

Quasars: A Brief Introduction & the Continuum

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Lecture 1

Science Magazine 1 July 2005

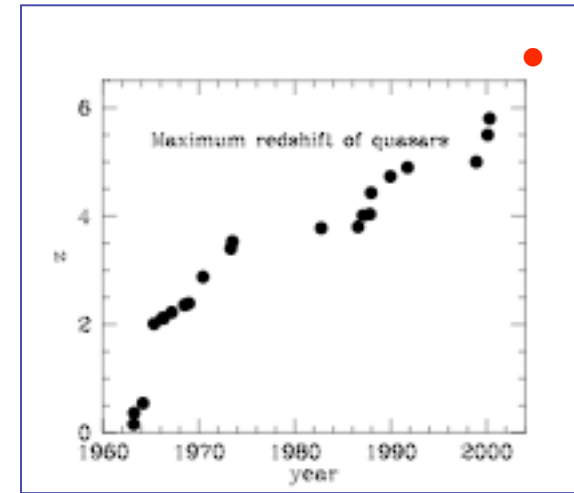
“125 Questions”: What don't we know?

#25: What power quasars?

“The mightiest energy fountains in the universe probably get their power from matter plunging into whirling supermassive black holes. But the details of what drives their jets remain anybody's guess.”

Quasars: A Quick History

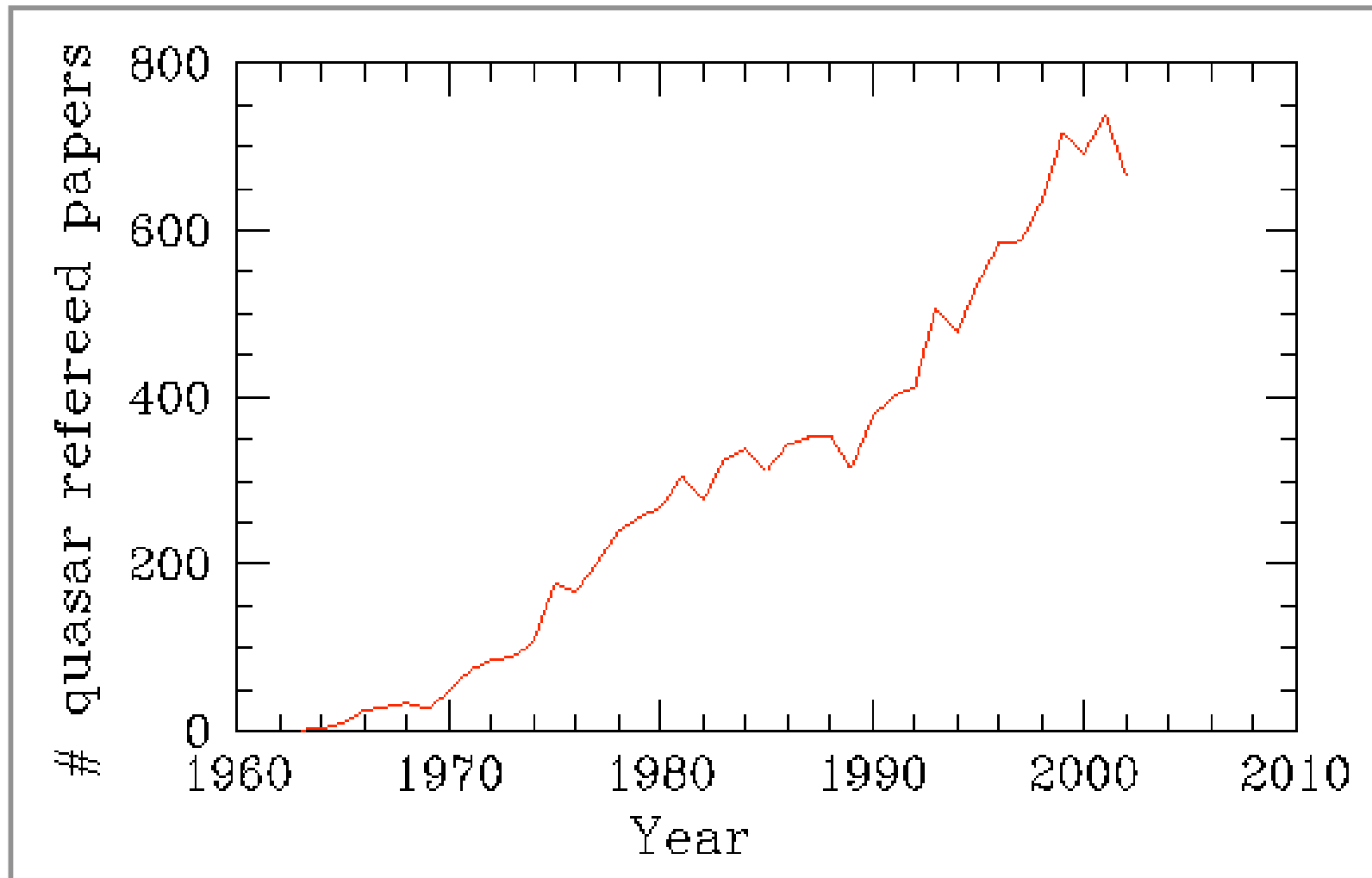
- 1917: Slipher - broad em. Lines from NGC1068
- 1918: Curtis - optical jet from M87 nucleus
- 1943: Seyfert- extremely broad lines in ~6 galaxy nuclei
- 1953: radio sources found to be double (but unidentified)
- **1963**: huge redshift (0.158) of radio star 3C273
 - Implies huge luminosity
 - Variability of 3C48 implies small size
 - **Shock!** Is redshift really cosmological?
- 1963-2006:
 - Redshifts above 6
 - >100,000 quasars
 - Pan-chromatic mapping
 - Black hole masses



12,277 Papers on Quasars since 1963*

*ADS to 4/18/03, refereed only, search on abstract containing 'quasar' | 'AGN'

1/day. Now 2 per day = 5% of all astronomy papers



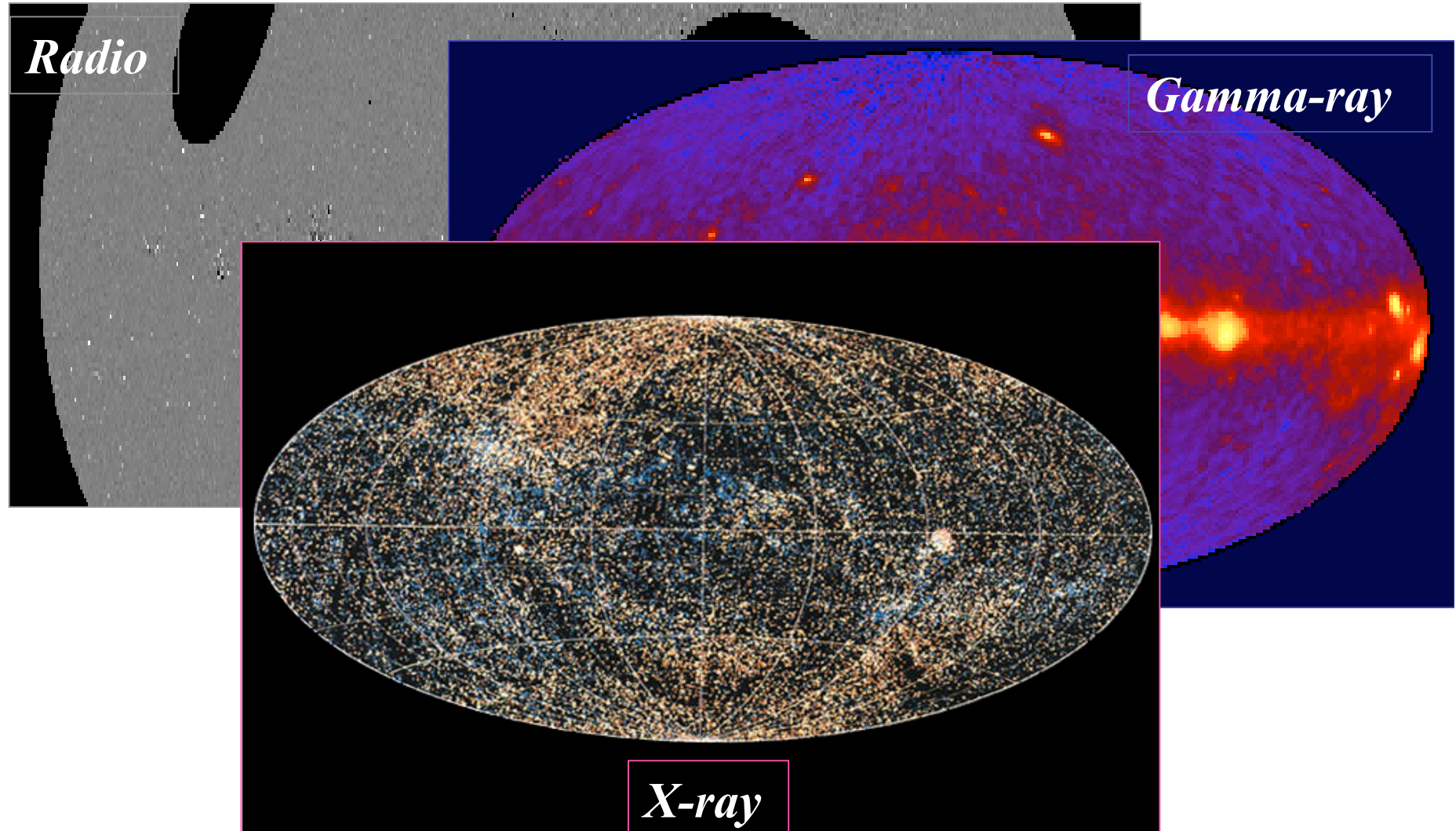
Terminology: Taming the Zoo

- I will use “*Quasar*” for all types of ‘non-stellar’ activity in galaxy nuclei
 - Often reserved for high luminosity objects
 - Originally only for radio-loud (obsolete)
- *AGN = Active Galactic Nucleus* is a near synonym of quasar
 - type 1 = broad em. Lines; type 2 = narrow em. lines
- *Blazar* is used for quasars with a relativistic jet pointing at us
- *Seyfert galaxy* = lower luminosity AGN, radio-quiet.
 - *Radio galaxy* is radio-loud version
- There are **many** other terms in the literature. They are *mostly* not worth learning.

Quasar
 AGN
 QSO
 Seyfert galaxy
 Type1/1.2/1.5/1.8/1.9/2
 NELG
 XBONG
 FR-I / FR-II
 Blazar
 BL Lac
 OVV
 Radio galaxy
 N-galaxy
 CSS
 GPS
 CSO

Why Study Quasars: 1. An Astronomer's Answer

Quasars dominate the sky over wide ranges of the spectrum

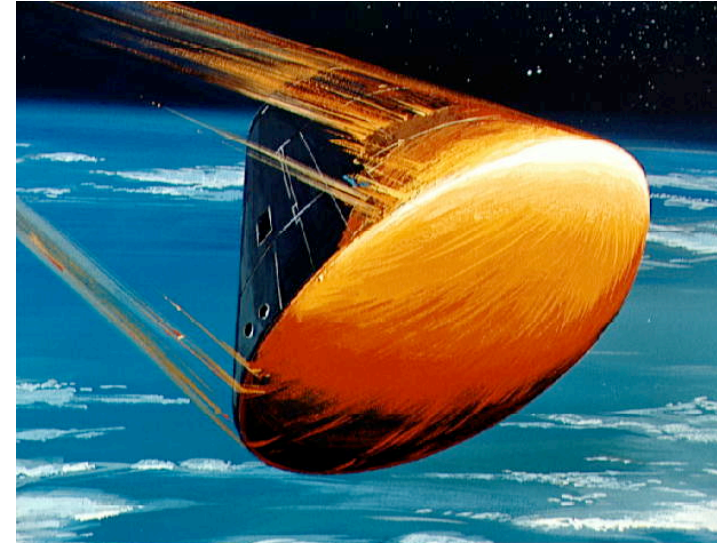


2. An Astrophysicist's Answer

Gravity powered, not fusion.

via **Black Holes** $10^6 - 10^9$ as massive as the Sun.
Gas heats up falling toward it, like a spacecraft
on re-entry.

The power available from gravity for heating is all
too obvious following the Columbia tragedy

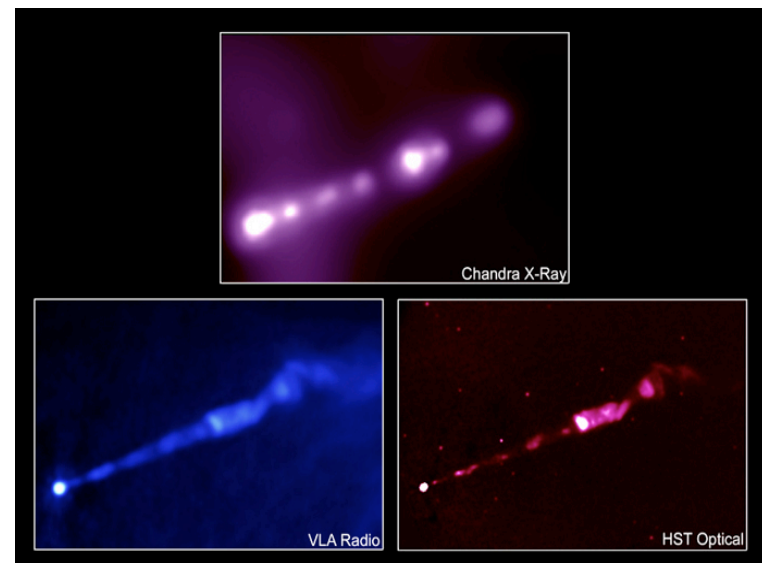


Emit strongly from radio to γ -rays.

How do they do that?

Billions of times brighter than
stars. *Can outshine a whole galaxy*

Make galaxy length jets

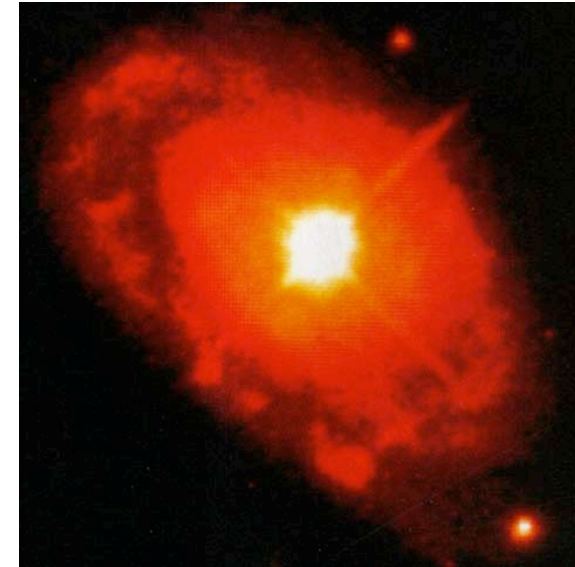


3. A Cosmologist's Answer

Quasars know about their host galaxies:

Galaxy mass and quasar black hole mass are tightly connected. Maggorrian et al, Ferrarese & Merritt, Gephardt et al.

*How? Should be governed by different processes. Requires **Feedback***



Emit up to 1/5 of power in Universe:

Important input, may dominate in some places, times.

Already exist at $t < 1 \text{ Gyr}$ ($z=6$)

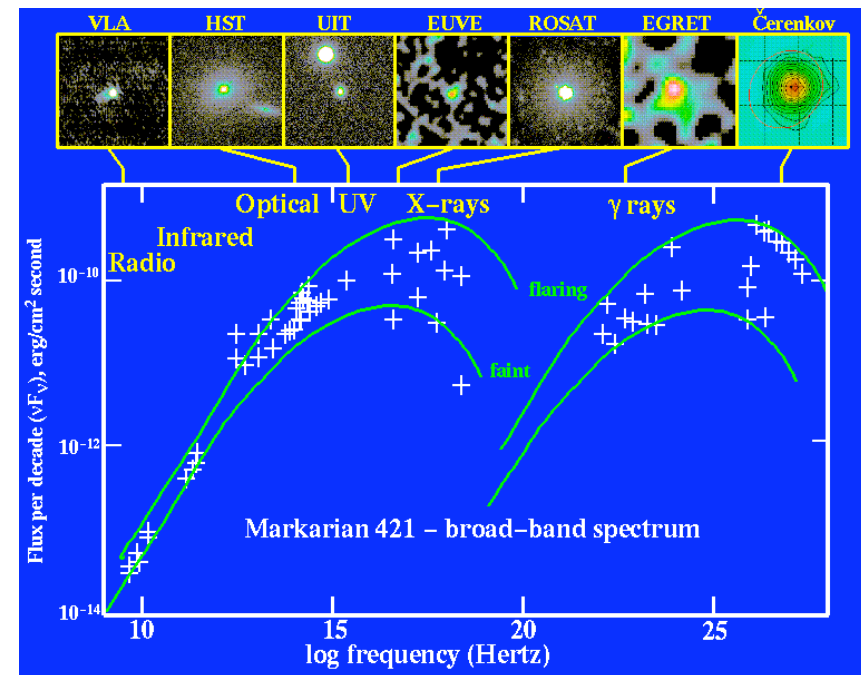
FIRST survey discovery, Becker et al.

$< 1 \text{ Gyr}$ from reionization at $z=11$

special role in early Universe?

reionization, seeding galaxies...

element creation, star formation catalyst via dust creation?



4. A Physicist's Answer

Eject bulk gas at 99.50% speed of light
 $\Gamma=10$

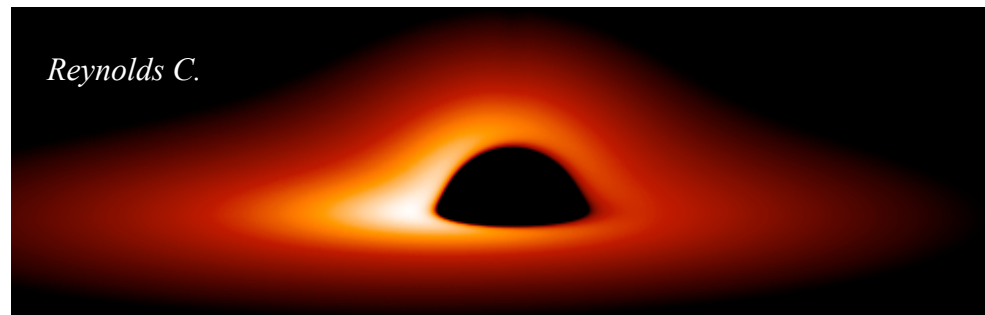
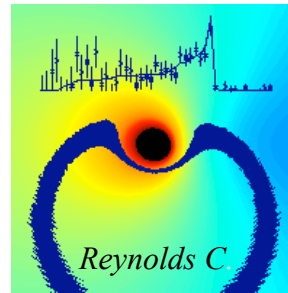
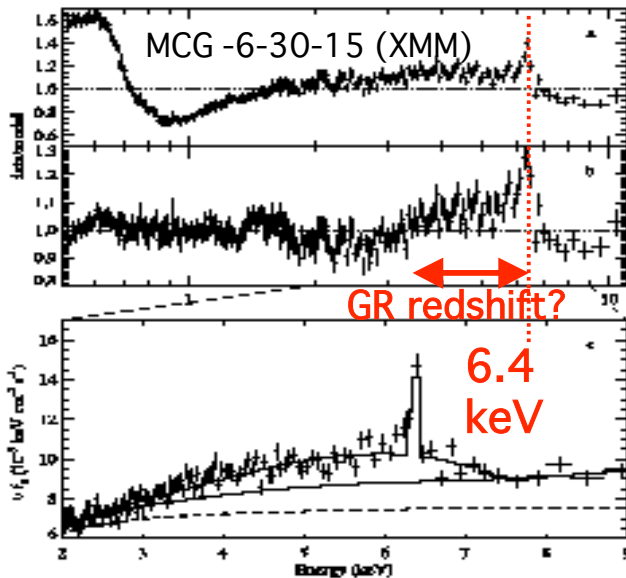
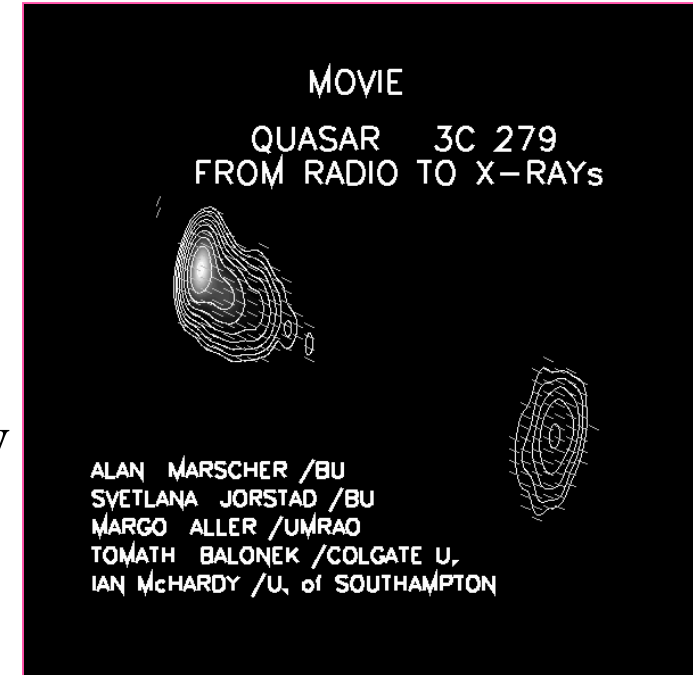
similar to proton in Fermilab Tevatron 99.88% c

Impacts gas of intergalactic medium. \rightarrow what emerges?

Accelerates e^- to $\gamma \sim 1000 \rightarrow$ TeV photons

X-rays come from region of Strong Gravity

seen in 6.4 keV 'Fe-K' (=Fe Lyman- α) emission line?



Quasars compared with Stars

Property	Stars range value	Quasars range value
Luminosity range	10^9 $10^{-4} - 10^5 L_{\odot}$ (M8-O5)	$>10^7$ $10^7 - 10^{14} L_{\odot}$
Mass range	1000 $0.05 - 50 M_{\odot}$	1000 $10^6 - 10^9 M_{\odot}$
Temperature range	10 $3,000 \text{ K} - 50,000 \text{ K}$	$\sim 10?$ [big blue bump]
Lifetime	$10,000$ $1 \text{ Myr} - 10 \text{ Gyr}$	$<1000?$ $\sim 10 \text{ Myr} - 10^? \text{ yr}$
Spectra	\sim black body	\sim power-law

Why Study Quasars?

Seven Quasar Mysteries

- Enormous luminosities from tiny regions
 - Fusion power is inadequate **Alessandro Marconi**

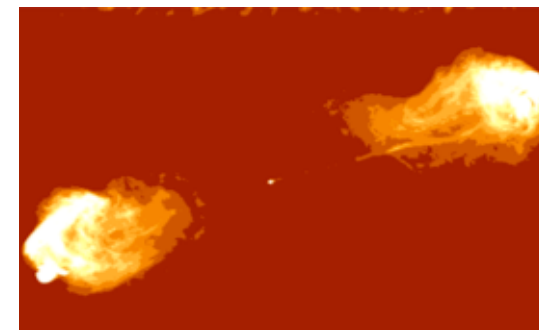
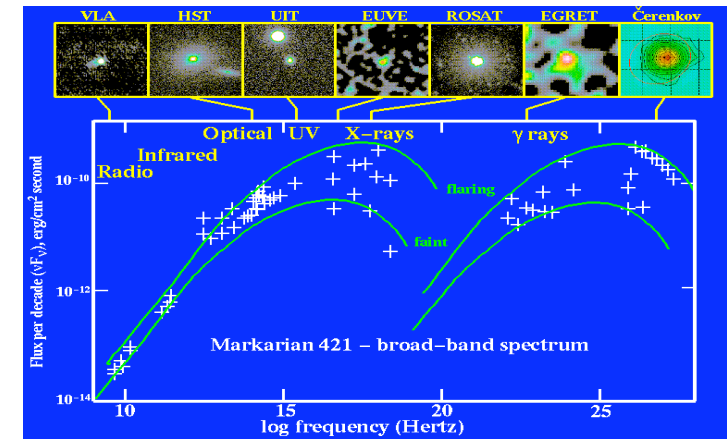
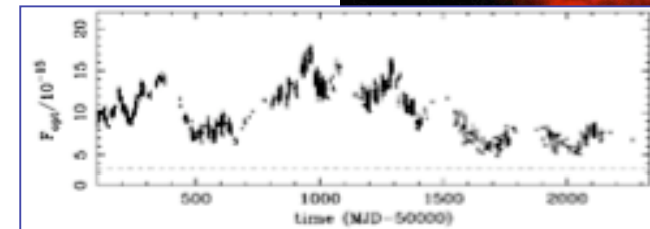
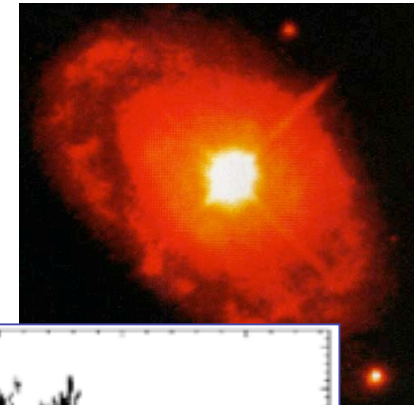
- Spectra that are nothing like starlight
 - similar power/decade from Far-IR to X-ray **This lecture**

- Accelerate material to high velocities
 - $V \sim c$ **Annalisa Celotti,**
- Linear symmetry **Tiziana Venturi**
 - 'spherical cow' models not much use

- Far less common now than in the past
 - Evolution. Not a steady state universe

- Most are not radio sources '*radio-quiet*'
 - Though first discovered in radio

- Most are hidden optical sources
 - Obscured by dust and gas **Günther Hasinger**



Lecture 1: The Quasar Continuum

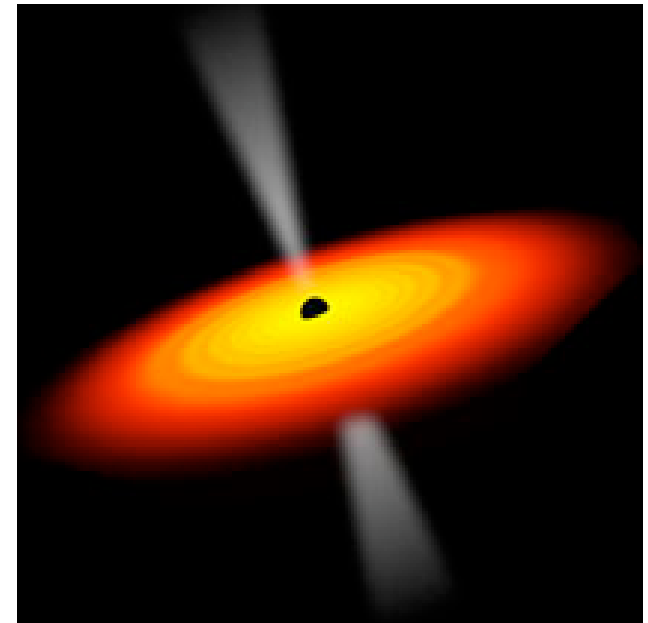
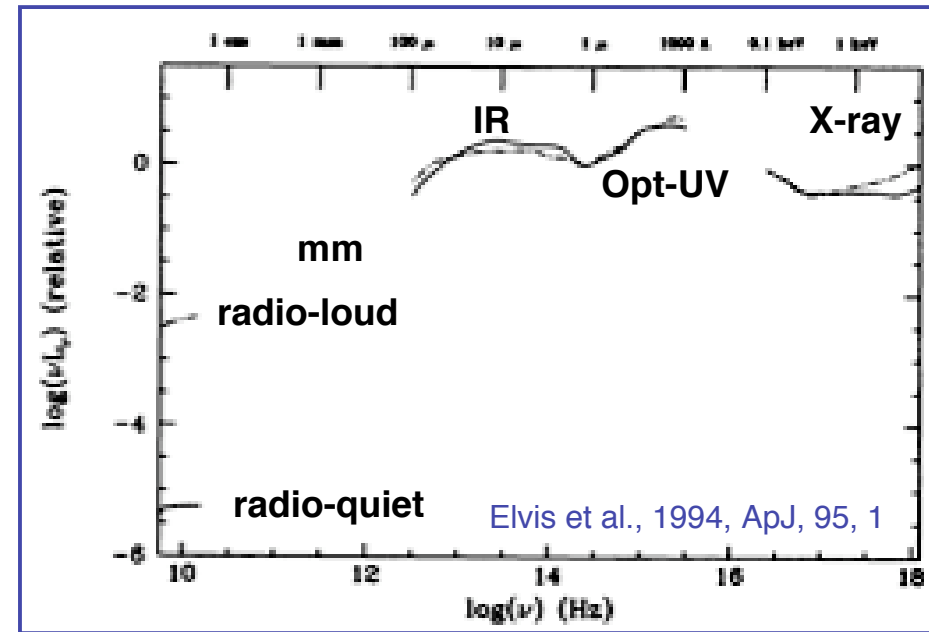
- The central problem:
 - Luminosities of a Galaxy from a Solar System sized region
 - Requires high efficiency of rest mass to luminosity conversion, $\epsilon \gg 1\%$ of fusion
 - Black holes [Lynden-Bell 1969](#)
- Plan:
 1. Description of radio to X-ray continuum; range of properties
 2. Likely mechanisms for each part; questions
 3. How we can make progress
 - Industrial methods
 - Physical correlations

Quasars SEDs are interesting because...

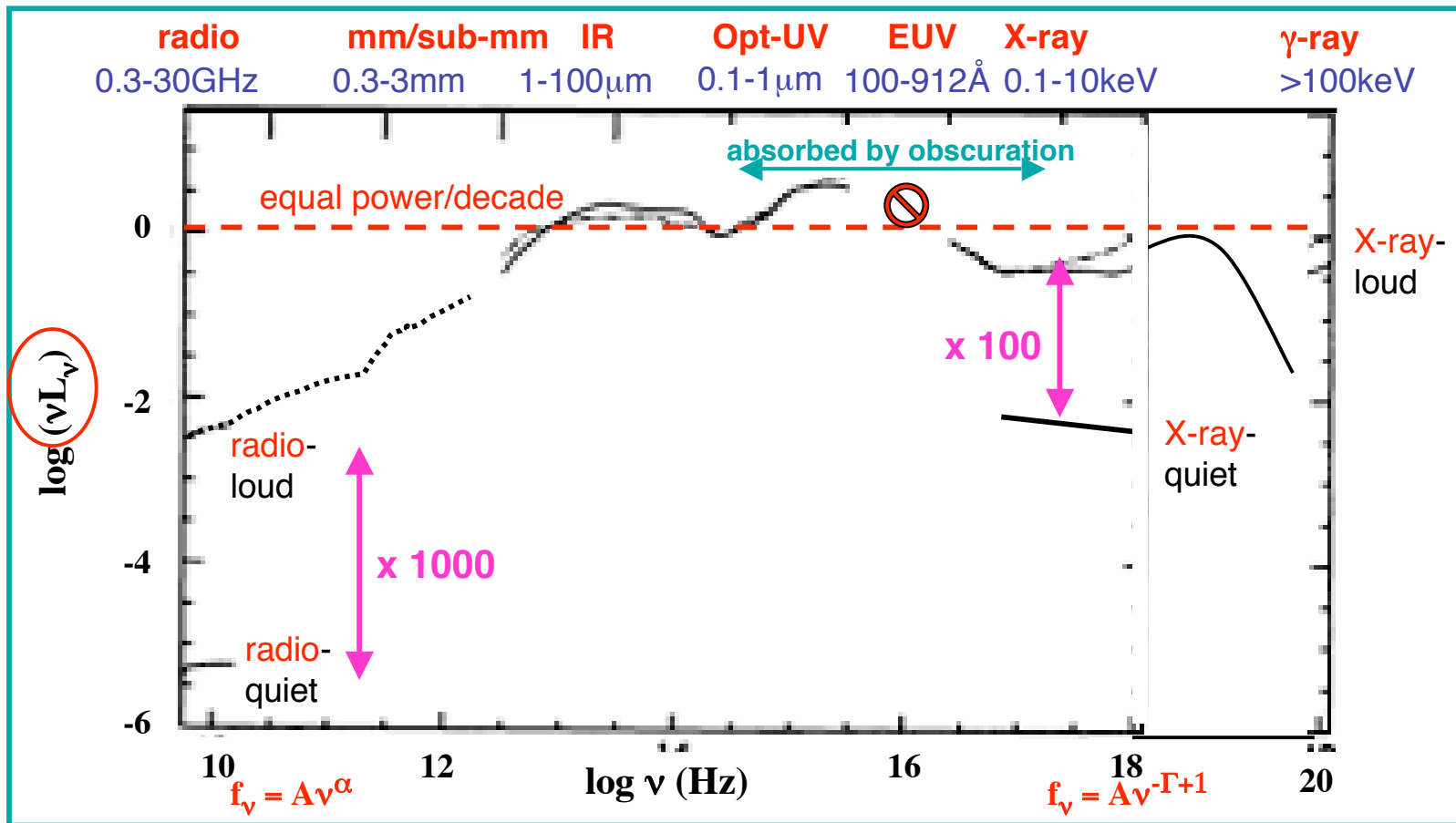
- **Black hole growth** occurs mostly during ‘active’ quasar phase.
- Black Hole and Galaxy mass are correlated: **M - σ_v relation**
- Quasars contribute a **substantial fraction of the luminosity of the Universe**: 5%-25% L_{universe} [Fabian & Iwasawa 1999](#), [Yu & Tremaine 2002](#), [Elvis, Risaliti & Zamorani 2002...](#)
- Quasars form **the X-ray background**
- May determine **Black hole Spin**
- High **Black hole accretion efficiency**
 - Soltan argument + $L_{\text{acc}}(\text{Universe})$

And, of course...

- **#25: What power quasars?**
 - Physics of accretion (disks)
 - vs. BH mass, acc. Rate



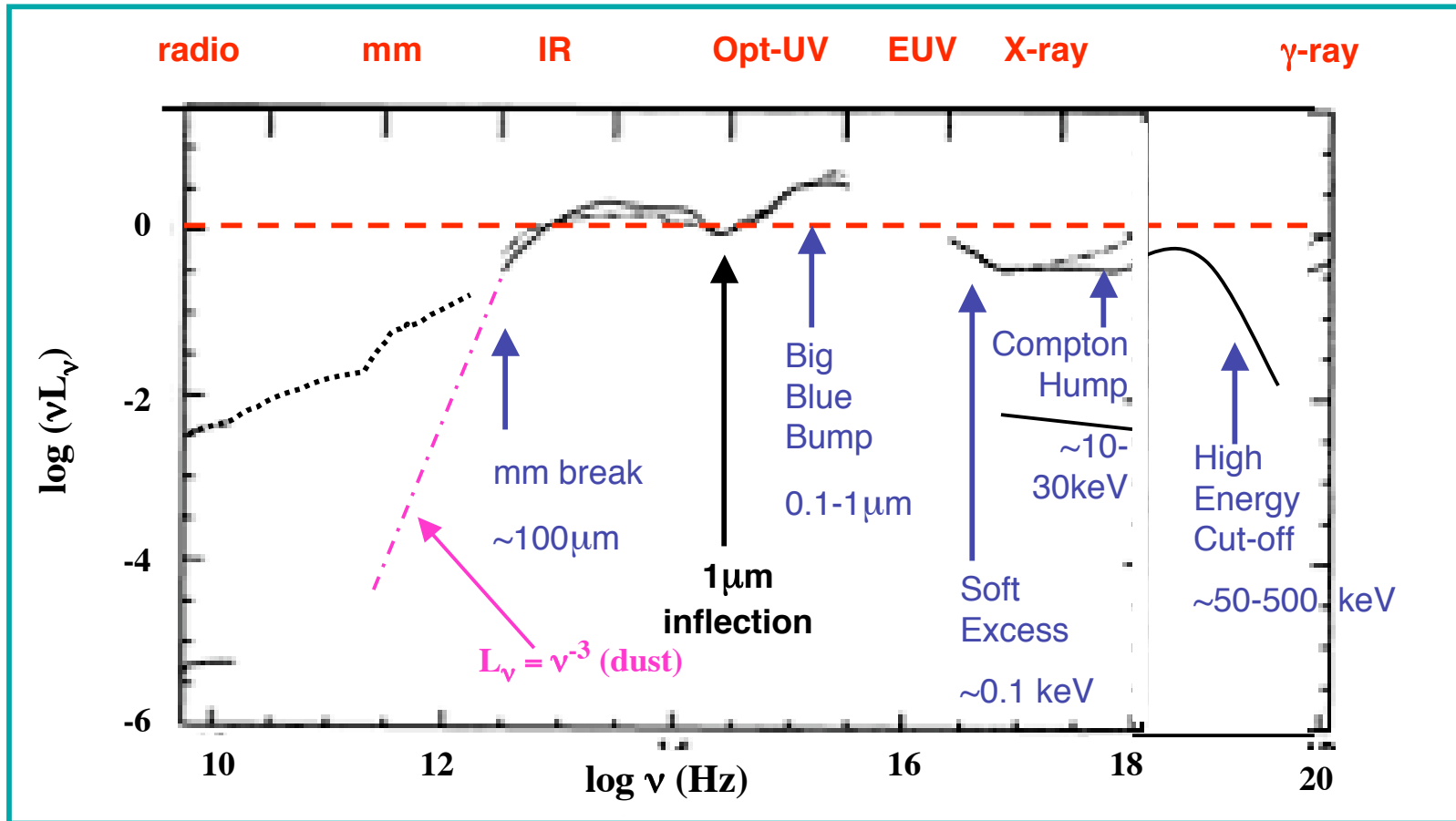
Quasar Continuum: A Field Guide



Quasar 'Spectral Energy Distribution' (SED)

Elvis et al., 1994, ApJS, 95, 1

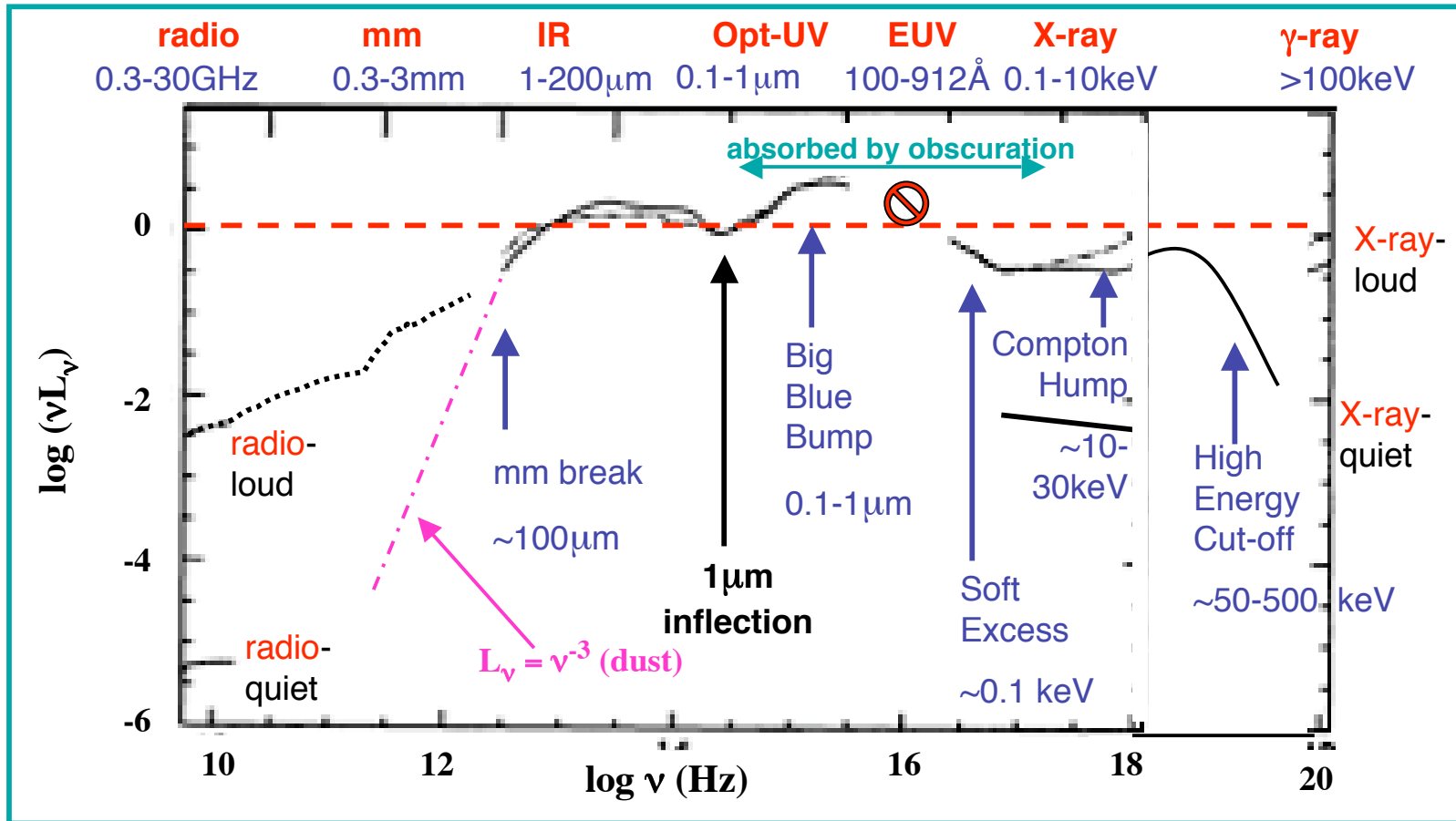
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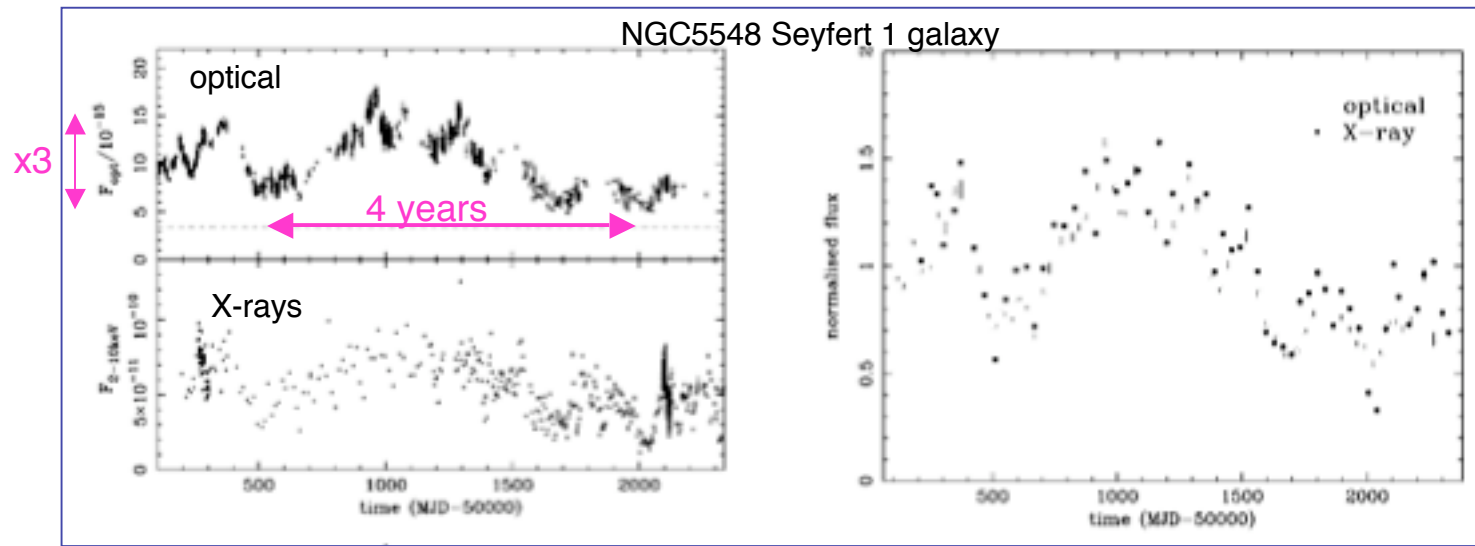
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Quasar 'Spectral Energy Distribution' (SED)

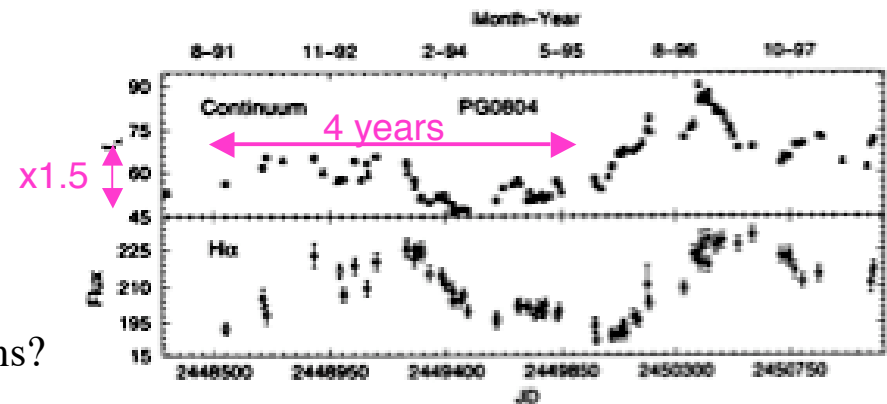
Elvis et al., 1994, ApJS, 95, 1

Quasar Continuum Variability



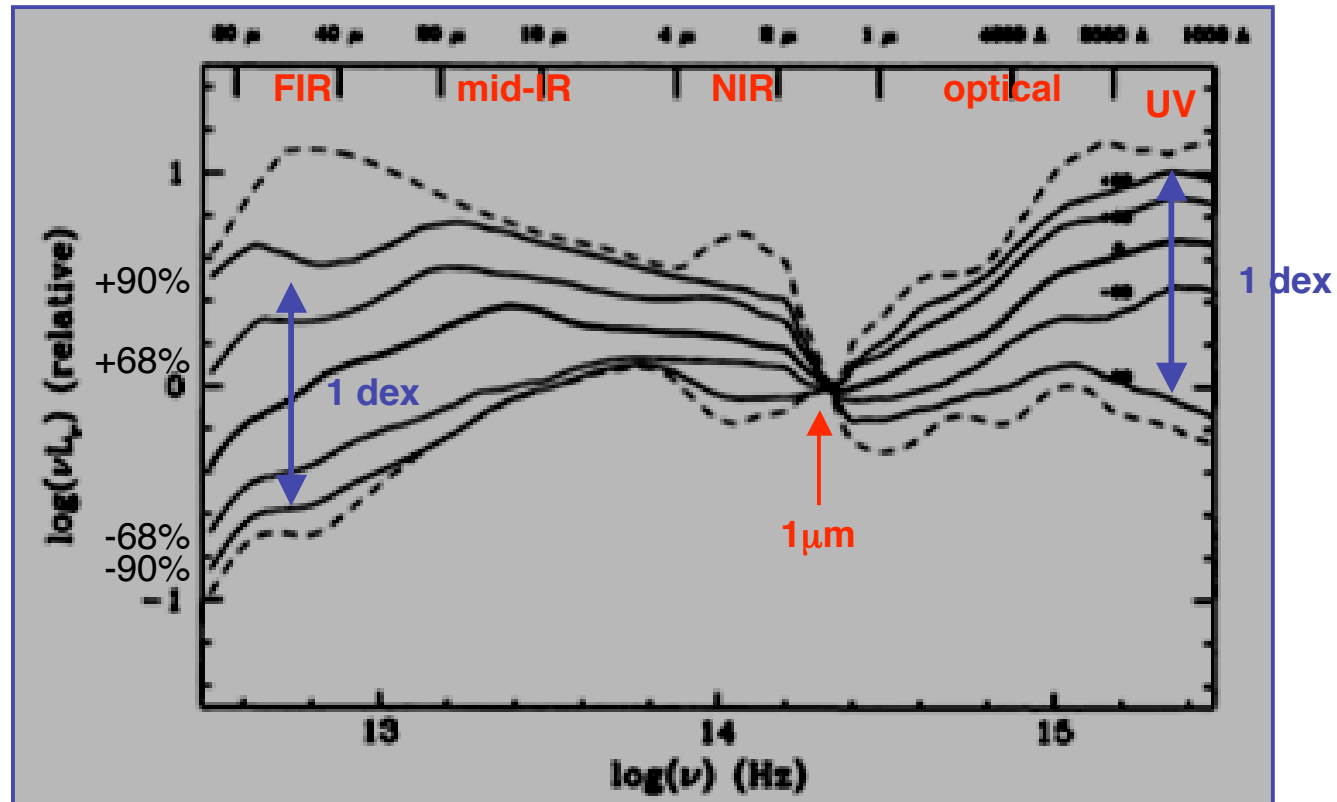
Uttley et al. 2003, ApJ, 584, L53

- Typical variability:
 - X-ray: factor 2 in \sim months
 - Optical: slightly larger amplitude
 - Starlight/non-blue-bump dilution
- ⇒ Small emission region
- correlated on \sim 1yr timescale
 - Disk instability? Local m_{dot} variations?
- Smaller, slower at high L



Kaspi et al. 2000, ApJ, 533, 631

Diversity of X-ray to Radio SEDs of Quasars



SED spread: No theory, no correlations

Elvis et al., 1994, ApJ, 95, 1

Two primary sources of continuum in Quasars

massive black hole

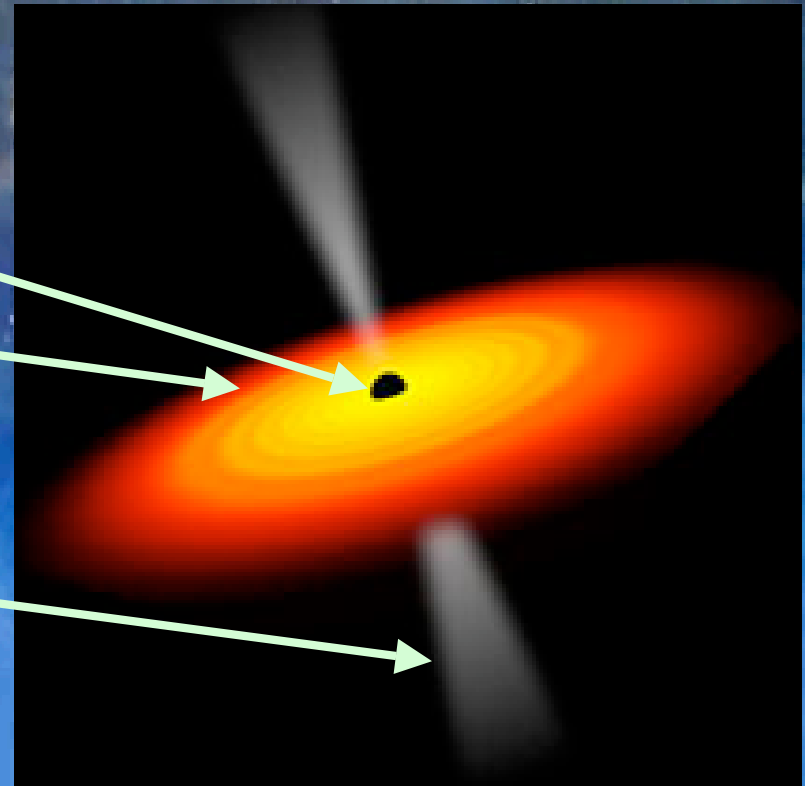
Lynden-Bell 1969

1. accretion disk

Lynden-Bell 1969, Pringle & Rees 1972,
Shakura & Sunyaev 1972

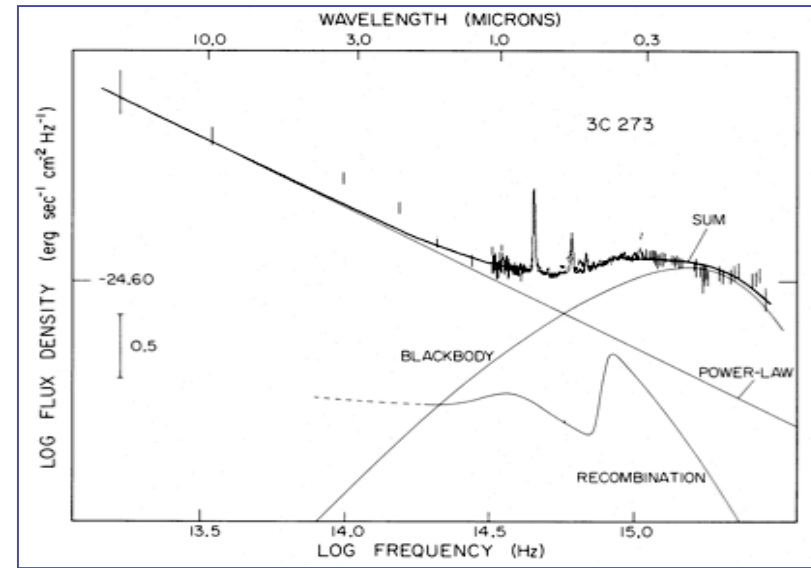
2. relativistic jet

Rees 1967 [PhD], Blandford & Rees 1974



Big Blue Bump = Accretion Disk?

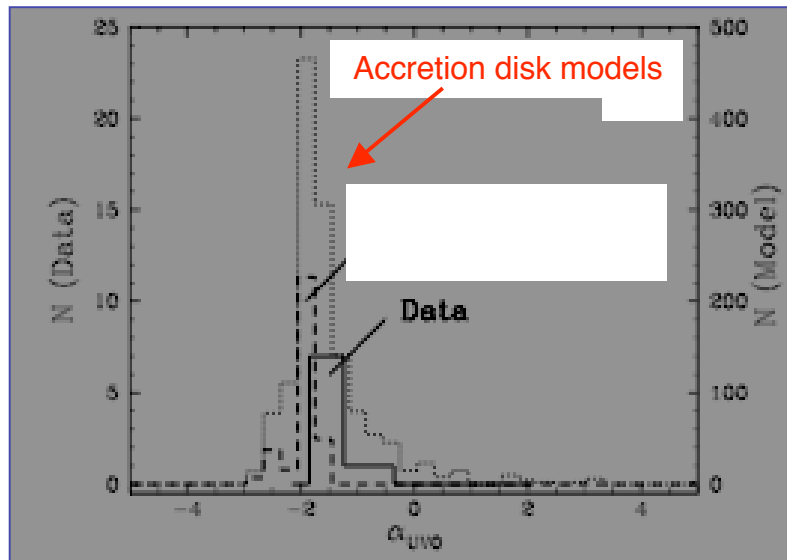
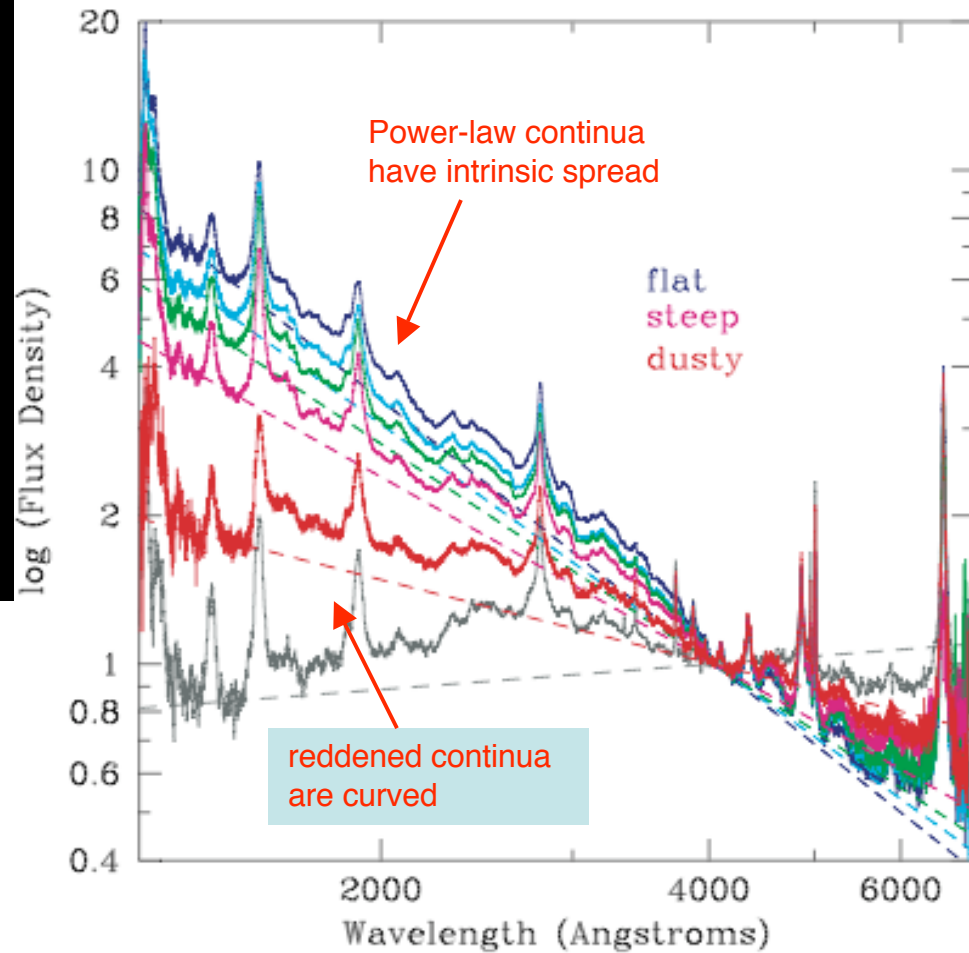
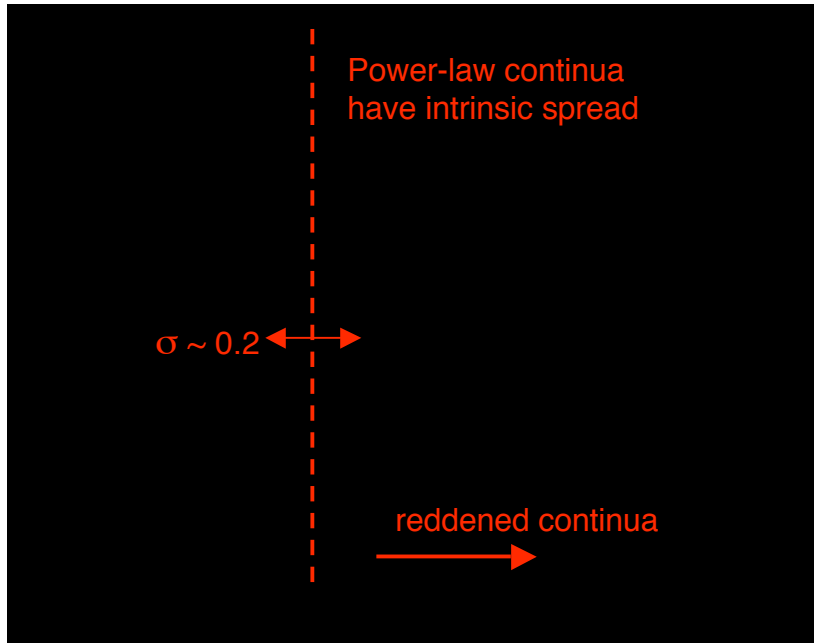
- Broader than a black body
 - Even reaches soft X-ray?
- Dominates luminosity
 - By factor few, usually
 - => primary radiation
- Universal
 - Though sometimes reddened, or dominated by jet.
- Weak redshift or luminosity changes
- Variable
 - no color dependence (when host is removed)
 - Factor 2 in months (Seyferts)
 - Less, slower at high L
- Accretion disk?
 - Roughly right shape
 - Ly-edge, polarization [Kinney et al](#)
 - Alternative: free-free [Barvainis 1993, ApJ, 412, 513](#)
- Underlying power-law?



Malkan & Sargent 1982, ApJ, 254, 22

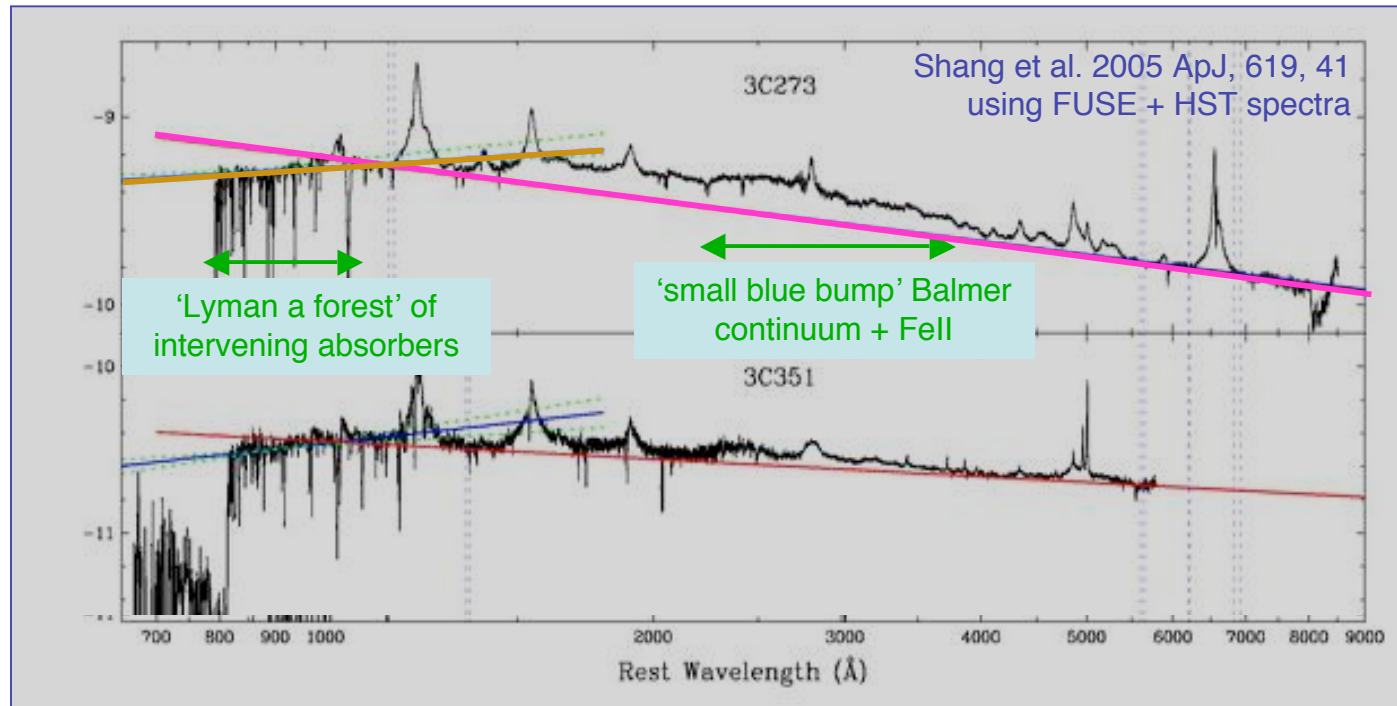
Big Blue Bump: long wavelength slope

Richards et al. 2002, ApJ, 126,1131. SDSS



Shang et al. 2005 ApJ, 619, 41
FUSE + HST spectra

Big Blue Bump: break at 1100Å

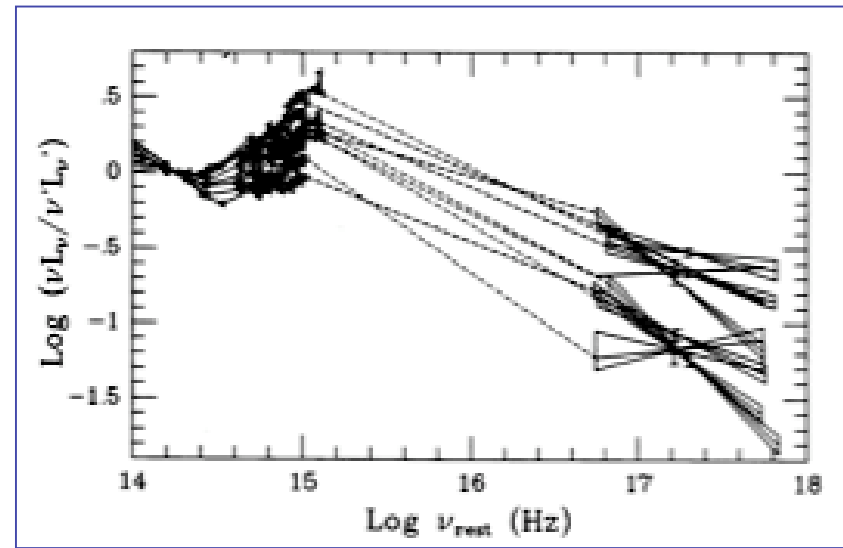


- Broader than a black body

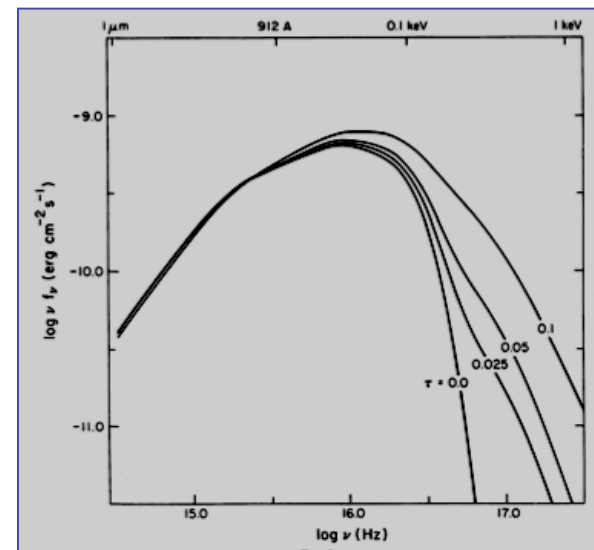
Zheng et al. 1997 ApJ,

Big Blue Bump: Connection to soft X-ray?

- Broader than a black body
 - Even reaches soft X-ray?
- Dominates luminosity
 - By factor few, usually
 - => primary radiation
- Universal
 - Though sometimes reddened, or dominated by jet.
- Weak redshift or luminosity changes
- Variable
 - no color dependence (when host is removed)
 - Factor 2 in months (Seyferts)
 - Less, slower at high L
- Accretion disk?
 - Roughly right shape?
 - Or is a power-law closer?



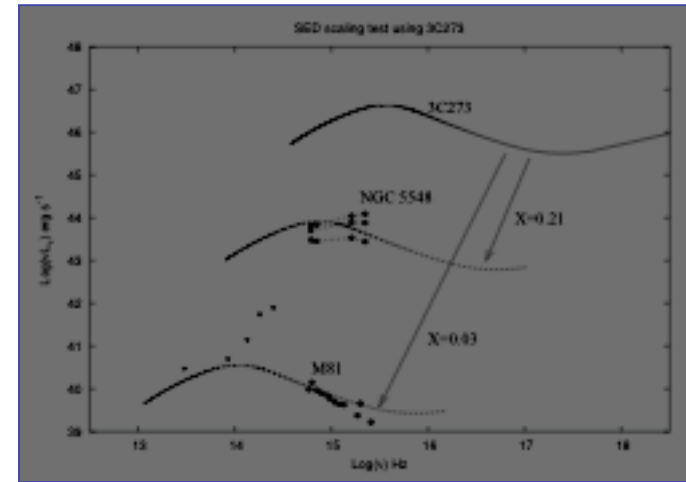
Laor et al. 1997 ApJ, 477, 93



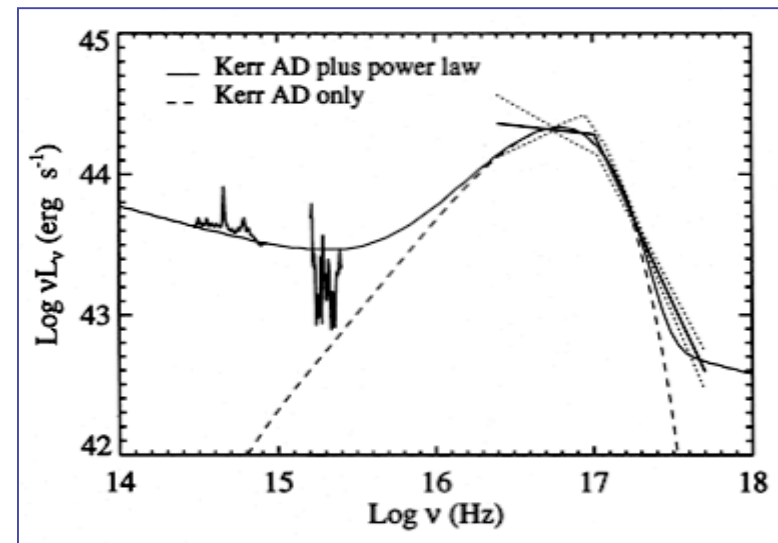
Czerny & Elvis 1997 ApJ, 321, 305
 See also: Hubeny et al. 2001, ApJ, 559, 680

Big Blue Bump: Scaling with Luminosity?

- T_{max} scales with $M^{1/4}$ and m_{dot} Frank, King & Raine 2000; Lawrence 2005 MNRAS, 363, 57
- X



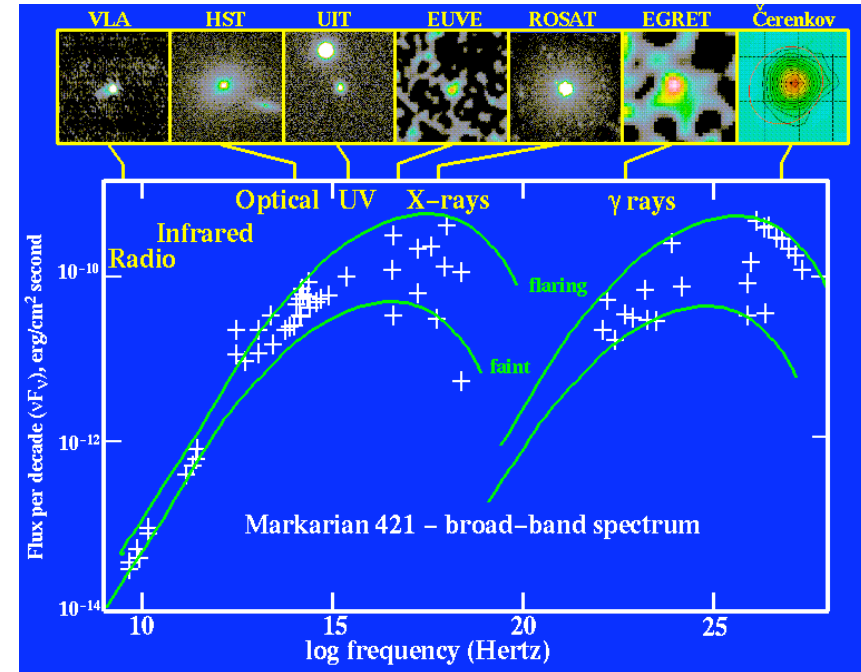
Lawrence 2005, MNRAS, 363, 57



Puchnarewicz et al., 1995, MNRAS, 276, 20P

Radio = synchrotron = jet

- Synchrotron:
 - Polarized
 - Variable
 - Power-law
- Relativistic particles
- Jet?
 - Clearly true in Blazars
 - Less obvious in radio-quiet quasars, Seyferts
- X-rays in radio-loud quasars= Comptonized synchrotron?

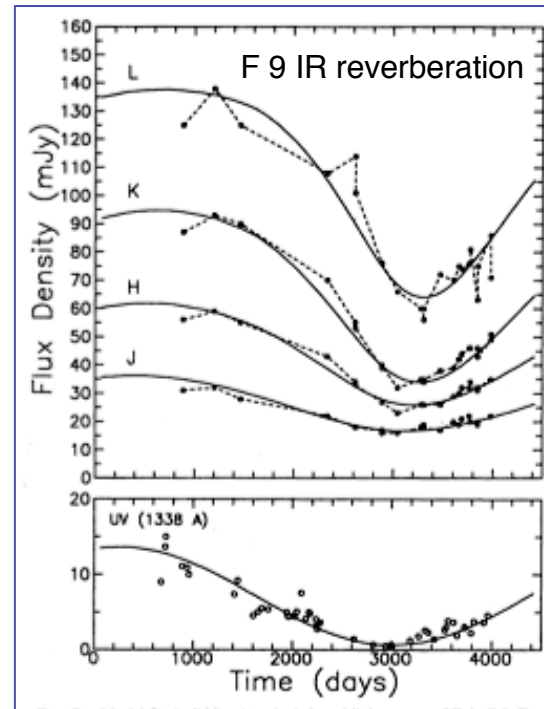


W. Keel U.AL www.

Infrared = dust, but where?

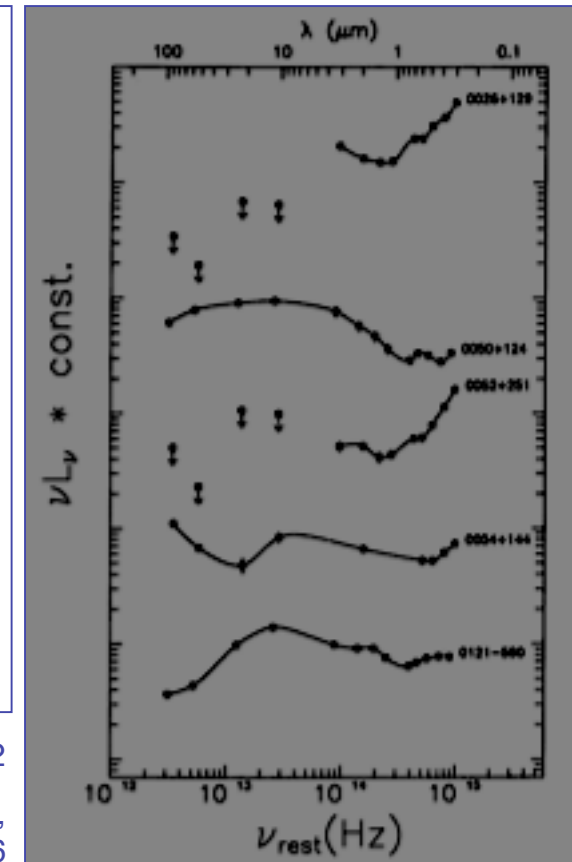
- Dust:
 - Inflection point at 1 μ m: maximum dust temperature
 - Reverberation gives sublimation distance
 - Irregular SED - multiple temperatures components
- Dust properties:
 - Equilibrium temperature:

$$R = 1.3 L_{UV,46}^{3/2} T_{1500}^{-2.8} \text{ pc}$$
 Barvainis 1987 ApJ 320, 537
 - $T_{\text{max}} \sim 1800 \text{ K}$ for C grains
 - T_{min} : ν^3 drop off at $\sim 100\mu\text{m}$
- Molecular torus? Wind? ISM?
- Alternatives to dust:
 - Non-thermal (synchrotron? free-free) baseline



Barvainis, 1992, ApJ, 400, 502

See also: Suganuma et al. 2006, ApJ, 639, 46



Barvainis, 1990, ApJ, 353, 419

See also:

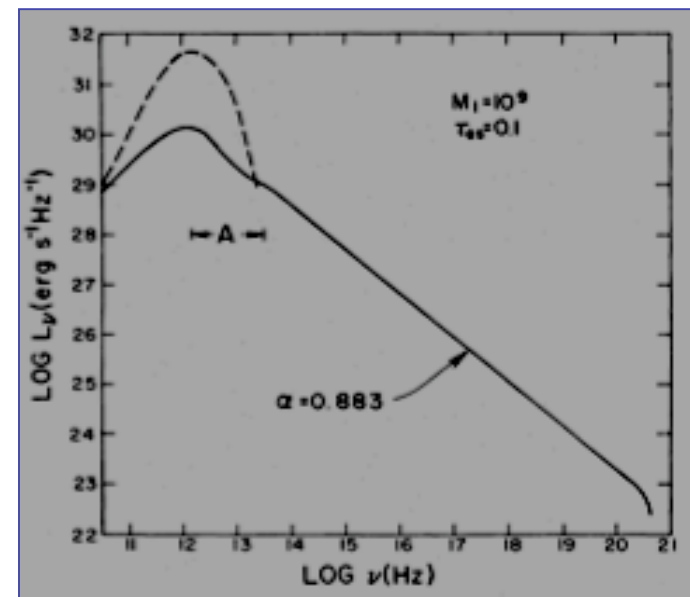
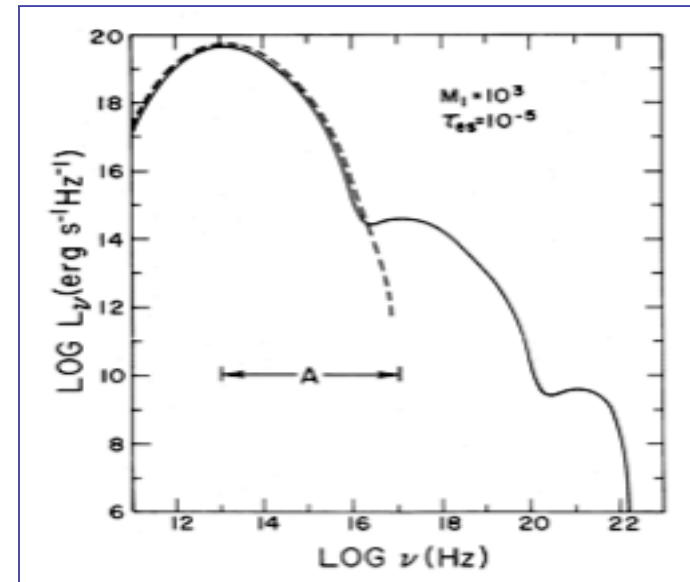
Ward et al, Carleton et al. 1997 ApJ, 477, 93

Sanders et al. 1997 ApJ, 477, 93

Elvis et al., 1994, ApJS,

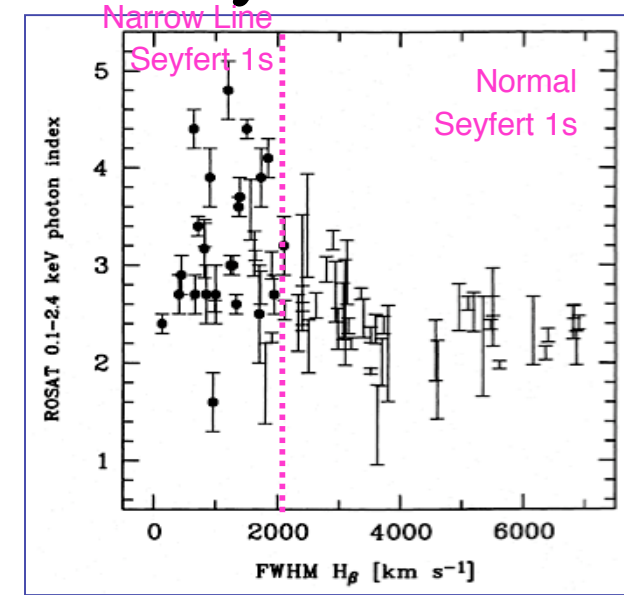
Hard X-ray: Comptonized disk radiation?

- Intrinsic properties
 - $\Gamma=2$, High E cut-off $\sim 100\text{keV}$
 - Rapid, large amplitude variability
- Origin: hot atmosphere ('corona' at 10^{12}K) above accretion disk is natural
 - Lightman-Eardley instability
 - Will Comptonize disk opt/UV to X-rays: low y parameter - copies original spectrum
 - Unsaturated thermal Comptonization higher y -parameter gives $\Gamma=2$ [Maraschi, Roasio & Treves 1982, ApJ, 253, 312; ApJ, 267, 371; Rybicki & Lightman 1979 ch.7.4](#)
 - Why are Narrow Line Seyfert 1s steeper?
- Alternative: Jet
 - possibly base of jet
 - Variability requires small size, but need not be central

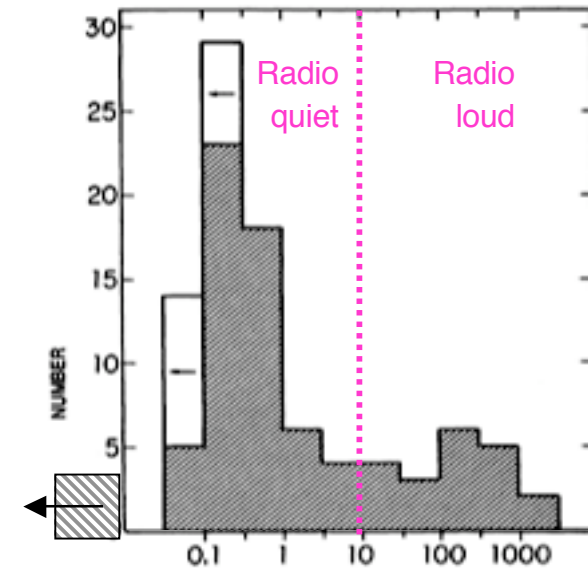


Spread of Quasar SEDs - Why?

- Narrow Line Seyfert 1s (NLSy1s):
FWHM(H β) < 2000 km/s c.f. \sim 5000 typical
 - steep, *highly* variable X-rays
 - high m_{dot} ? c.f. X-ray binaries [Pounds](#)
 - weak FeII, strong [OIII] ‘eigenvector 1’
- Radio-loud:
 - also have flat X-ray - 2nd component
 - Radio-*silent* - exist, little studied
- IR quiet:
 - Little known, but exist
- X-ray loudness:
 - Range of 100 [Risaliti et al. 2003, 2005](#)
 - Obscuration?
 - Intrinsically faint?
 - Highly variable



Boller, Brandt & Fink, 1996, A&A,305,53



$$R = f_R / f_{\text{Ont}}$$

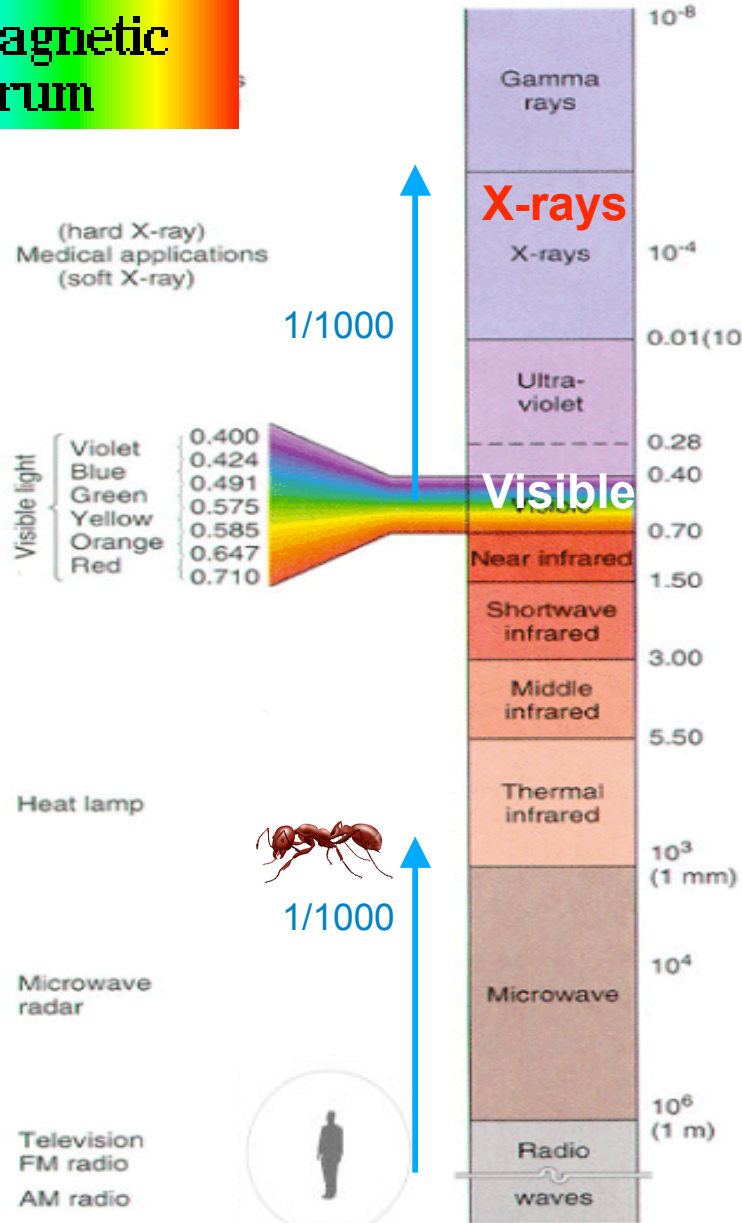
Kellerman et al. 1989 AJ, 98, 1195; also SDSS (Ivezic?)

Quasars SEDs need Many Telescopes



Electromagnetic Spectrum

10¹⁵ range of wavelength in astronomy



- Whipple 10 meter** (Gamma rays)
- Compton gamma-ray Observatory** (X-rays)
- Chandra** (X-rays)
- Hubble** (Visible)
- MMT** (Near infrared)
- Sub-millimeter array** (Microwave)
- VLA** (Radio waves)

Source: Christopherson (2000) Geosystems

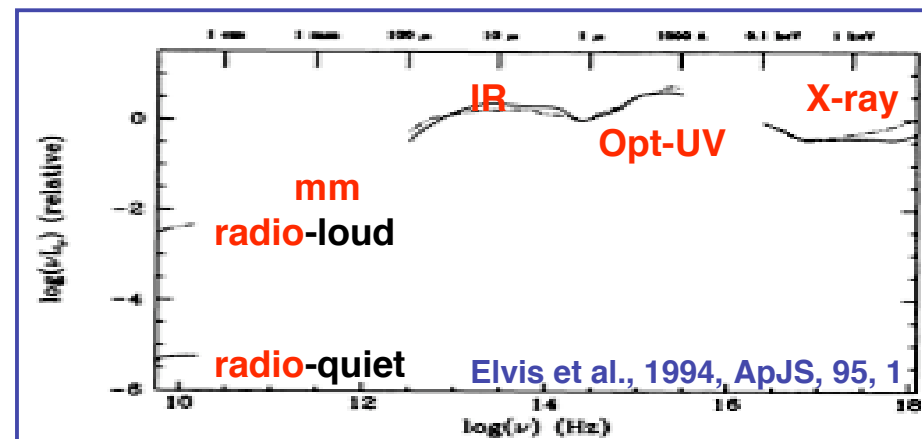
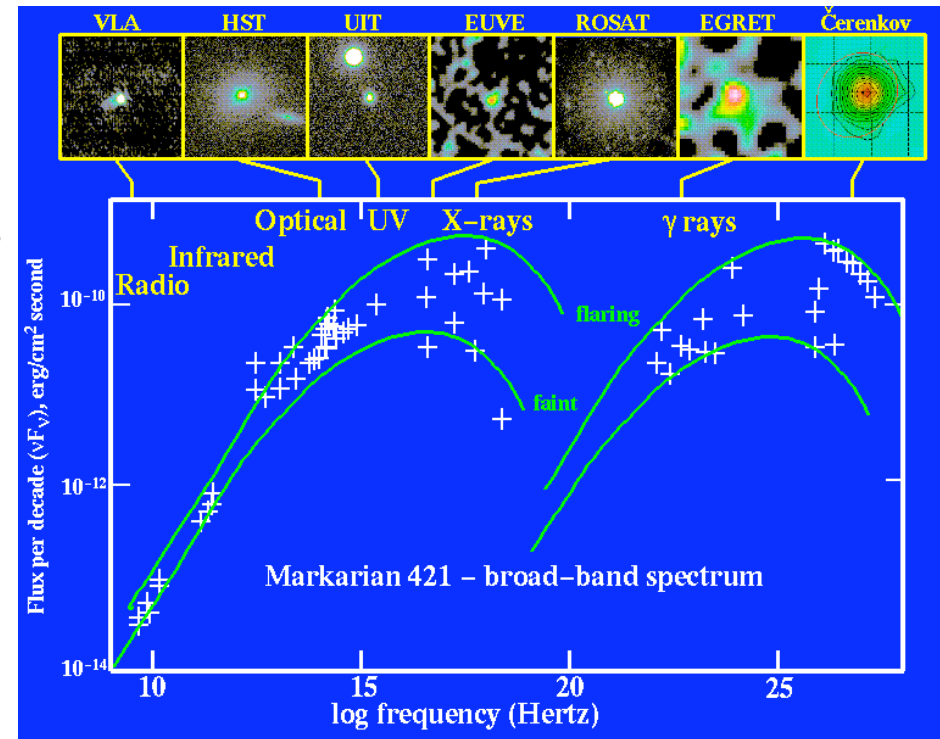
Complications

- **Survey Properties:**

- Selection biases
 - UV selection finds no red quasars!
 - fake redshift-luminosity correlations, due to narrow flux ranges
 - emission lines in bands
 - redshifting of bands,
- Small samples

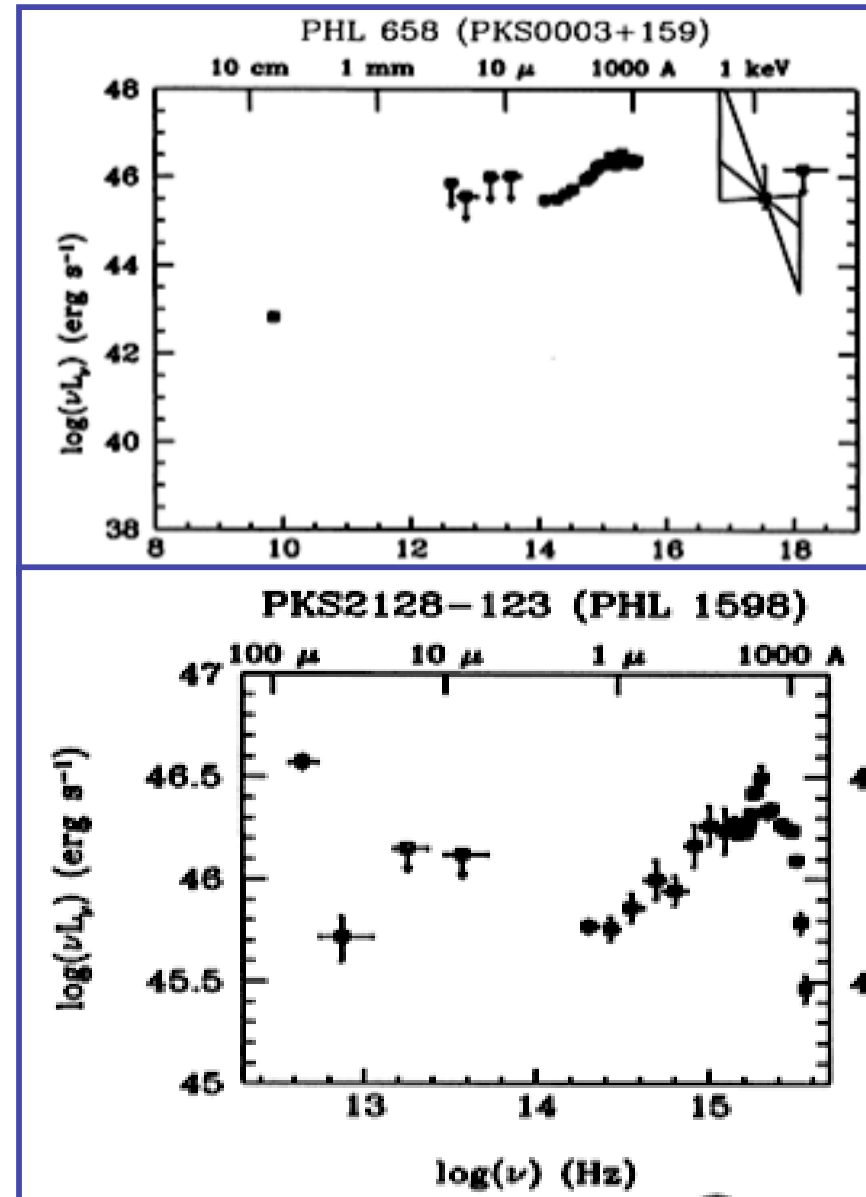
- **Quasar Properties:**

- Obscuration by dust & gas
- Variability
- Host galaxy contamination
 - starlight (Magorrian relation)
 - dust (IR)
- Extended AGN emission
 - radio lobes, jets
 - opt/X-ray photoionization nebulae



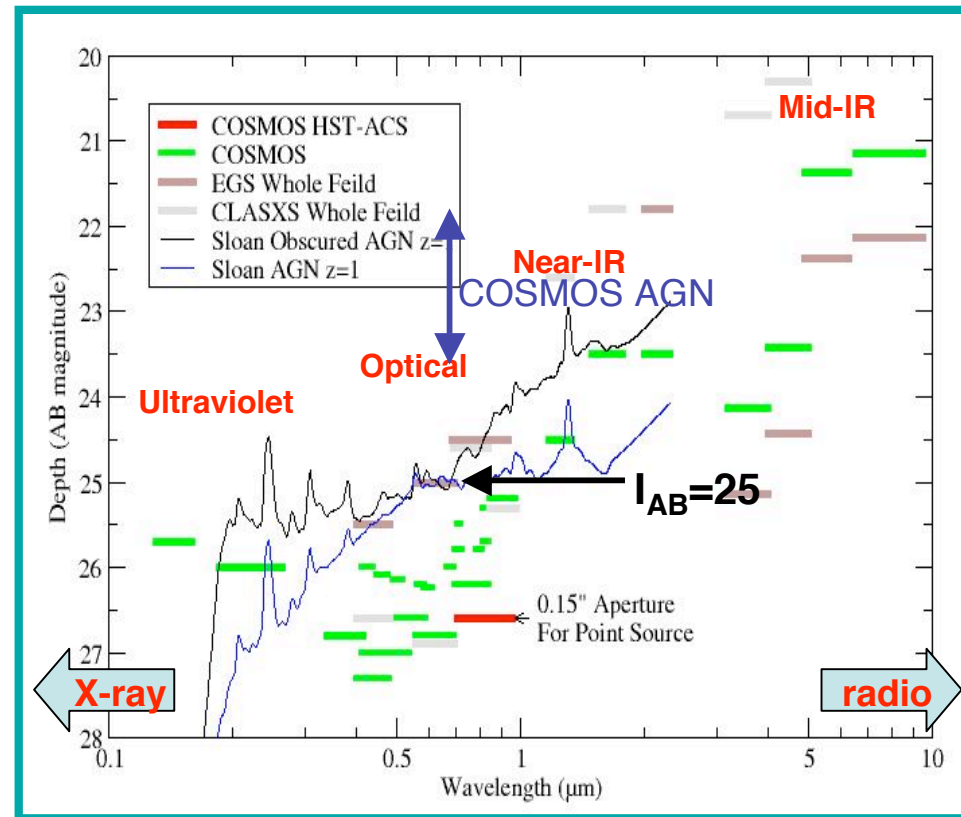
Quasar SEDs Today

- After a decade, Atlas from Einstein/IUE era is still state of the art: [Elvis et al. 1994](#)
 - C.f. Downsizing
- Primitive:
 - **Small sample:** 29 radio-quiet, 18 radio-loud
 - **Low z:** 0.05 - 0.9
 - **Low S/N:** in X-ray, UV, FIR
 - **Biased:**
 - toward X-ray loud
 - small α_{ox} for *Einstein* detection
 - toward UV bright
 - (U-B) selection of PG RQQ
- Artisanal - pointed one-at-a-time
not the way to go



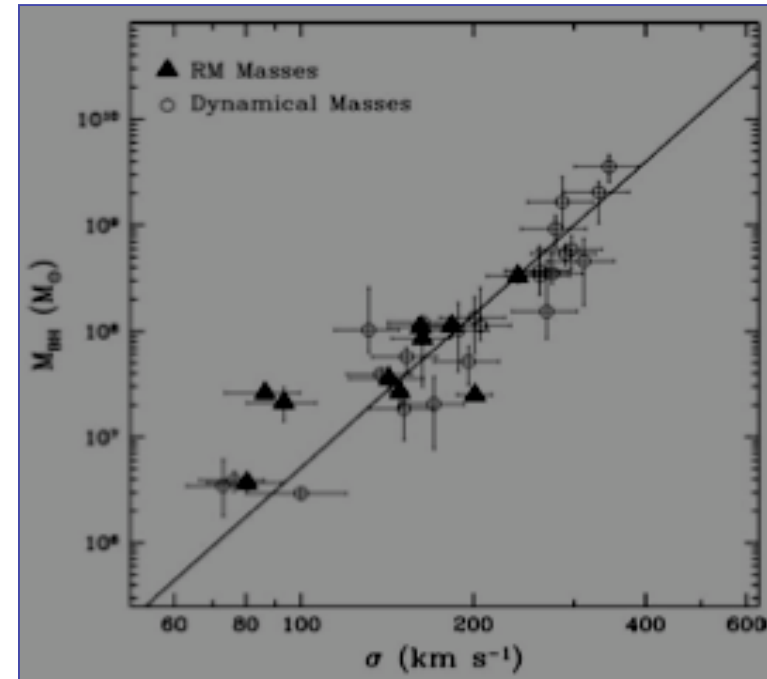
Future: Mass-produced SEDs - COSMOS

- Industrial: ~ 1000 SEDs at once
 - Wide range of z , α_{OX} , L
 - High S/N
- Easily detect most AGN at all wavelengths: X-ray-UV-midIR-radio
- \rightarrow Sensitive to deviant SEDs
- ACS i-band imaging gives host galaxy subtraction
 - Important at all L , given Magorrian $M_{\text{bulge}}-M_{\text{BH}}$ relation

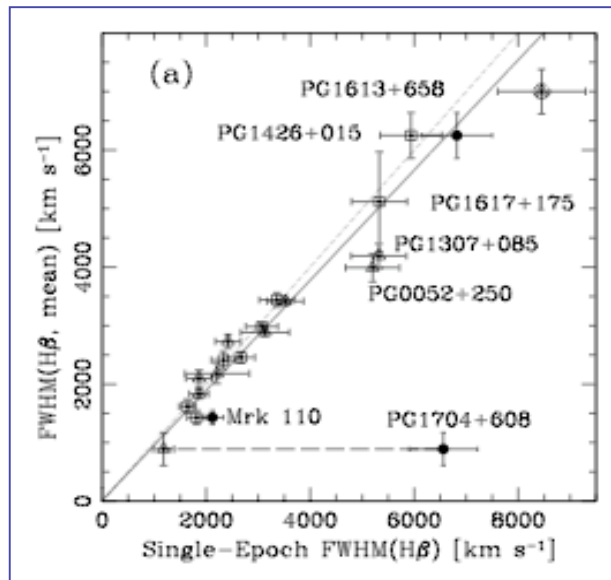


Future: Physically based models

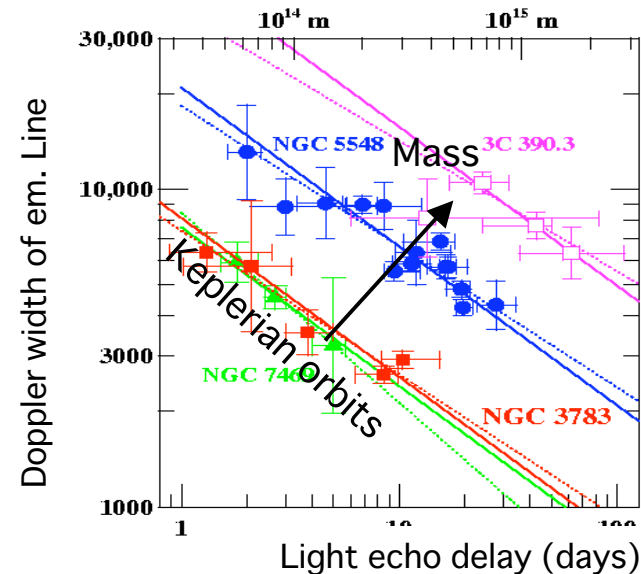
- Black hole mass measurements revolutionizing the field
 - STIS rotation curves
 - Reverberation BELR mapping
- secondary methods reach high z
- Have (M, mdot) for large samples
- Can relate continuum to underlying physics at last
- *But:* - no inclination Core/lobe ratio, VLBI, Xray
 - assumed efficiency



Ferrarese & Ford 2005



Vestergaard, 2002



Peterson & Wandel 2000 ApJ 540, L13