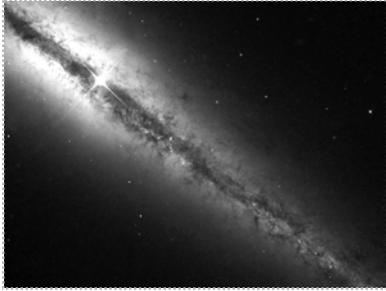


ASTR 1120: Stars & Galaxies



Edge-on
spiral galaxy
NGC 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

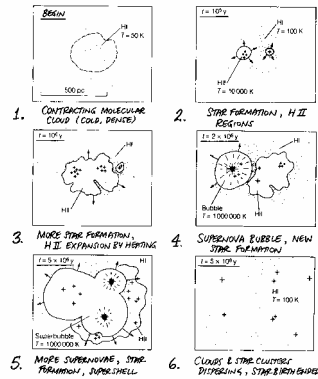
REMINDER

ISM is a pretty violent place

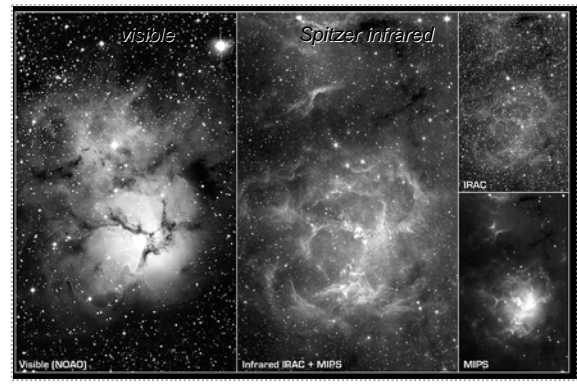
"Life cycle" in a molecular cloud

INTERSTELLAR MEDIUM IS A "VIOLENT" PLACE

LIFE CYCLE IN A MOLECULAR CLOUD:



Trifid emission nebula "O & B star associations"



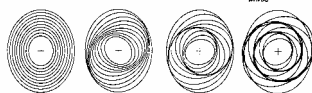
"Density wave" story – how spiral structure is built

Gravitational instability of disks (gentle)

THEORY OF SPIRAL STRUCTURE ...

DENSITY - WAVE THEORY

1. "SPIRAL ARMS ARE STELLAR TRAFFIC JAMS"
2. STARS SLOW DOWN (DUE TO GRAVITY), THEREFORE BUNCH UP
3. SLOWDOWN PATTERN HAS SPIRAL SHAPE, PERTURBS ITSELF (ROTATES LIKE A PINWHEEL)
4. EFFECT ON GAS IN DISK IS MOST PRONOUNCED, SINCE STRONG COMPRESSION AND SHOCKS \Rightarrow STAR FORMATION
5. SPIRAL TRACERS: YOUNG MASSIVE STARS (O & B) BRIGHT EMISSION NEBULAE COLD GAS CLOUDS
6. STARS AND GAS CLOUDS CAN OVERTAKE SPIRAL ARMS AND PASS THROUGH THEM

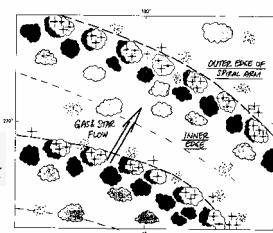


Stars and gas move through spiral wave

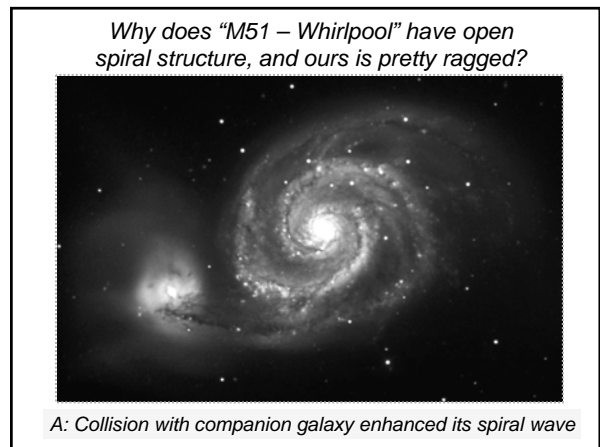
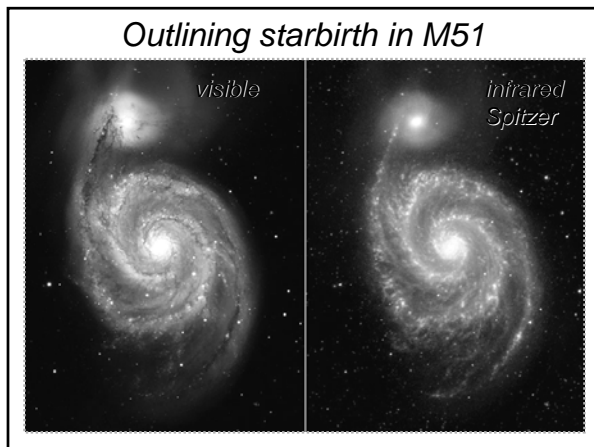
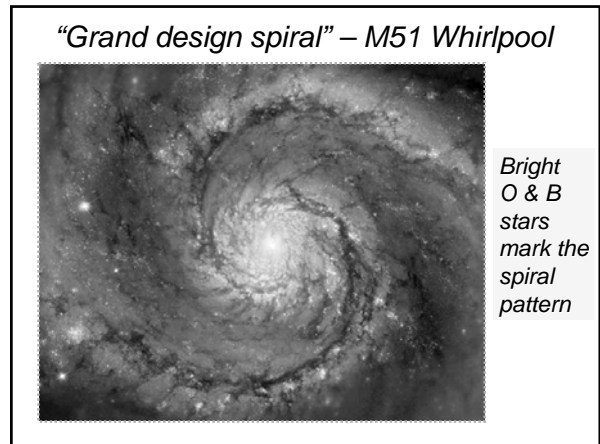
Star birth strongly enhanced by shock

DENSITY WAVES AND SPIRAL ARMS

FASTER MOVING GAS AND STARS OVERTAKE A DENSITY WAVE (COMPRESSION SHOCK WAVE)
STRONGLY ENHANCED STAR FORMATION AHEAD SHOCK



SPIRAL DENSITY WAVE IS A ROTATING (FIXED) PATTERN WITH STARS & GAS MOVING THROUGH IT



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

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

CARTOON SKETCH OF "OUR GALAXY" (MILKY-WAY)

RAISED OPEN-ARMED SPIRAL

EDGE-ON VIEW

GLORIOUS CLOUDS IN SPHERICAL HALO
OLDEST STARS ARE IN HALO (ABUNDANT!!) (MADE BY METALS)

SUN'S LOCATION

28,000 LY (~8 kpc)

3000 LY THICK (~1 kpc)

DISK

BOULE OF NUCLEUS

RANGE OF DISK (DIAMETER 80,000 LY OR MORE) (~25 kpc)

LUMINOSITY: $20 \times 10^9 L_{\odot}$

MASS: $150 - 200 \times 10^9 M_{\odot}$

NUMBER OF STARS: $\sim 400 \times 10^9$

TOP VIEW

SUN

ROTATION

SPIRAL ARMS

YOUNGEST STARS ARE IN SPIRAL ARMS (FRAGMENTED, RICH IN METALS)

SUN'S VELOCITY AROUND CENTER OF GALAXY: 230 KM/SEC

SUN'S PERIOD OF REVOLUTION: ~230 MILLION YEARS

21 cm emission (radio)

21 CM WAVELENGTH RADIO EMISSION FROM NEUTRAL HYDROGEN ATOMS (HI)

Parallel spins \Rightarrow Antiparallel spins

LOW ENERGY STATE

SPONTANEOUS TRANSITION

EMISSION 21.11 cm PHOTON (1420 MHz ENERGY)

... COLLISIONS WITH PROTONS FROM POP ELECTRON BACK TO PARALLEL SPIN STATE

DETAILED RADIO SURVEYS OF INTENSITY AND DOPPLER SHIFT OF 21 cm EMISSION

\Rightarrow MAPS OF VELOCITY AND DENSITY OF NEUTRAL HYDROGEN (HI) IN GALAXY!

MAPPING OUR GALAXY

Radio mapping cool H clouds in MW disk

RADIO ASTRONOMERS DETERMINED SPIRAL STRUCTURE OF MILKY WAY BY USING:

- 21 CM EMISSION FROM NEUTRAL HYDROGEN GAS CLOUDS (HI REGIONS) IN DISK
- MEASURING DOPPLER SHIFT IN EMISSION PERIODS

... AND THEN USE ROTATION MODELS TO TRY TO SORT IT ALL OUT!

Doppler shifted radio emission

21-CM RADIO EMISSION

WAVELENGTH → RED SHIFT

BLUE SHIFT

USING 21 CM EMISSION FROM HI GAS TO TRACE OUT SPIRAL STRUCTURE

Another view of 21 cm radio mapping

Beam cuts across different spiral arms

PORTION OF SPIRAL ARMS

DOPPLER SHIFTED 21-CM EMISSION

ROTATION VELOCITY

ROTATION CURVE OF GALAXY

TO MAKE MAPS OF DENSITY OF HI WITH DISTANCE: NEED TO USE MODEL OF ROTATION CURVE OF GALAXY TO GET A DISTANCE SCALE

Radio map (21 cm) of spiral structure in MW

Ragged spiral structure revealed

Emitted radio waves can penetrate through gas and dust

SUN

GALAXY CENTER

SPIRAL ARMS IN "OUR NEIGHBORHOOD"

Close-up view of our vicinity

CONCENTRATIONS OF O STARS AND SUPERGIANTS

ORION ARM

SUN

toward galactic center

Center of our galaxy

Located in direction of constellation Sagittarius

Seemingly nothing very interesting there (at least in visible images)

Clicker – galaxy center

- We want to map out the structure of the central core of the Milky Way. What wavelength 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

Unusual activity at galaxy center

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

EVIDENCE FOR UNUSUAL ACTIVITY AT CENTER:

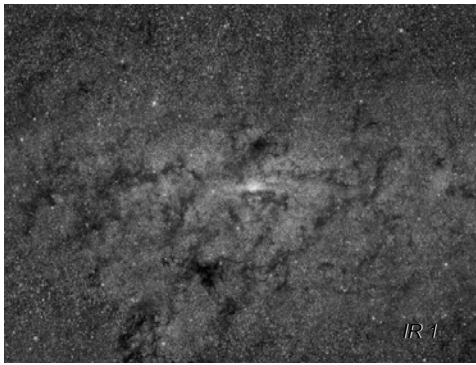
1. HIGH SPEED GAS - STREAMERS
2. DENSE CLUSTERS OF STARS
3. COMPACT X-RAY, γ -RAY SOURCES

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

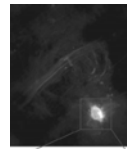
⇒ MASSIVE BLACK HOLE ?

.... BUT COULD BE STARS

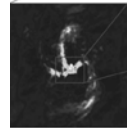
Galactic center: IR light reveals a dense star cluster



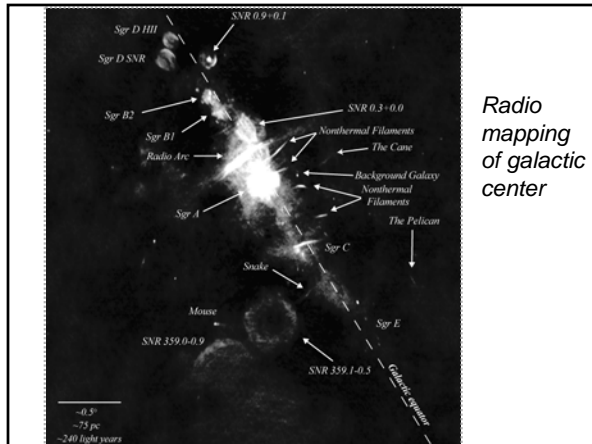
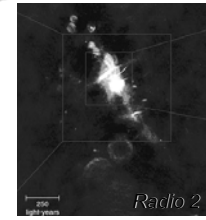
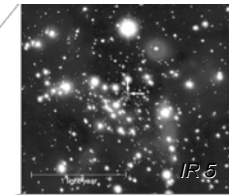
Radio 3



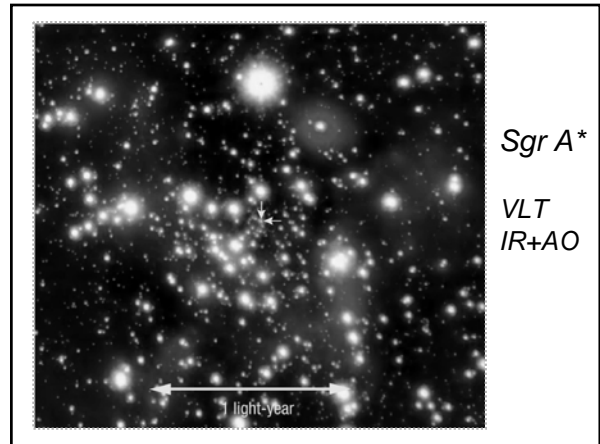
Radio 4



Zooming in on Sagittarius A*



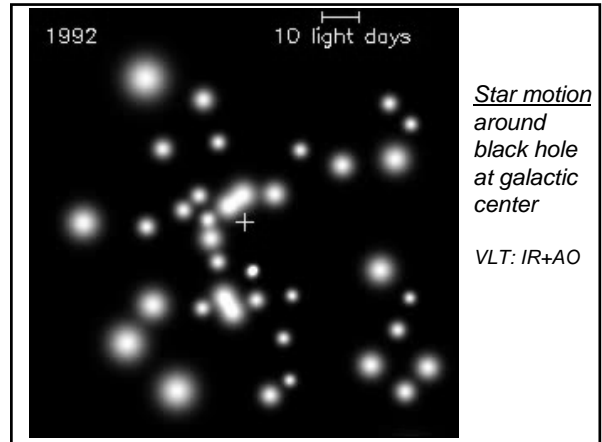
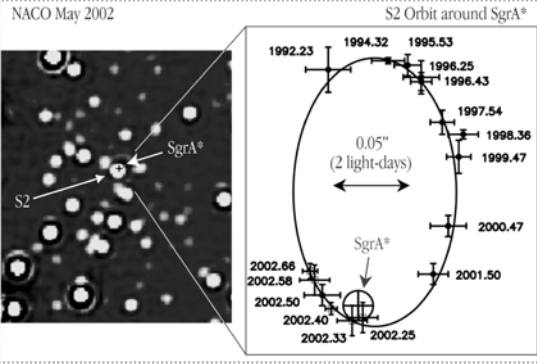
Radio mapping of galactic center



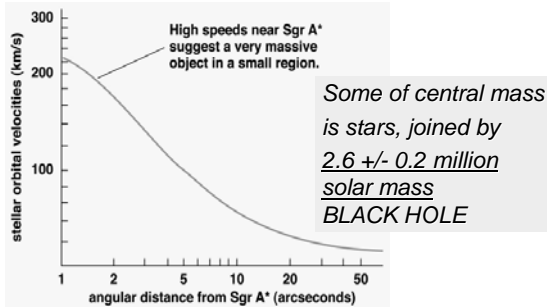
Sgr A*

VLT IR+AO

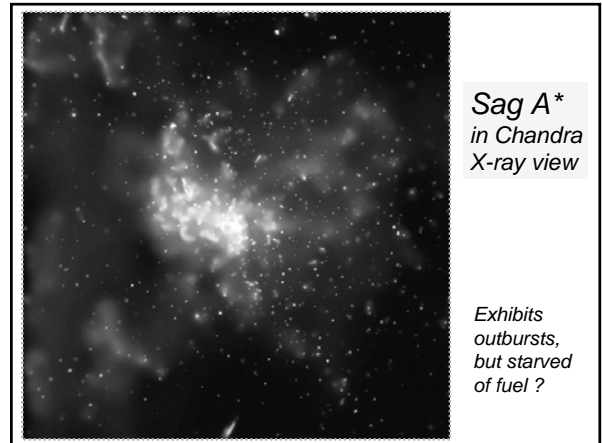
Sgr A* : VLT in IR + adaptive optics



Rotation velocity at galaxy center



Black hole still less than 1/1000 of MW mass



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?

