Uncovering the full population of elusive growing black holes with X-ray and multiwavelength surveys

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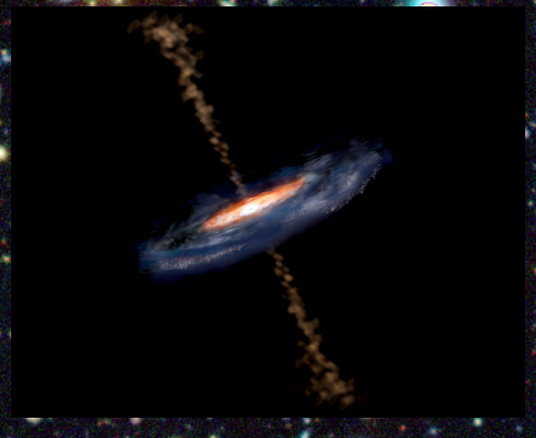
Dartmouth

Elusive AGN in the Next Era
George Mason University
13 June 2017

Illustration courtesy ESA/NASA



Many (if not most) of these galaxies contain elusive AGN!

Subaru/HSC

However, most AGN are **“elusive”**

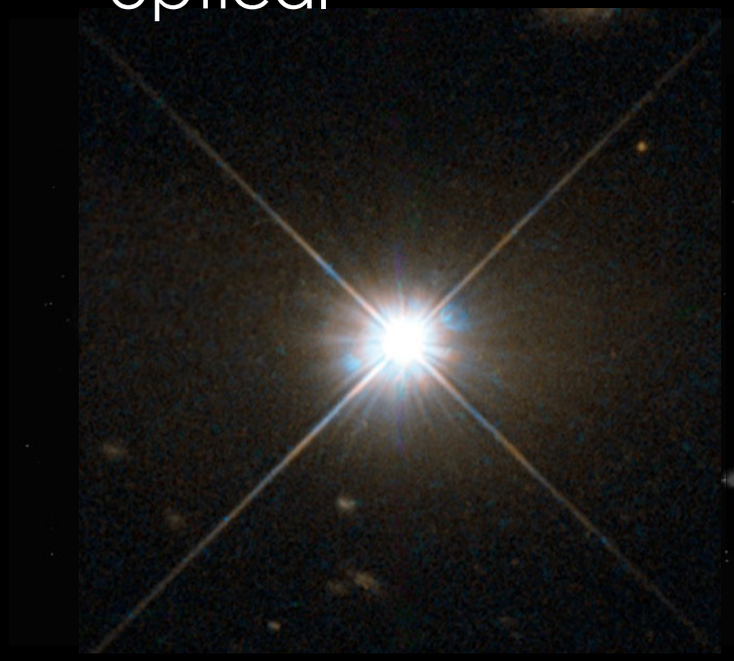
(A) because of **dilution** by host galaxy light

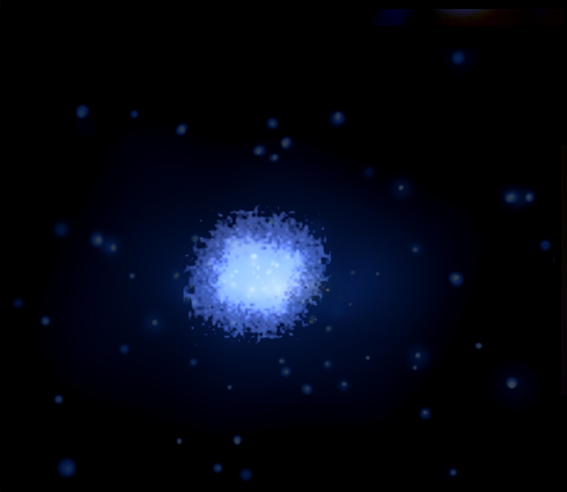
mid-infrared

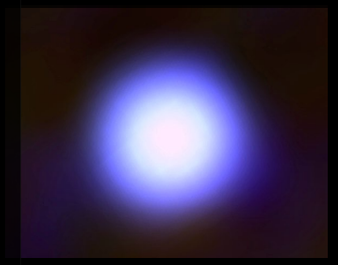
optical

soft X-rays

hard X-rays







[OIII] line emission

< 10 keV

> 10 keV

(e.g. Hopkins et al. 2009, Trump et al. 2016, Jones et al. 2016)

However, most AGN are **“elusive”**

(B) because of **obscuration** by gas and dust

mid-infrared

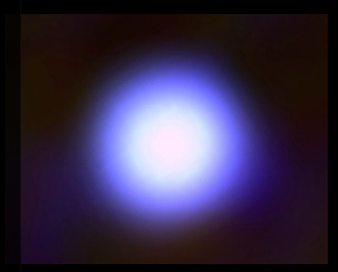
optical

soft X-rays

hard X-rays

[OIII] line emission

< 10 keV



> 10 keV

(e.g. Hickox et al. 2007, Treister et al. 2010, Merloni et al. 2014, Assef et al. 2015, Hickox et al. 2017 submitted)

Images courtesy SSC/WISE/HST/CXC/Swift

Take-home messages

New statistical methods are allowing us to uncover **low-Eddington** or **low-mass** AGN in **star-forming galaxies** that are missed due to dilution by the host; at some level **all galaxies may be hosting an AGN**

Powerful obscured quasars are **very common and often heavily buried** and we can now reliably identify **hundreds of thousands** of them in the mid-IR with *WISE*

With **improved models** and **even better data** (including the possibility of the ***Lynx*** X-ray mission) the future is bright!

(A) Elusive AGN that are **“hidden” beneath the light of their host galaxies**

mid-infrared

optical

soft X-rays

hard X-rays

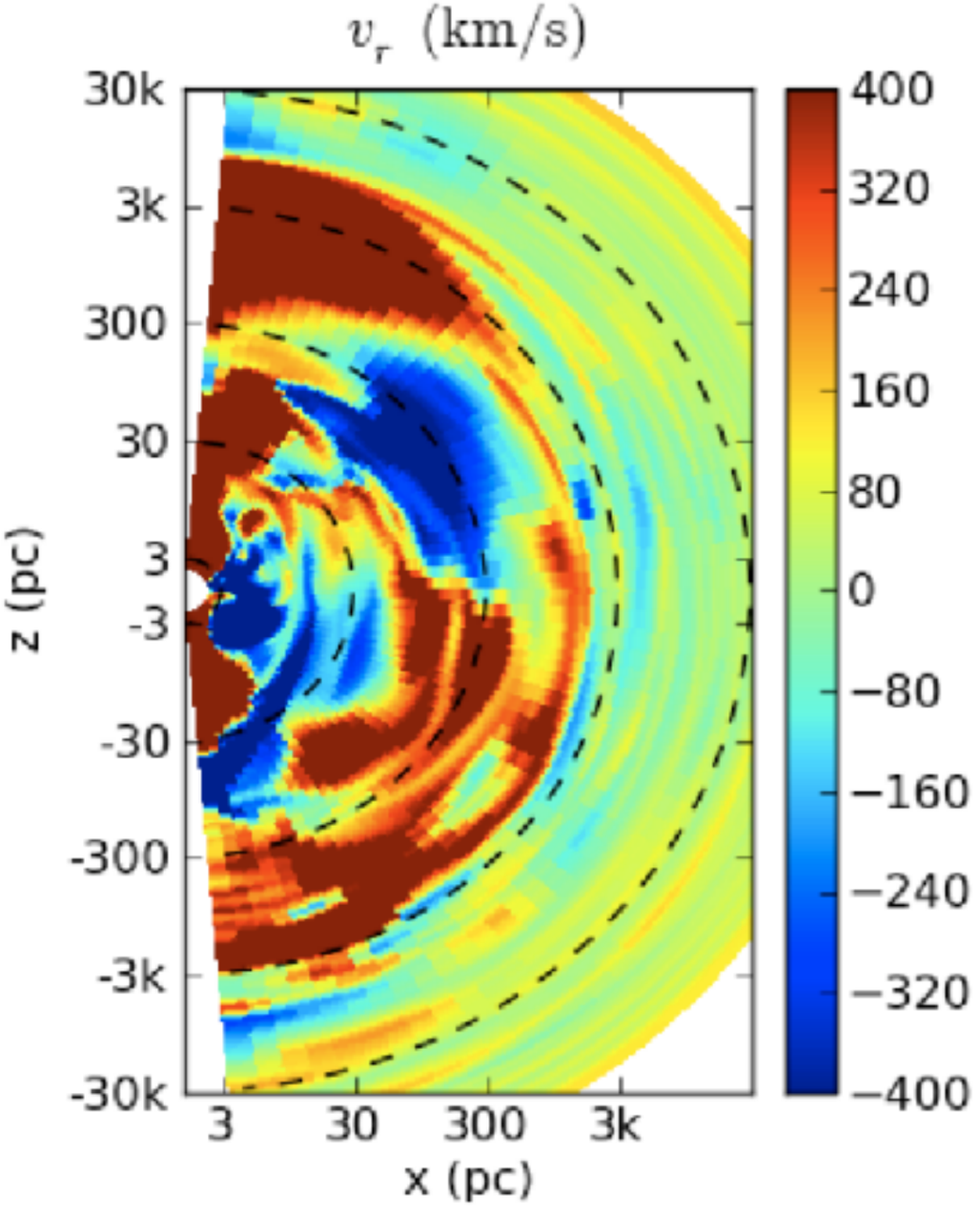
< 10 keV

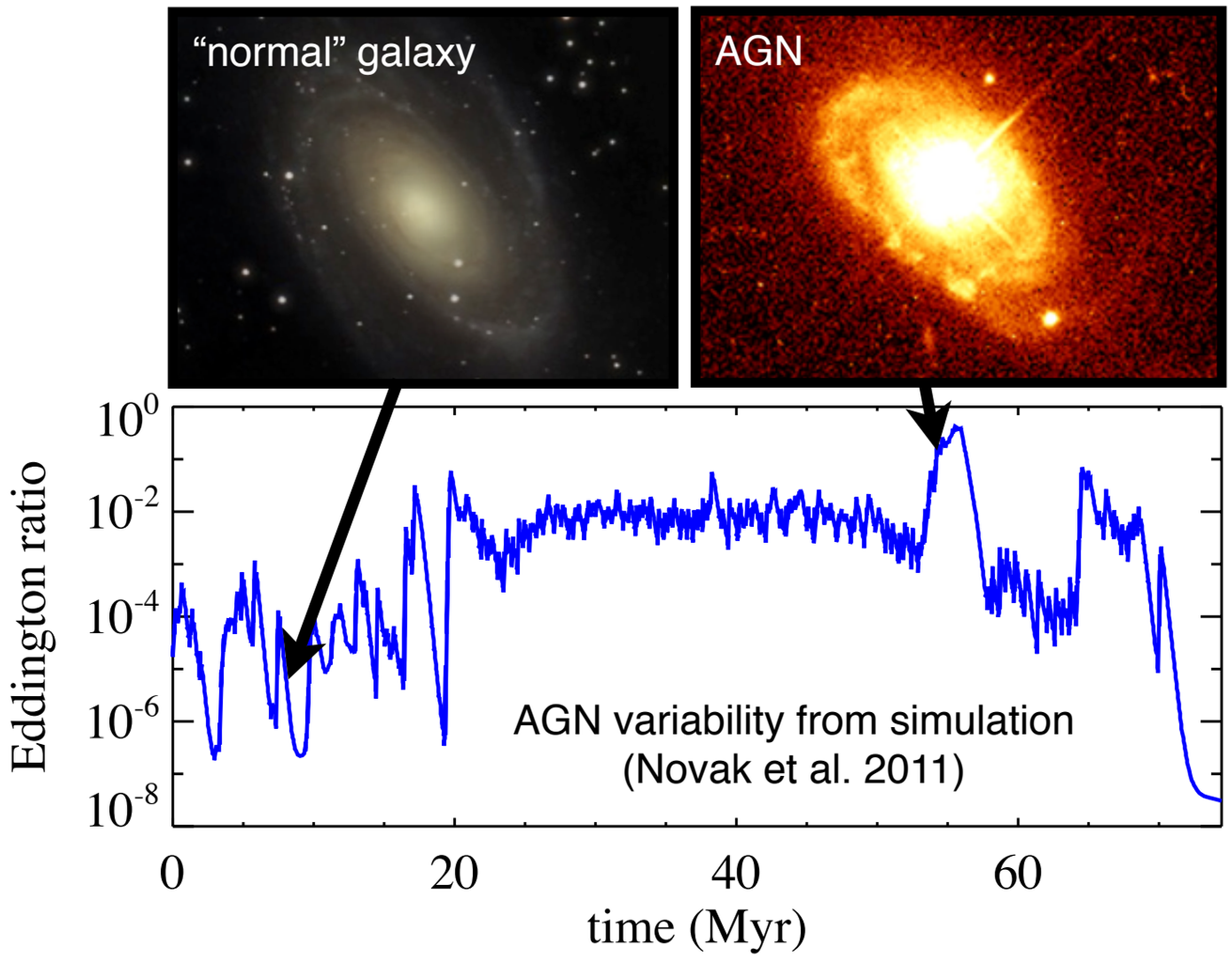
> 10 keV

[OIII] line emission

Simmons et al. (2011)

AGN are highly stochastic!

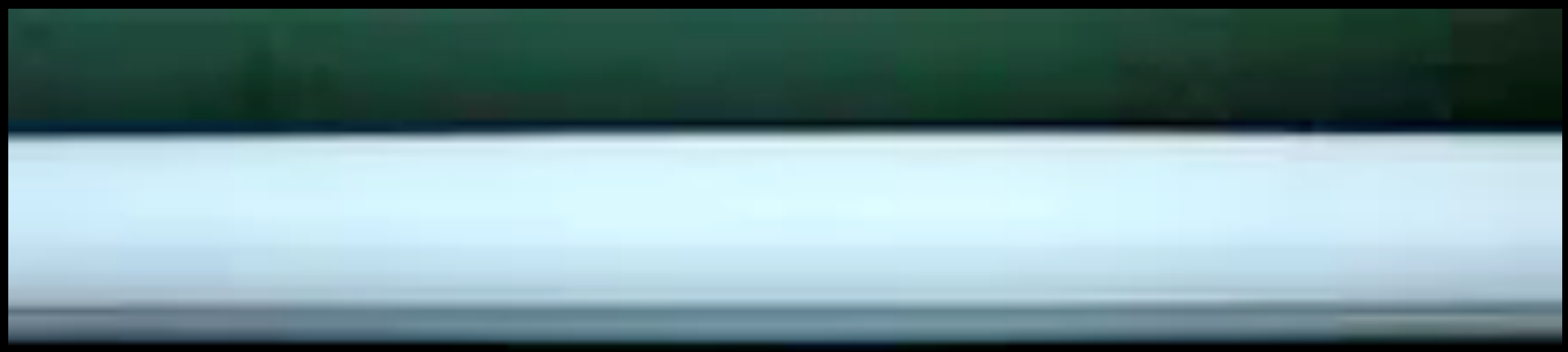




Hickox et al. (2014); see also e.g., Schawinski et al. (2015)

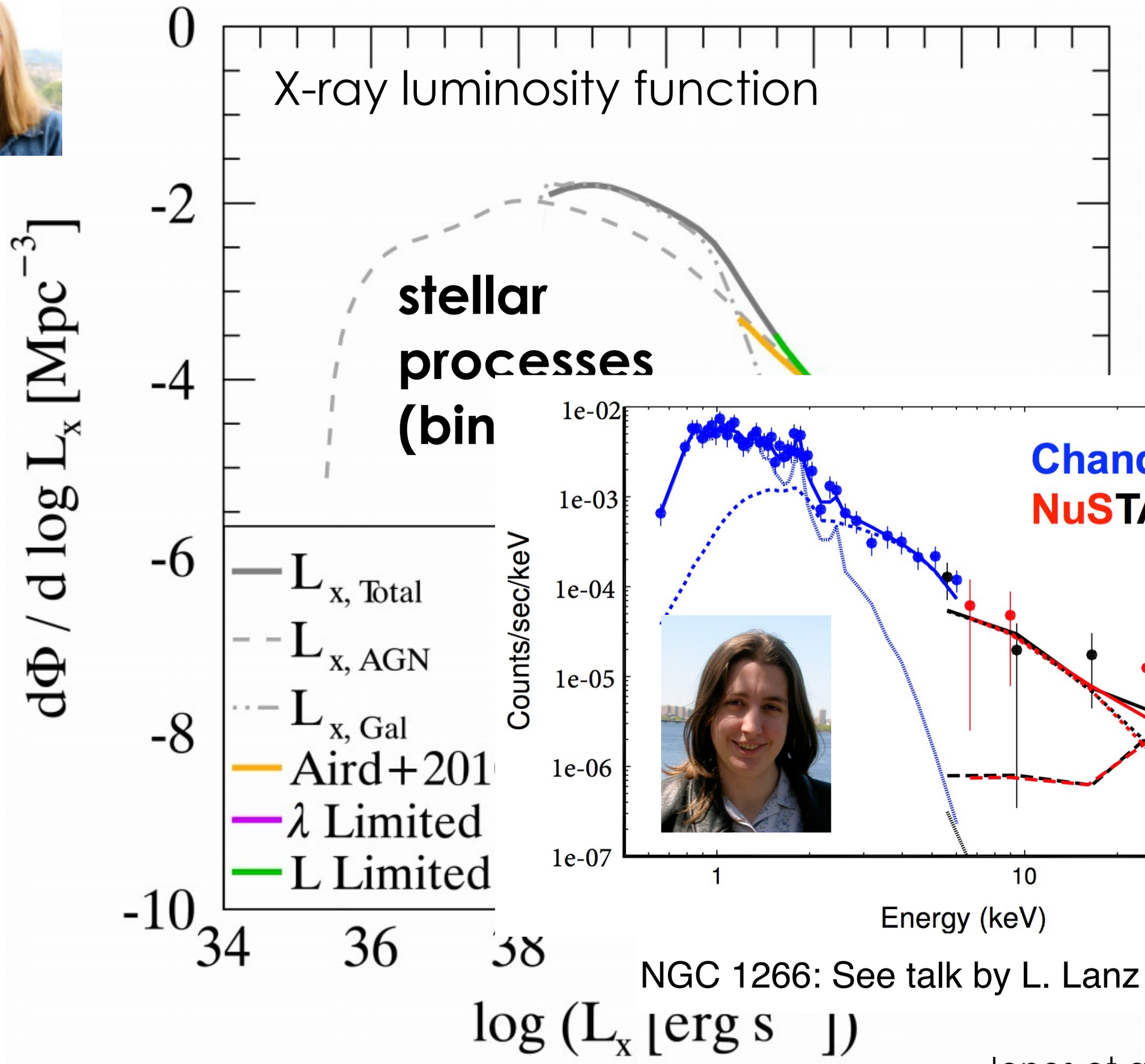
Do *all* galaxies host a flickering AGN?

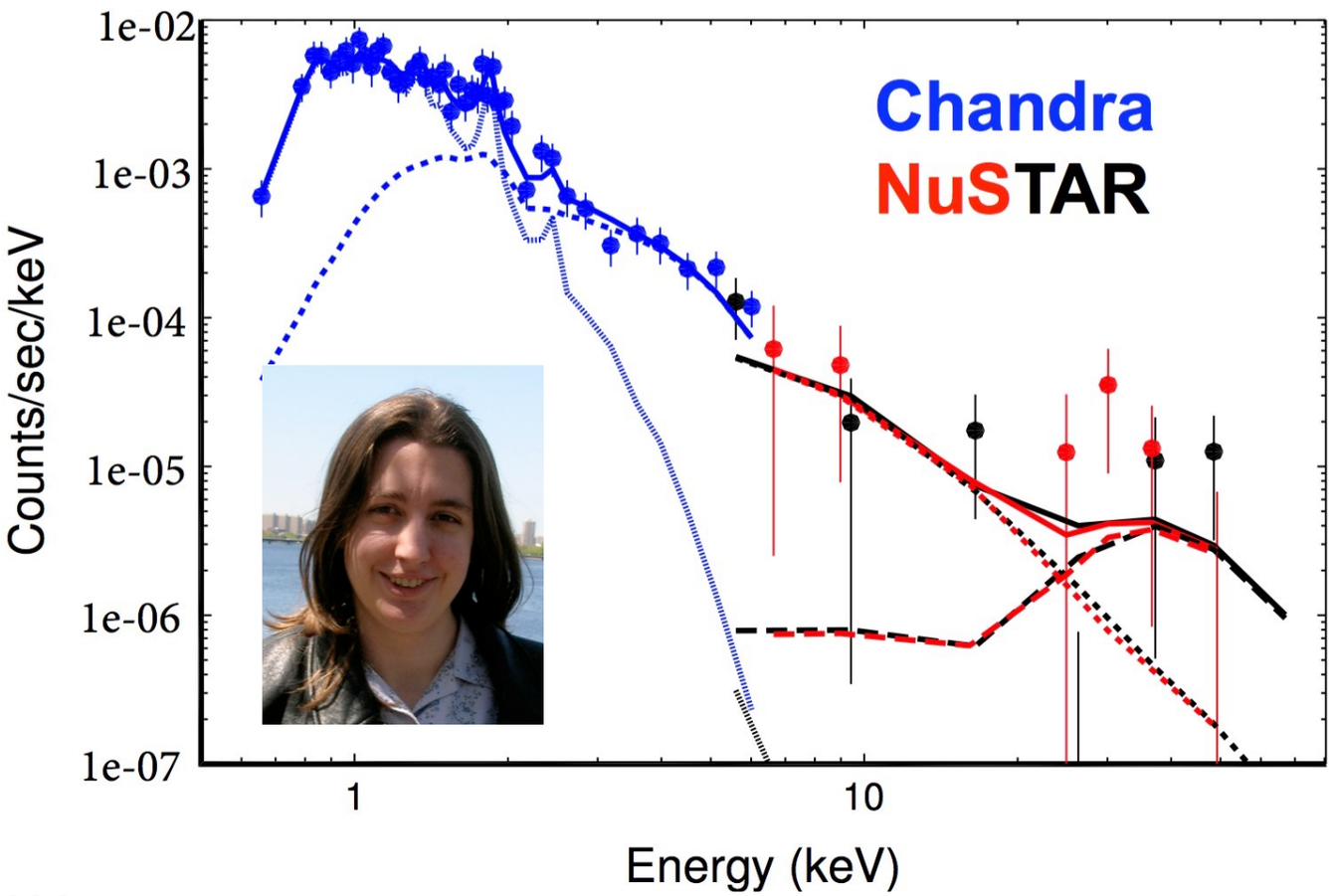
Need to measure the Eddington ratio distribution down to low L/L_{Edd}!



A fluorescent bulb at 1000 frames per second (http://www.youtube.com/watch?v=5pNtjOYkAbA)

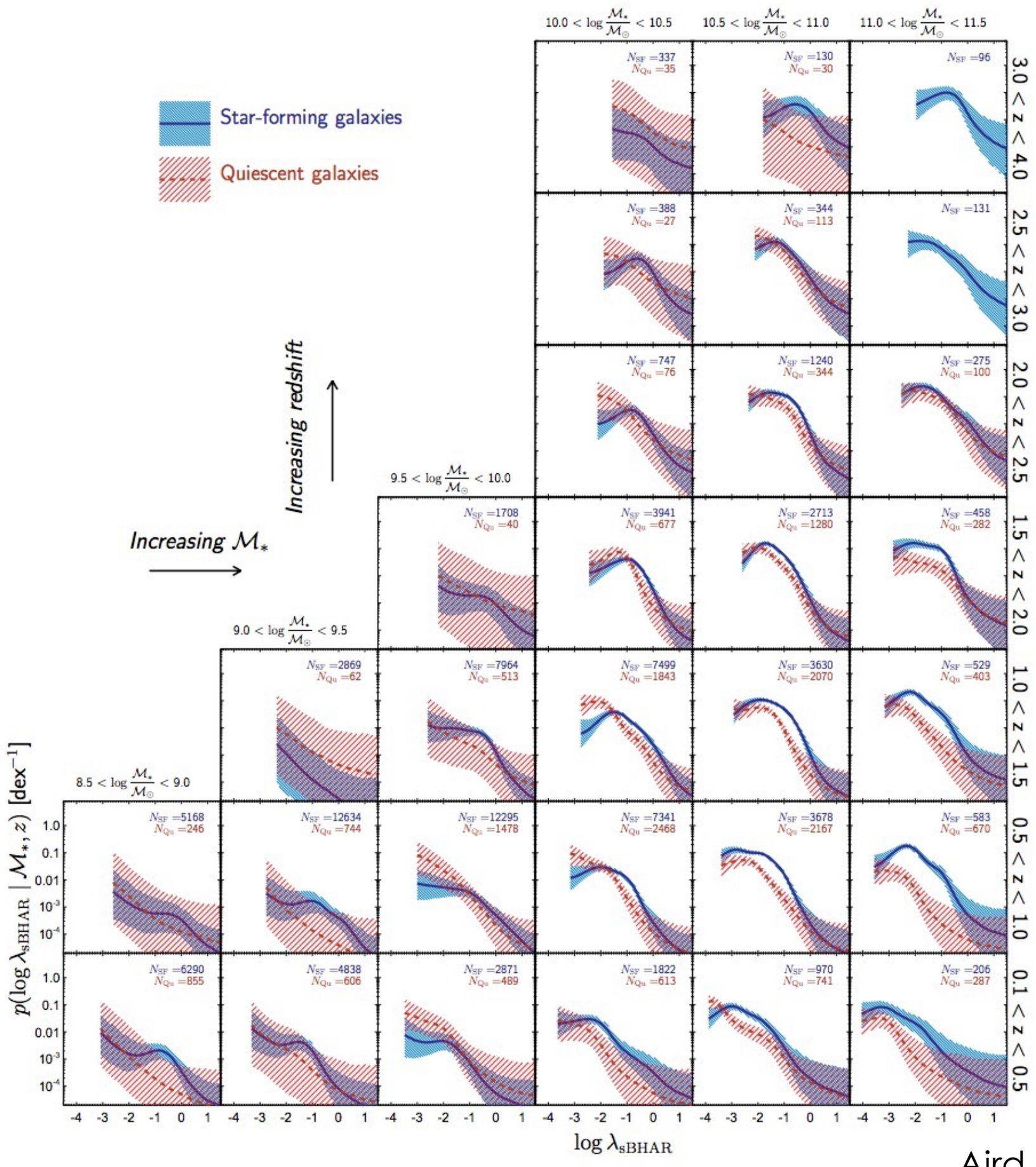
X-rays





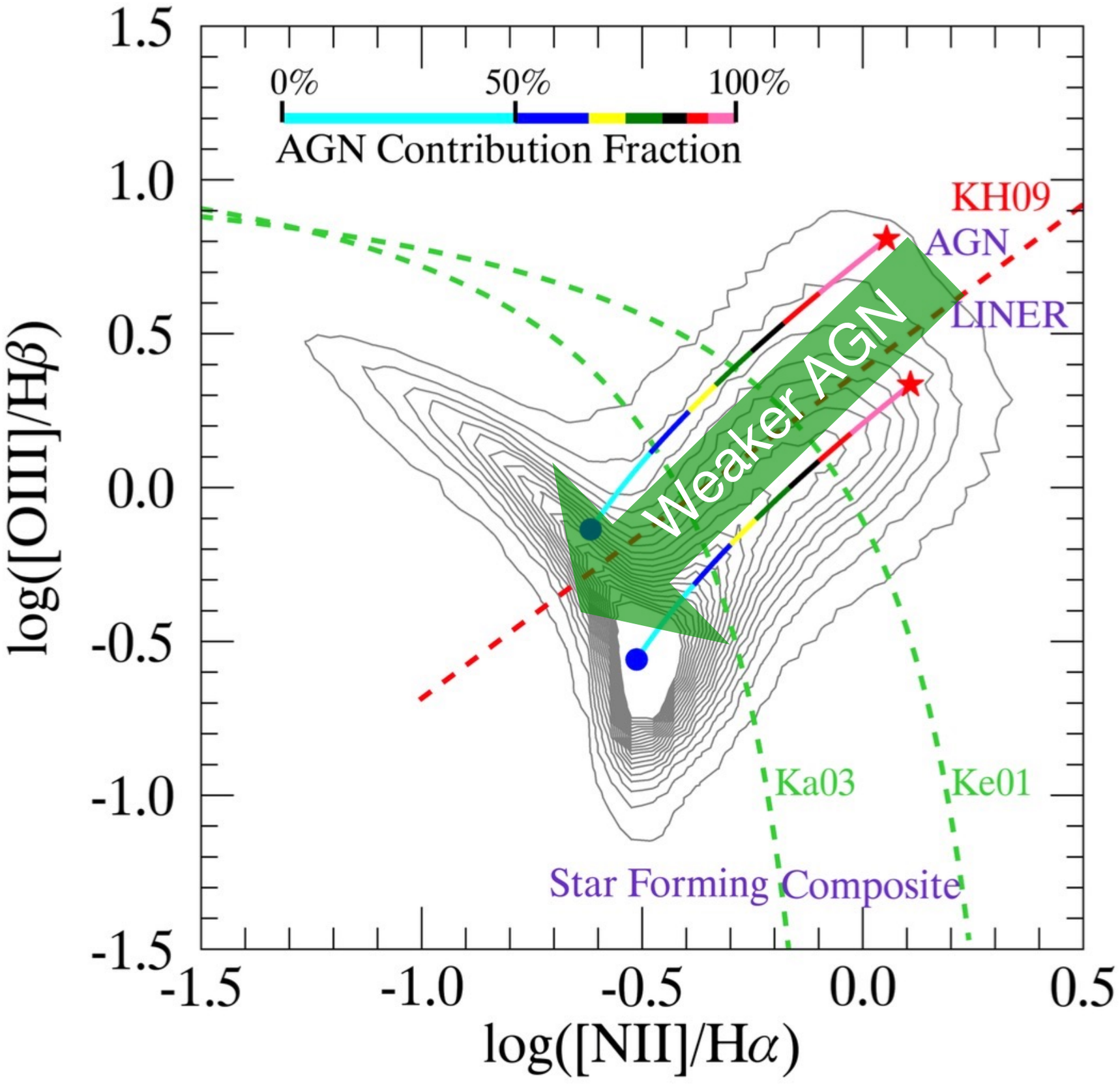
NGC 1266: See talk by L. Lanz

Jones et al. (2017)



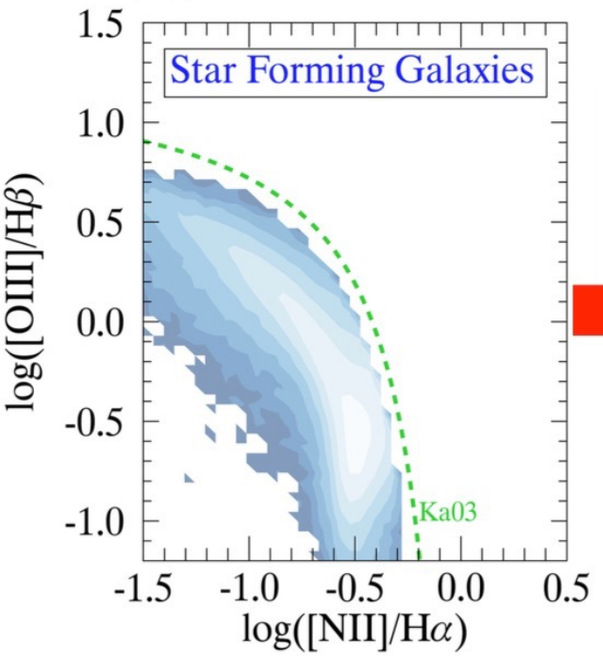
Aird et al. (2017)

optical

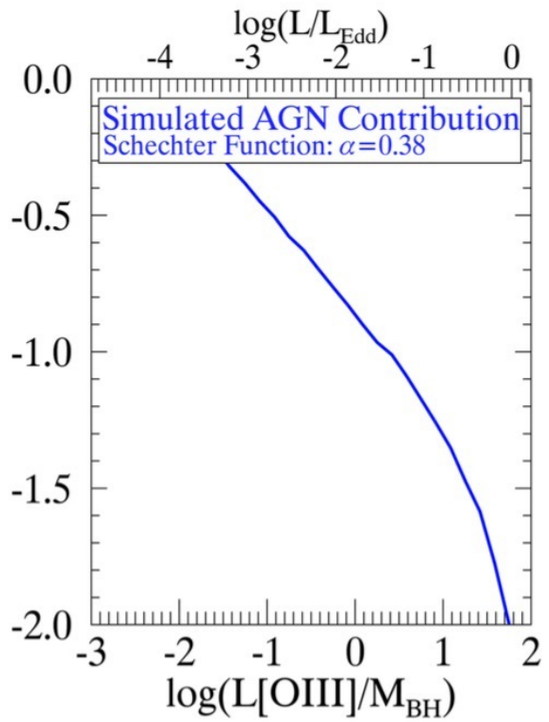


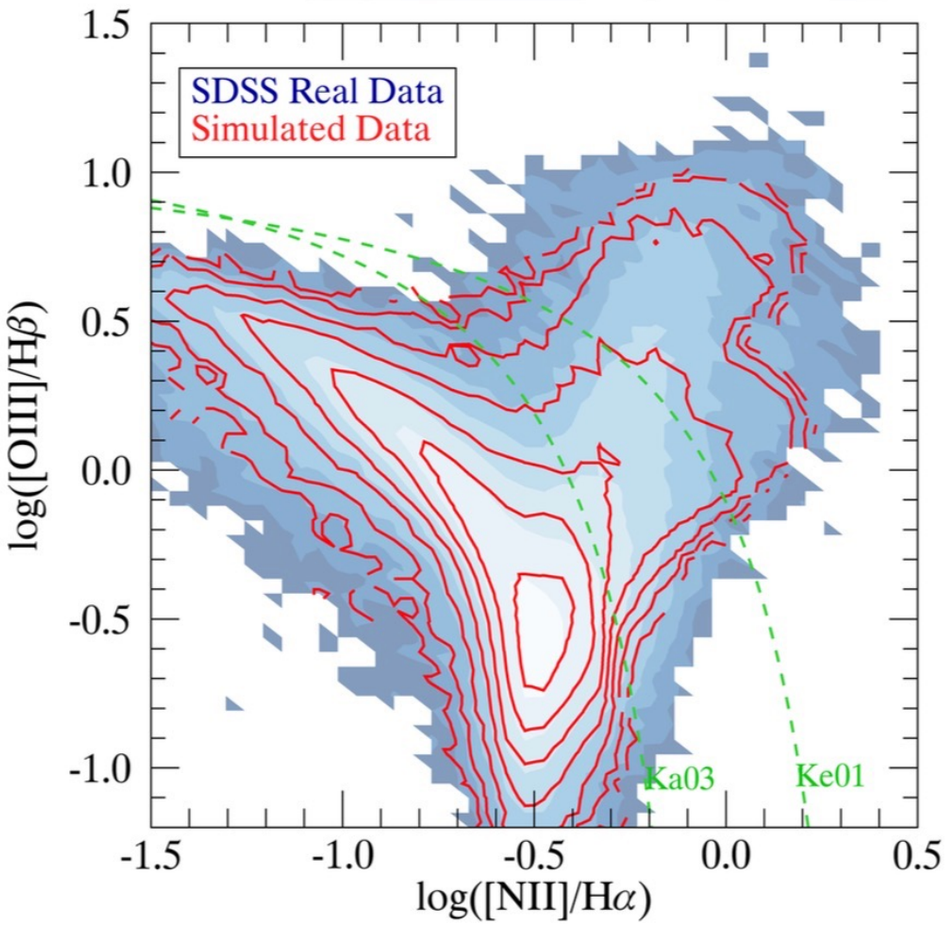
Jones et al. (2016)

Parent Sample

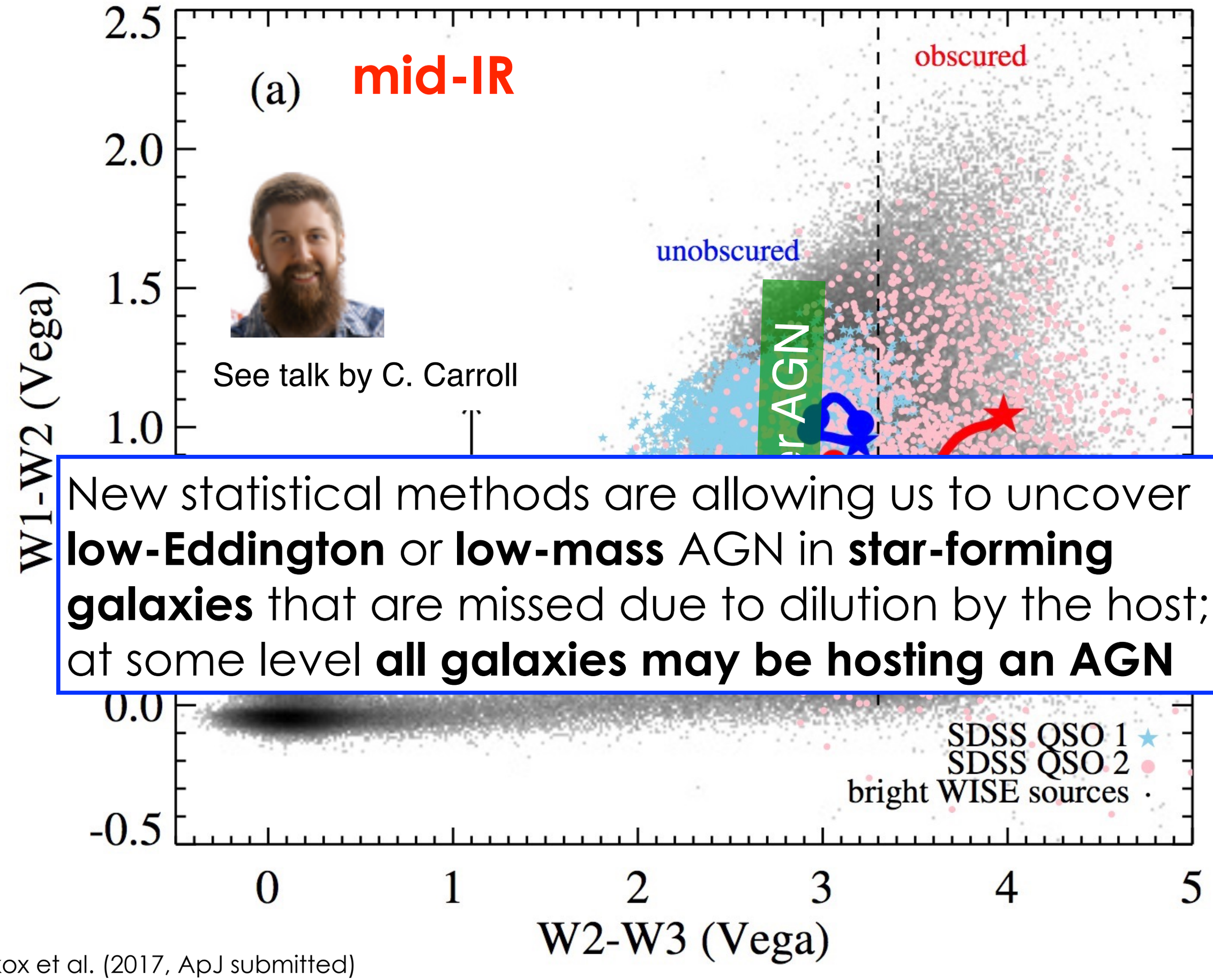


Simulated AGN





Jones et al. (2016)



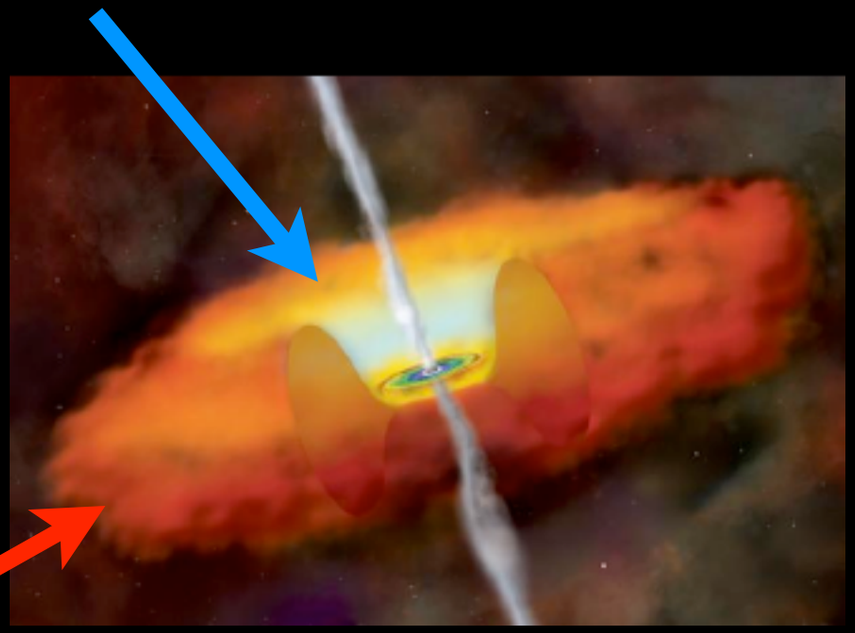
See talk by C. Carroll

New statistical methods are allowing us to uncover **low-Eddington** or **low-mass** AGN in **star-forming galaxies** that are missed due to dilution by the host; at some level **all galaxies may be hosting an AGN**

Hickox et al. (2017, ApJ submitted)

(B) Elusive AGN that are **heavily obscured** by gas and dust

Unobscured



?

Obscured

(e.g., Hickox et al. 2007, Treister et al. 2010, Merloni et al. 2014, Assef et al. 2015)

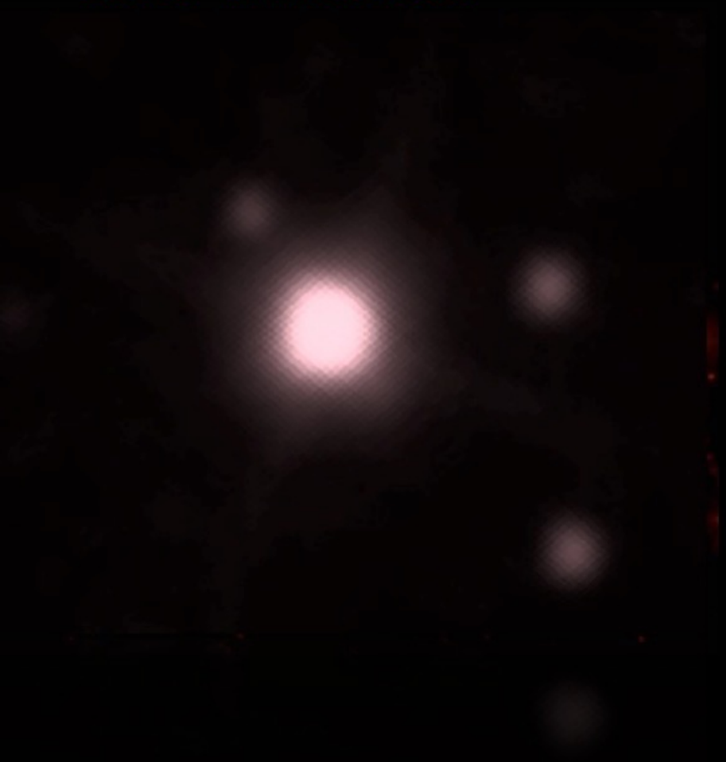
How do we **find** obscured quasars?

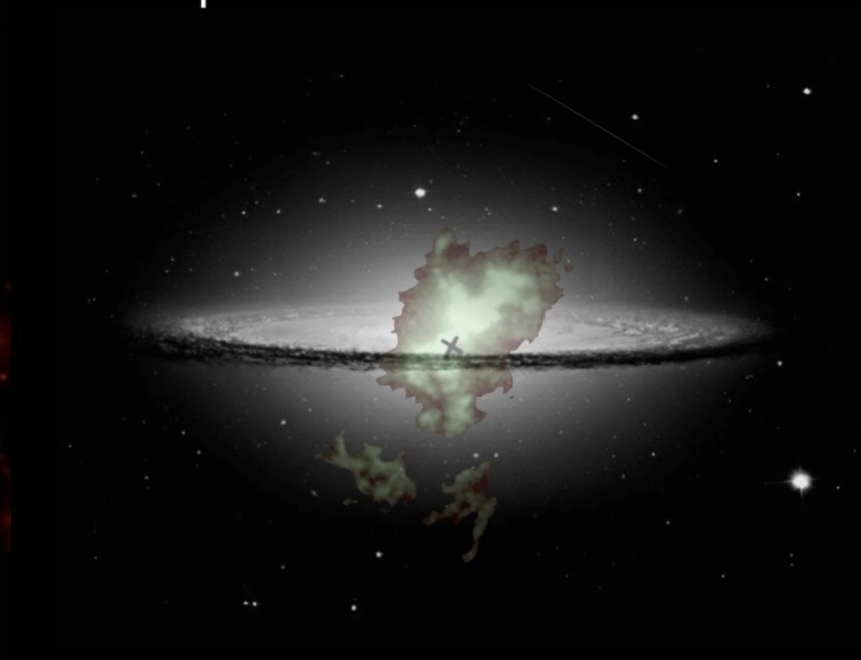
mid-infrared

optical

soft X-rays

hard X-rays





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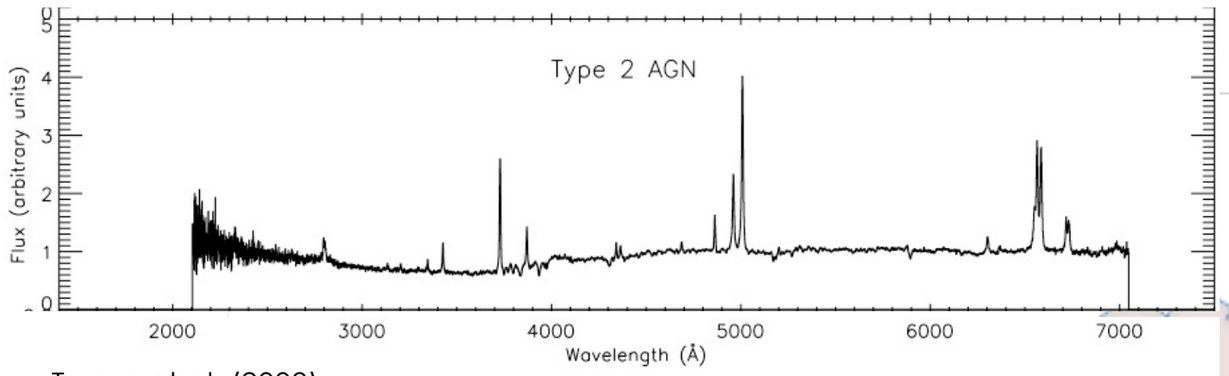


Trump et al. (2008)

optical

Optical emission lines
$[OIII]_{5007Å}$,$[NeV]_{3426Å}$

NLR

mid-IR

Mid-IR selection

X-rays

Compton reflection from the torus (e.g., XMM, Chandra)

Very hard (>10 keV) X-rays (e.g., NuSTAR)

AGN disc emission reprocessed by the torus

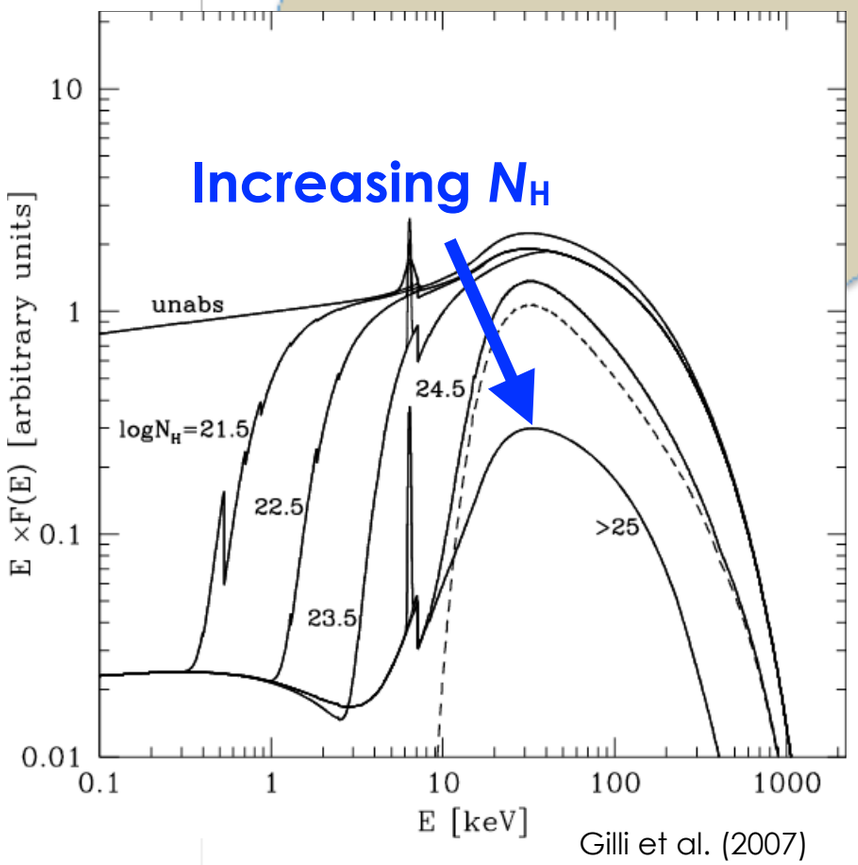
BLR

torus

accretion disc

BLR

NLR

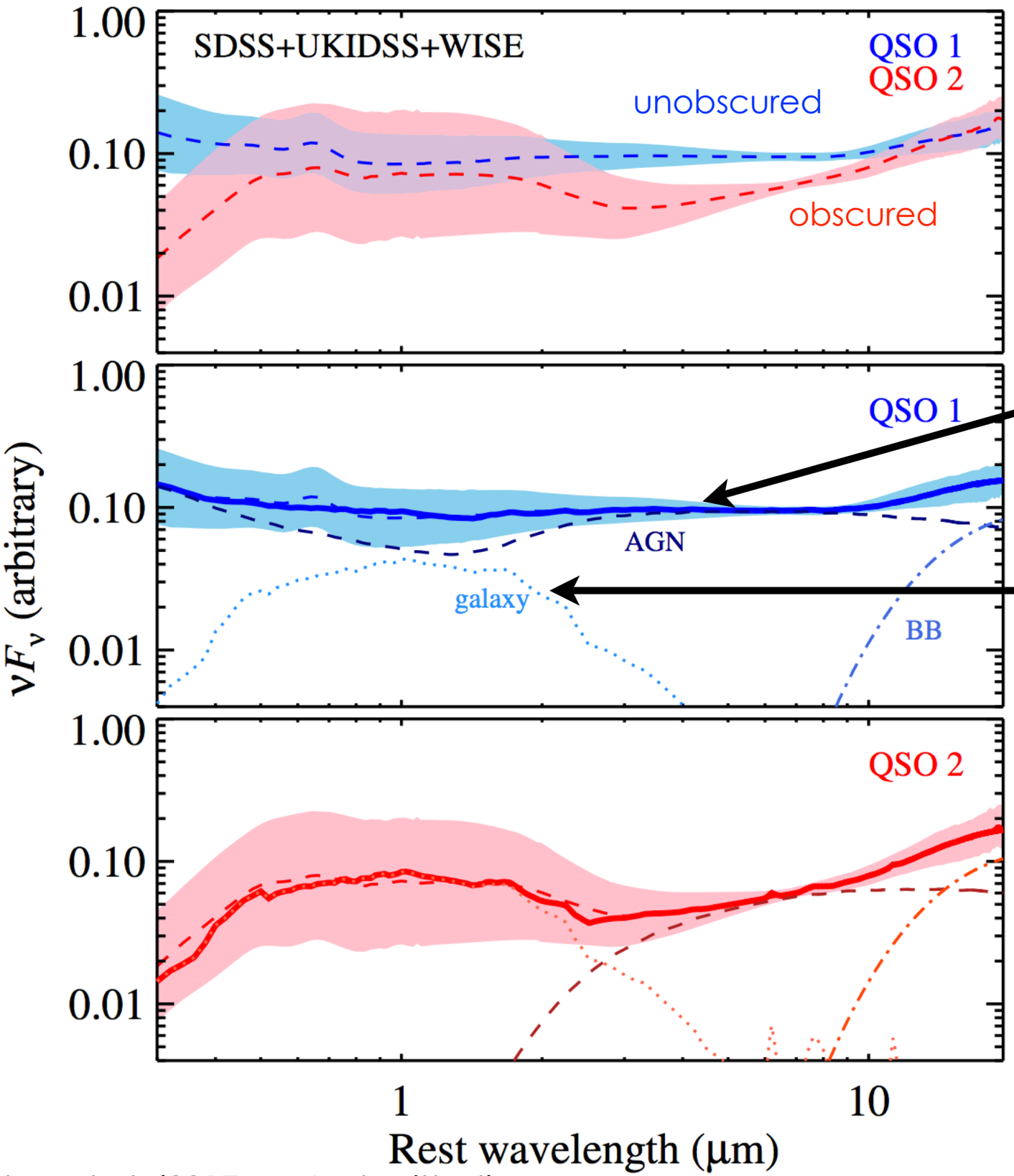


Gilli et al. (2007)

Vignali (2014)

How do we **find** obscured quasars?

mid-IR



The only main difference between Type 1 and Type 2 quasar SEDs is nuclear **dust extinction**

quasar (Richards et al. 2006)

galaxy (Assef et al. 2010)

Both obscured and unobscured quasars have **red colors in the mid-IR**, but obscured quasars are **faint and extended in the optical**

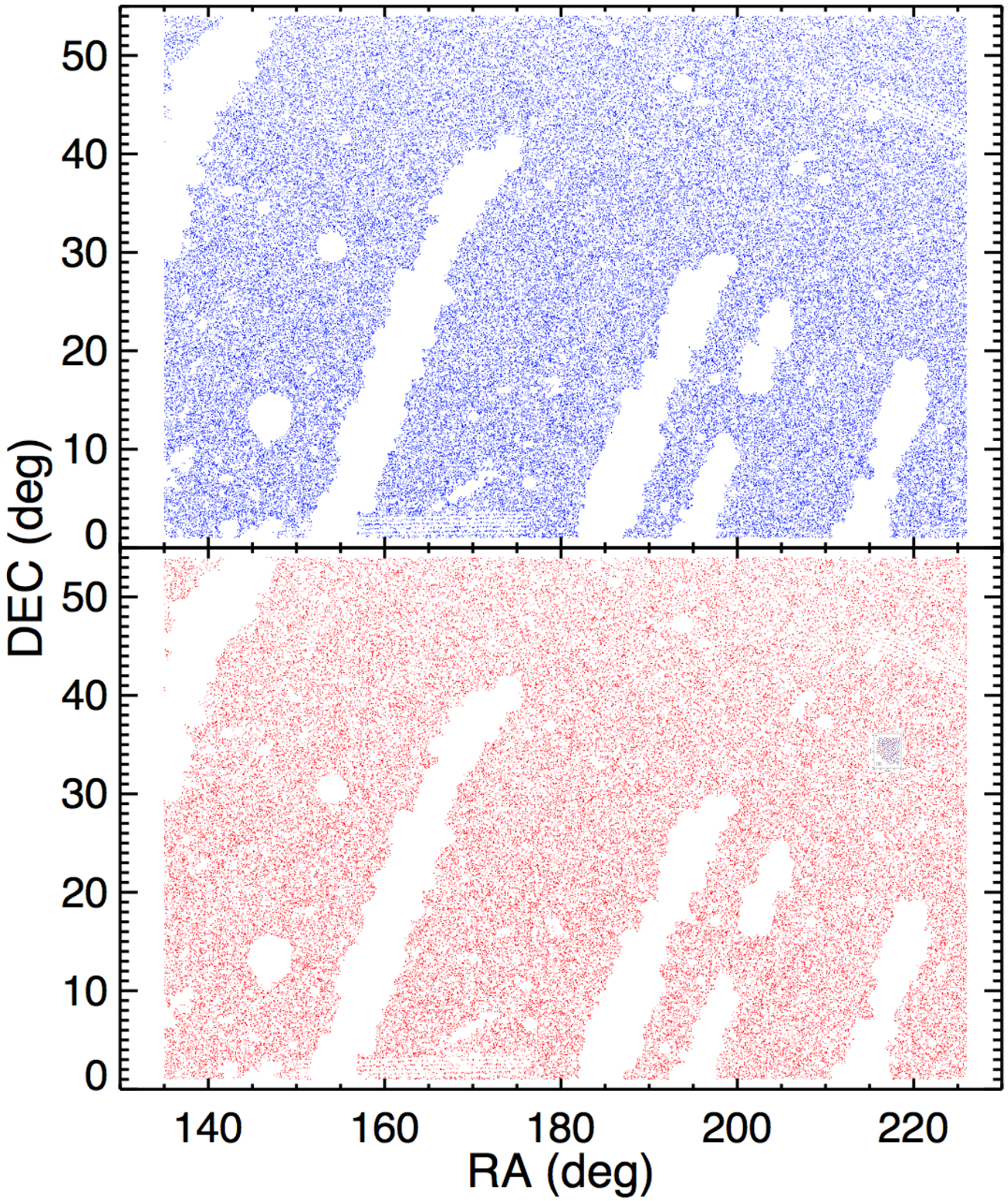
(e.g., Hickox et al. 2007)

Hickox et al. (2017, ApJ submitted)

How do we **find** obscured quasars?

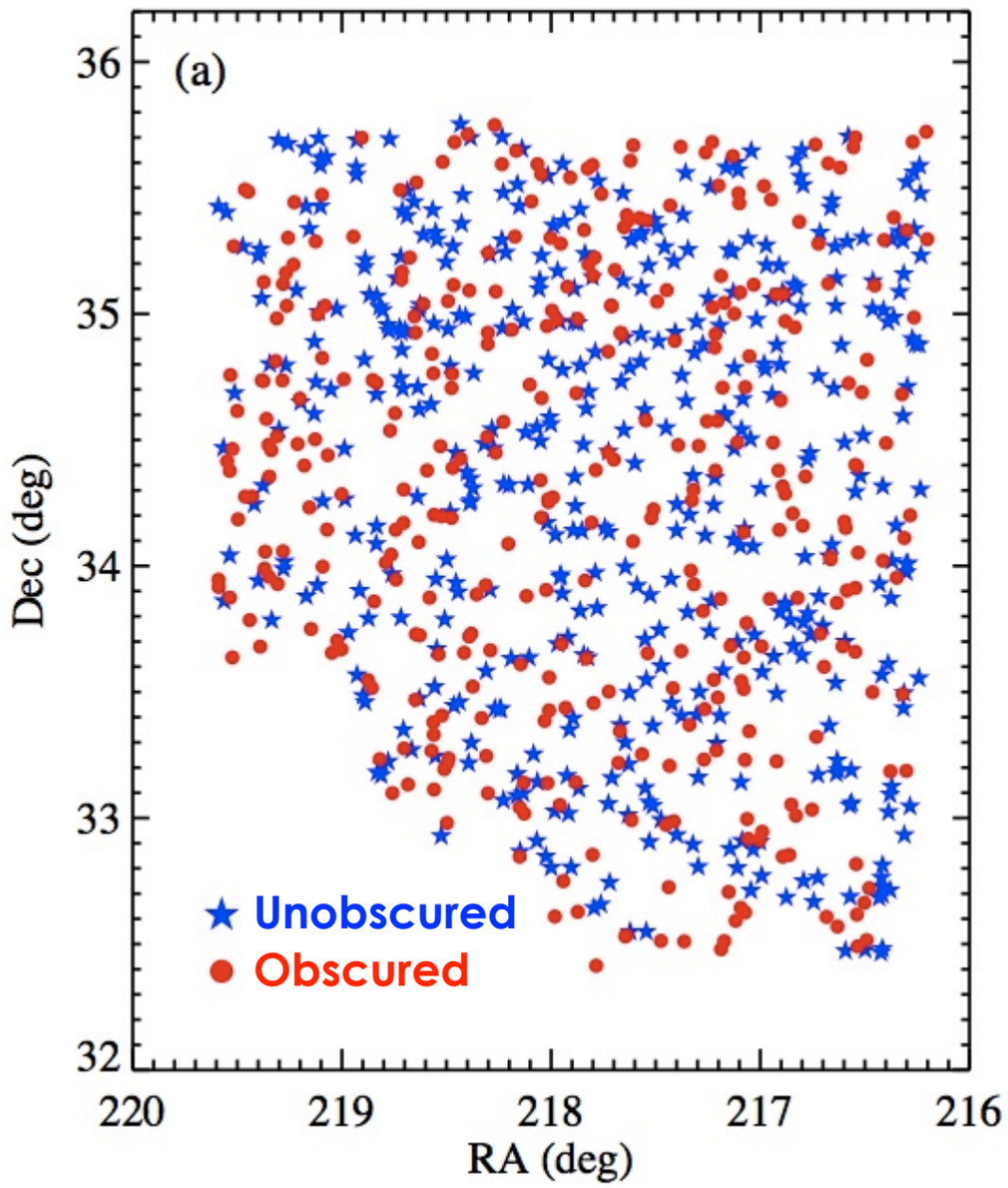
See talk by
M. DiPompeo

WISE (SDSS)



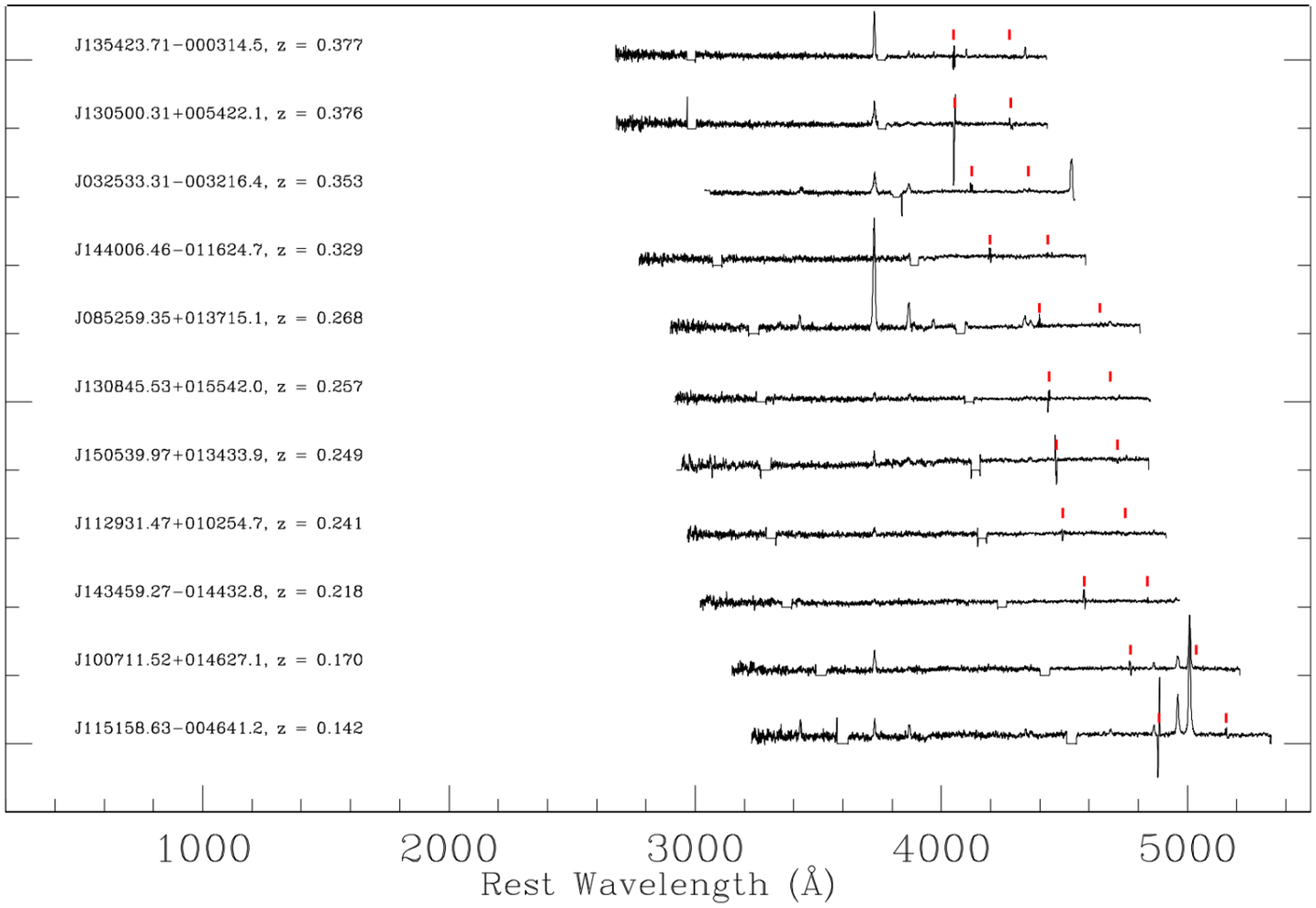
DiPompeo et al. (2014)

***Spitzer* (Boötes)**

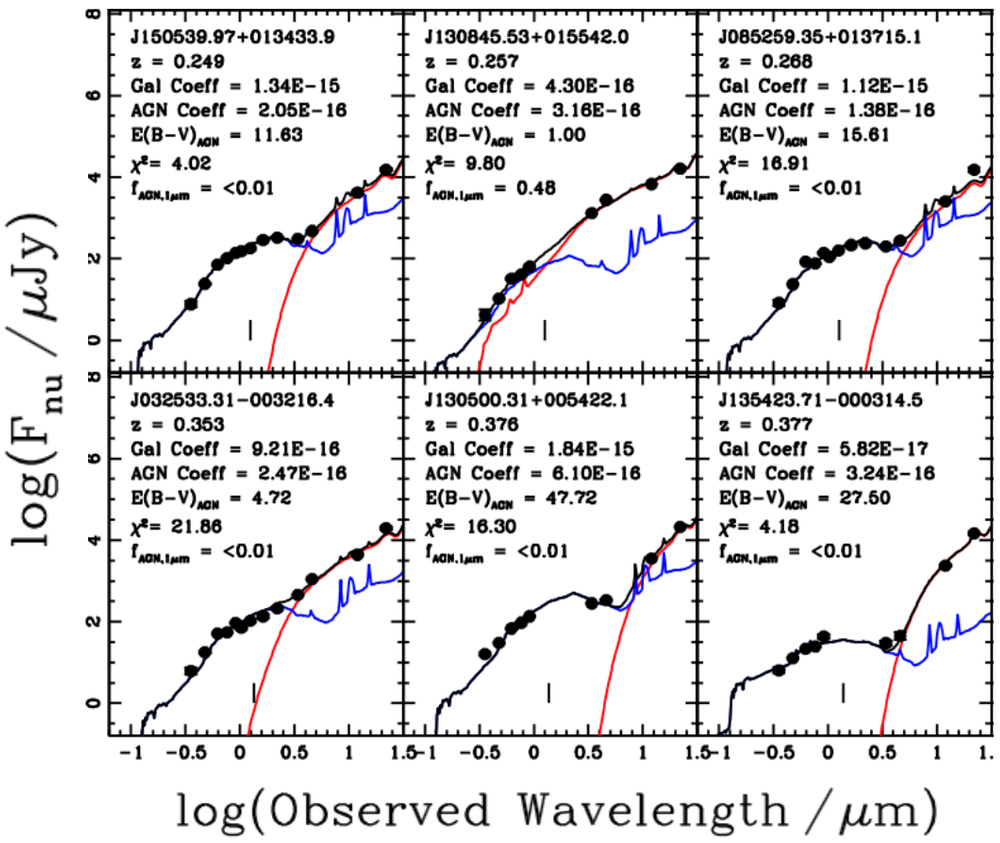


Hickox et al. (2007, 2011)

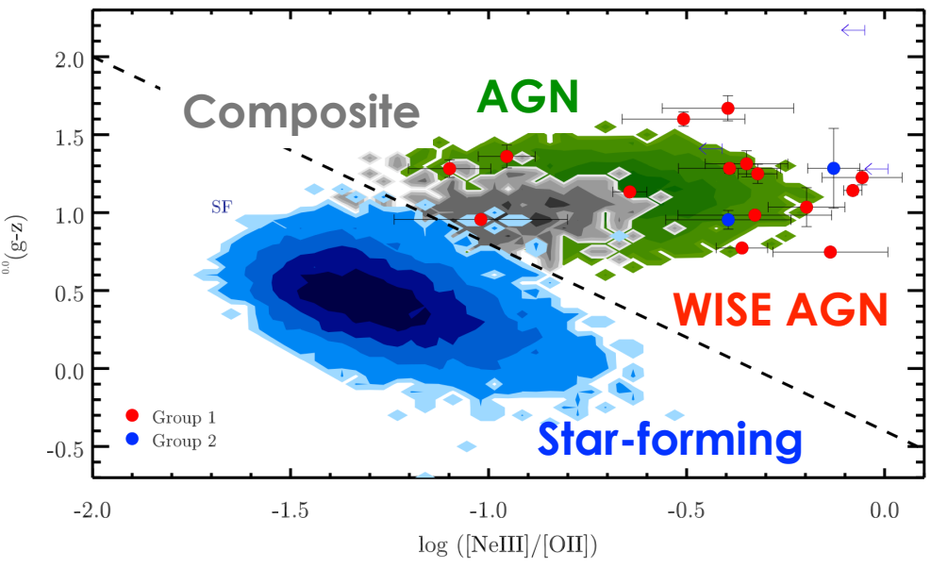
Redshifts and **SEDs** of *WISE*-selected obscured quasars



Hainline et al. (2014), Carroll et al. (2017 in prep), Hviding et al. (2017 in prep)



See also Lacy et al. (2013, 2015)

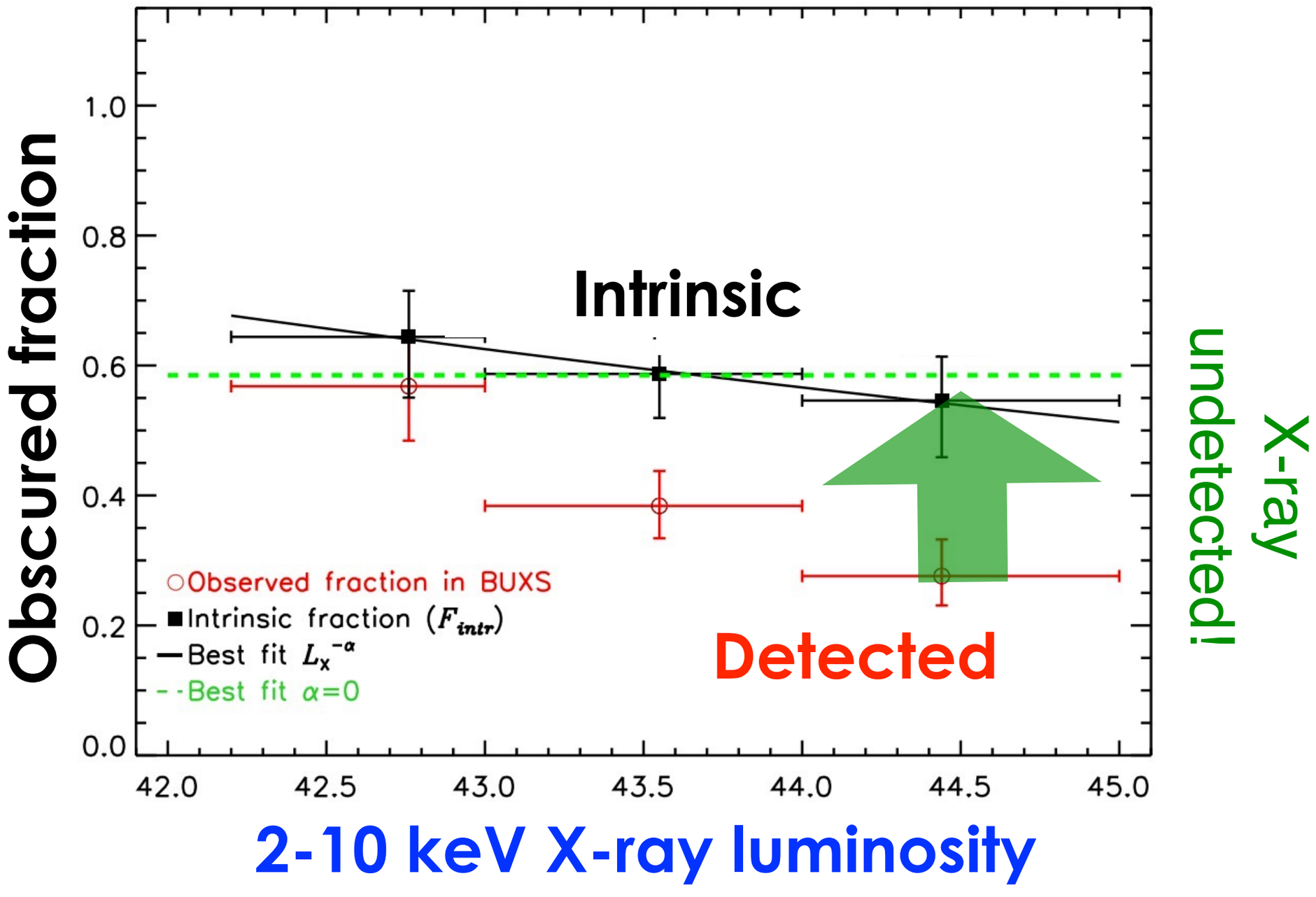


Southern African Large Telescope

How **heavily buried** are obscured quasars?

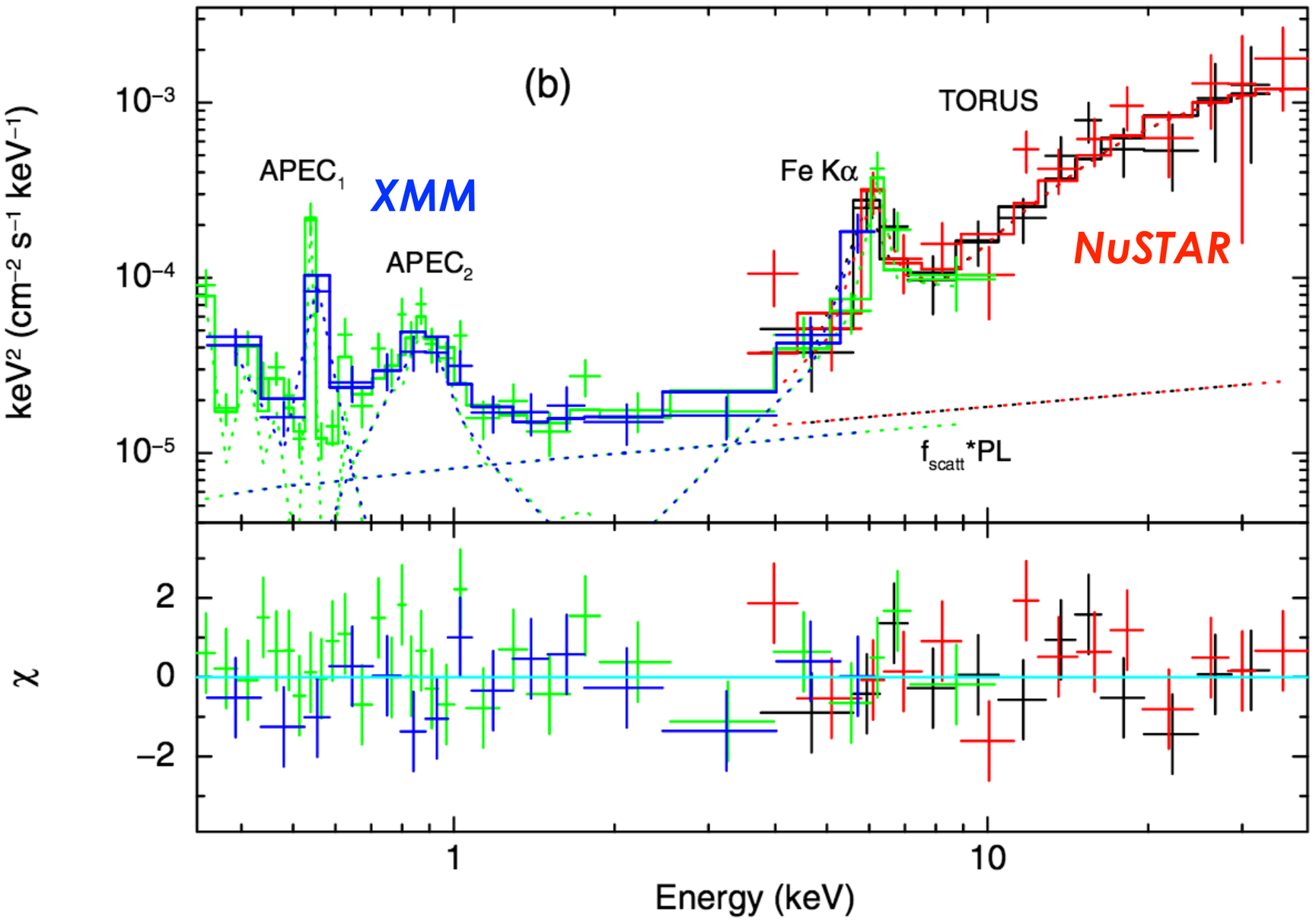
(What is the hydrogen column density N_H?)

How **heavily buried** are obscured quasars?



Mateos et al. (2017)

How **heavily buried** are obscured quasars?

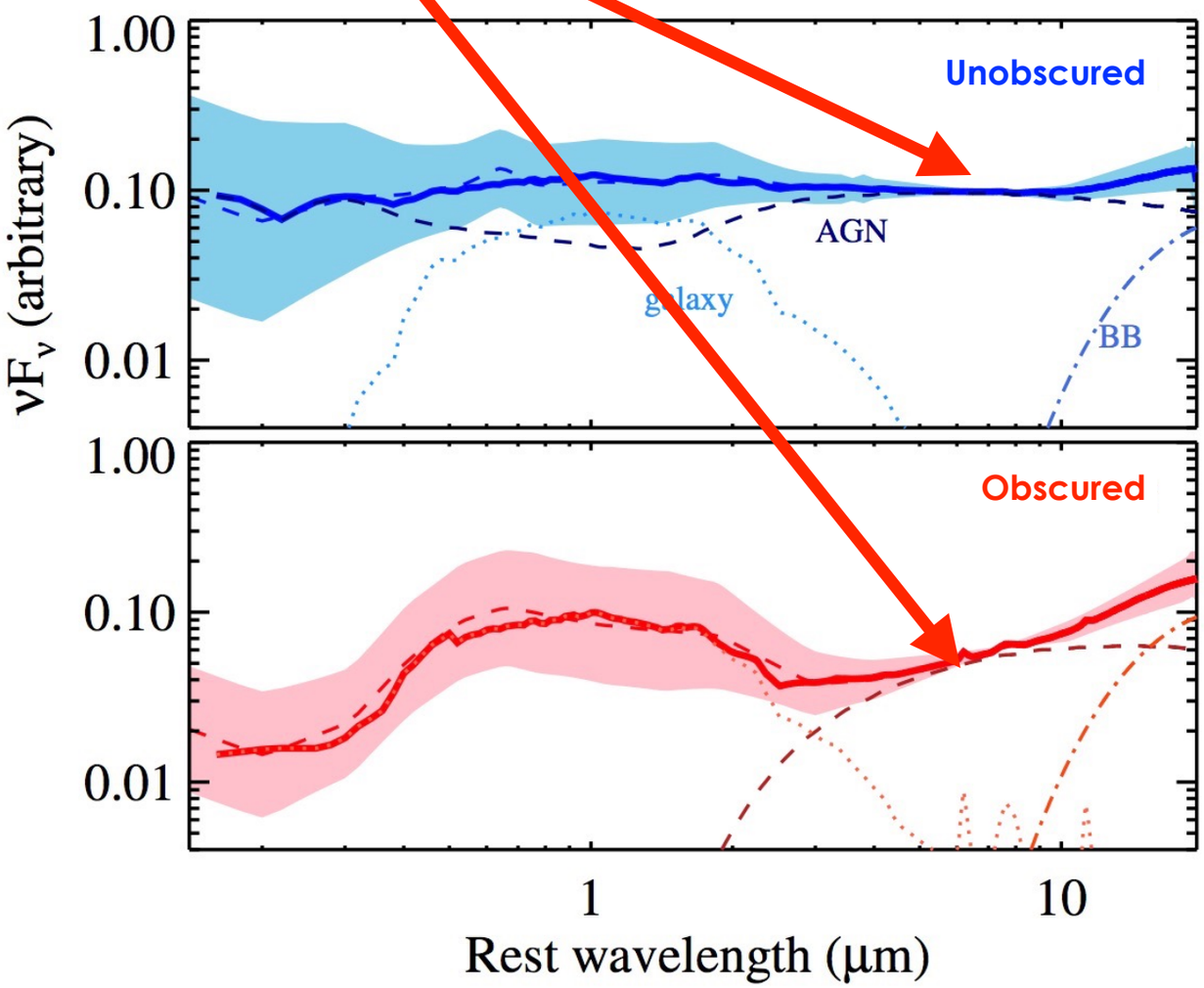


Gandhi et al. (2014)

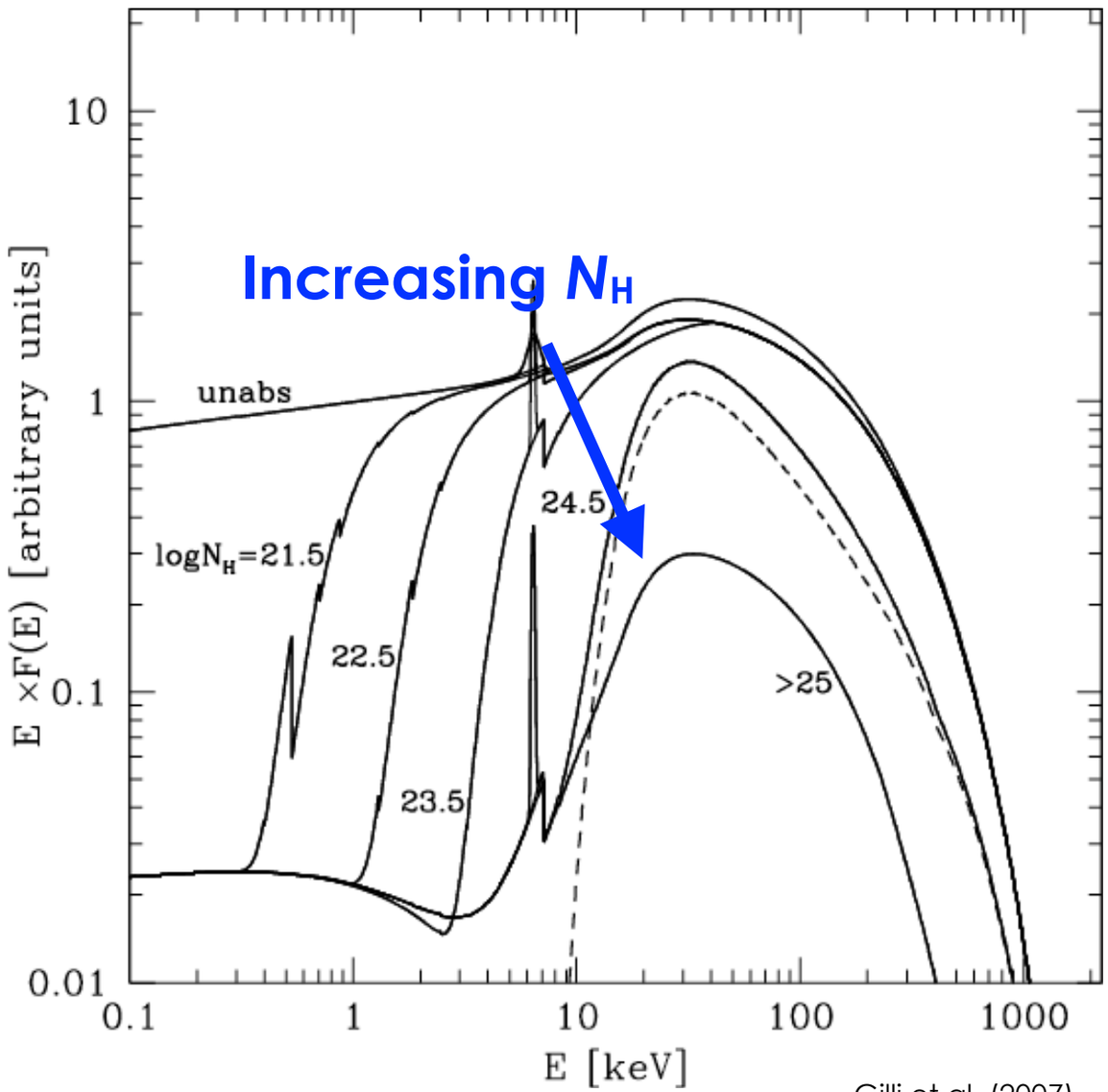
$N_H > 10^{25}$ cm^{-2}!

How **heavily buried** are obscured quasars?

Mid-infrared

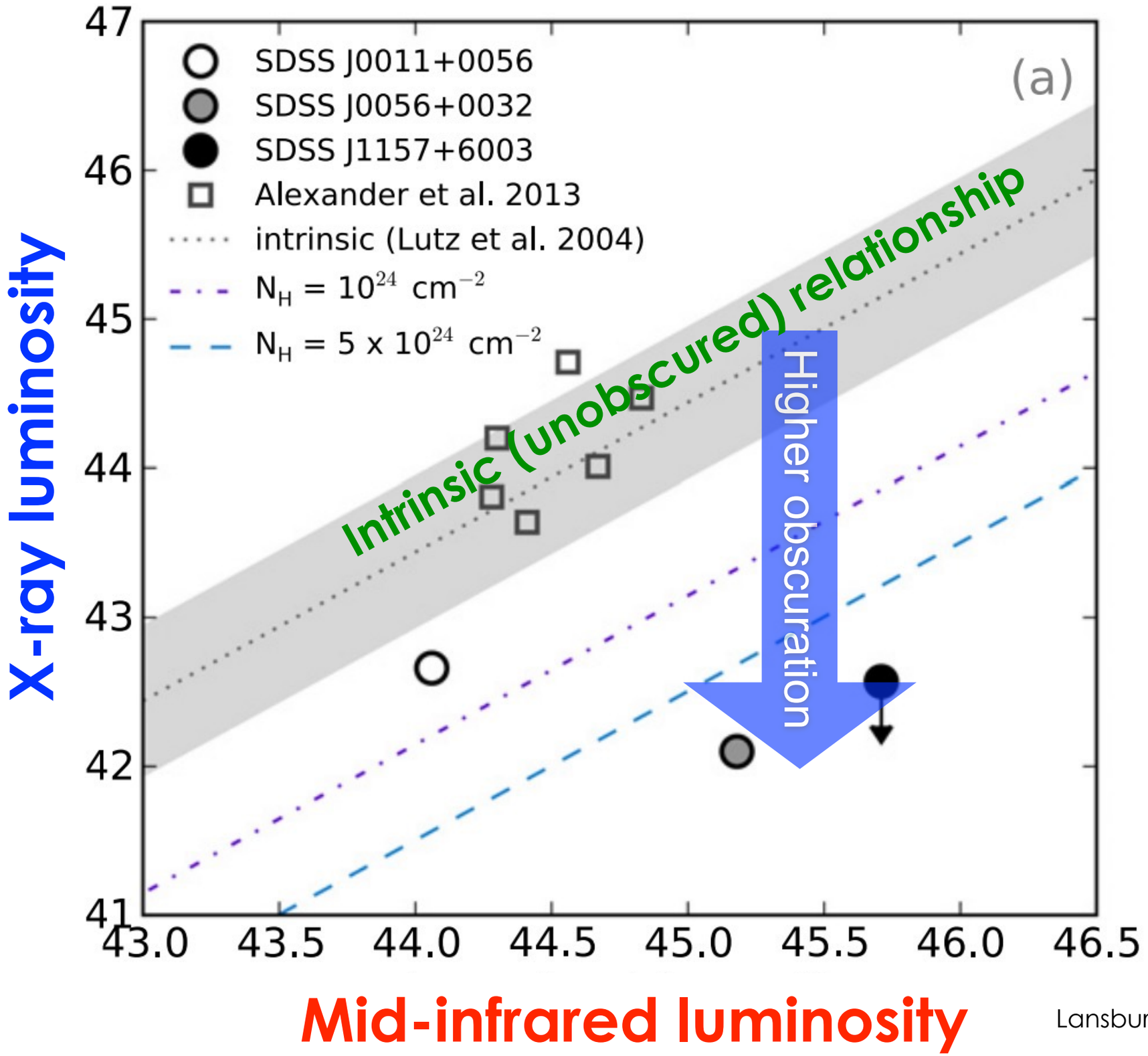


X-rays



Gilli et al. (2007)

How **heavily buried** are obscured quasars?

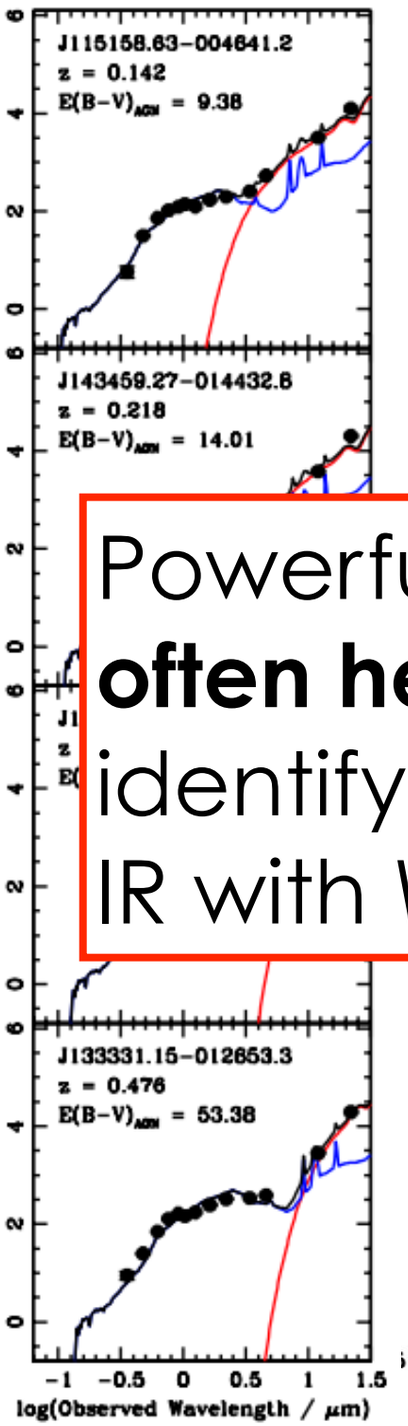


Lansbury et al. (2014)

NuSTAR observations of **"typical" WISE-selected quasars**

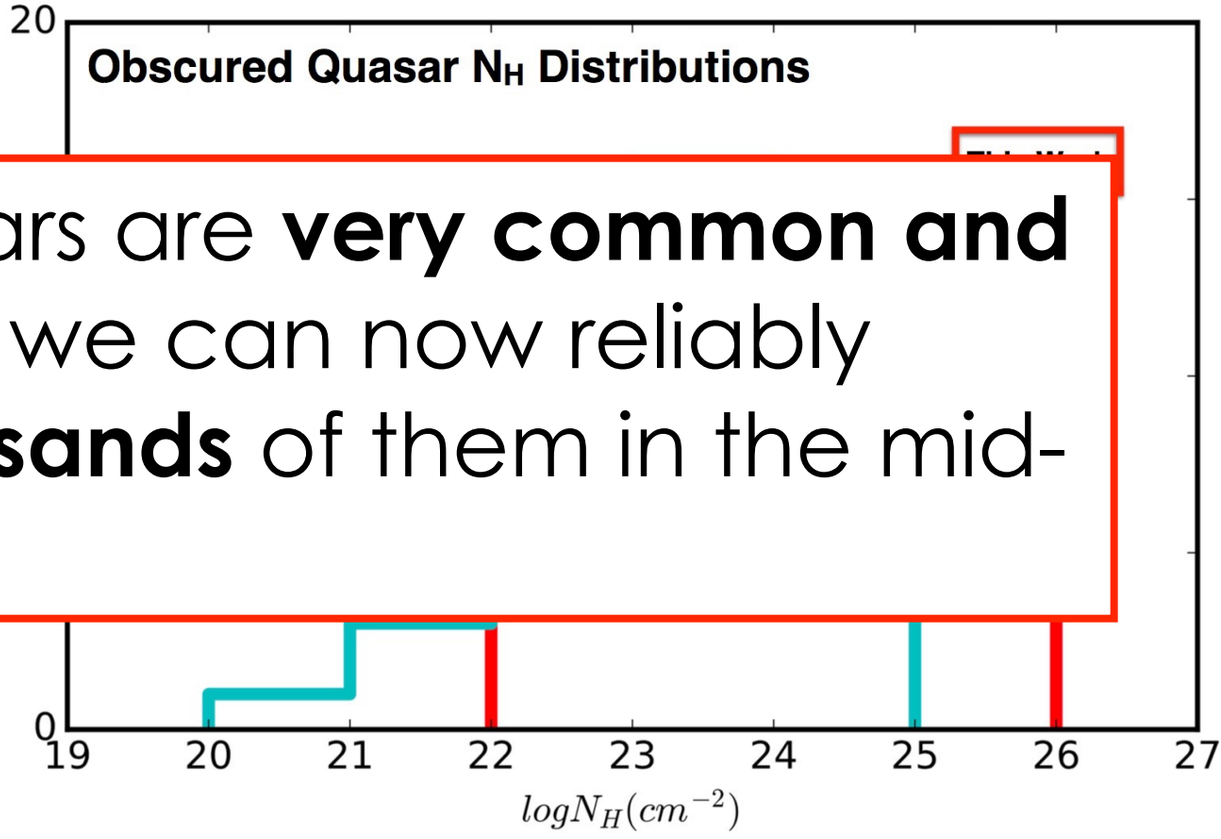
See poster by W. Yan

NuSTAR 3-24 keV



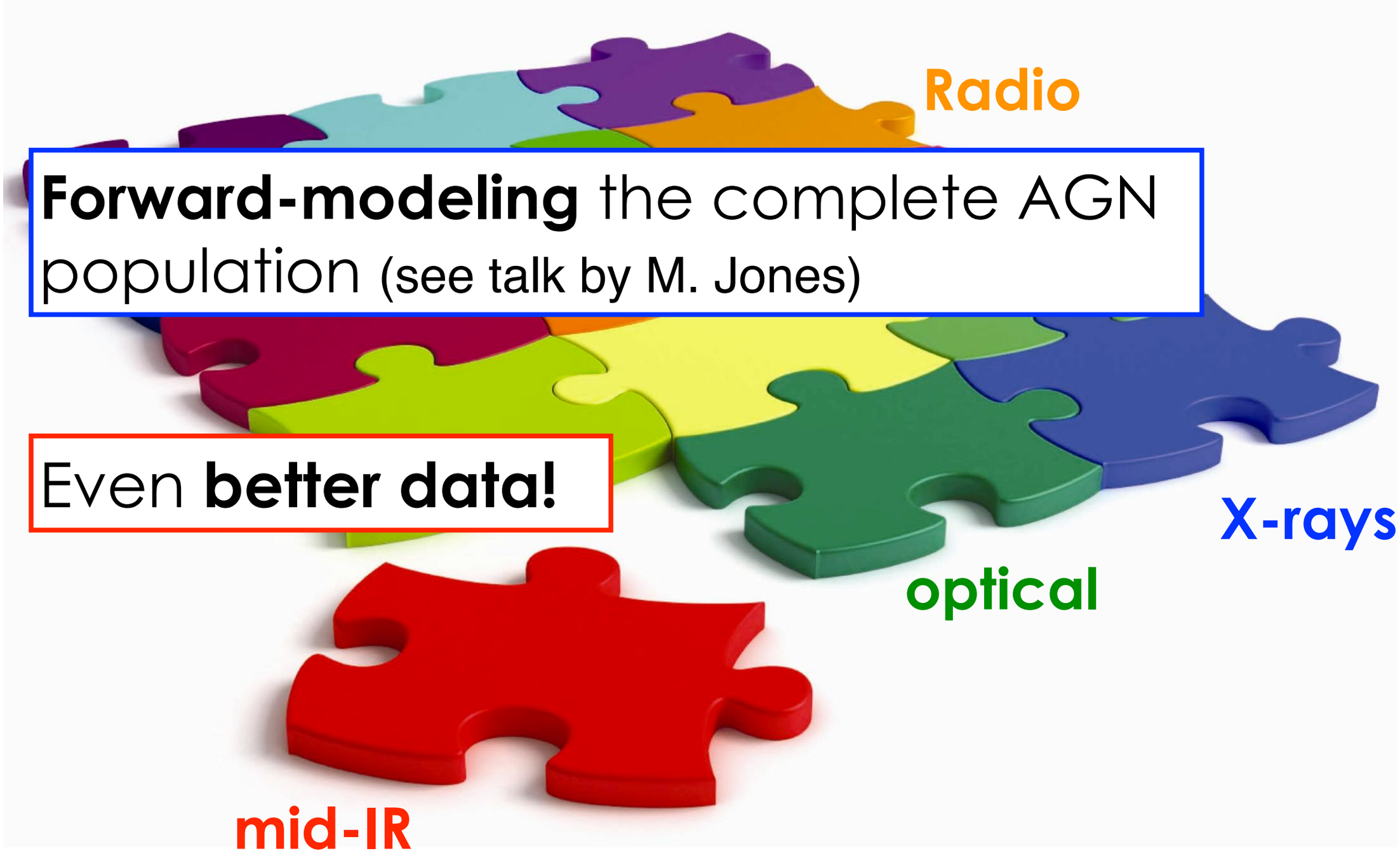
Target SEDs

Keck/LRIS



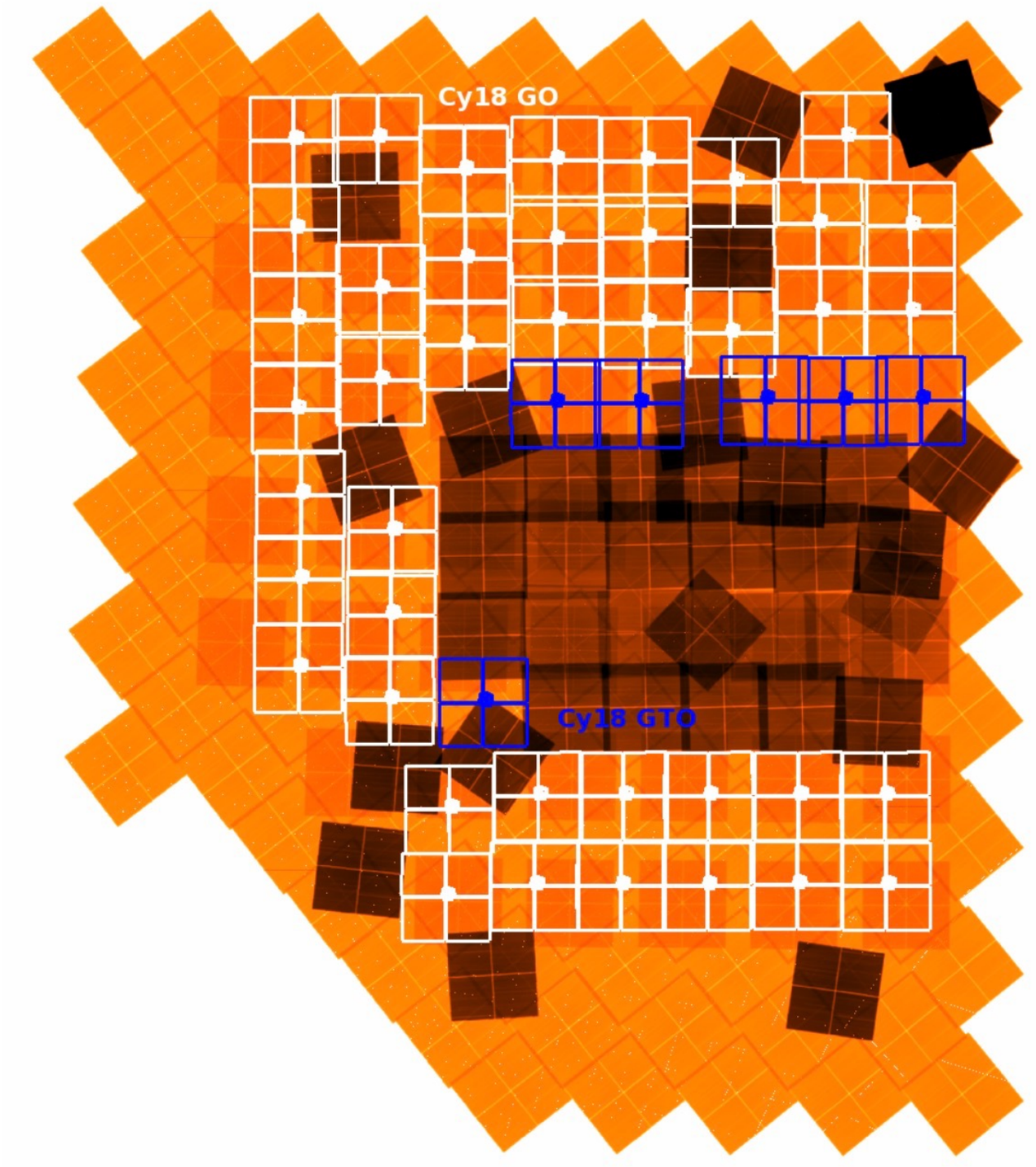
Powerful obscured quasars are **very common and often heavily buried** and we can now reliably identify **hundreds of thousands** of them in the mid-IR with *WISE*

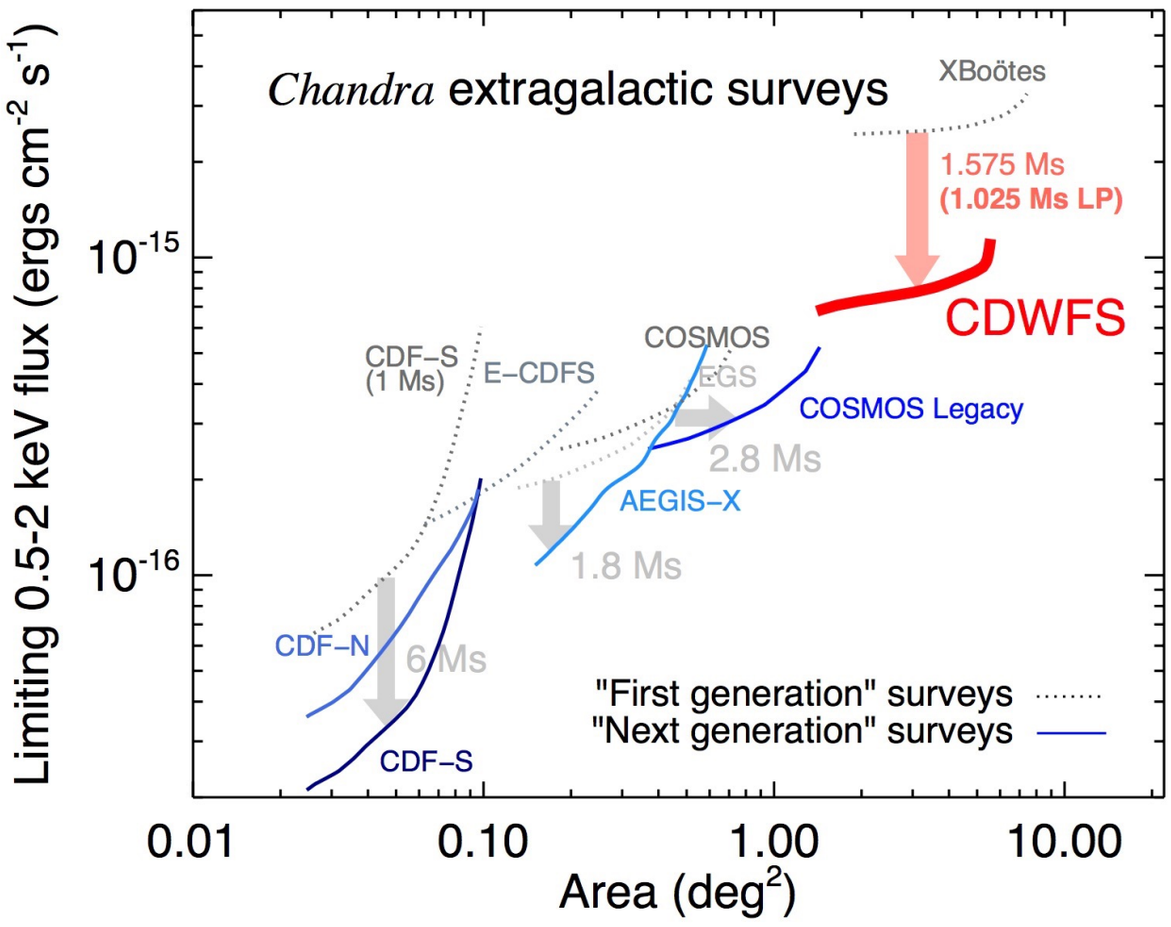
How do we piece this all together?



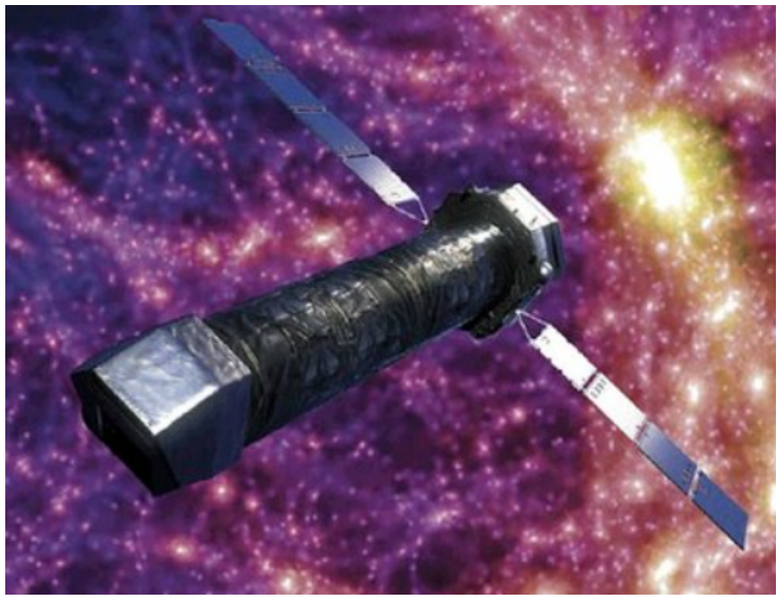
See also review by Padovani et al. (2017) from ESO AGN 2016 meeting

The ***Chandra* Deep Wide-Field Survey**
(1 Ms program in Cycle 18, PI: Hickox)

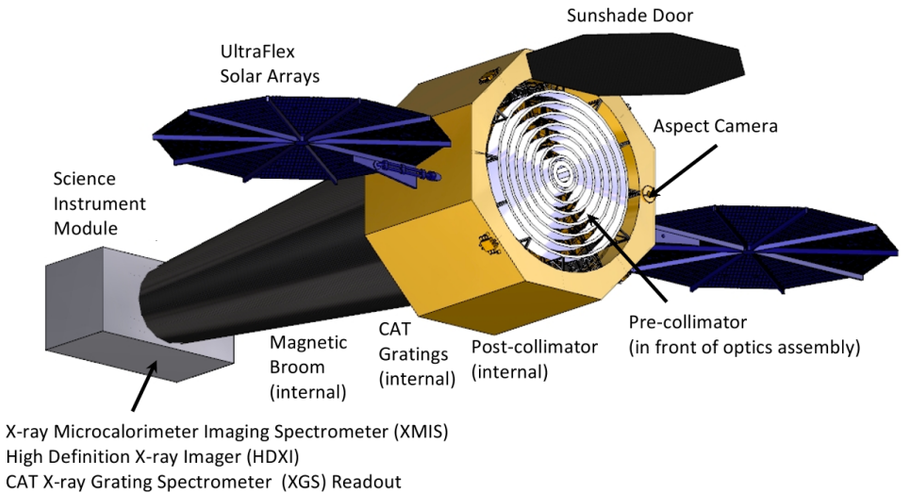




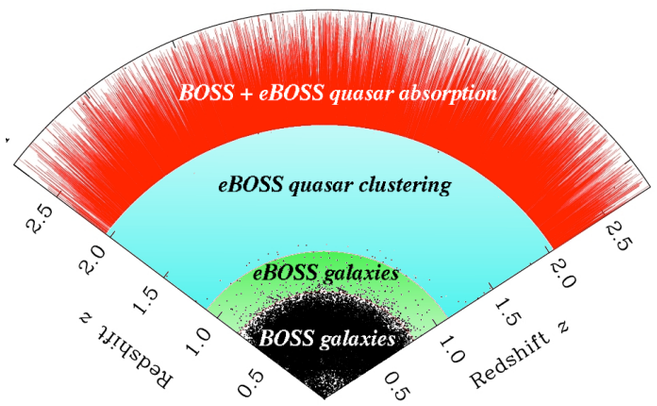
New large-scale galaxy and AGN surveys



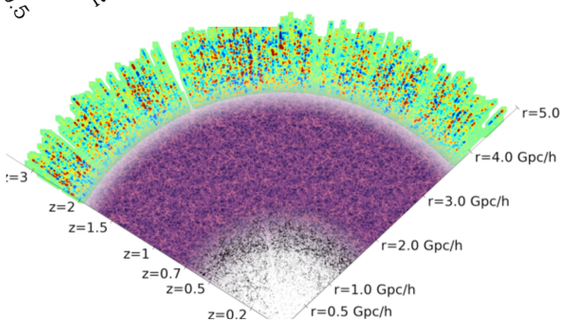
Athena



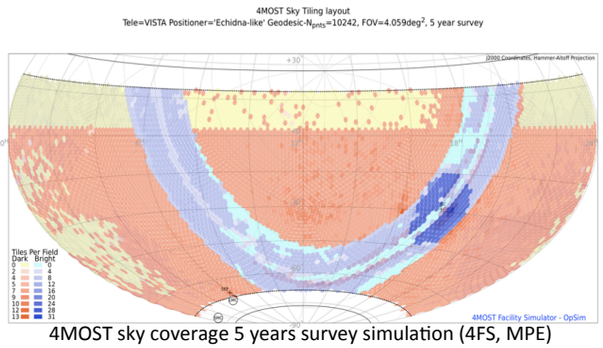
Lynx



eBOSS

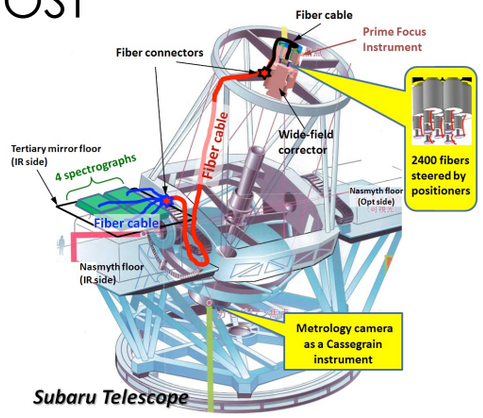


DESI

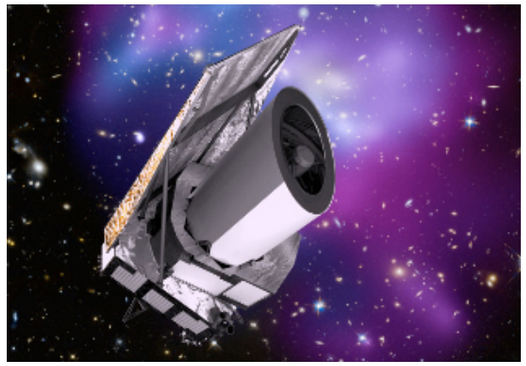


4MOST sky coverage 5 years survey simulation (4FS, MPE)

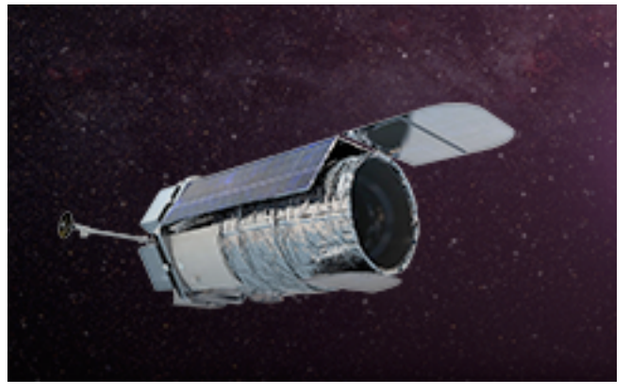
4MOST



Subaru PFS

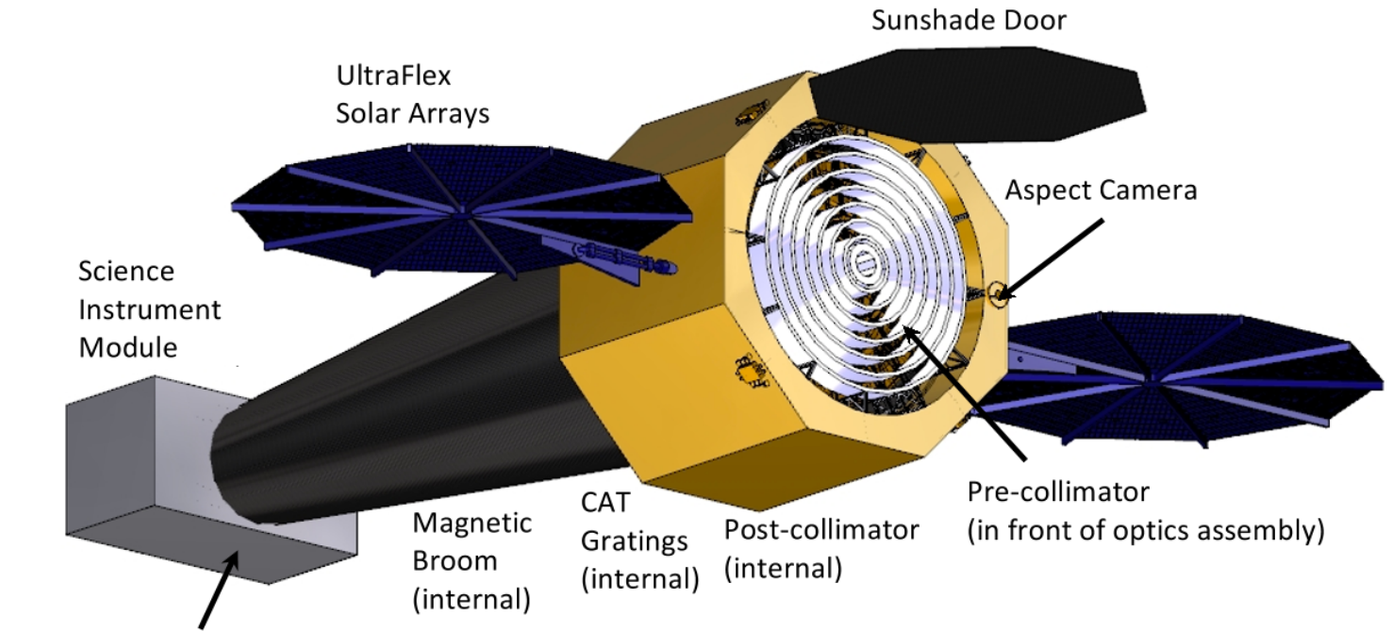


Euclid



WFIRST

New large-scale galaxy and AGN surveys



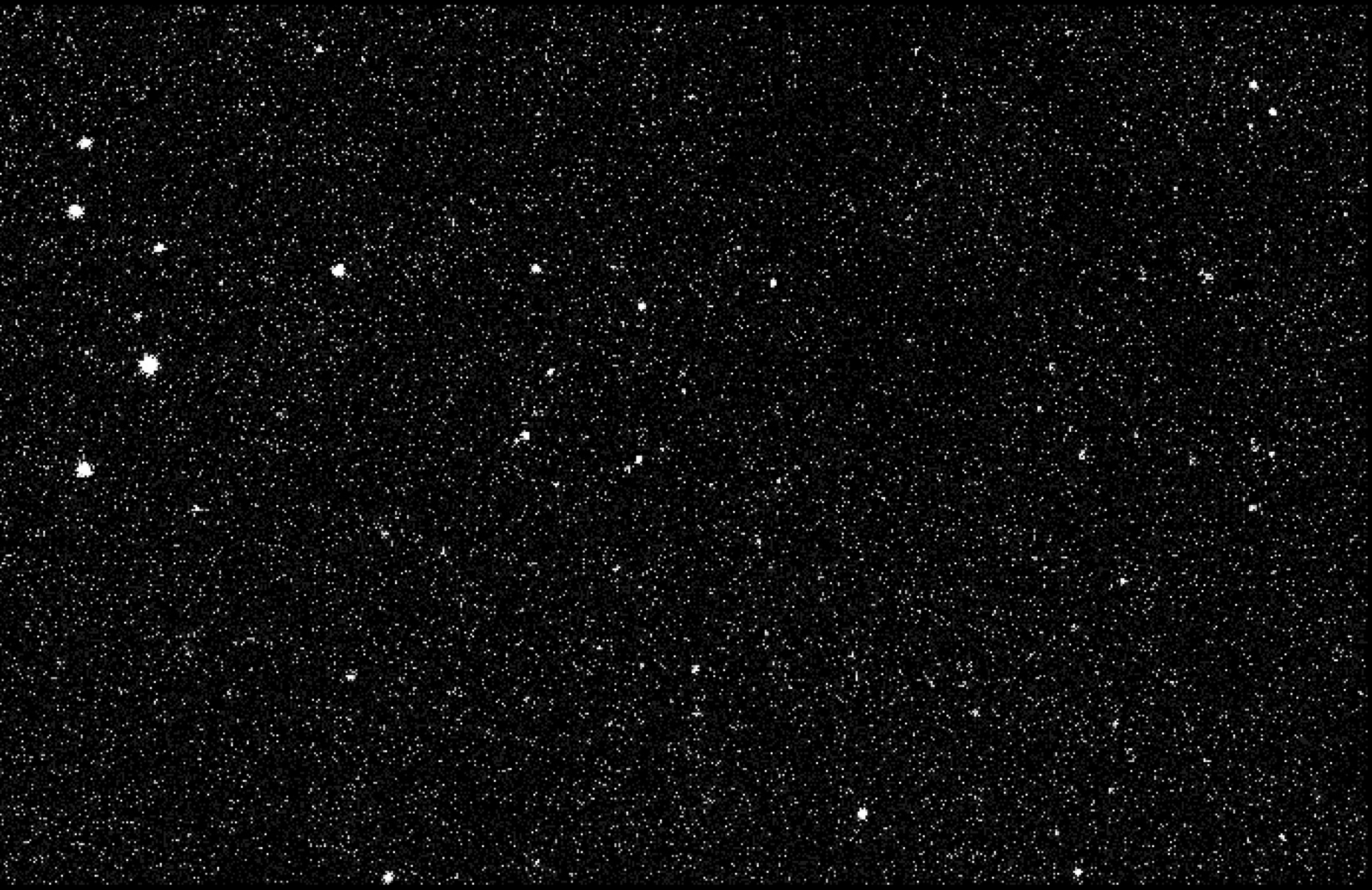
Lynx

Revealing the invisible Universe

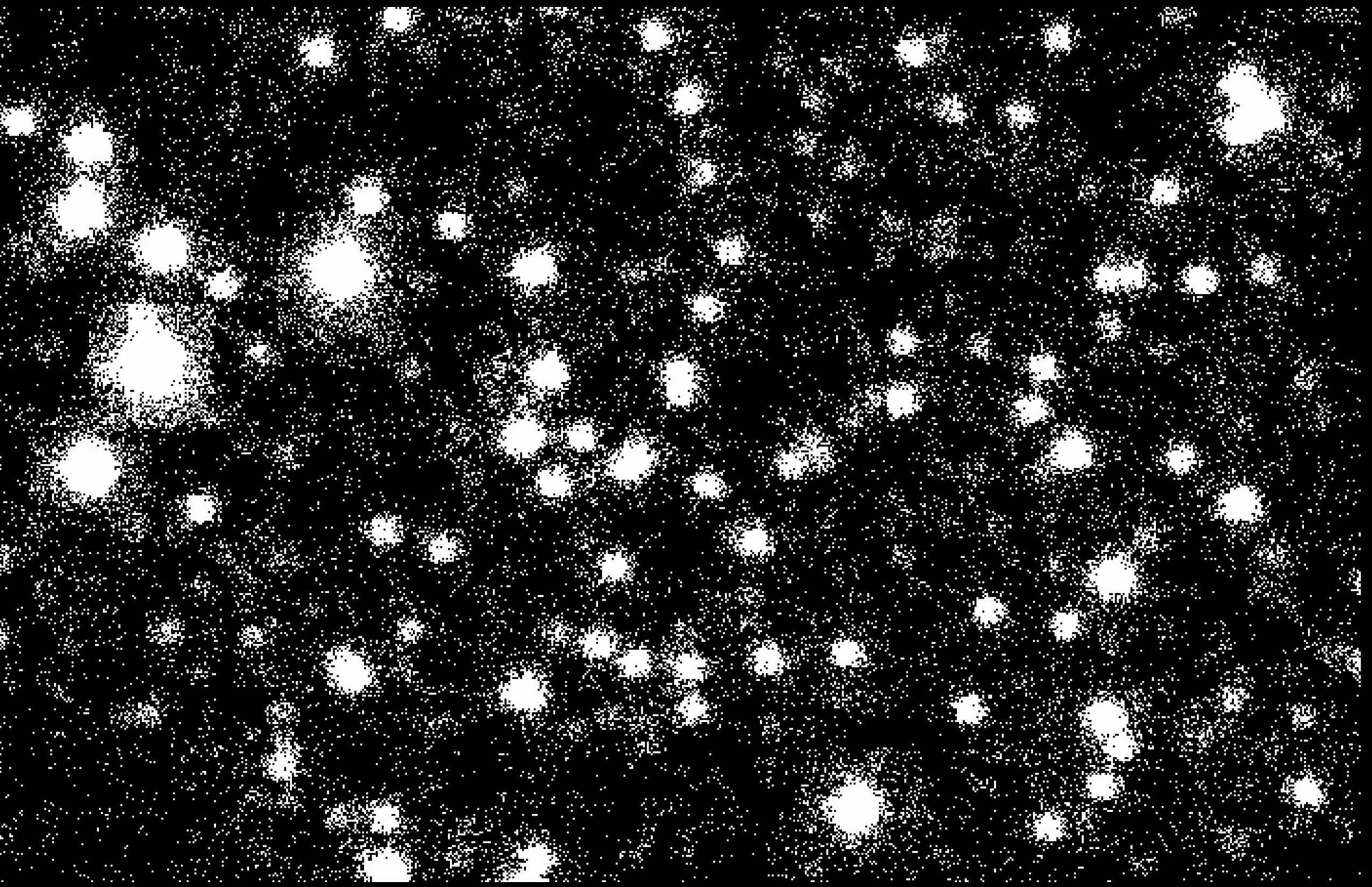
Lynx/X-ray Surveyor NASA mission concept

wwwastro.msfc.nasa.gov/lynx/

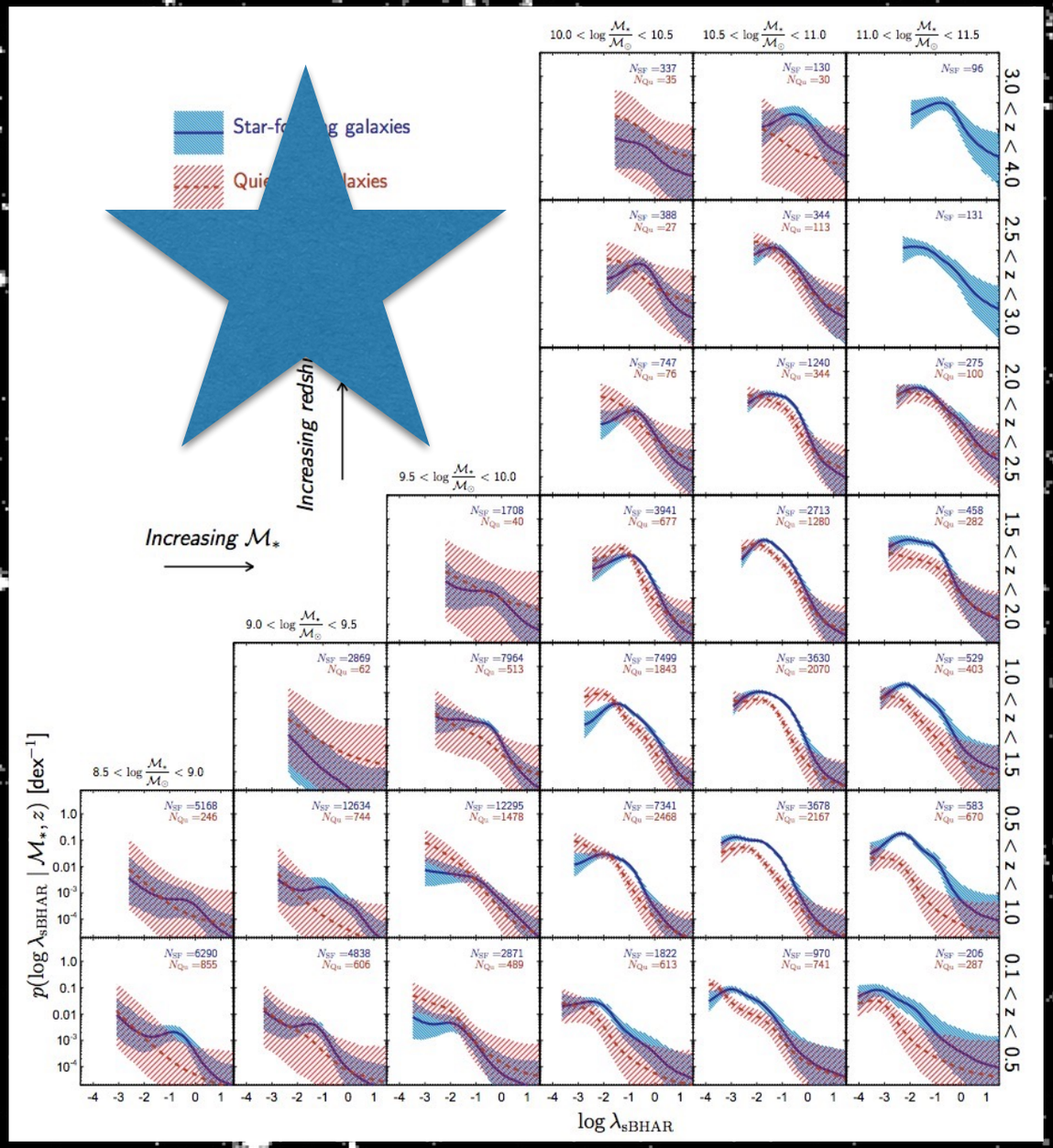
Chandra (7 Ms, Luo et al. 2017)



Athena-like (~5” PSF, 1 Ms)

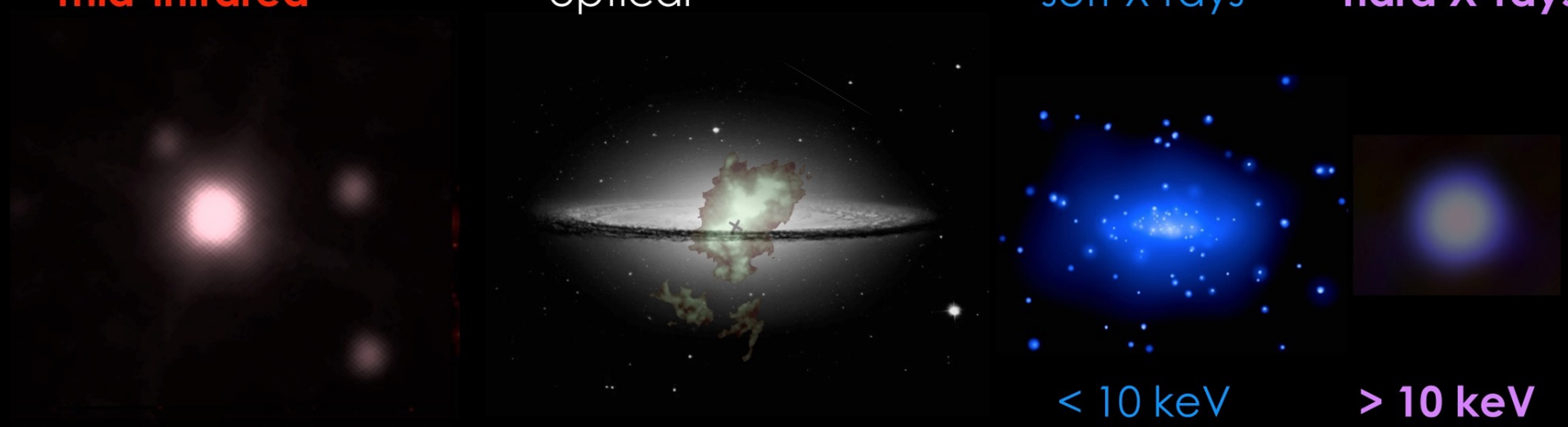


XRS HDXI (~1 Ms)


Star-fo g galaxies
Quie laxies
Increasing redsh
Increasing $\mathcal{M}_*$
$10.0 < \log \frac{\mathcal{M}_*}{\mathcal{M}_\odot} < 10.5$
$10.5 < \log \frac{\mathcal{M}_*}{\mathcal{M}_\odot} < 11.0$
$11.0 < \log \frac{\mathcal{M}_*}{\mathcal{M}_\odot} < 11.5$
$9.5 < \log \frac{\mathcal{M}_*}{\mathcal{M}_\odot} < 10.0$
$9.0 < \log \frac{\mathcal{M}_*}{\mathcal{M}_\odot} < 9.5$
$8.5 < \log \frac{\mathcal{M}_*}{\mathcal{M}_\odot} < 9.0$
$3.0 < z < 4.0$
$2.5 < z < 3.0$
$2.0 < z < 2.5$
$1.5 < z < 2.0$
$1.0 < z < 1.5$
$0.5 < z < 1.0$
$0.1 < z < 0.5$
N_{SF} =337 N_{Qu} =35
N_{SF} =130 N_{Qu} =30
N_{SF} =96
N_{SF} =388 N_{Qu} =27
N_{SF} =344 N_{Qu} =113
N_{SF} =131
N_{SF} =747 N_{Qu} =76
N_{SF} =1240 N_{Qu} =344
N_{SF} =275 N_{Qu} =100
N_{SF} =1708 N_{Qu} =40
N_{SF} =3941 N_{Qu} =677
N_{SF} =2713 N_{Qu} =1280
N_{SF} =458 N_{Qu} =282
N_{SF} =2869 N_{Qu} =62
N_{SF} =7964 N_{Qu} =513
N_{SF} =7499 N_{Qu} =1843
N_{SF} =3630 N_{Qu} =2070
N_{SF} =529 N_{Qu} =403
N_{SF} =5168 N_{Qu} =246
N_{SF} =12634 N_{Qu} =744
N_{SF} =12295 N_{Qu} =1478
N_{SF} =7341 N_{Qu} =2468
N_{SF} =3678 N_{Qu} =2167
N_{SF} =583 N_{Qu} =670
N_{SF} =6290 N_{Qu} =855
N_{SF} =4838 N_{Qu} =606
N_{SF} =2871 N_{Qu} =489
N_{SF} =1822 N_{Qu} =613
N_{SF} =970 N_{Qu} =741
N_{SF} =206 N_{Qu} =287
$p(\log \lambda_{\rm sBHAR} \mid \mathcal{M}_*, z)$ [dex^{-1}]
1.0
0.1
0.01
10^{-3}
10^{-4}
-4 -3 -2 -1 0 1
$\log \lambda_{\rm sBHAR}$

Take-home messages

mid-infrared | optical | soft X-rays | **hard X-rays**



[OIII] line emission

< 10 keV | **> 10 keV**

New statistical methods are allowing us to uncover **low-Eddington** or **low-mass** AGN in **star-forming galaxies** that are missed due to dilution by the host; at some level **all galaxies may be hosting an AGN**

Powerful obscured quasars are **very common and often heavily buried** and we can now reliably identify **hundreds of thousands** of them in the mid-IR with *WISE*

With **improved models** and **even better data** (including the possibility of the ***Lynx*** X-ray mission) the future is bright!