Connecting Star Formation, Galaxy Evolution and the Growth of Black Holes

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Results published:

4 Ms *Chandra* Deep-Field South
The redshift distribution of the sources peak at $z \sim 1$. Quasars, the most powerful AGN, are mostly found at $z \sim 2-3$. The sources typically have X-ray luminosities $< 10^{44}$ erg/s. Again much less than quasars ($> 10^{45}$ erg/s).
Connection to Star-Formation History?

Juneau et al. (2005)
Prediction: *An AGN Type 2/Type 1 ratio that evolves with z*

Now good evidence for this:

Ballantyne et al. (2006) found that a Type 2 fract. $\propto (1+z)^{0.3}$ can fit the XRB and X-ray number counts.

Confirmed by Treister & Urry (2006) [0.4] and Hasinger (2008) [0.5]
Toward a Physical Model

- Need to explore the physics of a starburst disk around a black hole.
  - What properties (star-formation rate, fueling rate, metallicity) are required in order for a disk to obscure an AGN?
  - How might this change with the host galaxy’s evolution?
  - How does the AGN luminosity affect the disk structure?

- Currently, only simple analytic models are available (Thompson et al. 2005).
- Toomre’s Q=1
- Eddington limited
- Global torque assumed to operate on disk
- Competition between star-formation and accretion

Ballantyne (2008)

$M_{\text{BH}} = 10^8 \, M_\odot$
dust/gas factor $= 1$
m = 0.05
$R_{\text{out}} = 100 \, \text{pc}$
$f_{\text{gas}} = 0.90$
• 1260 starburst models
• Parameters:
  • $M_{BH}$
  • $R_{out}$
  • $f_{gas}(R_{out})$
  • Strength of angular momentum transport in disk
  • dust-to-gas ratio
• ~40% produce a pc-scale starburst

Radius of peak SFR

Ballantyne (2008)
- Nearly 55% of pc-scale starbursts have max. SFRs < 20 \( M_\odot \) yr\(^{-1}\)

- 10-30 \( M_\odot \) yr\(^{-1}\) most common

- When gas extinguished, left with a nuclear star cluster???
SFR from COSMOS AGN

- z < 1 X-ray selected AGNs
- Radio stacks of undetected AGNs
- Corrected for AGN nuclear emission
- Residual flux interpreted as SF

Pierce et al. (2011)
Compton Thick AGNs

- But, the observed HXLFs cannot fit the XRB. Need Compton thick AGNs to fit the peak of the spectrum at \(\sim 20-30\) keV.
- When \(N_H > \sim \sigma_T^{-1} \approx 10^{24}\) cm\(^{-2}\) Compton scattering of photons becomes important and can remove the vast majority of photons from the lines of sight
- How common are they?
- What sort of galaxies do they inhabit?
- What else are we missing?
Correcting for flux suppression in the BAT band gives an estimated local CT fraction of ~20%.

A good measurement of the local distribution of column densities. Should this hold for all $z$?

Are CT AGNs really just an extension of the local absorption distribution?
• Radiation pressure on dusty obscuring gas will remove Compton-thin material.

• What will the $N_H$ distribution look like in the quasar era?
A New Approach to the XRB

- Rather than correct the luminosity function for the `missing’ CT AGNs...
- Add them in at specific values of the Eddington ratio
- Combine the HXLF, BHMF, and the BH continuity equation:

\[
\frac{\partial n_M(M_\odot, t)}{\partial t} + \frac{\partial [n_M(M_\odot, t) \langle \dot{M}(M_\odot, t) \rangle]}{\partial M} = 0,
\]

to obtain the evolving accretion rate function
Red = $L_X > 10^{43}$ erg/s

Blue = $L_X > 10^{44}$ erg/s

Dashed: CT in all $\lambda$

Dot-dashed: $\lambda > 0.90$

Solid: $\lambda > 0.90$ & $\lambda < 0.01$

Draper & DRB (2010)
Draper & DRB (2010)

Final Numbers:

\~86\% of $\lambda > 0.90$ AGN are CT

\& \~60\% of $\lambda < 0.01$ AGN are CT
Take Home Point

- At $z > 0$ Compton Thick AGN may be beacons of rapid black hole growth and fueling
- A complete census of the growth of SMBHs must include these objects
- How to test?
  - Hard X-ray surveys that push past $z > 0$
Implications

• The star formation and AGN in the XRB galaxies are fueled by interactions and minor mergers
• Seyferts are distinct from quasars in more than their luminosity!
• How to quantify these ideas?
Two Populations of AGNs

- Consider the **space density of major-mergers** of gas rich galaxies.
- Assume each merger creates an AGN

\[
dN_{\text{merg}}(z) = \frac{d^2\Psi}{dN\,dt} N_{\text{gal}}(M_* > M^\text{min}_*(z)) \, f_g(z) \, dt \, \text{Mpc}^{-3}
\]

Merger rate/galaxy/Gyr
Hopkins et al. (2010)

Fraction of gas rich galaxies
Treister et al. (2010)

Space density of massive galaxies
Perez-Gonzalez et al. (2008)
AGNs can also be triggered by `secular’ effects (i.e., minor mergers, cold-flow accretion, starburst winds, etc.)

\[
dN_{sec}(z) = f_{sec} N_{gal} \left( M_* > M_{*}^{min}(z) \right) f_g(z) \, dt \, \text{Mpc}^{-3}
\]

Fractional rate of AGNs triggered per Gyr \( \ll 0.3 \)

free parameter

Light-curve for all AGNs:

\[
\lambda(t) = \left[ 1 + \left( |t|/t_Q \right)^{1/2} \right]^{-2/\beta}
\]

\( \lambda = \) Eddington ratio
\( t_Q(\eta,t_0), \beta = \) free parameters

Hopkins & Hernquist (2009)
- Combine with evolving BHMF and BH continuity eqn. (as before).

Black = total HXLF  
Red = merger-triggered AGNs  
Blue = secular triggered AGN

Draper & Ballantyne (2012)
BH mass grown through luminous accretion provided by major mergers (cf. Soltan)

Integrated accretion light dominated by secularly-triggered AGNs
Galaxy evolution changes character at $z \sim 1$.

From merger to secular-dominated.
Conclusions

• A simple, non-evolving torus cannot alone provide the AGN obscuration over all cosmic time
  • the shape of the XRB spectrum may be due to obscuration correlated with the SFR in the host galaxy
  • CT AGN are likely associated with rapid fueling/galaxy growth
• The host galaxies of the XRB population can have SFRs consistent w/ LIRGs
• Starburst disks are a potential source of AGN obscuration at z~1
• Seyfert galaxies, which mainly produce the XRB, are likely fueled by minor mergers and interactions
  • there may be a sig. delay b/w the interaction and the subsequent ignition of the AGN