Chalonge - de Vega 20th Paris Cosmology Colloquium July 2016

Abbreviated notes by Peter L. Biermann[1,2,3,4],

[1] MPI for Radioastronomy, Bonn, Germany

[2] Dept. Physics., Karlsruher Institut für Technologie, Karlsruhe, Germany

[3] Dept. of Phys. & Astron., Univ. of Alabama, Tuscaloosa, AL, USA

[4] Dept. of Phys. & Astron., Univ. of Bonn, Germany

Anthony Lasenby (Cambridge, UK), CMB observations and some current questions in cosmology: many questions, one being on whether there is structure in the primordial power spectrum; ΛCDM has six parameters, Ω_b, Ω_{DM}, 100 $\theta_\star$, τ, n_s, and A_s; power spectrum written as power-law with amplitude A_s and $k^{(n_s-1)}$; hint of possible dip at $l = 25 - 30$; general depression at low l; use Bayesian approach; Handley et al. 1502.01856, 1506.00171; method called "polychord"; using one extra "chord", two, three,..., suggests a turndown at low k; may have physical interpretation and meaning; using sum of all possibilities confirms ΛCDM at large scales, same confirmation for ΛWDM at large scales; Hee et al. 1607.00270 on w parameter; looks as if $w(z)$ could be even more negative; reionization history in models 1605.03507; 1605.02985 reionization history from various data sets, measured in τ, the Thomson depth to reionization; 0.055 ± 0.009; limit is 0.048 astrophysical minimum; 1502.02024; history of star formation; not many star forming and ionizing galaxies beyond redshift 8; 1502.01597 clustering; discrepancy between MWBG and SZ clusters; bias in determining σ_8; 1507.05552 DE survey (DES) cosmology results; discrepancy between DES, CHFT lensing and Planck around $k \simeq 0.3$ $(Mpc/h)^{-1}$; amplitude of tensor (gravity wave) component is measured by r, ratio of tensor to scalar mode at some given scale; 1510.09217 Keck results; $->$ $r > 0.07$ at 95 %; using BI-

CEP2, Keck and Planck; 1607.04148 initial power spectrum may suggest early kinetic dominance, before inflation; argues about window in GWs from mHz to 1 Hz; could be observed by "Big Bang Observer", and perhaps by GAIA via induced proper motions; effect by individual proper motions 10^8 to 1, so very many stars required; ends on project QUIJOTE.

Christian Weinheimer (Münster), KATRIN and next generation Tritium beta-decay experiments for keV sterile neutrinos: emphasizes the "beyond standard model" aspects; recent review Drexlin et al. Adv HE Phys. 293986, 2013; KATRIN sensitivity 2 eV to 200 meV; adiabatic electron guiding and T_2 reduction factor of about 10^{14}; start data taking in 2017; MAC-E-Filter Picard et al. NIM 63, 345, 1992; problem: radon decays in air, so produces ^{210}Pb; sometimes neutral H atoms are emitted then, and they are not caught; they in turn get ionized by the Black Body radiation of the walls; ^{163}Ho decays by electron capture to ^{163}Dy with ejection of an electron via an excited state; ECHo; Asner et al. PRL 114, 162501, 2015; Steinbrink et al. NJP 113020, 2013; Mertens et al. JCAP 020, 2015; at reduced rate of Tritium in 2017 some search possible; thinks of pulsed acceleration of electrons to improve TOF statistics; Nuciotti 1511.00968; summary: keV neutrino search possible with KATRIN, first search will be done in 2017.

Work with **Hector de Vega** on WDM cosmology, presented by **Norma Sanchez** (Paris): ΛCDM does not agree with galaxies, it does agree with CMB + LSS; ΛWDM agrees with CMB + Large Scale Structure (LSS) + Small ScaleS tructure (SSS) (galaxies); DM distribution function freezes out at decoupling; WDM predicts correct structures for small scales when the quantum nature of WDM is taken into account; power cut at scales $< 73\ (\mathrm{keV}/M_{DM})^{1.45}$ kpc/h; $m_{DW} \simeq 2.85\,(m_{FD}/\mathrm{keV})^{4/3}$; $m_{SF} \simeq 2.55\,m_{FD}$;

$m_{\nu MSM} \simeq 1.9\, m_{FD}$; FD stands for Fermi-Dirac decoupling in thermal equilibrium; DW out of TE, SF out of TE, νMSM out of TE; Marinacci et al. MNRAS 427, 1750, 2014: baryonic detailed physics do not allow to make big cusps; inside galaxy cores below about 100 pc quantum nature becomes important; she says that the constant galaxy surface density of about 120 $M_{\odot}/pc^2$ is reproduced in WDM (paper with Paolo Salucci and Hector de Vega 2010); it is attributed to keV scale order of the DM mass. The quantum nature of WDM is naturally captured in the Tomas-Fermi approach reproducing the cored density profiles with their right observed sizes.; de Broglie wavelength is $\lambda_{dB} = \hbar/(mv)$; $d = (m/\rho)^{1/3}$; $Q = \rho/v^3$; uses chemical potential in integrals; Fermi temperature deduced 10^{-3} K to 20 K; colder −> ultra-compact; predicted minimal galaxy mass, the observed known one is galaxy Willman I with $3.9\, 10^4 M_{\odot}$; this implies $m_{DM} > 1.86$ keV, Hector de Vega & Norma Sanchez; r_h vs M_h follows precisely this prediction; diluted and classical regime chemical potential (scaled) $\lesssim -5$, in compact regime $\gtrsim -5$; Hector de Vega & Norma Sanchez 1401.0726, 1401.1214; question on whether the data on dwarf galaxies are too sparse to make a strong statement on baryonic feedback; Norma Sanchez replies that the data compilation from large galaxies of different types and masses show cored profiles and the universal rotation curve provides clear evidence on cores vs cusps; in any case dwarfs are the most DM dominated; in response to a question by Tony Lasenby she emphasizes that for the thermal equivalent particle mass the allowed range is 2 to 4 keV; the Lyman alpha limit is not so precise, because of the well known uncertainties both observationnal and baryonic astrophysical modelling in such processes she says.

Sinziana Păduroiu (Geneva), Numerical Simulations, structure formation and filaments in WDM: emphasizes that ΛCDM simulations never produce large pure-disk galaxies, and fail in various other ways; she emphasizes very strongly how much influence is with the initial velocity of the particles; arranges simulations according to particle mass, and velocities separately; shows simulations with zero initial velocities and with thermal velocities, but differences do appear at the scale of 1 Mpc; she notes that Gao & Theuns 2007 is the WDM simulations with extremely high resolution, the highest ever done; there stars are formed before halos are formed; in terms of the numerical mass used as minimum this simulation is a 1000 times better than the next best; shows several simulations in movies, most happens at fairly low redshift; shows many caustics; talks about collapsing of filaments, and the numerical problems, which give an apparent fragmentation; in conclusion emphasizes again that the initial velocity is crucial for DM; phase (space) density (PSD) is an important tool.

Dmytro Iakubovskyi (Niels Bohr Inst., Copenhagen), Summary of 3.5 keV line searches, and reionization: he starts by asking whether the evidence of DM is convincing, but it is just plausible that it is particles; he likes neutrinos; normal neutrinos violate phase density bound and make trouble for structure formation; normal neutrinos "too hot" for LSS and CMB; $m_{DM} \sim 7\,\mathrm{keV}(\theta^2/10^{-?})^{-1/5}$, $(\tau_{DM,dec}/\tau_H)^{\cdot\cdot}$; if decay lifetime were just like the Hubble time, at least 10^6 too much, so very much longer lifetime necessary; goes through the classical arguments about the visibility of the X-ray photon decay of a DM particle; he says M31 + Perseus give 3.52 ± 0.02 keV, 4.4 σ; he works with Esra Bulbul, 1508.05186; Franse et al. 1604.01759 detects line at 7 σ; Boyarsky et al. 1408.2503 3.539 ± 0.011 keV; Ruchayskij, D.I., et al. 1512.07217; Hofmann et al. 1604.... not seen; correct dependence on redshift, no effect depending on brightness; problem with lines of K XVIII at 3.47 - 3.515 keV, but then ought to also see K XIX - not seen; S XVI line at

3.45 - 3.47 keV; Ar XVIII 3.682 - 3.685 keV; observations point to $\tau_{DM} = (3.5 - 8)\, 10^{27}$ sec; non-observations are at 2 σ tension; review by D.I. 1510.00358; 1607.04487 Perseus observations by Astro-H in the few days that were possible; Dayal et al. 1501.02823, Rudakovskysi & D.I. 1604.013441, Bose et al. 1605.03179; he did not take into account the formation of molecular Hydrogen as we did in PLB & Kusenko 2006.

Anastasia Fialkov (Harvard, Cambridge, US), Signatures and constraints on WDM from star formation, reionization, 21cm HI line, and galaxies: first halos of about 10^5 or $10^6\, M_\odot$ start around $z \simeq 65$, collapse to form some stars, but most stars formed much later; Visbal, Barkana & Fialkov 2013; Fialkov et al. 2013; radiation from stars and qsos gradually heat and ionize gas; various arguments all suggest that $m_X > 1 - 3$ keV, Polisensky & Ricotti 2011, Lovell et all 2011, ..; JWST will probe the very early stages; talks about the 21 cm line profile from the earliest structures; Brooks 2014 shows a $10^{10} M_\odot$ clump in different models of DM, looks quite different; Sitwell et al. 2014, Pacucci et al. 2013; Schultz et al. 2014; Maio & Viel 2014; delay in very early star formation by 0.1 Gyrs; Dayal et al. 2014; in WDM star formation later, but then much faster; also shows the graph about the LF from Menci et al. 2016 demonstrating that WDM particle better be < about 3 keV; Dayal et al. 2015; Gao, Theuns, & Springel 2015; in WDM atomic line cooling allows gas in the centers of filaments to cool, leading to very different looks than in CDM; Hirano et al. 2014; Magg et al. 2016; claim that WDM suppresses early Pair-Instability (PI) SNe; so detecting PI SNe refutes this WDM model; Sitwell et al. 2014; Mesinger et al. 2014; Yue & Chen 2012; Haiman et al. 2001, Benson et al. 2001, Barkana & Loeb 2002; Dayal et al. 2015; in CDM stalling of reionization;in WDM quicker end of "Epoch-of-Reionization" (EoR); she confirms that none of these simulations includes the effect of enhanced formation of molecular Hydrogen induced by DM decay (PLB & K 06); Sinziana Păduroiu mentions that in her simulations star formation can be triggered very early in dense filaments even without the enhancement in molecular Hydrogen formation; many caveats.

July 23:

PL Biermann: Several good questions: i) Tony Lasenby asked about the efficiency after the GW data suggest 0.05 rather than 0.5; my answer was on the dependence of the efficiency on initial and final spin, and stellar BHs and SMBH spin; since SMBH spin is derived from orbital angular momentum, it is expected to be high. In fact, using the formula of Hawking (1971 PRL) the maximal efficiency in the case of all spins maximal and equal initial masses is $1 - 1/\sqrt{2}$, so about 30 percent; however, this formula ignores orbital spin. Gerry Gilmore commented that flat rotation curves were first published many years before Vera Rubin by Morton Roberts; Morton Roberts had a review article about flat rotation curves in 1975, and the first major article by Vera Rubin and co was 1978; in fact several of the initial articles by Vera Rubin et al were with Morton Roberts. Paolo Salucci asked about how long one can see the cross in radio emission of radio galaxies that just had a major merger; my answer was that in Cen A Gopal-Krishna et al. gave 50 million years, and in M87 it was probably similar or a bit more, and I ventured the guess that one could see this for 100 million years. Norma Sanchez said that it would be good to have statistics on many arcs, not just one: actually one can see many more arcs directly in the data. Cristina Falvella noted that LPF just measured the precision with which they could measure GWs once they have LISA, Fig 1 in the LPF paper sets no limits on GWs.

Benjamin Wandelt (Paris), Cosmology and DE with cosmic voids: Using voids is a different perspective on describing the soap-bubble-like structure of the universe; Hamaus et al. 1602.01784, 1307.2571; standard candles, standard length scales, he introduces standard spheres, and then goes on to void statistics; Hamaus et al. 1403.4599, 2014 PRL; can determine Ω_{matt} from void statistics $0.28 \pm 0.0..$; voids are not empty, they have substructure which contains information that is frozen in; Alpaslan et al. fine filaments of galaxies inside voids; Liang et al. 2015, Melchior et al. 2013 SDSS, Sanchez et al. 2016 DES SV; Pisani et al. 1503.07690 counting voids to probe DE; Jasche & Wandelt 1203.3639 (2013), Jasche et al. 1409.6308 (2015); 1606. ...; uses a Bayesian path to invert the MWBG fluctuations to get the DE distribution at given redshifts such as $z = 100$, or $z = 0$; on questioning he says that voids are defined by luminous galaxies; inside voids the galaxies are weaker, lower luminosity, bluer, so later Hubble-type; Sinziana Păduroiu emphasizes that the distribution of galaxies inside voids can be vastly different in CDM and WDM model simulations.

Casey Watson(Millikin Univ., Decatur, IL), Using dark globular clusters and dwarf galaxy data to constrain the properties of the DM particle: determine best-fit Burkert halo parameters; find strong correlations between parameters; baryonic infall an adiabatic compression; dark globular clusters, and classical globular clusters; evidence for DM in such dark globular clusters; these DM globular clusters typically have $10^7 M_\odot$; suggests $10^7 M_\odot$ special scale $->$ DM mass; Gerringer-Sameth et al. 2014, 2015; goes through the eqs assuming stationarity; core radius is roughly linear with half-light radius; Horiuchi et al. 2014?; $\rho \sim r_{hf}^{-1.6}$, $\sigma \sim r_{hf}^{0.2}$ $->$ $Q \sim r_{hf}^{-2.2}$; then after some algebra moves on to the infall idea based on Blumenthal et al. 1986, Ryden & Gunn 1987; dark globular clusters Taylor et al. 2015; sizes and masses are intermediate between classical globular clusters and DM-dominated dwarf spheroidals; ultra compact dwarf galaxies and compact ellipticals are found in all kinds of environments, suggesting, that stripping is not relevant; Norris & Kannappan 2011, Huxor et al. 2013, Paudel et al. 2014, ..; −> half light radius of first halos $r_{hf,fs} = 40^{+37}_{-21}$ pc; −> $m_{th} = 2.02 \pm 0.35$ keV; Q is $\sim 10^{-3}\,Q_{\star}$ primordial; $Q_{\star} = 10^{-4}(M_{\odot}/\mathrm{pc}^3)(\mathrm{km/s})^{-3}$; gives a concentration parameter of pretty well defined at 10.2 ± 1.1; thermal 2 keV behaves like 7 keV Shi-Fuller particle; conclusion is that all points to $m_{th} \simeq 2$ keV; Norma Sanchez had stated that $m_{SF} \simeq 2.55\,m_{th}$, so 2 to 2.5 keV gives 5.1 to 6.3 keV, somewhat less than the Bulbul et al 7 keV; but this is within the error bars; Felix Mirabel asks about confining the baryons in the early universe, before re-ionization; Sinziana Păduroiu comments that the Lyman-alpha arguments use Bode & Ostriker model for initial velocities.

Gerard Gilmore (Cambridge), Cosmology with Gaia: one billion pixels for one billion stars; Gaia data release 1 Sep 14, 2016; work started 1993, launch 12/2013, operations started 7/2014, project ends 2023+, total cost 960 M Euro; most stable satellite ever, he claims; Gaia is 10 to 100 times better than Hipparcos; sky scanning principle; shows Gaia HRD, a Y-shaped blob; precision 50 pico-rad; L2 orbit; 700 by 170 thousand km; two telescopes to break degeneracy, and so allows absolute measurements; Gaia keeps 400 people busy with data processing and analysis; can observe Earth-orbit dangerous asteroids; 1411.1173 Perryman et al.; Jupiter-like planets are easy astrometric detections; found already 25+ new satellites of our Galaxy, and several streams; the stars' velocity distribution in the Solar neighborhood is far from equilibrium; parallel project to measure stellar polarization to 0.3 % and compare with distances; GW energy in range picoHz to nanoHz; globally accurate reference frame to $\sim 0.4\ \mu$as/yr; cosmology via multiple images in lensing; will find about 10^4 nearby SNe within Cepheid overlap regime; about half of all Cepheids are binary stars; diffraction spikes can look like micro-lensing; for 300 million stars they can measure brightness to better than 0.5 milli-magnitude, so all better than the best from HST; 1507.02963; 1 million stars measured per hour, 10 million astrometric measurements taken, 300,000 spectra made of 100,000 stars; Tony Lasenby is the one working on setting limits on Ω_{GW} at nanoHz and below; after questioning Tony Lasenby says, they are not even sure this will work, so he cannot give any estimate of the accuracy; sounds like an understatement; Gerry Gilmore explains that different from Planck and Hipparcos they publish all data, put them on-line, so everybody can do an analysis.

Felix Mirabel (Buenos Aires and Paris), Stellar BHs as sources of gravitational waves and heating in the reionization epoch of the universe: he cites himself that in galaxies at redshift > 6 a large fraction of Pop II-III stars end up as stellar BHs; X-rays and jets overtake the HII regions ionized by UV, heat and partially ionize the IGM over large volumes of space; Krumholz et al. 2009 Science; Turk et al. Science 2009, Clark et al. Science 2009, Stacy et al, etc; Fryer et al. 1999, Heger et al. 2003, Georgy et al. 2009, Woosley et al. 2008, Nomoto et al 2010, Linden & Kalogera 2011; Mirabel & Rodriguez Science 2003, Mirabel et al. Nature; Belczynski et al. 2011, Ziosi et al. 2014, Fixsen et al. 2011, Seiffert et al. 2011, Condon et al. 2013, so proposes that stellar BHs are the sources of the non-thermal radio background; Belczynski et al. Nature 2016; talks about failed SN supernova collapse (this may ignore how little we know about SNe); some core collapse models give BHs without any explosion, Sukhold et al. 2016, Nomoto et al., Woosley & Heger, Fryer & Kalogera; estimates say that 300 million BHs exist in Galaxy, we know 20

BH-XRBs, 5 BH-μQSOs; Cyg X-1 was the first (Mirabel & Rodriguez 2003 Science); one can estimate from distance to parent star cluster that $< 1\, M_{\odot}$ was ejected in SN explosion; parent star should have been a WR star $> 40\, M_{\odot}$; $->$ stars of $\sim 40\, M_{\odot}$ and $Z \simeq Z_{\odot}$ may collapse directly to BH; GRS1915+105 also gives progenitor mass $> 38\, M_{\odot}$; maximum ejected material in SN explosion $< 2\, M_{\odot}$; Mirabel et al. 2001 Nature; XTE J1118+480, GRO J1655-40, and V404 Cyg all may have been member of a triple system, he proposes, NOT kick from energetic SN; all these three systems are consistent with momentum of massive star ejected from multiple system, but all three have a low mass binary partner; Smartt 2015 looks for progenitors of bright SN, and did not see anything; claims that stars $> 20\, M_{\odot}$ collapse directly to BHs; Gerke et al. 2015; Reynolds et al. 2015; Lovergrove & Woosley 2013; Williams et al. 2014, Jerkstrand et al. 2014; he claims that all stars $> 20 M_{\odot}$ do not produce visible SNe; he gives the masses as the masses as those just before the explosion, not as ZAMS = zero age main sequence mass; he mentions that they have five GW events now, and soon expect about a thousand; Abbott et al. 2016 ApJL 818, L22; Douna, Pelizza, Mirabel AA 2015; according to a comment in another discussion, there may be no stars at all with $> 20 M_{\odot}$ left just before the explosion; Felix Mirabel confirms that this mass refers to the mass just before the explosion.

David Harvey, Observing and constraining the self-interaction of the DM particle (SIDM): Massey, Harvey et al. 2015 MNRAS, group of four elliptical galaxies in cluster gives very tight constraints on DM distribution; except on small galaxy which is misaligned by about 1.6 ± 0.48 kpc with its own DM halo; Shu et al. 2016 similar claim, with 1.1 ± 0.2 kpc; question: is this a sign of DM self-interaction? shows diagram of DM self-interaction cross-section in units of cm^2/g; SIDM halos look very different from CDM halos; Peter et al. 2013; SIDM halos are more spherical for instance; Buckley et al. 2012; there are less small scale SIDM sub-halos; this result is degenerate with WDM; SIDM halos have cores, again as WDM; says that at a cross-section of 0.1 cm^2/g SIDM gives many phenomena similar to WDM; question: can one explain the bullet cluster with SIDM? peak shift and trailing DM and mass loss (”evaporate”); Markevitch et al. 2004, Randall et al. 2008, Mertens et al. 2011, Bradac et al. 2008; in his PhD he developed a method to do this for a large cosmological sample; Harvey et al. 2015 Science; used the methods on 30 cluster halos; find no shift at all in ”galaxies - DM”; transformed into a cross section of 0.47 cm^2/g, so sub-barn/GeV; Massey, Harvey et al. 2015 MNRAS; Kahlhoefer et al. 2015 MNRAS; Robertson et al. 2016; such observations are difficult, as many methods give different answers; conclusion: ”we cannot say”.No conclusion from the speaker but conclusion from the audience: self-interaction DM negligeable.

Sinziana Păduroiu said that it was quite conceivable that the density contrast in Zeldovich pancakes was significantly larger than 1 already at redshift 100 for some initial possible velocity dispersions of DM particles; obviously, such a velocity dispersion would have to be very low.

July 24:

Nicola Menci (Rome), Galaxy formation and star formation in WDM cosmology: now the title is <WDM scenario for galaxy formation: constraining the WDM candidates>. Emphasizes that CDM gives huge number of small scale structures; Schnedider et al. 2012, Lovell et al. 2012, 2013; critical issues, abundance of faint galaxies, abundance of satellite DM halos, density profiles, $M_\star - M_{halo}$ relation,..; DM vs feedback degeneracy; Guo et al. 2009, 2011; Governato et al. 2009, 2014; Brooks & Zolotov 2014; Brook & Di Cintio, ...;

Bozek et al. 2015; Menci et al. 2012; again ignores the enhanced formation of molecular Hydrogen a la PLB & AK 2006 PRL; small mass galaxies have an observed low quiescent fraction (defined as SSFR $< 10^{-11} yr^{-1}$, and SSFR $= \dot{M}_{\star}/M_{\star}$, differing from all CDM models; $m_X > 4\,\mathrm{keV}$ is indistinguishable from CDM in terms of galaxy formation; Dodelson & Widrow $m_{DW} = 2.9\ m_X$, while for Shi & Fuller $m_{SF} = 2.5\ m_X$; m_X is the thermal equivalent mass; Viel et al. 2005 - 2013; Lovell et al. 2012, 2014; Maccio et al. 2012; Viel et al. 2013; Schultz et al. 2014, Lapi & Danese 2015; Pacucci 2013; shows his plot again of low luminosity function (LF); Hubble Frontier Fields, the fields with lots of lensing, so enhancing the background faint galaxies, to get the faint end LF at high redshift; enhancement by factor of 10 - 20; Menci et al. 2015; now 164 galaxies at z $>$ 6; some lensing magnification $>$ 50 times; best fit $\log \Phi_{obs}/Mpc^3 = 0.54$, 1 σ 0.26, 2 σ 0.01, and 3 σ - 0.36; Menci et al. 2016; 3 σ lower limit to m_X of 2 keV, 1 σ $>$ 3 keV; Alavi et al. 2015 z = 2, Parsa et al. 2015 z = 3 - 4, Livermore et al. 2016 z $>$ 6; Bozek et al. 2015; ultra-deep LF at z = 6 extremely powerful probe; shows M_{ster} vs $\sin^2 2\theta$; includes Bulbul et al. 2014, LF at high redshift, and X-ray bounds; quite constraining; Schneider et al. 2015?6; Lovell et al. 2015; Merle et al. 2013; other pathways this leads to a constraint on the Yukawa coupling term $y > 10^{-8}$ at 2 σ level; Schive et al. 2014, 2016; model that DM is Bose-Einstein (BE) condensate of ultra-light axion of order 10^{-22} eV; this class of models is ruled out; Marsch et al. 2015; find Shi-Fuller best, $-10.4 < \log \sin^2 2\theta < -9.8$ for $m_{SF} = 7$ keV; thermal relic equivalent $m_X > 2.4$ keV at 2 σ; Discussion: Livermore, Finkelstein, Lotz 2016 obtained LFs of z = 6 galaxies to $M_{UV} = -12.5$; general agreement that the coming constraints from deep lensing will be great.

Paolo Salucci (Trieste), The observed structural properties of galaxies lead to WDM:

new paper on dwarf spirals now submitted; argues that there are no biases, and so deduces co-added Rotation Curve (RC) for low luminosity spirals; compares with NFW - fails both at low velocity (small radii) and also at high velocity (large radii); tight correlation between core radius and half light radius; defines planes in 3D space using concentration parameter, characteristic radius, and characteristic mass; so in a particular direction it looks like a linear relation, classical fundamental plane argument; however, this fundamental plane differs from the large spirals; he claims then that ΛCDM + feedback is in trouble; he states that only a WDM particle can unify all the extremely different properties of galaxies; comments that URC is defined out to 6 R_D; he does not know yet whether the ultra faint galaxies detected by the new instrument of Toronto/Yale etc also show this minimum DM mass of $10^7 M_{\odot}$.

Gerard Gilmore talked about the history of flat rotation curves, Roberts vs Rubin, and he explained that he was motivated to really read all the old papers, and the priority is clearly for Morton Roberts; Casey Watson and Sinziana Păduroiu talked about how to reconcile the data on small galaxies, including Paolo Salucci's dwarf spirals, with the notion, that the very first clumps formed near redshift 100, as indicated by the arc; the arc has basically no other explanation than the cut of a baryonic shell with a flat Zeldovich DM pancake, as suggested by George Smoot 2015; so the DM could have an unperturbed velocity dispersion which is very small at redshift 100, and this velocity dispersion strongly increases in the perturbations due to the first clumps; in phase density Q this effect might be visible; then one question was whether the faint galaxies shown in Nicola Menci's talk could refer to the perturbed velocity dispersion or the unperturbed velocity dispersion; my hunch is that all these galaxies refer to the perturbed velocity dispersion.

Norma Sanchez (Paris), WDM galaxy structure in agreement with observations: includes the newest results from this week's lectures, like on self-interacting dark matter (SIDM); she emphasizes the diagram of tensor/scalar ratio r with index n_s, what is refered in the literature to as the "cosmic banana"; Hector de Vega, Claudio Destri, & Norma Sanchez, Ann.Phys. 326, 578 (2011); argues for "no running of primordial spectral index n_s" (negligeable value) , "no primordial non-gaussianity" (negligeable amount) ; Hector de Vega & Norma Sanchez IJMPA 2016; Hector de Vega & Norma Sanchez 2014 MNRAS; then goes through the distribution function of DM to describe galaxies, usually dilute or Boltzmann-like for large galaxies, while nearly degenerate for small compact galaxies, approach to DM galaxies analogous to Eddington for globular clusters; Inverse approach with respect to Thomas-Fermi approach. Density profiles from observations determine galaxy distribution functions. Cored density profiles determine DM thermalization.g In galaxies, DM obtained is thermalized, temperature constant for radii < 3 halo radius; outwards slowly decreasing; all these results justify shows the derived mass-radius scaling relations for the galaxy mass ranges, mentions Harvey et al. 2015 Science on non - self-interaction of DM; lists what DM is not; she shows that she and Hector de Vega had predictions for Planck, AMS, Auger; in the discussion I mention the fine-grained phase space distribution in the core region of our own Galaxy which shows clear evidence of recent small mergers.

George Smoot (Berkeley and Paris), Last news from the CMB: Our GRB pathfinder and the Mikhailo Lomonosow satellite launch: starts about GRBs; long type GRBs associated with massive star collapse SNe; two main types of GRBs, in flux ratio vs time, 10 - 300 keV vs 25 - 100 keV; the times center on 30 s, and less than 1 s; idea for short GRBs is two very compact objects, merging and making a BH; in the variant using a massive star also compact engine, probably also BH formation; shows video of neutron star in-spiral; numerical modelling from MPI Potsdam; new spacecraft does not swivel the space-craft, but just a mirror, so a much faster process; coded mask aperture.

Matthew Greenhouse (NASA Greenbelt, JWST project office): JWST: says the JWST was designed to be in between COBE and HST, so the idea is from the mid-nineties; shows the debris disk around the star Formalhaut seen by HST; technical details of JWST: mirrors made from Beryllium for thermal properties; HST 6 times heavier per element; precision of primary mirror 25 nm, secondary mirror 19.8 nm, tertiary,... focal,..; sun protection shield stays at 40 K on mirror side, while on sun-side reach about 350 K; the spectrometer can obtain spectra of 100 compact galaxies simultaneously.

Maria Christina Falvella (Italian Space Agency, Rome), gravitational waves with LPF mission and the way forward to GW detection: describes the steps and science history of LPF; talks about speeding up the launch of LISA; but right now it is planned for 2034; they still hope to get the US back into the team, which they lost in 2011. General comment: Question how one can measure a steady background of GWs, that is composed of so many individual events, that any individual event is hard to see. Gerry Gilmore said, that Gaia could not see a flat spectrum of GWs, but could see a steep spectrum. Therefore at the highest frequencies visible to Gaia there would be a competition with Pulsar Timing Arrays, but it is not clear whether the mergers of SMBHs would be strong enough at that frequency to be detectable. Open question whether the laser frequency comb by Hänsch (Predehl et al. 2012 Science) can be used to help in the detection of gravitational waves.

Hector de Vega medal: This time to Gerry Gilmore and Anthony Lasenby. [Previous (in Meudon this year) to PLBiermann)], and in the science culture sessions to Alba Zanini and Nadia Charbit Blumenfeld.

More on the Hector de Vega Medal at:

http://chalonge.obspm.fr/HectordeVegaMedal.pdf

More on the Colloquium and all Lecturer's presentations at:

http://chalonge.obspm.fr/colloque2016.html