AGN- Ch 14 of MBW, Ch9 of S&G

Roughly speaking, a galaxy is said to host an AGN if one or more of the following properties

are observed:

(i) a compact nuclear region much brighter than a region of the same size in a normal galaxy;

(ii) non-stellar (non-thermal) continuum emission;

(iii) strong emission lines;

(iv) variability in continuum emission and/or in emission lines on relatively short time scale (several light crossing times of R_{sch})

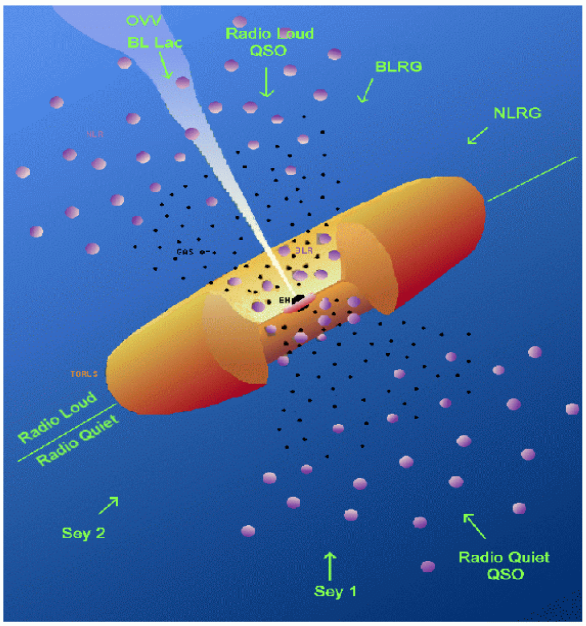
(v) luminous non-thermal radio or x-ray emission

(vi) presence of luminous relativistic jets

(see Ferrarese and Ford 2009 http://arxiv.org/pdf/astro-ph/0411247v1.pdf)

AGN- Alias **Active** Galactic Nuclei

- AGN are **'radiating'** supermassive black holes-
  - They go by a large number of names (Seyert I, Seyfert II, radio galaxies, quasars, Blazars etc etc)
  - The names convey the observational aspects of the objects in the first wavelength band in which they were studied and thus do carry *some* information
- See http://nedwww.ipac.caltech.edu/level5/Cambridge/Cambridge_contents.html for an overview



Schemtaic diagram of regions near the SMBH
Urry and Padovani 1995

What are the fundamental questions?

- 1) How do AGN "work"- e.g. how is energy produced/extracted and transformed into radiation. What is the role of relativistic effects
- 2) *How is the* ***MBH*** *connected to host galaxy*
  - how do they form and affect the galaxy
  - how do they affect the formation and structure of the universe
- 3) What is the origin of the wide range of apparent types?
  - what causes the difference (*Unified Models*)
- 4) How do they evolve with cosmic time? (Mass, luminosity, number)
- 5) What can we learn about strong gravity ?
- 6) What is the nature/geometry of the central regions ? (winds, disks, torus, jets)
- 7) What is the source of the material responsible for accretion

6 Main areas of AGN research

- What is the nature of the source of energy
  - Accretion
  - Spin
- Physics of matter close to a black hole
  - broad Fe K line
  - timing signatures
- **Affect of AGN on the formation and structure of the universe**
  - winds
  - jets
- physics of the radiation- what produces the photons (thermal, non-thermal, relativistic phenomena)
- structure of the region 'near' the BH
- Evolution of BHs across cosmic time and it connection to galaxy growth and formation

From Taos Meeting 1989 (!)

- Origin of the Energy and the Continuum

- At present we have no "reliable" theory for either the origin of the energy in the high energy continuum or of the creation of the spectrum.

- Most of the proposed theories for photon creation are "best" tested by looking at time variable spectral shape and/or spectral features at E>>20 kev. It is not clear if we have any "testable" theory for the origin of the energy. However if it is due to "relativistic" phenomena (such as tapping the spin of the black hole, shock acceleration of particles or magnetic reconnection) this bound also applies.

•While results from GRO, Granat, Ginga, SAX and XTE will probably suggest a "best" theory for low redshift, low luminosity objects these missions are not sensitive enough to test the evolution with cosmic time of the underlying physical conditions.

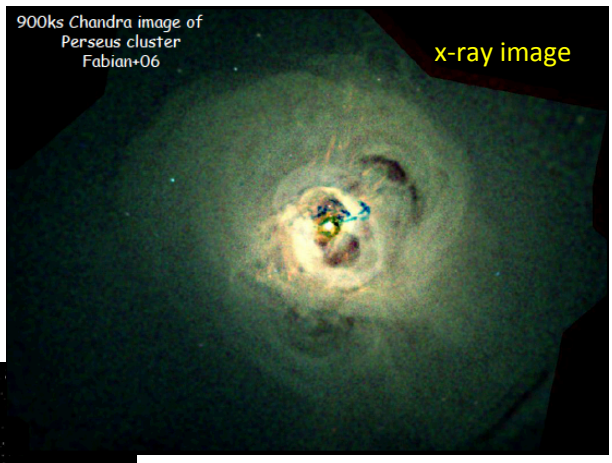
•There are strong reasons to believe that the physical mechanism(s) should vary with cosmic time (e.g the spin and mass of the central object, the relative accretion rate and angular momentum of material etc) and luminosity (compactness ratio of "disk" to non-thermal luminosity).

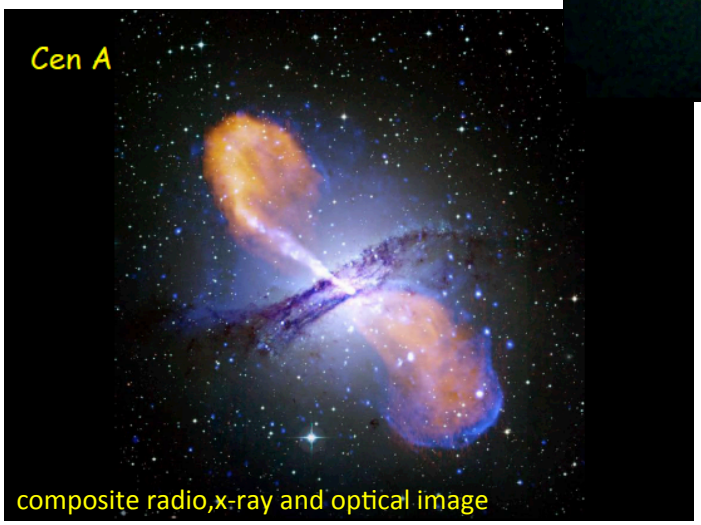
•Missions with sensitivity >10x that of XTE are required to start such a study.

Course evaluations are open- Please Respond!

- www.courseevalum.umd.edu
- Why?
  - For the benefit of your peers
  - Because your comments count and we use it to improve our teaching and/or redesign the course
  - Because your opinion is used to evaluate our performance
- Don't put it off till Dec 11th!

AGN- Black Holes



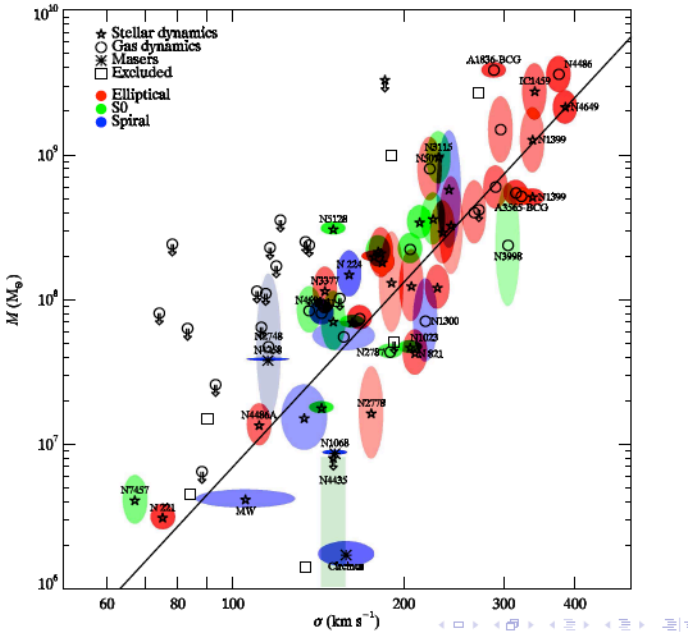


It is now believed that almost all massive galaxies have supermassive ($M>10^6 M_\odot$) black holes

But at z=0 only ~10% are 'active'

Mass of Black Hole Compared to Velocity Dispersion of Spheroid

- Sample of non-active galaxies compare mass of black hole (derived later) with velocity dispersion of stars
- Very high detection rate of BHs in 'normal' galaxies- both spheroids and disks.



Gultekin 2009

BH Mass vs Galaxy Luminosity

- The BH mass correlates with the bulge but not the disk luminosity (Savorgnan et al 1511.07437v1.pdf)

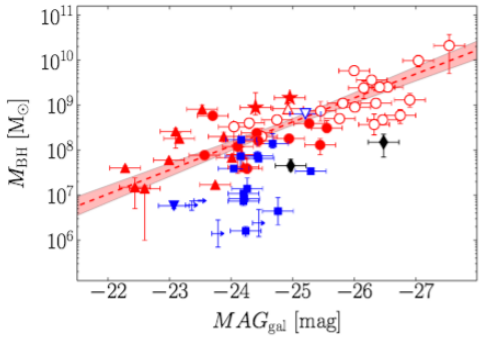


FIG. 1.— Black hole mass plotted against 3.6 μm galaxy absolute magnitude. Symbols are coded according to the galaxy morphological type: red circle = E, red star = E/S0, red upward triangle = S0, blue downward triangle = S0/Sp, blue square = Sp, black di-

BH mass vs **bulge** luminosity luminosity- red= ETGs blue =LTGs

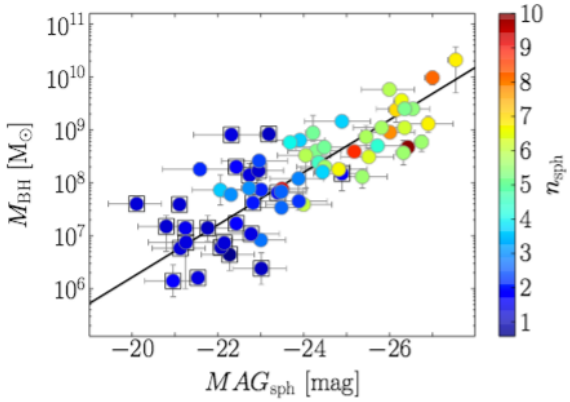


FIG. 3.— Black hole mass plotted against 3.6 μm spheroid absolute magnitude (as in Figure 2). Symbols are color coded according

BH mass vs *total galaxy luminosity*- red= ETGs blue =LTGs

BH Mass vs Spheroid Mass

- BH mass and spheroid mass are correlated but with wide scatter
- M_{BH}~5x10^{-3} $M_{spheroid}$

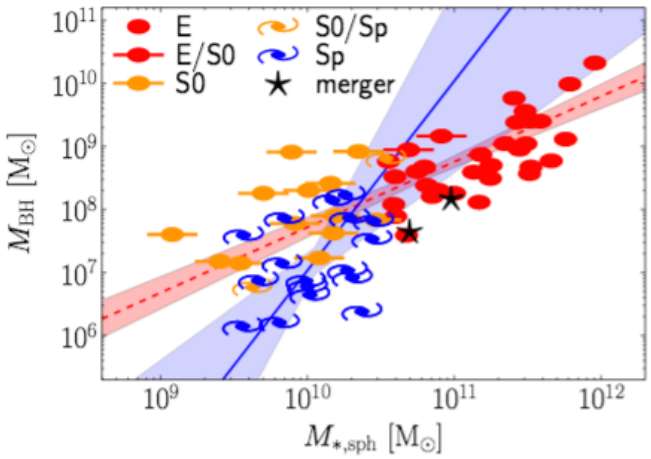


FIG. 5.— Black hole mass plotted against spheroid stellar mass.

Los Angeles Times | SCIENCE

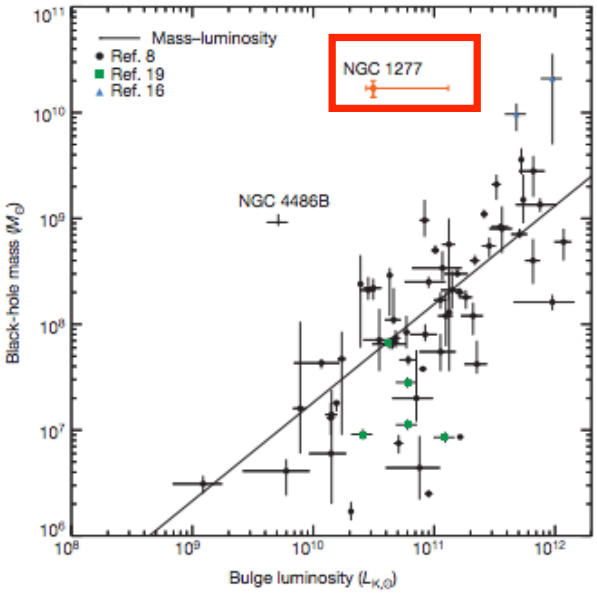
Gargantuan black hole baffles scientists

A hunt for supermassive black holes reveals a monstrous one at the heart of galaxy NGC 1277, which may force theorists to rethink their understanding of black holes.

The enormous black hole was found at the center of NGC 1277, a flat, compact yellowish galaxy near the center of this galaxy cluster in the constellation Perseus. (David W. Hogg-Michael Blanton, SDSS Collaboration / November 29, 2012)

Related photos »

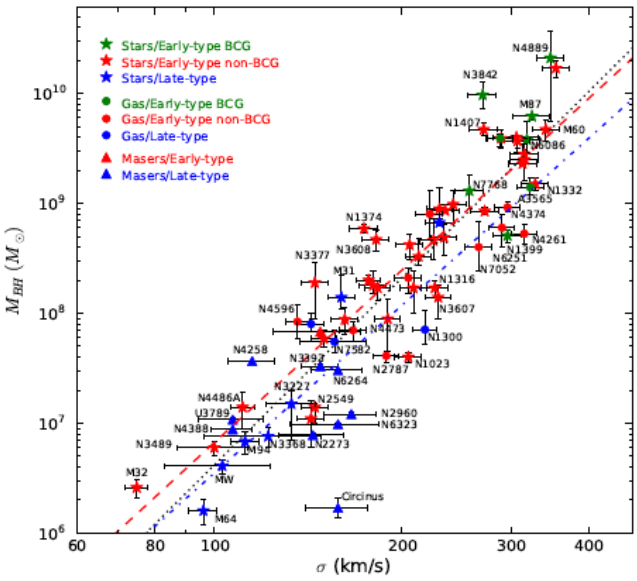
Not everything fits



- Yesterday In Nature the object with the highest ratio of BH mass to total galaxy mass 2:3 was discovered.
- \

Mass of Black Hole Compared to Velocity Dispersion of Spheroid

- Assume a fixed ratio of M_{BH} to M_{bulge}.
- Since L_{bulge} ~$\sigma^4$and as indicated earlier
- M/L~ ~ $L^{1/4}$ which gives M_{BH} ~σ^5
- **However the relation is very tight** (see Silk and Rees 1998) which show that feedback is needed
- **Read [2013ApJ...764..184M](#) McConnell, Nicholas J.; Ma, Chung-Pei**



McConnell & Ma 2013

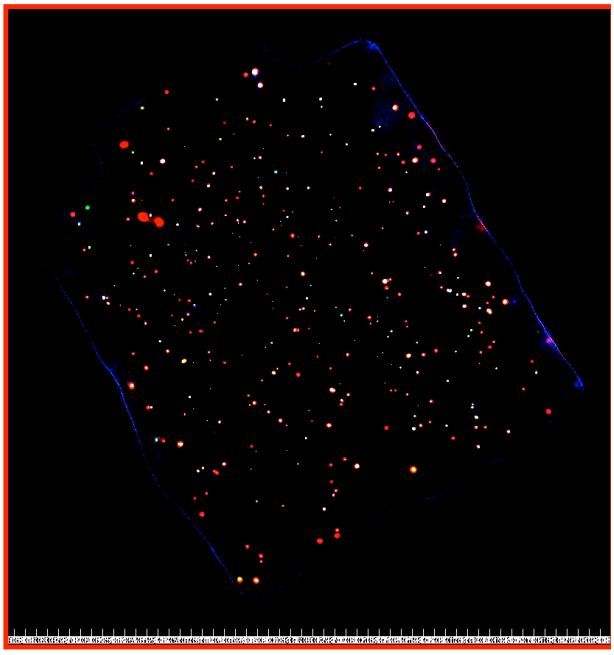
- "This galaxy seems to be very old," Dr Van den Bosch said. "So somehow this black hole grew very quickly a long time ago, but since then that galaxy has been sitting there not forming any new stars or anything else.

The History of Active Galaxies

- Active Galaxies (AKA quasars, Seyfert galaxies etc) are radiating massive black holes with $L \sim 10^{8}\text{-}10^{14} L_{sun}$

- The change in the luminosity and number of AGN with time are fundamental to understanding the origin and nature of massive black holes and the creation and evolution of galaxies

- ~20% of all energy radiated over the life of the universe comes from AGN- a strong influence on the formation of all structure.



X-ray Color Image (1deg)
of the Chandra Large Area X-ray Survey-all of the 'dots' are x-ray detected AGN- except 2 red blobs which are clusters

Galaxy formation and accretion on supermassive black holes appear to be closely related

see Kormendy and Ho 2013 ARA&A , vol. 51. 511- for a recent review

Black holes play an important role in galaxy formation theories

Observational evidence suggests a link between BH growth and galaxy formation:

- M_B-σ relation
- Similarity between cosmic SFR history and quasar evolution

Theoretical models often assume that BH growth is self-regulated by **strong** feedback:

- Blow out of gas in the halo once a crtitical M_B is reached
  Silk & Rees (1998), Wyithe & Loeb (2003)

Feedback by AGN may:

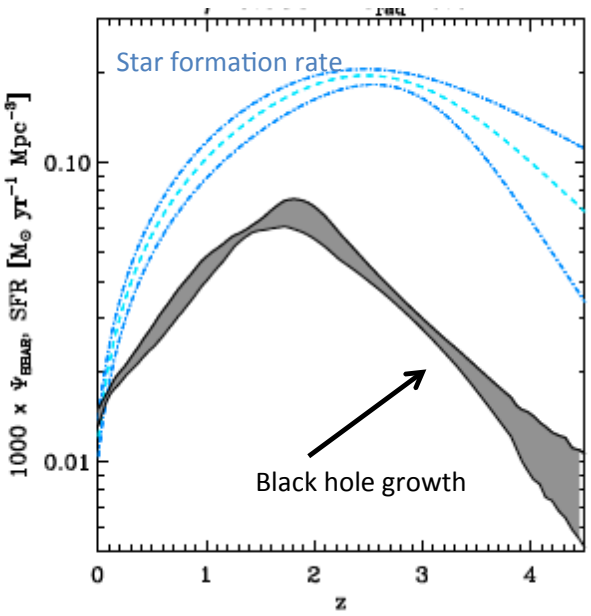
- Solve the cooling flow riddle in clusters of galaxies
- Explain the cluster-scaling relations, e.g. the tilt of the L_x-T relation
- Explain why ellipticals are so gas-poor
- Drive metals into the IGM by quasar-driven winds
- Help to reionize the universe and surpress star formation in small g

Springel 2004

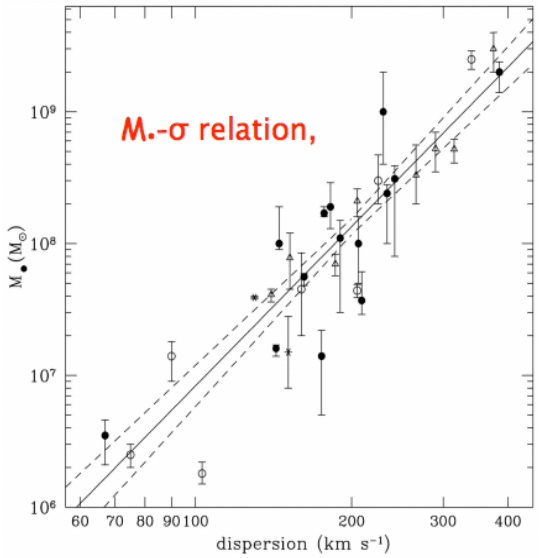
Galaxy formation models need to include the growth and feedback of black holes !

SFR Rate and AGN Growth

- To first order the growth of supermassive black holes (as traced by their luminosity converted to accretion rate) and the star formation rate are very similar
  - showing similar rises and falls
  - It this cause and effect?



Merloni 2010



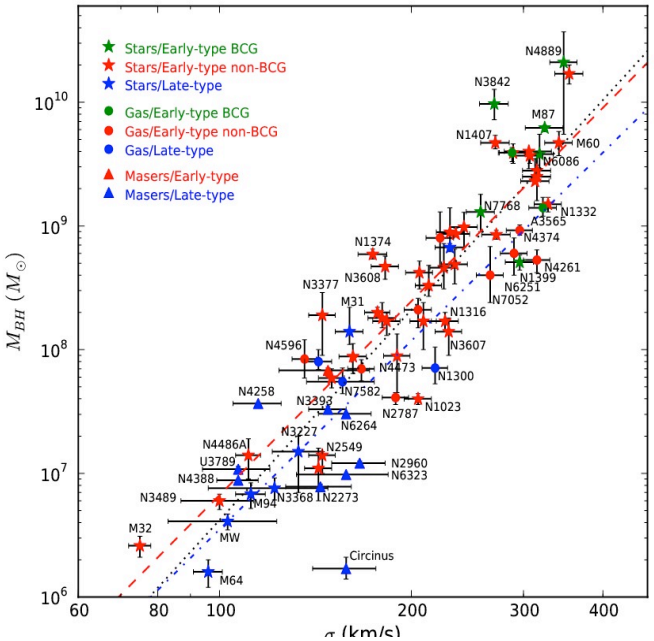
- Black hole mass correlated to host galaxy bulge mass.
- Formation of bulge and growth of black hole are related.
- AGN play a significant role in the evolution of galaxies

Magorrian et al. 1988; Gebhardt et al. 2000; Ferrarese & Merrit 2000; Tremaine et al. 2002

- Relation of mass of central black (M_{BH}) hole to the velocity dispersion of the stars in the bulge (σ)

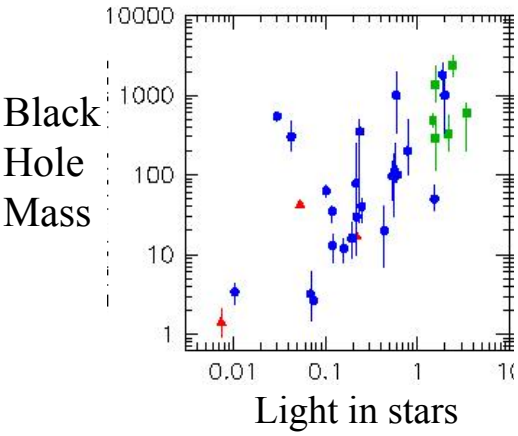
M-Sigma relation

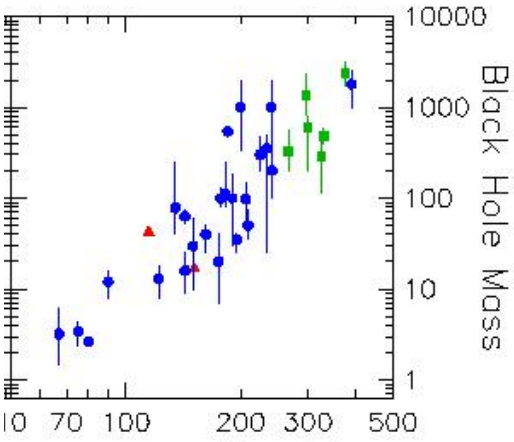
- **Hunting for Supermassive Black Holes in Nearby Galaxies with the Hobby-Eberly Telescope arXiv: 1502.00632**
- R van den Bosch K.Gebhardt K. Gültekin , A. Yıldırım , J. Walsh



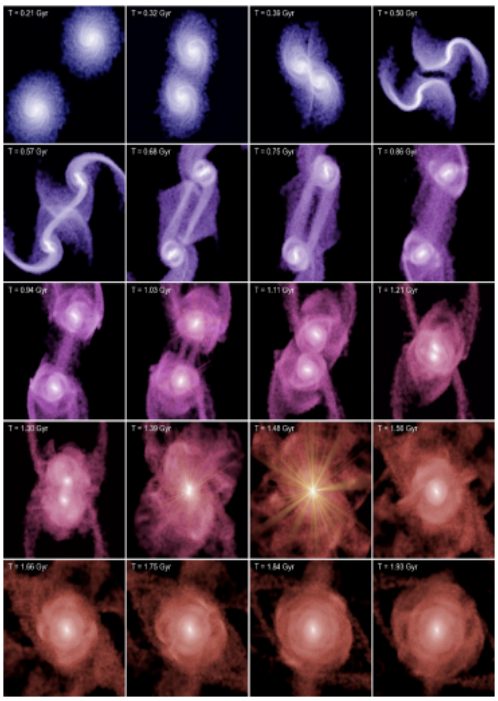
Strong relationship between galaxy and its central massive black hole

- The mass of stars in the galaxy is strongly correlated with the mass of the central black hole
- Black holes have had a strong influence on galaxy formation and vv





Scaling relations that allows estimate of BH mass in distant galaxies



- Gas rich major merger
- Inflows trigger BH accretion & starbursts
- Dust/gas clouds obscure AGN
- AGN wind sweeps away gas, quenching SF and BH accretion.

Hernquist (1989)
Springel et al. (2005)
Hopkins et al. (2006)

Problems with the Formation of the Universe

- How did the universe come to look like it does?
- Detailed numerical simulations show that gravity+ hydrodynamics does not produce the universe we see -many things are wrong e.g. galaxies are too big, too bright too blue, form at wrong time, wrong place
- What else is required?
  - FEEDBACK-The influence of objects on the universe (stars and AGN)
  - Stars don't have enough energy
  - So it has to be AGN
    - How ?
    - Where ?
    - When ?

Paradiso Canto 31

Reasons to believe in feedback

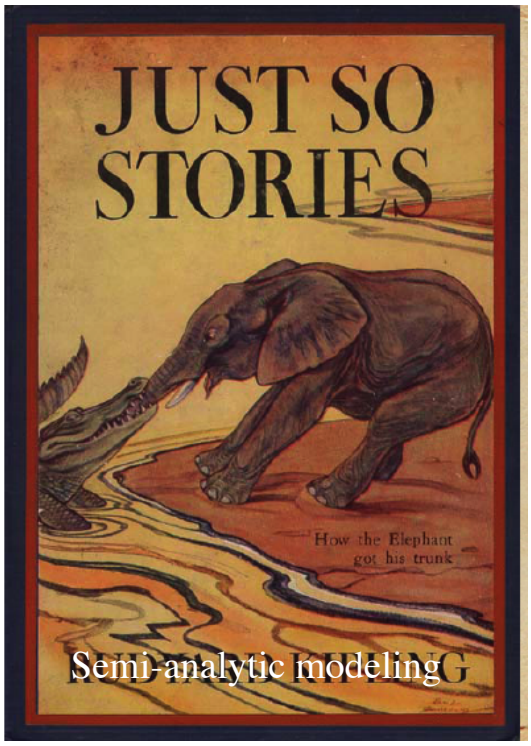
- Ability to match galaxy mass function with a CDM halo function
- AND
  - baryon fraction in galaxies,
  - IGM absorption in metal lines at moderate z
  - Entropy in groups
  - Detection of effects of radio sources on gas in galaxies and clusters

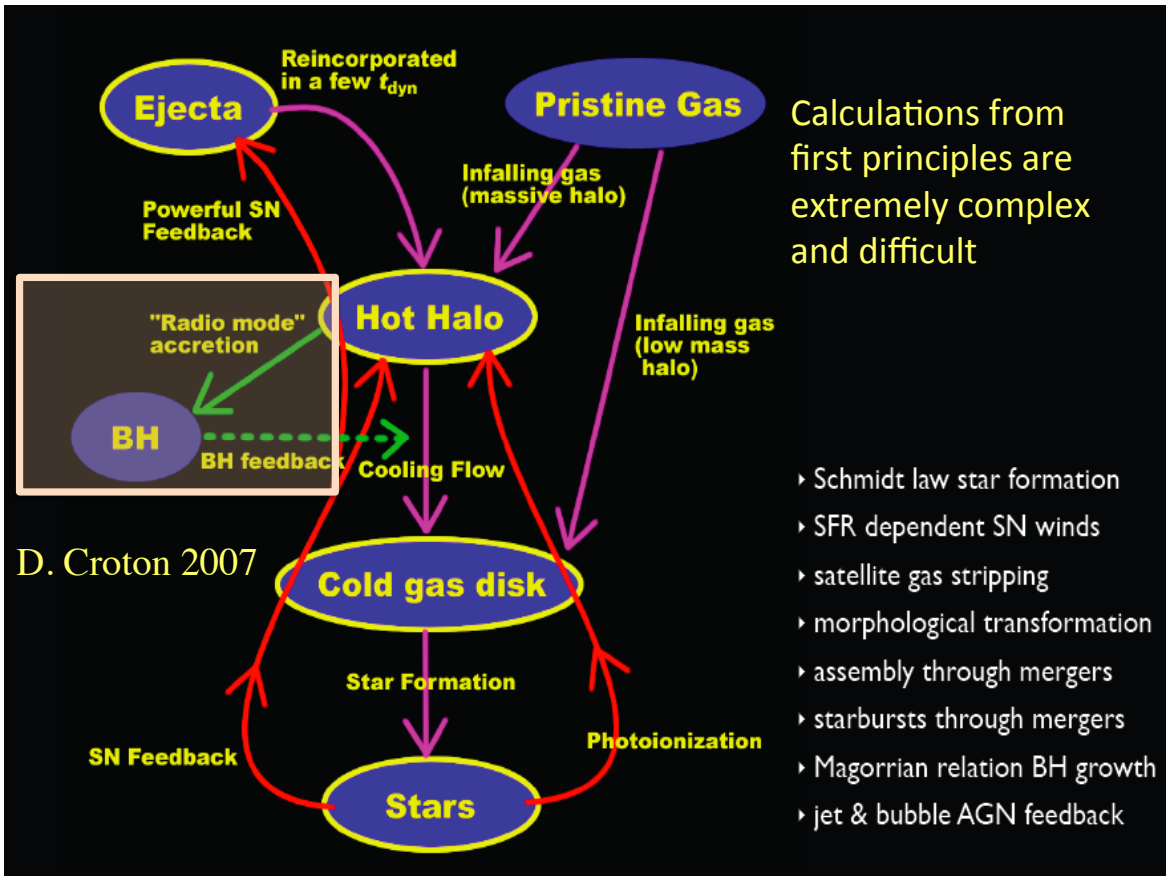
Problems feedback is invoked to solve

- Maintain the close correspondence between the growth of SMBH and galaxies across cosmic time
- Ensure a tight relationship between BH mass and galaxy velocity dispersion/spheroid mass
- Prevent galaxies from getting too massive in a LCDM universe
- Solve the cooling flow problem in clusters

How the Observable Universe Came to Be

- Dark matter evolution in the universe now understood
  - **it is not at all understood how 'baryonic structures' (galaxies, groups, clusters) form.**
- For models to fit the data additional physics (beyond gravity and hydrodynamics) is required (heating, cooling, mass and metal injection, gas motions etc)
- Up until now this has been parameterized in 'semi-analytic' models -
- ***The critical problem is to put physics into these stories***

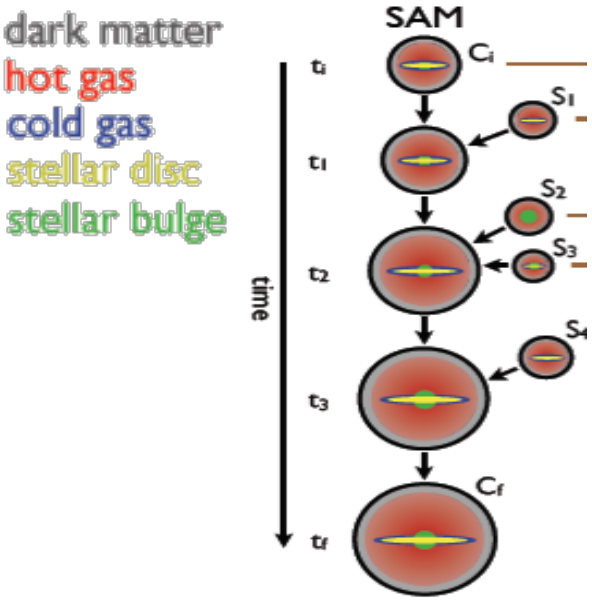




How to Include Baryonic Physics

When baryonic physics is added to the dark matter N-body realizations a lot of the predictive power is lost in the addition of many adjustable parameters required to describe the many physical processes at work:

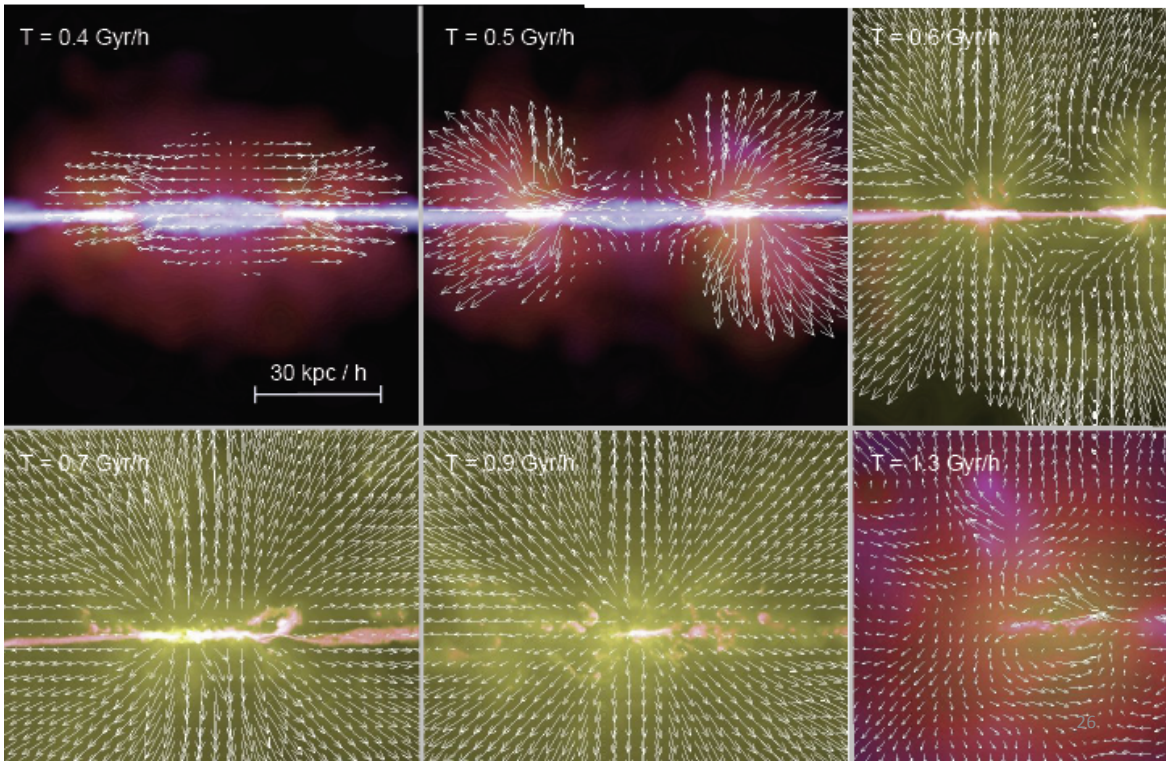
star formation, galactic winds, cold streams, supermassive black holes (formation, feedback), chemical evolution, galaxy mergers, starbursts, supernova feedback, dust effects etc, .

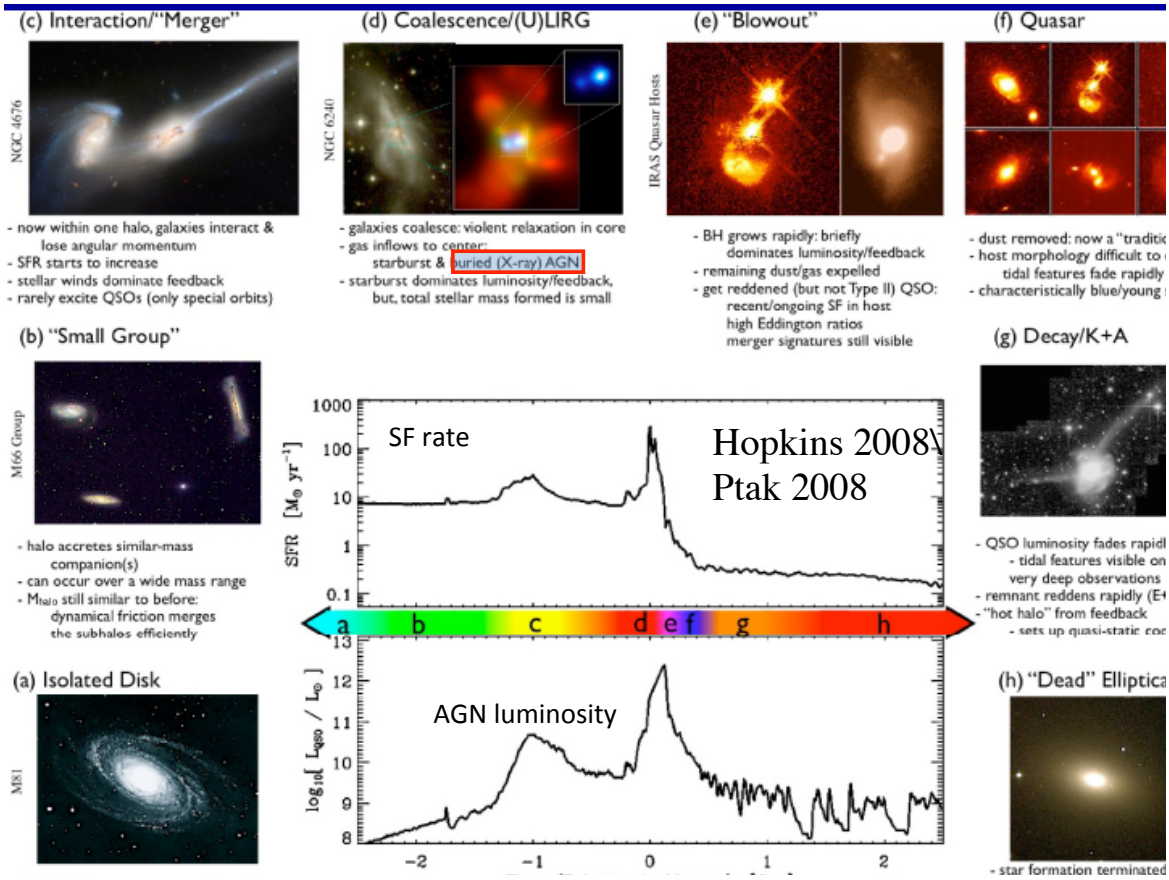


Moster, Maccio and Somerville

The feedback by the central black activity may drive a strong quasar wind

GAS OUTFLOW BY AGN FEEDBACK (outflow reaches speeds of up to ~1800 km/se




(c) Interaction/"Merger"
NGC 4676
- now within one halo, galaxies interact & lose angular momentum
- SFR starts to increase
- stellar winds dominate feedback
- rarely excite QSOs (only special orbits)
(d) Coalescence/(U)LIRG
NGC 6240
- galaxies coalesce: violent relaxation in core
- gas inflows to center: starburst & buried (X-ray) AGN
- starburst dominates luminosity/feedback, but, total stellar mass formed is small
(e) "Blowout"
IRAS Quasar Hosts
- BH grows rapidly: briefly dominates luminosity/feedback
- remaining dust/gas expelled
- get reddened (but not Type II) QSO: recent/ongoing SF in host, high Eddington ratios, merger signatures still visible
(f) Quasar
- dust removed: now a "traditi
- host morphology difficult to
tidal features fade rapidly
- characteristically blue/young
(b) "Small Group"
M66 Group
- halo accretes similar-mass companion(s)
- can occur over a wide mass range
- M_{halo} still similar to before: dynamical friction merges the subhalos efficiently
(a) Isolated Disk
M81
SF rate
Hopkins 2008\
Ptak 2008
SFR [$M_\odot$ yr^{-1}]
1000
100
10
1
0.1
a
b
c
d
e
f
g
h
AGN luminosity
$\log_{10}[L_{QSO} / L_\odot]$
13
12
11
10
9
8
−2
−1
0
1
2
(g) Decay/K+A
- QSO luminosity fades rapidl
- tidal features visible on
very deep observations
- remnant reddens rapidly (E+
- "hot halo" from feedback
- sets up quasi-static coo
(h) "Dead" Elliptica
- star formation terminated