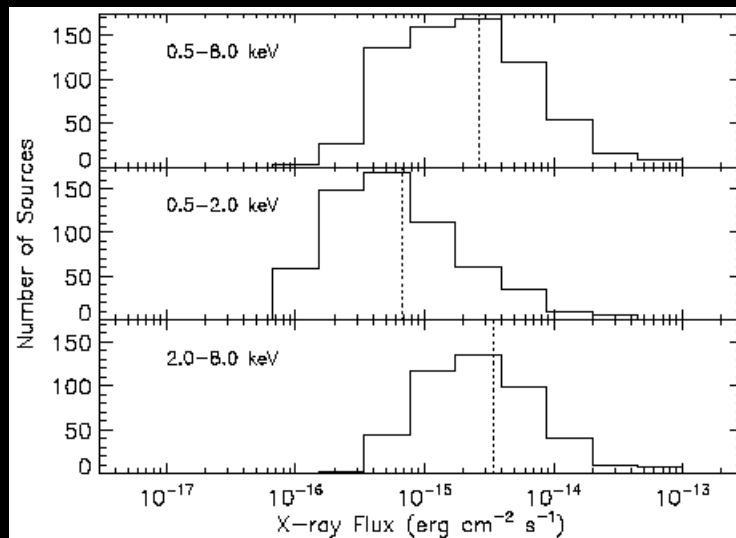
- Source catalog & properties; Clusters:
 - Lehmer et al. 2005, ApJS 161, 21
- Alpha_{ox} over redshift and luminosity:
 - Steffen et al. 2005, ApJ, submitted [Poster #1.18]
- Off-nuclear ULX sources
 - Lehmer et al. 2005 [Poster #4.9]
- Angular auto-correlation function (ACF)
 - Gilli et al. 2005
- X-ray / galaxy cross-correlation function (CCF)
 - Miyaji et al. 2005 [Poster #4.10]
- Optical follow-up spectroscopy:
 - Silverman et al. 2005
- EXOs / High-redshift AGN:
 - Koekemoer et al. 2005



Catalogs Lehmer et al. 2005, ApJS 161, 21

*E-CDFS Overview: Anton Koekemoer
6 Years of Science with Chandra - Nov 2005*

- Obtained with WAVDETECT
- LogN LogS improve on CDFS
- Main catalog:
 - 762 sources in 250ks data
 - 589 new sources
 - (326 sources in orig CDFS)
- Supplementary catalog:
 - 33 weak sources, $R < 23$





Clusters

Lehmer et al. 2005, ApJS 161, 21

*Chandra X-ray Observatory: Anton Koekemoer
6 Years of Science with Chandra - Nov 2005*

- Searched for using Voronoi tessellation & percolation
- Criteria following Bauer et al. (2002) - yielded 3 sources
- Co-incident with optical clusters
- Fitted with Raymond-Smith $kT = 1.0$ keV

$$z = 0.73$$

$$z = 0.7$$

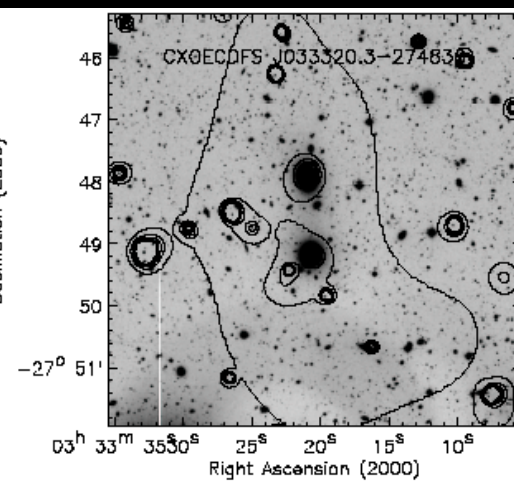
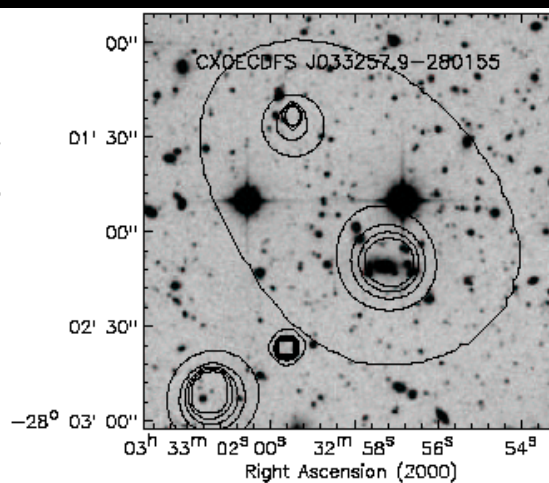
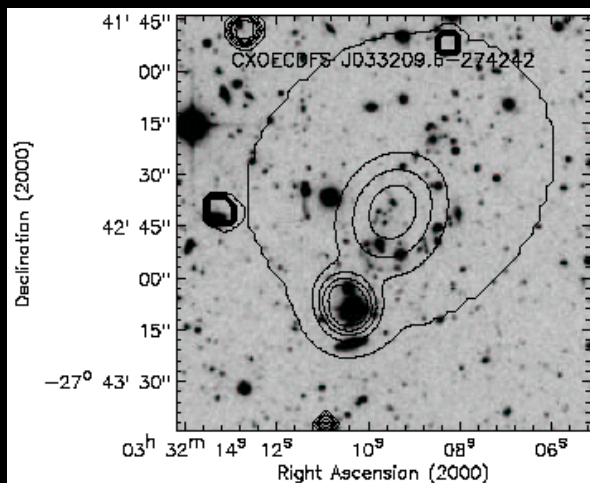
$$z = 0.1$$

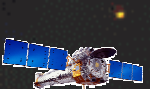
$$F_{0.5-2} = 2.2 \times 10^{-15}$$

$$F_{0.5-2} = 1.7 \times 10^{-15}$$

$$F_{0.5-2} = 1.7 \times 10^{-15}$$

$$L_X = 4.8 \times 10^{42} \text{ erg/s} \quad L_X = 4.1 \times 10^{42} \text{ erg/s} \quad L_X = 7.0 \times 10^{41}$$

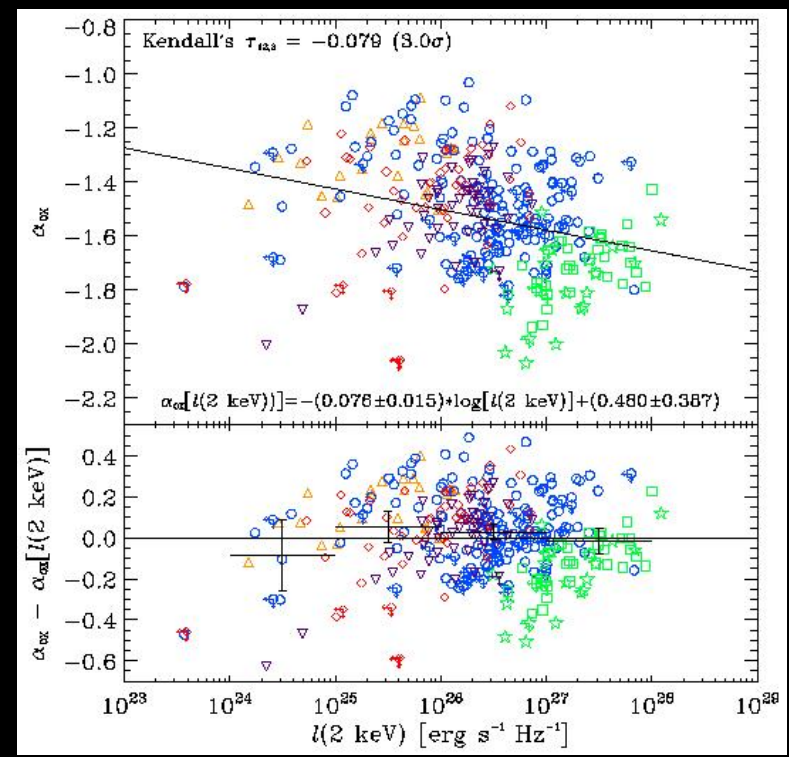
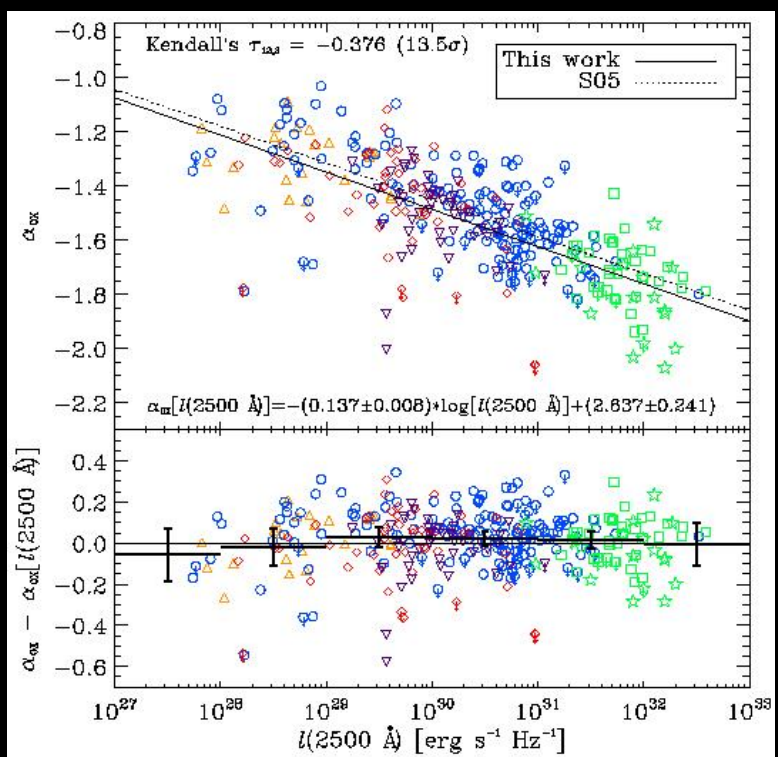


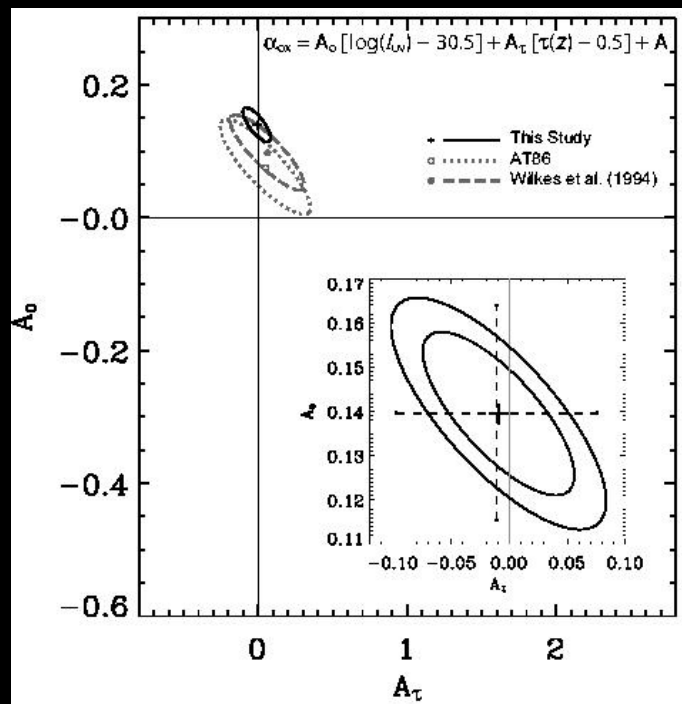
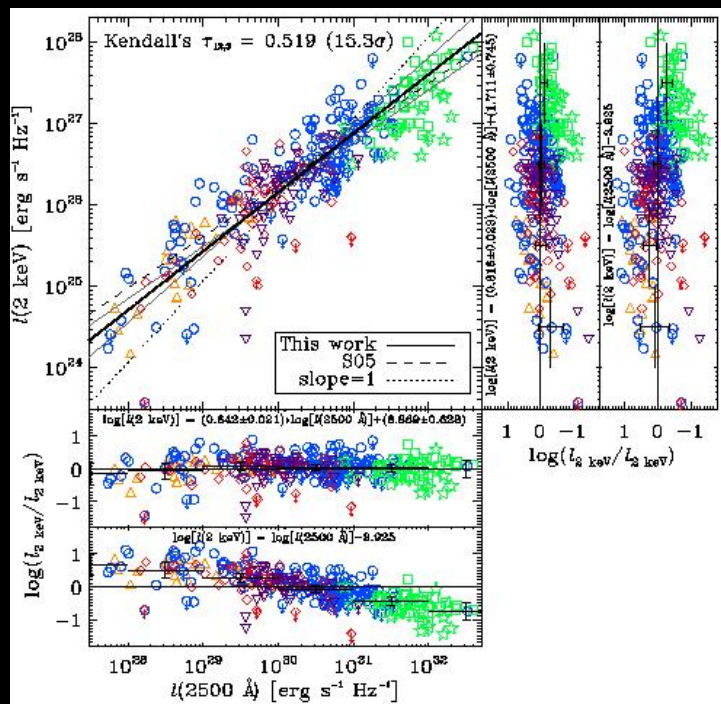
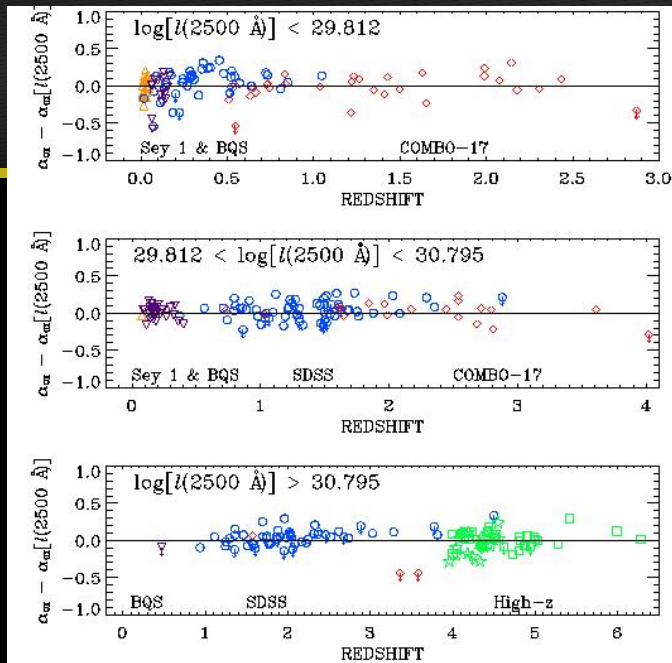
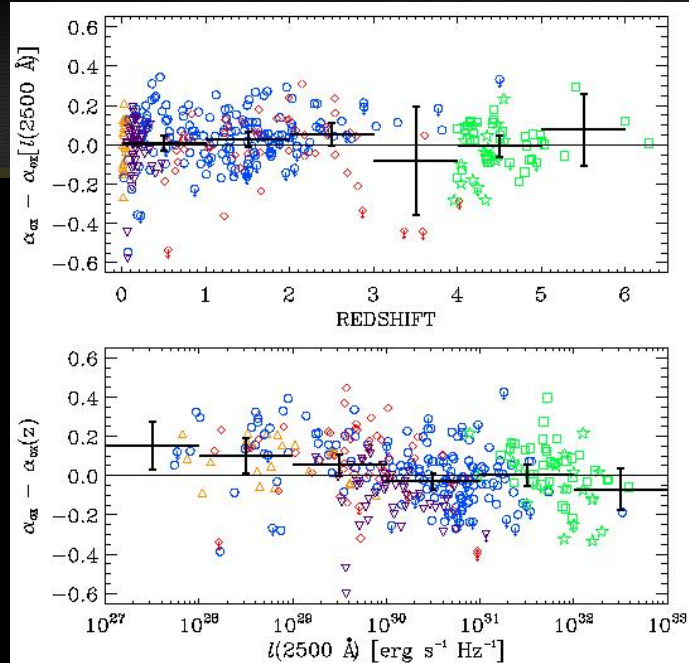


α_{OX} Steffen et al. 2005, ApJ subm [Poster #1.18]

Chandra Science Overview Anton Koekemoer
6 Years of Science with Chandra - Nov 2005

- α_{OX} strongly anti-correlates with I_{2500A} (13.5σ)
- Slope of correlation may depend on I_{2500A}
- α_{OX} anti-correlates with $I_{2\text{ keV}}$ (3σ)
- No significant correlation between α_{OX} and redshift (1.2σ); maximum evolution is 30% from $z \sim 0 - 5$



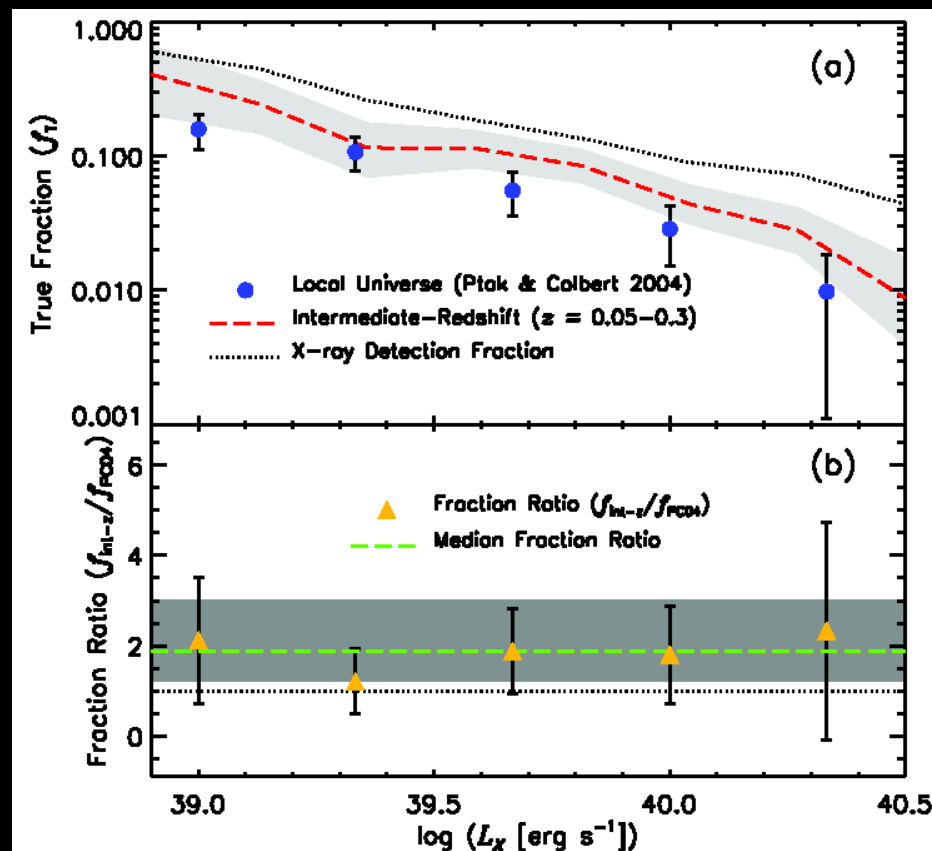
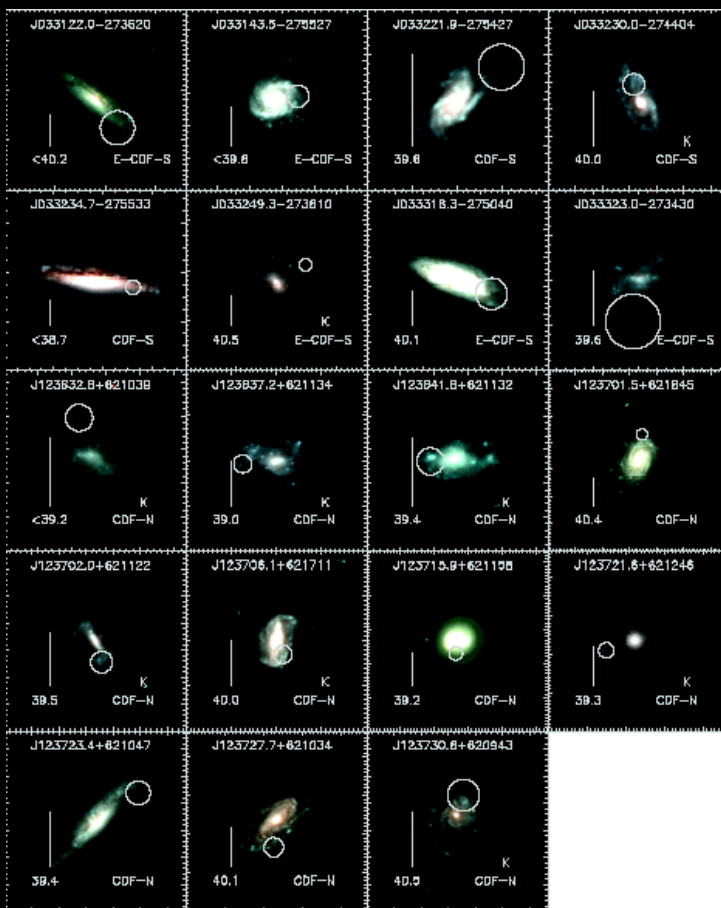


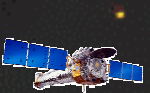


ULXs Lehmer et al. 2005 [Poster #4.09]

E-CDF-S Overview: Anton Koekemoer
6 Years of Science with Chandra - Nov 2005

- Expanded sample with E-CDF-S: 19 galaxies
- Fraction of galaxies containing ULX incr by 2x from $z=0-0.1$
- May correspond with increase in global SFR with z





- Two-point angular auto-correlation function (ACF) for 415 X-ray sources detected with $F_{2-10\text{keV}} > 2 \times 10^{-15} \text{ ergs}^{-1}\text{cm}^{-2}$
- Random sample generated using position-dep det limit
- Used Landy & Szalay (1993) minimum variance estimator:

$$w(\theta) = (DD - 2DR + RR)/RR$$

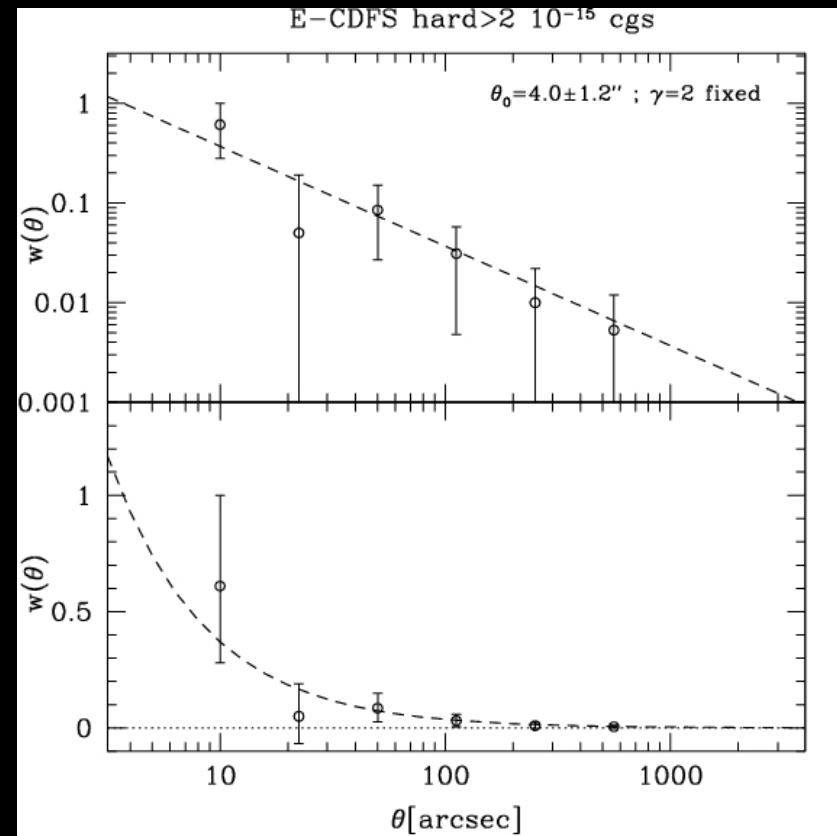
where DD, DR and RR are the normalized source-source, source-random, random-random pairs as a function of θ , respectively

- Detect 3σ correlation length:

$$w(\theta) = (\theta/\theta_0)^{1-\gamma}$$

$$\theta_0 = 4.0'' \pm 1.2''$$

if slope is fixed at $\gamma=2.0$

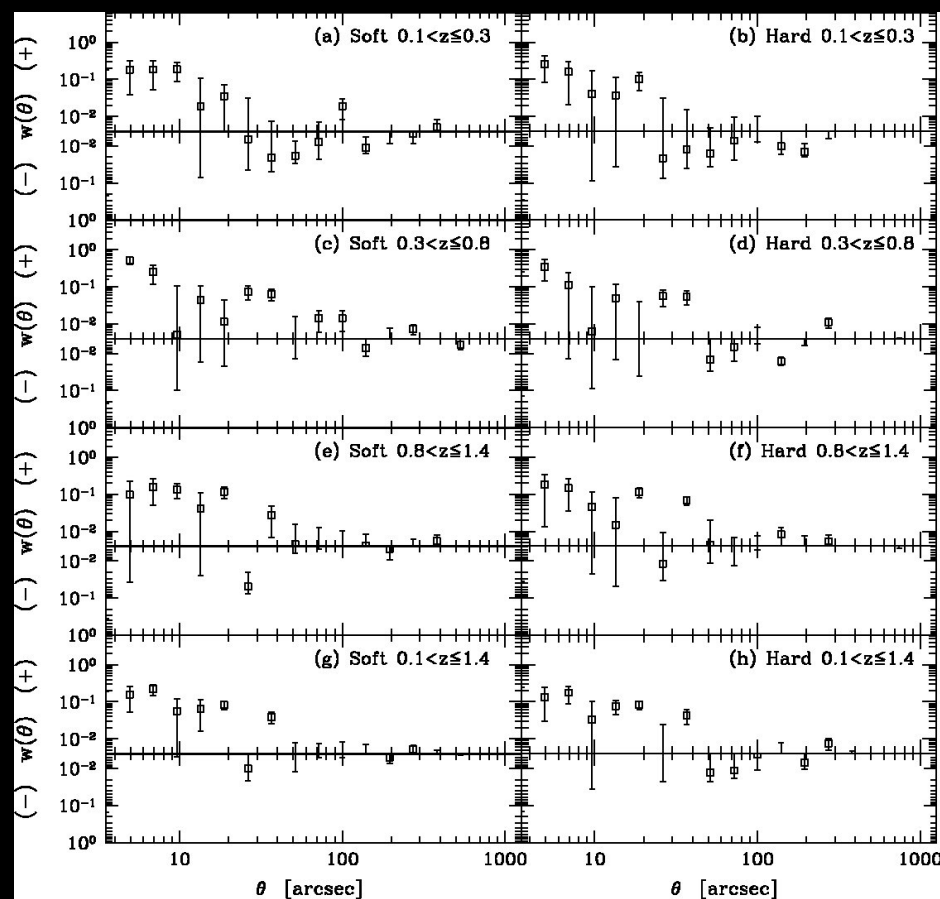


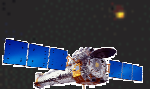


- Cross-correlate between Combo17 & X-ray sources
- Used modified Landy & Szalay estimator for X-ray/Galaxies:

$$w(\theta) = (D_X D_G - D_X R_G - R_X D_G + R_X R_G) / R_X R_G$$

- Used region where CDFS & Combo17 overlap: 0.25 sq deg
- Number of X-ray srcs:
 - soft: 453
 - hard: 371
- Number of Combo17:
 - z=0.1-0.3: 6931
 - z=0.3-0.8: 9981
 - z=0.8-1.4: 12855
- Detect signal for some

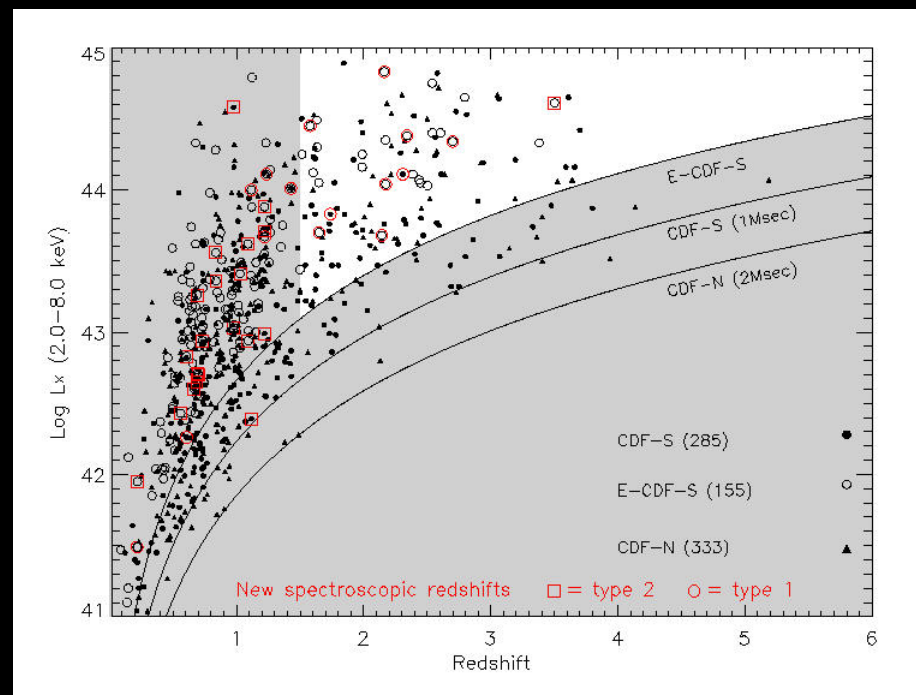
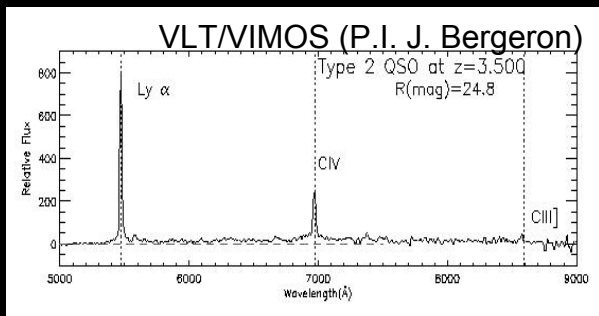
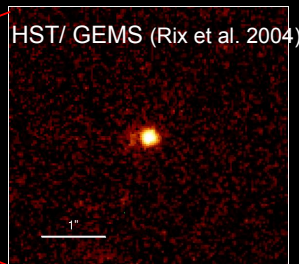
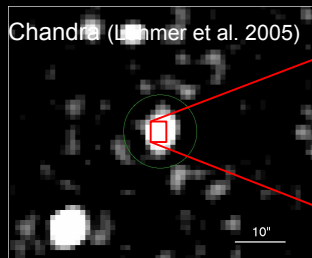




VLT Spectroscopy Silverman et al. 2005

E-CDF-S Survey: Anton Koekemoer
6 Years of Science with Chandra - Nov 2005

- Observe 4 VIMOS masks by end 2005 (PI: J. Bergeron)
- Proposed for 16 more VIMOS masks (PI: G. Hasinger)
- 67 new redshifts for X-ray sources in E-CDF-S
- 17 redshifts in the 1 Msec CDF-S field:
 - 8 new ids
 - 9 ids from Szokoly et al. 2005 confirmed with high confidence
- **New QSO2 at z=3.5:**



Summary

E-CDF-S - general properties:

- unique combination of area (0.3 sq deg) and depth (250ks)
- extensive multi- λ followup

Current results:

- E-CDF-S X-ray catalog: [Lehmer et al. 2005, ApJS 161, 21](#)
- α_{ox} anti-corr with $I_{2500\text{\AA}}$, $I_{2\text{ keV}}$ (Steffen et al. 2005) [#1.18]
- ULX's incr 2x by $z \sim 0.1$ (Lehmer et al. 2005) [#4.9]
- ACF: $\theta_0 = 4.0'' \pm 1.2''$ (3σ) with $\gamma=2$ (Gilli et al. 2005)
- CCF: some tentative detection (Miyaji et al. 2005) [#4.10]
- VLT: 67 new z 's, QSO2 at $z=3.5$ (Silverman et al. 2005)

Future/on-going work:

- HST/ACS-derived morphologies
- Radio, Spitzer properties
- More VLT spectroscopy . . .