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Tracking the Moving Optical Photocenters of Active Galaxies: Binary Black Holes, Accretion Disks, and Relativistic Jets

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Understanding the fundamental AGN power source

- Accretion onto massive black holes fuels the energetic AGN phenomena-- but how does it work?
  - How are galaxy mergers related to the AGN phenomenon?
  - Are binary black holes (resulting from mergers?) common?
  - What are the sizes and geometric relations between the components of the 'core' region: jets, accretion disk, hot corona ?
  - How much do viewing direction and observational selections affect the picture?

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Three AGN questions which SIM will address:

1. Does the most compact non-thermal optical emission from an AGN come from an accretion disk or from a relativistic jet?
2. Do the cores of galaxies harbor binary supermassive black holes remaining from galaxy mergers ?
3. Does the separation of the radio core and optical photocenter of the quasars used for the reference frame tie change on the timescales of their photometric variability, or is the separation stable ?

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Key Project Strategy

The AGN/Reference Frame *SIM Key Projects* have 3% of SIM observing time

- Monthly observations should yield results within the first year of operation
- Observe several target-rich 'permatiles', not a statistical sample
- Validate use of AGNs as reference frame objects

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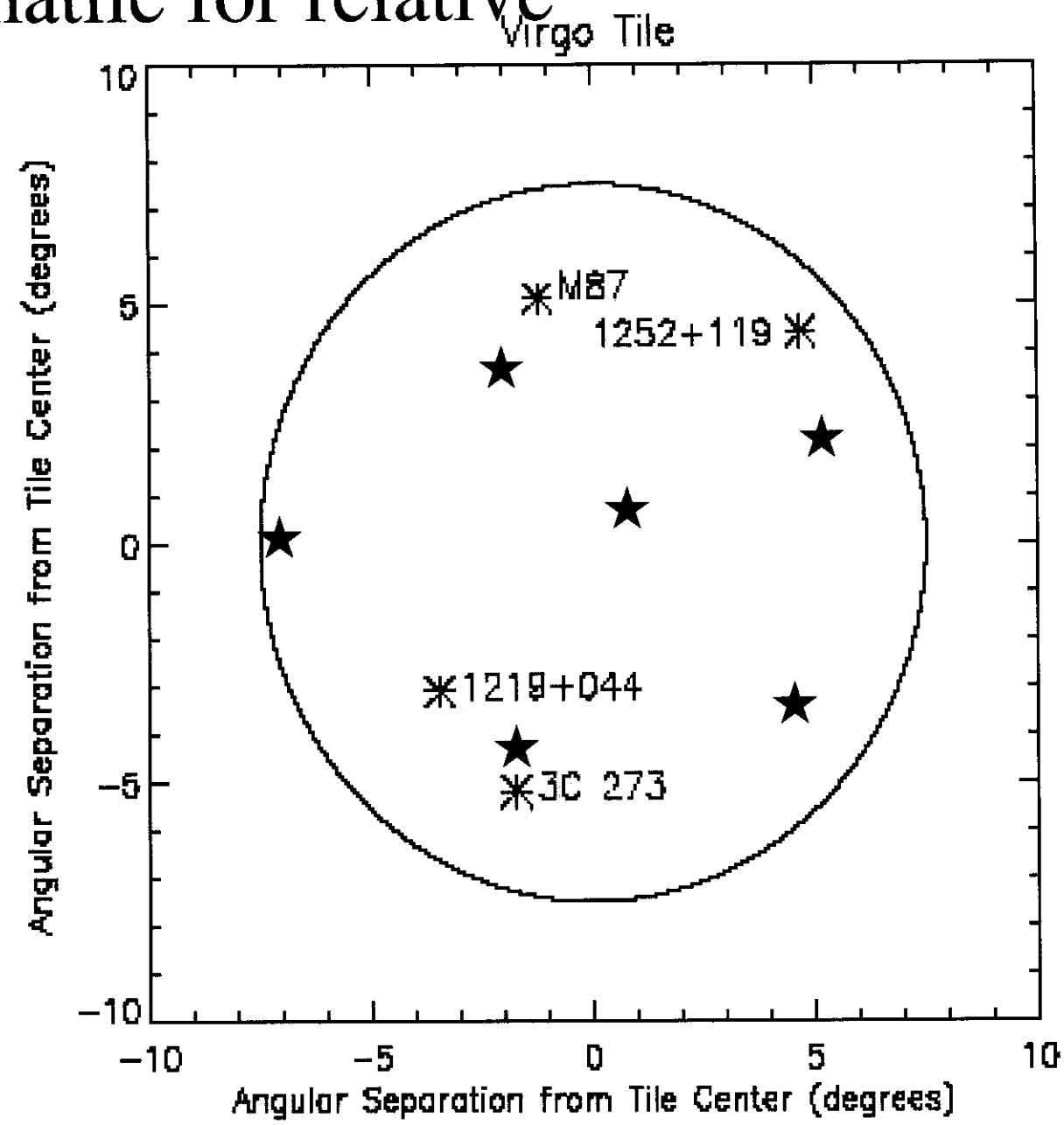
SIM will make 3 kinds of AGN measurements

- Relative astrometry between quasars and reference stars or other quasars
  - Differential wide-angle observing at levels of ~ few μas (depending on magnitude)
  - select permatiles that contain *both* "interesting" and potentially "stable" AGN, then measure the changes
- Global astrometry: motion of quasars relative to global reference frame
  - Frame accuracy is ~ 4 μas
  - Detect quasar motions at about this level
  - Statistical properties of ~50 quasars as part of the grid
- Astrometric shifts as a function of wavelength
  - Directly provide structure information on scales of 10s of μas

Sample permatile for relative astrometry

- Select tile centers for objects of interest
- Virgo permatile contains:
  - M87
  - 3C 273
  - Two ICRF quasars
  - 6 - 8 grid stars



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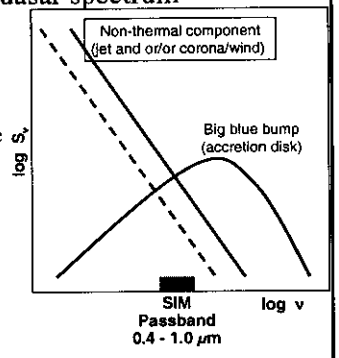
Representative quasar spectrum

- SIM observes in the optical band
- Strongly 'concave' spectrum indicates transition between components



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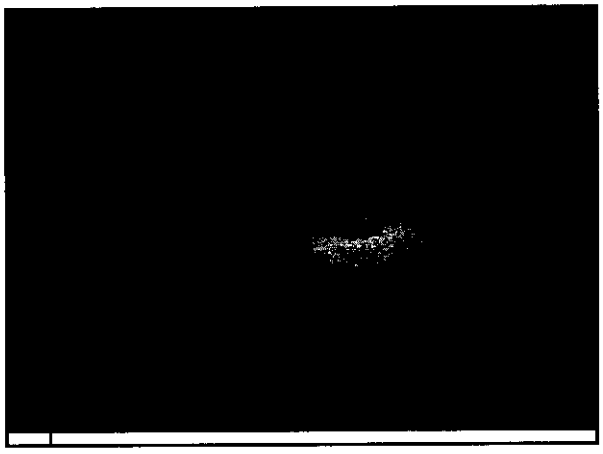
Estimating the emission region size

- Accretion disks are small
  - ~ 160 μas (at 15 Mpc - M87)
  - ~ 2 μas (at 3C345 - z = 0.6)
- Hot corona region is also small
  - ~ 70 R_s corresponds to ~ 1 μas at z = 0.6
- News: Seyfert nuclei of NGC 4151 and NGC 1068 detected by Keck Interferometer and VLTI, respectively, (Swain et al. 2003 ApJ Letters 596, 163; ESO press release 2003)
  - Implication: *AGN nuclei are indeed compact enough to get fringes on with SIM*
- News: Optical flare within the jet of M87 outshone the nucleus! Observed with HST; timescale ~ 4 weeks, variability size scale corresponds to 30 μas (Perlman et al. 2003 ApJ Letters)
  - Implication: *Shocks/knots in jet may be bright and compact enough to observe with SIM*



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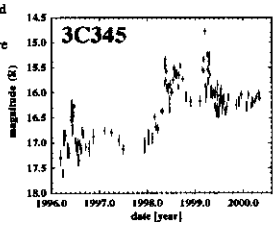
Reference Frame Tie - two requirements

(1) SIM needs a *non-rotating frame* (for Galactic structure studies)
- We don't *have to* select radio-loud quasars
- Maybe radio-quiet quasars are more suitable?

(2) Need to reference to the ICRF
- internationally recognized
- Need radio and optically loud quasars to tie SIM to the ICRF

Could pick two different quasar samples:
- *radio-loud*
- *radio-quiet*
  - not yet a solved problem



- Probably a poor choice for reference frame tie object !

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Overview of Preparatory Science Work 2004-2006

1. Quasar Radio Stability
   Measure separations of radio quasar groups within 15° permatiles (4 permatiles, at least 20 quasars per year)
2. Target Choice and Development of Observing Strategy
   Investigate how many quasar groups, number of radio stars, brightness of targets, effects of brightness varying during measurements, "crowded and complex field" simulations
3. Optical Monitoring of Photometric Variability
   Compact radio quasars vary by up to 5 magnitudes on timescales of months/years. Monitor selected target candidates at ground-based optical observatories to get good historical database.
4. Keck Interferometry
   Note that KI and VLTI groups detected their first AGNs in 2003; we anticipate that quasar detections (13th magnitude and fainter) should be possible in 2005

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Accomplishments this year (1 of 2)

- Conducted first set of VLBA phase referencing experiments on selected AGN to see if the cores are moving with respect to nearby ICRF sources (joint proposal with Johnston, Fey et al. group)
  - 2 experiments, data analysis in progress
- Began to evaluate historical optical variability of ICRF and astrophysically interesting AGN to establish timescale and magnitude of variability
  - Analysis of microvariability results in literature
  - Overview of active optical monitoring programs for possible collaboration
- Advertised for postdoc

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Accomplishments this year (2 of 2)

- Using SIMsim, verified that predicted ~14 μas differential wide angle performance of SIM can be achieved on *targets of 13th magnitude with a single look*
- Produced samples of potential targets: radio-loud and radio-quiet quasars matched in redshift and (probably) in black hole mass
- Published papers describing Key Project and technique of using differential-colors to determine locaion of optical non-thermal jet emission
  - Wehrle et al. 2002 SPIE
  - Jones et al. 2003 New Astronomy Reviews, 47, 681.

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Next Year's Work

- Analyze VLBA data; propose and conduct additional experiments to address question of relative stability of radio photocenters within selected permatiles
- Quantify how brightness and structure in optical quasars will affect SIM measurements ("crowded and complex field") for simple model structures
- Work on AGN target choices, also exploring which radio stars should be included for reference frame tie (coordinating with Johnston et al.
- Analyze performance of SIM using differential color phase
- Use PTI to develop team expertise in ground-based optical interferometers
- Our postdoc will start in early 2004 (top candidate identified and contacted)

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Summary

- We have started the long-term monitoring of potential SIM targets to quantify the motion of radio photocenters
- We have characterized optical monitoring and analysis programs
- Our collaboration with Ken Johnston's Key Project team is underway
- Our top postdoc candidate has been contacted
- The addition of a postdoc to devote concentrated attention to the Key Project and the allocated funding to support the involvement of the co-investigators enable our Key Project to get up and running.