



**ΕΘΝΙΚΟ ΜΕΤΣΟΒΙΟ  
ΠΟΛΥΤΕΧΝΕΙΟ**

**ΣΧΟΛΗ ΕΦΑΡΜΟΣΜΕΝΩΝ  
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**Διατμηματικό Πρόγραμμα Μεταπτυχιακών Σπουδών**

**«Φυσική και Τεχνολογικές Εφαρμογές»**

**Η συνάρτηση φωτεινότητας των ενεργών  
γαλαξιακών πυρήνων στα σμήνη γαλαξιών**

**ΜΕΤΑΠΤΥΧΙΑΚΗ ΔΙΠΛΩΜΑΤΙΚΗ ΕΡΓΑΣΙΑ**

**του Σπύρου Σισμάνη**

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**Αθήνα, Οκτώβριος, 2021**

## Ευχαριστίες

Η παρακάτω διπλωματική εργασία εκπονήθηκε σε συνεργασία με το Εθνικό Αστεροσκοπείο Αθηνών και υπό την επίβλεψη των Ηλίας Κουλουρίδη και Ιωάννη Γεωργαντόπουλου, τους οποίους ευχαριστώ θερμά για την καθοδήγηση και την υποστήριξή τους.

## Περίληψη

Η συνάρτηση φωτεινότητας αποτελεί ένα χρήσιμο εργαλείο για τον υπολογισμό της πυκνότητας των ενεργών γαλαξιακών πυρήνων σε διαφορετικά περιβάλλοντα και σε διαφορετικές εποχές του σύμπαντος. Στην εργασία αυτή, κατασκευάσαμε τη συνάρτηση φωτεινότητας για τις πηγές που βρίσκονται στα σμήνη γαλαξιών του *XXL* και τη συγκρίναμε με τη συνάρτηση φωτεινότητας του πεδίου *XXL*. Επιπλέον, μελετάμε τον τρόπο με τον οποίο η πυκνότητα των ΕΓΠ (Ενεργών Γαλαξιακών Πυρήνων) εξαρτάται από την ακτινική απόσταση από το κέντρο του σμήνους. Για το σκοπό αυτό, χρησιμοποιήσαμε τις πηγές του καταλόγου *3XLSS* και τα σμήνη του καταλόγου "*XXL 365 clusters catalogue*". Το πεδίο *XXL* καλύπτει μία περιοχή 50 τετραγωνικών μοιρών, ενώ περιλαμβάνει 26 056 αντικείμενα. Αποτελεί έτσι, ένα ιδανικό δείγμα για τη μελέτη μας.

Με την ολοκλήρωση της παρούσας μελέτης, βρίσκουμε ότι η δραστηριότητα των ΕΓΠ ενισχύεται πιο κοντά στο κέντρο των σμηνών ενώ η πυκνότητα προσεγγίζει την τιμή του πεδίου στις εξωτερικές περιοχές των σμηνών. Ως εκ τούτου, θα πρέπει να υπάρχουν φυσικοί μηχανισμοί, που οδηγούν στη ενεργοποίηση των ΕΓΠ στις κεντρικές και πιο πυκνές περιοχές των σμηνών.

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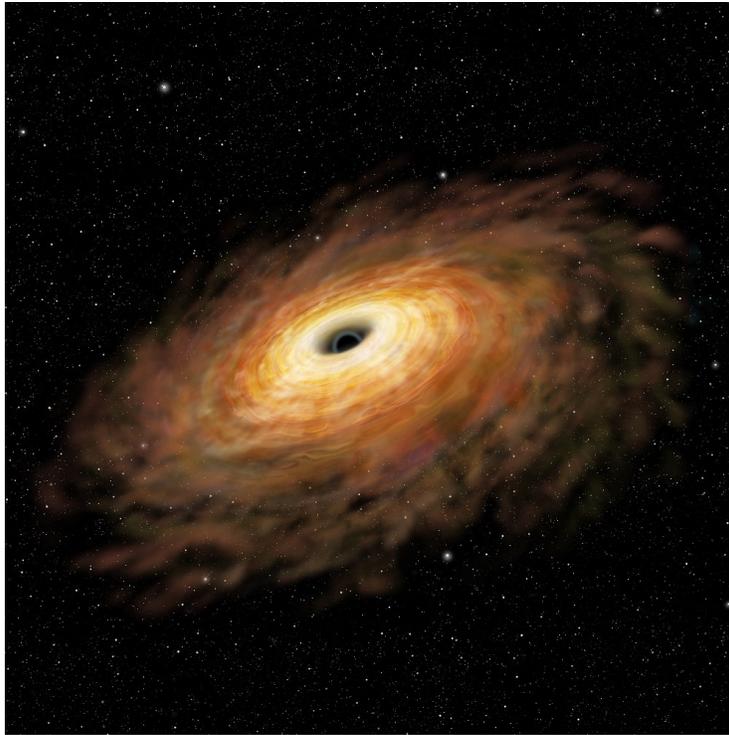
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# 1 Εισαγωγή

## 1.1 Ενεργοί Γαλαξιακοί Πυρήνες

Οι ενεργοί γαλαξιακοί πυρήνες βρίσκονται ανάμεσα στα πιο λαμπρά αντικείμενα στο σύμπαν. Λόγω της πολύ υψηλής φωτεινότητάς τους ( $10^{42} - 10^{48} \text{ erg/s}$ ) αποτελούν ένα χρήσιμο εργαλείο για τη μελέτη του κοσμικού υποβάθρου ακτίνων X και των δομών μεγάλης κλίμακας. Ο μηχανισμός λειτουργίας τους βασίζεται σε μία υπερμεγέθη μελανή οπή η οποία κατοικεί στην κεντρική γαλαξιακή περιοχή και απορροφά ύλη από το κοντινό περιβάλλον της. Η ύλη θερμαίνεται στο δίσκο προσαύξεσης και ακτινοβολεί τεράστια ποσά ενέργειας.



Σχήμα 1: Μία καλλιτεχνική απεικόνιση υπερμεγέθους μελανής οπής, η οποία περιβάλλεται από το δίσκο προσαύξεσης.

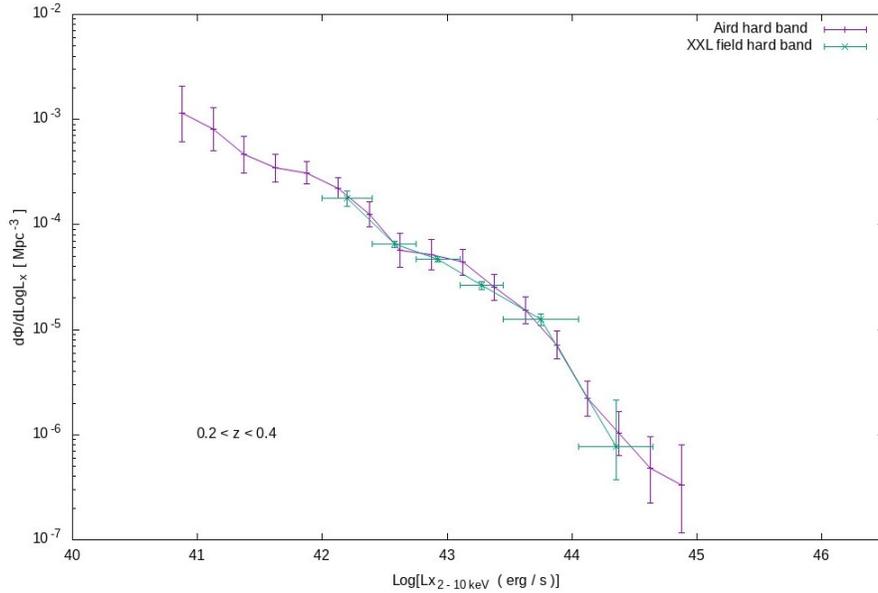
Στην παρούσα εργασία εξετάζουμε την εκπομπή των ΕΓΠ στις ακτίνες X. Οι ακτίνες X αποτελούν ένα ιδανικό μήκος κύματος για τη μελέτη μας, καθώς κάθε ΕΓΠ αποτελεί μία ισχυρή πηγή ακτίνων X. Επίσης, οι ακτίνες X έχουν μικρό ποσοστό απορρόφησης από το διαγαλαξιακό υλικό σε σχέση με τα υπόλοιπα μήκη κύματος.

## 1.2 Η μέθοδος για την κατασκευή της συνάρτησης φωτεινότητας

Η συνάρτηση φωτεινότητας αντιπροσωπεύει ένα από τα πιο χρήσιμα στατιστικά εργαλεία για τον προσδιορισμό της εξέλιξης των υπερμεγέθων μελανών οπών στην ιστορία του σύμπαντος. Μέσω αυτής προσδιορίζουμε την πυκνότητα των ΕΓΠ σαν συνάρτηση της φωτεινότητας και της ερυθρομετατόπισής τους. Η συνάρτηση φωτεινότητας εκφράζει τον αριθμό των ΕΓΠ ανά όγκο και ανά μονάδα φωτεινότητας:

$$\Phi(L, z) = \frac{d^2 N(L, z)}{dV dL} \quad (1)$$

Στην παρούσα εργασία κατασκευάζουμε τη συνάρτηση φωτεινότητας για τους ΕΓΠ χρησιμοποιώντας τη μέθοδο  $1/Vmax$ . Η μέθοδος αυτή χρησιμοποιείται για να δοθεί η απαραίτητη διόρθωση στα αντικείμενα χαμηλής φωτεινότητας. Πιο συγκεκριμένα, δεδομένου ότι τα αμυδρά αντικείμενα είναι δυσκολότερο να παρατηρηθούν, πολλαπλασιάζουμε τον αριθμό τους με έναν παράγοντα αντιστρόφως ανάλογο του μέγιστου όγκου στον οποίο μπορούμε να τα παρατηρήσουμε με βάση τη λαμπρότητά τους. Έτσι, όσο πιο αμυδρό είναι ένα αντικείμενο, τόσο μεγαλύτερη είναι η διόρθωση στη συνάρτηση φωτεινότητας.



Σχήμα 2: Συνάρτηση φωτεινότητας για τους ΕΓΠ στο πεδίο *XXL*, στο διάστημα  $0.2 < z < 0.4$  (Πράσινη γραμμή) και η αντίστοιχη από το άρθρο των *Aird et al.* 2015 (μωβ γραμμή.)

### 1.3 Δεδομένα

Στο κεφάλαιο αυτό παρουσιάζουμε το πεδίο *XXL* μαζί με τους καταλόγους που χρησιμοποιήσαμε για να κατασκευάσουμε τη συνάρτηση φωτεινότητας.

#### 1.3.1 Ο Δορυφόρος

Ο δορυφόρος *XMM Newton* εκτοξεύτηκε στις 10 Δεκεμβρίου 1999 από την Ευρωπαϊκή Διαστημική Υπηρεσία και αποτελεί τον μεγαλύτερο επιστημονικό δορυφόρο που χτίστηκε ποτέ στην Ευρώπη. Μεταφέρει τρία τηλεσκόπια ακτίνων X με μεγάλη συλλεκτική επιφάνεια που παρέχουν μεγάλες εκθέσεις υψηλής ανάλυσης. Ο δορυφόρος περιλαμβάνει τρεις *EPIC* (*European Photon Imaging Camera*) ανιχνευτές που λειτουργούν παράλληλα με δύο φασματογράφους. Περίπου το 44% της εισερχόμενης ακτινοβολίας φτάνει τους ανιχνευτές, ενώ η υπόλοιπη καταλήγει στους φασματογράφους. Έτσι επιτυγχάνεται η φωτομετρία μέσω της φασματοσκοπικής ανάλυσης της πηγής.

Ο δορυφόρος *XMM Newton* εκτελεί τροχιά υψηλής εκκεντρότητας γύρω από τη Γη, έτσι ώστε τα όργανά του να μην επηρεάζονται από τις ζώνες ακτινοβολίας. Ολοκληρώνει μία τροχιά σε 48 ώρες, ώστε οι αστρονόμοι να έχουν συνεχόμενες παρατηρήσεις των ουράνιων πηγών. Καθώς η ατμόσφαιρα της γης απορροφά τις ακτίνες X, ο δορυφόρος *XMM Newton* είναι ιδιαίτερα χρήσιμος για παρατηρήσεις υψηλής ανάλυσης.

#### 1.3.2 Το πεδίο των παρατηρήσεων

Το *XXL* αποτελεί μία επισκόπηση του ουρανού σχεδόν σε όλα τα μήκη κύματος από τις ακτίνες X έως τα ραδιοκύματα με σκοπό τον εντοπισμό χιλιάδων ΕΓΠ και χιλιάδων σμηγών κατάλληλων για κοσμολογικές μελέτες. Παρέχει υψηλής ανάλυσης δεδομένα στις ακτίνες X και αποτελεί τη μεγαλύτερη διαθέσιμη επισκόπηση για τα σμήνη γαλαξιών. Ο βασικός στόχος της επισκόπησης είναι να ερμηνεύσει την κατανομή των σμηγών γαλαξιών στο χωροχρόνο και να ορίσει τους περιορισμούς στην εξίσωση σκοτεινής ύλης. Επιπλέον, ενισχύει τη μελέτη των ΕΓΠ και παρέχει πληροφορίες για την εξέλιξη και τη δομή του υποβάθρου των ακτίνων X. Η επισκόπηση *XXL* είναι το μεγαλύτερο πρόγραμμα του δορυφόρου *XMM – Newton* και καλύπτει δυο εξωγαλαξιακές περιοχές 25 τετραγωνικών μοιρών η κάθε μία, το βόρειο και το νότιο πεδίο, χρησιμοποιώντας μέσο χρόνο έκθεσης τα 10 κιλοδευτερόλεπτα. Η επιλογή των πεδίων έγινε με βάση διάφορους παράγοντες, όπως την ανάγκη για την ανίχνευση δομών μεγάλης κλίμακας, τη χαμηλή γαλαξιακή απορρόφηση κ.ά.

#### 1.3.3 Κατάλογοι Δεδομένων

Τα δεδομένα των πηγών που χρησιμοποιήθηκαν στην εργασία αυτή βρίσκονται στον κατάλογο *3XLS* ο οποίος δημοσιεύτηκε στο άρθρο των (*Chiappetti et al.* 2018). Ο κατάλογος *3XLS* περιέχει 26 056 αντικείμενα στο βόρειο και στο νότιο πεδίο καλύπτοντας μία περιοχή περίπου 50 τετραγωνικών μοιρών.



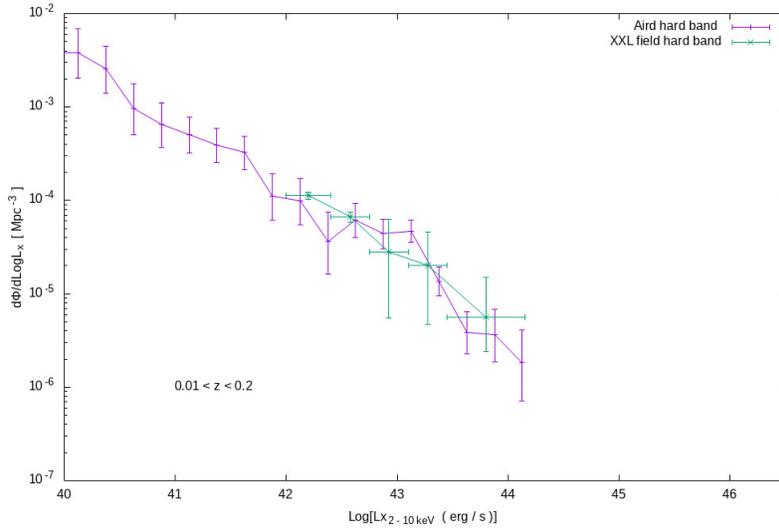
## 2 Η συνάρτηση φωτεινότητας

### 2.1 Η συνάρτηση φωτεινότητας των ΕΓΠ στο πεδίο

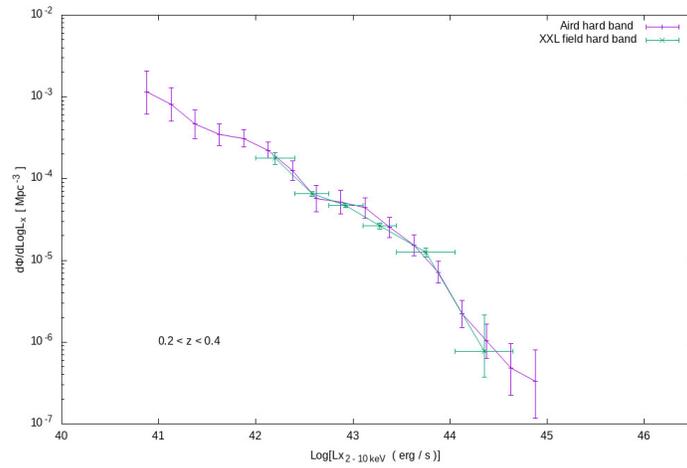
Χρησιμοποιώντας τη μέθοδο  $1/V_{max}$  κατασκευάσαμε τη συνάρτηση φωτεινότητας για τις πηγές του πεδίου *XXL*. Για τον υπολογισμό του όγκου  $V_{max}$  προτιμάμε τις φασματοσκοπικές ερυθρομετατοπίσεις των πηγών. Για τις πηγές χωρίς φασματοσκοπικές ερυθρομετατοπίσεις, χρησιμοποιήσαμε τις φωτομετρικές. Κρατάμε μόνο τις πηγές με φωτεινότητες μεγαλύτερες των  $10^{42}$  *erg/s*. Για να εξετάσουμε εάν η μέθοδός μας παράγει σωστά αποτελέσματα, συγκρίνουμε τη συνάρτηση φωτεινότητας με αυτή από το άρθρο των *Aird et al.* (2015). Χωρίζουμε το δείγμα μας σε 10 διαστήματα ερυθρομετατόπισης, όπου και κατασκευάζουμε τη συνάρτηση φωτεινότητας. Τα σφάλματα σε κάθε διάστημα φωτεινότητας υπολογίζονται μέσω της στατιστικής *Poisson* σύμφωνα με τη σχέση:

$$\delta\Phi(L) = \frac{\sqrt{N}}{\int_{L_{min}}^{L_{max}} \int_{z_{min}}^{z_{max}} \Omega(L, z) \frac{dV}{dz} dL dz} \quad (2)$$

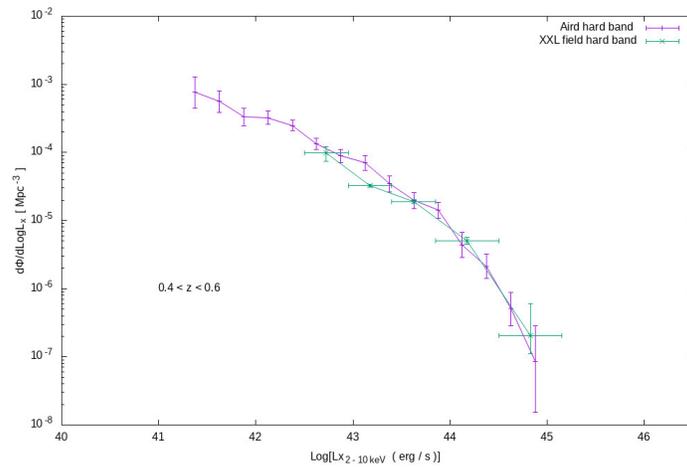
Τα αποτελέσματά μας παρουσιάζονται παρακάτω. Για να έχουμε στατιστικά σωστά αποτελέσματα θεωρούμε ότι σε κάθε διάστημα φωτεινότητας θα πρέπει να περιλαμβάνονται τουλάχιστον 15 αντικείμενα.



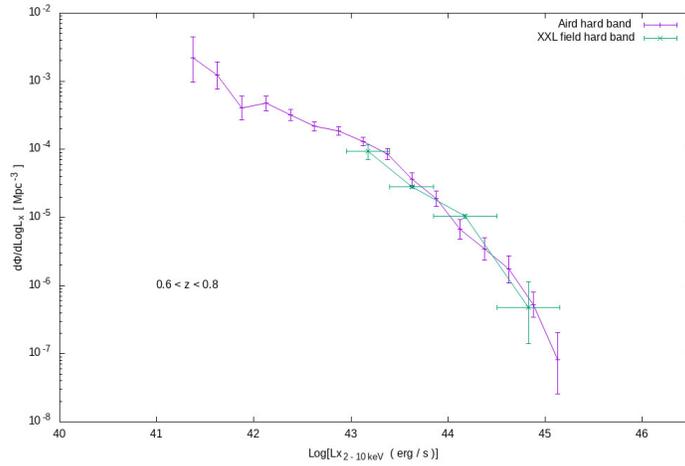
Σχήμα 3: Η συνάρτηση φωτεινότητας για το πεδίο *XXL* στη σκληρή μπάντα, στο διάστημα ερυθρομετατόπισης:  $0.01 < z < 0.2$  (πράσινη καμπύλη). Η μωβ καμπύλη απεικονίζει τη συνάρτηση φωτεινότητας από το άρθρο των *Aird et al.* 2015



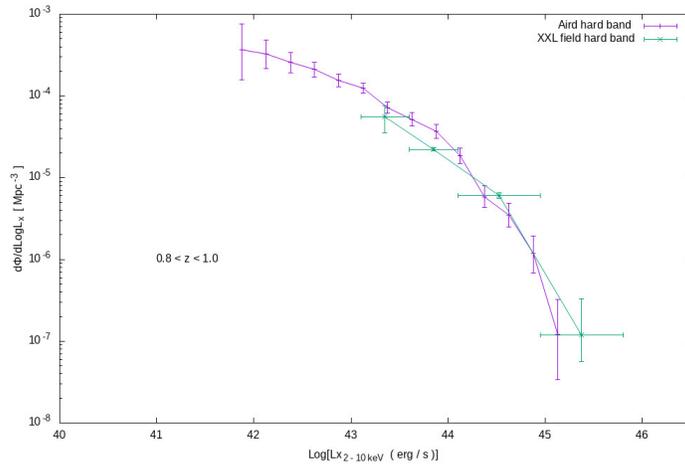
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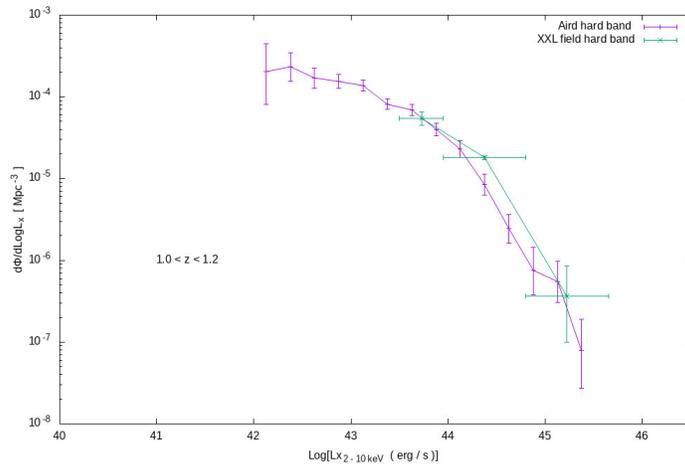
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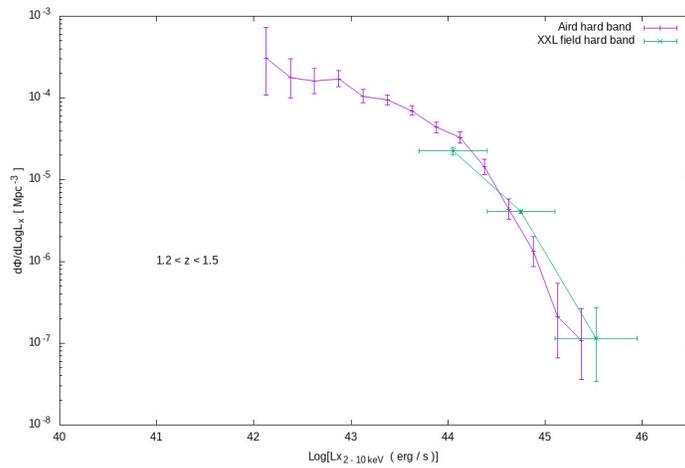
Σχήμα 6: Η συνάρτηση φωτεινότητας για το πεδίο *XXL* στη σκληρή μπάντα, στο διάστημα ερυθρομετατόπισης:  $0.6 < z < 0.8$  (πράσινη καμπύλη). Η μωβ καμπύλη απεικονίζει τη συνάρτηση φωτεινότητας από το άρθρο των *Aird et al.* 2015.



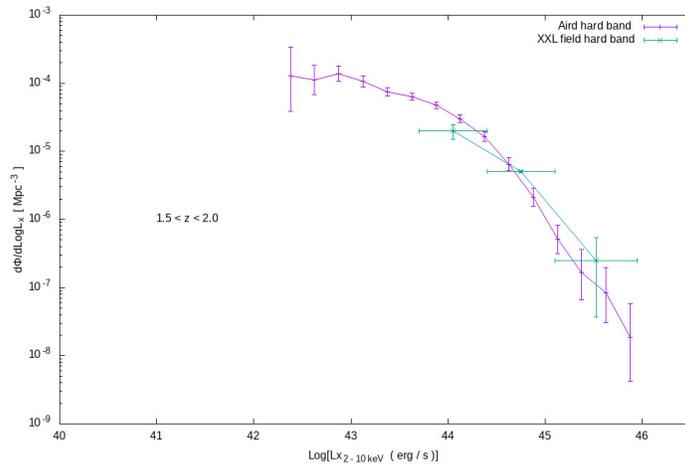
Σχήμα 7: Η συνάρτηση φωτεινότητας για το πεδίο *XXL* στη σκληρή μπάντα, στο διάστημα ερυθρομετατόπισης:  $0.8 < z < 1.0$  (πράσινη καμπύλη). Η μωβ καμπύλη απεικονίζει τη συνάρτηση φωτεινότητας από το άρθρο των *Aird et al.* 2015



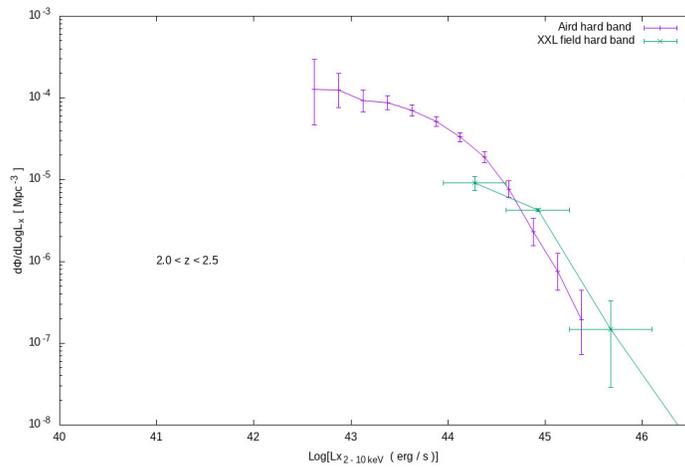
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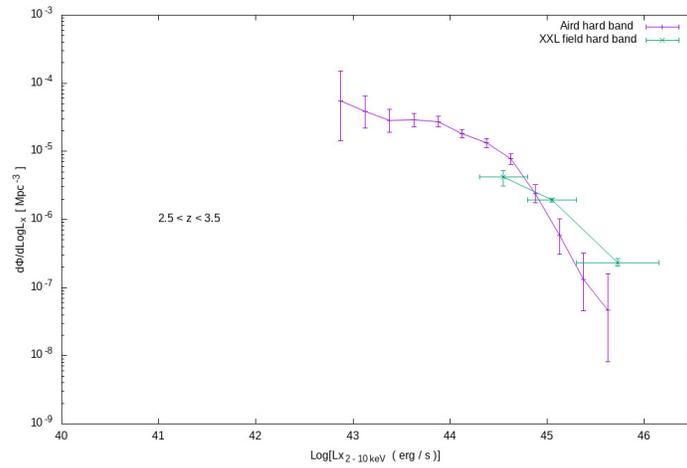
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Σχήμα 10: Η συνάρτηση φωτεινότητας για το πεδίο *XXL* στη σκληρή μπάντα, στο διάστημα ερυθρομετατόπισης:  $1.5 < z < 2.0$  (πράσινη καμπύλη). Η μωβ καμπύλη απεικονίζει τη συνάρτηση φωτεινότητας από το άρθρο των *Aird et al.* 2015.



Σχήμα 11: Η συνάρτηση φωτεινότητας για το πεδίο *XXL* στη σκληρή μπάντα, στο διάστημα ερυθρομετατόπισης:  $2.0 < z < 2.5$  (πράσινη καμπύλη). Η μωβ καμπύλη απεικονίζει τη συνάρτηση φωτεινότητας από το άρθρο των *Aird et al.* 2015.



Σχήμα 12: Η συνάρτηση φωτεινότητας για το πεδίο *XXL* στη σκληρή μπάντα, στο διάστημα ερυθρομετατόπισης:  $2.5 < z < 3.5$  (πράσινη καμπύλη). Η μωβ καμπύλη απεικονίζει τη συνάρτηση φωτεινότητας από το άρθρο των *Aird et al.* 2015.

## 2.2 Η συνάρτηση φωτεινότητας των ΕΓΠ στο στα σμήνη

Μετά την κατασκευή της συνάρτησης φωτεινότητας για τους ΕΓΠ στο πεδίο  $XXL$ , κατασκευάσαμε τη συνάρτηση φωτεινότητας για τους ΕΓΠ που ανήκουν στα σμήνη του  $XXL$ . Ο κατάλογος για τα σμήνη του  $XXL$  που χρησιμοποιήσαμε έχει δημοσιευθεί στο άρθρο των (Adami *et al.* 2018). Ο κατάλογος *365 clusters catalogue* περιλαμβάνει 365 φασματοσκοπικά επιβεβαιωμένα σμήνη στο διάστημα  $0 < z < 1.2$ . Για την κατασκευή της συνάρτησης φωτεινότητας, χωρίσαμε την περιοχή γύρω από κάθε σμήνος σε 3 δακτύλιους ακτίνας  $2 \times r_{500}$ <sup>1</sup> ο κάθε ένας. Η ακτίνα  $r_{500}$  είναι χαρακτηριστική ποσότητα για τα σμήνη και εξαρτάται από τις ιδιότητες του κάθε σμήνους. Θεωρούμε ότι μία πηγή με φασματοσκοπική ερυθρομετατόπιση, ανήκει στο σμήνος εάν η διαφορά ακτινικών ταχυτήτων μεταξύ πηγής και σμήνους είναι  $\pm 2000(z_{spec} + 1) \text{ km/s}$ . Η τιμή αυτή αντιστοιχεί σε διαφορά ερυθρομετατόπισης  $\Delta z \simeq \pm 0.007$ . Για τις πηγές χωρίς φασματοσκοπία, χρησιμοποιούμε τις φωτομετρικές ερυθρομετατοπίσεις, με βάση τα παρακάτω κριτήρια.

1. 
$$|z_{photometric} - cz| < 0.1 * (1 + cz) \quad (3)$$

όπου  $cz$  είναι η ερυθρομετατόπιση του σμήνους.

2. 
$$(Z_{BEST68 \text{ HIGH}} - Z_{BEST68 \text{ LOW}}) < 0.5 \quad (4)$$

όπου τα  $Z_{BEST68 \text{ HIGH}}$  και  $Z_{BEST68 \text{ LOW}}$  αποτελούν την υψηλότερη και την χαμηλότερη τιμή αντίστοιχα, στο διάστημα 68% της περιοχής γύρω από το τη μέση ερυθρομετατόπιση ( $ZPDF$ ).

3. Πηγές με απόλυτο μέγεθος στην  $i$  μπάντα μεγαλύτερο από

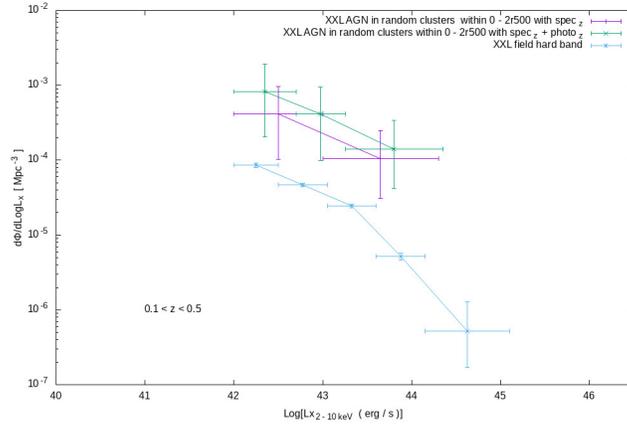
$$M_i \leq M_i^* + 1$$

όπου  $M_i^*$  το χαρακτηριστικό μέγεθος, όπως περιγράφεται από την εξίσωση (21).

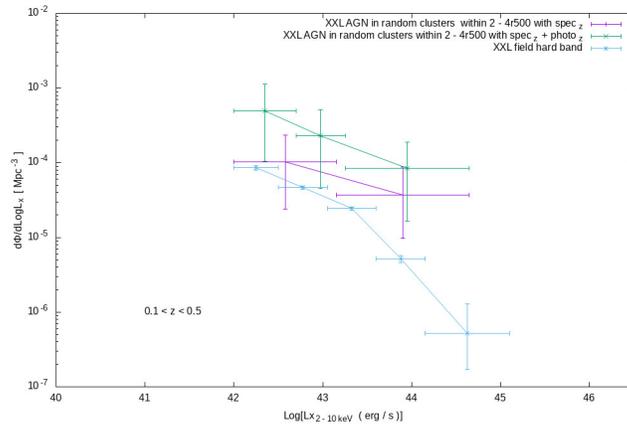
Για να υπολογίσουμε την τιμή  $M_i^*$  για κάθε πηγή θεωρούμε ότι αυτή αυξάνεται γραμμικά με την ερυθρομετατόπιση. Προσδιορίζουμε έτσι τη συνάρτηση φωτεινότητας στο διάστημα  $0.1 < z < 0.5$ . Τα αποτελέσματά μας παρουσιάζονται παρακάτω.

---

<sup>1</sup>Ως  $r_{500}$  ορίζεται η ακτίνα από το κέντρο του σμήνους, στην οποία η πυκνότητα του σμήνους είναι 500 φορές μεγαλύτερη από την κρίσιμη πυκνότητα του σύμπαντος στο συγκεκριμένο *redshift*.

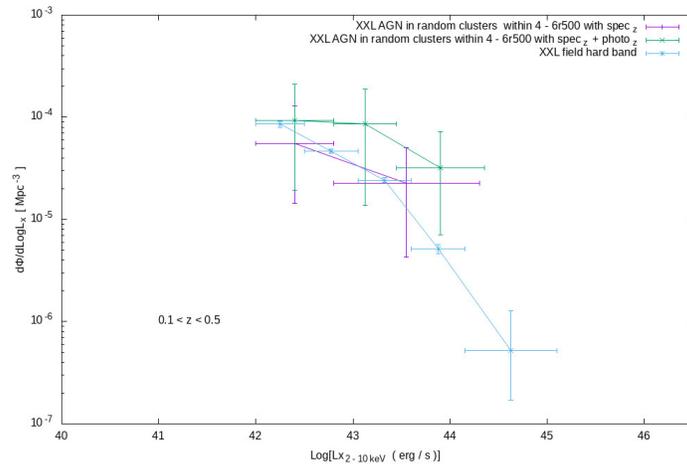


Σχήμα 13: Συνάρτηση φωτεινότητας των ΕΓΠ στα σμήνη, στο διάστημα  $z$ :  $0.1 < z < 0.5$  σε ακτίνα  $0 - 2r500$  από το κέντρο του σμήνους χρησιμοποιώντας μόνο φασματοσκοπικές ερυθρομετατοπίσεις (μωβ γραμμή) και χρησιμοποιώντας φασματοσκοπικές και φωτομετρικές ερυθρομετατοπίσεις (πράσινη γραμμή). Η μπλε γραμμή απεικονίζει τη συνάρτηση φωτεινότητας του πεδίου.



Σχήμα 14: Συνάρτηση φωτεινότητας των ΕΓΠ στα σμήνη, στο διάστημα  $z$ :  $0.1 < z < 0.5$  σε ακτίνα  $2 - 4r500$  από το κέντρο του σμήνους χρησιμοποιώντας μόνο φασματοσκοπικές ερυθρομετατοπίσεις (μωβ γραμμή) και χρησιμοποιώντας φασματοσκοπικές και φωτομετρικές ερυθρομετατοπίσεις (πράσινη γραμμή). Η μπλε γραμμή απεικονίζει τη συνάρτηση φωτεινότητας του πεδίου.

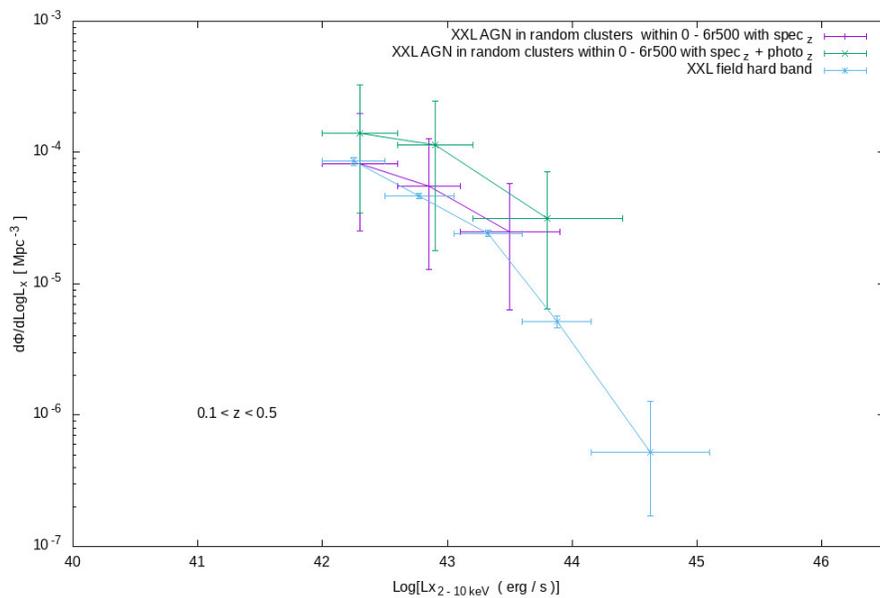




Σχήμα 15: Συνάρτηση φωτεινότητας των ΕΓΠ στα σμήνη, στο διάστημα  $z$ :  $0.1 < z < 0.5$  σε ακτίνα  $4 - 6r_{500}$  από το κέντρο του σμήνους χρησιμοποιώντας μόνο φασματοσκοπικές ερυθρομετατοπίσεις (μωβ γραμμή) και χρησιμοποιώντας φασματοσκοπικές και φωτομετρικές ερυθρομετατοπίσεις (πράσινη γραμμή). Η μπλε γραμμή απεικονίζει τη συνάρτηση φωτεινότητας του πεδίου.

## 2.3 Δείγμα ελέγχου

Για να επαληθεύσουμε εάν η μέθοδός μας αναπαράγει ακριβή αποτελέσματα, κατασκευάσαμε μερικούς δοκιμαστικούς καταλόγους ανακατεύοντας τις συντεταγμένες των σμηνών και διατηρώντας ως έχουν τα υπόλοιπα στοιχεία τους. Στο παρακάτω σχήμα παρουσιάζουμε τη συνάρτηση φωτεινότητας στα τυχαία σμήνη. Κάνοντας αυτή την άσκηση, επαληθεύουμε ότι η συνάρτηση φωτεινότητας με τη μέθοδο που χρησιμοποιούμε στα σμήνη, αναπαράγει το πεδίο αν τοποθετήσουμε τα σμήνη σε τυχαίες θέσεις στο *XXL*.

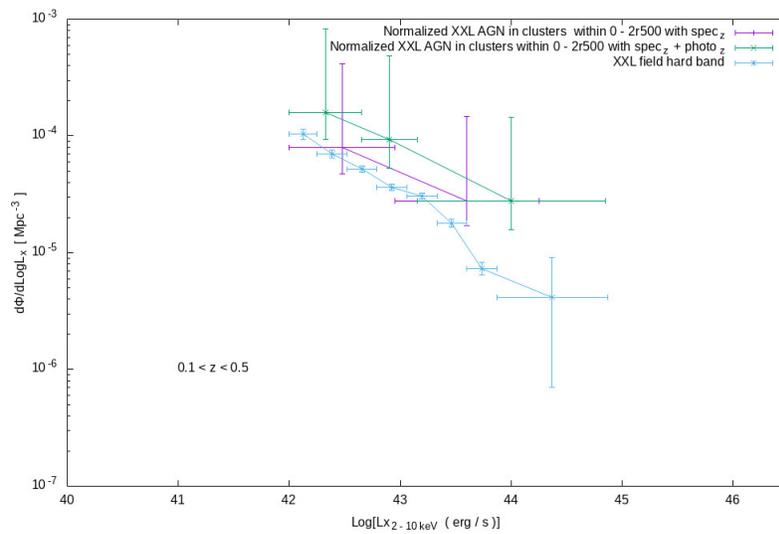


Σχήμα 16: Η συνάρτηση φωτεινότητας των ΕΓΠ στα τυχαία σμήνη. Συμπεριλαμβάνουμε κάθε πηγή που βρίσκεται σε ακτίνα  $6r_{500}$  από το κέντρο του σμήνους με φασματοσκοπικές (μωβ καμπύλη) και φασματοσκοπικές μαζί με φωτομετρικές (πράσινη καμπύλη). Η μπλε καμπύλη απεικονίζει το πεδίο

Παρατηρούμε ότι η συνάρτηση φωτεινότητας αναπαράγει το πεδίο χρησιμοποιώντας μόνο τις φασματοσκοπικές ερυθρομετατοπίσεις. Η συνάρτηση φωτεινότητας υπερεκτιμά την πυκνότητα των ΕΓΠ στα σμήνη χρησιμοποιώντας μαζί τις φασματοσκοπικές και τις φωτομετρικές ερυθρομετατοπίσεις. Παρόλα αυτά, τα αποτελέσματα συμφωνούν στα όρια του στατιστικού σφάλματος.

## 2.4 Κανονικοποιημένη συνάρτηση φωτεινότητας στον πρώτο δακτύλιο

Σύμφωνα με τα αποτελέσματα που παρουσιάστηκαν πριν, η πυκνότητα των αντικειμένων προκύπτει αυξημένη κοντά στην κεντρική περιοχή των σμήνων σε σχέση με τις εξωτερικές περιοχές. Στο επόμενο γράφημα παρουσιάζουμε την κανονικοποιημένη συνάρτηση φωτεινότητας για τις πηγές στον πρώτο δακτύλιο ( $0 - 2 \times r_{500}$ ). Εκεί η πυκνότητα των αντικειμένων έχει κανονικοποιηθεί με έναν παράγοντα ανάλογο της αύξησης που παρουσιάζουν οι γαλαξίες στα σμήνη σε σχέση με το πεδίο. Ο παράγοντας αυτός υπολογίστηκε με βάση τα αποτελέσματα στο άρθρο του *Ehlert* (2014). Η κανονικοποιημένη συνάρτηση φωτεινότητας παραμένει ψηλότερα από αυτή του πεδίου σε κάθε διάστημα φωτεινότητας.



Σχήμα 17: Κανονικοποιημένη συνάρτηση φωτεινότητας των ΕΓΠ στα σμήνη στο διάστημα  $z: 0.1 < z < 0.5$  σε ακτίνα  $0 - 2r_{500}$  από το κέντρο του σμήνους.

### 3 Συμπεράσματα

Χρησιμοποιώντας τον κατάλογο *XXL 365 clusters catalogue* για τα σμήνη και τον κατάλογο *3XLSS* για τους ΕΓΠ, κατασκευάσαμε τη συνάρτηση φωτεινότητας για τους ΕΓΠ στα σμήνη. Σε συμφωνία με προηγούμενες μελέτες βρίσκουμε σημαντική αύξηση των ΕΓΠ στα σμήνη γαλαξιών (*koulouridis et al.* 2018). Η πυκνότητα των ΕΓΠ προσεγγίζει την τιμή του πεδίου στις εσωτερικές περιοχές των σμηνών ( $< 0.5r_{500}$ ). Ωστόσο, όταν κανονικοποιούμε με την πυκνότητα των γαλαξιών βρίσκουμε ότι η αύξηση δεν είναι τόσο σημαντική. Συμπεραίνουμε, έτσι, πως οι ΕΓΠ δεν είναι αυξημένοι σε σχέση με τους γαλαξίες στα σμήνη. Επιπλέον, βρίσκουμε ότι η αύξηση των ΕΓΠ είναι ανεξάρτητη της φωτεινότητας.

Η γρήγορη ανάπτυξη στις εξωγαλαξιακές επισκοπήσεις θα οδηγήσει σε μεγαλύτερους καταλόγους στο μέλλον. Παρά το γεγονός ότι το *XXL* είναι ένα πλήρες δείγμα, περιέχει λίγες πηγές στα σμήνη σε ερυθρομετατοπίσεις  $z > 0.5$ . Επίσης, παρόλο που το δείγμα μας καλύπτει μεγάλη στερεά γωνία, η συνάρτηση φωτεινότητας παρουσιάζει μεγάλα σφάλματα καθώς οι ΕΓΠ είναι σπάνιοι στα σμήνη. Η χρήση μεγαλύτερων και βαθύτερων δειγμάτων στο μέλλον θα βελτιώσει τη γνώση μας για τη συνάρτηση φωτεινότητας και για την κατανομή των ΕΓΠ στο χωροχρόνο.

## Abstract

The X - Ray Luminosity function (XLF) is a powerful tool in order to estimate the distribution of AGNs through cosmic time and between different environments. In this thesis we construct the XLF for the sources found in the XXL galaxy clusters and we compare it with the one produced at the field. Moreover, we investigate the way that the AGN distribution depends on the radial distance from the cluster center. For this purpose we use the point sources from the 3XLS catalogue and the galaxy clusters from the 365 clusters catalogue. The XXL survey covers a total area of  $50deg^2$  while it contains 26 056 objects and thus it consists an ideal sample for our study. We find that the AGN activity is enhanced closer the cluster cores and it drops to the field value at the cluster outskirts. Hence, there are physical mechanisms which are responsible for the AGN triggering in the cluster's densest regions.

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# 1 Introduction

## 1.1 Active Galactic Nuclei

Active galactic nuclei (AGNs) are among the most energetic and exotic objects in the Universe. Due to their high luminosities ( $10^{42} - 10^{48} \text{ erg/s}$ ) they consist a powerful tool for studying the cosmic background and the large scale structure especially at X - rays. Their distribution vary from the local Universe and the low redshifts, where their space density is dominated by the low luminosity objects, to high redshifts ( $z \geq 5$ ) where the high luminosity AGN are more common. Their extreme luminosities and their strong radiation can be explained by the matter accreting at the galactic centers. A super massive black hole that habits in the central galactic region is fed by continuous flow of matter from the surrounding environment and causes the core to be so luminous.

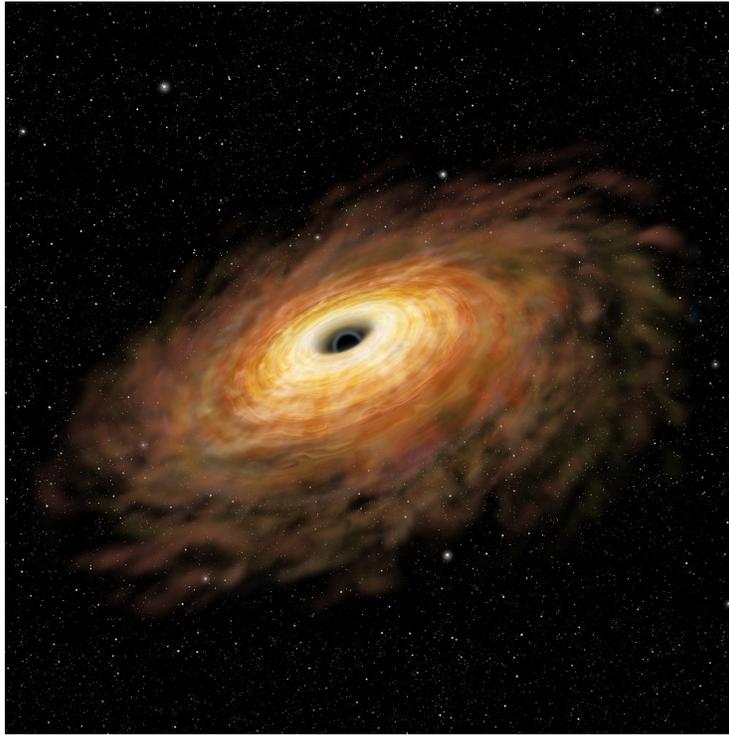


Figure 1: An artist's illustration of an active supermassive black hole surrounded by an accretion disk.

Apart from the strong X - ray emission, AGN can also produce significant radiation over a wide range of wavelengths from radio waves to gamma rays.

## 1.2 A brief history of AGN

The first to discover an AGN was Edward A. Fath in 1908. Fath detected strong emission lines in the optical spectra of galaxy NGC 1068 which was different from absorption spectra of normal galaxies. During the following years several observers such as Slipher (1917) [1] and Hubble (1926) [22], found emission lines in the spectra of NGC 1068, NGC 4151 and NGC 4051. In 1943 Carl Seyfert [31] also noticed high excitation nuclear emission lines in the optical spectra of six spiral galaxies. The presence of those wide emission lines implies hot gas moving with a high velocity. In honor of Seyfert's systematic work galaxies such as the ones described above were named after him. They could be separated in two different subclasses; Seyfert-1 and Seyfert-2. Type 1 Seyfert galaxies show both broad and narrow emission lines while type 2 have only narrow lines present in their spectra.

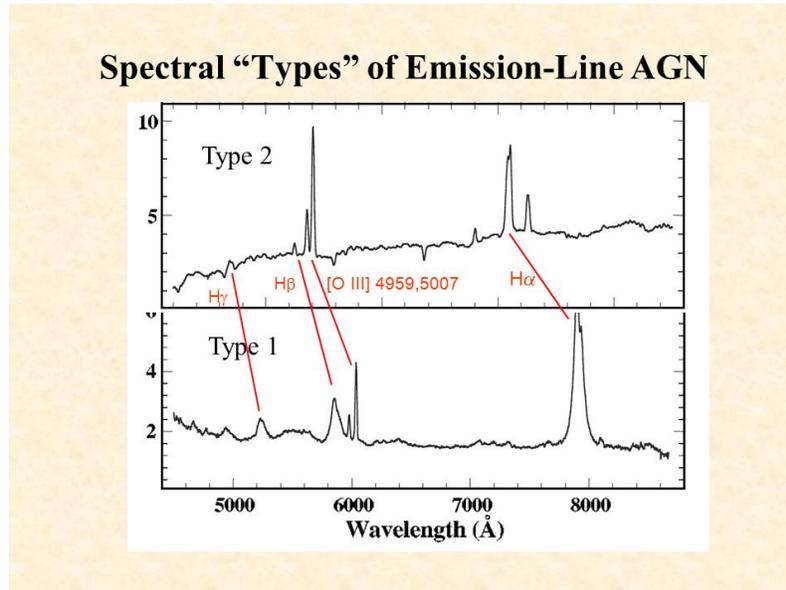


Figure 2: An example of the different Seyfert-1 and Seyfert-2 galaxies spectra. The broad  $H\beta$  line is present only at the Seyfert-1 while both spectra have the strong narrow [OIII] and  $H\alpha$  lines.

The development of radioastronomy has also made a remarkable contribution in the understanding of the AGN phenomenon. Karl Jansky in 1935 found that radiation came from the center and disk of the Milky Way galaxy. In the following years the first radio surveys of the sky were performed while several catalogs such as the Third Cambridge Catalog (3C) were published. Extragalactic radio sources in those surveys were later found to be bright point like sources known today as Quasars. They are the brightest type of the AGN and they are of-

ten observed in high redshifts. Due to their "star-like" appearance they are called QSOs (quasi stellar objects). According to the strength of their radio emission AGNs can be further classified to "Radio-loud" and to "Radio-quiete" with strong and weaker radio emission respectively. In 1963 Martin Schmidt identified the emission lines of Hydrogen in a QSO named 3C 273 and showed that they were redshifted. That discovery was the basis for the identification of the massive black holes in the galactic nuclei.

Another important counterpart of AGN are the radiogalaxies. The first to be discovered was Cygnus A and it is still the brightest observable radiogalaxy. Like the rest of AGN, radiogalaxies show non thermal spectra and a bright nuclei. They can be separated in two subcategories; the Broad-Line Radio Galaxies (*BLRG*) with both broad and narrow lines and the Narrow Line Radio Galaxies (*NLRG*) with only narrow lines. In some occasions their material is ejected through extended narrow jets forming two radio lobes on scales of tens of kiloparsecs away from the galaxy. Jets are observed as the electrons move along strong magnetic fields, producing synchrotron emission.

Based on spectral properties AGN can be further classified as Blasars and LINERs. Blazars are high-polarization objects with variable and non thermal continuum. They include the BL Lac objects which are characterized by rapid flux variability. Liners were identified by Heckman in 1980 [18] and they are mostly elliptical galaxies. They spectroscopically resemble Seyfert 2 galaxies but they show low-ionization nuclear emission regions as their acronym reveals.

### 1.3 AGN mechanism

The extreme luminosities of AGNs imply a powerful engine in the central galactic region emitting the observed energy. Such amounts of energy can be explained by the theory proposed by Lynden-Bell (1969) [28] for Quasars. According to him, the observed energy comes from gravitational energy, which transforms constantly to kinetic energy through matter accretion from the disk. At first, Lynden-Bell showed that it is impossible to power up Quasars only with nuclear activity. Moreover, large observed variations on short timescales in Quasar luminosities prove that the central region hosts a compact object. The fact that the energy is transferred from the inner region with the speed of light implies that the source has a tiny radius. The efficiency of nuclear reactions is  $\sim 0.7\%$ . Therefore in order to fuel the Quasar the mass of the center object would be at least  $M_* \simeq 10^6 M_\odot$ . Meanwhile, the relativistic jets seem to be boosted by the same region in the core. According to the physical procedures described above, it is obvious that the observed energy is a product of gravitational contraction from a black hole. The mass of the central object can reach up to  $\simeq 10^{10} M_\odot$  (Kormendy & Richstone 1995) [24], while it's size is strongly related with the evolution of both the host galaxy (Hopkins et al. 2007; [20] , Kormendy & Bender 2009 [23]) and the AGN.

The observed correlation between the mass of the SMBH and the mass of the host galaxy reveals that the AGN activity can have an impact on the life and evolution of the host galaxy. The huge amounts of energy released from the

central region in the form of winds and jets are able to prevent the cooling of the gas or they can totally remove it (Silk & Rees 1998) [33]. Hence, the star formation of the host galaxy can be affected. Therefore the large ejected outflows could affect the fueling of the AGN itself. On the contrary, the same procedure can possibly trigger star formation while the launched outflows interact with the cold interstellar medium of the host galaxy (Silk 2013) [32]. As a result the AGN feedback could be neither positive or negative by triggering or suppressing the star formation and thus the physical mechanism by which it operates is still unclear.

#### 1.4 AGN across wavelengths

Compared to normal galaxies AGNs have a significantly broader range in their electromagnetic spectrum. Except for their high luminosity, they are also characterized by a continuum emission across  $\sim 20$  order of magnitude in frequency. Both thermal and non - thermal radiation contribute to the SED (Spectral Energy Distribution) with the one or the other dominating in a given spectral band.

An important part of AGN spectra is X - ray radiation. It is now accepted that AGN are able to produce almost the entire cosmic X - ray background while they consist the brightest X - ray sources in the Universe. The X - ray observation offers the maximum contrast between the central black hole and the host galaxy's light while at the same time, obscured and low - luminosity AGNs can be found than in optical and uv bands. Additionally, the X-ray selection benefits from the density squared scaling of the gas emission, which suppresses projection and improves centering.

The dominant mechanism behind X - ray emission is thought to be the inverse Compton scattering [17]. During this process, thermal seed photons from the accretion disk are accelerated by hot electrons in a region called "corona" located above the SMBH. The geometry and the origin of hot corona is still undetermined. Therefore, the AGN spectra can be described as a power law with a photon index  $\Gamma \sim 2$ . Meanwhile, a part of the initially emitted radiation is absorbed by the molecular torus, the broad line region and the disk. The absorption occurs through Compton scattering and photoelectric absorption, which start being effective at column densities  $N_H \sim 10^{21} \text{ cm}^{-2}$  and  $N_H \sim 10^{24} \text{ cm}^{-2}$  respectively. As a result, the reprocessed radiation forms a Compton hump peaking around 30-40 keV and an iron  $K\alpha$  emission line at 6.4 keV on the X -ray spectrum. If the material that causes the reprocess has a column density  $N_H > 1.5 \times 10^{24} \text{ cm}^{-2}$  the AGN is classified as compton - thick and it is difficult to be identified due to high obscuration. Otherwise, we classify the source as compton - thin AGN.

X - ray surveys are ideal for AGN studies due to their small contamination by non-AGN sources. Additionally the peak of their SED is at soft X - rays. Hence we conclude that, X-ray surveys are the most efficient method to identify AGNs. In the present study we select AGN as the sources with soft X - ray luminosities higher than  $L_X = 10^{42} \text{ erg/s}$ .

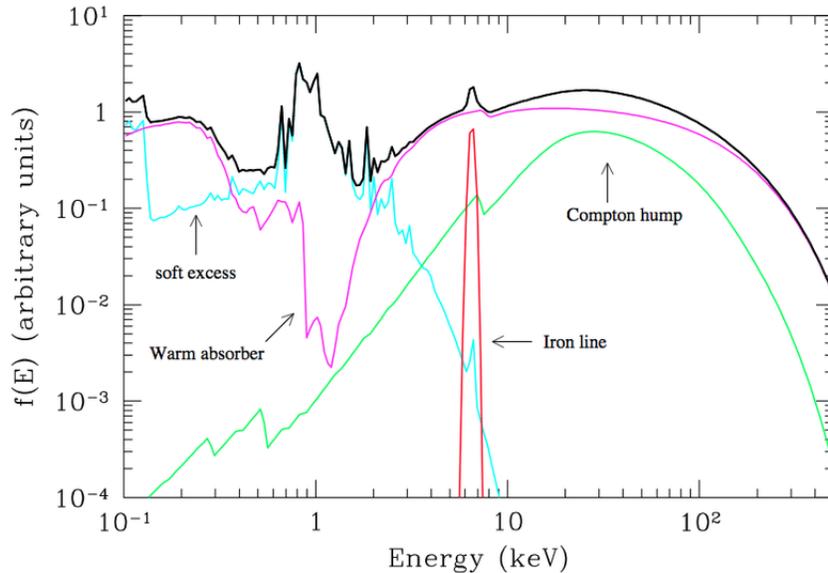


Figure 3: A type I AGN X-ray spectrum showed as the black line and its components by (Guido Risaliti and Martin Elvis 2004). The pink line indicates a power law absorbed at soft energies while the green line shows the Compton hump. The cyan and red line represent the soft excess and the Ka iron emission respectively.

AGNs produce significant radiation at optical and at UV wavelengths as well. The accretion disc has a higher temperature compared to the galaxy stars, resulting in thermal emission which peaks in the blue and in the UV wavelengths. Hence the emission from the disk can be differentiated from the one produced by stars. However the emission produced by AGNs located in high redshifts is absorbed by the intergalactic medium and thus the distant point like sources are difficult to be identified. The dust located around the accretion disk and on a larger scale compared to the broad line region, absorbs the UV/optical radiation and re-emits it in the infrared band. As a result the infrared radiation dominates the AGN spectra at wavelengths  $\lambda \simeq 1 \mu m$  up to a few  $\mu m$ .

In the radio band AGNs are identified due to sychrotron emission. Relativistic particles which have been accelerated through magnetic fields produce non - thermal radiation usually parametrized by a power law.

### 1.5 The unified model

The unified model proposes that all the different types of AGN are intrinsically the same object which is viewed from a different angle. Based on that scheme and aimed at explaining the fact that the broad H I emission lines were observed

in the polarized light of a type II galaxy (Antonucci, 1982) [6], the theory was applied to Seyfert galaxies (Antonucci, 1993) [7] and generalized to other classes of AGNs (Urry and Padovani, 1995) [36].

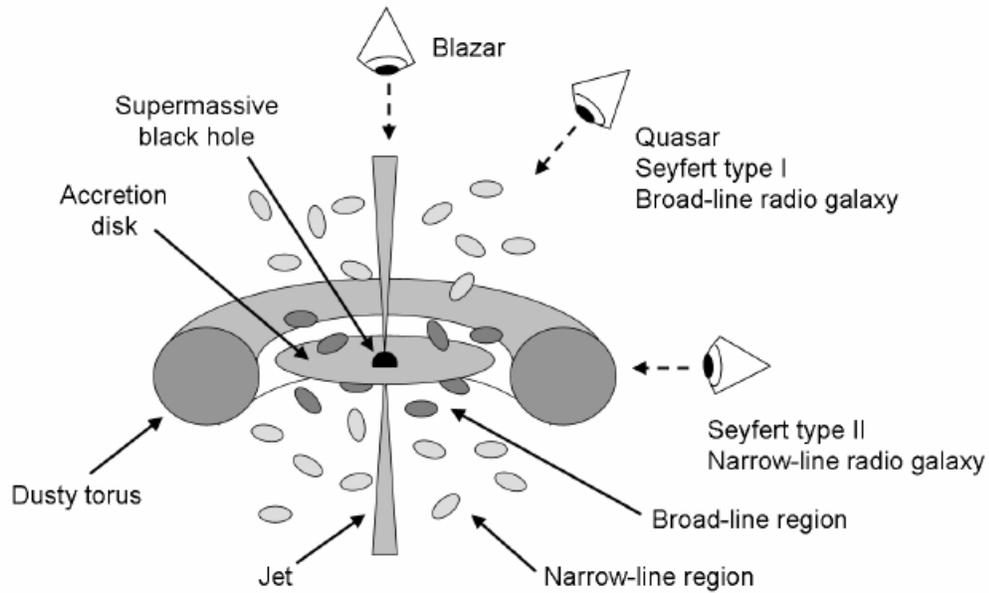


Figure 4: The unification model of AGN. The approximate viewing angles of certain types of AGN have been indicated.

The AGN mechanism consists of the central accreting SMBH which is fueled by the accretion disk as described above. Furthermore, it is believed that clouds of hot gas exist in the volume surrounding the accretion disk. While orbiting the central area, the hot gas produces the broad lines observed at type I AGN. The region where the broad lines are produced forms the broad line region (BLR) and at the same time more slowly moving clouds above the central region form the narrow line region (NLR). Additionally, beyond the BLR an optical thick molecular torus of colder gas exists. In case that the orientation of the source allows the observer to identify the broad line region, the source is observed as a type I. On the contrary, if the torus is located perpendicularly to the observation axis, only the narrow lines can be identified. In that case the source is observed as a type II galaxy. Since the optical torus is formed by gas and dust, it absorbs the optical radiation which is reprocessed as infrared emission. Hence, the wide variety of AGNs can be correlated with the different viewing angles.

Although the unified model seems to solve the mystery among the different subclasses of AGN, some of their spectral properties still imply physical differ-

ences between these objects. Therefore it is still not fully understood whether there are different intrinsic procedures that drive to the wide observed variety or we just observe the same kind of objects.

## 1.6 Large scale structure

### 1.6.1 Galaxy groups and clusters

The term large scale structure accounts for the observable distributions of matter on the largest scales where gravity is the dominant force. As gravity pulls the galaxies together, the majority of them are collected into regions called galaxy groups and galaxy clusters (Eke et al. 2004; [13] Calvi et al. 2011 [9]). Galaxy groups contain a few galactic members and their masses can reach up to  $10^{14}M_{\odot}$ . They are observed as extended x - ray sources, filled with low-density gas. Galaxy groups with masses greater than  $10^{14}M_{\odot}$  are usually categorized as galaxy clusters. Thus, galaxy clusters consist the deepest potential wells in the Universe while they can be used as probes of the cosmology as well. Additionally, in many cases clusters are grouped together forming superclusters which are the largest known structures until this moment. The M/L (mass to light) ratio in superclusters reveals evidence about the dark energy distribution throughout the Universe.

Galaxy clusters are extended sources with X - ray luminosities greater than  $10^{42} \text{ erg/s}$ . Similarly to galaxy groups, they consist of galaxies, gas and dark matter. Dark matter makes up around 85 per cent of the total cluster mass. It can be detected only by gravitation effect on other matter and light passing near it. On the contrary, the gas, which is also referred as the intercluster medium (ICM), radiates strongly at X - rays through the Bremsstrahlung emission process. The high temperatures ( $\sim 10^8 K$ ) lead to the gas ionization producing the X - ray spectra. This X-ray luminosity can be used as a mass proxy. Apart from the X - ray surveys, clusters and groups can be identified by optical and infrared observations as well.

#### The Sunyaev – Zeldovich effect

At microwave wavelengths clusters are observable due to the Sunyaev – Zeldovich effect [34]. During that process, the CMB photons are scattered via Inverse Compton scattering by the intra-cluster medium. Hence a distortion is caused in the spectrum of the CMB. The flux of CMB photons is increased at high frequencies while the flux decreases at low frequencies. Since the Sunyaev – Zeldovich effect is redshift-independent, it can be used as proxy for galaxy clusters lying at high redshifts and it constitutes a useful tool for the study of the large scale structure of the Universe.

#### Superclusters, Filaments and Voids

On larger scales, most galaxy groups and clusters are bonded together forming superclusters. Their typical sizes are up to  $50h^{-1}$  Mpc while their masses can reach up to  $10^{16}M_{\odot}$ . Hierarchically, they are the next largest units above galaxy



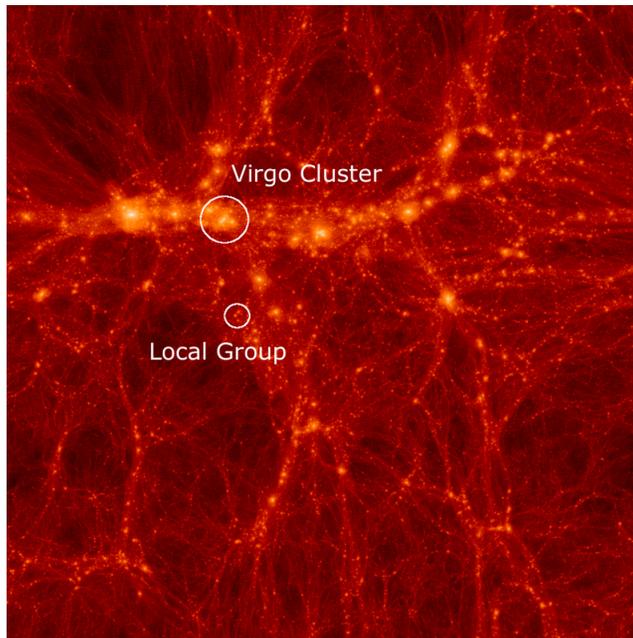


Figure 5: Simulated dark matter distribution showing the Virgo cluster and the local group as parts of the cosmic web. The image was taken from <https://www.cosmosim.org>.

clusters. Milky way is part of local group which in turn is included in Virgo supercluster. The Virgo supercluster was named after Virgo cluster which is the larger structure in it. It contains tens of groups and clusters and it has a diameter of 33 Mpc. Superclusters are themselves parts of larger structures named filaments. The Longest of them can reach up to  $80h^{-1}$  Mpc. Between filaments and due to the strong clustering in the surrounding environment, large, dark (low - density) regions named voids exist. They contain a few observable galaxies, gas and stars.

Observing the large scale structure shows that our Universe is not evenly distributed. Instead the mass has been clumping together forming large structures with deep gravitational potentials. The study of galaxy groups and clusters provides evidence about the basic cosmological properties of the Universe such as its expansion speed  $H_0$ , the dark matter density and the strength of the initial matter density fluctuations. Additionally they reveal the effect of environment on different phenomena like star-formation rates, etc

### 1.6.2 AGN and the connection with the large scale environment

Despite the fact that almost every massive galaxy hosts a B.H, only a few of them are active. We already know that the nuclei can be activated when large

gas inflows are accreted in the central region of the galaxy. However, it is still undetermined which physical mechanisms are responsible for the triggering of AGN. Furthermore, the effect of the environment at their activity is still under debate. More specifically, AGNs can be found isolated in the field but they are also observed within galaxy groups and clusters. Thus, their different properties shown between varying density environments could reveal the mechanisms that trigger or suppress them.

Many studies argue that AGN triggering could be the derivative of non-axisymmetric gravitational disturbances in galaxy clusters (Koulouridis et al. 2006 [25], Hopkins et al. 2014 [21]). One popular scenario suggests major galaxy mergers as the main fueling mechanism. During this process, massive galaxies with almost equal size collide together causing the gas to lose angular momentum and to fall into the existing black hole (e.g., Barnes and Hernquist 1996) [8]. In that case the galactic morphology could be changed but at the same time the galaxy stars are not affected as long as there is much space between them. However, other studies suggest that secular processes, such as supernova explosions, stellar bars, minor mergers and interactions are responsible for the B.H activation. In contrast to the major mergers, the secular processes do not disturb the large scale structure of the host galaxy (Hopkins et al. 2006) [19].

As mentioned above, the AGN activity is strongly related to the large scale environment. More specifically, the AGN activation seems more likely to occur in high density environments such as galaxy clusters, where larger amounts of gas exist. However, the present gas in clusters is mostly found at high temperatures rather than in cold form where it can be easily driven into the B.H. Moreover, in innermost cluster regions ram pressure stripping (RPS) could potentially unbind the galaxies' individual gas reservoirs and prevent the AGN feeding. There is strong evidence that the AGN activity is closely correlated with cluster's mass. Due to the high velocity dispersions, the ram pressure stripping is able to prevent the AGN activity in rich clusters with high masses while it is less effective in the low mass ones. Hence, the excess of AGNs in the less massive clusters is expected (Koulouridis et al. 2018) [27]. Concluding, it is obvious that many different parameters which affect the AGN density and their evolution exist. Except for the cluster's mass, the AGN evolution may depend on the adopted luminosity threshold for the AGN activity as well. Additionally, it is strongly believed that the distance from the cluster center and the richness of the cluster could affect the AGNs space density (Ehlert et al. 2014; [8] Koulouridis et al. 2014 [26]).

## 2 Background knowledge

### 2.1 Cosmological parameters

#### 2.1.1 Redshift

A common way to study the Universe is by observing the shifting of spectral lines. The spectral lines found in the spectrum of an astronomical object could reveal the chemical elements present in that object. However astronomers noticed that at the most cases the observed spectral lines are shifted to longer wavelengths. The first records of redshift in galaxies were obtained by Slipher (1917) [1]. Slipher found that the wavelengths of some spiral nebulae were increasing with distance. A few years later Hubble (1929) [2] proved that there is a linear relation between the velocity  $u$  of galaxies and their proper distance  $d$ :

$$u = H_0 \cdot d \quad (1)$$

where  $H_0$  is the Hubble constant measured in  $(km \ s^{-1} \ Mpc^{-1})$ . This relation led to the conclusion that the Universe is expanding. The cosmological redshift  $z$  refers to the shift at the wavelength of the observed light ray due to the expansion of the Universe and it is given by

$$1 + z = \frac{\lambda_o}{\lambda_e} = \frac{\alpha(t_o)}{\alpha(t_e)} \quad (2)$$

where  $\lambda_o$  is the observed wavelength and  $\lambda_e$  is the emitted wavelength. The parameter  $\alpha(t_e)$  is the scale factor at the time the photon was emitted while  $\alpha(t_o)$  describes the scale factor at the time when the photon was observed. We use the scale factor in order to describe the size of the Universe and it can be defined as

$$\alpha(t) = \frac{1}{1 + z} \quad (3)$$

where  $t$  is the time that the object originally emitted the observed light and  $z$  is its redshift.

For small velocities ( $u \ll c$ ) the shift of the observed emission line is

$$1 + z = \frac{\lambda_o}{\lambda_e} = 1 + \frac{u}{c} \quad (4)$$

where  $u$  is the radial velocity of the object. This relation describes the Doppler effect or the shift at the observed wavelength resulting in radial motion. If the object approaches the observer, then the wavelength is shifted towards the blue side of the spectrum. On the contrary, if the object moves away from the observer, the wavelength is shifted towards the red side of the spectrum.

#### 2.1.2 Density parameters

The fate of the Universe can be determined by the density parameter. The density parameter  $\Omega_0$  is given by:

$$\Omega_0 = \frac{\rho}{\rho_c} \quad (5)$$

where  $\rho$  is the mass density and  $\rho_c$  the critical density of the Universe (the density to slow the expansion to zero after an infinite time). For  $\Omega_0 < 1$  the Universe would expand for ever. Otherwise if  $\Omega_0 > 1$  it would stop the expansion and it would recollapse. In a matter dominated, homogeneous and isotropic Universe [29] the geometry can be defined as

$$\Omega_M \equiv \frac{8\pi G\rho_0}{3H_0^2} \quad (6)$$

and

$$\Omega_\Lambda \equiv \frac{\Lambda}{3H_0^2} \quad (7)$$

where

$$\Omega_\Lambda + \Omega_M + \Omega_R = 1 \quad (8)$$

The parameter  $\Omega_R$  measures the curvature of the Universe while  $\Omega_M$  and  $\Omega_\Lambda$  are the matter and vacuum energy density respectively. In the present study we consider a flat Universe with  $\Omega_M = 0.3$  and  $\Omega_\Lambda = 0.7$ .

### 2.1.3 Comoving distance

To define the comoving distance between two nearby objects in the Universe we begin from the following function

$$E(z) \equiv \sqrt{\Omega_M(1+z)^3 + \Omega_k(1+z)^2 + \Omega_\Lambda} \quad (9)$$

The quantity  $E(z)$  multiplied by  $H_0$  gives the Hubble's constant  $H(z)$  measured by an observer at redshift  $z$ . Thus, the comoving distance  $D_c$  is given by the integral

$$D_c = \frac{c}{H_0} \int_0^z \frac{dz'}{E(z')} \quad (10)$$

where  $c$  is the speed of light. In case two nearby objects are moving with the Hubble flow and at the same time their peculiar velocities <sup>1</sup> are negligible, the distance between them is defined as the comoving distance.

### 2.1.4 Luminosity distance

The equation for the luminosity distance is given by the relationship between bolometric flux  $S$  and bolometric luminosity  $L$ :

$$D_L \equiv \sqrt{\frac{L}{4\pi S}} \quad (11)$$

---

<sup>1</sup>The term peculiar velocity refers to the local motion of an object due to local gravitational effects.

where the bolometric luminosity and the bolometric flux are defined as the energy emitted across the whole electromagnetic spectrum.

Otherwise, if the energy is emitted within a finite waveband, the K correction must be applied. In that case and if the spectrum of the object is not constant the differential flux  $S_\nu$  is defined as

$$S_\nu = (1+z) \frac{L_{(1+z)\nu}}{L_\nu} \frac{L_\nu}{4\pi D_L^2} \quad (12)$$

where  $L_\nu$  is the differential luminosity and the ratio  $\frac{L_{(1+z)\nu}}{L_\nu}$  represents the K correction due to the fact that object emits its radiation in a different band of the one in which it is observed. The factor  $(1+z)$  accounts for the difference between the emitted and the observed flux due to the redshift effect.

The luminosity distance can be also defined as

$$D_L = (1+z) \frac{c}{H_0} \int_0^z \frac{dz'}{E(z')} \quad (13)$$

or by using equation (10)

$$D_L = (1+z)D_C \quad (14)$$

### 2.1.5 Angular diameter distance

To describe an object's angular size given its physical size and its redshift, we use the angular diameter distance. For an object located at redshift  $z$ , its angular distance is given by:

$$D_A = D_C/(1+z) \quad (15)$$

where  $D_C$  is its comoving distance. If we know the object's physical and angular sizes, the angular diameter distance is computed as:

$$D_A = x/\tan\theta \quad (16)$$

where  $x$  is the physical size and  $\theta$  it's the angular size of the object in radians.

### 2.1.6 The comoving Volume

The comoving volume describes the volume in which the number densities of objects moving with the Hubble flow are constant with redshift. The comoving volume element in a solid angle  $d\Omega$  which is included in a redshift interval  $dz$  is:

$$dV_c = \frac{c}{H_0} \frac{(1+z)^2 D_A^2}{E(z)} d\Omega dz \quad (17)$$

where  $D_A$  is the angular diameter distance at redshift  $z$ . For a flat Universe the total comoving volume of the sky is:

$$V_c = \frac{4\pi}{3} D_c^3 \quad (18)$$

where  $D_c$  is the comoving distance.

## 2.2 Luminosity function

The luminosity function represents one of the most useful statistical tools, which provides information about the growth of the SMBHs over the history of the Universe. It traces the space density evolution of luminous objects as a function of redshift and luminosity. The differential luminosity function describes the number of objects  $N$  per comoving volume  $V$  and per unabsorbed luminosity  $L$  defined as

$$\Phi(L, z) = \frac{d^2 N(L, z)}{dV dL} \quad (19)$$

Constructing the luminosity function for different surveys is crucial for studying the AGN distribution for the different galaxy types and their evolution with luminosity and redshift at different wavelengths. Moreover, the cluster luminosity function for AGNs is important for understanding the AGN evolution in dense environments. Comparing the field LF to the one in clusters, is crucial in order to interpret how the denser environments affect the AGN activity.

### 2.2.1 Galaxy luminosity function

A parametric form in order to describe the galaxy luminosity function (GLF) is the Schechter function proposed by Schechter (1976) [3]. The Schechter function is the number of galaxies per unit volume  $\phi(L)dL$  in the luminosity interval from  $L$  to  $L + dL$  where

$$\phi(L)dL = \frac{\phi^*}{L^*} \left(\frac{L}{L^*}\right)^\alpha \exp\left(-\frac{L}{L^*}\right) \frac{dL}{L^*} \quad (20)$$

The parameters  $\phi^*$  and  $L^*$  are the values of characteristic space density and characteristic luminosity respectively, at the point where the luminosity function exhibits a rapid change in the slope. Beyond this point the LF is described as a power law representing the way the less luminous galaxies are distributed. The more luminous objects located below the break are described by an exponential law. The slope of the luminosity function at the faint end is given by the dimensionless parameter  $\alpha$  which is typically negative, implying large numbers of the low luminosity AGNs.

Concerning the optical wavelengths, it is more convenient to write the Schechter function in terms of magnitudes using the following relation

$$\frac{L}{L^*} = 10^{-0.4(M-M^*)} \quad (21)$$

The number density of galaxies with absolute magnitude in the interval  $M, M + dM$  can be expressed as

$$\Phi(M) = 0.4 \ln 10 \phi^* [10^{0.4(M^*-M)}]^{1+\alpha} \exp[-10^{0.4(M^*-M)}] \quad (22)$$

where  $M^*$  is the characteristic absolute magnitude at the normalization point  $\phi^*$ .

### 2.2.2 Evolution across cosmic time

The evolution of AGNs through cosmic time reveals the cosmic history of accretion onto SMBHs and the connection between the AGN and the host galaxy. Several studies at different wavelengths in the past decades suggest that the AGN population is strongly evolving with redshift. In particular the less luminous AGN peak their comoving space density at lower redshifts while the bright ones were more common earlier in cosmic time (Aird et al. 2010 [3], Ueda et al. 2003 [35]). This behavior is typically referred to as the "AGN downsizing". Moreover, the XLFs indicate that the most massive SMBHs are formed at higher redshifts while the lower mass black holes grew later in the Universe. The observed drop in the number density at the most luminous objects results from the cold gas extinction in their massive halos due to strong and early star formation, feedback, or merging activity. On the other hand, the low luminosity AGNs are evolving at a lower rate and they remain numerous across cosmic time. In the following figures we plot the comoving number density for both XXL fields in the soft band. We divided our sample in four luminosity bins ( $42 \leq \log L \leq 43$ ,  $43 < \log L \leq 43.5$ ,  $43.5 \leq \log L < 44$  and  $44 \leq \log L < 44.5$ ) where the number density of AGNs peaks at a different epoch of the Universe.

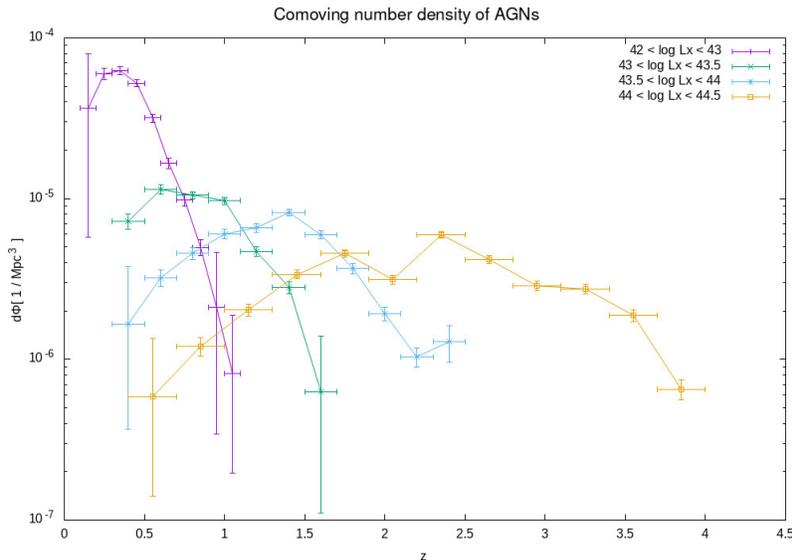


Figure 6: Comoving number density of AGNs for the XXL - South field

Subsequently, we plot the comoving density of spectroscopic AGNs in XXL galaxy clusters, in the soft band with respect to the field. The results are presented at figures 8 and 9. AGNs located within  $6r_{500}$  from the cluster's center peak around the same redshift compared to the ones in the field.

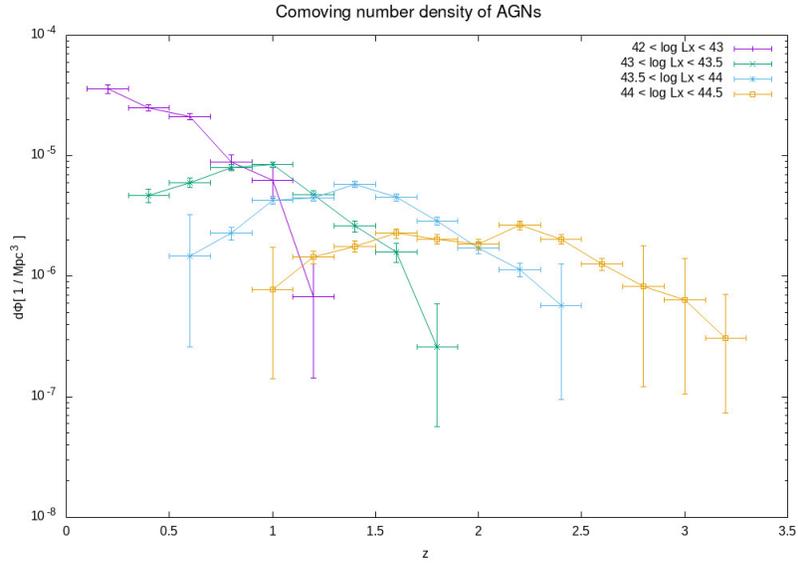


Figure 7: Comoving number density of AGNs for the XXL - North field

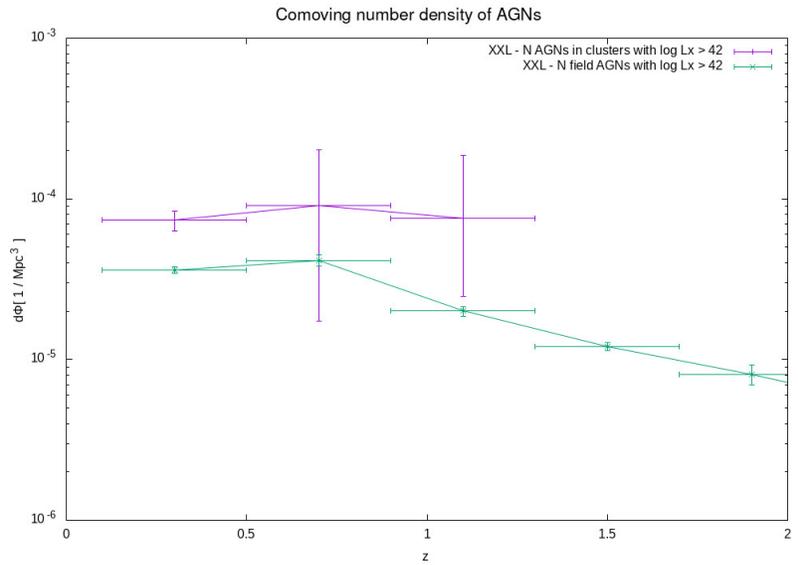


Figure 8: Comoving number density of AGNs within XXL - North clusters with respect to the field



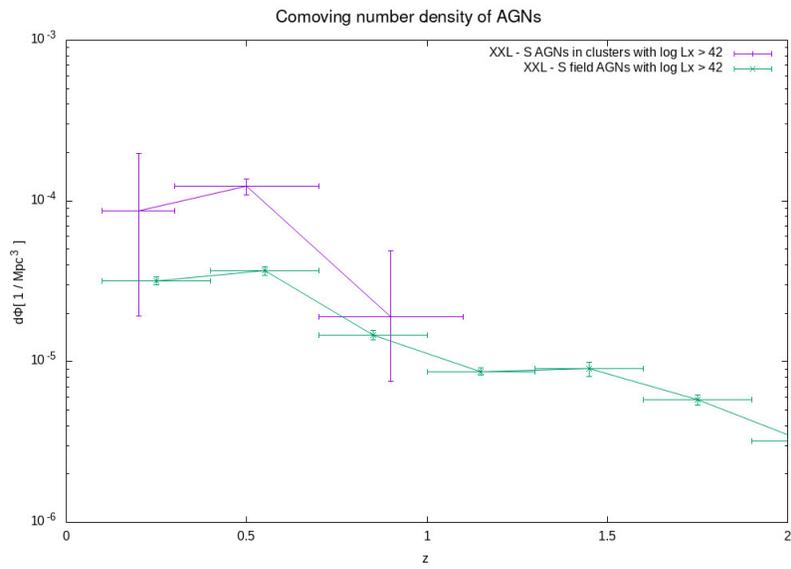


Figure 9: Comoving number density of AGNs within XXL - South clusters with respect to the field.

### 3 Data

In this section, we present the XXL survey followed by the catalogues we used in order to construct the X - ray luminosity function.

#### 3.1 XMM - Newton

The X - Ray multi mirror mission (XMM - Newton) was launched on December 10th, 1999, by the ESA and it consists the biggest science satellite ever built in Europe. It carries three X-ray telescopes with a large collecting area providing long exposures with high resolution. The satellite is also equipped with three EPIC (European Photon Imaging Camera) imaging detectors; an EPIC PN and two EPIC MOS that operate simultaneously with the two RGS (Reflection Grating Spectrometers). About of 44 % the incoming flux reaches the MOS cameras while the rest of it is diverted to the spectrometers. Thus, photometry can be provided with the spectral analysis of the target.

XMM - Newton performs a highly eccentric orbit around earth, so that its instruments are not affected by the radiation belts. It completes its orbit in 48 hours and this way astronomers can have uninterrupted observations of celestial sources. While atmosphere blocks X-rays from reaching the Earths' surface, XMM - Newton is ideal for highly sensitive observations.

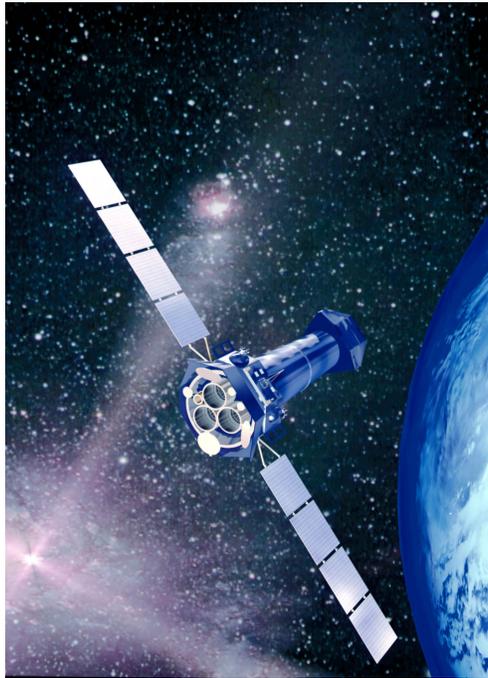


Figure 10: An artistic view of the XMM-Newton satellite (credit ESA).

### 3.2 The XXL Survey

The XXL survey is a multi-wavelength (from X-ray to radio) survey with the aim of identifying thousands of AGNs and hundreds of clusters suitable for cosmological studies. It provides one of the best views of the X-ray sky yet obtained, while it consists the largest available survey of galaxy clusters. The main purpose of the survey is to interpret the spacetime distribution of galaxy clusters, in order to define the constraints on the dark energy equation. Moreover, it enhances the study of the AGNs' characteristics that provides information about their evolution and the study of the x-ray background as well. The XMM-XXL survey is the largest XMM Newton programme as it covers two extragalactic areas of  $25 \text{ deg}^2$  each, using XMM observations with a median at 10 ks, where the point source sensitivity is  $5 \times 10^{-15} \text{ erg/s/cm}^2$  in the soft [0.5 - 2keV] band. It consists of the XXL - North field which is located around (RA, Dec) of (2h 20m, -4.5deg) and the XXL - South field which is located around (23h 30m, -55deg). Both fields are covered by a different number of surveys. The choice of the XXL fields was driven by several factors such as the need of having good XMM visibility, the necessity to probe large scales combined with cosmic variance, the selection of low galactic absorption etc.

### 3.3 Observational Data

#### AGN sample

The data which used in the present study were obtained from the 3XLSS X-ray source catalogue, described in (Chiappetti et al. 2018) [10]. The 3XLSS catalogue contains 26 056 objects in two sky regions, covering a total area of  $\sim 50 \text{ deg}^2$ . In a sample of 14 168 objects located at the North field, 13 770 of them are found to be point like sources, while the rest 398 of them were classified as extended sources. Similarly, from the 11 888 objects located in the South field, the 11 413 of them are point like sources and 475 are found to be extended. The limiting flux (at  $3\sigma$ ) is  $F_{0.5-2keV} = 10^{-15} \text{ erg/s/cm}$  in the soft band and  $F_{2-10keV} = 3 \cdot 10^{-15} \text{ erg/s/cm}$  in the hard band. In order to construct the XLF in the field, we used only the data associated with the point like sources from that catalogue.

Table 1: Point sources included in XXL catalogues

	South field	North field
AGN with spectroscopic z	3298	2780
AGN with photometric z	9206	11714
Total	11562	13844

### The 365 clusters catalogue

The cluster sample was obtained by the 365 clusters catalogue, which was published by (Adami et al. 2018) [14]. The cluster catalogue consists of 341 spectroscopically confirmed clusters lying in the redshift interval  $z: 0 - 1.2$ . The cluster masses vary from  $10^{13}M_{\odot}$  up to  $4 \times 10^{14}M_{\odot}$  and thus the sample is dominated by poor and moderately rich clusters. 211 out of the 365 clusters are located in the northern area while 154 are located in the south. Moreover, 261 structures are spectroscopically confirmed sources with at least three spectroscopic galaxy members. The sample is further divided to the (C1) , (C2) and (C3) categories due to the contamination from the point sources. The C1 clusters consist a pure sample with 183 spectroscopically confirmed sources in both XXL fields. The C2 sample has 50 % contamination by misclassified point sources while the C3 sample is associated with sources with weak X - ray emission.

### 3.4 Area Curve

The first step in an attempt to build the X - ray luminosity function includes the area curve determination. The area curve describes the survey's sky coverage available for a source as a function of its flux. Given the XXL-N pointings<sup>2</sup> catalogue, we reproduced the area curve in the northern XXL field. To prevent overlapping between different pointings we considered a  $10''$  radius around each pointing center. Moreover, we converted the background counts according to the following relation

$$flux = (sbcg/exptime) * scv \quad (23)$$

where the term sbcg accounts for the background counts, scv is the conversion factor and exptime is the exposure time at each pointing. The reproduced area curve is illustrated in figure 7. In our study, we used two different area curves, one for the north field and one for the south field, as they are presented at figure 3 in (Chiappetti et al. 2018) [10].

Concluding, deeper surveys provide better statistical samples for the faint point like sources, but over relatively small areas. On the contrary, larger surveys lack in depth and, thus, they miss the faint sources located at high redshifts, while they are ideal for studying the large scale structure and for environmental studies.

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<sup>2</sup>The XXM-Newton observation referred to as pointings.

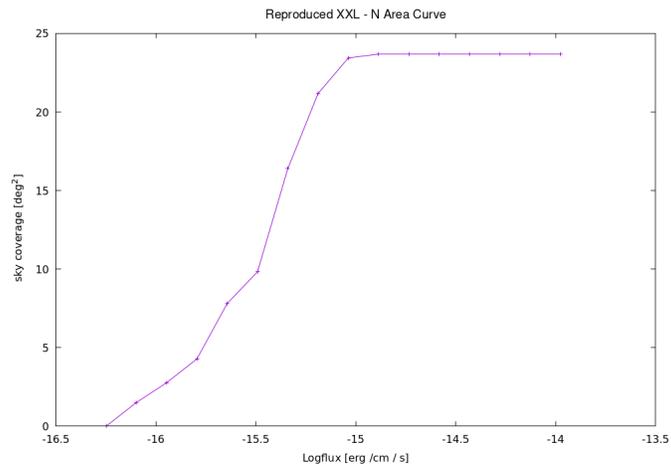


Figure 11: Reproduced sky coverage in the northern XXL field in the soft band. The plot is in agreement with the one published in Chiappetti 2018.

## 4 Methodology

### 4.1 AGN luminosity function in the field

A binned approximation to the luminosity function is determined by the method proposed by (Schmidt 1968) [30].

$$\frac{d\Phi(L, z)}{d\log L} = \frac{1}{\Delta\log L} \sum_{i=1}^n \frac{1}{V_{max}} \quad (24)$$

The so called  $1/V_{max}$  method corrects the spatial density corresponding to the detected objects, by a factor inversely proportional to the maximum volume that each object could be identified and still remain into the sample. Errors in each luminosity bin is calculated by assuming Poisson statistics using the following relation:

$$\delta\Phi(L) = \frac{\sqrt{N}}{\int_{L_{min}}^{L_{max}} \int_{z_{min}}^{z_{max}} \Omega(L, z) \frac{dV}{dz} dL dz} \quad (25)$$

(Condon 1989) [11]. In case that we find less than 50 AGNs in a luminosity bin the error is estimated according to Gehrels 1986 [16]. More luminous objects are more difficult to be identified and thus larger corrections should be applied. Given the fact that the larger luminosity bins are expected to contain more objects, the density value is corrected again by dividing with the luminosity bin width  $\Delta L$ . The maximum volume  $V_{max}$  for a source corresponds to the source's maximum redshift  $z_{max}$  which is determined by the source's luminosity and the minimum redshift of the bin. We divided our sample in different redshift bins and we chose the spectroscopic redshift of each source to find out in which bin it belongs. In case where there wasn't a measurement for the spectroscopic redshift, we used the photometric redshift of the source. The photometric redshifts of the sample are available by (Fotopoulou et al.) [15], and they are computed using wide and at the same time deep photometric observations.

Applying the method described above, we constructed the XLF for the point like sources located in the XXL's southern and northern fields. The XLF is computed at the soft and at the hard band separately. We present below our results in comparison with the ones published in Aird's 2015 paper [4]. Only sources with luminosities greater than  $L = 10^{42} \text{ erg/s}$  are considered as AGNs and thus we discard sources found below that limit.

### 4.2 AGN luminosity function in clusters

Aiming to build the XLF in clusters, we begin by counting all the X - ray point like sources found within  $6r_{500, MT}$  from the center of the cluster. We divide the area around each cluster into six rings of  $r_{500}^3$  radius and we construct six

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<sup>3</sup> $r_{500}$  is considered as the distance from the cluster's center where the mean density is 500 times the critical density of the Universe  $\rho_c$  computed at the cluster's redshift.

different catalogues, containing the objects found within each  $r_{500}$  ring. We consider that each source which has an available spectroscopic redshift, belongs to the cluster whether its radial velocity difference between the galaxy and the cluster lies in the interval  $\Delta u = \pm 2.000(z_{spec} + 1) \text{ km/s}$ . In terms of redshift, we count the sources with redshift difference  $\Delta z \approx \pm 0.007$  from the cluster's spectroscopic redshift. For the sources of which spectroscopic redshifts are not available, we choose only the ones with photometric redshifts that correspond to the following relations:

1. 
$$|z_{photometric} - cz| < 0.1 * (1 + cz) \quad (26)$$

where  $cz$  is the cluster's redshift.

2. 
$$(Z_{BEST68 \text{ HIGH}} - Z_{BEST68 \text{ LOW}}) < 0.5 \quad (27)$$

where  $Z_{BEST68 \text{ HIGH}}$  and  $Z_{BEST68 \text{ LOW}}$  are the highest and the lowest value respectively, enclosing 68% of the area around the median redshift value (ZPDF).

3. Sources having optical counterparts with absolute magnitudes in the  $i'$  band given by

$$M_i \leq M_i^* + 1$$

where  $M_i^*$  is the characteristic magnitude as described by equation (21).

To compute the value  $M_i^*$  for each source we used a linear interpolation given each source's redshift. We determine the XLF using AGNs and clusters in two different redshift intervals  $0.1 < z < 0.5$  and  $0.5 < z < 1$ . The second redshift bin does not contain enough AGN in order to present statistical correct results. Finally we divide the number of X - ray sources found in each annulus with a factor proportional to the overdensity corresponding to the optical cluster galaxies with respect to the optical field galaxies. Thus we used the projected density profile of the optical sources from the COSMOS field as they are presented at Ehlert 2014 [12]. In order to apply the 1/Vmax method, we consider that the total available area for a source depends on the source's  $z_{max}$ . The flux limit of each cluster is selected as the flux limit of the XXL field where the source belongs. The maximum volume  $V_{max}$  for each source corresponds to the comoving volume that ranges within  $\pm 0.007$  from the cluster's redshift. We estimate the uncertainty of a given luminosity bin by assuming Poisson statistics where we have a number of objects greater than or equal to 50. In the bins where less than 50 AGNs were found, we used the tables in Gehrels (1986) [16]. To test if our method is valid, we constructed a few mock cluster catalogues by shuffling each cluster's coordinates. In figure 12 we show the AGN XLF using the random clusters in the soft band while in figure 13 we show the XLF produced in the hard band. Using this method, we verify that the derived XLF coincides with the field XLF at any redshift and at both soft and hard bands.

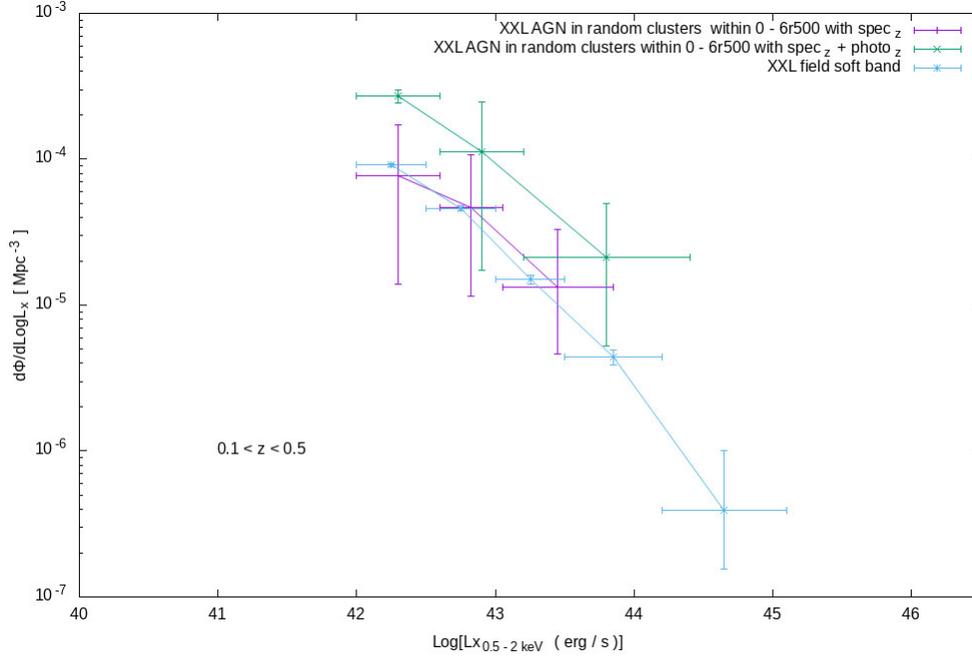


Figure 12: AGN XLF in the soft band using sources within the random clusters which were produced by randomizing the positions of the XXL clusters. We included only sources located within  $6r_{500}$  from the cluster center.

Table 2 and table 3 present the number of sources with available spectroscopic and photometric redshifts (when  $spec_z \leq 0$ ) found in each  $2 \times r_{500}$  annulus for the two different redshift bins.



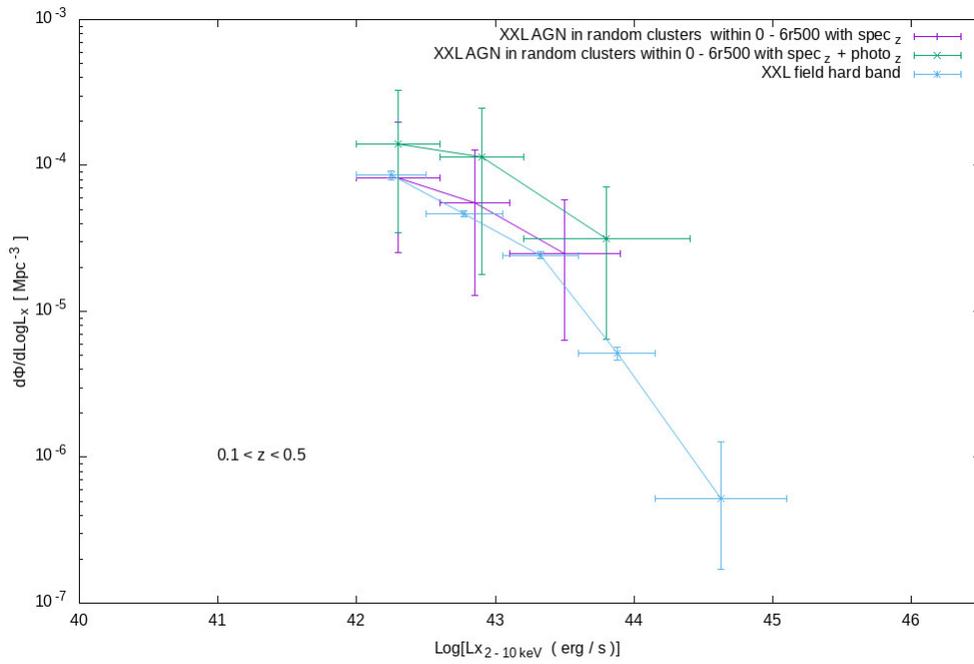


Figure 13: AGN XLF in the hard band using sources within the random clusters which were produced by randomizing the positions of the XXL clusters. We included only sources located within  $6r_{500}$  from the cluster center.

Table 2: Number of AGN with available spectroscopic and photometric redshifts within 3 different  $2 \times r500$  rings in the range  $z: 0.1 - 0.5$

Distance from the cluster center	South field	North field
0 - 2r500	17 <i>photo<sub>z</sub></i>	37 <i>photo<sub>z</sub></i>
	38 <i>spec<sub>z</sub></i>	38 <i>spec<sub>z</sub></i>
2 - 4r500	52 <i>photo<sub>z</sub></i>	103 <i>photo<sub>z</sub></i>
	47 <i>spec<sub>z</sub></i>	32 <i>spec<sub>z</sub></i>
4 - 6r500	65 <i>photo<sub>z</sub></i>	126 <i>photo<sub>z</sub></i>
	56 <i>spec<sub>z</sub></i>	45 <i>spec<sub>z</sub></i>

Table 3: Number of AGN with available spectroscopic and photometric redshifts within 3 different  $2 \times r500$  rings in the range  $z: 0.5 - 1.0$

Distance from the cluster center	South field	North field
0 - 2r500	14 <i>photo<sub>z</sub></i>	9 <i>photo<sub>z</sub></i>
	7 <i>spec<sub>z</sub></i>	8 <i>spec<sub>z</sub></i>
2 - 4r500	28 <i>photo<sub>z</sub></i>	18 <i>photo<sub>z</sub></i>
	5 <i>spec<sub>z</sub></i>	10 <i>spec<sub>z</sub></i>
4 - 6r500	47 <i>photo<sub>z</sub></i>	30 <i>photo<sub>z</sub></i>
	13 <i>spec<sub>z</sub></i>	15 <i>spec<sub>z</sub></i>

## 5 Results

At the following section we present the XLF in the field and within the XXL clusters using the  $1/V_{\max}$  method as it was discussed in section 4.

### 5.1 XLF in the field

Our sample was divided in ten redshift bins and we selected the AGNs with X-ray luminosities:  $L_x \geq 10^{42} \text{ erg/s}$ . The soft and the hard band are plotted separately using all the sources located in both XXL fields. Our results are in agreement with the XLF produced by (Aird et al. 2015) [5].

#### 5.1.1 XXL - soft band

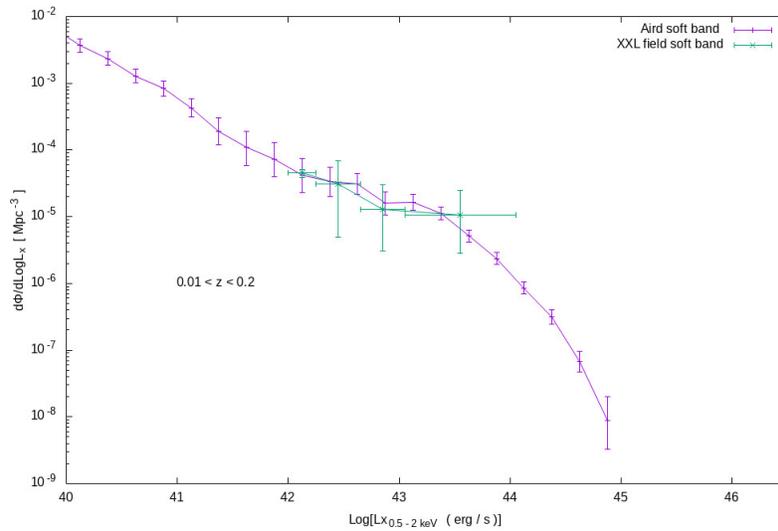


Figure 14: XXL field Luminosity function in the soft band in the redshift interval  $z: 0.01 < z < 0.2$ .

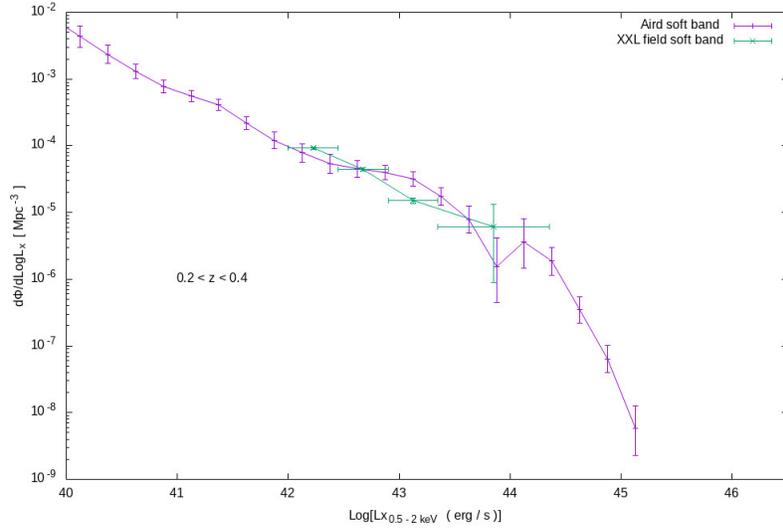


Figure 15: XXL field Luminosity function in the soft band in the redshift interval  $z: 0.2 < z < 0.4$ .

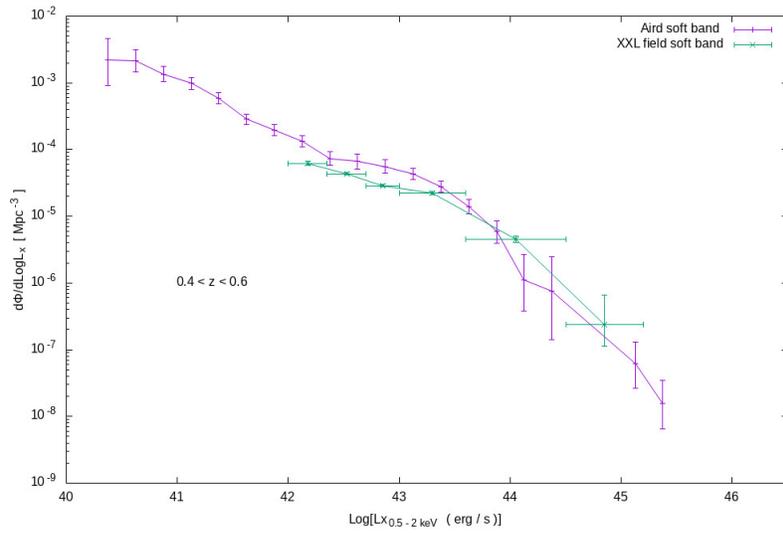


Figure 16: XXL field Luminosity function in the soft band in the redshift interval  $z: 0.4 < z < 0.6$ .

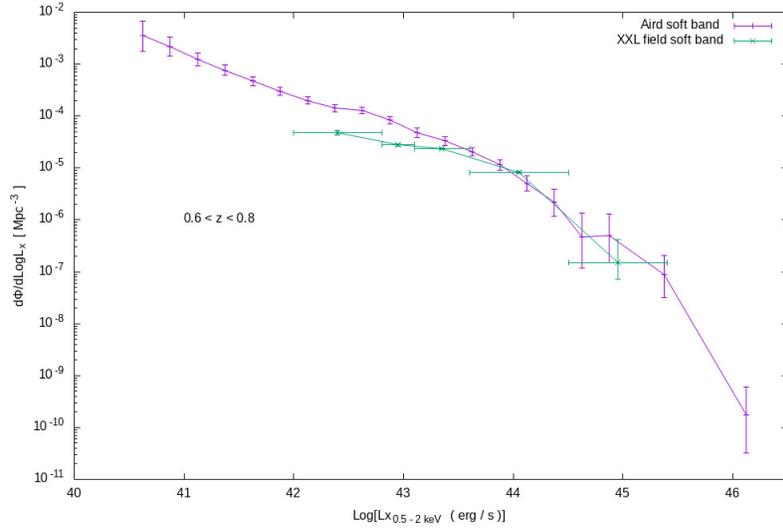


Figure 17: XXL field Luminosity function in the soft band in the redshift interval  $z: 0.6 < z < 0.8$ .

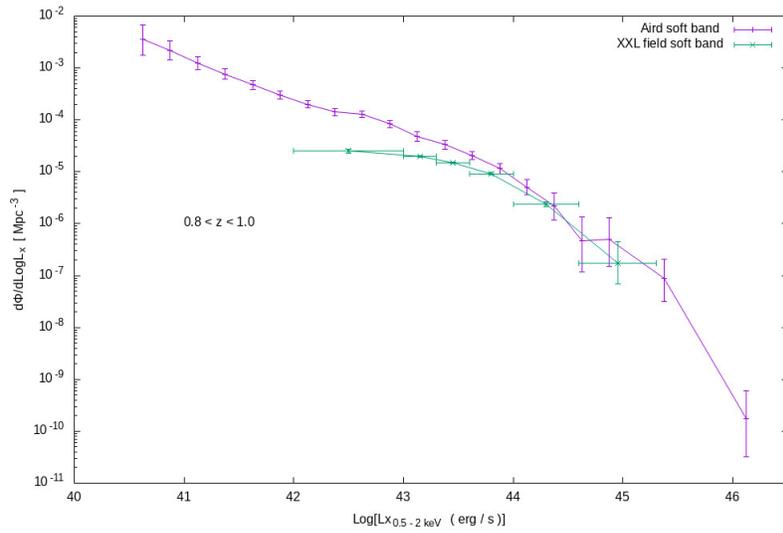


Figure 18: XXL field Luminosity function in the soft band in the redshift interval  $z: 0.8 < z < 1.0$ .

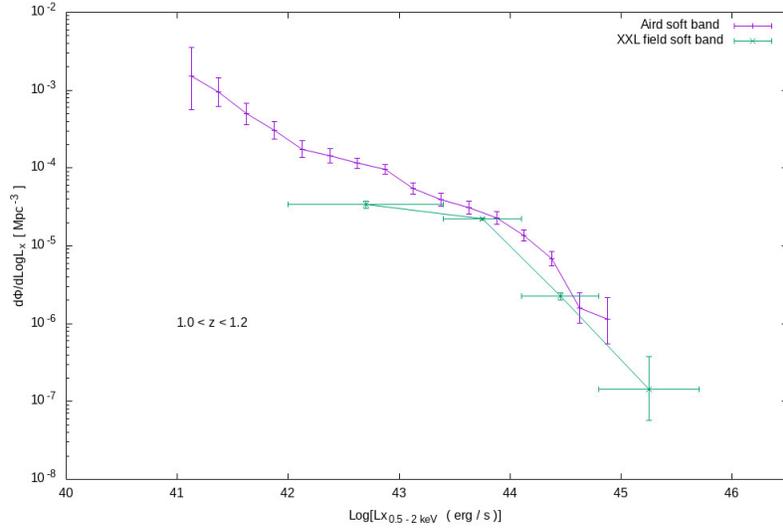


Figure 19: XXL field Luminosity function in the soft band in the redshift interval  $z: 1.0 < z < 1.2$ .

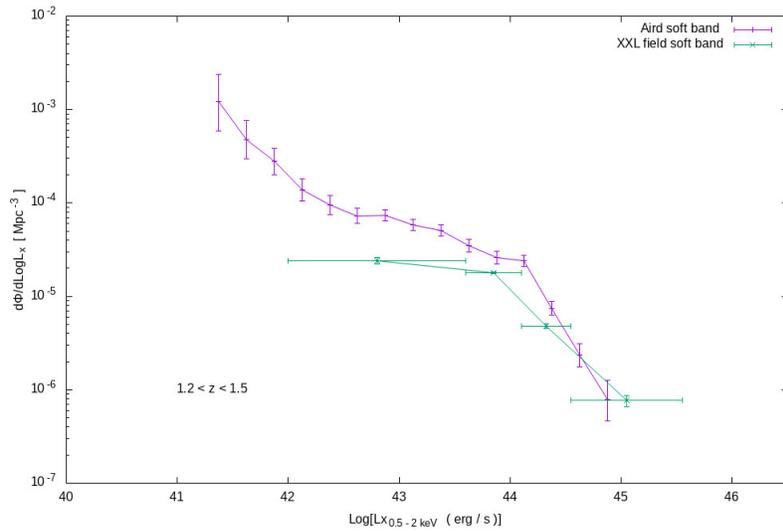


Figure 20: XXL field Luminosity function in the soft band in the redshift interval  $z: 1.2 < z < 1.5$ .

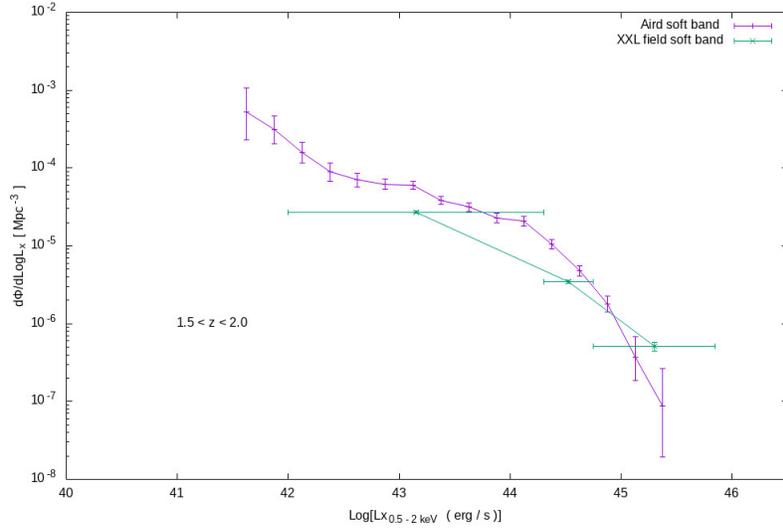


Figure 21: XXL field Luminosity function in the soft band in the redshift interval  $z: 1.5 < z < 2.0$ .

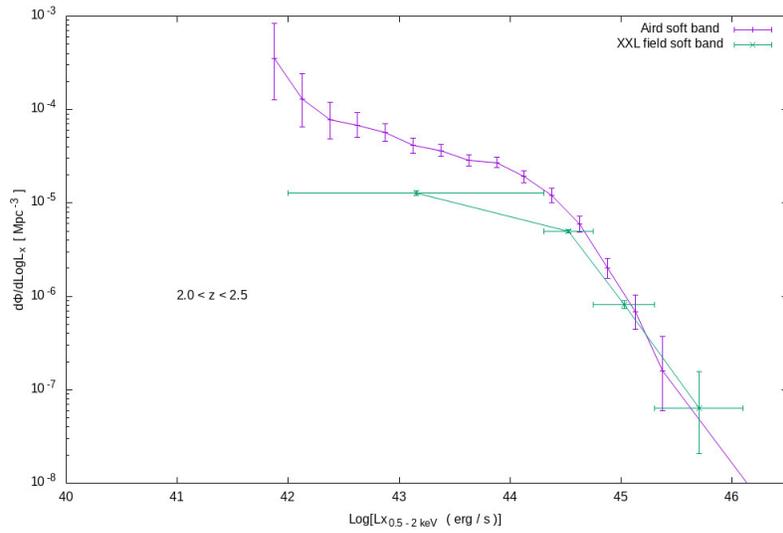


Figure 22: XXL field Luminosity function in the soft band in the redshift interval  $z: 2.0 < z < 2.5$ .

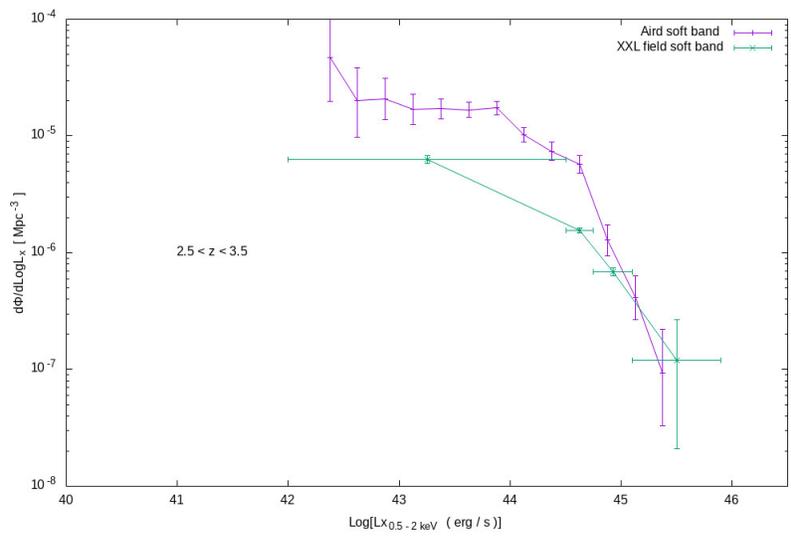


Figure 23: XXL field Luminosity function in the soft band in the redshift interval  $z: 2.5 < z < 3.5$ .



### 5.1.2 XXL - hard band

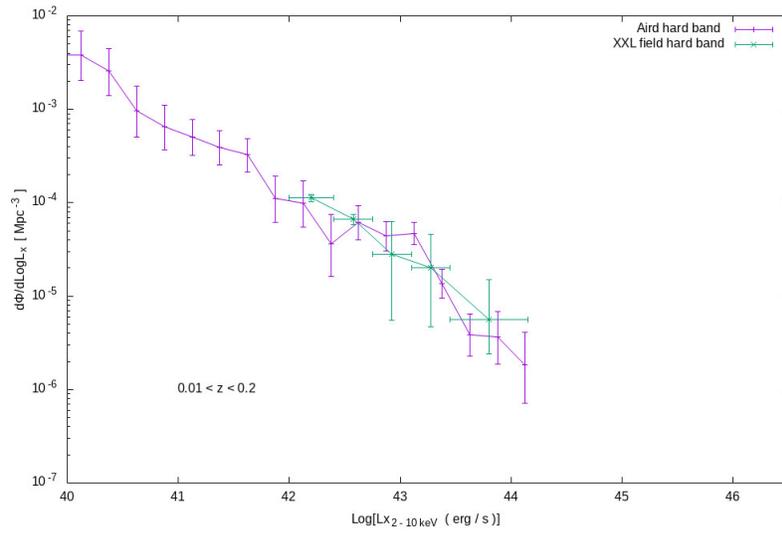


Figure 24: XXL field Luminosity function in the hard band in the redshift interval  $z: 0.01 < z < 0.2$ .

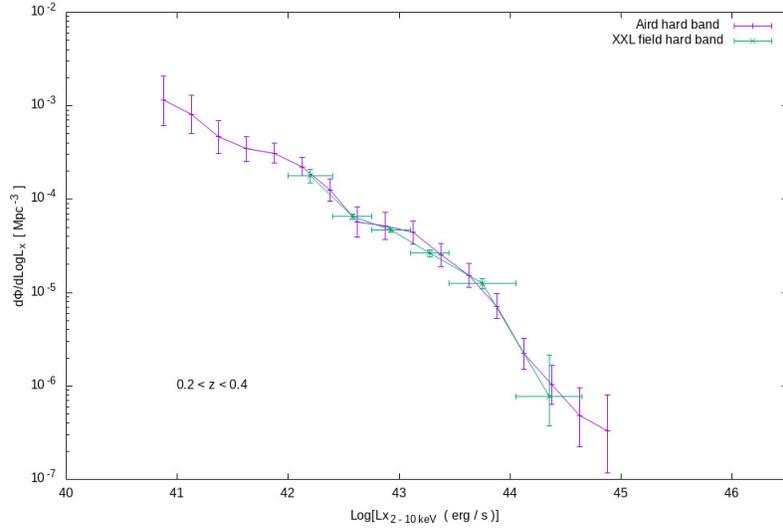


Figure 25: XXL field Luminosity function in the hard band in the redshift interval  $z: 0.2 < z < 0.4$ .

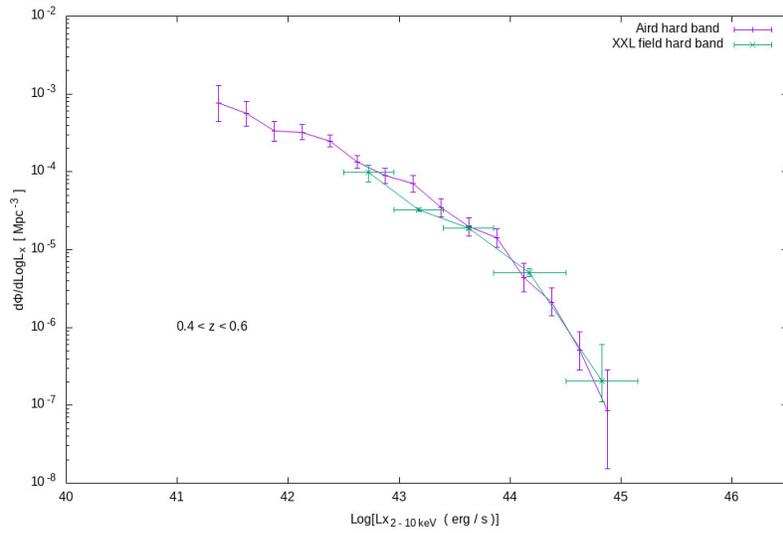


Figure 26: XXL field Luminosity function in the hard band in the redshift interval  $z: 0.4 < z < 0.6$ .

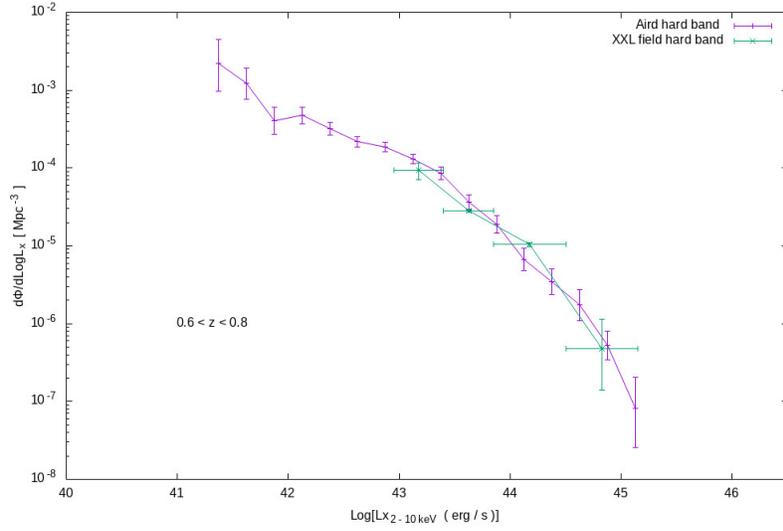


Figure 27: XXL field Luminosity function in the hard band in the redshift interval  $z: 0.6 < z < 0.8$ .

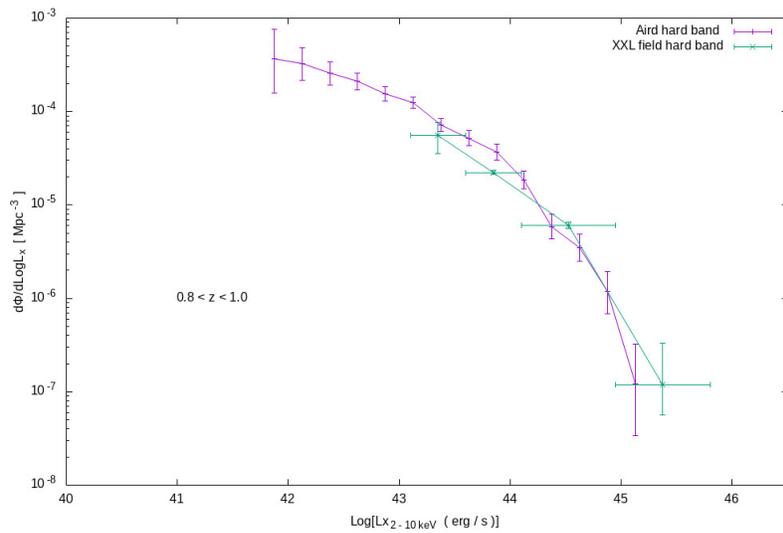


Figure 28: XXL field Luminosity function in the hard band in the redshift interval  $z: 0.8 < z < 1.0$ .

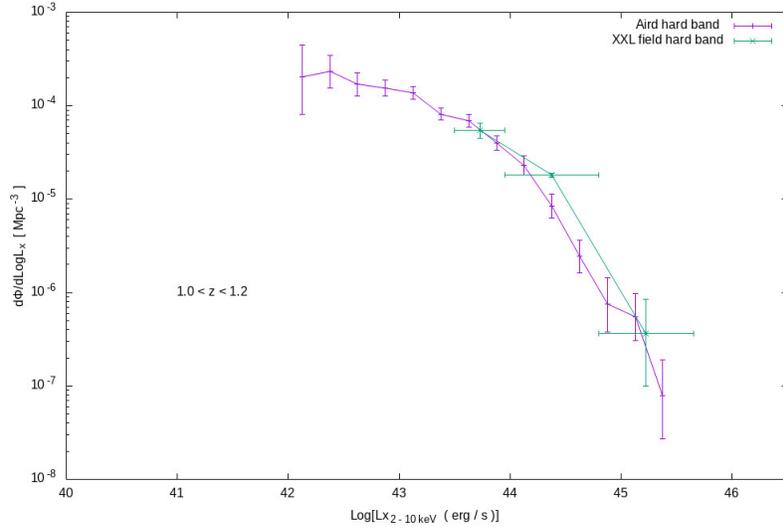


Figure 29: XXL field Luminosity function in the hard band in the redshift interval  $z: 1.0 < z < 1.2$ .

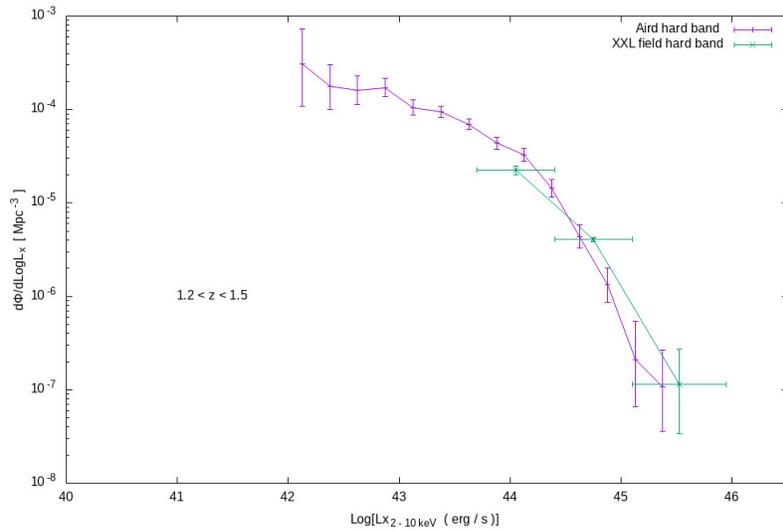


Figure 30: XXL field Luminosity function in the hard band in the redshift interval  $z: 1.2 < z < 1.5$ .

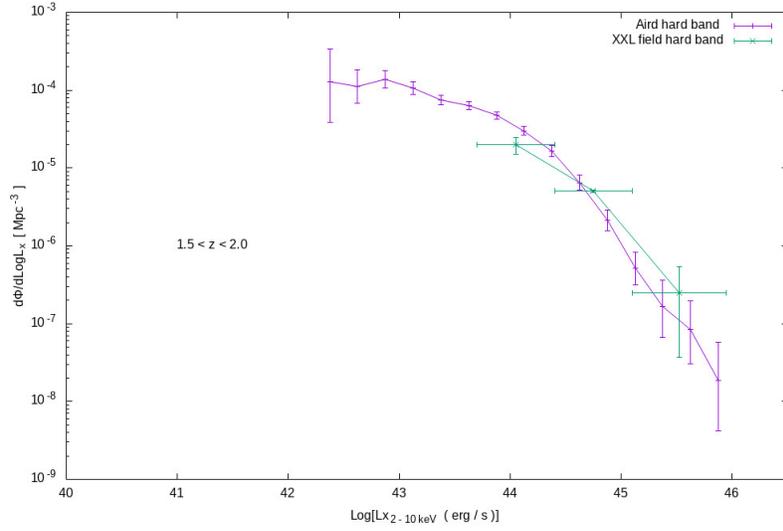


Figure 31: XXL field Luminosity function in the hard band in the redshift interval  $z: 1.5 < z < 2.0$ .

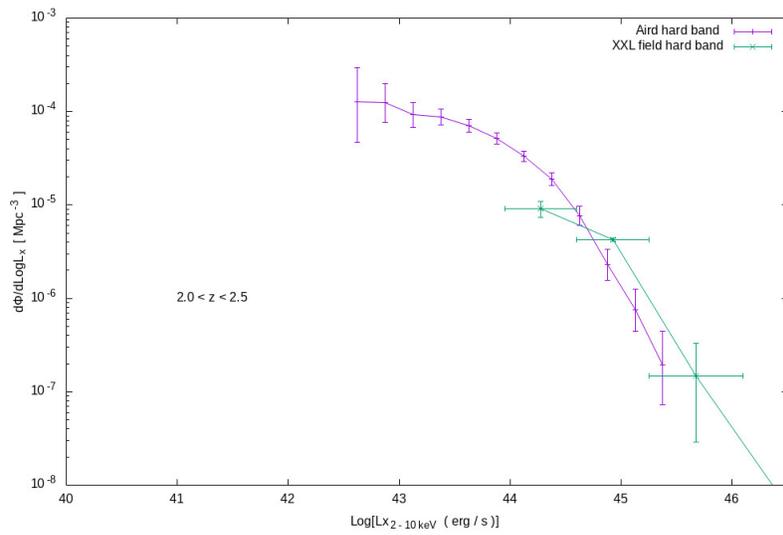


Figure 32: XXL field Luminosity function in the hard band in the redshift interval  $z: 2.0 < z < 2.5$ .

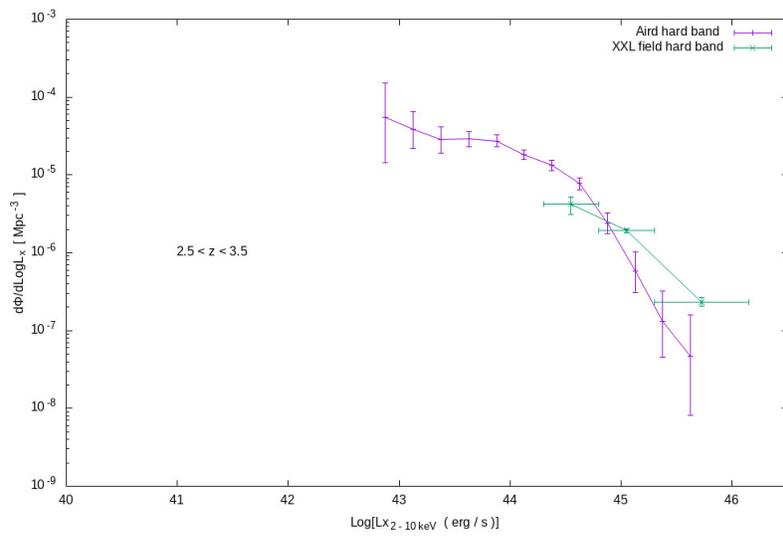


Figure 33: XXL field Luminosity function in the hard band in the redshift interval  $z: 2.5 < z < 3.5$ .

## 5.2 AGN XLF in galaxy clusters

Subsequently, we present the AGN XLF for the sources found in XXL galaxy clusters. Each plot shows the AGN distribution within three different  $2 \times r_{500}$  annulus, using sources only with spectroscopic redshifts and sources with both spectroscopic and photometric redshifts. The results are plotted separately for the soft and the hard band. In each plot we present the XLF produced from the field in order to compare it with the one produced from AGNs within the galaxy clusters in the same redshift interval.

### 5.2.1 XXL clusters in the soft band

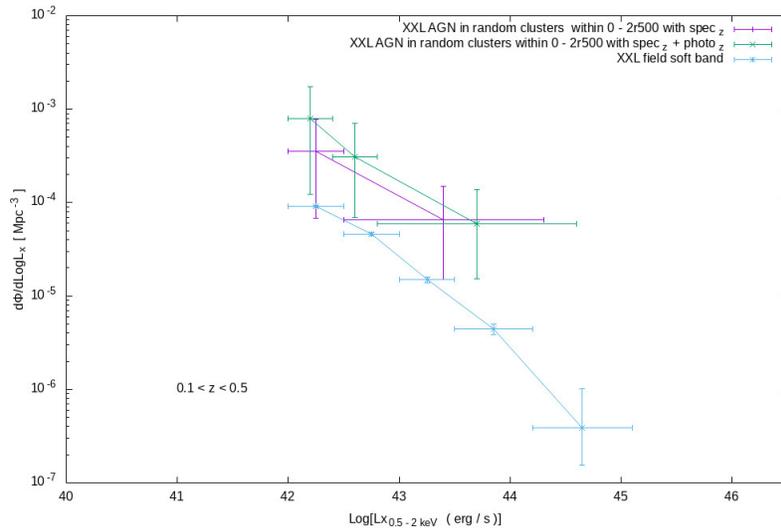


Figure 34: AGN within XXL clusters luminosity function in the soft band, in the redshift interval  $z: 0.1 < z < 0.5$  within  $0 - 2r_{500}$  from the cluster's center.

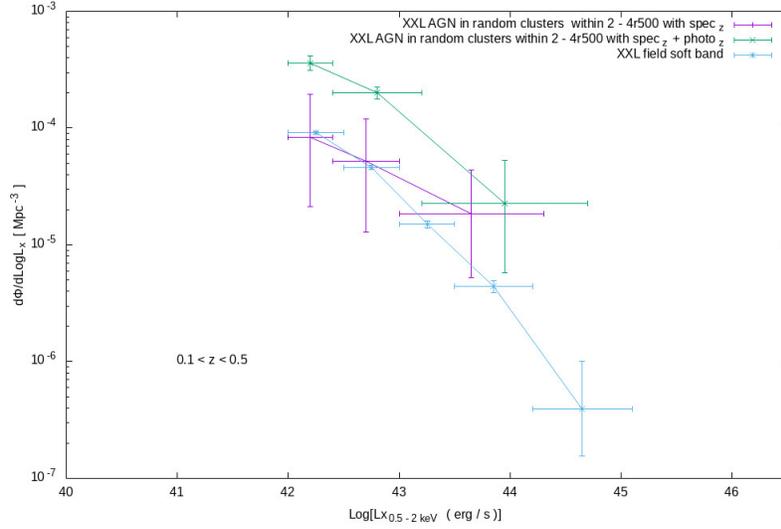


Figure 35: AGN within XXL clusters luminosity function in the soft band, in the redshift interval  $z$ :  $0.1 < z < 0.5$  within  $2 - 4r500$  from the cluster's center.

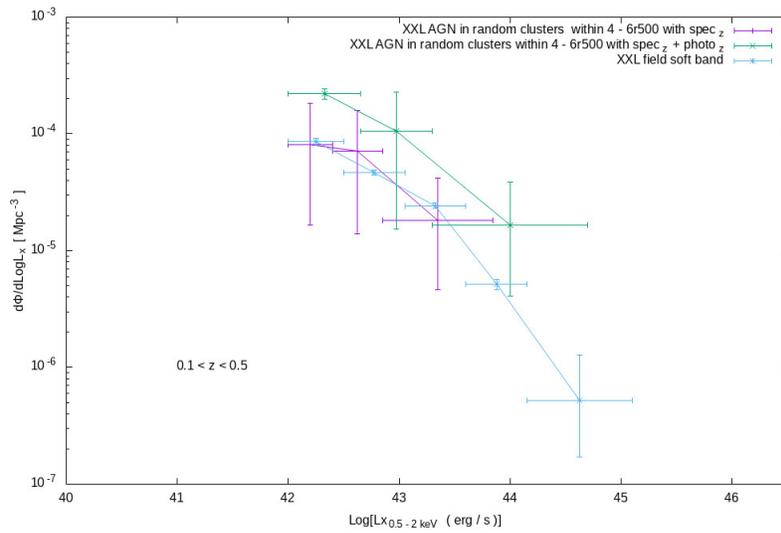


Figure 36: AGN within XXL clusters luminosity function in the soft band, in the redshift interval  $z$ :  $0.1 < z < 0.5$  within  $4 - 6r500$  from the cluster's center.



## 5.2.2 XXL clusters in the hard band

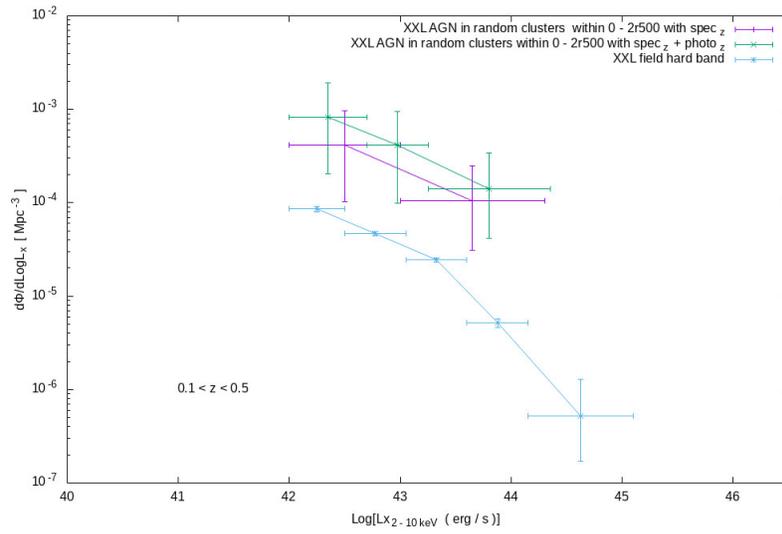


Figure 37: AGN within XXL clusters luminosity function in the hard band, in the redshift interval  $z$ :  $0.1 < z < 0.5$  within  $0 - 2r_{500}$  from the cluster's center.

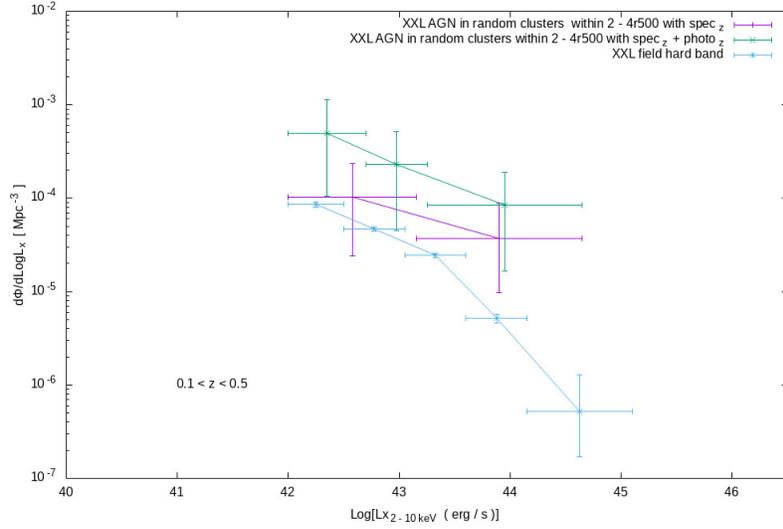


Figure 38: AGN within XXL clusters luminosity function in the hard band, in the redshift interval  $z$ :  $0.1 < z < 0.5$  within  $2 - 4r500$  from the cluster's center.

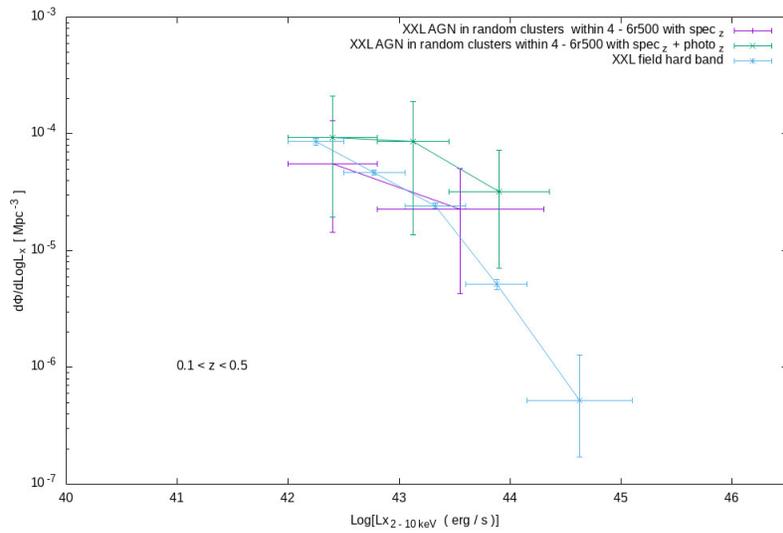


Figure 39: AGN within XXL clusters luminosity function in the hard band, in the redshift interval  $z$ :  $0.1 < z < 0.5$  within  $4 - 6r500$  from the cluster's center.

### 5.2.3 Normalized XLF within the first annulus

According to the previous findings, it is obvious that the AGN density is higher within the inner clusters' regions compared to the clusters' outskirts and with respect to the field. In figures 40 and 41 we present the normalized XLF for the sources located within  $2 \times r_{500}$  annulus. At these plots, the AGN number density was divided by a factor which is equal to the ratio between galaxies in galaxy clusters and the galaxies in the field. The factor was computed from the projected density of cluster galaxies given by Ehlert (2014) [12]. The normalized XLF remains higher than the field for each luminosity bin.

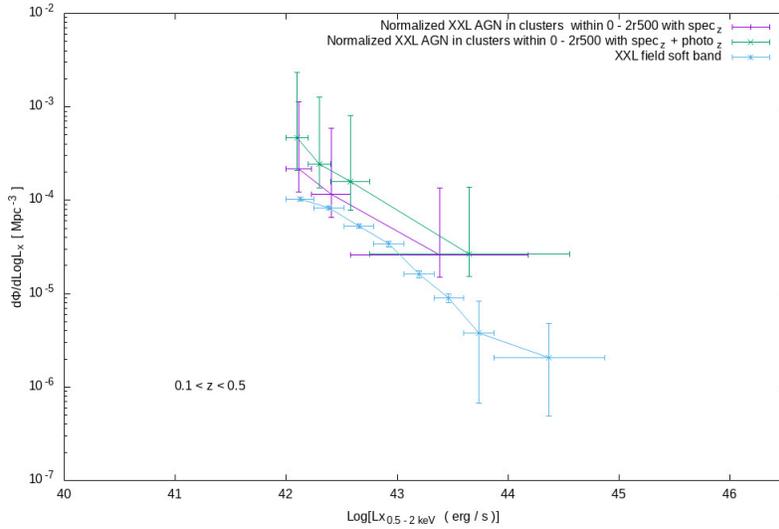


Figure 40: AGN within XXL clusters luminosity function in the hard band, in the redshift interval  $z: 0.1 < z < 0.5$  within  $0 - 2r_{500}$  from the cluster's center.

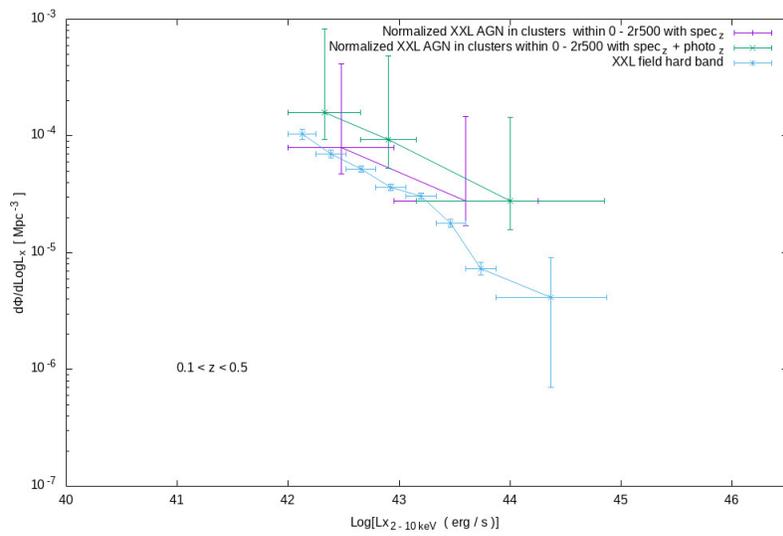


Figure 41: AGN within XXL clusters luminosity function in the hard band, in the redshift interval  $z: 0.1 < z < 0.5$  within  $0 - 2r_{500}$  from the cluster's center.

## 6 Conclusions

Using the XXL 365 clusters catalogue and the observations from the 3XLSS catalogue, we constructed the XLF for the AGNs in galaxy clusters. Our sample mostly comprises low mass and moderately massive clusters ( $M \leq 4 \times 10^{14} M_{\odot}$ ) where AGNs are more numerous as it has been shown from previous studies (e.g. Koulouridis et al. 2018) [27]. In agreement with previous works, we find a significant excess of X - ray AGNs up to radius  $2r_{500}$ . The normalized results in the clusters inner regions show that the excess of AGNs is almost equal with the excess of galaxies. The AGN spatial density seems to drop to the field value in the cores ( $< 0.5r_{500}$ ). Moreover, we find that the excess is not depended with luminosity while the AGN XLF in clusters has almost the same shape compared to the one in the field and especially in the soft band where AGNs are easier to be observed. Therefore, we summarize that the low luminosity AGN activity is not enhanced within the clusters' environment while our results present a flat excess.

The rapid progress on deep extragalactic surveys could lead to even larger X - ray catalogs in the future. Despite the fact that the XXL sample is a complete sample in terms of redshift, it contains only a few sources within clusters at high redshift ( $z > 0.5$ ) as it presented at Table 3. XXM - Newton is more sensitive in the soft band than in the hard and the very hard bands. Therefore, the soft XLF shows the most objects (points) in the redshift interval ( $0.1 < z < 0.5$ ). Although our sample covers a wide solid angle, the XLF shows large errorbars while AGN are in general rare in clusters. The use of deeper and larger samples in the future would improve our understanding of the AGN X - ray luminosity function in clusters at high redshifts and it would reduce the statistical errors.

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