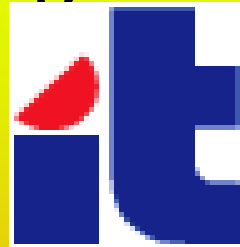


Astronomia Extragaláctica

Domingos Barbosa



Grupo de RadioAstronomia

Enabling Sciences & Supporting Technologies

IT – Aveiro

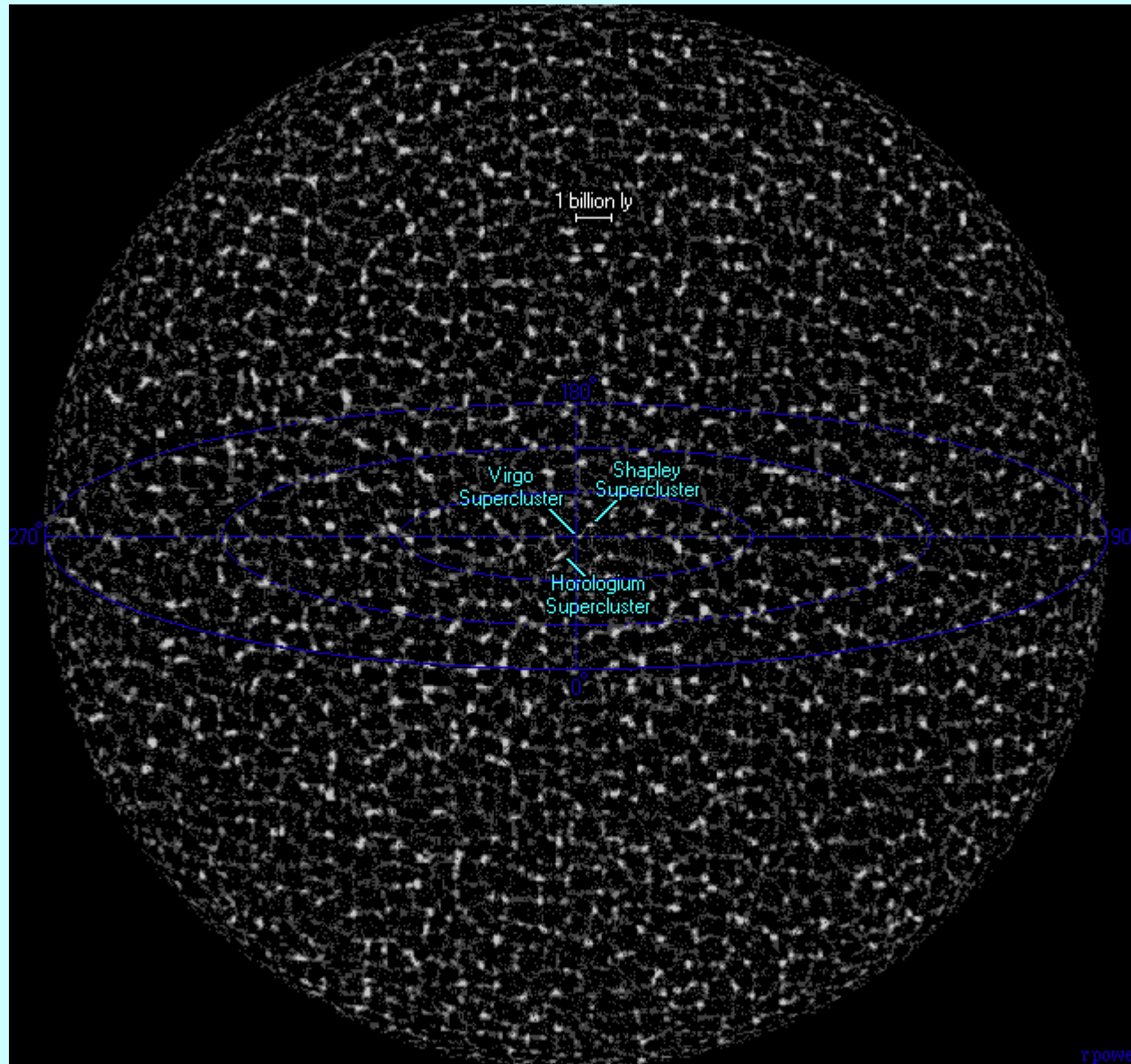
4ª. EAG 2008

1 - Dos objectos: da nossa galáxia á vizinhança

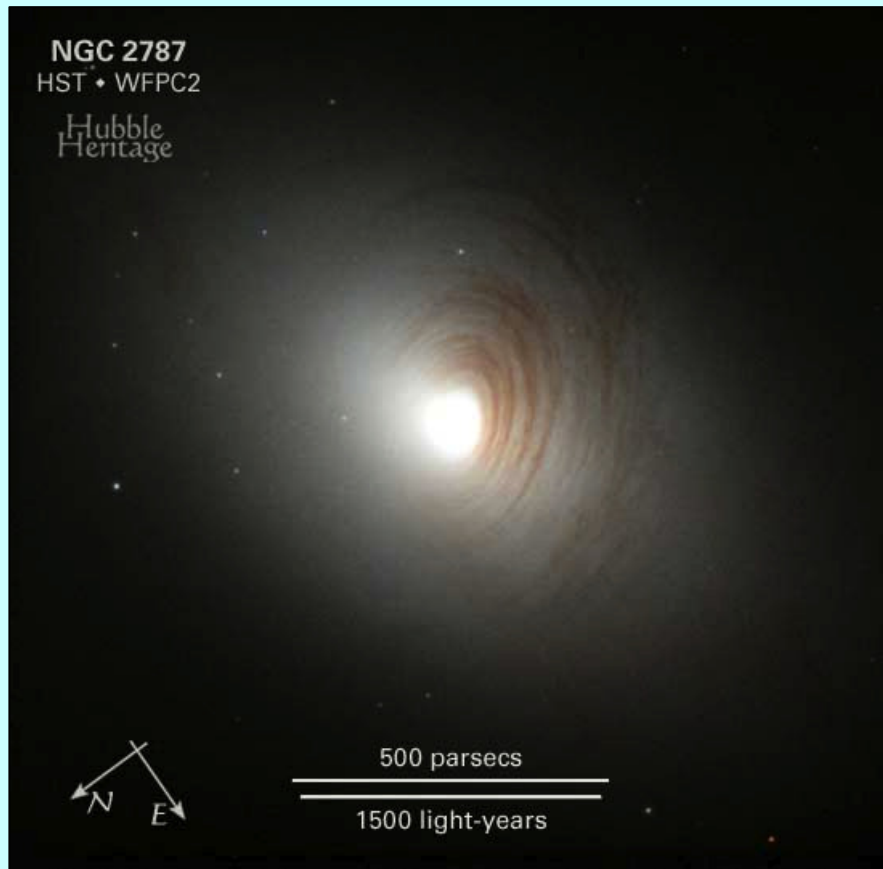
2- Da matéria: dinâmica e evolução

3- Da Radiação: dos fósseis ás sombras

O Universo em larga Escala



Galáxias Espirais







Galaxias são enormes !

- Sist. Solar = cristal sal
 - Galaxia = Lisboa
- Muito Vazio
 - Tamanho Sol = virus (micron)
 - @ Sol: espaço entre partículas = 1m
 - @ núcleo : espaço entre partículas = 1cm
- Não colisional
 - Média de difusão a 2-corpos ~ 1 arcsec
 - Significativo após 10^4 orbitas = 100 x idade do Universo
 - Estrelas evoluem num potencial suave



Constituintes

- **Matéria Escura**

- Domina em grandes escalas
- Não-bariônica & não-colisional

- **Estrelas**

- Cerca de 10% da massa total
- Domina parte luminosa

- **Gás**

- Cerca de 10% massa
- Colisional → perde energia por radiação
- No fundo do poço de potencial -> e forma estrelas
 - Disco : gás cria estrelas (“frio”)
 - Nucleo : gera potenciais fortes e profundos
- Historicamente TODAS as estrelas se formam de gás, por isso este é importante dinamicamente.





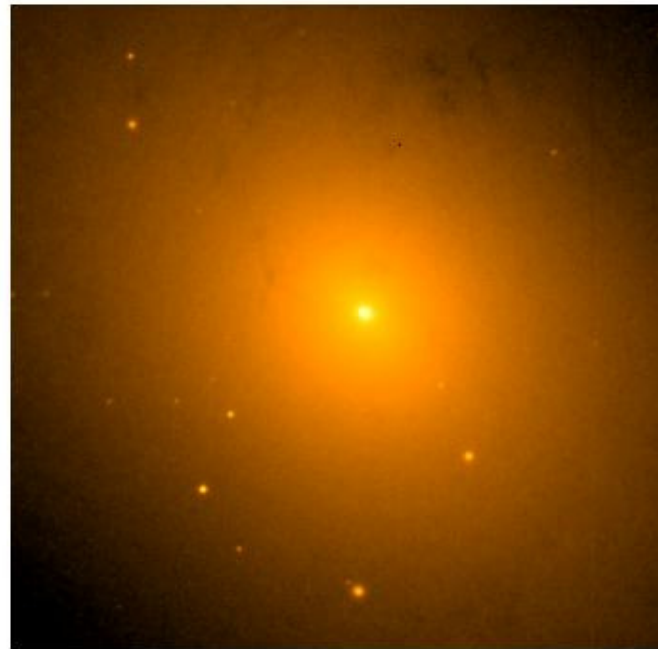
M 31

The Andromeda Galaxy



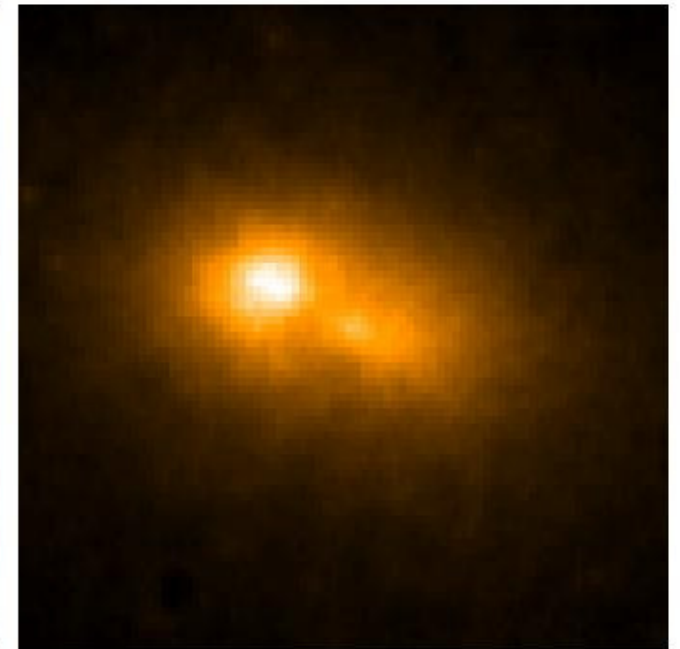
40,000 LY

Ground View of Galaxy



2,000 LY

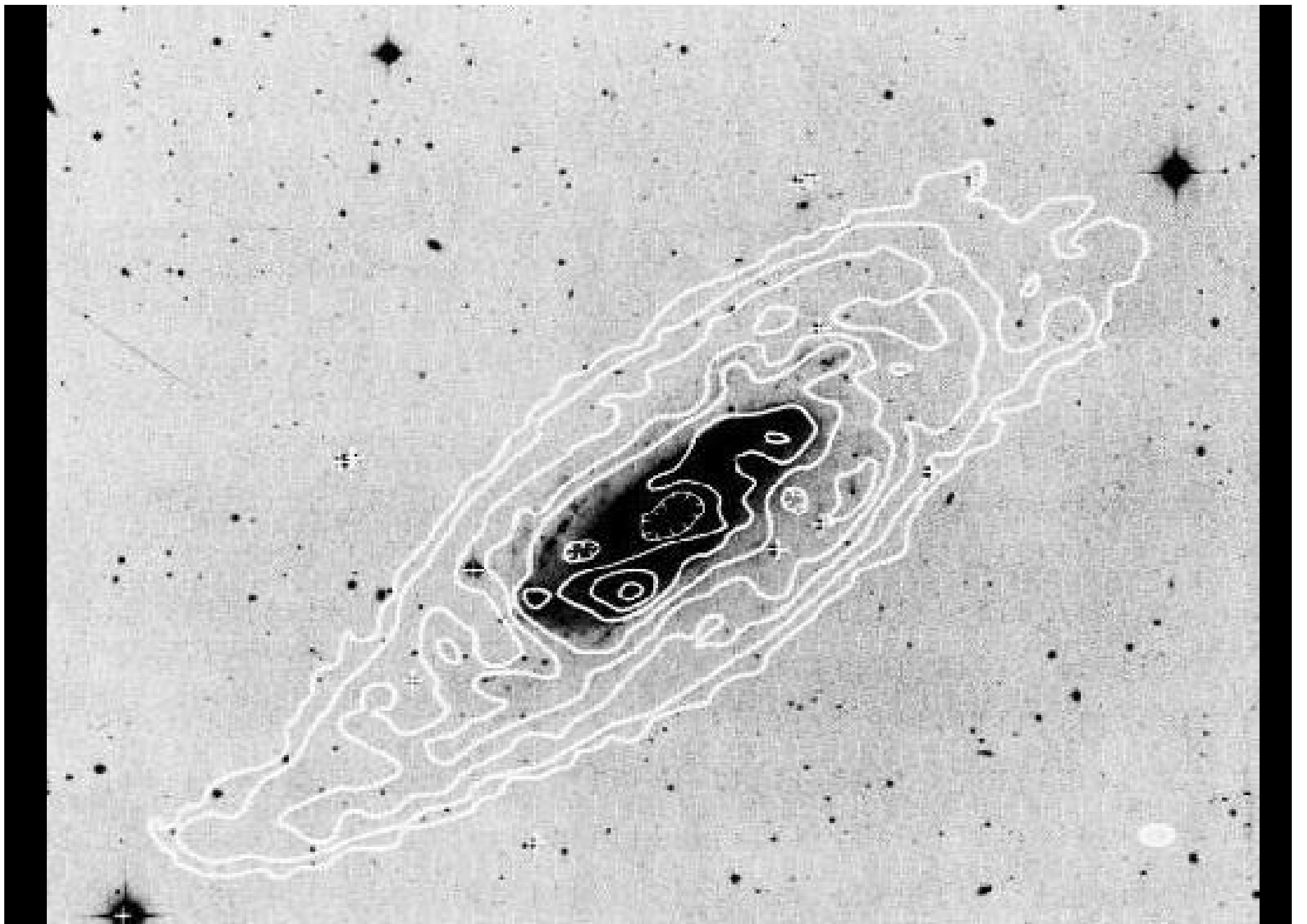
Ground View of Galaxy Core




40 LIGHT-YEARS

HST View of Galaxy Nucleus

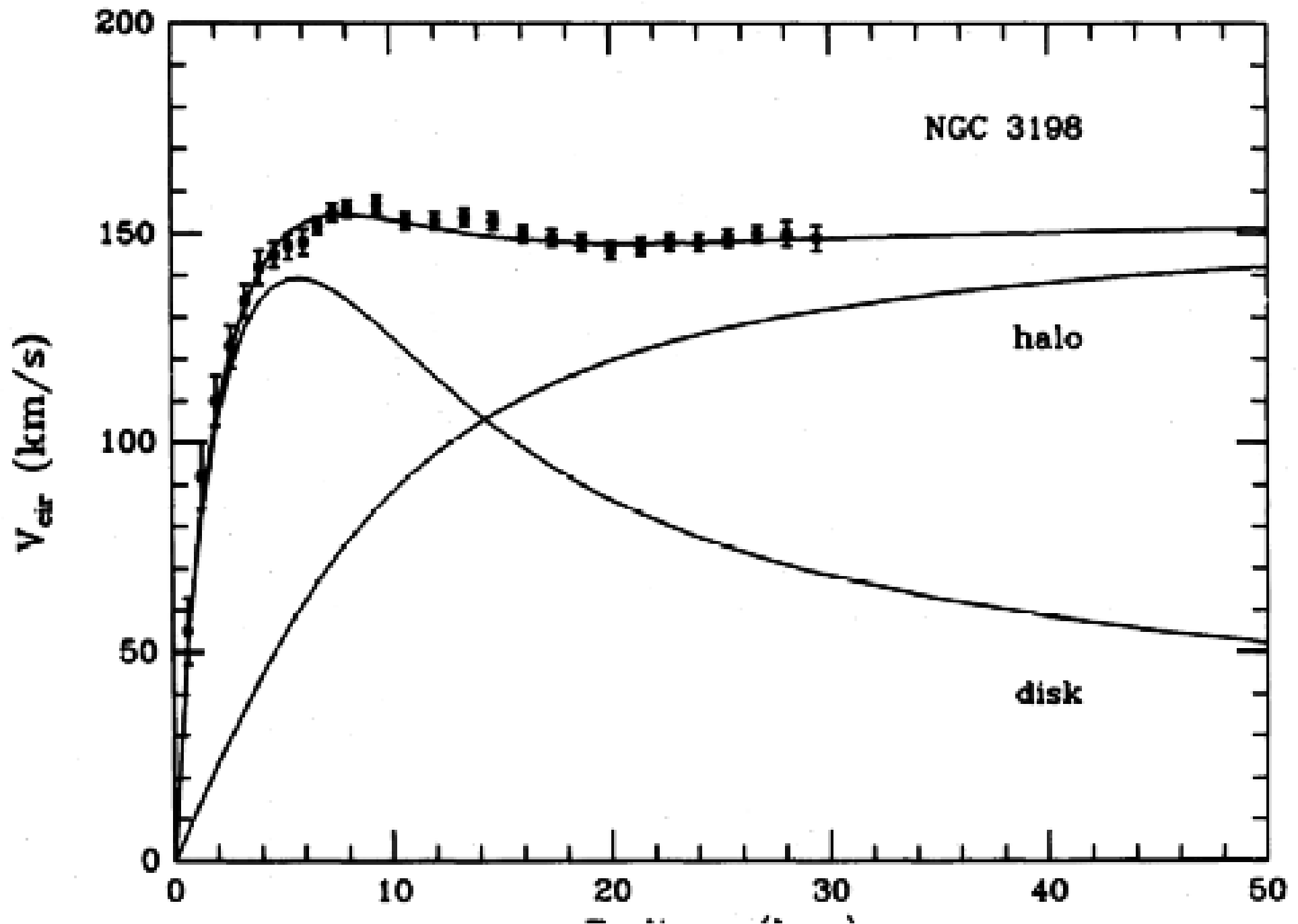






Curvas de
rotação das galáxias

DISTRIBUTION OF DARK MATTER IN NGC 3198



- Numa estrela que pertença ao disco galáctico, a velocidade é:

$$m \frac{v^2}{R} = G \frac{M' m}{R^2} \quad \wedge \quad M' = \rho \left(\frac{4}{3} \pi R^3 \right)$$

$$\frac{v^2}{R} = \frac{4}{3} \pi G \rho R$$

$$v = \left(\frac{4}{3} \pi G \rho \right)^{\frac{1}{2}} R$$

$$v \propto R$$



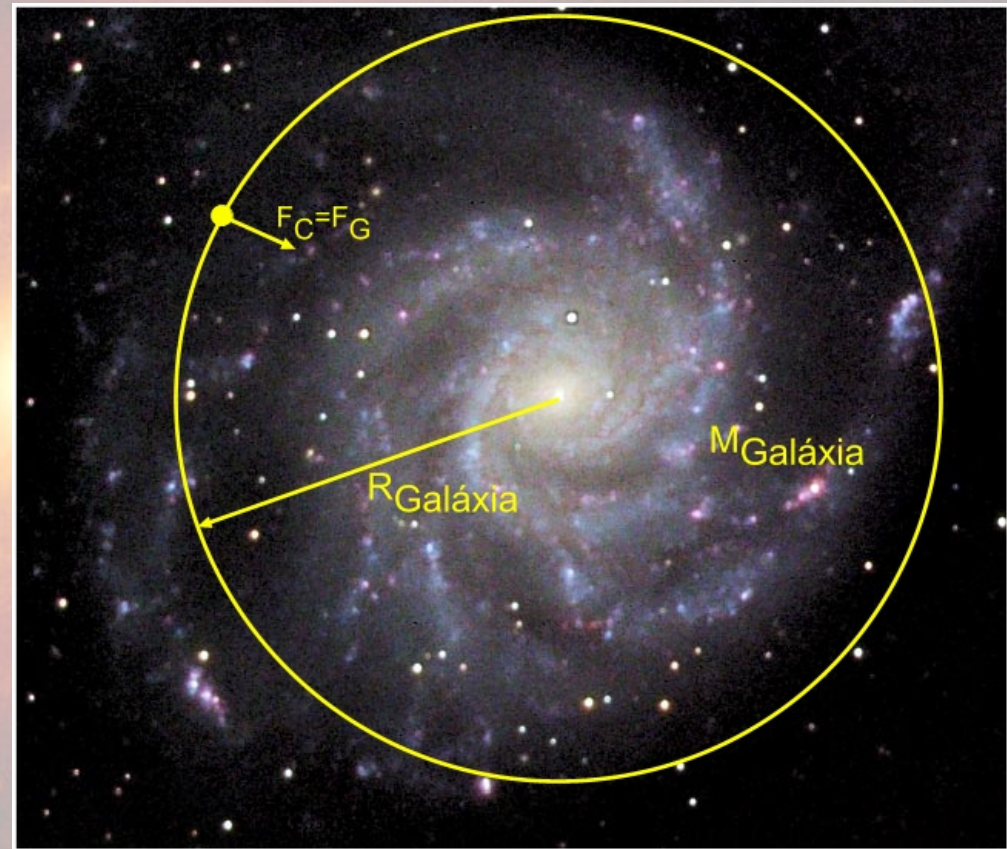
•Numa estrela que se encontre na fronteira da galáxia a velocidade é:

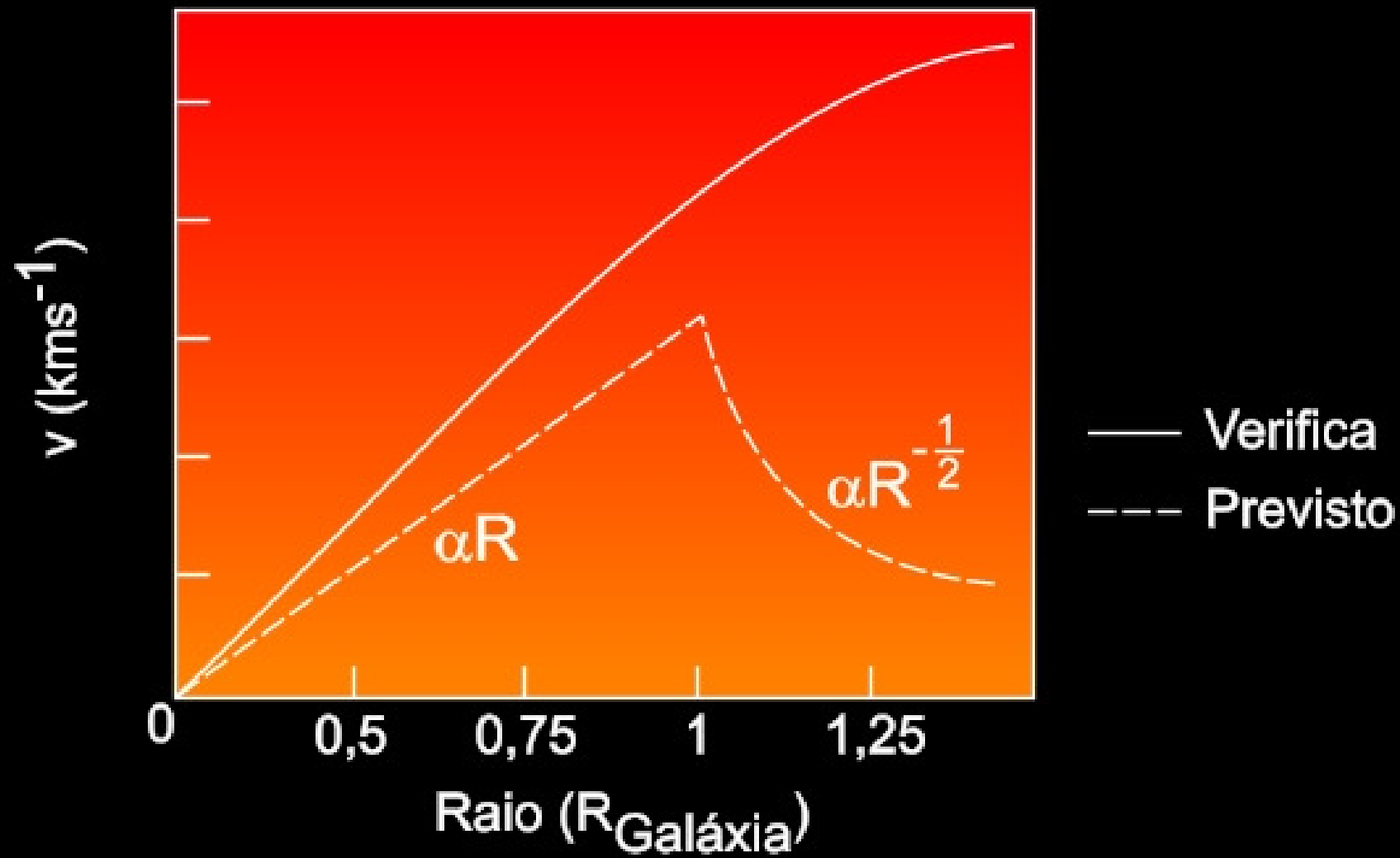
$$m \frac{v^2}{R} = G \frac{Mm}{R^2}$$

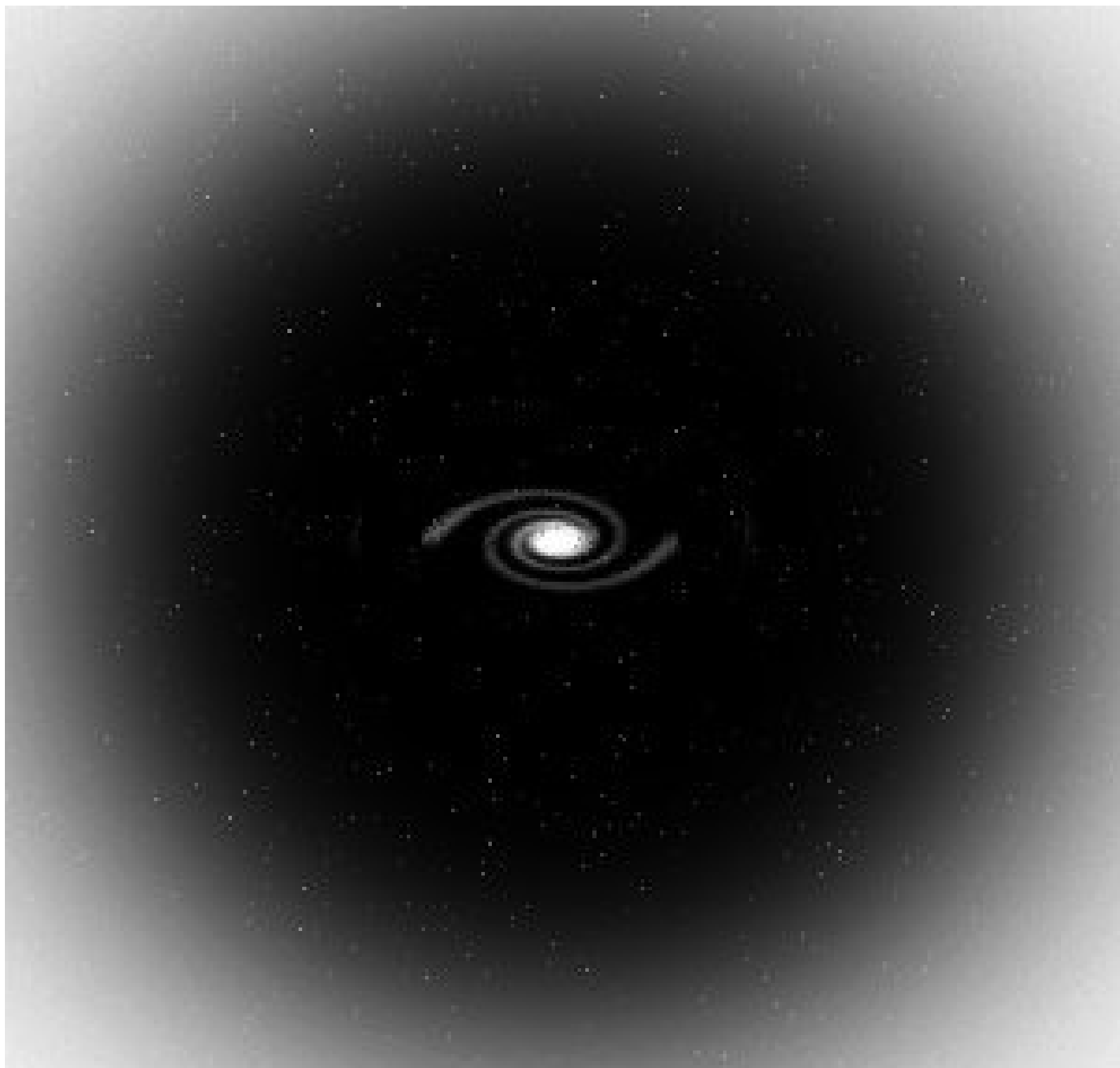
$$v^2 = G \frac{M}{R}$$

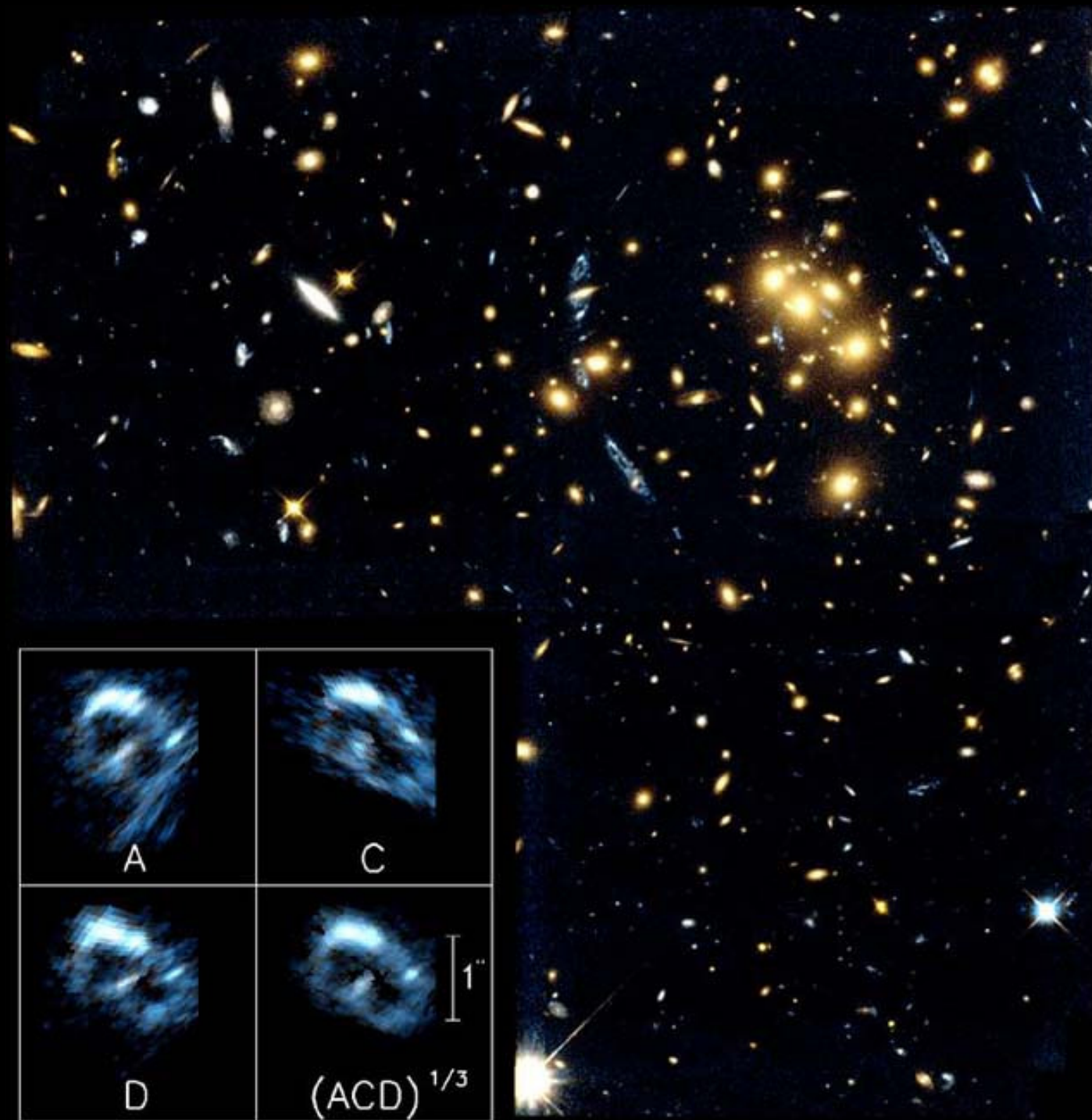
$$v = \left(G \frac{M}{R} \right)^{\frac{1}{2}}$$

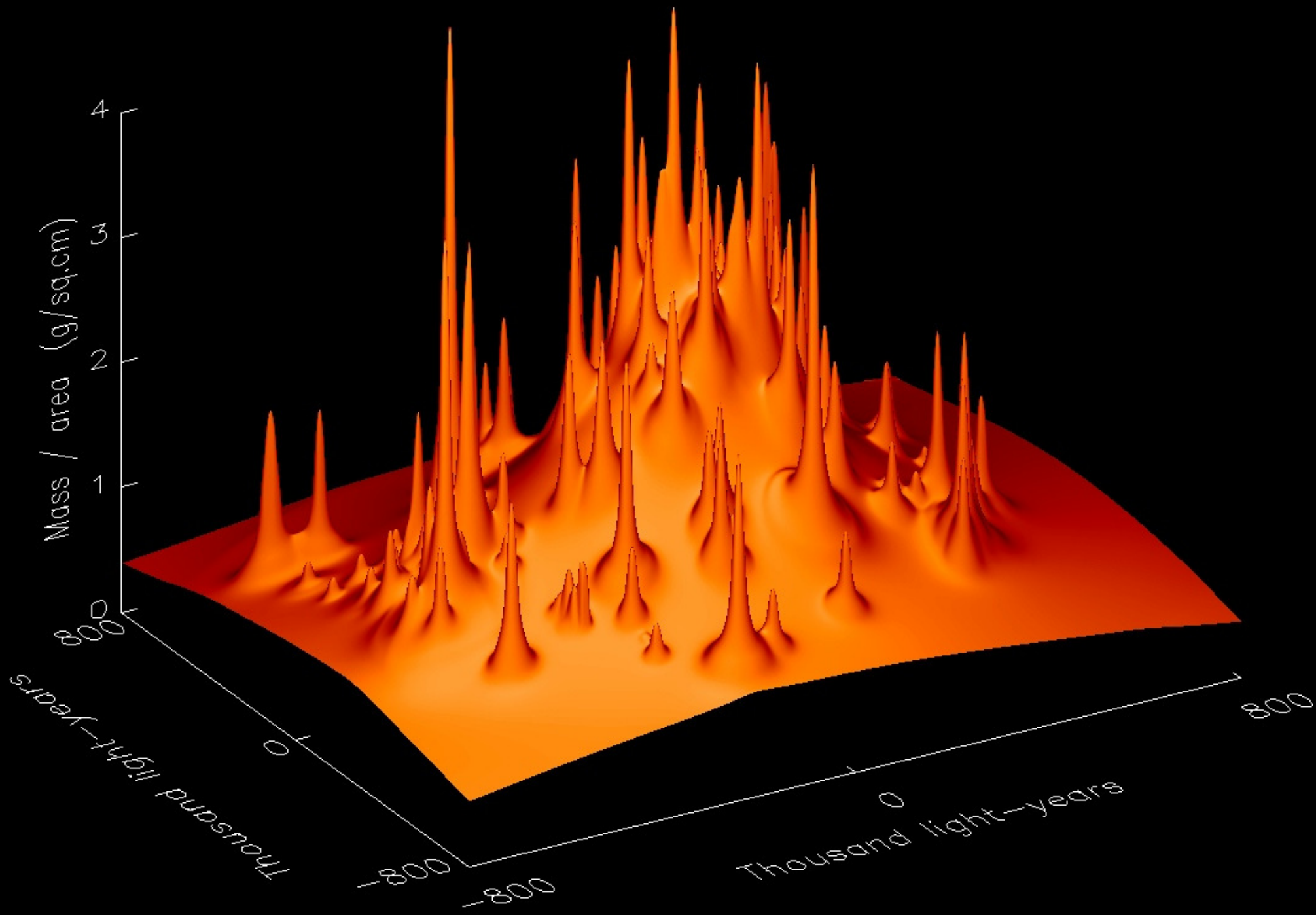
$$v \propto R^{-\frac{1}{2}}$$





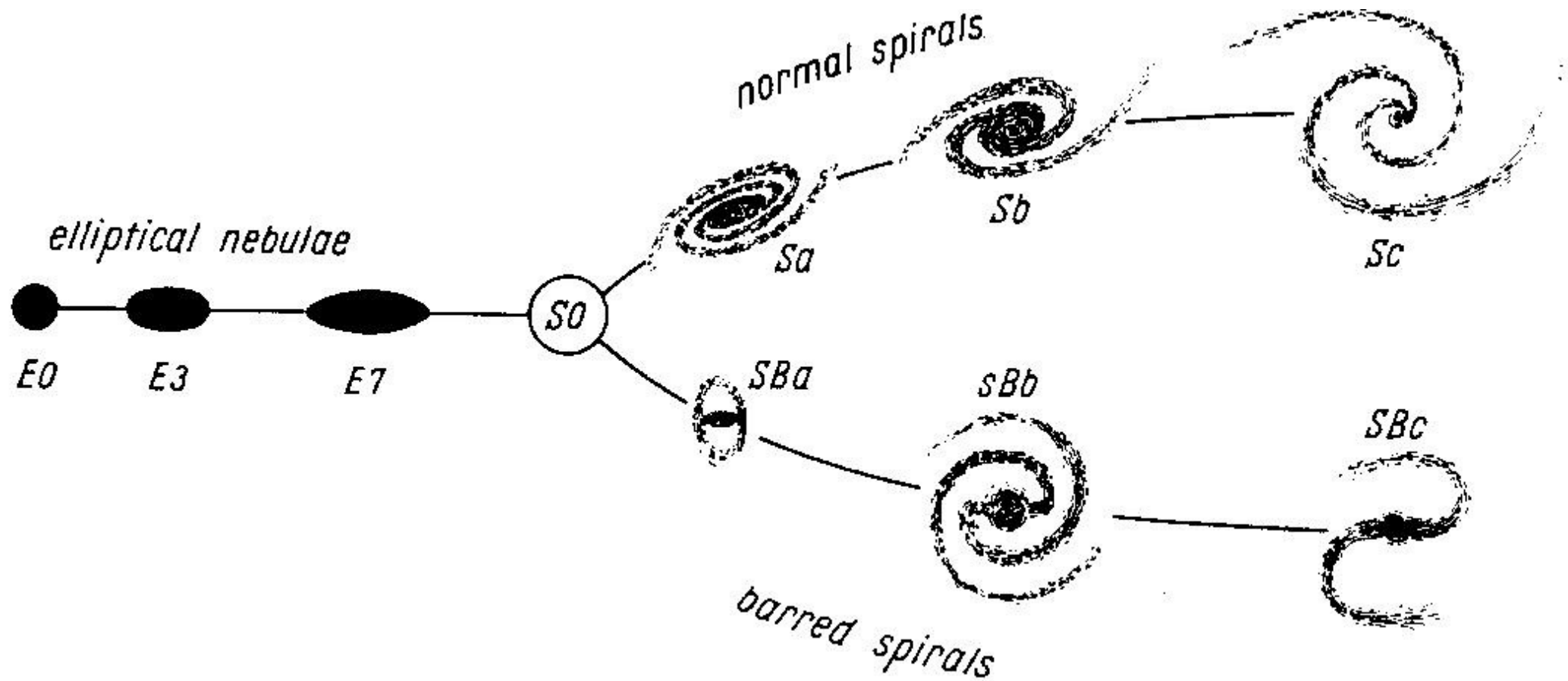


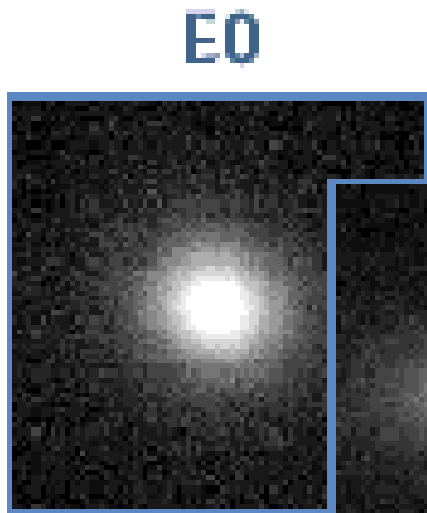




Núcleos & discos

- Radicalmente diferentes
- Vários tipos (E – S0 – Sa – Sb – Sc – Sd)
- Concentrações diferem (compacta vs extensa)
- Dinâmica difere (dispersão vs rotação)
- Diferentes histórias (cedo vs tarde)

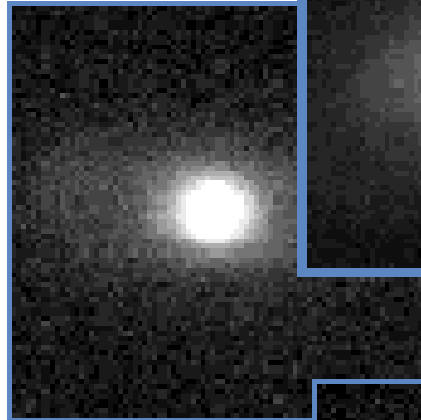




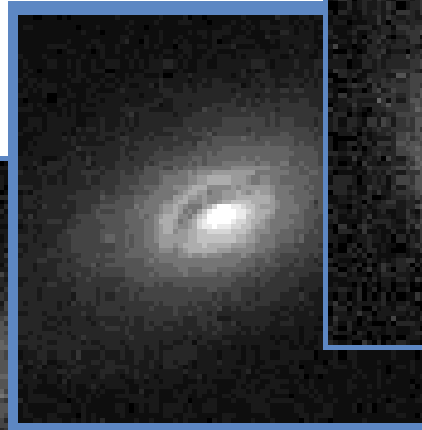
E0



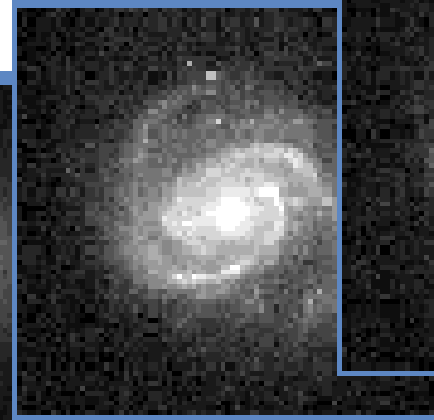
E7



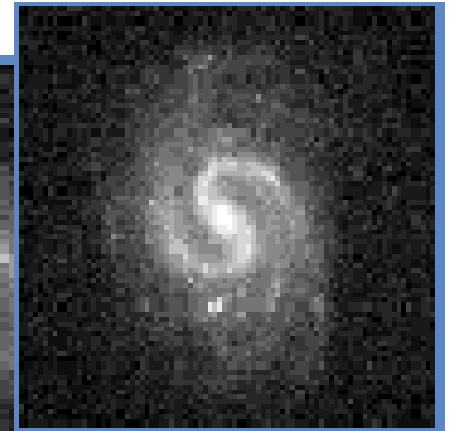
S0



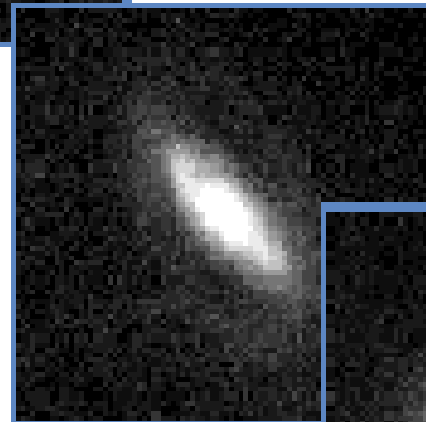
Sa



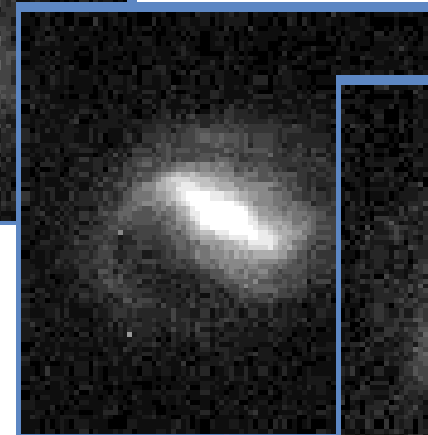
Sb



Sc



SBa



SBb

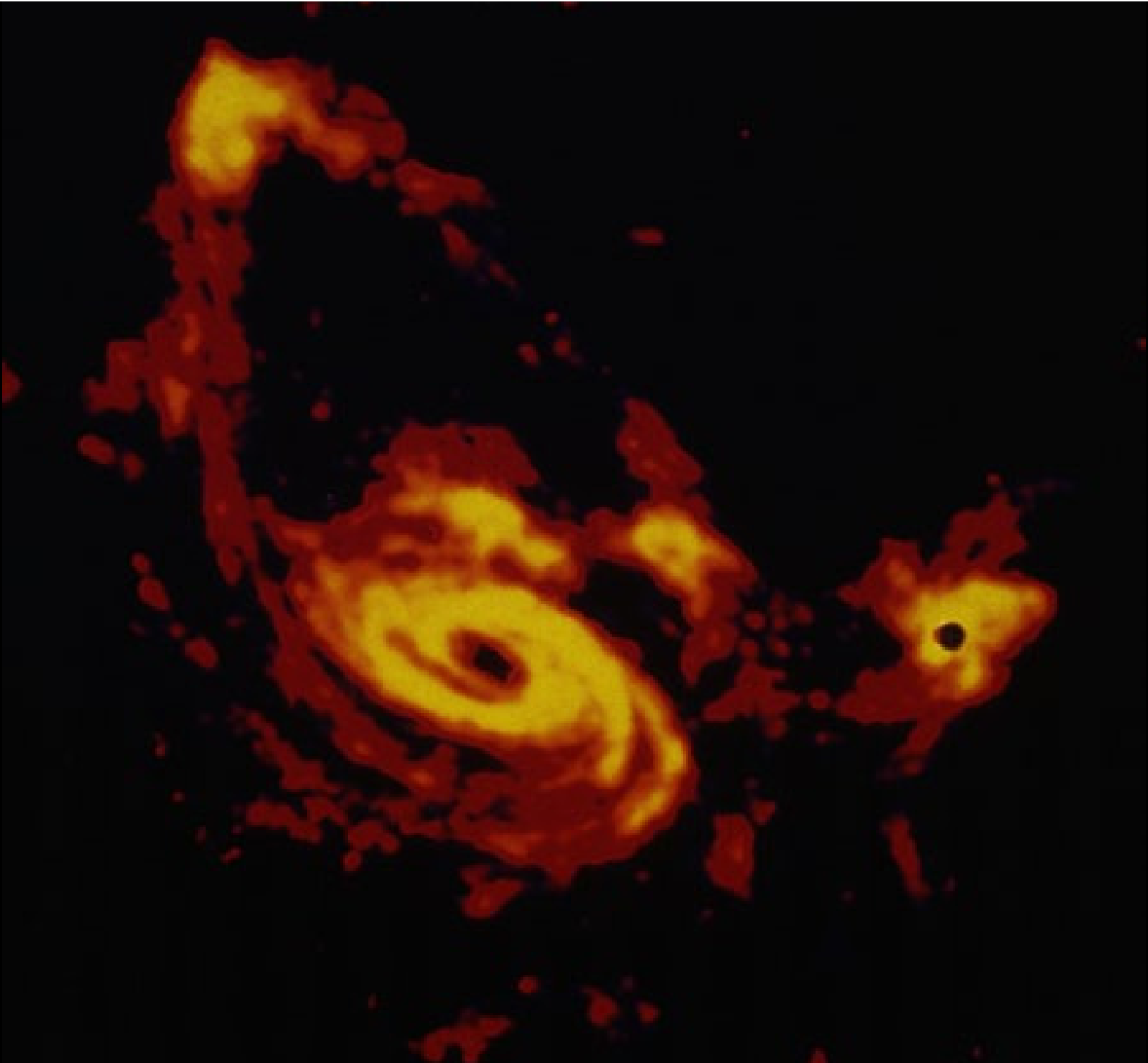


SBc

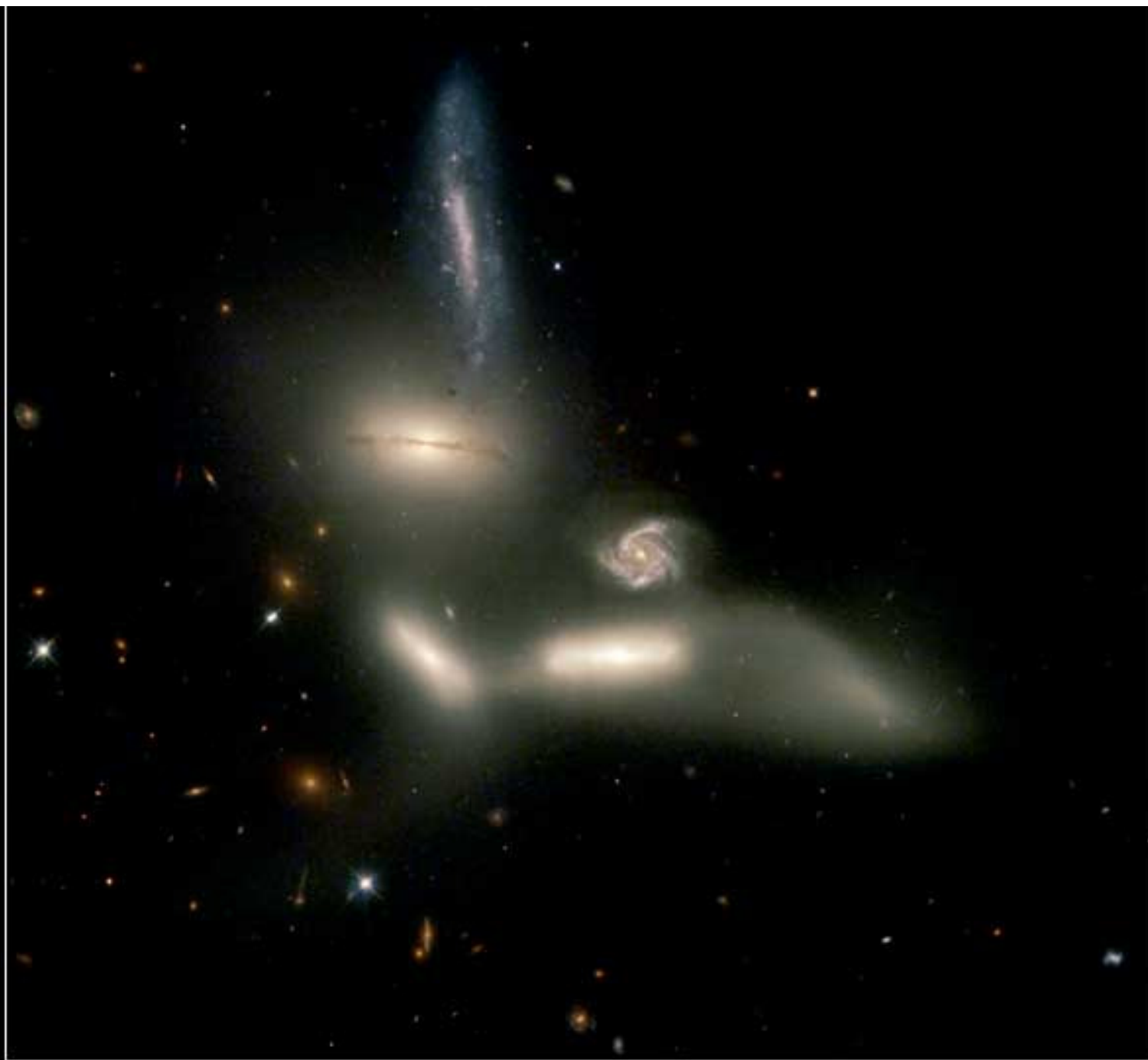
Interações & Mergers

- Geração de núcleos (espiral + espiral = elíptica)
- Gás vai para o centro
- Intensa formação estelar (starbursts)
- Ventos de Supernova
- Poluição química
- Formação estelar Cósmica







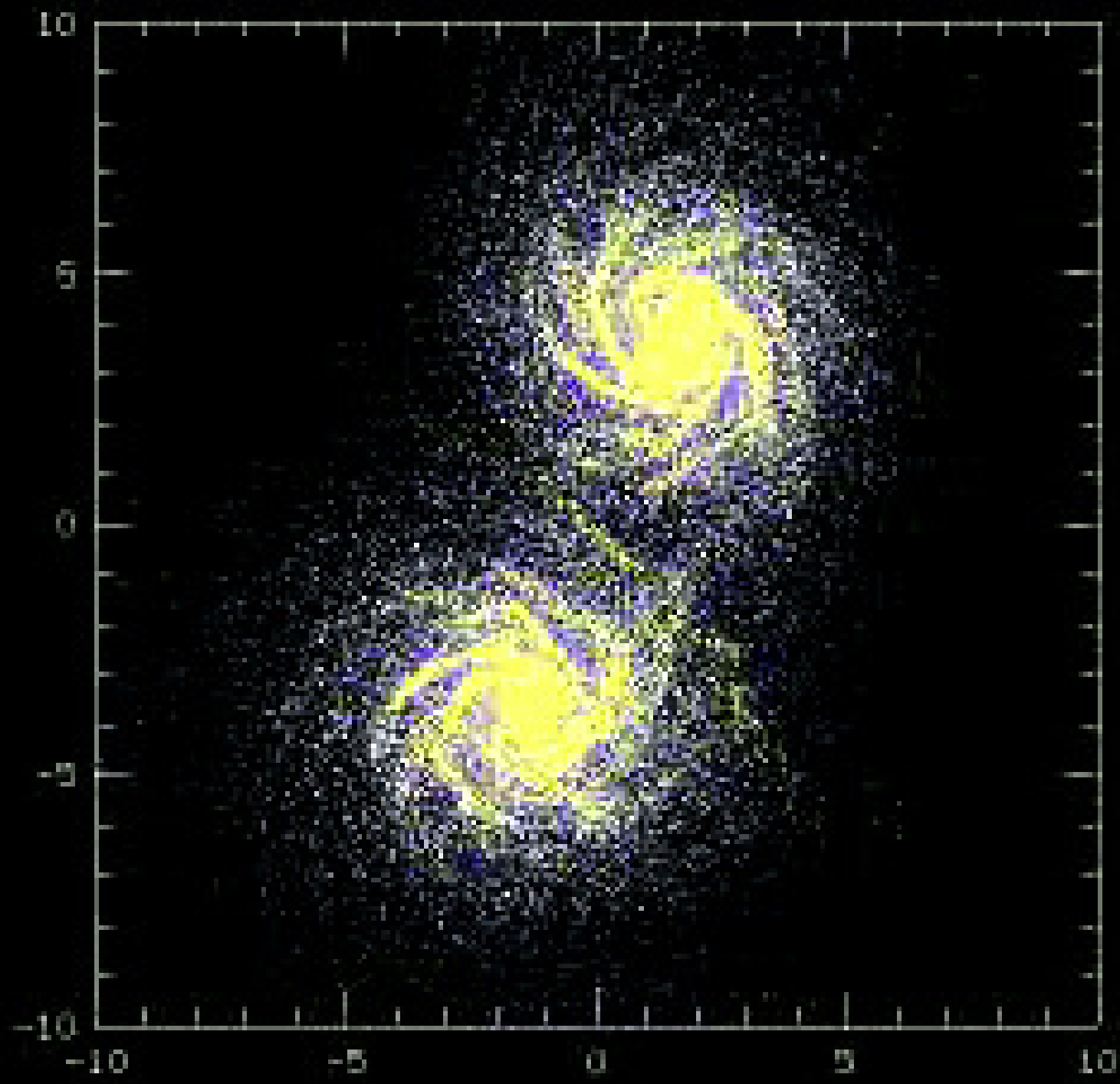


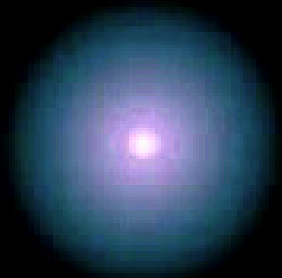
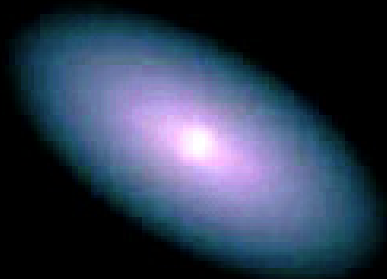
Galaxy Group Seyfert's Sextet

HST ♦ WFPC2

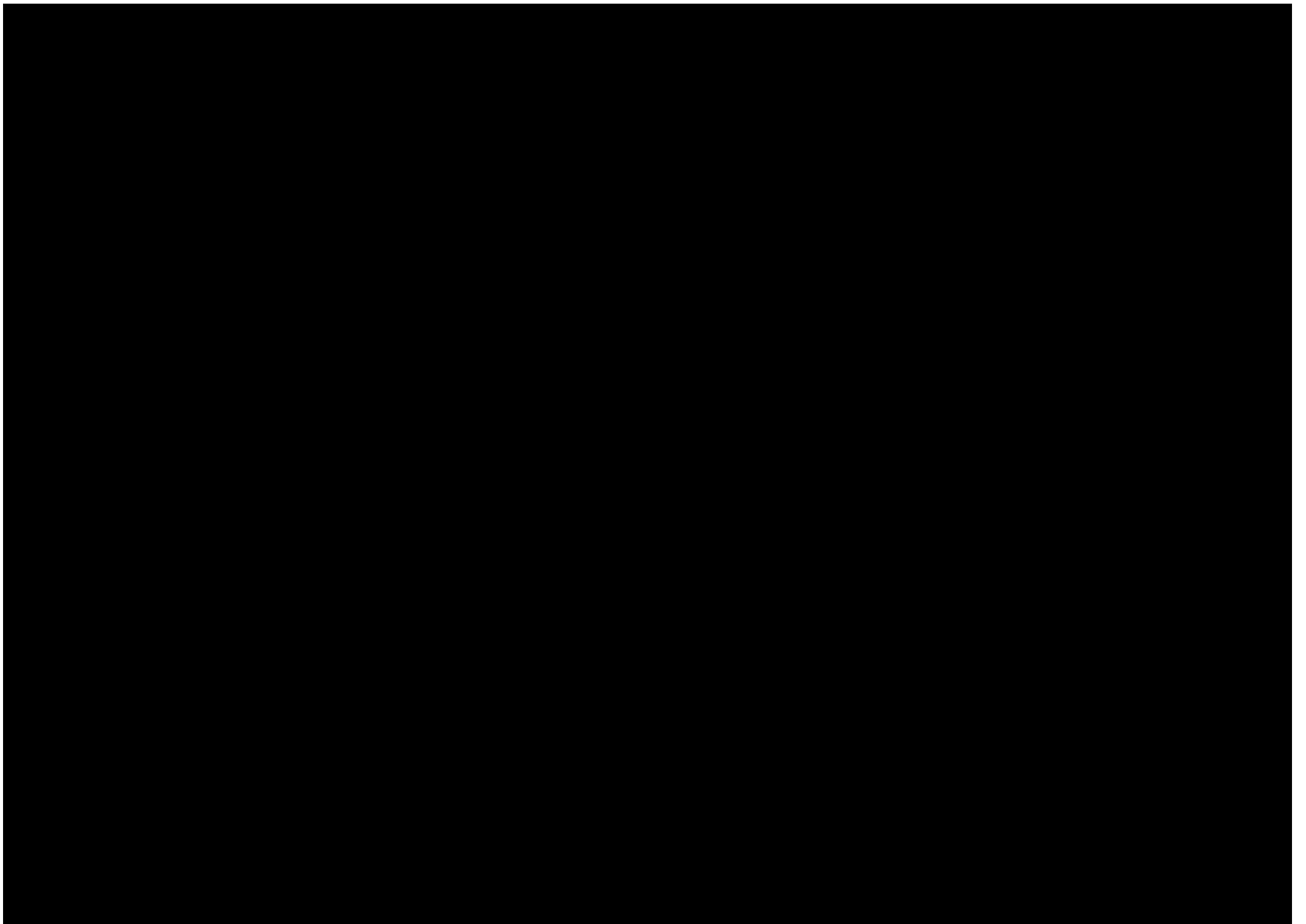
NASA, J. English (University of Manitoba)

and G. Palma (Pennsylvania State University) • STS-105-02-001

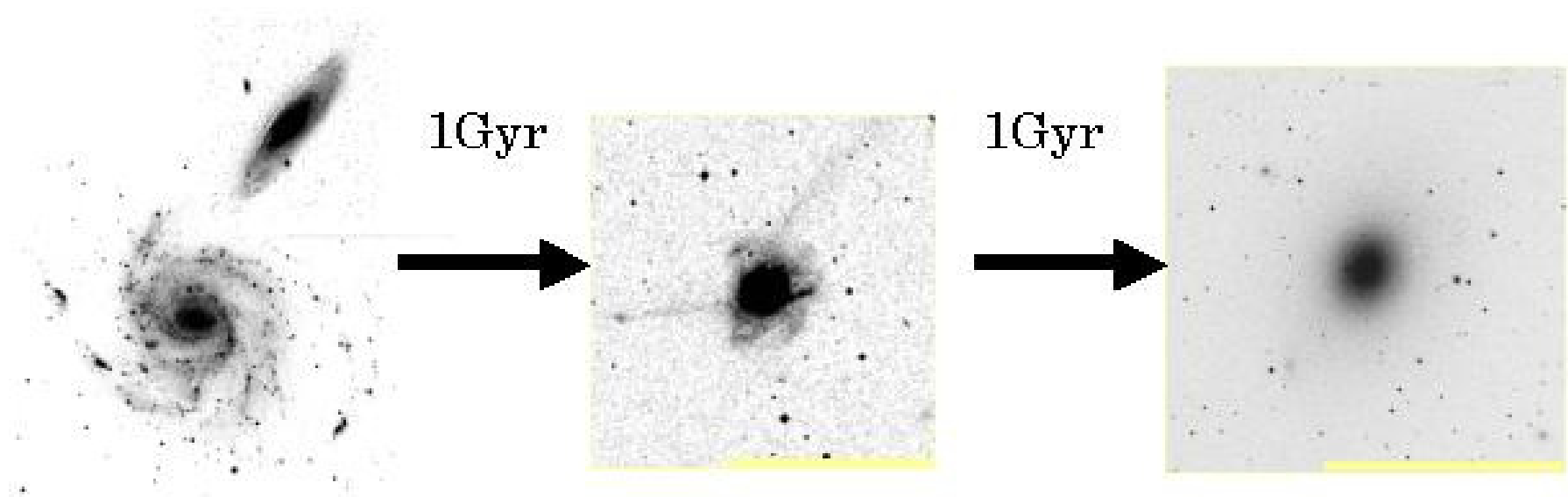








Spiral mergers can make Ellipticals



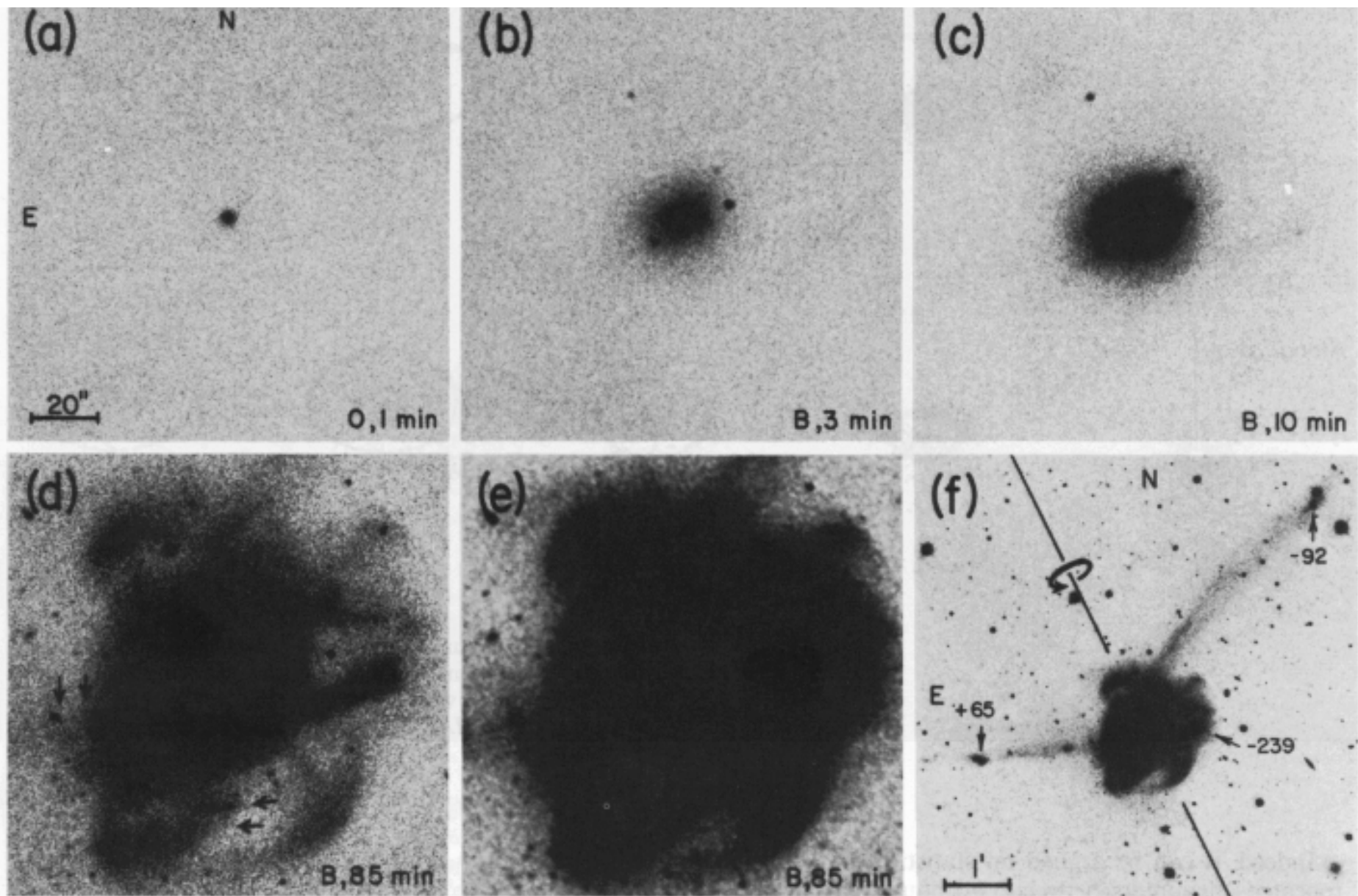


Figure 14.5. Successively deeper photographs (a–e) of NGC 7252 reveals a complex set of filaments surrounding a central body that resembles a giant elliptical galaxy. Spectra of some of the features show the counter-velocities (f) in two tails that are characteristic of interacting disk galaxies of comparable mass. For these reasons, this system is regarded as an excellent candidate for a merger between two giant spiral galaxies. (From F. Oort, *Astronomical Journal*, 1991)

tend to bring the two galaxies close together, consistent with the constraint of the conservation of total angular momentum and total energy. This expectation is based on the second law of thermodynamics, which when applied to trillions of stars still states that order tends to be replaced by disorder (Chapter 4). The close encounter of two bound spiral galaxies, containing much energy

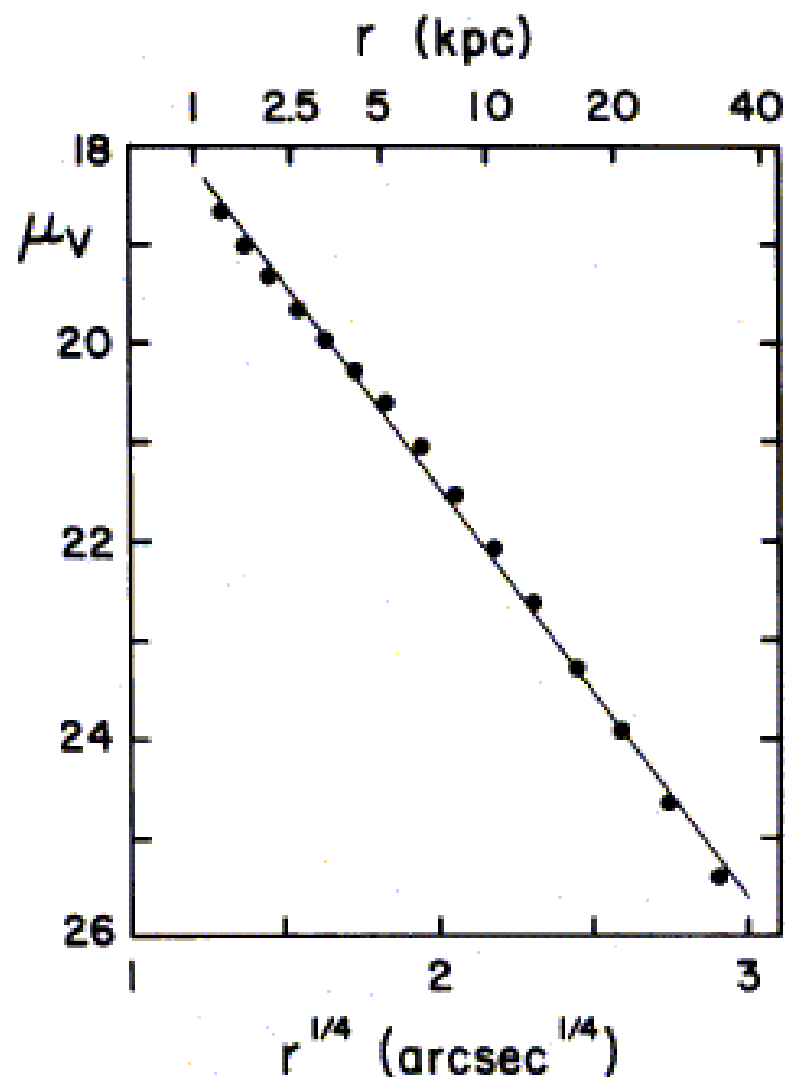
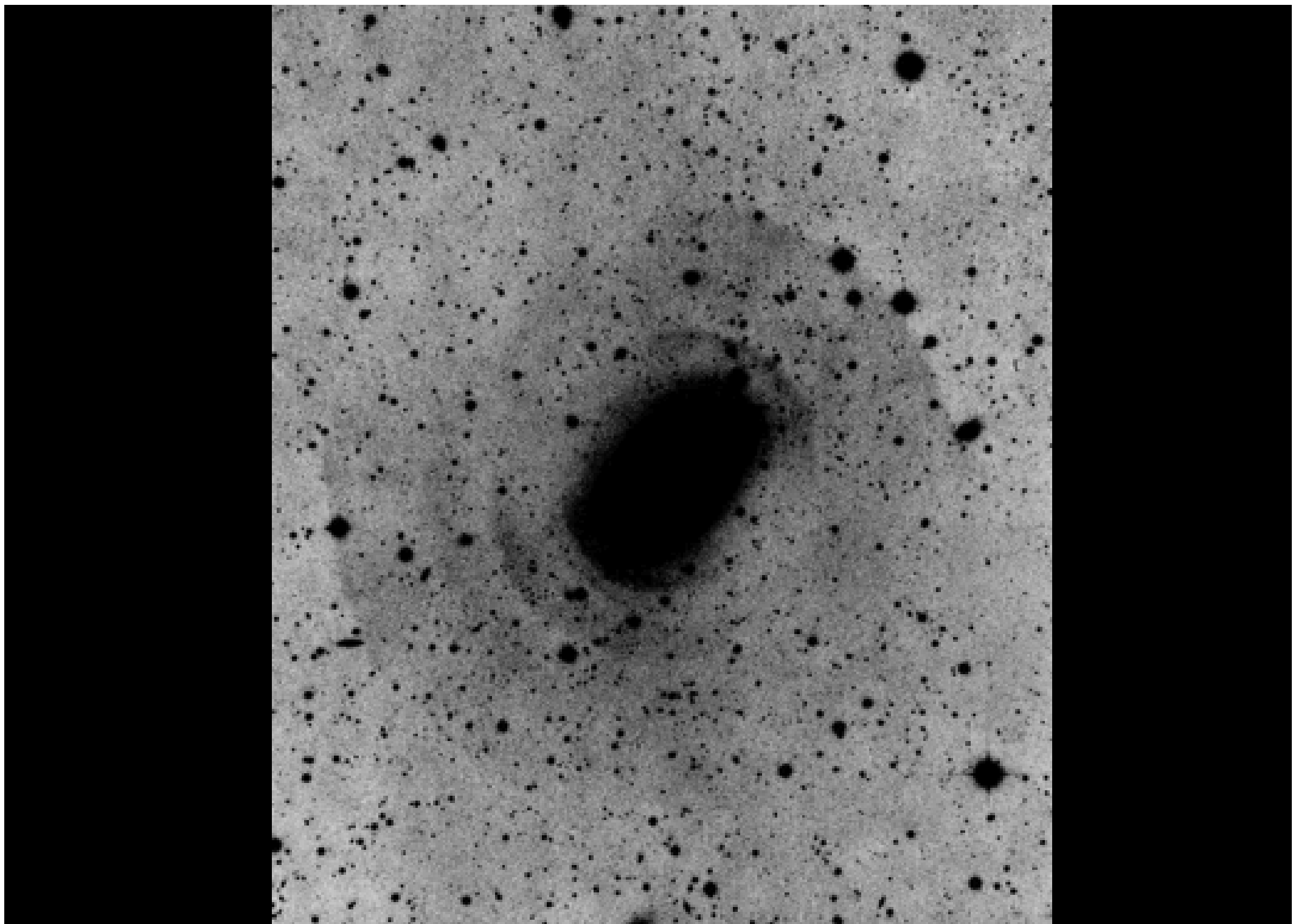


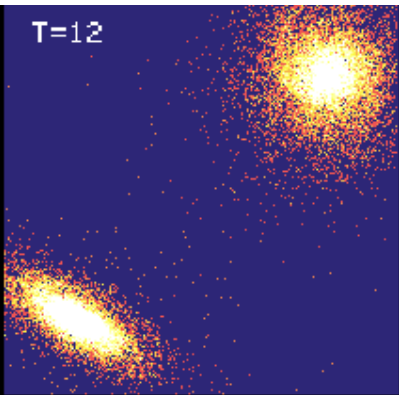
FIG. 6.—Radial light distribution of NGC 7252; visual surface brightnesses μ_V (in mag arcsec $^{-2}$) are plotted vs. the fourth root of the radius. The data points represent values calculated from the adopted growth curve of Fig. 5 by numerical differentiation. The light distribution closely resembles that of an elliptical galaxy, as illustrated by the least-squares-fitted $r^{1/4}$ law (*straight line*).



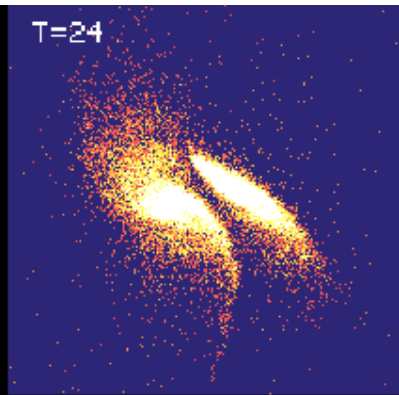
Durante interacções :

- Gas perde momento angular
- \rightarrow para o centro
- Aprofunda o potential
- Forma estrelas em starburst

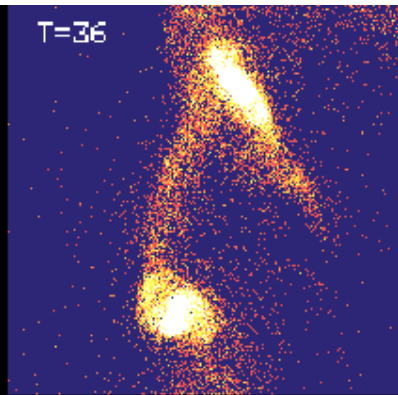
T=12



T=24

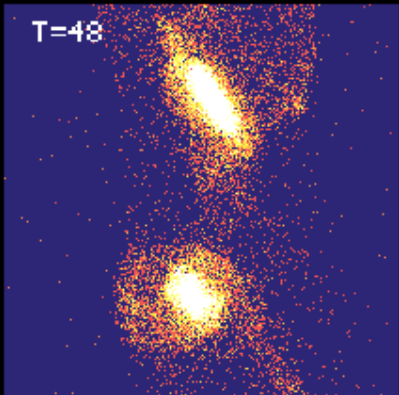


T=36

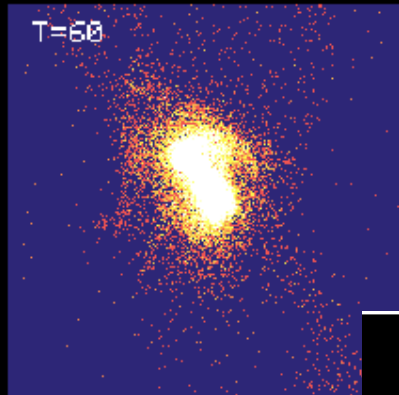


stars
↙

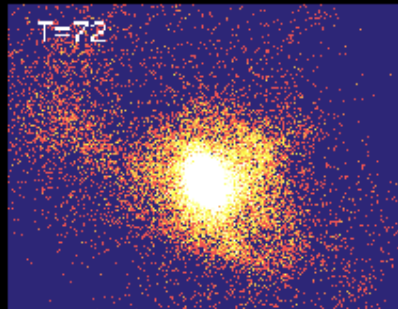
T=48



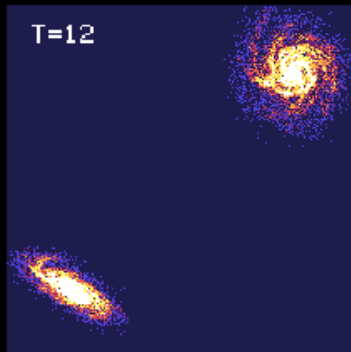
T=60



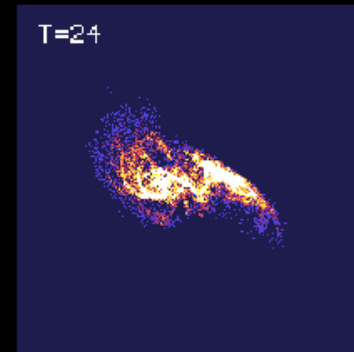
T=72



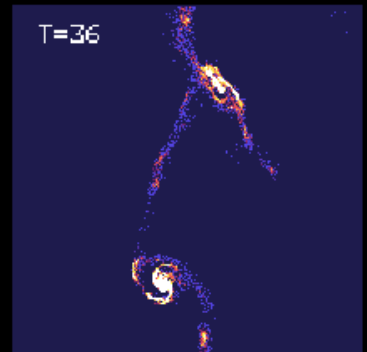
T=12



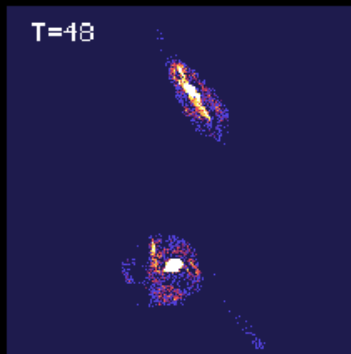
T=24



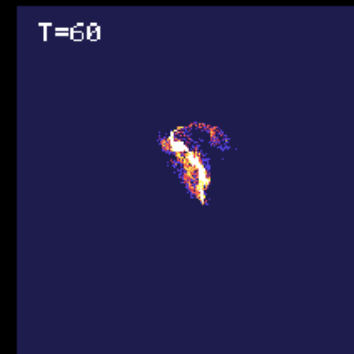
T=36



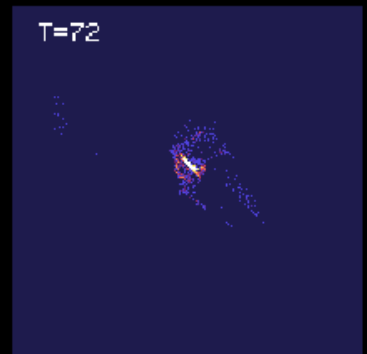
T=48



T=60



T=72



Gas/SFR
↗

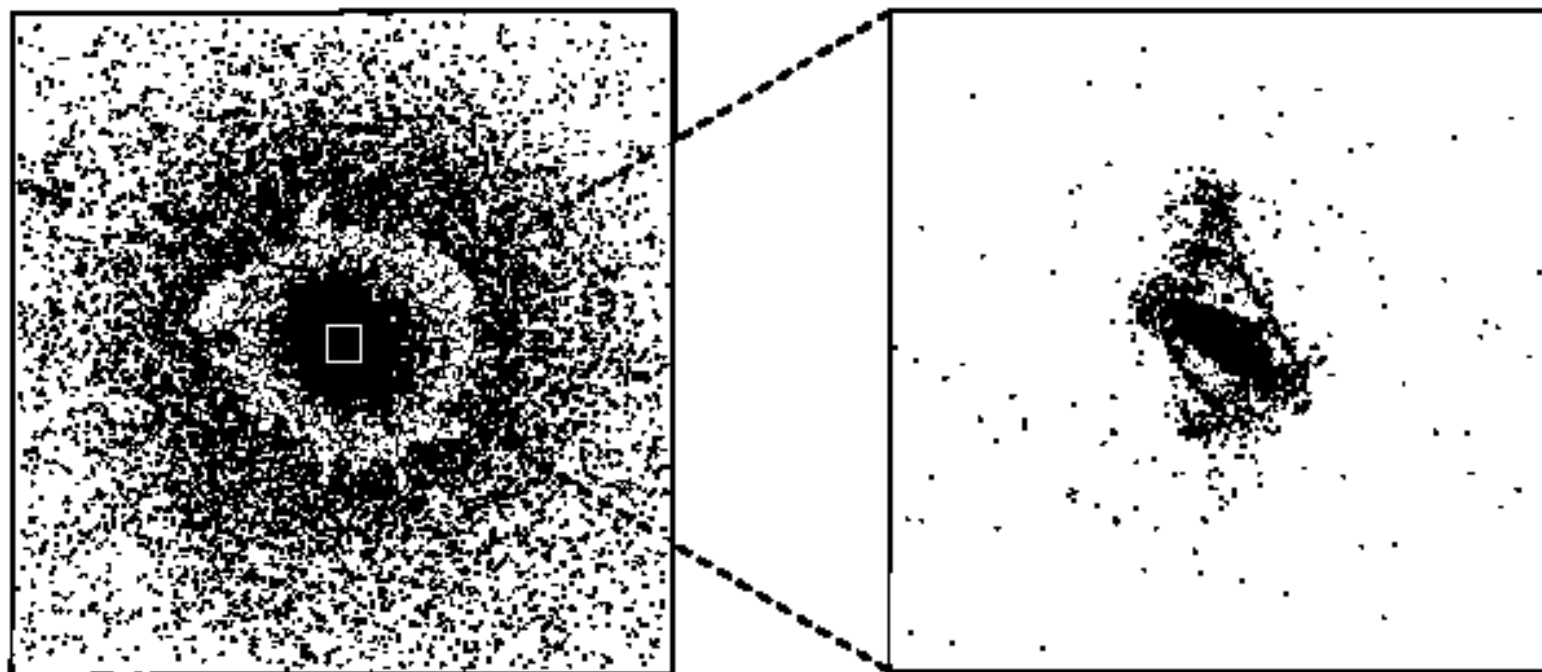
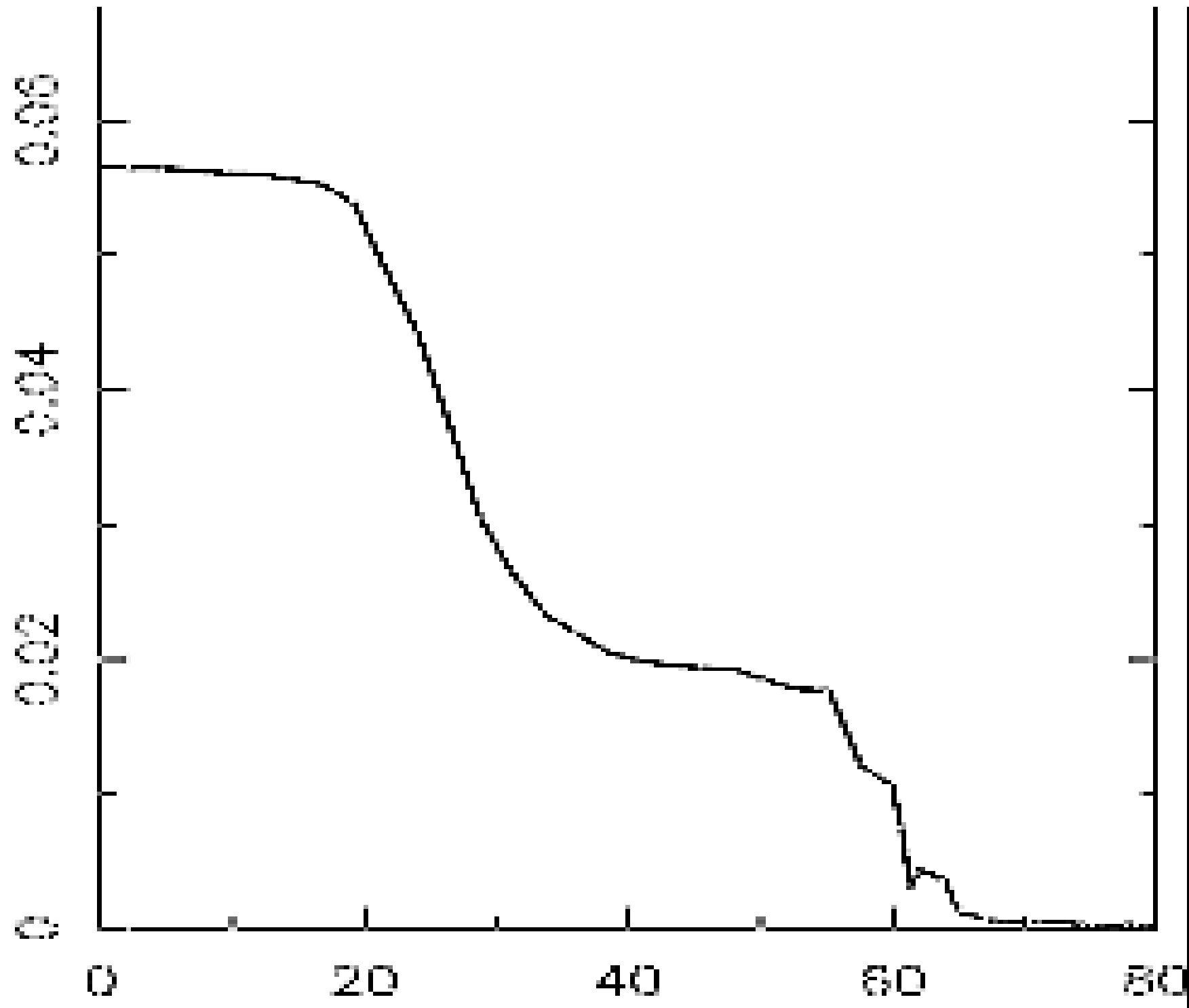
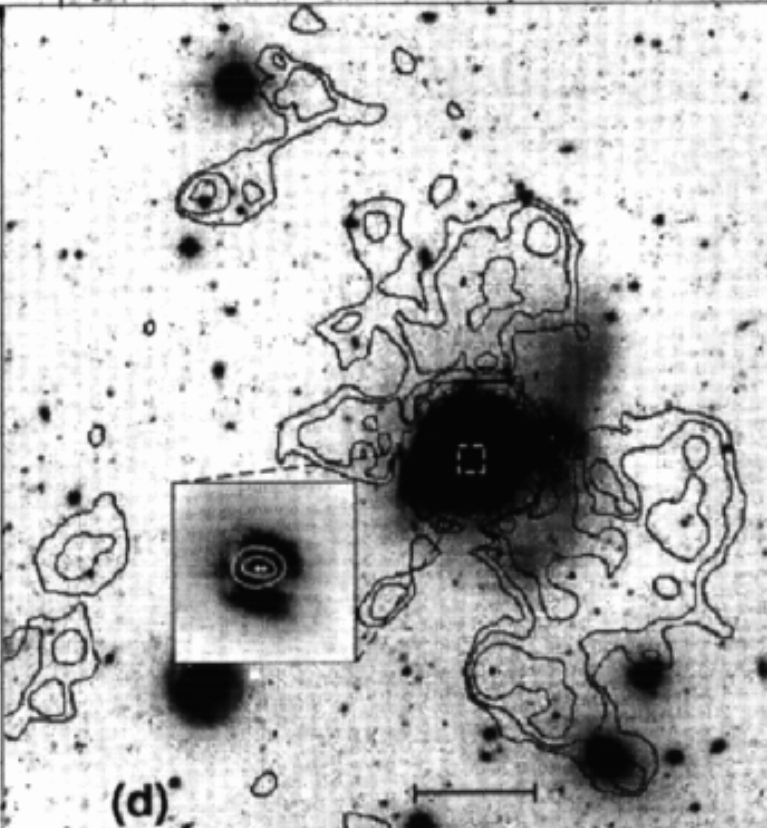
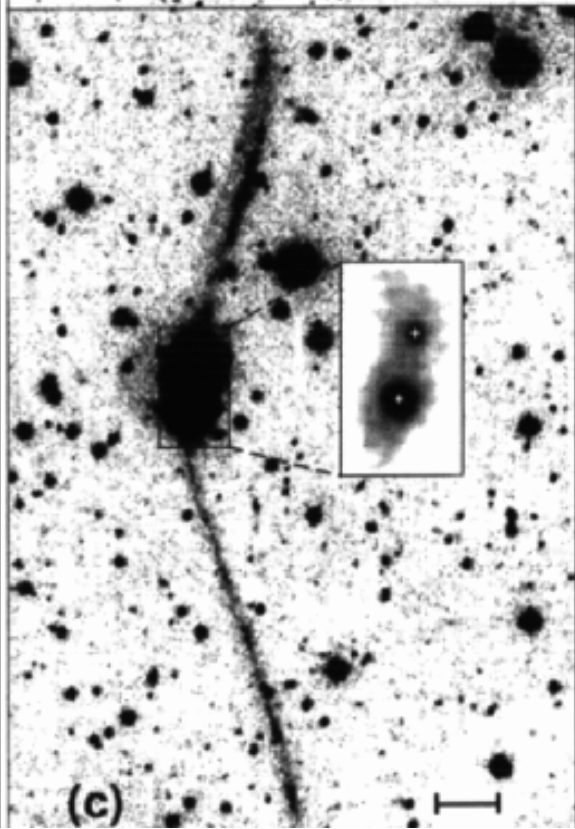
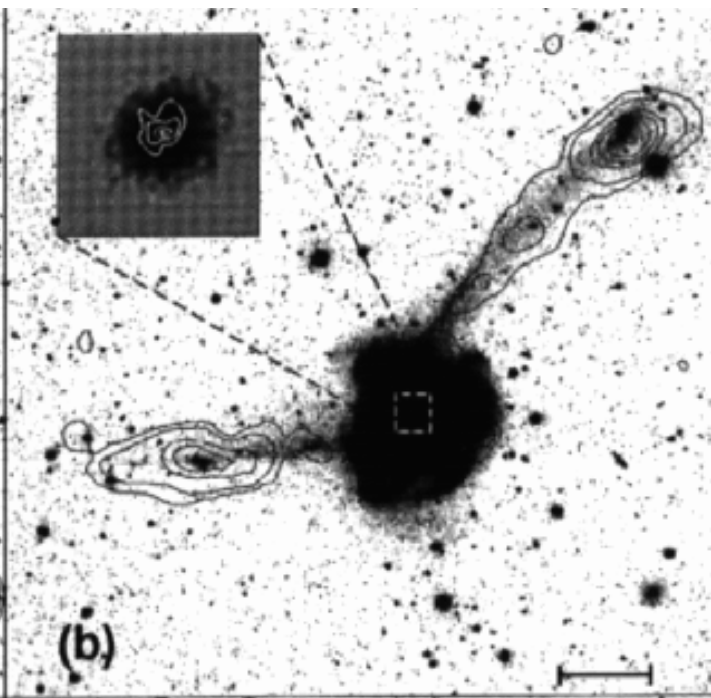
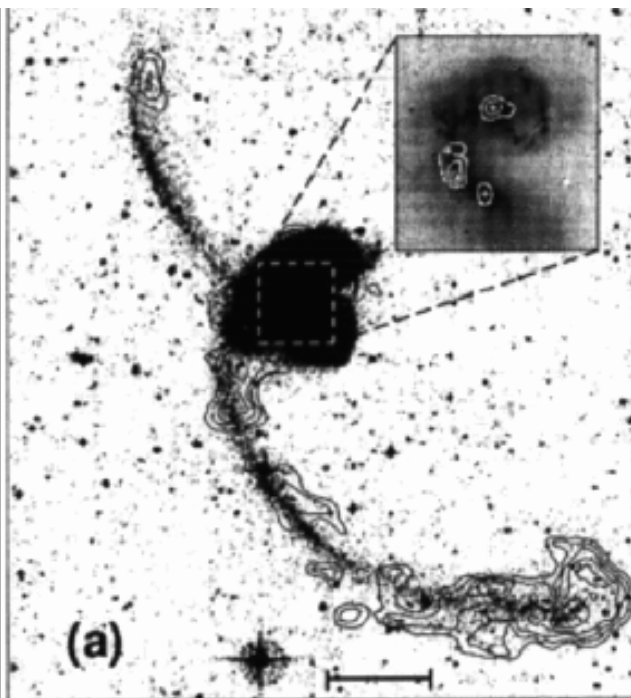


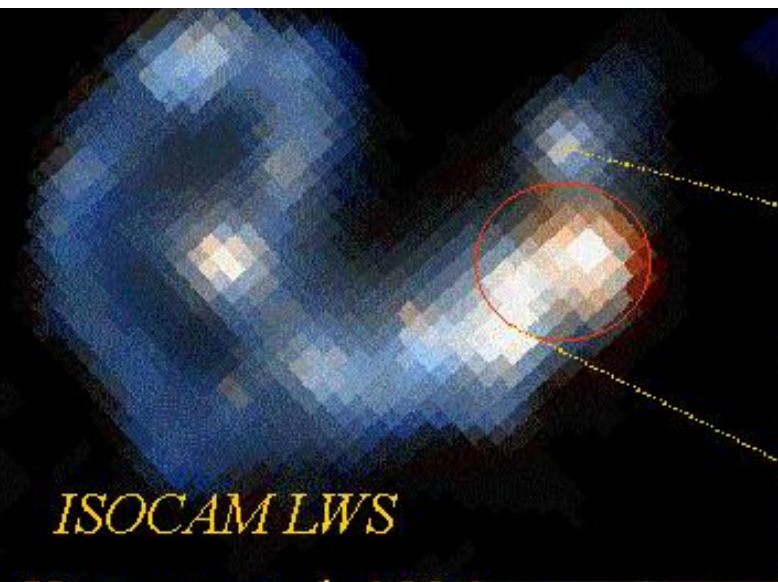
FIG. 14.—Views of stars (*left*) and gas (*right*) in the merger remnant produced by encounter A at time $t = 6$. The stellar view is 0.8×0.8 length units, while the view of the gas is enlarged by a factor of 20. Over 60% of all the gas in this remnant lies in this dense central blob.

5



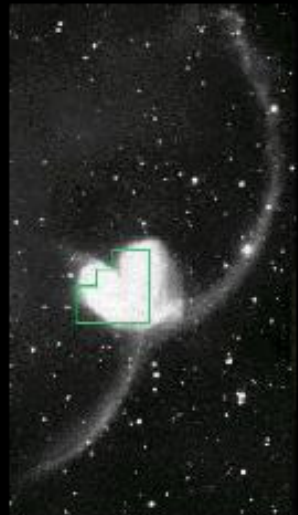
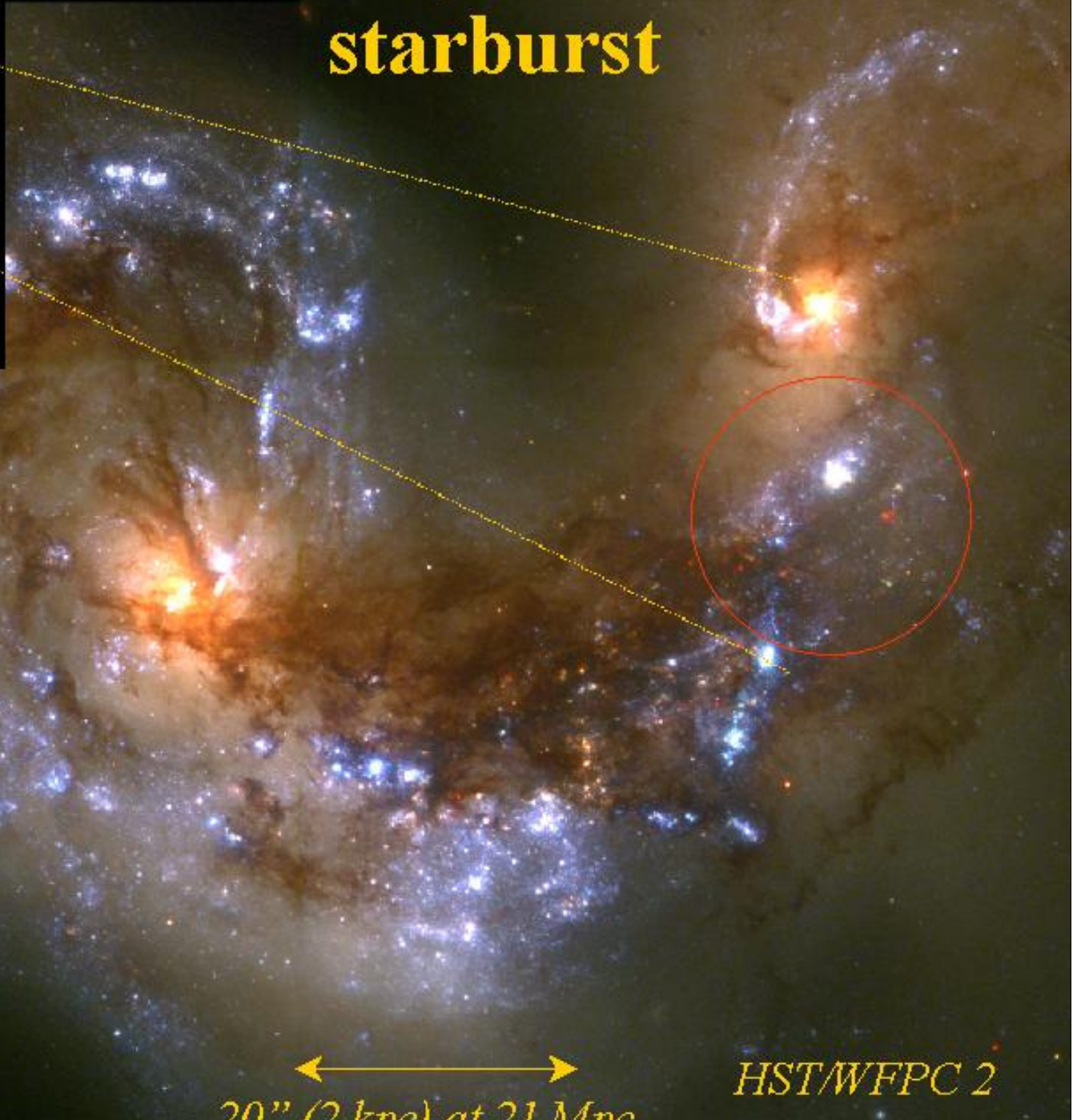


galaxy collision triggers starburst



ISOCAM LWS

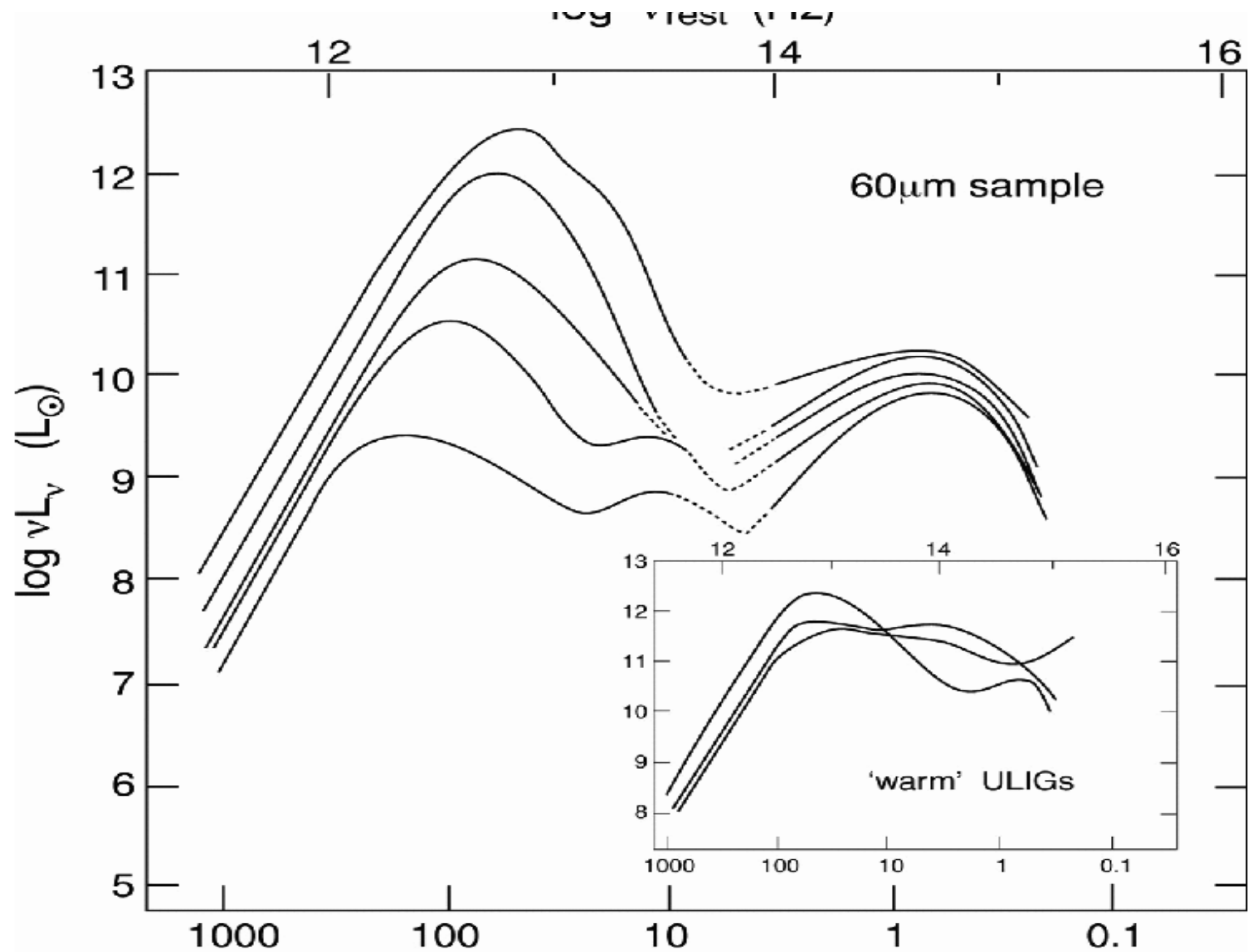
Vigroux et al. 1996



NGC 4038/39

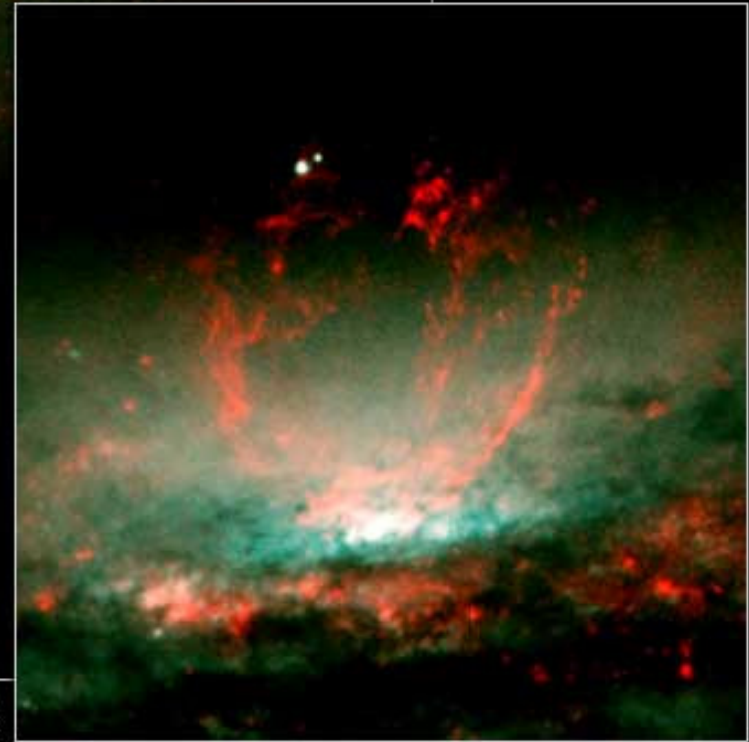
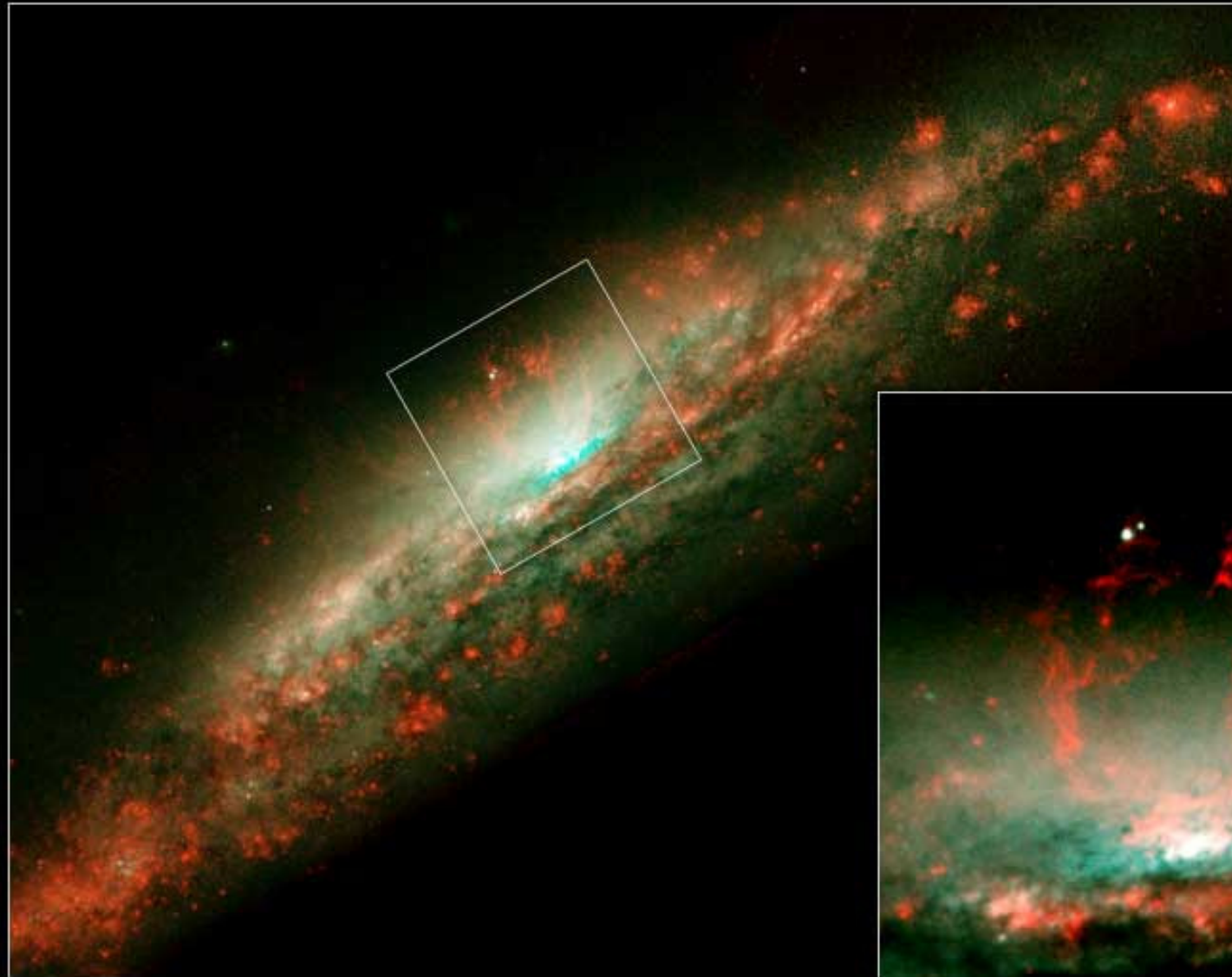
←→
20" (2 kpc) at 21 Mpc

HST/WFPC 2



Property	Spiral disks	Circumnuclear regions (including starbursts)
Radius	1–30 kpc	0.2–2 kpc
Star formation rate (SFR)	0–20 $M_{\odot}\text{yr}^{-1}$	0–1000 $M_{\odot}\text{yr}^{-1}$
Bolometric luminosity	10^6 – 10^{11} M_{\odot}	10^6 – 10^{13} M_{\odot}
Gas mass	10^8 – 10^{11} M_{\odot}	10^6 – 10^{11} M_{\odot}
Star formation time scale	1–50 Gyr	0.1–1 Gyr
Gas density	1–100 $M_{\odot}\text{pc}^{-2}$	10^2 – 10^5 $M_{\odot}\text{pc}^{-2}$
Optical depth (0.5 μm)	0–2	1–1000
SFR density	0–0.1 $M_{\odot}\text{yr}^{-1}\text{kpc}^{-2}$	1–1000 $M_{\odot}\text{yr}^{-1}\text{kpc}^{-2}$
Dominant mode	steady state	steady state + burst
Type dependence	strong	weak/none
Bar dependence	weak/none	strong
Spiral structure dependence	weak/none	weak/none
Interactions dependence	moderate	strong
Cluster dependence	moderate/weak	moderate
Redshift dependence	strong	?

Ventos : poluição ambiental via
“furacões”

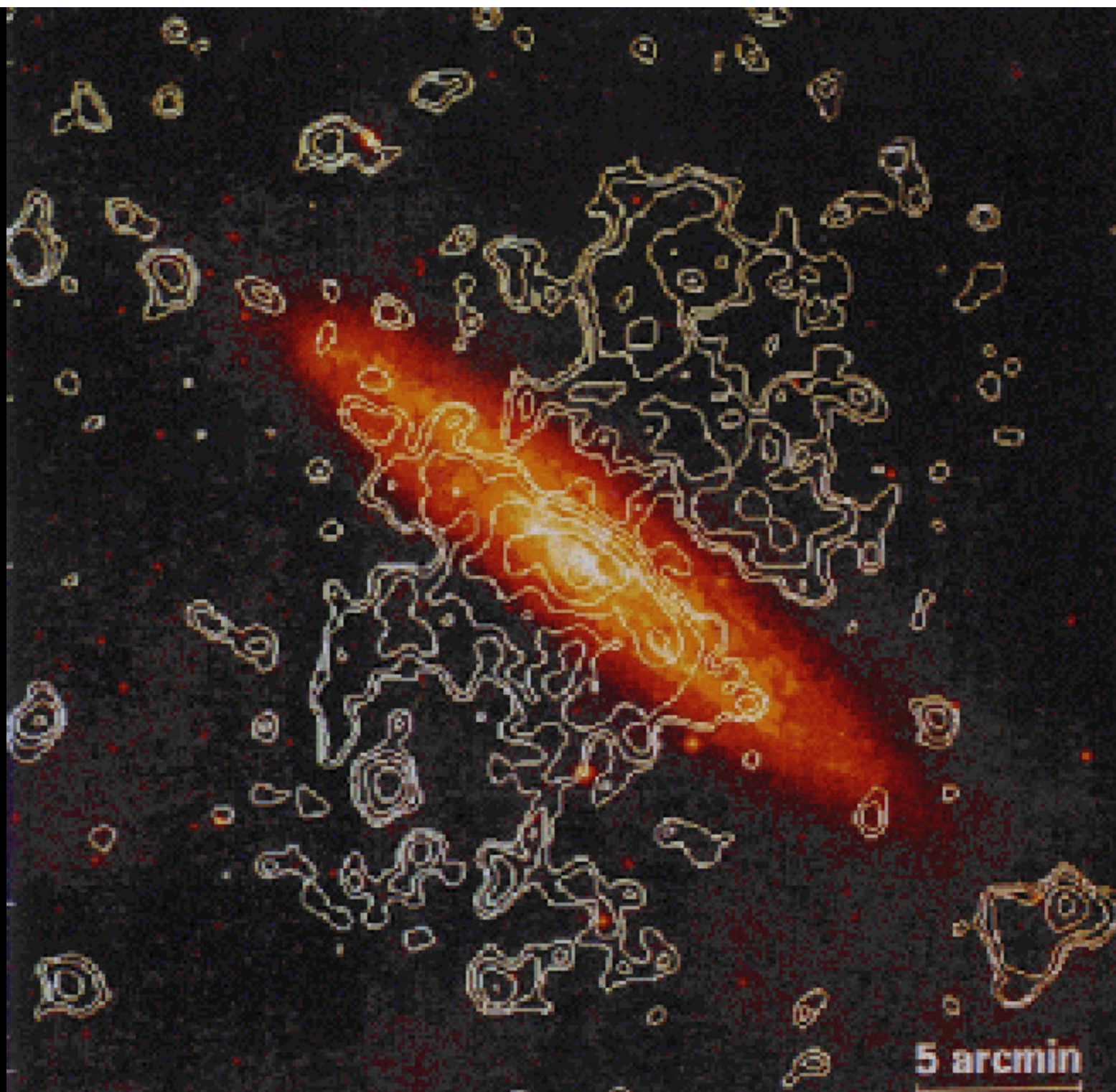


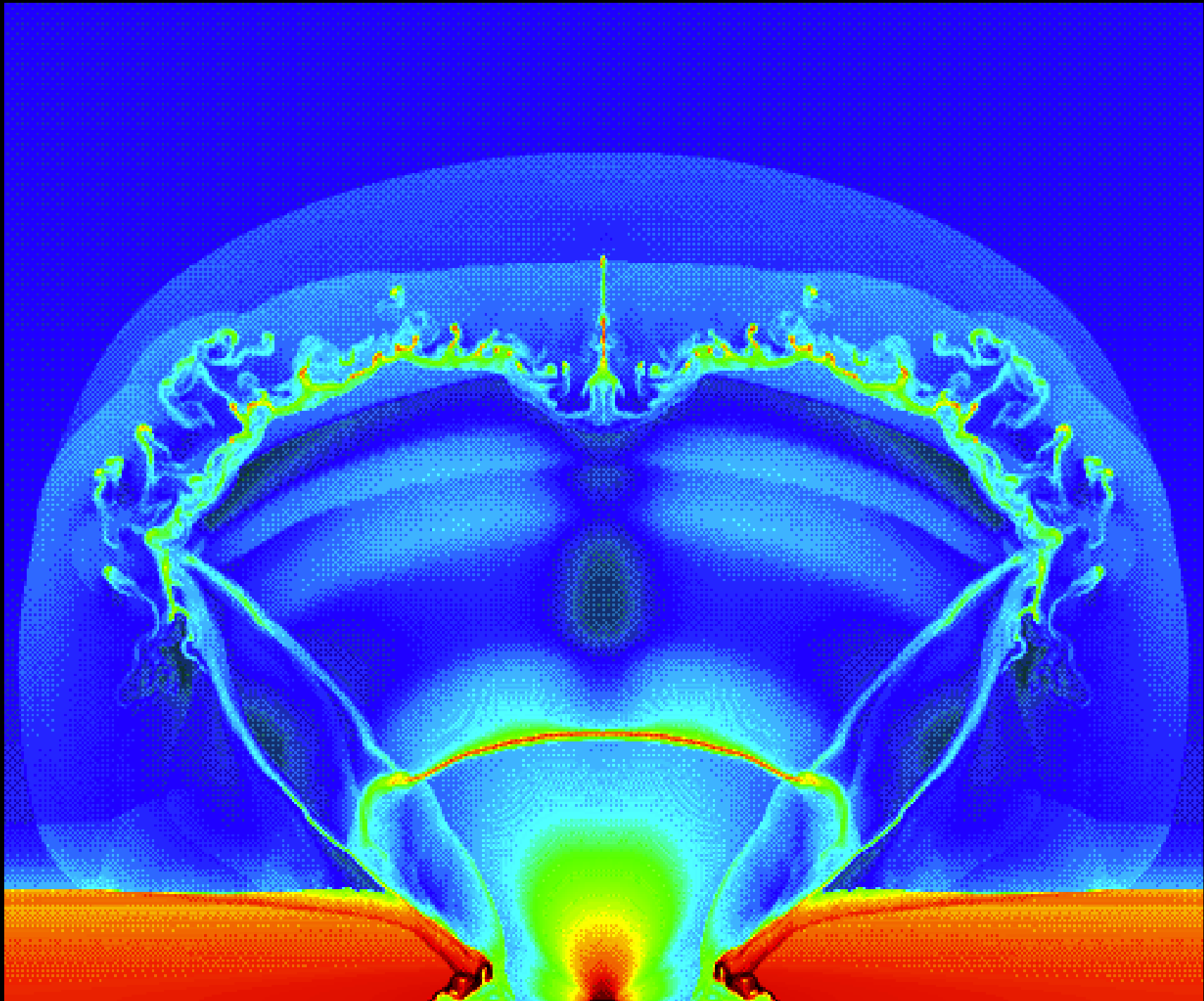
Galaxy NGC 3079

HST • WFPC2

NASA and G. Cecil (University of North Carolina) • STScI-PRC01-28



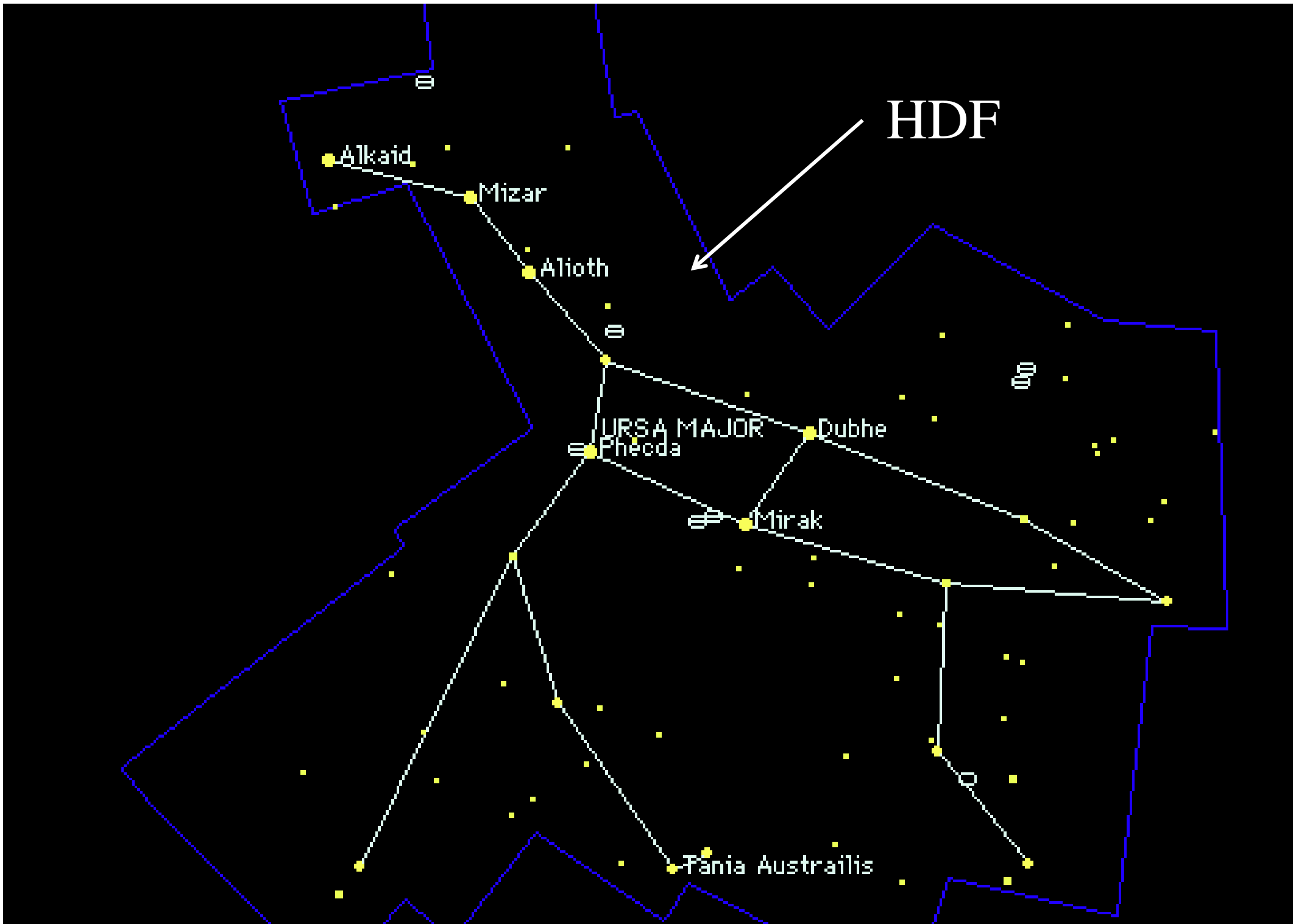


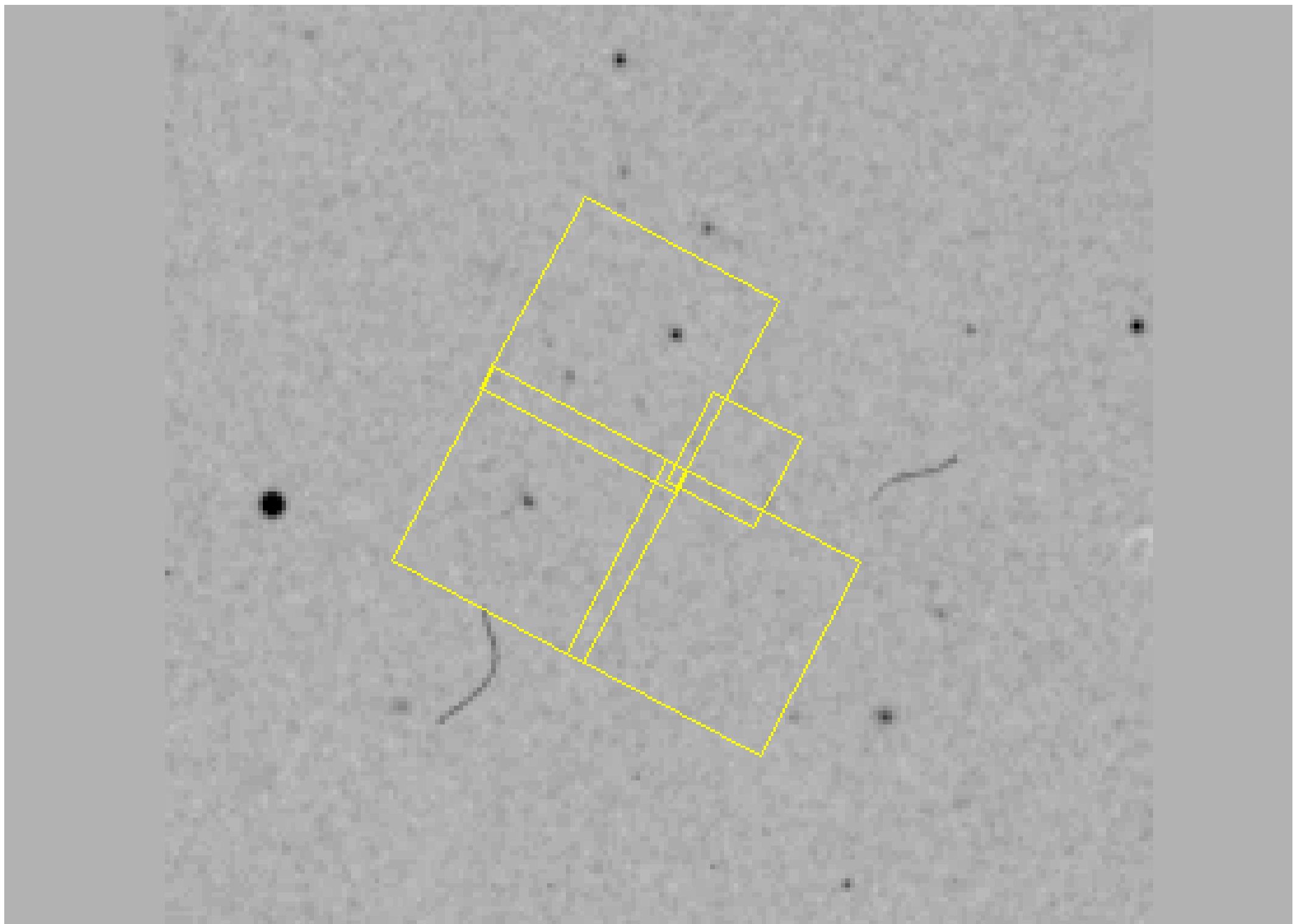










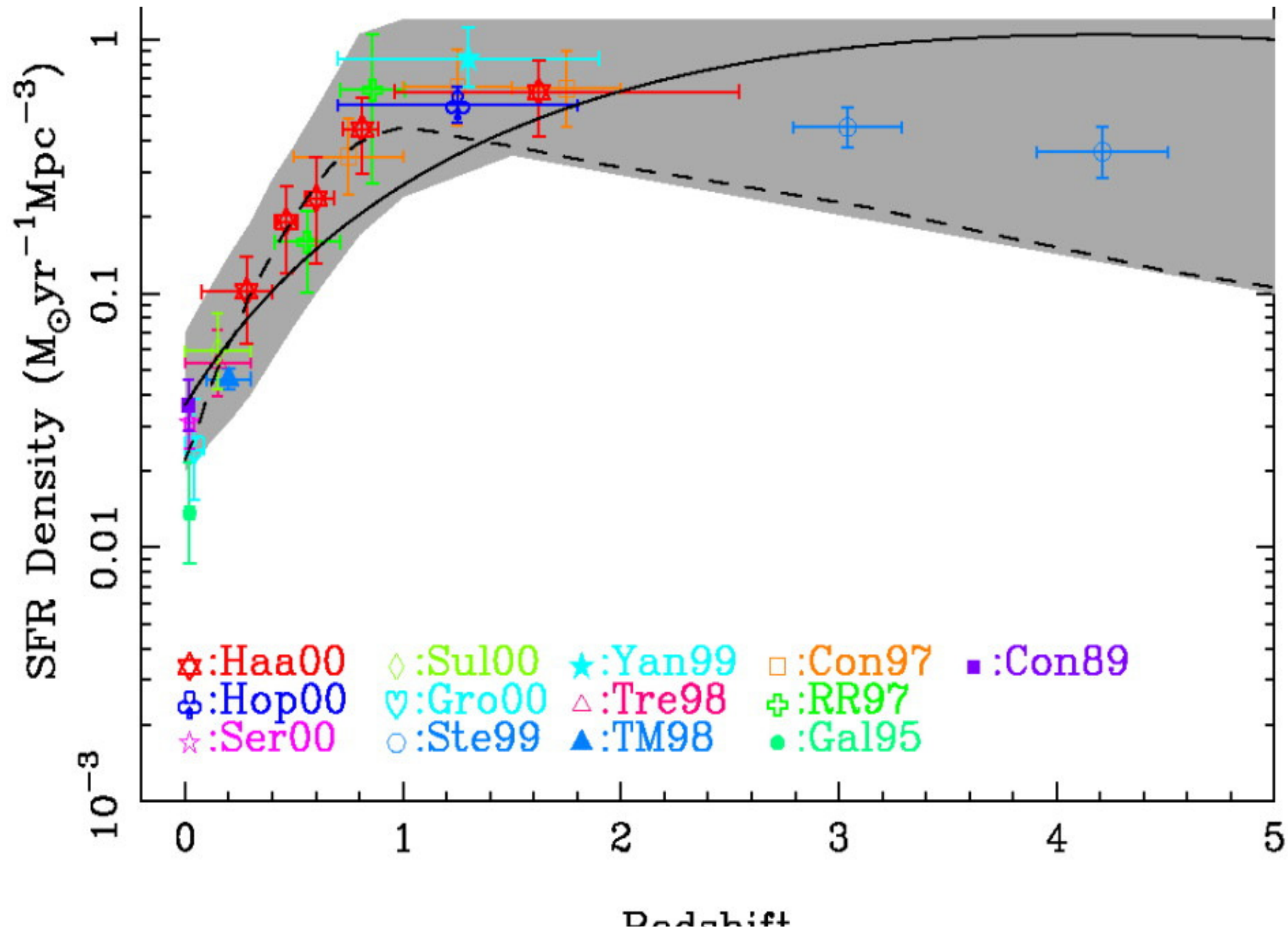






Galaxy Building Blocks

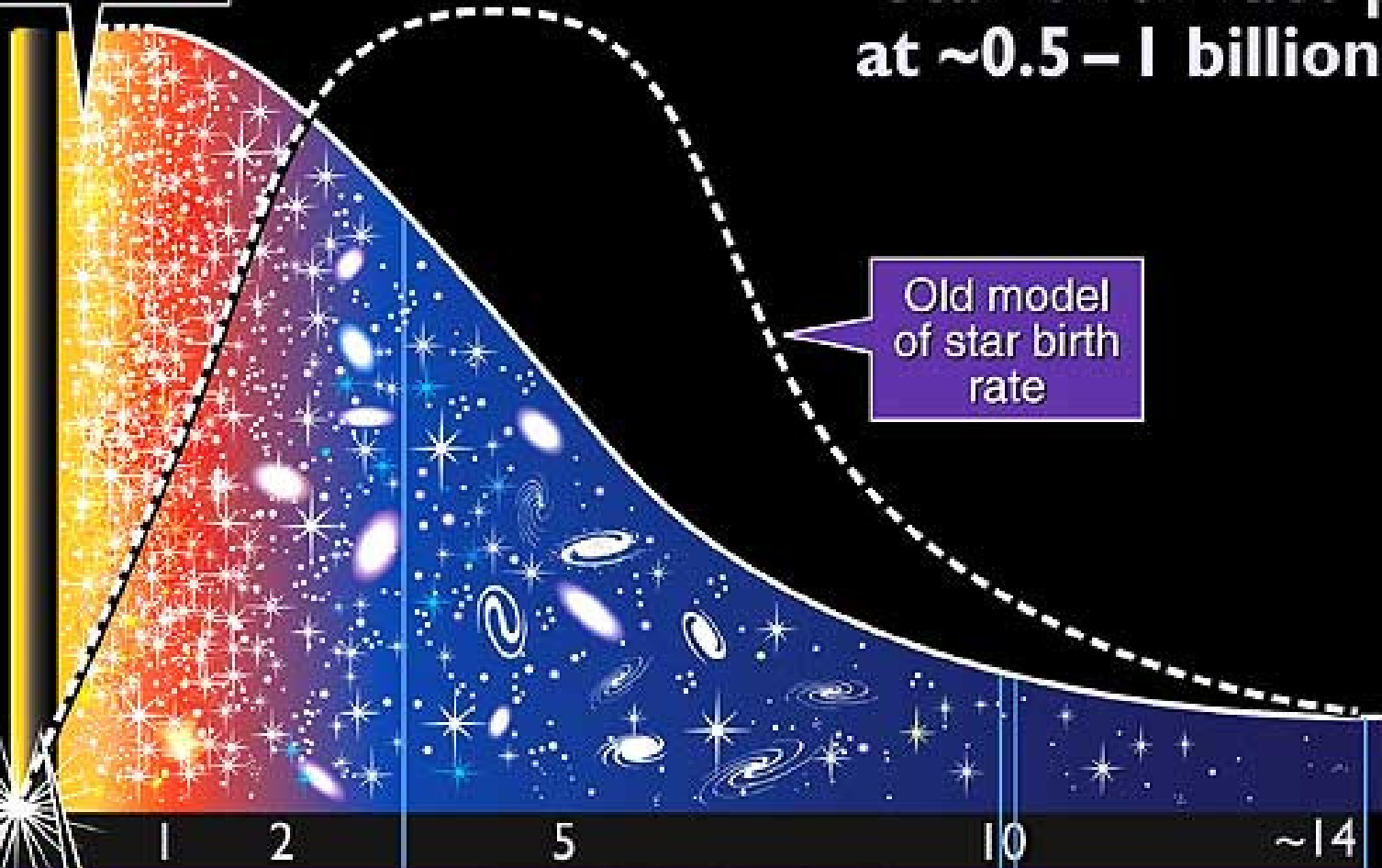
Hubble Space Telescope - Wide Field Planetary Camera 2



New model: Star birth rate peaks at ~0.5 – 1 billion years

Star birth begins

Old model of star birth rate



1 2 5 10 ~14
BILLIONS OF YEARS

Big bang

Dark era

Milky Way galaxy forms

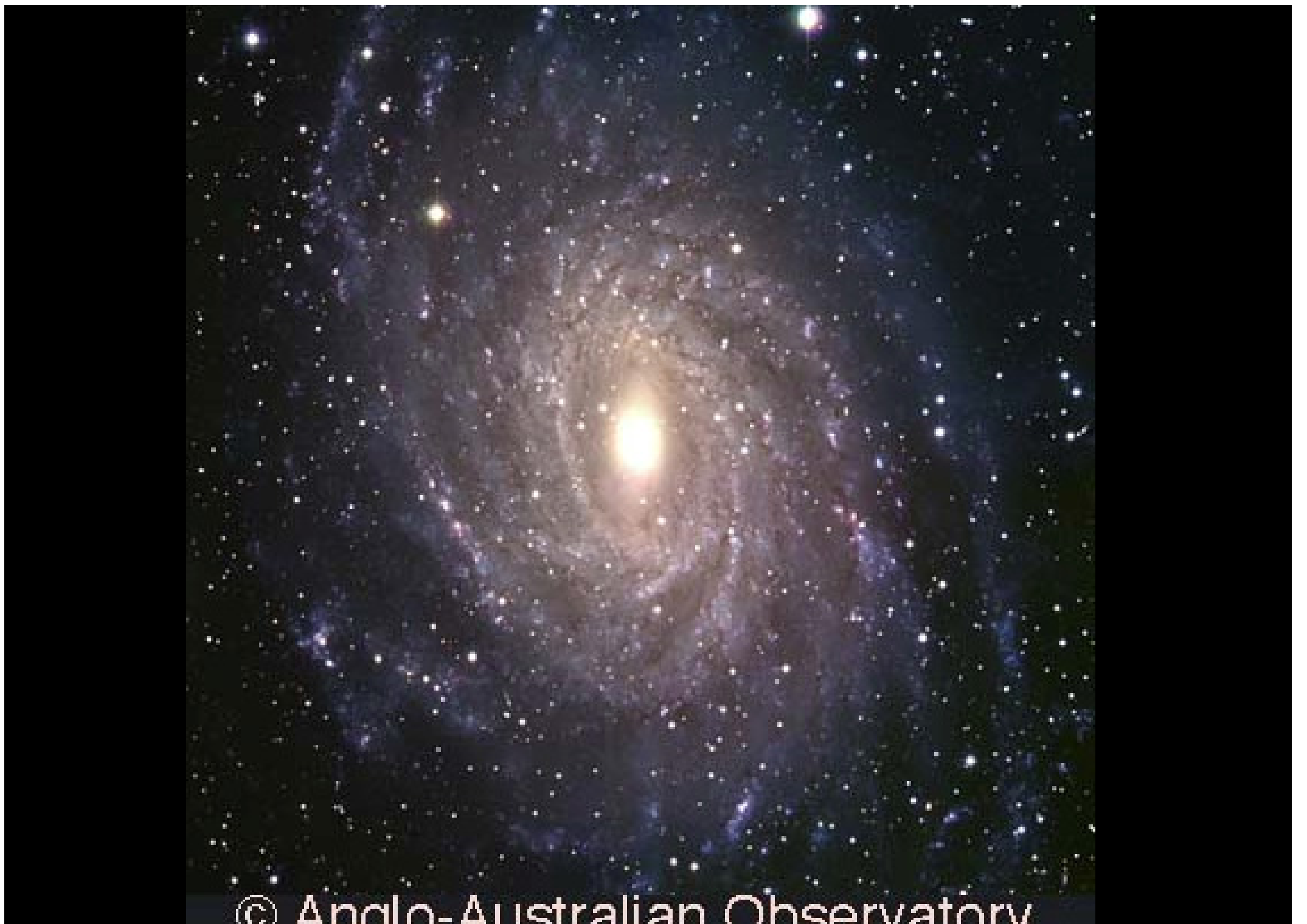
Our Solar System forms

Life appears on Earth

Humankind evolves

Buracos negros

- Dificuldades & métodos
- Exemplo #1 : a Via Láctea
- Outros exemplos : gás, estrelas, masers
- Demografia de buracos negros – > nucleos!
- Acreção Buracos Negros : actividade nuclear
Evolução Cósmica – via mergers e SF



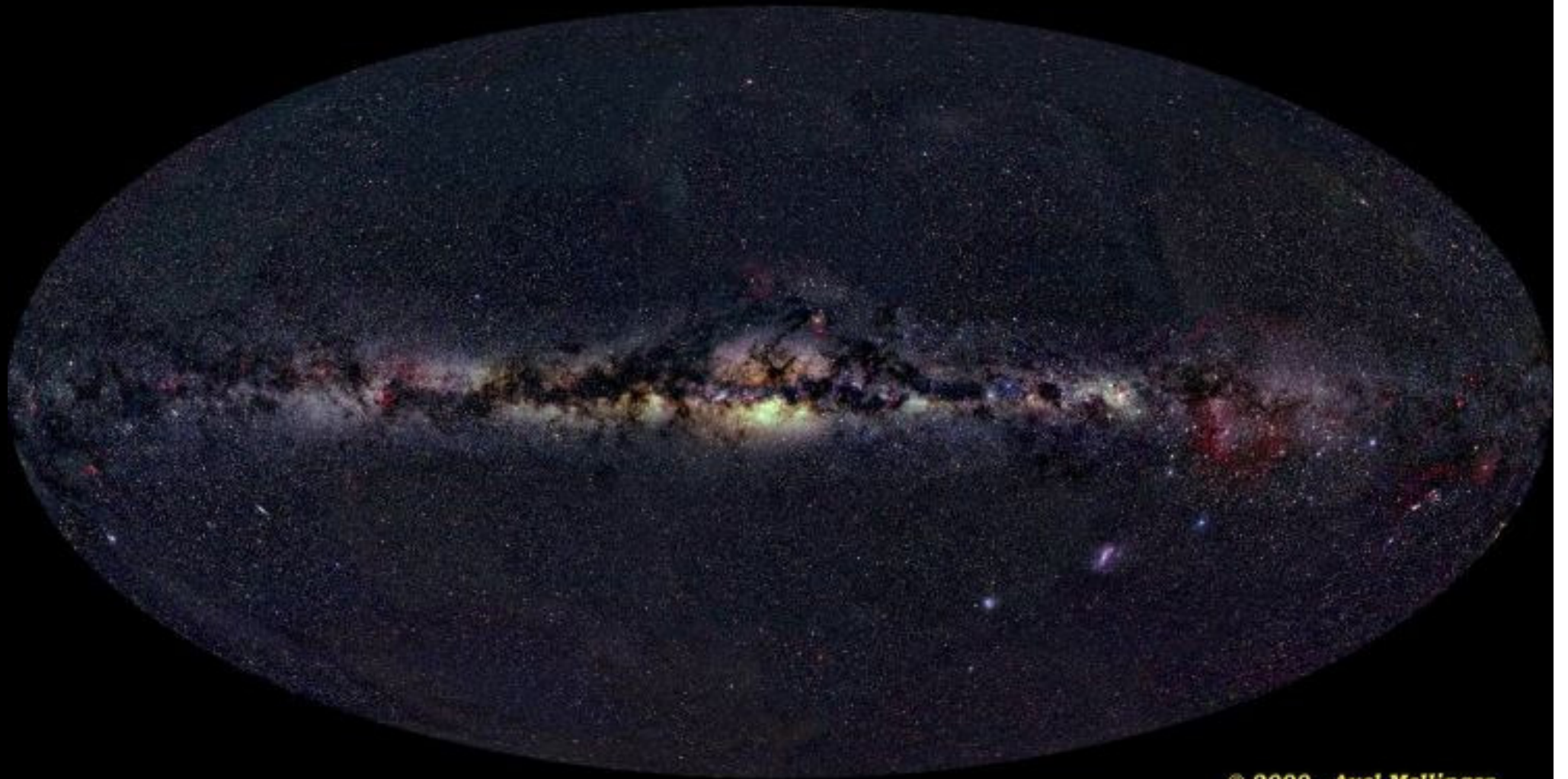
© Anglo-Australian Observatory

- High spatial resolution is critical

The region influenced by the black hole is *small* (call this r_{BH}):
for nuclear velocities V_c or σ far from the BH, we have :

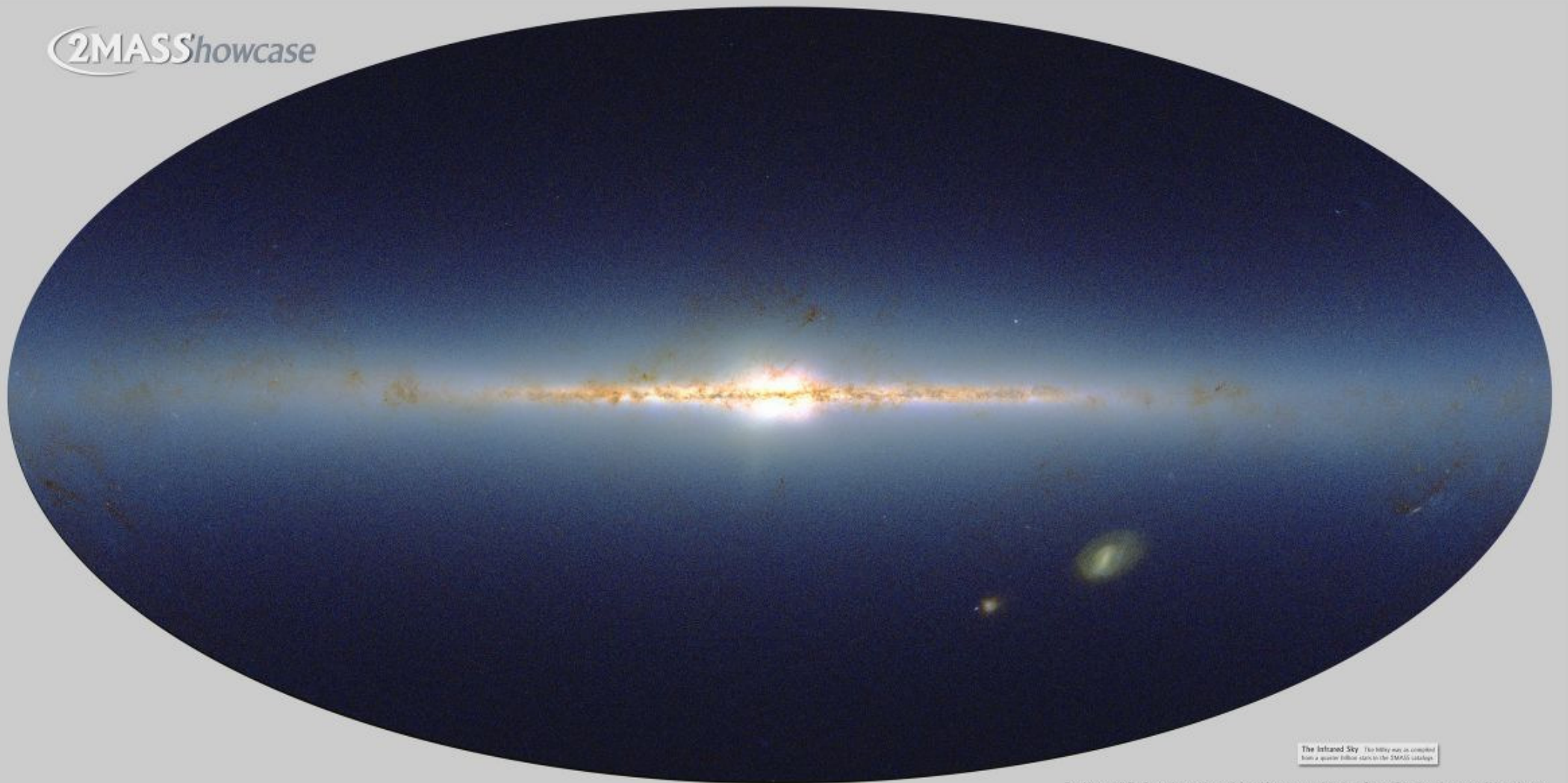
$$r_{\text{BH}} \approx GM_{\text{BH}} / V_c^2 \approx GM_{\text{BH}} / \sigma^2 \approx 1.5 M_7 \sigma_{200}^{-2} \text{ pc}$$

Example #1 : the milky way



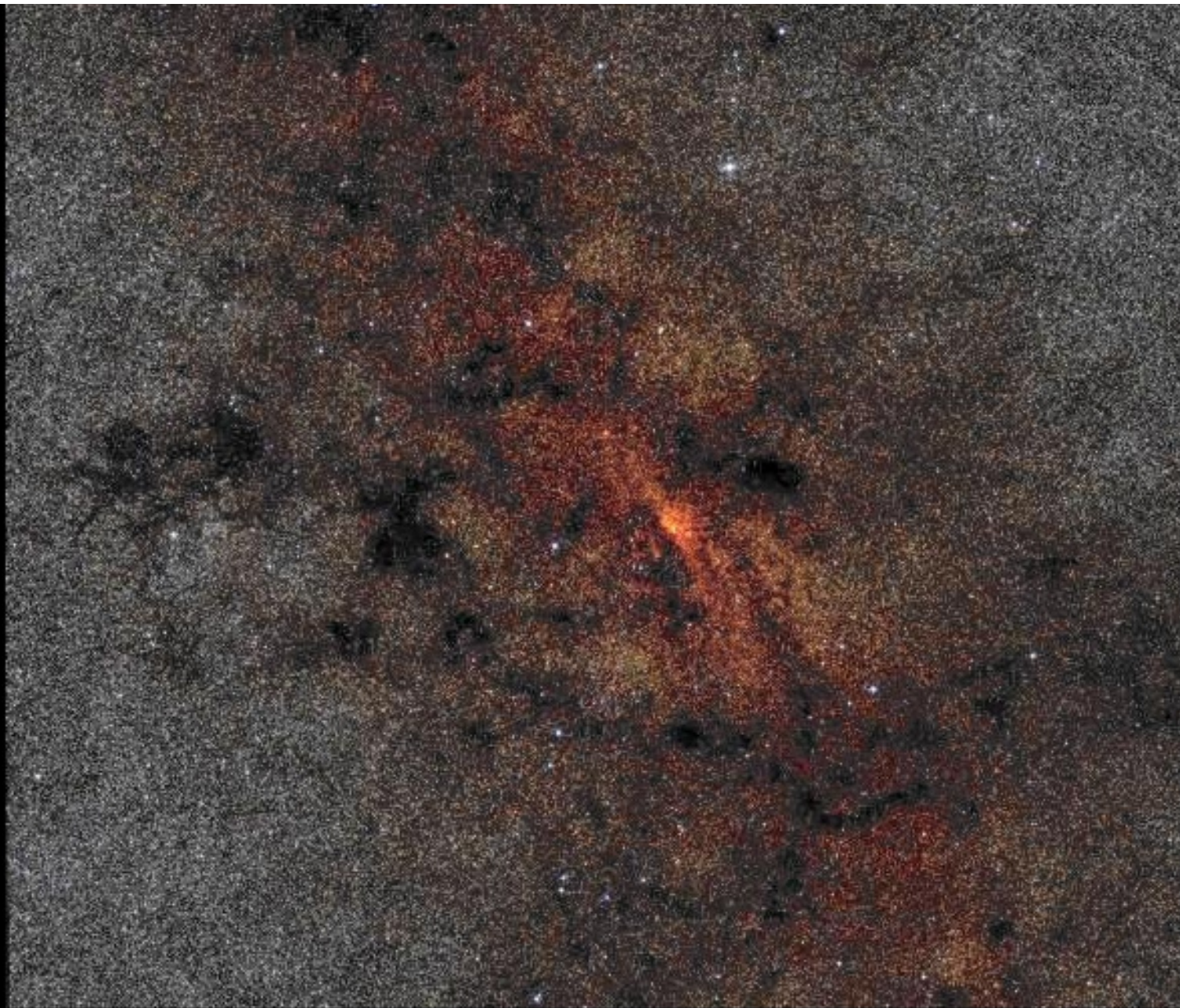
© 2000, Axel Mellinger

2MASS' showcase



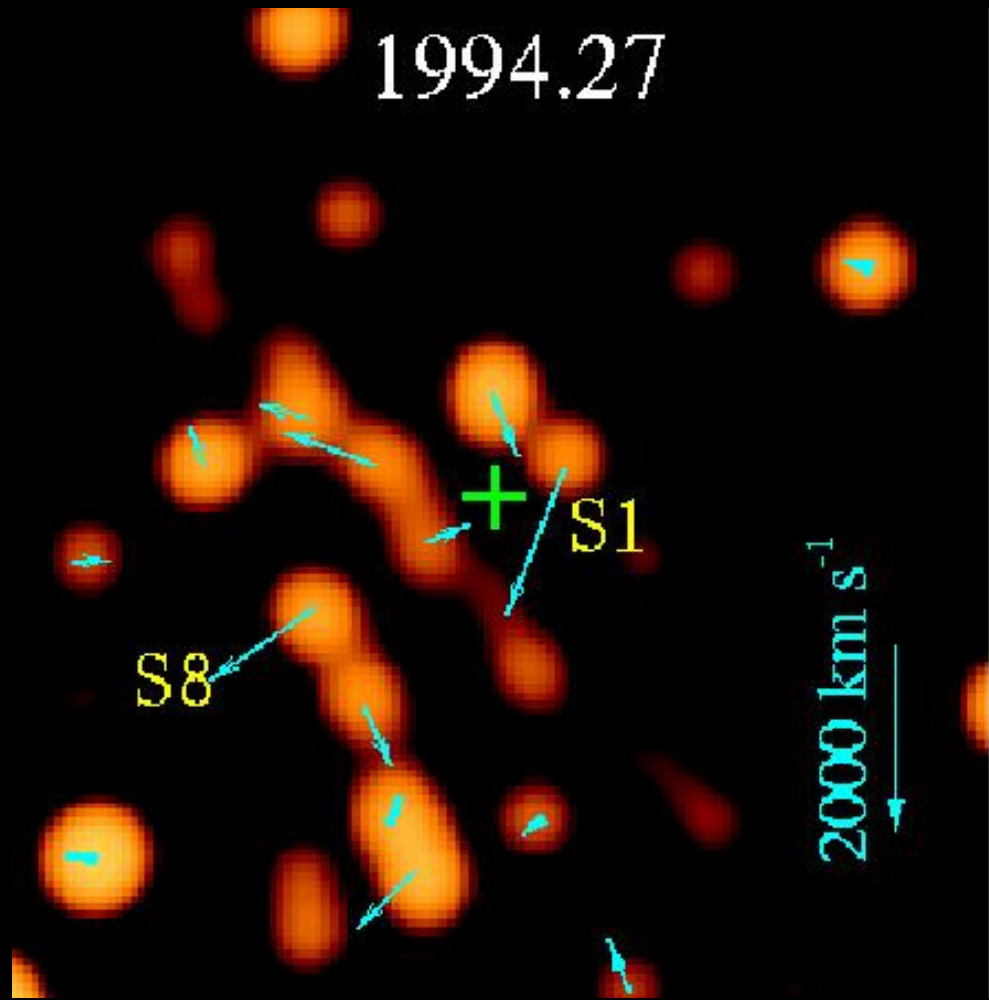
The Infrared Sky This image was compiled from a quarter billion stars in the 2MASS catalog.

Two Micron All Sky Survey Image Mosaic: Infrared Processing and Analysis Center/Caltech & University of Massachusetts

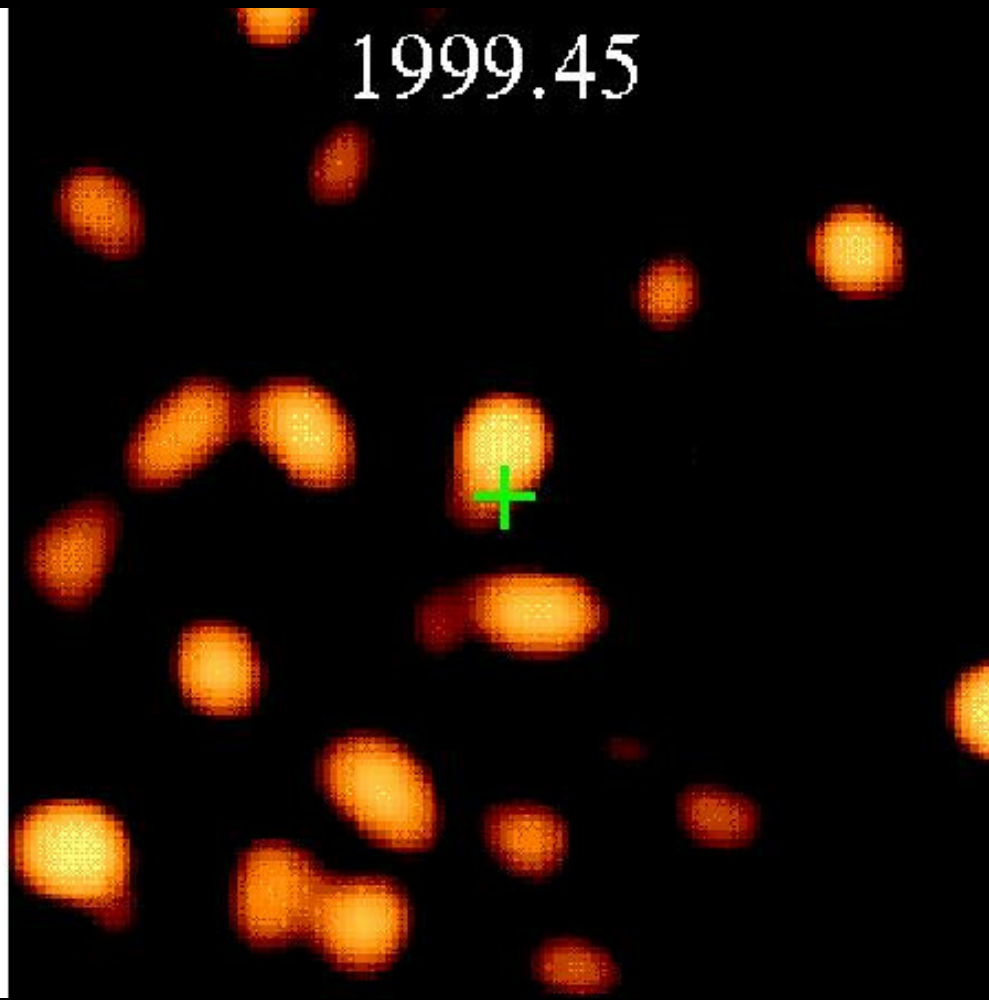


Two Micron All Sky Survey
– Southern Facility –
2MASS Atlas Image Mosaic

1994.27



1999.45

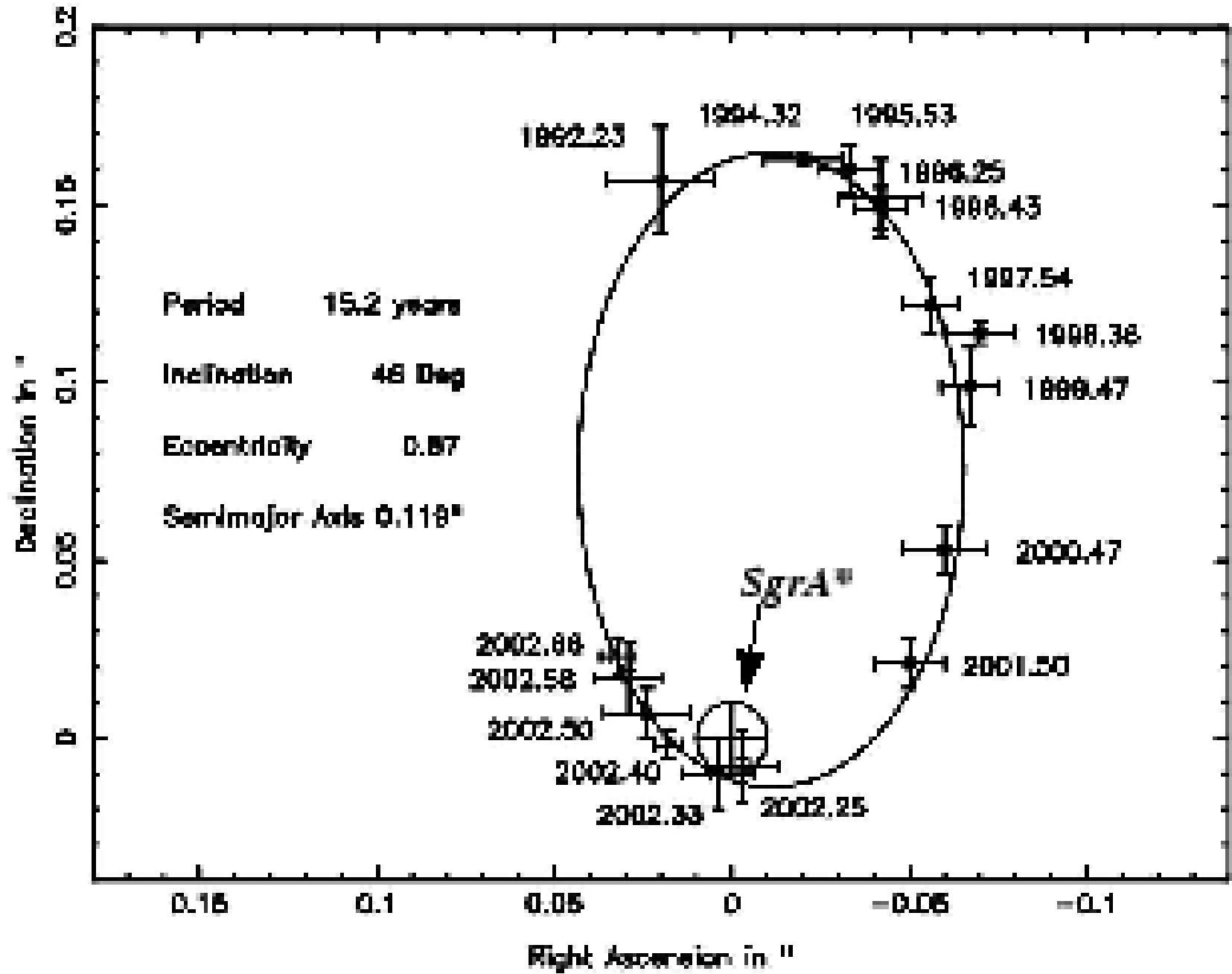


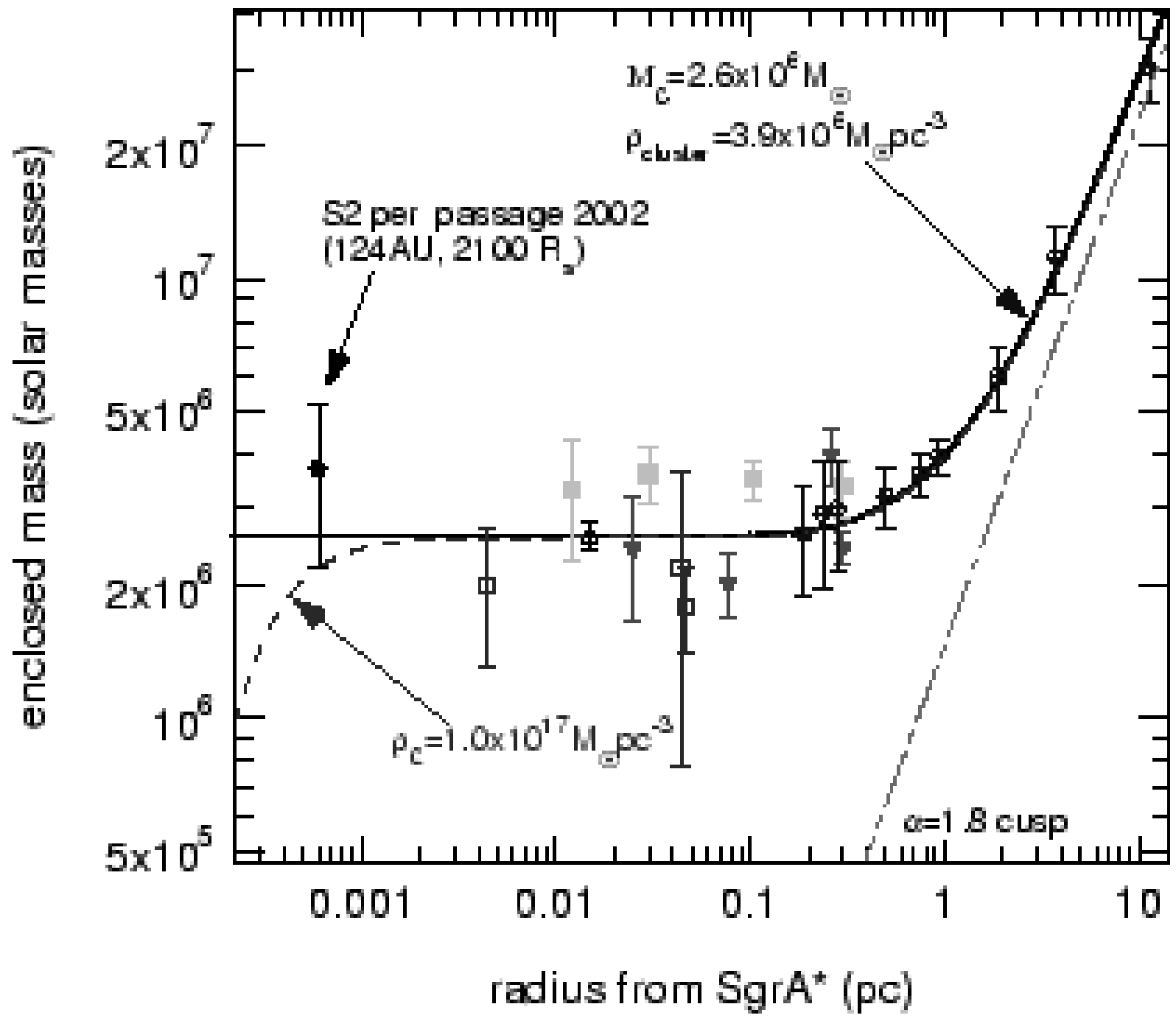
1992

10 light days



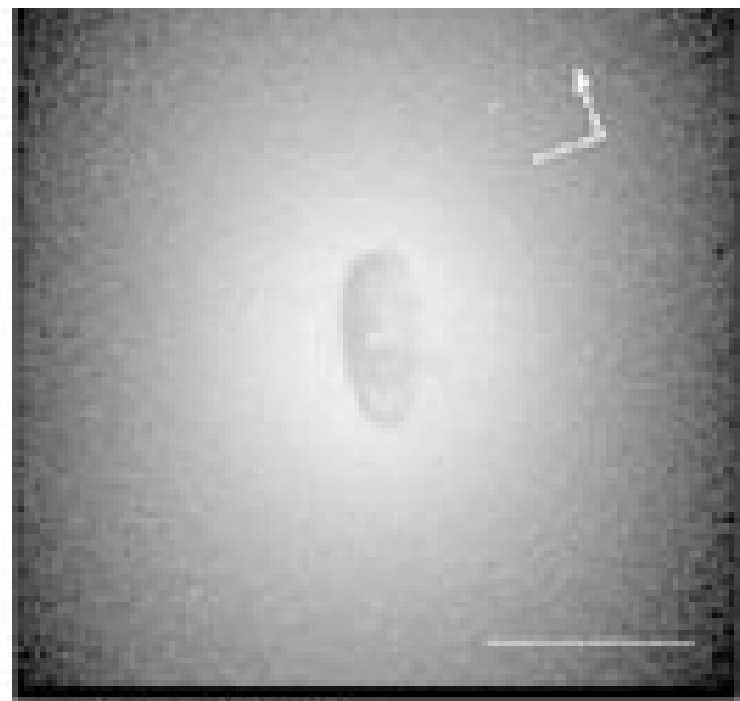
Orbit of 92



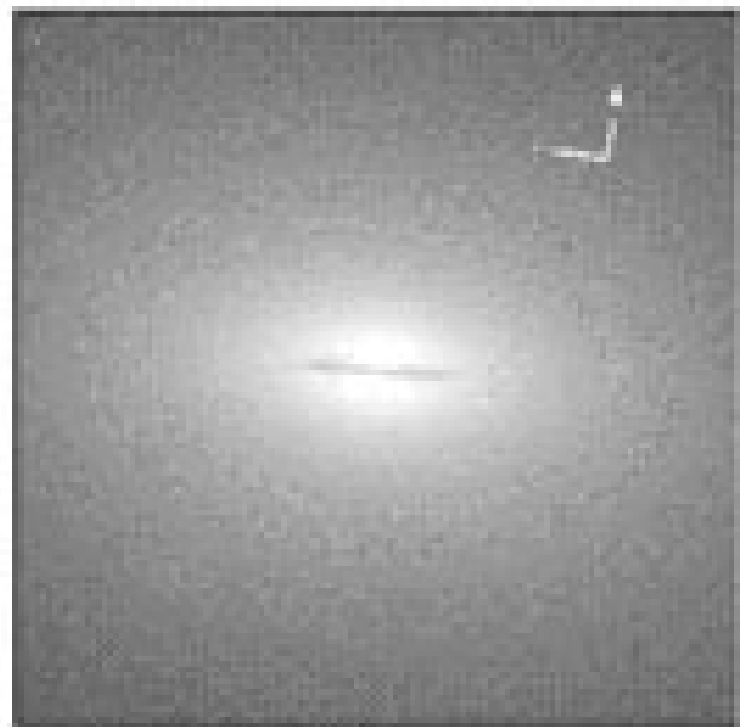
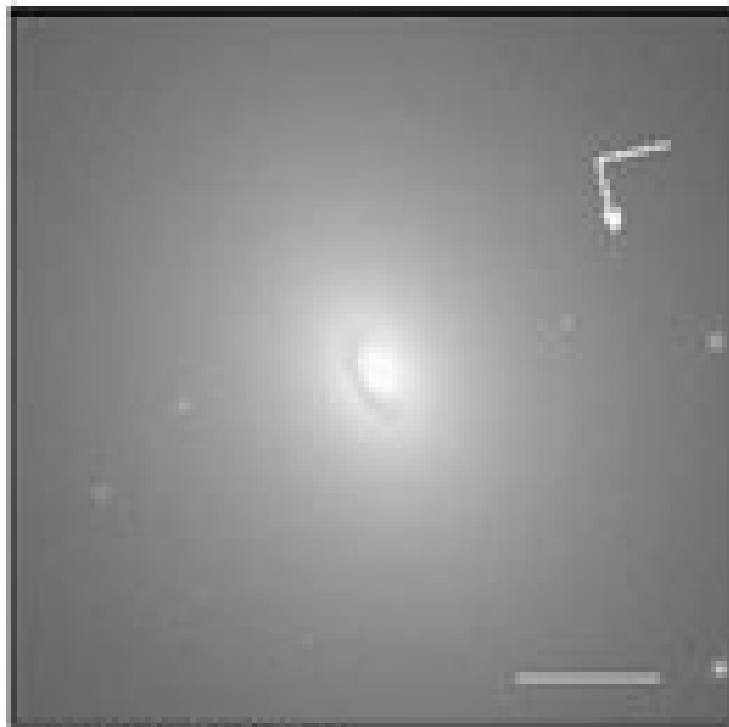




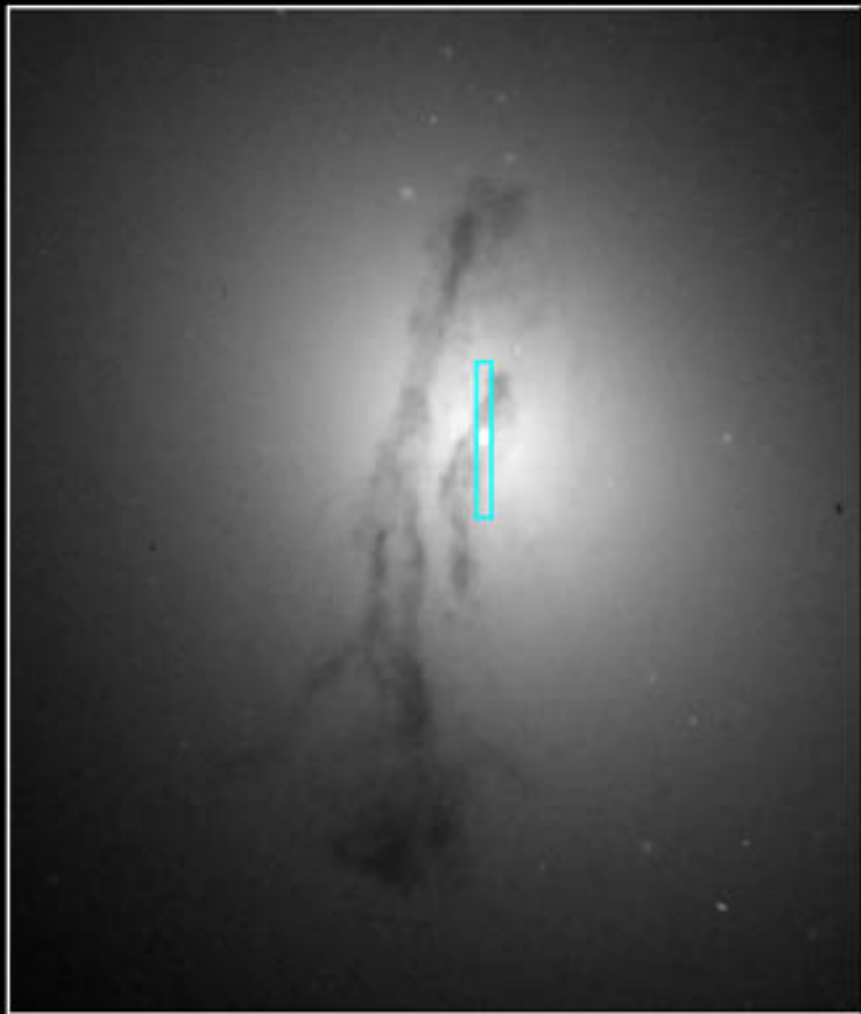
NGC 315



NGC 4281

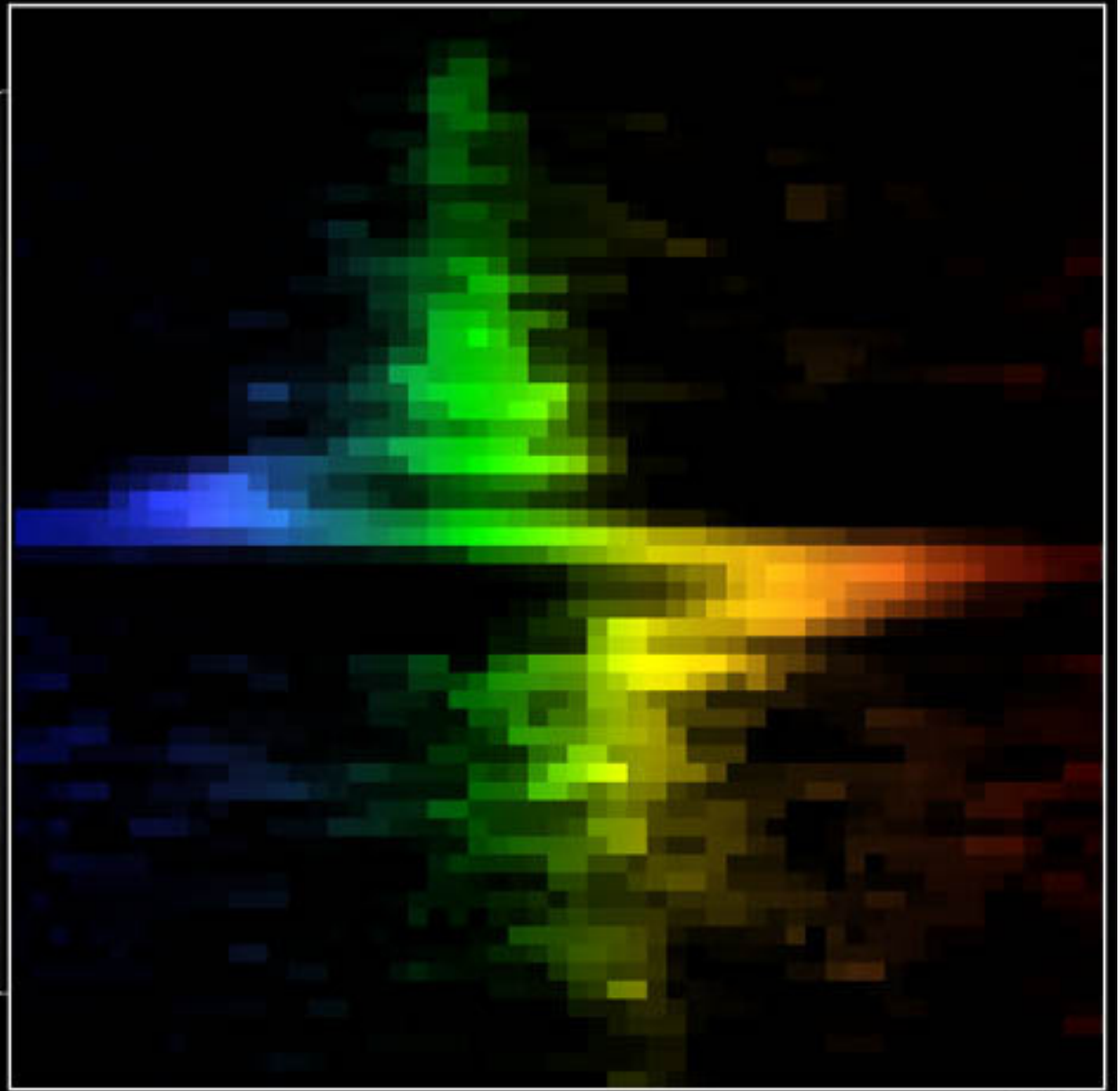


Galaxy M84 Nucleus

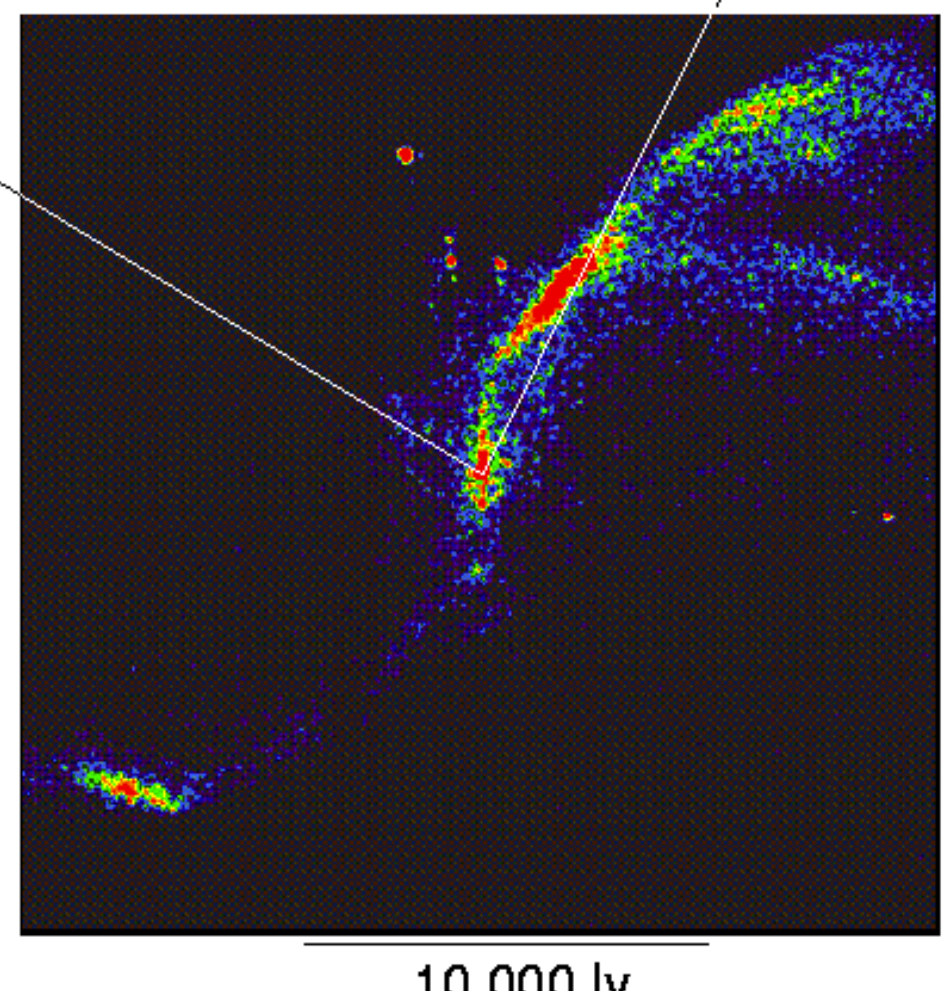
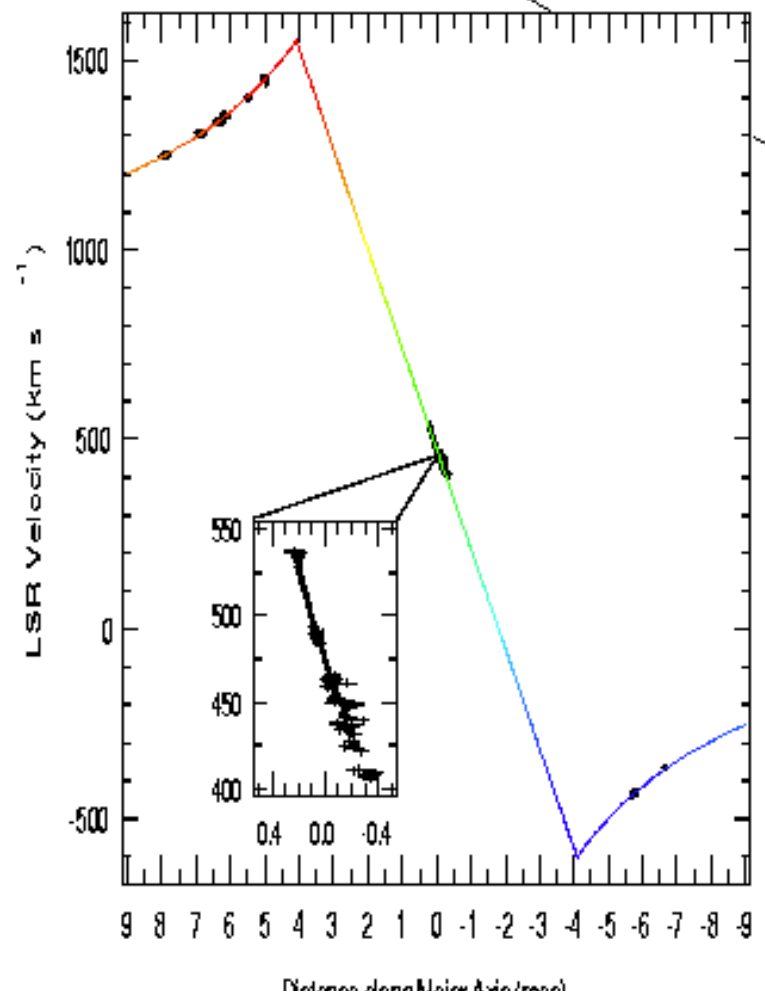
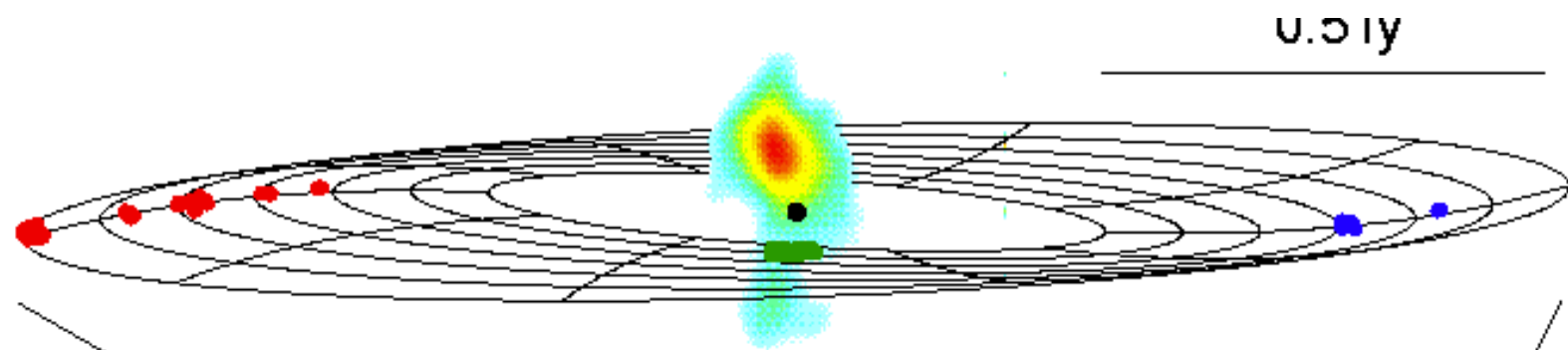


WFPC2

Hubble Space Telescope

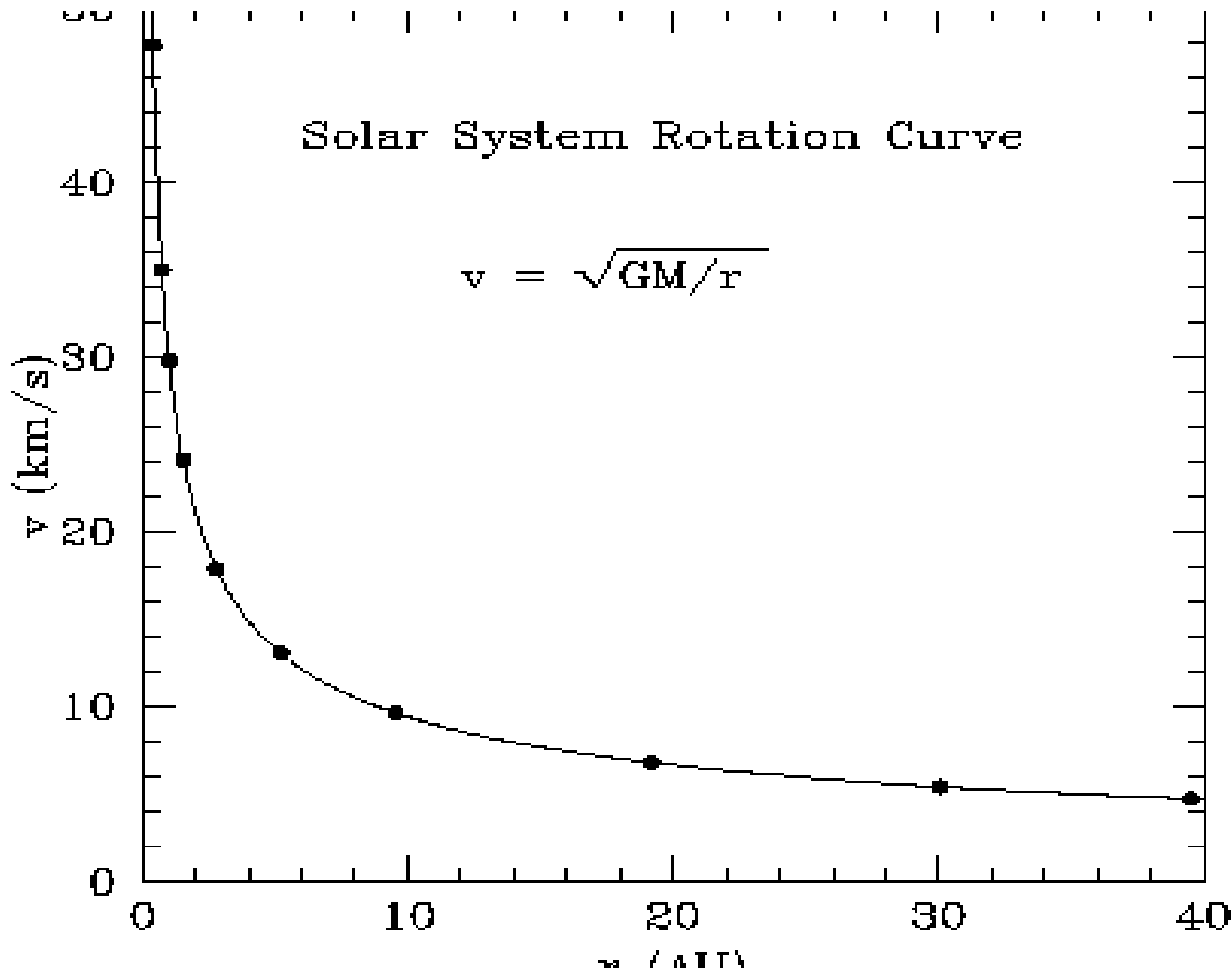


STIS



Solar System Rotation Curve

$$v = \sqrt{GM/r}$$



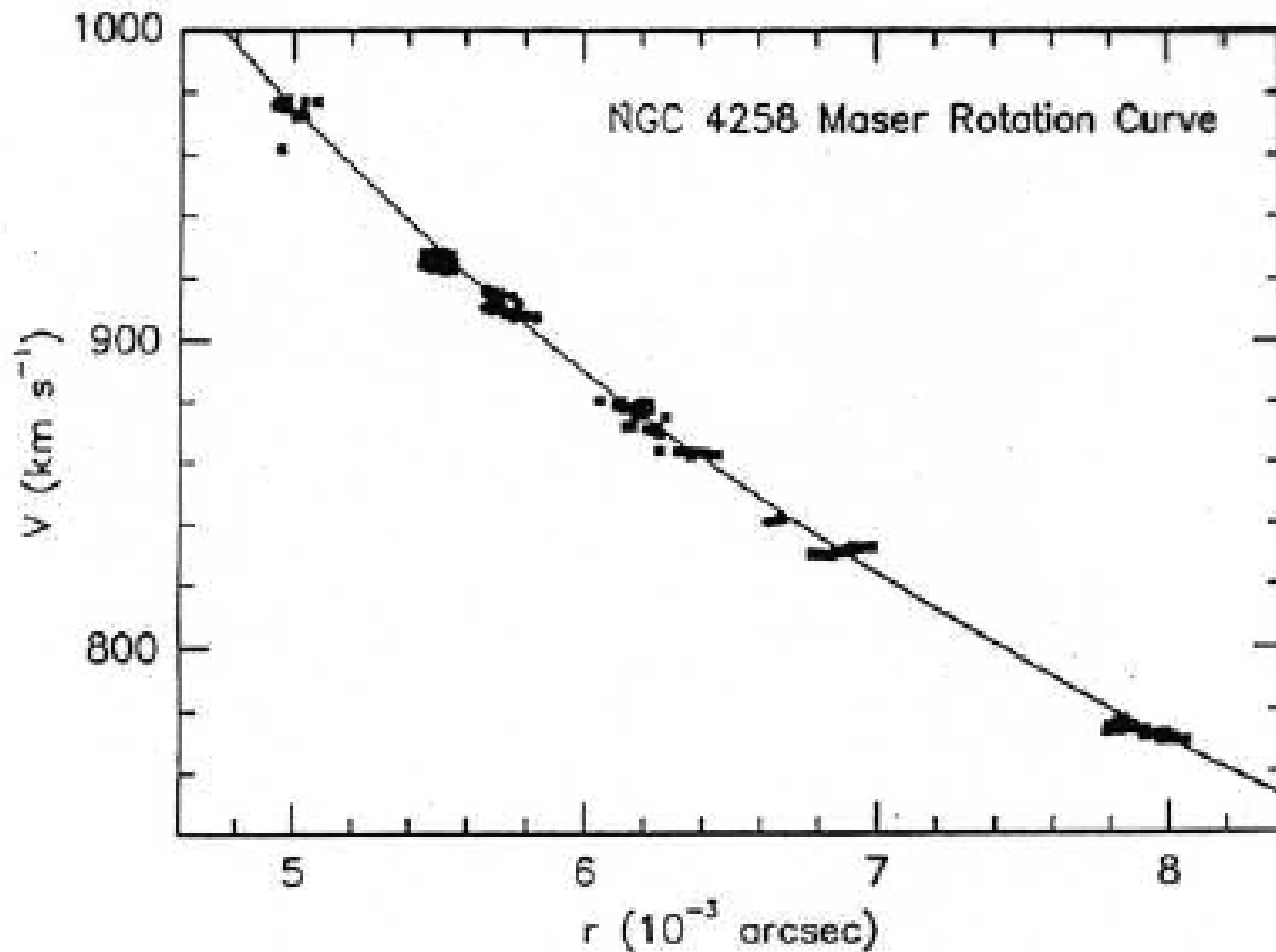


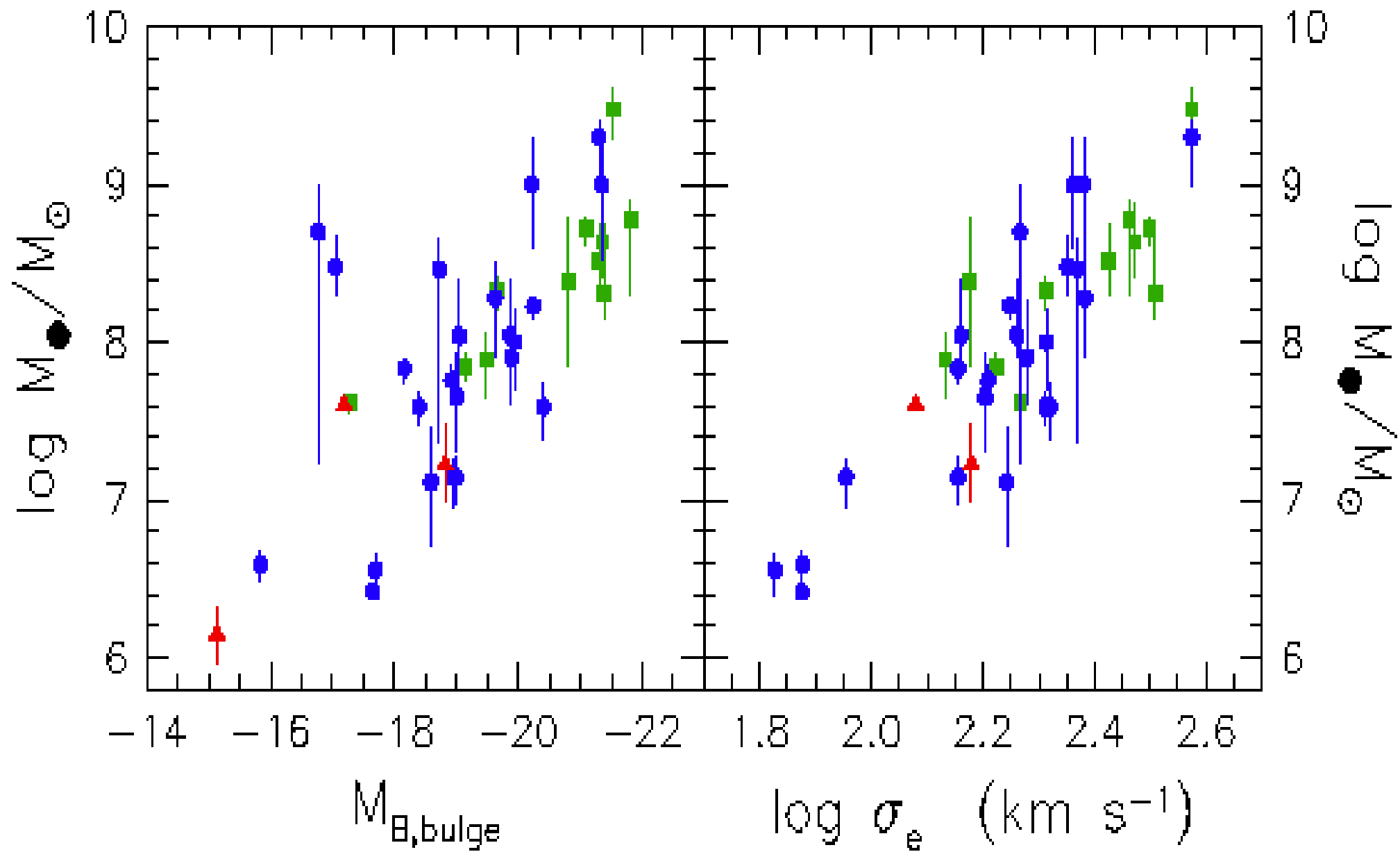
Figure 13 Rotation curve for maser sources in NGC 4258 (from Miyoshi et al 1995). The line is the Keplerian $V(r)$ given in the text.

TABLE 1
Census of Supermassive Black Holes (2001 March)

Galaxy	Type	$M_{E,bulge}$	M_{\bullet} (M_{low} : M_{high}) (M_{\odot})	σ_e (km/s)	D (Mpc)	r_{cusp} (arcsec)	Reference
Galaxy	Sbc	-17.65	2.6 (2.4-2.8) e6	75	0.008	51.40	See notes
M31	Sb	-19.00	4.5 (2.0-8.5) e7	160	0.76	2.06	Dressler + 1988; Kormendy 1988a
M32	E2	-15.83	3.9 (3.1-4.7) e6	75	0.81	0.76	Tonry 1984, 1987
M81	Sb	-18.16	6.8 (5.5-7.5) e7	143	3.9	0.76	Bower + 2001b
NGC 821	E4	-20.41	3.9 (2.4-5.6) e7	209	24.1	0.03	Gebhardt + 2001
NGC 1023	S0	-18.40	4.4 (3.8-5.0) e7	205	11.4	0.08	Bower + 2001a
NGC 2778	E2	-18.59	1.3 (0.5-2.9) e7	175	22.9	0.02	Gebhardt + 2001
NGC 3115	S0	-20.21	1.0 (0.4-2.0) e9	230	9.7	1.73	Kormendy + 1992
NGC 3377	E5	-19.05	1.1 (0.6-2.5) e8	145	11.2	0.42	Kormendy + 1998
NGC 3379	E1	-19.94	1.0 (0.5-1.6) e8	206	10.6	0.20	Gebhardt + 2000a
NGC 3384	S0	-18.99	1.4 (1.0-1.9) e7	143	11.6	0.05	Gebhardt + 2001
NGC 3608	E2	-19.86	1.1 (0.8-2.5) e8	182	23.0	0.13	Gebhardt + 2001
NGC 4291	E2	-19.63	1.9 (0.8-3.2) e8	242	26.2	0.11	Gebhardt + 2001
NGC 4342	S0	-17.04	3.0 (2.0-4.7) e8	225	15.3	0.34	Cretton + 1999a
NGC 4473	E5	-19.89	0.8 (0.4-1.8) e8	190	15.7	0.13	Gebhardt + 2001
NGC 4486B	E1	-16.77	5.0 (0.2-9.9) e8	185	16.1	0.81	Kormendy + 1997
NGC 4564	E3	-18.92	5.7 (4.0-7.0) e7	162	15.0	0.13	Gebhardt + 2001
NGC 4594	Sa	-21.35	1.0 (0.3-2.0) e9	240	9.8	1.58	Kormendy + 1988b
NGC 4649	E1	-21.30	2.0 (1.0-2.5) e9	375	16.8	0.75	Gebhardt + 2001
NGC 4697	E4	-20.24	1.7 (1.4-1.9) e8	177	11.7	0.41	Gebhardt + 2001
NGC 4742	E4	-18.94	1.4 (0.9-1.8) e7	90	15.5	0.10	Kaiser + 2001
NGC 5845	E	-18.72	2.9 (0.2-4.6) e8	234	25.9	0.18	Gebhardt + 2001
NGC 7457	S0	-17.69	3.6 (2.5-4.5) e6	67	13.2	0.05	Gebhardt + 2001
NGC 2787	SB0	-17.28	4.1 (3.6-4.5) e7	185	7.5	0.14	Sarzi + 2001
NGC 3245	S0	-19.65	2.1 (1.6-2.6) e8	205	20.9	0.21	Barth + 2001
NGC 4261	E2	-21.09	5.2 (4.1-6.2) e8	315	31.6	0.15	Ferrarese + 1996
NGC 4374	E1	-21.36	4.3 (2.6-7.5) e8	296	18.4	0.24	Bower + 1998
NGC 4459	SA0	-19.15	7.0 (5.7-8.3) e7	167	16.1	0.14	Sarzi + 2001
M87	E0	-21.53	3.0 (2.0-4.0) e9	375	16.1	1.18	Harms + 1994
NGC 4596	SB0	-19.48	0.8 (0.5-1.2) e8	136	16.8	0.22	Sarzi + 2001
NGC 5128	S0	-20.80	2.4 (0.7-6.0) e8	150	4.2	2.26	Marconi + 2001
NGC 6251	E2	-21.81	6.0 (2.0-8.0) e8	290	106	0.06	Ferrarese + 1999
NGC 7052	E4	-21.31	3.3 (2.0-5.6) e8	266	58.7	0.07	van der Marel + 1998
IC 1459	E3	-21.39	2.0 (1.2-5.7) e8	323	29.2	0.06	Verdoes Kleijn + 2001
NGC 1068	Sb	-18.82	1.7 (1.0-3.0) e7	151	15	0.04	Greenhill + 1996
NGC 4258	Sbc	-17.19	4.0 (3.9-4.1) e7	120	7.2	0.36	Miyoshi + 1995
NGC 4945	Scd	-15.14	1.4 (0.9-2.1) e6		3.7		Greenhill + 1997

(b) The Ubiquity of Nuclear Black Holes

- Kormendy's March 2001 census lists 37 measured black hole masses (viewgraph)
a similar number can be added by combining ground based spectroscopy with HST imaging
- *All classes of galaxy are found, with the exception of those with little or no bulge*
When detection threshold allows (see below), a black hole is found $\approx 95\%$ of the time
 - *almost all galaxies with bulges seem to have nuclear black holes*
 - *This is a remarkable result!*





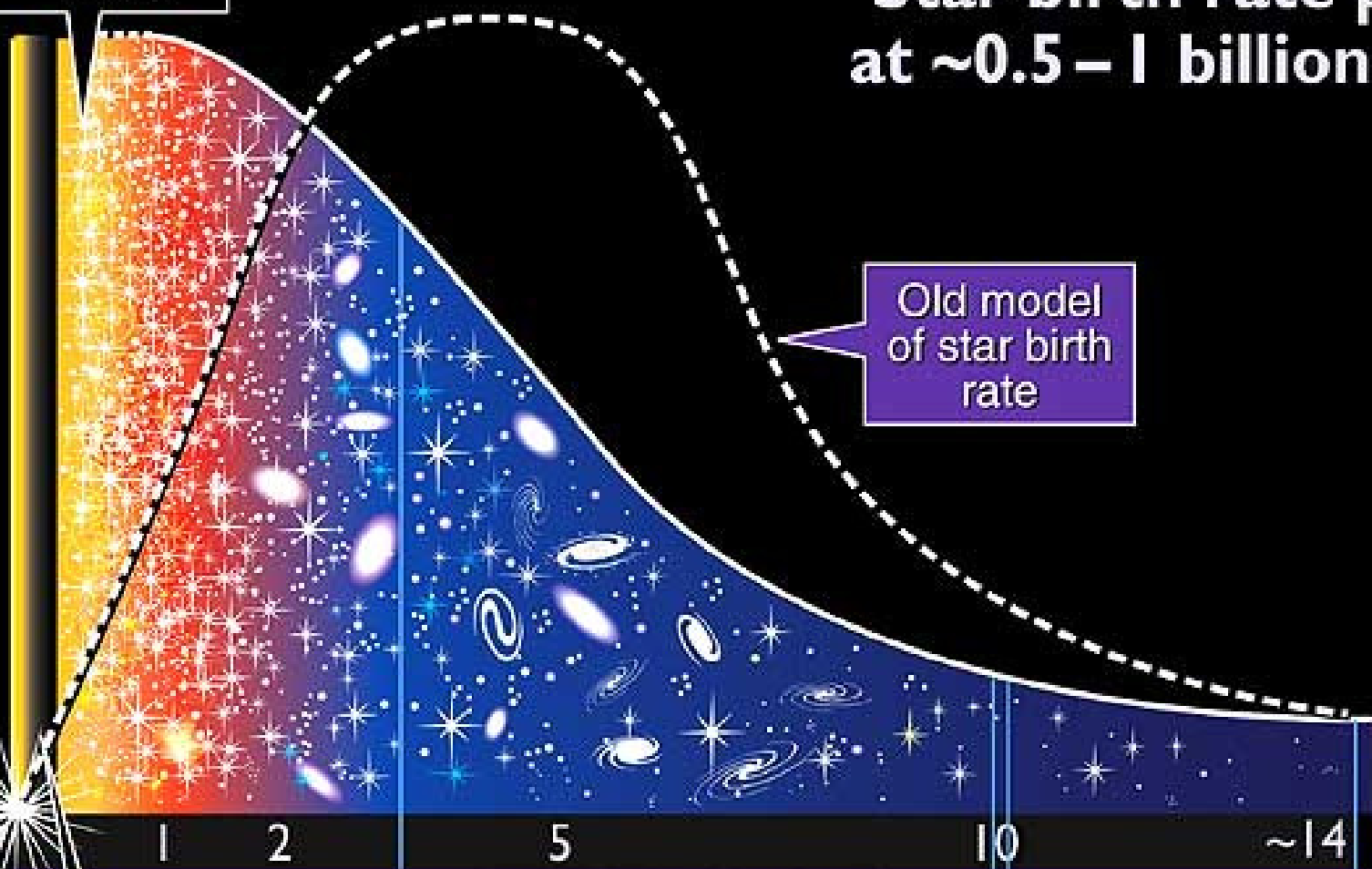
M87 © Anglo-Australian Observatory
Photo by David Malin



New model: Star birth rate peaks at ~0.5 – 1 billion years

Star birth begins

Old model of star birth rate



Big bang

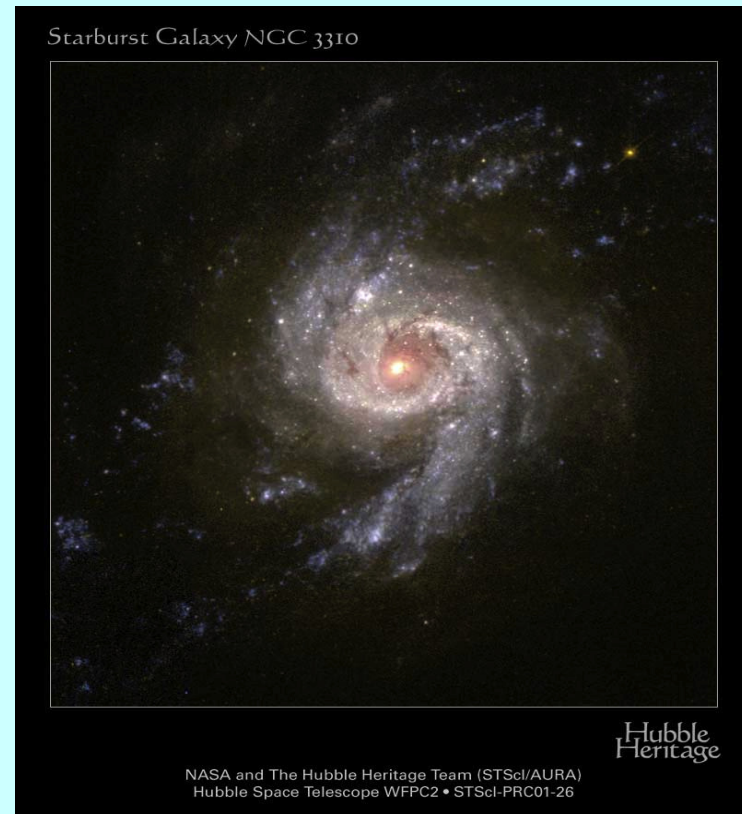
Dark era

Milky Way galaxy forms

Our Solar System forms

Life appears on Earth

Humankind evolves



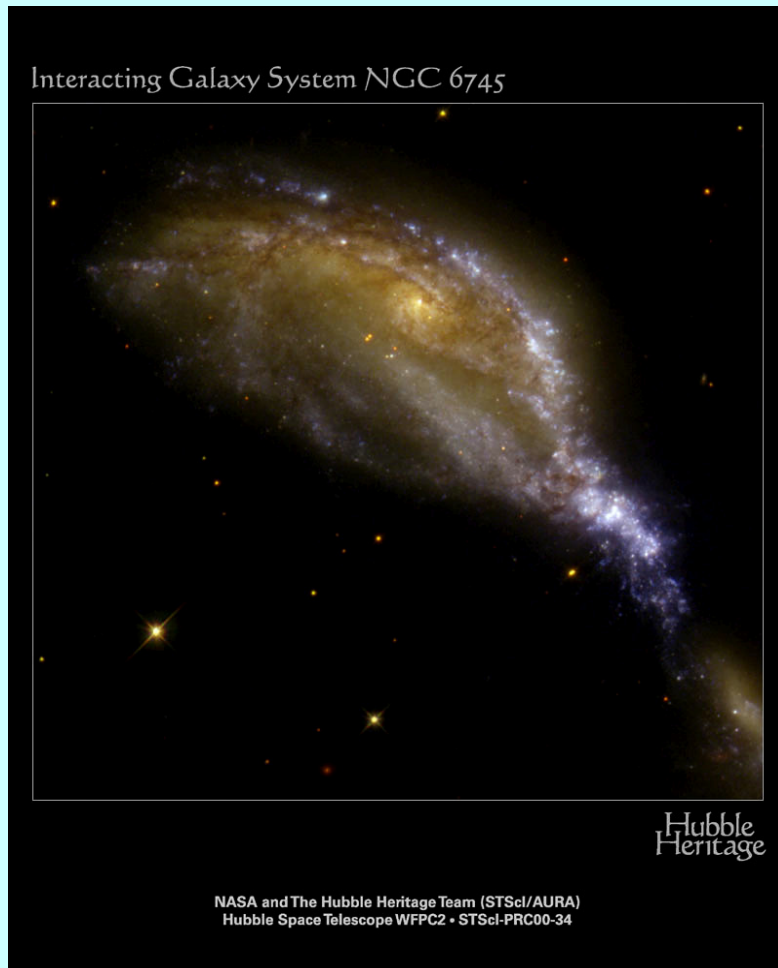
Galáxias Elípticas



*Forma de um elipsoide, sobretudo estrelas antigas. Pouco gás e poeira. Massivas: as maiores do Universo: o final da "linha" para as galáxias espirais.

Pouca formação estelar!

Galáxias irregulares

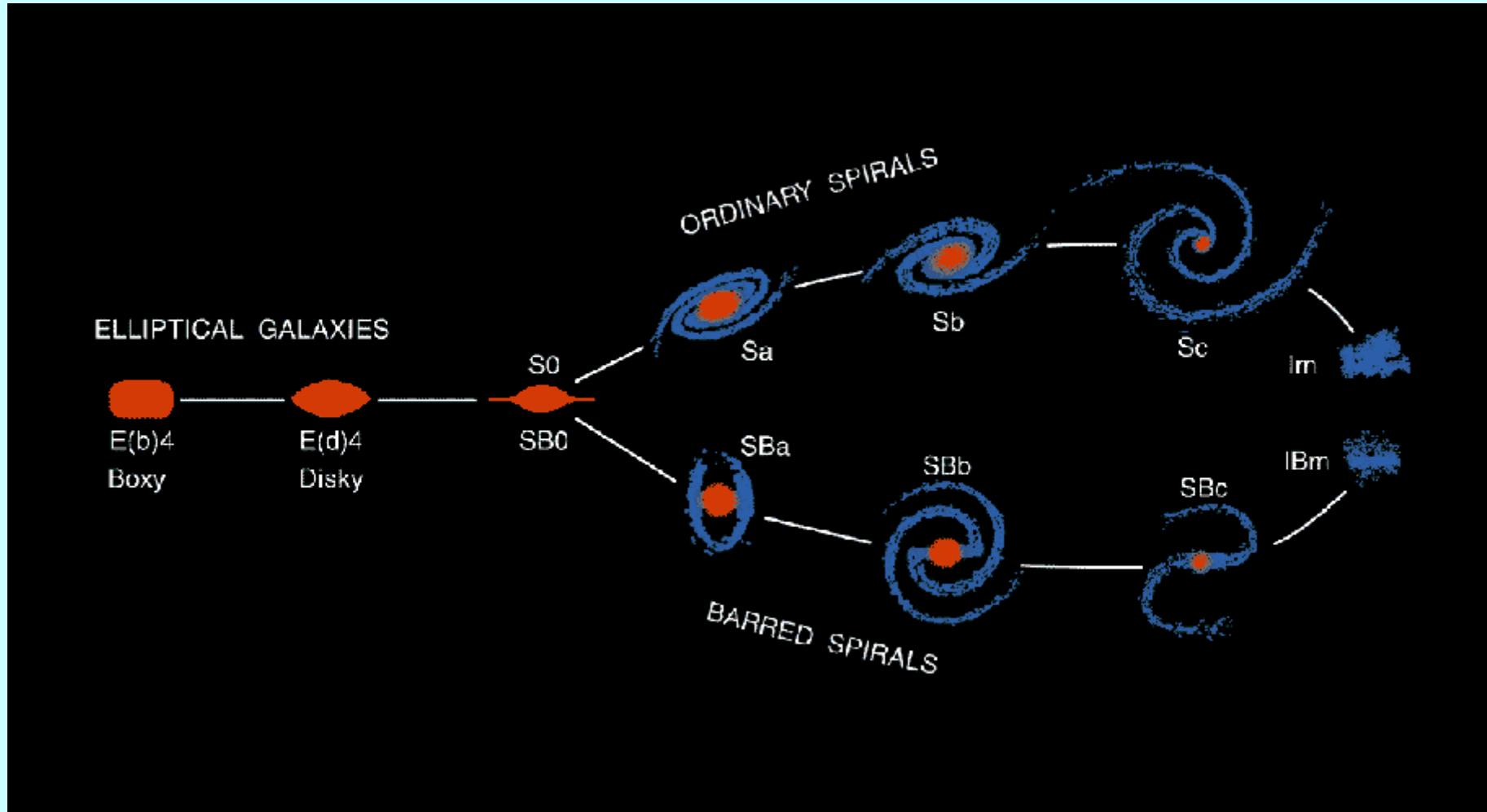


Ou em formação ou vítimas de fusões e canibalismos. De pequeno ou médio porte.

Características das galaxias

- Todas possuem Matéria escura até 90% da massa
- Quase todas parecem possuir uma massa central enorme : um buraco negro ?
- Espirais: estrelas jovens, ricas em pó , mais "azuis"
- Elípticas: podem ser super-massivas, estrelas velhas, pouco pó, as maiores são o resultado de fusões.
- Irregulares: chapa batida. Restos de colisões...

A sequência de Hubble : uma proposta com fundamento?

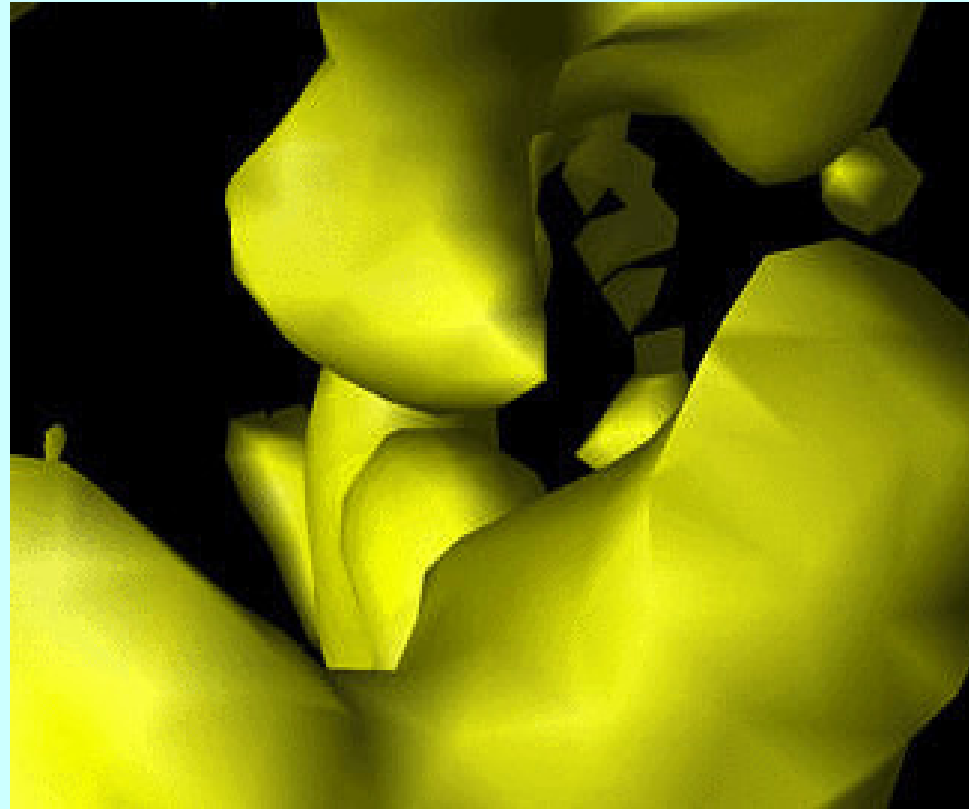


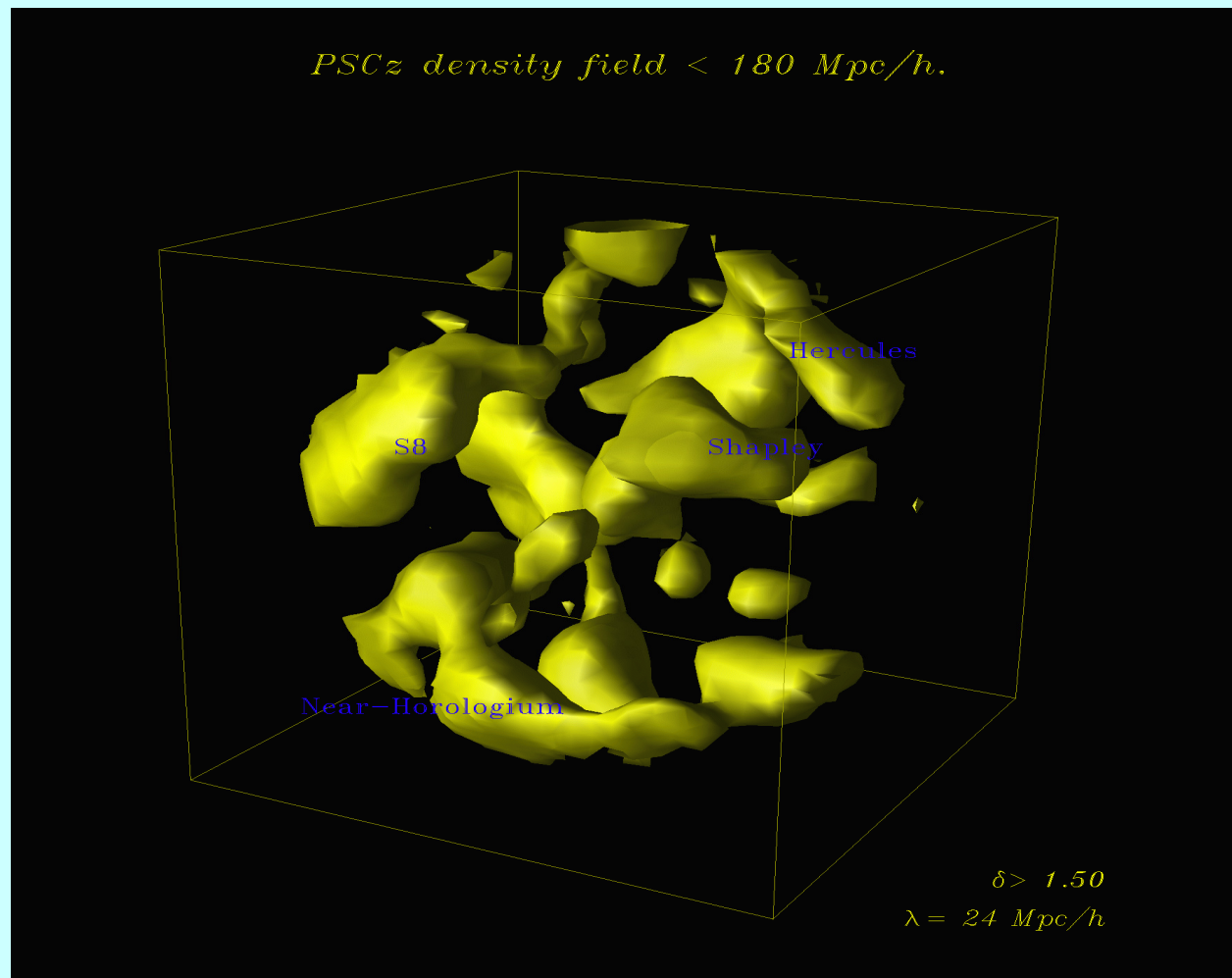
Sim! As simulações numéricas N-corpos assim o parecem mostrar.
Com milhares de partículas de matéria escura, bariões, gás =>

A sequência de Hubble : uma proposta com fundamento?

- * As nuvens primordiais que colapsam estão sujeitas a forças de maré intensas: a nuvem radia heterogeneamente. Irregulares. HST!
- * A nuvem de gás e poeira relaxa. Formam um disco. A presença de matéria escura provoca rotação diferencial. Espirais.
- * O gás é usado. Estrelas velhas. Relaxe do sistema. Equipartição de energia => bola elíptica. Grandes colisões de galáxias também formam elípticas.
- * fase intermédia : galaxias irregulares: dismantelar da estrutura de gas..
- * Ingredientes simulações: matéria escura, gás, partículas estelares. Feedback em mecânica de fluidos.

Sim! As simulações numéricas N-corpos assim o parecem mostrar. Com milhares de partículas de materia escura, bariões, gás =>





O Universo local : survey PSCZ. Compilação de galáxias (v,z) e determinação de densidades : efeito Doppler, dinâmica de binários. Mapas de velocidades peculiares.

A distribuição de galáxias

As galáxias aparecem em grupos ou enxames => agrupamento hierárquico obedecendo à gravitação.

Gravidade: forma objectos e despoleta as reacções nucleares (por compressão do gás).

*** “Surveys” de galáxias : respostas estatísticas aos modelos de formação: testes cosmológicos.*

**** Enxames de galáxias: pequenos universos : amostra significativa de gás primordial!*

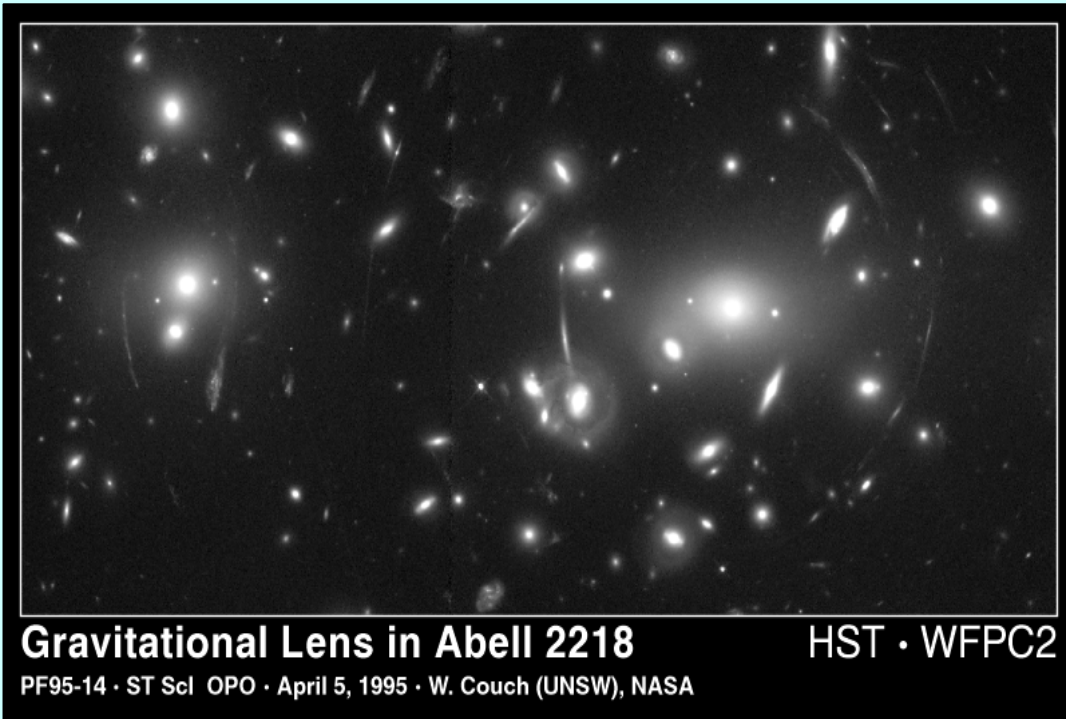
Efeito Doppler-Fizeau:

- Lei de Hubble : $v=Hd$ (segundo a linha de visão)
- Galáxias próximas: $v=c z$
- Galáxias longínquas: $v=c z f(\lambda)$. A dispersão de velocidades (ou largura de riscas) = lei de Hubble + v peculiar.
- Determinação de massas.
- Exemplo: Grupo local: $5 \times 10^{12} M_{\odot}$. 90% ME

Grupos e aglomerados



Aglomerados



Gravitational Lens in Abell 2218

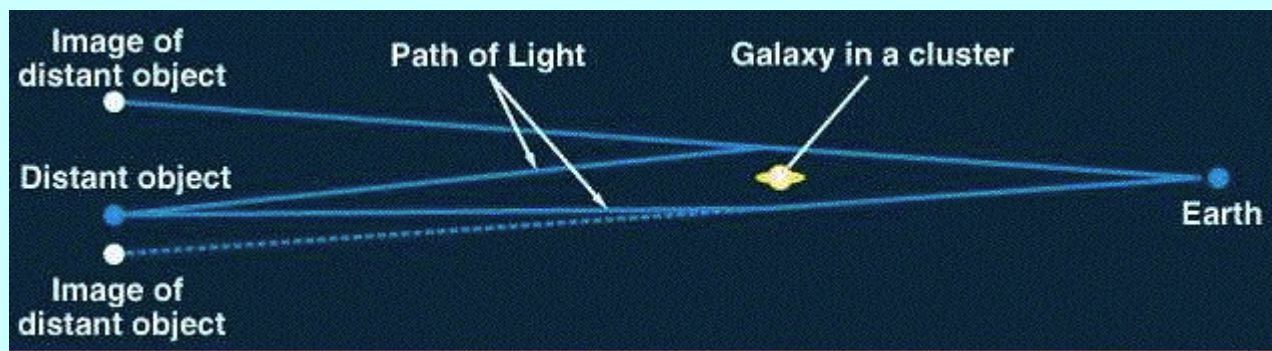
HST · WFPC2

PF95-14 · ST ScI OPO · April 5, 1995 · W. Couch (UNSW), NASA

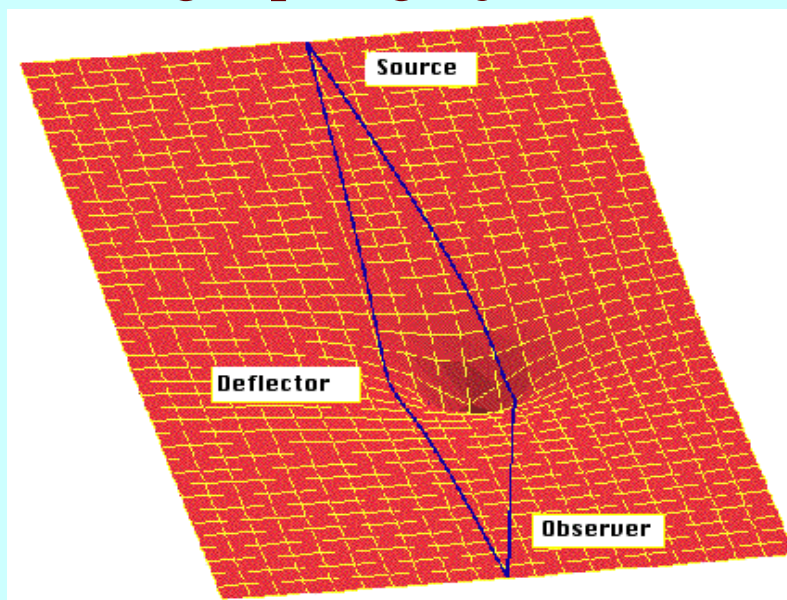
Características morfológicas:

- Aproximadamente esféricos.
- Densidade de galáxias aumenta para o centro = fundo do poço de potencial.
- Centro pode conter uma galáxia elíptica gigante (galaxias CD) :a dinâmica gravitacional => taxa enorme de colisões.
- Raios X: $L_x = n^2 T^{1/2} V$
- Temperatura = risca Fe XXII => Massa!
- Raios X mais fiáveis que o óptico.

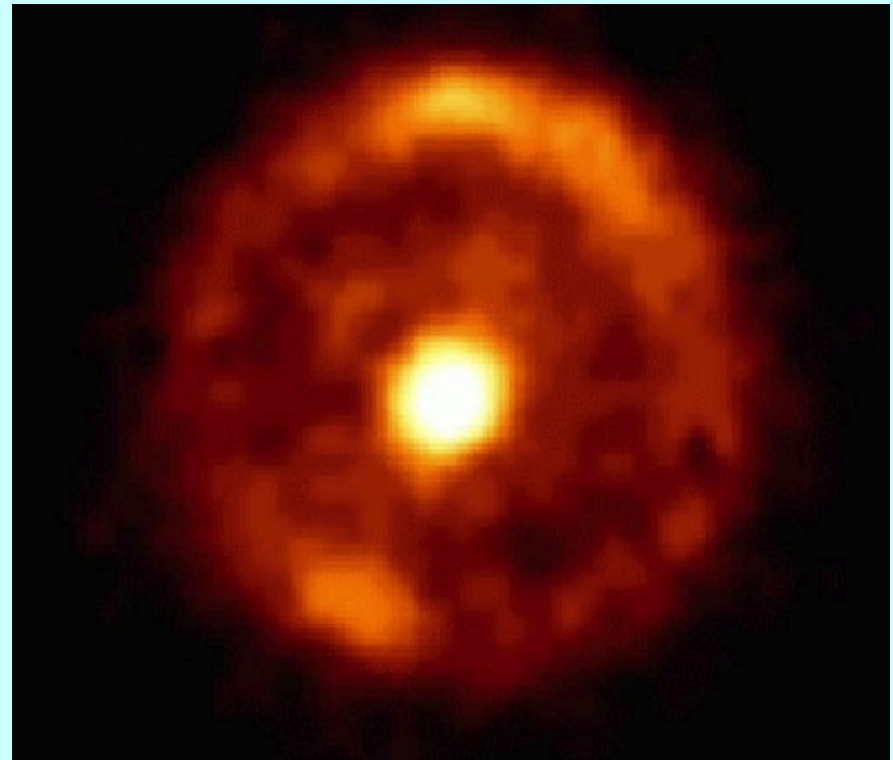
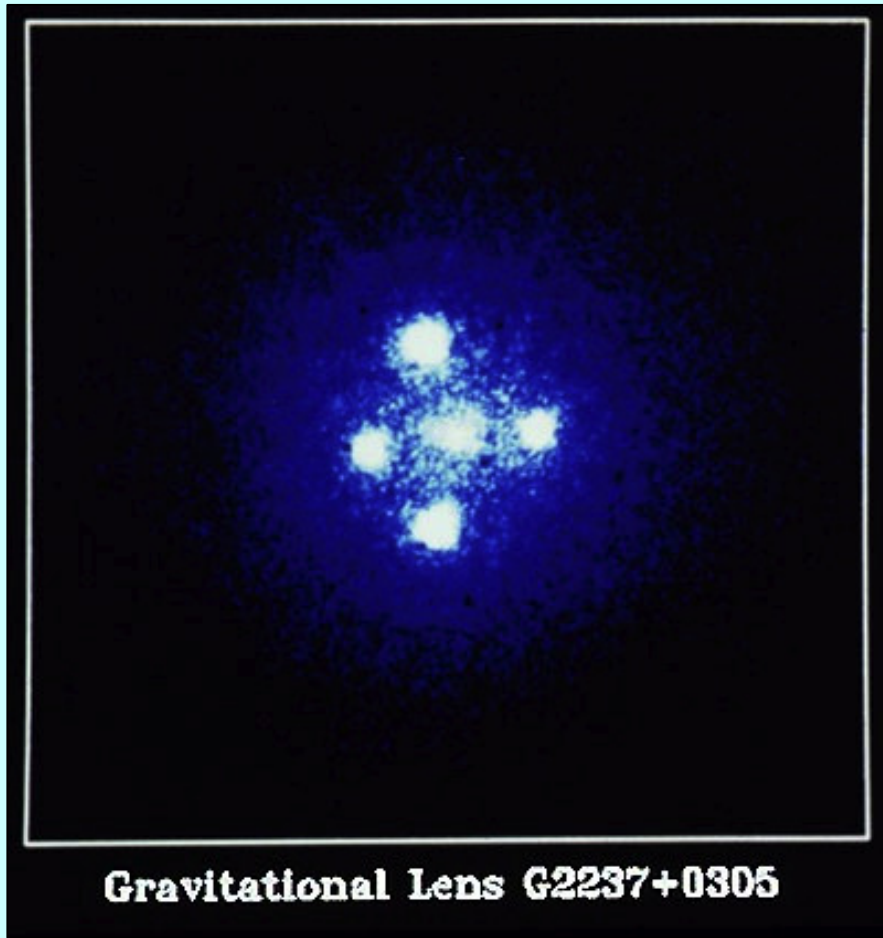
Aglomerados: lupas cósmicas



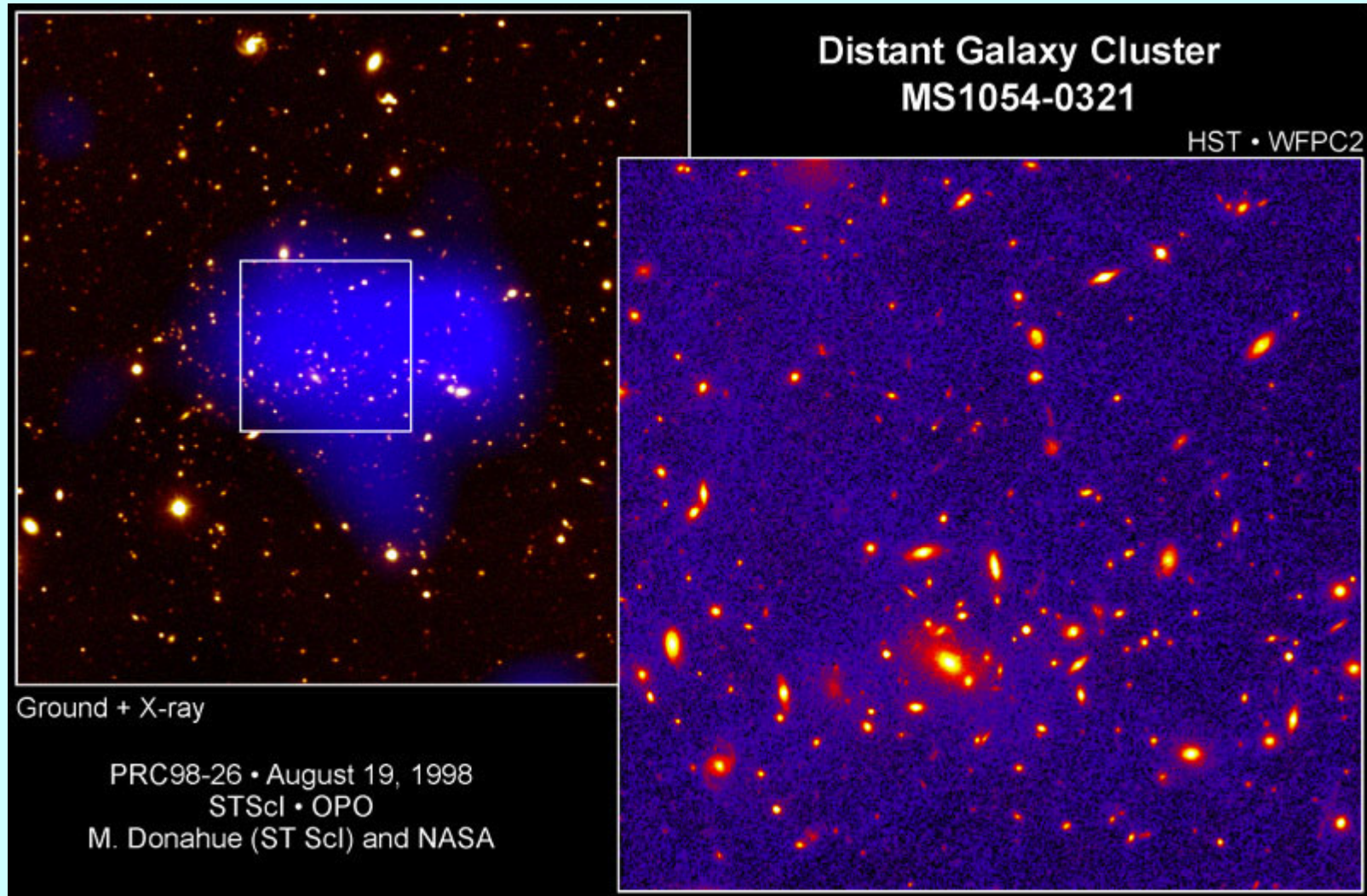
Observação de galáxias longínquas graças á deformação do espaço-tempo



Lentes:

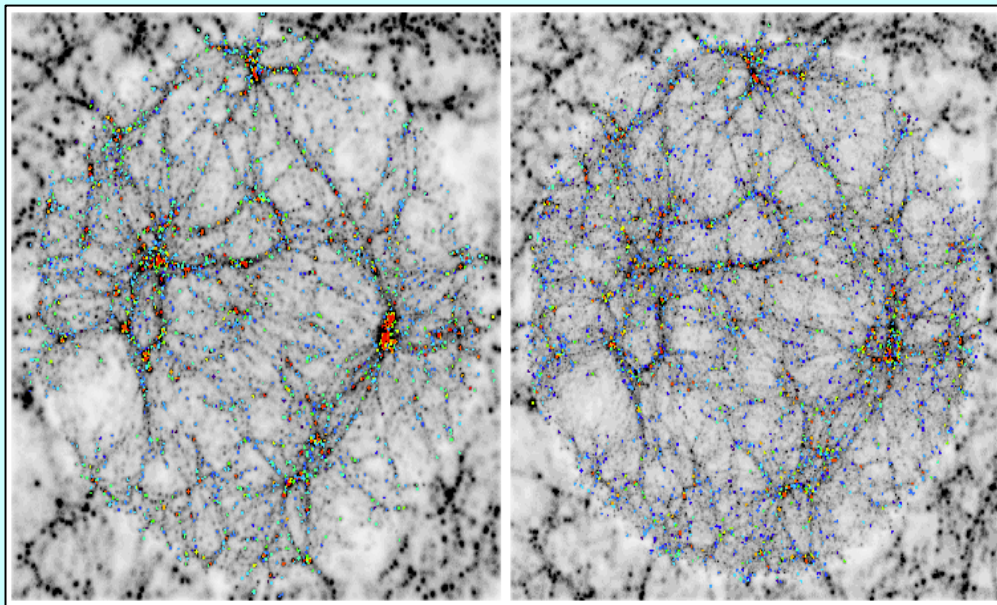


Gás mais concentrado

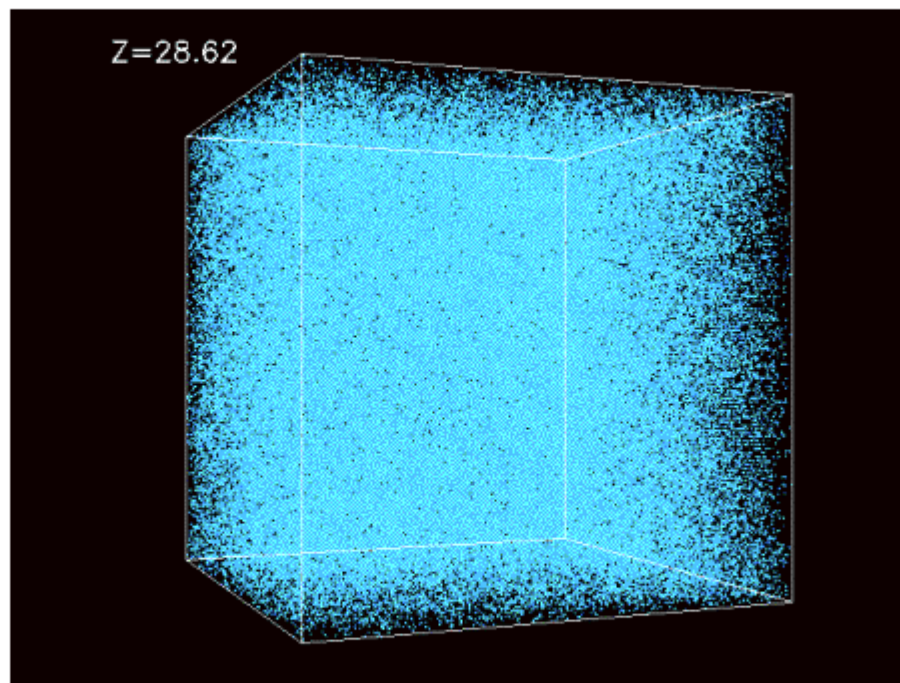


Mas melhor sonda cosmológica que a emissão visível.

A distribuição das galáxias

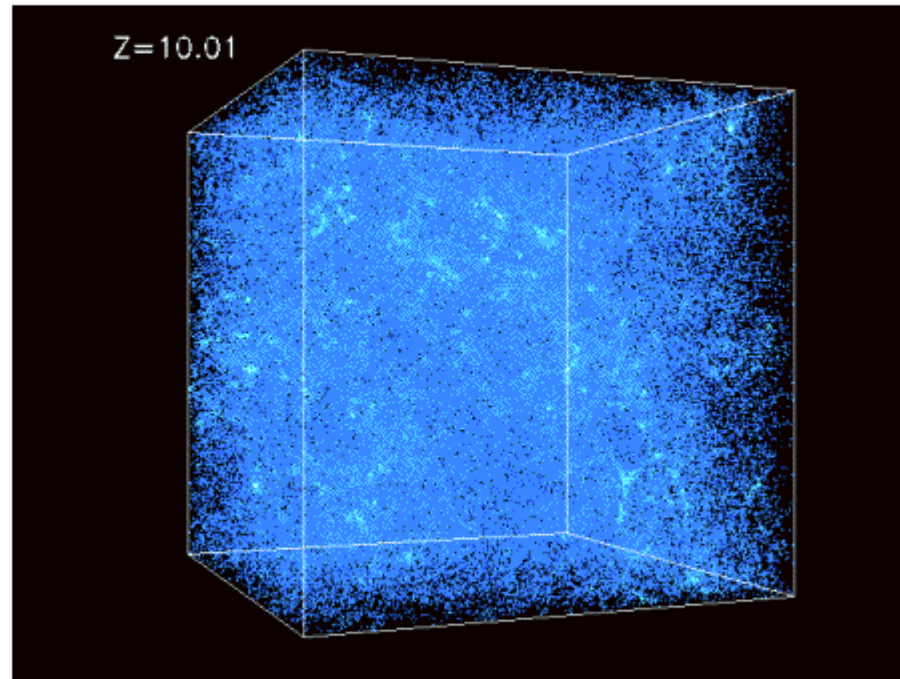


Formação Galáctica



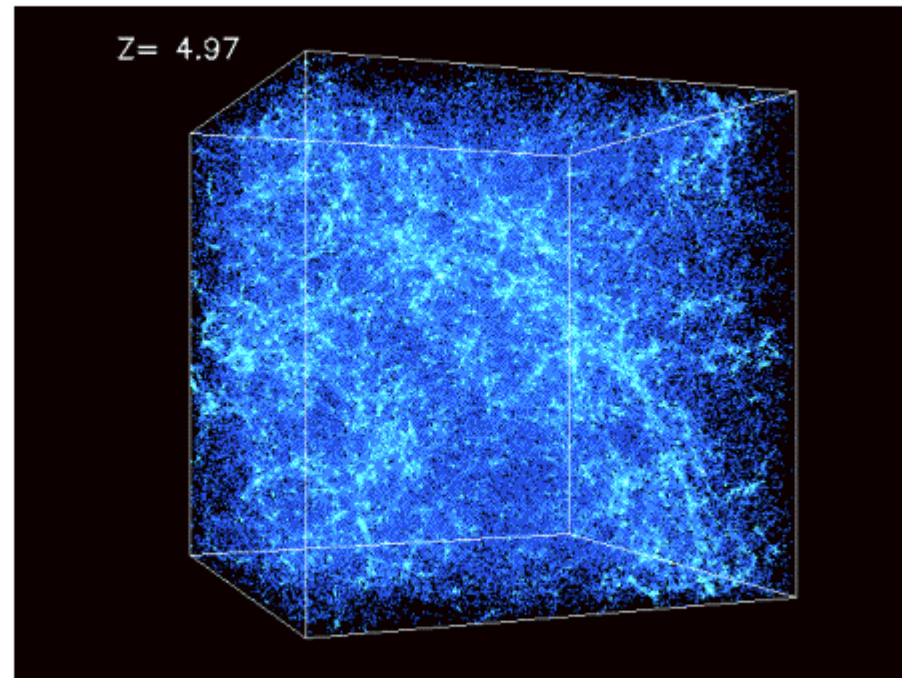
Simulação numérica: caixa de gás uniforme até $1/100\,000$ (a mesma magnitude que existe nos dados do COBE). Deixemos evoluir cosmicamente...

Formação Galáctica

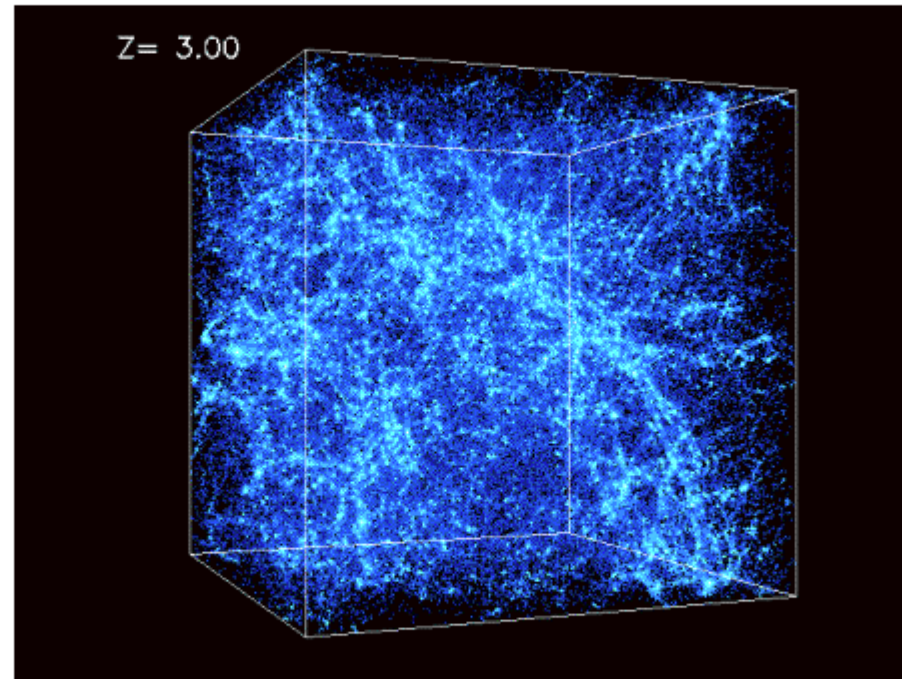


Simulação numérica: a gravidade começa lentamente a fazer-se sentir. Começam a notar-se pequenos grumos de matéria...

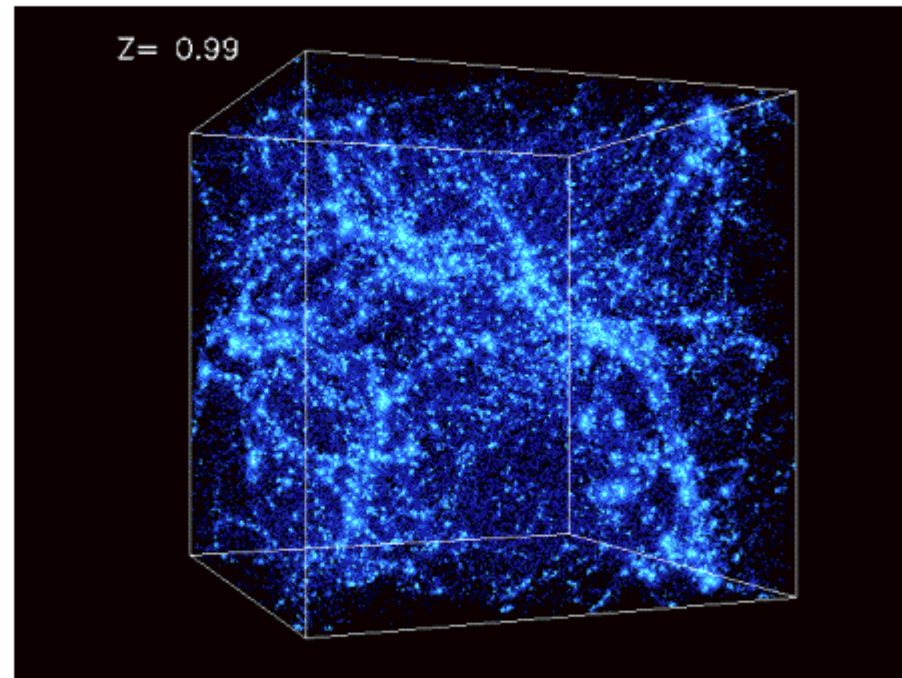
Formação Galáctica



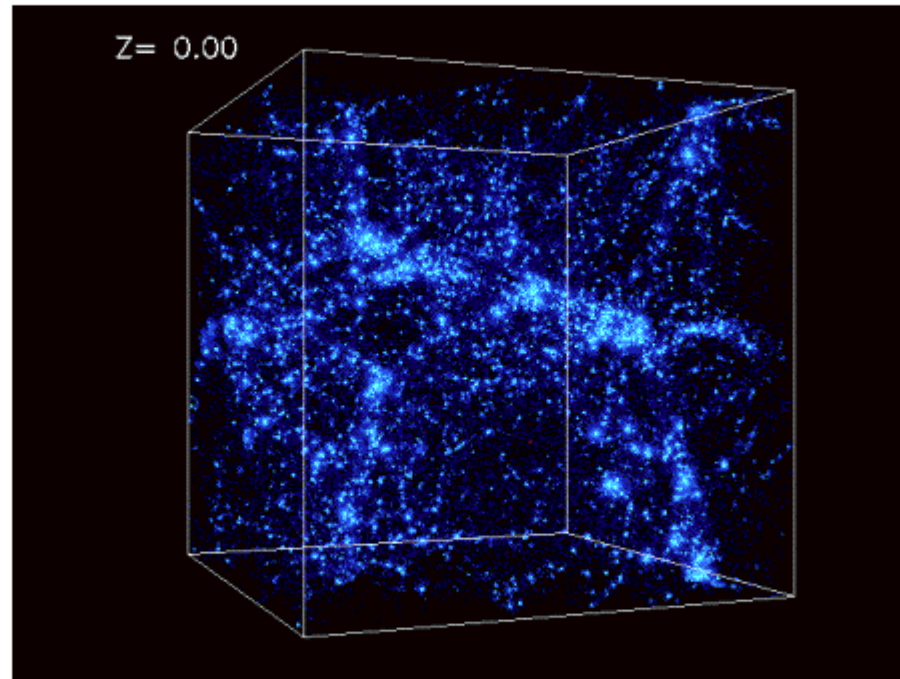
Formação Galáctica



Formação Galáctica

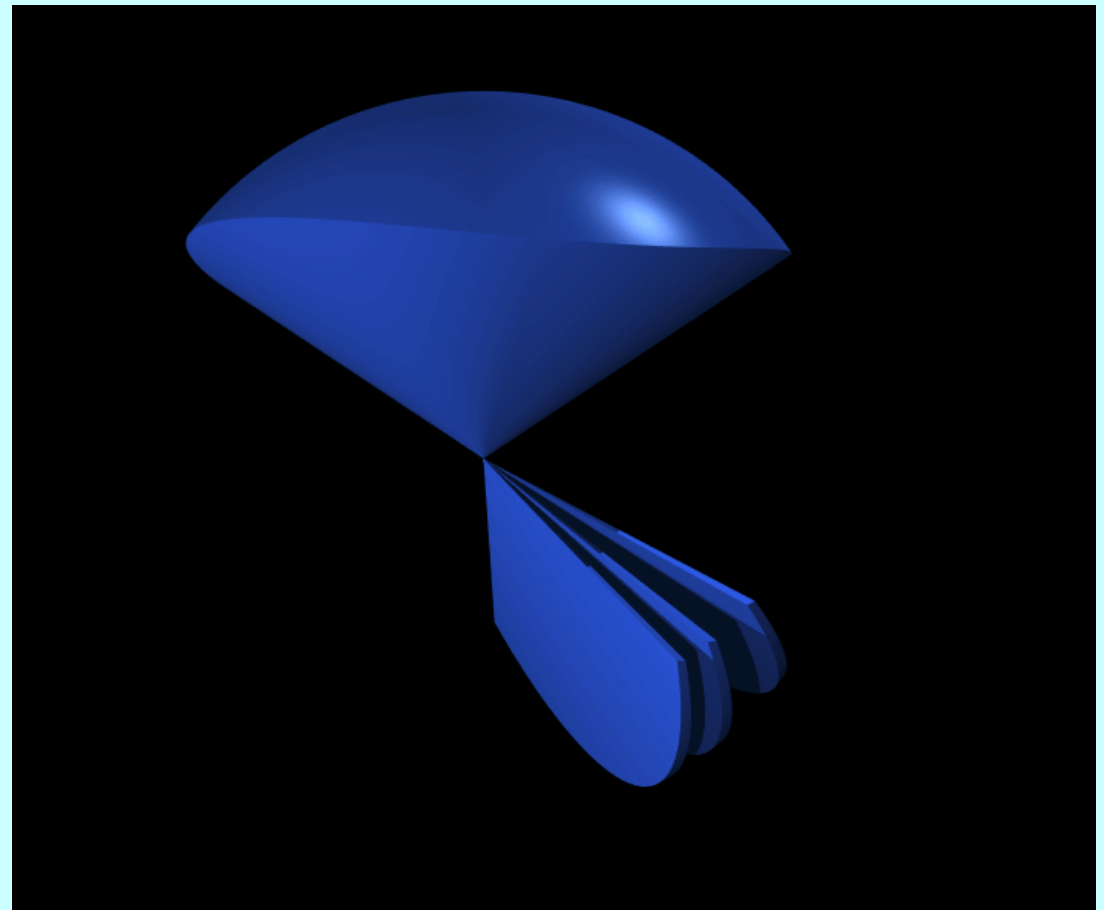
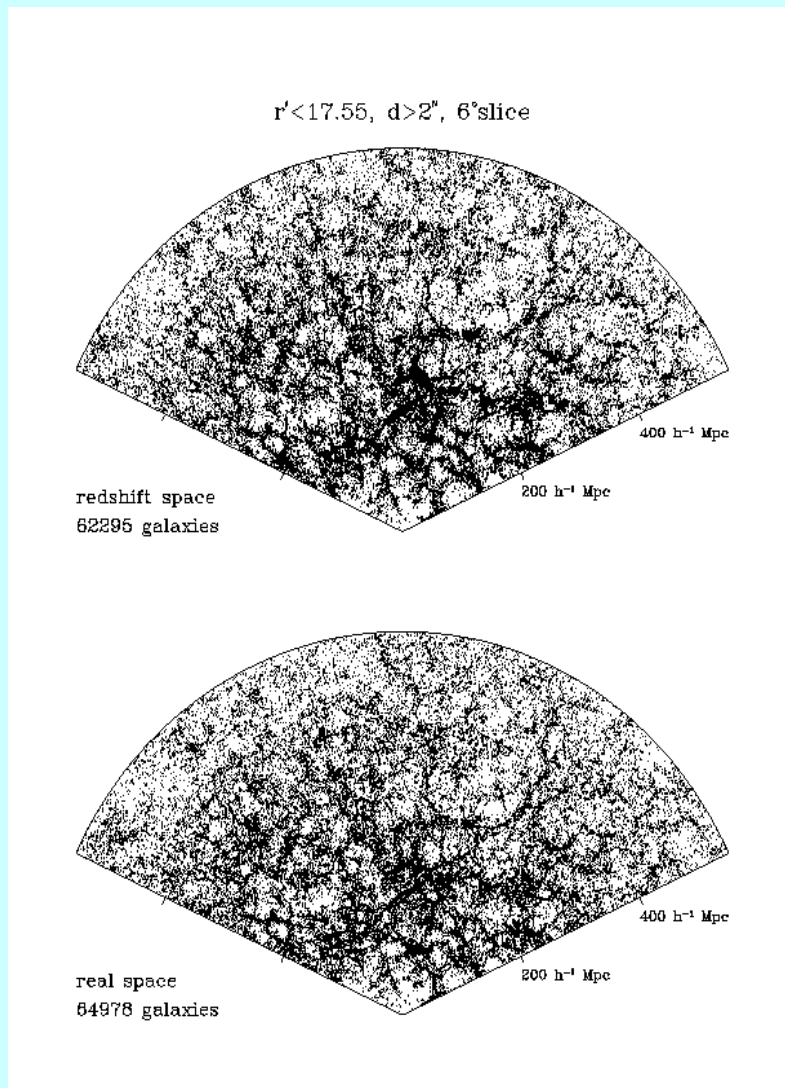


Formação Galáctica



As pequenas irregularidades do fluido cósmico de $1/100\,000$ acabaram por formar galáxias em estruturas filamentosares... tal como vemos hoje nos “surveys” de galáxias

Os surveys: Sloan Project



Grande esforço tecnológico

- Caracterização de centenas de milhares de galáxias.
- Reconstrução da espuma cósmica
- Profundidades da ordem de ~ 1000 Mpc
- Teste aos modelos cosmológicos: fótons carregam a informação geométrica do Universo e atravessam a matéria no seu percurso.
- Vários anos de trabalho: várias dezenas de pessoas a limpar espectros e fotometria.

Galáxias Activas

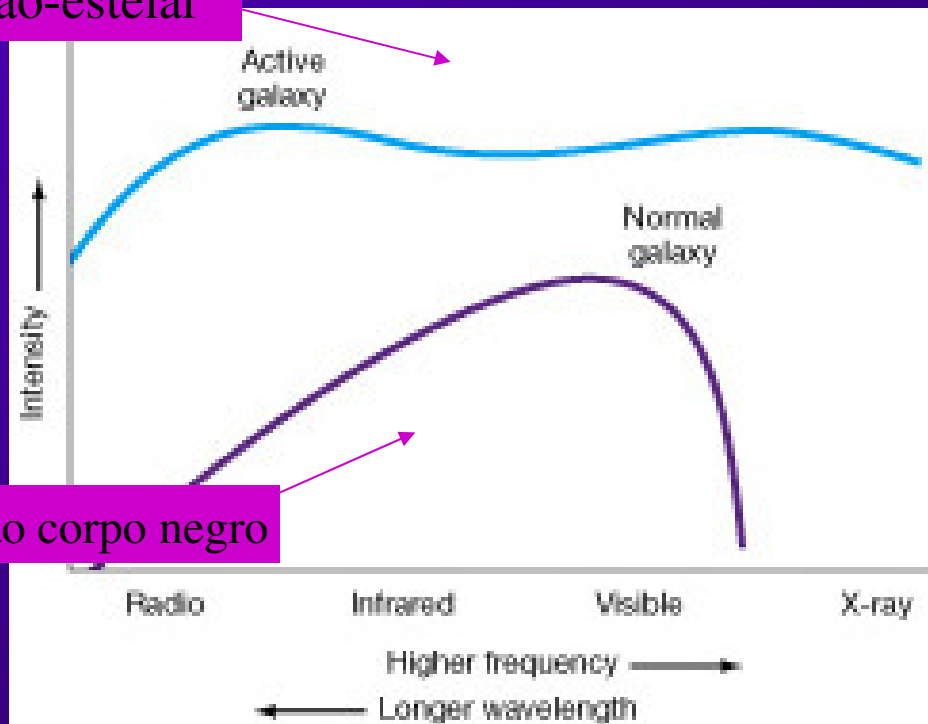


O que são Galáxias Activas ?

Galáxias Activas tem energia para além da atribuída às estrelas. A energia provem da acreção num *buraco negro supermassivo*.

Têm luminosidades mais altas e espectros muito diferentes das galáxias normais. Constituem cerca de 10% das galáxias.

Radiação “não-estelar”



estelar, radiação corpo negro

Algumas classes de GA :

- Quasars
- Galaxias Seyfert (Tipo I e Tipo II)
- Radio galaxias
- LINERs

Quasars

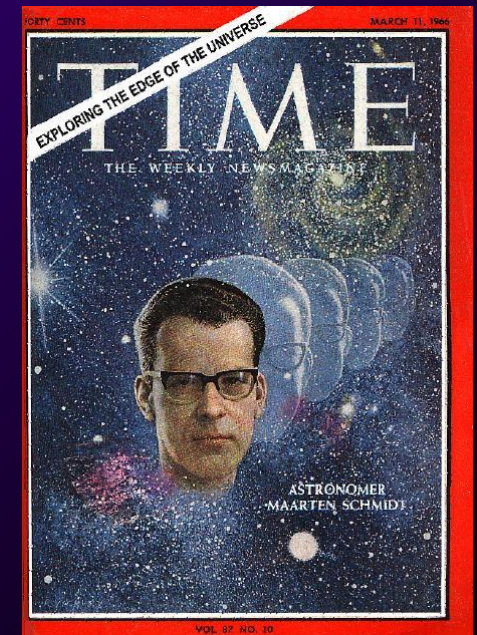
- Descobertos no anos 1960s.
- Detectadas radio fontes com emissão óptica pontual.
- Emissões ópticas estranhas.
- Intensa emissão em raios X
- Emissão em rádio associada a saltos de raios gama (Tev)
- Maartin Schmidt foi o primeiro a reconhecer que estas riscas são riscas de H a muito grande z .

$D = 660 \text{ Mpc}$ (2.2 bilhões anos luz) de 3C273

1340 Mpc (4.4 bilhões anos luz) de 3C 48

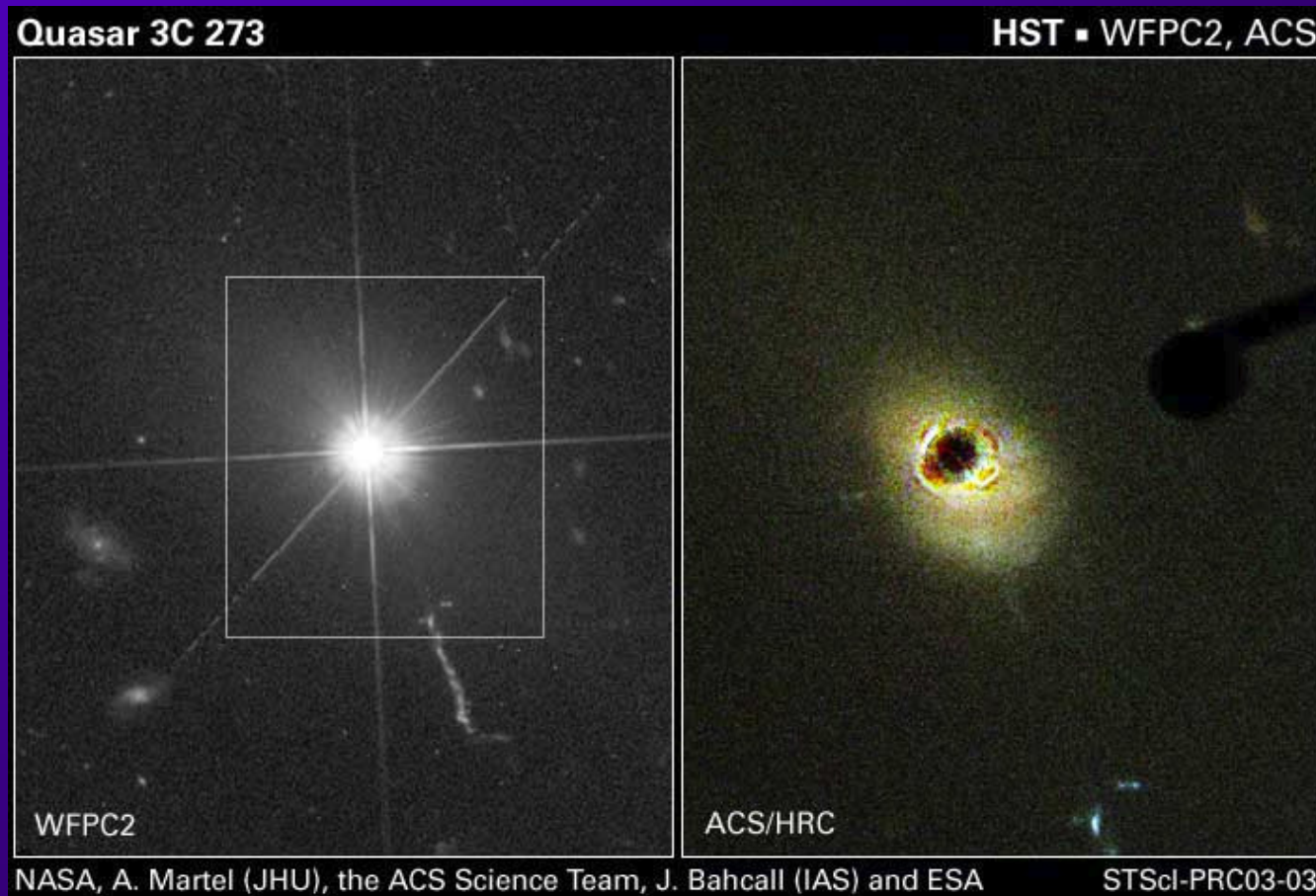
$L = 2 \times 10^{13} L_{\text{sol}}$ para 3C273.

- Em ~ 2 anos, quasars foram descobertos com :
 $z > 2$ e $L \approx 10^{14} L_{\text{sol}}$
- *QSO mais distante* $z = 6.42$



Bloqueando a parte luminosa de um quasar, → evidência da "galáxia hospedeira".

Quasares aparecem numa variedade grande de tipos de galáxias- de galáxias estranhas a normais E's e espirais.

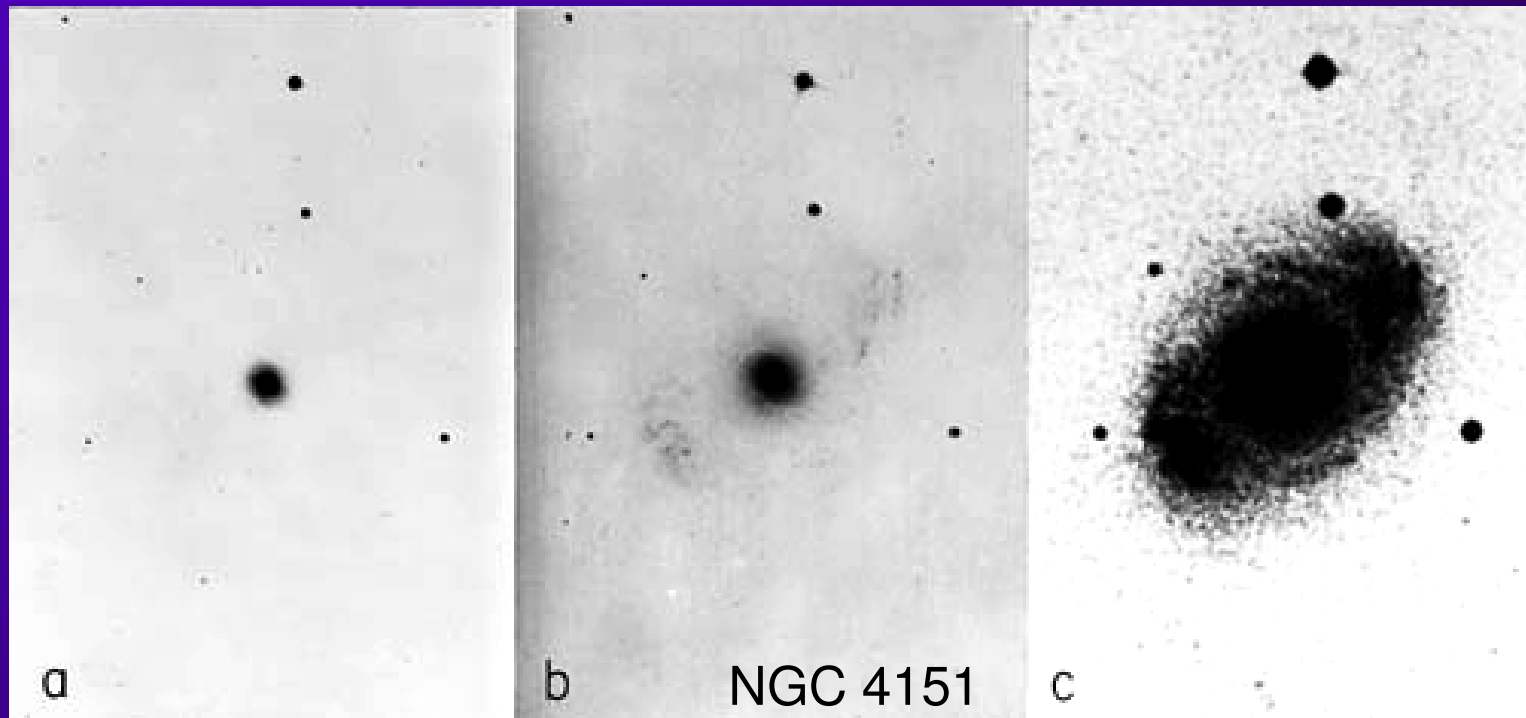


Galáxias Seyfert → descobertas por Carl Seyfert in 1943.

Características observacionais :

Quase todas a luminosidade provem de uma **região pequena (não resolvida)** do núcleo galáctico.

Núcleos têm $M_B > -23$



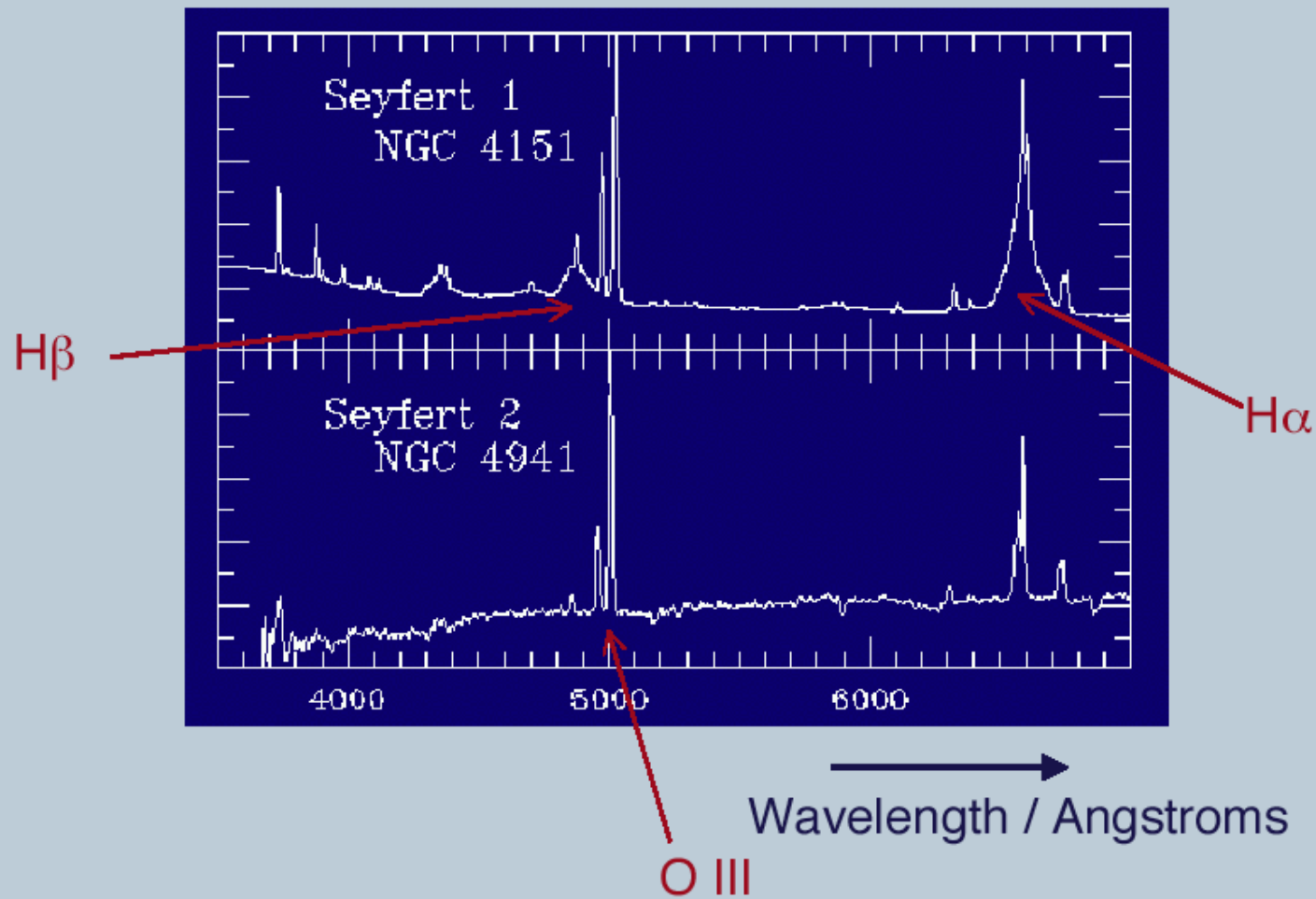
Exposição
curta

Exposição
longa

10000 x brilhante que o nosso núcleo galáctico!

Seyferts : riscas largas (como quasars) e riscas estreitas.

Modern spectra of Seyfert galaxies

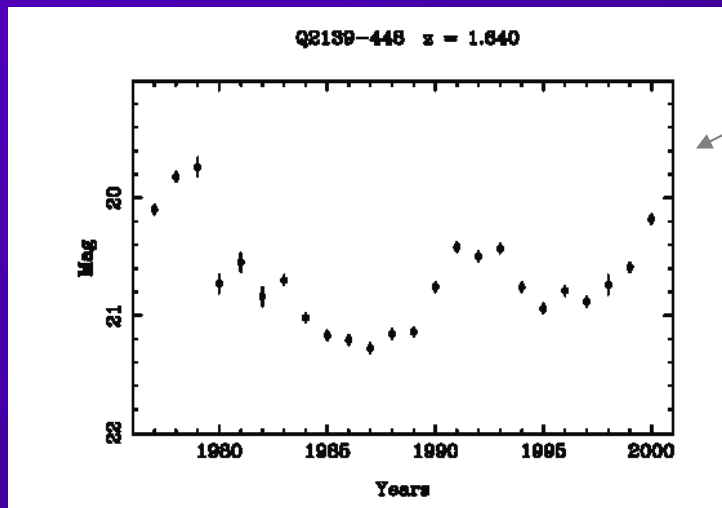


Seyfert 1:
Riscas
largas

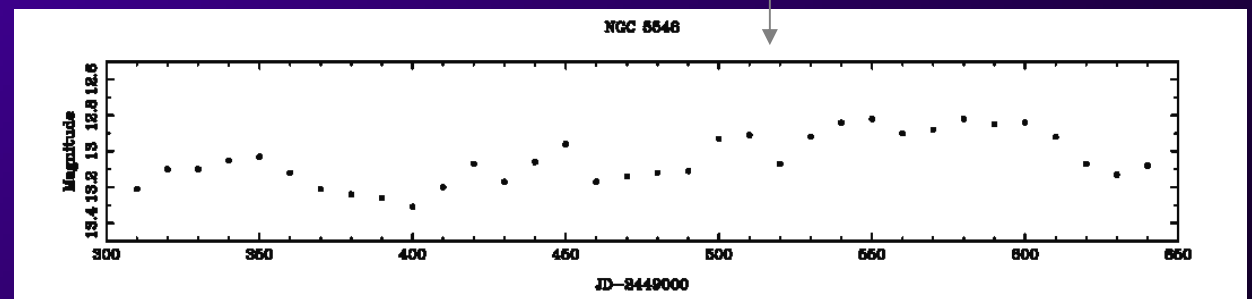
Seyfert 2:
Só riscas
estreitas

Variabilidade das AGNs

- QSOs e Seyferts são variáveis (de meses a anos)
- Causas ? – instabilidades nos discos de acreção, SN ou starbursts, microlentes.....



curva de luz de QSO ~ 25 anos
Curva de luz de Seyfert ~ 11 meses



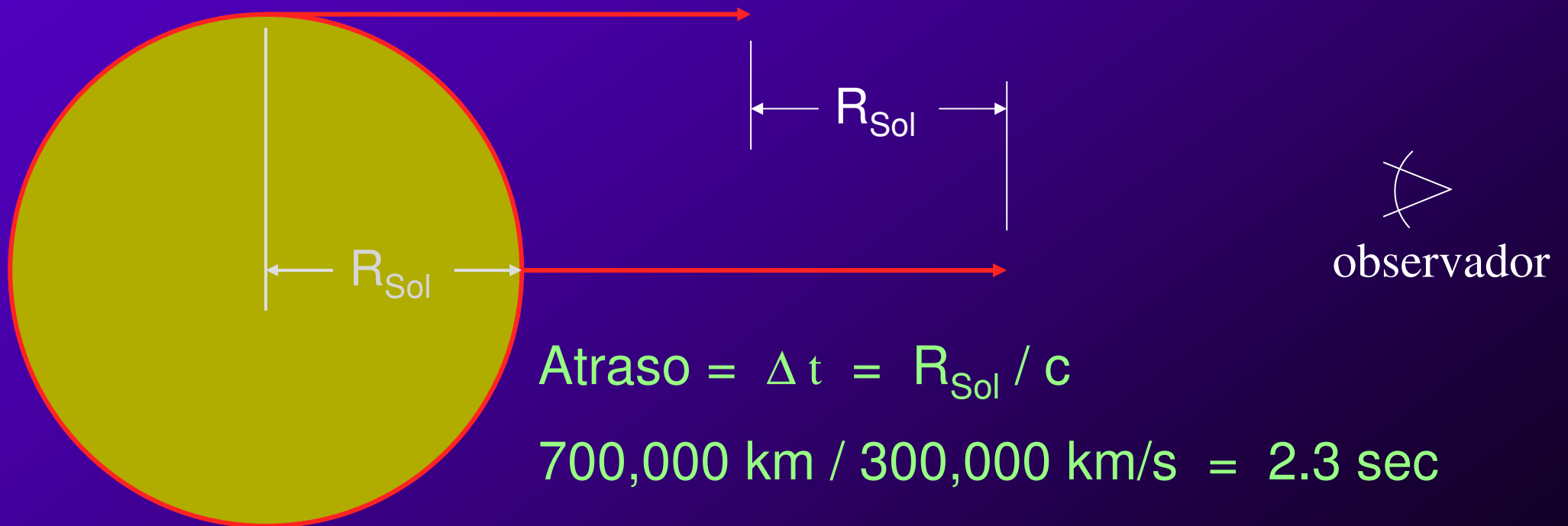
Hawkins 2002

Variabilidade : de raios-X ao rádio

Isto indica que flutuações são originárias de um objecto compacto.

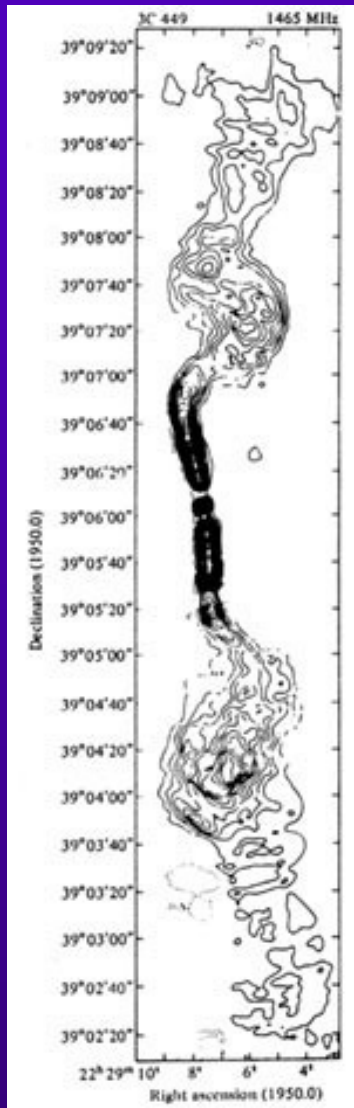
Variabilidade → uma medida das dimensões ?

Considerem um objecto como Sol. Qualquer Any flash instantaneo aparece “blurred” em $\Delta t = R_{\text{Sol}} / c$.

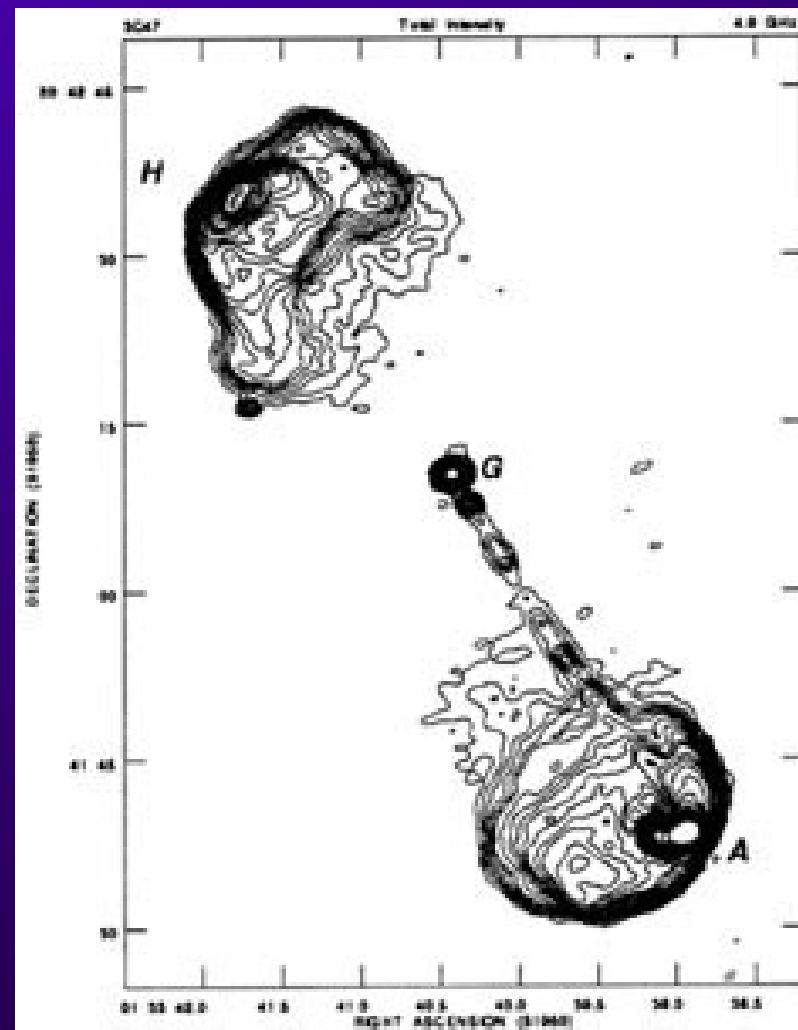


Algumas variações (Seyfert) ocorrem em dias ou semanas. Isto implica que a fonte tem menos de algumas semanas-luz!
Comparação: orbita de Plutão: 5.5 horas-luz. Nuvem cometária solar (Nuvem de Oort) ~ 10 meses-luz.

FR I - 3C 47



FR II - 3C 449

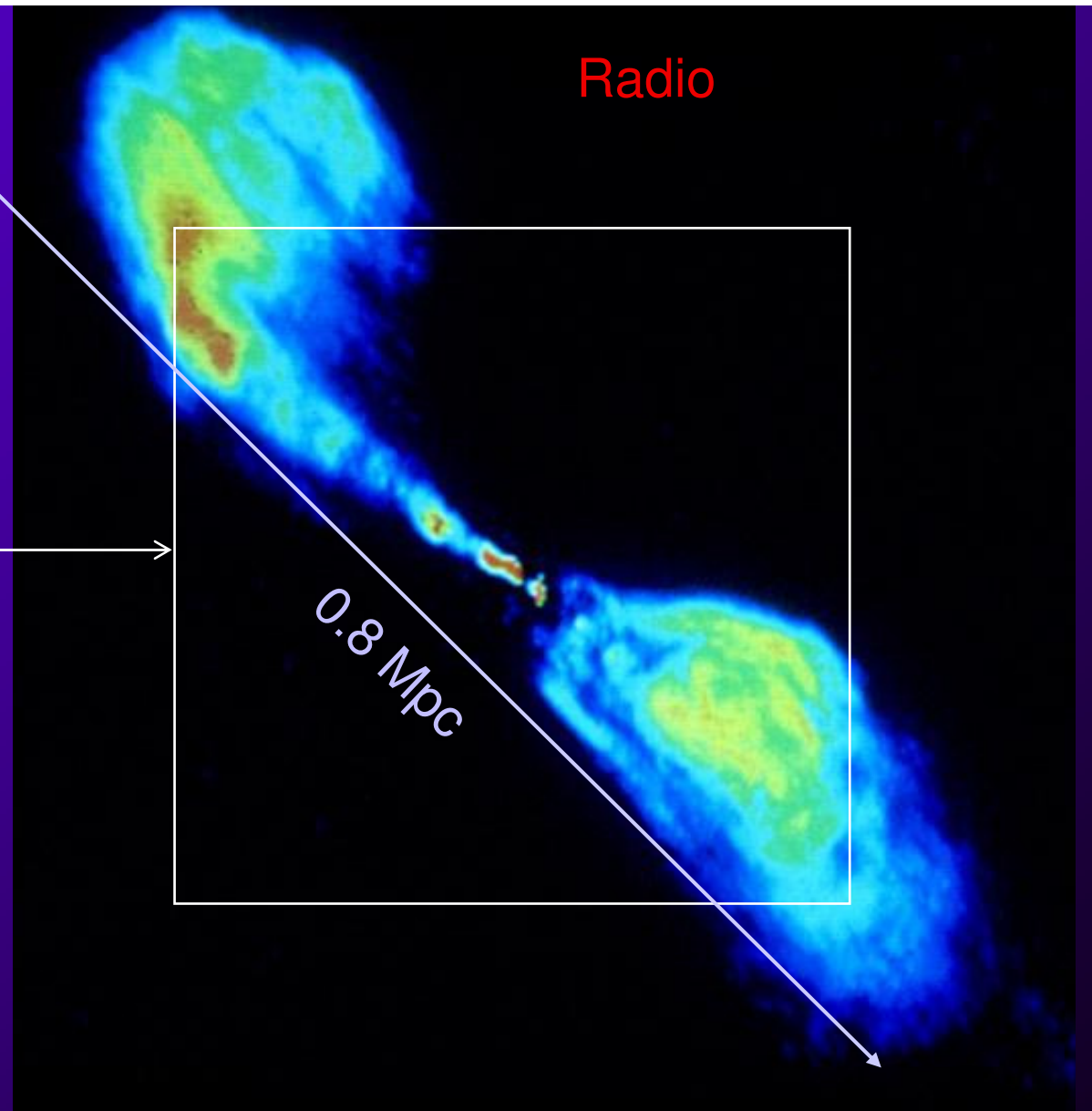


FR II radio galáxias: a maior parte da emissão → lobos !

Centaurus A

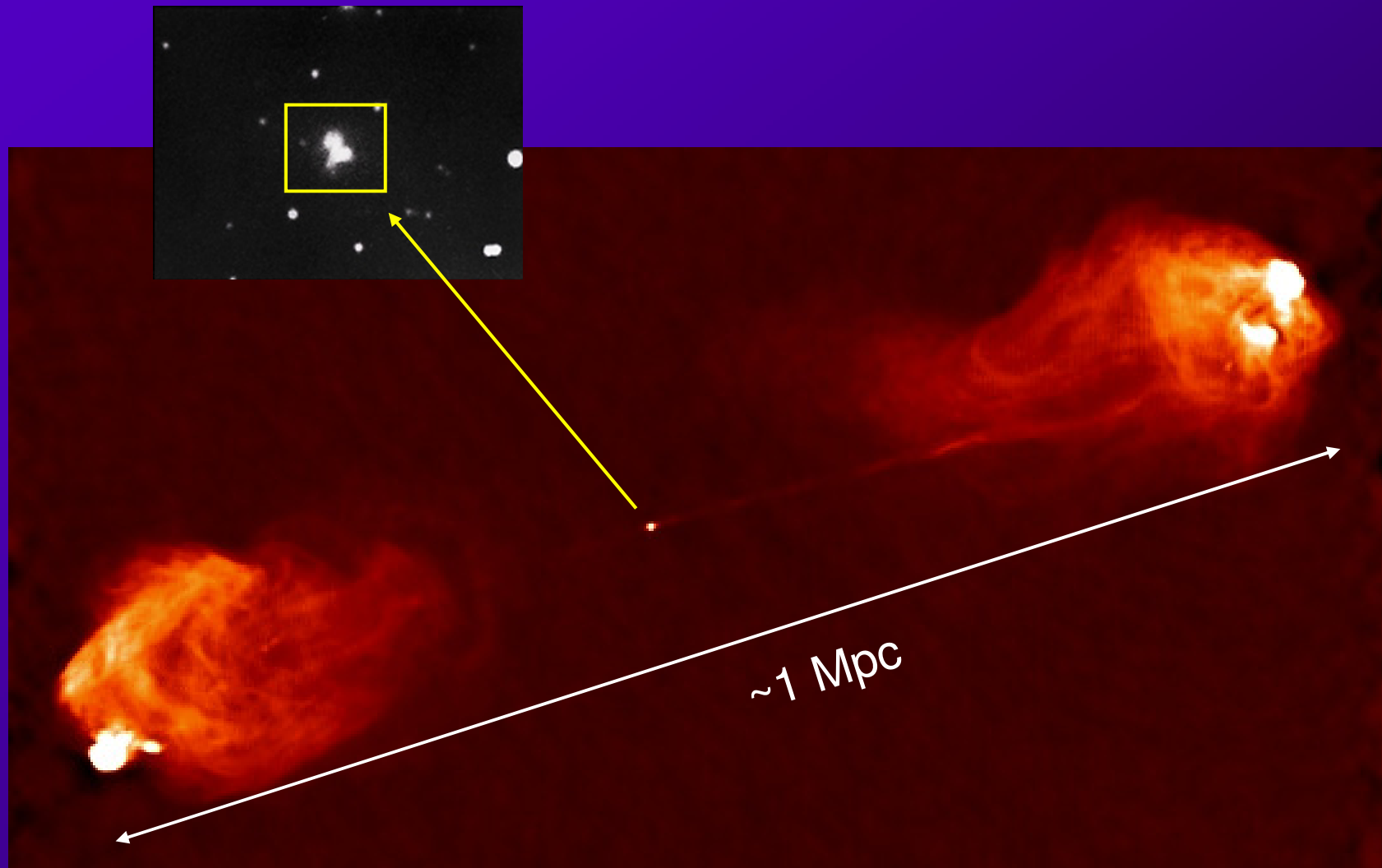


Luz visível



Os lobos rádio → 10 graus no céu!
Lobos → material ejectado do núcleo.

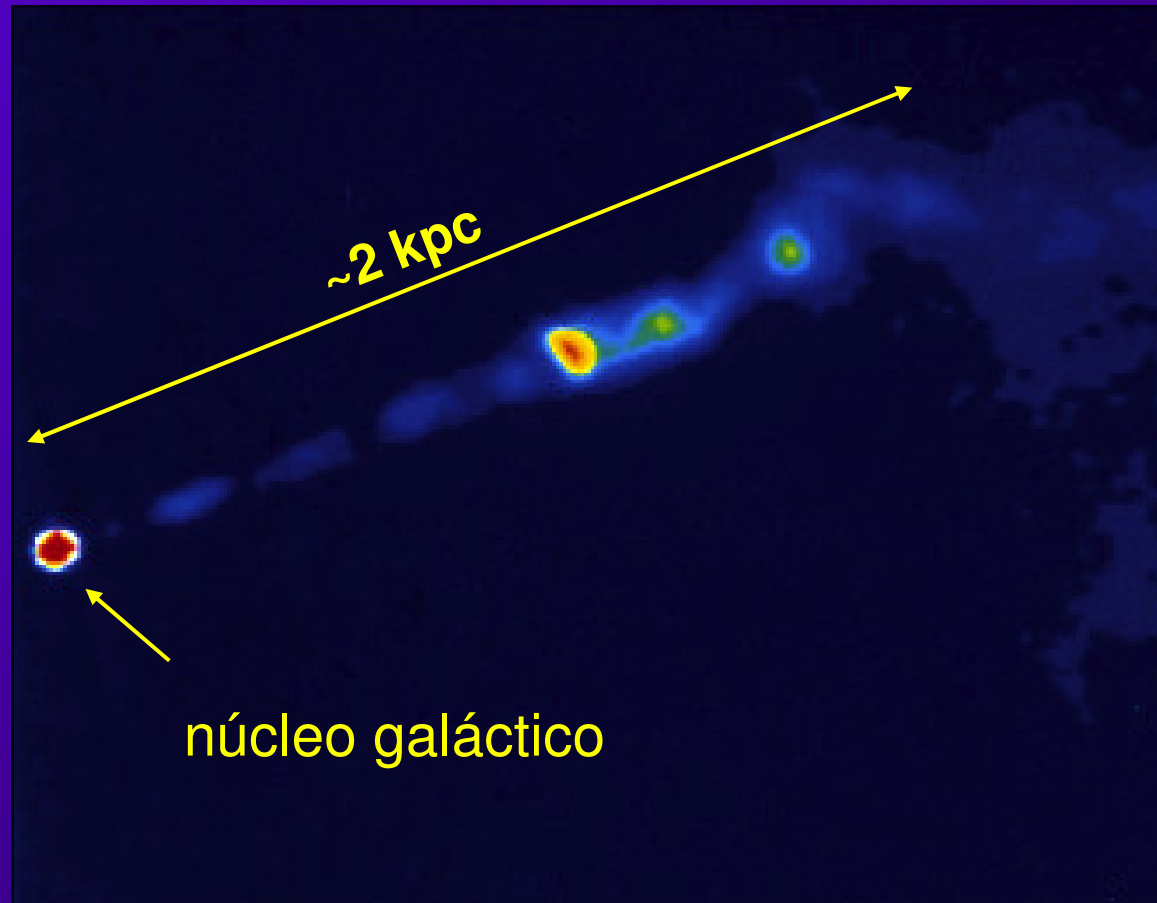
Radio imagem de Cygnus A.



ENORMES radio lobos.

Estes lobos ocorrem onde jatos penetram gas intraenxame.

Close-up de M87 em rádio.



O jacto → “blobs”, ejetados, movendo-se a metade de c

Claramente não-estelar.

Radio imagens

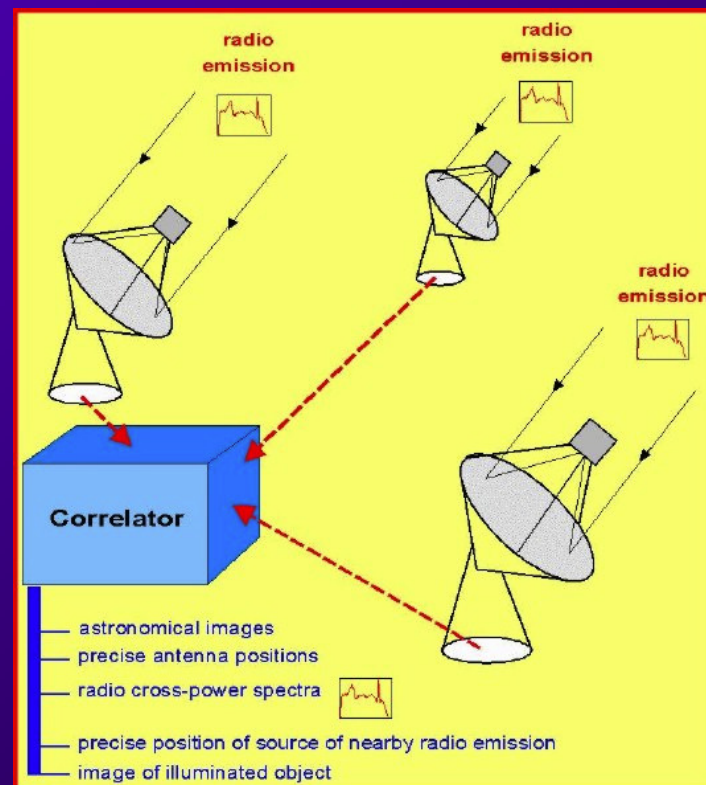
A maior parte dos jactos observados com interferometria rádio

Resolução angular

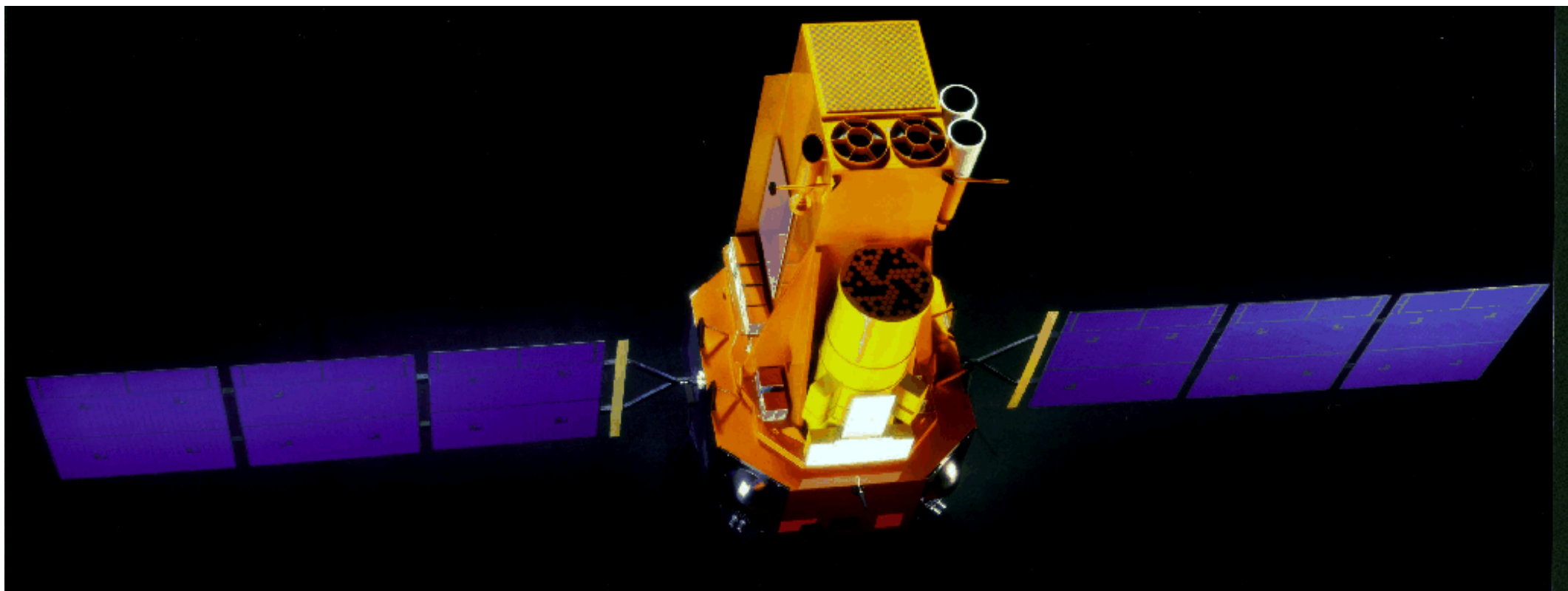
$$\delta\theta \sim \lambda/D$$

λ : de m - mm

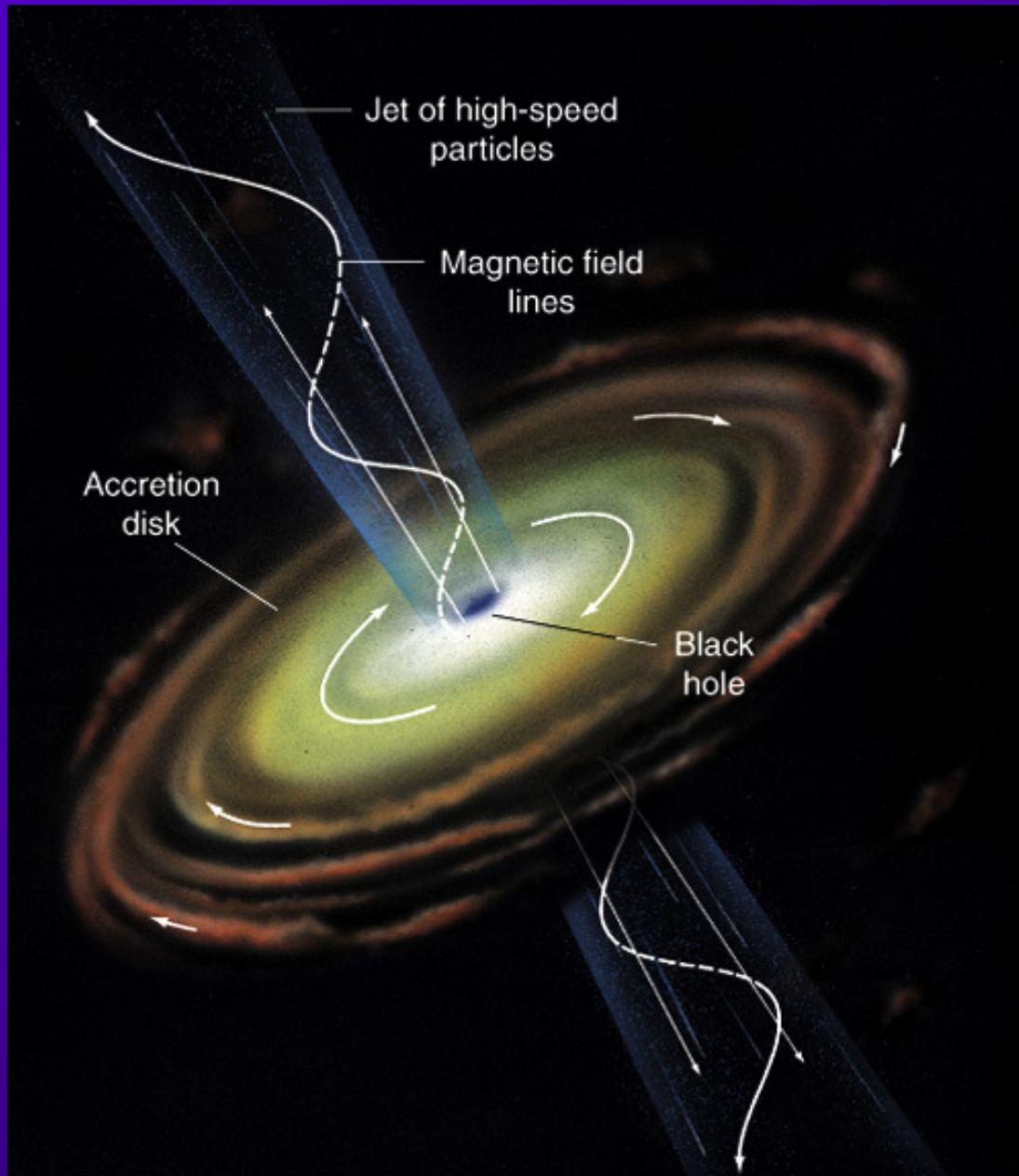
D : extensão até $\sim 10^3$ km



VLA : resolução ~ 1 arcsec (\sim óptico)
Corresponde a resolução linear $d \sim$ kpc (galáxia normal ~ 30 kpc)
Revela estruturas colimadas gigantescas \sim Mpc

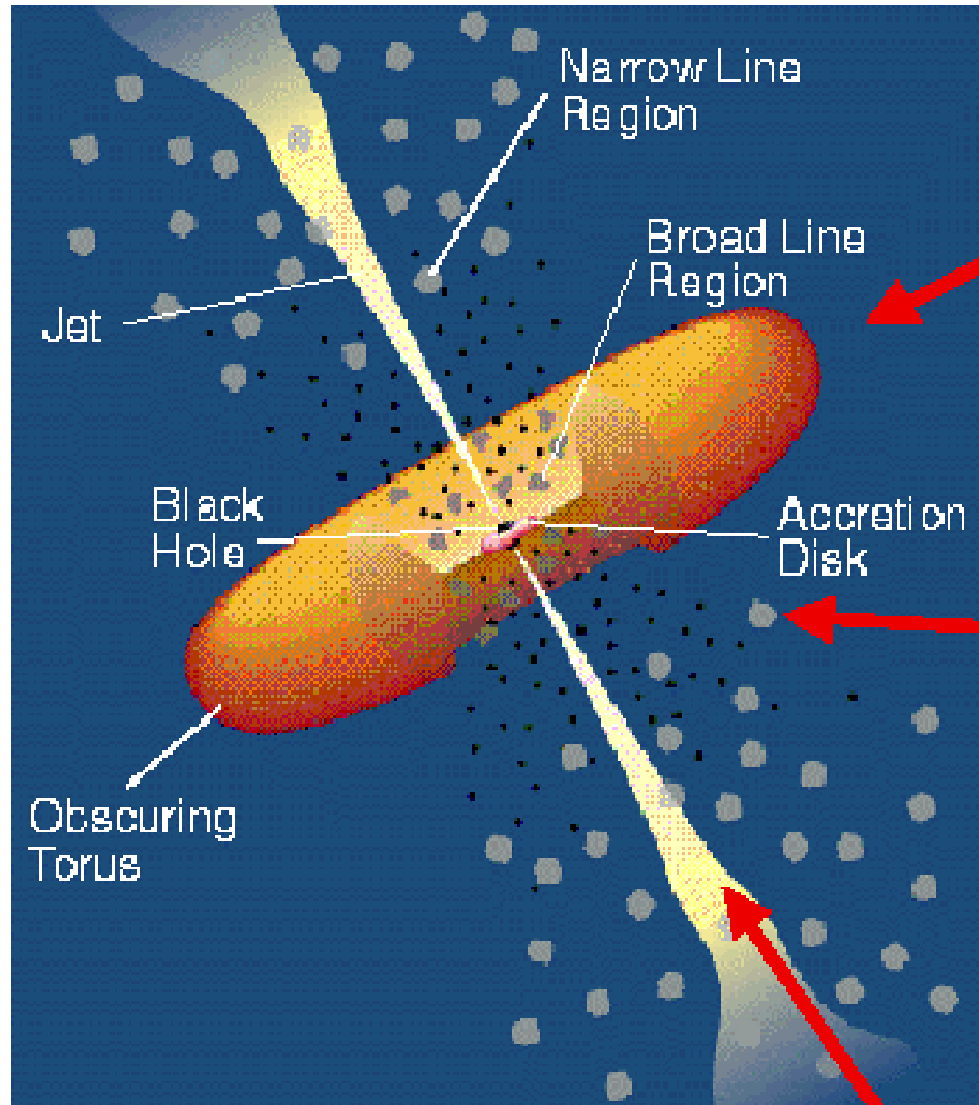


Potência das AGNs ??



- (1) Fonte compacta central com campo gravitacional intenso. Para AGNs, o buraco negro $M_{\text{BN}} = 10^6 - 10^9 M_{\text{sol}}$
- (2) Gás em “queda livre” -> disco de acreção em torno do BN.
- (3) Gás espirala para o interior, fricção -> aumento de temperatura → emissão desde óptico a raios-X
- (4) Algum gás é conduzido e “despachado” pelo campo magnético.

Teoria Unificada das AGNs



Radio galaxies,
Seyferts 2

Observador vê o BN
através do disco; não vê
emissão central, $D \sim$ dias-
luz a meses-luz; $\rho \sim 10^9$
 $/\text{cm}^3$

Quasars

Seyfert 1

Observador vê o centro
do disco acreção; riscas
de emissão larga

Doppler; $D \sim 10 - 1000$
pc; $\rho \sim 10^3 - 10^6 /\text{cm}^3$

Blazars

Eficiência energética ?

Antes de desaparecer no horizonte do BN
→ fracção de massa é convertida em energia. Emissão radia energia potencial gravítica .

Raio BN : $R_s = 2GM/c^2 = 0.25 M_8$ horas luz (típico). Órbita mais interior, estável $\sim 3R_s$.
100% eficiência : energia potencial libertada , quando $R \sim$ infinito a $3R_s$. GR indica eficiência = 6% - 40% (depende de rotação do BN).

números

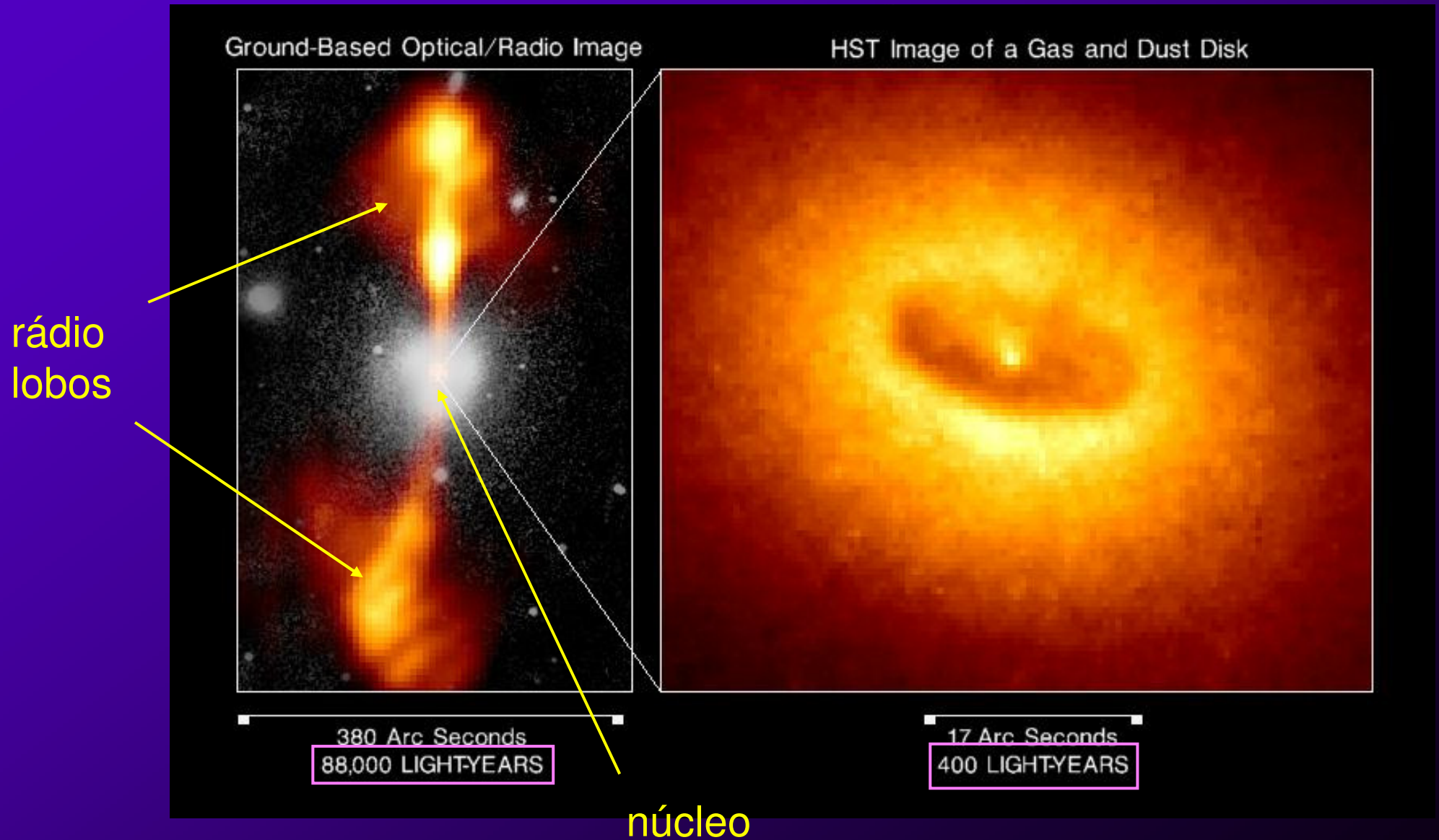
- Massa $M \sim 10^7 - 10^{10} M_{\text{sol}}$,
- $M_8 = M/10^8 M_{\text{sol}}$

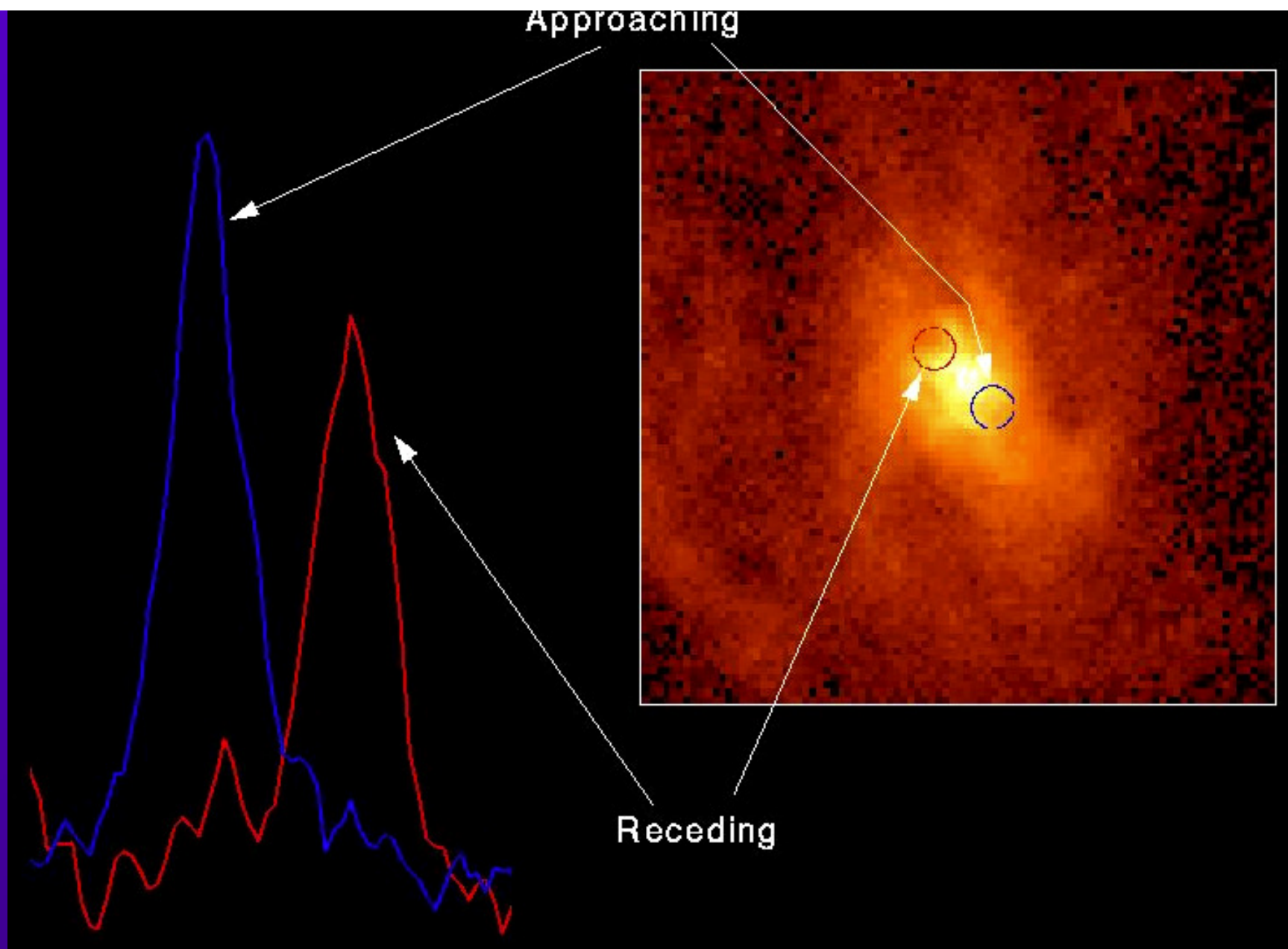
• Raio (Schwarzschild) $R_g = 2GM/c^2 = 3 \cdot 10^{13} M_8 \text{ cm}$
(2 u.a., ou $2 \cdot 10^{-4} \text{ pc}$)

• Dimensão lumínica $t_g = R_g/c = 1000 M_8 \text{ s}$ (20 min)

Exemplo: consumindo $1 - 10 M_{\text{sol}}/\text{ano}$
($\sim M_{\text{Terra}}/\text{min}$), BN $\sim 100 - 1000 L_{\text{Via Láctea}}$

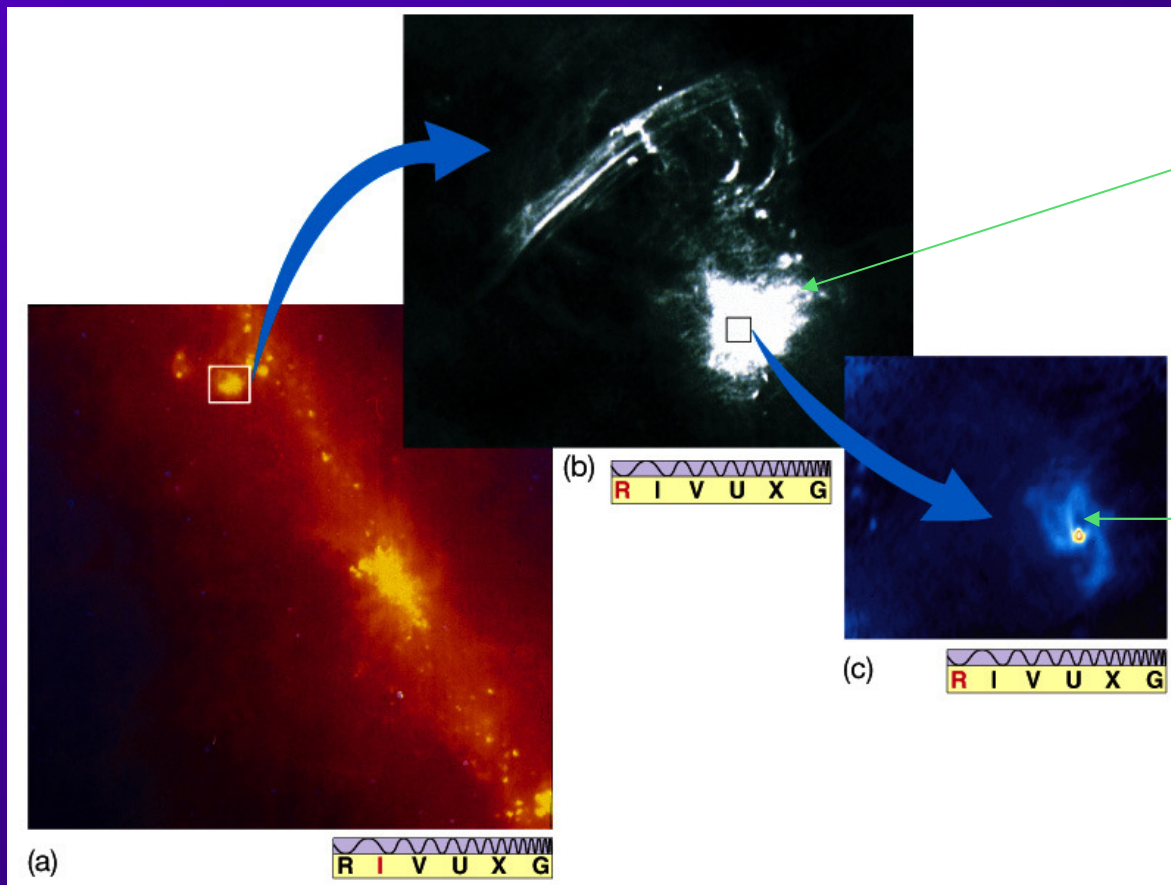
Evidência de buraco negro com disco de acreção : imagem do HST do núcleo de NGC 4261





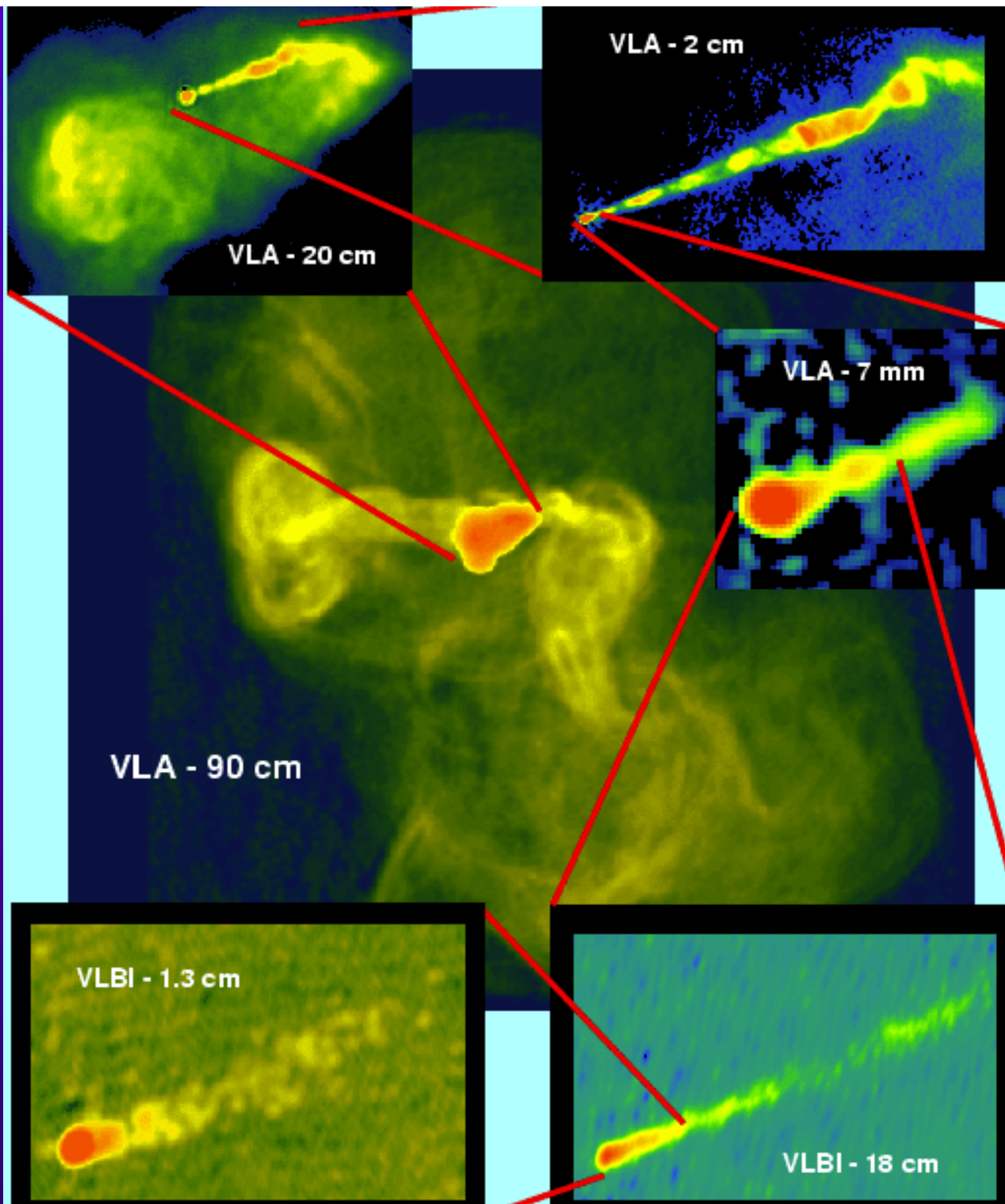
Velocidades derivadas do efeito Doppler requerem ~3 bilhões de Msol.
⇒ buraco negro!

A maior parte das galáxias contêm buracos negros supermassivos . Se são activas ou não : depende do material disponível na vizinhança do BN.

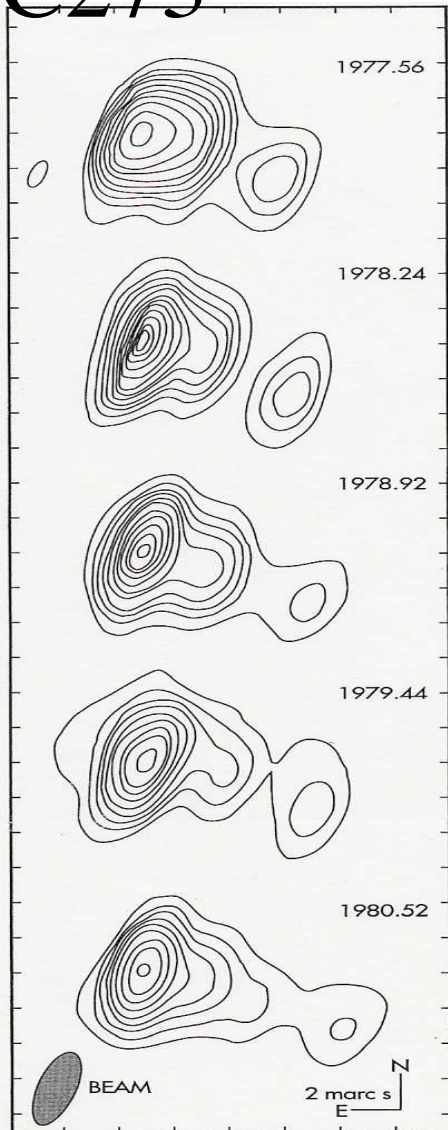


Sagittarius A:
rádio fonte brilhante no centro da Galáxia

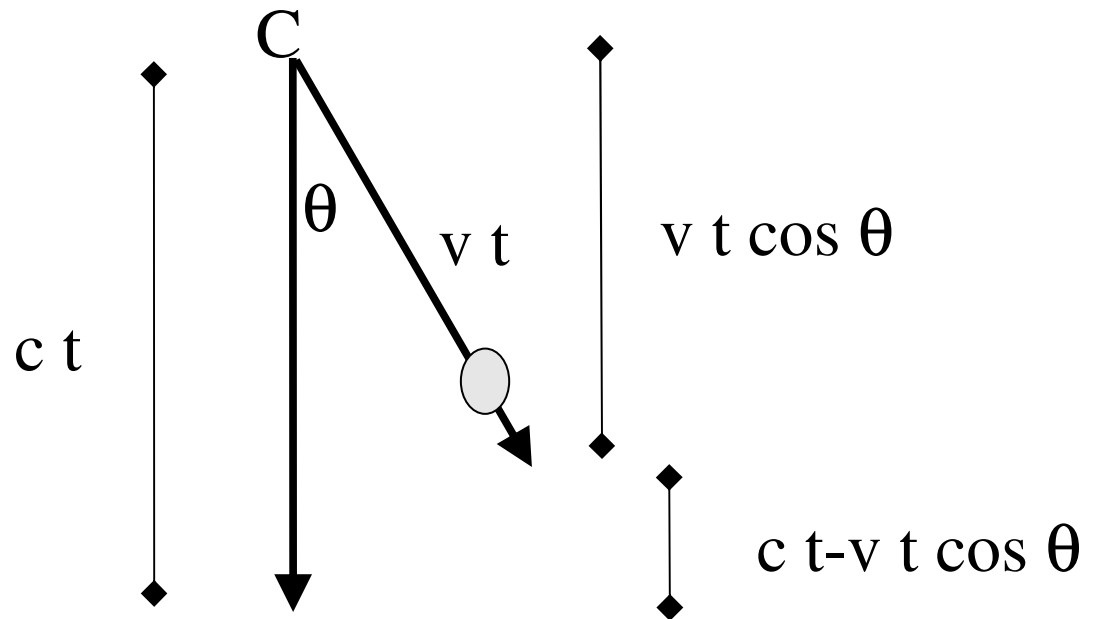
Sagittarius (Sgr) A*:
objecto na parte central,
 10^6 Sol (IV, radio, X, e gama)



mapas VLBI de 3C273



Contour lines of radii from the quasar 3C273 showing a bright "knot" of plasma moving away from it at a speed greater than the speed of light. The time of each image is given as calendar year and fraction. Horizontal scale divisions are in units of 2 mas.



Observador

Explicação:

Após tempo t ,

distância percorrida ao longo da linha de visão : $v t \cos \theta$

distância transversa percorrida : $v t \sin \theta$

atraso temporal visto pelo observador : $t (1 - \beta \cos \theta)$

Logo,

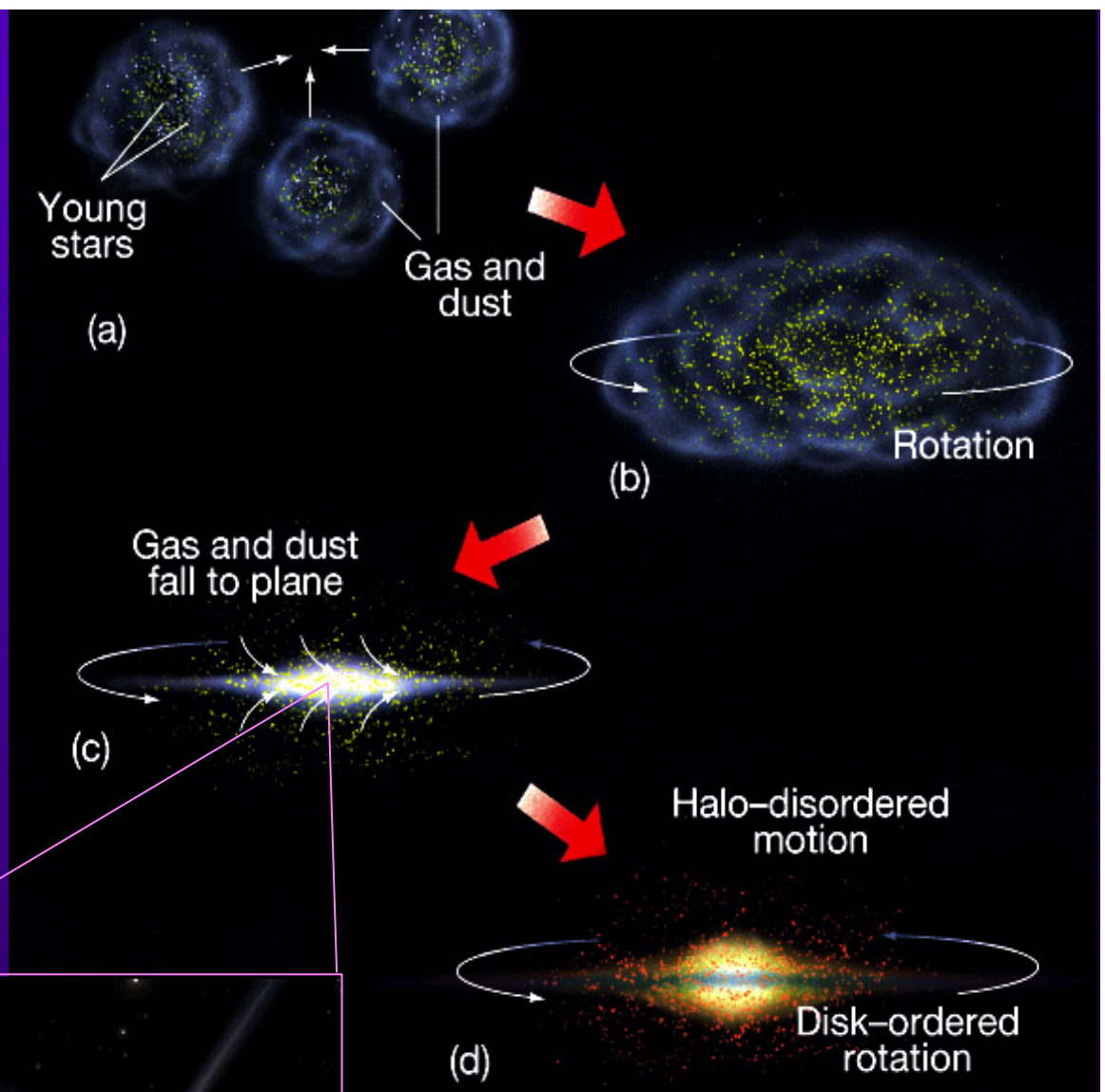
A velocidade transversa aparente é:

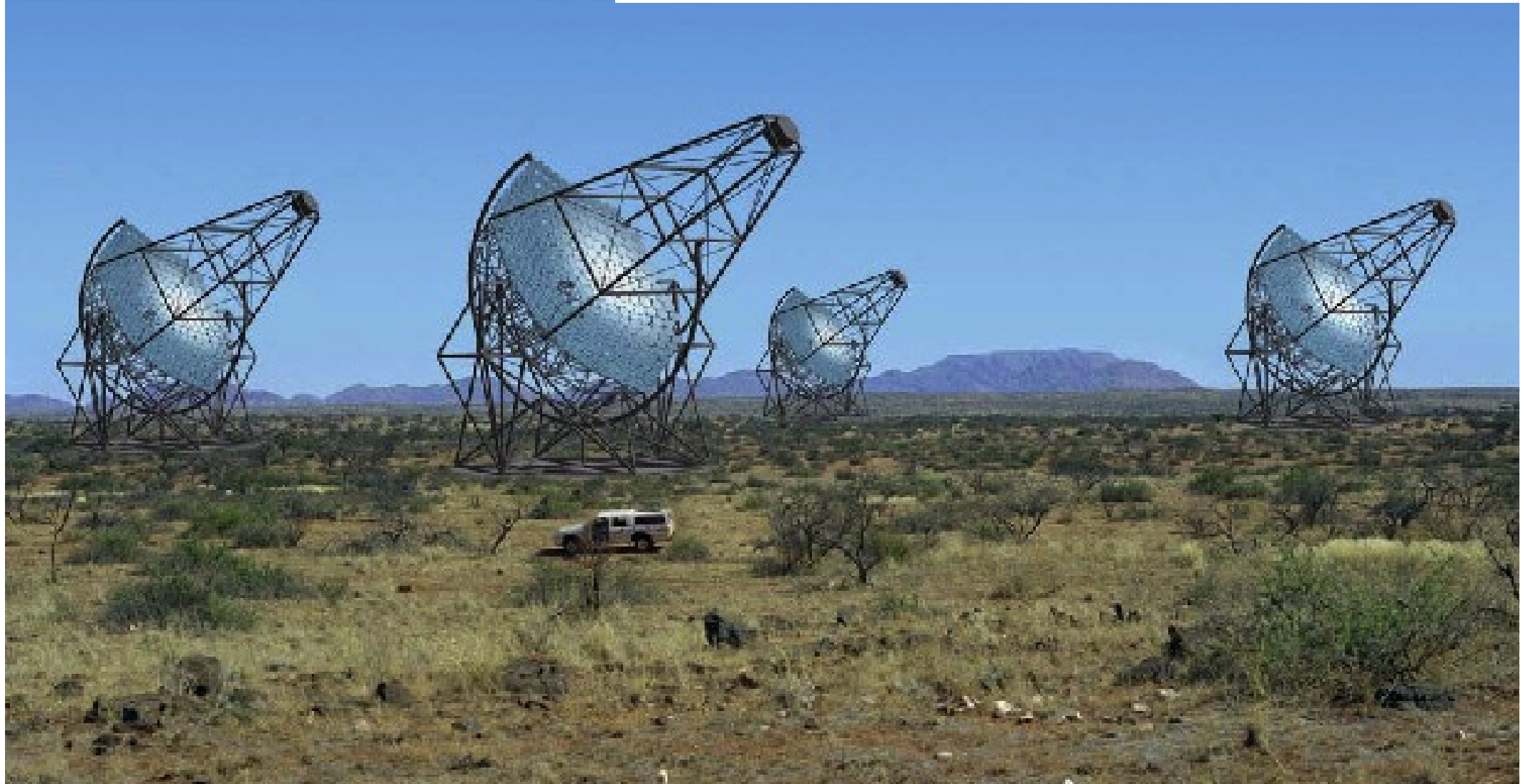
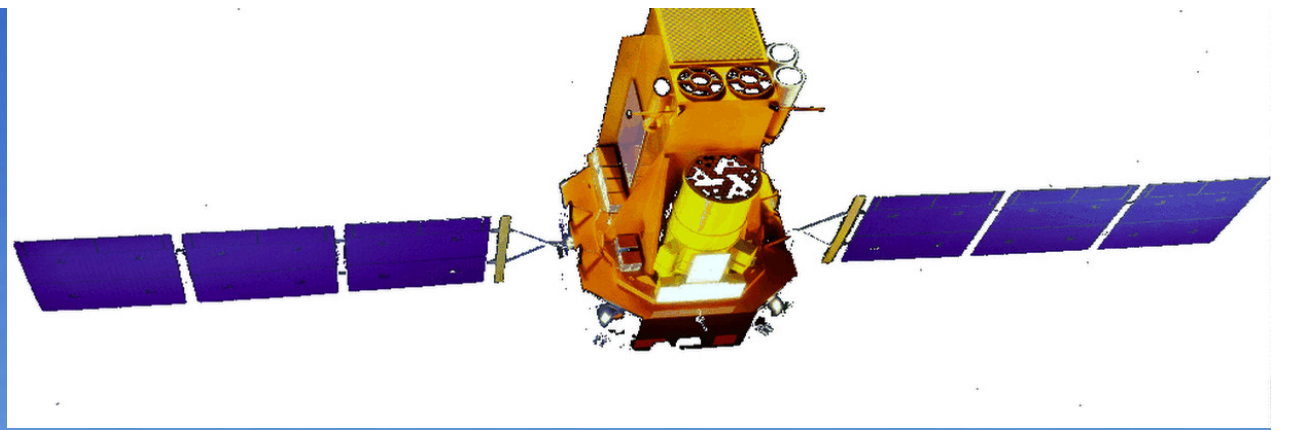
$$v_{ap} = v t \sin \theta / t (1 - \beta \cos \theta)$$

$$\beta_{ap} = \beta \sin \theta / (1 - \beta \cos \theta)$$

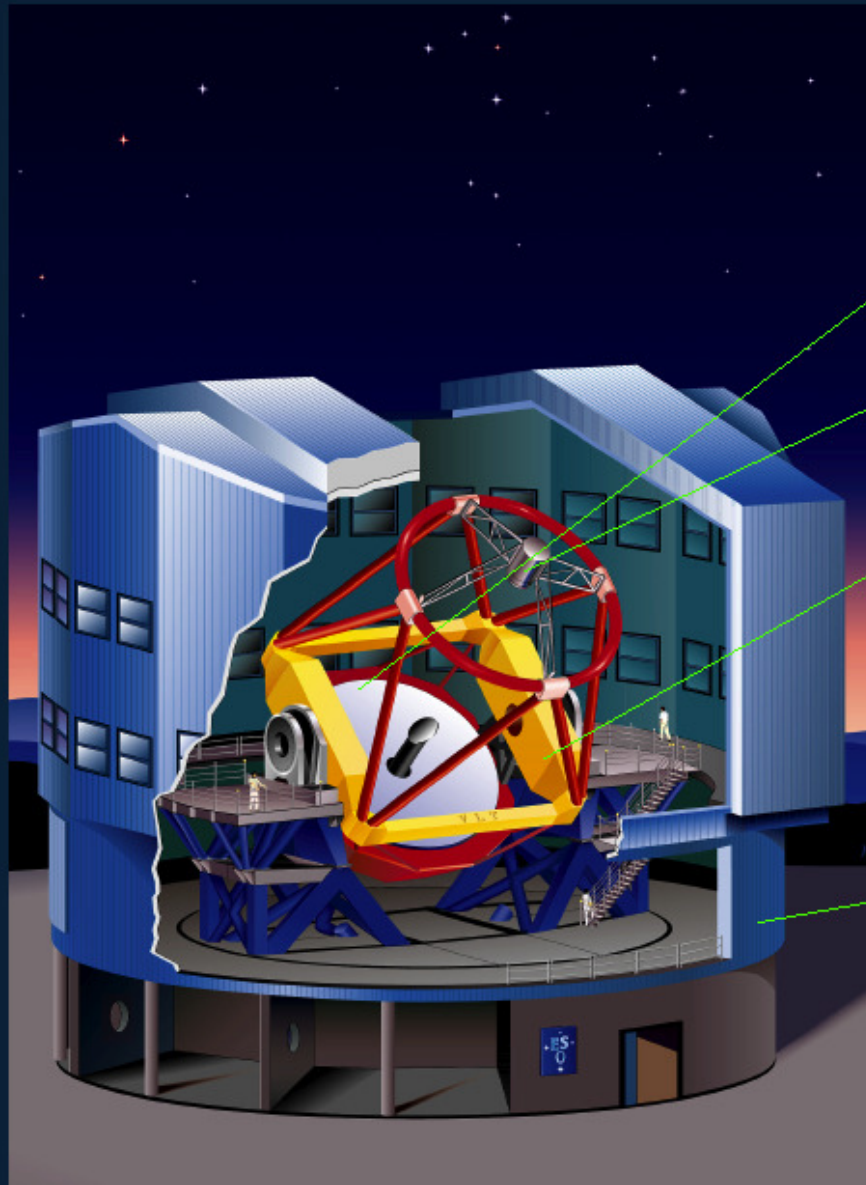
Exemplo: se $\theta \sim 8^\circ$ e $v \sim 0.99c$; $v_{ap} > 10c$!

- Quasars comuns no passado - época de formação galáctica
- Porquê?
- BN formam-se nos centros de jovens Galáxias.
- BN "brilham" como AGN (Quasars) até gastar o fuel (gas acretado) .
- A maior parte dos QSOs já se foram, mas BN ficam...





THE VLT UNIT TELESCOPE



Optics:

- 8.2 m, f/1.8 primary mirror, actively supported (150 axial/64 lateral supports)
- 1.2 m chopping secondary mirror with “tip/tilt” system

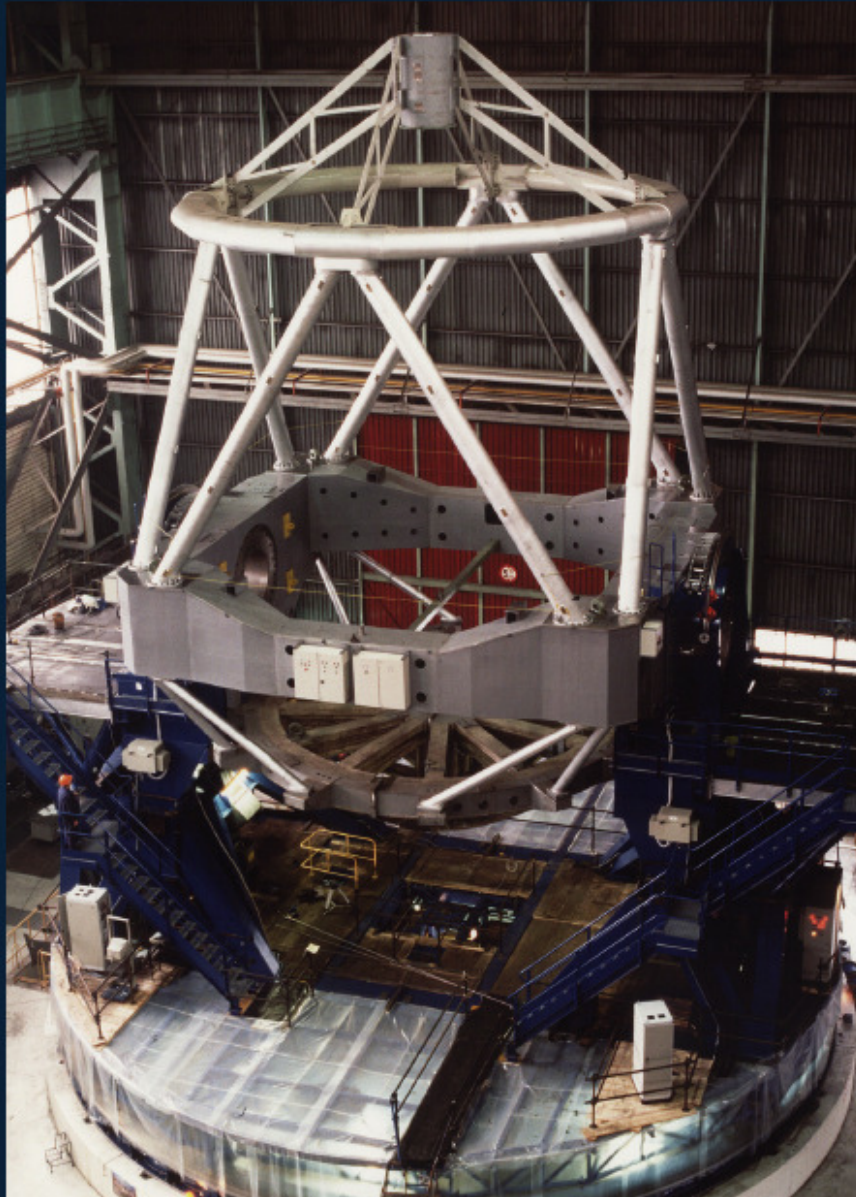
Mechanical structure:

- Very high mechanical precision
- Backlash and friction free torque motor drives
- High angular resolution encoders

Enclosure:

- Designed to minimize thermal effects
- Earthquake resistant (7.8 on Richter Scale, 65 sec, 100 km dist.)

THE MAIN MECHANICAL STRUCTURE



Mount:
Alt-Az

Moving Mass:
430 t (total 542 t)

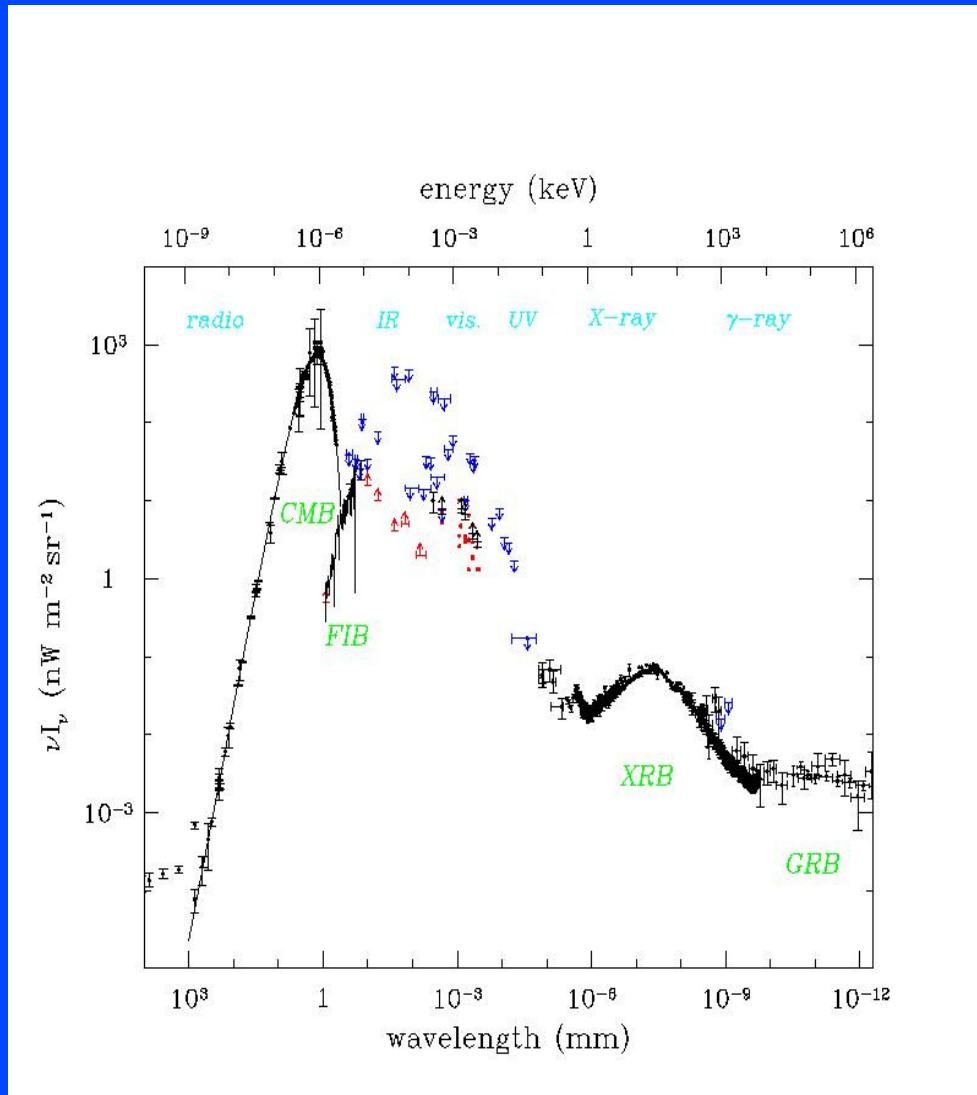
Lowest mechanical eigenfrequency:
8 Hz

Drive motors:
Direct (no gears)

Encoders:
Strip Encoders

Bearings:
Hydrostatic

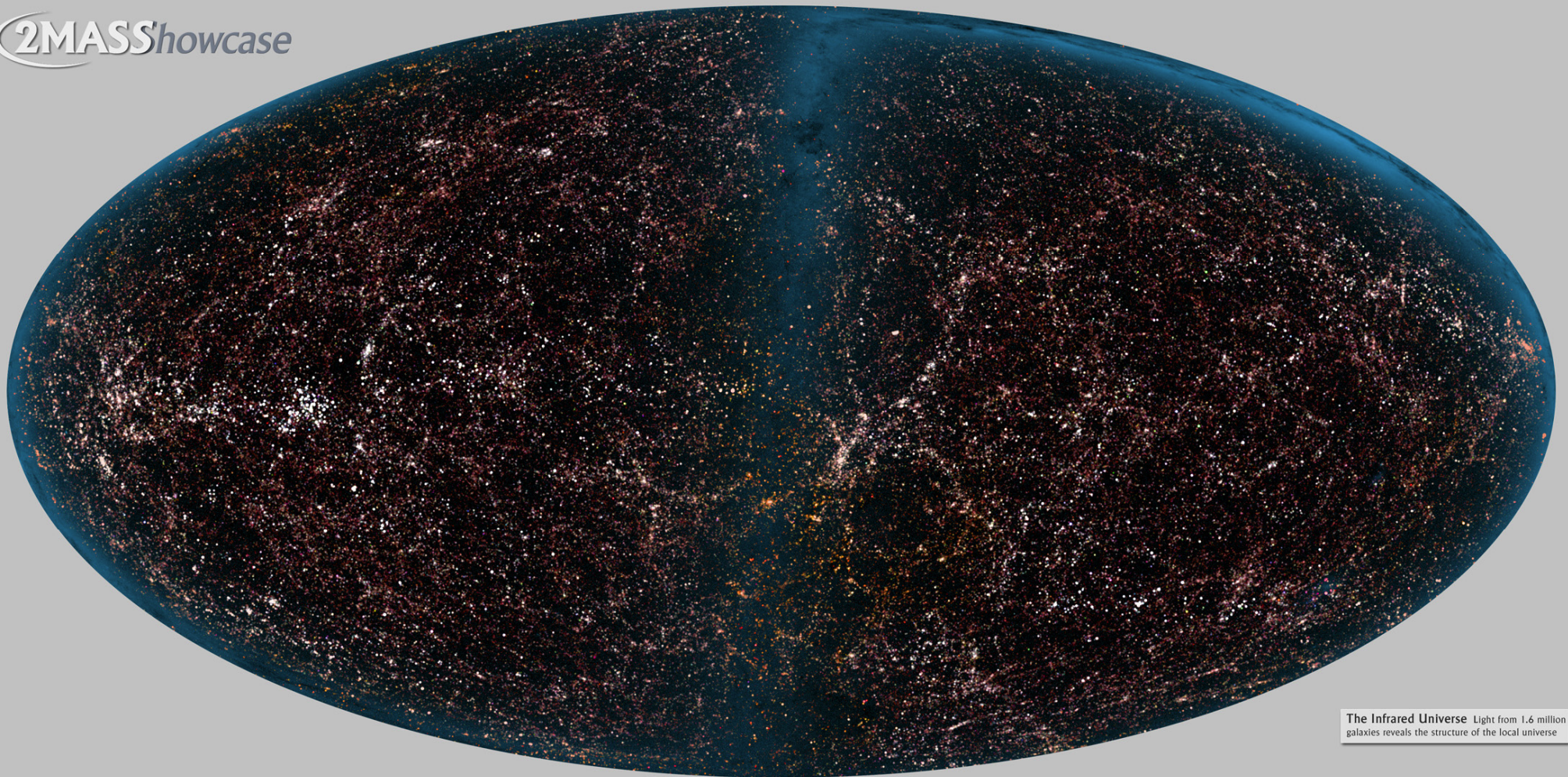
FRCM – domina a energia do Universo



- Primordial : 380 000 anos após o Big-Bang.
- 400 fotões por cm cúbico.
- Temperatura de 3K
- Quase ~ 100% do conteúdo energético sob forma de radiação electromagnética

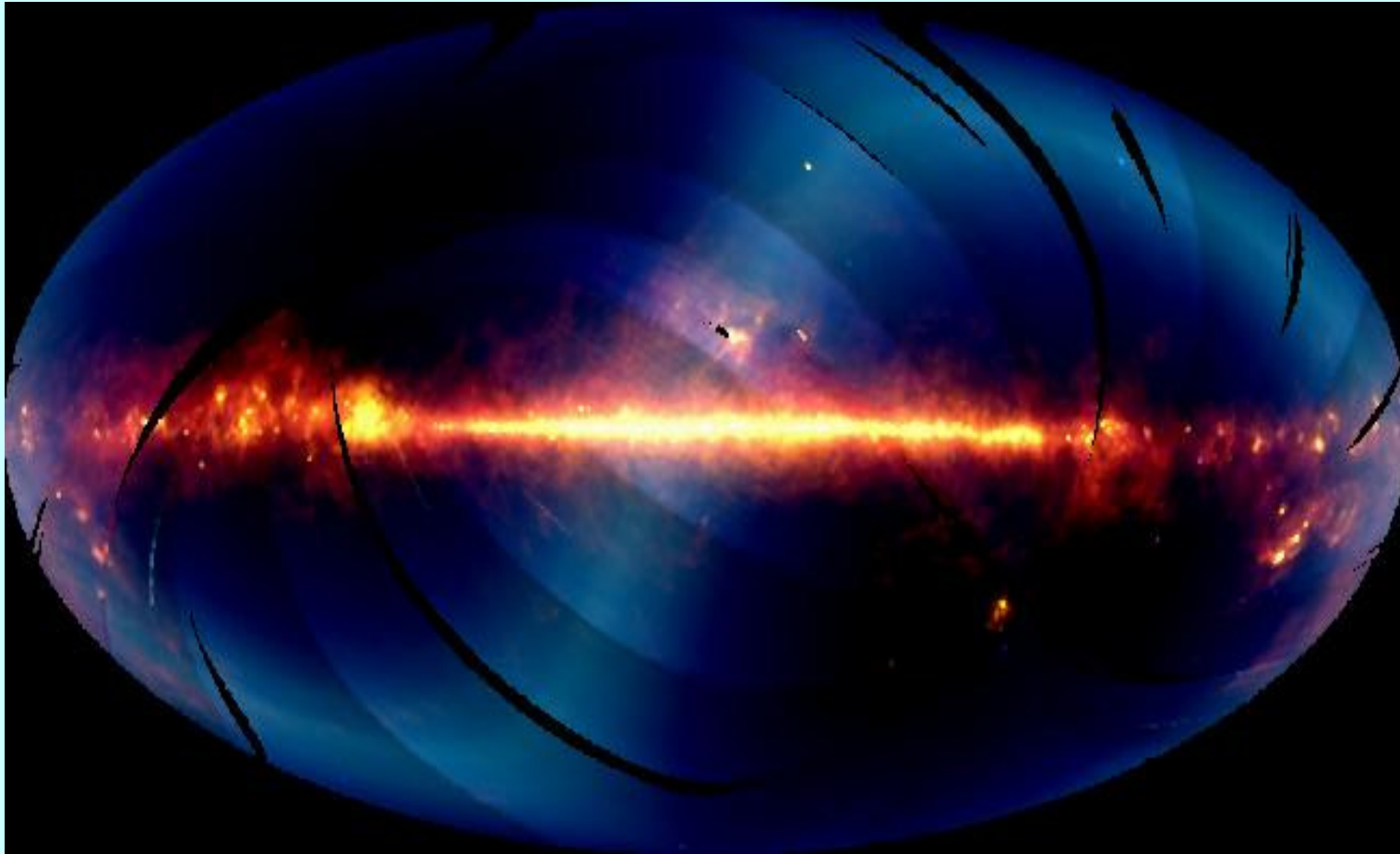
2MASS > 2 Milhões de galáxias!

2MASS *showcase*

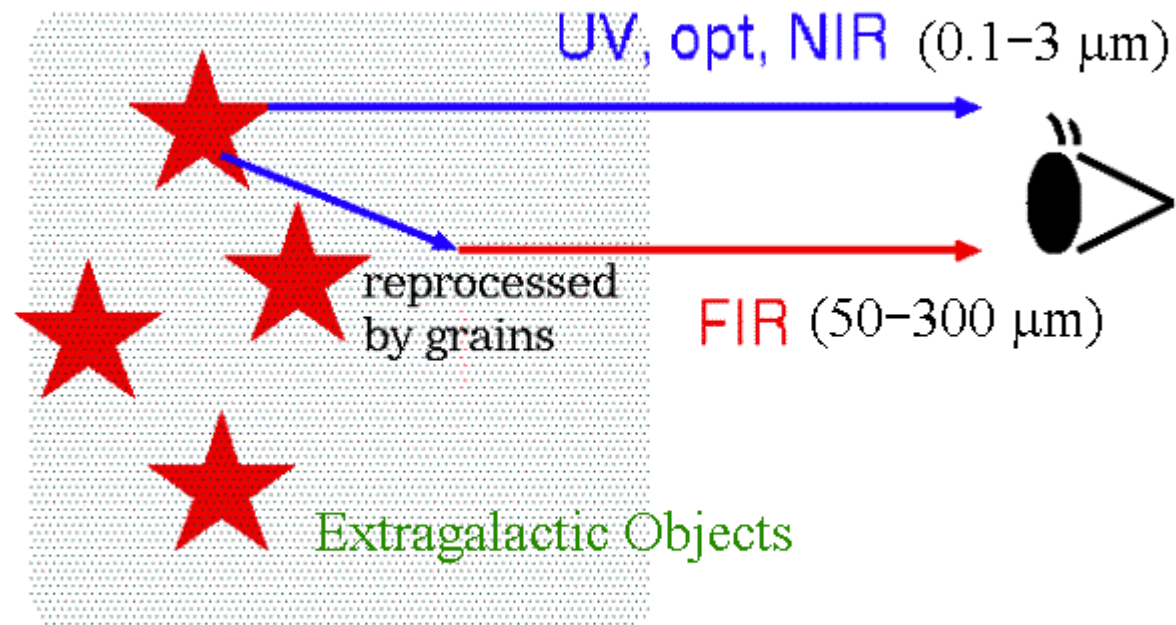


The Infrared Universe Light from 1.6 million galaxies reveals the structure of the local universe

Infravermelho (IRAS)



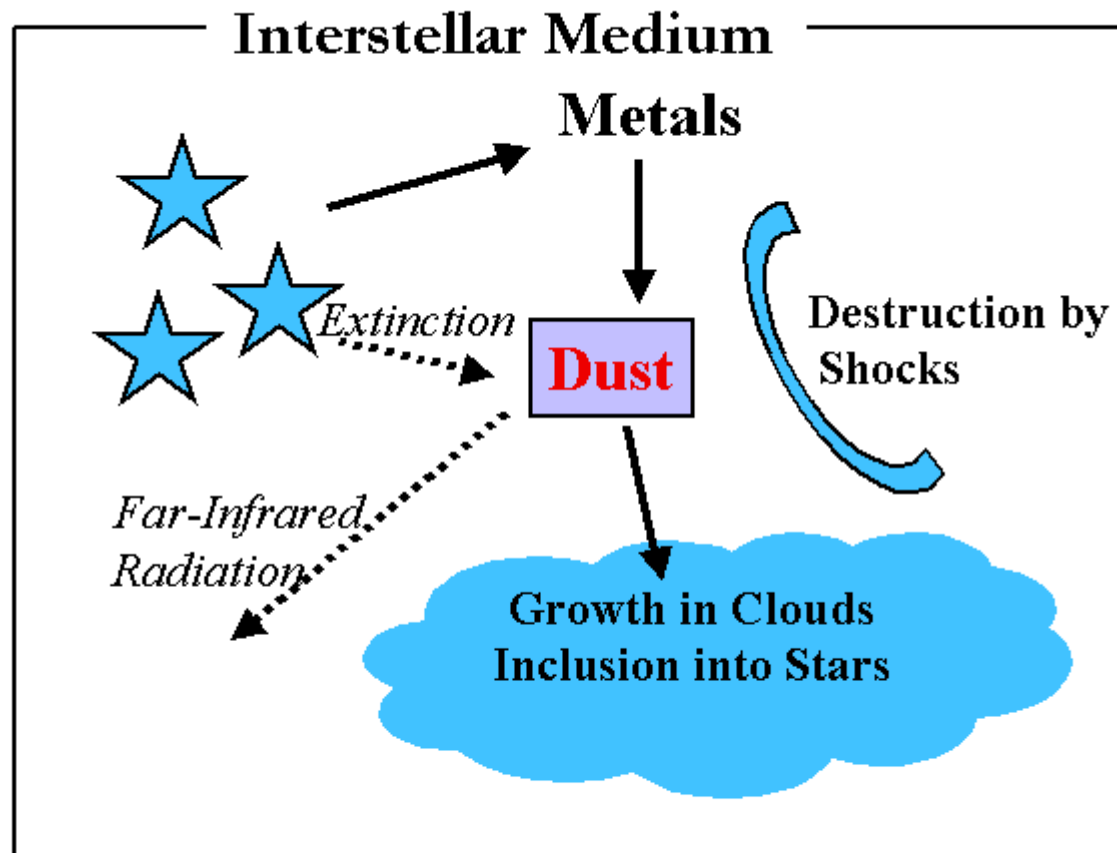
1. Importance of Galaxy Dust



Interstellar dust **determines the distribution of radiative energy** between the UV/optical/NIR and FIR.

Poeira Cósmica

- Contêm 50% dos metais : história do enriquecimento metálico do meio intergaláctico.
- Universo local : ~50% do UV e óptico absorvidos e reprocessados no IR -> determina a forma do espectro das galáxias do UV-IR.
- Primeiras épocas de FG : baixa metalicidade. Arrefecimento sem metais pouco eficaz. => através de emissão vib-rotacional de H₂ para ajudar a formar a galáxia. H₂ forma-se com eficácia junto dos grãos de poeira.
- Poeira Cósmica: central na formação galáctica.



Formação Galáctica primordial

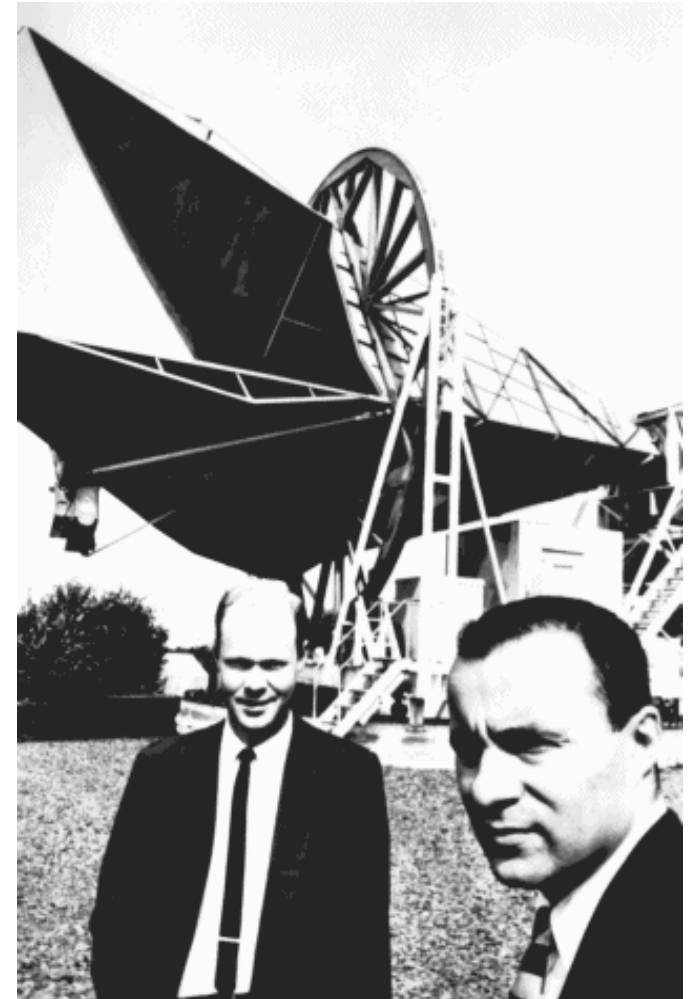
- Grãos de poeira: compostos de metais produzidos em estrelas (ejectados no meio na parte final do ciclo estelar).
- Estrelas massivas produzem metais e são a primeira fonte de injeção metálica no meio intergaláctico.
- Estrelas com $M > 8M_{\odot}$ finam como supernovas de tipo II ($t_{\text{vida}} \sim 50 \times 10^6$ anos). Importante para épocas com baixo t_{Hubble} .

Evolução da poeira galáctica

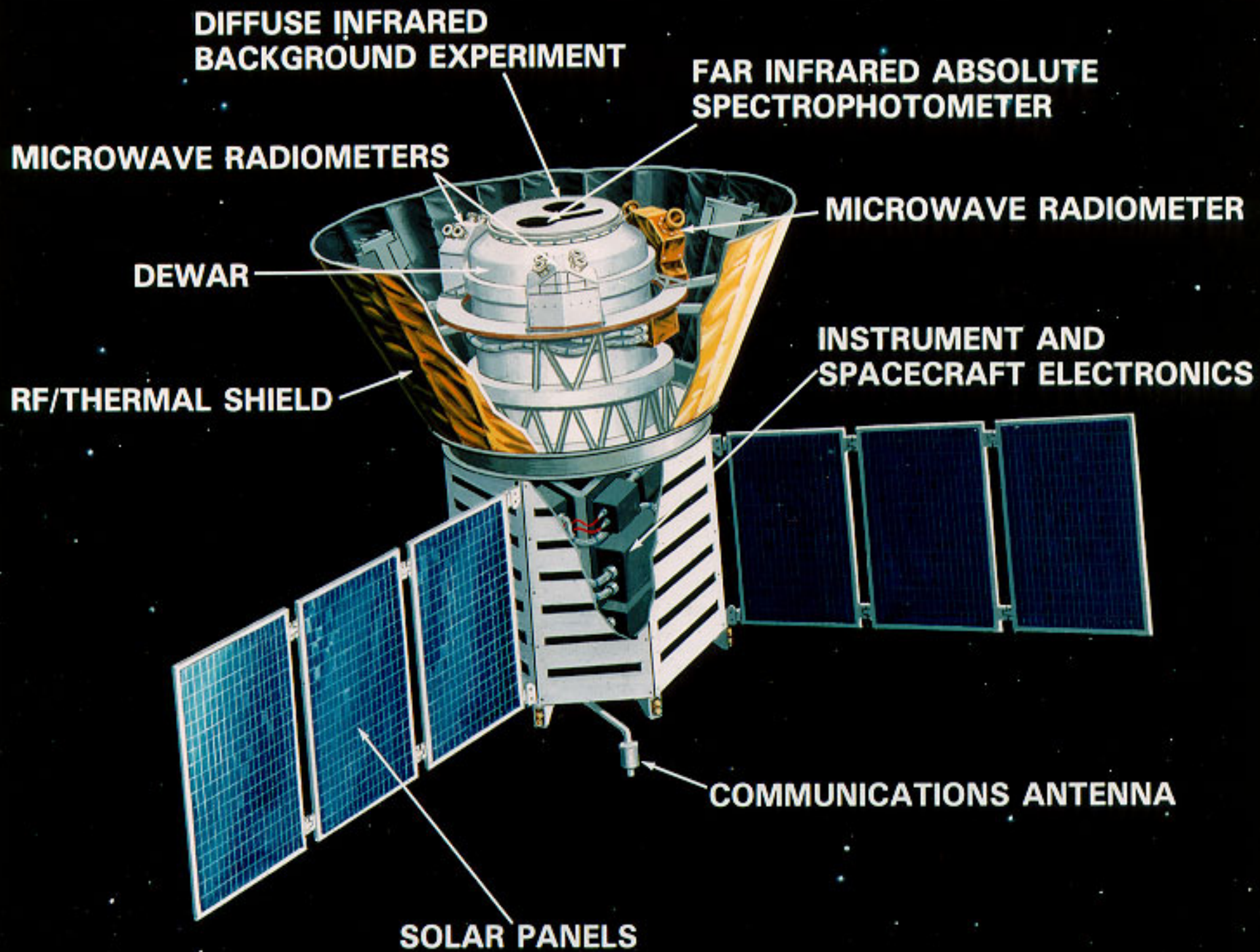
- Se $t_{gal} > 1 \text{ Gy} \Rightarrow$ estrelas massivas produzidas \Rightarrow ventos estelares enriquecem a poeira cósmica.
- Grãos crescem até $\sim > 1 \text{ mm}$.
- Absorbem a emissão estelar e aquecem com $T \sim 10\text{-}100 \text{ Kelvin}$. \Rightarrow pico no Infravermelho.
- Galáxias com forte formação estelar têm forte emissão IR
- **Astrofísica no IR : teste da formação galáctica.**

O FRCM: uma “pequena” História

- **1948**: Alpher, Gamow, Herman prevêm a existência do FRCM
- **1964**: Dicke, Peebles, Roll & Wilkinson (Princeton) **começam a procurar**
- **1964**: Penzias & Wilson (AT&T Bell Labs) (accidentally) **encontram-na !**
 - **$T = 3K$, constante em todo o céu**
 - nota: Já observada, dados CO do 1940s!



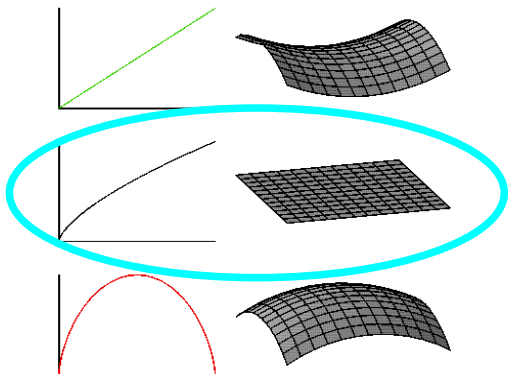
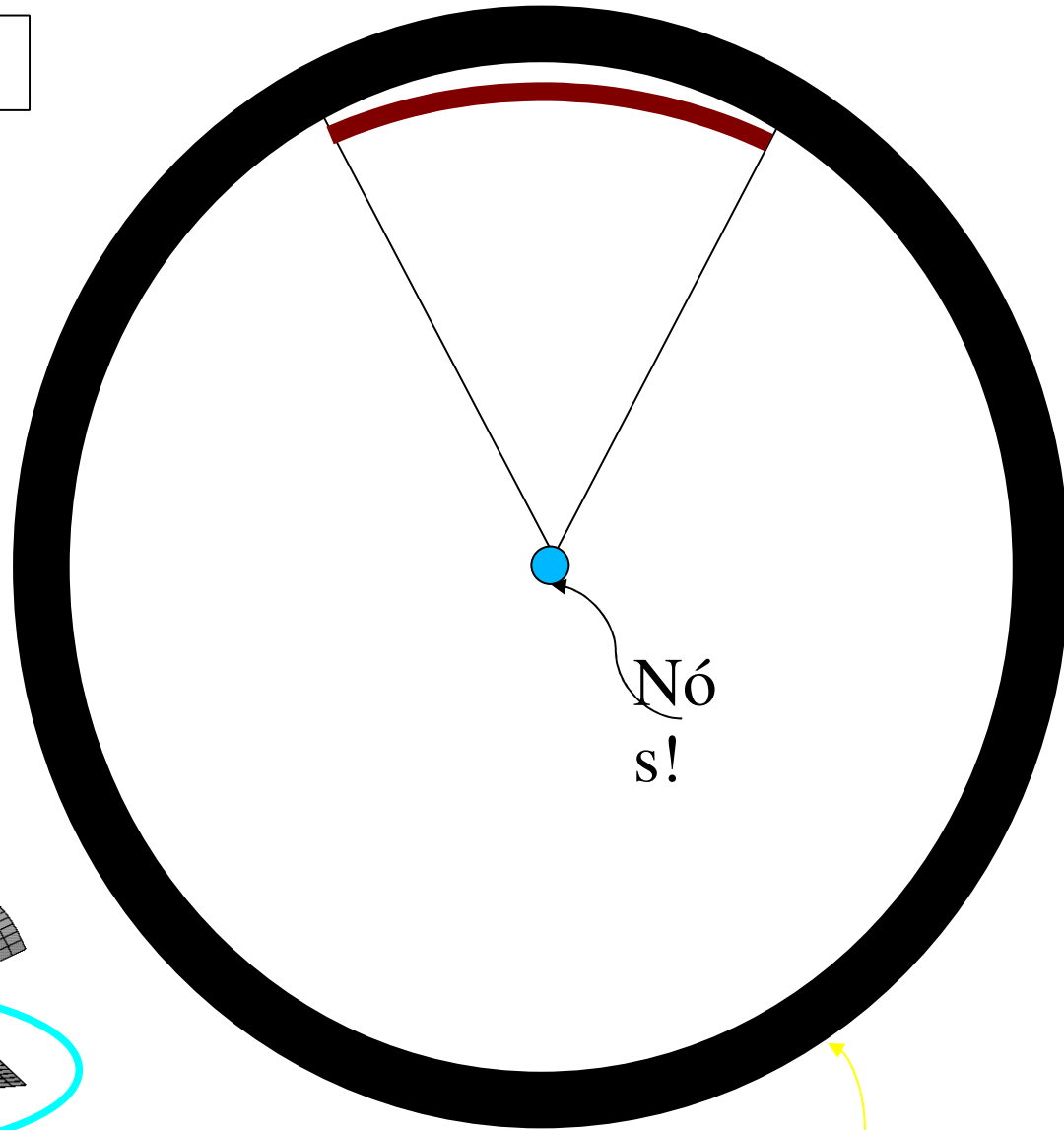
Penzias & Wilson in NJ



Medindo a Curvatura com o FRCM

Plano

$\Omega=1$

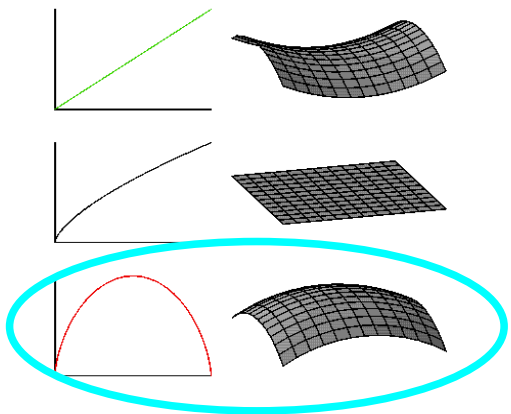
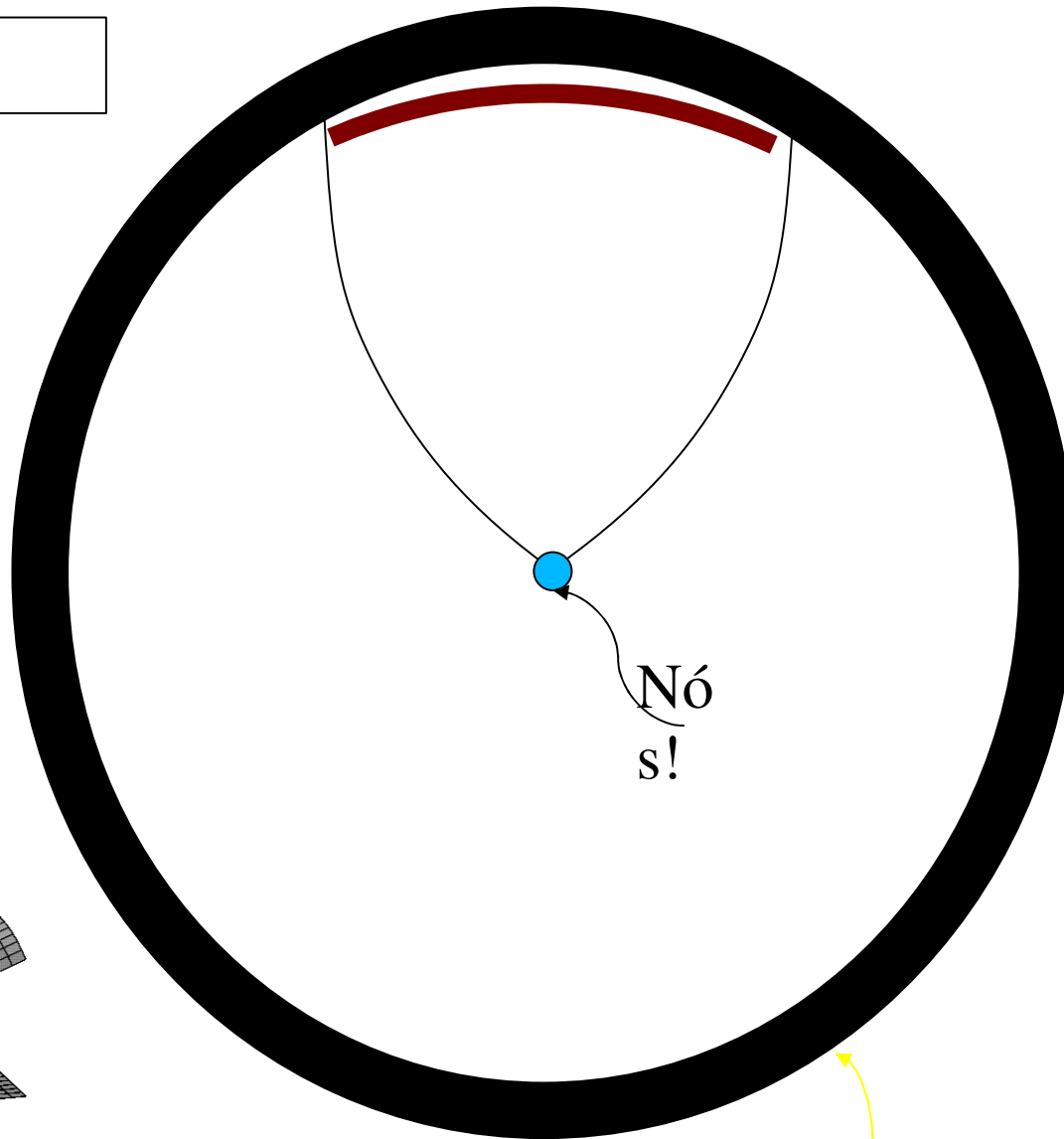


Última superfície de

Medindo a Curvatura com o FRCM

Fechado

$\Omega > 1$

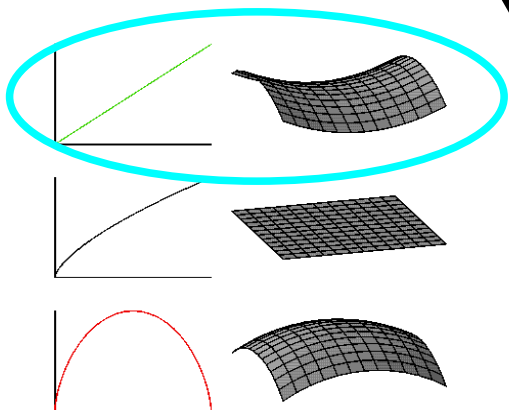
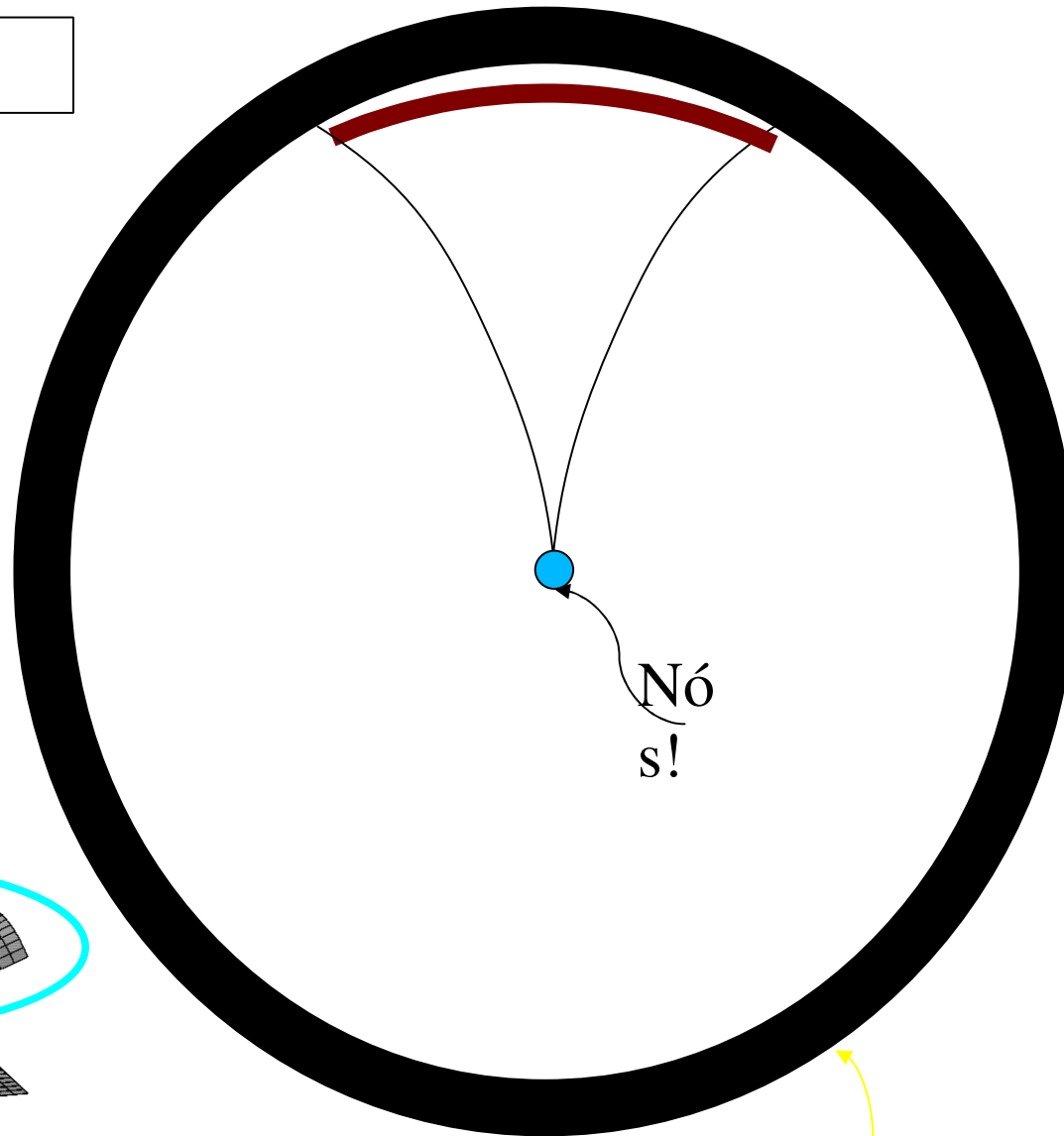


Última superfície de

Medindo a Curvatura com o FRCM

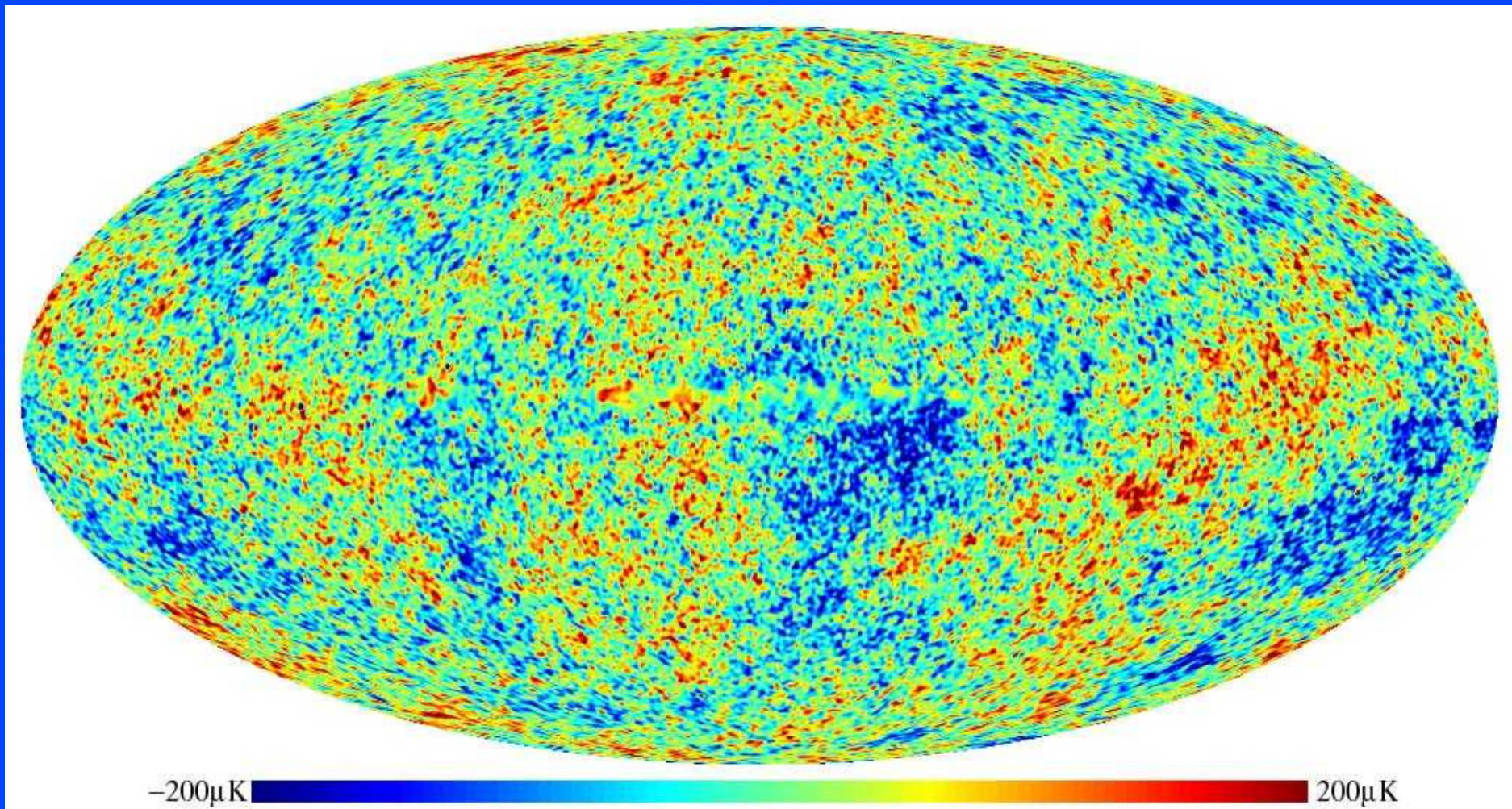
Aberto

$\Omega < 1$



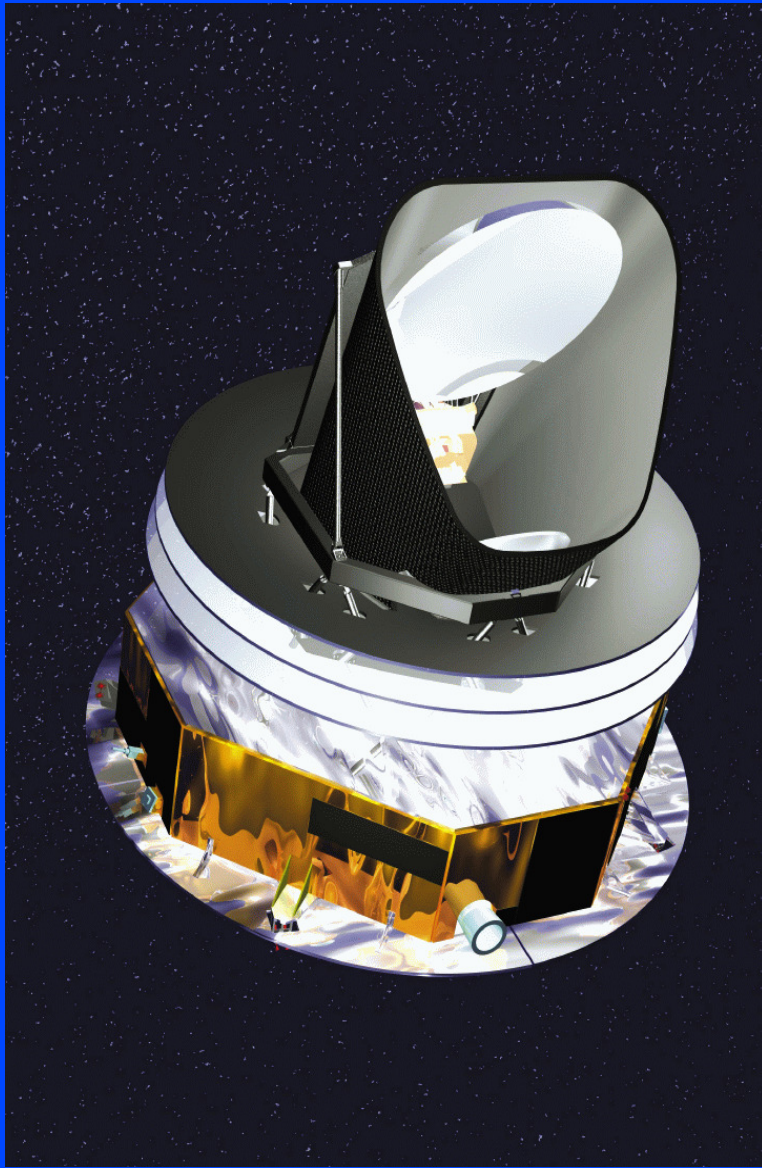
Última superfície de

E o WMAP chegou!!!



Precisão de 15 arcmin $∴ l = \text{inverso}(\text{ângulo}) \sim 900$!

E o futuro ? *Planck Surveyor (ESA, 2007)*

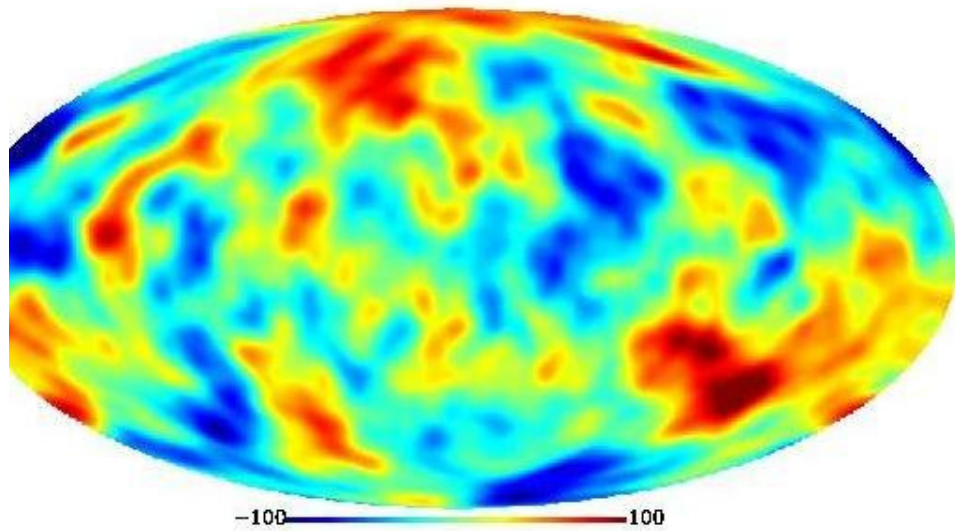


Grande precisão:
5 minutos de arco

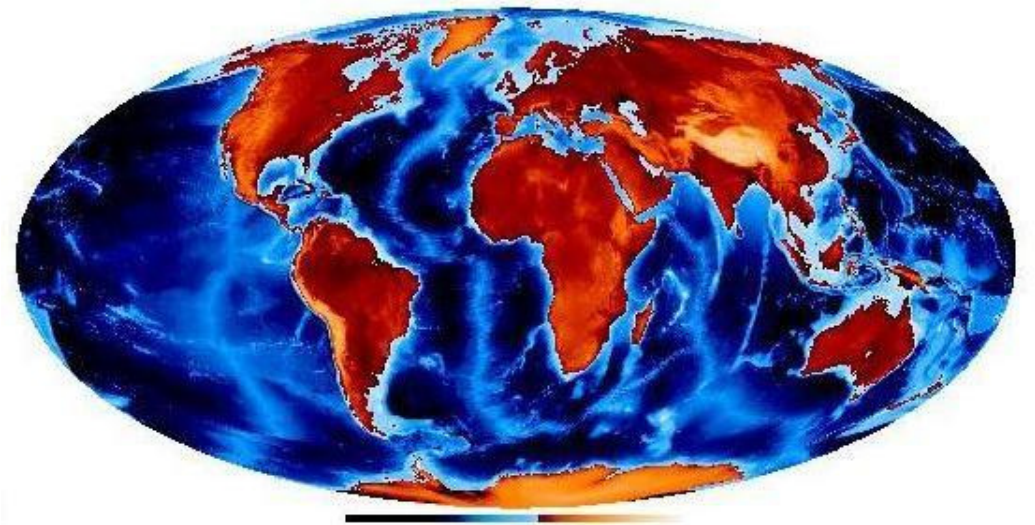
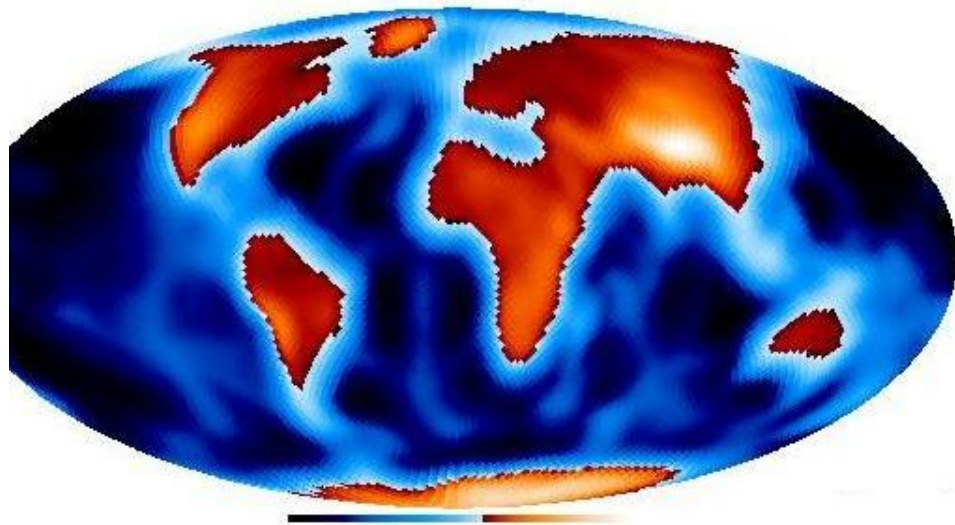
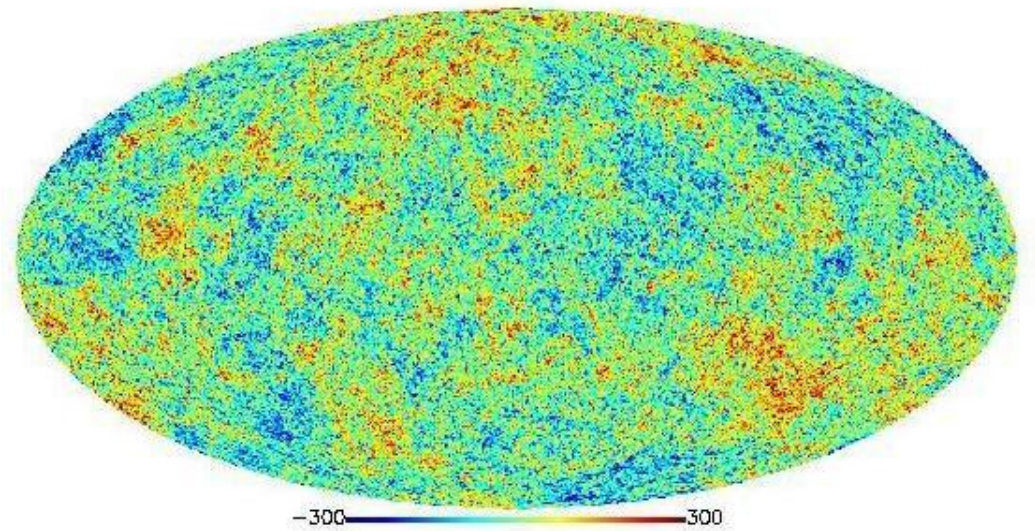
$l=3000$

geometria e conteúdo com
cerca de 1%.

COBE-DMR resolution

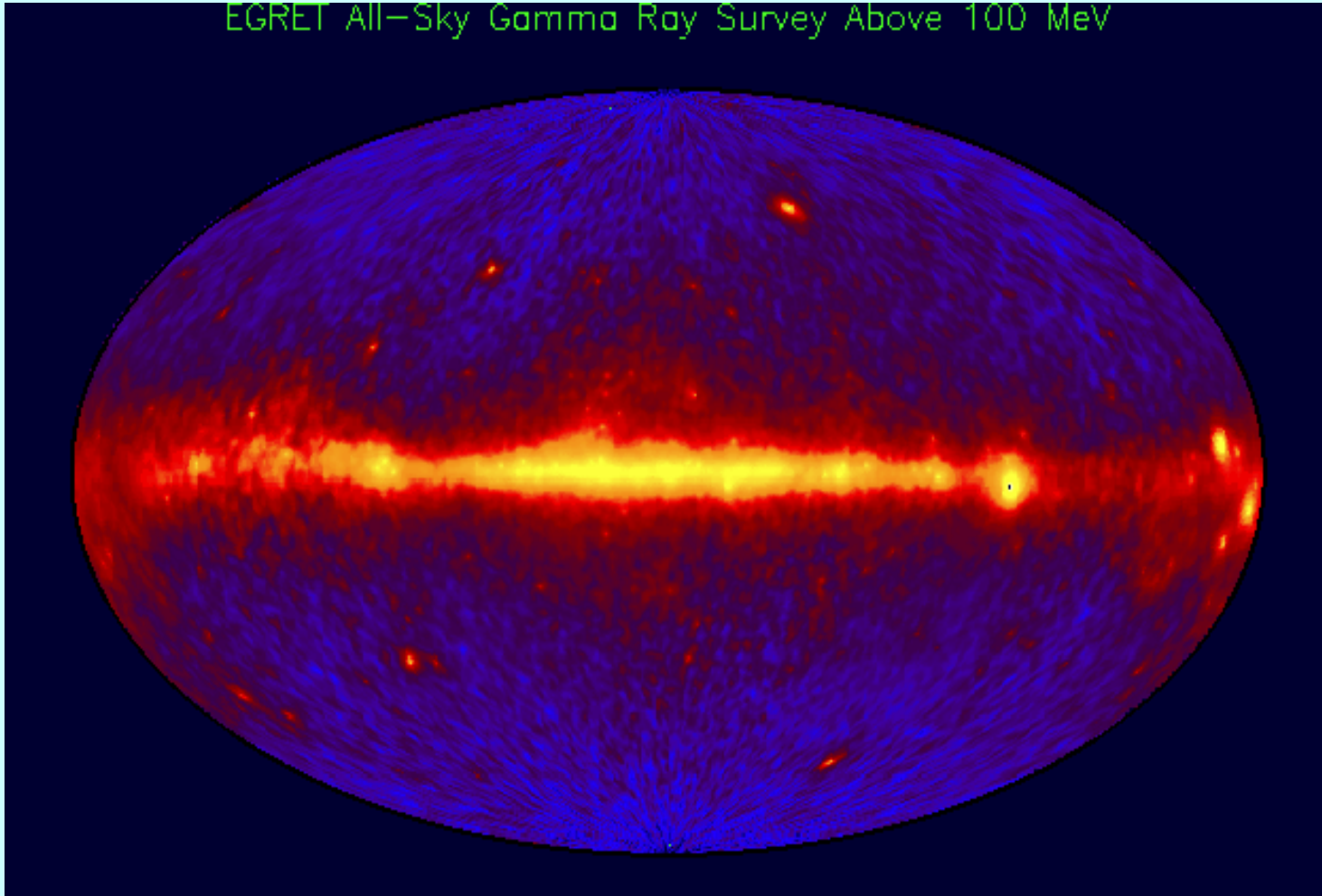


Planck Surveyor resolution



Raios Gamma

EGRET All-Sky Gamma Ray Survey Above 100 MeV



À procura dos Gamma ray Bursts! ->

Explosões de raios Gamma

Saltos de emissão rápidos.

Curta duração : ~ms – 2s.

Longa duração: ~100s. (hipernovas ($M > 20M_{\odot}$)
cosmológicas)

Hipernovas = colapsar = Wolf-Rayet.

Taxa: ~ 1 SN/gal/séc. ; 10^{11} gal. No Universo Observável

$t_{\text{gal}} \sim 10^{10} \text{anos} \Rightarrow 10^9 \text{ Sns/ano no Universo (30 Sns/s)}$

1/100 000 Sns dão hipernovas \Rightarrow 1 GRB/dia (o que é observado !!!)

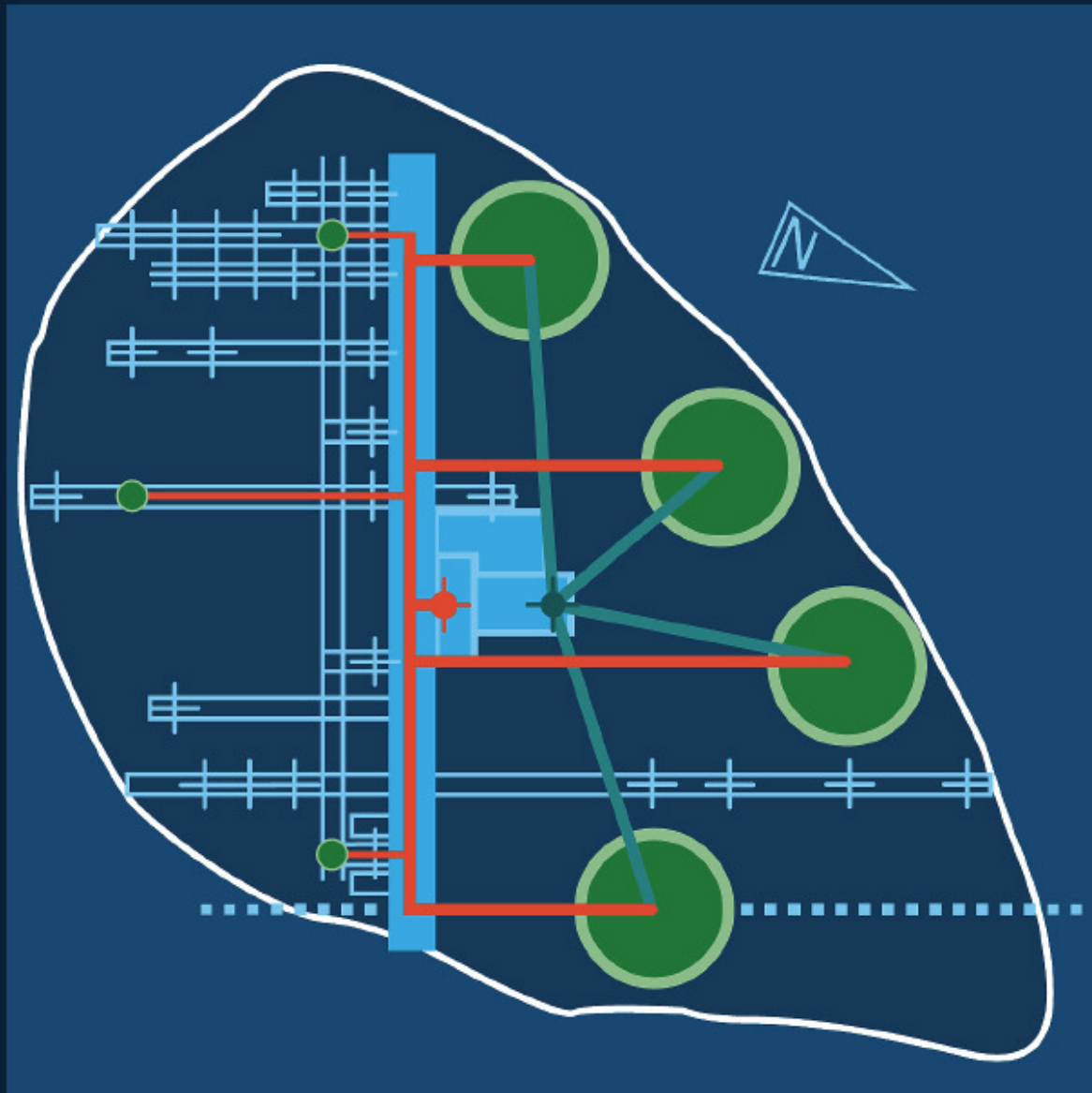
Conclusão

- A astronomia extragaláctica é:vasta!
- Esquema unificador de formação galáctica: das espirais às elípticas.
- A matéria escura , medida dinamicamente é o motor da formação (e o puzzle). Reponsável por 90% da massa do Universo.
- Todas as galáxias contêm buracos negros.
- Formação galáctica em esquema hierárquico:
- Dos objectos á estatística: testes cosmológicos.

Conclusão II

- Os fundos cósmicos - sombras de um passado glorioso.
- Fundo em raios X : assinatura das AGN e aglomerados de galáxias.
- Braços (e cabeças pensantes) precisam-se !
- Alistem-se na Astrofísica.

THE VLT INTERFEROMETER



No. of combined telescopes:
2 to 7 (8)

Baselines:
30 to 130 m (UTs)
8 to 200 m (ATs)

Delay line stroke:
60 m

Angular resolution:
 $0''.001$ at $1 \mu\text{m}$

Wavelength coverage:
480 nm - 20 μm

A BIRD'S VIEW OF PARANAL



December 1997