TIME DOMAIN STUDIES OF ACTIVE GALACTIC NUCLEI: INTRINSIC VARIABILITY AND PROPAGATION EFFECTS

Steve Croft, UC Berkeley

Hayley Bignall, Curtin

Keith Bannister, Talvikki Hovatta, Jun Yi Koay, Joseph Lazio, Jean-Pierre Macquart, Anthony Readhead, Cormac Reynolds and Mark Walker
Advancing Astrophysics with Ye Unaided Eye
Or, Ye Olde Astronomer’s Telegramme

“We request ye photometric & ye spectroscopic follow-up”
(Brahe 1573)
A SNAPSHOT
A SNAPSHOT
SNAPSHOTS

Bicknell+00

Croft+06

Correlation Between Black Hole Mass and Bulge Mass

Croton+06

NASA, ESA, CXC, STScI, NRAO, B. McNamara, L. Birzan and team.
SNAPSHOTS MISS THE ACTION
BLACK HOLE GROWTH

Snacking, Gorging, and Cannibalizing
(Tidal Disruptions, Steady Accretion, and Mergers)

SKA1 Headline Science:
“Strong-field Tests of Gravity with ... Black Holes”
KEY AREAS OF INTEREST
(INTRINSIC)

- Red and white noise variability and QPOs from variations in accretion rate; flares, turbulence, and shocks in disks and jets; transitions between soft and hard states; and other processes near the black hole
- Disk - jet connection
- Constraints on black hole mass (from variability power spectrum break and TDE lightcurves)
- Demographics, radio loudness, and correlation with host properties and environment (can find “buried” sources too)
- Multi-wavelength (cf. VLBI + Fermi; SKA + CTA)
PROPAGATION

Extragalactic source

intergalactic medium between galaxies in the Universe

interstellar medium between the stars in our own Galaxy

interplanetary medium within our Solar system

atmosphere surrounding Earth

Order of magnitude distances

~ Gigapc

~ kilopc

~ 10 cm

~ 0.1 cm

~ 100 km

~ AU

~ 10 cm

~ 0.1 cm

~ 100 km

~ AU

Order of magnitude electron densities
Radio waves are scattered as they propagate through ionized, intervening media with density inhomogeneities. This produces observable effects:

- Intensity Scintillations
- Angular Broadening
- Pulse Broadening

Scattering effects are worse for compact sources such as transients!
TWINKLE, TWINKLE, LITTLE AGN COMPONENT

J. Y. Koay

Mostly intrinsic

Mostly ISS

Steve Croft, UC Berkeley - Advancing Astrophysics with the SKA, 2014 June 10
INTERSTELLAR SCINTILLATION

PKS 1257-326, ATCA, 2011 Jan 15

Flux density (Jy)

16 18 20 22 24

Time (hr UT)

4540 MHz 5564 MHz 8040 MHz 9064 MHz
4668 MHz 5692 MHz 8168 MHz 9192 MHz
4796 MHz 5820 MHz 8296 MHz 9320 MHz
4924 MHz 5948 MHz 8424 MHz 9448 MHz
5052 MHz 6076 MHz 8552 MHz 9576 MHz
5180 MHz 6204 MHz 8680 MHz 9704 MHz
5308 MHz 6332 MHz 8808 MHz 9832 MHz
5436 MHz 6460 MHz 8936 MHz 9960 MHz

H. Bignall
EXTREME SCATTERING EVENTS

0954+658
2695 MHz

8085 MHz

Fiedler+94

Flux Density (Jy)

Year

79 80 81 82 83
KEY AREAS OF INTEREST (EXTRINSIC)

- Nature of local scattering plasma in the ISM
- Probe “dark” lensing structures causing ESE (could be substantial component of the Galaxy by mass)
- Polarization and frequency-dependent structure of jets with μas precision (jet mag. field, particle density, pressure, geometry)
AGN DOMINATE

(even for SKA)
WIDE-FIELD AGN VARIABILITY PATHFINDER
WIDE-FIELD AGN VARIABILITY PATHFINDER
WIDE-FIELD SURVEYS

Croft+14, in prep.
PIGSS ELAIS

RA, DEC, FREQ = 16:12:42.243, 53:48:31.02, 3.03997350E+00 GHz at pixel (621.00, 513.00, 1.00)
Spatial region: 1.1 to 1432.1356
Pixel map image: mos3040-01-01-11.cm (elasni1-0001) Min/max = -0.01334/0.1865 Range = 4×10^-5 to 0.02 JY/BEAM (lin)

PIGSS AGN VARIABILITY

PIGSS AGN VARIABILITY

\[
D_\nu (\tau) = \frac{1}{N_\tau} \sum_{j,k} (S_{\nu,j} - S_{\nu,k})^2
\]

\(\chi^2_{\nu} (3140) = 8.9\)
\(\chi^2_{\nu} (3040) = 9.8\)

\(\chi^2_{\nu} (3140) = 15.1\)
\(\chi^2_{\nu} (3040) = 9.1\)


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PUSHING SENSITIVITY AND AREA

~1 transient per 40 deg$^2$

(models from Frail+12)

Flux Density ($\mu$Jy)

Surface Density (deg$^{-2}$)

Rare

Faint

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INSPIRAL SIGNATURES

- Unlikely to catch brief flares hours before merger
- Could maybe see modulation of emission at earlier times

O’Shaughnessy, Croft & Kaplan in prep.
SKA

- Strawman survey with SKA1-sur or SKA1-mid: entire visible sky every day to an RMS ~100 \( \mu \text{Jy} \) / beam
- AGN still dominate in surveys, even for SKA1 (millions monitored daily with 10\( \sigma \) ~ mJy; cf. NVSS / FIRST)
- 1\% will vary at 25\% on year timescales (Thyagarajan+11); more at lower levels / fluxes / different timescales
- Band 5 of SKA1-mid (and MeerKAT X-band receivers) along with two lower frequency bands, will provide a powerful discriminant between intrinsic and extrinsic variability (especially in conjunction with LSST and high energy)
SKA

- Wide frequency coverage is important
- Synoptic surveys using outer antennas of SKA1-mid
- Fast follow-up to identify ESE lenses
- SKA2 pushes FOV at high frequencies (key for intrinsic variability surveys)
- VLBI capabilities for SKA2 for intrinsic variability and ESE models