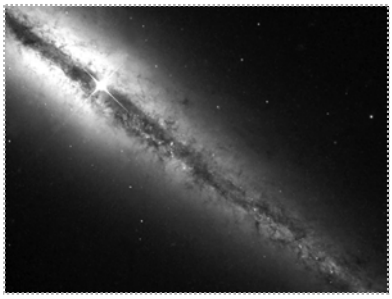
ASTR 1120: Stars & Galaxies



Edge-on spiral galaxy NGG 4013

Prof. Juri Toomre TA: Ben Brown

Lecture 30 Mon 28 Mar 05

zeus.colorado.edu/astr1120-toomre

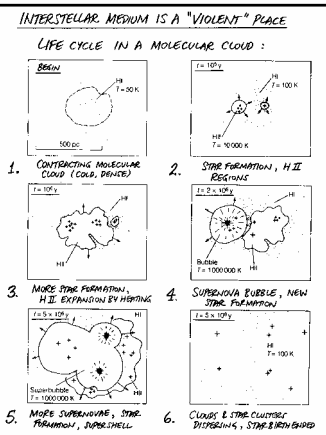
Today's Events

- More on *density waves and spiral making*
- How can we *map the spiral arm structure* of our Milky Way galaxy?
- Today turn to the mysterious *galactic center* in our Milky Way galaxy
- Discovery of *supermassive black hole* at galactic center
- Overview read *Chap 20 Galaxies*
- New *Homework Set 8* on `*Cosmic Distances and Hubble Law*' passed out today – due Mon Apr 4

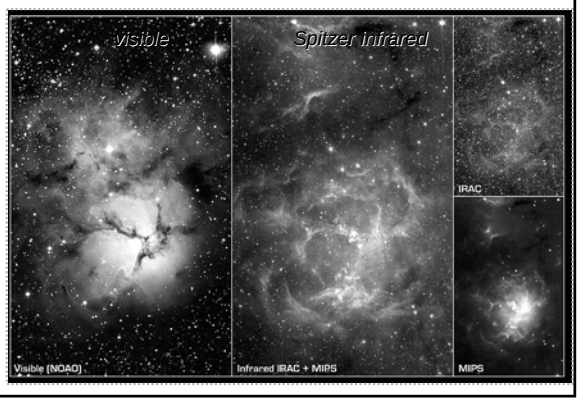
REMINDER

ISM is a pretty violent place

"Life cycle" in a molecular cloud

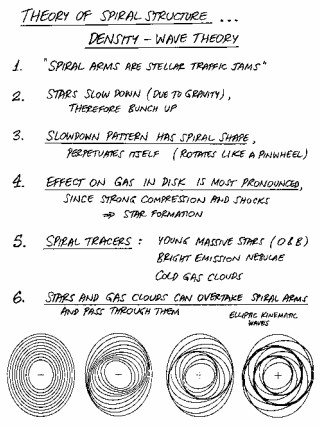


Trifid emission nebula "O & B star associations"



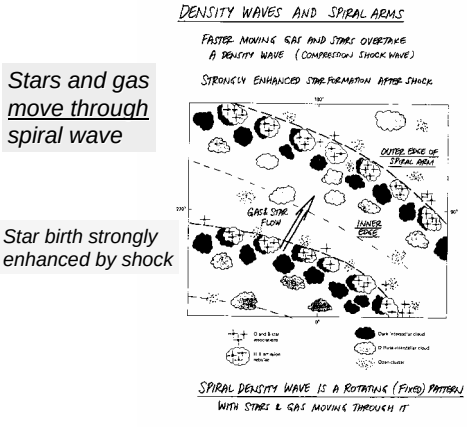
"Density wave" story – how spiral structure is built

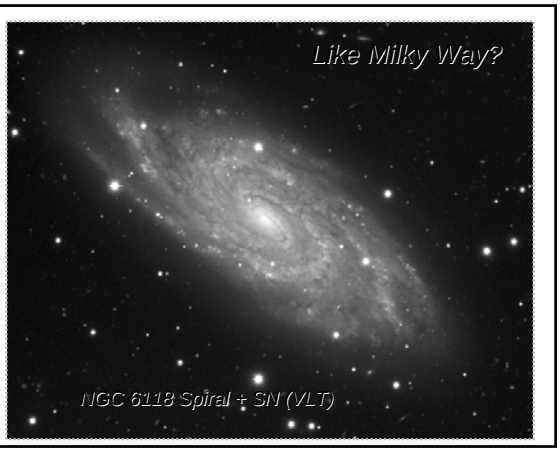
Gravitational instability of disks (gentle)



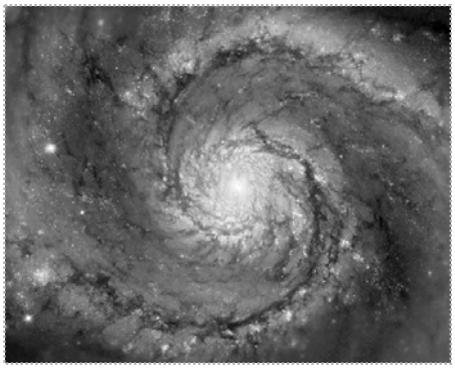
Stars and gas move through spiral wave

Star birth strongly enhanced by shock



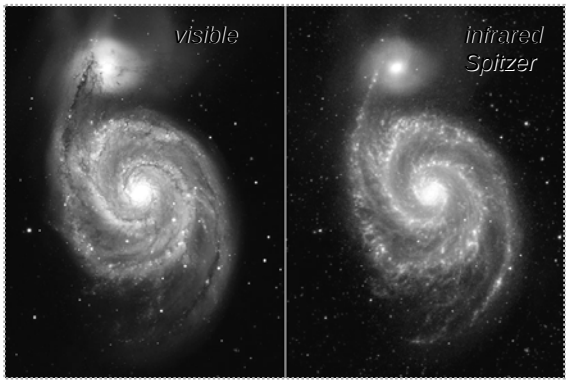


"Grand design spiral" – M51 Whirlpool

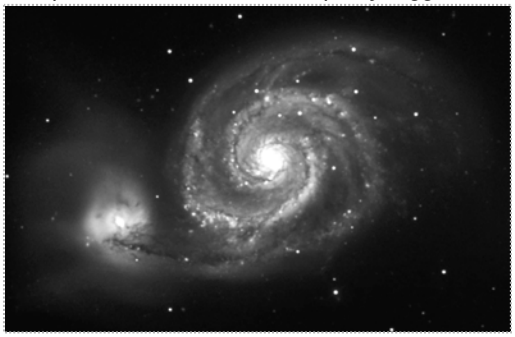


Bright O & B stars mark the spiral pattern

Outlining starbirth in M51



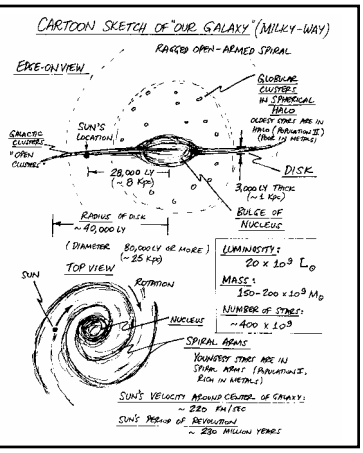
Why does "M51 – Whirlpool" have open spiral structure, and ours is pretty ragged?



A: Collision with companion galaxy enhanced its spiral wave

Q: Just HOW do we know that MW has spiral structure?

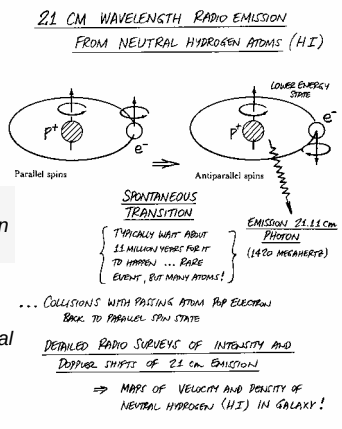
A: Radio astronomers could map it with 21-cm line of hydrogen



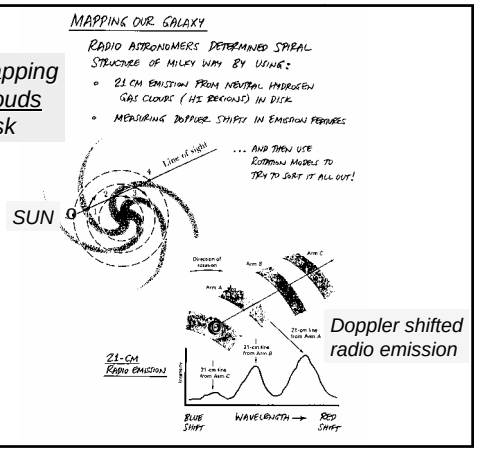
21 cm emission (radio)

Sampling neutral hydrogen atoms (cold)

also how MRI does it in medical imaging!

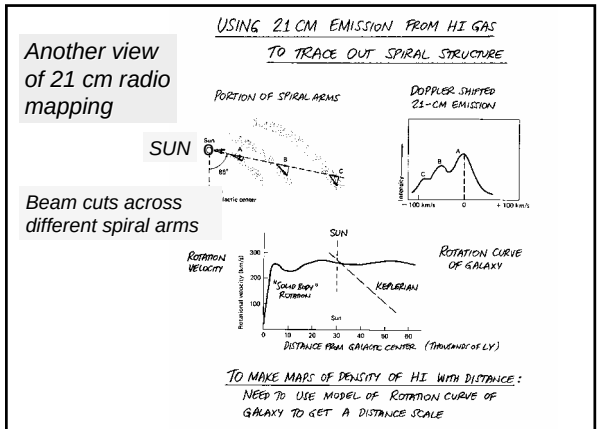


Radio mapping <u>cool H clouds</u> in MW disk



Doppler shifted radio emission

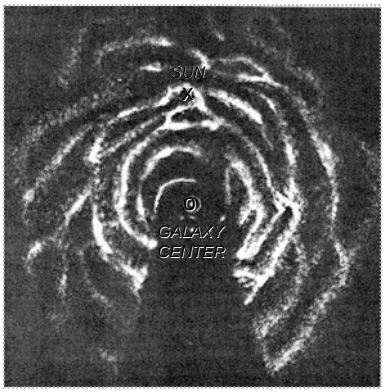
Another view of 21 cm radio mapping



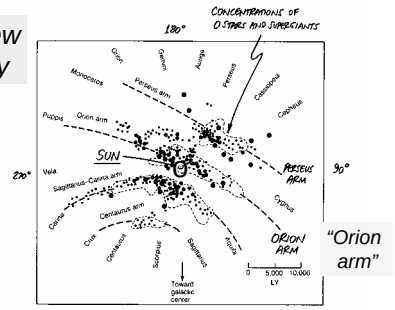
<u>Radio map</u> (21 cm) of spiral structure in MW

Ragged spiral structure revealed

Emitted radio waves can <u>penetrate through gas and dust</u>



Close-up view of our vicinity



"Orion arm"

0° toward galactic center

Center of our galaxy

Located in direction of constellation <u>Sagittarius</u>

Seemingly <u>nothing very interesting</u> there (at least in visible images)

Clicker – galaxy center

- *We want to map out the structure of the central <u>core</u> of the Milky Way. What <u>wavelength</u> should we be using, and why?*

- *A.* IR or radio
- *B.* visible light
- *C.* X-rays

A.

- *Dust obscures our vision of much of the galaxy in visible and UV light.*
- *X-rays only highlight the hottest and weirdest places*
- *IR and radio light pass through unaffected, show dust, stars, gas*

THE GALACTIC CENTER

TOTALLY OBSCURED IN VISIBLE LIGHT

VISIBLE IN: RADIO, IR, X-RAY, γ-RAY, MILLIMETER

EVIDENCE FOR UNUSUAL ACTIVITY AT CENTER:

1. HIGH SPEED GAS — STREAMERS
2. DENSE CLUSTERS OF STARS
3. COMPACT X-RAY, γ-RAY SOURCES

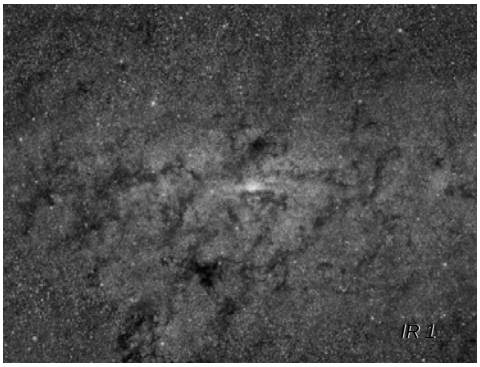
APPEARS AS IF $> 10^6 M_\odot$ IN INNER FEW PARSECS !

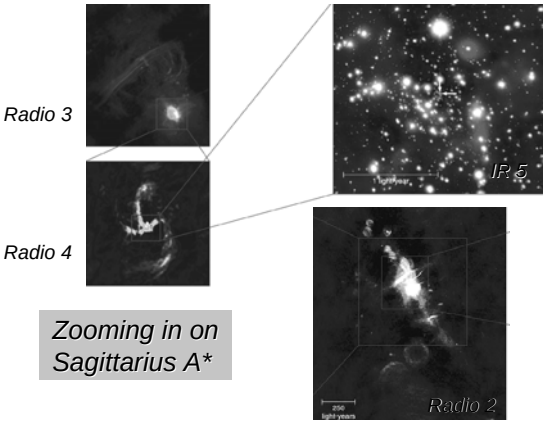
⇒ MASSIVE BLACK HOLE ?

. . . . BUT COULD BE STARS

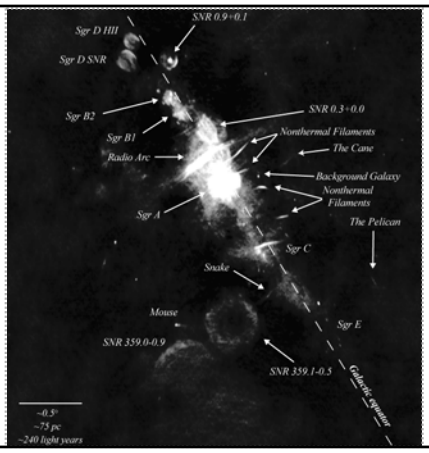
Unusual activity at galaxy center

Galactic center: IR light reveals a dense star cluster

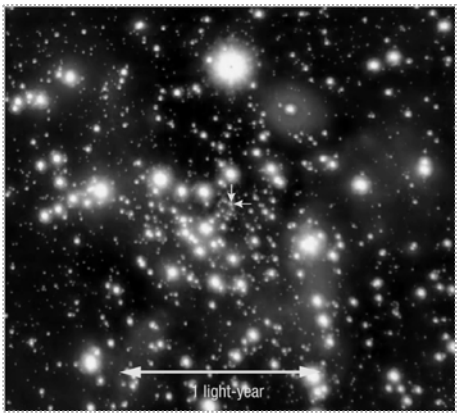




*Zooming in on Sagittarius A**



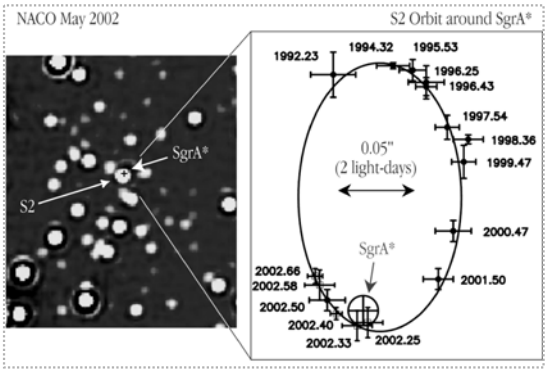
Radio mapping of galactic center

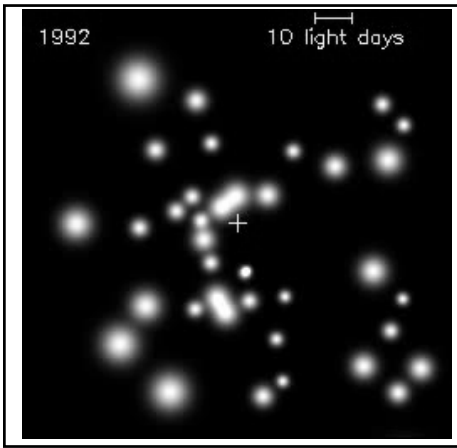


*Sgr A**

VLT IR+AO

Sgr A : VLT in IR + adaptive optics*

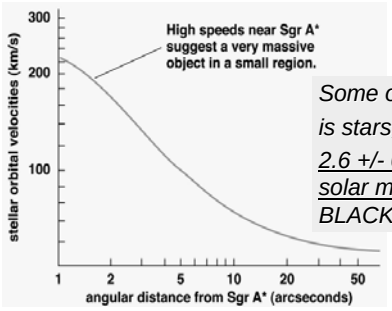




Star motion around black hole at galactic center

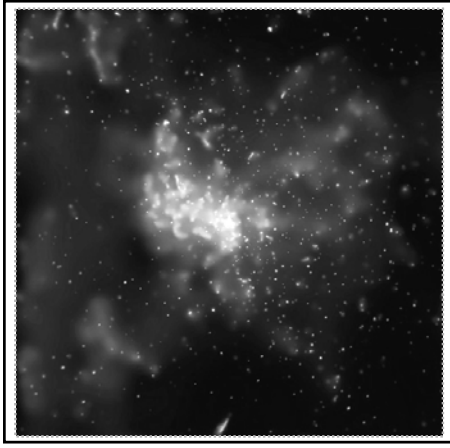
VLT: IR+AO

Rotation velocity at galaxy center



Some of central mass is stars, joined by 2.6 +/- 0.2 million solar mass BLACK HOLE

Black hole still less than 1/1000 of MW mass



Sag A in Chandra X-ray view*

Exhibits outbursts, but starved of fuel ?

Why doesn't massive black hole have a powerful jet and accretion disk?

- *Why not much emission in X-rays ?*
- *Maybe eaten everything it can – at least for now ?*