The realm of X-ray astronomy

Astrophysical Black Holes

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Congresso Nazionale SIF 2020

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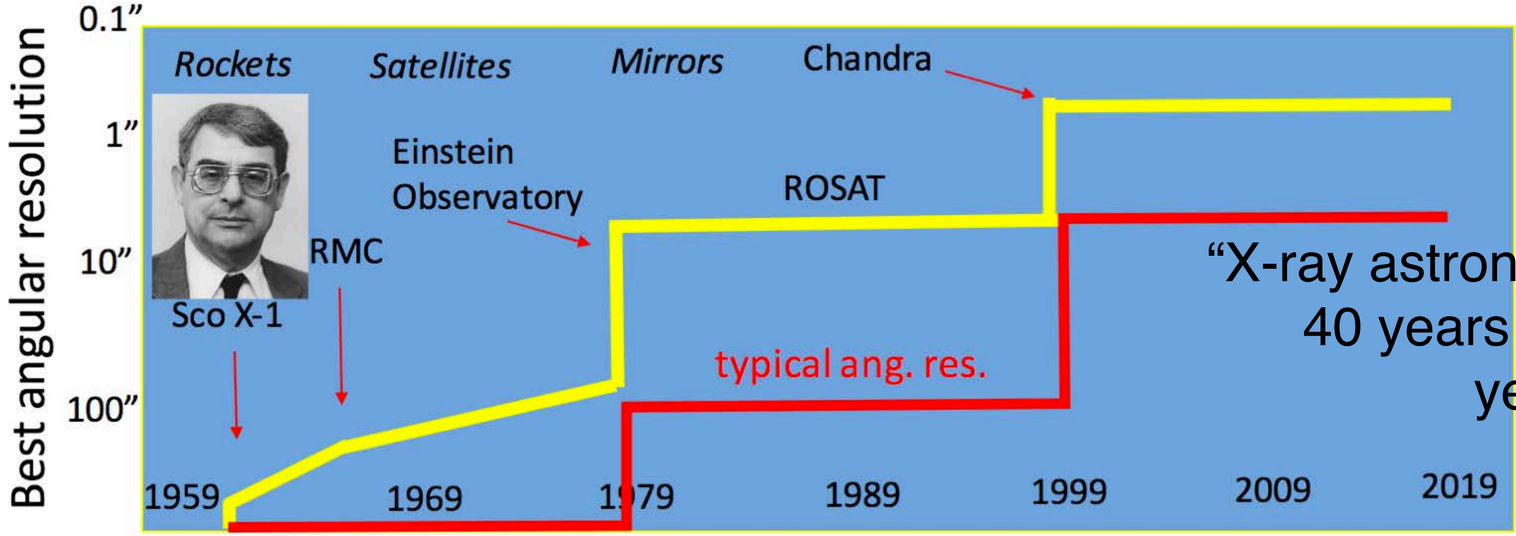
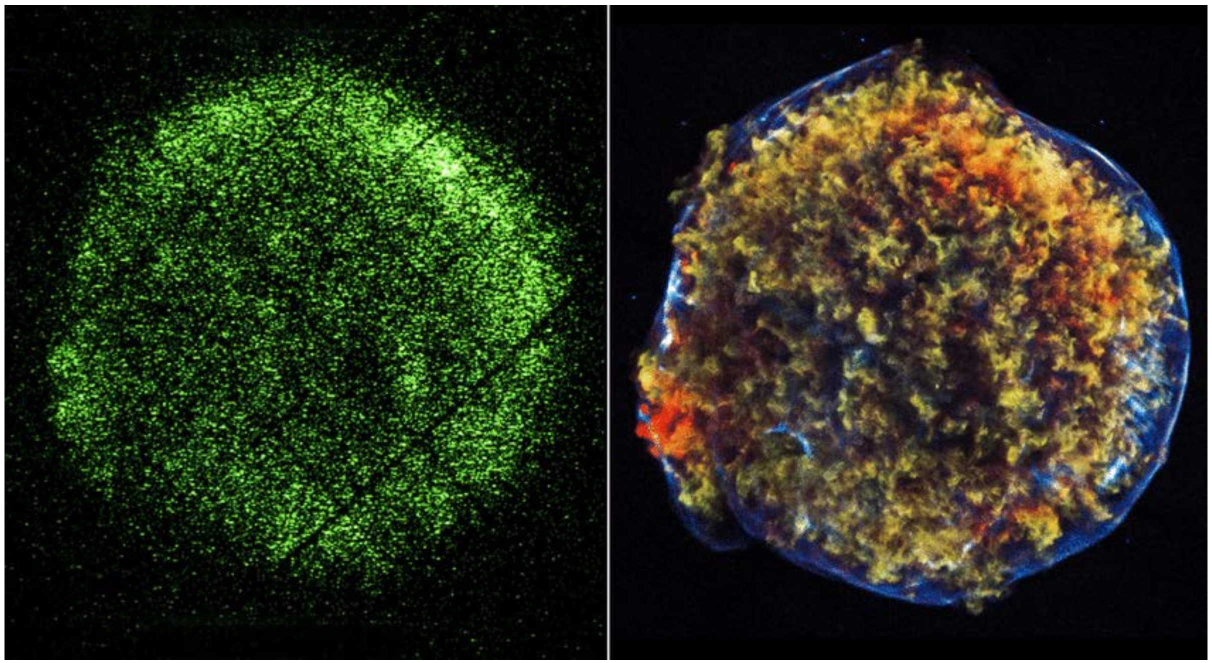
40 years of X-rays.. spatial resolution



HST

“X-ray astronomy took just 40 years to match 400 years of optical astronomy”

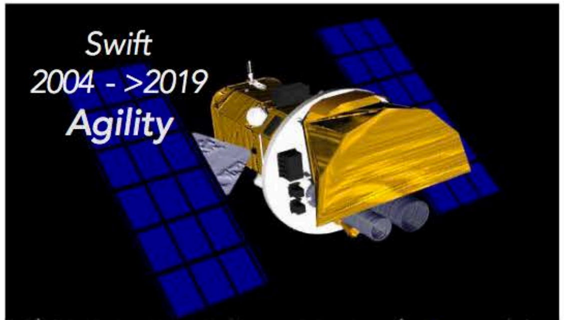
credits: M. Elvis

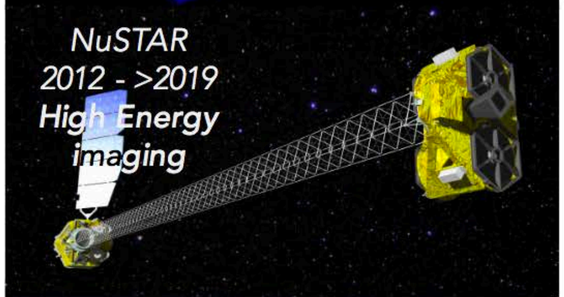


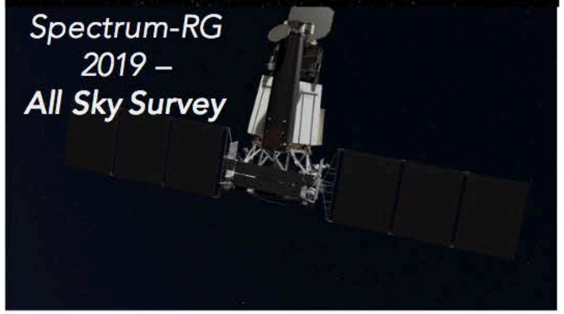
Tycho's SN remnant
Einstein Observatory (5”) vs Chandra (0.5”)

NASA/CfA; NASA/CXC/SAO

the present: the golden age of X-ray astronomy?



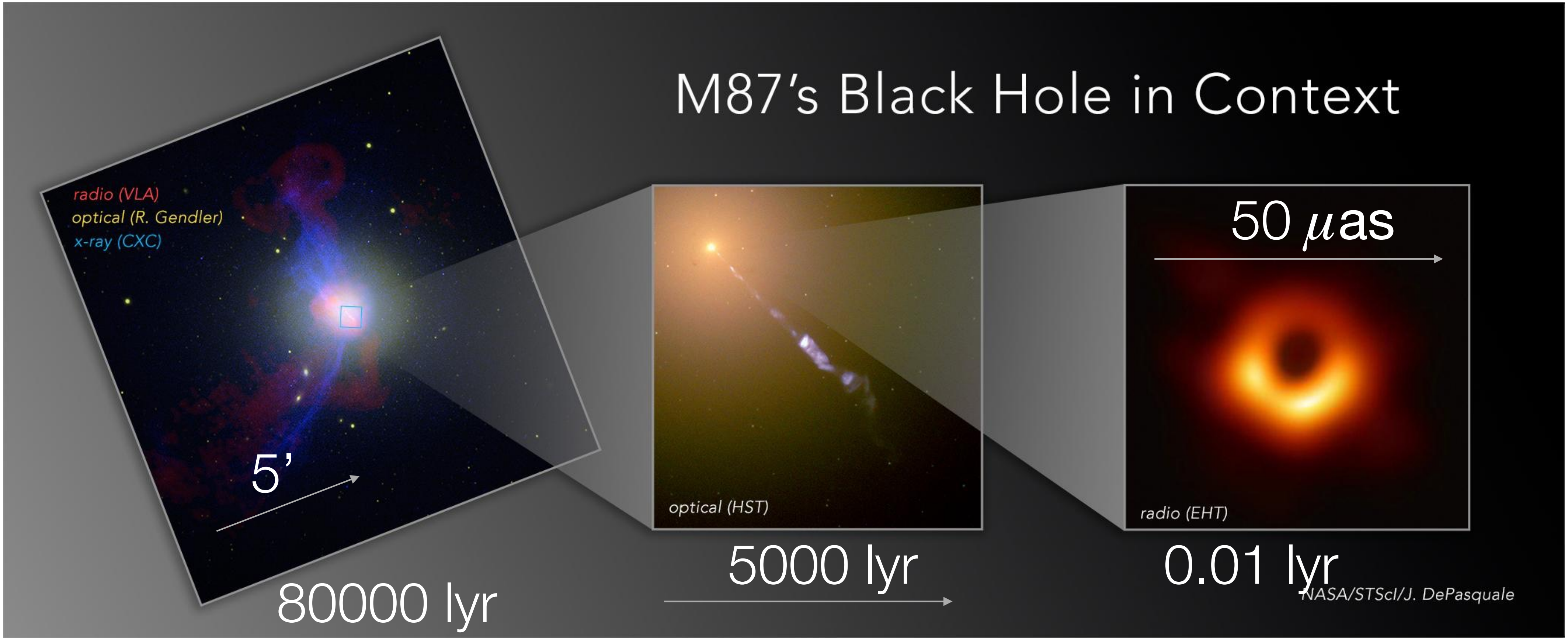




Effective area
Energy resolution
Angular resolution
Timing
Energy range
Fast repointing

Lots of answers.. but lots of new questions!

astrophysical black holes

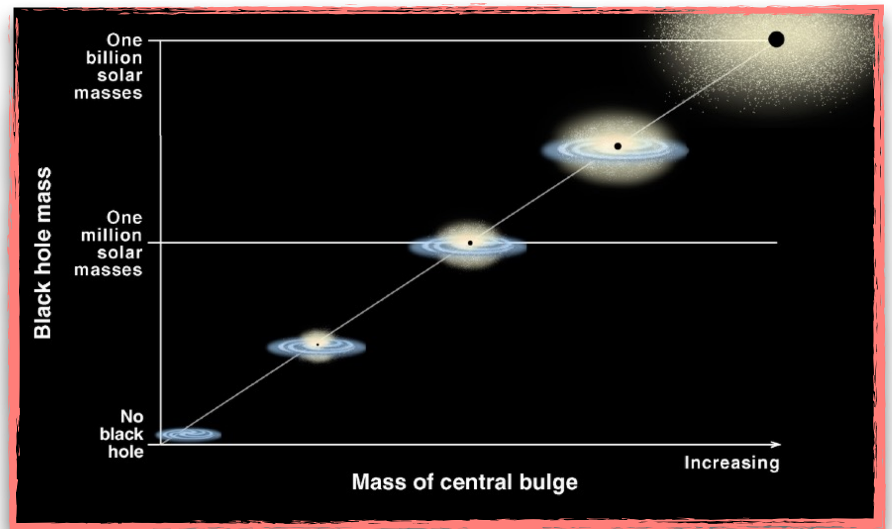


astrophysical black holes: Why do we care?

BH formation and evolution

accretion under strong field gravity regime

BH and galaxy coevolution



open (BIG) questions

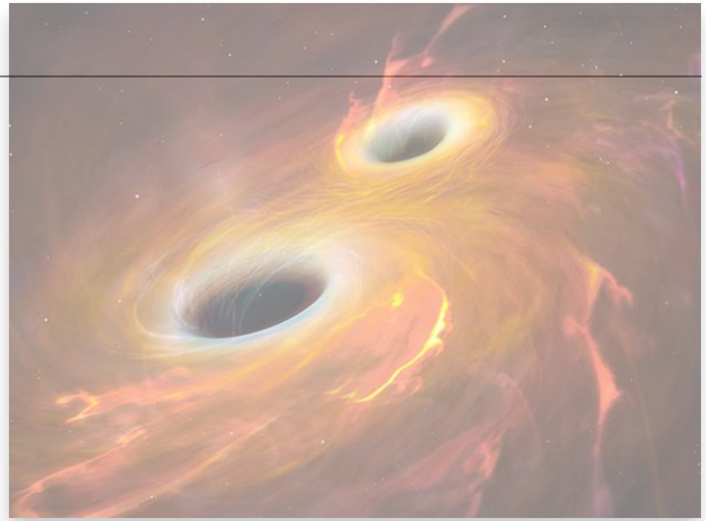
- Inner accretion flow physics and geometry. How the matter behaves under SFG regime? How accretion evolves among different flux states?

- SMBH from inner regions to the nuclear environment: what is the role of the BH the galaxy evolution - feedback

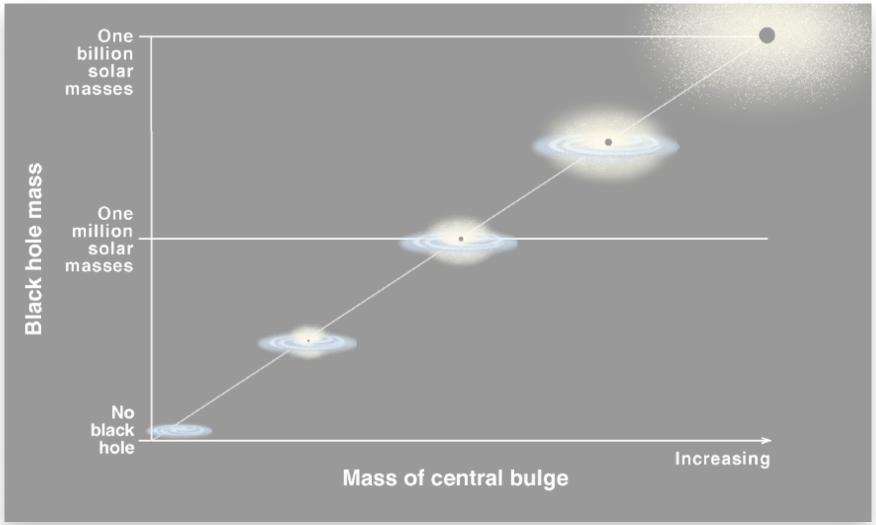
- where and when do the first BH evolve?

Why do we care?

BH formation and evolution



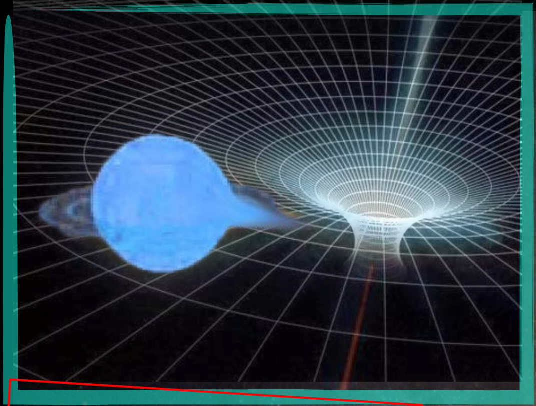
BH and galaxy coevolution

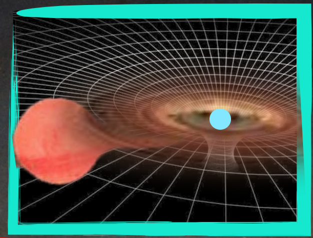


accretion under strong field gravity regime

Accretion flows under Strong Field Gravity regime

STRONG CURVATURE



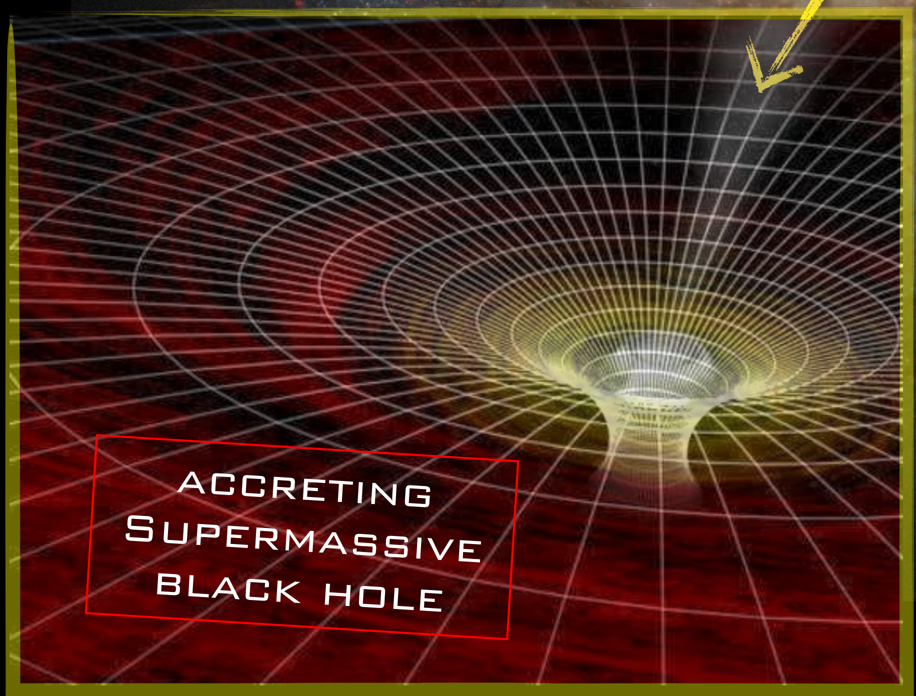


stellar mass BHs /NSs scattered in galaxies (X-ray binaries)

supermassive BHs in the center of galaxies (AGN and quasars)

Close to the BH, most of the physical processes are the same. we can learn a great deal by comparing the two families

WEAK CURVATURE

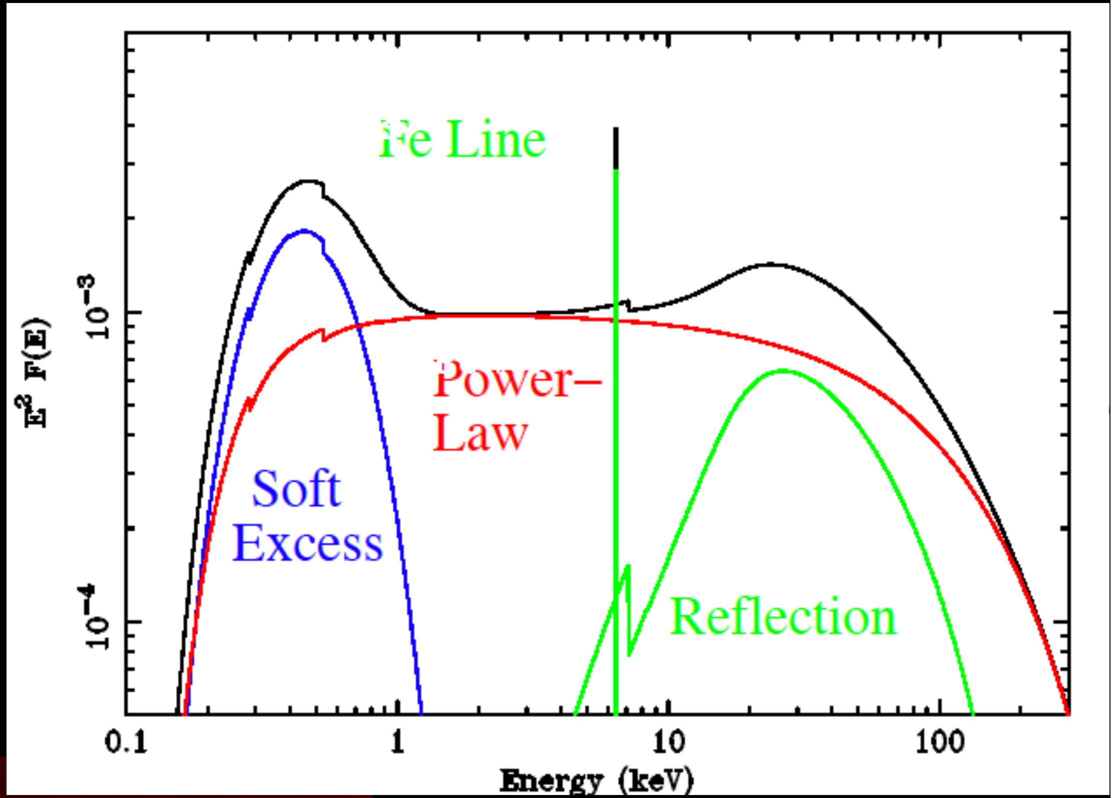


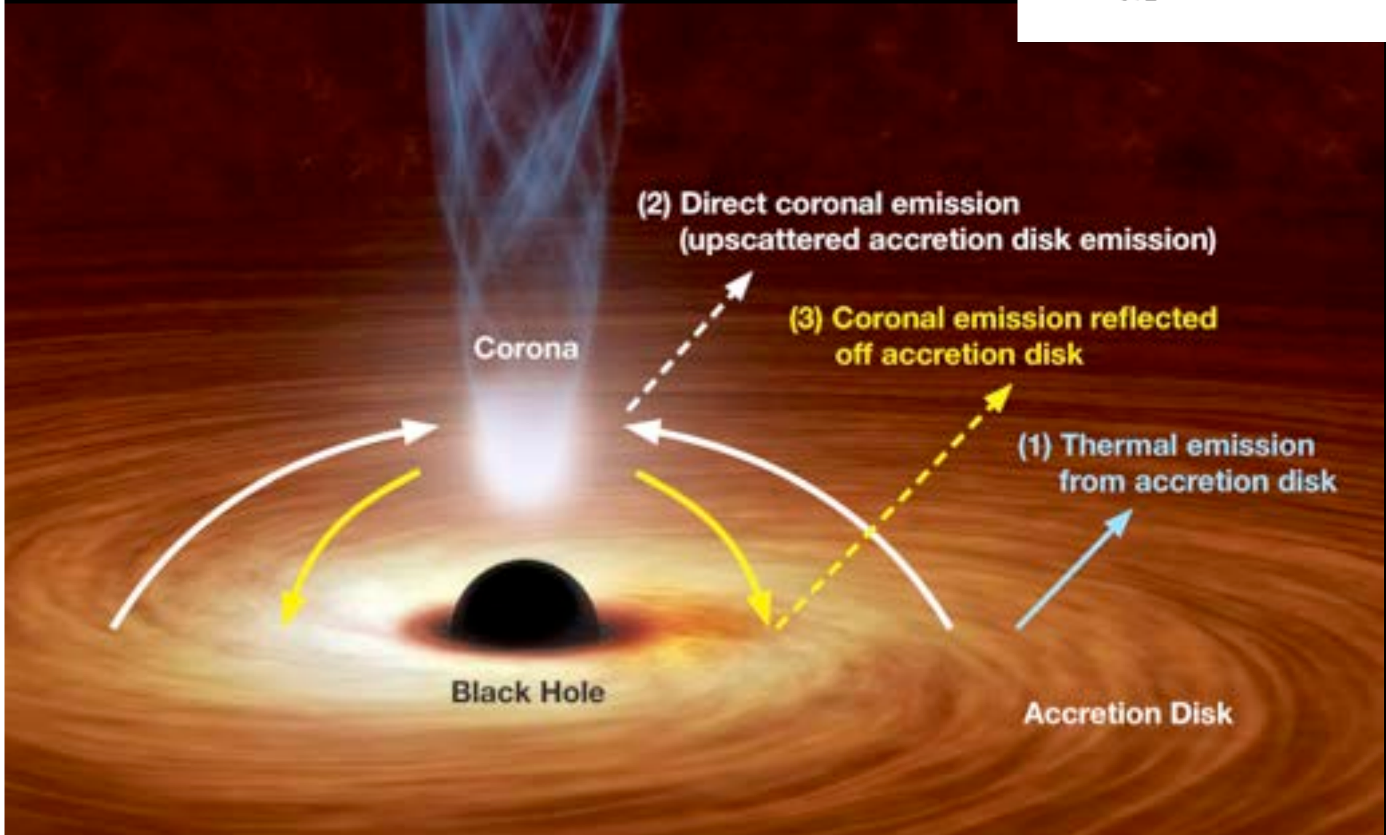
What really matters in these studies is the n. of photons (i.e. flux, F_{obs}) per unit of light crossing time scale $\sim R_g/c \sim GM/c^3 \sim 500\ M_8$ s

Possible to probe AGNs with 10^4 times more (X-ray) photons per unit of Rg than XRBs

THE INNER 100 RG DISC-CORONA

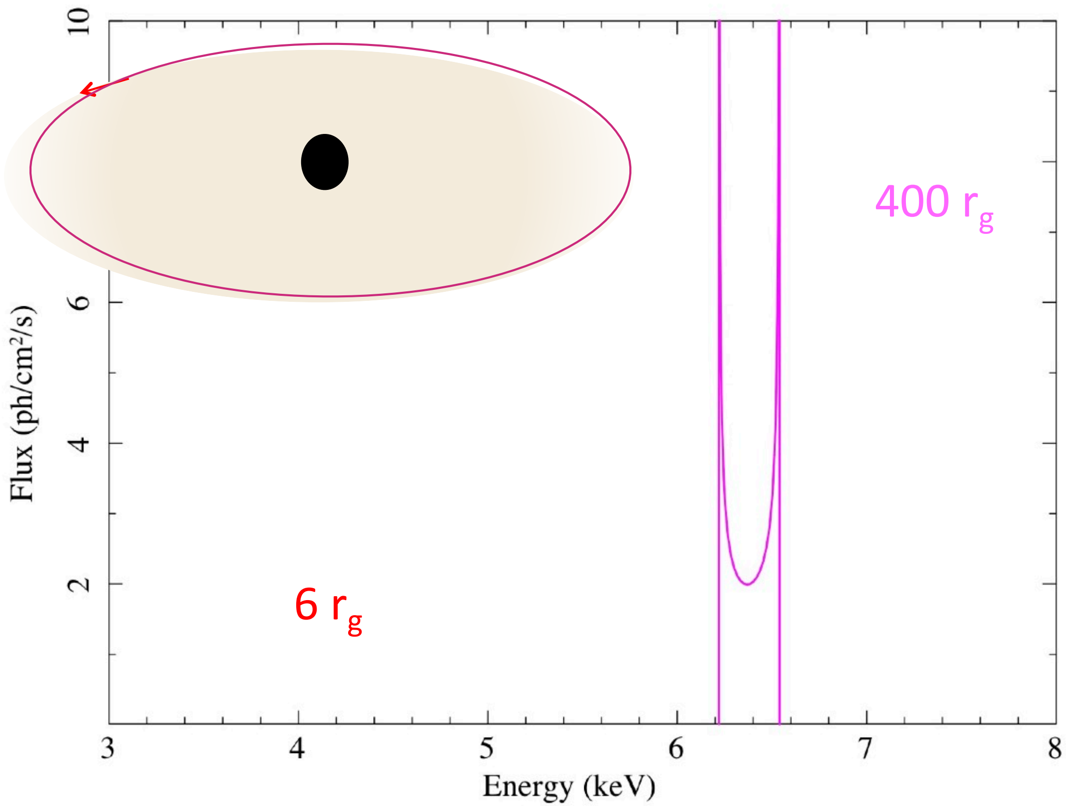
BH Accretion disc emits a thermal black body radiation in the UV(AGN) soft-X rays (XRB). The disc photons comptonize the hot corona producing a power-law spectrum in the hard X-rays (1-100 keV).





The hard X-rays from the corona interacts with the disc through scattering Compton and photo-absorption followed by fluorescence or Auger electron emission

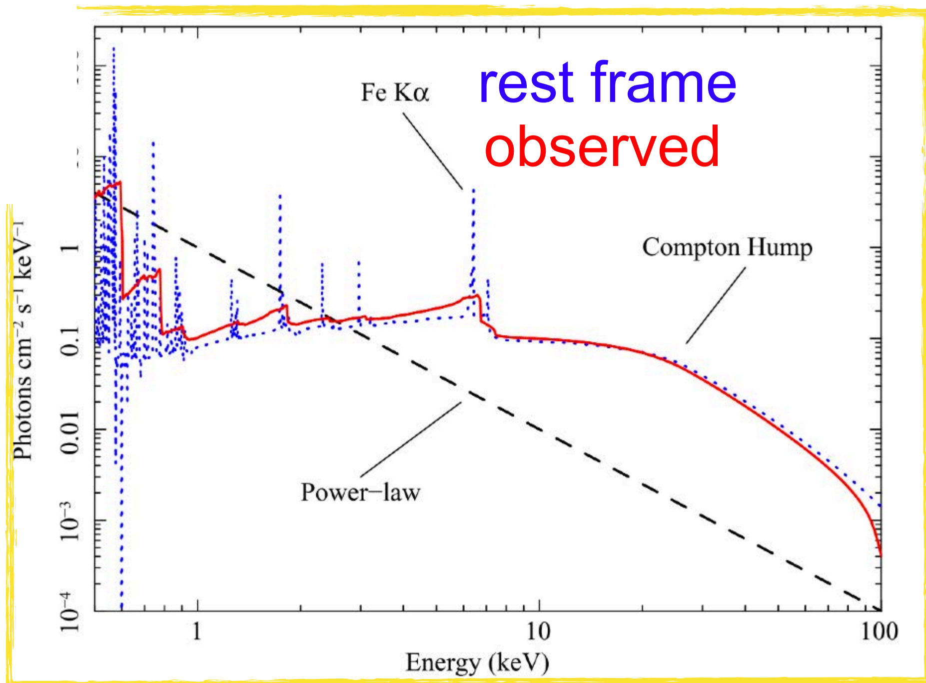
mapping the inner regions in X-rays: Fe Kα emission line from different disc radii



The big advantage of this method: independent on the BH's mass. Everything is expressed in terms of $R_g=GM/c^2$

BUT

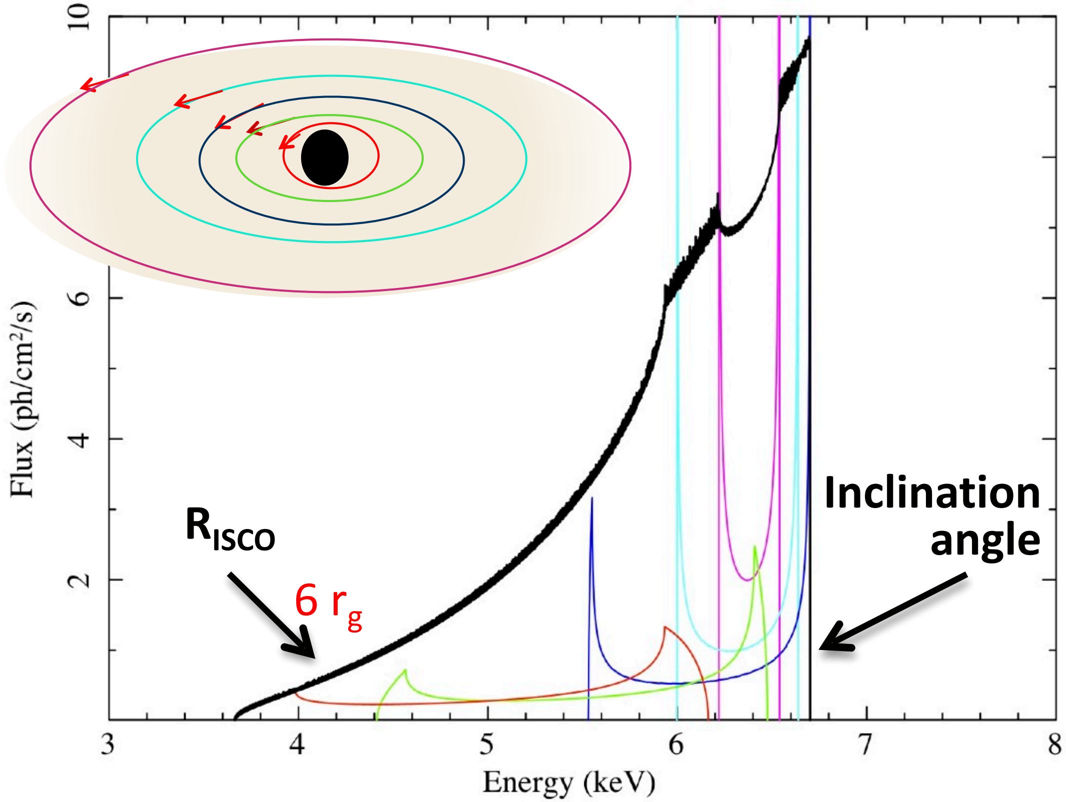
"*there is the danger that one will end up with very precise but inaccurate spin measures*"



The Effects of strong field gravity are all involved in the spectral in a wide energy band

Brenneman & Reynolds 2006; Dauser+ 2010, Fabian+1989

mapping the inner regions in X-rays: Fe Kα emission line from different disc radii



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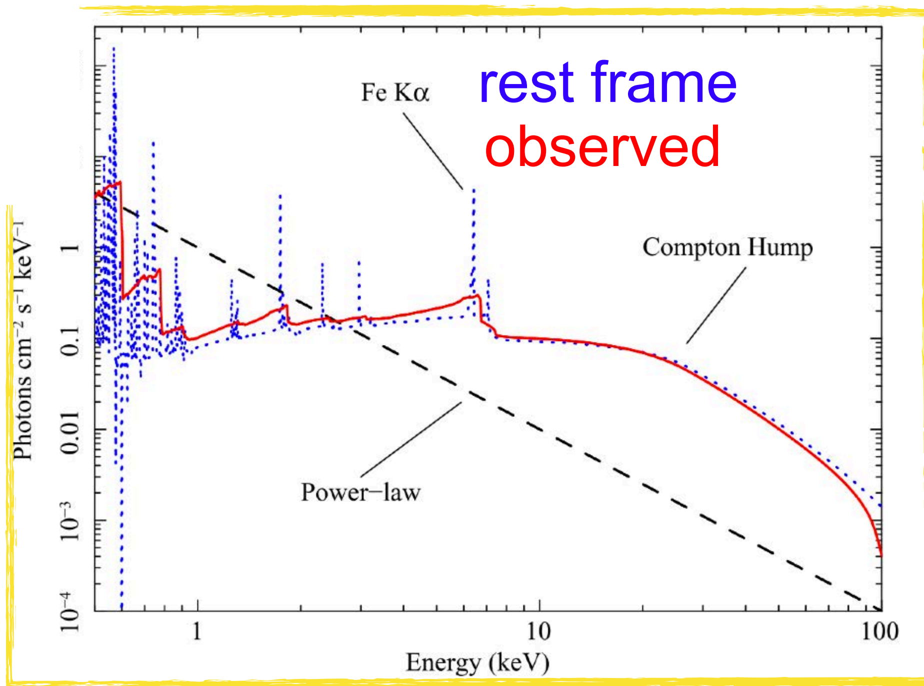
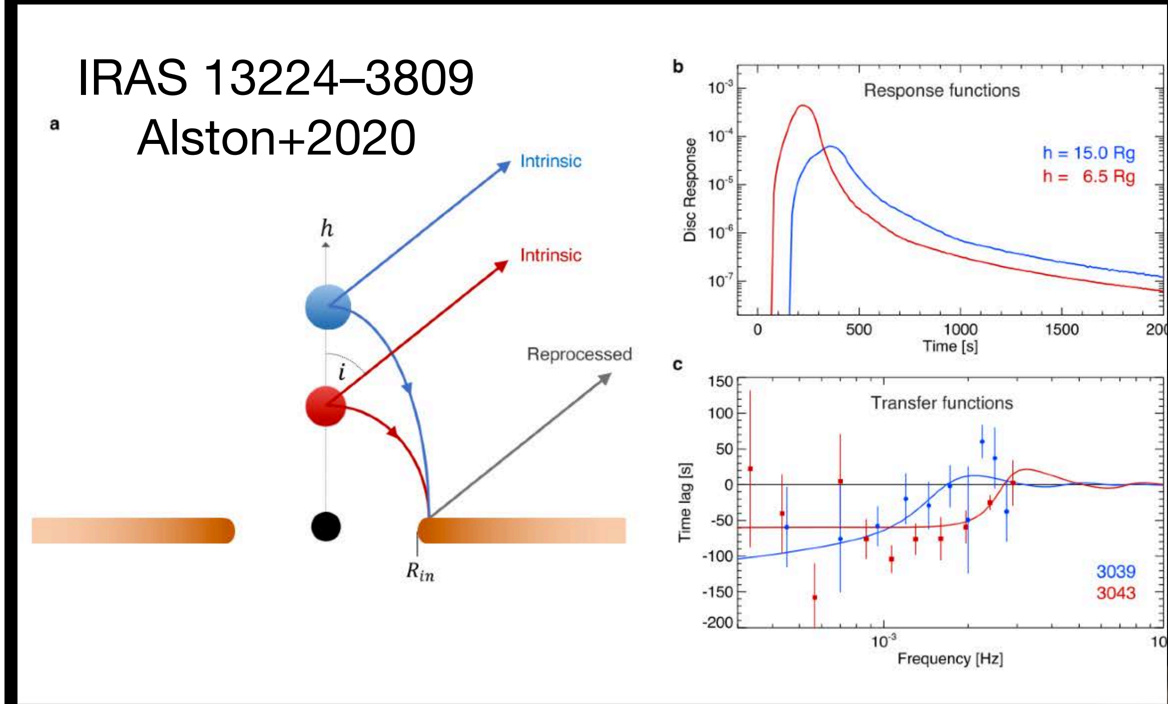
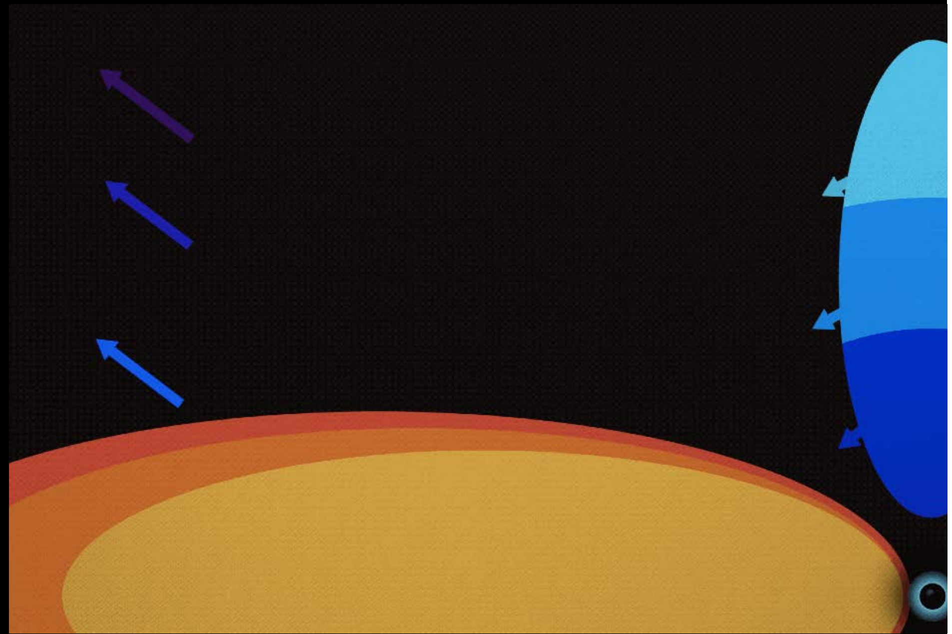


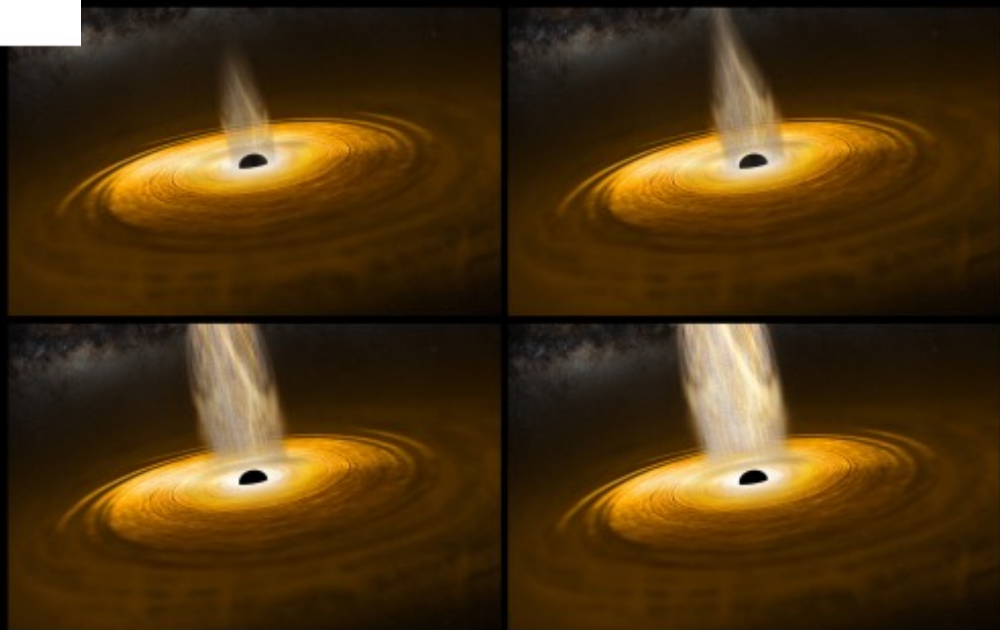
Brenneman & Reynolds 2006; Dauser+ 2010, Fabian+1989

mapping the inner regions: spectral-timing



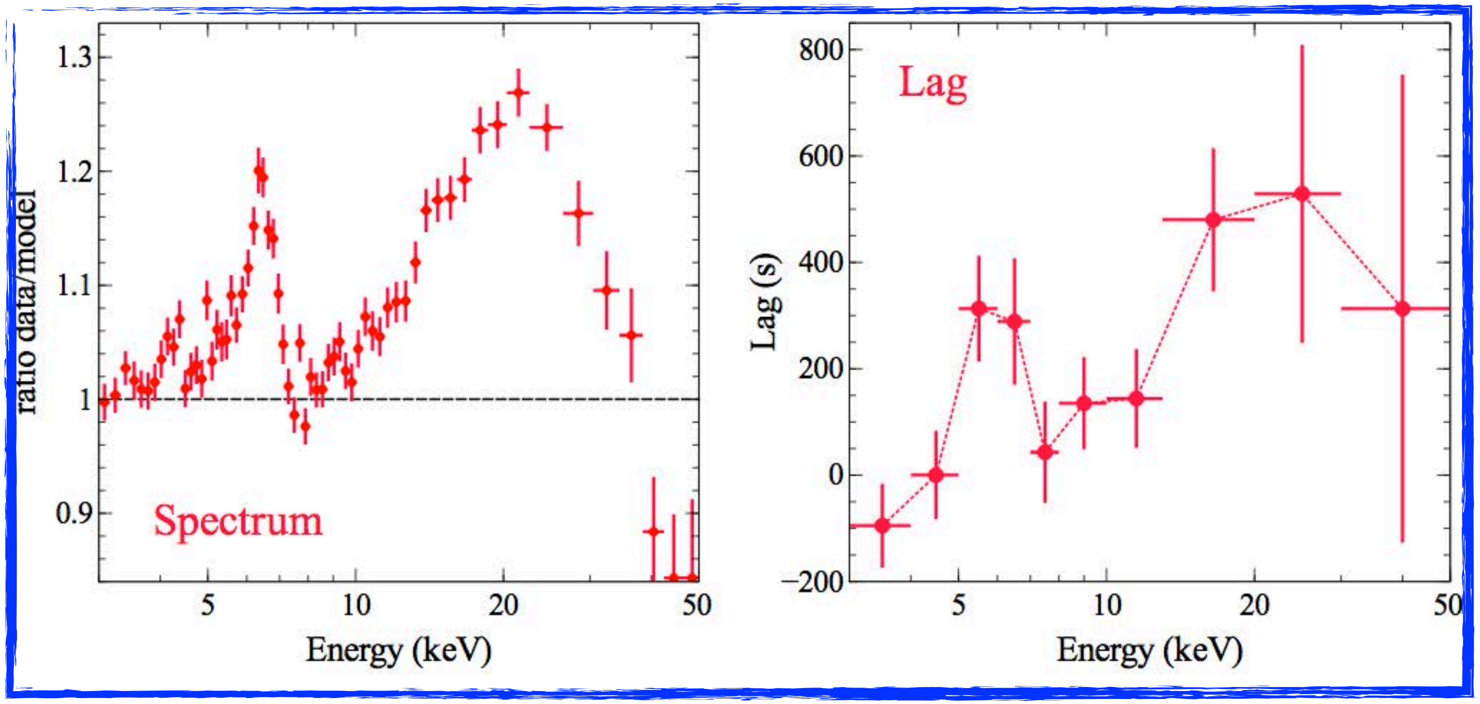


Alston+2020, Kara+19, Fuerst+15, Garcia+15



Time lag (X-ray reverberation) can be used to constraint the geometry in AGN and XRBs

X-ray reverberation and spectra: where we are



De Marco+16

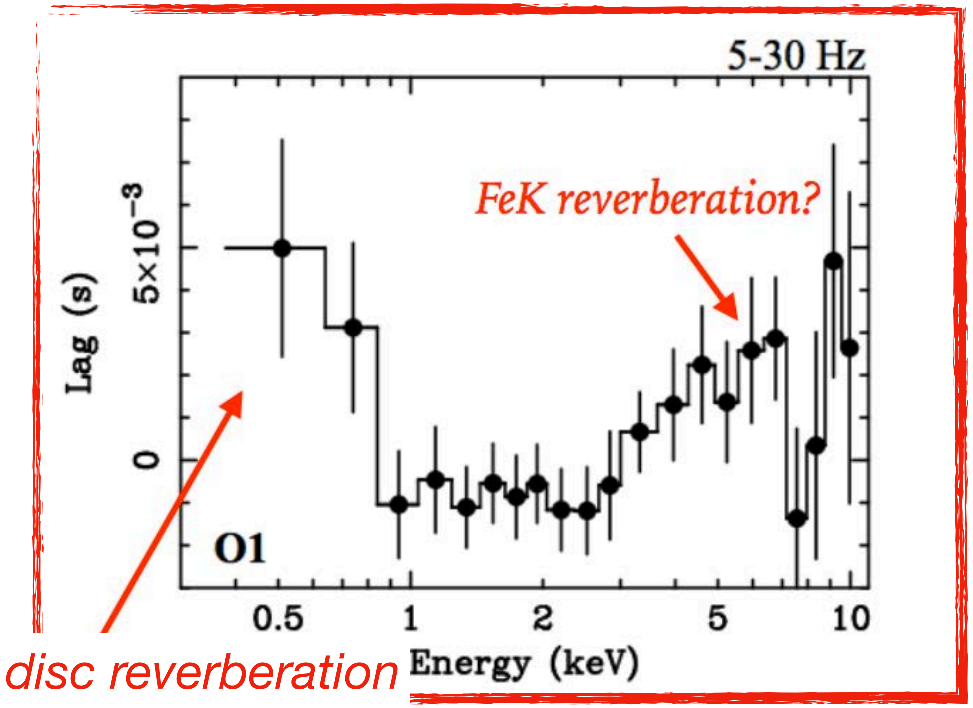
Kara+15

De Marco+17

see also Kara+18

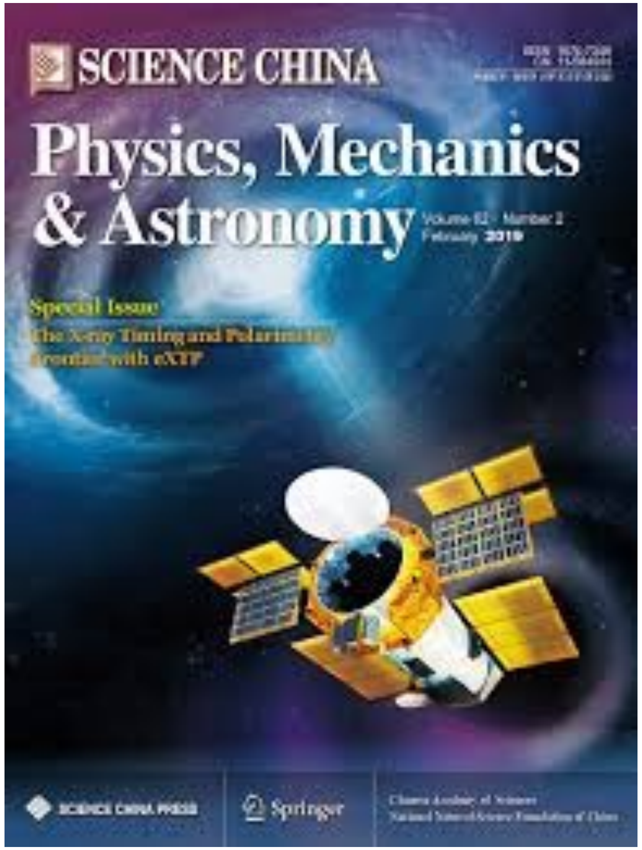
Hard lag in AGN difficult to measure. Large statistical uncertainty

in binary BH Thermal and FeK lag consistent with reprocessing occurring in the same region of the disc



the future of the X-ray timing spectroscopy (and polarimetry)

Nasa Probe class mission

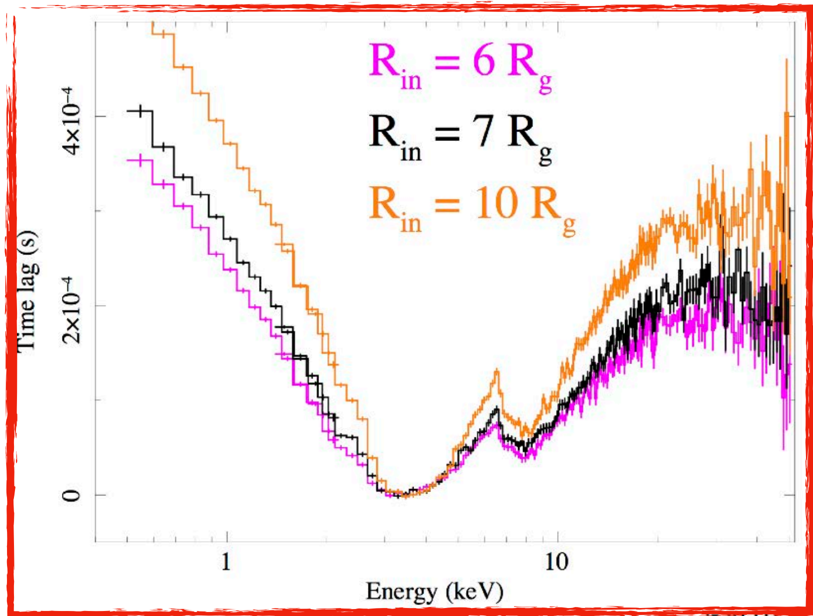


eXTP: enhanced X-ray timing and polarimetry mission

China-European proposed mission

eXTP simulation

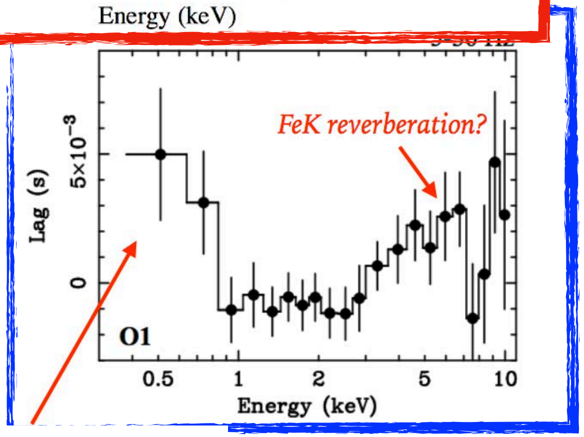
100 ks – 1Crab XRB hard state



De Marco et al. 2017

De Rosa et al. 2019

Uttley 2011

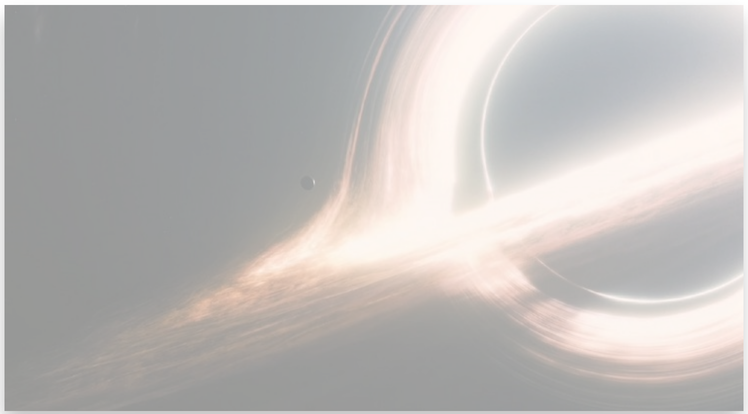


disc reverberation

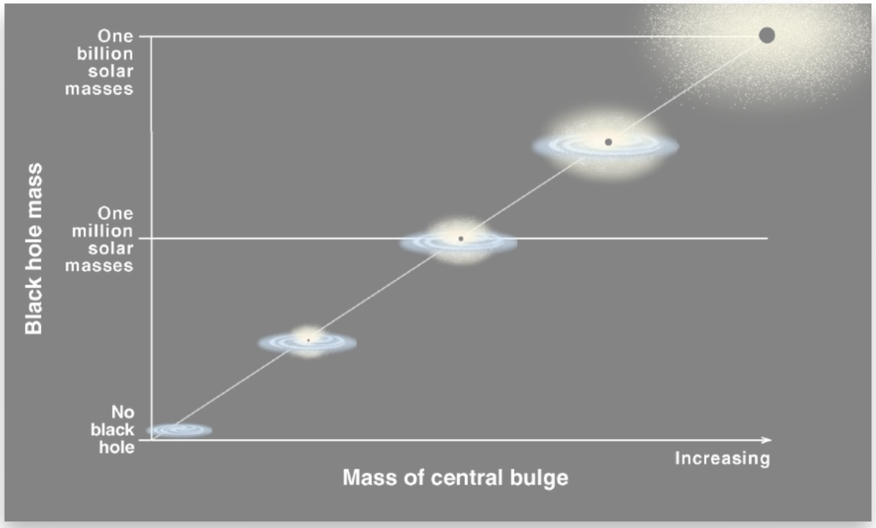
Why do we care?

BH formation and evolution

accretion under strong field gravity regime



BH and galaxy coevolution

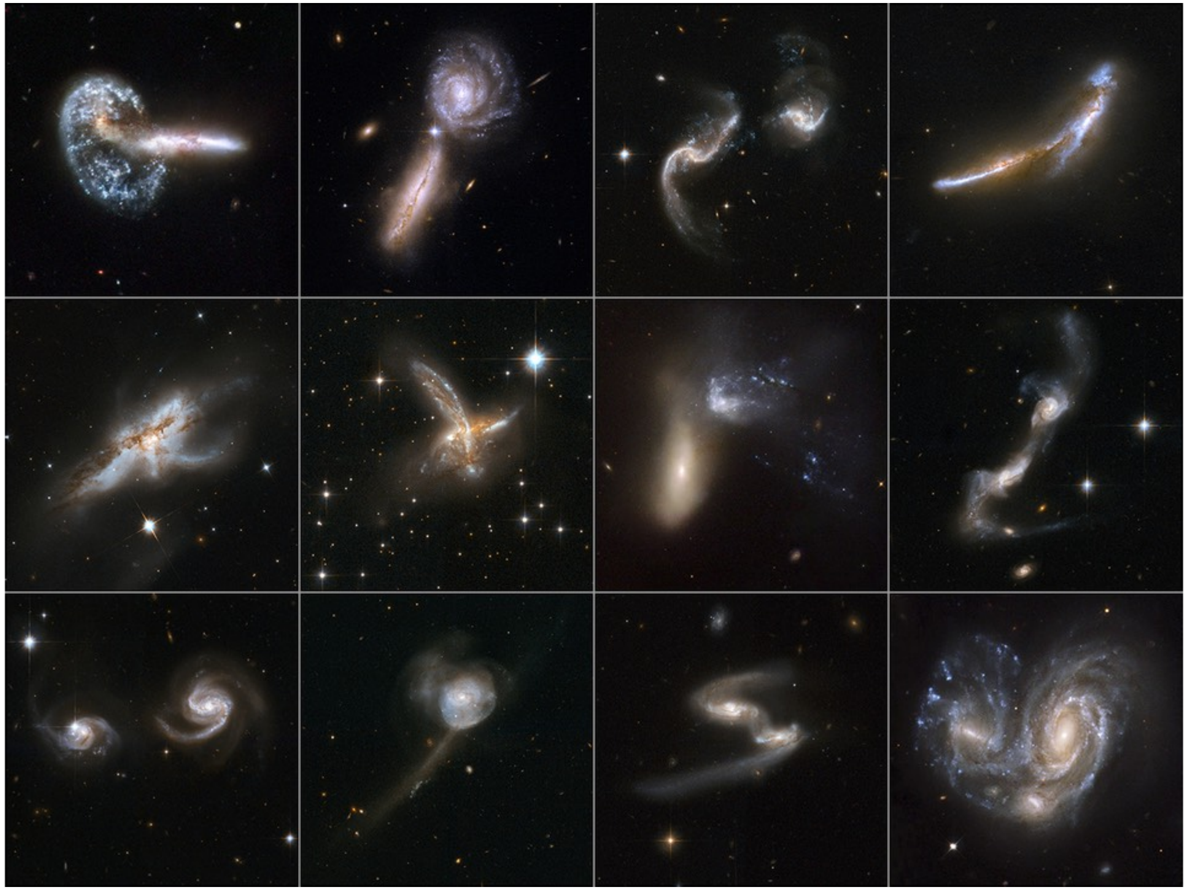


Massive BHs grow along with galaxies through accretion and MBH-MBH mergers

proto-galaxies grew massive through repeated mergers and accretion of matter from filaments of the cosmic web

mergers should invariably result in the formation of massive black-hole binary systems at the centre of the newly formed galaxy.

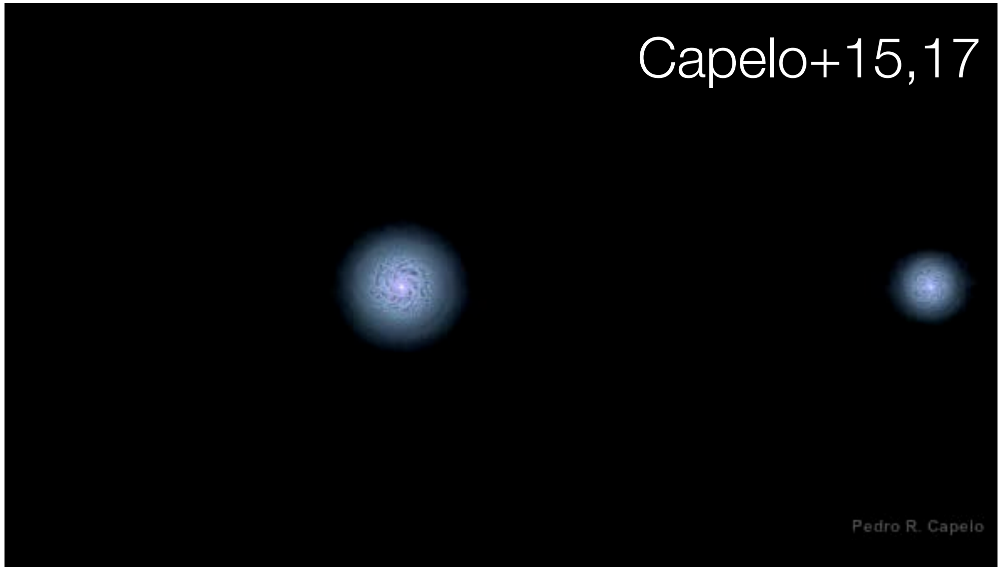
due to stellar or gas dynamical processes the SMBHs ultimately coalesce by emitting a burst of gravitational waves



BH seed can form and evolve, necessary to build massive BH at z=7

there is growing evidence that major mergers trigger the most luminous AGN

merger simulation: AGN triggering



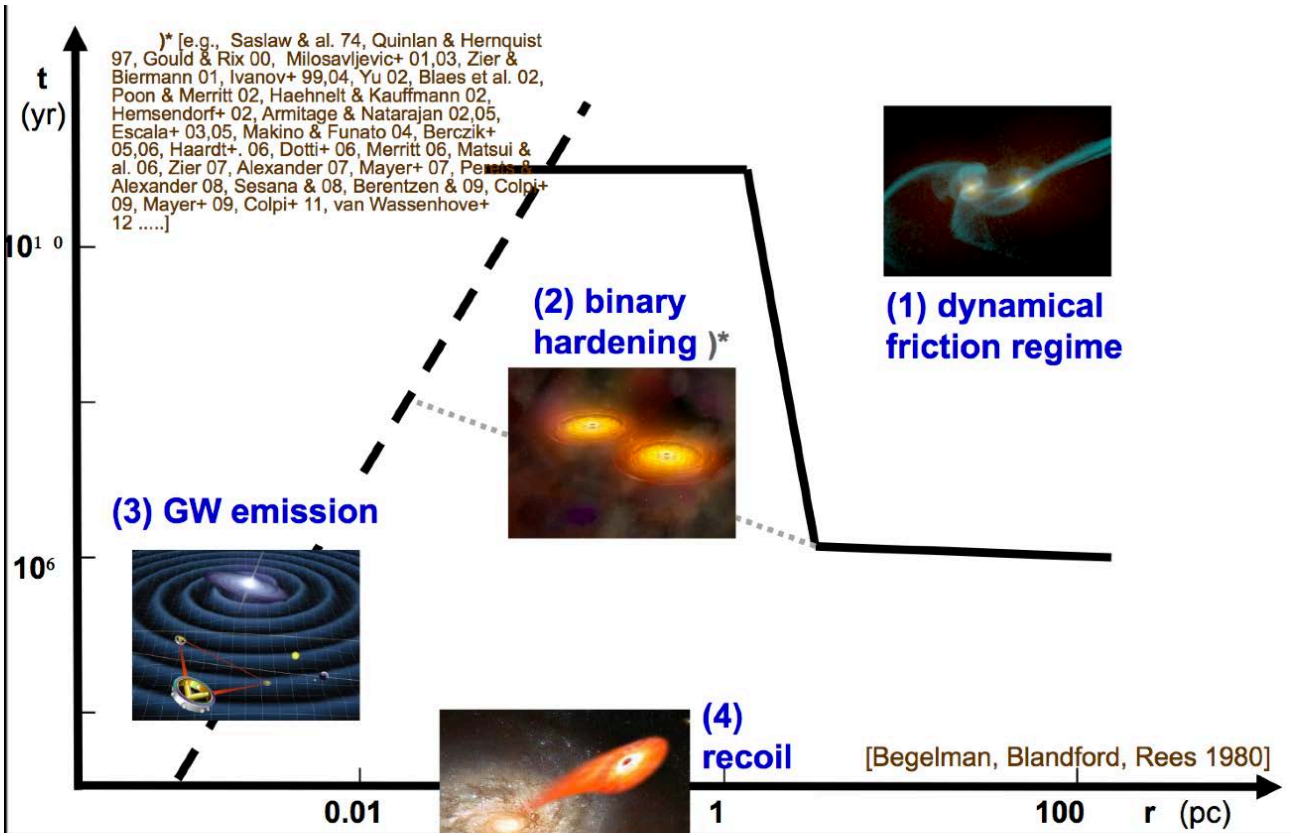
✓not all AGN activity is merger driven, however the merger stage enhances the AGN activity

✓AGN trigger strongly depends on how effective physical processes are in inducing the gas to lose angular momentum

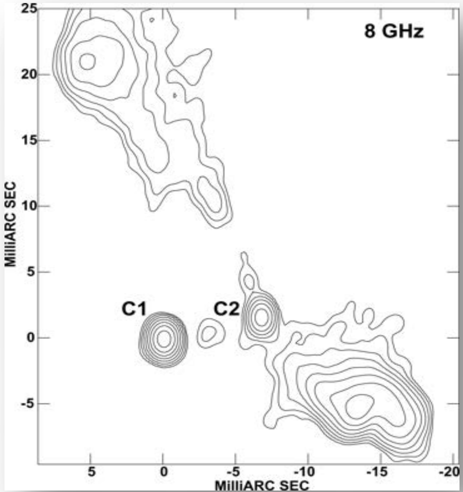
✓The probability of dual AGN increases with decreasing BH separation

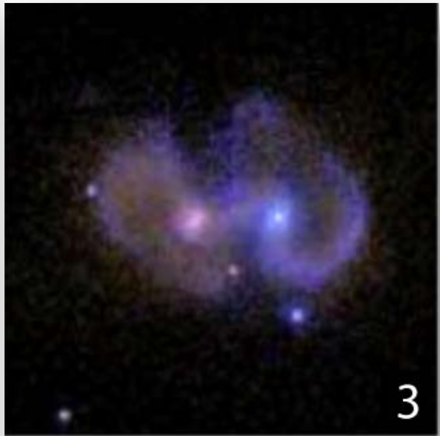
✓The BH mass ratio changes significantly during the merger: very unequal BH pairs q tend to evolve towards higher q, whereas pairs with an initial q > 0.25 tend to increase the BH mass contrast.

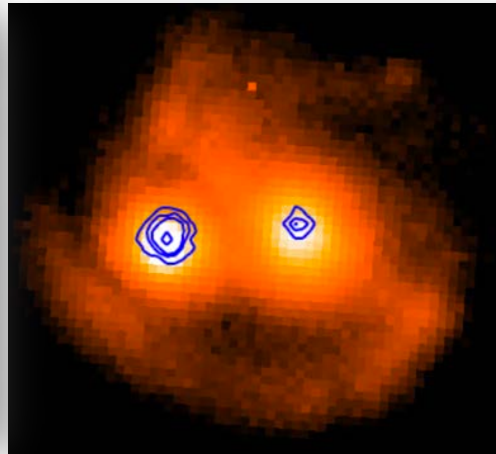
✓Dual AGN require large gas reservoir



1. dual AGN: what do we see?







projected separation

pc	~100 pc	kpc	kpc-Mpc
radio core	*IR host*	*X-ray*	*hard X-ray*

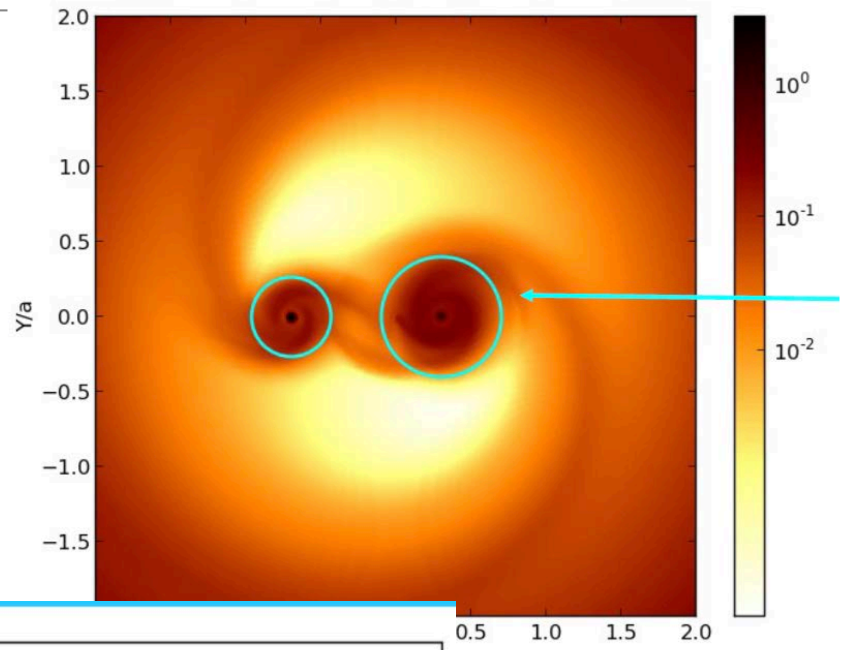
Rodriguez+07,Kocevski+15, Comerford+09, Elvis+09, Komossa+03, Koss+11, Ricci+17, Bianchi+13, Guainazzi+05, Koss+11,12, Ricci+17, De Rosa,15, 18,19, Foord+19

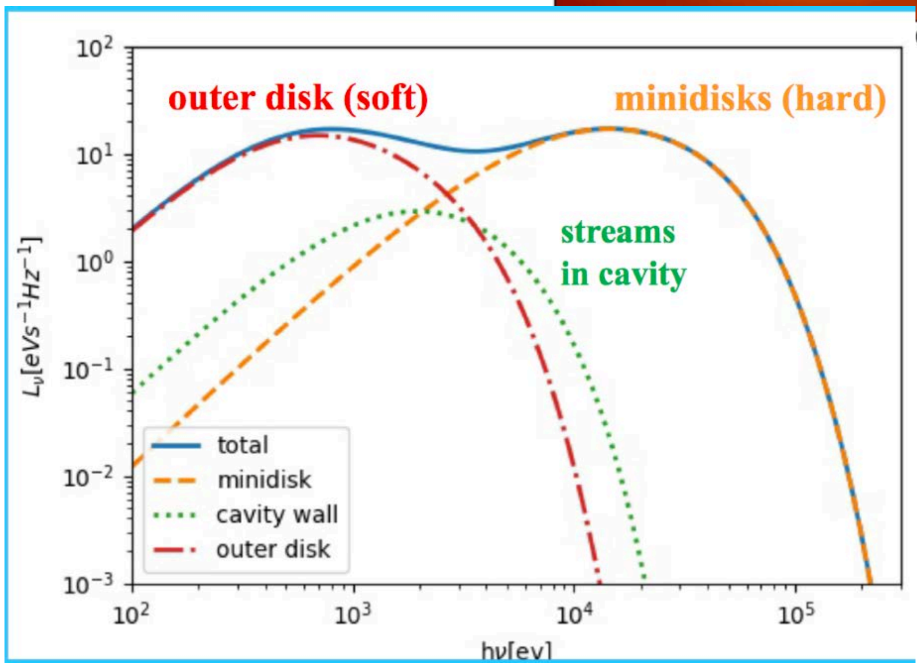
2. Binary SMBHs: Is there any gas around SMBHs before the coalescence?

Focus on the final stages of the mergers – after
the MBHs have formed a binary

Sub-pc to milli-pc separations
In a gas-rich environment: formation of a circumbinary disc

Optical – X-ray emission from quasars from 10-100 Rg:
- Minidisc ~ quasar disc
- Doppler effect modulates brightness at O(v/c)



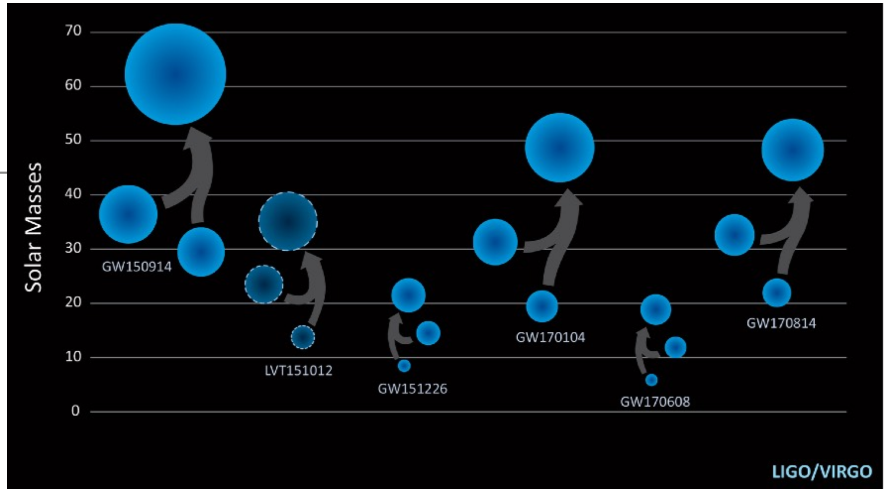


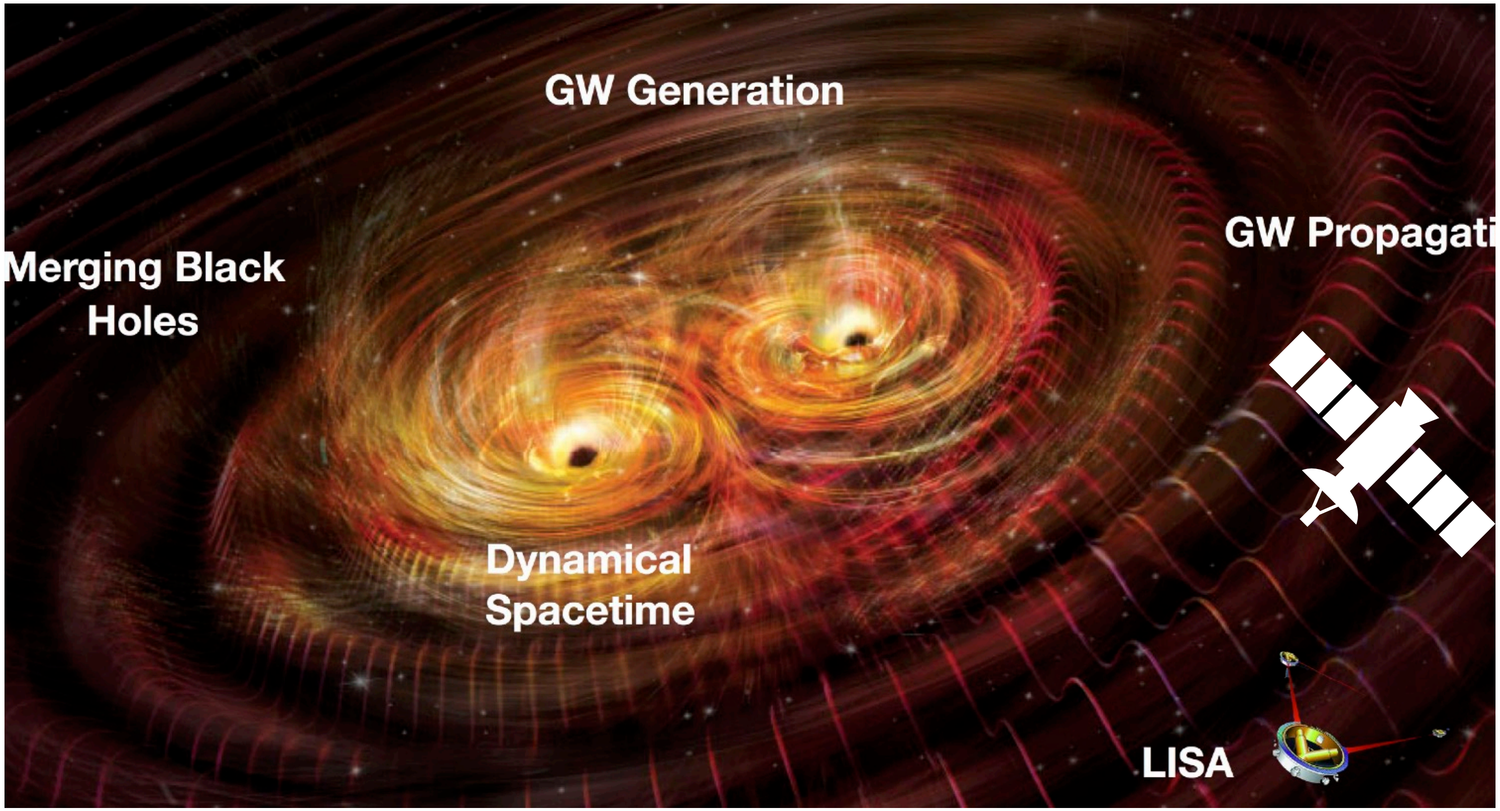
X-ray chirp is inevitable!

Farris+15,17
Tang+18

what happens when two SMBHs merge?

multi-messanger and transient astrophysics
GW & EM universe

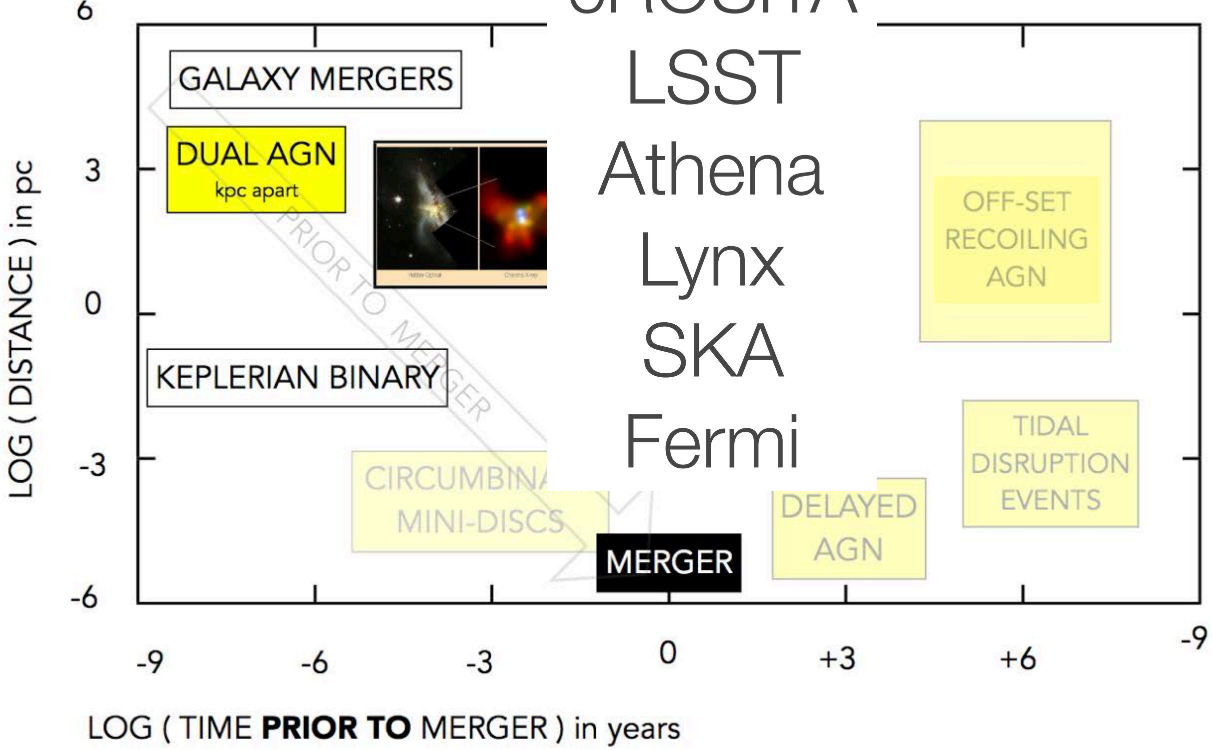




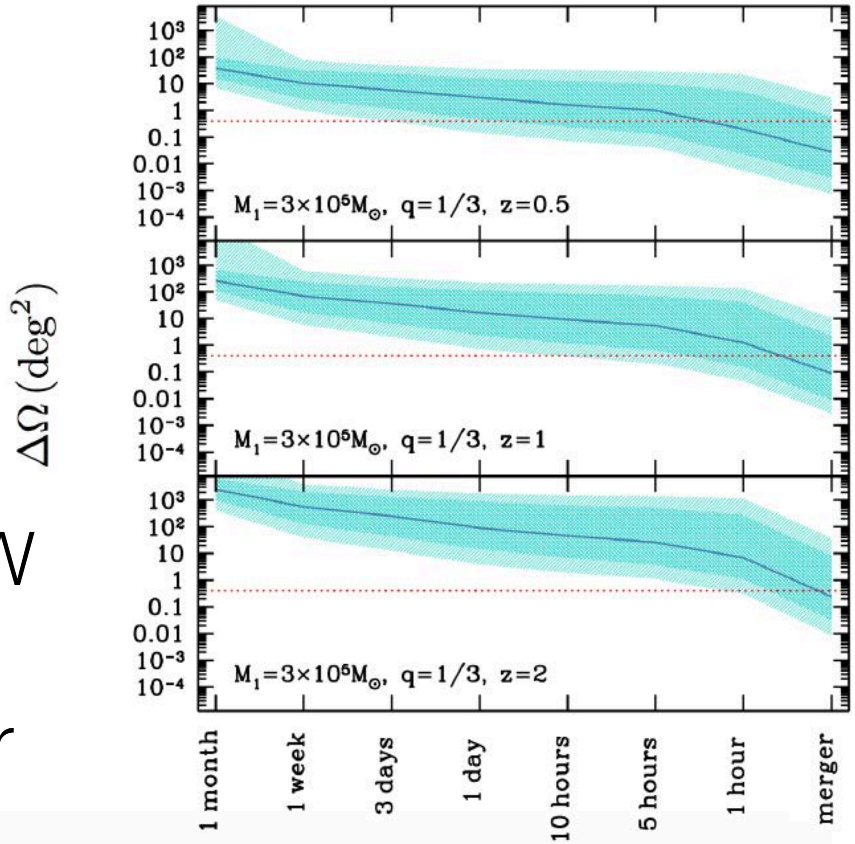
Girl reading, H. Matisse

the (costly) GW and EM Universe

eROSITA
LSST
Athena
Lynx
SKA
Fermi



Mangiagli+20

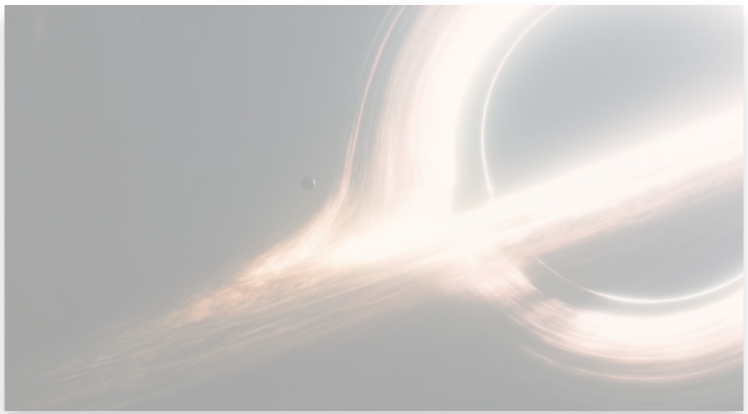


sky localization of LISA GW
events improve with S/N
errors get lower at merger

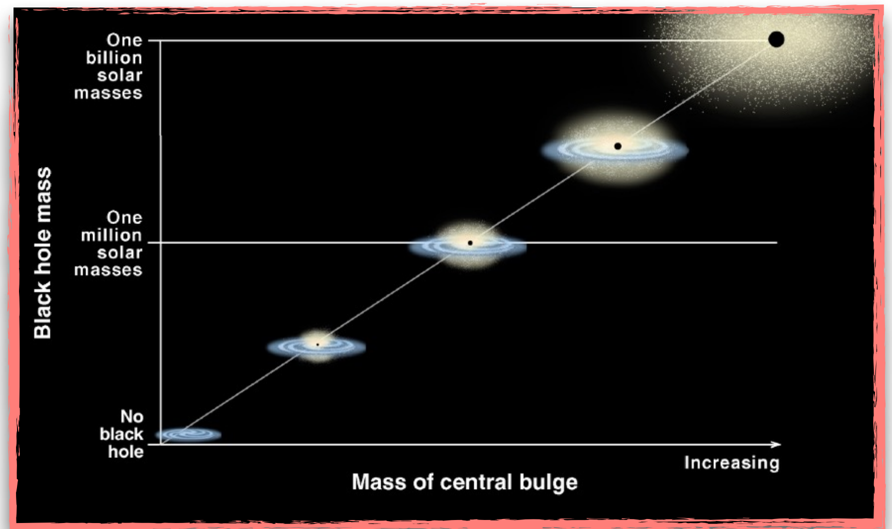
Why do we care?

BH formation and evolution

accretion under strong field gravity regime

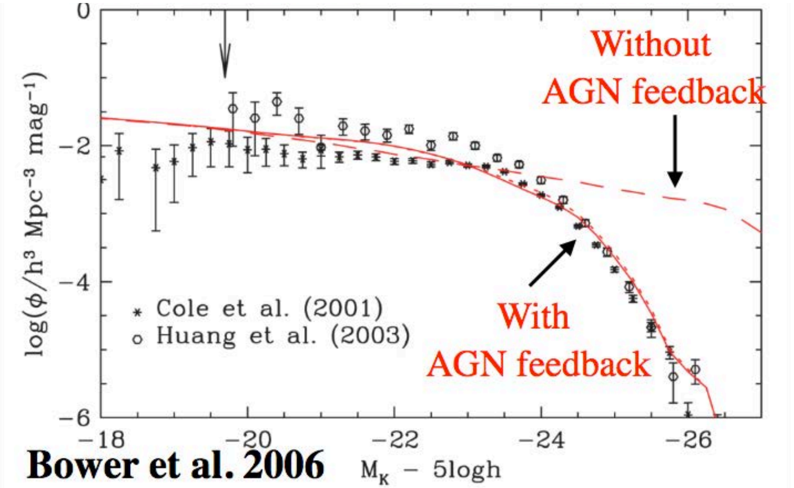


BH and galaxy coevolution

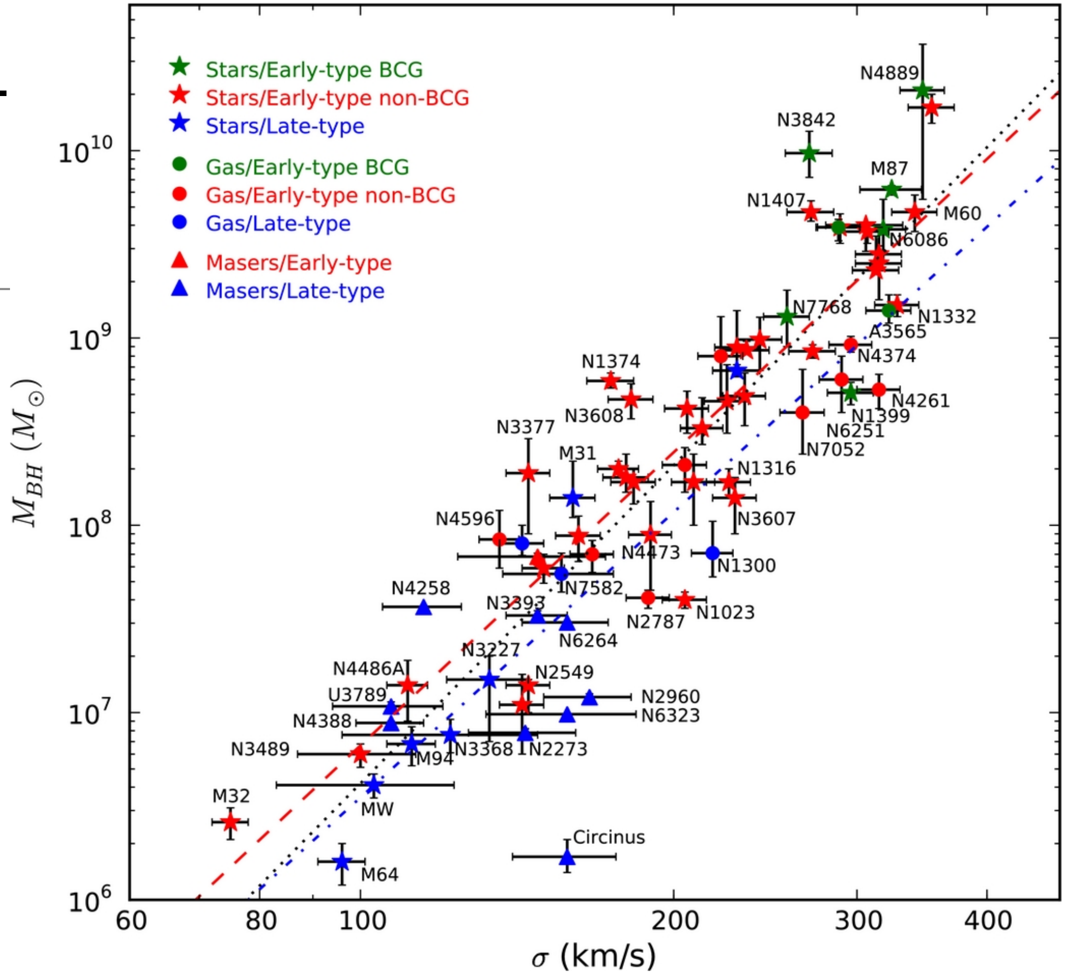


BH-galaxy coevolution - the AGN feedback

galaxy luminosity function



Hydrodynamical simulations require SF to be regulated by BH feedback



If the power of AGN feedback is equivalent to a tiny fraction of the AGN luminosity (0.5–5%), this process can regulate the growth of the galaxy by altering its star formation Hopkins & Elvis 2010

Kormendy and Richstone 1995, Magorrian+1998, Gebhardt+2000, Ferrarese+2000,Tremaine+2002, Gultekin+2009, Kormendy& Bender 2012

Idea is that accreting SMBH produces relativistic jets which heat diffuse hot gas in surrounding halo, preventing further cooling of halo gas onto central galaxy, and so quenching further star formation

Croton+2006, Bower+2006, Cattaneo+2006

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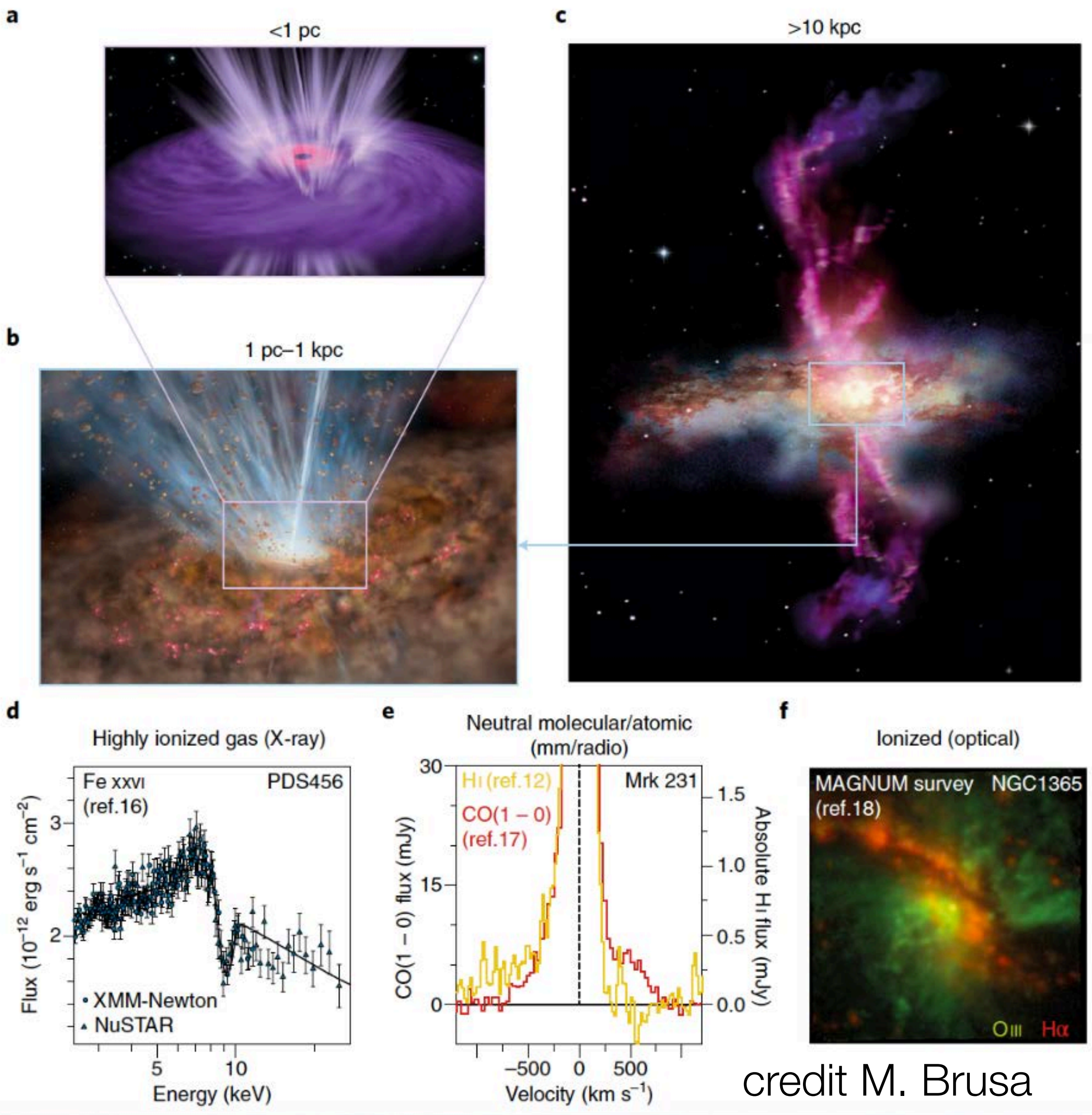
Croton+2006, Bower+2006, Cattaneo+2006

AGN winds and fast outflows



credit M. Brusa

gas flows in the form of energetic winds may play a pivotal role in galaxy evolution.

These winds are detectable through strongly blue-shifted absorption lines associated with highly ionized iron atoms (Fe xxv and Fe xxvi) observable at energies E>6 keV

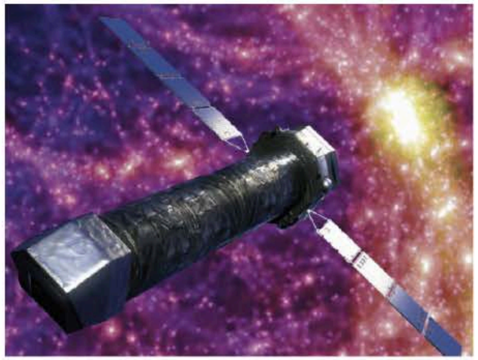
The AGN outflows have a multiphase nature, as revealed by observations and expected from simulations

King & Pounds 2015

the future is even brighter!

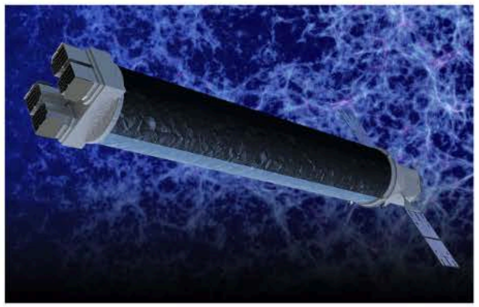
The Future of X-ray Spectroscopy: Planned and Proposed Missions

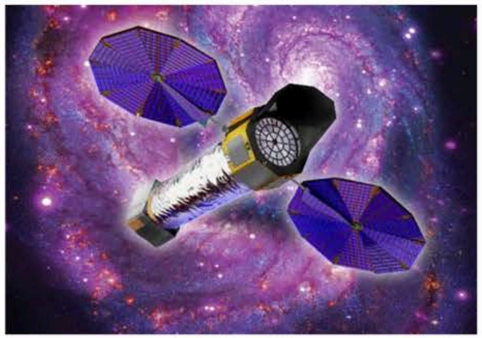
XRISM (2022)
7 eV uCal
~1 arcmin resolution



Athena (early 2030s)
2.5 eV uCal
~5 arcsec resolution

Arcus
$\lambda/\Delta\lambda = 2500$ grating
Point sources

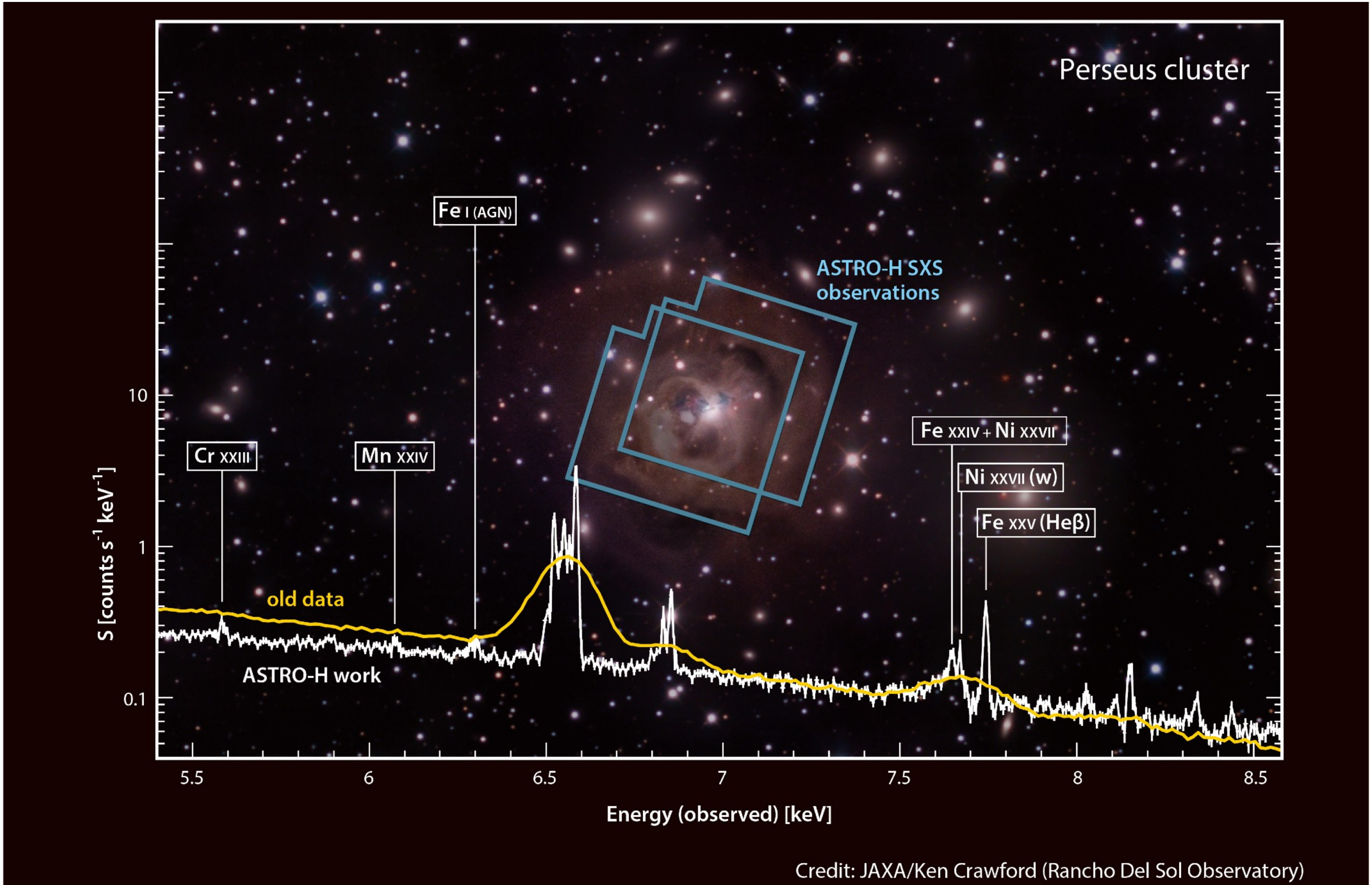




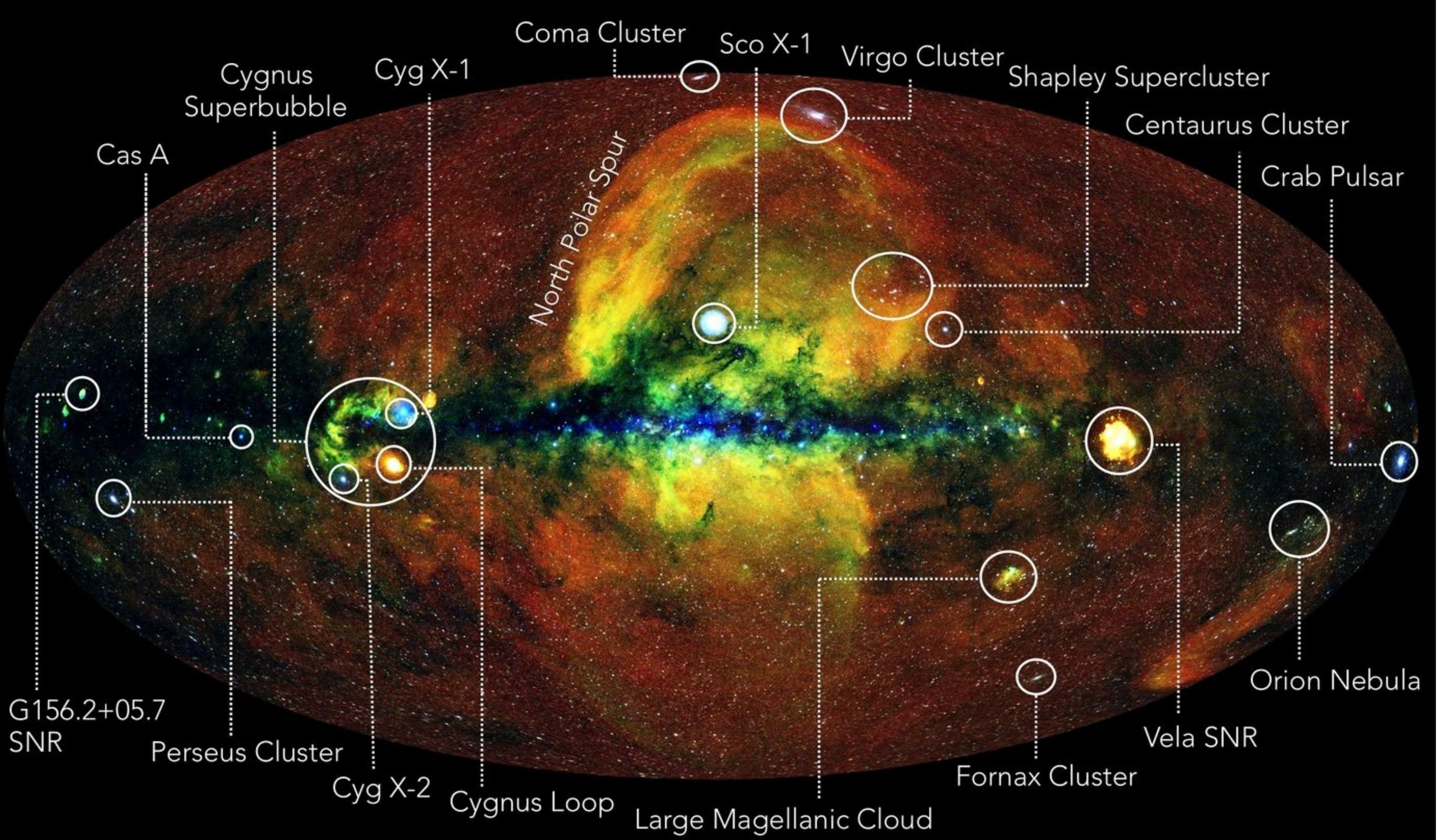
Lynx
3 & 0.3 eV uCal
$\lambda/\Delta\lambda > 5000$ grating
<1 arcsec resolution

credits R. Smith

Hitomi observation of Perseus cluster



Navigating the eROSITA X-ray sky



IKI

SRG/eROSITA 0.3-2.3 keV - RGB Map

MPE