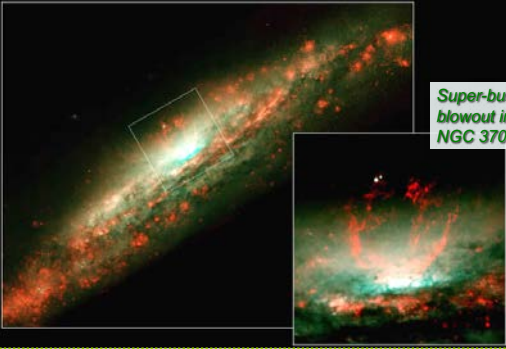


ASTR 1040: Stars & Galaxies



Super-bubble blowout in NGC 3709

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Lecture 22 Thur 6 Apr 2017
zeus.colorado.edu/astr1040-toomre

Tour of Galaxies

- Look at complex effects of dust in galaxies
- Examine how 21-cm radio emission works: can map our galaxy (and its spiral structure)
- Super-massive black hole at center of MW
- Hubble using 'Cepheid variables' showed Andromeda is a distinct "island universe" – another Galaxy!
- The rich range of galaxies: spiral, barred spirals, ellipticals, and irregulars
- Hubble's scheme to classify galaxies

Our Schedule

- Observatory #7 last night: status
- Homework #10 due today, new HW #11
- Read with care 20.2 'Measuring Cosmic Distances' and 20.3 'Hubble's Law'.
- Start reading Chap 21 "Galaxy Evolution"

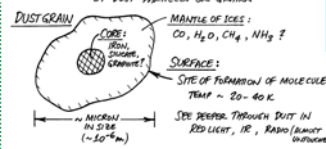
INTERSTELLAR DUST

... MINOR COMPONENT, BUT BIG EFFECTS!

REVISIT


ISM:
A little DUST goes a long way!

- 1. REDDENING OF LIGHT** "INTERSTELLAR REDDENING"
PREPREFERENTIAL SCATTERING OF BLUER PHOTONS BY DUST PARTICLES OR GRAINS
"Reddens" the light
- 2. GENERAL EXTINCTION OR DIMMING OF LIGHT**
SOME AREAS APPEAR DARKER TO STARLIGHT
Absorbs the light
- 3. POLARIZATION OF LIGHT**
MAGNETIC FIELDS CAN SERVE TO ALIGN DUST GRAINS WHICH MAY BE ELONGATED IN SHAPE → SELECTIVE ABSORPTION OF LIGHT IF THE ORIENTATIONS




SEMI-WARM stuff: dust

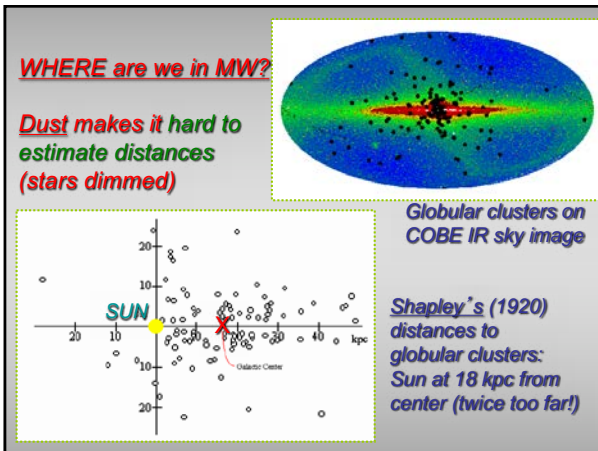
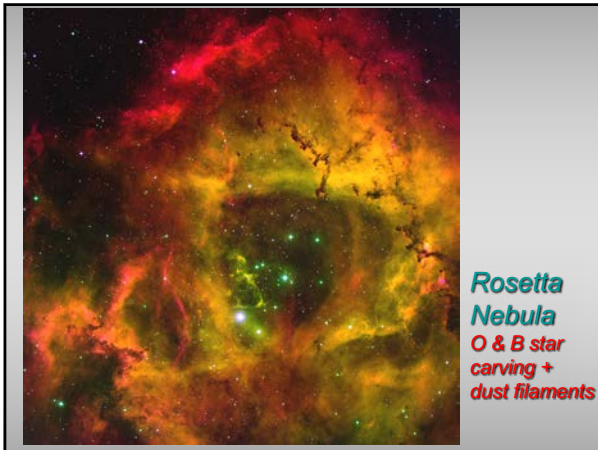
- **DUST:** absorbs visible and UV light
- **Transparent to long wavelengths** (red, IR, radio)
- **Emits IR light**



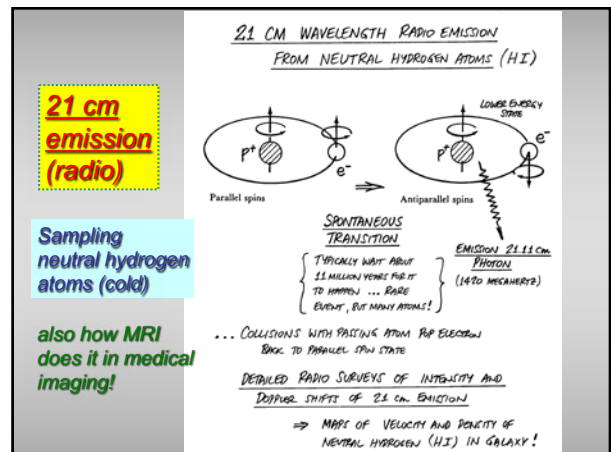
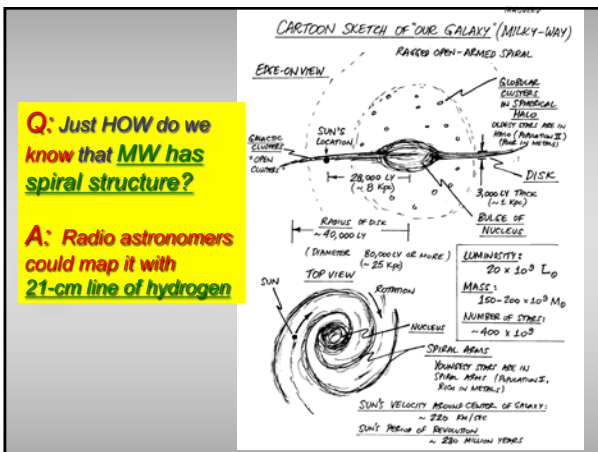
Horsehead Nebula

Clouds + dust in Eagle Nebula





- Large-scale structure in Milky Way**
- We can observe the atomic hydrogen in interstellar gas in Milky Way with _____.
- A. space-based ultraviolet telescopes
 - B. x-ray telescopes
 - C. ground-based visible light telescopes
 - D. 21 cm observations by radio telescopes





MAPPING OUR GALAXY

RADIO ASTRONOMERS DETERMINED SPIRAL STRUCTURES OF MILKY WAY BY USING:

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

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

Radio mapping cool H clouds in MW disk

Doppler shifted radio emission

The diagram shows a spiral galaxy with a 'Line of sight' and 'SUN' at the center. It illustrates '21-CM Radio Emission' from different arms (A, B, C) and a graph showing 'Doppler shifted radio emission' with 'Blue Shift' and 'Red Shift' regions.

Another view of 21 cm radio mapping

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

PORTION OF SPIRAL ARMS

DOPPLER SHIFTED 21-CM EMISSION

SUN

Beam cuts across different spiral arms

ROTATION VELOCITY

ROTATION CURVE OF GALAXY

DISTANCE FROM GALAXY CENTER (THOUSANDS OF LY)

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

The diagrams include a 'PORTION OF SPIRAL ARMS' with 'SUN' at the center, a 'DOPPLER SHIFTED 21-CM EMISSION' graph showing velocity vs. distance, and a 'ROTATION CURVE OF GALAXY' graph showing rotation velocity vs. distance from the galaxy center.

Radio map (21 cm) of spiral structure in MW

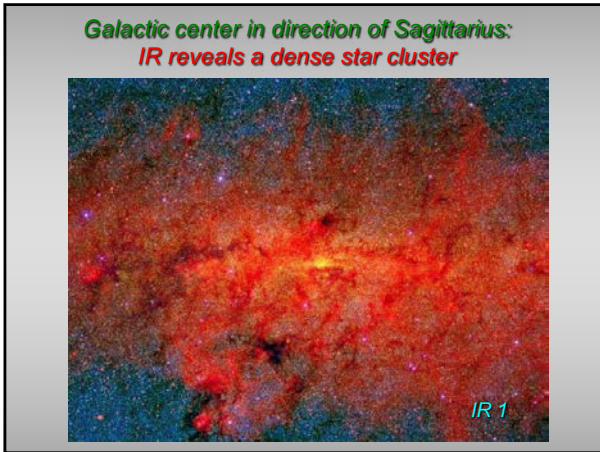
Ragged spiral structure revealed

Emitted radio waves can penetrate through gas and dust

SUN

GALAXY CENTER

The radio map shows the spiral structure of the Milky Way with labels for 'SUN' and 'GALAXY CENTER'.



THE GALACTIC CENTER

TOTALLY OBSCURED IN VISIBLE LIGHT

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

Unusual activity at galaxy center

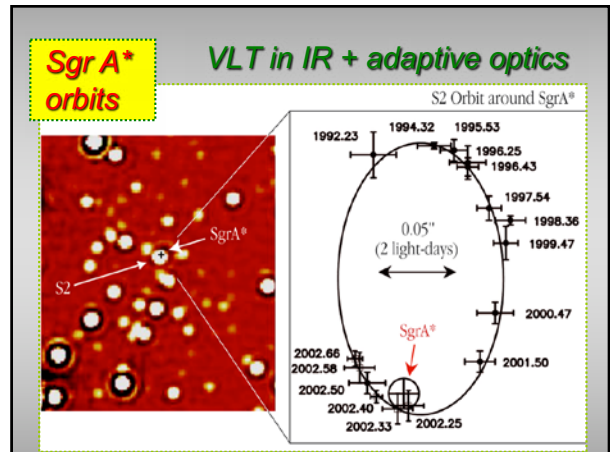
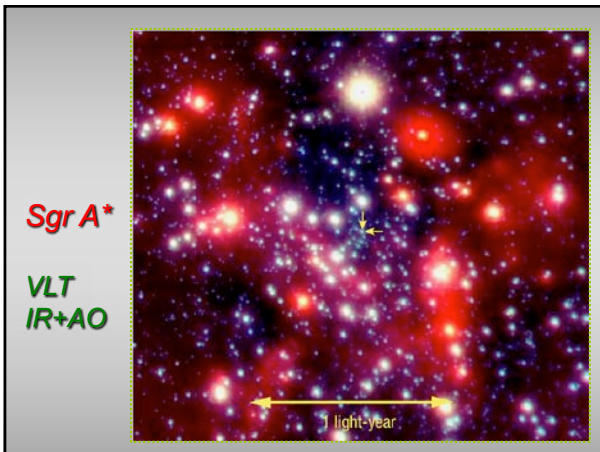
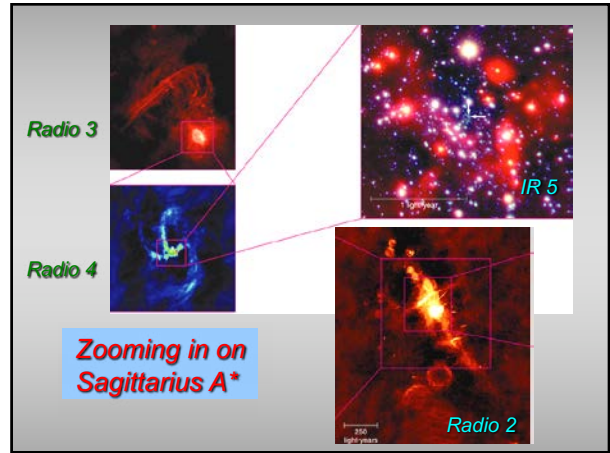
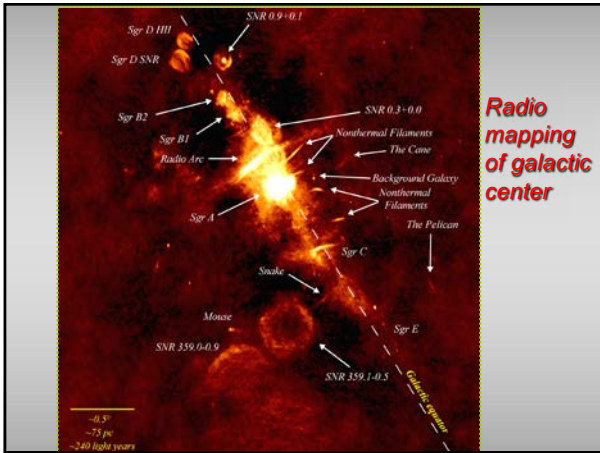
EVIDENCE FOR UNUSUAL ACTIVITY AT CENTER :

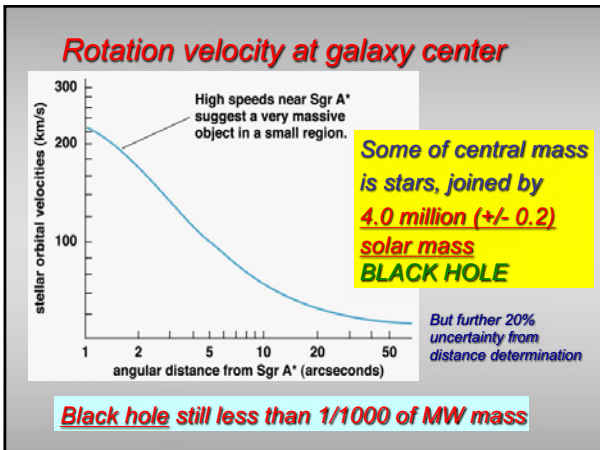
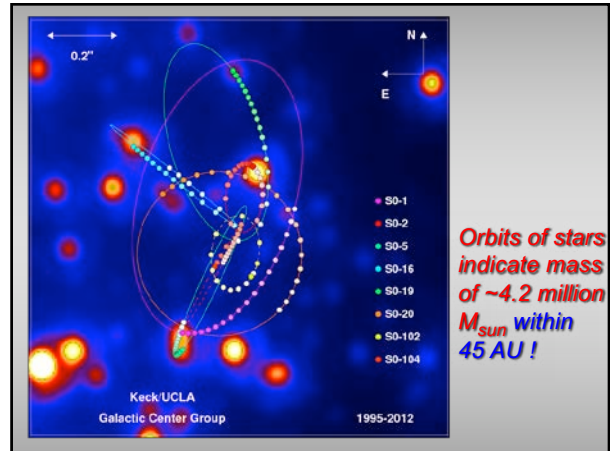
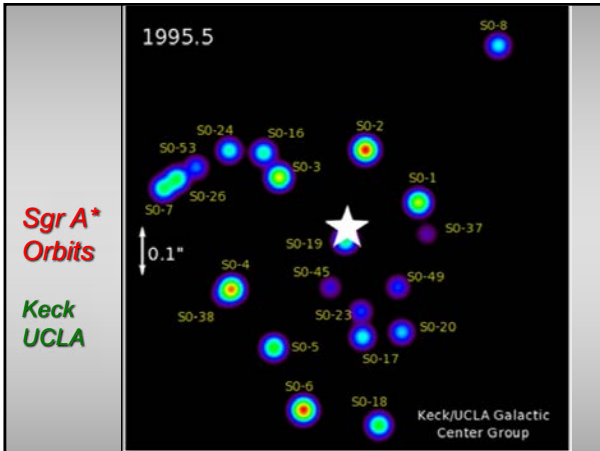
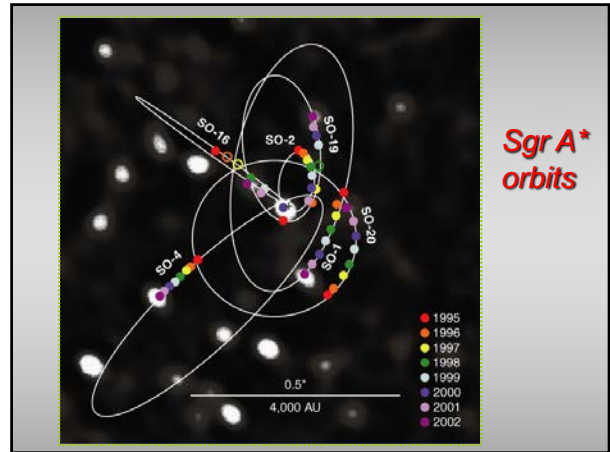
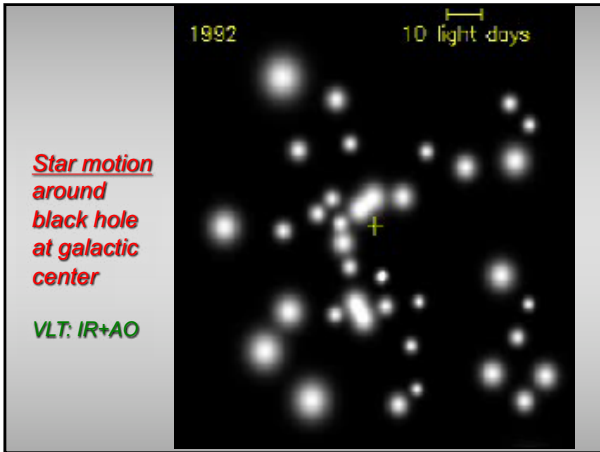
1. HIGH SPEED GAS - STREAMERS
2. DENSE CLUSTERS OF STARS
3. COMPACT X-RAY, γ -RAY SOURCES

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

\Rightarrow MASSIVE BLACK HOLE ?

... BUT COULD BE STARS





Question: Why no powerful jet and accretion disk near MW's supermassive black hole?

- Modest emission in X-rays...though other signs of activity
- Answer:** maybe it has eaten all it can – at least for now?



Clicker – reading ahead

- What are the **Magellanic Clouds**? **C.**
- A.** Two nebulae in disk of Milky Way visible only in southern hemisphere
- B.** Clouds of dust and gas in many places throughout the Milky Way galaxy
- C.** Two small galaxies that orbit Milky Way
- D.** Star-forming clouds in constellation Orion


HOW DID IT ALL BEGIN?

Measuring galactic distances

Edwin Hubble made breakthrough using **Cepheid variables** to measure distance

Found **Andromeda** far outside **Milky Way**

Huge step forward in thinking about universe



NGC 4414

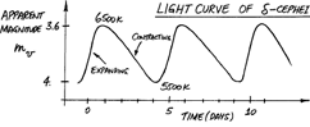
Cepheid variable stars as distance indicators: "standard candle"

PULSATING VARIABLE STARS

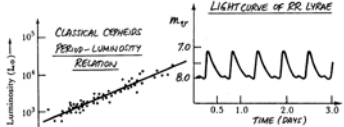
STARS BECOME UNSTABLE TO LARGE-AMPLITUDE PULSATIONS AS THEY EVOLVE ACROSS "INSTABILITY STRIP"

AS STARS PULSATE, THEY EXPAND AND CONTRACT, CHANGING BRIGHTNESS AS THEY DO SO...

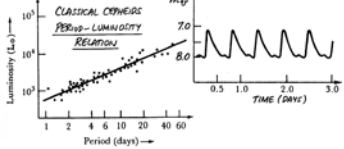
LIGHT CURVE OF δ -CEPHEID



LIGHT CURVE OF RR LYRAE



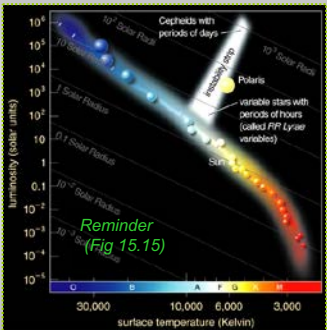
CLASSICAL CEPHEIDS PERIOD-LUMINOSITY RELATION



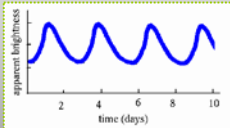
Vital discovery by **Henrietta Leavitt (1912)**

Cepheid stars in H-R diagram

- "**Instability strip**" -- region in H-R diagram with large, bright stars
- Outer regions of star are unstable and tend to pulsate
- Star expands and contracts, getting brighter and fainter



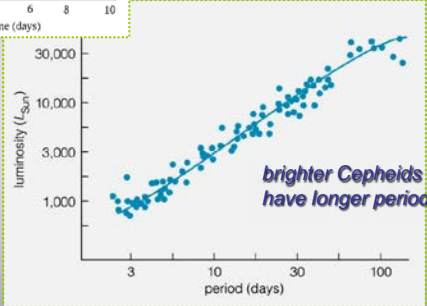
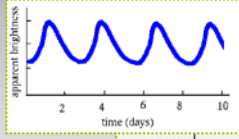
Reminder (Fig 15.15)



Cepheid variable stars

Period - Luminosity relation

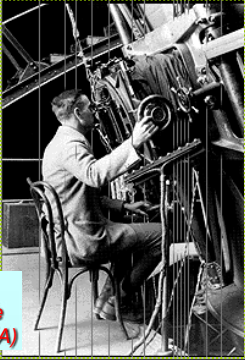
brighter Cepheids have longer periods

Andromeda found to be far outside Milky Way – another “island universe” : galaxy!

- **Edwin Hubble in 1924 identified Cepheids in Andromeda (M31) → showed they were far outside of Milky Way!**
- **Now known distance: 2.54 million ly (778 kp)**
- **His first big discovery (more to come) ...**

Hubble using new 100” Hooker telescope at Mt. Wilson (above LA)

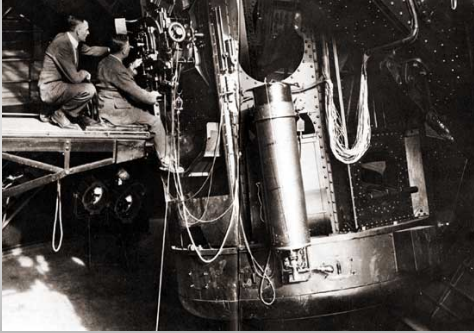


100” Hooker telescope at Mt Wilson



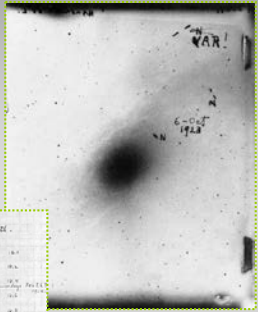
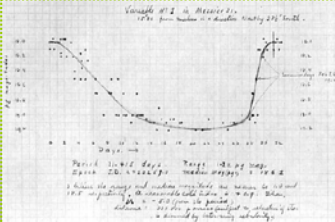
Begins new era in 1924 !

Andromeda found to be far outside Milky Way – another “island universe” : galaxy!

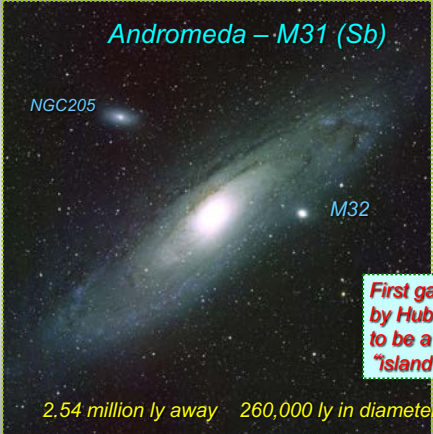


Hubble (and Jeans) at new 100” Hooker telescope on Mt. Wilson

Edwin Hubble in 1924 identified Cepheids in Andromeda (M31) → showed they were far outside of Milky Way!


Andromeda – M31 (Sb)



First galaxy shown by Hubble (1924) to be a distinct “island universe”

2.54 million ly away 260,000 ly in diameter

LATEST IR IMAGING



M31 from WISE + M32 (below) + M110 (NGC 205)

Clicker Question

Two Cepheid stars, Fred and Barney, have the same apparent brightness. Fred has a period of 10 days, and Barney of 100 days. Which is closer?

- A. Fred
- B. Barney
- C. They are both the same distance
- D. Not enough information to tell

