

# 第六章 银河系

(Chapter 23)

§ 6.1 银河系的整体结构

§ 6.2 银河系的转动

§ 6.3 银河系的旋涡结构

§ 6.4 银心和银晕

§ 6.5 银河系的起源



# What Are Galaxies?

- Collection of billions of stars
- Held together by gravity



NGC 4603 and NGC 4881

## § 6.1 银河系的整体结构

### 1. 银河系全貌

银河是天空中的一个环带，在人马座附近最亮、最宽，它的中心线近似为天球上的一个大圆。

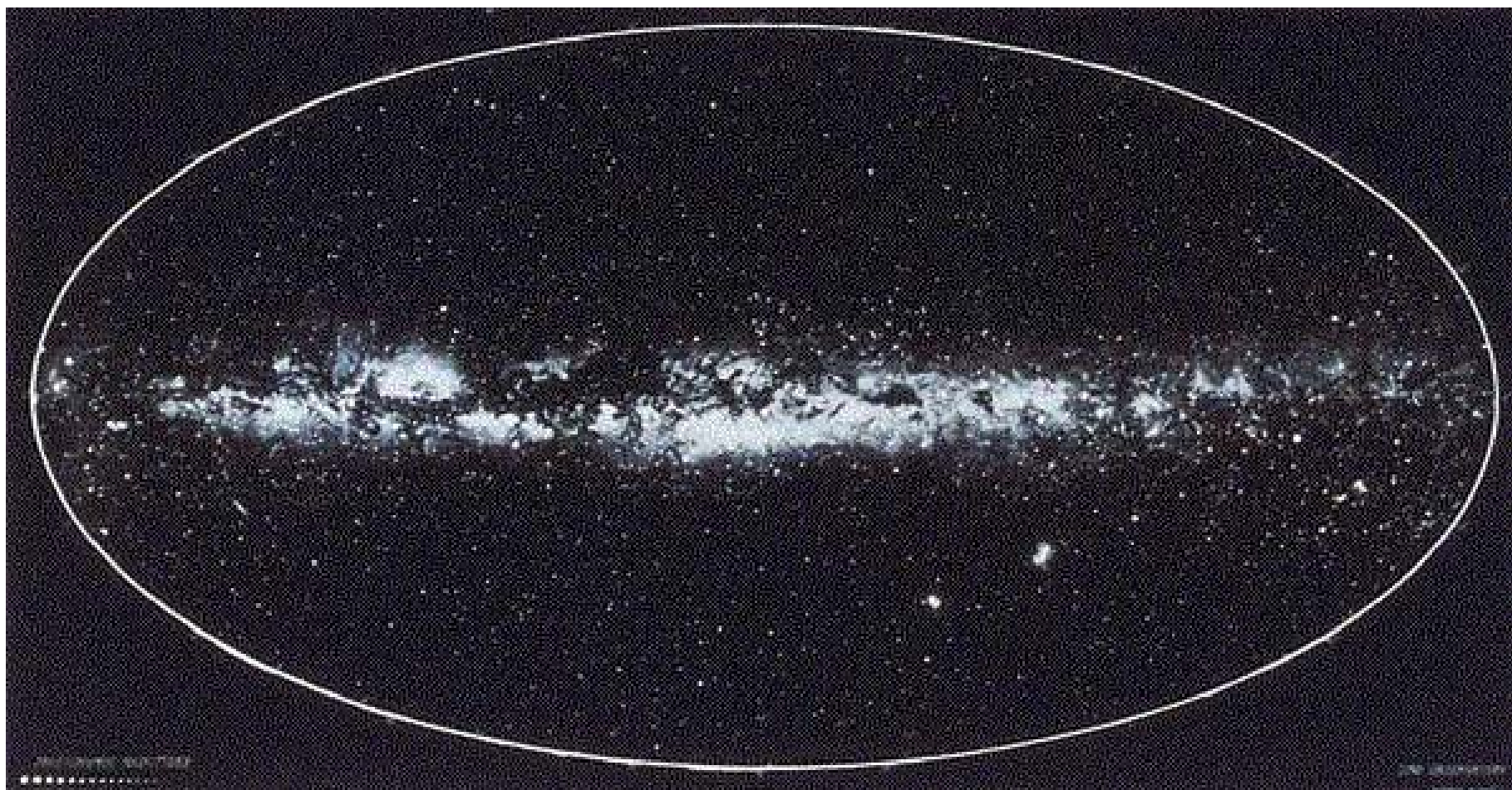


银河系广角图像

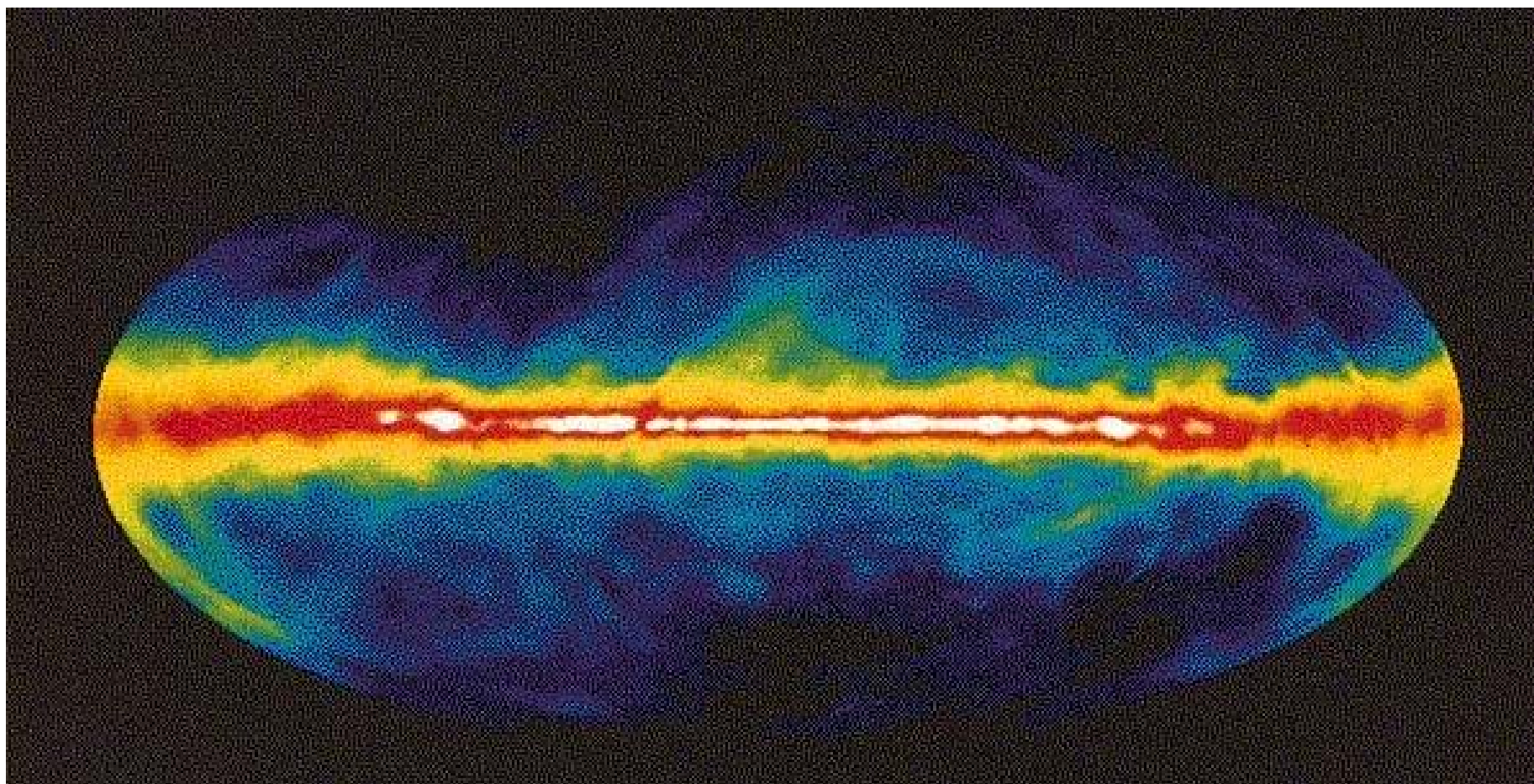


360-degree Milky Way Panorama

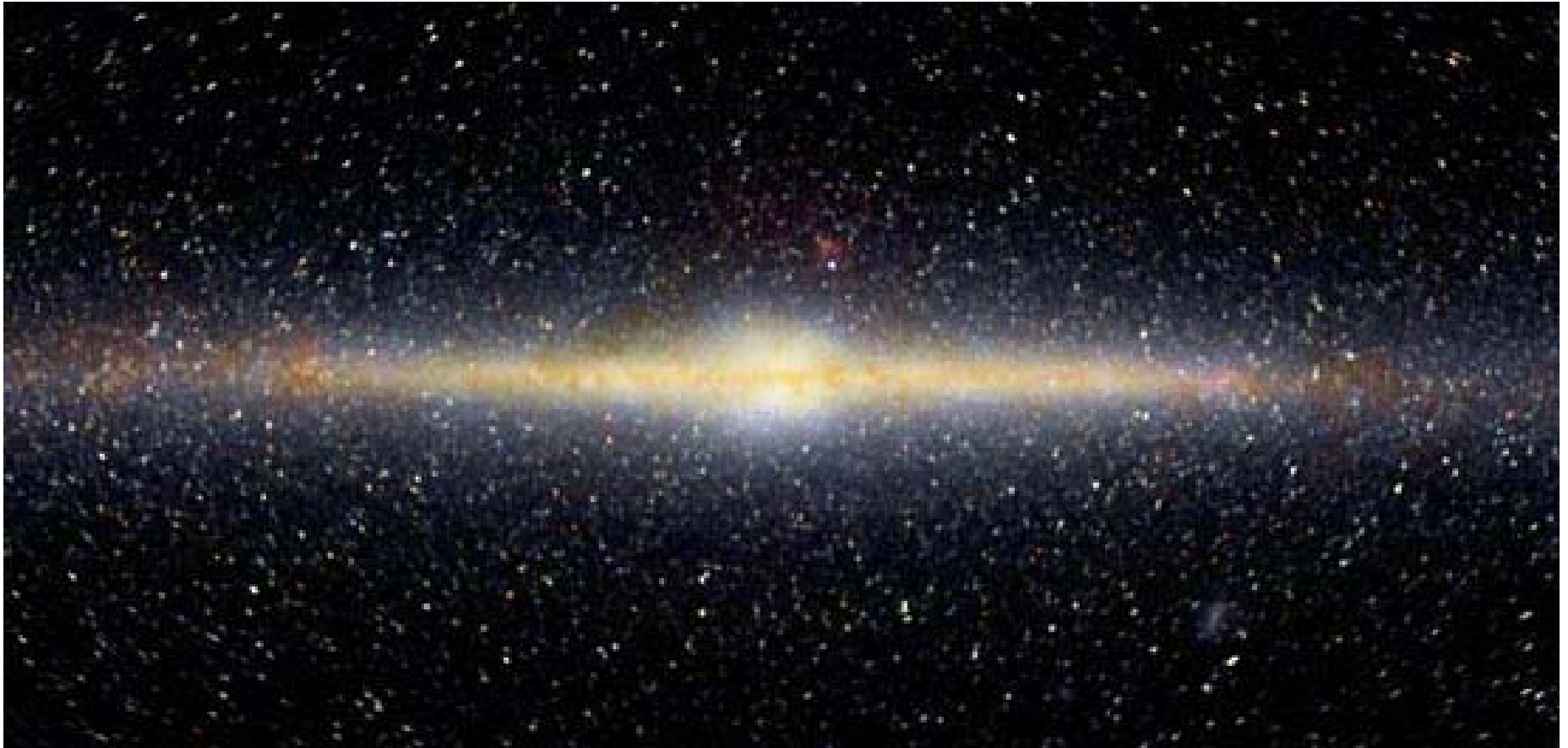
# 光学波段的银河系



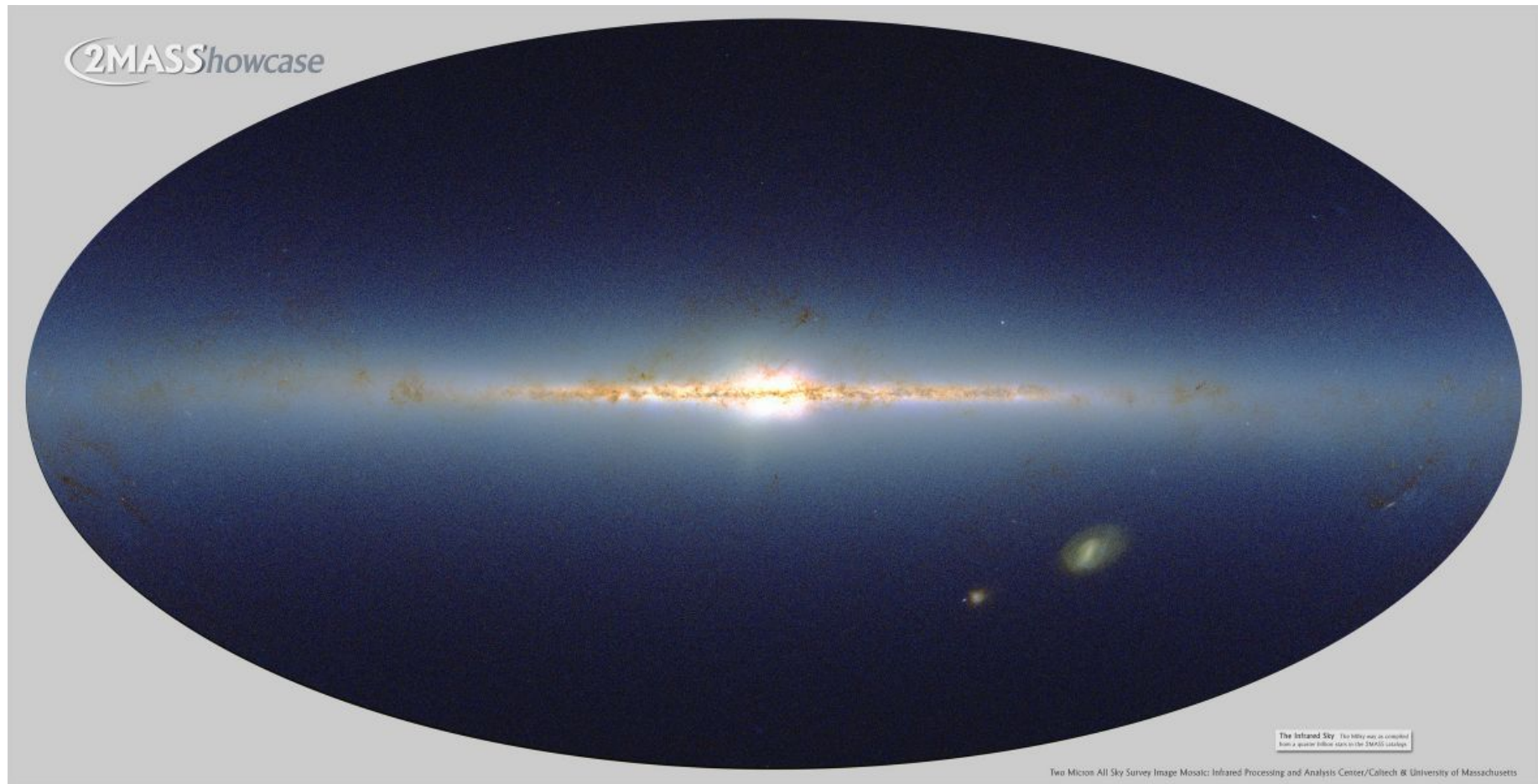
## 射电波段的银河系



## 红外波段的银河系

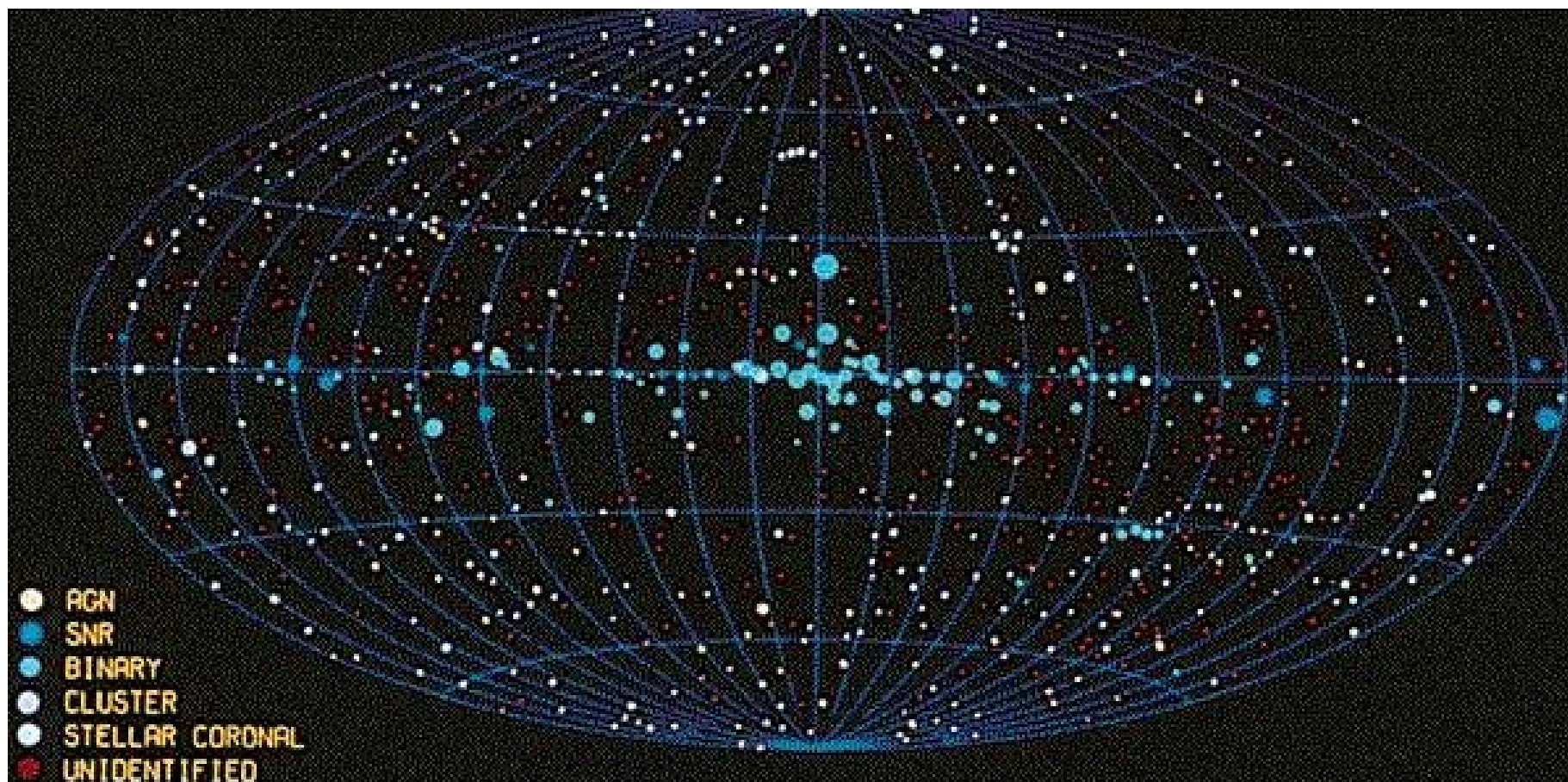


# 近红外波段的银河系

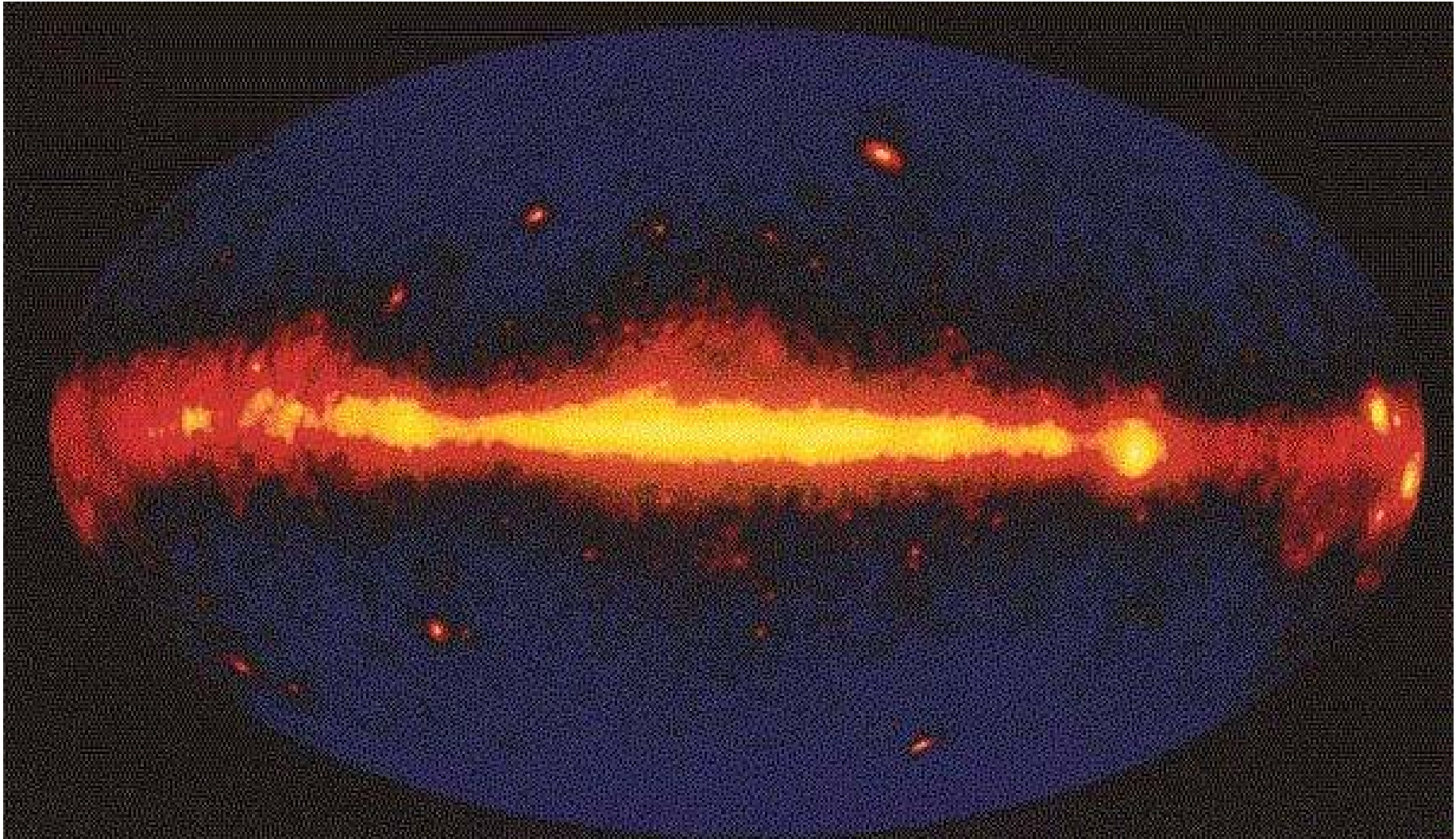




# X射线波段的银河系

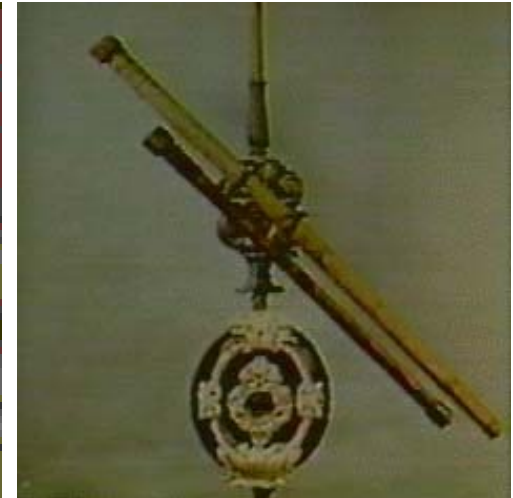
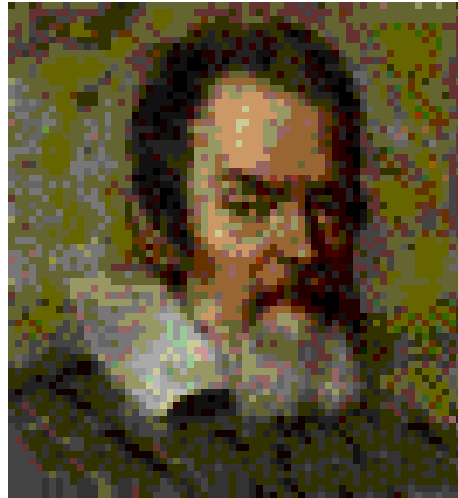


# $\gamma$ 射线波段的银河系



## 2. 银河系研究简史

- 1610年Galileo Galilei (意) 首先用望远镜发现银河由无数恒星组成。

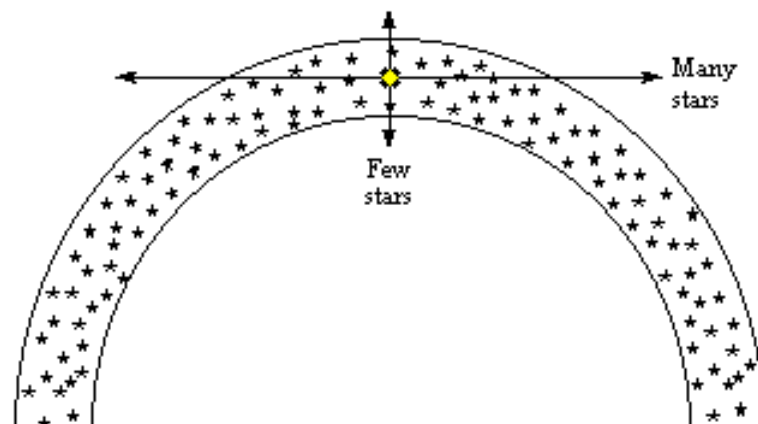


*"For the Galaxy is nothing else than a congeries of innumerable stars distributed in clusters."*

——in *The Starry Messenger*

● 1750年 T. Wright  
(英)：

太阳是球壳状分布的无数  
恒星中的一颗。



● 1755年 I. Kant (德)：

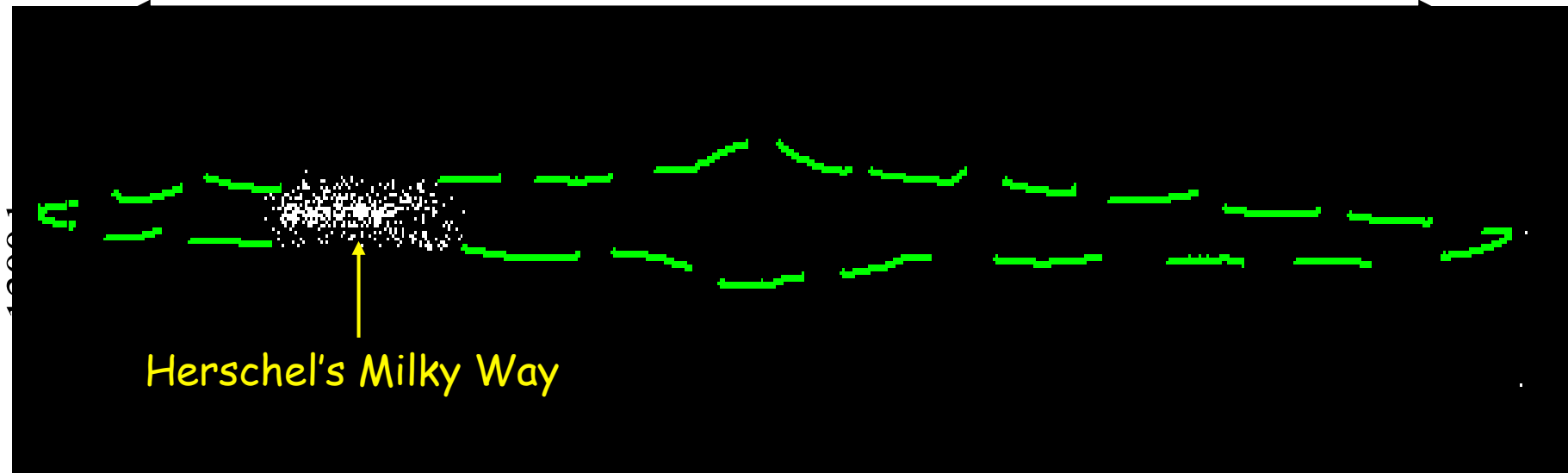
银河系是恒星组成的旋转扁盘系  
统，是“宇宙岛”之一。



- 1785年W. Herschel (英) 通过计量不同方向的恒星密度, 得到第一幅银河系整体图像: 银河系为扁盘状, 太阳位于中心附近。



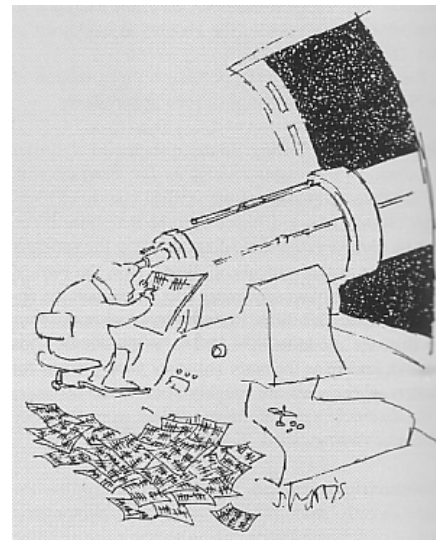
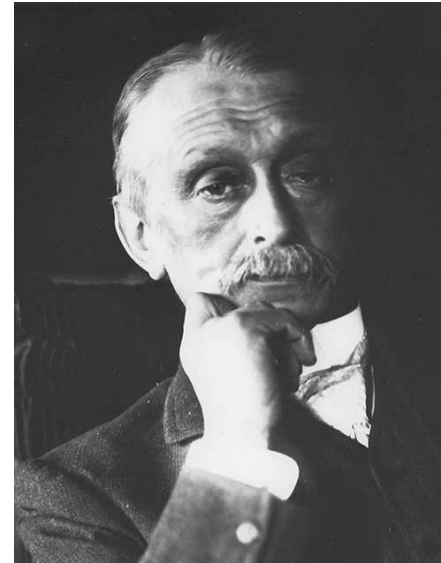
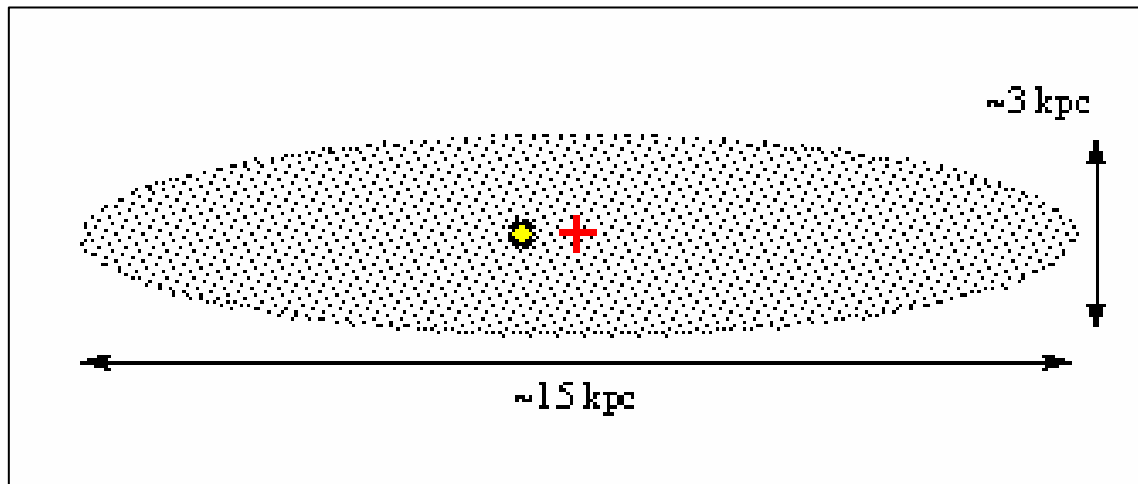
6400 ly



Herschel's Assumptions :

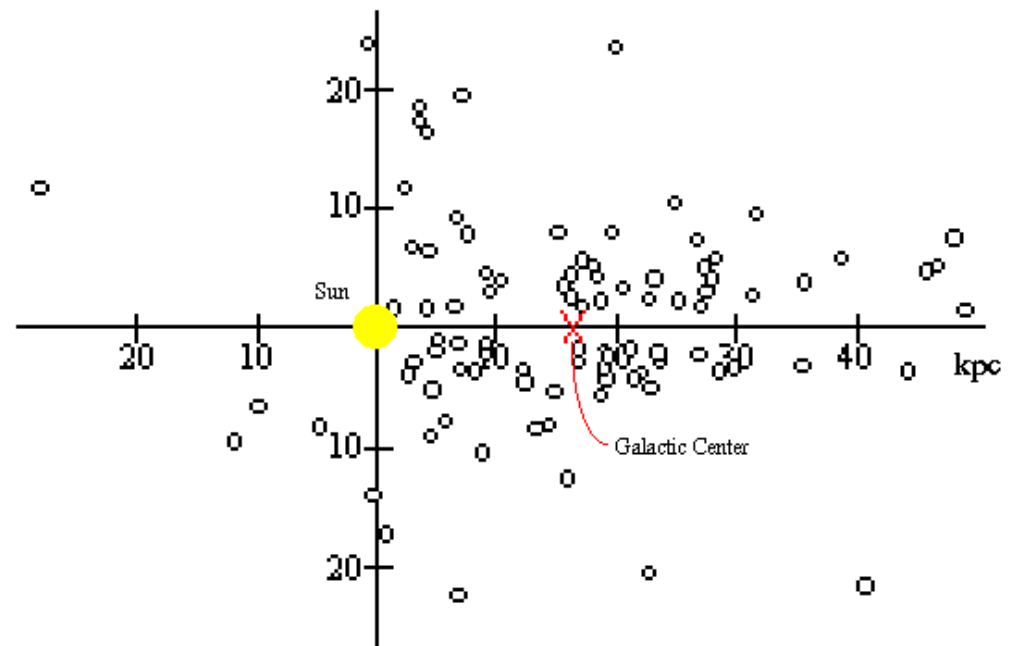
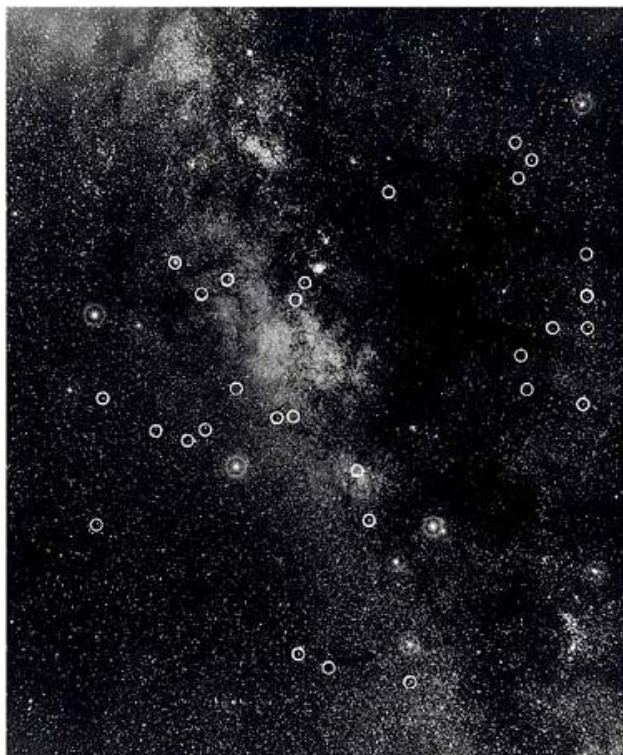
- (1) All stars have the same brightness;
- (2) Space is transparent between the stars.

- 1922年J. Kapteyn (荷) 利用照相底片测量不同天区的恒星密度，用统计视差求得恒星距离，首次估计银河系直径为~50,000 ly，厚度为~10,000 ly，他认为太阳位于银河系中心附近。



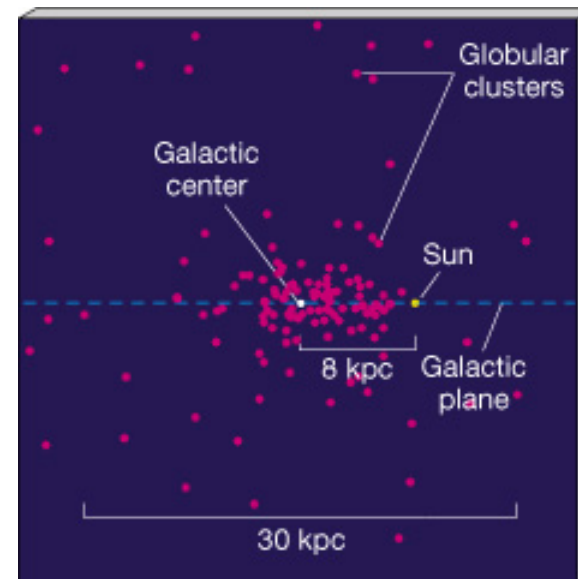
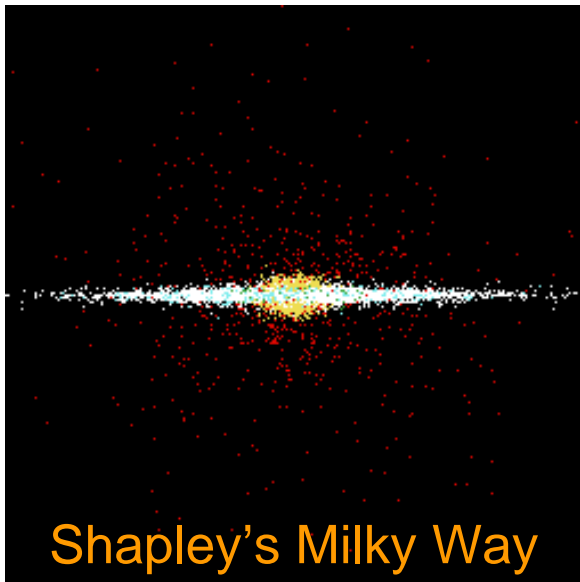
- 1920年H. Shapley (美) 利用球状星团内的天琴RR型变星测量星团距离，并给出球状星团的空间分布。

Shapley发现球状星团均匀地分布在银河的两侧，并且有向人马座聚集的倾向。



# The Creator Milky Way

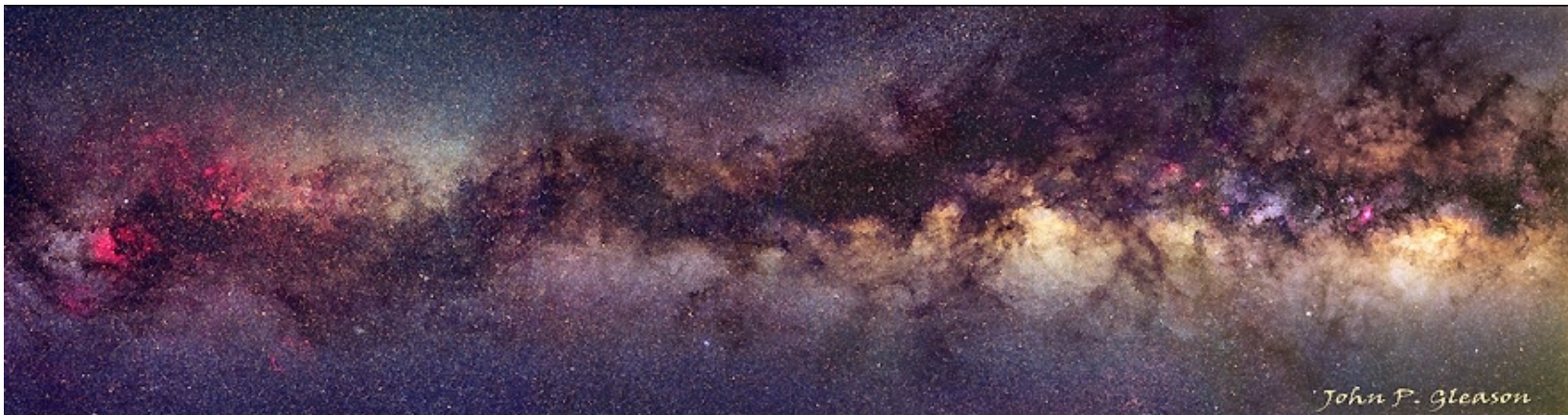
- Shapley认为球状星团是银河系的子系统，并以银心为分布中心。
- Shapley由此估计太阳系到银心的距离为16 kpc.
- 在Shapley的模型中，银河系的结构是扁盘状的，直径为100 kpc.





## 星际介质与银河系的大小

- 早期对银河系的研究集中在可见光波段，由于天文学家并不了解星际介质的存在及其消光作用，因而得到关于银河系结构的错误的结论。
- 直到20世纪30年代人们才认识到星际介质的分布范围及其对观测的重要影响。并发展了射电与红外的手段来研究银河系的结构。



### 3. 银河系结构

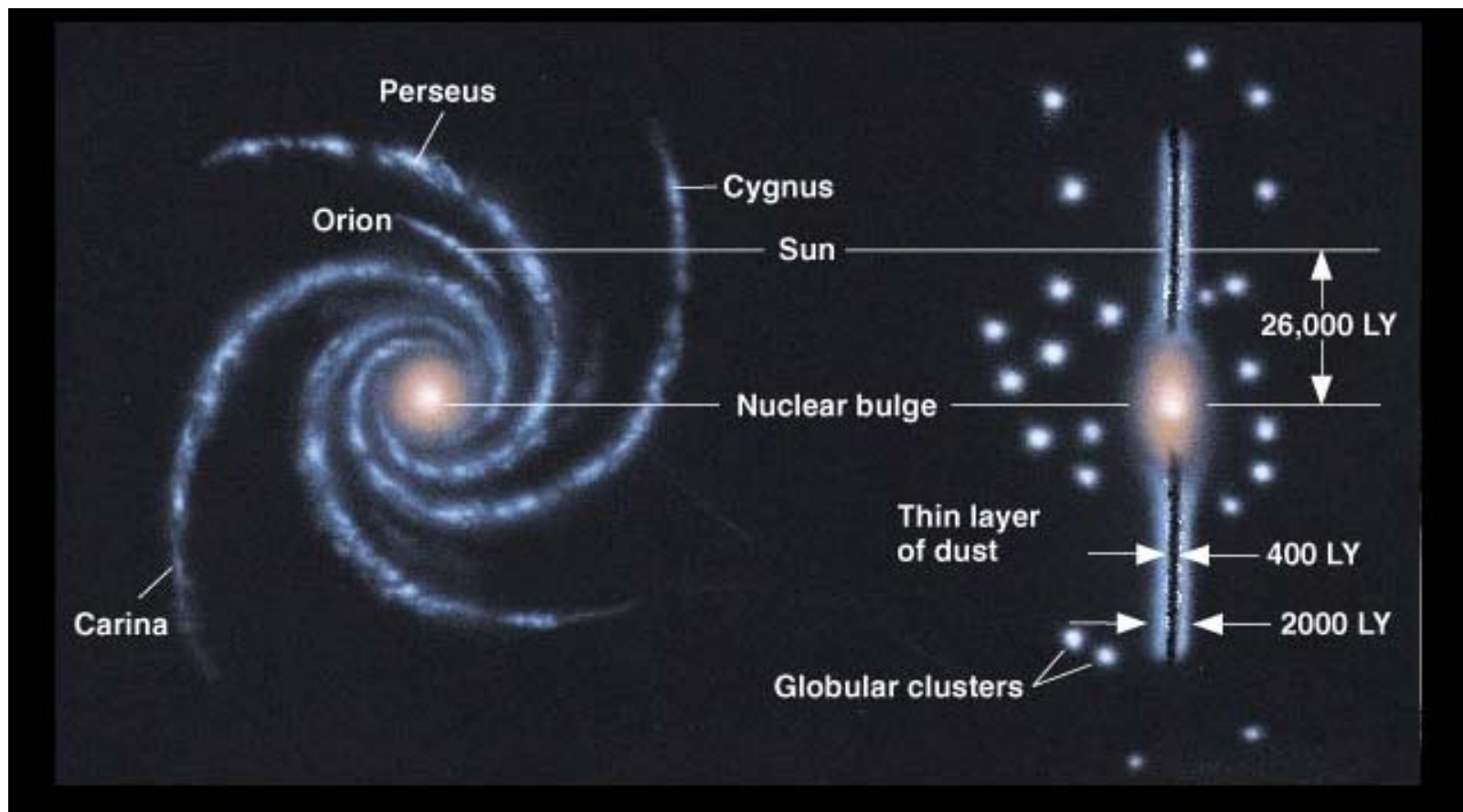
- 银河系是一个包含 $2 \times 10^{11}$ 颗恒星的、具有旋涡结构的盘状星系。

质量 $\sim 10^{12}M_{\odot}$ ，直径 $\sim 10^5$  ly (30 kpc)

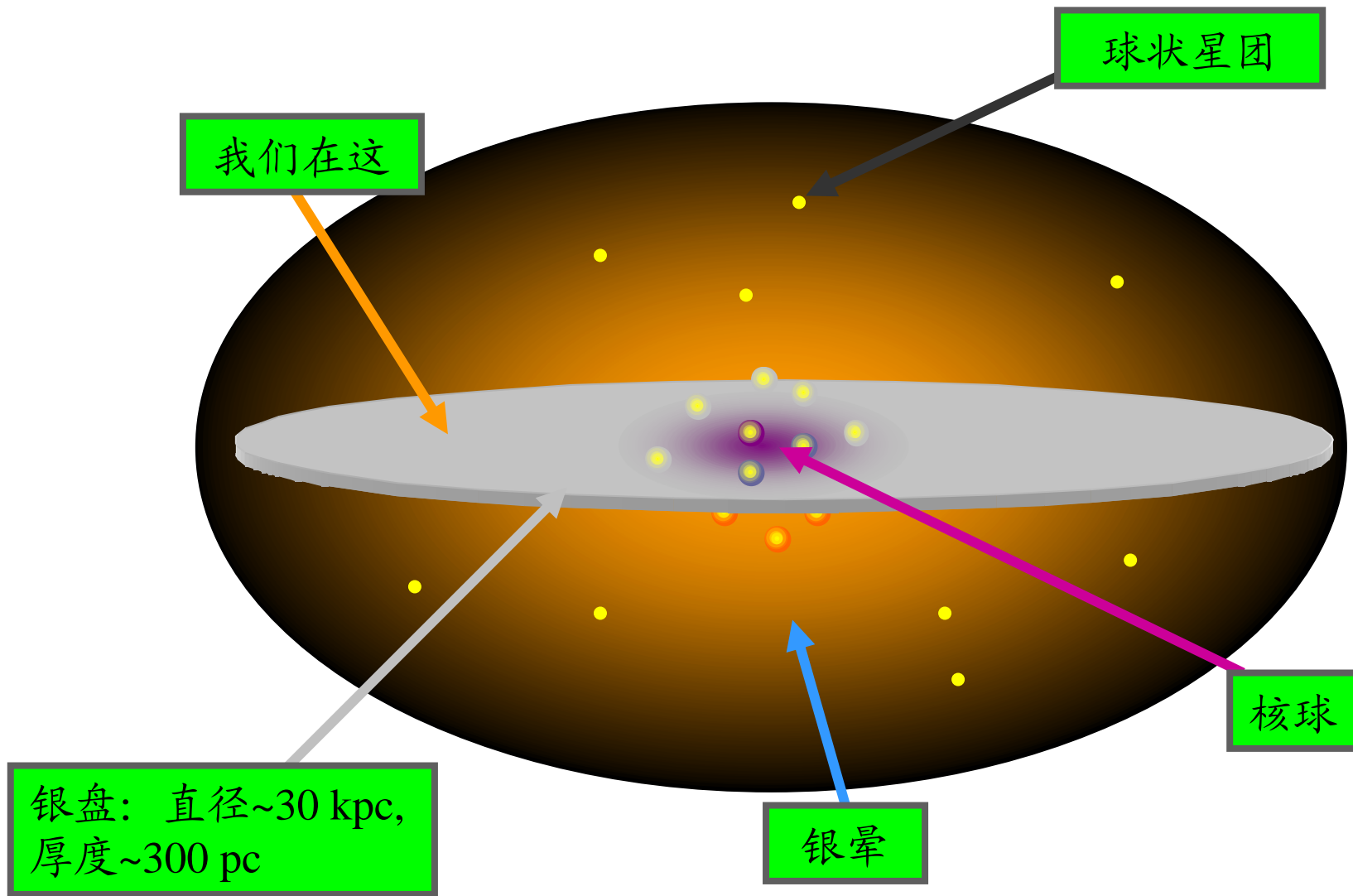


## ● 主要成分

(1) 银盘 (disk) (旋臂 spiral arm)、(2) 核球 (bulge)、(3) 银晕 (halo)、(4) 银冕 (corona)



# 银河系结构



## 4. 银道坐标系

- 原点：观测者

- 坐标系平面：银道面

- 银心方向：

$$\alpha = 17^{\text{h}} 45.7^{\text{m}}, \delta = -29^{\circ} 00'$$

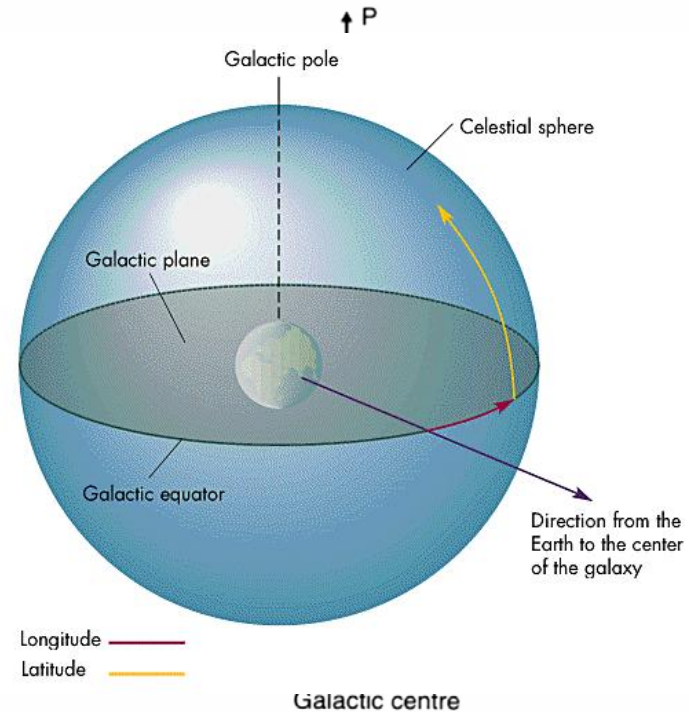
- 北银极坐标：

$$\alpha = 12^{\text{h}} 51.4^{\text{m}}, \delta = 27^{\circ} 08'$$

- 天体位置在银道坐标系中的计量

**银经 (longitude)  $l$**  ( $0^{\circ} \sim 360^{\circ}$ ) 从银心方向开始、沿银道面按逆时针方向计量。

**银纬 (altitude)  $b$**  ( $-90^{\circ} \sim 90^{\circ}$ ) 从银道面量起，向北为正，向南为负。



## 5. 星族 (population)

- 1944年Walter Baade发现星系晕与核球中的恒星明显比盘中的恒星颜色偏红。
- Baade由此提出星族的概念。

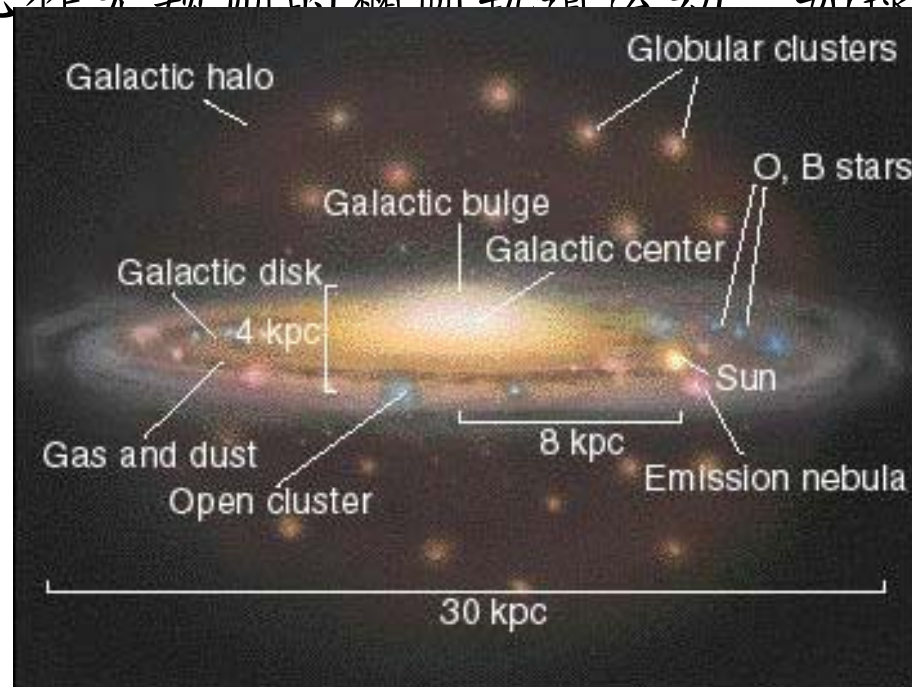


- 星族I恒星

年轻的、富金属恒星（金属丰度为太阳值的0.1-2.5倍）  
主要位于银盘中，绕银心作圆轨道运动。如疏散星团。

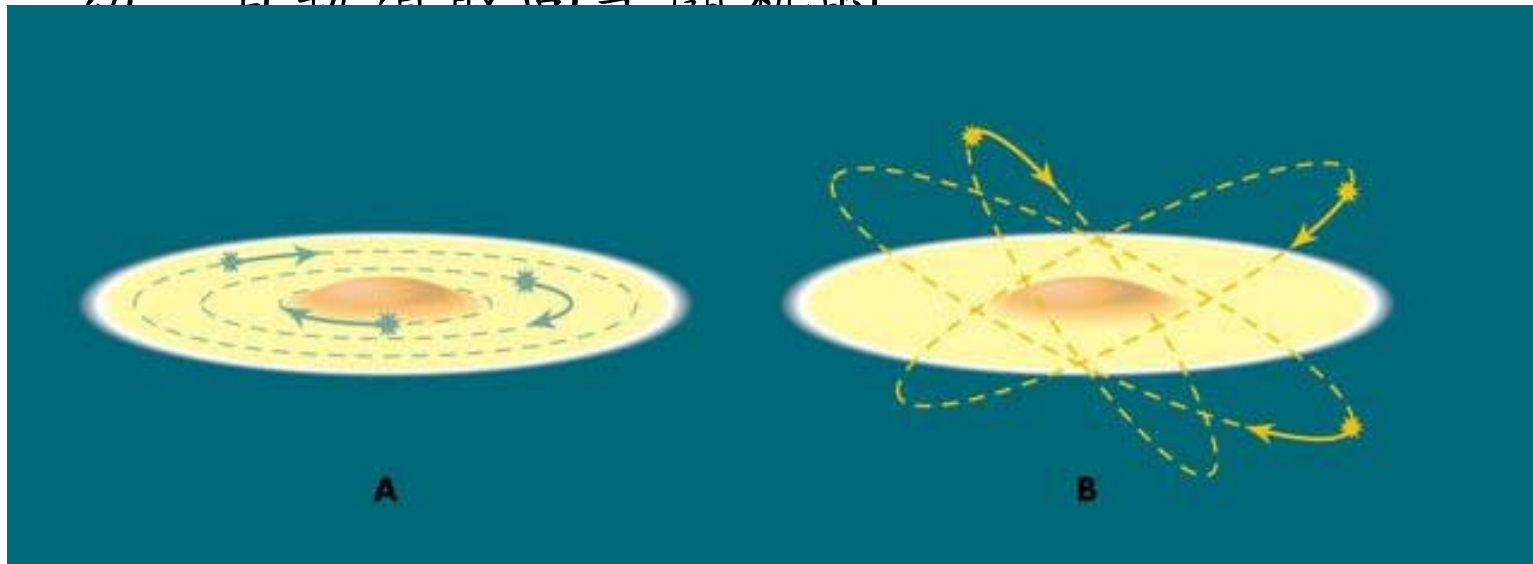
- 星族II恒星

年老的、贫金属恒星（金属丰度为太阳值的0.001-0.03倍），主要位于银晕和核球中，以银心作为中心球对称分布绕银心作无规则的椭圆轨道运动。如球状星团。



## 不同星族恒星的轨道运动特征

- 星系盘内的恒星绕银心作规则的圆轨道运动。
- 晕中的恒星绕银心作高偏心率的椭圆轨道运动，且轨道取向是随机的。





## 不同星族天体的特征比较

星族	极端星族II (晕星族II)	中介星族II	盘星族	中介星族I (年老星族I)	极端星族I (年轻星族I)
典型天体	亚矮星、球状星团、天琴RR型星	长周期变星	行星状星云、新星	A型星、经典造父变星	气体、尘埃、超巨星
平均年龄 ( $10^9$ yr)	17-12	15-10	12-2	2-0.1	0.1
垂向距离	2000 pc	700 pc	400 pc	160 pc	120 pc
垂向速度	75 $\text{kms}^{-1}$	25 $\text{kms}^{-1}$	18 $\text{kms}^{-1}$	10 $\text{kms}^{-1}$	8 $\text{kms}^{-1}$
金属丰度	0.001	0.005	0.01 - 0.02	0.02	0.03-0.04

● 金属丰度越低的恒星离银道面越远 → 银河系演化

## § 6.2 银河系的转动

### 1. 银河系的转动

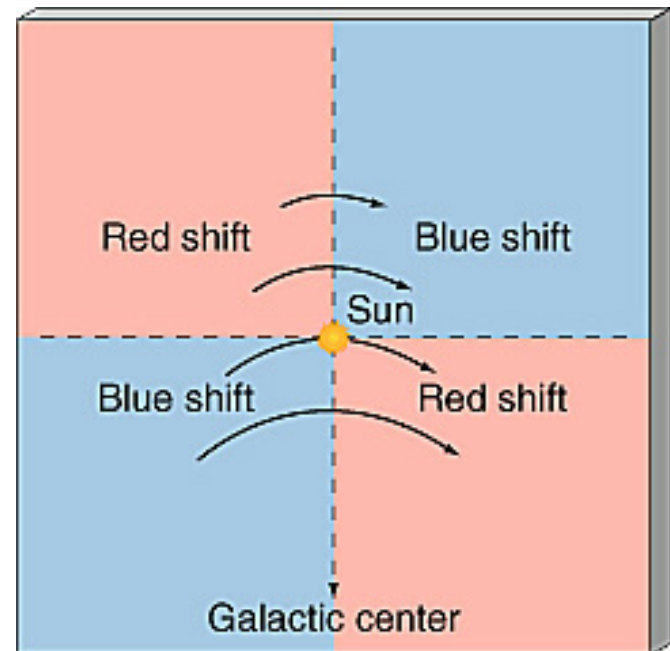
#### (1) 银河系的较差转动

- 方法

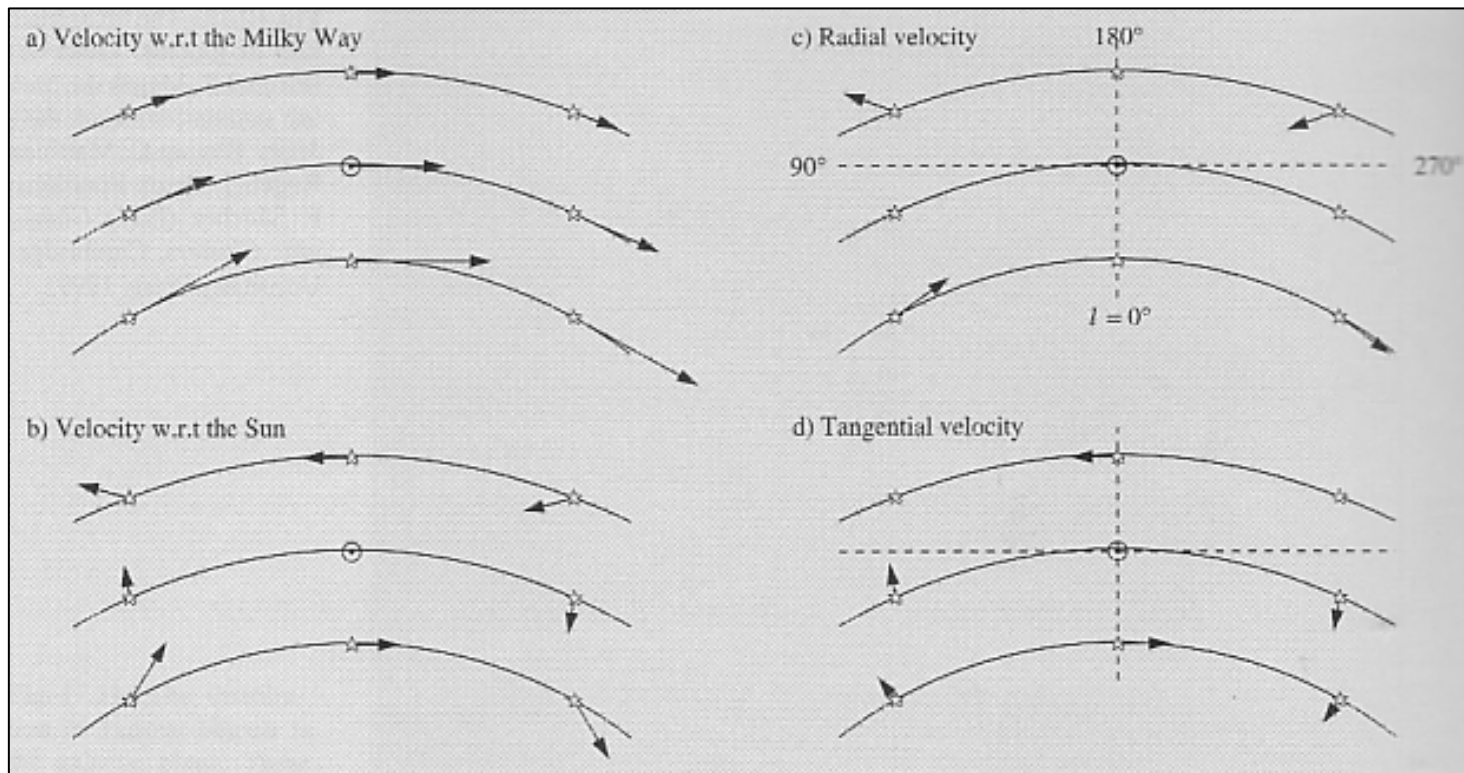
测量恒星和气体云谱线的Doppler位移（视向速度）随银经的变化。

- 太阳附近恒星视向速度（或自行）的周期性变化：

在太阳周围360度的范围内，恒星的谱线位移表现出周期性的蓝移和红移。



- 银河系的转动是较差转动  
在太阳附近，距离银心越远，转动速度越小



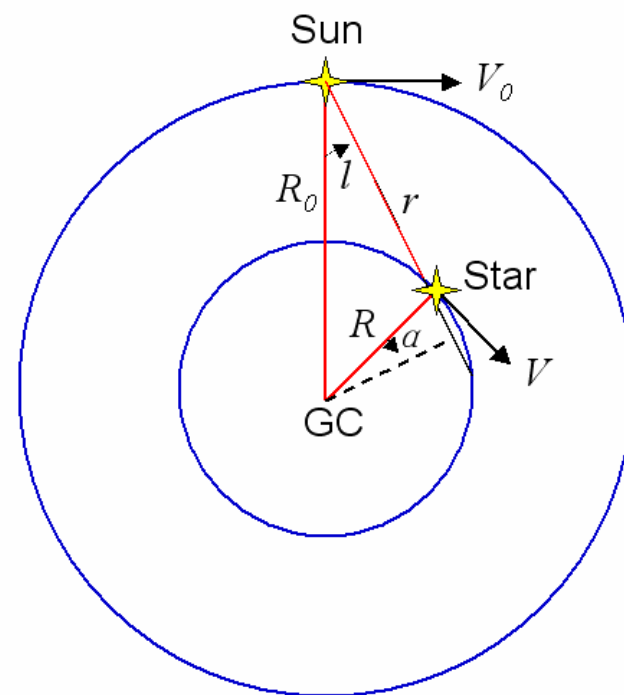
## (2) Oort公式

令银经为  $l$  的恒星和太阳的转动角速度分别为  $\omega = V/R$  和  $\omega_0 = V_0/R_0$ ,

恒星相对于太阳的视向速度为

$$V_r = V \cos \alpha - V_0 \sin l$$

$$\cos \alpha = R_0 \sin l / R$$



$$\rightarrow V_r = R_0 (\omega - \omega_0) \sin l, \quad V_t = R \omega \sin \alpha - R_0 \omega_0 \cos l$$

$$R \sin \alpha = R_0 \cos l - r \quad (r \text{ 为恒星和太阳的距离})$$

$$\rightarrow V_t = R_0 (\omega - \omega_0) \cos l - \omega r$$

在 $R = R_0$ 附近将 $\omega - \omega_0$ 进行泰勒级数展开,

$$\omega - \omega_0 = \left(\frac{d\omega}{dR}\right)_{R_0} (R - R_0) + \dots \approx \frac{1}{R_0^2} \left[ R_0 \left(\frac{dV}{dR}\right)_{R_0} - V_0 \right] (R - R_0)$$

对 $R \approx R_0 \gg r$ ,  $R - R_0 \approx -r \cos l$

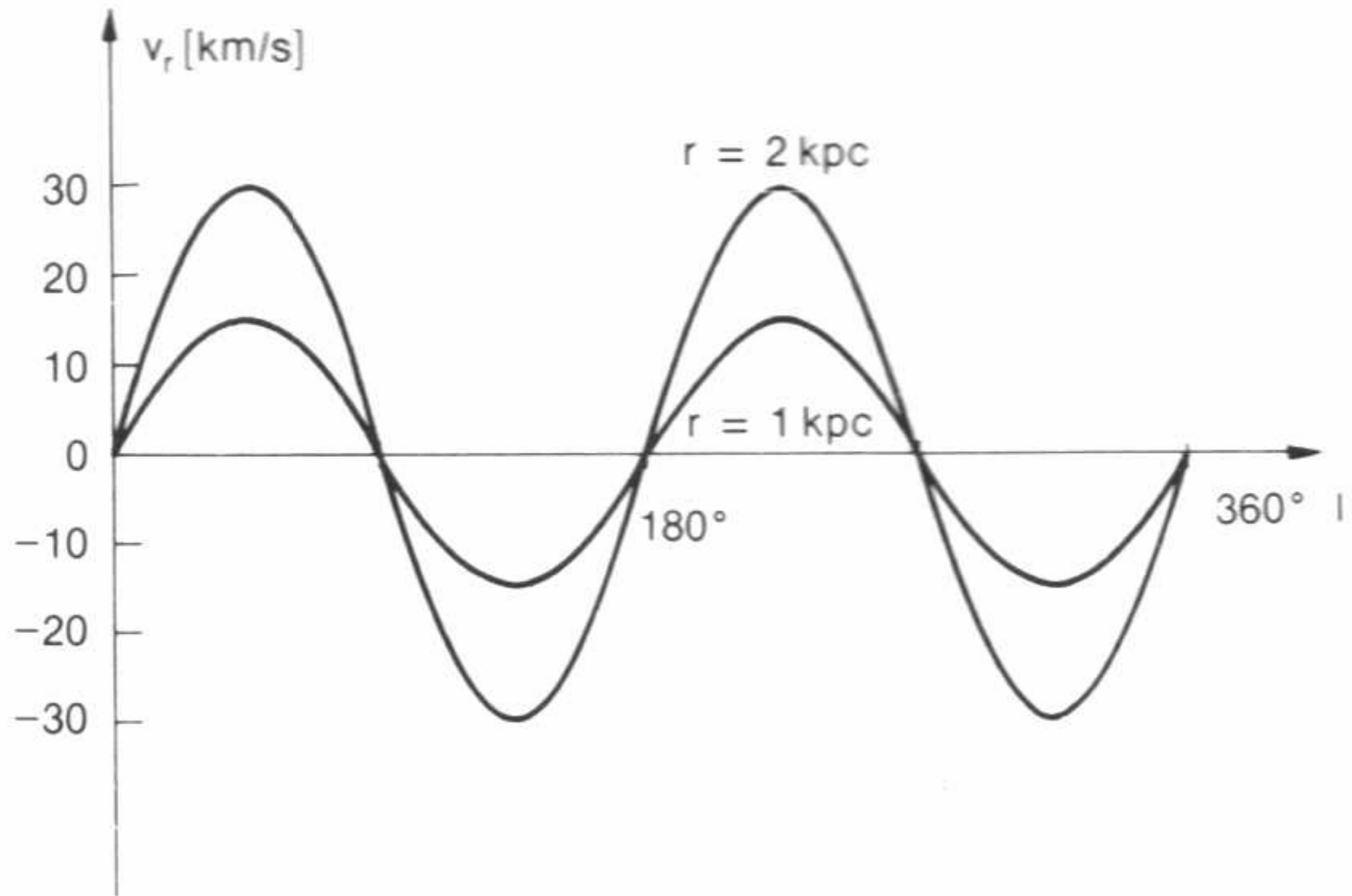
$$V_r = Ar \sin 2l, \quad V_t = Ar \cos 2l + Br \quad \text{或} \quad \mu = A \cos 2l + B$$

其中Oort常数为

$$A = \frac{1}{2} \left[ \frac{V_0}{R_0} - \left(\frac{dV}{dR}\right)_{R_0} \right] = 15 \text{ kms}^{-1}\text{kpc}^{-1}$$

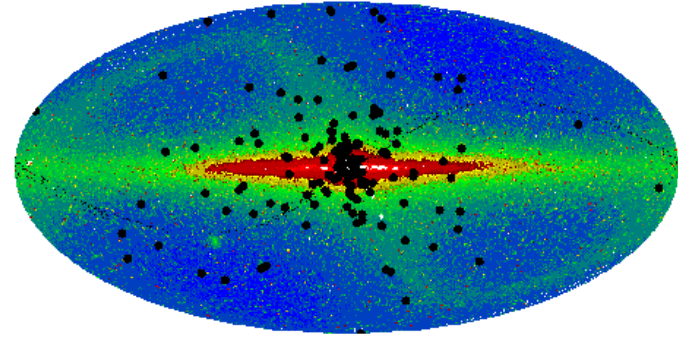
$$B = -\frac{1}{2} \left[ \frac{V_0}{R_0} + \left(\frac{dV}{dR}\right)_{R_0} \right] = -10 \text{ kms}^{-1}\text{kpc}^{-1}$$

## 太阳附近恒星的视向速度的变化



### (3) 利用球状星团测定 $R_0$ 和 $V_0$

- 球状星团的空间分布大致是球对称的，它们组成的次系的中心就是银心。
- 球状星团绕银心旋转的轨道是无规的，可以认为它们作为一个整体相对于银心是不动的。



→ 测定星团的距离，就可以定出太阳到球状星团次系中心的距离，即太阳到银心的距离。

→ 通过观测星团的速度可以求出太阳相对于球状星团次系的运动，即太阳绕银心的转动，

$$R_0 = 8.5 \text{ kpc}, \quad V_0 = 220 \text{ kms}^{-1}$$

太阳的转动角速度  $\omega_0 = A - B = 25 \text{ kms}^{-1}\text{kpc}^{-1}$ ，转动周期为  $2.2 \times 10^8 \text{ yr}$ .

## 2. 银河系的自转曲线和质量分布

(1)  $R < R_0$ : HI云

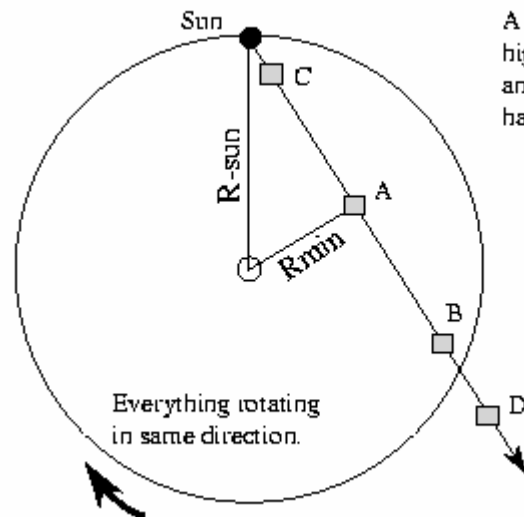
测量在视线方向上的一系列HI云的21厘米谱线的最大位移

→ 最大视向速度  $V_{r, \max}$

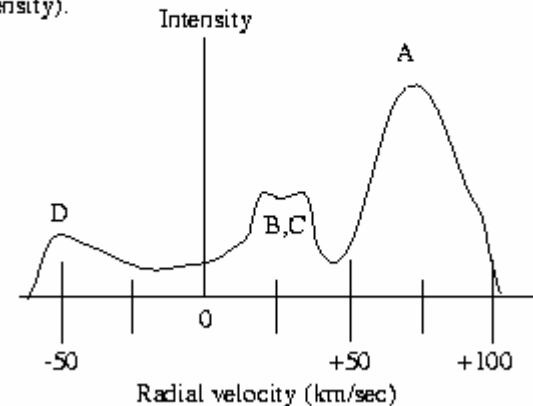
→ 轨道运动速度  $V_{r, \max} = R(\omega - \omega_0)$

→ 轨道半径  $R = R_0 \sin l$

→  $\omega(R), V(R)$



A has greatest angular speed and moving fastest from sun. A has higher density of H. B & C moving at about same angular speed > sun's angular speed. D is outside solar distance—slower angular speed and has less material (density).





## (2) $R > R_0$ : CO分子云和HII区

- 转动角速度  $\omega (R)$  :

观测HII区的发射线、分子云的CO分子毫米波谱线和脉泽(maser)谱线测定视向速度

利用Oort公式  $V_r = R_0 (\omega - \omega_0) \sin l$

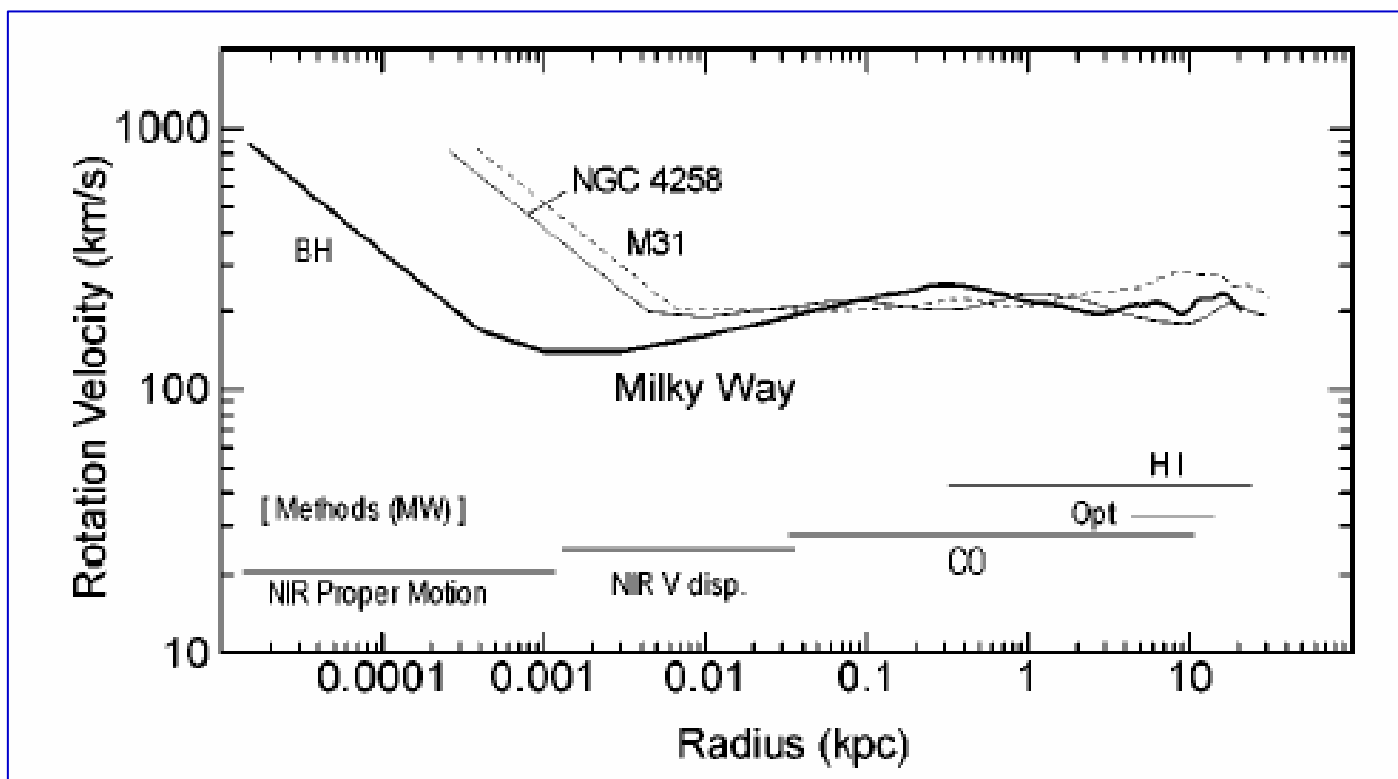
→  $\omega (R)$

- 轨道半径 $R$ :

CO分子云常和HII区成协，可以由HII区内的高温恒星测定其距离。

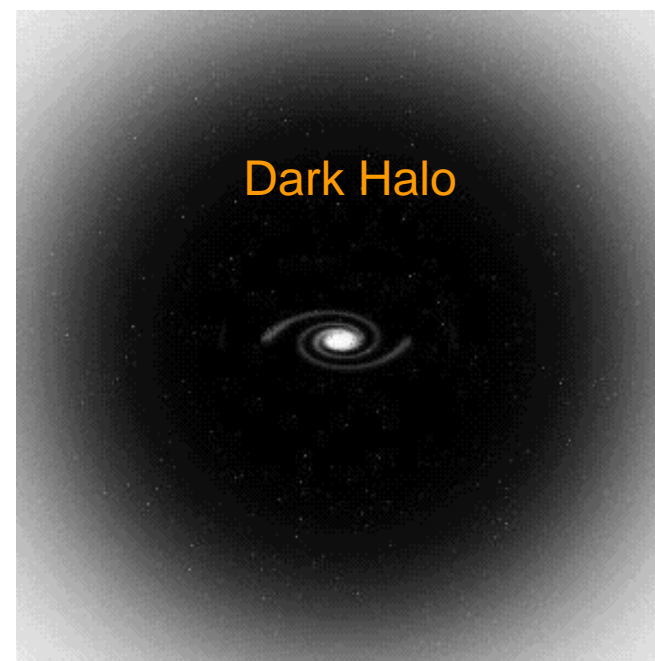
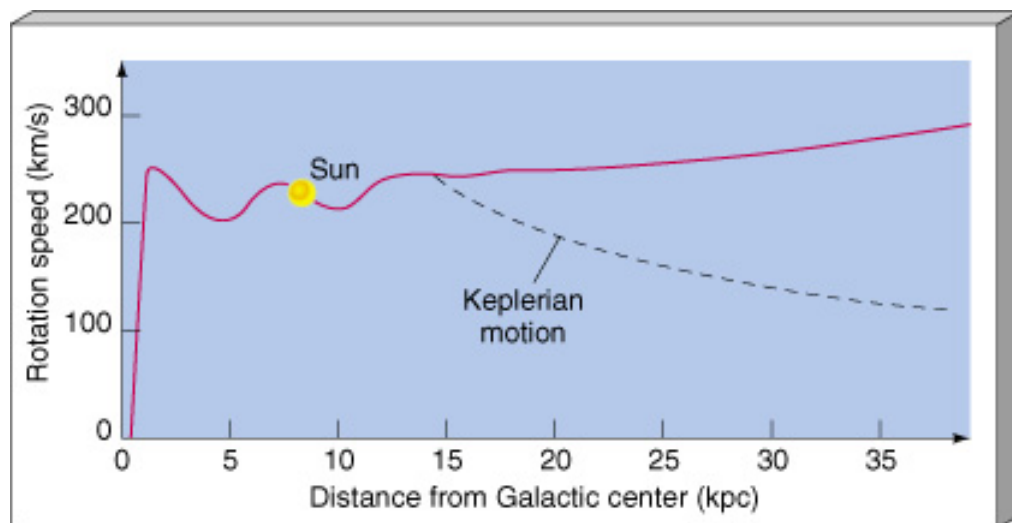
### (3) 自转曲线

- 内区：刚体转动，外区：较为平坦。



#### (4) 银河系质量

- 在太阳轨道内包含的质量为：  
 $M = R_0 V_0^2 / G \approx 1.0 \times 10^{11} M_{\odot}$
- 银河系的可见质量约为  $2.0 \times 10^{11} M_{\odot}$
- 银河系的实际质量远超过  $10^{11} M_{\odot}$ ，表明在银晕中存在大量的暗物质(dark matter)。



## § 6.3 银河系的旋涡结构

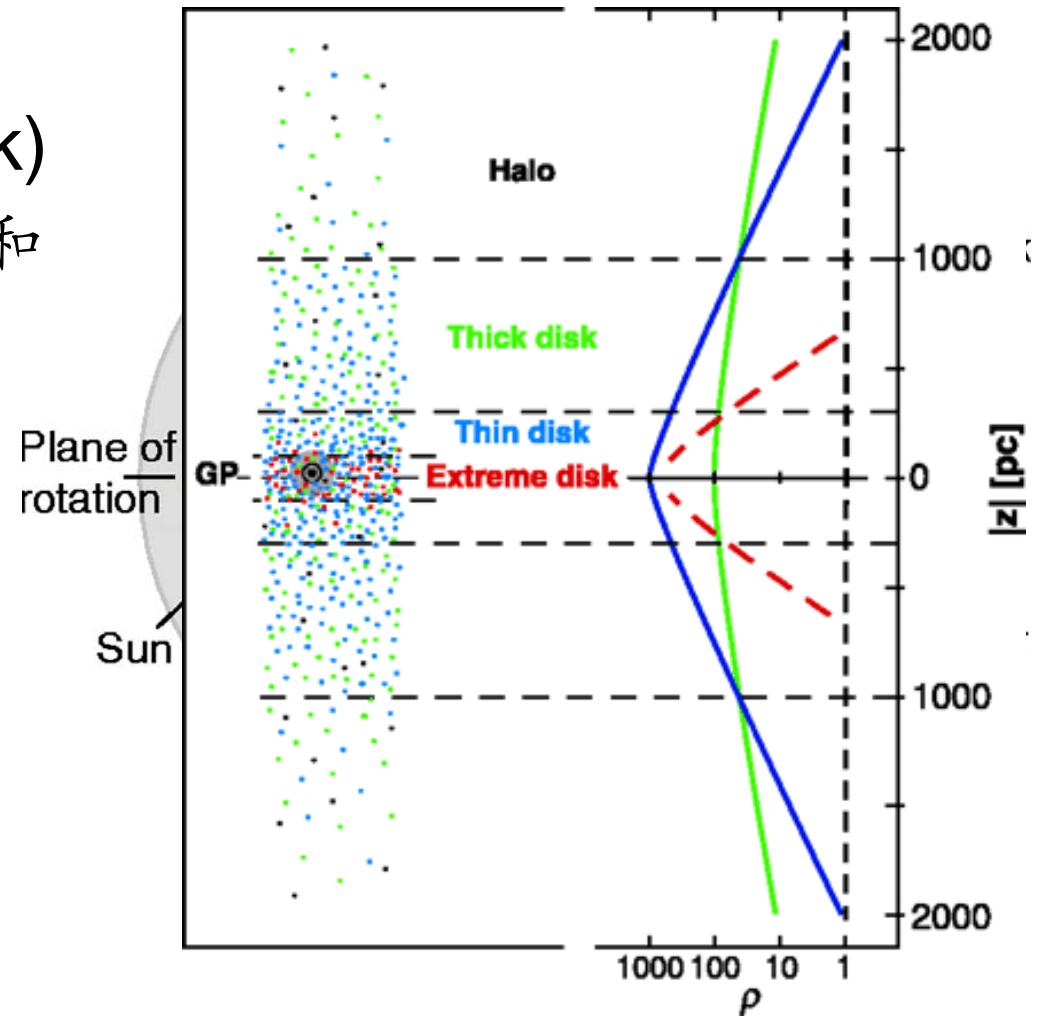
### 1. 银盘 (Galactic disk)

构成: 星族I恒星、气体和尘埃

直径:  $D \sim 30$  kpc

厚度:  $h \sim 70-300$  pc

$D \gg h$



## 2. 银河系旋臂的证认

### (1) 光学观测

- 示踪天体

O, B型星、年轻的疏散星团、发射星云和HII区、经典造父变星。

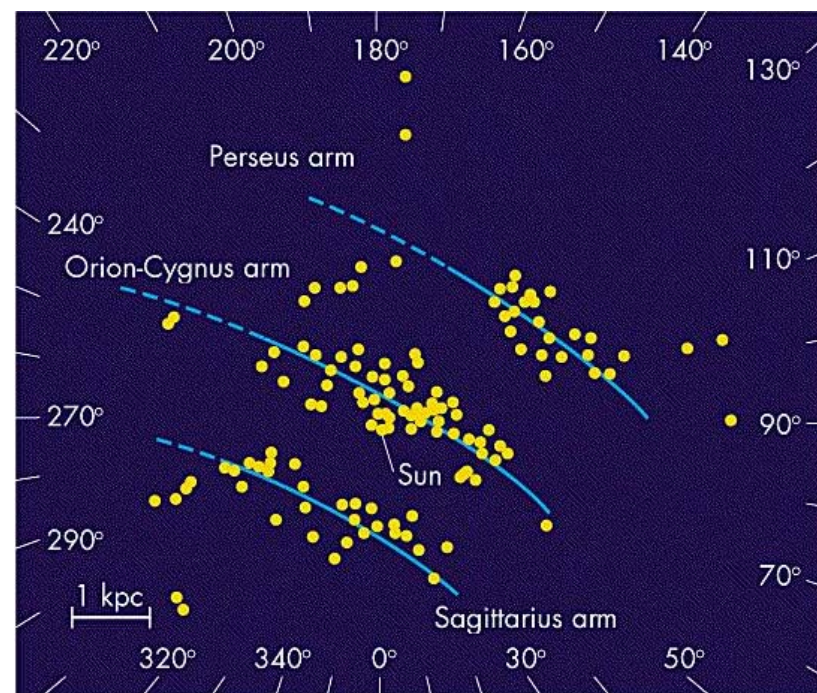
- 方法

标准烛光

造父变星周光关系

- 限制

星际尘埃消光



太阳附近恒星的分布

## (2) 射电观测

- 示踪天体

HI区、分子云。

- 方法

测量HI区21 cm谱线和分子云的毫米波谱线Doppler谱线位移

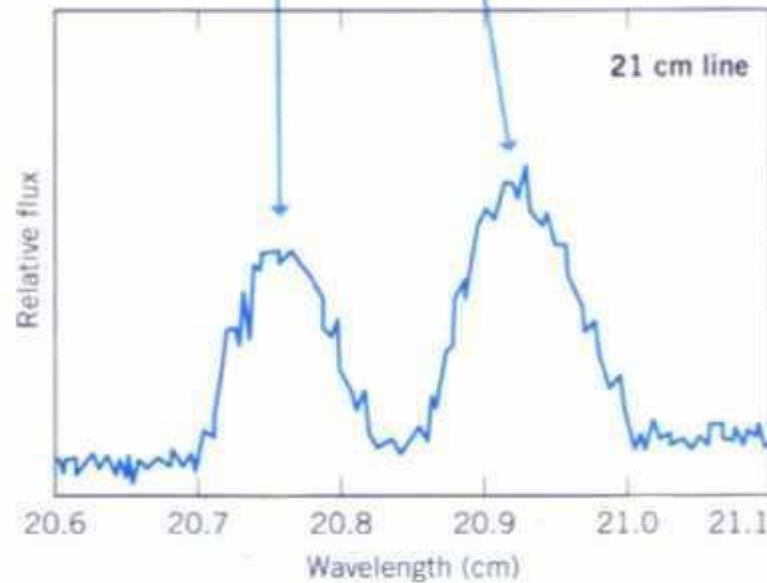
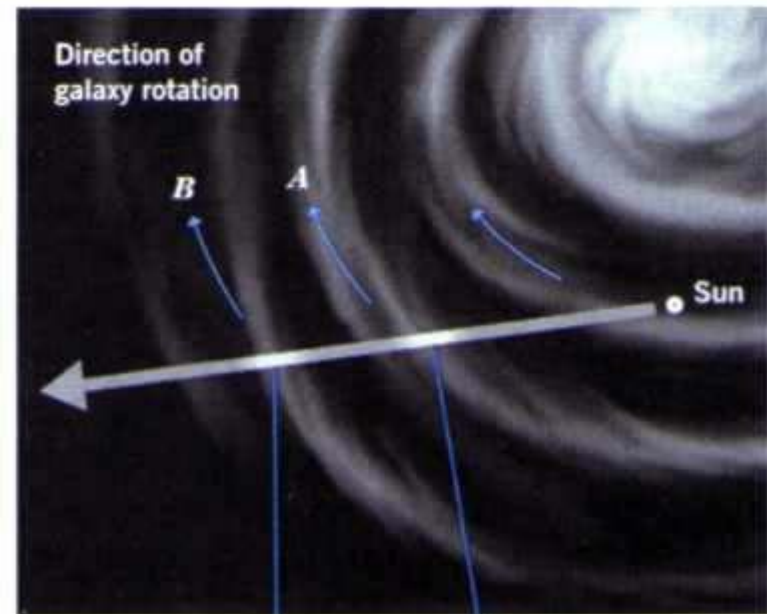
→ 视向速度 → 转动速度

比较银河系自转曲线

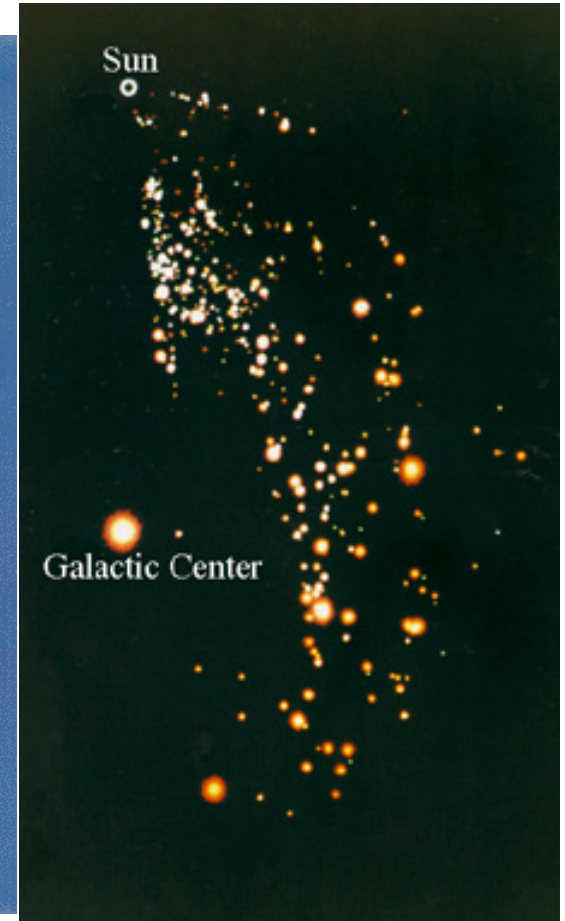
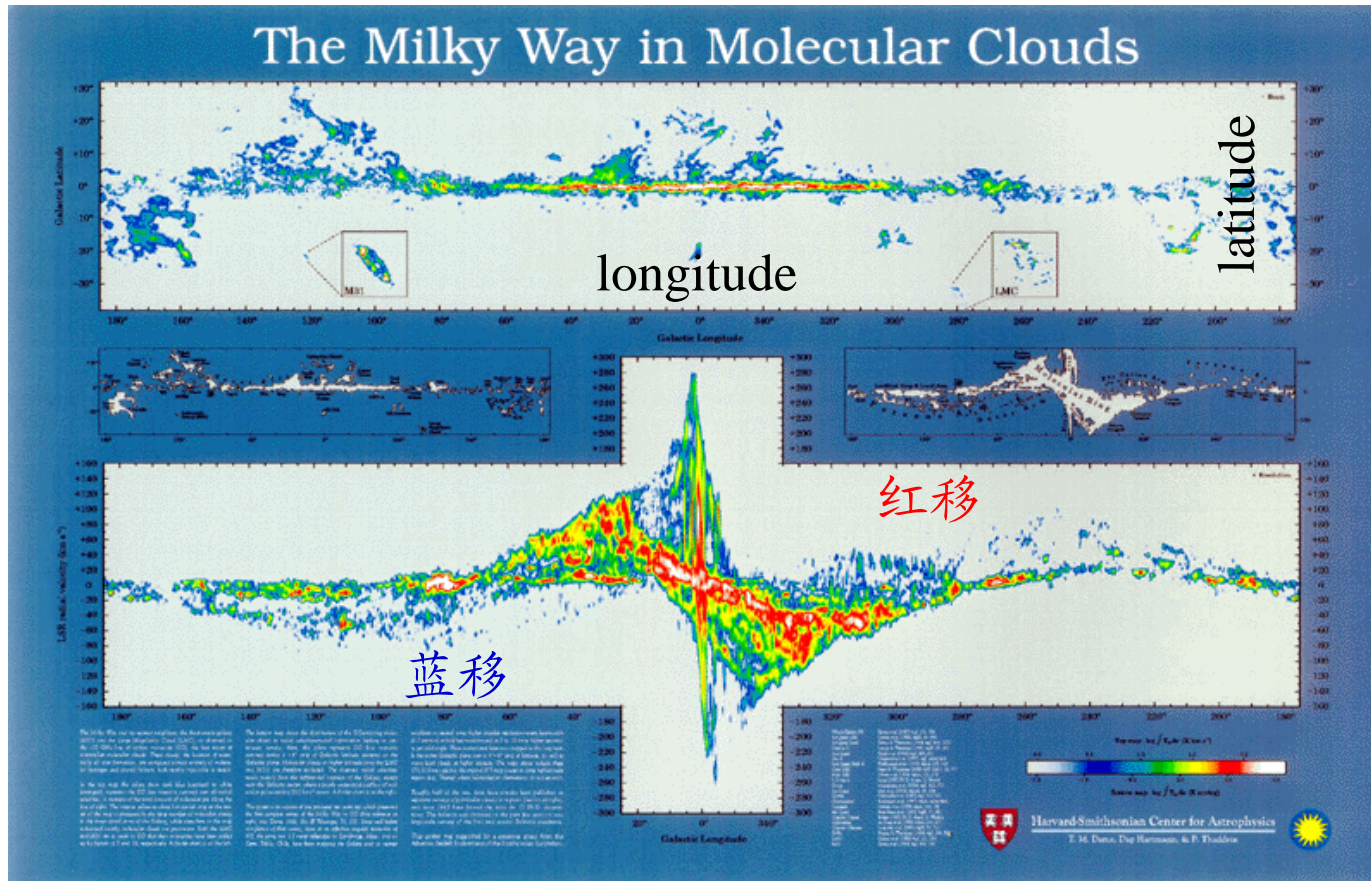
→ 距离

- 限制

气体云的转动是非圆的，在圆运动的同时还有无规运动。

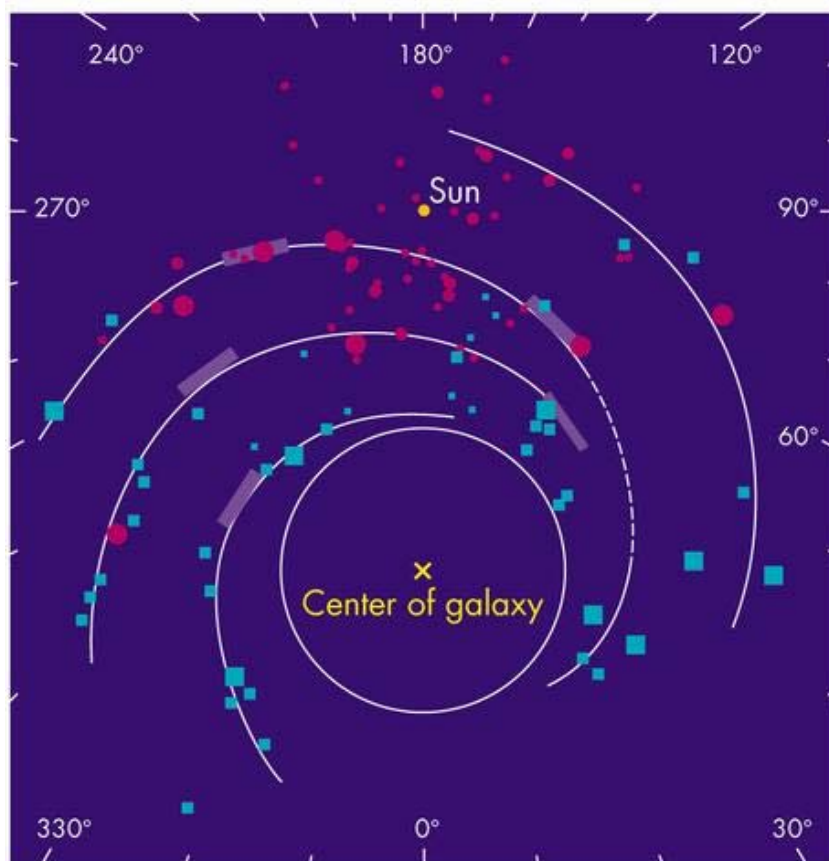


# CO分子辐射的强度与视向速度分布

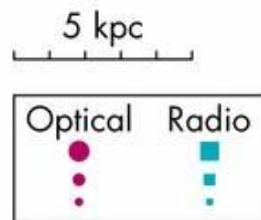


谱线位移 → 距离 → 分子云的分布

### (3) 观测结果

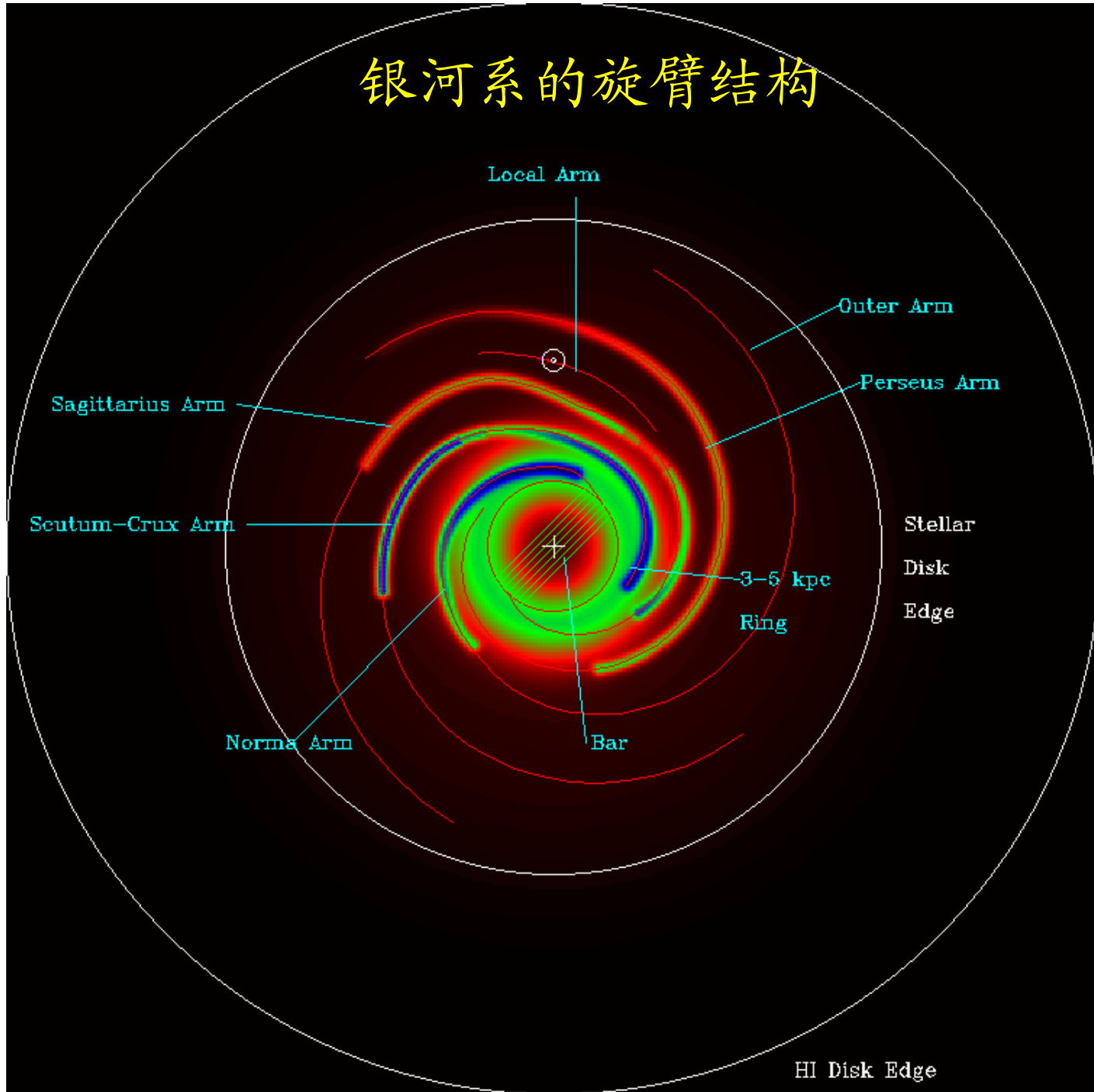


- 银河系的旋臂结构
  - 天鹅 (Cygnus) 臂
  - 英仙 (Perseus) 臂
  - 猎户 (Orion) 臂
  - 人马 (Sagittarius) 臂
  - 盾牌 - 南十字臂 (Scutum-Crux arm)
  - 矩尺 (Norma) 臂
  - 太阳位于猎户臂上

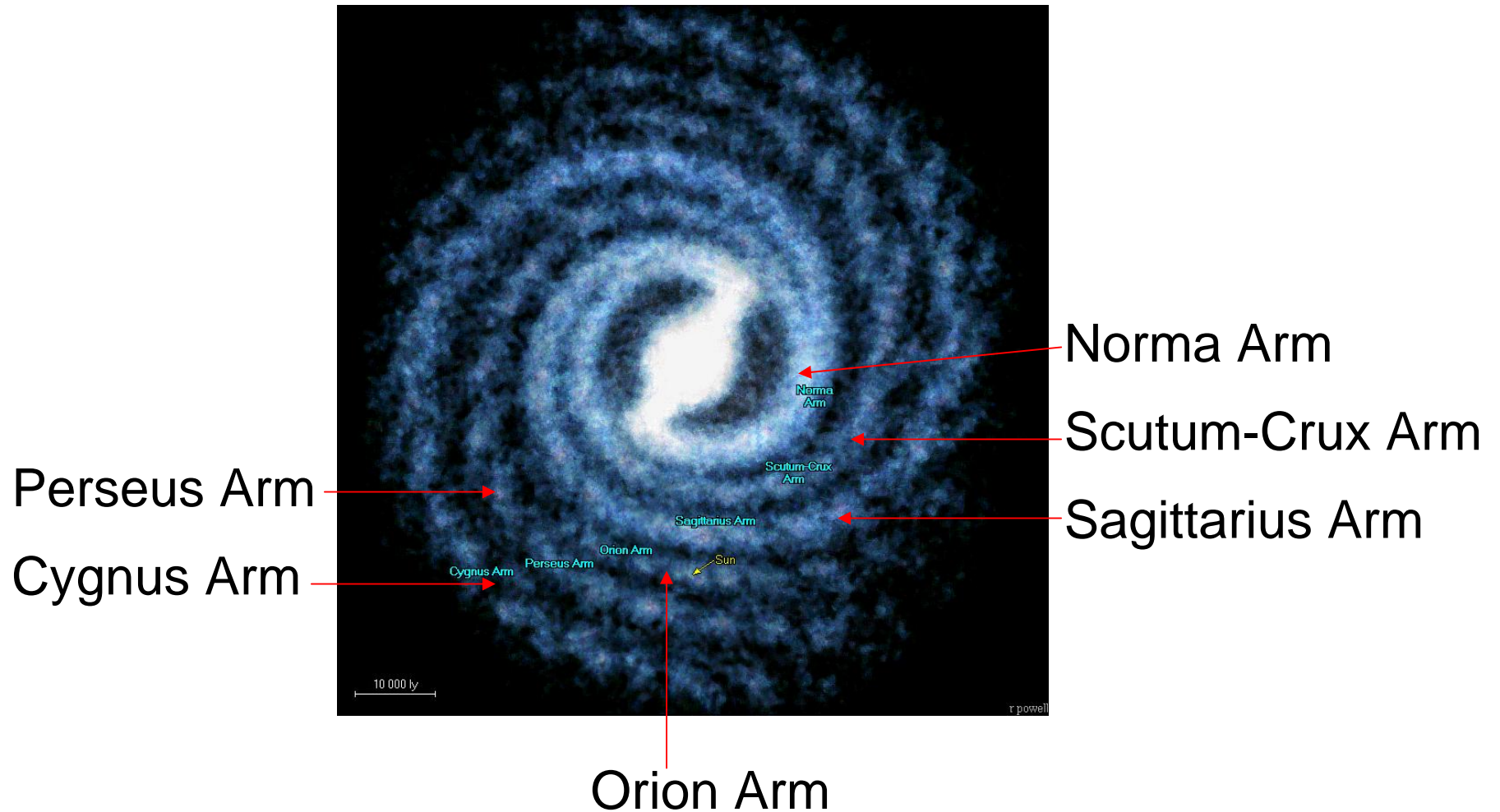


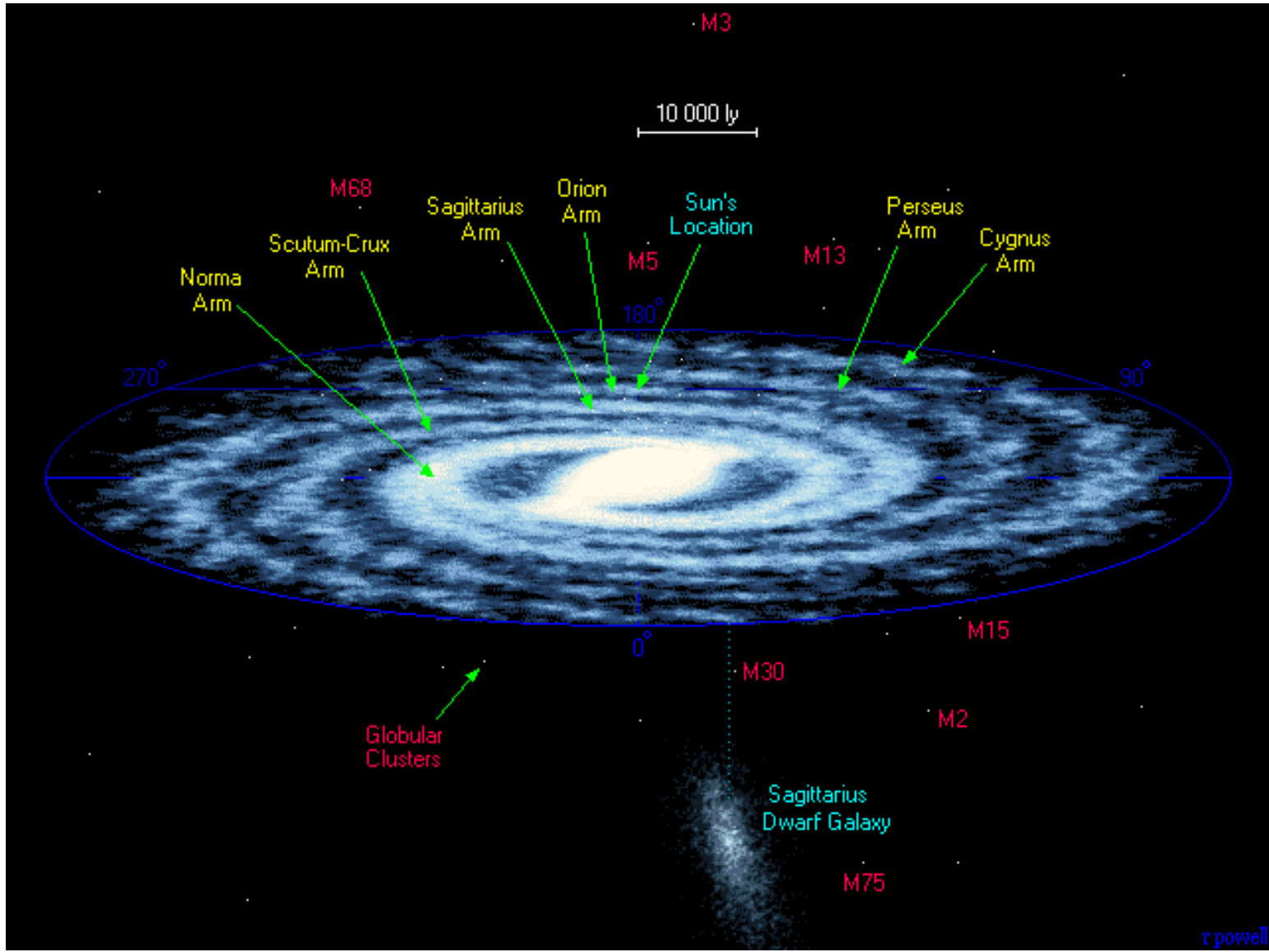


# 银河系的旋臂结构



# 银河系的旋臂结构





问题:

- 银河系的旋涡结构是怎样形成的?

- 旋涡结构为什么能维持很长时间?

(在银河系和其他盘星系中发现旋臂存在说明旋臂的维持时间相当长)



### 3. 旋臂的理论解释

#### (1) 旋臂不是物质臂

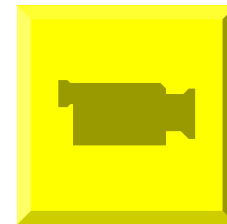
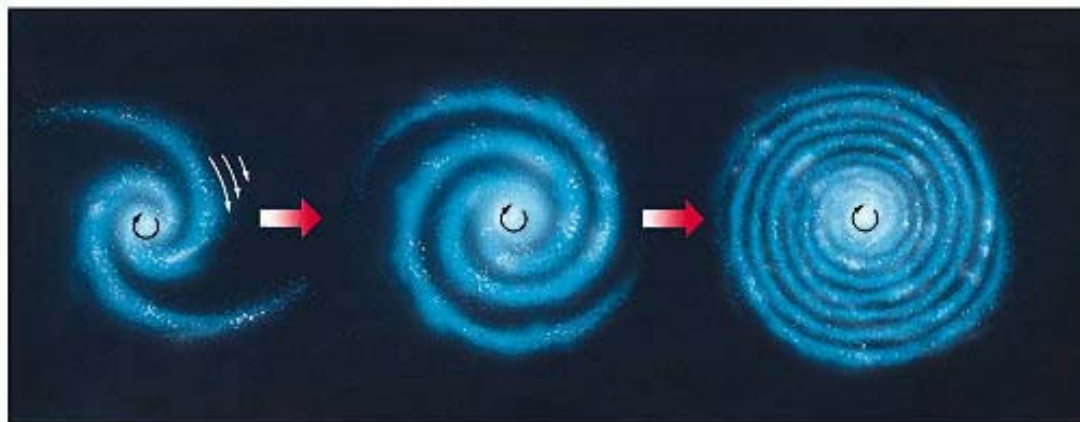
● 如果旋臂始终由同样的物质构成:

- 太阳公转周期  $\sim 2 \times 10^8$  yr, 太阳年龄  $\sim 5 \times 10^9$  yr  
→ 太阳绕银心至少转了20圈

较差转动 → 旋臂缠绕 (或放松) → 旋臂消失

- 表征旋臂的主要是年轻天体

大质量恒星的寿命  $\leq 10^7$  yr → 旋臂消失

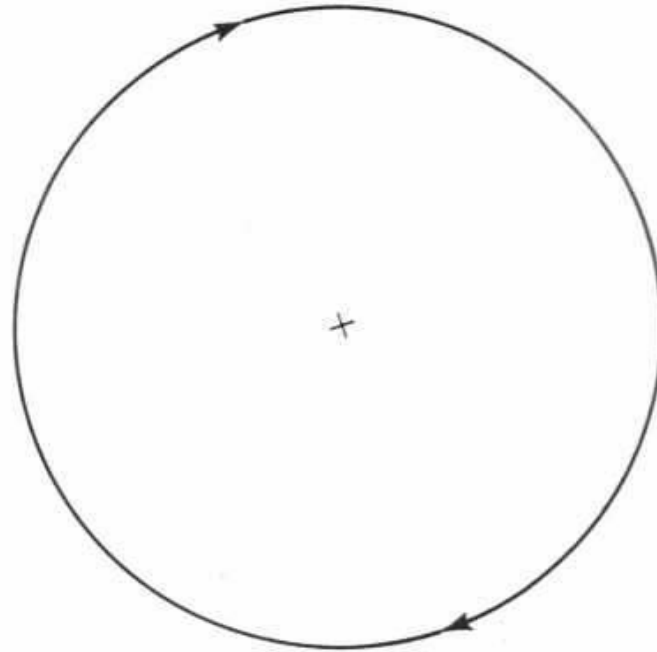


## (2) 密度波理论(Density Wave Theory)

- 由林家翘和徐遐生1963年在Lindblad工作的基础上提出——旋臂是密度波的表现。
- 星系引力势扰动
  - 银盘内的天体以椭圆轨道运动
  - 运动速度变化
- 轨道取向相互耦合
  - 物质密度的规则变化
  - 密度波
- 密度波在银盘内传播，导致物质压缩和恒星形成

- 密度波的形成

在无扰动势 $f$ 的情况下，引力势是轴对称的，银盘上的恒星与气体云的运动为匀速圆轨道运动。

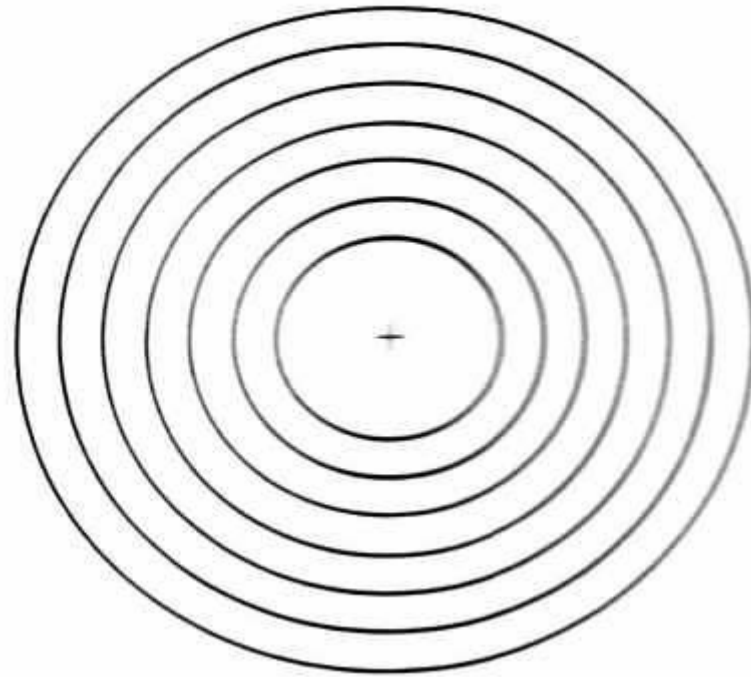


$$f = 0$$

加入扰动引力势  $f = A(r)\cos(m\phi)$

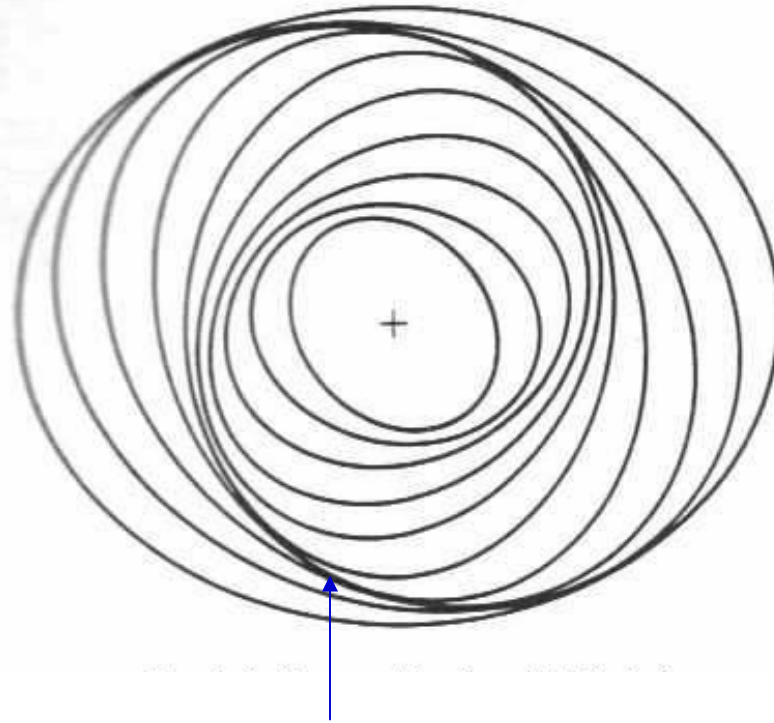
→ 同轴椭圆轨道 ( $m=2$ )

由于引力势随方位角的变化而变化，天体的运动速度不再是均匀的。



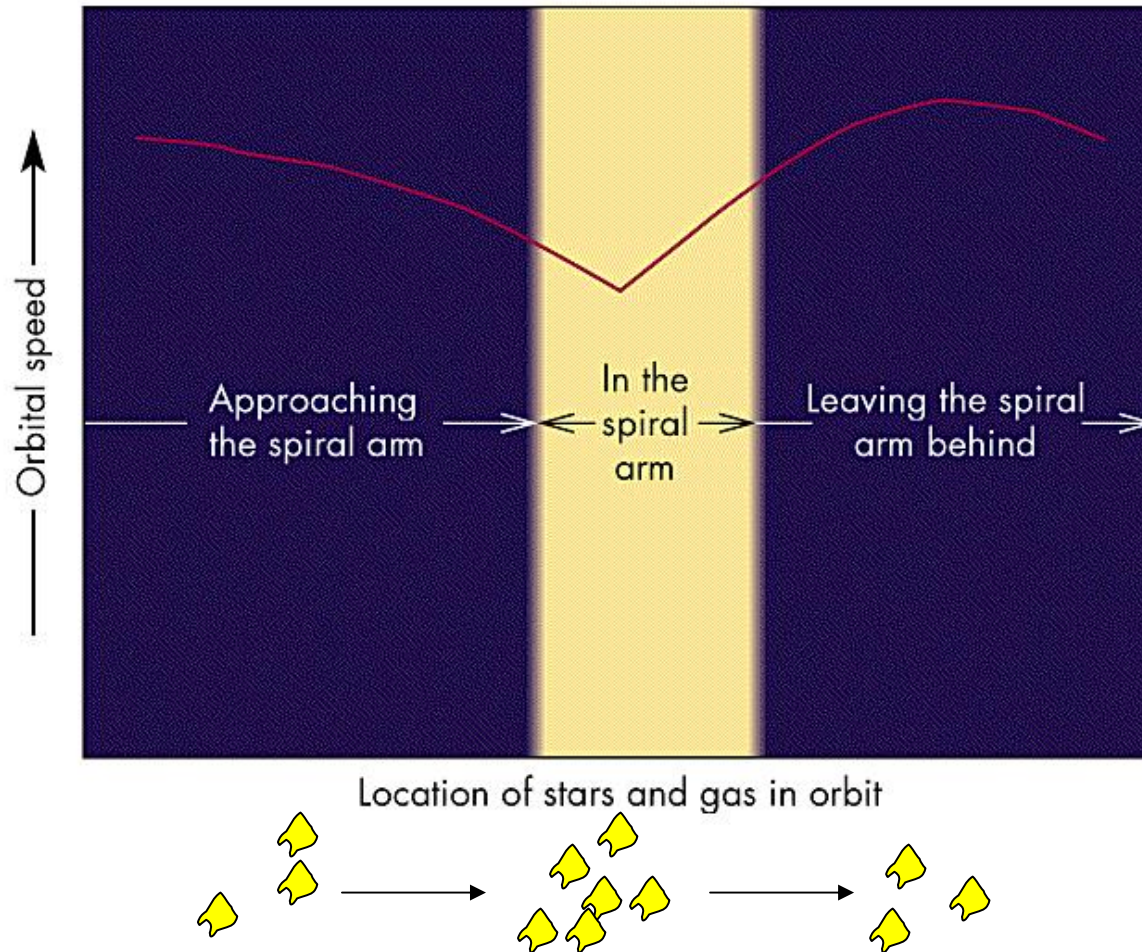


加入扰动引力势  $f = A(r)\cos[m\phi - \Psi(r)]$   
→非同轴椭圆轨道

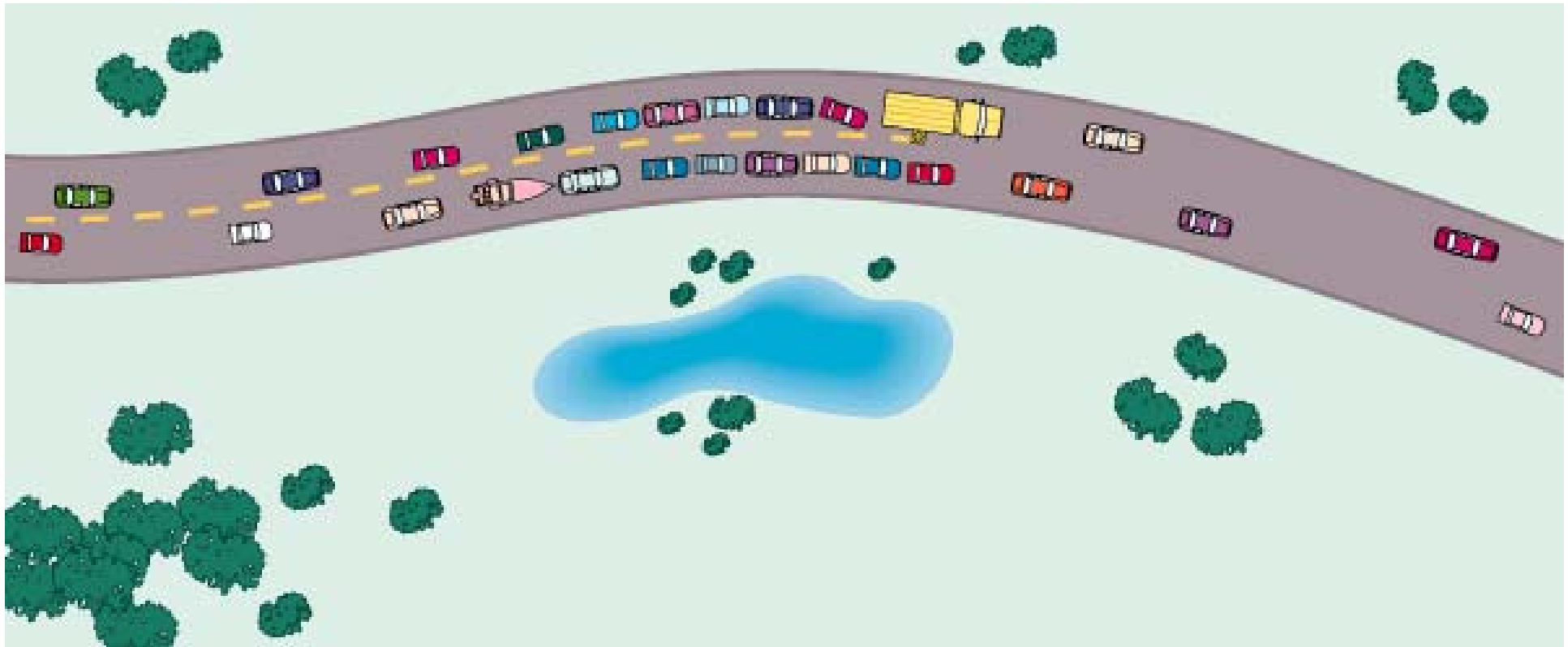


引力势极小值位置

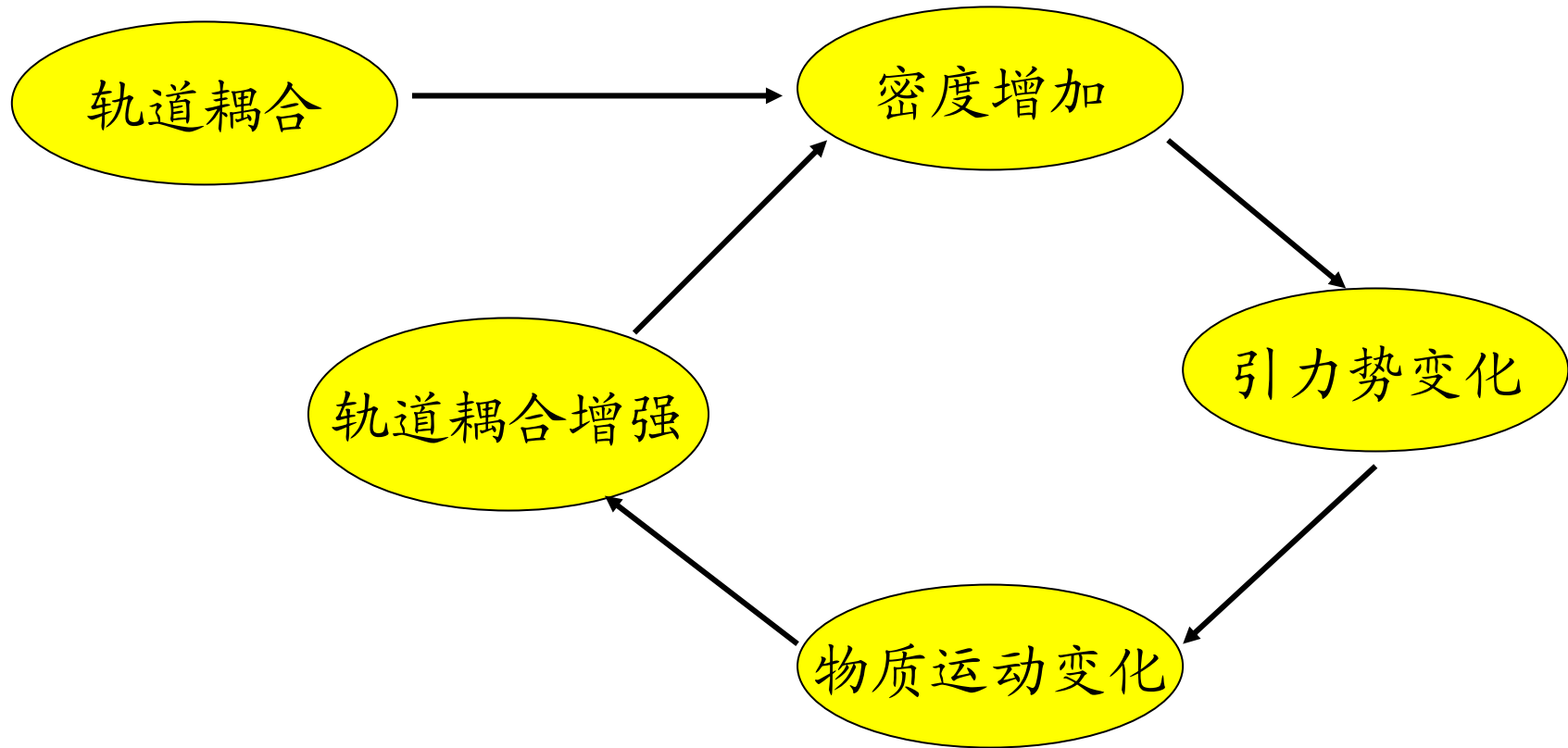
在引力势波谷处，物质速度减慢、密度增大。  
椭圆轨道相互耦合 → 密度波



# 生活中的密度波



- 密度波形成原因：  
物质趋向于最低能态 → 轨道收缩 → 角动量损失（通过密度波传递角动量）
- 密度波维持机制——自组织(self-organization)过程

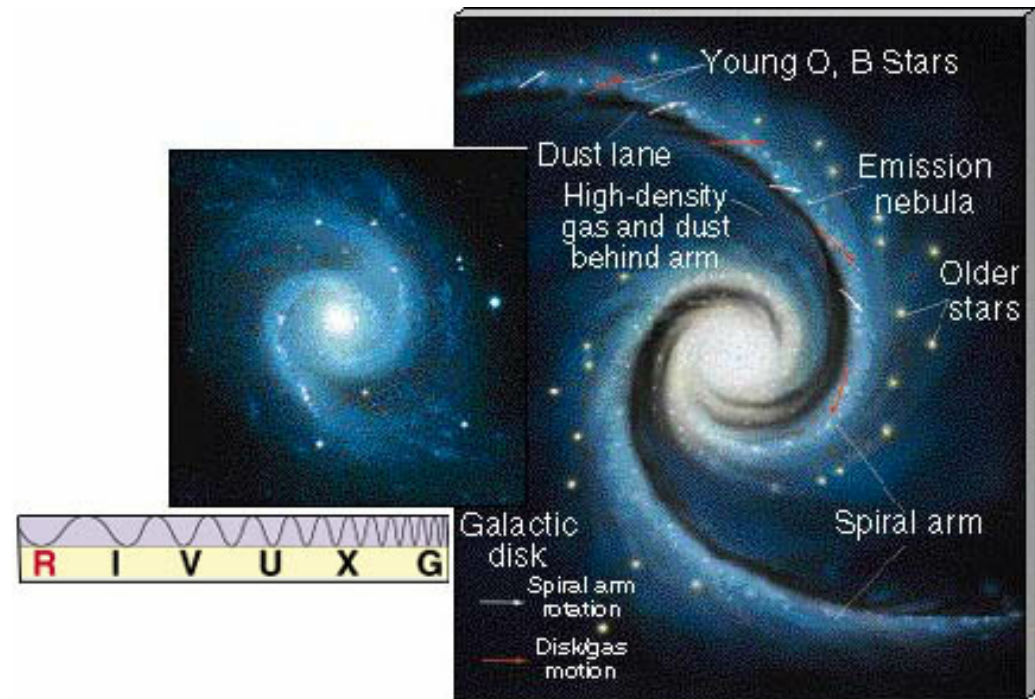


- 旋臂的运动

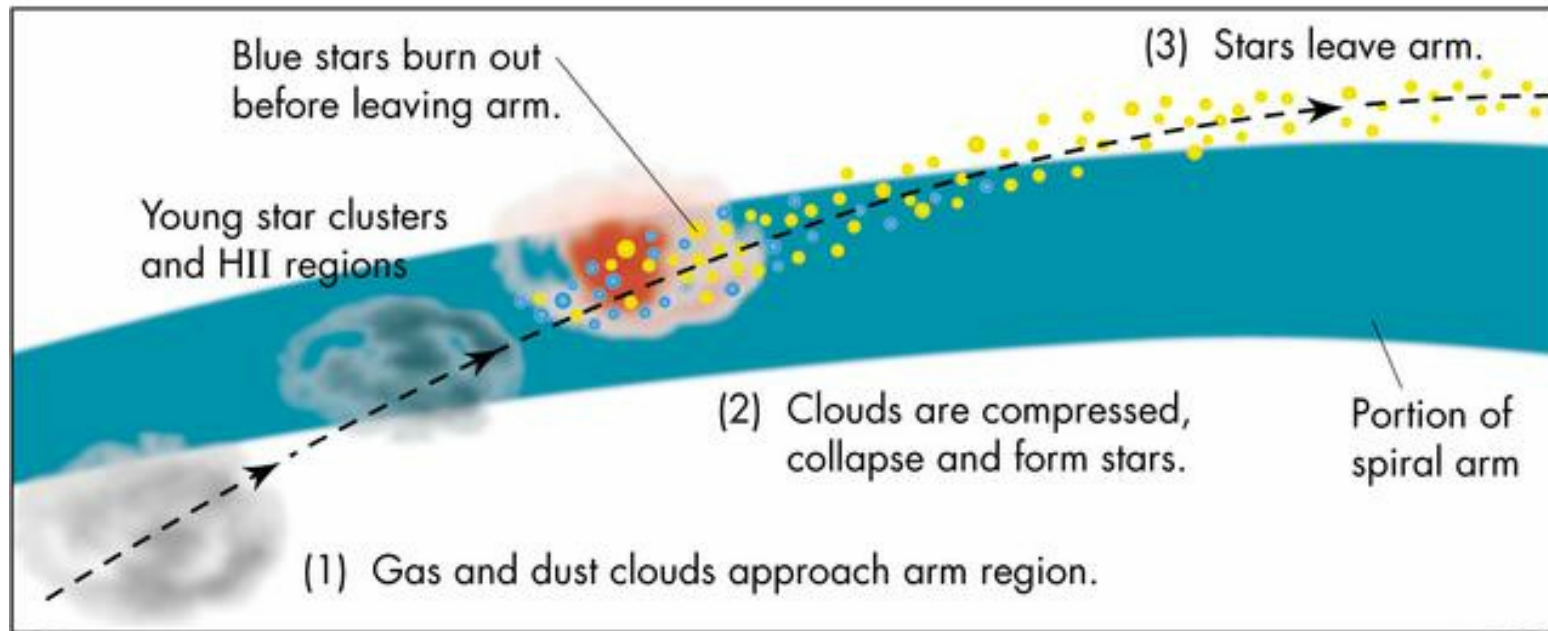
密度波旋涡图样绕银心刚体转动， $\omega = 13.5 \text{ kms}^{-1}\text{kpc}^{-1}$   
在银河系内区天体的运动速度超过旋涡图样速度( $\omega_0 = 25 \text{ kms}^{-1}\text{kpc}^{-1}$ ); 在外区天体比旋涡图样运动得更慢。

- 旋臂上年轻天体的形成

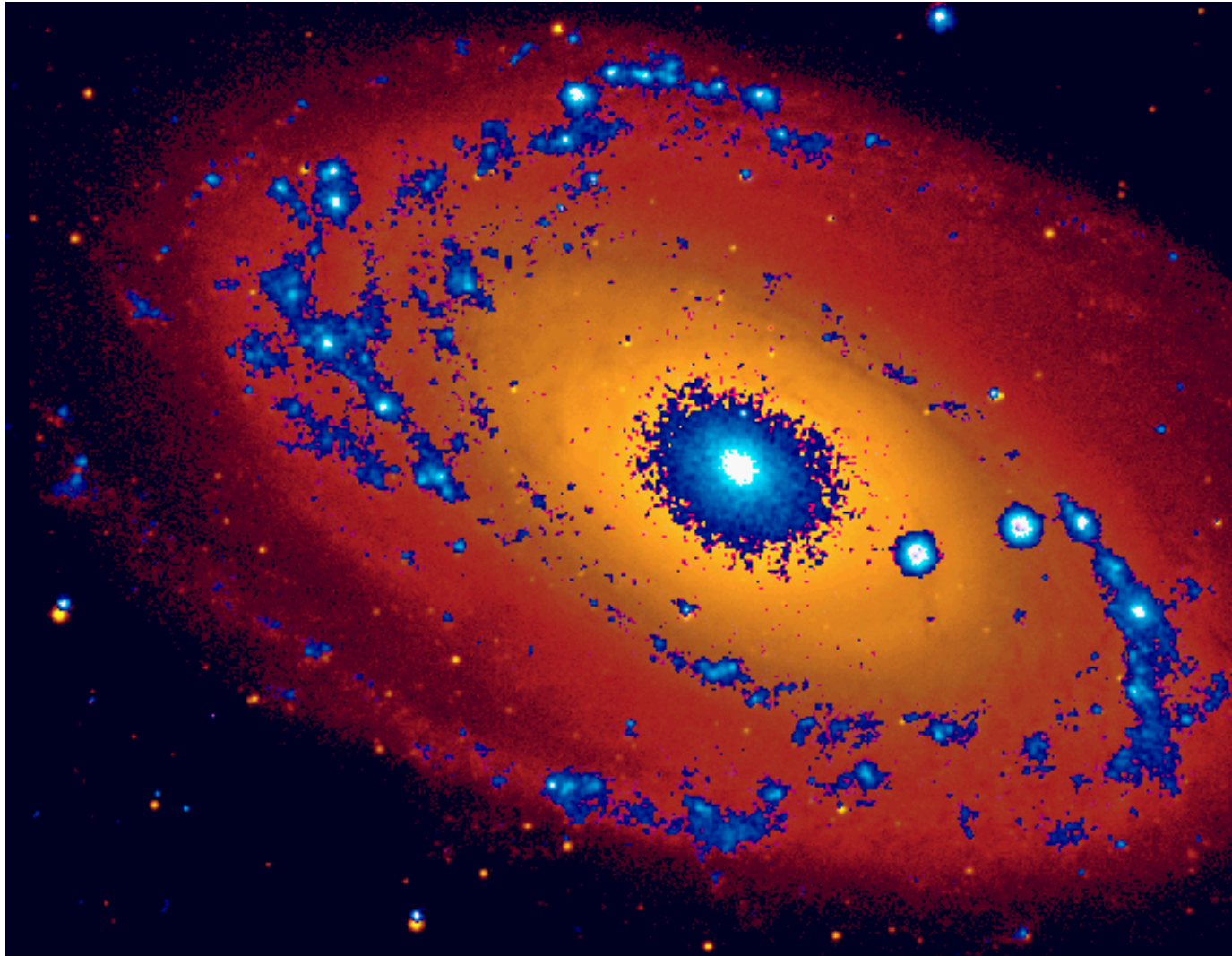
气体云运动 → 接近旋臂  
→ 压缩、碰撞 → 尘埃带  
→ 气体云坍缩  
→ 恒星和HII区形成



# 旋臂上的恒星形成与演化



*Example:* Star Formation in the Spiral Galaxy M81

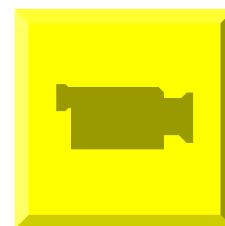


● 未解决的问题：引力扰动势的起源是什么？

核球附近气体的不稳定性？  
伴星系的引力扰动？  
核球中棒状结构的影响？



M51





### (3) 自传播恒星形成理论 (Self-propagating star formation or supernova chain reaction theory)

#### ● 旋臂的形成

恒星形成的链式反应：

气体云坍缩 → 年轻星团

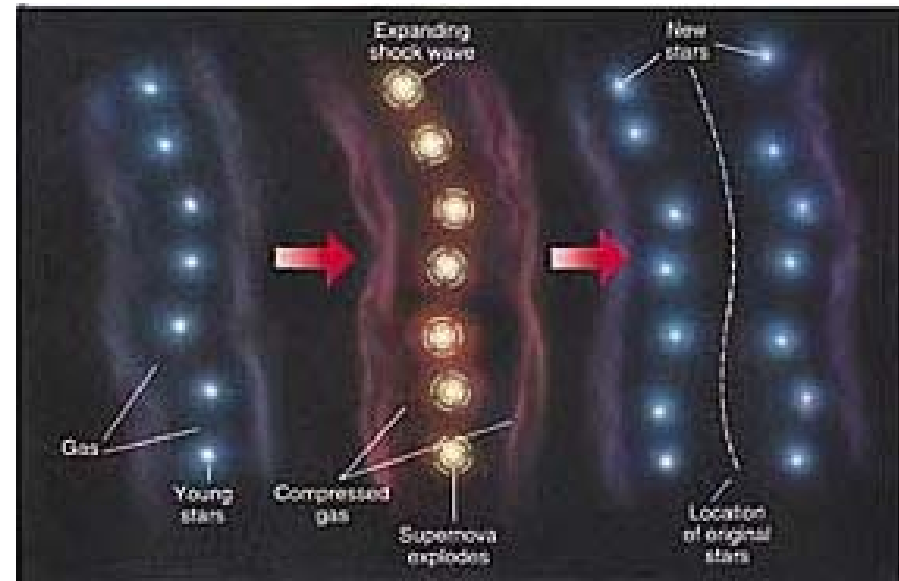
大质量恒星的辐射和超新星爆发

→ 激波 → 压缩周围气体

→ 下一代恒星诞生 → ...

天体绕银心较差转动 → 高密恒星和星际气体旋臂

旋臂的维持时间较短。



#### (4) 两类模型的比较

密度波理论	自传播恒星形成理论
旋臂 → 恒星形成	恒星形成 → 旋臂
对称的整体旋臂 (the grand design)	粗糙的、绒毛状旋臂 (片断)



- 对银河系，两种效果可能同时起作用，密度波建立旋臂的基本结构，超新星爆发进一步改变旋臂的形态。

## § 6.4 银心和银晕

### 1. 核球 (bulge)与银心 (Galactic center)

#### (1) 特点

银心在人马座方向，

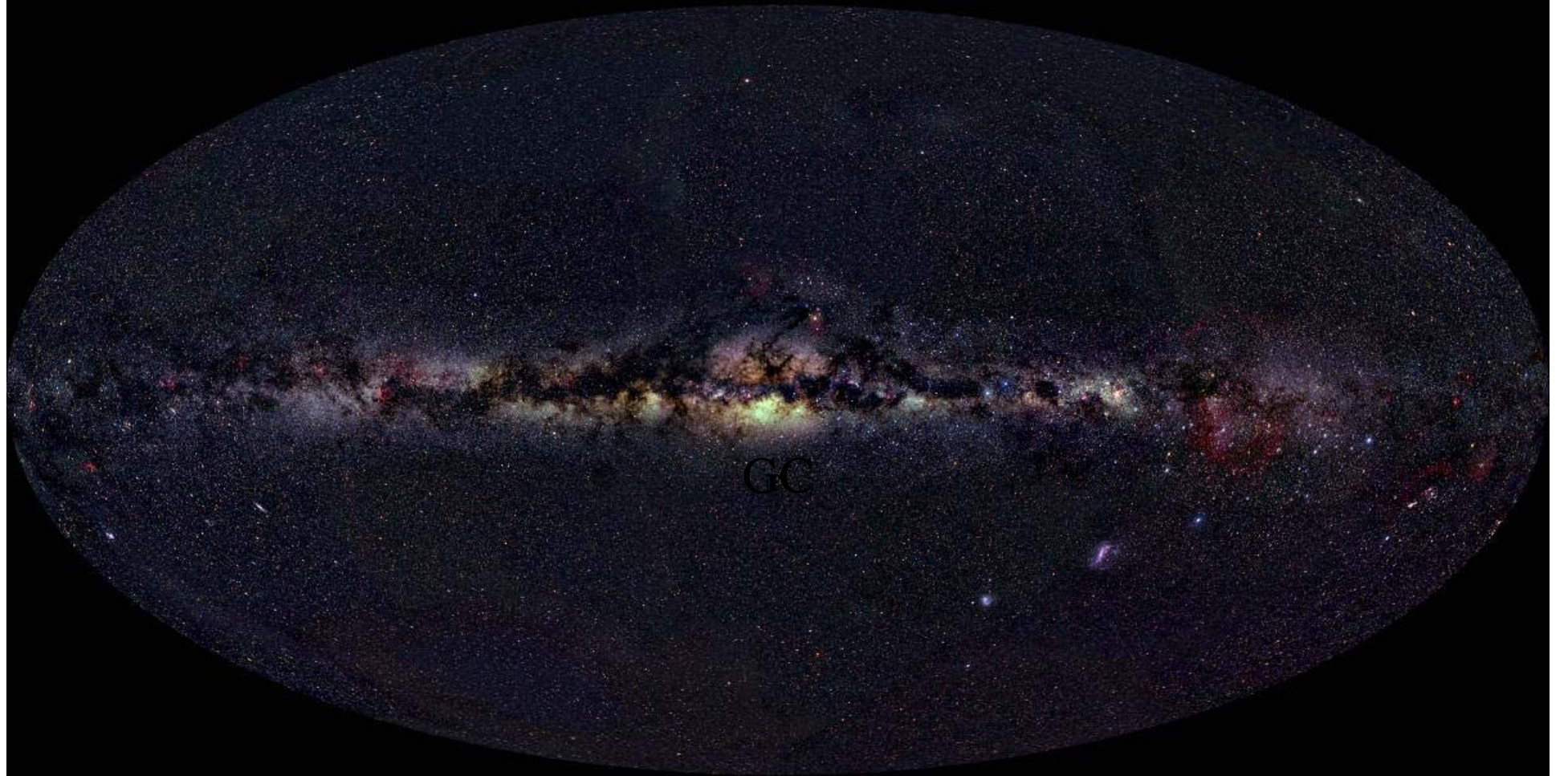
核球呈椭球形，大小约  $6 \times 4$  kpc，

恒星分布十分密集，

数密度  $\sim 1,600 \text{ ly}^{-3}$ ，是银河系平均恒星密度的  $10^5$  倍。



# *The Deep Sky*



## (2) 光学观测

- 在光学波段，核球附近区域受星际气体和尘埃的遮挡。
- 辐射主要来自年老的星族I天体（如红巨星）。

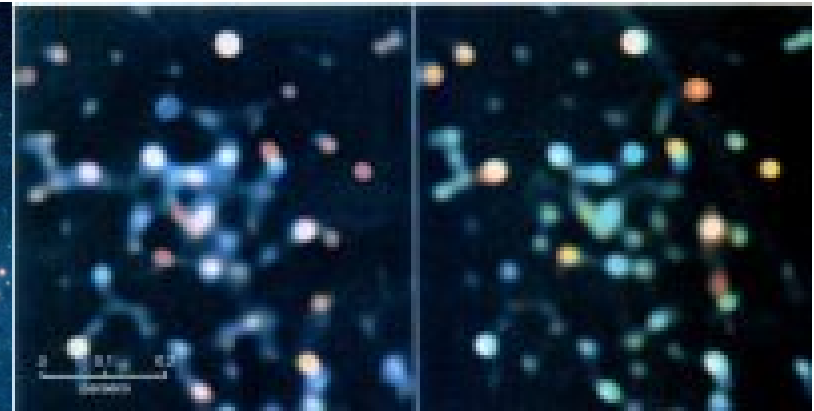


### (3) 红外与射电观测

- 红外和射电辐射受到星际消光的影响较小，是研究银心的主要途径。
- 红外观测表明银心区域的恒星分布高度密集 ( $\sim 5 \times 10^4 \text{ pc}^{-3}$ )，比太阳附近恒星密度高 $10^5$ 倍。



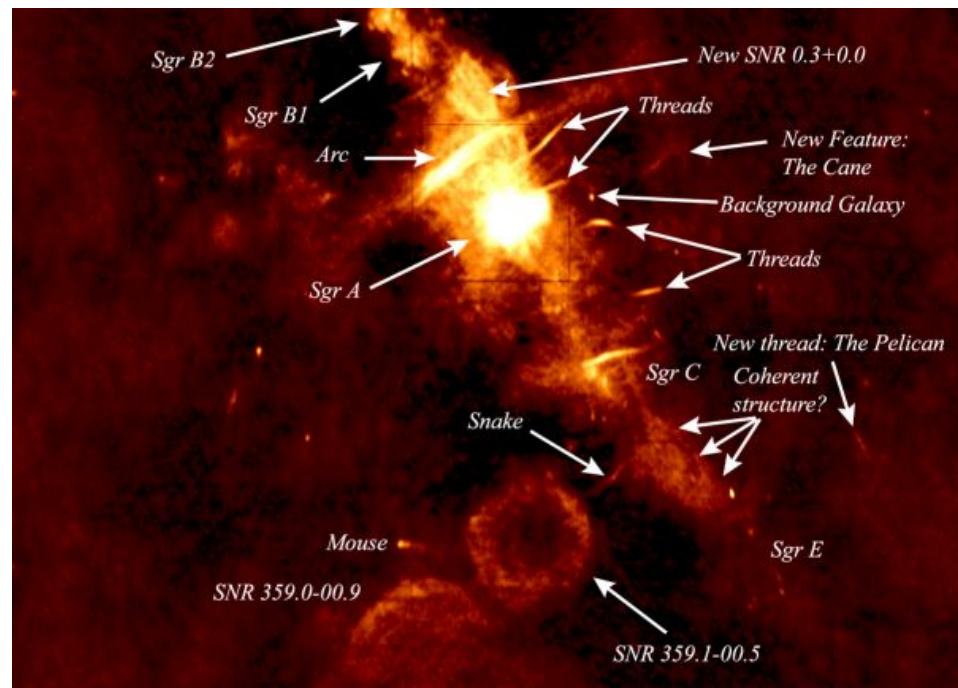
Mid-infrared image



对银心区域的近红外( $2.2 \mu\text{m}$ )  
观测 (辐射主要来自年老的星  
族I恒星)

## 强射电源——人马座(Sagittarius) A\*

- The Galactic Center region is filled with relativistic electrons and magnetic fields, producing strong radio emission.
- The nucleus is marked by a bright radio source, Sagittarius A\*.



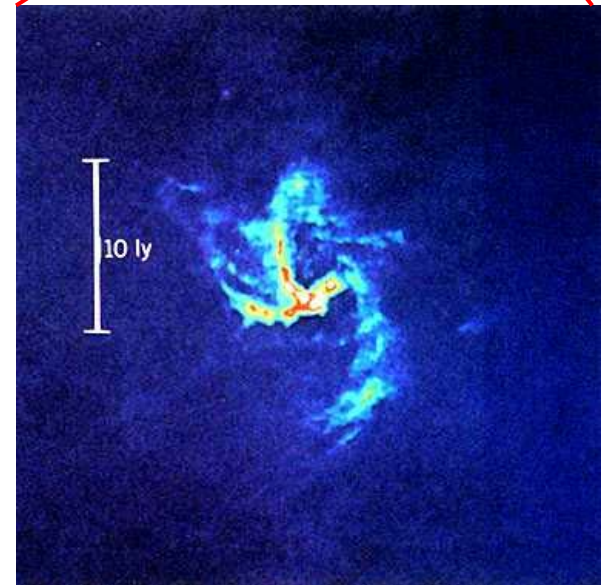
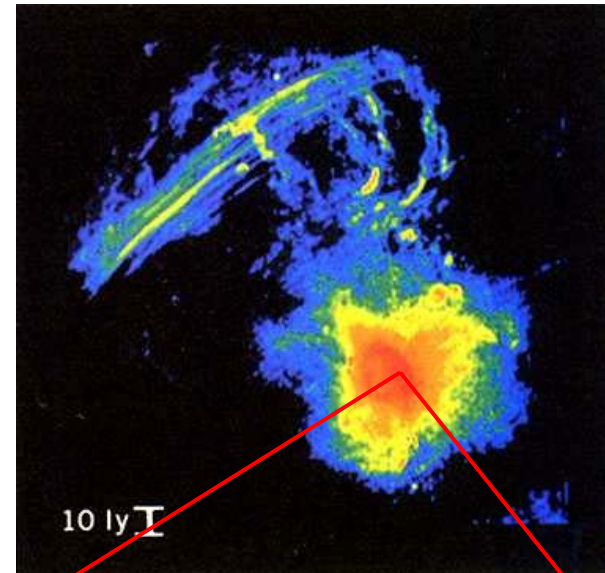
- 100 pc around the GC

The extended parallel filaments (perpendicular to the Galactic plane), stretched along magnetic field lines in the vicinity of the center

- 10 pc around the GC

Minispiral: Gas and dust streamers ionized by stars and spiraling around the very center.

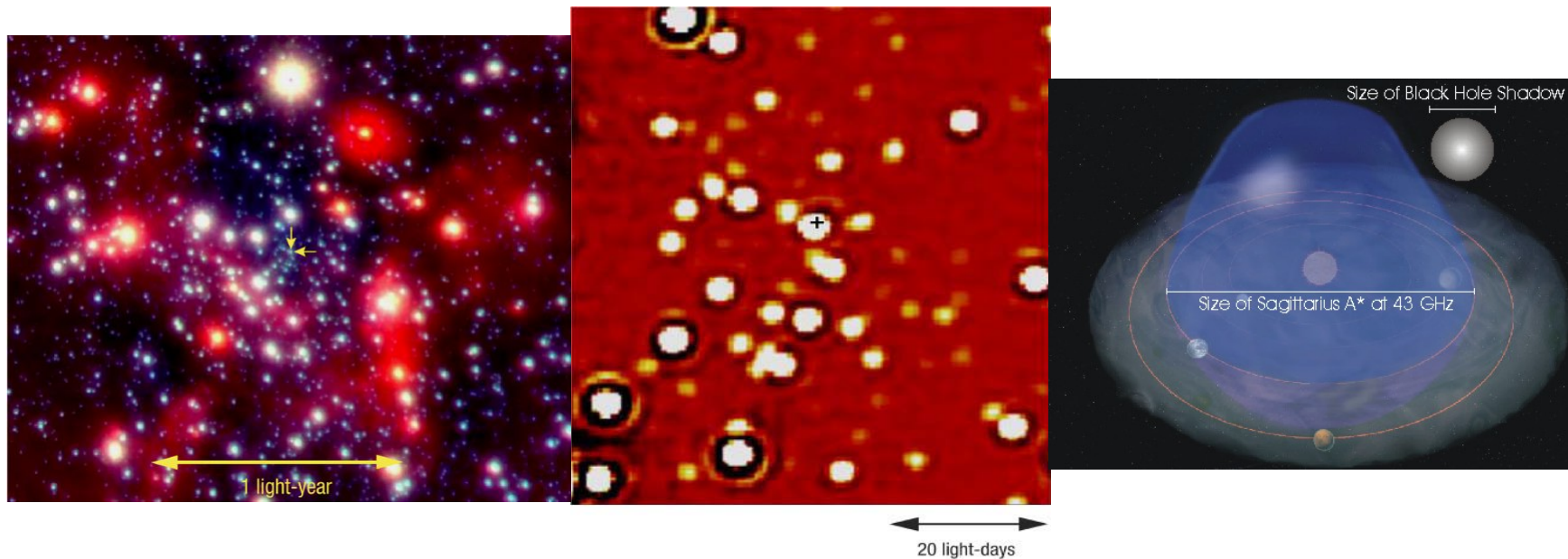
At the center of the mini-spiral is a strong, very compact radio source Sagittarius A\*



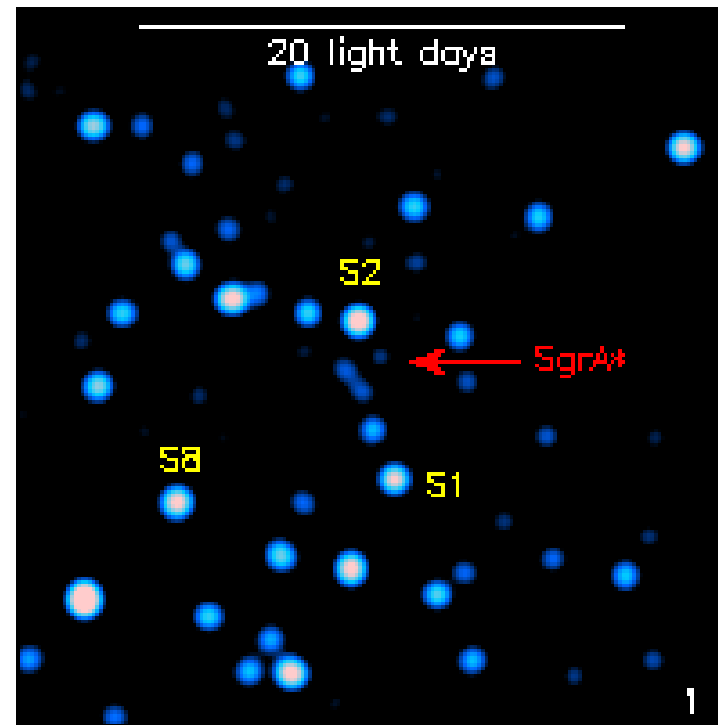
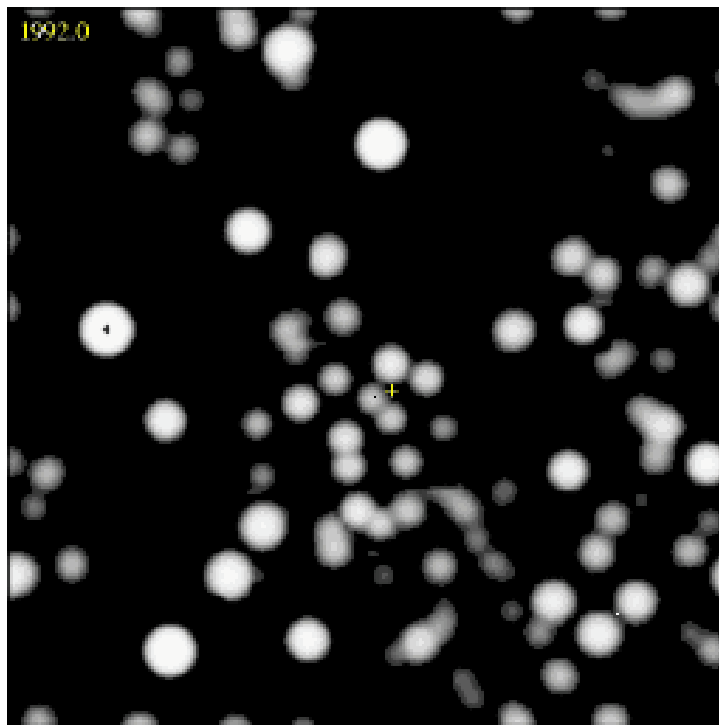


## More Close to the Galactic Center

- 红外观测精确测定银心附近恒星的位置和运动。
- 射电干涉观测确定射电源 Sgr A\* 的大小仅有  $\sim 2$  AU.

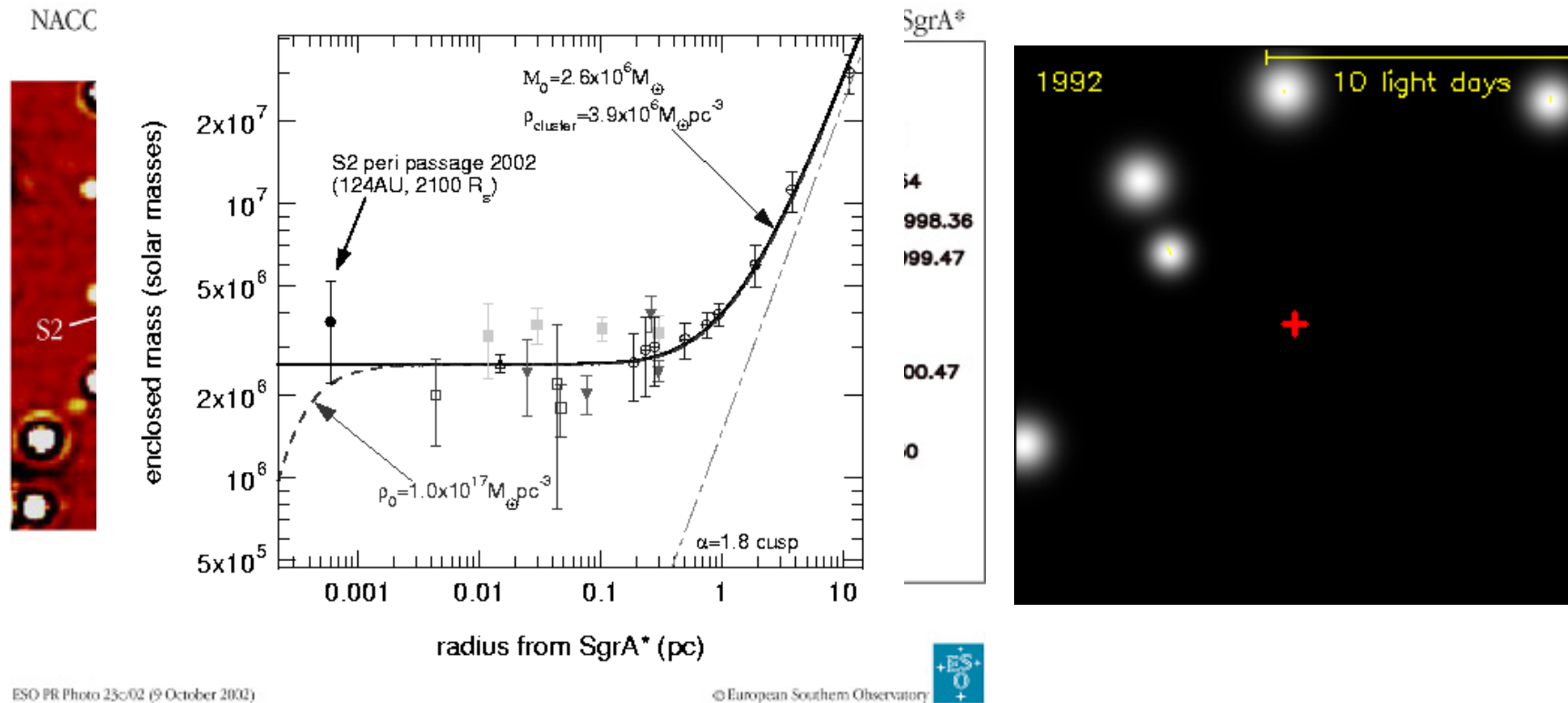


# Stellar Motion around the Center of the Milky Way

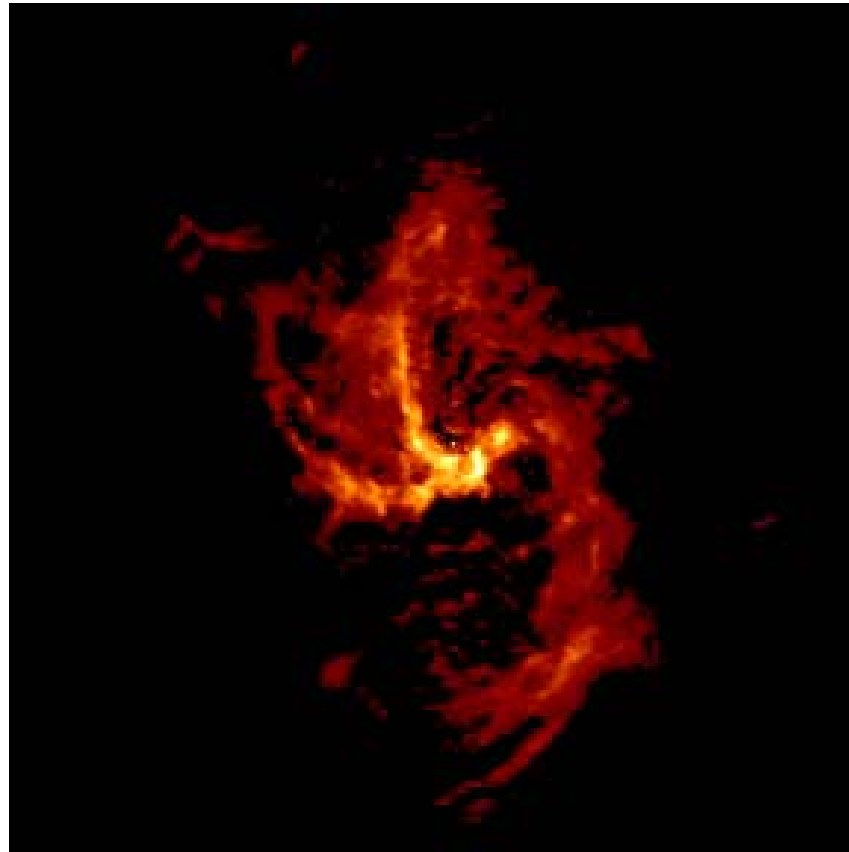


# The Supermassive Black Hole at the Center of the Milky Way

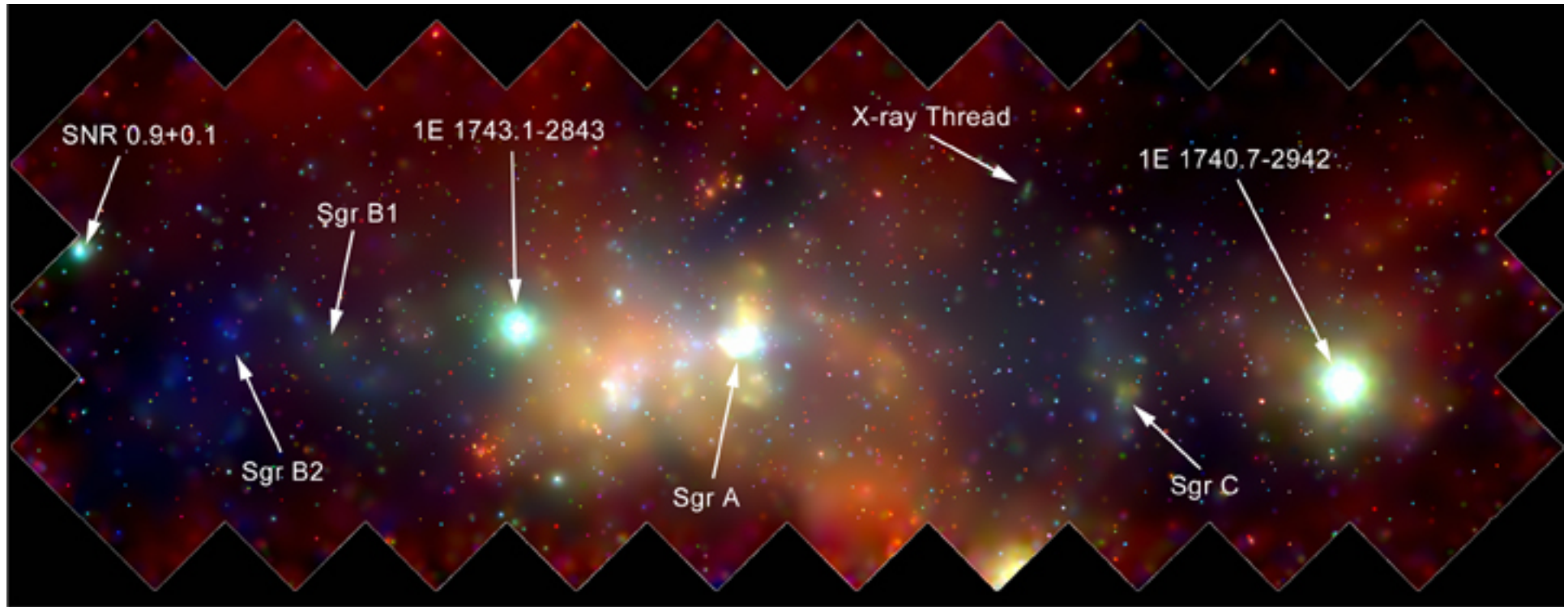
- Star S2 in a 15.2 yr Orbit around Sgr A\*
- $M_{\text{BH}} \approx 2.6 \times 10^6 M_{\odot}$



# A Journey to the Galactic Center



#### (4) X射线观测

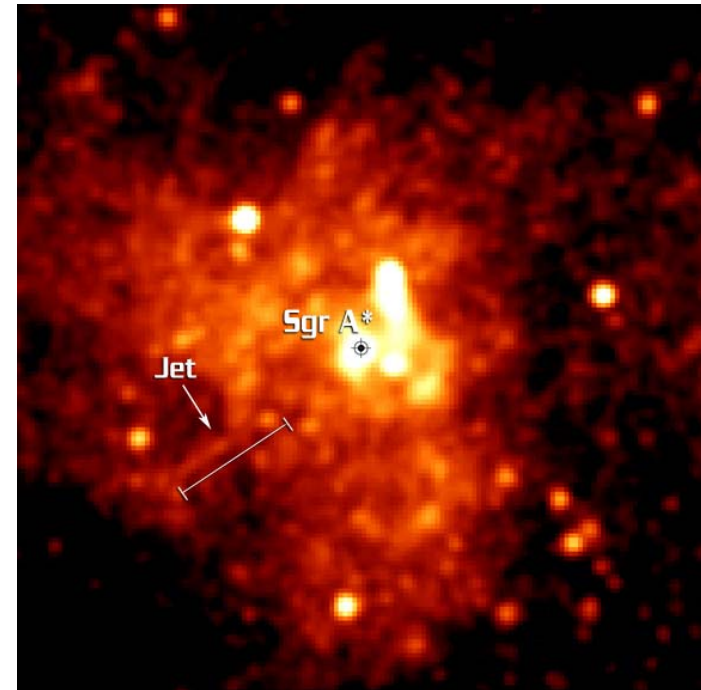


Red: 1-3 keV   Green: 3-5 keV   Blue: 5-8 keV

*Chandra X-ray Survey of the Galactic Center*

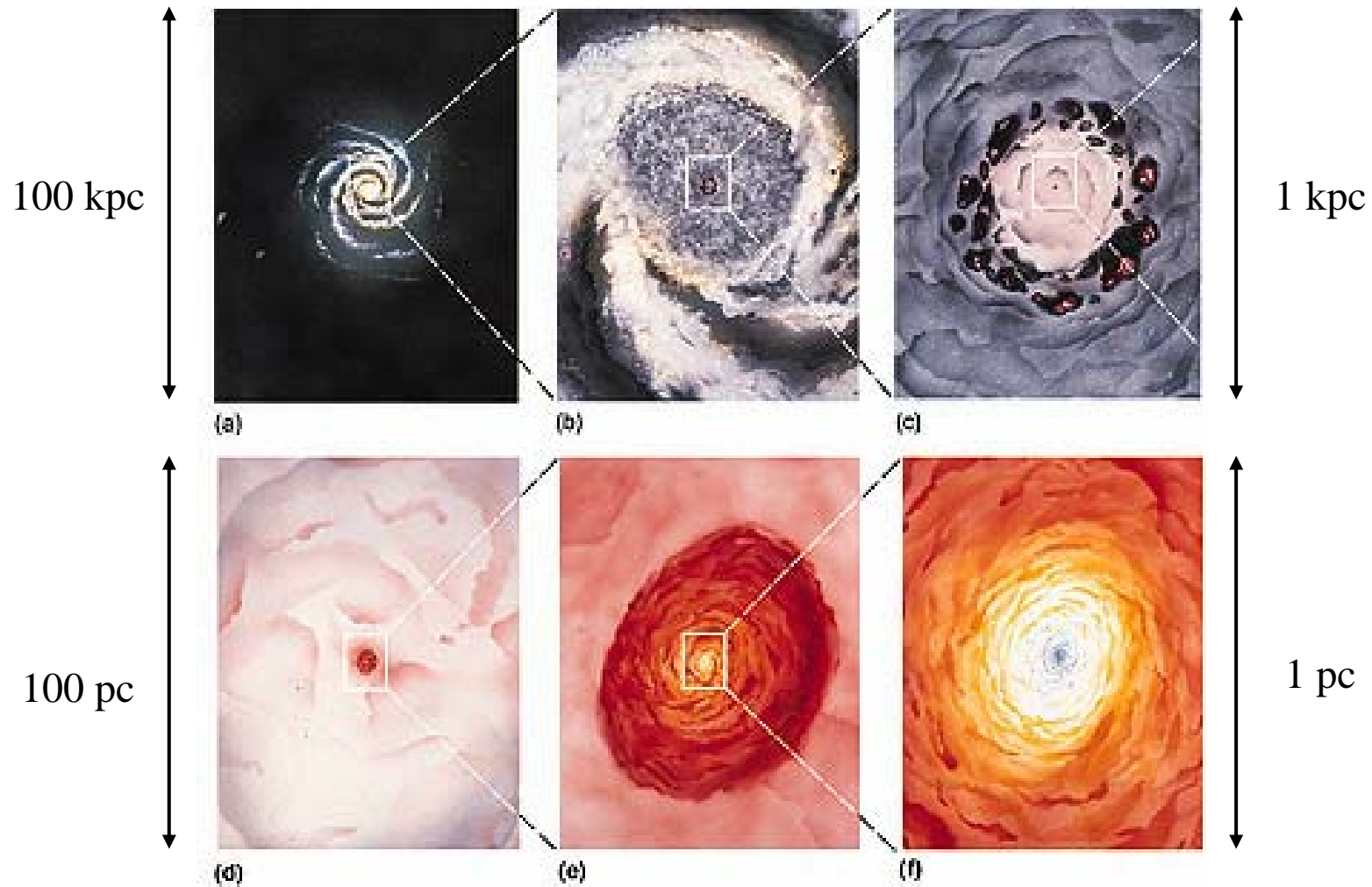
## X-ray Emission from Sgr A\*

- Sgr A\* shows either weak X-ray emission in quiescence, or X-ray flares with a period of about one per day. During these flares, the emission rises by factors up to 100 during several tens of minutes and a distinctive point source becomes visible at the location of SgrA\*.



The short rise-and-decay times of the flares suggest that the radiation must originate from a region within less than 10 Schwarzschild radii of a 3.6 million solar mass black hole.

# Summary

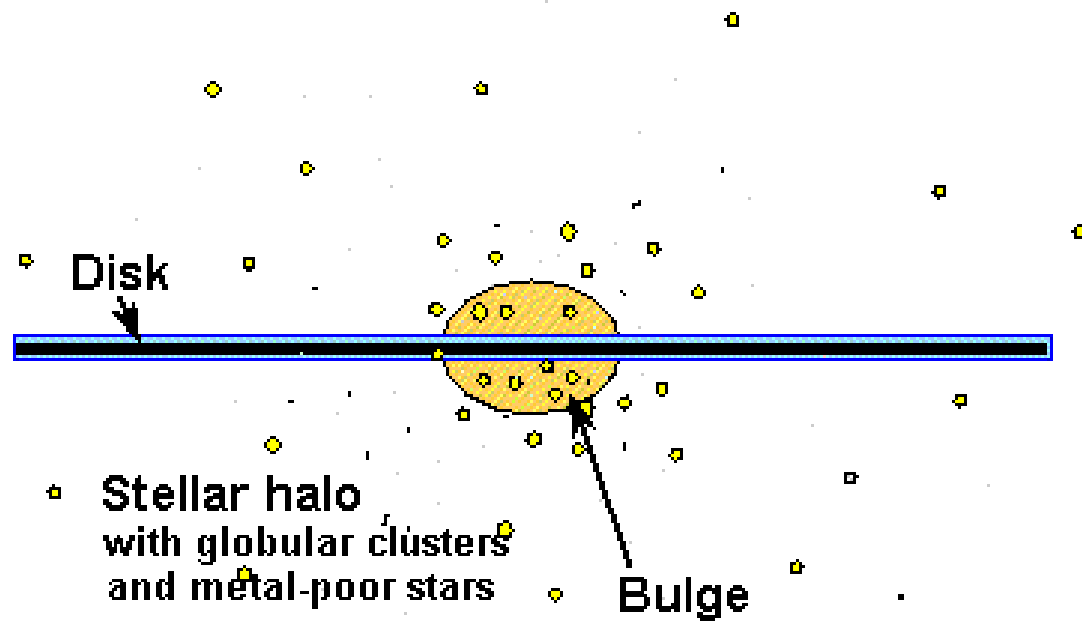


银河系中心的10倍放大想象图

### 3. 银晕 (the Galactic halo)

#### (1) 球状星团

年老的星族II恒星、以银心为中心球状分布，  
在椭圆轨道上绕银心旋转（ $V \sim 100 \text{ km s}^{-1}$ ），  
离银心最远距离达100 kpc。



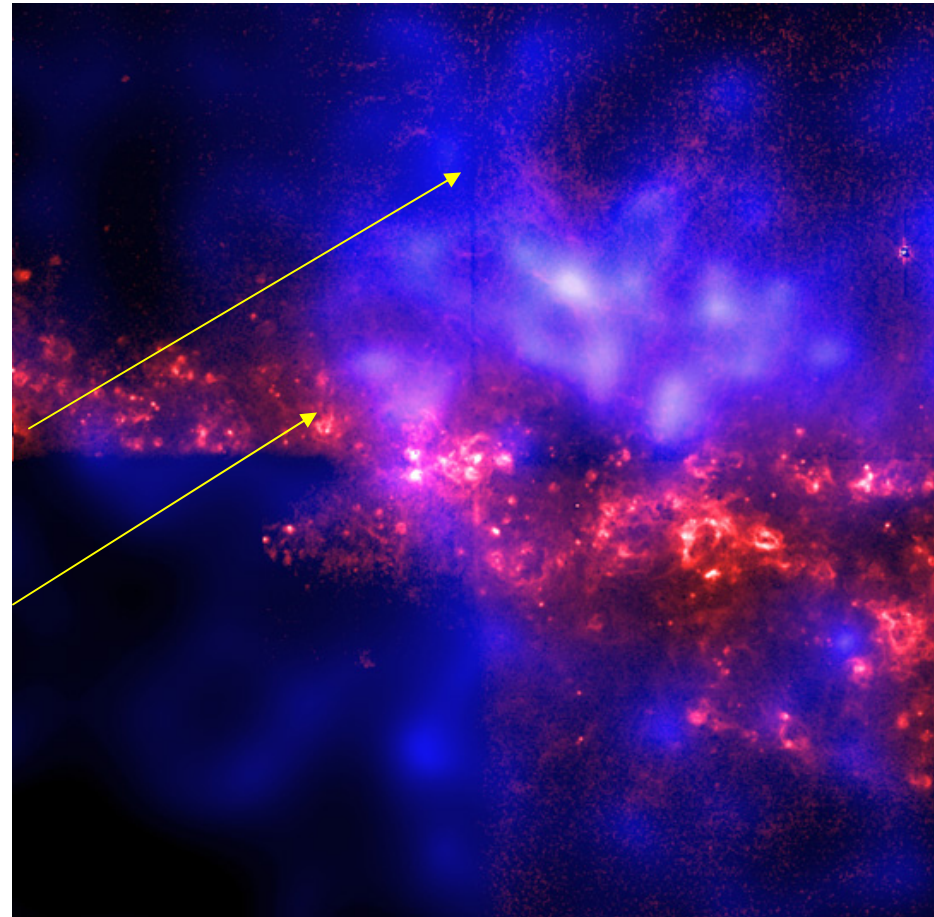


## (2) 热气体

- 弥漫的X射线辐射表明在银晕中存在大量的热气体。

热气体晕 (X射线)

恒星 (光学)

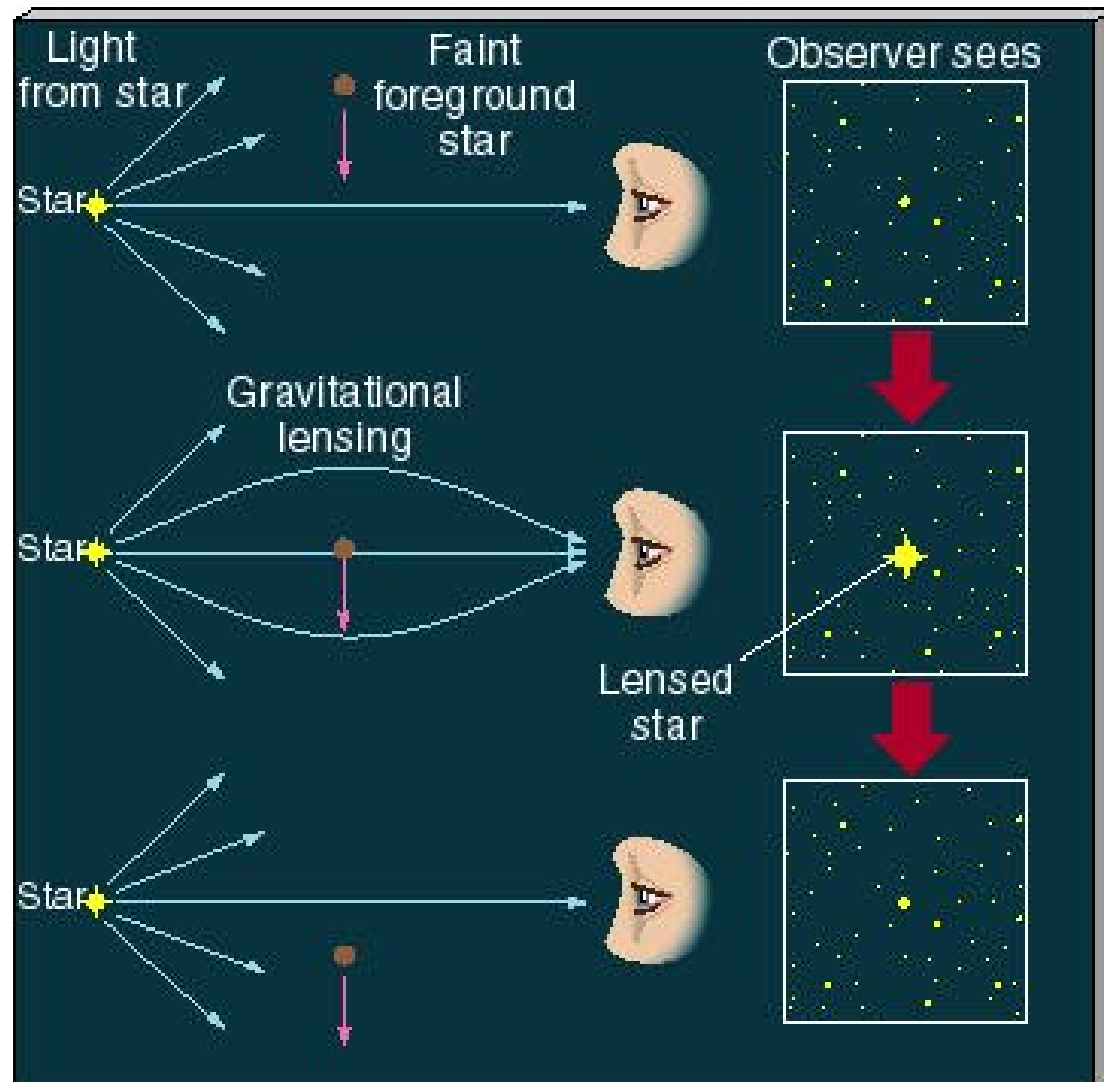


NGC 4631

### (3) 暗物质 (dark matter)

- 由银河系的自转曲线得知，银晕中的不可见物质质量远远超过银河系可见物质质量。
- 暗物质的特征：在所有波段都不产生辐射，仅有引力作用。
- 暗物质的可能成分：
  - ① MACHOs (Massive Compact Halo Objects)  
brown dwarfs, planets, neutron stars, black holes etc
  - ② WIMPs (Weakly Interacting Massive Particles)  
little weak subatomic *non-baryonic* matter

# 引力透镜 (gravitational microlensing)



## The MACHO Project

- The primary aim of the project is to test the hypothesis that a significant fraction of the dark matter in the halo of the Milky Way is made up of objects like brown dwarfs or planets.



LMC

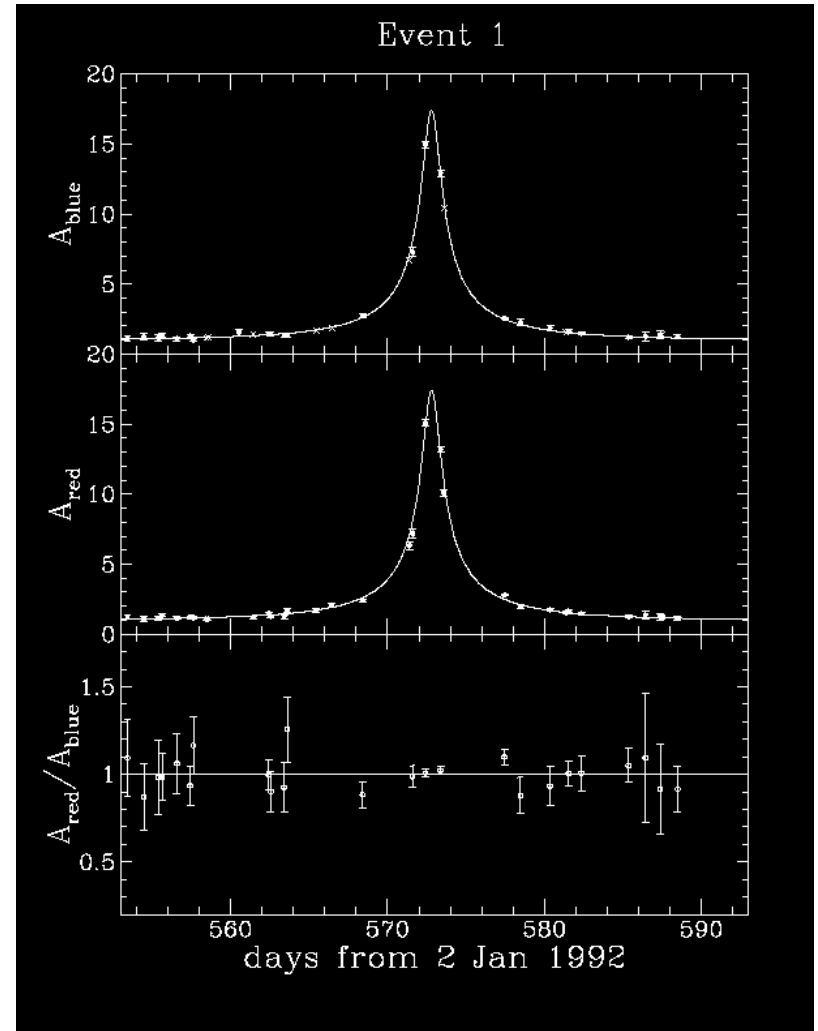
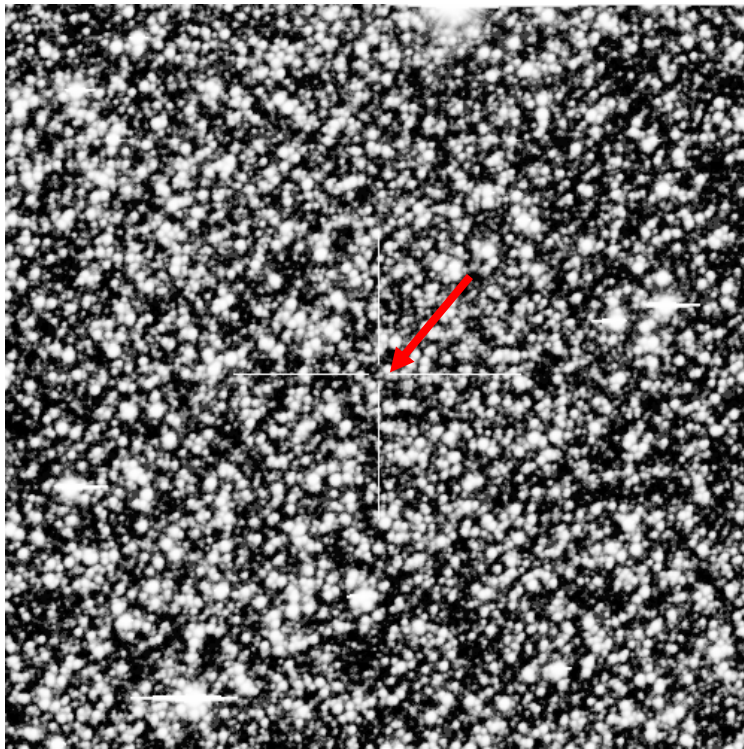


Mount Stromlo Observatory, Australia

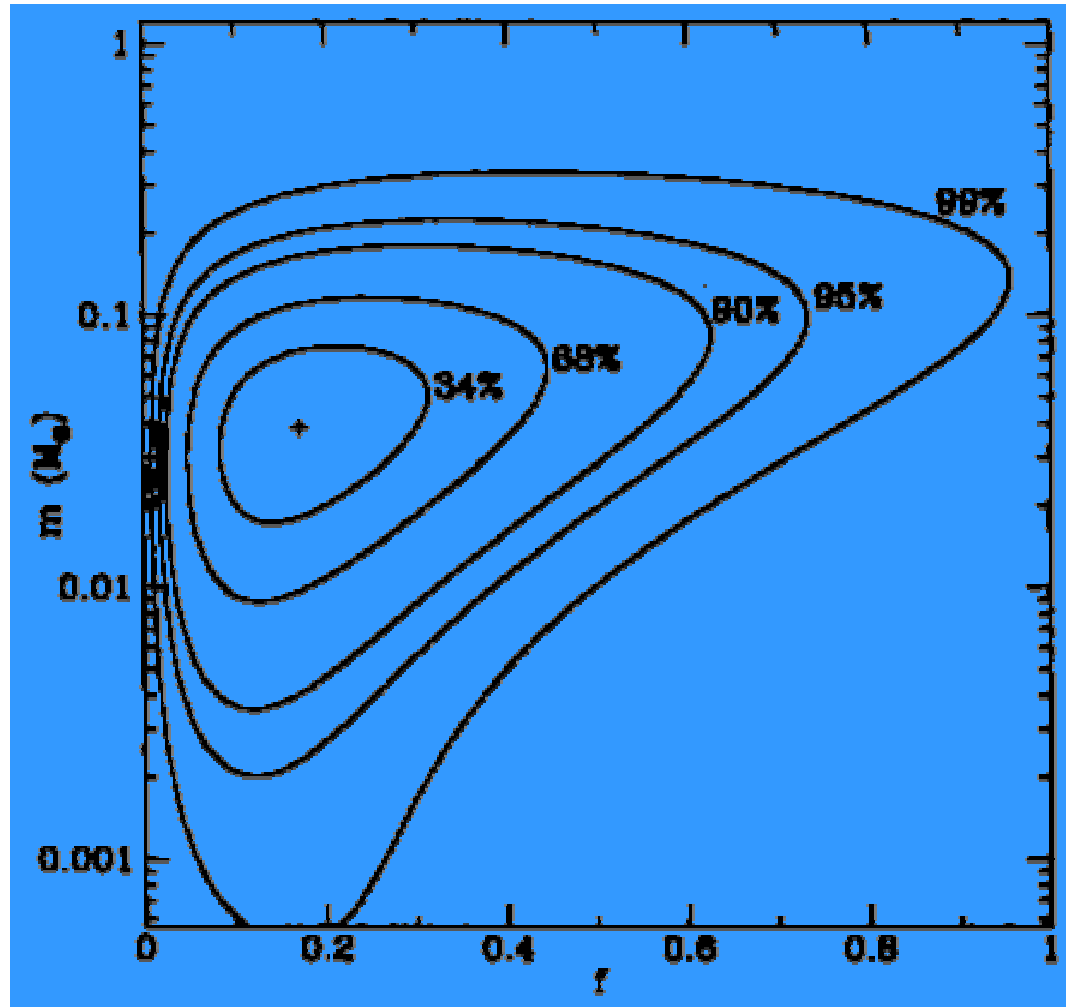
对大麦哲伦云和核球中的恒星的研究结果:

银晕中MACHO质量 $\sim 2 \times 10^{11} M_{\odot}$

单个MACHO的质量 $\sim 0.01-1 M_{\odot}$



# Limits on MACHO Mass and Halo Fraction



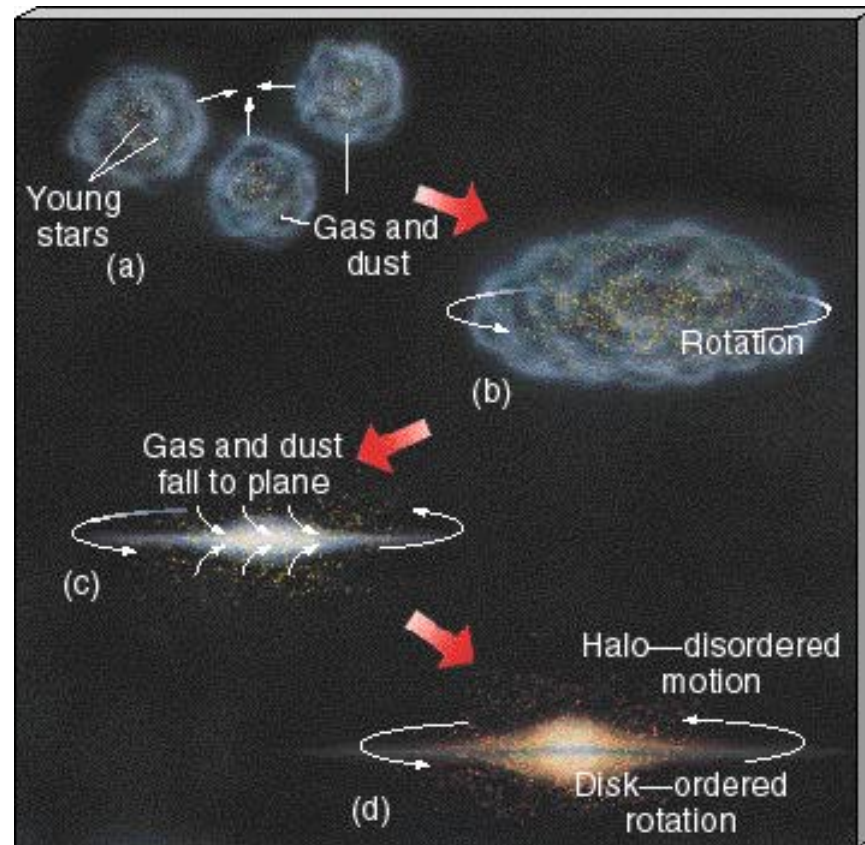
# Detection of WIMPs

- Proving WIMPs exist rests on the theory that, on occasion, a WIMP will interact with ordinary matter.
- A rare WIMP interaction can take place inside a solid object. The trick to detecting a WIMP is to witness one of these interactions.



Cryogenic Dark Matter Search

## § 6.5 银河系的起源





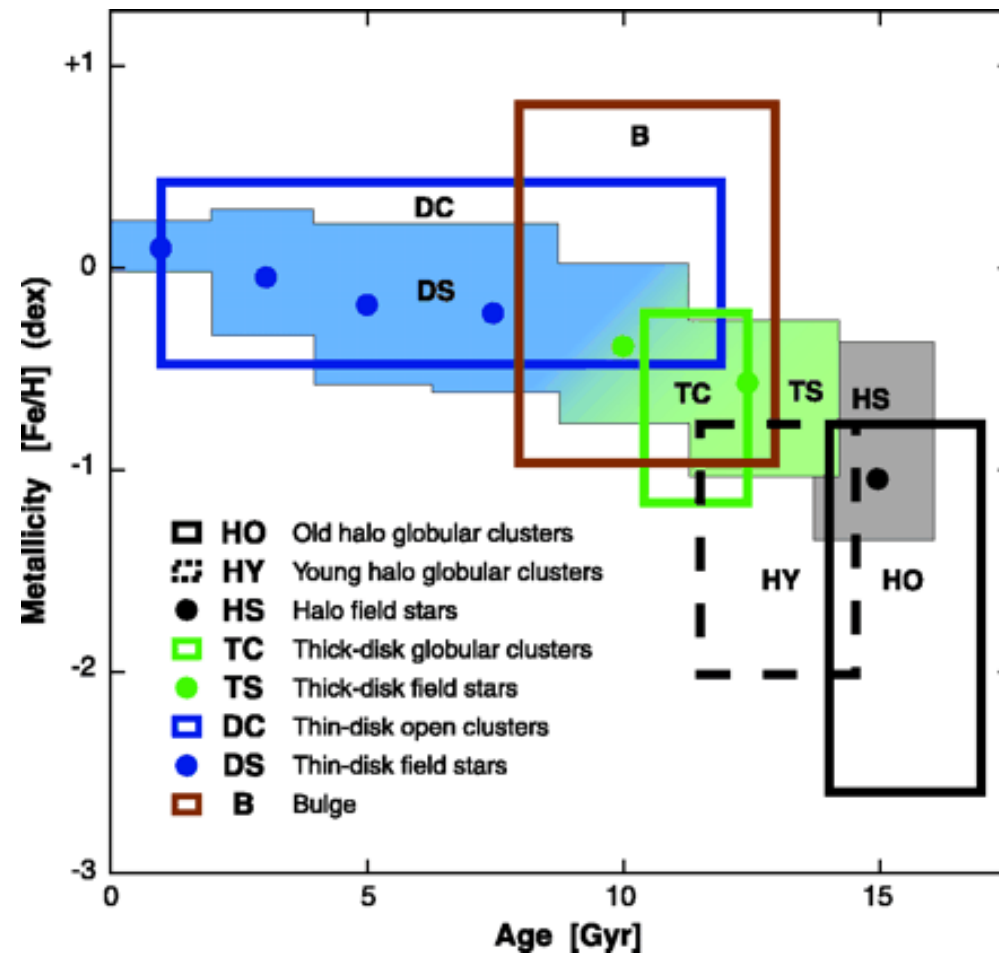
# 1. Overall properties of the Galactic disk, halo, and bulge

<b>GALACTIC DISK</b>	<b>GALACTIC HALO</b>	<b>GALACTIC BULGE</b>
Highly flattened	Roughly spherical— mildly flattened	Somewhat flattened and elongated in the plane of the disk
Contains both young and old stars	Contains old stars only	Contains both young and old stars
Contains gas and dust	Contains no gas and dust	Contains gas and dust, especially in the inner regions
Site of ongoing star formation	No star formation during the last 10 billion years	Ongoing star formation in the inner regions

## Overall properties of the Galactic disk, halo, and bulge

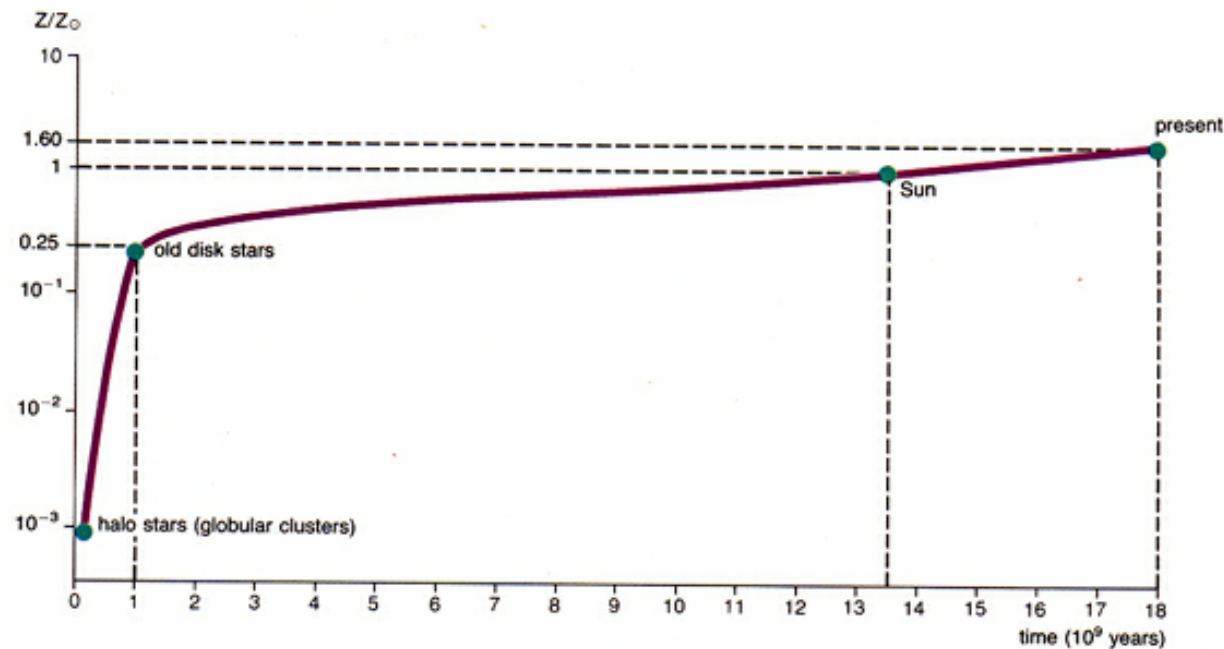
<b>GALACTIC DISK</b>	<b>GALACTIC HALO</b>	<b>GALACTIC BULGE</b>
Gas and stars move in circular orbits in the Galactic plane	Stars have random orbits in three dimensions	Stars have largely random orbits but with some net rotation about the Galactic center
Spiral arms	No obvious substructure	Ring of gas and dust near center; Galactic nucleus
Overall white coloration, with blue spiral arms	Reddish in color	Yellow-white

# The Age-Metallicity Relation



## 2. Chemical evolution

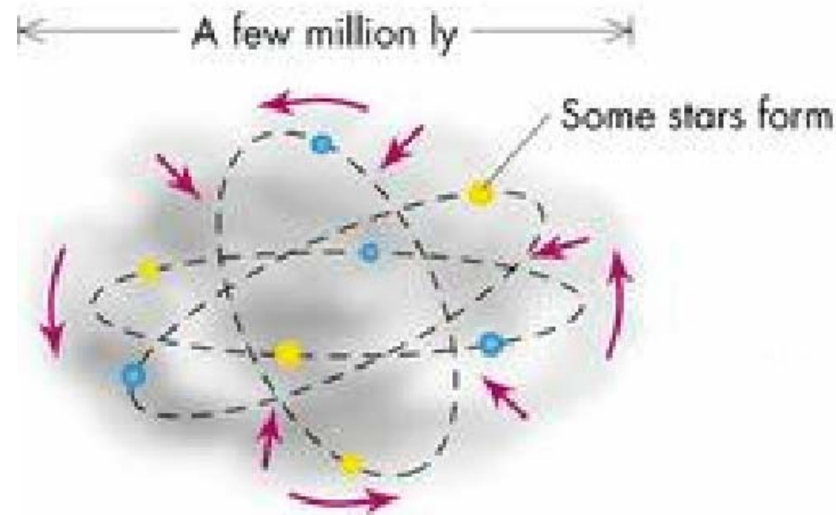
- Metals form by fusion inside of massive stars
- Supernova explosions enrich the interstellar medium with metals.
- The next generation of stars form out of the metal-enriched interstellar gas.
- Successive generations get more metal rich.



### 3. Origin of the Milky Way galaxy

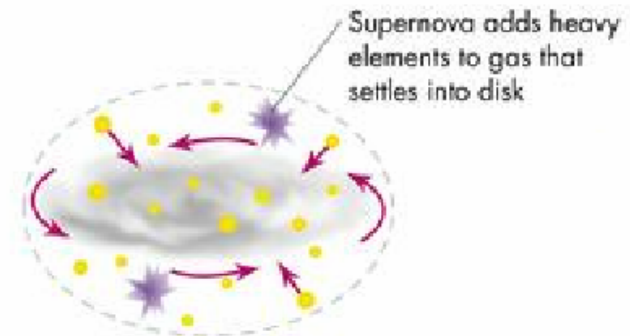
#### (1) the monolithic collapse model

- Originally suggested by O.J. Eggen, D. Linden-Bell and A. R. Sandage (1962)
- A large rotating gas cloud consisted entirely of hydrogen and helium, collapsed rapidly, in about a few  $10^8$  years.



## Phase I Spheroid Formation

- The cloud breaks up into fragments during collapse.
- First generation of stars to form are metal-poor spheroid & globular cluster stars (Pop III and Pop II)
- The cluster stars remain the kinematical features of the collapsing cloud.
- Massive Pop II stars go supernova and enrich the gas with metals. Low-mass Pop II stars are still around today.
- Star formation stops early-on in the spheroid.

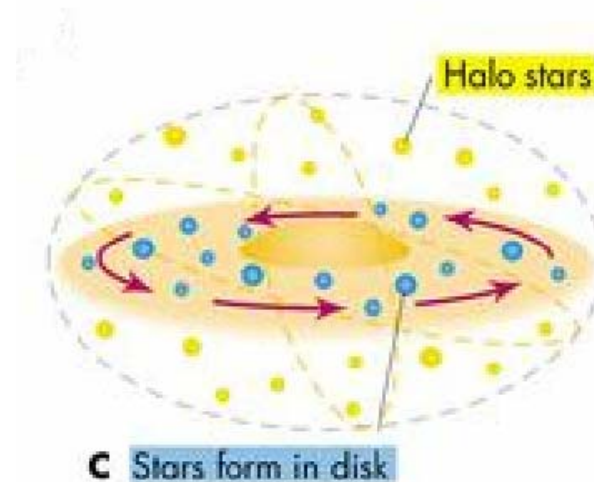


**B** Some stars form in collapsing gas, some gas collects in disk.



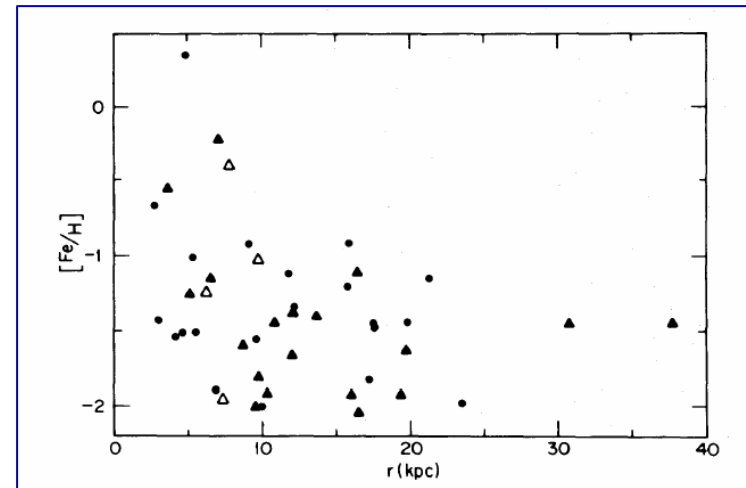
## Phase II: Disk Formation

- As the cloud fell inward on itself, the protogalaxy began to rotate more quickly and the disk appears.
- Next generation (old Pop I) stars have more metals, and ordered disk rotation.
- Massive old Pop I stars go supernova, enriching the disk gas further.
- Following generations (young Pop I) have even more metals (e.g., the Sun).
- Star formation is still going on in the disk



## Problems in the ELS Model

1. The abundance of heavy elements does not change significantly outside 8 kpc.
2. Many halo stars move in retrograde orbits, suggesting that the protogalaxy was quite clumpy and turbulent.

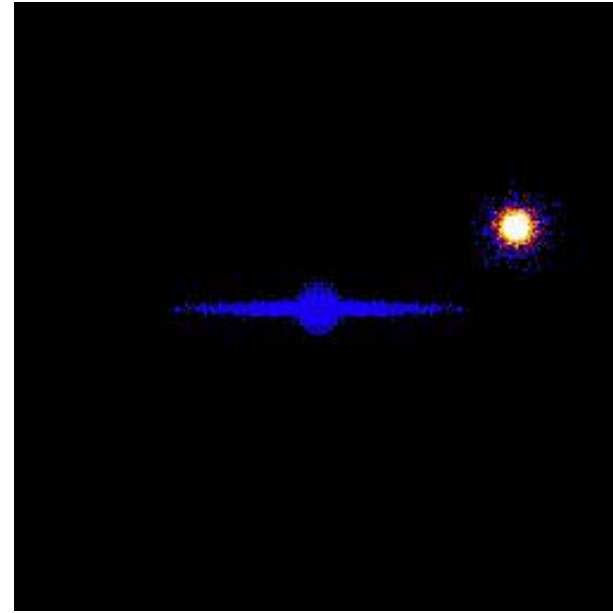
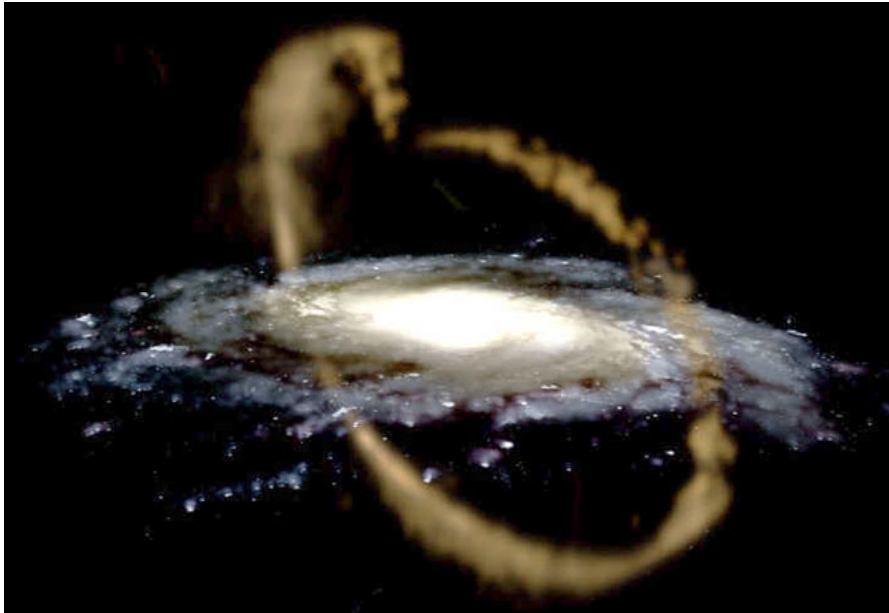


3. The observed age range of globular clusters indicates that the collapse of the outer halo is likely to have taken an order of magnitude longer than that in the ELS model.



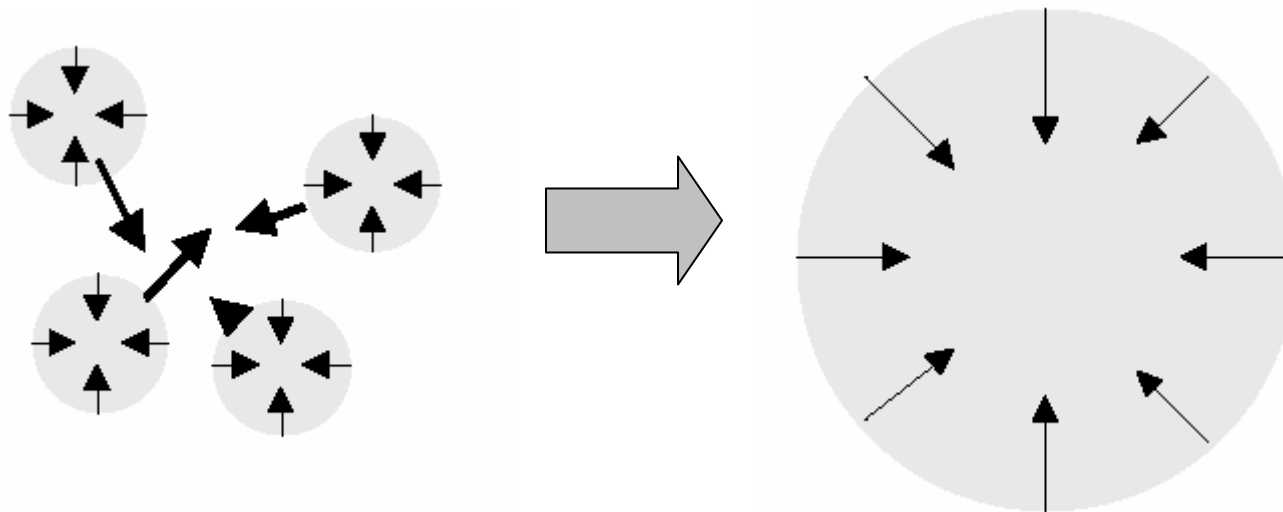
## The Sagittarius Dwarf Tidal Stream

- Our Galaxy is not a system in isolation but is still interacting with its environment in the Local Group.



## (2) the fragmented merger and accretion model

- Originally suggested by L. Searle and J. Zinn (1972)
- Many small galaxies coalesced to form the proto Milky Way galaxy



No radial chemical gradient but age and metallicity spread.

## The Merger and Accretion Model

- The ancestral fragments may have evolved in chemically unique ways, leading to differences in chemical signature among the halo populations.
- Galaxy disk is assumed to be built up by continuous accretion and merger of gas clumps.
- As the accreted gas flows inwards, it dissipates and spins up, and eventually adds to an existing gaseous disk.

## Origin of the Milky Way Galaxy

- It is possible that more than one model work for the formation of the Galaxy.
- The ELS scenario may apply to the dense bulge and inner halo.
- After the formation of the clusters in the inner halo, the more rarefied outer parts the Galaxy may have developed by the merger of fragments, along the lines theorized by Searle and Zinn.

In hierarchical cosmogonies (e.g. CDM), the formation of galaxies is basically a process of accretion and merging. An important new aspect: galaxies form in dark halos.

## More on the Origin of the Milky Way Galaxy

- The modern collapse model including cosmological infall and feedback from supernovae are more complicated, and can be in some respects (e.g. age, metallicity distribution) qualitatively different from traditional collapse models.
- An analysis of more than 14,000 stars in the Milky Way disk reveals that the evolution of the Milky Way was far more complex and chaotic than traditional, simplified models. Supernova explosions, galaxy collisions, and infall of huge gas clouds have made the Milky Way a very lively place.