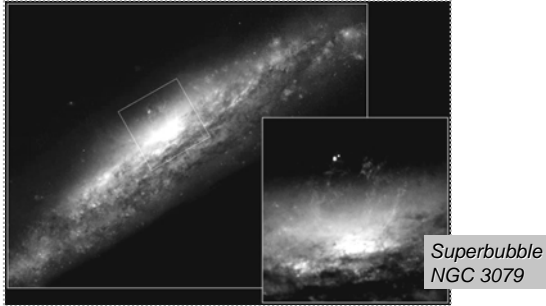


ASTR 1040 Accel Astro: Stars & Galaxies



Prof. Juri Toomre TA: Nick Featherstone
Lecture 21 Tues 3 Apr 07
zeus.colorado.edu/astr1040-toomre

Today in Milky Way

- Look at why *spiral patterns are made in the disk* of galaxies, including our own
- Examine the *Star-Gas-Star Cycles* working in our galaxy disk, and its ingredients
- Respond to discussion Q on such cycles by *Thur*
- *Interstellar Medium (ISM)* – gas and dust, plus *super-bubbles* blown by multiple supernovae
- *Recycling* on a grand scale, and building the heavier atoms
- Complete your reading of 19.4 *Mysterious Galactic Center*
- *Observatory Night 5 this Wed 8:30pm*

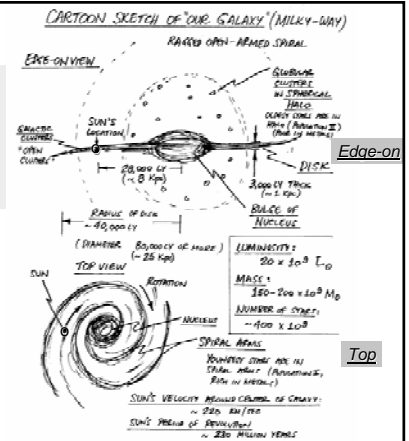
Clicker on deductions about Milky Way's stars

C.

- Why are stars in the halo poor in the common elements carbon, nitrogen and oxygen?
- A. Those elements have been used up in halo stars
- B. C, N and O are biological elements, and there is no life out there to make them
- C. The halo stars formed before these elements were made in abundance
- D. Making C, N and O requires massive stars, and these have been absent in the halo

Review: One-page story

Cartoon sketch of Milky Way

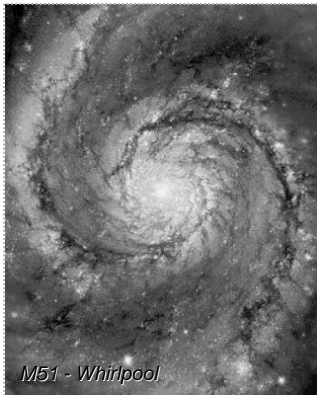


Why spiral arms?

"Density waves" – stars move in and out of denser regions

More like ripples in a pond than arms of a pinwheel

In dense regions, star formation is more intense, so "arms" are brighter

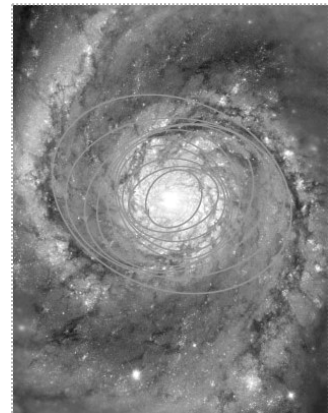


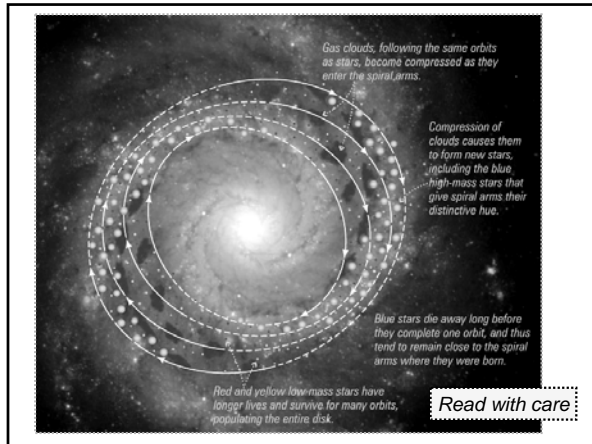
M51 - Whirlpool

Push and pull of gravity in disk

Gas/stars are pulled a little forward or backward toward the high density regions

Such clumping helps create a spiral pattern





"Density wave" story – how spiral structure is built

Gravitational instability of disks (gentle)

THEORY OF SPIRAL STRUCTURE ...
DENSITY - WAVE THEORY

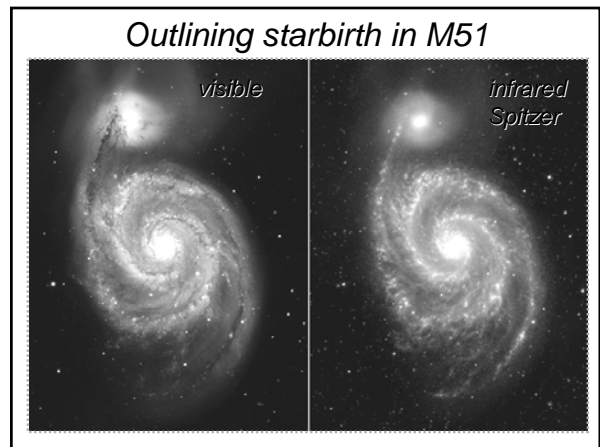
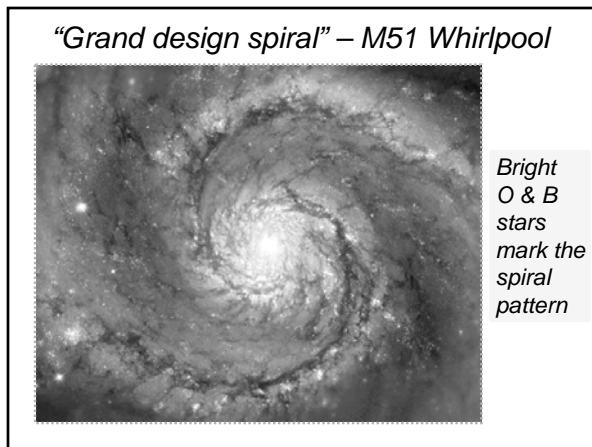
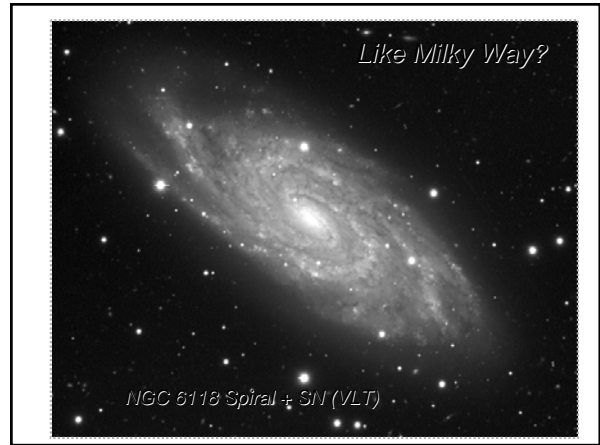
1. "SPIRAL ARMS ARE STELLAR TRAFFIC JAMS"
2. STARS SLOW DOWN (DUE TO GRAVITY), THEREFORE BUNCH UP
3. SLOWDOWN PATTERN HAS SPIRAL SHAPE, PERMEATES ITSELF (ROTATES LIKE A PINWHEEL)
4. EFFECT ON GAS IN DISK IS MOST PRONOUNCED, SINCE STRONG COMPRESSION AND SHOCKS → STAR FORMATION
5. SPIRAL TRACERS: YOUNG 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

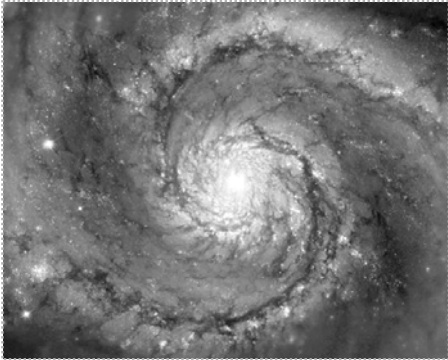
Star birth strongly enhanced by shock

DENSITY WAVES AND SPIRAL ARMS
FASTER MOVING GAS AND STARS OVERTAKE A DENSITY WAVE (COMPRESSION SHOCK WAVE)
STRONGLY ENHANCED STAR FORMATION AFTER SHOCK

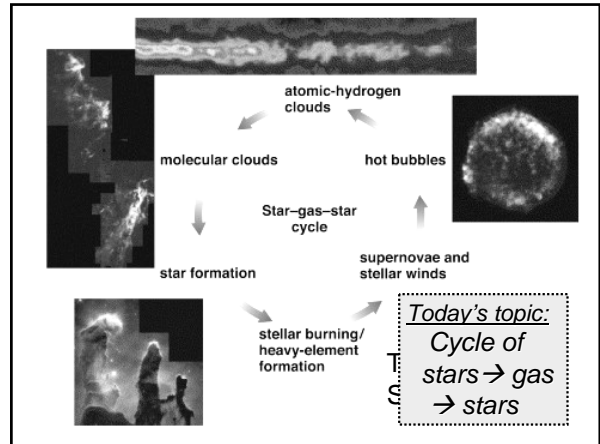
SPIRAL DENSITY WAVE IS A ROTATING (FIXED) PATTERN WITH STARS & GAS MOVING THROUGH IT



Crash/bang of star birth and recycling: rotating through the spiral arms in the disk



M51 Whirlpool Galaxy HST



REMINDER

INVENTORY OF MILKY WAY

Inventory of "stuff" making up our galaxy

+ "dark matter"

- STARS** FEW HUNDRED BILLION, $\approx 10^{11} M_{\odot}$

 - BULGE** MEDIUM TO OLD, "METAL POOR"
 - DISK** YOUNG, "METAL RICH" INCLUDES OPEN CLUSTERS, OR ASSOCIATIVE
 - HALO** OLDEST, METAL POOR INCLUDES GLOBULAR CLUSTERS
- GAS** 10% MASS OF STARS

MOSTLY IN DISK INTERSTELLAR MEDIUM

 - VERY COLD GAS IN THIN SHEET SITE OF STAR FORMATION (MOLECULAR CLOUDS)
 - WARM ATOMIC AND IONIZED H CLOUDS EMISSION NEBULAE (BRIGHT NEBULAE)
 - HOT GAS HEATED BY STELLAR WINDS, SUPERNOVAE

HALO VERY HOT GAS BLOWING OUT OF GALAXY
- DUST** 1% MASS OF GAS, 0.1% MASS OF STARS MOSTLY IN CLOUDS IN DISK

Stars

Gas

Dust

COMPONENTS OF INTERSTELLAR MEDIUM

Ingredients of Interstellar Medium (ISM) (stuff between the stars)

- GIANT MOLECULAR CLOUDS** $\sim 10^5 M_{\odot}$

 - SITES OF INTENSE STAR FORMATION
 - NEARLY 50 MOLECULES DETECTED BY EMISSION LINES OBSERVED IN RADIO
 - COMBINATIONS OF H, C, N, O FORM MOLECULES (AS MANY AS 11 ATOMS!)
 - \rightarrow AMMONIA, WATER, FORMALDEHYDE, METHYL & ETHYL ALCOHOL, CYANIDE, CARBON MONOXIDE (CO) ...
 - CO IMPORTANT FOR DOPPLER ANALYSIS OF CLOUDS WITH RADIO OBSERVATIONS
- DIFFUSE CLOUDS OF GAS** (AND SOME DUST)

HI REGIONS: CLOUDS OF COOL, NEUTRAL HYDROGEN ATOMS (REFLECTING NEBULAE) 21 cm RADIO EMISSION

HII REGIONS (EMISSION NEBULAE): GLOWING, IONIZED HYDROGEN SURROUNDING YOUNG HOT STARS (O & B STARS)

Very cold gas: star birth

Cool gas: neutral H

Hot H

INTERSTELLAR MEDIUM ...

More stuff in ISM inventory

- HOT INTERCLOUD GAS** $> 10^6$ K

 - HEATED BY SUPERNOVAE, STELLAR WINDS
 - FILLS HALO, GALACTIC WIND?
 - HIGHLY IONIZED GAS, NO DUST EMITS X-RAYS, YIELDS IN EMISSION... LIKE OXIDIZED (OXIDIZED FORM OF S ELEMENTS!)
- COSMIC RAYS** VERY ENERGETIC ATOMIC NUCLEI (PARTICLES)
- INTERSTELLAR DUST** NOT MUCH BY MASS, BUT... REDDENS STARLIGHT, ABSORBS SOME OF IT, POLARIZES THE LIGHT

Really hot gas

Dust

Now let us look at them in turn

States of gas in ISM

State of Gas	Primary Constituent	Approximate Temperature	Approximate Density (atoms per cm^3)
Hot bubbles	Ionized hydrogen	1,000,000 K	0.01
Warm atomic gas	Atomic hydrogen	10,000 K	1
Cool atomic clouds	Atomic hydrogen	100 K	100
Molecular clouds	Molecular hydrogen	30 K	300
Molecular cloud cores	Molecular hydrogen	60 K	10,000

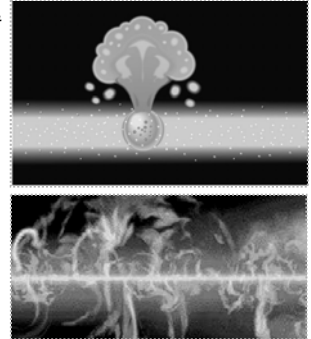
ISM Contents: some stuff is HOT

- Bubbles of hot gas blown out by SUPERNOVAE
- $T = \text{million degree K}$
- Mixing with rest of galactic gas → enrichment with heavy elements



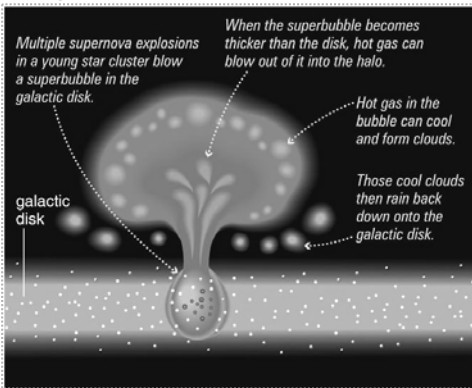
Super-bubbles & Fountains

- Supernovae can burst hot gas even out of the galaxy!
- “Enriches” gas between galaxies
- Some will rain back down and mix into galaxy

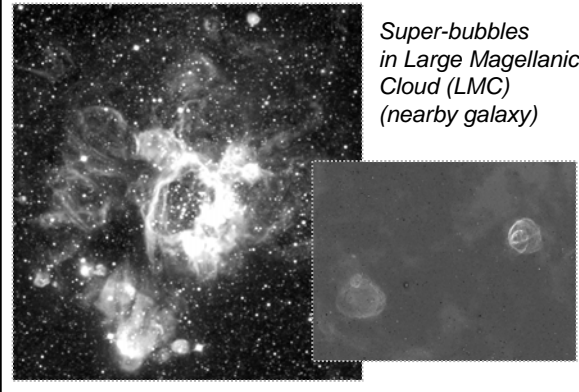


Artists' conceptions!

Super-bubble breakout from disk

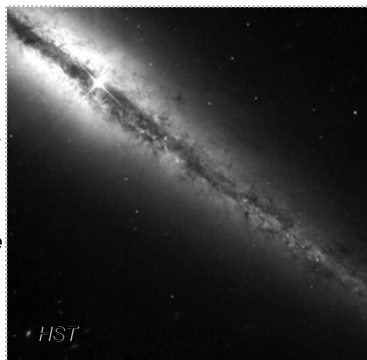


Super-bubbles in Large Magellanic Cloud (LMC) (nearby galaxy)

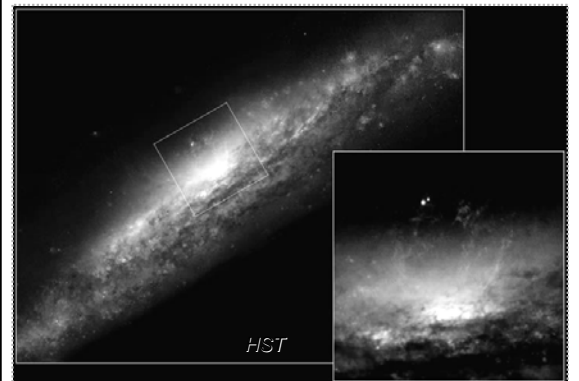


Edge-on view of spiral galaxy NGC 4013

- Dust/gas in disk obscures light
- Plumes and fuzz sticking out are “fountains” & “superbubbles” from supernovae

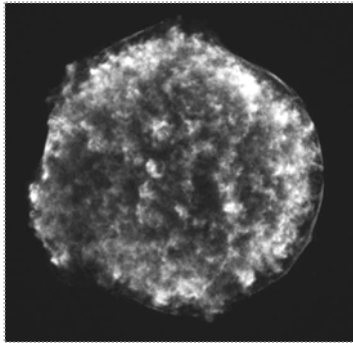


Super-bubbles in spiral galaxy NGC 3079



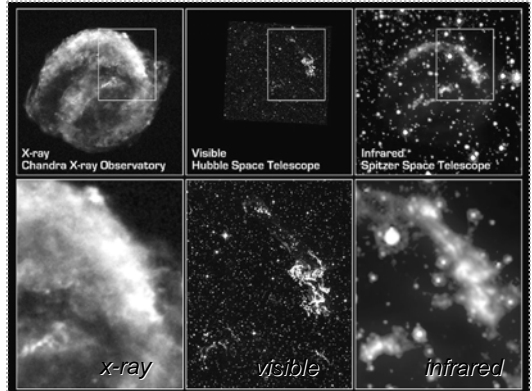
Fast electrons & magnetic fields

- Synchrotron emission from SNR
- X-ray and radio
- Traces very hot gas bubbles (SNR)

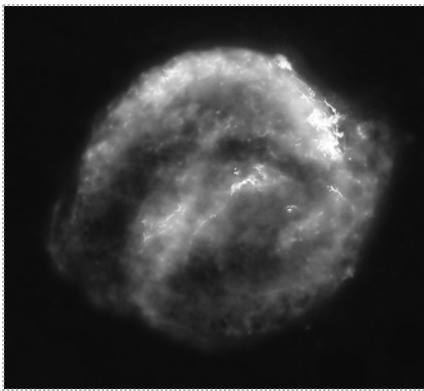


Chandra X-ray image of Tycho Brahe 1572 supernova remnant

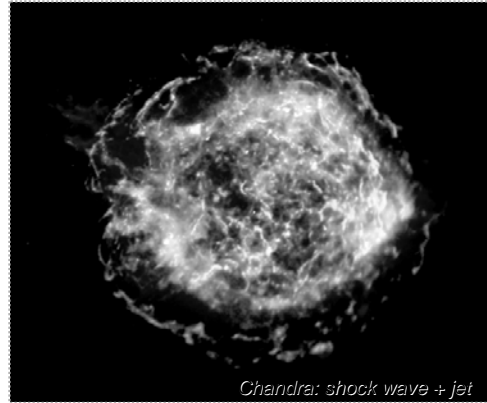
Kepler's SNR (1604) latest SN in MW



Kepler SNR (1604) Chandra X-ray

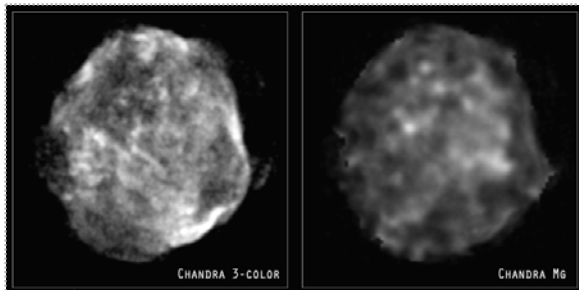


Really HOT: Cass A Supernova Remnant



Chandra: shock wave + jet

Supernova Remnant N49B in LMC

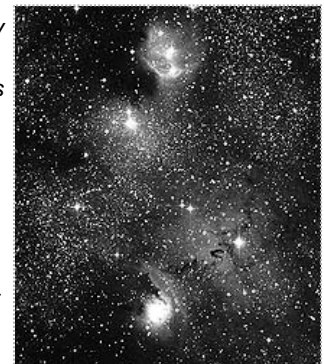


Chandra x-ray images reveal ~one solar mass of magnesium blasted into space by SN

Some stuff is WARM

- Gas & dust heated by stars
- GAS -- emission lines from hydrogen and other elements (ionization nebulae)

T~ 10,000 K near hot young stars
 T~ 100 K between star forming regions



ISM – hot gas:
Emission nebula (H II region)

UV radiation from hot O or B star ionizes a big cavity

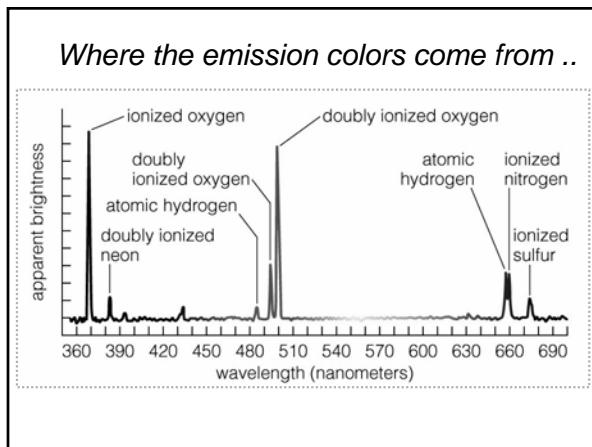
THE GLOWING H II REGION
"EMISSION NEBULA"

AT CENTER : SINGLE HOT STAR, OR SEVERAL YOUNG STARS ... O & B ASSOCIATION

Emission nebulae
"O & B star associations"

- Emission lines from hydrogen and other ionized elements
- T ~ 10,000 K near hot young stars

Lagoon



O & B star associations

O & B ASSOCIATIONS CAN BLOW "BIG BUBBLES"

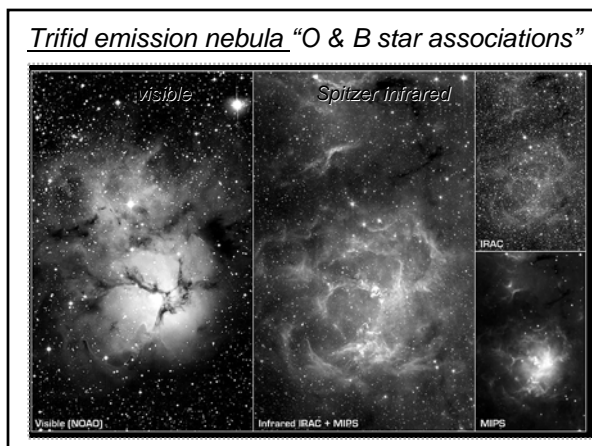
INTENSE UV RADIATION AND WINDS FROM CLUSTER OF YOUNG O & B STARS

⇒ YIELDS SHOCK WAVE WHICH EXPANDS INTO SURROUNDING GIANT MOLECULAR CLOUD "MUNCHES IN!"

many cluster stars join to blow "big bubbles"

Old cluster, Young cluster, Expanding H II region, Compact H II region and infrared sources, Shock wave, Giant molecular cloud

SHOCK TRIGGERS NEW STAR FORMATION DEEPER IN CLOUD ... AND CLUSTER EXPANDS WITH AGE



INTERSTELLAR DUST
... MINOR COMPONENT, BUT BIG EFFECTS!

ISM:
A little DUST goes a long way!

1. REDDENING OF LIGHT "INTERSTELLAR REDDENING"
DEPENDENT ON SCATTERING OF BLUE PHOTONS BY DUST PARTICLES OR GRAIN

"Reddens" the light

2. GENERAL EXTINCTION OR DIMMING OF LIGHT
SOME AREN'T APPROX. CAPABLE TO TRANSMIT

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 OF ONE ORIENTATION

DUST GRAIN, CORE: IRON, SILICON, CARBON, MANTLE OF ICES: CO, H₂O, CH₄, NH₃?, SURFACE: SITE OF FORMATION OF MOLECULES! TEMP ~ 20-40 K, SIZE: ~ MICRON IN SIZE (~10⁻⁶ m), SEE PENETR. THROUGH DUST IN RED LIGHT, IR, RADIO (LONG WAVELENGTH)