2006 Mar 26, @Alexandria, Egypt

Cosmic Jets

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contents

- Introduction
- Astrophysical jets
  - active galactic nuclei (AGN)
  - close binary system
  - young stellar object (YSO)
- Solar jets
- What is the origin of cosmic jets ?

1. Introduction

- 19C static universe

↓

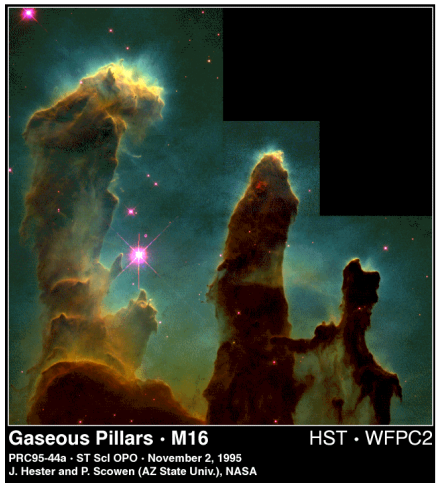
- mid 20C evolving universe

↓ radio、X-ray、infrared

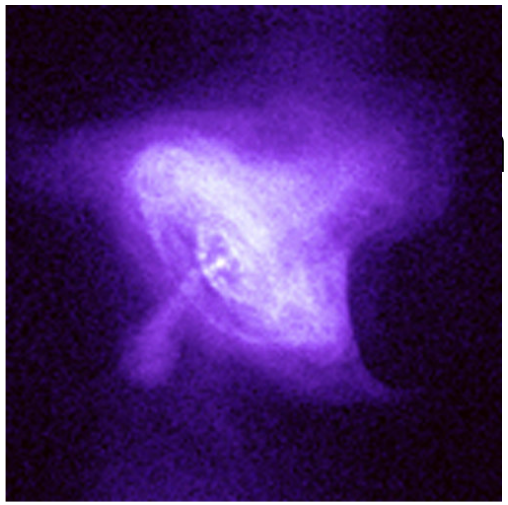
- late 20C active universe

universe is full of explosions and jets !

evolution of stars



- formation interstellar cloud
  = > stars (Sun)
- evolution stars (Sun)
  = > giant stars
- Death (low mass stars: Sun) planetary nebula
  = > white dwarf
  (high mass stars) supernova
  = > black hole
  neutron s



Quasar was discovered in 1960's
(QSO : 3 C 2 7 3)

Looks like a star, but actually a nucleus of galaxies

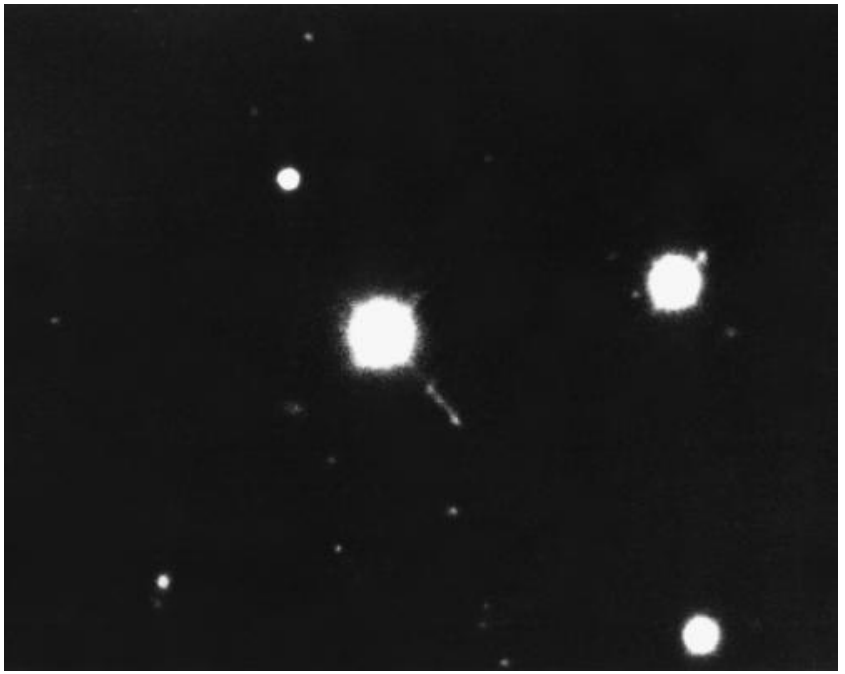
=> Active Galactic Nulei (AGN)

Distance ~ 300 million light years

=> huge energy release rate ~10^{46} erg/s

Total released energy ~10^{62} erg

optical



Most energetic ojbect in our universe

My dream when I was young

I wanted to resolve active galactic nuclei (AGN) and their jets, the most puzzling object in the universe, while I am alive

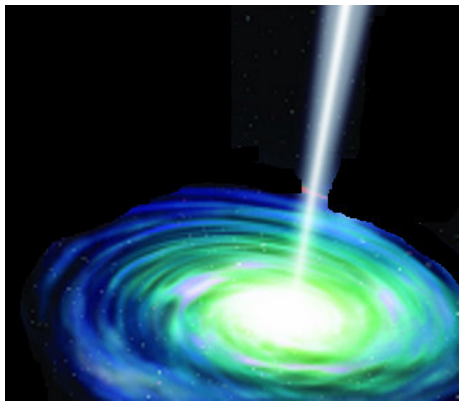
However, AGNs are too far from us to reveal.

So, I thought it would be clever to study solar jets at first using observations and theory, and then apply solar jet theory to these puzzling AGN jets

Astrophysical Jets

- AGN (active galactic nuclei) jets
- Close binary system jets
- YSO (young stellar object) jets

=> jets from accretion disks

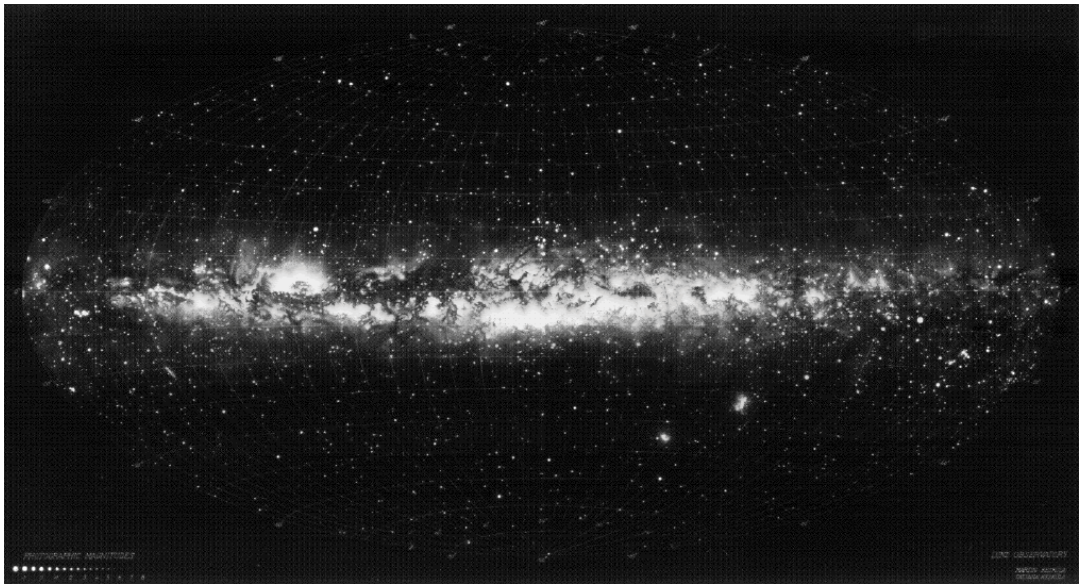


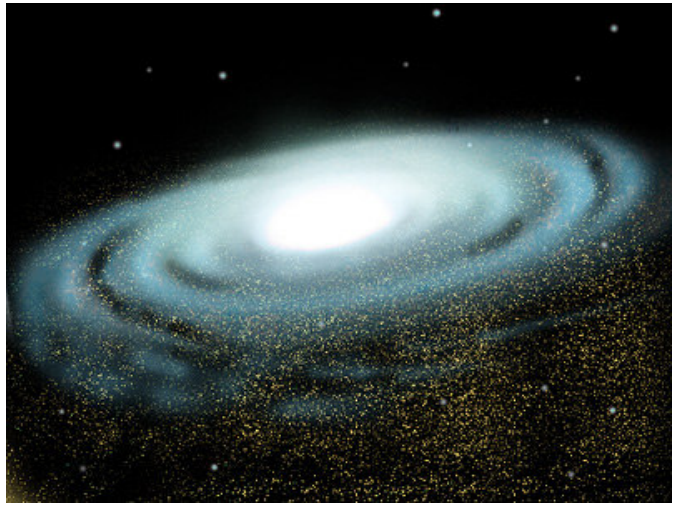
Active galactic nuclei (AGN) jets
= jets from nucleus of galaxies

Milky way

Milky way (Our Galaxy)

Milky way is a disk Galaxy containing a huge number of stars,
~ 100 bilion stars

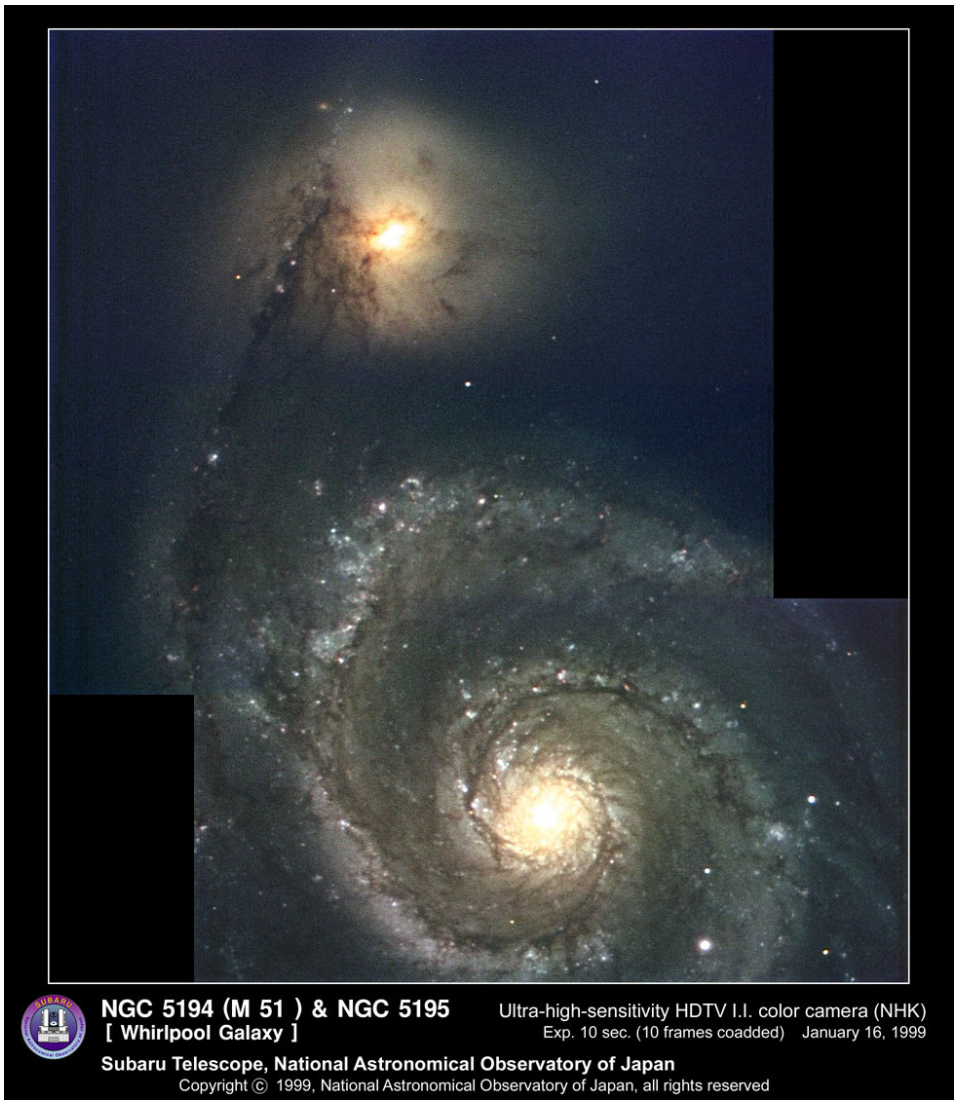




Hypothetical view

M31 (Andromeda galaxy)

M51


NGC 5194 (M 51) & NGC 5195
[Whirlpool Galaxy]
Ultra-high-sensitivity HDTV I.I. color camera (NHK)
Exp. 10 sec. (10 frames coadded) January 16, 1999
Subaru Telescope, National Astronomical Observatory of Japan
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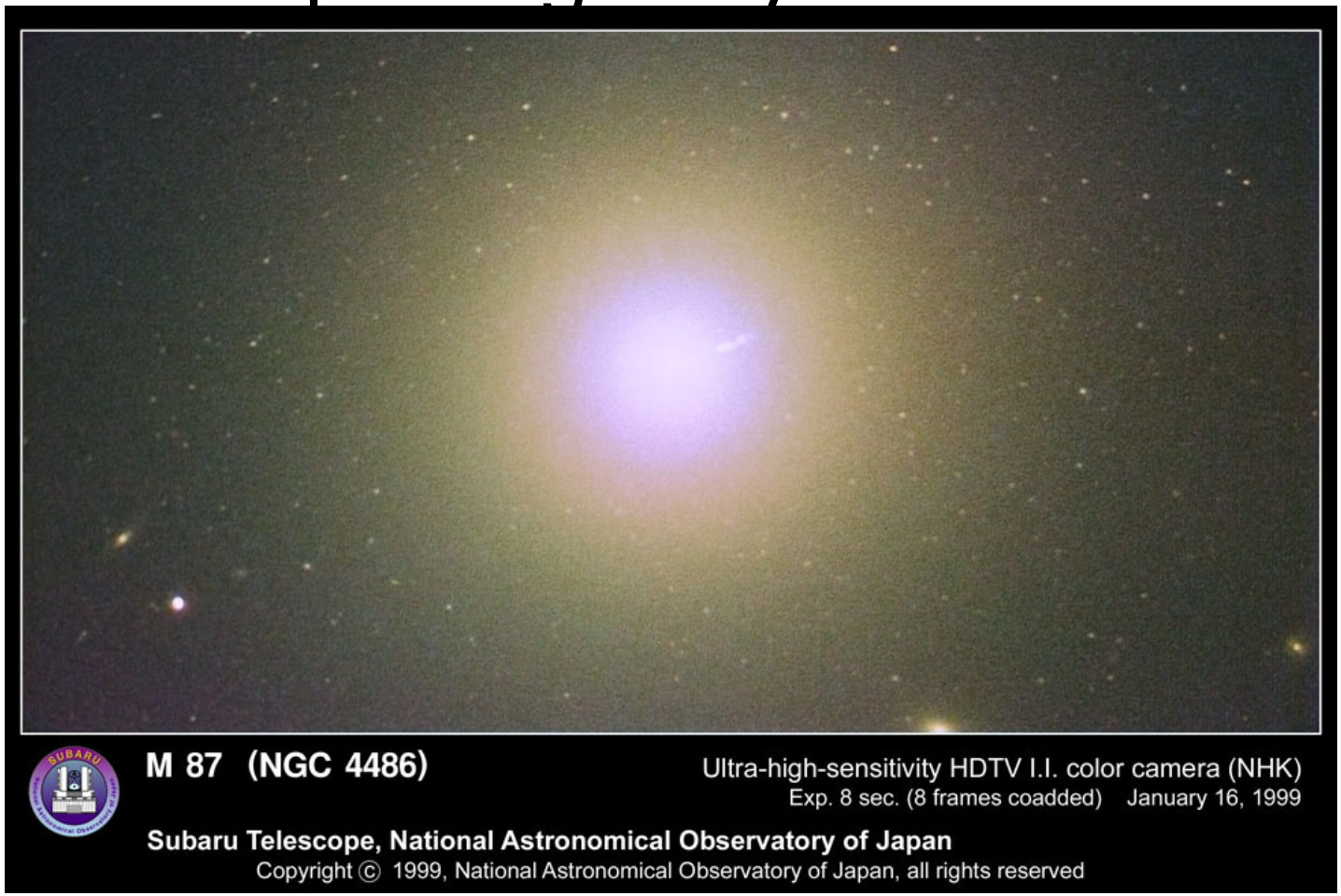
Whirlpool Galaxy • M51

Hubble Heritage

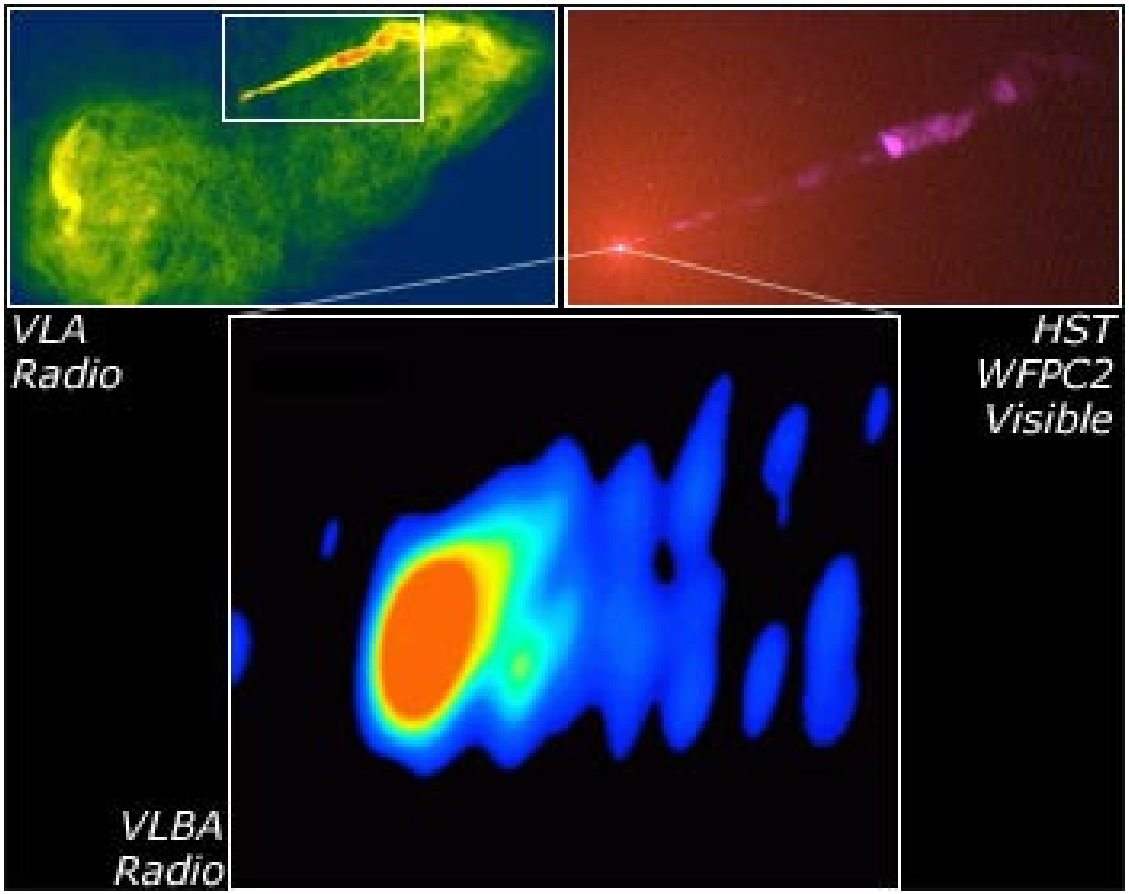
NASA and The Hubble Heritage Team (STScI/AURA)
Hubble Space Telescope WFPC2 • STScI-PRC01-07

First Discovered Jet （Curtis, 1917）
Elliptical galaxy M87



First Discovered Jet （Curtis, 1917）
Elliptical galaxy M87

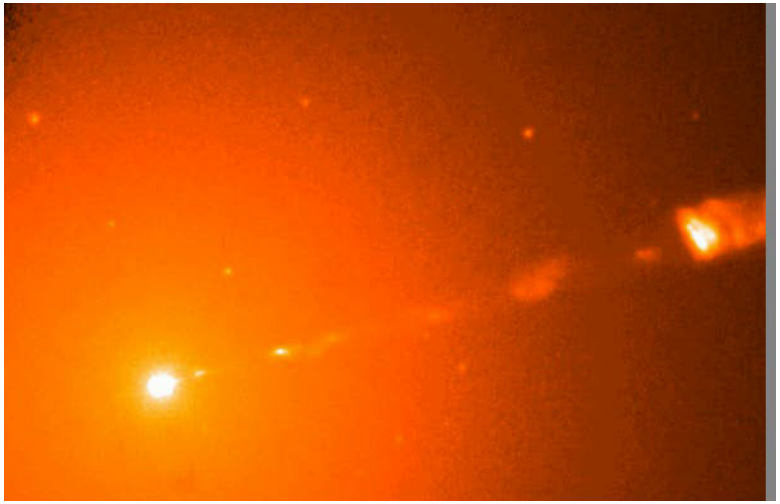
M 8 7 = radio galaxy = active galactic nuclei

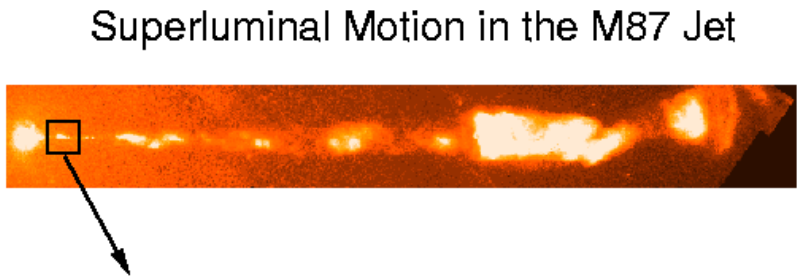


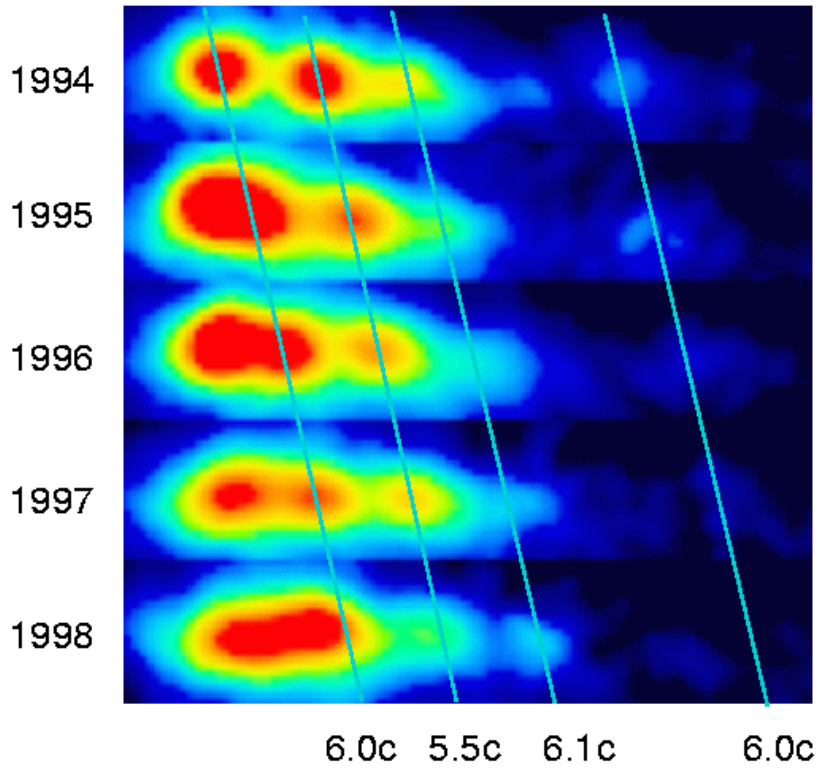
- Energy source of double radio source is jets
- The direction of jet is fixed from 3 light year to 300000 light year

Superluminal motion

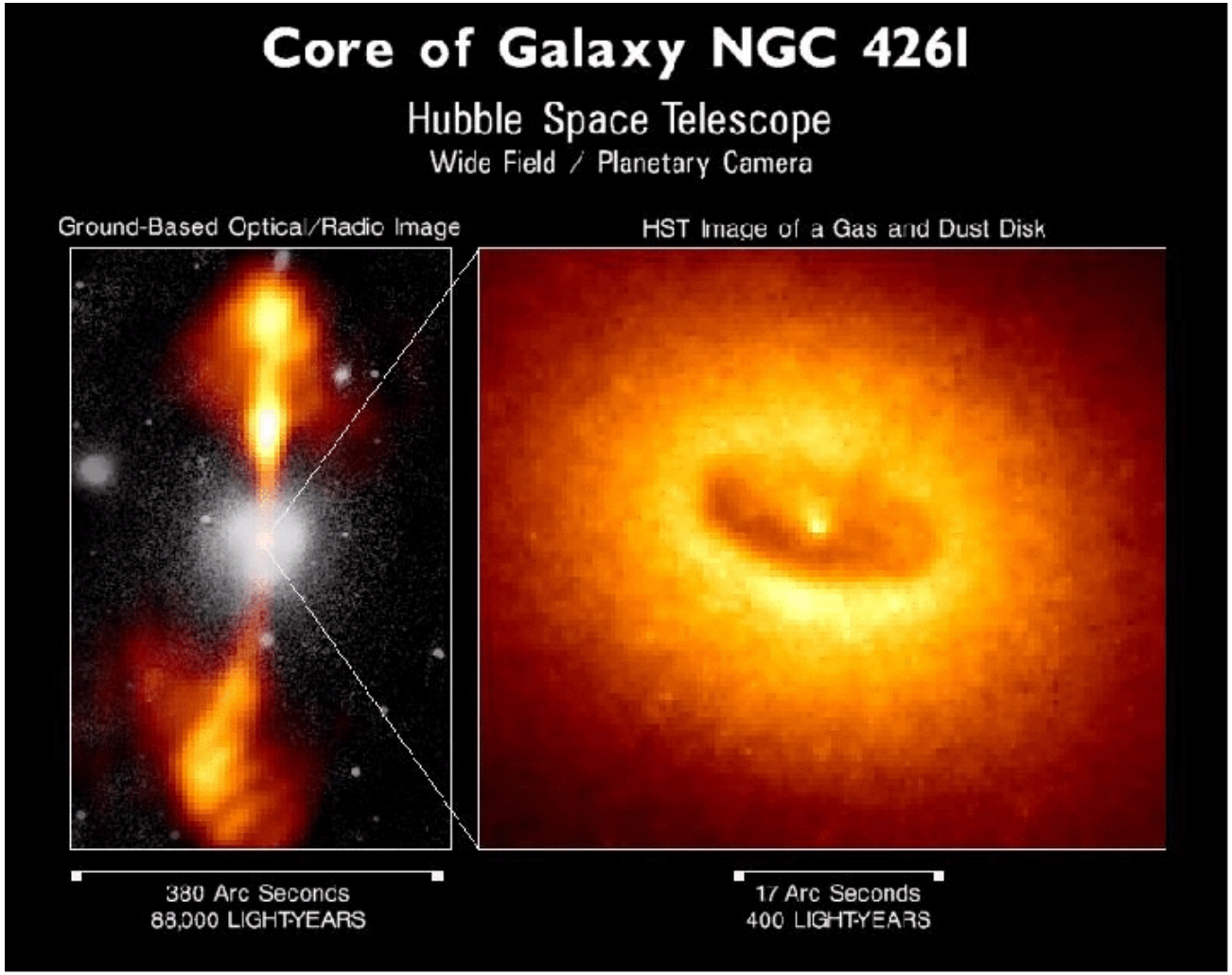
velociy of jet exceeds the speed of light







Accretion disk (tori) was found at footpoint of AGN jets



What is active galactic nuclei (AGN) ?

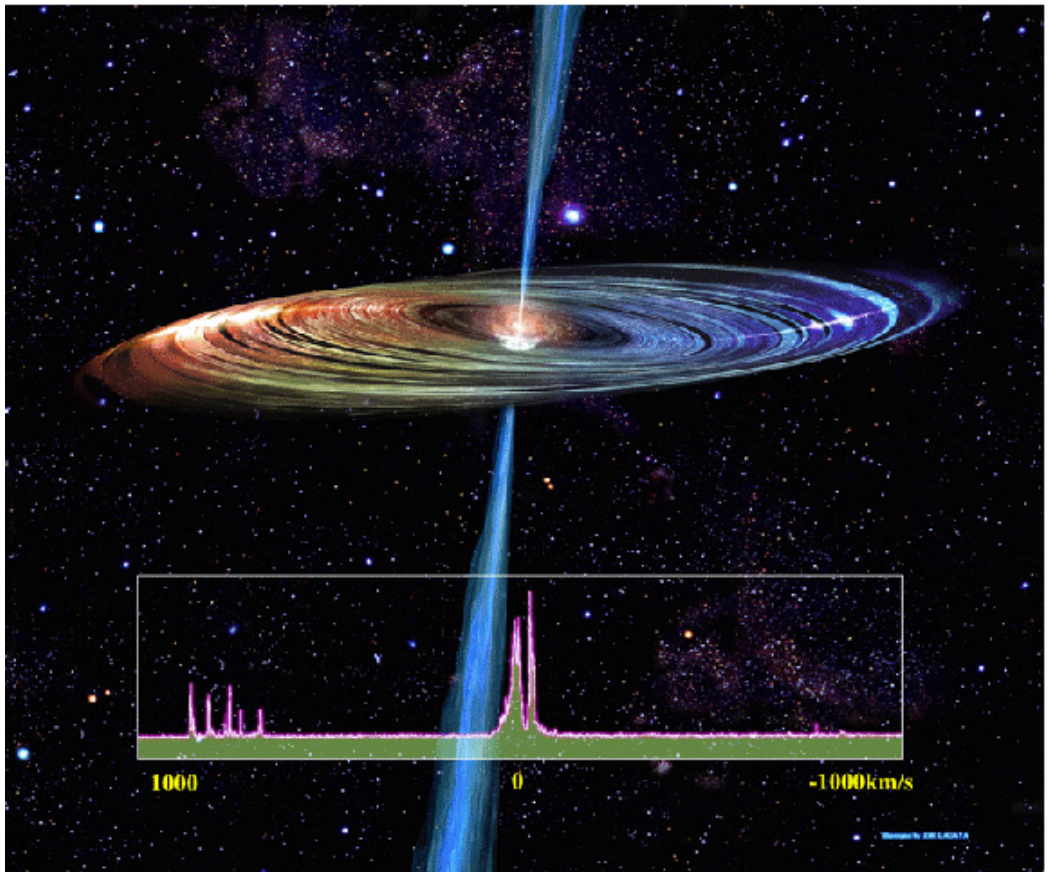
It is a supermassive black hole !

Miyoshi, Nakai,
Inoue et al.
(Nature 1995)

discovered

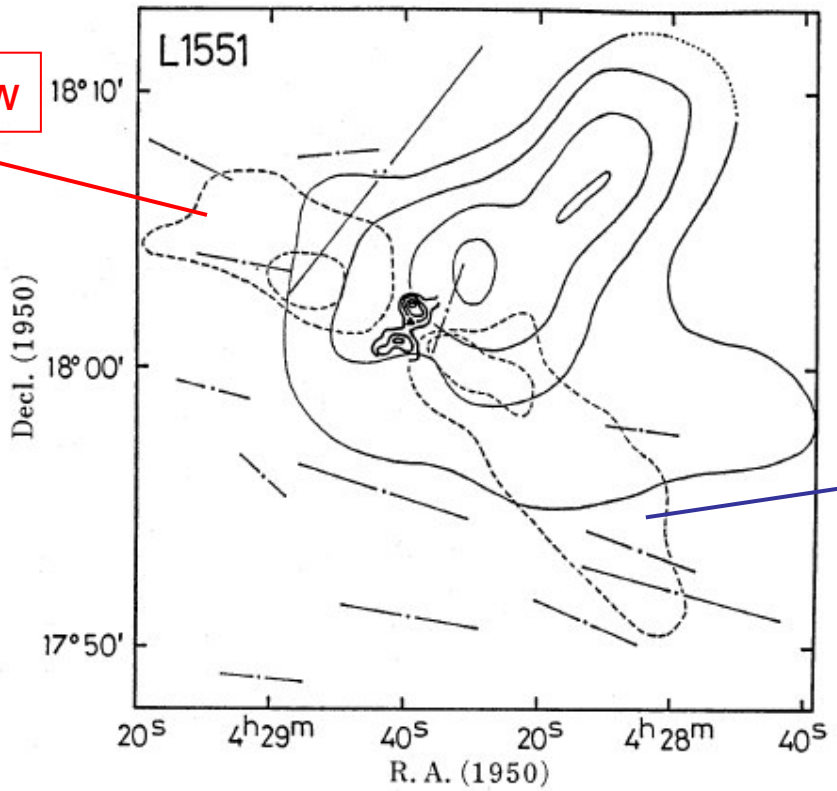
10 million solar mass black hole in the center of a galaxy

Using Nobeyama 45m radio telescope and VLA



Young Stellar Object (YSO) jets

Bipolar molecular flow was discovered in star forming region L1551 by Snell et al. (1980)

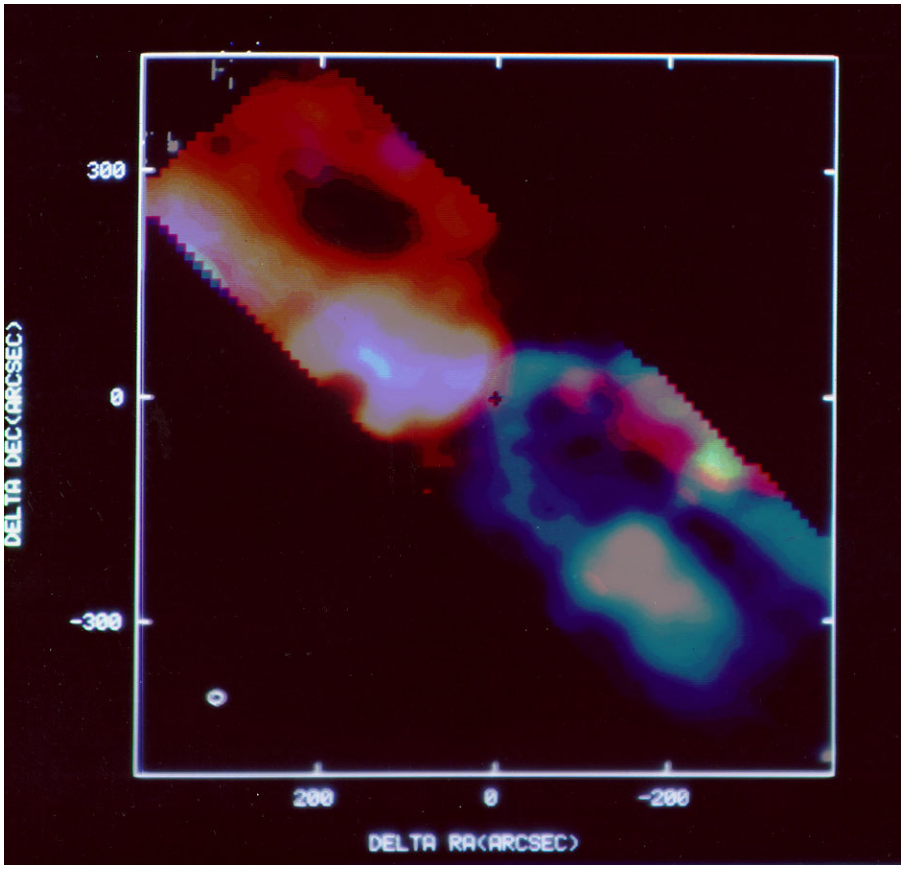


Red shifted flow

Blue shifted flow

Fig. 1. Figure taken from Kaifu et al. (1984) in which the contours of CS intensity (thick-line contours) is overlain on the contours of CO (dashed-line contours) by Snell et al. (1980).

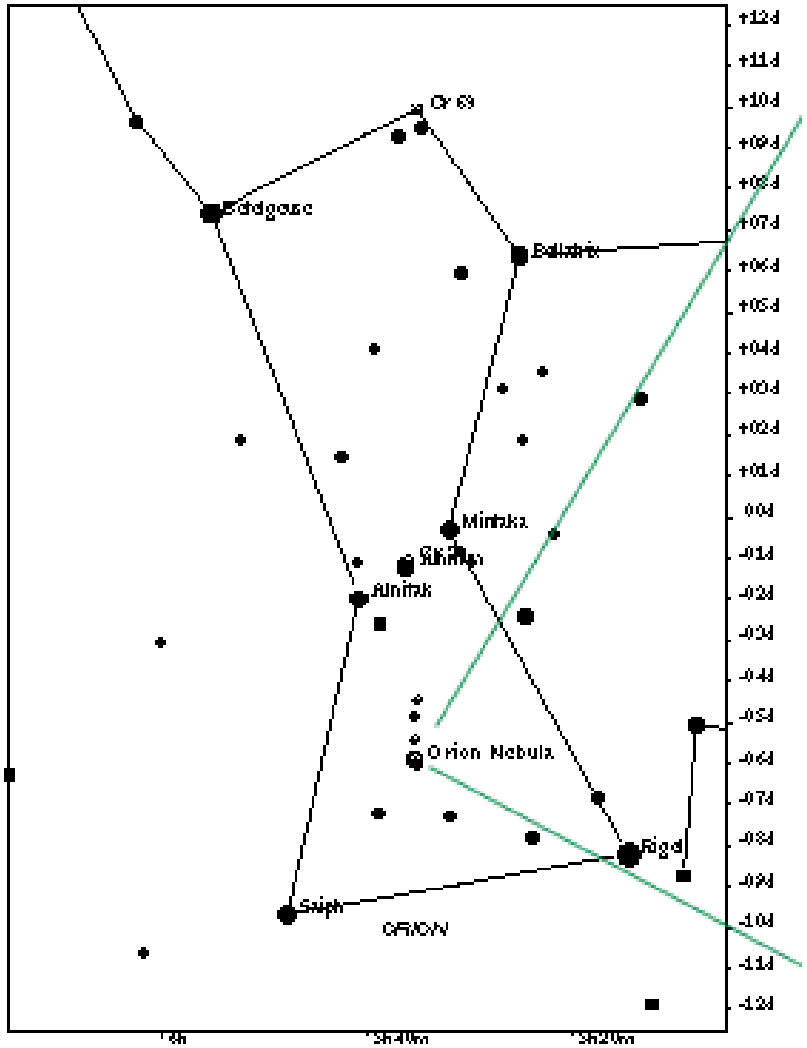
Molecular bipolar flows ejected from protostar L1551



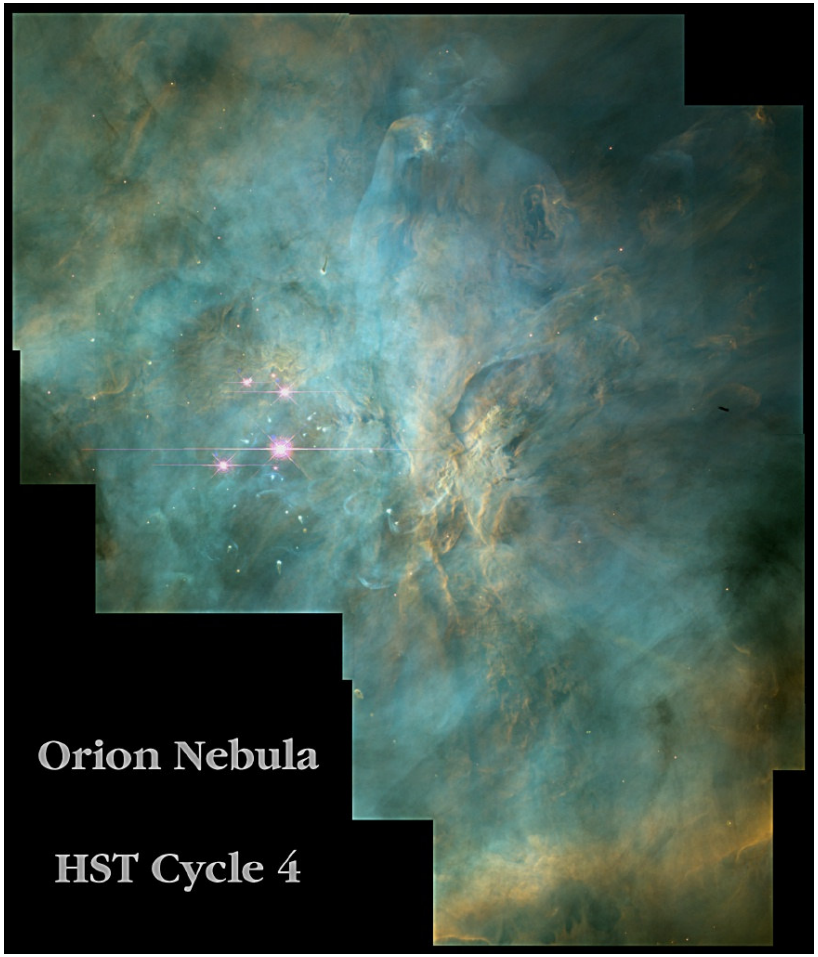
Velocity ~ 10 km/s

(Uchida et al, 1988, by Nobeyama 45 m radio telescope)

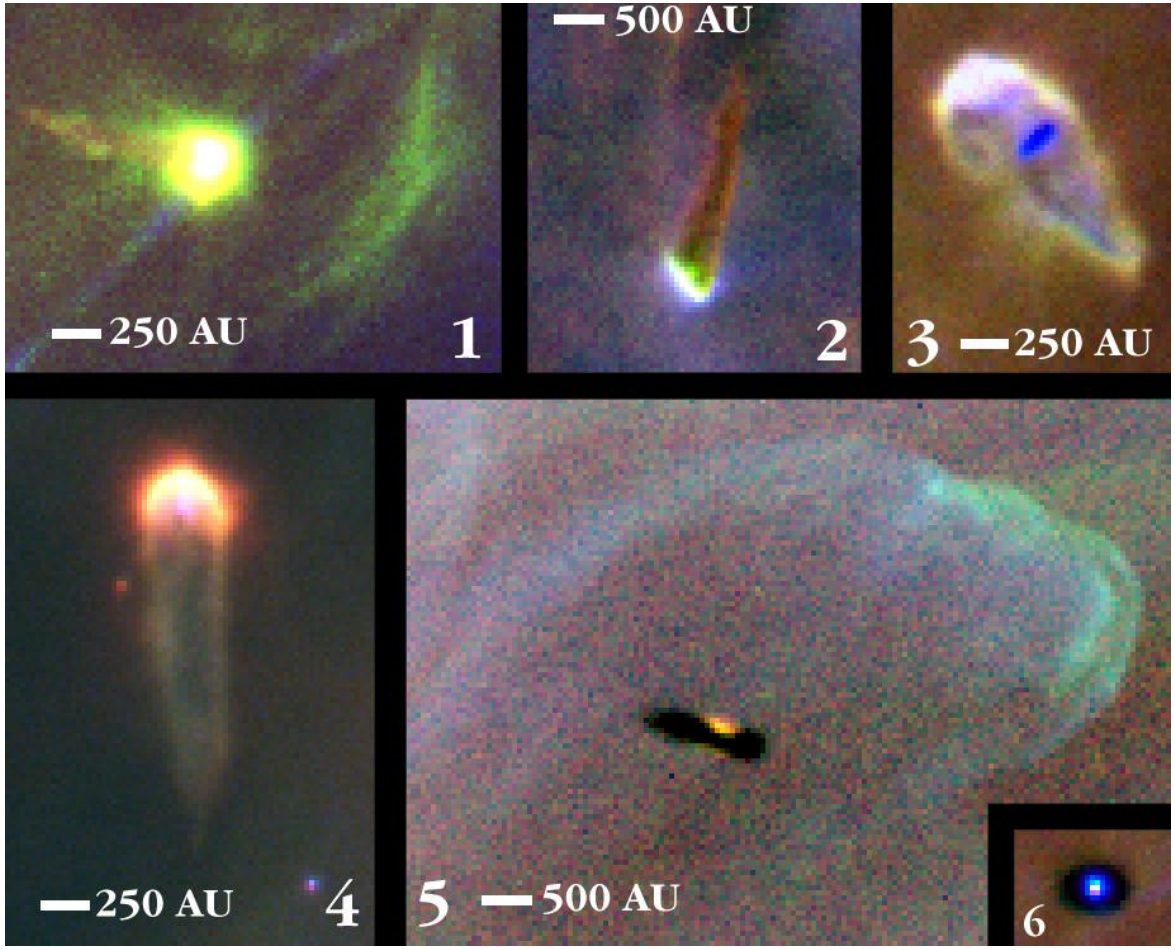
What is a star forming region ? - Orion



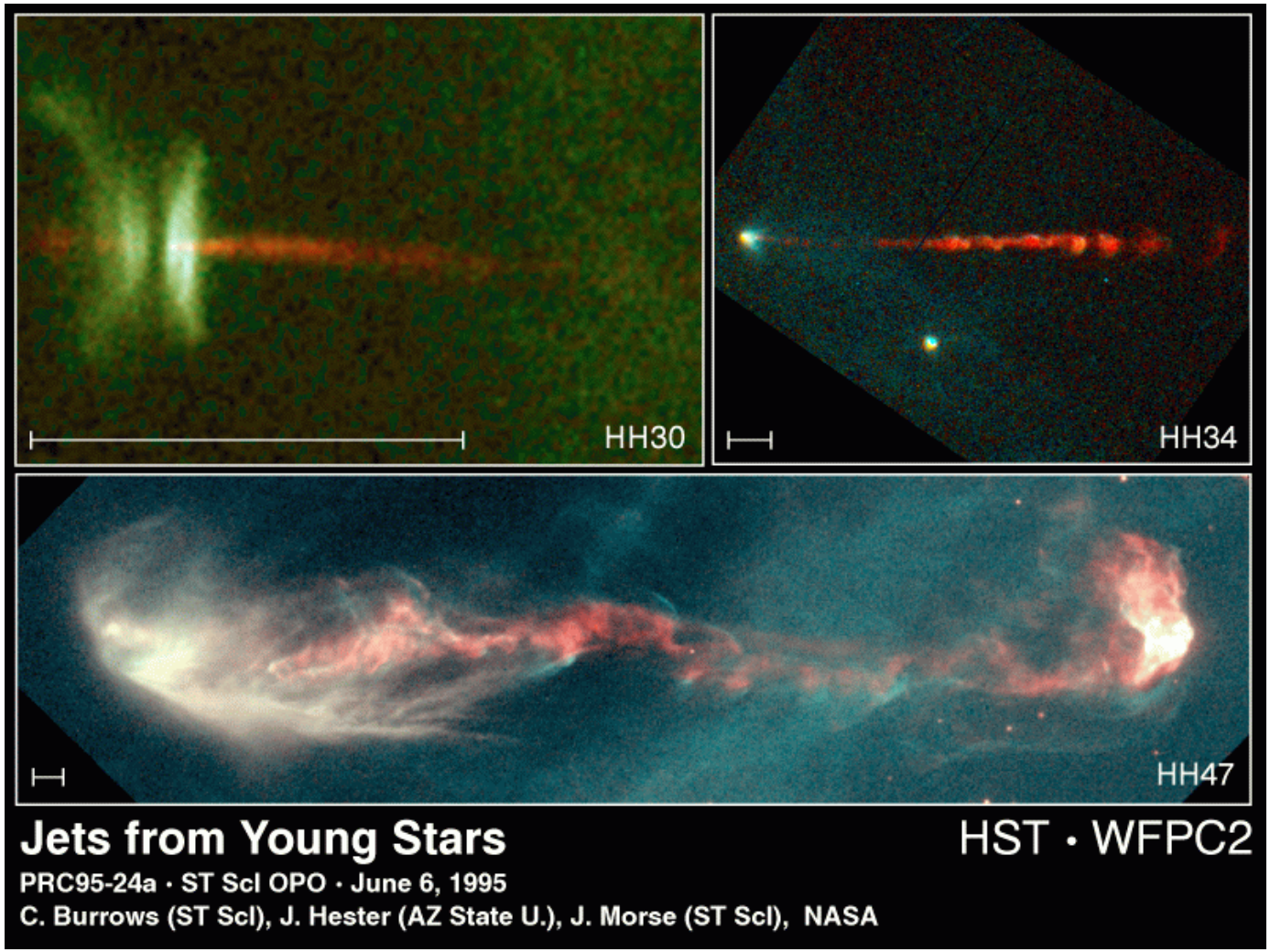
Orion cloud



Orion small solar system



YSO (Young Stellar Objects) jets

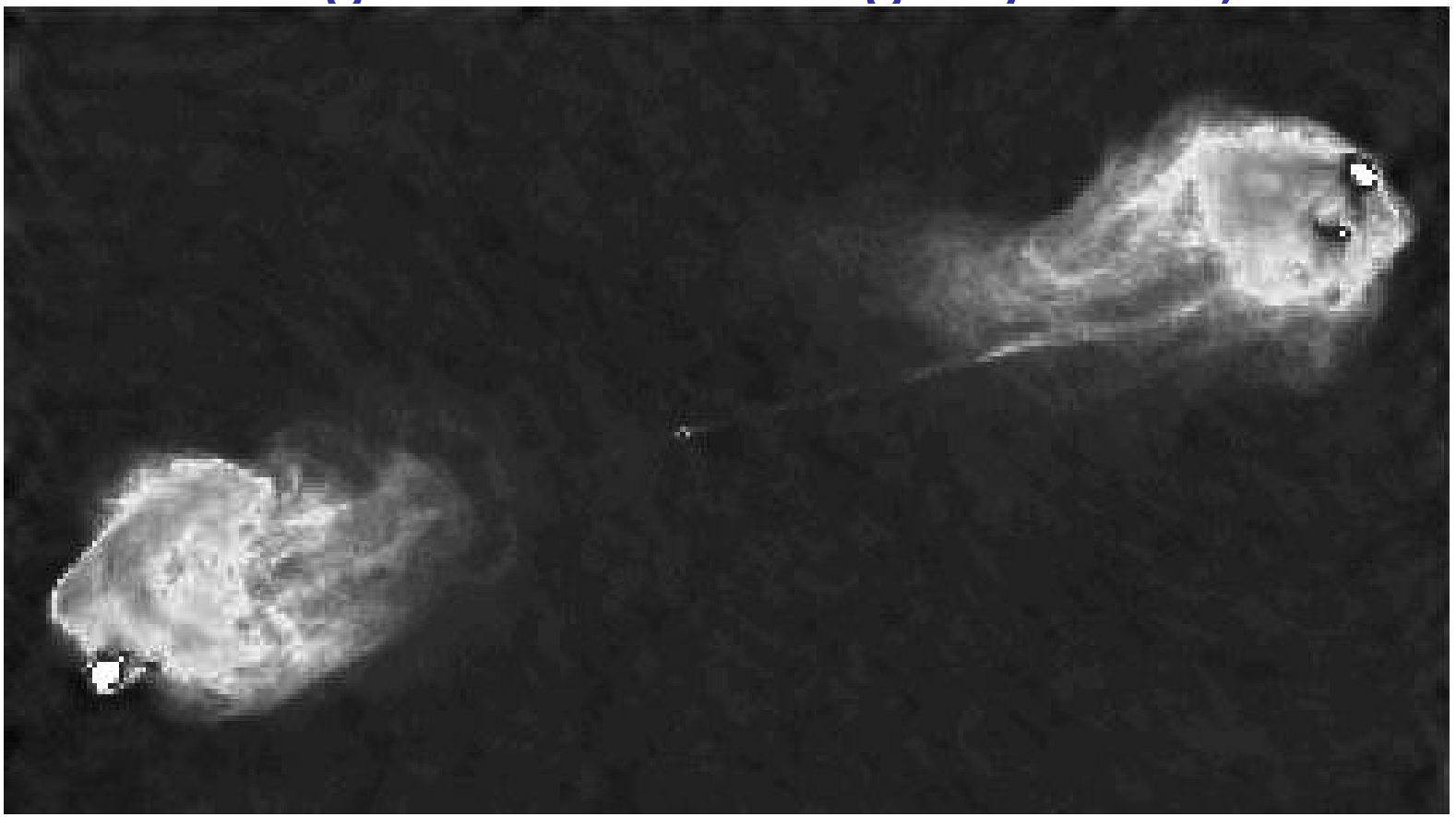


Protostellar Jet (HH1/2)
(length ~ 3 light year)

Optical/ Hubble

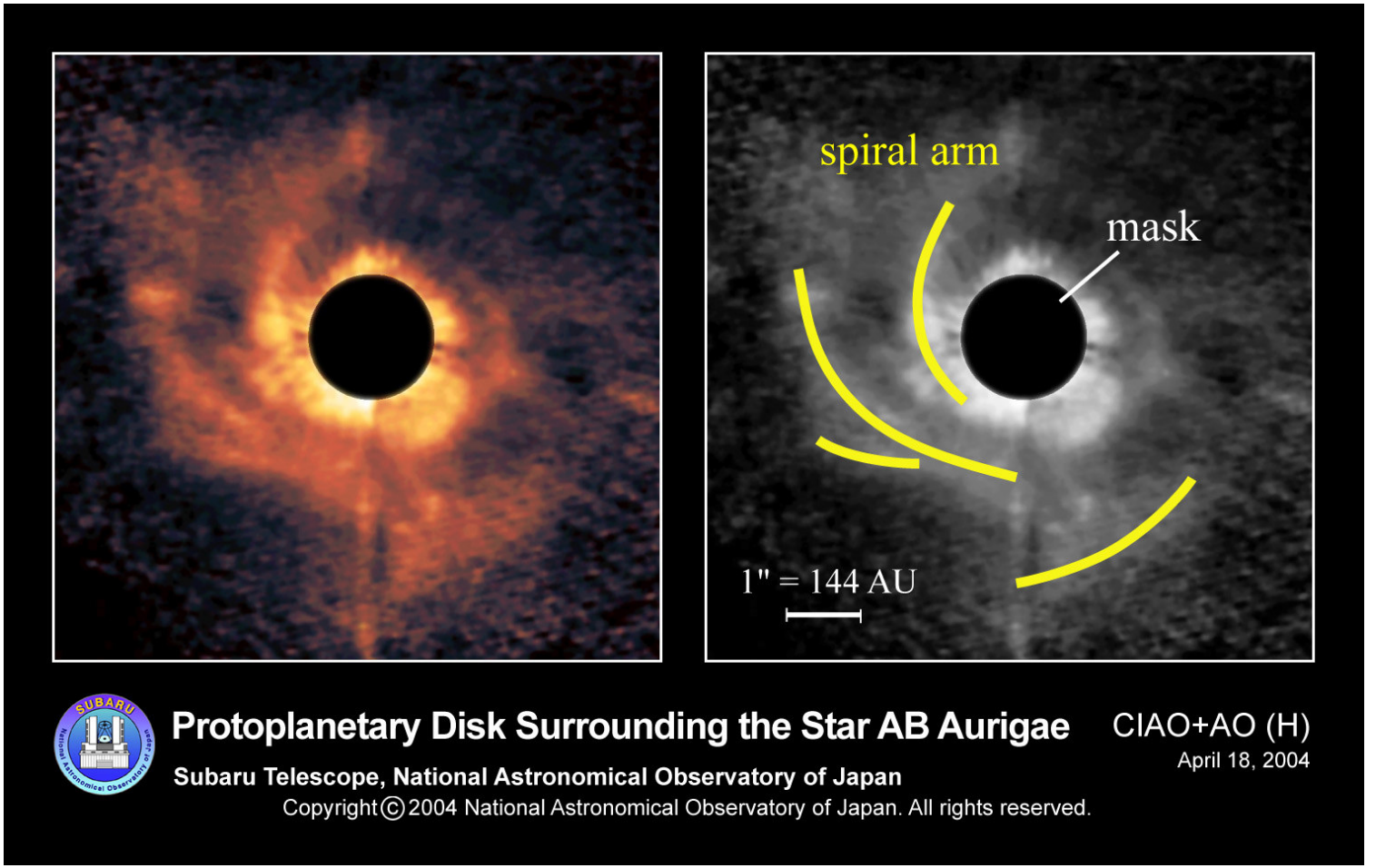
Radio Galaxy (Cygnus A) : AGN

(distance ~ 450 million light years、
length ~ 300 000 light years)

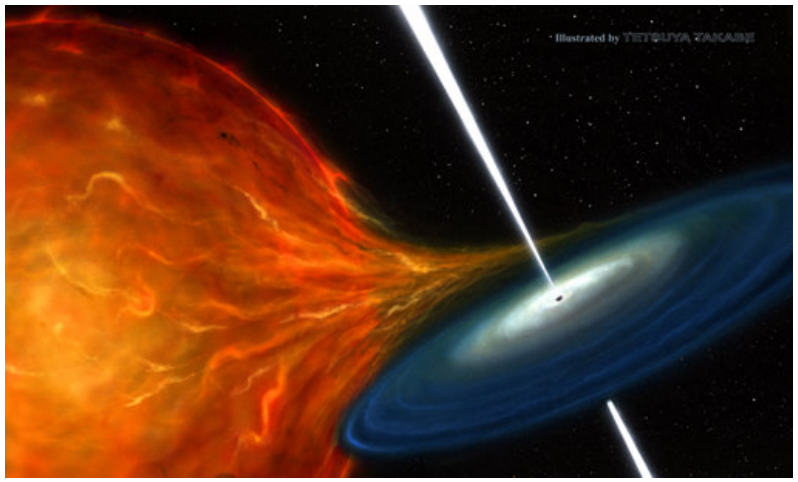


Radio/VLA

Proto-planetary disk was observed



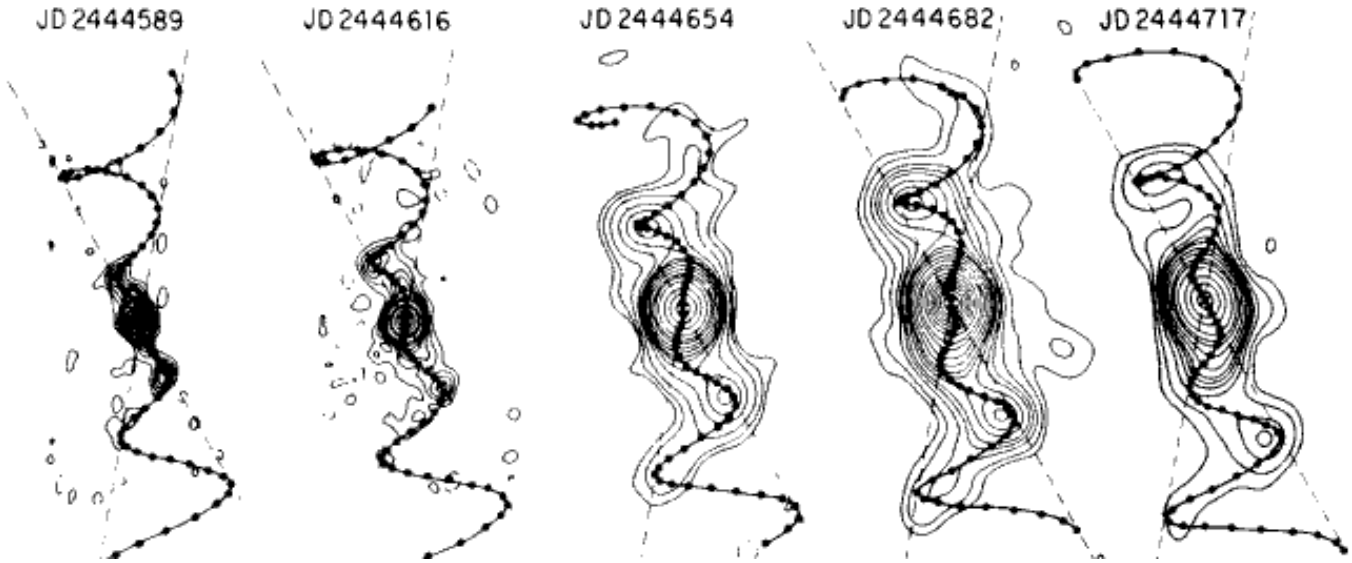
Jets from close binary system



SS433

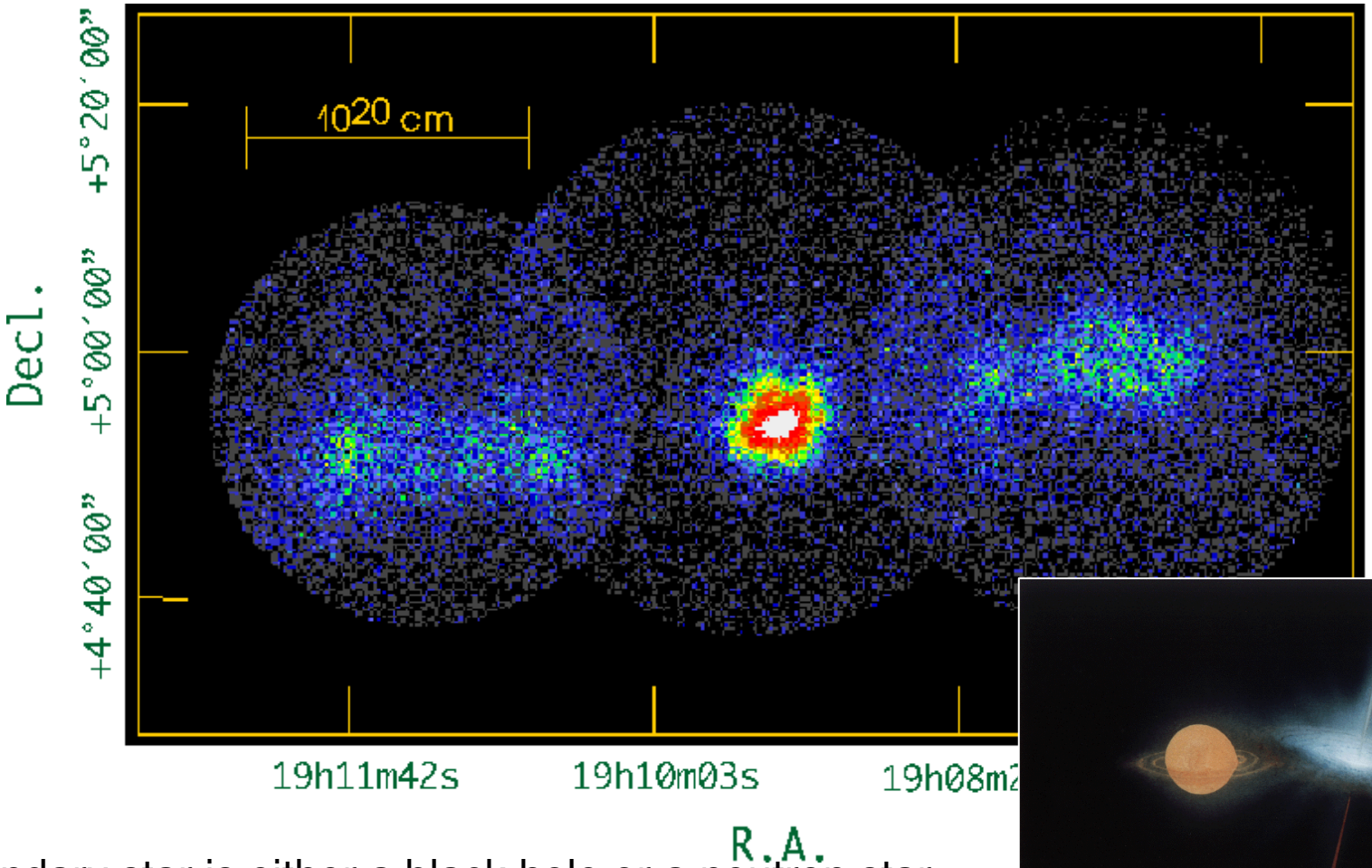
- SS433 jet was discovered by Margon in 1984

（ radio、velocity = 0.26c ）



close binary system jet

(SS433: X-ray/ASCA)



Secondary star is either a black hole or a neutron star

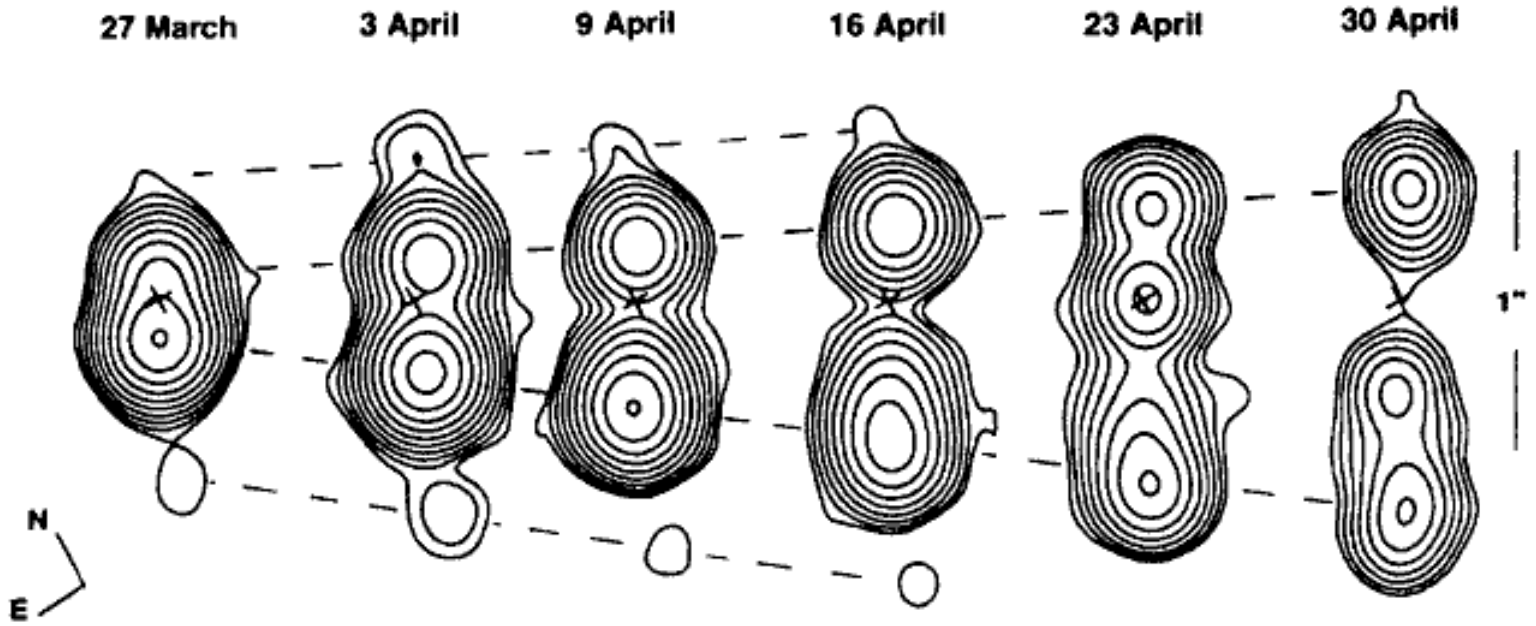
Superluminal motion in jets from close binary system

(microquasar)

(jet velocity ~ 1 . 2 5 c、

GRS 1915+101

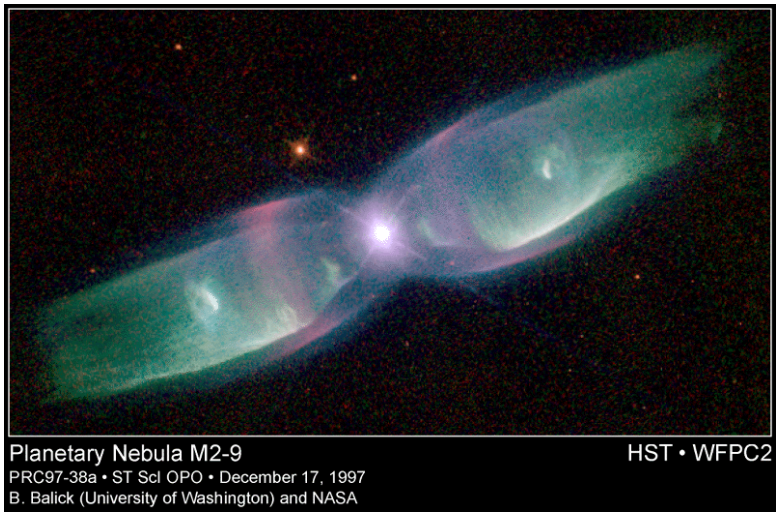
5)



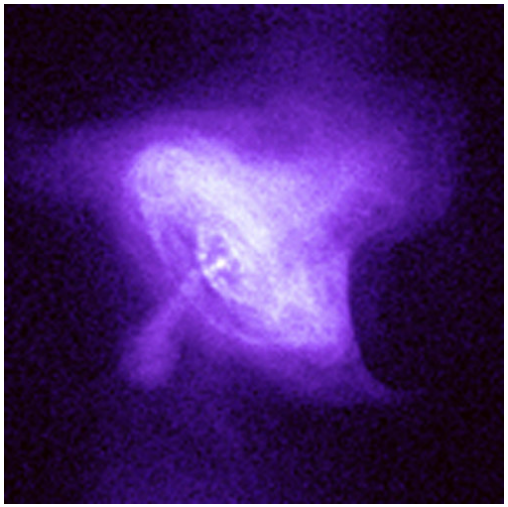
Summary of Characteristics of Astrophysical Jets

	AGN (active gal. nulcei)	Close binary system	YSO (young stellar obj.)
Central object	Supermassive black hole	Black hole or neutron star	protostar
Jet length	3 M light year	10 light year	1 light year
Jet velocity	c (light speed)	0.3c - c	100km/s
Escape velocity	c	0.3c - c	100km/s

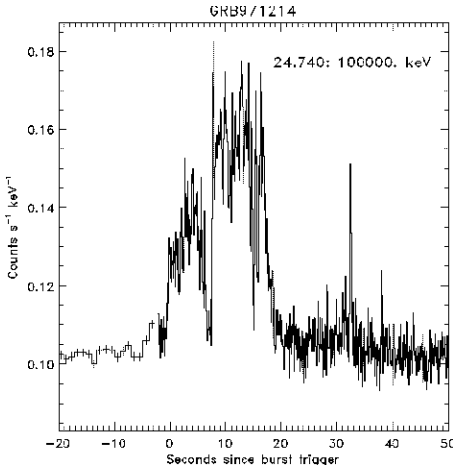
Universe is full of jets !

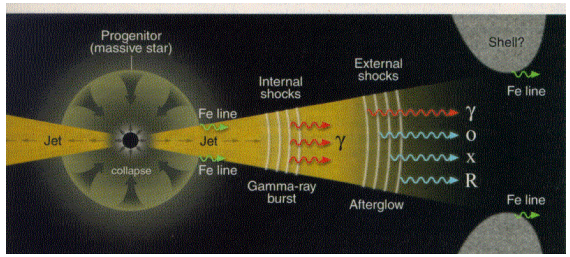


Planetary nebula

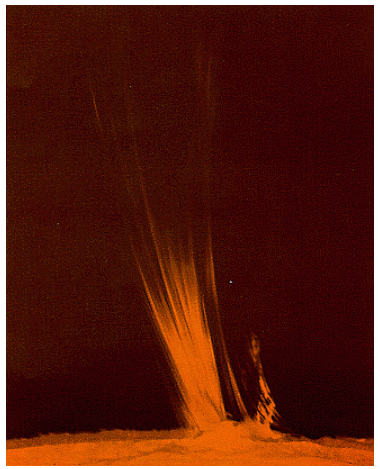


Pulsar jet





Gamma ray bursts

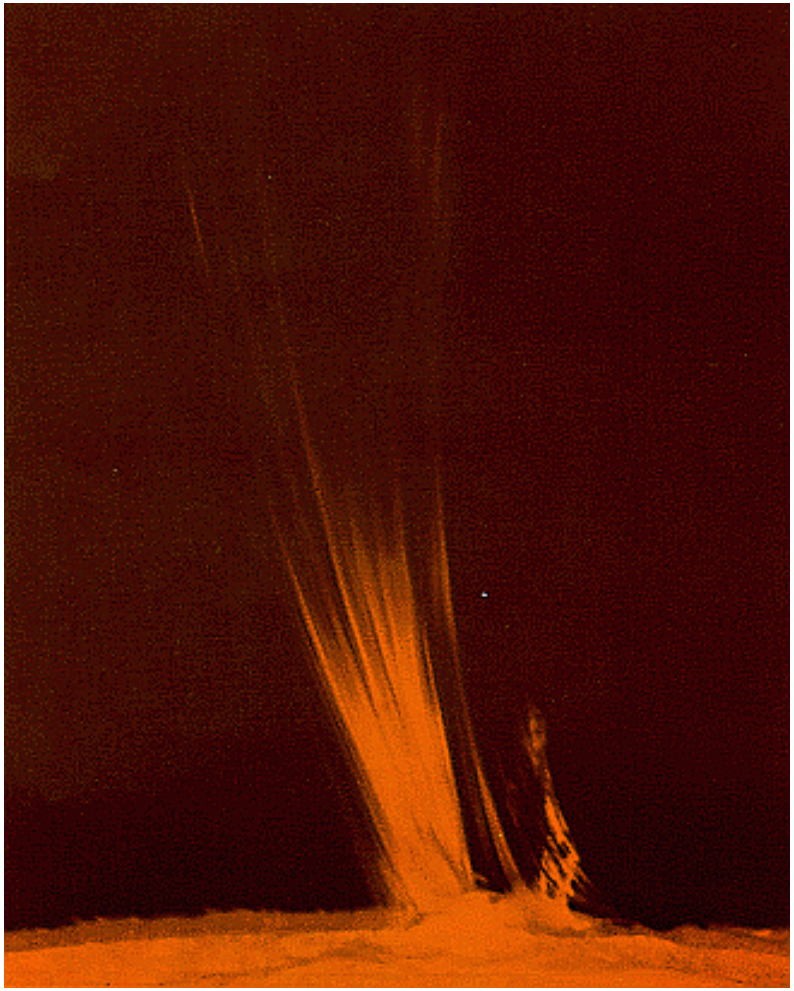


Solar jet

Solar jets

Solar Jet

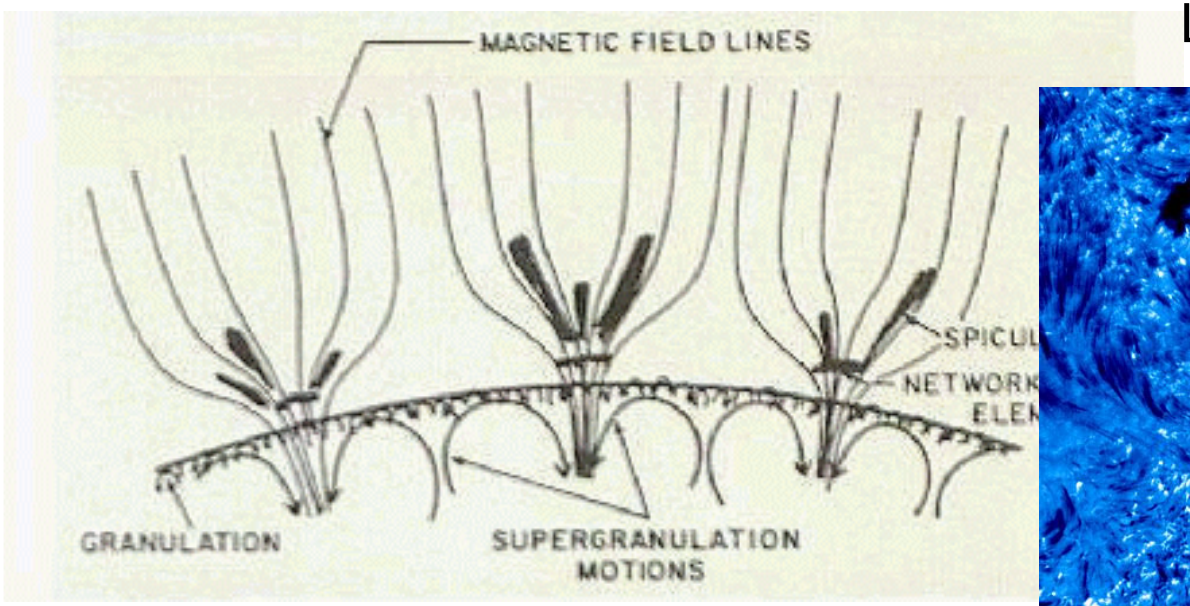
(length ~ 10^5 km, velocity ~ 100 km/s)



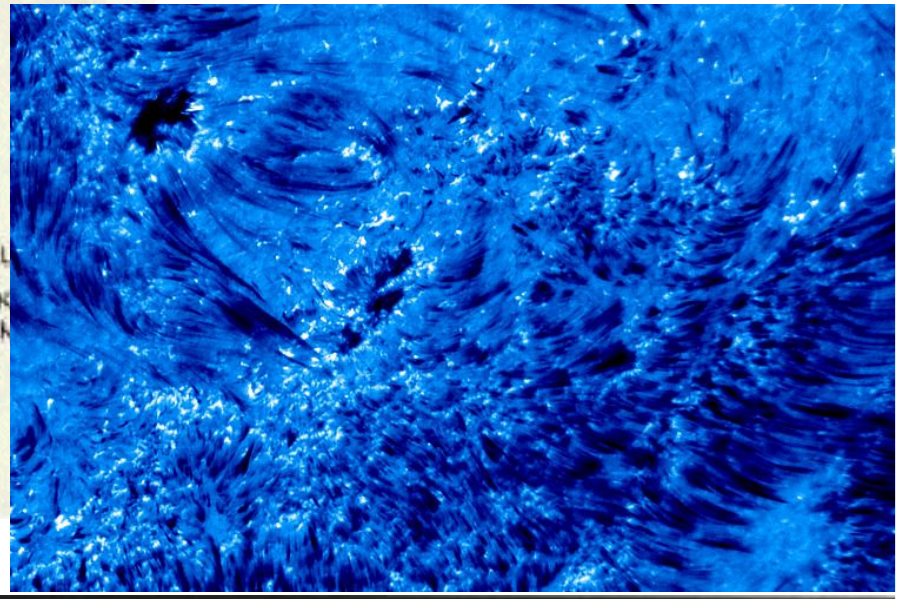
H alpha surge observed at Hida observatory of Kyoto University

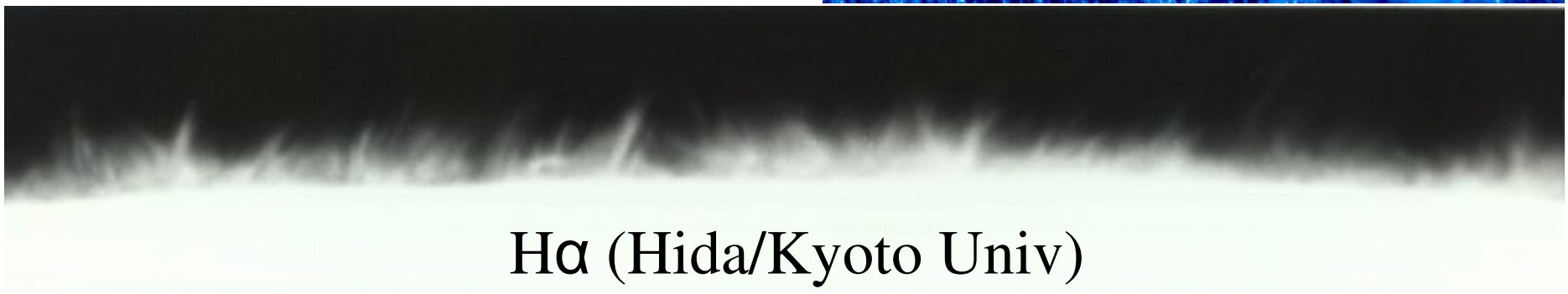
Magnetic field is essential

Solar spicule
(supersonic jet in the solar chromosphere)



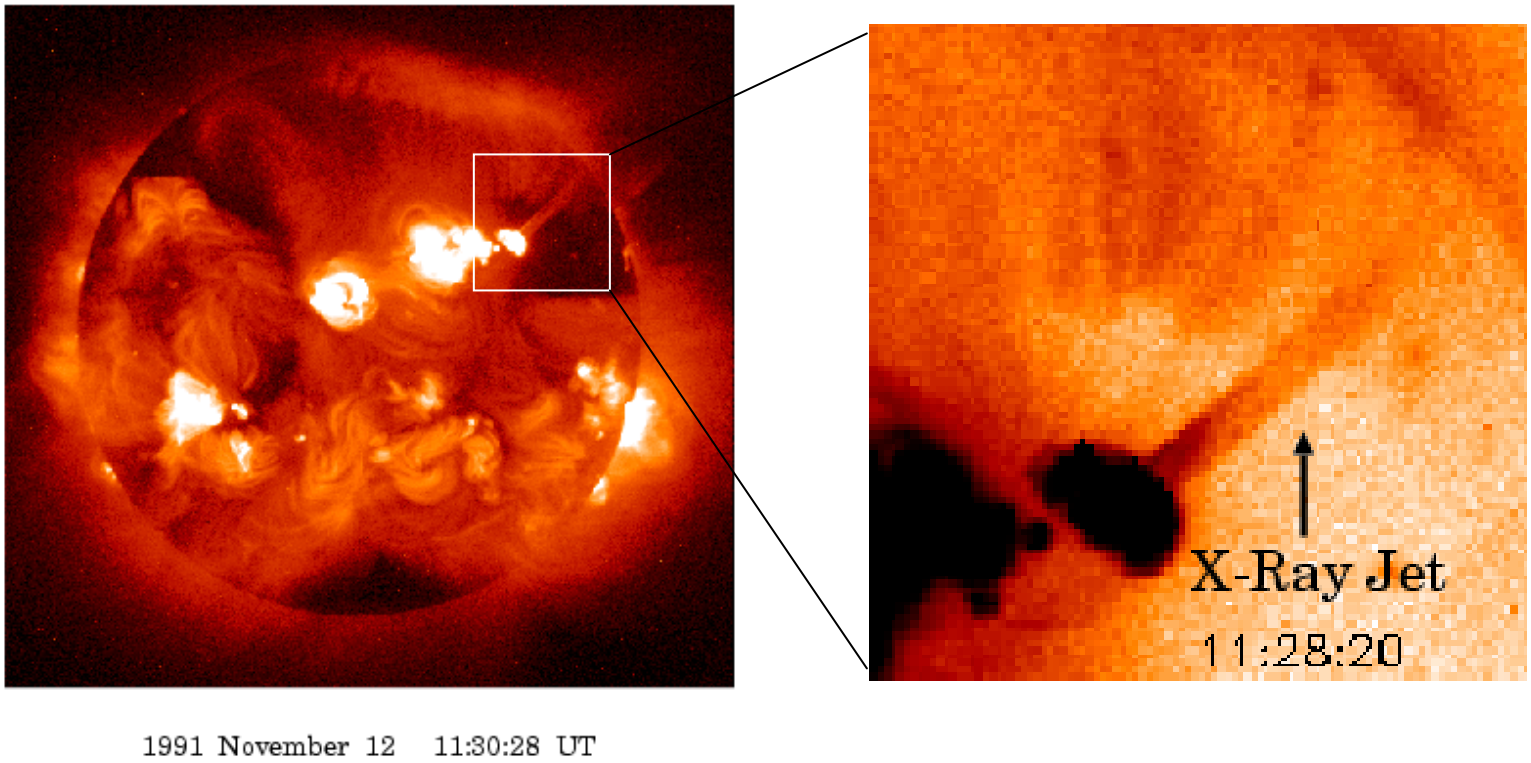
LaPalma new 1m telescope





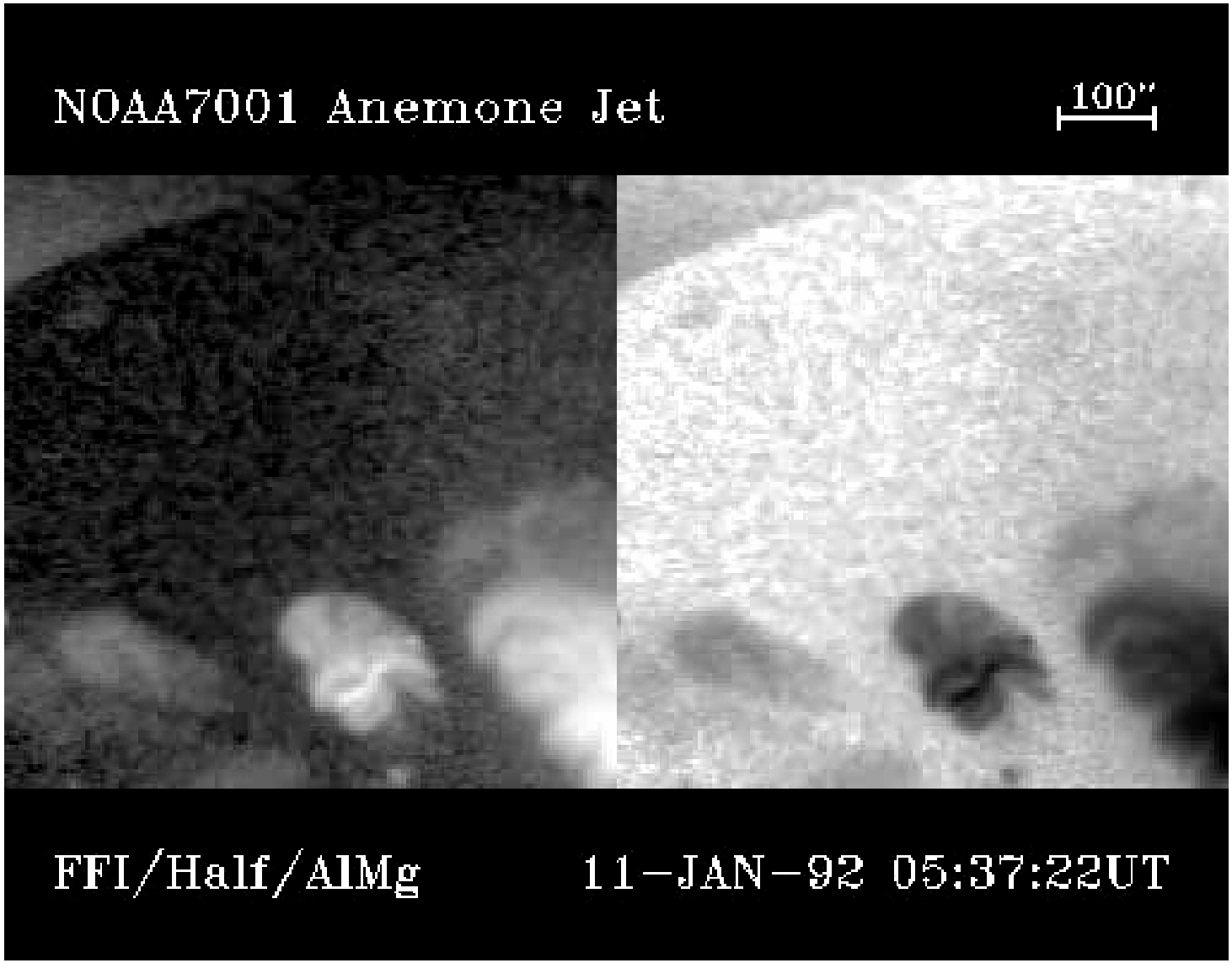
Hα (Hida/Kyoto Univ)

X-ray jet in the solar corona was discovered in 1991

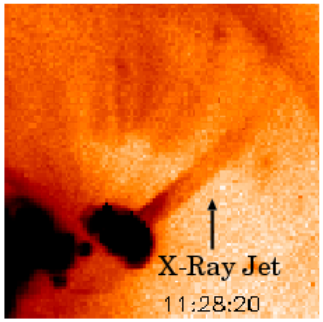


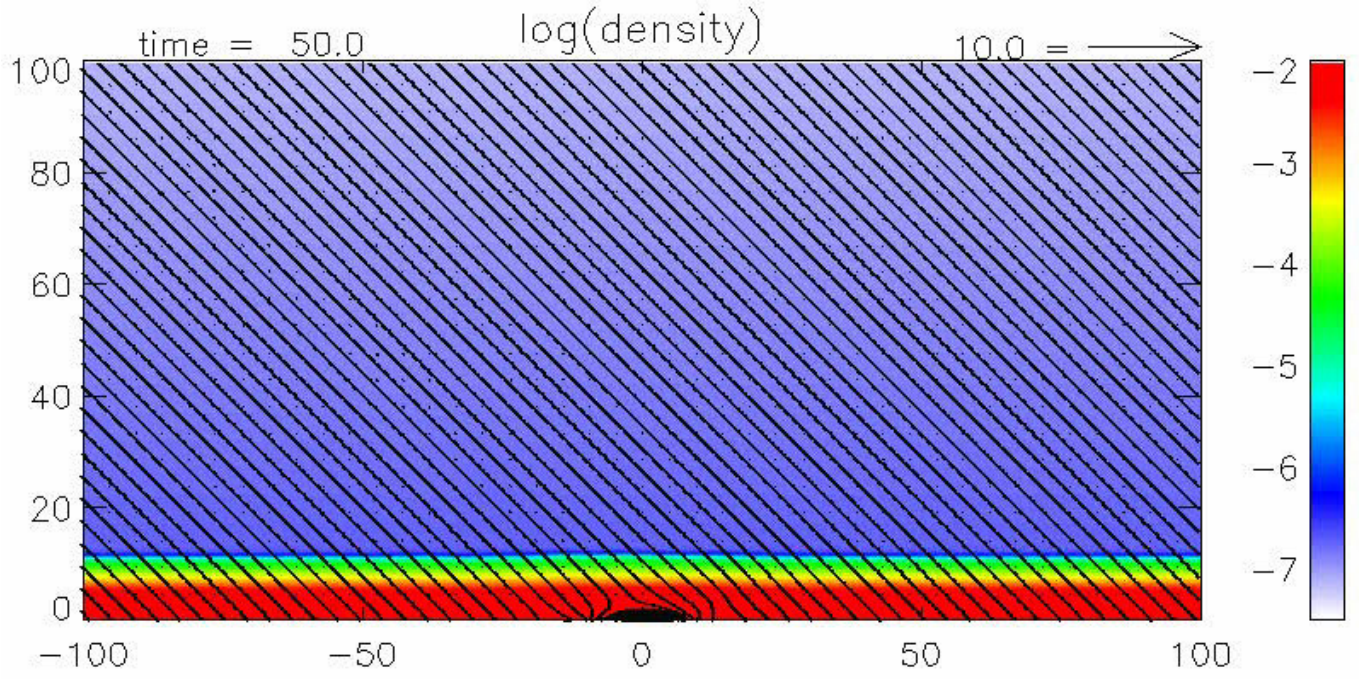
(Shibata et al., 1992)

X-ray coronal jet



Magnetic reconnection model of Solar coronal jets

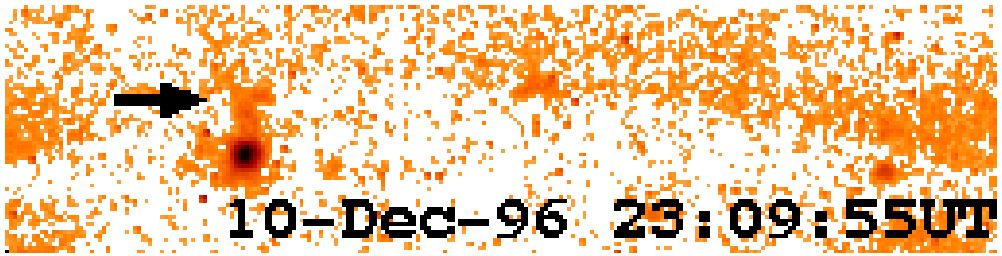




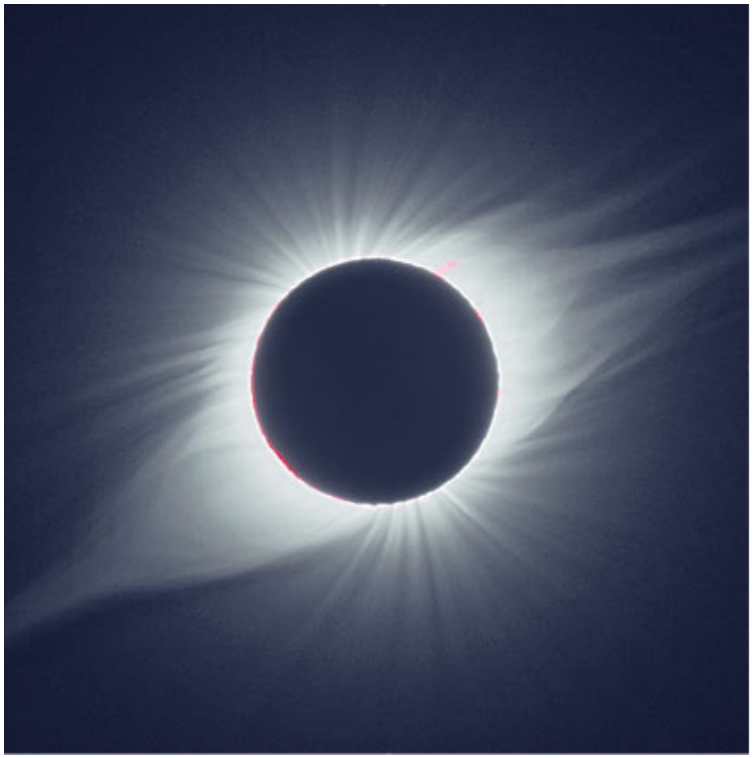
Solar coronal X-ray jet
(Yohkoh/SXT: Shibata et al. 1992, Shimojo et al. 1996)

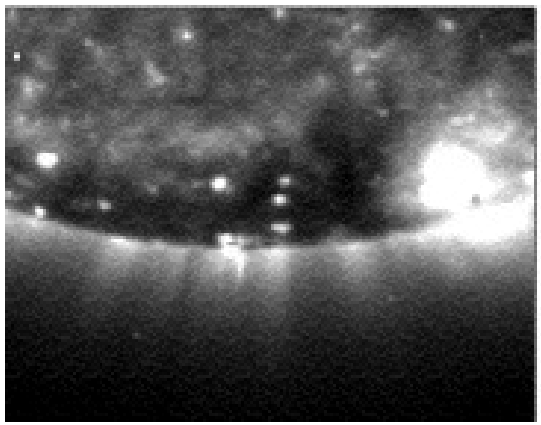
New simulations (Shimizu et al., 2006) of magnetic reconnection model of Solar coronal jets
(Yokoyama and Shibata 1995, 1996)

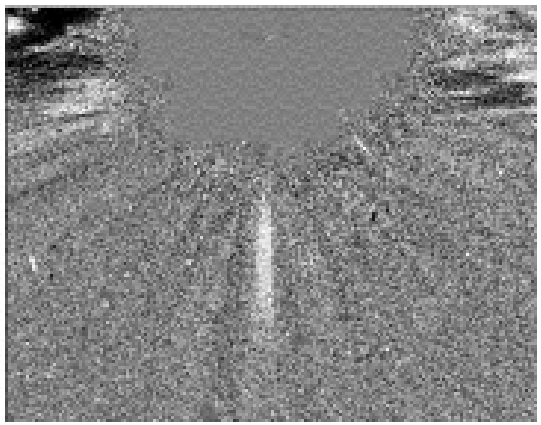
Polar jet



(Koutchmy et al.,
Wang-Sheeley)

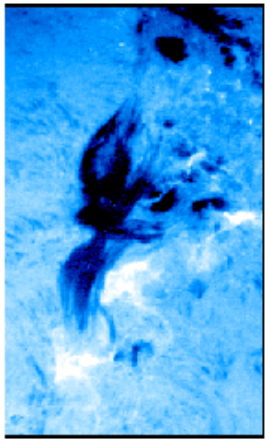


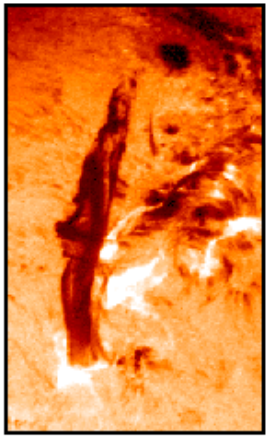


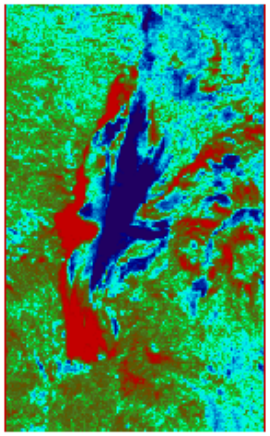


jets

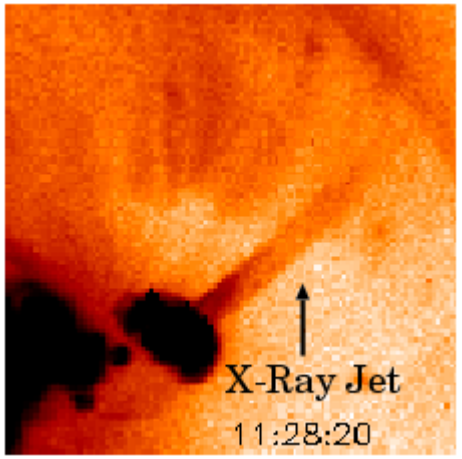
solar atmosphere is much more dynamic than had been thought, and full of jets, nanoflares, and reconnection



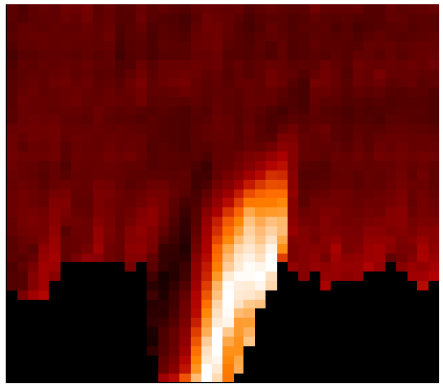




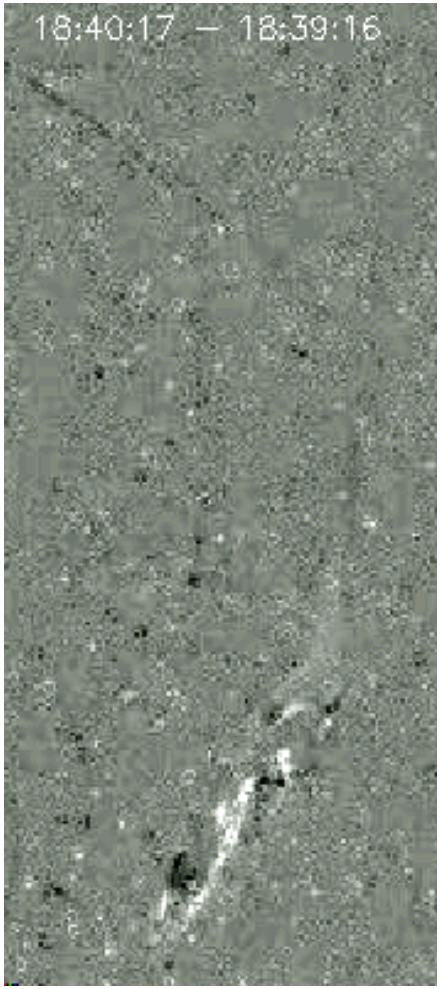
Hida (Hα) (Kurokawa et al)



Yohkoh
(Shibata, Shimojo,,,)

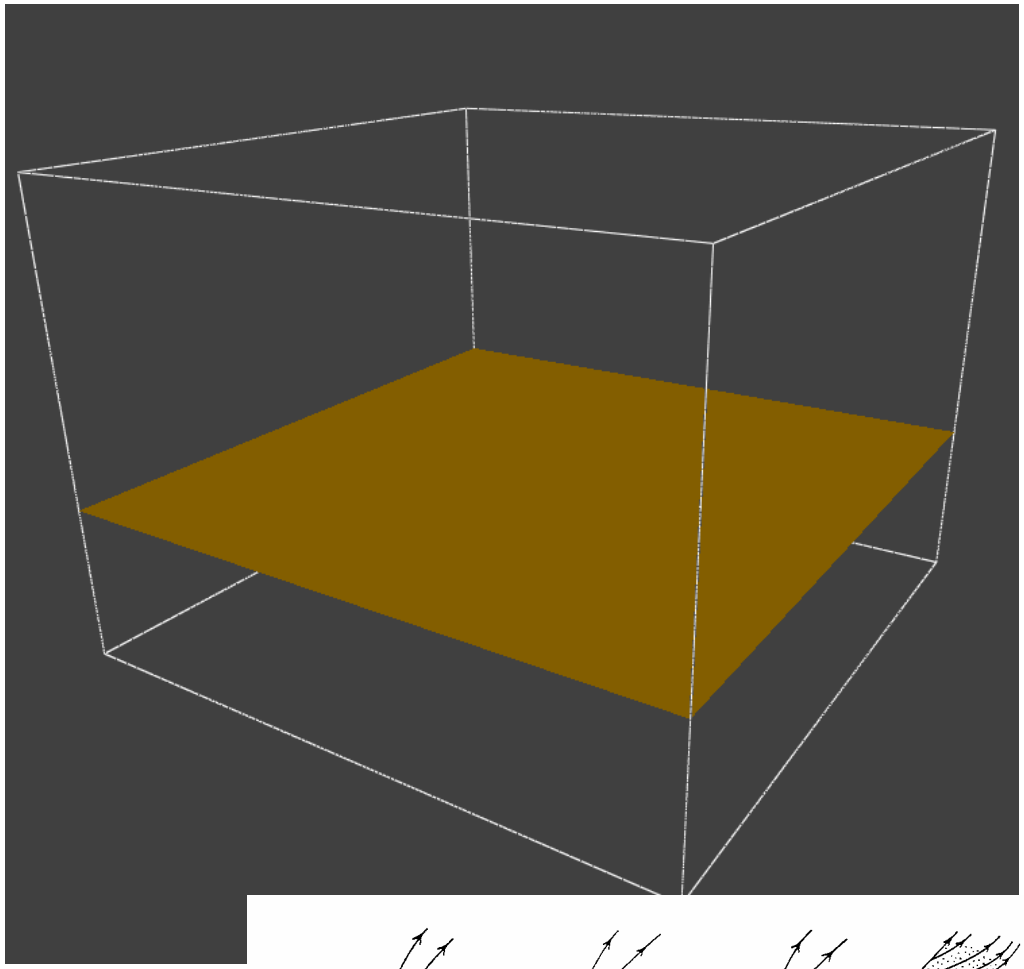


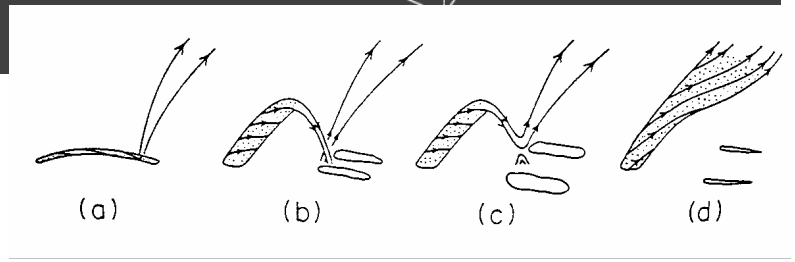
SOHO/CDS (Pike&Mason)

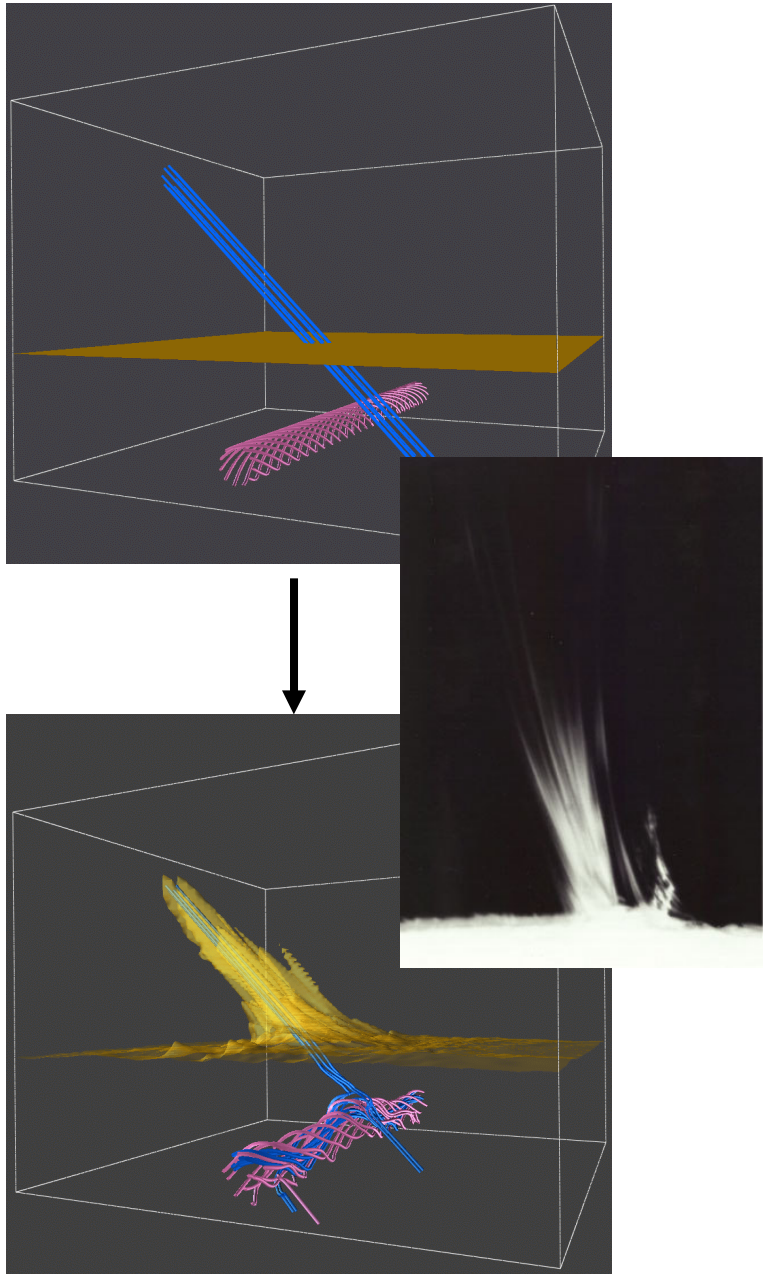


TRACE (Alexander and Fletcher)

3D simulation of jets (Miyagoshi et al. 2006)







What is the origin of cosmic jets ?

Puzzle of Astrophysical Jets

- Why do jets have stable ejecting direction from 1 light year to 1 million light year ?
  => rotation

- How are jets accelerated ?
- What is the collimation mechanism of jets ?

What is the mechanism of jet formation ?

- Energy source is gravitationa energy
- Gas accretion occurs onto central ojbect
- Accreting gas forms accretion disks because of angular momentum

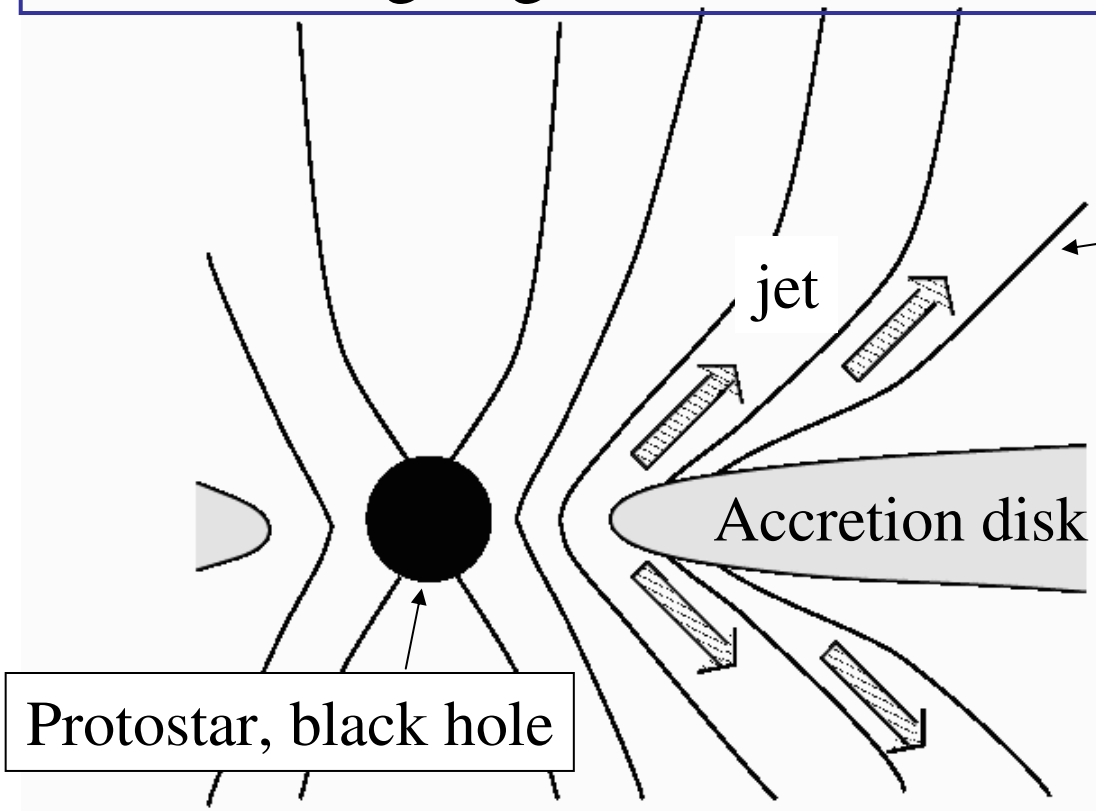
- How are accretion disk plasmas accelerated to polar direction ?

A hint is given from solar jet observations
=> effect of magnetic field

magnetic model of astrophysical jets

Accelerates jets by magnetic field and rotation

Extracting angular momentum from disks

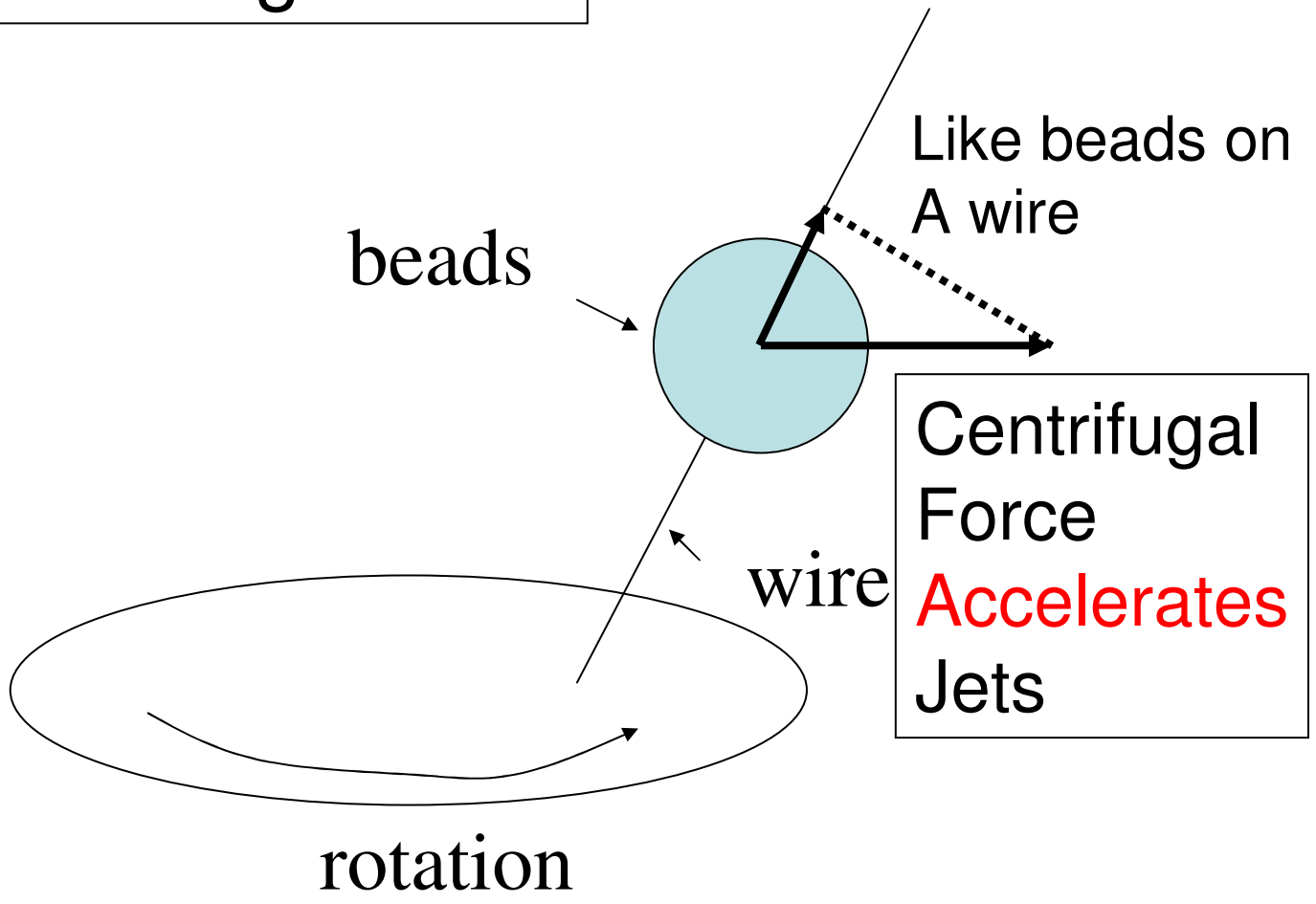


Centrifugal force

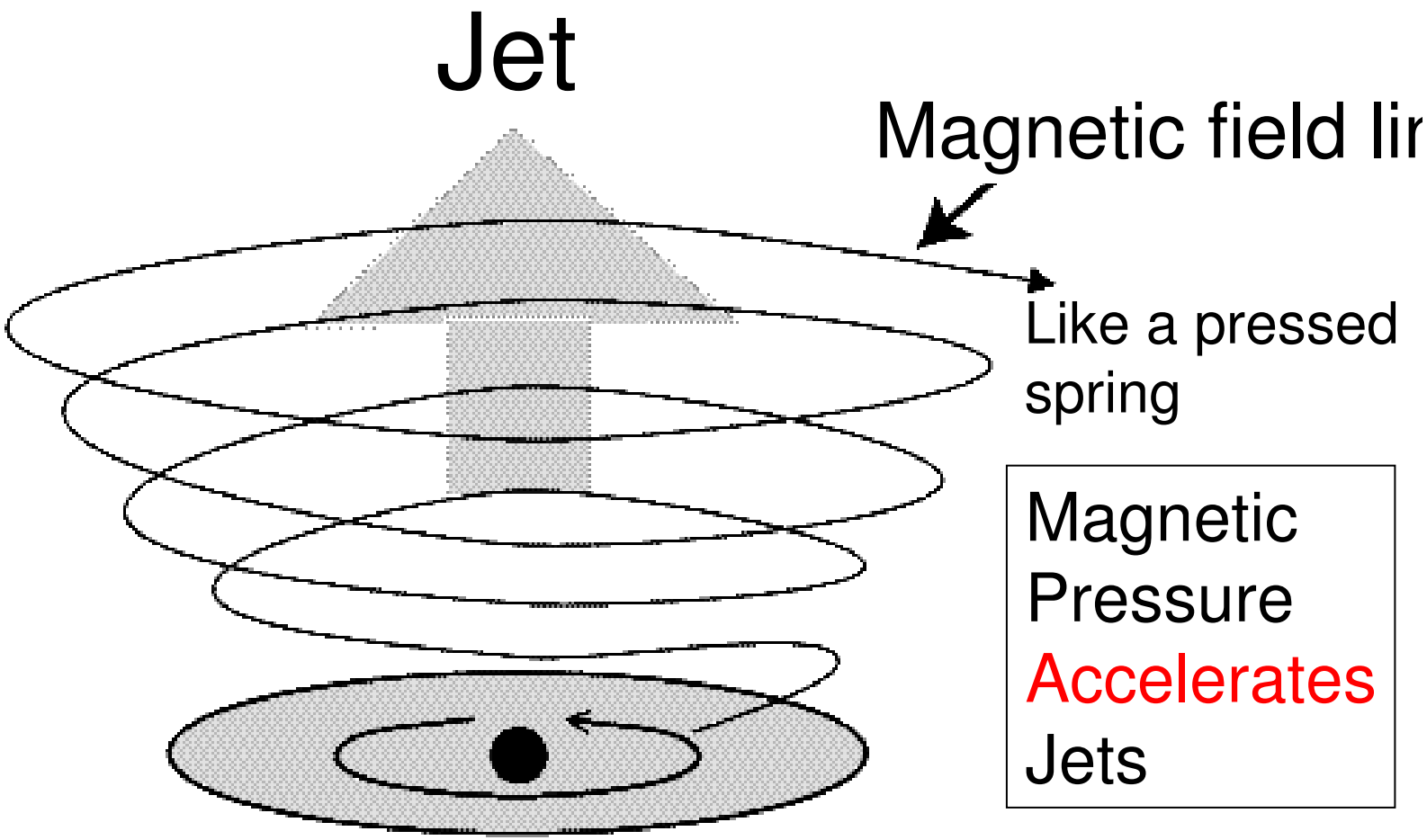
Magnetic pressure

Blandford-Payne 1982, Lovelace et al 1986,
Pudritz-Norman 1986, Uchida-Shibata 1985, Shu et al. 1994, …

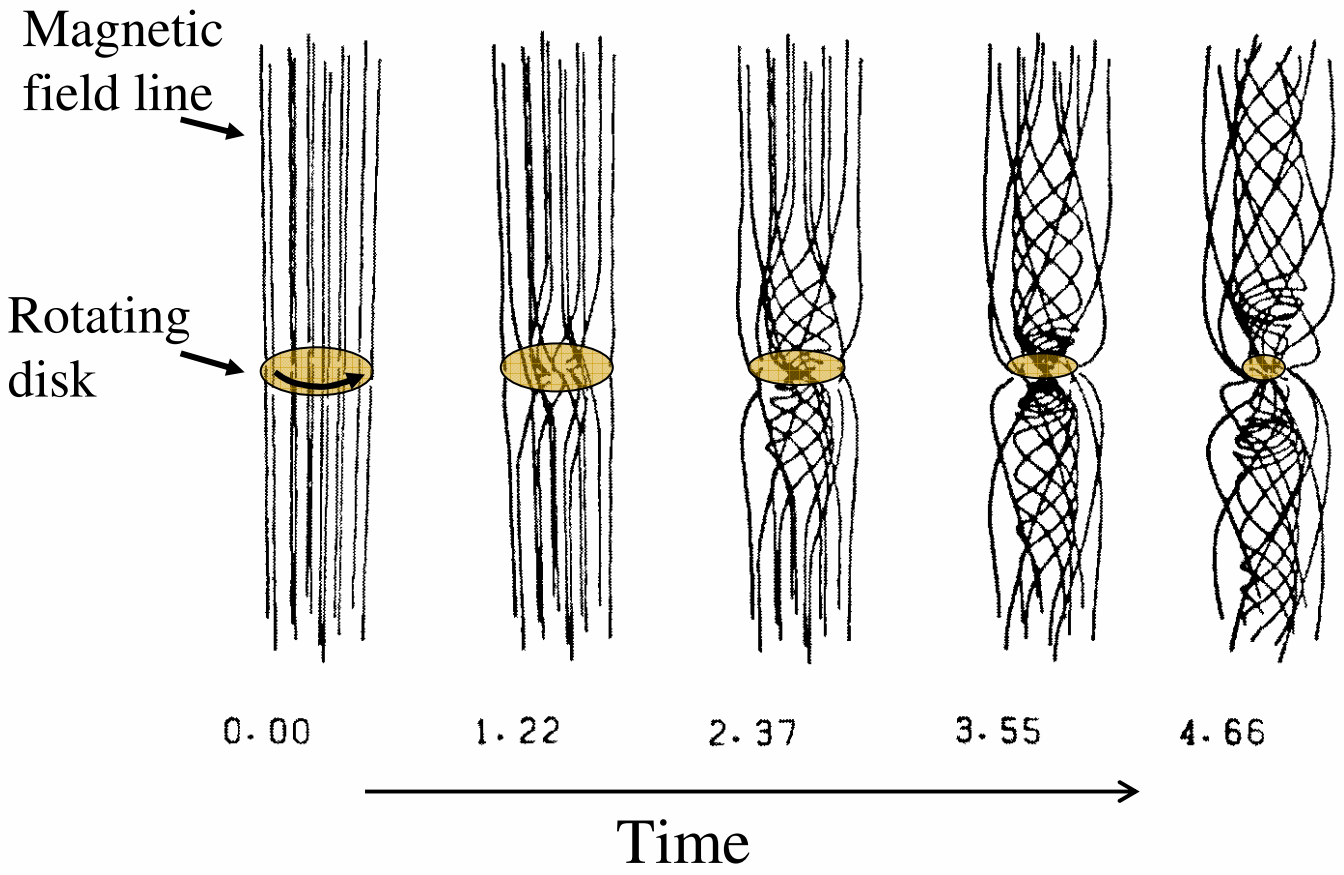
Magneto-centrifugal force



Magnetic pinch due to helically twisted magnetic field collimate jets



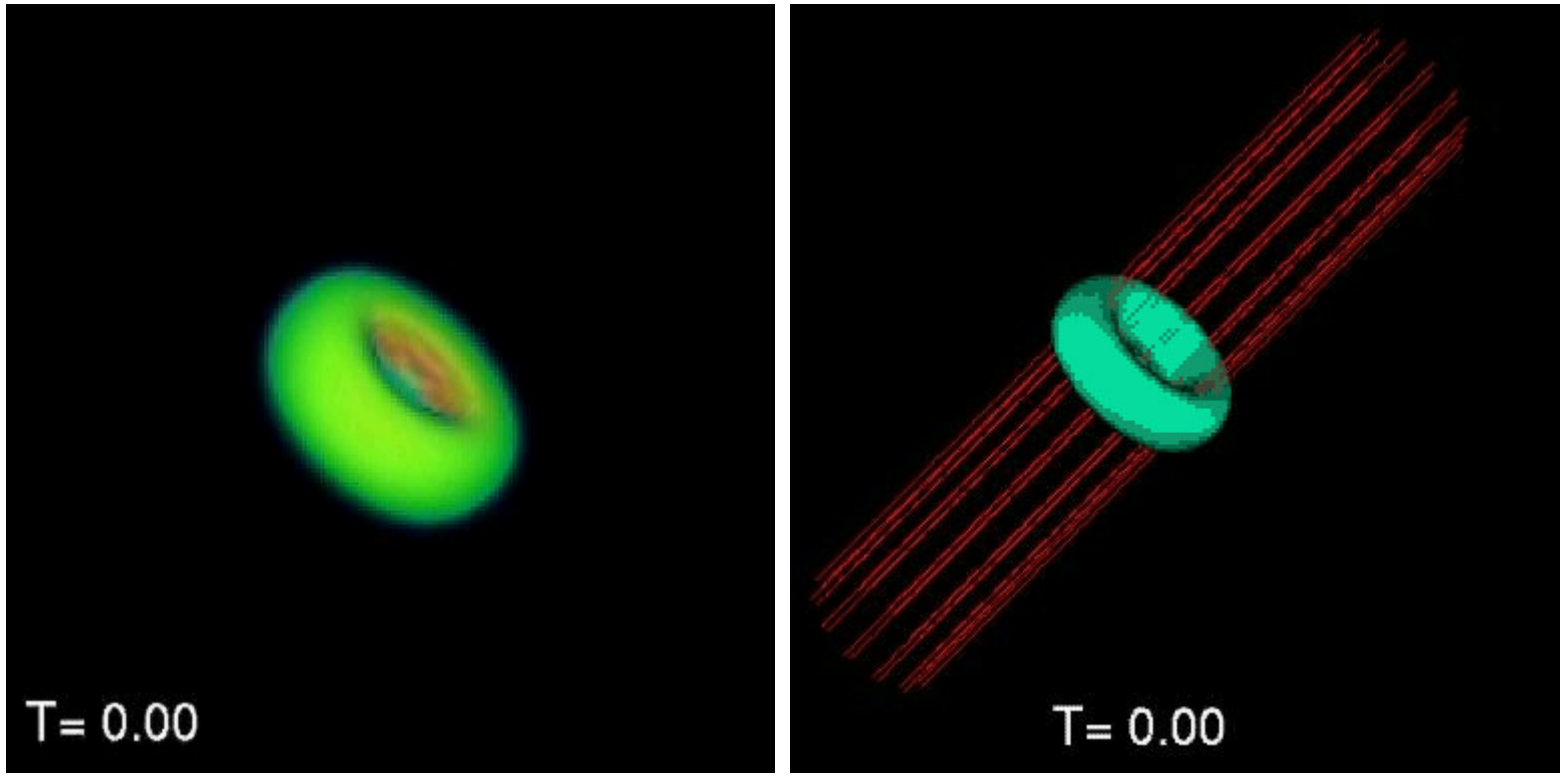
Magnetic model of astrophysical jets



Shibata & Uchida (1986)

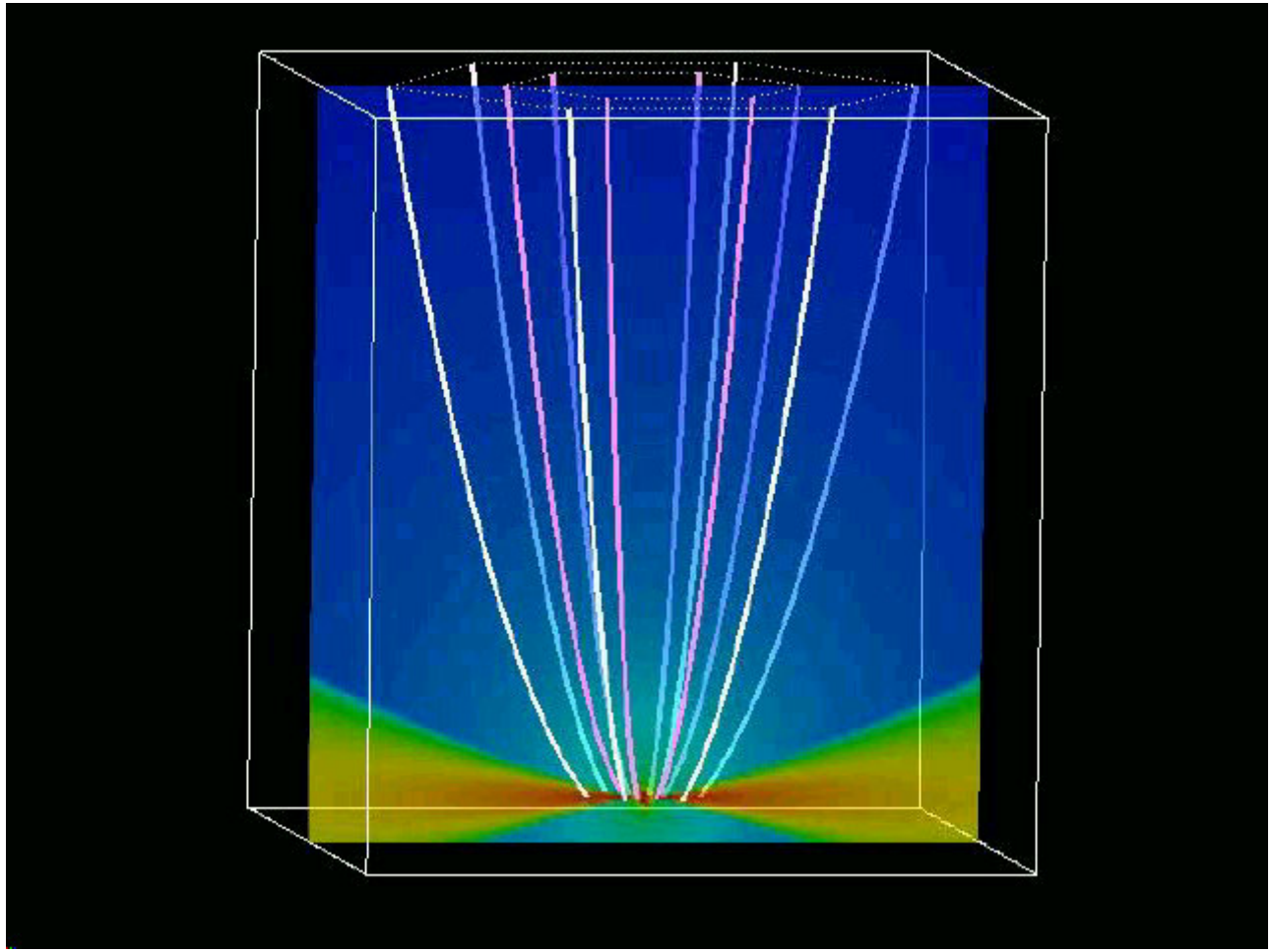
Jet velocity ~ Kepler veloicty
(rotation velocity of the disk)

Three dimensional model of magnetic jet
(Matsumoto and Shibata 1997)

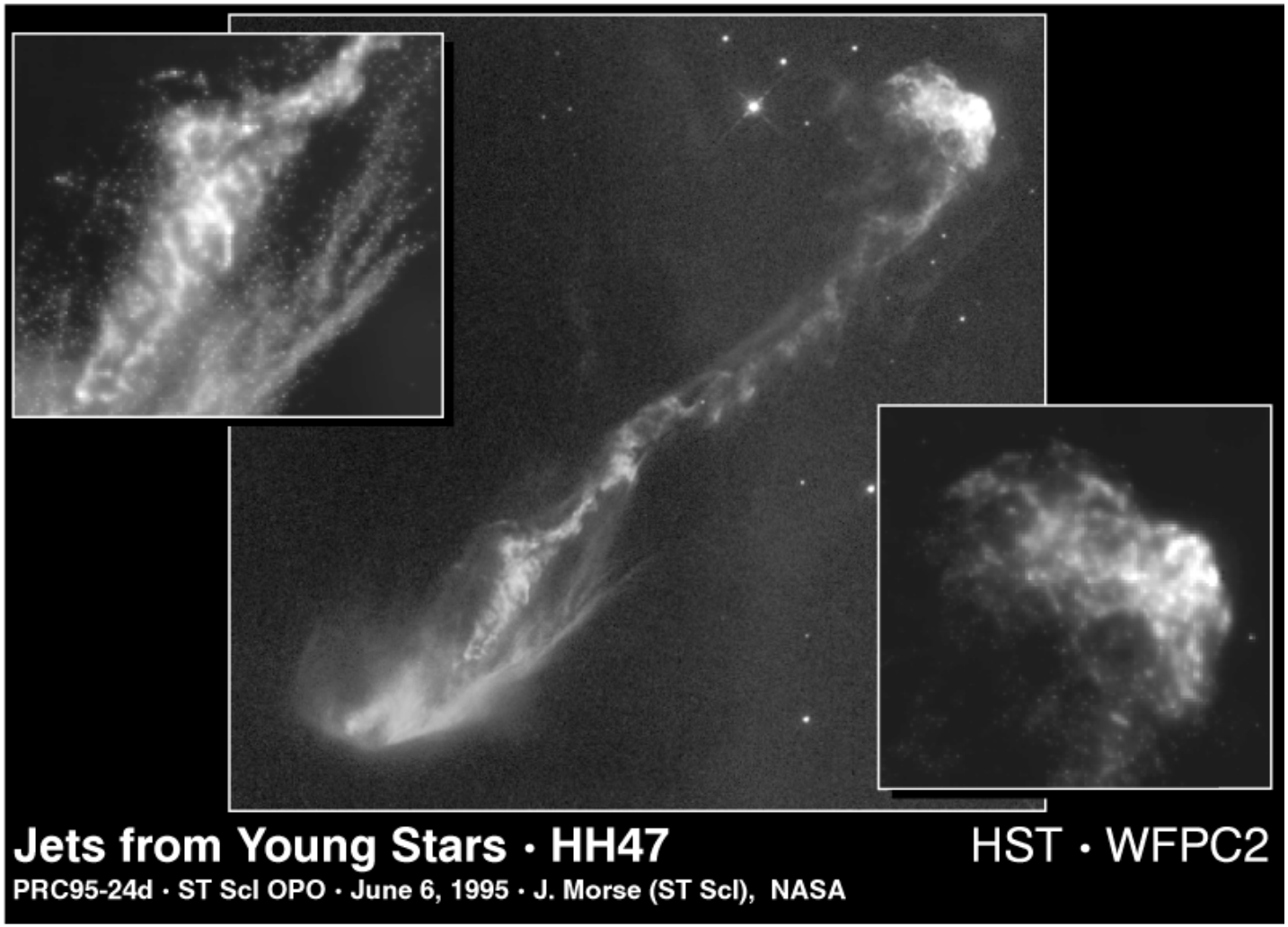


Magnetic jet with bow shock

(Kudoh, Matsumoto, Shibata 2006)

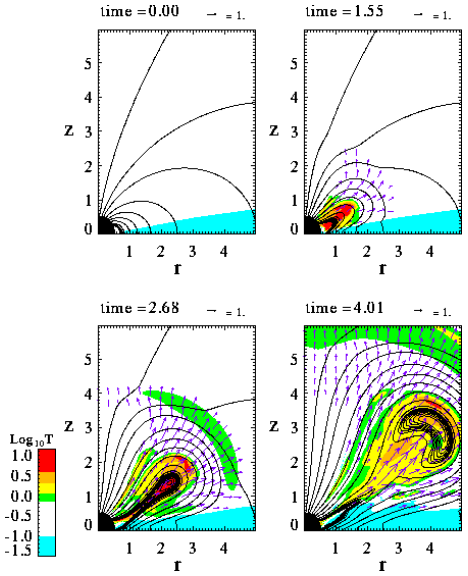


Helical protostellar jet

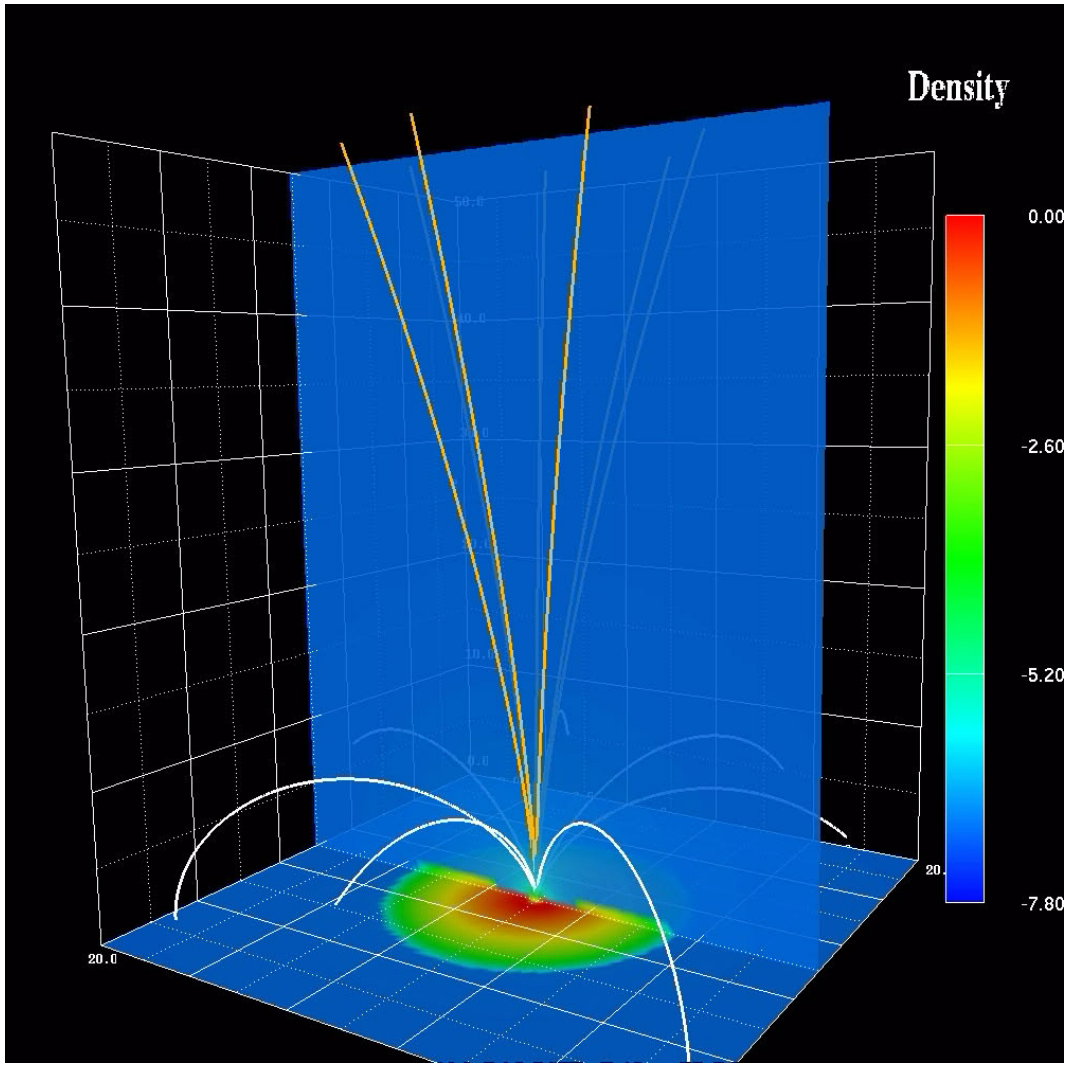


magnetic model of protostellar jet

(Uehara et al. 2006)



Hayashi et al (1996)

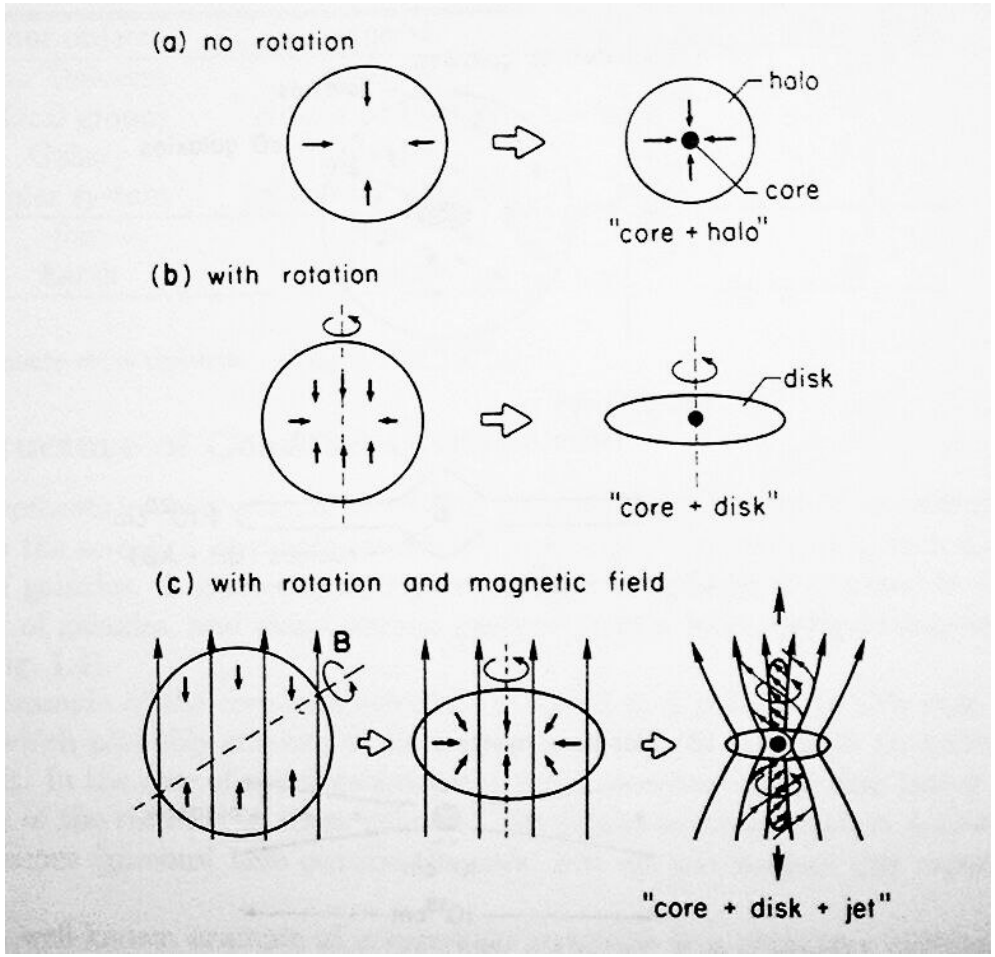


A jet consists of two component:
reconnection outflow and
disk wind

What is the role of jets in the formation and evolution of astronomical objects ?

- Jets (especially magnetic jets) extract angular momentum efficiently from the accretion disk, so that the central object (stars, black holes) are formed in a short time.
- Jets produce shock waves, which may be the site of cosmic rays.
- Jets provide disturbance to ambient medium, so that another star/planet/galaxy formation may be triggered.

Formation of astronomical objects (stars and galaxies)



Basic physical Processes are common for Star and galaxy Formation, so that AGN jets and YSO Jets are so similar

Summary

- Recent astronomical observations revealed that our universe is full of jets. As observational accuracy becomes better, more and more jets are found. These jets seem to play an important role in formation and evolution of astronomical objects, such as stars, galaxies, even planets and life.
- Solar observations revealed that the solar atmosphere is full of jets. It has been established that these solar jets are formed by the magnetic mechanism.
- Although the origin of cosmic jets are still puzzling at present, It is likely that cosmic jets are formed by the magnetic mechanism similar to the mechanism operating in solar jets.