Synergy of IXO with future multiwavelength facilities

Randall Smith for
Richard Mushotzky

Richard

Randall –
Not Richard

Also Not Richard

Randall –
Not Richard

Time for …

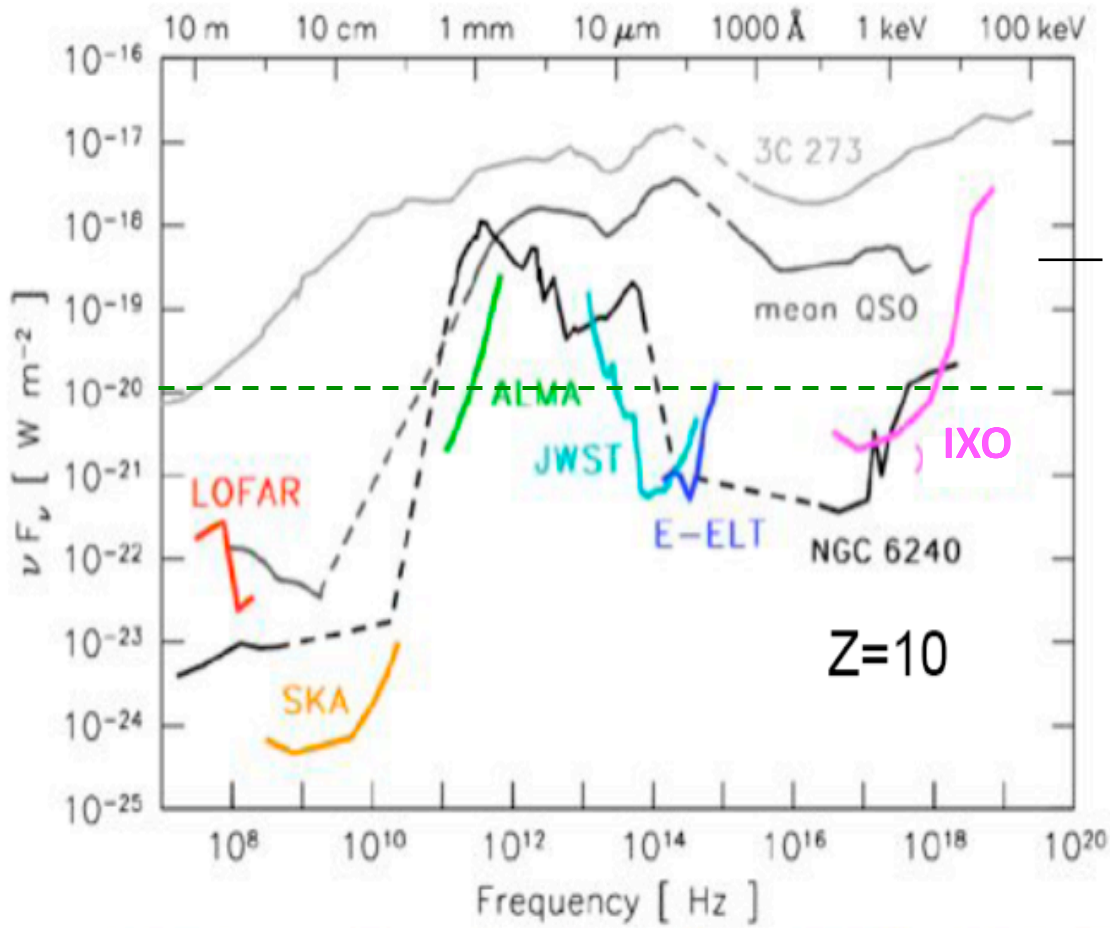
2nd Generation of 'Great Observatories'

- In every λ band a new generation of Great Observatories is **being built**
  - Herschel 2009
  - LOFAR (2009?) radio
  - ALMA (2010) mm
  - JWST (2013)IR/optical
  - Skymapper/Pan-STARRS… (2009) optical

Or **planned**

  - SKA (2016+) radio
  - LSST (2016) optical
  - TMT (2018) optical
  - JDEM (2015) Optical/IR
  - SPICA (2017) IR
  - LISA (2018+) grav waves
  - WFMOS(2016+) optical
- How will the IXO science goals and capabilities compare??

Relative Sensitivity



And even more are planned – see the **Science Vision for European Astronomy**

Observational Context in 2008

- **Full maturity of current 8m-class optical telescopes**
  - **At least 16 6m-10m telescopes with optimised instrumentation**
  - **AO → λ/D performance, 3rd-generation instruments- high angular resolution in near-IR from ground**
  - **Massive surveys and other large-scale, long-term programs**
- **Deep, whole-sky imaging at many wavelengths and epochs**
- **Interferometry: maturity of VLT-I, Keck, etc.**
- **Infrared: "Faint object" regime (K~20), astrometry (μas)**
- **mm-submm: ALMA offers equivalent of optical facilities**
- **Radio: E-VLA, VLBI, LOFAR, ASKAP, MWA…**
- **Space telescopes: JWST, IXO, GAIA, Planck, LISA…**

The Rest of the Future…

There are **many** projects under development in

High Energy Astrophysics

Auger North (Cosmic Rays)

Cherenkov Telescope Array (TeV)

IceCube (neutrinos-2010) , Km3Net (neutrinos),

NuStar (2011) , Simbol-X (2013) Astro-H (2013) (hard x-ray)

Spektr-RG (x-ray survey) (2012)

Advanced LIGO (2011) , LISA, Advanced VIRGO (Grav Waves)

SVOM (γRBs)

Other

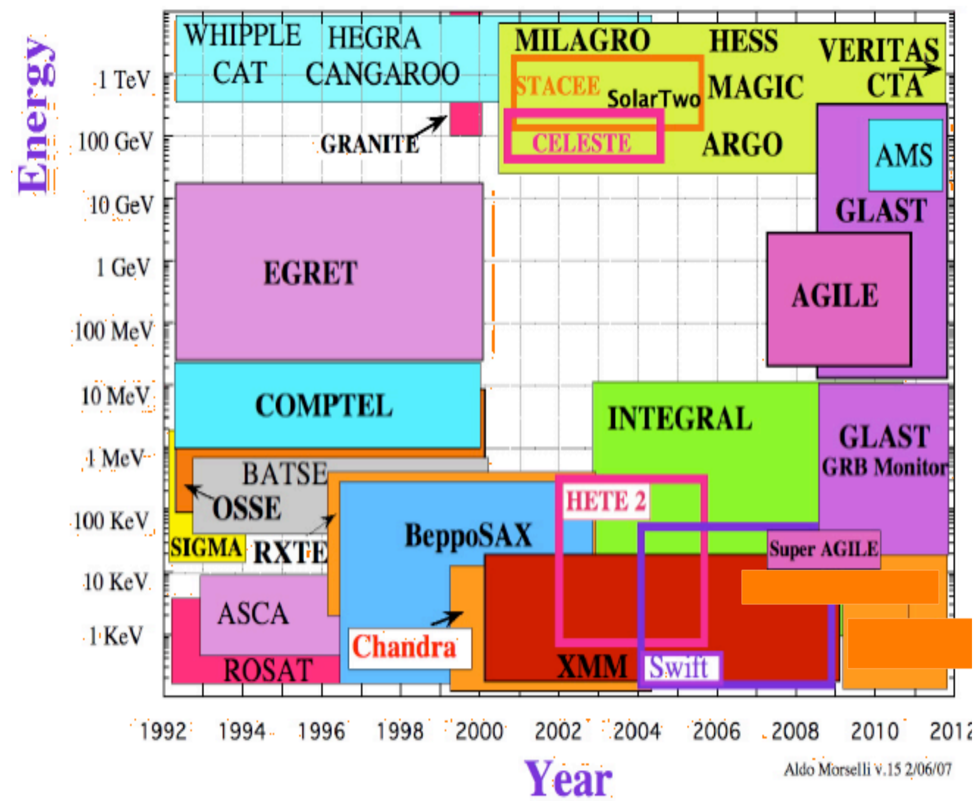
APEX(mm), CCAT (submm)

GAIA 2011 (astrometry)

WSO (UV telescope)

Planck (mm)

The High Energy Future till 2012



Golden Age of High E Astro : Now!

RXTE, Chandra, XMM, Suzaku, Integral, Fermi

X-ray Astronomy – The Next Steps

- By 2015, we will have high quality x-ray spectra of every type of celestial object with $F_X > 10^{-12}$ ergs/cm^2/sec
  - the rough limit of the Astro-H/Chandra/XMM spectrometers
- Chandra and XMM will obtain 1000's of high quality x-ray images to a flux of ~10^{-14} ergs/cm^2/sec for extended sources and 10^{-17} for point sources
- eRosita will survey the sky to 50x fainter than ROSAT
  - Providing a huge number of targets for IXO in the process
- No planned missions devoted to timing to replace XTE (except AstroSAT).
- First sensitive exploration of the hard (E> 10 keV) x-ray sky: BAT with ~1000 AGN, NuStar, Astro-H, Simbol-X 100-1000x more sensitive
- Possible opening of x-ray polarimetry

X-ray Astronomy – The Next Steps

- The sensitivity thresholds of the Chandra/XMM data for **imaging** are more sensitive than ground based telescopes for **spectroscopy** of x-ray selected AGN (many objects at I>23.5)

- **The x-ray spectroscopic threshold is severely limited both in sensitivity and in angular resolution**

- IXO will emphasize:
    - Moderate resolution spectroscopy (R~300-3000) at sensitivity levels 10-100 better than the Astro-H/Chandra/XMM spectrometers with 3-10x better spatial resolution, and
    - sensitive wide field imaging (~ Chandra deep field sensitivity but 10-100x faster, over a wider field with a broader energy range)

Phase Space of Complementarity

- There are two ways of describing complementarity:

  A. Technical parameters

  e.g. angular resolution, sensitivity, spectral resolution, …

  B Scientific

  Can the mission answer the important science questions?

Connecting A and B requires a 100 page document

Phase Space of Complementarity

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Connecting A and B requires a 100 page document

X-ray astronomy cannot compete in 'raw' capability

Spatial resolution 0.5" at best – (optical, IR, radio much higher)

Spectral resolution <3000 – (optical, IR, radio much higher)

Sensitivity (e.g. nJy) - *except for x-ray objects (AGN, clusters, binaries*) less than (optical, IR, radio)

(X-ray mirrors are 3m^2, optical 50m^2 AND Optical has ~10^6 more photons/area

Phase Space of Complementarity

- There are two ways of describing complementarity:
  A. Technical parameters
    e.g. angular resolution, sensitivity, spectral resolution, …
  B Scientific
    Can the mission answer the important science questions?

We have to compete in area B!

BUT … We have nature on our side!

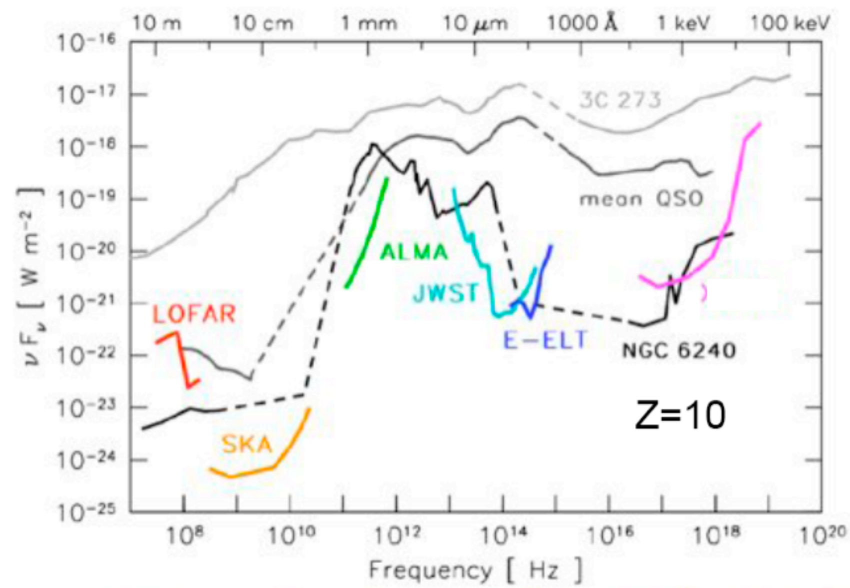
- Most of the baryons in the universe are hot/ionized
- Every* stage of ionization can be measured in x-rays
- Radiative transfer effects are small
- Dust is 'unimportant'
- Physics is (relatively) simple

**With enough effective area and resolution*

A few words on sensitivity…

- IXO can do O,B stars in LMC,SMC- but ELT,JWST can do O,B stars to D~5 Mpc
- IXO can detect 'normal' galaxies to z~0.5, but ALMA, ELT JWST can detect 'normal' galaxies to z>4
- IXO can detect clusters to z>1.5 (epoch at which they form) , similar to JWST, Spitzer, WISE, ELT
- IXO can detect AGN to z>6, similar to JWST, ELT etc
- IXO can detect SNR in nearby galaxies (e.g. M31) ELT JWST, SKA at D>5 Mpc
- **Bottom line is that IXO is not MORE sensitive for any class of objects than the future observatories in ANY other wavelength band** *with the exception of x-ray binaries and ULXs*.
- Similarly IXO will not have better angular resolution than any telescopes other than gravitational waves, γ-rays, or cosmic rays

The science case for IXO must rely on the unique capabilities of x-ray imaging, spectroscopy and timing and show that we are **SENSITIVE ENOUGH** to make major contributions to many important problems.

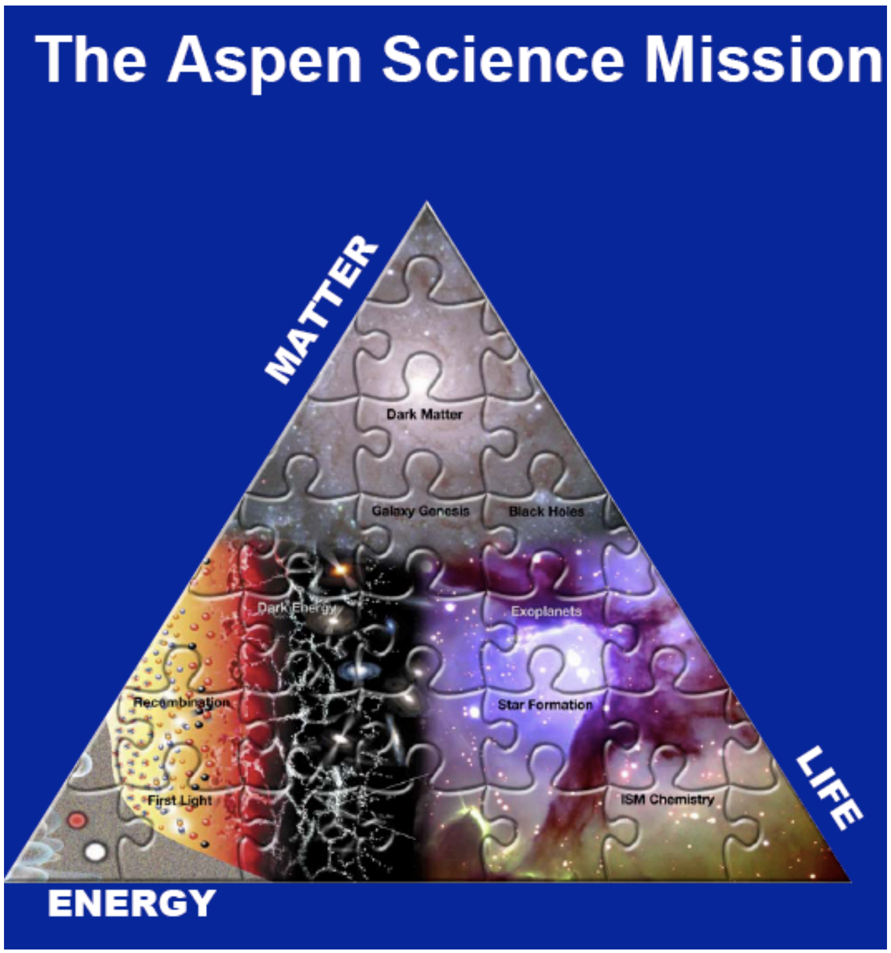


So What Are Those Other Missions Going After?

Science Goals of WFMOS (Wide Field Optical Spectroscopy)

(aka GEMINI)

- These (with the exception of planets) **are exactly the science goals of IXO.**
- So how do we establish complementarity and/or distinguish ourselves.



How do galaxies form?

What is the nature of dark matter?

What is the relationship between supermassive black holes and galaxies?

What is dark energy?

How did the cosmic dark age end?

How common are extrasolar planets?

How do stars and planets form?

How are the elements of life formed?

ELT Goals

*IXO

- Exo-planets
  - Direct detection
  - Radial velocity detection
- Initial Mass Function in stellar clusters
- Stellar disks
- Resolved Stellar Populations
  - Colour magnitude diagrams
  - Abundances and kinematics
  - Detailed abundances
- Black Holes
- The physics of galaxies
- Metallicity of the low-density IGM
- The highest redshift galaxies
- Dynamical measurement of the Universal expansion

ELT effort re-oriented at the end of 2005 towards "the best affordable ELT Facility that can be built on a competitive timescale and with acceptable risks"

Thirty Meter Telescope

*IXO

The big questions

- What is the nature and composition of the Universe? *
- When did the first galaxies form and how did they evolve? *
- What is the relationship between black holes and galaxies? *
- How do stars and planets form?
- What is the nature of extra-solar planets?
- Is there life elsewhere in the Universe?

The most progress will come from combined studies at many different wavelengths using ground and space-based facilities. Several major new telescopes will begin operation in the next decade. These include the James Webb Space Telescope (JWST) and the Atacama Large Millimeter Array (ALMA). Soon to follow will be theSquare Kilometer Array (SKA). By providing powerful new capabilities at infrared, microwave and radiowavelengths, these facilities will open new frontiers.

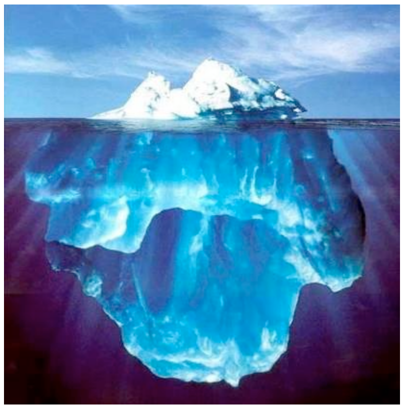
NOTICE THE COMPLETE ABSENCE OF X-RAY ASTRONOMY- despite the fact that we have the same science drivers !!!

In the 100 page document on science with the TMT there is 1 mention of x-rays (using x-rays to gauge stellar youth)

IXO

LSST Science Requirements focus on 4 Representative and Divergent Programs

Dark Energy-Dark Matter

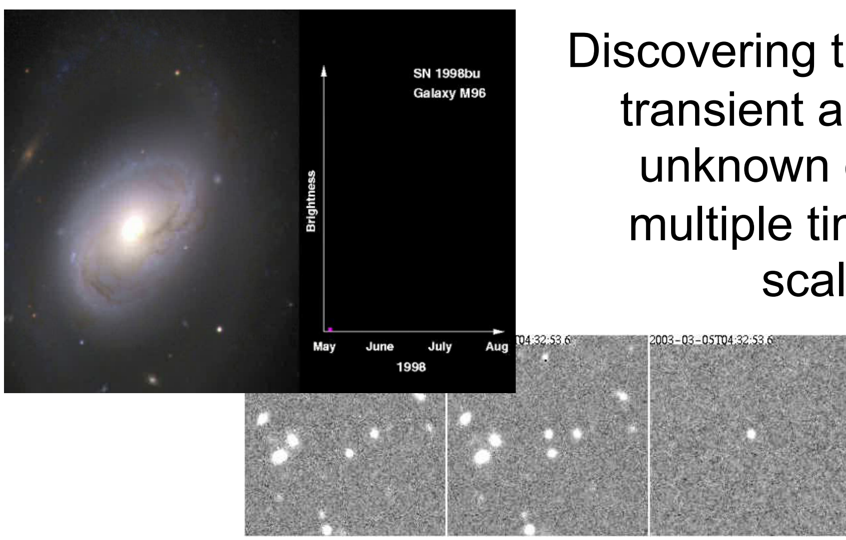


LSST enables multiple investigations into our understanding of the universe

Exploring our Solar System

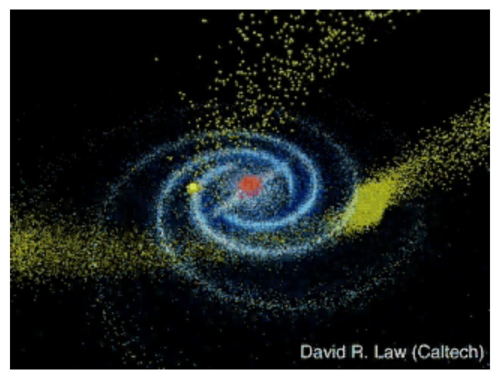
LSST will find 90% of hazardous NEOs down to 140 m in 10 yrs

"Movie" of the Universe: time domain



Discovering the transient and unknown on multiple time scales

Mapping the Milky Way



LSST will map the rich and complex structure of our Galaxy.

Large Ground Based Optical Telescope

- key science goals
  - Star and planet formation
  - * Stellar populations and chemical evolution
  - * The nature of dark matter and dark energy
  - * The evolution of galaxies and intergalactic matter
  - * Black hole growth
  - * The first stars and galaxies

In the GMT science case the only appearance of the word ‘x-ray’ occurs with respect to LMXBs !

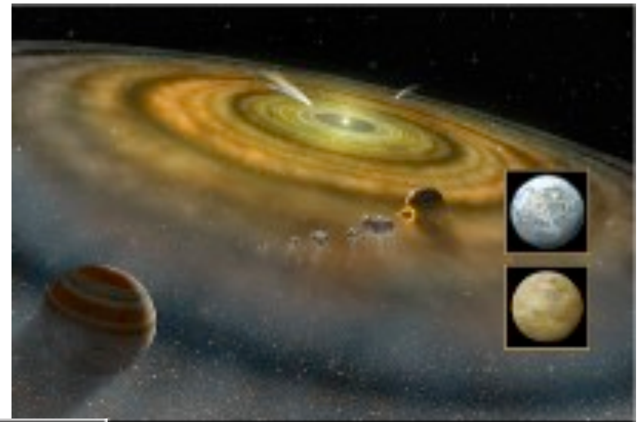
In the TMT science case x-rays only occurs in the discussion of active stars

* IXO

"To answer these questions, and many others, advances in technology are needed. The most progress will come from combined studies at many different wavelengths using ground and space-based facilities.
Several major new telescopes will begin operation in the next decade. These include the James Webb Space Telescope (JWST) and the Atacama Large Millimeter Array (ALMA). Soon to follow will be the Square Kilometer Array (SKA). By providing powerful new capabilities at infrared, microwave and radio wavelengths, these facilities will open new frontiers."

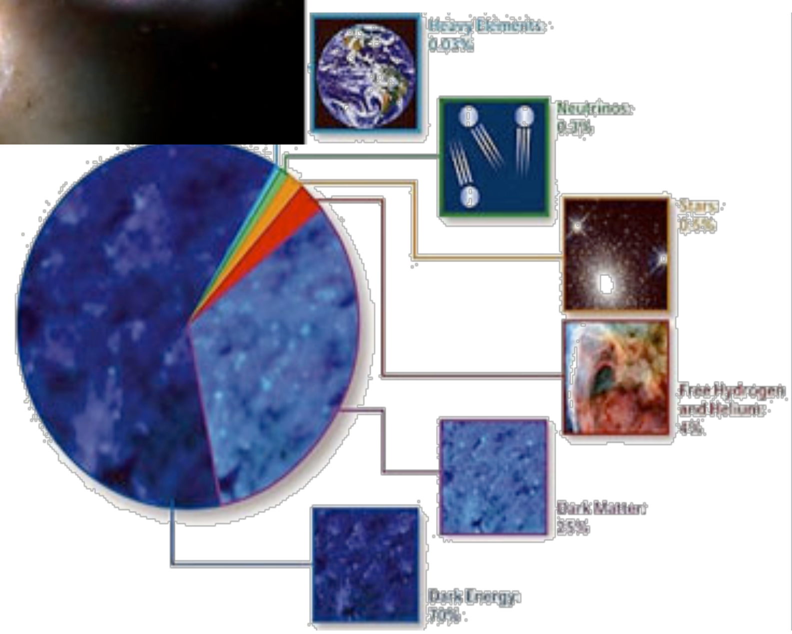
Direct quote from TMT science case- no mention of a new x-ray mission !!!!

42-m E-ELT Science drivers



- Planets in other stellar systems
  - Imaging *and* spectroscopy
  - Earth-like planets *may* become accessible

- Stellar populations
  - In galaxies inaccessible today (e.g. ellipticals in Virgo cluster)
  - Across the whole history (i.e. extent) of the Universe
- Cosmology
  - The first stars/galaxies
  - Direct measure of deceleration
  - Evolution of cosmic parameters
  - Dark matter, dark energy



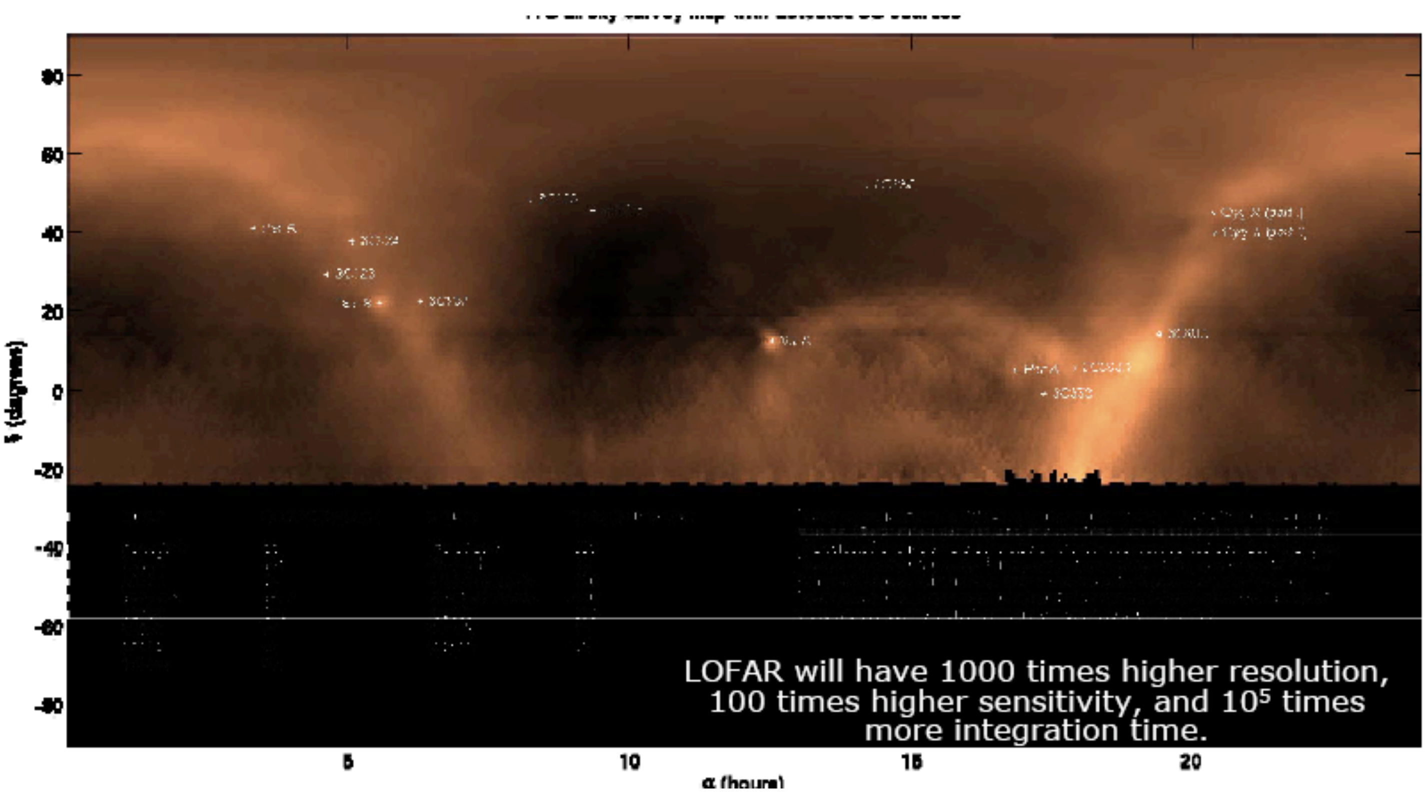
SKA Key Science Drivers

- **Galaxies, cosmology and dark energy**: map hydrogen in a wide variety of environments over a huge range of redshifts
  - the huge field of view will allow surveying and identification of galaxies over significant cosmic volume, and provide 3-D data for dark energy studies as f(z)
- The **epoch of re-ionization**: imaging the high redshift intergalactic medium as it is progressively ionized by the first stars and galaxies
- **Strong field tests of gravity** using pulsars and black holes through pulsar timing measurements
- **Origin and evolution of cosmic magnetism** through all-sky observations of radio polarization and Faraday rotation
- **Protoplanetary disks** and **search for life** elsewhere in our Galaxy. Very high angular resolution observations of disks in which planetary formation is ongoing.
- + **the Unknown**.....

Mapped to the SV Themes: A1, A2, A6, A8, B1. B6, C1, C4

LOFAR science case

- Cosmology –Epoch of Reionization
- All-Sky Surveys (–Star forming galaxies, AGN, Clusters, etc.)
- Transient detection–Everything that bursts and varies
- Astroparticle Physics
  - – Direct detection of cosmic rays
  - – Cosmic rays& neutrinos impacting the moon



5 sec with LOFAR

We Don’t Get Respect

- ~20-25% of all published papers are in high energy astrophysics -out of 2697 ApJ non-planet papers in 2006, 697 has the word x-ray in the abstract (25.8%)
- In astronet in Europe 3/26 panel members are high energy astrophysicists
- Do we have a major marketing job to do ??
  - Science is not democratic
  - We need to show that the “important” problems in astrophysics REQUIRE the PROPER x-ray astronomy data and that we have the right properties in IXO to provide that data.

Science Vision Working Group
Tim de Zeeuw chair Sterrewacht Leiden Netherlands
John Peacock chair A Royal Observatory Edinburgh UK
Claes Fransson co-chair A Stockholm Observatory Sweden
Jacqueline Bergeron chair B Institut d’Astrophysique France
Rob Kennicutt co-chair B Institute of Astronomy Cambridge UK
Leonardo Testi chair C Osservatorio Astrofisico di Arcetri Italy
Rafael Rebolo co-chair C Instituto de Astrof´ısica de Canarias Spain
Oskar von der Luhe chair D Kiepenheuer-Institut f ¨ ur Sonnenphysik Germany
Therese Encrenaz co-chair D Observatoire de Paris France
Reinhard Genzel MPI-E Garching Germany
Michael Perryman European Space Agency Netherlands
Alvio Renzini INAF-OAPD Padova Italy
Rashid Sunyaev MPI-A Garching Germany
Catherine Turon Observatoire de Paris France
Michael Bode Roadmap lead Liverpool John Moores University UK
Frank Molster NWO Netherlands
Panel A: Do we understand the extremes of the Universe?
John Peacock chair Royal Observatory Edinburgh UK
Claes Fransson co-chair Stockholm Observatory Sweden
Juan Garcia-Bellido Universidad Aut´onoma de Madrid Spain
Francois Bouchet Institute d’Astrophysique de Paris France
Andrew Fabian Cambridge UK
Bruno Leibundgut ESO Germany
Subir Sarkar Oxford University UK
Peter Schneider Universit¨at Bonn Germany
Ralph Wijers Sterrenkundig Instituut Anton Pannekoek Netherlands
Bernard Schutz MPI-G Potsdam

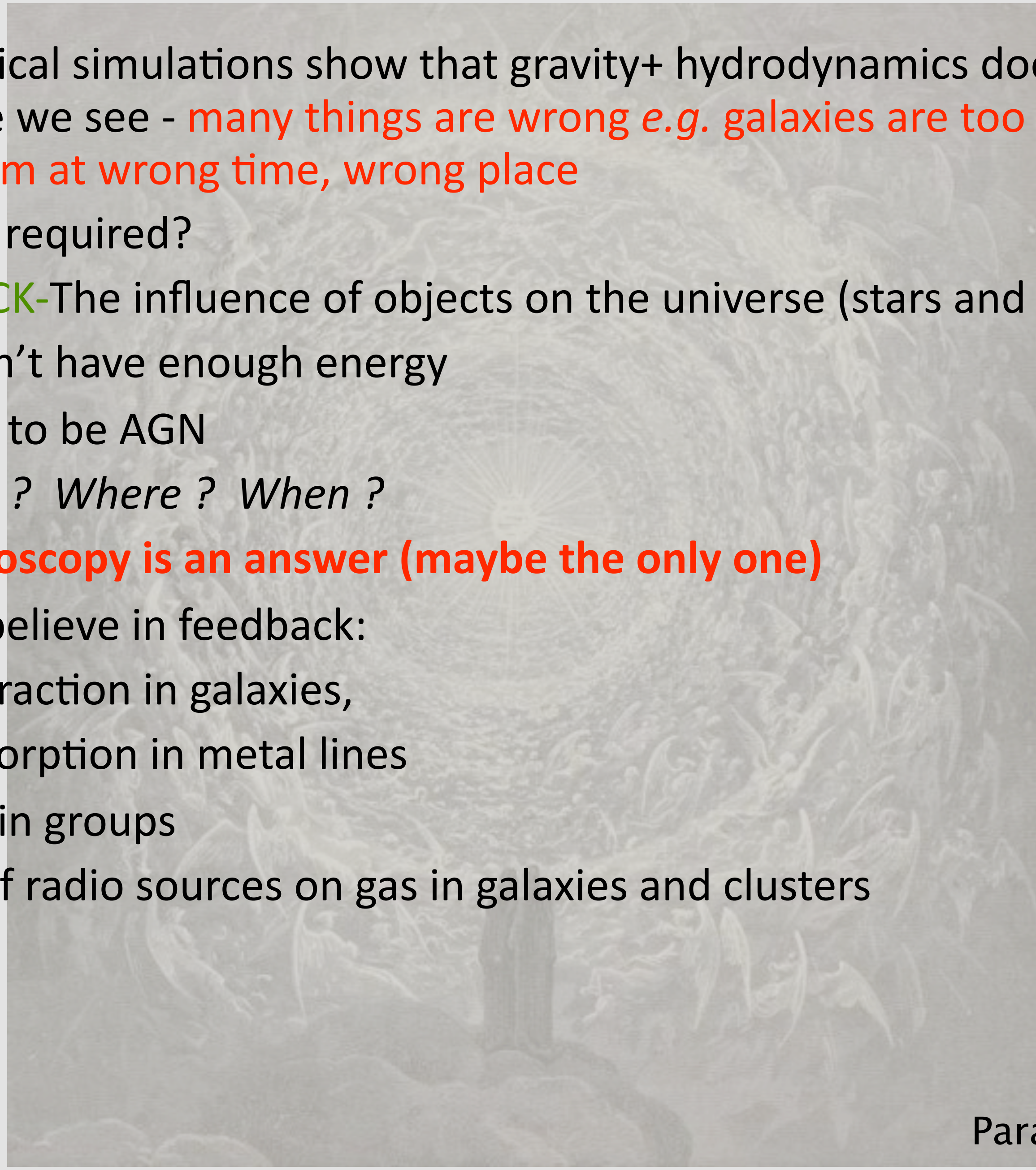
Connecting X-rays to Other λ

- Some topics have obvious X-ray connections: Cosmology, AGN (Black Holes), GR Tests.

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 ?*
- **X-ray spectroscopy is an answer (maybe the only one)**
- Reasons to believe in feedback:
  - baryon fraction in galaxies,
  - IGM absorption in metal lines
  - Entropy in groups
  - effects of radio sources on gas in galaxies and clusters



Paradiso Canto 31

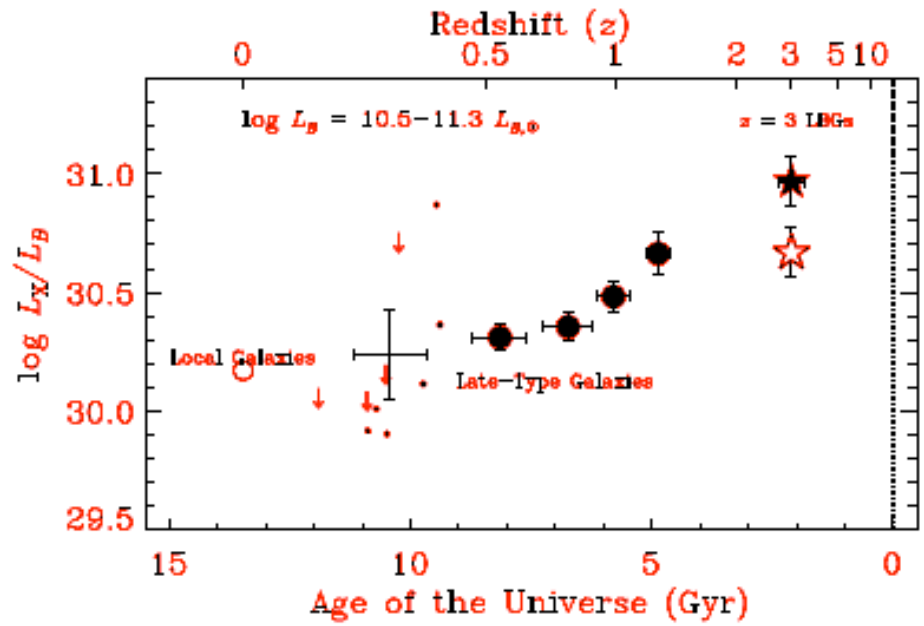
Connecting X-rays to Other λ

- Some topics have obvious X-ray connections: Cosmology, AGN (Black Holes), GR Tests.

- Focus on Galaxy Evolution / Star Formation – major topics in every other wavelength's plan.

How Structures Form

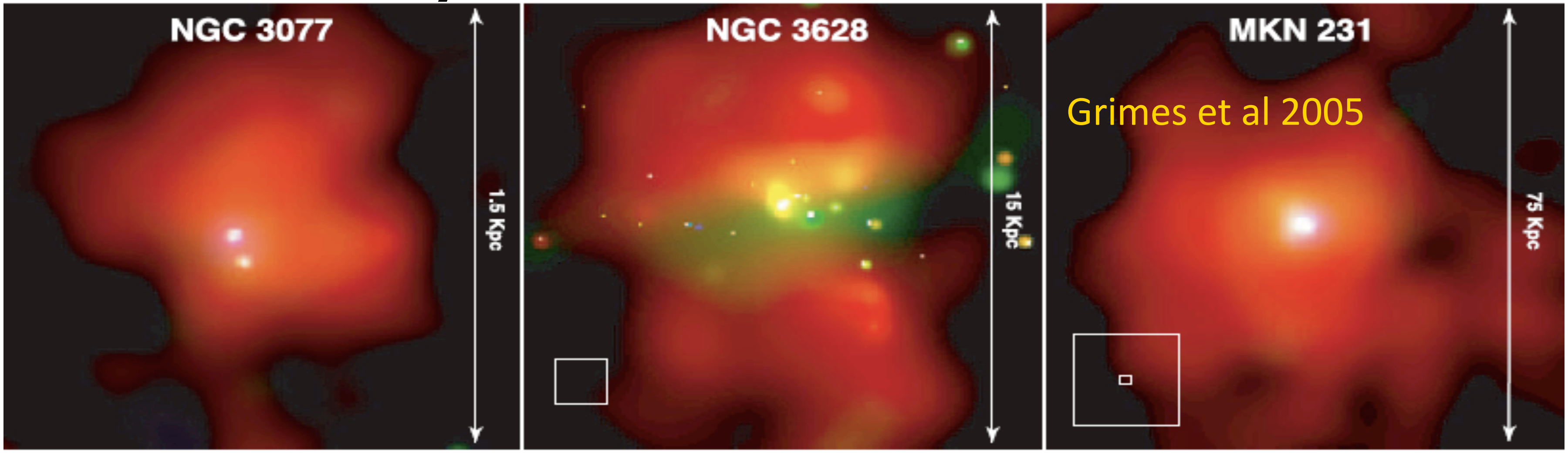
- **All future astronomical observatories feature "galaxy formation and evolution" as one of their prime goals**
- The x-ray to IR (or optical) luminosity ratio of galaxies is low (10^{-2}-10^{-3}) and thus is a strong test of the power of IXO.
- Recent data indicate L(x)/L(B) increases at high z- making it easier to observe galaxy formation with IXO



Lehmer+ 2007

if IXO can make a strong contribution to understanding galaxy formation then the 'x-ray loud' objects like AGN and clusters are 'easy' compared to the capabilities of other observatories.

X-rays and Star formation



Most of mass and energy is in the hot phase only observable with x-rays

Less affected by dust

Can differentiate (via spectroscopy) between AGN & star formation

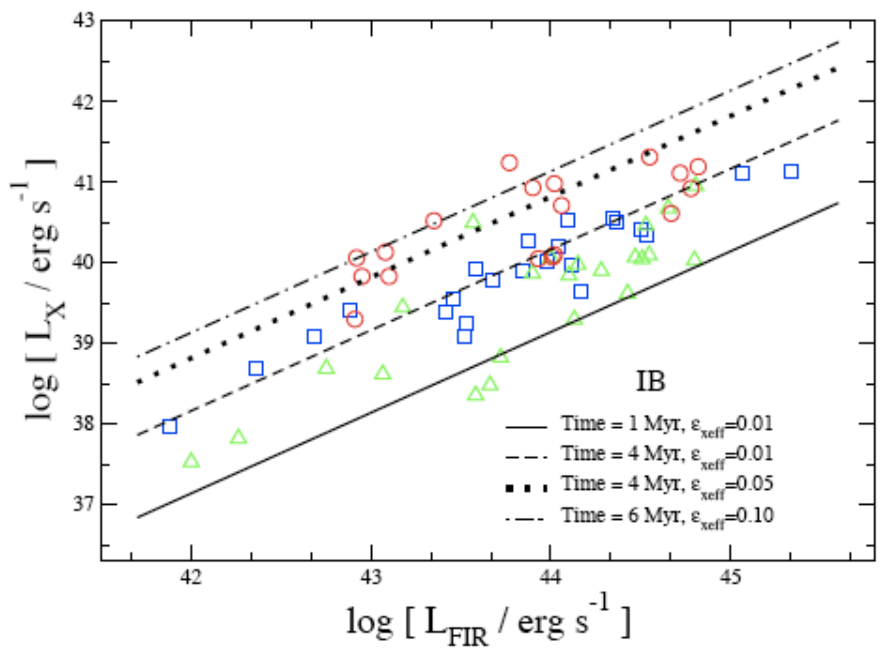
Radiative transfer effects small

L_x/L_{FIR}~10^{-3} (Mas-Hesse 2008)

100M/yr ~10^{42} ergs/sec.

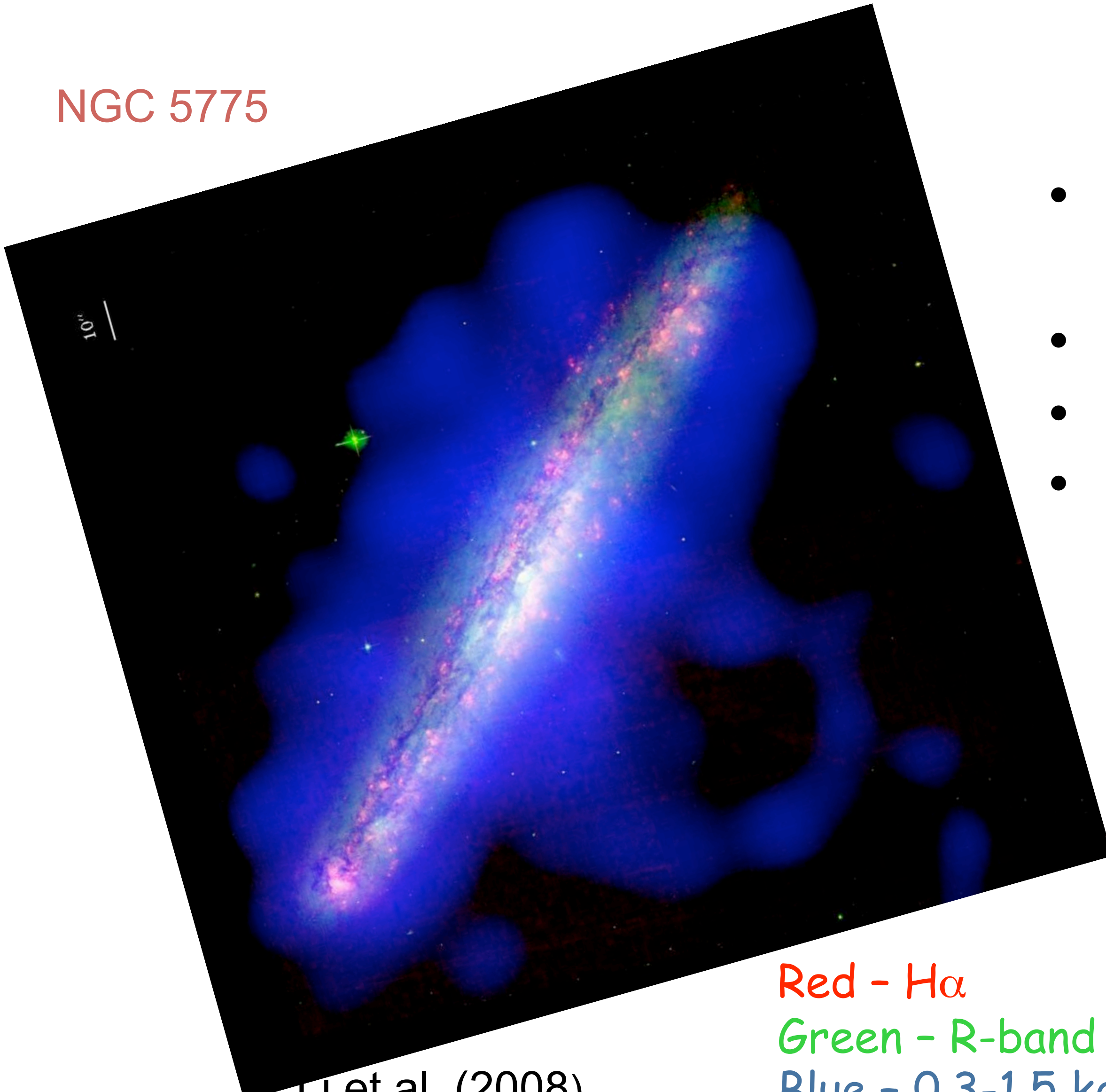
F(x) ~10^{-15} at z=0.5 - **within reach of IXO**

Lowest surface brightness ~0.1 IXO cts/sec/ arcmin²



Feedback from disk-wide star formation

NGC 5775



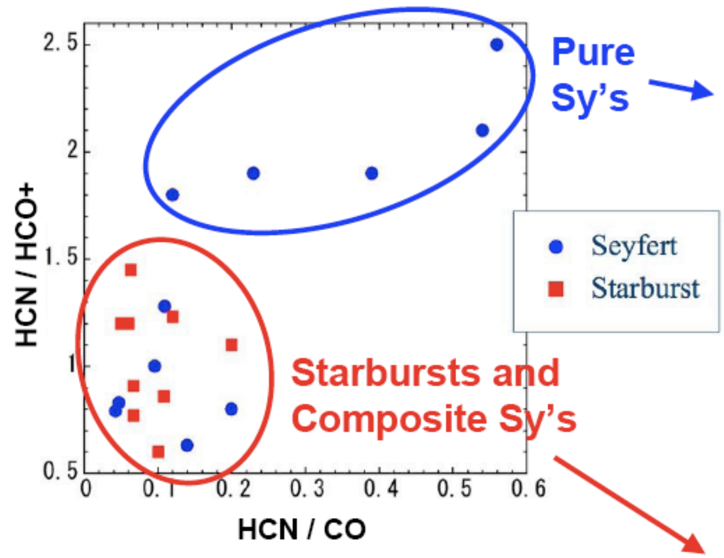
Li et al. (2008)

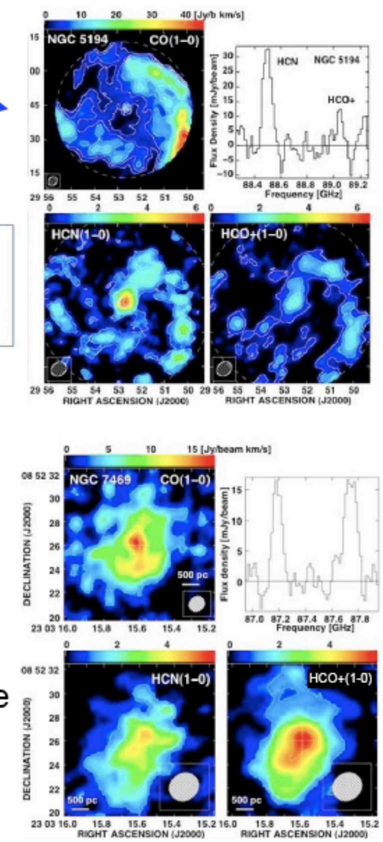
Red – Hα
Green – R-band
Blue – 0.3-1.5 keV

- Scale height ~ 2 kpc + more distant blobs.
- $T_1 \sim 10^{6.3}$ K, $T_2 > 10^{7.1}$ K
- L_x(diffuse) ~ 4×10^{39} erg/s
- Notice that **x-ray** is more extended than Hα

Complementarity of IXO and ALMA

- Spitzer observations show the apparent presence of a population of IR selected AGN (Fiore et al 2008) which are not detected by Chandra
- Are these really AGN ?
  - IXOs vast increase in sensitivity at E>7 keV
  - ALMAs ability to detect lines indicative of XDRs at high z
- XDR (x-ray dominated regions) are found in far-IR thru the presence of high HCN/HCO+
- Combination of ALMA and IXO will allow studies of high column density objects at high redshifts



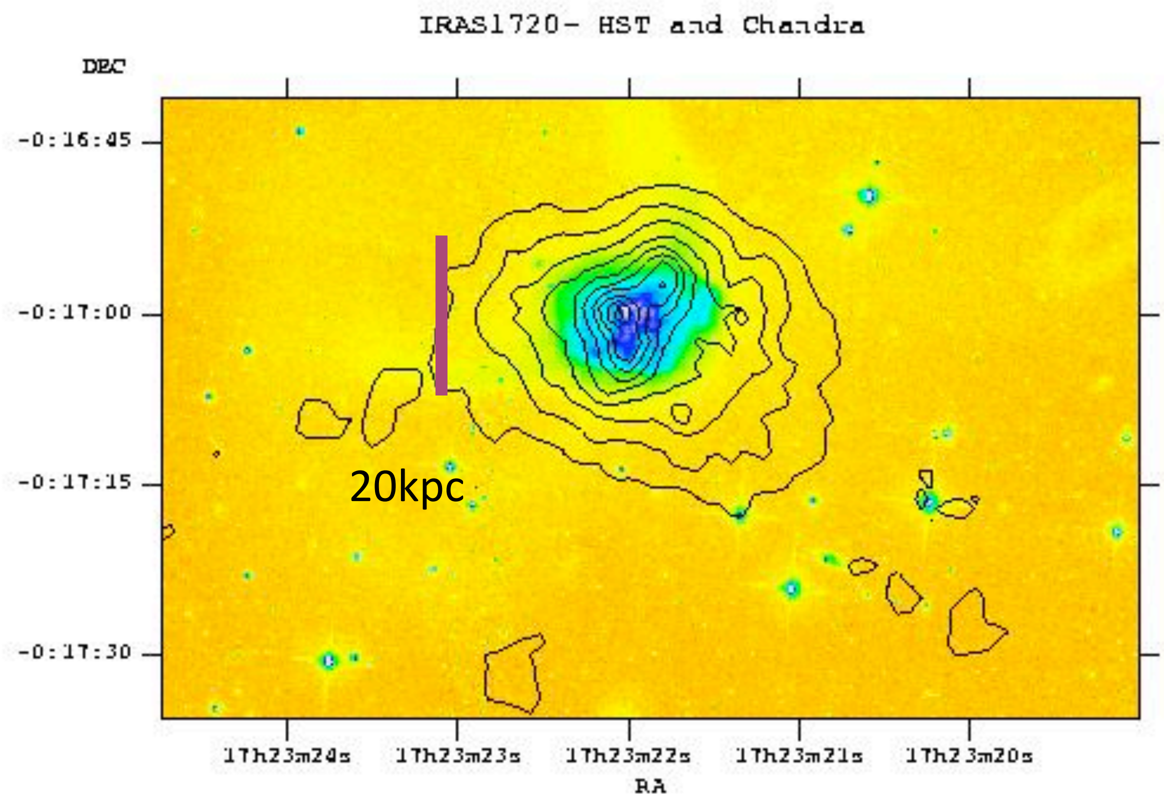


- Use of HCN as a tracer of dense molecular gas in questions when an AGN is present
- XDR-enhanced species can identify the presence of hidden/elusive AGNs (totally optically obscured, without NLR, Compton thick)

Maiolino 2007

Size of X-ray Halos

- Frequently the size of the x-ray halo is much bigger than the optical image
- Lots of metal enriched material
- Only other way to study these is via absorption lin spectroscopy of background light (very rare)
- Major component of results of star formation
- **With 5" IXO can study these objects to z~0.1-0.2**

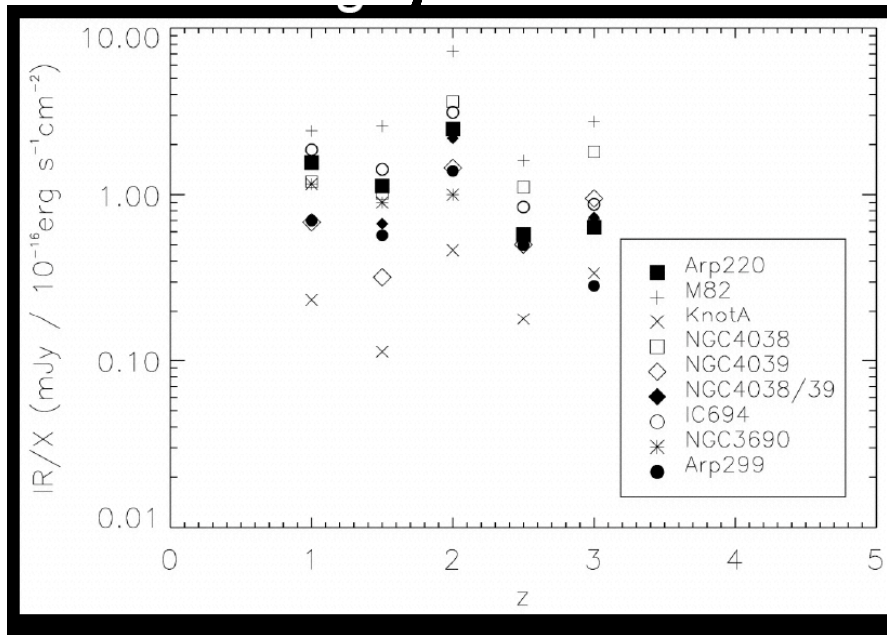


Chandra soft contours + HST Image IRAS 1720
Chandra Image +XMM Spectrum AGN (2×10^{41})+Hot Gas (Lx) ~8×10^{40}

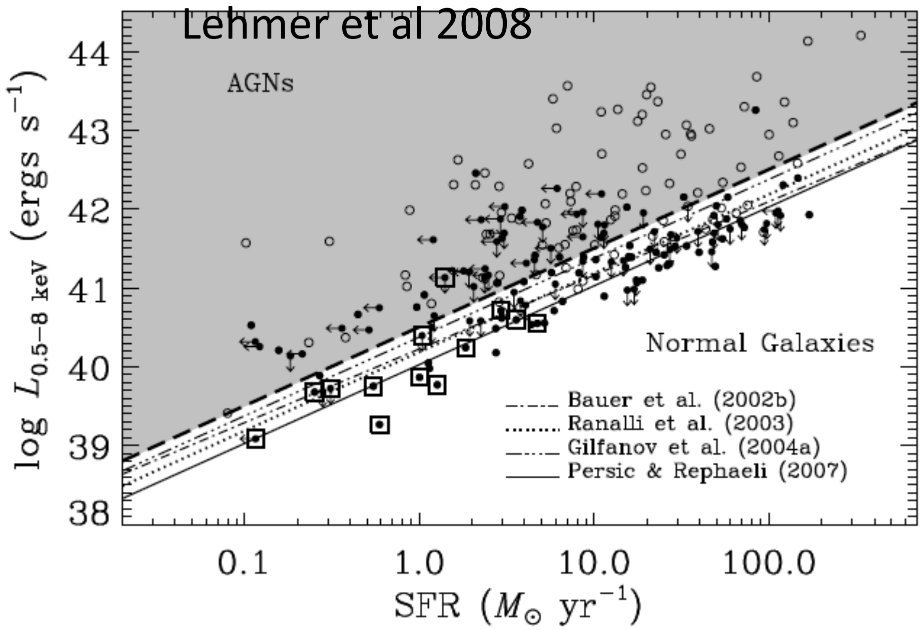
Spitzer analysis (Nardini et al) shows <7% of 6μ light is AGN !
X-rays crucial to interpreting star formation indicators

Star Formation vs UV and X-ray Luminosity

- Classical starforming objects:
  - flux ~mJy at z=1-3 *implies*…
  - x-ray fluxes of 0.1-10x10^{-16} cgs
  - this is 'easily' reached by the WFI
  - ~10x too dim for spectroscopy
- Need x-ray spectra!
  - can reach 100M/yr at z=0.5 (F(x)= 10x10^{-16}).
- At z<0.5 ~1/3 of all star formation occurs
- Highest SFR galaxies (500M/yr) have x-ray flux of 1x10^{-15} at z=0.5
  - Suzaku spectra of NGC461 shows a 2 T model (kT=0.14, 0.31) similar to MW and abundances ~solar in both disk and halo
  - Direct evidence of metals driven out into halo

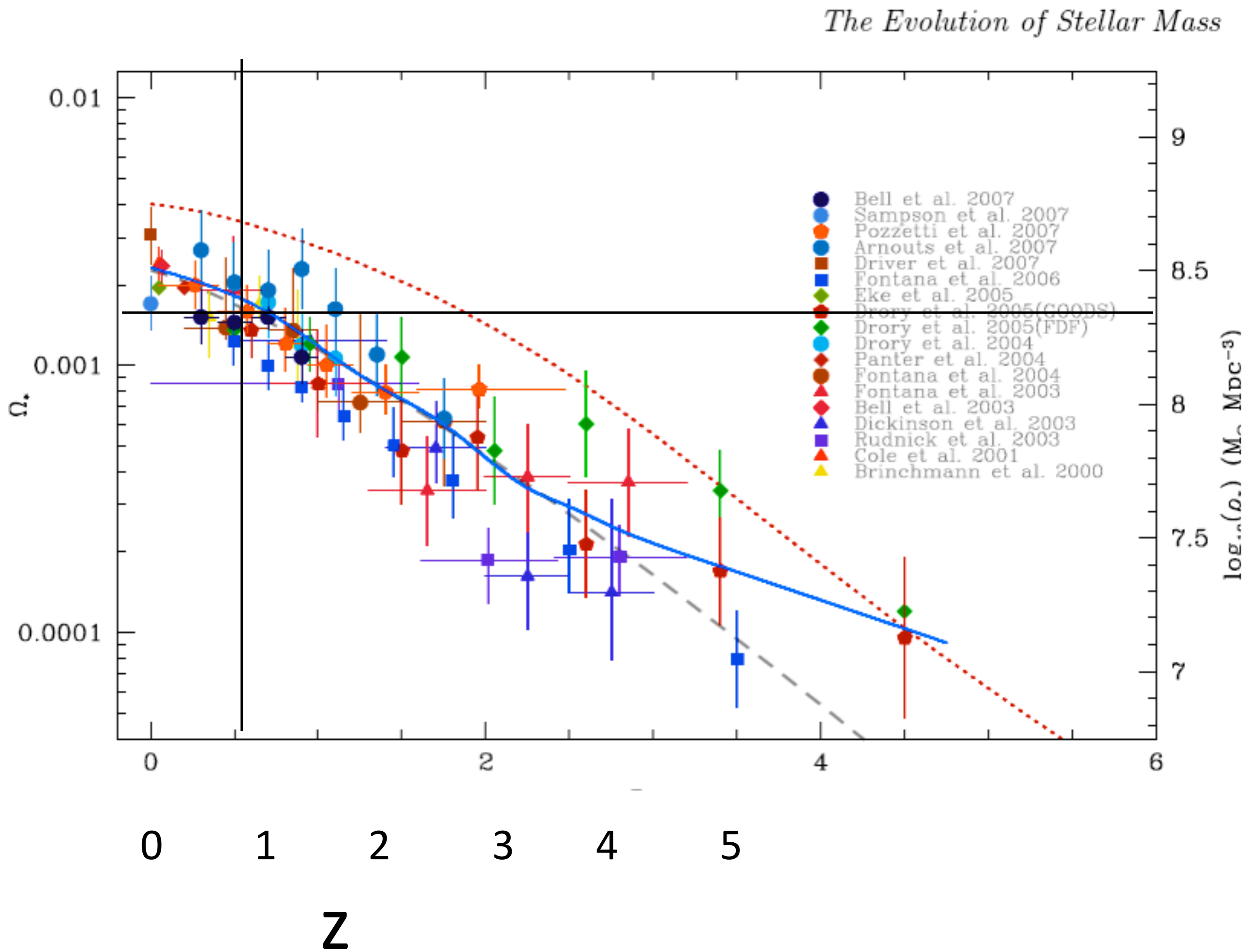


Lehmer et al 2008



Integrated Mass of Stars vs Redshift

- ~1/3 of all mass in stars formed since z~0.5
- IXO can probe these objects with detailed spectra and images
- At z~0.5 a 20 kpc halo from galactic winds has r~ 120”=20kpc and thus should be well resolved.



Wilkins et al 2008

Conclusion

- IXO and the other new observatories of the next decade have very similar science goals (with the exception of exoplanets)

- IXO is sufficiently sensitive to do the most difficult of these goals- understand star formation to z~1 for spectroscopy and z>>1 for imaging
- X-ray astronomy has unique attributes which we have to remind our colleagues of for things other than AGN and clusters.
- There is a very strong connection between the IR and the x-ray for AGN and star formation (ALMA JWST)
- Need ELT capabilities to measure optical spectra of IXO AGN

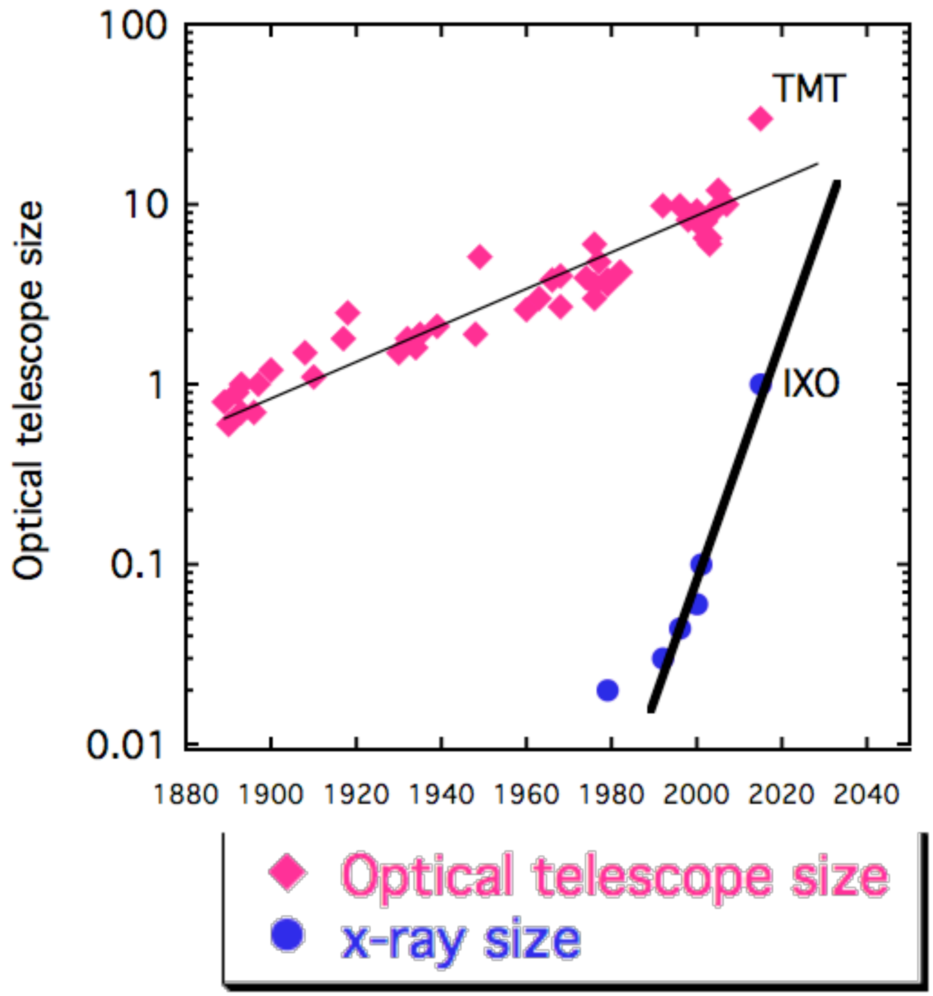
Backup Material

Telescope Size vs Time

- Optical telescopes have a ~50 yr e-folding timescale for growth. Telescope aperture has increased by 3 orders of magnitude and collecting area by **10^6 in 400 yr**.

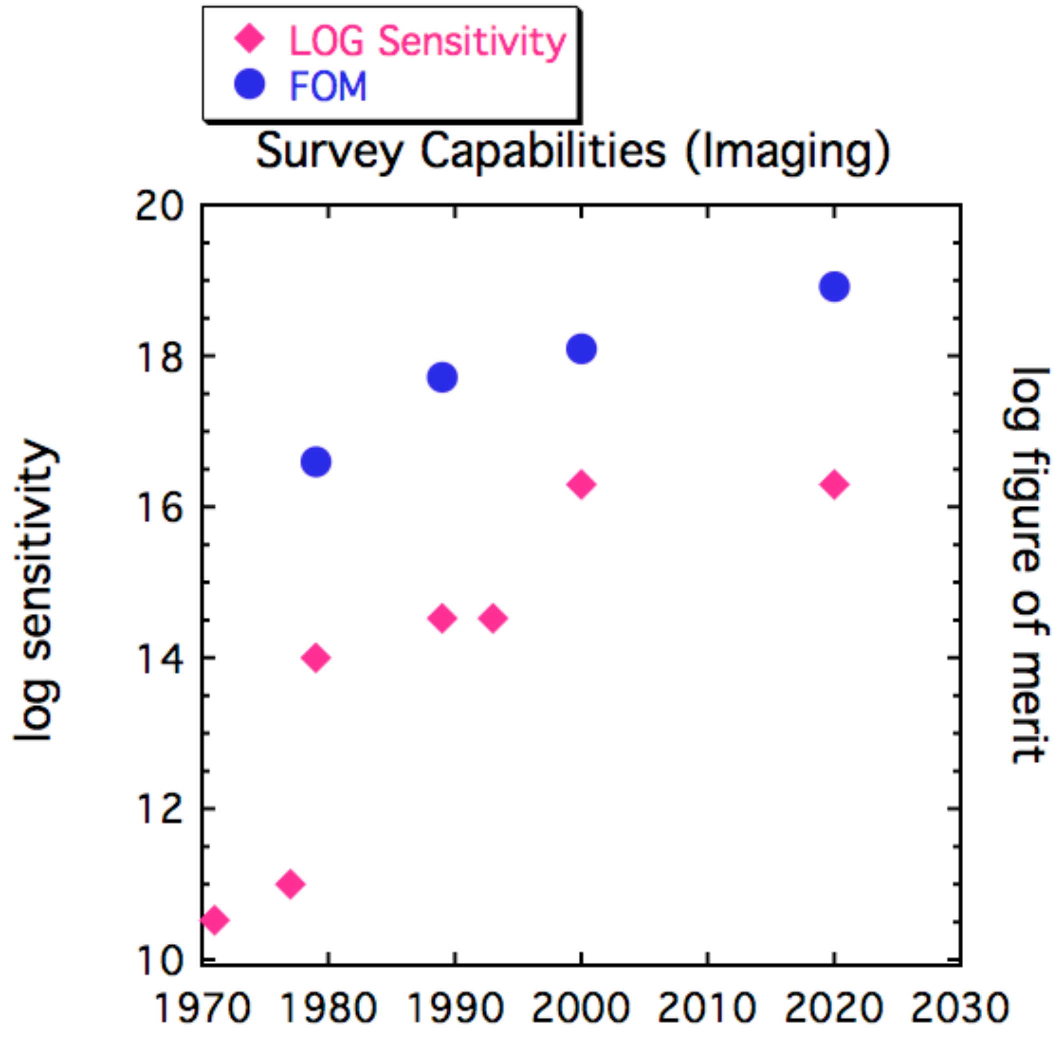
In high energy physics factor of 10^6 in 70 years in energy

- **IXO represents MUCH FASTER growth in x-ray optics size vs time:**
  - Since 1971 (Uhuru) increase of **10^6 in sensitivity, 200 in energy resolution, 2000 in spatial resolution.**



Sensitivity for Surveys

- Vast increase in survey figure of merit (Log sensitivty+log solid angle) for pointing observations- **factor of 10^9 in 45 yrs** (Sco-X1 to Chandra deep field)
- Optical, radio , IR, UV surveys have a similar large increase
- Optical pointed data have gone from 19th mag to 28 mag (only 4000 !) in 40 years (Palomar with film to HST with CCDs)

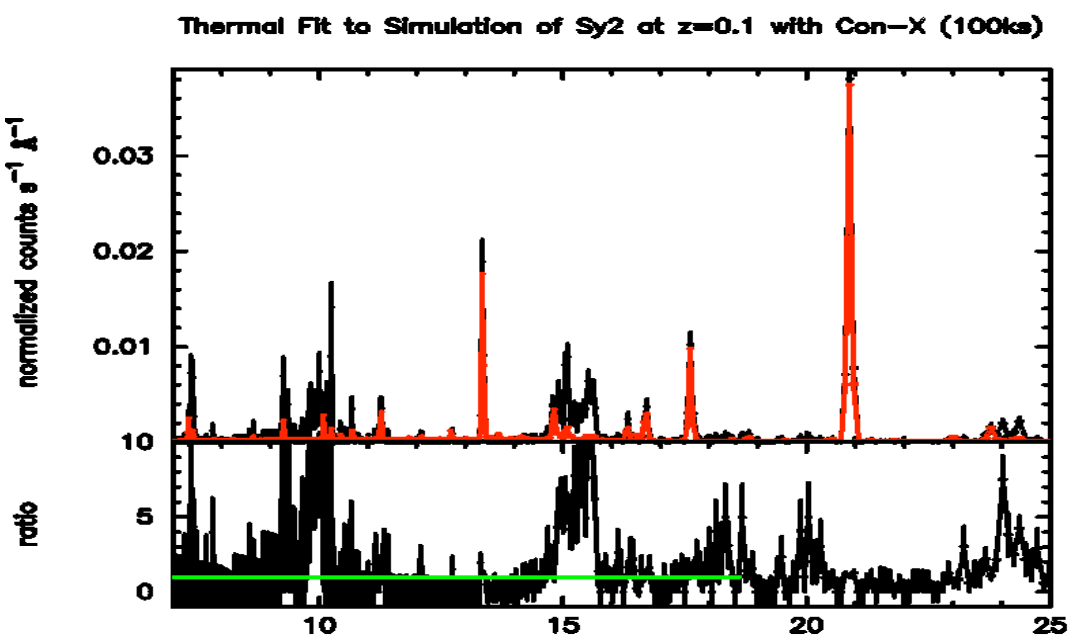


Implications for IXO

- Using NGC 4631- OVII and OVIII line fluxes ~10^{-6} ph/cm^2/sec/ arcmin^2

~0.03 cts/sec for IXO TES.

A star forming galaxy like NGC 3628 at z~0.1 will subtend ~ 0.2 sq arc min and thus need an IXO exposure of ~ 25ks for 100 ph in OVIII.



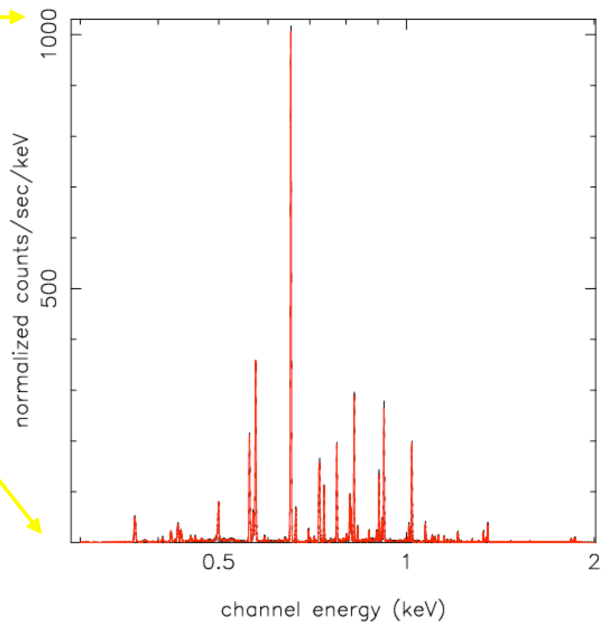
Such an exposure will allow breaking the degeneracy in IR data between AGN and starburst using x-ray spectral lines

E. Behar

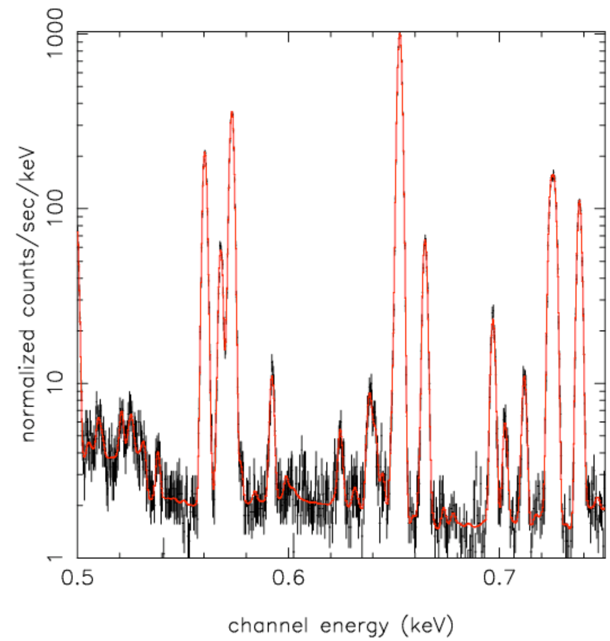
Supernova (Stellar) feedback

Wind plasma diagnostics (D. Strickland, JHU)

M82 Chandra central 5x5 kpc
0.3-1.1 keV,
1.1-2.8 keV
2.8-9.0 keV



Simulated 20 ks Con-X northern halo observation, 0.3-2.0 keV.



O VII and O VIII region. Well resolved triplet, high S/N in continuum.

With calorimeter ~2-eV resolution we can determine T, n_e t, [Z/H], v_{HOT} accurately in many extended winds (not just M82).

existing (and secured) high-energy facilities

- Space - ESA XMM-Newton, Integral
  - with NASA SWIFT, GLAST
  - national Agile
  - bilateral SRG, SVOM
- Ground - Cerenkov HESS, Magic
  - Cosmic Rays Auger South
  - Neutrinos Amanda, Anta
  - Gravity Waves Ligo, Virgo, Geo600

Why X-rays ?

- The Ionization balance, as in all other energy bands is a strong function of temperature and ionization parameter- but can observe most of the ions directly
- The atomic physics is extremely simple (compared to other λ bands) since the strongest lines are H and He-like.
- The x-ray band is sensitive to all stages of ionization from absorption by cold material (e.g. CI) to emission by hot material (e.g. Ni XXVII) and thus provides a wealth of diagnostics
- The scattering of x-rays by dust depends strongly on grain properties and thus allows a measure of dust composition and size distribution.
- 'Relatively' easy to distinguish method of ionization (e.g. collisional, shocks photoionization)
- Weak radiative transfer difficulties
- Unique 'penetrating' capabilities (e.g. most of the universe is obscured (AGN and star formation)
- Most of the baryons in the low z universe can only be observed in the x-ray band

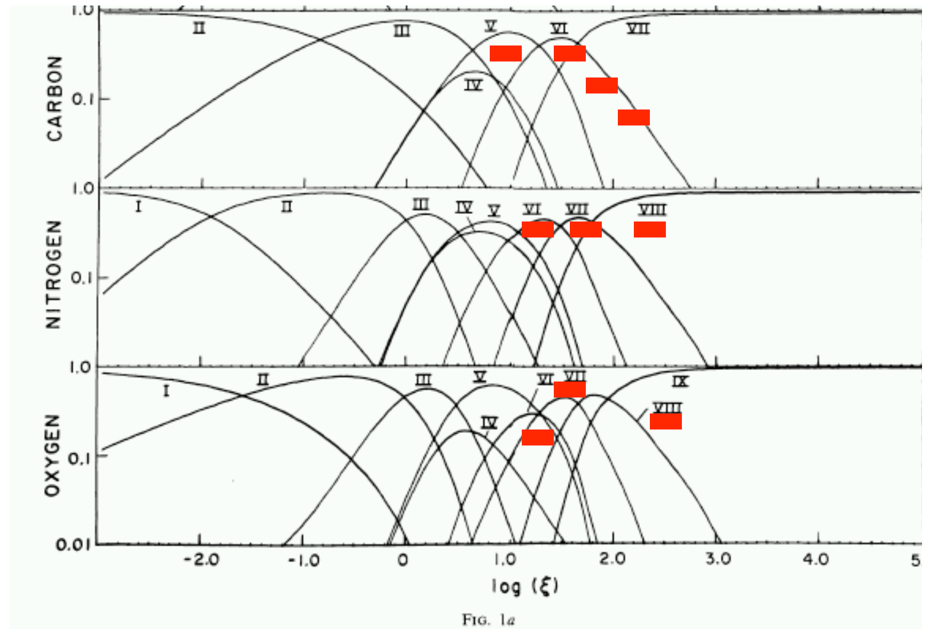


FIG. 1.—Ionization structure of model 1. Relative abundances of the ions of each element are shown as a function of log $-3 < \log \xi < 5$.

Log Ionization parameter

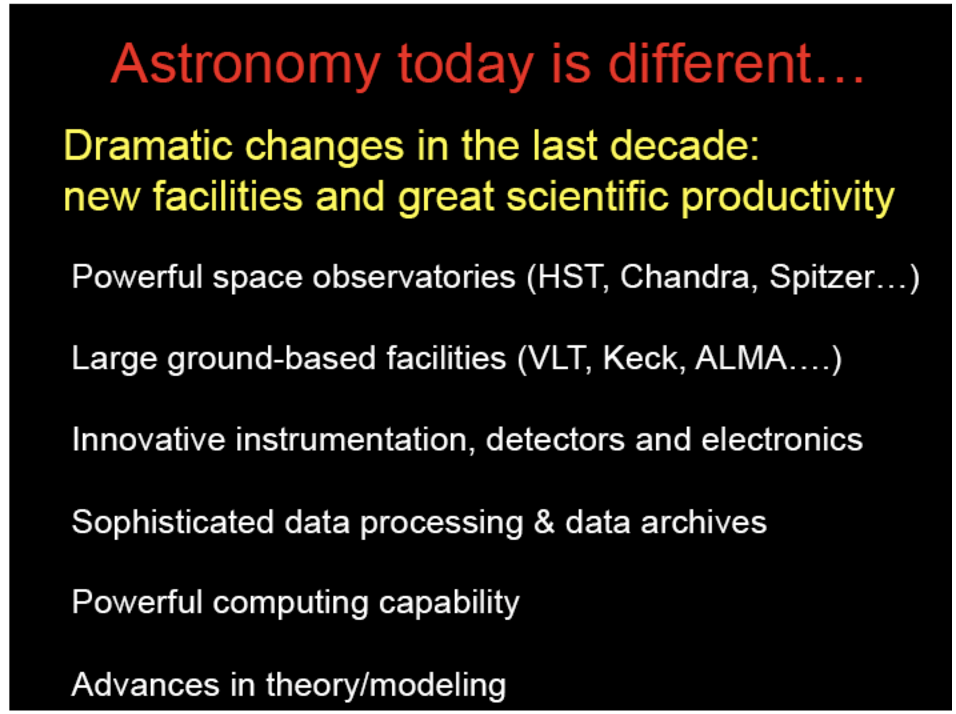
Ion populations for for C,N,O,Ne,Mg and Si in a photoionized plasma as a function of ionization parameter

Main question is do we have sufficient sensitivity, spectral and spatial resolution to be competitive in the next few decades.

Sometimes other folks mention X-rays

- One thing that has become clear over the last decades is that proper study of galaxy evolution requires a pan-chromatic approach, with the optical revealing the stars and warm gas, the IR and (sub)mm revealing the cool gas and dust, the cm revealing the star formation, and the X-rays revealing the hidden AGN.

  Fortunately, with the advent of ALMA, the EVLA, and the current and future Great Observatories, such a panchromatic view of galaxy formation, right back to the very first galaxies within reionization, is within reach.- **Chris Carilli-**

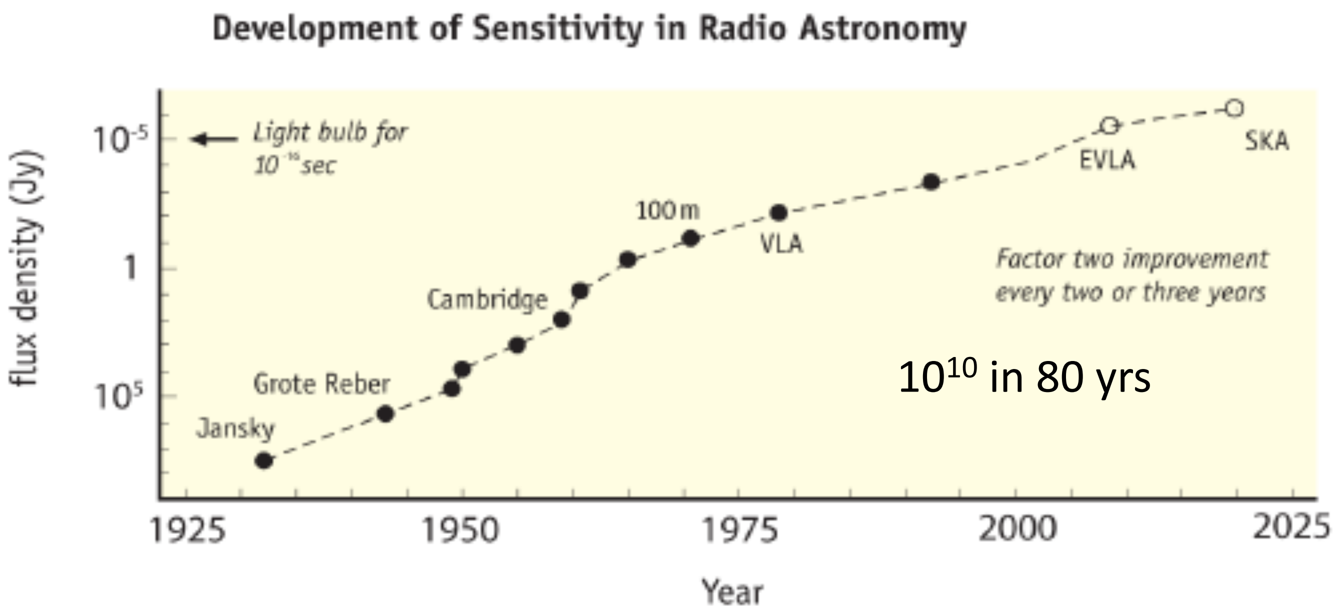


G. Illingworth

Notice that he does not mention the x-rays revealing star formation, the hot or warm gas or the total energy or mass of metals

What’s Happening Now

Herschel, Planck, Gaia, JWST, Sofia, BepiColombo, GTC, ALMA, VST, LBT, VISTA, LOFAR Auger …. .



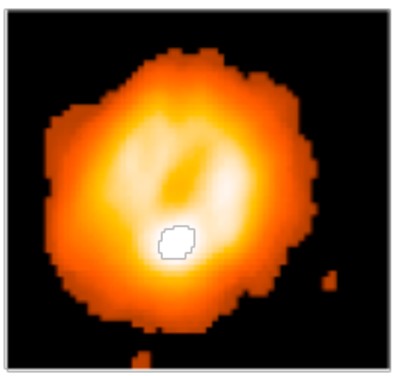
All data will be linked

- Large scale optical-IR surveys will be available via VO.
- Need 'balanced' set of observations over all wavelengths

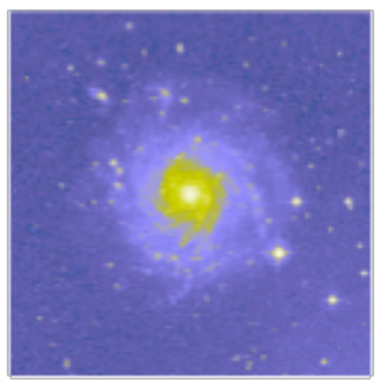
The Future: Virtual Observatory

- Globally distributed data servers with an abstracting middleware layer
- Draw disparate data sets together e.g. views across the electromagnetic spectrum
- rapidly expand the parameter space accessible to astronomical studies

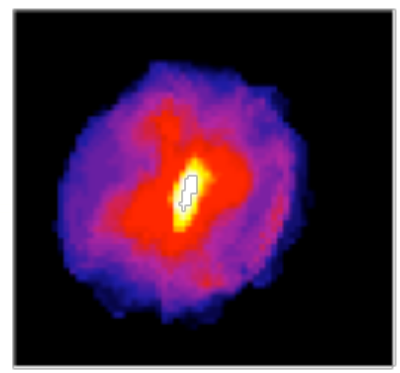
Hopefully the software tools to analyze the broad band data properly



X-ray



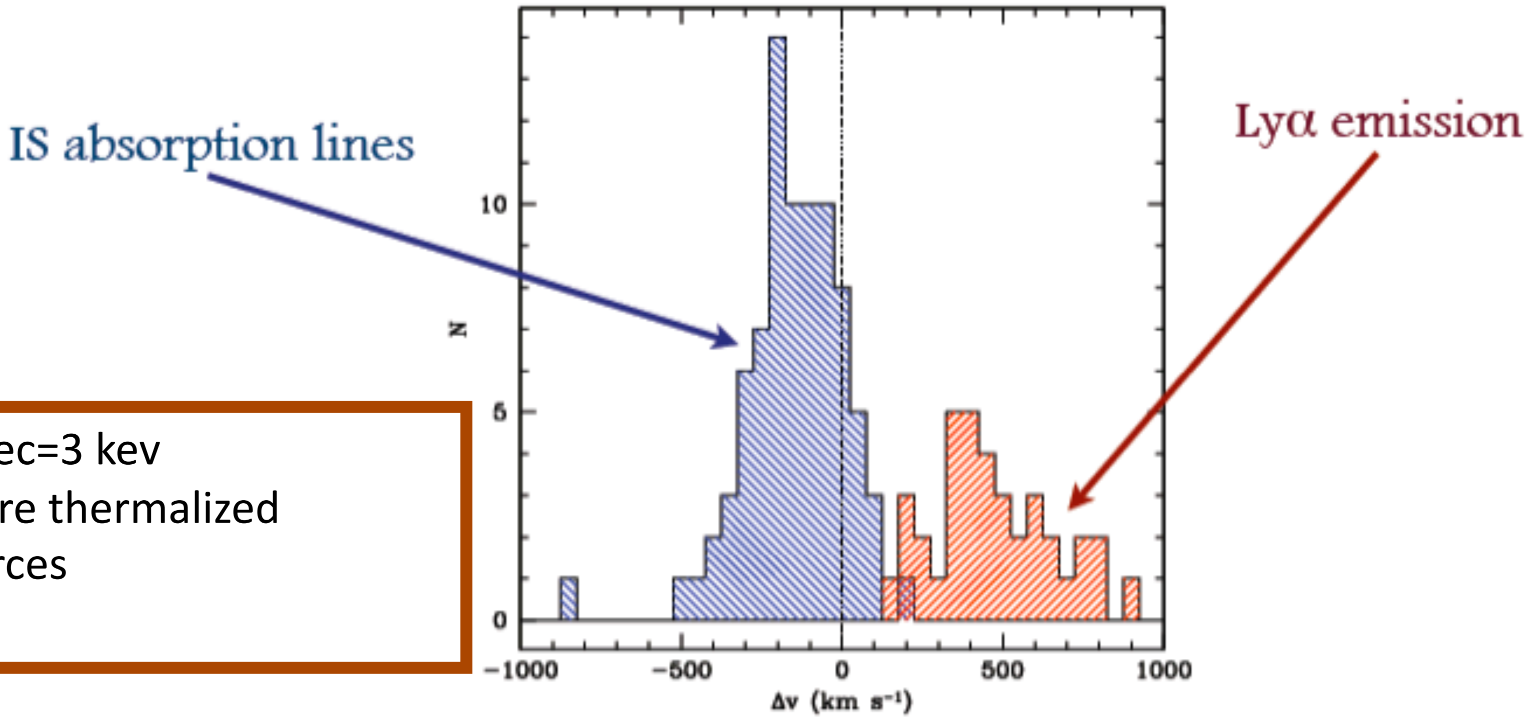
Optical



Radio

Galactic Outflows and Feedback

Almost all high z galaxies have outflows

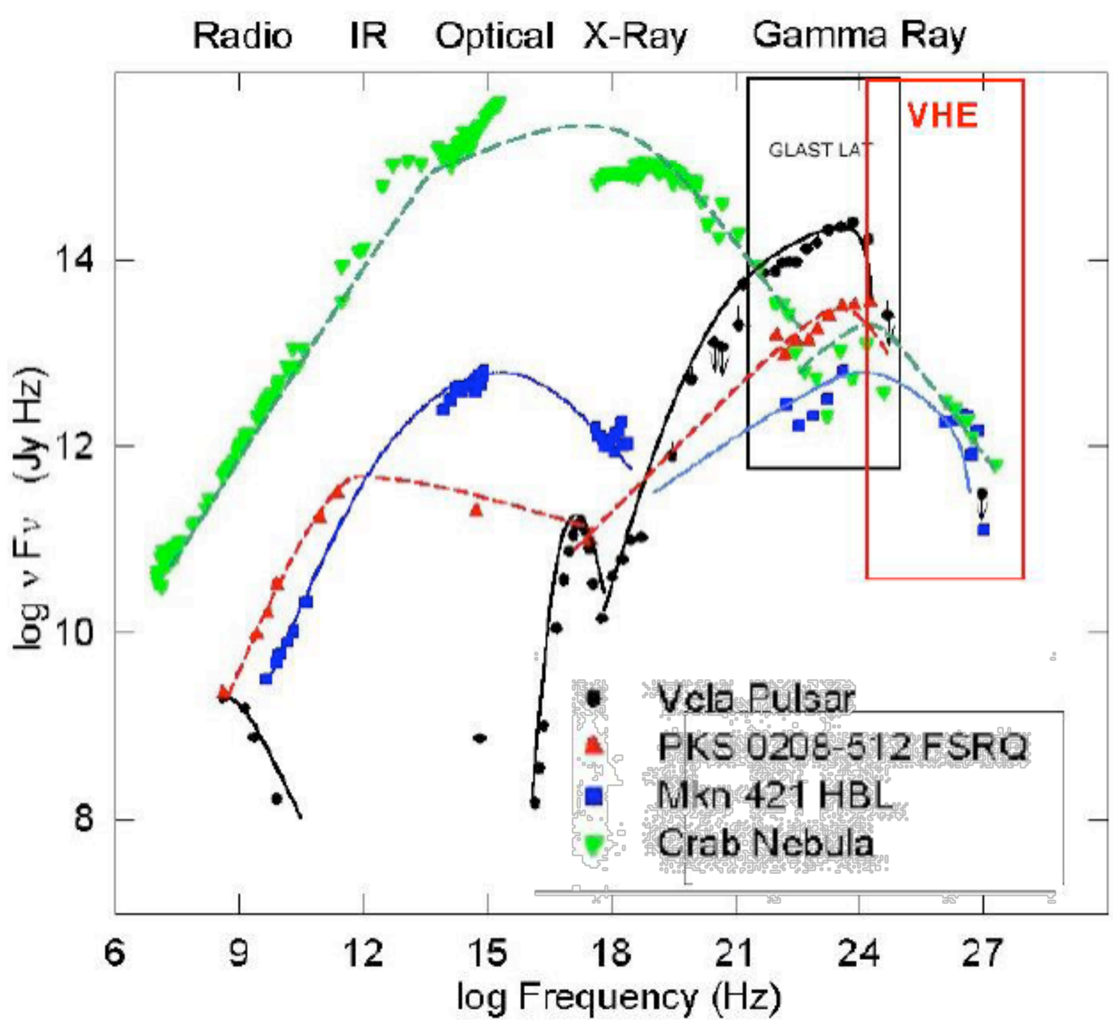


500km/sec=3 kev
If winds are thermalized
X-ray sources

- Offsets of several hundred km s^{-1} observed between nebular emission lines, interstellar absorption lines, and Lyα
- Explained by galactic-scale outflows
  - Regulate star formation through feedback
  - Deposit metals in IGM
  - Mass-metallicity relation
  - Allow escape of Lyman continuum photons?

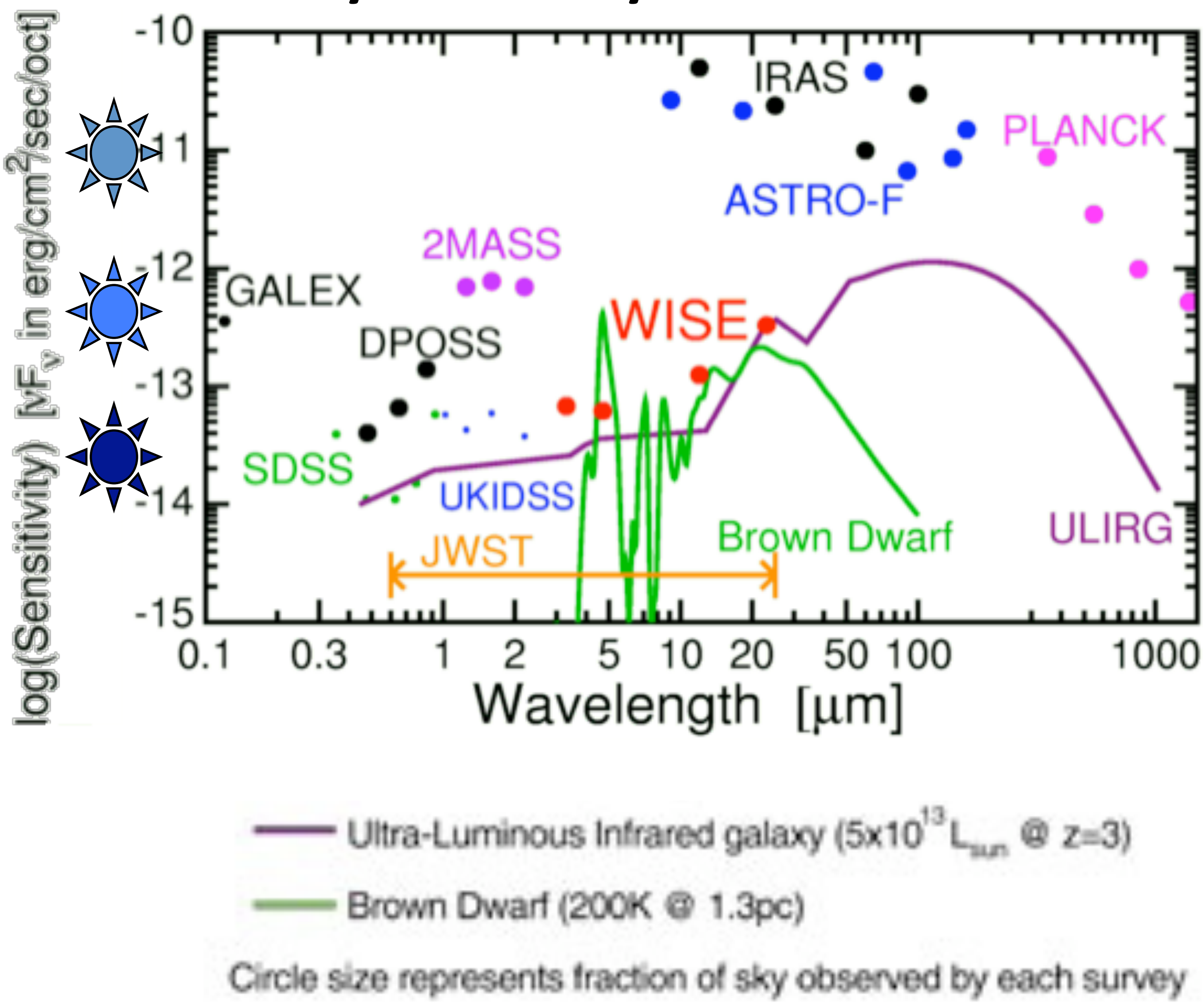
Why Have All these Observatories?

- Different classes of objects have vastly different behavior as a function of frequency
- Different phenomena revealed
- Two pulsars (Crab and Vela) differ in luminosity by $10^{3.5}$ at x-rays, similar γ-ray luminosity
- How does one decide the 'best' way of studying a problem ??
  - Look for unique signatures
  - Follow the photons
  - *Interpretable signatures*
    - ***Very often frequency where the flux is the largest has very difficult to interpret data***



All Sky surveys

- Increase in sensitivity of large solid angle surveys in UV-far IR X-ray (Heao-1, Rosat, eRosita)
- Sensitivity of all sky x-ray surveys are well matched to those in other wavelength bands
- e.g. star forming galaxies $L_X/L_{FIR} \sim 10^{-4} - 10^{-3}$ eRosita is matched to Akari-
- need IXO to match to WISE for ULIRGDS



Buried AGN vs starburst- Imanishi

1. Hard X-ray ➡ Compton-thick buried AGNs undetectable at E < 10 keV

2. IR spectral shape

   IR   Subaru + Spitzer

3. Geometry (energy sources and dust)

   IR   Subaru + Spitzer

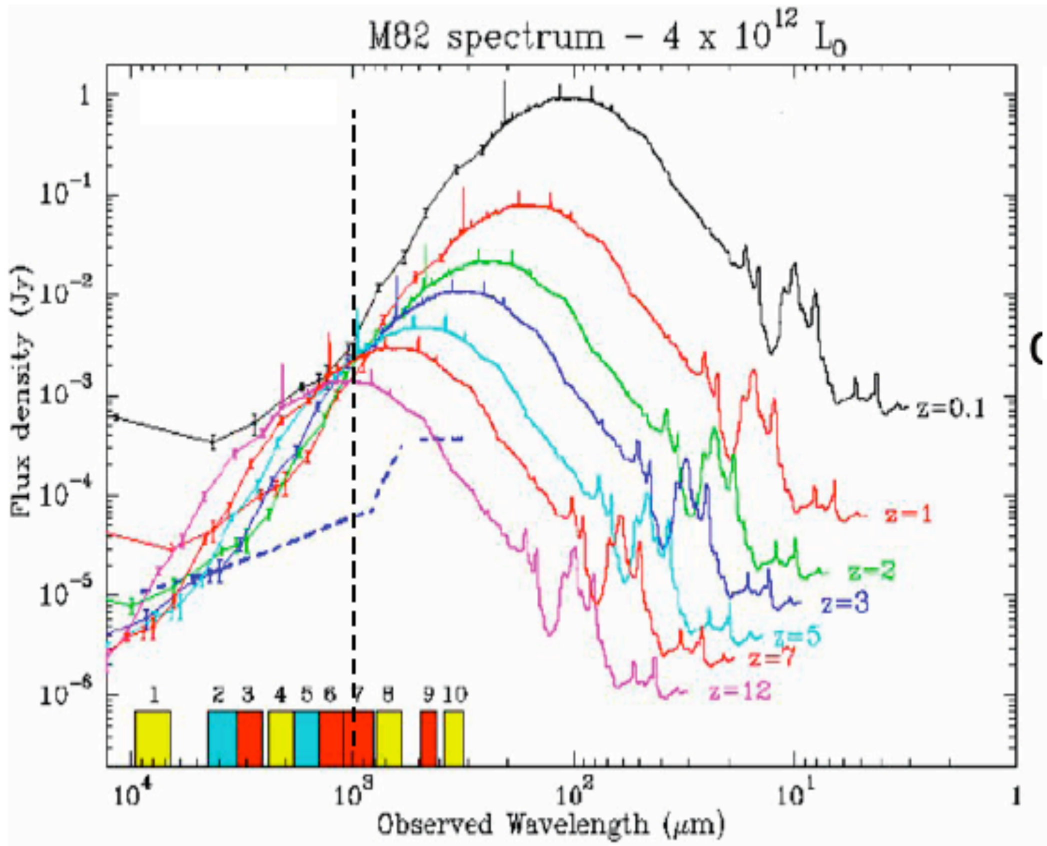
4. XDR around a buried AGN

   (sub)mm   NMA+ALMA   +IXO

Mid-Far IR and IXO

- Present day Spitzer observations show the apparent presence of a population of IR selected AGN (Fiore et al 2008) which are not detected by Chandra
- Are these really AGN ?
  - IXOs vast increase in sensitivity at E>7 keV
  - ALMAs ability to detect lines indicative of XDRs at high z

Strong negative K-correction at mm-submm wavelengths



At λ ~ 1 mm detecting a source at z=10 is as easy as at z=1

The steep submm SED counteracts the $1/D^2$ cosmological dimming

Maiolino 2007

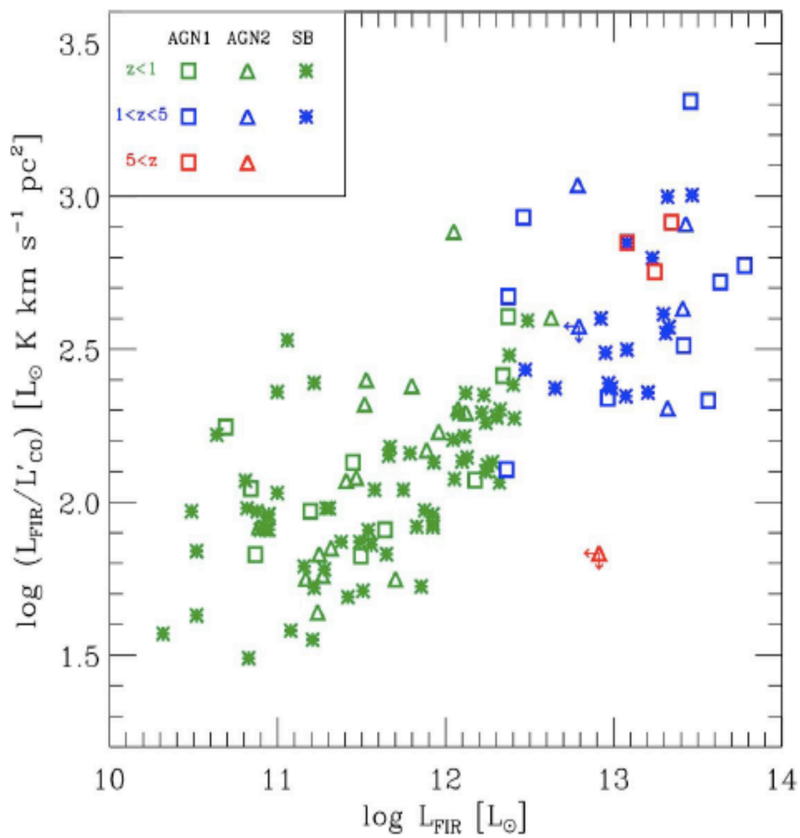
Mid-Far IR and IXO

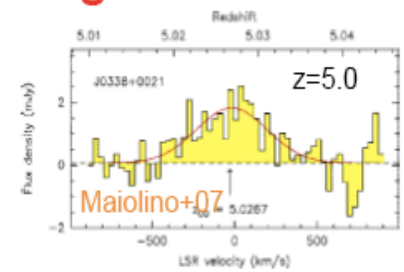
- Star formation – AGN connection
  - ALMAs can measure the ‘true’ SFR
  - IXO can measure the ‘true’ hard x-ray luminosity and find the AGN.

Molecular gas in high-z QSO radio galaxies

CO detected in ~23 QSOs and radio galaxies at z>1
(+some HCN,HCO+ detections)

Solomon & Vanden Bout ‘05, Omont ‘07





Same L_{FIR}/L_{CO} ratio as in powerful starbursts

QSO hosts characterized by intense, short-lived ($\sim10^7$ yrs) starbursts

↓

Tracing early, co-eval formation of BH and galaxies?

Maiolino 2007

ELT and the Astronet Science Vision

A. *Do we understand the extremes of the Universe?*
- Measure the evolution of the dark-energy density
- Test for a consistent picture of dark matter and dark energy
- Understand the astrophysics of compact objects and their progenitors

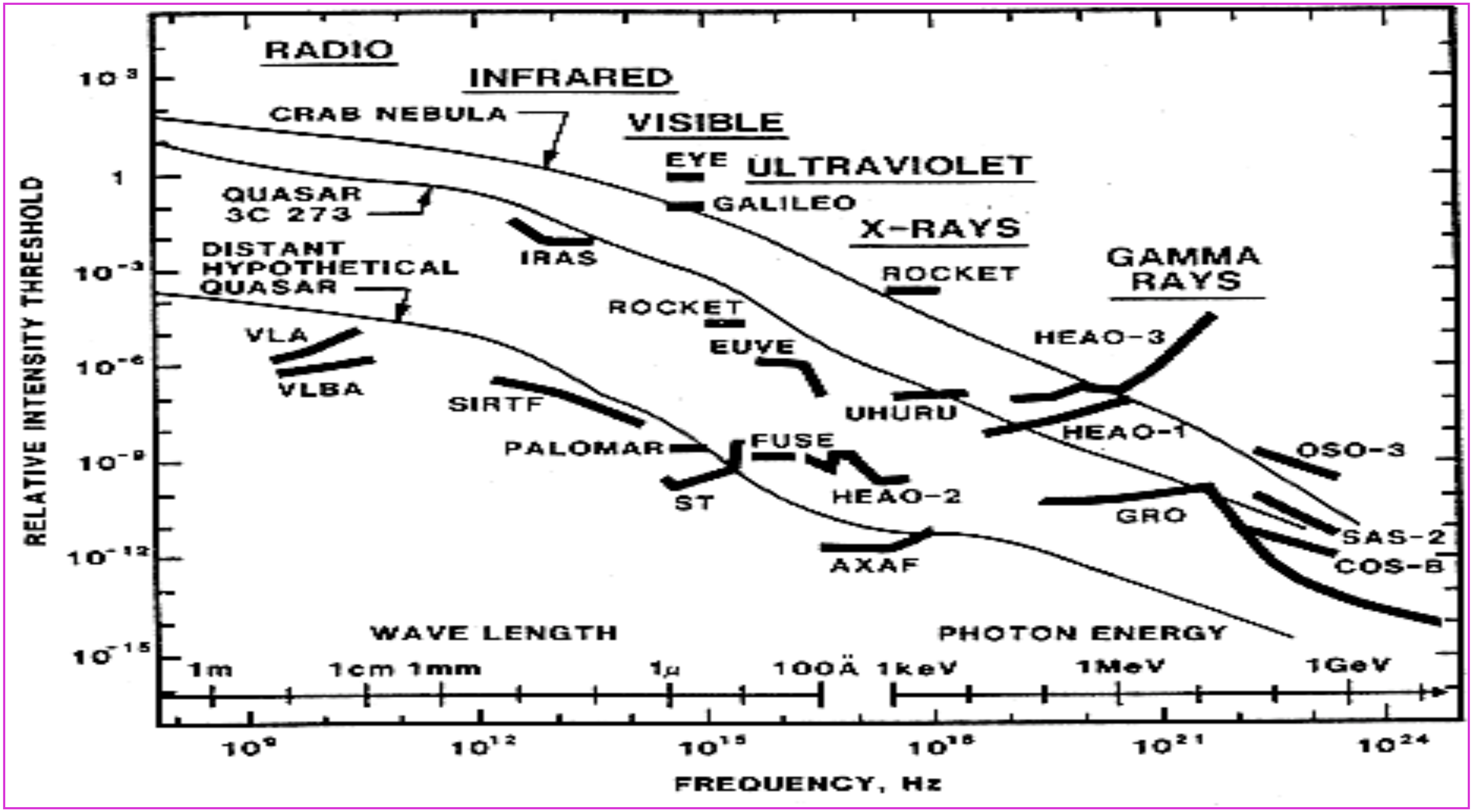
B. *How do galaxies form and evolve?*
- Map the growth of matter density fluctuations in the early Universe
- Detect the first stars, black holes, and galaxies
- Determine the evolution of the galaxy cluster mass function
- Make an inventory of the metal content of the Universe over cosmic time
- Measure the build up of gas, dust, stars, metals, magnetic fields, masses of galaxies

C. *What is the origin and evolution of stars and planets?*
- Determine the initial physical conditions of star formation
- Unveil the mysteries of stellar structure and evolution, also probing stellar interiors
- Understand the life cycle of matter from the interstellar medium
- Determine the process of planet formation
- Explore the diversity of exo-planets in a wide mass range from giants to Earth-like
- Determine the frequency of Earth-like planets in habitable zones and push towards direct imaging

D. *How do we fit in?*
- Constrain the models of internal structure of planets and satellites
- Studies of Titan, Mars, Europa and other outer satellites.

X-ray Astronomy in the "next" Decade

- *Where does X-ray astronomy lie with respect to other λ bands ?*
- It needs to match well to present generation of radio, optical, IR telescopes for imaging (AGN and clusters) -over a wide range in redshifts/luminosities-



Funding Situation

- “The national funding agencies have proven to be very supportive of astronomy and Solar System exploration over many years, *but funding of substantial facilities which are continuing to grow in complexity, and whose capital costs are growing commensurately, clearly becomes more problematic*.” AstroNet report

So how do we maximize scientific return-

two possibilities each mission (telescope/ observatory) is “Best” in a given area (e.g. γRBs)

Synergy of many observatories

J. Hayes Oct 2007

What We Know About the Halo today

- NGC 4631 (Yamasaki et al 2008), M82 (Tsuru) - gas is enriched into the halo abundance pattern is different than clusters In NGC 4631

  mass of the X-ray emitting gas is 1.3×10^8M

  stored thermal energy is 2×10^{56} erg, the O mass in the hot gas in both the disk and the halo is ~10^6M

  the cooling time in the disk is about~ 6 $\times 10^8$ yrs the required energy input rate is 3×10^{47} erg a mass transfer rate of ~0.2-2M/yr

IR data imply a SFR of ~3M/yr

Similar to results of Strickland and Heckman the SFR and mass outflow rates are similar

these data require that 3% of the typical explosion energy of 10^{51}erg and 20M. from the ejecta and ambient material have to escape into the halo.

Indicating that the halo gas is produced very efficiently

O-Mg ~solar, Fe ~.4 solar-
Ratio of SN II/SNI ~3:1
In M82 kT~0.2, 0.6 kev, NGC4631 cooler kT~0.1,0.3 kev

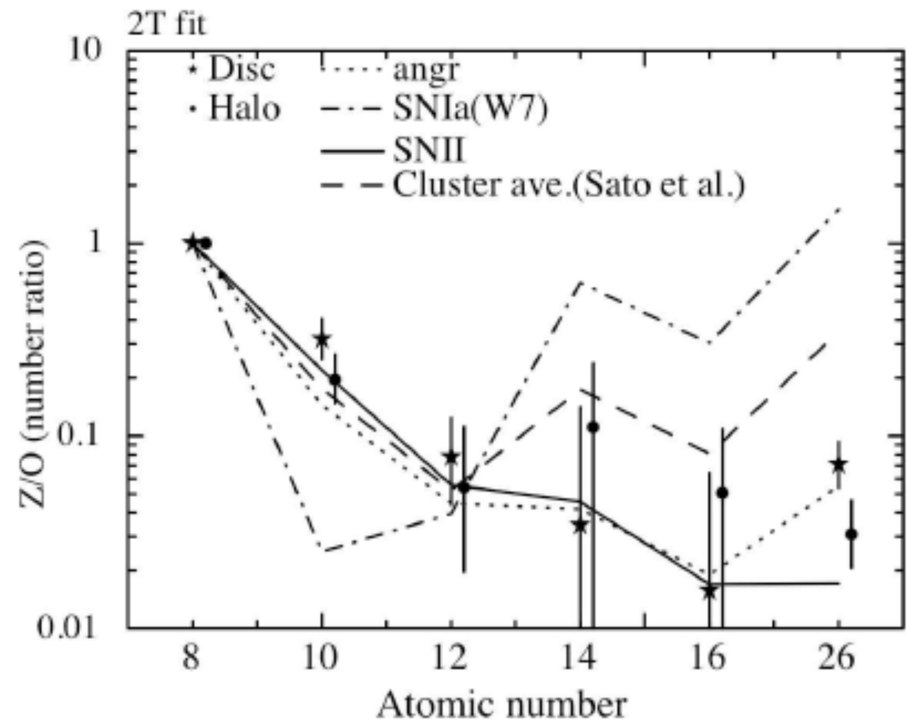


Fig. 4. Number ratios of Ne, Mg, Si, S, and Fe to O for disk