Multifrequency studies of active galactic nuclei

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Today:

- Active galactic nuclei
- Multifrequency studies
- Planck satellite data
  - Modelling of AGN
- Low luminosity AGN
  - Narrow-line Seyfert 1 galaxies & other young AGN
Active Galactic Nuclei (AGN)

Supermassive black hole

Plasma jets shooting out matter at almost the speed of light, shocks moving in the jet.

~10% radio-loud
Core of Galaxy NGC 4261

Hubble Space Telescope
Wide Field / Planetary Camera

Ground-Based Optical/Radio Image

HST Image of a Gas and Dust Disk

380 Arc Seconds
88,000 LIGHTYEARS

1.7 Arc Seconds
400 LIGHTYEARS
Observed Properties of Jets and the Angle to the Line of Sight $\theta$
Metsähovi Radio Observatory

Located in Kylmälä, Kirkkonummi

Diameter 13.7 m

Main frequencies 22 and 37 GHz

The Sun, AGNs, Very Long Baseline Interferometry
AGN @radio
Multifrequency observations of AGN

Radio

Optical

Gamma-rays

X-rays

TeV
Multifrequency studies: Radio and gamma-ray flares
Marscher et al., Nature 2008

http://www.bu.edu/blazars/
37 GHz vs. EGRET on CGRO
37 GHz vs. Fermi
Planck satellite

- 14.5.2009 – 23.10.2013
- CMB + foreground sources
- 9 frequencies 30 – 857 GHz
  - Low Frequency Instrument
  - High Frequency Instrument
- 5 to 8 full sky surveys
  - every six months
Planck’s view of Centaurus A

Intensity
30 GHz
44 GHz
70 GHz
100 GHz
143 GHz
217 GHz
353 GHz

Polarisation
Far-infrared
Visible
X-rays

ESA/Herschel/SPIRE/PACS
ESO
ESA/XMM-Newton/EPIC
Planck early results. XV. Spectral energy distributions and radio continuum spectra of northern extragalactic radio sources (Planck Collaboration 2011)
Simultaneous radio spectra: 
\textit{four epochs}

- Planck 30 – 857 GHz single-survey data
- Metsähovi 37 GHz
- RATAN-600 1 – 22 GHz
- OVRO 15 GHz
- UMRAO 4.8, 8, 14.5 GHz
- SMA 230, 345 GHz (five sources)

- 104 sources

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Fitted with a broken power-law model
What kind of radio spectra do we see over 2 years?

- Evolving shocks, achromatic variations, non-variable

Planck ERCSC 2011

Planck single-survey 2016
3C 454.3

Planck spectra
Examples of Planck spectra
Variability models

Marscher & Gear shocked jet model
- Evolving shocks in the strongest outbursts only?

Turbulent extreme multi-zone (TEMZ) model
- Explains essentially both of the above.

Achromatic variations
- This study says yes, some others no.
- Sampling too sparse for catching entire flares.

Geometric models
- Predicts periodicities which are not observed over long time scales.
Our next Planck paper: Spectral energy distributions (SEDs)

- Planck, 9 frequencies, 8 surveys
- Radio
  - Planck, Metsähovi, RATAN-600, OVRO, UMRAO, SMA
  - (VLA, ATCA, Effelsberg, IRAM, APEX, Medicina)
- Optical
  - Tuorla + KVA (La Palma)
- X-rays (+optical+UV)
  - Swift
- Gamma-rays
  - Fermi
Example of SED and radio spectrum from the Planck Early paper
SED modelling

Bonnoli et al. 2010

Tammi et al.
Low luminosity AGN (LLAGN)

- AGN in low luminosity states \((L < 10^{42} \text{ erg s}^{-1})\)
- ADAF models vs. relativistic jets?

- Sgr A*
  - LLAGN characteristics
  - Supermassive black hole
Seyfert galaxies

- ~10% of all galaxies (although this depends on wavelength and luminosity).
- Almost all are spiral galaxies and easily detectable.
- Bright core.
- Bright and broad, variable emission lines caused by high velocities.
...Seyfert galaxies

- Type 1: both broad and narrow lines.
- Type 2: only narrow lines, or weak broad lines.

- Not all Sy2 have a hidden broad line region (HBLR).
  - Non-HBLR do not have a Sy1 core
  - Two types of Sy2!
Narrow-Line Seyfert 1 (NLS1) galaxies

- Seyfert 1 galaxies with narrow BLR lines and extreme X-ray properties.

- Relatively low black hole masses, high accretion rates, possibly young.

- The effect of orientation is unclear.

- Presumed mostly radio-quiet or radio-silent.
NLS1 galaxies at radio: jets!

- ~7% radio-loud, only 2.5% very radio-loud.
  - Very little radio data exists, virtually none at high $f$!

- Very compact radio morphology, steep spectrum.

- Radio jets similar to blazars in a handful of objects.
- A few detected also in gamma-rays.

Richards et al. 2014
Open questions

- Presumed radio-quiet or even silent. They are not. So, which mechanism produces the radio-loudness? Spirals are not supposed to have jets...
- Host galaxy type? Mostly spirals, however, also interacting, peculiar systems.
- Black hole mass?
- ADAF vs. relativistic jets?
- What is the parent population of NLS1 galaxies?
- How does orientation affect the way we see them?
- Where do they belong to in the AGN universe? They are not a homogeneous class.
- Evolution of young AGN? Evolutionary connection between Type 1 and 2? Mergers or secular evolution?
- ...

Confusing results ?!

- We do not have enough (simultaneous) data.

- How to proceed?
  - See what you get with what you have.
  - Get more data.
The Metsähovi NLS1 "pilot survey"

- 37 GHz observations to probe the detection rate and the variability of NLS1 galaxies at high radio frequencies.
  - ~160 sources
  - At least 3 observations separated by a few months.

- First results accepted for publication in *Astronomy & Astrophysics* (Lähteenmäki et al. 2017)
  - Metsähovi, Planck, RATAN-600, and OVRO data for approx. 80 sources.
  - Multifrequency data from literature.
Main results

- Detection rate ~19% at 37 GHz. Some sources detected only once (variability!).
- Detections of radio-silent NLS1 galaxies.
- Average synchrotron peak frequency is approx. 13.2 which is exactly the same as for a sample of bright blazars (Planck Collaboration XV 2011).
Light curves
Radio spectra
Spectral variability

![Graph showing spectral variability with different markers for 2009 November, 2011 May, 2013 November, and 2014 October. The graph plots Flux density [Jy] against Frequency [GHz].]
Large-scale environments of NLS1 galaxies using SDSS LRG and BOSS surveys
SDSS LRG: NLS1s vs. others

+ BOSS density field
Current and future work on NLS1 galaxies

- Radio-silent NLS1 galaxies detected at 37 GHz ?!
- VLBI 1.7 GHz and NOT NIR observations
  - Two samples: detected (flat spectrum) vs. non-detected (steep spectrum).
  - Morphology: jets vs. no jets, spirals vs. interacting...
- Large-scale environments of other young AGN?
  - NLS1, GPS, CSS, ...
- Extensive statistical studies
  - Correlations, PCA, SOM, ...

**GOALS:**
1. Formation and evolution of relativistic jets.
2. Evolution (and unification?) of young AGN.