# The Accretion Disk Structures Black Hole Masses and Cosmic Distances

The New Radio Universe

*Lincoln Greenhill (Harvard-Smithsonian CfA)*

- What do we know about accretion disk structure at $R < 1$ pc?
- What do disks tell us about BHs and AGN?
- What do disks have to do with distances?

## Accretion Disks in Seyferts

What has been seen (by "conventional means")?

- Images of kpc circumnuclear rings
- Images of disks (tori?) at $R$=100 pc
- Spectra of ionized gas @ 3-10 $R_{Sch}$

What is missing from this list?

- *Images* of structures firmly within $R_g$, the SMBH sphere of influence, $R < 1$ pc. *(Regions for which $A_V$= 100s or 1000s)*

## Investigating sub-pc Disks

The goal: *actual images*

The means:

- X-ray irradiation heats gas
- Dense regions self-shield, molecules form
- In trace $H_2O$, heating stimulates MASER emission

*…and as seen time and again…*

- Masers inspire radio astronomers to pursue VLBI

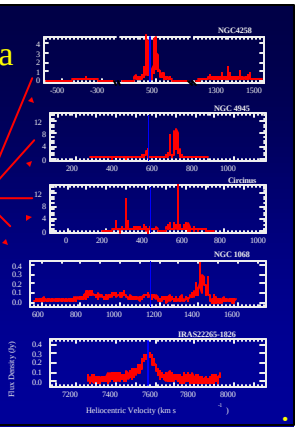
## $H_2O$ Maser Precis

- Particular conditions required
  - Dense ($10^8$ - $10^{10}$ cm$^{-3}$)
  - Warm (300 - 800 K)
  - Quiescent ($\Delta v \sim \Delta v_D$)
- Exotic sounding but pedestrian in fact
- Masers trace "hotspots" in underlying structures
  - Compact ($\theta < 1$ mas)
  - High surface brightness ($T_B \sim 10^7$ - $10^{15}$ K)
  - Yield $\theta_x$, $\theta_y$, $V_{los}$, $\dot{\theta}_x$, $\dot{\theta}_y$, d[$V_{los}$]/d[los]

## What do the spectra look like?

The most interesting show (symmetrically) offset high-velocity lines

This is what fore-warns of a disk, approaching & receding material.

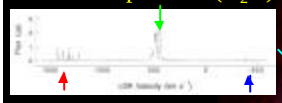



## What do the disks look like?

- Warped
- Thin
- Keplerian - or nearly so
- Aligned w/ outflows - marking SMBH axes
- In the way...
  - Obscuring the SMBHs
  - Channeling outflows

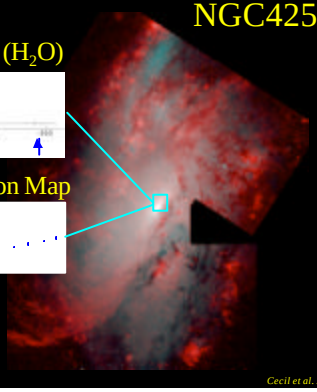
## NGC4258

Emission Spectrum ($H_2O$)



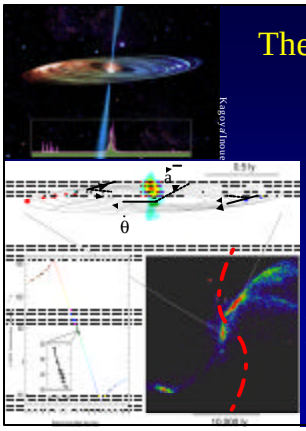
Archetypal Emission Map

What is this?



Cecil et al. 2000

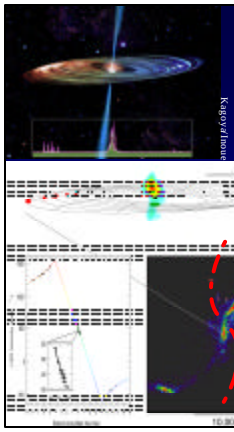
## The NGC4258 Disk



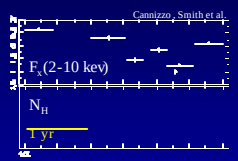
- Warped (a few °)
- Thin (< 1%)
- Aligned (a few °)
- Indicator of mass

Review

Accretion Disk & Black hole mass
*Miyoshi et al. 95*
Jet @ 4000$R_s$: *Herrnstein et al. 97*
Accelerations: *Nakai et al. 95*
*Greenhill et al. 95*
*Bragg et al. 00*
Distance±7%: *Herrnstein et al. 99*



- Where is the obscurer?
- No torus known ($R \gg R_{disk}$)
- Yet C.E. is just $0.1R_{in}$ above the disk



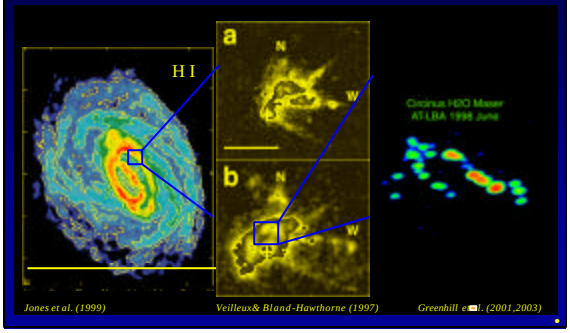

XTE monitoring (see also Maloney 1999; Reynolds et al. 2000)

- $\tau_{disk} \sim \tau_{obscuration}$

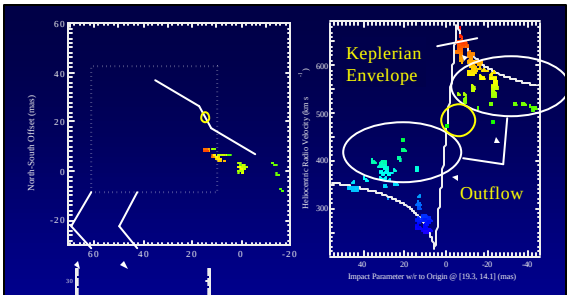
Warped accretion disks rather than tori may account for X-ray absorbing columns in some systems.

Speculation: Sub-pc warped disks may also dictate the pattern of photoionization in the NLR on kpc scales.

## Consider the Circinus galaxy...

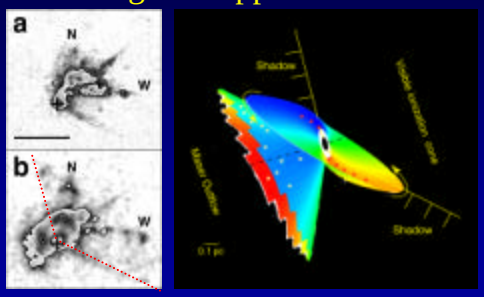



Jones et al. (1999) Veilleux& Bland-Hawthorne (1997) Greenhill et al. (2001,2003)




- The circumnuclear disk may support $H_2O$ masers in an edge-on accretion disk
- Imposed shadow
- And constrains flow & illum
- a nuclear outflow

## In Seyferts, sub-parsec warped disks can regulate appearances




*Veilleux & Bland-Hawthorne (1997)* *Greenhill et al. 2003*

## From here, how do we estimate D?

Observe $v_{los} \propto \theta^{-1/2}$

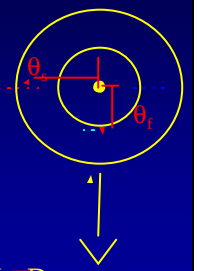
$v_{los}^2 \propto M/D\theta_s$ → M/D

$dv_{los}/d\theta \propto [M/D\theta_f^3]^{1/2}$ → $\theta_f$

$a_{los} \propto v^2/D\theta_f$ → D → M

or

$\dot{\theta} \sim v_t/D \propto (M/D)^{1/2}/D\theta_f^{1/2}$ → M → D

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NGC4258
$M_{bh} \sim 3.9 \times 10^7 M_{sun}$
D ~ 7.2 Mpc (7%)

Promising systems:
NGC1068 Circinus
IC2560 NGC2639
NGC5793 Braatz-1
Tid-2

## *The Future is Now ...*

## Known $H_2O$ Masers in AGN

MpcJy

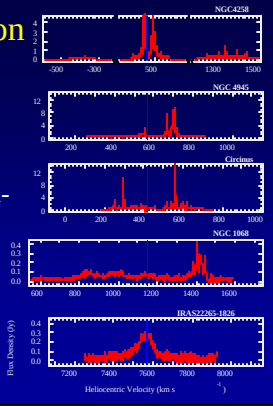
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| NGC4258 | 7.3 | 4 | NGC1052 | 20 | 0.3 | ESO103-G35 | 53 | 0.7 |
| M51 | 3.3 | 0.2 | NGC5506 | 24 | 0.6 | Mrk1210 | 54 | 0.2 |
| NGC4945 | 3.7 | 4 | NGC5347 | 32 | 0.1 | PB106 3-0034 | 97 | 0.2 |
| Circinus | 4 | 4 | NGC3735 | 36 | 0.2 | Mrk348 | 63 | 0.0 4 |
| NGC3079 | 16 | 6 | C25 60 | 38 | 0.4 | Mrk1 | 65 | 0.1 |
| NGC1068 | 16 | 0.6 | NGC2639 | 44 | 0.3 | IC1481 | 93 | 0.4 |
| NGC1386 | 12 | 0.9 | NGC5793 | 50 | 0.4 | NGC6240 | 97 | 0.0 5 |
| | | | | | | PG226 9-1826 | 100 | 0.3 |
| Braat zt | | | Peek-Henkel | | | Peck-Henkel2 | | |
| Peek-Henkel3 | | | Ti dbIbi lls-1 | | | Tidb llbilb- 2 | | |

VLBI thin disk, possible disk, jet/possible jet, VLBI nondetection, VLBI detection.

## A New Generation of Surveys

Designed to detect perhaps the most interesting disks, high-velocity disks

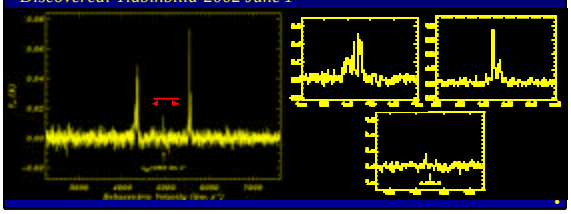
Effelsberg
Madrid DSN
Tidbinbilla DSN
GBT



## A New Generation of Surveys

A new high-velocity disk

*Discovered: Tidbinbilla 2002 June 1*



## *The Future is...*

Detailed study of accretion disk geometry and its role in shaping AGN

Precision black hole mass estimates

Geometric distances to nearby AGN

and, of couse ,

More $H_2O$ masers