

Sommersemester 2006



Neue Ergebnisse und  
Perspektiven der  
Radioastronomie



# Neue Ergebnisse und Perspektiven der Radioastronomie



## Organisatorisches

- jede 2. Woche, 6 Vorlesungen
- E-mail: [sbritzen@mpifr-bonn.mpg.de](mailto:sbritzen@mpifr-bonn.mpg.de)
- Tel: 0228 525 280
- ppt im pdf-Format auf [www.mpifr-bonn.mpg.de/staff/sbritzen/](http://www.mpifr-bonn.mpg.de/staff/sbritzen/)  
Literatur zu den Themen, links



# Neue Ergebnisse und Perspektiven der Radioastronomie



Themen  
& Daten

- **Heute:** Einführung & Übersicht
- 12.05. Radioteleskope & Radiobilder & Katastrophen
- 26.05. Der Radiohimmel im Licht der 21cm-Linie
- **09.06.** Pulsar-Astronomie (heute & in Zukunft)
- **23.06.** AGN & Binäre Schwarze Löcher (NEUES!)
- 07.07. Maser & das Interstellare Medium & AGN & Merger
- 21.07.

# Neue Ergebnisse und Perspektiven der Radioastronomie

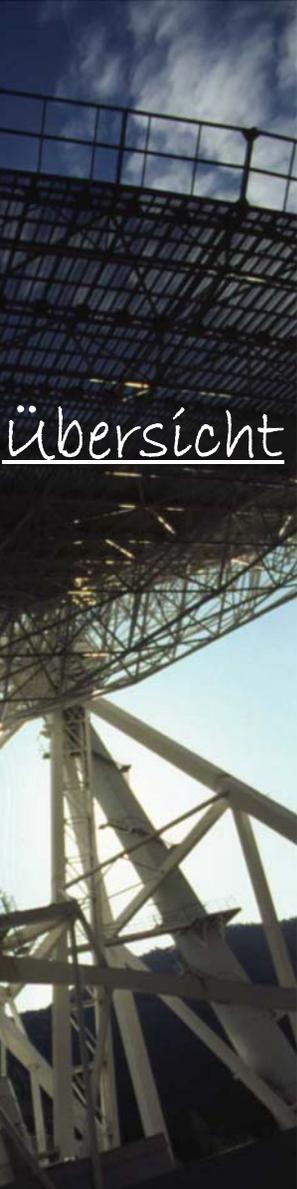


Vorlesung

& WM

- 09.06. Deutschland-Costa Rica (18 Uhr)
- 23.06. Ukraine – Tunesien (16 Uhr); Saudi-Arabien – Spanien (16 Uhr); ...
- 07.07. Vorlesung / kein Spiel
- 09.07 Finale / keine Vorlesung

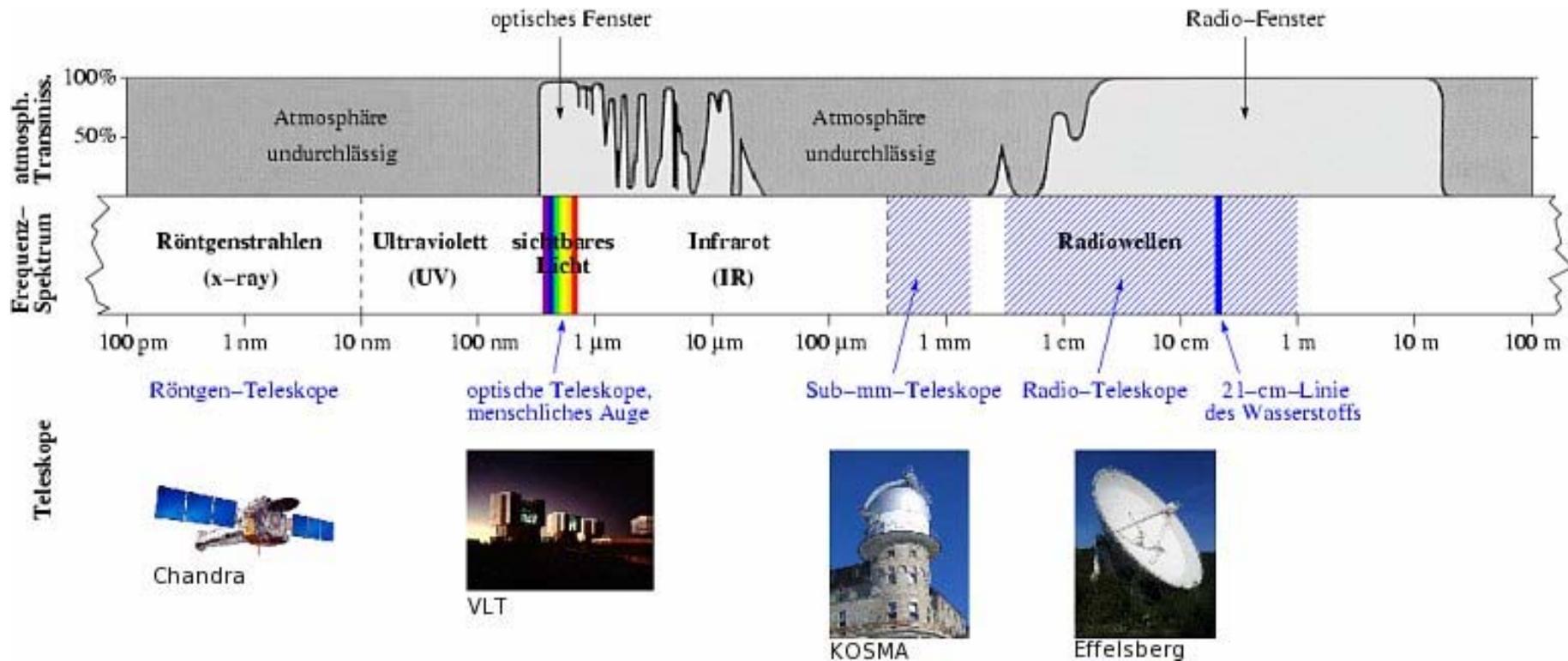
# 12.05. Radioteleskope & Radiobilder



Übersicht

- (Ganz) kurze Geschichte der Radioastronomie
- Radiostrahlung und wie sie entsteht
  - Kontinuum
  - Linien
  - Maser
- Radioteleskope / Interferometer
  - Neuigkeiten von ALMA, LOFAR, SKA
- Teleskop-Katastrophen
  - Greenbank, etc.

# Radiostrahlung & Quellen



**Linienstrahlung:** 21 cm-Linie des atomaren Wasserstoffs

**Thermische Strahlung:** Molekülwolken

**Synchrotronstrahlung:** Aktive Galaxienkerne, Sonnenflares

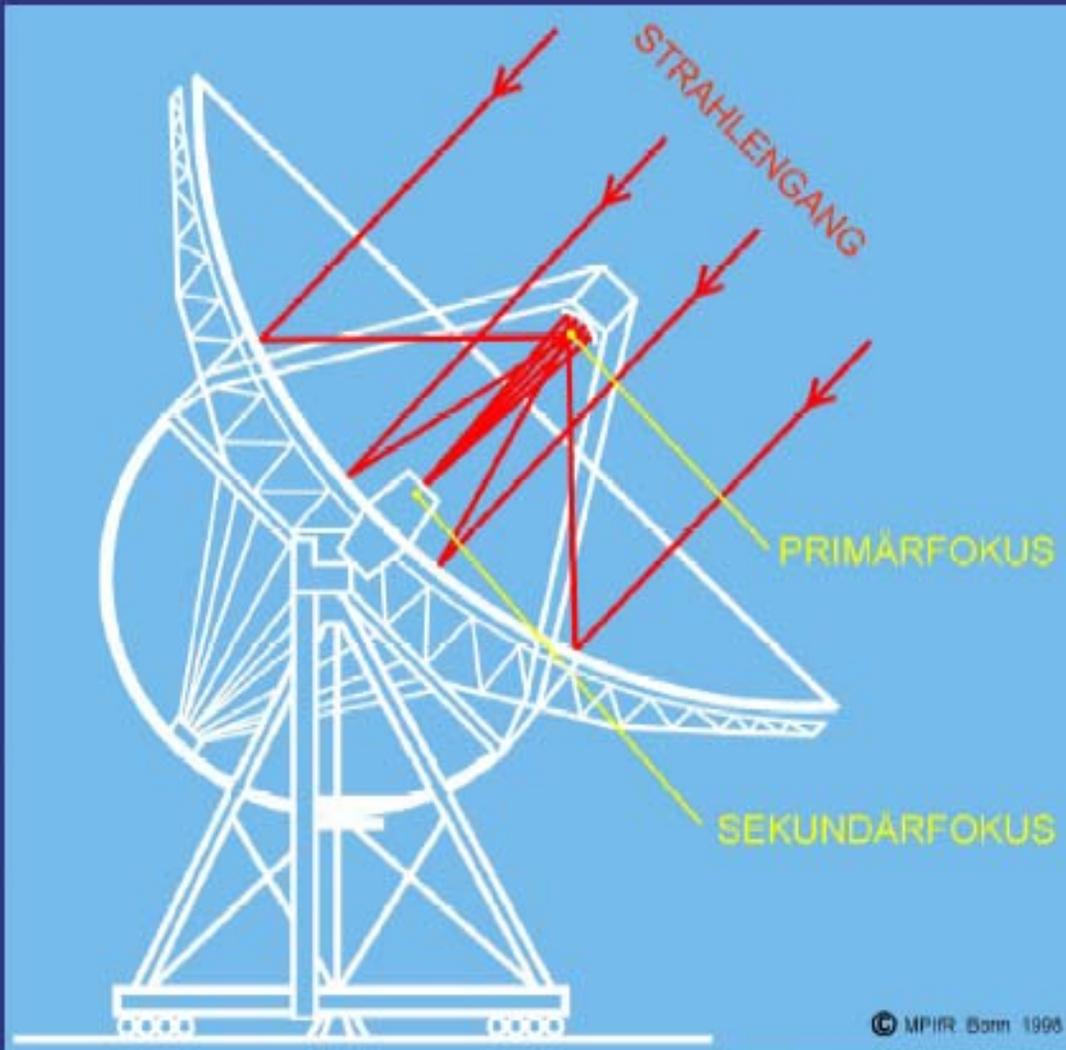
**Maserstrahlung:** Sternentstehungsgebiete, Aktive Galaxienkerne, Merger

# Die größten freibeweglichen Antennen

- Robert C. Byrd Green Bank Teleskop
- 100 x 110 m, 16 Mio Pfund Gewicht
- Aperturbene ungestört
- 2004 Panels können einzeln bewegt werden (Hochfrequenzbeobachtungen)
- Laser-System, Licht wird reflektiert und erlaubt die Deformation unter Gravitation, Wind und Temperaturdifferenzen zu beobachten und zu kompensieren



# Antennen & Verstärker



- Parabolspiegel
- Hornantennen + Verstärker
- Datenverarbeitung



Effelsberg



Westerbork Array



Jodrell Bank MKIA



Jodrell Bank MkII



Cambridge 32m



Chilbolton



Defford



Knockin



Medicina



Noto



Matera



Wetzell



TIGO



Weilheim



Pinguin



Hohenbuenstorf



Pico Veleta



Onsala 20m



Onsala 25m



Metsähovi



Torun 15m



Torun 32m



Robledo DSS-62



Robledo DSS-63



Robledo DSS-65



Plateau de Bure



Nançay



Yebes



Ny-Alesund 20m



Simeiz

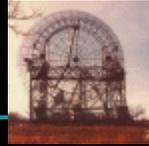




Algonquin



Haystack



Haystack Ionospheric



Westford



Green Bank 43m



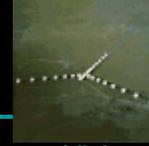
Green Bank 85-3



Owens Valley



VLBA Owens Valley



VLA



VLBA Brewster



VLBA Fort Davis



VLBA Hancock



VLBA Iowa



Kitt Peak



VLBA Los Alamos



Pie Town



Goldstone DSS-14



Goldstone DSS-15



Gilcreek



Hat Creek



Mohave



Quabbin



Arecibo



Itapetinga



Fortaleza



Mauna Kea



Hartesbeesthoek



Ussuriysk



Ooty



Bangalore



Urumqi



Shanghai 6m



Shanghai 25m



Kashima 26m



Kashima 34m



Nobeyama



Parkes



Tidbinbilla1



Tidbinbilla2



Hobart



O'Higgins



Syowa

# VLBI: Erste Experimente (1968)



Beste Auflösung: 6 Milli-Bogensekunden, Green-Bank/ Onsala, 6319 km, 5 GHz

## Radio Interferometry at One-Thousandth Second of Arc

Intercontinental interferometer base lines are used to refine our knowledge of compact radio sources.

M. H. Cohen, D. L. Jauncey, K. I. Kellermann, B. G. Clark

The angular resolution of large optical telescopes has always been limited, by atmospheric turbulence, to about 1 second of arc. At this resolution the

fringes may also be thought of as the "beat" arising from the fact that radiation from the source is received with slightly different Doppler shifts at the

... many radio ... a superheterodyne ... signals down to ... ate frequency, ge ... megahertz. The ou ... ometer is the prod ... of the signals from ... the coherence fun ... ment—essentially t ... of the local oscill ... ments. Coherence ... tors, as well as the ... mediate-frequency ... veniently achieved ... conventional coax ... tween the two ele ... base lines of mo

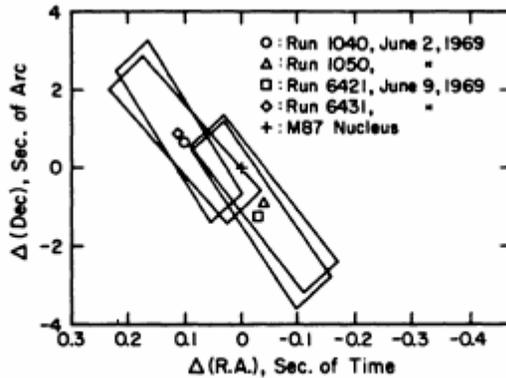
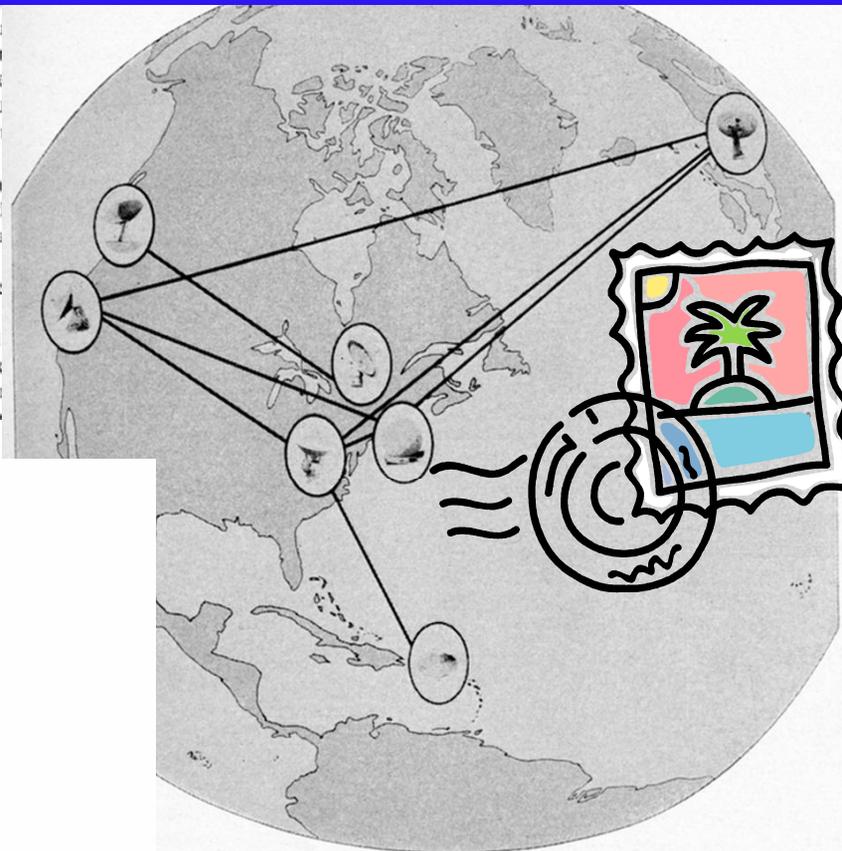
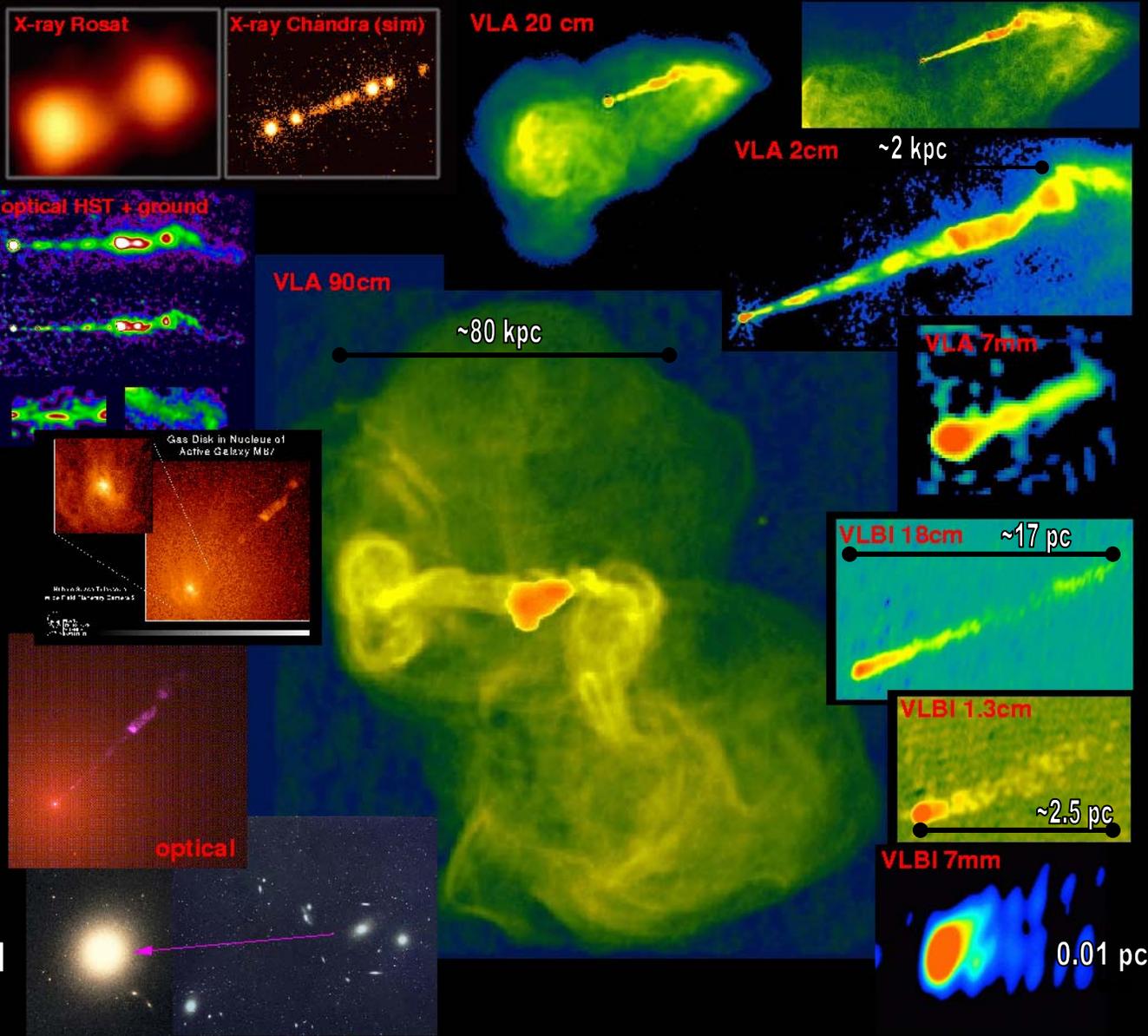


FIG. 1.—Positions for the compact radio component in 3C 274. The position for the nucleus of M87 is due to Griffin (1963): R.A.  $12^{\text{h}}28^{\text{m}}17^{\text{s}}.57$ , decl.  $+12^{\circ}40'01''.6$  (1950).



... showing the various baseline configurations used in the long-baseline observations. Details of the individual base lines are given in Table 1. Short base lines between the National Radio Astronomy Observatory (Green Bank) and the Maryland Point Observatory and between the Algonquin Radio Observatory (Ontario) and the Defense Research Telecommunications Establishment (Ottawa) are not shown.

# M87 (Virgo A) - From half a million light years to 0.1 light years



# Heute: Höchste Auflösung mit mm-VLBI Beobachtungen



## Die Teleskope:

100m Effelsberg, Deutschland

6x15m Plateau de Bure, Frankreich

30 m Pico Veleta, Spanien

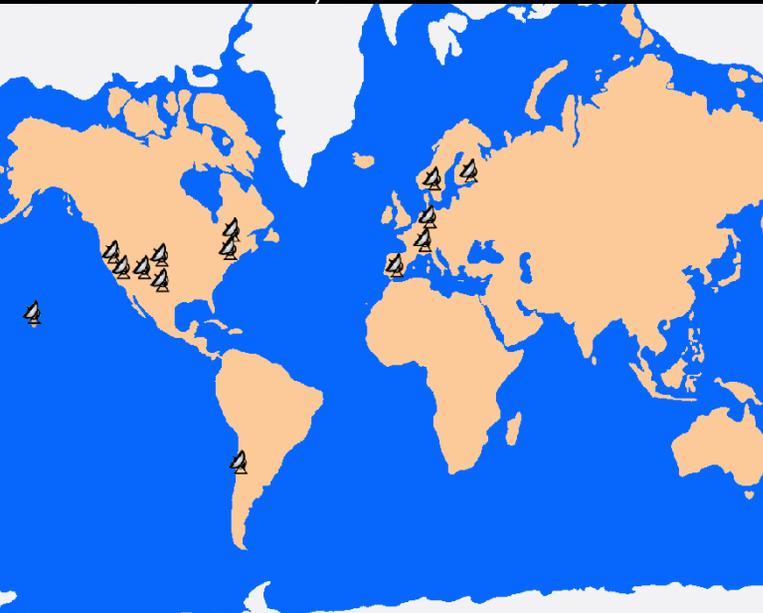
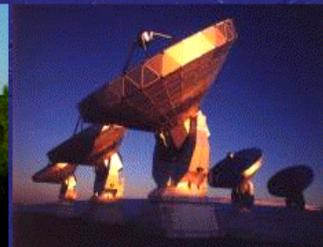
20 m Onsala, Schweden

15 m Metsähovi, Finland

8 x 25 m VLBA, USA

45 Mikro-Bogensekunden Auflösung bei 86 GHz

## The Global mm-VLBI Array

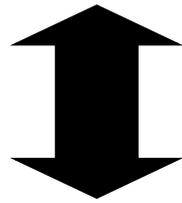


For comments which help to improve this page, please contact [J. Klare](#) or [T.P. Krichbaum](#)

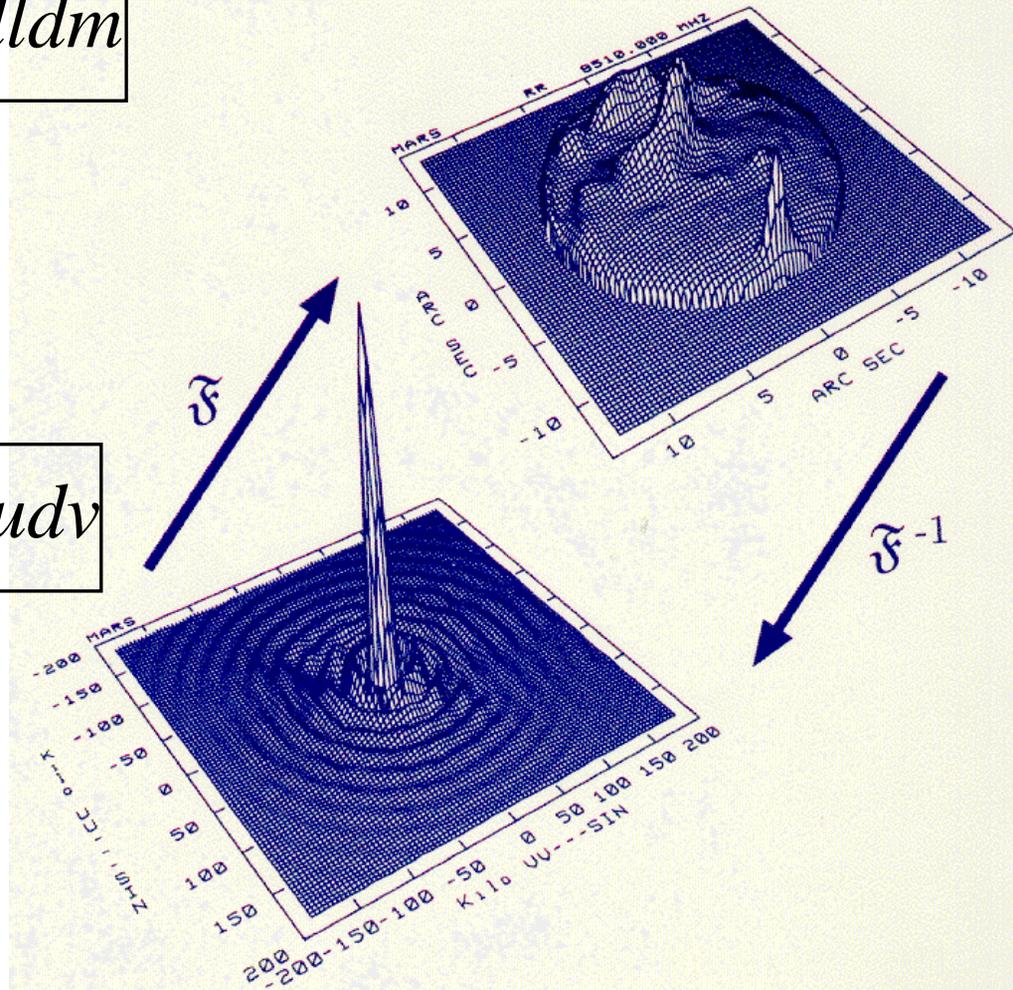
# Inversion der Kohärenz Funktion



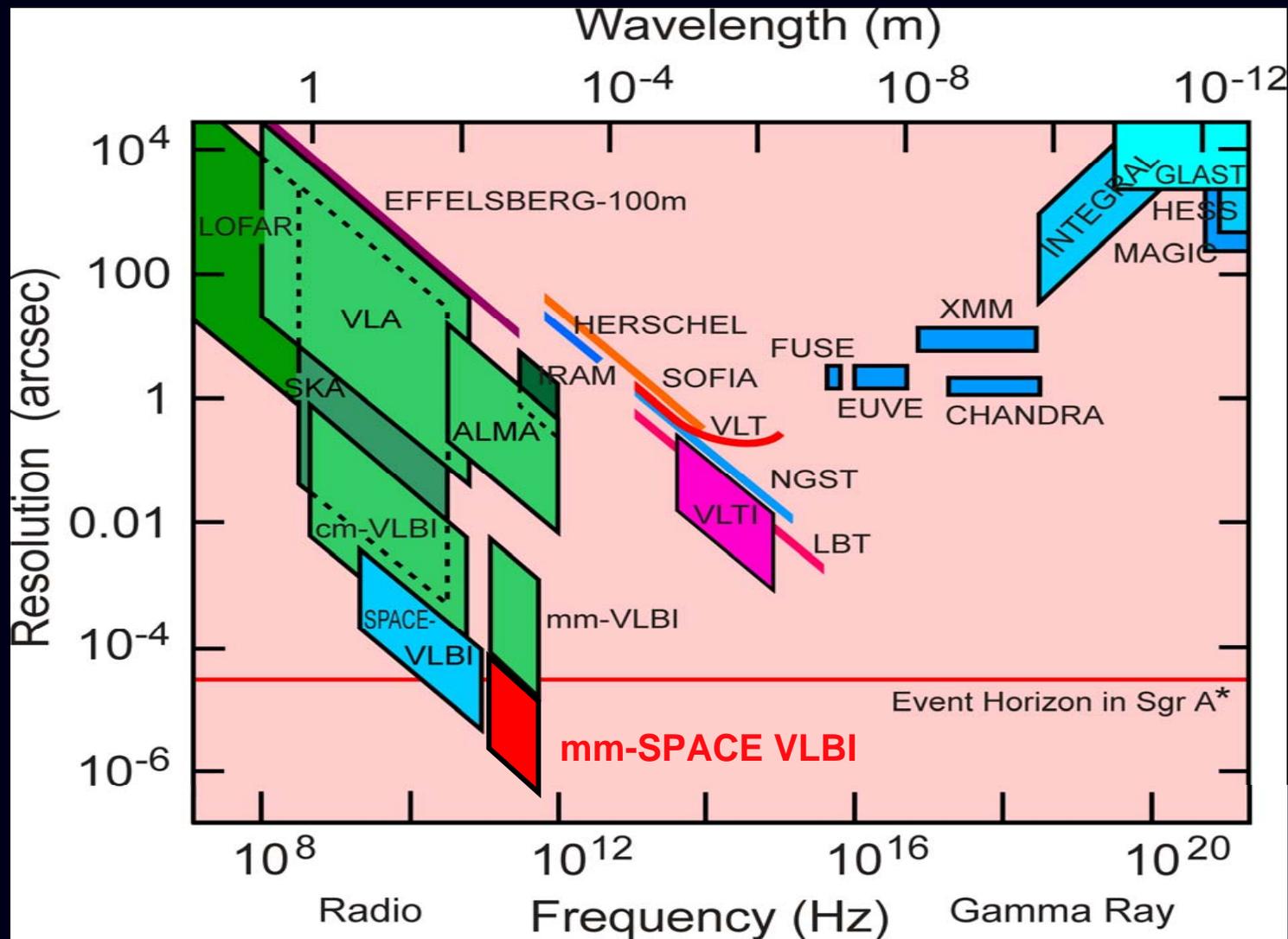
$$V_v(u, v) = \iint I_v(l, m) e^{-2\pi i(ul+vm)} dl dm$$



$$I_v(l, m) = \iint V_v(u, v) e^{2\pi i(ul+vm)} du dv$$



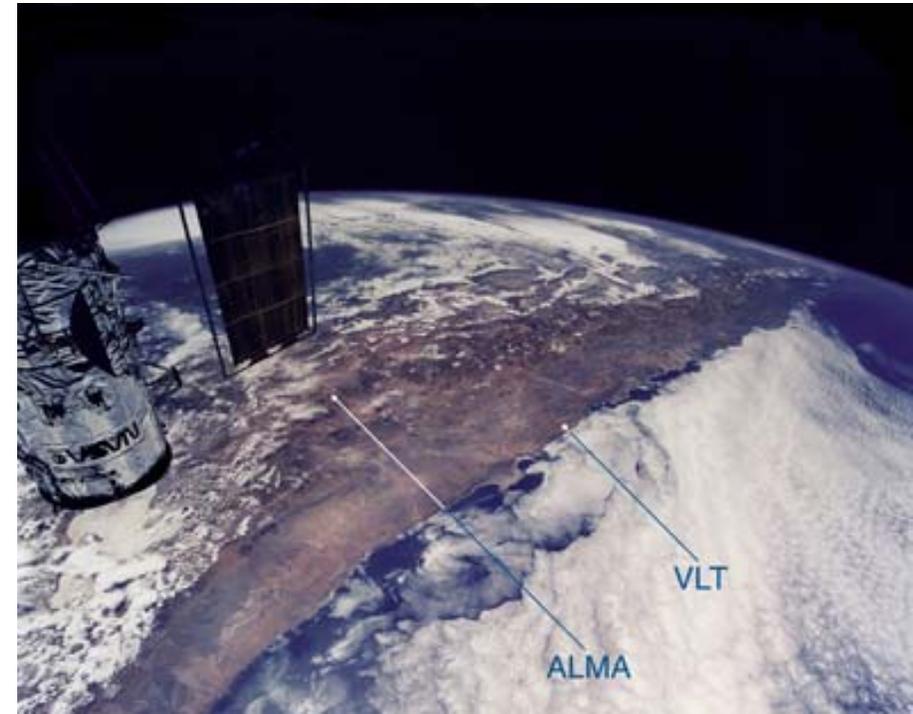
# Höchste Auflösung mit mm-VLBI Beobachtungen



# Neue Generation von Hochfrequenz-Radioteleskopen



- The **Atacama Large Millimeter Array (ALMA)** is an international collaboration between Europe and the North America to build a synthesis radio telescope that will operate at millimeter and submillimeter wavelengths. Japan may also become a partner, making this a truly global collaboration.



# Neue Generation von Niederfrequenz-Radioteleskopen



**LOFAR**

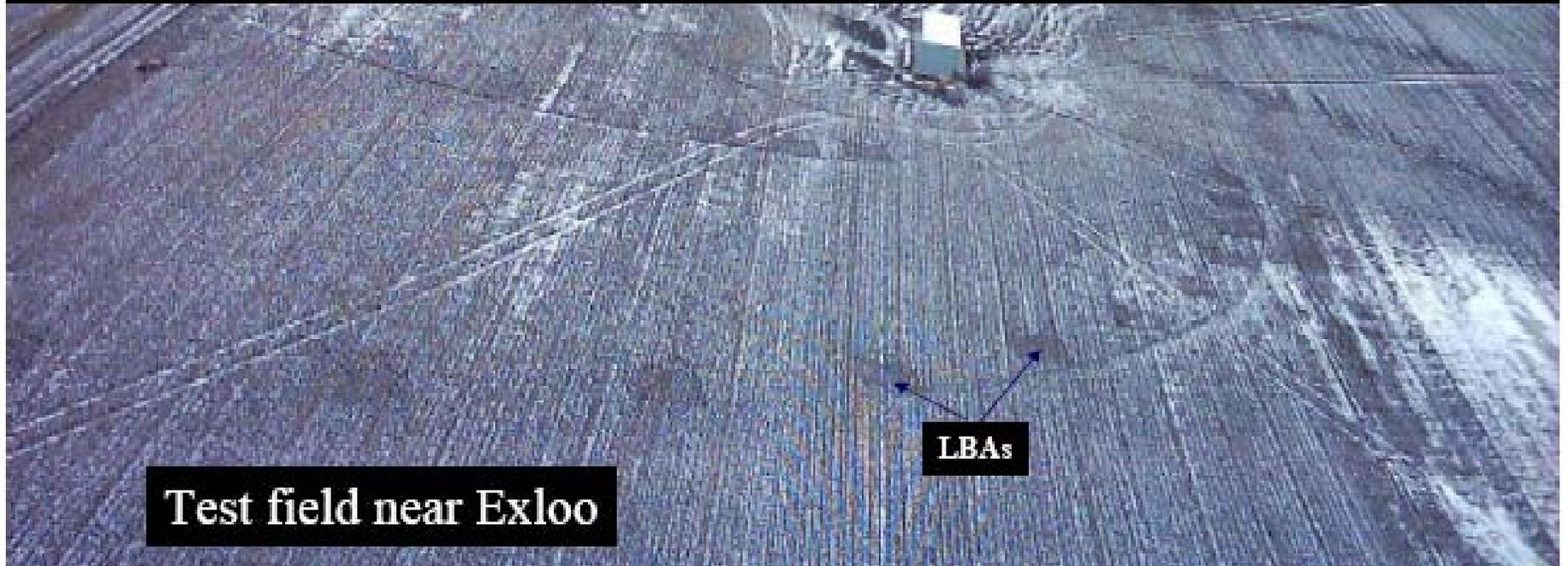
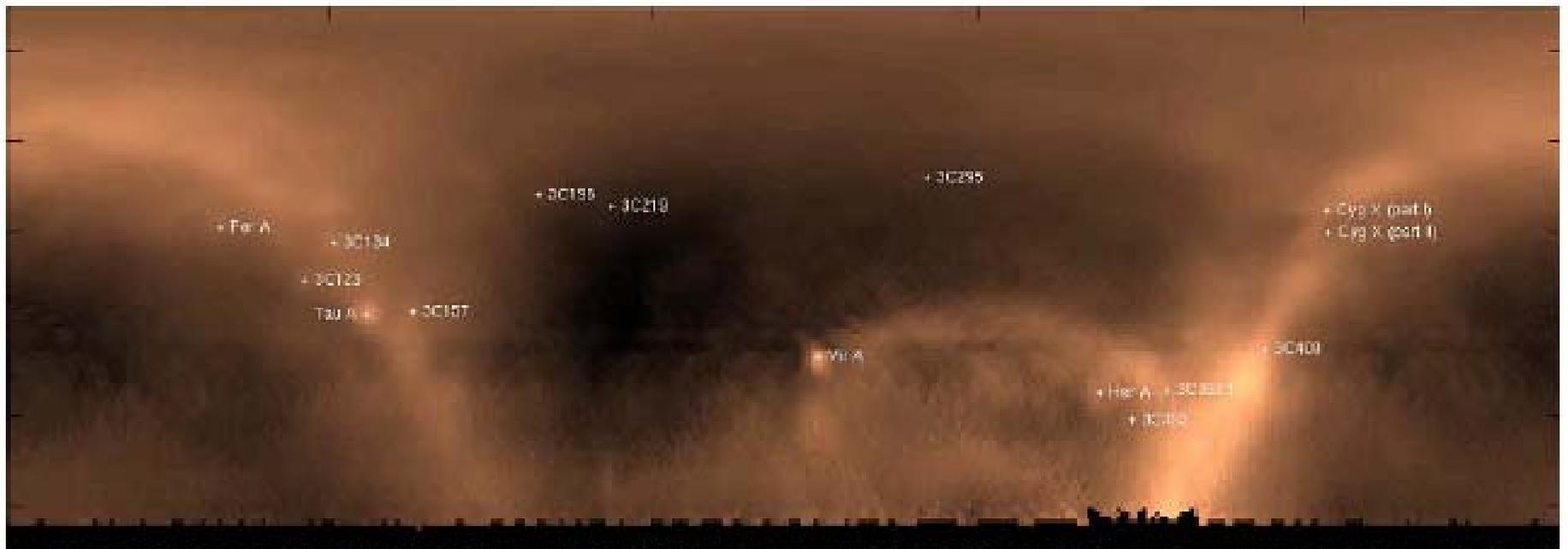


**Prototype Low Band antennas**



**Prototype High Band antennas**





Test field near Exloo

# LOFAR: nicht-astronomische Anwendung



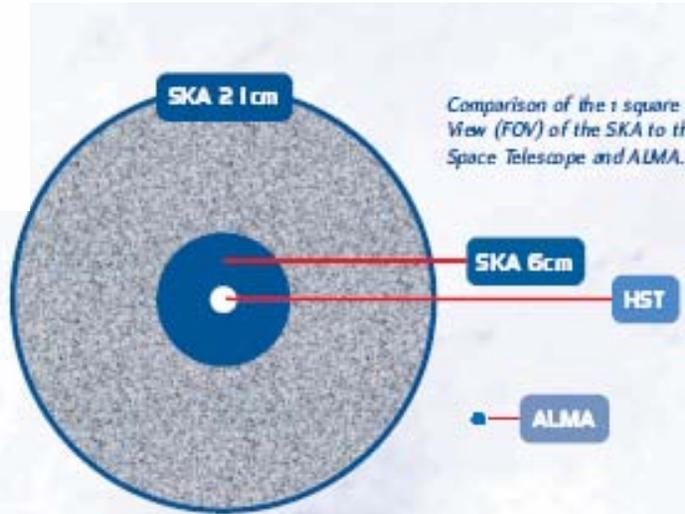
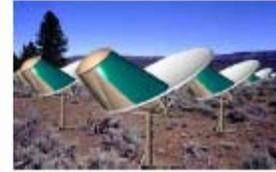
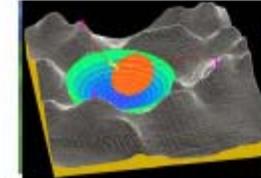
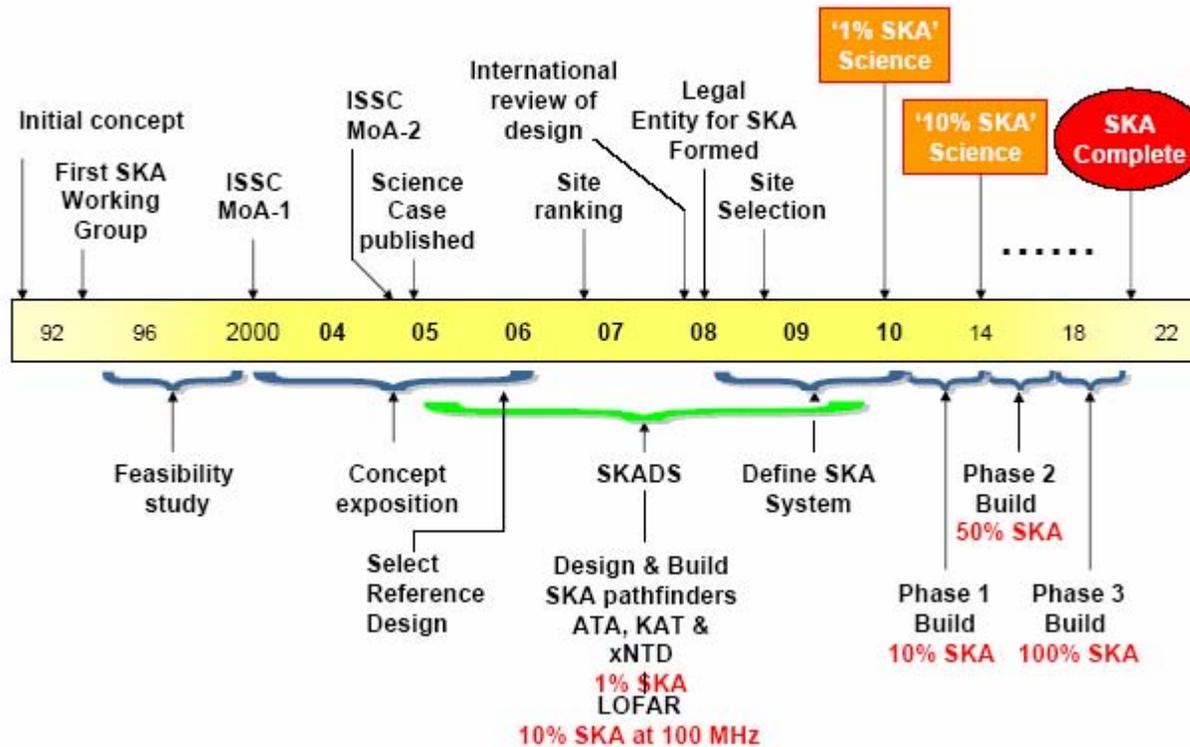
## Non-astronomical research



# Neue Generation von Niederfrequenz-Radioteleskopen: SKA



## SKA timeline



# Radioteleskope - Katastrophen



about patent rights if other groups learned of the results and reproduced them.

On approximately 21 March, the University of Utah decided to announce the fusion results in a press conference 2 days later. The university administration "agonized" over the decision, Brophy said, but they could wait no longer. "We decided to stop at the point where they could demonstrate fusion without explaining it," Brophy said.

Jones was not informed of the decision, although he spoke with Pons over the telephone 2 days before the planned news conference. When Jones heard Pons say at the press conference that his team had already submitted a paper to a journal, he decided that Pons had broken their agreement, and he submitted his paper to *Nature*.

At the University of Utah, the fact that Jones contacted Pons after seeing his grant application has generated widespread rumors and innuendos that Jones was attempting to steal some of the credit for Pons and Fleischmann's work. In addition to the uneasy relationship between the two schools, some of those suspicions may have come from Pons himself, who has hinted, a couple of observers said, that Jones had stolen ideas from his grant application.

But nonpartisan observers who are familiar with the situation say Jones almost certainly came up with the ideas for his work independently of and prior to seeing the University of Utah grant proposal. For his own part, Jones said he can prove the work in his paper came completely out of his own lab. "Our log books prove we have been studying this since 1986." In fact, Jones said, he had a page from his notebook dated 7 April 1986 notarized. That notarized page contains an outline of experiments his team planned to run, including explicit reference to looking for cold fusion in palladium electrodes, he said. A drawing done in May 1986 of a fusion cell looks very similar to what Pons and Fleischmann eventually used, he said, although that is not too surprising because "there are only so many ways [to design it] once you get the idea of doing electrolysis." None of his team's work was done because he saw Pons and Fleischmann's grant application. "I've stuck to my reviewer's agreement," he said. "We had our program outline and we've followed it."

Meanwhile, Utah governor Norm Bangerter has announced he will call a special session of the state legislature to provide \$5 million for a fusion center at the University of Utah, and former NASA head James Fletcher has accepted the position of director. If the discovery pans out, said Bockris of Texas A&M, "the University of Utah will be the richest university in the country in 5 years." ■ ROBERT POOL

## Telescope Collapse Unraveled

The fracture of a single highly stressed steel plate has been identified as the most likely cause of the spectacular collapse of the 300-foot radio telescope at the National Radio Astronomy Observatory at Green Bank, West Virginia, last November. An independent panel appointed by the National Science Foundation, which funds the facility, and Associated Universities, Inc., which manages it, reached that conclusion after examining the suspect plate and performing a computerized stress analysis.

The panel found that parts of the telescope were under far higher stresses than would be permitted today, and that "from the beginning of its life, the structure was marginal with respect to structural failures of a minor or perhaps major nature." The plate that failed was a critical connection in the support structure of the instrument and it was subjected to high stresses when the telescope was moving. Half of the plate was recovered from the wreckage and a metallurgical analysis indicated that small cracks had been developing in it before it suddenly failed. The telescope was being swiveled when it collapsed around 10 p.m. on 15 November.

The panel absolves the managers of the facility from blame. It says there is no indication that the telescope was inadequately maintained—the plate itself was hidden from view and could not have been examined without disassembling the telescope—nor was it being operated inappropriately. The panel also notes that computerized stress analysis would identify potential failure points in telescopes built today, but these methods were not available when the instrument was built in 1962.

Now that the apparent cause of the collapse has been identified, attention is likely to focus on NSF's plans for replacing the instrument. In testimony before the House Appropriations Committee last month, NSF director Erich Bloch said that the foundation's top priority for its next major astronomy facility is an observatory to search for gravity waves. Known as the Laser Interferometer Gravity Wave Observatory, or LIGO, it would consist of a pair of facilities situated near the East and West coasts. LIGO has been in the planning and R&D stage for several years, and NSF was hoping to include funds in its 1991 budget to begin construction. The total cost would be about \$100 million.

West Virginia Senators Robert Byrd (D) and Jay Rockefeller (D) have other ideas, however. In a statement released last month, they said that replacing the collapsed telescope with a modern instrument should have higher priority than LIGO. A replacement telescope, which would cost about \$75 million, would be "the best promise for jobs, education, tourism, and scientific prestige," for their state, they said.

Byrd, who is chairman of the Senate Appropriations Committee, said he "will aggressively pursue funding" for the telescope. Rockefeller is on the Senate Commerce committee, which oversees NSF.

■ COLIN NORMAN



**Before and after.** The cause of the collapse has been determined, but whether the instrument will be replaced may become a political question.



Photograph of the 300 Foot radio telescope taken on November 16, 1988. The telescope collapsed at 9:43 PM on November 15, 1988.



# 26.05. Der Radiohimmel im Licht der 21cm-Linie



Übersicht

- Die 21cm-Linie
- Die Quellen
- Kinematik der Galaxien, Rotationskurven, Dunkle Materie
- Dunkle Galaxien
- Wechselwirkende Galaxien
- Perspektiven: die Reionisation und die 21cm-Linie

# 26.05. Der Radiohimmel im Licht der 21cm-Linie



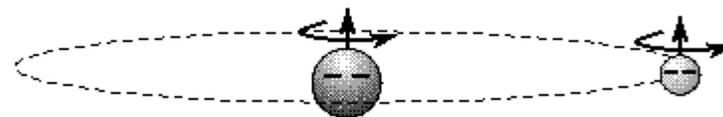
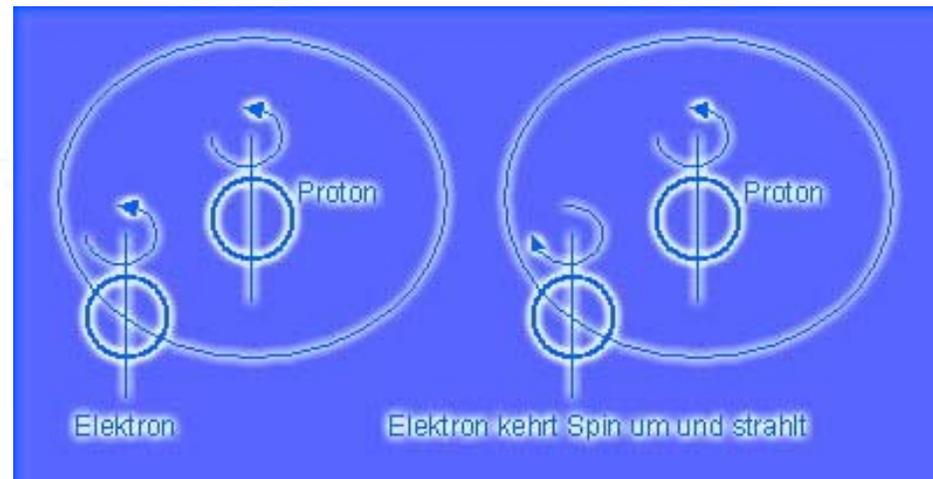
## Neutraler Wasserstoff

beobachtbar durch Resonanz-Linie (Lyman-Serie) im UV  
911-1215Å

oder im Radiobereich (21cm) als Hyperfeinstruktur-Übergang  
des Grundzustands:

Übergangswahrscheinlichkeit  
 $2.87 \cdot 10^{-15} \text{ s}^{-1}$

→ Lebensdauer 11 Mio. Jahre  
nur beobachtbar, weil konkurrierende  
Stoßabregung durch die geringe  
Dichte weit genug unterdrückt ist  
unter irdischen Hoch-Vakuum  
Bedingungen nicht beobachtbar



# 26.05. Der Radiohimmel im Licht der 21cm-Linie



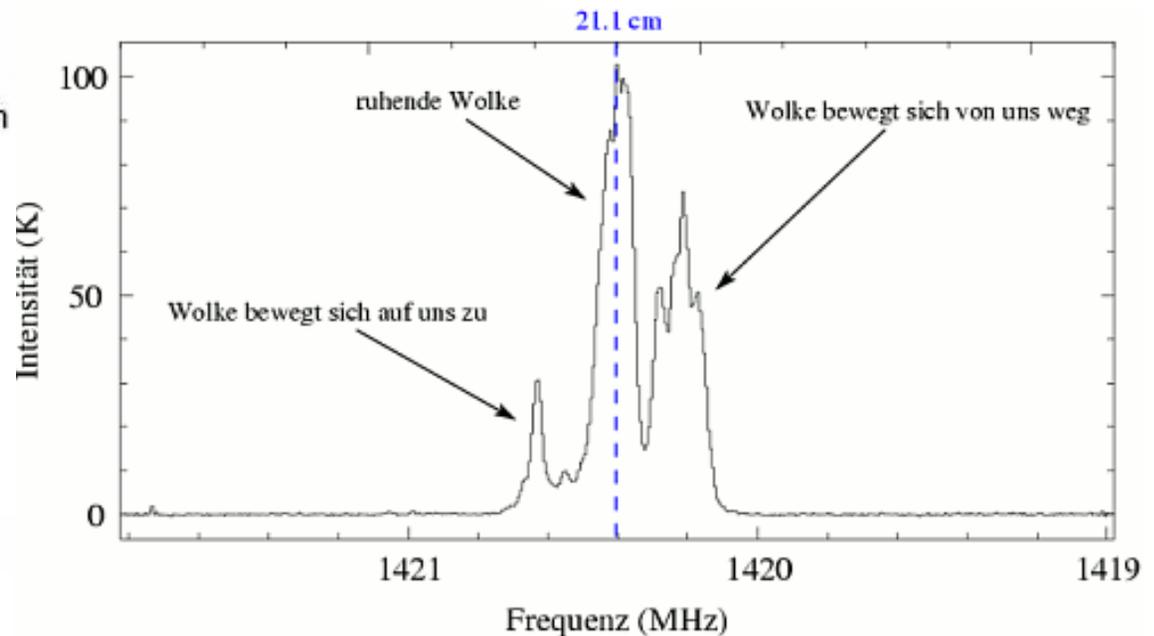
## 21 cm Linie

21 cm Linie (1420.4MHz) des neutralen Wasserstoffs wichtig für Bestimmung von:

- Geschwindigkeiten
- Temperaturen  $T=30 \dots 80 \text{ k}$
- Teilchendichten  $n=100 \dots 800 \text{ cm}^{-3}$
- Magnetfelder
- Struktur und Kinematik von Galaxien

Meist optisch dünn

- Emission
- Große Reichweite



# 26.05. Der Radíohimmel im Licht der 21cm-Línie



Image courtesy of NRAO/AUI and Tom Oosterloo, Astron, The Netherlands

- NGC 2403 Spiralgalaxie, rechts sichtbares Licht von Sternen, links Wasserstoff-Scheibe, Größe des Vollmonds
- Gasscheibe weitaus größer als optische Galaxie
- Löcher durch Supernovaexplosionen

# HI-Halo der Milchstraße

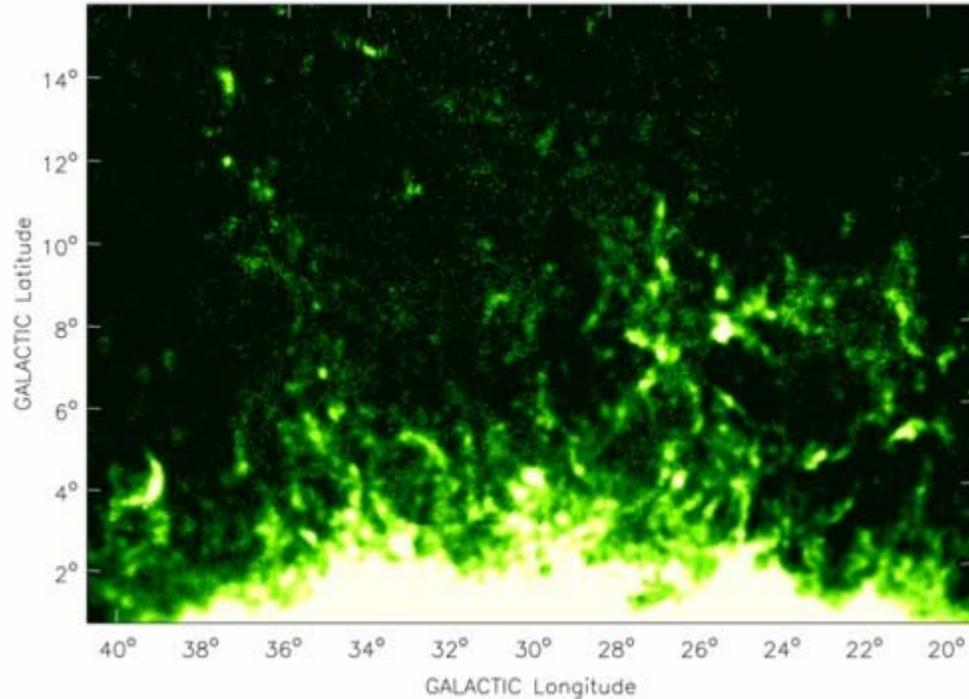
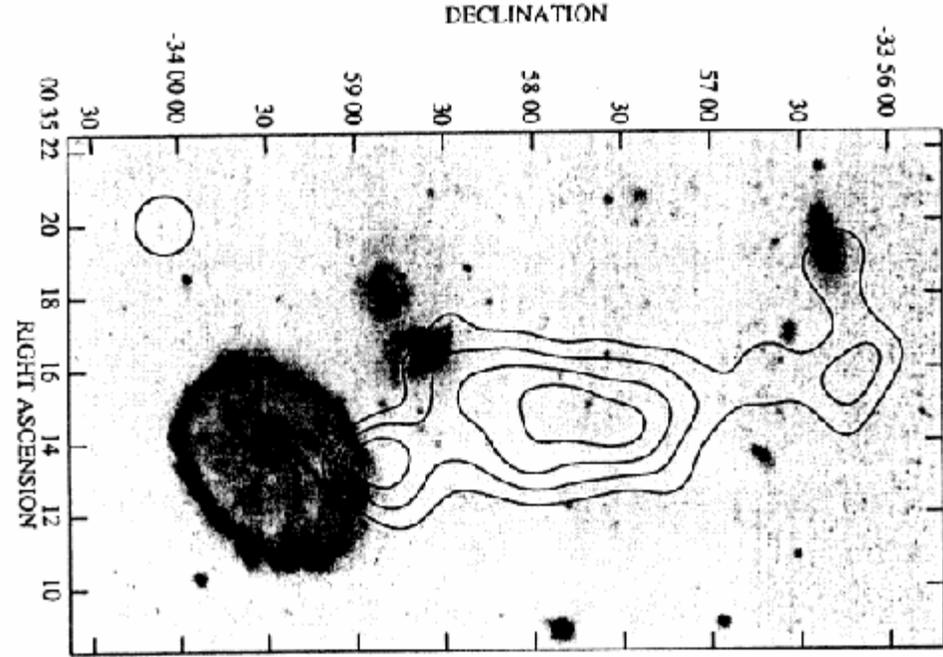
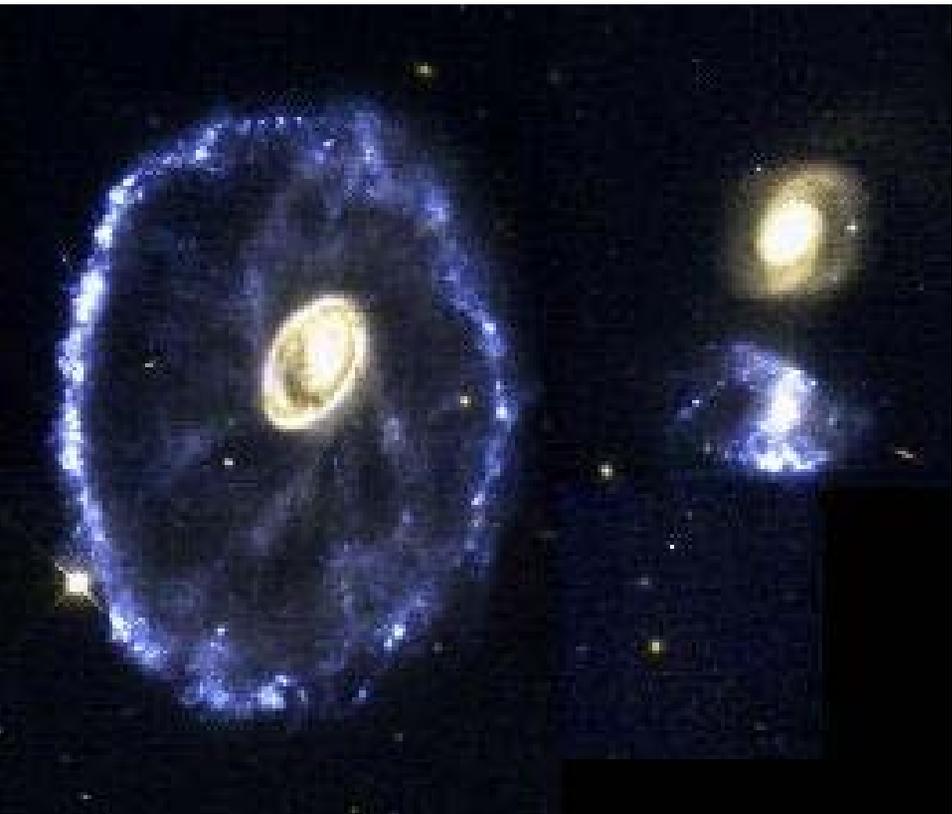
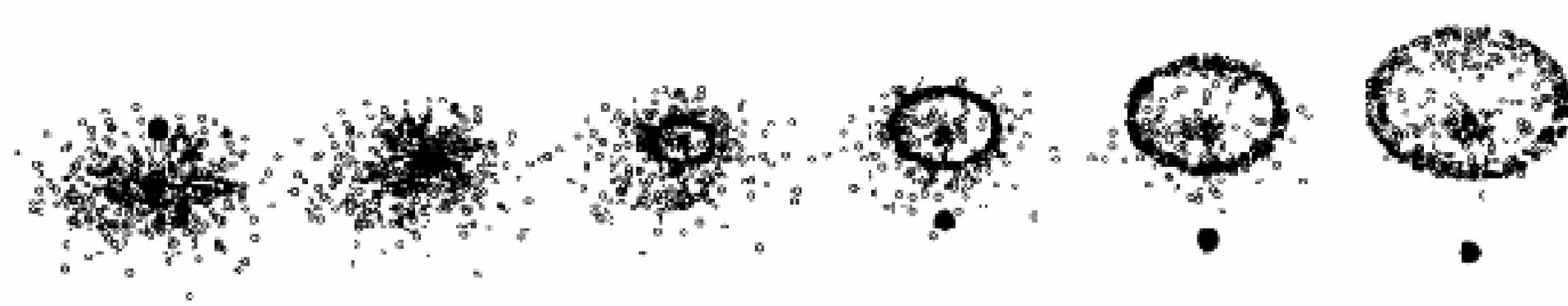


Image courtesy of NRAO/AUI and Yurii Pidopryhora,  
NRAO & Ohio University

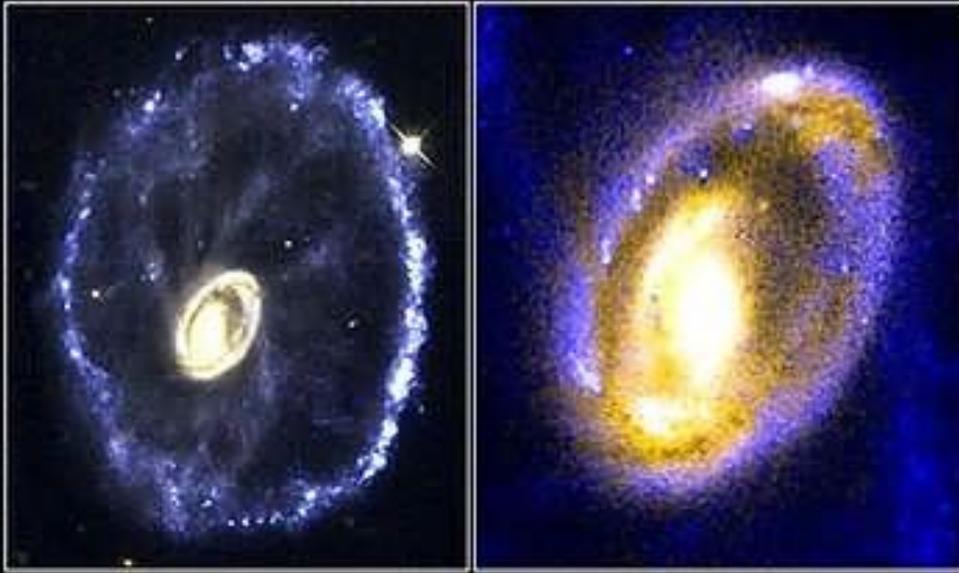
- Falschfarben-Bild, HI-Halo der Milchstraße, 7kpc von der Sonne, 4 kpc vom galaktischen Zentrum
- Wolken und Filamente, jede kleine Wolke: einige 10 pc und 10-100 Sonnenmassen
- Phänomen ungeklärt
- 100 m Green Bank Teleskop



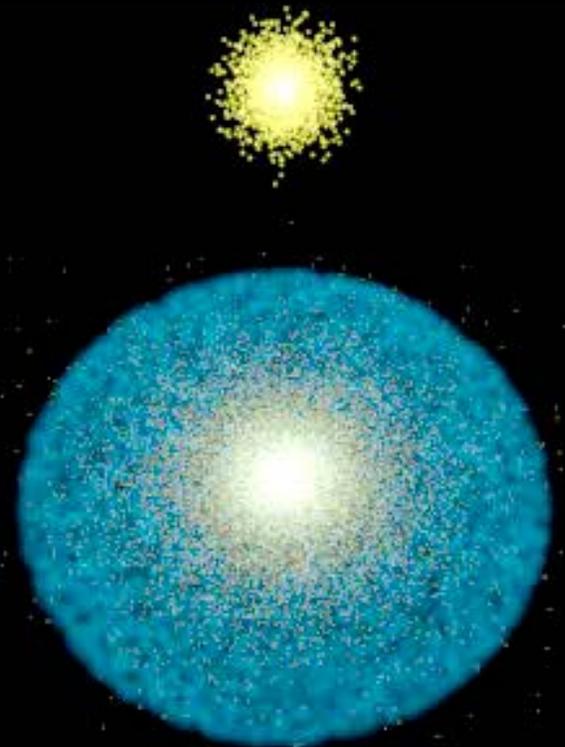
# Wagenrad-Galaxie



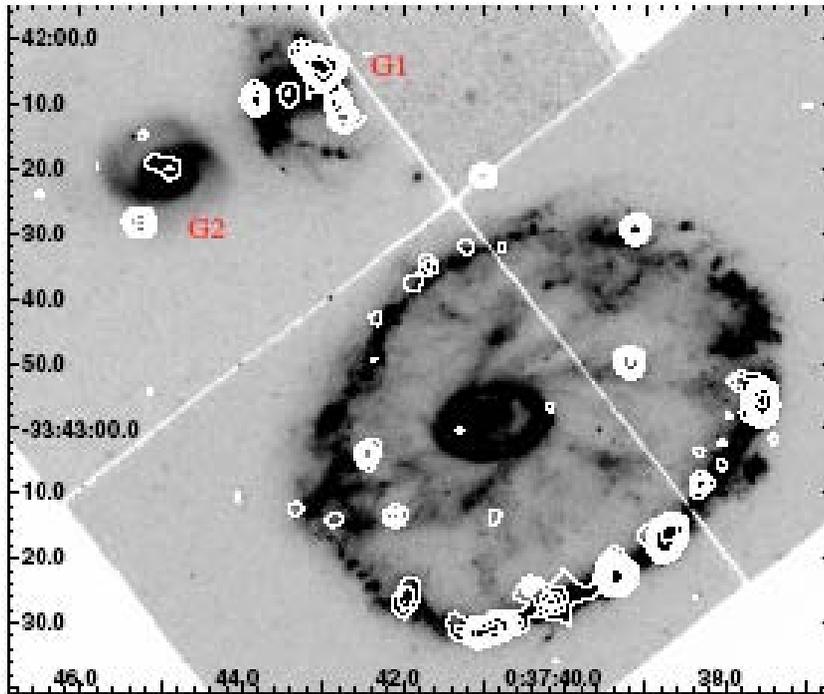
# WW: Wagenrad-Galaxie



- Expansionsrate des Rings: 60 km/s
- Alter: 300 Mio Jahre
- Erster Ring schwach und beobachteter Ring ist zweiter Ring
- Speichen sind natürliche Konsequenz der Instabilitäten im Gas hinter der expandierenden ringförmigen Dichtewelle



Die Geschichte geht weiter ...

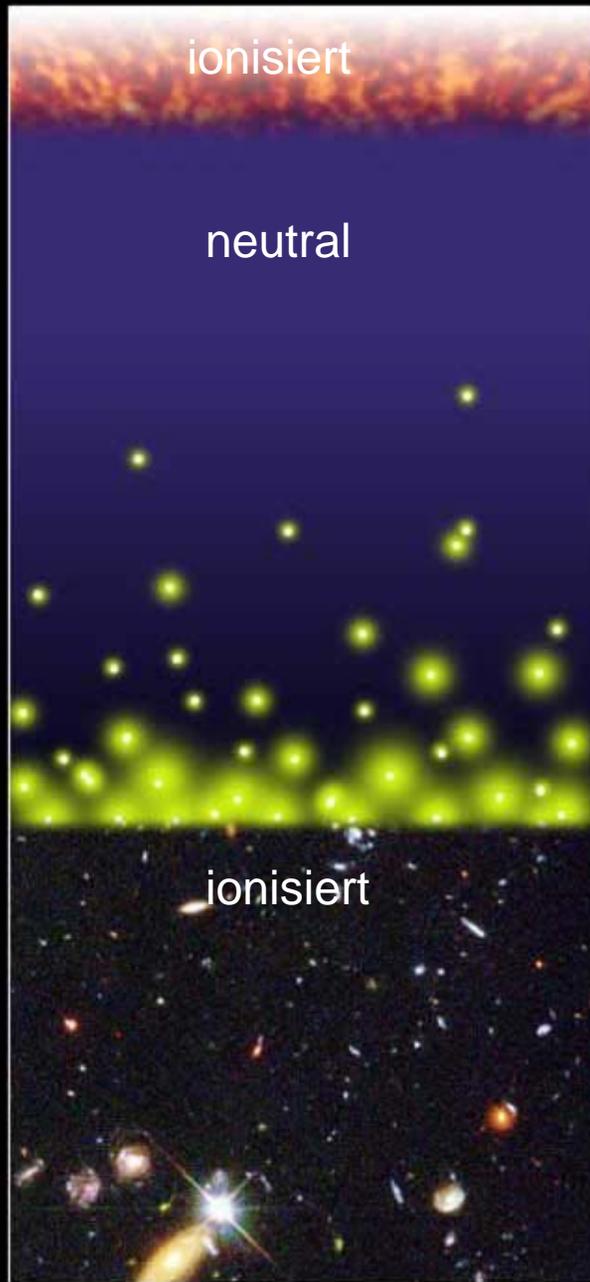


- Leuchtkräfte zu groß
- Schwarzes Loch im Zentrum ?

Fig.2. The X-ray contours in the 0.3–7 keV Chandra image over-plotted on the optical image in the *F450W* filter from the HST archives. X-ray contours are:  $7.9 \times 10^{-06}$ ,  $1.6 \times 10^{-05}$ ,  $2.4 \times 10^{-06}$ ,  $3.2 \times 10^{-06}$ ,  $5.3 \times 10^{-05}$ ,  $1.1 \times 10^{-04}$ ,  $2.1 \times 10^{-04}$ ,  $4.2 \times 10^{-04}$  cnts/s/arcsec<sup>2</sup>.

# A Schematic Outline of the Cosmic History

Time since the Big Bang (years)



~ 300 thousand

ionisiert

neutral

~ 500 million

~ 1 billion

ionisiert

~ 9 billion

~ 13 billion

← The Big Bang

The Universe filled with ionized gas

← The Universe becomes neutral and opaque

The Dark Ages start

Galaxies and Quasars begin to form  
The Reionization starts

## Epoche der Reionisation

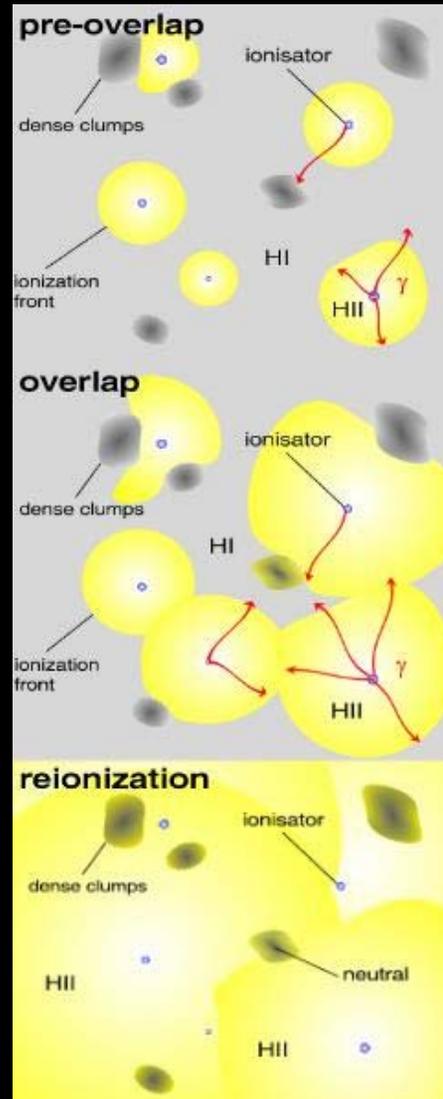
The Cosmic Renaissance  
The Dark Ages end

← Reionization complete, the Universe becomes transparent again

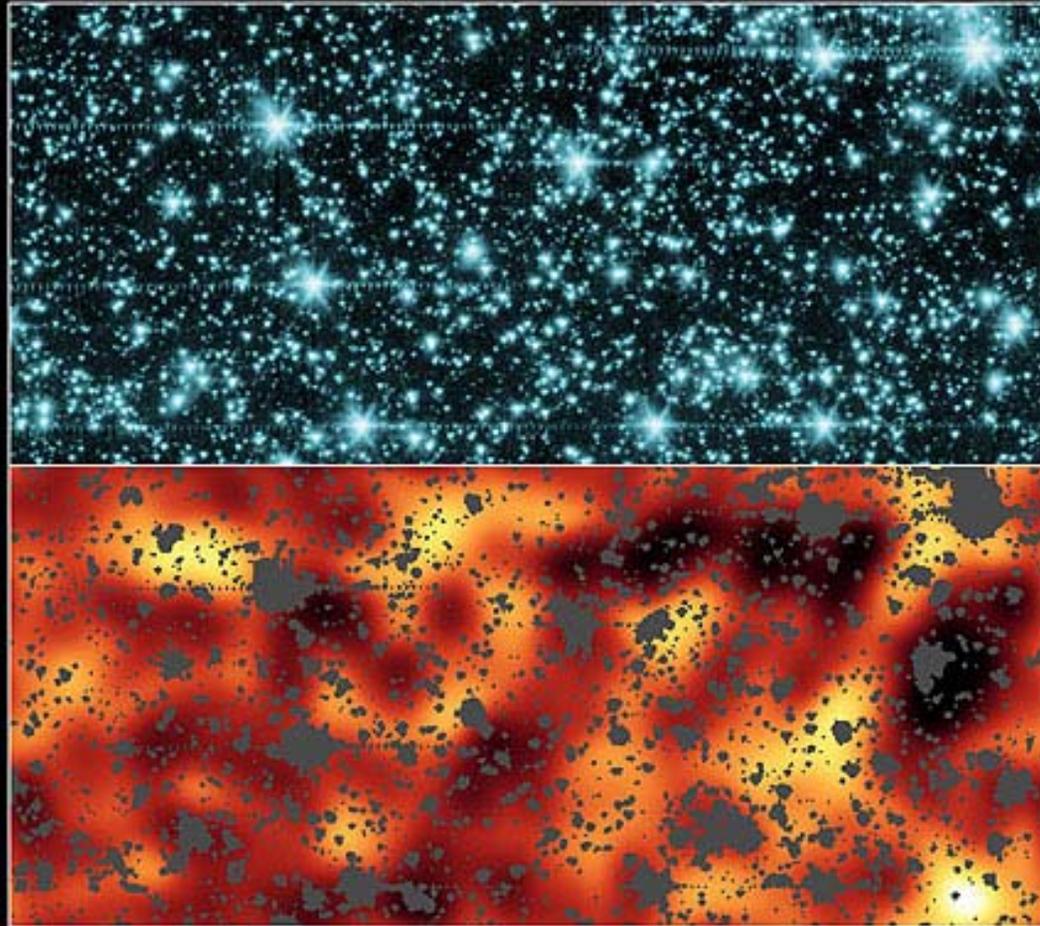
Galaxies evolve

The Solar System forms

Today: Astronomers figure it all out!



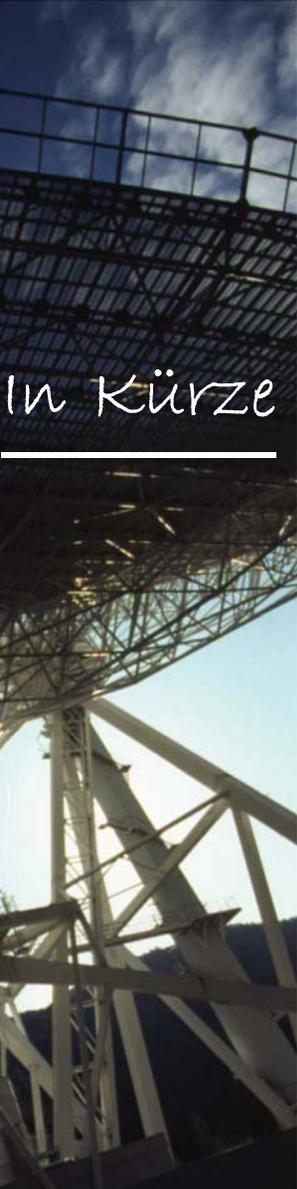
# 26.05. Der Radiohimmel im Licht der 21cm-Linie



Infrared Background Light from First Stars Spitzer Space Telescope • IRAC  
NASA / JPL-Caltech / A. Kashlinsky (GSFC) ssc2005-22a

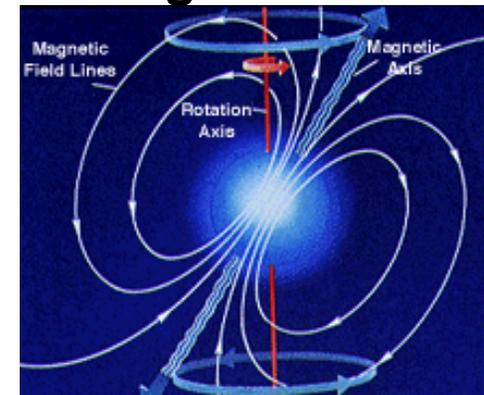
- Spitzer Space Telescope
- Sterne und Galaxien , 50 -100 Mio Lichtjahre (6-12 Bogenminuten)
- Infrarot, 3.6 microns
- Unteres Bild: Sterne, Galaxien und Artefakte aus dem Bild genommen, Hintergrund verstärkt: Glühen der ersten Sterne?

# 09.06. Pulsar-Astronomie (heute & in Zukunft)



In Kürze

- **Geschichte der Pulsare**
  - Jocelyn Bell und Dr. Antony Hewish und der „Little Green Man 1“ (Hewish Nobelpreis 1974)
  - Hulse und Taylor: binärer Pulsar und Gravitationswellen (Nobelpreis 1993)
- **Vom Stern zum Pulsar**
  - Neutronenstern mit 1.5-1.8 Sonnenmassen, Durchmesser ca. 15 km
  - Schnellster Pulsar: 716 Rotationen/s
  - Aufbau eines Pulsars, Entstehung der gepulsten Strahlung, Magnetfelder, Multiband-Strahlung
- **Röntgen Pulsare**
- **Binärer Pulsar**
- **Pulsare & Gravitationswellen**



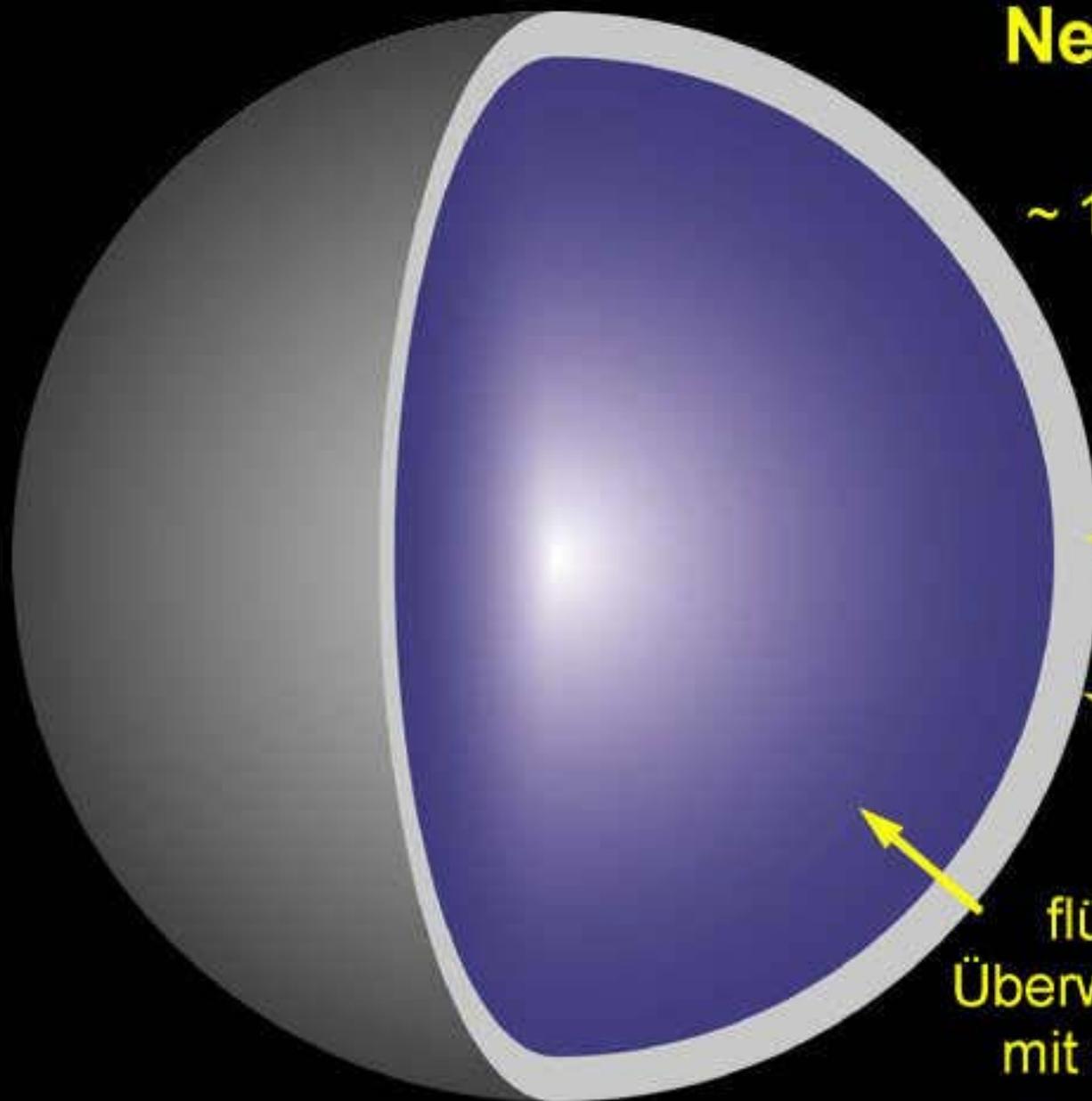
# Neutronenstern

Masse  
~ 1,5 Sonnenmassen

Innere Kruste  
~ 1 - 2 km Dicke

Durchmesser  
~ 20 km

flüssiges Inneres:  
Überwiegend Neutronen,  
mit anderen Teilchen

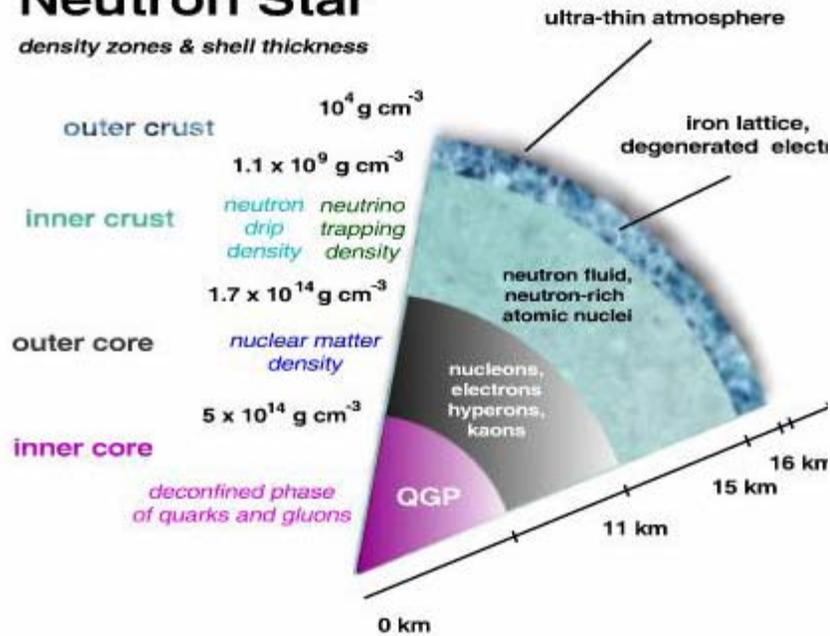


# 09.06. Pulsar-Astronomie (heute & in Zukunft)



## Neutron Star

density zones & shell thickness

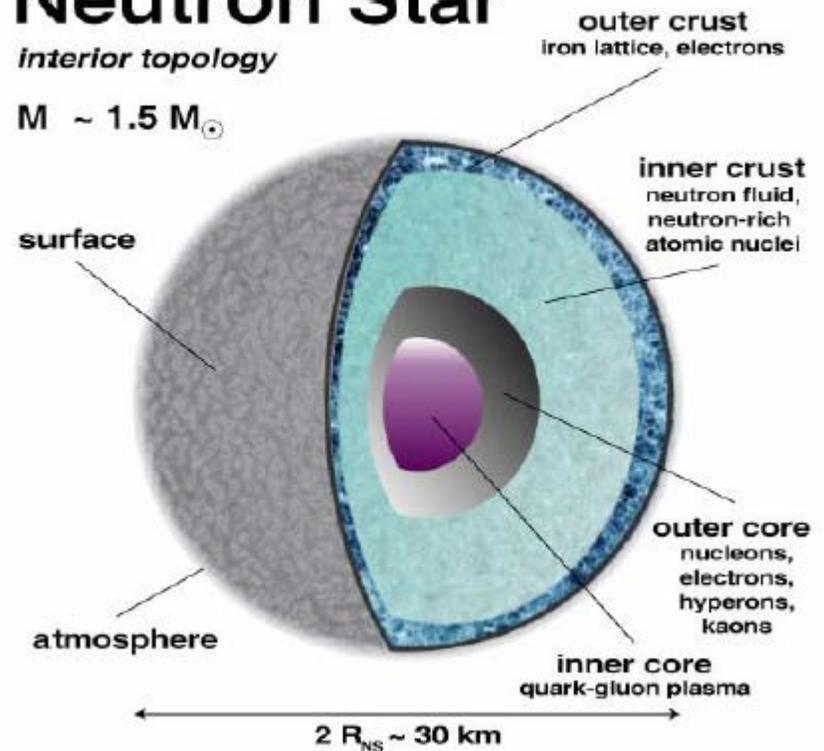


Festkörperphysik

## Neutron Star

interior topology

$M \sim 1.5 M_{\odot}$



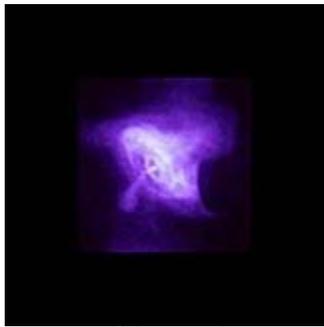
Kernphysik, Quantenchromodynamik, Teilchenphysik

# 09.06. Pulsar-Astronomie (heute & in Zukunft)

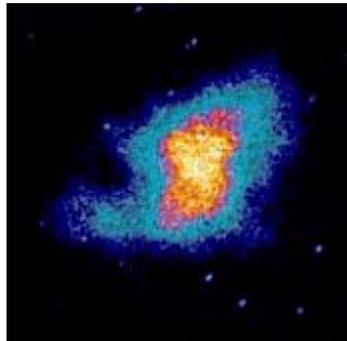


## • Krebsnebel

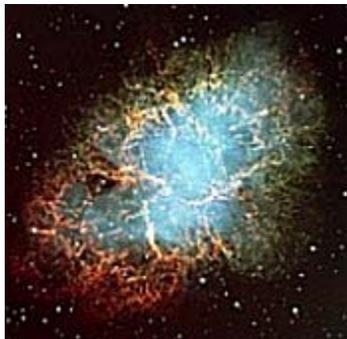
- Erster detektierter Pulsar (1967), Cambridge, 1054 AD
- 30 Rotationen/s
- Durchmesser: 10 km
- 1000 km/s



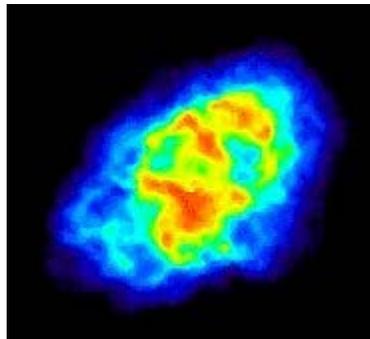
Chandra



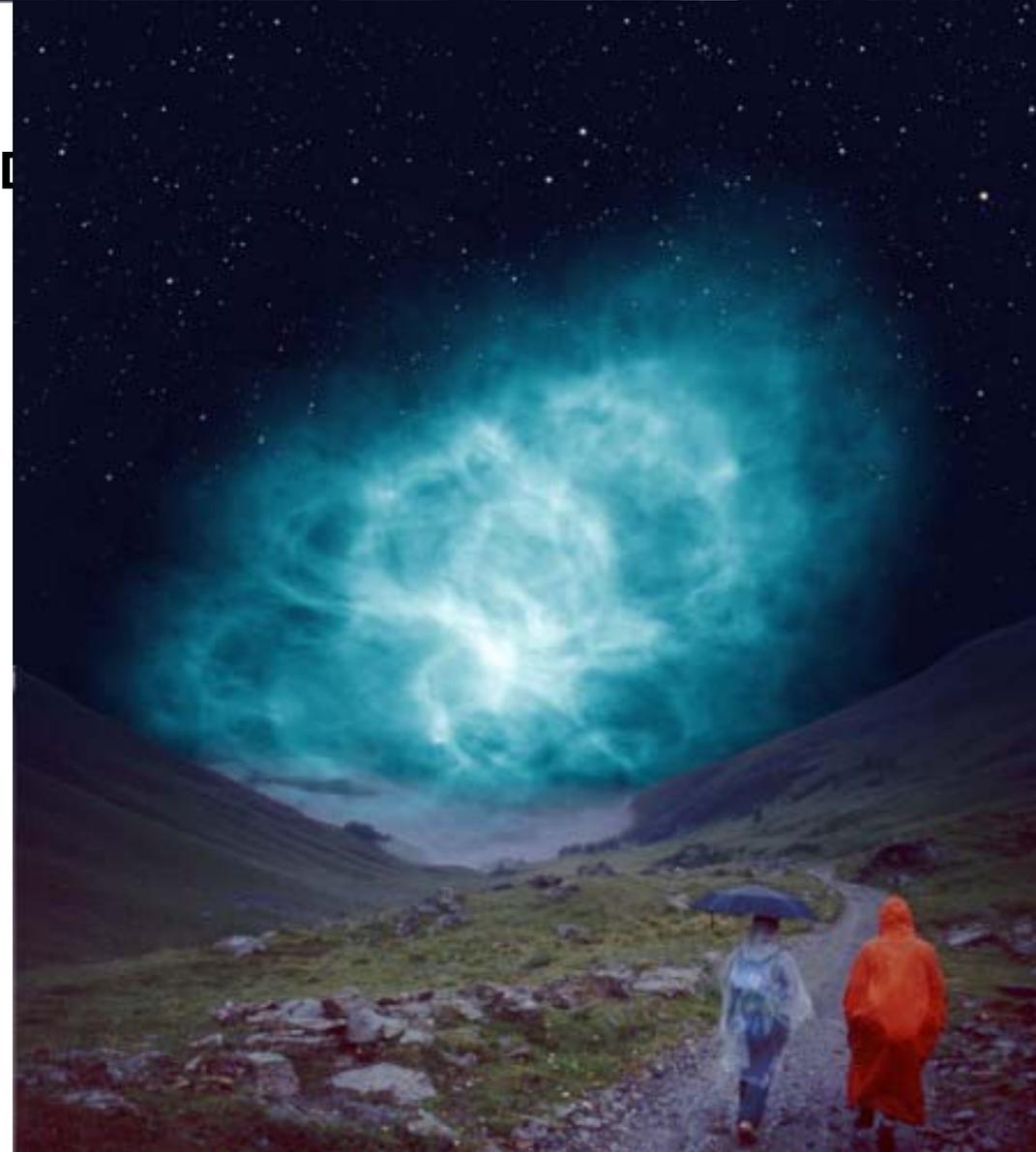
UV



optisch



Radio



# Pulsar im Krebs/Velanebel



**Krebs Pulsar**



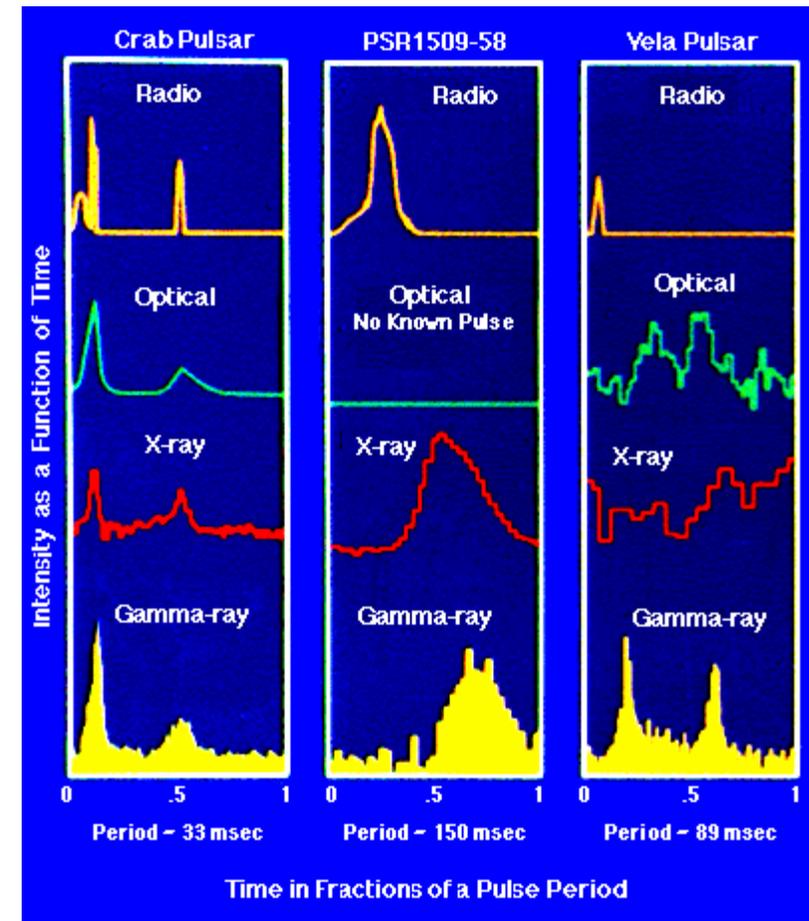
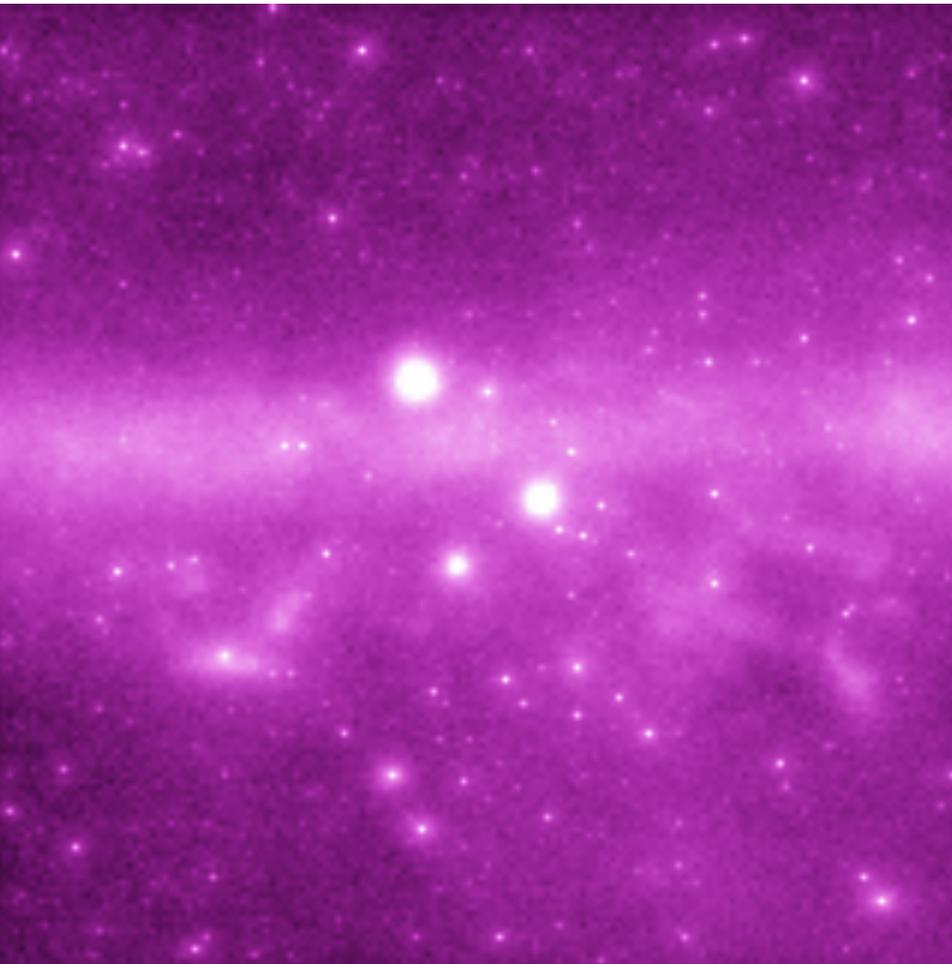
**Vela Pulsar**

# 09.06. Pulsar-Astronomie (heute & in Zukunft)



## Gamma-Pulsare

- Crab & Vela Pulsar,
- 1500 Radio Pulsare, 7 Gamma-Pulsare



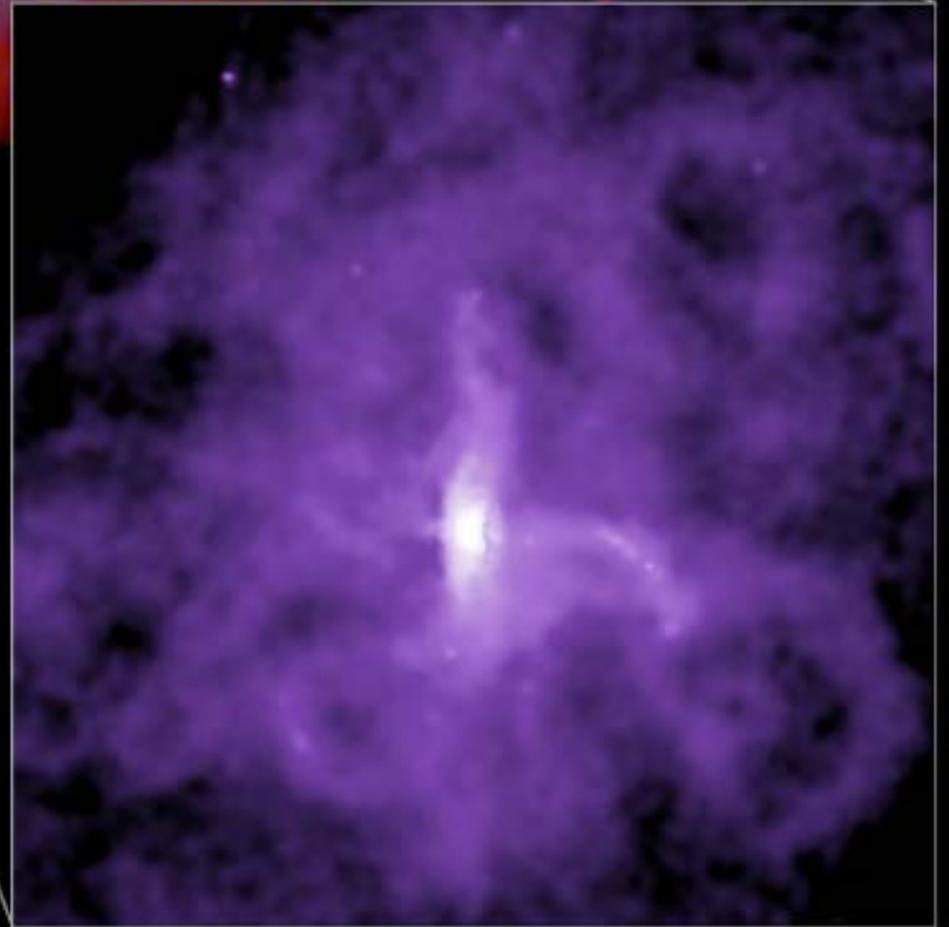
# 3C58: VLA

Überbleibsel einer Supernova beobachtet 1181 durch chinesische und japanische Astronomen



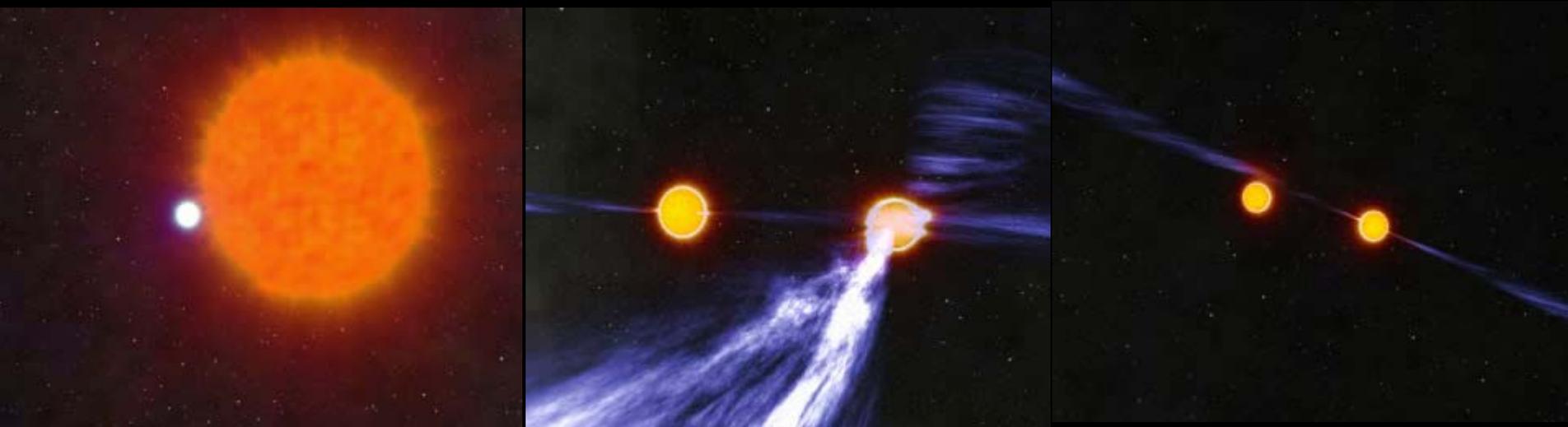
Image courtesy of NRAO/AUI and Michael Bietenholz, York University

3C58: CHANDRA



CLOSE-UP OF TORUS

# Doppel-Pulsare

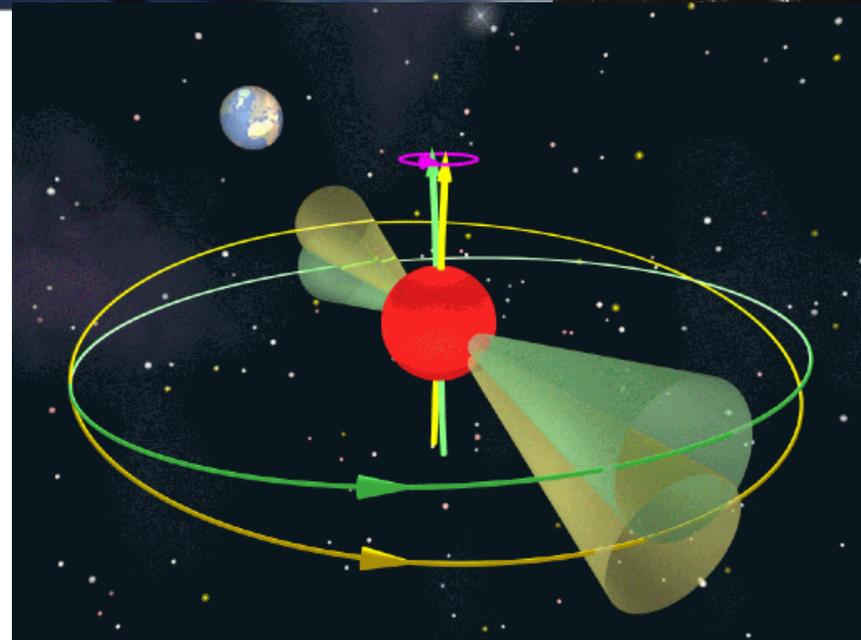
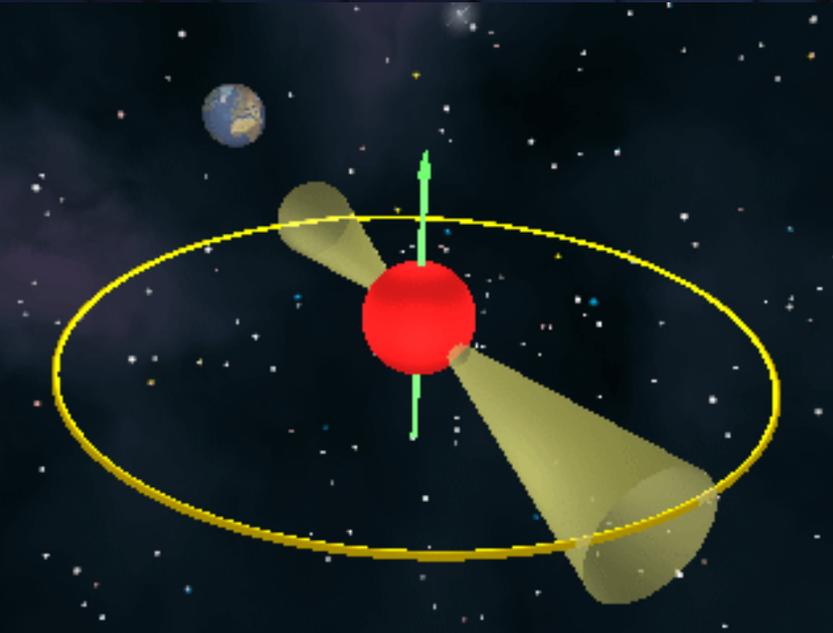


John Rowe Animation/Australia Telescope National Facility, CSIRO

J0737-3039

8. Januar 2004: erster Doppel Pulsar entdeckt

# Pulsare: Kreisel im Tummel



- Schwankungen im Röntgenspektrum, Änderung der Temperatur (um 100 000 Grad) auf der Oberfläche-> Präzession der Achse, nicht symmetrisches Magnetfeld
- „Schubs durch die Supernova“

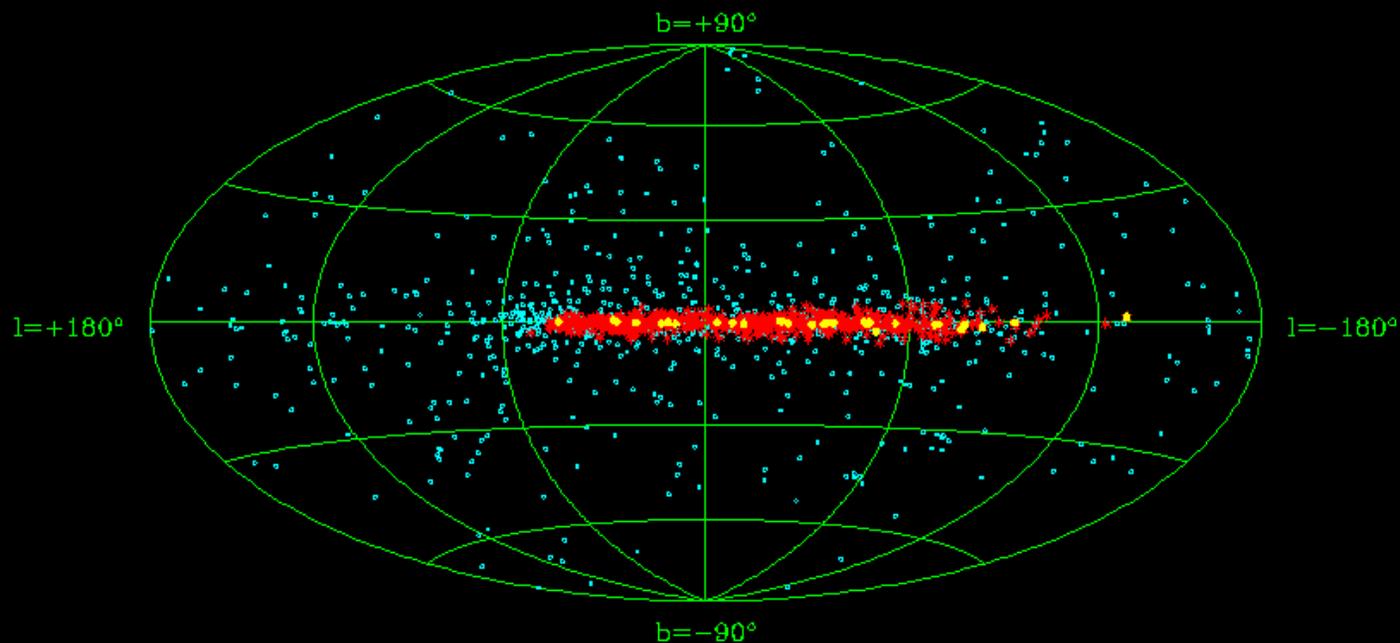
# Pulsar mit Schleudertrauma



Bill Saxton, NRAO/AUI/NSF

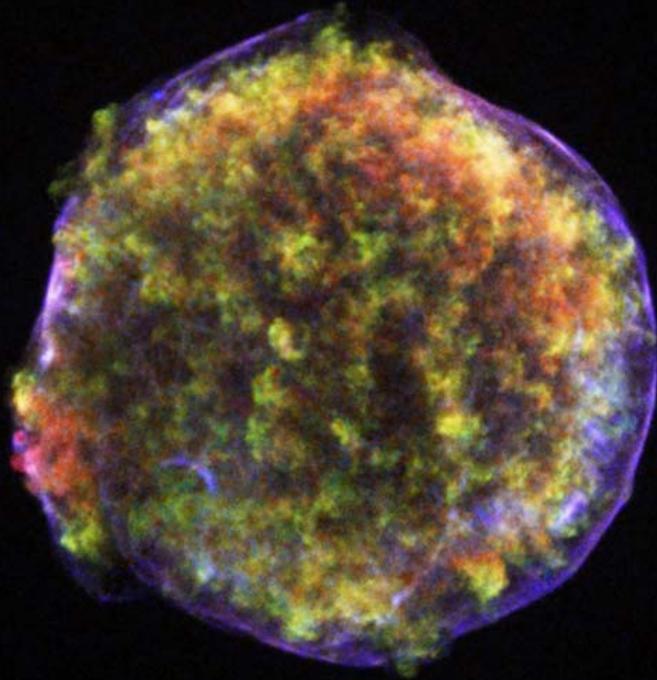
- In 2.5 Mio Jahren ist der Pulsar B1508+55 über ein Drittel des Nachthimmels gewandert -> 1100 km/s, wird in 1 Mio Jahren unsere Galaxis verlassen haben
- Supernova kann Neutronenstern auf Geschwindigkeiten von maximal 200 km/s beschleunigen
- Heimat: Haufen schwerer Sterne mitten in der galaktischen Ebene der Milchstraße
- Supernova kann Pulsar aus der Scheibe herausgeschossen haben, oder aus Doppelsternsystem (Kettenkarussell)

# Binäarer Pulsar / Relativitätstheorie



- New energetic radio pulsars
- \* Parkes Multibeam survey
- All known pulsars

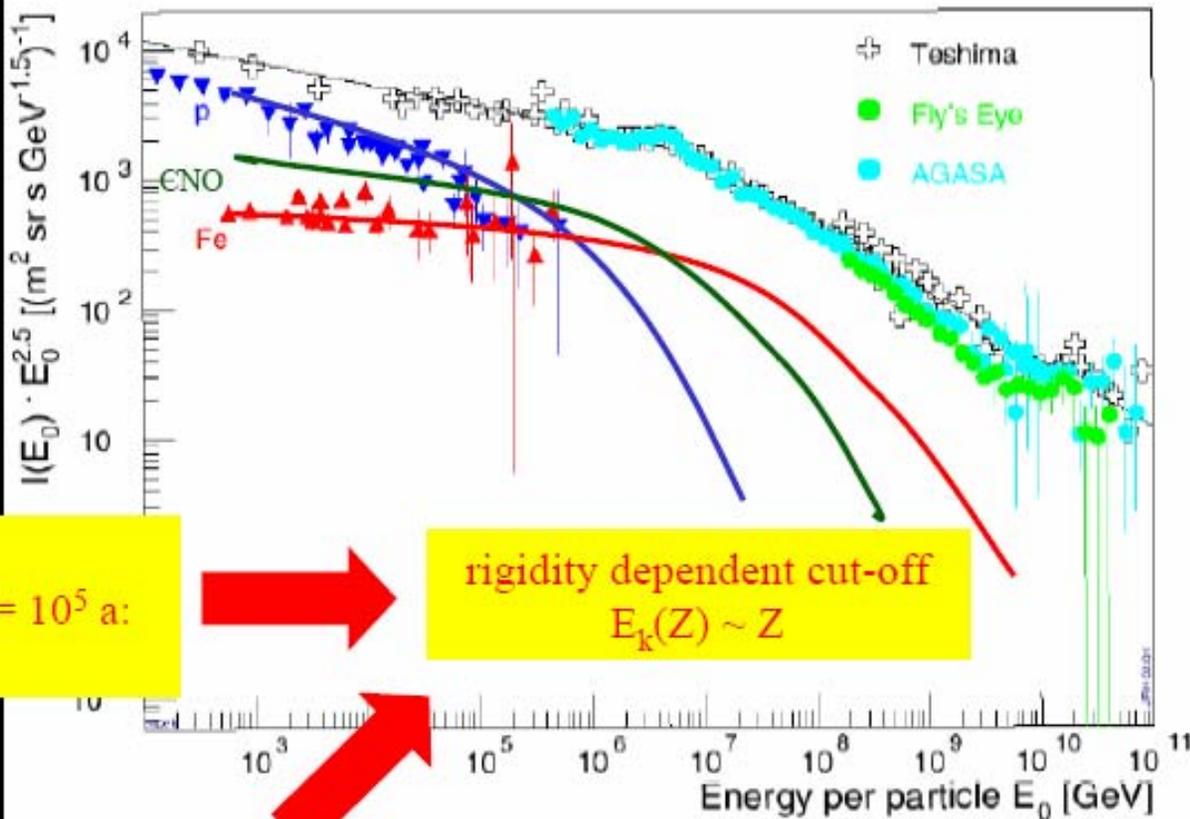
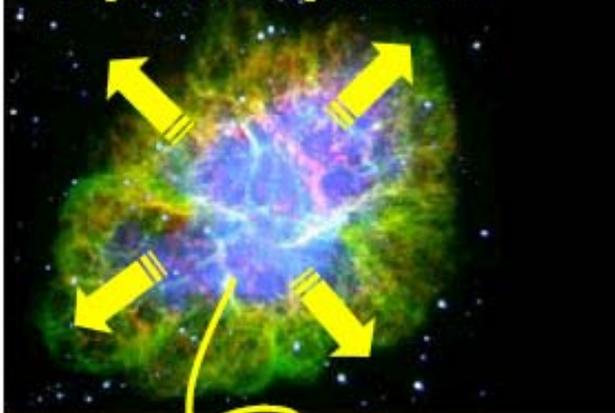
# Pulsare - Supernova



- 1572 von Tycho Brahe beobachtet und entdeckt, Cassiopeia
- Schockwellen können noch nicht erklärt werden
- 6 Mio Meilen/Stunde
- Evidenz für beschleunigte Kosmische Strahlung

ASA/CXC/Rutgers/J.Warren &  
15J.Hughes et al.

acceleration of CR in supernova explosions:



Fermi acceleration  
finite lifetime of shock front  $\tau = 10^5$  a:  
 $E_{\max} \sim Z \cdot 10^{15}$  eV

rigidity dependent cut-off  
 $E_k(Z) \sim Z$

propagation through galaxy:

Leaky box model:  
gyromagnetic radius  $\sim 1/(B Z)$   
escape probability  $\sim 1/Z$

$B = 3 \mu\text{G}$



# 23.06. AGN & Binäre Schwarze Löcher (NEUES!)



Übersicht

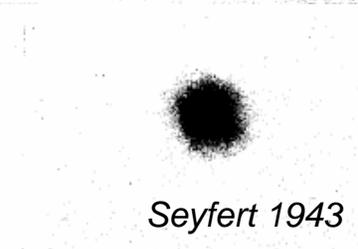
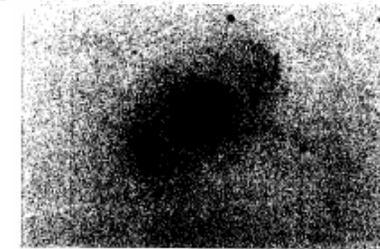
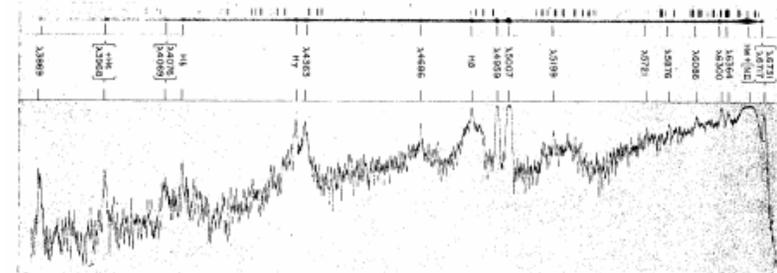
- Aktive Galaxienkerne (ganz kurz!!)
- Wechselwirkende Galaxien & Binäre Schwarze Löcher
- Aktivitätszyklen Aktiver Galaxienkerne
- Neues zum Galaktischen Zentrum
- Das Füttern des Monsters

# Aktive Galaxienkerne (AGK) / Historisch



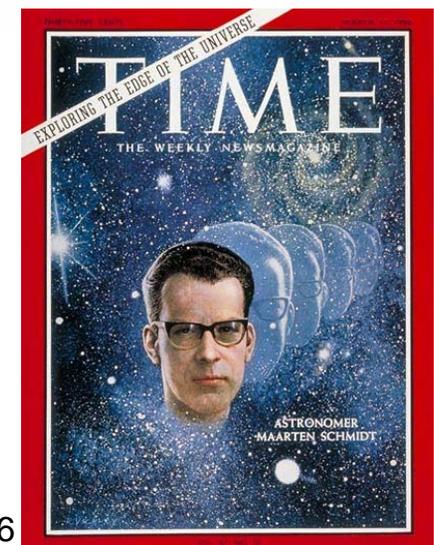
NUCLEAR EMISSION IN SPIRAL NEBULAE\*

CARL K. SEYFERT†  
PLATE I



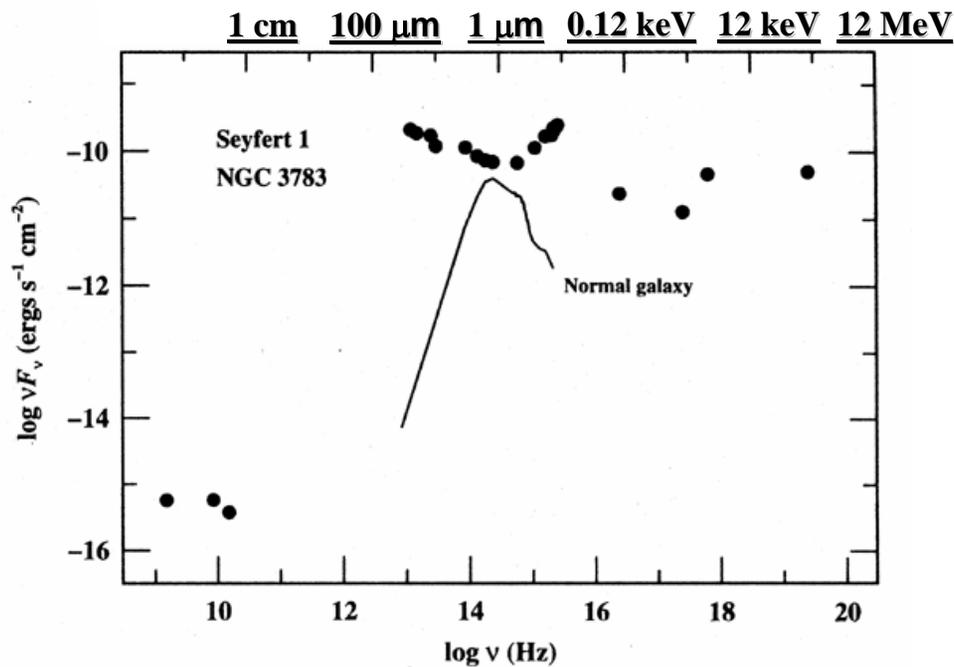
Seyfert 1943

- **H. D. Curtis (1918):** "curious straight ray apparently connected with the nucleus by a thin line of matter"
- **Carl K. Seyfert (1943):** Spiralgalaxien, deren helle („stellare oder semistellare“) Kerne Strahlung mit einem Emissionslinienspektrum und charakteristisch breiten Emissionslinien aufweisen
- **C. Hazard (1963):** Mondbedeckung erlaubt genaue Positionsbestimmung der Radioquelle 3C273.
- **M. Schmidt (1963):** leitet die Rotverschiebung anhand des Spektrums der Quelle 3C273 ab: Kern einer Galaxie, welche sich mit 170 Millionen km pro Stunde von uns wegbewegt. Quasistellares Objekt.
- **AGK: höchstenergetische Objekte im bekannten Universum**

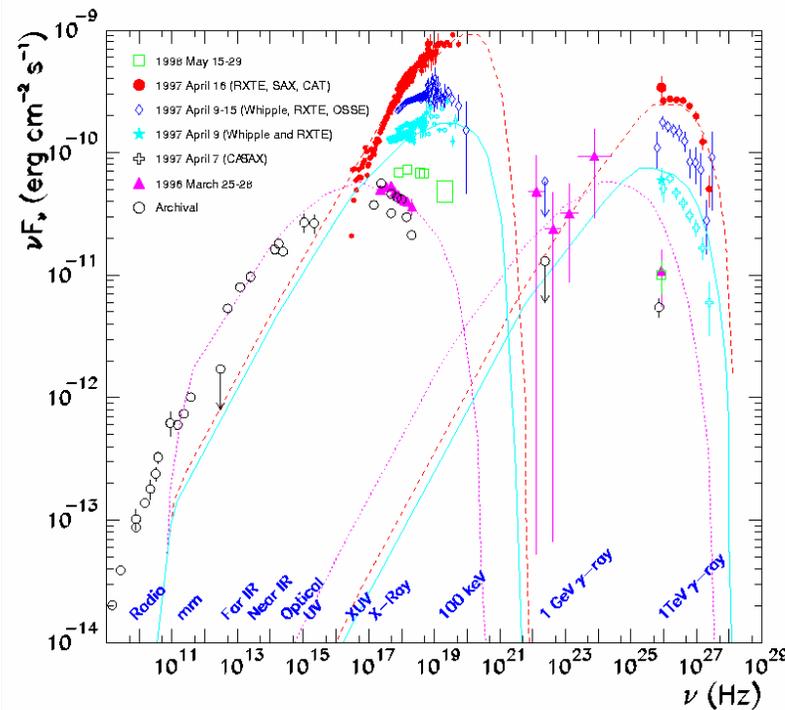
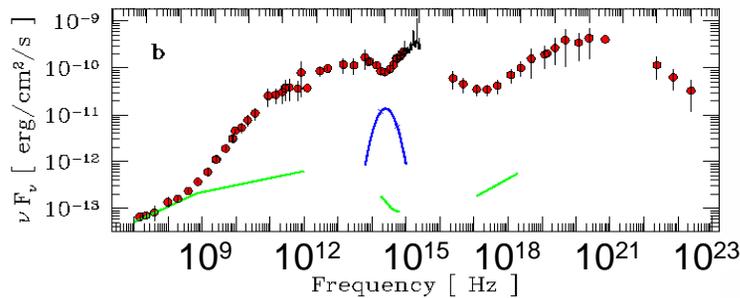


11.03.1966

# Aktive Galaxienkerne



## Quasar 3C273



# Zwei aktive Galaxienkerne:

Quasar PKS 1127-145 ( $z=1.187$ ), 3C273 ( $z=0.158$ )

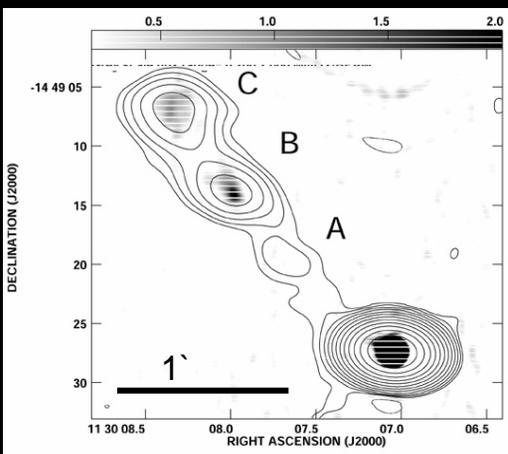


VLA, MERLIN

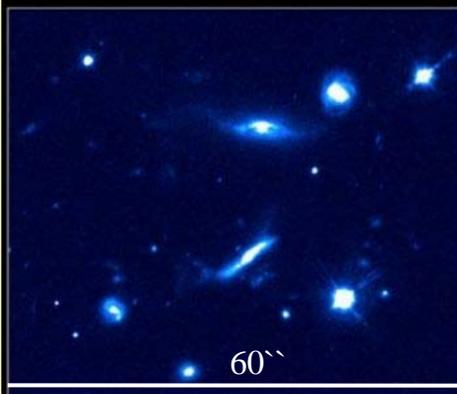
HST

CHANDRA

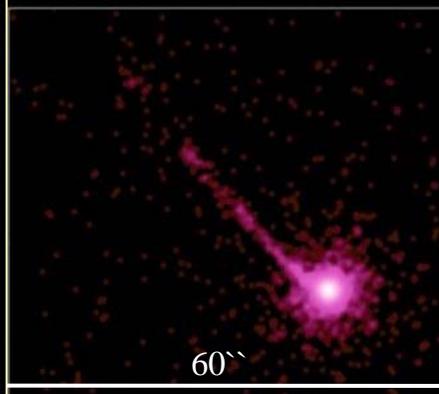
EGRET



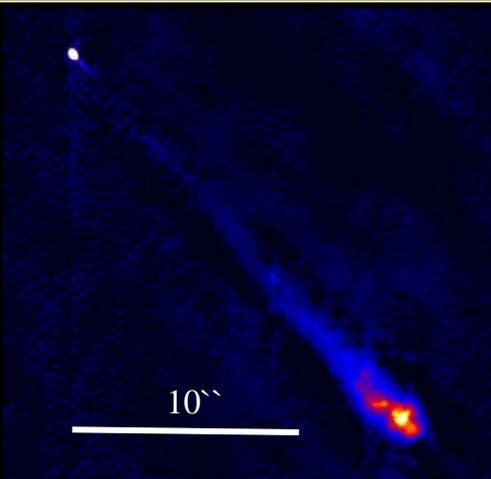
Siemiginowska et al. (VLA)



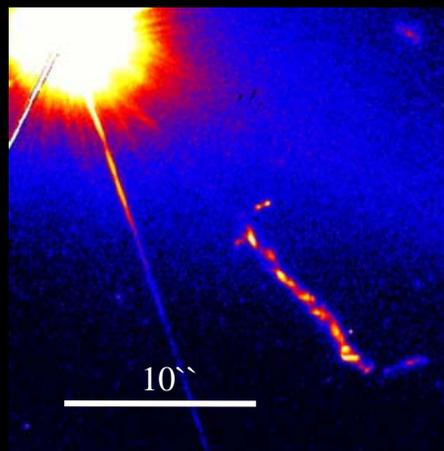
A. Siemiginowska (CfA) & J. Bechtold (U. Arizona), et al., NASA



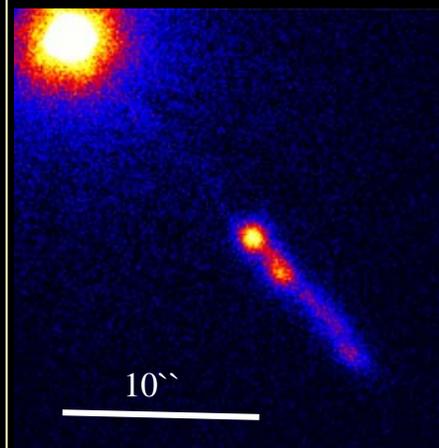
Detektiert,  
leider kein Bild



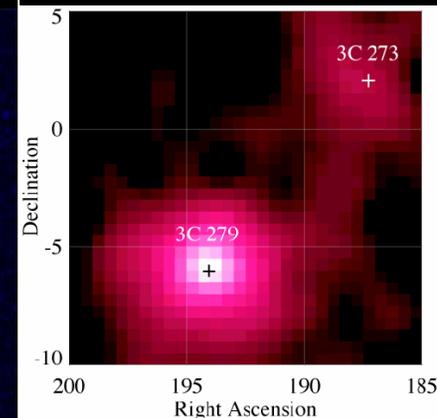
MERLIN



NASA/STScI



NASA/CXC/SAO  
/H. Marshall et al.

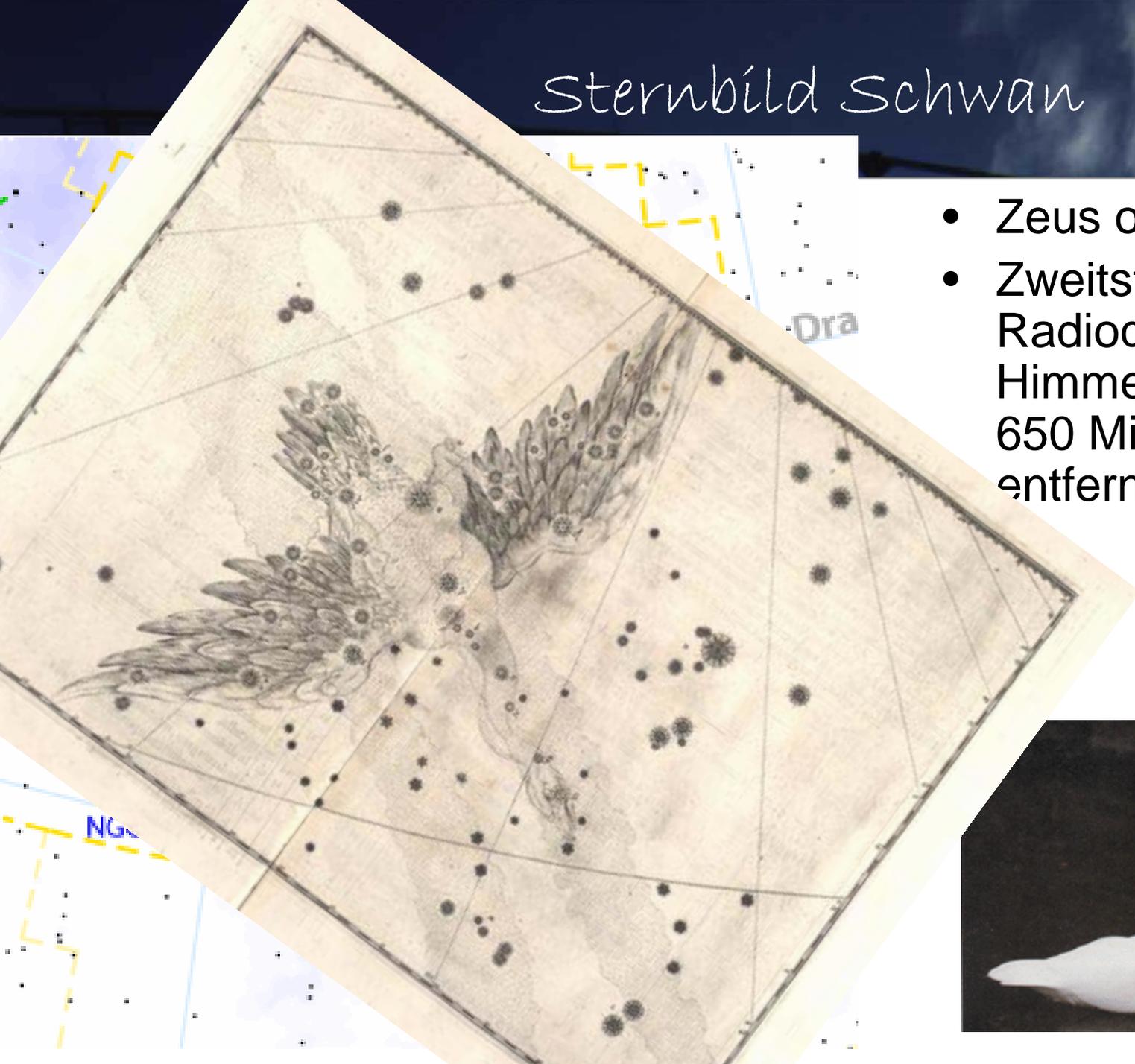


NASA/CGRO

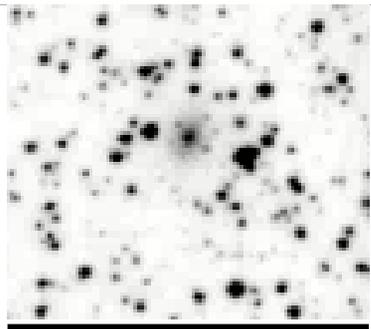
# Sternbild Schwan



- Zeus oder Phaeton?
- Zweitstärkste Radioquelle des Himmels: Cygnus A, 650 Mio Lichtjahre entfernt



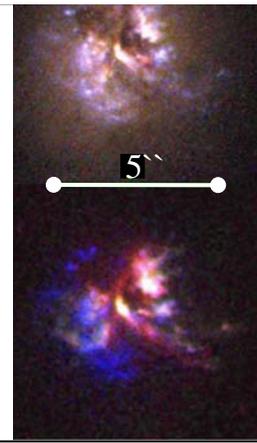
# Aktive Galaxienkerne / Cygnus A



3"  
Palomar 48-inch Schmidt

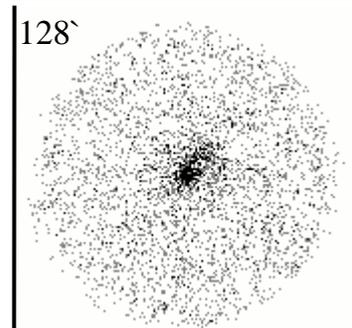


Erste Aufnahme von Walter Baade mit dem 200" Hale-Reflektor

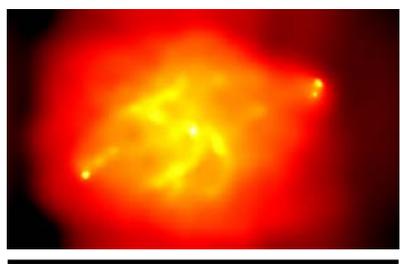


HST

optisch

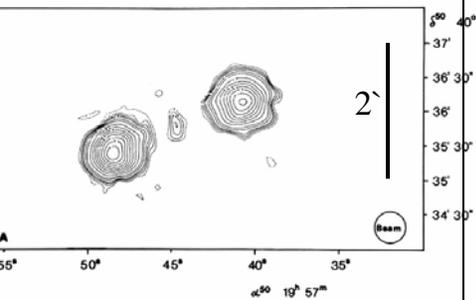


128"  
ROSAT, 0.1-2.4keV 1995

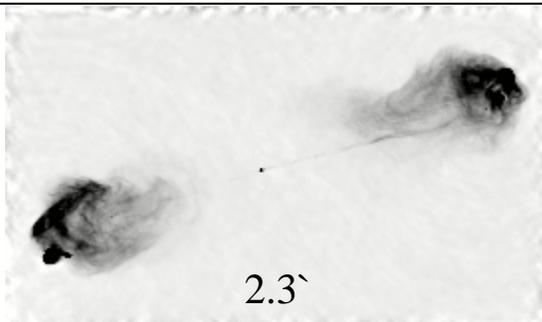


3.3"  
CHANDRA, 0.1-10keV 2003

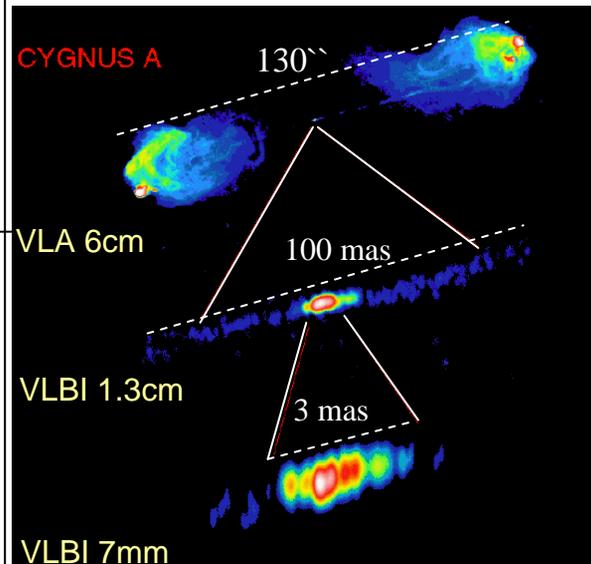
Röntgen



Effelsberg, 8.5 mm, 1976



2.3"  
VLA, 6cm



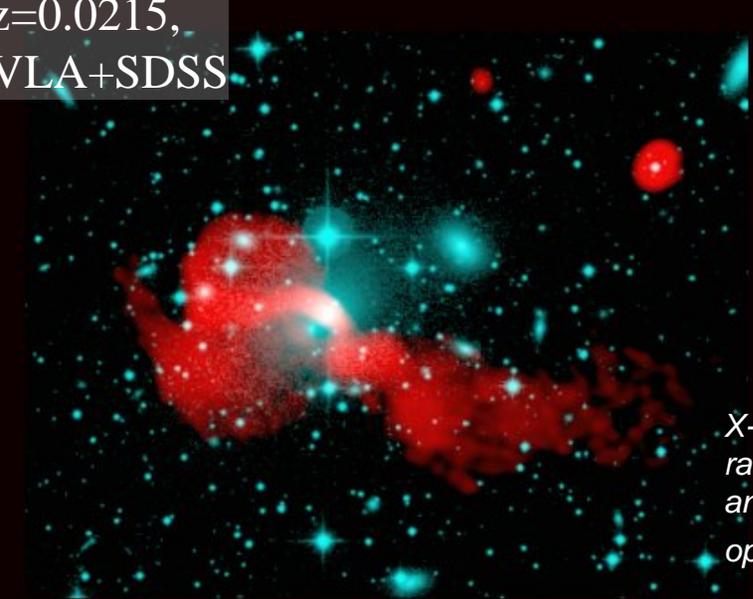
VLA 6cm

VLBI 1.3cm

VLBI 7mm

Radio

$z=0.0215$ ,  
VLA+SDSS

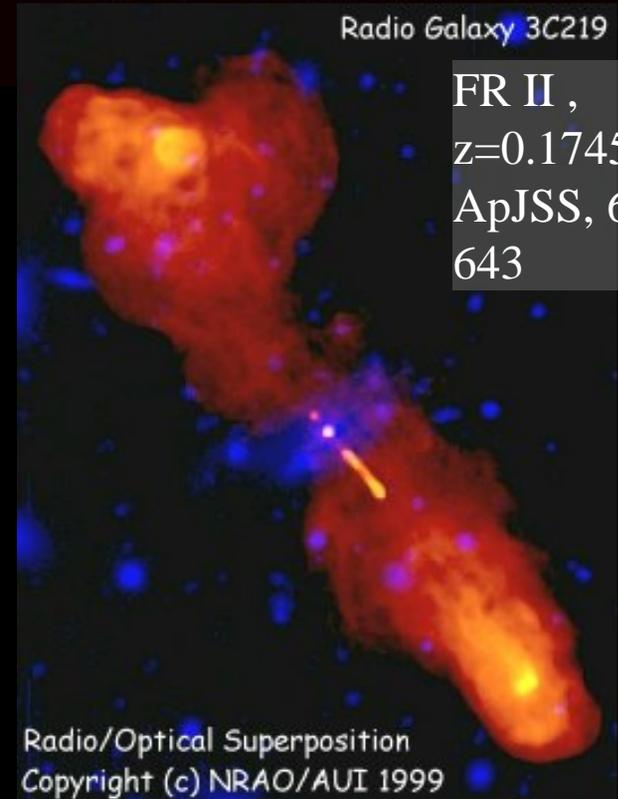


*X-ray (CXC/NASA/Karovska et al, 2002);  
radio 21-cm (NRAO/VLA/Schiminovich et al),  
and continuum (NRAO/VLA/Condon et al); and  
optical (Digitized Sky Survey/UK Schmidt/STScI)*

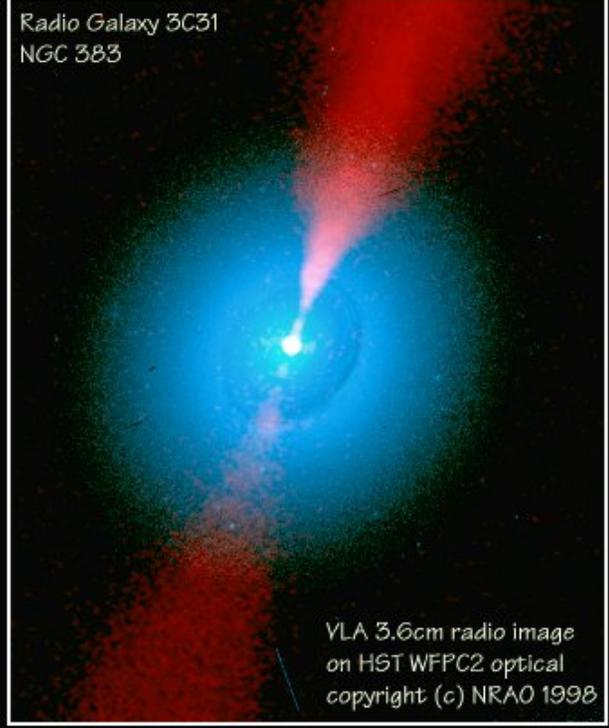
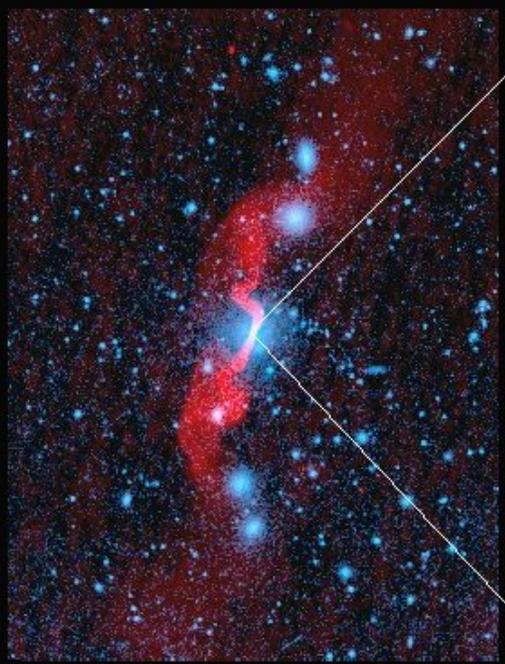


Radio Galaxy 3C219 (left), 3C31, VLA+SDSS (links), VLA+Hubble (rechts),  $z=0.0169$

FR II,  
 $z=0.1745$   
ApJSS, 6  
643



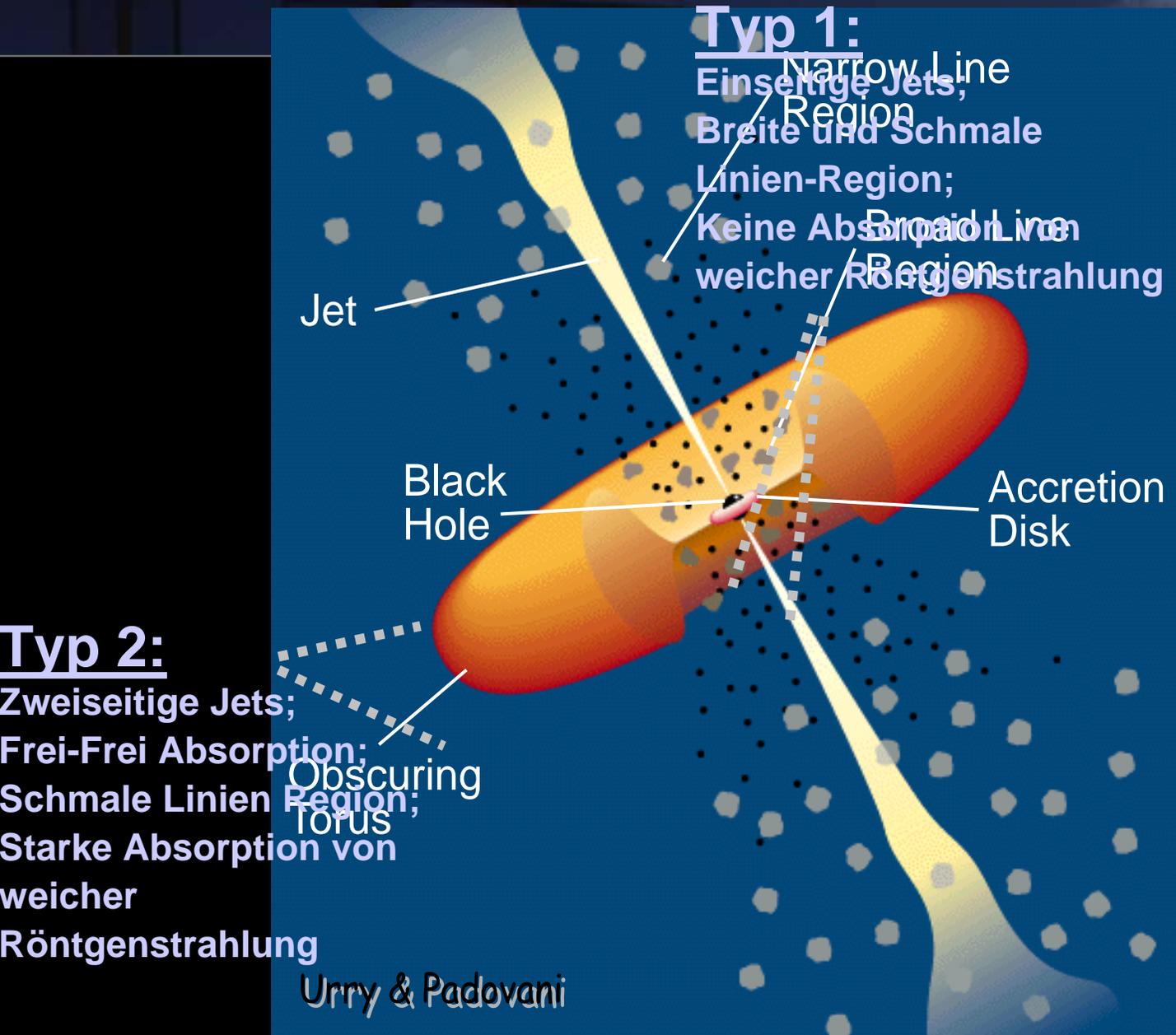
Radio/Optical Superposition  
Copyright (c) NRAO/AUI 1999



Radio Galaxy 3C31  
NGC 383

VLA 3.6cm radio image  
on HST WFPC2 optical  
copyright (c) NRAO 1998

# Paradigma der Aktiven Galaxienkerne



**Jets:** Radio,  
optisch, Röntgen,  
Gamma

**Galaxie:** alle  
Bänder

**Torus:** IR, optisch,  
UV, Radio

**SMBH:** alle Bänder

**Akkretionsscheibe**  
optisch, UV,  
Hochenergie

**BLR/NLR:** optisch,  
UV, Hochenergie

**Interstellares  
Medium:** alle  
Bänder

# Aktive Galaxienkerne

NGC 4696



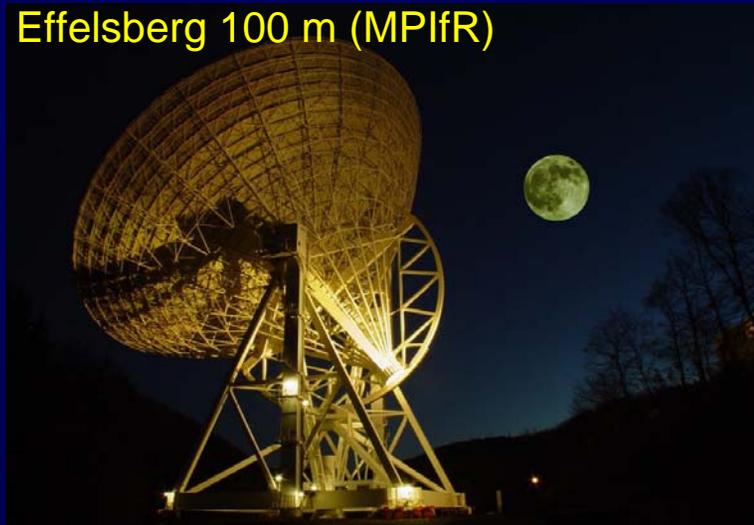
# Aktive Galaxienkerne / Typische Parameter



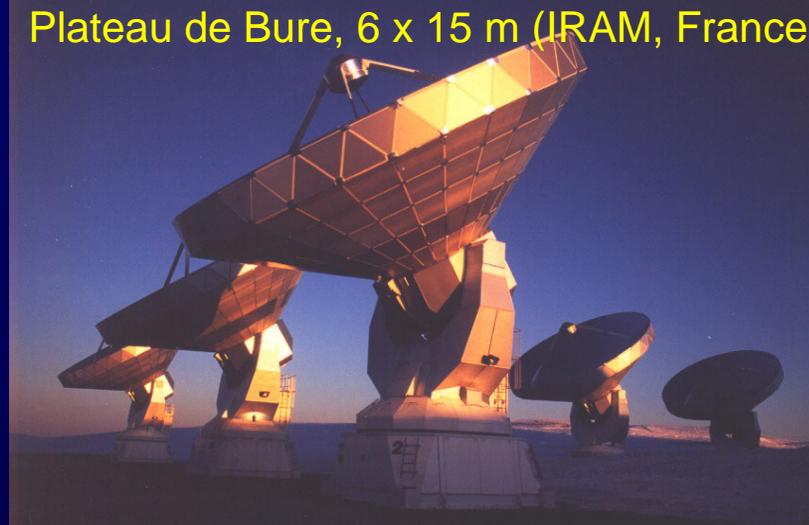
Leuchtkraft	$10^{43} - 10^{46}$ erg/sec
Masse der Schwarzen Löcher	$10^6 - 10^9 M_{\text{Sonne}}$
Schwarzschildradius	$3 \text{ km}/M_{\text{Sonne}}$
Jet Länge	$- 10^6$ Lichtjahre
Jet Öffnungswinkel	einige Grad
Jet Geschwindigkeit	nahe $c$
Variabilität (Radio – TeV-Bereich)	Minuten - Monate

# 3mm VLBI Observations of Sgr A\* with the 3 largest European mm-telescopes:

Effelsberg 100 m (MPIfR)



Plateau de Bure, 6 x 15 m (IRAM, France)



Baseline lengths (km):

	PdB	PV
EB	658	1700
Pdb		1146

Pico Veleta 30 m (IRAM, Spain)



fringe spacing: 0.4 – 1.1 mas, sensitivity > 60 mJy ( $7\sigma$ )

# The Diameter of the Light-Cylinder and the Jet Width:

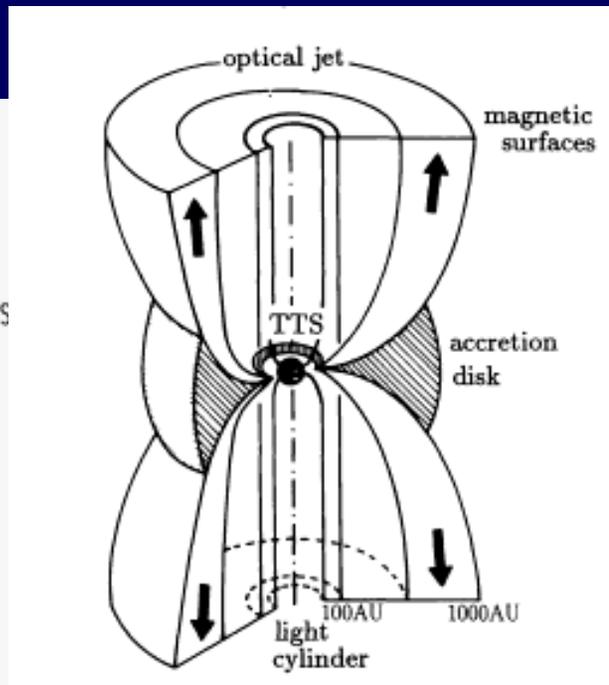
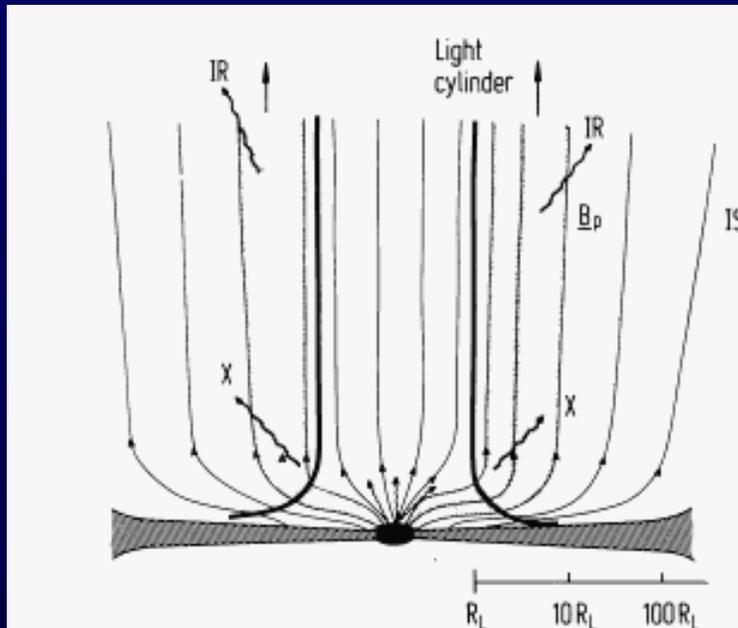
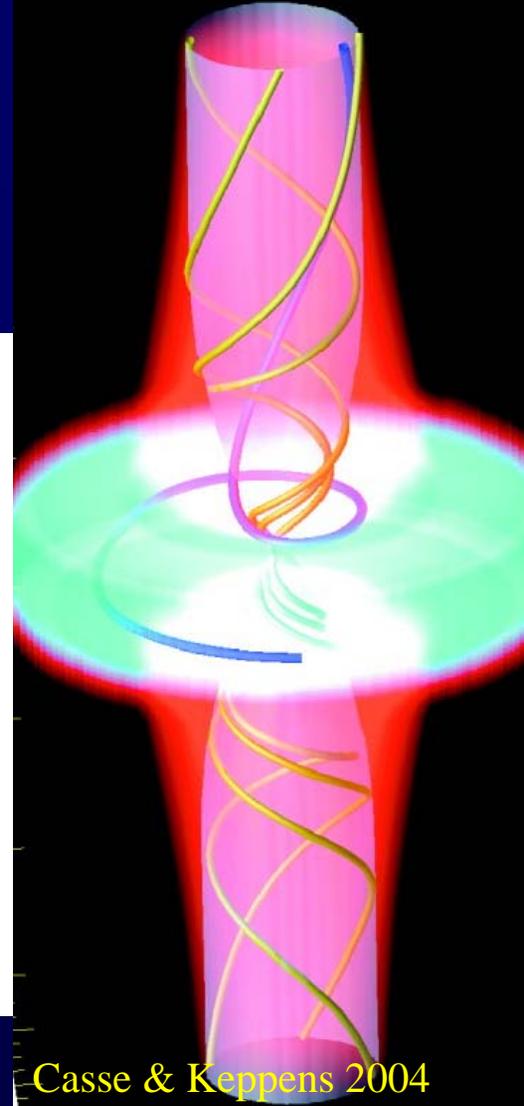


Fig. 11. The parsec-scale structure of magnetized jets in Quasars (Courvoisier and Camenzind, 1989). The central accretion disk carries a rotating magnetosphere which is strongly deformed by the presence of the light cylinder. The escaping disk-wind material is collimated outside the light cylinder by pinching forces. Stationary synchrotron emission (IR) occurs either near the light cylinder or the outer edge of the jet. The hot wind material can efficiently cool by Comptonization of the UV-flux from the inner disk and produce the hard X-ray emission (X).



$> 40 R_s$

Camenzind, 1990

jet width  $\geq 2 \gamma R_s$

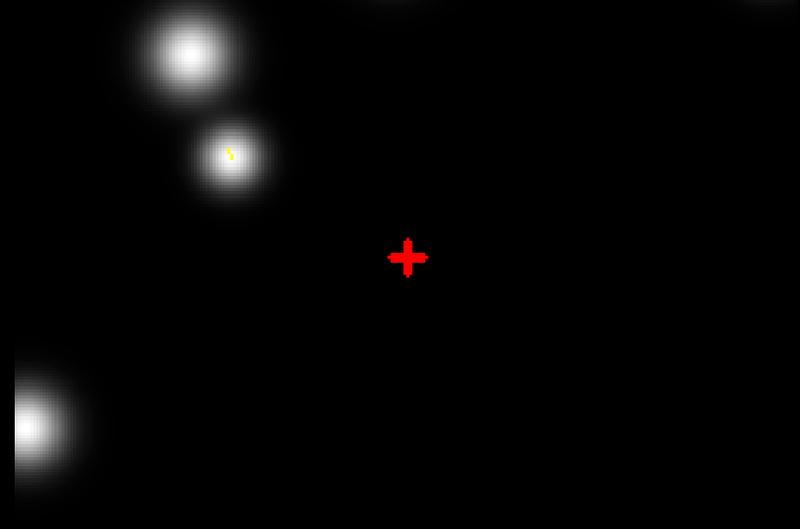
# Galaktisches Zentrum



*False color near-infrared image of the central parsec of the Milky Way.*



1992

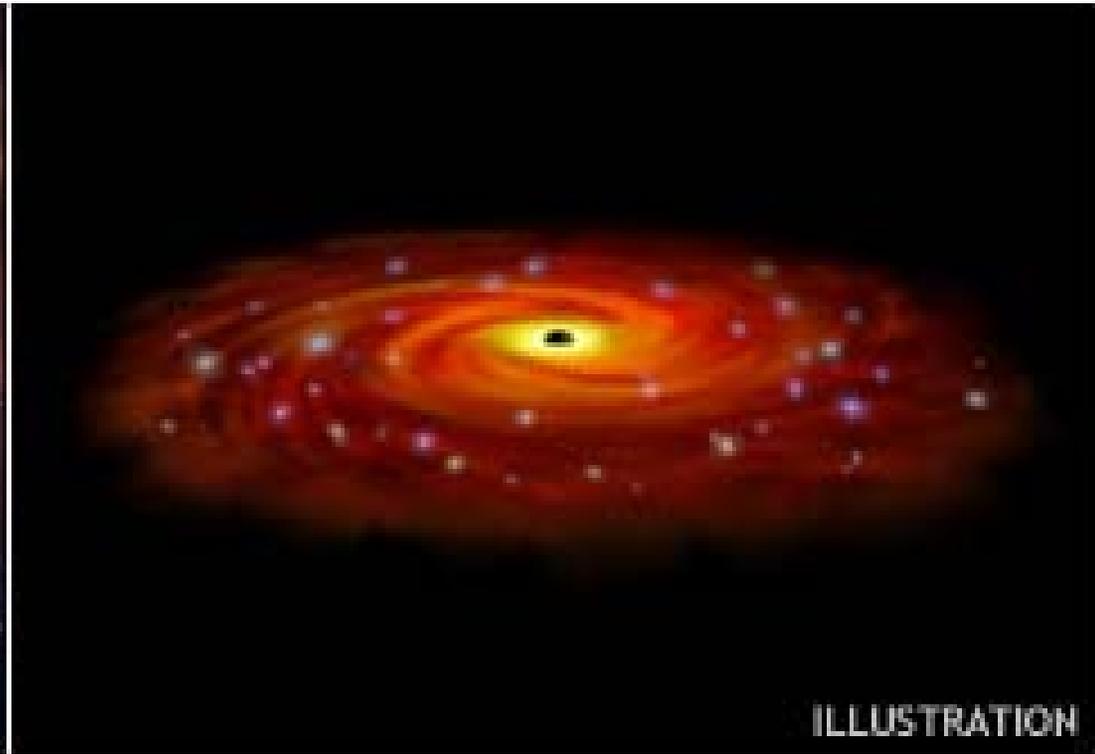


- Seit 1992, zentrale pc Region des galaktischen Zentrums im nahen Infrarot beobachtet; Eigenbewegungen der Sterne; 30 Lichttage von Sgr A\* (Genzel, Eckart, et al.)

# Sternentstehung in der Nähe von Sgr A\*



CHANDRA X-RAY



ILLUSTRATION

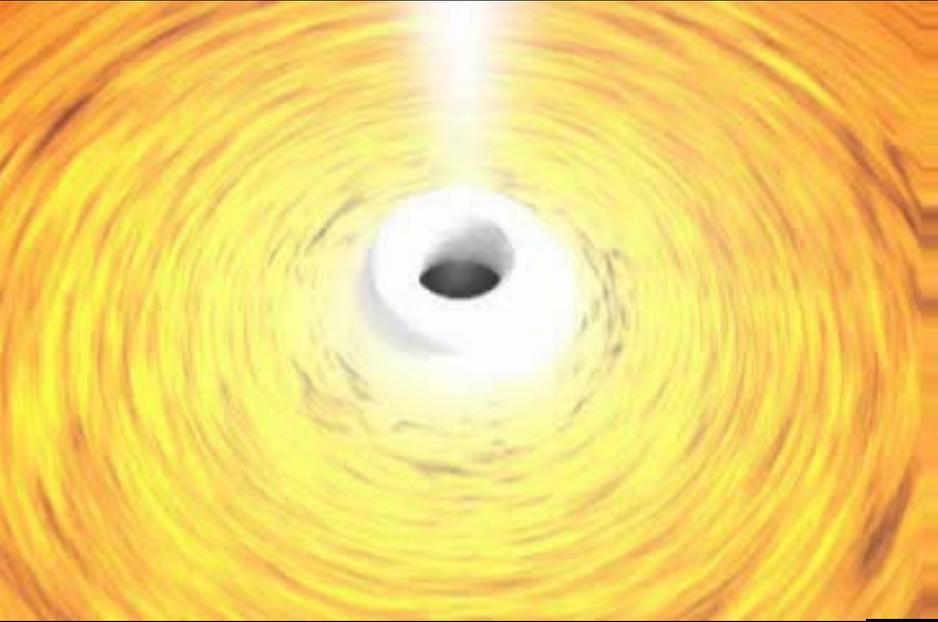
- Infrarotsterne hätten durch Gezeitenkräfte zerrissen werden müssen

# Sternentstehung in der Nähe von Sgr A\*



- 2 Modelle:
  - Scheibenmodell: Gravitation in der dichten Gasscheibe hebt Gezeitenkräfte auf, Sterne können sich bilden
  - Migrationsmodell: Sterne bilden sich in Sternhaufen weit entfernt vom Schwarzen Loch und migrieren um dann den Ring der massiven Sterne zu bilden, sagt Million sonnenartiger Sterne in einem Ring voraus
- Sgr A\* enthält nur 10 000 leichte Sterne:  
Scheibenmodell, Sterne wurden dort geboren

Sternentstehung in der Nähe von Sgr A\*

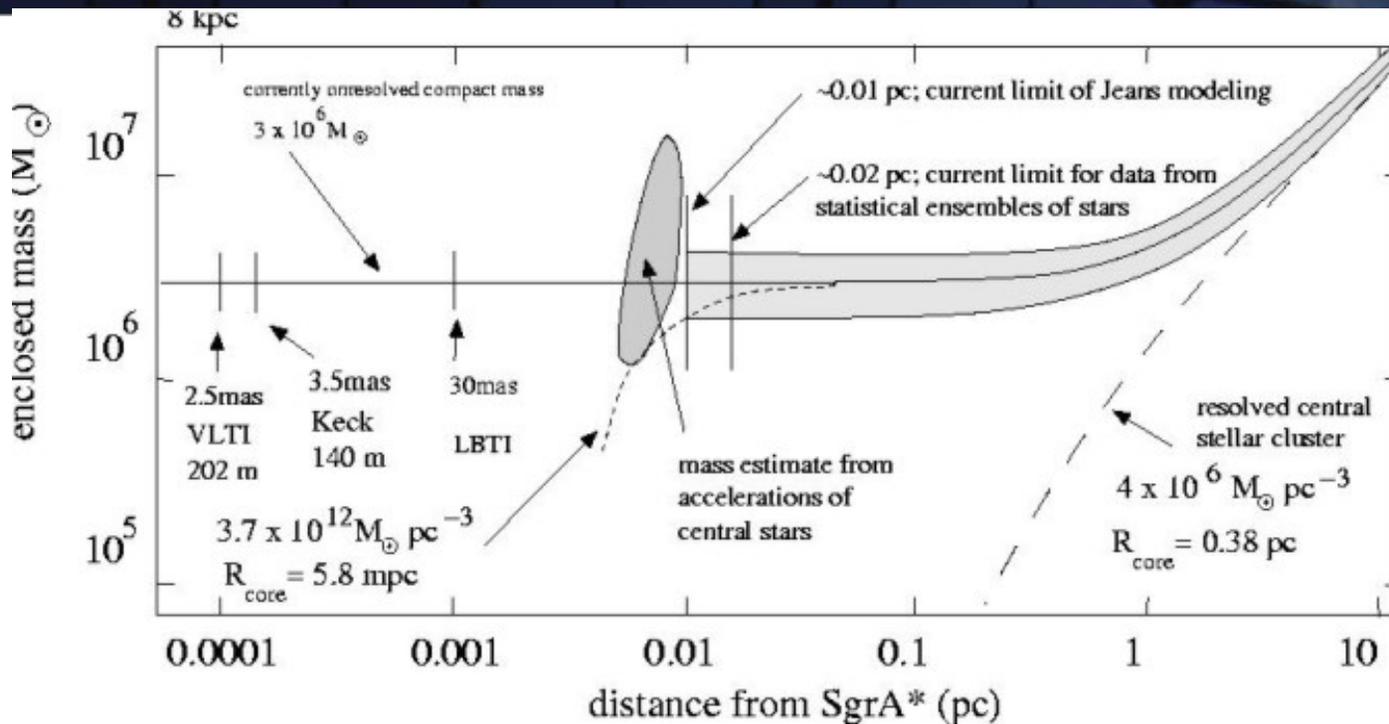


Scheibenmodell

Migrationsmodell



# Die Masse des Schwarzen Lochs:



Ghez et al. 1998 (Infrarot, Sternbewegung): 2.6 Mio Sonnenmassen

Genzel et al. 2000: 2.6-3.3 Mio Sonnenmassen

Ghez et al. 2000: 3 Mio Sonnenmassen

Eckart et al. 2002: 2-8 Mio Sonnenmassen

2002: 3.3 Mio Sonnenmassen

=> insgesamt: 2.4-2.8 Mio Sonnenmassen, Schwarzschildradius von 8 Mio km, im Falle maximaler Rotation: halber Wert

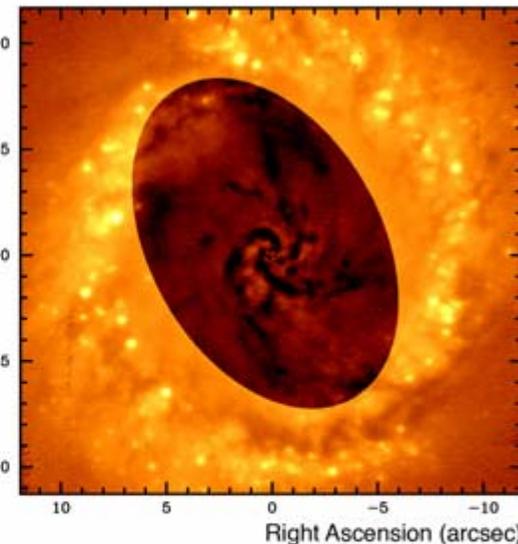
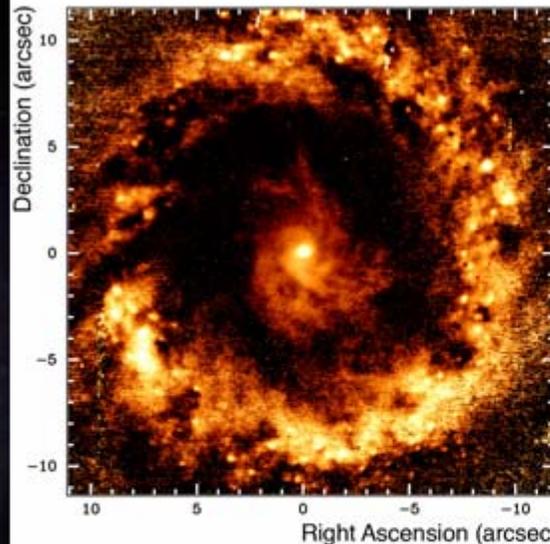
„Das Monster füttern“



The Centre of the Active Galaxy NGC 1097  
(NACO/VLT)

ESO PR Photo 33a/05 (October 17, 2005)

© ESO



Network of Filamentary Structures in NGC 1097  
(NACO/VLT)

ESO PR Photo 33b/05 (October 17, 2005)

© ESO

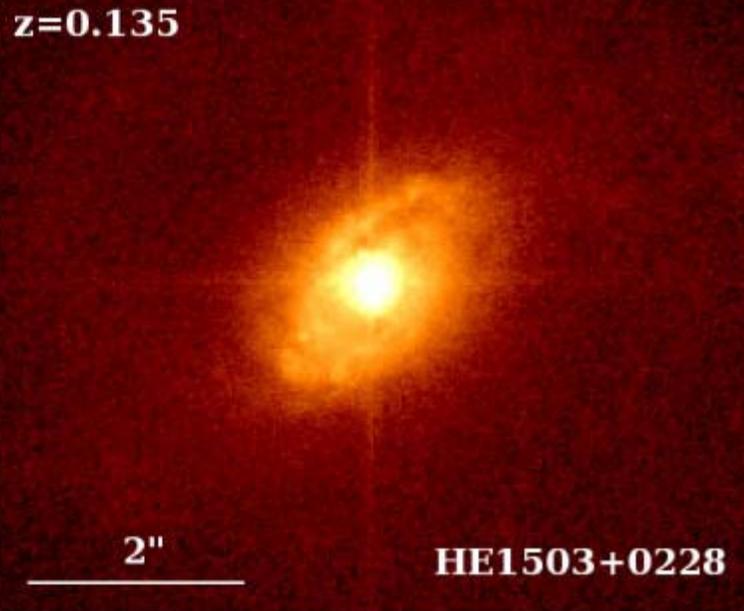
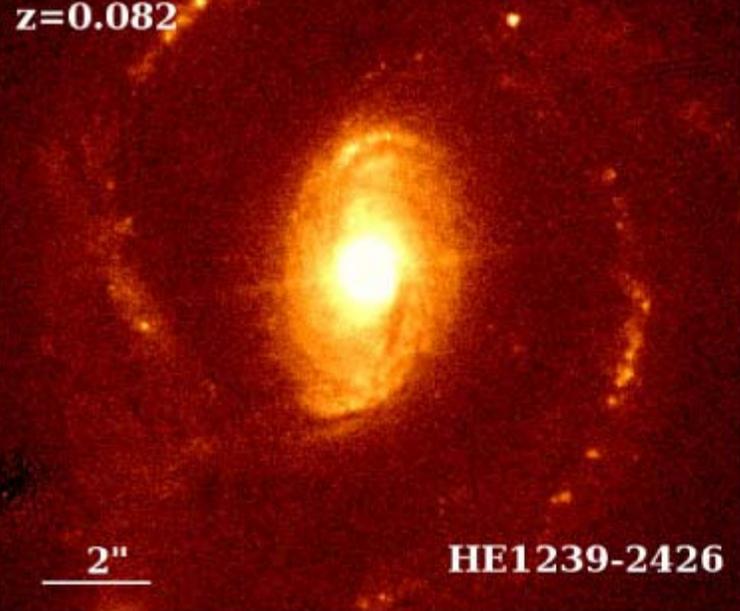


- 45 Mio Lj, Nahinfrarot-Aufnahmen, mehr als 300 Sternentstehungsregionen: HII-Regionen als weiße Spots
- AGN im Zentrum, Filamente sind kalter Staub, Gas spiraliert nach innen
- Zentrale Spiralarme reichen bis zu 1300 Lj

# Andromeda: Sternenscheibe

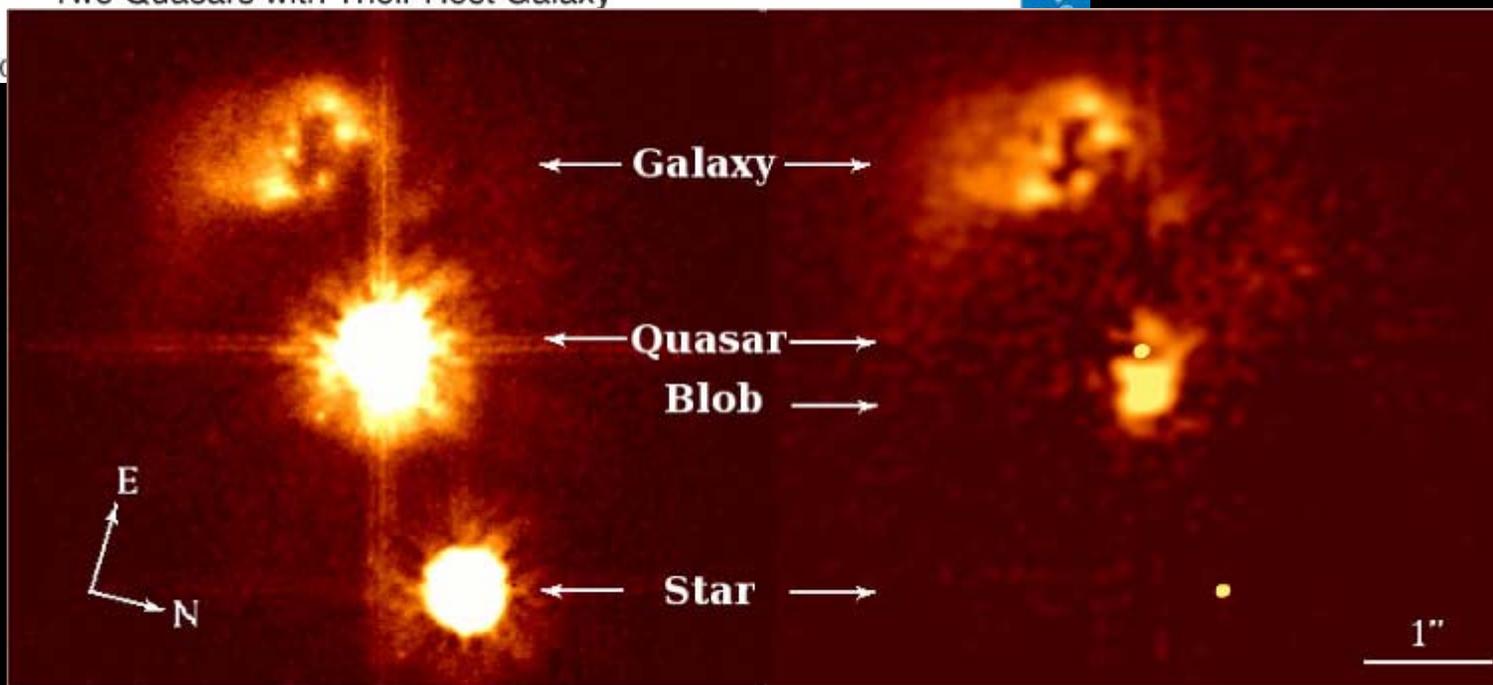


- Mysteriöses blaues Licht in Andromeda enträtselt: Scheibe junger, heißer Sterne, sehr nahe am Schwarzen Loch
- Unklar, wie sich diese Sterne haben bilden können, mehr als 400 Sterne aus starburst vor 200 Mio Jahren
- Große Geschwindigkeit: 3.6 Mio km/h, 1000 km/s, 40 Sekunden zur Erdumrundung, 6 Minuten zum Mond
- Blauen Sterne sind zu kurzlebig, 12 Milliarden Jahre Geschichte der Andromeda Galaxie, könnte mehrfach gebildet worden sein
- Doppel-Sternhaufen? Ring alter Sterne?



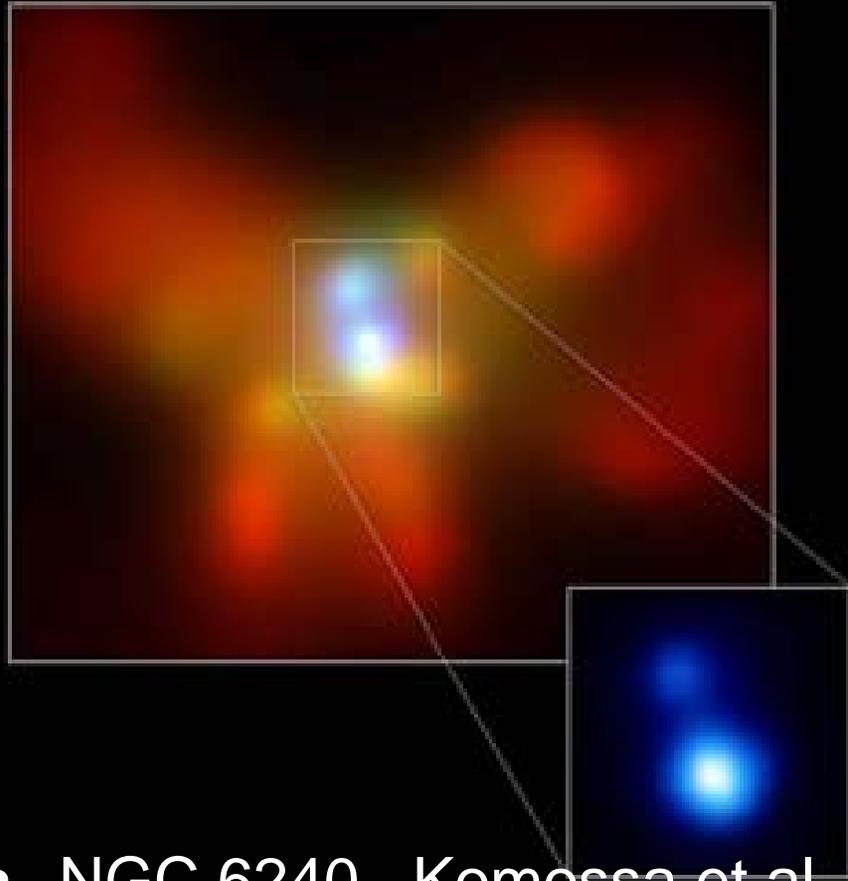
Two Quasars with Their Host Galaxy

ESO PR Photo 28a/05 (September 14, 2005)

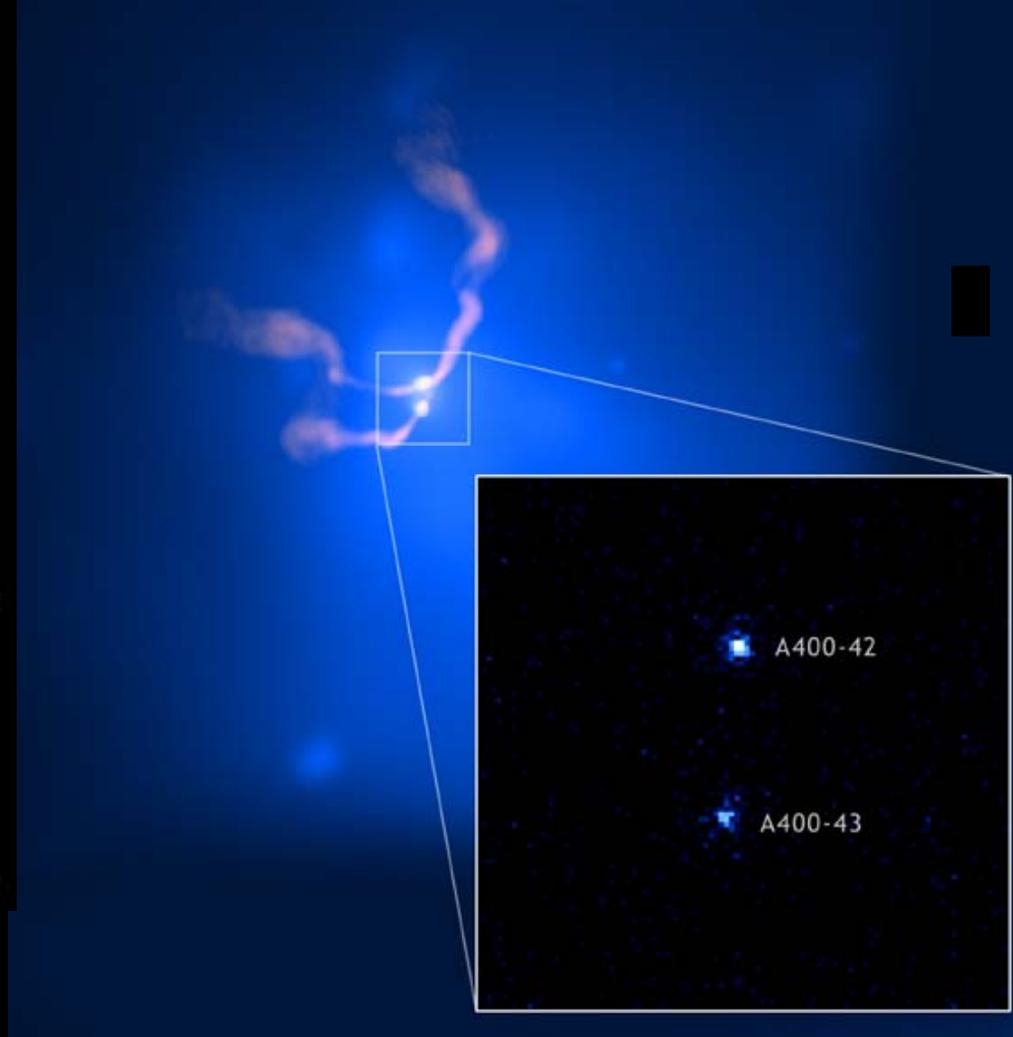


The Quasar without a Home: HE0450-2958

# Supermassive Binäre Schwarze Löcher?



- NGC 6240 , Komossa et al.
- 3000 light years apart
- "starburst" galaxy
- Merger: 30 million years ago



3C75 in Abell 400, Röntgen, Radio

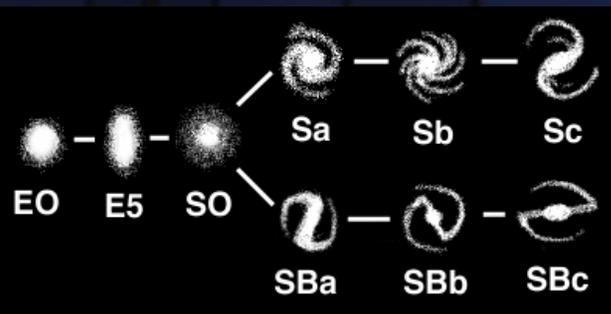
# Supermassive Binäre Schwarze Löcher?



NGC 1128

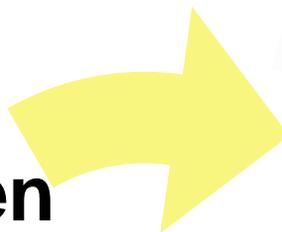
- Merger zweier großer Galaxien
- Oder Koinzidenz: zwei Galaxien bewegen sich aneinander vorbei, „Schiffe in der kosmischen See“
- Galaxien und beide Schwarze Löcher gebunden
- Schwarze Löcher 25000 Lichtjahre voneinander entfernt, früheres Stadium der Evolution als NGC 6240 (3000 Lichtjahre entfernt)

# Zyklus der Aktivität?



Hubble 1926

**Galaxien**



**Merger**



Toomre & Toomre 1972

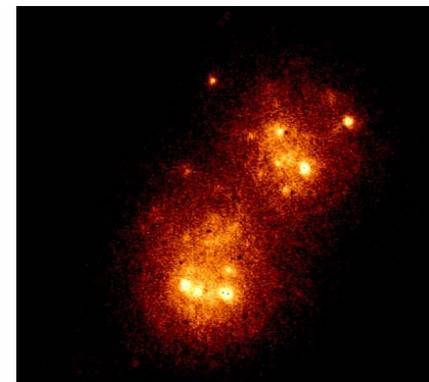


**Aktive  
Galaxienkerne**



**Starburst**

NGC 1741

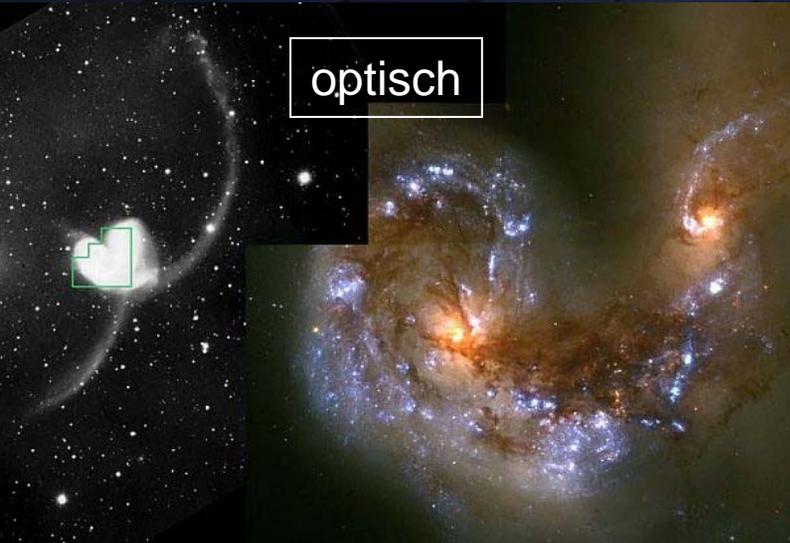


Cen A

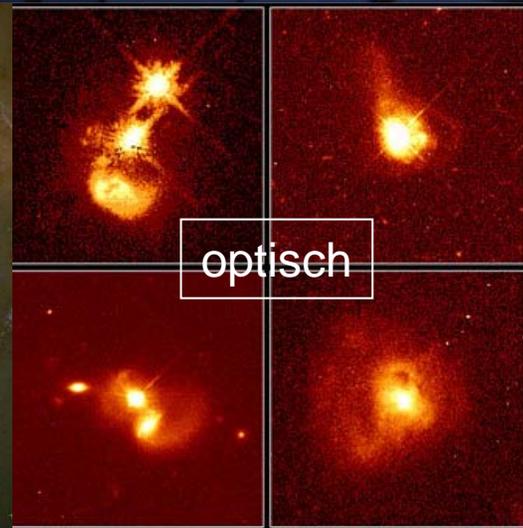


NASA/Chandra/CXOM, Karovska et al.

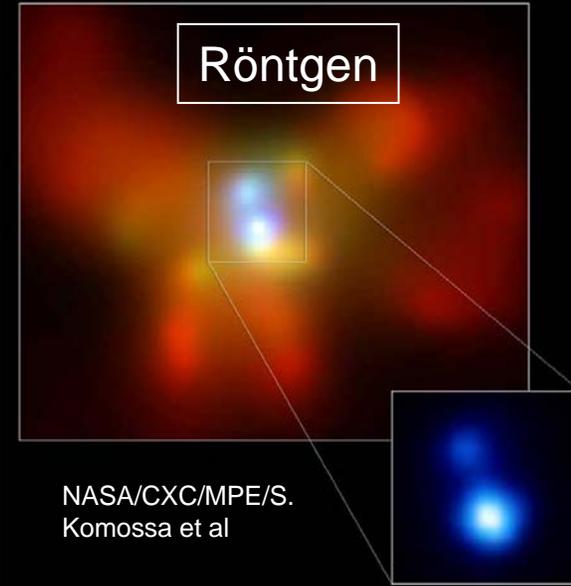
# Supermassive Binäre Schwarze Löcher unterschiedlichen Entwicklungszuständen?



optisch



optisch

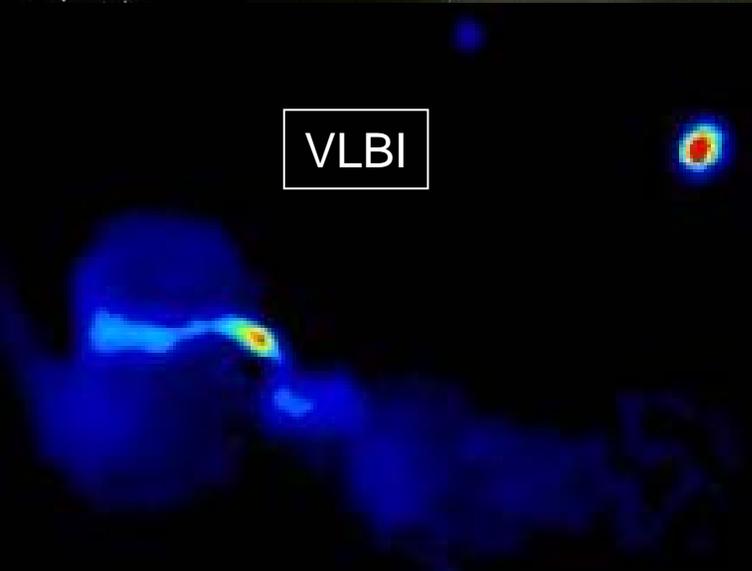


Röntgen

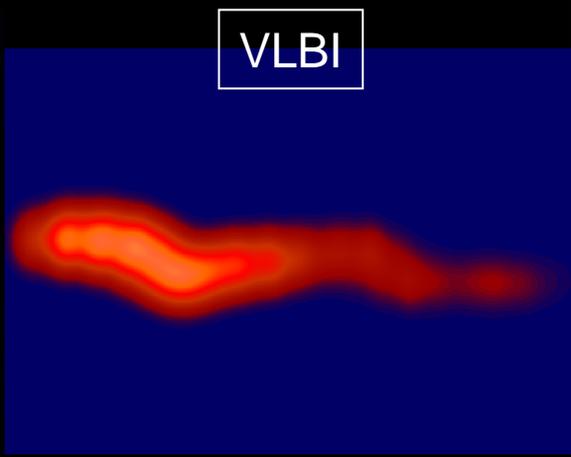
NASA/CXC/MPE/S.  
Komossa et al

Quasar Host Galaxies  
e Telescope - Wide Field Planetary Camera 2

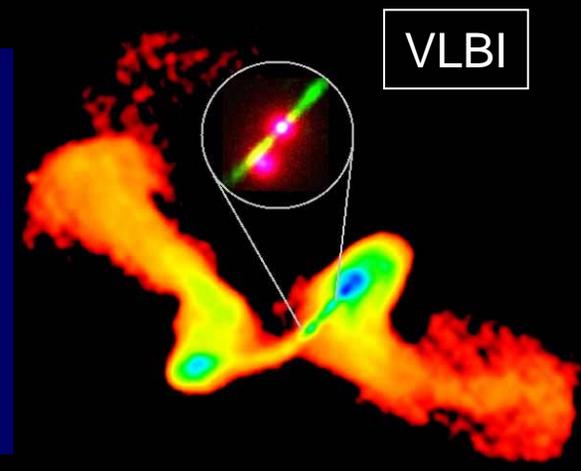
J. Bahcall (Institute for Advanced Study), M. Disney (University of Wales) and NASA



VLBI



VLBI



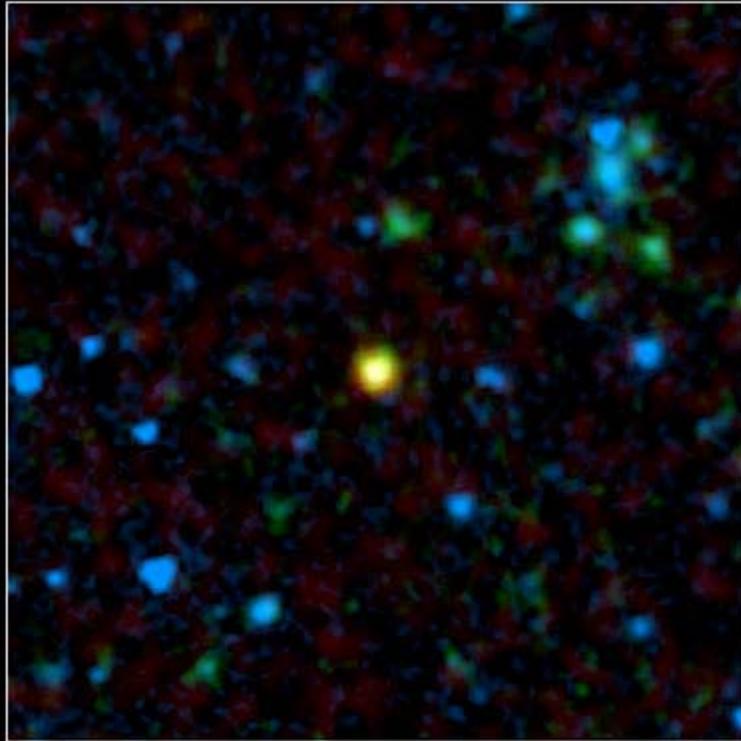
VLBI

Hardcastle et al. 1996

Lobanov & Roland 2004

Murgia et al.

# Verstecktes, Hungriges Schwarzes Loch



Dust-Enshrouded Quasar

Spitzer Space Telescope • IRAC • MIPS

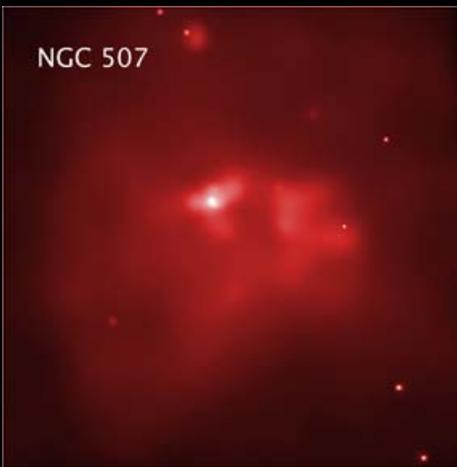
Radio: NRAO • VLA

NASA / JPL-Caltech / A. Martinez-Sansigre (Oxford, University)

ssc2005-17a

- Spitzer: neue Population verstaubter Quasare
- Röntgen-Hintergrund
- Versteckt durch Staubring
- Versteckt durch staubige Galaxien
- Beide gefunden, 21 Beispiele

NGC 507



NGC 4374



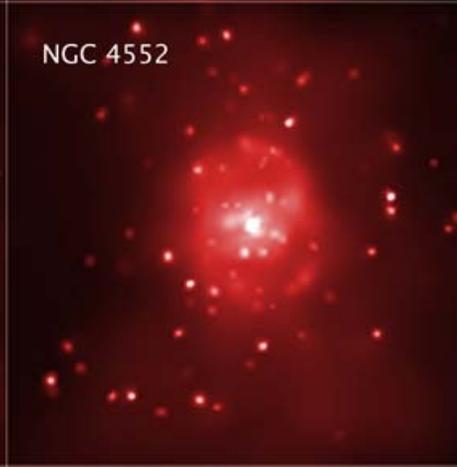
NGC 4472



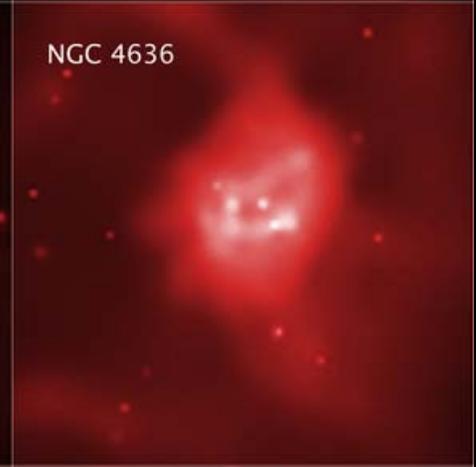
NGC 4486



NGC 4552



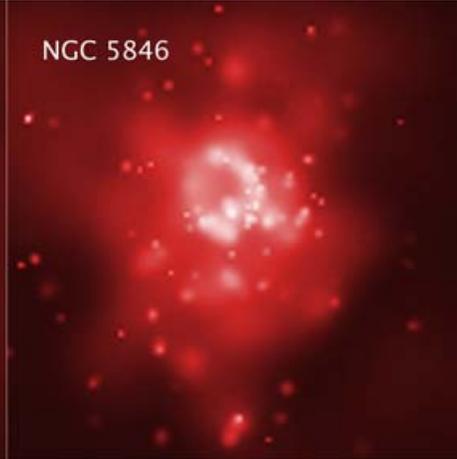
NGC 4636



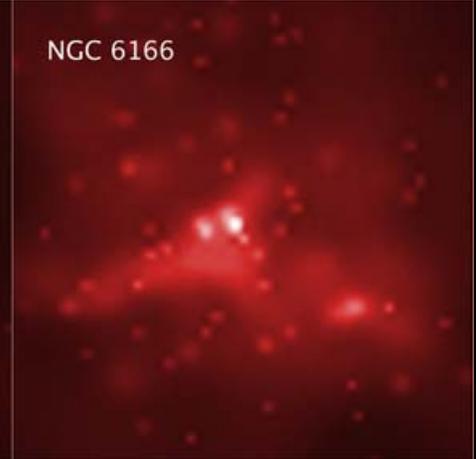
NGC 4696



NGC 5846



NGC 6166



# Schwarze Löcher

## Gelöste Probleme

# offene Fragen

- Bislang kein direkter Nachweis der Existenz Schwarzer Löcher ...
- Wie „wachsen“ die Schwarzen Löcher ? Und die Galaxien?
- Wann, Warum und Wo entstehen Jets ?
- Was unterscheidet „radio-laute“ und „-leise“ AGK ?
- Wodurch und Wie wird die Aktivität der AGK getriggert ?
- Ist die Massenskala der Schwarzen Löcher kontinuierlich ?
- etc.

# 07.07. Maser & das Interstellare Medium & Merger & AGN



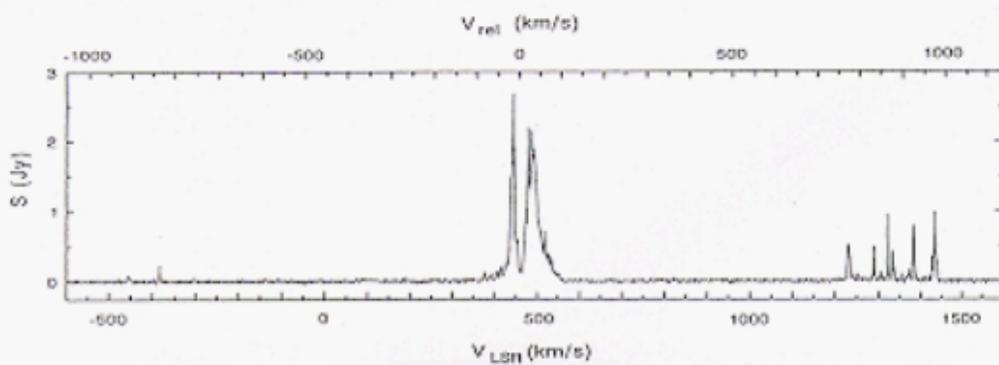
Übersicht

- Einführung: Maser
- Maser (Hydroxyl, Wasserdampf, Siliziummonoxid, Methanol)
  - Interstellare
  - Extragalaktische (Mega & Gigamaser)
  - ...
- Maser & Sternentstehung
- Megamaser & Merger-Galaxien
- Starburst oder AGN?
- Megamaser & Akkretionsscheiben in AGN

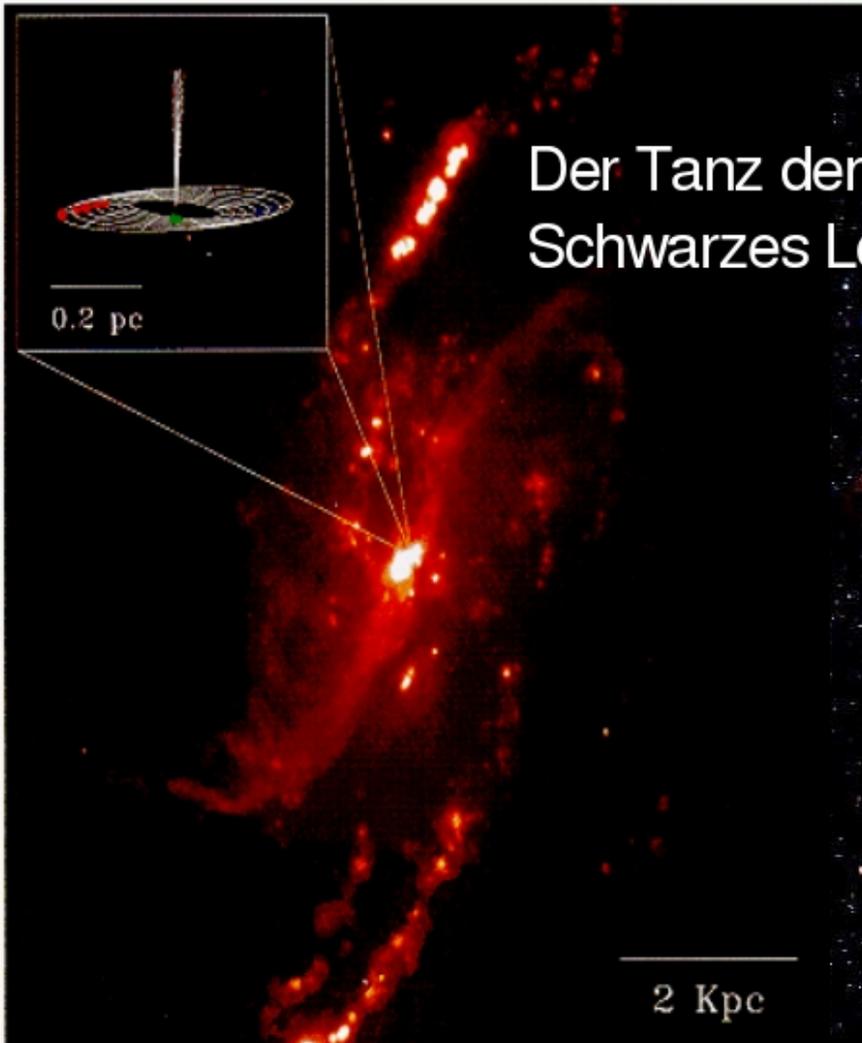
# Maser / Megamaser



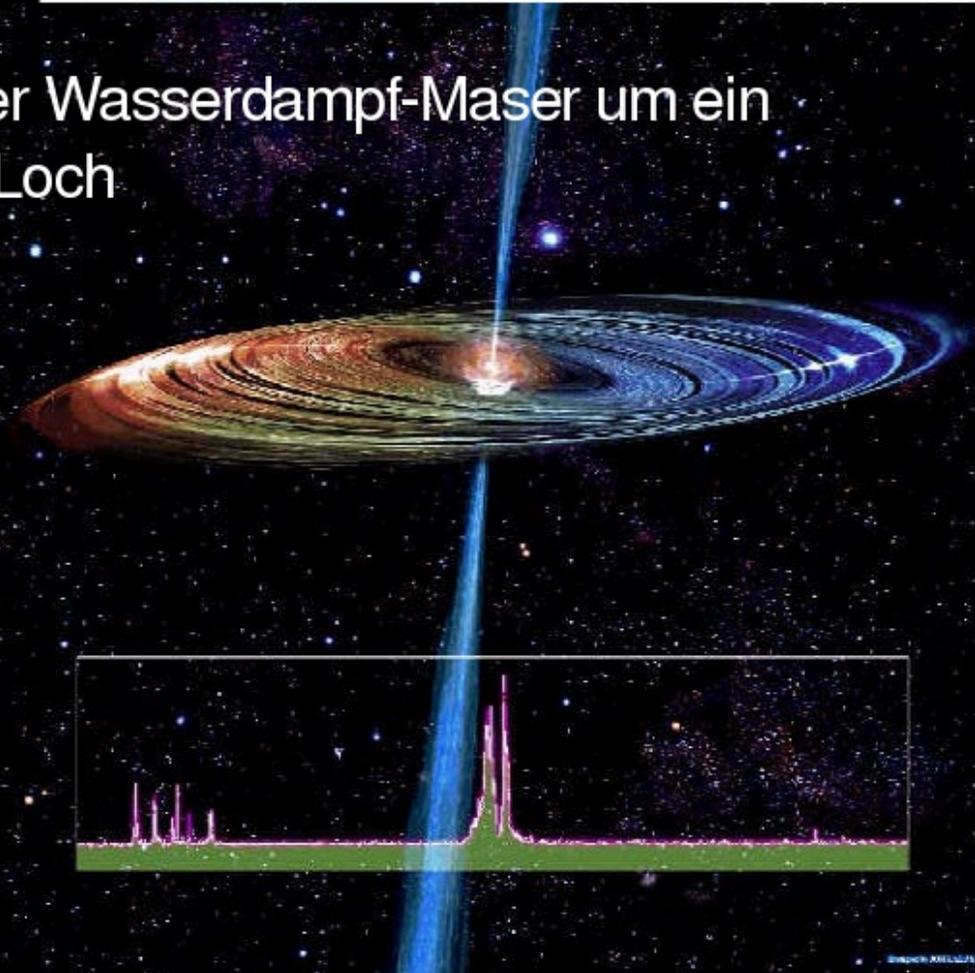
- Kosmische Maser: **Microwave Amplification by Stimulated Emission of Radiation**
- Dem Laser vergleichbare Verstärker von Radiowellen
- Megamaser: in extragalaktischen Galaxien gefundene extrem starke Maser mit einer Leuchtkraft von 100- bis mehrere 1000-Sonnenleuchtkräften
- Angeregter Wasserdampf strahlt z.Bsp. bei 1.3 cm Wellenlänge in Form einer einzigen, besonders intensiven Spektrallinie
- Liefert Informationen über Struktur und Dynamik seiner Umgebung



- ★ b) Megamaser Kinematik in M106 (Miyoshi et al. 1995); NGC4258; natural microwave amplifier=MASER (1982); 40 Mio Sonnenmassen



Der Tanz der Wasserdampf-Maser um ein Schwarzes Loch



# „Quantensprung auf der kosmischen Entfernungsleiter“

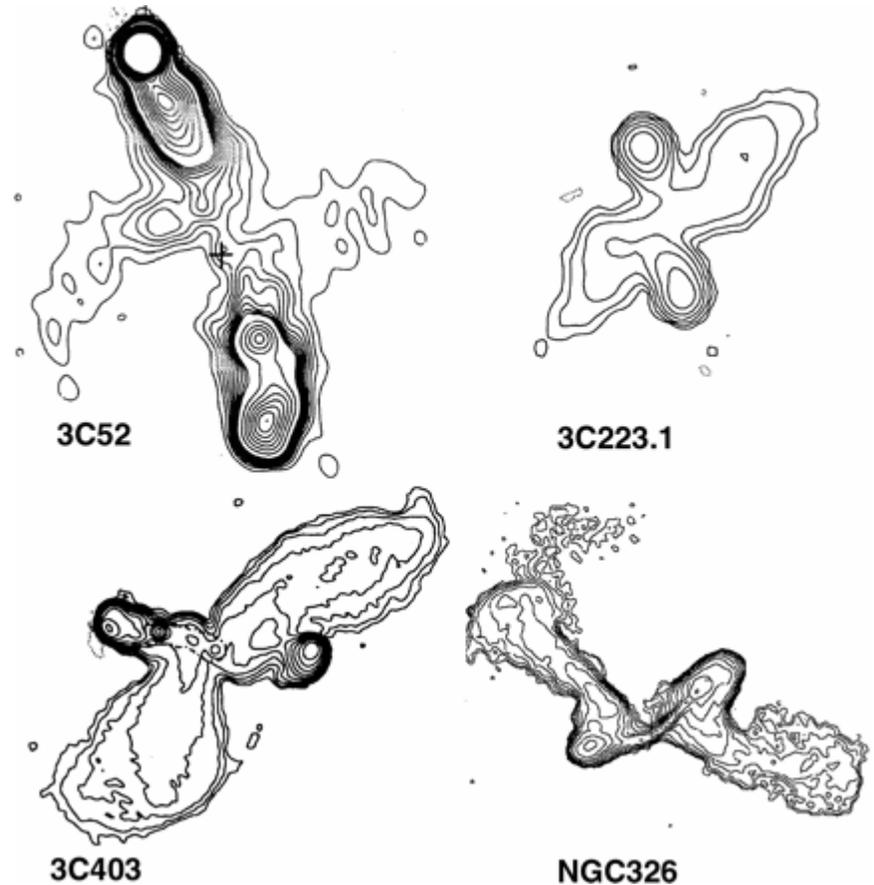


- Systematische Drift der H<sub>2</sub>O-Maser, pro Jahr um 10 km/s beschleunigt, außerdem mit 1000 km/s auf die Erde zu oder von der Erde weg
- Keplerbahnen, 0.1 Millibogensekunden in dreijähriger Messkampagne
- **Abstand Erde/Galaxie NGC4258 (Sternbild Jagdhunde) mit 23.5 Mio Lj bestimmt**
- **Kein Eichen an bekannten, galaktischen Objekten notwendig**
- **Direkt die Bewegung in einer Akkretionsscheibe um den aktiven Kern einer Galaxie beobachtet**

# Binäre Supermassive Schwarze Löcher Änderung der Jetrichtung durch Spin-flip?



- 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)

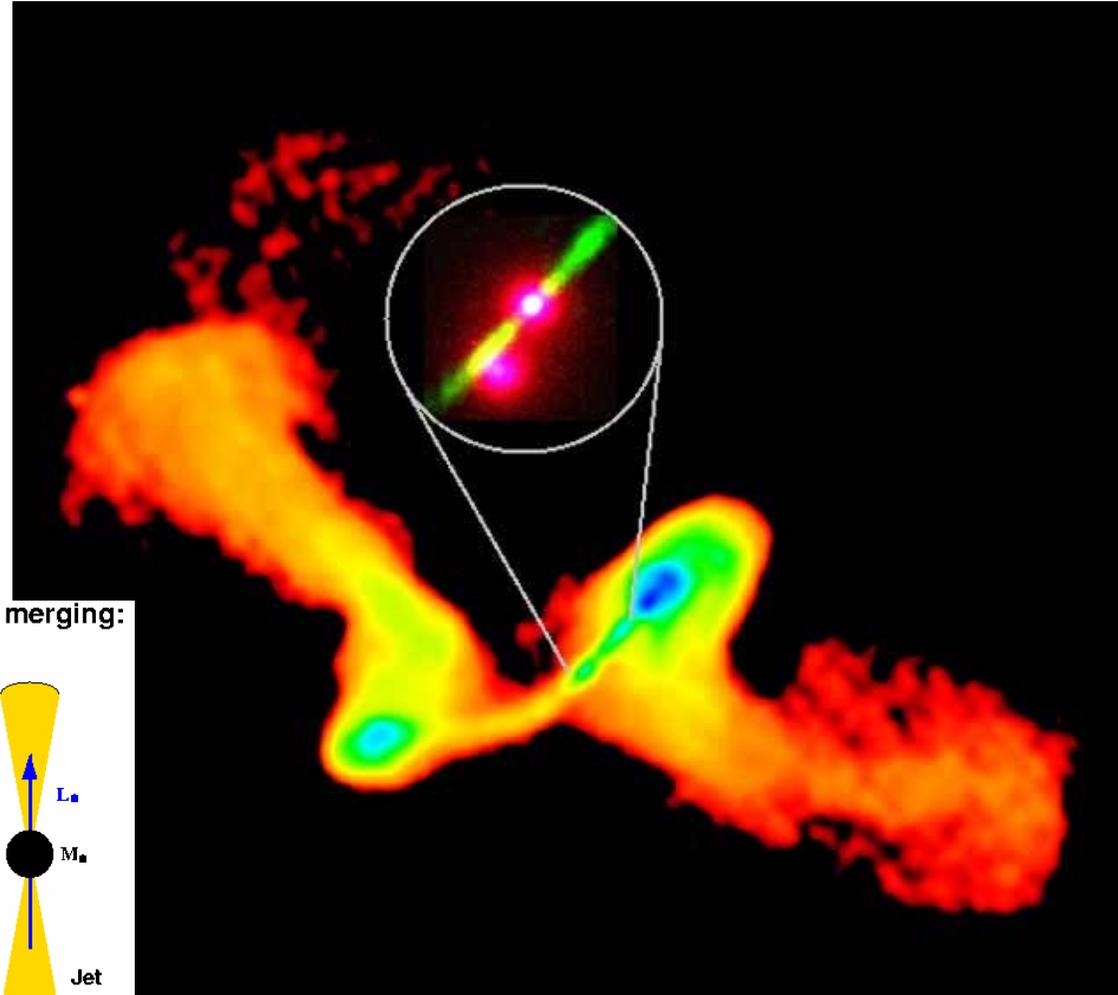


Merritt D. & Ekers R., 2002, Science 297, 1310

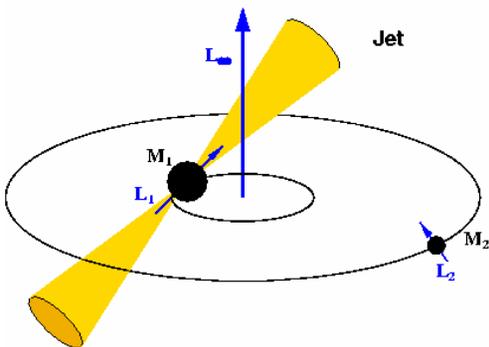
# Nach der Verschmelzung von SBBH Änderung der Jet-Ausrichtung durch einen Spin-Flip?



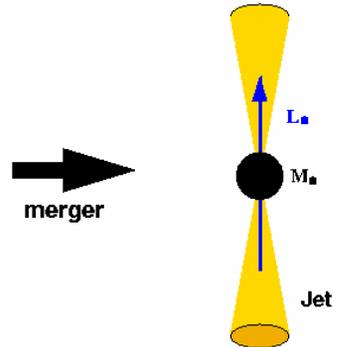
- NGC 326
- Verschmelzung der Schwarzen Löcher: Jets ändern ihre Richtung
- Jet-flip aufgrund eines Spin-flips des primären Schwarzen Lochs (dem orbital angular momentum folgend)



Before merging:

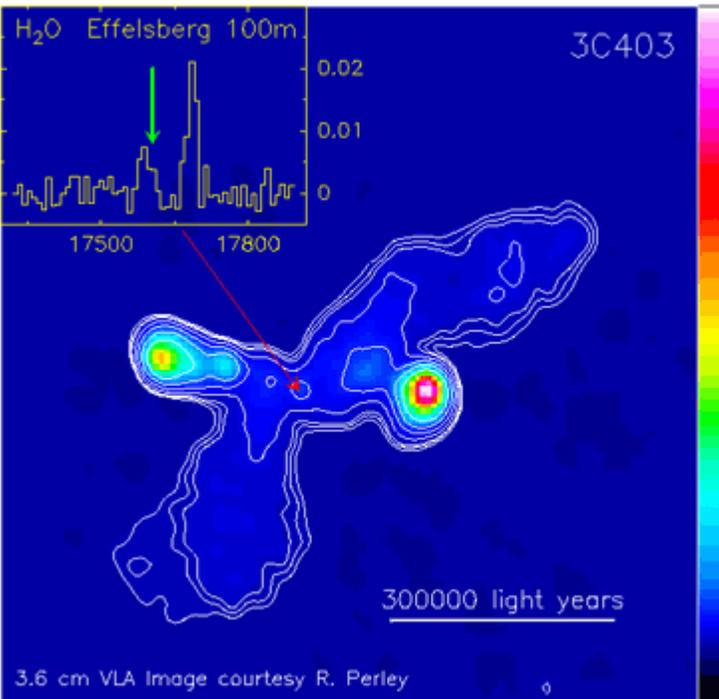


After merging:



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

# Megamaser in AGN



Aufnahme mit dem VLA, 3.6cm, Pfeil zeigt Galaxienkern, Spektrum gemessen mit Effelsberg, Flußdichte gegen Geschwindigkeit, grüner Pfeil zeigt Systemgeschwindigkeit der Galaxie

- Weitest entfernte Megamaser in der Galaxie 3C403 (750 Mio Lj)
- Strahlung in einer Spektrallinie tausendfach stärker als die der Sonne im gesamten Spektralbereich
- Zum ersten Mal in „klassischer“ Radiogalaxie gefunden
- Beobachtete Geschwindigkeitsverteilung entspricht Erwartungen für eine scheibenförmige rotierende Materieverteilung um den Galaxienkern
- „Soviel Wasser habe ich in meinem ganzen Leben noch nicht einmal gesehen“
- Bislang: 31 H<sub>2</sub>O Megamaser-Galaxien detektiert

# Megamaser / ULIRGs



- Ultraleuchtkräftige infrarot Galaxien (Merger):  
Energiequelle unbekannt
  - AGN
  - Oder starburst?
- Mit OH-Megamaser können die Bedingungen in den inneren Regionen untersucht werden -> daraus auf die Energiequelle schließen
- Bsp.: Arp220, warme ausgedehnte Natur deutet auf starburst