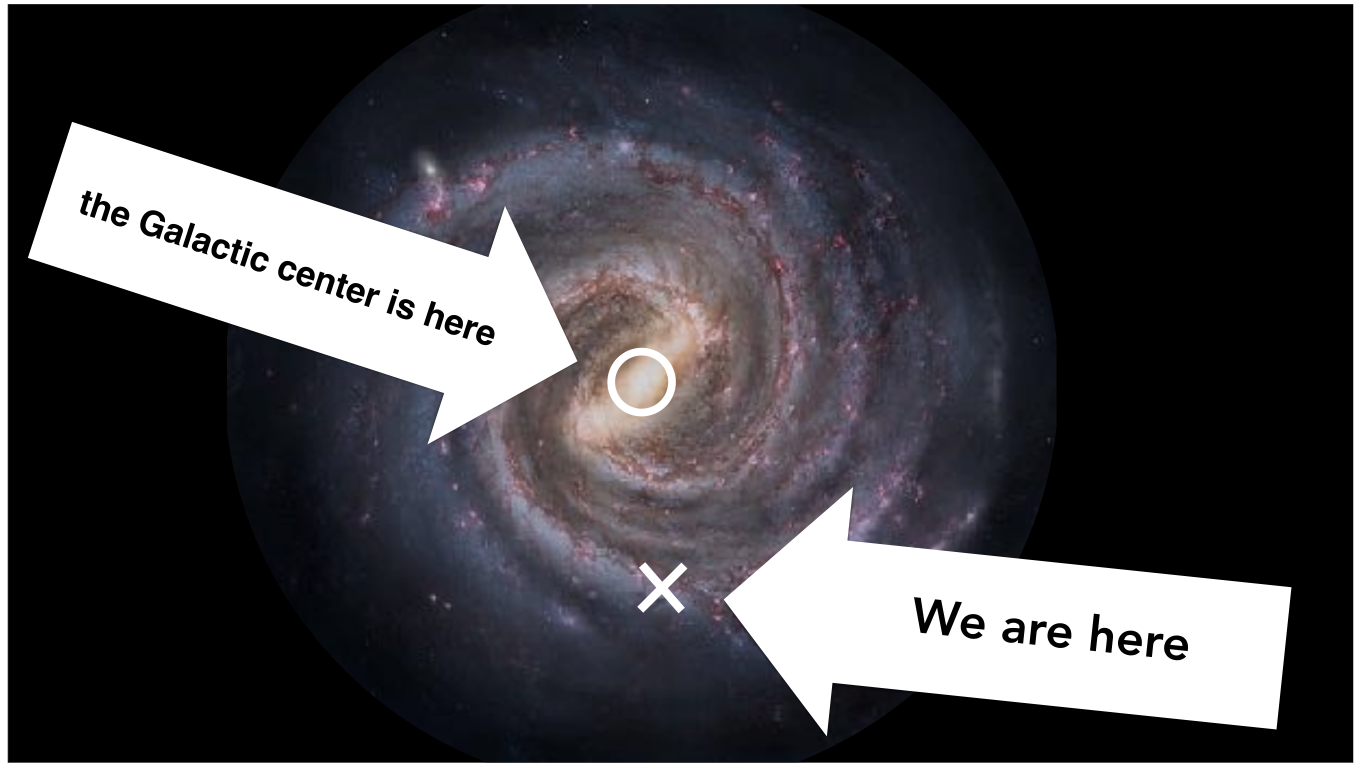
I am excited to be here, to tell you about the center of our galaxy and give you a close-up tour of its structure and contents.

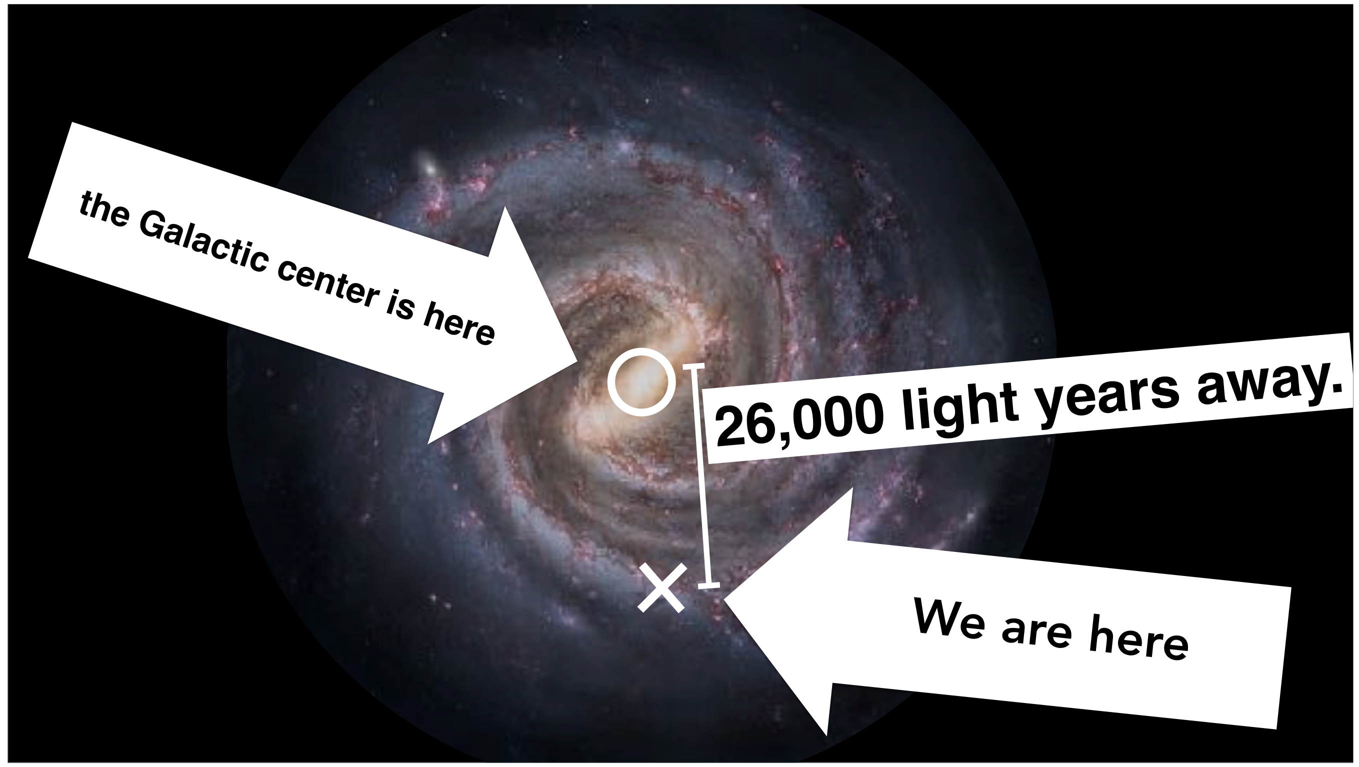
But I also want to acknowledge the incredible privilege so many of us have to be focusing on astronomy today. And so I ask you all to take a moment of silence to remember Ahmaud Arbery, George Floyd, Breanna Taylor, Tony McDade, and so many others who have died at the hands of police violence. Consider as you do how racism is present in academia as well, and think about how we can better act in solidarity with our Black colleagues and students, many of whose hearts and minds are elsewhere as their communities and families grieve. And acknowledge while you are doing so the absence in our midst, the lost Black students and potential colleagues who never had the chance to pursue their dreams of science because of the toll that police violence and racism continues to take in our country.


Tony McDade
George Floyd
Breonna Taylor
Ahmaud Arbery
Atatiana Jefferson
Botham Jean
Antwon Rose Jr.
Stephon Clark
Philando Castile
Alton Sterling
India Kager
Darrius Stewart
Sandra Bland
Tamir Rice
Tanisha Anderson
Laquan McDonald
Michael Brown
Eric Garner

We live inside of the Milky Way galaxy, a relatively normal and quiet barred spiral galaxy. The sun is located in a spiral arm on the outskirts of the galaxy.

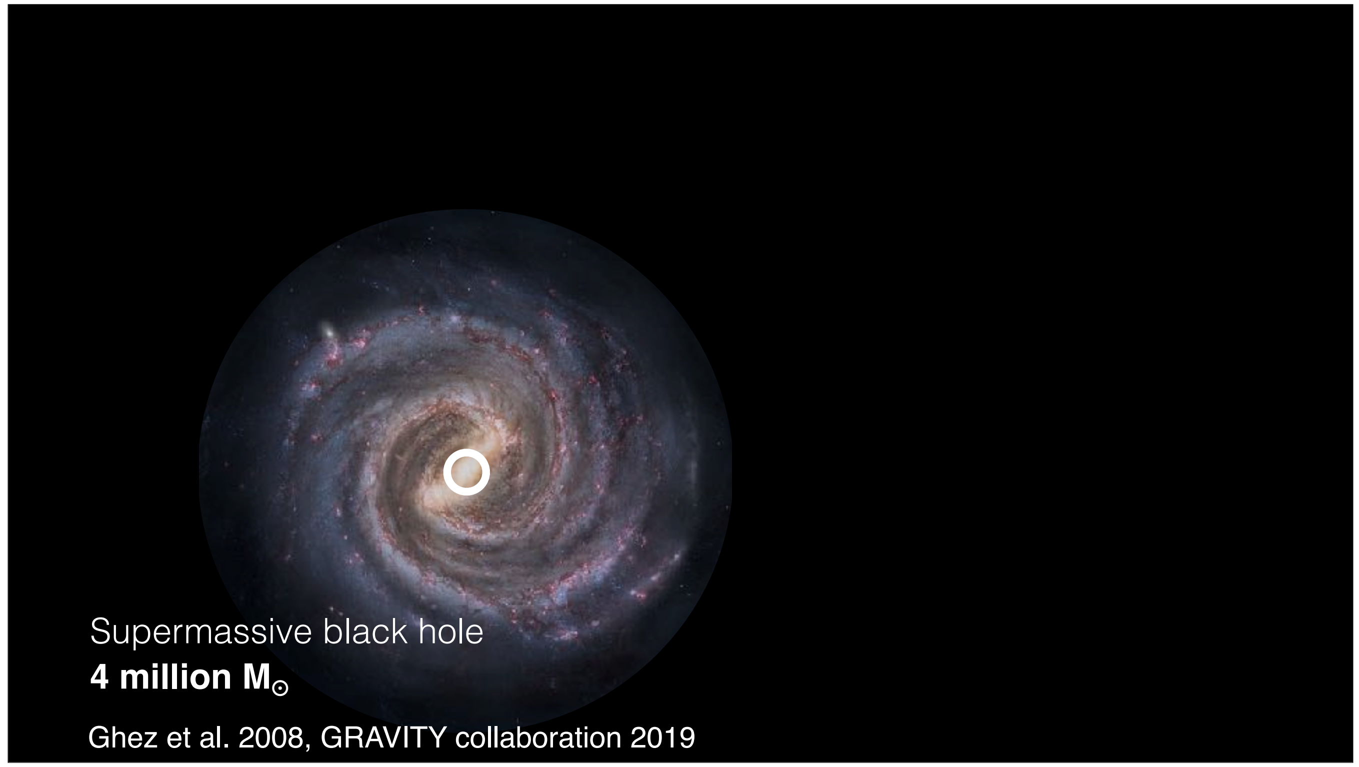


Today I am going to be focusing on the center of the galaxy

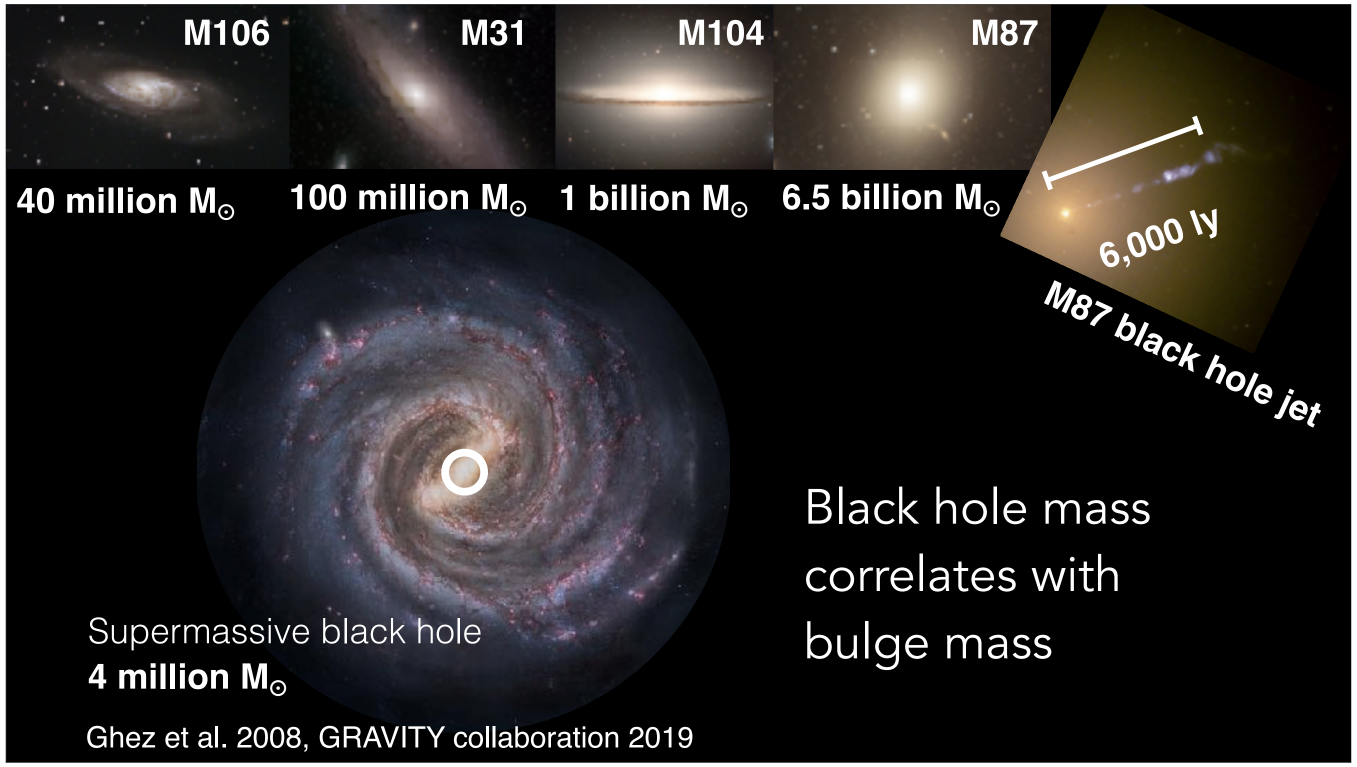


… approximately 26,000 light years away. That means that every photon I show you today took 26,000 years to travel all the way from this central region to reach the detectors of our telescopes.

This is a fantastic distance: we can’t hope travel there to take close up pictures or collect samples. And yet, it isn’t necessarily as far away as it seems, because we believe that all of the physics that happens in these central regions can have an outsized impact on the surrounding galaxy as a whole.



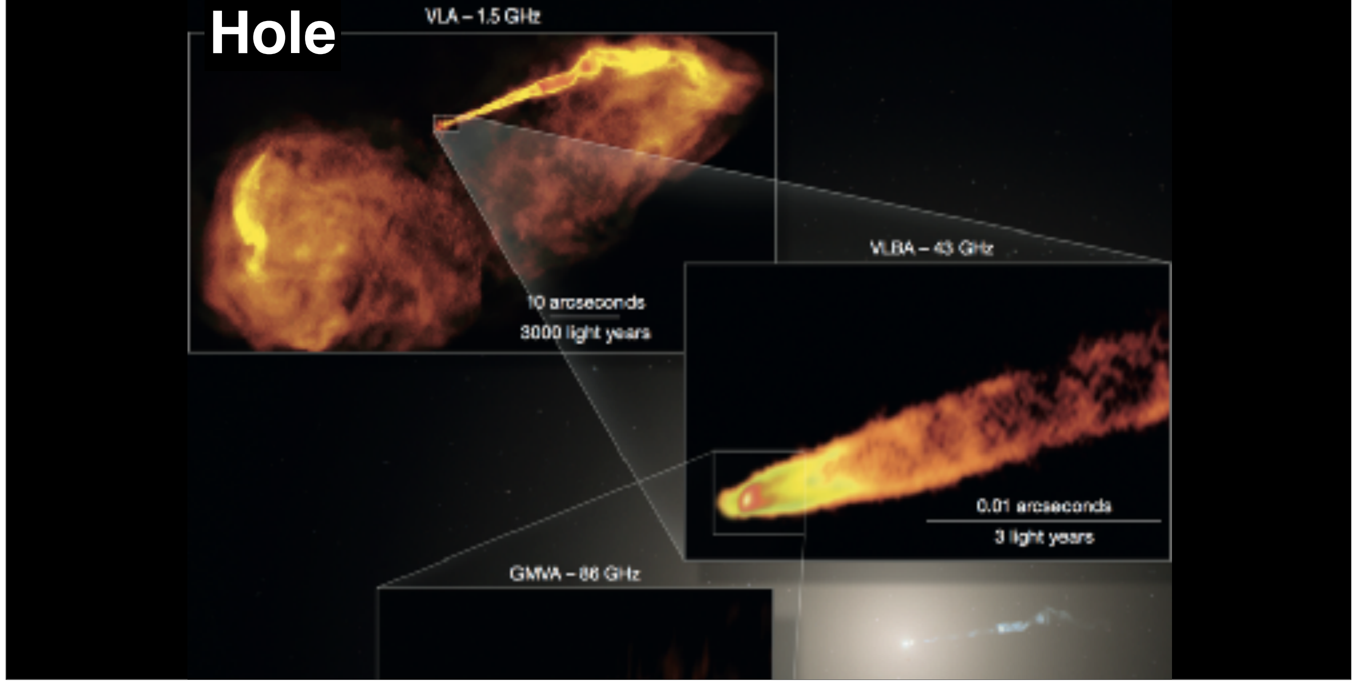
How do we know this? The center of our galaxy, like all other galaxies its size and larger, hosts supermassive black hole. Observations of other galaxies show that when we measure the mass of the supermassive black hole mass, it correlates with galaxy properties on much larger size scales: specifically, the mass of a galaxies bulge, on kiloparsec scales. While it is still not clear whether this is just correlation (Same processes lead to building up BH and bulge), there is good evidence to suggest that this relationship could be causal (and that the black hole and its process of growth shapes the surrounding galaxy).



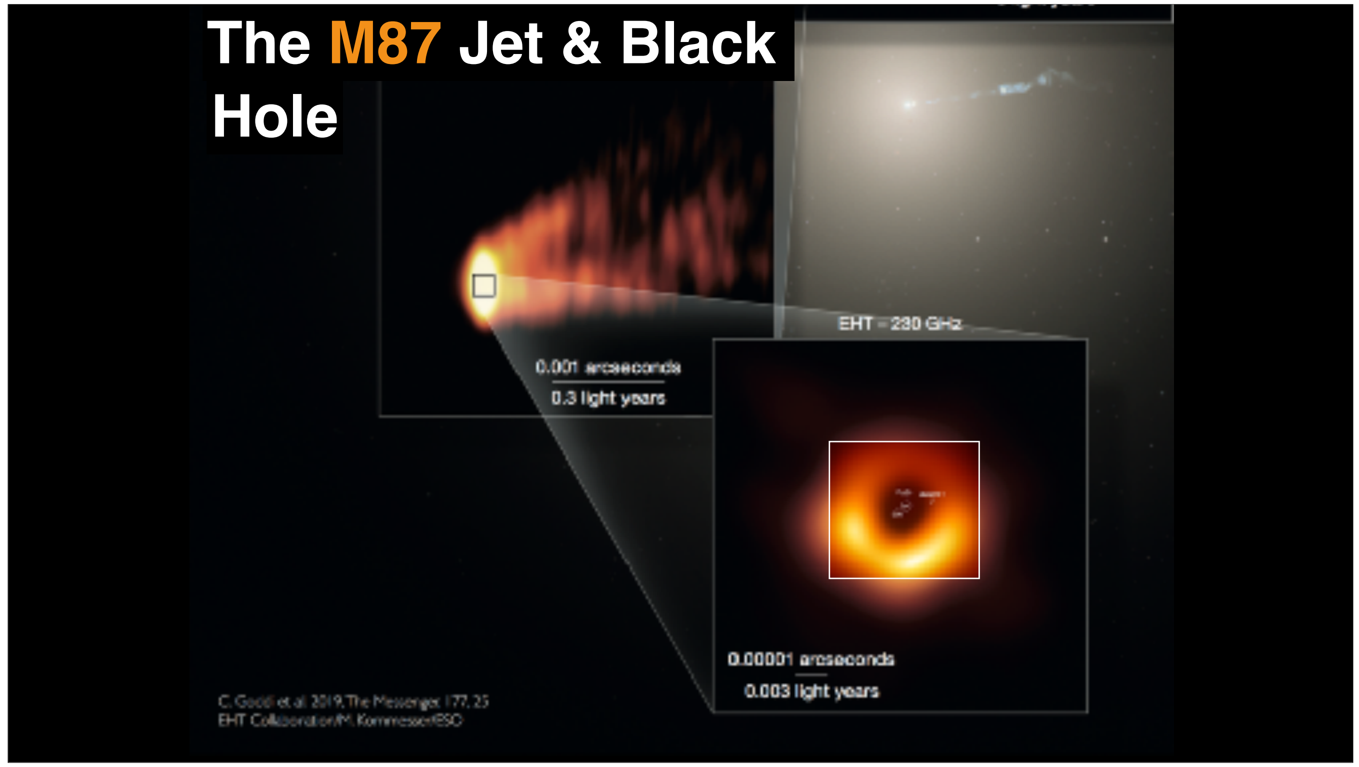
We see that many of these compact but massive black holes are responsible for launching jets of relativistic plasma and particles far beyond the center of the galaxy, all the way out into the space between galaxies

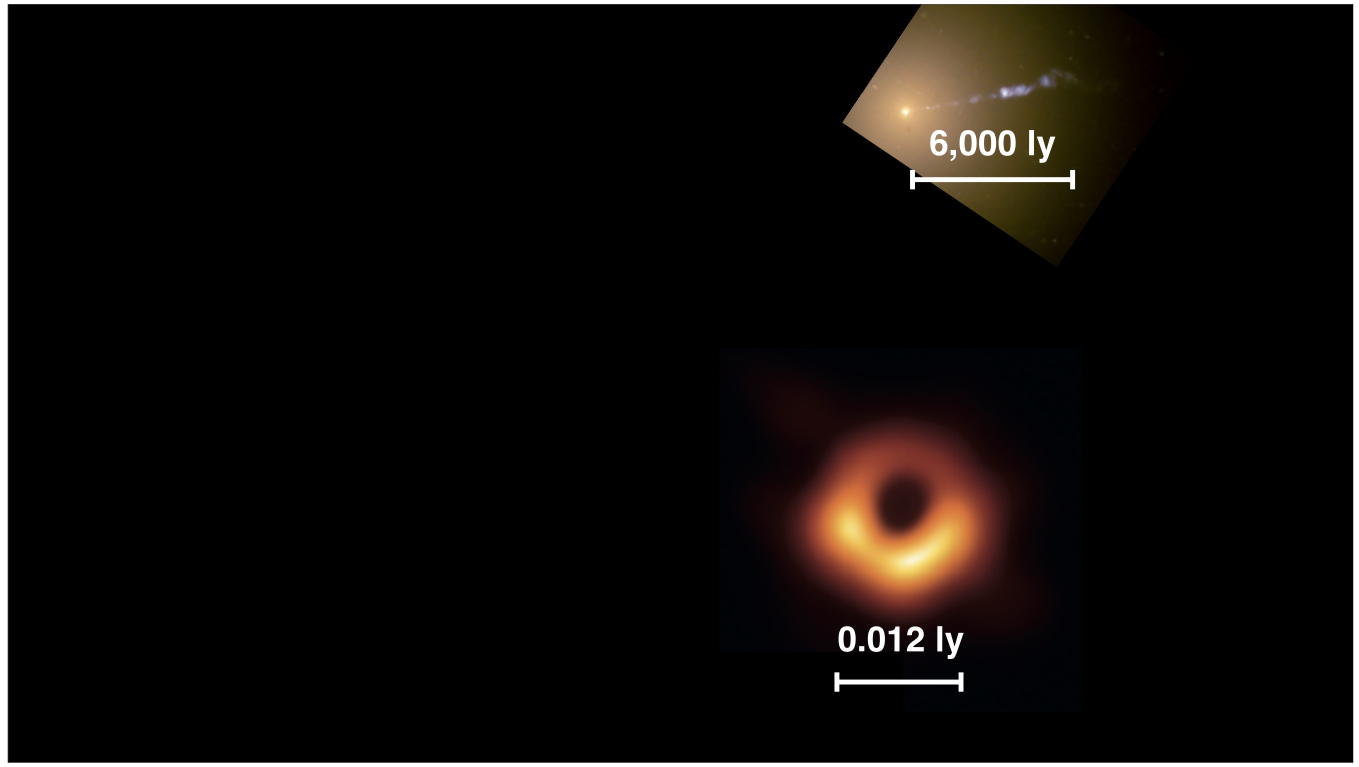
And this huge eruption of potentially galaxy-shaping energy, this cosmic light display of enormous lobes of plasma around galaxies, originates on scales so small that they are comparable to the size of our own solar system.

The M87 Jet & Black Hole

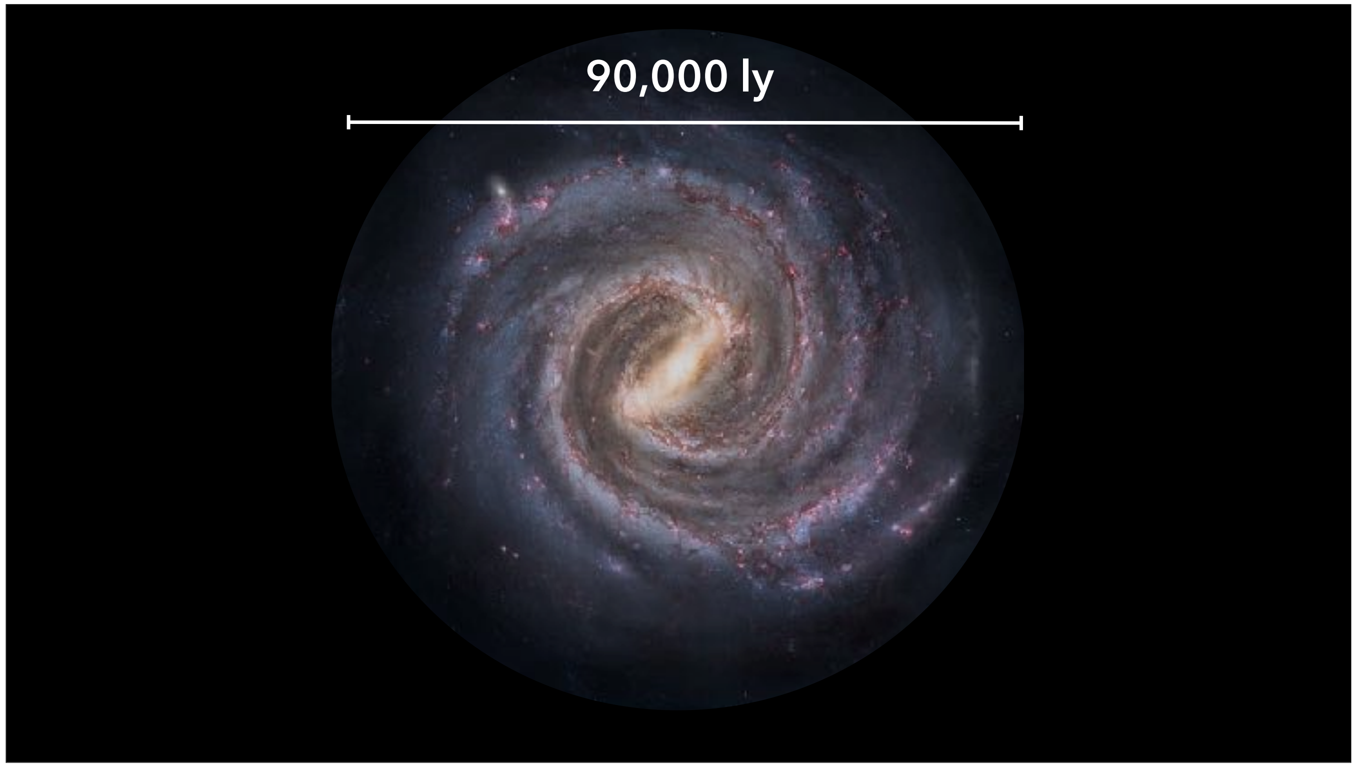


The M87 Jet & Black Hole

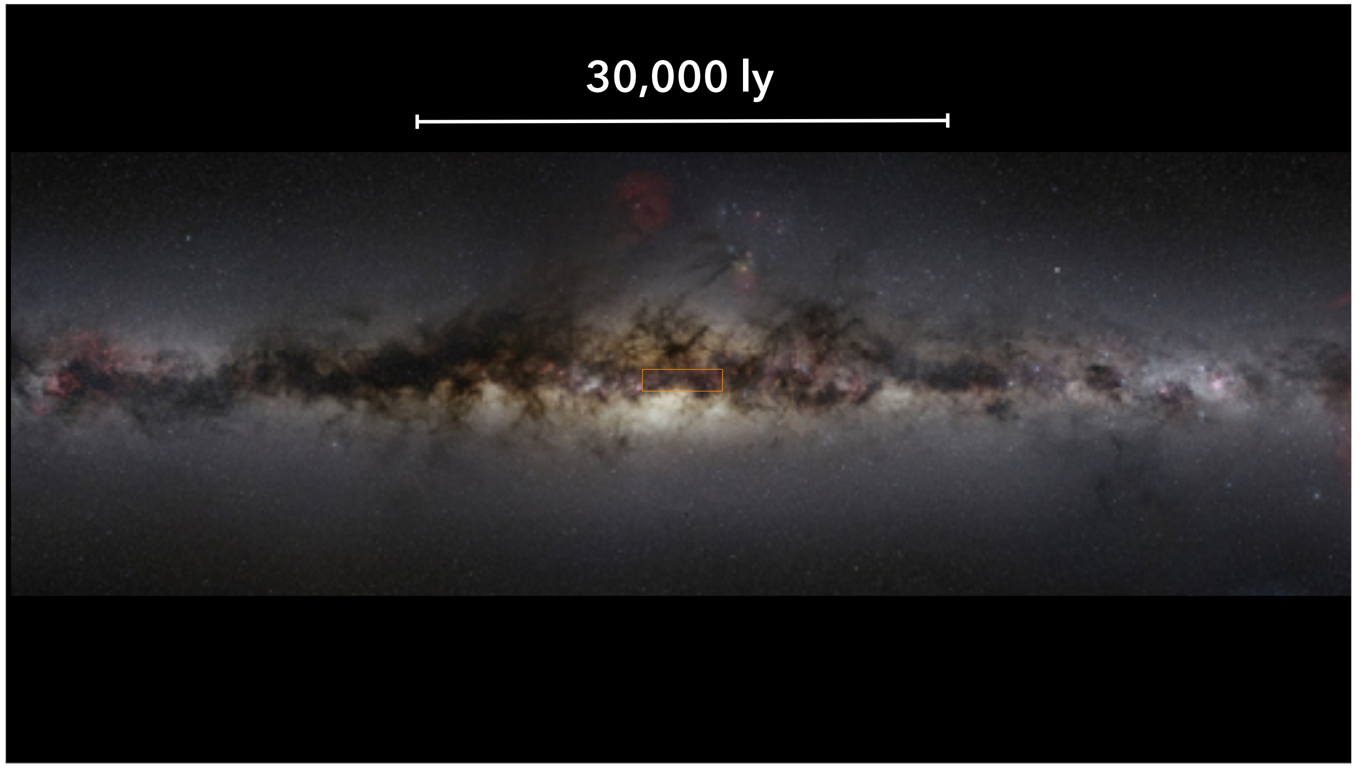




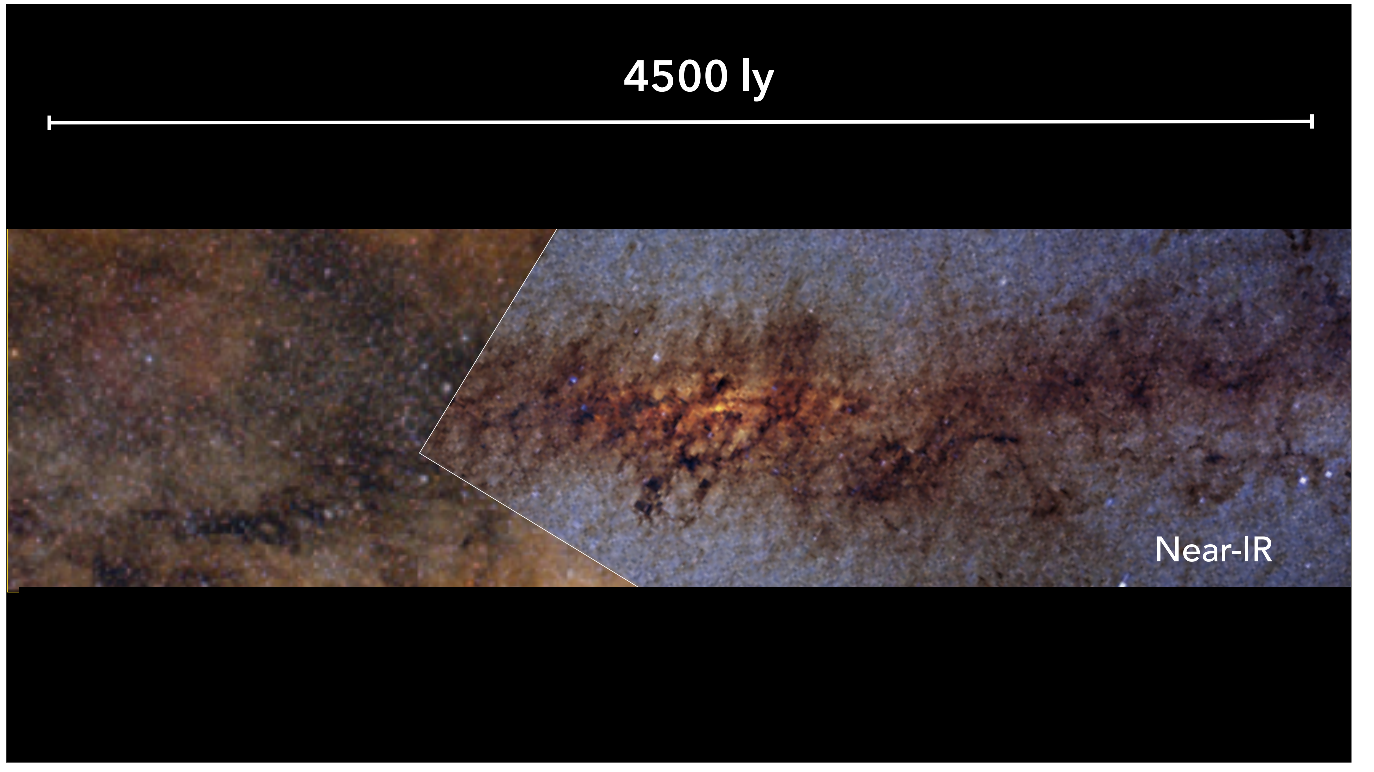
From this we can see the fantastic range of size scales associated with galaxy centers: over 6 orders of magnitude from the central black hole to the scales it can influence.
But lets bring the focus back now to our own Milky Way and what lurks in its center.

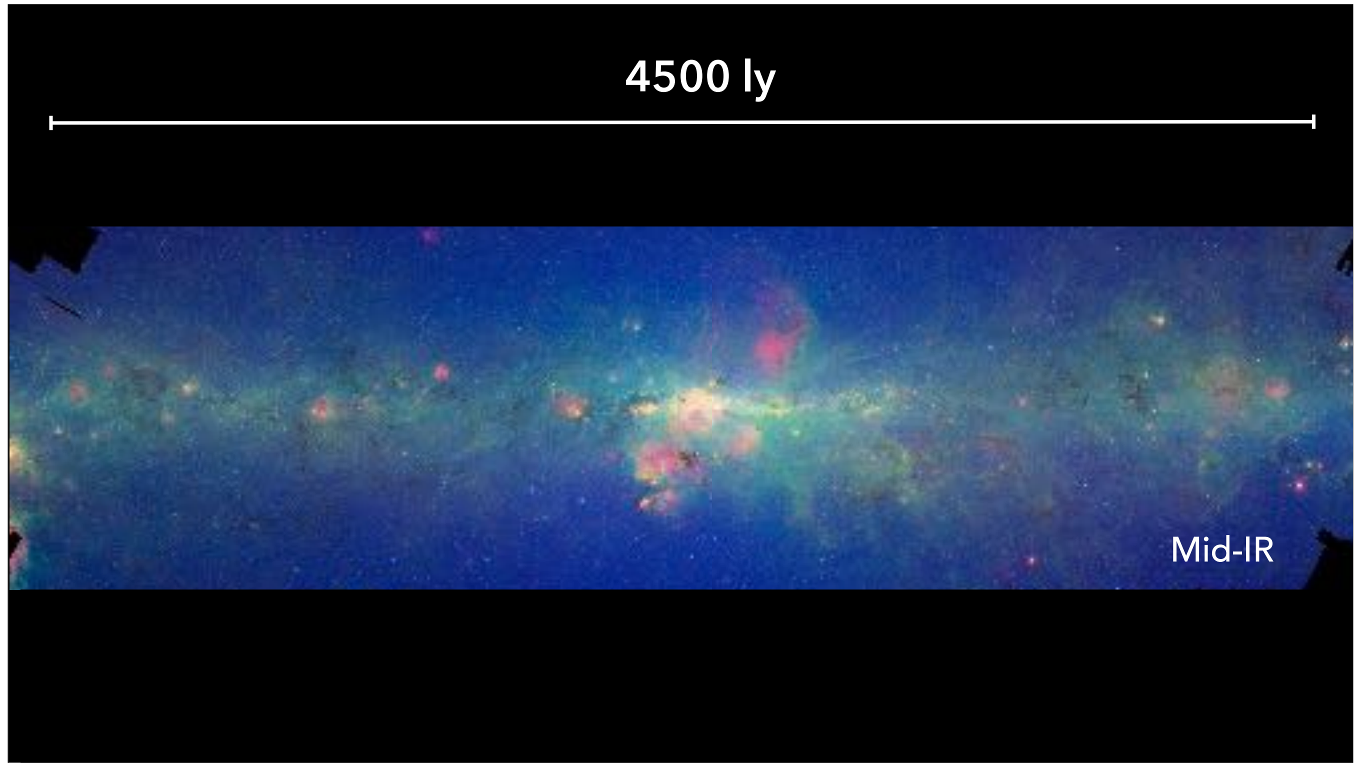


Of course, living inside of our galaxy, means we never actually get to look at it like this. Instead, we have to peer through all those 26,000 light years of the disk and the gas and dust they contain in order to see the center.

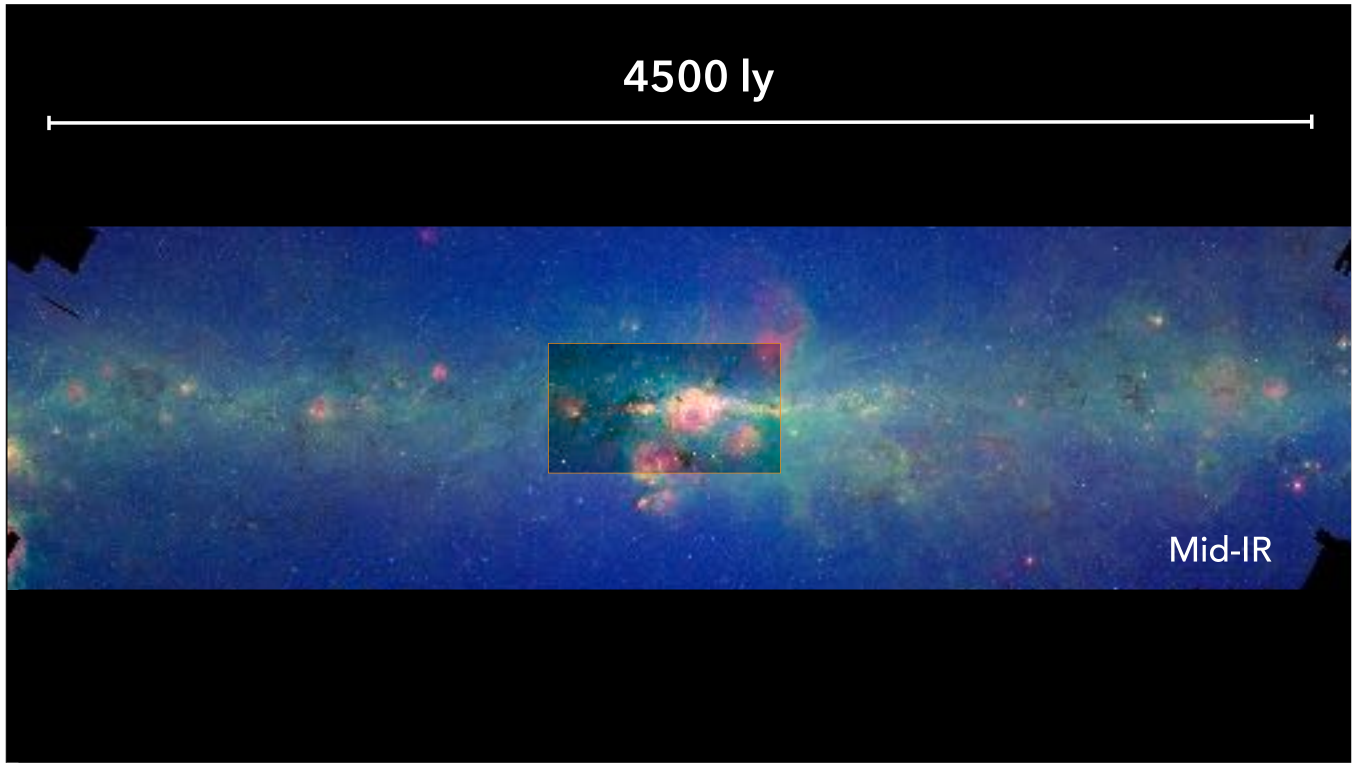

30,000 ly

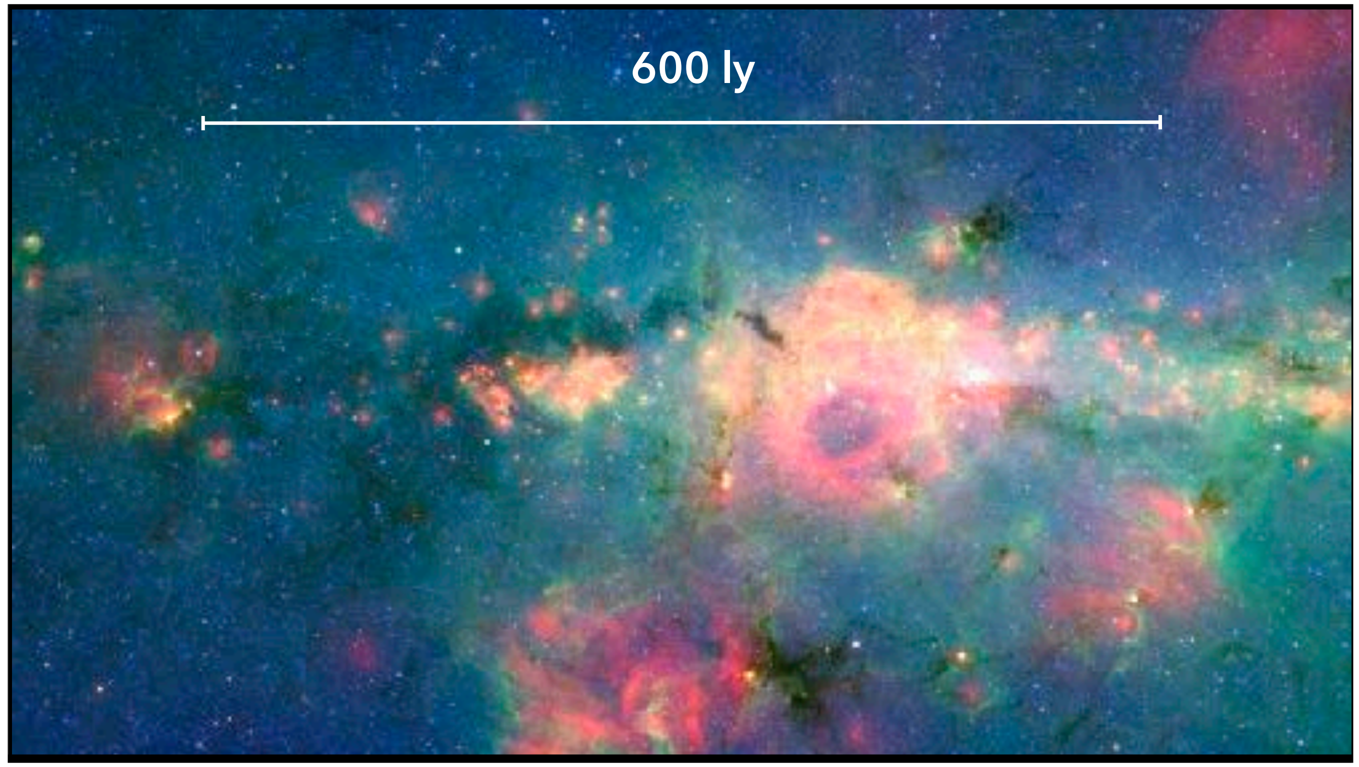
And that means when you view it at optical wavelengths, you see this: a whole lot of nothing (or at least, nothing that actually comes from the galaxy center). If we want to study this region, this forces us to move to either longer wavelengths (or more energetic wavelengths like x-rays and gamma rays). Here, we push on to longer infrared wavelengths to pierce this veil and even really see evidence that we are looking at the right place, and that this place is the energetic powerhouse of our galaxy. To fully see through the intervening veil of dust, we go all the way into the mid infrared, where we can now clearly see that there is a central concentration of stellar energy being reprocessed by the dust.


4500 ly
Near-IR

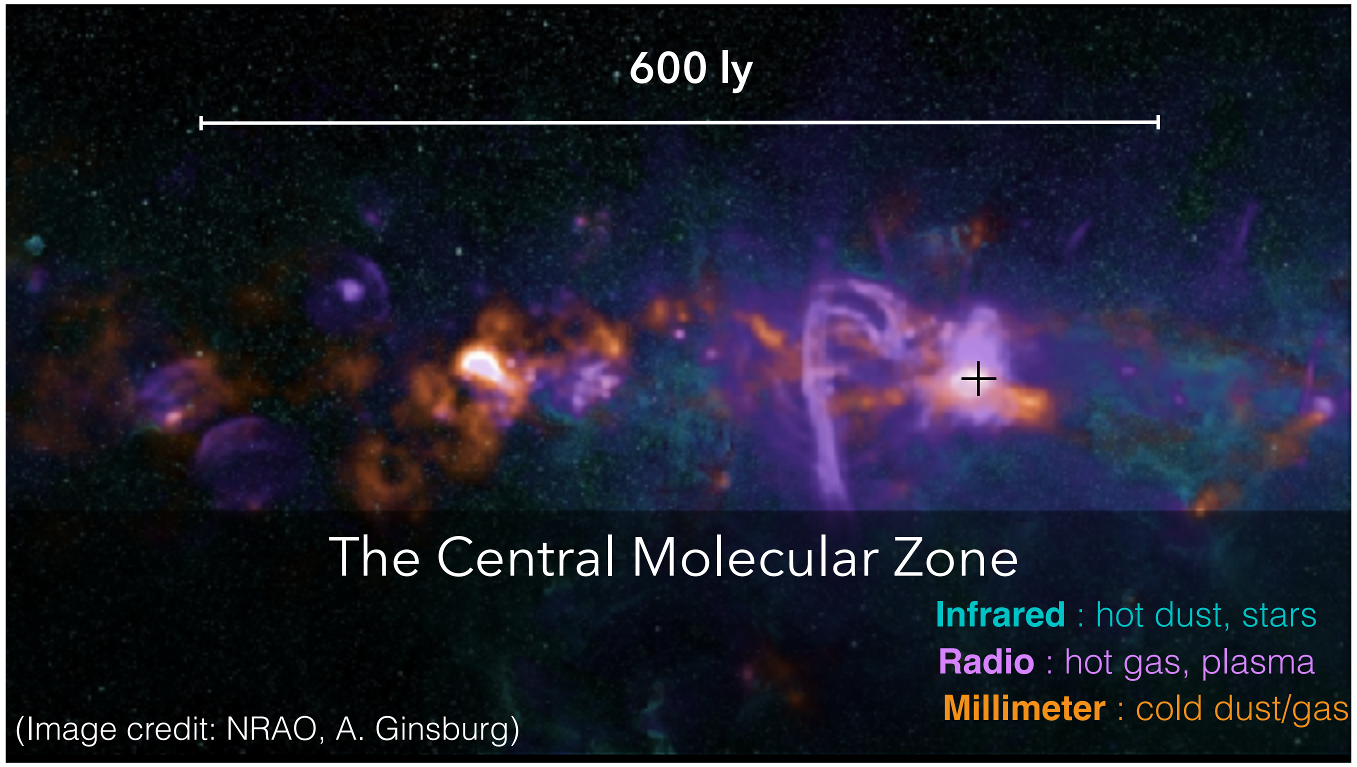


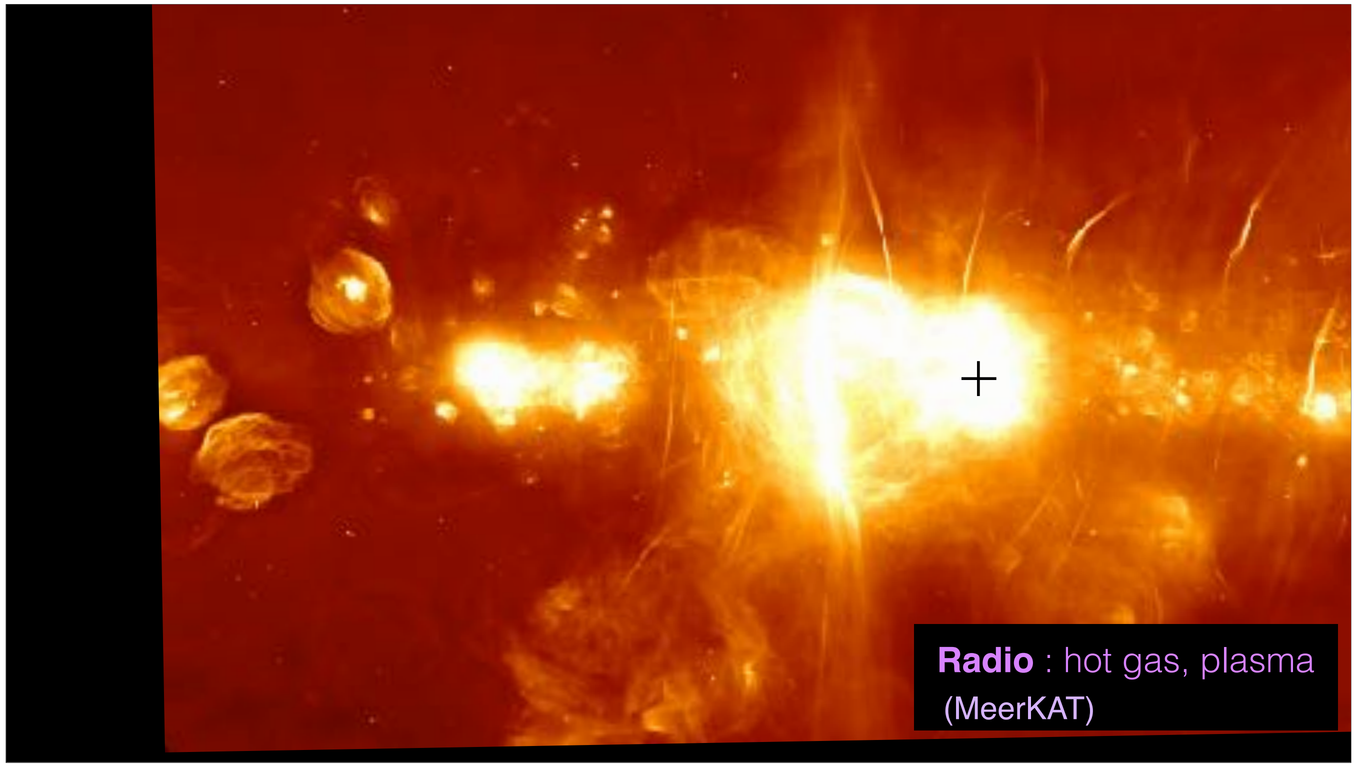
Although mid-infrared wavelengths are sufficient to see through the dust between us and the galaxy center, the gas clouds in the center itself are so thick and dense that they continue to block background radiation, appearing as infrared dark clouds.


4500 ly
Mid-IR

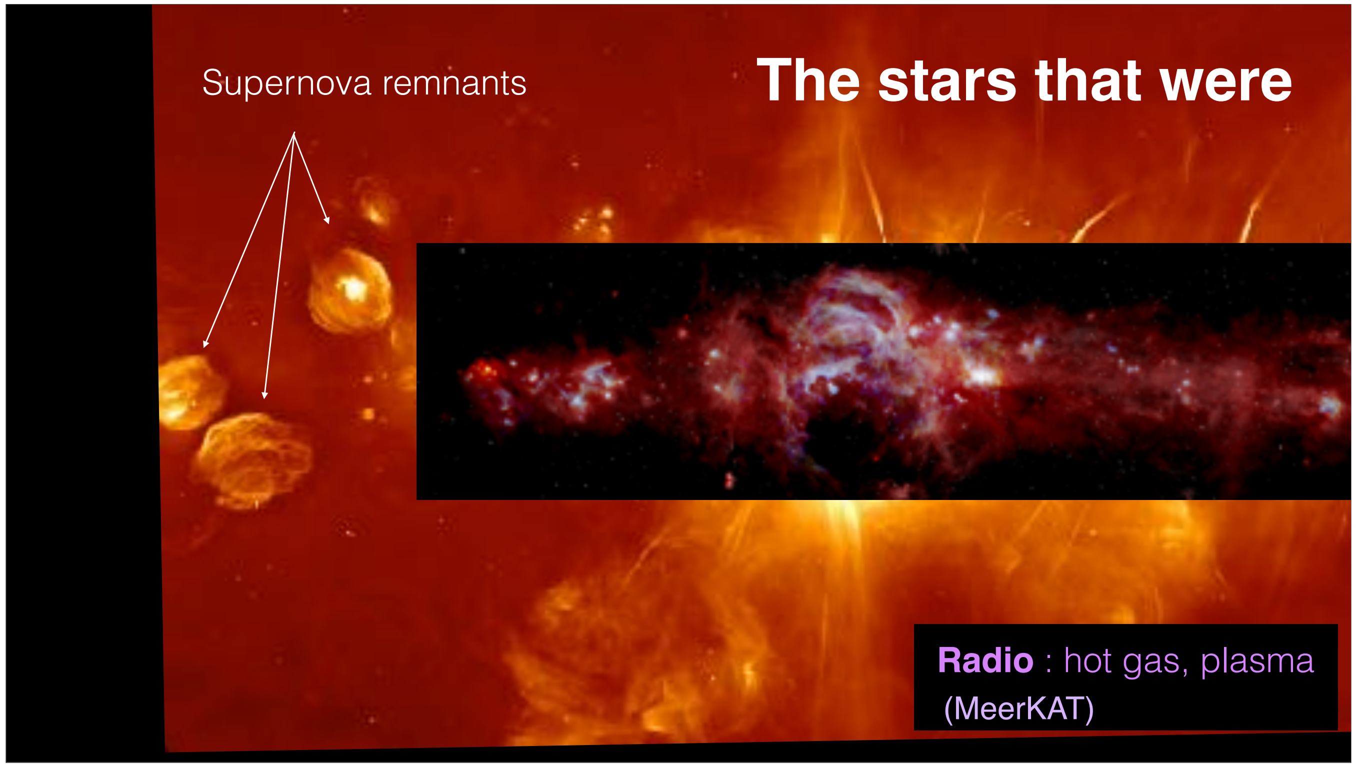


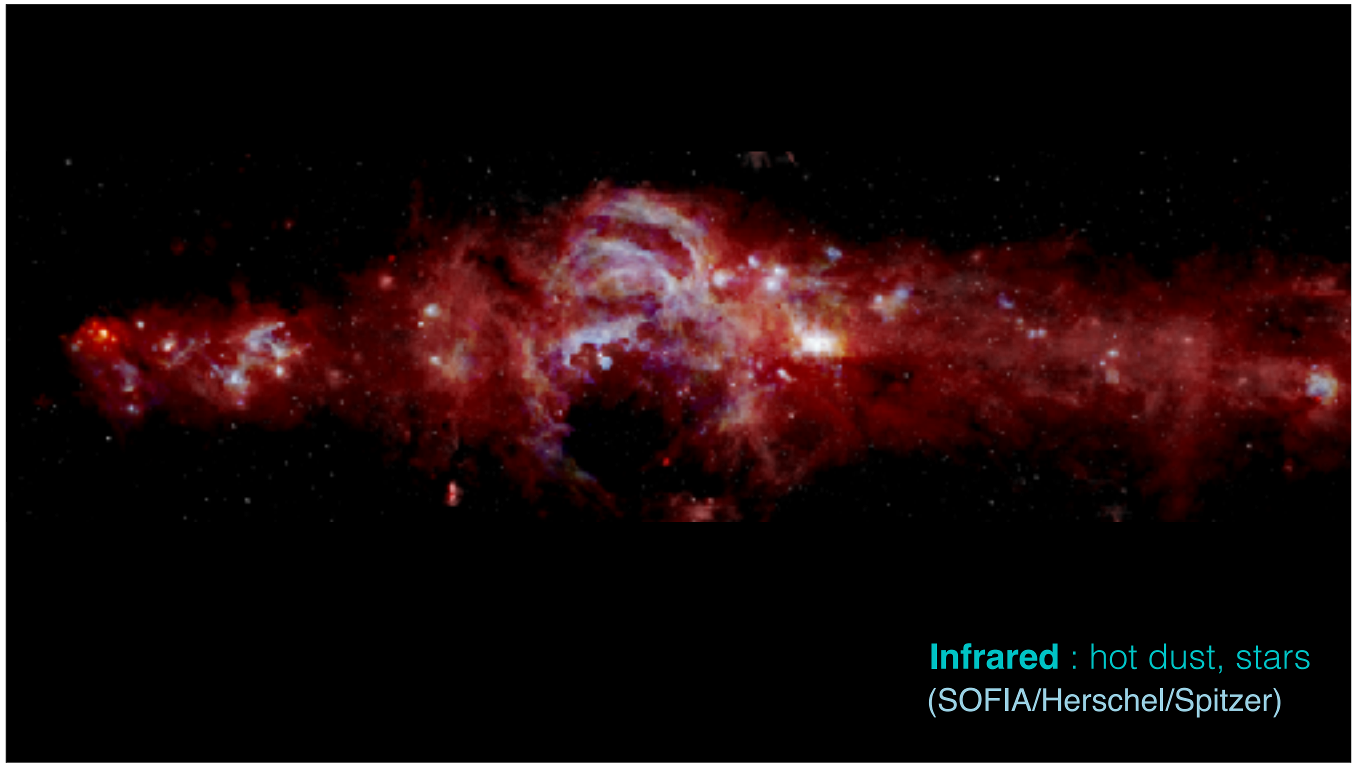
At last, we reach the region where these clouds dominate: this is one of the big stops on our journey: the central molecular zone. The location of the black hole is marked with a cross. The orange emission is thermal emission from the cold dust in galactic center clouds. Each one of these unremarkable blobs actually contains 100,000 to a million solar masses worth of molecular gas. This is a huge reservoir of molecular gas, and the region for this region's name. Although we cannot get an optical or UV view of this region, the long wavelengths represented in this image actually tell a complete story of the stars in this central region.


600 ly
The Central Molecular Zone
Infrared : hot dust, stars
Radio : hot gas, plasma
Millimeter : cold dust/gas
(Image credit: NRAO, A. Ginsburg)



At radio wavelengths we see most strongly the impact of past generations of stars. In this gorgeous image from MeerKAT, a pathfinder instrument for the upcoming Square Kilometer Array, we can see shells of magnetized plasma that are the remnants of former stars, now dead in enormous supernova explosions. In radio we also see evidence of extremely high-energy and poorly understood phenomena like the magnetized gas filaments that appear to pervade this region.

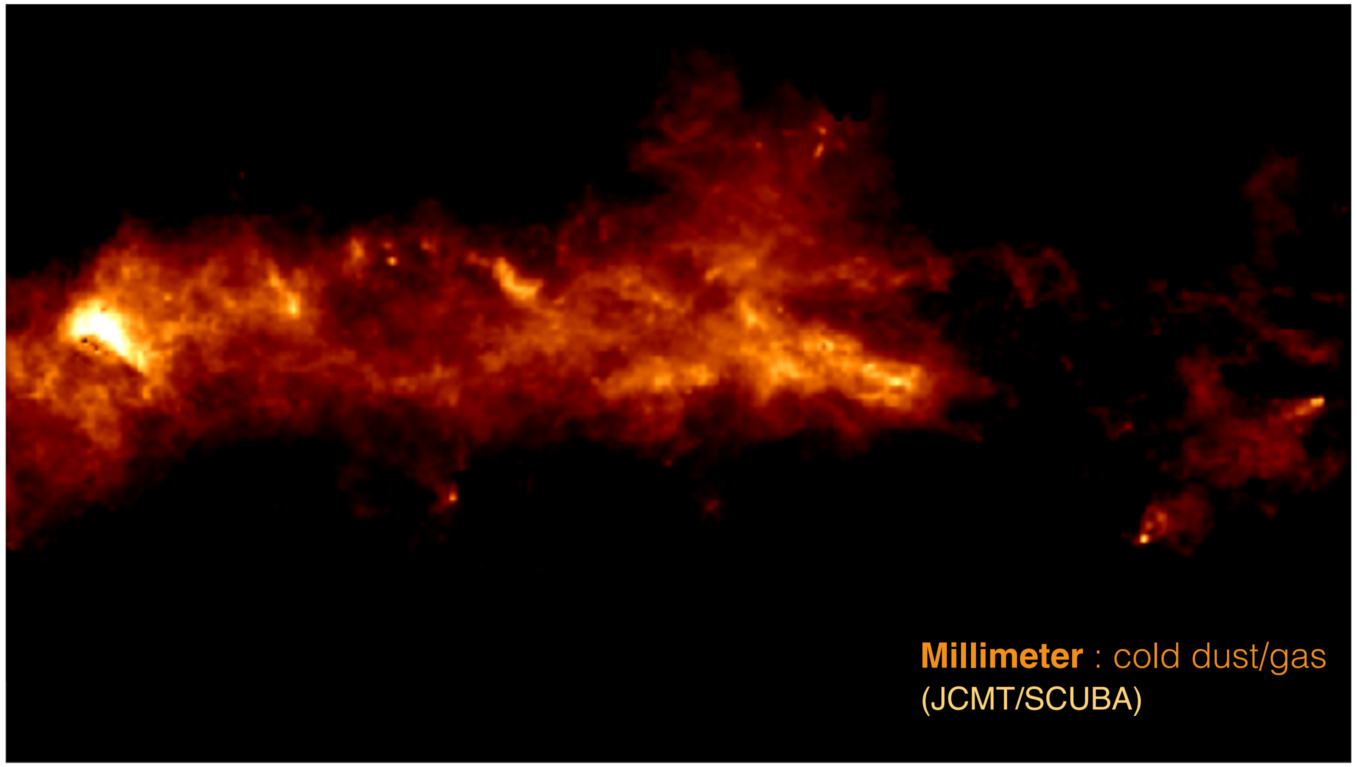

The stars that were
Supernova remnants
Radio : hot gas, plasma
(MeerKAT)



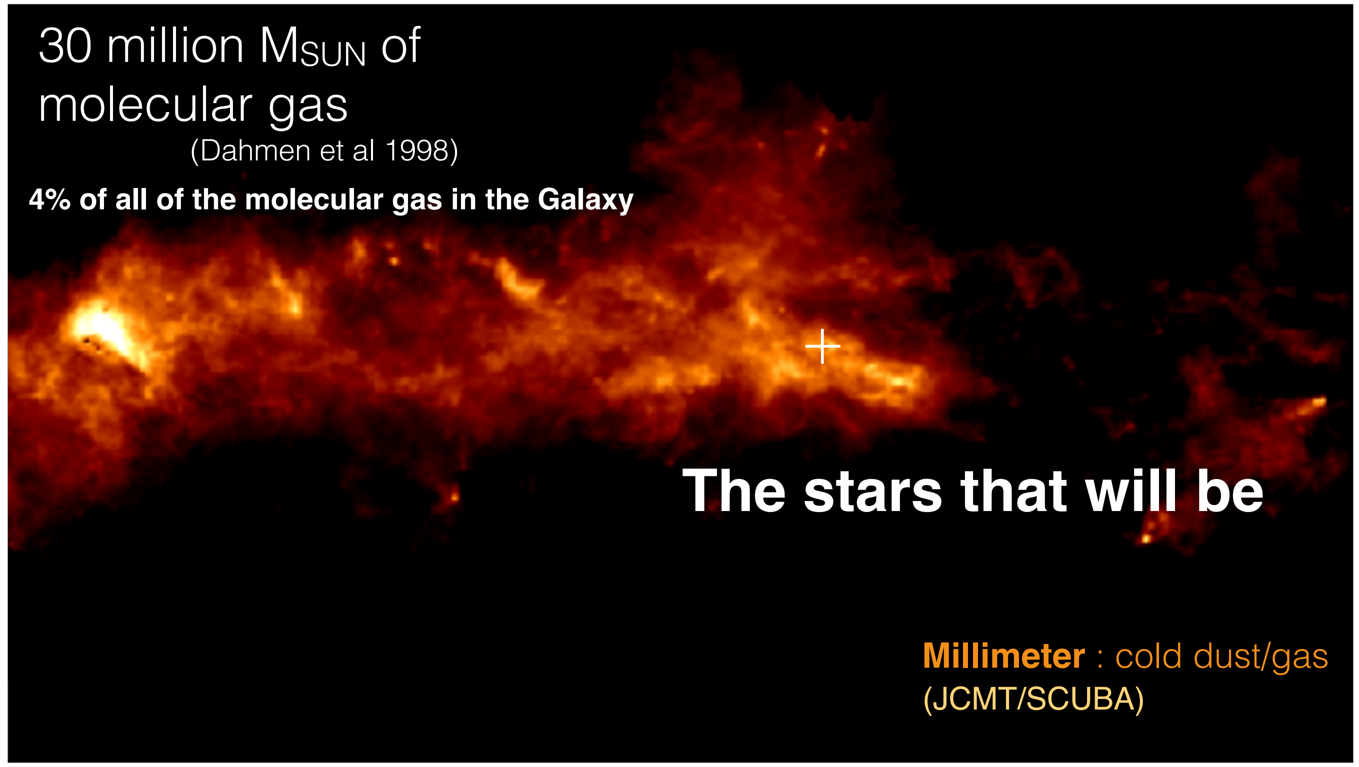
Moving to the infrared, now we see a region lit up by the stars of today. In this composite image from Spitzer, Herschel, and the SOFIA observatory, we see the impact that these current stars are having on their surroundings: heating, ionizing, and disrupting the surrounding gas and dust. In the clusters of stars we also see some evidence that this environment, so different from the rest of the Milky Way disk where our sun formed, may have an impact on the nature of these stars. We see in these clusters a possible deviation from the initial mass function: the standard distribution of masses with which stars in a cluster are born.

1×10^9 M_{SUN} of stars
(Launhardt et al 2002)
2% of all of the stars in the Galaxy

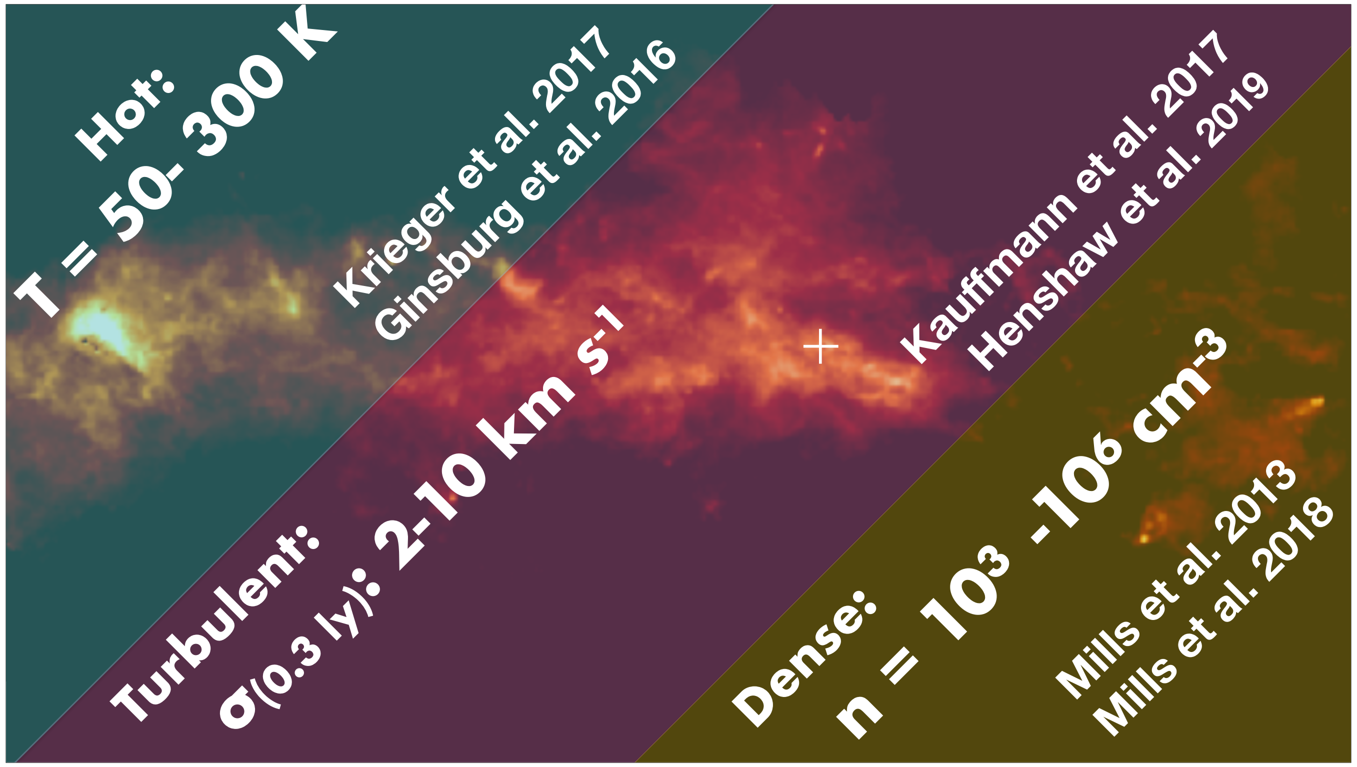
Infrared : hot dust, stars
(SOFIA/Herschel/Spitzer)



As we return to millimeter wavelengths we now see what for me is the most exciting component of this stellar life cycle: the tens of millions of solar masses worth of gas that represent potential in the center of our galaxy for future star formation as well as future fueling of the black hole. This gas experiences an environment like that nowhere else in our galaxy. And it shows.


30 million M_{SUN} of
molecular gas
(Dahmen et al 1998)
4% of all of the molecular gas in the Galaxy
The stars that will be
Millimeter : cold dust/gas
(JCMT/SCUBA)

If you ask what this gas is like, you quickly see that it is several orders of magnitude more extreme than gas in the Milky Way disk based on almost any indicator you choose.



Hot:
T = 50- 300 K
Krieger et al. 2017
Ginsburg et al. 2016
Turbulent:
σ(0.3 ly): 2-10 km s-1
Kauffmann et al. 2017
Henshaw et al. 2019
Dense:
n = 10³ -10⁶ cm-3
Mills et al. 2013
Mills et al. 2018

And the big question is why. This may seem like a silly question because in some ways this is a case of too many suspects, because there are so many reasons to expect that the gas here would be extreme! But we can't just be satisfied by saying that ONE of these many reasons explains what we see. to understand how galaxy centers evolve, we need to isolate the physics that is most responsible for making the gas here so different than gas in the rest of our Galaxy. We need to identify the mechanisms that drive these conditions to see if they are the same as those that drive conditions in more extreme galaxy nuclei, and if the Milky Way center is at all representative.

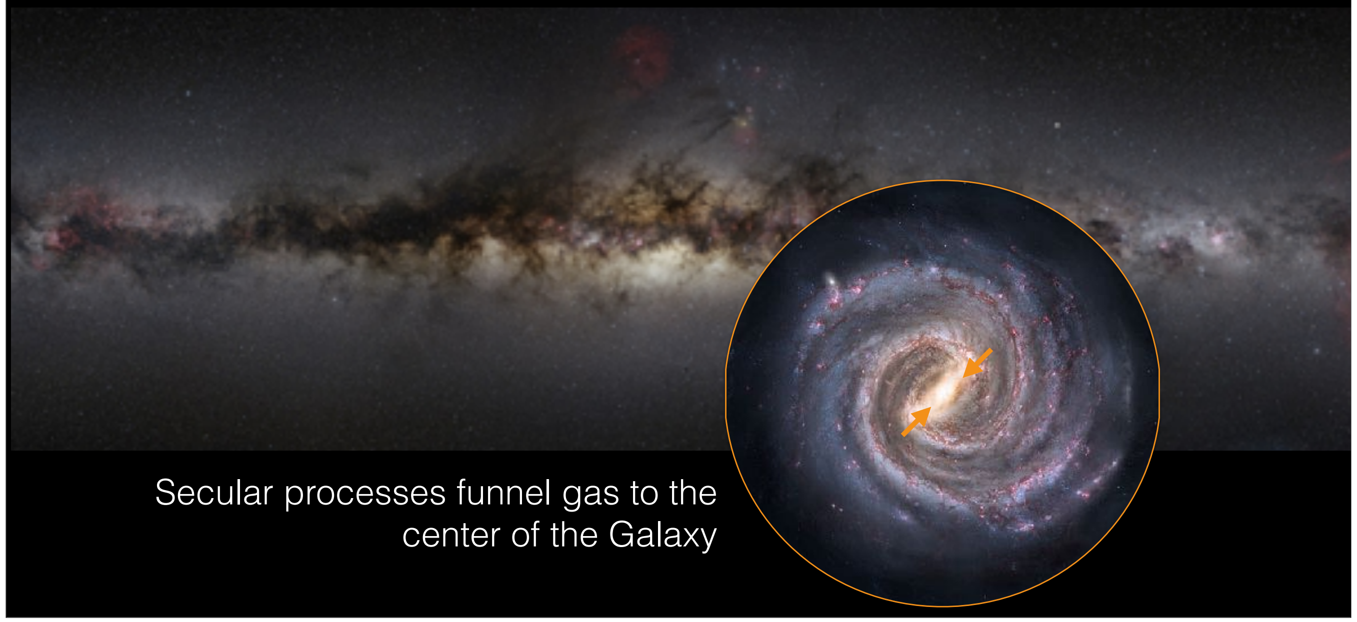
One group of suspects is environmental. By virtue of existing in the center of the galaxy, this gas is exposed to environmental stresses unique to its location.

Is it the Destination?

- Supermassive black hole
- High UV background
- X-ray irradiation
- Enhanced cosmic ray ionization rate

However, we also know that this gas has not always been where it is today, at the galaxy's center. Various processes, including those acting inside a galaxy, independent of mergers and external accretion, can act to funnel gas to the galaxy center. The resulting shocks, loss of angular momentum, and release of kinetic energy may start to fundamentally change the properties of the gas before it even arrives at its destination.

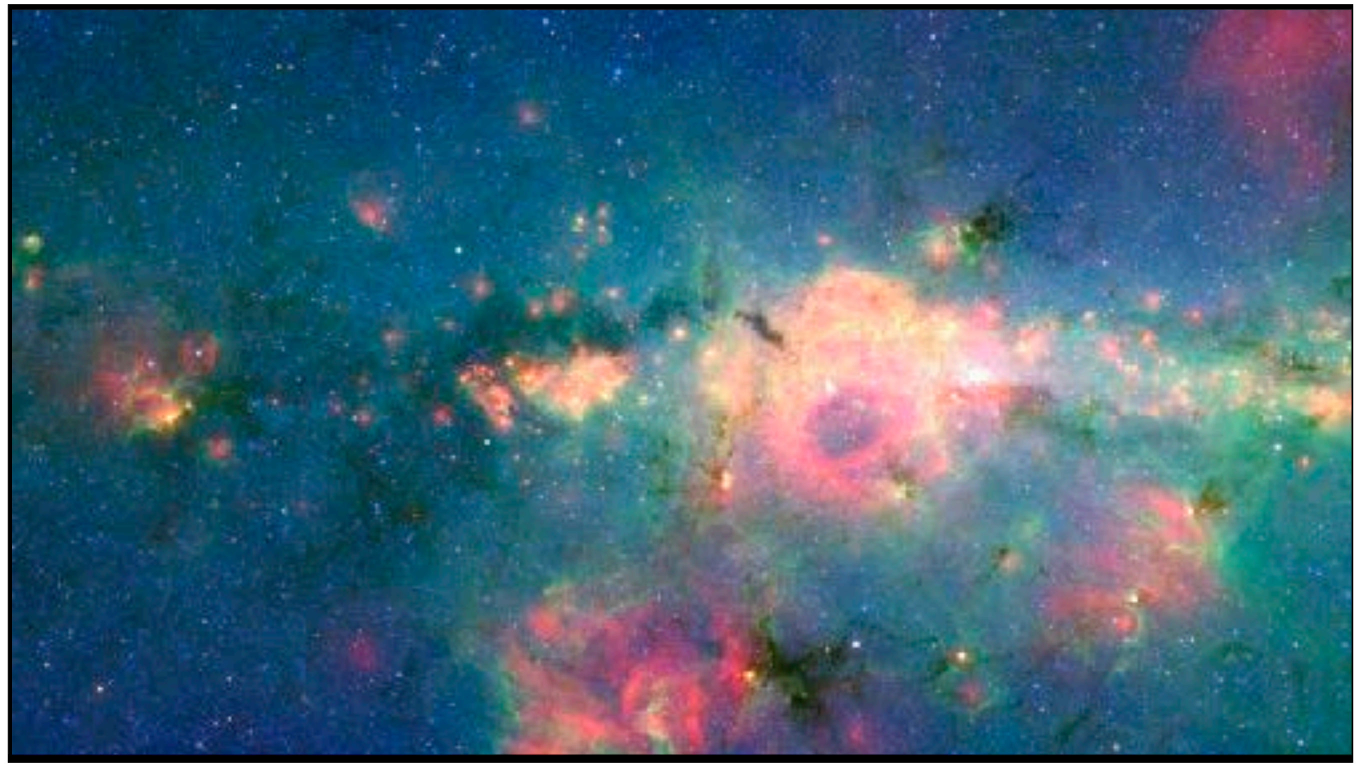
Or is it the journey?



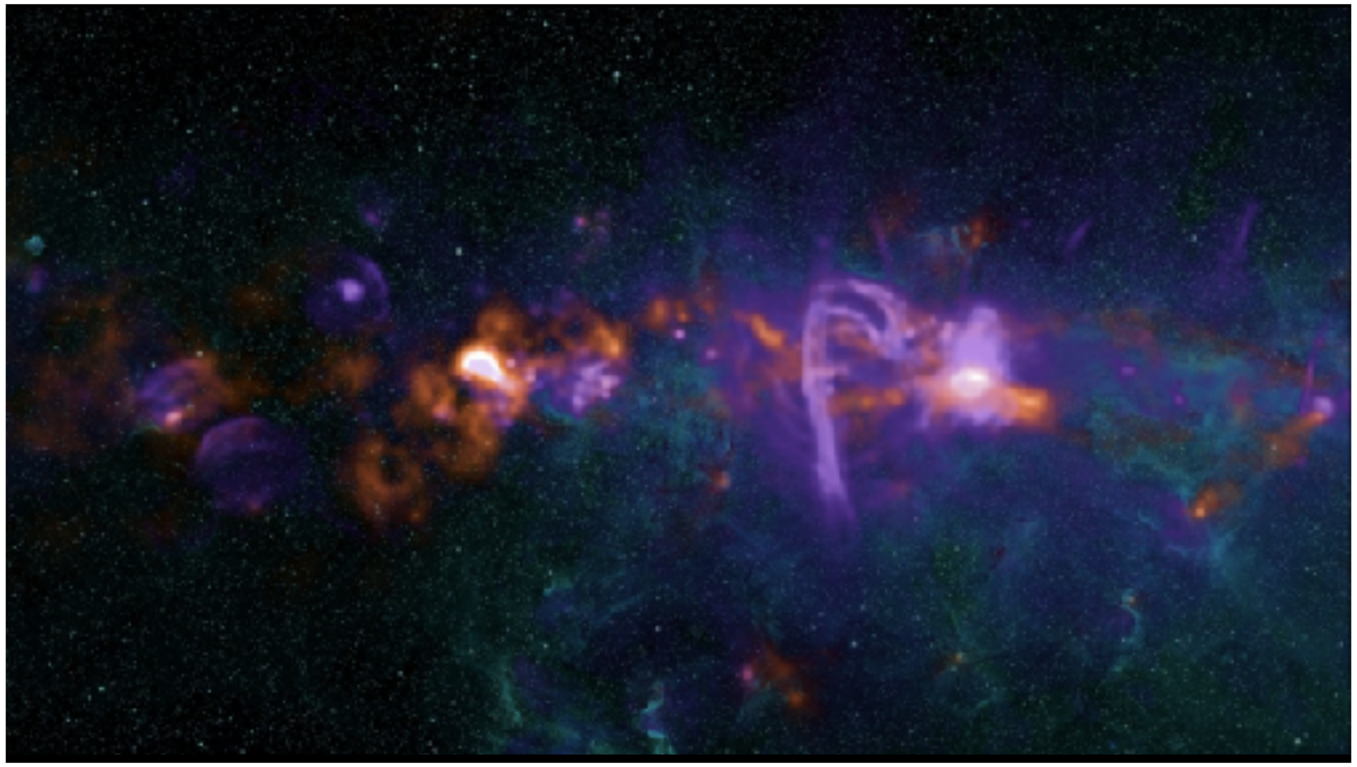
Secular processes funnel gas to the center of the Galaxy

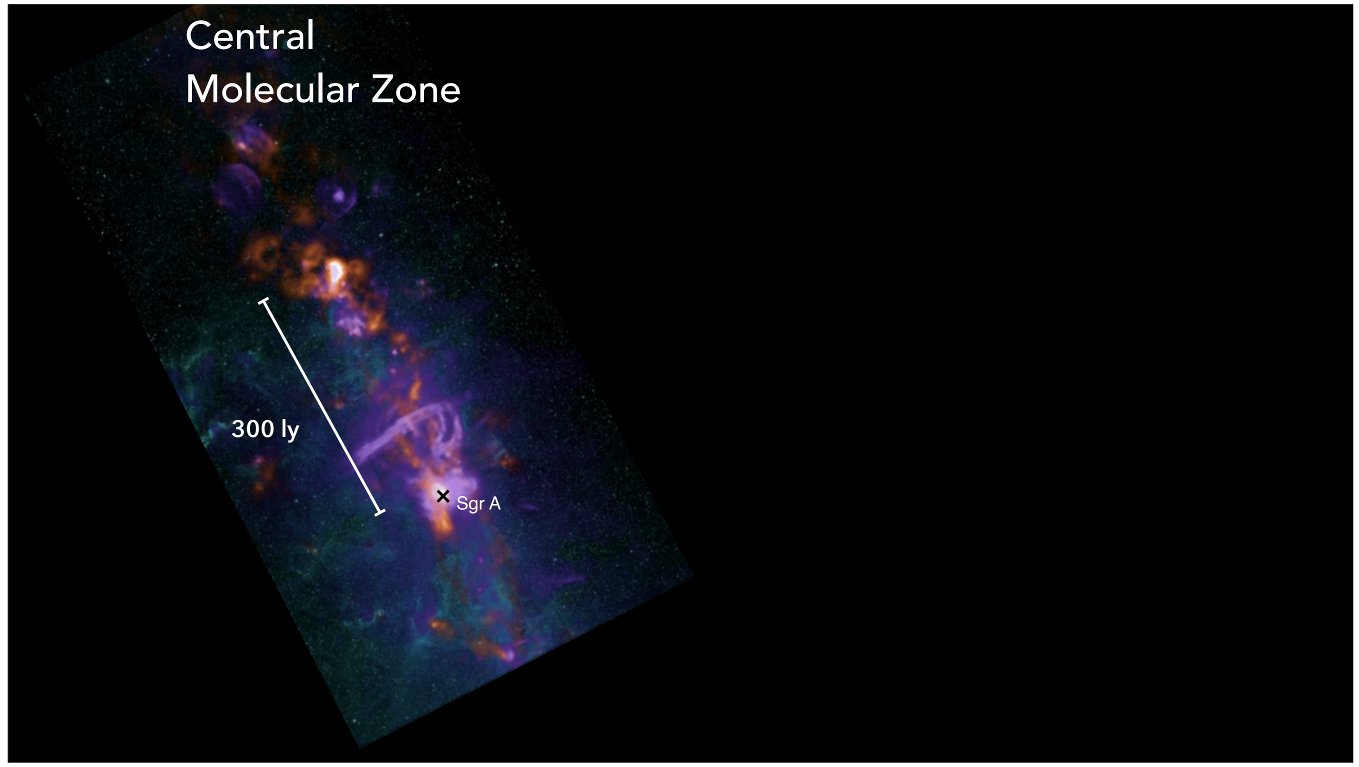
To isolate the most important variables and investigate whether journey or destination is more important for shaping the gas, we have to follow the gas even further in to the Galactic center. Because— speaking of the Journey— we still haven't made it all the way down to the central black hole.

Speeding back in to the center

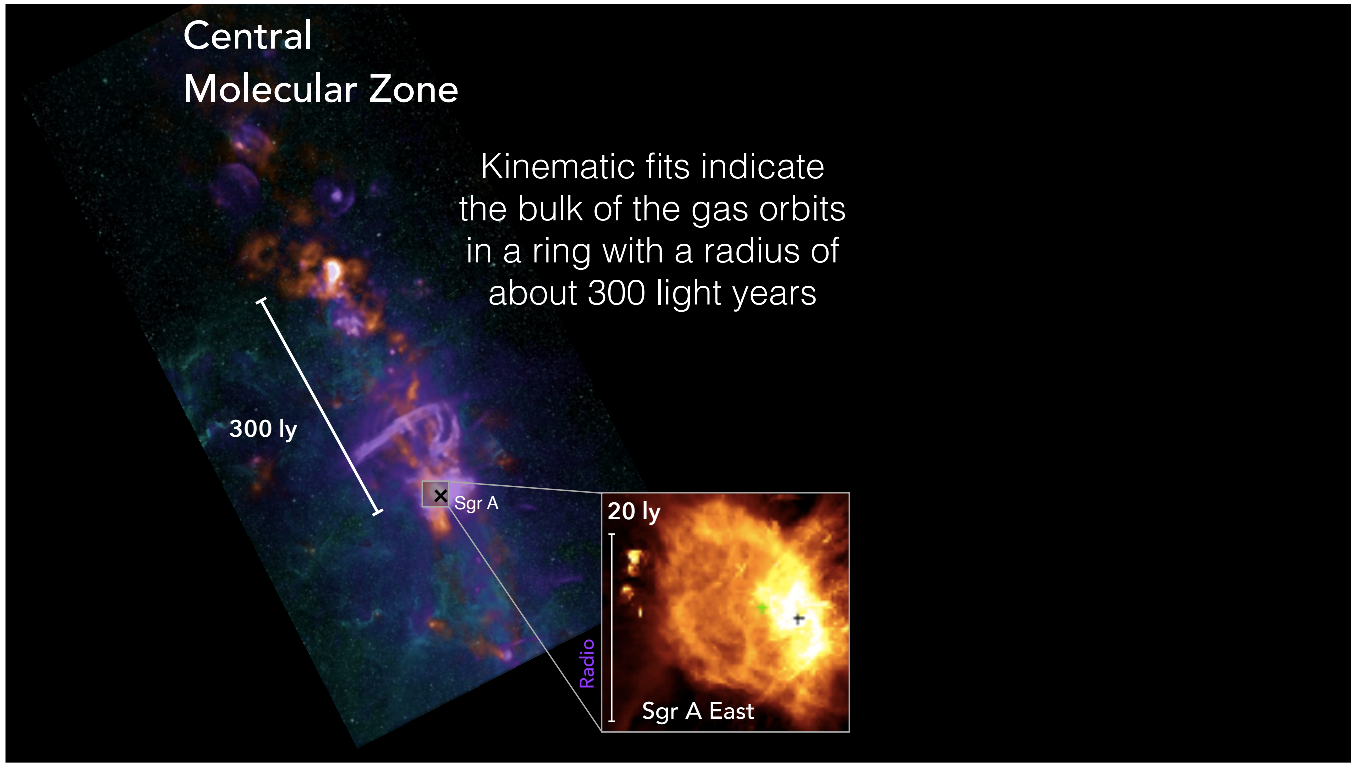


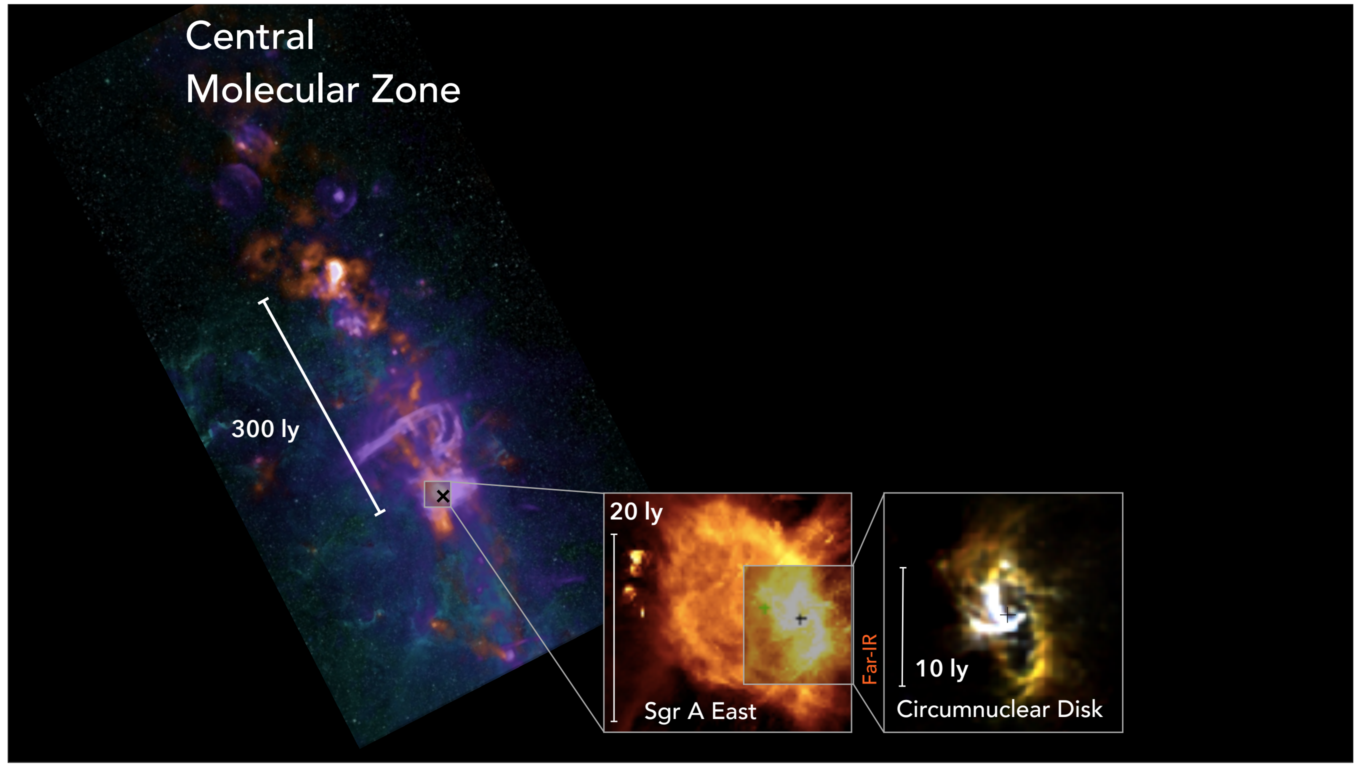
We are now going to move through the central molecular zone to yet smaller scales.



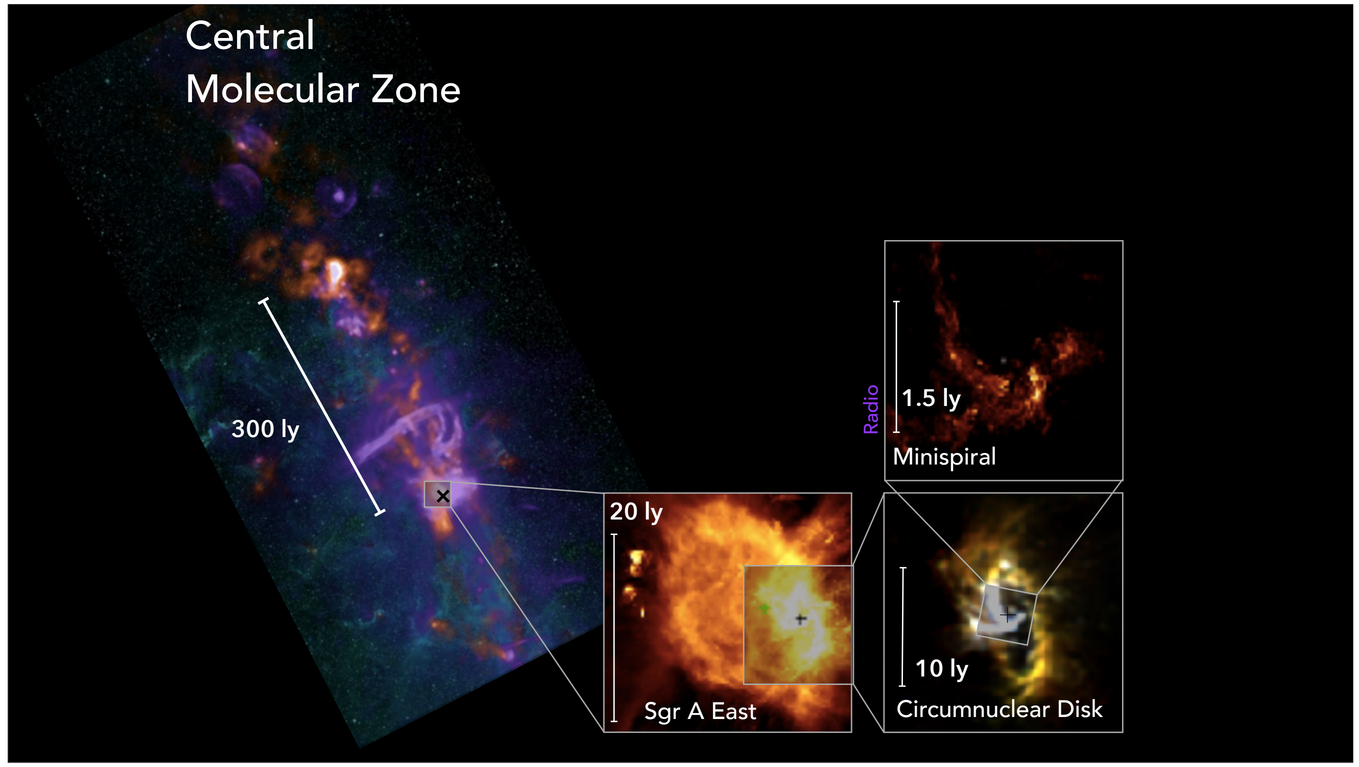


One difficulty in studying structure in the galactic center is knowing its 3D position, since we see it edge on. Studies of gas kinematics indicates that 99.9% of the dense gas we see is in a ring at least 300 ly from the black hole. So, as we zoom in toward the black hole in this inset RADIO image, while we appear to see signs of recent star formation (hii regions and a supernova shell) within the central 20 ly, appearances here can be deceiving and these are likely at least 100 light years in front of the black hole.

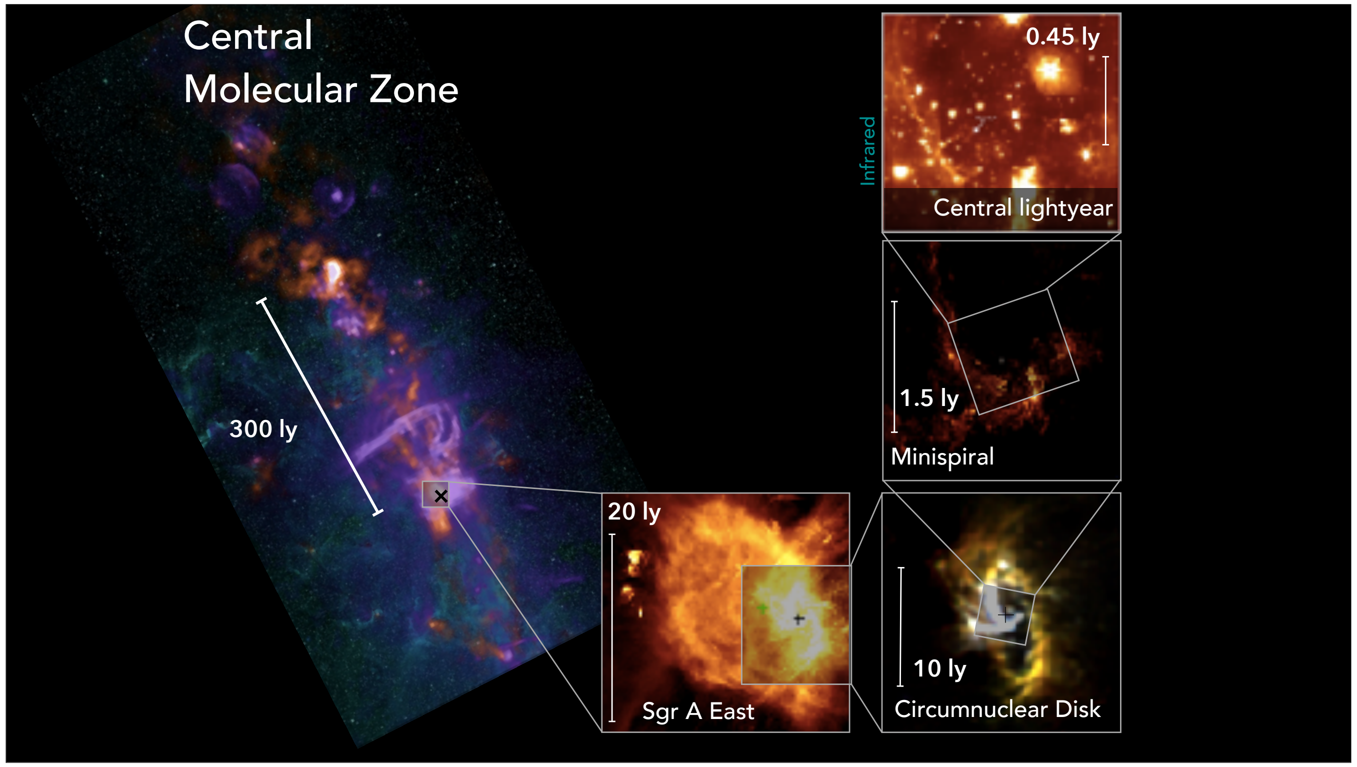

Central
Molecular Zone
Kinematic fits indicate
the bulk of the gas orbits
in a ring with a radius of
about 300 light years
300 ly
Sgr A
20 ly
Radio
Sgr A East



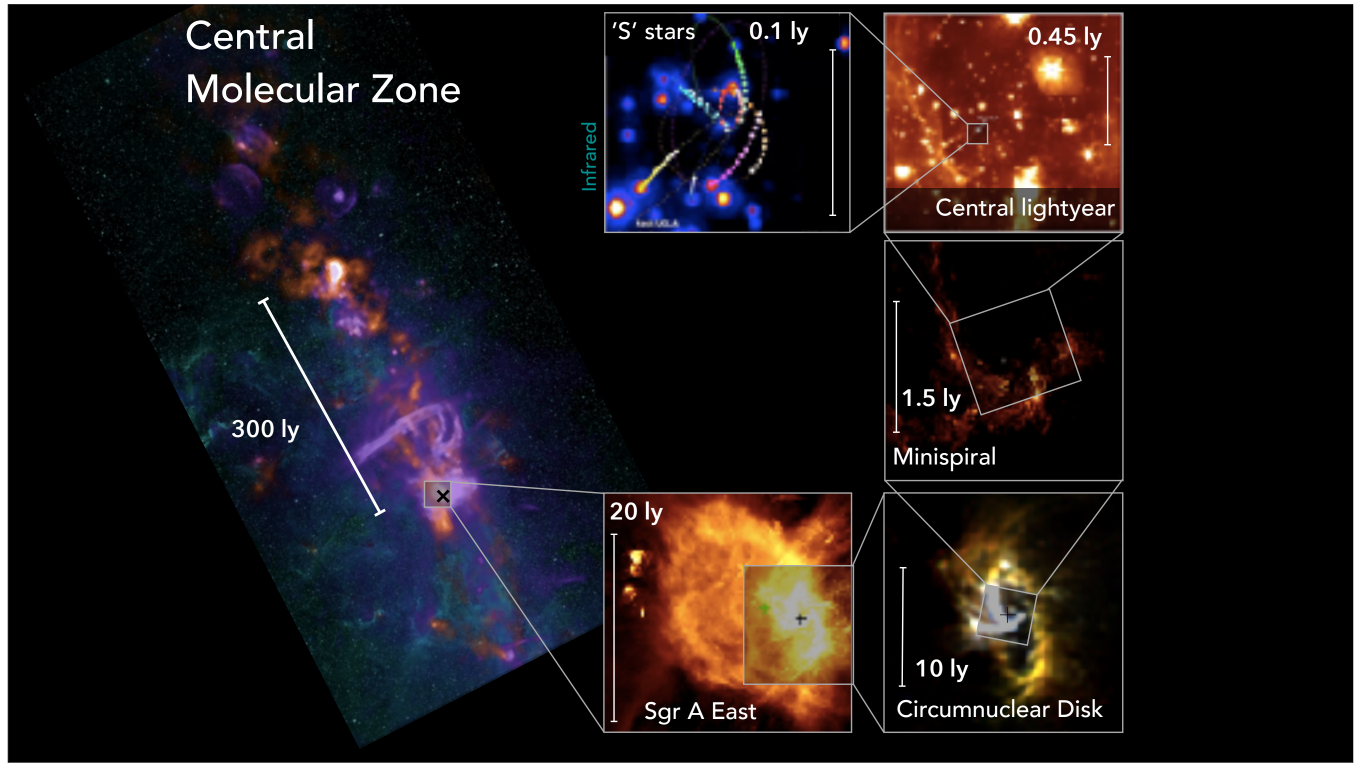
Moving closer in and here is some gas that we know from its motions is truly close to the black hole. Far-infrared: picking up the warm dust in the last reservoir of the molecular gas: only 0.1% of the molecular gas, about 10,000 solar masses makes it this far, into a ring-like structure surrounding the black hole (perhaps analogous to an AGN torus, though our black hole is not active). Inside of this ring is even less gas: only a few hundred solar masses worth of neutral atomic gas.



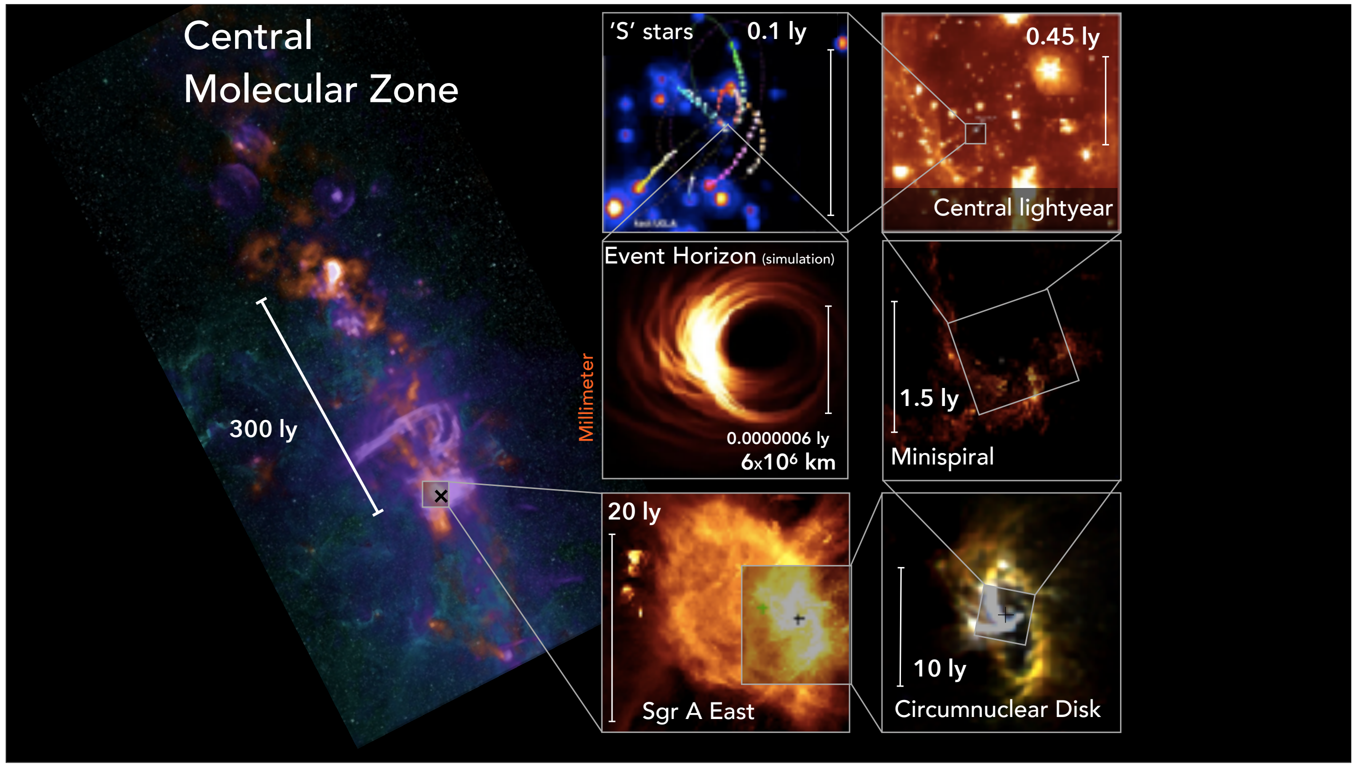
From this point onward, everything is ionized. See the radio mini spiral: comprising only a few TENS of solar masses worth of ionized gas. Also notable: everything inside of the CND is now dominated by the gravitational potential of the supermassive black hole (whereas just outside of it, you have a roughly equal contribution from the black hole and the stars in a central nuclear cluster).



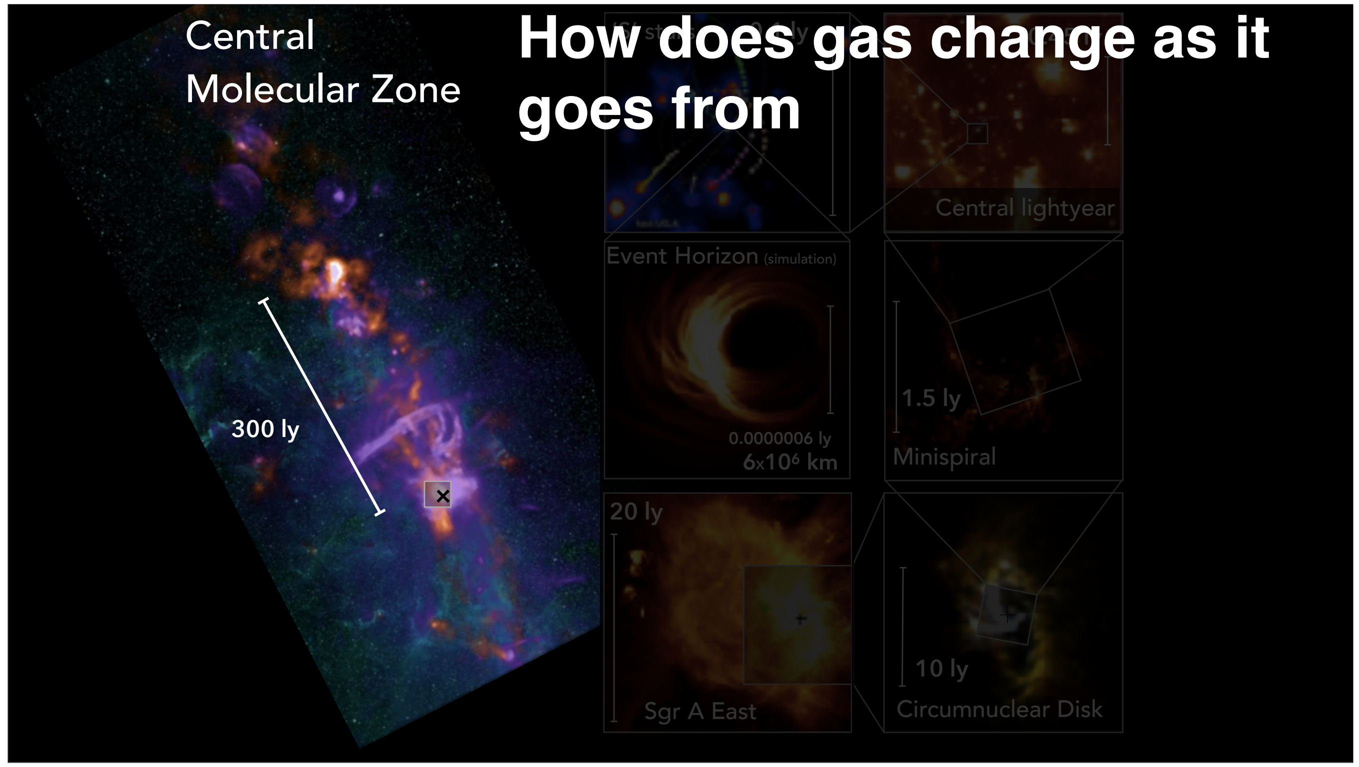
Move into the central light year, and now basically all you see is those stars. Their stellar winds alone are sufficient to account for the small amount of accretion onto the black hole: right now, the gas from larger radii is not making it this far in.



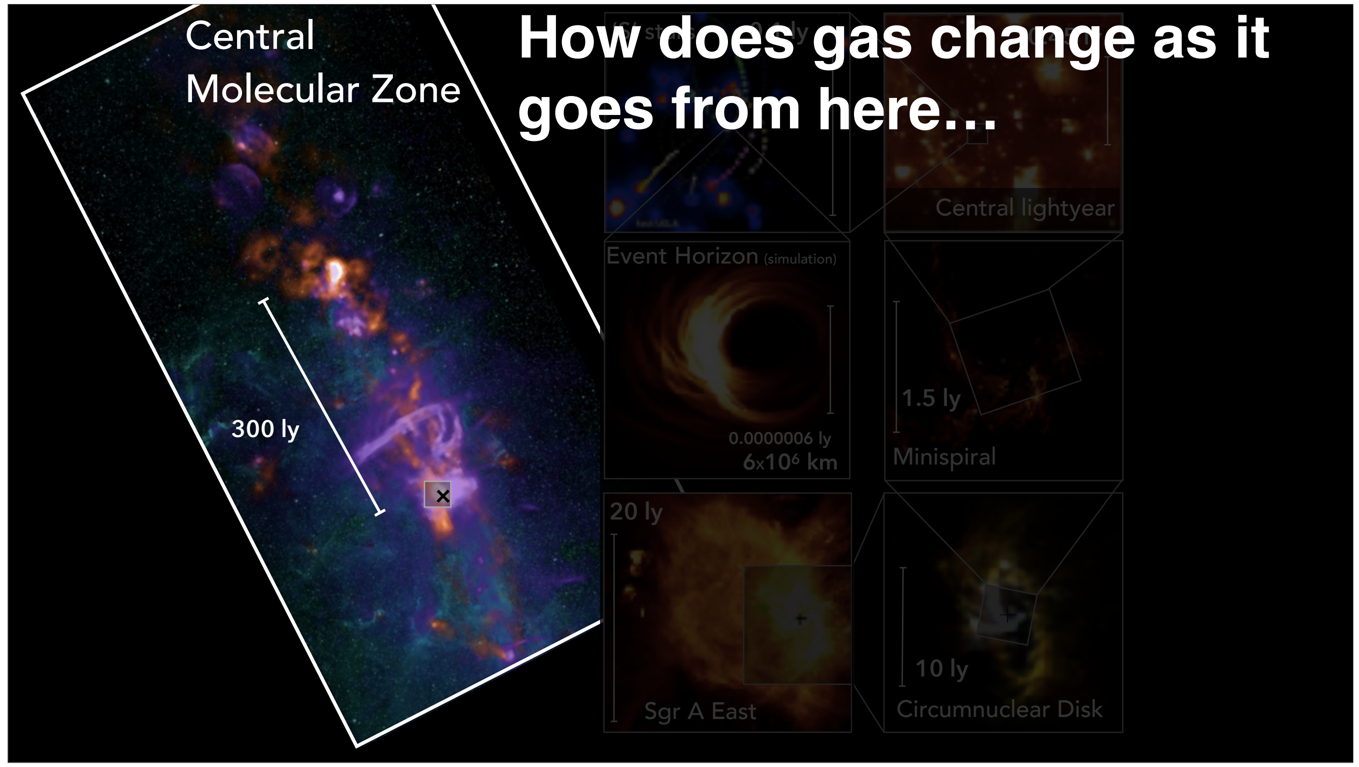
Even though gas isn't making it this close in today, we believe it did only a few million years ago: The young stars in the central lightyear, the innermost of whose orbits are famously used to determine parameters of central supermassive black hole, are suggested to have formed in-situ in one of the most extreme environments imaginable: in an incredibly dense gas disk a fraction of a light year from the black hole.



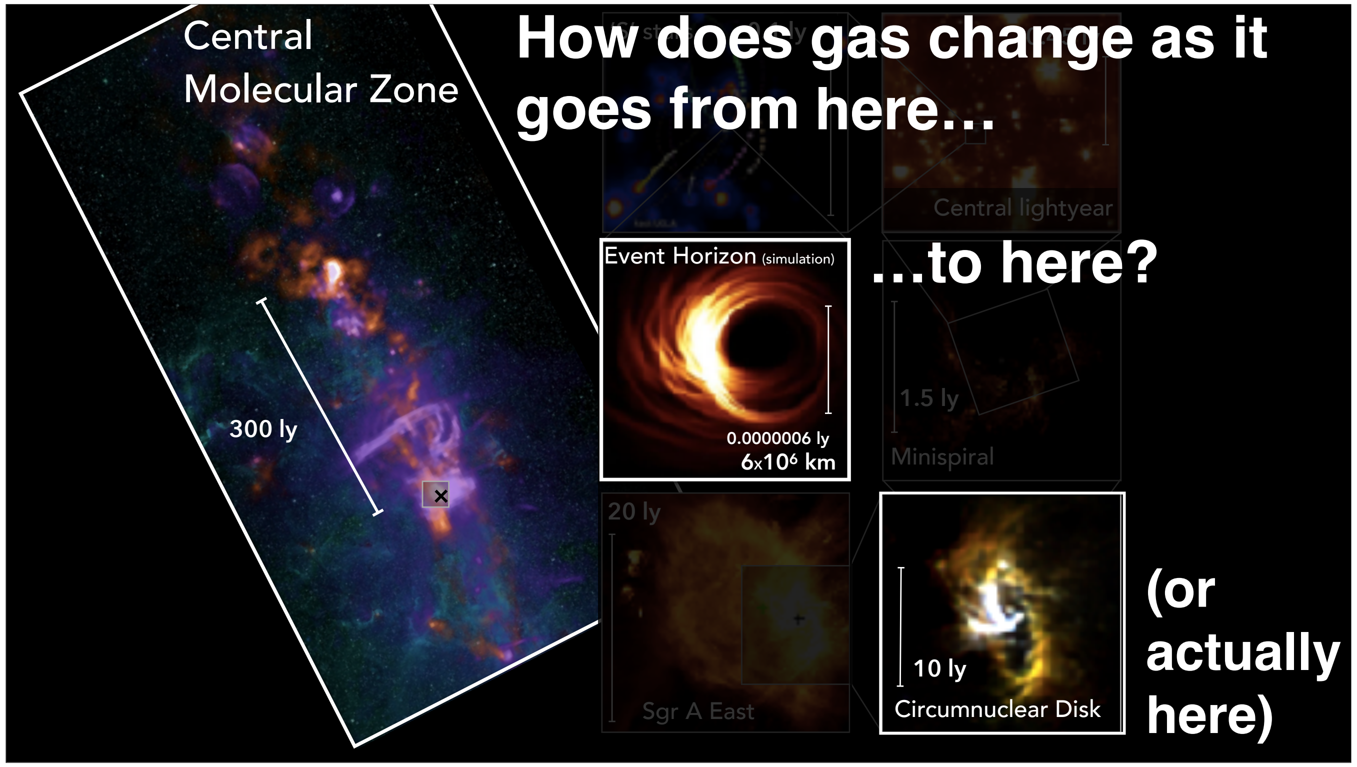
And now we have to make an enormous jump to get to the scales on which minuscule amounts of gas are currently accreting on to our black hole — that is six zeroes, so less than a micro parsec— these are the scales that will soon be probed with the event horizon telescope. We have travelled orders of magnitude in scale to from kilo parsecs of the disk and bar down to less than a micro parsec to reach the supermassive black hole. This is the journey that the gas must take— and has taken, in order to build up a supermassive black hole weighing 4 million times as much as our sun.

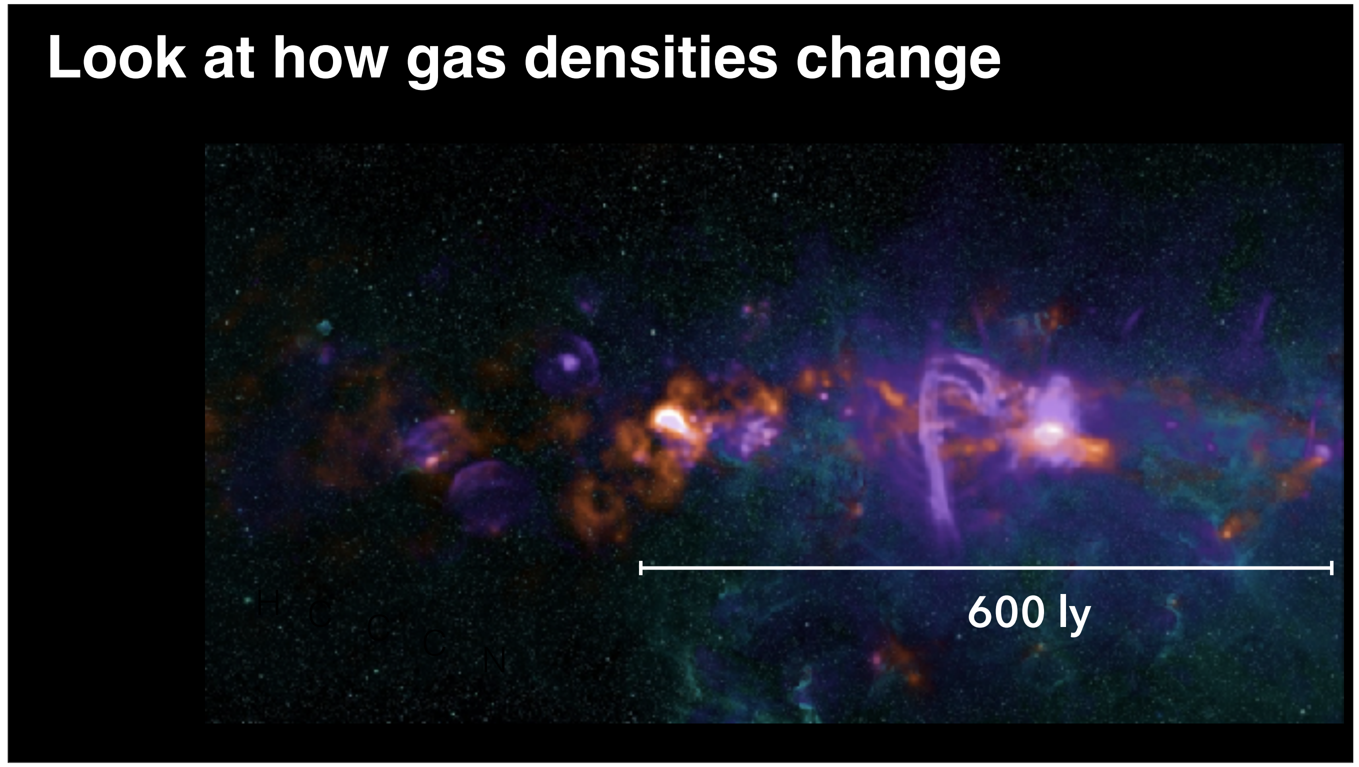


To return to question of journey or destination: if the journey is primarily responsible for shaping the gas, should see gas properties get significantly more extreme the closer the gas gets to the black hole. As the black hole is inactive and there is apparently no ongoing SF in the central tens of light years, we do not expect that gas would encounter a substantially more extreme environment than it already experiences at radii of hundreds of light years.


Central
Molecular Zone
How does gas change as it goes from here…
300 ly
Central lightyear
Event Horizon (simulation)
0.0000006 ly
6x10⁶ km
1.5 ly
Minispiral
20 ly
Sgr A East
10 ly
Circumnuclear Disk

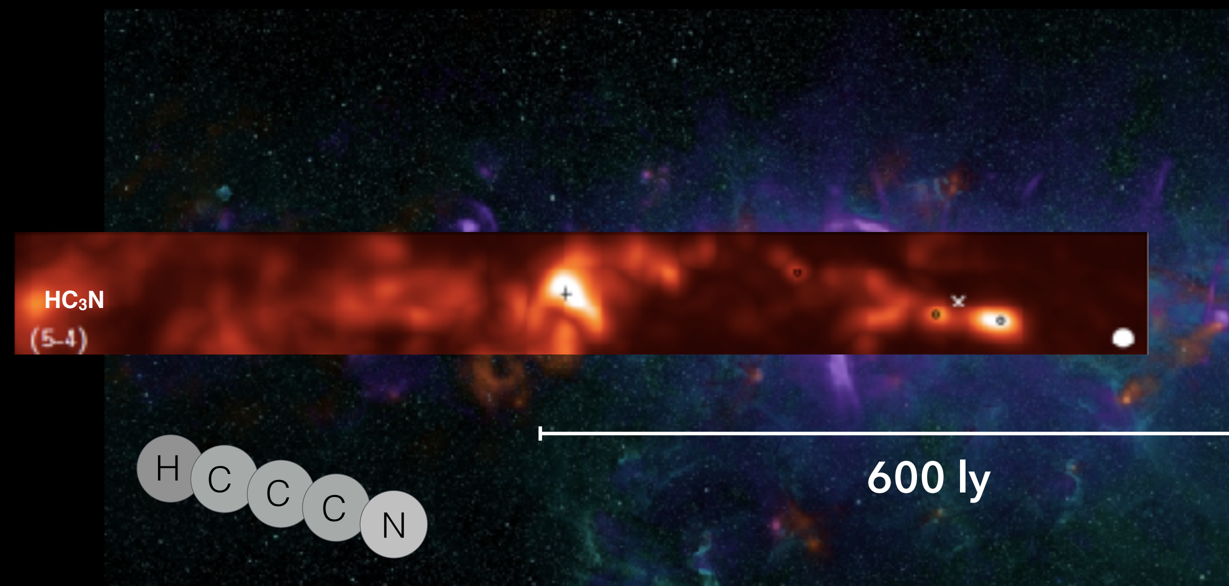

How does gas change as it goes from here…
…to here?
Central Molecular Zone
300 ly
Event Horizon (simulation)
0.0000006 ly
6x10^6 km
Central lightyear
1.5 ly
Minispiral
20 ly
Sgr A East
10 ly
Circumnuclear Disk

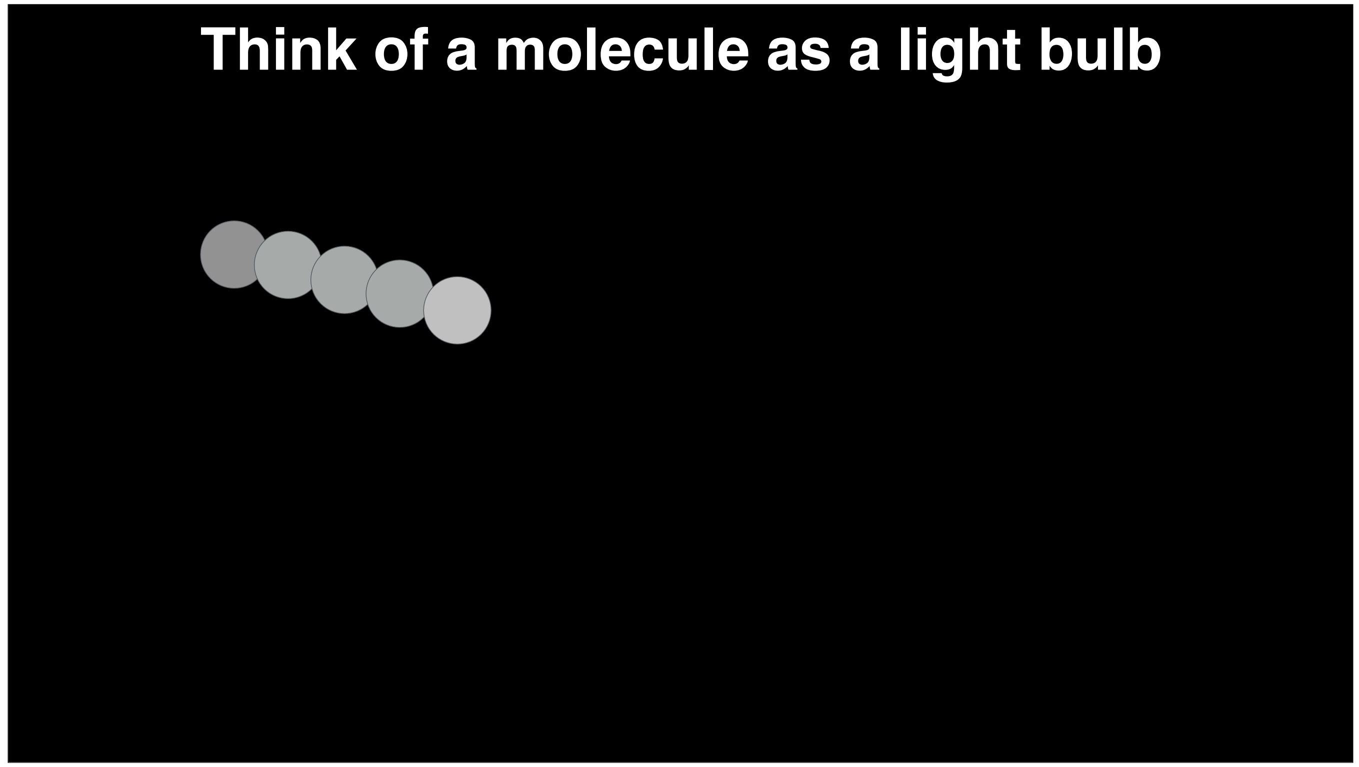

Central
Molecular Zone
300 ly
How does gas change as it goes from here…
…to here?
Event Horizon (simulation)
0.0000006 ly
6x10^6 km
Central lightyear
1.5 ly
Minispiral
20 ly
Sgr A East
10 ly
Circumnuclear Disk
(or actually here)



Start by focusing on the gas density, and investigating how it changes as a function of radius. To measure the density, turn to the molecule HC3N, or cyanoacetylene. Why HC3N? It is has several important properties. First, it is a linear molecule with a simple transitions. It is also relatively heavy, which means it has relatively closely-spaced energy transitions that are easily accessible with our instruments from radio to millimeter wavelengths. Finally, it has a low enough abundance to be optically thin (for each billion molecules of H2 there are only a few HC3N molecules)

Look at how gas densities change



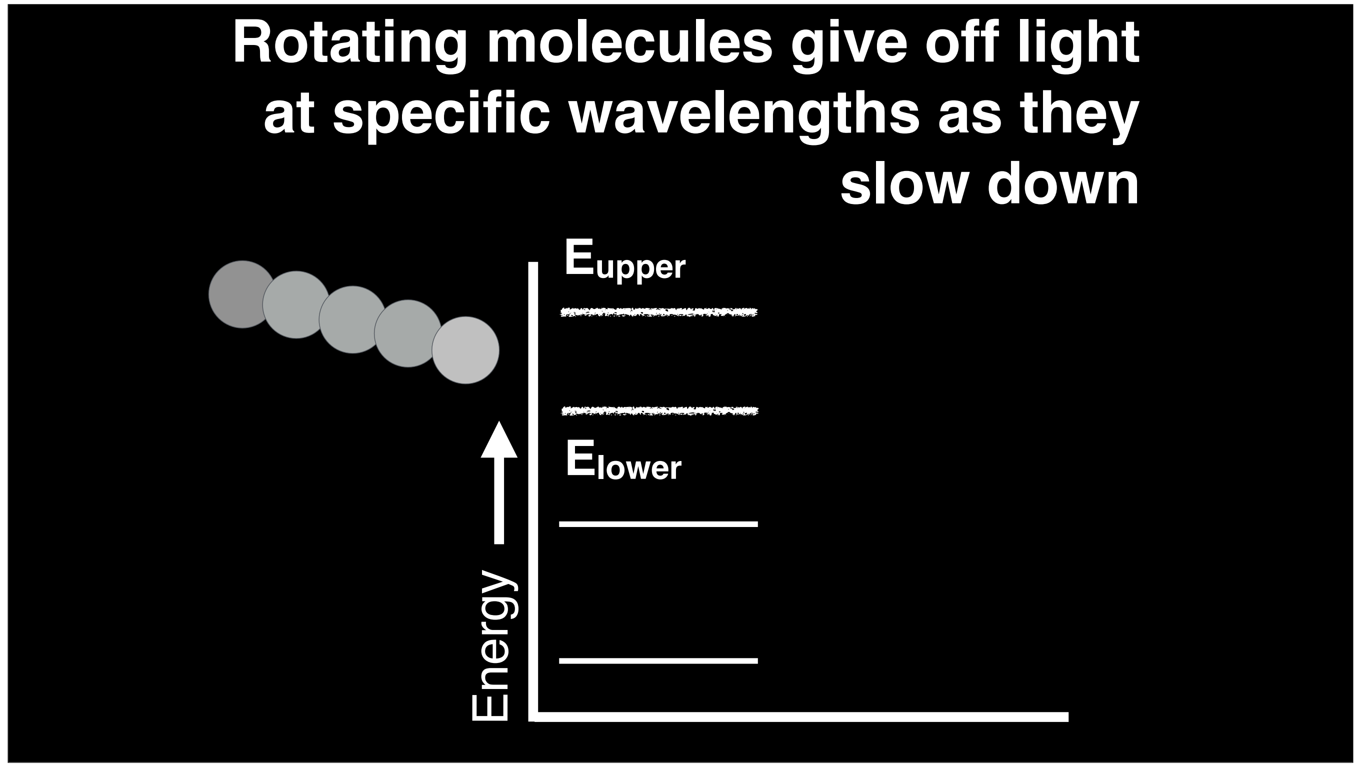


Why is it important that it be optically thin? Well, the most basic way to think about detecting light from molecules in space is that each molecule acts like a fixed-watt light bulb, and so counting the amount of light lets you count how many molecules are there. However, if there are too many present, the light gets blocked (actually reabsorbed) and you no longer can detect every molecule that is present.

Think of a molecule as a light bulb

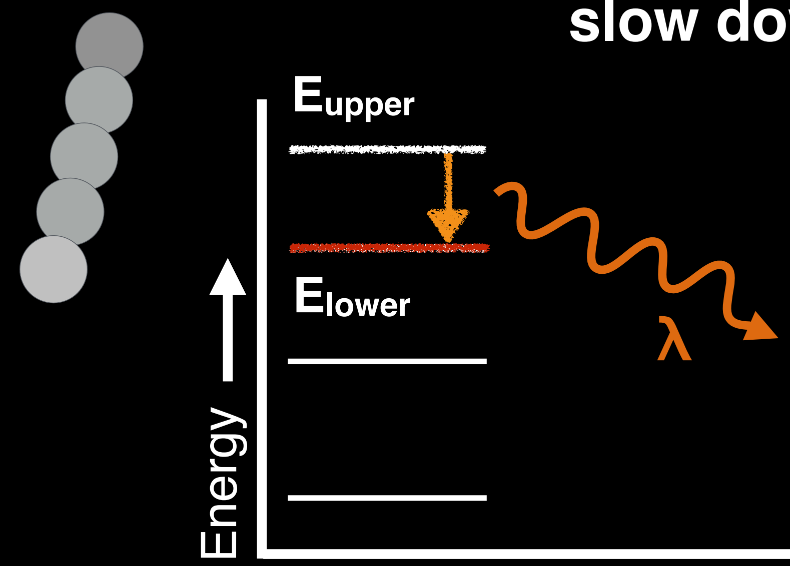
Think of a molecule as a light bulb

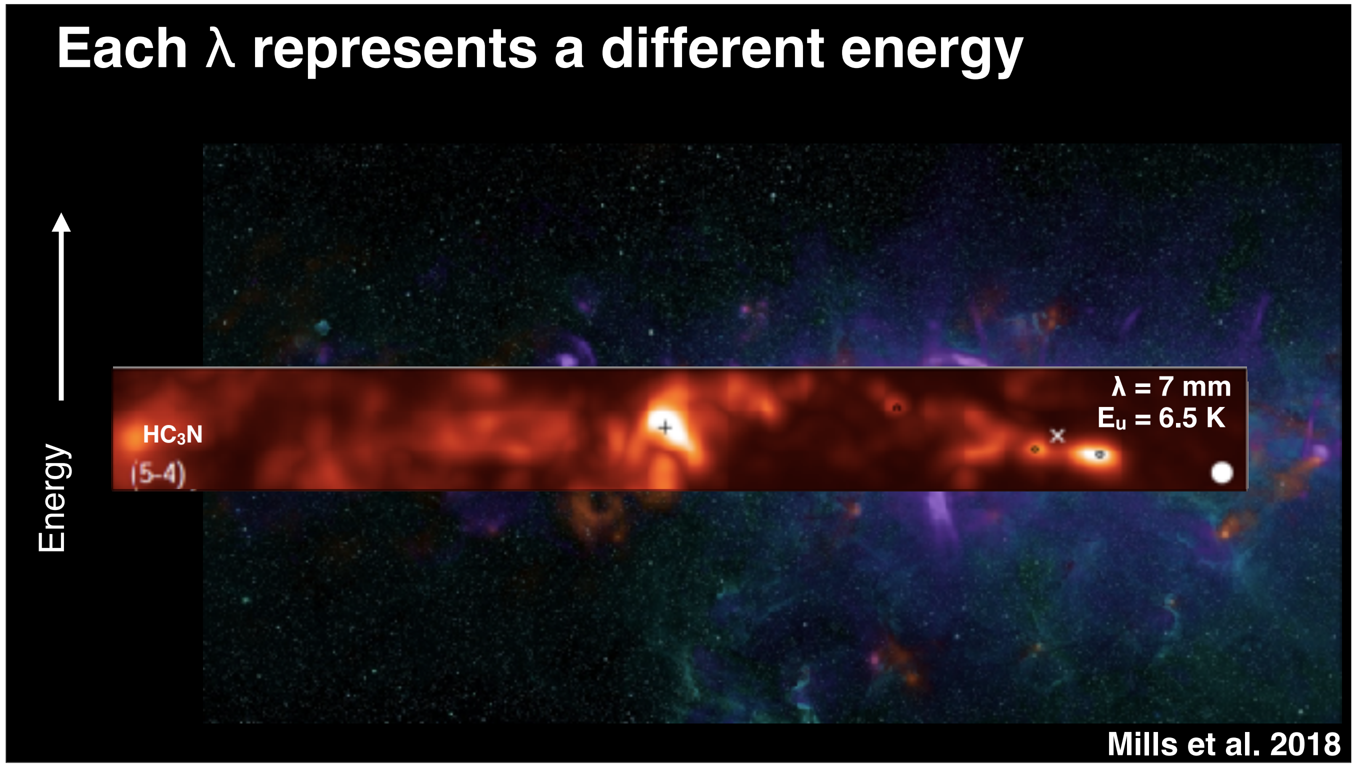
The amount of light you observe
(basically) tells you how many
molecules there are.



Of course, a molecule is not a light bulb. It gives off light at discrete frequencies. The energy in molecules is quantized: when you consider rotational transitions, this means molecules spin with fixed values of angular momentum, and can absorb and emit photons to move between these states. Molecules in space that are spinning are fundamentally lazy: want to stop spinning, and to do so have to lose energy by giving off a photon.

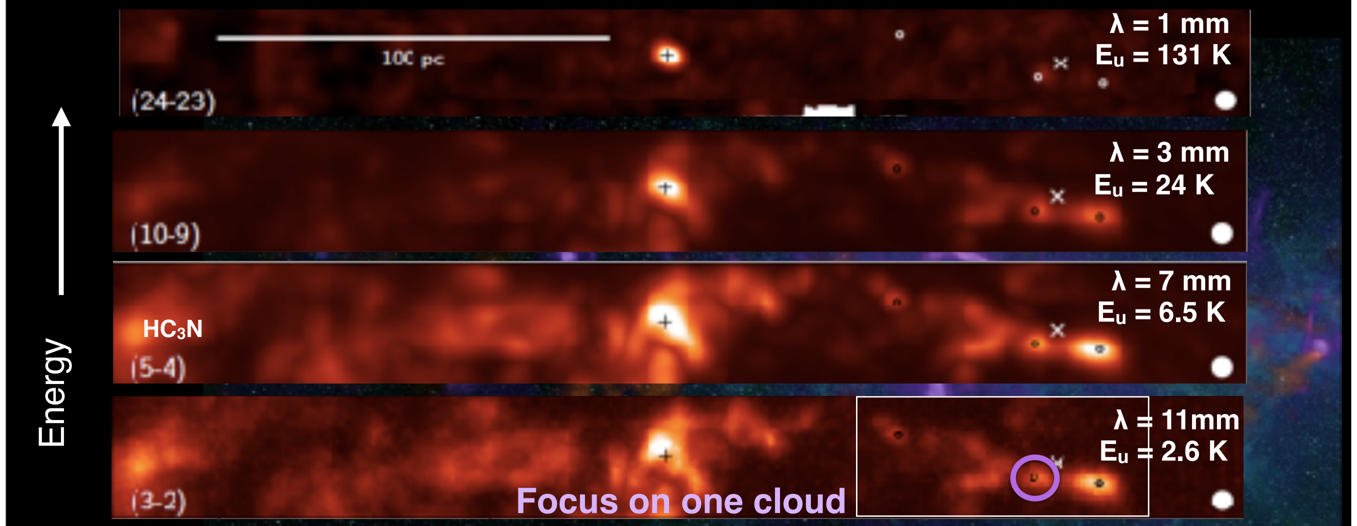
Rotating molecules give off light at specific wavelengths as they slow down





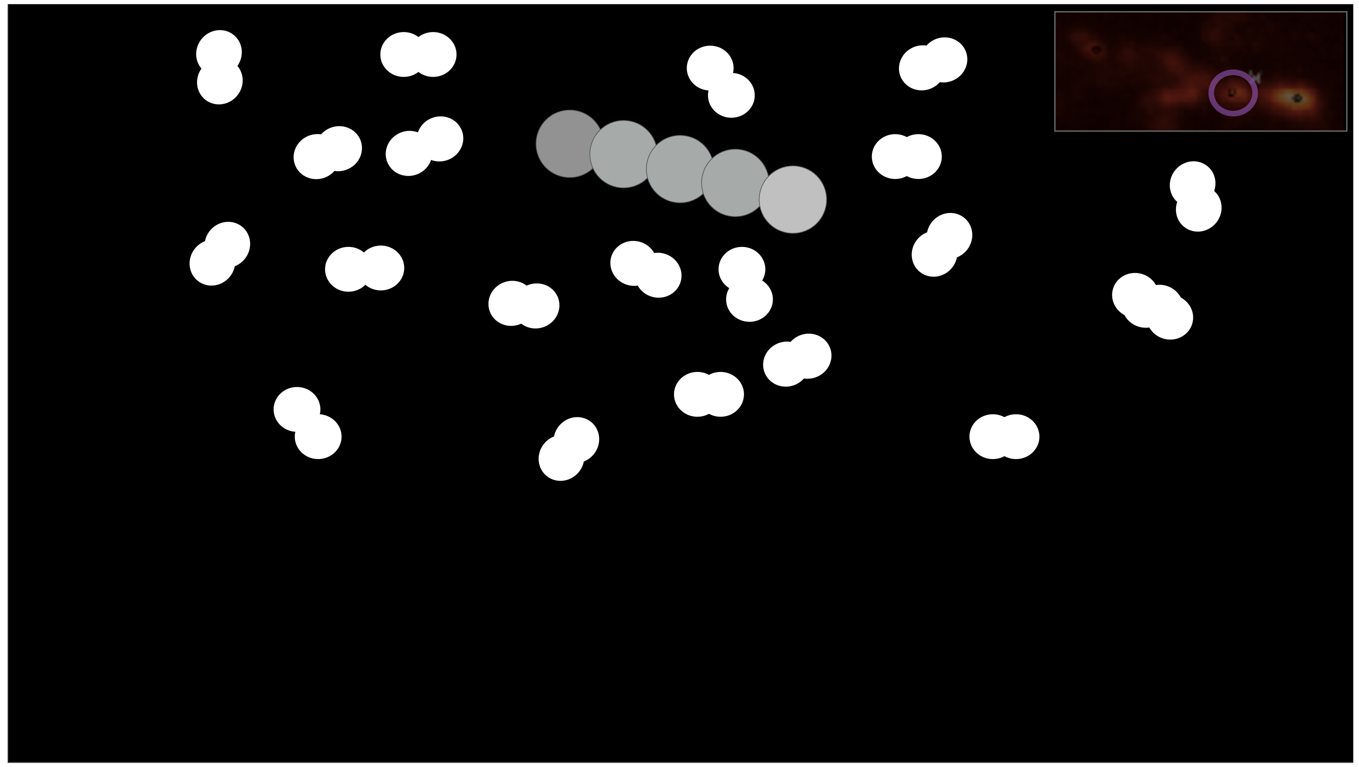
This means that observing different transitions tells you about the fraction of the HC3N molecules at each energy. The amount of gas corresponding to each excitation state. We are going to focus specifically on one cloud for which we have additional spectra at even more energies. What determines the range of energies that HC3N molecules have?

Each λ represents a different energy

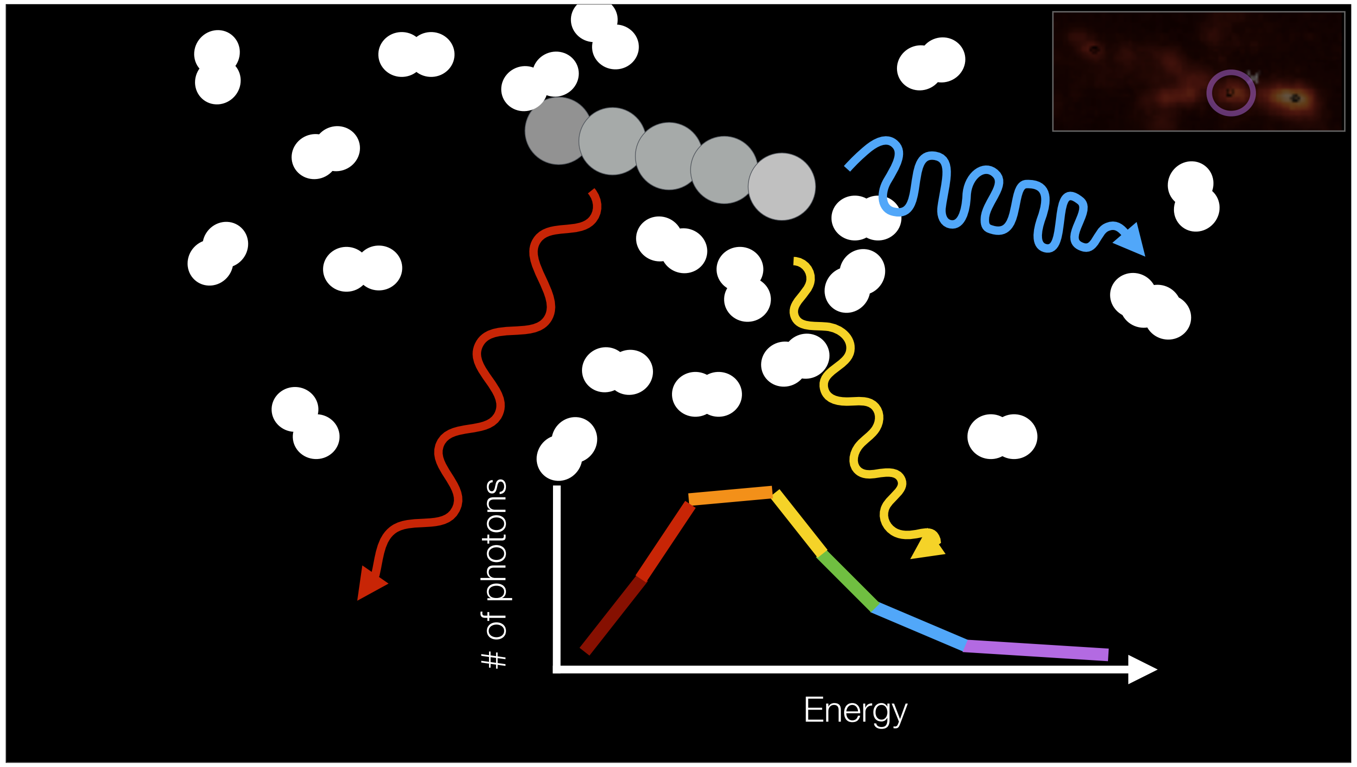


What sets the distribution of energies?

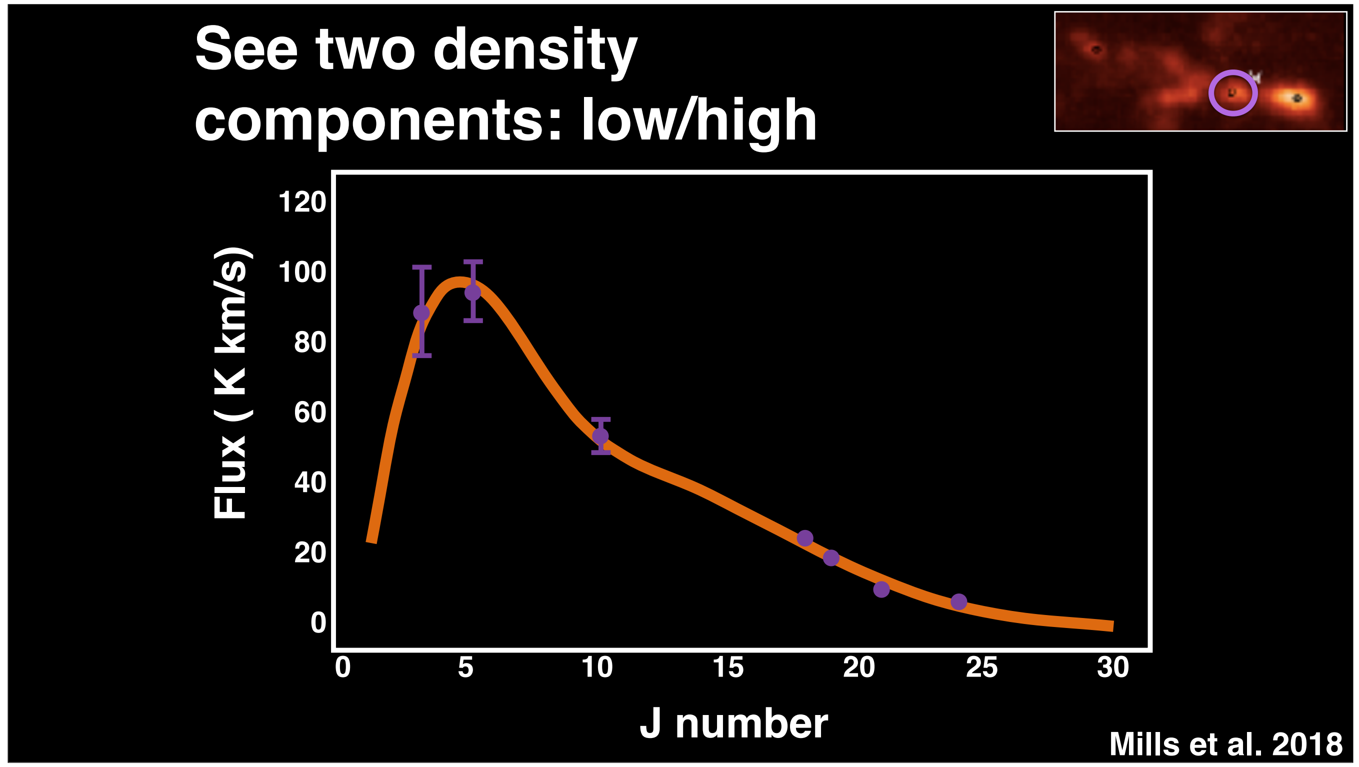
Mills et al. 2018



Remember that HC3N is far from being the most common molecule in a cloud. Most is H2. A collision with H2 bumps the molecule up in energy, but it can quickly decay back to a lower-energy state by giving off a photon. Occasionally however, it happens to undergo another collision before it can give off that photon, and so it is bumped up to a higher energy level and it will give off a correspondingly more energetic photon when it decays. So now, the number of photons you detect from the molecule at each energy level is a measurement of how frequently the molecule is undergoing collisions, which is controlled by the density of the gas.

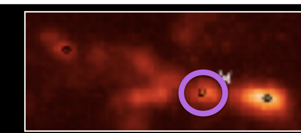


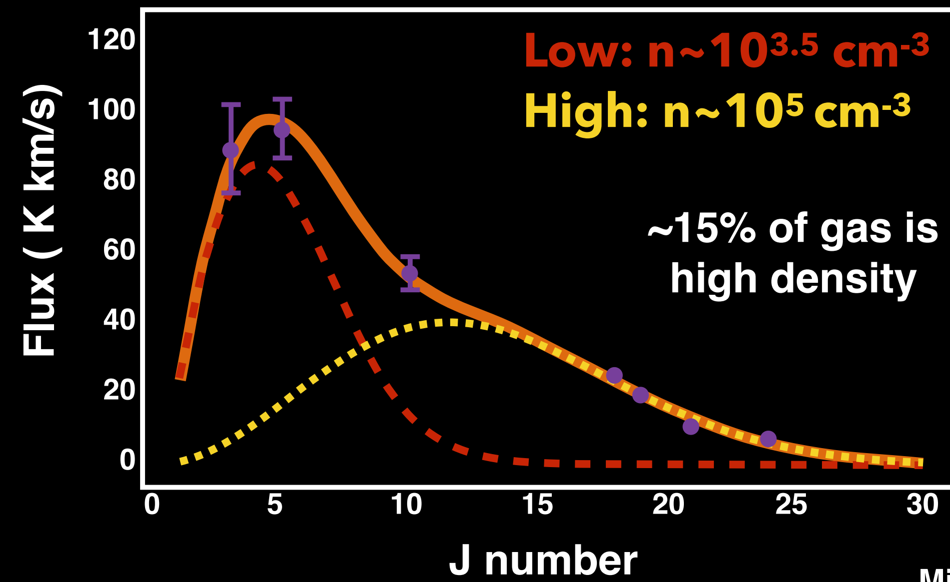
# of photons
Energy



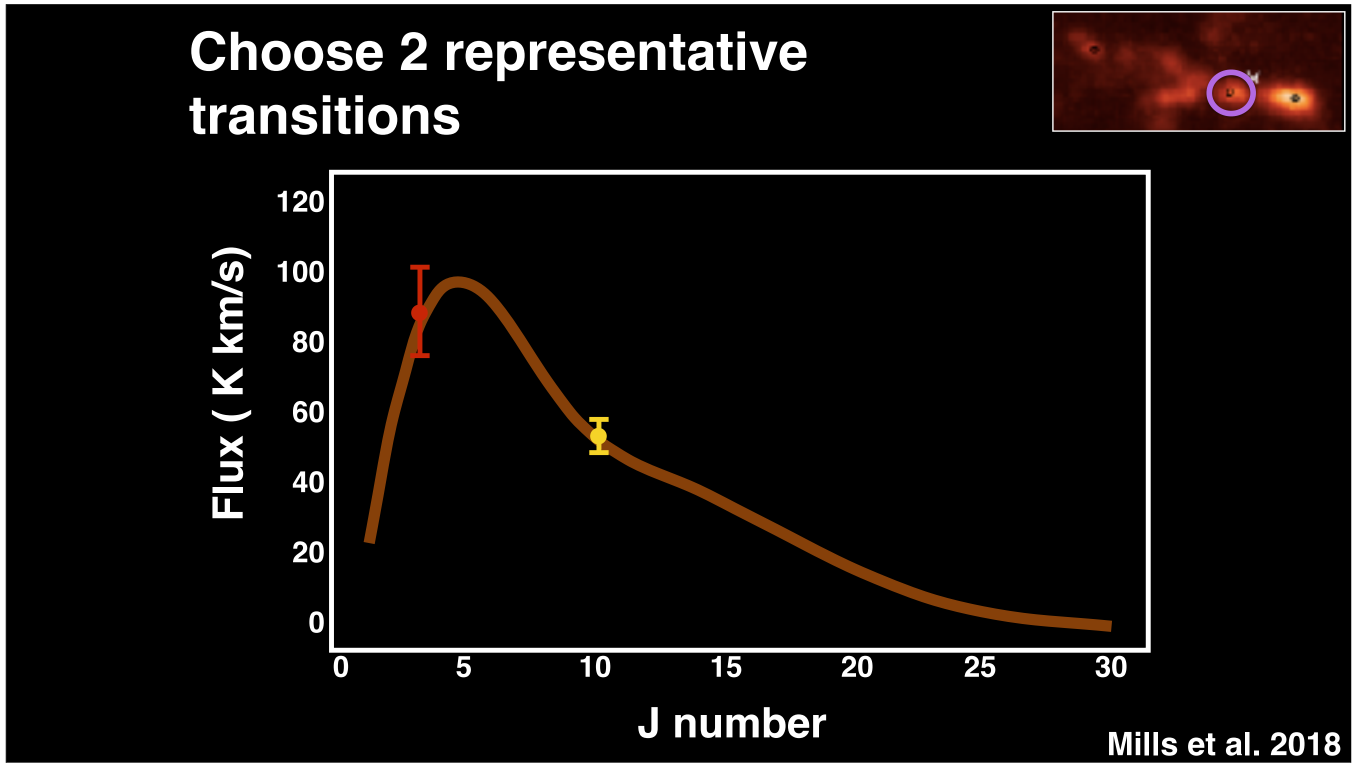
What we see in looking at gas in the Galactic center is actually two-peaked structure: there are two different density components: one in that is low excitation, in which the molecule is not experiencing so many collisions, indicating low-density gas, and one that is highly-excited from undergoing many collisions (and so represents a higher density component). The fits here are from radiative transfer models, in which we essentially simulate a big slab of gas, and replicate how bright the lines would appear for different amounts of gas (column density) and hundreds of different combinations of temperature and density.

See two density components: low/high



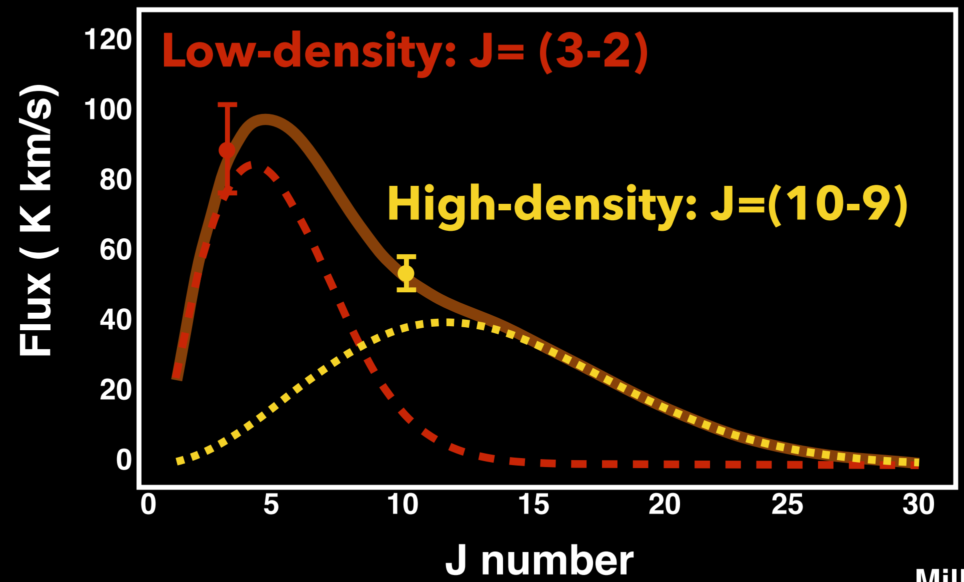


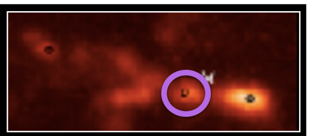
Mills et al. 2018



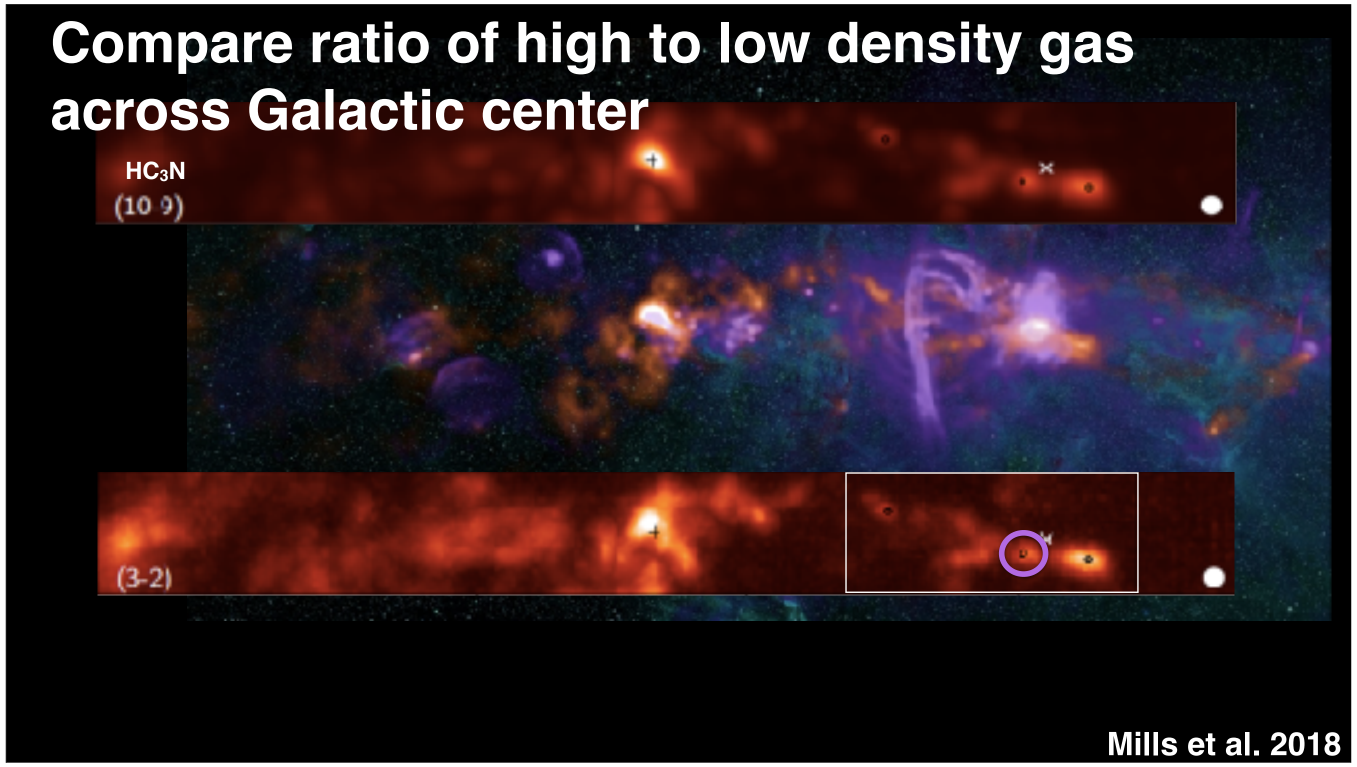
Take the results from more numerous spectra that we have toward this single cloud, and apply it back to the maps we have of the entire galactic center, to determine the relative amount of high and low-density gas across the galactic center.

Choose 2 representative transitions

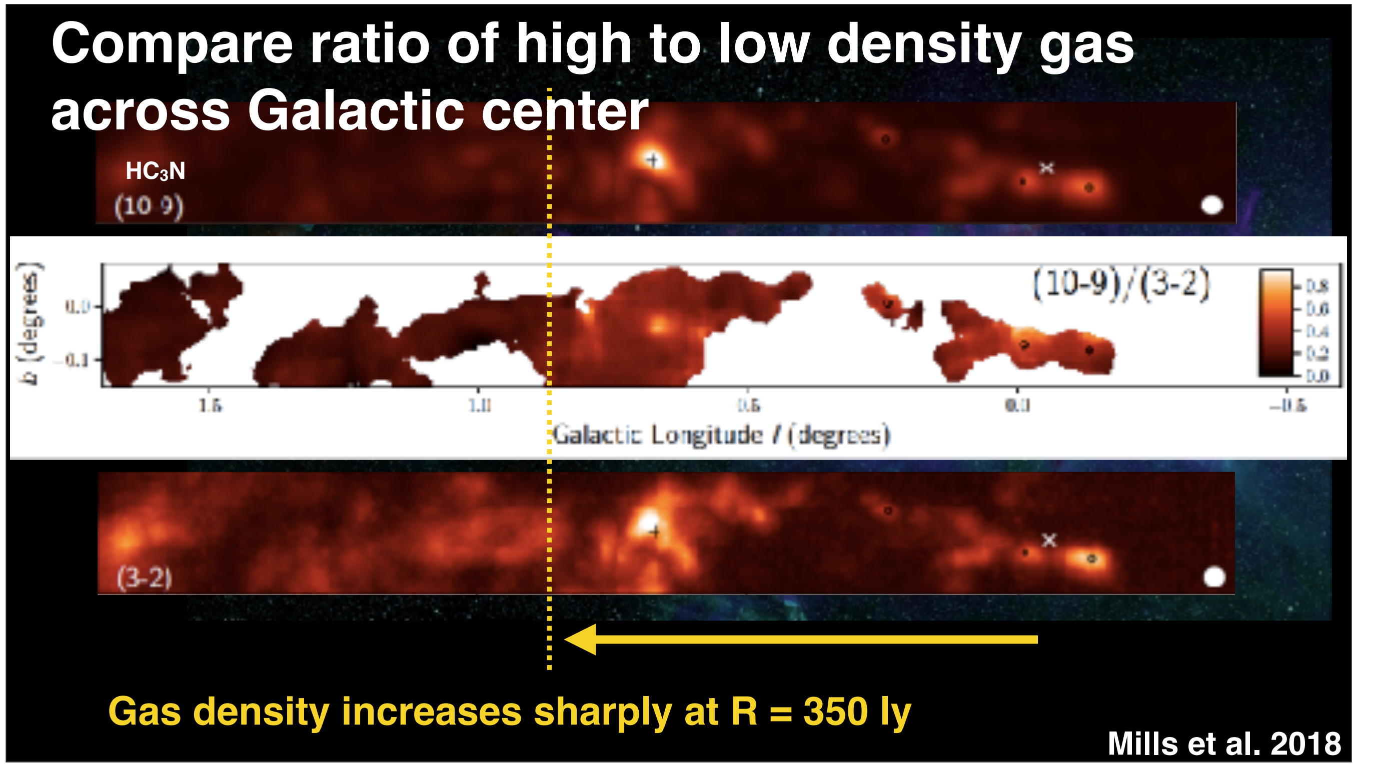




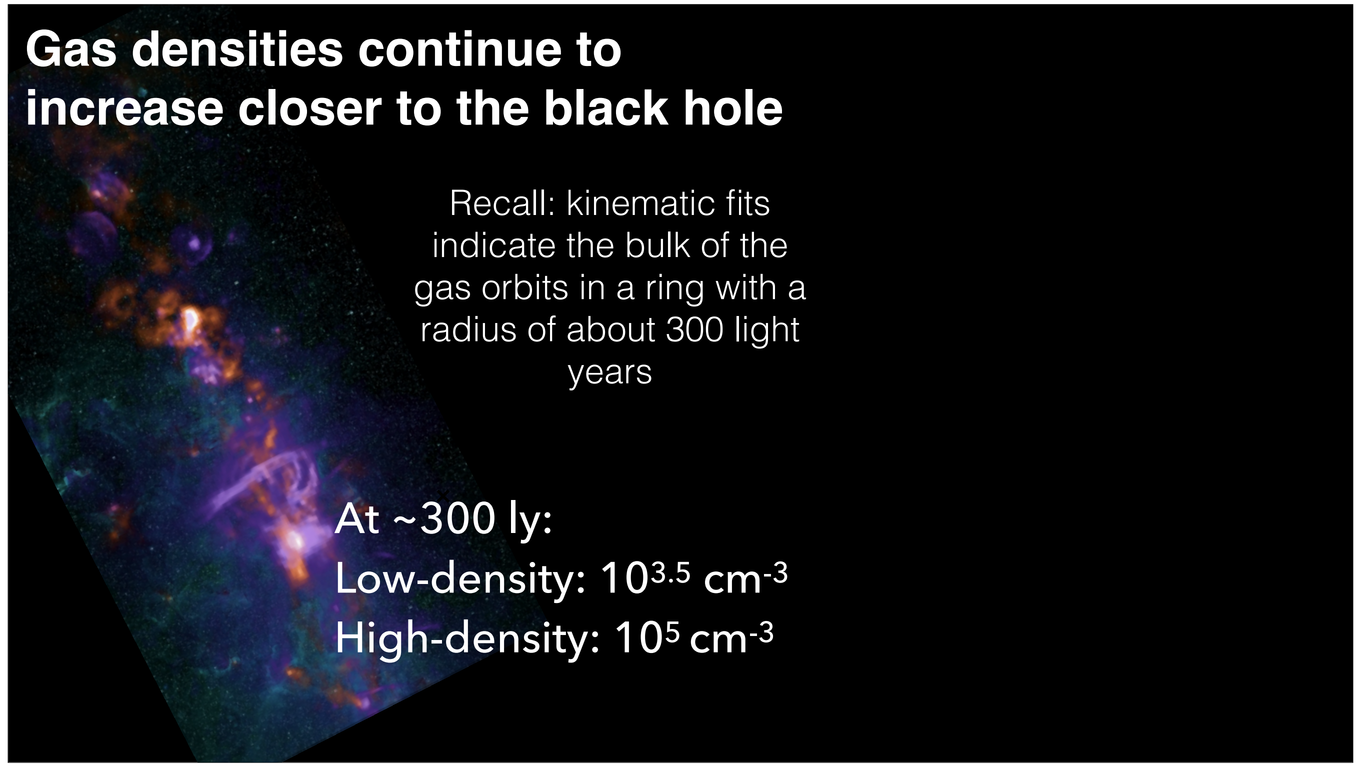
Mills et al. 2018



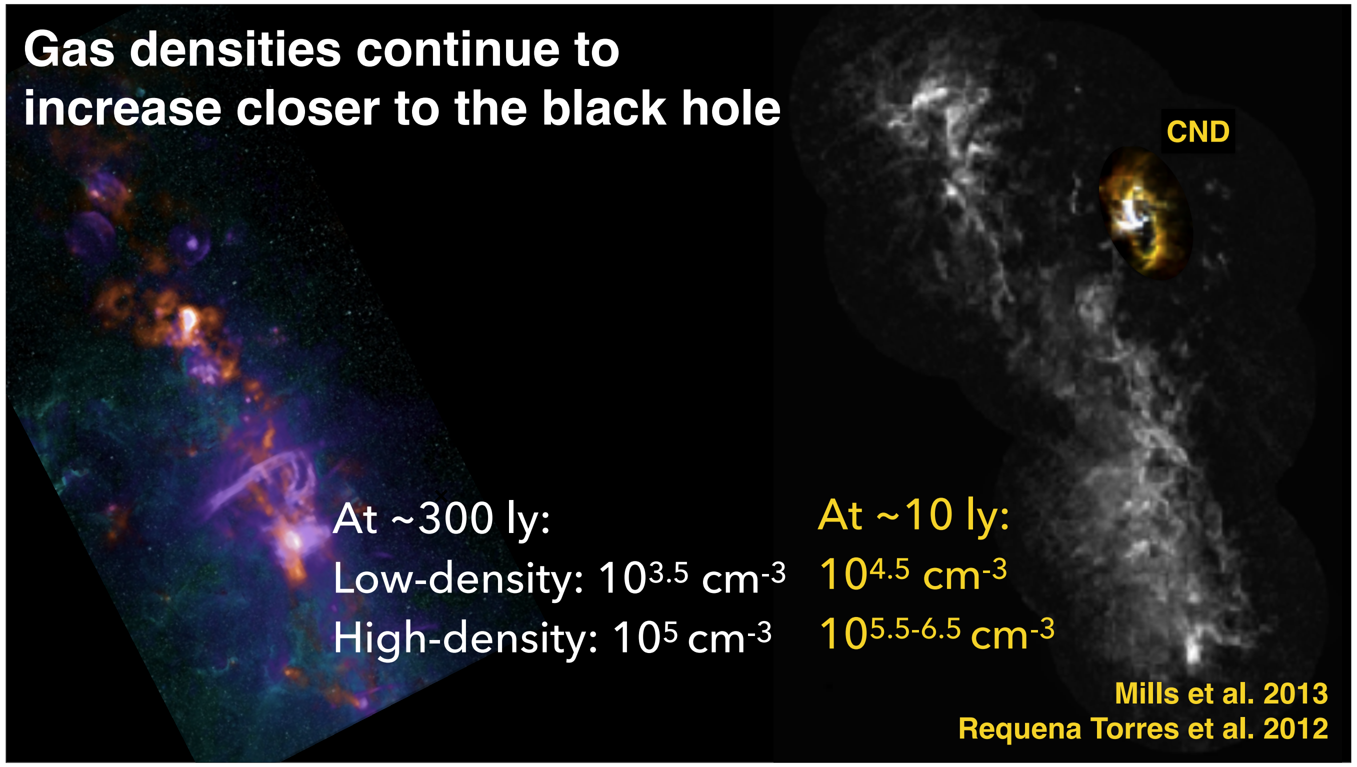
Can then make a ratio map. What you want to notice here is that there is a shift in this map from dark colors (low ratios) to lighter colors (high ratios), indicating that the overall gas density (the fraction of high-density gas) increases at a radius of about 350 ly. Around this radius, expect shocked gas on x1 orbits along the bar to be starting to accumulate in x2 orbits perpendicular to the bar.



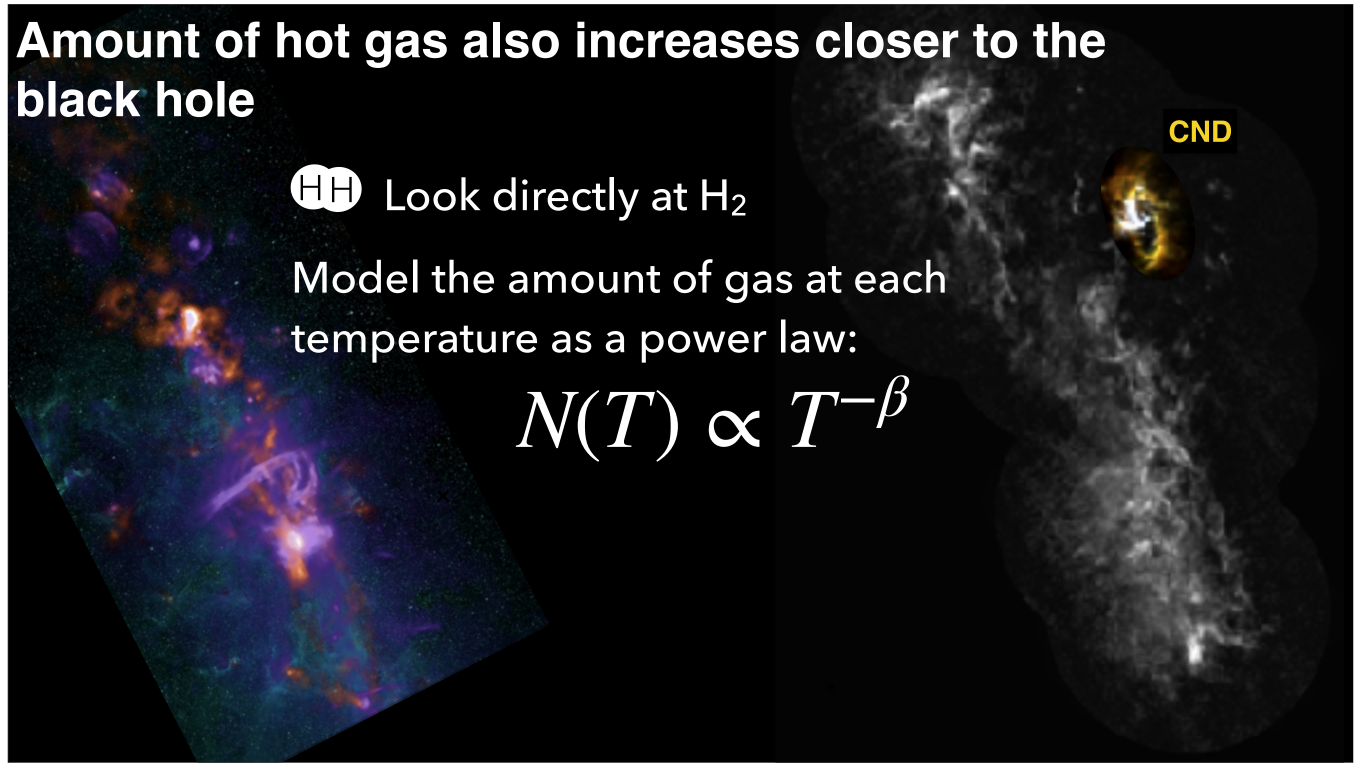
Compare ratio of high to low density gas across Galactic center
HC3N
(10 9)
(10-9)/(3-2)
b (degrees)
Galactic Longitude l (degrees)
(3-2)
Gas density increases sharply at R = 350 ly
Mills et al. 2018



But it doesn't stop here. Recalling that the gas in the central few hundred light years is mainly distributed in a ring, at least 300 ly from the black hole, we can compare the densities we measure for this gas to the range of densities measured in the circumnuclear disk: gas that is within 10 ly of the black hole.

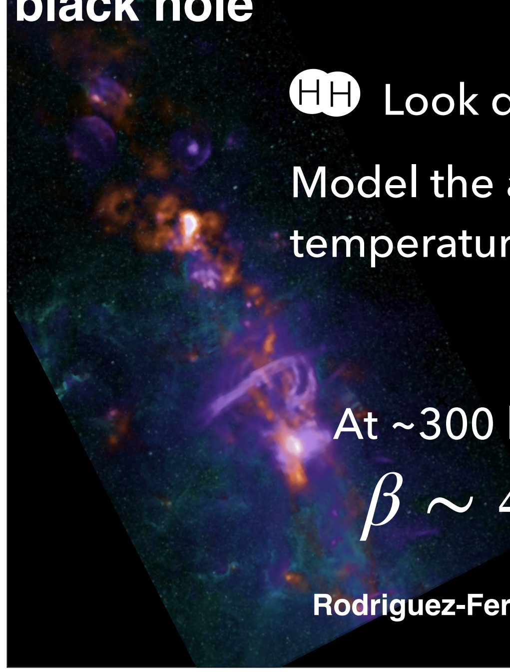


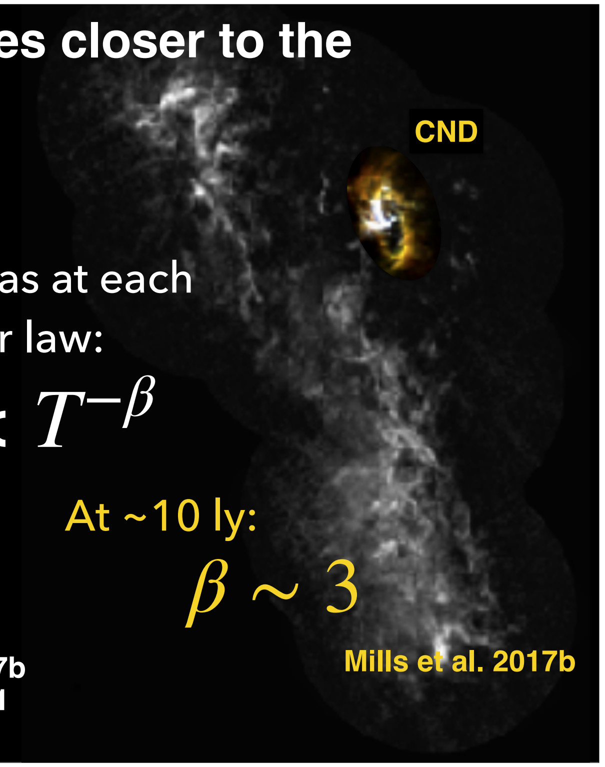
And we see that this trend continues: The gas within 10 ly is also significantly denser than this gas within 300 ly.



The same is true of the gas temperature: Using direct measurements of H2, can look at the distribution of gas temperatures. Find that there is more warm/hot gas close to the black hole than far from the black hole. Furthermore, the heating is consistent with expectations for shocks, and this implies that the gas closer in has experienced more/stronger shocks.

Amount of hot gas also increases closer to the black hole





HH Look directly at H_2

Model the amount of gas at each temperature as a power law:

$$N(T) \propto T^{-\beta}$$

At ~300 ly:

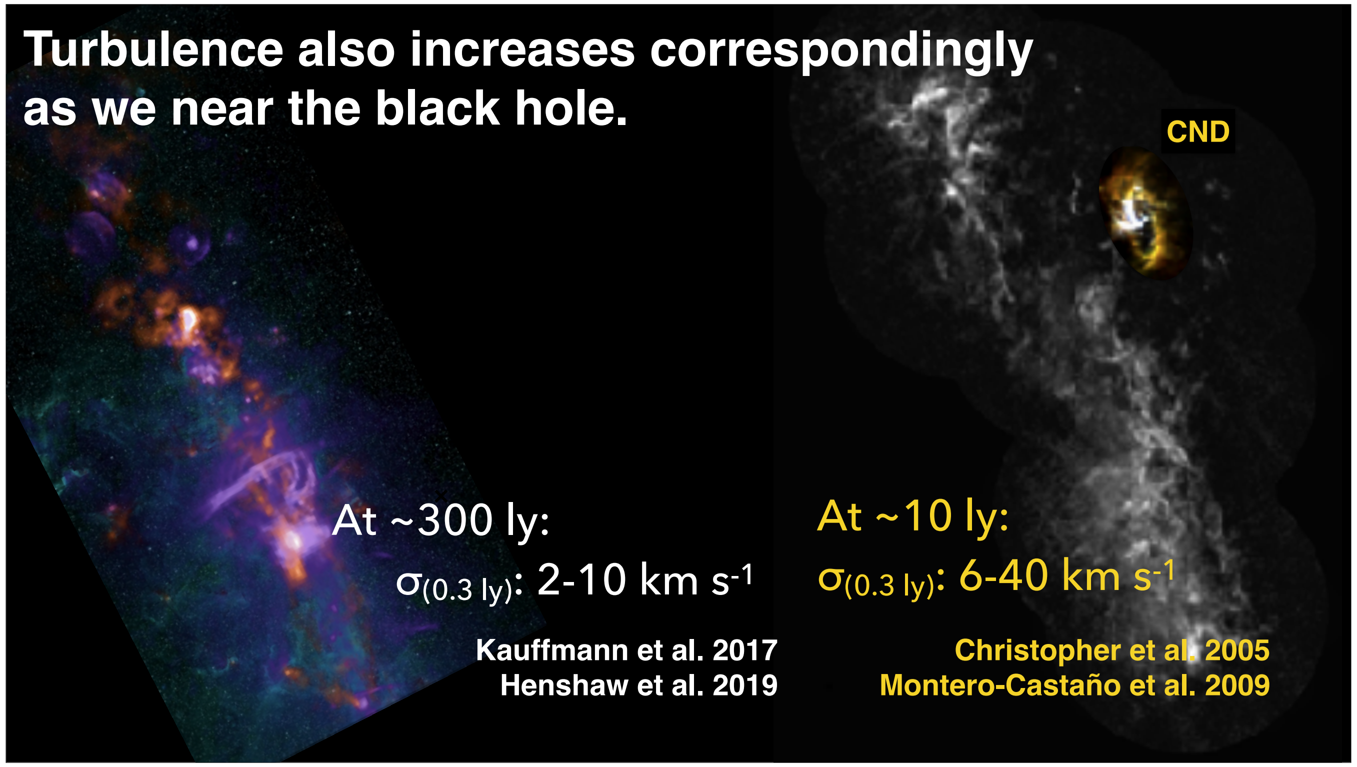
$$\beta \sim 4 - 6$$

Mills et al. 2017b
Rodriguez-Fernandez et al. 2001

At ~10 ly:

$$\beta \sim 3$$

Mills et al. 2017b

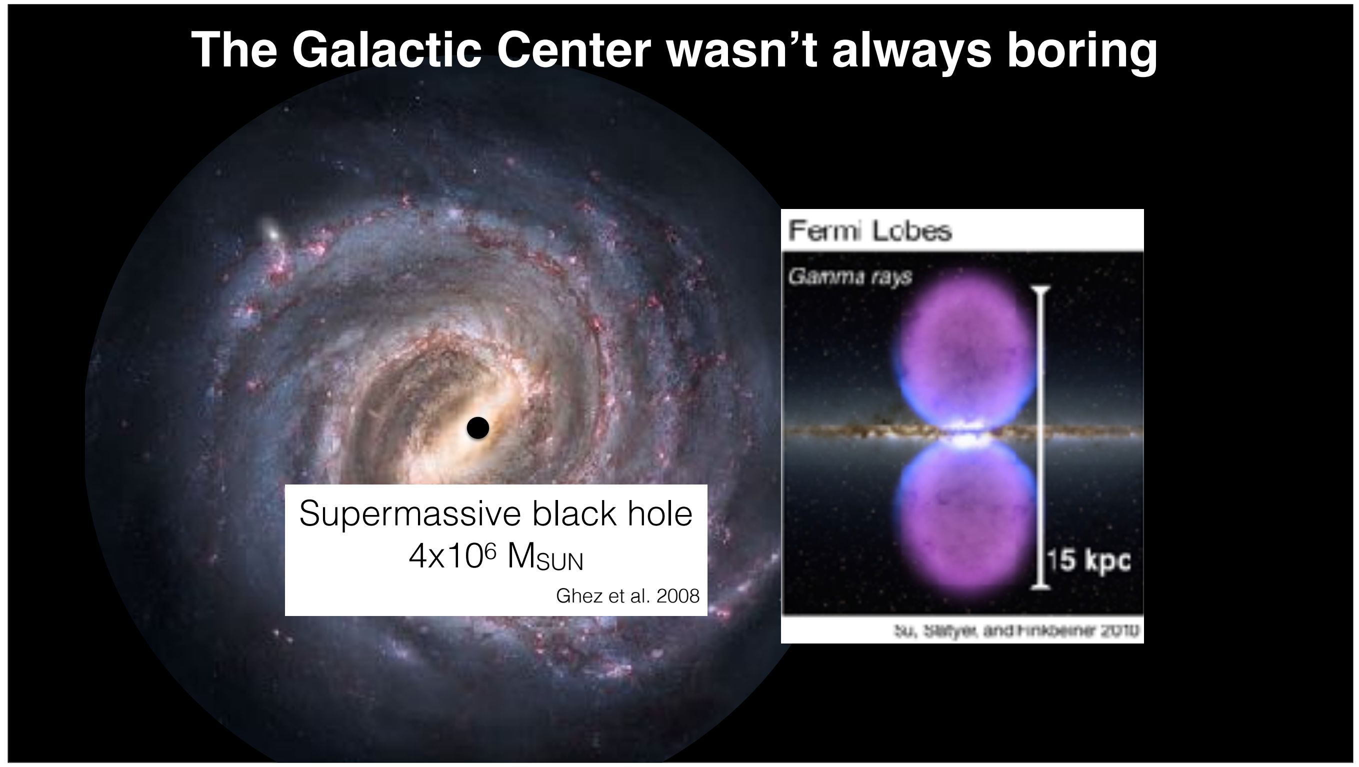


And this matches what you see from the turbulent line widths: larger line widths consistent with larger shock velocities closer in. Together, this begins to suggest that gas in the center of our galaxy is most strongly affected by the shocks it experiences as it moves inward. Gas properties change substantially as gas gets closer to the center, despite the fact that the black hole is quiescent, and the star formation is minimal.

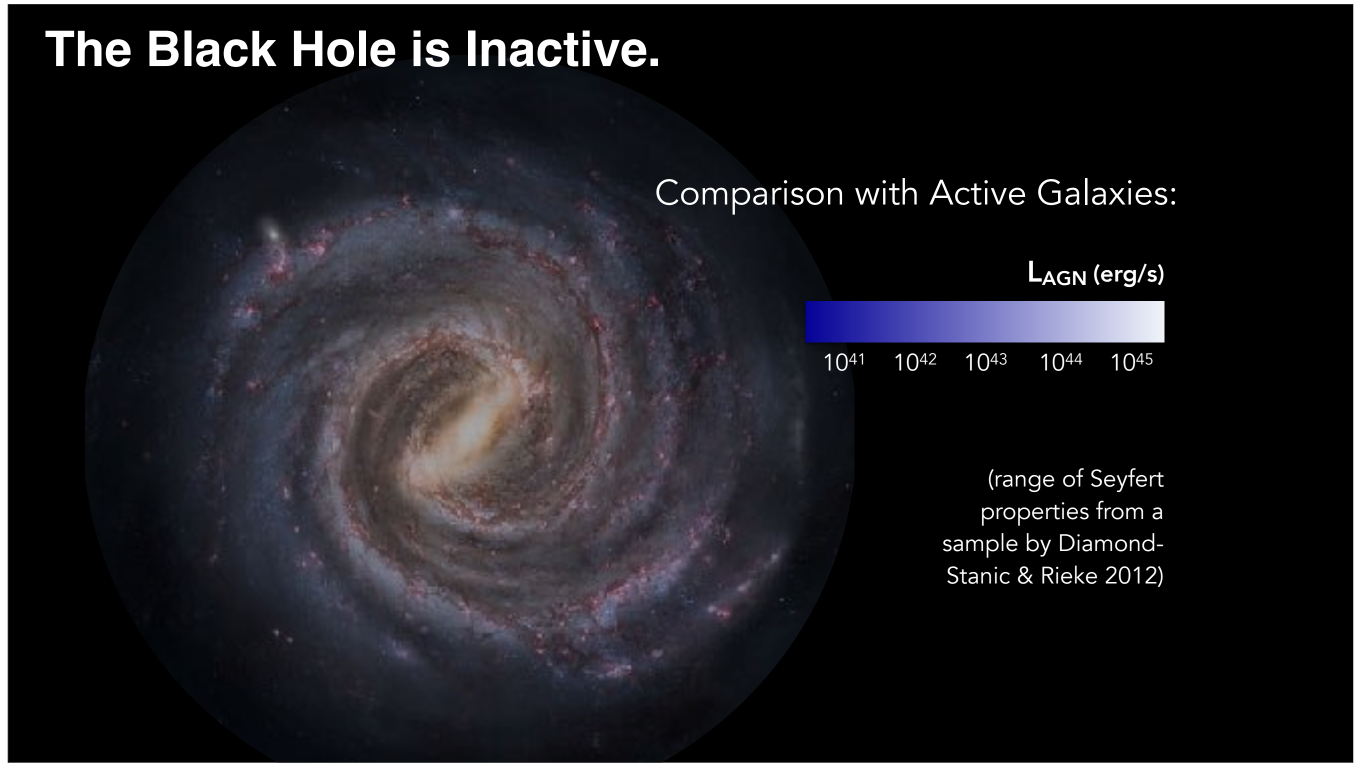
But is this a universally important conclusion? If inflow processes are most important for setting conditions in our own galactic center, is this a conclusion that can be broadly applied to other galaxy centers?

In the Milky Way, the Journey Matters.

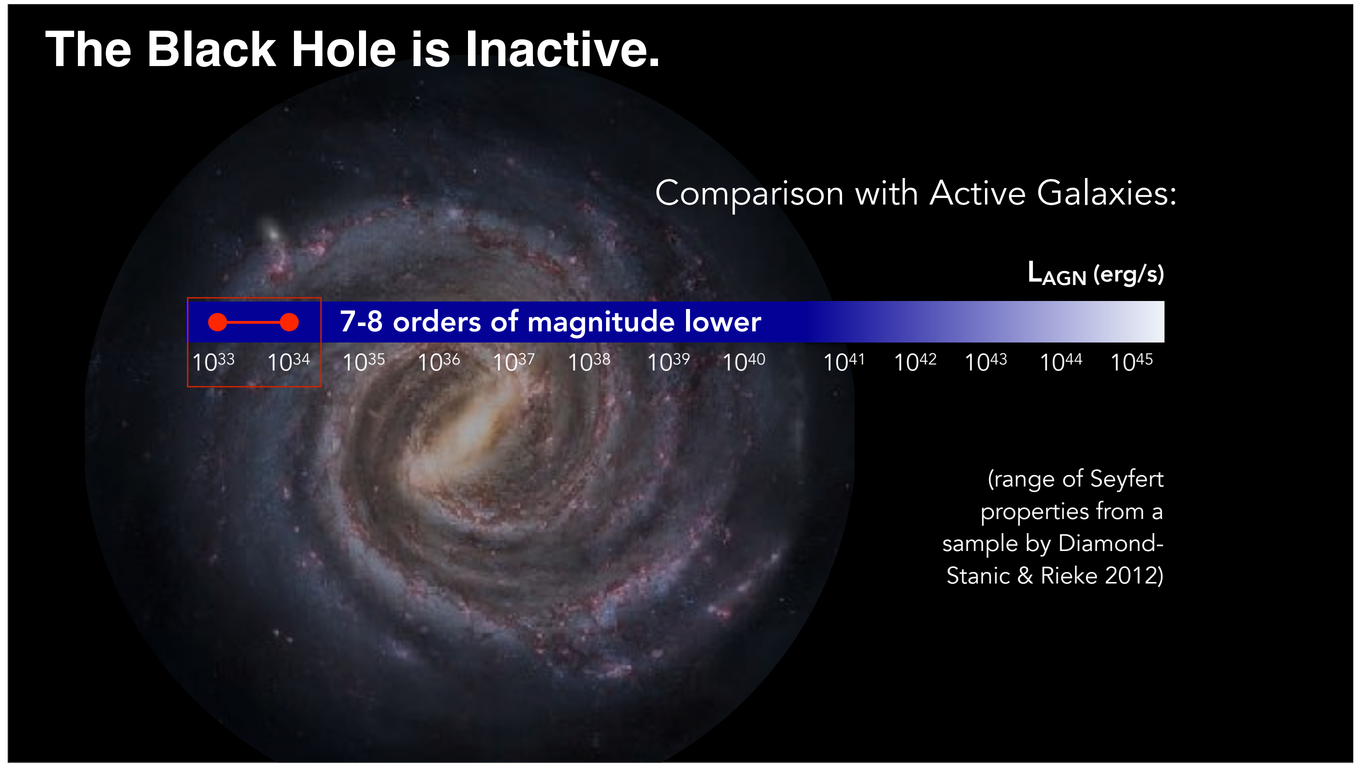
How does this change in more extreme systems?

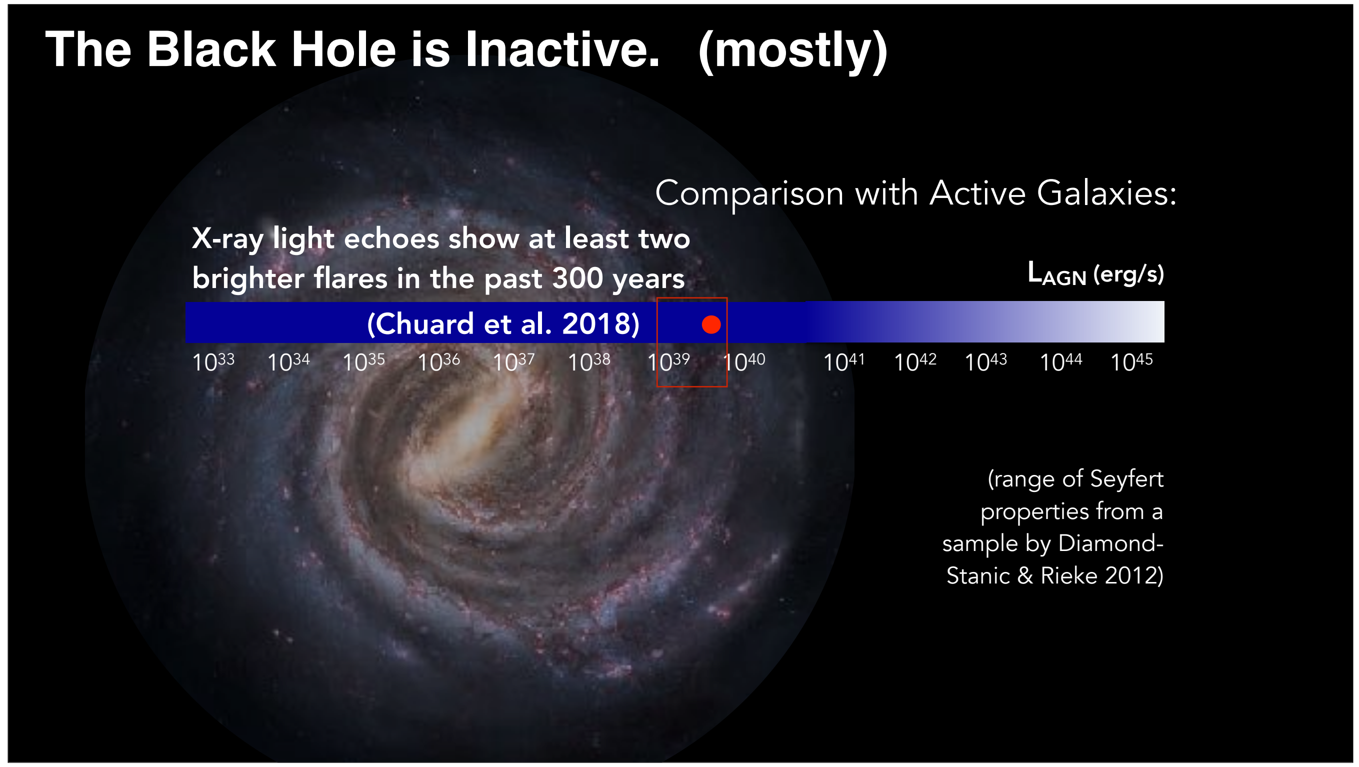


We have to ask that because (despite how much I am excited about the Galactic center) there's not actually much happening here, on a cosmic scale. Historically, our Galaxy shows evidence of past (cycles of) activity in both star formation and black hole growth. Has built a sizable central supermassive black hole. We also see fossil evidence of a large outflow that is believed to have been driven by a past AGN or starburst, and is likely young as 10 million years old. So while our galaxy center wasn't always boring

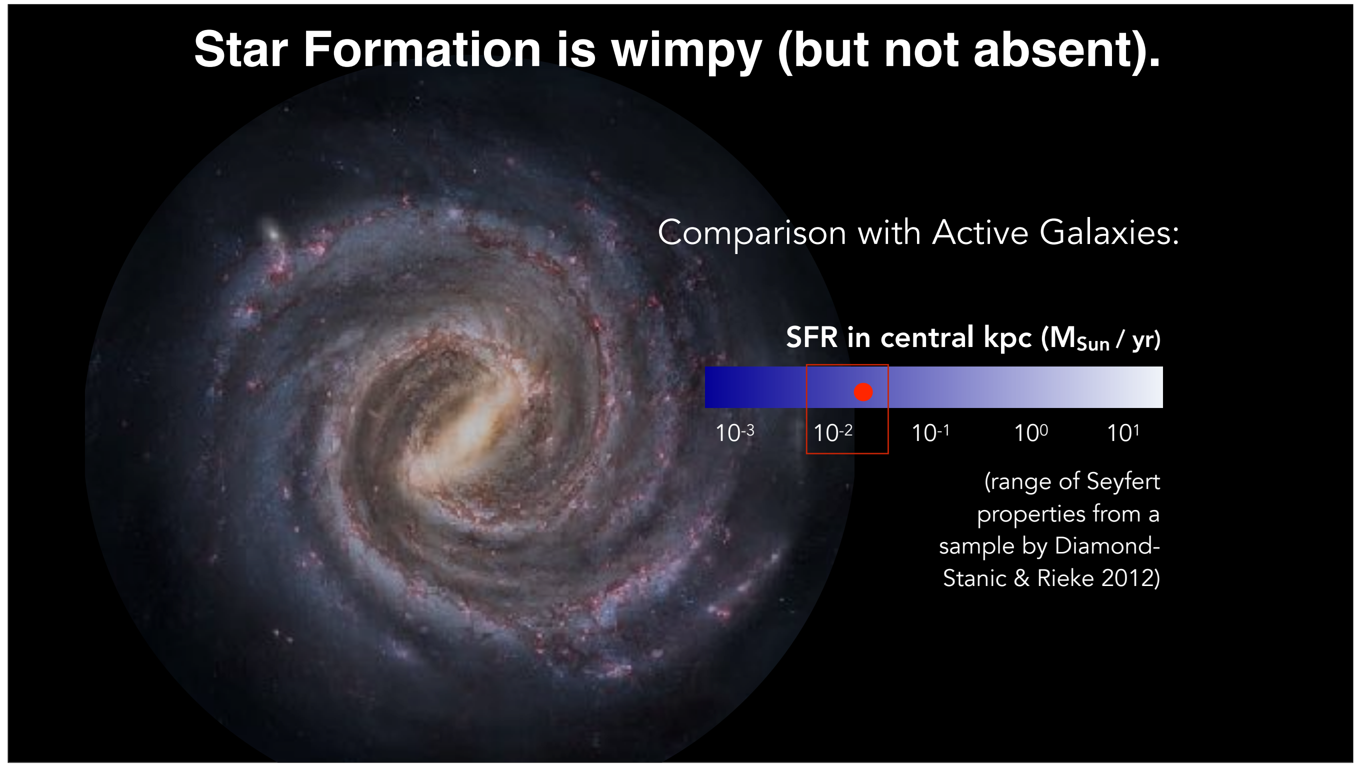


It kind of is right now. If you compare the black hole to the range of luminosities typically seen in AGN, our black hole is off the charts: in the wrong direction.

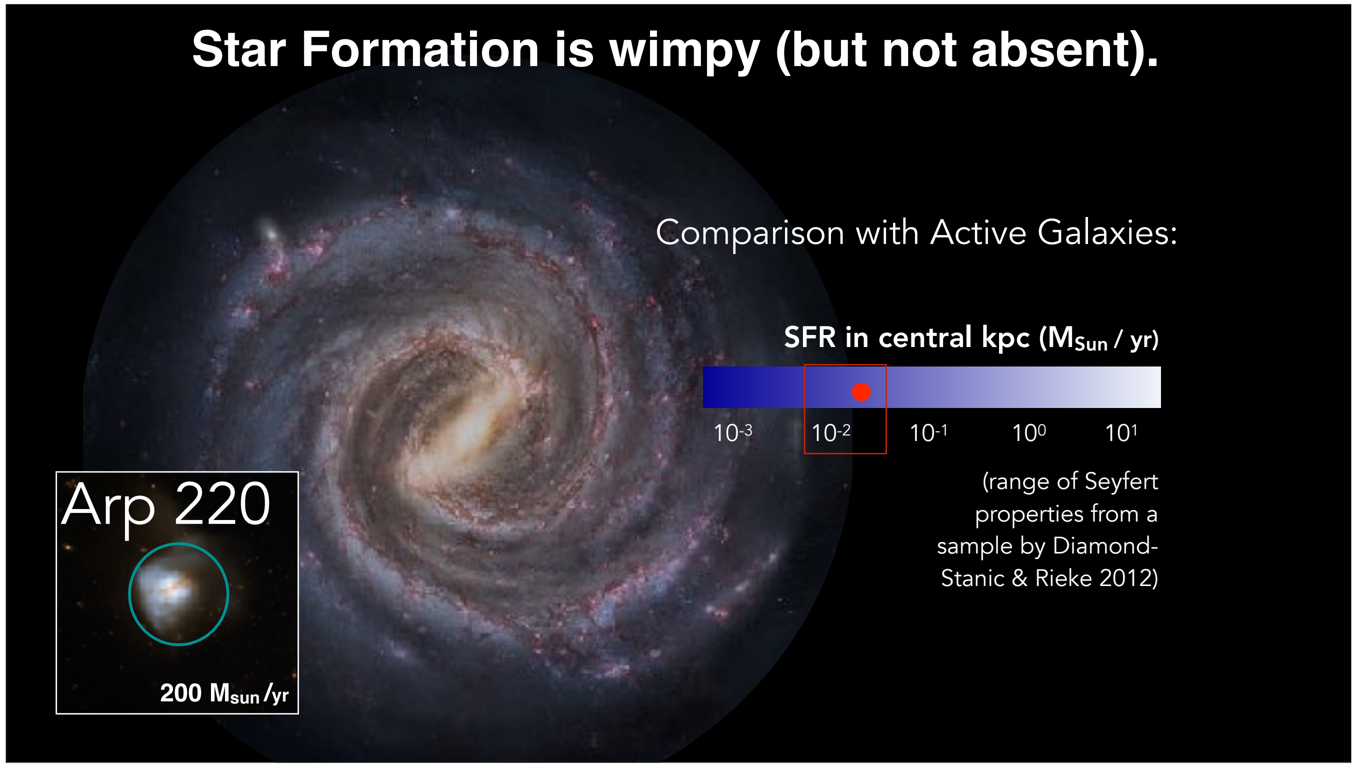

The Black Hole is Inactive.
Comparison with Active Galaxies:
L_AGN (erg/s)
7-8 orders of magnitude lower
10^33 10^34 10^35 10^36 10^37 10^38 10^39 10^40 10^41 10^42 10^43 10^44 10^45
(range of Seyfert properties from a sample by Diamond-Stanic & Rieke 2012)



Even allowing for recent activity in the past few hundred years which we can detect from the x-ray light of these outbursts reflecting off of clouds a few hundred light years from the black hole… our black hole is no AGN.

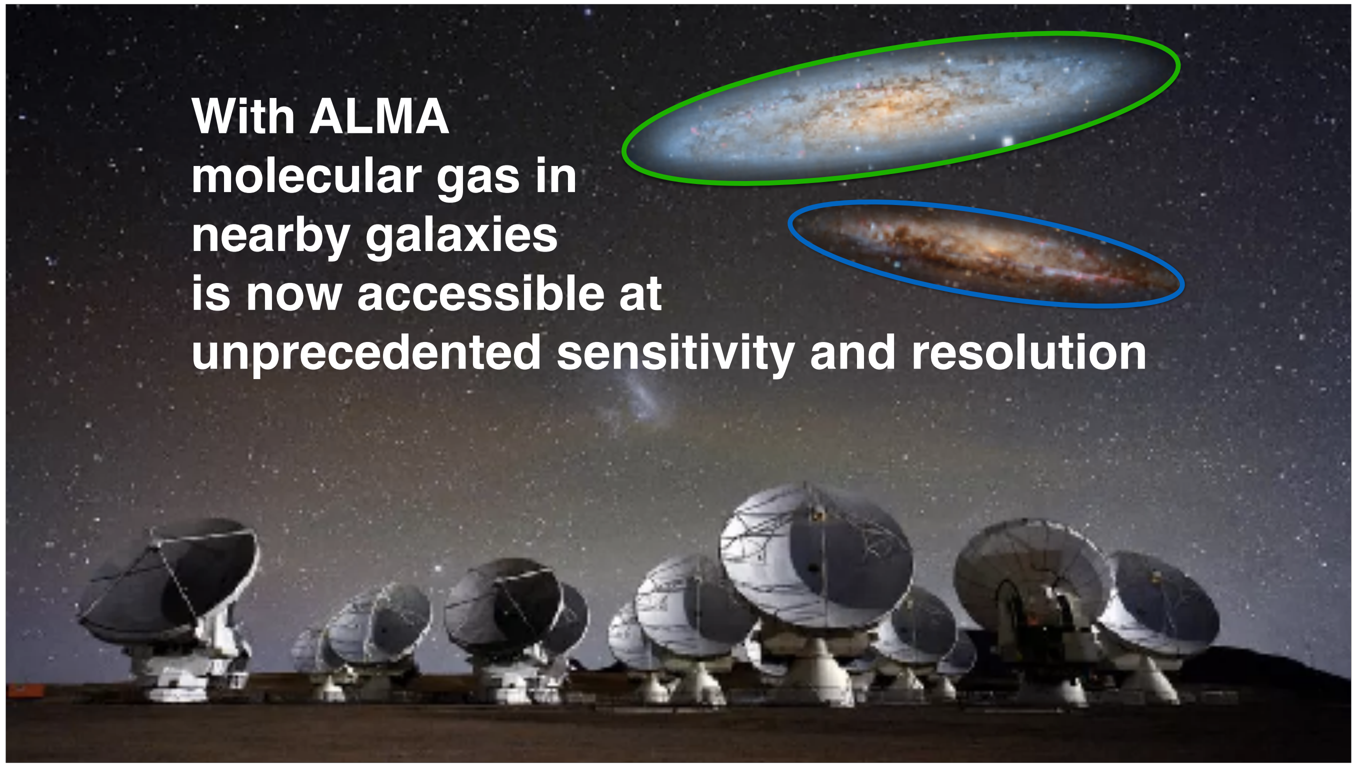


And the star formation isn't much to speak of either. Compared to this sample of AGN (which have a central concentration of gas to fuel the active black hole), its SFR is on the low end. And if you look at extreme examples outside of this sample, like Arp 220— well, star formation of less than a tenth of a solar mass per year in the central kiloparsec is just peanuts compared to SFRs of hundreds of solar masses per year.

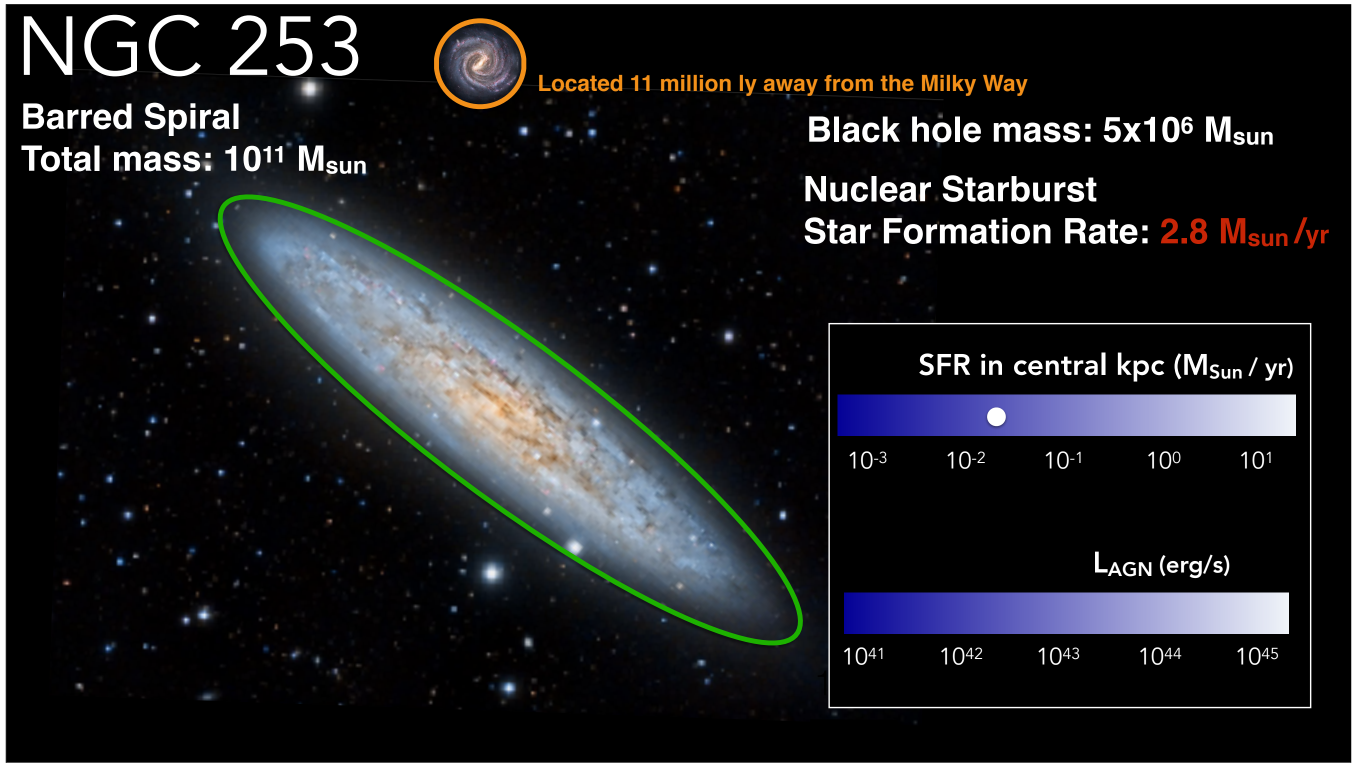

Star Formation is wimpy (but not absent).
Comparison with Active Galaxies:
SFR in central kpc (Msun / yr)
10-3
10-2
10-1
100
101
(range of Seyfert properties from a sample by Diamond-Stanic & Rieke 2012)
Arp 220
200 Msun /yr

Because other galaxies are much more distant— at least 400x more distant (10 million light years away)— we have not been able to examine their centers with the same resolution we have been able to use to probe the center of our own galaxy. Luckily, we have recently been able to make huge progress overcoming this obstacle.

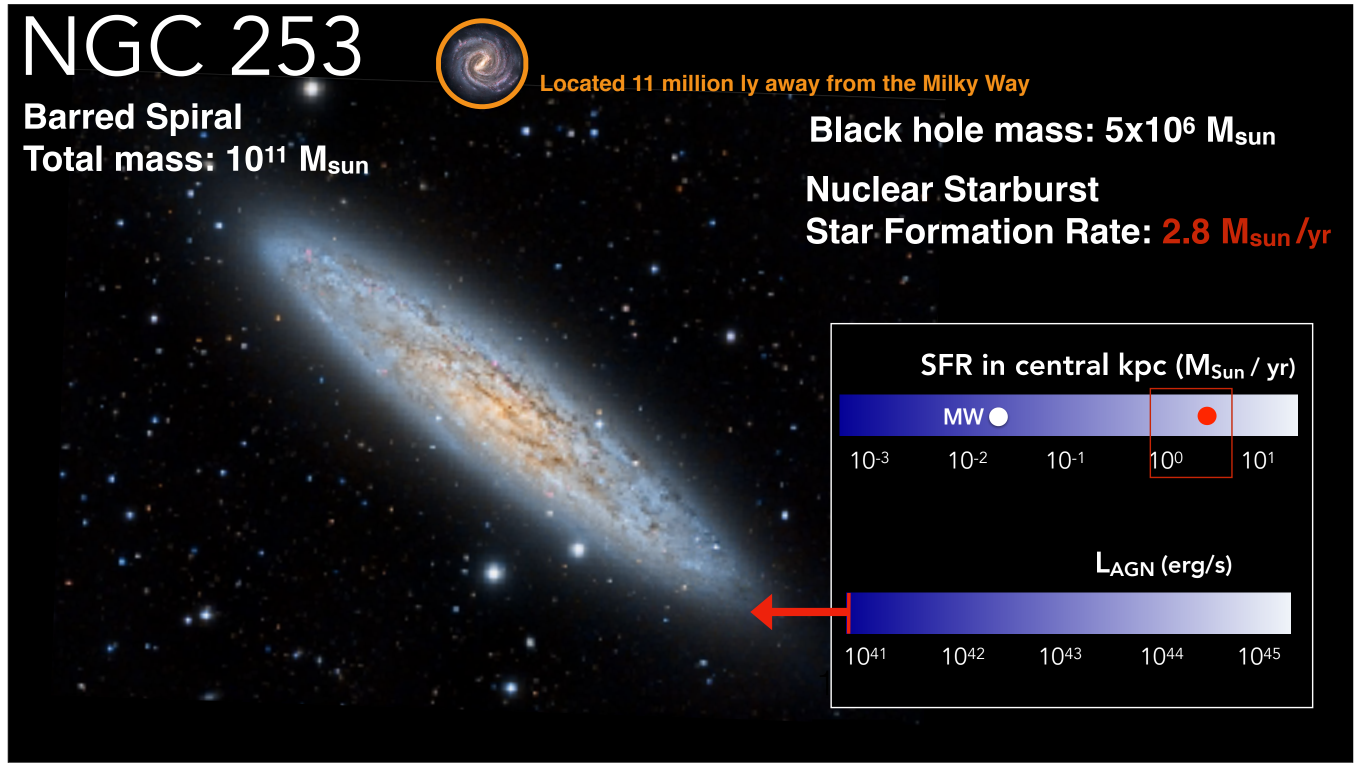

Problem:
More active galaxies are at least 400x more distant
But our tools are getting better



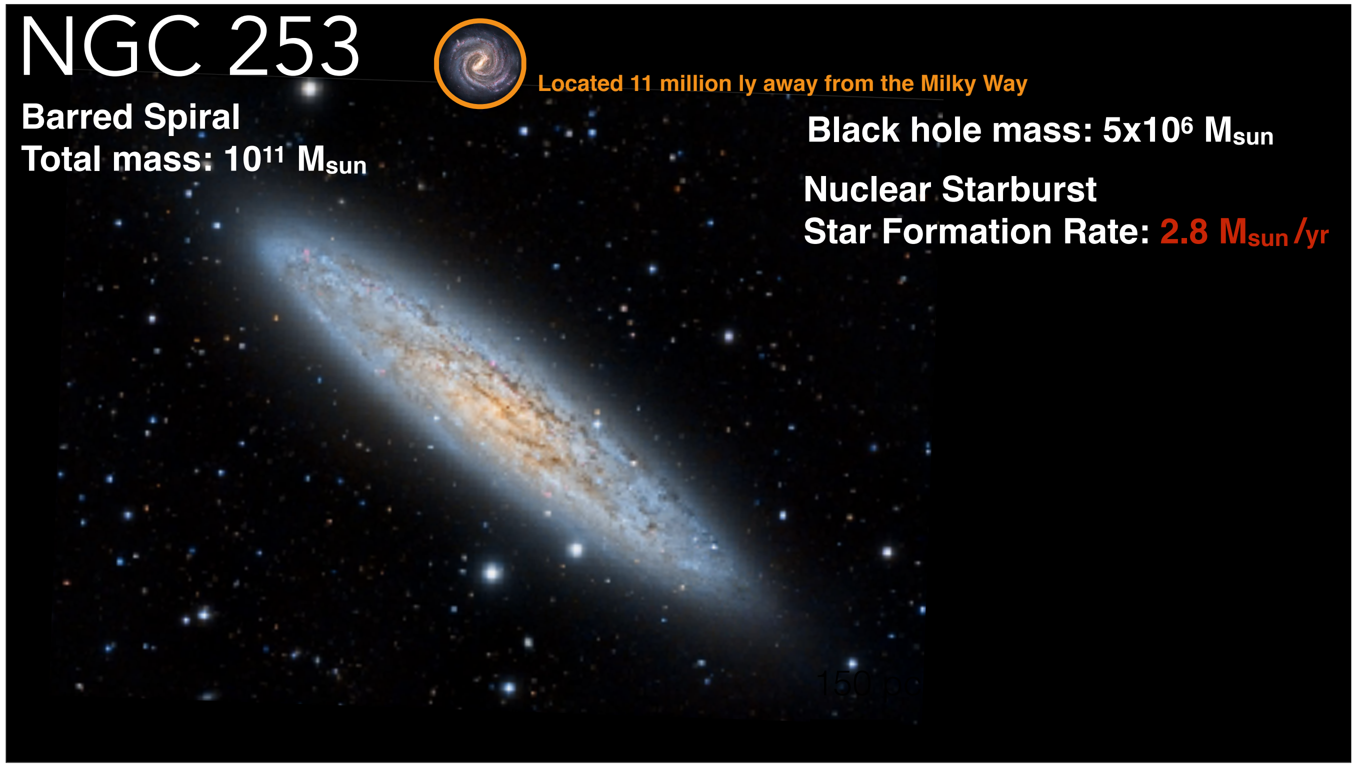
With ALMA, star forming gas in the centers of some of the most nearby galaxies is accessible with sub-parsec resolution— totally unprecedented and more than 100x better than we were able to achieve with previous telescopes.



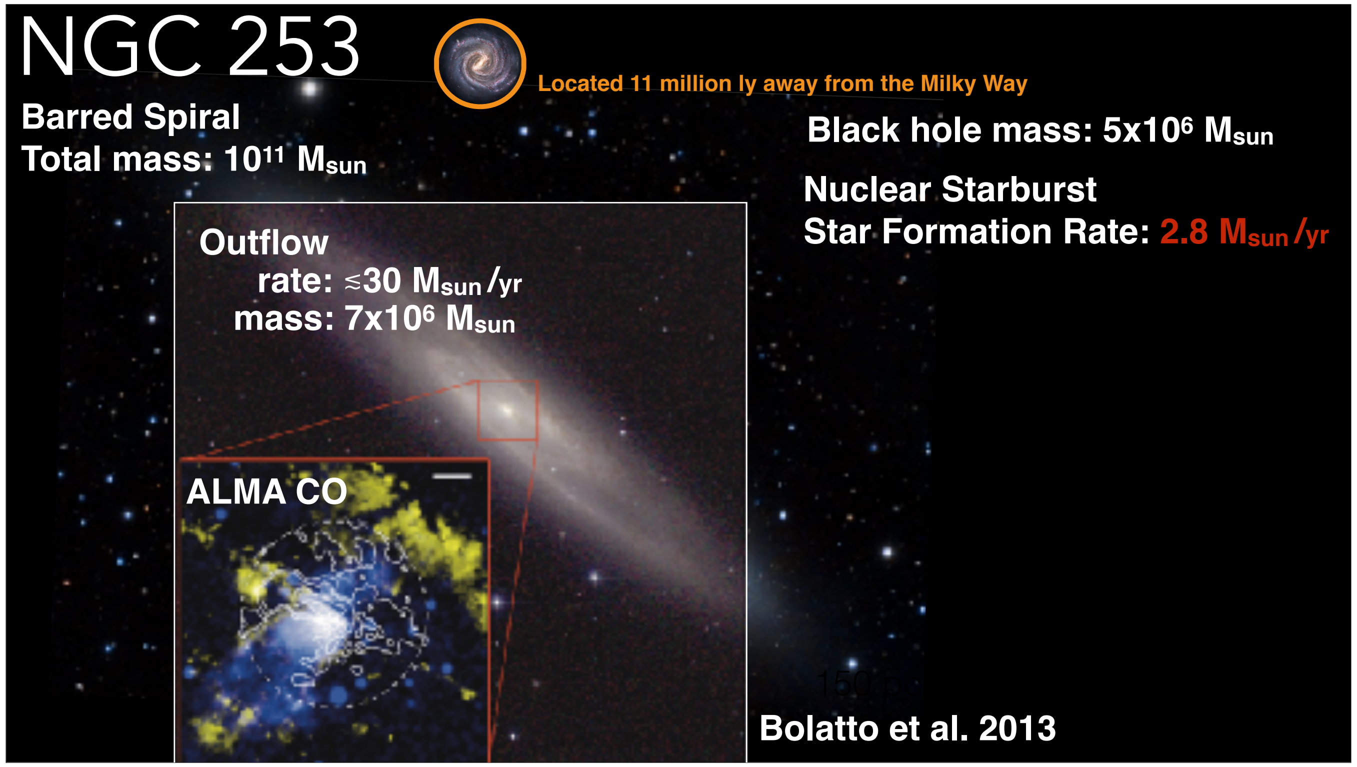
This allows us to star dissecting the extreme conditions in other galaxies. NGC 253 is a nearby galaxy which is similar to the Milky Way in many respects, except that it hosts a nuclear starburst (though similar to our galaxy, no obvious AGN).



NGC 253
Located 11 million ly away from the Milky Way
Barred Spiral
Total mass: 10^{11} M_{sun}
Black hole mass: $5x10^6$ M_{sun}
Nuclear Starburst
Star Formation Rate: 2.8 M_{sun}/yr
SFR in central kpc (M_{Sun} / yr)
MW
10^{-3} 10^{-2} 10^{-1} 10^0 10^1
L_{AGN} (erg/s)
10^{41} 10^{42} 10^{43} 10^{44} 10^{45}

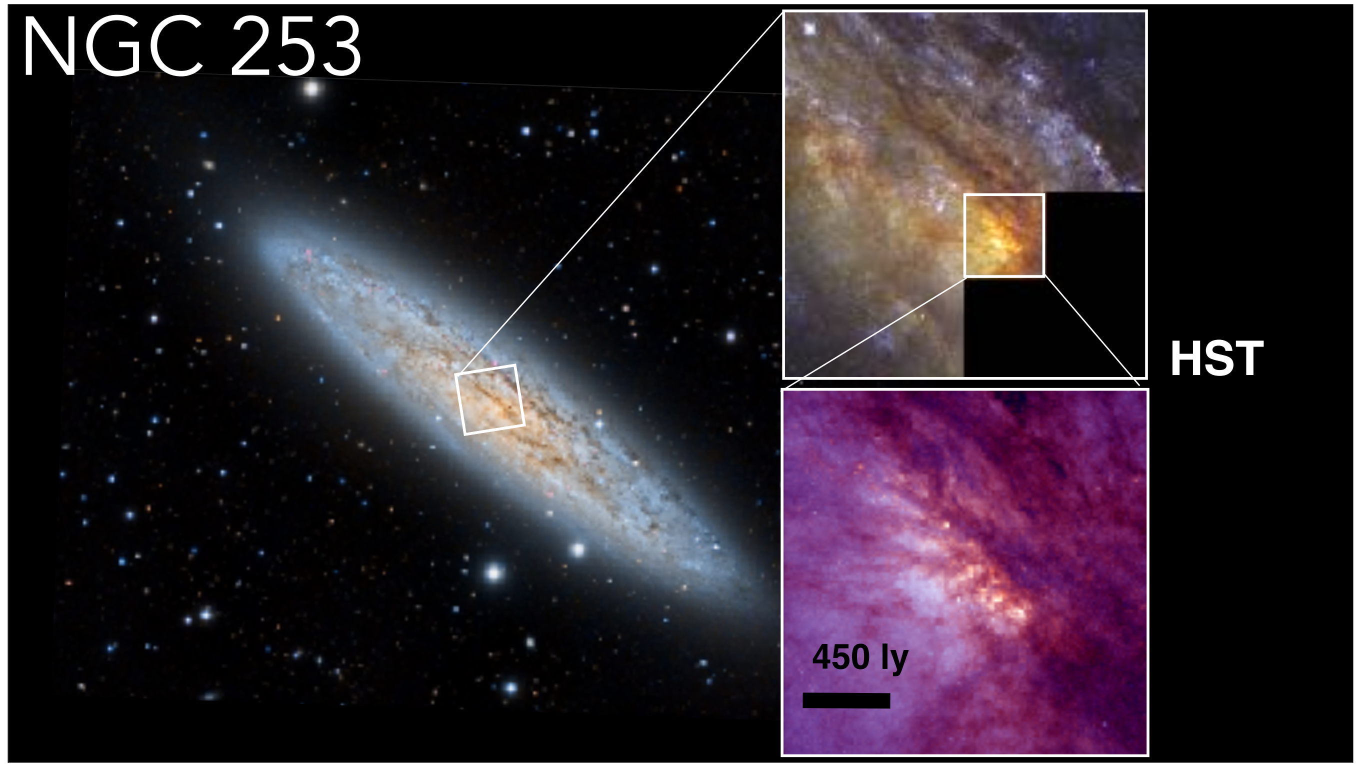


Unsurprisingly, this much star formation is driving a massive molecular outflow

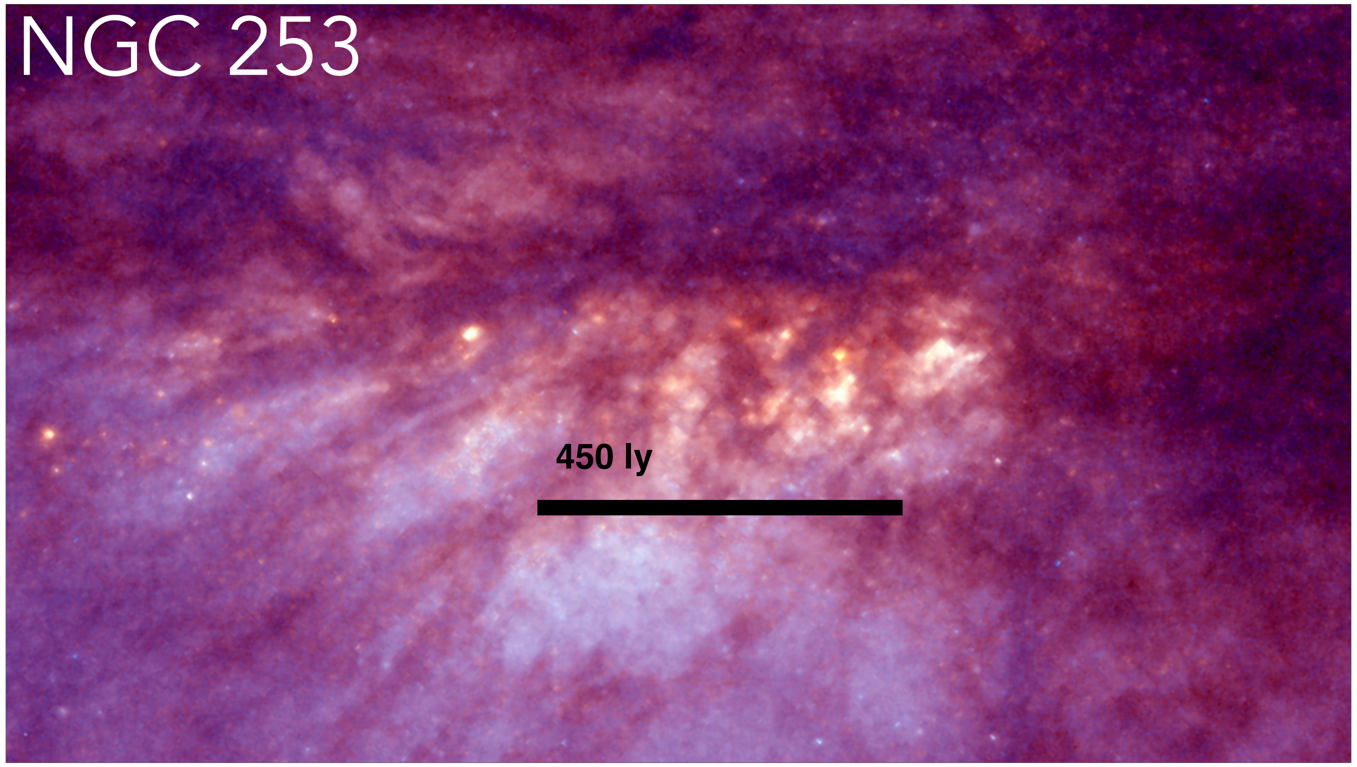


NGC 253
Located 11 million ly away from the Milky Way
Barred Spiral
Total mass: 10¹¹ Msun
Black hole mass: 5x10⁶ Msun
Nuclear Starburst
Star Formation Rate: 2.8 Msun /yr
Outflow
rate: ≲30 Msun /yr
mass: 7x10⁶ Msun
ALMA CO
Bolatto et al. 2013

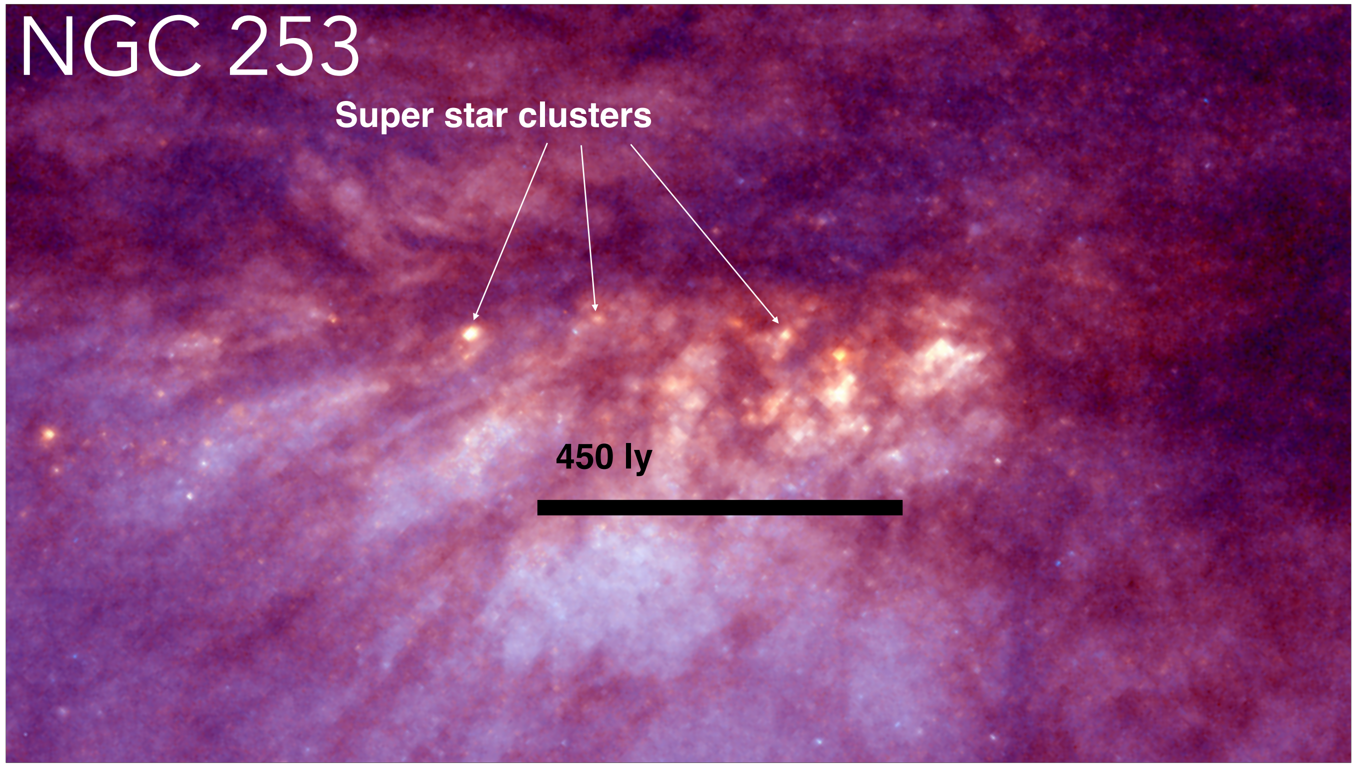
Once again, we can zoom in to the central regions. Note that NGC 253 appears strongly tilted though not perfectly edge-on.

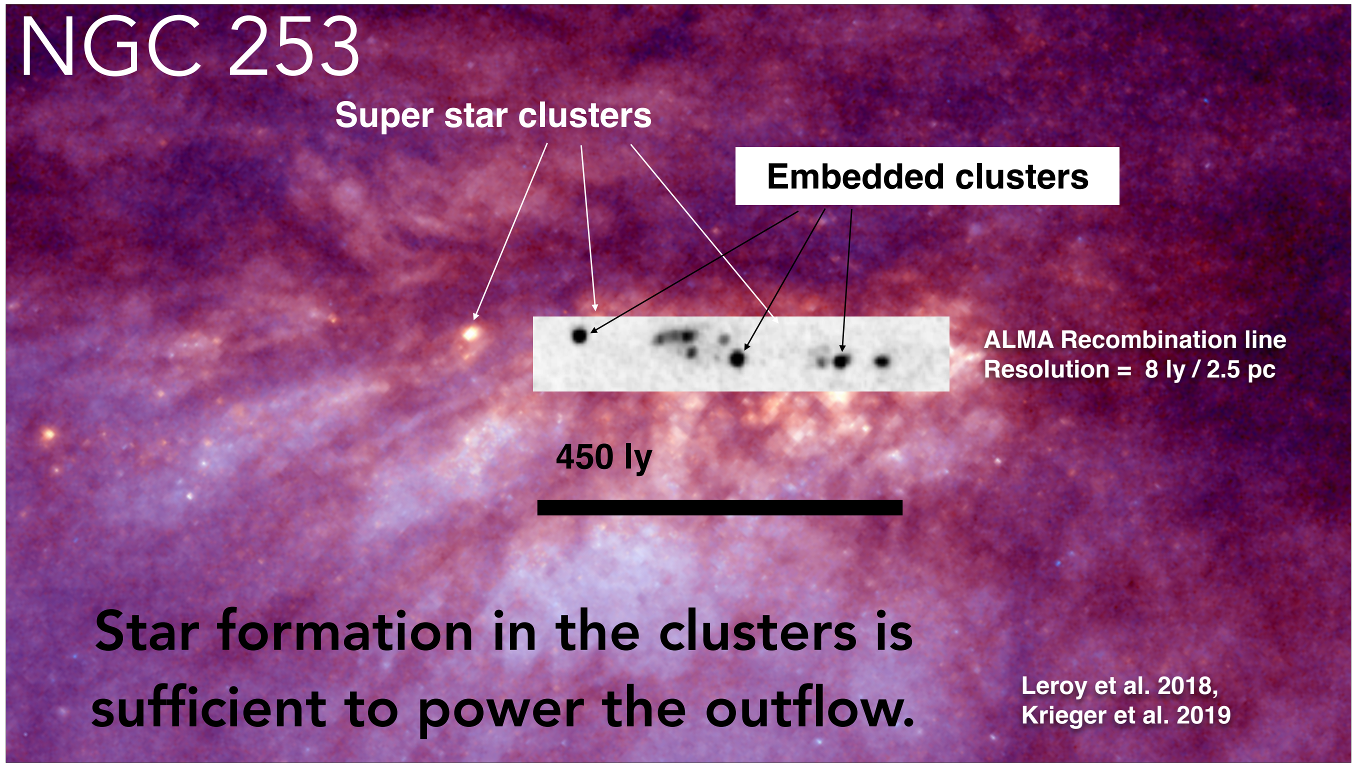


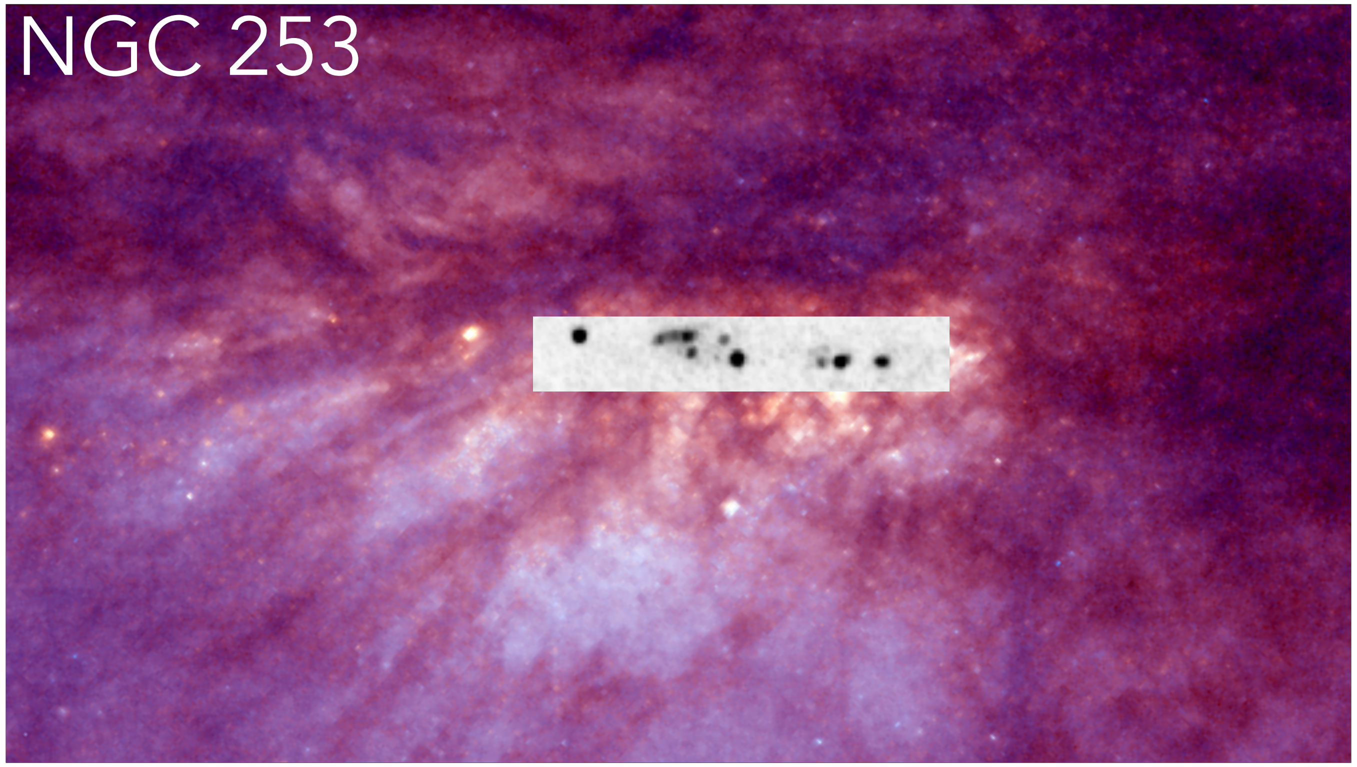
Here we have Hubble’s view of the inner regions at optical and near-IR wavelengths. Note that we sure can pick them: once again we are stuck with a nearly edge-on view of the central regions!



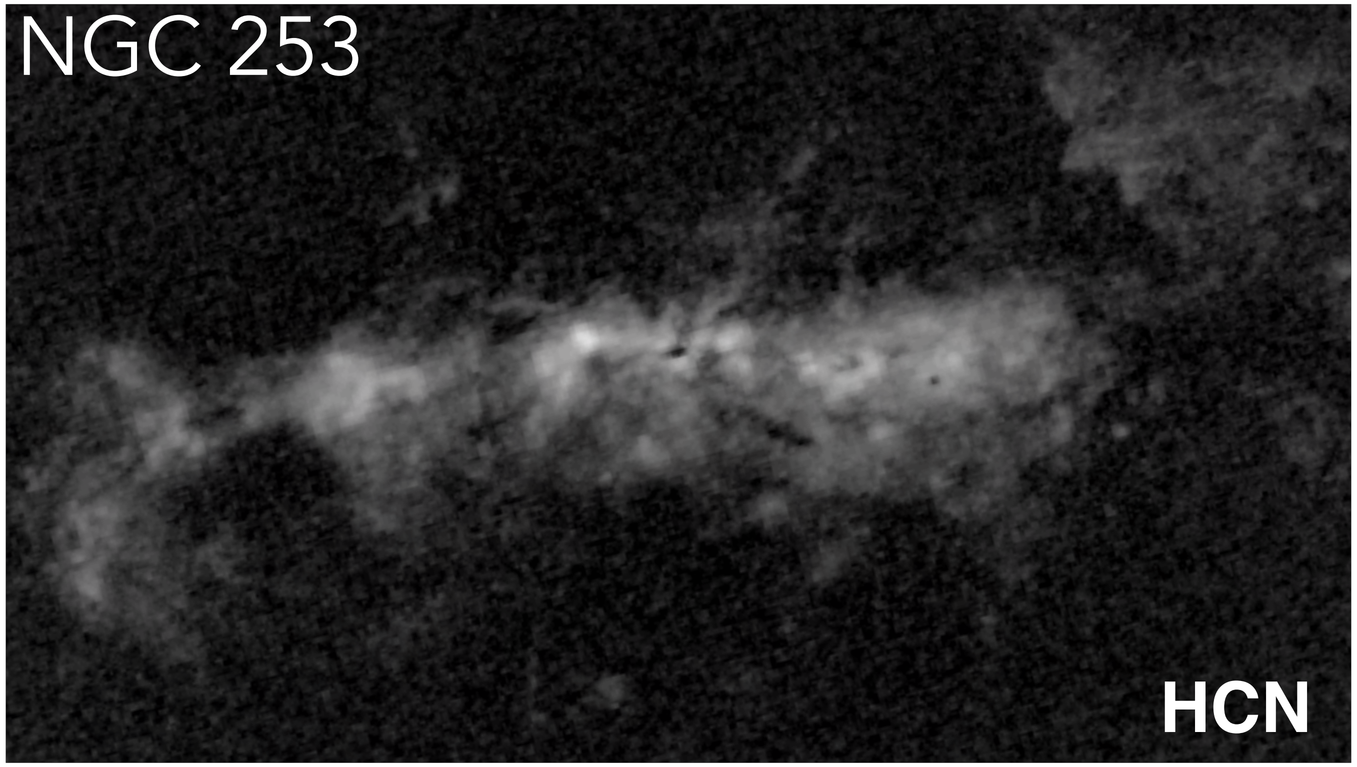
Reflective of its current starburst state, each of these bright spots is a massive super star cluster. Like the Milky way, because of intervening dust you really need longer wavelengths to see what is truly happening in this region. Did not have the combination of resolution and sensitivity to look at molecular gas before now, before ALMA. Show you what ALMA sees here— actually in an ionized gas line. Resolution of this image is less than 3 pc. ALMA uncovers more than a dozen embedded super star clusters, sufficient to account for the observed outflow.

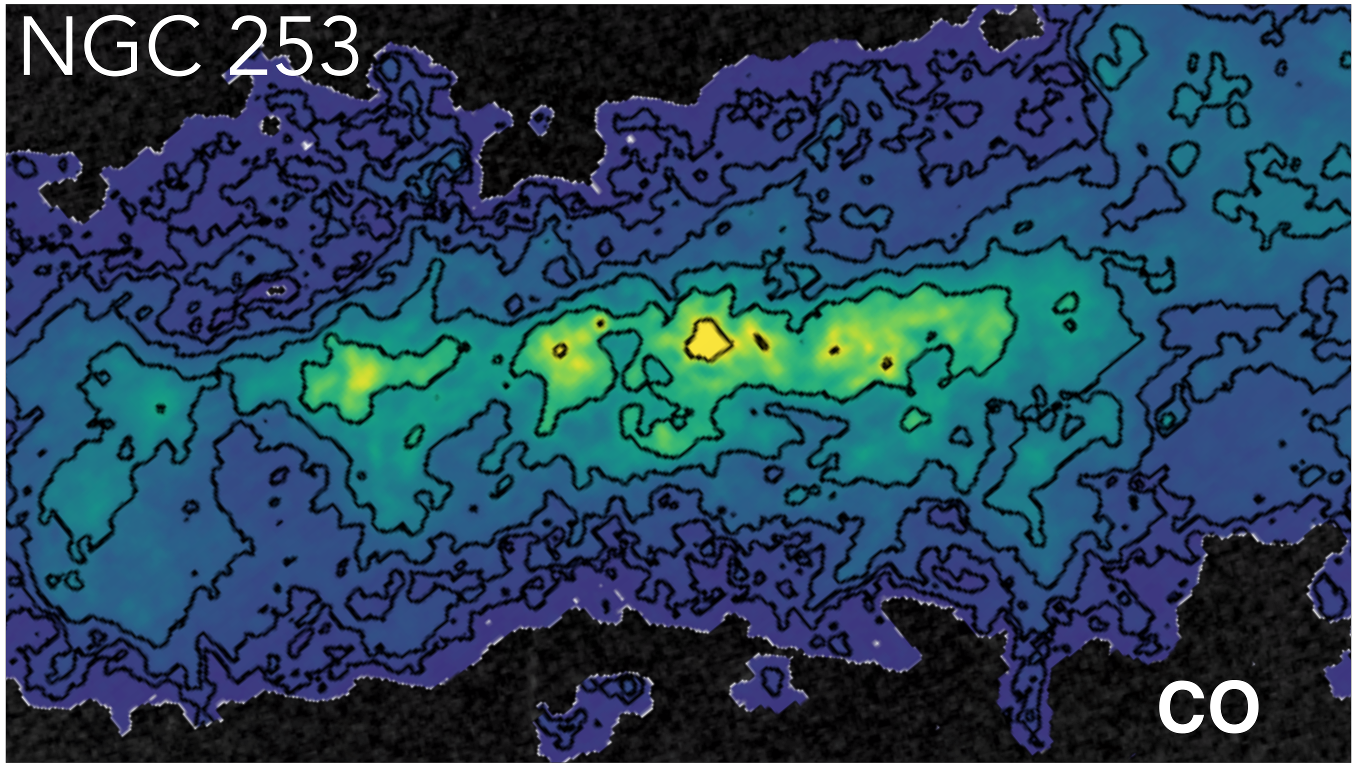

NGC 253
Super star clusters
450 ly

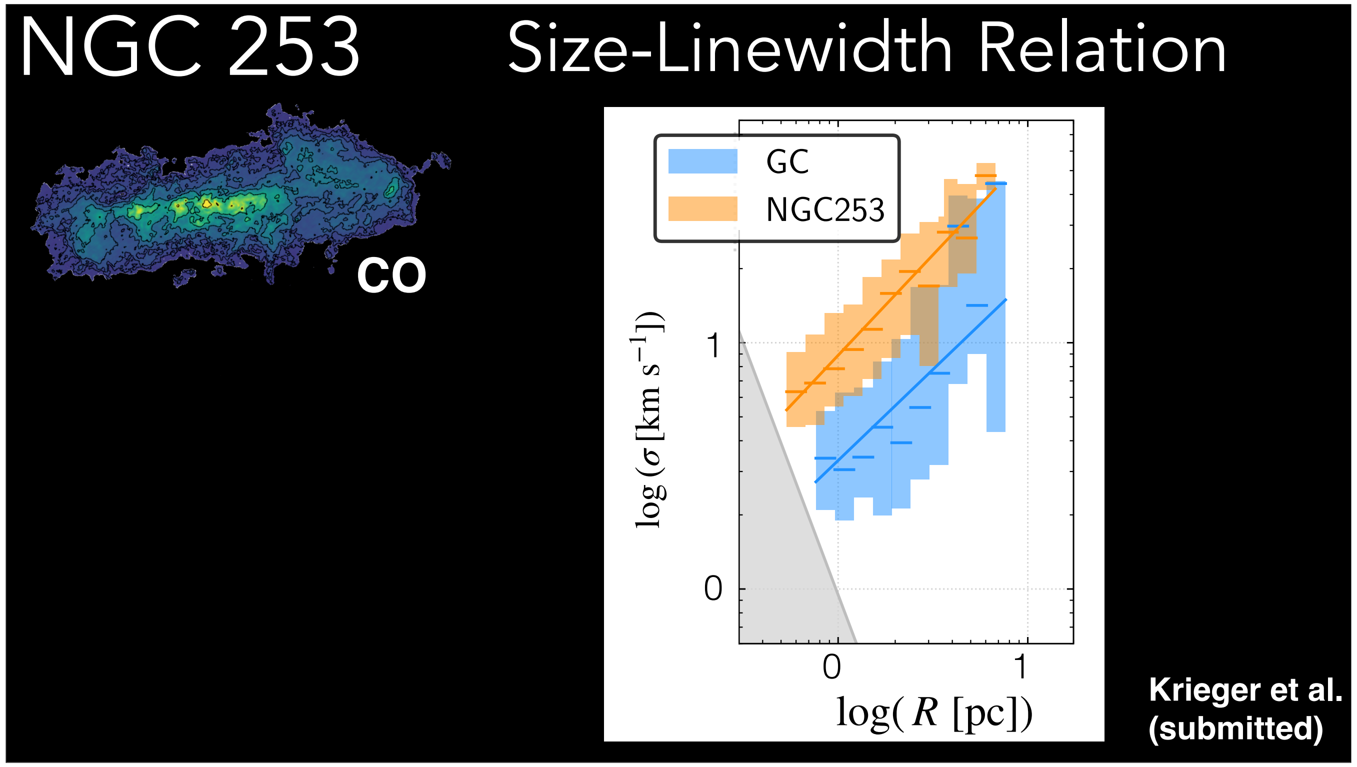

NGC 253
Super star clusters
Embedded clusters
ALMA Recombination line
Resolution = 8 ly / 2.5 pc
450 ly
Star formation in the clusters is
sufficient to power the outflow.
Leroy et al. 2018,
Krieger et al. 2019



And ALMA gives you much more than just the ionized gas. Can see dense molecular gas, in which the clusters are still embedded, and more diffuse molecular gas, some of which belongs to the outflow.

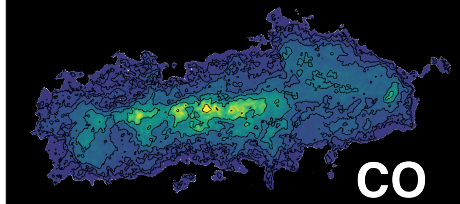

NGC 253
HCN

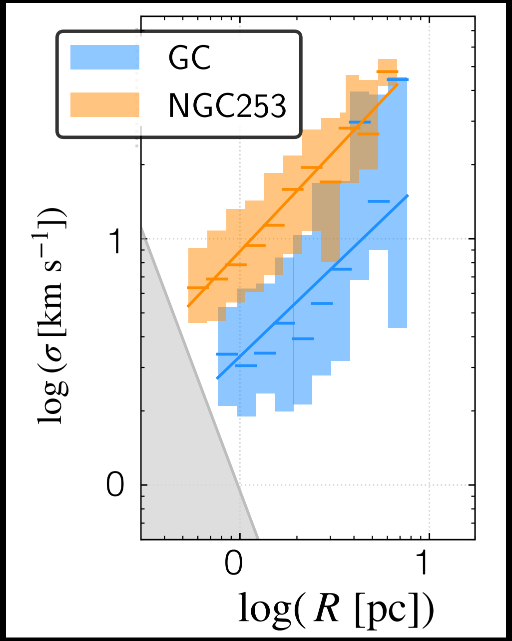

NGC 253
CO



Focusing on the CO, can make one of the first comparisons between the gas properties in the Milky Way and the more extreme center of NGC 253: see elevated turbulence on all spatial scales probed here.

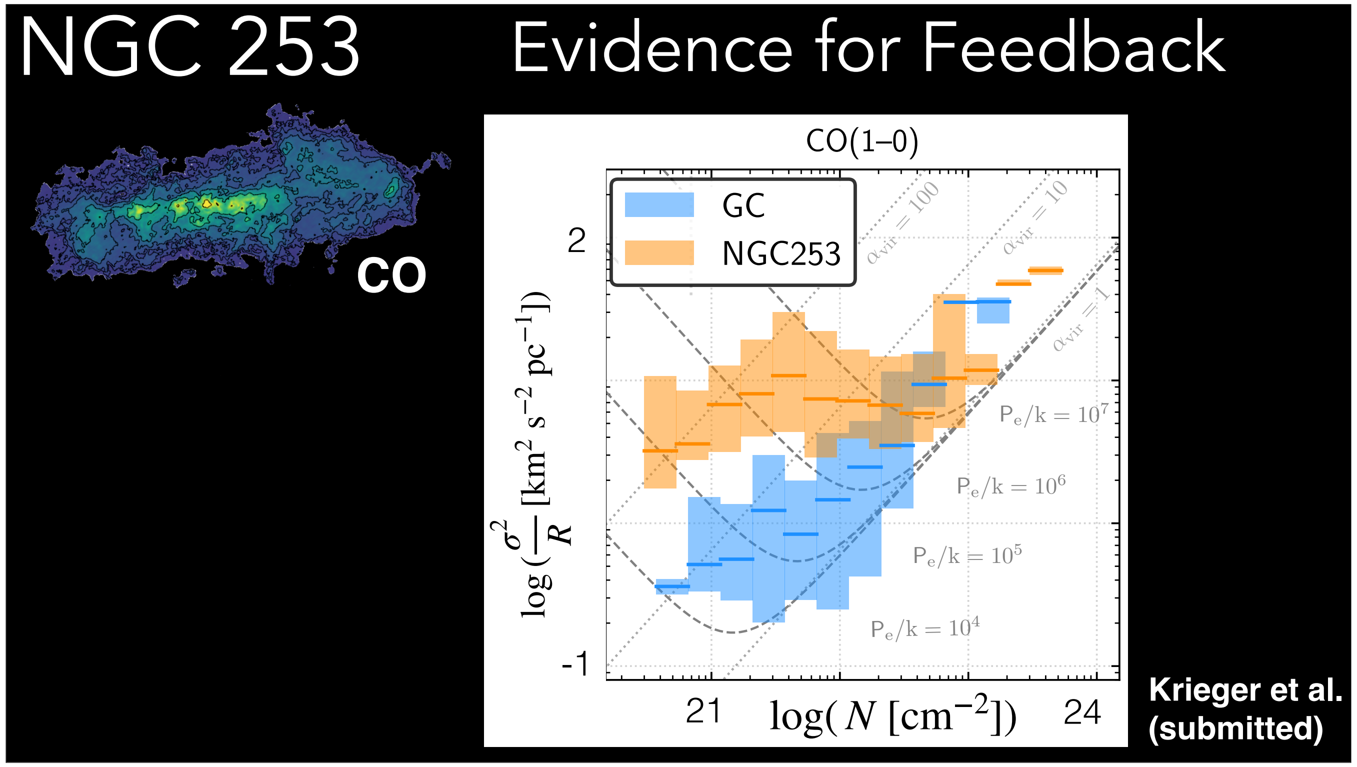
NGC 253 Size-Linewidth Relation





See linewidths 2-3x larger than in the Milky Way center

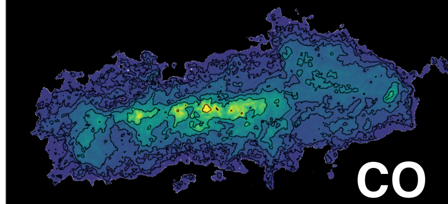
Krieger et al. (submitted)



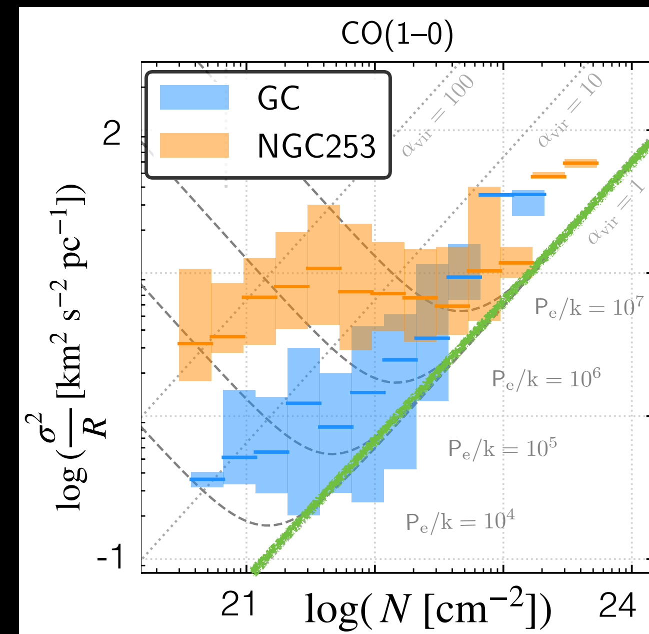
What is the origin of these larger line widths? Can compare the relationship we would expect between the line width coefficient (sigma-squared over R) and the column density, if the gas is self-gravitating and in virial equilibrium. While gas at almost all column densities in the Galactic center is found in gravitational bound structures, this is only true for the highest column-density gas in NGC 253 — consistent with a scenario where feedback from the clusters is injecting energy that is leading to transient structure and even unbinding the gas.

NGC 253

Evidence for Feedback

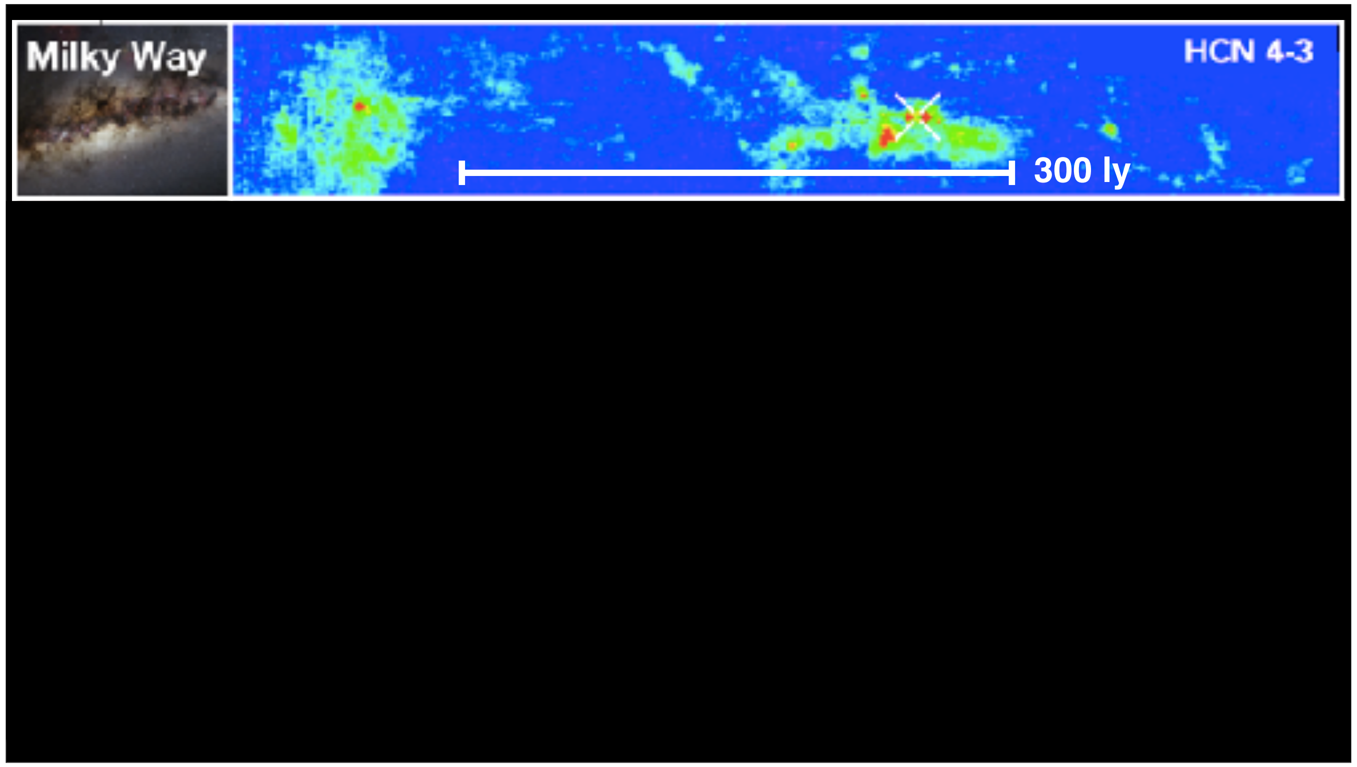


Line widths in low column-density gas in NGC 253 are larger than expected for gravitationally- bound clouds

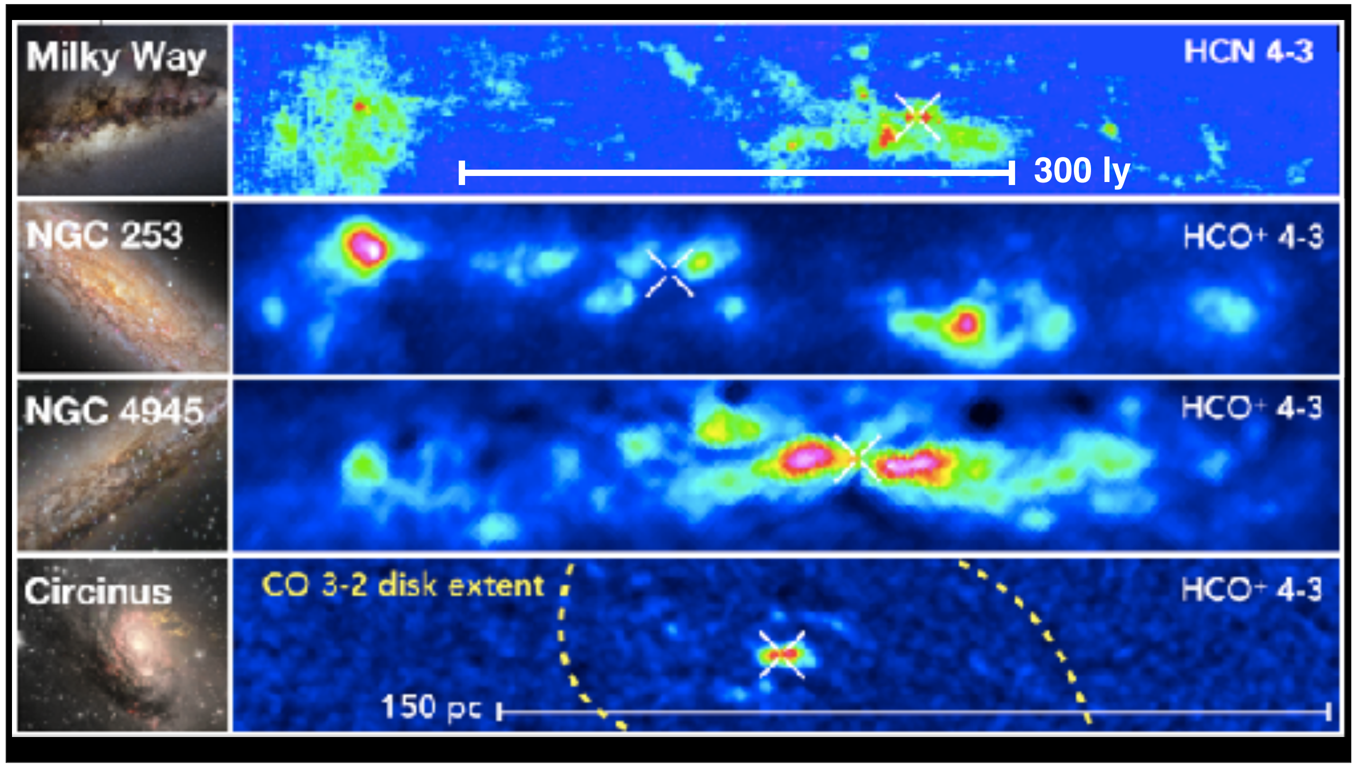


$$\frac{M_{vir}}{M} = 1$$

Krieger et al. (submitted)



With ALMA, many other galaxy centers are also coming into focus, which allows for many rich future possibilities, to use the quiescent milky way galaxy as a control and to isolate the impact that different feedback variables have on the gas properties.


Milky Way
HCN 4-3
300 ly
NGC 253
HCO+ 4-3
NGC 4945
HCO+ 4-3
Circinus
CO 3-2 disk extent
HCO+ 4-3
150 pc

Milky Way
HCN 4-3
Little star formation or black hole activity
300 ly
NGC 253
HCO+ 4-3
Lots of star formation, no black hole activity
NGC 4945
HCO+ 4-3
Lots of star formation and black hole activity
Circinus
CO 3-2 disk extent
HCO+ 4-3
Little star formation, lots of black hole activity
150 pc

I want to leave you with the message that this is a time of excitement, when the center of our galaxy no longer has to be a sample size of one from which to try to draw conclusions. With nearby galaxies now within reach, we can place the Milky Way's center in its true context, and understand both what it can and what it cannot teach us about the physics that governs the evolution of galaxy nuclei.