The European Extremely Large Telescope and accreting black holes

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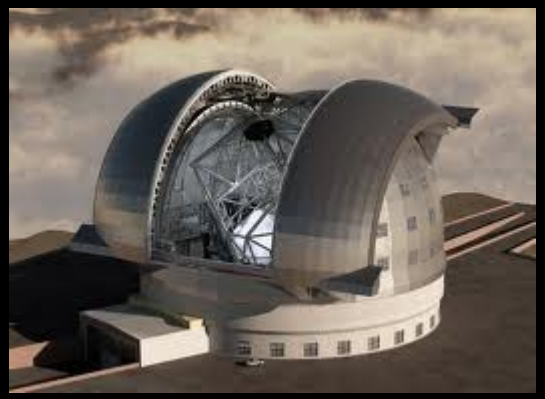


Accreting black holes at different masses

So far, we could confirm the presence of...

...stellar mass black holes : M = tens of solar masses
...suppermassive black holes: $10^5 < M < 10^9$

We are still looking for black holes at intermediate masses.

BH X-ray binaries

AGN

Ultraluminous X-ray sources and the E-ELT

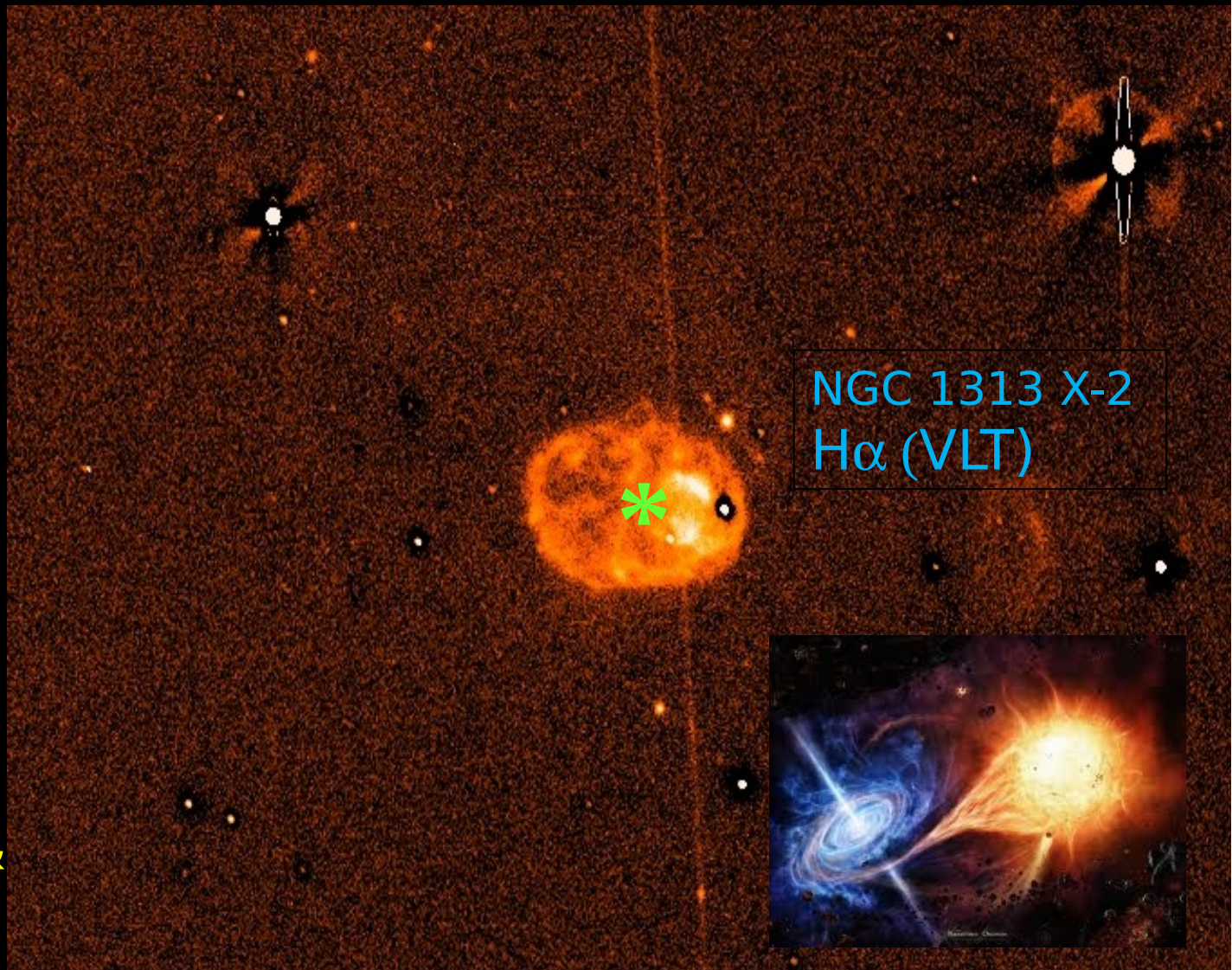
What is a ULX ? – An extragalactic, *non-nuclear*, very strong and compact X-ray source with $L_x > 3 \times 10^{39}$ erg/s

Their optical counterparts generally have $V > 22$-23

They are often surrounded by emission nebulae that indicate

$$L_{mech} \approx L_X$$

(result found in the optical band, Pakull & Mirioni 2003)



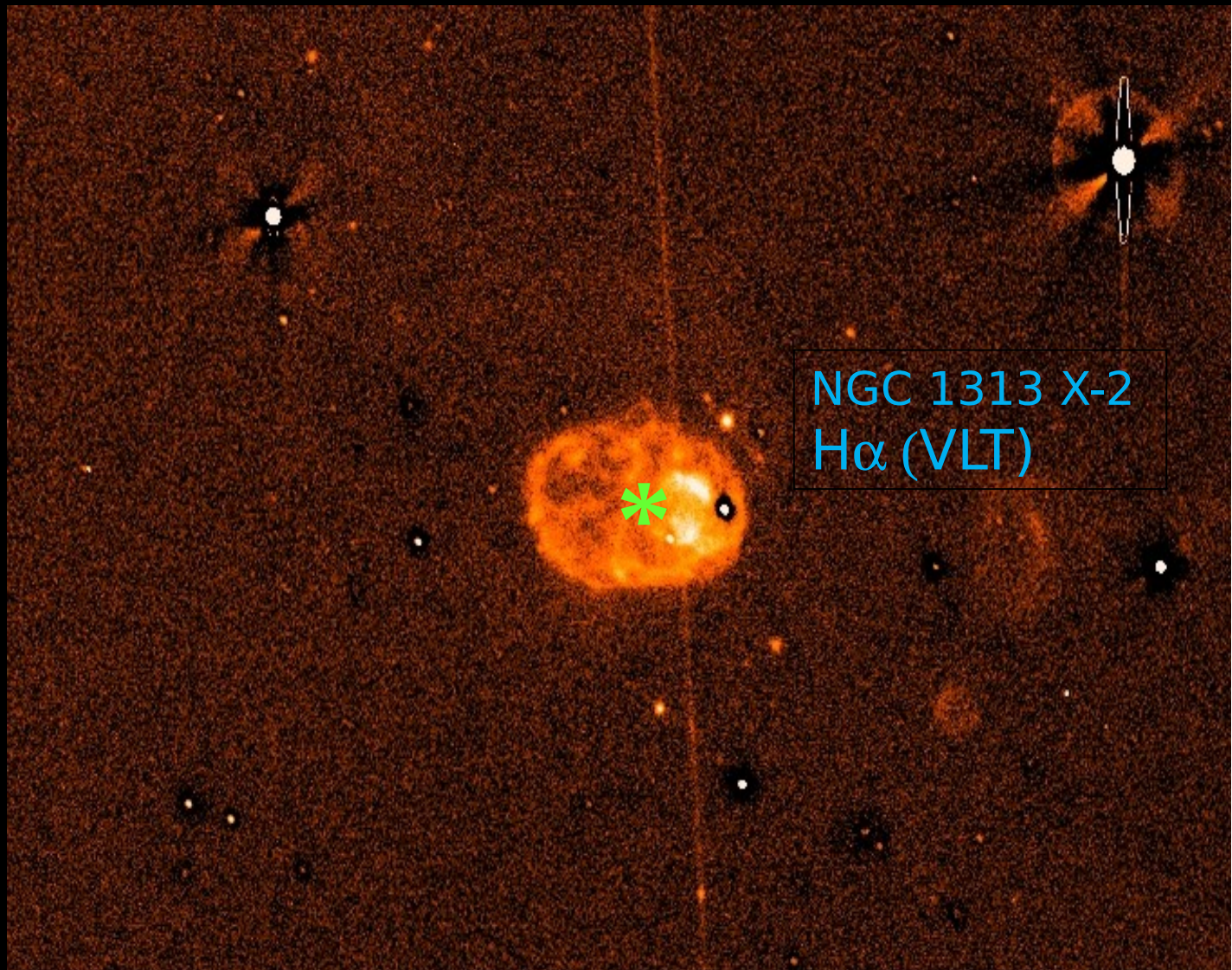
Ultraluminous X-ray sources and the E-ELT

How do ULXs work ? – By accretion onto a compact star (most probably a black hole in a binary system).

- stellar mass black hole and accretion at super-Eddinton rate ?

- accretion onto an intermediate mass black hole ?

- dominated by beamed emission ? **No!** Derived from X-ray photo-ionized nebulae (Pakull & Mirioni 2002)



Ultraluminous X-ray sources and the E-ELT

Do ULXs host IMBH or are they super-Eddington sources ?

The most reliable method is to measure the dynamical mass of black holes in ULXs (relying on Kepler's 3rd law) : long-term, medium resolution, optical monitoring of ULXs to derive the velocity curve of the companion star.

Results: so far, most often disappointing!

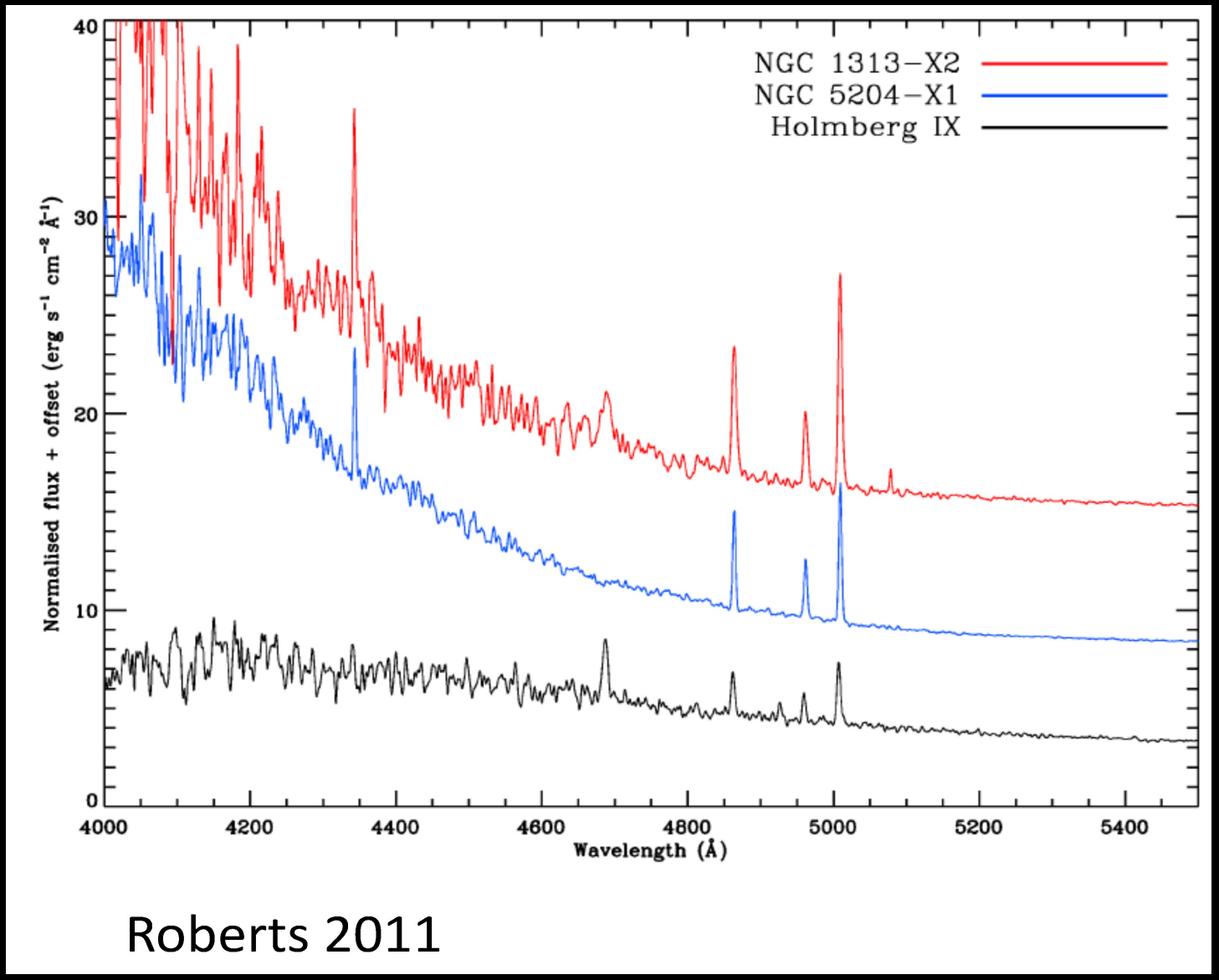
- One can find the HeII λ4686 line being the hallmark of a binary system (from the accretion disk), but hardly any absorption lines from the stellar wind of the companion.

- *Even Worse:* HeII λ4686 often has an erratic time-dependence and the system period must be carved out by time-dependent, high resolution spectroscopy

→ task for the E-ELT to reach far away ULXs!

Ultraluminous X-ray sources and the E-ELT

What can be done nowadays with the VLT for ULXs...

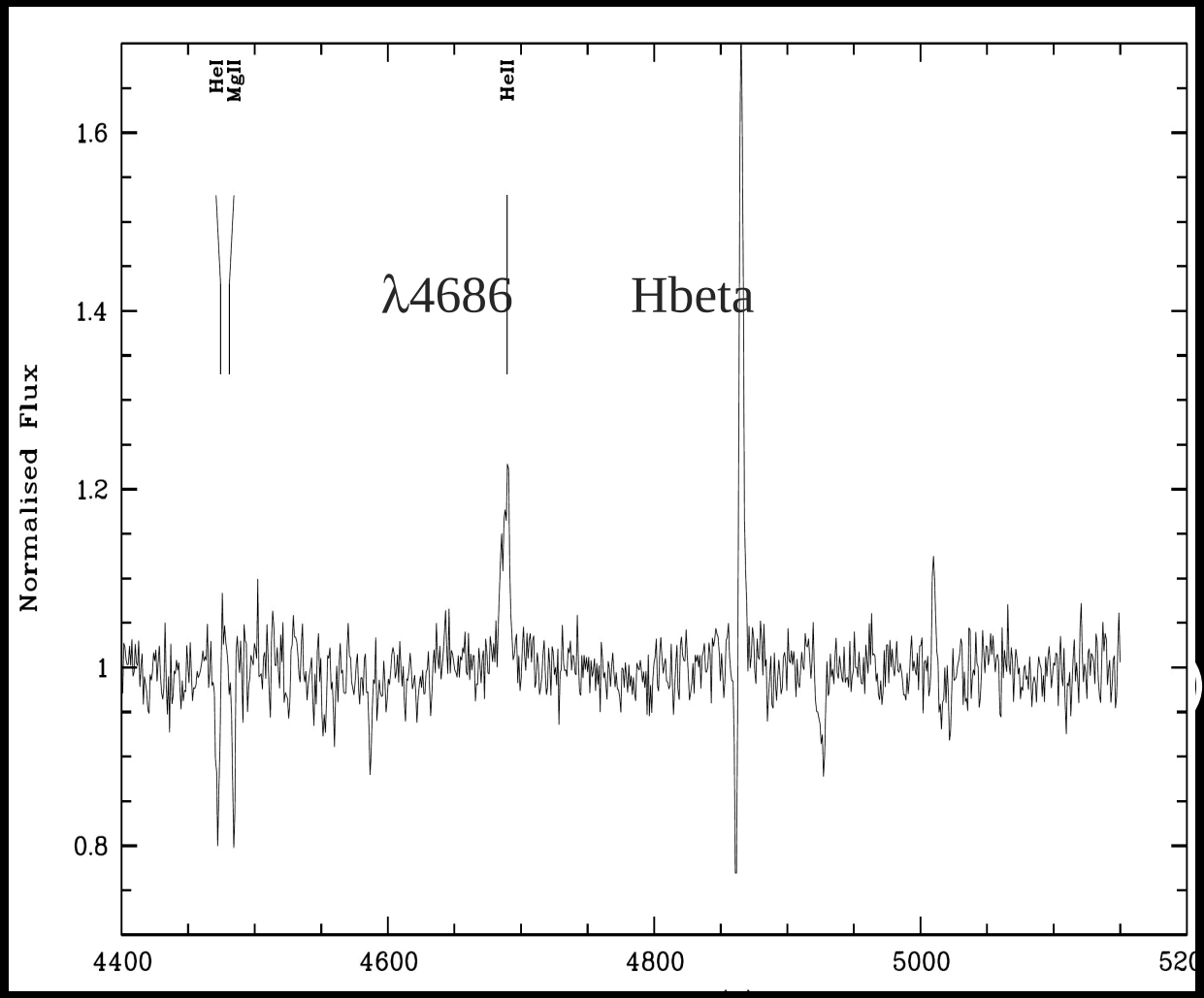


Roberts 2011

Spectra still rather noisy, absorption lines hard to disentangle...

Ultraluminous X-ray sources and the E-ELT

What can be done nowadays with the VLT for
the optically brightest ULX in th sky: NGC 7793
in the Sculptor galaxy at a distance of 3.7 Mpc...



$V \sim 20.5$
10x brighter than
other ULX!

$P_{orb} = 65$ days;
dynamical mass
$M < 15\ M_{sol}$

(Motch, Pakull, Soria,
& Grisé 2013)

The E-ELT can go 10x
lower in brightness!

The Galactic Center: one of the richest regions of the sky

* Distance ~ 8 kpc

* High column density along the line-of-sight: $N_H \sim 5\text{-}7 \times 10^{22}$ cm^{-3} ($A_v \sim 25\text{-}30$)

$\Rightarrow$ 'only' observable in radio, IR, X-rays ($\geq$ 1-2 keV) and γ-rays

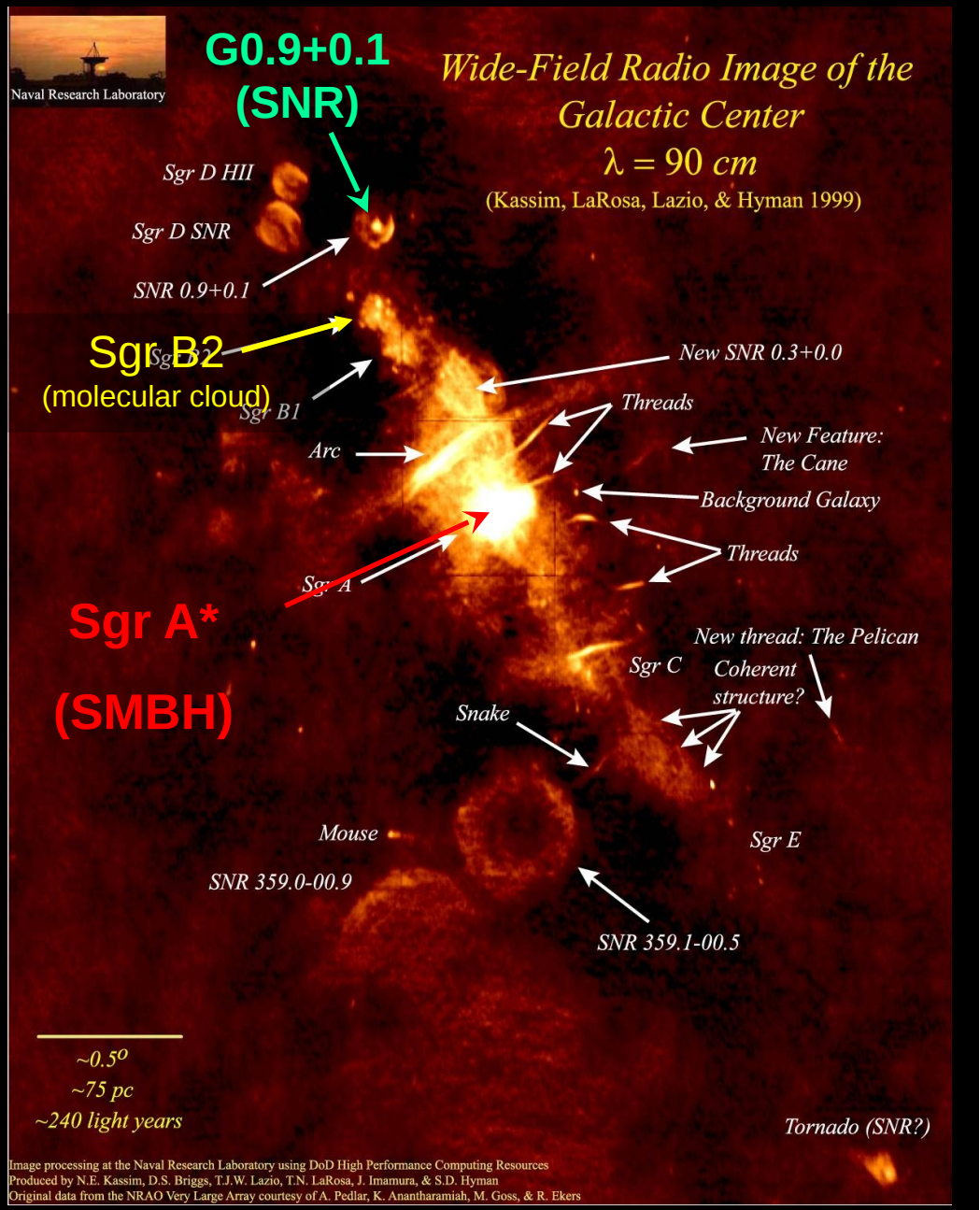
* Extended objects:

SNR, molecular clouds, non-thermal, filaments, diffuse emission, …

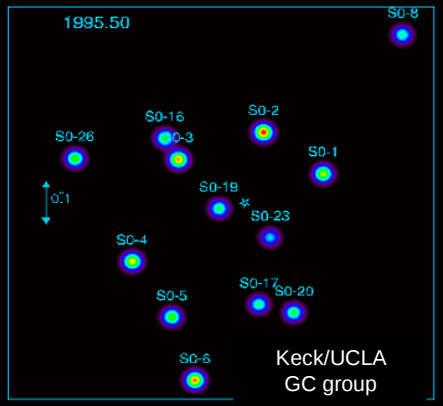
* Stars

* Compact objects:

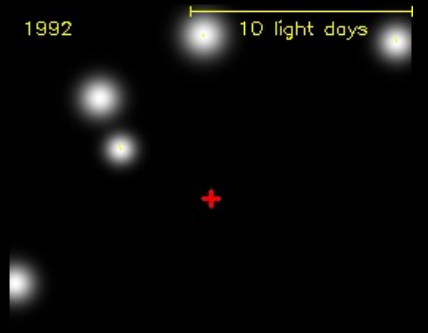
X-ray binaries (neutron stars, black holes, white dwarfs), **Sgr A***, …



Sgr A*: a SMBH at the Galactic center



- Closest supermassive black : D ~ 8 kpc
- Stellar orbits ⇨ M_{BH} ~ 4 x 10^6 M_{sun}

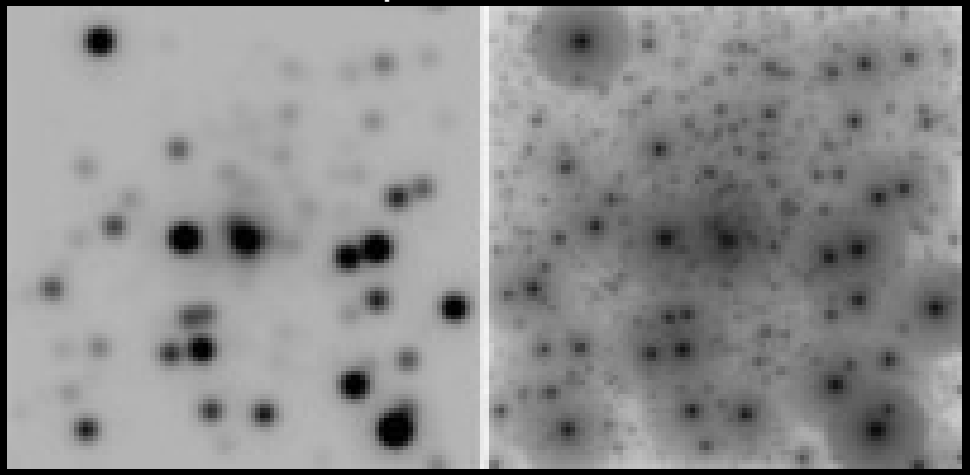


Schödel, R. et al. 2002, Nature

Largest black hole (in projection)
⇨ best place to test GR directly in a strong gravitational field.

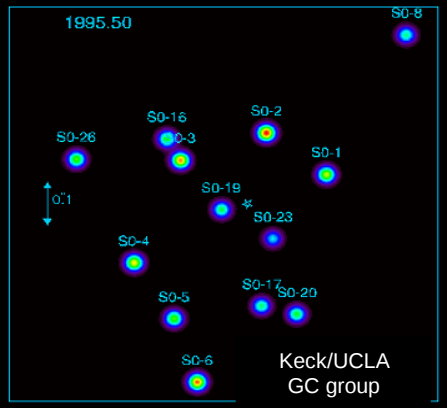
But current studies are confusion-limited in both the spatial and spectral dimension

8–10 m telescopes E-ELT/MICADO

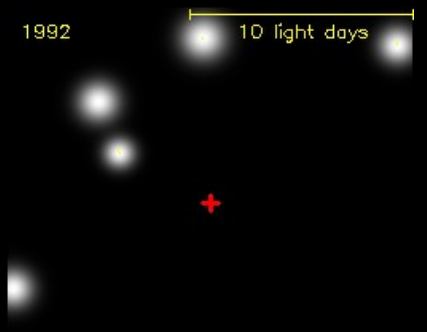


(Trippe et al. 2010; Paumard et al. 2010)

Central 1×1 arcsec^2 (8000×8000 a.u.) of the nuclear star cluster of the Milky Way at 2.2 μm.



Perspectives with the E-ELT



Schödel, R. et al. 2002, Nature

- Study of stars as close as 100 R_s (8.2 a.u.) where v_{orb} ~ 1/10 c
  (i.e. 10 time closer than achieved with the current 10-m telescopes) thanks to:
  - Extremely accurate measurements of the positions of the stars (50-100 mas)
  - Radial velocity measurements with ~1 km/s precision

- Test the predicted relativistic signals of BH spin and the gravitational redshift caused by the BH, and even detection of GW effects.

- DM distribution around the BH (predicted by cold DM cosmologies).

- The distance to the GC and mass of SgrA* will be measured to < 0.1%
  (Size and shape of the Galactic halo, and the Galaxy's local rotation speed)

(See Paumard et al. 2010)

Sgr A* a “quiescent” SMBH but not inactive

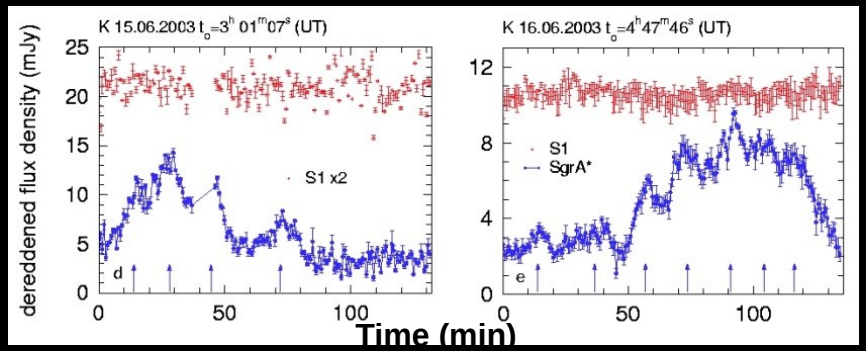
- Bolometric luminosity: L_{bol}~10^{36} erg/s ~ x 100 L_{sun} ! << AGN (≥ 10^{42} erg/s)
  10^{-8}-10^{-9} times weaker than the Eddington luminosity

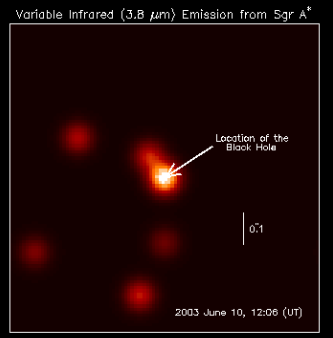
⇒ Extremely low radiative efficiency and low accretion rate.

BUT not inactive: flares first discovered in X-rays (Oct. 2000), then in IR in 2003.

⇨ new perspectives for the understanding of the processes at work in the Galactic nucleus and in “quiescent” supermassive black holes in general.

Genzel et al. (2003): VLT/NACO adaptive optics





Keck II 10 m: adaptive optics L’ (3.8 μm)

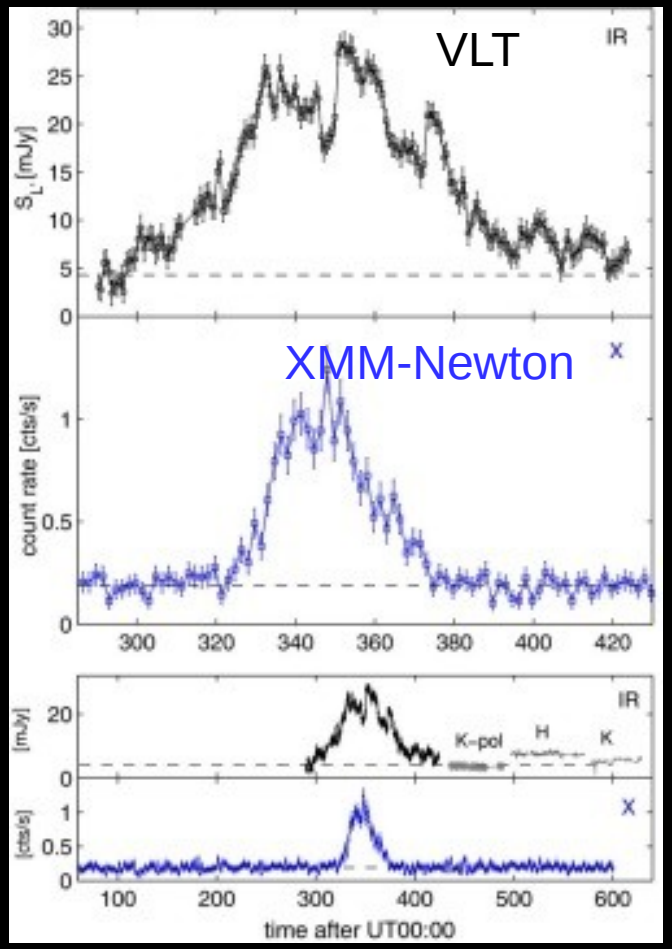
Ghez et al. (2004)

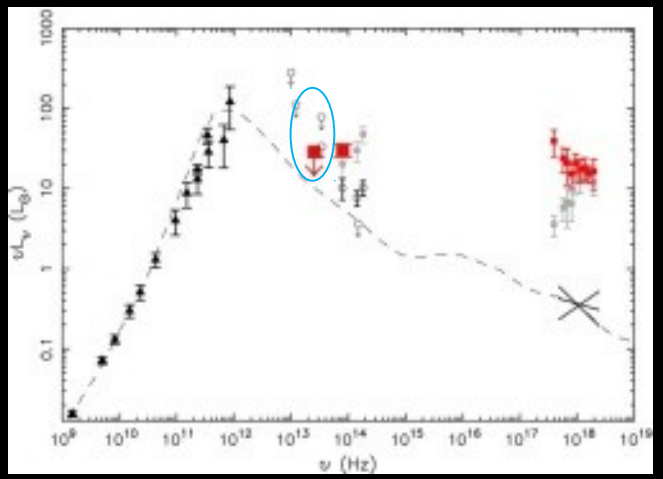
IR flares:

- Position within < 10 mas from Sgr A*
- Frequency: several per day (~30-50% of time), with duration ~ 20 - 130 min
- Origin: Synchrotron emission

Brightest IR/X-ray flare (April 4th 2007)

(Porquet et al. 2008; Dodds-Eden et al. 2008)





⇨ Most viable scenario for the X-ray emission: synchrotron from an electron distribution with a cooling break.

However other scenarios have also been proposed: Synchrotron self-Compton (Sabha et al. 2010) and Inverse Compton (Yusef-Zadeh et al. 2012).

Strong timing and spectral constraints in both MIR/NIR (E-ELT) and X-rays (ATHENA):

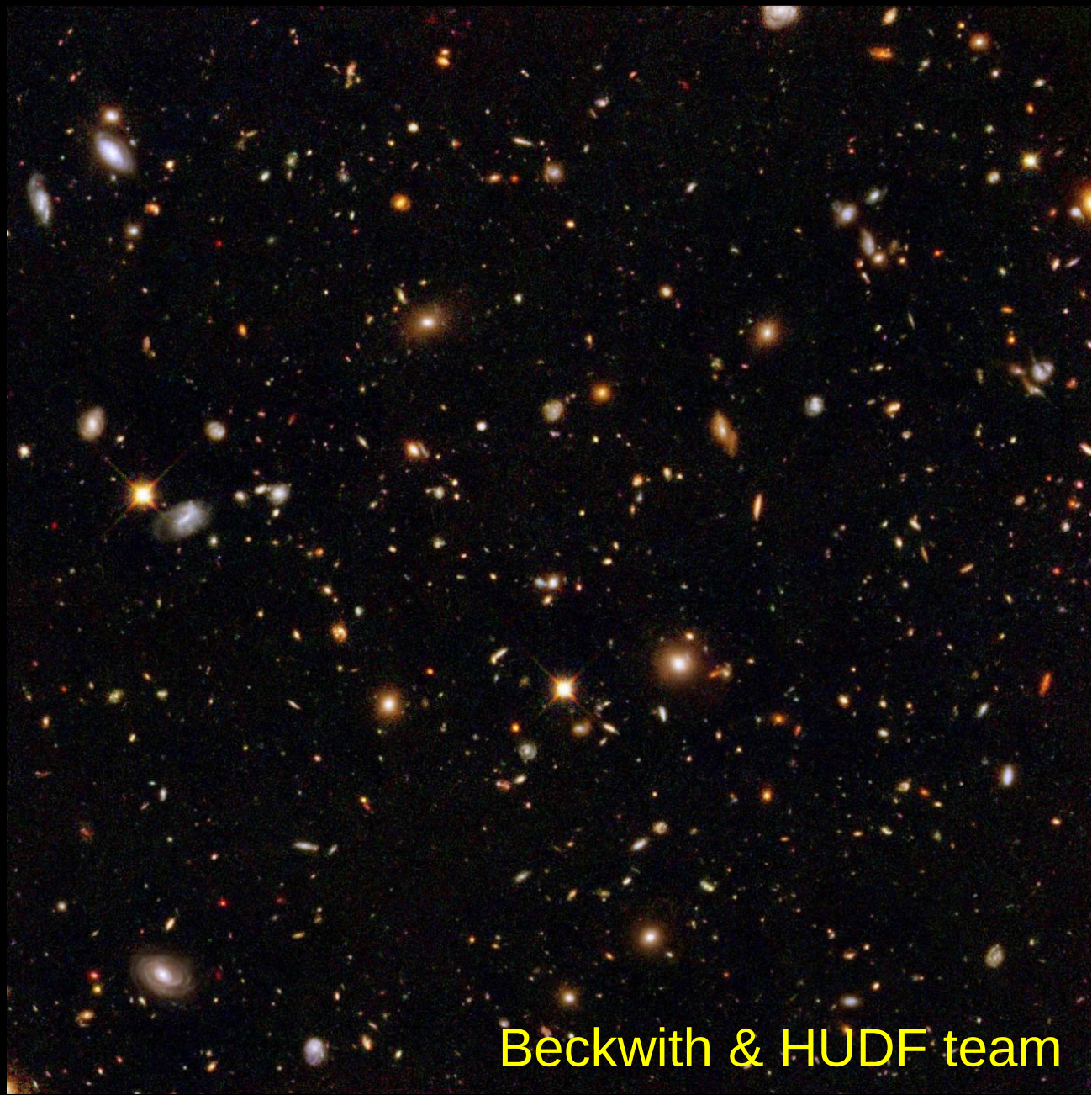
⇨ determination of flaring X-ray emission mechanisms that can produced x160 amplitude flares in flux ! ;

⇨ Determination of the physical properties of the IR/X-rays flaring emitting region, e.g.: Size, electron temperature, total number of synchrotron emitting electrons, electron distribution, magnetic field, …

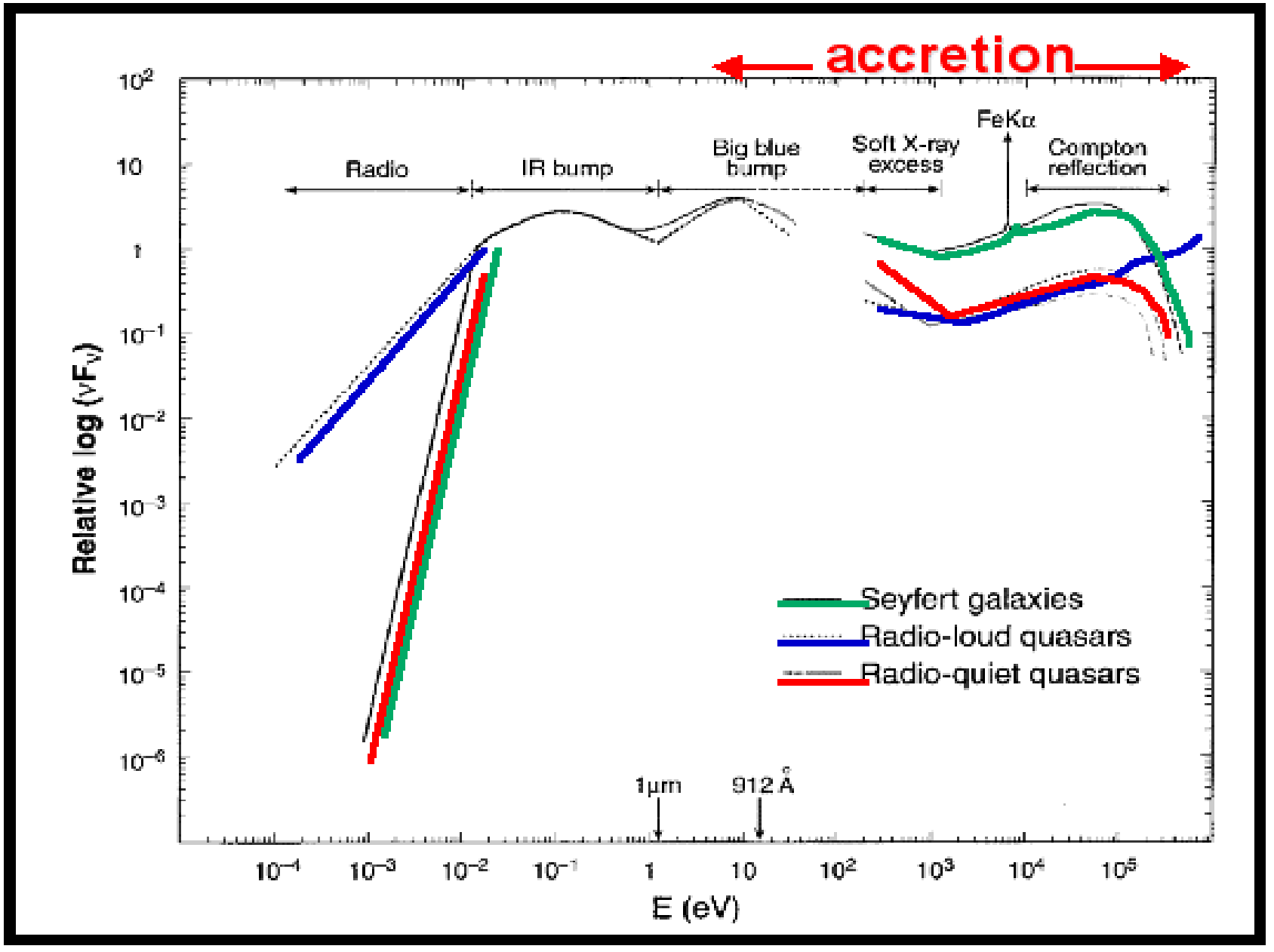
The role of Active Galactic Nuclei in Astrophysics

- *very luminous* from the X-ray to the radio band
  - → tracers of baryonic matter in the far-away universe
  - → contribution to the re-ionization of the universe
  - → connection to the evolution of galaxies

- contain a *supermassive black hole* at the center
  - → application of General Relativity in strong fields
  - → laboratory for black hole accretion



The AGN spectrum and the standard model



Collin (2001), Sanders et al. 1989

Optical fact sheet for the unified model of AGN

- Strong energy release in a limited spatial region due to accretion onto a central supermassive black hole (10^6—10^9 solar masses)
- In radio-quiet objects, the bulk continuum emission comes from an accretion disk.
- In radio-loud objects (~10% of all AGN), strong continuum emission also comes from the jets.
- Around the accretion disk, high velocity clouds reprocess the continuum producing broad emission lines.
- The broad lines are seen at lines of sight not going through the equatorial dust lanes (type-1 AGN).
- At viewing angles blocked by the dust, only narrow lines are seen (type-2 AGN).

What the E-ELT can do for AGN

- Direct determination of stellar dynamics and gas rotation very close to the central engine of active galactic nuclei:
  - ➔ mass measurements for more and/or more distant SMBH
  - ➔ better constraints on the $M_{BH} - \sigma$ relation
  - ➔ Imaging of the morphology of the outer accretion flow: geometry of the "torus" and nuclear outflows

- Imaging of the stellar star cluster and discrimination between an active nucleus and star bursts:
  - ➔ better constraints on possible feed-back scenarios in galaxy evolution

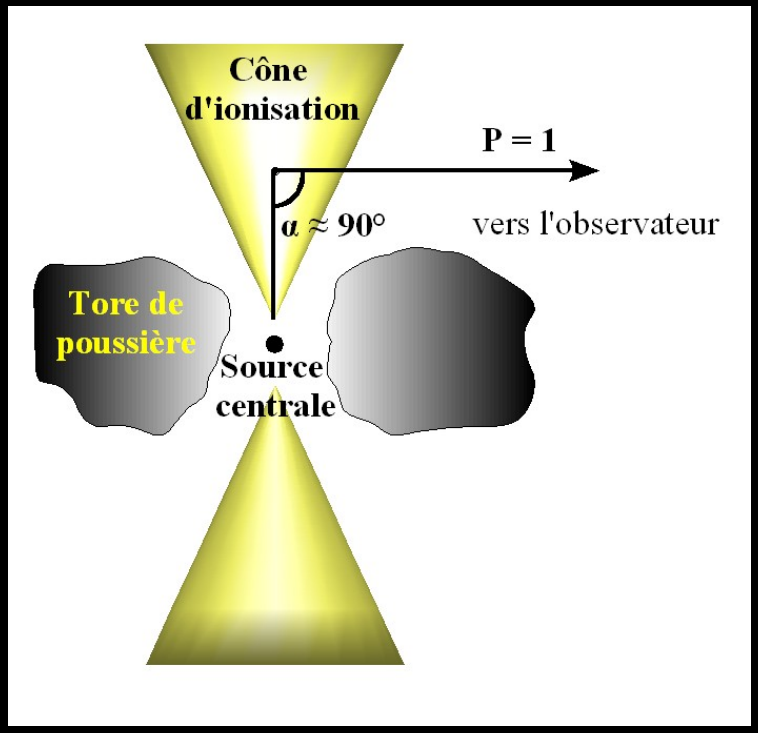
- Interferometric, infrared observations with the VLT allow us to observe the outer parts of the obscuring dust (Hönig et al. 2012):

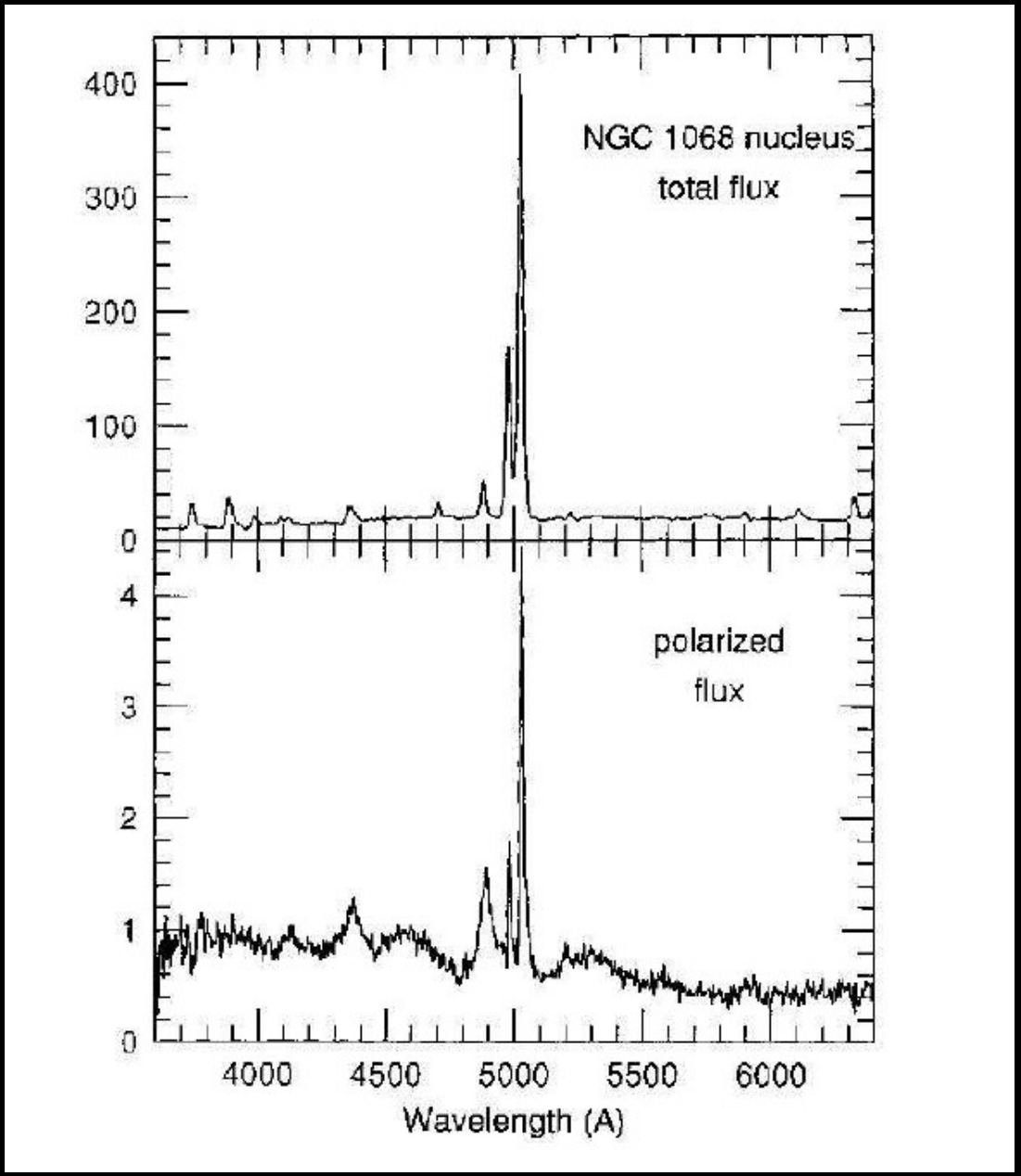
→ **Synergy with the E-ELT will allow us to further zoom in!**

Why we should opt for an E-ELT polarimeter!

A major break-through for the unified model for NGC 1068 (Antonucci & Miller 1985)

→ **periscope view of AGN in polarized flux**

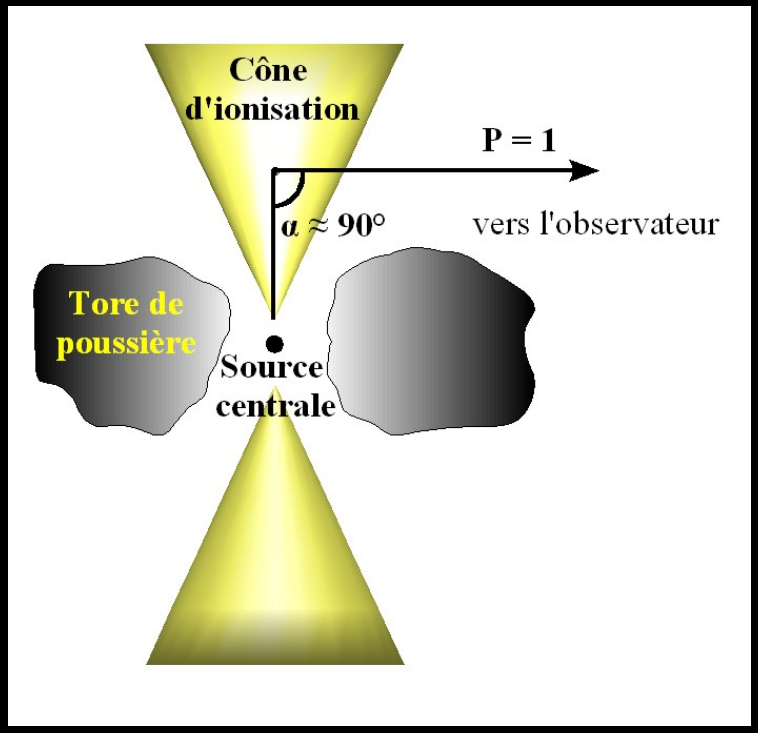


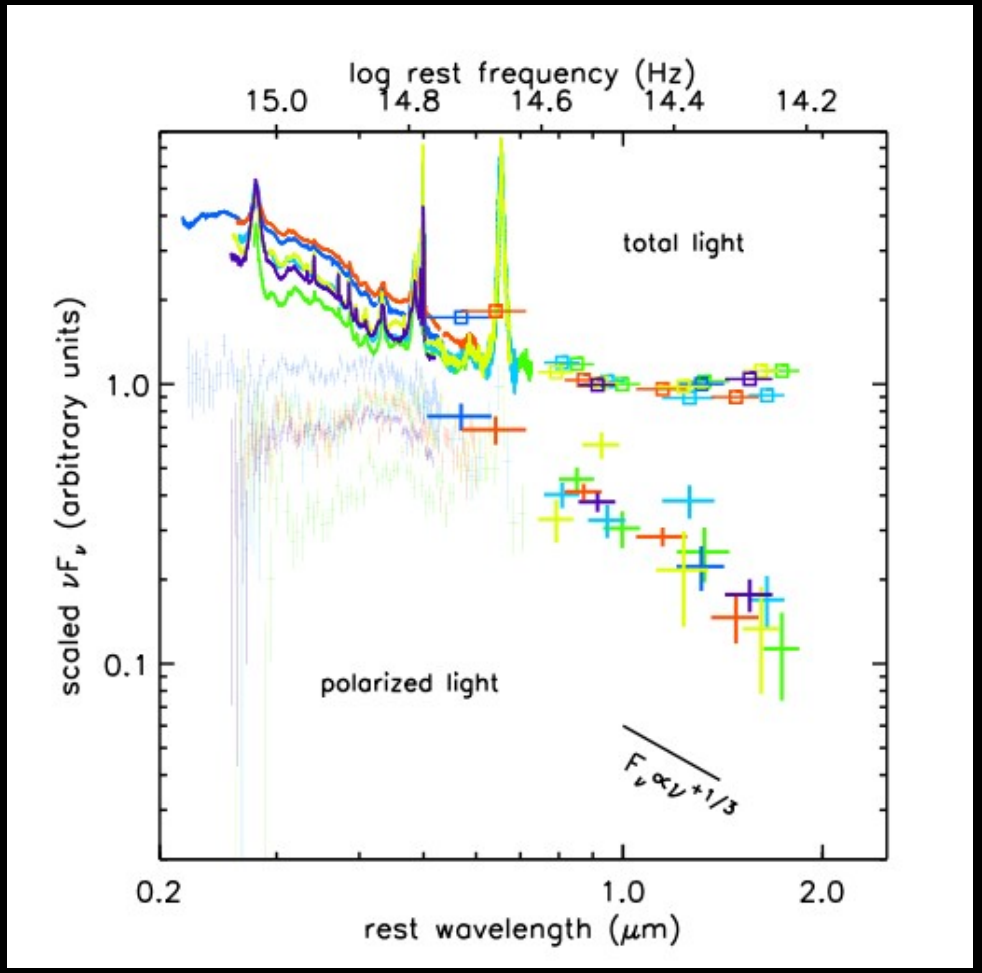


Recovering the hidden accretion disk spectrum

Through the periscope, the hidden continuum spectrum of the disk can be revealed. We look at the same object from two directions!

It follows a multiple-blackbody shape with power-law slope of $\nu^{-1/3}$





Kishimoto et al. 2008

A polarimeter on the E-ELT enables us to systematically apply the "periscope view" to AGN also at higher redshifts!

Conclusions : The E-ELT is going to allow us to...

- measure dynamical black hole masses in a significant number of ultra-luminous X-ray sources

- measure the velocity of numerous stars close to Sgr A* and determine precisely the mass of and the distance to Sgr A*
- detect and follow X-ray flares of Sgr A* in the infrared
- probe how much the Galactic Center is influenced by effects of dark matter and General Relativity

- zoom in further on the inner structures of nearby and more distant active galactic nuclei
- discriminate feed-back due to accretion onto a supermassive black hole from the effects of nuclear starbursts
- construct the most powerful spectro-polarimeter ever and look at AGN (and other objects) from two directions simultaneously (periscope)