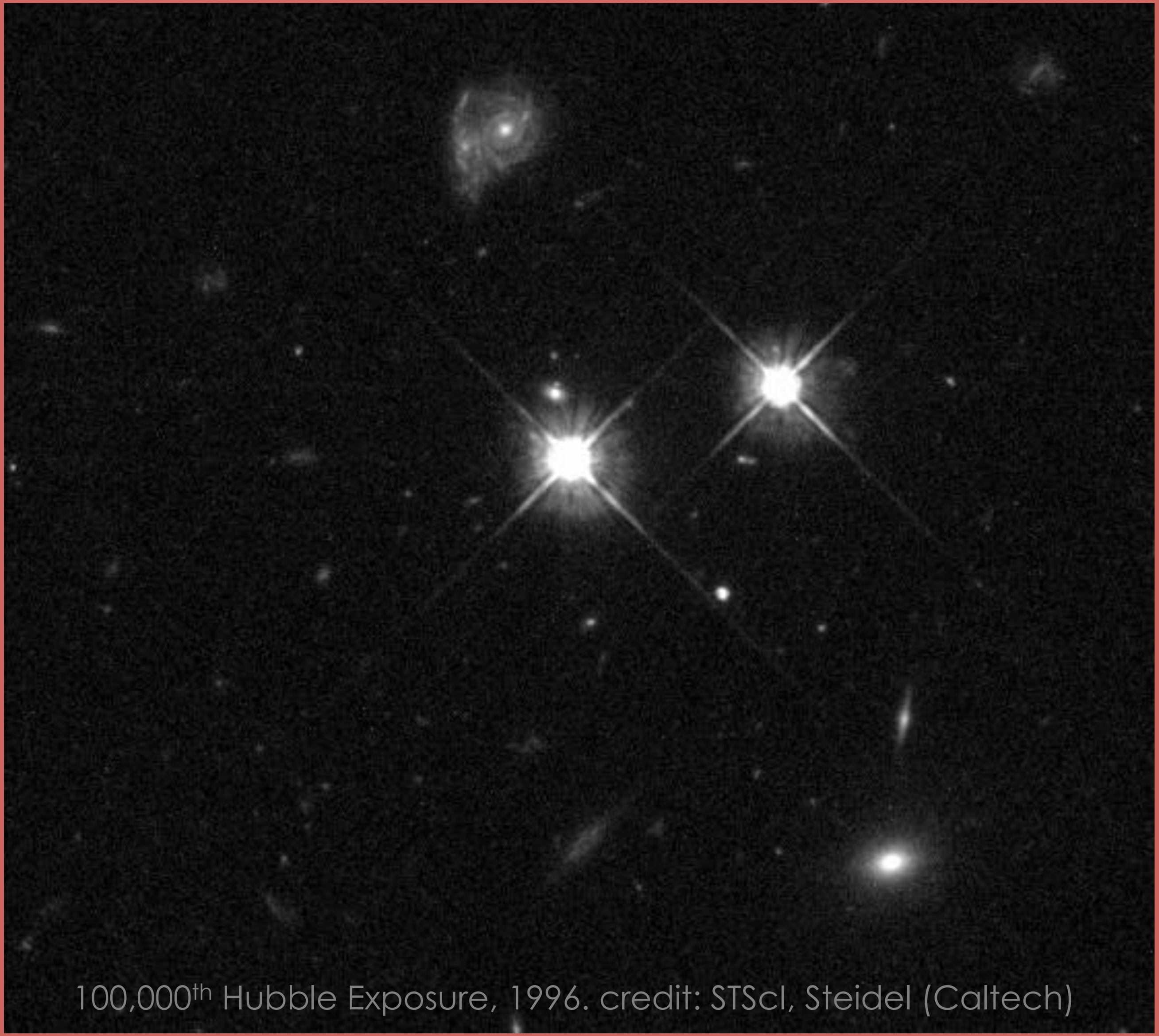
The Structure of Active Galactic Nuclei on Scales from 100mas to 100μas

Martin Elvis

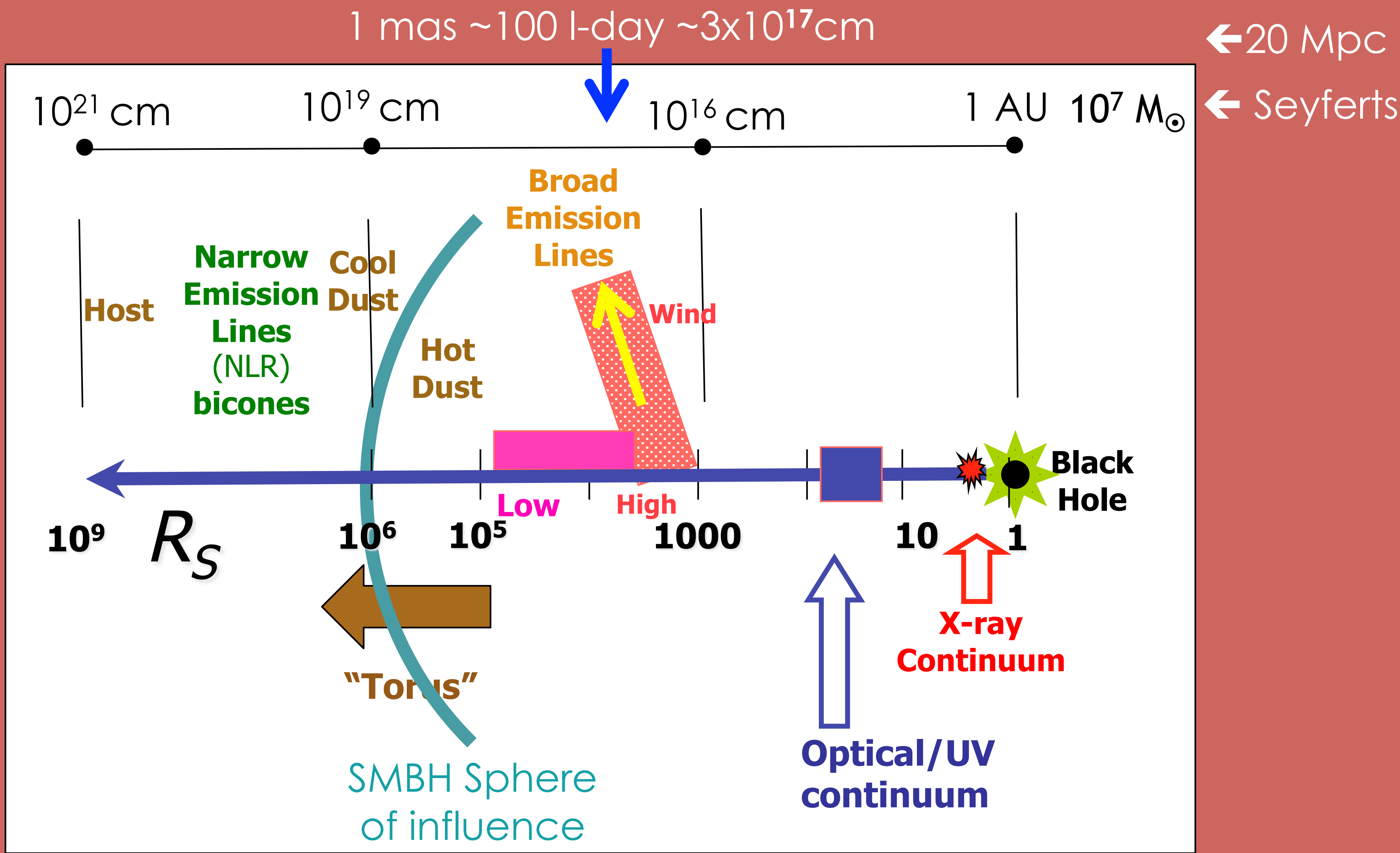
Harvard-Smithsonian Center for Astrophysics

Quasars – the Quintessential Point Sources


100,000th Hubble Exposure, 1996. credit: STScI, Steidel (Caltech)

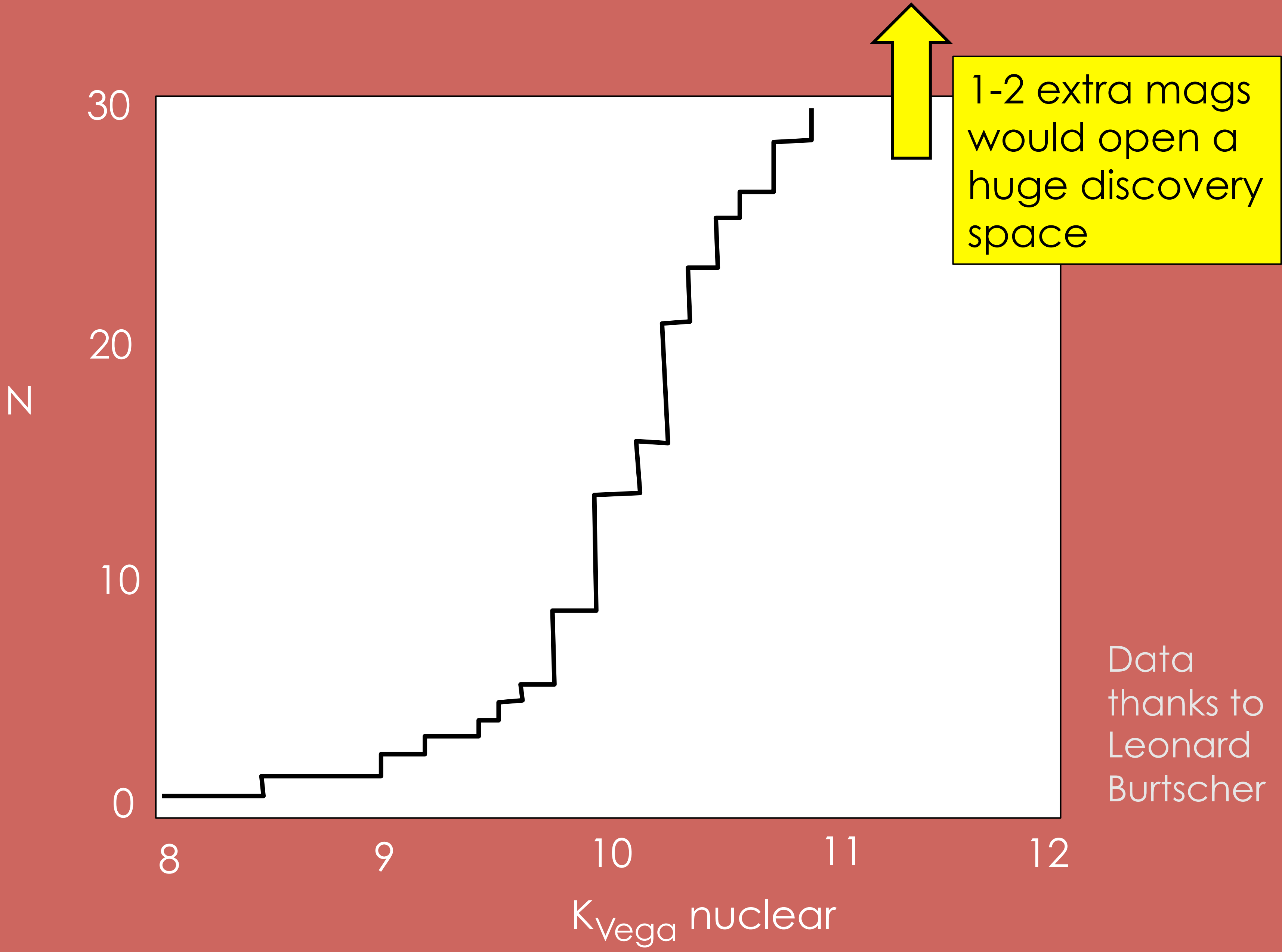
Scales in AGNs

Painfully deduced from decades of spectroscopy and variabiity studies



Many structures in common with stars

Sensitivity is Crucial



Data thanks to Leonard Burtscher

The Quasar Standard Model

No prediction of:

Atomic Features: AGN ‘types’

Maximally Hot dust

X-rays

Evolution

massive black hole

Lynden-Bell 1969

accretion disk

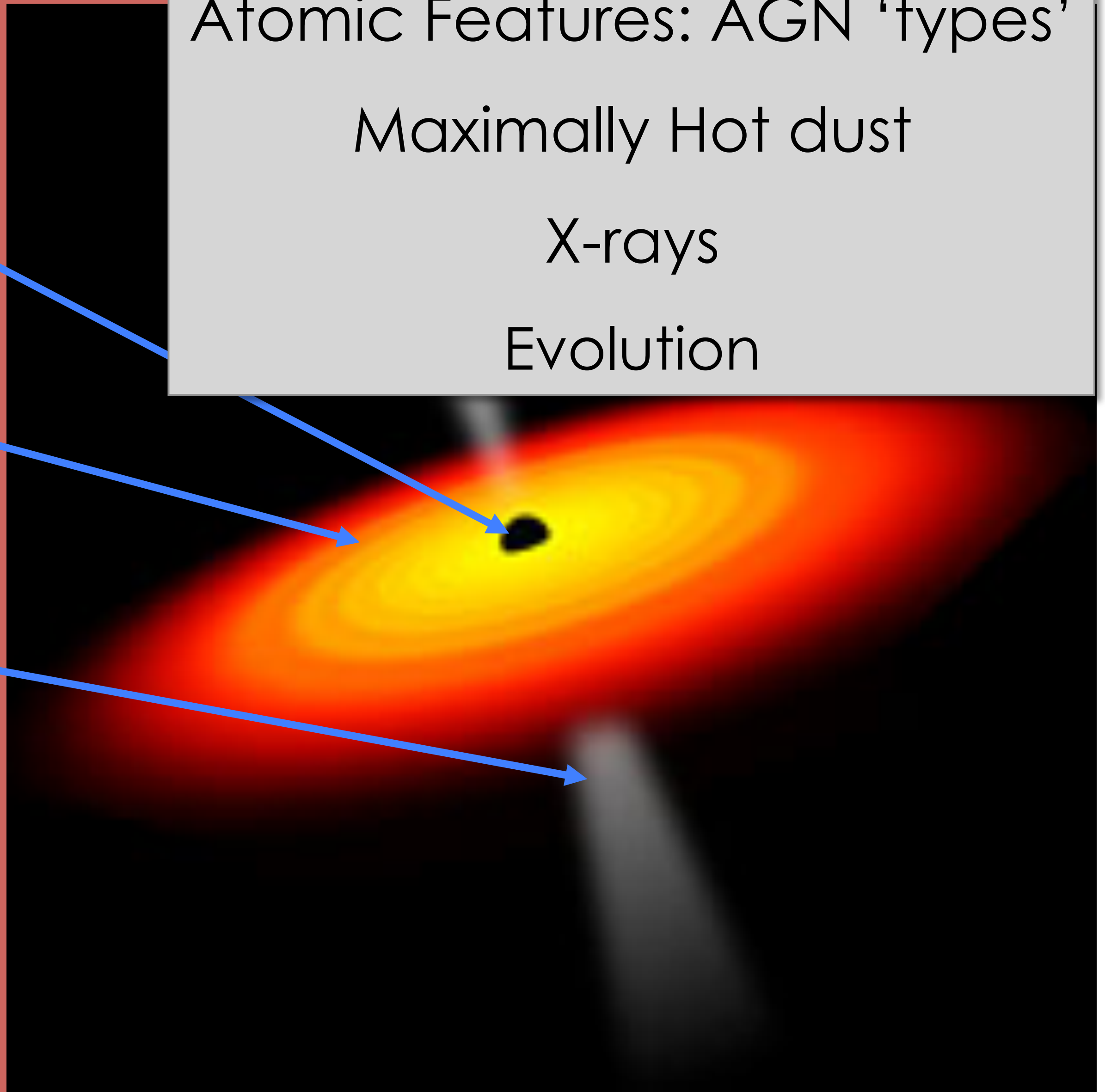
Lynden-Bell 1969, Pringle & Rees 1972,

Shakura & Sunyaev 1972

relativistic jet

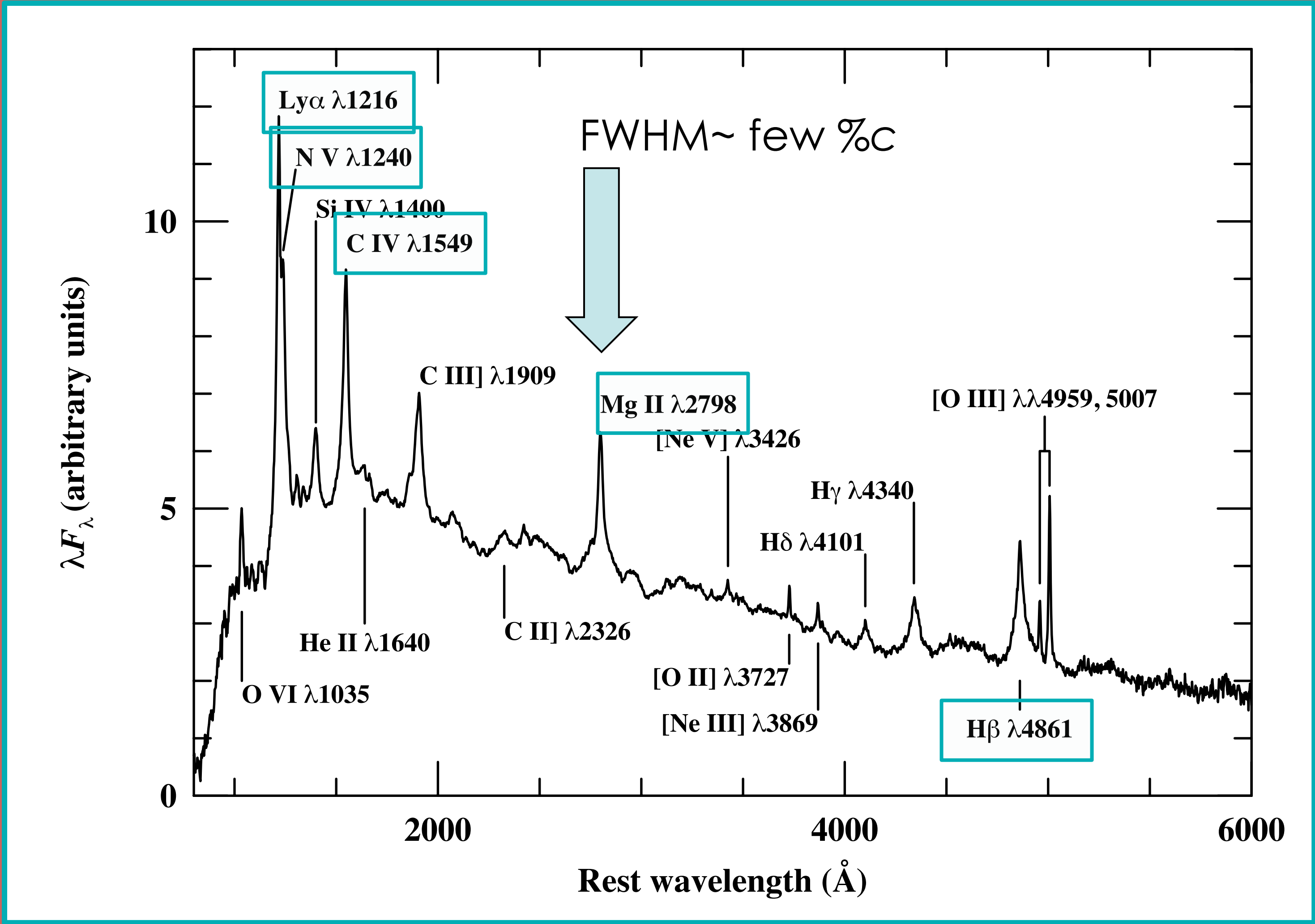
Rees 1967 [PhD],

Blandford & Rees 1974



The Broad Emission Line Region

Quasar Atomic Features: Broad Emission Lines

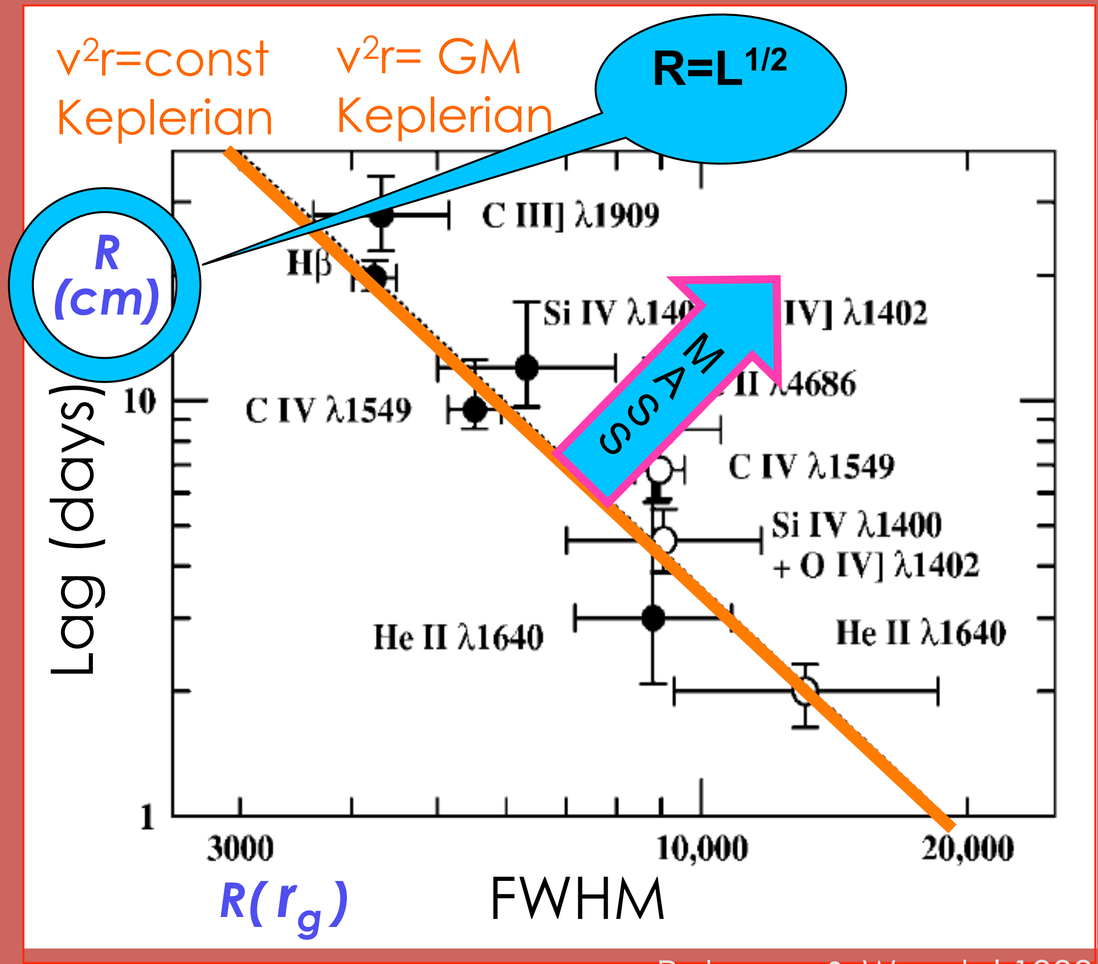


Peterson 1999

Dense, high ionization gas close to black hole

Quasar Sizes (& Black Hole Masses)

~0.3 mas
In
Nearest
AGNs



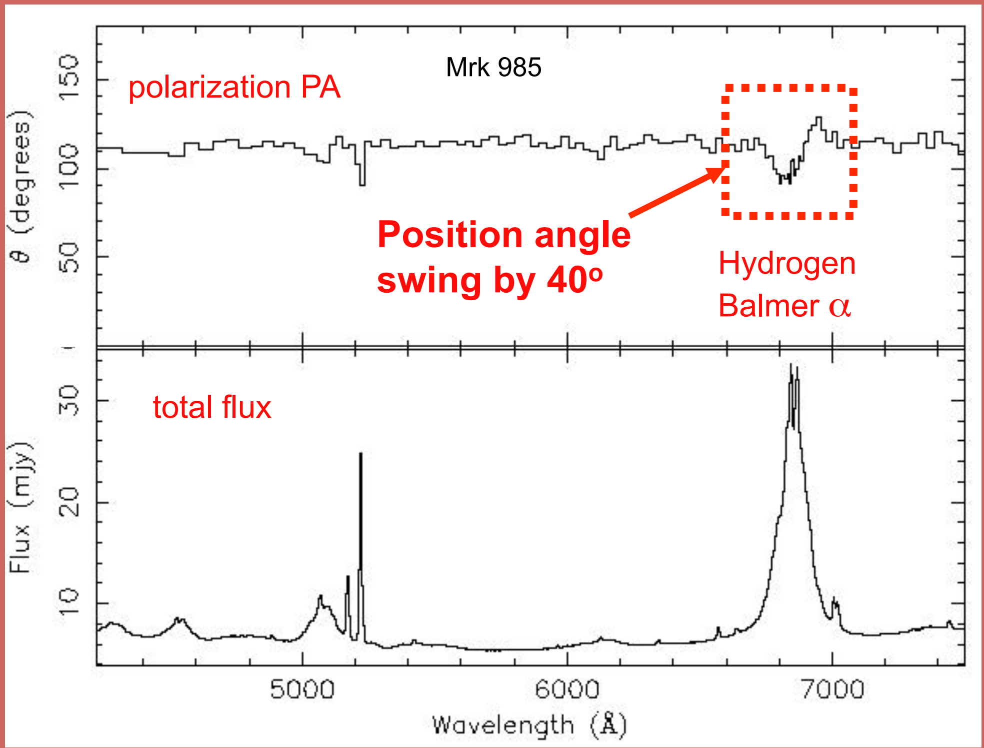
Peterson & Wandel 1999

Reverberation
Mapping

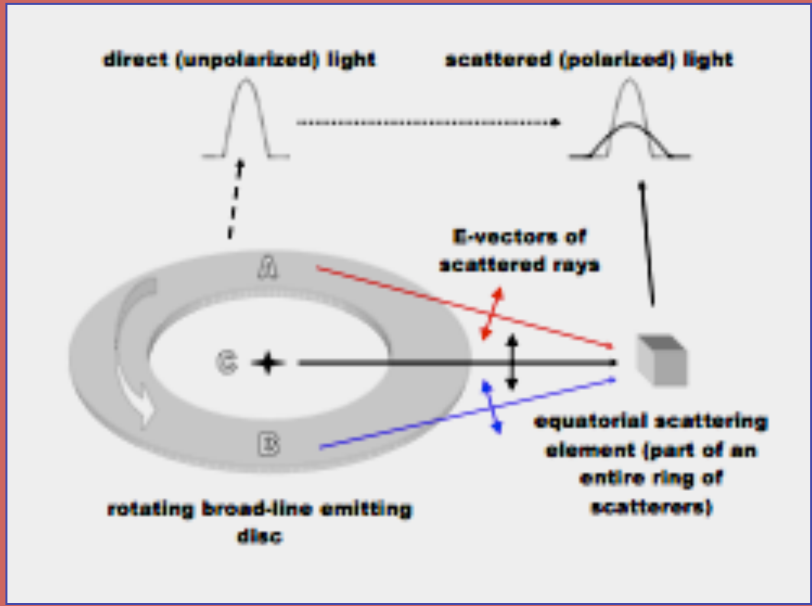
Peterson et al. 1993, PASP, 105, 247; 2006MmSAI.. 77..581P

BEL Polarimetry

Warning: Implies significant electron-scattered light



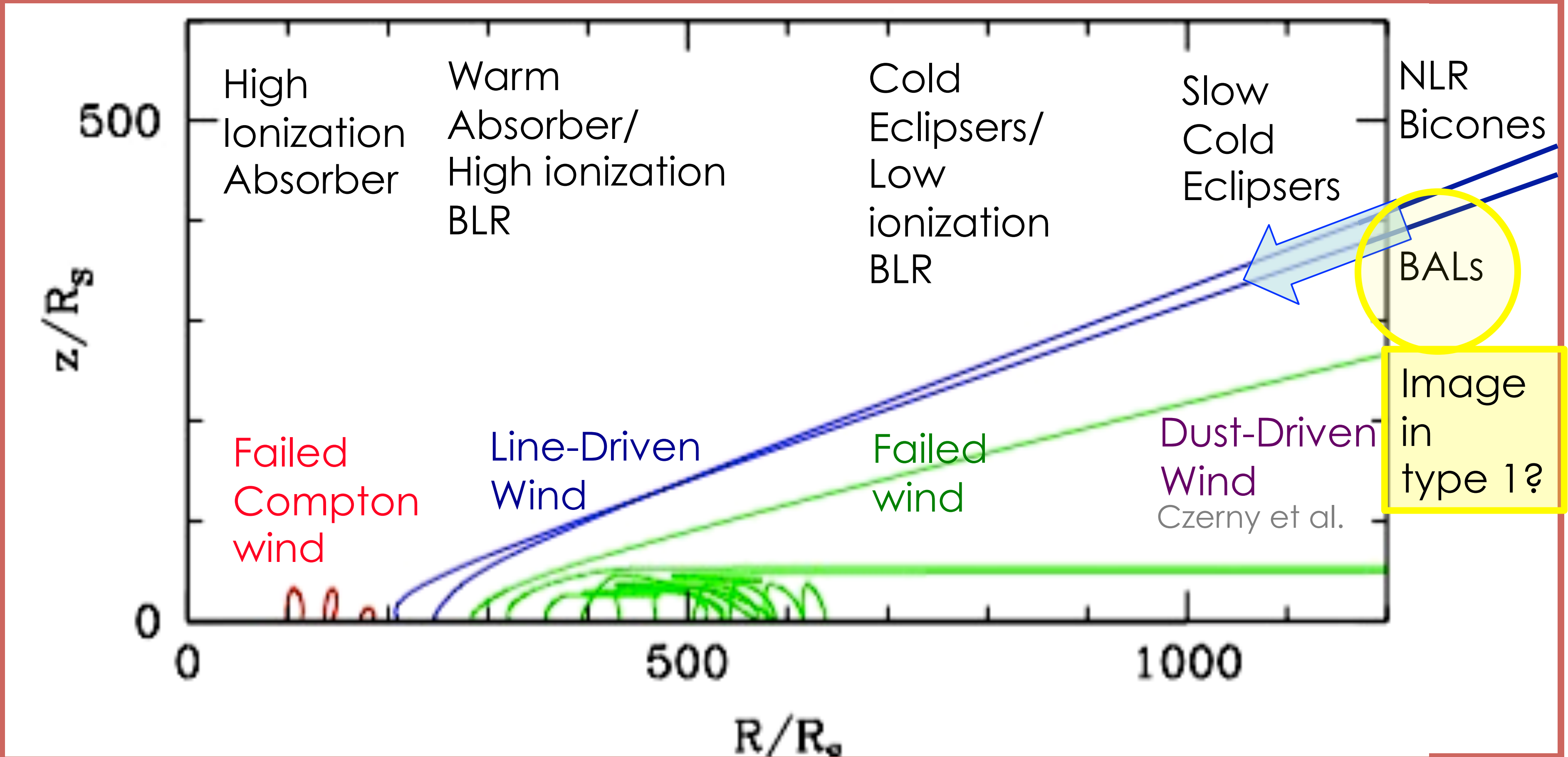
Smith J.E., 2002, MNRAS astro-ph/0205204



Smith J.E., 2005, MNRAS astro-ph/0501640

A Simple Wind Model

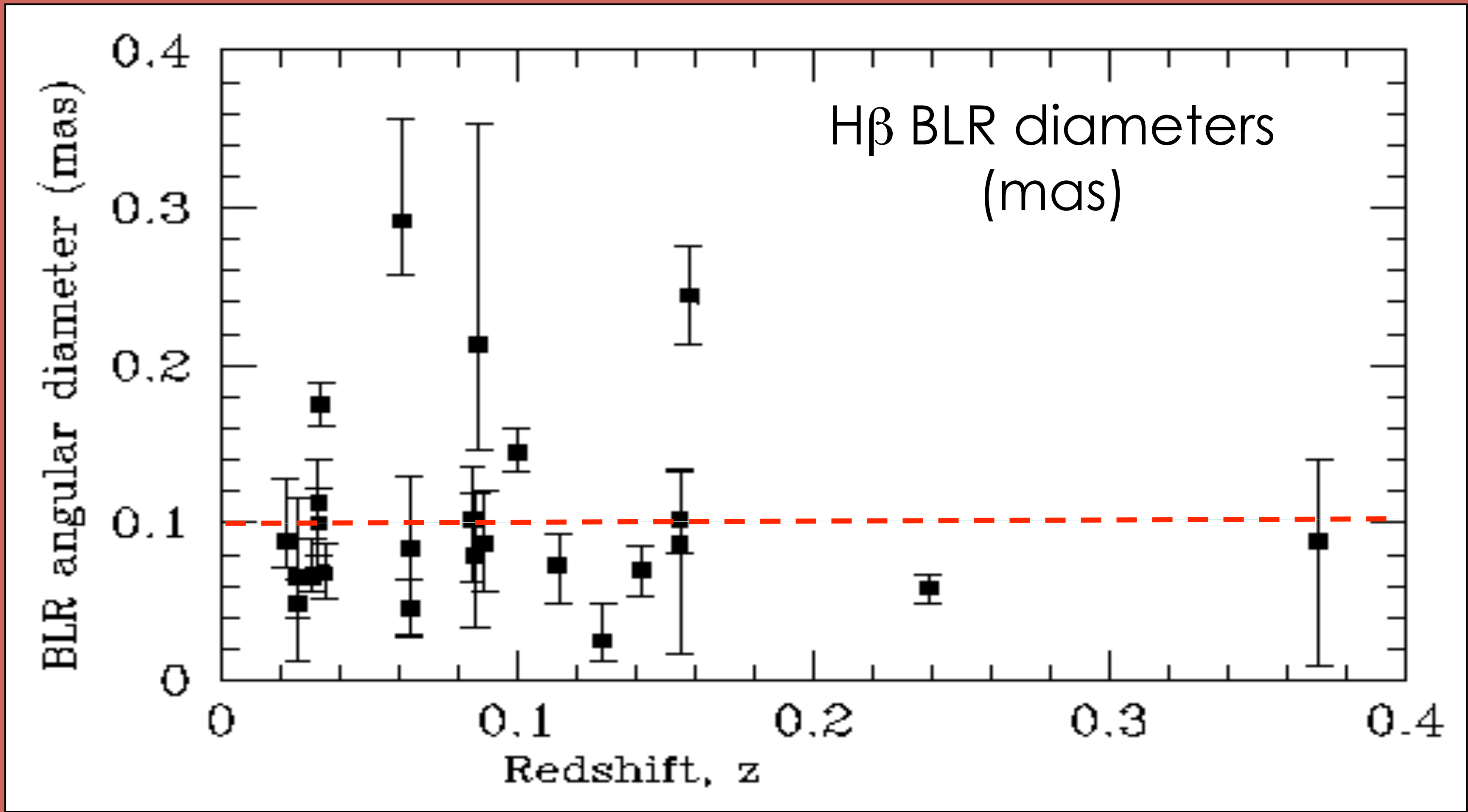
Risaliti & Elvis, 2010, A&A 516, A 89



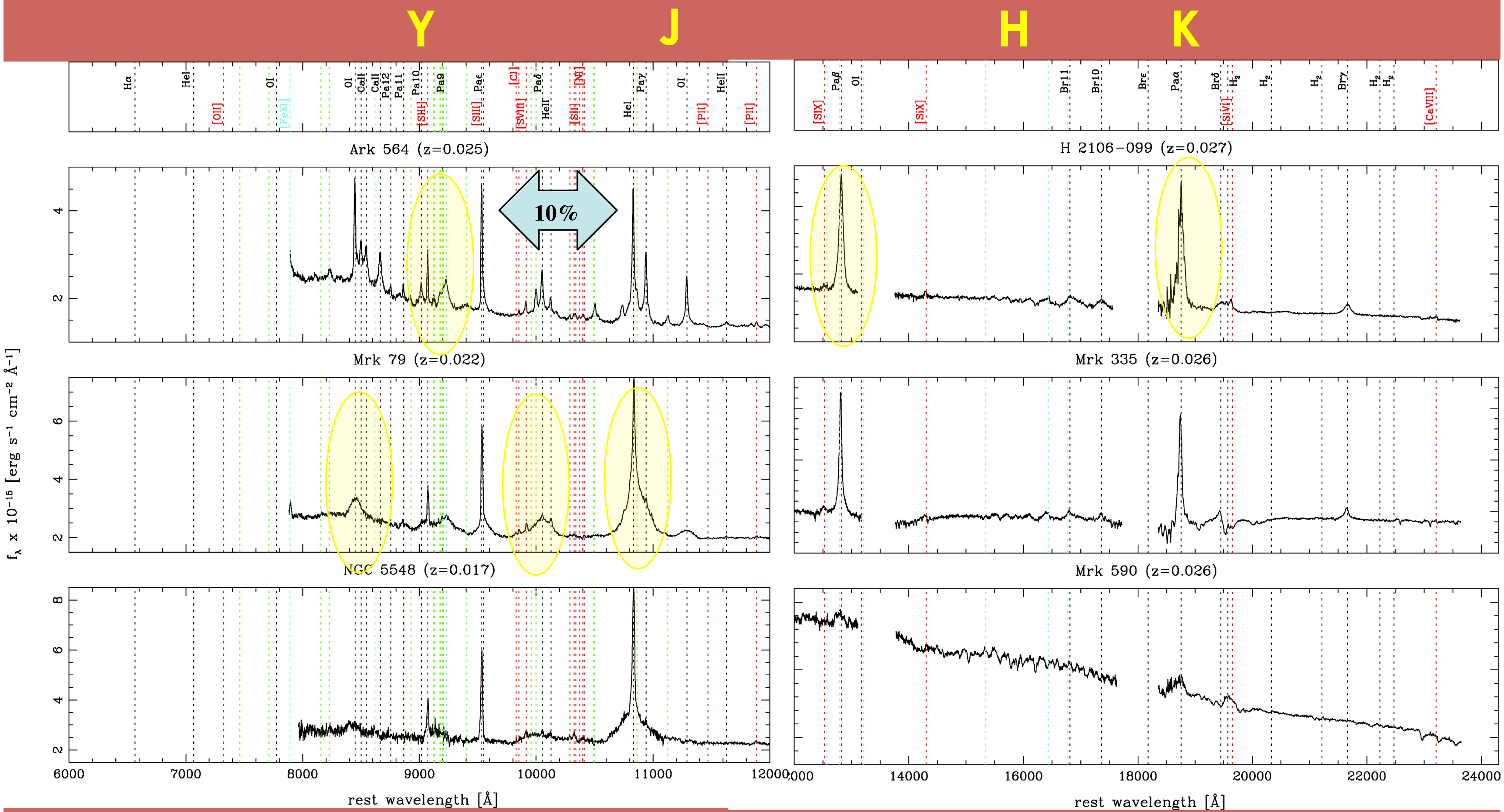
The 3 Forms of Radiation Pressure Explain Quasar Structure

Resolving the Broad Emission Line Region

Elvis & Karovska, 2002 ApJ, 581, L67



Near-Infrared Broad Emission Lines



IRTF/SPEX YJHK Spectra of AGN

Landt et al. 2008

Accretion Disk Winds: the 4th Element

Explains ALL Emission & Absorption Lines

massive black hole

Lynden-Bell 1969

accretion disk

Lynden-Bell 1969, Pringle & Rees 1972,

Shakura & Sunyaev 1972

relativistic jet

Rees 1967 [PhD],

Blandford & Rees 1974

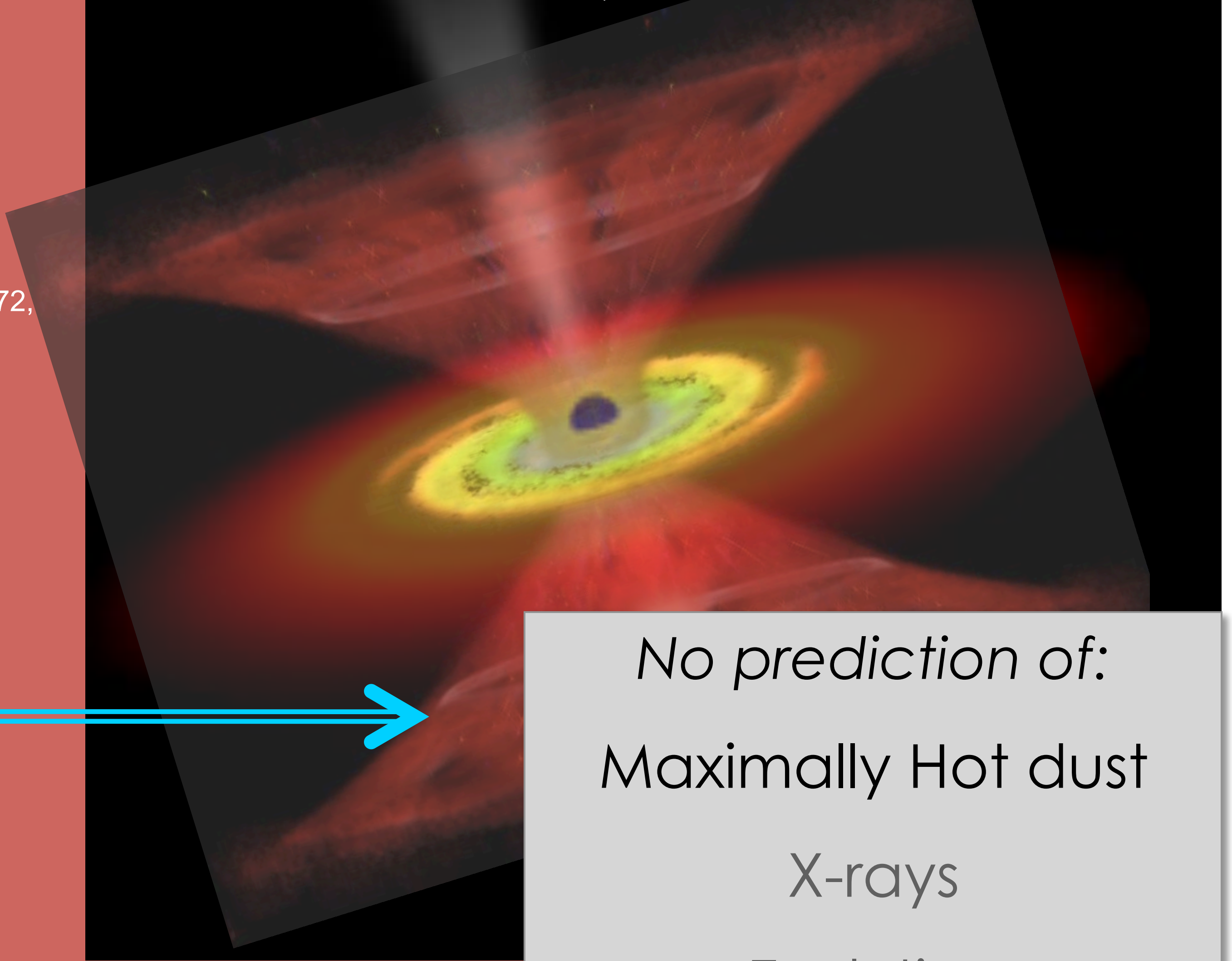
disk winds

Murray et al., 1995

Elvis 2000

Nenkova et al., 2008

Explains: Broad, Narrow Absorption Lines, High Ionization Emission Lines, hot dust



No prediction of:

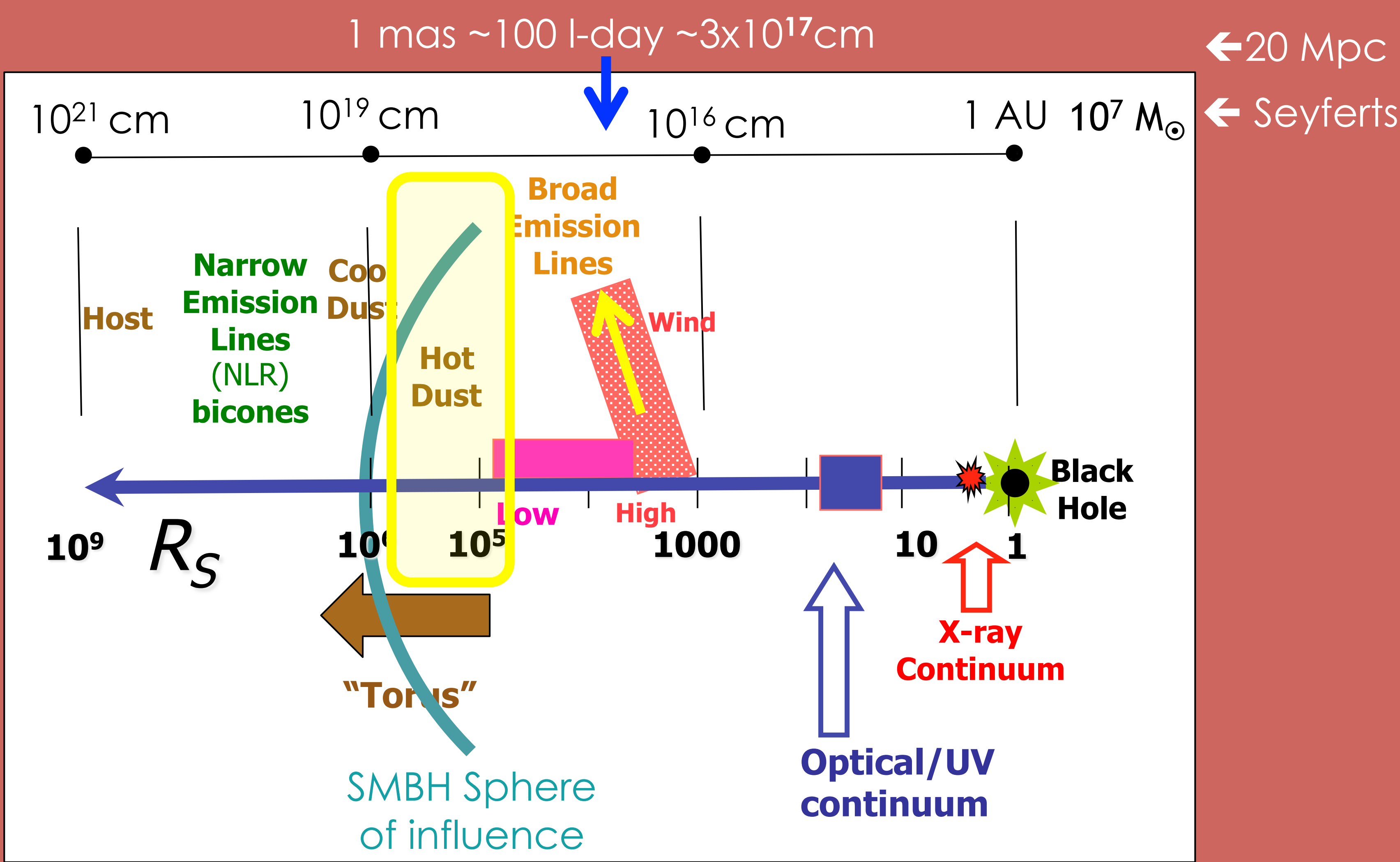
Maximally Hot dust

X-rays

Evolution

Hot Dust in AGNs

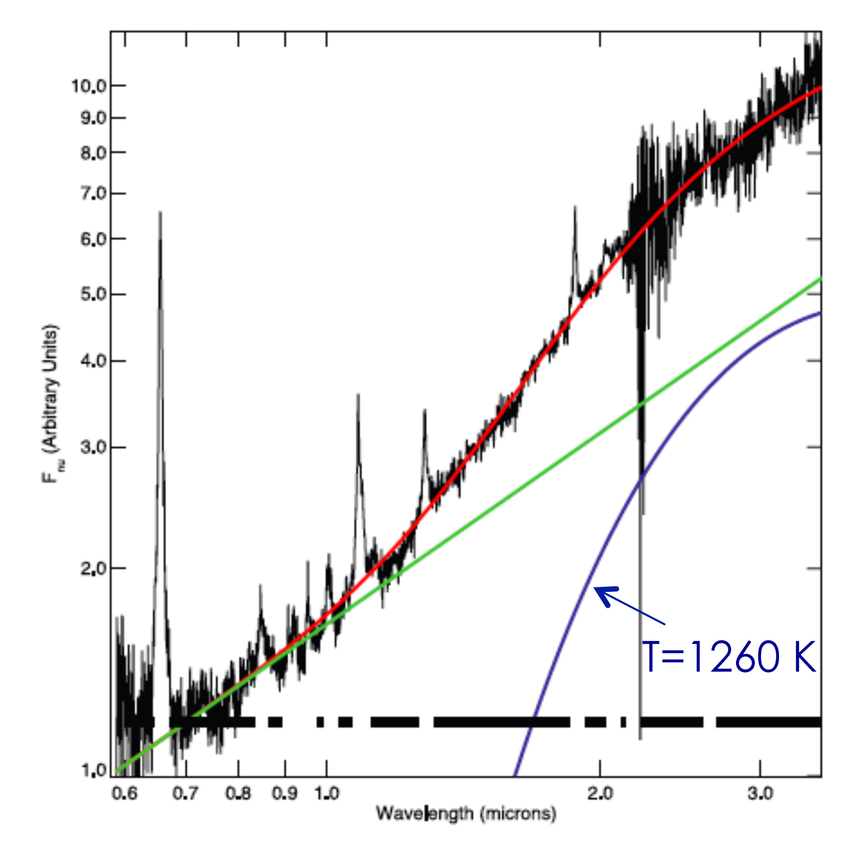
Scales in AGNs



Maximally Hot Dust

Glickman et al. 2005

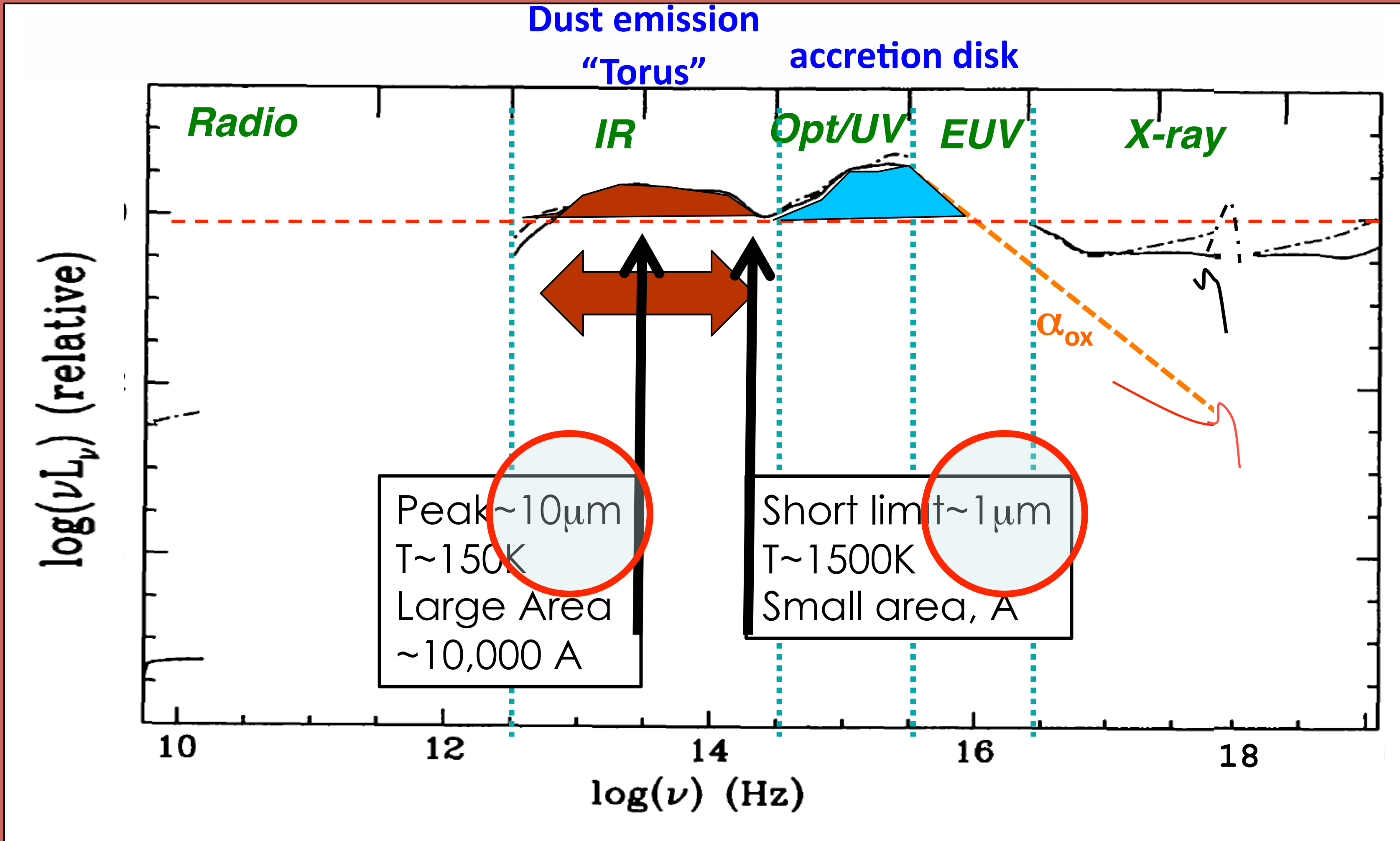
Not seen in starburst galaxies



$$R_{sub} = 0.13\, L_{44}^{1/2}\, T_{1500}^{-2.8} = 1.5\times10^{6} \ldots R_g$$

Barvainis 1987, Lawrence & Elvis 2010

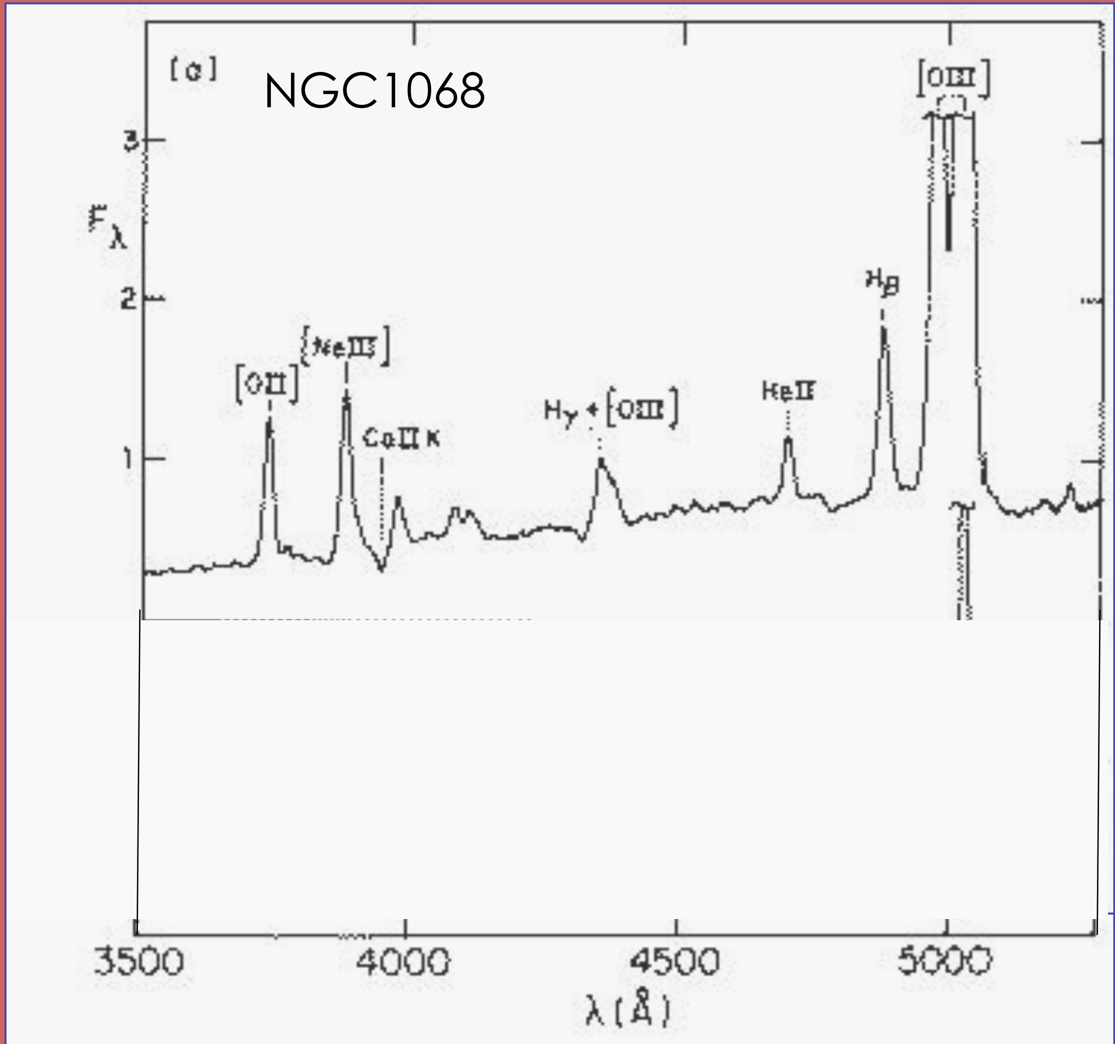
The Quasar "Torus" Emission



Elvis et al. 1994 ApJS, 95, 1

Well-suited to interferometry

AGN Flattened Obscurers

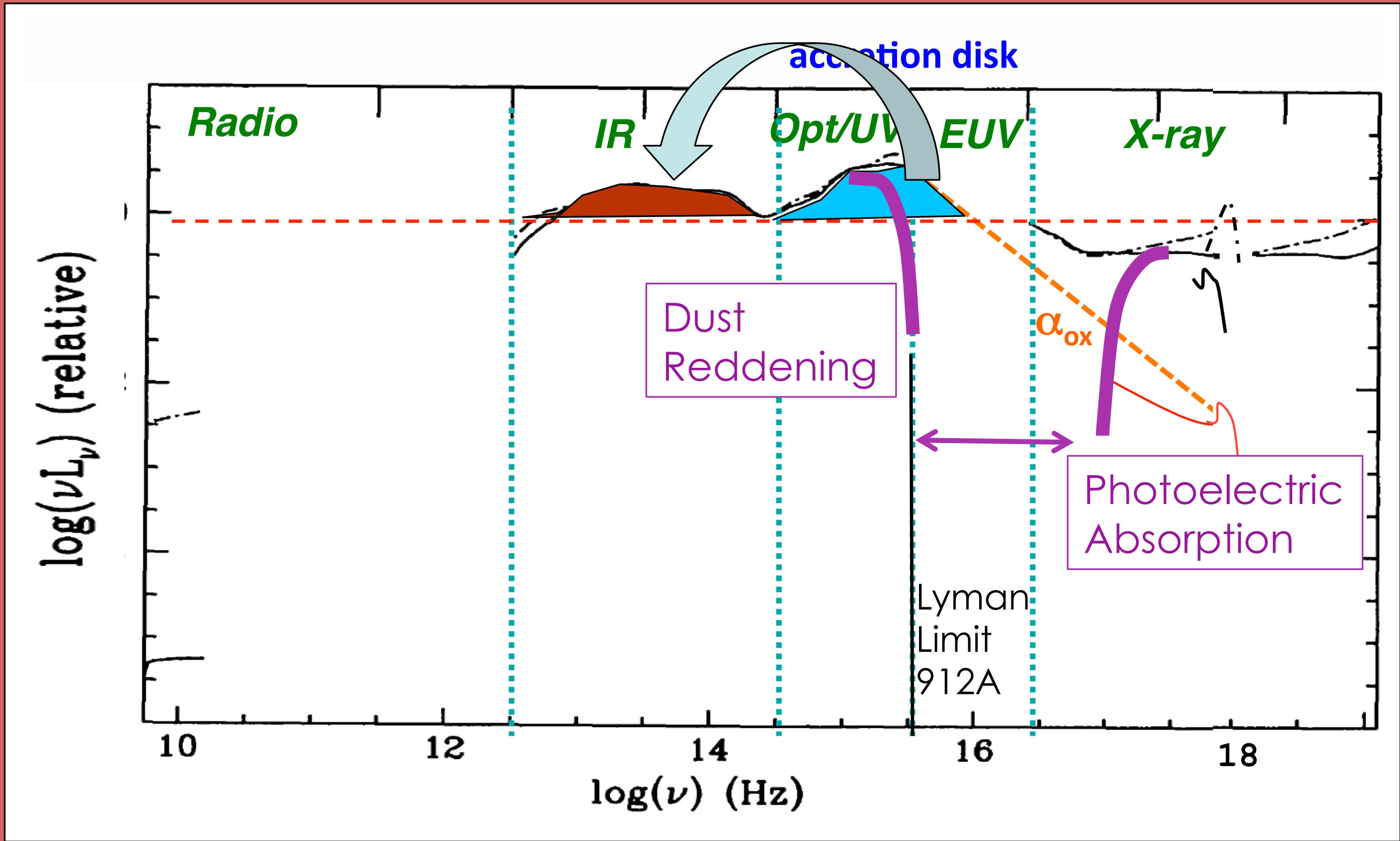


Polarized flux spectrum

Antonucci & Miller 1985 ApJ 297, 621

Warning: Implies significant electron-scattered light

Dust reprocesses UV, X-rays

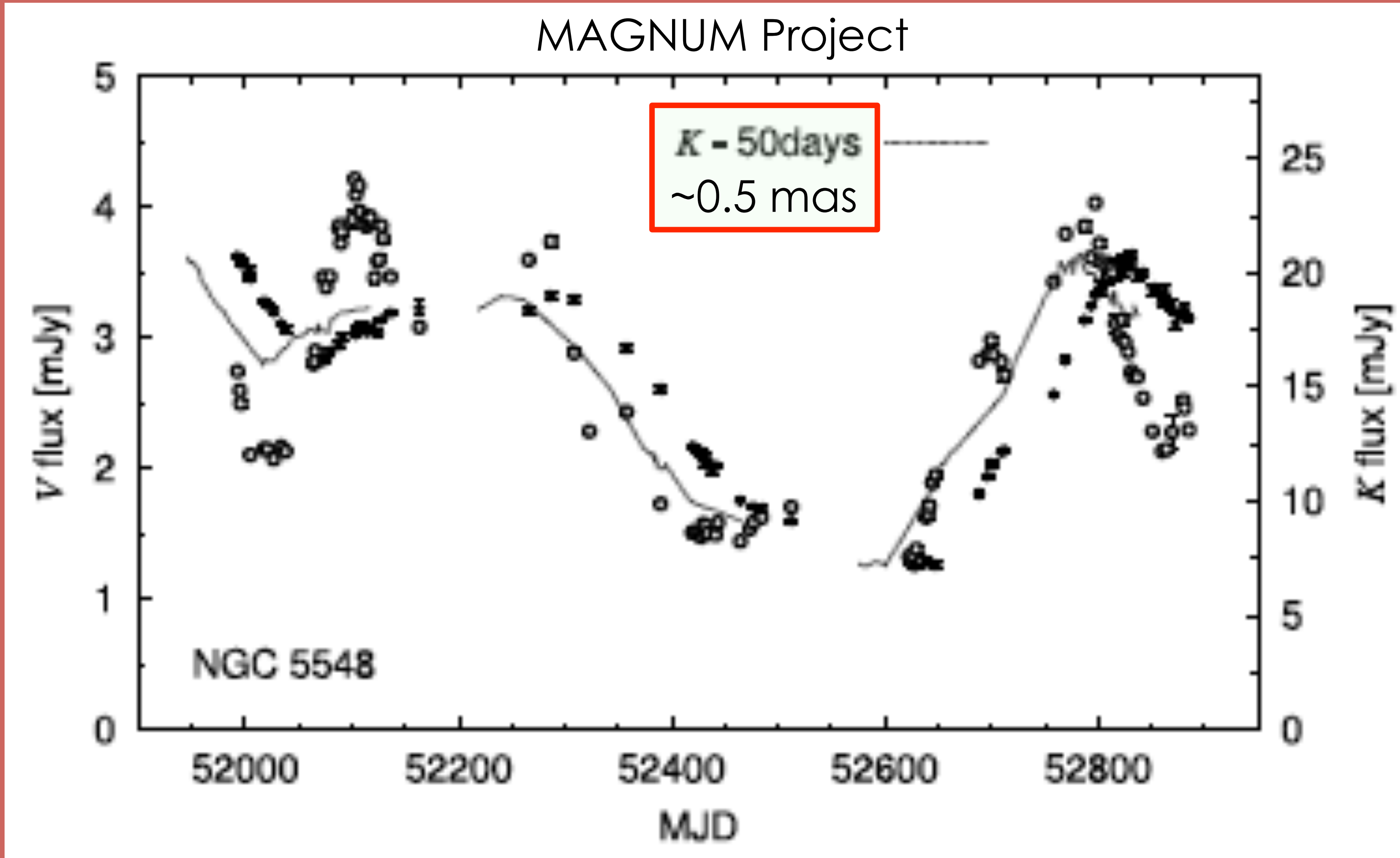


Elvis et al. 1994 ApJS, 95, 1

Hot Dust Region Size

Suganuma et al. 2006 ApJ, 639, 46

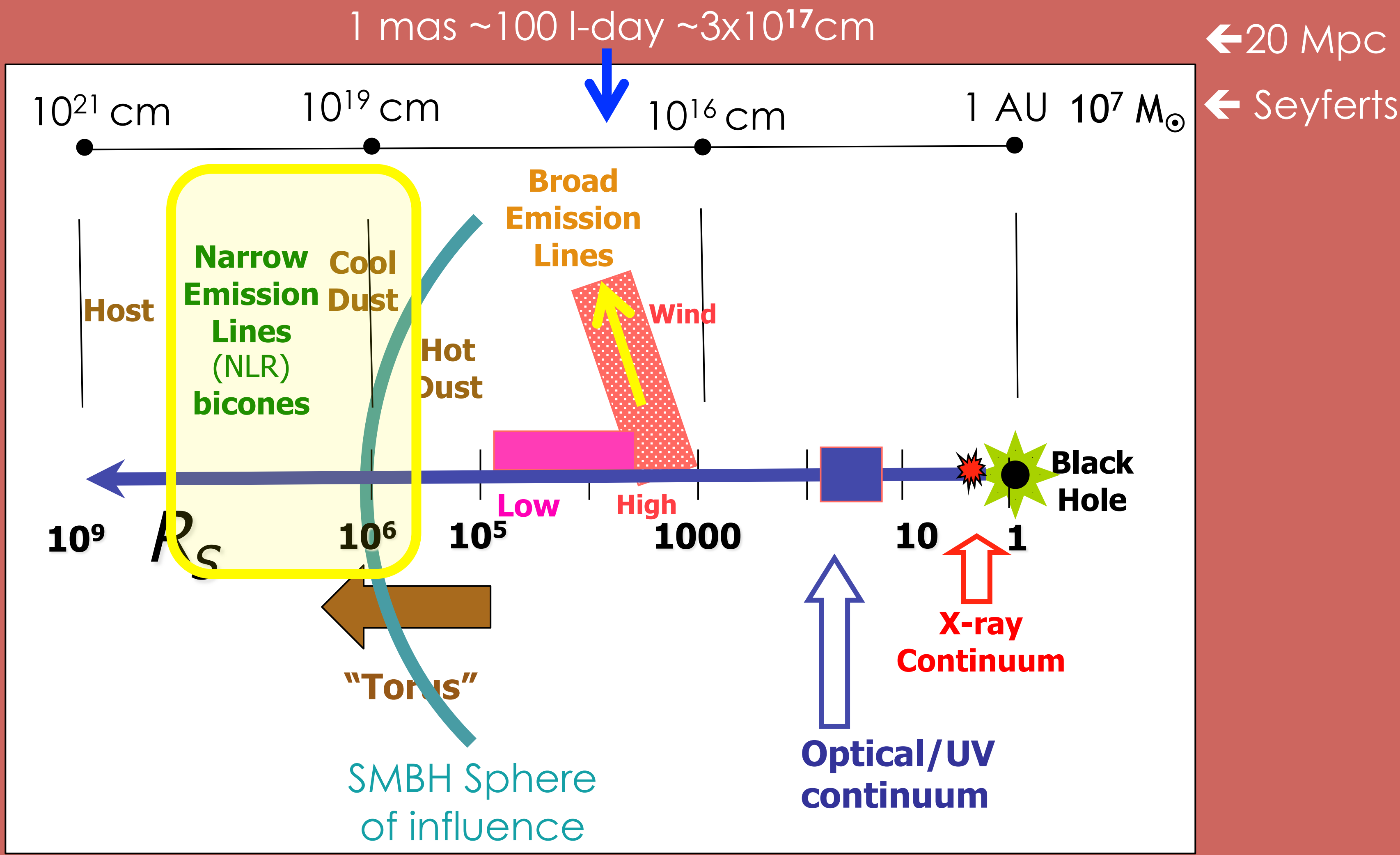
Agrees roughly with Prediction
➔Details tell dust properties



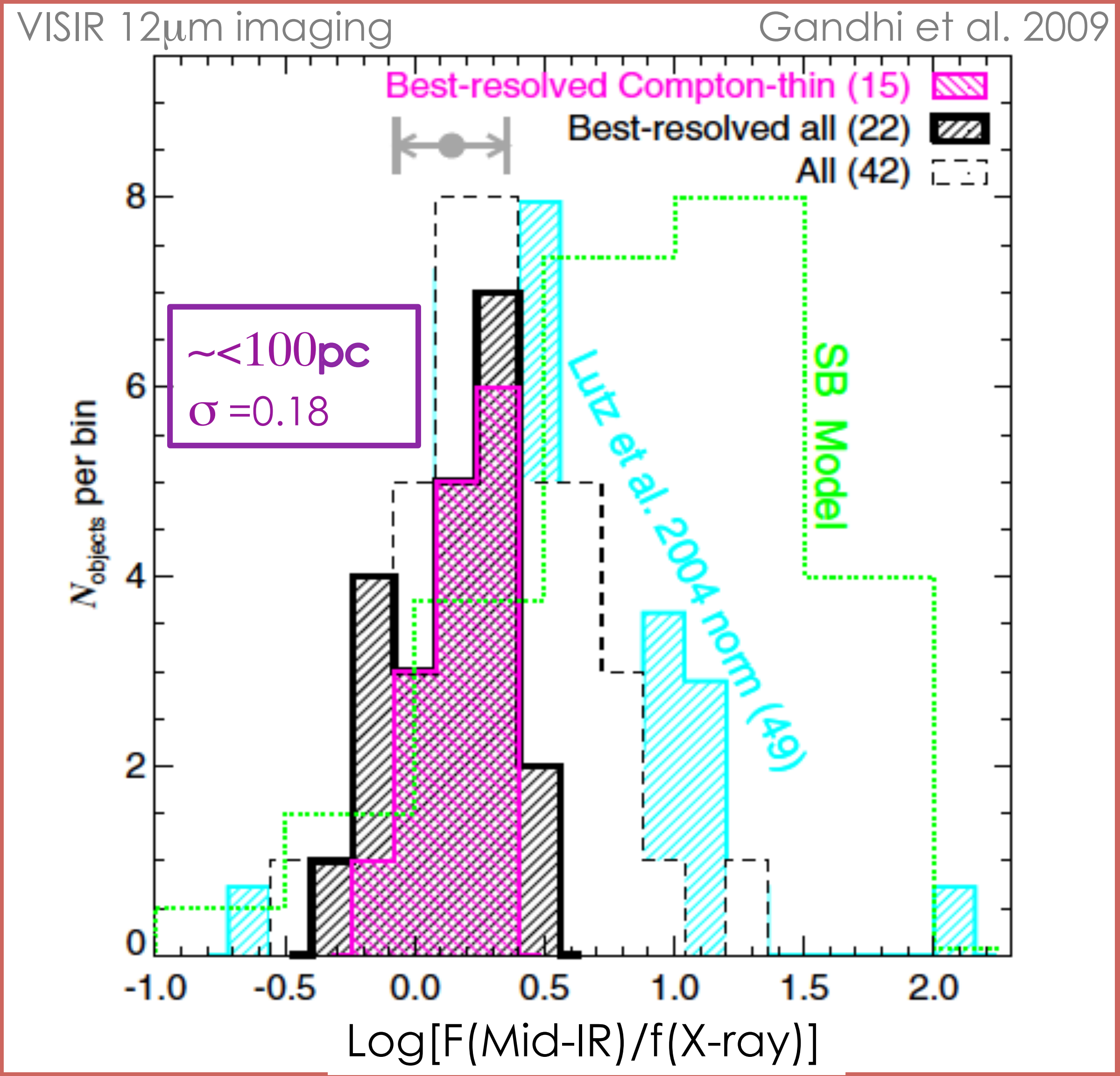
Rapid dust formation as AGN luminosity dims (~1yr)
Koshida et al. 2009

The Mid-IR Dust and Narrow Emission Line Regions

Scales in AGNs

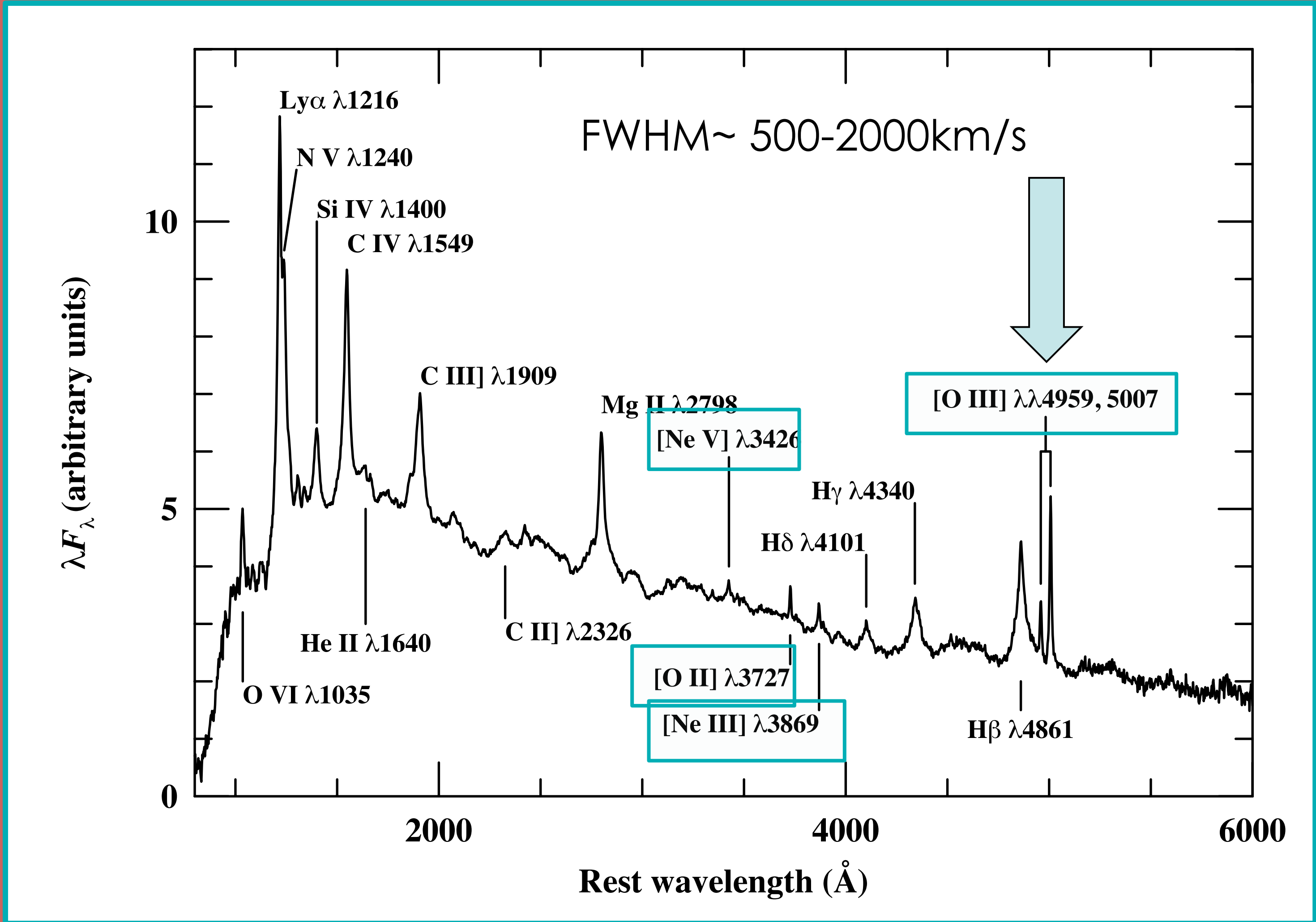


Gap between100pc and sub-100pc mid-IR emission



Well-defined IR 'core'

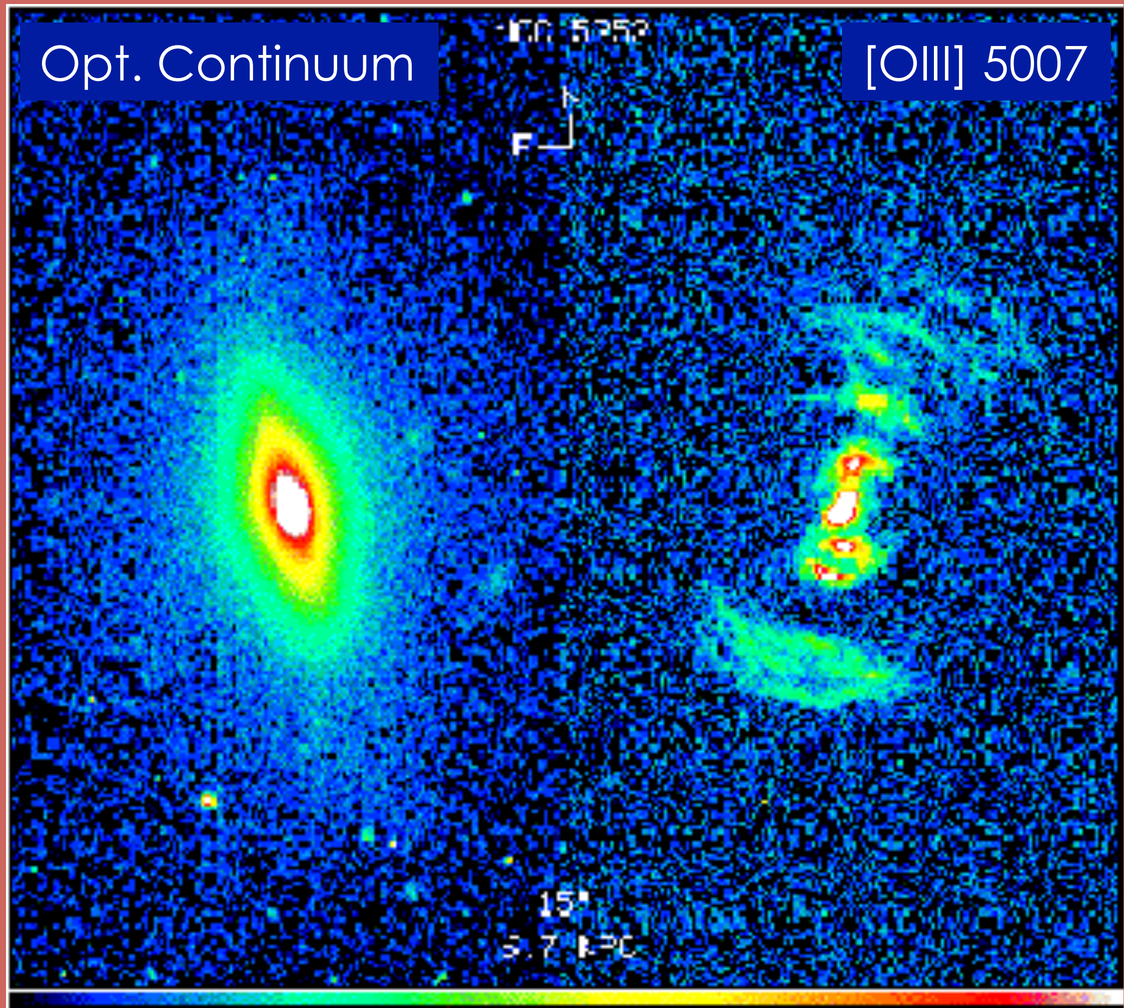
Quasar Atomic Features: Narrow Forbidden Emission Lines



Peterson 1999

Low density, high ionization gas far from the black hole

Narrow Line Bi-cones in AGNs



Tadhunter & Tsvetanov 1989 Nature 341, 422

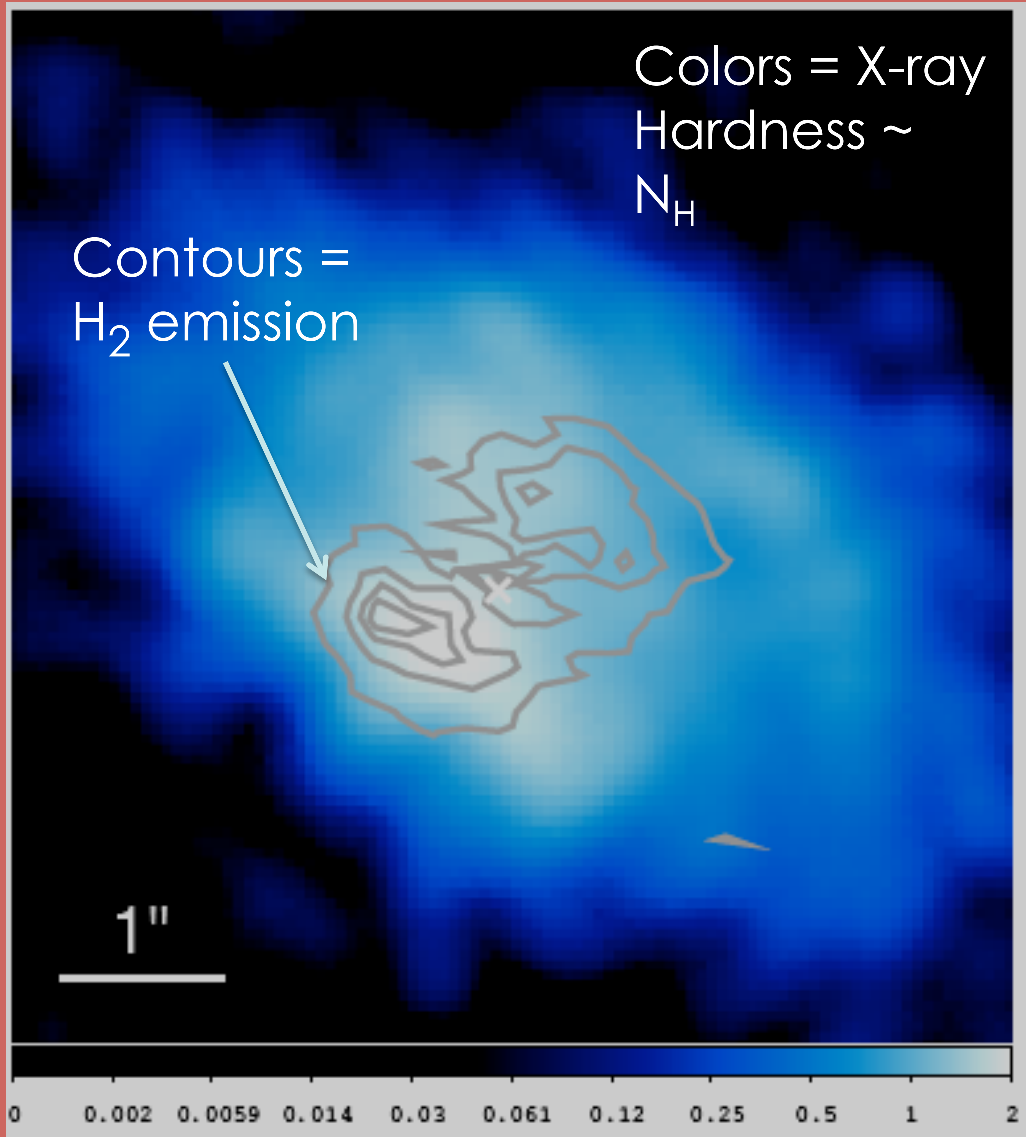
The Bi-cone Region: Feeding and Feedback

Storchi-Bergman et al.; Wang J. et al. (2011a)

NGC4151:

- Bicones show feedback
- 'Spiral' inflow shows feeding
- Need to follow structure well within black hole sphere of influence

<10pc, <100 mas



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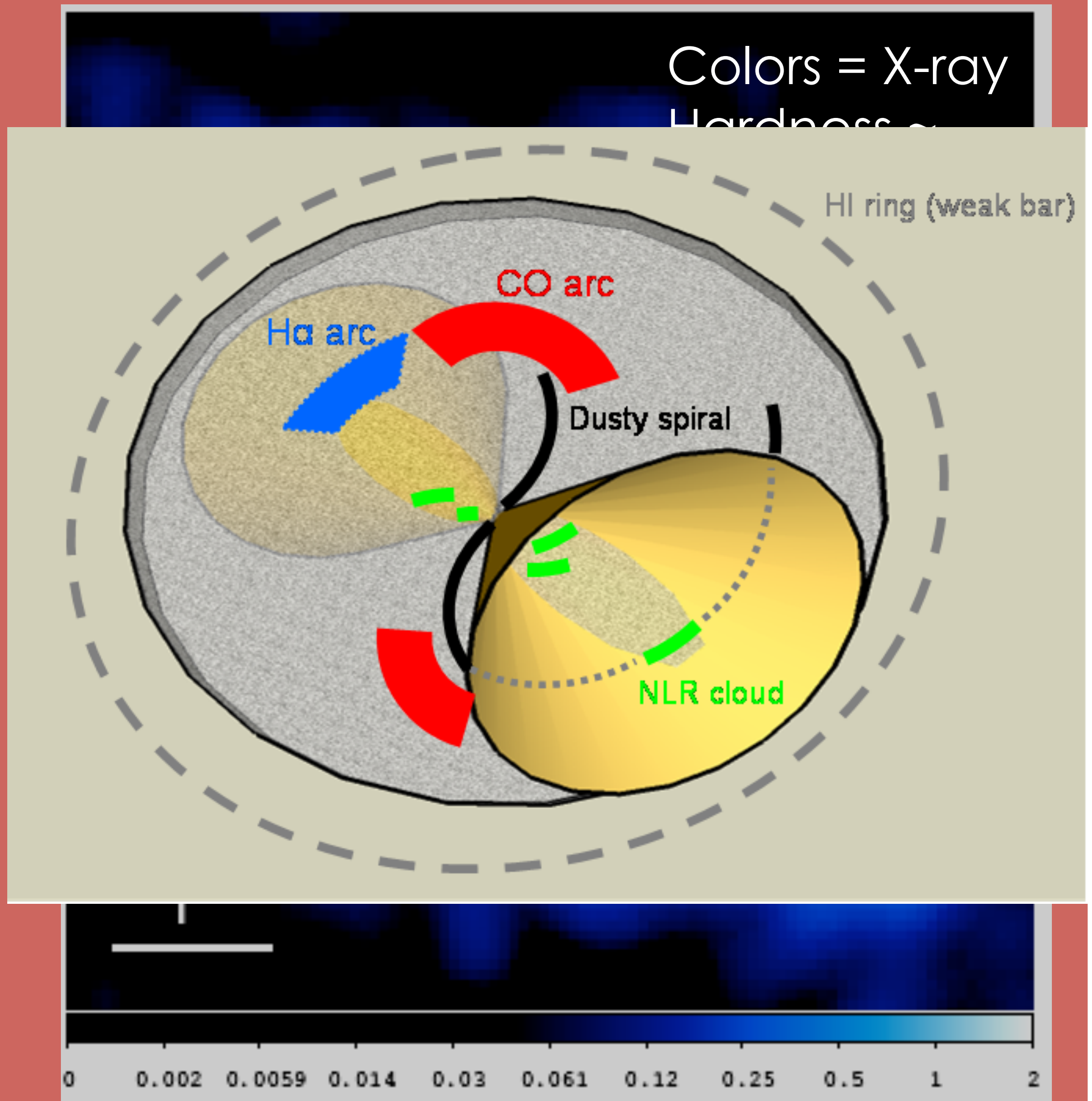
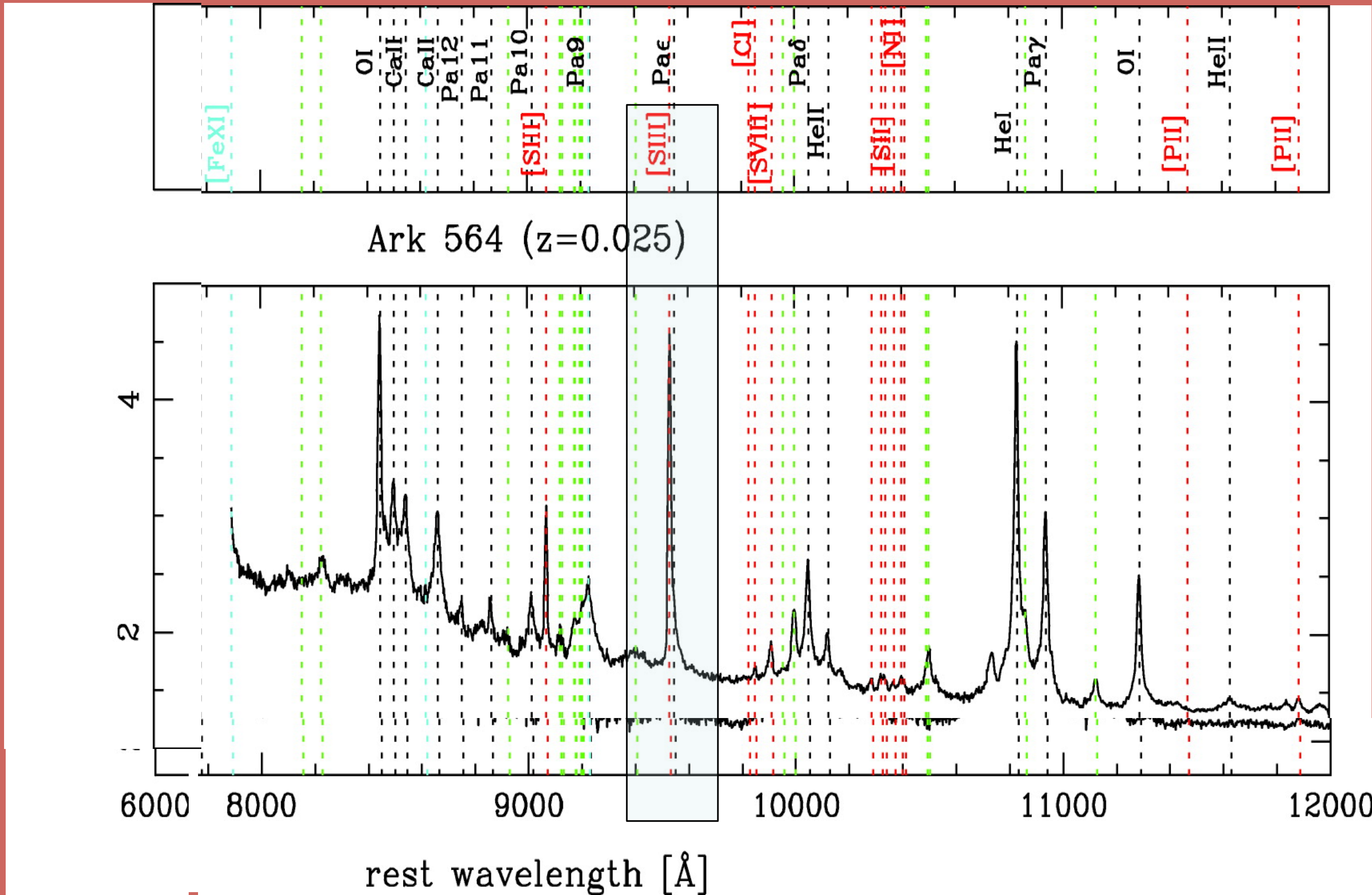


Near-Infrared Narrow Emission Lines

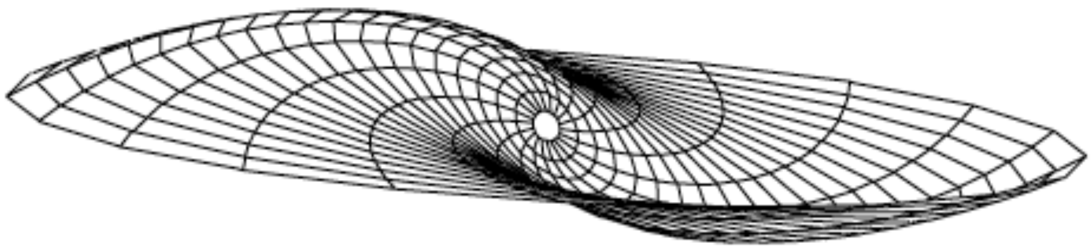
Mostly weak



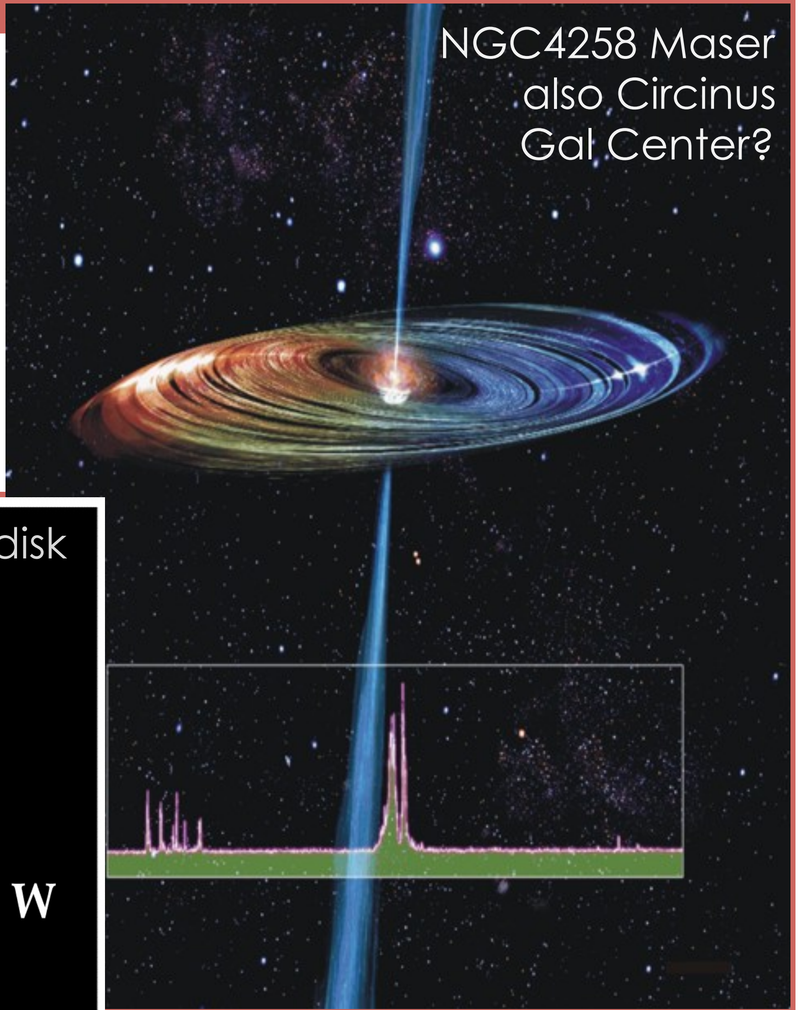
Landt et al. 2008

Warped Disk Obscurers

Lawrence & Elvis 2010 ApJ, 714, 561



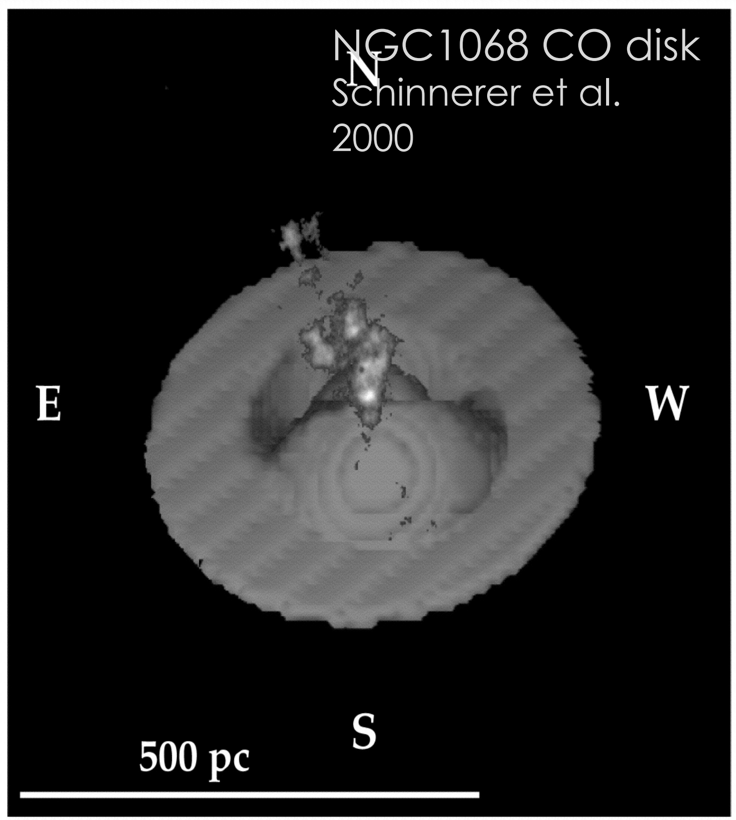
Rijkhorst et al. 2005



Observed warps:

- Maser disks
- CO disks

Produced by isotropic accretion molecular clouds or minor mergers
Volonteri et al. 2007



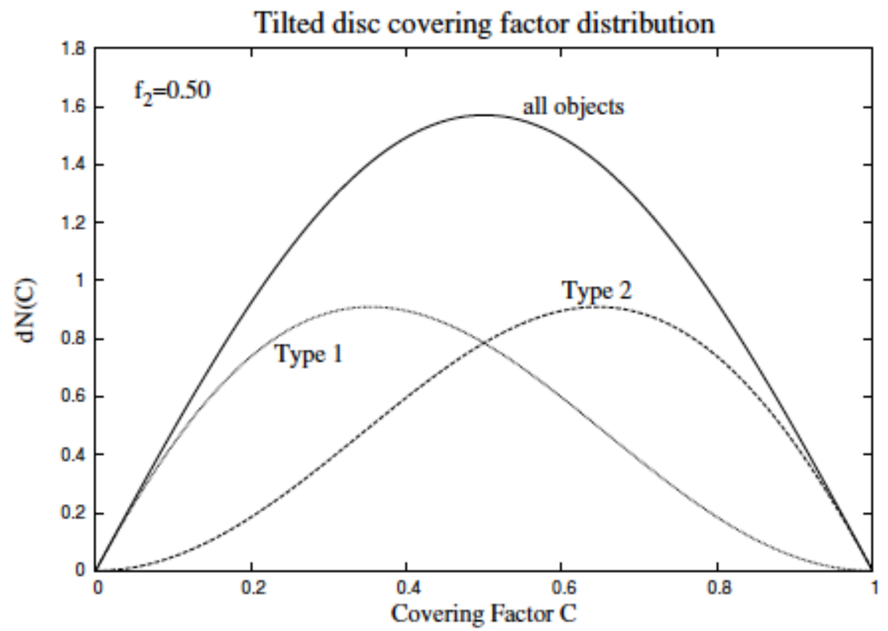
Warped Mid-IR Disk Obscurers

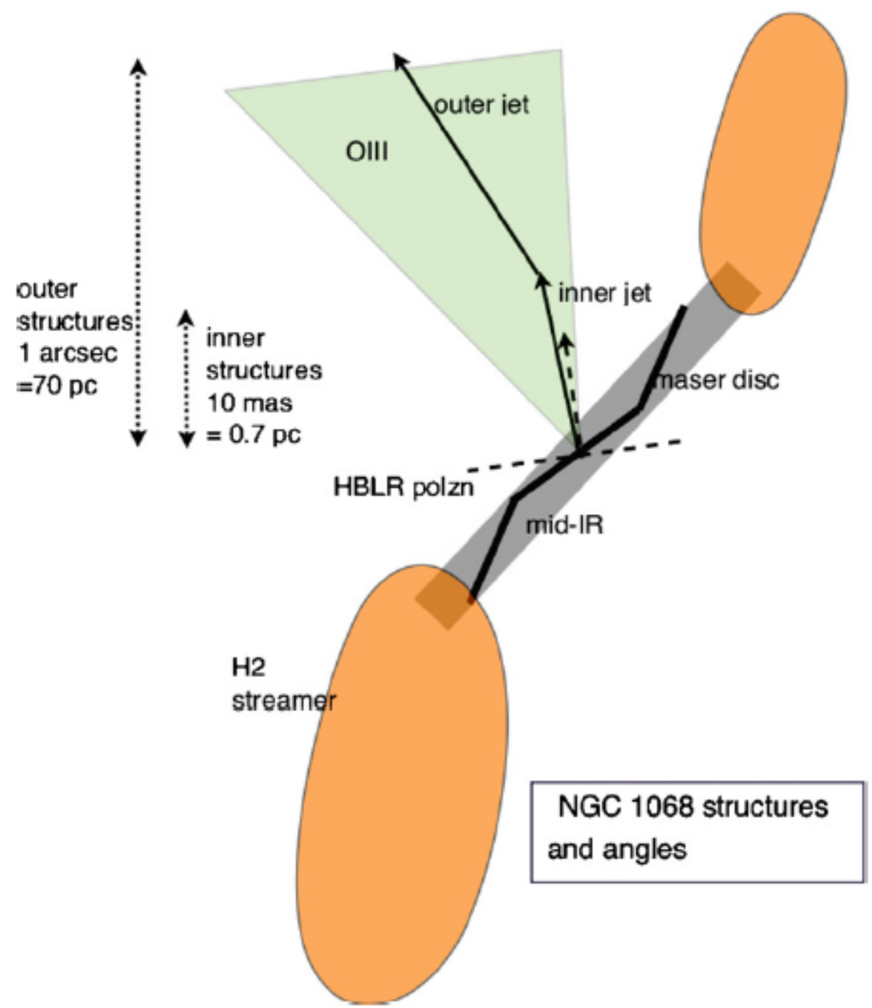
Predicts:

- correct Type1:Type2 ratio*
- Jet-obscurer axis misalignments

Observable with VLT-I MIDI?

Lawrence & Elvis 2010 ApJ, 714, 561



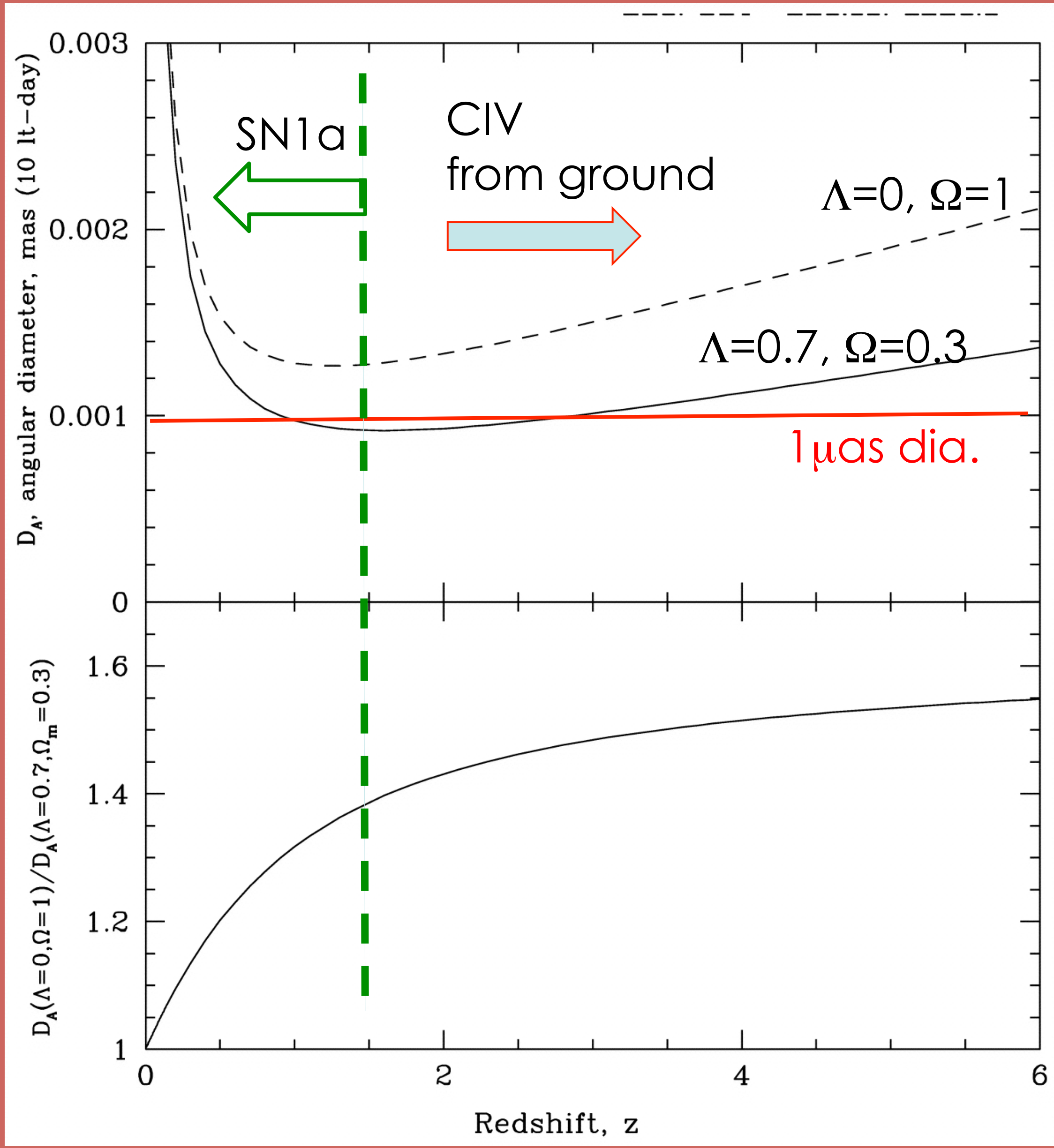


High Redshift Quasars

Cosmology: Angular dia. vs. Linear dia. = metric

Elvis & Karovska, 2002 ApJ, 581, L67

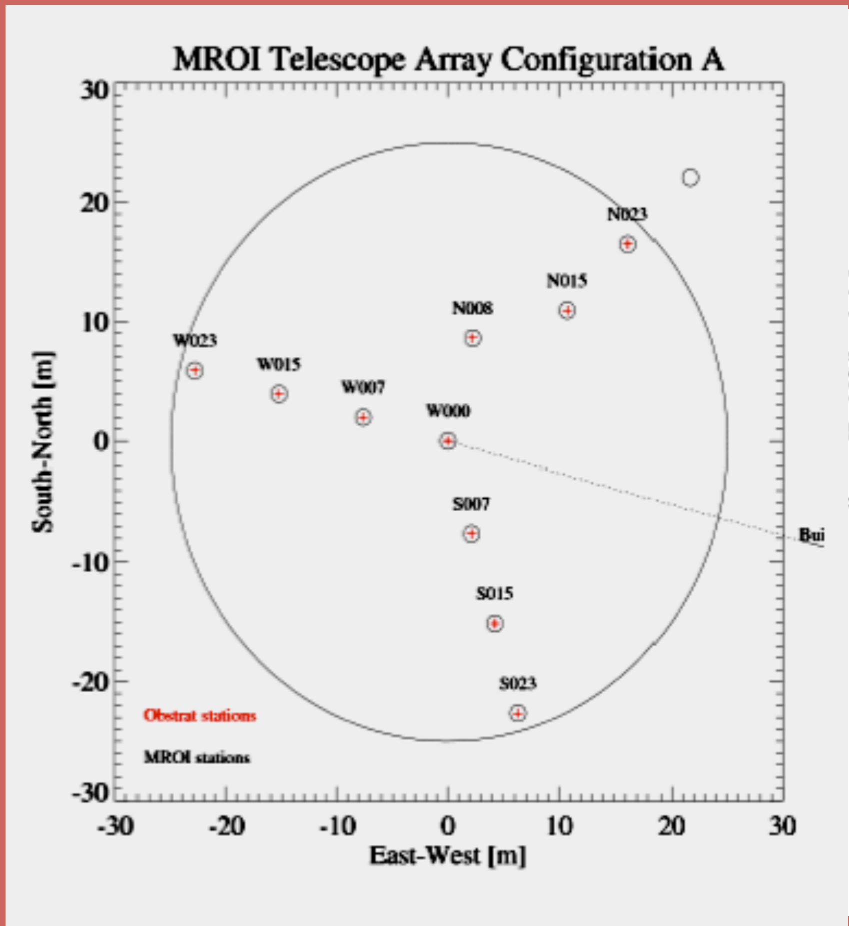
Angular dia. vs. z

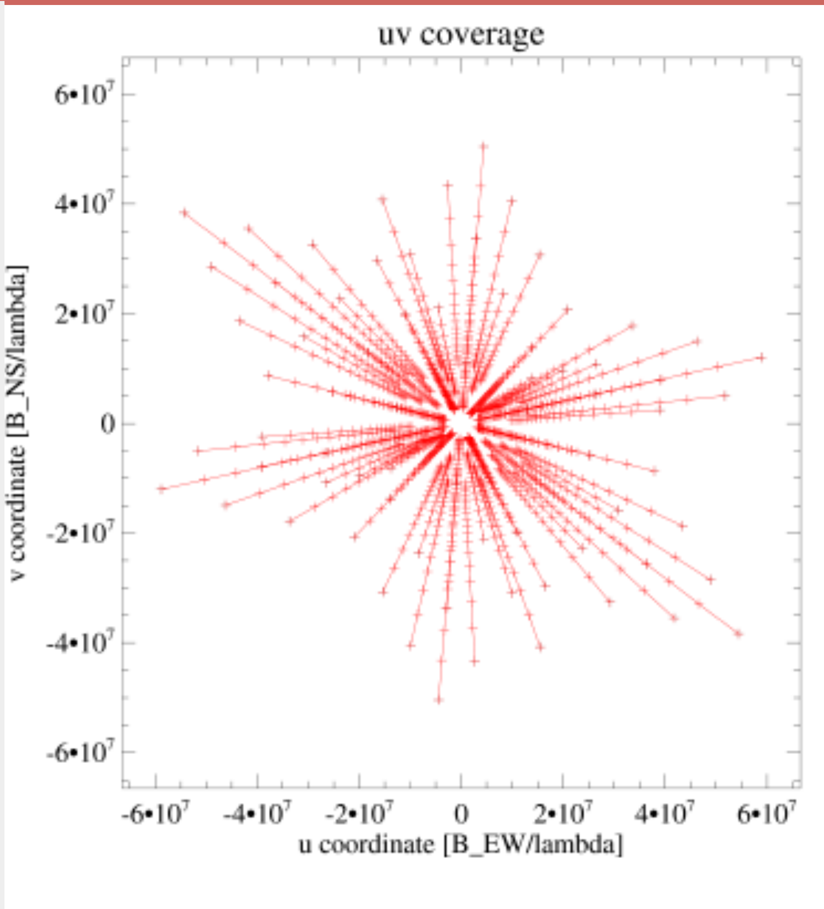


Magdelena Ridge Observatory Interferometer

Magdelena Ridge Observatory Interferometer

True imaging with many baselines: ~1mas ~0.1pc = Hot dust region

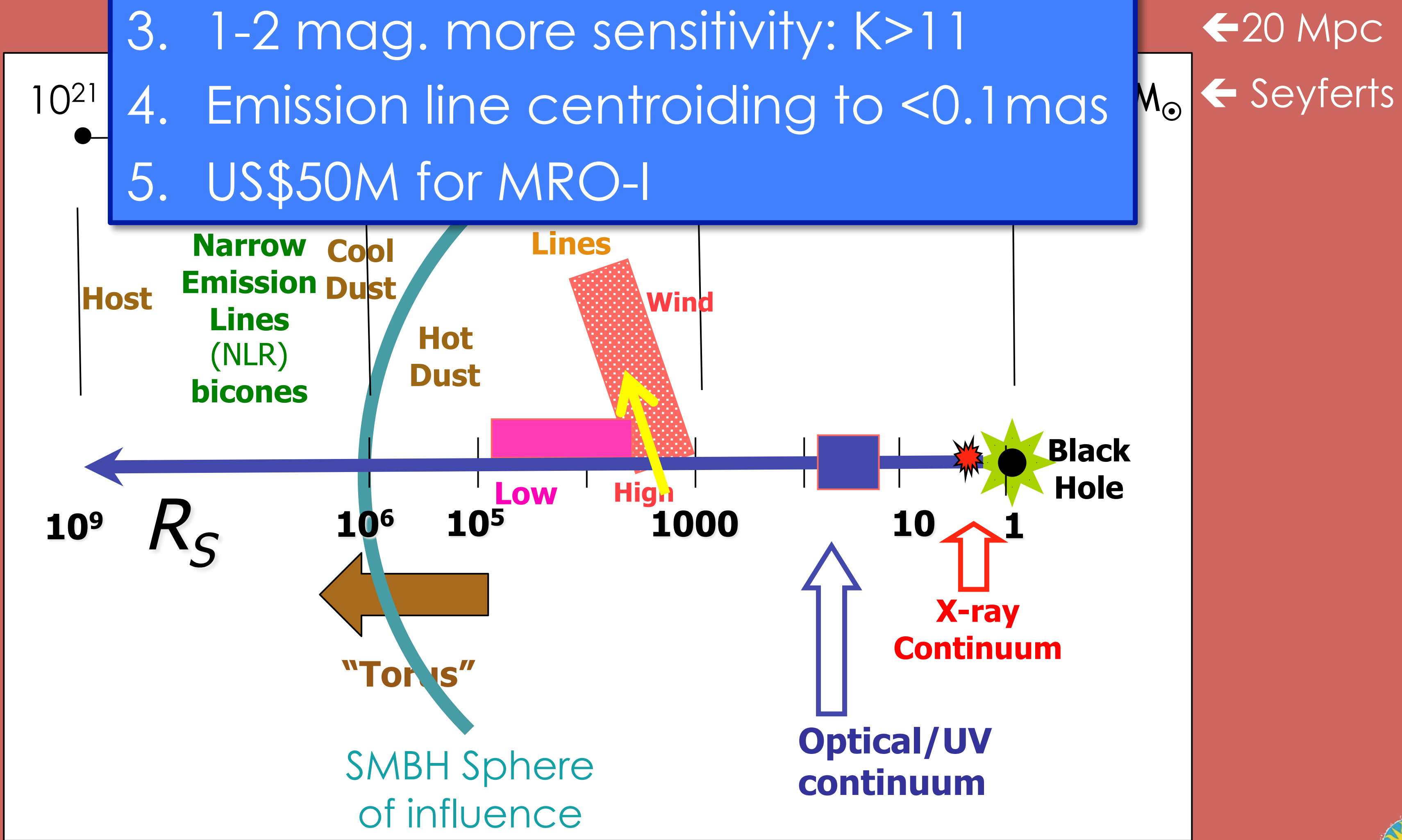




Sensitive enough to detect many AGNs:
Needs ~US$50M

AGN Interferometer Wish List

1. K ~0.1mas
2. N~1mas
3. 1-2 mag. more sensitivity: K>11
4. Emission line centroiding to <0.1mas
5. US$50M for MRO-I



Broader Interferometry Considerations

Movies, not Snapshots

Astronomy suffers from a 'static illusion'

What we can image changes on timescales longer than our lifetimes

At sub- arcsec resolution we start to see changing structures

At mas resolution *everything moves*

Qualitatively new view of universe

A partial list: *(please send additions)*

- Galactic Center stars (AO)
- HH-30 expanding jets (HST)
- Rotating pinwheel around WR104
- XZ Tau expanding jet (HST)
- Mizar A binary orbit
- V1663Aql - Nova expansion
- SN 1987A expansion/rings (speckle, HST)
- Crab nebula wisps (Chandra)
- Vela SN jet (Chandra)
- Superluminal radio jets (VLBA)

http://hea-ww.harvard.edu/~elvis/motion.html

Imaging Quasars

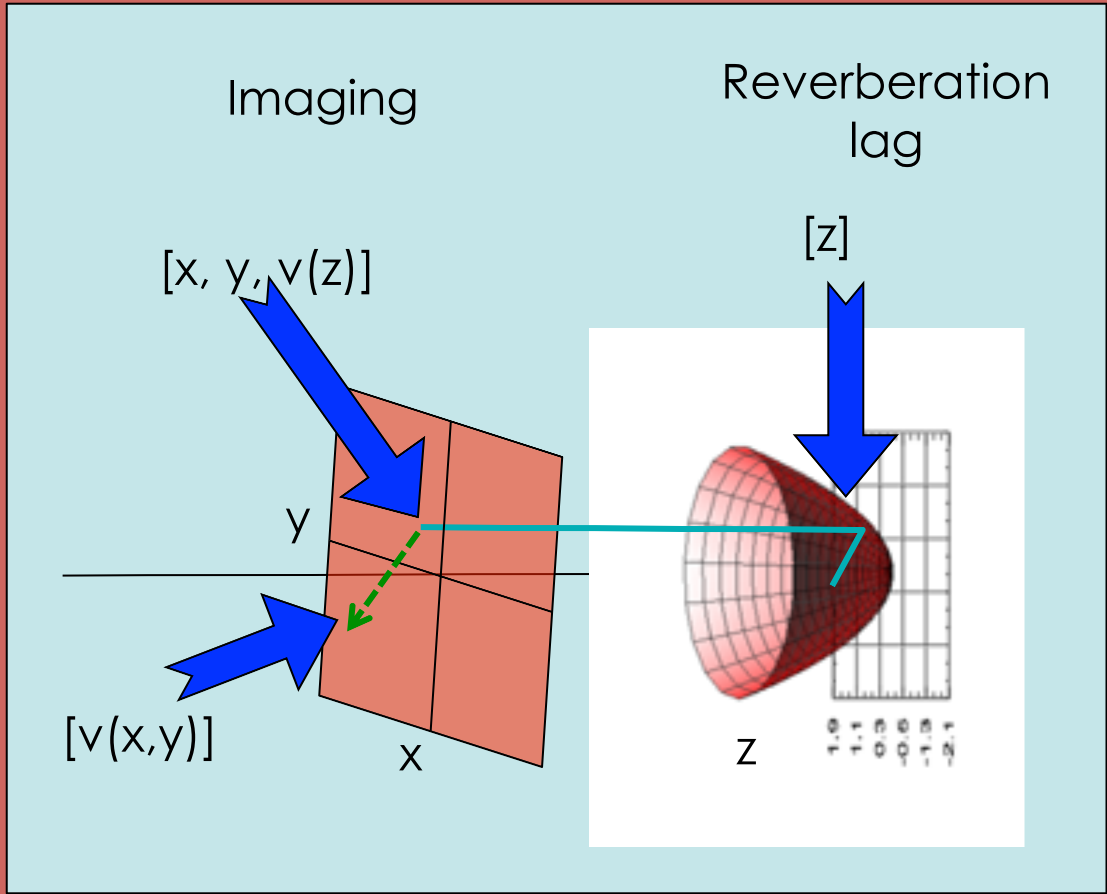
Elvis & Karovska, 2002 ApJ, 581, L67

What we really want is to *look* at quasar structure

Imaging reverberation mapping *of Broad Emission Line Region:*

6-D: 3 space, 3 velocity

Also hot dust region



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Elvis & Karovska, 2002 ApJ, 581, L67

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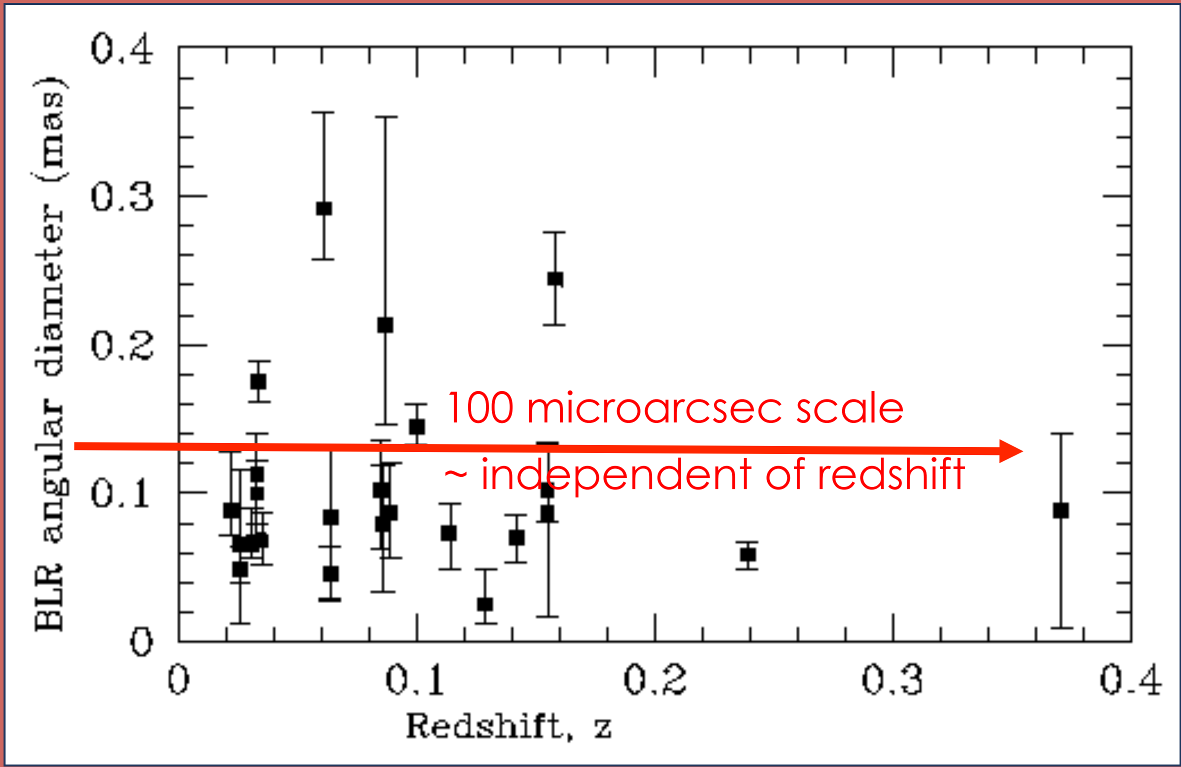


Ideal:

- 5 km-10 km IR 2μm interferometer at Antarctica Dome A or C, Greenland ice peak
- ½-1km UV space interferometer

A Sociological Note

Extragalactic astronomers don't ask for
high angular resolution because
what they do
doesn't need it

What they do
doesn't need
high angular resolution because
they *can't* do it

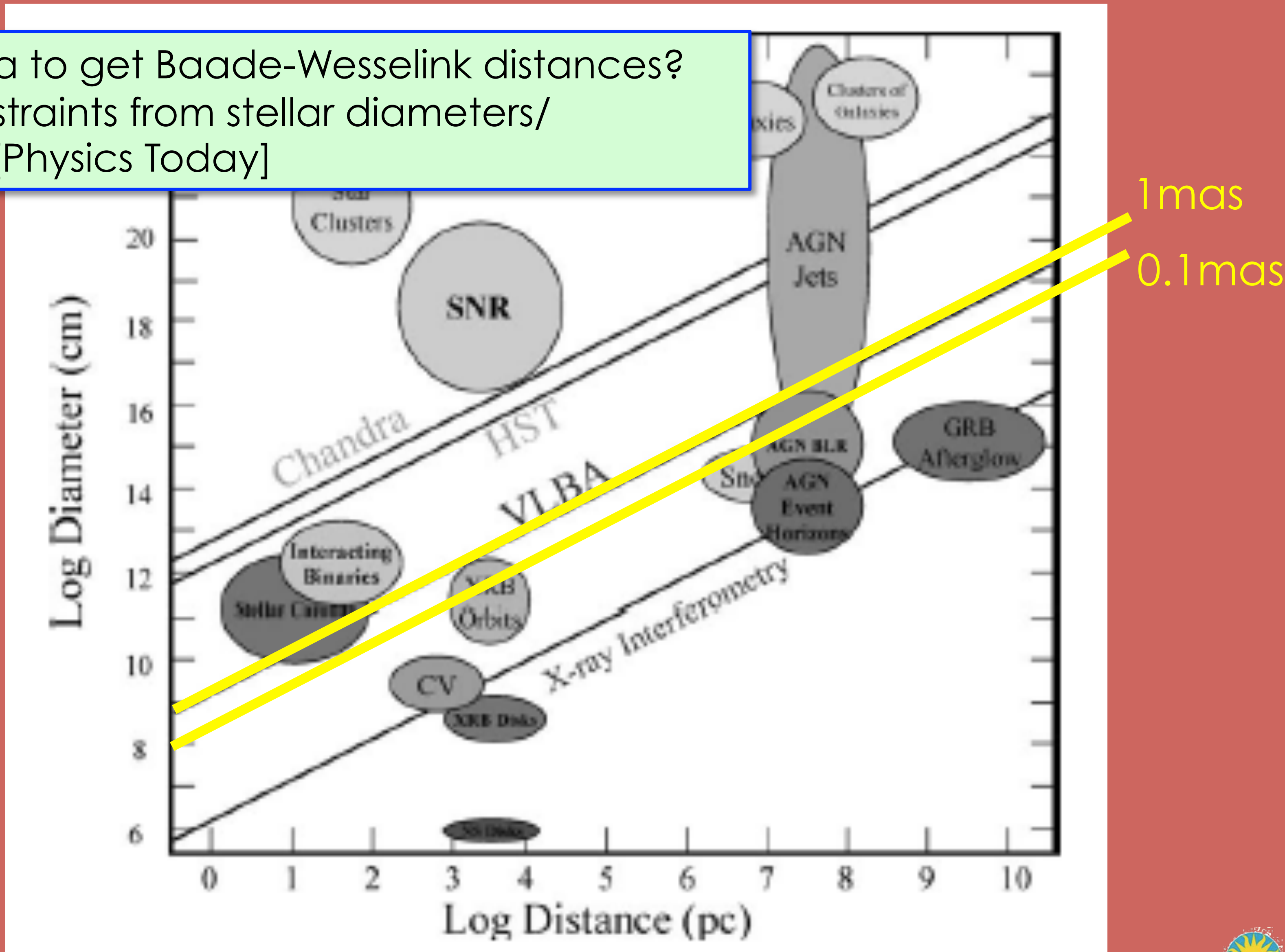
I.e. *They never thought about it*

Need to proseletyse

Angular Sizes of Astronomical Objects

Are we missing classes of objects?

- Image Sn1a to get Baade-Wesselink distances?
- axion constraints from stellar diameters/ pulsations? [Physics Today]



X-ray Interferometry

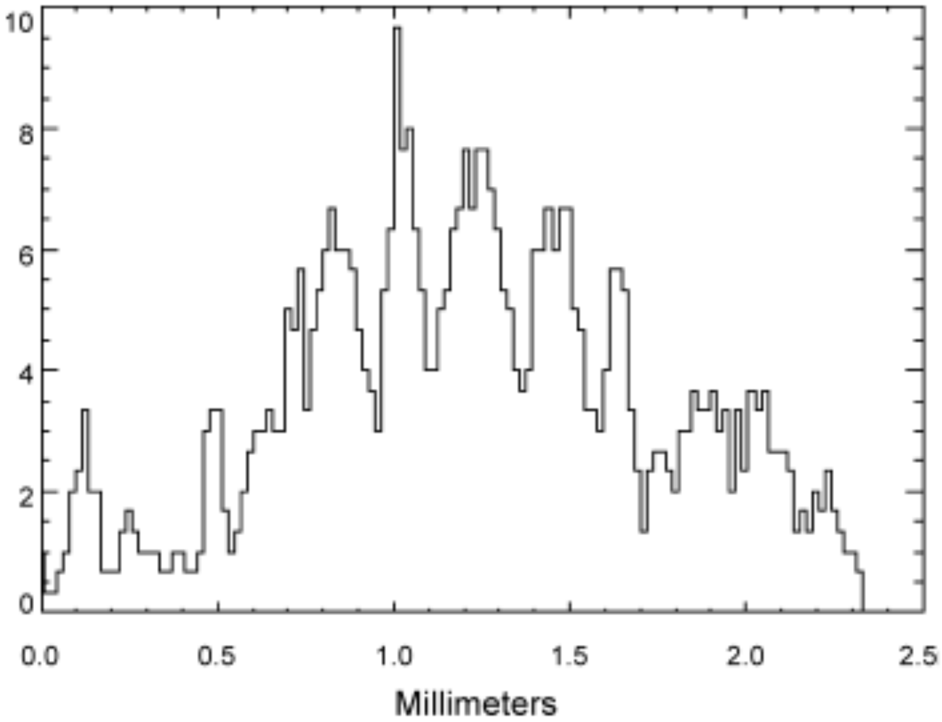


Figure 17. Fringes created with the double reflection interferometer have been achieved in the laboratory. The above fringes are from Cash et al. (2000).

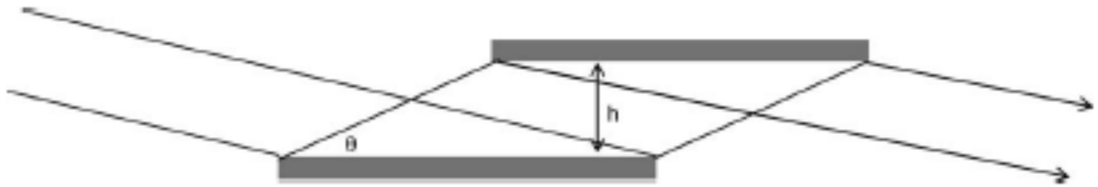
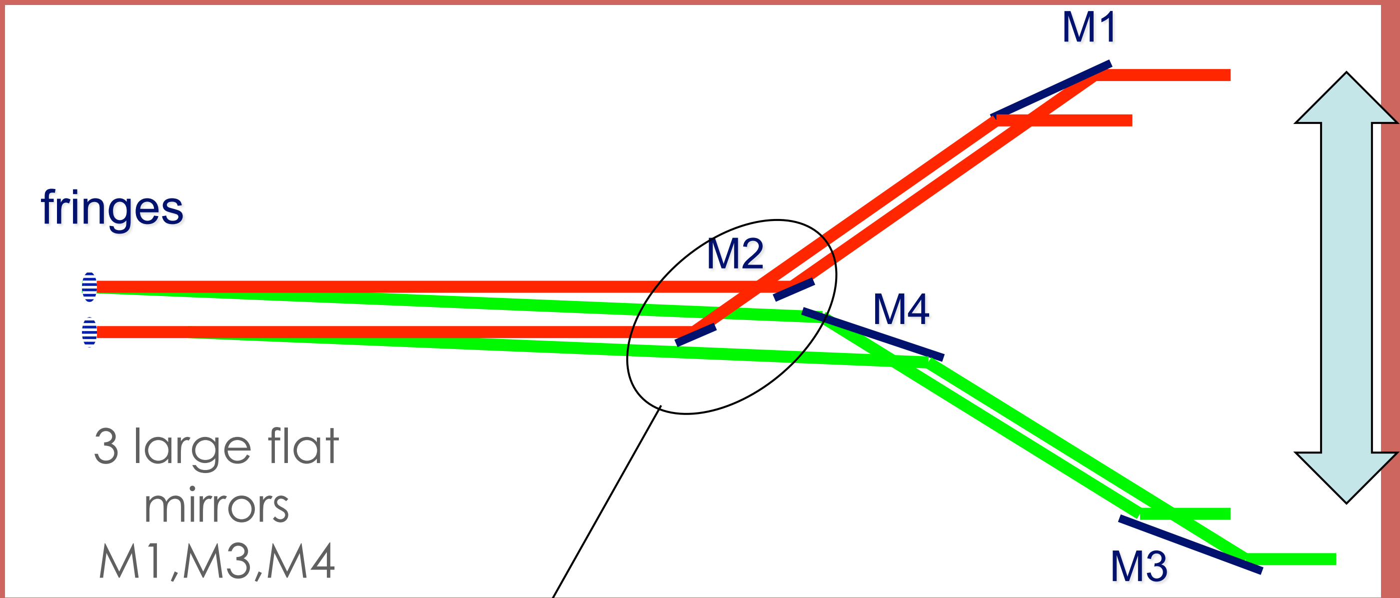


Figure 18. A two mirror periscope. h is the separation between the mirrors. $h \sin\theta$ is the delay in path length.

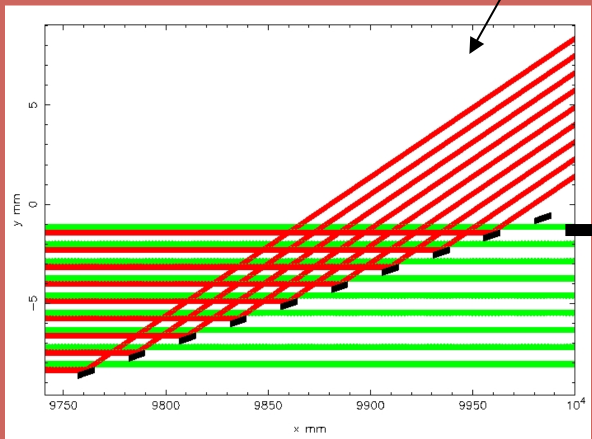
X-ray lab fringes
Cash et al. 2003
Nature

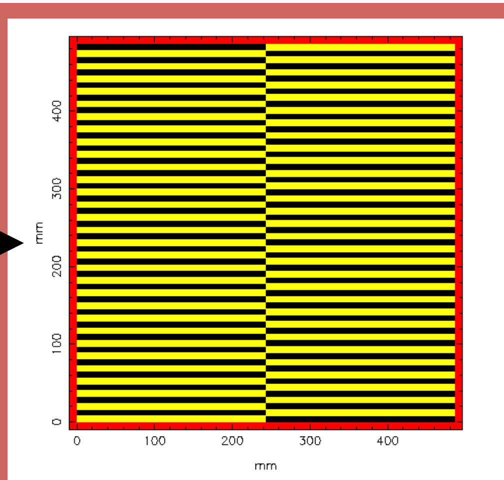
X-ray Telephoto Interferometer

Willingale, Butcher &Stevenson, 2005 SPIE, 5900, 432



~1 meter
~0.1mas
@ 1keV

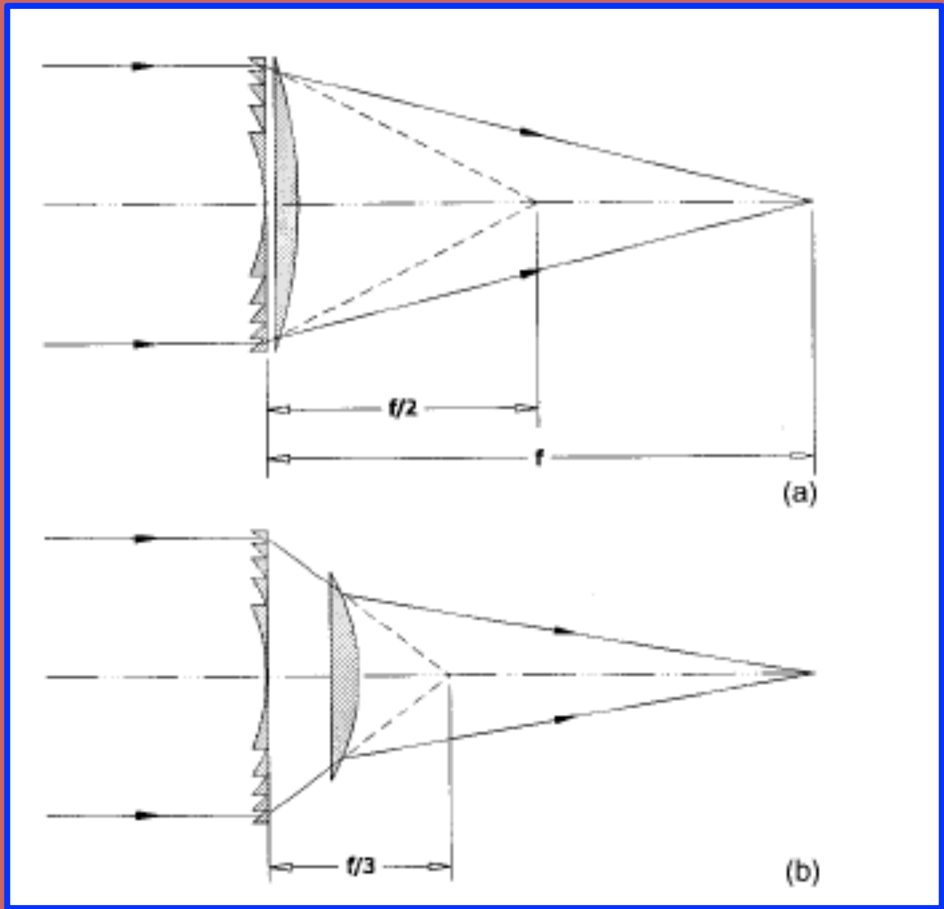




Nesting of parallel systems. Slatted mirror M2

Gamma-ray Interferometry

~0.1 μarcsec,
~100,000 km focal length



Fresnel/Laue Imagers
In Gamma-rays
Skinner G. , 2004
Applied Optics, 43, 4845