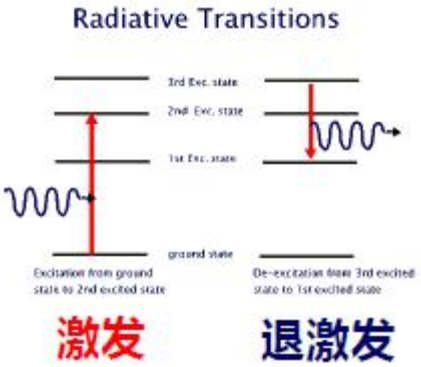
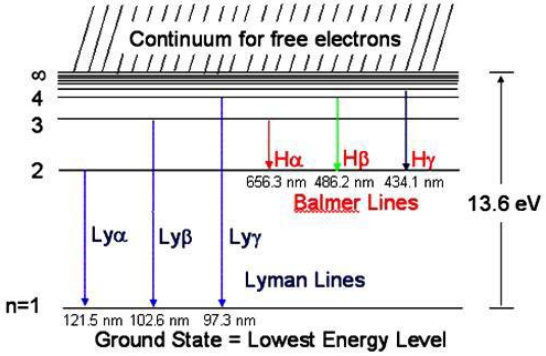
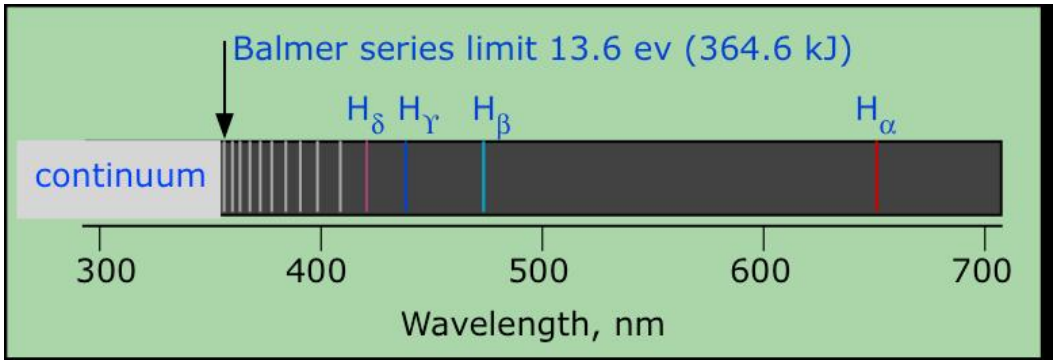
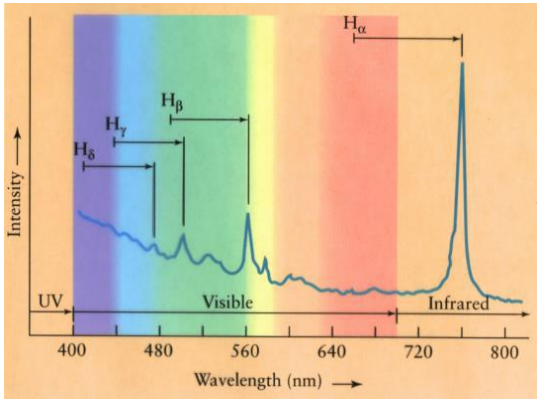
1.2.3 天体辐射过程

- 激发态寿命一般短于10^{-8}秒：电子很快跳回到低能级
- 复合辐射：当离子的电子从较高能级跃迁到较低能级时，产生的辐射称为复合辐射
- 辐射光子携带的能量，等于两个能级之间的能量差







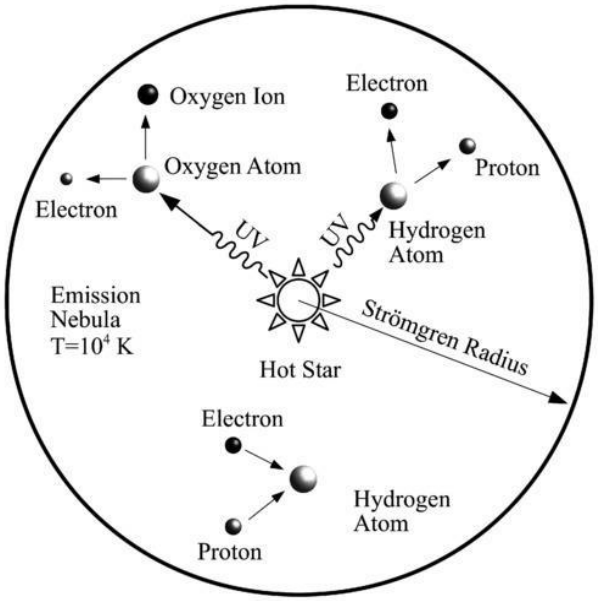


Balmer spectral line	Wavelength
Hα	656.4 nm
Hβ	486.1 nm
Hγ	434.2 nm
Hδ	410.2 nm
etc.	

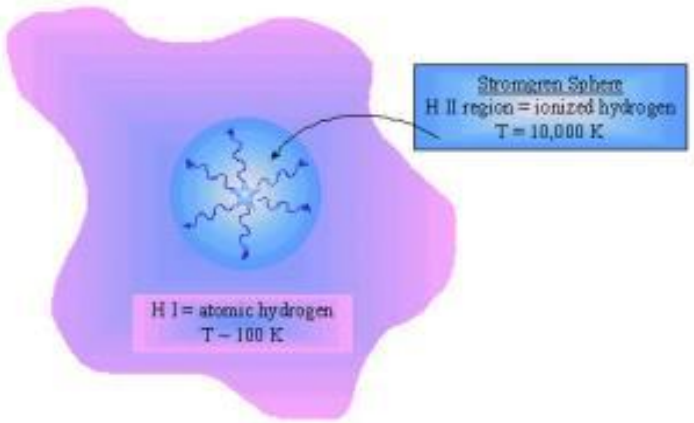
- Lyman-α线：H＋俘获一个电子变为中性，从n=2降到n=1。释出光子的波长为1216Å，能量为10.2eV
- 氢的Balmer线：n>2的能级，降到能级n=2 的各种跃迁，Hα、Hβ…

光致电离

- O、B型恒星表面温度高，产生大量紫外(UV) 光子
- UV光子被气体中原子/离子（H、O）吸收，引起光致电离
  - 紫外光子将电子从原子中释放出来：形成了自由电子
  - 光致电离条件：光子能量大于或者等于原子的电离能
  - O、B型星产生l < 912 Å的UV光子、电离H：HII区

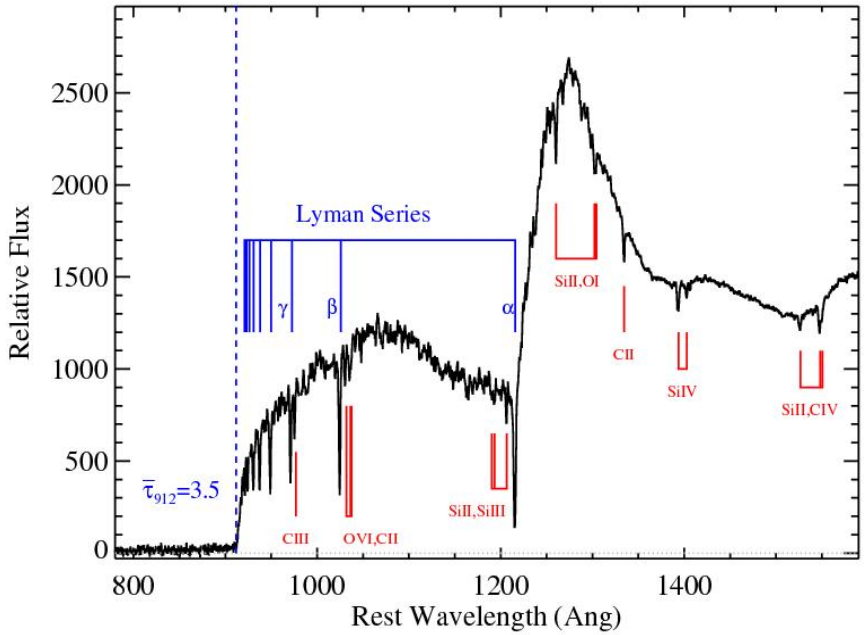


斯特龙根球：年轻的O、B型恒星周围存在的电离氢区



光致电离

- Lyman limit is the short-wavelength end of the hydrogen Lyman series, at 912 Å：处于基态H原子电离对应的能量
- 光致电离的结果：产生大量的自由电子
- 自由电子之间相互频繁碰撞，建立电子气的平衡态速度分布



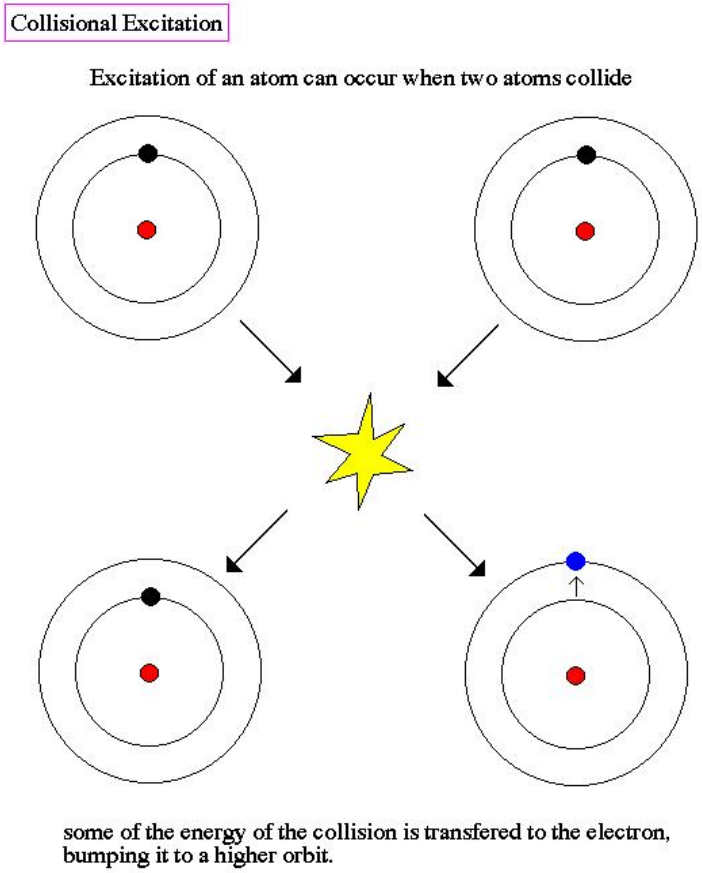
碰撞激发

- **碰撞激发：** 自由电子与气体内的原子或离子发生非弹性碰撞，引起它们被激发（动能 → 内能）

原子A同原子B碰撞，形成激发态A*

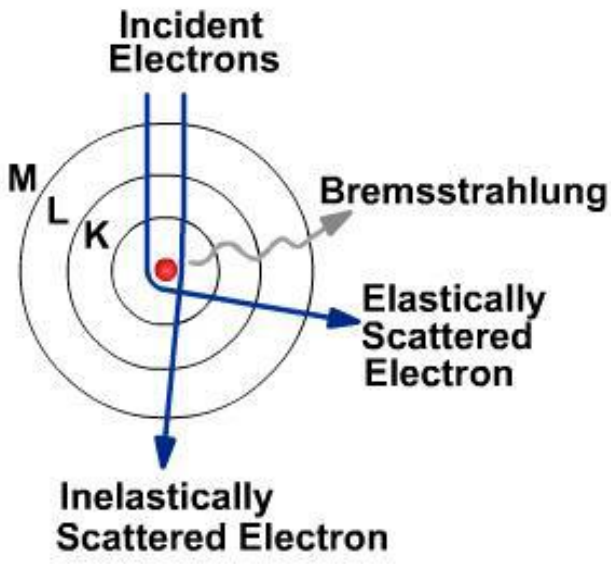
$$A + B \longrightarrow A^* + B, \quad A^* \longrightarrow A + \nu h_P.$$

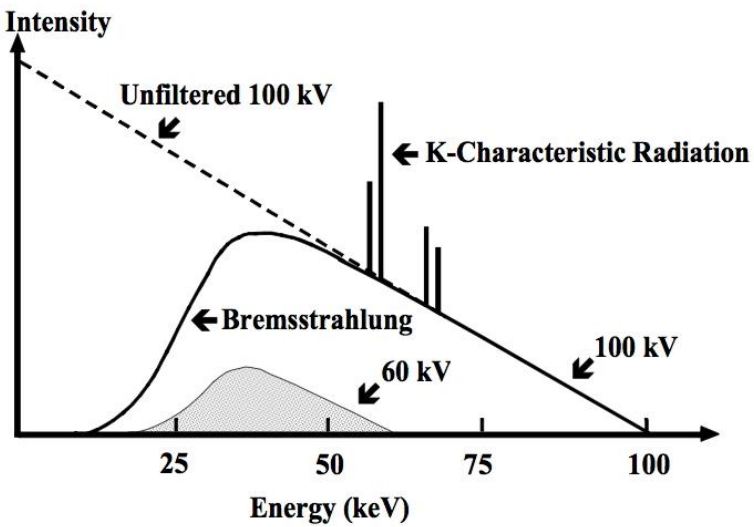
- 被碰撞激发的原子或离子回到基态时，会发射出光子，这些光子组成的谱线称碰撞激发线
- 只有当A*态在再次碰撞前衰变，才能看到一条发射线：1）衰变要迅速，or 2)气体密度相当低（密度较高的气体，会进行相反的碰撞退激程序）
- 碰撞激发线通常只能在密度非常低的气体中观察到：通常每立方厘米只有几千个粒子



碰撞激发

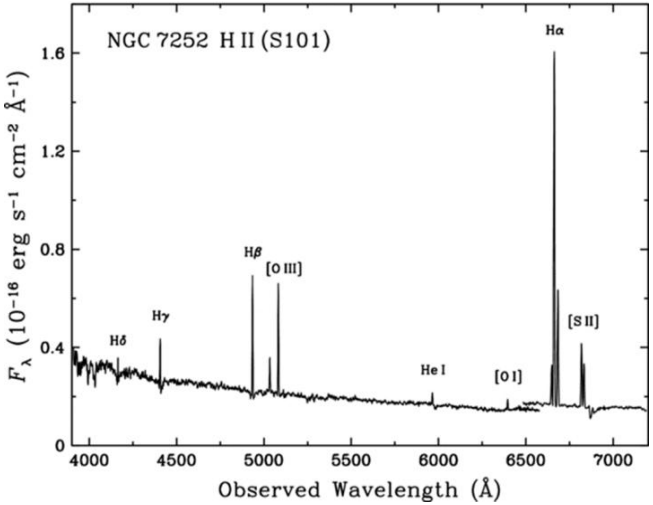
- **韧致辐射：自由电子与离子发生近碰撞，库仑力作用使电子获得加速度，电子产生的辐射**
  - 电子在辐射过程前后都是自由的，又称自由-自由跃迁
  - 韧致辐射是连续辐射





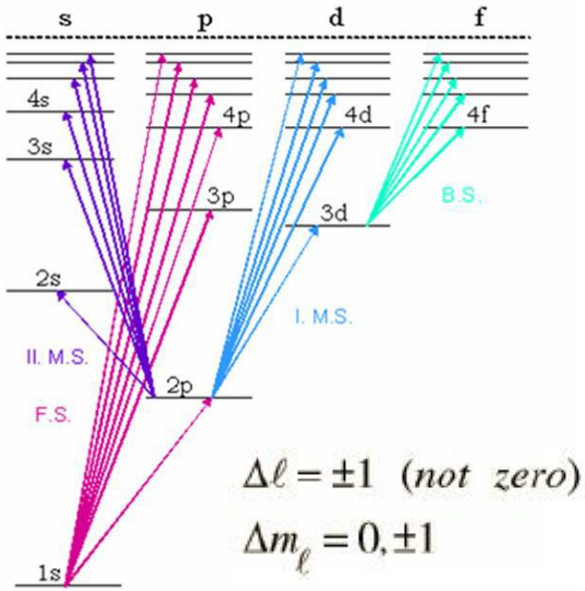
禁线

- 在极度稀薄状态下的氧发射线：禁线，即通过禁戒跃迁产生的谱线；[OIII]λ4959; [OIII]λ5007



禁戒跃迁

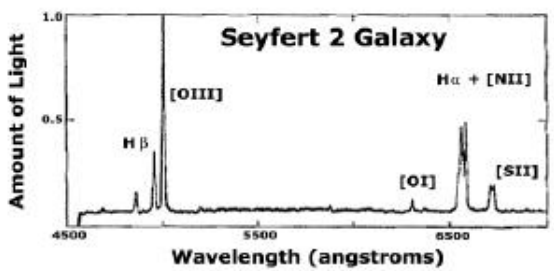
- 通常的谱线是由电偶极辐射产生，电偶极辐射服从选择定则（角量子数l，磁量子数m）
- 禁戒跃迁是指跃迁概率很小的跃迁，破坏了电偶极辐射选择定则：电四极辐射和磁偶极辐射
- P(电偶极辐射)>>P(电四极辐射和磁偶极辐射)



P(容许跃迁) >> P(禁戒跃迁)：如果同时存在，则不会观测到禁线，禁线只能在密度非常低的环境

光学、红外波段的禁线

- 地球上，禁线不可能出现：处于亚稳态的原子在衰变前已被碰撞，离开亚稳态（允线跃迁只需10^{-8}s，禁线>1s或更长）
- 禁线的发射谱线只在极低密度的外太空或地球极端的高层大气的中出现
- 因为禁线强度非常强烈地依赖于发射禁线气体的密度n和温度T
- 禁线可以用来确定星系发射线区的密度和温度
- 禁线标识：用元素符号加方括号[ ]来标记；如λ = 5007Å的[OIII]线



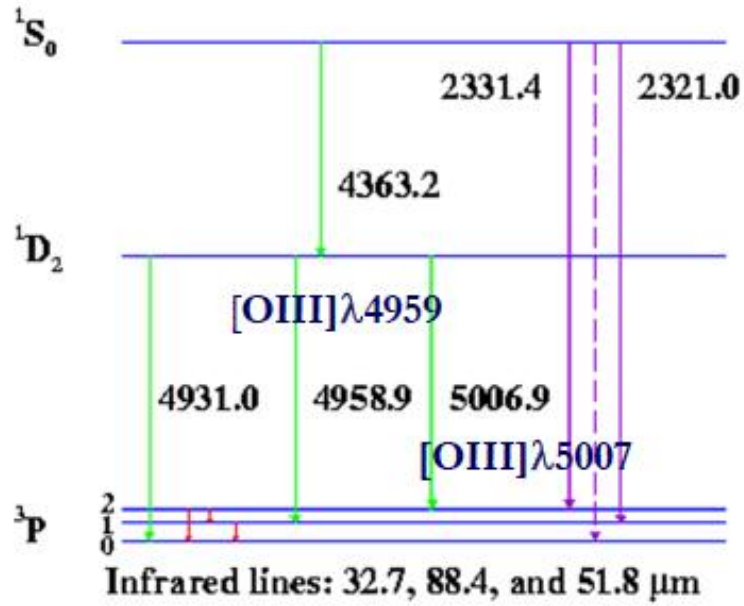
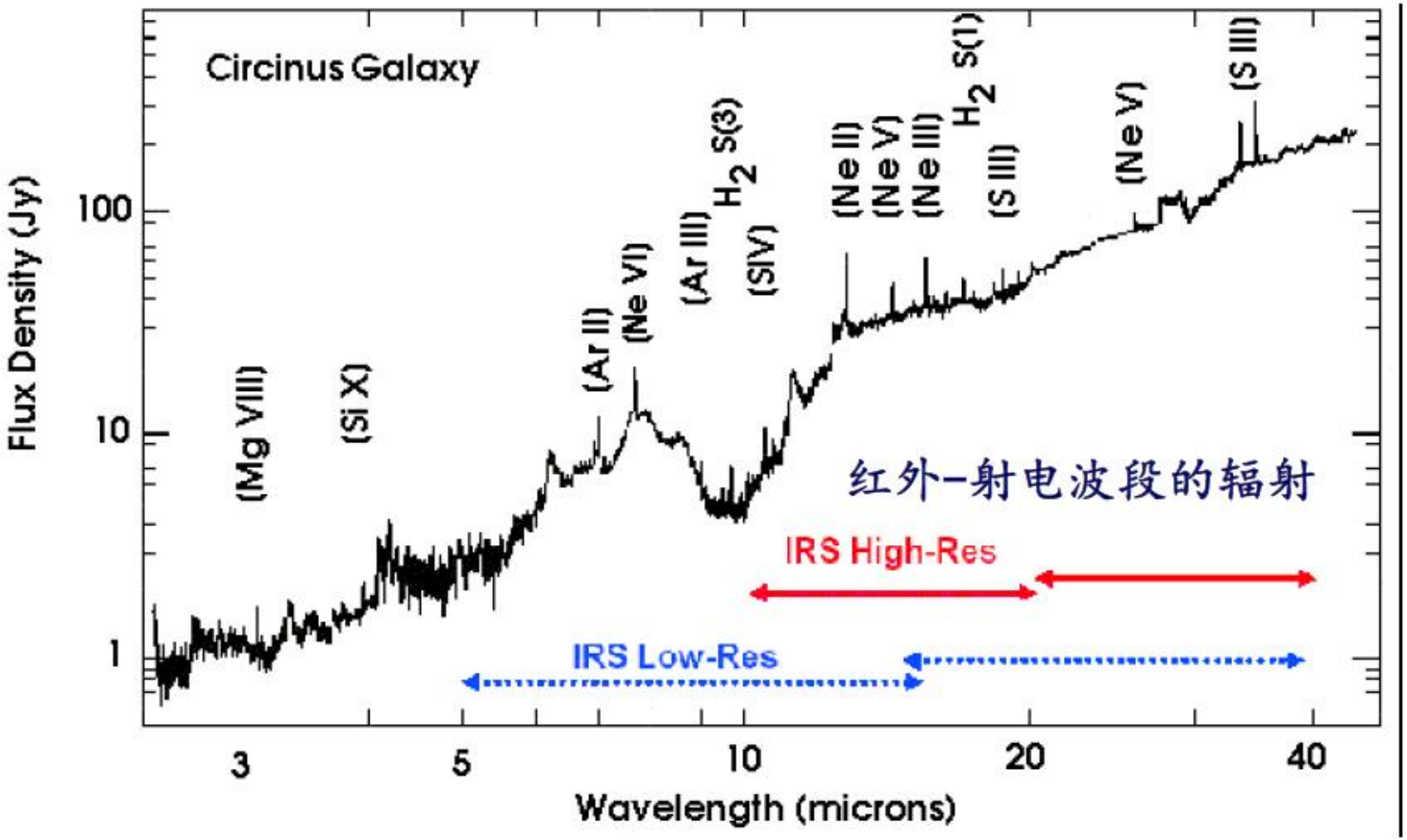


Table 1.7 Some common optical and infrared forbidden lines of atoms

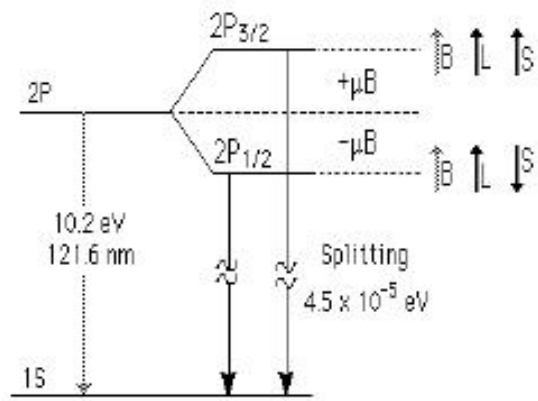
Atom	*Transition*	*Wavelength*	n_{crit} (cm^{-3})
CI	$^3P_1 \rightarrow {}^3P_0$	610 μm	500
	$^3P_2 \rightarrow {}^3P_1$	371 μm	1 000
CII (C^+)	$^2P_{3/2} \rightarrow {}^2P_{1/2}$	158 μm	50
NII (N^+)	$^1D_2 \rightarrow {}^3P_2$	6583 Å	66 000
	$^1D_2 \rightarrow {}^3P_1$	6548 Å	66 000
OI	$^1D_2 \rightarrow {}^3P_2$	6300 Å	2×10^6
	$^3P_1 \rightarrow {}^3P_2$	63.2 μm	30 000
	$^3P_0 \rightarrow {}^3P_1$	145.5 μm	8 000
OII (O^+)	$^2D_{5/2} \rightarrow {}^4S_{3/2}$	3729 Å	3 400
	$^2D_{3/2} \rightarrow {}^4S_{3/2}$	3726 Å	15 000
OIII (O^{++})	$^1D_2 \rightarrow {}^3P_2$	5007 Å	7×10^5
	$^1D_2 \rightarrow {}^3P_1$	4959 Å	7×10^5
	$^1S_0 \rightarrow {}^1D_2$	4363 Å	2×10^7

原子、分子谱线

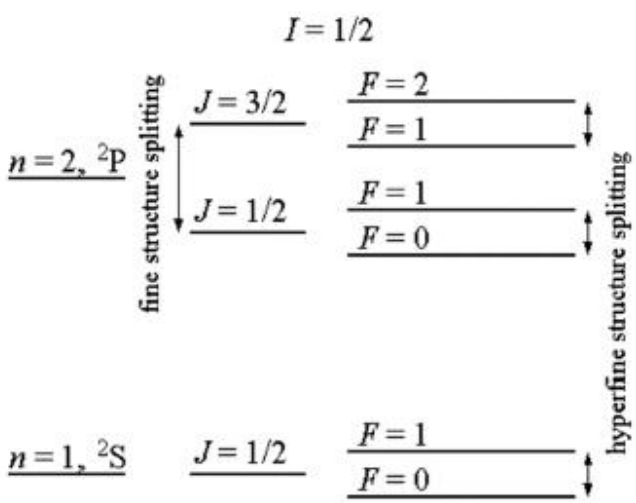

Circinus Galaxy
Flux Density (Jy)
100
10
1
(Mg VIII)
(Si X)
(Ar II)
(Ne VI)
(Ar III)
H2 S(3)
(SIV)
(Ne II)
(Ne V)
(Ne III)
H2 S(1)
(S III)
(Ne V)
(S III)
红外-射电波段的辐射
IRS High-Res
IRS Low-Res
3
5
10
20
40
Wavelength (microns)

精细/超精细结构线

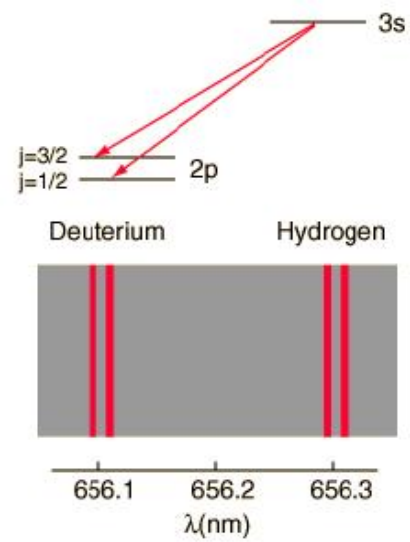
- **精细结构：电子自旋和轨道角动量产生的磁矩之间的相互作用（耦合）**
- **相应的能量差大约只有主能级之间差的 $1/137^2$，所以辐射波长主要在远红外区域**
- **超精细结构：是核自旋和轨道电子产生的磁场之间耦合结果。能级分裂比精细结构谱线还要小2000倍 → 21cm线**



Fine structure splitting in the Hα emission spectrum.

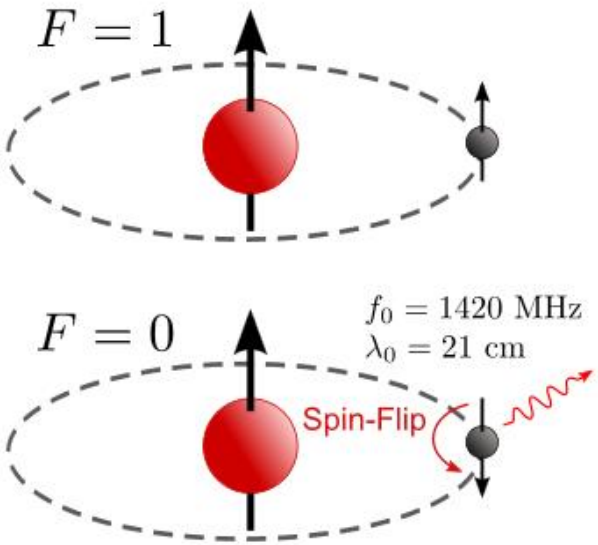


Schematic illustration of fine and hyperfine structure in hydrogen



H原子 21 厘米谱线

- H原子中的电子自旋与原子核自旋处于平行状态和反平行状态间的跃迁，产生的辐射：频率1.42 GHz，波长21厘米
- H原子21厘米谱线(射电波段)－H原子基态的两个超精细能级之间发生的禁戒跃迁线，t=107yr
- 1944 年荷兰天文学家H. van de Hulst预言：可能在银河系观测到中性H 原子谱线发射
- 1951 年，Ewen& Purcell在哈佛大学莱曼物理实验室首次观测到来银河系中性氢发射的21厘米线（所使用的号角型天线）
- 尽管单个H 原子的跃迁概率极低，但由于星际空间中的中性氢非常丰富，其产生的21厘米谱线仍然能够观测到
- 射电波段受尘埃的影响小：21cm线是研究银河系、大尺度结构的重要手段。

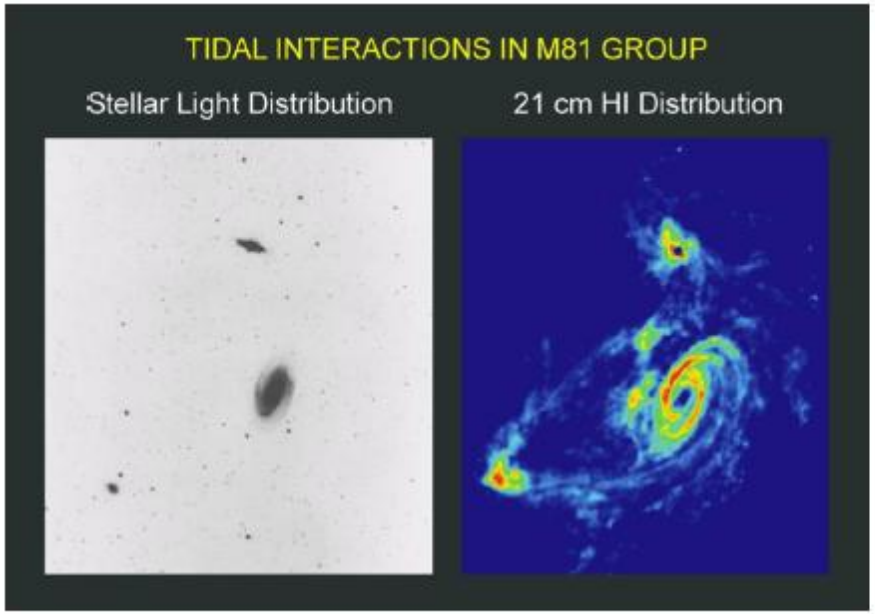


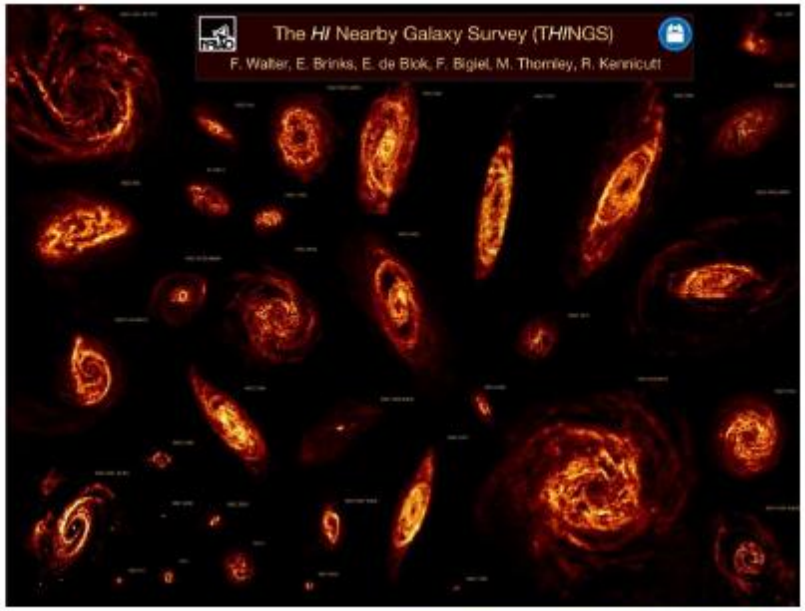
银河系HI发现

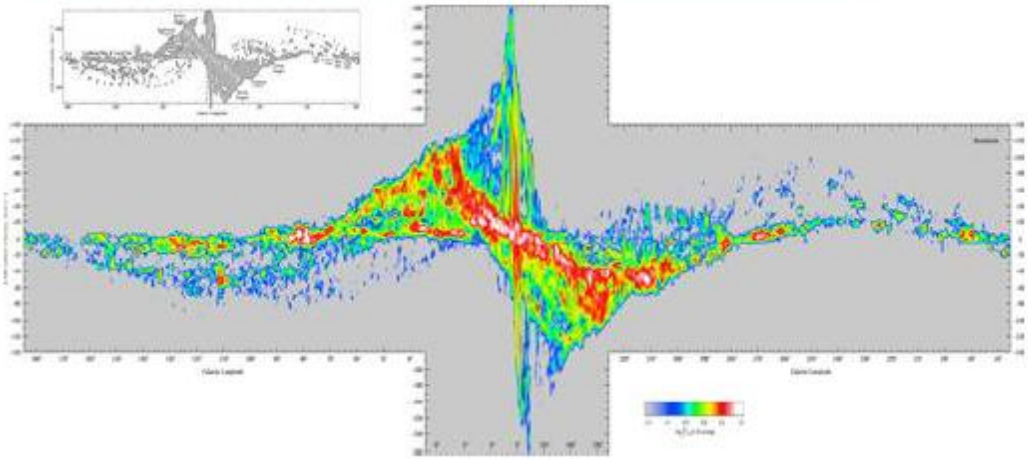
- 荷兰莱顿天文台的简·奥特（Jan Oort）敏锐地意识到，如果光谱中存在射电波段的发射线，将对天文学是巨大的推动。
- Jan Oort将寻找这条谱线的任务交给了他的学生亨瑞克·范德赫尔斯特（Hendrik van de Hulst）：后者于1944年发表了一篇论文，在理论上预言了21 厘米谱线的存在，可他在论文里也怀疑到底能不能观测到。
- 美国哈佛大学的爱德华·帕塞尔（Edward Purcell）和他的学生哈罗德·伊文（Harold Ewen）于几年后开始寻找21 厘米谱线：认为悲观的荷兰人可能不会真的去找这条线。
  - 帕塞尔负责找钱（500 美元）：全部用来造了接收天线、波导和电子配件
  - 伊文负责出力：全职工作是为一个新的回旋加速器设计建造组件，只能用业余时间在帕塞尔的指导下建造观测21 厘米谱线的天线
- 1951年3月25日，从收到那500 美元起的一年后，伊文和帕塞尔第一次成功地观测到了来自银河系的氢原子21 厘米发射线！频率切换的核心技术
- 原来荷兰人已经辛苦工作了好几年。伊文：如果我们早知道的话，就不会去尝试了。

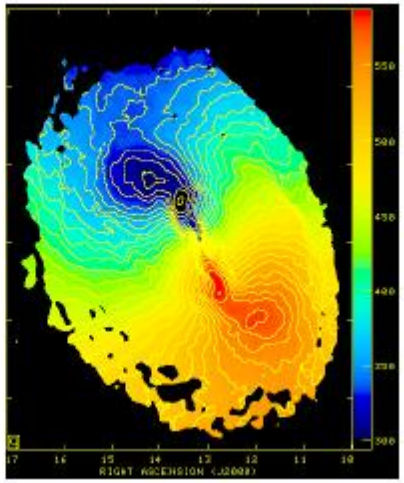
哈佛实验组要钱没多少钱，要人没多少人，连竞争对手的敌情都完全搞错了，这要能先搞出来还有天理吗?!

HI in Nearby Galaxies

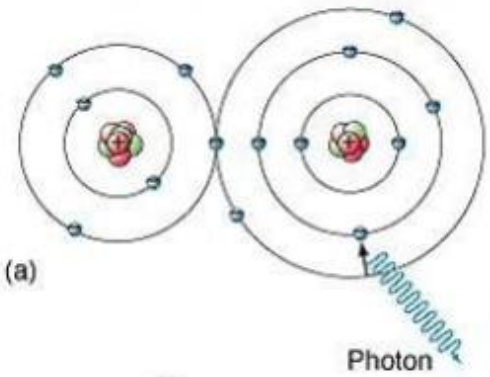


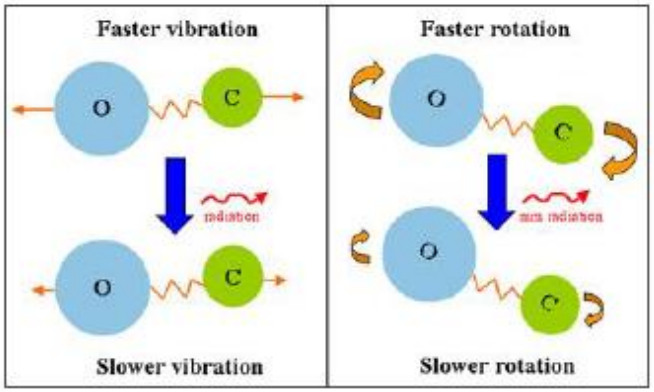






分子辐射





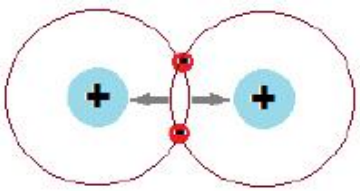
- **电子跃迁**：当分子的电子在不同能级之间跃迁，分子能够像原子一样产生辐射 → 主要辐射在紫外和光学波段
- **转动跃迁**：分子转动变慢 → 射电波段
- **振动跃迁**：分子振动变慢 → 红外波段

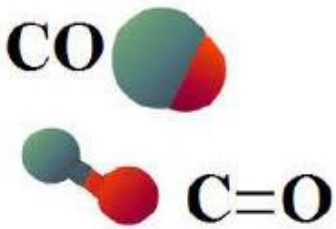
Table 1.8 Commonly observed lines from molecular clouds

Molecule	*Transition*	*Frequency* ν	*Wavelength* λ	E_{upper}/k_B (K)	[a]*Typical* n_H (cm^{-3})
H_2	$v = 1-0$, S(1)	140 THz	2.128 μm		
H_2 ortho	$v = 0-0$, S(0)	11 THz	28.2 μm	510	
	$v = 0-0$, S(2)	24 THz	12.3 μm	1682	
H_2 para	$v = 0-0$, S(1)	18 THz	17.1 μm	1015	
CO	$J = 1 \rightarrow 0$	115.3 GHz	2.6 mm	5.5	~100
	$J = 2 \rightarrow 1$	230.5 GHz	1.3 mm	17	~1 000
	$J = 3 \rightarrow 2$	345.8 GHz	0.87 mm	34	10^3–10^4
CS	$J = 1 \rightarrow 0$	49 GHz	6.1 mm	2.4	>5 000
	$J = 5 \rightarrow 4$	244 GHz	1.2 mm	35	10^6
SiO	$J = 2 \rightarrow 1$	86.8 GHz	3.5 mm	6.3	[c]shocks
	$J = 5 \rightarrow 4$	217.1 GHz	1.4 mm	31.3	[c]shocks
	$J = 8 \rightarrow 7$	347.3 GHz	0.86 mm	75	[c]shocks
HCO^+	$J = 1 \rightarrow 0$	89 GHz	3.4 mm	4.3	>3 000
	$J = 3 \rightarrow 2$	268 GHz	1.1 mm	26	>30 000
HCN	$J = 1 \rightarrow 0$	89 GHz	3.4 mm	4.3	>10 000
	$J = 3 \rightarrow 2$	266 GHz	1.1 mm	26	$>10^5$

示踪分子

- H_2分子具有对称结构，无偶极距： H_2分子辐射极弱
- CO分子丰度仅次于H_2分子：1.3mm和2.6mm的转动跃迁在密度n(H2) ~100-1000 cm^3通常最强
- 利用CO分子的毫米射电辐射，可研究H_2分子的分布





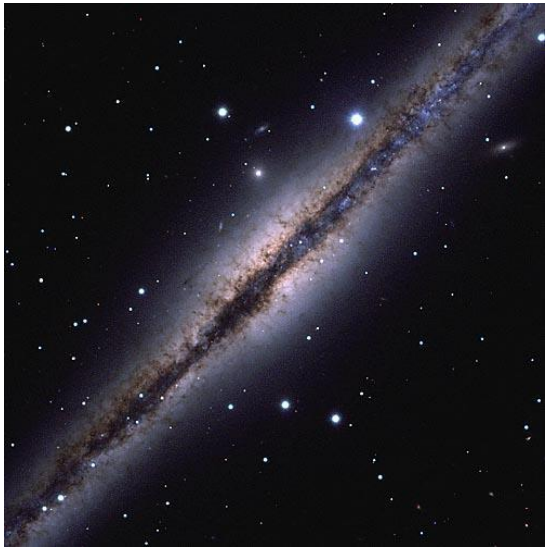
As a consequence, astronomers frequently employ CO emission to measure molecular gas masses. The standard methodology posits a simple relationship between the observed CO intensity and the column density of molecular gas, such that

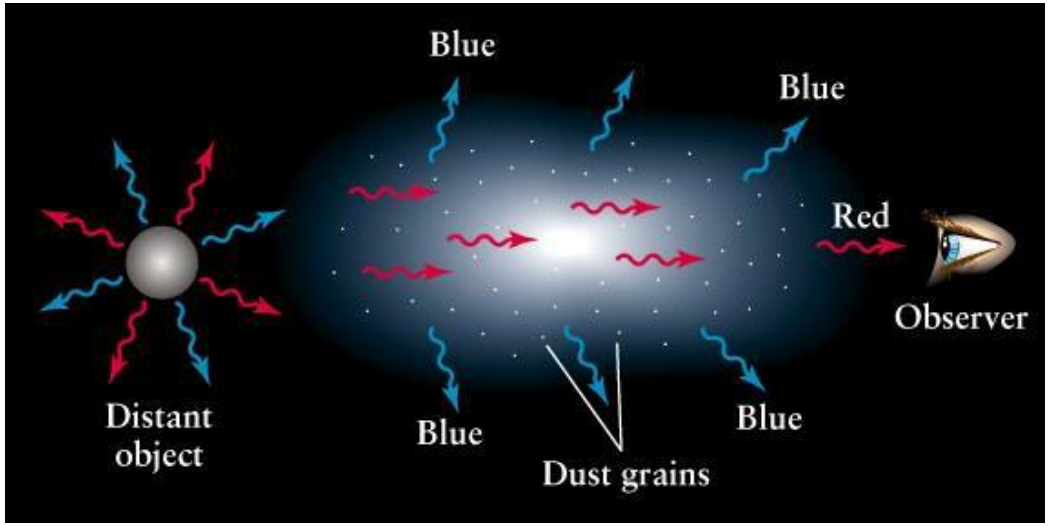
$$N(H_2) = X_{CO}\, W(^{12}C^{16}O\ J = 1 \rightarrow 0), \quad (1)$$

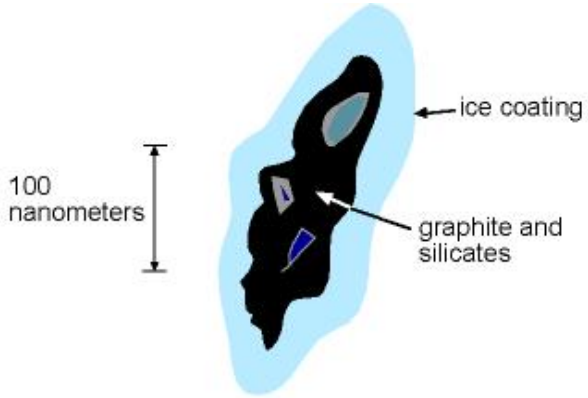
where the column density, $N(H_2)$, is in per centimeters squared and the integrated line intensity, W(CO), is in traditional radio astronomy observational units of Kelvins kilometers per second

1.2.4 星际尘埃

- 星际物质中，尘埃粒子的质量~1%
- 主要是硅酸盐和碳粒，尺寸< 1微米
- 尘粒能有效地散射和吸收波长小于其自身尺度的辐射
- 被弥漫的星光加热的尘埃具有T~10－20K，在200微米处辐射；亮星附近的尘埃较热







A typical dust grain (note the tiny scale!).

尘埃消光

For the simple case in which there is a single point-like light source behind a screen of dust:

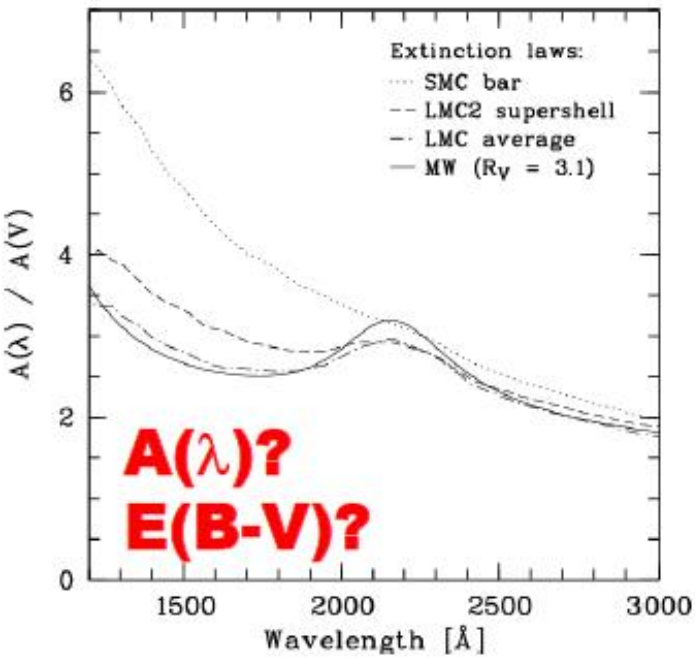
$$\frac{dI_\nu}{d\tau} = -I_\nu \qquad I_\nu = I_\nu^o \, e^{-\tau}$$

$I_{\nu,0}$ 是无尘埃吸收时，测量到的天体的光度；

I_ν 是被尘埃吸收后的光度

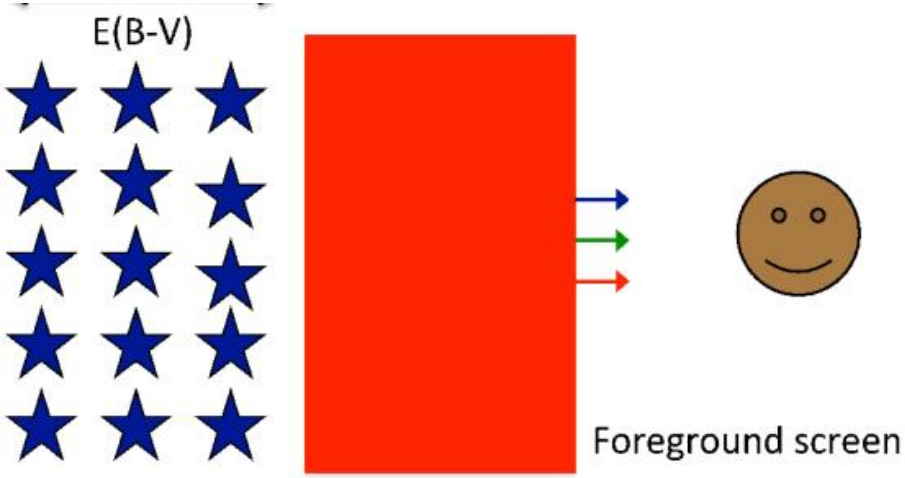
尘埃层的光深 (Optical depth):

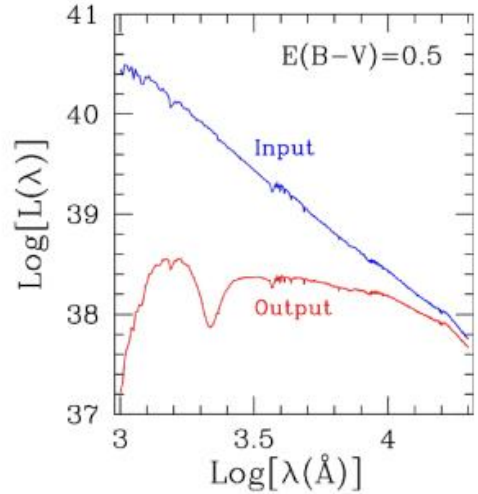
$$\tau_\lambda = 0.921 \; A(\lambda) = 0.921 \; E(B-V) \; \kappa(\lambda)$$

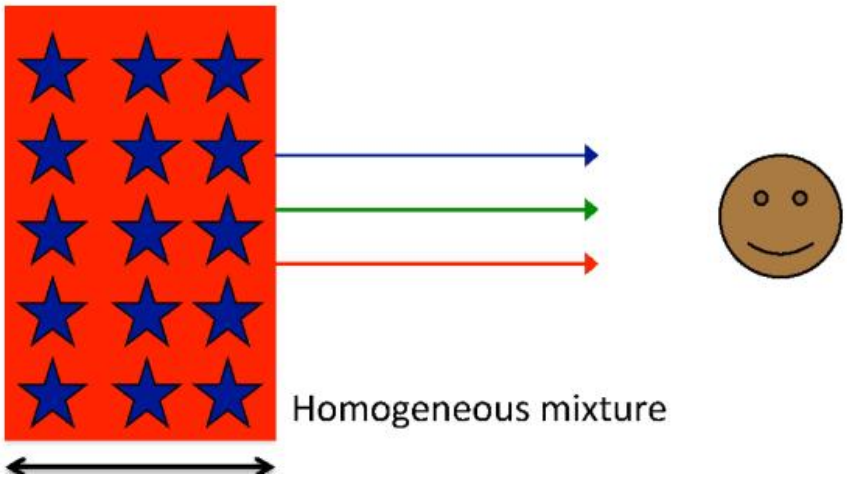


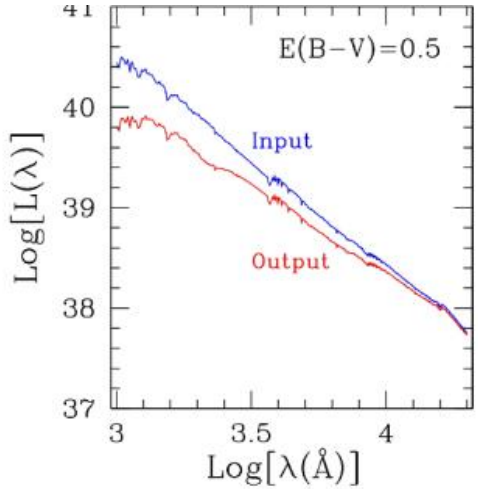
不透明度κ：物质对辐射吸收能力强弱的量

尘埃消光


E(B-V)
Foreground screen

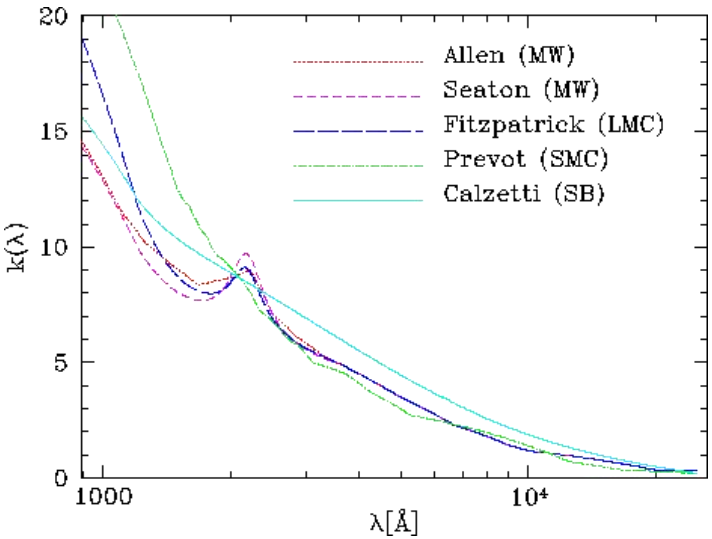

E(B−V)=0.5
Input
Output
Log[L(λ)]
Log[λ(Å)]
41
40
39
38
37
3
3.5
4


Homogeneous mixture


E(B−V)=0.5
Input
Output
Log[L(λ)]
Log[λ(Å)]
40
39
38
37
3
3.5
4

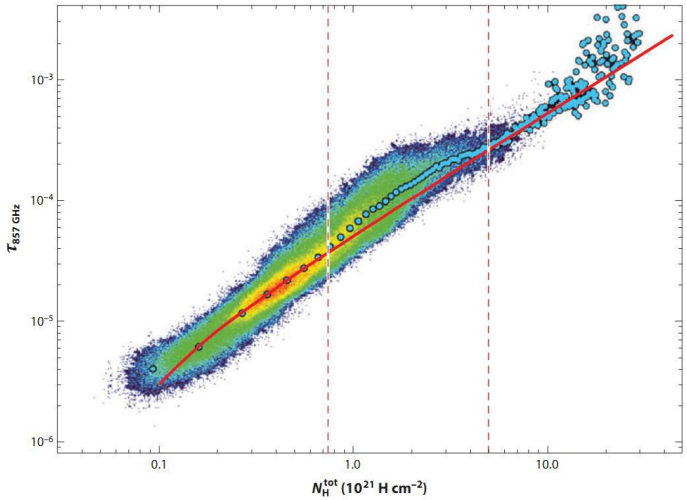
尘埃消光

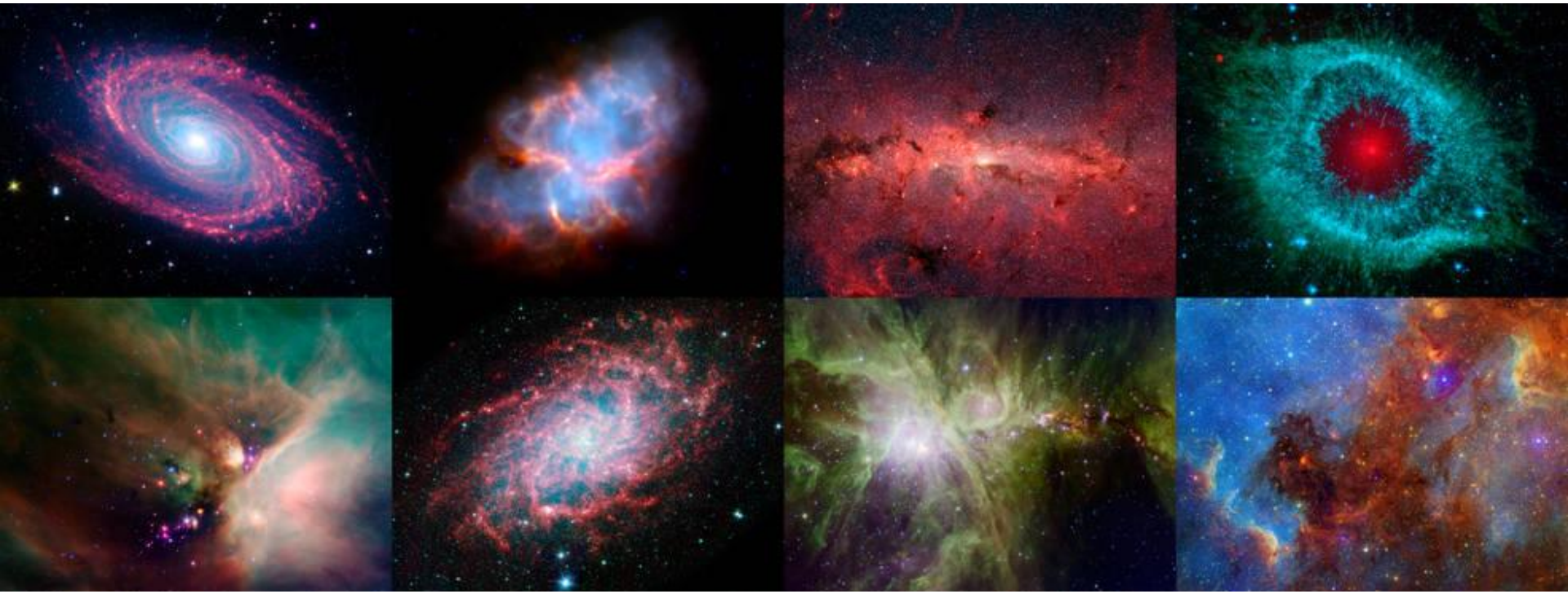
- 蓝和紫外辐射比红光被尘埃散射和吸收得更多：**波长越短消光越严重**
- 观测者和恒星间尘埃，使恒星显得更暗、更红：**尘埃消光**
- 可见光波长3000Å< λ<1nm的范围内，星际尘埃的κ可取近似$\kappa_\lambda \propto 1/\lambda$.



- **尘埃和气体成团状分布**，高银纬处可假设尘埃量与气体量成正比
- 利用测量中性氢的21厘米线辐射，可以估计银河系的消光A_V：

$$N_H \approx 1.8 \times 10^{21}\ \mathrm{cm}^{-2} \times A_V(\mathrm{magnitudes}).$$

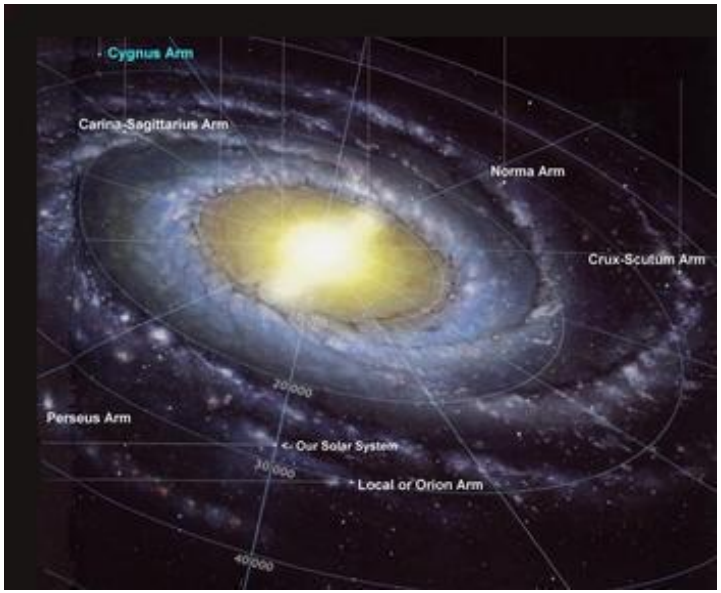


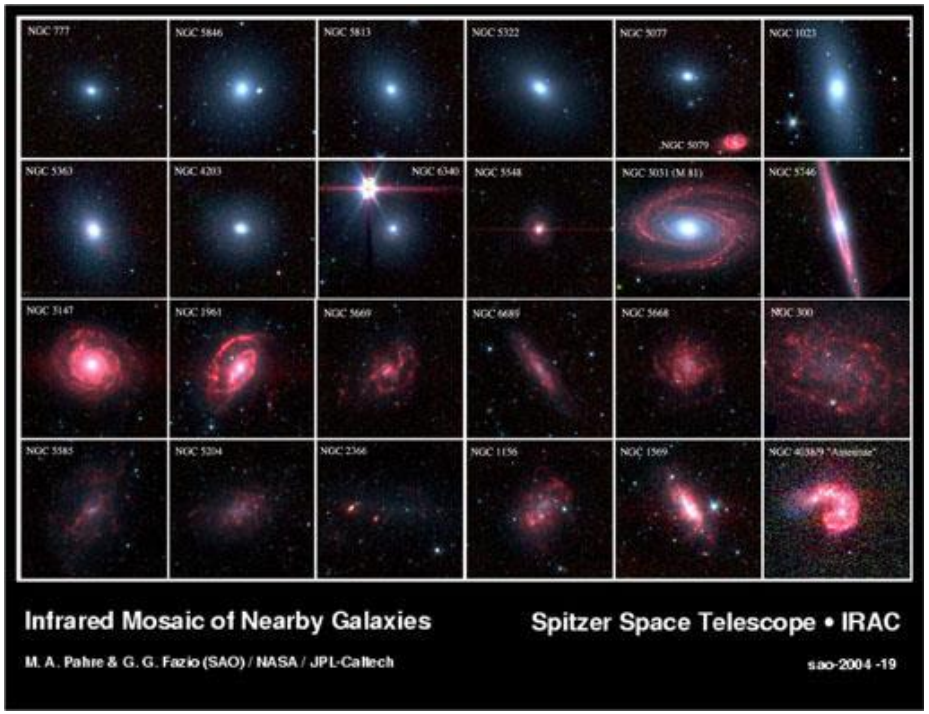


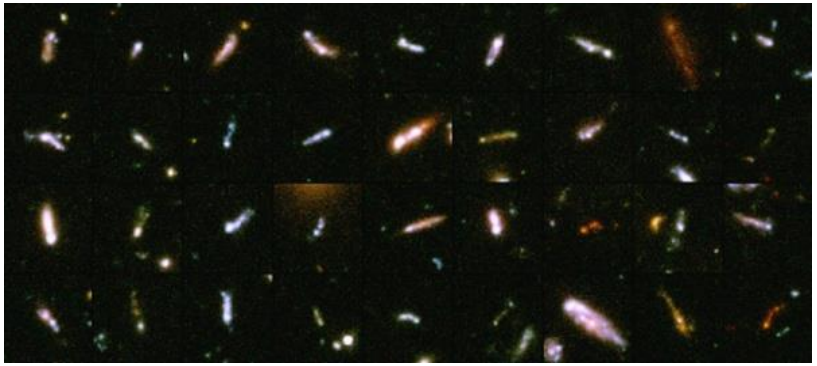
1.3 河外星系

Galaxy Zoo

- 河外星系有和银河系相似组成
- 每个星系的恒星数目$10^6 - 10^{12}$个
- 有大量的气体、尘埃、暗物质
- 星系大小(矮、巨) 和形态多样







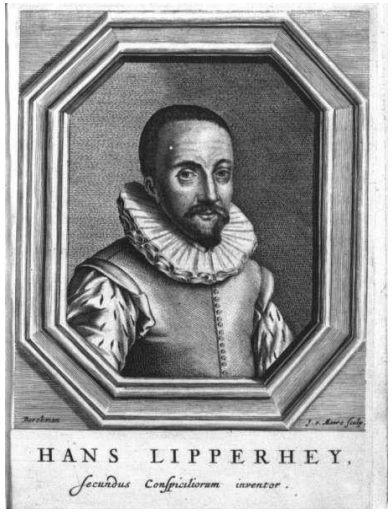
1.3.1 星系的研究历史

- 银河系组成？是否存在其它星系？星系如何形成，何时形成？

- 银河系似乎是不可能被彻底了解的星系：
  - 恒星间相互阻挡，星际气体尘埃存在；银河系中大多数恒星不可见

银河系的组成？

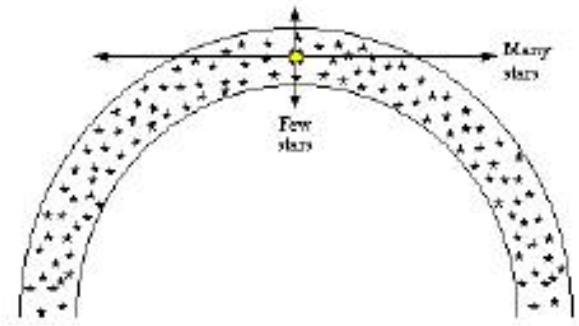
- 1608年，出生于德国的荷兰眼镜制造商汉斯·利伯希发明了世界上第一台折射望远镜
- 1609年，意大利天文学家伽利略把他自己新制作的望远镜指向银河
- 银河系并非流体，肉眼看到的模糊亮带原来是数不清的恒星－解决了银河系组成的争论



银河系的结构？

- 英国天文学家Thomas Wright在1750年发表“An original theory or new hypothesis of the universe”：银河系是由恒星组成薄球壳
  - 太阳系位于薄球壳层的中间；沿着球壳层，看到许多恒星－银河；沿着垂直方向看，恒星稀少
- 1755年，德国天文学家康德发表《自然通史和天体论》
  - 银河是由恒星组成的盘状物，银河的恒星绕某个中心公转
- 1785年，赫歇尔发表了有史以来第一幅银河结构图：盘状物，太阳在盘中心附近
  - 威廉·赫歇尔设计并制造了当时最大的反射望远镜：镜筒长度12米，口径1.26米
  - 提出新方法－恒星计数：将天空分为683不同方向，测量这些方向上恒星数目，研究银河系结构

Wright's Milky Way (1750)



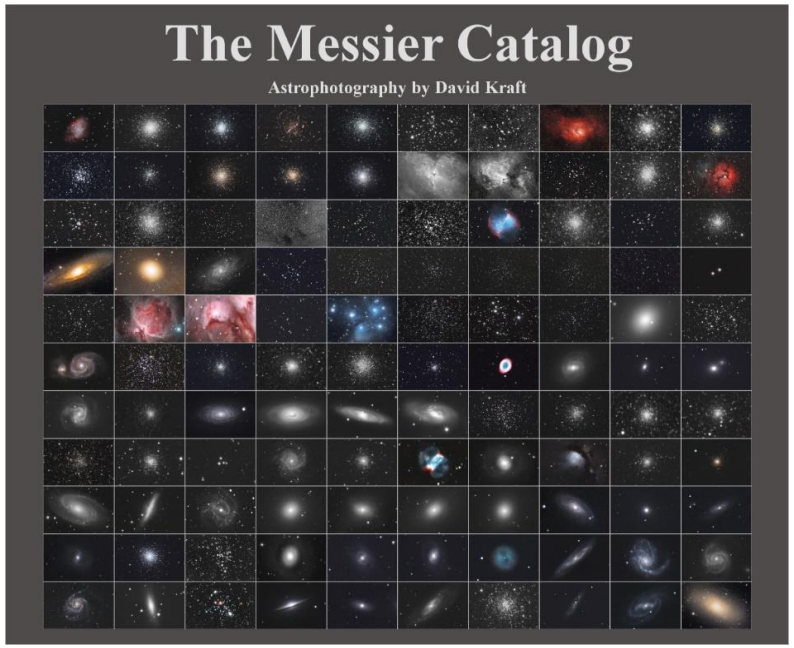
银河系之外？

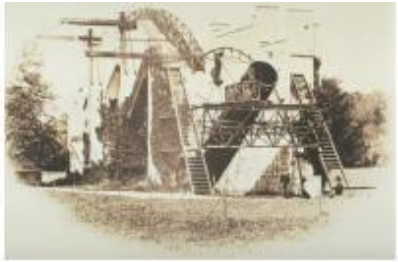
梅西耶星云星团表

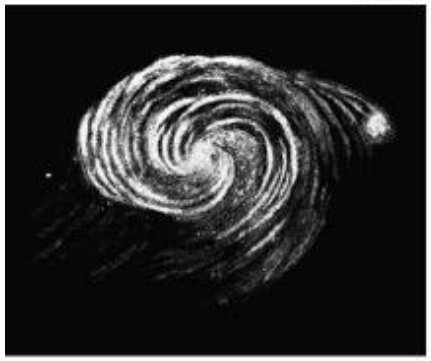
- 1781年法国天文学家，梅西耶发表了北天亮星云表
- 目的：将这些持久弥漫光斑和彗星区分开(后来知道其中40个为河外星系)

星云是什么？

- 1845年，William Parsons，利用72英寸(1.83m)反射望远镜，观测研究星云
- 发现某些星云具有旋涡结构，而另外一些具有规则椭圆外形

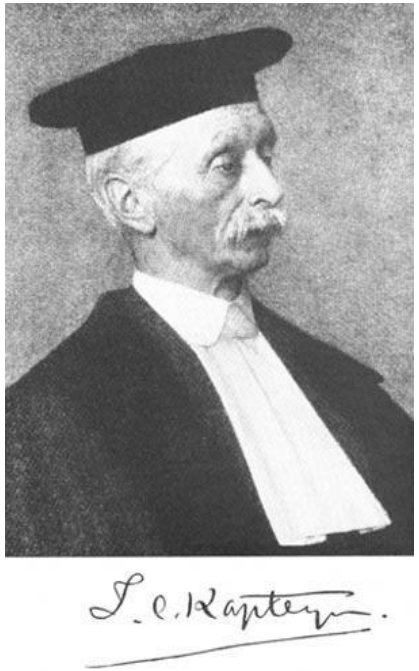




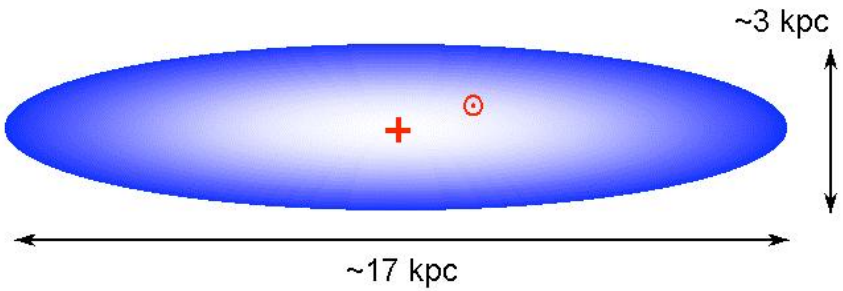


卡普坦的小宇宙

- 雅各布·卡普坦:1851-1922,荷兰天文学家
- 1906年，卡普坦设计了一个深度银河系巡天计划：观测天空不同区域的206小天区内的恒星
- 分析其中恒星的计数、视亮度和自行 → 银河系模型：恒星组成的盘；长度17kpc，厚度3kpc，太阳靠近盘中心d=650pc



Kapteyn Model (1922)

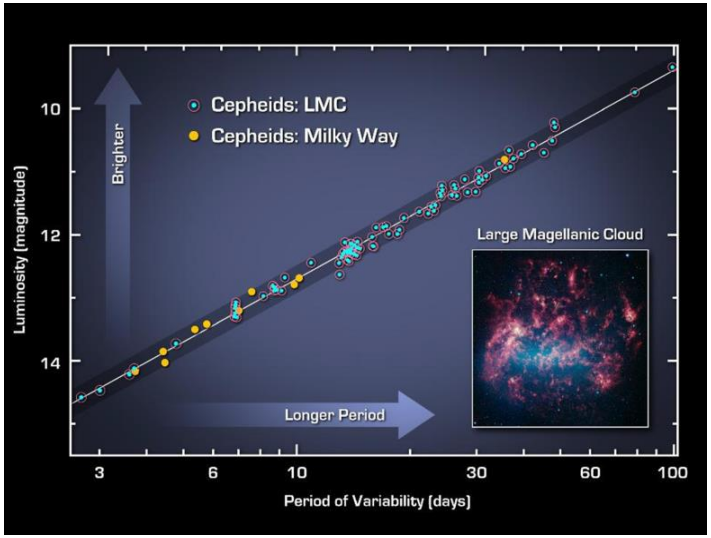


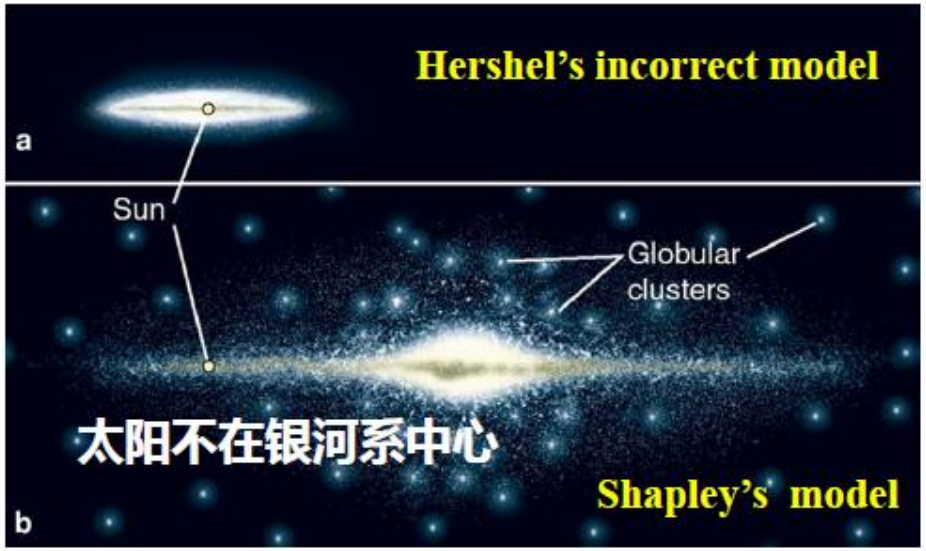
kpc = kiloparsec = 1000 pc

基于恒星间没有吸光物质的假设：导致一个过小的，太阳接近其中心的银河系。

沙普利的大银河

- 研究对象选取了**星团**，而不是恒星：观测距离更远
- 距离测量：利用**造父变星**的周期--光度关系，测定星团距离
- 测量**球状星团**的分布：银河系的大小和太阳的位置





globular cluster *(has lots of Cepheid variable stars in it!)*

银河系大小 ~100 kpc（卡普坦模型~17kpc）；银心在人马座方向，太阳距银心 d ~ 15 kpc.

沙普利-柯蒂斯之争

- 时间：1920年4月，美国科学院
- 人物：威尔逊山天文台的沙普利和利克天文台的希伯·柯蒂斯
- 焦点：宇宙的尺度
  - 银河系的大小?
  - 旋涡星云是否为河外系统?

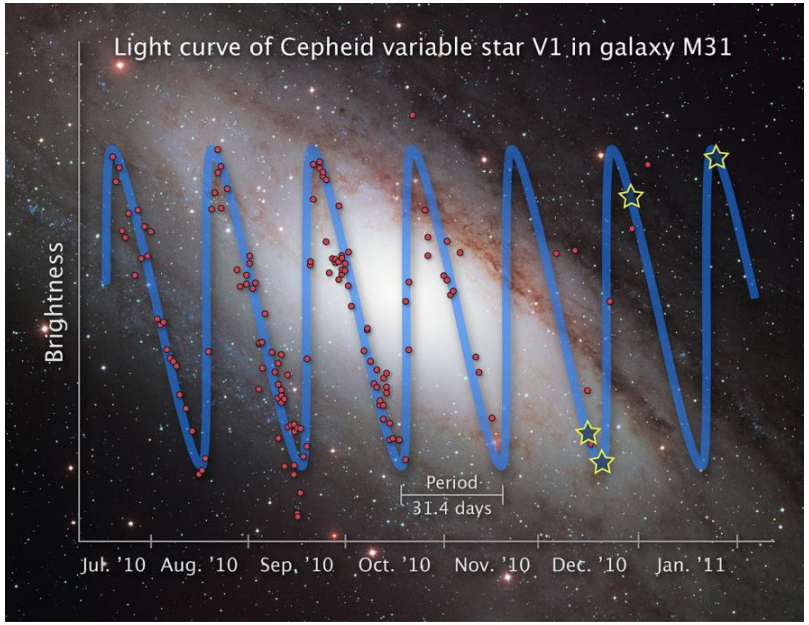
Harlow Shapley
1885-1972

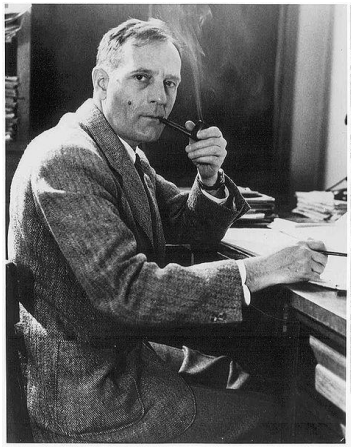
Heber Doust Curtis
June 27, 1872–January 9, 1942

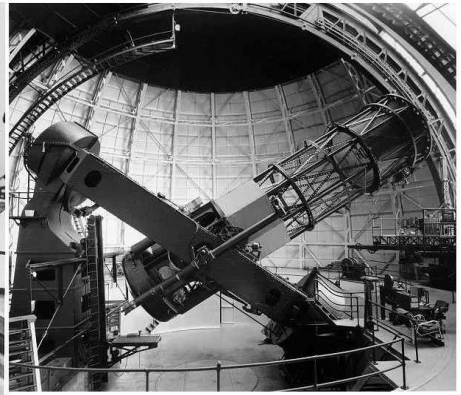
The Great Debate

哈勃的裁决

- 1923－1924年，哈勃利用位于威尔逊山2.5m望远镜:
  - 在M31中分解出几十个造父变星
  - 证实M31 是由恒星组成的系统
- 由造父变星周光关系
  - 估计M31的距离d ~ 285 kpc
  - 大于最远的球状星团距离(d ~ 100 kpc)，即远大于沙普利提出的银河系的大小(D ~ 100kpc)
- M31是一个象银河系一样的星系：存在河外星系



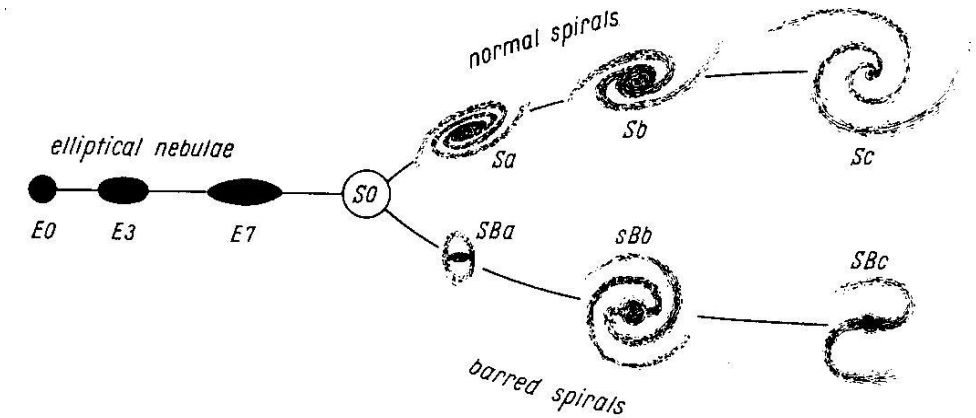




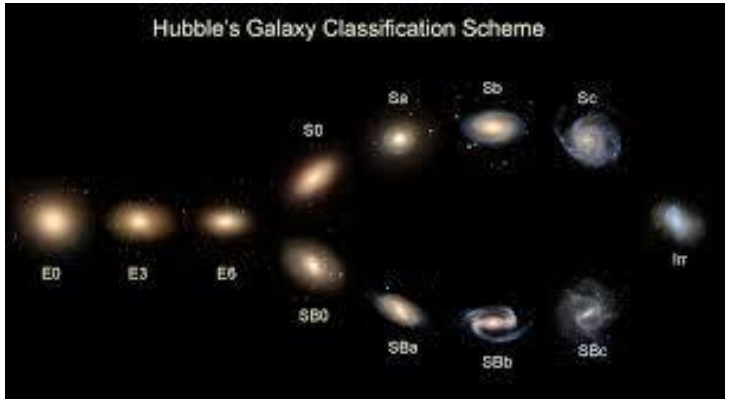
Edwin Hubble (1889-1953) and Hooker Telescope (2,5m), Mt.Wilson Observatory
Sources: Wikipedia, http://www.astro.caltech.edu/

星系的分类－哈勃音叉图

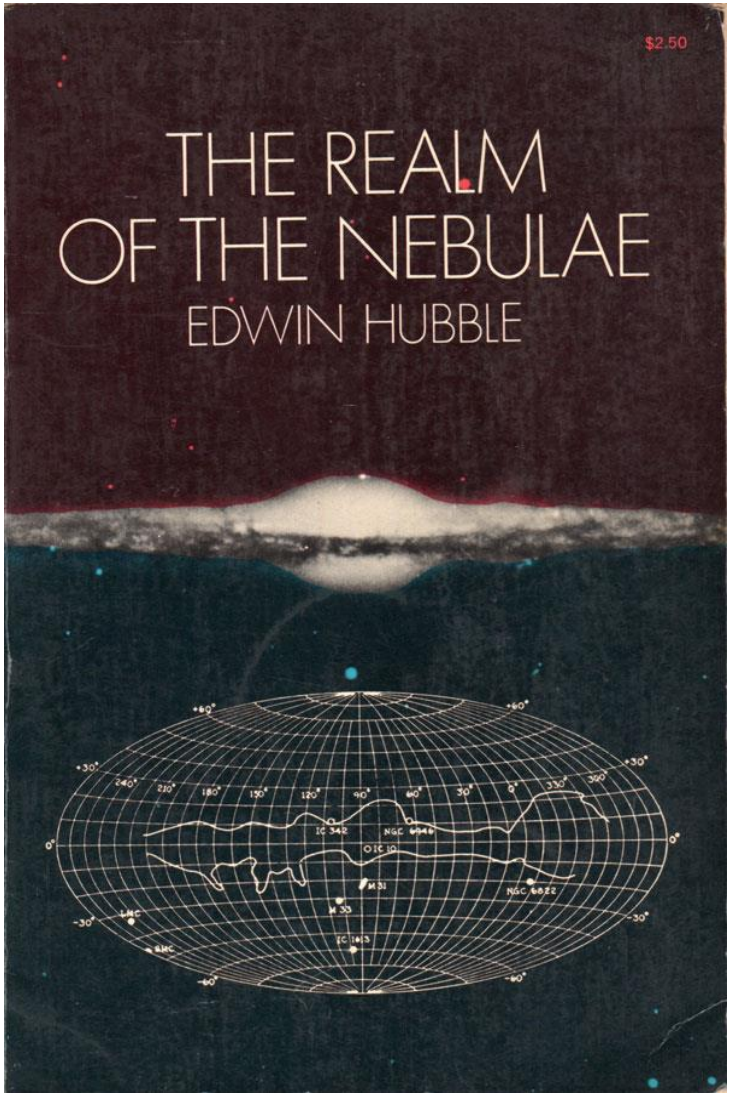
1936年，哈勃提出了星系形态分类in his book “The Realm of the Nebulae”



星系：椭圆星系、旋涡星系、棒旋星系

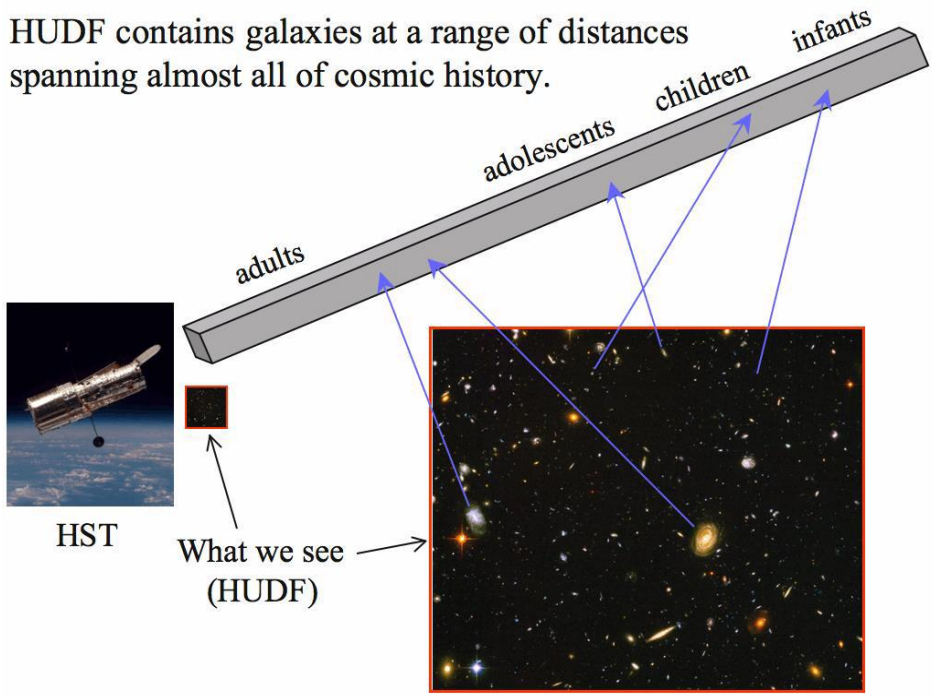


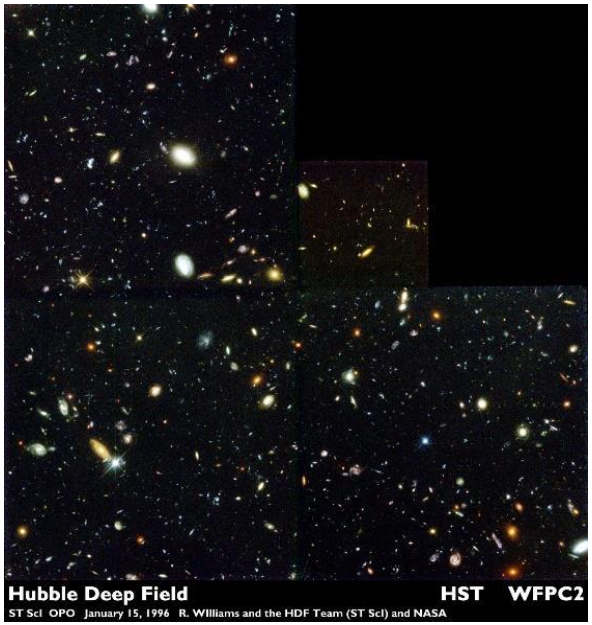
不规则星系



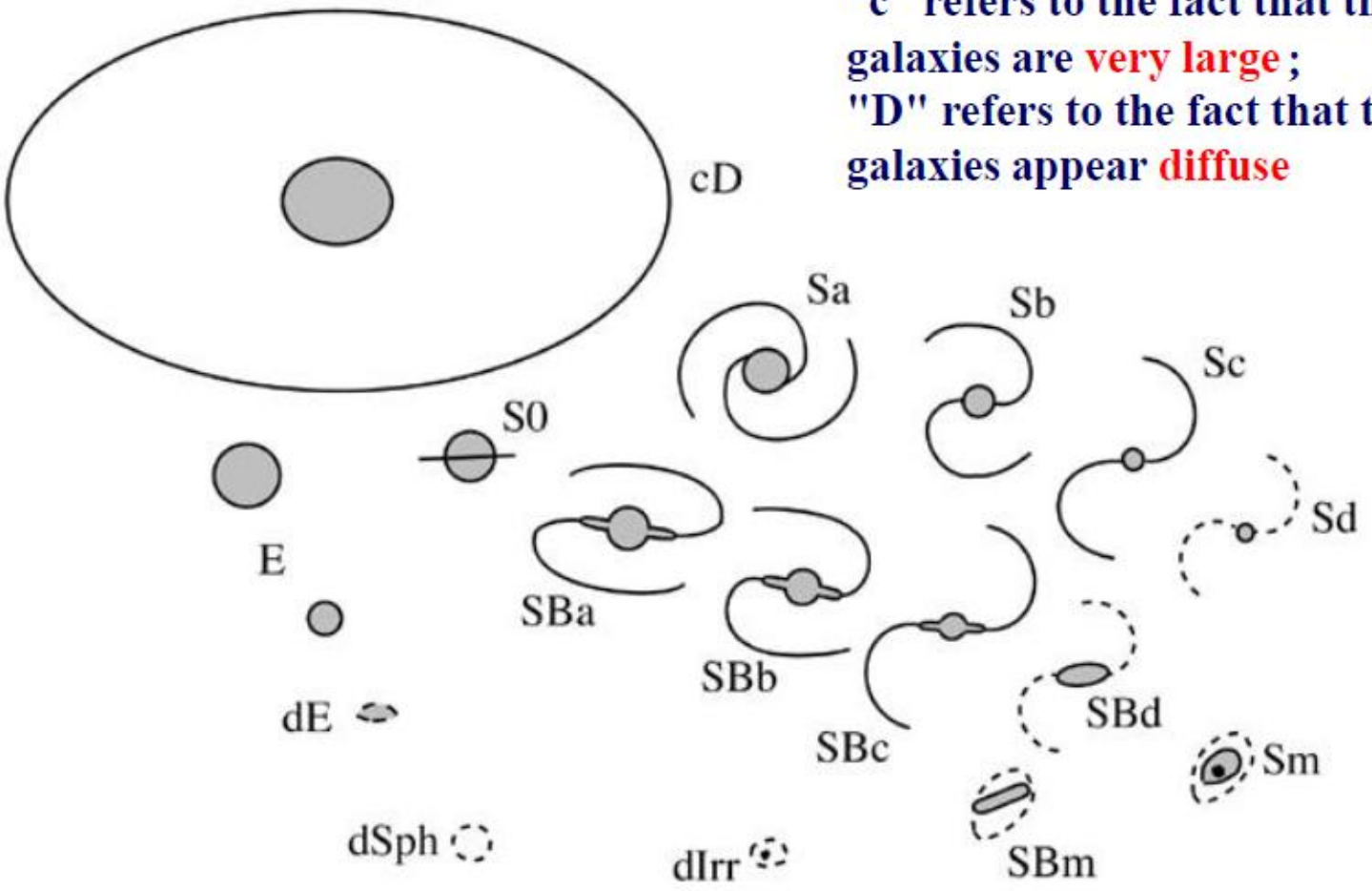
HST's HDF-high z

- 1990年4月25日哈勃空间望远镜发射
- 1996年，HST HDF(深场) 观测完成
- 深度~29星等，out to z ~ 3，高红移
- 高红移星系研究开始；2004，HUDF



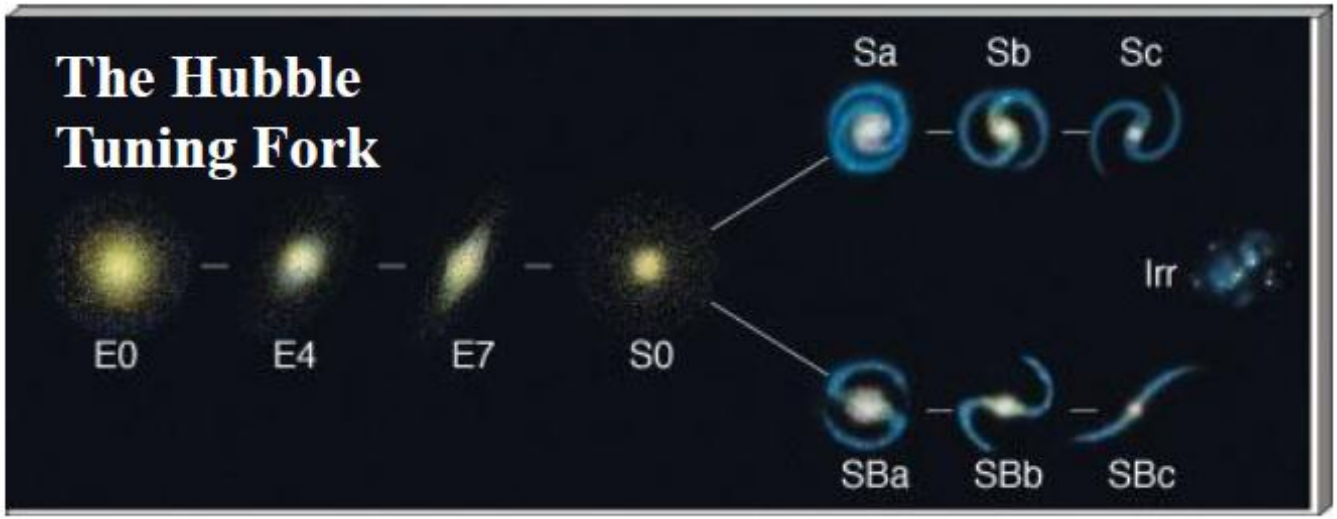


1.3.2 星系形态分类



"c" refers to the fact that the galaxies are very large ;
"D" refers to the fact that the galaxies appear diffuse

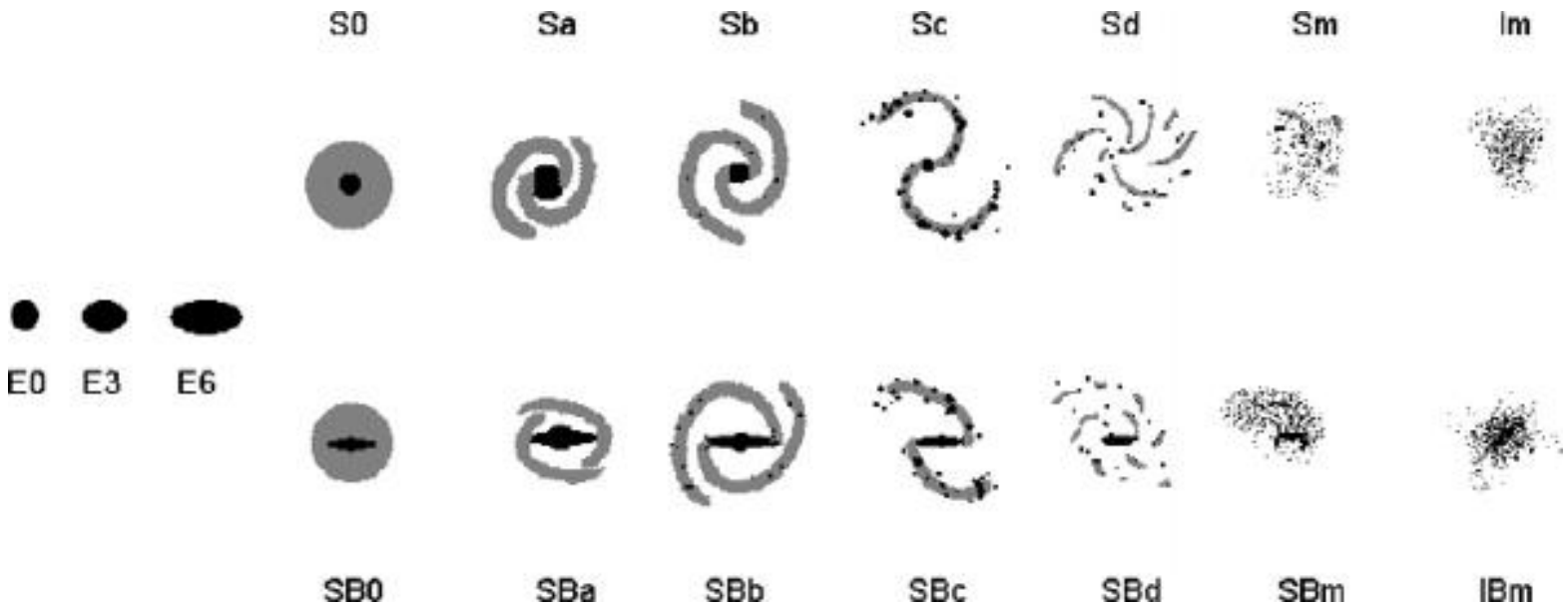
Examples of Three Main Morphological Galaxy Types



1926 : Hubble introduces simple tuning fork (ApJ 64 321).

1936 : Hubble adds S0 & SB0

Hubble Sequence

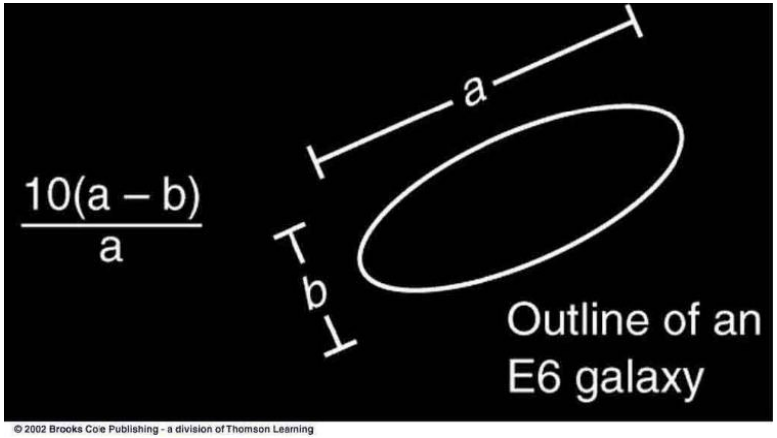


Four Basic Components : Spheroid; disk; bar; arms.

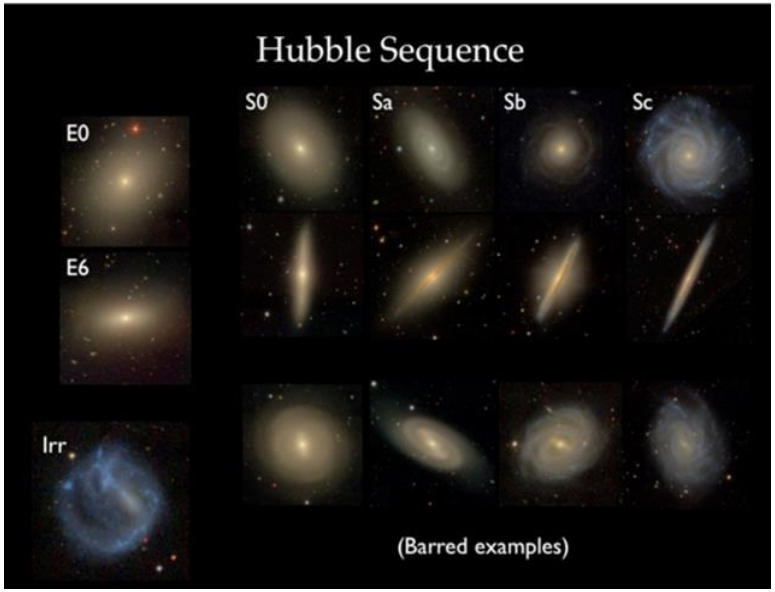
- **Presence/absence & relative strength of these components defines class**
- **For historical reasons the terms Early(left) to Late(right) are used**

椭圆星系（Elliptical galaxies，E）

- 椭圆星系的分类：按照椭率大小分类.
  - En：E0、E1…E7 等八个次型
  - n=10(a-b)/a；a和b为半长/短轴



- 椭圆星系特性：
  - 椭圆星系没有星系盘，颜色偏红；主要由年老的恒星构成
  - 没有或仅有少量的冷气体和尘埃，有大量的热气体
  - 富星系团中椭圆星系占主导地位；星系中心最亮，亮度向边缘递减

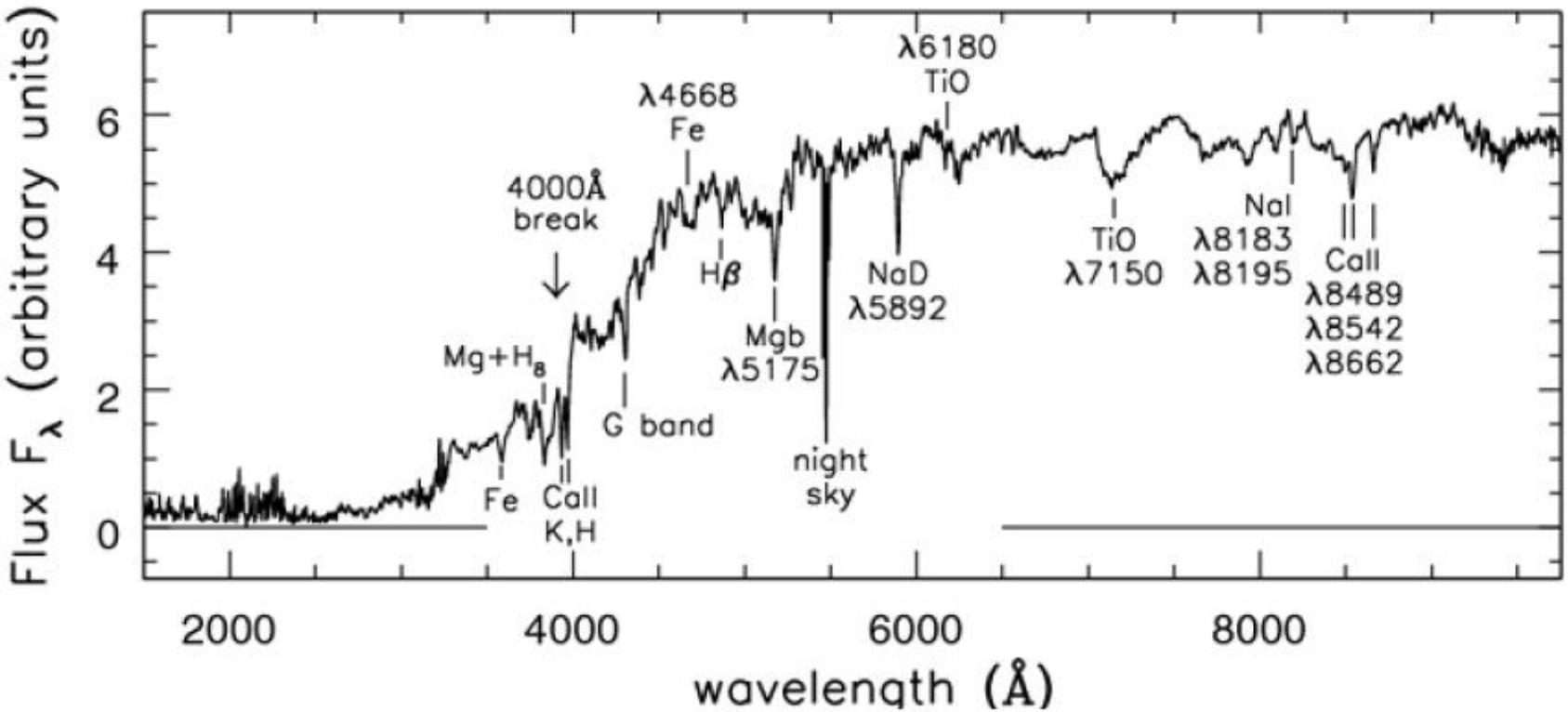


- 椭圆星系的光度决定了椭圆星系的很多特性：结构、恒星运动（第六章）

椭圆星系特性

- 光度不同的椭圆星系
  - cD星系：巨椭圆星系，为星系团中最明亮的星系。巨大弥漫包层可以延伸到~数百kpc；比银河系亮100倍以上
  - 普通椭圆星系：光度为银河系数倍，特征尺度为数十kpc
  - 暗椭圆星系：光度不足银河系光度十分之一，分为致密矮椭圆星系；暗弱的弥漫矮椭圆星系；更暗的矮椭球星系。
- 椭圆星系中的恒星运动
  - 亮椭圆星系：恒星随机运动为主；旋转少
  - 较暗椭圆星系：有较多的旋转运动；随机运动较小
  - dE和dSph星系：矮星系内部恒星几乎没有有序旋转

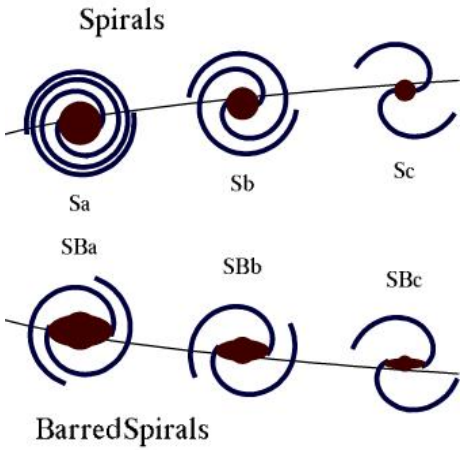
Spectrum of E's

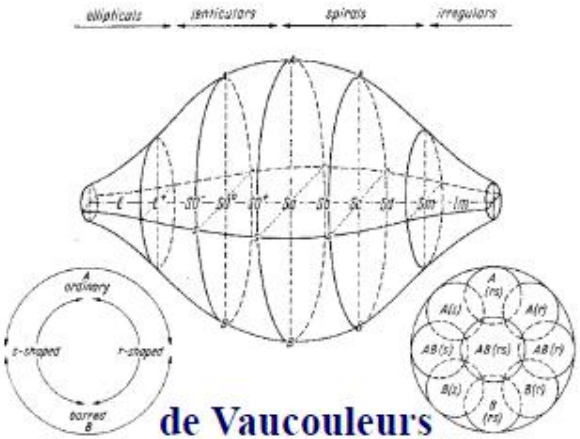


- Elliptical galaxy spectra are characterized by strong absorption lines, due to metals in the stellar atmospheres of the low luminosity stellar population.
- We see few to no emission lines ([OII]3727 and/or [NII]6583 are occasionally present), as there are essentially no young stars and no cold gas.

旋涡星系(Spiral galaxies)

- 旋涡星系构成：核球+（棒、环）+ 盘+ 旋臂+ 晕
- 旋涡星系分类：核球大小和旋臂的缠卷程度
  - Sa中心区最大，旋臂紧卷
  - Sb中心区较小，悬臂开展
  - Sc中心区成为一个小亮核，悬臂松弛
  - Sa → Sc：星系盘中，年轻的恒星、气体比例增加



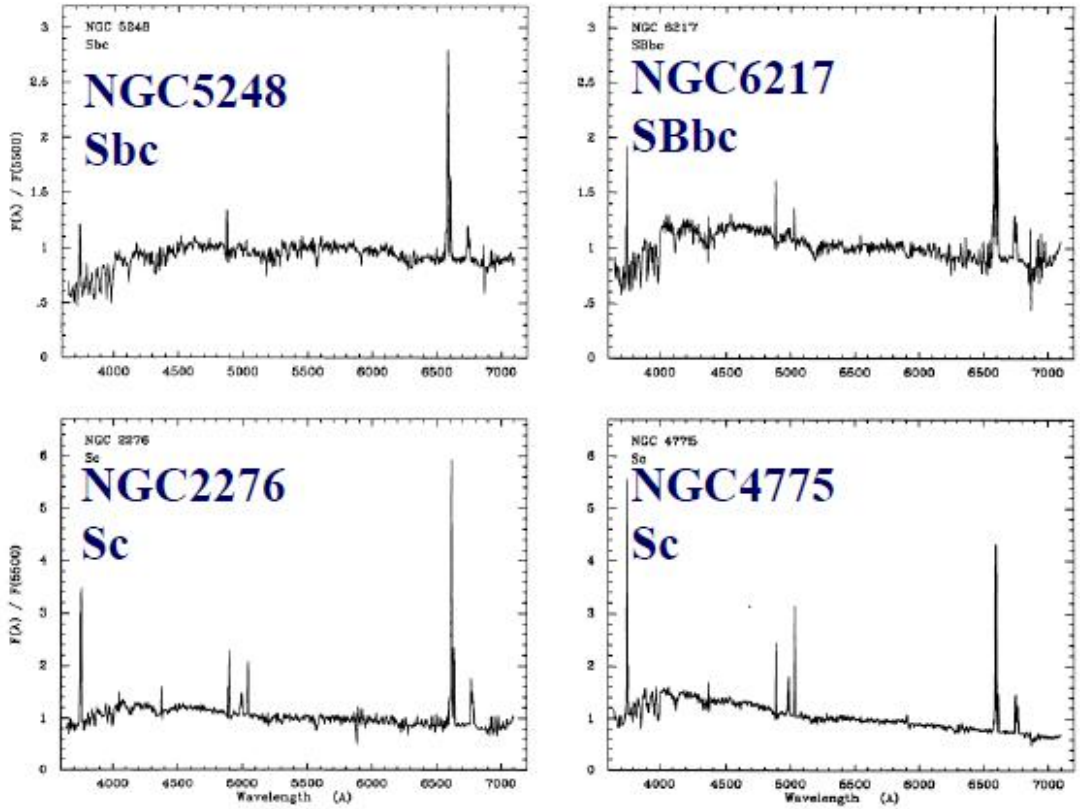


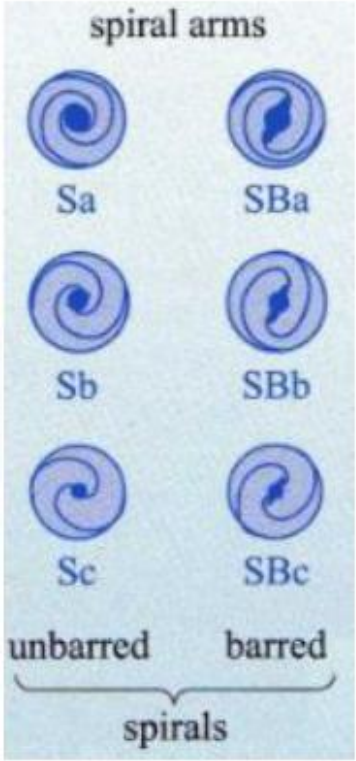
de Vaucouleurs

de Vaucouleurs introduces T integer (-5 to +10) which tracks the stage (E to Im)

Type	E	E+	S0⁻	S0°	S0⁺	S0/a	Sa	Sab	Sb	Sbc	Sc	Scd	Sd	Sdm	Sm	Im
T	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10

Spiral Galaxy Spectra

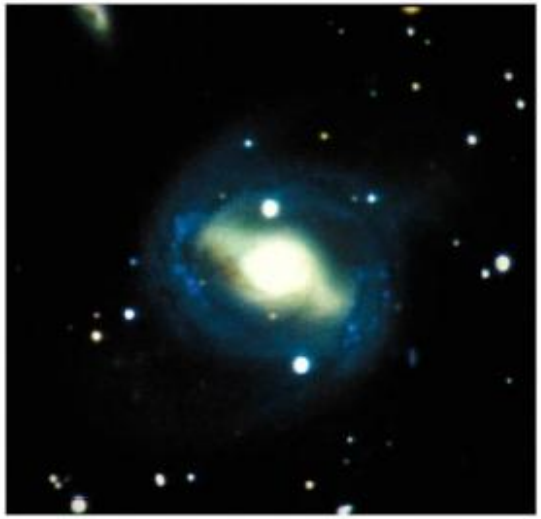




- Spiral galaxy spectra are characterized by strong emission lines, due to hot young stars which heat the surrounding gas, and by absorption features due to the older, underlying stellar population

棒旋星系(Barred spiral galaxies, SB)

- 由恒星组成的棒贯穿其核心部分的旋涡星系
- 旋臂源于棒的两端，~1/2的旋涡星系中有棒
- 按照棒的大小和旋臂的缠卷程度可以分为：
  - SBa,SBb,SBc：棒逐渐变弱；旋臂缠卷松散
  - 银河系可能是一个SBb或SBc型的棒旋星系



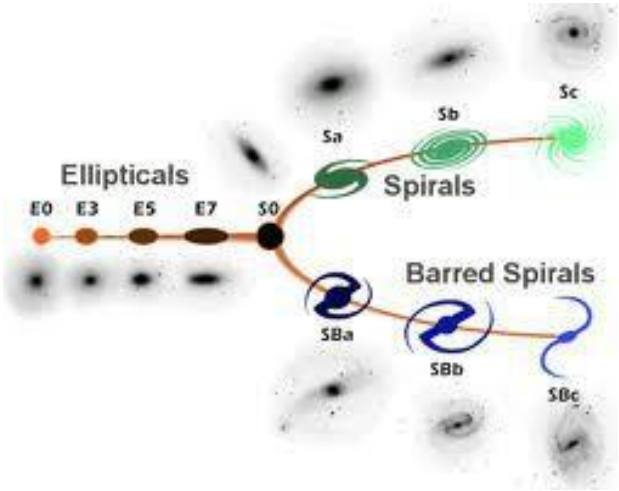
a SBa (NGC 4650)

b SBb (M83)

c SBc (NGC 1365)

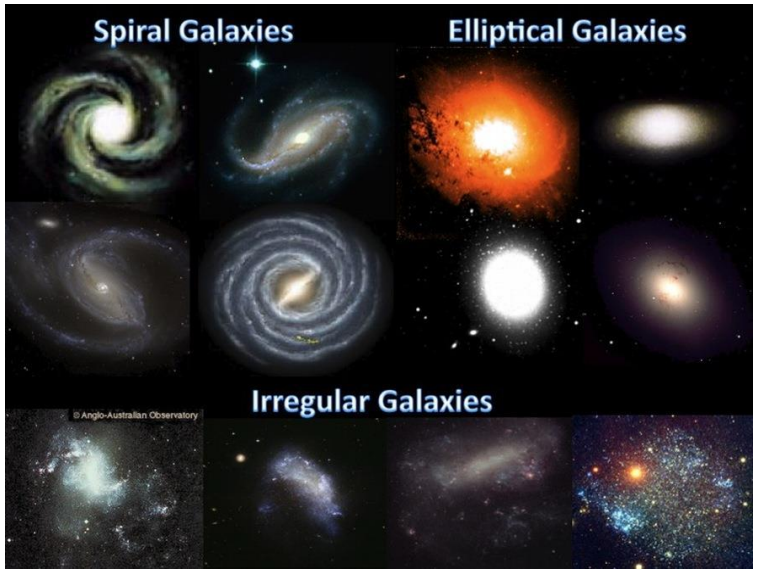
透镜星系(Lenticular galaxies，S0)

- 介于椭圆星系和旋涡星系之间的过渡型星系
- 无旋臂的盘星系，外形像侧视的透镜而得名
- 根据核心是否有棒状结构，相应为S0或SB0
- 透镜状星系与旋涡星系主要差别是没有旋臂
- 透镜状星系与椭圆星系的主要差别是它有星系盘
- 透镜星系偏向于处在星系的密度较高的空间区域
- 主要由年老恒星组成，气体少，与椭圆星系相似
- 有旋转盘，但该盘缺乏任何旋臂或延伸的尘埃带

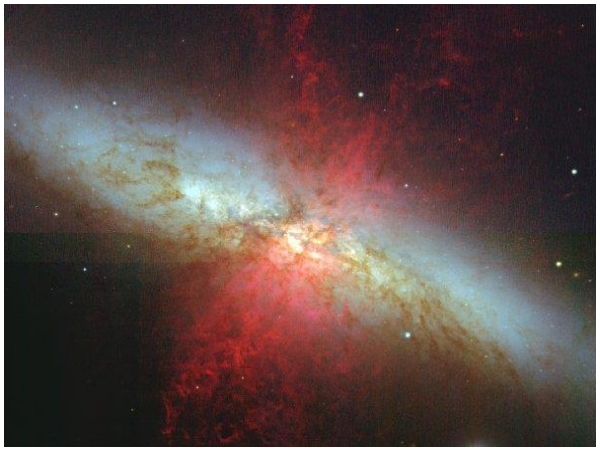


不规则星系(Irregular galaxies，Irr)

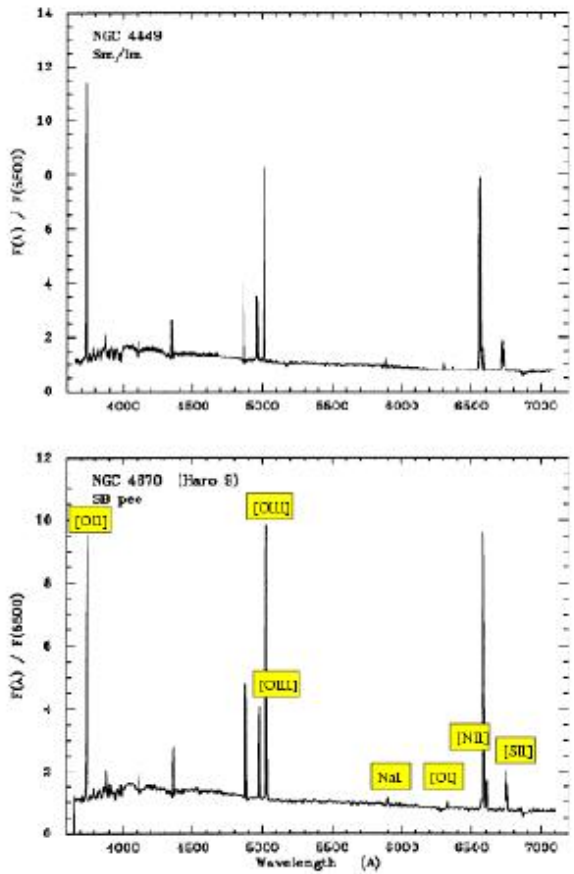
- 没有旋涡结构，也没有椭圆形态，外形不规则的一类星系。数目占星系总数的四分之一



- 小的不规则星系称为矮不规则星系；与矮椭球星系的不同之处是它们有气体和年轻蓝星
  - 矮椭球星系很可能是失去或用尽了气体的矮不规则星系
  - 内部以年轻星族为主、气体含量多，质量不大：$< 10^{10} M_{\odot}$
  - 不规则星系中包括星暴星系、并合星系等恒星形成星系



Irregular Galaxy Spectra



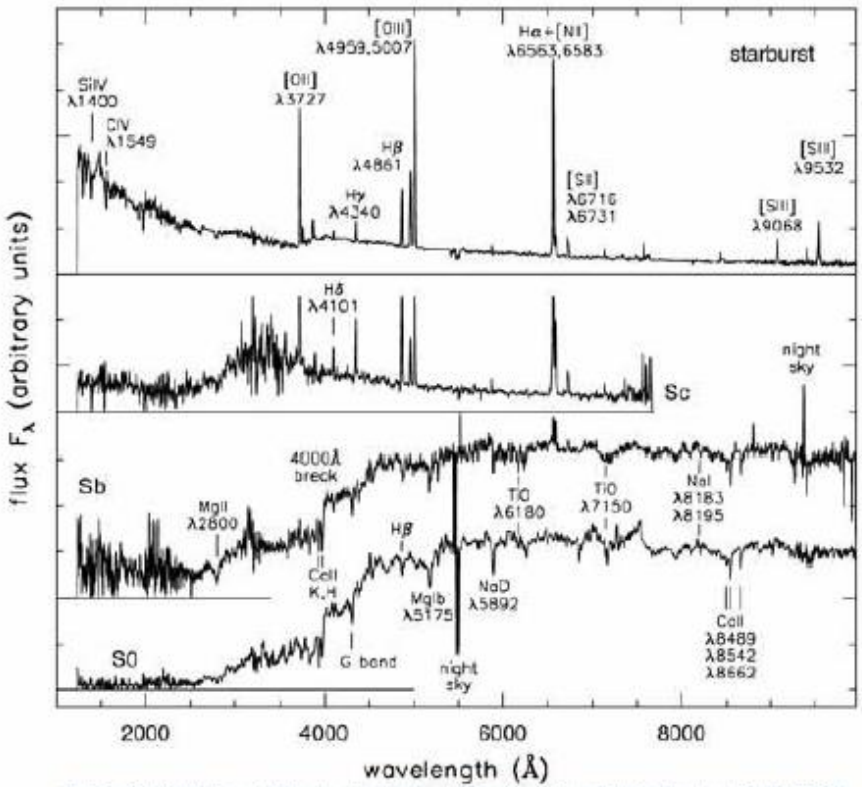
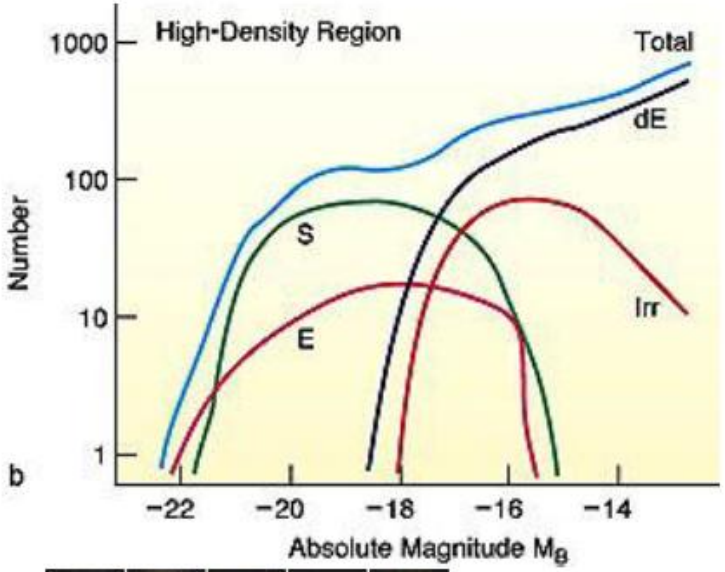
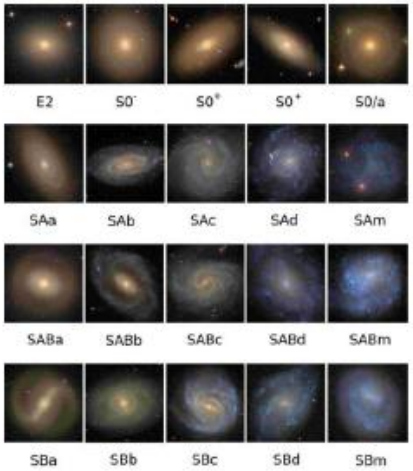
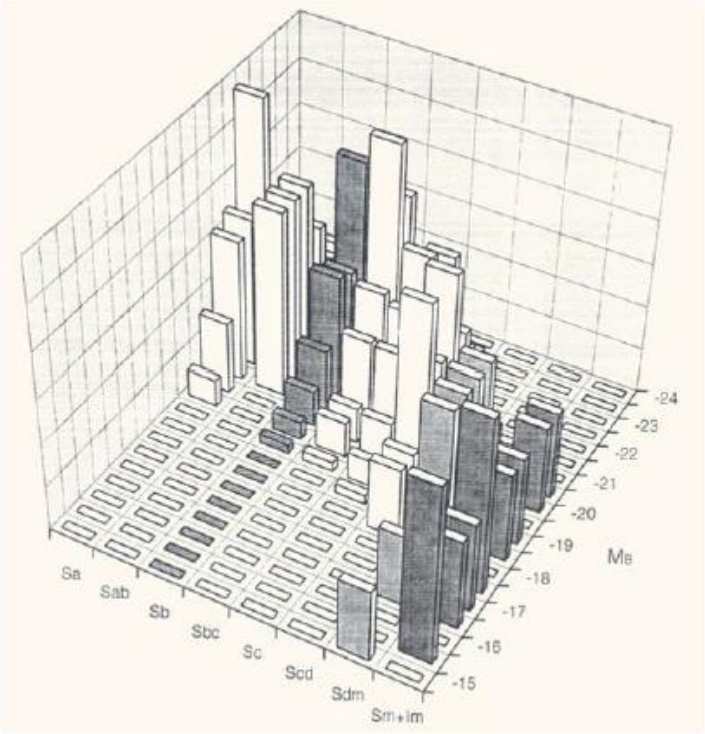


Fig 5.24 (A. Kinney) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

- **Irregular galaxy spectra are characterized by strong emission lines, due to hot young stars and surrounding HII regions.**





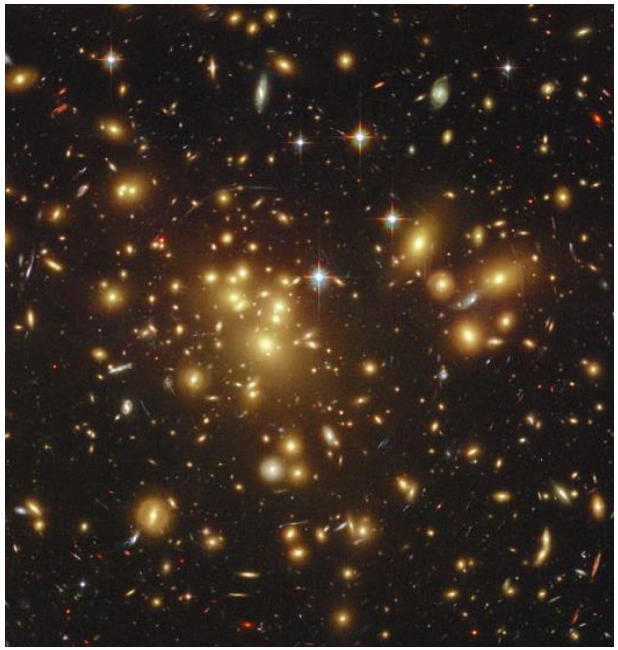


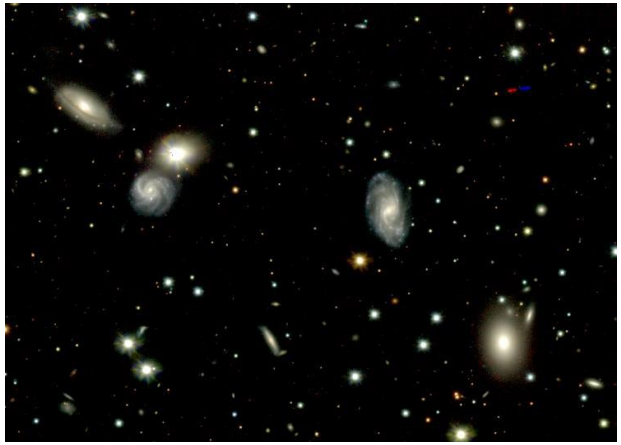
- **Late type galaxies are often lower-luminosity galaxies; E and S0 are high luminosity.**

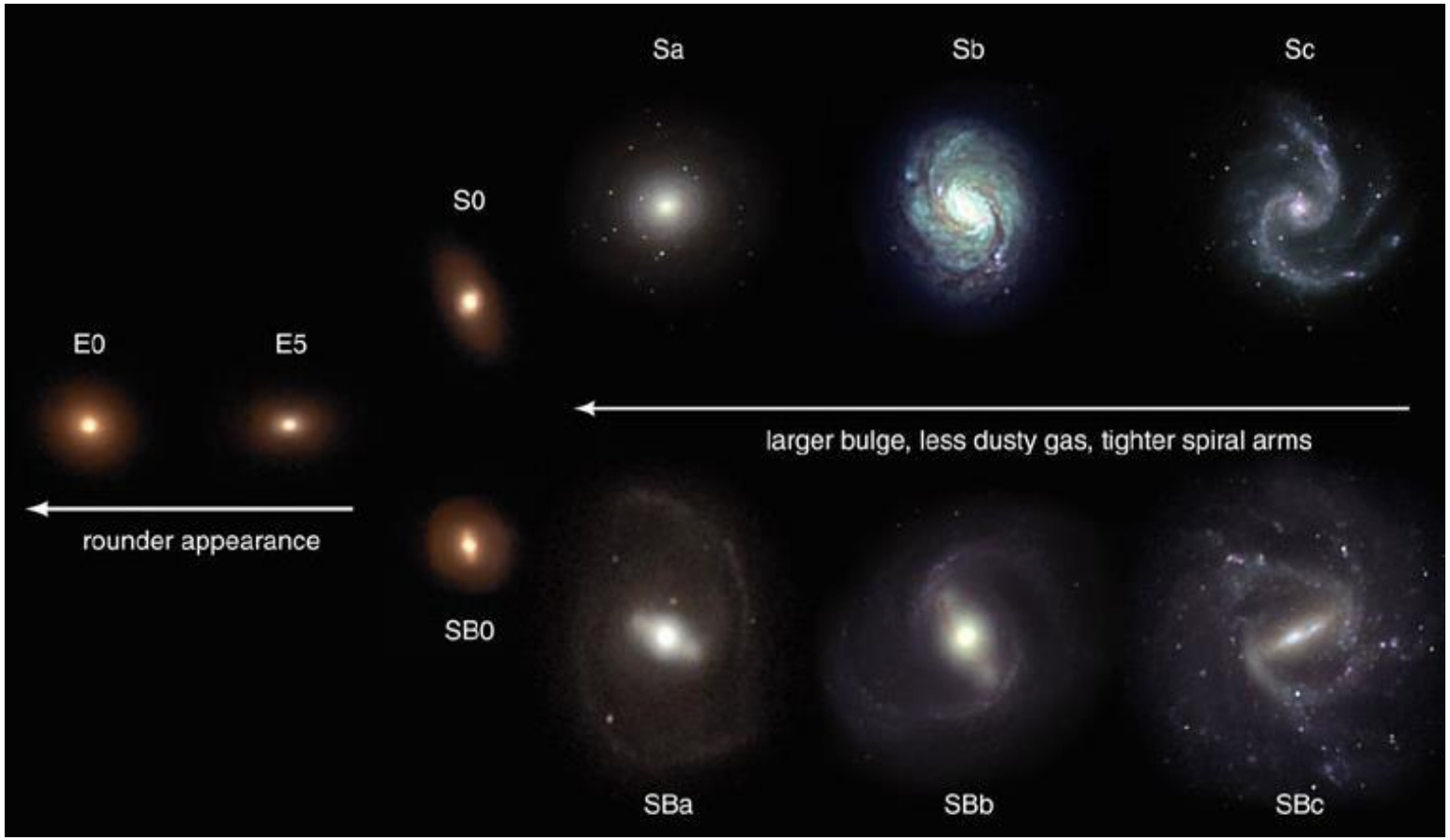
星系形态与环境

- 近邻星系样本中：旋涡星系比例~70%，~30%的E和S0星系，~3%的不规则星系（选择效应，星等限样本）
- 旋涡星系多位于星系群中(由几十个星系组成)；椭圆星系多位于星系团中(成百上千个星系组成)

	Ordinary	Barred	
E+E/S0	173	...	...
S0+S0/a	142	SB0+SB0/SBa	48
Sa+Sab	123	SBa+SBab	42
Sb+Sbc	187	SBb+SBbc	96
Sc	293	SBc	77
Scd+Sd	26	SBcd+SBd	8
Sm+Im	13	SBm+IBm	9
S	16	...	...
Special	18	...	...
Totals	991	...	285

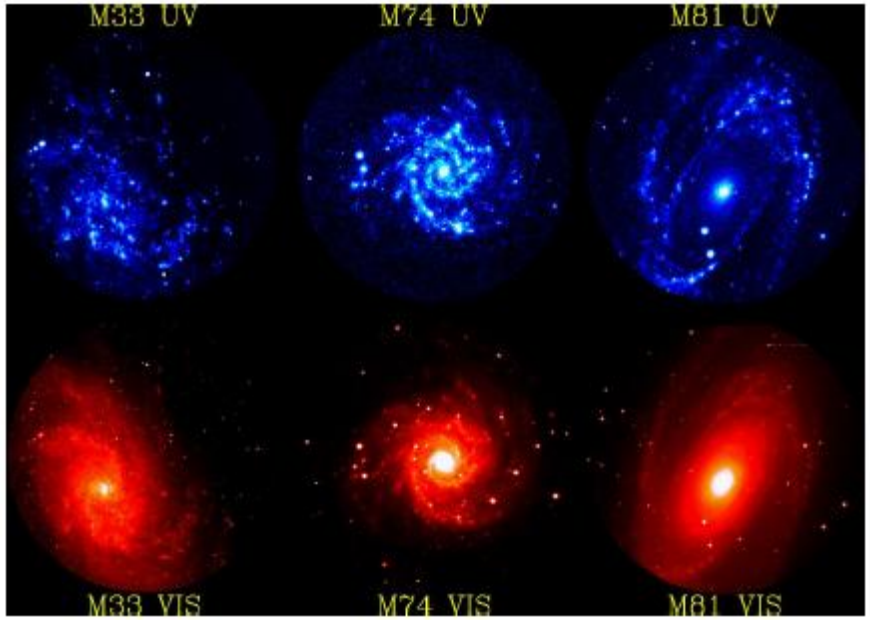


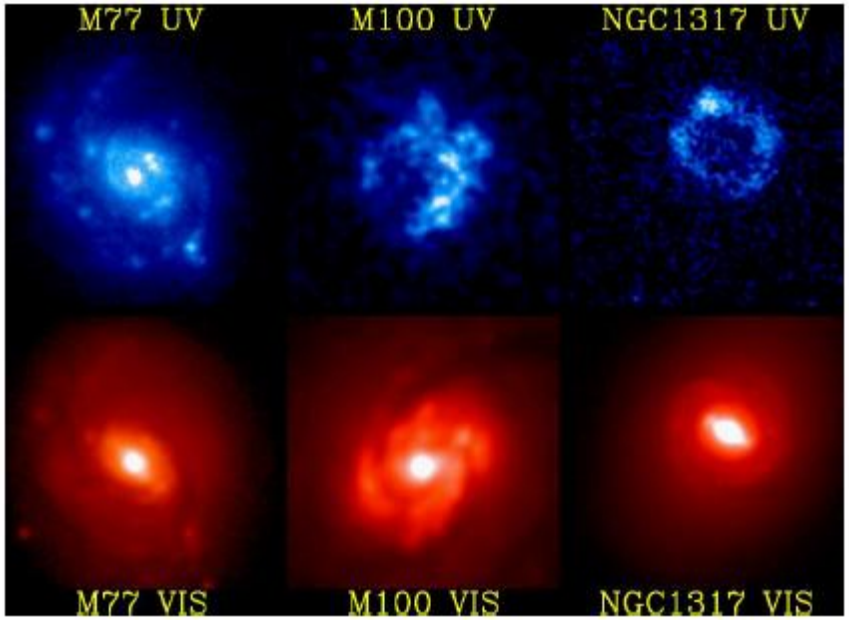




‘早型’和‘晚型’用来描述星系在从椭圆星系通过S0到Sa，Sb和Sc型旋涡星系序列中的位置：非演化关系

UV vs Visual comparisons





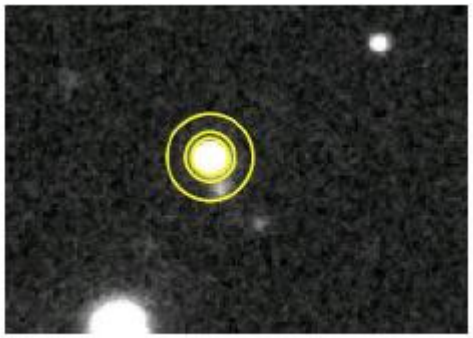
- Appearance can vary greatly with waveband.
  - care classifying with R or I images;
  - difficult comparing galaxies at high-z since rest UV can look very different.

星系形态小节

旋涡/棒旋星系 (S, SB)	椭圆星系 (E)	不规则星系
由恒星和气体构成的扁盘和星系晕。棒旋星系的核心有棒状结构	球形或椭球形，除中心核区外无其他结构	无明显结构
盘包含年轻和年老的恒星，晕只有年老的恒星	只有年老的恒星	包含年轻和年老的恒星
盘包含大量气体和尘埃，晕中的气体和尘埃很少	没有或只有很少的气体和尘埃	富含气体和尘埃
旋臂中有恒星形成过程	近10^{10} yr没有明显的恒星形成过程	强烈的恒星形成过程
盘中的恒星和气体绕核心作圆轨道运动，晕中的恒星绕核心作无规则运动	恒星绕绕星系核心作无规则轨道运动	恒星和气体作无规则运动

1.3.3 星系测光

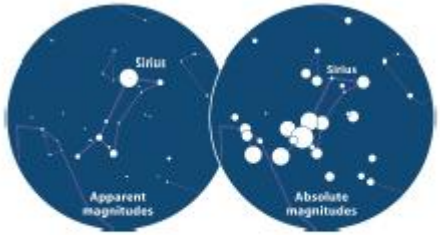
- 星系形态分类是定性描述星系特性，测光是定量描述
- 恒星是点源：利用孔径测光，可方便测量其积分星等
  - 视星等 or 绝对星等



Conversion between AB and Vega for some of the filters is given in table 1.

Band	λ_{eff} (Å)	$m_{AB} - m_{Vega}$	M_{AB}	M_{Vega}
U	3571	0.79	6.35	5.55
B	4344	-0.09	5.30	5.45
V	5456	0.02	4.80	4.78
R	6442	0.21	4.61	4.41
I	7904	0.45	4.52	4.07
K_s	23000	1.85	5.14	3.29
u	3546	0.91	6.36	5.47
g	4670	-0.08	5.12	5.20
r	6156	0.16	4.64	4.49
i	7472	0.37	4.59	4.16
z	8947	0.54	4.51	3.71

Table 1: Conversion between AB and Vega magnitude systems from [2] based on solar spectrum. *UBRVI* filters from [4], K_s from [4], u,g,r,i,z from SDSS DR4 web site.



AB and Vega magnitude systems

Galaxy brightness in optical passbands is represented in logarithmic magnitude scales. Magnitude of an object is calculated based on a magnitude and radiation flux of a reference object.

$$m - m_{ref} = -2.5 log_{10} \frac{f}{f_{ref}} \quad (1)$$

Magnitudes can be calculated in AB or Vega magnitude systems ([2, 5]).
In Vega system magnitudes are calculated in respect to Vega (α Lyrae):

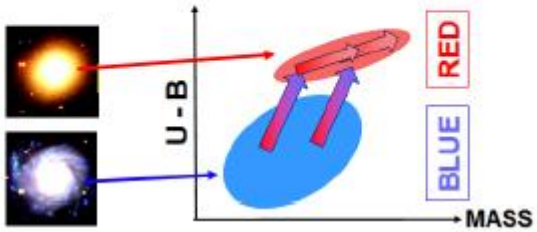
$$m_{Vega} = -2.5 \cdot log_{10} \left(\frac{\int f_\nu \cdot S_\nu \cdot d\nu}{\int f_\nu(Vega) \cdot S_\nu \cdot d\nu} \right) \quad (2)$$

where f_ν is flux per unit frequency in $ergs \cdot s^{-1} \cdot cm^{-2} \cdot Hz^{-1}$, S_ν - unitless transmission of a passband filter.
Magnitude in AB magnitude system is defined as:

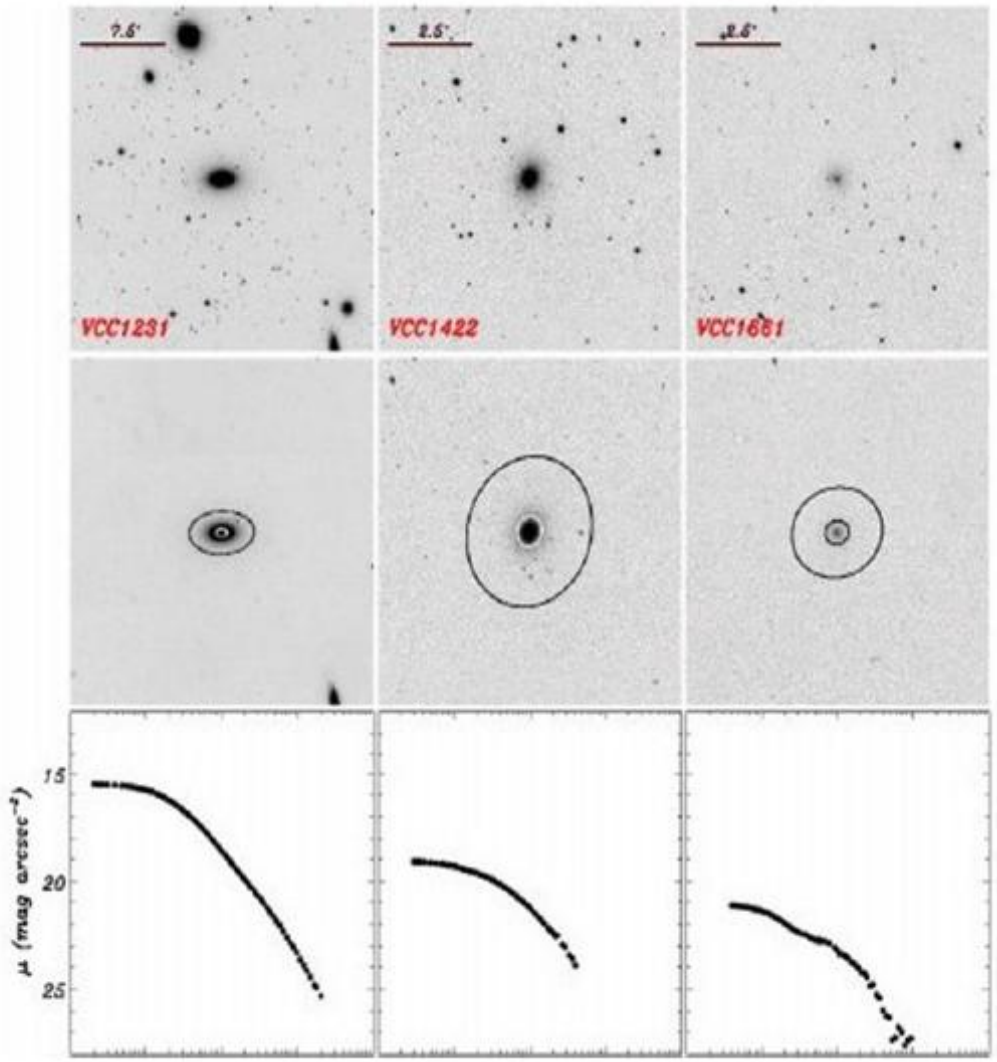
$$m_{AB} = -2.5 \cdot log_{10}(f_\nu) - 48.60 \quad (3)$$

$$M_V = m_V - 5 \ Log \left(\frac{d}{10} \right)$$

d is distance in parsecs



- 星系是延展源，尺寸可延展到几个角分，外围的亮度可能比天光还暗，积分范围很难确定
- 描述方法：
  - 二维面亮度分布 I(x)
  - 测光星等：
    - 孔径星等
    - 总星等
  - 一维径向分布 I(r)



面亮度Surface Brightness

- 星系测光，要测量不同区域在某一波段有多少光发射出来 - 面亮度概念

- 星系面亮度I(x)：是指星系图像上的一个特定点x处，每平方角秒天空的光量 mag/arcsec^2

at what wavelengths, is emitted by the different regions. The *surface brightness* of a galaxy $I(\mathbf{x})$ is the amount of light per square arcsecond on the sky at a particular point $\mathbf{x}$ in the image. Consider a small square patch of side D in a galaxy that we view from a distance d, so that it subtends an angle $\alpha = D/d$ on the sky. If the combined luminosity of all the stars in this region is L, its apparent brightness F is given by Equation 1.1; then the surface brightness is

$$I(\mathbf{x}) \equiv \frac{F}{\alpha^2} = \frac{L/(4\pi d^2)}{D^2/d^2} = \frac{L}{4\pi D^2}. \tag{1.23}$$

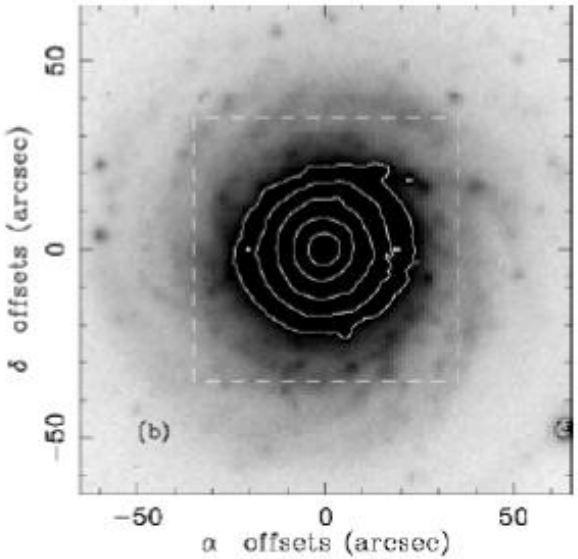
I is usually given in mag arcsec^{-2} (the apparent magnitude of a star that appears as bright as one square arcsecond of the galaxy's image), or in $L_\odot$ pc^{-2}. The surface brightness at any point does not depend on distance unless d is so large that the expansion of the Universe has the effect of reducing $I(\mathbf{x})$; we discuss this further in Section 8.3. Contours of constant surface brightness on a galaxy image are called *isophotes*. Equation 1.23 shows that the position of an isophote within the galaxy is independent of the observer's distance.

星系任何一点的面亮度，不依赖于星系光度距离 d（当d不是特别大时）

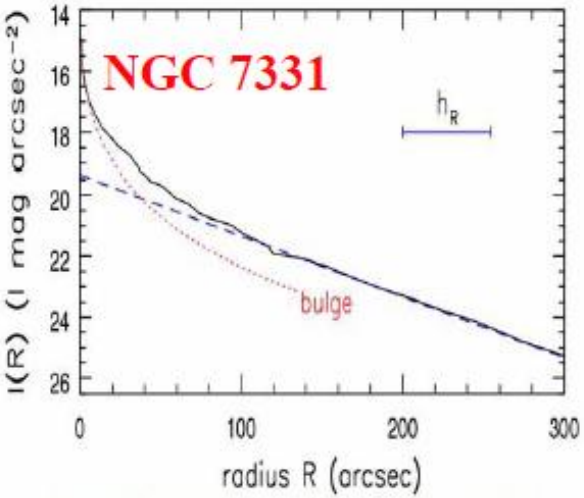
$$I\ (\mathrm{mag/arcsec^2}) = M_\odot + 21.572 - 2.5\log_{10}L\ (L_\odot/\mathrm{pc}^2)$$

等照度线（isophotes）

- 等照度线：星系图像上面亮度相等像源（pixel）的连线（等面亮度轮廓线）
  - 星系等照度线的位置与观测者的距离无关
  - 星系面亮度随径向的分布，没有明显截断
  - NGC 7331，I-band 中心面亮度I(0) = 15 mag arcsec^{-2}，比天光亮100倍；外区亮度只有天光亮度的~1%



- 星系大小
  - 星系没有清晰的边缘，常利用固定的等照度线处，测量它们的大小
  - 经常选择$I_B(x)$ = 25mag arcsec^{-2} (B波段25等的等照度线)处，测量星系半径，记为R_{25}
  - NGC7331： R_{25}=315” (B-band λ=4000Å)
  - 或用$I_B(x)$=26.5mag arcsec^{-2} 霍姆伯格半径



夜天亮度

紫外 - 红外波段的平均天光面亮度

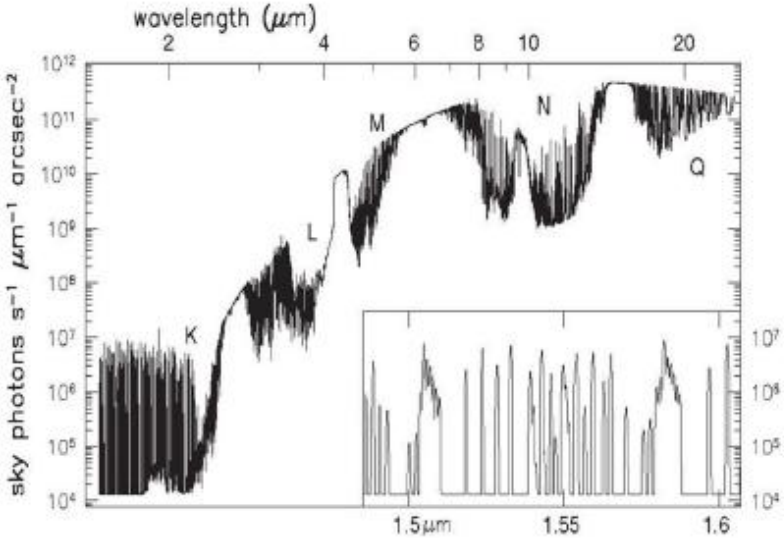
Table 1.9 Average sky brightness in ultraviolet, optical, and infrared wavebands

Band	Wavelength	*Full moon* (mag arcsec^{-2})	*Dark sky* (mag arcsec^{-2})	*From space* (mag arcsec^{-2})	*From space* (μJy arcsec^{-2})	*South Pole* (μJy arcsec^{-2})
	1500 Å			25.0		
	2000 Å			26.0		
	2500 Å			25.6		
U	3700 Å		22.0	23.2		
B	4400 Å	19.4	22.7	23.4	1.8	
V	5500 Å	19.7	21.8	22.7		
R	6400 Å	19.9	20.9	22.2		
I	8000 Å	19.2	19.9	22.2	3.2	
J	1.2 μm	15.0	15.0	20.7	2.4	300–600
H	1.6 μm	13.7	13.7	20.9	4.4	800–2 000
K	2.2 μm	12.5	12.5	21.3	1.9	300–700
K'	2.2 μm	13.7	13.7	21.3	1.9	500
L	3.3 μm				1.1	10^5
M	4.9 μm				8.0	10^6
N	10.6 μm				220	4×10^7
Q	19 μm				400	3×10^8

The two columns headed 'from space' differ only in their units.

天空比星系的大部分区域亮。星系测光观测须在无月夜进行

夏威夷Mauna Kea的天空发射



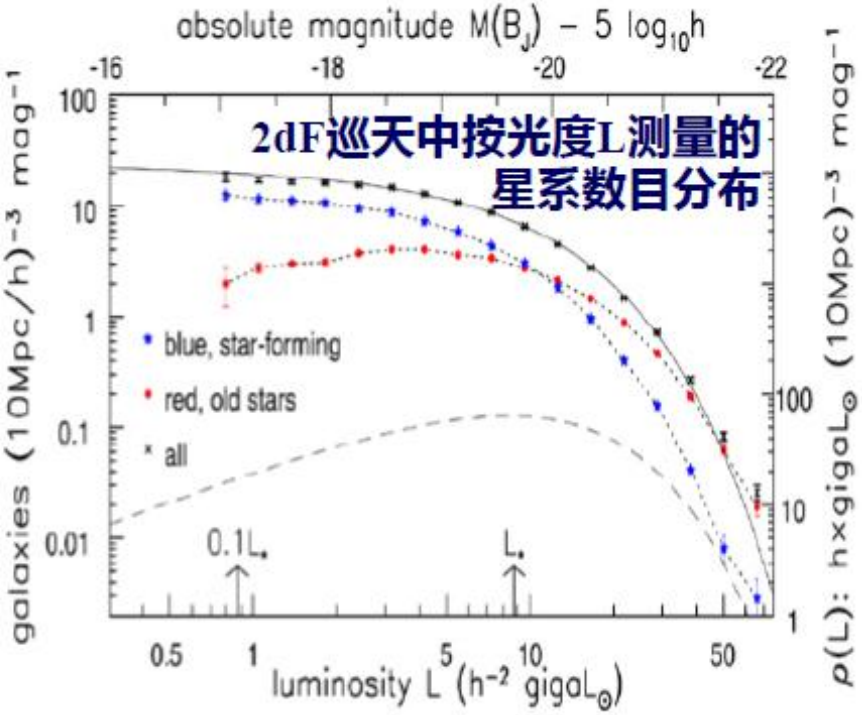
天空背景主要由相隔很近的发射线组成

- **天光背景**
  - 遥远、暗弱河外星系漫射光；银河系内暗弱、未分辨的恒星星光
  - 黄道光：太阳系中的颗粒散射太阳光；大气辐射产生的红外谱线

1.3.4 光度函数

- **光度函数：单位体积、单位光度间隔内的星系（恒星）平均数目，描述星系（恒星）相对数目随光度（绝对星等）的变化.**

$\phi(L)\mathrm{d}L$, which describes the number density of galaxies with luminosities in the range $L \pm \mathrm{d}L/2$. Fig. 2.25 shows the luminosity function in the photometric b_j-band obtained from the 2dFGRS. At the faint end $\phi(L)$ seems to follow a power- law which truncates at the bright end, where the number density falls roughly exponentially. A similar behavior is also seen in other wavebands,



- **多数非常亮的星系是红色的:多为椭圆星系和 S0星系**
- **多数暗星系是S和Irr:内部有新诞生的、大质量恒星，呈现为蓝色**
- **尽管S和Irr数目众多, E却包含了恒星总质量的大约一半**

小而暗的星系比大而亮的星系多得多：具体如何描述？

Schechter Function

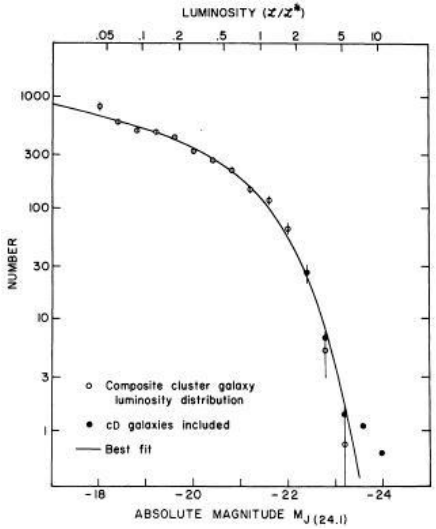
- Press-Schechter (1974)：构建星系形成理论模型，得到了星系的质量函数
- Schechter (1976)：结合观测数据，引入光度函数解析形式: Schechter 函数(1976 ApJ, 203, 297)

so that the galaxy luminosity function is commonly fitted by a Schechter function (Schechter, 1976) of the form

$$\phi(L)\mathrm{d}L = \phi^* \left(\frac{L}{L^*}\right)^{\alpha} \exp\left(-\frac{L}{L^*}\right) \frac{\mathrm{d}L}{L^*}. \tag{2.34}$$

Here L^* is a characteristic luminosity, α is the faint-end slope, and ϕ^* is an overall normalization.

- L^*：特征光度，亮于光度L^*的星系数目非常迅速地下降
- 实线对应于$L^* \approx 9 \times 10^9 h^{-2} L_\odot$，$M^* = -19.7 + 5\log 10h$
- 当$L < L^*$时：constant（星系数密度几乎不变），其时有：$\phi^* = 0.02\ h^3 Mpc^{-3}$ 和$\alpha = 0.46$.



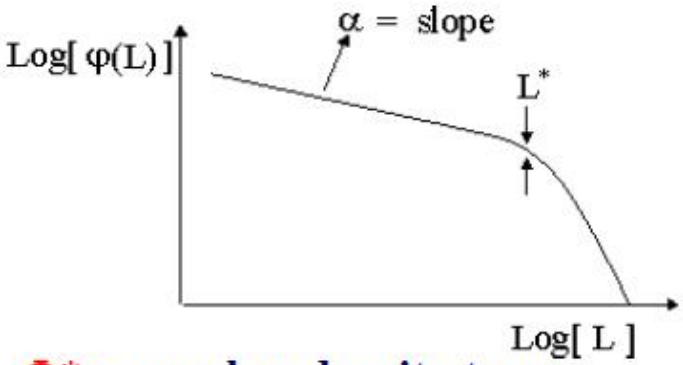
如何测量星系光度函数?

星系光度函数测量

- 场星系和星系团样本LF，方法不同
- 星系团样本：
  - 相对简单，因成员星系有相同的距离
  - 将星系按视星等分区间，求星系计数：$\phi(m)$
  - 利用星系团红移，视星等→绝对星等：$\phi(M)$
  - 修整前景和背景星系影响（主要是低光度部分）
- 场星系样本：样本的完备性
  - 样本有一定的面亮度极限，暗星系无法观测到
  - 需要引入各种方法（V/V_{max}），进行修正；复杂

Galaxy LF important for :

- Galaxy formation models
- Galaxy evolution mechanisms
- Galaxy properties



Φ^* = number density term
α = slope of faint end of LF
L^* = a characteristic L value (break pt. of LF)

L*, are dependent on environment ; LF is not "universal".