Variability-selected Active Galactic Nuclei in the VST Survey of the COSMOS Field

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in collaboration with

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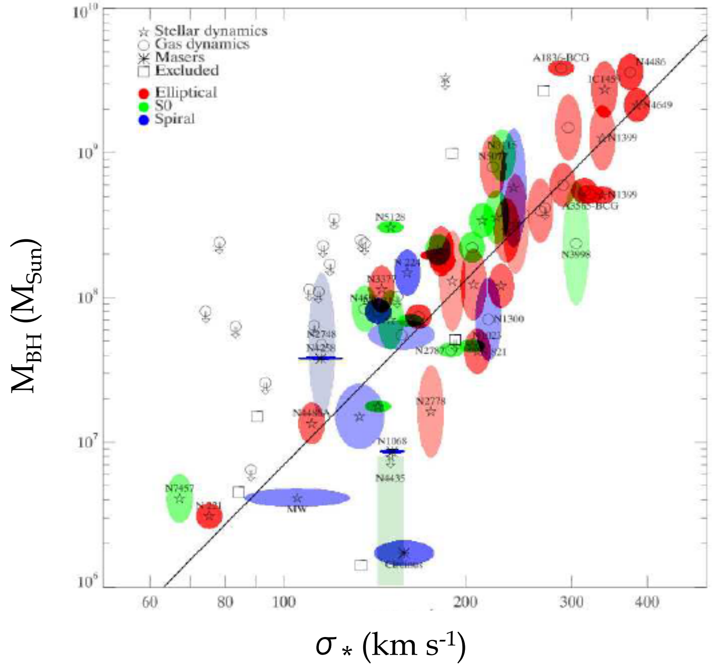
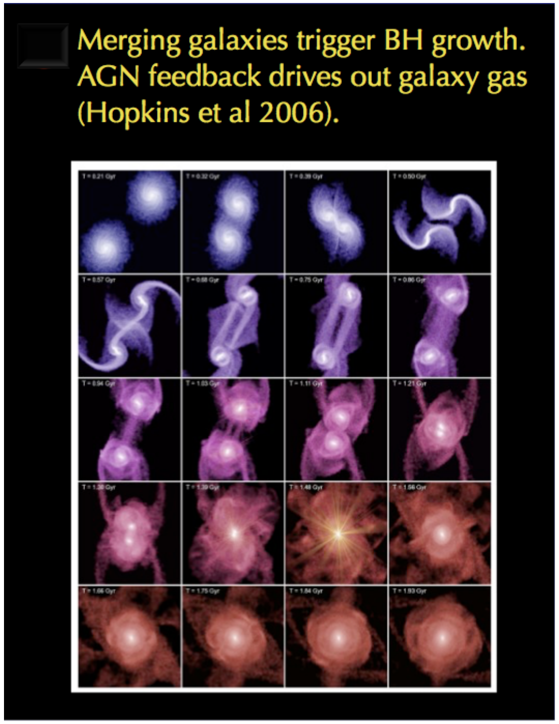
Why AGNs?

- further evidence of the theory of General Relativity in the strong gravity regime
- chance to study the physics of accretion
- evidence of a **feedback** between the central black hole and the host galaxy, after empirical relations linking some properties of the black hole to properties of the galaxy (e.g., $M_{BH} - \sigma_*$, $M_{BH} - L$ relations)

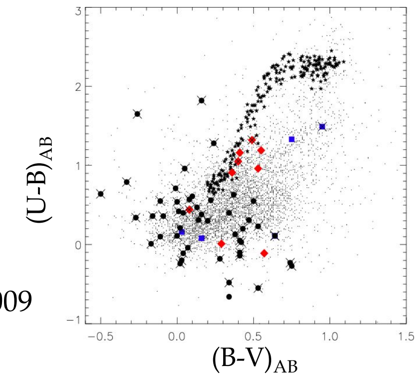


Gültekin+ 2009

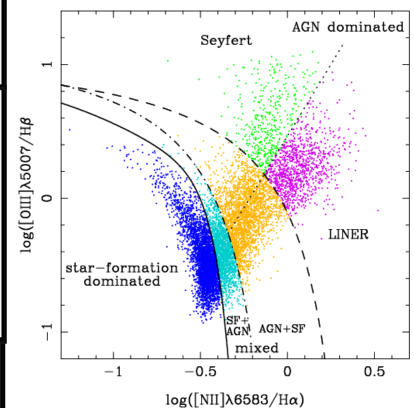


AGN Selection

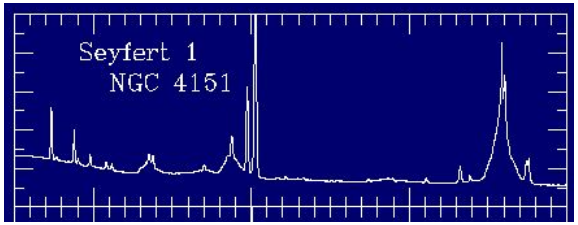
SELECTION TECHNIQUE	PROS	CONS
Spectroscopy	prominent lines, broader than those in the spectra of normal galaxies	time-consuming; not suitable to select AGNs with weak lines
X-rays	high penetrating power; large amplitude, fast variability	high cost, limited field of view
UV/optical/IR colors	different spectral energy distributions with respect to other sources, hence different colors	not suitable where the host galaxy dominates



Boutsia+ 2009



Bamford+ 2008



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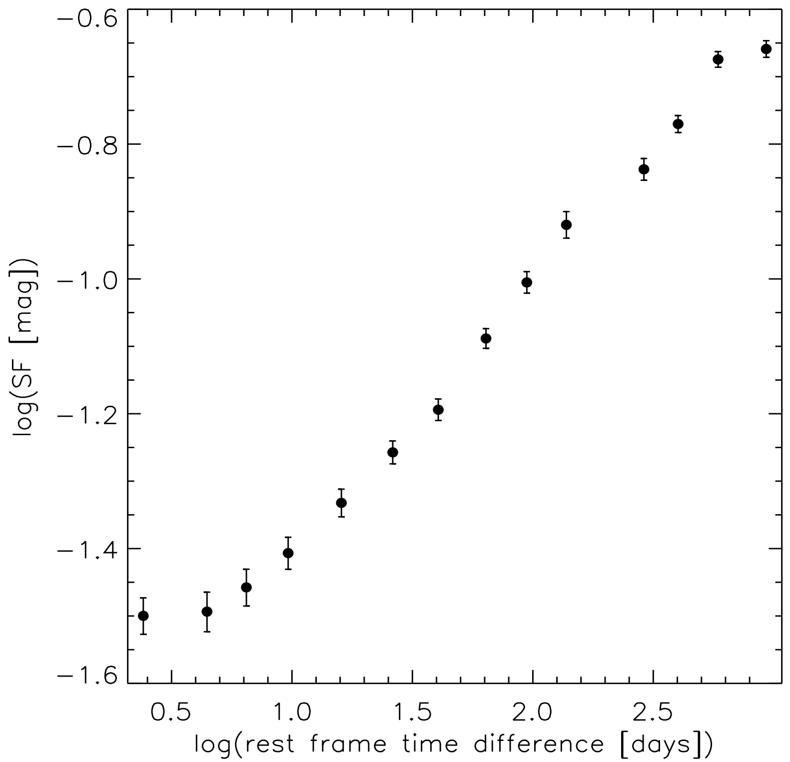
AGN Variability (I)

Origin: instabilities in the accretion disk and changes in the accretion rate and obscuration.

Timescales: from hours to years, depending on the observing waveband. Different extent of variations at different wavelengths.



Optical variability: typical timescales of the order of days, amplitude variations usually of 10^{-2} - 10^{-1} mag.

Widely used to identify unobscured AGNs in multi-epoch surveys.

AGN Variability (II)

Using optical variability to identify AGNs in multi-epoch surveys allows to:

- identify AGNs characterized by a **low X-ray to optical flux ratio** (hence missed by X-ray surveys);
- idetify **low-luminosity AGNs**, because of the anti-correlation between luminosity and variability amplitude (e.g., Barr & Mushotzky 1986, Lawrence and Papadakis 1993, Cristiani et al. 1996);
- **explore large areas** not accessible by current X-ray and deep IR surveys.

The VST-SUDARE Survey

De Cicco et al. 2015; De Cicco et al. in prep.; Falocco et al. 2015; Poulain et al., in prep.

COSMOS field: **1 sq. deg. area**

> 3yr observing baseline, 47 epochs

surveyed by most of space- and ground-based observatories

→ multi-wavelength coverage

CDFS: 4 sq. deg. area

CDFS1: 27 epochs, 5 months

CDFS2: 22 epochs, 4 months

CDFS3: 32 epochs, ~ 2 yr

CDFS4: 30 epochs, 16 months

***r* band exposures: once every 3 days**

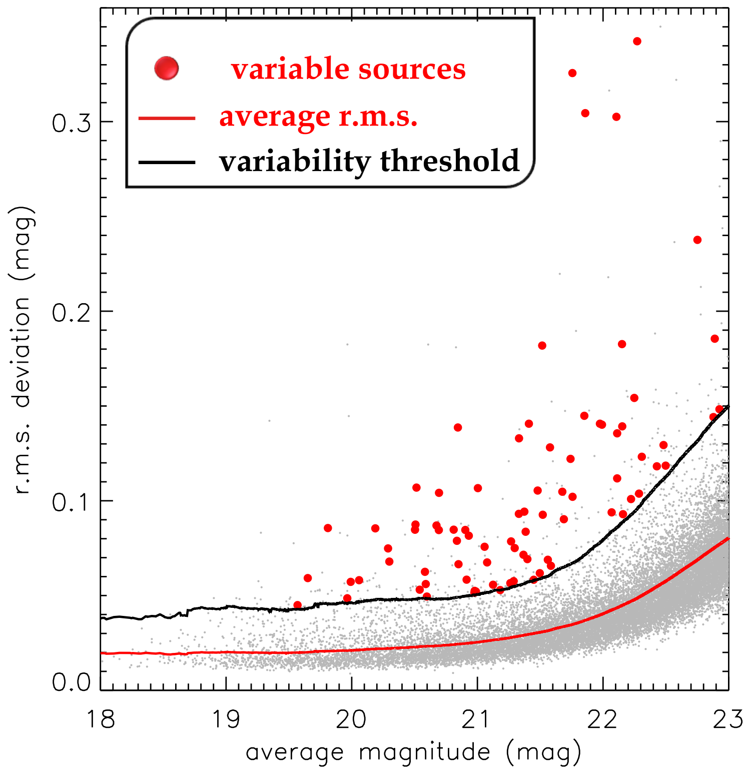
g, *i* band exposures: once every 10 days

Variable Source Selection

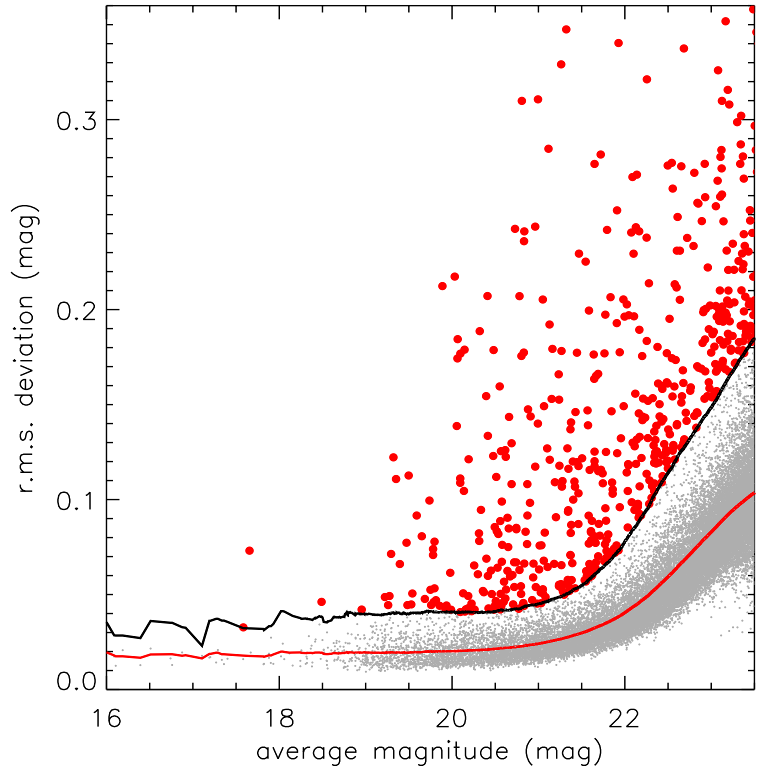
All the sources detected in at least 20% epochs and with < 23 mag constitute our sample.

A source is assumed to be variable if $\sigma \geq <\sigma> + 3 \times rms_{<\sigma>}$.

5 months, 83 AGN candidates



3 yr, 265 AGN candidates



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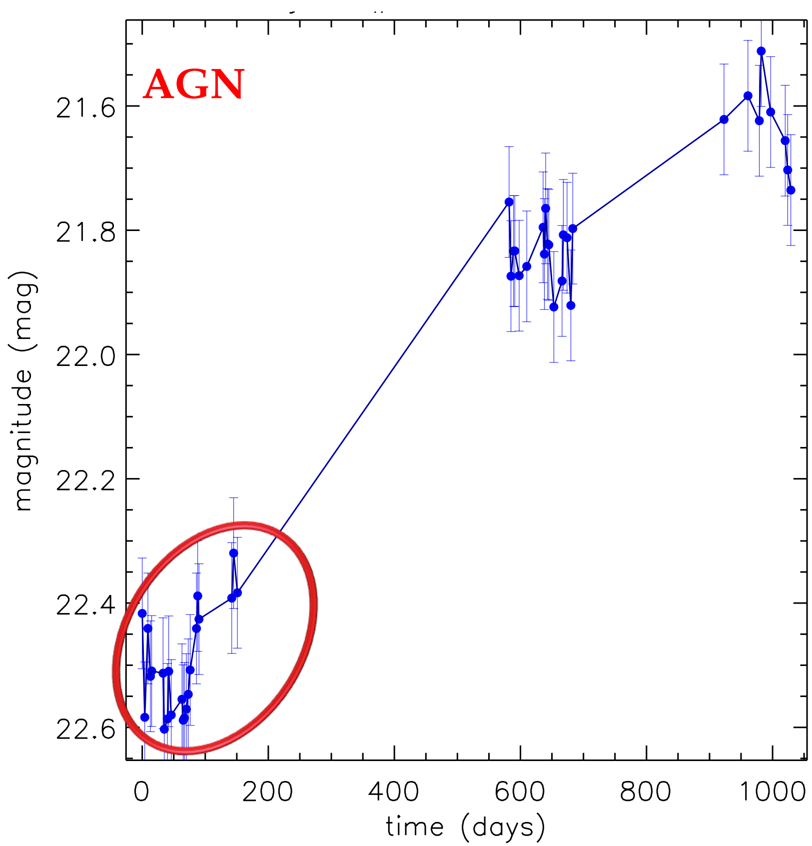
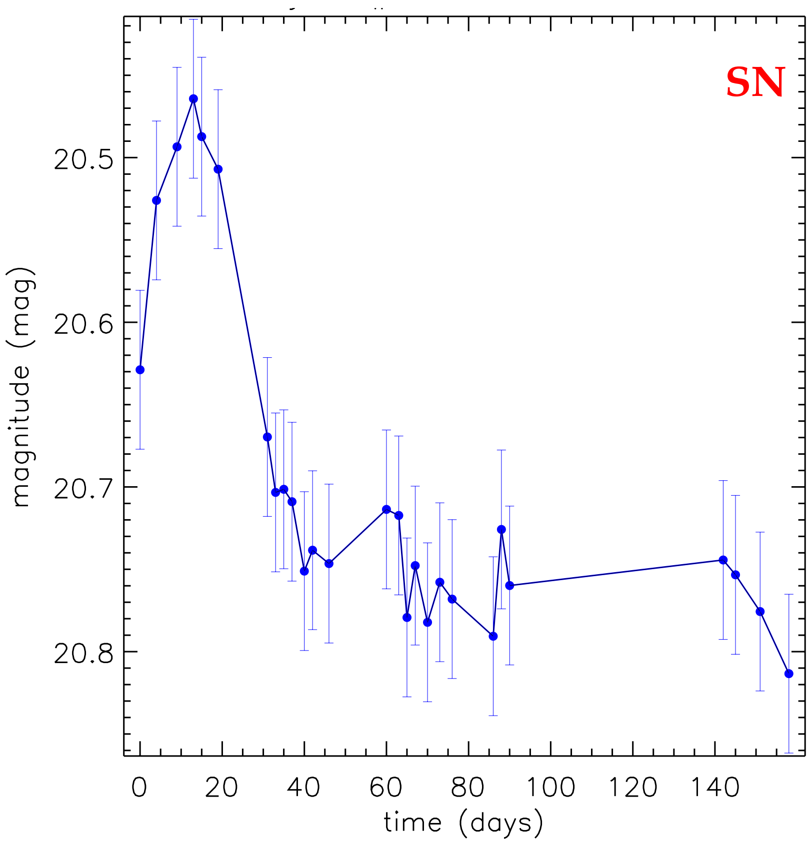
Variable Source Light Curves





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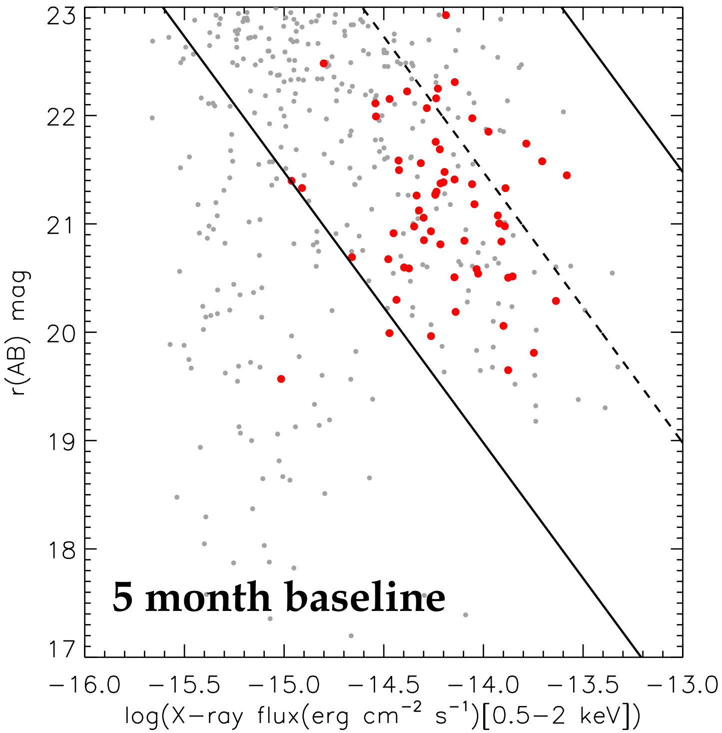
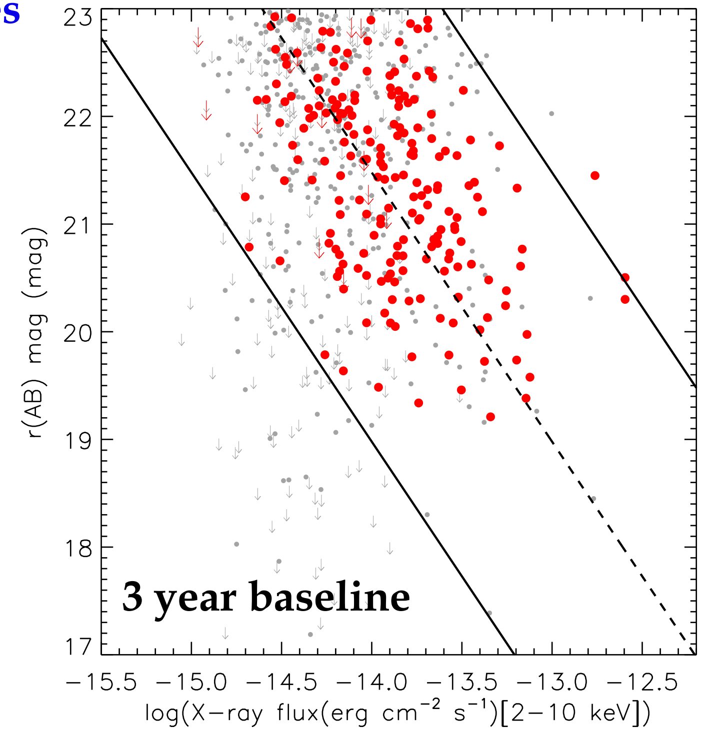
X-ray Properties

78% of the AGN candidates (76% in the 5 month sample) confirmed by their X-ray properties





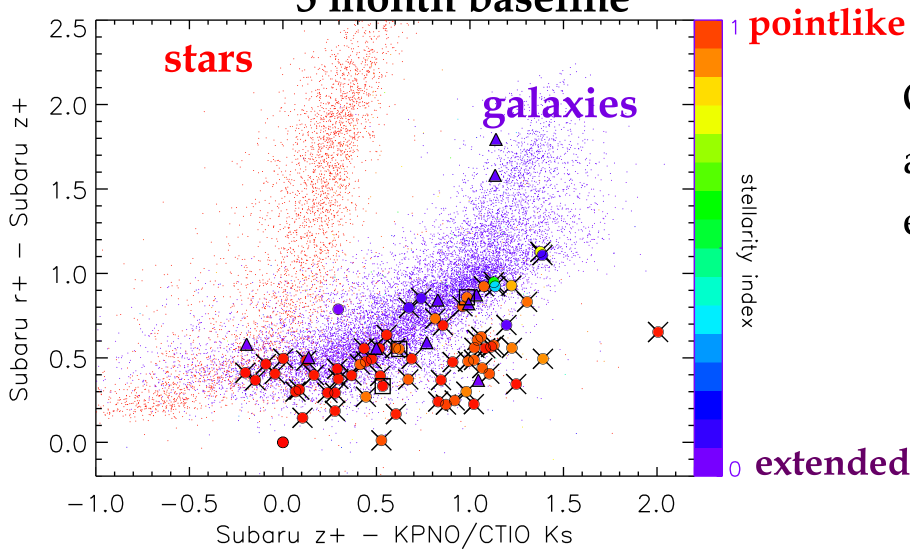
VST AGN candidates with an X-ray counterpart

reference population

$\log_{10}(f_X/f_{opt}) = \pm 1$

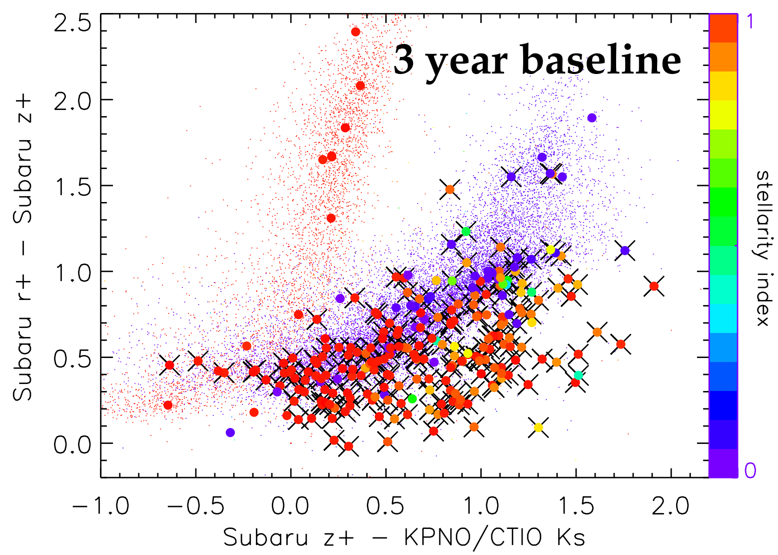
$\log_{10}(f_X/f_{opt}) = 0$

Optical/IR Diagnostic



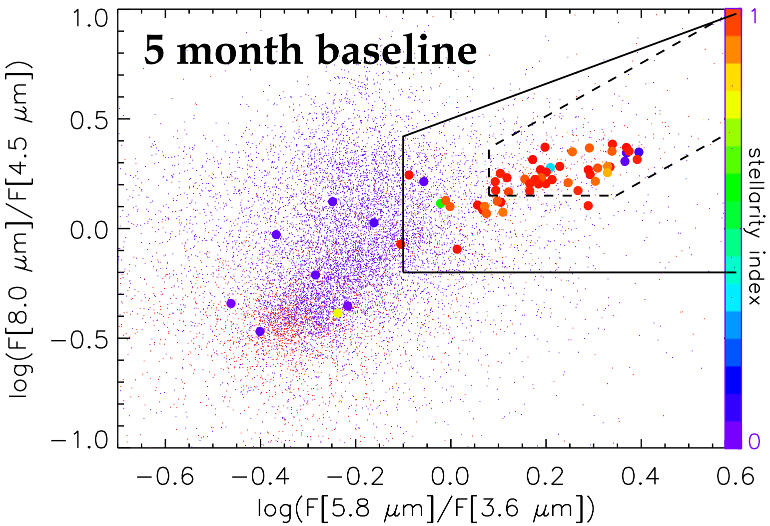
QSO spectral energy distributions are characterized by an excess of emission in the *k* band.

- VST AGN candidates
- reference population
- × confirmed AGNs
- ▲ SNe



65% of the AGN candidates (same as in the 5 month sample) confirmed by their colors

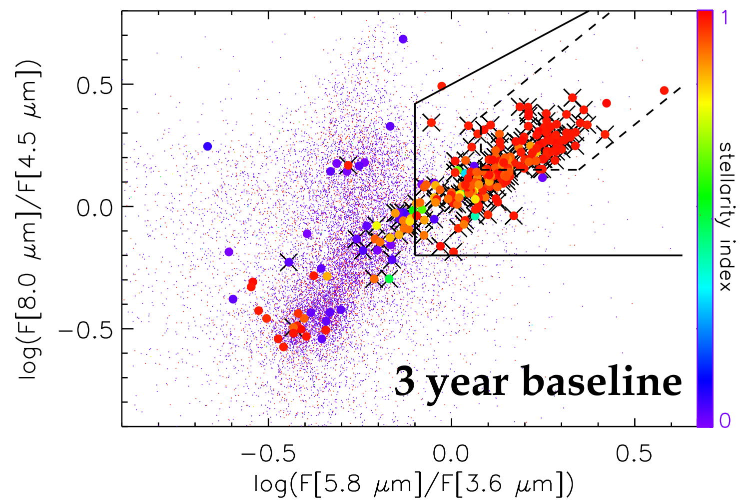
MIR Diagnostic



VST AGN candidates
reference population
confirmed AGNs
SNe

AGN region (Lacy et al. 2007)
AGN region (Donley et al. 2012)

34% of the AGN candidates (60% in the 5 month sample) in the Donley region, 72% (80% in the 5 month sample) in the Lacy region



Some Results

COSMOS, De cicco et al. 2015

5 month baseline

purity of the sample: **81%** (**94%** if we exclude SNe)

completeness with respect to the X-ray counterparts that are confirmed AGNs: **15%**

contamination by SNe: 12%

COSMOS, De cicco et al., in prep.

>3 yr baseline

purity of the sample: > **83%**

completeness with respect to the X-ray counterparts that are confirmed AGNs: **41%**

longer observing baseline

↓

higher completeness

CDFS 1+2, Falocco et al. 2015

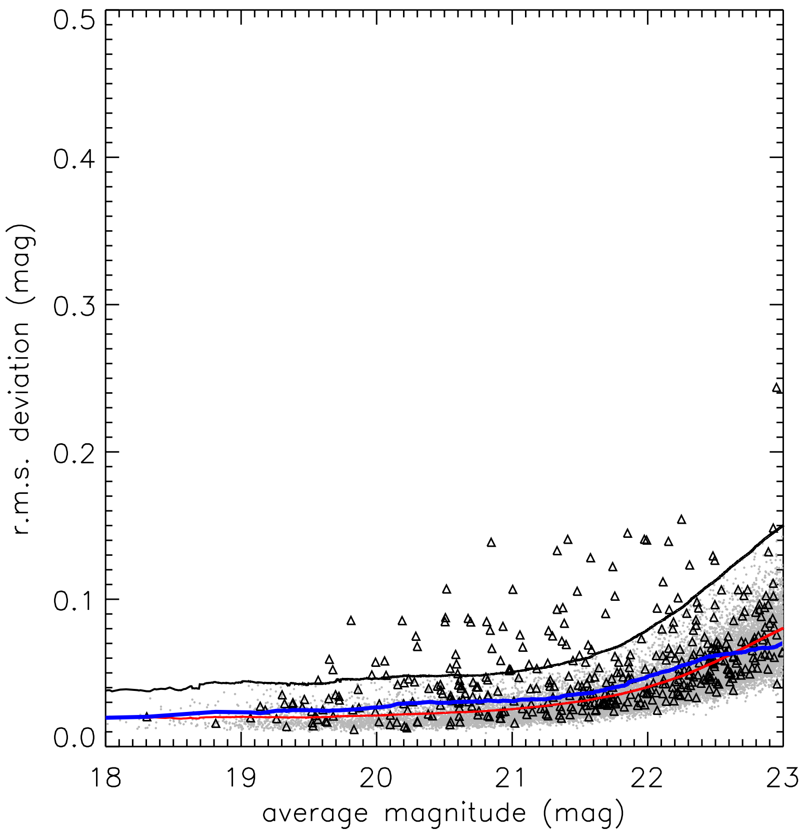
purity of the sample: **58%** (66% if we exclude SNe, **80%** if we consider only sources with diagnostics)

completeness with respect to the sources within the Donley region: **22%**

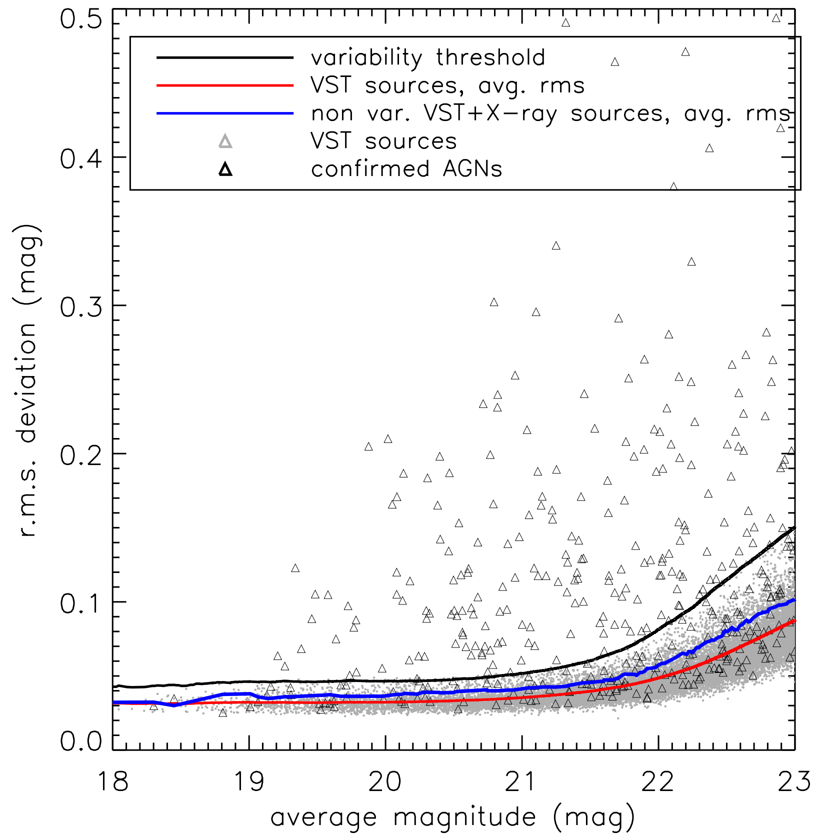
contamination (stars + SNe): **15%**

Optical Variability of X-ray Counterparts

5 month baseline



3 year baseline



15% above threshold

41% above threshold

Structure Function (I)

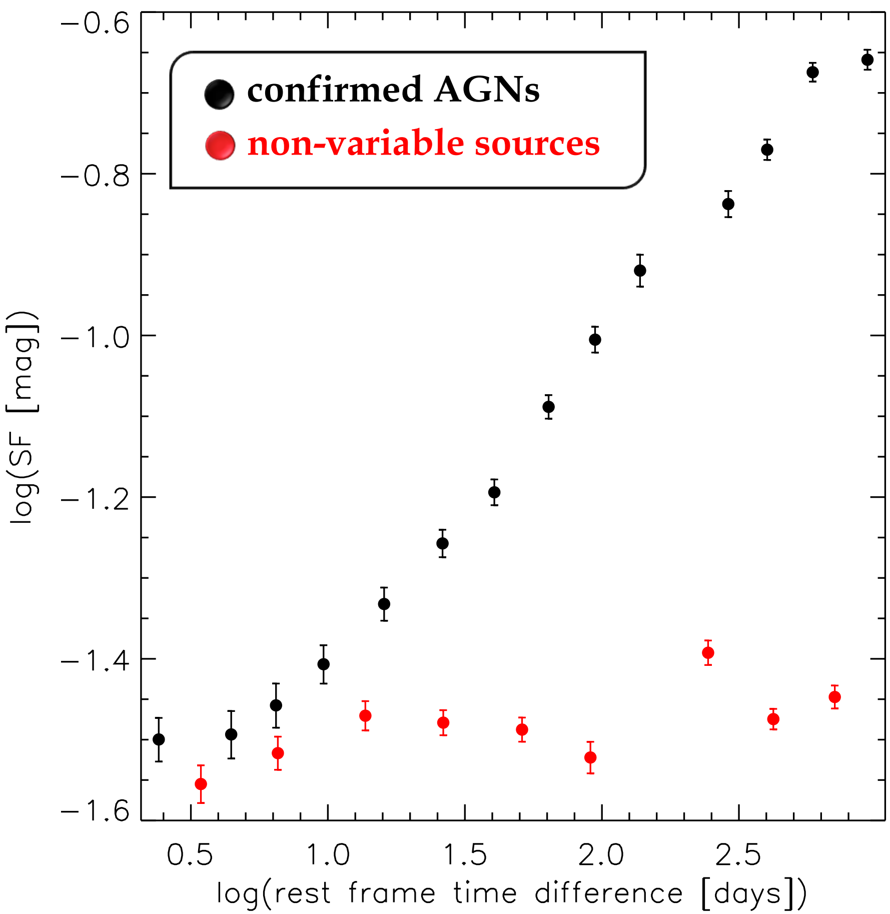
Structure function (SF): describes the time dependence of the variability of a sample of sources.

Several definitions are proposed in the literature (e.g., Simonetti et al. 1985, di Clemente et al. 1996, Graham et al. 2014); basically, the SF **shows the ensamble variability amplitude as a function of the time lag between different epochs**:

$$SF = \langle [\mathrm{mag}(t+\Delta t) - \mathrm{mag}(t)]^2 \rangle$$

Structure Function (II)

$$SF = \sqrt{\frac{\pi}{2}\langle|m(t) - m(t-\tau)|\rangle^2 - \langle\sigma^2\rangle}$$



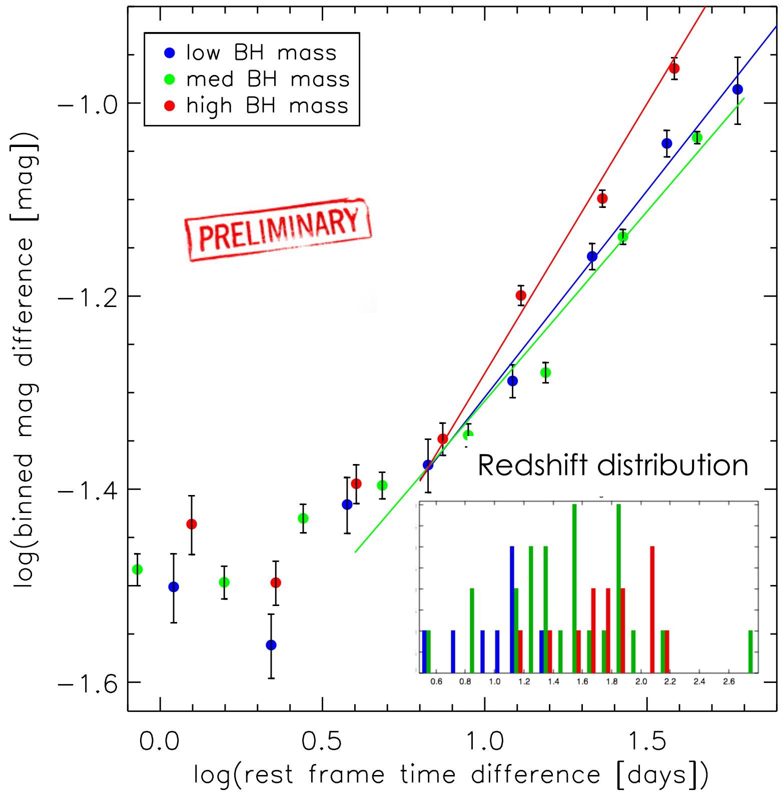
SF slope: 0.40 ± 0.08

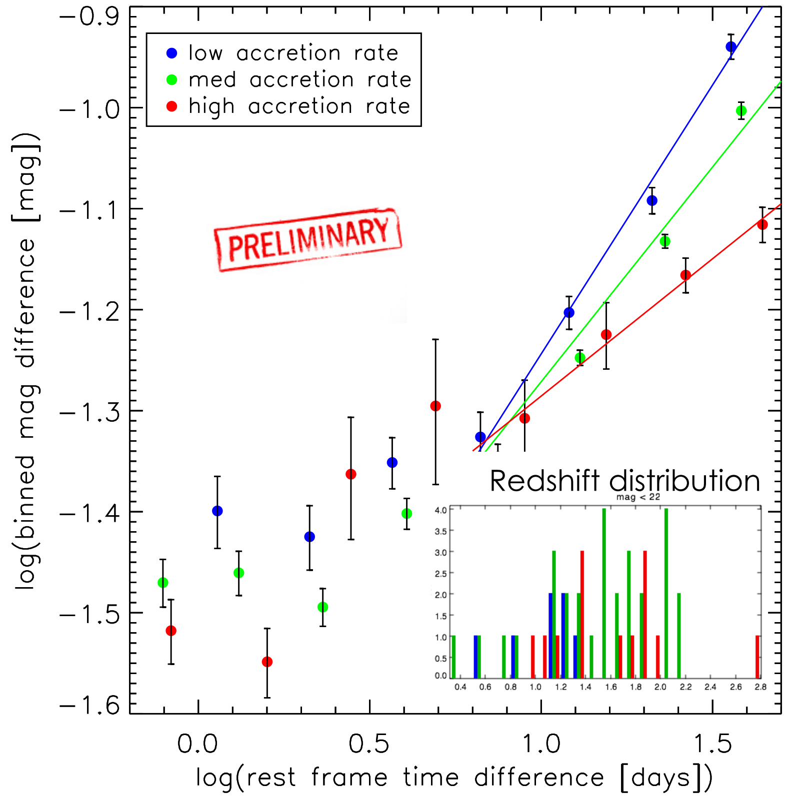
0.3607 ± 0.0075 Bauer+ 2009

0.336 ± 0.033 Vanden Berk+ 2004

0.45 ± 0.02 Schmidt+ 2010

Dependance on Accretion Rate and BH Mass





Conclusions

- Variability is an effective tool to identify (prevalently unobscured) AGNs yielding very pure samples.
- The completeness of the variability-selected samples depends strongly on the temporal baseline. Observations over a few years yield samples that are 40% - 50% complete down to $m_r \sim 23$
- Variability anti-correlates with luminosity and accretion rate, less clear the dependence on mass.
- Testbed for application to current and future wide-field surveys (e.g., LSST, CRTS, etc.).