The Galactic Centre
- Strong extinction due to dust
  At optical wavelength the absorption is almost total

  Information from the 21 line, IR and radio

  Region between \(10^{14}\) and \(10^{22}\) cm

  1 arcsec at the distance of 8 kpc = 0.04 pc
21 cm line (HI):

- Strong decrease of H within 4pc from the centre
  - Not only circular motions
- Between ~200 and ~1500pc the gas is on a plane inclined of 30 deg. with respect the galactic plane
- The disk is in rapid rotation v ~200 km/s seen tangentially
  \( r(\text{disk}) = 260\text{pc} \)
  - Ring at 750pc

Within 1kpc the mass can be computed:

\[ M(\text{totale}) = 2 \times 10^{10} \text{M(\text{sol})} \]
21 cm line (HI):

- Prominent structure between SgrA and the Sun, it disappears at $l=338$ deg. where the radial velocity is $\sim 140$ km/s. In this point:

$$R = R_0 \left| \sin(338^0) \right| \approx 3.2\text{kpc}$$

From this distance the name: 3 kpc arm. The expansion velocity is $\sim 50$ km/s. It is not a typical spiral arm because there is no star formation. Probable explosive phenomenon ($\sim 10^7$ yr ago) in the nucleus with ejected matter ($v \sim 600$ km/s progressively decreased up to the observed value)
The nuclear region of the Milky Way (<260pc) is called Sagittarius (Sgr).

In this region we have: Sgr A, Sgr B, Sgr C, Sgr D, Sgr E.

The Galactic Center and the surrounding Central Molecular Zone comprise the most active star formation region in the Milky Way. This 2 x 1 degree field was imaged at 20 cm (purple) with the NRAO Very Large Array, tracing H II regions that are illuminated by hot, massive stars, supernova remnants, and synchrotron emission. Emission at 1.1 mm (orange) was observed with the Caltech Submillimeter Observatory and highlights cold (20-30 K) dust associated with molecular gas. Some of this material will form stars within in the next few million years; the remainder will be blown away. The diffuse cyan and colored star images are from the Spitzer Space Observatory's Infrared Array Camera. The cyan is primarily emission from stars, the point sources, and from polycyclic aromatic hydrocarbons (PAHs), the diffuse component.
**Sgr D:** two components

- North: complex of HII regions (~20 pc)
- South: SNR (~15-20 pc).

In the vicinity molecular gas
**Sgr B**: many HII regions with H$_2$O and OH masers (density ~15 particles /cm$^3$)

Sgr B2 (north) dense HII regions ( ~100 particles/cm$^3$, 20pc, $10^4$ M$_{sol}$)

We discovered the organic molecule amino acetonitrile (NH$_2$CH$_2$CN) in the hot dense core Sgr B2(N) with the IRAM 30m telescope, the IRAM Plateau de Bure interferometer, and the Australia Telescope Compact Array. Amino acetonitrile is a molecule chemically related to - and probably a direct precursor of - glycine (NH$_2$CH$_2$COOH), the simplest amino acid, which has not yet been found in space (Belloche et al. 2008)
**Sgr B:**

M(HII) total $\sim 10^6$ M(sol), necessary $\sim 1000$ O6 stars in
$\sim 170$pc (strong star formation)

Filaments between the two components of Sgr B, probably
originate by the interaction of stars and molecular gas
It is, in the complex, a thermal source
**Sgr C**: shell + filament; few information, filaments similar to the filaments in Sgr A

**Sgr E**: discrete regions (diameter <2")

Probably HII regions with molecular gas
**Sgr A** is the most studied region of the MW

IR source ($\lambda=2$ $\mu$m), probable star cluster ($3\times10^6$ M(sol))

Dimension: 4’ (~10 pc)

Non-thermal radio flux at frequencies $\geq 200$ MHz with $\alpha \sim 0.3$ ($\nu^\alpha$)

The radio source is composed by two components:
- **Sgr A East** with thermal spectrum
- **Sgr A West** with thermal spectrum + non thermal source, compact and powerful (**Sgr A***)
Sgr A East
(map at 20 cm obtained with the VLA)

Extended emission, probably SNR:
~5pc, ~1000km/s, 5000 yr

Sgr A* (compact source, in red)
Sgr A West
(map at 6 cm obtained with the VLA)

Spiral structure: probably emission due to ionized gas heated by young and hot stars plentiful in this region
Arc north to Sgr A

Non thermal origin, it could trace the magnetic field

Probably associated with the arc present in Sgr C
Sgr A: summary

**Sgr A East** (blue): highly energetic region ($\approx 10^{52}$ ergs) probably SNR of $\approx 5000$ yr. A diffuse X-ray emission is present.

**Sgr A West** (red): filaments of dust and gas ionized by stars they move around the galactic centre

**Sgr A**: bright and compact radio source in the centre of the intersection of the Sgr A West arms.

VLA, 6 cm
With $S \propto \nu^\alpha$

$\alpha = 0.17$ between 1.3 and 8.5 GHz

$\alpha = 0.30$ between 15 and 43 GHz

During 20 yr of observations (see fig. in Zhao et al. 2001) $\alpha = 0.28$ between 1.4 and 22 GHz

The error bars are indicative of the variability of Sgr A*

Excess in mm and sub-mm range ($\alpha \approx 0.6$ in $10^{11} - 10^{12}$ Hz), probably due to reemission of dust
VARIABILITY of Sgr A*

It depends on the frequency emission:

**Modest at low frequencies** (540 observations, Green Bank radiotelescope, Falcke + 1999)
- ~ 2.5% at 2.3 GHz
- ~ 6% at 8.3 GHz

Variability time scale very similar (50-250 days)
Variability not due to ISM (in the hypothesis of refractive interstellar scintillation $t_{\text{var}} \propto \lambda^2$)

**High in mm/sub-mm**
- ~ 20 – 40% at $\nu > 100\,\text{GHz}$; variability time scale of 1 hour

**Very high in IR**
- ~ factor 5 for $\lambda \sim 1.6 – 3.8\,\mu\text{m}$; variability time scale of hours

**Extreme variability in X-ray**
- ~ factor 160 for $E \sim 0.5 – 10\,\text{keV}$; daily burst with time scale of 1 hour
The ratio between the IR-X fluxes is NOT the same, but the spectral indices are constant \((\alpha \approx -0.6)\) even if during the bursts.

Consistent with X-ray emission by Synchrotron-Self Compton (SSC)
Polarization of Sgr A*

**Broad band continuum polarimetry:**
linear polarization $< 0.1\%$ at $\nu < 86\text{GHz}$ (*)
$\approx 10\%$ at $\nu > 100\text{GHz}$ (observations with low resolution, possible contribution of the circumnuclear disk and of the mini-spirals of Sgr A West)

(*)Low values due to:

a) Differential Faraday rotation (so high that within the observation band the polarization vector rotates more than $180^\circ$ and cancels)

b) Variation of Faraday rotation in the scattering screen (depolarization)

Excluded the depolarization due to Faraday rotation ($\Delta \phi > 180^\circ$) caused by a medium (Bower + 1999)
The Galactic Centre in IR

In Sgr A West: the relevant part of the emission is due to red giant stars (spectral type K) and to interstellar dust. From the density distribution of stellar mass a mass of \( \sim 5 \times 10^8 \) Msol within 50 pc is obtained.

Ionized gas is present \( (\sim 5 \times 10^6 \) Msol within 0.4pc, a factor 3 greater than the mass obtained from the H distribution in the nuclear regions)
Masers in the MW

Hundreds of masers (OH, H$_2$O, CH$_3$OH methanol, H$_2$CO formaldehyde) in the Galaxy.

Not known the excitation mechanism.

Observations for H$_2$CO (VLBA+VLA, Hoffman+2007).

The observations are necessary to obtain:

• Brightness T

• Variability studies to have dimensions

• Precise astrometry to establish the relations among the most common masers.
Molecules in the Galactic Centre

To understand the physics of the galactic cores it is necessary to measure directly the parameters, as temperature and density in the different gas phases.

CO survey (Dame + 2001):
• CO intensity is 4x that in the other regions of the plane. Non circular motions up to 250 km/sec;
• 3kpc arm is present;
• Objects with radius of ~ 75pc are present; the line width is about 10x that of other molecular clouds (GMCs) of MW; their nature is unknown
• The gas T has been measured trough ammonia (ATCA survey, 2005, with resolution of ~ 1pc): T ~ 20-30°K in SgrA*, (the gas could be warmer in the regions with prominent radio continuum emission).
High energy emission (X and $\gamma$ bands)

The observations have shown very strong luminosity.

Map observed with X-ray Chandra (0.5-7 keV) superimposed to the 6 cm contours (Baganoff + 2003)

Observed with Chandra (Nature 2001) a rapid X-ray flare, possible accretion onto the BH.
Integral (X-ray ray satellite)

Map of the central region of the MW
(20-30 keV, duration of the observation $7 \times 10^6$ s).

A persistent flux from the MW centre is detected.

The positions of Sgr A, Sgr B and Sgr C are marked.
Proper motions of 17 stars in K band with the Keck telescope within 0.4 arcsec from Sgr A*, in order to study the BH and its effect with the best spatial resolution ever obtained.

The results are:
- Accurate position (±1.3mas)
- Mass $3.7(±0.2) \times 10^6 \,(R_{\text{sol}}/8\text{kpc})^3\,M_{\text{sol}}$ within 45 AU

The object position coincides with SgrA*, dynamical centre of the Galaxy. The radio emission could be due to the release of potential gravitational energy of the matter accreting onto the BH.

SgrA* is fainter at all the frequencies (mostly in X-ray) than the value computed using the standard model.
BH in SgrA*
The strong emission of γ-ray from Sgr A* (started ~350 yr ago and lasted many years) travelled through the space towards Sgr B2. This radiation was absorbed and reemitted from the cloud of molecular H (Sgr B2).

Sgr B2 is detectable in the γ-ray range.
Radio emission from Sgr A* 

Radio image distorted by the ionized medium, obtained at 5, 8, 15, 32 and 43 GHz.

Falcke et al. 2003
Fitting the size of SgrA* with 1.3mm wavelength VLBI.

Observed and intrinsic size of SgrA* as a function of wavelength.

At high frequencies the spatial resolution of observations is limited by interstellar scattering.

Red circles: major-axis observed sizes from VLBI observations.

Green points: derived major-axis intrinsic sizes.

At 1.3mm the intrinsic diameter is $37(+16/-10)$ microarcsec, less than expected suggesting that the bulk of emission may not be centered on the black hole but arises in the surrounding accretion flow.
Imagine an X-ray of the MW galactic centre.