RAE 1968 – discovered AKR → v. little on gal. bgnd.

Ground based – low resolution, wait for solar minimum

Science – old electron, interplanetary shocks, ne in ISM, scattering/refraction
individual sources, clusters of galaxies

0.5-10 MHz range → 60′ → 0.′4 HPBW (+) high res at 30 MHz. Magnetospheric physics

NASA Explorer class mission ~100 M$.

M Kaiser. RAE bgnd maps hard to interpret ∴ no good comparison
Don't even know whether they make sense!
But solar results v. useful. also Jupiter bursts.
RAE-2 220-min lunar occs. of Jupiter noise
Occultations of the Earth → ground breakthrough on night side.
20-40-50 dB above background.
→ also magnetospheric emission → AKR auroral kilometric radiation.
midnight zone.

narrow band Rx → tuners. Broadband saturated even far out of band
(750 kHz → 2.5 MHz) better for getting away from AKR and breakthrough
Frequencies of narrow band channels determined by resonances
in the antenna. also tried for protected bands.

K. Weiler 1-26 MHz. Independent satellite interferometer.
All sky imaging. Massive transforms needed.
Geophysics of geopotential from baseline determination.
8-satellite array.
→ galactic relativistic electron spectra ? not thermal obs.
→ astrophysical paleontology. Tred → 1/Ho.
SNR's. and SNR/HII region connections.

LFSA Science

Map nonthermal bgd. α, diffuse free free abs.
Measure local synchrotron emissivity.
ISM scattering refraction/diffraction scintillation
extragalactic sources. mapping, thermal media
pulsars (msec have steep spectra).
down to what freqs? "Energy Crisis"
Solar System
Geopotential

Solar powered navigation or tracking. Circular orbit needed for formation flying.

orbit radius > 20,000 km
baseline determination to ~1m or better.
antennas: 3 mutually orthogonal dipoles
Freqs 1.5, 4.4, 13.4 and 25.6 MHz. (15′ … 10″ FWHM)
Tunability ~10% around center frequency.
Sys. temperature dom by bgd rad^n & interference.
expanding u,v coverage by orbital precession
(+ some active adjustment).
Integrate over ~1 yr → dense coverage expanding to slowly expanding diffuse coverage.

Need huge DFT
Calibration sources (Io bursts? - know where they are)
A ϕ closure.
Interference rejection techniques

Bring down all the IF's and record on a VLBI recorder.

J.O.B.

Lunar Observatory

NASA directed to study return to Moon, look at science.

LFRA obs. part of this discussion. (21st cent first decade).

Lunar geoscience orbiter in consideration as a preliminary.

→ need to image Moon at hires to choose moon base locations.

→ mid-1990's. Put some LFRA aboard?

2 redundant pairs of spacecraft. initial elliptical orbit 100 → 1000 km orbit.

mother + gravity sats. → gravity subsatellite

Final mother craft orbit in 100 km orbit. Lifetime several yrs. (limited by mascons)

Put dipoles ~20 m long and "Radio Shack" technology 30 kHz → 30 MHz

Options. ① RAE revisited. Improved dyn. range & calibration. (narrow band)

② Single baseline interferometry between 2 spacecraft.

IFFY! ③ 4 satellites if also used gravity subsatellites

→ – or if more spacecraft added (e.g. by Soviets?)

Goals | Characterize interference environment.

Lunar occultations of strong sources → several arcs across them. size determinations.

Single dipole | Fresnel pattern ~ 3 arcmin at 30 MHz.

→ all sky map.

LF turnover freqs for strong sources.

2-dipole Some angular size info. on strong sources.

1-2" limit for scattering @ 30 MHz.

"Instabilities & radiative processes in low density plasmas"

Data rates — 1 kb/s for single dipole, 1 Mb/s for interferometer ← High!

Hale Sun?

Major 10^9 \$
Moderate 10^8 \$
Modest 10^7 \$
Minute 10^6 \$

Must come up with compelling reasons for moderate mission.
Have only a small community interested.
But modest/minute can and should be done.

Where to do it? Earth, Earth orbit, Moon orbit, Moon.

Moon base

i) it will happen
ii) ultrahigh vacuum, solid surface.
- ionosphere may be will inhibit VLF & grow with time.
- lo gravity, no wind
iii) common bearing system.

Make each mission to moon take a few kg of astronomy.
VLF dipoles would be especially simple "site testers".
- must explore lunar ionosphere & RF environment.

Q - will the farside advantages be realisable on time scale of anyone alive in this room, or do we concentrate on smaller, nearer projects (& can smaller nearer ones do something useful?)

T. Kuiper — Lunar low frequency imaging array. (response to Basart proposal).
19-station T array 36 km arms.
6 km apart.
zero-mass electronics like Sony digital radio!
Mass is all in power supplies. Can use only Earth daytime.
i.e lunar nighttime.
22kHz BW tunable → 18' @ 1MHz, 2' @ 10MHz.
Sensitivity limited by galactic background, not electronics!
Deployable by a lunar rover with 20 small boxes.
Real-time study of freq agility → can you beat the RFI dynamically?

J. Basart — Lunar far side array.

D. Jones — LFSA — high Earth orbit must be paid for.

T. Gergely — WARC 1992 Spain 1st Quarter
Agenda to be established June 1990.
3-30MHz Most congested region of entire spectrum
Doubling time for assignments ~ 10 yrs.
Over-horizon radars.

Radio astronomy has 13.36 – 13.41 MHz / 25.55 – 25.67 MHz } are the bands used? are there plans?
Unless strong arguments for keeping, these will be lost!

Far-side allocation — likely nothing will be done.

E. Dulk

<u>Sun</u> Several degrees in size at 30MHz!
Bigger and <u>less bright</u> (T_b) below 100MHz.

Bursts from behind the Sun – 96% seen on both sides!
Scattering by inhomog in solar wind.
n_e in ISM very inhomogeneous & filamentary. Many complex scattering geometries!
→ look at solar wind acceleration region not yet properly studied.

Gopalswamy LF Solar.

<u>M. Desch</u> Planets.

Spherics	(manmade & lightning) ~1MHz & up	Polarized, v. strong, continuous
Type III	20KHz	V. strong, continuous
AKR	20–750KHz	V. strong
Electron noise	dc → 2000KHz	moderate
Jupiter	20KHz → 40MHz	moderate, episodic
Saturn, etc		moderate to weak.

Strong sources can wipe out observations of sidereal sources.

800KHz → 3 or 4MHz	~ 50% duty cycle	based on RAE-1
4 – 10 MHz	~	
>10 MHz	<u>almost unimportable.</u>	

(RAE) Detected <u>Jupiter</u> based on summaries of <u>minimum</u> levels at clear times.
↑

AKR/TKR Can be seen on lunar farside, ∴ on nightside of Earth far out. Depends on solar wind emission props.

Brian Dennison

Calculated phase corruption due to Earth magnetosphere @ 1.5MHz

Refractions of 25° max. $R = 1.5 R_E$, $l_{mag} = 20°$

At $2 R_E$, effects ~ 3x less.

$2.5 R_E$ down to ~ 1°.

→ interferometric phase shifts $\Delta\phi \sim 3$ radians per km of baseline at $R = 1.5 R_E$

Two modes differ by ~ 1 rad/km of baseline.

Conclude: serious propagation problems in near-Earth orbit
$\Delta\phi$ and birefringence.
Bandwidth smearing.
Must be above at least $2.5 R_E$ at 1.5 MHz!

and then you have to worry about the radiation coming in from the plasmasphere behind you. (focussing).

T. Carr Jupiter @ 18MHz Fringe phase over 6980km ~ 90° in 5 min – probably solar. Venezuela → Chile

Ron Reynolds Composition & structure of ISM via free free abs. @ 1-2MHz

$$\tau_{ff} = 0.53\, \nu_{MHz}^{-2}\, T_4^{-1.5}\, g(\nu,T) \int n_e^2\, ds$$

HII confined to ±100pc EM 10^2–10^4 cm^{-6} pc $\tau_{ff} > 1$ for $\nu \sim 10$–30MHz

intercloud medium ±1kpc EM ~ 5 cm^{-6} pc b=0 per kpc

~2 b=90°

Power required to ionize the thick disk ~10% of SNR output.
90% of material in this medium?

H recomb emission from diffuse component → emission measure
$\tau_{ff} \approx 1.5\ \nu_{MHz}^{-2}\ T_4^{-0.5}\ I_{H\alpha}$ (rayleighs)
Info about T from line widths & detection of forbidden lines

Observe Hα, SII with Fabry Perot @ Wisconsin
0°.8 beam. Filling factor ~0.2 $n_e \sim 0.2\,cm^{-3}$ — ff may be b-dependent.
Compare with a low freq background survey, could →
synchrotron emission distrib^n in depth (again!)

Namir — T_B, T_I, ? from abs^n holes.
Want several low frequencies to disentangle dependencies.

RogerC. SNR's Young shells (nonradiative shocks) α~0.6–0.7
Old radiative shocks 0.3–0.4
Plerions 0.1, 0.3
Cas A → spectrum flattening with time.
→ "flare" at 38 MHz Other peculiarities at LF?
Would be useful to get broad freq spectrum & variable coverage

→ Look for absorption due to radiative shock fronts?
"local" abs^n and abs^n in ISM.

Harry P. n~1000 lines blend into continuum (~6 MHz)
Need wide ν range to interpret.
14.7 MHz, n=768! seen in Cas A.
Observed lines at low freq are C atoms.
} not clear whether the molecular gas or the HI

Steve S. Measure scattering sizes as probe of ISM
What could you do above ionosphere at <100 MHz?

$$P_{\delta n}(\kappa) = C_n^2 \kappa^{-\alpha} \qquad \kappa_1 < \kappa < \kappa_2 \qquad (<10^9\,cm \text{ to } >10^{14}\,cm)$$

$$\theta_{FWHM} = 2.24\,(C_n^2\, z_{pc})^{0.6}$$

↑ Scattering measure

$$= \frac{8.0 \times 10^7\, \sigma_n^{1.2}\, z_{pc}^{0.6}}{L_0^{0.4}}$$

(for Kolmogorov spect $\alpha = 11/3$)

L_0 ↖ outer scale of turbulence

Couple of orders of magn. in C_n^2 relative to GHz VLBI.

1) Can we see out of Solar System? IP Scatt?
2) Prospects of diffuse ISM turbulence – can we measure the inner scale?
3) Turbulence near shocks in ISM

* Armstrong model of IPM → resolution limit is imposed by IPM, not by diffraction at 10 MHz.

4) Remote sensing of solar system plasma (comets, interplan shocks)

Y. Gupta Refractive Interstellar Scint.
74 MHz 10 pulsers. time scales of fluct 30–300 days.
At lower freqs, expect reduced refract fluct on longer τ.
(years of yrs at 3 MHz)

J. Cordes   LF Scattering in ISM and pulsar obs.

Observables 1) angular size of scattering disk
2) temporal broadening by multipath prop.
3) intensity scintillations
4) dispersion variations (1 part in 10^5 over ~1 yr)

C_n^2 varies by at least 10^4 across Galaxy.

Typical l.o.s. depr.
- Diffraction
- Int. Scint $\Delta\nu_d \sim \lambda^{-4.4}$ (Predicted bandwidths quench scint)
- $\Delta t \sim \lambda^{-1.2}$
- Temp broadening $\tau \sim \lambda^{4.4}$ (Smear out periodicity of pulsars!)
- $\angle^r$ broadening $\theta_d \sim \lambda^{2.2}$

Will see time of arrival variations and angular broadening

20" scattering out of plane @ 10 MHz   1° at 1 MHz
30° *in* the plane @ 10 MHz

N.B. predicted that observable LWA effects @ 10 MHz.

Tony Phillips (Arecibo).

Are *some* long-period steep-spectrum pulsars.
Look for these at low freqs?
Low freq @ Arecibo → *no* change in the pulses / *no* superdispersion } Soviet data incorrect again!

Lack of superdispersion etc → limits on range of heights in pulsar magnetosphere from which rad. comes → 25 MHz → 5 GHz all comes from within 2000 km of each other.

John B. — Want detail to compare with cm AA.
Hot spots SSA
Spectral gradients } 1" @ 30MHz

At 3MHz, "new" sources (positions will be terrible, etc)

Why aren't there more "dead" sources detected?
Either die very suddenly or very slowly (not at all?)

$$U_{\tau=1} \text{ for } \gamma=2.2 \quad \propto \quad (1+k)^{0.0645}\, \phi^{-0.387} \left(\frac{S\nu_0^{\alpha}}{\sigma}\right)^{0.387} \ell^{-0.645}$$

↑ l.o.s. length

very insensitive to e:p ratio and l.o.s. depth.

3C295 turns over at the appropriate ν for a filling factor of 1.
So can use turnover freq. as a test of filling factor.
Predict turnovers in the range 25 – 1 MHz for most sources.

150km ionospheric scale travelling at 150m/s.
φ slopes 10°/km at 38 MHz under best winter night conditions
Isoplanatic patch is > 1° at 10 MHz under these conditions

N. Rees — 38MHz new survey δ > 60° 5-6,000 sources.
58 20-m Yagi's
Need a large collecting area to calibrate surveys.
How will a space array do this?

W. Webber — Galactic CR population
Pioneer-10 & Voyager 1-2 $\quad \epsilon_{CR} \gtrsim 1.5\ eV/cm^{-3} \equiv \frac{B^2}{8\pi} \approx 8\mu G$
maybe → 2
(Higher than usual assumptions)
Does field control CR or vice-versa?
Electrons in CR are only a few % of total energy.
Normalisation to the radio spectrum calls for $B \sim 6$ to $8\mu G$
Emissivities → lower fields 3-5μG.

> Low freq radio & γ-ray will survey e⁻ & nuclei @ ~150 MeV.

Malcolm — Radio emissivity ① Estimate disk thickness
② HII region absorption method
Agrees need B ~ 6 μgauss to fit unmodulated spectrum and radio spectrum. May be high-field weighted.
Key problem — find variation of radio emissivity through galaxy to check weighting factors in different directions. Need opaque clouds that fill beam!

10-100 MeV
low energy γ-ray relativistic bremsstrahlung → the low energy electron spectrum also. HIS.
$N(\gamma) \propto E_\gamma^{-a}$ for $N(E) \propto E^{-a}$

> → with ground-based & CR from hi-E γ
> → look for evidence on lifetimes of electrons & loss mech.

D. Harris — Cyg A vs 0151o327 low rel to hi-ν spec.
→ electron spectrum bending, or SSA (Cauro?) or free free?

How far down do spectra stay steep?
Any sign of low energy deficits?

P. Kronberg — Coma - A1367 bridge. $B_{eq} = 0.3 \mu G$
— search for large-scale diffusive escape?

T. Jones — "Ino Around Lobes"
Perhaps if any coherent mechanisms, would show at low ν.
Emission line gas around lobes?
Where are the relics? C⁻¹ losses snuff highest freqs.

V. Lind — Jet Simulations.
Low freqs not effected by synch. losses.