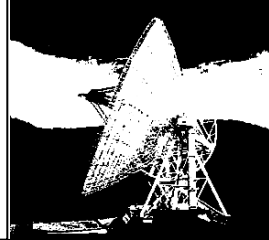


Sommersemester 2005



Aktive Galaxienkerne vom Radio- zum Gamma-Bereich



Silke Britzen

e-mail: sbritzen@mpifr-bonn.mpg.de

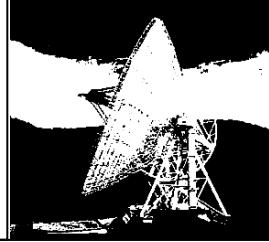
<http://www.mpifr-bonn.mpg.de/staff/sbritzen>

Max-Planck-Institut
für
Radioastronomie



Sommersemester 2005

Termine & Programm



15.04.:Ausblick (dieses Semester) &

Zusammenfassung (letztes Semester)

29.04.:Beobachtungstechniken

13.05.:Ausgewählte AGN - typische Eigenschaften &

Spektrale Energieverteilung

27.05.:Zusammenfassung & Schwarze Löcher, Multiple Systeme

10.06.:Kosmologie & AGN

24.06.:

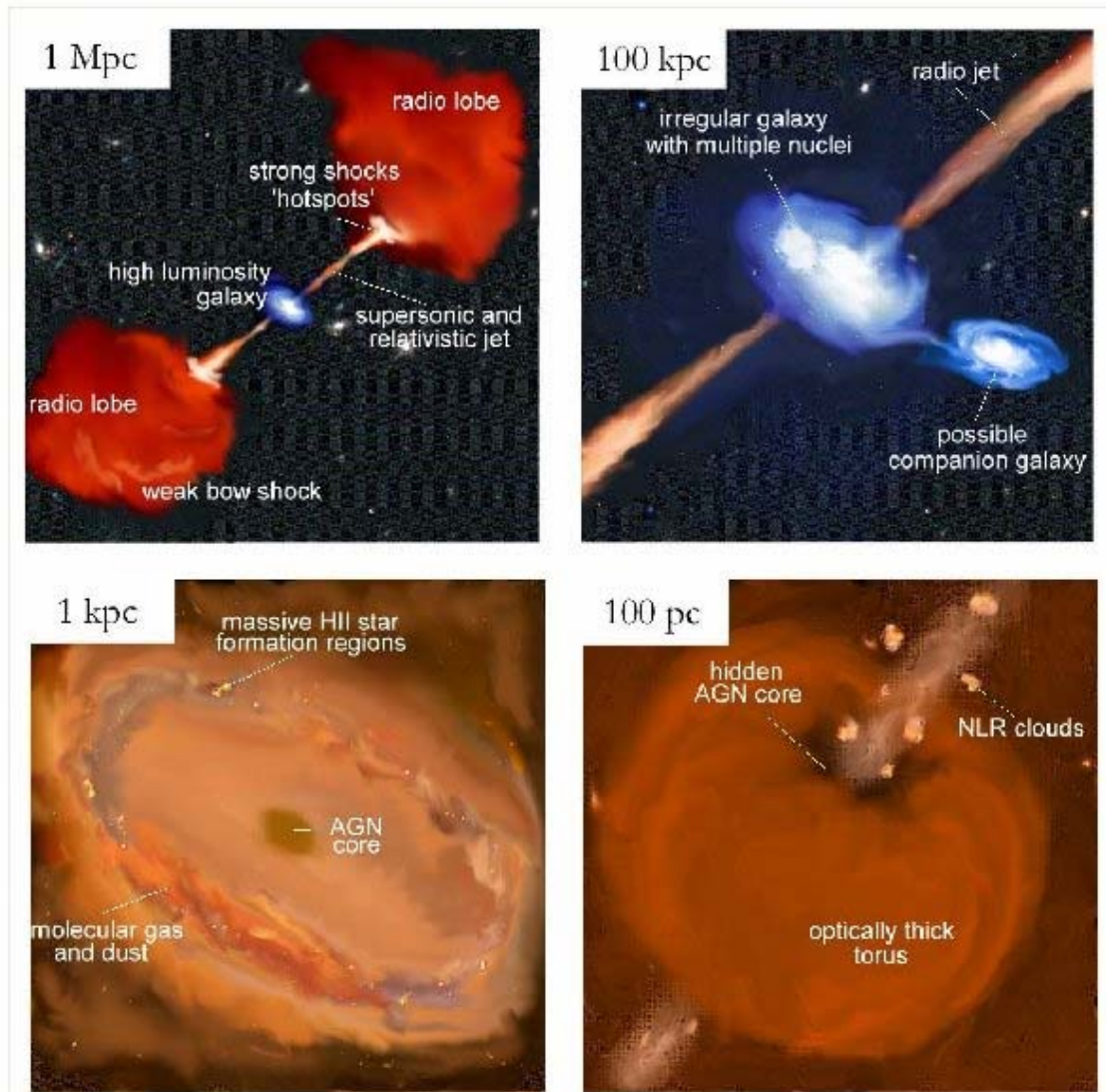
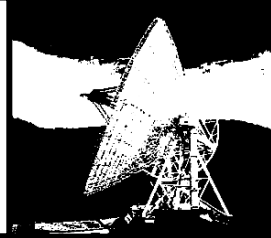
01.07.:

15.07.:.....



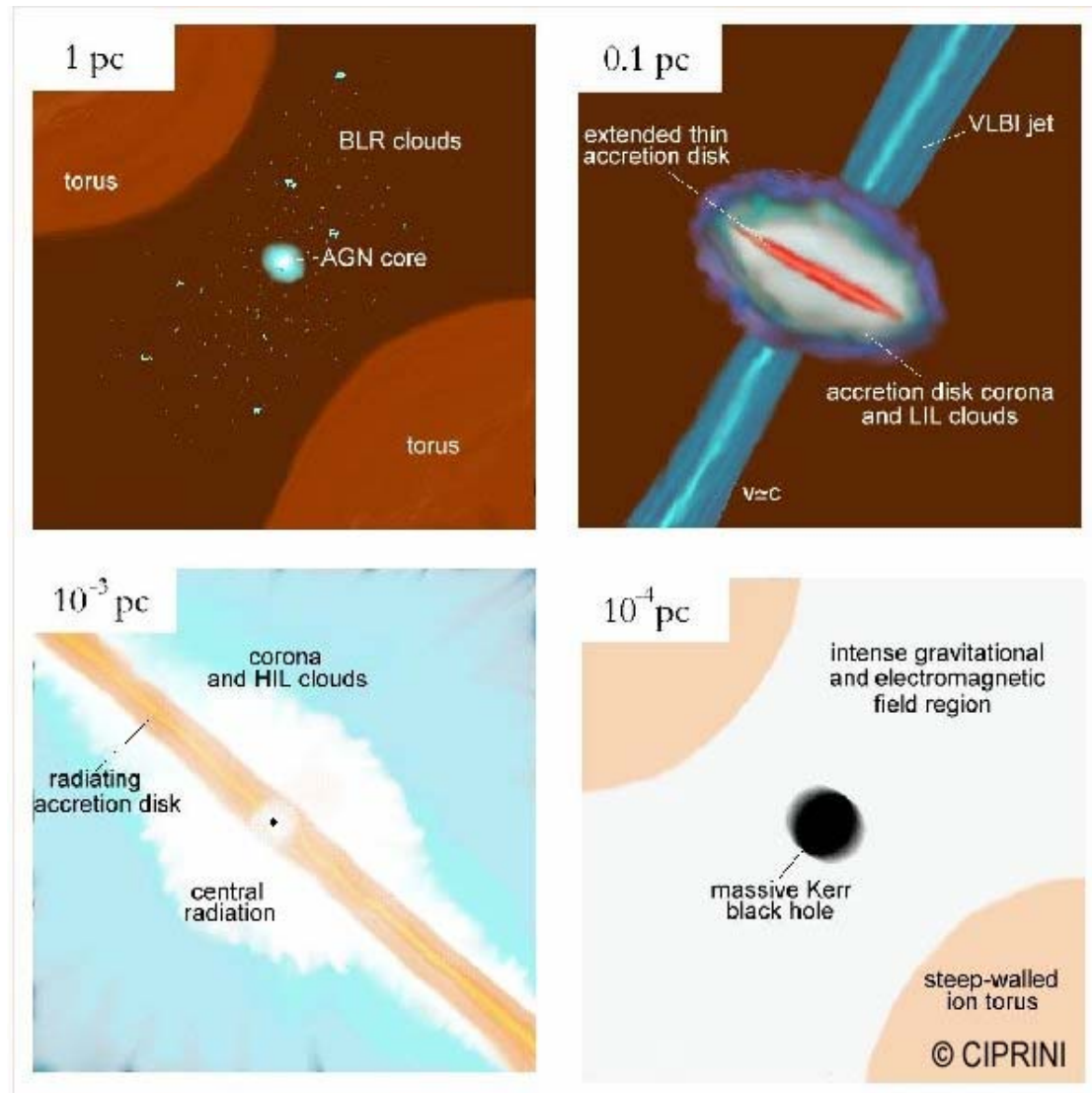
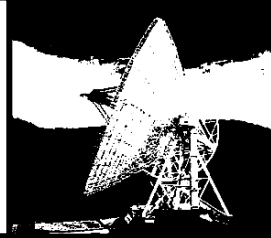
Zusammenfassung

Komponenten eines Aktiven Galaxienkerns

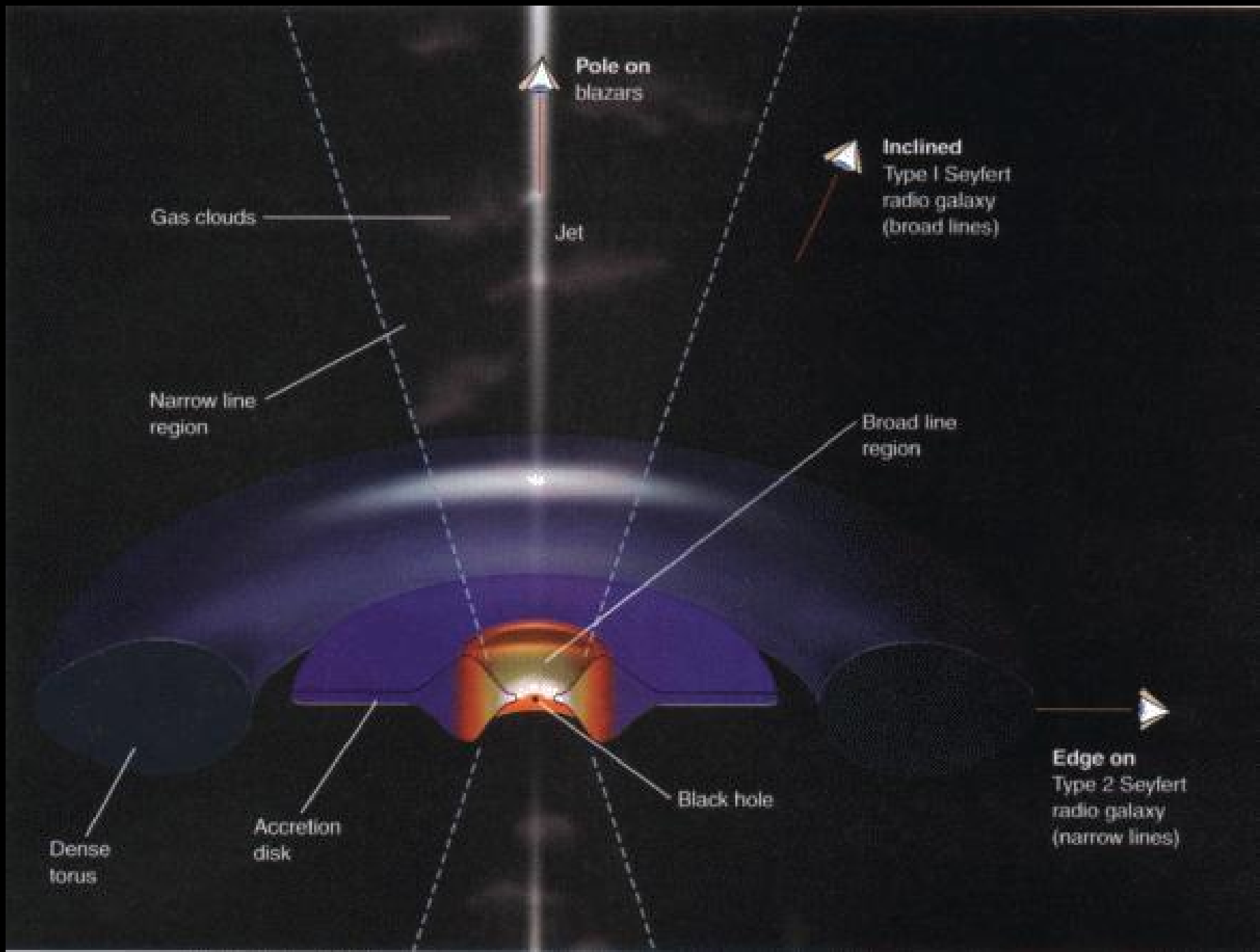


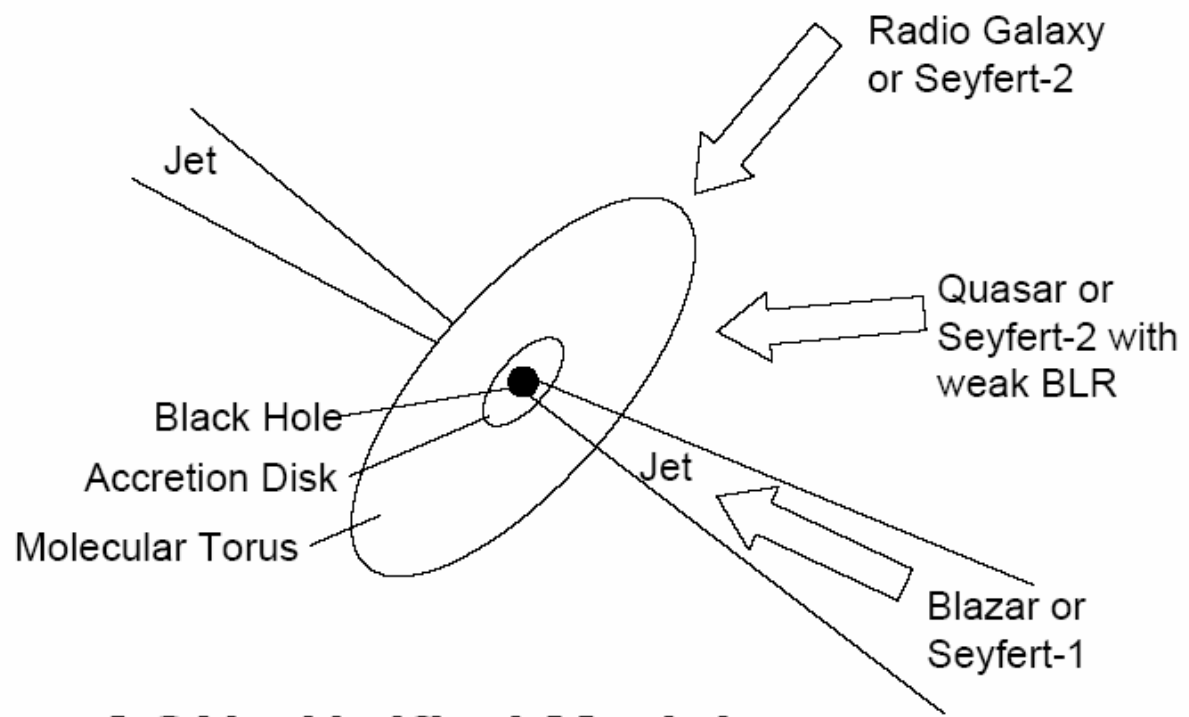
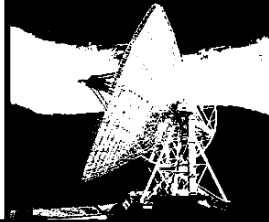
Cartoon of the representative scale sizes of an AGN. (Adapted from Blandford R.D.: "Active Galactic Nuclei. Saas-Fee Advanced Course 20." 1990, Berlin: Springer-Verlag)

Komponenten eines Aktiven Galaxienkerns

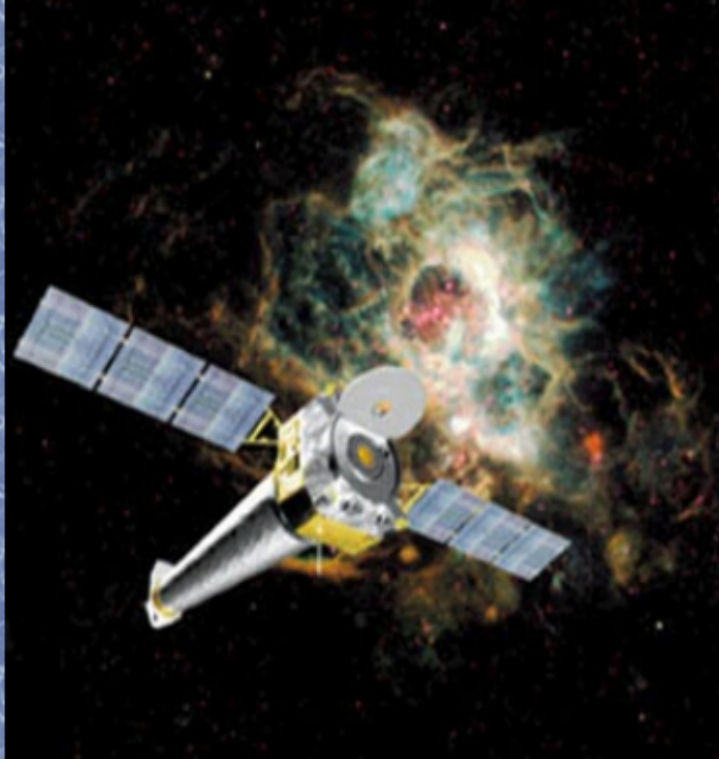


Cartoon of the representative scale sizes of an AGN. (Adapted from Blandford R.D.: "Active Galactic Nuclei. Saas-Fee Advanced Course 20." 1990, Berlin: Springer-Verlag)

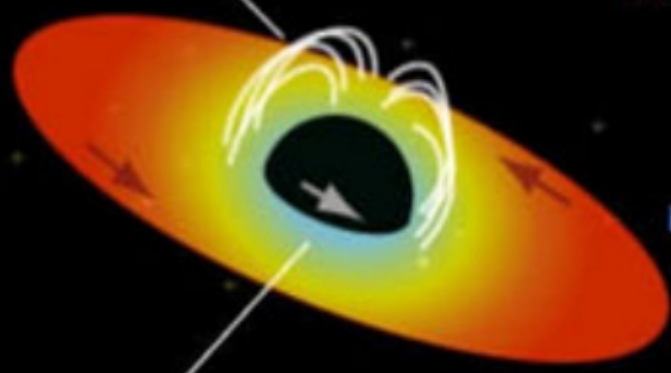




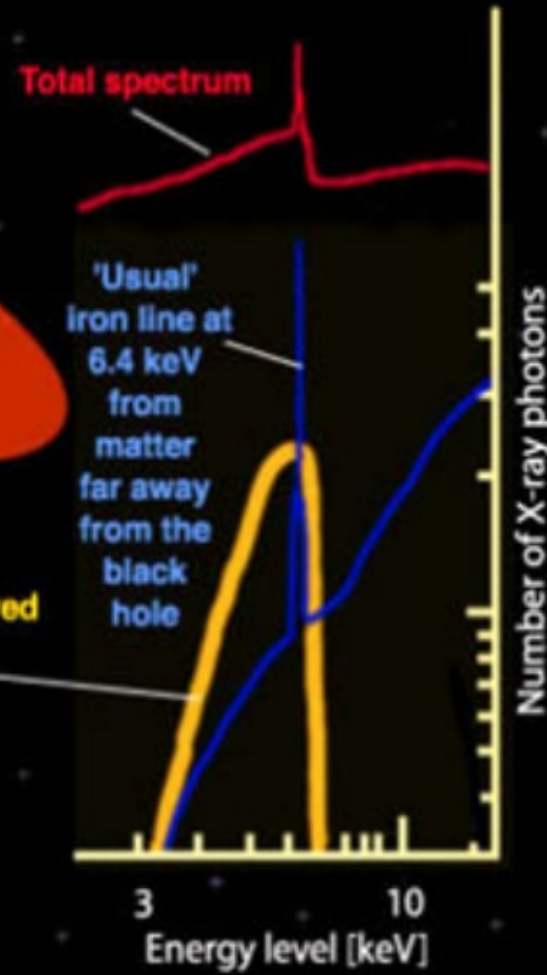
AGN - Unified Model



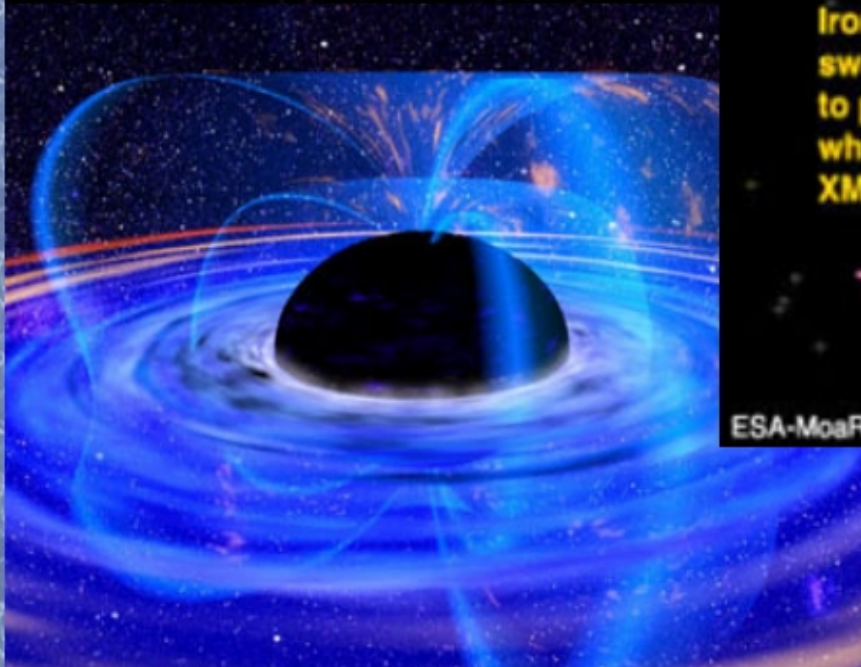
Rotating black hole in magnetic field releasing energy to inner areas of accretion disk ?



Iron nearest to being swallowed by the black hole believed to produce the strong, broad line which is fully revealed by XMM-Newton

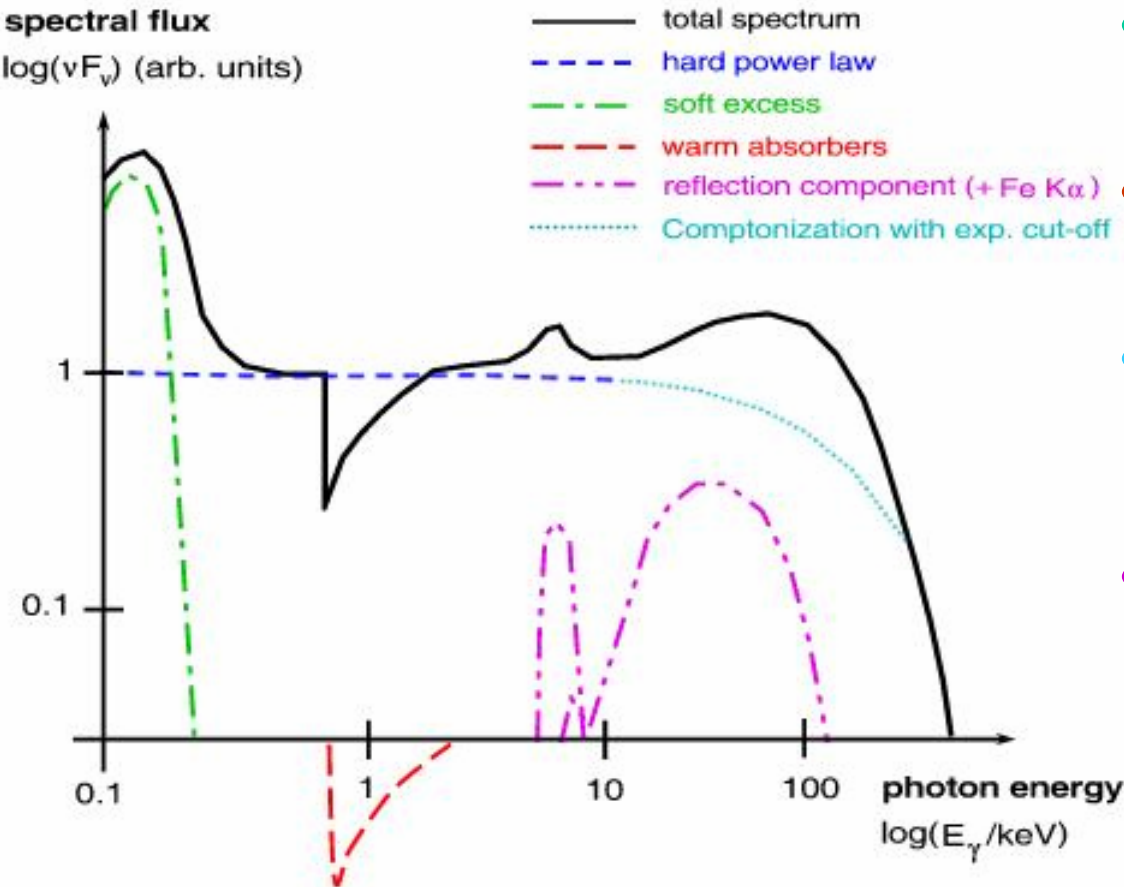
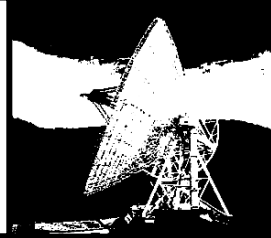


The surprising spectrum from MCG-6-30-15



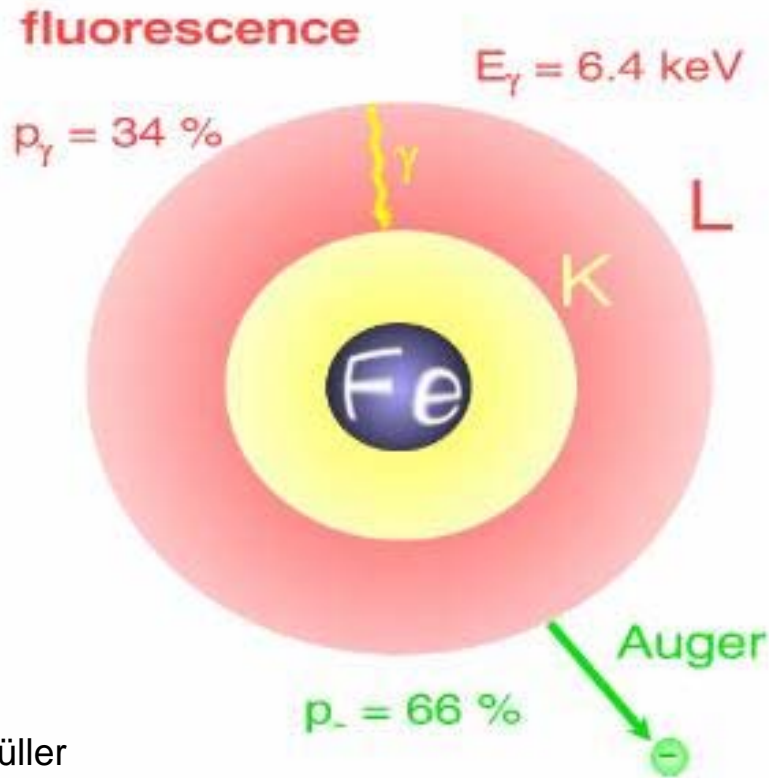
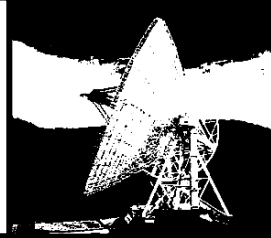
ESA-MoaR

Röntgen!



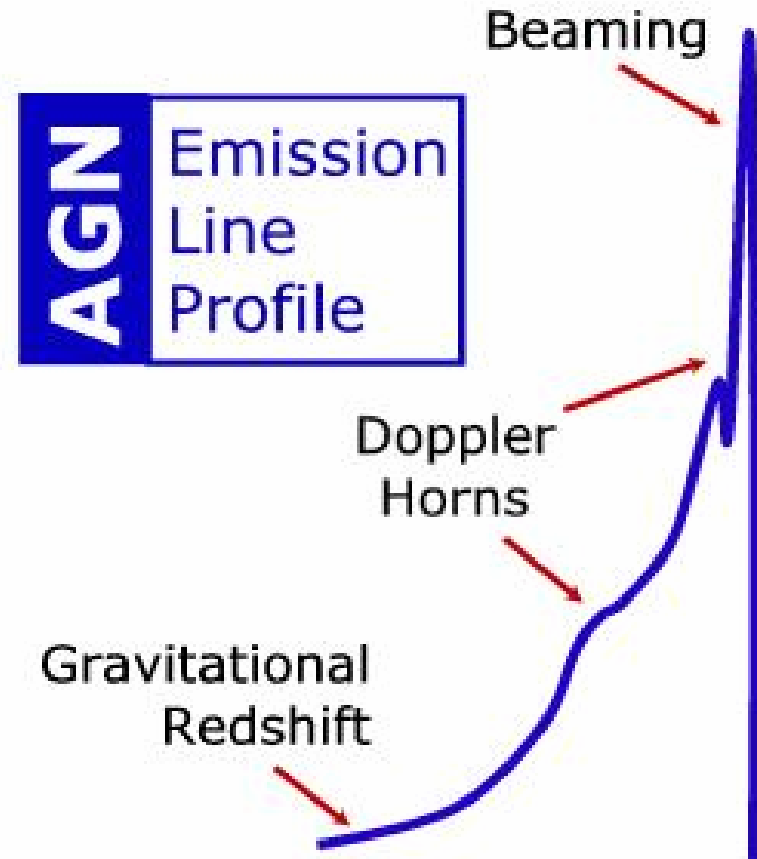
- **Weicher Exzess:** modifiziertes Schwarzkörper-Spektrum (Akkretionsscheibe)
- **Warme Absorber:** ionisierte Materie, bevorzugt Sauerstoff & Neon
- **Kontinuum:** Comptonisierung weicher Eingangsstrahlung (Akkretionsscheibe oder Hintergrundstrahlung)
- **Reflexionskomponente:** zw. 5-100 keV, Emissionslinie (Fluoreszenz von Eisen, Nickel oder Chrom) + breiter Buckel (Antwort der AS auf Primärstrahlung aus Korona)

Röntgen – die Eisen-Linie



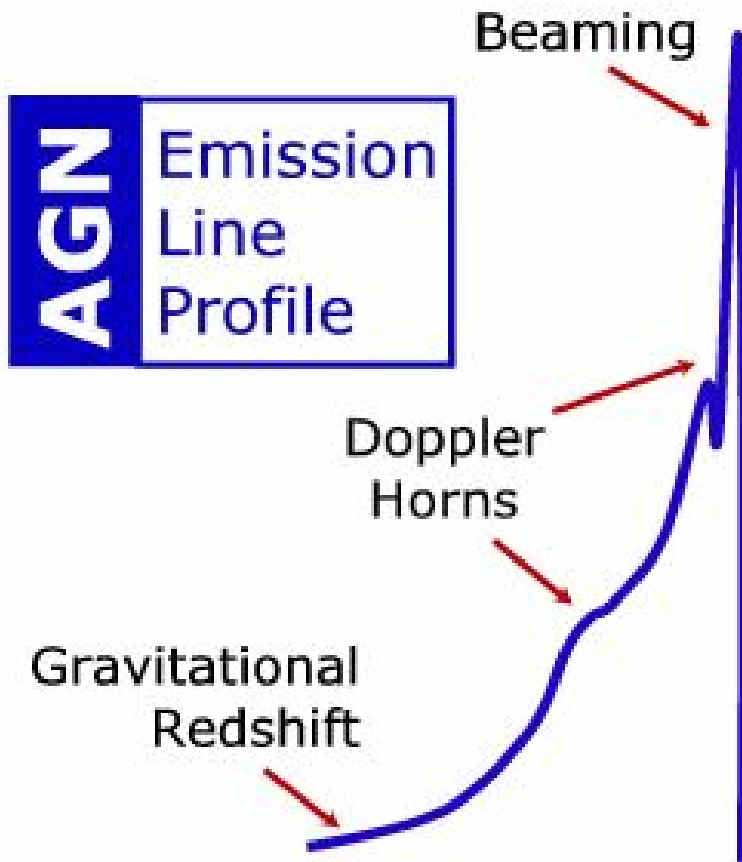
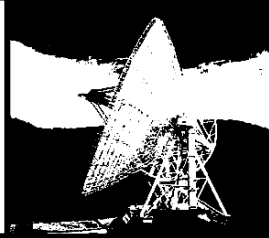
A. Müller

Ab Schwellenenergie von 7.1 keV wird die harte Eingangsstrahlung der Korona absorbiert.



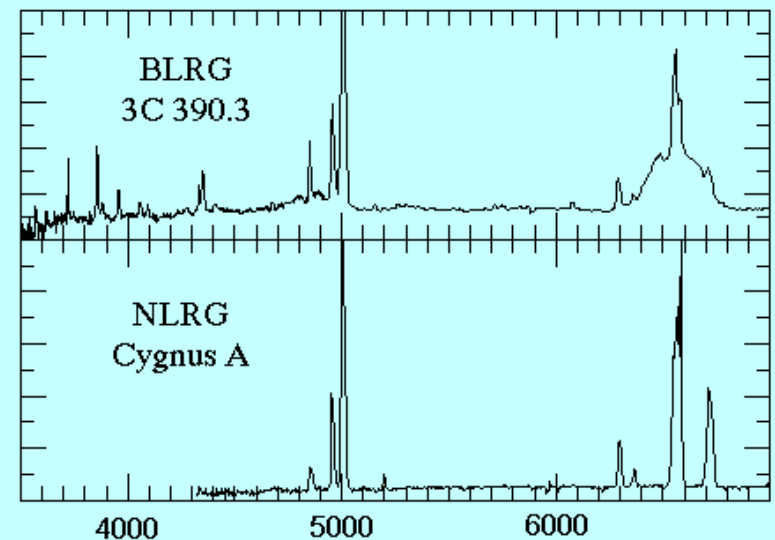
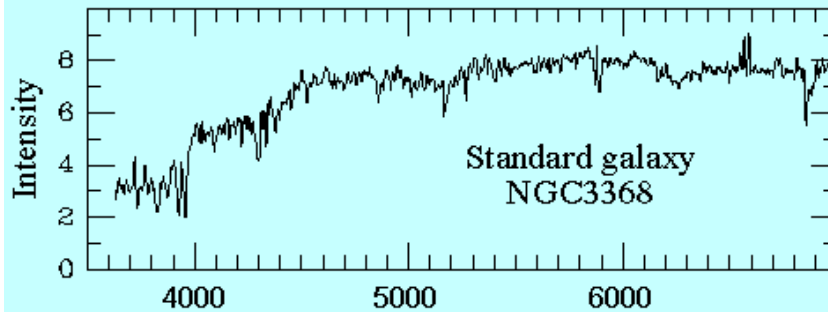
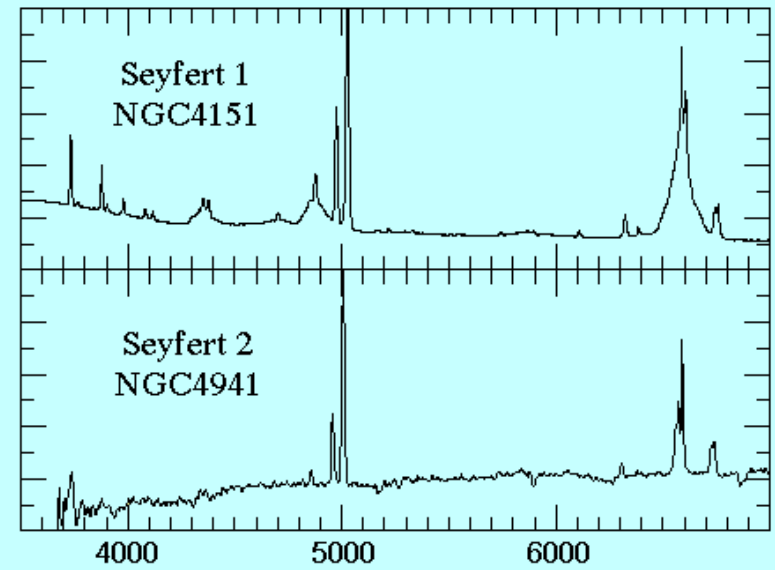
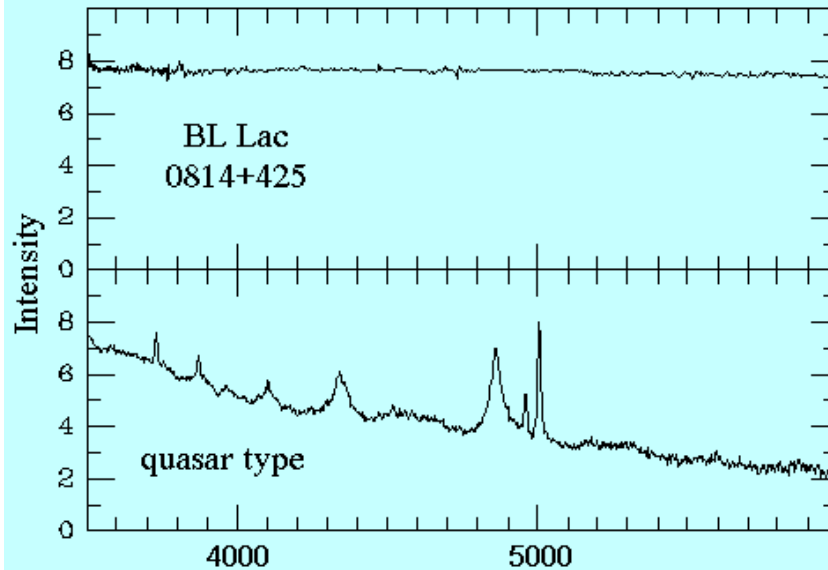
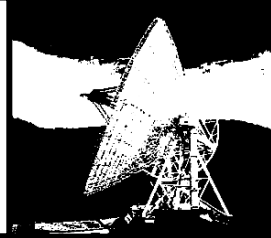
Röntgenphotonen breiten sich in der gekrümmten Raumzeit des Schwarzen Lochs aus.

Röntgen – die Eisen-Linie



- Doppler: Rotation der emittierenden Scheibe
- Gravitationsrotverschiebung: Effekt der Allgemeinen Relativitätstheorie, Photonen verlieren an Energie beim Versuch das Gravitationsfeld zu verlassen
- Beaming: Spezielle Relativitätstheorie, Strahlung gebeamt

Optische Spektren verschiedener AGK

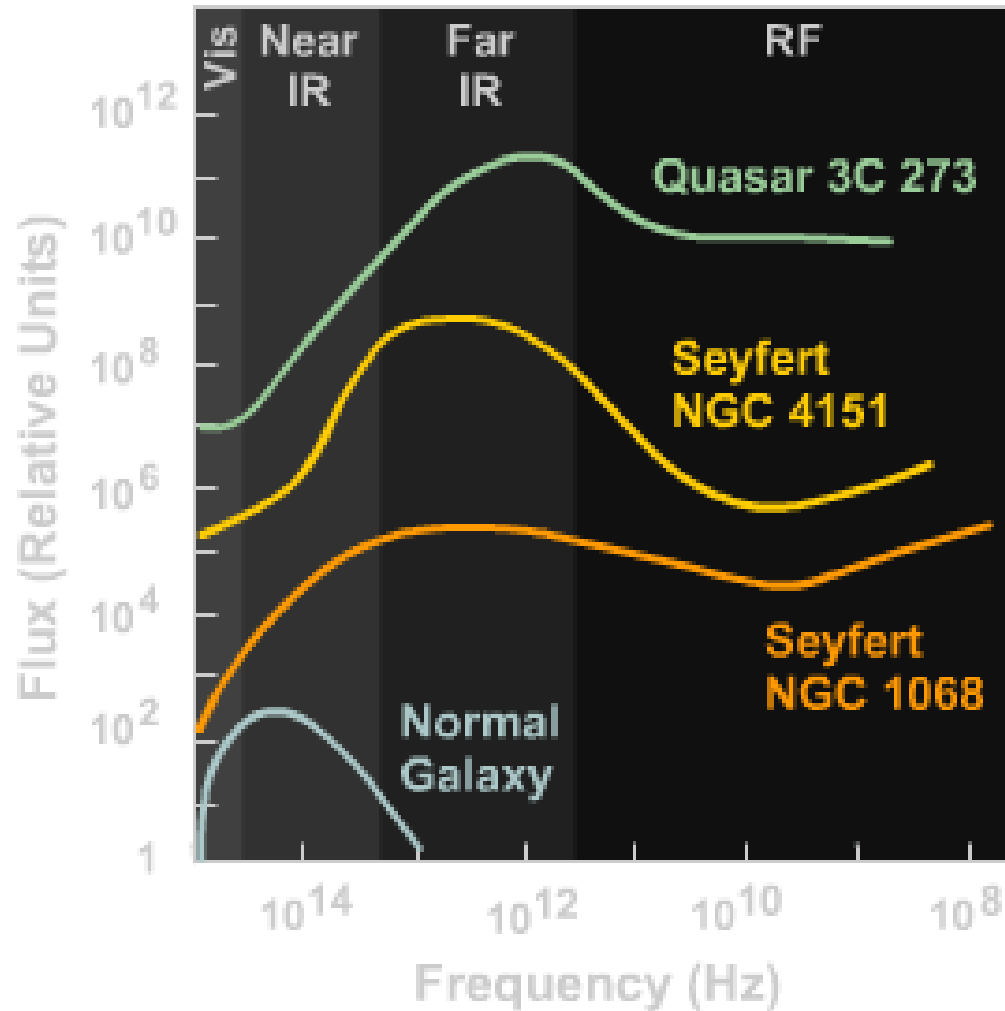
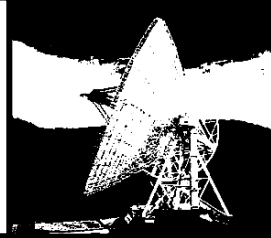


BLRG : Broad Line Radio Galaxy
Radio Galaxie à Raies Grandes

NLRG : Narrow Line Radio Galaxy
Radio Galaxie à Raies Etroites

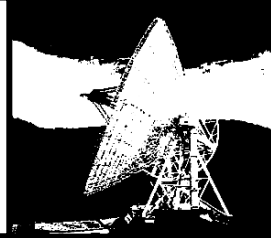
Wavelength (\AA)

Emissionsspektren verschiedener AGK



Emission Spectra for Active Galaxies

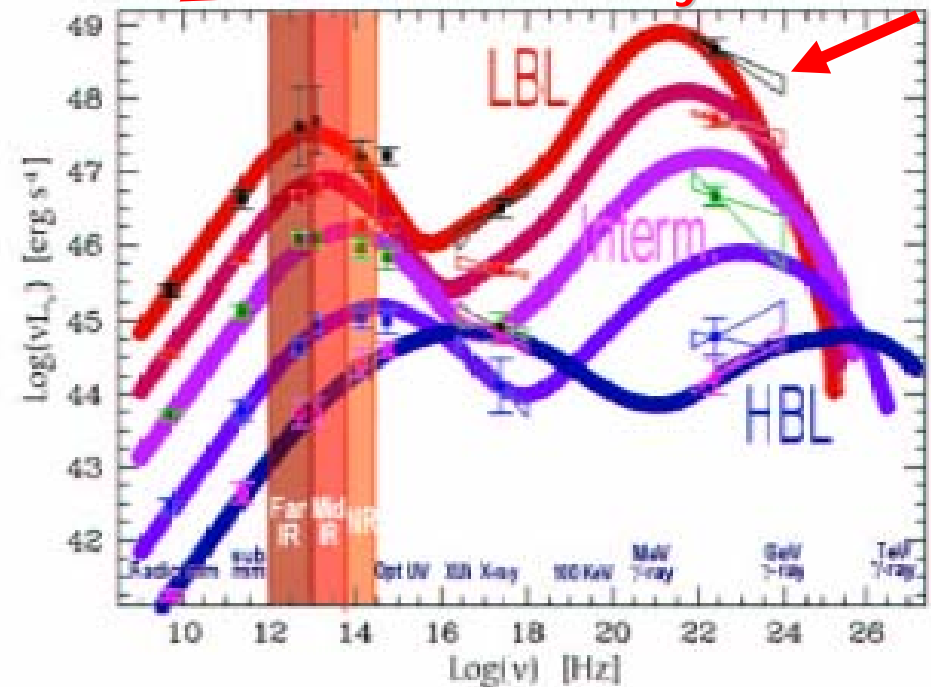
Spektrale Energieverteilung (SED) Blazare



- SEDs der Blazare zeigen typische 2-Komponenten Struktur aus Synchrotron und Invers Compton-Strahlung
- Verschiedene Möglichkeiten der Erzeugung der Invers-Compton Komponente: SSC, Photonen aus AK-Scheibe, BLRG,

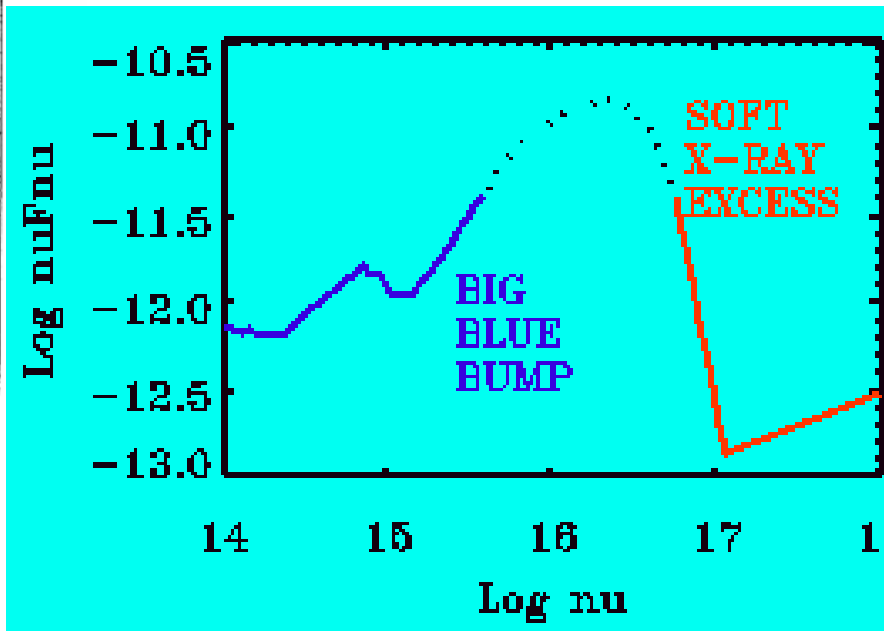
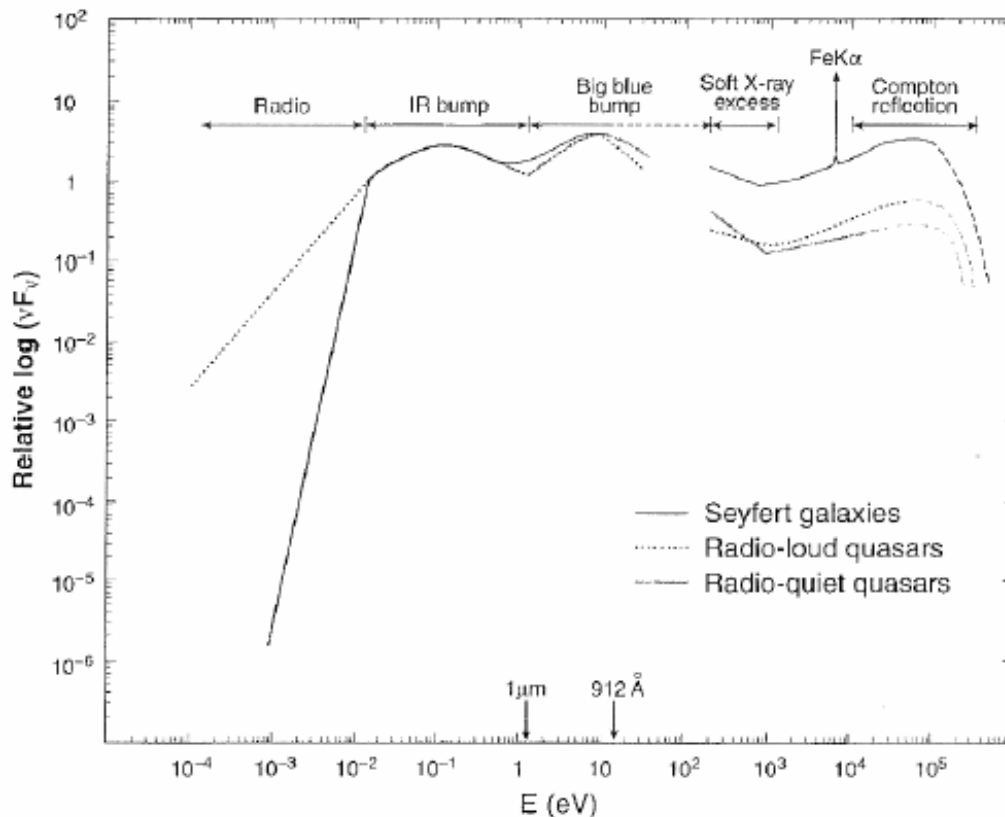
Electron
synchrotron

SSC?
 p^0 decay?
proton
synchrotron?

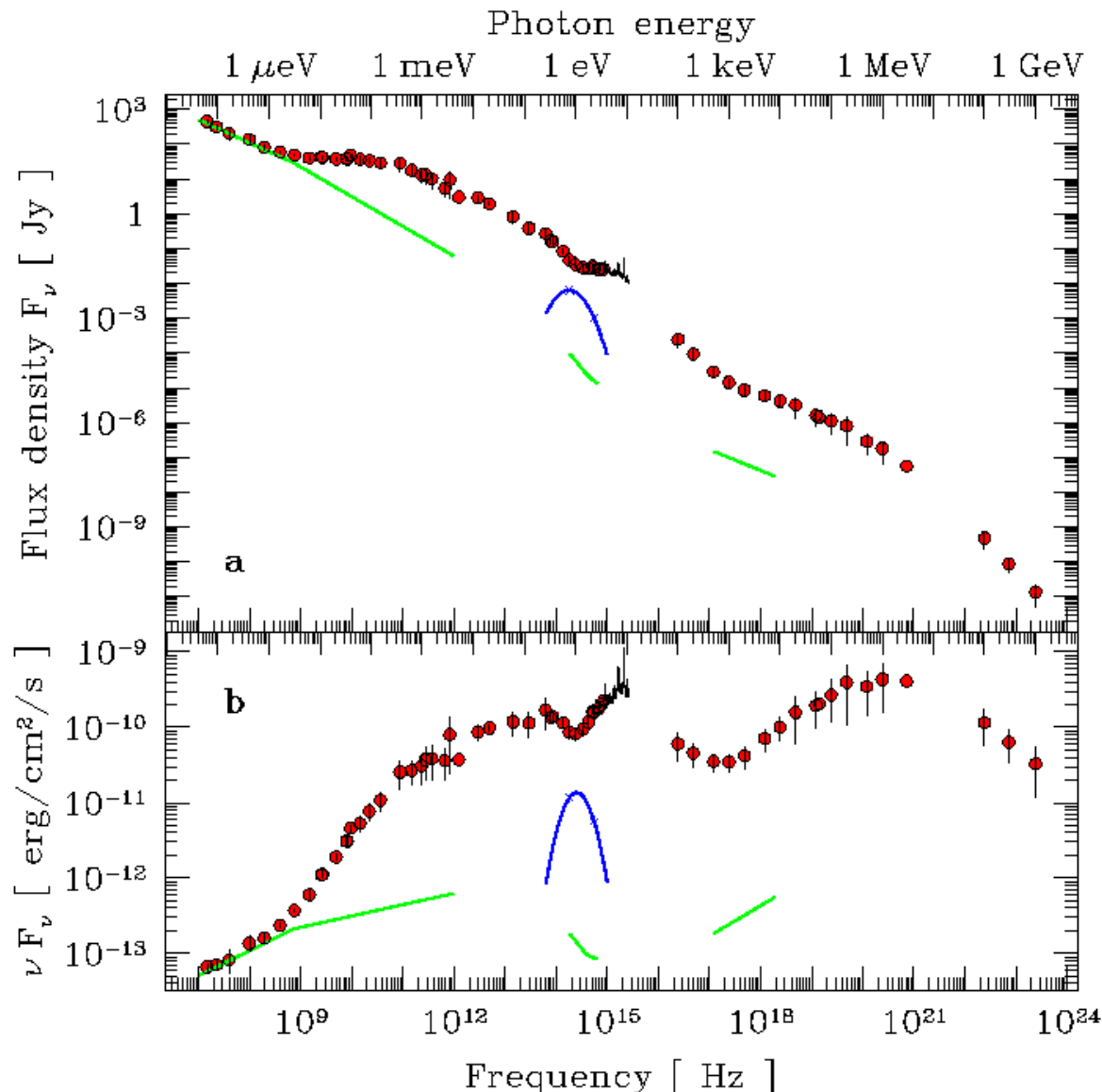
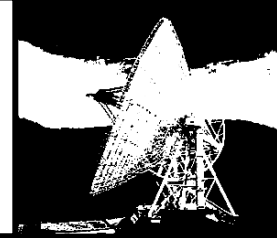




- Emittieren ihre Energie über 20 Dekaden im elektromagn. Spektrum
- Verschiedene Komponenten der Strahlung
- Synchrotron und Invers Compton-Strahlung
- Quasar SED (Spektrale Energieverteilung)



Spektrale Energieverteilung (SED) Quasare, Komponenten

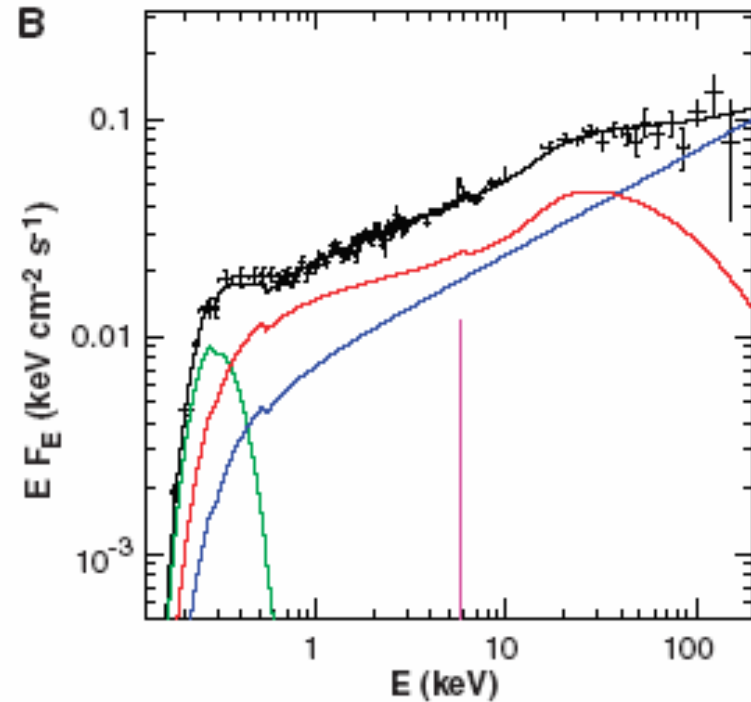
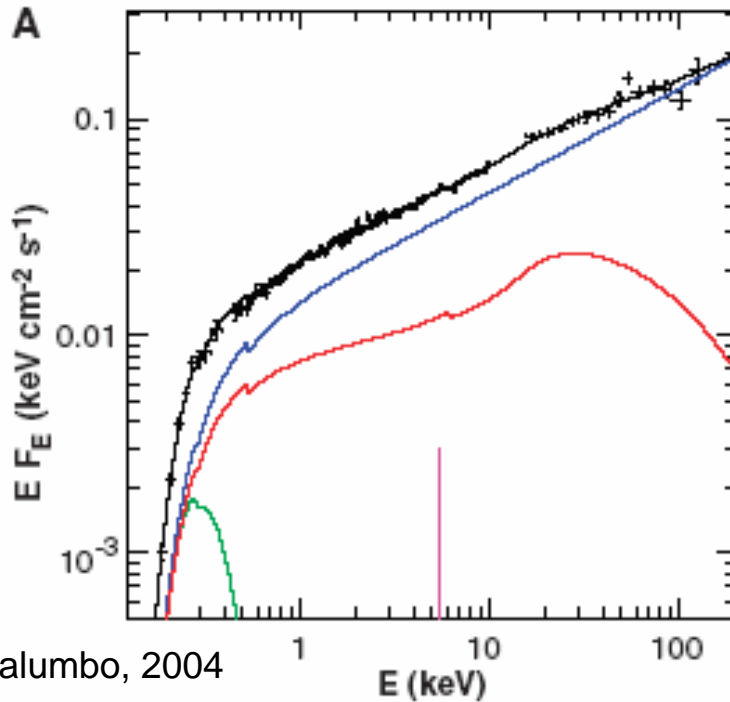
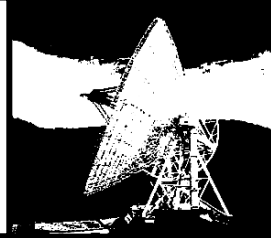


Mittleres Spektrum von 3C273.

Beitrag des äußeren
Jets (Conway et al.
1993) im Radio-Bereich;
Optisch und Röntgen
(Marshall et al. 2001)

Beitrag der elliptischen
host galaxy (E4)

Quasar 3C273, zerlegt in Einzelteile

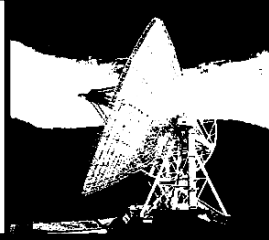


Grandi & Palumbo, 2004

(A) 3C 273 spectrum observed in January 1997, as untangled in its components: a jet (blue line), a Seyfert-like component (red line), a black body (green line), and the Fe line (magenta). The jet is the dominant component. The jet and the Seyfert-like flux ratios are $\dot{E}3$ in the 2 to 10 keV band and 7 in the 20 to 200 keV bands.

(B) Opposite spectral configuration observed in June 2001. The Seyfert-like component (red) overcomes the jet (blue) up to 40 keV. The Doppler-enhanced nonthermal radiation can emerge only when the thermal component declines because of the high-energy cutoff. The jet and the Seyfert-like flux ratios are 0.7 in the 2 to 10 keV region and $\dot{E}2$ in the 20 to 200 keV regions.

Variabilität: viele Zeitskalen, auf der Suche nach Korrelationen



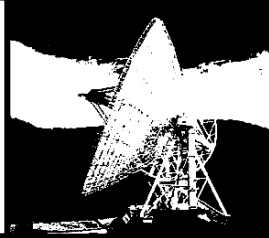
– Extrinsische Effekte

- Mikrolinsen (Chang & Refsdal (1979), aber: hoher duty-cycle, immer aktive, Sterne können sich nicht so schnell bewegen (relativistisch)
- **Interstellare Szintillation**, frequenzabhängig; Fluktuationen im streuenden ISM $I^{-2.2}$; kann nicht die optische Variabilität erklären; jedes kompakte Objekt muß RISS zeigen

– Intrinsische Effekte

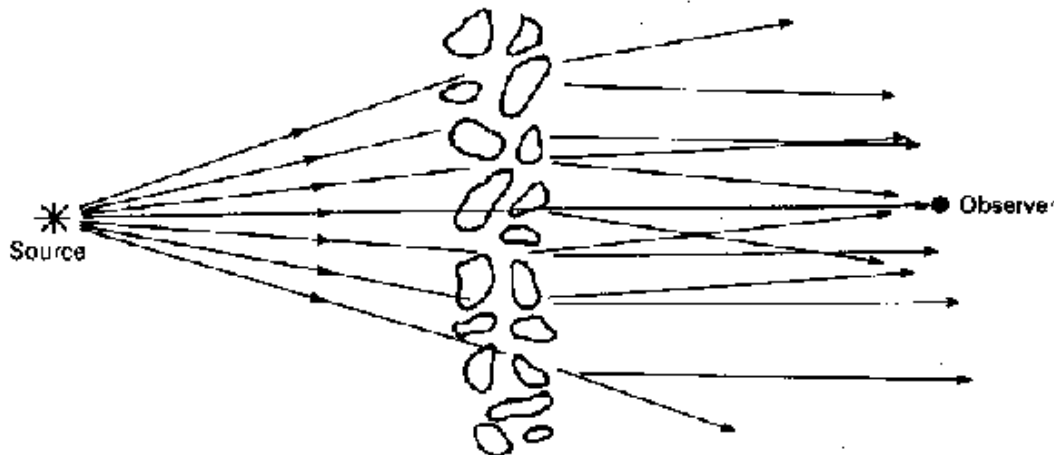
- Stoßwellen in Jets
- Modifikationen der Geometrie
- Strahlungsmechanismen: kohärente Prozesse
- Kompakte Jets
- Wird die Variabilität in der Scheibe erzeugt?

Variabilität: extrinsisch

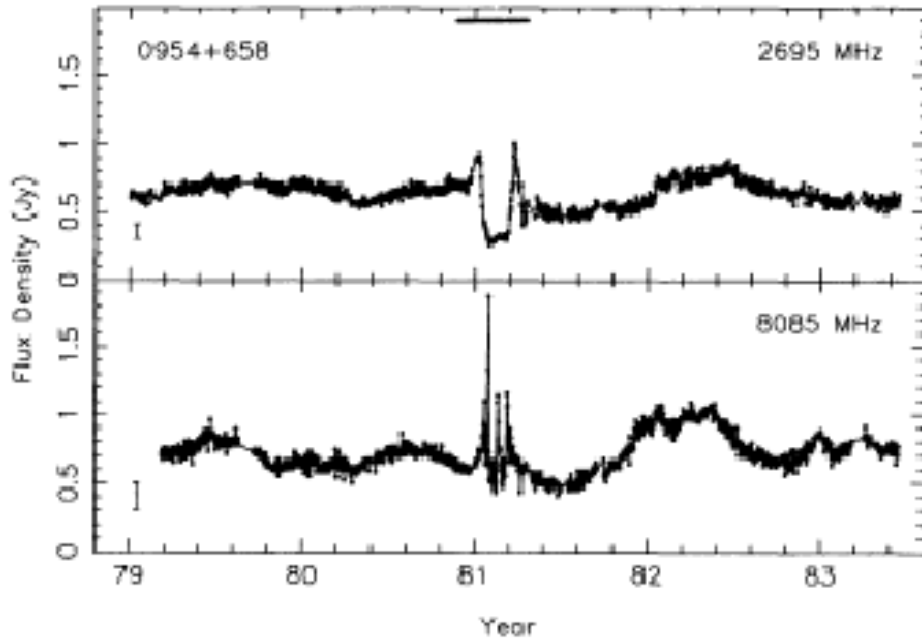
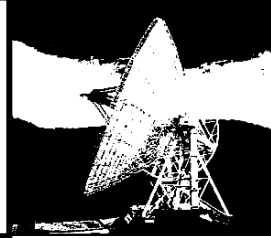


– Extrinsische Effekte

- Mikrolinsen (Chang & Refsdal (1979), aber: hoher duty-cycle, immer aktive, Sterne können sich nicht so schnell bewegen (relativistisch))
- **Interstellare Szintillation**, frequenzabhängig; Fluktuationen im streuenden ISM $I^{-2.2}$; kann nicht die optische Variabilität erklären; jedes kompakte Objekt muß RISS zeigen
 - Außerhalb der Quelle: Streuung durch gravitationelle Ablenkung (Mikro-Linsen); Dichte-Inhomogenitäten der Elektronen im interstellaren Medium erzeugen refraktive und diffraktive Effekte=> Bildverbreiterung und scheinbare Variabilität (Shapirovs kaya 1978; Rickett 1990)

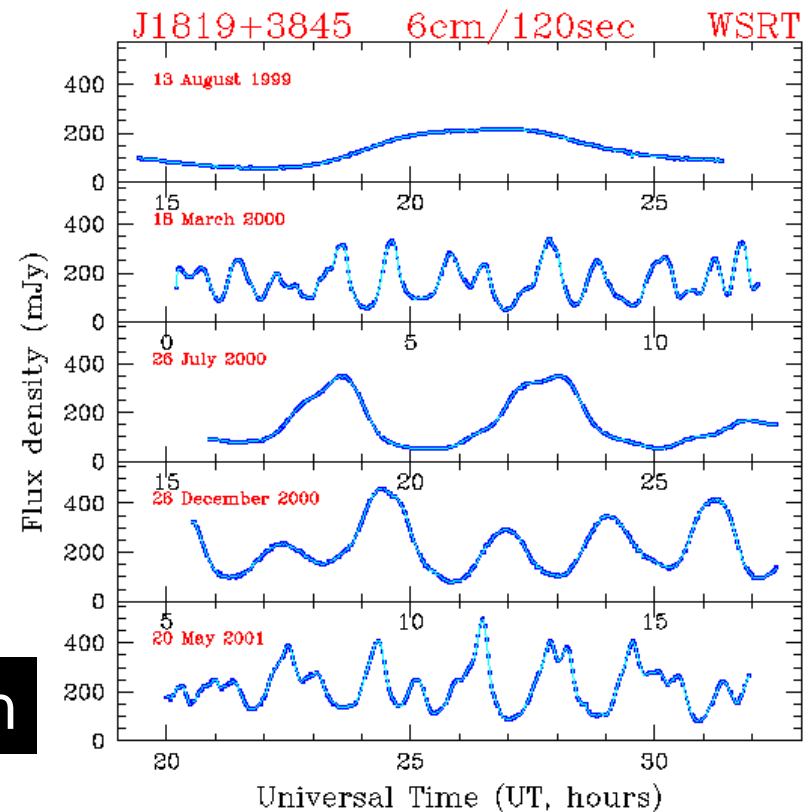


Variabilität: extrinsisch



ESE: Extremes Streuereignis

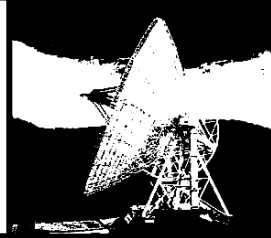
Fiedler et al.



Jahreszeitenabhängige Szintillation

G. de Bruyn

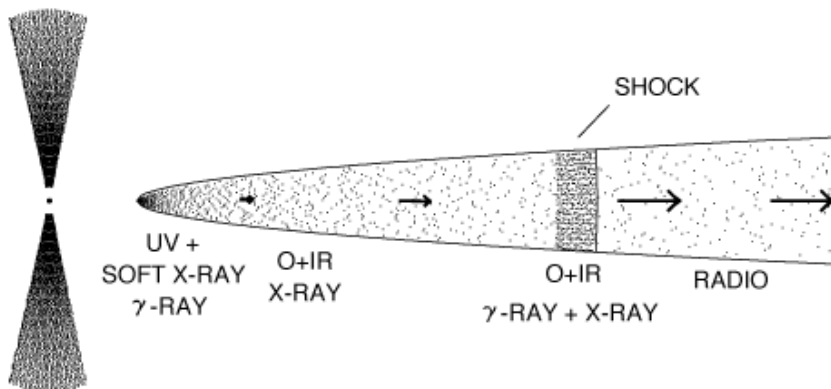
Variabilität: intrinsisch



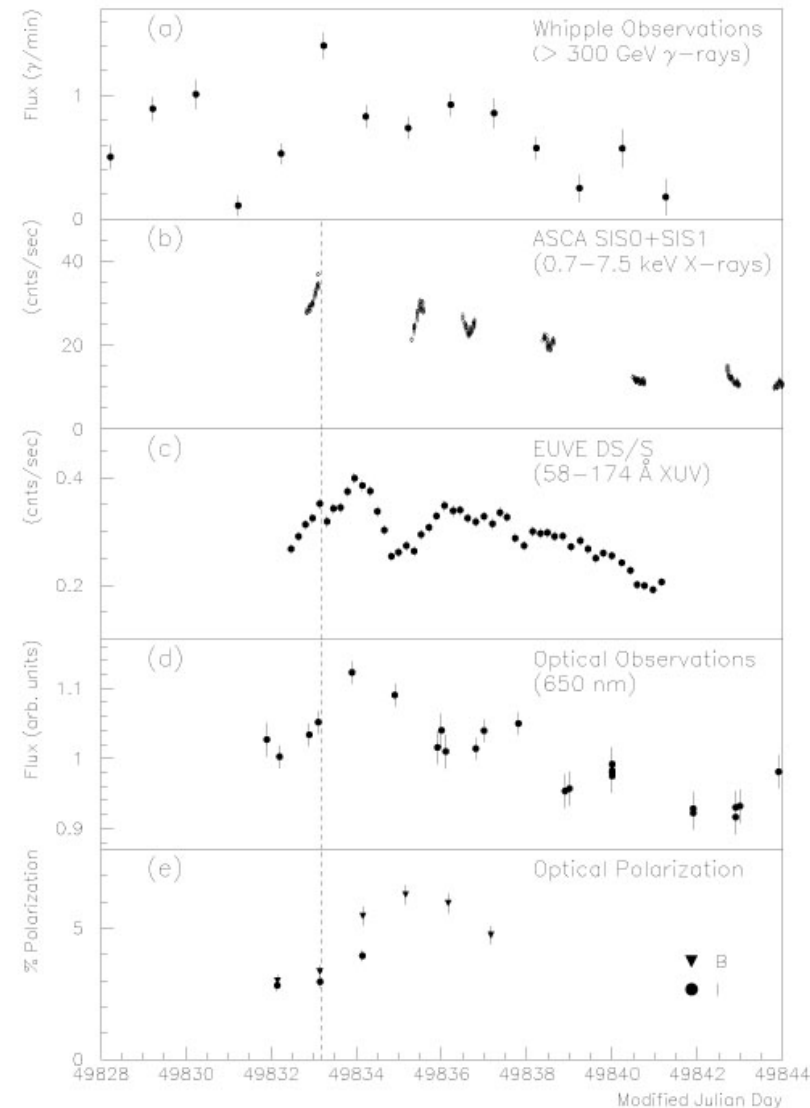
Intrinsische Effekte

- Stoßwellen in Jets
- Modifikationen der Geometrie
- Strahlungsmechanismen: kohärente Prozesse
- Kompakte Jets
- Wird die Variabilität in der Scheibe erzeugt?

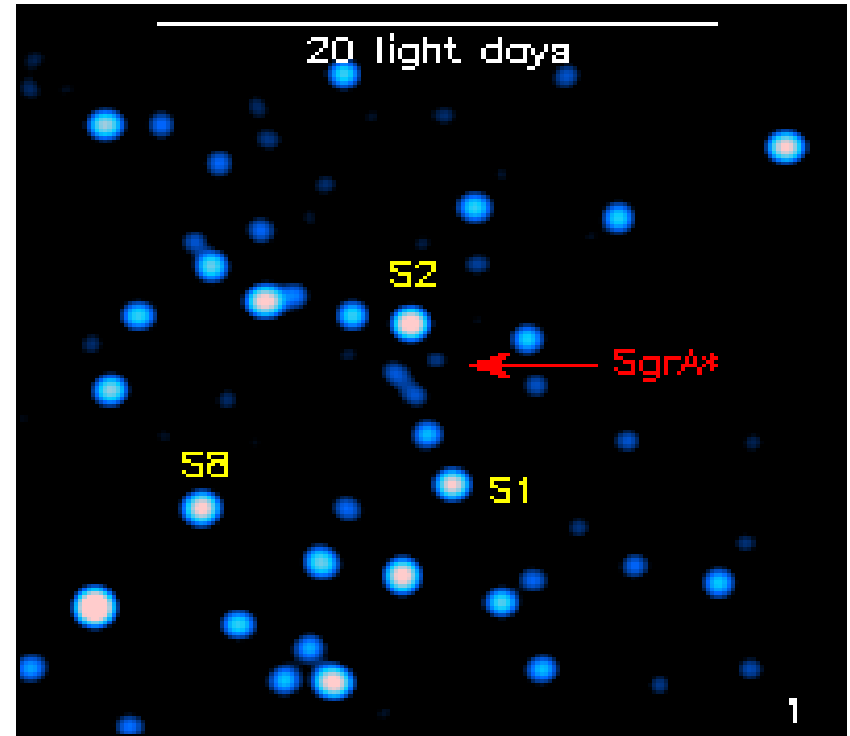
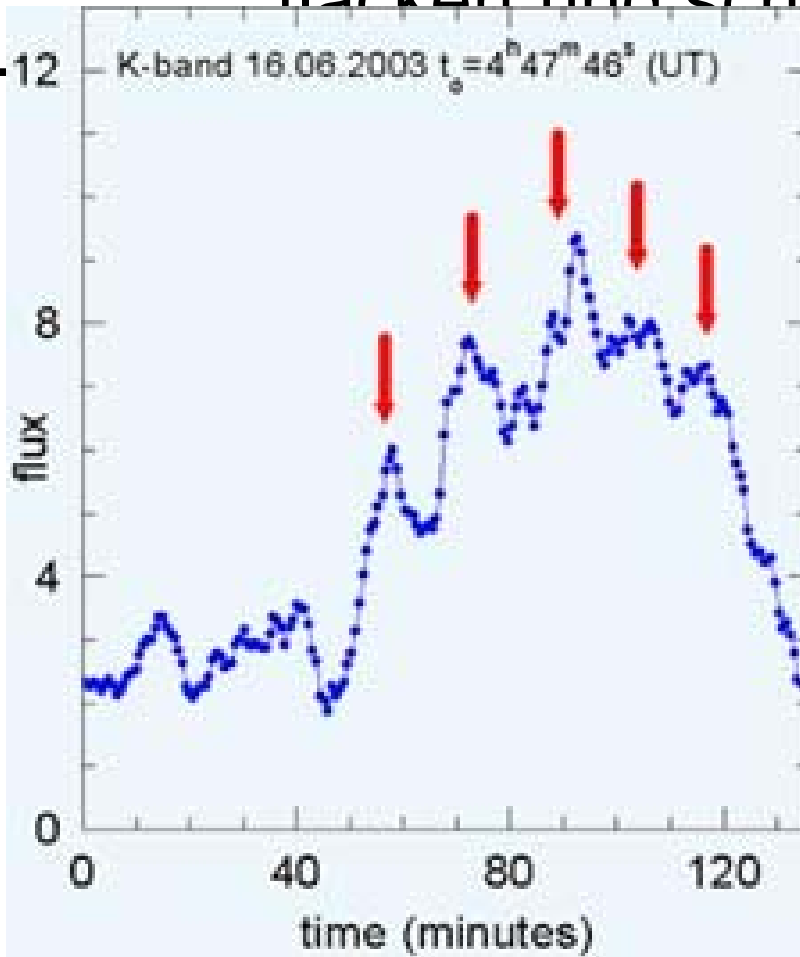
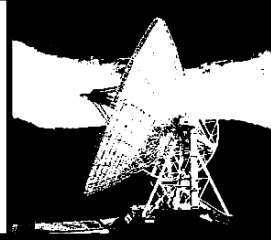
A MODEL FOR THE INNER JET



Marscher et al.

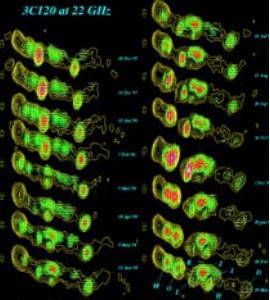


Das Massemonster im Herzen der Milchstraße flackert und scheint zu rotieren



Das Flackern des Flares: Die roten Pfeile in dieser Lichtkurve vom 16. Juni 2003 markieren eine Periodizität von 17 Minuten. Stammt der Flare von wirbelnden Gaswolken, dann muss auch das Schwarze Loch selbst rotieren – mit etwa der halben von der Allgemeinen Relativitätstheorie zugelassenen Höchstgeschwindigkeit.

Bild: Europäische Südsternwarte/Max-Planck-Institut für extraterrestrische Physik



„Ein massives Schwarzes Loch füttert seinen Jet“

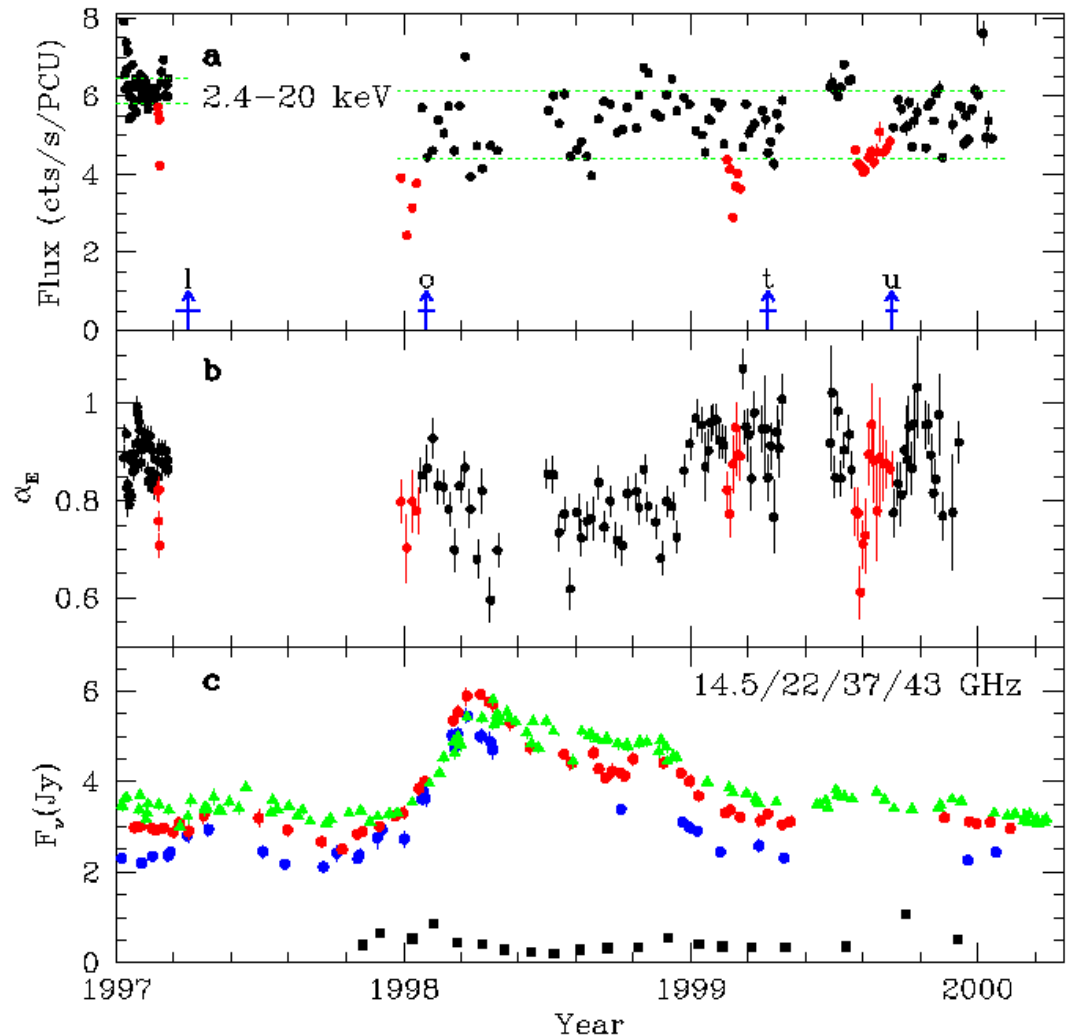
3C120 - Röntgenfluß sinkt ab 0.1 Jahre bevor neue Jetknoten ausgestoßen werden

X-ray flux (RXTE), dips in red

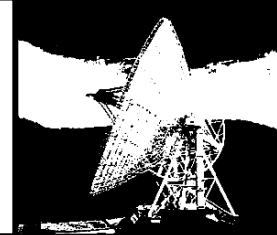
jet component ejection in blue

X-ray spectral index (RXTE)

variability in the radio bands (UMRAO)



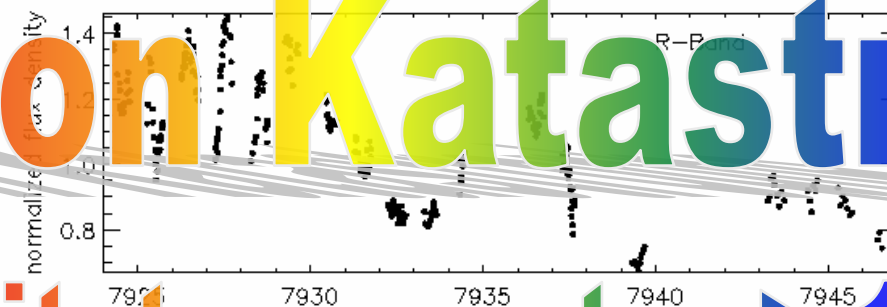
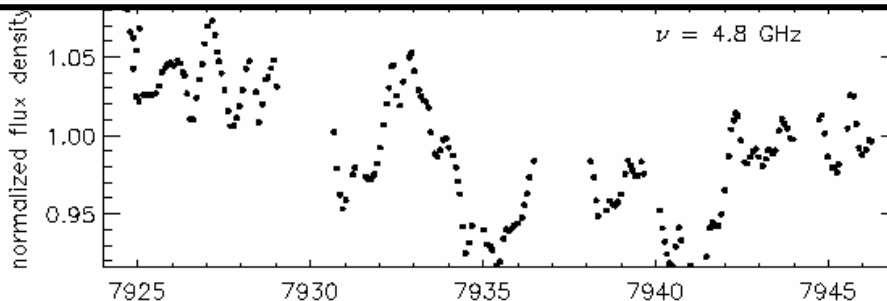
Variabilität: intrinsisch?



Korrelierte

Radio-

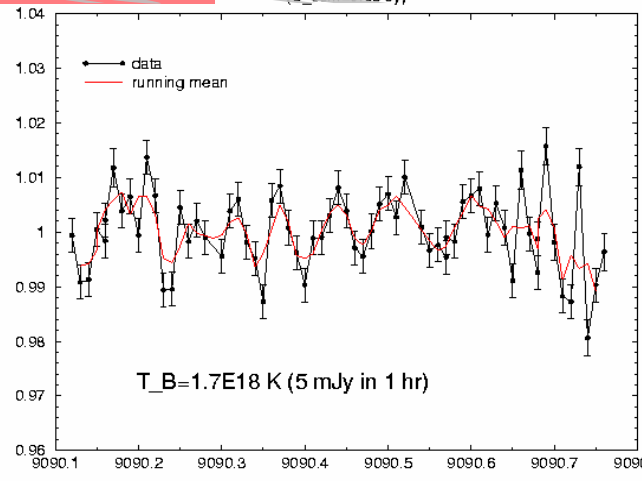
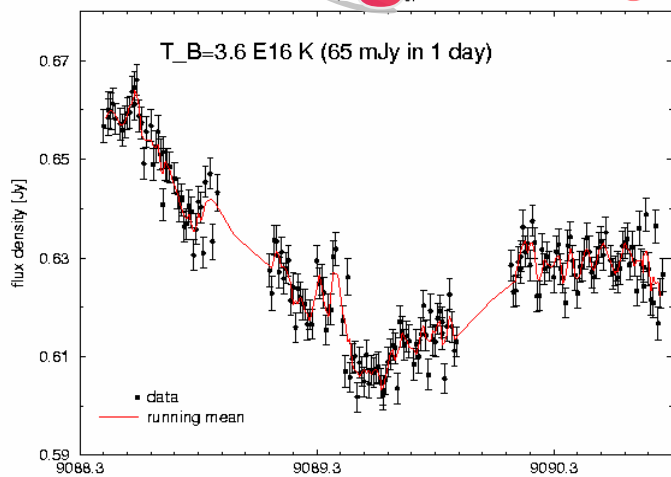
0716+714



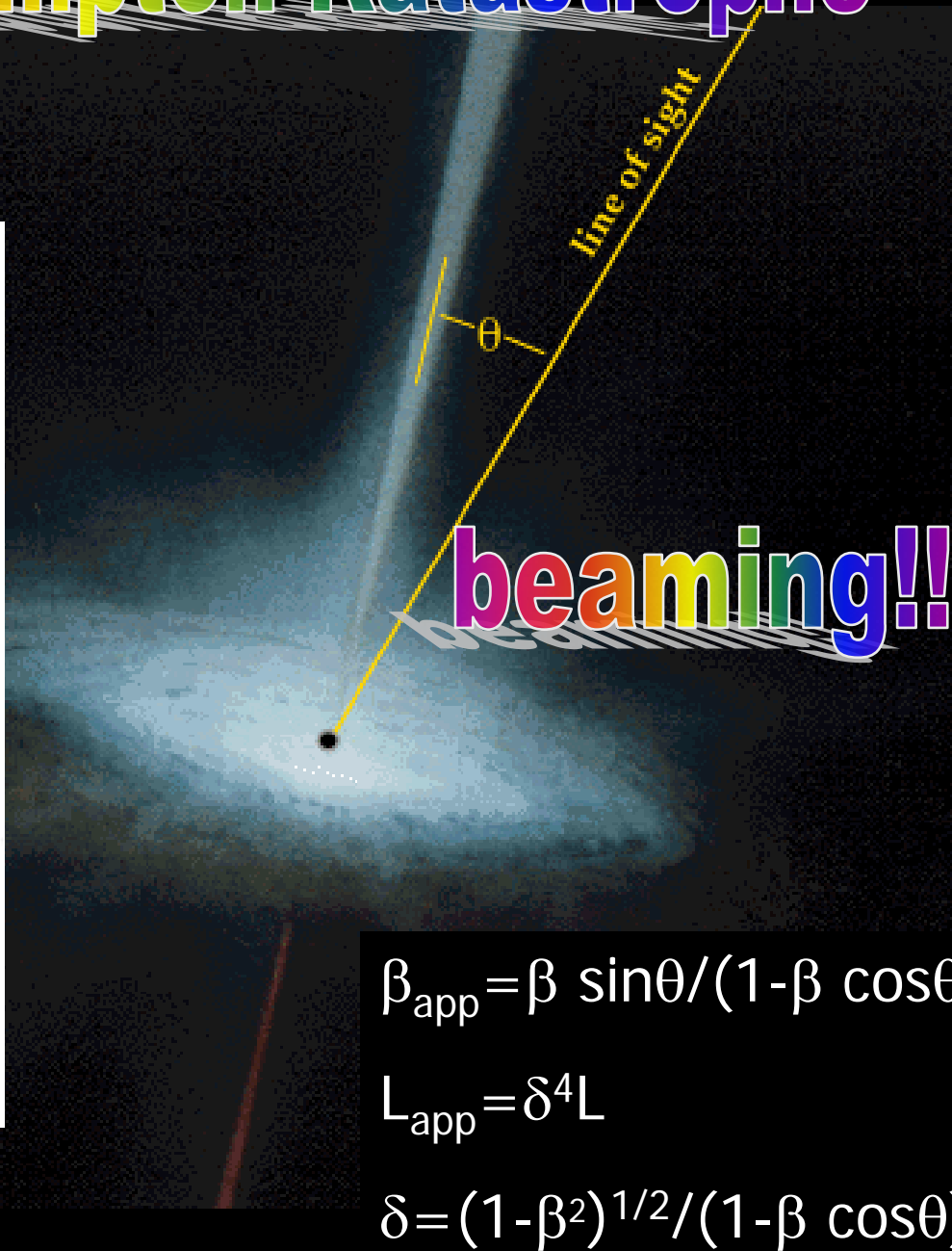
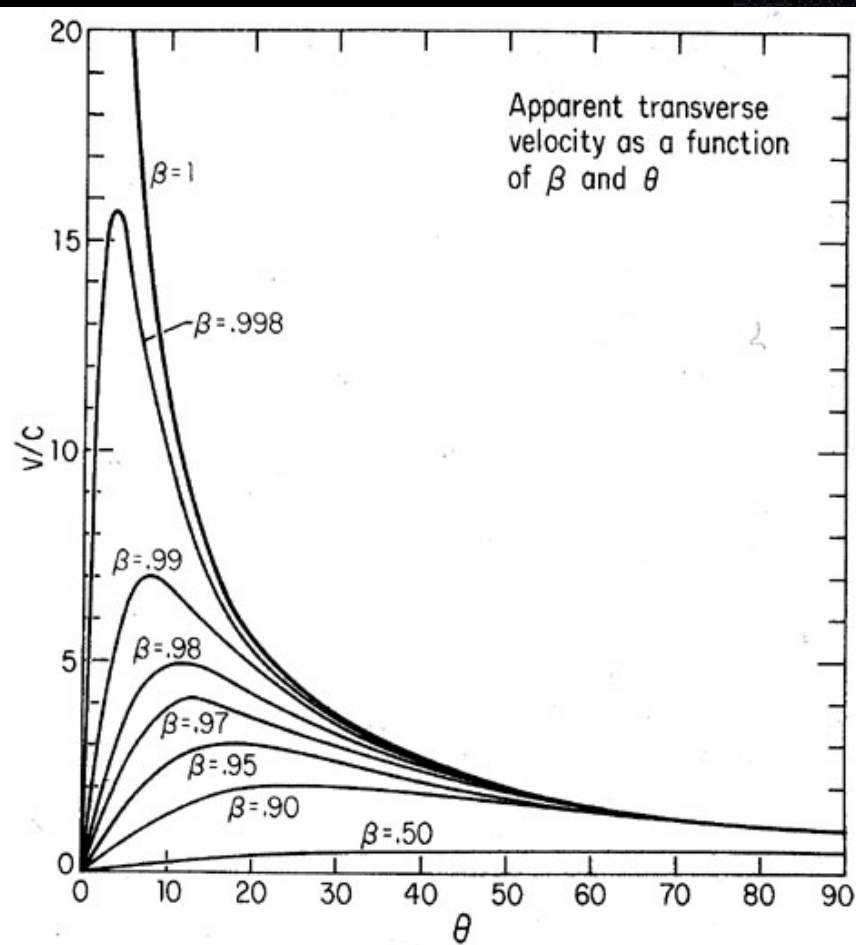
Compton Katastrophe

Wagner & Witzel
ARA&A 1995

Helligkeitstemperatur $> 10^{12}$



Lösung der Compton Katastrophe

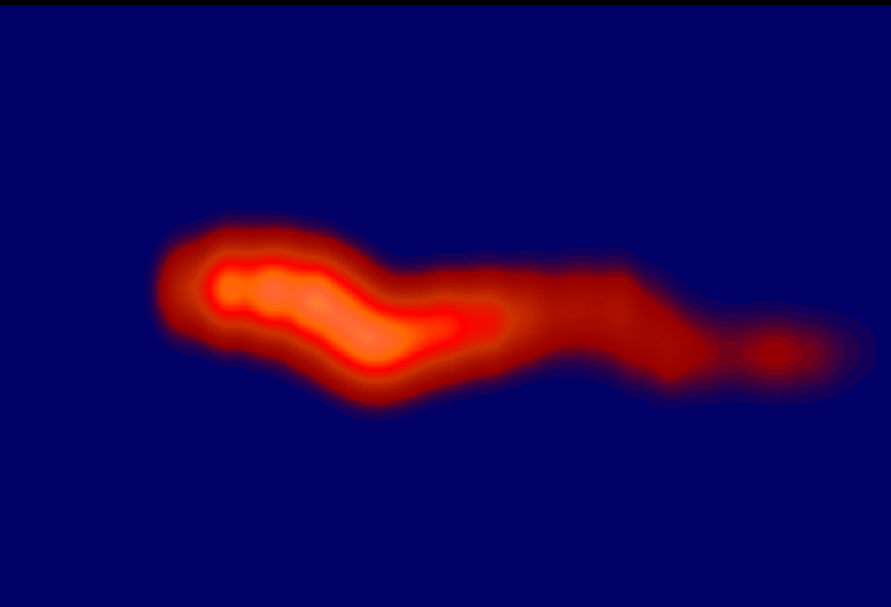


$$\beta_{\text{app}} = \beta \sin\theta / (1 - \beta \cos\theta)$$

$$L_{\text{app}} = \delta^4 L$$

$$\delta = (1 - \beta^2)^{1/2} / (1 - \beta \cos\theta)$$

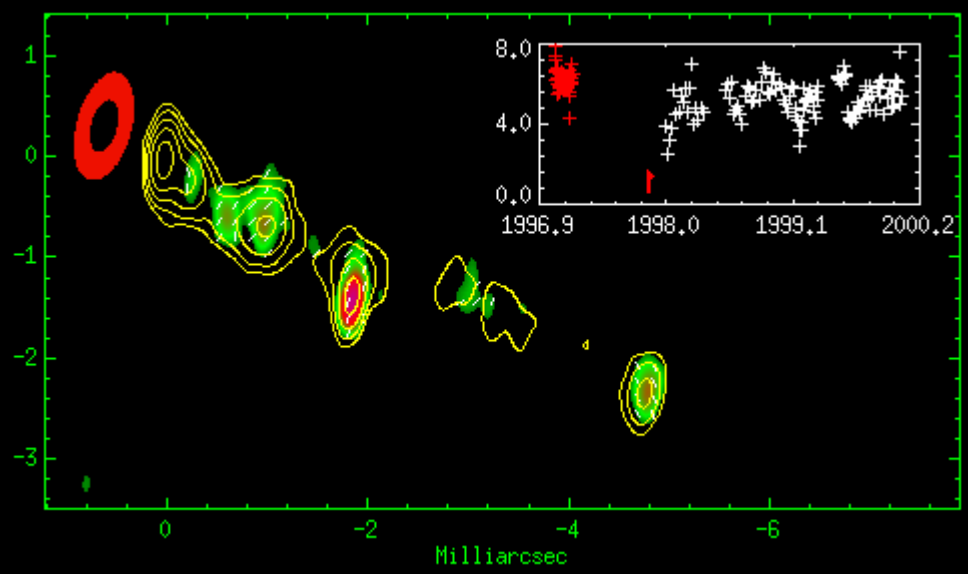
Vorhersage scheinbarer überlichtschnelle Bewegungen



3C345, Lobanov & Roland 2002



M87, Biretta et al.



3C120, Gomez et al.



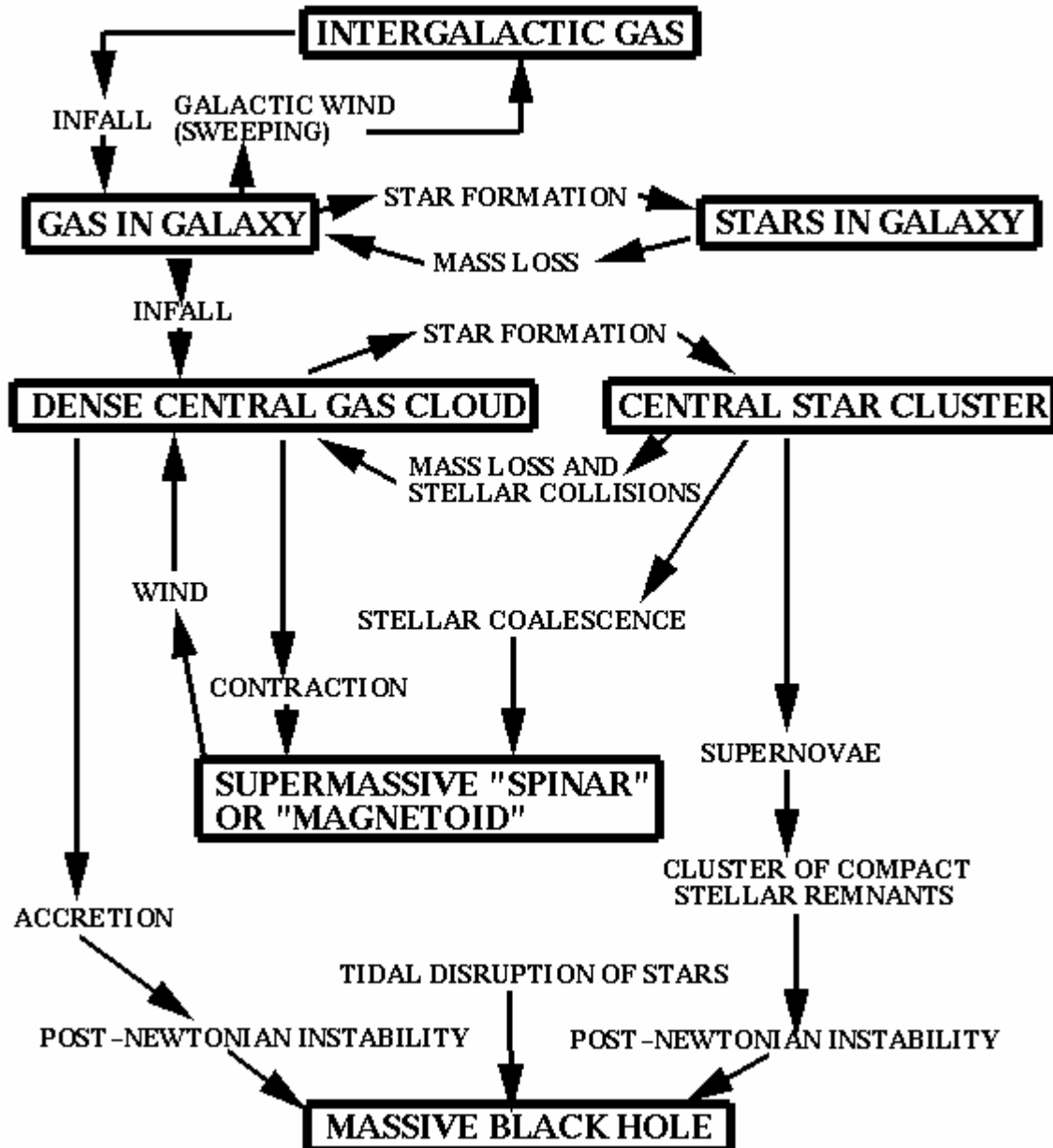
TeV Blazar

T = theras = τερας = monster
(Homer's Iliad IV, 73)

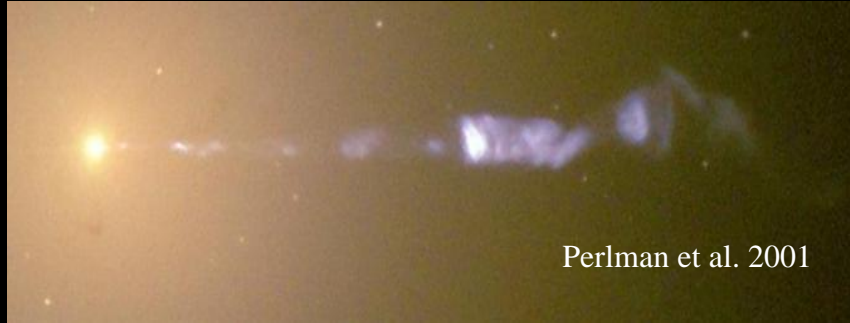
A field of white daisies with yellow centers, growing in a green field. In the background, there are green trees and a blurred orange car. A white rectangular box is overlaid in the center of the image, containing the text "Schwarze Löcher".

Schwarze Löcher

Es führt kein Weg an ihnen vorbei ...



Evidence for SMBH

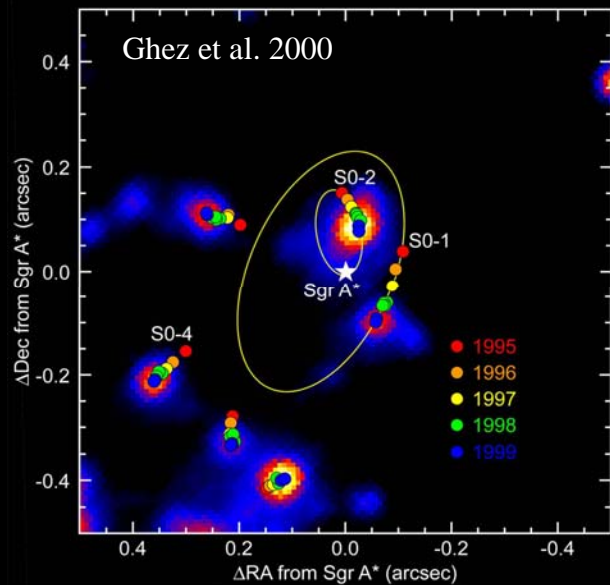
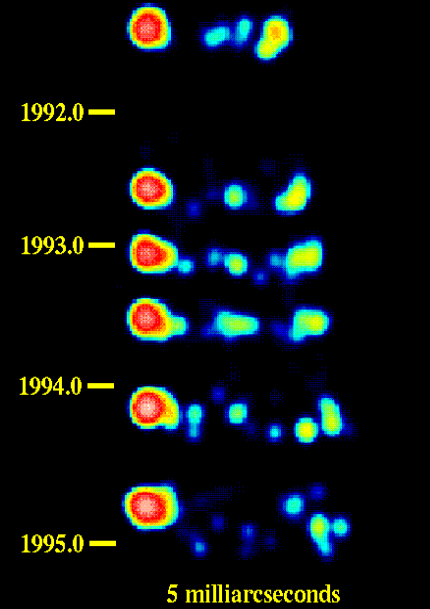


Exceptional stability of jet direction on timescales of $\sim 10^6$ years
Proper motions of stars around Sgr A* imply a black hole of 10^5 solar masses

Superluminal motions: apparent speeds $b_{app} \sim 20$, which requires an effective mechanism for energy release

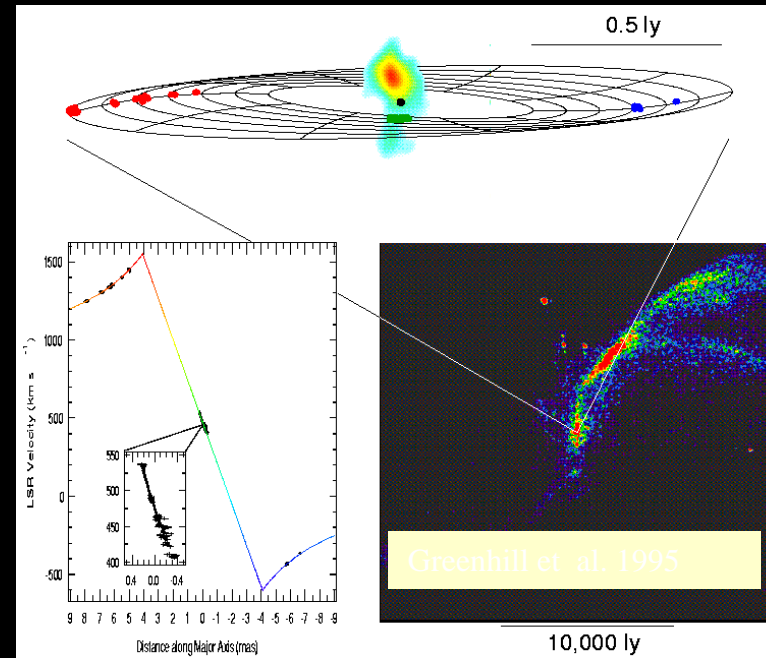
Observations of accretion disks: Keplerian motions imply densities of $\sim 10^{12} M_{sol}/pc^3$

3C 279
 Superluminal Motion
 Wehrle et al. 1998

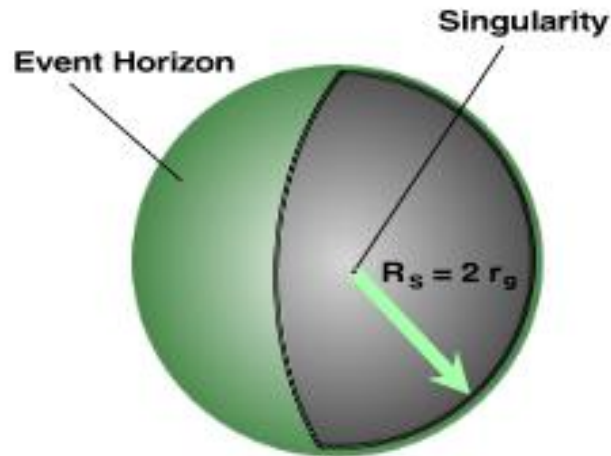


Other evidence: rapid variability, emission line width, gravitational redshift of Fe K line, etc.

A. Lobanov

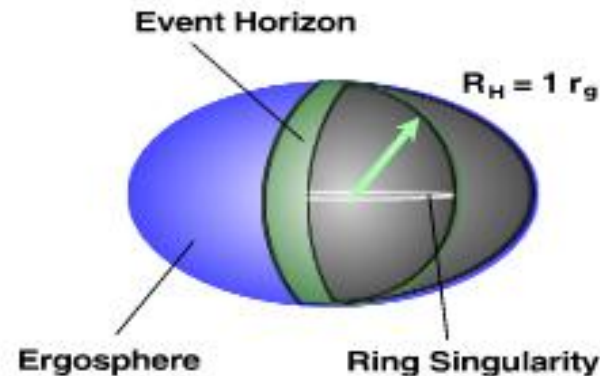


Black Holes



Schwarzschild

$$a = 0$$

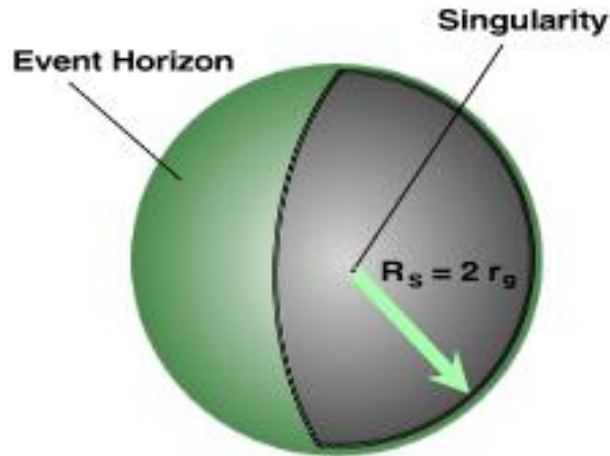


Kerr

$$a = 1$$

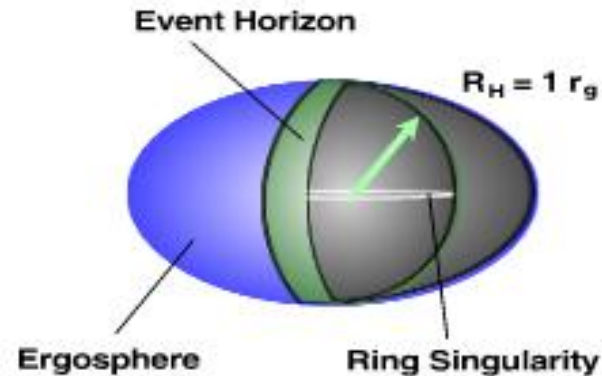
- Besonders kompakte Objekte, die so dicht sind, daß ab einem bestimmten Abstand, dem Ereignishorizont (event horizon), nicht einmal Licht zu entweichen vermag.
- Schwarzschildradius: $R = 2 G M / c^2$
- Eddington Leuchtkraft: für eine gegebene zentrale Masse kann die Leuchtkraft nicht die Eddington Leuchtkraft übersteigen:
 $L < 1.26 \times 10^{38} M / M_{\text{Sonne}} \text{ erg sec}^{-1}$

Black Holes



Schwarzschild

$$a = 0$$



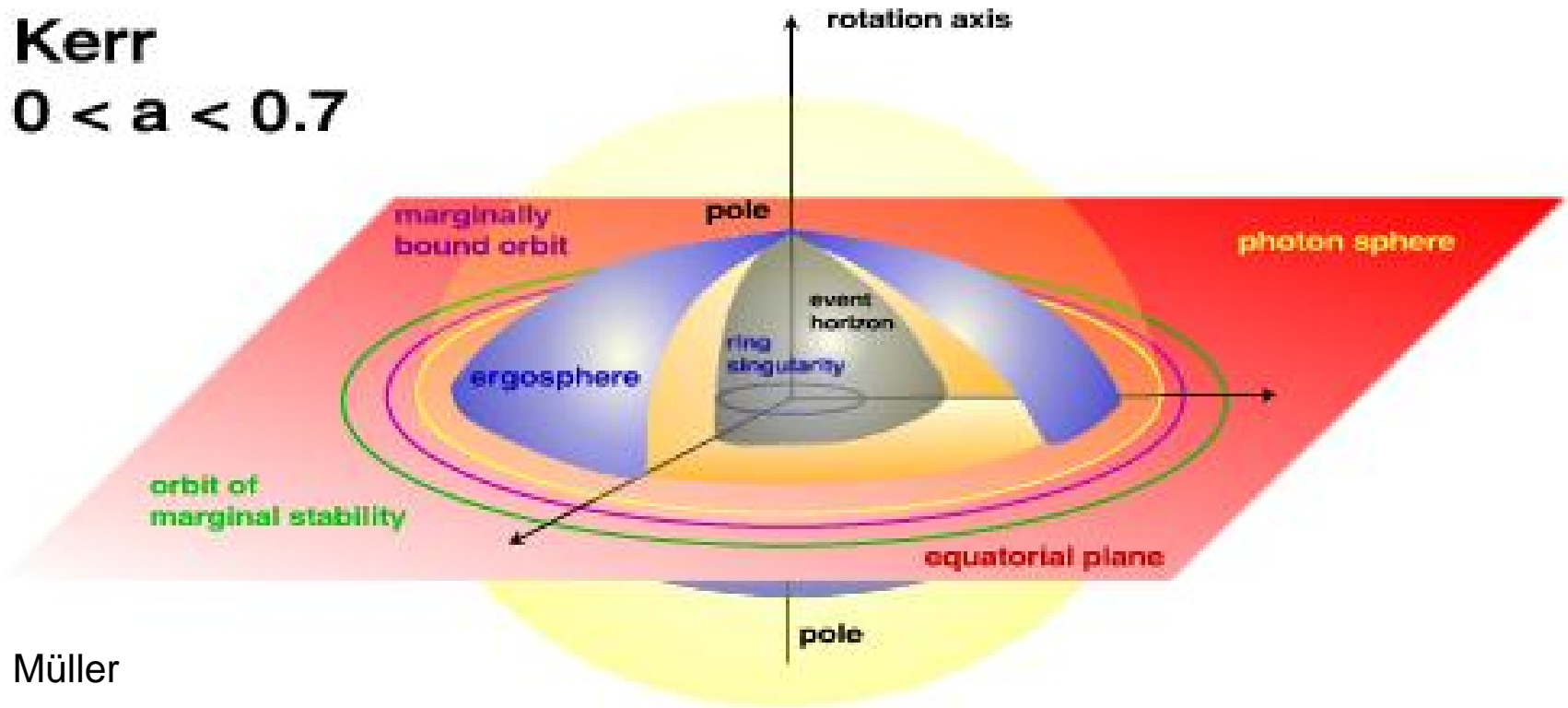
Kerr

$$a = 1$$

- Schwarzschild beschreibt nicht-rotierende, die Kerr-Lösung rotierende Schwarze Löcher
- Oben: gleiche Massen, aber Kerr-Loch ist kleiner, Rotation wird mit Kerr-Parameter dargestellt: $\alpha=0$, keine Rotation; $\alpha=-1$ maximale retrograde Rotation; $\alpha=1$ maximale prograde Rotation: abhängig von Vorgeschichte, Alter und Akkretionsaktivität des Schwarzen Lochs

Die Kerr-Lösung

Kerr
 $0 < a < 0.7$



Ringsingularität: Massenfluß in einem unendlich dünnen Ring,
Quelle des rotierenden Gravitationsfeldes

Radien Schwarzer Löcher

	<u>Masse</u>	<u>Radius des Schwarzen Lochs</u>
--	--------------	-----------------------------------

• Erde	$5.98 \times 10^{27} \text{ g}$	0.9 cm
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• Sonne	$1.989 \times 10^{33} \text{ g}$	2.9 km
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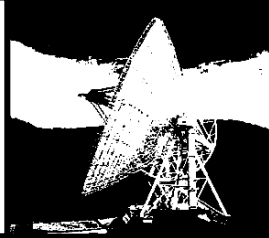
• Stern 5-facher Sonnenmasse		
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	$9.945 \times 10^{33} \text{ g}$	15 km
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Galaxienkern

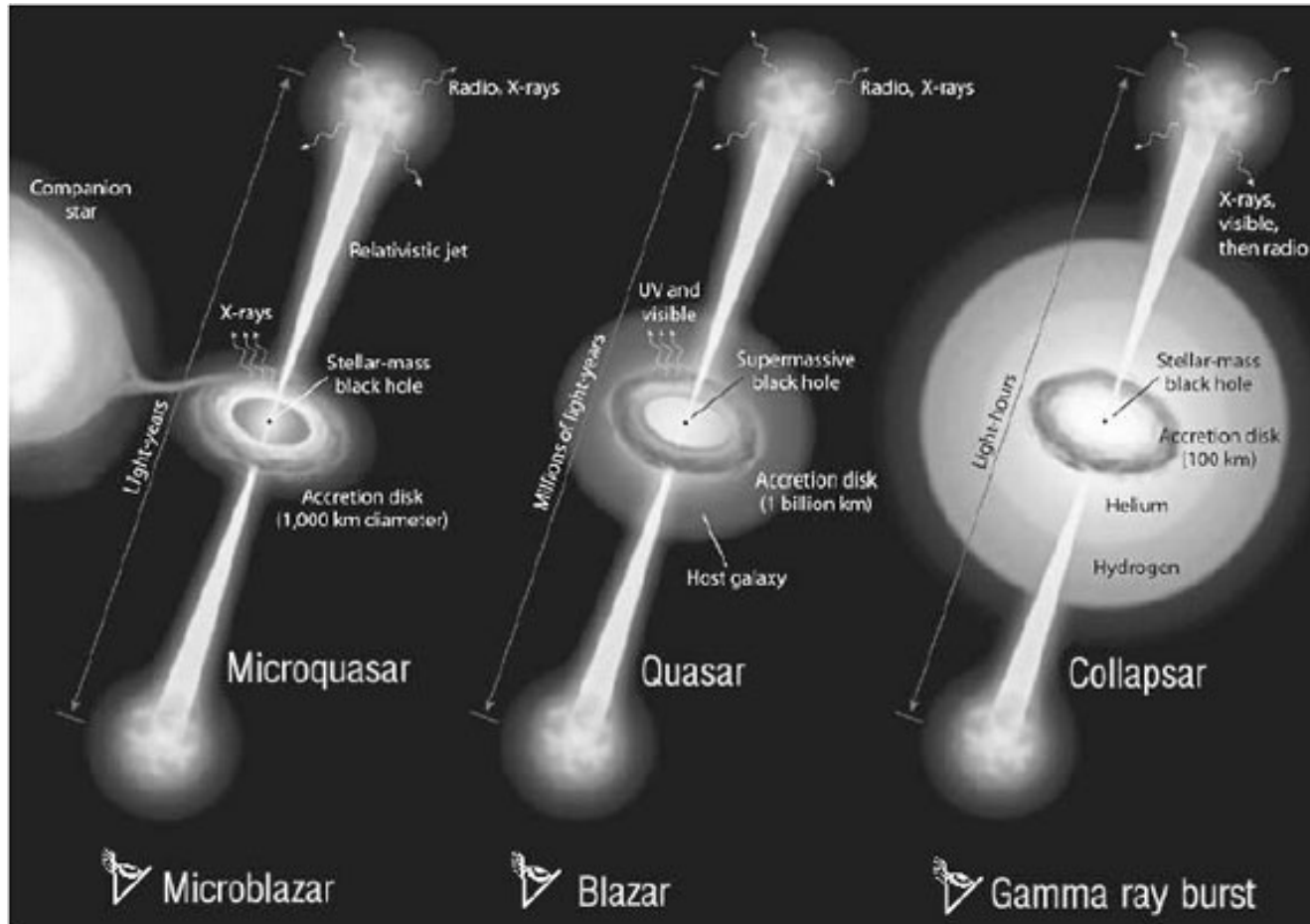
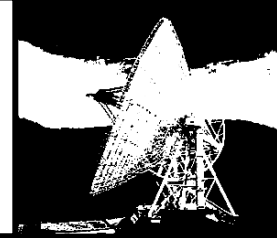
	10^9 Sonnenmassen	$3 \times 10^9 \text{ km}$
--	---------------------	----------------------------

Massenskala Schwarzer Löcher



- Schwarzes Loch kann beliebige Massen haben
- Primordiale Schwarze Löcher (Mini-Löcher): sehr klein, Massen von 10^{-15} Sonnenmassen, Radius des Ereignishorizonts 10^{-12} m, Existenz spekulativ, Frühphase des Universums? Keine Hinweise auf Existenz aus Beobachtungen
- Stellare Schwarze Löcher: entstehen im Rahmen der Sternentstehung, wiegen wenige Sonnenmassen bis 100 Sonnenmassen; kompakteste Endkonfiguration neben Weißen Zwergen, Neutronensternen; entstehen aus Sternexplosionen (Supernovae)

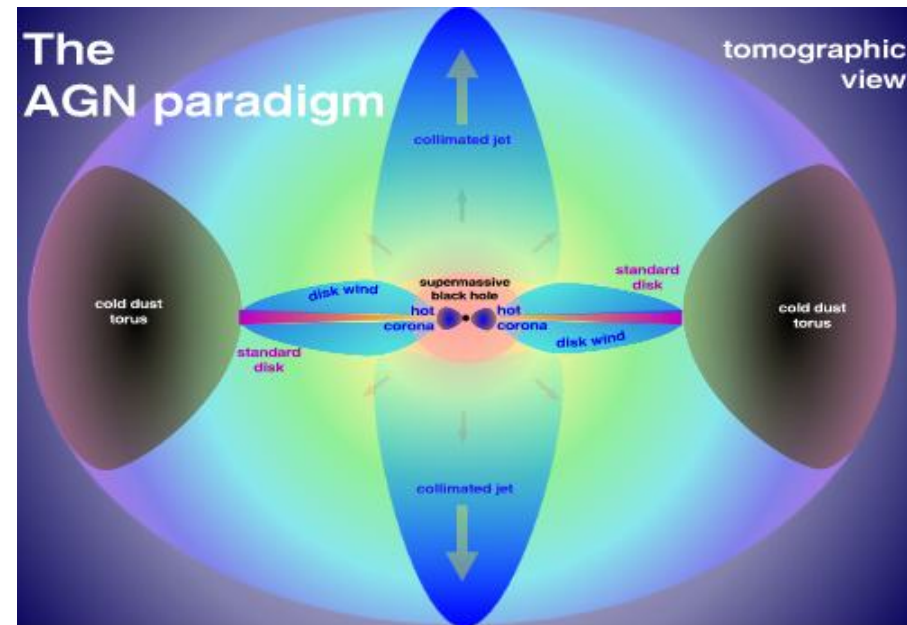
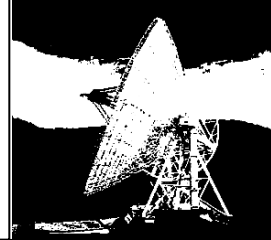
Mikroquasare



F. Mirabel


Diagram illustrating current ideas concerning microquasars, quasars and gamma-ray bursts (not to scale). It is proposed that a universal mechanism may be at work in all sources of relativistic jets in the universe. Synergism between these three areas of research in astrophysics should help to gain a more comprehensive understanding of the relativistic jet phenomena observed everywhere in the universe.

Massenskala Schwarzer Löcher



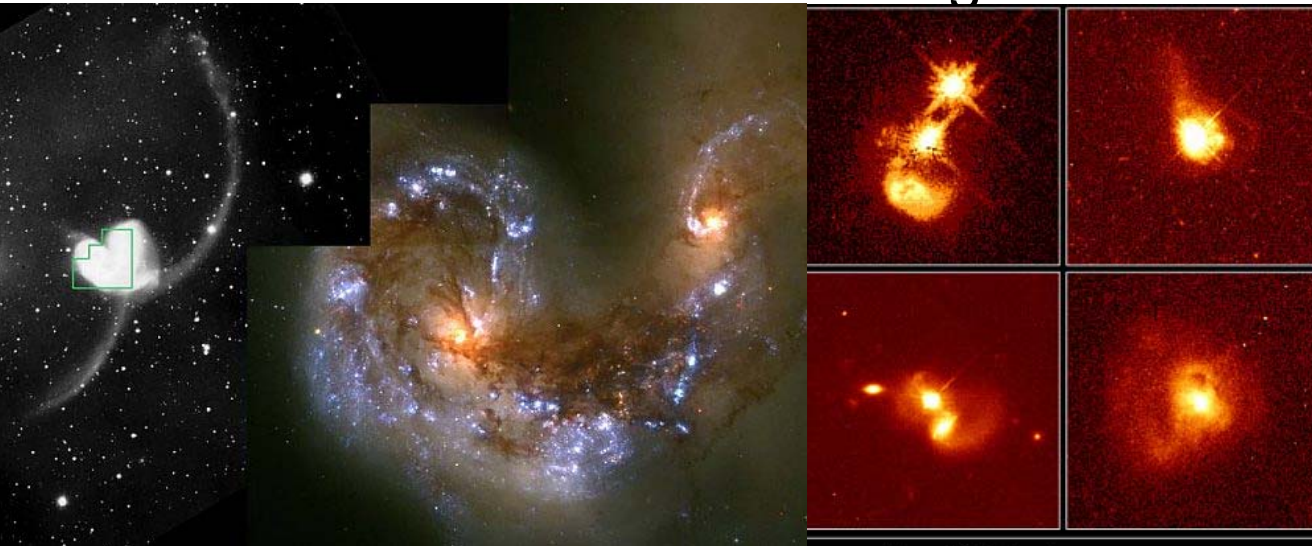
A. Müller

- Massereiche Schwarze Löcher: 10^2 bis 10^5 Sonnenmassen; muß in Zentren von Kugelsternhaufen existieren (M15, G1); hungernde Schwarze Löcher
- Supermassereiche Schwarze Löcher: Zentren von Galaxien (jeder Galaxie); über Akkretion von Plasma wird die enorme Helligkeit der AGN gespeist;

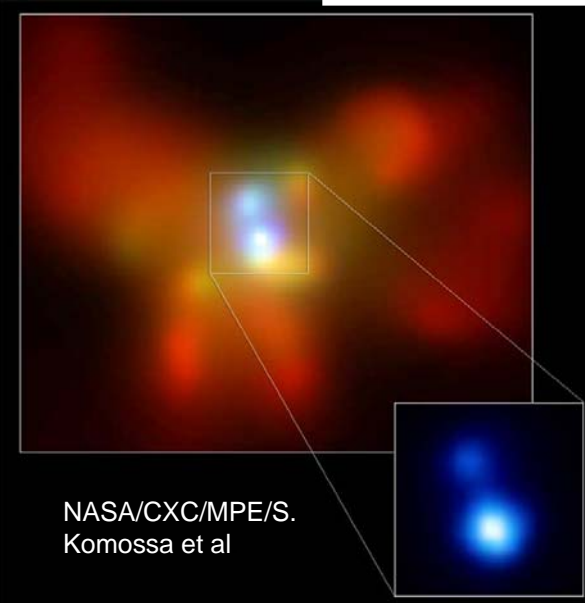


Supermassive Binäre Schwarze Löcher

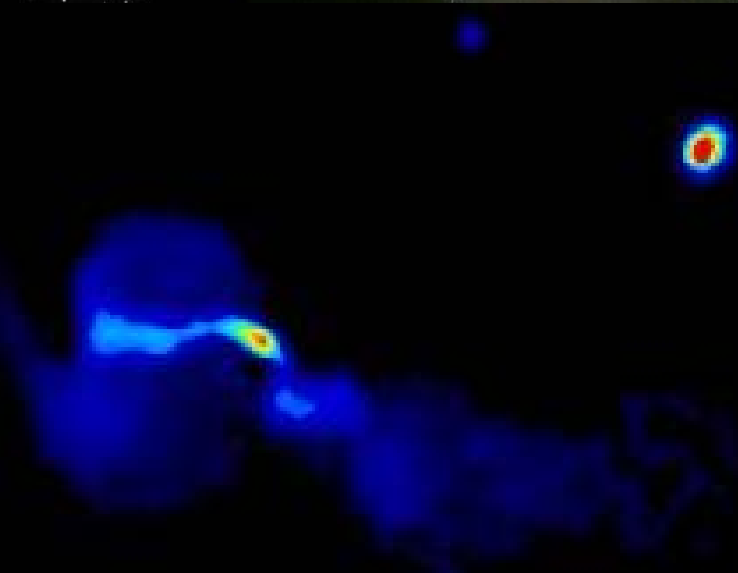
Binäre Supermassive Schwarze Löcher auf verschiedenen Skalen, in verschiedenen Entwicklungsstadien



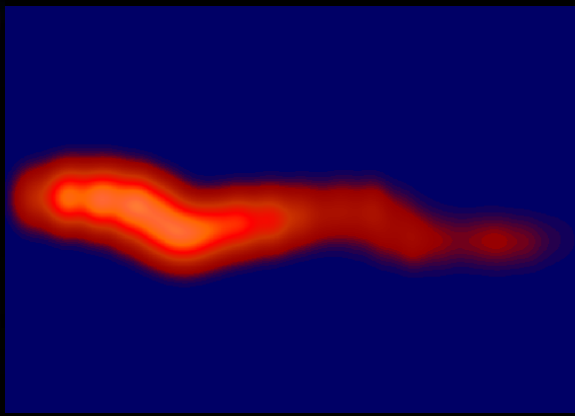
Quasar Host Galaxies
Hubble Space Telescope - Wide Field and Planetary Camera 2
J. Bahcall (Institute for Advanced Study), M. Disney (University of Wales) and NASA



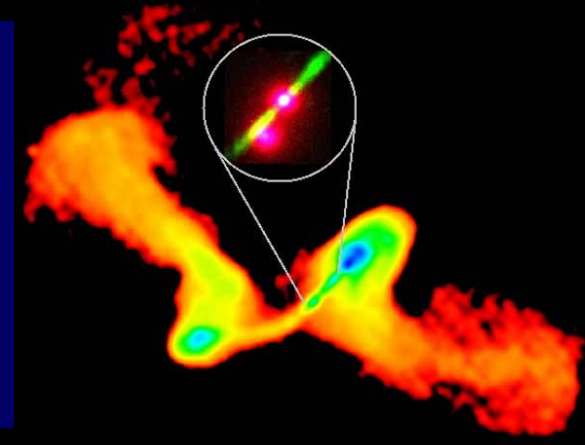
NASA/CXC/MPE/S.
Komossa et al



Hardcastle et al. 1996

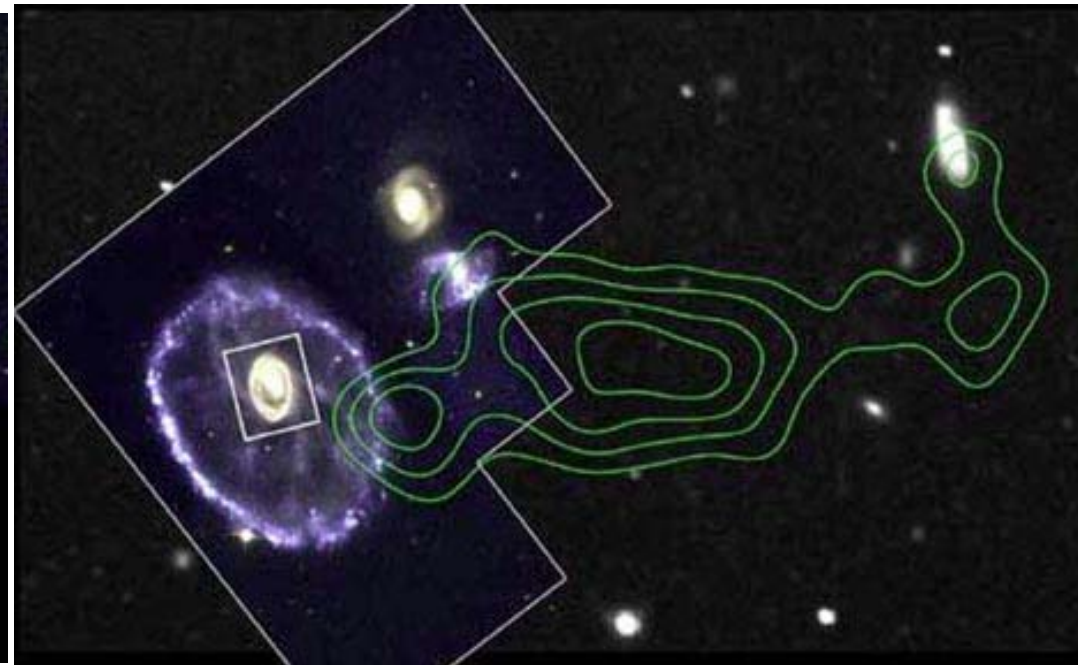
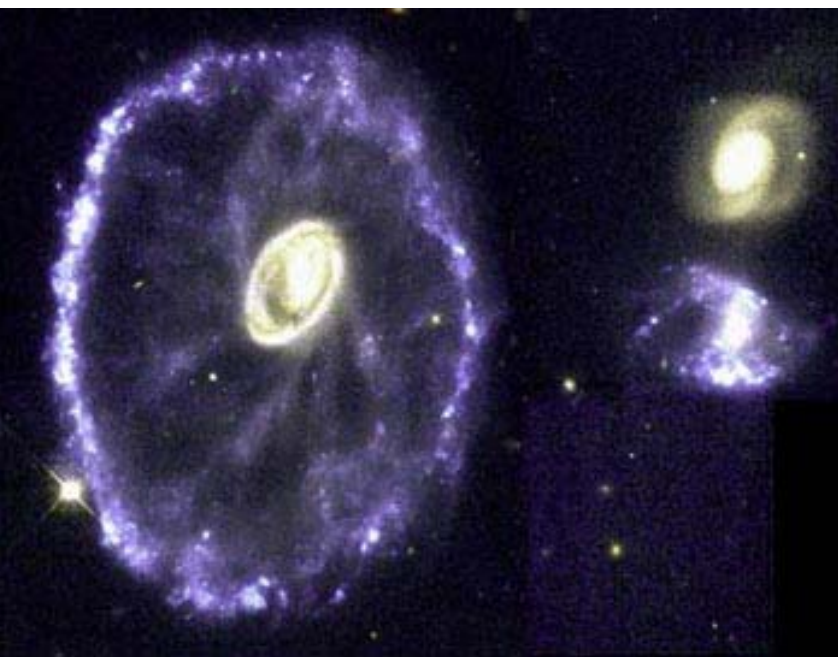
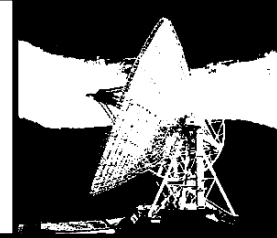


Lobanov & Roland 2004



Murgia et al.

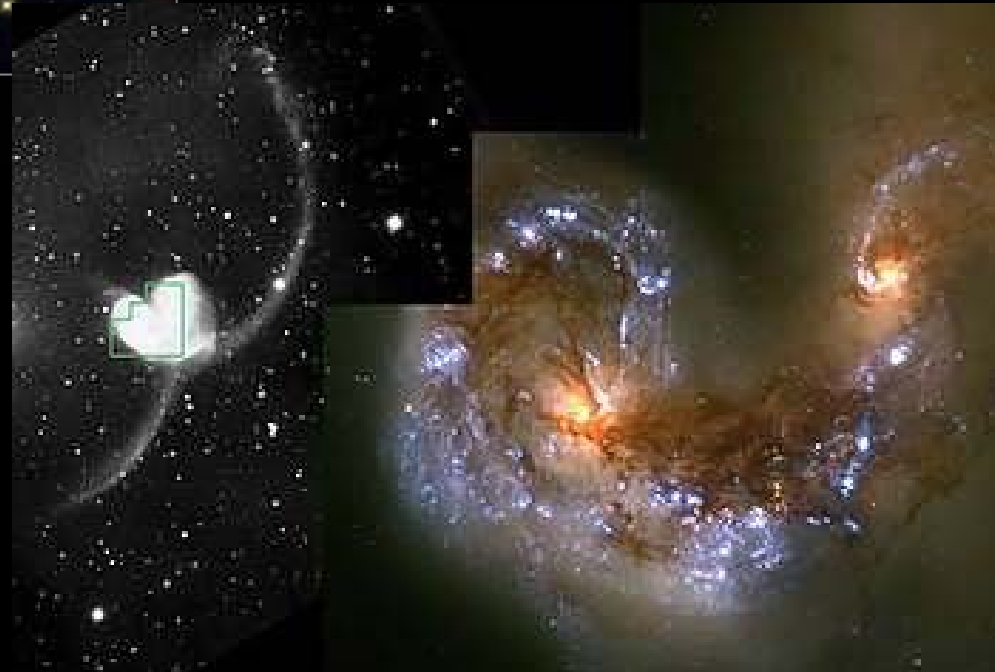
Galaxien in Kollision: Wagenrad-Galaxie



Higdon 1995

Kosmisches Spektakel: Wechselwirkende Galaxien

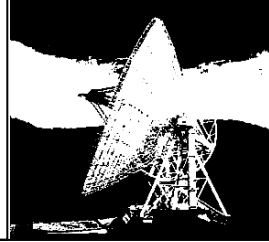
Galaxies NGC 2207 and IC 2163



Kosmisches Spektakel: Wechselwirkende Galaxien



Milchstraße / Andromeda Kollision

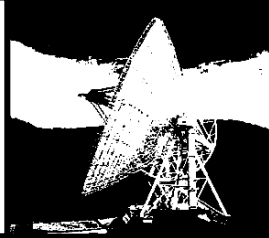


Entfernung 2.2 Mio LJ, Kollision in 2-3 Milliarden J, Annäherung mit 500 000 km/h

Galaxy collisions awaken dormant black holes



Commercial!



Colliding Galaxies - simulation of interacting galaxies

colliding galaxies - software to simulate interacting galaxies. create breathtaking AVI-videos!

Version:

1.2

Price:

\$32 (USD) Instant Download

Platform:

Windows All Versions

Description of Colliding Galaxies - simulation of interacting galaxies:

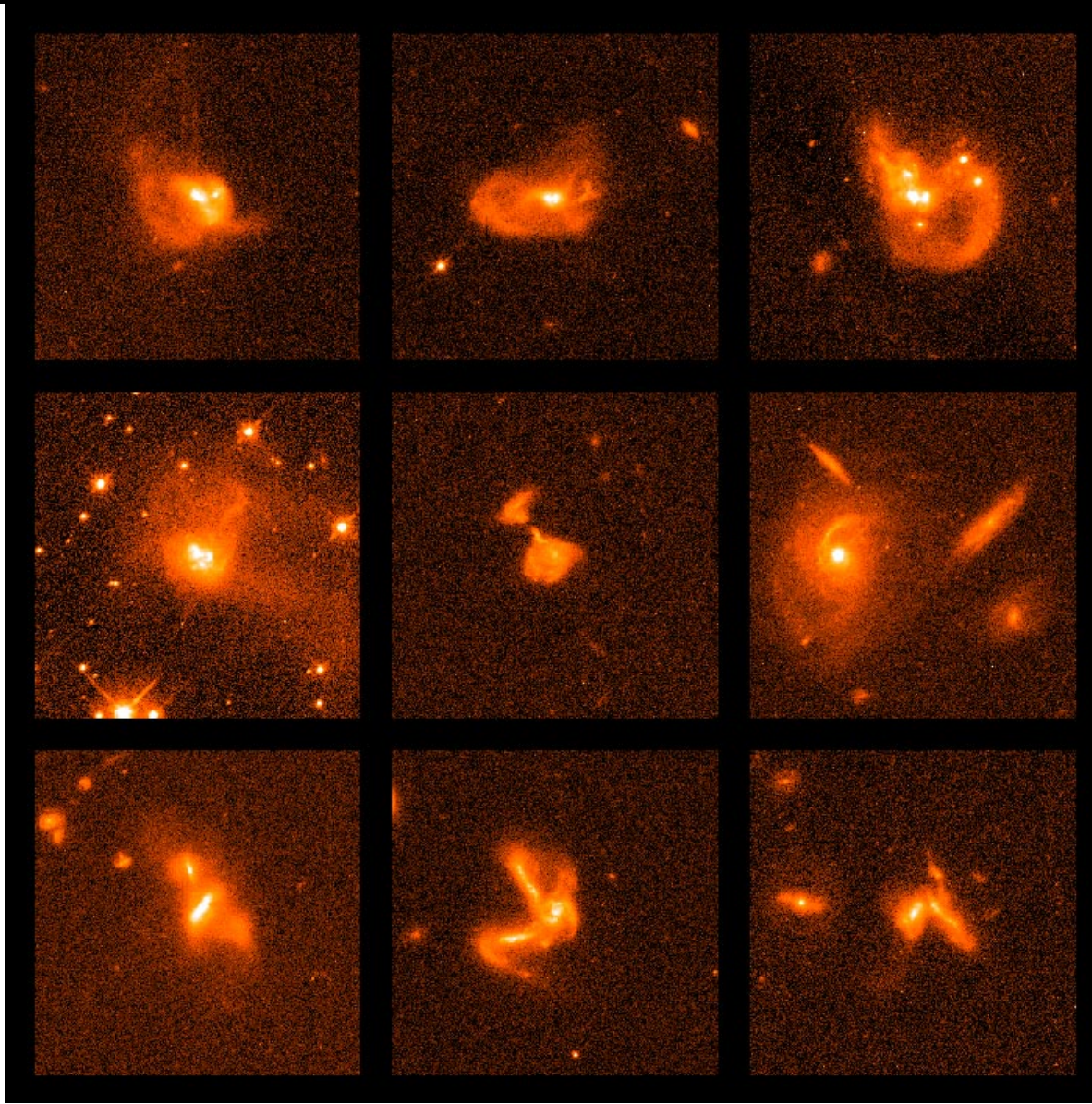
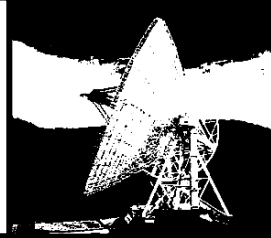
Colliding Galaxies is a program to simulate interacting galaxies.

Features:

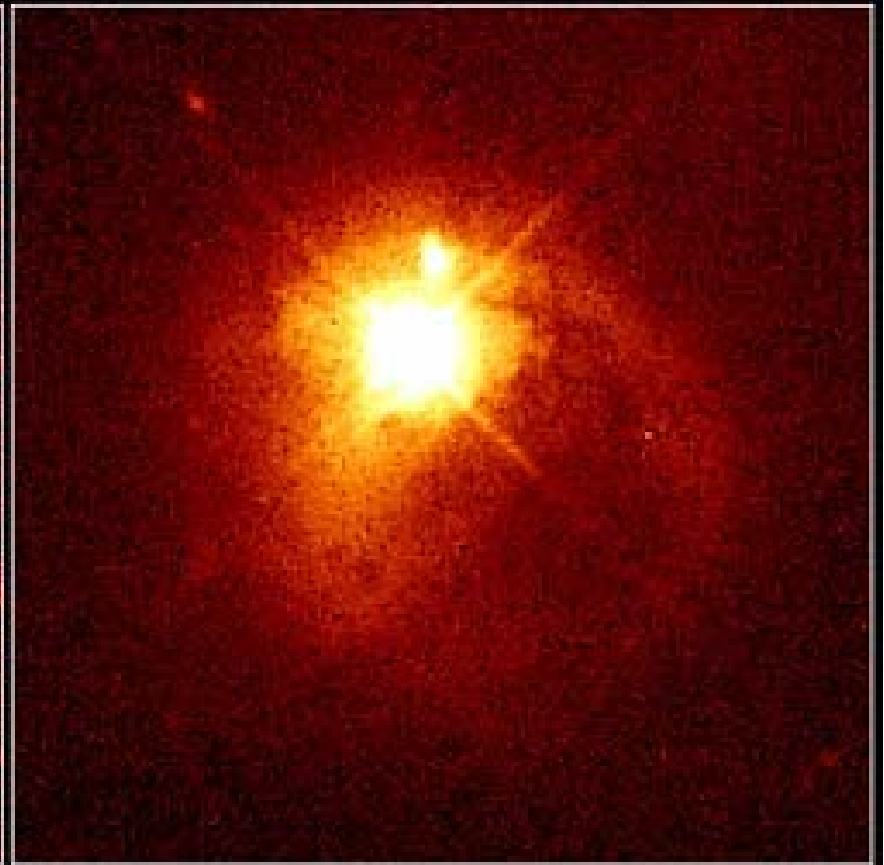
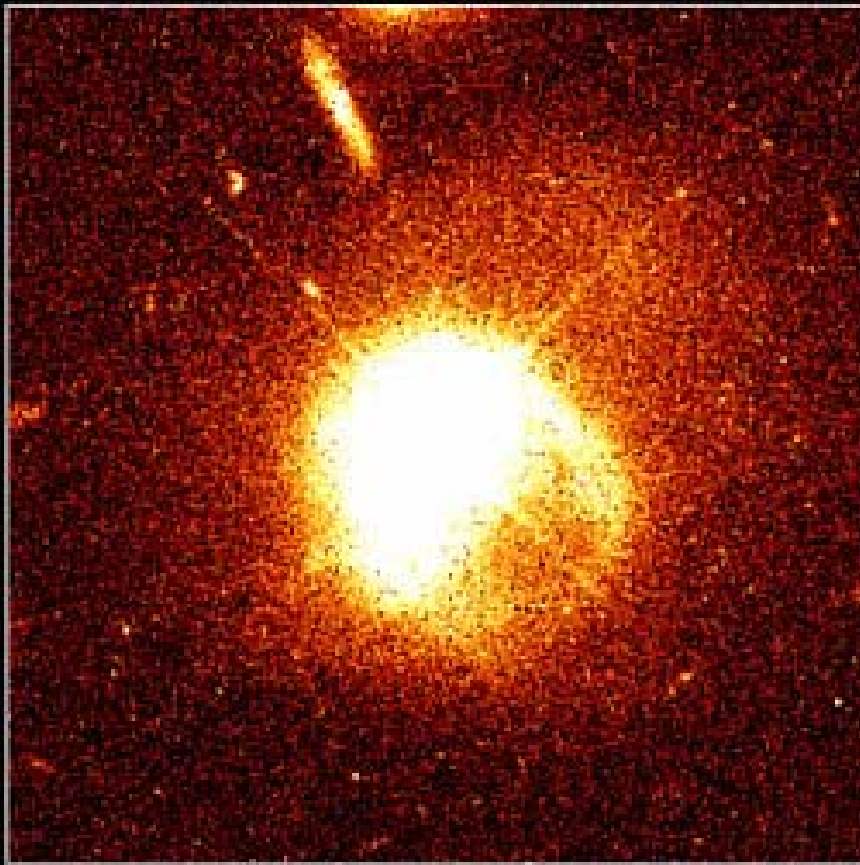
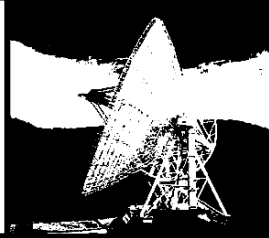
- up to one million particles (stars)
- editor to create real galaxies
- creating AVI-videos
- free cameraposition (zoom, rotation)
- stereo-mode for real 3D!
- Doppler effect (redshift)
- manual in english and german



Wechselwirkende Galaxien



Quasar hosts: Wechselwirkungen



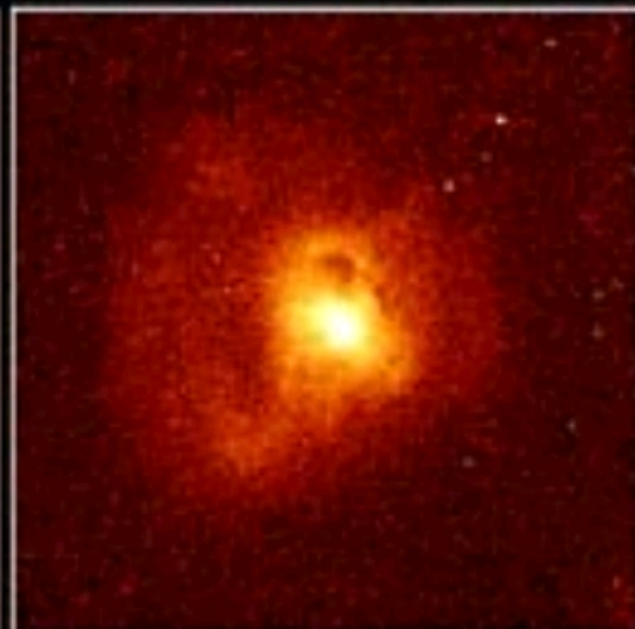
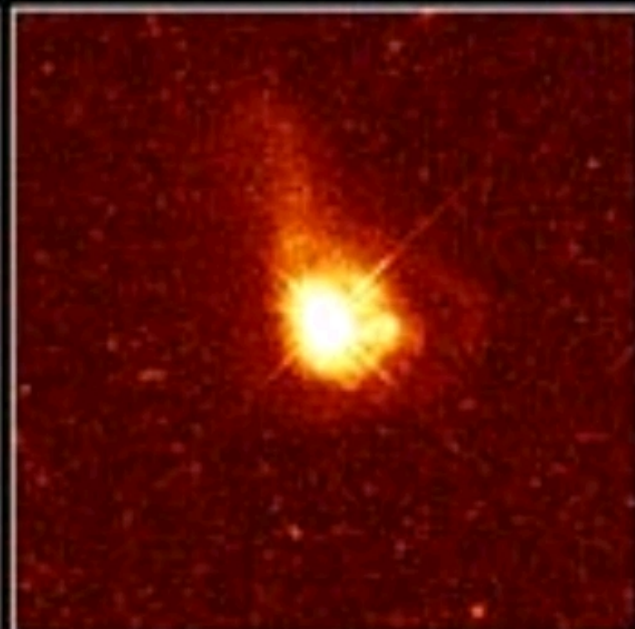
Quasar PKS 2349

Hubble Space Telescope · Wide Field Planetary Camera 2

normale Spiralgalaxie

zerrissen, $z=0.286$

?, $z=0.265$

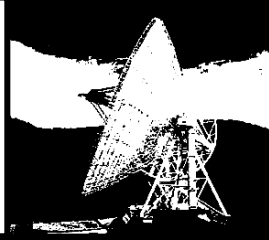


normale elliptische Galaxie

"merger", $z=0.187447$

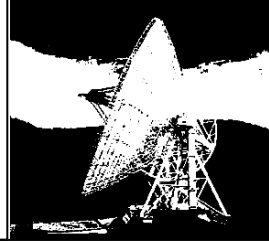
"merger", $z=0.205102$

Supermassive Binäre Schwarze Löcher

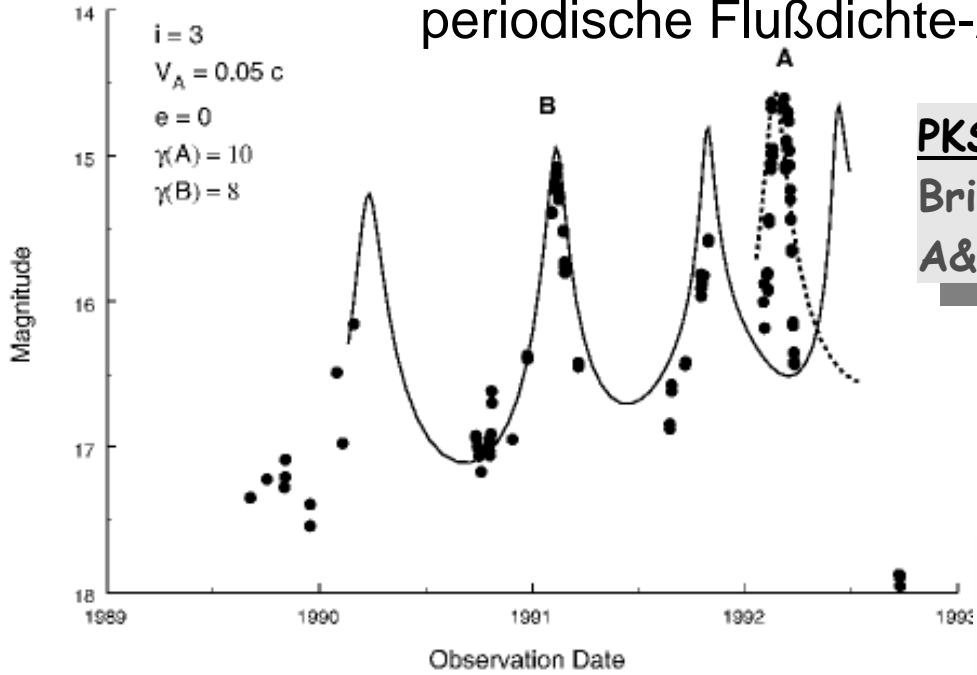


- Sind von weitreichender astrophysikalischer Relevanz:
 - Spekuliert wird, daß sie die AGN-Aktivität verstärken können
 - Erklären u.U. verschiedene Klassen radiolauter AGN
 - Verschmolzene Systeme können eine Falschausrichtung zw. der Richtung der Radio-Jets und der Scheibe erzeugen
 - erzeugen (semi) periodische Abweichungen der Jetrichtung von einer geraden Linie
 - (semi) periodische Ausbrüche in Lichtkurven ...

Supermassive Binäre Schwarze Löcher



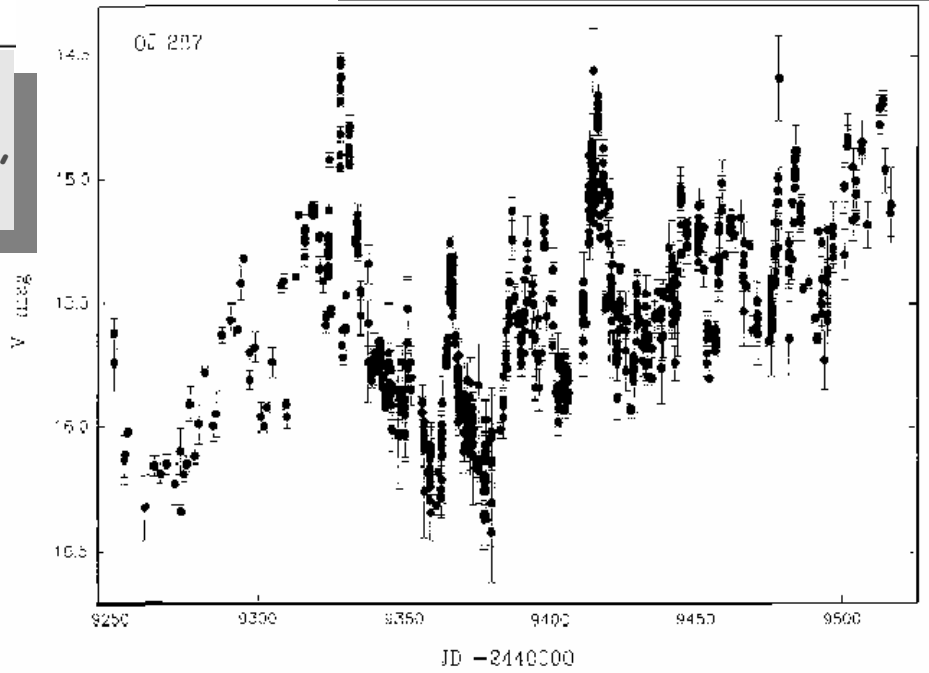
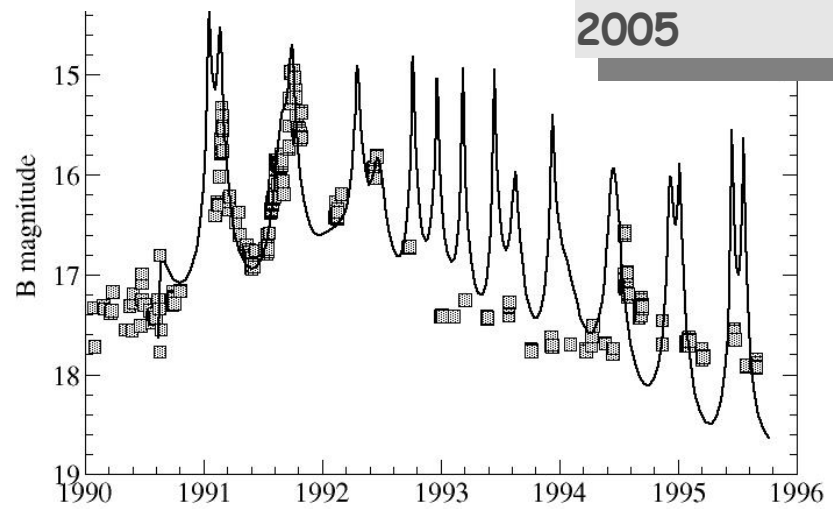
periodische Flußdichte-Ausbrüche



PKS 0420-014:
Britzen, et al., 2001,
A&A 374, 748

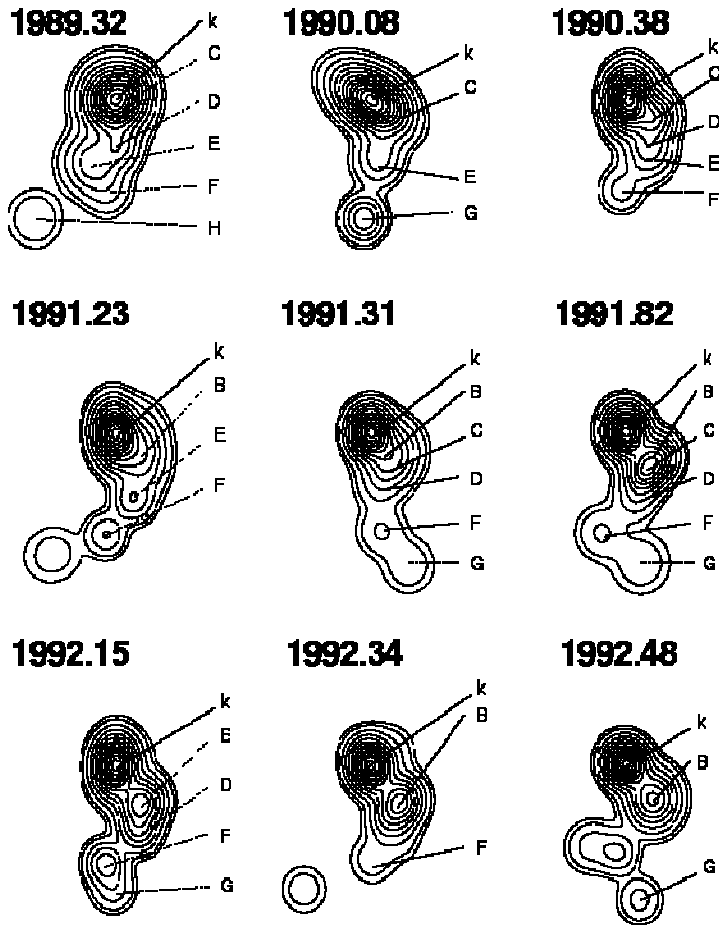
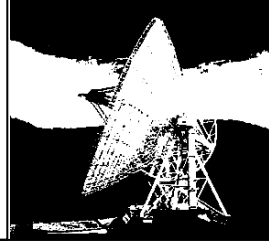
**OJ287: The Rosetta
Stone of Blazars**
e.g., Takalo 1994,
Abraham 2000, A&A 355, 915

3C 345:
Lobanov & Roland,
2005

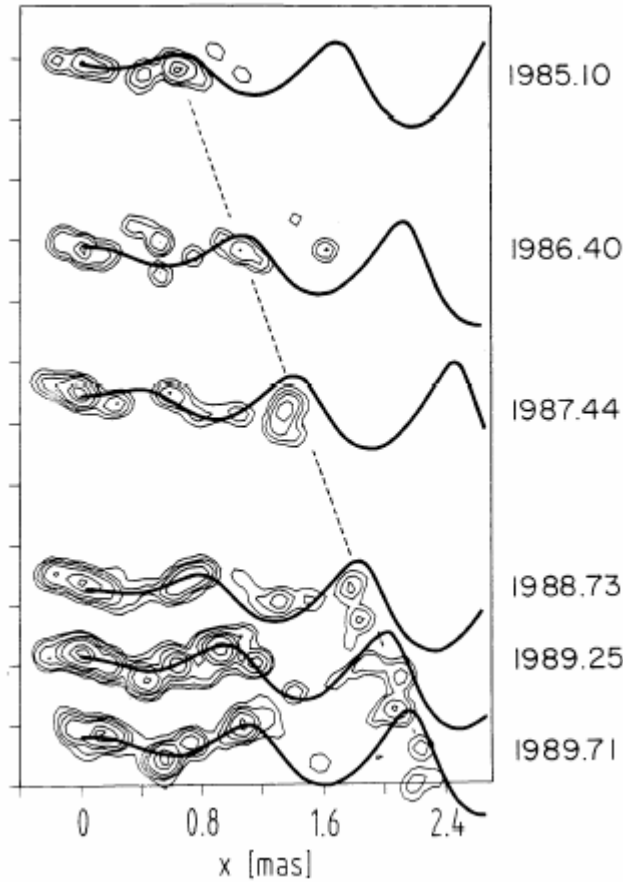
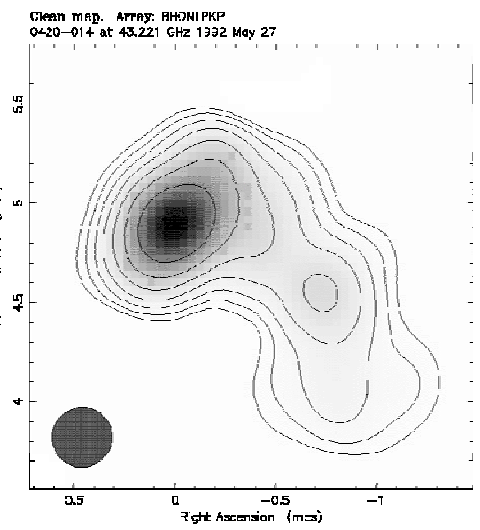


Supermassive Binäre Schwarze Löcher

periodische Abweichungen von einem geraden Jet



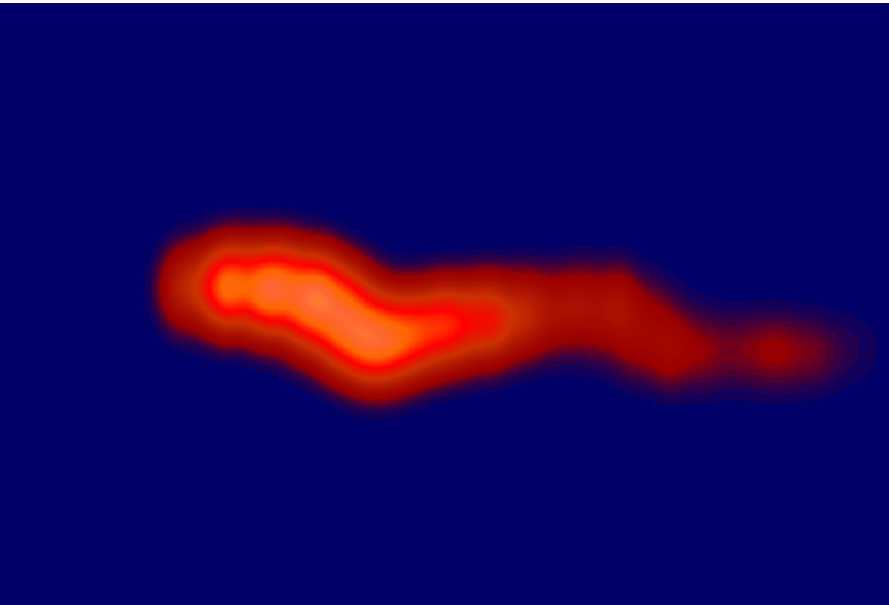
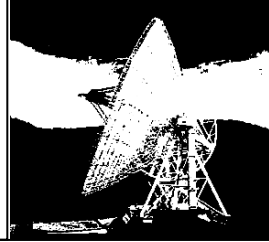
PKS 0420-014
z= 0.95



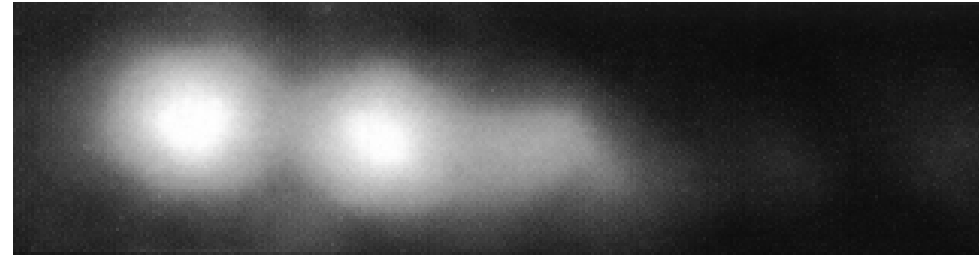
1928+738
z= 0.3

Supermassive Binäre Schwarze Löcher

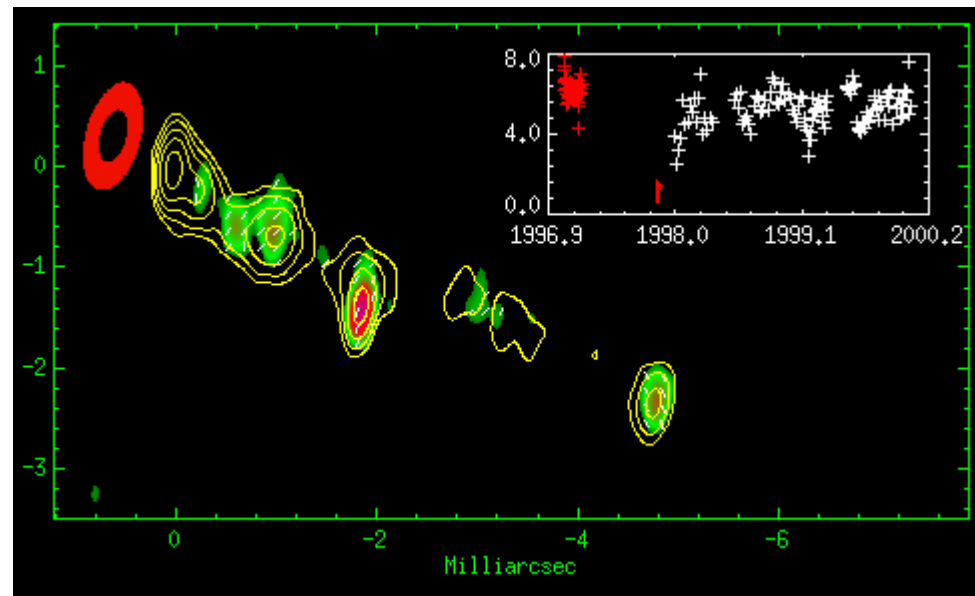
periodische Abweichungen von einem geraden Jetverlauf



3C345, Lobanov & Roland 2002



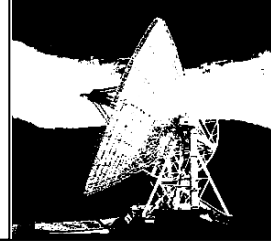
M87, Biretta et al.



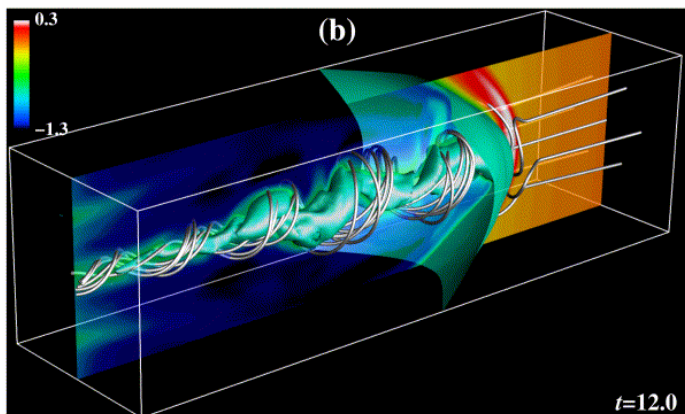
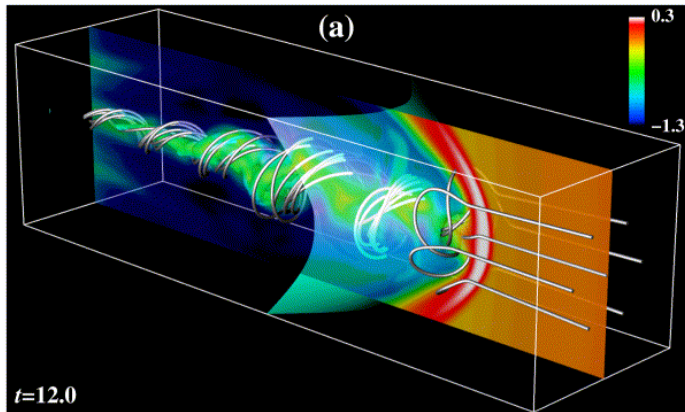
3C120, Gomez et al.

Supermassive Binäre Schwarze Löcher

periodische Abweichungen ... Modelle

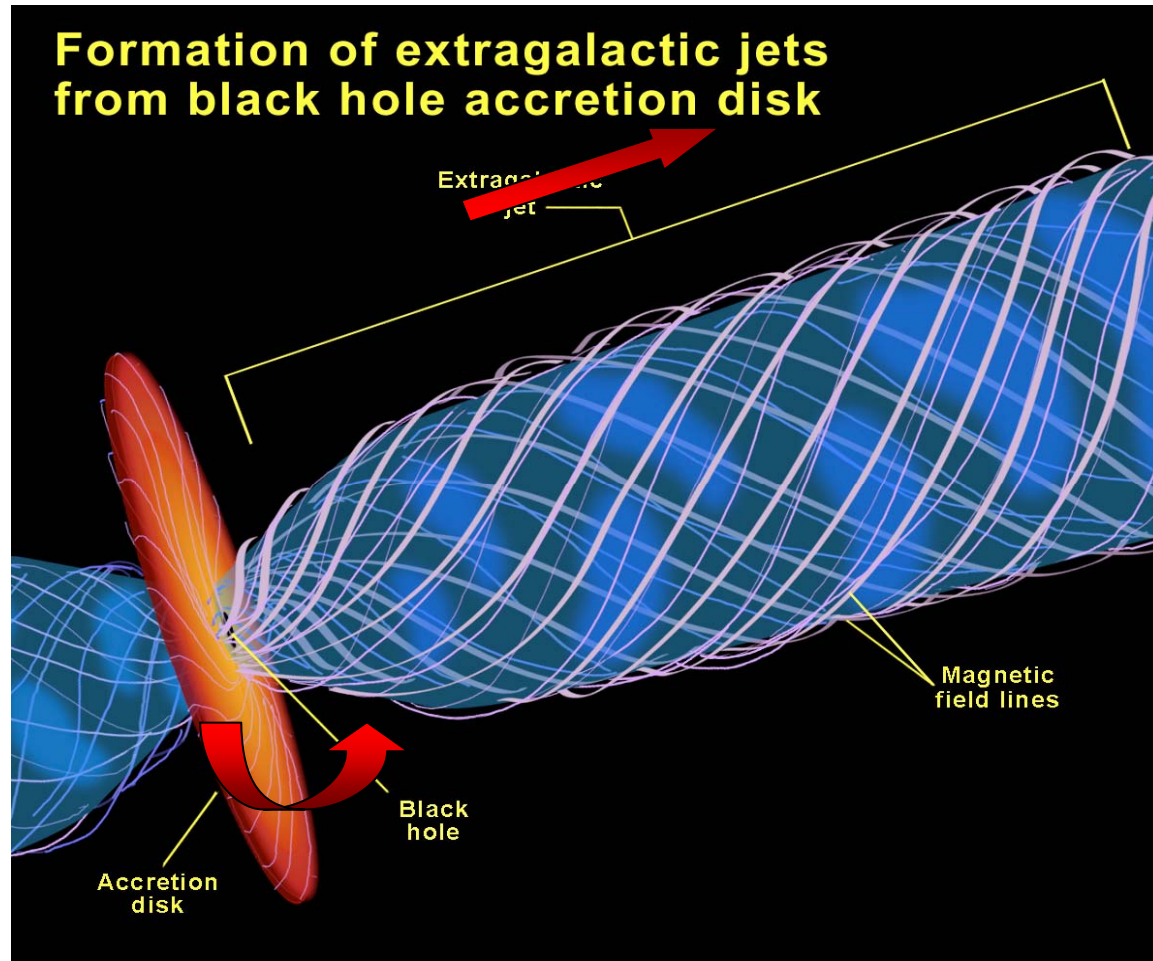
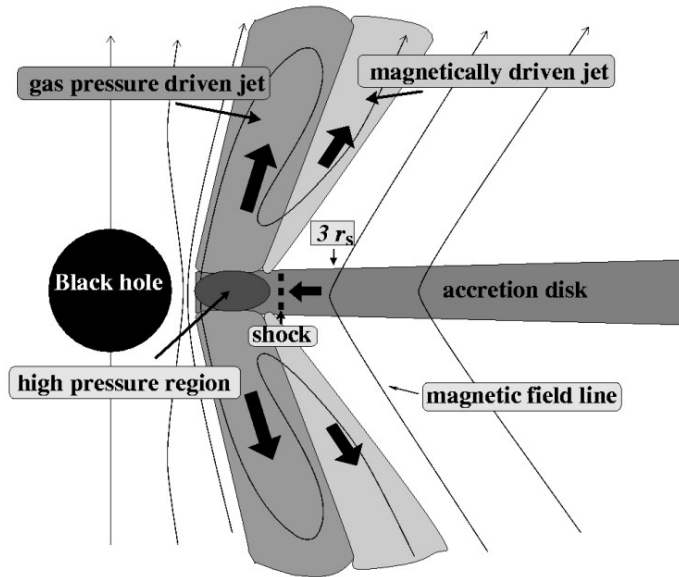
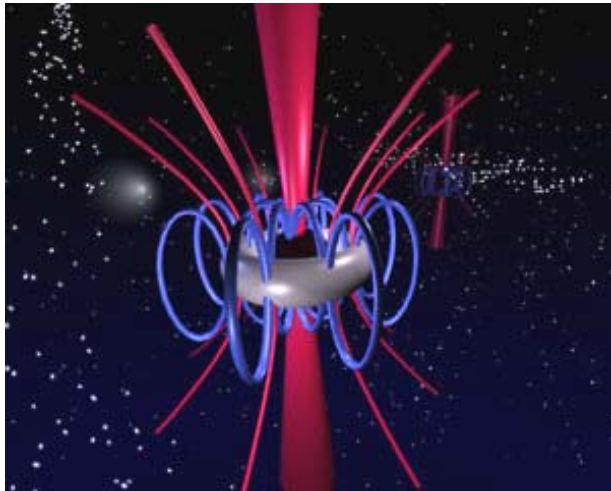
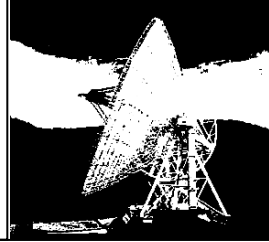


- Sweeping magnetic twist mechanism (Nakamura et al. 2001, *New Astronomy* **6**, 61)
- Spin-induced Precession in Active Galactic Nuclei (Caproni et al. 2004, *ApJ* **616**, 99)
- etc.
- Binary Black Holes:
 - **Orbital motion** of the jet-emitting black hole (Kaastra & Roos 1992)
 - **Precession effects**, either precession of the accretion disk around the jet-emitting black hole under gravitational torque (Katz 1997), or to geodetic precession (Begelman et al. 1980)



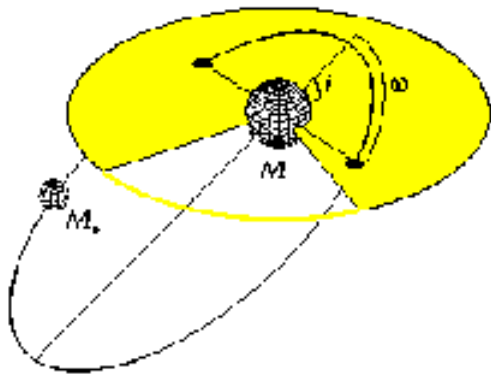
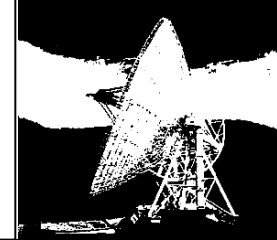
Supermassive Binäre Schwarze Löcher

periodische Abweichungen ... Modelle



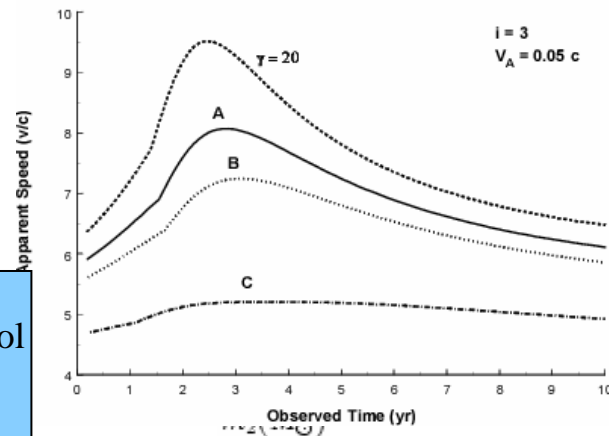
MHD simulation of a confining B-field anchored in a rotating disk

Binäre Supermassive Schwarzes Löcher in PKS 0420-014?

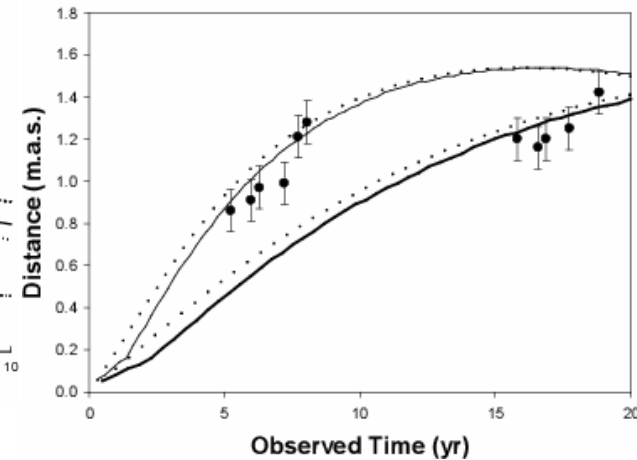


$M_1 = 7 \cdot 10^7 M_{\text{sol}}$, $M_2 = 2 \cdot 10^8 M_{\text{sol}}$
 $P_{\text{orb}} \approx 150 \text{ years}$,
 $P_{\text{prec}} \approx 10000 \text{ years}$

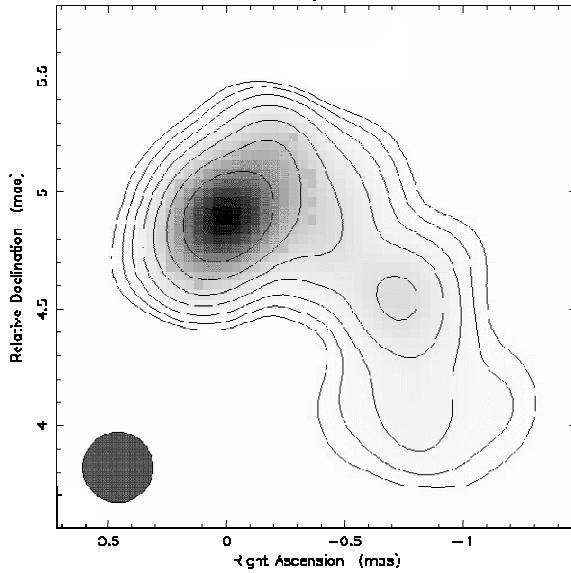
VLBI Components: Apparent speeds



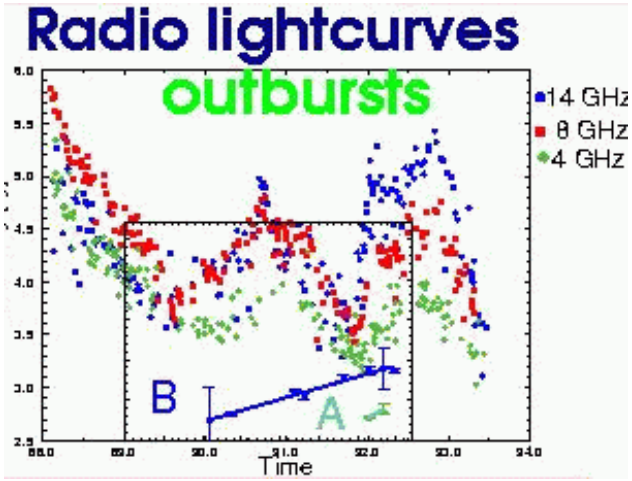
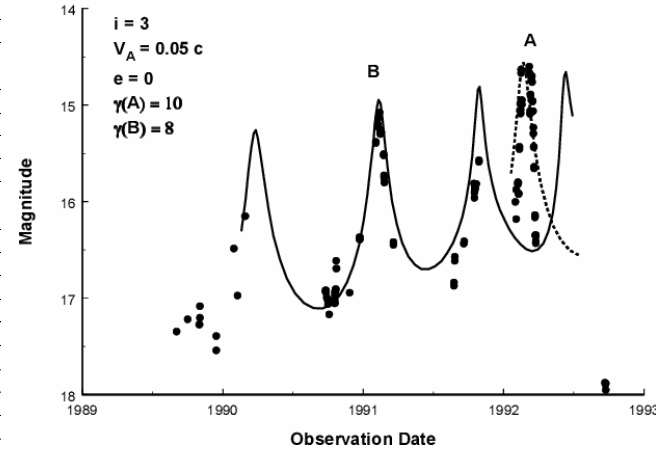
Core Separation: Components D & E



Clean map. Array: RHONIPKP
0420-C14 at 43.221 GHz - 992 May 27



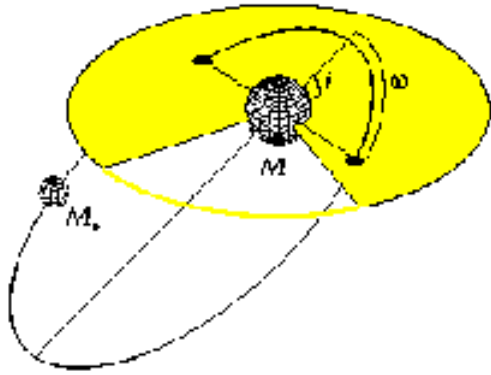
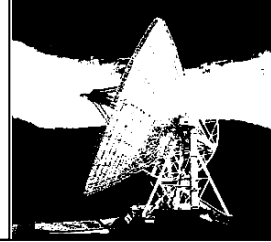
Optical Light Curve



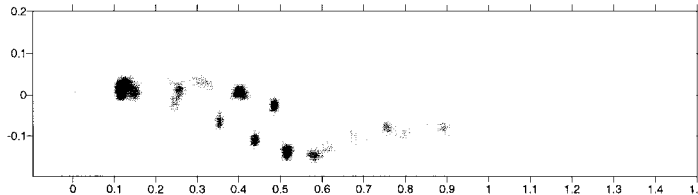
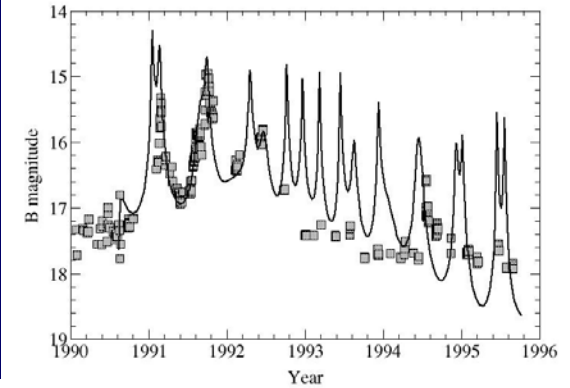
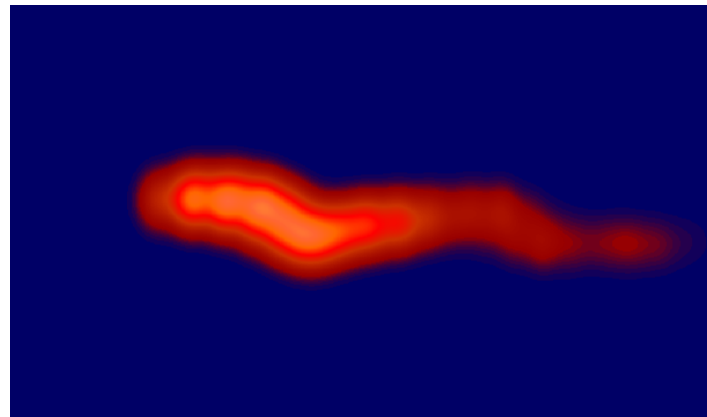
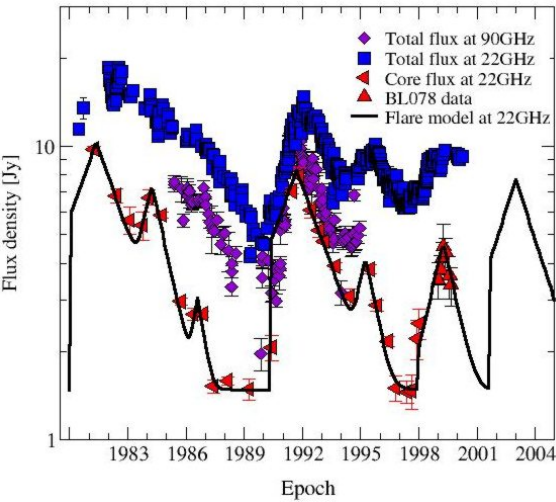
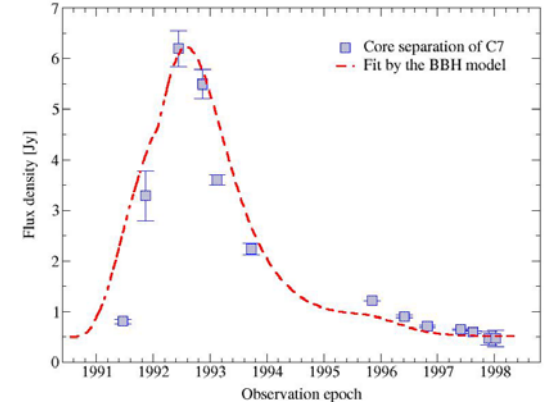
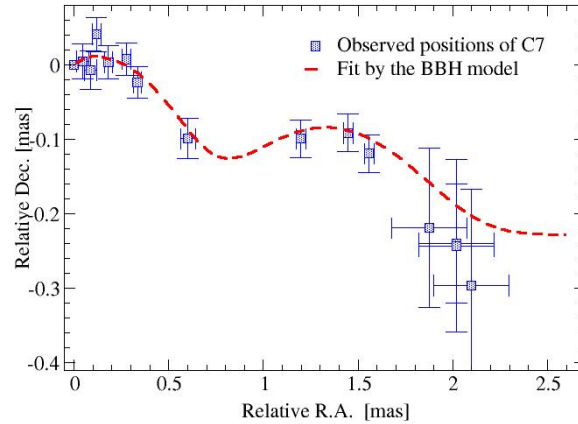
Britzen et al., 2000, A&A **360**,
 65; 2001, A&A **374**, 784

Binäre Supermassive Schwarzes Löcher

in 3C 345?

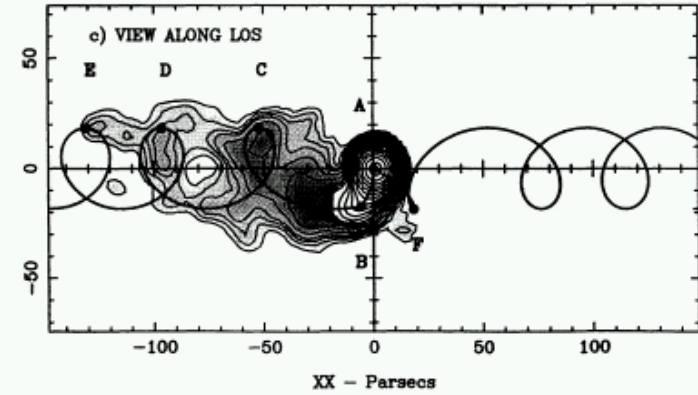
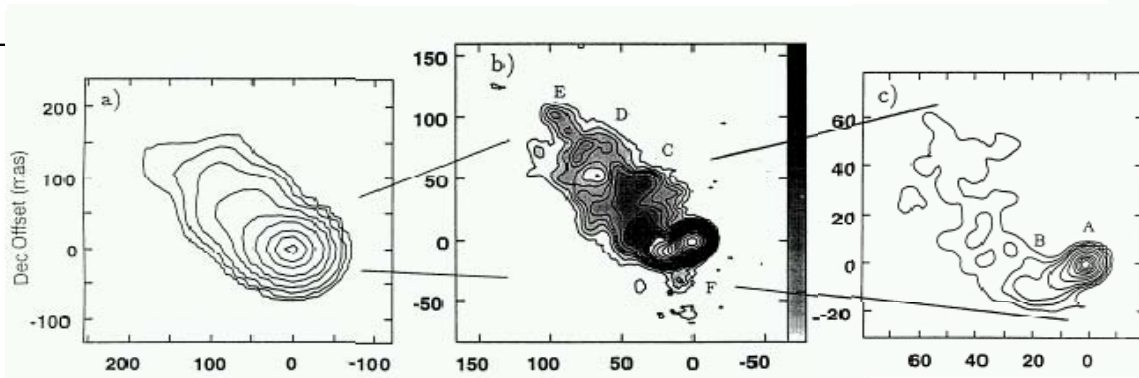


$M_1 = 1 \cdot 10^9 M_{\text{sol}}$, $M_2 = 5 \cdot 10^8 M_{\text{sol}}$
 $a_{\text{maj}} = 0.63 \text{ pc } (0.13 \text{ mas})$, $e = 0.1$
 $P_{\text{orb}} \approx 170 \text{ years}$,
 $P_{\text{prec}} \approx 2500 \text{ years}$



Lobanov & Roland 2005

Krümmungen auf kpc-Skalen

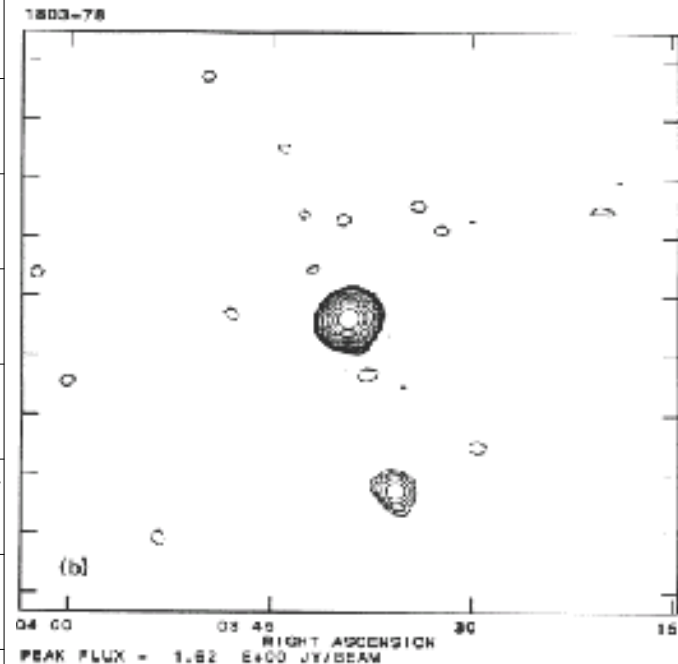
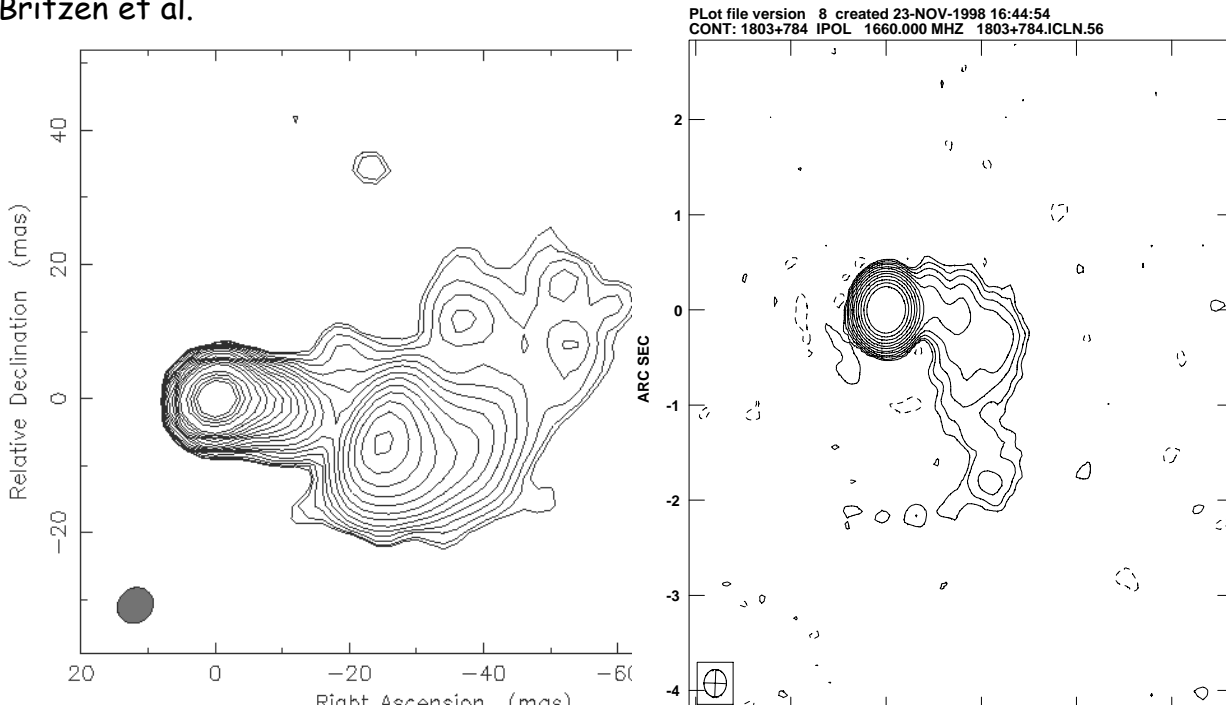


Mrk 501 .

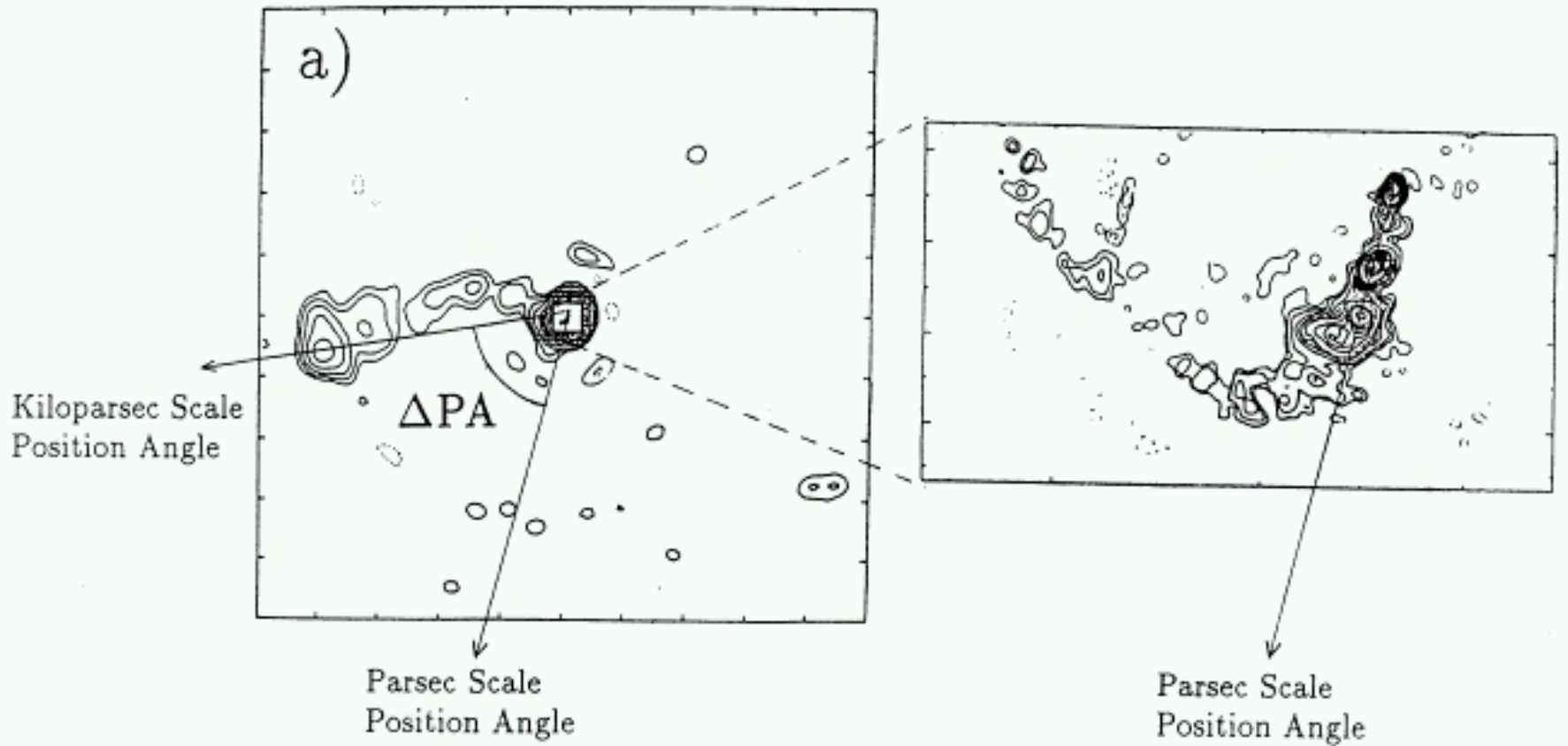
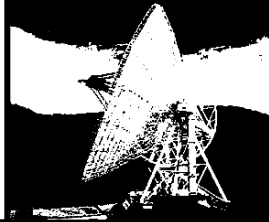
Conway & Wrobel, 1995, ApJ 439, 98

1803+784

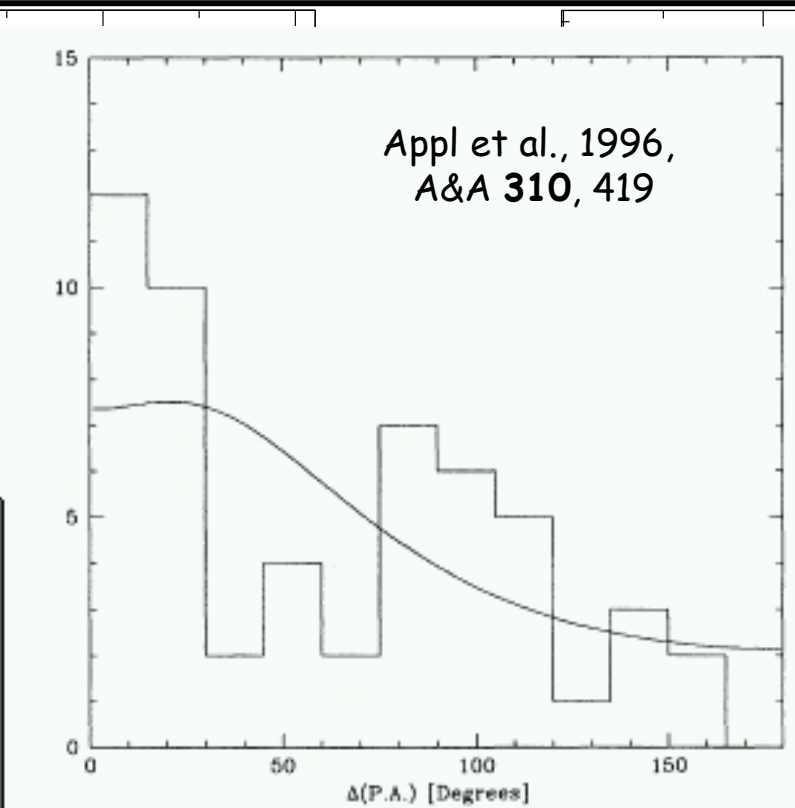
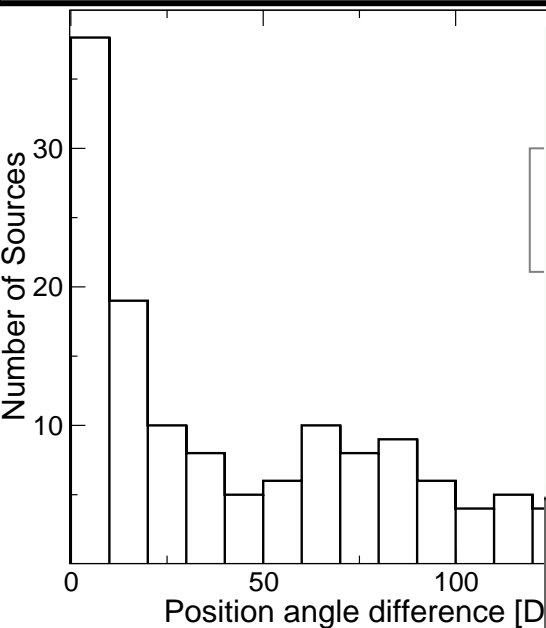
Britzen et al.



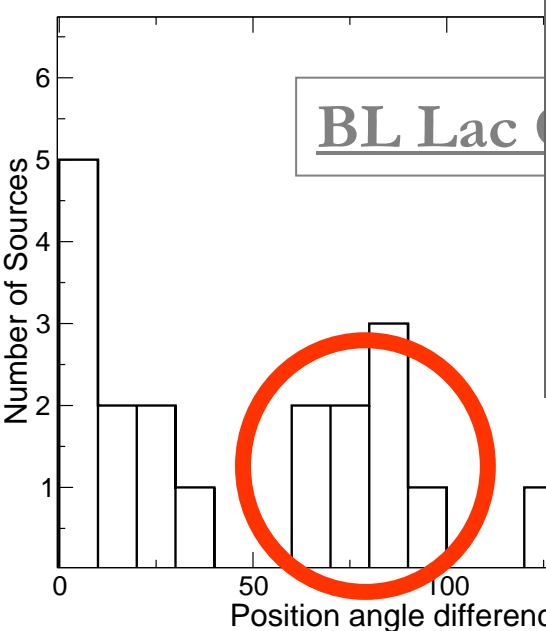
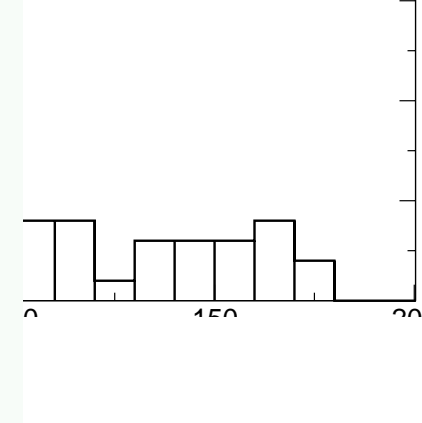
Falschausrichtung der Jets zwischen pc- und kpc-Skalen



Falschausrichtung der Jets zwischen pc- und kpc-Skalen



Quasars



Galaxies

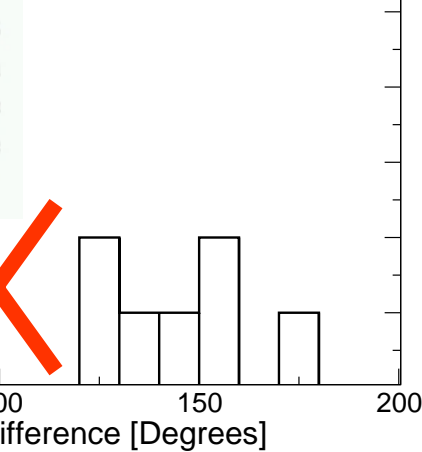
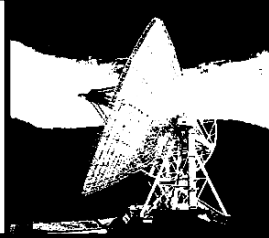


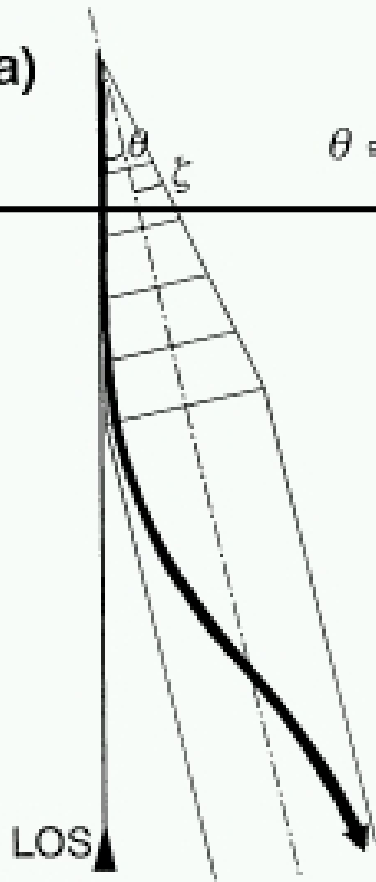
Fig. 1. Histogram of misalignment angle $(\Delta PA)_{\max}$ between nuclear jet and extended structure for 54 sources of the samples PEA88, KOL92, WEH92 and CON93. There are 55% of sources with $\Delta PA > 45^\circ$. The solid line shows the best fit obtained by a simple bend model with $\psi = 6.5^\circ$ and $\gamma = 10$. Its probability to be compatible with the data is only 20% (see Table 1).



a)

Mögliche Lösung: Projektion

$$\theta \equiv \zeta$$

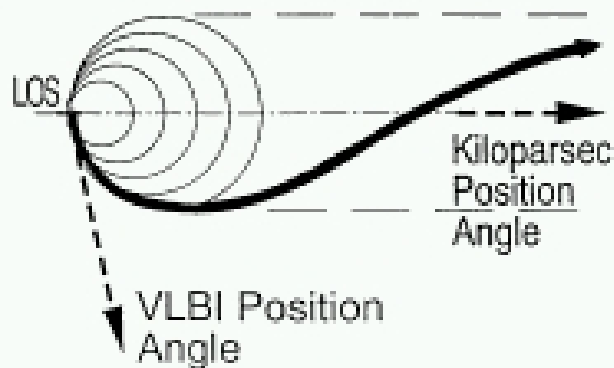


- werden die Jets tatsächlich um 90 Grad gekrümmt von pcs zu kpcs? Unwahrscheinlich, bislang keine befriedigende Theorie oder Modell

- **Lösung1:** pc-Jet bewegt sich in **helikaler Art**, Doppler Verstärkung erzeugt einen bevorzugten Sichtwinkel für den helikalen Jet : exakt 90 Grad für die “gebeamten”

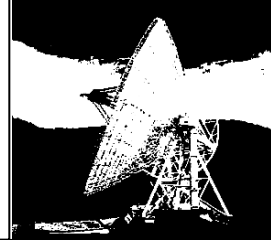
- => VLBI Jet Quellen zeigt nicht die wahre Richtung des Stroms

b)



Binäre Supermassive Schwarze Löcher

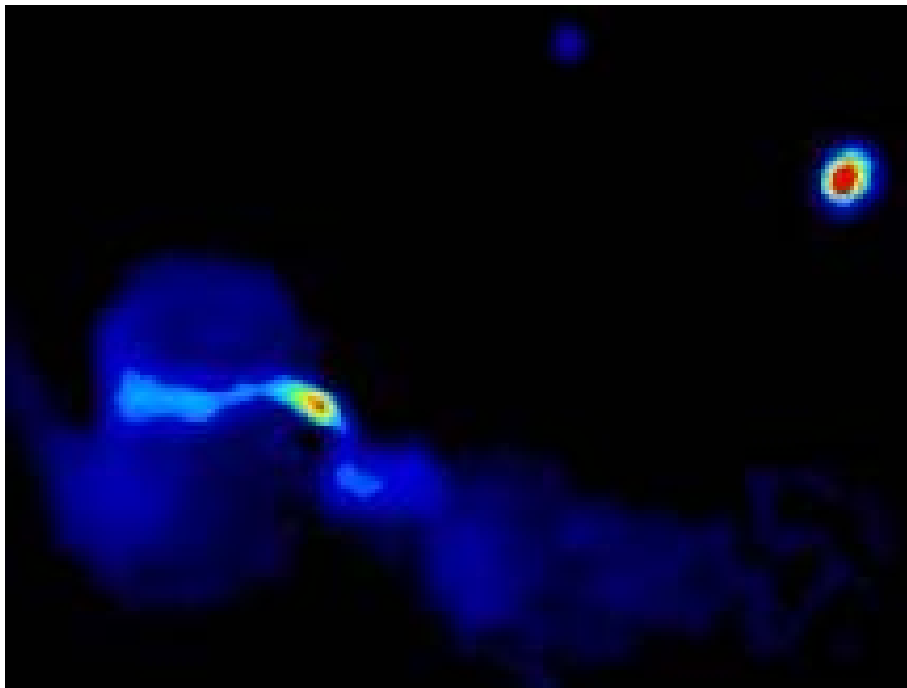
VLBI Phasen-Referenz-Beobachtungen



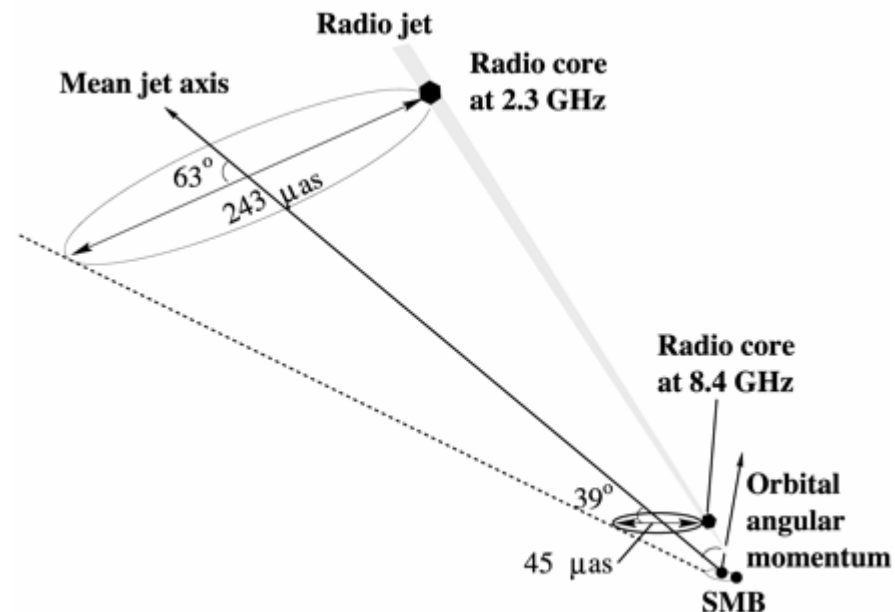
VLBI phase-referencing
observations

Radio Galaxy 3C 66B

The unresolved radio core shows well defined elliptical motions with a period of 1.05 ± 0.03 years, which provides a direct detection of an SMB

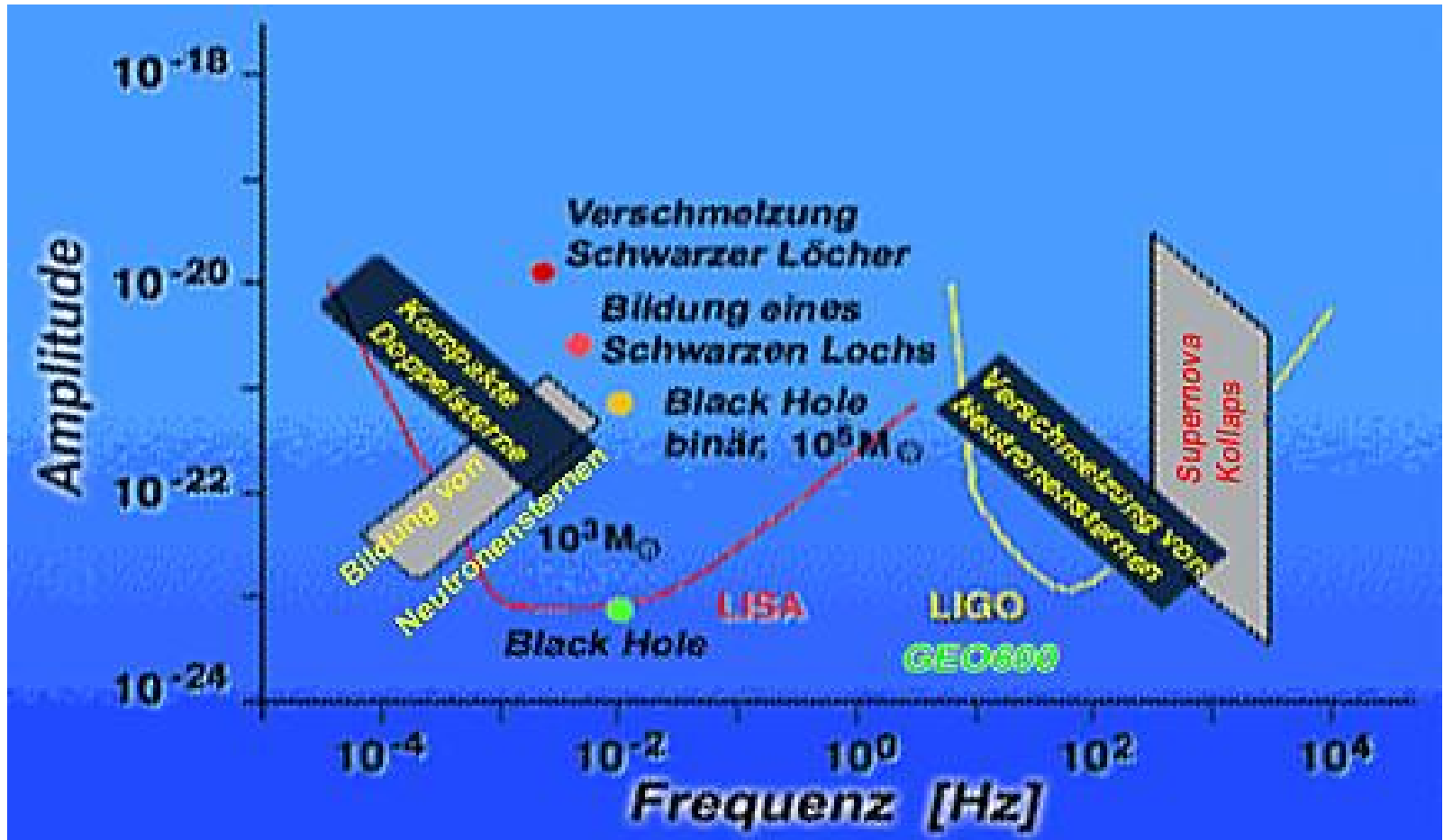
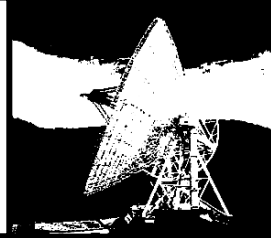


Hardcastle, M. J., et al., 1996, MNRAS **278**, 273



Sudou, H., et al., 2003, Science **300**, 1263

Binäre Supermassive Schwarze Löcher Gravitationswellen beim Verschmelzen

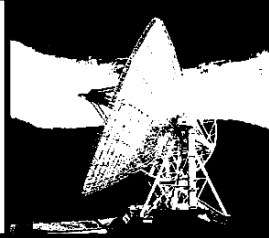


Einstein: 1916 Allgemeine Relativitätstheorie,

1936: sie existieren nicht, sie existieren doch

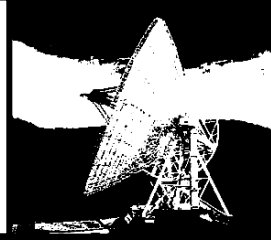
Feynman 1962: theoretische Existenz der Wellen sei schlecht für seinen Kreislauf

Gravitationswellenexperimente



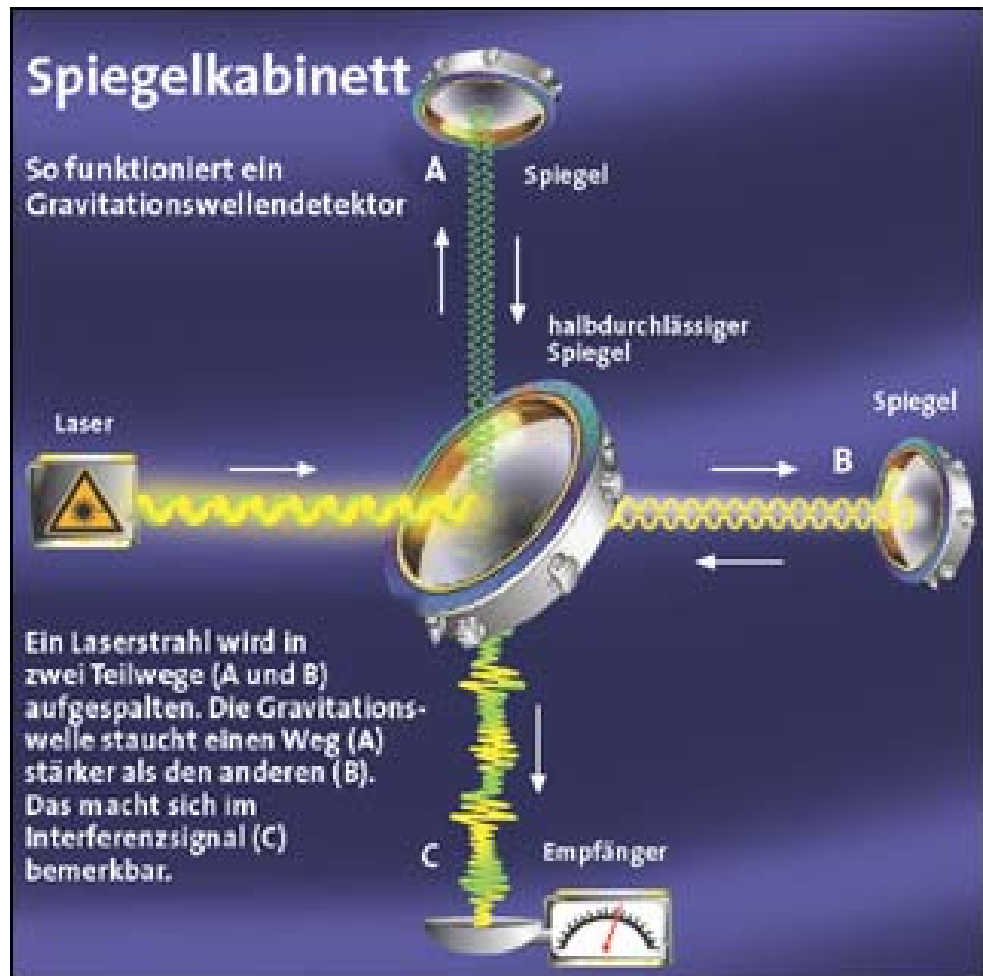
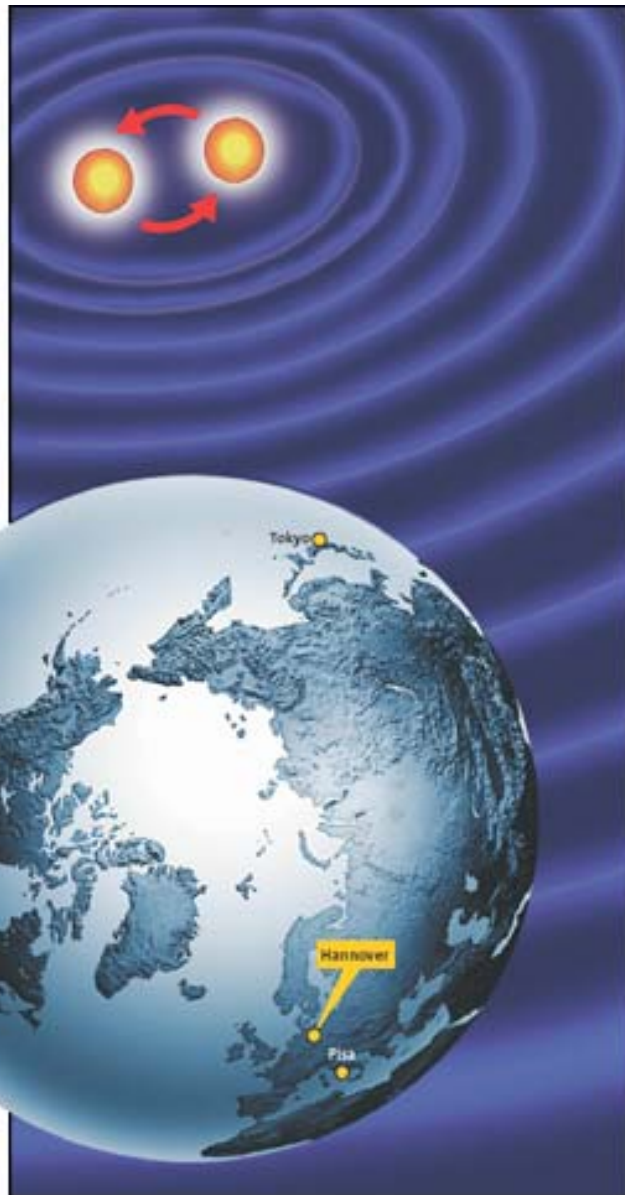
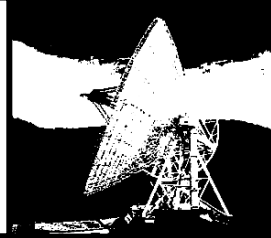
- [LISA](#), ein Weltraumprojekt von 5 Millionen km Länge
- [LIGO](#), ein USA- Bodenexperiment von 4 km Ausdehnung
- [VIRGO](#), italienisch- französisches Gemeinschaftsprojekt, 3 km
- [GEO600](#), britisch- deutsches Projekt in Hannover, 600 m
- [TAMA300](#), japanisch, 300 m

Gravitationswellenexperimente

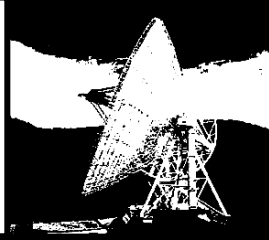


- Dies alles sind Experimente, die auf der Interferometrie (Überlagerung von Wellen) beruhen. Es laufen jedoch auch Projekte, welche die Längenveränderung von massiven Körpern ausnutzen:
- [GRAIL](#), ein holländisches Projekt
- [EXPLORER](#), Italien
- Weitere Experimente mit ebenfalls klingenden Namen sind **TIGA**, USA; **SFERA**, Italien; **OMEGA**, Italien **GRAVITON**, Brasilien; **ALLEGRO**, USA, **NAUTILUS**, Italien sowie **AURIGA**, ebenfalls in Italien.

Gravitationswellenexperimente



Gravitationswellenexperimente

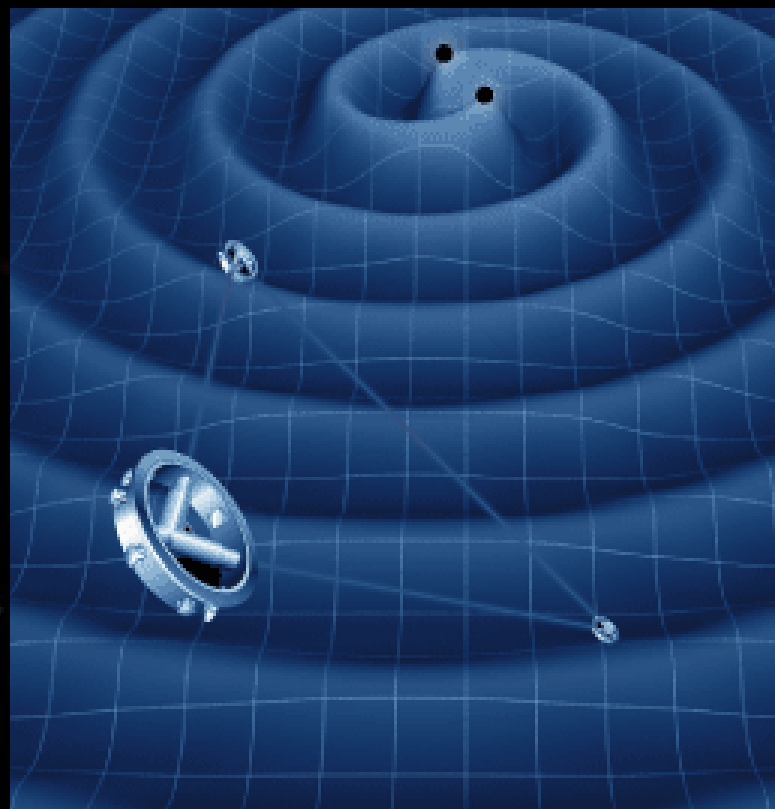
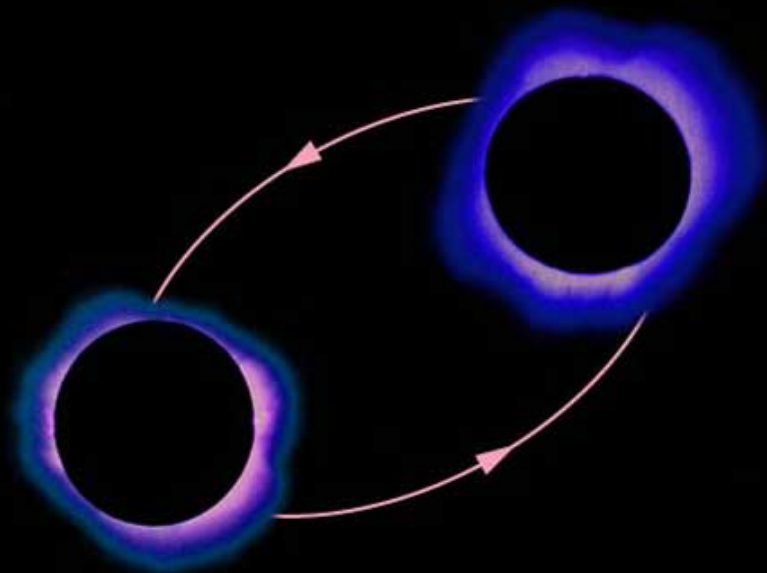
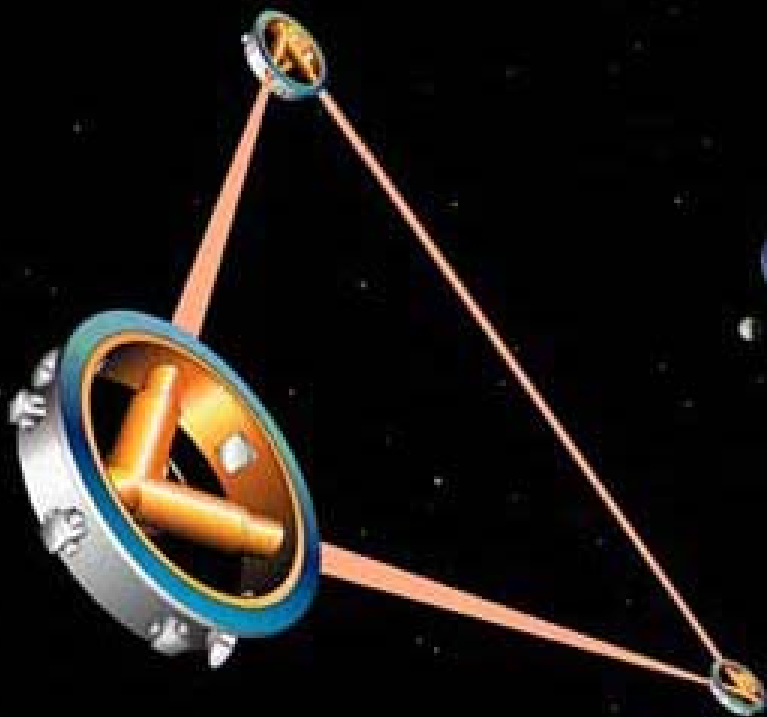


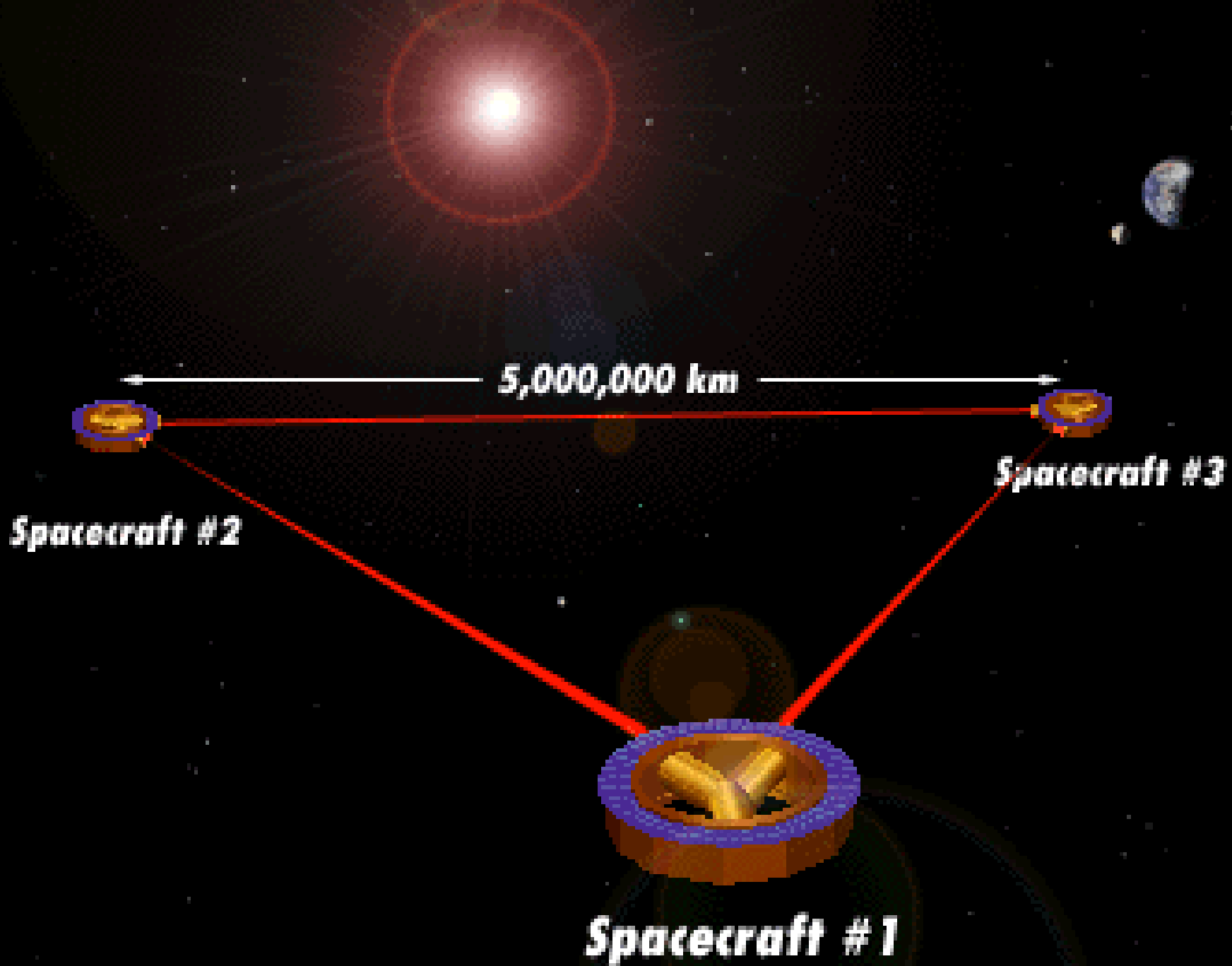
- LIGO (Laser Interferometer Gravitational-Wave Observatory): täglich Signale, leider die falschen
 - Washington: Wind läßt Erde vibrieren
 - Tokio: registriert das Rauschen des Stadtverkehrs
 - Louisiana: Holzfäller in den Sümpfen
 - Hannover: Nordseebrandung, ICE, Vögel

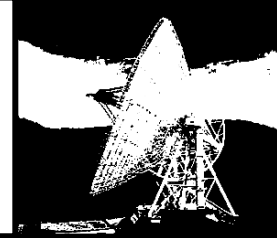
LISA

Opening a new window on the Universe

Laser Interferometer Space Antenna







- **MISSION NAME:** Laser Interferometer Space Antenna, a Structure and Evolution of the Universe 2003 Roadmap, "Beyond Einstein" Great Observatory mission.
- **OBJECTIVE:** To detect gravitational waves from sources involving galactic (within the Milky Way) binaries and extra-galactic (outside our Galaxy) massive black holes.
- **MISSION DURATION:** Five years for nominal mission (10 years extended mission).
- **ORBIT:** 20 degrees behind Earth's orbit of the Sun, at 1 AU (astronomical unit) from the Sun, with the plane of orbit inclined at 60 degrees to the ecliptic.
- **SPACECRAFT MASS:** Each spacecraft has a mass of 203 kilograms (447.5 pounds). Each propulsion unit weighs 132 kilograms (291 pounds) and requires 27 kilogram (59.5 pounds) of propellant. Total launch mass is 1407 kilograms (3102 pounds).
- **INSTRUMENT:** identical in each of LISA's three spacecraft —30 centimeter (almost 12 inches) diameter f/1 Cassegrain telescope
- **POWER SUPPLY:** Gallium Arsenide solar array and 9 amps per hour lithium ion battery
- **CONSUMABLES:** No consumable fuel needed in orbit. 27 kilograms (59.5 pounds)

Gravitational Waves Escape from the Earliest Moments of the Big Bang

BIG BANG

Big Bang plus 10^{-43} Seconds

Big Bang plus 300,000 Years

Big Bang plus 15 Billion Years

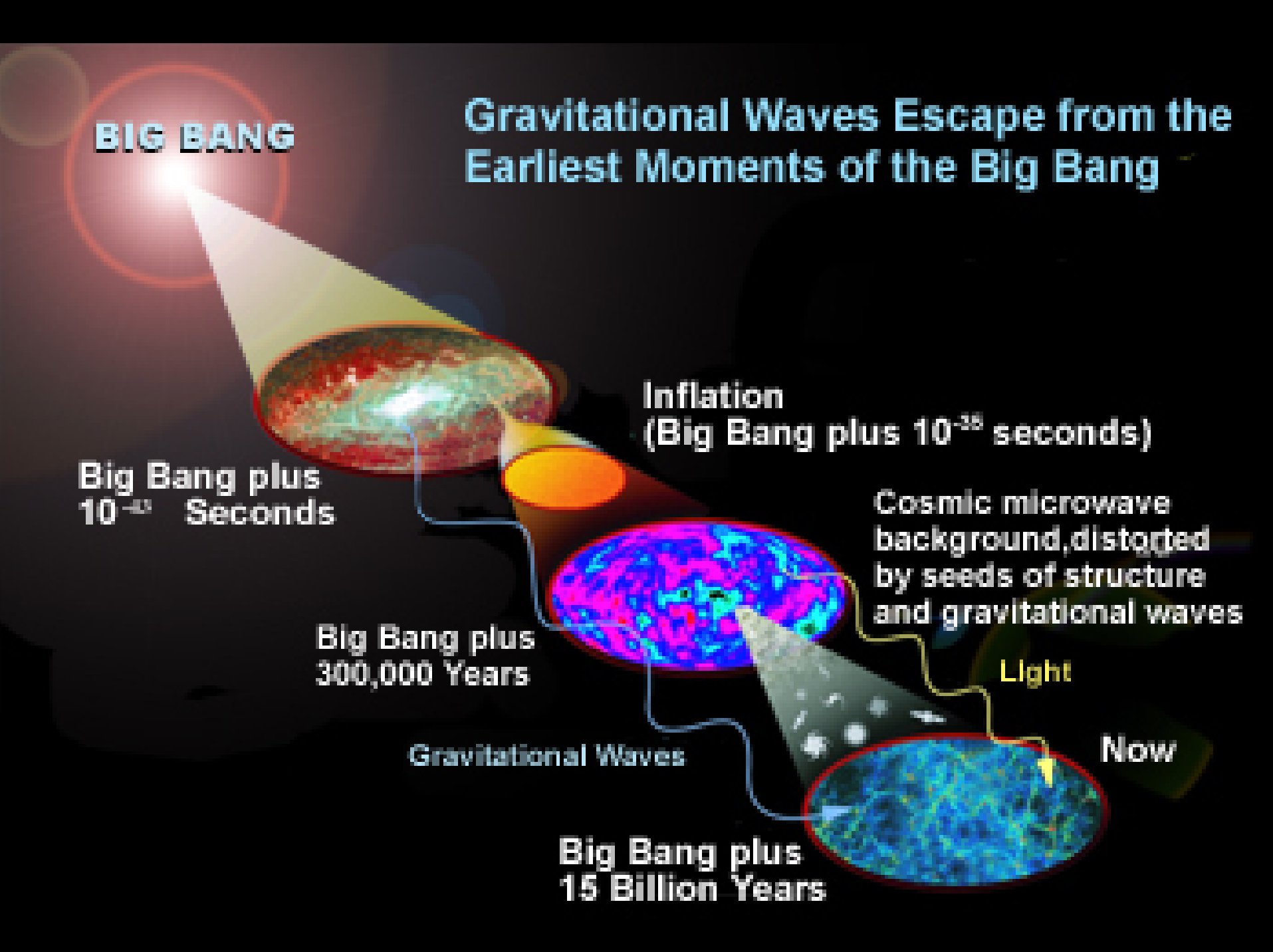
Inflation (Big Bang plus 10^{-36} seconds)

Cosmic microwave background, distorted by seeds of structure and gravitational waves

Gravitational Waves

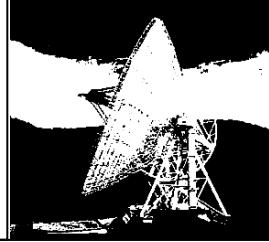
Light

Now

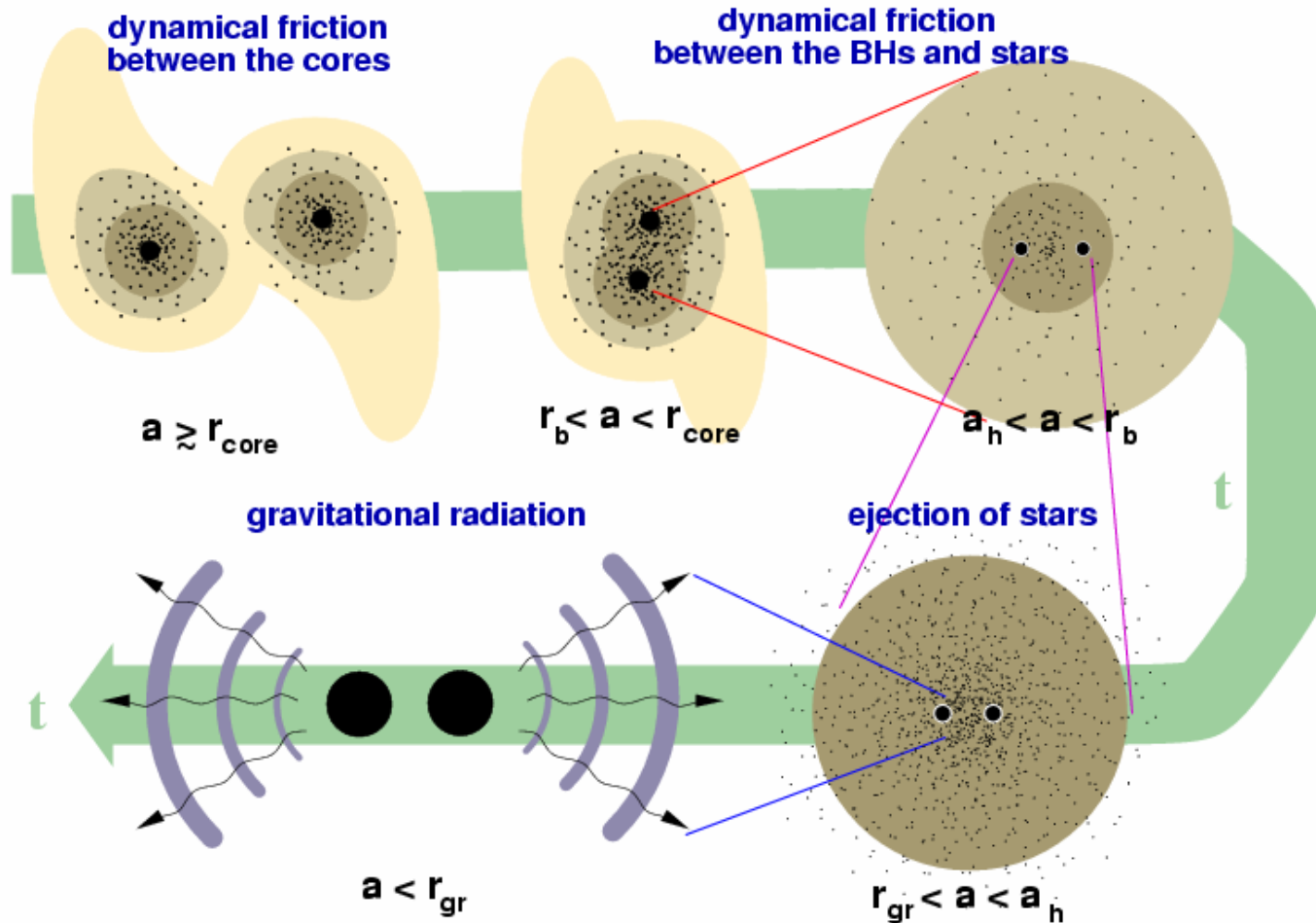


Binary Supermassive Black Holes

change in jet-orientation due to spin-flip?

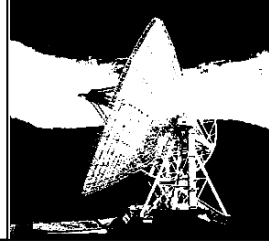


MERGING OF BHs DUE TO

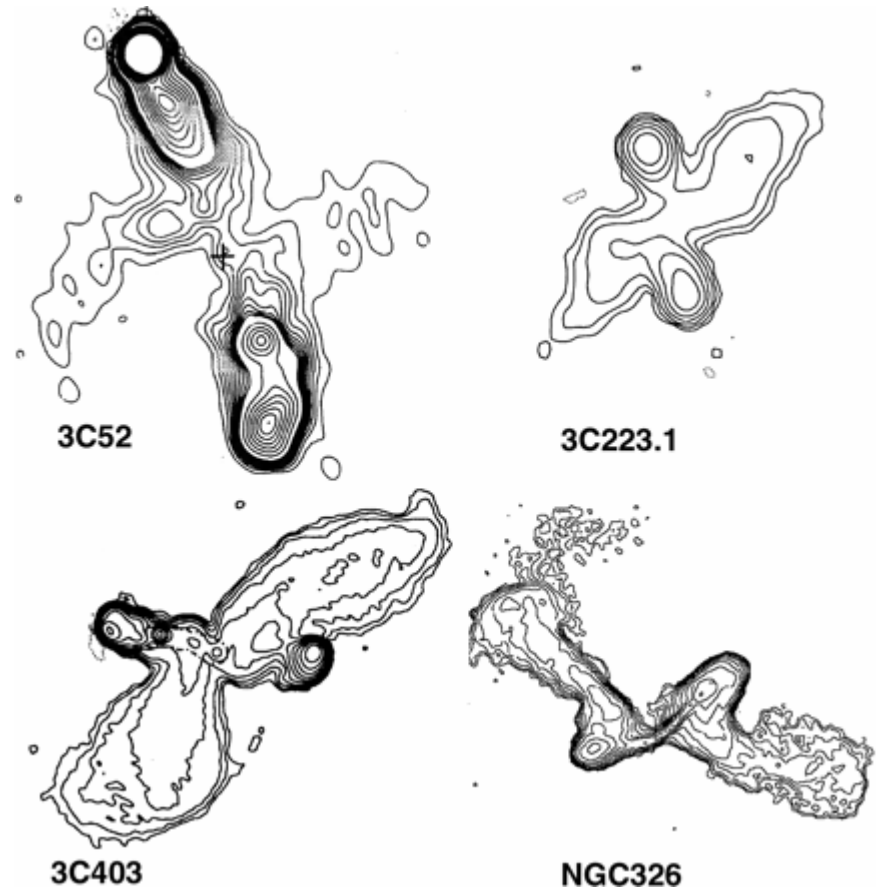


Binäre Supermassive Schwarze Löcher

Nach der Verschmelzung?

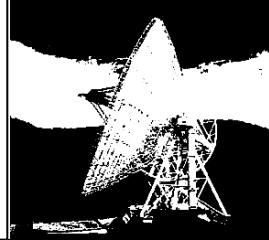


- A composite of four clear examples of the X-shape morphology.
- VLA radio observations of 3C52 (Leahy & Williams, 1984, MNRAS 210, 929), 3C223.1, 3C403 (Dennett-Thorpe et al., 1999, MNRAS 304, 27), and NGC 326 (Murgia et al., 2001, A&A 380, 102)



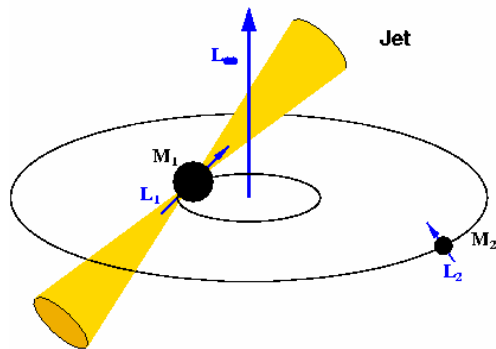
Binäre Supermassive Schwarze Löcher

Nach der Verschmelzung? Jet-flip aufgrund von Spin-flip?

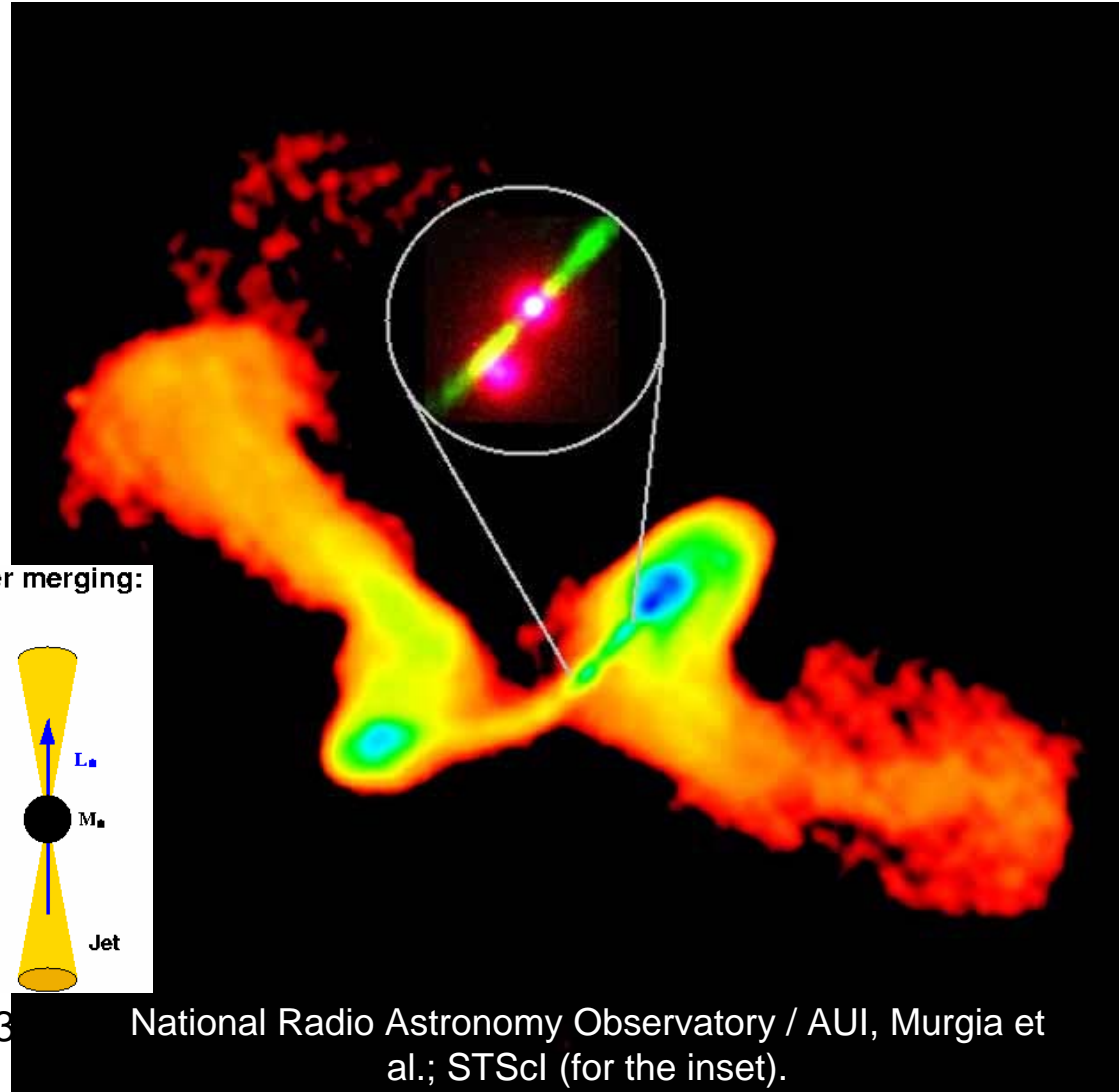
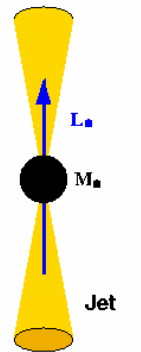


- NGC 326
- Black hole merging: jets change direction
- Jet-flip due to spin-flip of the primary BH (follows orbital angular momentum)

Before merging:



After merging:

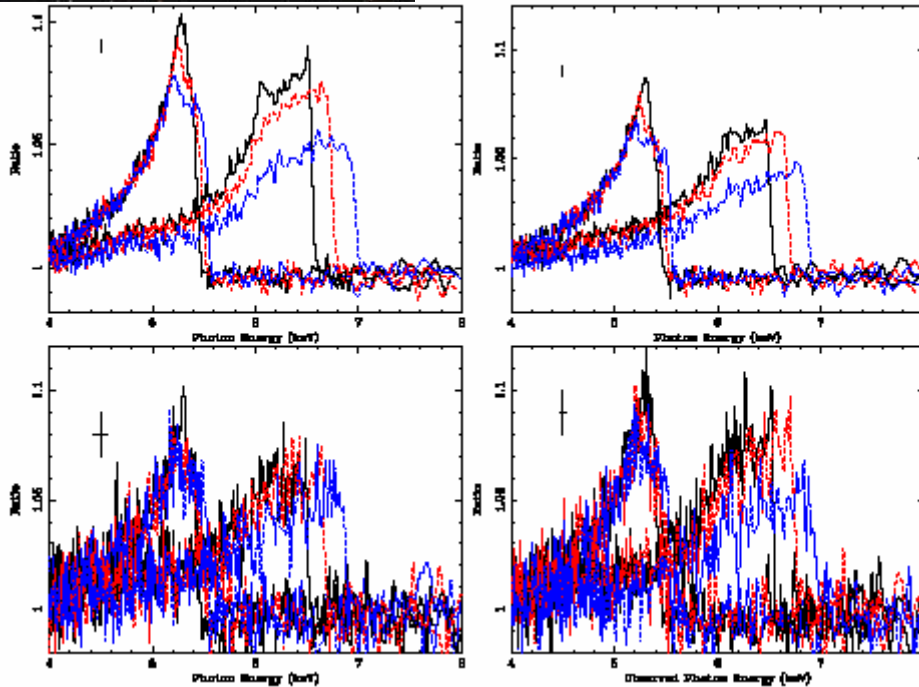
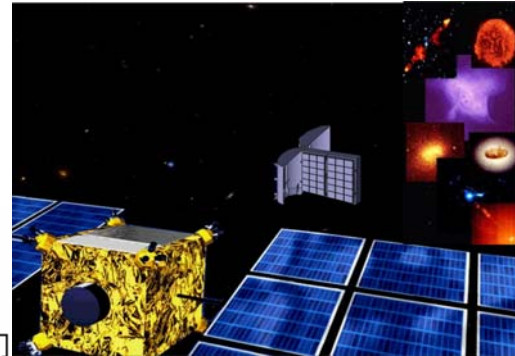


Zier C., Biermann P.L. 2001, A&A 377, 23

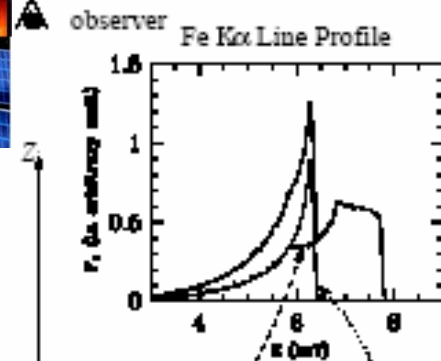
National Radio Astronomy Observatory / AUI, Murgia et al.; STScI (for the inset).

Binäre Supermassive Schwarze Löcher

Zukunft: neue Beweise durch Variation der Fe K_α-Linie?

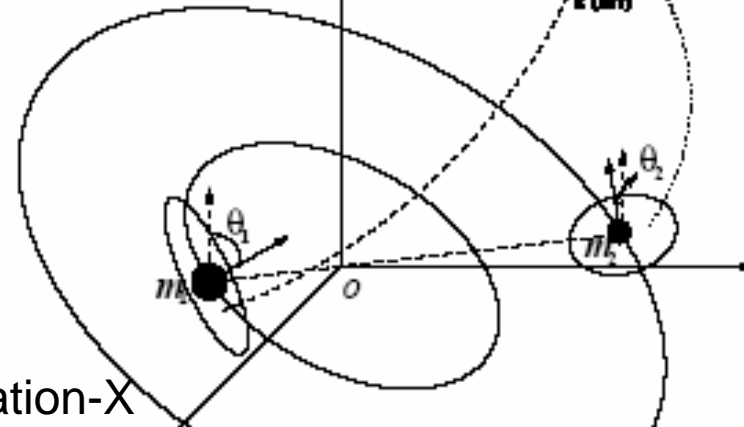


Torres et al. 2003, ApJ 596, 31



XEUS

Constellation-X



Yu & Lu, 2001, A&A 377, 17
XEUS