Inspiraling, Binary, and Recoiling Black Holes in Nearby Galaxies

Jim Condon (NRAO), Jeremy Darling (Colorado),
Yuri Kovalev (Astro Space Center), & Leonid Petrov (NASA)

Atacama Large Millimeter/submillimeter Array
Expanded Very Large Array
Robert C. Byrd Green Bank Telescope
Very Long Baseline Array

NRAO

Method and science goals

Make a high-resolution 8.6 GHz VLBA search for off-nuclear and binary SMBHs in a complete sample of ~10^3 nearby (<D_A> ~ 200 Mpc) massive galaxy bulges to:

(1) discover off-nuclear inspiraling SMBHs predicted by the "merger tree" theory for massive galaxy evolution

(2) resolve "stalled" binary SMBHs in tight (d ~ 10 pc) orbits

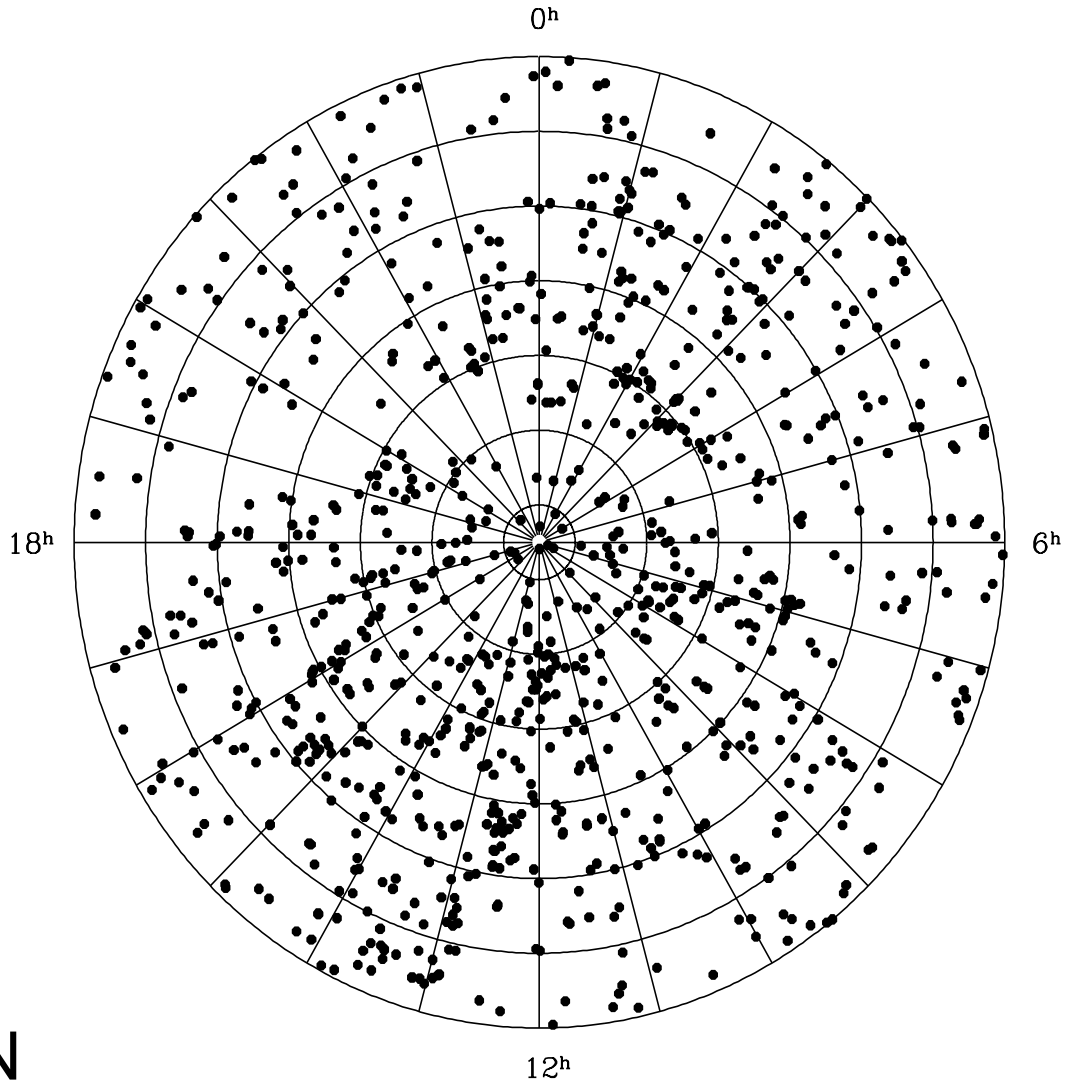
(3) discover off-nuclear recoiling SMBHs kicked out by the strong anisotropic gravitational radiation sought by LISA and NANOgrav

(4) discover currently active nearby SMBHs (no dust bias)

Nearby galaxy sample

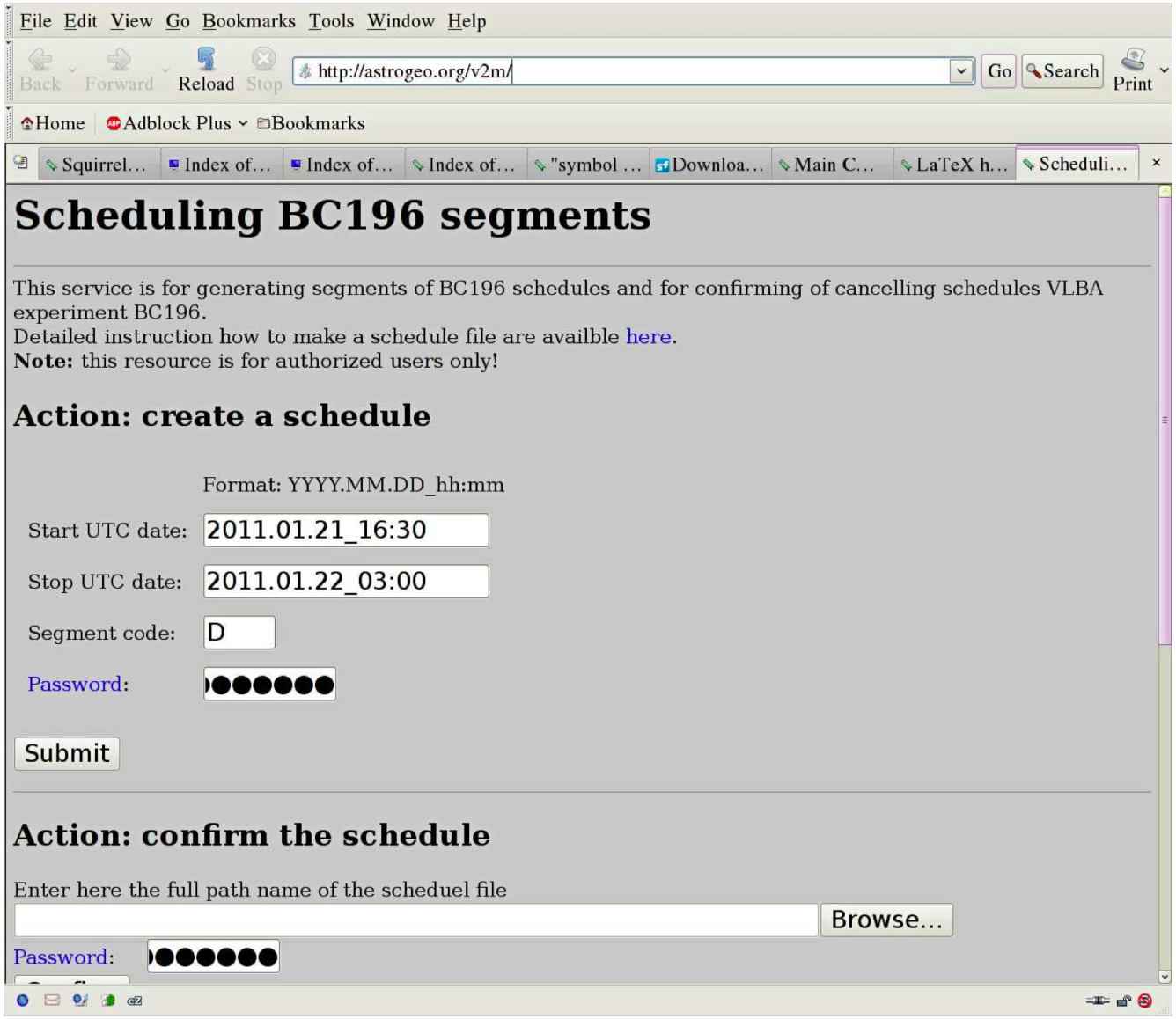
2MASS K_{20fe} < 12.25
NVSS $S_{1.4}$ > 100 mJy
δ ≥ −40°, |b| ≥ 5°
N = 923 galaxies

$\langle D_A \rangle$ ~ 200 Mpc so
1 mas ~ 1 pc
$\langle L_{1.4} \rangle$ ~ 10^{24} W Hz^{-1}
> 90% are radio-loud AGN



δ ≥ −40°, |b| ≥ 5°

Automated Dynamic Scheduling



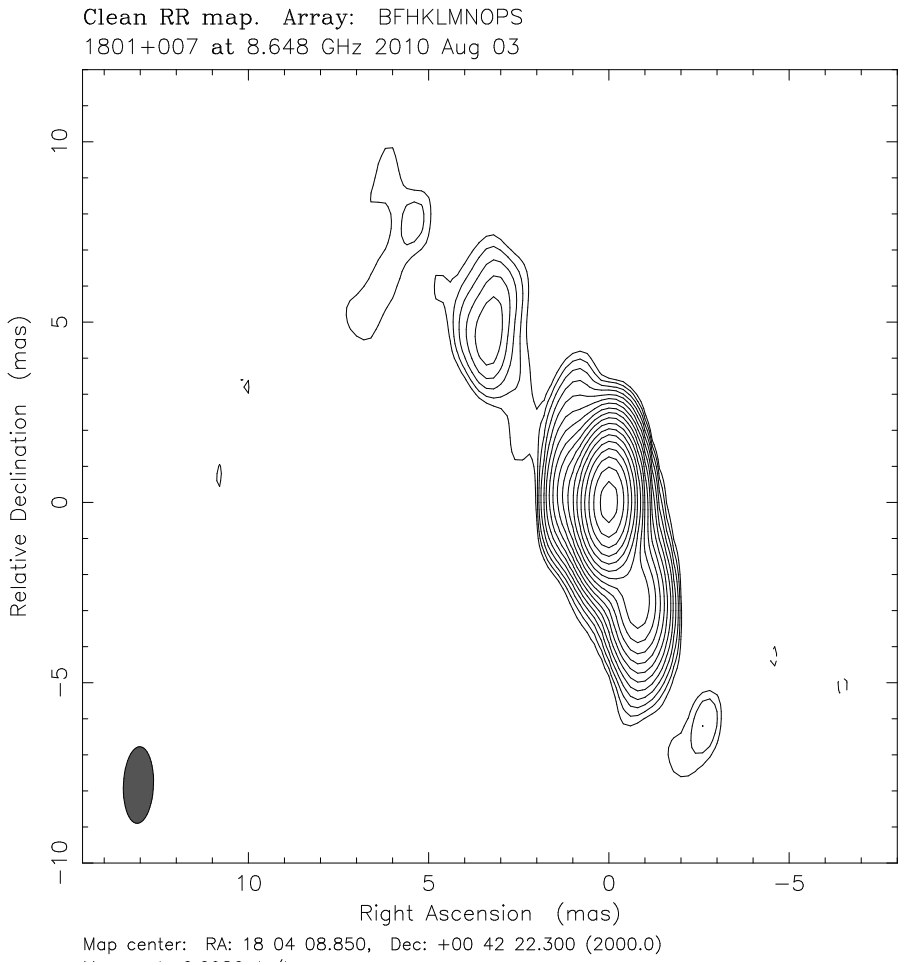
Automated Analysis

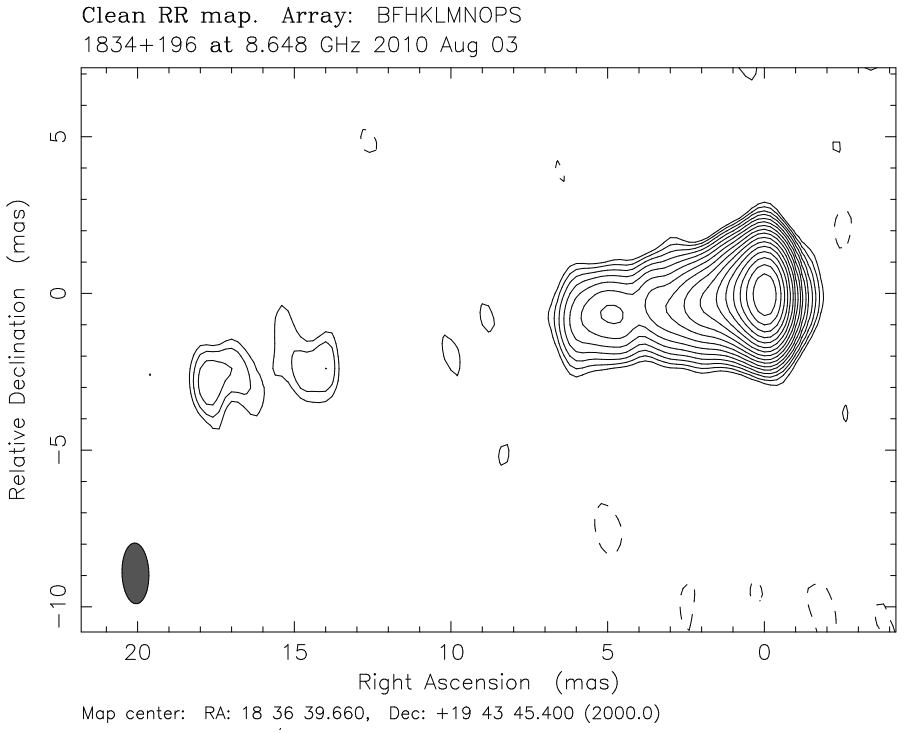
- Fringe-fitting: dedicated AIPS-independent software $\mathcal{PIMA}$. Results are exported to
  1. Astrometry software VTD/post-Solve for source position estimation;
  2. Program flux_est for coarse flux density estimation;
  3. DIFMAP for imaging.
- Quality control and interactive astrometric analysis. Second run of re-fringing outliers.
- Coarse flux density estimation.
- Global astrometric analysis using all astro/geo VLBI data since 1980 through present.
- Update of the project web page.

Typical cost for a 6^h segment: 20^h CPU time and 0.5^h human time.

X-band Images

5σ ~ 6 mJy in 8 min
Δα, Δδ ~ 1-3 mas
Θ ~ mas
DR ~ 100:1





First results