# SEAFOG

*Studies of eROSITA And FLASH Obscured Galaxies*

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IMAGE CREDIT: A. CHERNEY

# Obscured galaxies and peaked spectrum sources

I'm interested in **HI and X-ray absorption**

PS are often **compact**, **radio bright** + multi-wavelength emitters ( O'Dea 1998, O'Dea & Saikia 2021)

→ great for **absorption** studies

Are PS sources truly **young** (Stanghellini+1997) or **confined** AGN (Bicknell+1997) ... or both?

← Absorption studies inform us about the **gaseous environment**

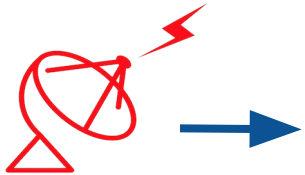
# Where this talk is headed:

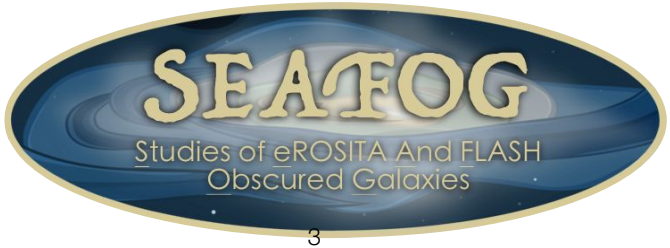
Why **HI** and **X-ray** absorption in particular?

**Previous work** connecting Hi + X-rays:
Moss+2017 → connections in an unconstrained radio sample

Re-visiting **historic samples**:
What percentage are PS?
Are PS sources more likely to be absorbers?

**New samples**: SEAFOG, eROSITA and SWAG-X




# Obscured AGN in HI and X-rays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Helen Johnston (USyd)
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Joe Callingham (Leiden)

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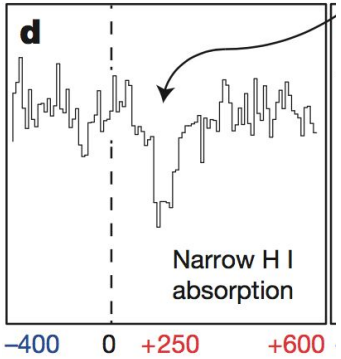
Antonis Georgakakis (MPE)
Riccardo Arcodia (MPE)
Steven Tingay (Curtin)
Tobias Beuchert (ESO)
Matthias Kadler (Wuerzburg)
Joern Wilms (Erlangen)

# Absorption in AGN

## HI (21cm)

**Associated** or **intervening,** profile shape reveals kinematics (e.g. Curran+2016, Maccagni+2017)

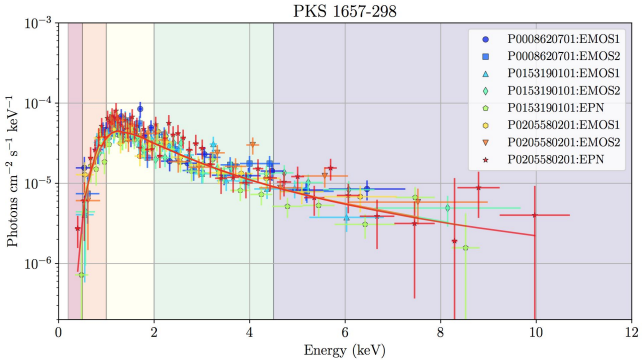
Used to derive $\mathbf{N_{HI}}$ estimate




## X-ray

**Associated**, possibly due to accretion onto SMBH or jets (Vink+2006, Worrall 2009, Ostorero+2010)

Used to derive $\mathbf{N_H}$ estimate




**Typically $N_H > N_{HI}$**

**Can $N_{HI}$ and $N_H$ estimates be made more consistent? (Liszt 2020)**

Tremblay+2016, Moss+2017

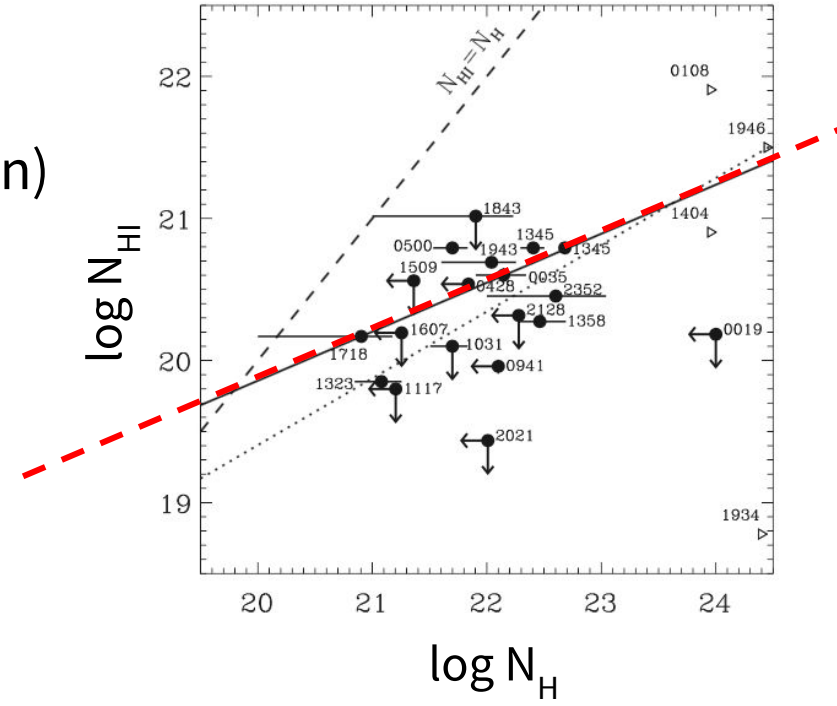
# Obscured AGN in HI and X-rays: previous work

Positive correlation between $N_{HI}$ (HI absorption) and $N_H$ (X-ray absorption)

May depend on optical morphology (galaxy or quasar)

Samples $\lesssim 20$

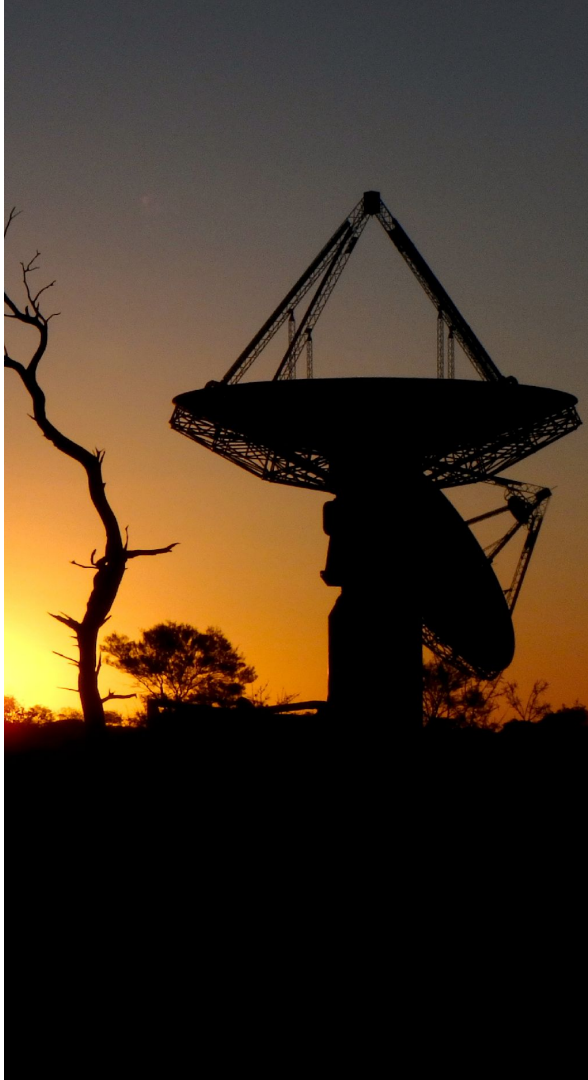
**Selected to be GPS/CSS**




Vink 2006, Siemiginowska+2008,2016, Ostorero+2010,2017, Mingo+2014, Glowacki+2017, Moss+2017, Morganti & Osterloo 2018, Sobolewska 2019

# Part I

Results from ASKAP-BETA (Moss+2017)

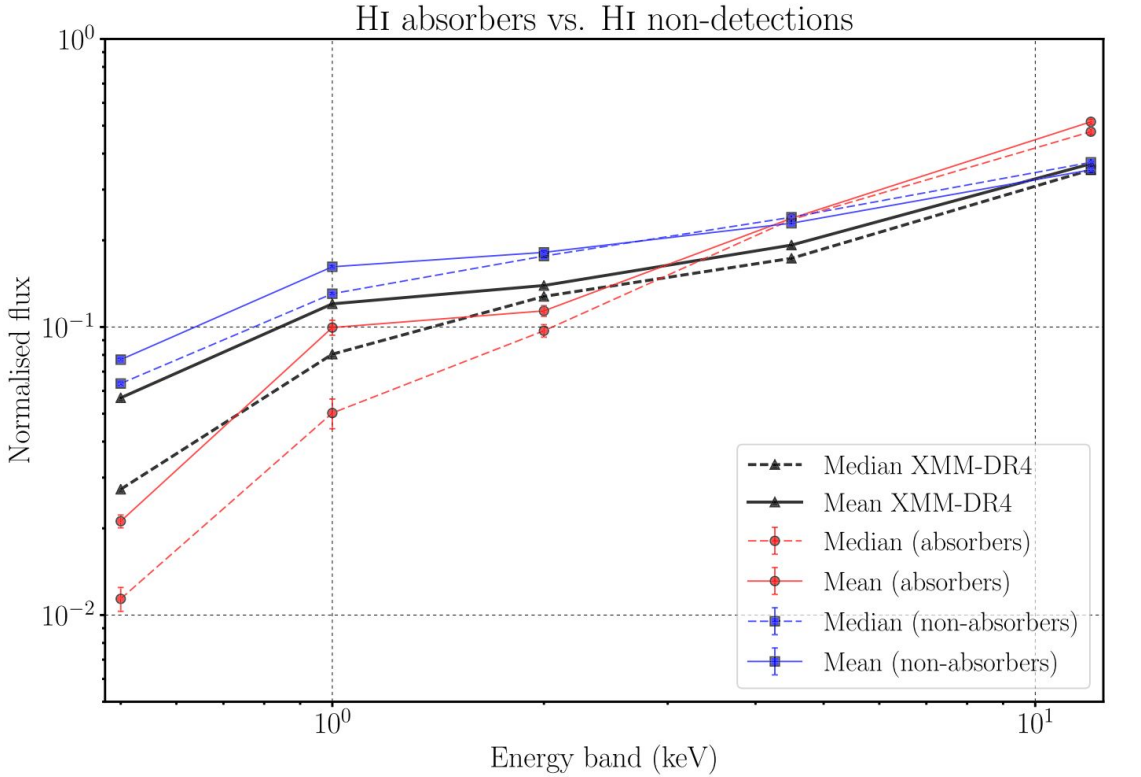


# X-ray hardness of radio loud AGN

94 radio sources with detections in X-ray from XMM-DR4 (XMM-SSC, 2013)

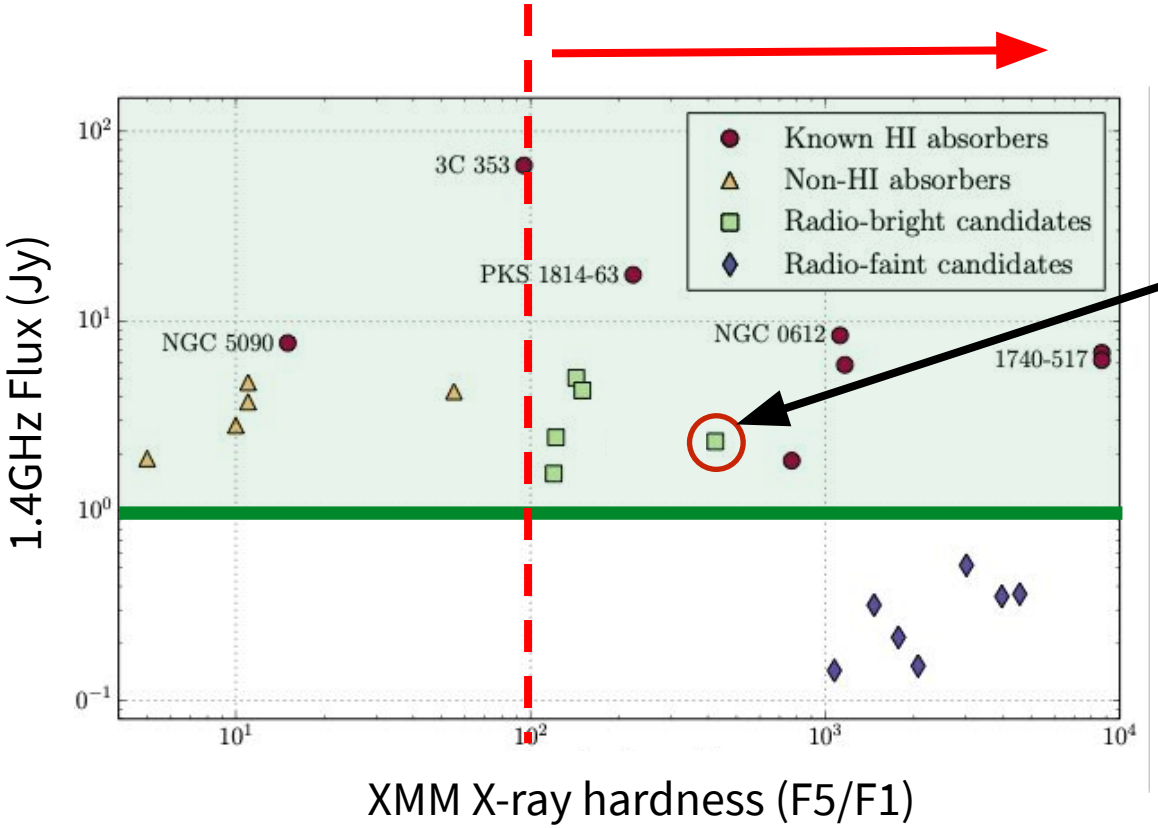
20 HI absorbers
74 non-detections

Unconstrained by flux, morphology or position limits




MOSS+2017

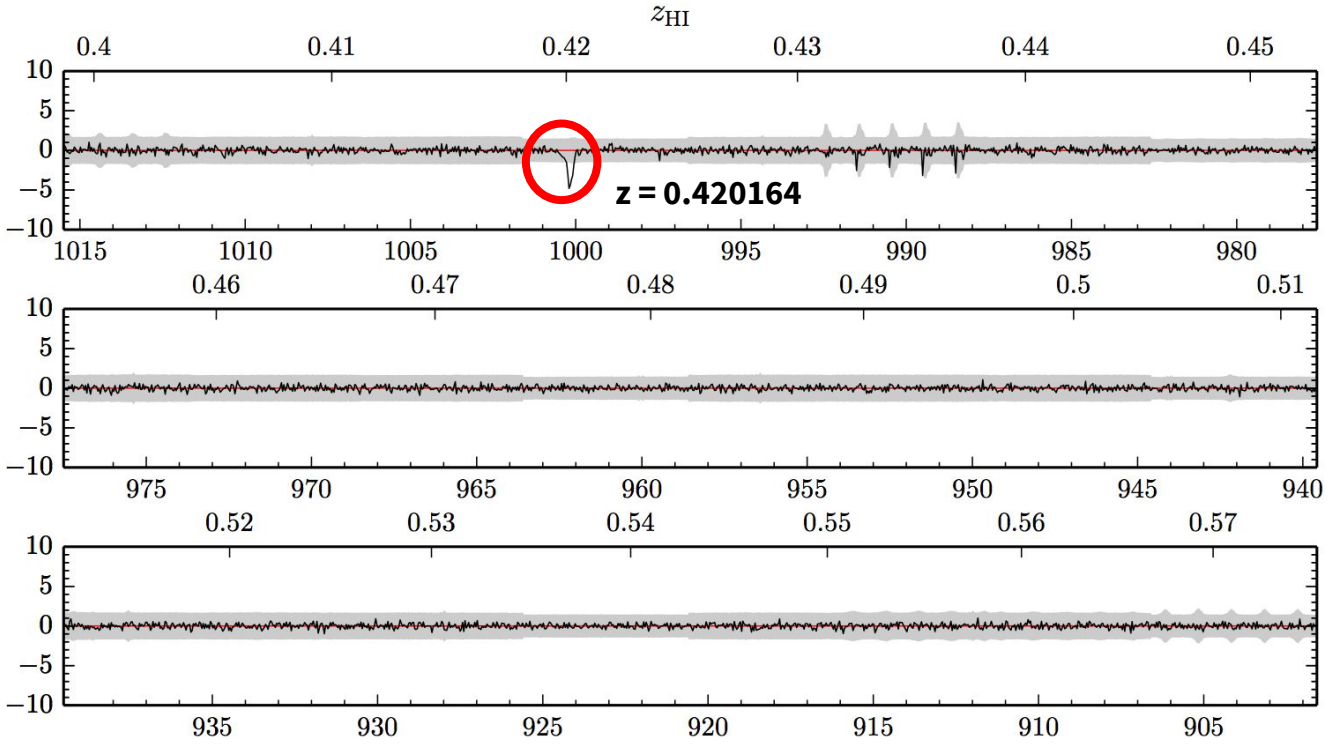
# The ASKAP-BETA X-ray sample






MOSS+2017

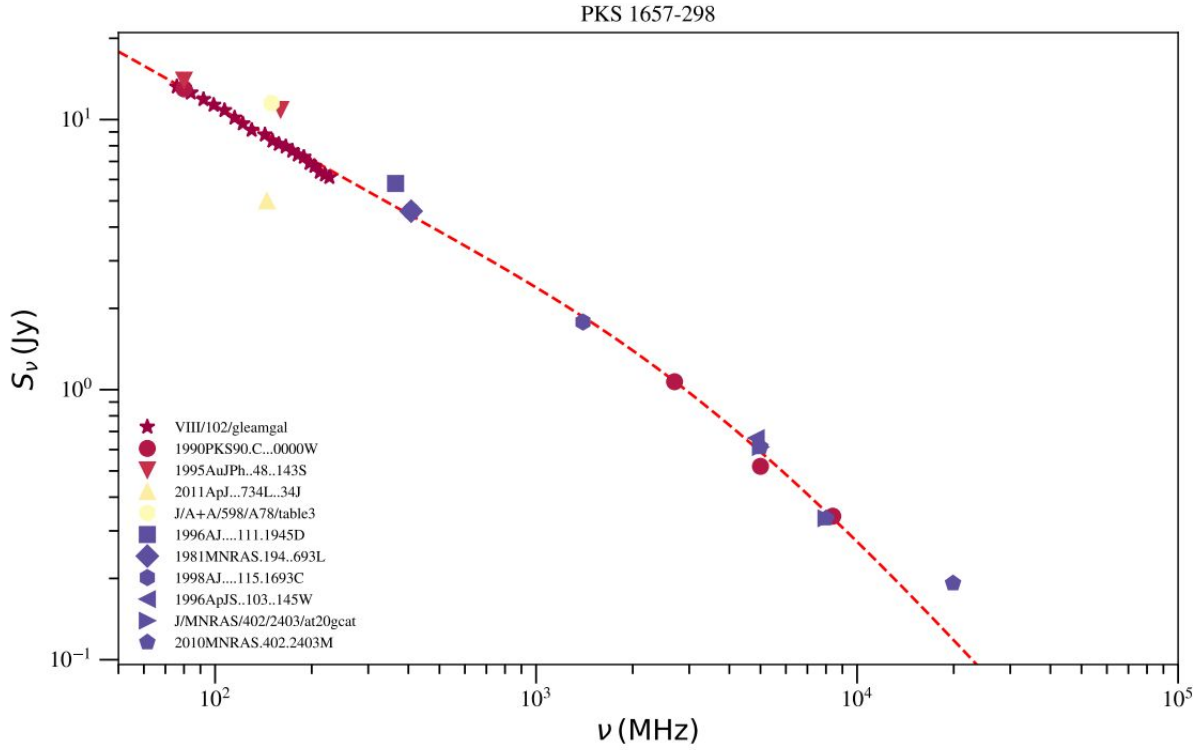
# HI detection: PKS 1657-298




Line-width = **63 km s$^{-1}$** Peak optical depth = **0.046** $N_{HI}$ = **5.3 x 10$^{20}$ cm$^{-2}$**

# HI detection: PKS 1657-298

A **CSO** not a PS source - would a broader radio sample reveal more like this?






MOSS+2017

# Part II

PS in the absorber population

# Absorption searches: historic sample

**Moss+2017** (94 + 5) and **Curran & Whiting 2010** (70)

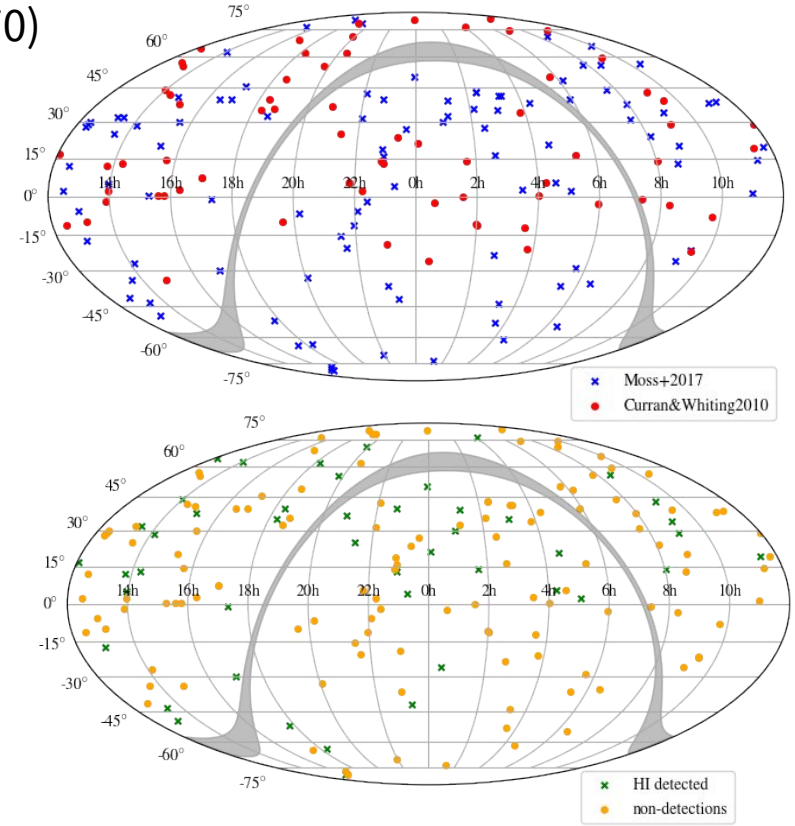
Moss+2017 → X-ray selected
Curran & Whiting 2010 → not X-ray selected

Both interested in **HI absorption**

Curran & Whiting 2010 also provide radio classifications (GPS,CSS, EORG, BLG…)

**How many of this entire 'historic sample' are peaked sources?**

**How many also exhibit HI, X-ray absorption?**



# Re-identifying PS sources

Moss+2017 → not classified
Curran & Whiting 2010 → inhomogeneous classification

**Alternatives:**

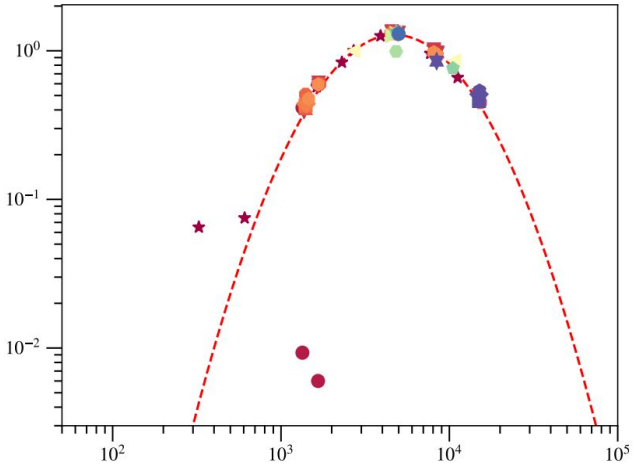
- NED classifications - also inhomogeneous
- Radio SED fitting (Allison+2019)

**SED fitting:**

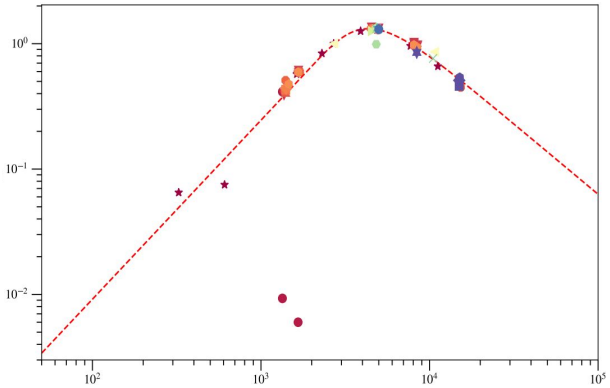
NED photometry (< 100GHz) + additional surveys:

- GLEAM (74-231MHz)
- VLSSr (74MHz)
- TGSS (150MHz)
- MRC (408MHz)

False detections? It's possible! (Orienti et al. 2007, Stanghellini et al. 2009, O'Dea and Saikia 2021)



Simple analytic model (Orienti+2007, Hogan [thesis])



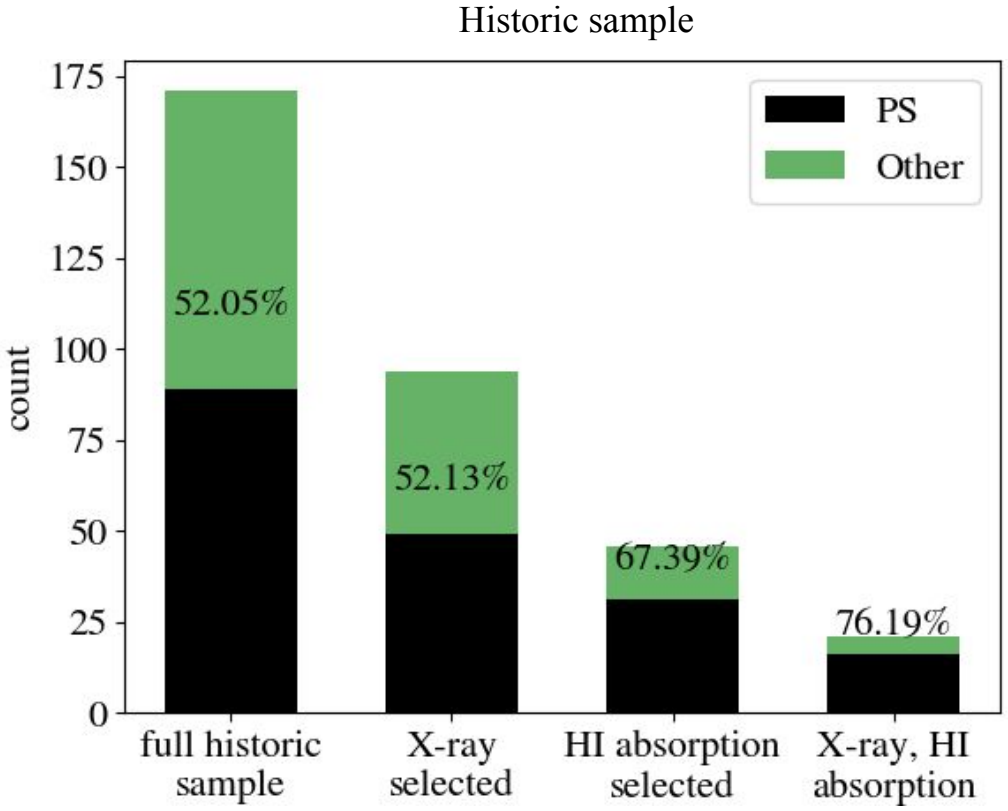
Commonly used (but more complex) model (Moffet 1975)

# PS proportions

O'Dea 1998:
PS are **~10-30%** of the bright radio population

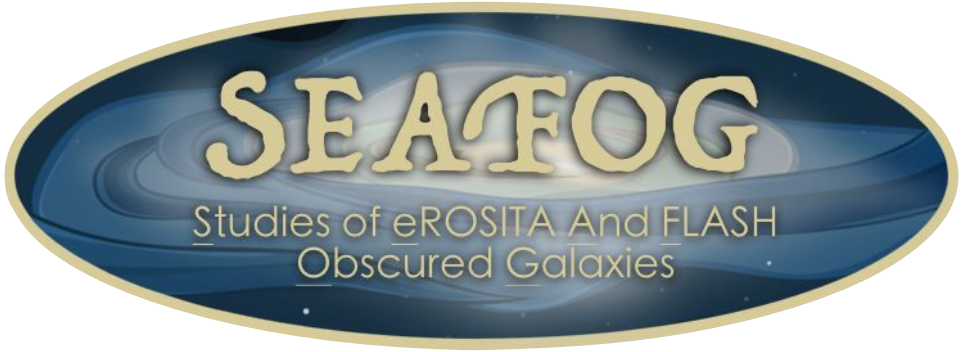
Callingham+2017:
PS sources are only **~4.5%** (lower frequency sample)

Why do we see the proportions on the right?
**Selection bias?**



# Part III

A new sample: SEAFOG



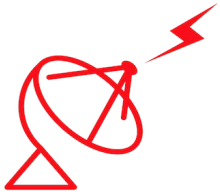

***eROSITA**: M. Salvato, A. Merloni, A. Georgakakis, J. Buchner, T. Dwelly*

***FLASH**: V. Moss (PI), E. Sadler, J. Allison, E. Mahony, E. Kerrison*

Ongoing MoU collaboration between **AAL** and **eROSITA_DE**

Precursor to future **SKA/Athena** synergy

**Unbiased**, **untargeted** sample in both radio and X-ray



ASKAP-FLASH

First Large Absorption Survey in HI

# FLASH+ eROSITA

**FLASH:** 150,000 sources > 50 mJy, **~20’’**
With ~300MHz spectral range
(hundreds of HI detections expected)

**eROSITA:** Launched 2019, eFEDS (test field) observed, first all-sky survey pass complete.
All-sky mapping: **15”-30”** resolution in five bands covering 0-10 keV

eROSITA aboard Spektr-RG

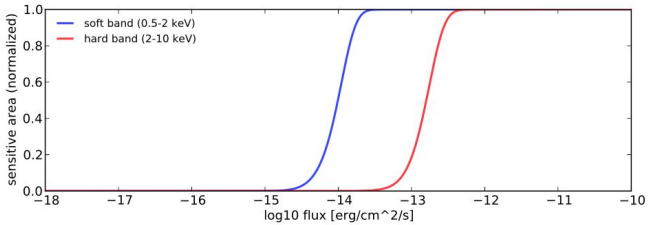
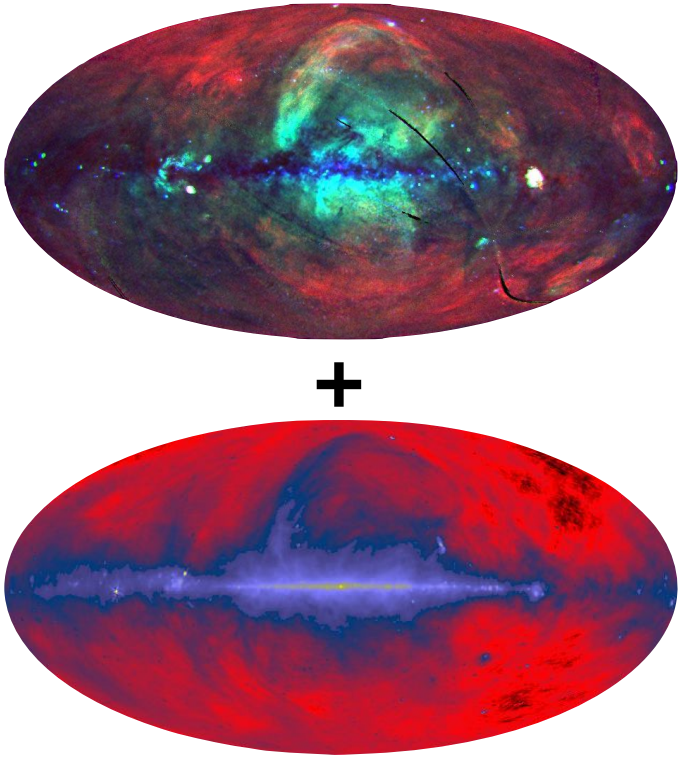



*Figure 4.3.2: Sensitivity curves for the full 4-years eROSITA survey: the normalized sensitive area is plotted as a function of the limiting flux for point source detection for both soft (blue) and hard (red) band. The computations are based on the exposure map and background model of Fig. 3.1.2*

DLR, Merloni+2012

# FLASH + eROSITA

- What do we learn from a **FLASH/eROSITA** survey?
- Connection between radio AGN **with/without** X-rays: emission mechanism
- What kinds of galaxies have: 1) radio AGN, 2) X-ray AGN, 3) HI absorption, 4) X-ray absorption?
  - Trace **multi-wavelength** properties
- **$N_H$ vs. $N_{HI}$** for a large sample (~100s of galaxies)
- True fraction of **PS** sources (and **PS absorbers**)
- Studies of **variability** in radio/X-rays



X-RAY (FREYBERG+1999) VS. 408 MHZ SKY (HASLAM+1982)

# SEAFOG active projects

- Follow-up of PKS 1657-298: optical spectrum, X-ray redshift constraints, ASKAP-36 zoom spectrum
- Radio + X-ray variability in PKS 1718-649: continuum + HI observations alongside X-ray variability (e.g. Beuchert+ 2018)
- VLBI observations of PKS 1740-517: Australia LBA data at 1/2/8 GHz to study the compact structure of this object
- SEAFOG pilot fields: FLASH pilot data + eROSITA eFEDS data of the GAMA fields (since launch, determined to be GAMA 09): SWAG-X

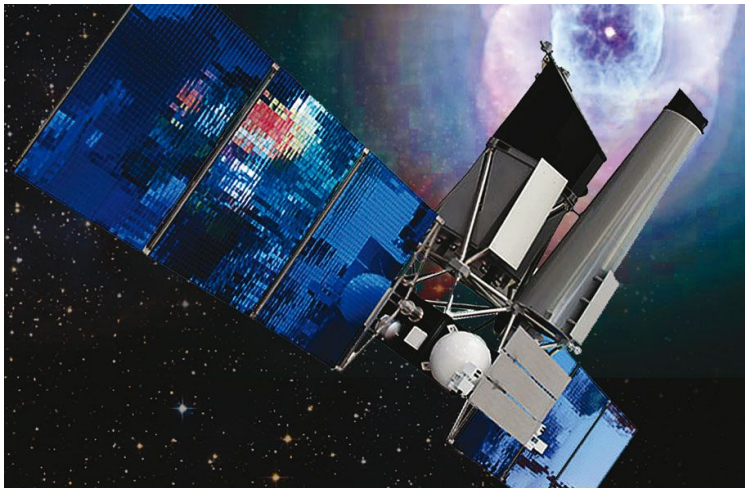
# SWAG-X: early results

**S**urvey **W**ith **A**SKAP of **G**AMA-09 + **X**-ray - 10-20'', 9 hour observation

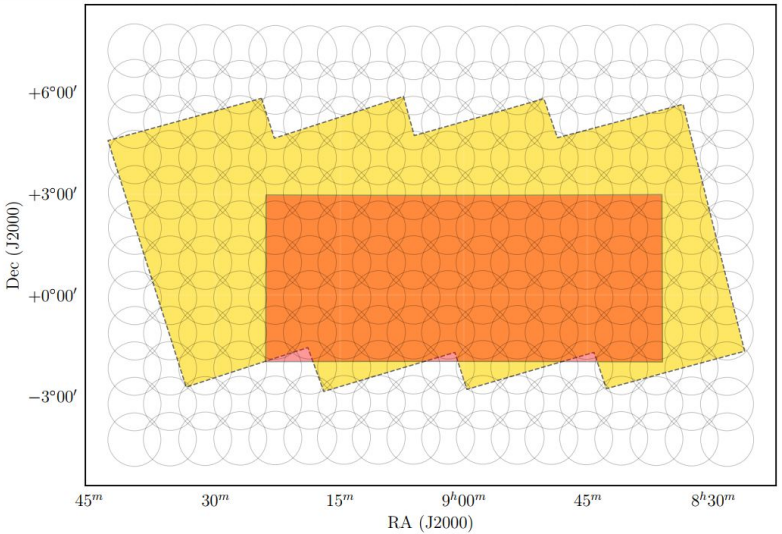
SWAG-X Low: 288MHz wide (888 MHz)
SWAG-X High: 144MHz wide (1296 MHz)

**SWAG-X test field**: observed Oct. 2019
~270 deg$^2$ including GAMA-09 and eFEDS

continuum + spectral data



~6400 sources > 10mJy

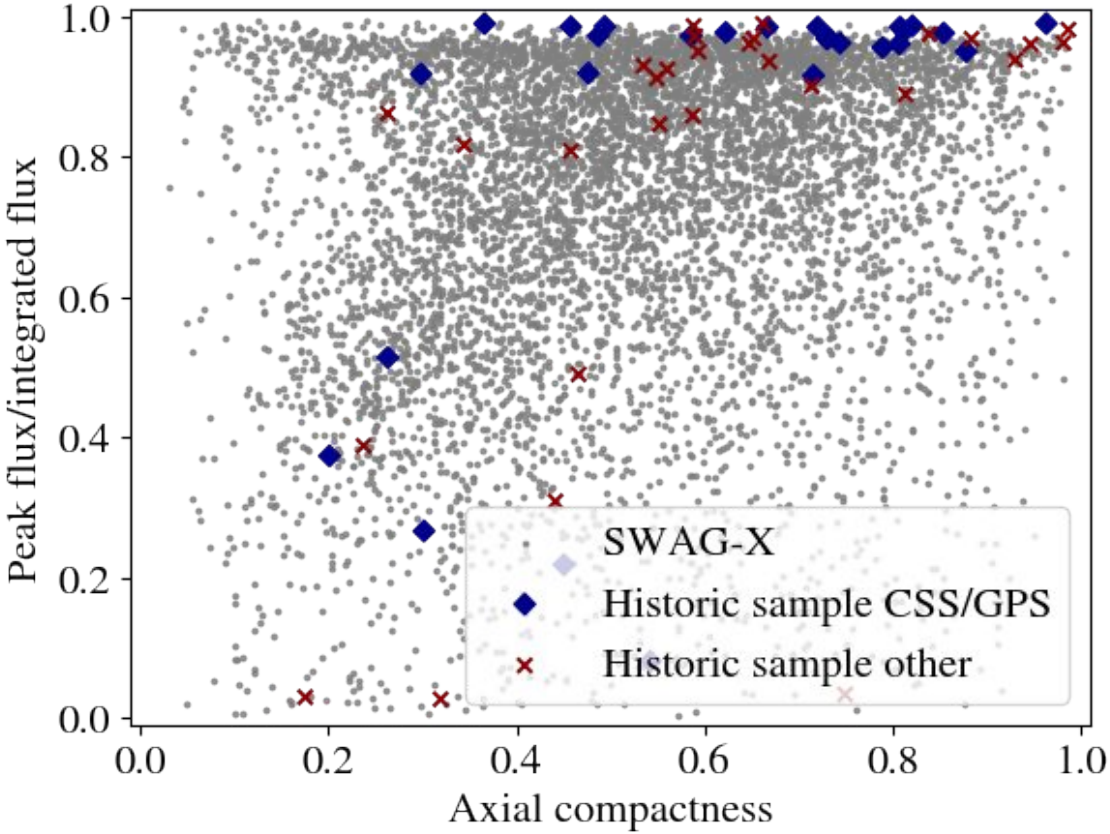



*DLR, Moss et al., in prep*

# SWAG-X + historic sample: radio

Compactness
(shown here)

Peaked spectrum?
(forthcoming spectral
data)



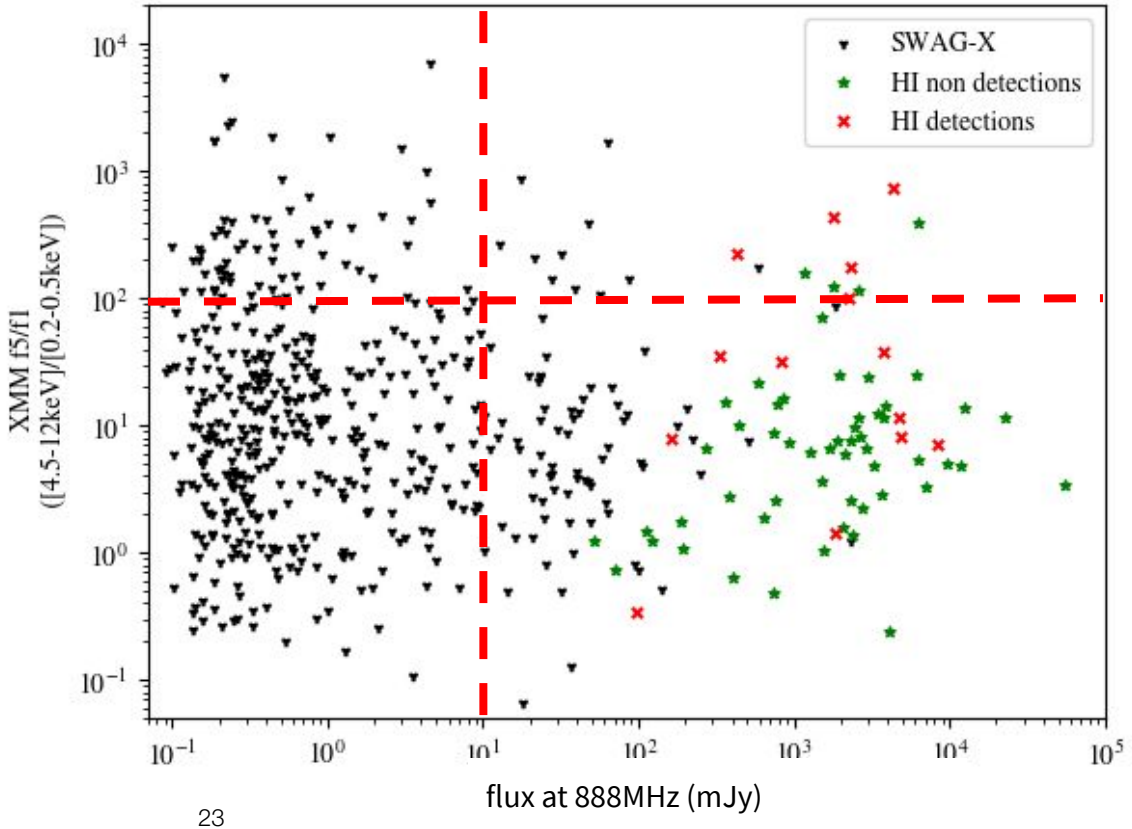
# SWAG-X + historic sample: X-ray

Since Moss+2017
XMM-Newton DR9 has been released (Webb+2020)

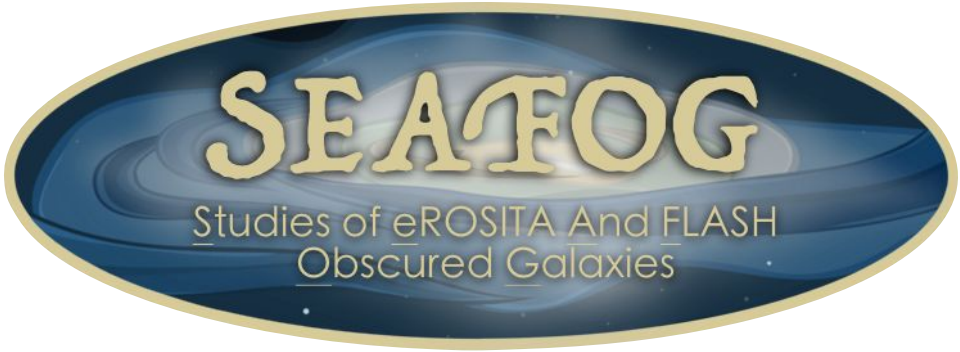
**~600 sources** in the SWAG-X field have XMM counterparts within 6''

**~120** with significant X-ray absorption (F5/F1 > 100)

But with eFEDS we will have even better X-ray data!



# Next steps




**My project:**

eFEDS for SWAG-X → Exploring other metrics for X-ray absorption (eROSITA sensitivity different to XMM-Newton)

SWAG-X spectra → Search for low-power, PS sources + consider fraction of total (and absorbed) population. Examine X-ray and HI properties of absorbers + extrapolate to FLASH fields

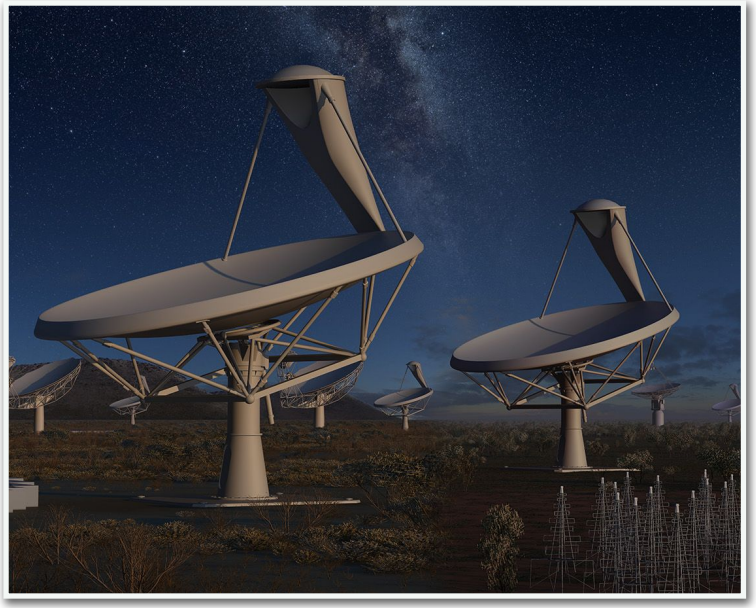
**Longer term:**

FLASH + eROSITA → SKA + Athena

# Long term connections

SQUARE KILOMETRE ARRAY
MID-FREQUENCY
**(SKA MID)**

***Redshift coverage (HI line)**: 0 < z < 3*
***Channel sensitivity (SKA1-SCI-5):** 0.25 mJy at 2" (2 years)*



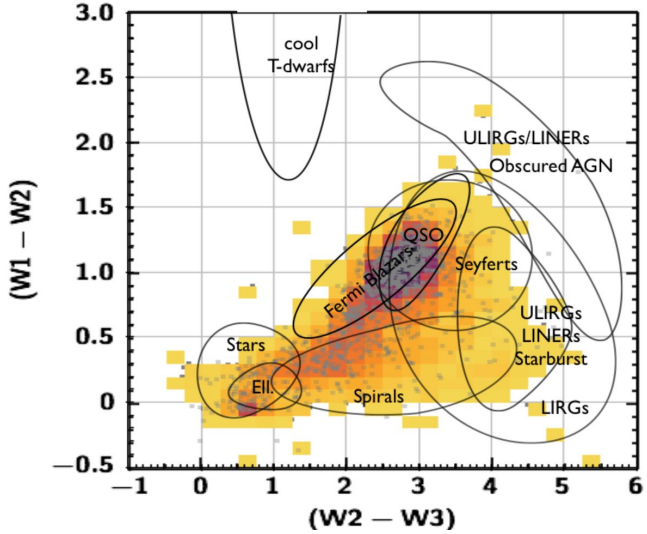
ADVANCED TELESCOPE FOR HIGH ENERGY
ASTROPHYSICS
**(ATHENA)**

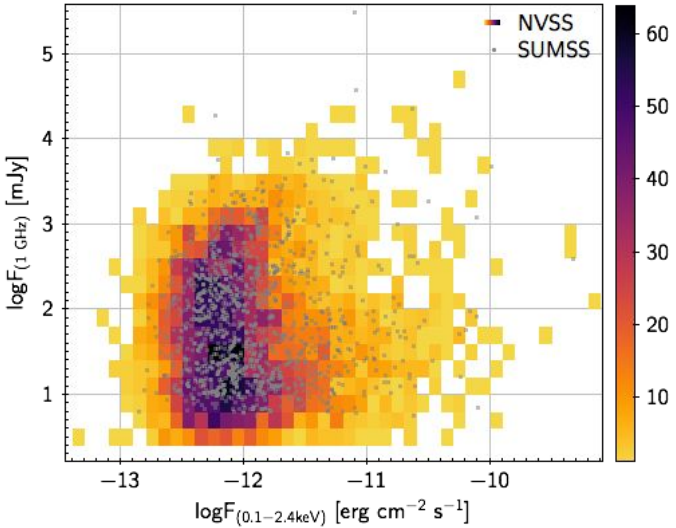
***Spectral coverage (WFI):** 0.2-15 keV at ~80 keV resolution*
***Sensitivity:** 10x XMM-Newton*

# Key points

- Absorption and PS studies are mutually beneficial
- There is a correlation between **HI** and **X-ray absorption**
  → is this stronger in PS sources?
- Historic samples **don't reflect the true fraction** of PS sources
- SEAFOG: SWAG-X, ASKAP-FLASH and eROSITA
  → **unbiased sample** → true population fractions

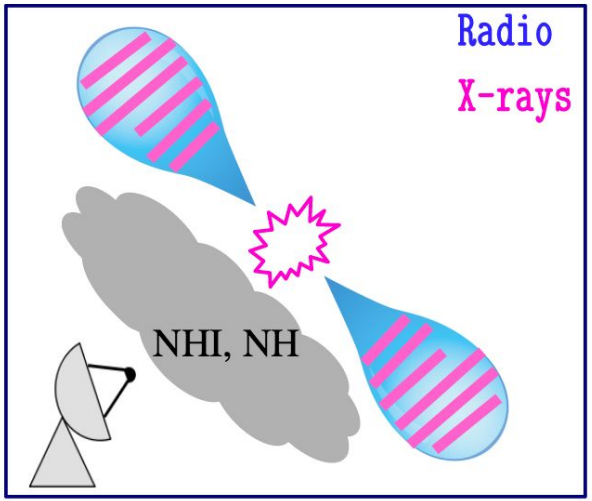
# FLASH + eROSITA

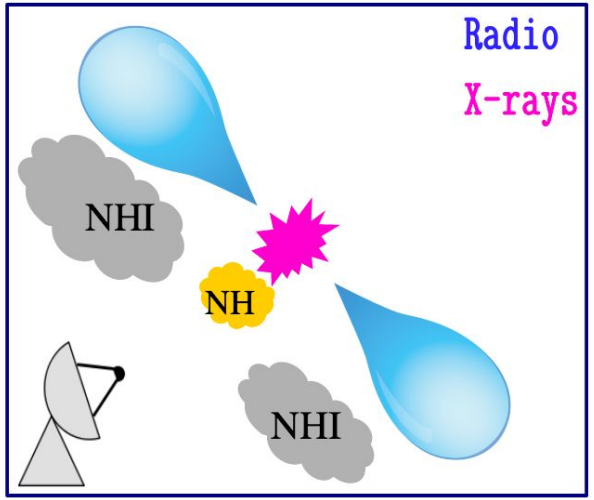



- **Expected radio/X-ray population** based on NVSS/SUMSS and 2RXS
- We predict **complete sensitivity** in X-rays to all radio AGN detected in FLASH
- eROSITA will allow study of a **much deeper** population than previously accessible

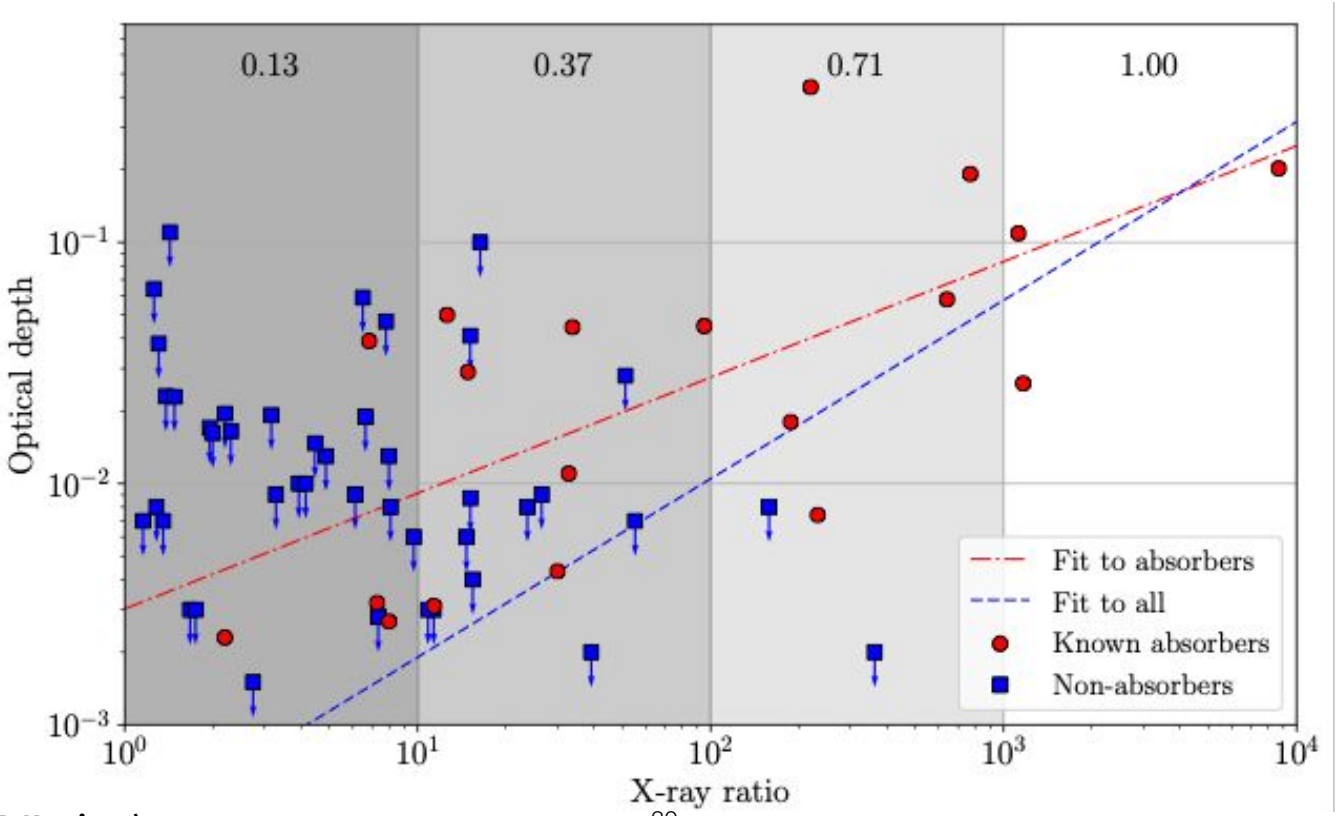
# Connecting X-rays and HI




Ostorero+2015

# Optical depth vs. X-ray hardness




MOSS+2017

# Obscured galaxies and peaked spectrum sources

## Obscured galaxies

→ hidden by **associated** or **intervening** dust and gas (molecular and atomic)

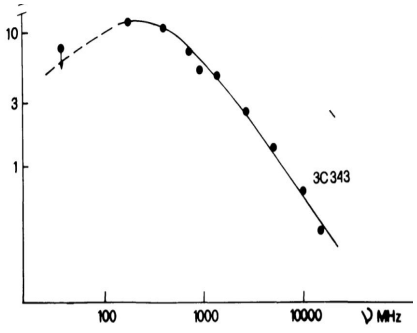
→obscured black holes produce strongest emission, appearing as **AGN** (Hickox+2018)

→observations from **absorption** and subsequent **re-emission** reveal kinematics and gas composition (e.g. Radio: Morganti+2018, IR: Stern+2005, IR + X-ray: Ramos+2017 )

## Peaked spectrum sources

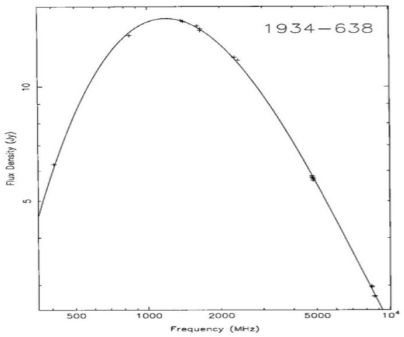
**CSS**
<500MHz peak
≲15kpc
(Fanti+1990)

e.g. 3C 343




**GPS**
500MHz-1GHz peak
≲ 1kpc
(O'Dea 1998)

e.g. PKS 1934-638




**"Peaked Spectrum"**



Fanti+1985, Fosbury+1987, Reynolds 1994

# Obscured AGN in HI and X-rays: previous work

Vink 2006 → radio/X-ray luminosity ratio higher than general population in 5 bright GPS/CSS sources

Sieminginowska+2008 → X-ray absorption in quasars but not galaxies from 15 GPS/CSS sources

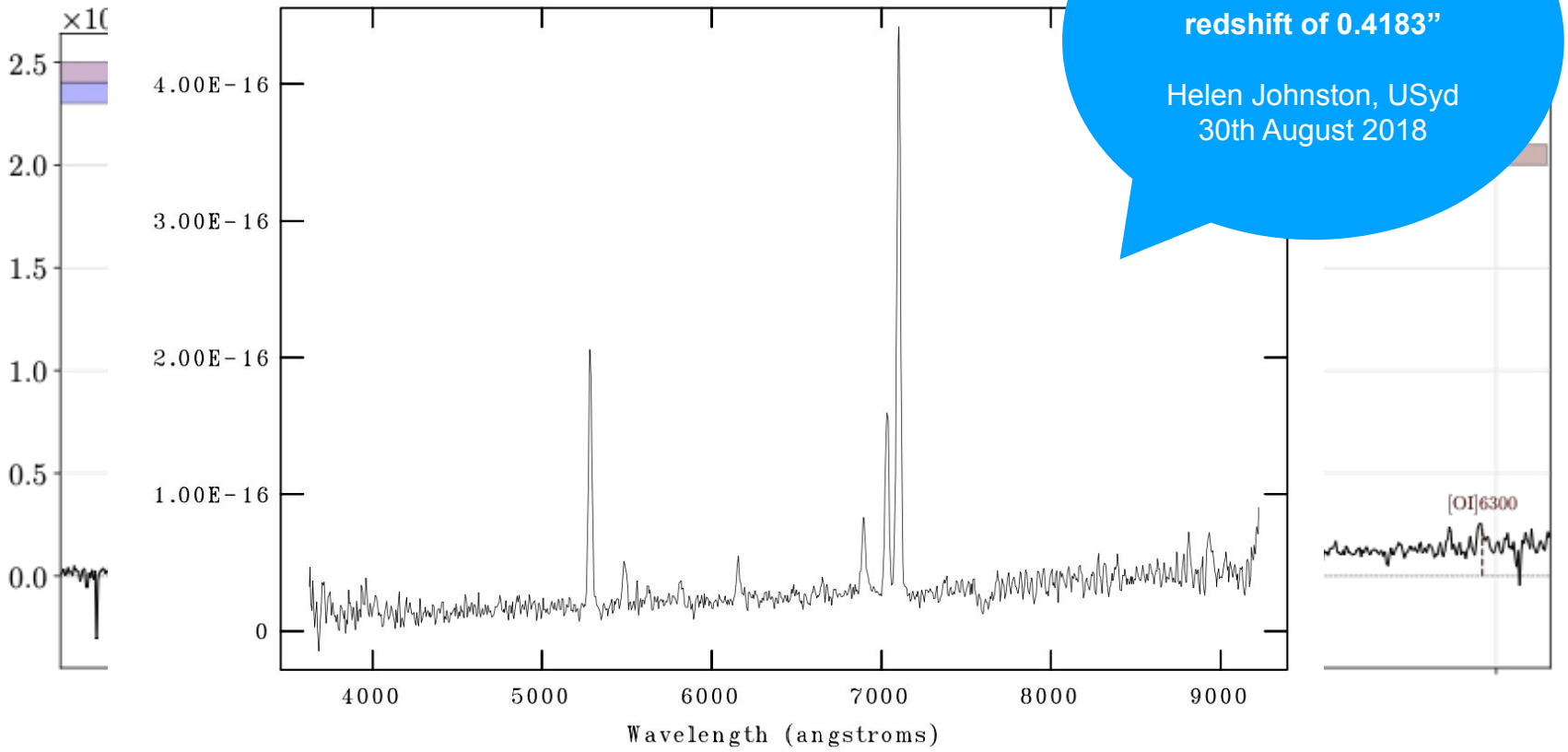
Ostorero+2010 → tentative correlation between $N_{HI}$ and $N_H$ in 11 GPS/CSS sources

Mingo+2014 → derives accretion rates for 45 radio loud AGNs (6 FRI, 32 FRII, 7 CSS) from X-ray emission

Ostorero+2017 → Significant, positive correlation between HI and X-ray absorption in 22 GPS/CSS sources

**Moss+2017 → further correlation between $N_{HI}$ and $N_H$ in AGN sample without morphology constraints**

# Follow-up in optical




**"We can clearly see various lines for a redshift of 0.4183"**

Helen Johnston, USyd
30th August 2018

NEW REDUCED SPECTRUM: H. JOHNSTON