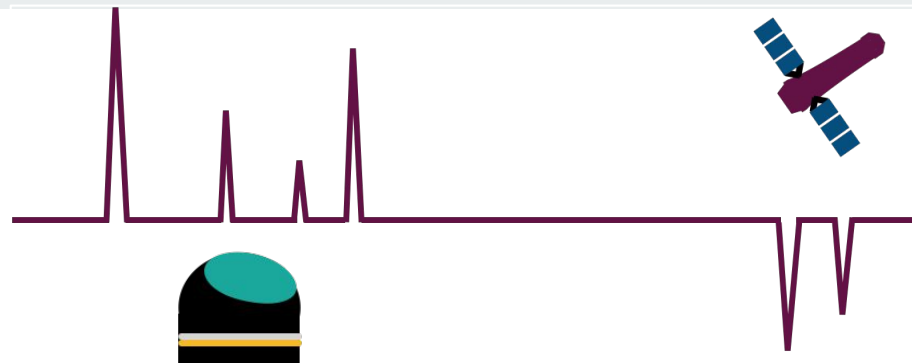




High-resolution spectroscopy of ionized plasmas in the Universe

Junjie Mao (毛俊捷)

Tsinghua/DoA

Jan. 12, 2021

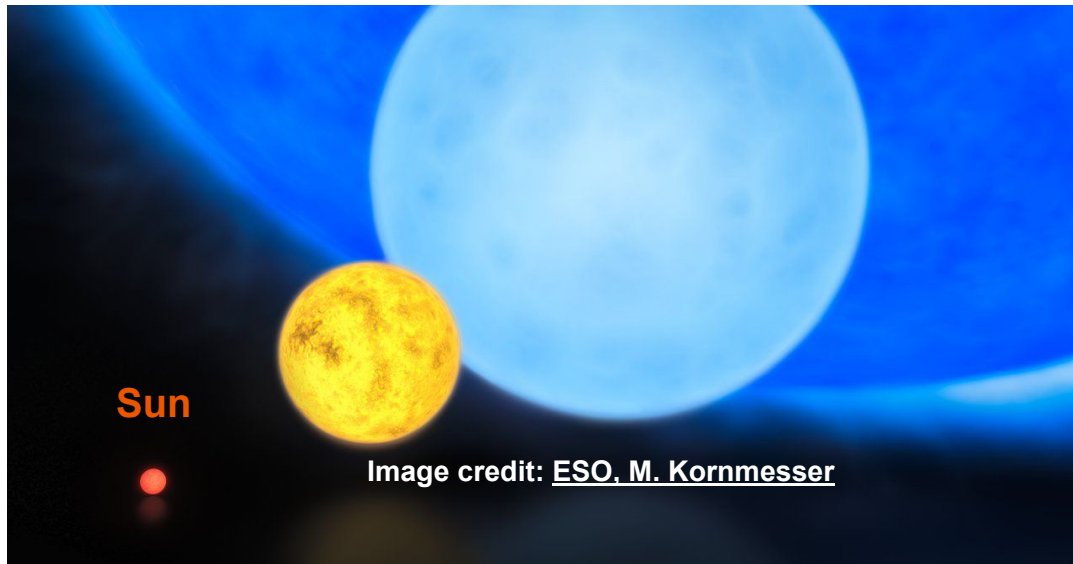


Image credit: [ESO, M. Kornmesser](#)

Galaxies, stars, and black holes in the Universe

cosmo social distance

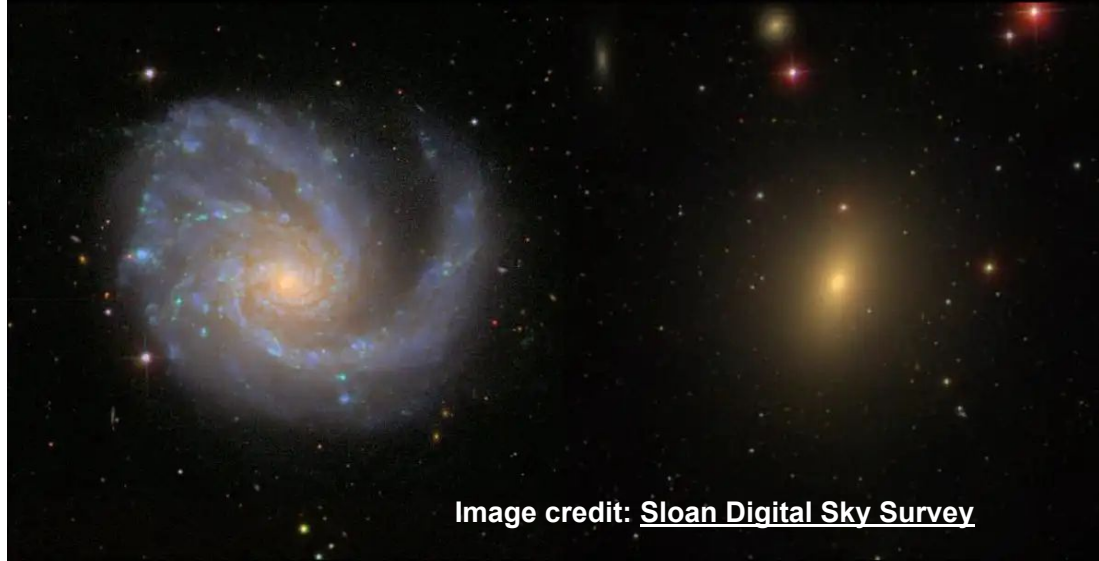


Image credit: [Sloan Digital Sky Survey](#)

Image credit: [UCLA Galactic Center Group](#)

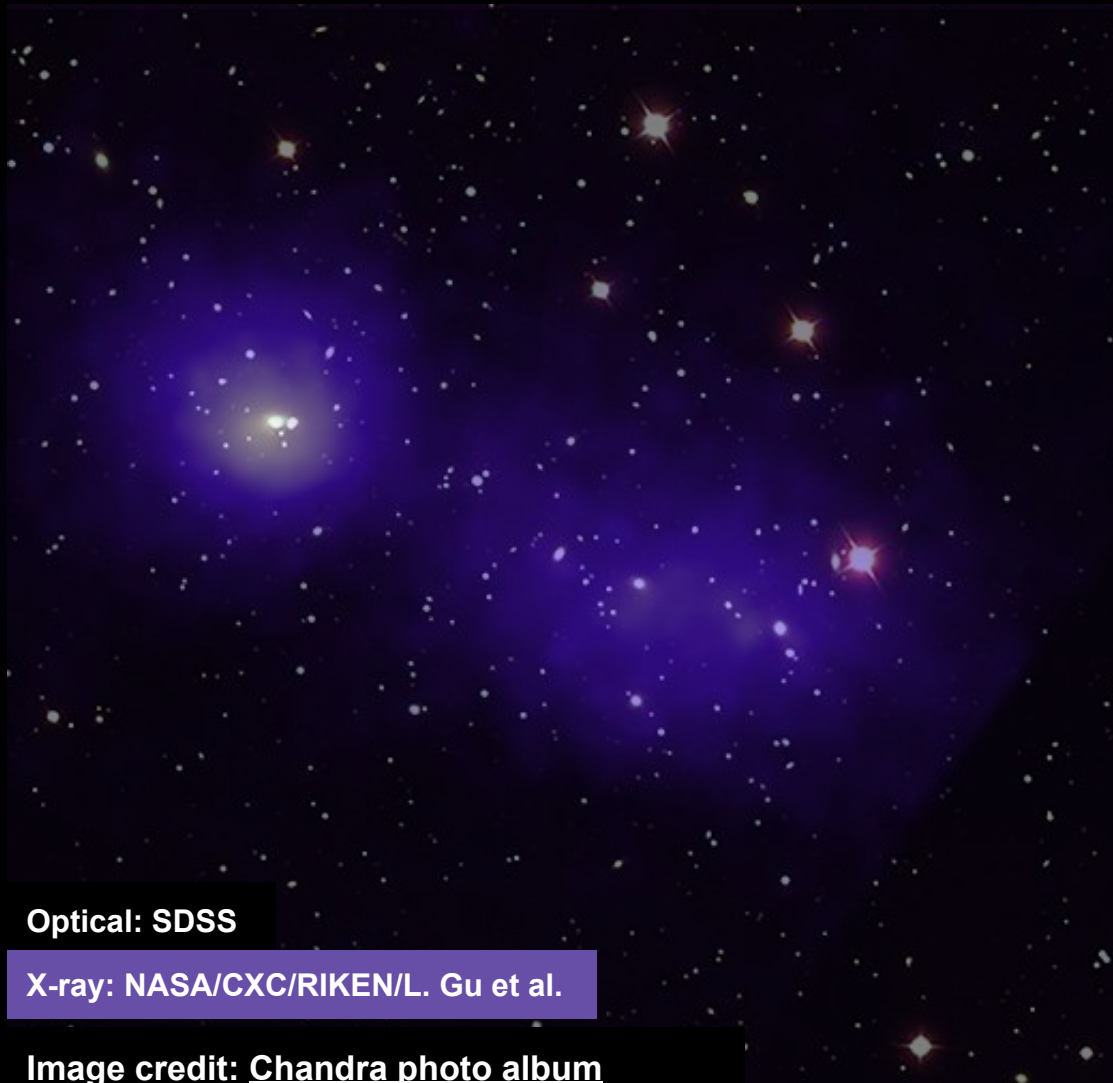
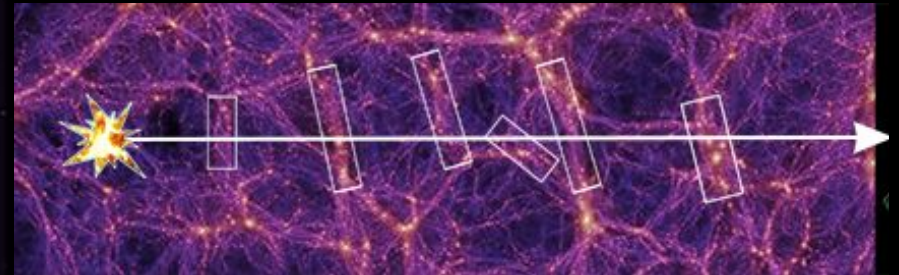
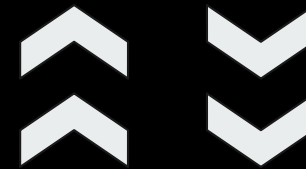


Image credit: [Chandra photo album](#)



Ionized plasmas



**Black holes, stars, and
galaxies.**

CIELO-RGS



A catalog of ~12000 lines from ~1600 RGS spectra
(stellar coronae, XRBs, SNRs, AGN, galaxies, etc.)

RGS Spectrum

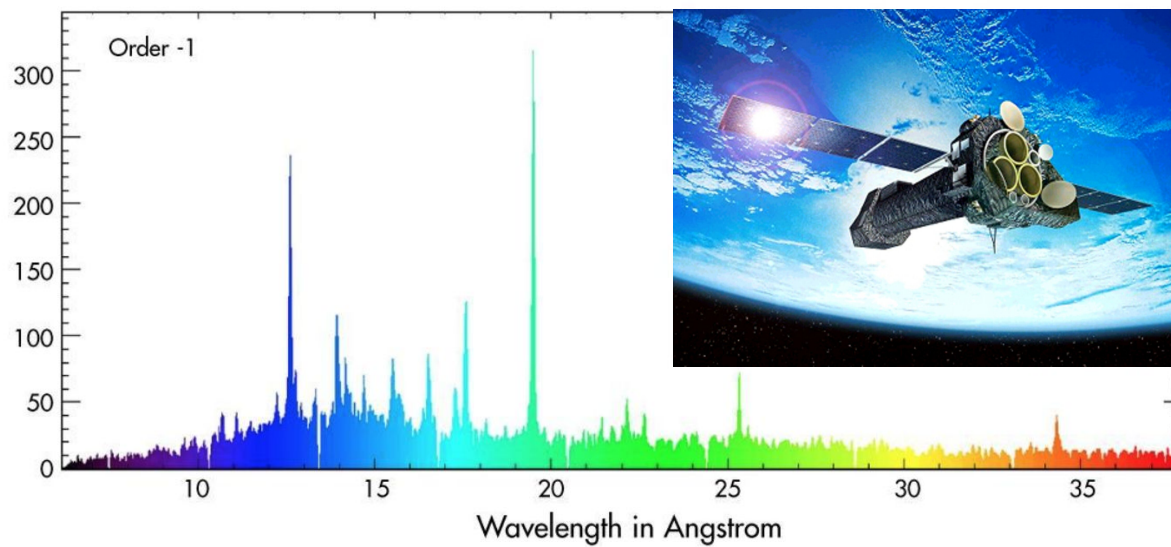
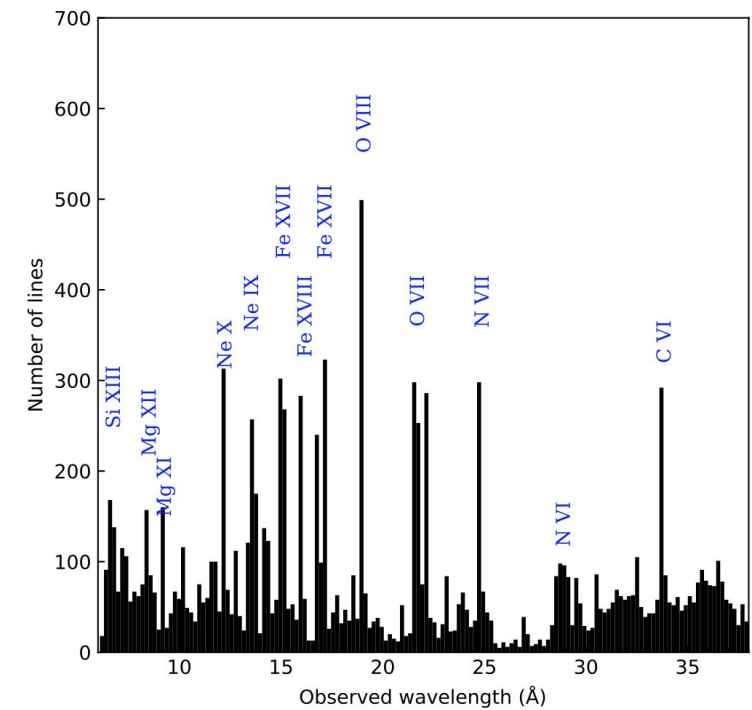


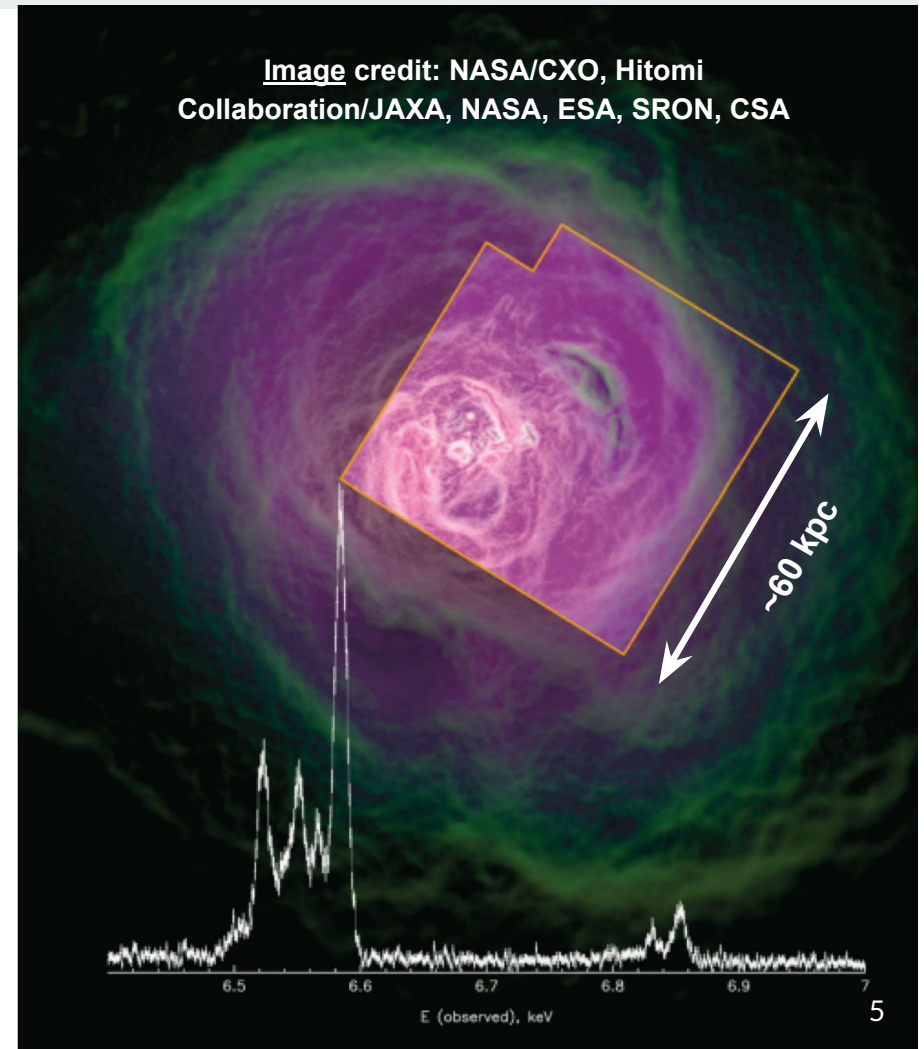
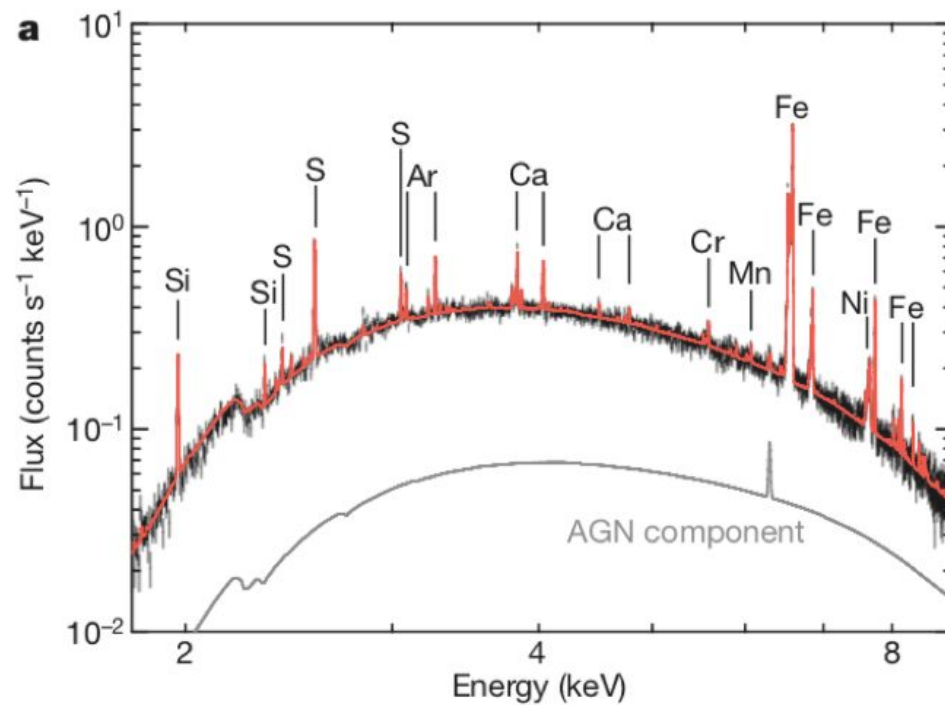
Image credit: [XMM image gallery](#) & [ESA](#)

Mao et al. 2019c



Perseus galaxy cluster

[Hitomi collaboration, 2017, Nature](#)



Supernova (SN)

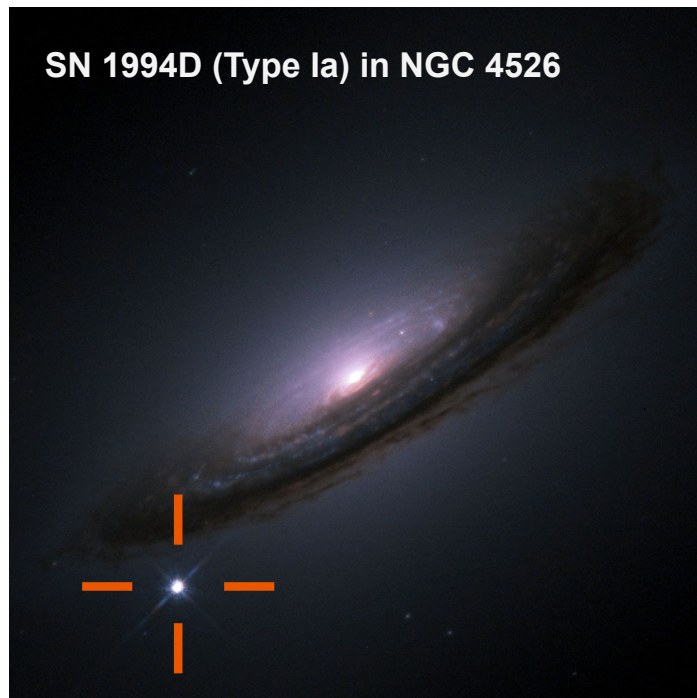


Image credit: NASA/ESA, The Hubble Key Project Team and The High-Z Supernova Search Team

Location of elements in supernova remnant
Cassiopeia A (Type IIb)

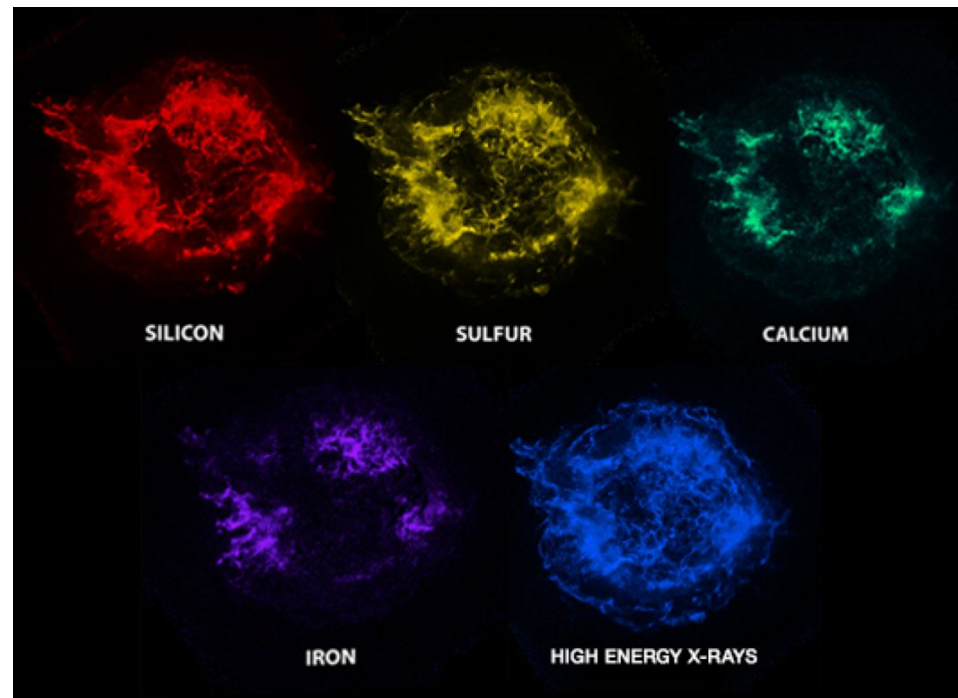
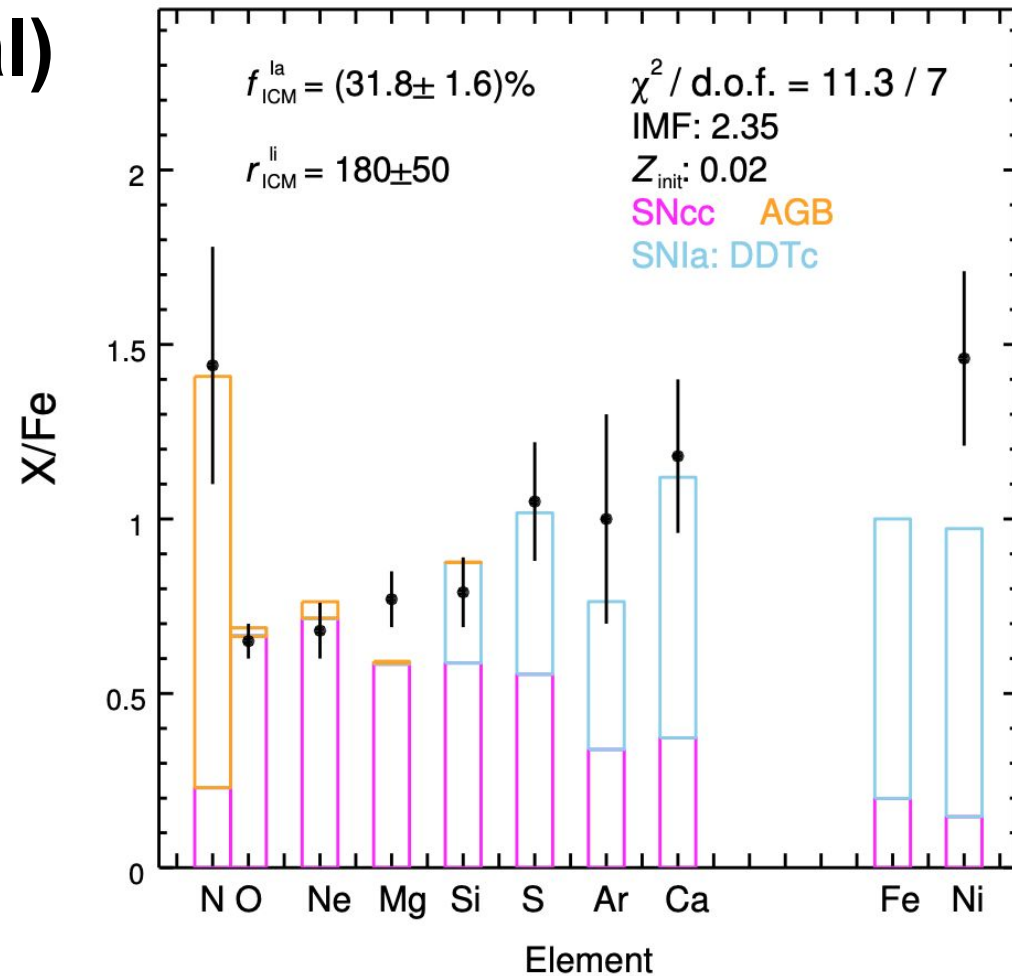


Image credit: NASA/CXC/SAO

NGC 5044 (elliptical)

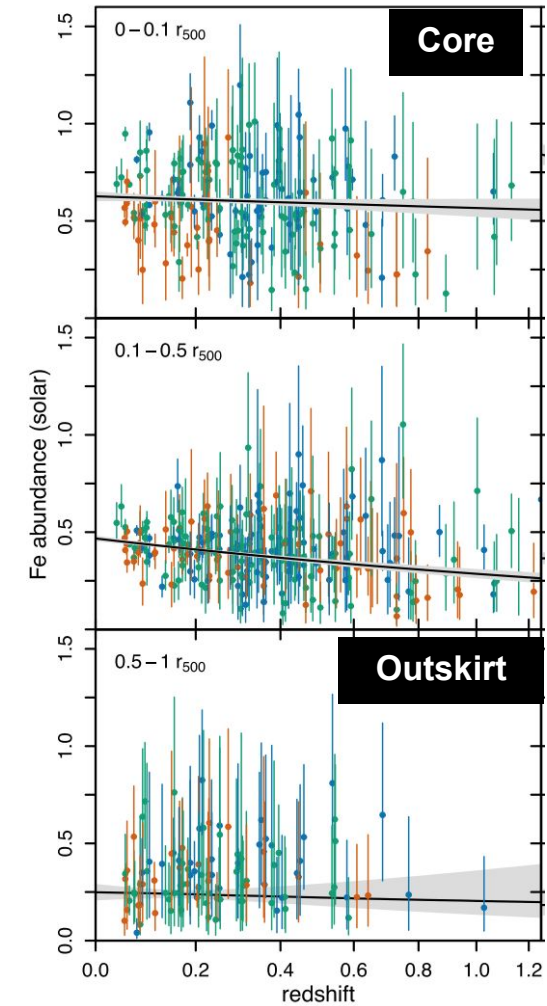
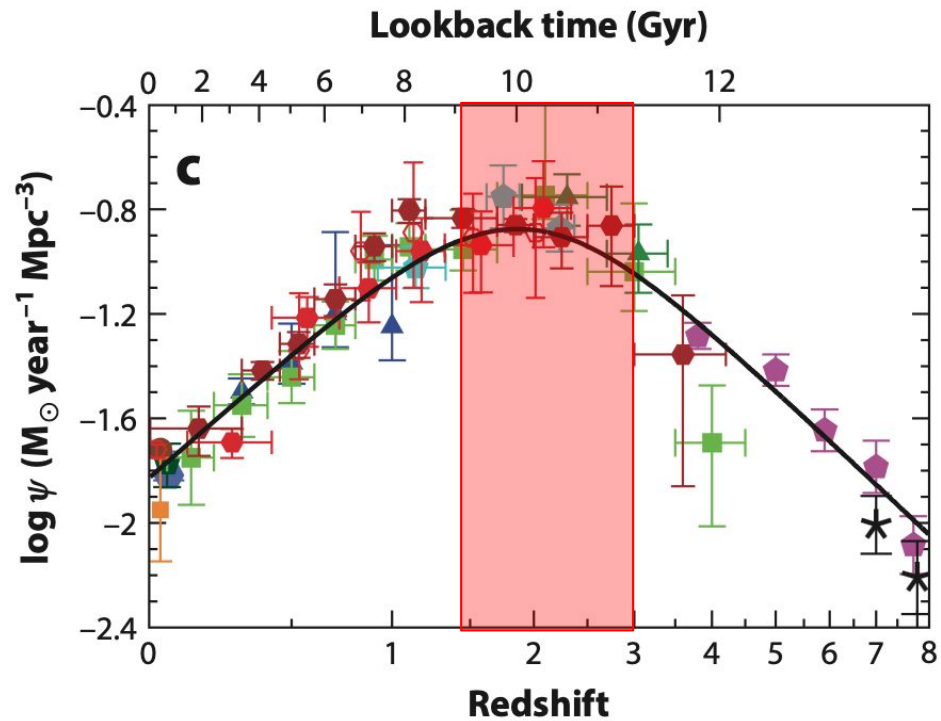
- Type Ia supernovae (SNIa): the main metal factory of Fe and Ni
- Core-collapse supernovae (SNcc) are the main metal factory of O to Mg
- AGBs: the main metal factory of N
- Still more to learn

[Mao et al. 2019a](#)



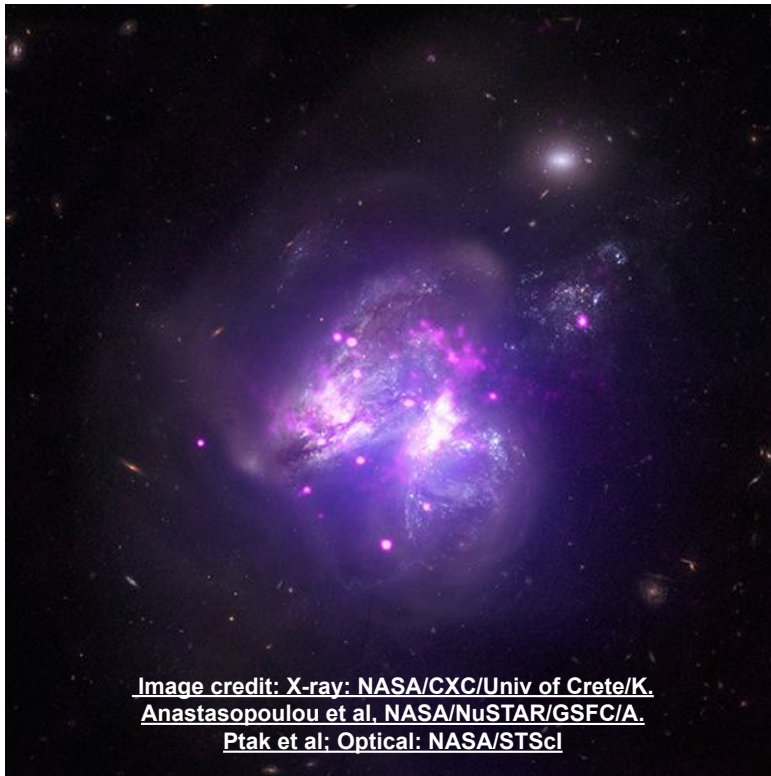
Early enrichment

[Madau & Dickson, 2014, ARAA](#)



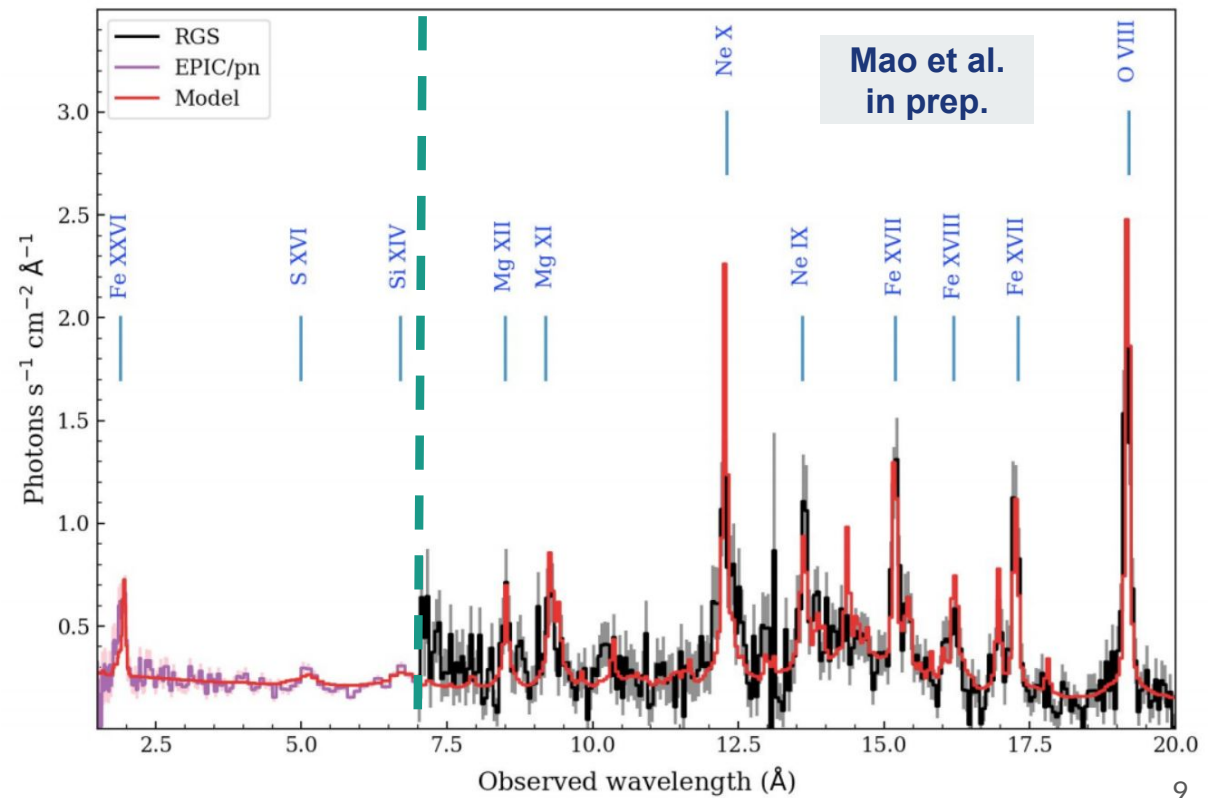
[Mantz et al. 2017 \(see also Ettori et al. 2015 and McDonald et al. 2016\)](#)

Arp 299 (LIRG)



Missing high-mass SNcc progenitors (Smartt 2015)

- Theory: SNcc from massive stars with 8 to 40 M_{sun}
- Observation: SNcc from massive stars up to 25 M_{sun}



AGN ionized winds

- Warm absorber (WA)
- Ultrafast outflow (UFO)
- Obscuring wind

雙
發



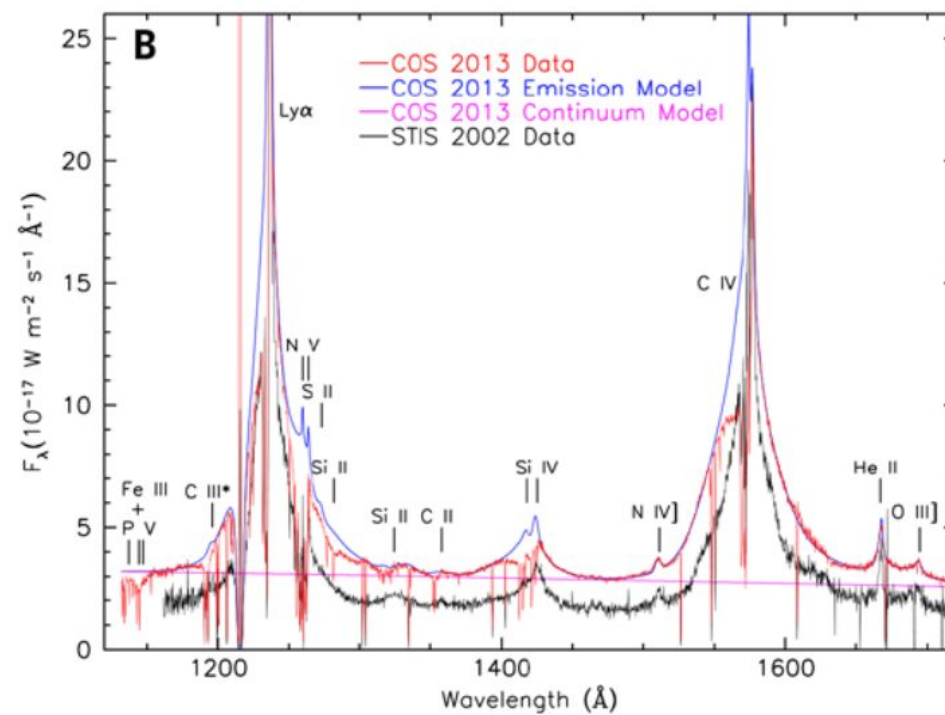
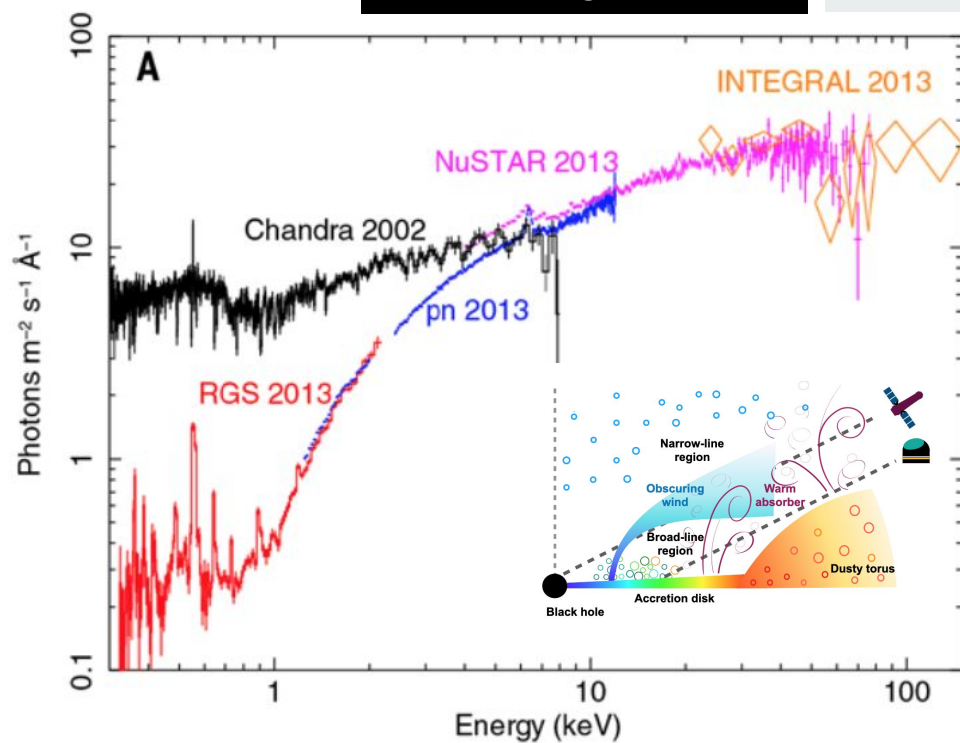
Artist impression of AGN winds
Image credit: NASA

NGC 5548 (Seyfert 1)

X-ray: XMM-Newton,
Chandra, NuSTAR,
INTEGRAL

[Kaastra et al. 2014, Science](#)

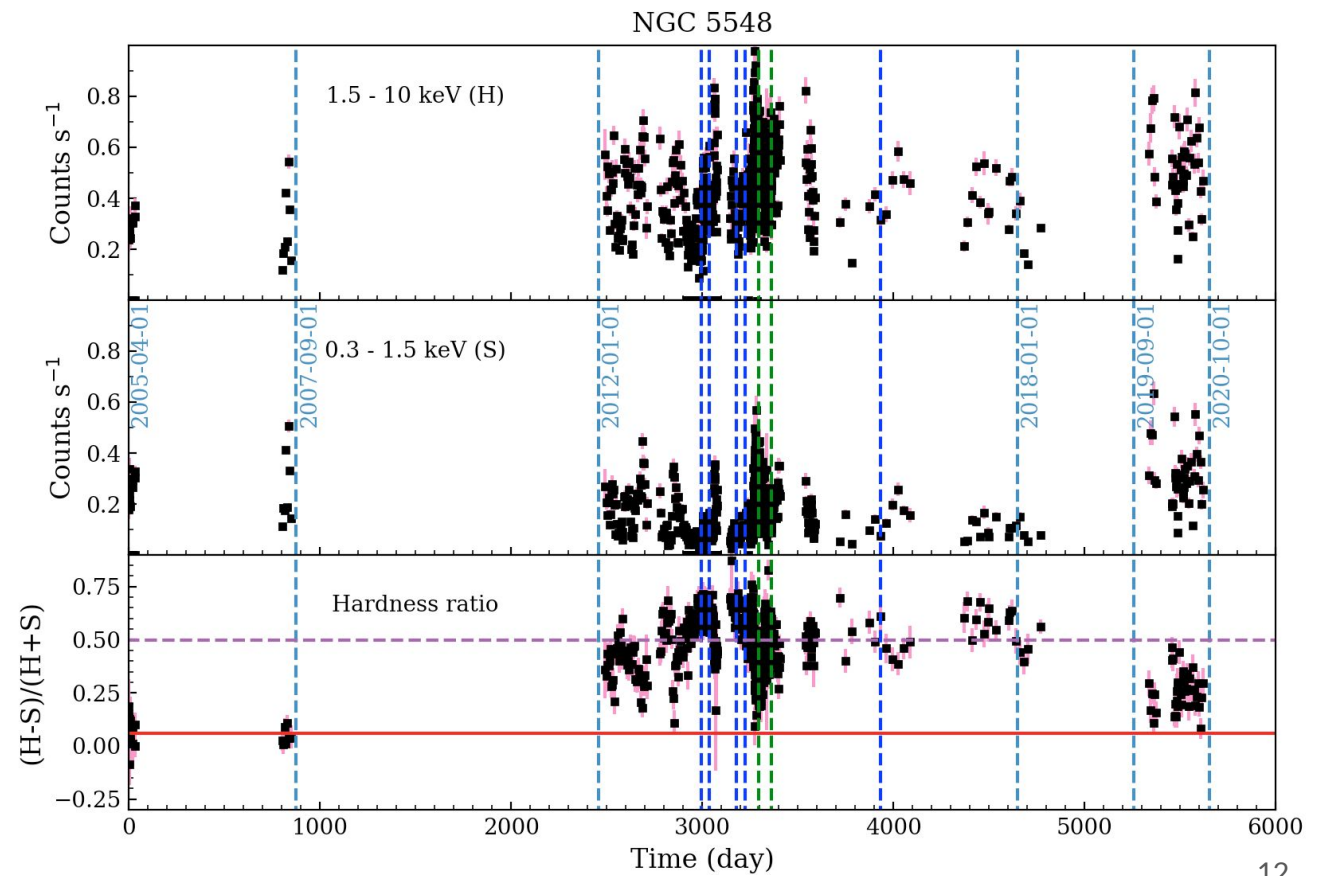
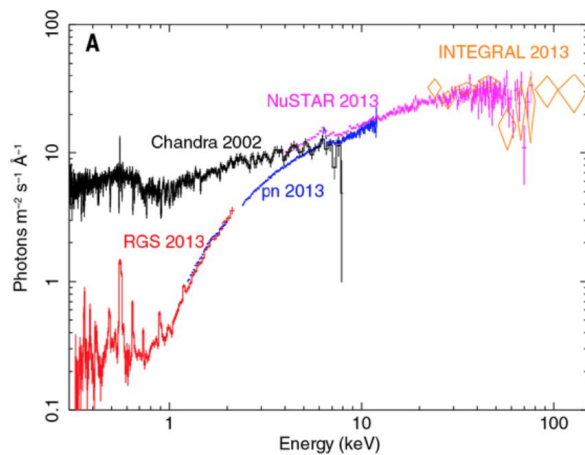
UV: Hubble Space Telescope
STIS or COS



Hardness ratio

Long lasting

- NGC 5548
 - [Kaastra et al. 2014](#)

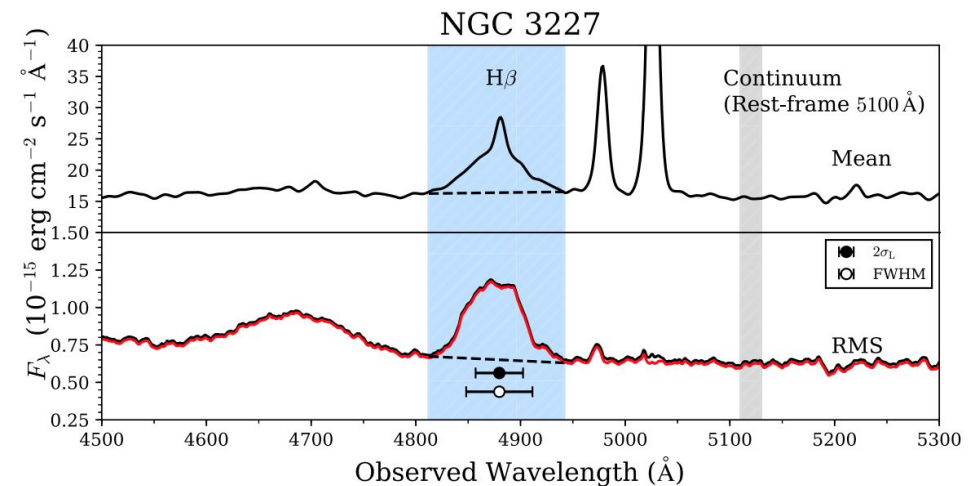
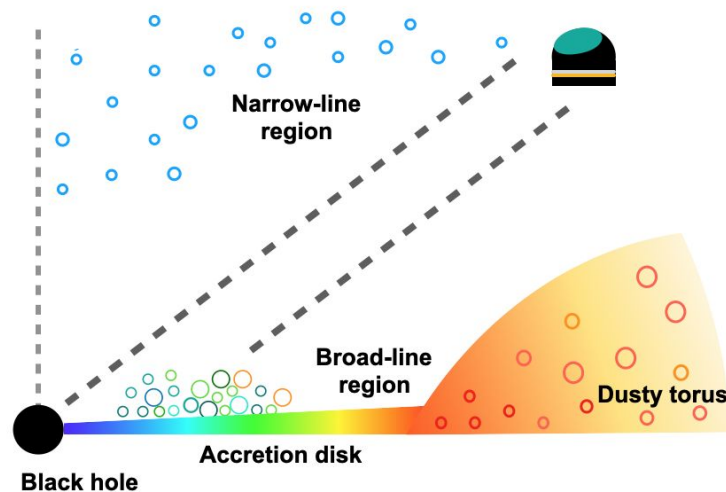


Reverberation mapping

- Textbook anatomy
 - [Urry & Padovani \(1995\)](#)
- Broad-line region
 - Reverberation mapping → M_{SMBH}

$$M_{\text{BH}} = f \left(\frac{c \tau \Delta V^2}{G} \right),$$

[De Rosa et al. 2017](#)

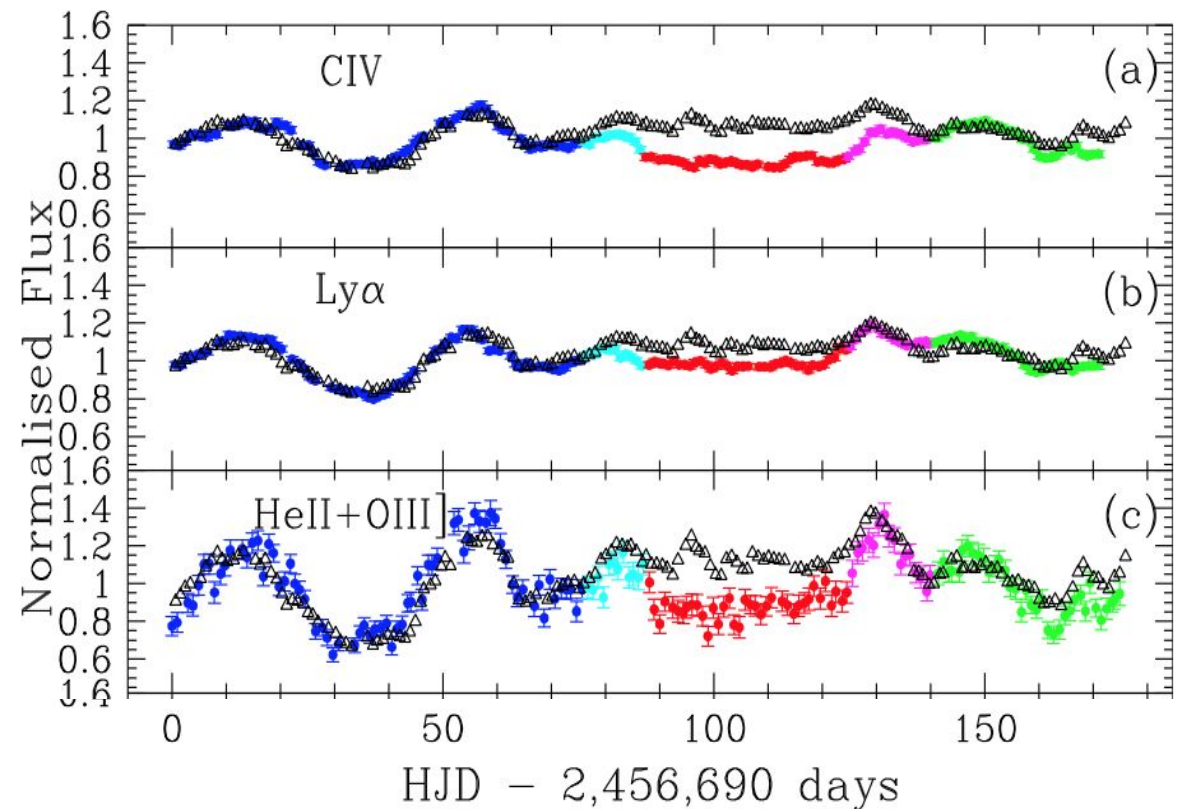


Broad (em.) line holiday

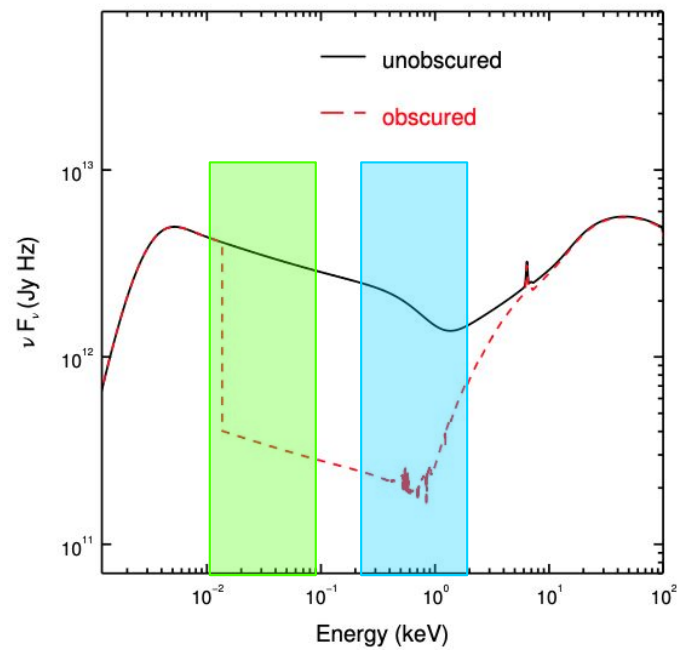
[Goad et al. 2016](#)

NGC 5548

- In 2014, ~70 days of holiday where the broad emission line decorrelates the continuum

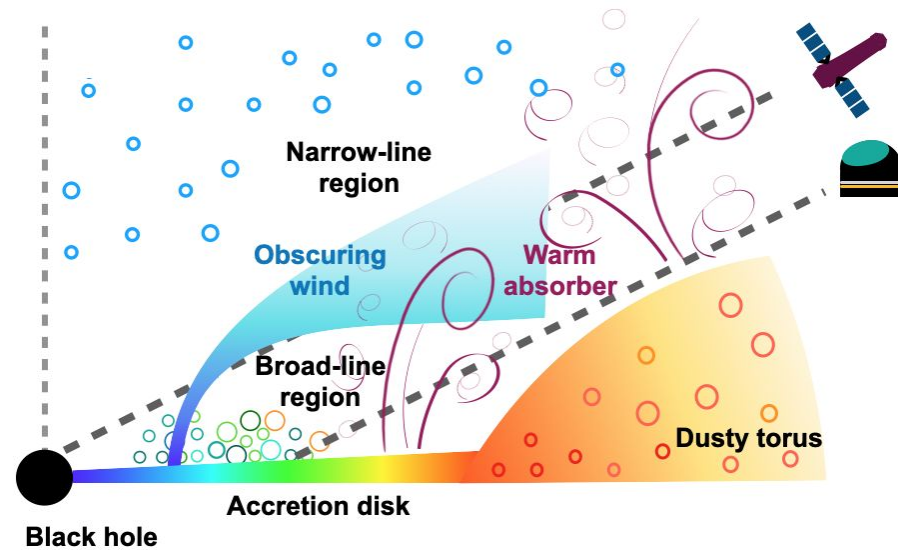


When the wind blows



UV Soft X-ray

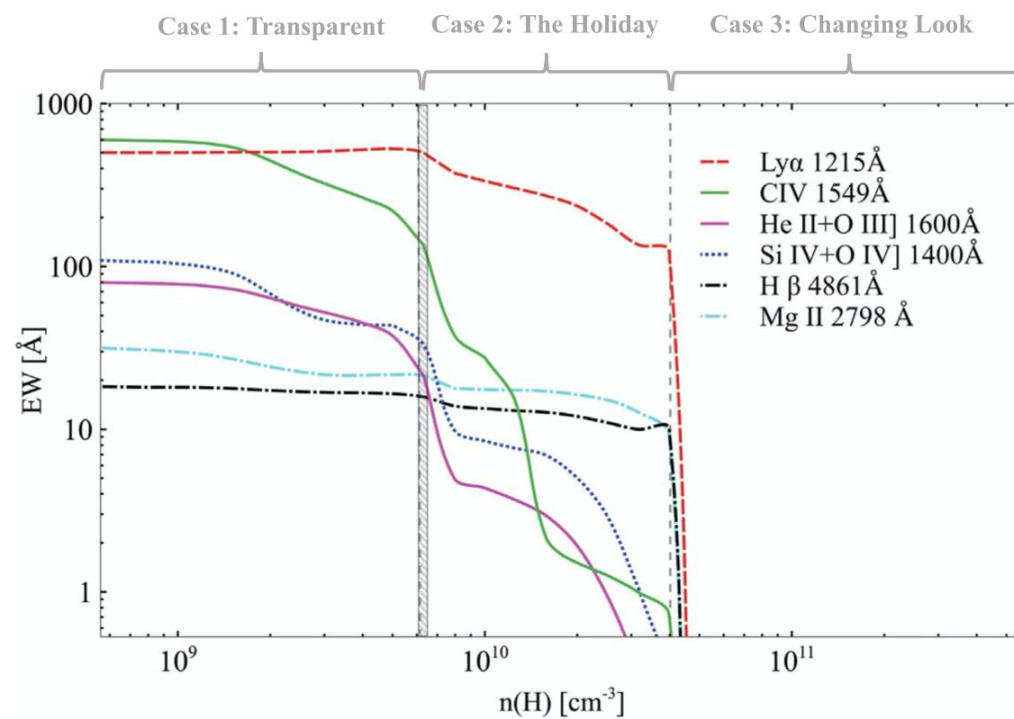
[Mehdipour et al. 2015](#)



Obscuring effect



Dehghanian et al. 2019

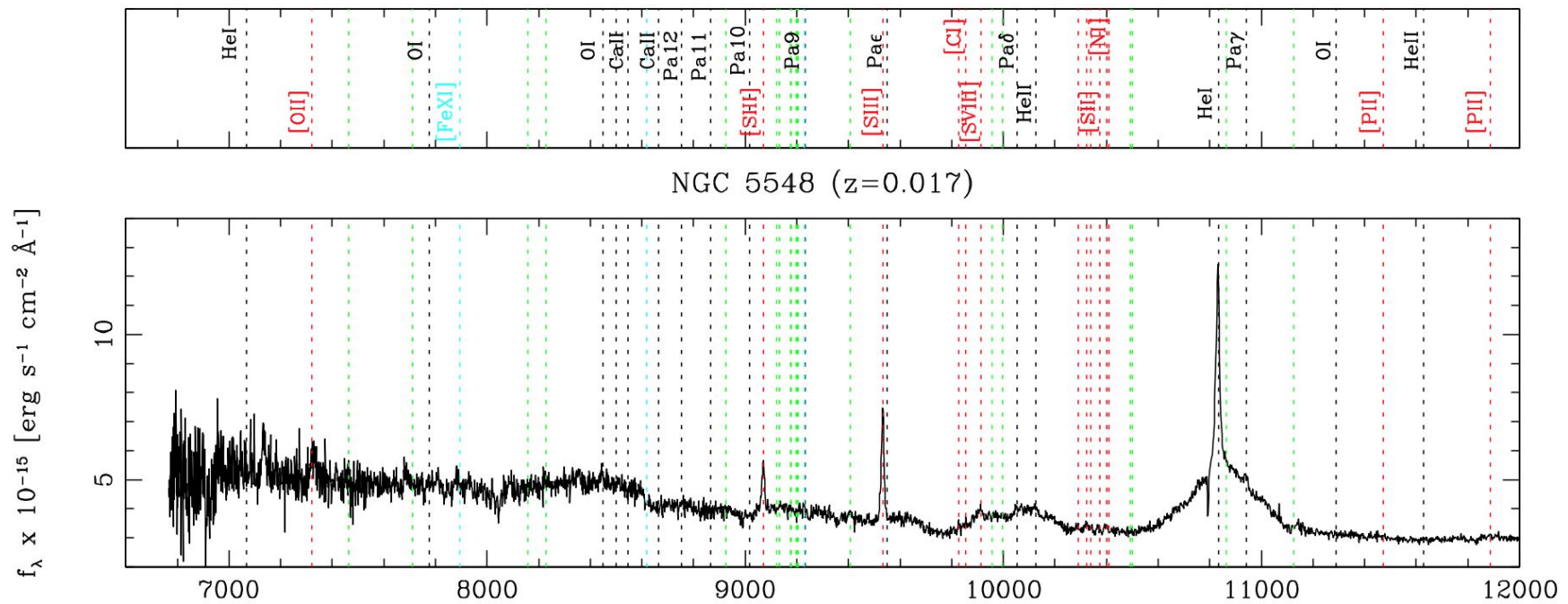


Fingerprints in the NIR band

- NGC 5548 (2016 - 2017)

- He I 1.08* micron

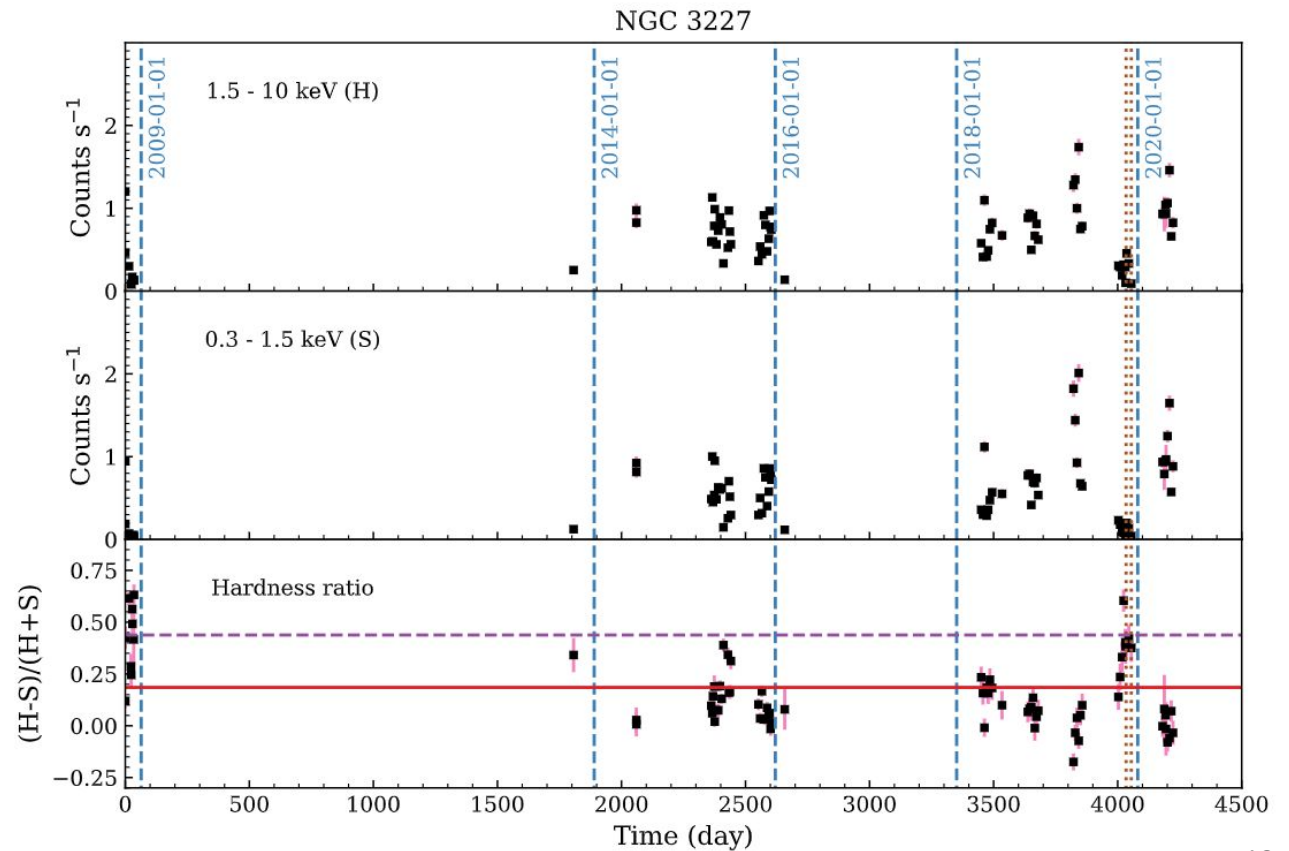
[Landt et al. 2019](#)
[Wildy et al. 2021](#)



Obscuring wind

Long-lived Short-lived

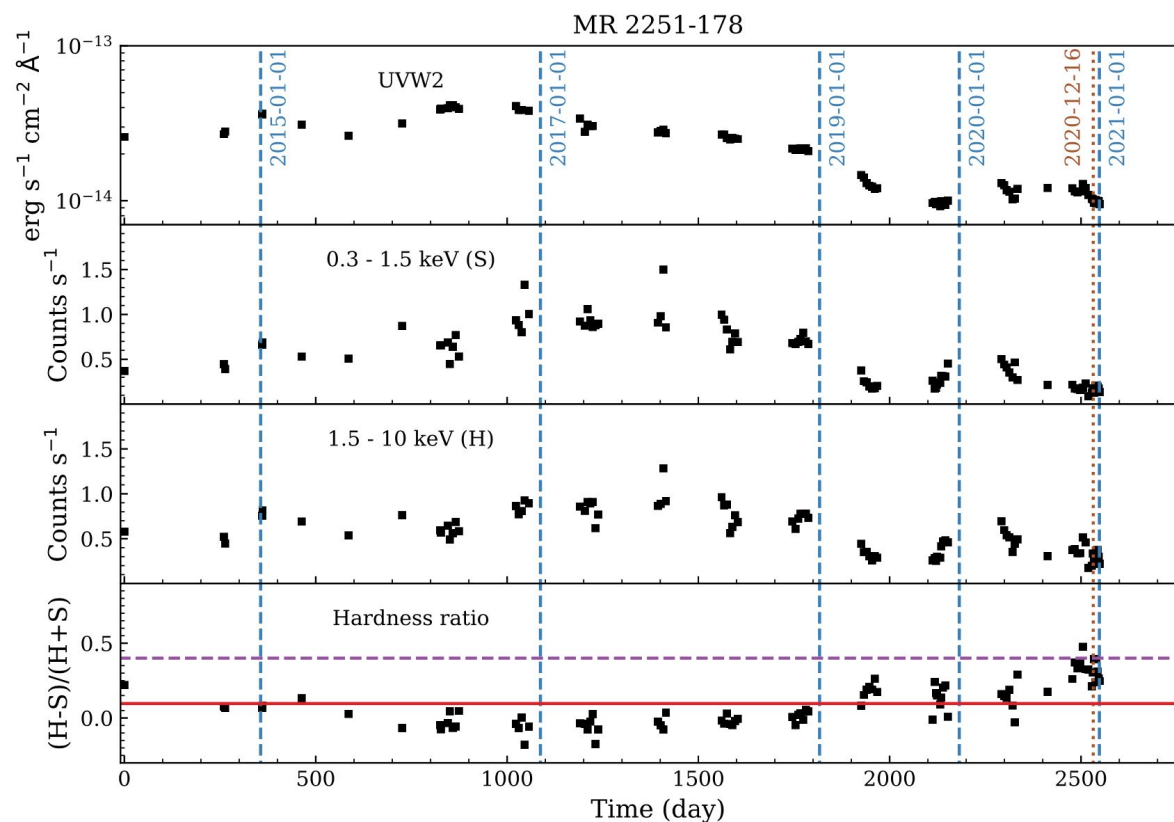
- **NGC 5548**
 - [Kaastra et al. 2014](#)
- **Mrk 335**
 - [Longinotti et al. 2019](#)
- **NGC 985**
 - [Ebrero et al. 2016](#)
- **NGC 3783**
 - [Mehdipour et al. 2017](#)
- **NGC 3227**
 - [Mao et al. in prep.](#)



MR 2251-178 (quasar)

Long-lived Short-lived
Unknown (yet)

- **NGC 5548**
 - [Kaastra et al. 2014](#)
- **Mrk 335**
 - [Longinotti et al. 2019](#)
- **NGC 985**
 - [Ebrero et al. 2016](#)
- **NGC 3783**
 - [Mehdipour et al. 2017](#)
- **NGC 3227**
 - [Mao et al. in prep.](#)
- **MR 2251-178**
 - [Mao et al. in prep.](#)



Opportunities and challenges

Hitomi collaboration, 2016

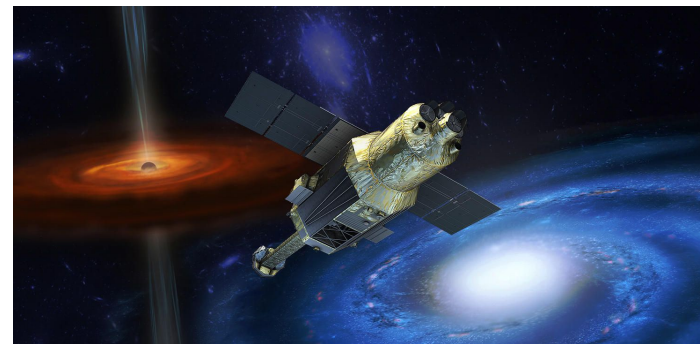
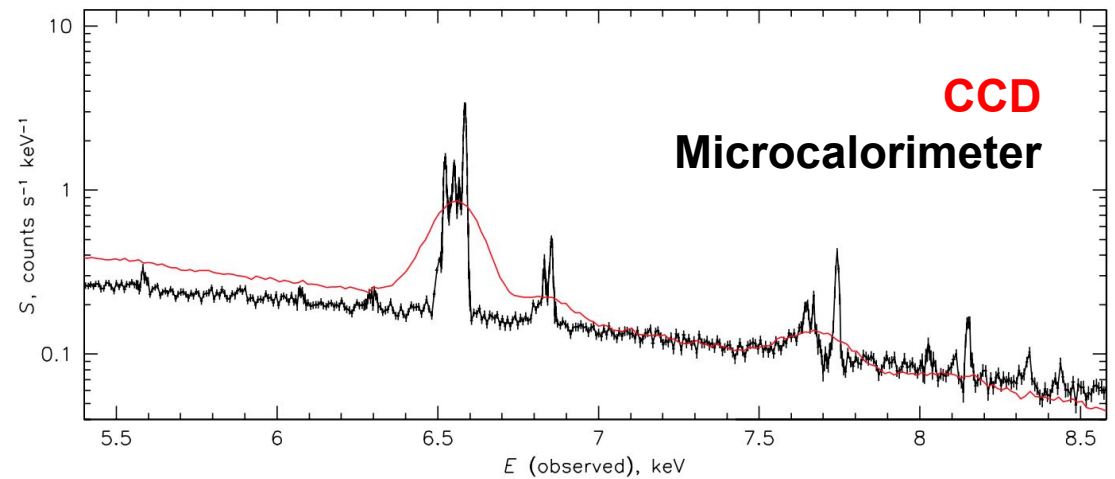
Plasma codes

- AtomDB/APEC v3.08
- CHIANTI v8.0
- SPEX v3.03.00

Uncertainty

- Fe abundance: 16%
- Statistical: ~1%

Hitomi collaboration, 2018, PASJ, 70, 12
(The Atomic Paper)



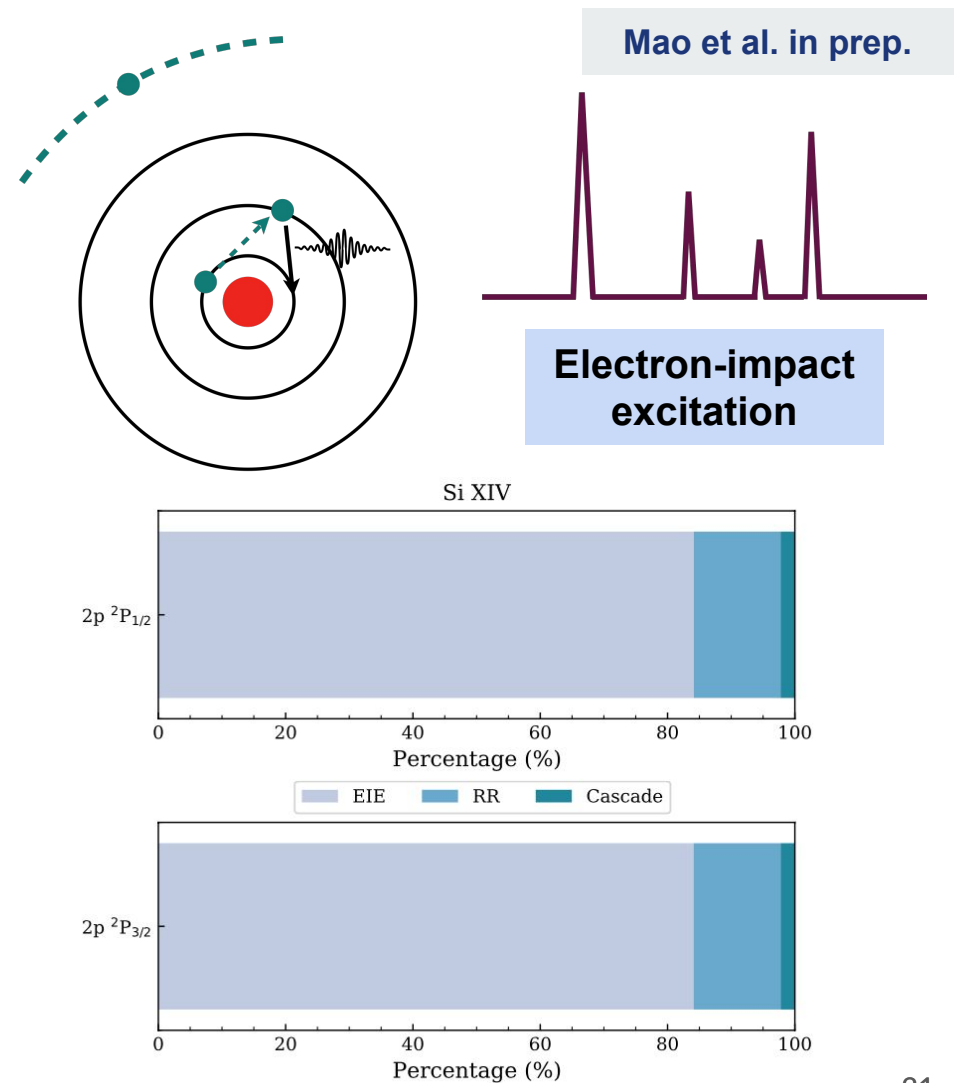
Hitomi
Image credit:
ISAS

Atomic data

Plasma codes are built on a large and ever-increasing amount of atomic data

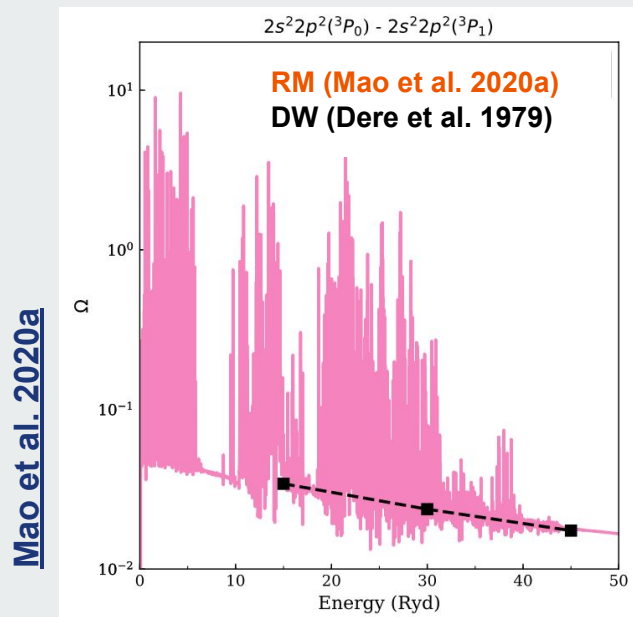
- (de-)Excitation
 - Electron
 - Proton
- Ionization
 - Photon
 - Electron
- Recombination
 - Radiative + dielectron
 - Charge exchange

... ..

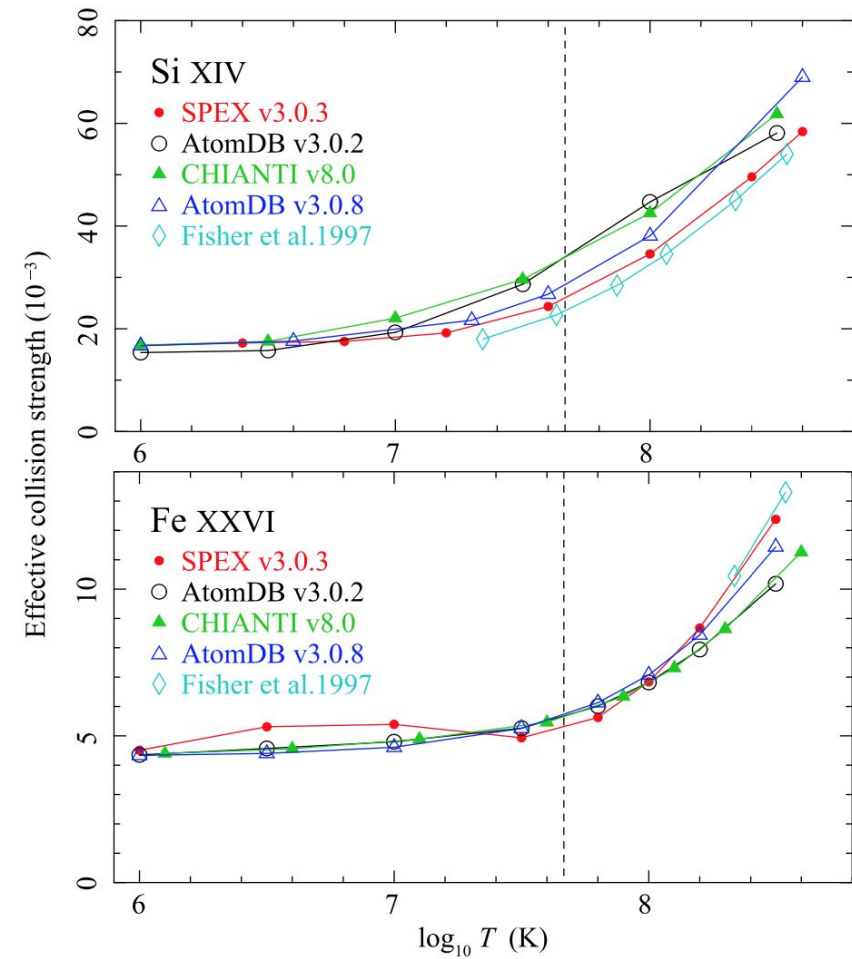


Electron-impact excitation

- Distorted wave (DW)
- R-matrix (RM)



[Hitomi collaboration, 2018, PASJ, 70, 12](#)



Summary

- High-resolution spectroscopy of ionized plasmas linking black holes, stars, and galaxies
 - AGN classical and obscuring winds
 - Chemical enrichment of hot atmosphere of galaxies
 - Continuous development of plasma codes (incl. atomic data)



xmm-newton



1999 -- 2020 -- 2030+

