Quasars, Active Galaxies and Other Ultrahigh Energy Sources

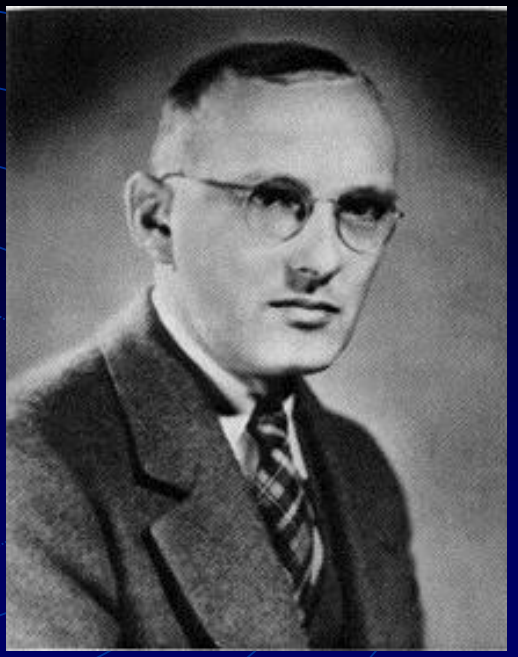
What Do you think?

- What does "*quasar*" stand for?
- What do quasars look like?
- Where do quasars get their energy?

Quasars

- Grote Reber 於1936年在 Illinois 自己家後方建了第一台電波望遠鏡
- 1944年偵測到來自 Sagittarius、Cassiopeia，以及 Cygnus 的強烈電波源，其中 Sagittarius A (Sgr A) 為銀河中心，Cassiopeia A (Cas A) 為超新星遺骸，這兩個為本銀河系的天體。
- 但是第三個 Cygnus A (Cyg A) 則越觀測越令人不解。Walter Baade 與 Rudolph Minlkowski 使用 Mount Palomar 當時最大的 200 吋（5公尺）望遠鏡發現它是個黯淡的星系 (galaxy)，但是紅移高達 14,000 km/s.

Karl Guthe Jansky (1905-1950)



- Bell Telephone Laboratories, late 1920s
- Studied static interference of phone reception
  → thunderstorms and more
- ‘Signal’ peak moved at sidereal rate
  ➔ extraterrestrial! (1932)

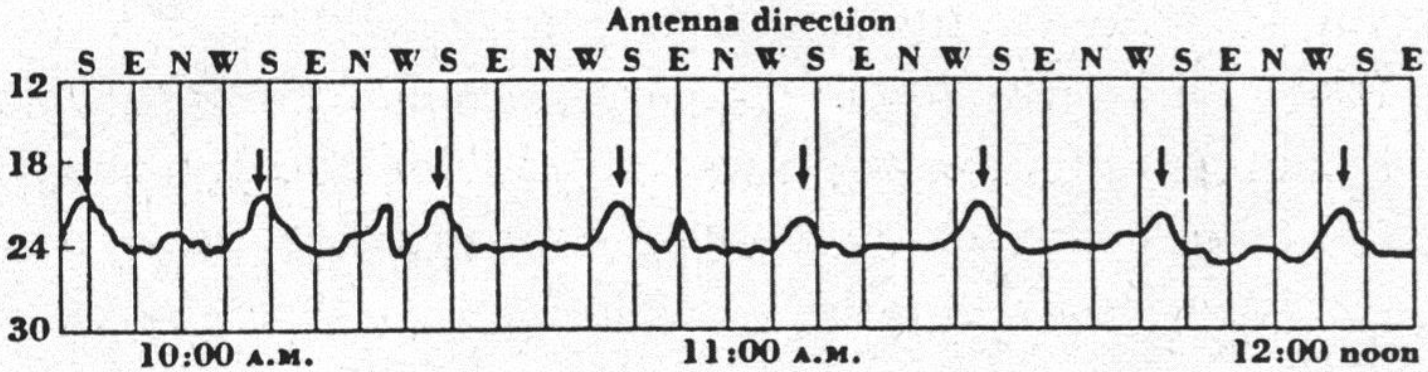


Fig. 16.11. A portion of one of Jansky’s records from February, 1932. The changing direction of the peak indicates that the source cannot be on the earth.

Jansky Antenna

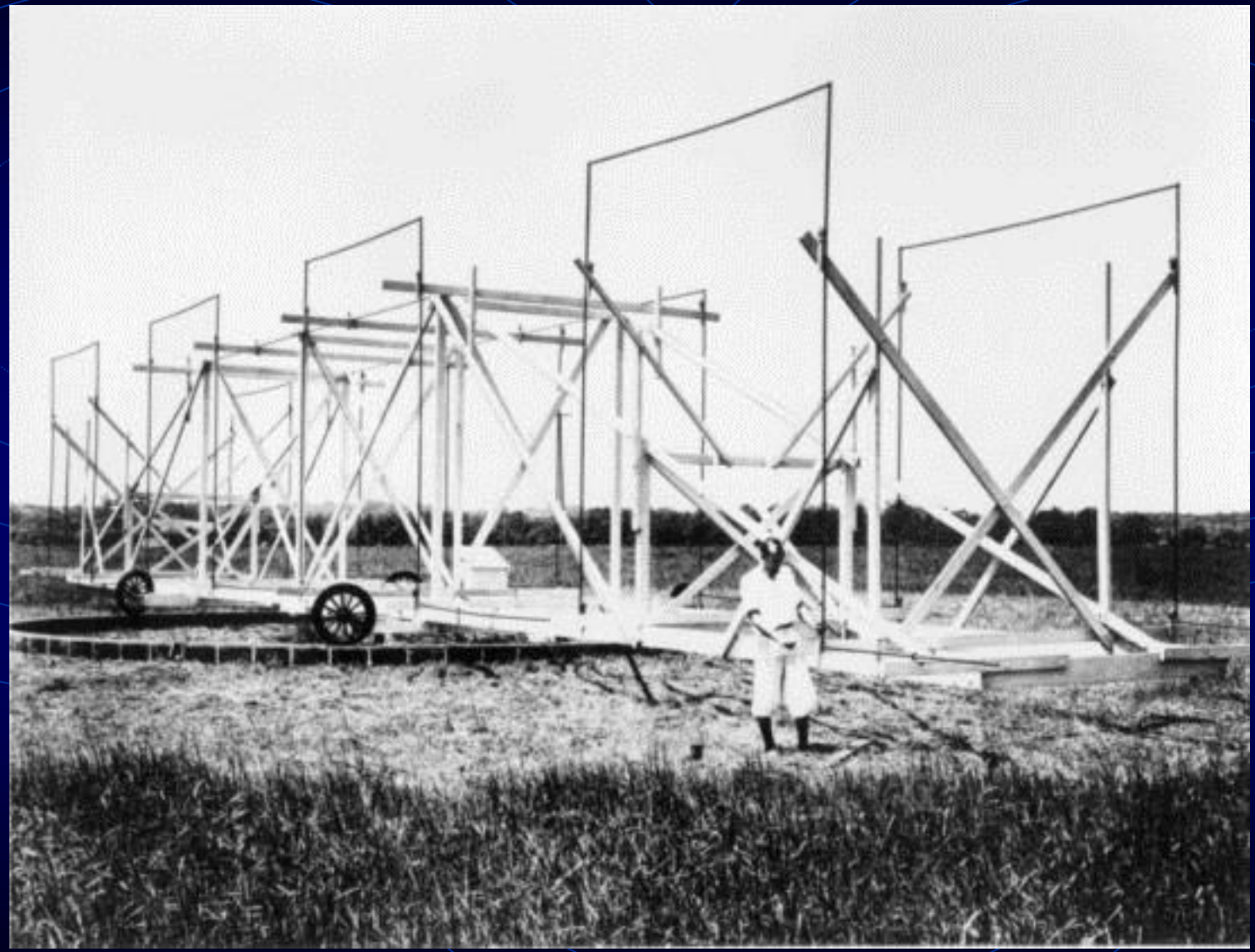


Image courtesy of NRAO/AUI

- Source toward Sagittarius (1936); paper published in engineering journals!!
- Assigned to other project; pursue no more
- Jansky's serendipitous discovery gave birth to a new branch of astronomy
  ➔ radio astronomy
- In Jansky's honor, astronomers named the unit of radio flux “the jansky”
  (1 Jy= 10^{-26} W/m^2/Hz).

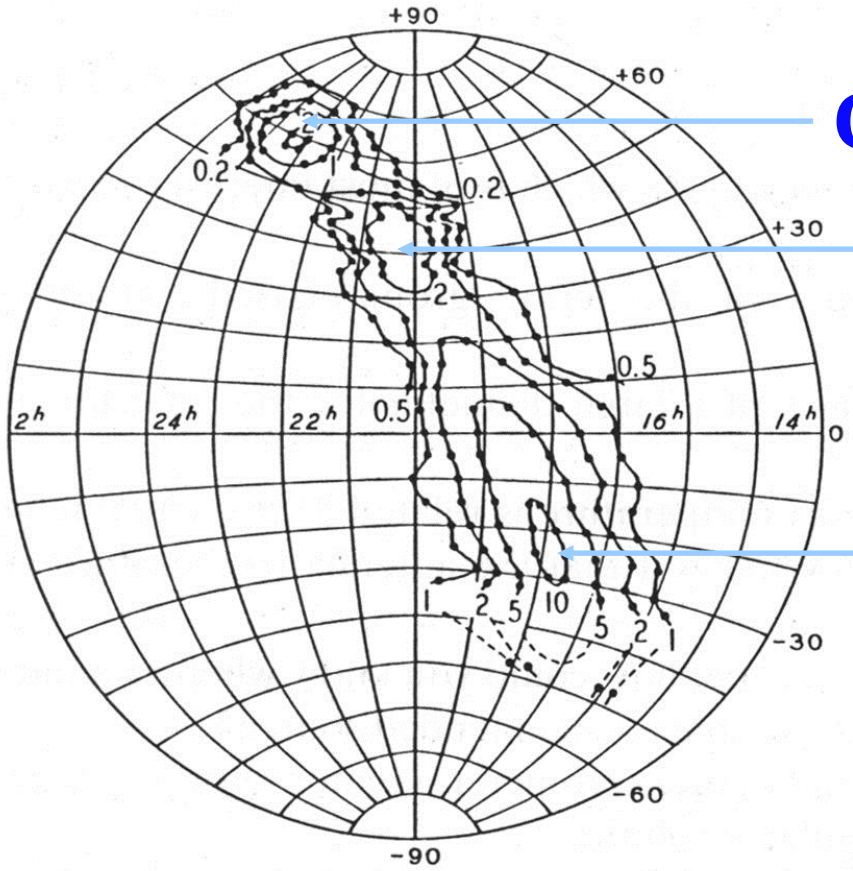
Grote Reber

Image courtesy of NRAO/AUI http://www.nrao.edu/imagegallery/php/level3.php?id=106

Grote Reber

- A radio engineer, lived in Wheaton, Illinois, near Chicago
- Learned about Jansky's result, and built a 9.5 m reflector
- Felt he needed astronomy background; took a course in University of Chicago, where he met Otto Struve, Bengt Stromgren, Gerald Kuiper
- They knew Reber was onto something
- Struve, then Editor of Astrophysical Journal, ensured Reber's paper got published (1940)

Grote Reber's original dish today at the NRAO in West Virginia



Cassiopeia

Cygnus

Sagittarius

Fig. 16.12. Grote Reber's map of the radio emission from the Milky Way. This was published by Reber in 1944. (Reprinted with permission from *The Astrophysical Journal*.)

Contour ➔ Milky Way!

Radio Astronomy Elsewhere …

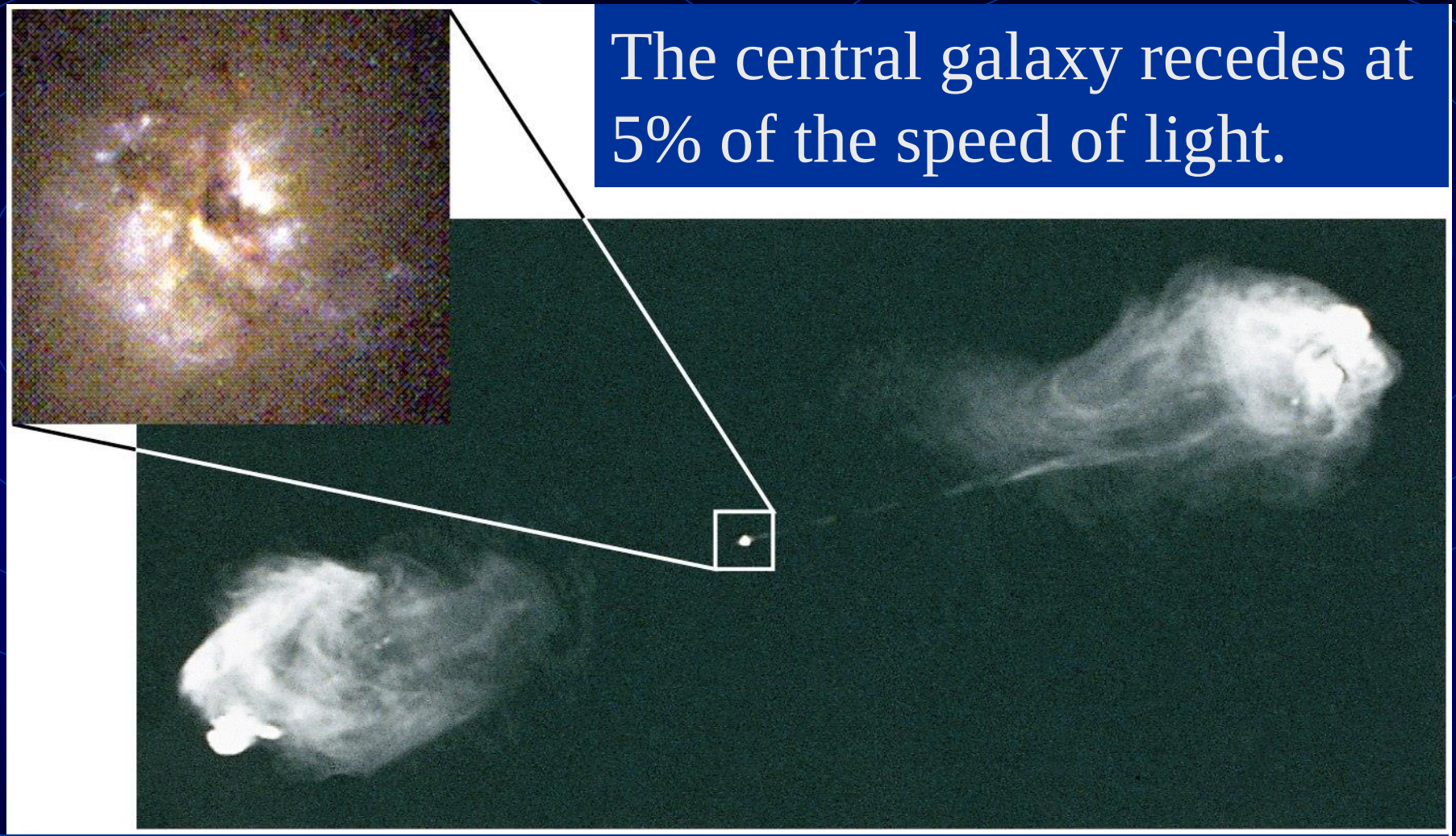
Meanwhile, in Leiden, Netherlands

- 1944, Jan Oort, director, showed Reber's paper to colleagues and asked J. C. van de Hulst to study it and pursue further
- van de Hulst proposed possible transition
  → **21 cm line of hydrogen**
- Useful as a tool to study gas motion
- Started to build equipment

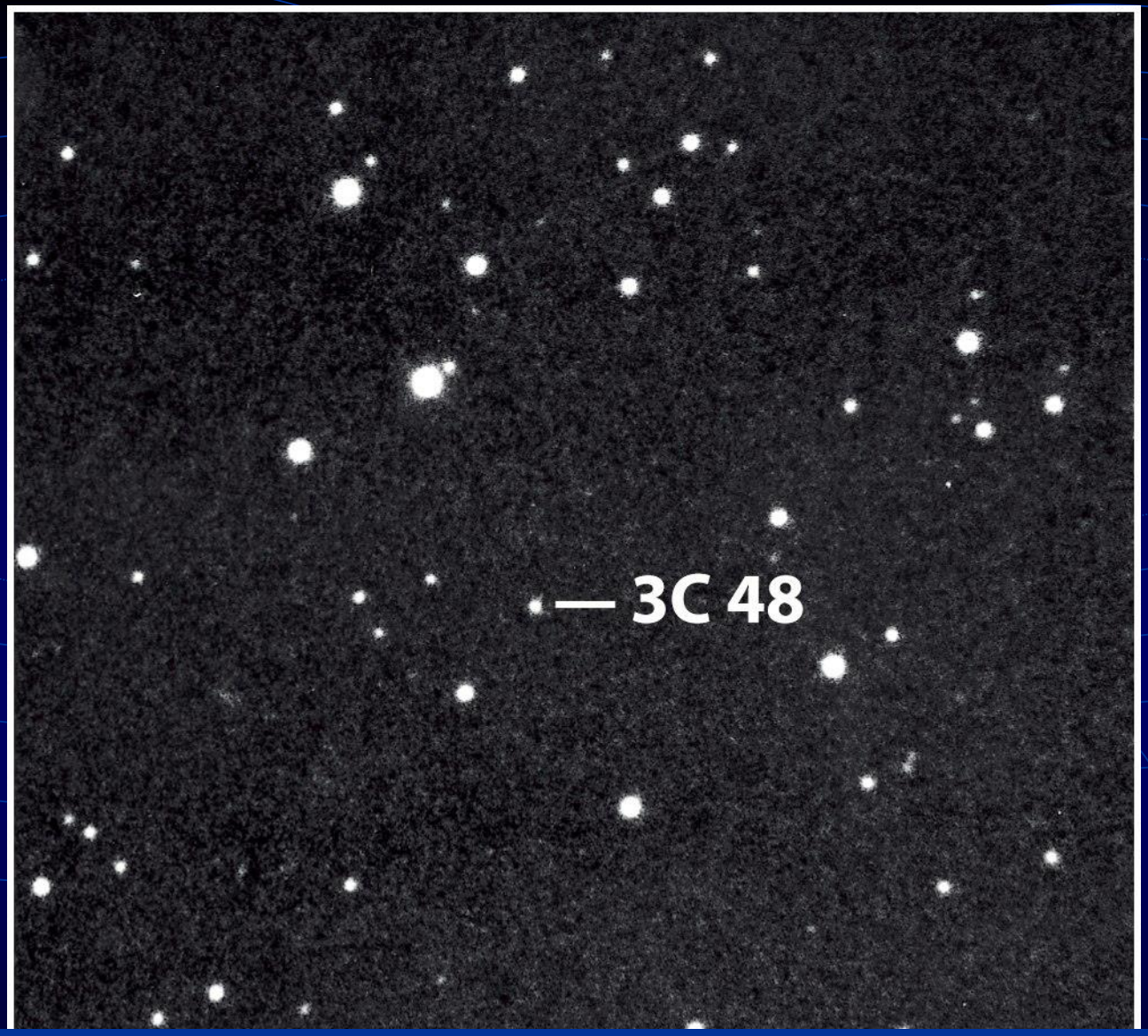
Efforts in USA and Australia, too …

- 這麼快的速度，如果以 Hubble law 來計算， Cyg A 距離達 194 Mpc（6億3500萬光年）
- 但是這麼遠的天體何以電波輻射卻這麼強？
- 之後系統性搜尋電波源，例如1959年出版的 The ***Third Cambridge Catalogue*** 包含了 471 個電波源，時至今日很多強電波源仍沿用 3C 編號，例如 Cyg A ＝ 3C 405
- 3C 48 在可見光的影像看起來像恆星；3C 273 有明亮噴流；光譜充滿發射線
- 這些天體，外表像是恆星（點光源），但明明不是，因為距離遙遠，能量龐大，稱為「類星體」(quasi-stellar objects, QSOs, 簡稱 quasars 魁炁)

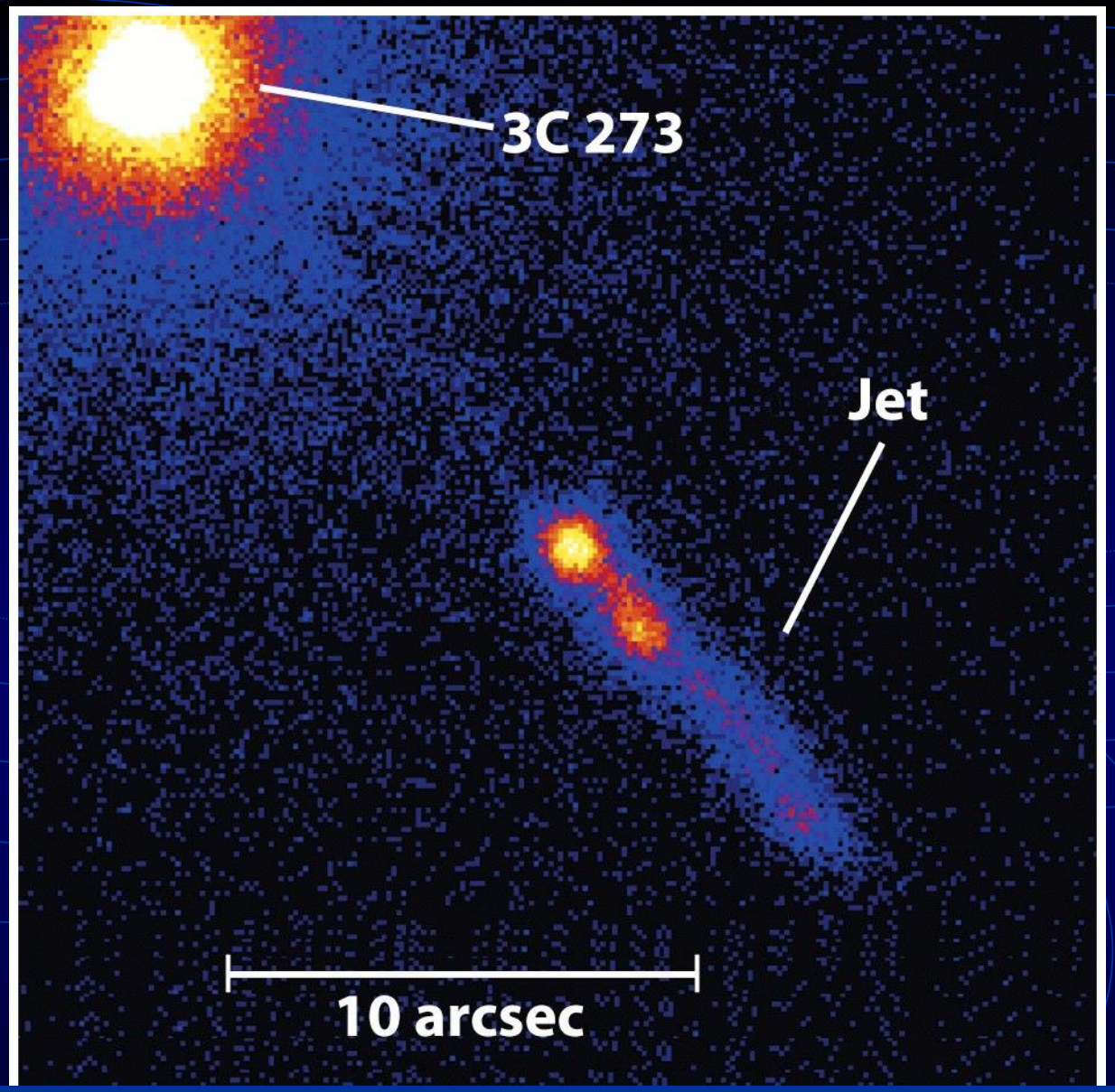
The central galaxy recedes at 5% of the speed of light.



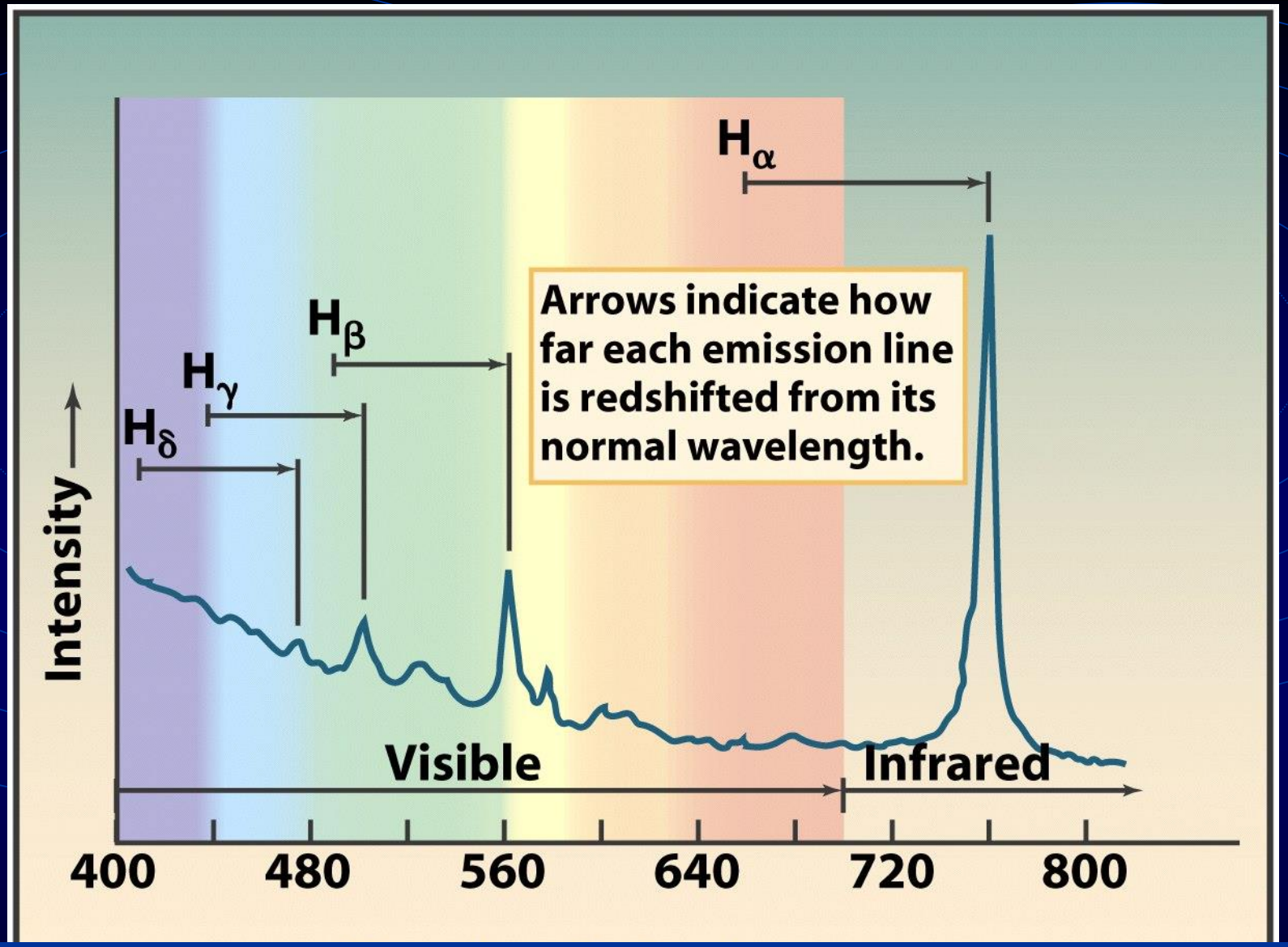
3C 405: Radio image by VLA. Each of the 2 radio lobes extends ~160,000 ly from the optical galaxy.



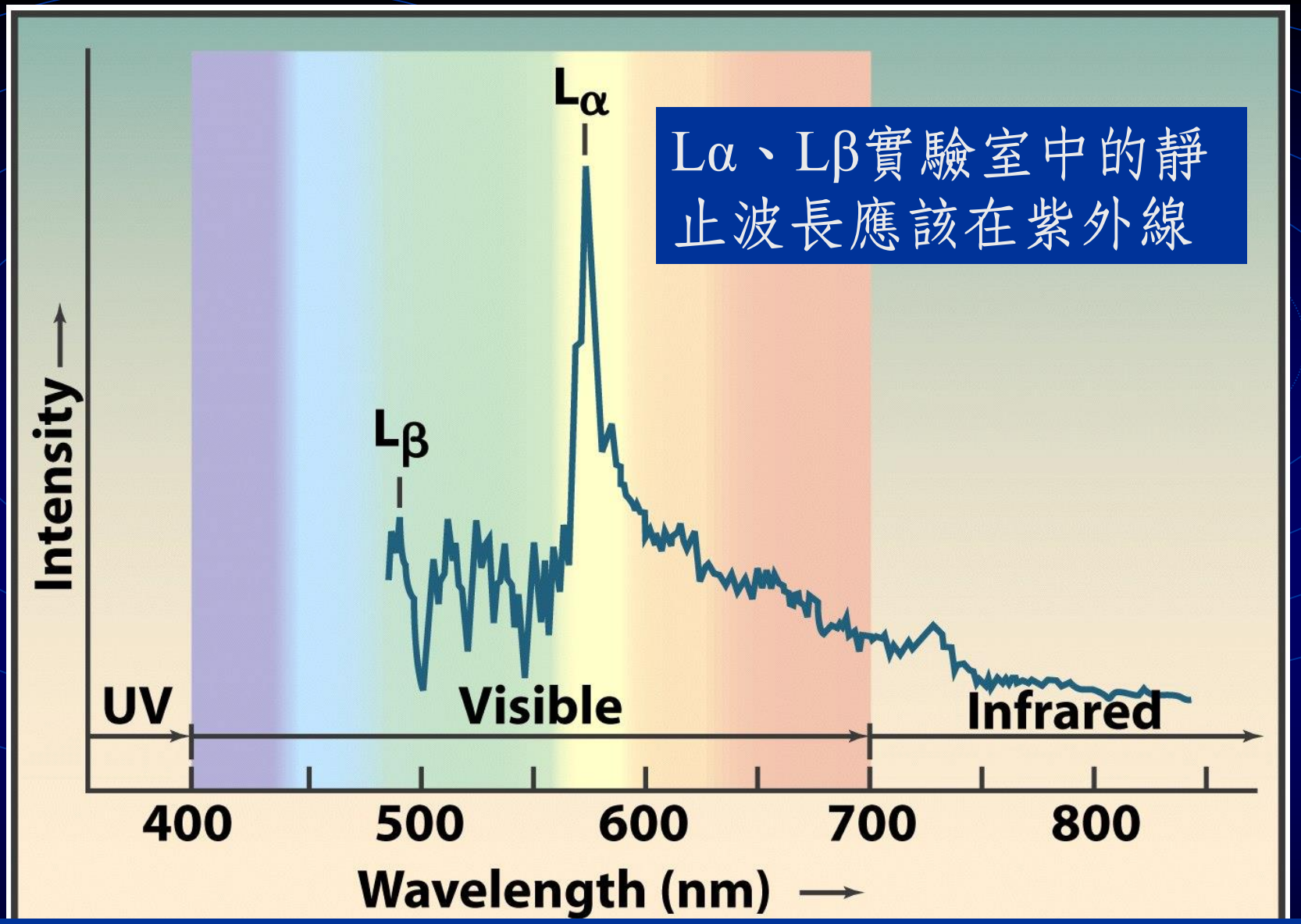
The quasar 3C 48 看起來好像顆恆星，
但是其紅移顯示距離大約為40億光年



3C 273距離我們20億光年，X 射線影像顯示像星點般的 3C 273 具有噴流結構



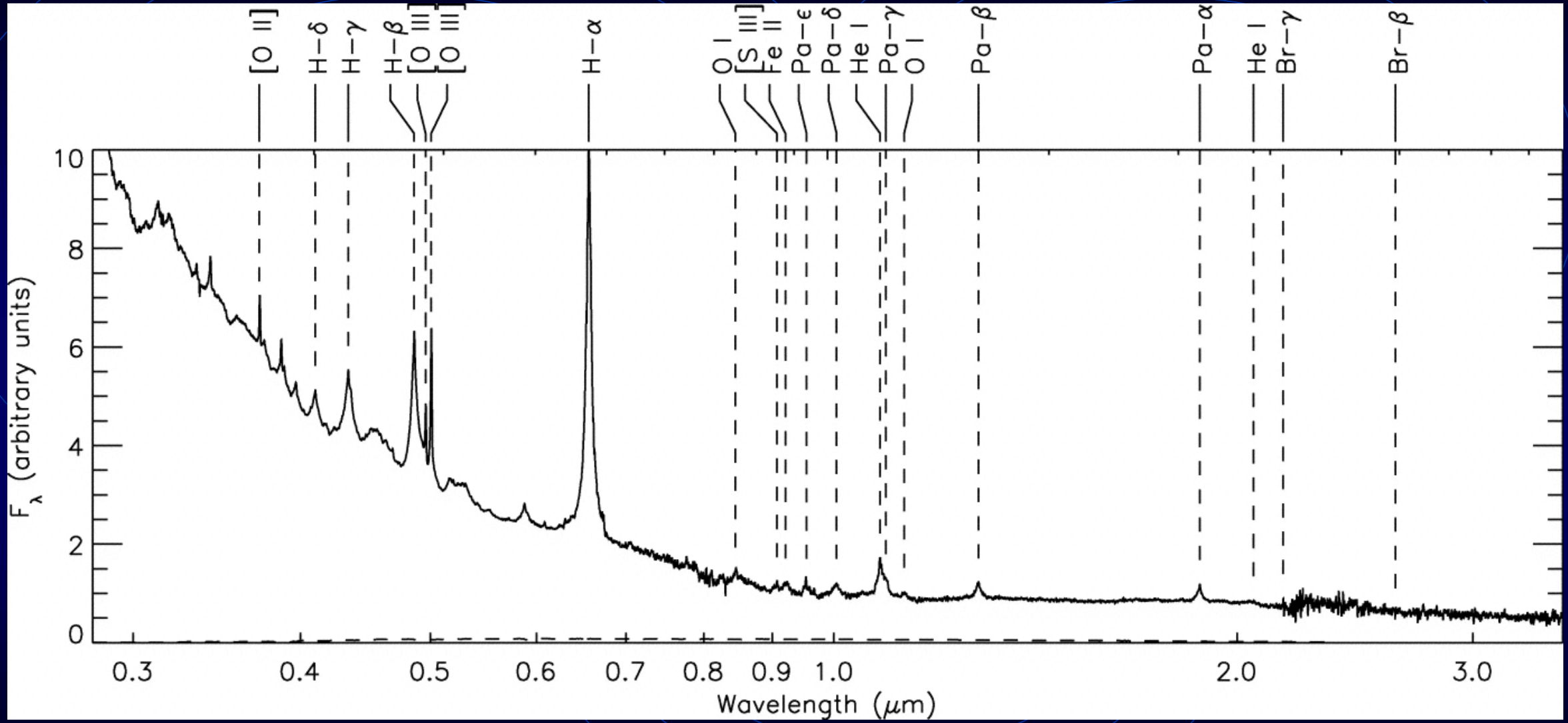
3C 273 的光譜有很多難以指認的發射線，後來發現這些是氫線，與靜止波長相比，紅移了16%



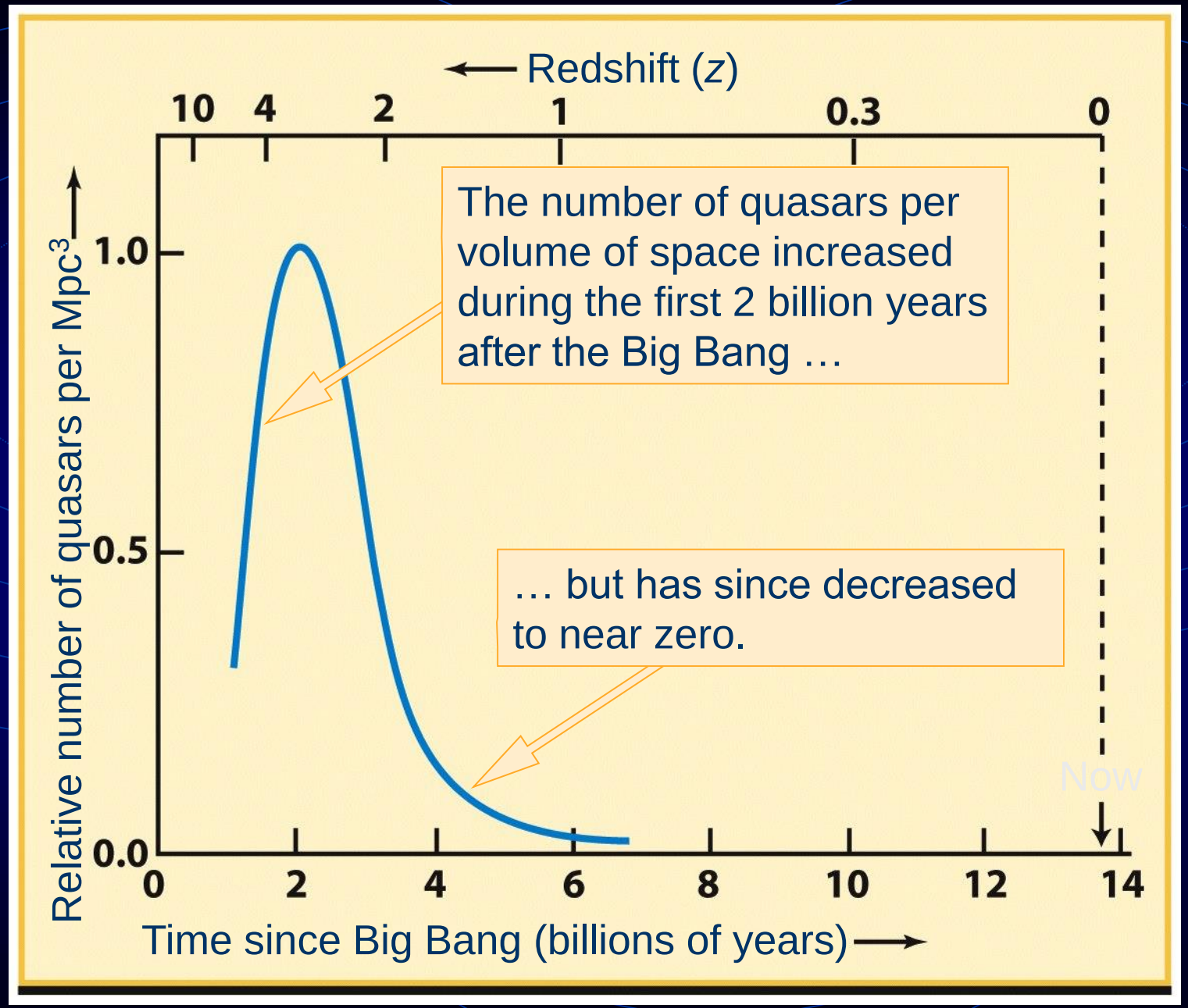
Lα、Lβ實驗室中的靜止波長應該在紫外線

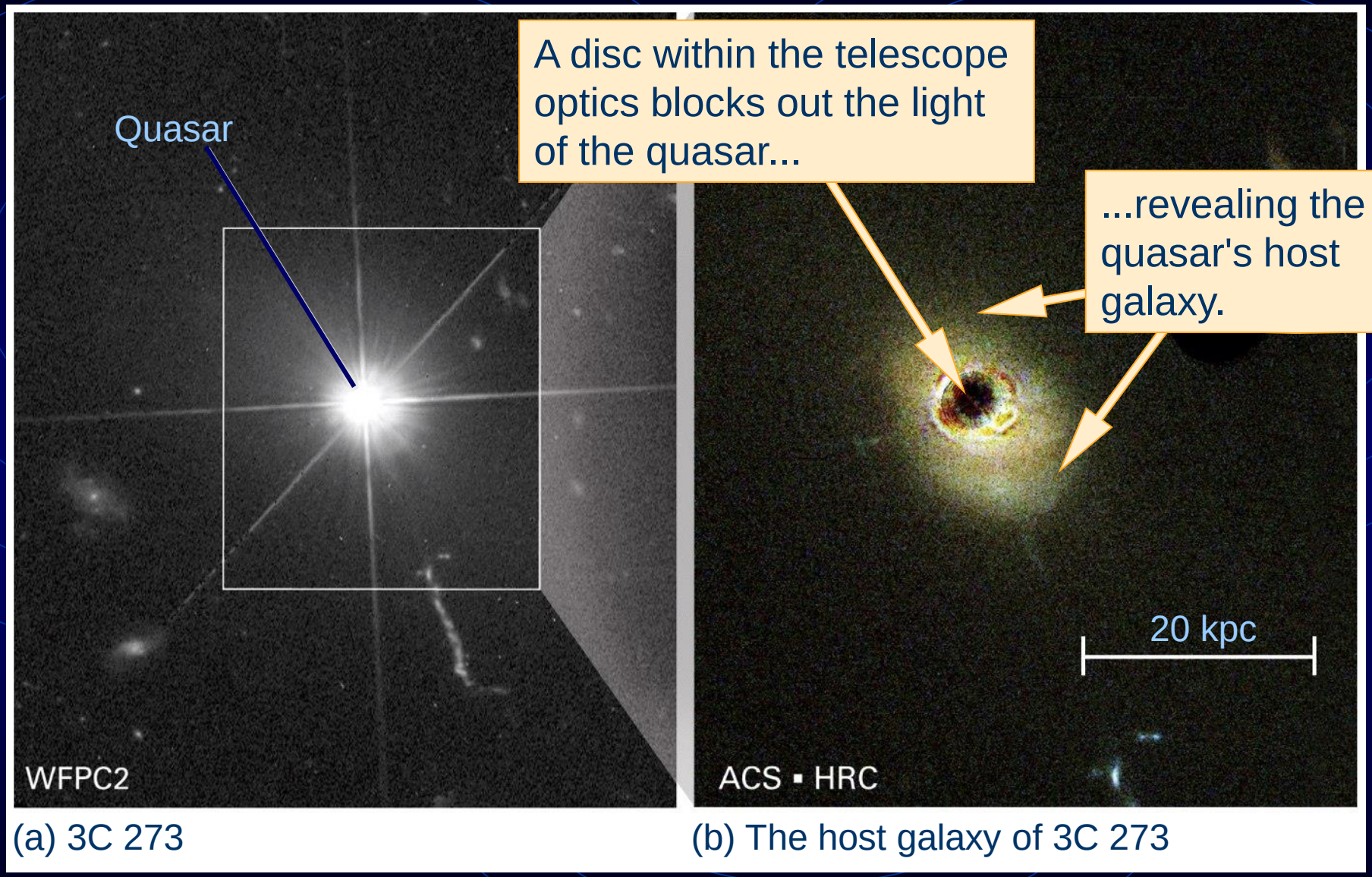
The quasar PKS 2000-330 has a receding speed of 92% speed of light ➔ 10.0～13.0 bly away

Quasars are blue!



Optical-to-near-infrared quasar composite spectrum (Glikman et al. (2006)


Redshift (z)
10
4
2
1
0.3
0
The number of quasars per volume of space increased during the first 2 billion years after the Big Bang …
… but has since decreased to near zero.
Now
Relative number of quasars per Mpc3
1.0
0.5
0.0
0
2
4
6
8
10
12
14
Time since Big Bang (billions of years)

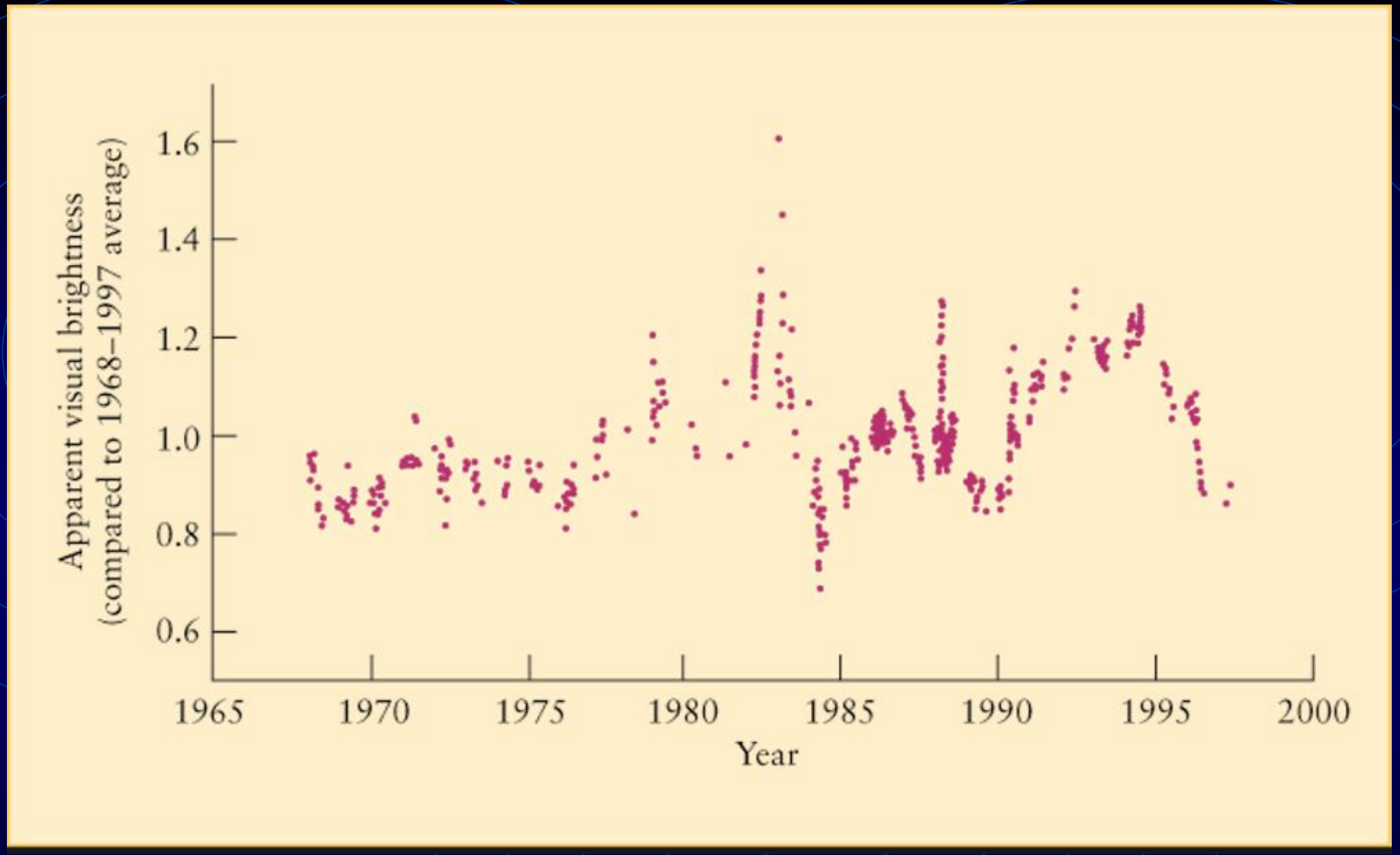


(a) 3C 273

(b) The host galaxy of 3C 273

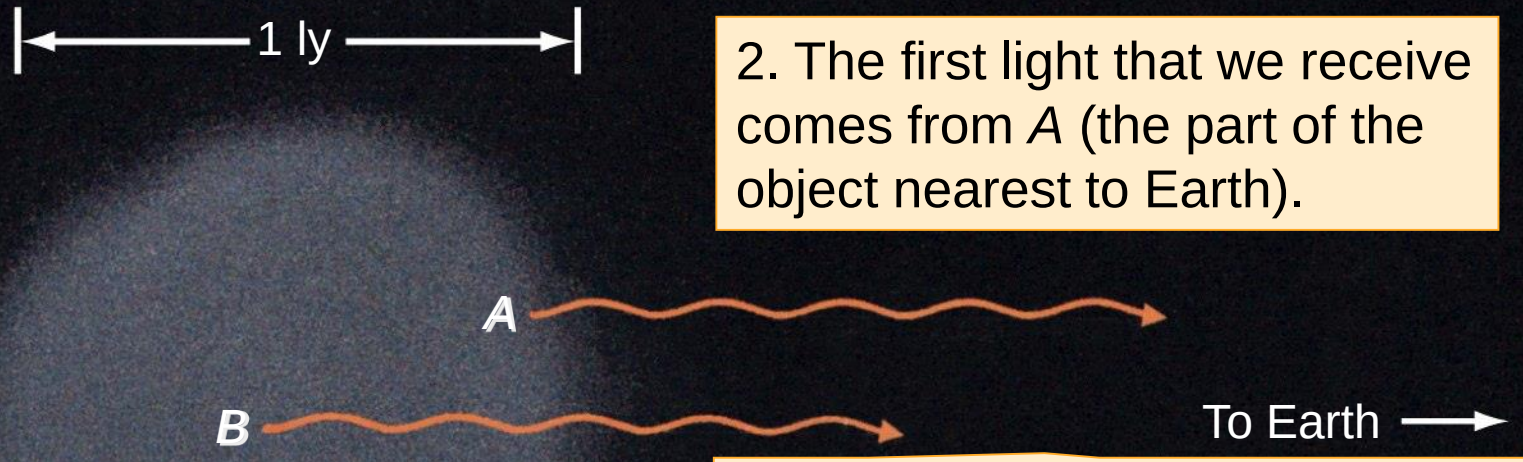
Active Galaxies

- Quasars 只是產生大量能量天體的其中一種
- 一些星系（的核心）非常活躍
- 這些**活躍星系核 active galactic nuclei (AGN)** 非常明亮，常具有發射線，亮度變化明顯，有些擁有噴流
- 主要分成兩大類
  - **radio galaxies —— 橢圓星系，發射總能量不大，但是電波輻射很強，且分佈範圍廣達數十萬光年**
  - **Seyfert galaxies —— 螺旋星系，核心明亮，高游離鐵發射線 →極高溫氣體；沒有大範圍的電波輻射**



Abrupt and irregular brightness variations of the quasar 3C 273

1. An object 1 light-year across emits a sudden flash of light.



2. The first light that we receive comes from *A* (the part of the object nearest to Earth).

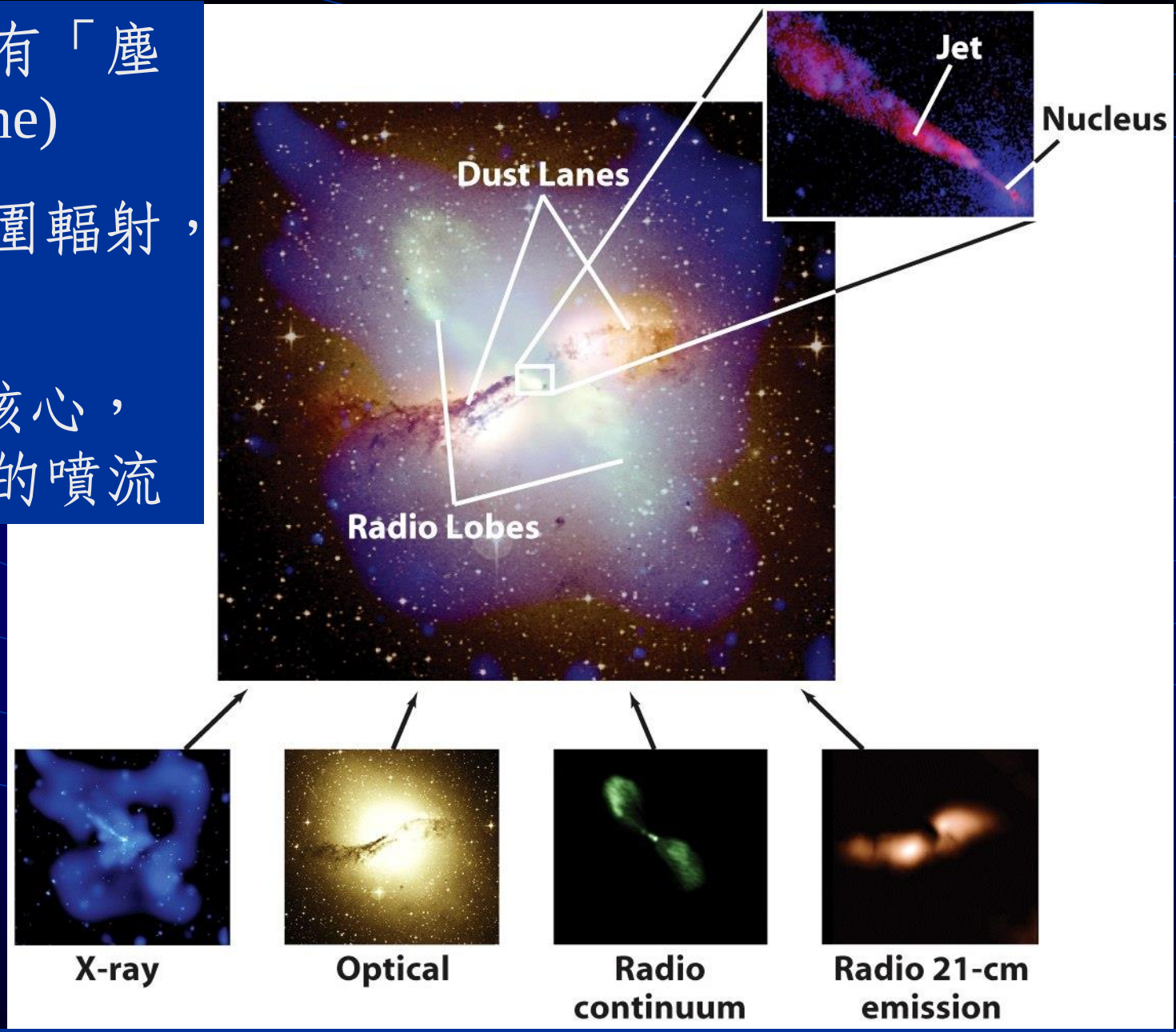
3. The light from *B* (the center of the object) has to travel an additional 1/2 light-year to reach Earth, so we see this light 1/2 year later than the light from *A*.

4. We see the light from *C* (the far side of the object) 1/2 year later than the light from *B* and 1 year later than the light from *A*. Hence we see the sudden flash of light spread over a full year.

可見光：中央有「塵埃巷」(dust lane)

電波：有大範圍輻射，與塵埃巷垂直

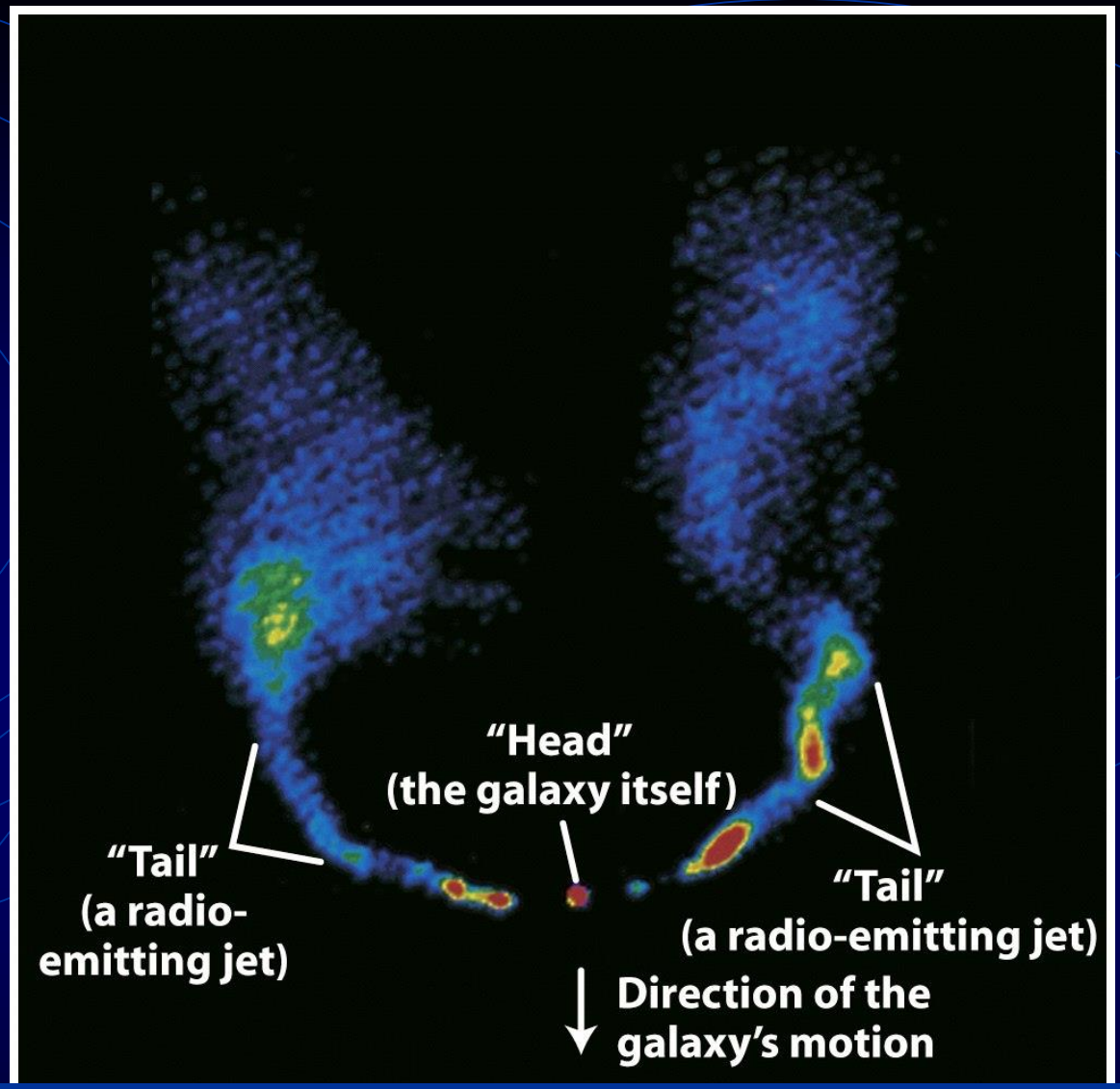
X射線：明亮核心，與塵埃巷垂直的噴流



The peculiar galaxy NGC 5128 (Centaurus A) 在各波段的奇異外型

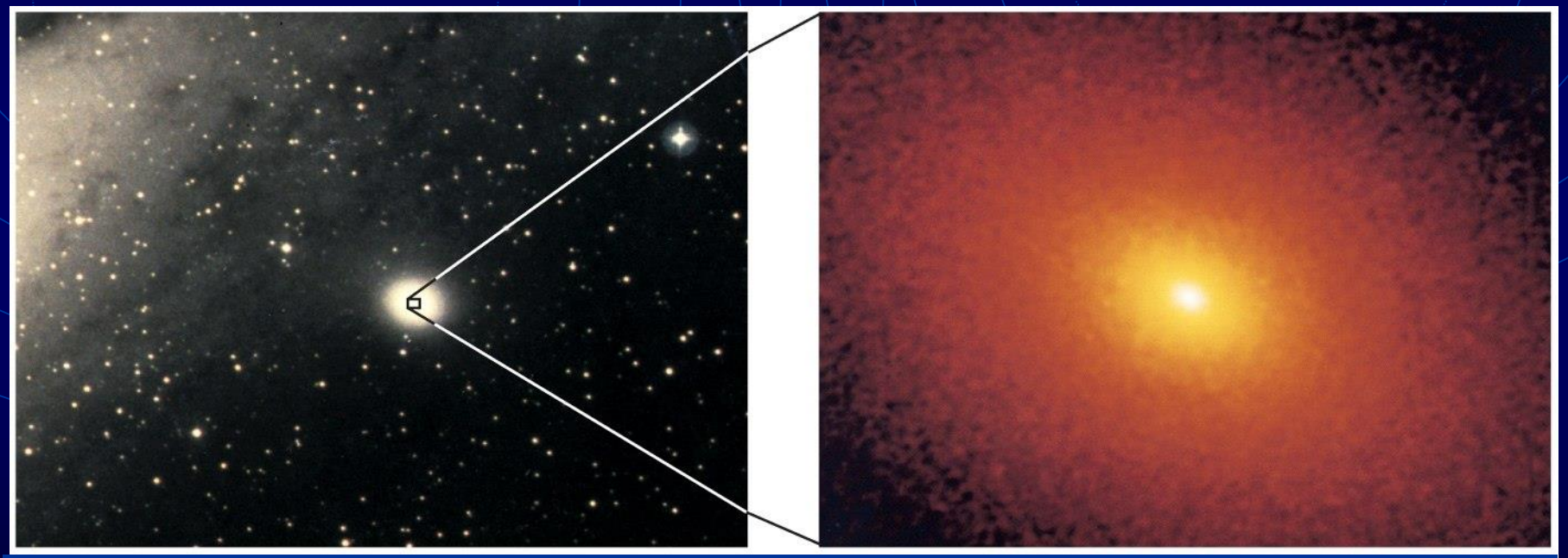
- 還有比 quasars 更明亮的天體，稱作 **BL Lacertae objects** (BL Lac，蝎虎座 BL 天體），其光譜特色就是沒有特色（只有非常微弱的譜線）
- 一般相信 BL Lac 天體是橢圓星系的 quasar 核心，正如 Seyfert（西佛星系）之於螺旋星系
- 這些天體光變快速，時間尺度小於一天者稱為 **blazars**

Double Radio Sources



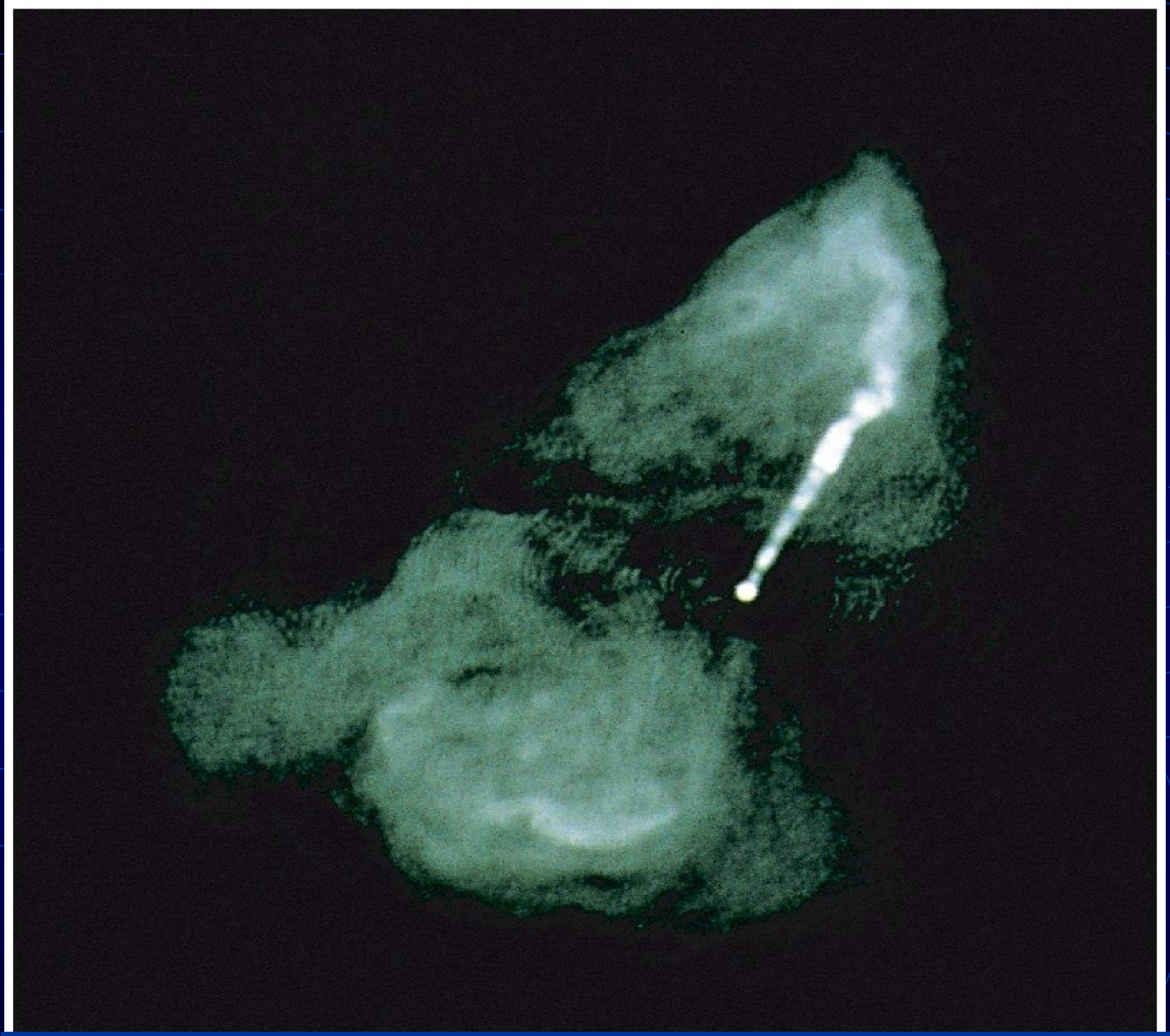
NGC 1265 是個活躍橢圓星系，以高速穿過 intergalactic medium，造成噴流「頭─尾」的形狀

Supermassive Black holes as the Central Engines of AGNs

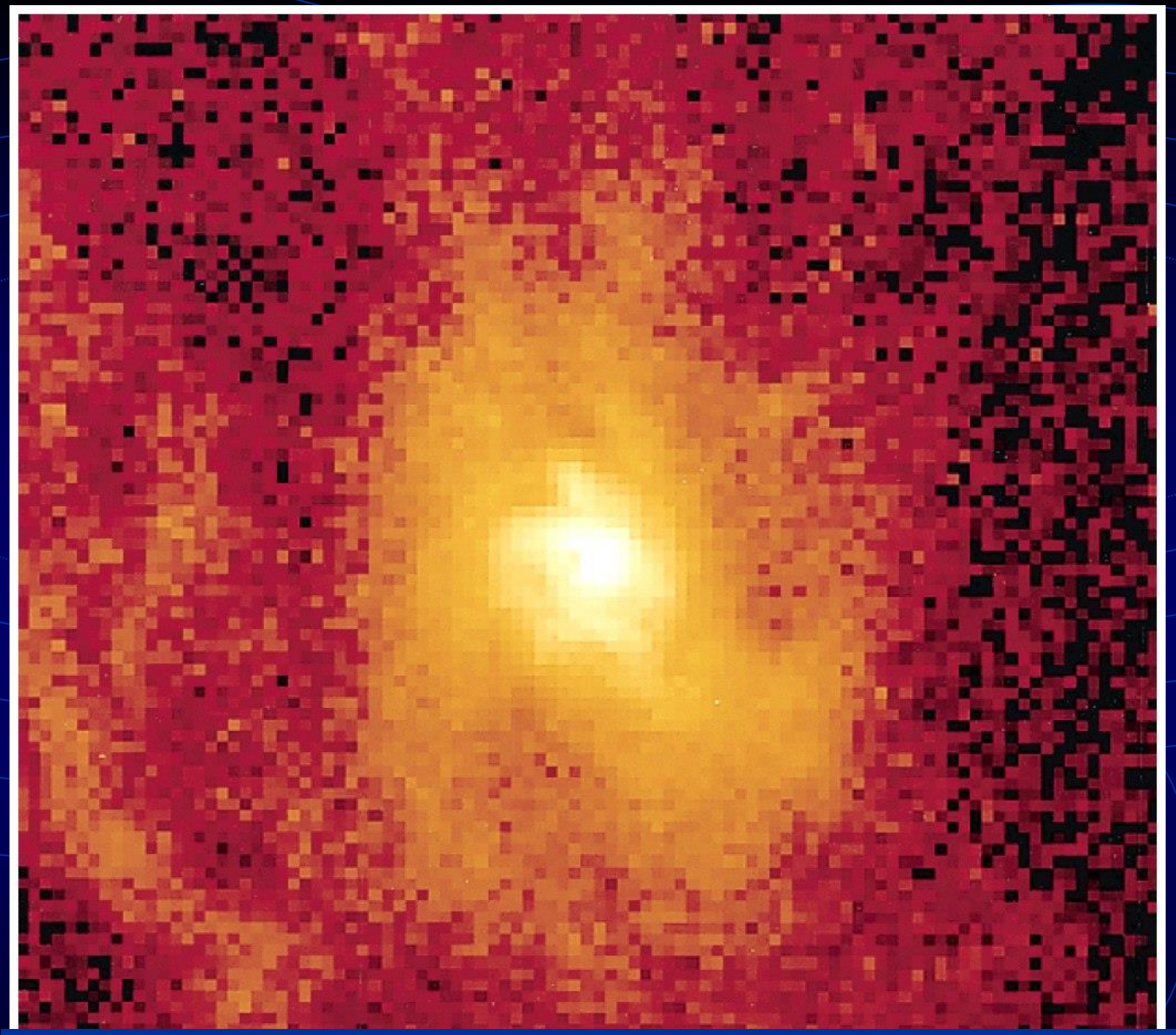


M32 (M31 的衛星星系）距離我們約220萬光年，有個明亮的核心 ，大小只有 175 光年

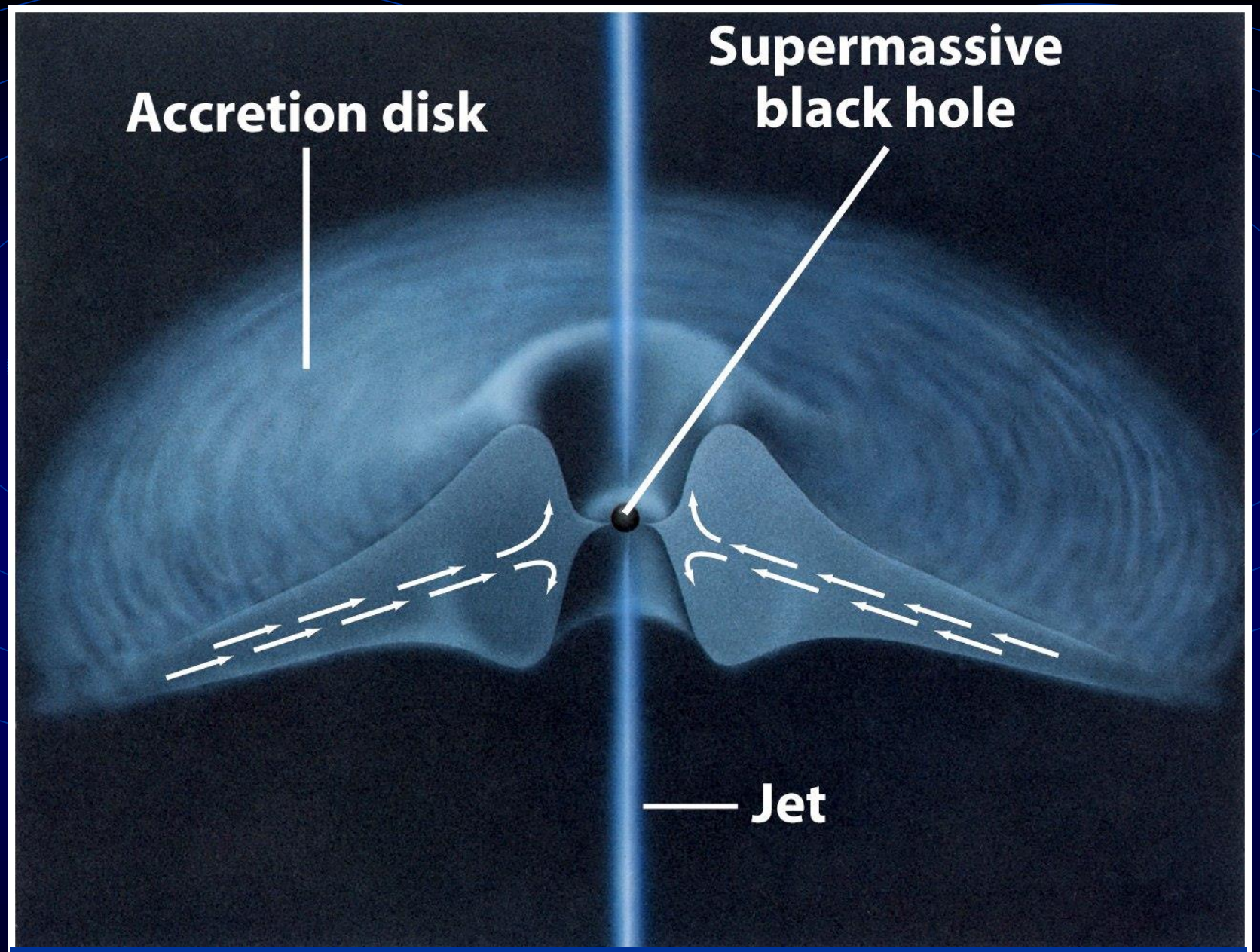
M87 是個巨型橢圓星系，距離我們5000萬光年，
這張長期曝光的照片可看到 M87 周圍的球狀星團



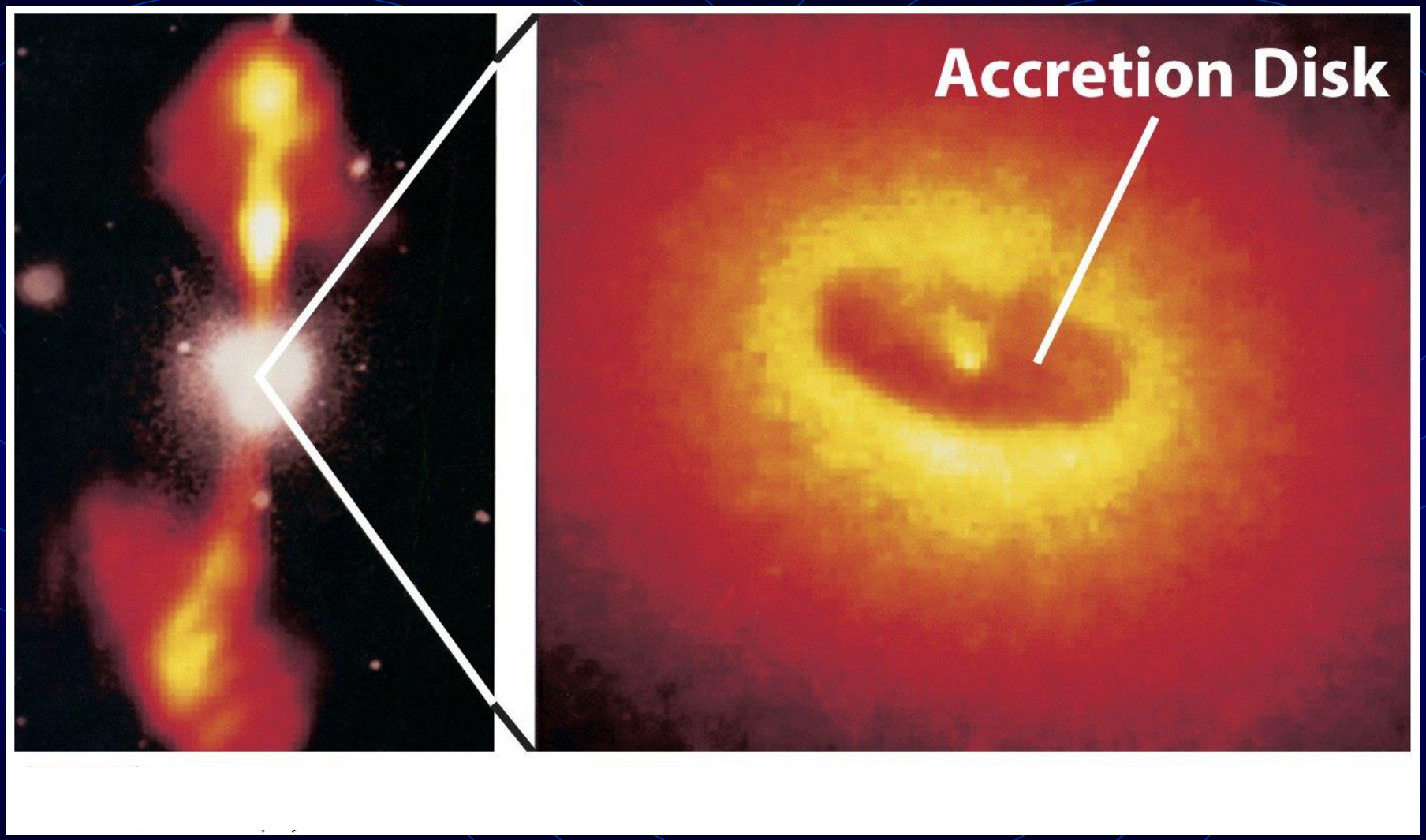
M87 周圍噴發出來的雲氣
（中央的白點為M87可見光的部分）

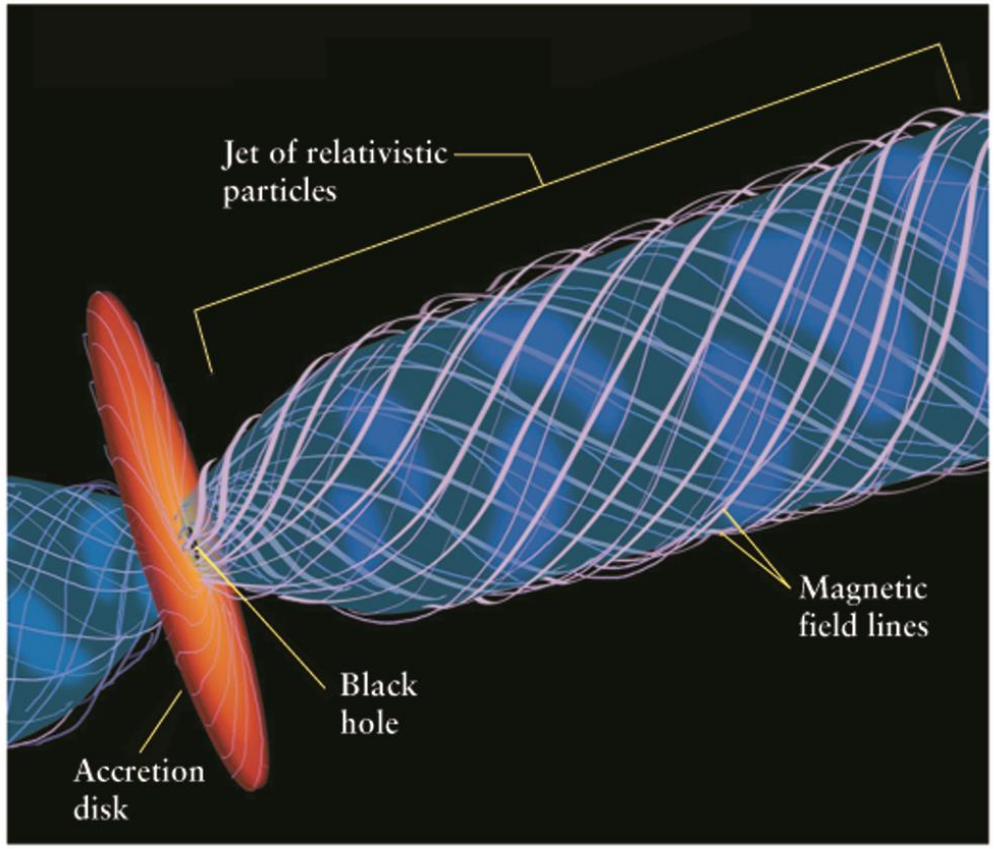


HST 所拍攝 M87 明亮核心的氣體噴流，
顯示核心的黑洞質量約為太陽的30億倍



Supermassive black hole as engines (animation)


Accretion Disk



Jets from a supermassive black hole

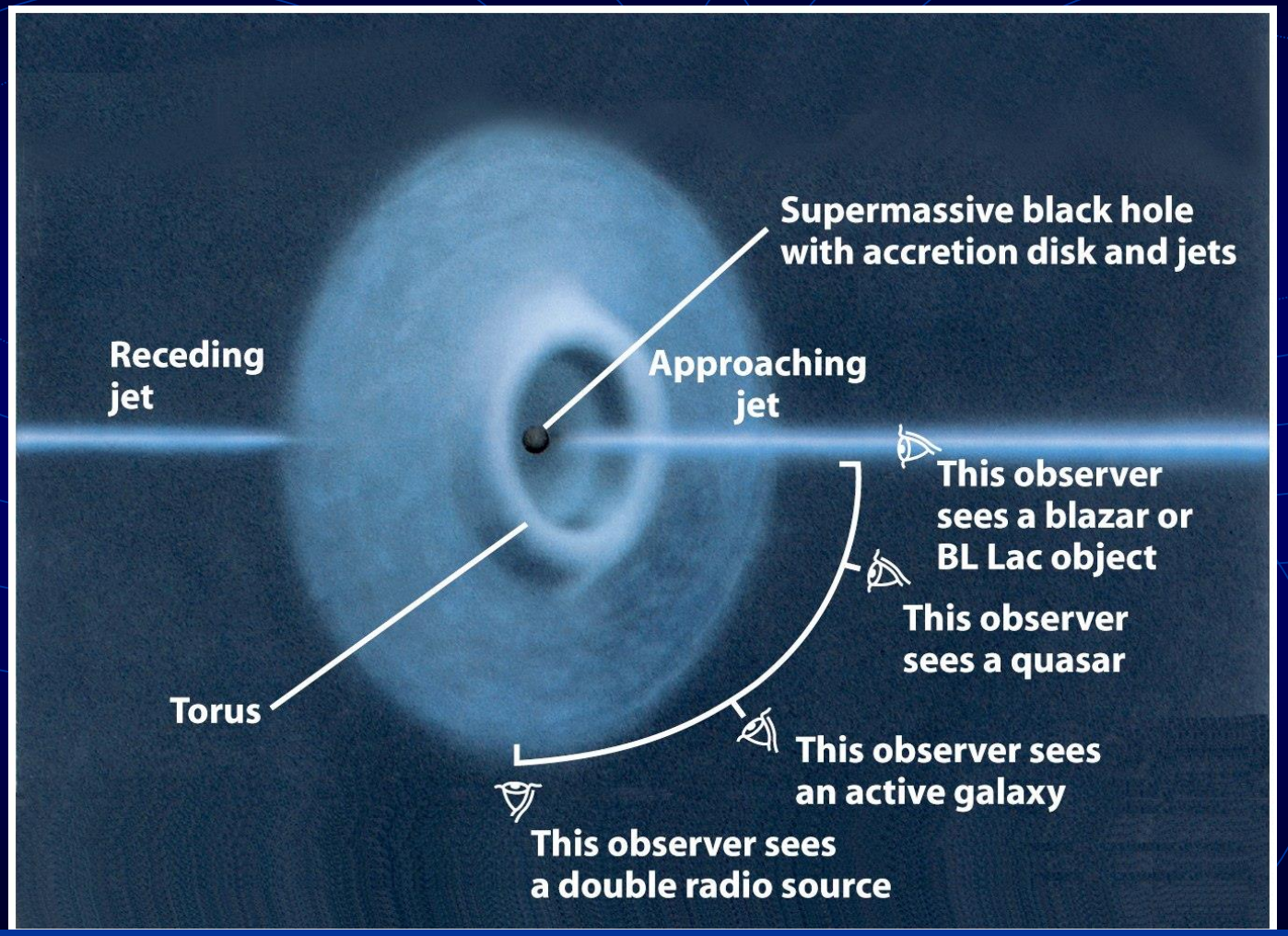
Accretion is a powerful mechanism to produce energy (from gravitational energy).

There is an upper limit to the luminosity that can be radiated by accretion onto a compact object such as a BH ➔ **Eddington limit**

$$L_{Edd}/L_{\odot} = 30,000\ (M/M_{\odot})$$

For example, 3C 273 has $L = 3 \times 10^{13}\ L_{\odot}$, so the black hole that is powering the quasar must be $M > 10^{9}\ M_{\odot}$

AGN 的大一統模型



端視觀察者看超大質量黑洞與吸積盤的角度