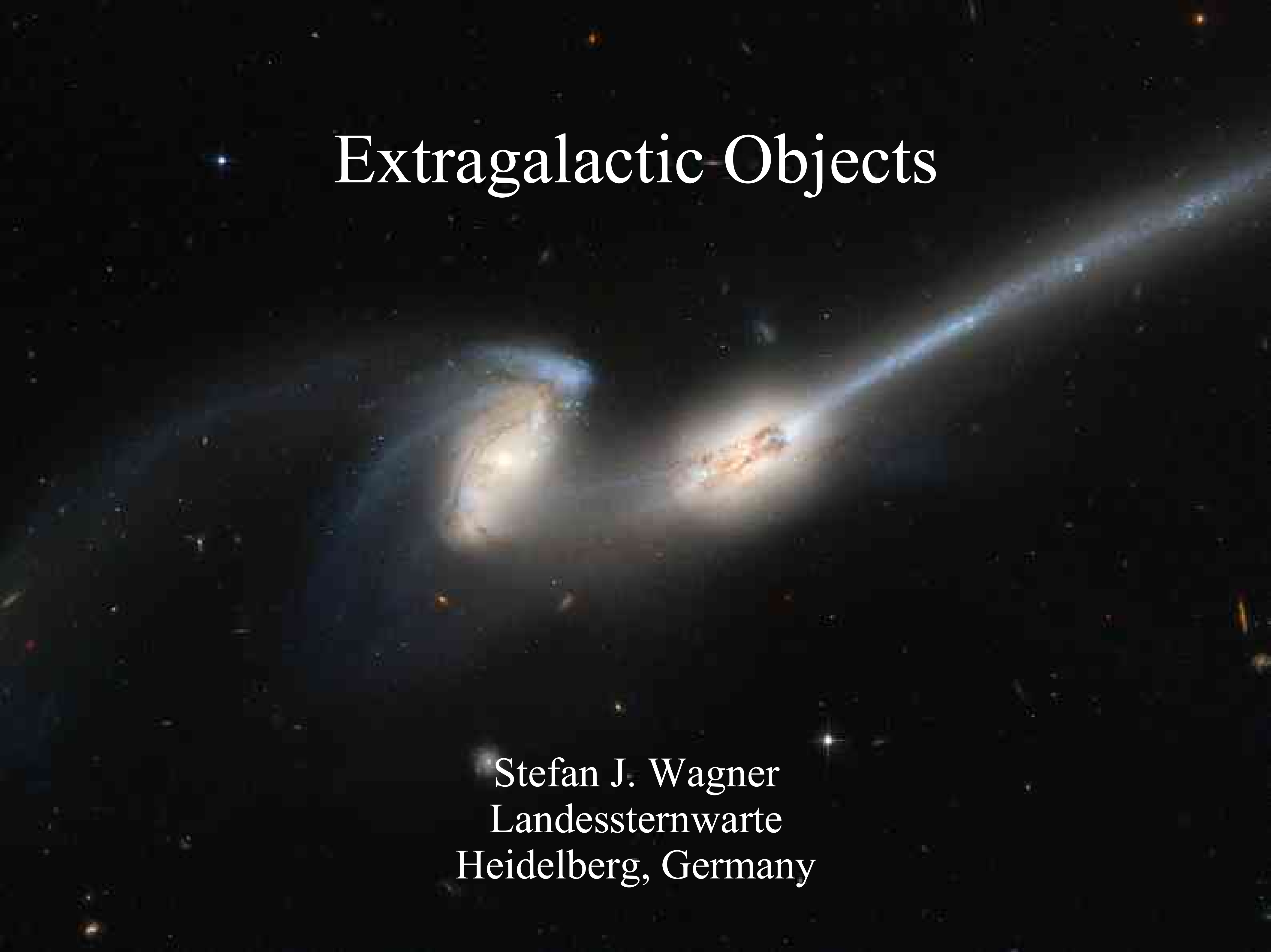
Extragalactic Objects



Stefan J. Wagner
Landessternwarte
Heidelberg, Germany

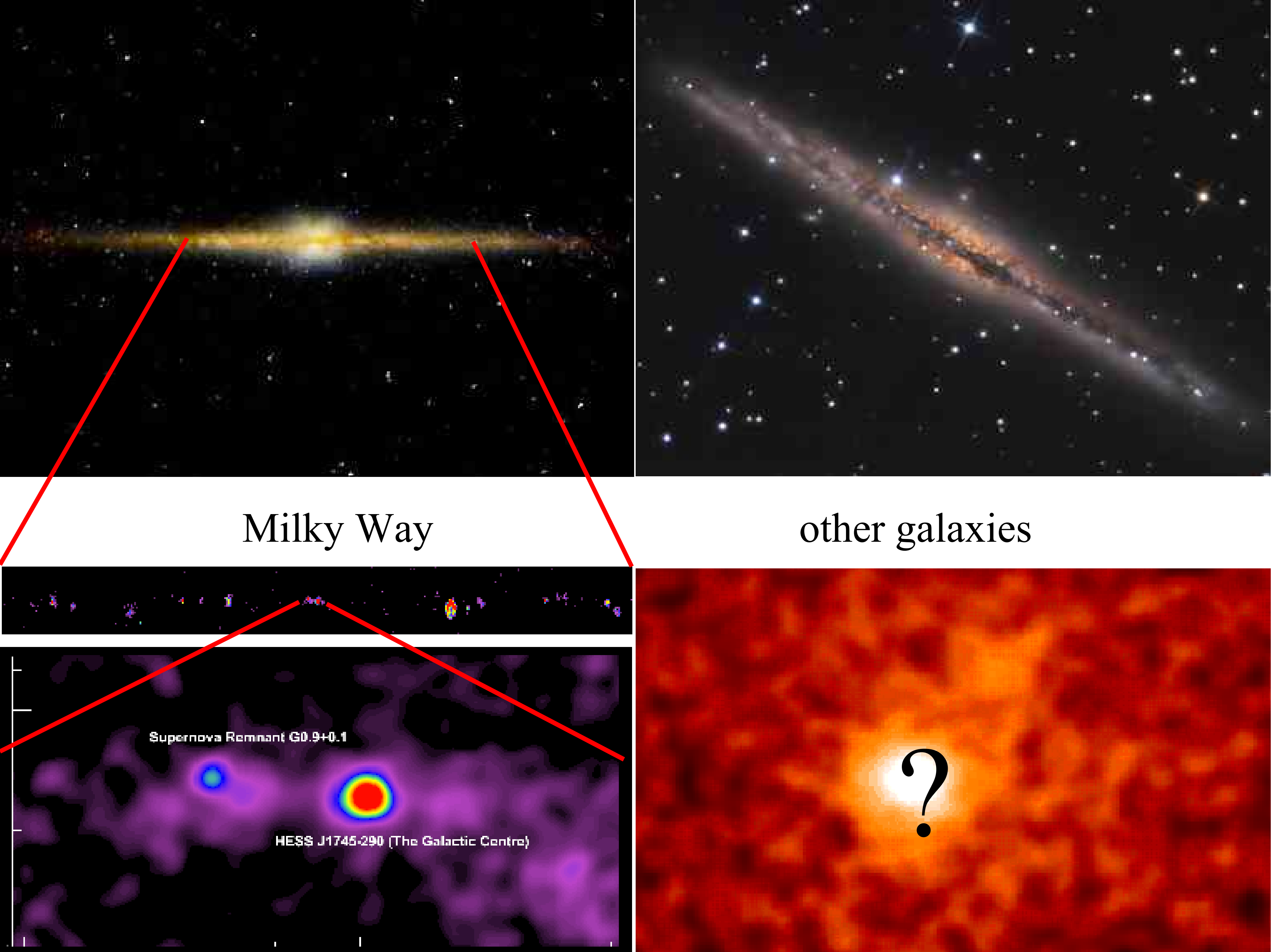
Extragalactic Objects

Numerous Galactic source-classes have been identified
(Galactic Surveys)
The extragalactic regime is more speculative.

“A proposal for searches in the first 1000h with the CTA“

10^{-14} erg/s cm² at 1 TeV allows detection of
extragalactic sources of 10^{40} (d/100 Mpc)² erg/s.

Almost all extragalactic sources will be unresolved.


Milky Way
other galaxies
Supernova Remnant G0.9+0.1
HESS J1745-290 (The Galactic Centre)
?

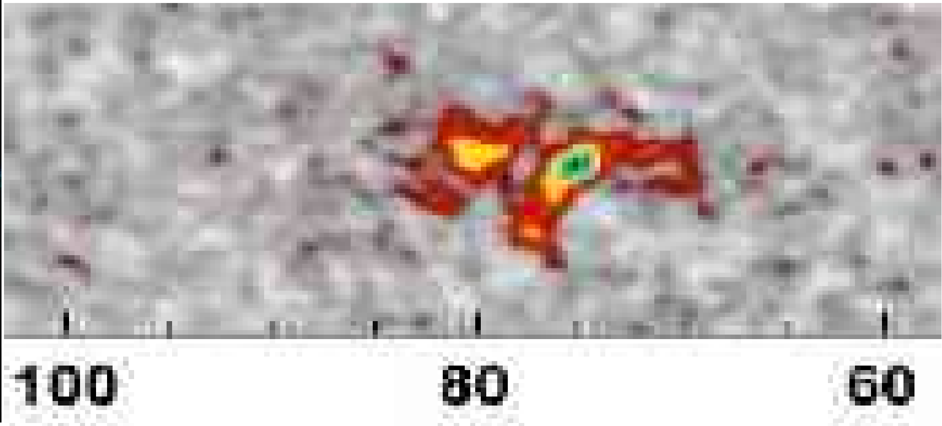
Starforming regions

Young Galactic star cluster
Westerlund2 with WR20a

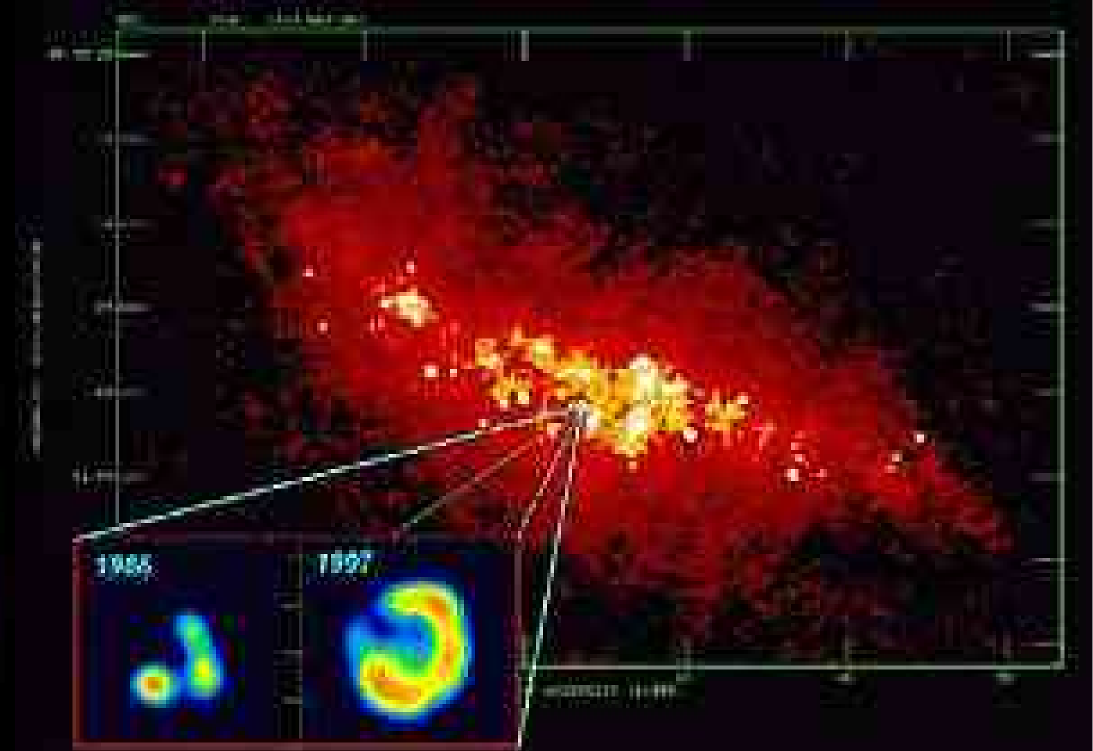
... is a VHE emitter
HESS J 1023-575

possibly other SF regions?

MILAGRO: Cygnus

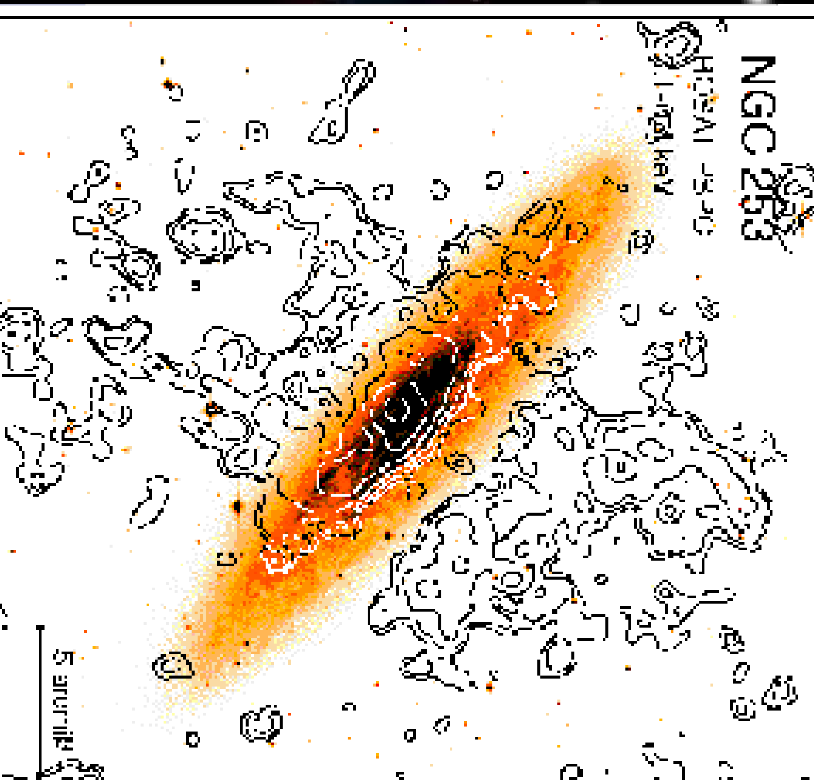


Starforming regions



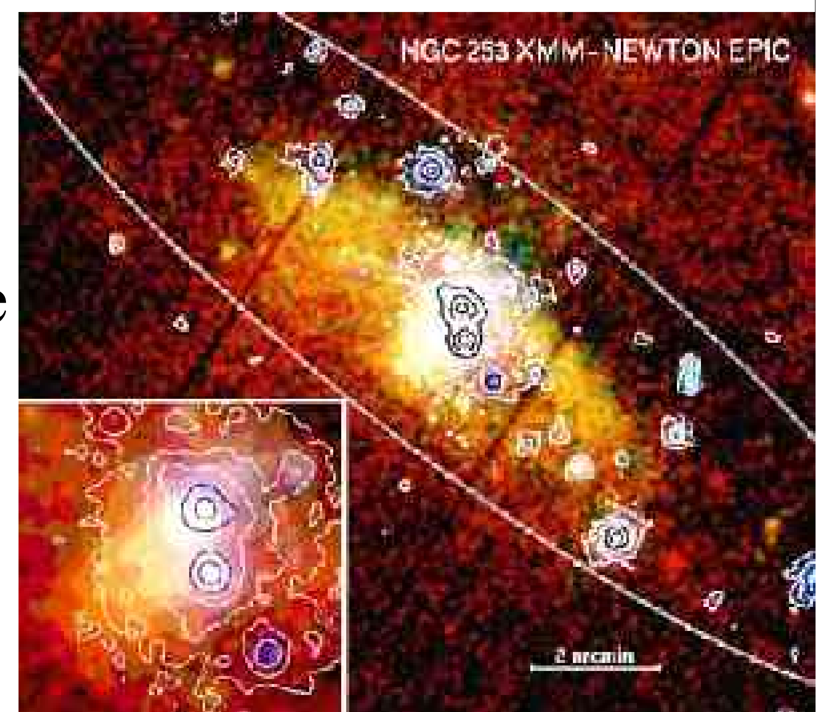
SN-driven starburst-winds

M 82



frequent, but
short-lived phase

NGC 253

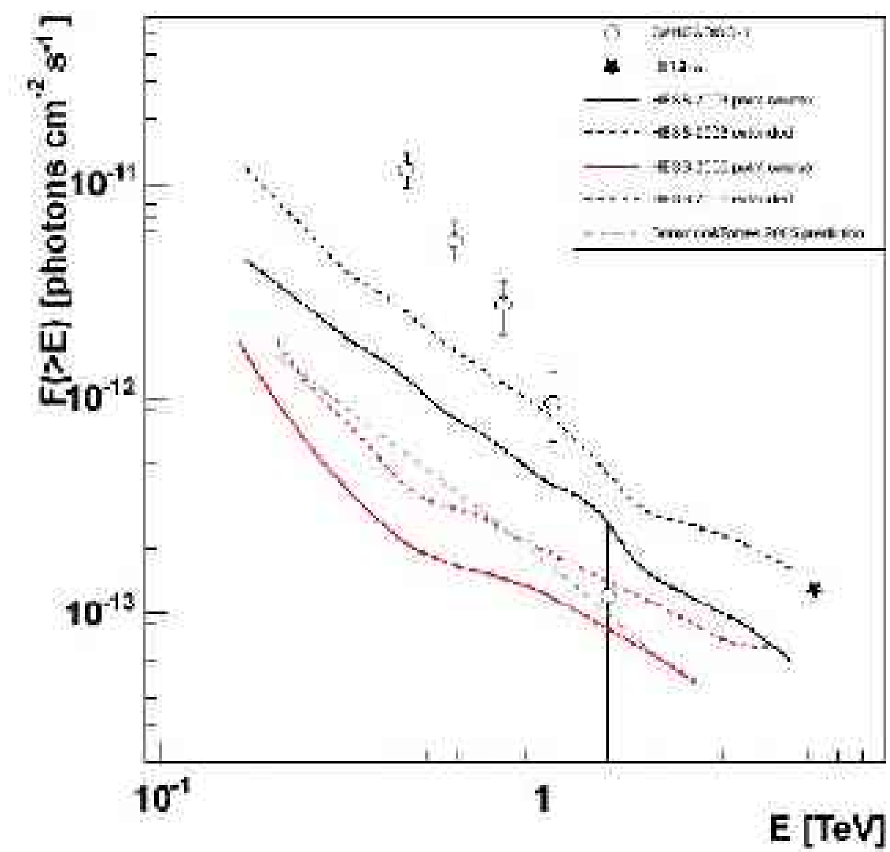


Starburst Galaxies

NGC 253: Comparison of upper limits from HESS to very detailed modelling (Domingo-Santamaria and Torres, astro-ph/0506240) provides constraints on particle distributions in starburst winds.

Physical parameters	Symbol	Value	Units	Comment
Distance	D	2.5	Mpc	ST
Inclination	i	[illegible]	degrees	ST
Infrared Luminosity of the innermost starburst (IS)	L_{IR}	2×10^{10}	$L_\odot$	ST
Radius of the IS	–	100	pc	ST
Radius surrounding disc (SD)		2000	pc	ST
Uniform density of the IS	n_{IS}	~ 600	cm^{-3}	ST
Uniform density of the SD	n_{SD}	~ 50	cm^{-3}	ST
Gas mass of the IS	M_{IS}	$\sim 3 \times 10^{7}$	$M_\odot$	ST
Gas mass of the SD	M_{SD}	$\sim 2.5 \times 10^{8}$	$M_\odot$	ST
Supernova explosion rate of the IS	$\mathcal{R}$	~ 0.08	SN yr^{-1}	ST
Supernova explosion rate of the SD	–	~ 0.01	SN yr^{-1}	ST
Typical supernova explosion energy	–	10^{51}	erg	ST
SN energy transferred to cosmic rays	η	~ 10	%	ST
Convective velocity	V	300 – 600	km s^{-1}	ST
Dust emissivity index	σ	1.5	–	OM
Dust temperature	T_{dust}	50	K	OM
Emission measure	EM	5×10^{5}	pc cm^{-6}	OM
Ionized gas temperature	T	10^{4}	K	OM
Magnetic field of the IS	B	300	μG	OM
Slope of primary injection spectrum	p	2.2–2.5		A
Maximum energy considered for primaries		100	TeV	A
Diffusion coefficient slope	μ	0.5	–	A
Proton-to-electron primary ratio	N_p/N_e	50	–	A
Diffusive timescale	τ_0	1–10	Myr	A

Arp 220: Upper limits (MAGIC)
- astro-ph/0611786 -
in an even more violent starburst



Galaxy Clusters

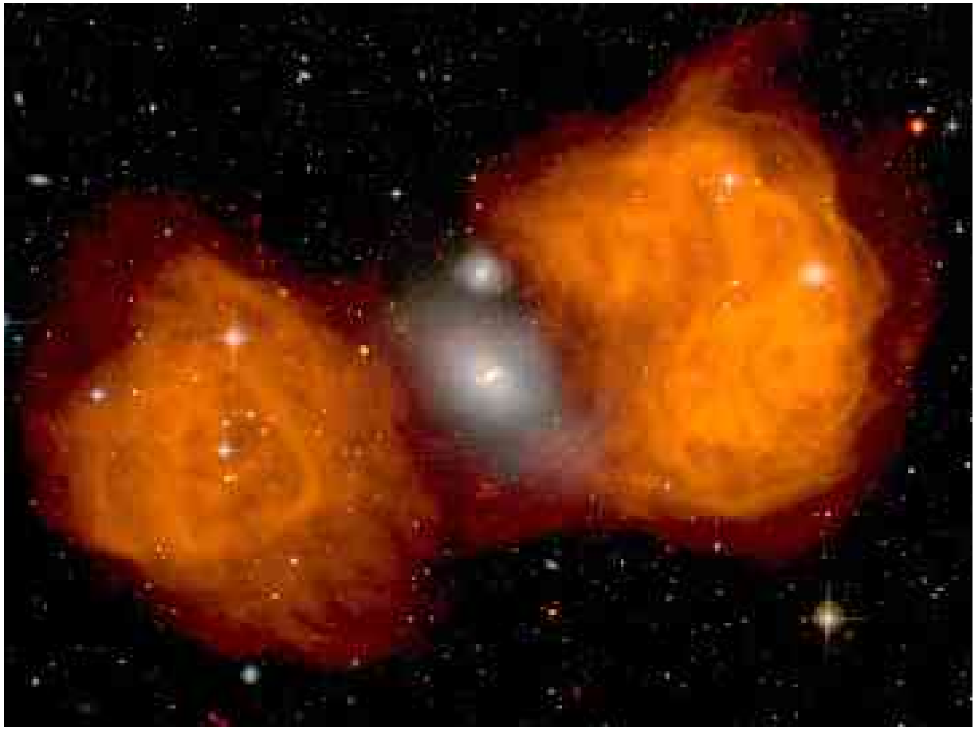
Winds escape galaxies, but are confined in potential wells of galaxy clusters.
During the formation of the most massive elliptical galaxies hot ICM (and CR) were accumulated.

CR accelerated further in, eg., cluster shocks or accretion shocks
Gamma-rays via (1) pp – $_0$, (2) leptonic IC, (3) UHE-cascades
Clusters are cosmic storehouses, Gamma-rays provide calorimetric information on non-thermal content.
Potentially important tracer in cosmic structure formation.
Upper limits only (e.g. Reimer et al.)
Might be moderately extended sites in VHE

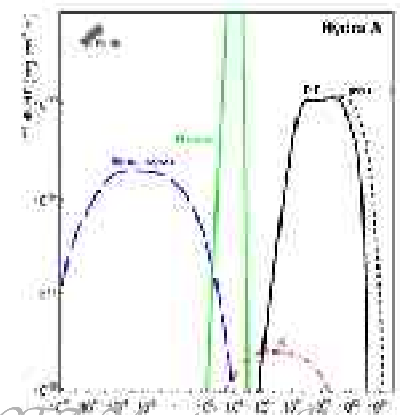
Windblown bubbles from relic AGN

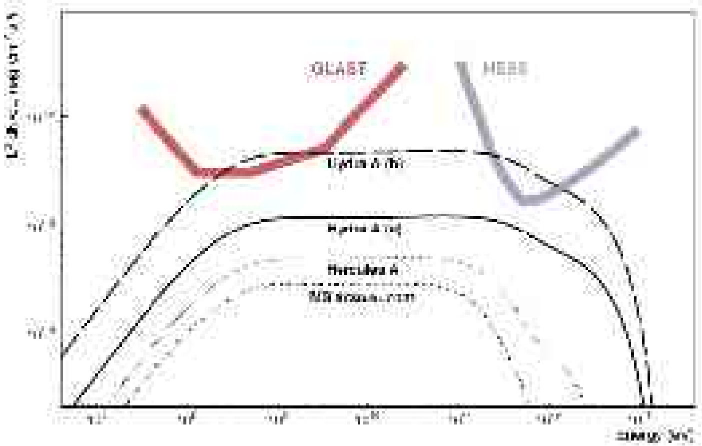
One additional input (to ICM) is provided by AGN winds

AGN are inefficient accretors (few 0.01 Eddington).
Remaining matter blown out.
Important feedback for evolution.
Up to 10^{62} erg in extreme cases.
pressure-supported cavities in hot X-ray gas observed (radio-lobes).



e.g. Fornax A (VLA/NRAO)

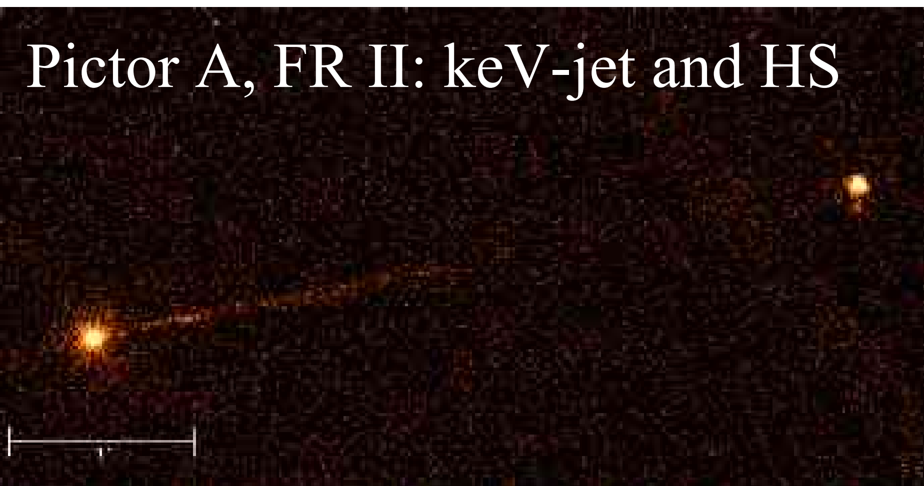


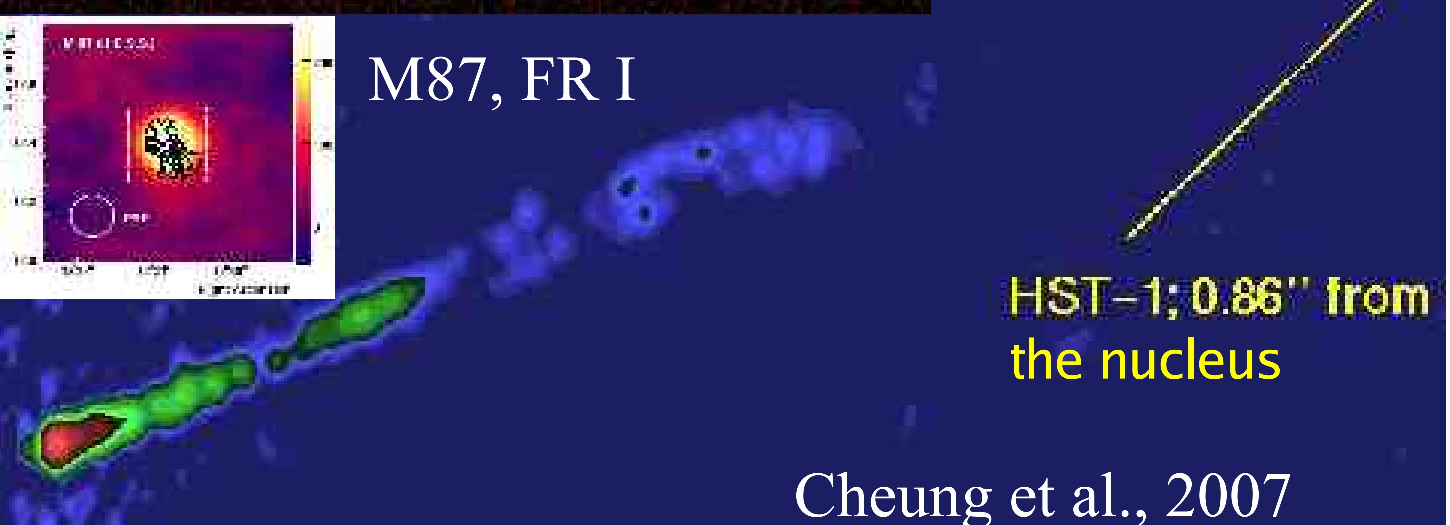


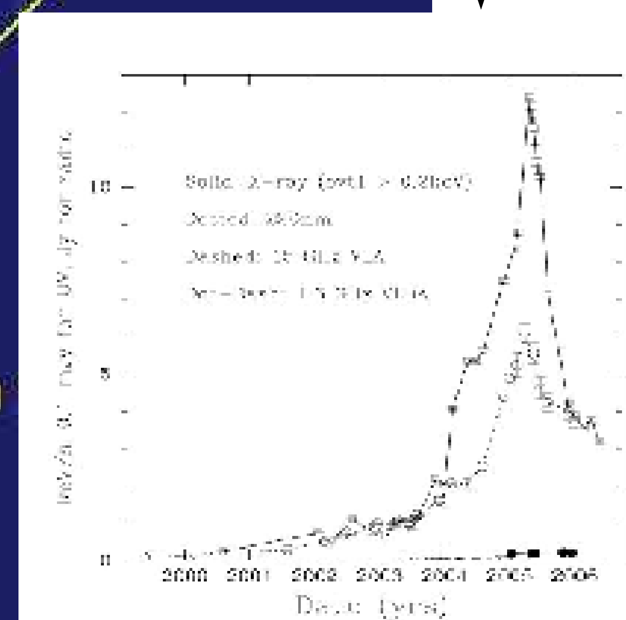
Model predictions
Hinton&Domainko
astro-ph/0701033

Large scale jets

Jets of FR I and FR II sources and hotspots of FR II jets
particle acceleration to high energies throughout jet
fast flares imply compact regions
different jets – matter content?







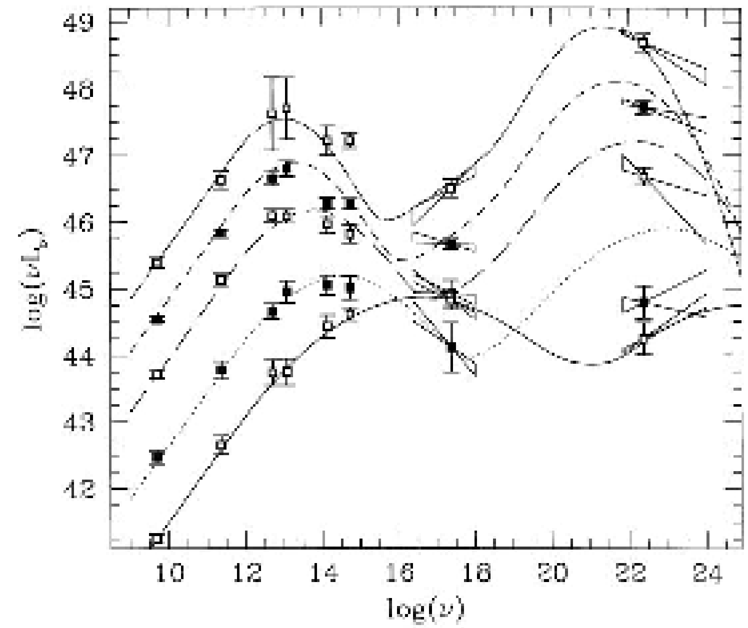
Blazars

The Blazar sequence :

Blazar models: measuring u_{rad}

The range in $_{max}$ (1 ES 1101-232)

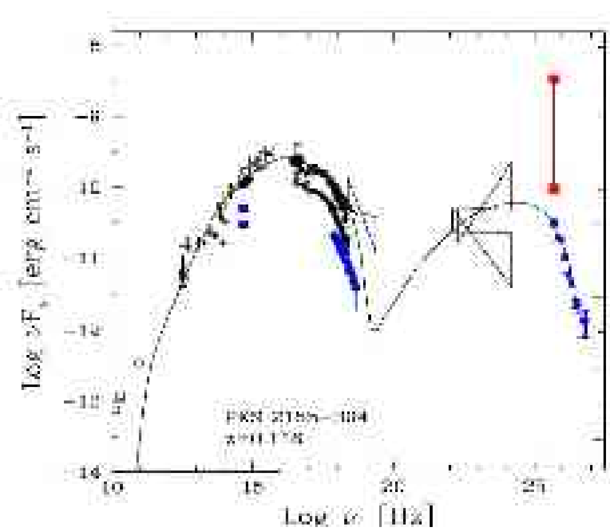
Probing Klein-Nishina



Blazars

How many parameters describe
the Blazar family?

Synchrotron peak frequency scales inversely with luminosity
Gamma max scales with synchrotron max
Compton dominance scales inversely with max



In the synchrotron domain the sequence
has been challenged (Padovani, 2006).

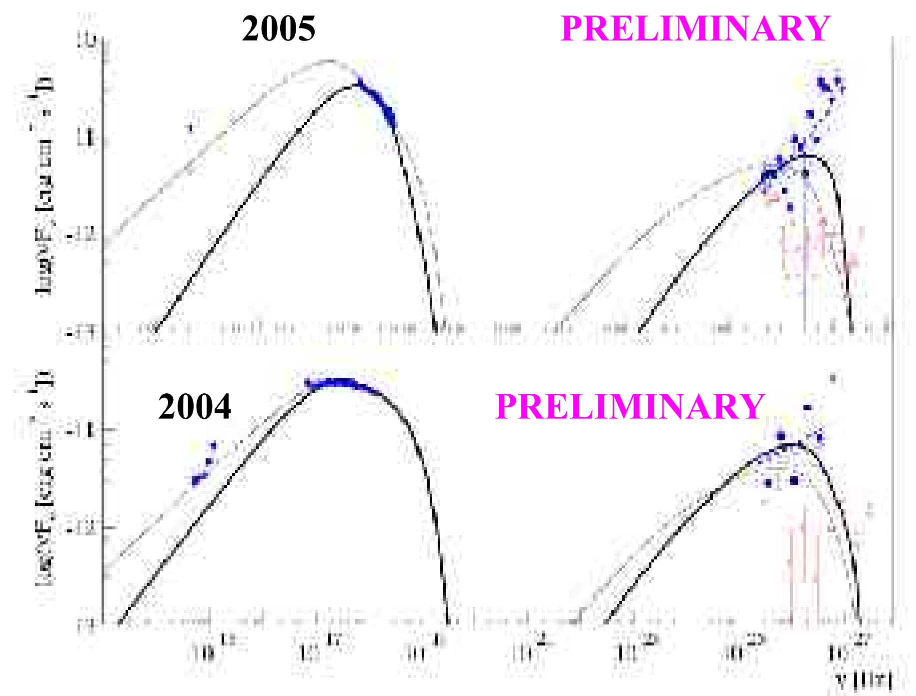
In the gamma-ray range we don't have the data.
Variability biases EGRET data severely.
Absence of evidence is not evidence of absence.

Blazars

Peaks in synchrotron and gamma regime do not change in lockstep. (Mrk 421, Mrk 501)

A very hard component revealed in 1ES 1101-232.
(This results from selection bias)

Pair absorption corrected using lower limits on EBL (the intrinsic spectrum cannot be softer).



strictly simultaneous SEDs

First source to peak above 1 TeV
$_{max}$ (synch) / $_{max}$ (gamma) > 10^{10}
Despite KN, I (synch) < I (gamma) ? - Compton dominates

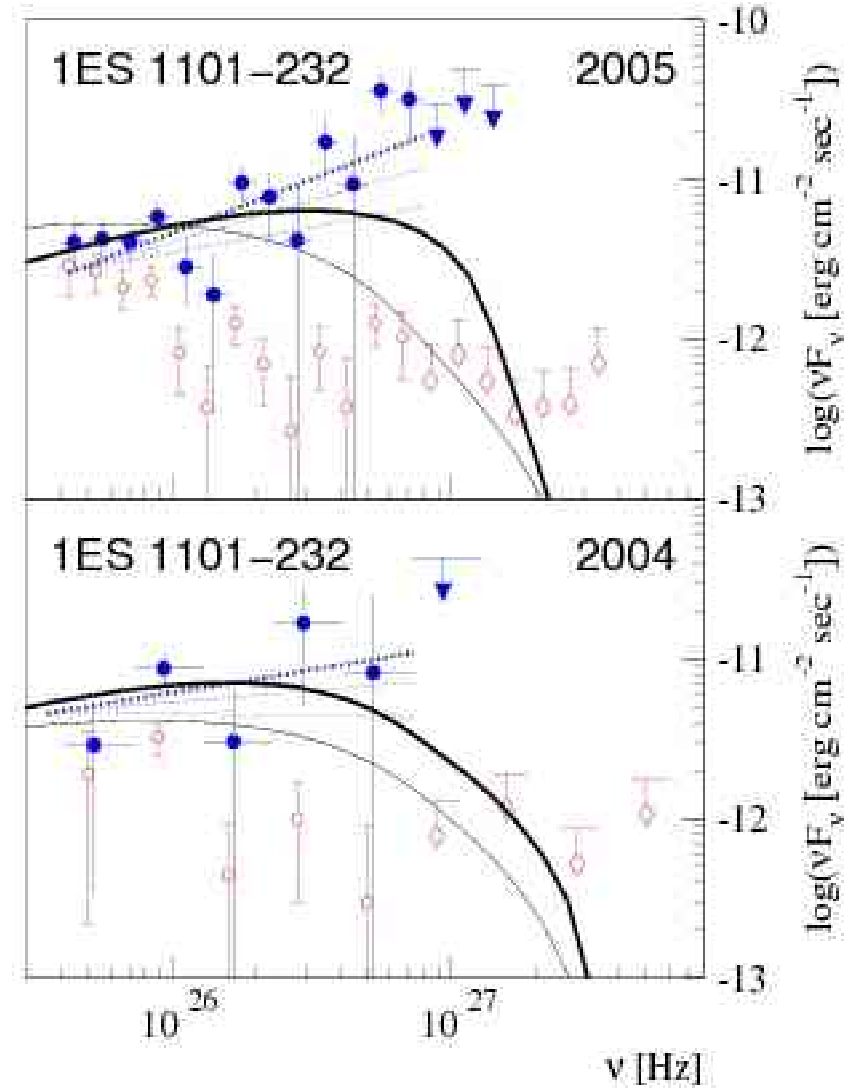
Blazars

CTA will detect more of these (hard) sources

One-zone leptonic emission models are challenged (ruled out).

Very high Lorentz factors required?

Single power-law distribution ftn?

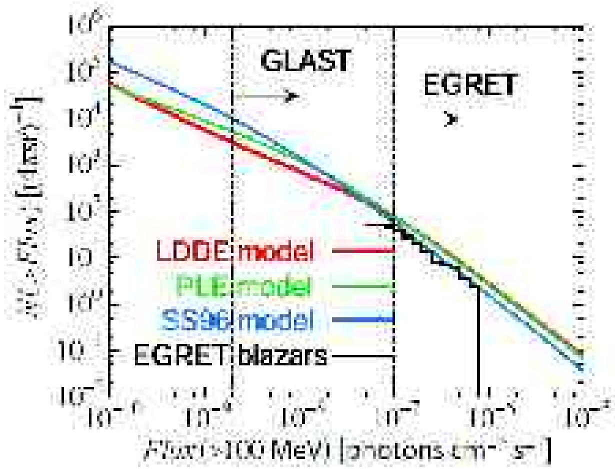


Blazars

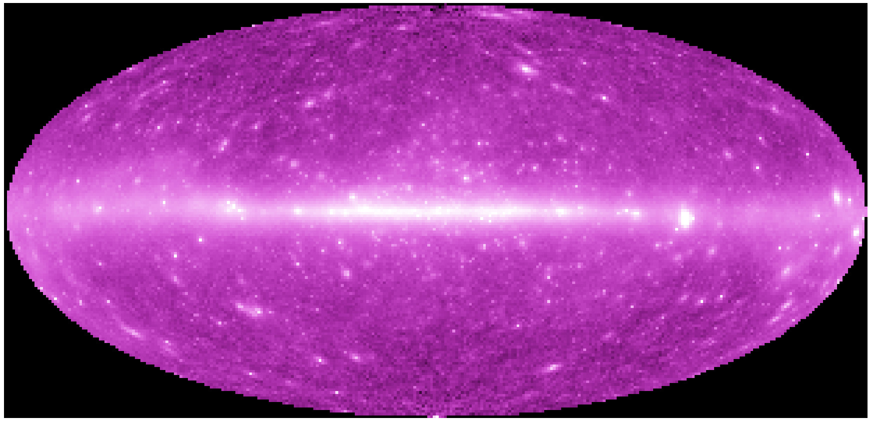
Cannot do full justize to Blazar physics:

(1) What are jets made of?
Hadronic-Leptonic models require broader coverage in energy.
(2) How do jets radiate?
Discovering quiescent emission from requires higher sensitivity.
(3) What is the maximum energy in particles?
Search for high energy cutoffs requires high energies.
(4) What are jet duty cycles?
Long-term lightcurves or large samples of sources.
(5) Do HBLs evolve in a different fashion than other AGN?
VHE & GLAST will provide unbiased sample

New Blazars



Extrapolated Blazar Luminosity Function (Narumoto et al.)


5000 New Blazars with GLAST

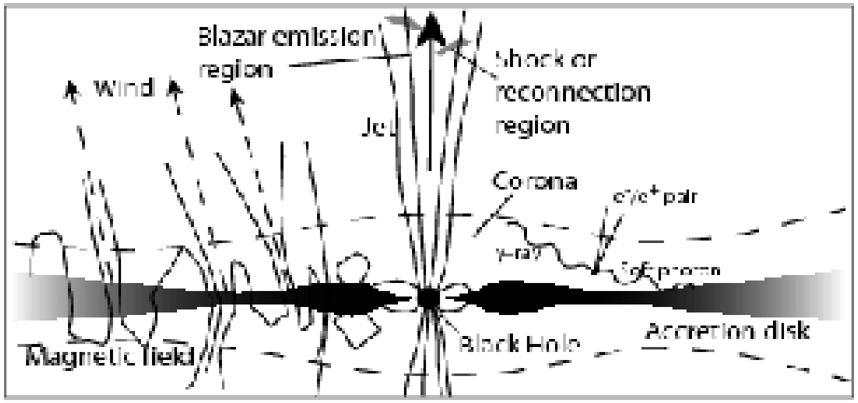
Blazars are difficult to identify in almost all wavebands but Gamma-rays.
Detections so far strongly biassed towards current catalogues
About half of EGRET detected Blazars still unidentified
Hard nearby GeV- emitting Blazars are likely to be bright in VHE band
At least 1000 Blazars within z<0.5 Distribution of spectral indices?
VHE bright Blazars with SEDs as Mkn 421 will show up
Symbiosis: VHE instruments will be ideal to identify the sources.
New classes of Blazars may emerge (extreme VHE dominance).
Currently inaccessible Blazar physics needs gamma-biassed survey

Central Engines

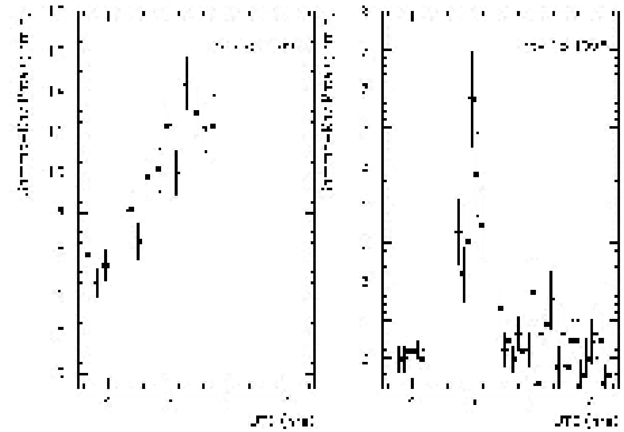
$$\tau_{\gamma\gamma} \approx \frac{\sigma_T}{5}\frac{1}{hc}\frac{d_L^2}{R}\frac{1}{\delta^3(1+z)}F(E_t\frac{\delta^2}{(1+z)^2})$$

Blazar emission from inner jet
Inference by analogy (GeV Blazars: variability)

VHE results pose problems with standard jet models.
Gamma-rays may also be emitted by other components associated with the central engines.
Advection of magnetic fields from accretion disks.
Testing Blandford-Znajek?
Searches for VHE emission in other non-Blazars.

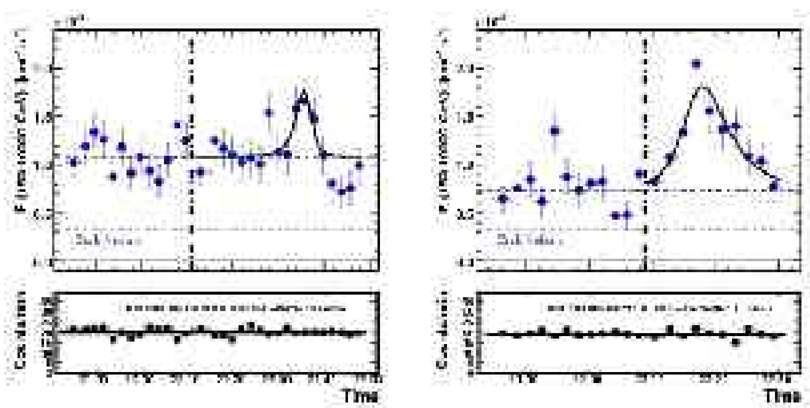


Variability

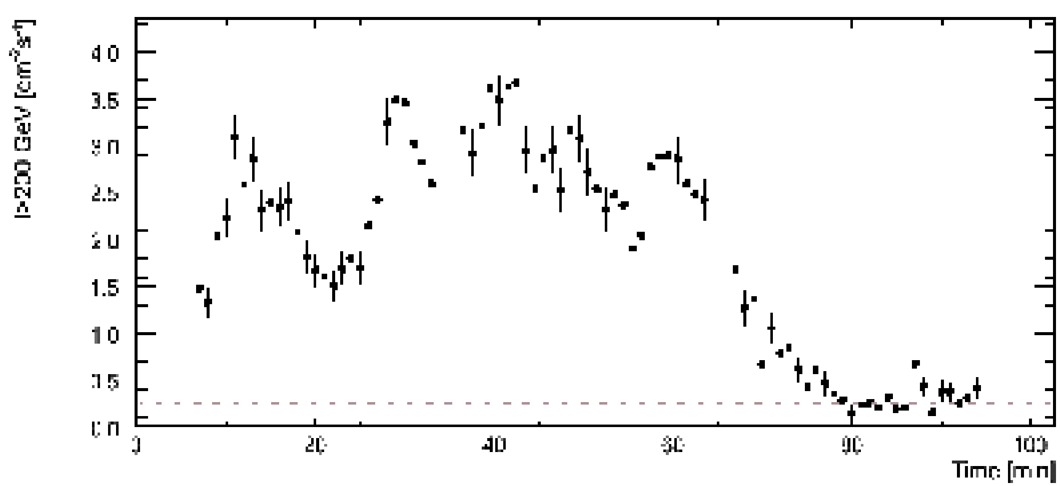


VHE probes very short timescales

Mrk 421
Gaidos et al., 1996 .... ~ 1000 sec



Mrk 501
Albert et al., 2006
astro-ph/0702008



PKS2155-304
Aharonian et al., 2007

Variability

Variability studies with the CTA:

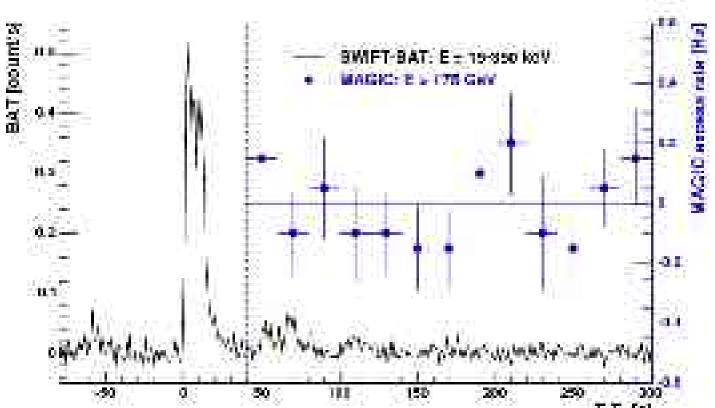
All three events have been observed within ~100 source-hours
They are not very rare (?) - observable with CTA
Increased sensitivity: probing variability on timescales of sec
Increased waveband range: spectral evolution

Previous extreme flares not triggered by other wavebands
Extreme events may have high VHE dominance, i.e.
Other wavebands may not be able to trigger VHE.
CTA may involve a trigger telescope

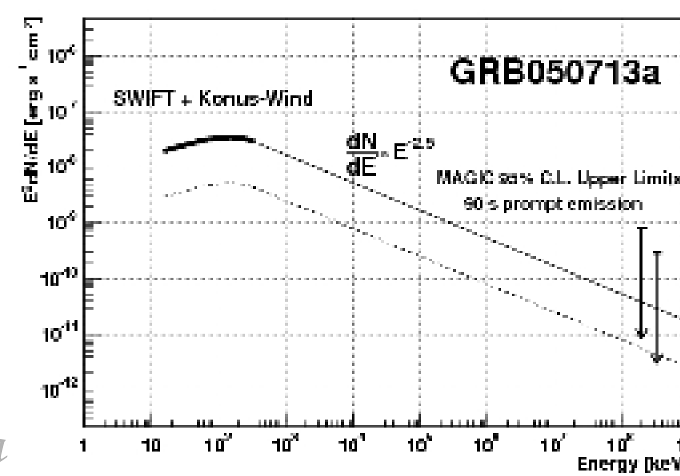
Gamma Ray Bursts

Physics of fast flares in Blazars may be related to other extreme events (Gamma-Ray Bursts) [PKS 2155-304 flares have 1050 erg/flare]

Despite intense studies many open questions:
Internal-external shocks, burst-afterglow distinction, radiation mechanisms (TeV expected)?
Internal pair-absorption and Doppler estimates



Albert et al.
(MAGIC collaboration)
astro-ph/0602231



Supernovae

1987A 20 years!

GRB are related to SNe.

More frequent events (absolute, detected)

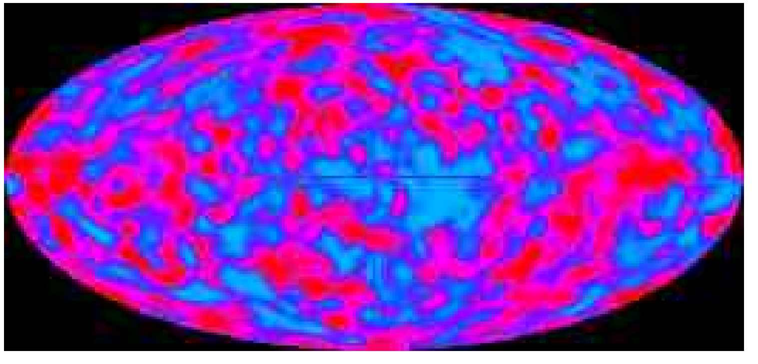
Beaming less important
Internal and external shocks are formed

One might expect very similar acceleration mechanisms.
In particular radio-supernovae might be expected to emit VHE
RSNe might be more isotropic analogues to GRB – absorption.
What is the maximum energy?
Direct CR injection from SNe? Cooling times?

Extragalactic dark accelerators

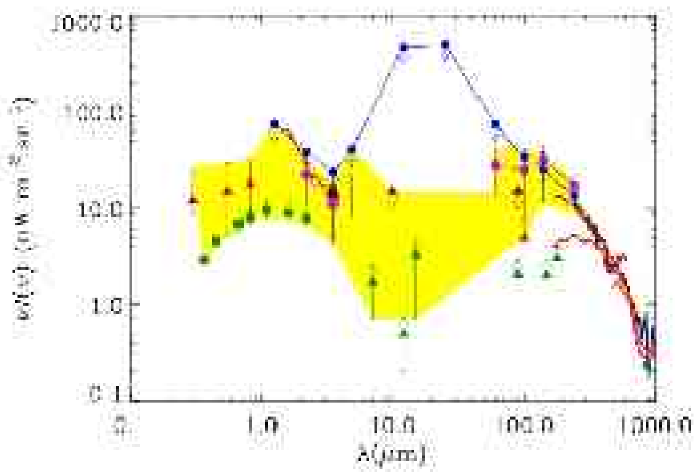
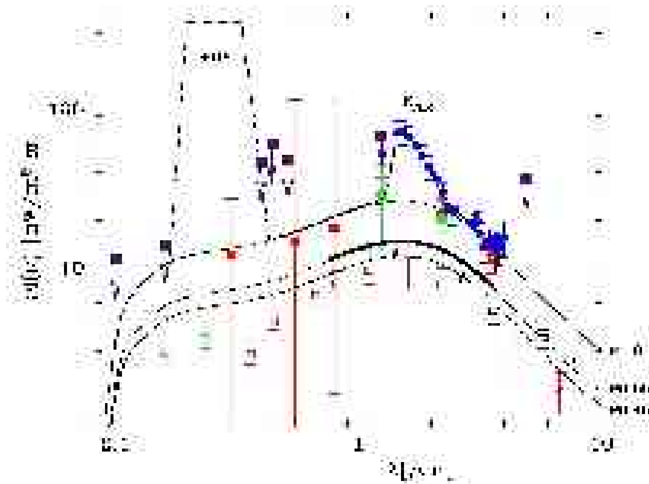
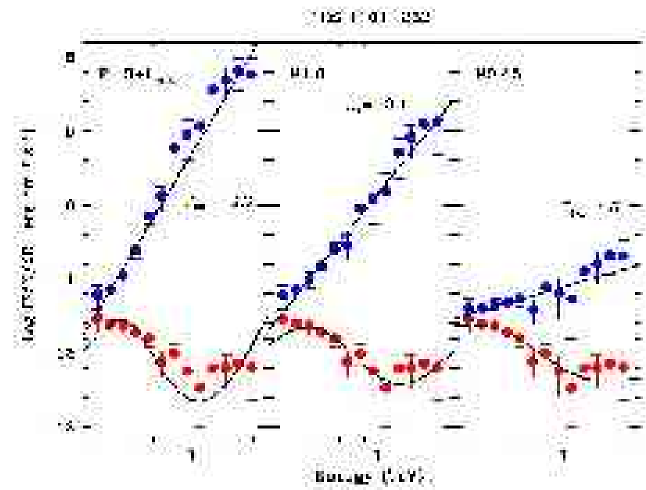
The origin of extragalactic Cosmic Rays

CR above ankle are mostly extragalactic.
CMB prohibits propagation beyond VHE horizon.
UHECR clusters (doublets, triplets,...)?
Mapping peaks in the all-sky distributions from CR experiments



The same goes for Neutrino “clusters“, maxima, sources.

Probing the EBL

Hauser&Dwek: ARAA 39, 249

Determining level, shape, and evolution of the absorbing EBL:
>10 TeV: Mapping the IR bump
10 TeV – 100 GeV: Samples and good spectra
<100 GeV: Into the blue regime: Towards larger distances

Main emphasis are low energies: steeper cutoff, lower ambiguity
larger distances, more sources, cosmological application

Pair Halos

Pair cascades resulting from VHE-EBL interactions are not lost (Aharonian, 1994).
Case 1: Very low magnetic fields: direct cascades observable.
Case 2: Strong magnetic fields (10^{-12} G): Lamor radius < mfp short lived (million yrs) isotropic halos are formed.

Easy signature: distinct spectral/spatial structure.
Requires/Probes hard extrapolations into > 10 TeV regime intergalactic magnetic fields

Potential cosmological use.

VHE cosmology

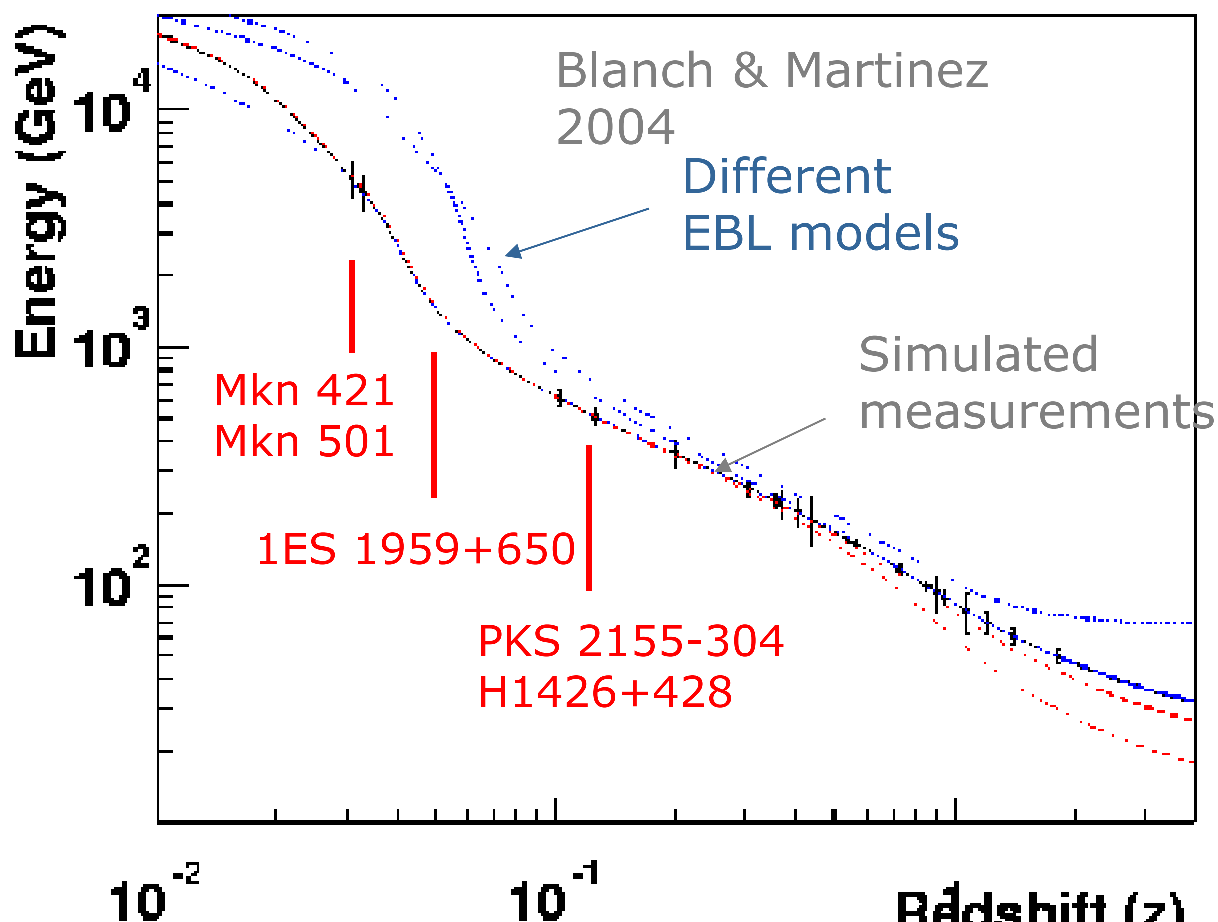
Absolute distances using absorption on EBL and pair haloes

Measuring cosmological parameters?

Variability:

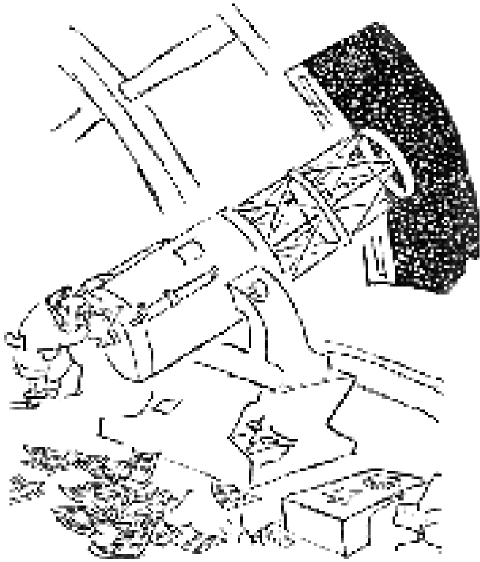
Constraints on quantum gravity

Fast flares and lensing characteristic



CTA Meeting, Paris, March 1, 2007

Surveys



All fields profit from surveys – always

A 1 sr extragalactic survey will find many of the sources mentioned so far. It will also find those which have high VHE fluxes, and, possibly, new classes of extragalactic sources (extragalactic dark accelerators?)

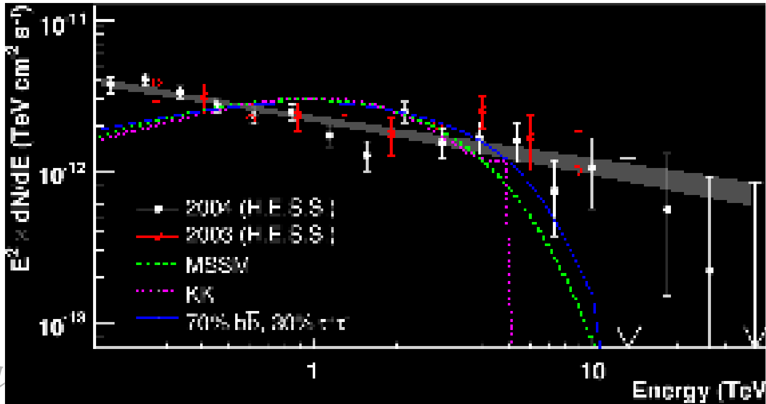
2 GeV-emitting AGN per fov of HESS camera.
Wide-field telescope likely to have 1 VHE AGN/fov

Dark Matter

In particular in extragalactic research one cannot ignore that most matter in the universe is dark
(M/L increases on larger scales).
In the VHE band DM may not be as dark as one might think.
Subject of the following talk, however:
If DM is gamma-bright, all extragalactic signals need to be decomposed as being of dark or “bright“ origin.

Relevant in particular for clusters.

Beyond astroparticle relevance,
much classical astrophysical use.



Outlook

Fascinating perspectives for extragalactic research with CTA

Normal galaxies
starformation
starburst galaxies
clusters
radio relics
extended jets
Blazars
Blazar families
Other AGN
GRBs
SNe
EBL
pair halos
cosmology
surveys
UHECR clusters
DM