Koevoluce galaxií a centrálních černých děr

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Jak vznikají aktivní galaktická jádra (AGN) ?

$L_{AGN} = 10^{39} – 10^{48}$ erg/s

REZENTACE/IMAGES/qu $= 10^{6} – 10^{15}$ Lo

Quasars (QSO): $L > 10^{45}$ erg/s

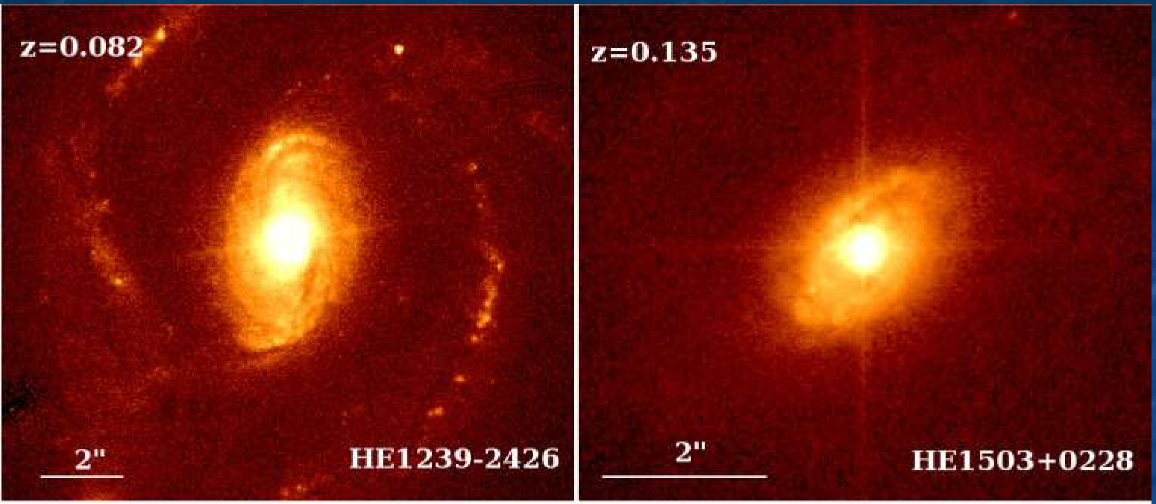
Low-luminosity AGN (LLAGN):

Seyfert gal.: $L = 10^{40} - 10^{45}$ erg/s

LINERs: $L = 10^{39} - 10^{44}$ erg/s

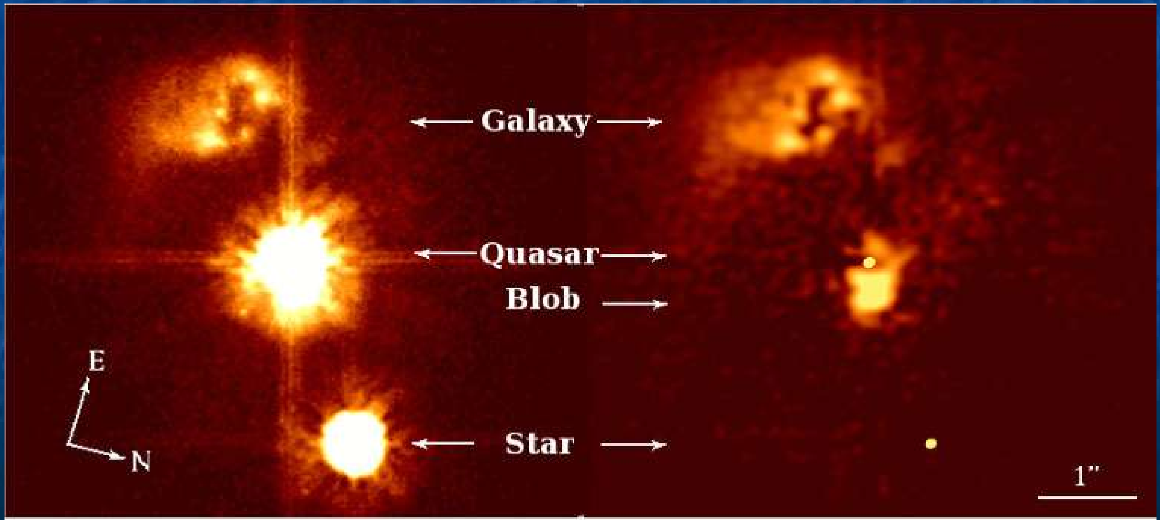
Ultra-low luminosity AGN

Quasar host galaxies



Two Quasars with Their Host Galaxy
(HST)

ESO PR Photo 28a/05 (September 14, 2005)

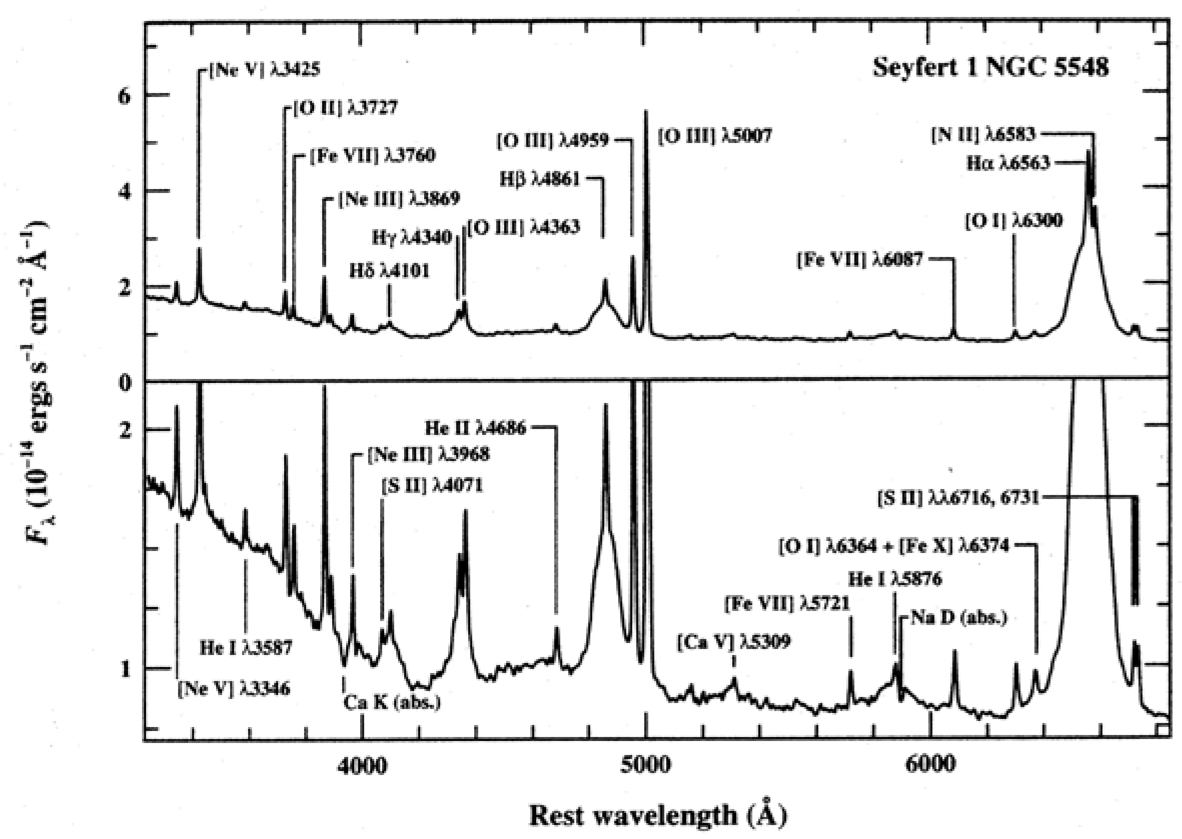


The Quasar without a Home: HE0450-2958
(HST)

ESO PR Photo 28b/05 (September 14, 2005)

Type 1 vs. Type 2 AGN

Seyfert 1 vs. Seyfert 2 galaxies
Type 1 vs. Type 2 quasars



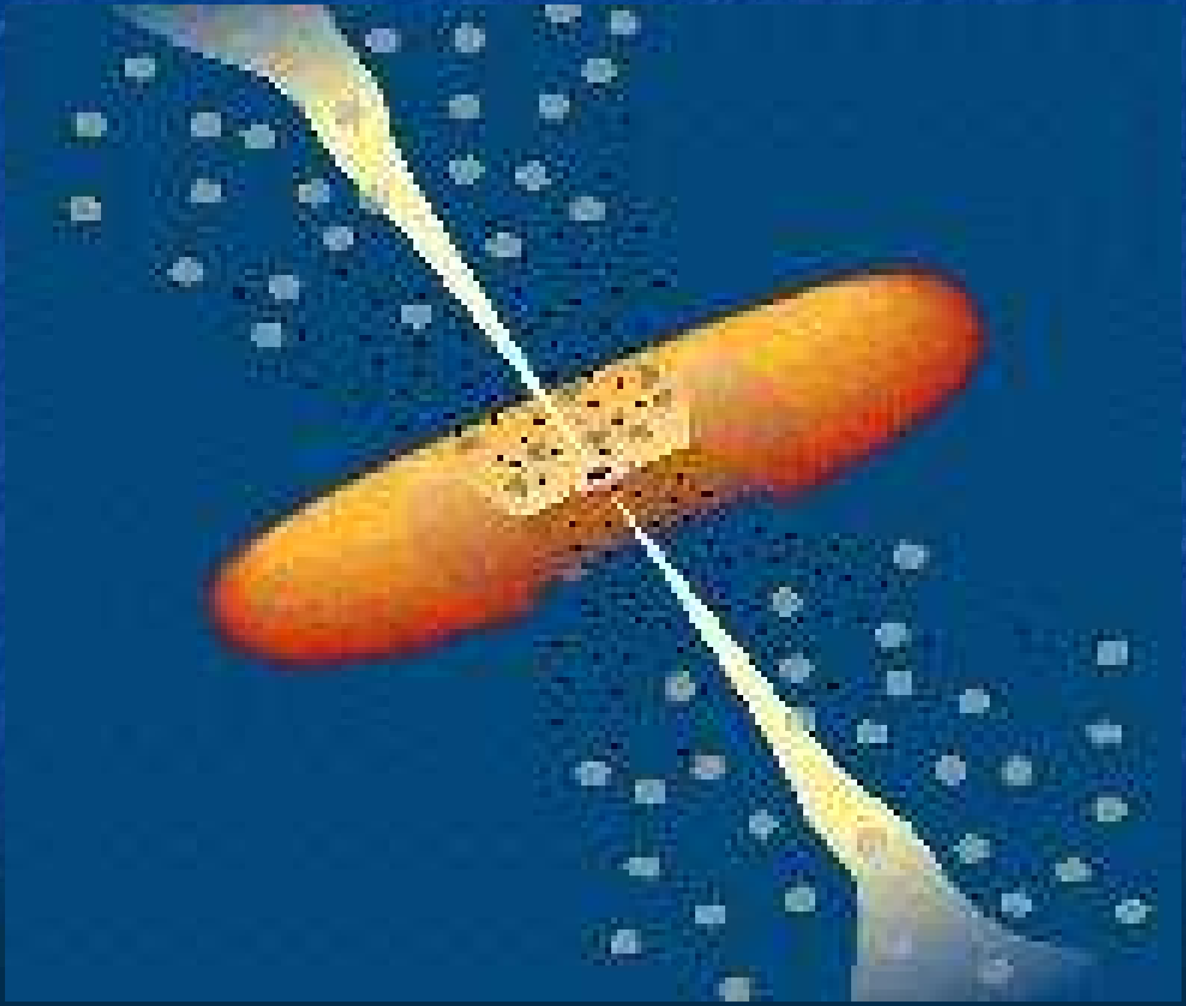
Type 1:

Broad emission lines (permitted)
+
Narrow emission lines (forbidden)

Type 2:
Narrow emission lines (permitted + forbidden)

Weak broad lines sometimes seen in the polarized light: Antonucci & Miller (1985)
--> Unification

Sjednocený model pro AGN (Unified AGN model)



Černá díra

Akreční disk

Broad-line region (BLR)

Torus

Narrow-line region (NLR)

Jet

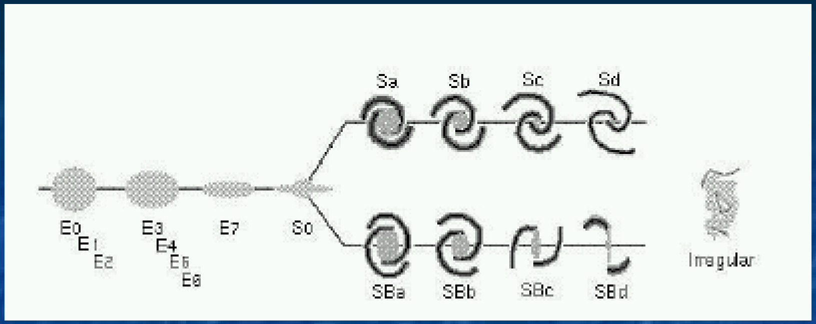
(fig. from Urry 2003)

AGN luminosity and accretion rate

$$L = \eta \, dM/dt \, c^2 = \eta \, dM/dt \, 5.7 \, 10^{46} \text{ erg/s}$$

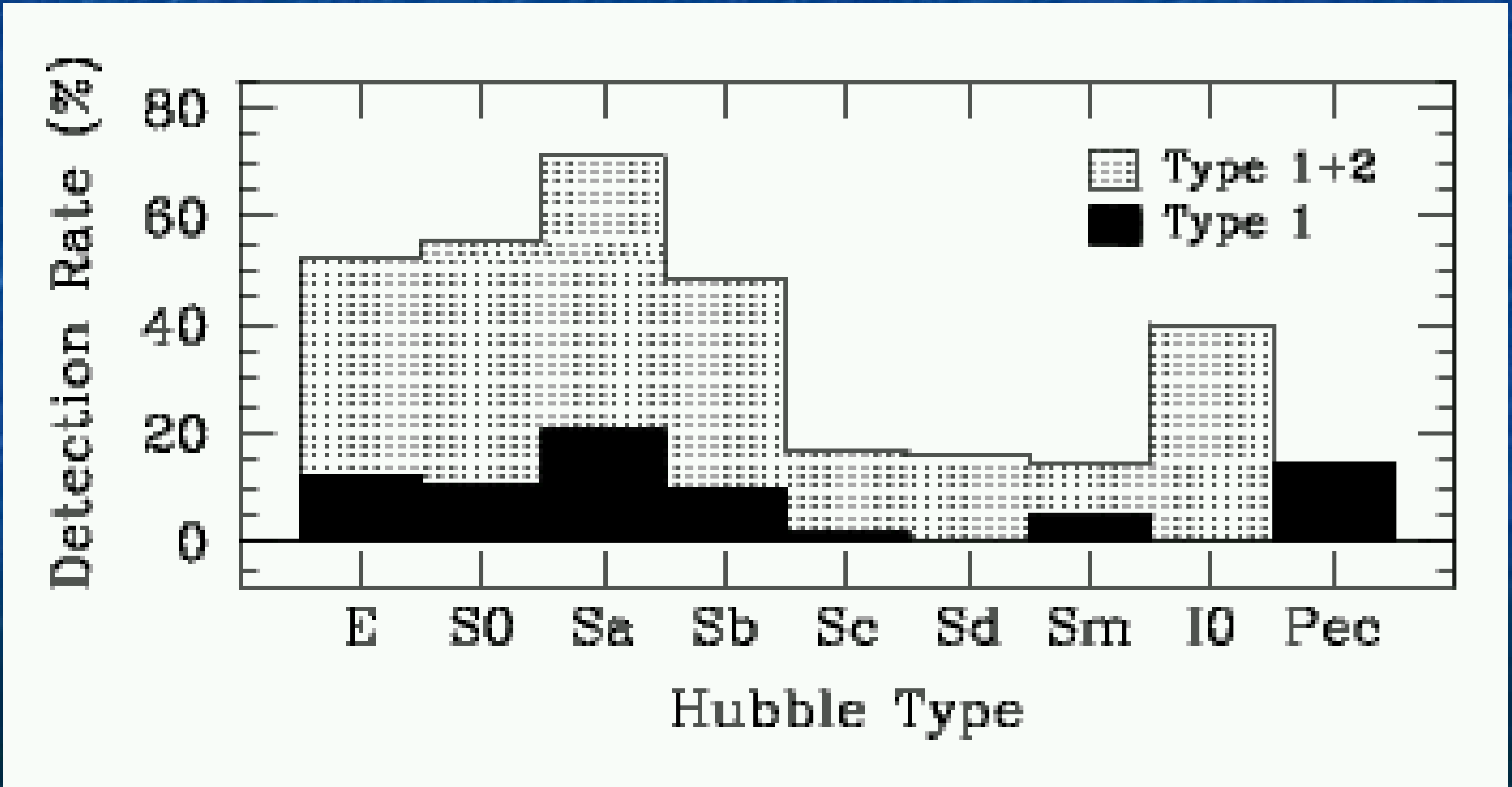
Eddington luminosity

$$L_E = 1.3 \, 10^{38} \, M/M_o \text{ erg/s}$$



Sa
Sb
Sc
Sd
E0
E1
E2
E3
E4
E5
E6
E7
S0
SBa
SBb
SBc
SBd
Irregular

from Ho (2004)



Detection Rate (%)
80
60
40
20
0
Type 1+2
Type 1
E
S0
Sa
Sb
Sc
Sd
Sm
I0
Pec
Hubble Type

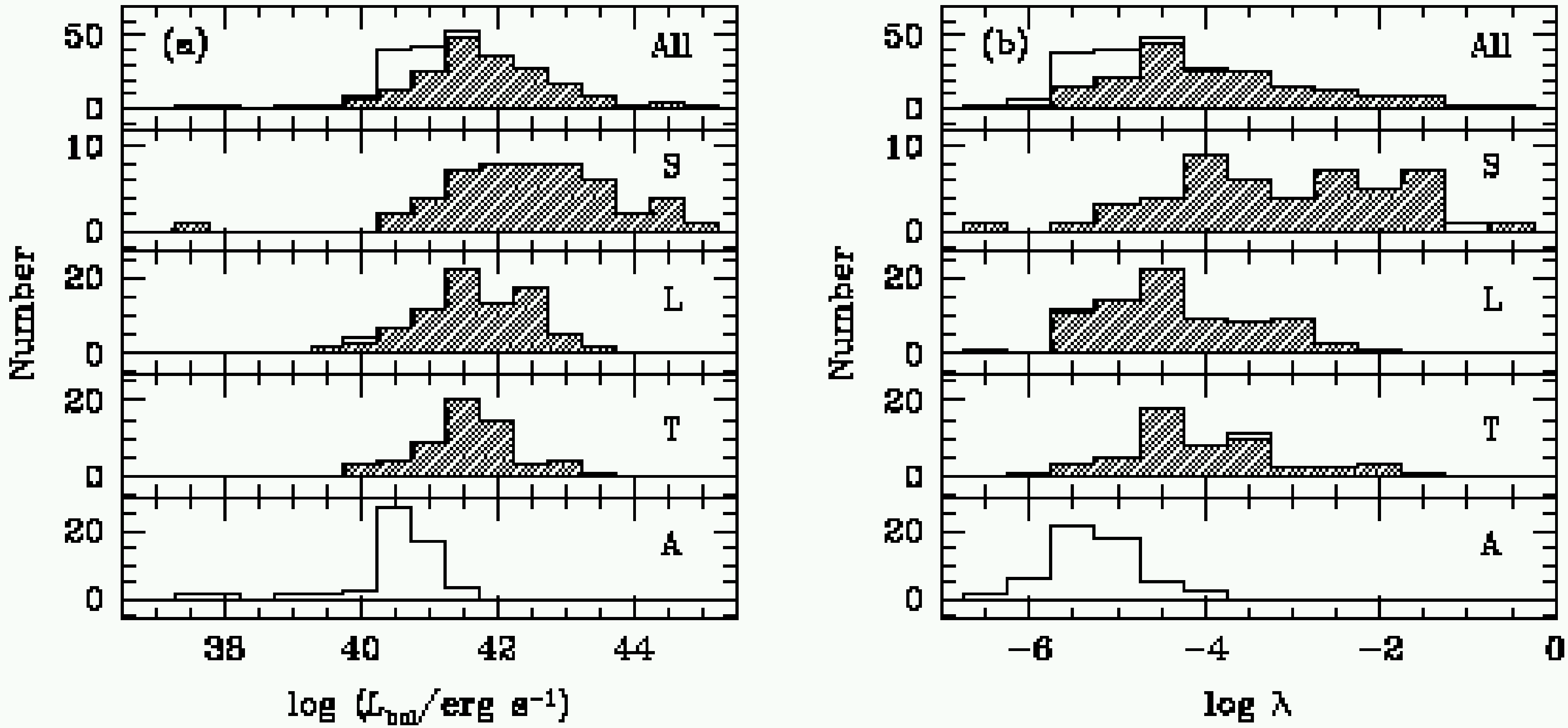


Fig. 1. Distribution of (*a*) nuclear bolometric luminosities and (*b*) Eddington ratios $\lambda \equiv L_{\rm bol}/L_{\rm Edd}$. S = Seyferts, L = LINERs, T = transition objects, and A = absorption-line nuclei. Open histograms denote upper limits. From Ho (2003.)

Black hole – bulge correlations

1) $M_{BH} - \sigma_*$ relation (log-linear):

$\log(M_{BH}/Mo) = \alpha + \beta \log(\sigma / \sigma_0)$

=> $M_{BH} \propto \sigma_*^{\beta}$

Ferrarese & Meritt (2000): $\beta = 5.27 \pm 0.4$

Gebhardt et al. (2000): $\beta = 3.75 \pm 0.3$

Tremaine et al. (2002): $\beta = 4.02 \pm 0.3$

2) $M_{BH} - M_{bulge}$ relation

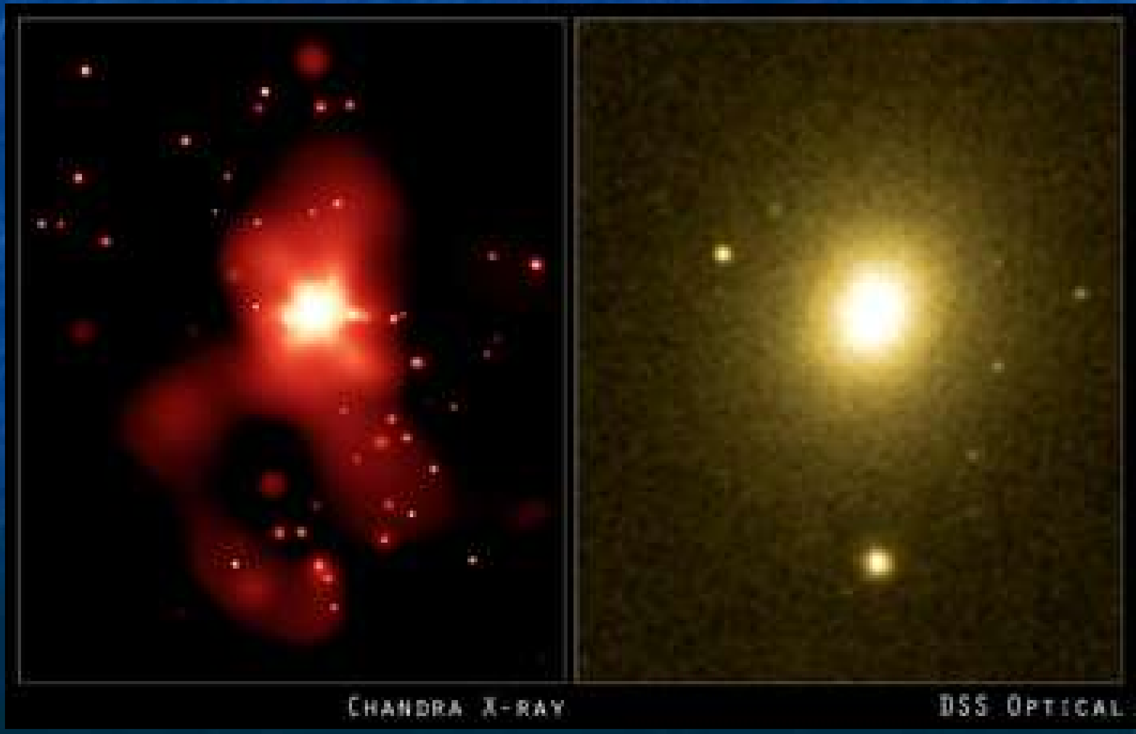
$M_{BH} = (0.001\text{-}0.002)\ M_{bulge}$

Bulge ve spirálních galaxiích

Eliptické galaxie

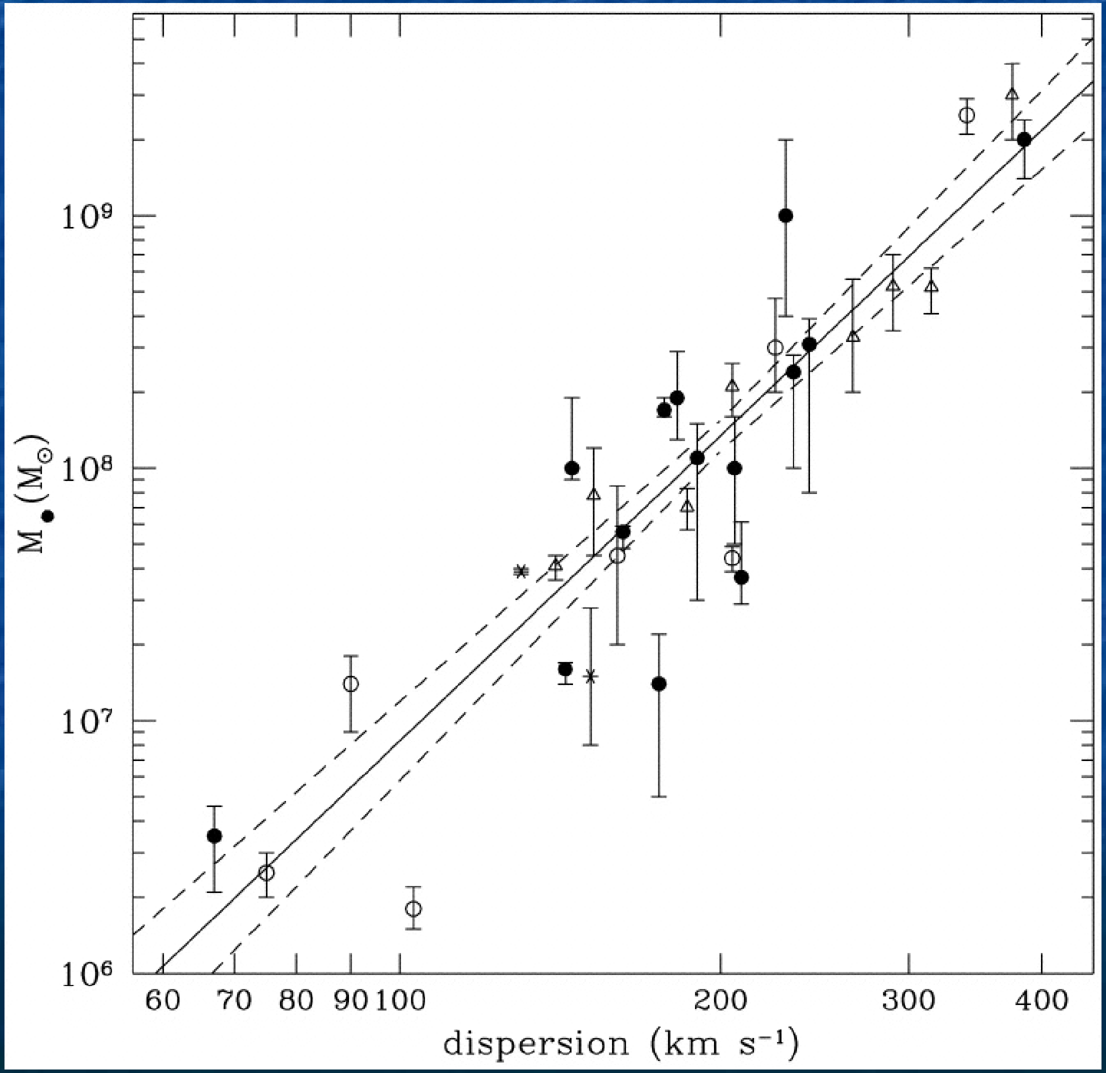
M 87

NGC 4261



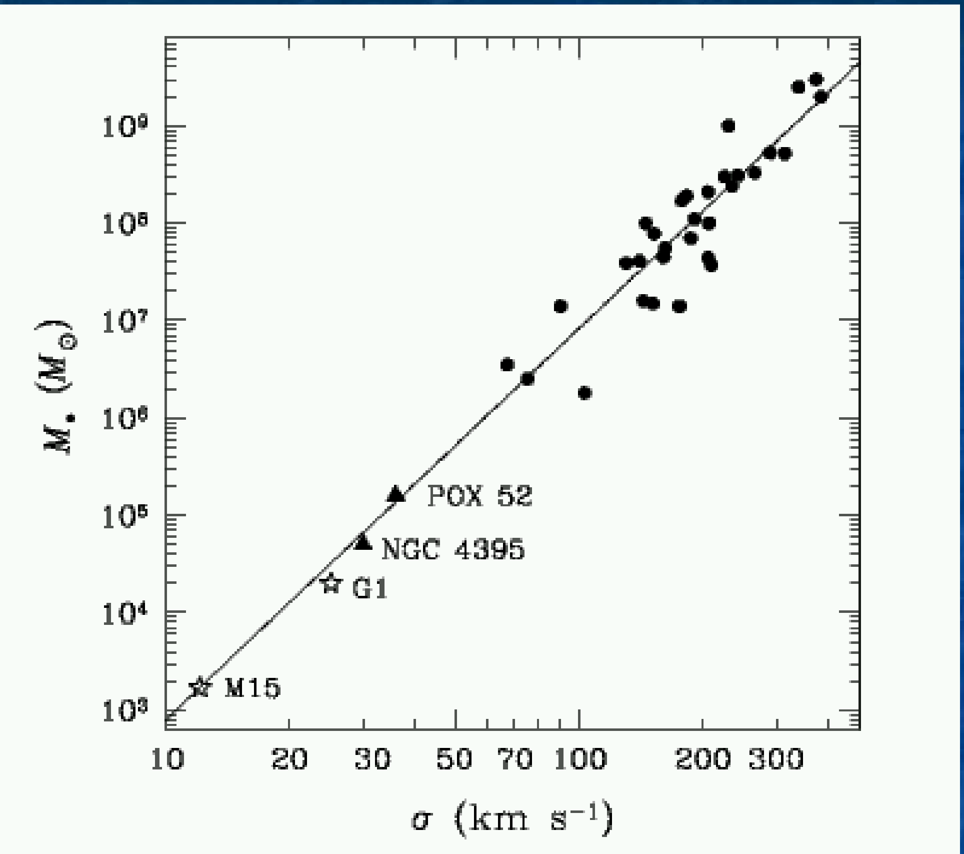
$M_{BH} - \sigma_*$ relation from Tremaine et al. (2002)

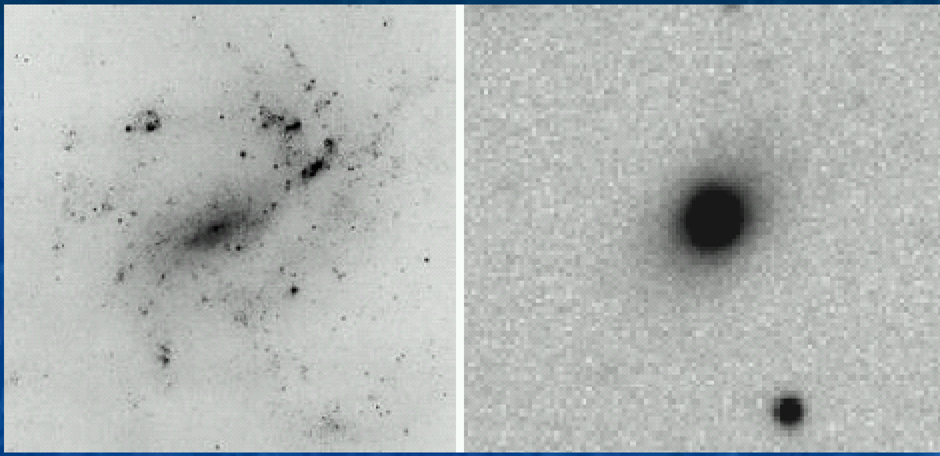
$M_{BH}/Mo = 1.35\ 10^8\ (\sigma_*/200\ \text{km/s})^{4.02} = 8.31\ 10^6\ (\sigma_*/100\ \text{km/s})^{4.02}$



	M_{BH}(Mo)	σ(km/s)
	10^5	33
	10^6	60
	10^7	105
	10^8	185
	10^9	330
Milky Way	$2\ 10^6$	100
M31 (Sb)	$4\ 10^7$	160
M32 (E2)	$2\ 10^6$	75
M87 (E0)	$3\ 10^9$	375

Detected intermediate-mass black holes (10^3 -10^5 Mo)





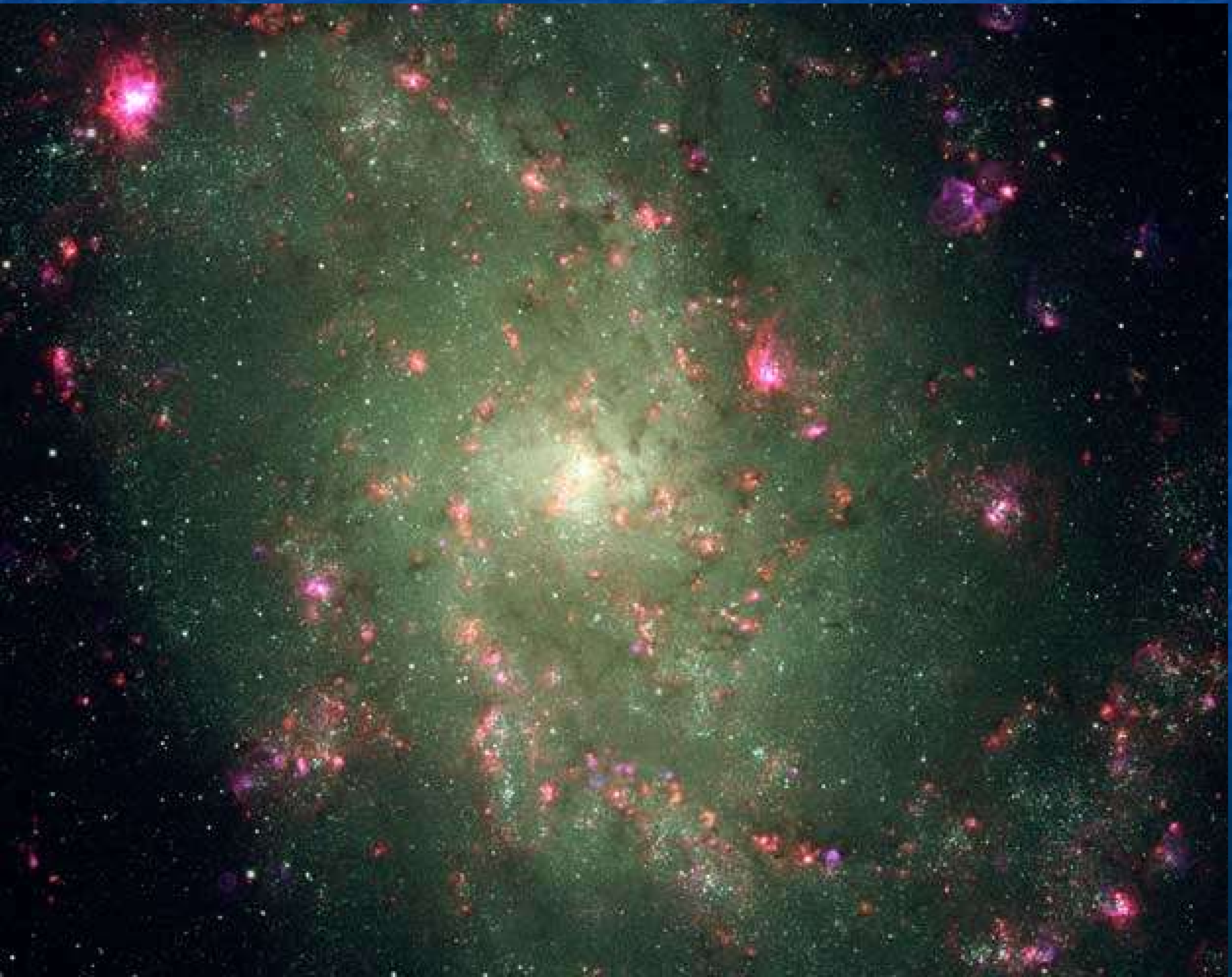
from Ho et al. 2004

NGC 4395 (Sd, Seyfert 1, D ~ 4 Mpc):
σ_* < 30 km/s, M_{BH} ~ 10^4 – 10^5 Mo

POX 52 (dE, Seyfert 1, D ~ 90 Mpc):
σ_* < 36 ± 5 km/s, M_{BH} ~ 1.6 10^5 Mo

Central black-holes in low-mass galaxies:

- occupation number of central BHs unknown, could be well below 1
- in most cases only upper limits on M_{BH} are known
- stellar and gas dynamical BH detections from HST: not enough spatial resolution to detect $M_{BH} < 10^6$ Mo for D > Local Group



M 33 (Sc)

$M_{BH} < 3\,000$ Mo

IC 342

$M_{BH} < 5\ 10^5$ Mo

dEs in Virgo

$M_{BH} < 10^6 - 10^7$ Mo

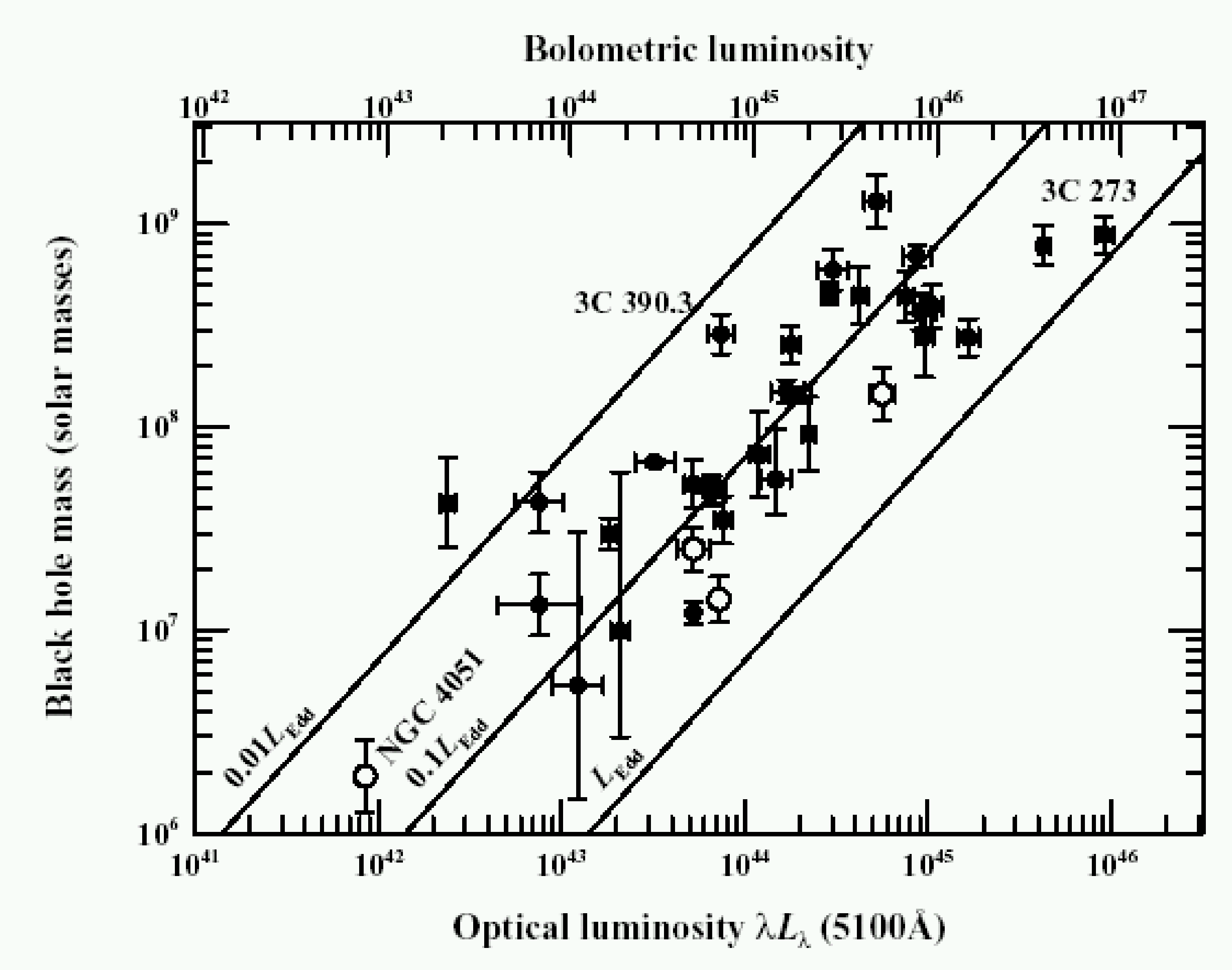
Sphere of influence of a black hole

R_{BH} (pc) = GM_{BH} / σ_*^2 = 0.43 ($M_{BH}/10^6$ Mo) / (σ_*/100 km/s)^2

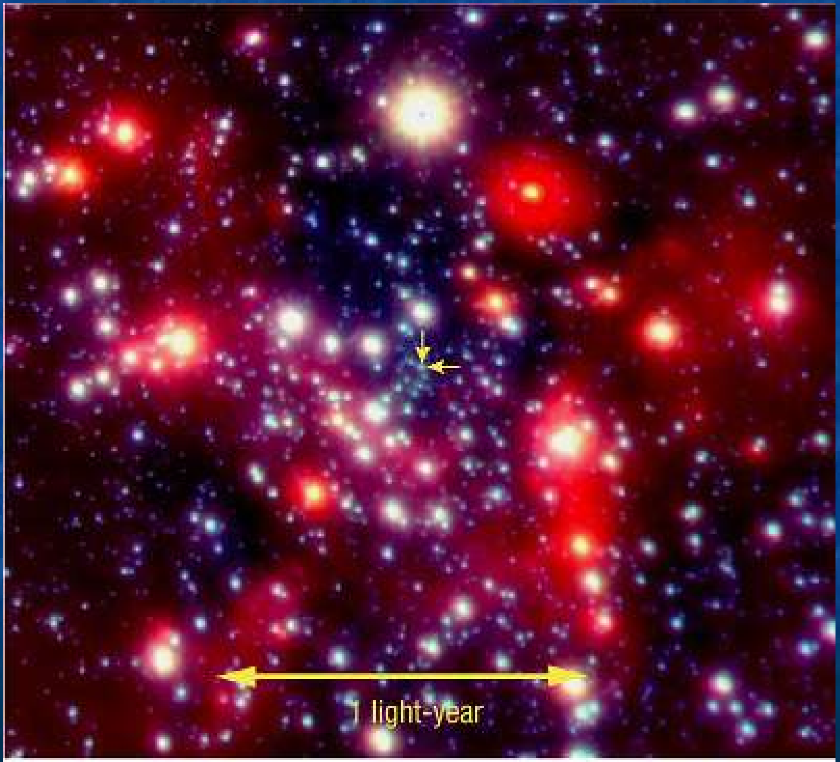
M_{BH}(Mo)	σ(km/s)	R_{BH} (pc)	R_S (pc)
10^6	60	1	10^{-7}
10^7	105	4	10^{-6}
10^8	185	13	10^{-5}
10^9	330	40	10^{-4}

Black hole masses from reverberation mapping

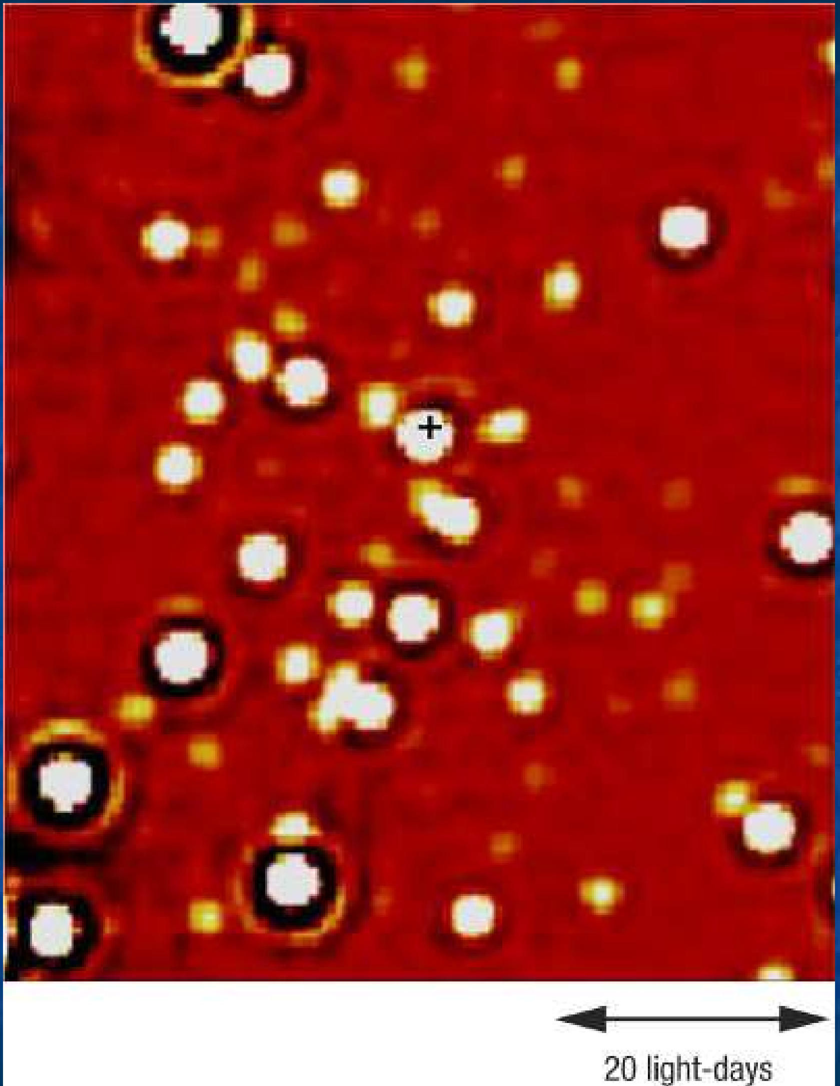
from Peterson (2004)



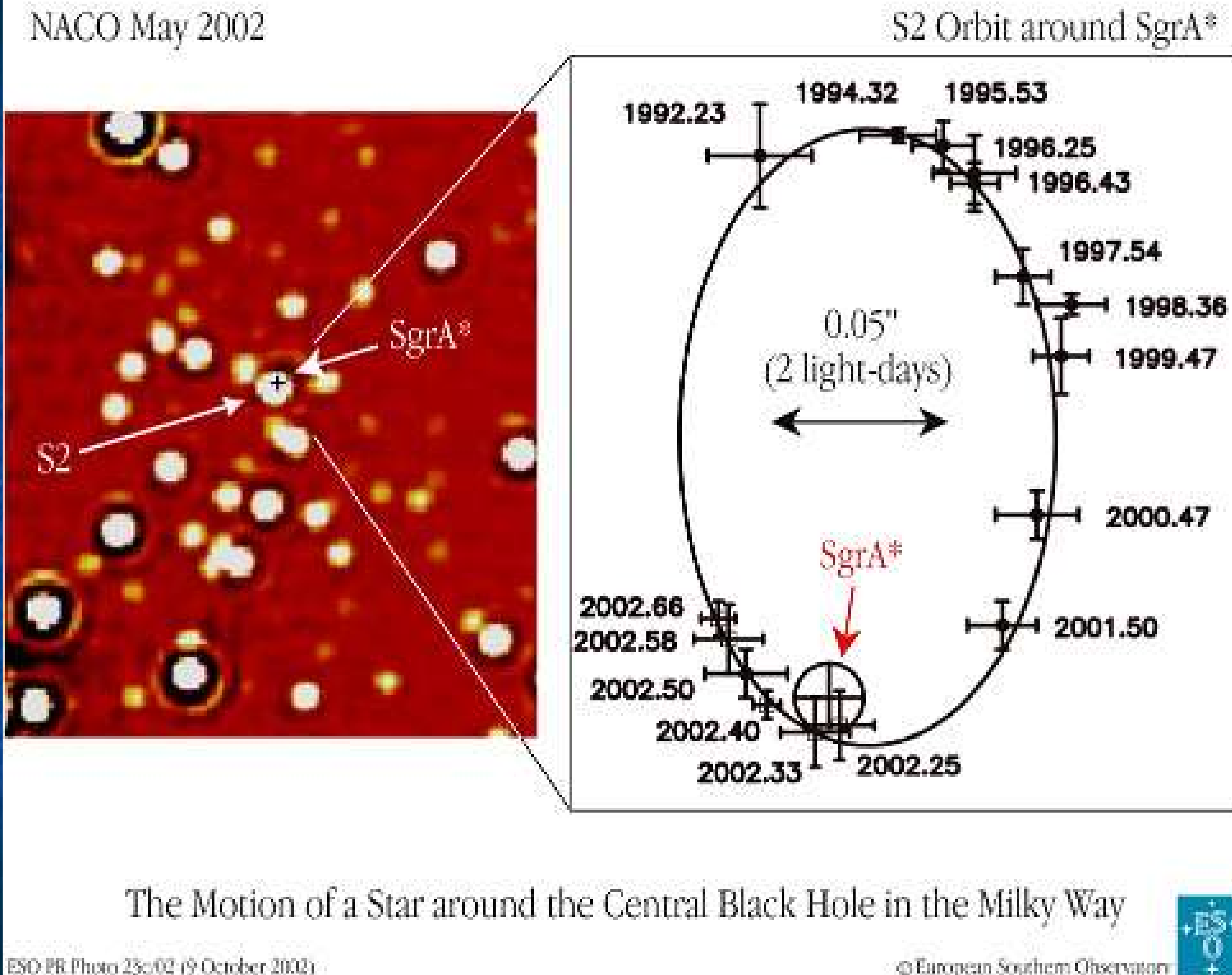
Stars in the Milky Way center



The Centre of the Milky Way
(VLT YEPUN + NACO)
ESO PR Photo 23a/02 (9 October 2002)
©European Southern Observatory

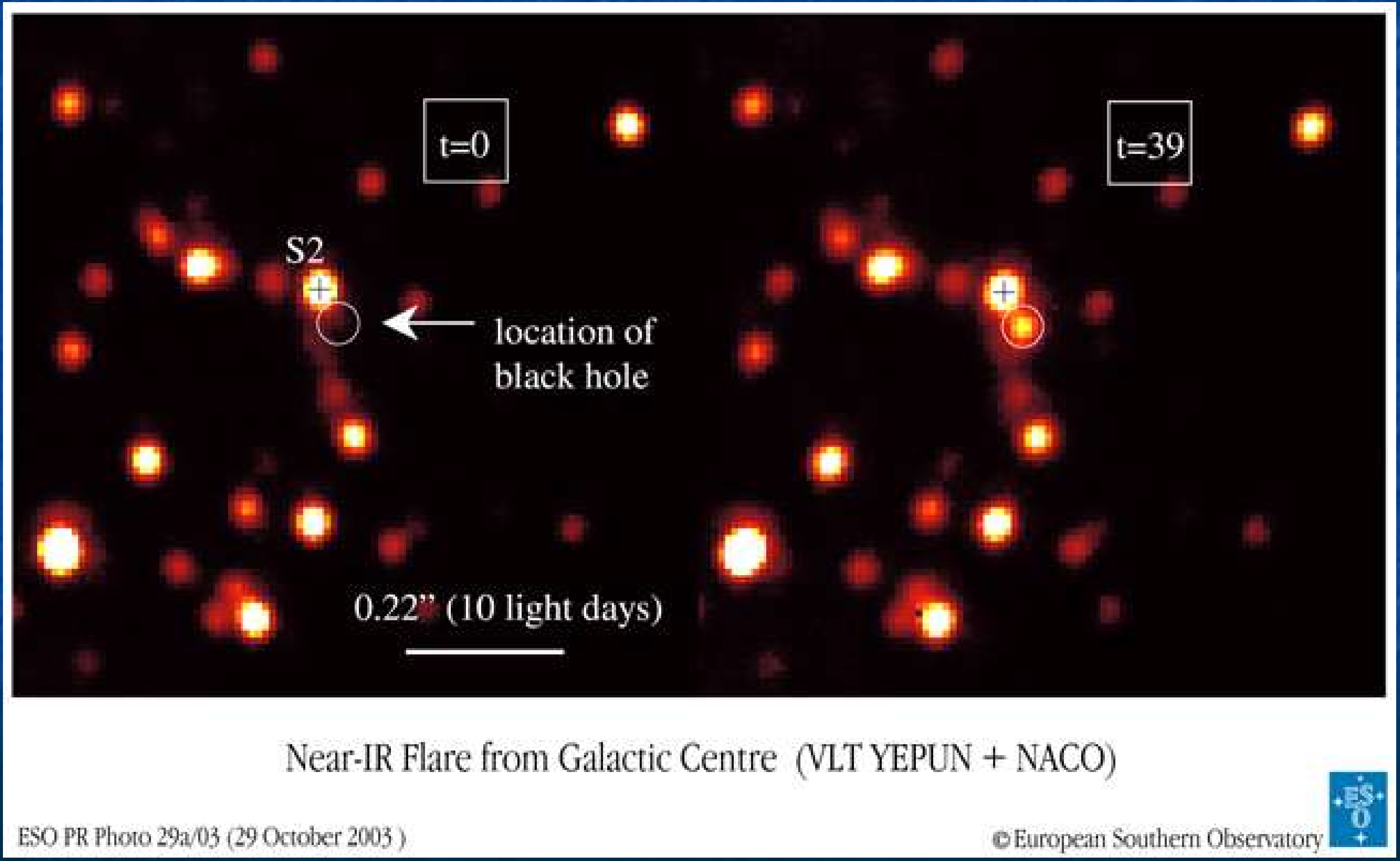


The Centre of the Milky Way (detail)
(VLT YEPUN + NACO)
ESO PR Photo 23b/02 (9 October 2002)
©European Southern Observatory



The Motion of a Star around the Central Black Hole in the Milky Way

Near infrared flares in the Milky Way Center



Black hole growth - Fuelling of “monsters” (AGN)

- fuel: gas / stars / black holes

- fuelling by gas from kpc-scales =>

Angular momentum problem

=> bars / interactions / mergers

Feeding the monster ...

(from S. Phinney 1997)

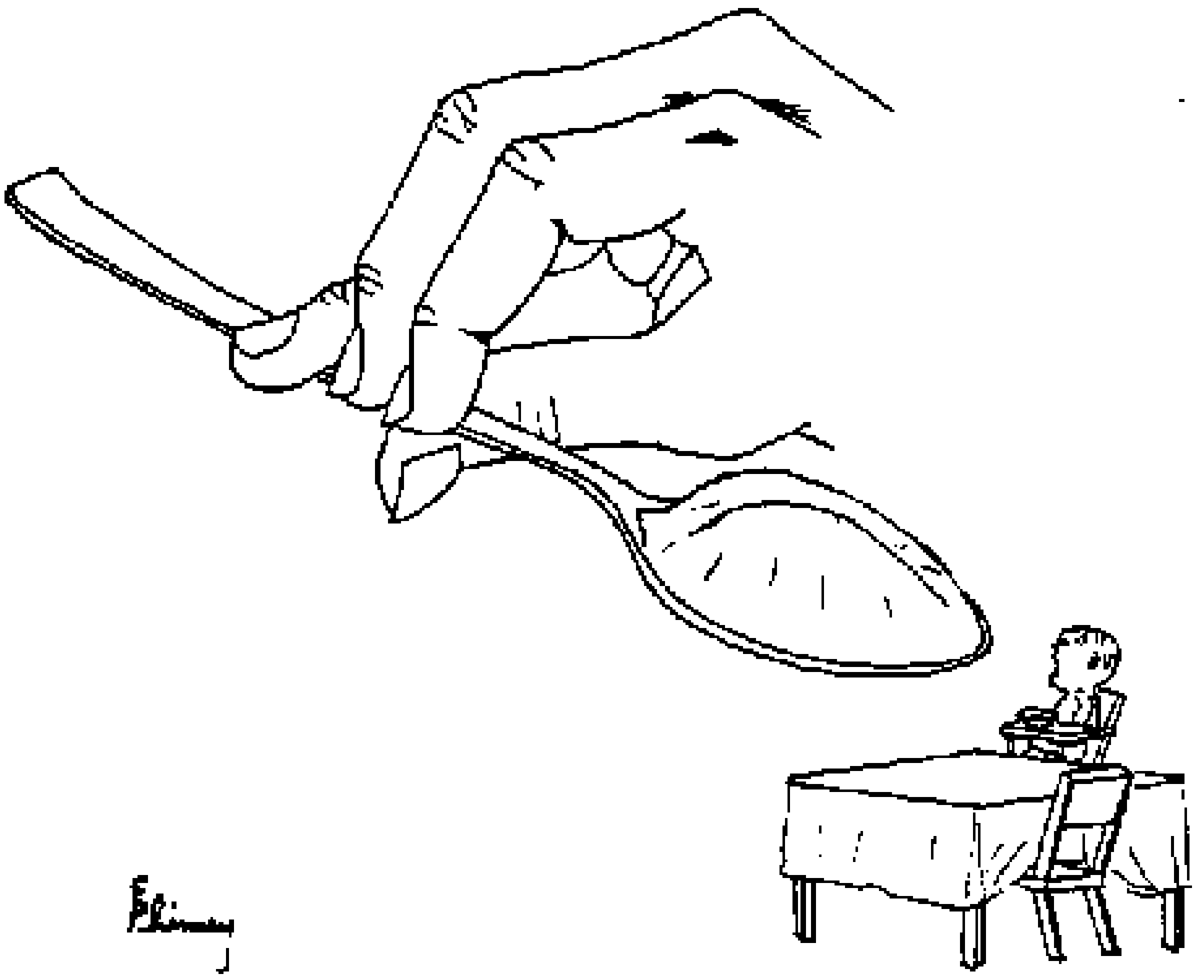


Fig. 1—The problem of feeding the monster: a large (angular momentum) spoon and a small (angular momentum) mouth. Hands and teeth (gravitational and magnetic forces, viscosity, . . .) are needed to guide and divide the food into morsels that can be metabolised during activity.

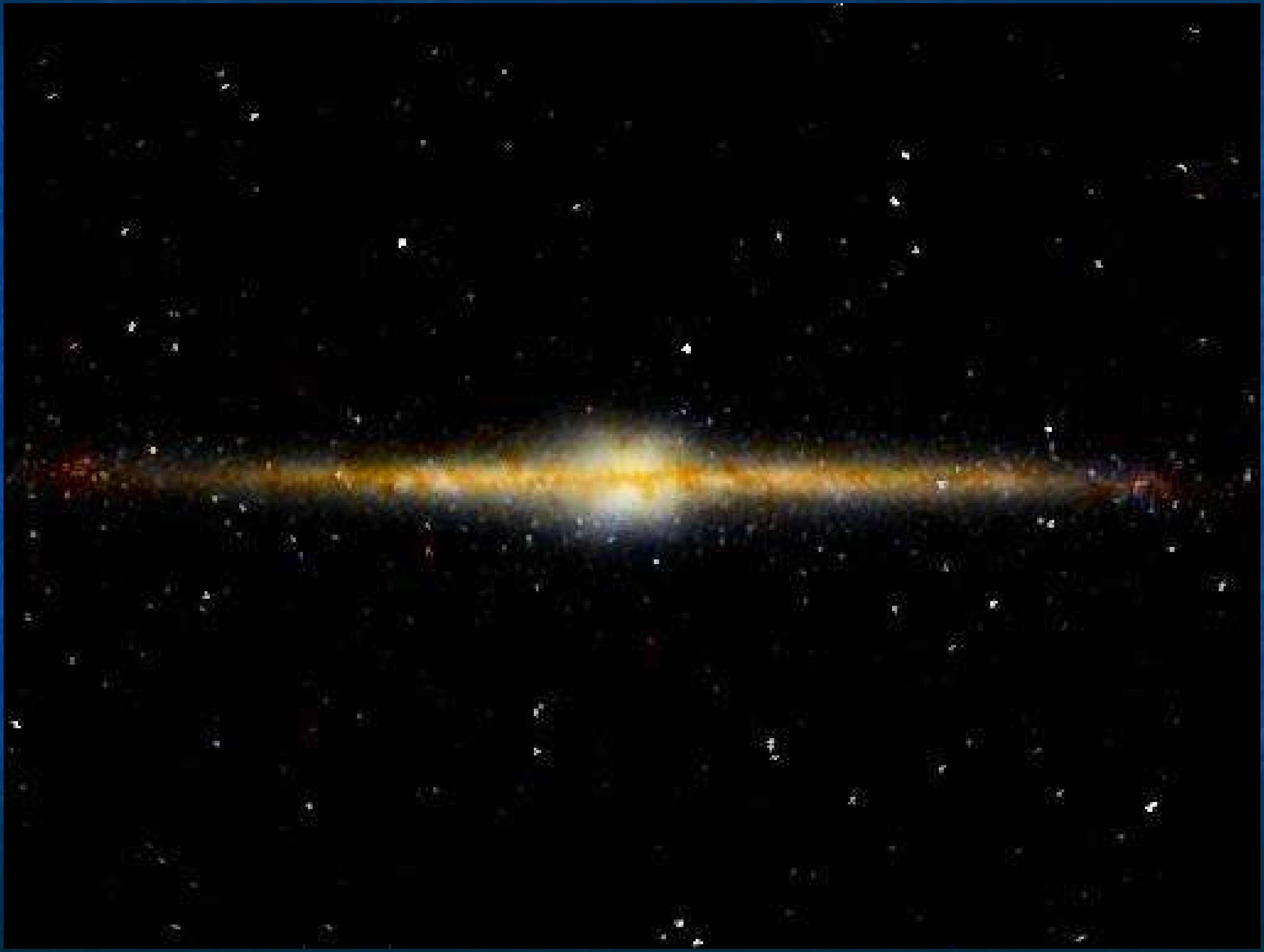
Příčky ve spirálních galaxiích

Spiral Galaxy Messier 83
(FORS / VLT)
ESO PR Photo 24b/05 (August 10, 2005) © ESO

Spiral Galaxy NGC 7424
(VLT MELIPAL + VIMOS)
ESO PR Photo 33c/04 (1December 2004) © European Southern Observatory

Spiral Galaxy NGC 1097
(VLT MELIPAL + VIMOS)

Milky Way in the near-IR (COBE/DIRBE)



N-body simulations of spiral galaxies

1) bar instability in a stellar disk (no gas present)

ome/bruno/video-t00.m

a) without bulge
$Q = 0$
$Q = 1$

b) with bulge
$Q = 0$
$Q = 1$
$Q = 2.5$

Q: Toomre stability parameter

$$Q_{stars} = \kappa\sigma \,/\, (3.36\ G\Sigma)$$

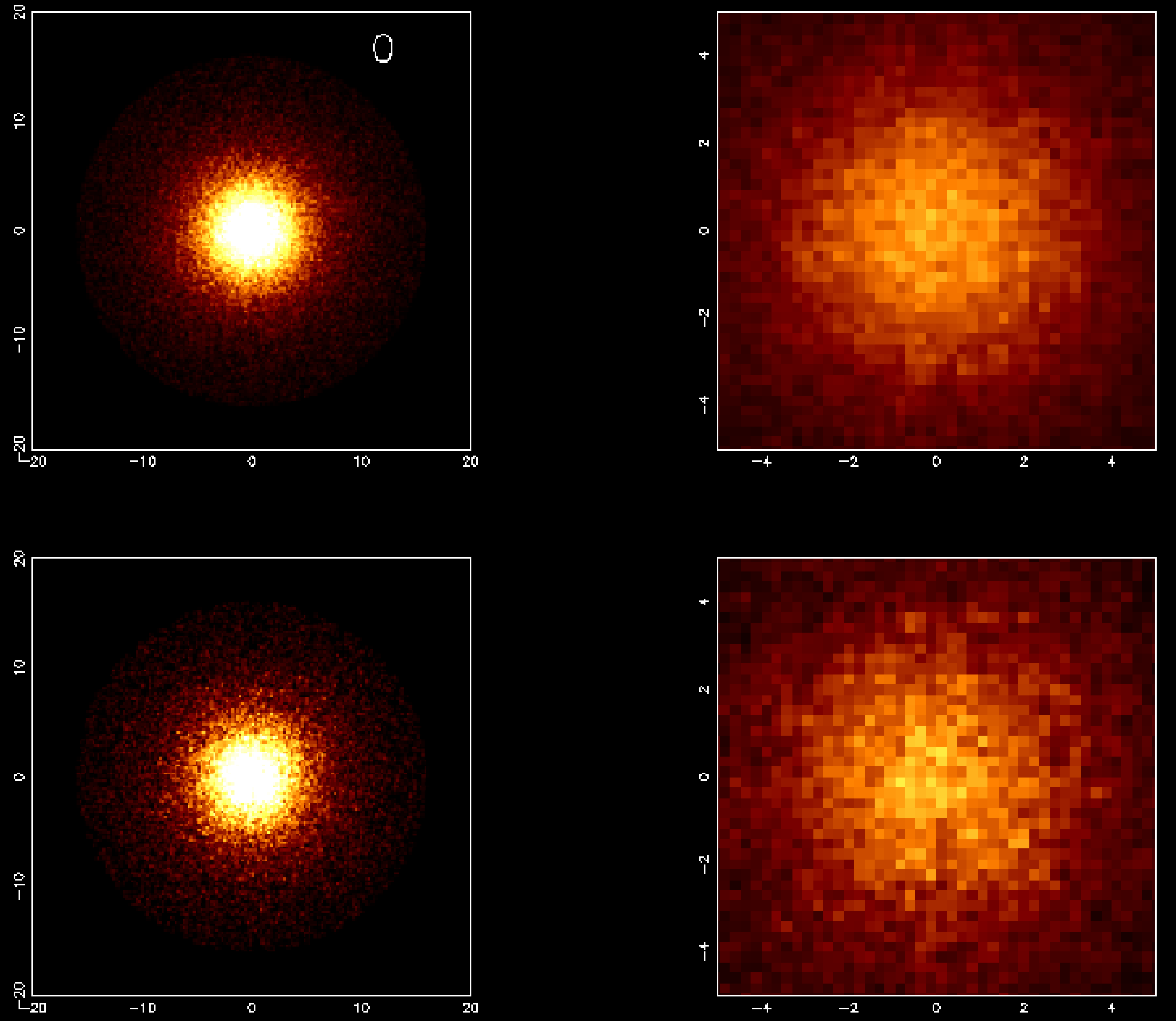
$$Q_{gas} = \kappa c \,/\, (\pi G\Sigma)$$

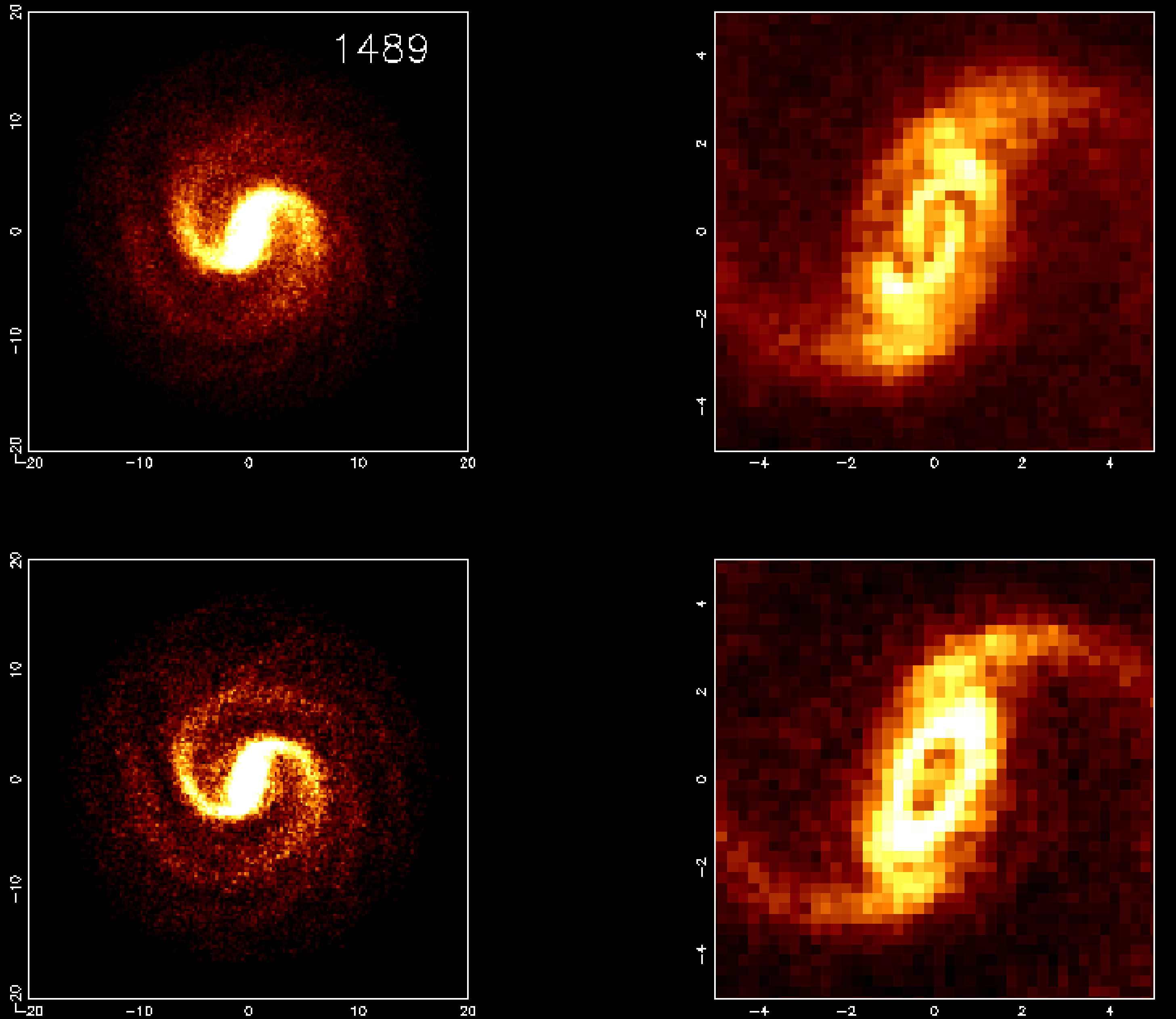
N-body simulations of spiral galaxies

2) stellar/gaseous disk (Mg/Ms = 0.1 & 0.3)

ome/bruno/video-t02.m

- bar formation
- gas inflow
- nuclear disk / outer ring
- bar destruction for Mg/Ms = 0.3
- long-living spiral arms in the gas


0
20
10
0
−10
−20
−20
−10
0
10
20
4
2
0
−2
−4
−4
−2
0
2
4



1489
20
10
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−10
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−10
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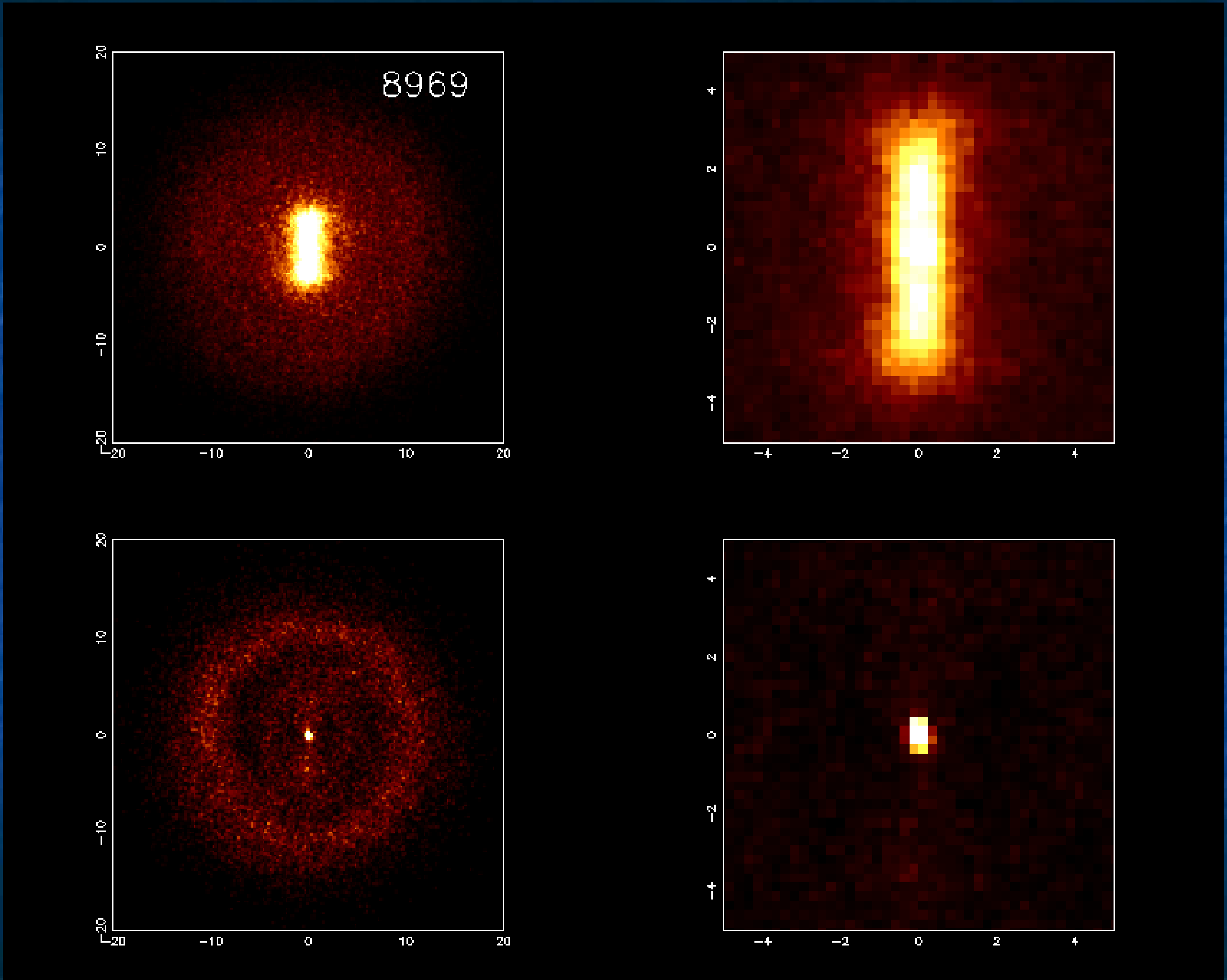
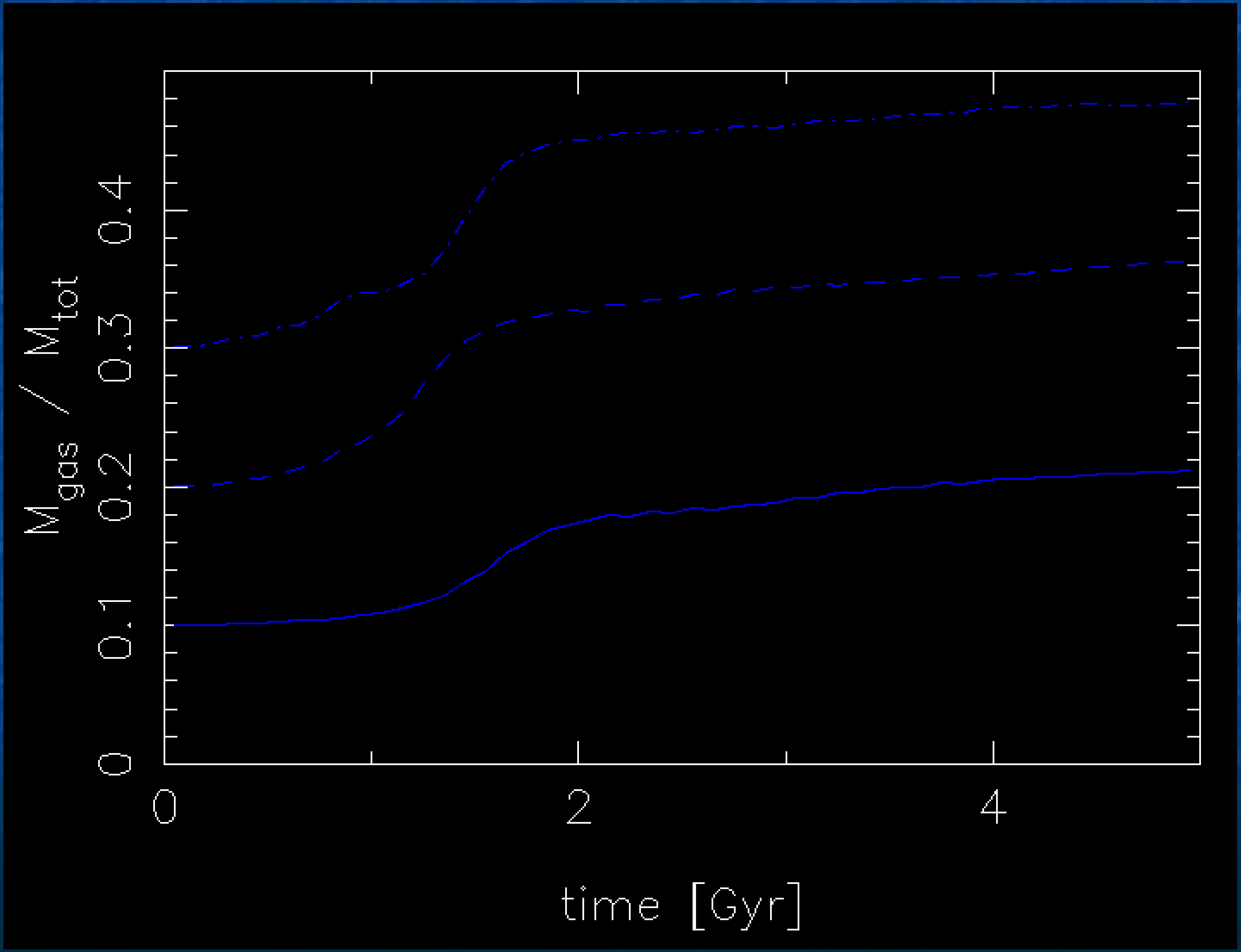
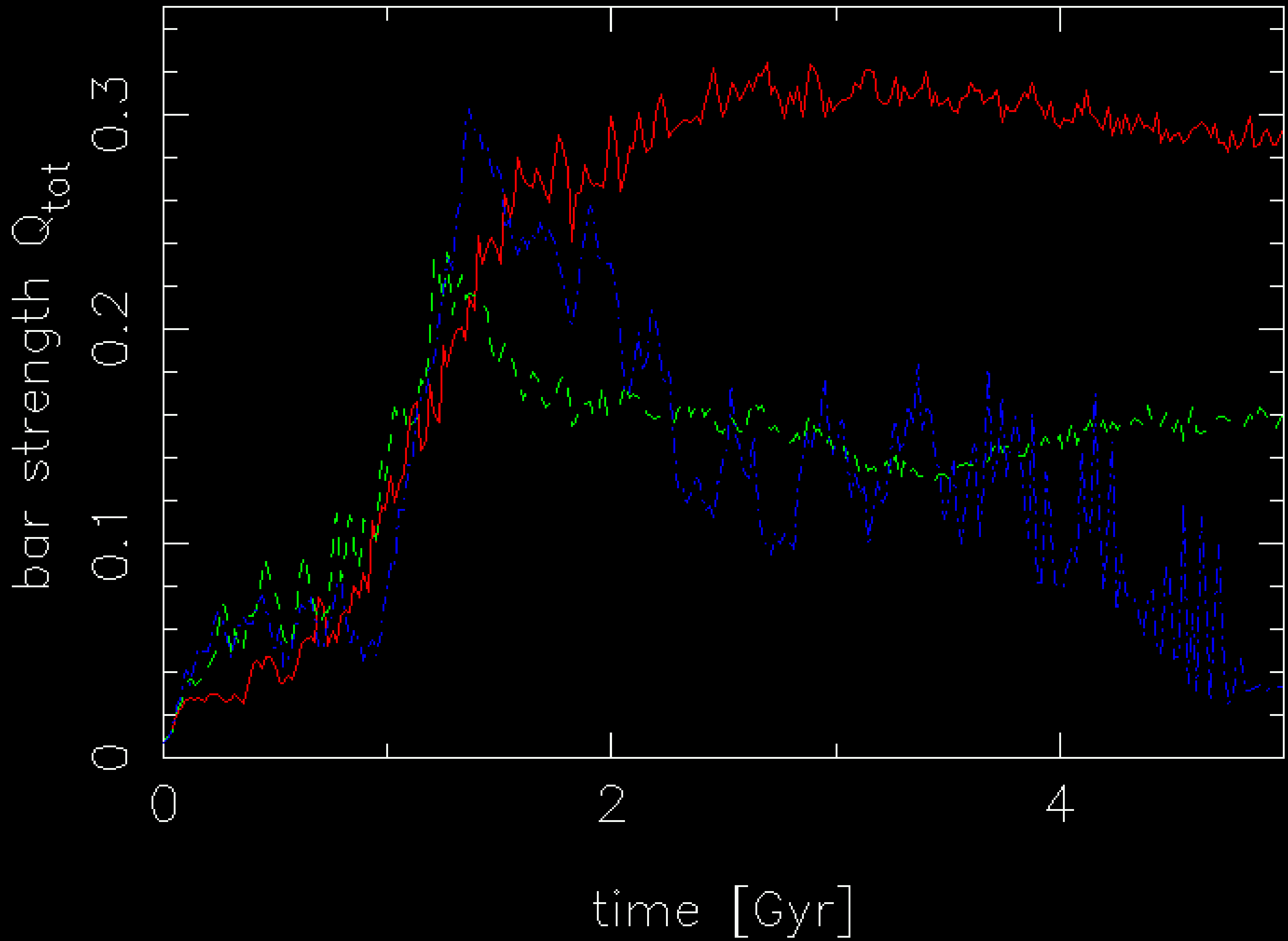
10
20
4
2
0
−2
−4


8969
20
10
0
−10
−20
−20
−10
0
10
20
4
2
0
−2
−4
−4
−2
0
2
4

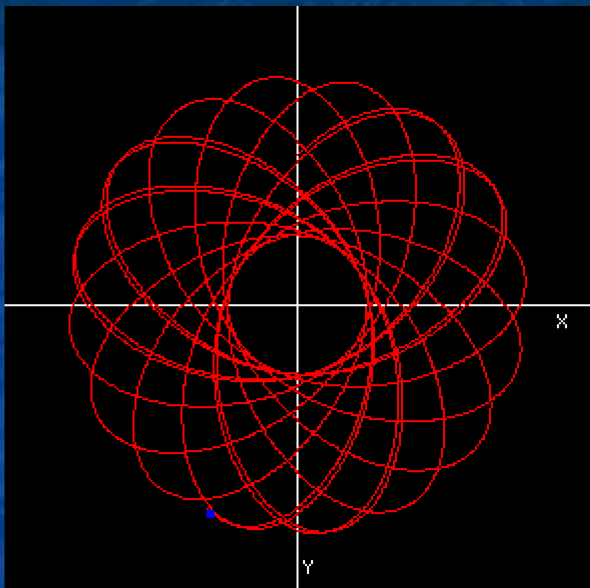
Gas inflow in a barred potential:
M_{gas}/M_{tot} in the central kiloparsec



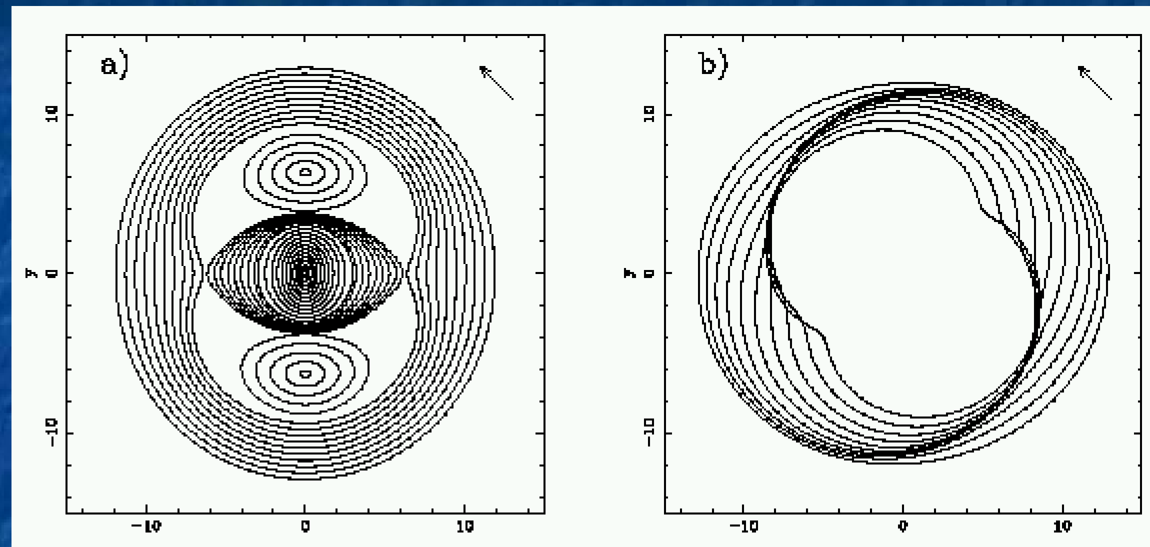
Bar strength evolution (bar destroyed for huge mass-inflow)



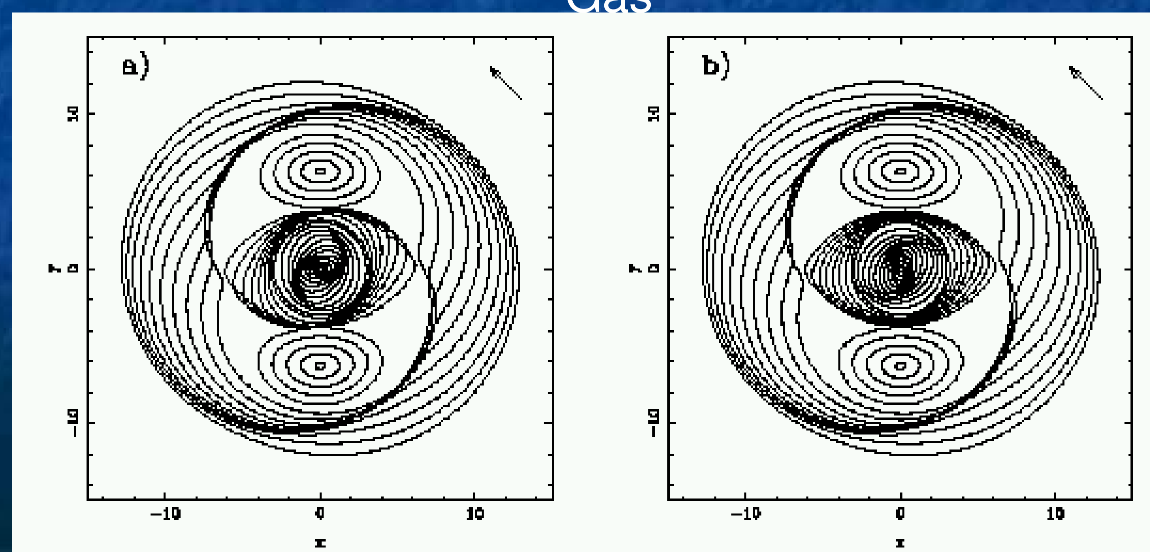
Orbits in barred and unbarred galaxies



Stars Gas

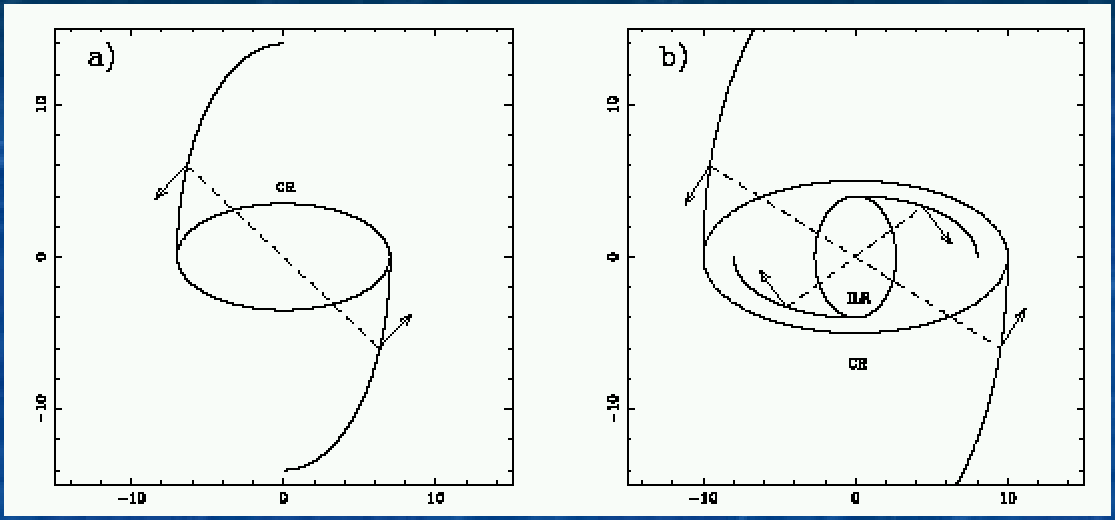


Gas



(from Combes 2003)

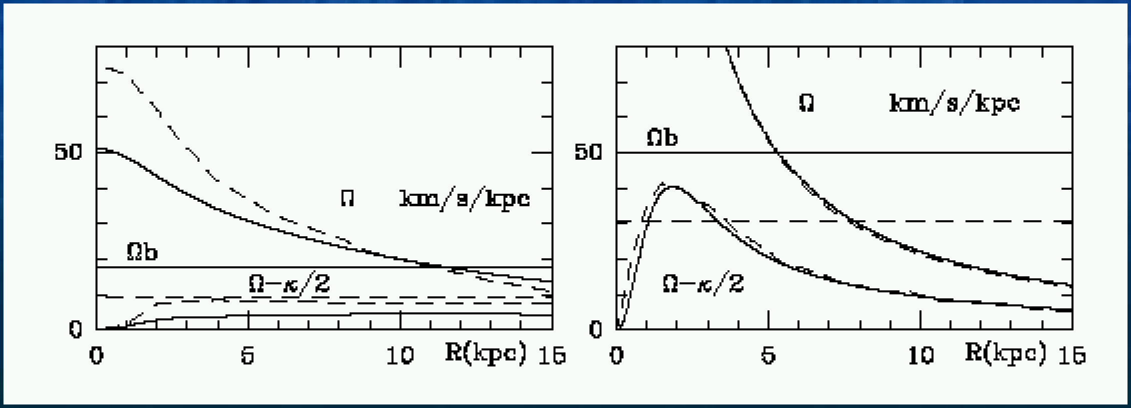
Gravity torque in non-axisymmetric potentials



Lindblad resonances and corotation

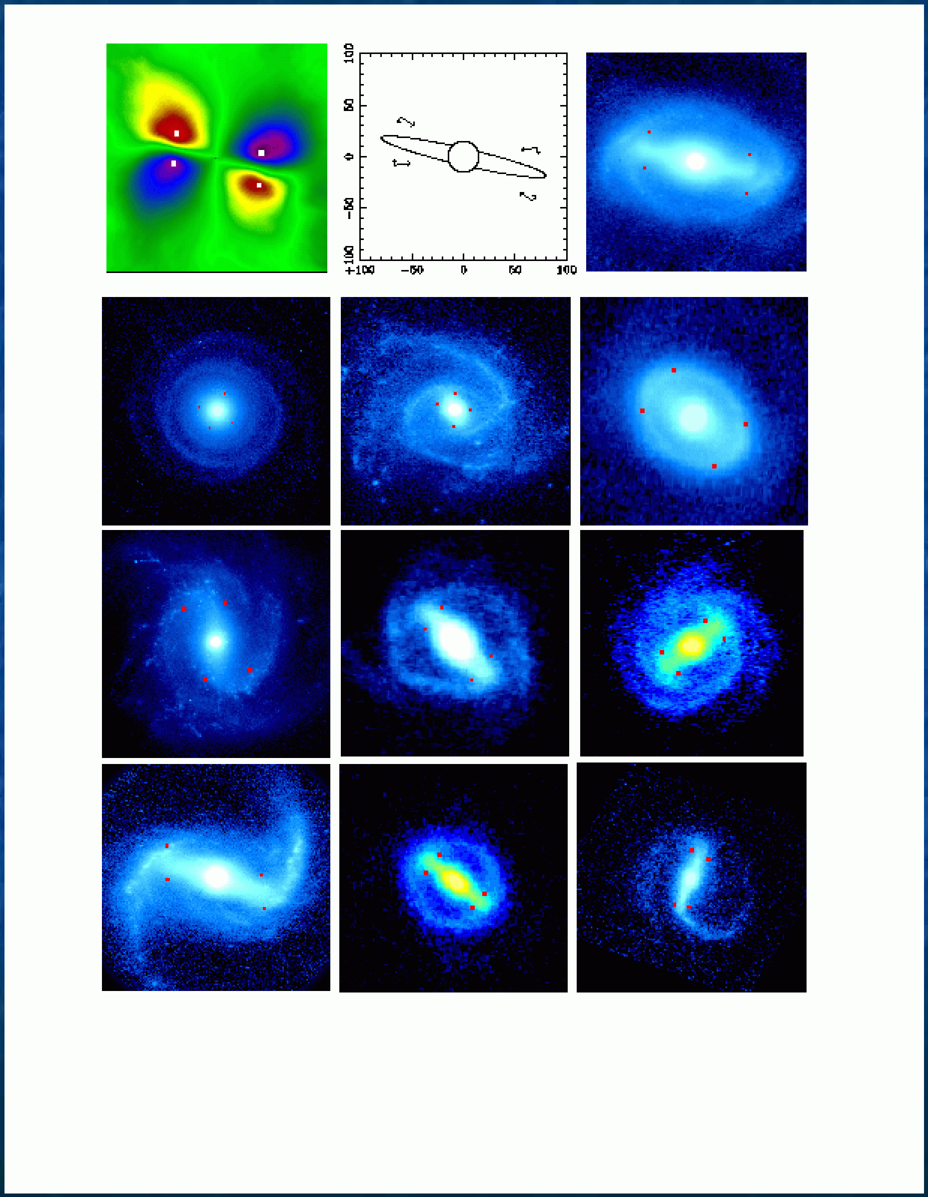
Late-type galaxy

Early-type galaxy

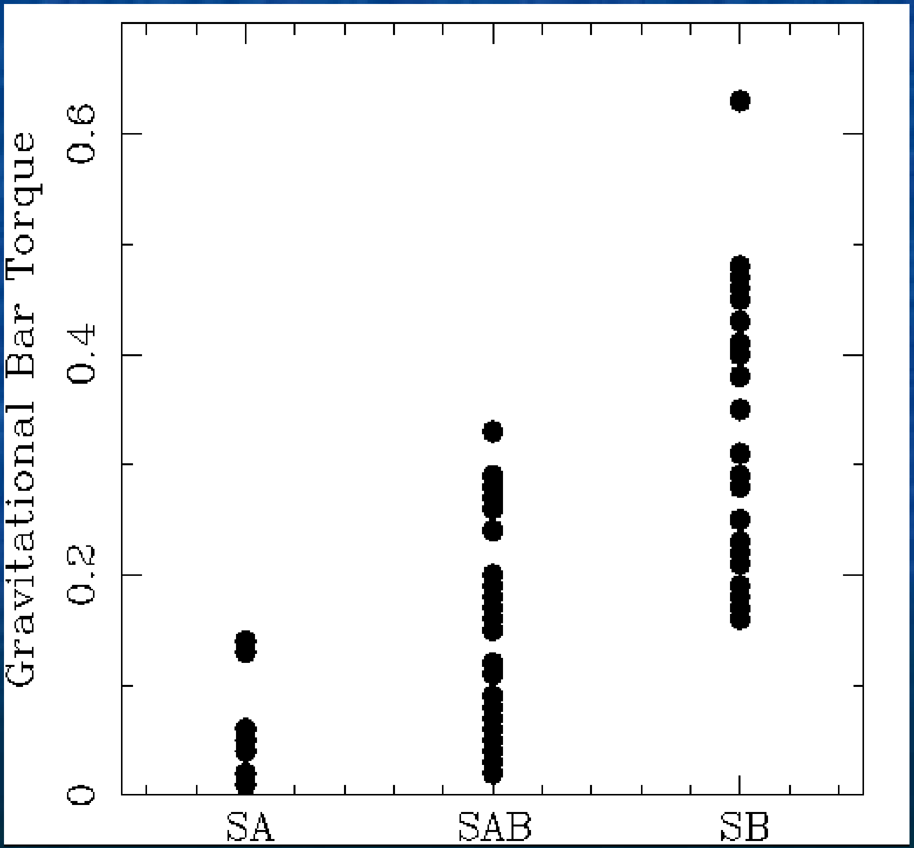


(from Combes 2003)

Gravitational torque in spiral / lenticular galaxies

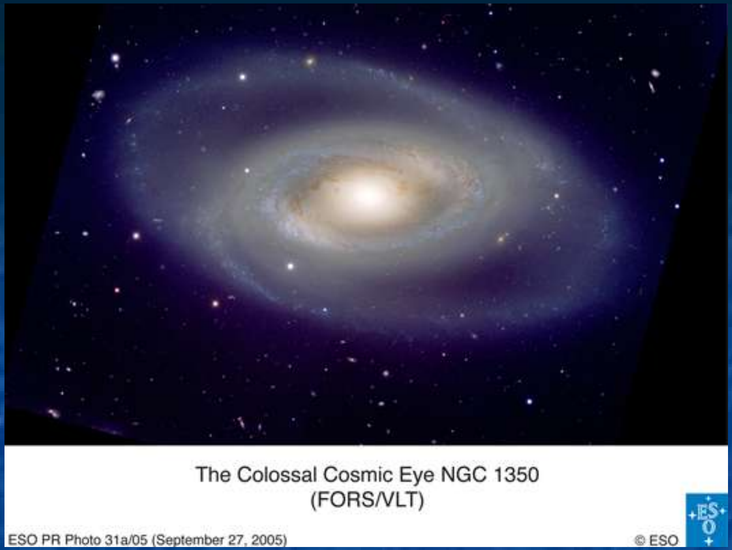


(from Buta et al.)

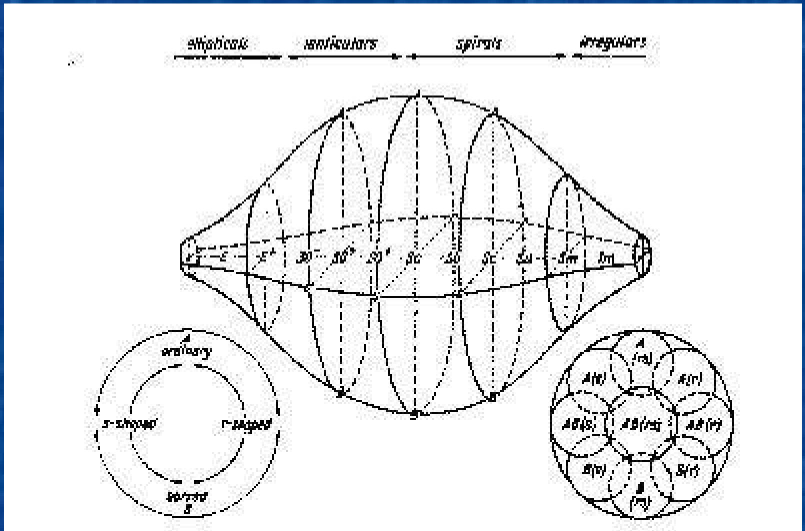


Prstence ve spirálních galaxiích

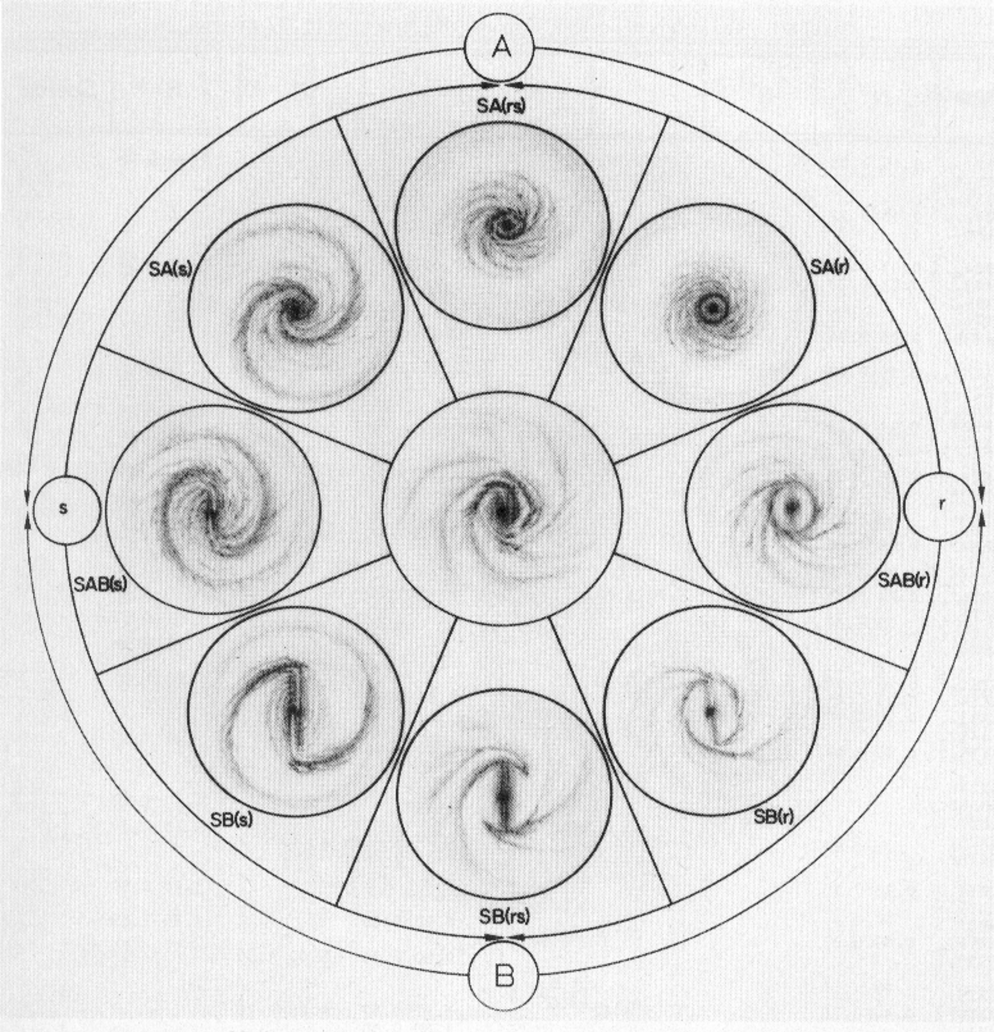
NGC 7020 (Buta, Combes 1996)

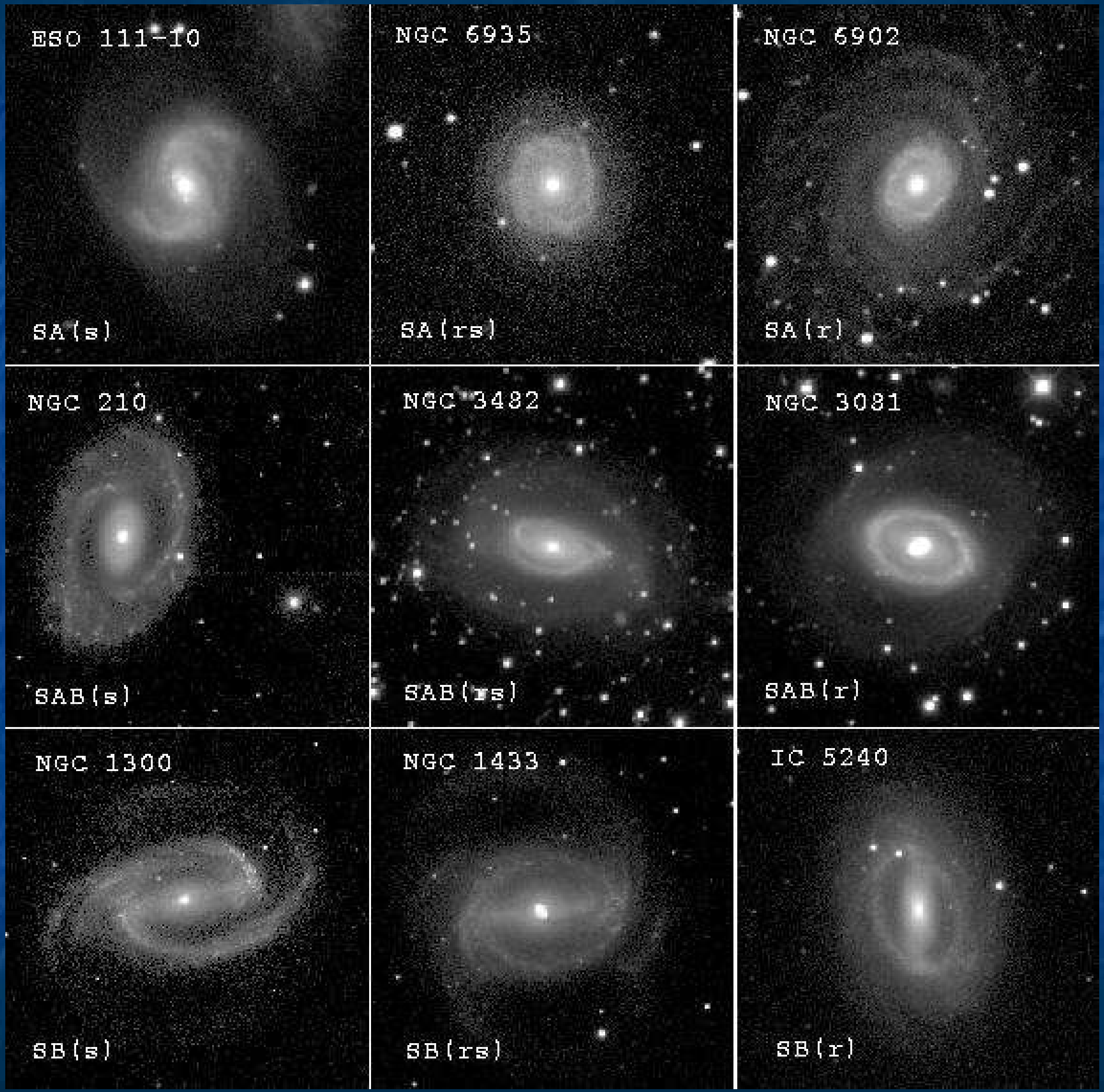


Families and varieties in the de Vaucouleurs Revised Hubble Classification system



(from Buta)




ESO 111-10
SA(s)
NGC 6935
SA(rs)
NGC 6902
SA(r)
NGC 210
SAB(s)
NGC 3482
SAB(rs)
NGC 3081
SAB(r)
NGC 1300
SB(s)
NGC 1433
SB(rs)
IC 5240
SB(r)

(from Buta)

Bar tranfers gas inwards to 100 pc scales

but the monster is still not fed ...

--> a) nuclear bars / nuclear spirals
b) viscous torques
c) dynamical friction

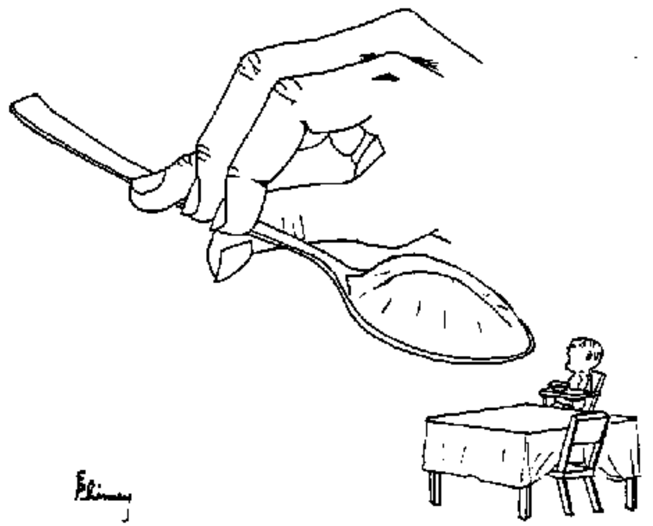


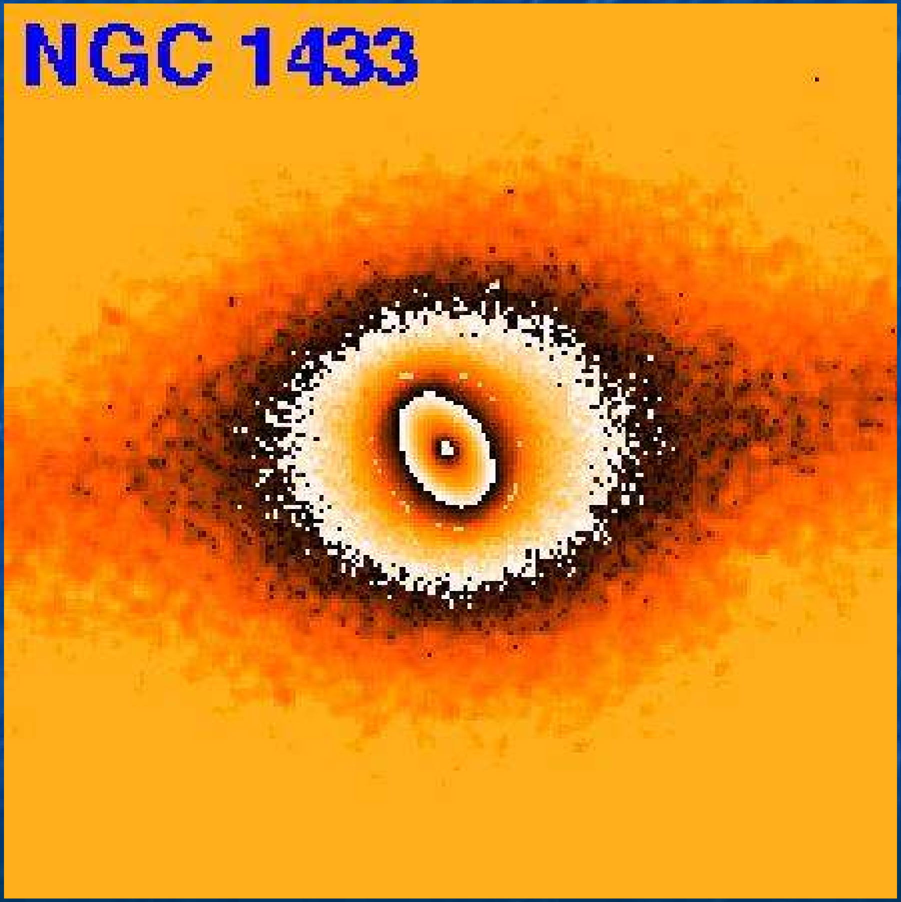
Fig. 1—The problem of feeding the monster: a large (angular momentum) spoon and a small (angular momentum) mouth. Hands and teeth (gravitational and magnetic forces, viscosity, . . .) are needed to guide and divide the food into morsels that can be metabolised during activity.

Double bar in NGC 1433

B band

(Buta & Combes 1996)

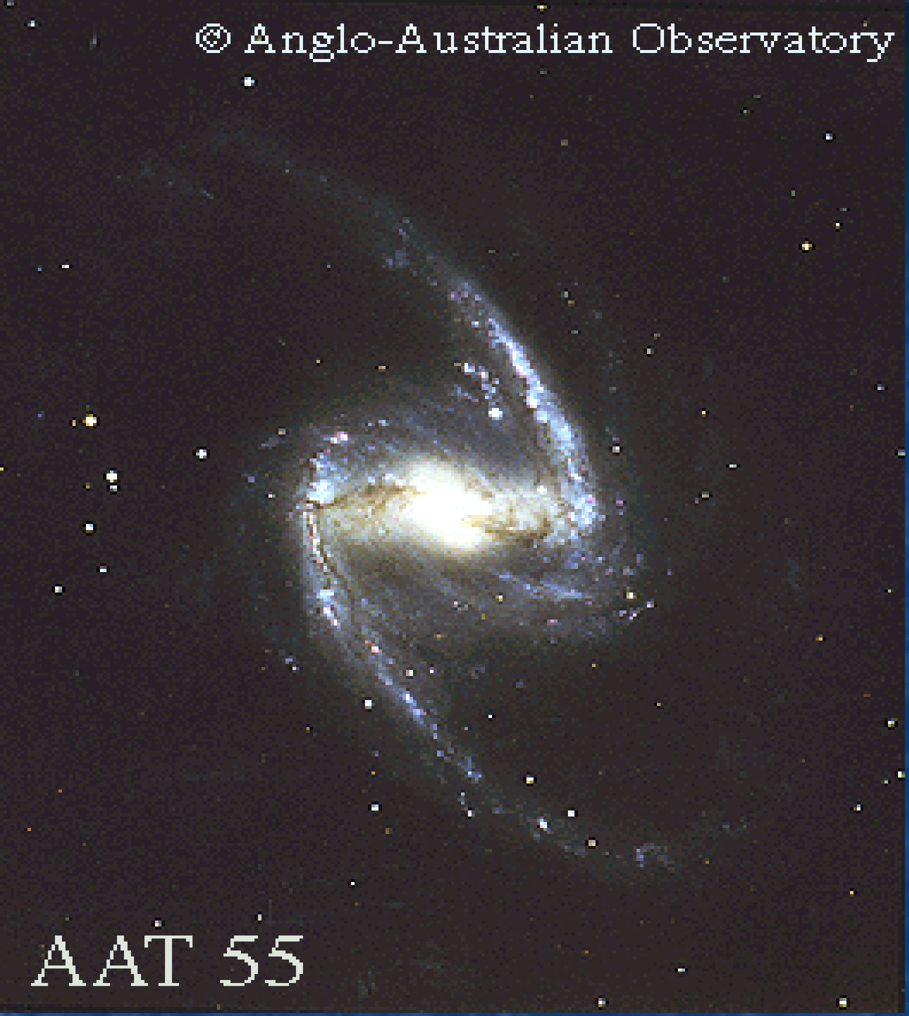
H band

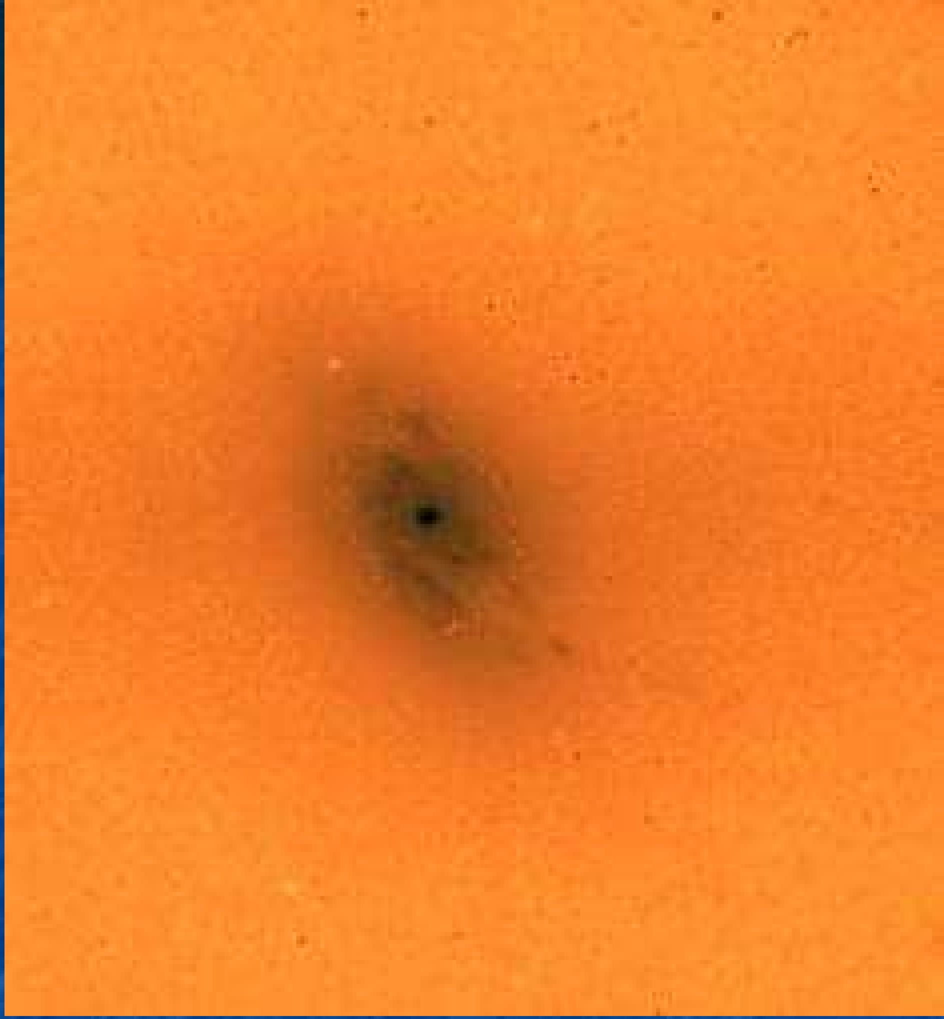


(Jungwiert, Combes & Axon1997)

Jungwiert, Combes & Axon 1997

Double bars in H-band





Jungwiert, Combes & Axon 1997

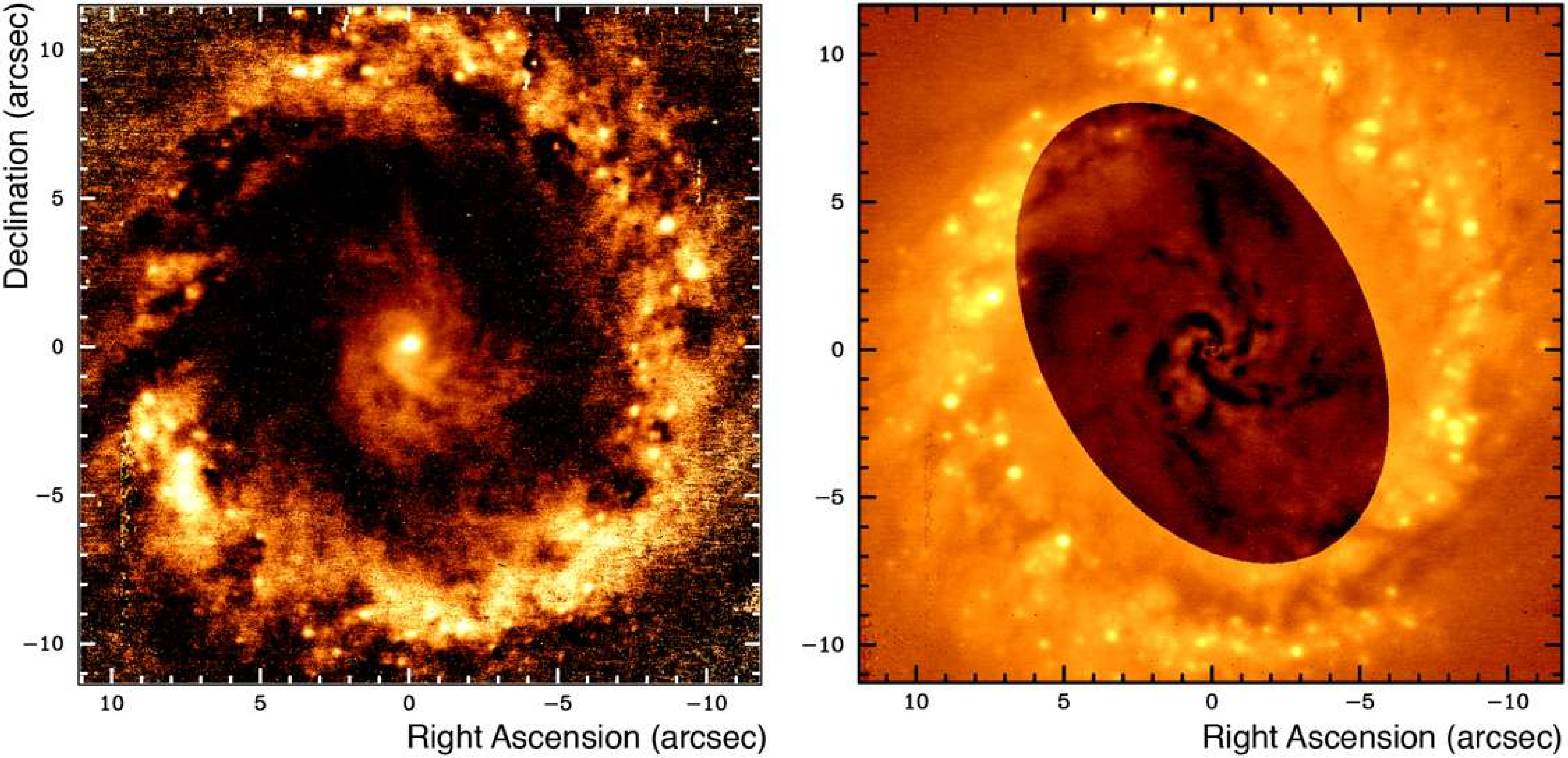
Nuclear spiral in NGC 1365 (H-band)

Spiral Galaxy NGC 1097
(VLT MELIPAL + VIMOS)

ESO PR Photo 35d/04 (22 December 2004)

The Centre of the Active Galaxy NGC 1097
(NACO/VLT)

ESO PR Photo 33a/05 (October 17, 2005)



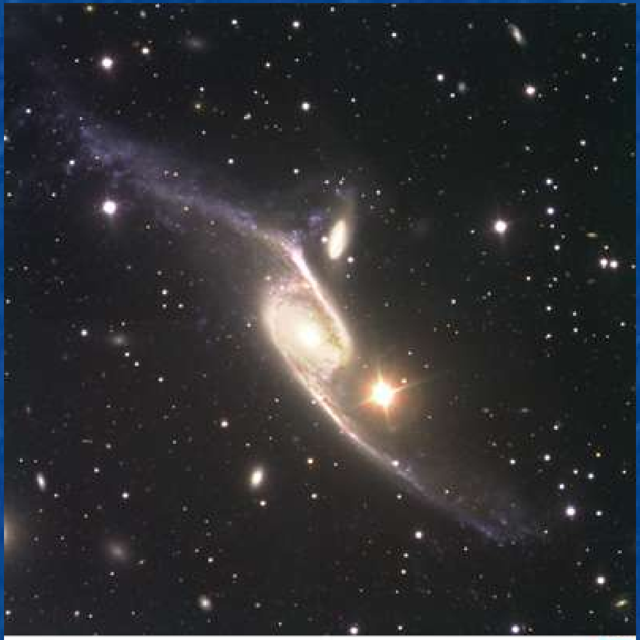
Network of Filamentary Structures in NGC 1097 (NACO/VLT)

ESO PR Photo 33b/05 (October 17, 2005)

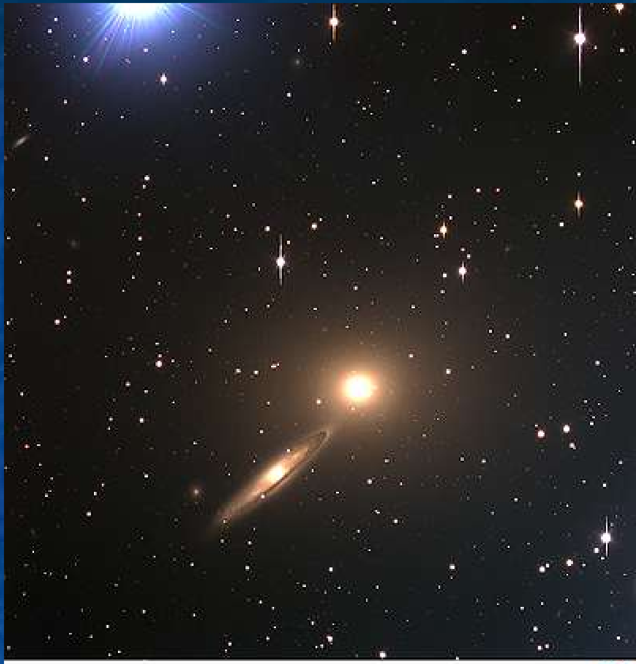
Interacting galaxies

Cosmic Ballet or Devil's Mask? - Galaxy Triplet NGC 6769-71
(VLT MELIPAL + VIMOS)

ESO PR Photo 12/04 (28 April 2004) © European Southern Observatory



Giant Interacting Galaxies NGC 6872 / IC 4970
(VLT ANTU + FORS1)



Galaxy Pair NGC 5090 + 5091
(VLT ANTU + FORS1)

Galaxies NGC 2207 and IC 2163

Hubble Heritage

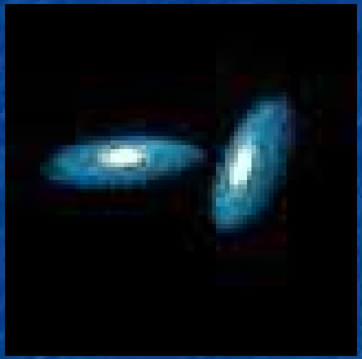
NASA and The Hubble Heritage Team (STScI) • Hubble Space Telescope WFPC2 • STScI-PRC99-41

Simulations of galaxy interactions / merging

1) J. Barnes, J. Hibbard

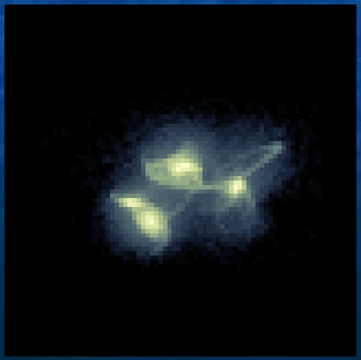
barnes-hibbard.mpg

2) F. Summers, C. Mihos, L. Hernquist

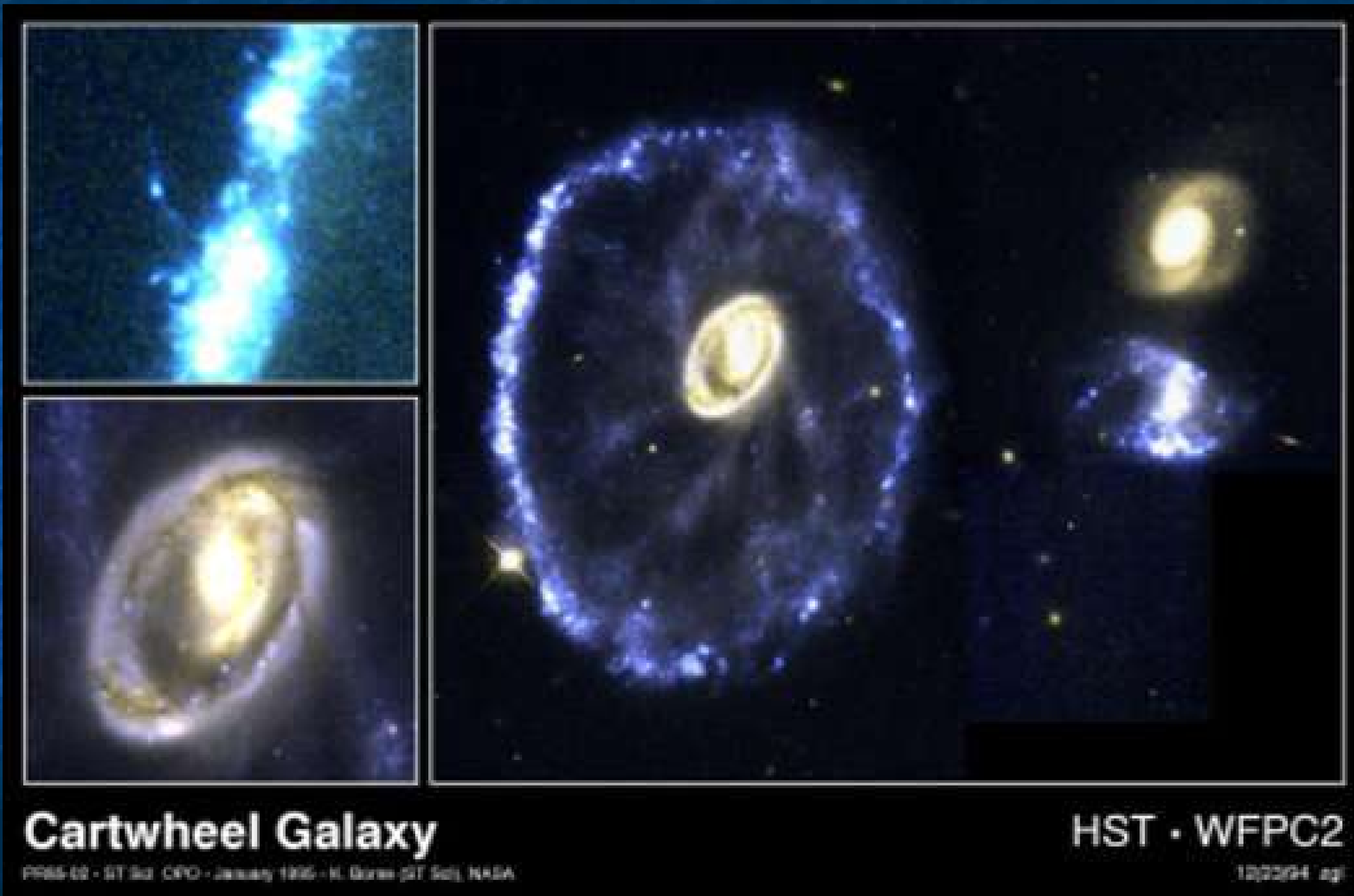


mmers-mihos-hernquist.mp

3) J. Barnes
Multiple-Galaxy Collision

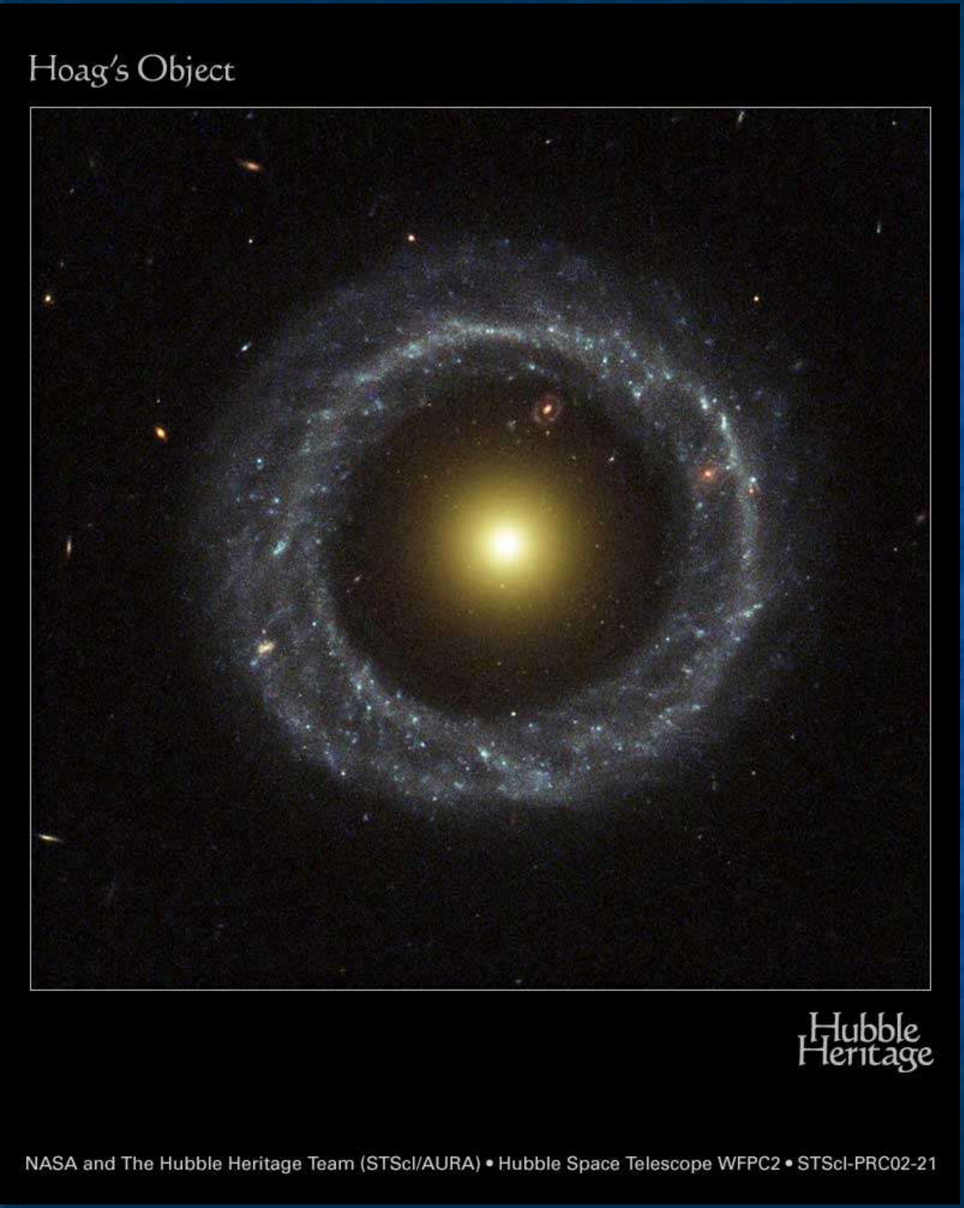


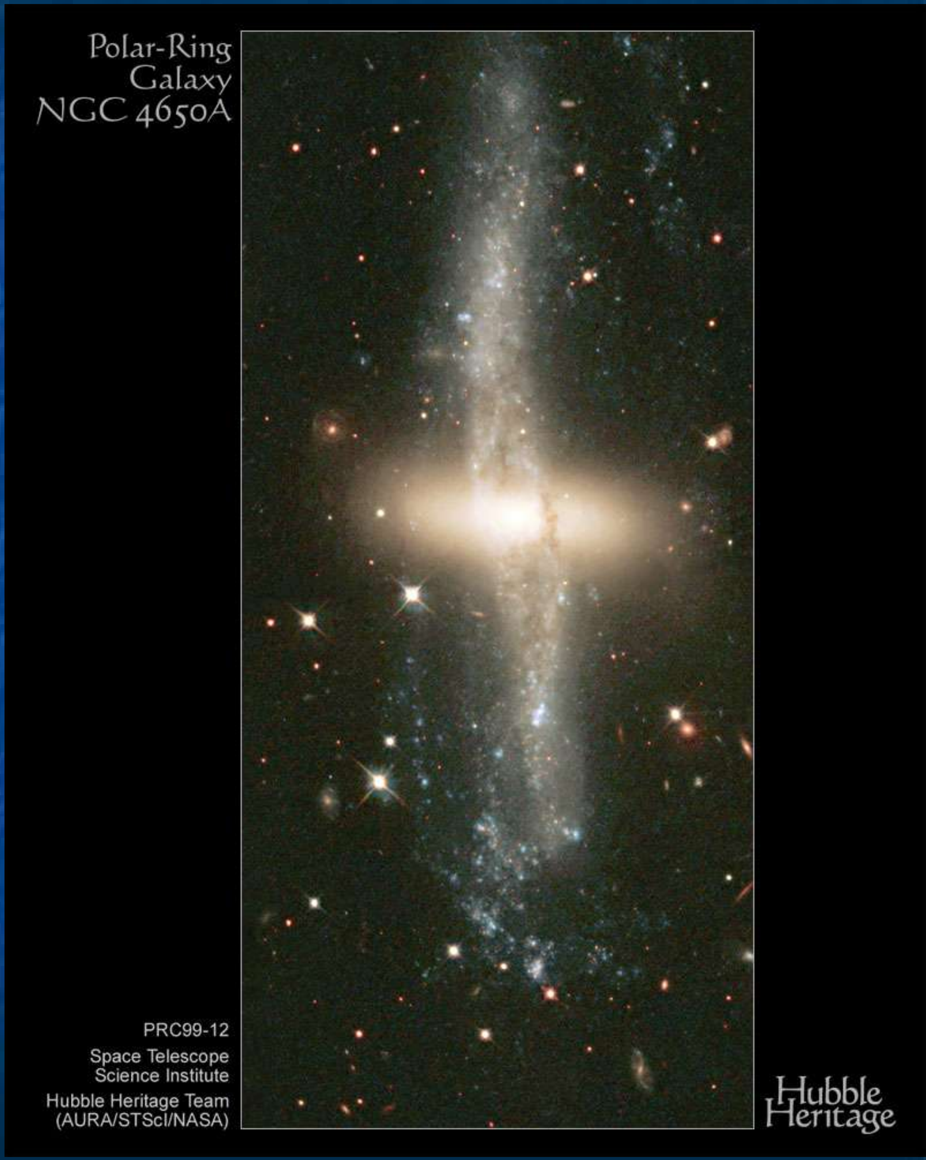
barnes-multiplecollision.mpg


Cartwheel Galaxy
HST • WFPC2

Hoag's object

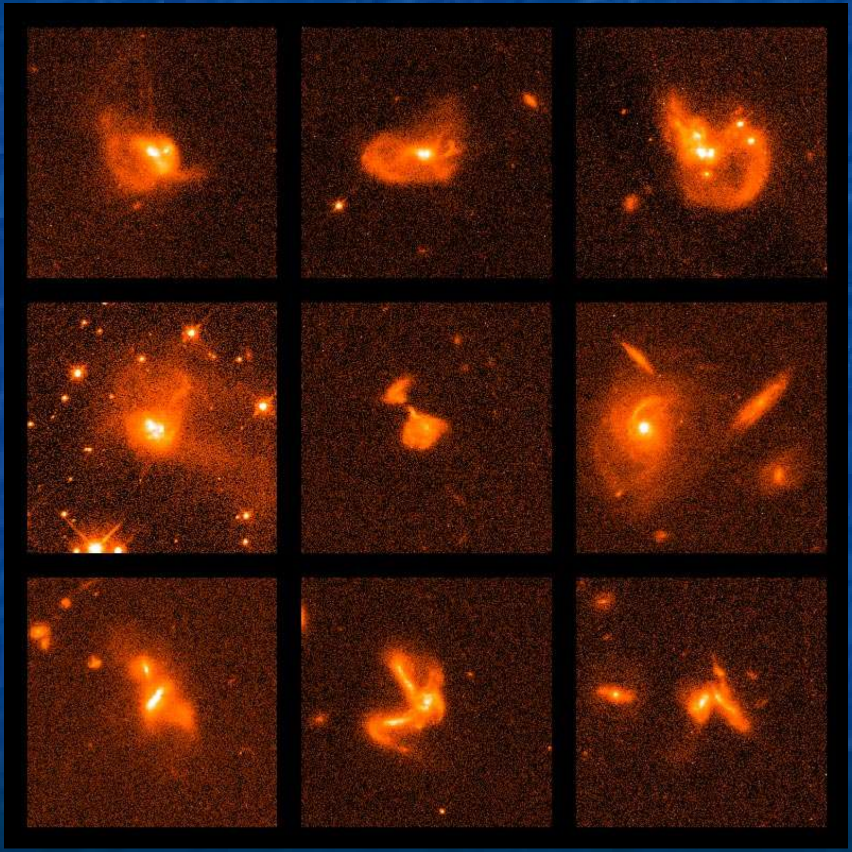
Polar ring galaxy NGC4650 A





(Credit: STScI/AURA, NASA)

Ultraluminous Infrared Galaxies (ULIRGs)



- $L_{IR} > 10^{12}$ Lo
- multiple mergers
- starbursts
- multiple nuclei
- quasar progenitors

HST/ACS (NASA/ESA)

Binary supermassive black-holes

1) galaxy interaction --> merging

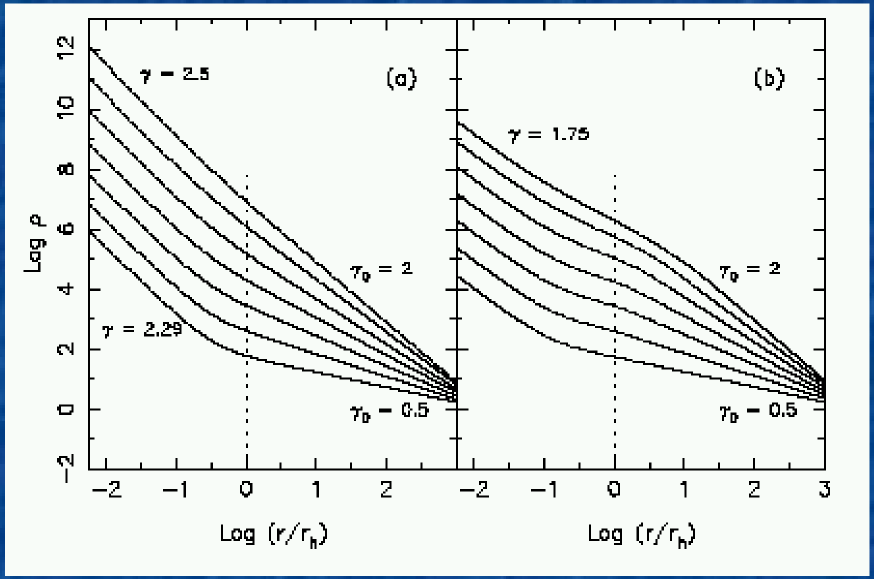
2) central black holes sink towards the merger center due to dynamical friction

3) BH binary hardening due to triple interactions with surrounding stars –> "gravitational slingshot"

4) gravitational waves

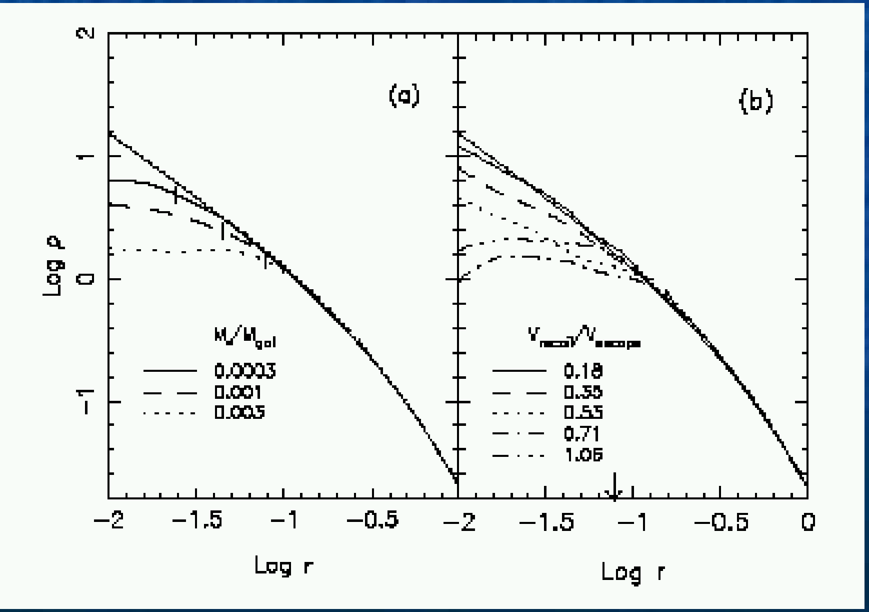
5) merging and radiation recoil --> wandering supermassive black holes ?

Stellar density profiles in galaxies with SMBHs

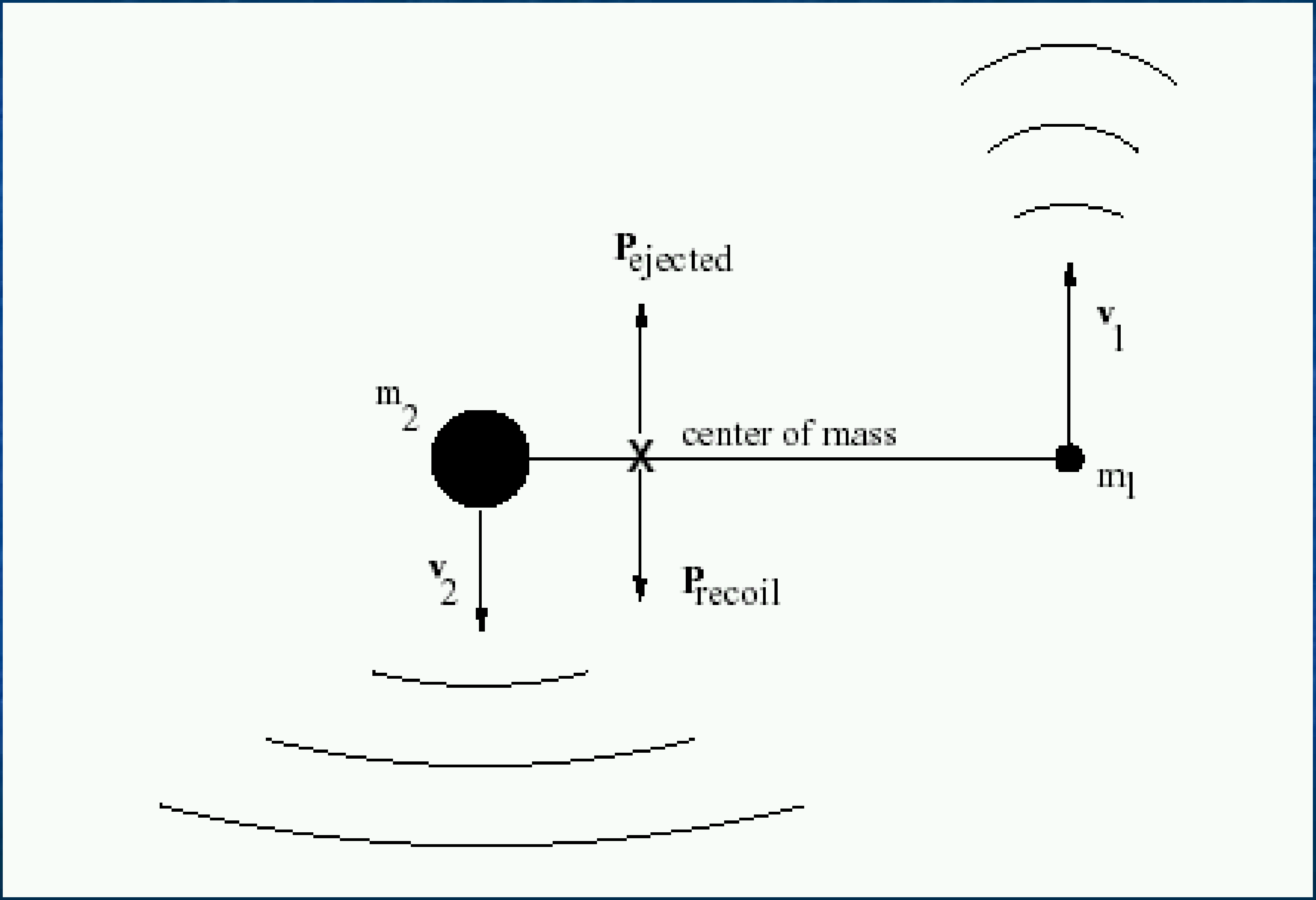


Stellar cusp destruction

(from Merritt 2005)



Radiation recoil in binary black hole mergers



(from Hughes et al. 2004)

Black hole – Galaxy feedback

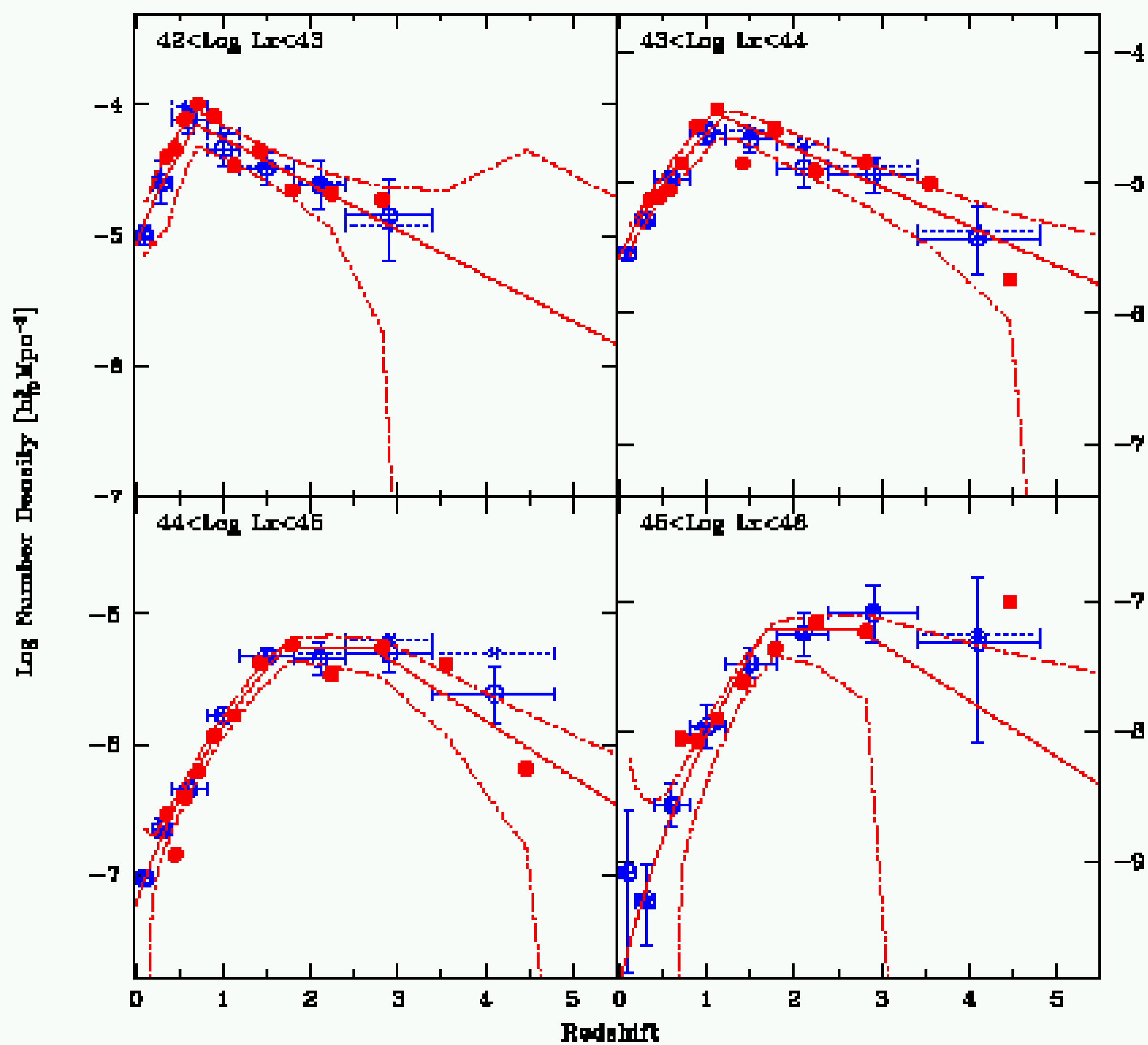
Di Matteo, Springel, Hernquist 2005

Energy input from AGN can quench:

1) further black hole growth

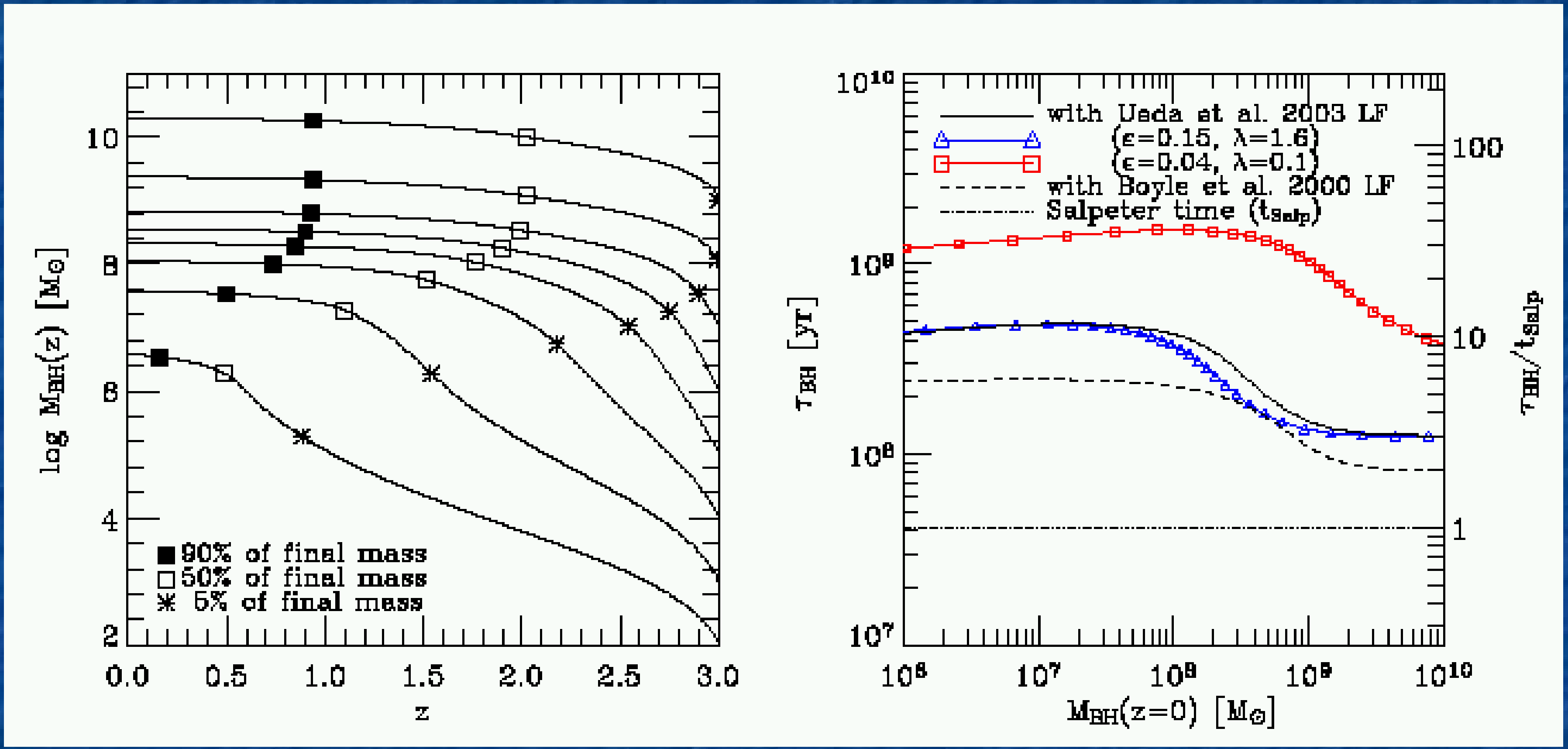
2) star formation in the galaxy

Cosmic downsizing



(from Hasinger 2005)

Anti-hierarchical black-hole growth



from Marconi et al. 2005

Some key questions:

1) What triggers AGN ? How long do they last ?

2) Physics of BH accretion (sub-Eddington vs. Eddington)

3) M-sigma relation at high redshift

5) AGN/SF feedback: how they regulate BH growth and SFR ?

6) complete census of AGN (obscured AGN)