Active Galactic Nuclei: the known and the unknown

Chandra image of Cen A

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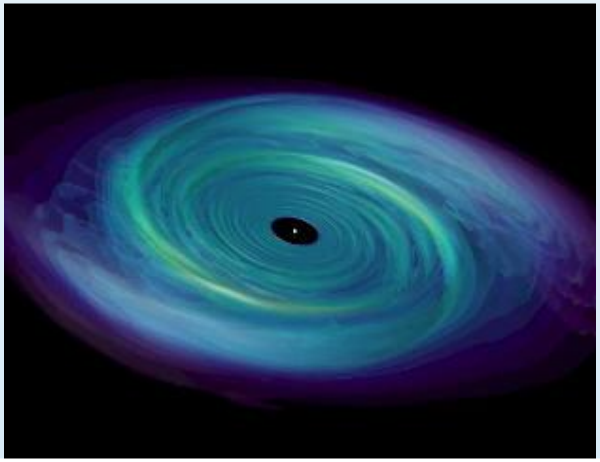
Active Galactic Nuclei

- Active Galactic Nuclei (AGN): most massive and luminous compact objects in the Universe
- Focus on 5 central aspects:
- Central engine: accretion and black hole (BH) rotation
- Jet formation
- Unification of AGN: are they all the same?
- Environment and feedback
- SMBH formation
- Open questions

Mrk 739 at z=0.03. Image: SDSS

Central Engine

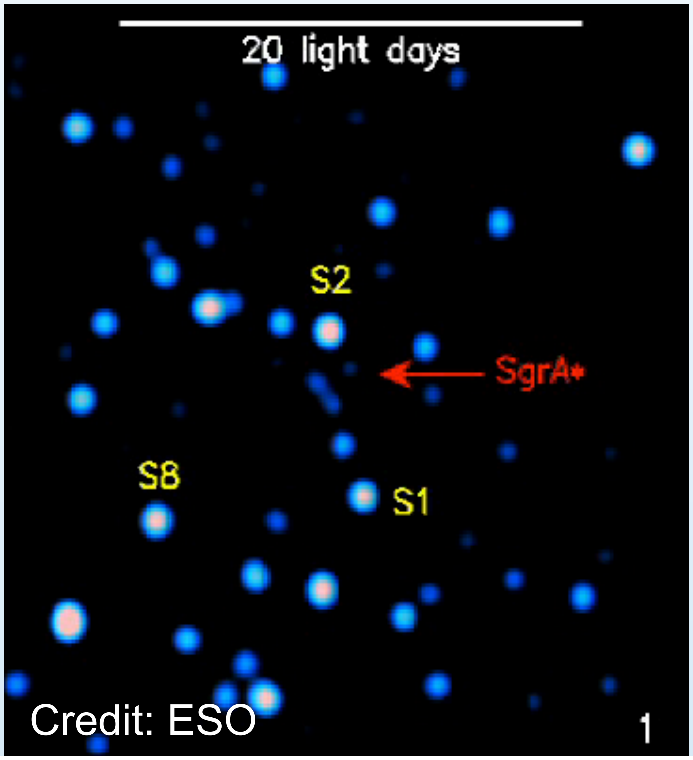
- AGN are bright (10^{41} - 10^{48} erg/sec), point-like (<<100 pc; Woltjer 1959) and persistent
- No stellar emission, nor supernova, etc.
- Accretion onto a massive black hole
- Masses (from reverberation mapping) in the range of 10^4 (NGC 4395) up to 10^{10} M_o (3C 273)
- Accretion
- Angular momentum → accretion disk → friction → heating → thermal emission



Artist's impression of an accretion disk
Credits: Owen/Blondin/NCSU

Central Engine

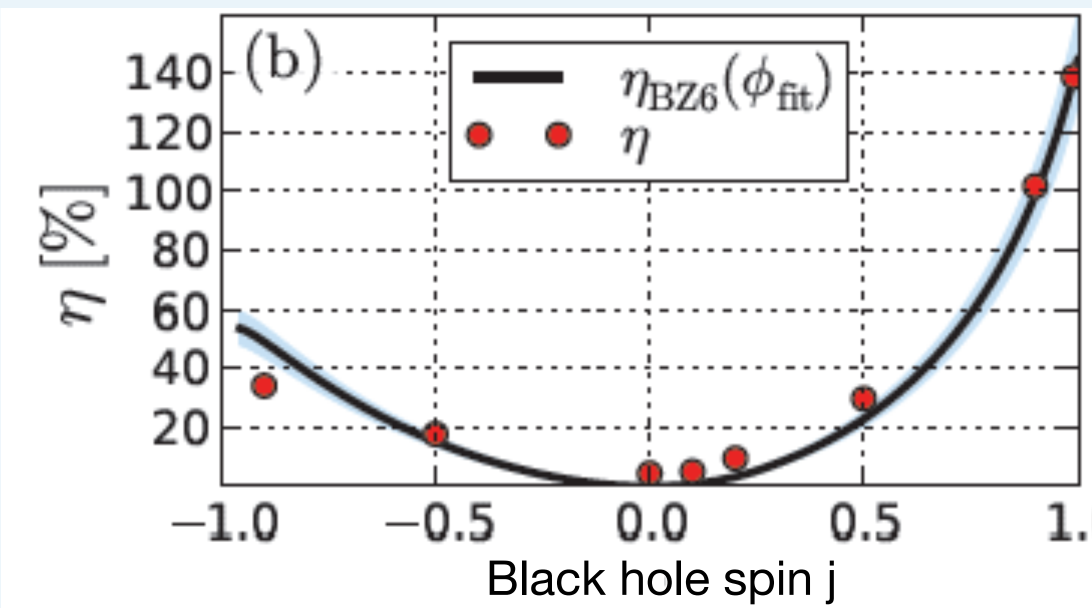
- alpha-disk: viscosity is some factor α times $c_s h$ (c_s = sound speed, h = scale height of disk)
- Radiative efficient: most of the energy is radiated away
- Eddington limit: $$L_{\rm Edd} = \frac{4\pi G M m_p c}{\sigma_T} \simeq 1.3 \times 10^{38} \frac{M}{M_\odot} \,{\rm erg\,s}^{-1}$$

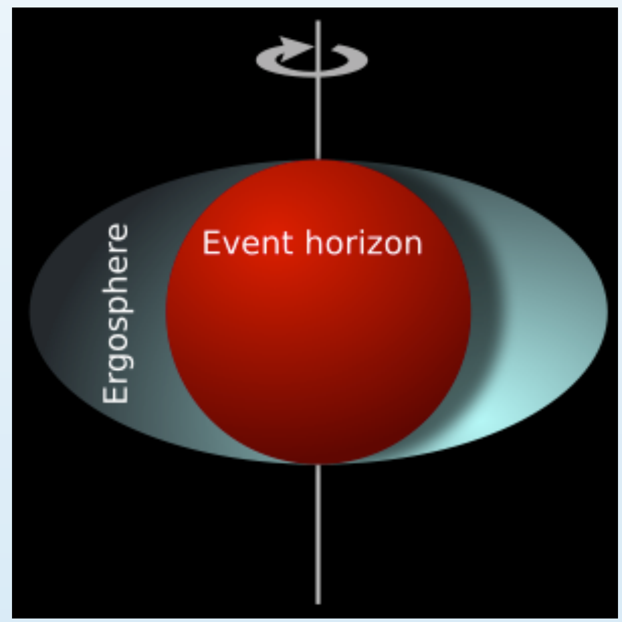


- Other problem: apparently some black holes accrete radiatively inefficient
- Sgr A*: 2×10^6 Mo and accretion 10^{-5} Mo yr^{-1} → <0.0001 L_{edd}

Kerr Black Holes

- Black holes can have spin $$j = \frac{c\,J}{G\,M_{\mathrm{BH}}^2}$$
- Swallowing matter with angular momentum makes a spin likely
- Non-rotating (Schwarzschild) black holes behave differently than maximal rotating (Kerr) black holes.
- Blandford-Znajek (1977) mechanism (aka as Penrose process) allows to extract rotational energy from a black hole (dragging of magnetic field lines)
- Important in the context of raising jets

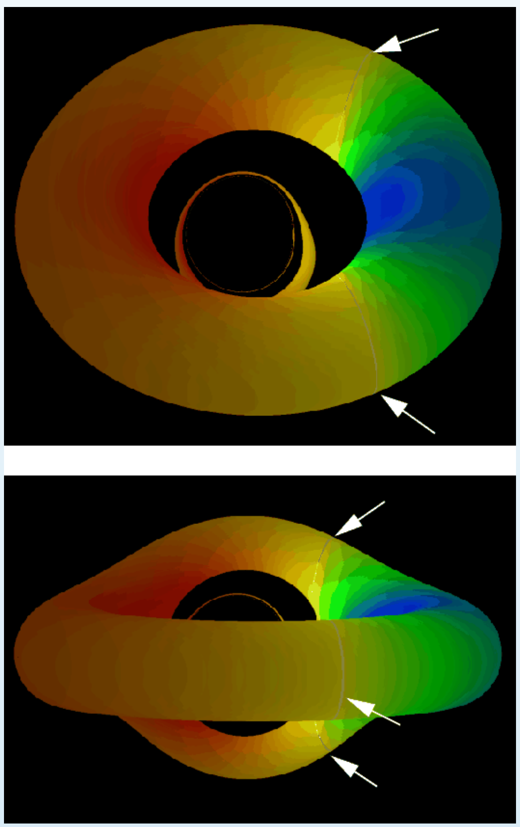




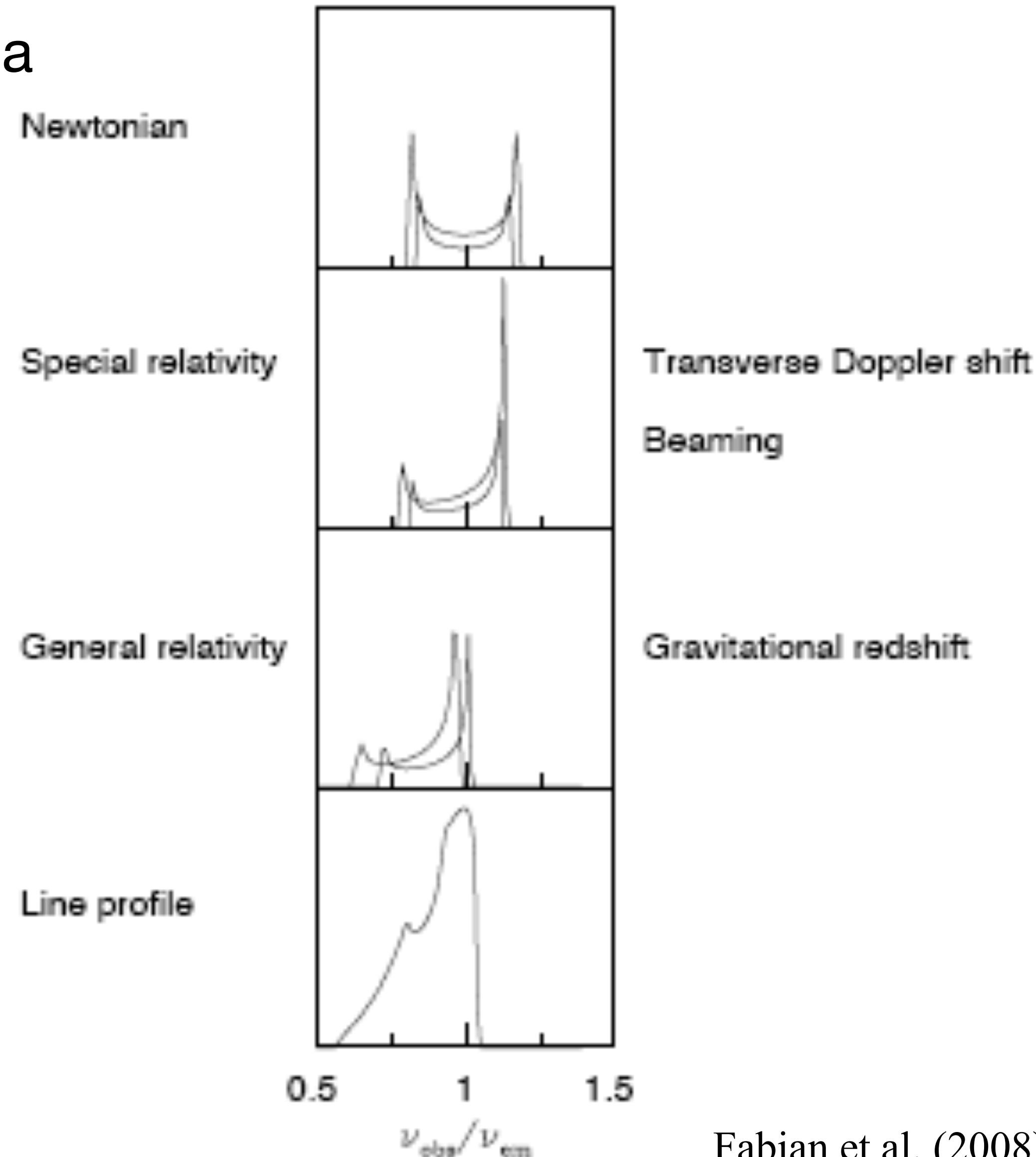
Tchekhovskoy et al. 2012

Kerr Black Holes

How do we proof that a black hole rotates?

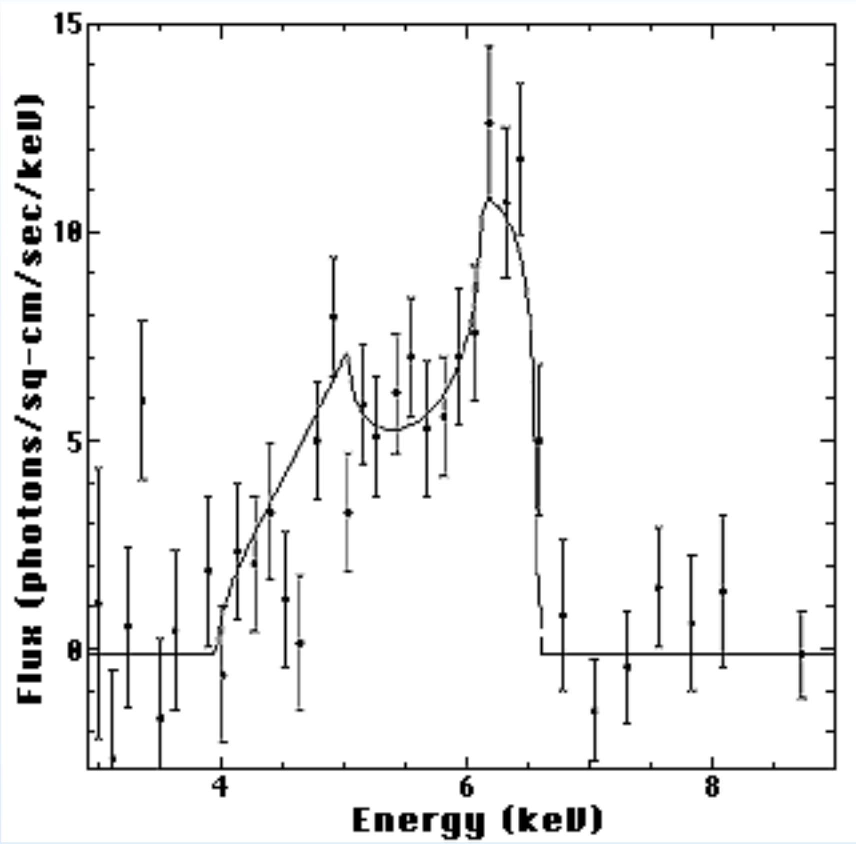


Fuerst & Wu (2004)



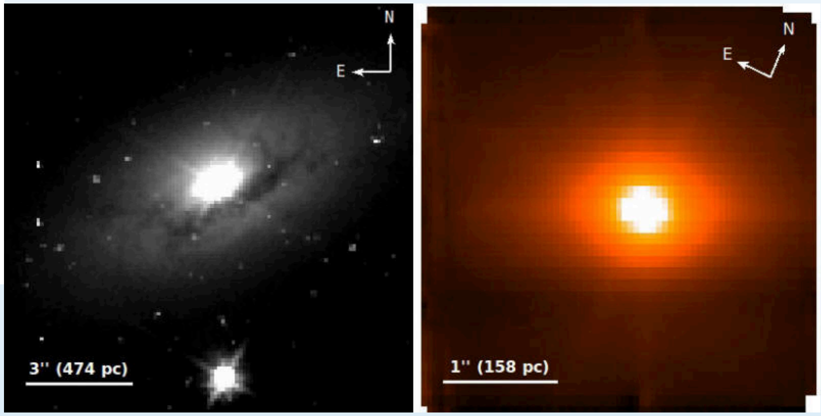
Fabian et al. (2008)

Kerr Black Holes



ASCA: Tanaka et al. (1995)

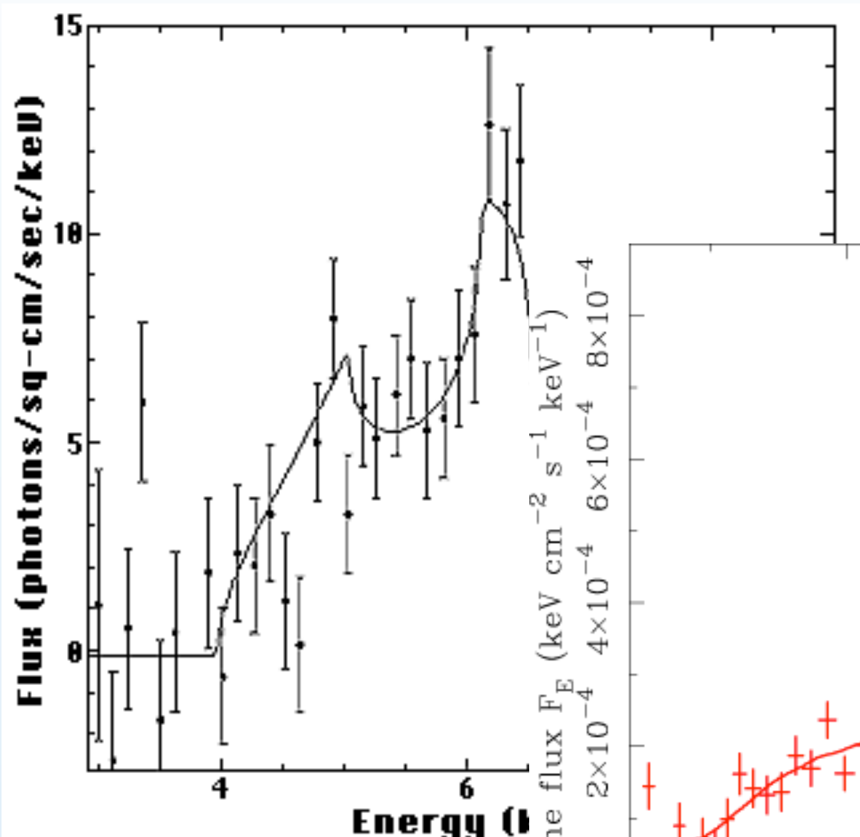
Fe Kα in MCG-6-30-15



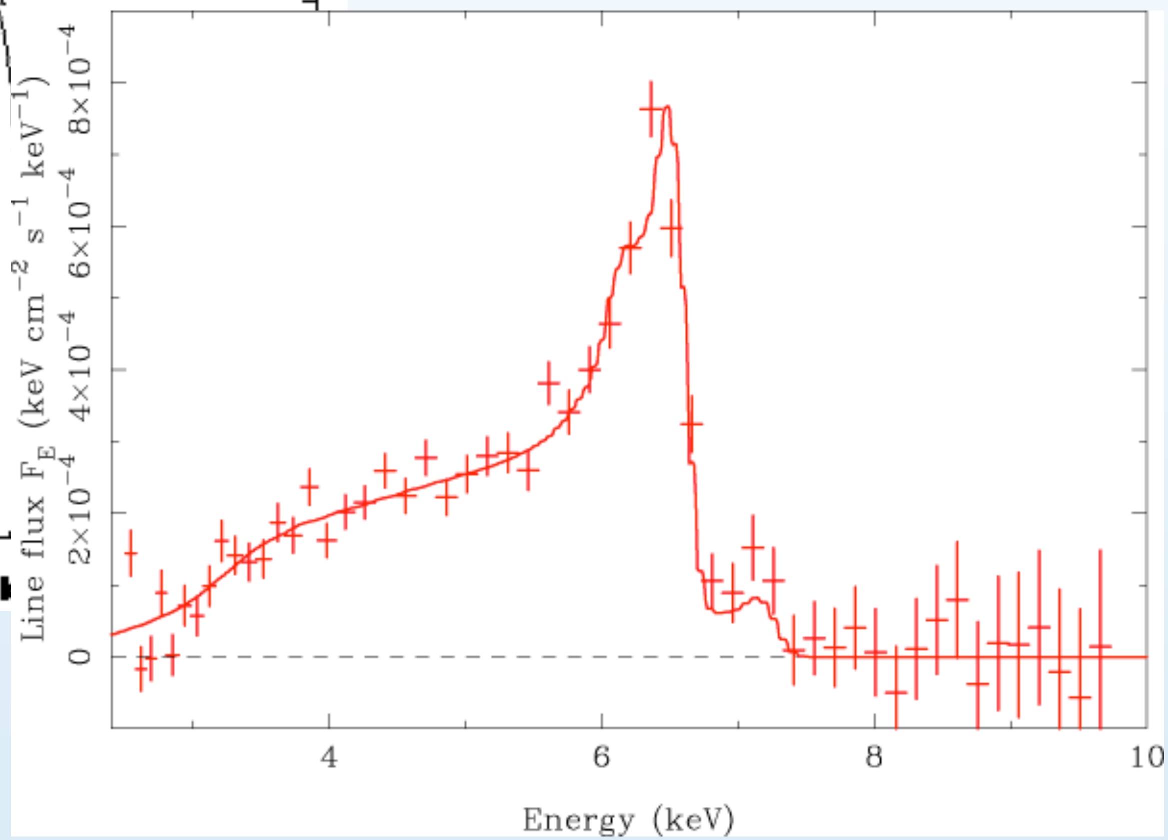
HST & SINFONI image: Raimundo et al. (2012)

Kerr Black Holes

Fe Kα in MCG-6-30-15

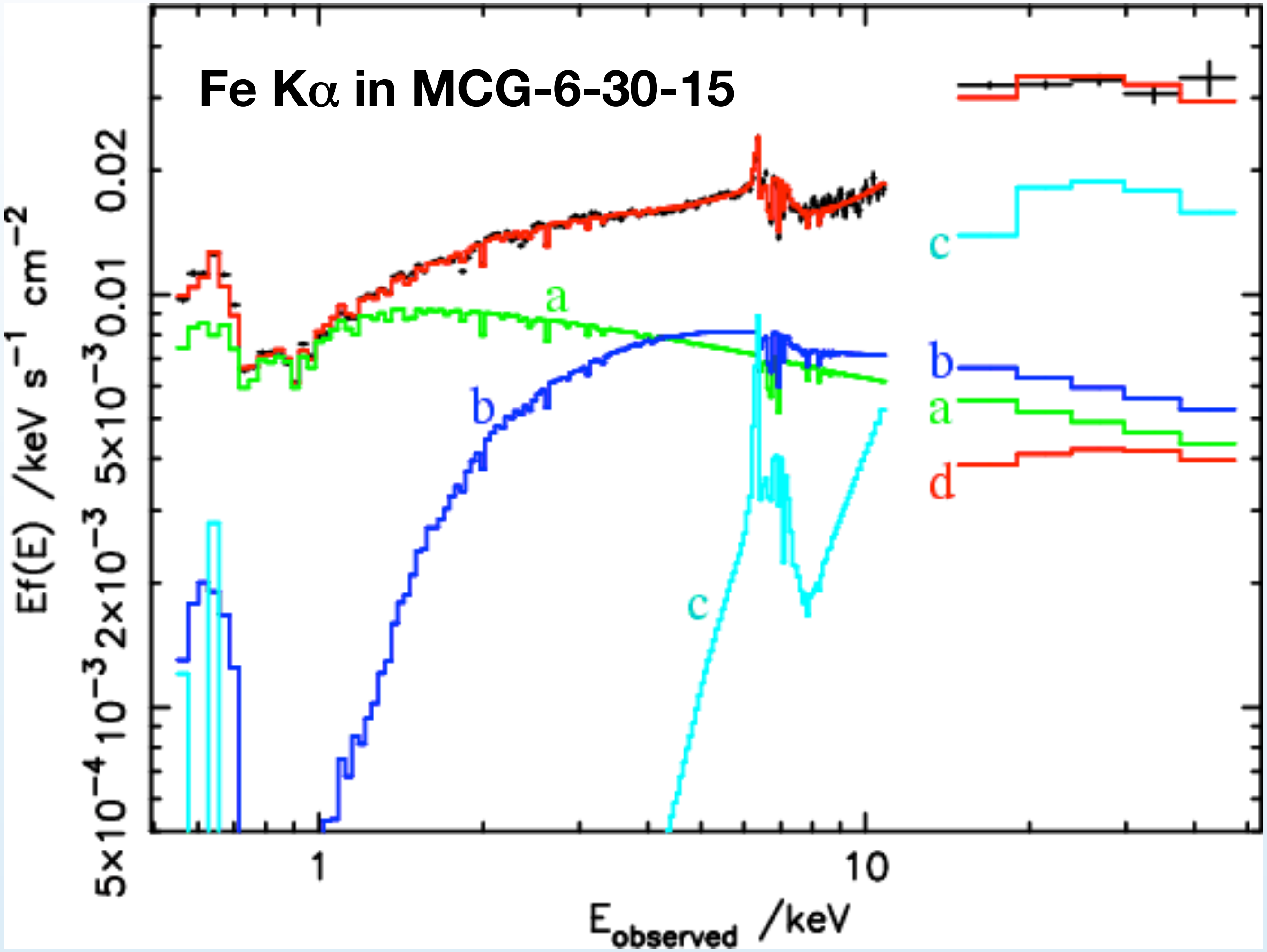


ASCA: Tanaka et al. (1995)



XMM-Newton: Fabian et al. (2002)

Kerr Black Holes ?



Miller, Turner, & Reeves (2008): « A relativistically-blurred Fe line is not required in this model. We suggest the partial covering zone is a clumpy wind from the accretion disk. »

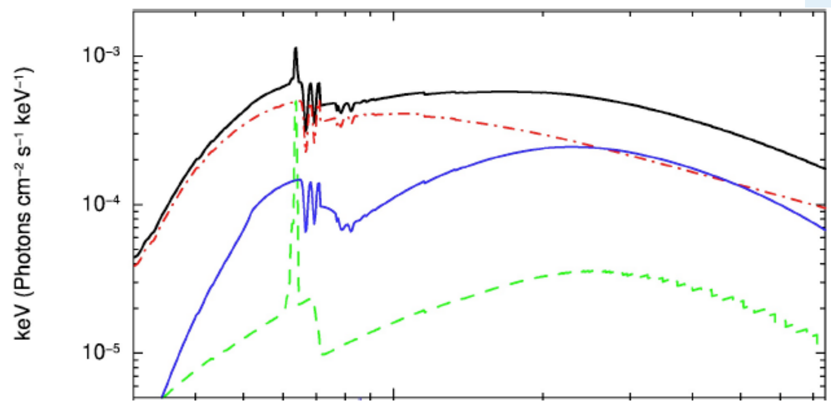
Kerr Black Holes?

Name	BH spin j
MCG –6–30–15	(a): > 0.98, (b): $0.5^{+0.2}_{-0.1}$, (h): 0.0
Fairall 9	(b,c) 0.65 ± 0.05, (i) 0.4 ± 0.2
SWIFT J2127.4+5654	(d): 0.6 ± 0.2
1H 0707–495	(e,k): > 0.98, (h): 0.0
Mrk 79	(f): 0.7 ± 0.1
NGC 3783	(g): > 0.98, (b): < -0.04
Mrk 335	(b): $0.70^{+0.12}_{-0.01}$
NGC 7469	(b): 0.69 ± 0.09

References: (a): Brenneman and Reynolds (2006), (b): Patrick *et al.* (2011), (c): Schmoll *et al.* (2009). (d): Miniutti *et al.* (2009), (e): Zoghbi *et al.* (2010), (f): Gallo *et al.* (2011), (g): Brenneman *et al.* (2011), (h): Miller *et al.* (2008, 2010) (iron line produced in accretion disc wind and not close to the black hole), (i): Anne Lohfink (2011) conference communication, (k): Fabian *et al.* (2011)

$$j = \frac{c\,J}{G\,M_{\rm BH}^2}$$

NGC 1365 NuSTAR/XMM-Newton observations:
j = 0.97 (Risaliti et al. 2013, Nature)



Kerr Black Holes?

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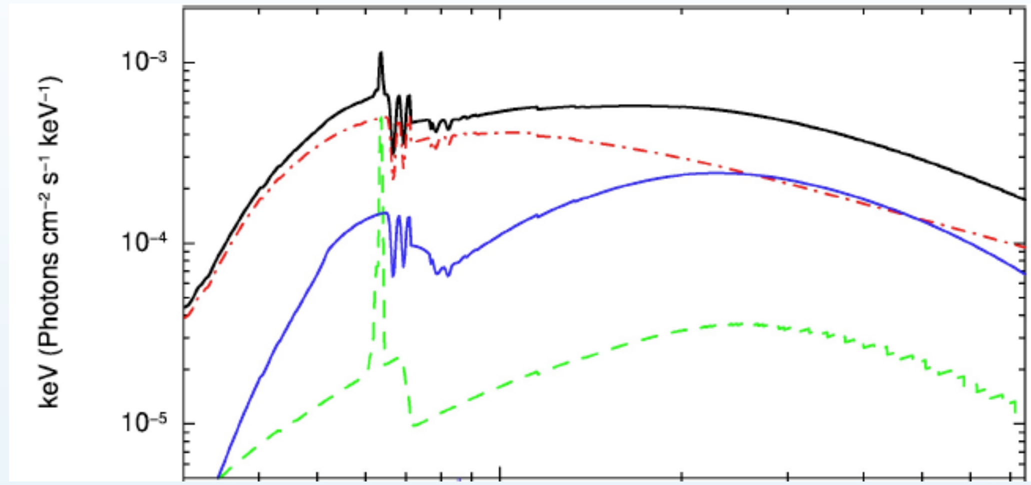
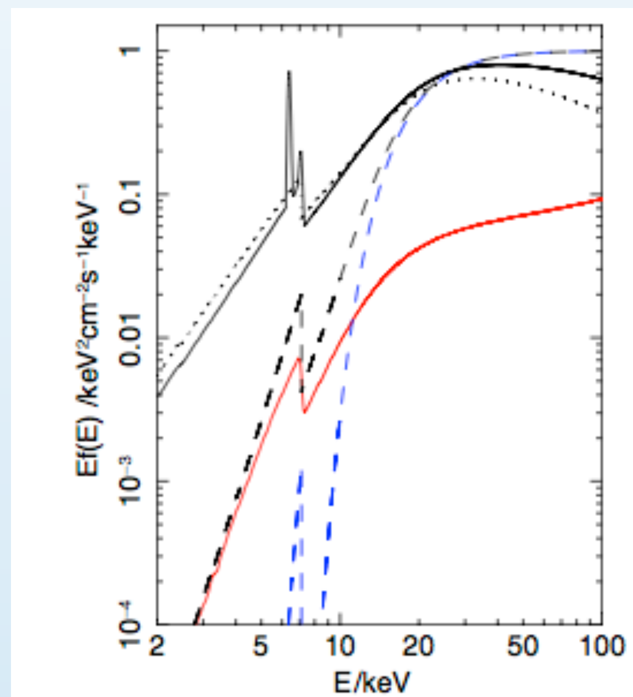


Miller & Turner 2013, ApJ 773, L5:
« The Hard X-Ray Spectrum of NGC 1365: Scattered Light, Not Black Hole Spin »

5. CONCLUSIONS

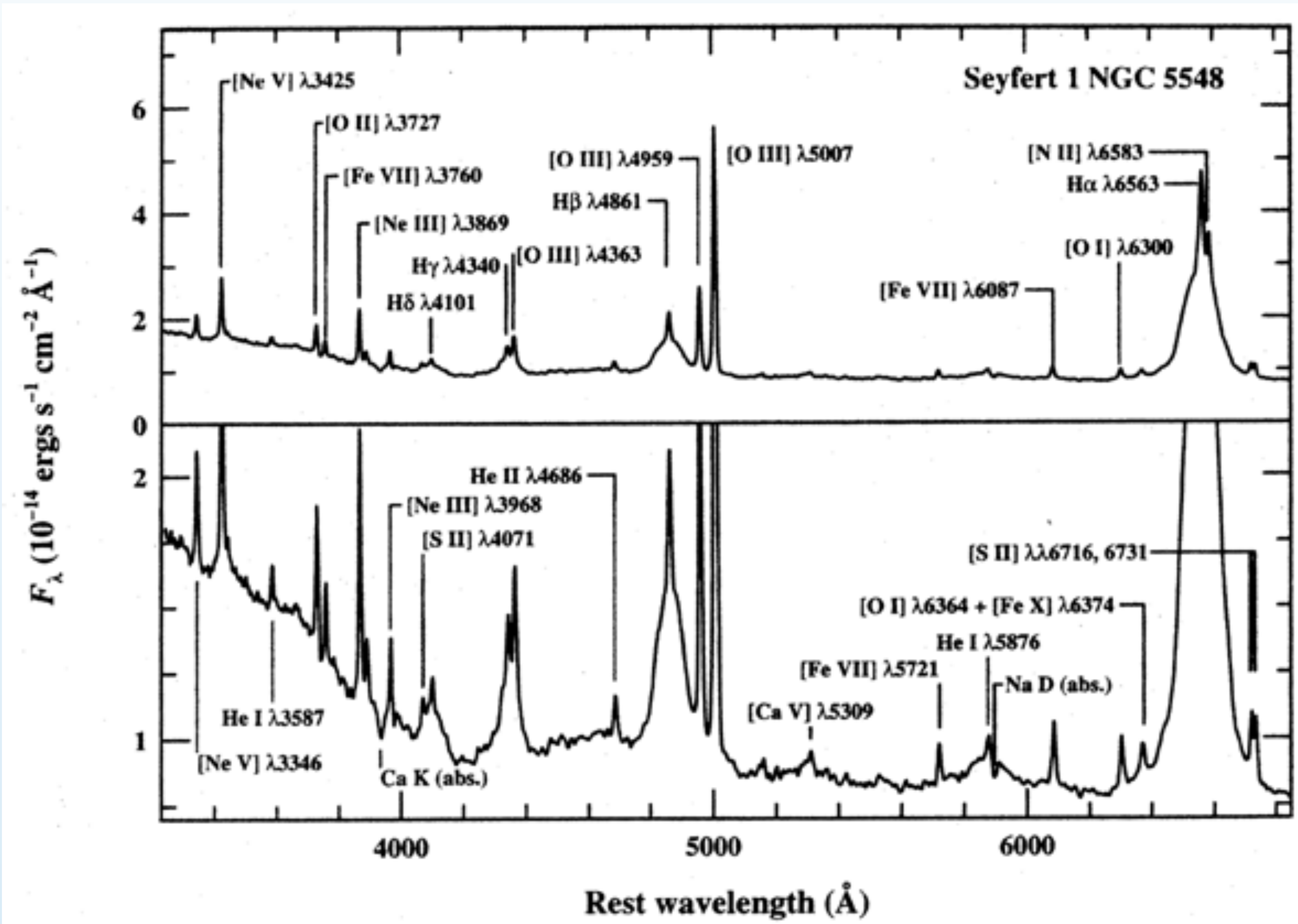
AGN spectra may contain significant levels of transmitted and scattered continua from partially covering circumnuclear gas, producing the time-invariant "red wing" below the Fe K edge and modifying the spectrum above 10 keV. Such gas is already known in NGC 1365. Geometry-dependent Compton scattering must be taken into account, using three-dimensional radiative transfer calculations, when making spectral models and when accounting for the source total luminosity. The expected



Gardner & Done (2013): high spins are rare

Unification

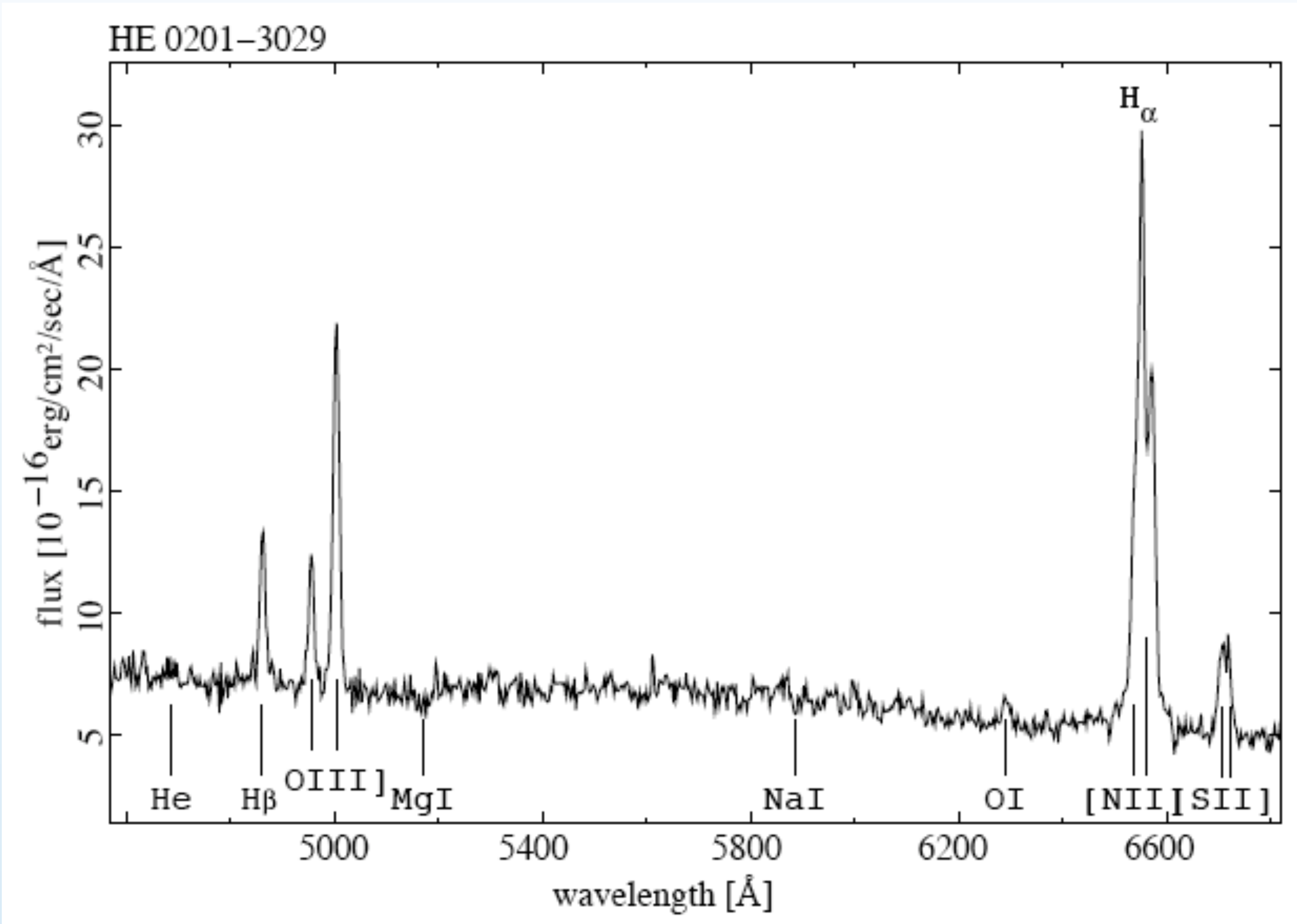
Task: find a model with the smallest number of parameters which explains all AGN.



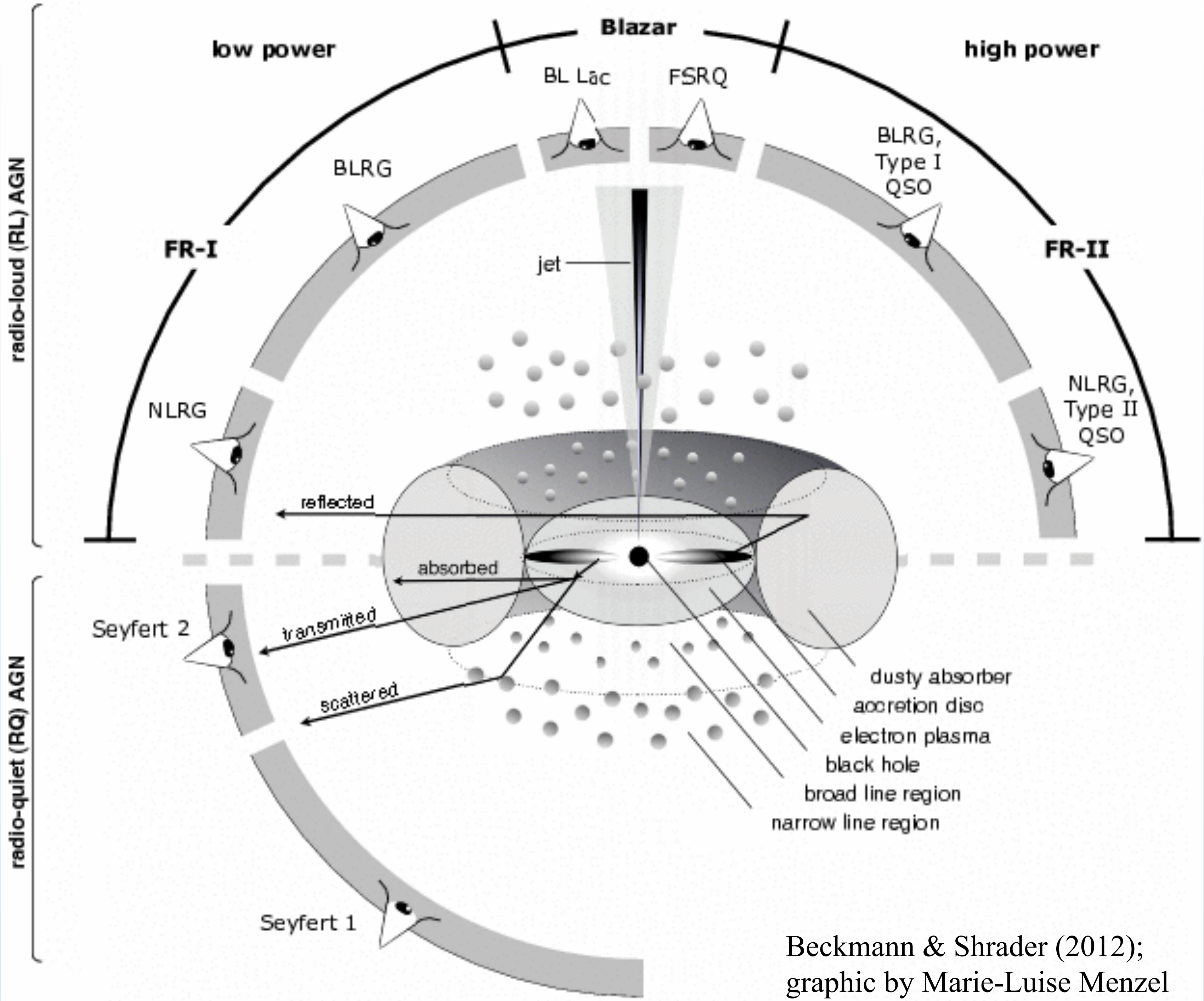
Seyfert 1 spectrum of NGC 5548; Peterson (1997)

Unification

Seyfert 2 do not show broad emission lines



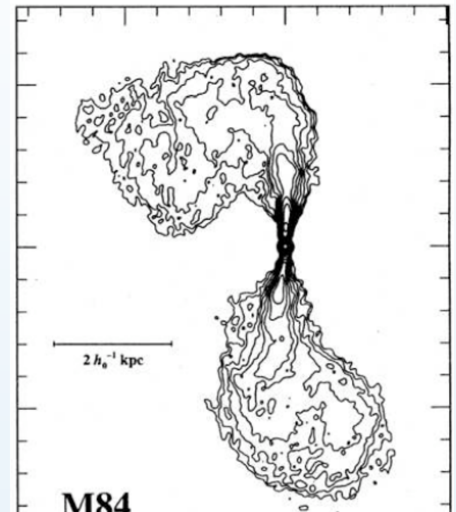
Seyfert 2 spectrum of HE 0201-3029; Beckmann & Shrader (2012)



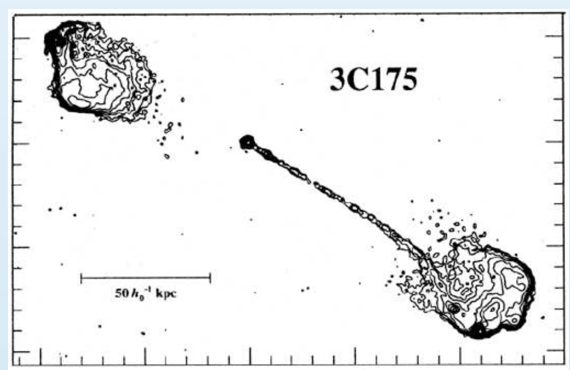
Beckmann & Shrader (2012);
graphic by Marie-Luise Menzel

Jets in AGN

- Why do some AGN have jets and some don't?
- Strong radio source: synchrotron emission (jet)
- Don't confuse radio quiet (RQ) and radio silent…
- Franceschini et al. (1998): $L_{\mathrm{r}} \propto M_{\mathrm{BH}}^{2.5}$
- Not found in all studies though
- Laor (2000): all quasars with M_{BH} > 10^9 Mo are RL
- All M_{BH} < 3 x 10^8 Mo are RQ
- M_{BH}, L/L_{Edd}, inclination angle
- Other effects: smaller black holes accrete at higher Eddington rate
- Luminosity: core only or include jets?
- E.g. Broderick & Fender (2011): Eddington ratio not strongly correlated to RL
- Environment? Black hole spin?
- B-field (Sikora & Begelman 2013) ?
- jets do not scale simply with mass and accretion rate (Gardner & Done 2013)



M84
Laing & Bridle (1987)

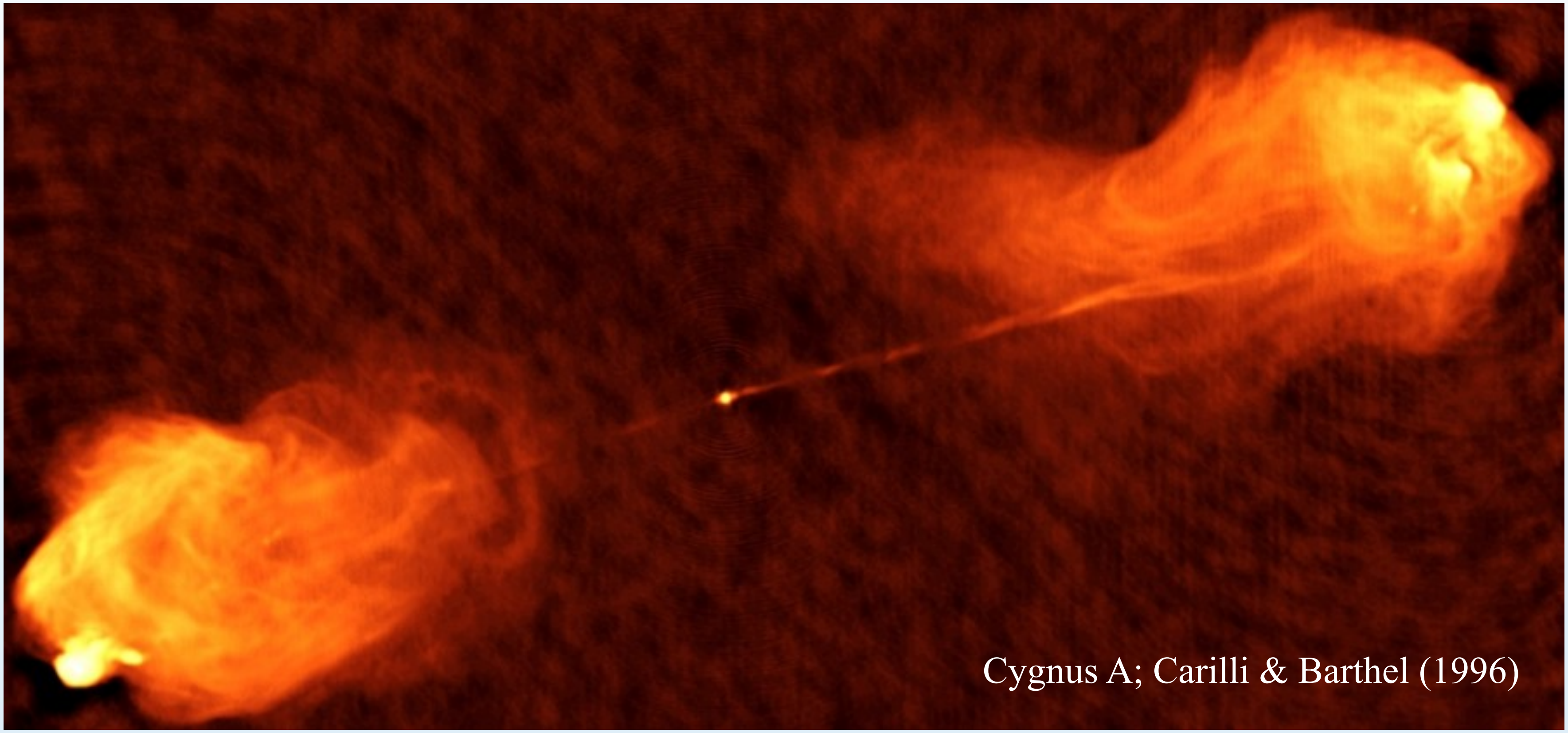


Bridle et al. (1994)

$$R^* = \left(\frac{f_{5\,\mathrm{GHz}}}{f_{2500}}\right)$$

Jets in AGN

Jets manage to stay confined for >50 kpc

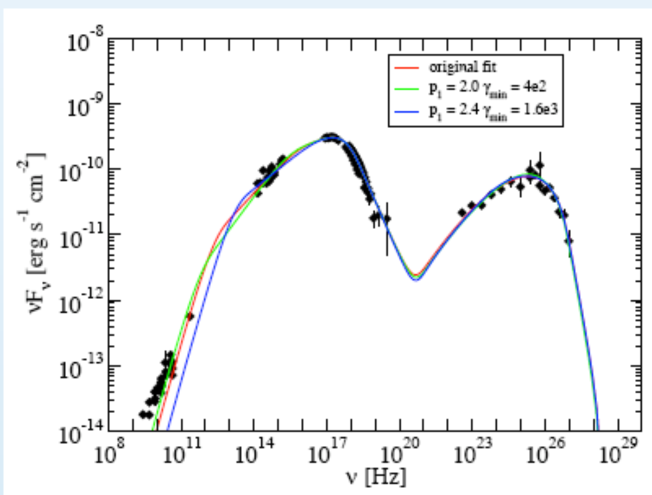


Cygnus A; Carilli & Barthel (1996)

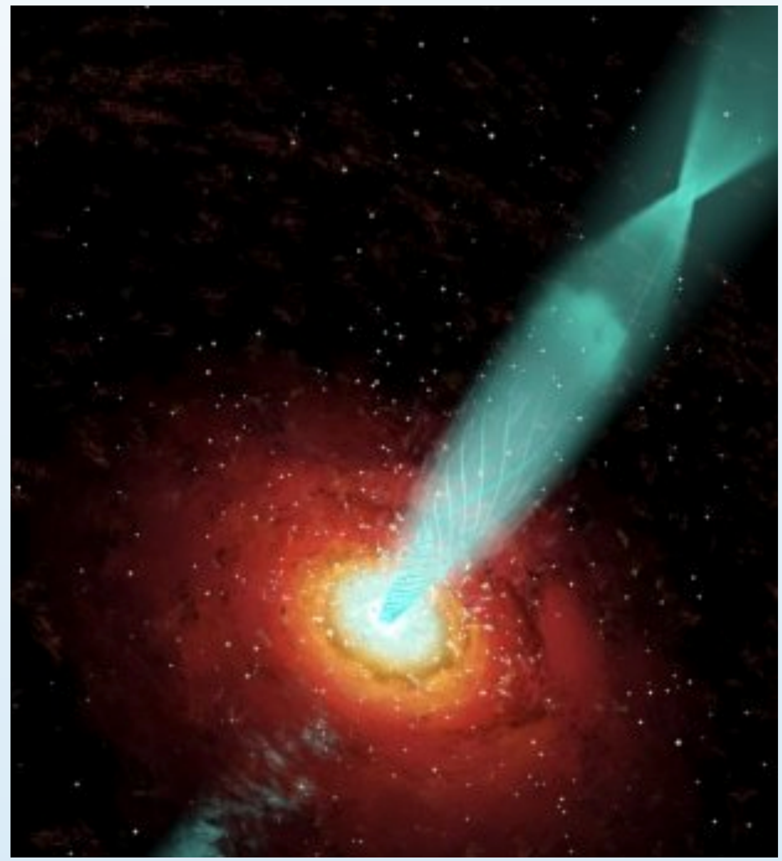
Protons take more energy for acceleration, but could explain better the confinement over long distances and times (>10^6 yrs)

Jets in AGN

- Radio galaxies to study morphology of jets
- Blazars show jet physics
- Spectral energy distribution (SED) and variability give:
- Size and density
- Magnetic field
- Doppler factor
- Particle energy distribution

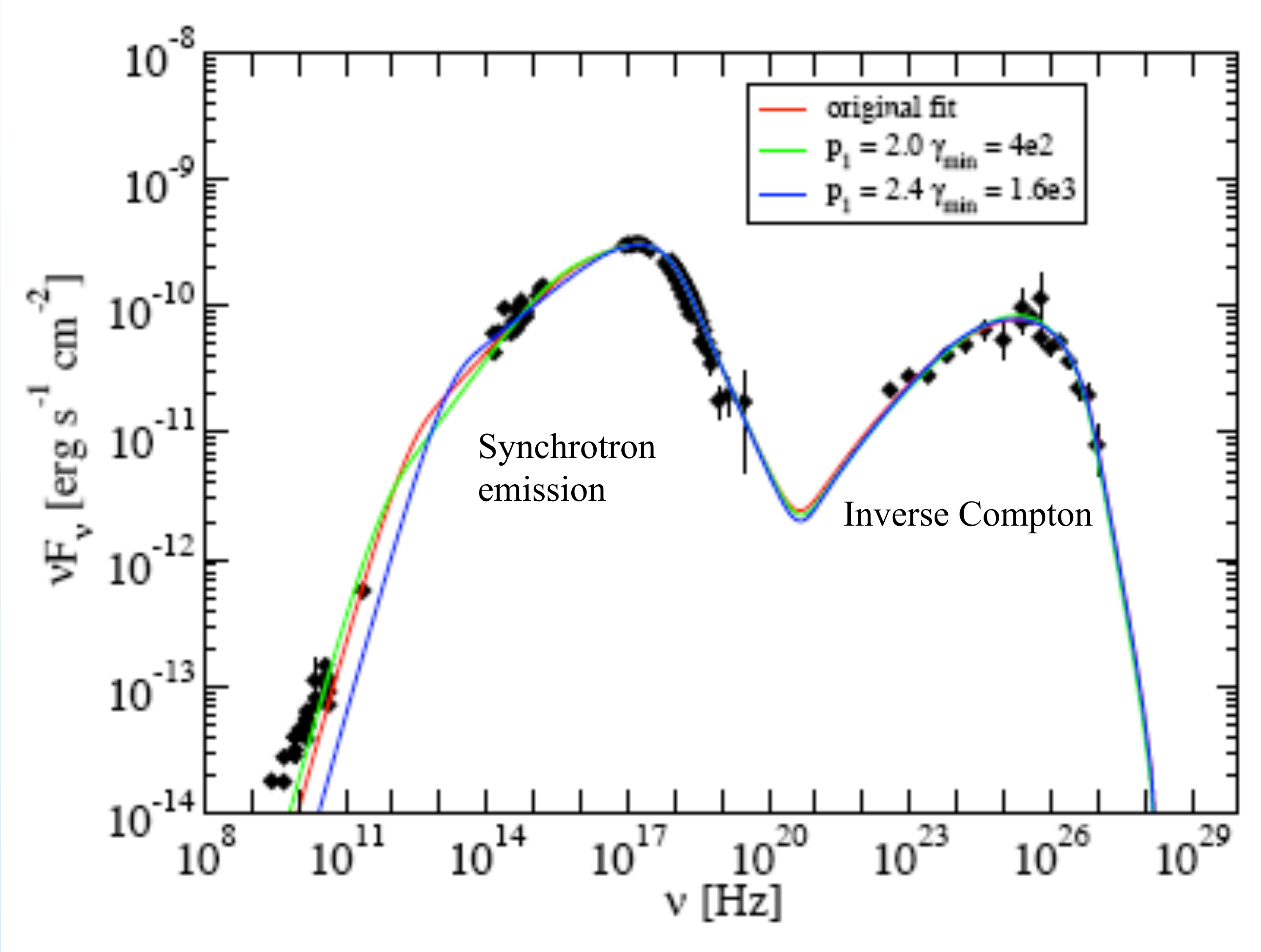


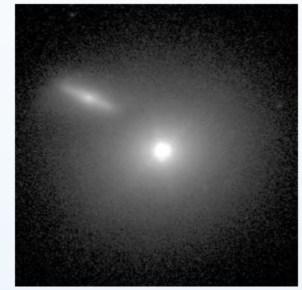
SED of Mrk 421 (Abdo et al. 2011)



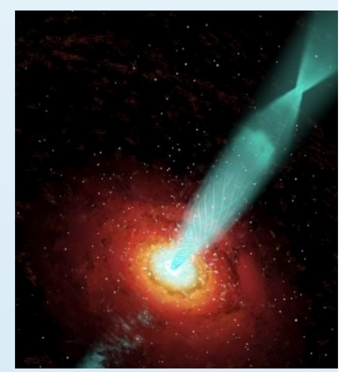
Courtesy: Alan Marscher (Boston Univ.)

Jets in AGN





Mrk 421



SED of Mrk 421 (Abdo et al. 2011)

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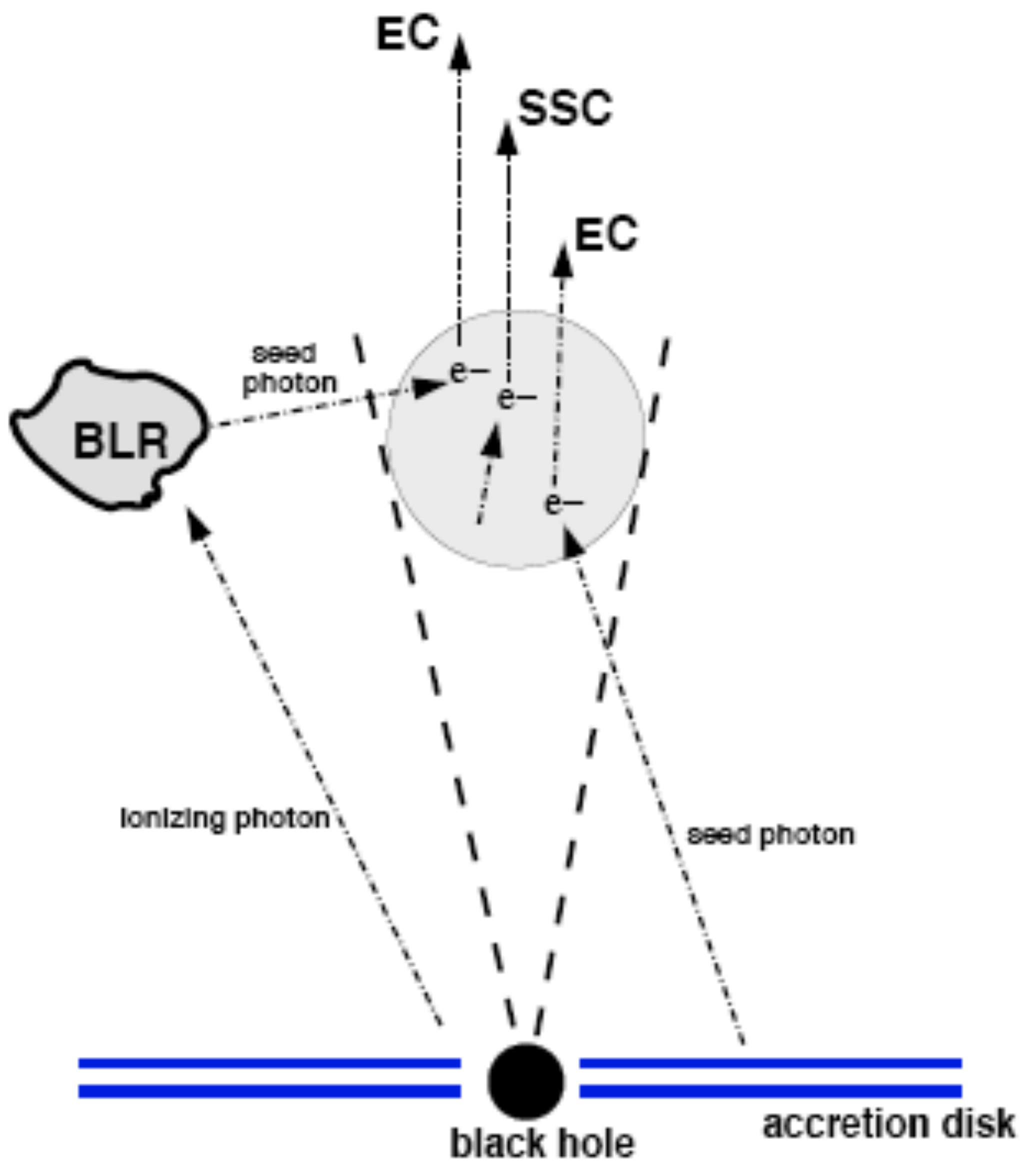
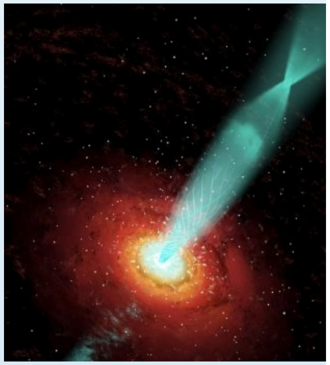
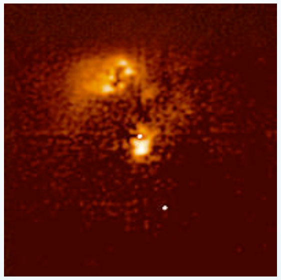


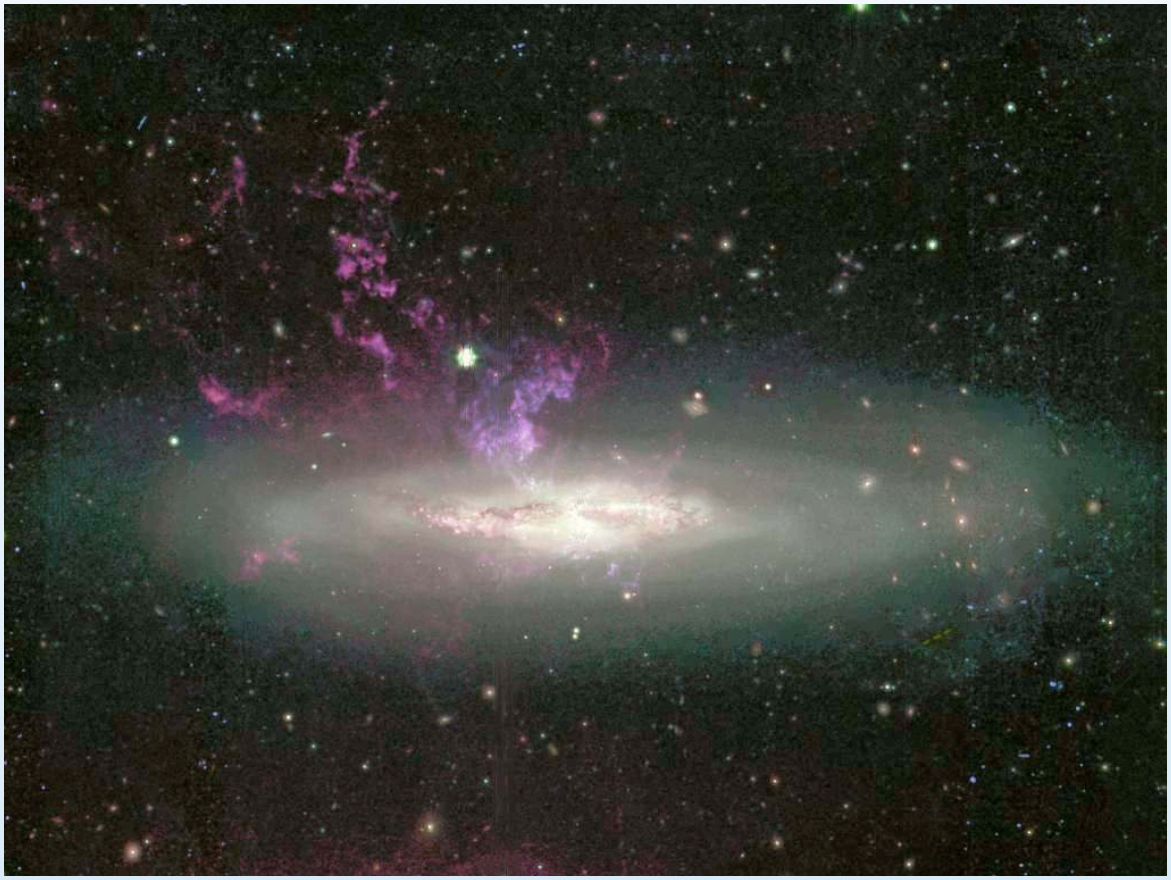


Graphic:
Beckmann &
Shrader (2012)

AGN environment

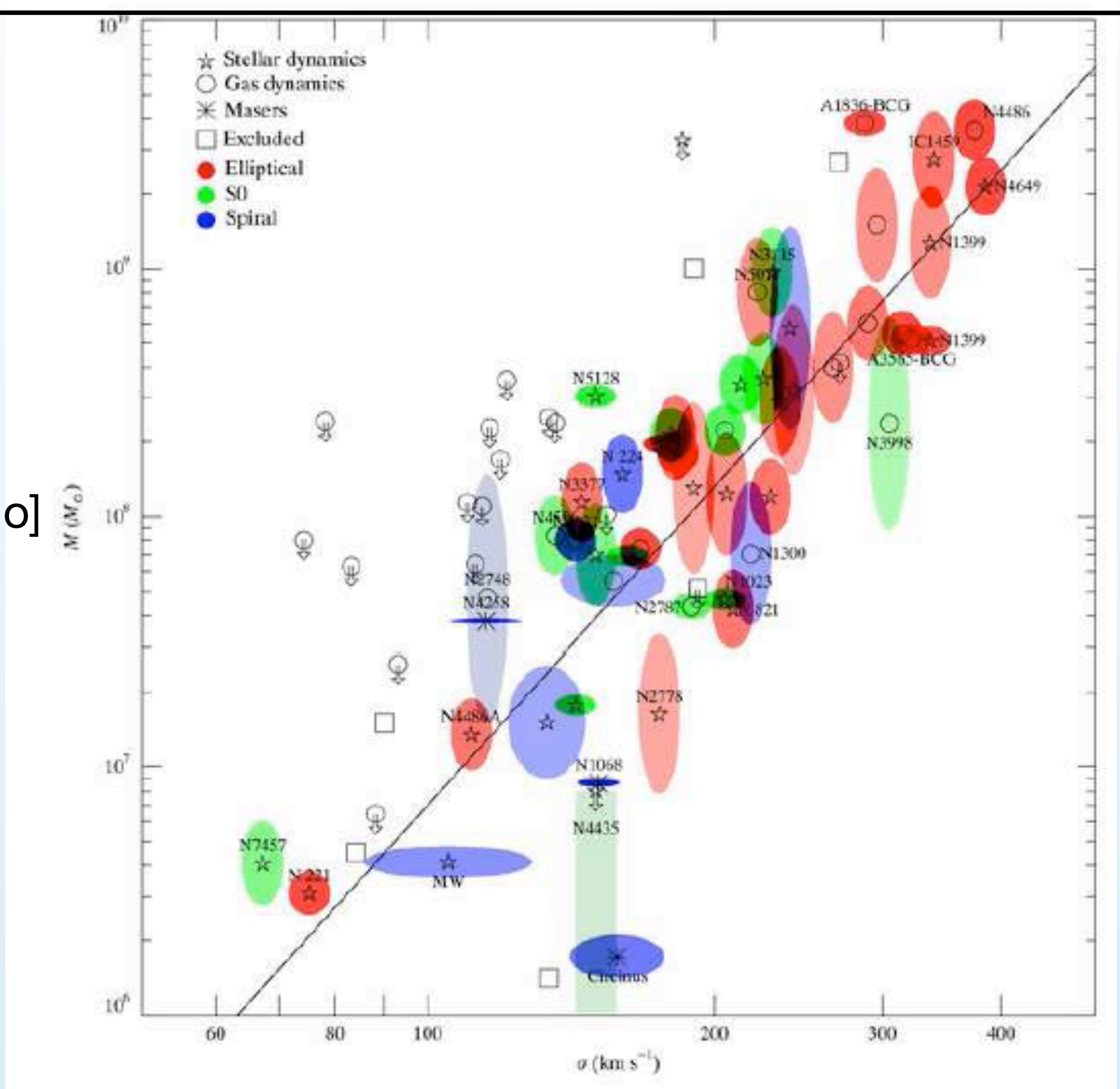
- There are no “naked” super-massive black holes
- AGN are at the center of galaxies
- Relation between AGN and its host?





Spiral galaxy NGC 4388 (Subaru Telescope, Suprime Cam, NAOJ)

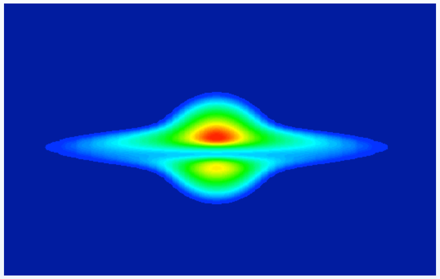
AGN environment



M_{BH} [Mo]

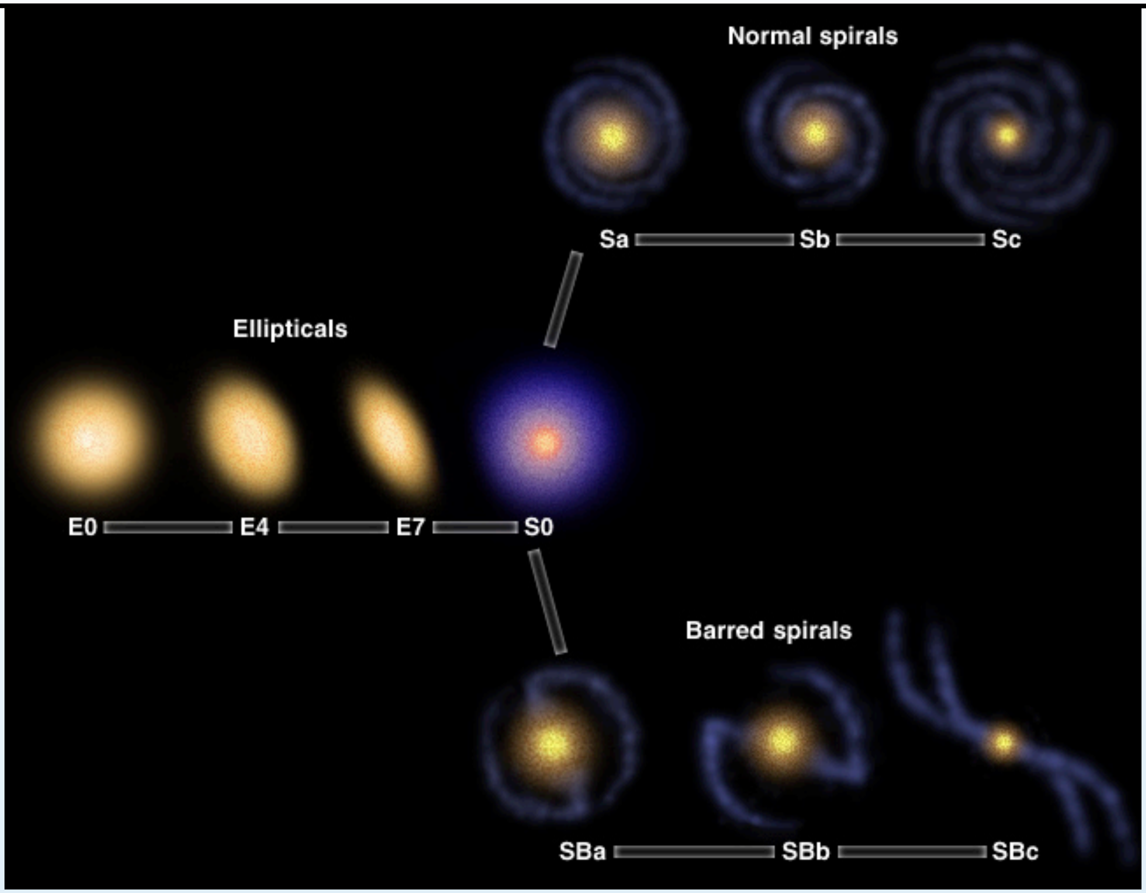
Velocity dispersion σ [km / s]

Gültekin et al. 2009



Semionov & Vansevicius 2006

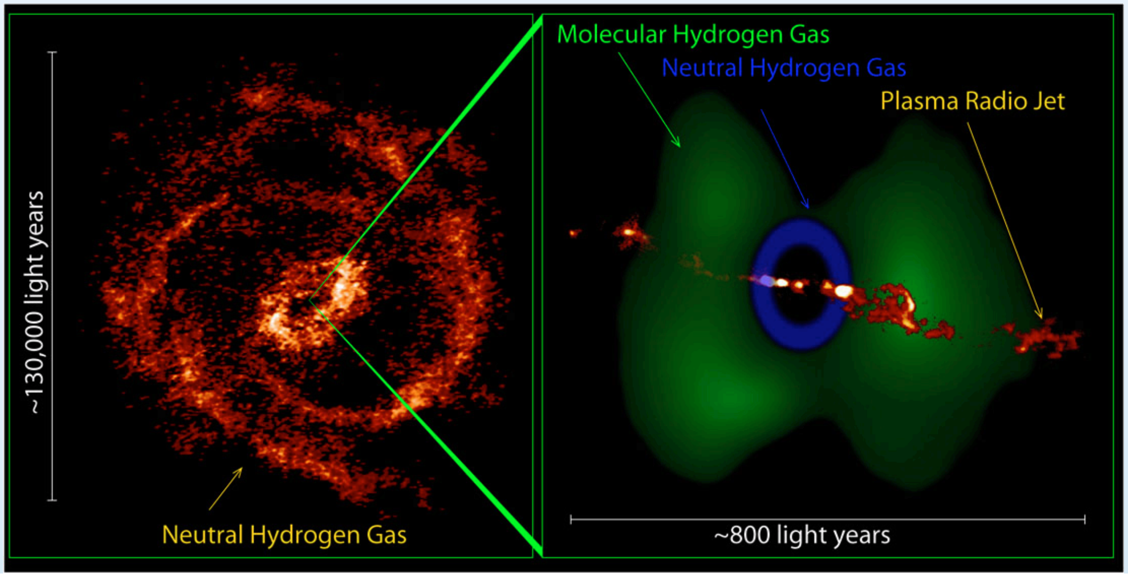
AGN environment



- There is no clear correlation with the type of host galaxy
- Massive SMBH sit rather in elliptical galaxies
  (but: ellipticals are on average more massive than spirals!)
- Role of bars on the AGN activity not clear (no correlation: Cardamone et al. 2011, correlation: Alonso et al. 2012)

AGN environment

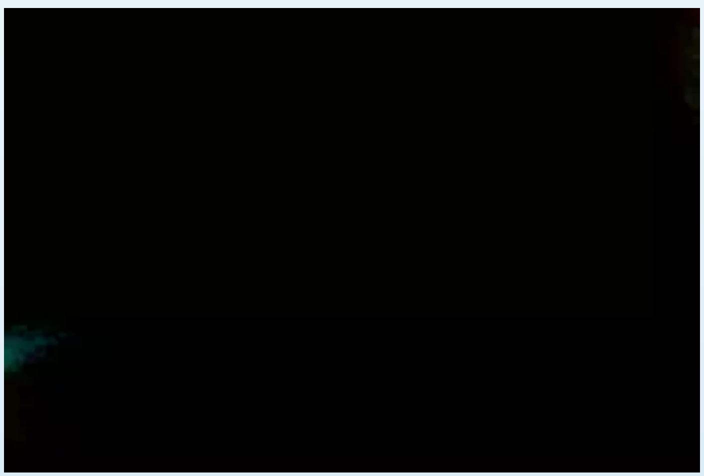
- Feedback between SMBH and host?
- Does the AGN regulate its own feeding?
- Does the AGN regulate the star burst activity in the host?
- Yes: e.g. De Young (2010), Fabian (2010)
- No: Jahnke & Maccio (2011), Jian et al. (2011), Juneau et al. (2012; but intrinsic absorption correlated with SFR)
- Gas is needed to feed AGN. 10% of galaxies at z~2 are AGN, but only 0.1% at z=0 (Dunlop et al. 2003)
- No correlation between AGN axis and host galaxy orientation (Keel 1980, Lawrence & Elvis 1982, Hopkins et al. 2011)

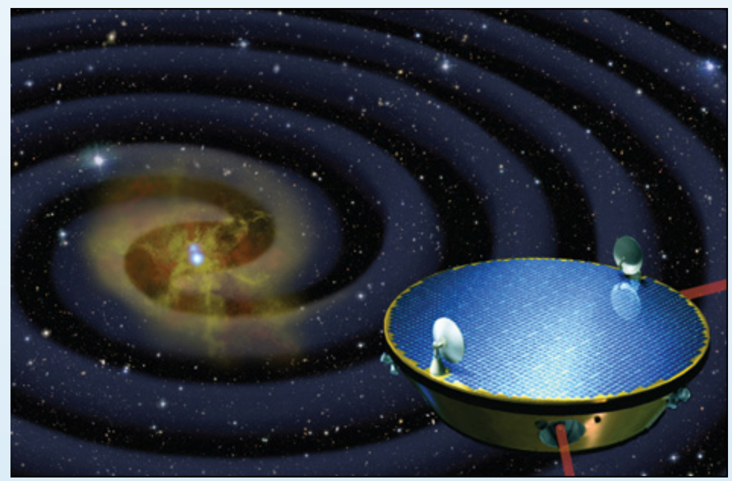


NGC 4151 (Mundell et al. 1999, 2002; Fernandez et al. 1999)

AGN & merger

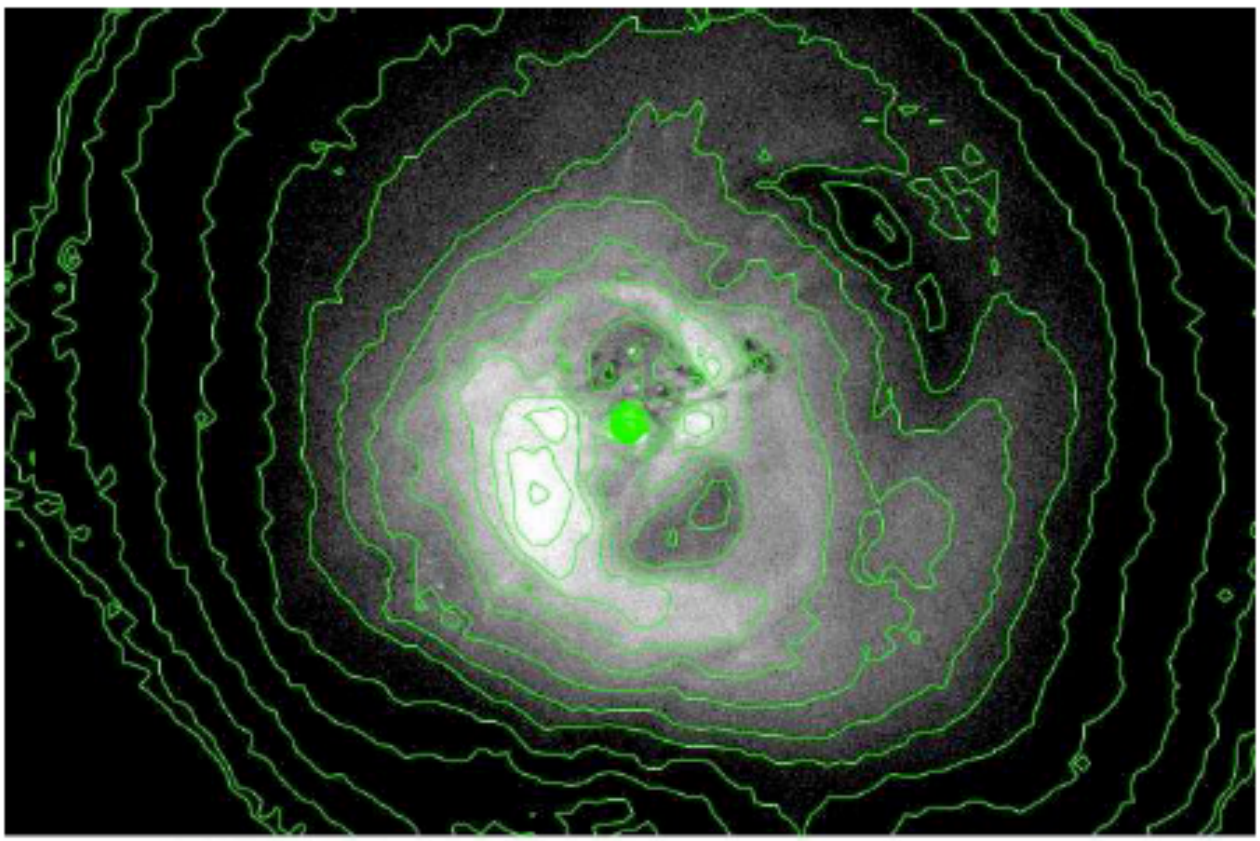
- Merging of host galaxies transports matter to the core
- Hopkins et al. (2010): uncertainty leaves room for any kind of scenario
- Kocevski et al. (2012): Chandra detected AGN + control sample: major merger do not trigger AGN at z~2 (but minor merger?)
- Difference between dry and wet (= gas-rich) merger?
- eLISA will tell us what the real AGN merger rate is





AGN & galaxy cluster

- AGN produce cavities in galaxy cluster
- 70% of the clusters with short cooling times show bubbles (Dunn & Fabian 2006)
- Enough to solve the cooling problem (Fabian et al. 2006) ?



NGC 1275 in the Perseus cluster. Chandra image. Beckmann & Shrader (2012)

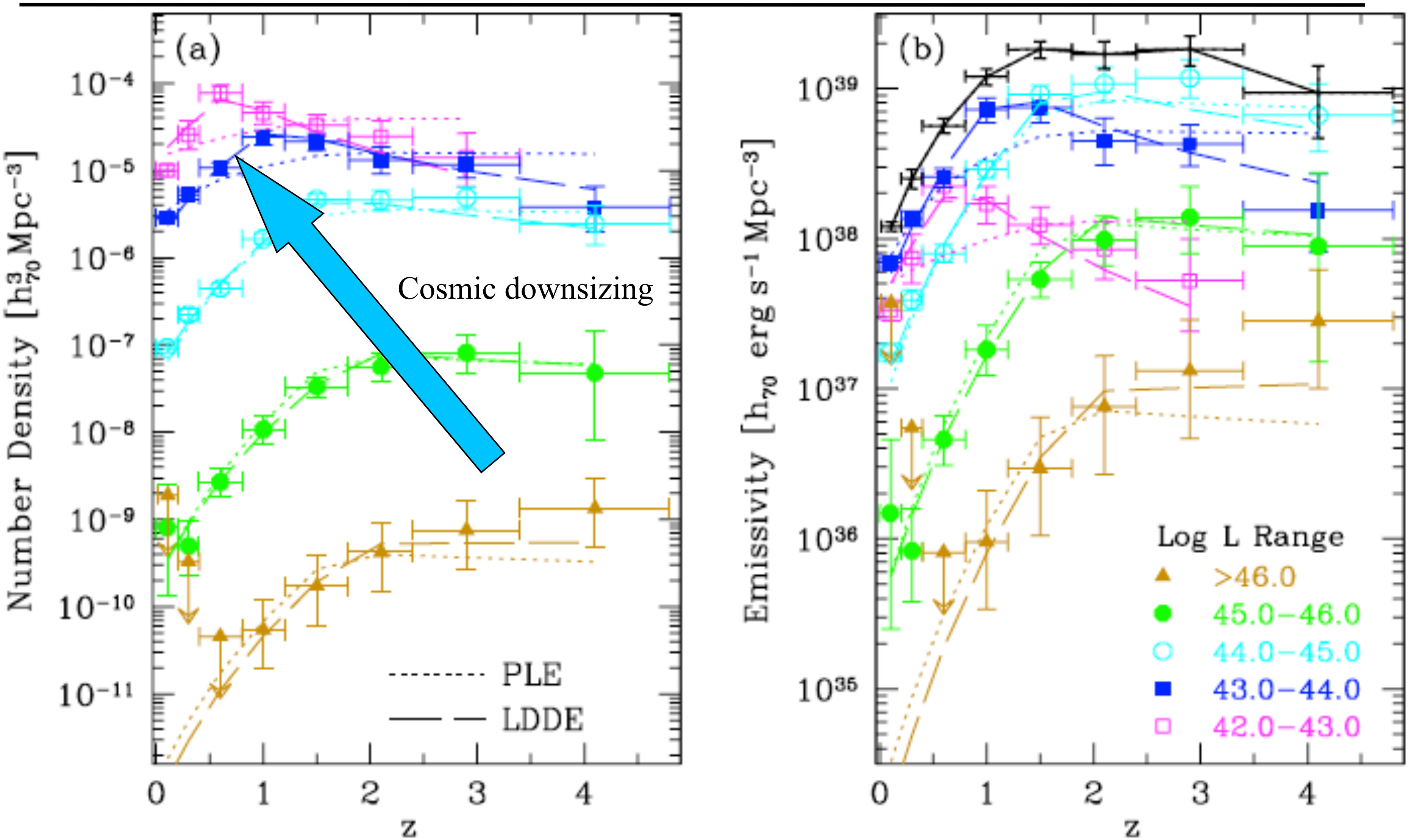
SMBH formation

- Quasars observed back to z=7.085 (Mortlock et al. 2011)
- How to form a M> 10^8 Mo black hole within < $6\text{x}10^8$ years ?
- Assume Eddington limited accretion λ=1, efficiency η =10%:
- M_0 = 10 Mo → $9\text{x}10^6$ Mo after $6\text{x}10^8$ years
- Either lower efficiency, or larger start mass:
- η = 0.09, M_0 = 150 Mo → M(z=7) = $6\text{x}10^8$ Mo
- But: accretion at the Eddington limit for 1 billion years?
- Initial mass function unknown
- Quasi stars (low J and metallicity) with direct collapse to 1000 < M < 10^6 Mo (Begelman et al. 2008) ?
- But: galaxies do not look very different at 6 < z < 8.7 (Mc Lure et al. 2011); similar colour and SFR as at z~2
- JWST to study first stars

SMBH formation

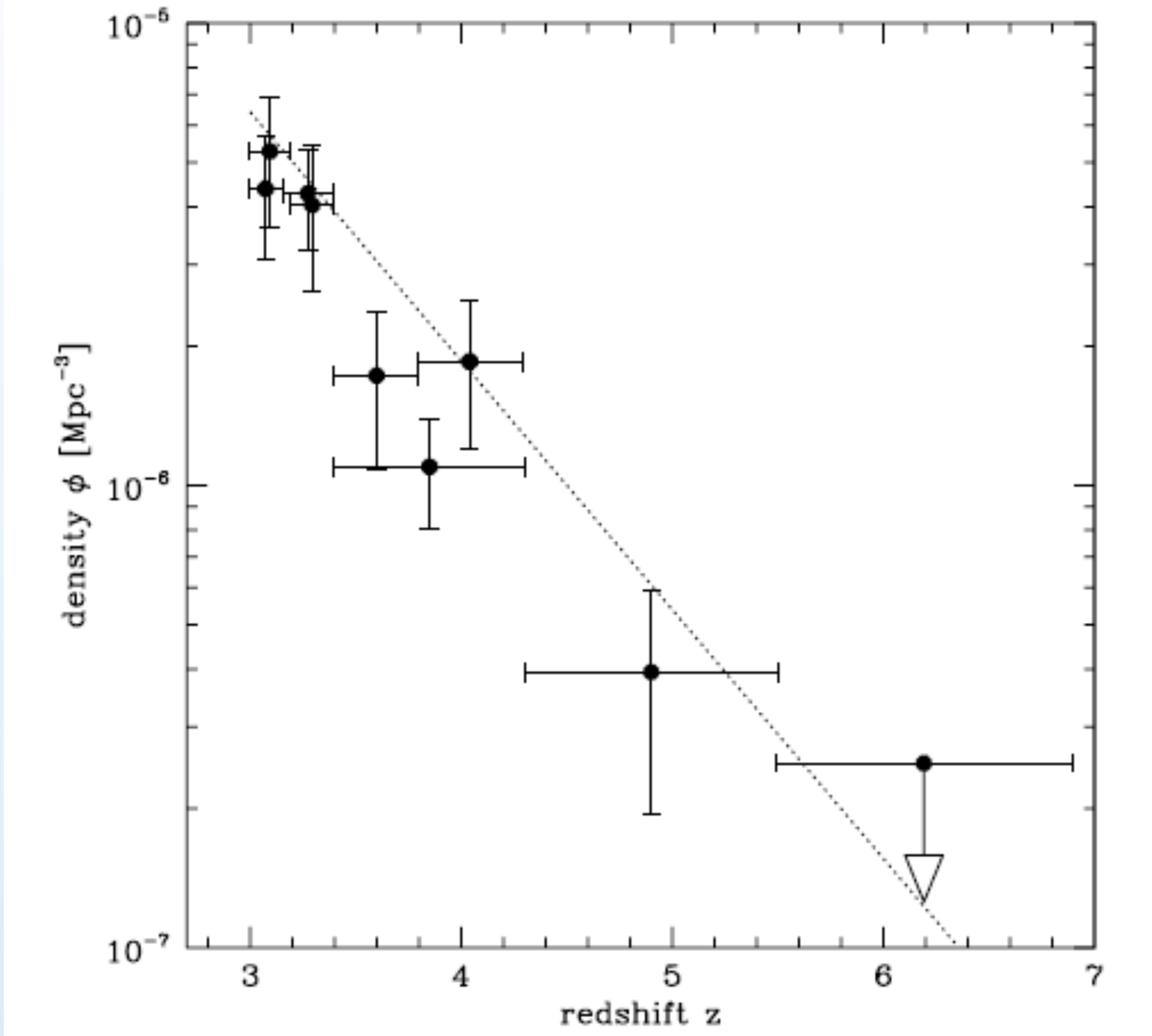
- Other solutions to get a large starting mass:
- Primordial black holes (e.g. Hawkins 2011)
- Merging of smaller black holes
- Problems with recoils (e.g. Campanelli et al. 2007) ?
- Starting with a black hole of M_0 ~ 1000 Mo it is “easy” to build SMBH until z~7 (e.g. simulations by Sijacki et al. 2009)

AGN evolution



X-ray luminosity function of AGN (Hasinger et al. 2005)

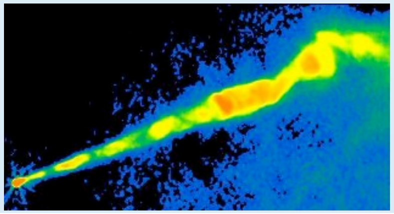
AGN evolution



Space density of X-ray AGN (Civano et al. 2011) and model by Gilli et al. (2007)

Open questions I

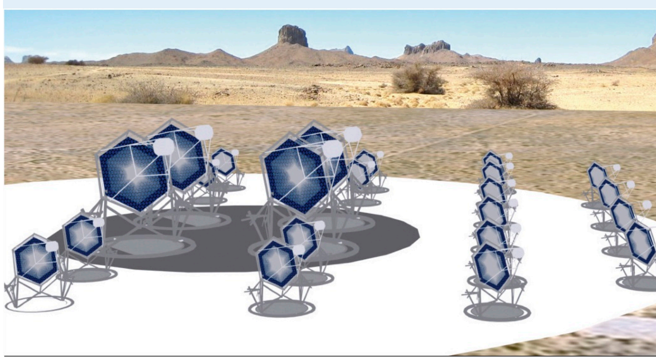
- Kerr black holes? Model independent measurement necessary, higher resolution and better coverage, e.g. NuSTAR, Astro-H, LOFT
- Accretion models: alpha-disk and Bondi accretion, ADAFs. Other forms of spherical symmetric accretion? Numerical simulations (3D, MHD)
- Geometry of AGN? Patchy corona? Better models + observations (X-ray/hard X-ray) necessary
- How to raise the jet? VLBI shows details and starting point
- Related to unknowns in accretion and BH spin
- GBH most luminous when there is no jet -- but AGN are most luminous as radio loud quasars
- GBH: baryons in jet (SS 433 Margon+ 1979 , 4U 1640-47 Diaz Trigo+ 2013)
- What collimates the jet?
- Polarization mapping, higher resolution radio observations, numerical modeling

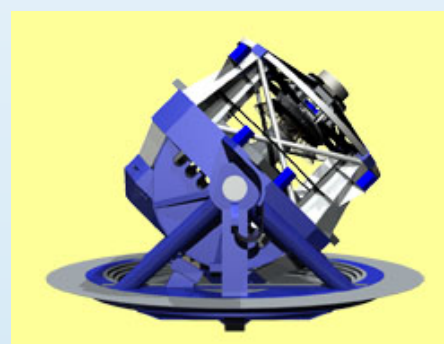
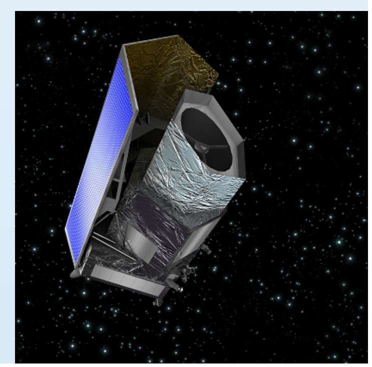


Open questions II

- SED modeling
- Synchrotron and EC / SSC / mix ?
- Better sampling needed (and not always the same blazars!)
- Flaring objects might not be representative
- Are all non-blazar gamma-ray bright AGN somehow intrinsic blazars?
- Fermi, CTA

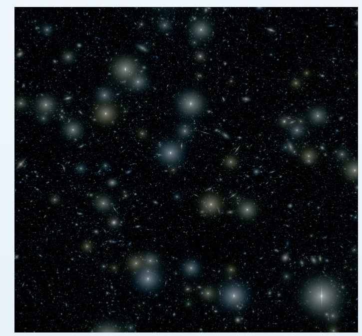
- Unification: statistics
- SDSS, SDSS-III, Gaia, eROSITA, LSST, Euclid … : 10^7 AGN
- New data treatment techniques needed



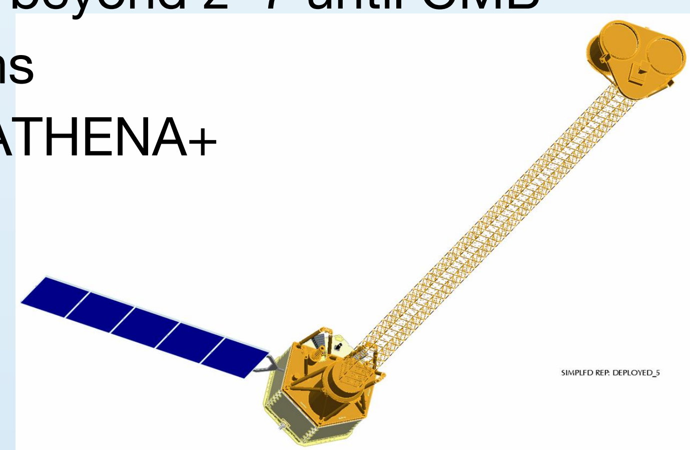



Open questions III

- Environment
- Is there feedback or not? Does the host galaxy play a major role (other than providing mass) ? Do bars play a role?
- Merging: important for the AGN? Minor or Major merger?
- better (control) samples needed
- Dark matter in the Universe important
- Euclid, DES, PanSTARRS, PAU, LSST …



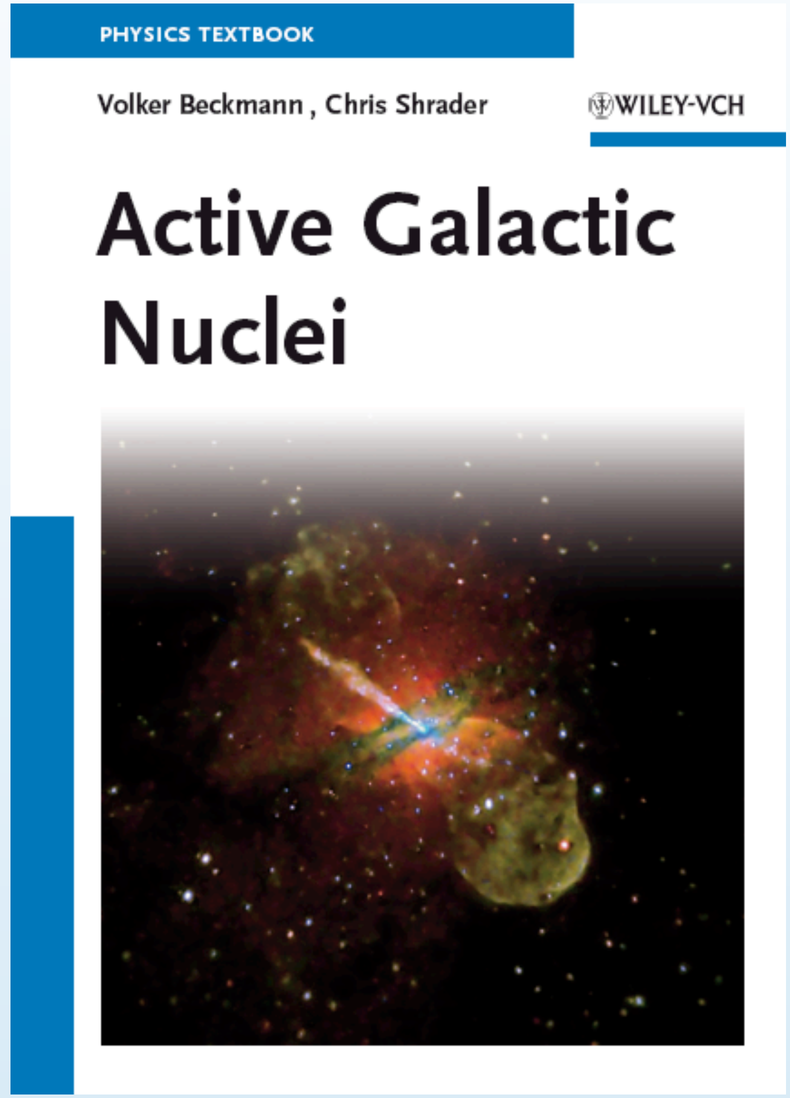
- SMBH: how to build a quasar until z~7 ?
- We do not know much about the Universe beyond z~7 until CMB
- JWST, E-ELT, theory, numerical simulations
- Absorption evolution? NuSTAR, Astro-H, ATHENA+
- Duty cycle of AGN?



What’s needed

- Theoretical models
- Simulations
- Observations
- Processing and data mining

- Get more students and colleagues on this exciting topic!



Beckmann & Shrader 2012,
“Active Galactic Nuclei”, Wiley-VCH,
382 pages
(see e.g. www.amazon.de)