12– to 15–arc min regional best fit parameters for this component. We derive a total mass of 8.35×10^{12} $M_\odot$ ($M_\odot$ = solar mass) and a cooling time of 1.27×10^9 years (the Hubble constant $H_0 = 50$ km s^{-1} Mpc^{-1}). The mass condensation rate to form cold matter, a quantity that does not depend on gas clumpiness, is then $\sim 6.6 \times 10^3$ $M_\odot$ per year, or $\sim 10^{14}$ $M_\odot$ over the age of Coma, which is phenomenal for a cluster with no signature of cooling flow. The above numbers are conservative estimates, because most of the gas is inside the annulus of 12 to 15 arc min and cools faster by virtue of its higher density. Apart from the question of the origin and destiny of the submegakelvin gas, the numbers obtained indicate that the gas may have important implications for the mass determinations in clusters. The parameters in Table 3 indicate that the two ratios of soft to hard emission measures do not scale with radial distance, which suggests the presence of cooler gases in the entire ICM of Coma. If true, the total mass budget would be significant.

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Extreme-Ultraviolet Flux from the Virgo Cluster: Further Evidence for a 500,000-Kelvin Component

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A surprising discovery in x-ray astronomy was that clusters of galaxies often contain vast quantities of hot (20 million kelvin) diffuse gas. Substantial diffuse extreme-ultraviolet (EUV) emission has recently been detected in the Virgo cluster of galaxies. Depending on the character of the interstellar medium in our galaxy, this emission could be either an aspect of the hot cluster gas or a previously undetected 500,000-kelvin component. Analysis of the observational data in combination with our current knowledge of the interstellar medium revealed that the EUV flux cannot be an effect of the interstellar medium. Hence, a warm cluster component appears likely.

Lieu *et al.* (*1*) studied Extreme Ultraviolet Explorer (EUVE) and Roentgen Satellite (ROSAT) data from the Virgo cluster of galaxies. Substantial EUV emission was found over a region 40 arc min in diameter centered on the giant galaxy M-87 in the center of the cluster. The ROSAT data showed a small (~20%), soft x-ray excess above that expected from the well-established high-temperature intracluster medium (ICM) (*2*). The reality of this soft x-ray excess could easily be questioned because the cutoff and the stability of the low-energy response of the ROSAT detectors are known to vary at least at the 10% level (*3*). However, for the Virgo ICM the EUV excess above that expected from the high-temperature gas is quite large (>70%) and the EUVE data seem robust. The EUVE telescopes have been recalibrated in flight every 2 months; the results of these recalibrations show the instruments to be stable to within the statistical uncertainty of the flux from the calibration sources and are better than 5% (*4*).

Lieu *et al.* (*1*) found that they could only fit the EUVE and ROSAT data from the ICM with a two-component gas, one component being the 20 million K x-ray–emitting gas and the other a warm component at 500,000 K. Although this interpretation fits the data, it is difficult to understand from a theoretical viewpoint because gas at 500,000 K is near the peak of the radiative cooling curve and will rapidly evolve to lower temperatures. This gas cannot be maintained by material cooling from the higher temperature gas; the cooling mass falls short of the required amount by more than a factor of 30. Dixon *et al.* (*5*) obtained a lower limit of 750,000 K for the temperature of this warm component from the nondetection from the Virgo cluster of emission from O VI (oxygen with five ionized electrons). At the higher temperature indicated by this observation, the cooling mass required is somewhat less but is still far greater than that which could be supplied by the x-ray gas.

Fabian (*6*) has emphasized the crucial role of absorption by the interstellar medium (ISM) of our galaxy in this interpretation. If absorption is less than expected because of the particular ionization state of this material, the EUV emission might simply be the low-energy tail of the well-established, high-temperature, x-ray–emitting ICM. It is important to establish whether the intense

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EUV flux is not an intrinsic property of the Virgo cluster ICM but is instead due to the character of the galactic ISM.

The EUV data were obtained with the EUVE deep survey telescope (*7*) in a 30,000-s observation of the core of the Virgo cluster on 25 and 26 May 1995. The ROSAT data (*8*) were from a 10,000-s exposure taken 2 through 9 July 1992. We used only the pulse height data from 0.18 to 2.0 keV from this exposure. We corrected both data sets for instrumental and environmental effects using standard procedures (*1*). For the effective area of the telescope, we used an in-flight calibrated response curve (9), which has an improved short-wavelength response. We established the background for the EUV data by averaging the data in the region >25 arc min, where the counts reach a stable value. The position-sensitive proportional counter (PSPC) background was derived from a region >50 arc min from M-87; the x-ray data are a complex mixture of astronomical and instrumental effects, and we followed the prescription of Lieu *et al.* (*1*) to establish this background.

The galactic hydrogen column density, N_H, was obtained from high-angular-resolution 21-cm observations taken with the 43-m telescope of the National Radio Astronomy Observatory (NRAO). The spatial resolution of this telescope is 21 arc min at 21 cm; data were obtained from a grid that oversampled the sky by a factor of ~3. The distribution of N_H over the core of the Virgo cluster was found to be smooth with no evidence of cloud structures or porosity. A small gradient in the H column was found over the 1.3° by 2° field. The column density is $N_H \sim 1.8 \times 10^{20}$ to 2.1×10^{20} cm^{-2} $\pm$ 1.0×10^{19} cm^{-2}.

We investigated the possibility that the intervening galactic ISM could be clumped on scales smaller than the 21–arc min radio telescope beam used by Lieu *et al.* (*1*). A study of the galactic neutral H distribution in the direction of the Virgo cluster was carried out with the Effelsberg 100-m telescope with a resolution of 9 arc min. These data do not show any additional features compared with the map of Lieu *et al.* (*1, 10*). In addition, the 100-μm Infrared Astronomical Satellite (IRAS) data for this region exhibit the same smooth profile as the columns for the Virgo cluster (*1*) and show a small-scale variation less than a factor of 2 at the 5–arc min resolution of the IRAS survey. No reasonable distribution of cloudlets is substantially uniform on scales >5 arc min yet has a substantial number of nonoverlapping cloud regions with attendant low EUV absorption. Observational evidence against the existence of such small-scale porosity is provided by comparisons of NRAO N_H results having 21–arc min resolution with N_H values derived from Lyman-α observations of stars and from the x-ray spectra of quasistellar objects (*11–14*).

The background-subtracted EUVE and ROSAT data were simultaneously fitted with a plasma emission code (*15*), absorbed by a galactic ISM computed with the cross sections of H I, He I, He II, and heavier metals (*16*). Many ISM cross sections do not include absorption for He II and hence are not appropriate for this type of analysis. However, as a check, we generalized the Morrison-McCammon code (*17*) to include the cross section of singly ionized He and checked our results with this model. The results obtained were similar, as would be expected at these wavelengths.

We considered a range of ionization conditions for the galactic ISM. Hydrogen could be present as either H I or H II. Although H II does not contribute to the EUV or x-ray absorption, a larger value for the total amount of H (H I + H II) will correspondingly increase the total amount of He, which will increase the total absorption. Helium was assumed to be He I or He II. Reynolds (*18*) has shown from observations of the ionization state of Si and S that He will not be doubly ionized in the ISM. Heiles *et al.* (*19*) obtained upper limits to the He II 268 and 269 α lines at ~1.4 GHz, which rule out the possibility that any significant He III is present in the diffuse ISM. We fitted a single-temperature ~20 million K plasma model as a function of H and He ionization fractions, holding the H fixed at 1.8×10^{18} cm^{-2}. Our results are shown in Fig. 1. The single-temperature fit is unacceptable unless He is highly ionized and H is nearly all neutral.

What is the ionization state for the galactic ISM? Vennes *et al.* (*20*) have used EUVE spectroscopy in the nearby ISM to show that He is singly ionized at 25% and H II is <27% in the direction of the hot white dwarf GD246 at a distance of 65 pc. Dupuis *et al.* (*21*) found H I <50% ionized in the direction of two hot white dwarfs at a distance of ~70 pc, also using EUVE spectroscopy. On a global galactic scale, Reynolds and Tufte (*22*) found that for regions with H II > 0.7, $\chi_{He}/\chi_H \lesssim 0.27$ from the ratio of the intensities of the diffuse optical He I 5876 and Hα lines, and Heiles *et al.* (*19*) found stringent upper limits on the H and He ionization from a comparison of the radio recombination lines of H and He at ~1.4 GHz. The ionization fractions used by these groups are defined differently; where necessary, we have converted ionization fractions to the single definition: ions per total. These limits are shown in Fig. 1.

The EUV excess from the Virgo ICM could be explained by emission from the hot x-ray–emitting ICM in combination with specific values for the ionization state of H and He in the ISM of our galaxy. However, the ionization required is grossly at variance with a variety of data on the actual values for this ionization locally and globally. A warm cluster component of the ICM in the Virgo cluster of galaxies appears to be indicated.

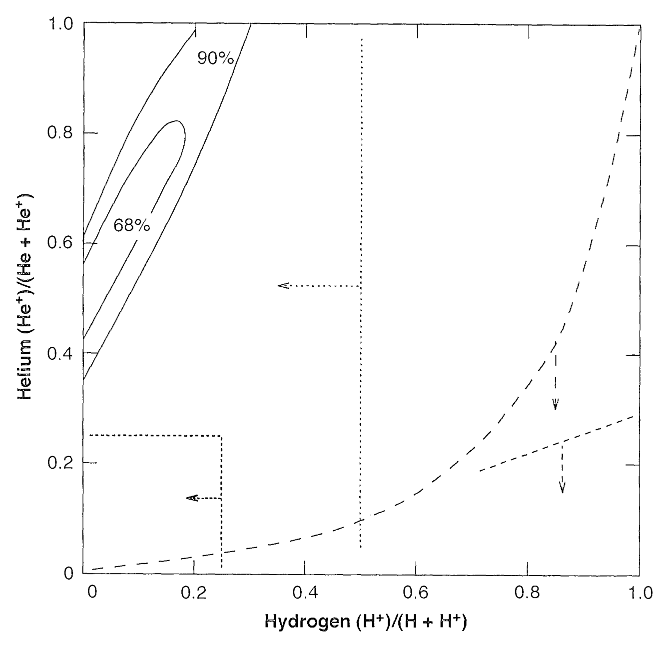

Fig. 1. Contours of constant χ^2 confidence for single-temperature emission models as a function of H and He ionization in the foreground (solid curves). We also show measurements and upper limits for the ionization state of the galactic ISM. Local (~70 pc): light dotted line, Dupuis *et al.* (*21*); heavy dotted line, Vennes *et al.* (*20*); global: long-dashed curve, Heiles *et al.* (*19*); short-dashed line, Reynolds and Tufte (*22*).

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Stratospheric Mean Ages and Transport Rates from Observations of Carbon Dioxide and Nitrous Oxide

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Measurements of stratospheric carbon dioxide (CO_2) and nitrous oxide (N_2O) concentrations were analyzed to investigate stratospheric transport rates. Temporal variations in tropospheric CO_2 were observed to propagate into the stratosphere, showing that tropospheric air enters the lower tropical stratosphere continuously, ascends, and is transported rapidly (in less than 1 month) to both hemispheres. The mean age *A* of stratospheric air determined from CO_2 data is approximately 5 years in the mid-stratosphere. The mean age is mathematically equivalent to a conserved tracer analogous to exhaust from stratospheric aircraft. Comparison of values for *A* from models and observations indicates that current model simulations likely underestimate pollutant concentrations from proposed stratospheric aircraft by 25 to 100 percent.

The chemistry of the stratosphere may be strongly perturbed by pollutants as a result of the long residence times (*1–10*) for gases and aerosols in the stratosphere. Rates of transport of pollutants into, within, and out of the stratosphere are thus important parameters that regulate stratospheric composition. The basic characteristics of stratospheric circulation are known from observations of trace gases such as water vapor and ozone (O_3) (*1*) and of particulates from nuclear tests (*10*) and volcanic eruptions (*11*). Air enters the stratosphere at the tropical tropopause, rises at tropical latitudes, and descends at middle and high latitudes to return to the troposphere (*1*, *12*). However, the rates for transport on global scales are poorly known, and quantitative information is critically needed to predict the response of stratospheric O_3 to climatic or chemical change (*13*) or to exhaust deposited in the stratosphere by proposed high-speed civil transports (HSCTs) (*14*).

We present here in situ observations of stratospheric CO_2 and N_2O concentrations that elucidate key aspects of stratospheric transport. Seasonal and annual variations in tropospheric CO_2 are shown to propagate into the stratosphere where CO_2 behaves as a conserved tracer (*15*); N_2O is nearly invariant in the troposphere and is removed by photolysis in the upper stratosphere. These tracers together provide an ideal probe of transport on time scales of importance in the stratospheric circulation.

Tropospheric CO_2 concentrations oscillate seasonally, reflecting hemispheric cycles of photosynthesis and respiration; seasonal amplitudes near the surface are 1 part per million (ppm) in the south and 3 to 15 ppm (increasing poleward) in the north, with the two hemispheres 6 months out of phase (*16*). In addition, CO_2 increases annually on average by 1.4 ppm year^{-1} as a result of fossil fuel combustion (*17*). The 5 years of near global scale observations of CO_2 reported here reveal that air enters the stratosphere in all seasons and that seasonal cycles of CO_2 in the stratosphere have identical phase in the Northern Hemisphere and Southern Hemisphere. Analysis of the measurements establishes a lower limit for the rate of quasi-horizontal transport from the tropics to mid-latitudes of both hemispheres and defines mean upwelling velocities in the tropics and the mean age of stratospheric air in mid-latitudes. The results also provide critical diagnostics for models of stratospheric transport.

We obtained simultaneous measurements of CO_2, N_2O, and other species at altitudes between 9 and 21.5 km from November 1992 to February 1996, using NASA's ER-2 aircraft. The longest interval between observations was 5 months, with near monthly time resolution between February and November 1994. Sampling included tropical, middle, and high latitudes from 70°S to 61°N (*18*).

Seasonal and annual changes in tropospheric CO_2 propagate across the tropical tropopause and slowly ascend, as shown by vertical profiles of CO_2 in the tropics (Fig. 1A). Maxima in CO_2 were observed at a potential temperature $\theta \approx 435$ K [corresponding to a pressure-altitude of 19 km (*19*)] in October 1994 and in November 1995. A minimum was observed at a similar altitude in February 1996. The observed extrema represent the annual maxima (or minimum) that entered the stratosphere 3 to 4 months earlier at the tropical tropopause at 390 K (~16 km). The 2-ppm increase from October 1994 to November 1995 reflects the trend in tropospheric CO_2 over that time interval. The amplitude of the seasonal variation at 435 K is about 80% of the variation for air entering the stratosphere (see below), a notably small attenuation indicating that vertical advection dominates both vertical diffusion and mixing of older air from mid-latitudes into the tropics (*20–22*).

Observations of CO_2 at northern and southern mid-latitudes show that seasonal variations in CO_2 are transported rapidly from the tropics poleward. However, the seasonality at mid-latitudes is not as well preserved with respect to altitude (or θ) (for

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